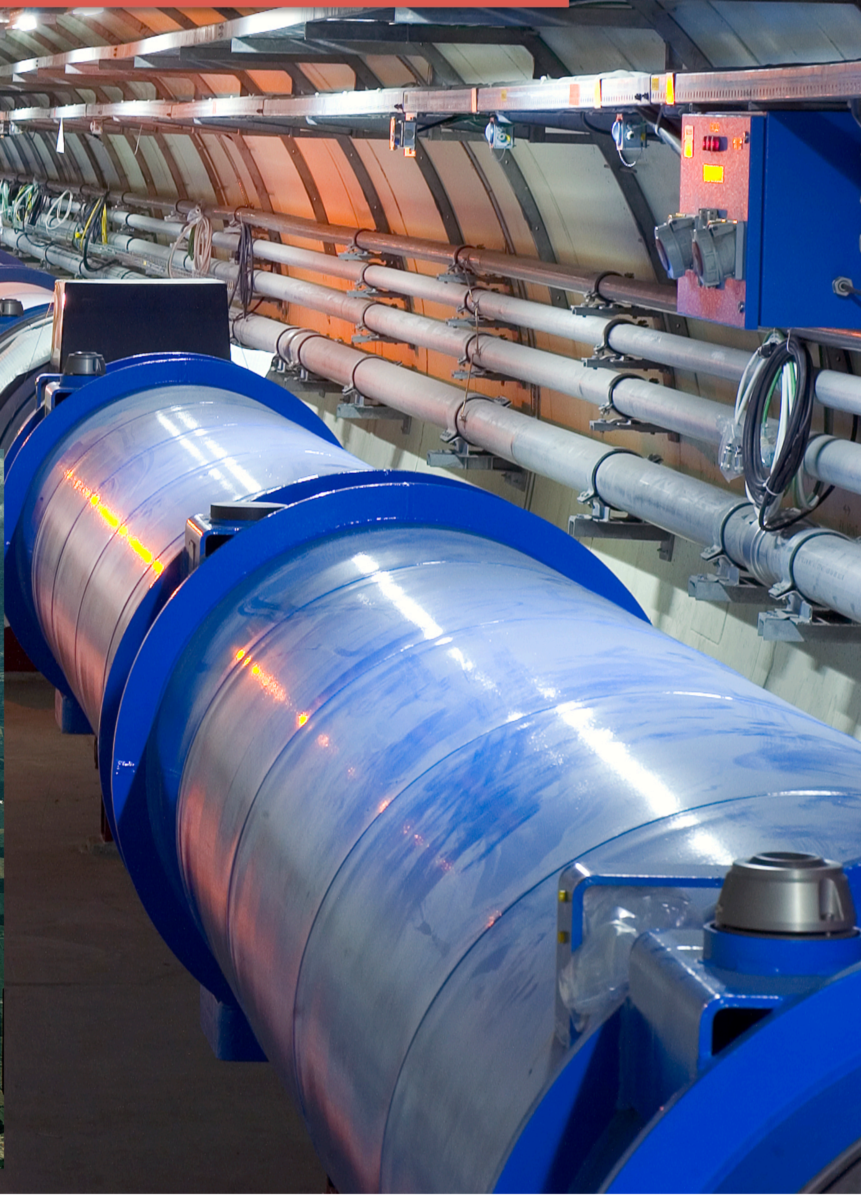
テラスケール物理
LHC実験の現状と最新成果

1. LHC加速器の現状と今後
2. SM 過程を用いた検出器performance
3. ヒッグス粒子　そろそろ？
4. 超対称性と暗黒物質　まだまだ？
5. 纏め

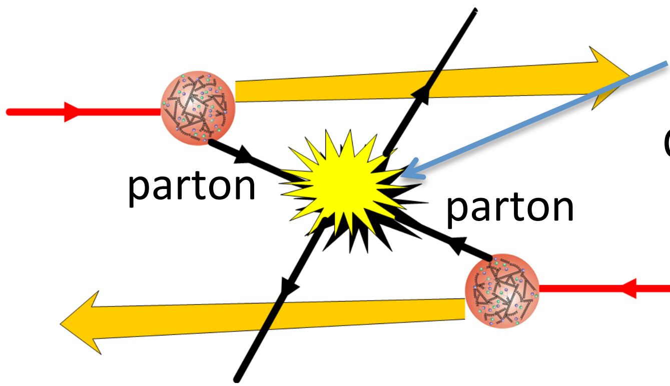
あさい

1. LHC加速器の現状と将来

- 14 TeV の陽子･陽子衝突型加速器
  （今は、接合部の不良で7TeV）
- 円周27km（1232台diploe 超伝導磁石）
- 700Klの液体He(1.9K) 最大級の冷い物
- 建設に14年
- 総建設費は約5000億円（半分磁石）



Luminosity is essence for Hadron collider

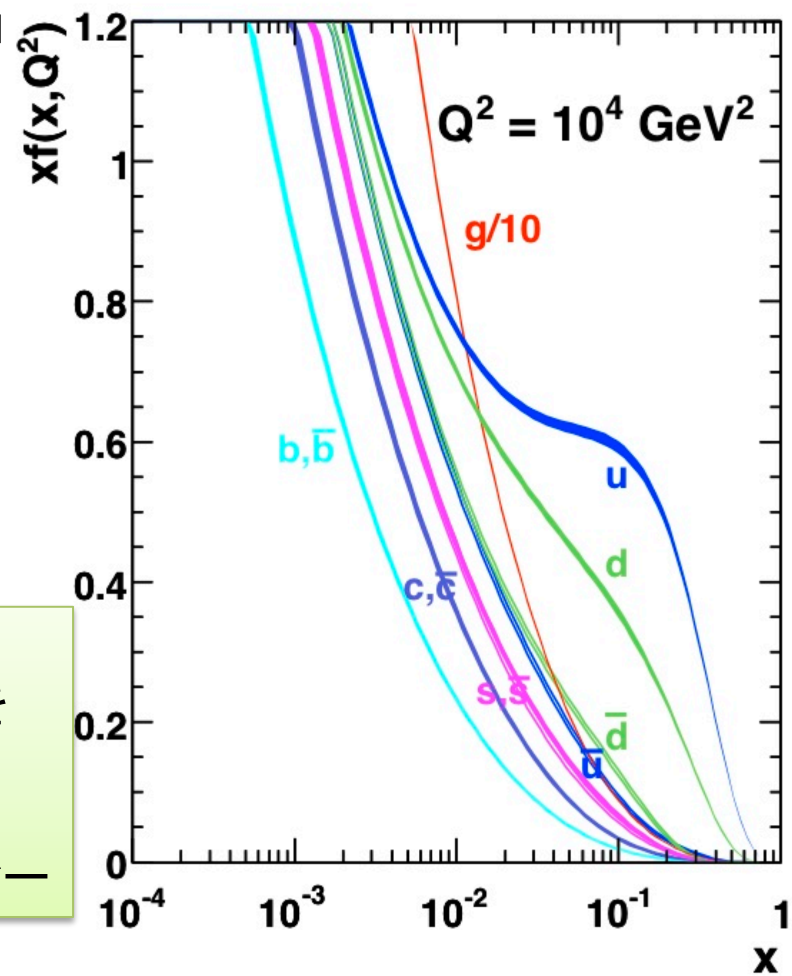


$$\sqrt{\hat{s}} = \sqrt{x_1 x_2}\sqrt{s_{pp}}$$

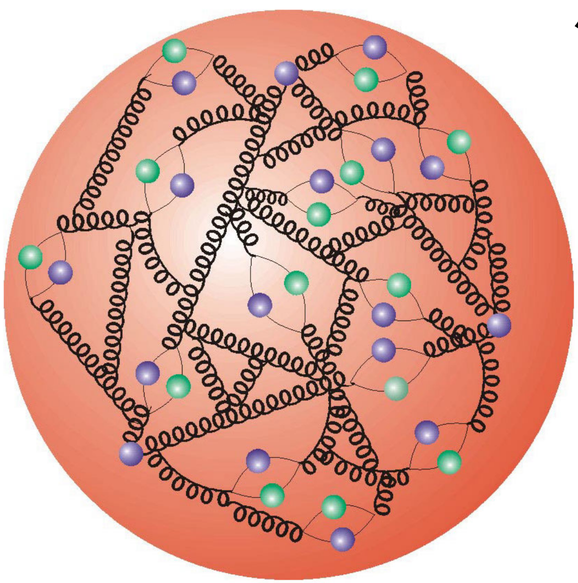
O(TeV)

(7-- 14TeV)

x is ratio of P carried by the parton over P of Proton.



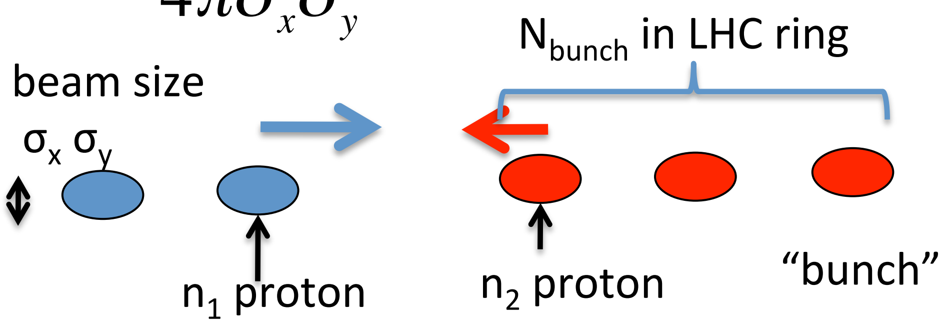
陽子は、quark, gluon, 反quarkの無数のパートンで構成



高いエネルギーの素粒子反応を探る
＝
高いルミノシティー

Bunch Structure of beam

$$L = \frac{n_1 n_2}{4\pi\sigma_x\sigma_y} f$$

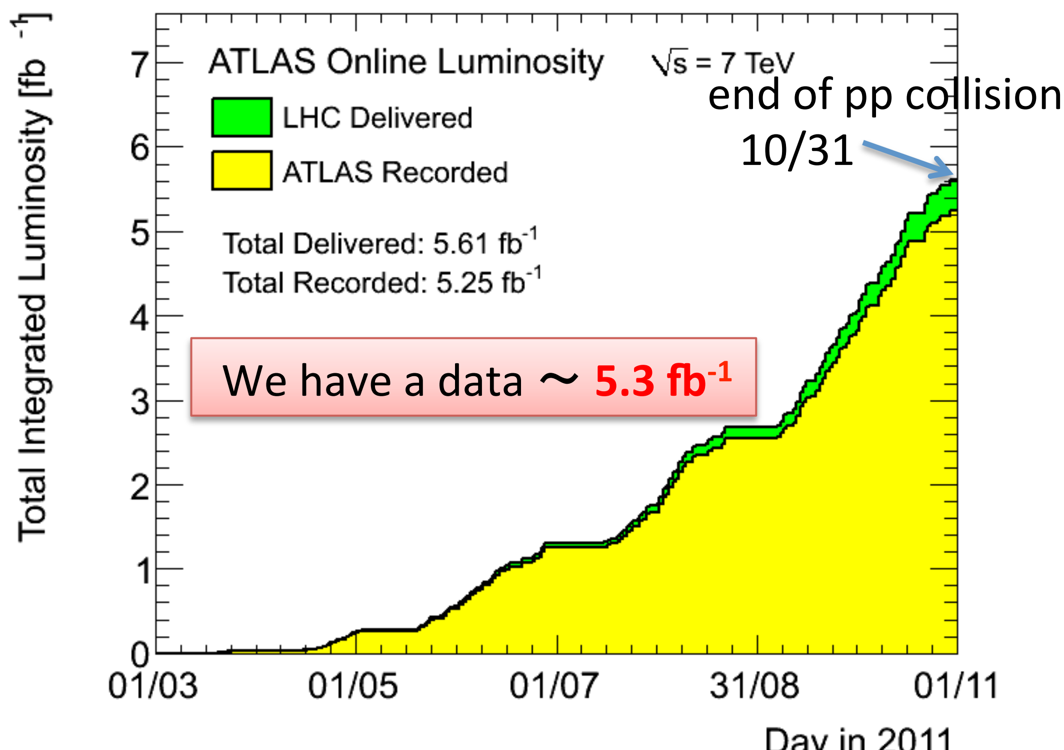


1.4 10^{11} 個の陽子が1つのバンチ
バンチサイズ　23*23μm　長さ 6 cm

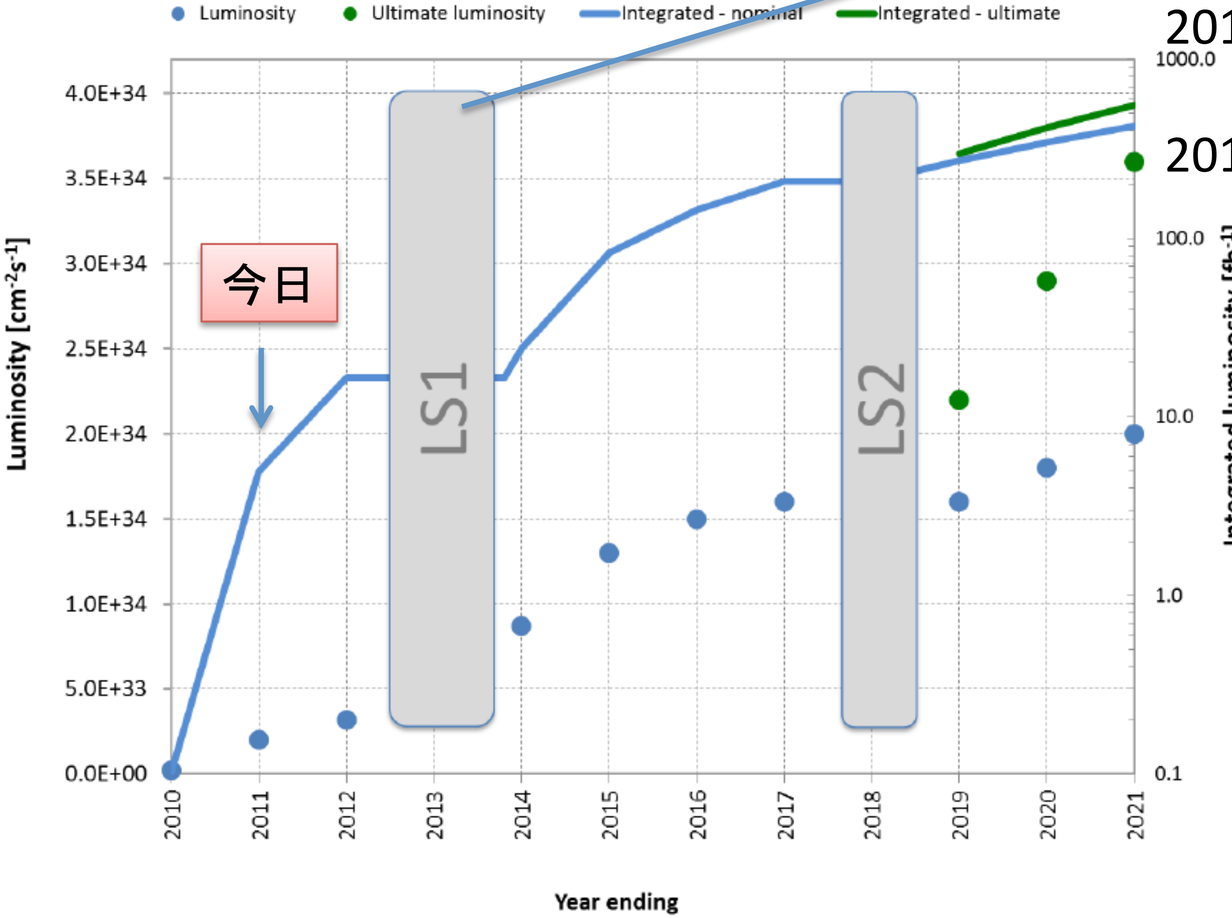
Nbunch　1380 (50nsec each 16m)
σ= 23 μm
n=1.4E11

$L=3.7 * 10^{33} cm^{-s} s^{-1}$

当初の予定　10^{33} cm^{-s} s^{-1}　factor 4 超え、
design Luminosity (10^{34})　に近い



LHC schedule



2012 ECM=**8 TeV L~15 fb^{-1}**

Higgs year + New phys.

2013 Shut down(18months)

2014 ECM=13-14TeV restart

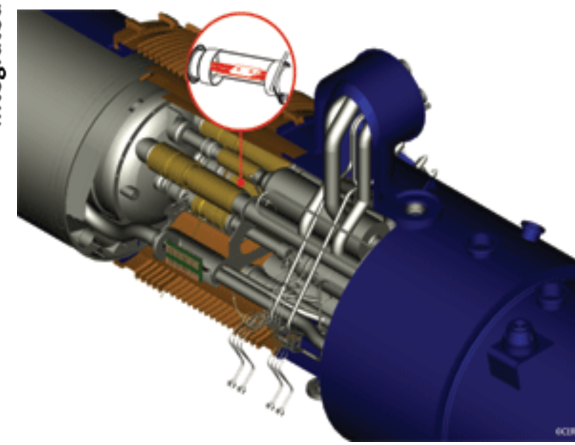
2015,16 L=50-100fb^{-1}

New Physics year

2018 Injector update

L>100 fb^{-1} /year

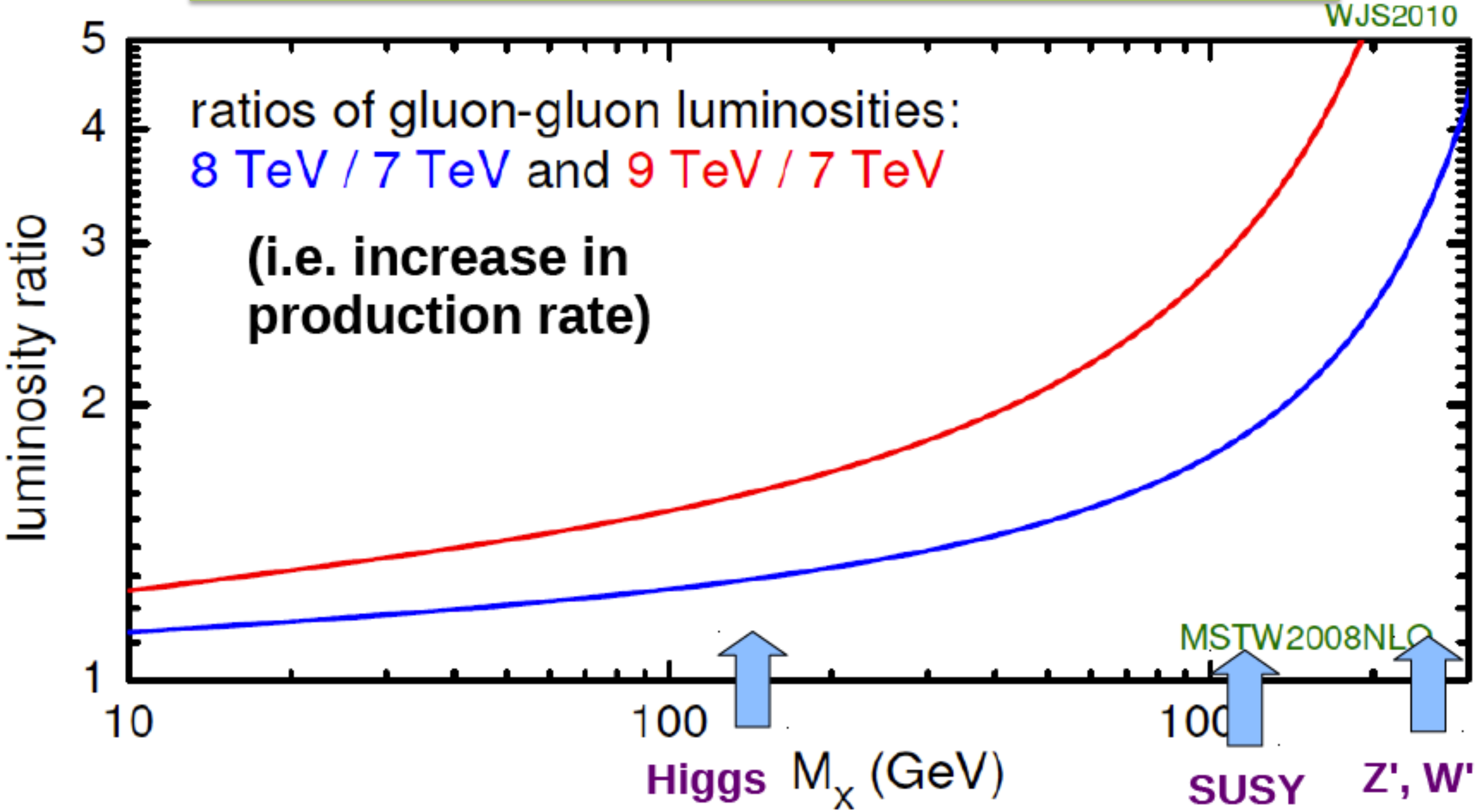
Precision measurements of Higgs & SUSY



2021- LH-LHC 10^{35} cm^{-2} s^{-1} L~ 1ab^{-1}/year ヒッグスのself coupling

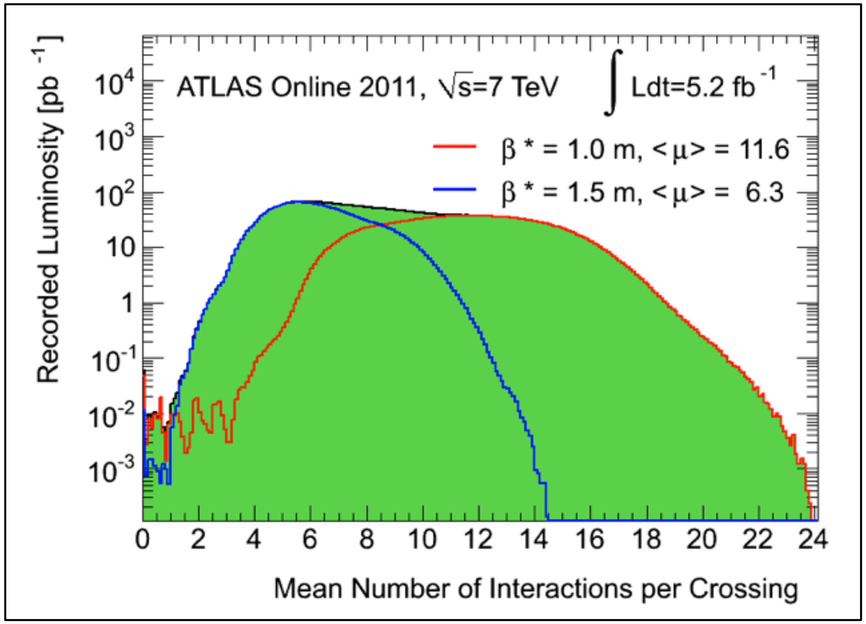
2030- HE-LHC ECM ~33 TeV 重いSUSYなど 物理結果依存

8TeVだと　断面積　Higgs 25 %ぐらいのゲイン （少し）
1.5TeV 重い SUSY　σ　> 2倍（大きく効く）



SUSY gluino, squark ~ 1.5-1.6 TeV が今年のもう一つの大きなtarget

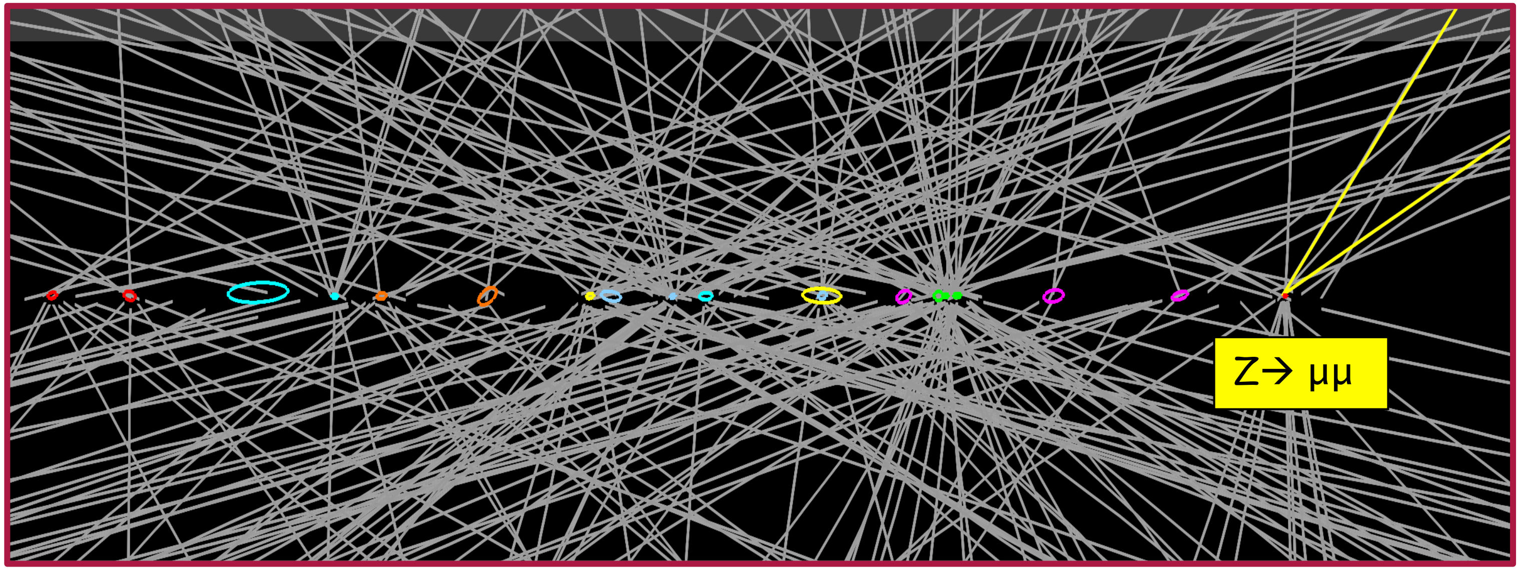
高いルミノシティーの代償:パイルアップ



20MHzでバンチが交差すると
平均11.6個の陽子・陽子反応
(ミニマムバイアス)
パートンの反応でなく、陽子同士の反応
断面積(70mb)

P_T~ Λ_{QCD} order のsoft particle
O(1000)放出され 検出器に負担
解析環境悪化

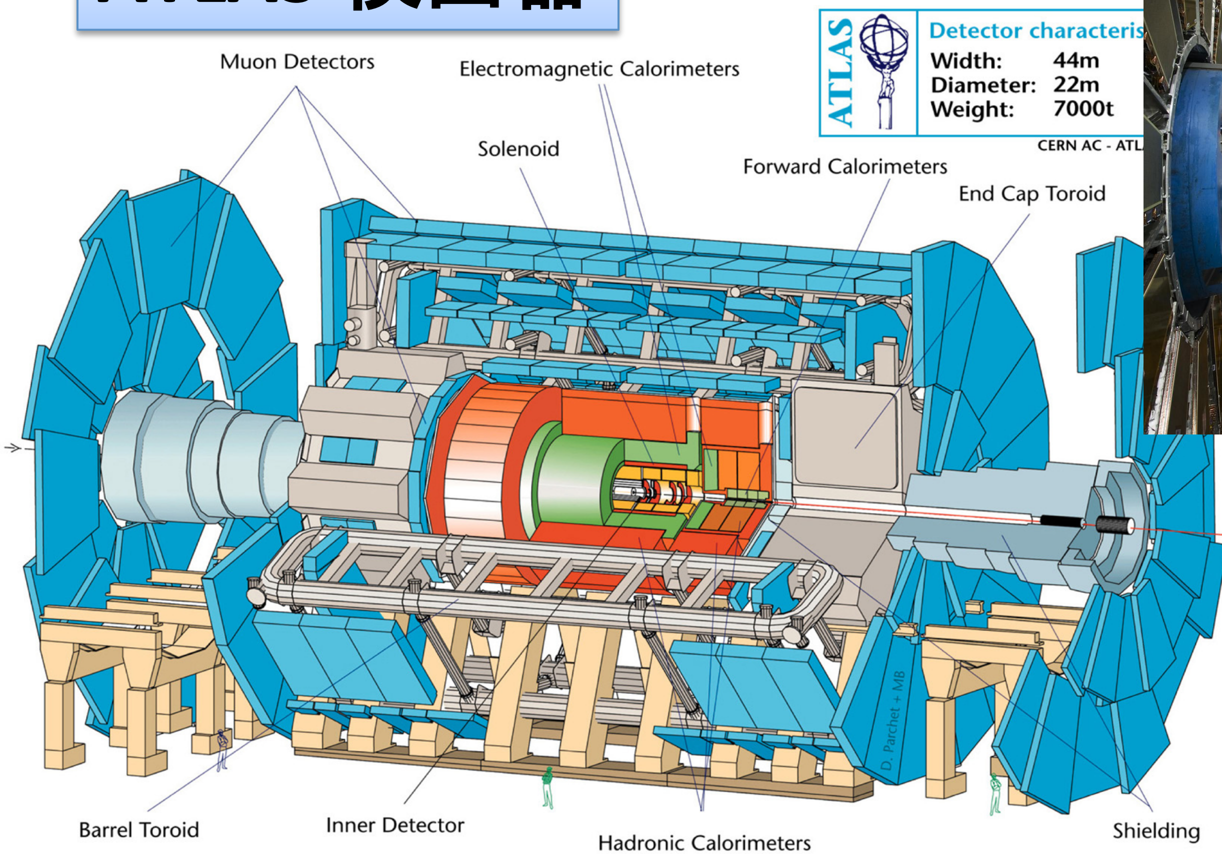
20個の陽子・陽子反応

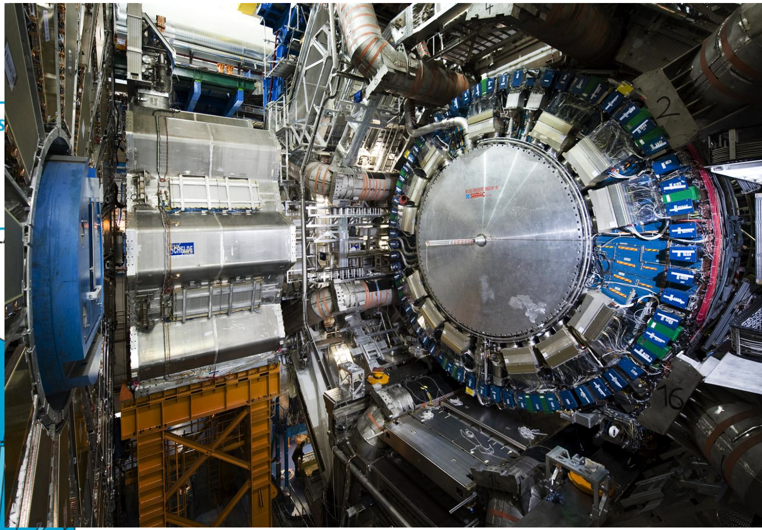


6cmぐらい

ATLAS 検出器

約3000人の国際共同



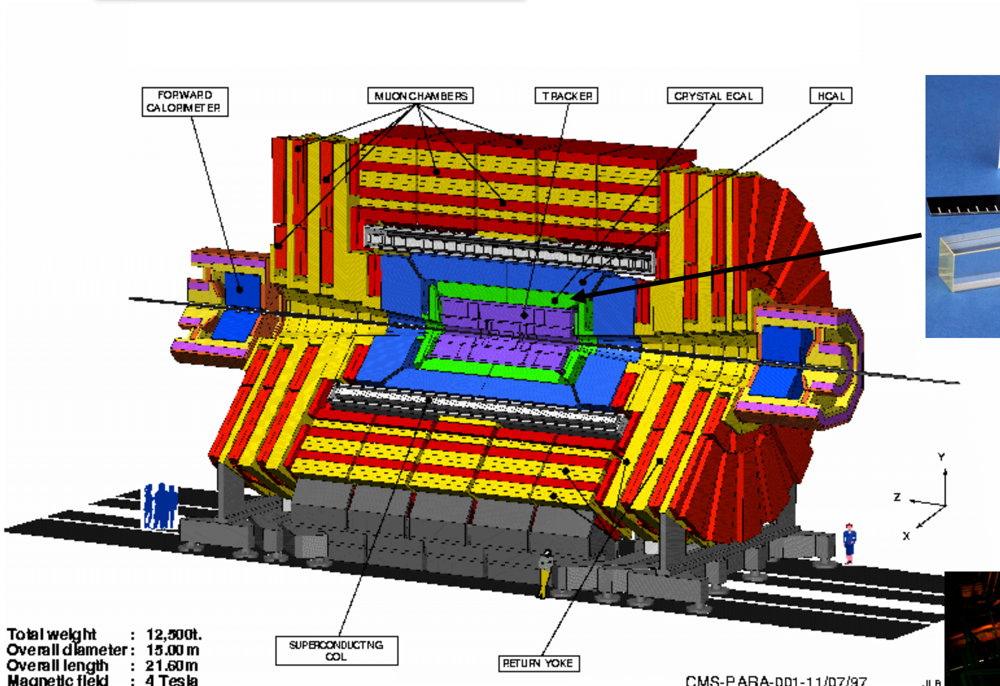


Resolution
(Pt=100GeV)

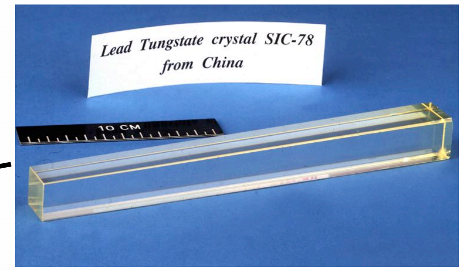
e, γ 1.5%
Muon 2-3%
Jets 8%

- 大きなDetector: **バランス 優先**のパフォーマンス とにかく大きい$\delta P/P \sim P/(BL^2)$ Lで勝負
- Accordion Shape of 液体 Ar カロリメータ （放射線耐性、**奥行き情報、Fine granuarity**）
- Large air-core toroidal magnet ミューオンシステム （トロイド磁石）

CMS検出器



$PbW0_4$

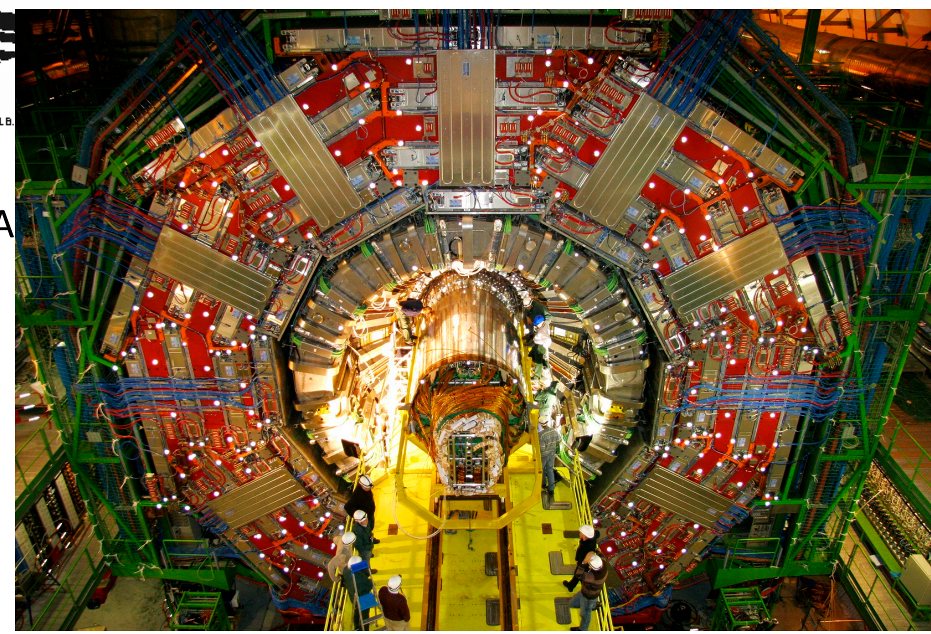


Resolution
(Pt=100GeV)

e, γ　0.9% !!
Muon　2-3%
Jets　12%

・小さくコンパクト　H=15m　L=22m (about half of ATLA
W=12,500ton (twice of ATLAS) 鉄のかたまり
return yoke　(密度3.2g/cc)

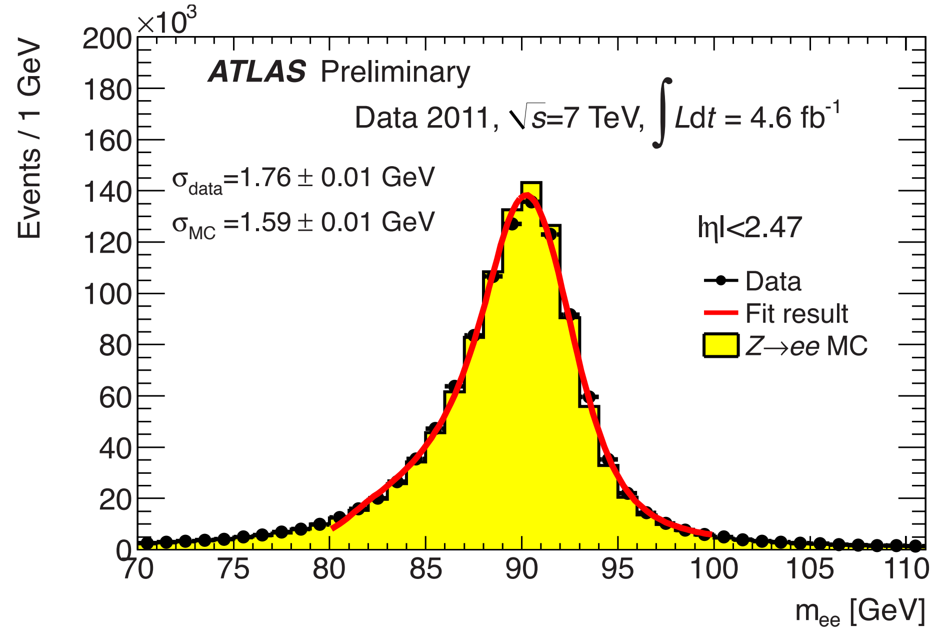
- 一点豪華主義
  $PbWO_4$ シンチ　　電子・γに賭けた（Higgs）
  (高いエネルギー分解能、奥行き情報無し)
- 4T（強力）ソレノイド磁石（小さいのでBで勝負）
  ハドロンの外側：（薄いハドロンカロリメータ）



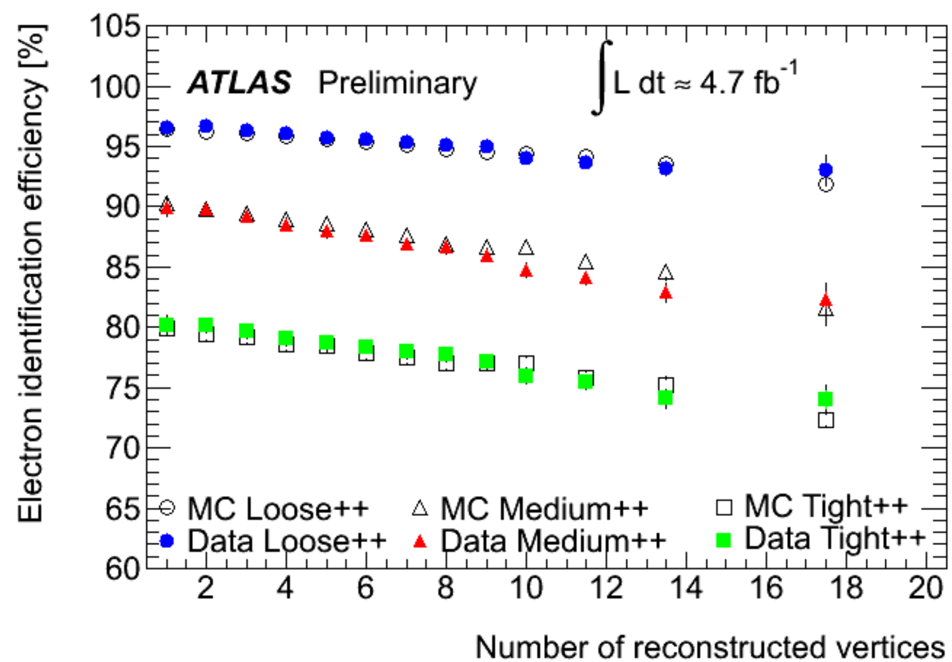
	ATLAS	CMS
特徴	アコーディオン型L.Ar トロイド磁石ミューオン バランスと細かさ	PbWO4　EM分解能 4Tソレノイド
飛跡検出器	B=2T　Lで勝負 連続飛跡可能（kink, disappear)	B=4T　Bで勝負 半導体不連続
電磁カロリ	LAr+Pb　10%/SQRT(E) 細かな+縦方向	シンチレーター　3%/SQRT(E) 細かく読み出せない
ハドロンカロリ	厚い鉄 + シンチレーター 50%/SQRT(E)	薄い真鍮 + シンチレーター 100%/SQRT(E)
ミューン	空芯トロイド multiple-scatter が少ない low PT もOK 磁場が複雑	ソレノイドのリターンヨーク 鉄　散乱が大きい 磁場が強く安定：前方は苦手
Trigger	3段構成 Hard + Local Soft + Full Reconst	2段構成 Hard + Full Reconst
つよみ	長生きもの ジェットが強い B-physics	e/γ もの simple なんでcalibrationが楽

2. 豊富な標準モデル過程
検出器 performance

ATLASの電磁カロリメーター
Z->ee



energy resolution σ =1.76GeV
2%



Identification efficiency ~ 80%
Pileupが増えても効果は小さい。
(80->75 %になるていど)
MCもほぼデータ再現
fake ~ 10^{-4} order

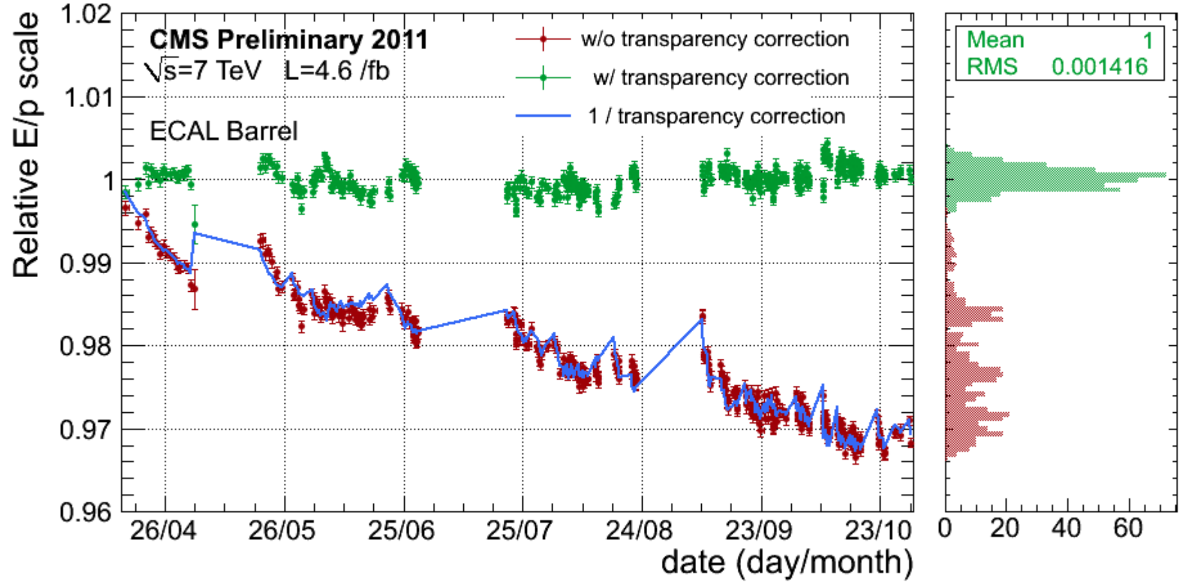
CMSの
電磁カロリメーター
Z->ee

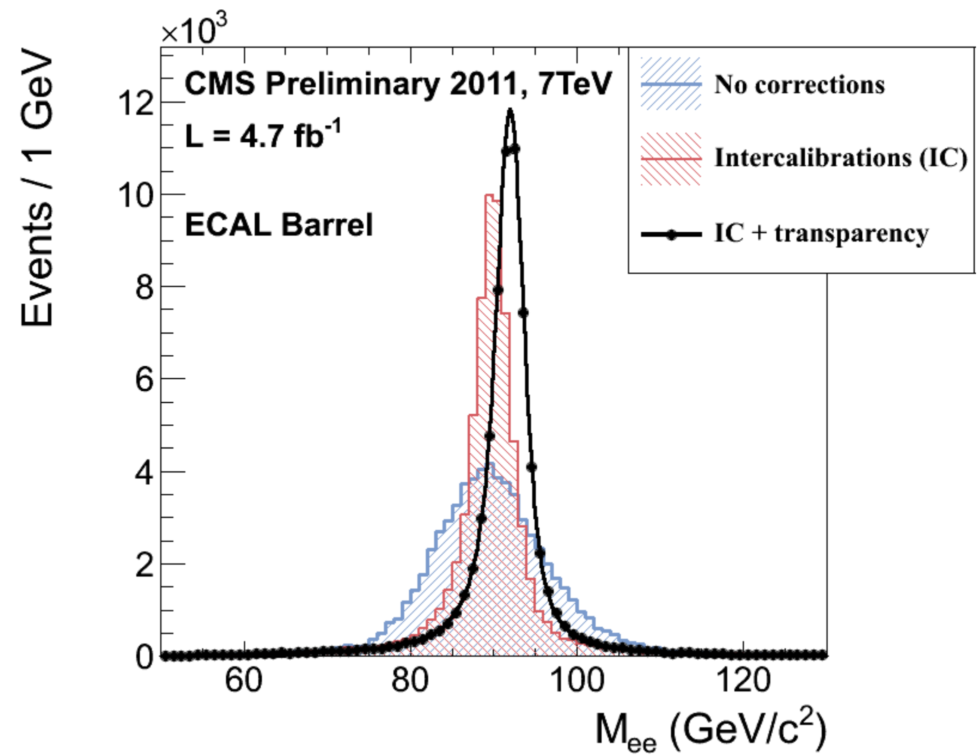
中性子のrad. damage で
透明度が変動する。
しかも、%のオーダーで
単調減少ではなく、beam
休止中にもどったり結構複雑
（中性子に長い間あてるテスト
　してなかった。）

レーザーで追尾して補正
σ~ 1GeV　1%までつめた。

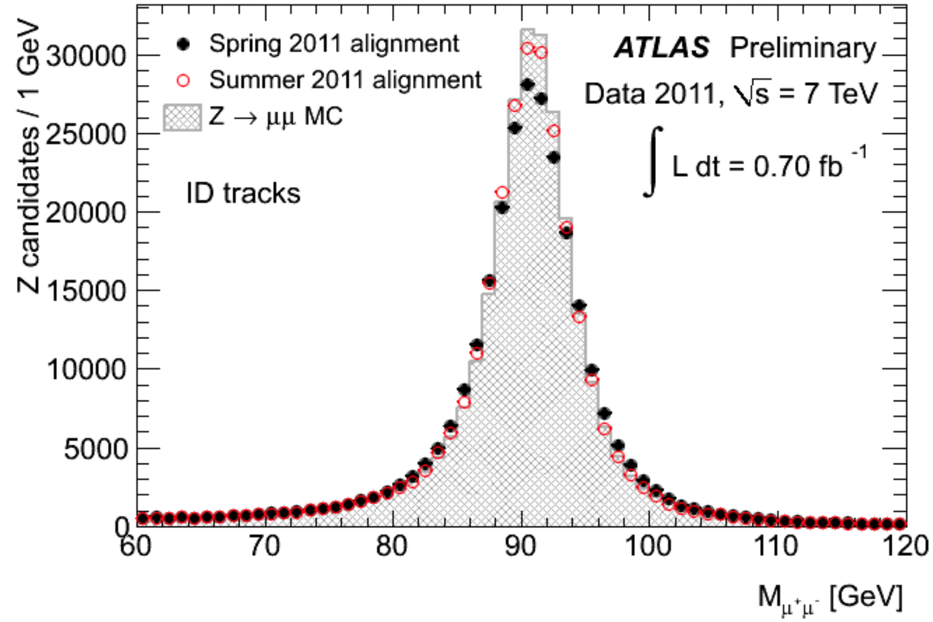
Barrel側だけ補正した
Endcap側はまだ。(rad. 多い)

Hart of CMSはまだ活かしきれ
いない



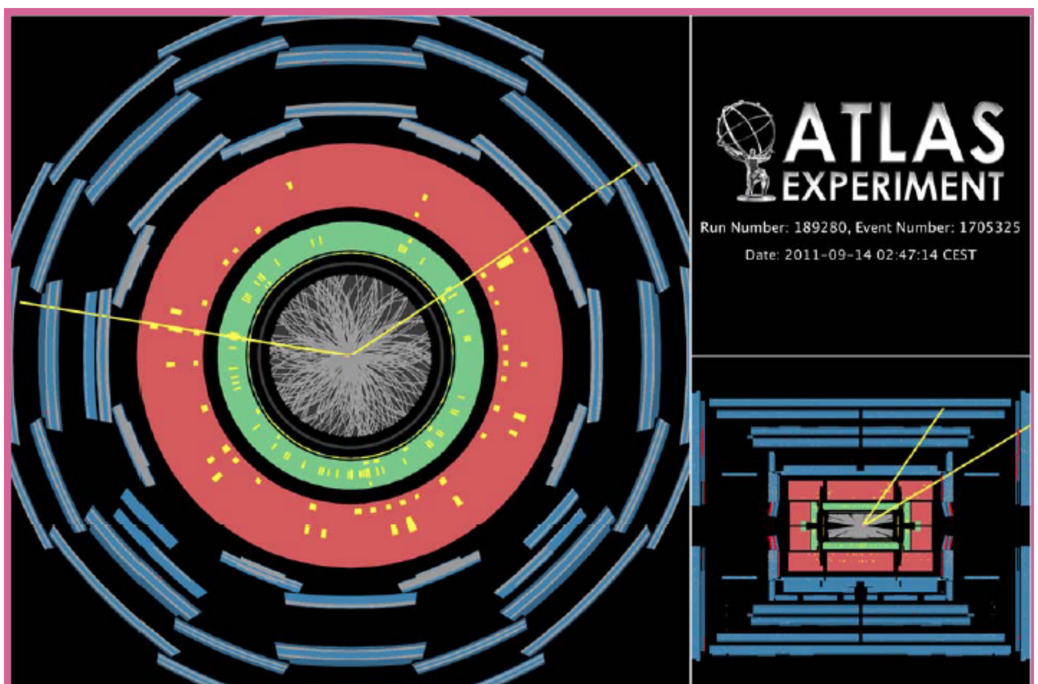


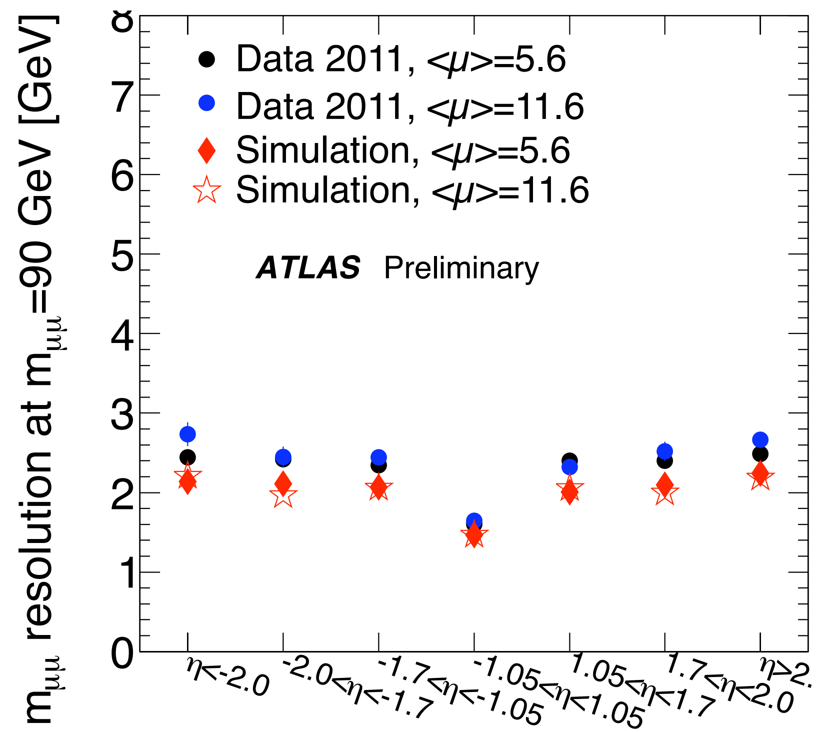
Z->mumu



muon のID efficiency
～ 90%
electronより高い
Fakeは10^{-5}　　Endcap側　多少悪化する

simulationとの差はcorrection
ている

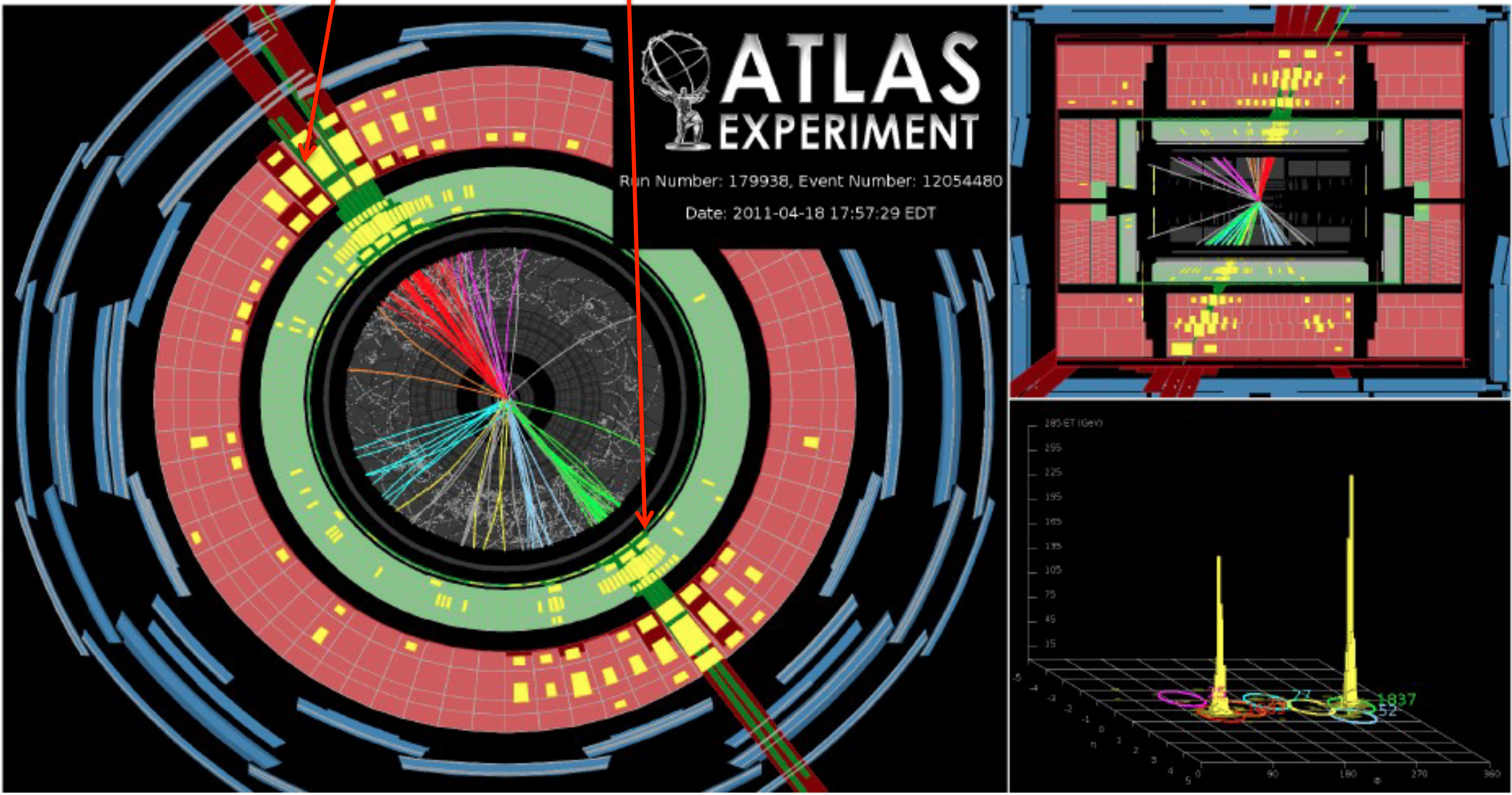




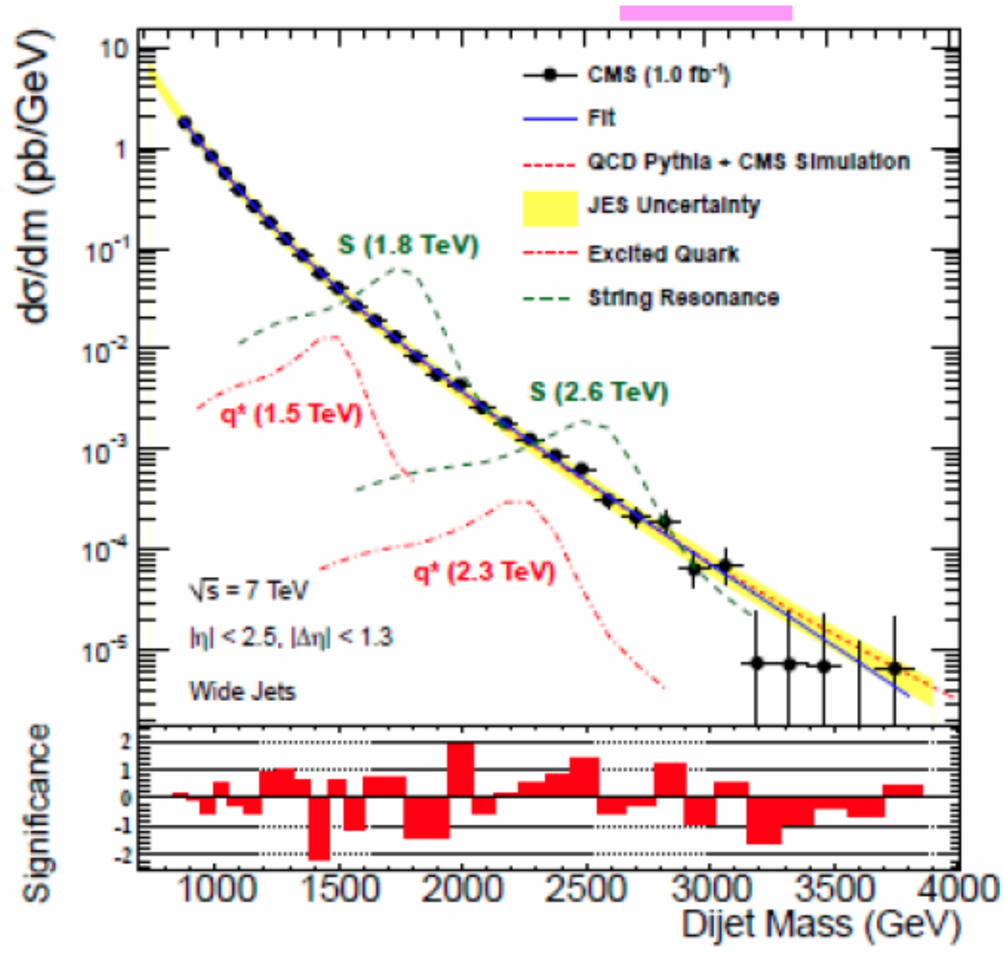
QCDジェット事象

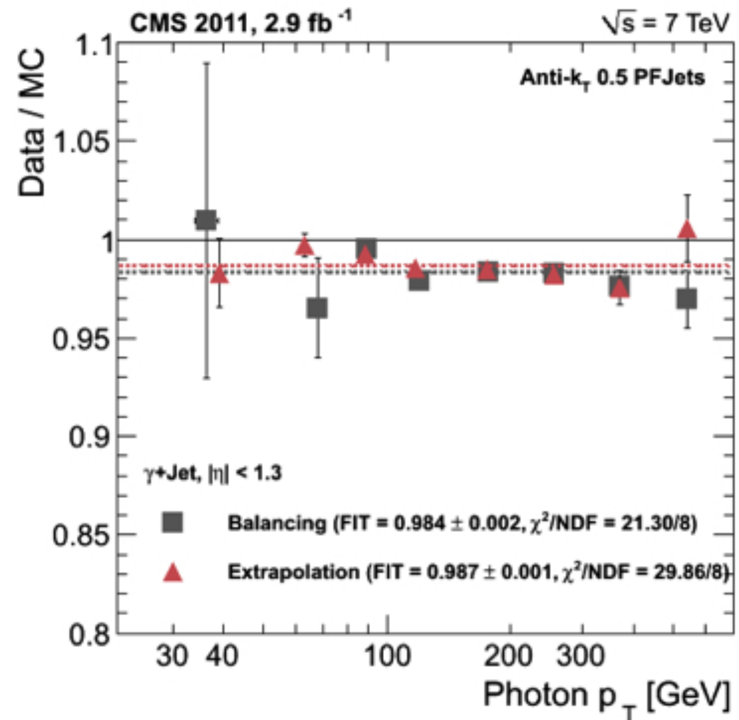
highest 2 jet mass

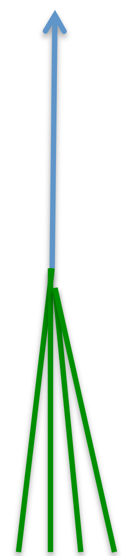
PT_1=1.8TeV　　PT_2=1.8TeV　　Mjj=4TeV　　x〜0.6



QCD Jet の断面積測定







γ、Z→ee

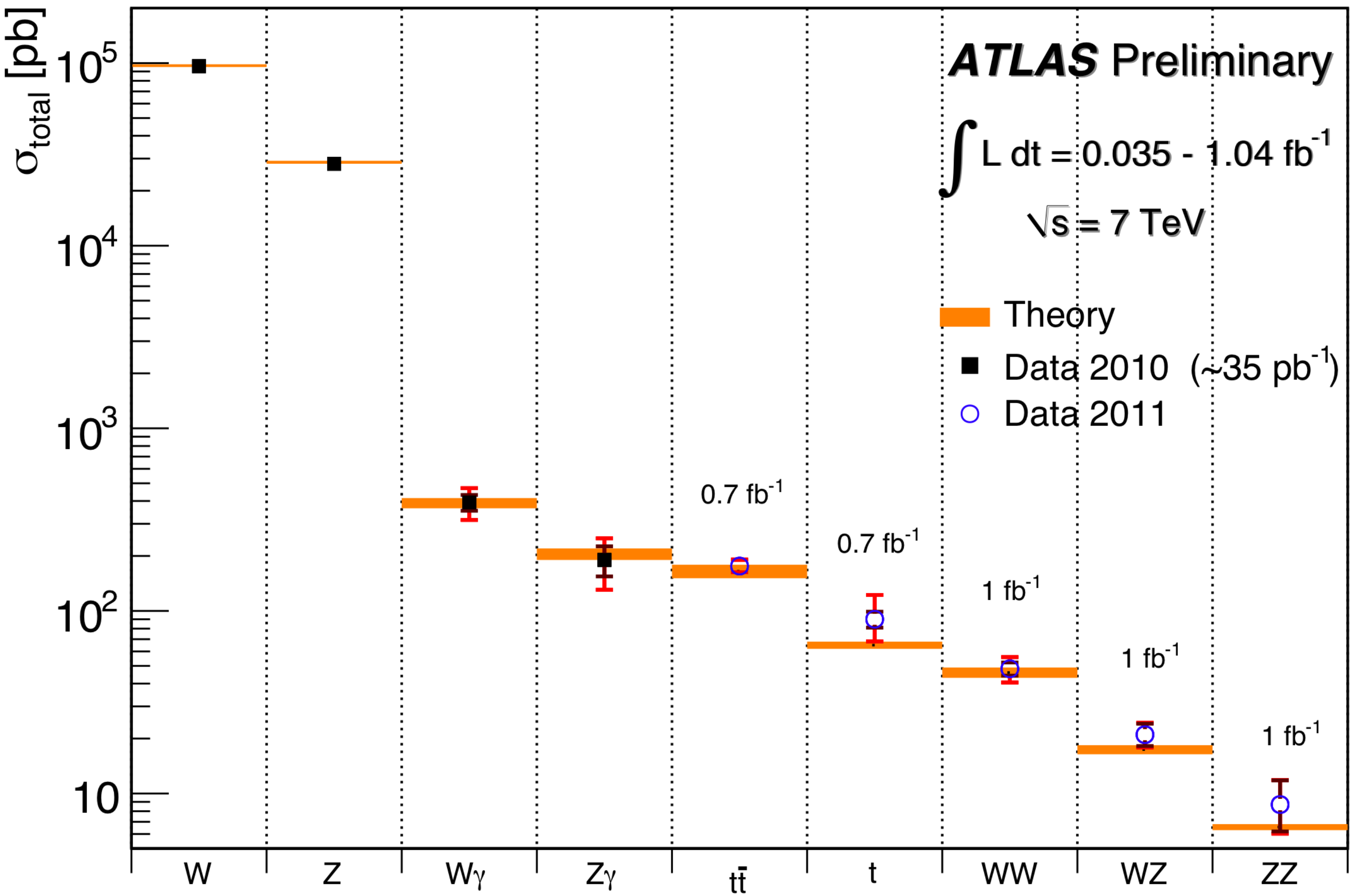
ジェット energy scale
2〜4%

最終的に 1%

ジェット

Pt jet, Mjj, もQCD(NLO)と一致
このバンド(JESの不定性)

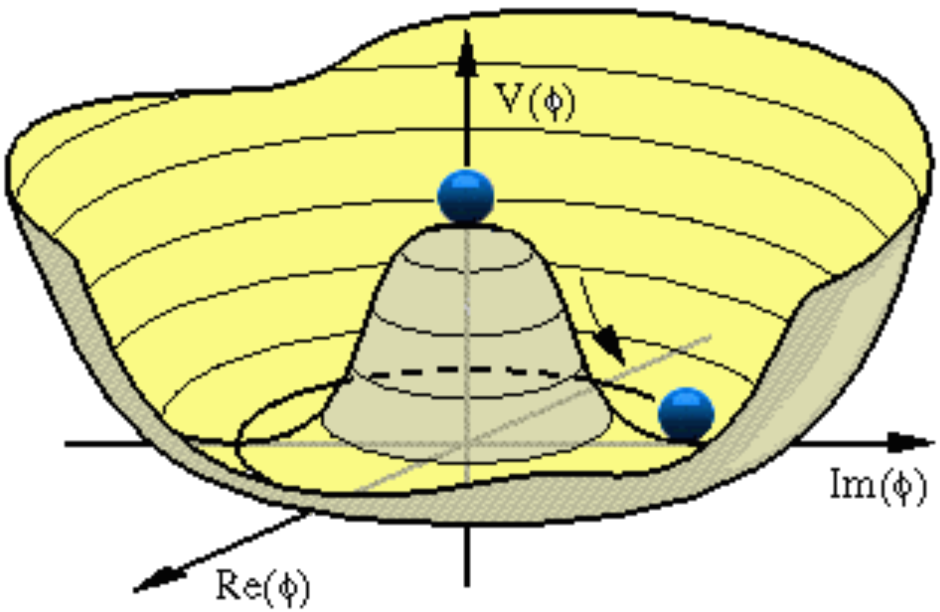
Standard Model 過程 の測定断面積を予言比較



よくあっている。 検出器の理解もだいぶ進んできている。

3. ヒッグス探索の最新結果

2008年ノーベル賞
南部先生
「自発的対称性の破れ」



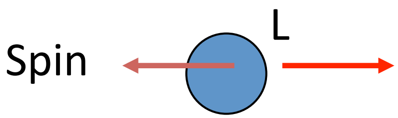
南部ゴールドストーンボソン
接線方向の自由度
Z,Wの縦波(mz=0)になり
Z、Wに質量を与えている

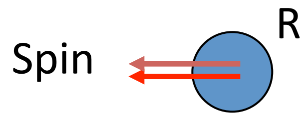
ヒッグス粒子　法線方向

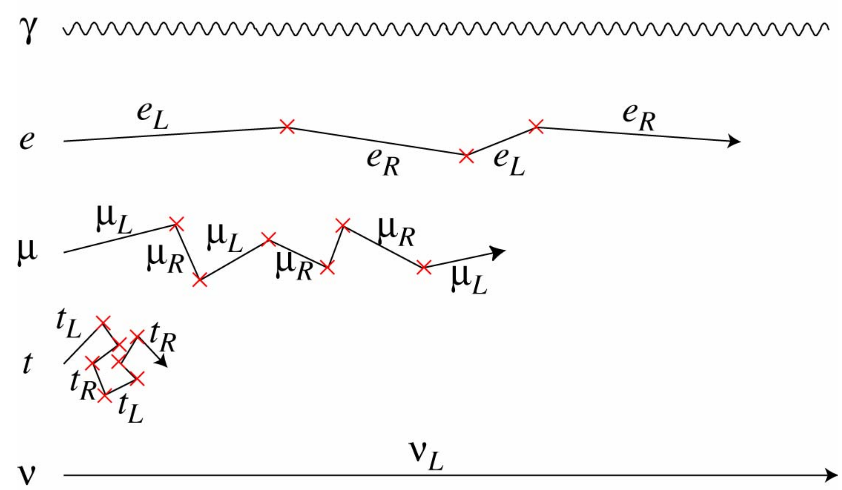
質量って？

慣性質量～重力質量
（弱い等価原理）

特殊相対論的な見地：
質量 があると、光速より遅くなる。 光速で運動する系から見ると、

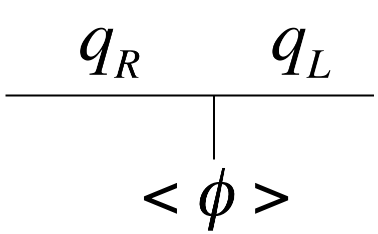






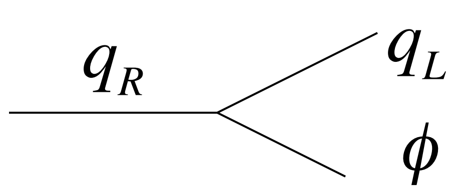
素粒子的にみると

R（右巻き）を消して、L（左巻き）
RとLはもともと全く違う粒子（量子数が違う）
弱い相互作用の電荷は　Lだけ

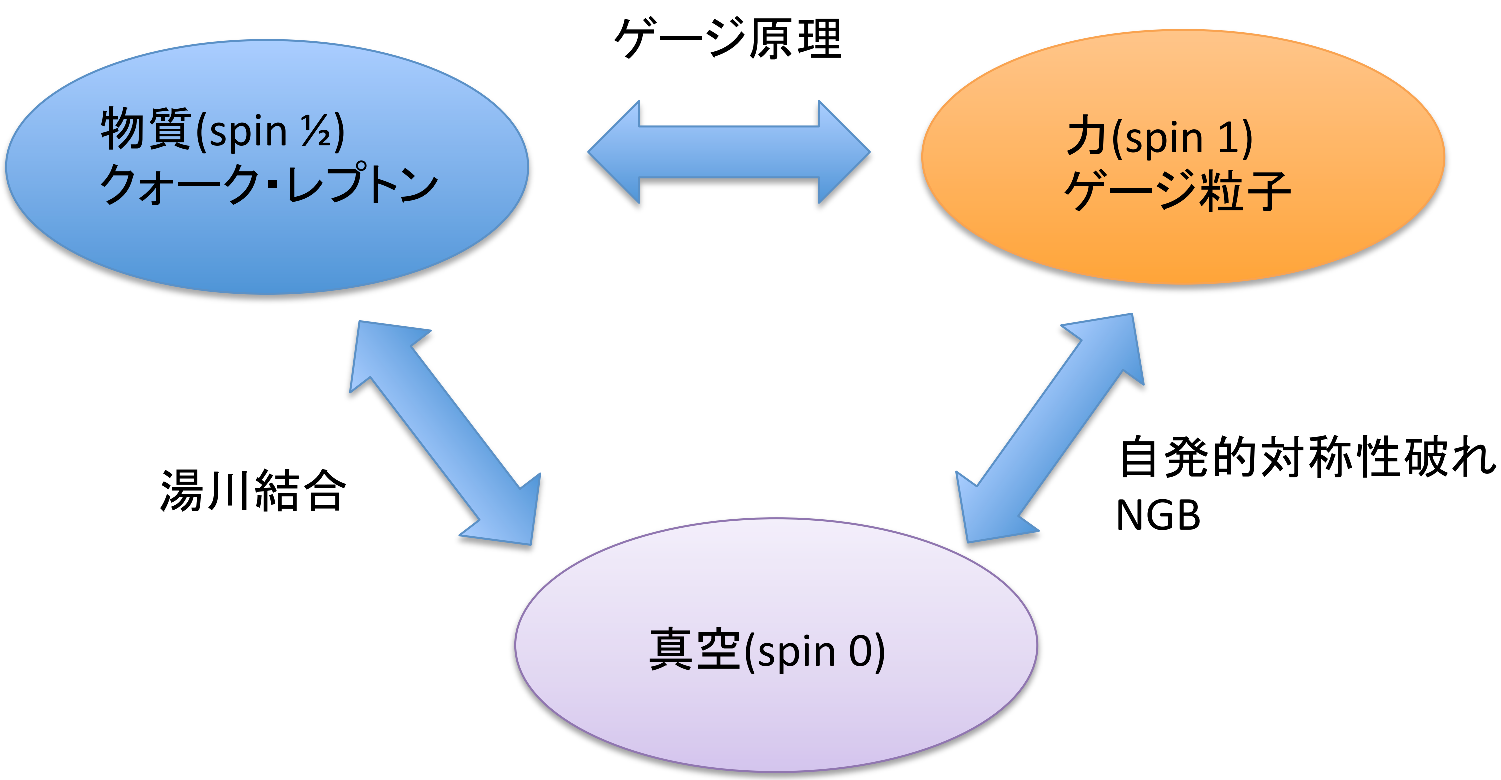


真空がΦを持っている
L-Rが絶えず交代しながら伝搬：
真空がL–Rの量子数の違いを吸収：
「真空は空ではない　」
非常に
豊かな構造をもっている

$$f_q \phi \bar{q}_L q_R$$



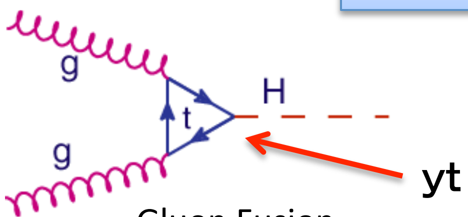
ヒッグス粒子発見の意義



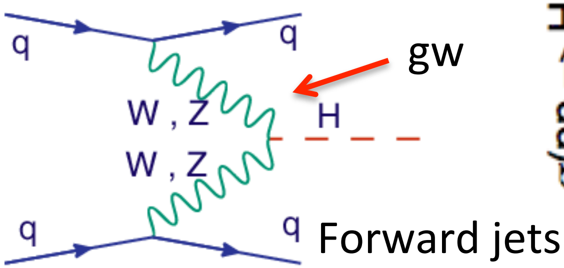
（1）真空に潜む場　（従来入れ物が極めて重要な役割を果たす）
（2）質量を与える役割　（二つの別の機構）

ヒッグス生成過程@ LHC

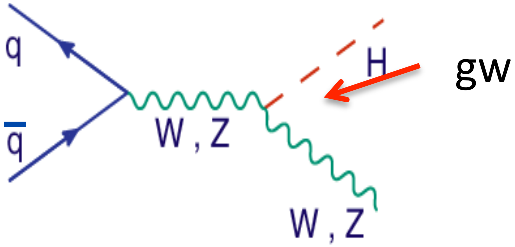
Leading



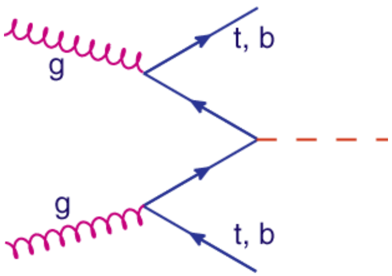
Gluon Fusion



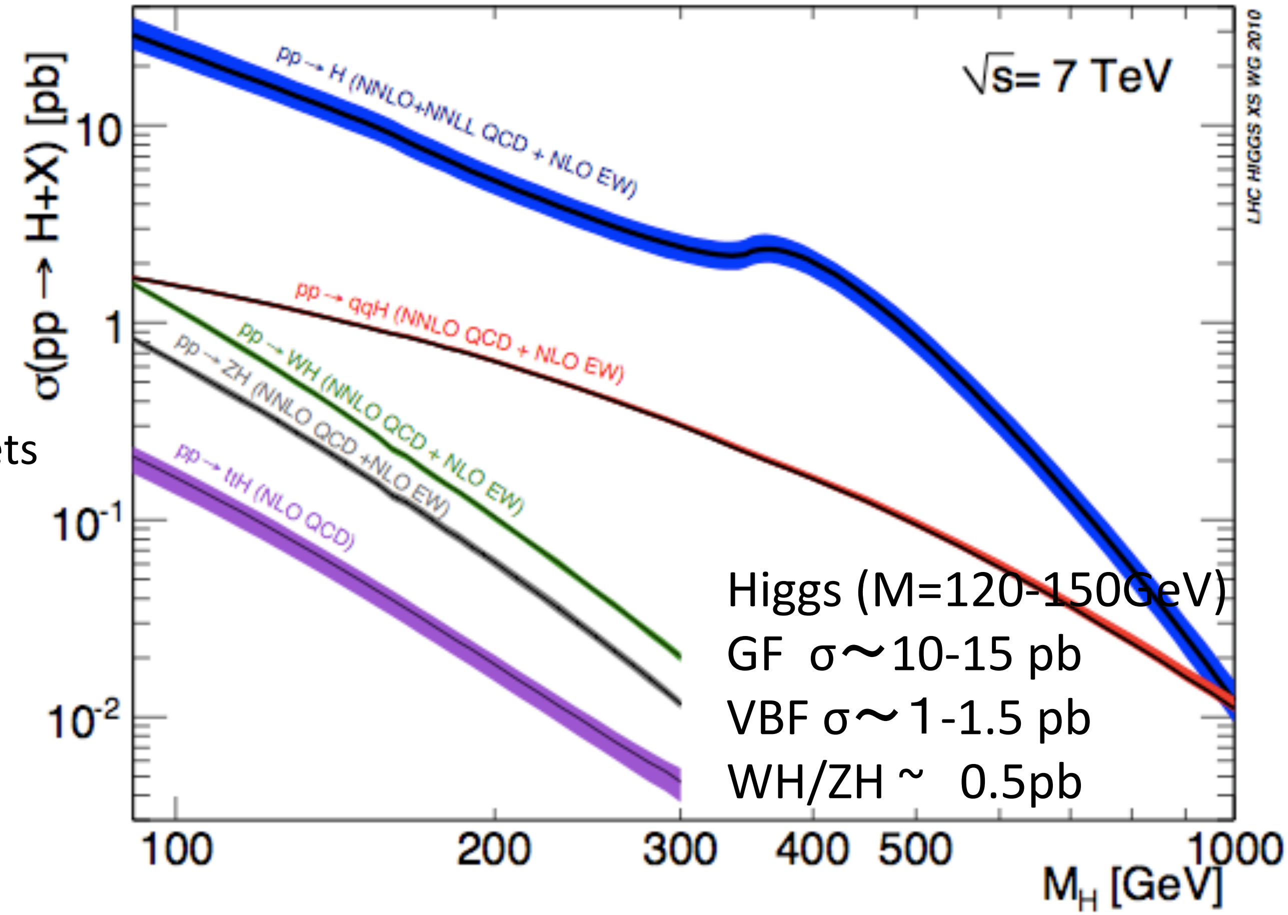
VBF



association production with W・Z



association production with top/b



Higgs (M=120-150GeV)
GF σ〜10-15 pb
VBF σ〜1-1.5 pb
WH/ZH ~ 0.5pb

湯川結合とGauge 粒子との結合と別々に見ることが可能：

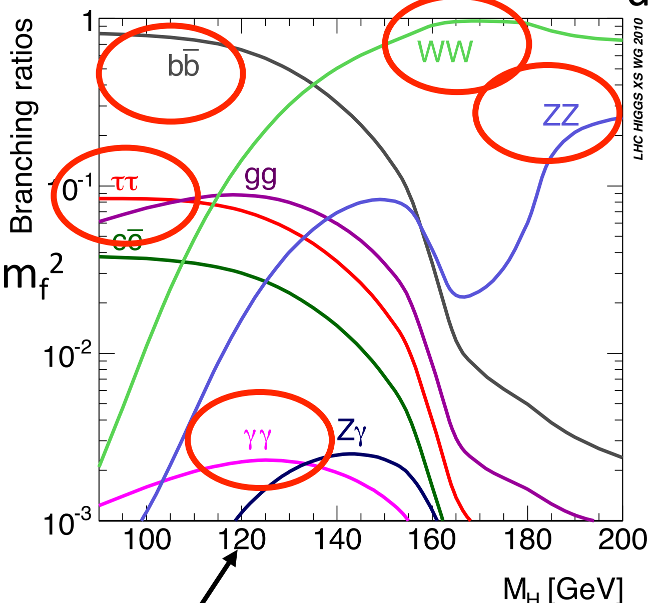
崩壊分岐比

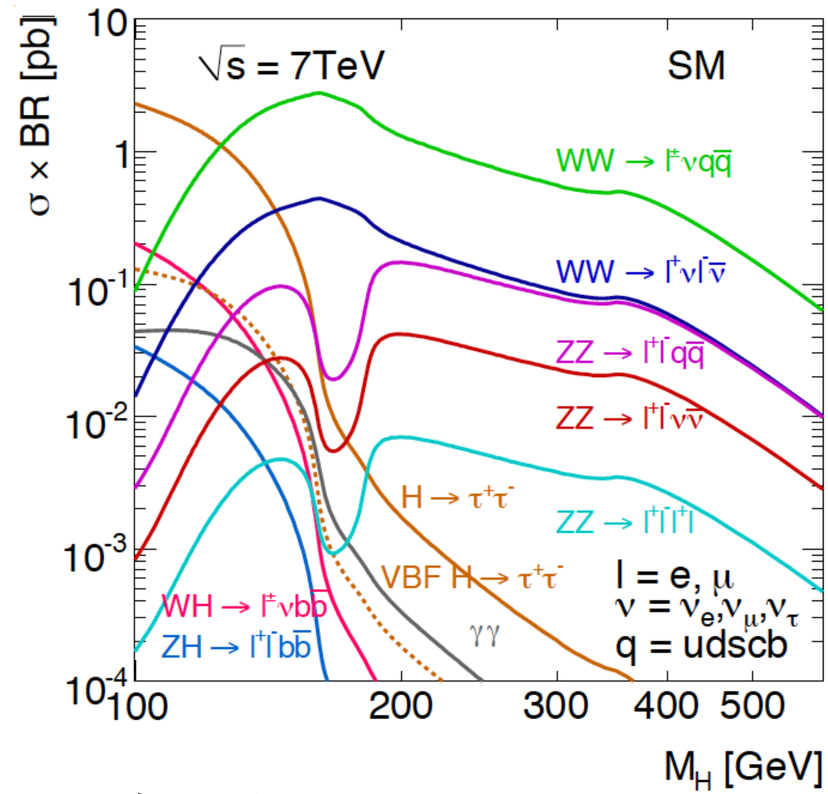
σ＊Br

Higgs decays into heavy particles:
5 important decay channels:

decay width
$\Gamma \sim m_h^3$

$\Gamma \sim m_h m_f^2$





Br = 2*10^{-3} small but clean

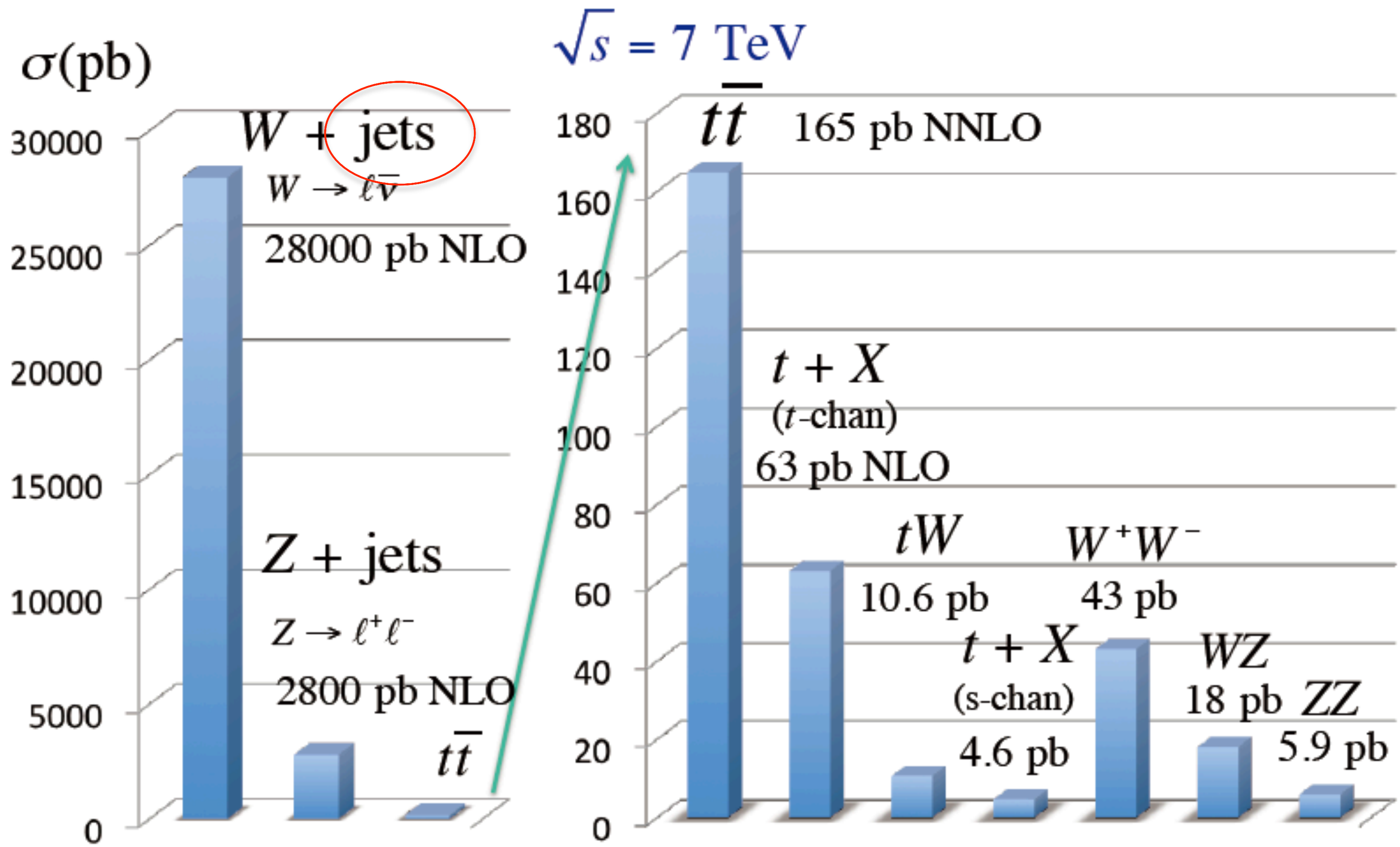
鍵となるチャンネル

GF(H-> γγ, WW(lvlv), VBF(tautau), WH(bb)
(M(H)～120 GeV)
GF (H→ WW(lvlv), WW(lvqq),ZZ(4l), ZZ(llqq))
(M(H)>130GeV)

bb, ττ, γγ mh < 135 GeV
WW , ZZ mh > 125 GeV

σ＊Br ~ 0.01-1 pb

Production σ of the SM background processes



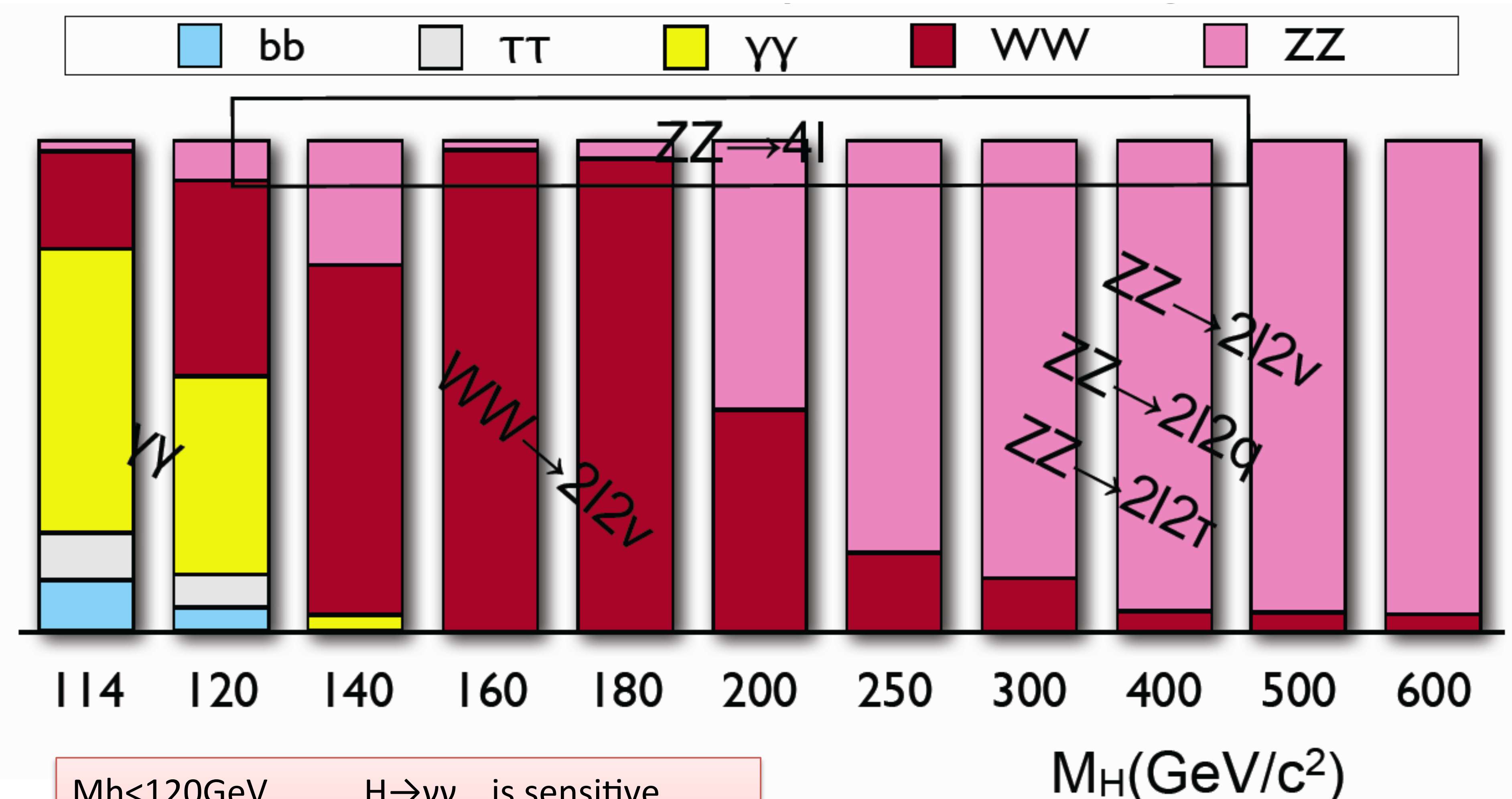
Gauge boson production factor ~ 10^4

top factor ~ 100

Di-boson irreducible factor ~ 10

Fake lepton: Jet is misidentified as lepton (Prob. 10^{-4})

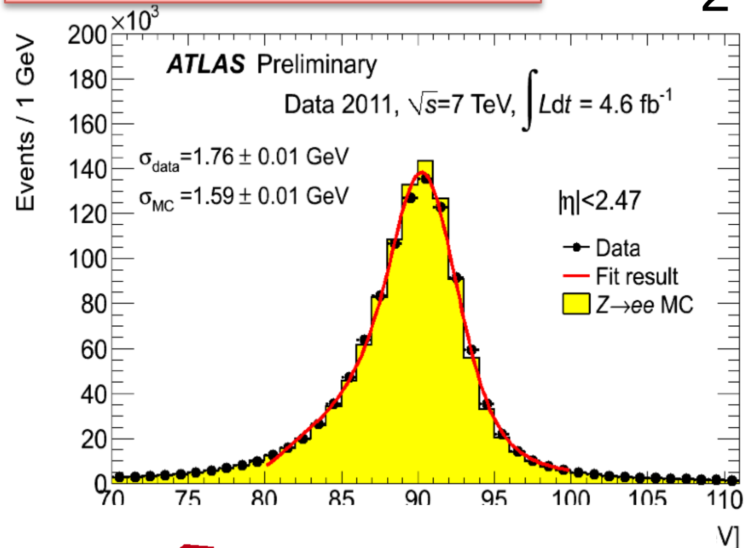
バックグラウンドまで考慮して、感度のあるチャンネルの貢献度を質量ごとのあわらすと

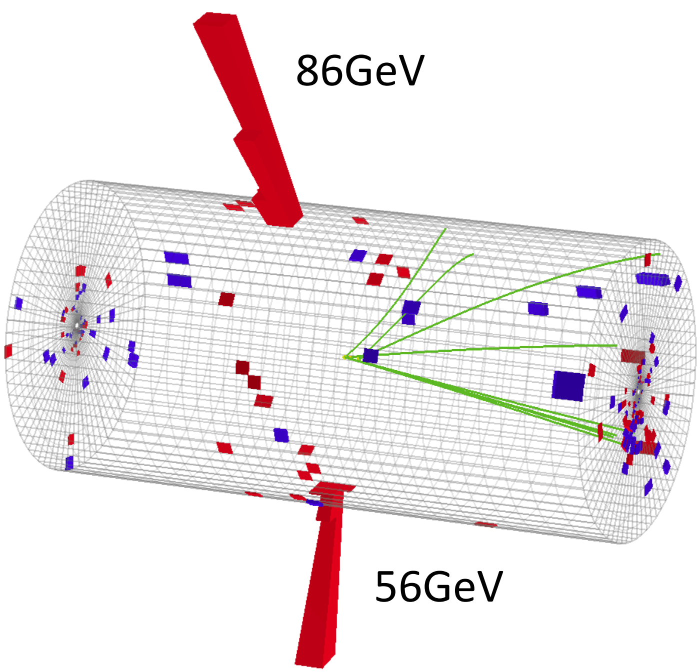


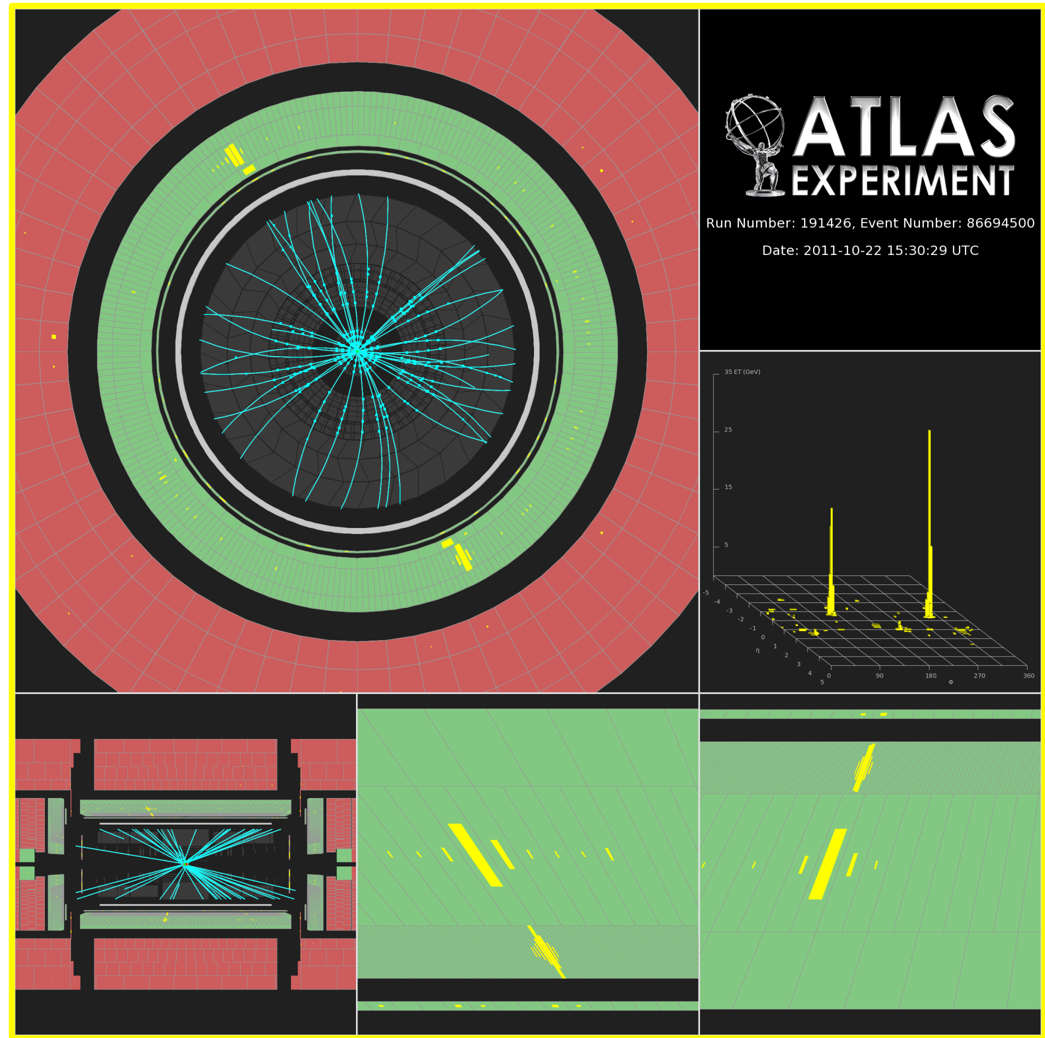
Mh<120GeV	H→γγ is sensitive
Mh=120-125GeV	H->WW,γγ, ZZ->4lepton
Mh=125-130GeV	H→WW,ZZ->4l, γγ
Mh>135GeV	H->WW,ZZ

[A] H→　γγ

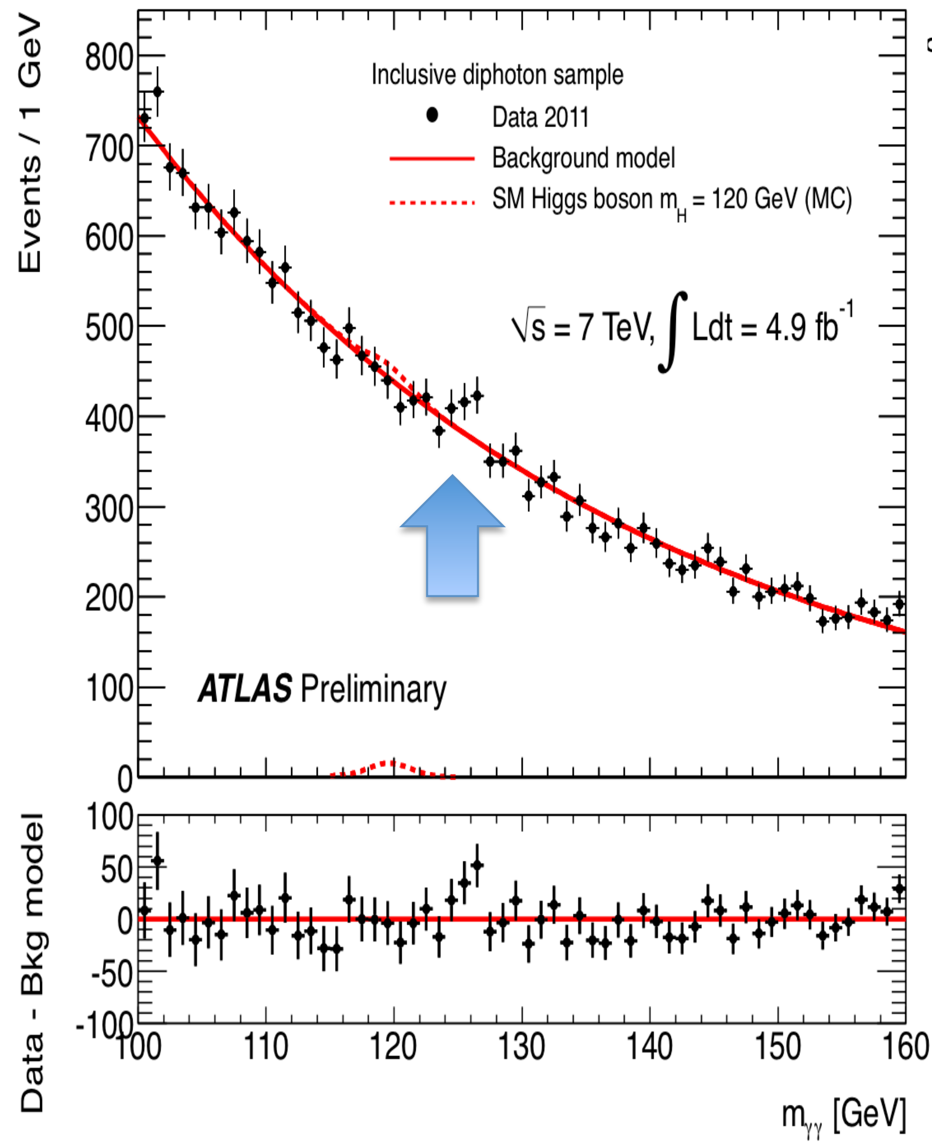
分岐比は、0.2%と小さいが
分解能がいい(σ　1.7GeV) ので綺麗なpeak
２つのγ(PT>40,25GeV)を要求

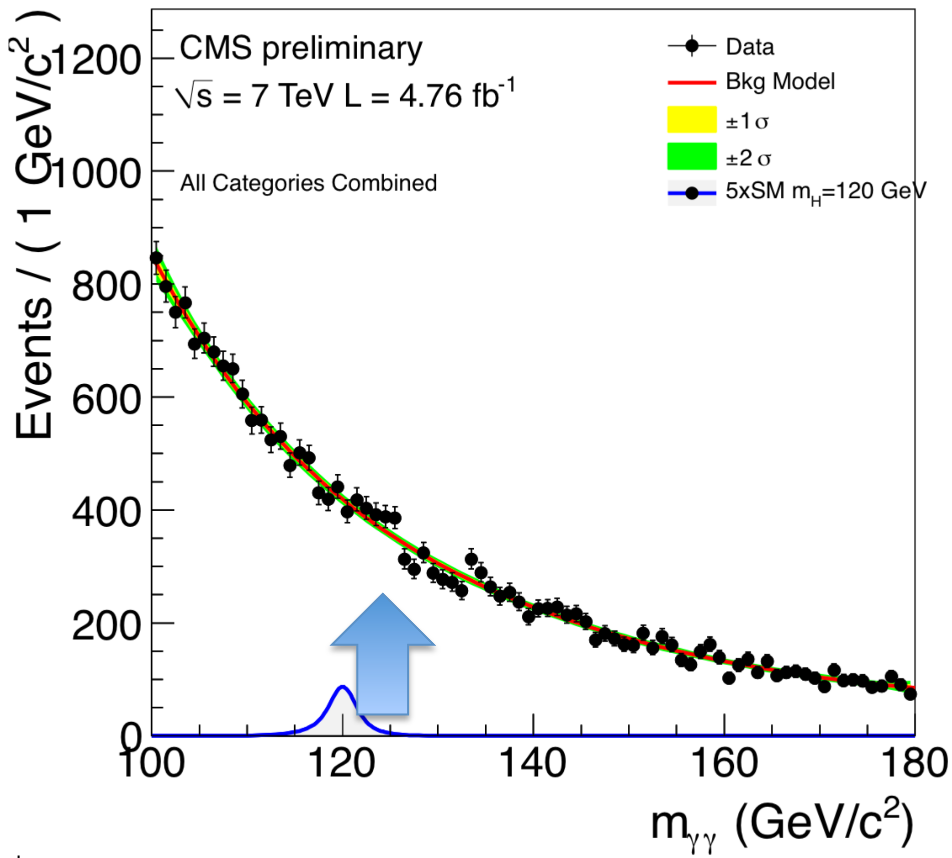






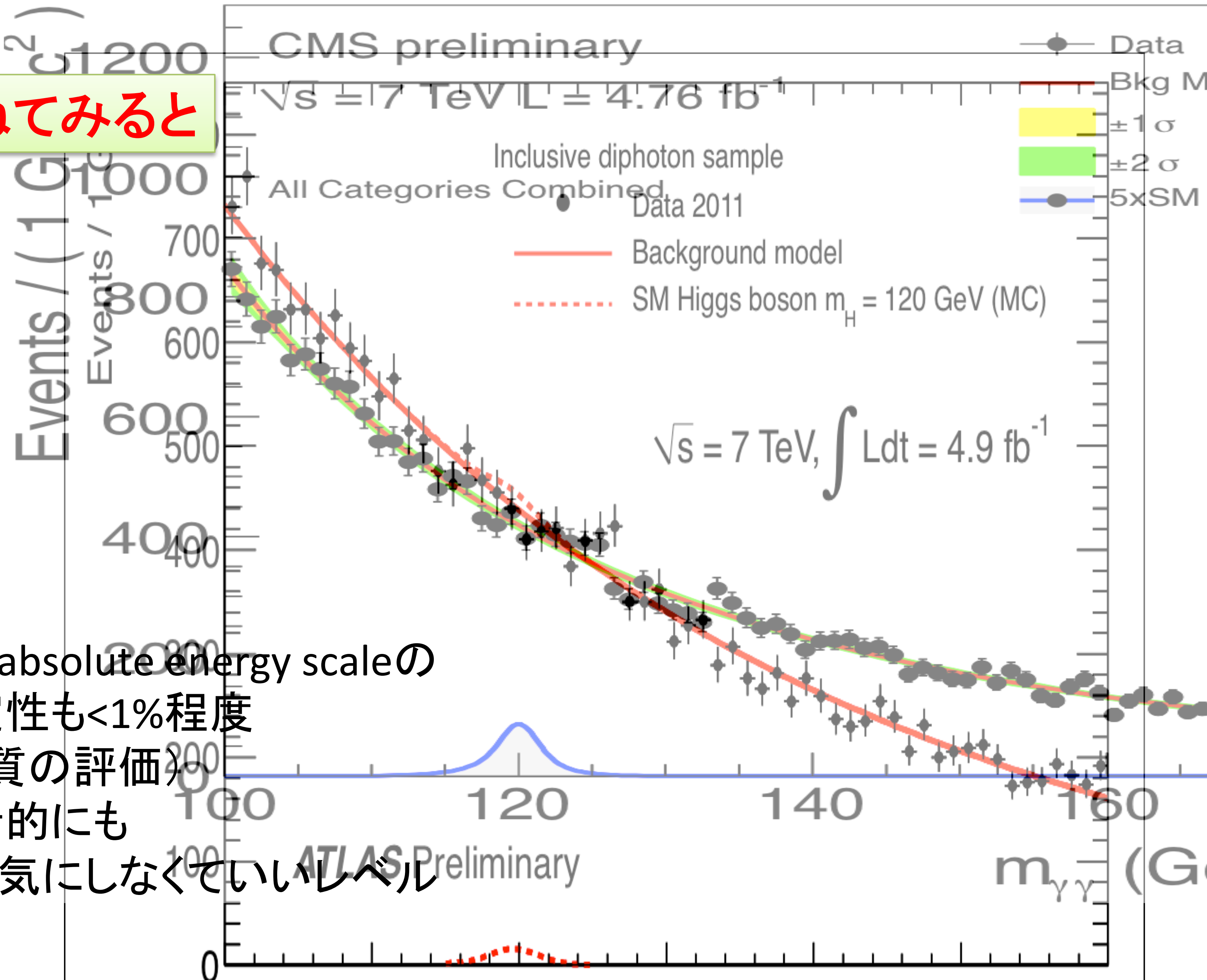
不変質量分布を出してみる



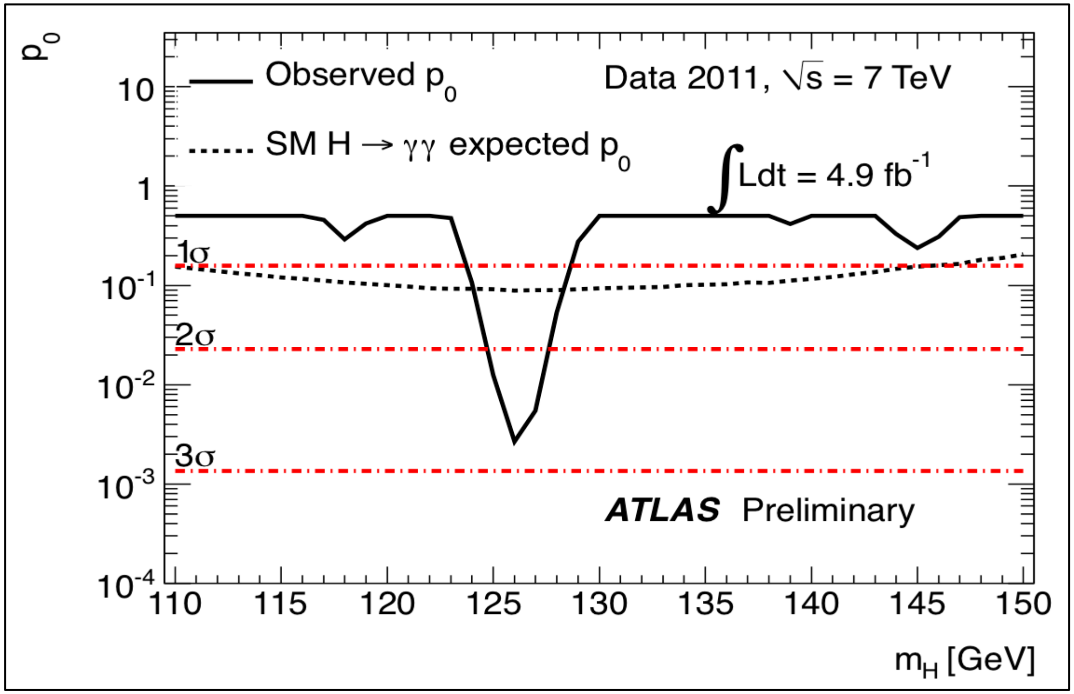


バックグラウンドは、実験データ
サイドバンドで評価

重ねてみると

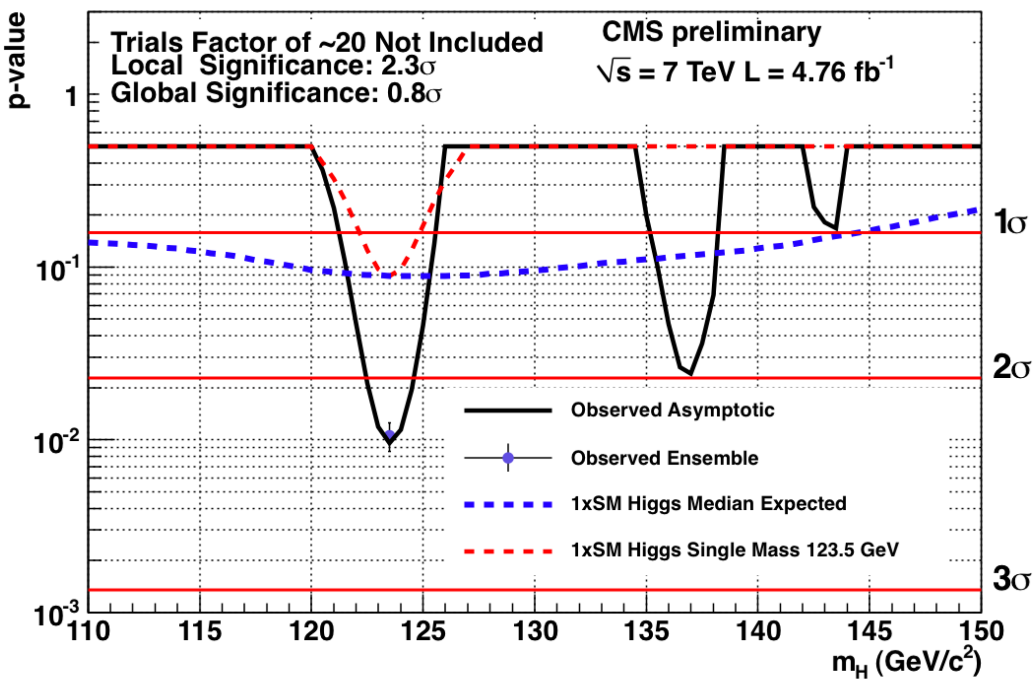


まだabsolute energy scaleの
不定性も<1%程度
(物質の評価)、
統計的にも
まだ気にしなくていいレベル



観測されたデータをバックグラウンドだけのふらつきで説明しようとする場合の確率　(local p value)

ATLAS　126 GeV　2.8σ　(0.27%)
CMS　124GeV 2.3σ (1%)



気になる点：

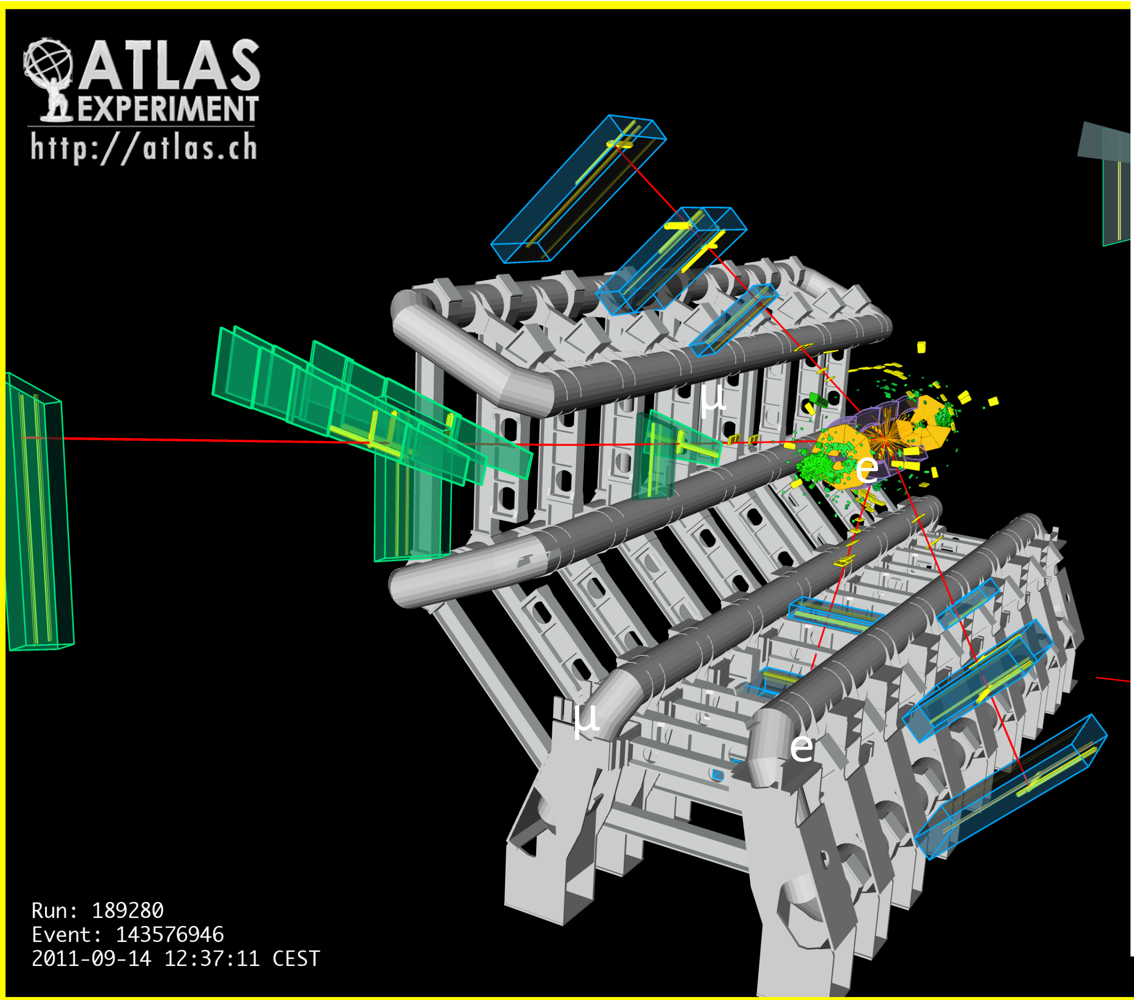
(1)　124 vs 126 まだ深刻でない

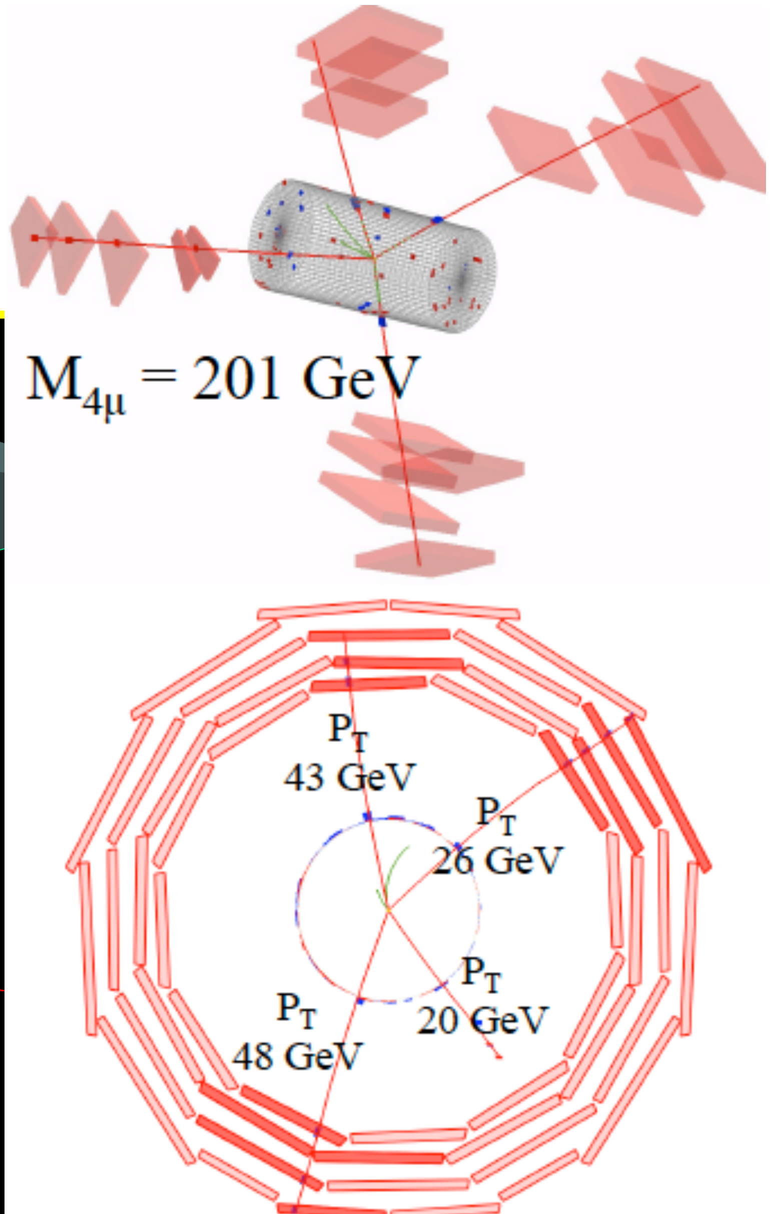
(2)どっちも　SMの予言２倍程度

- 統計でふらついて多めにでている？
- new physics?
  NMSSM など

[B] H→ZZ→4lepton

Good resolution of Lepton(e.mu) (ΔM_{4l}~ 3GeV)
Small BG (Almost BG free Mh<180GeV) **-> Gold-plated**
But Statistic is limited, since Br(Z->ee,mumu) is small

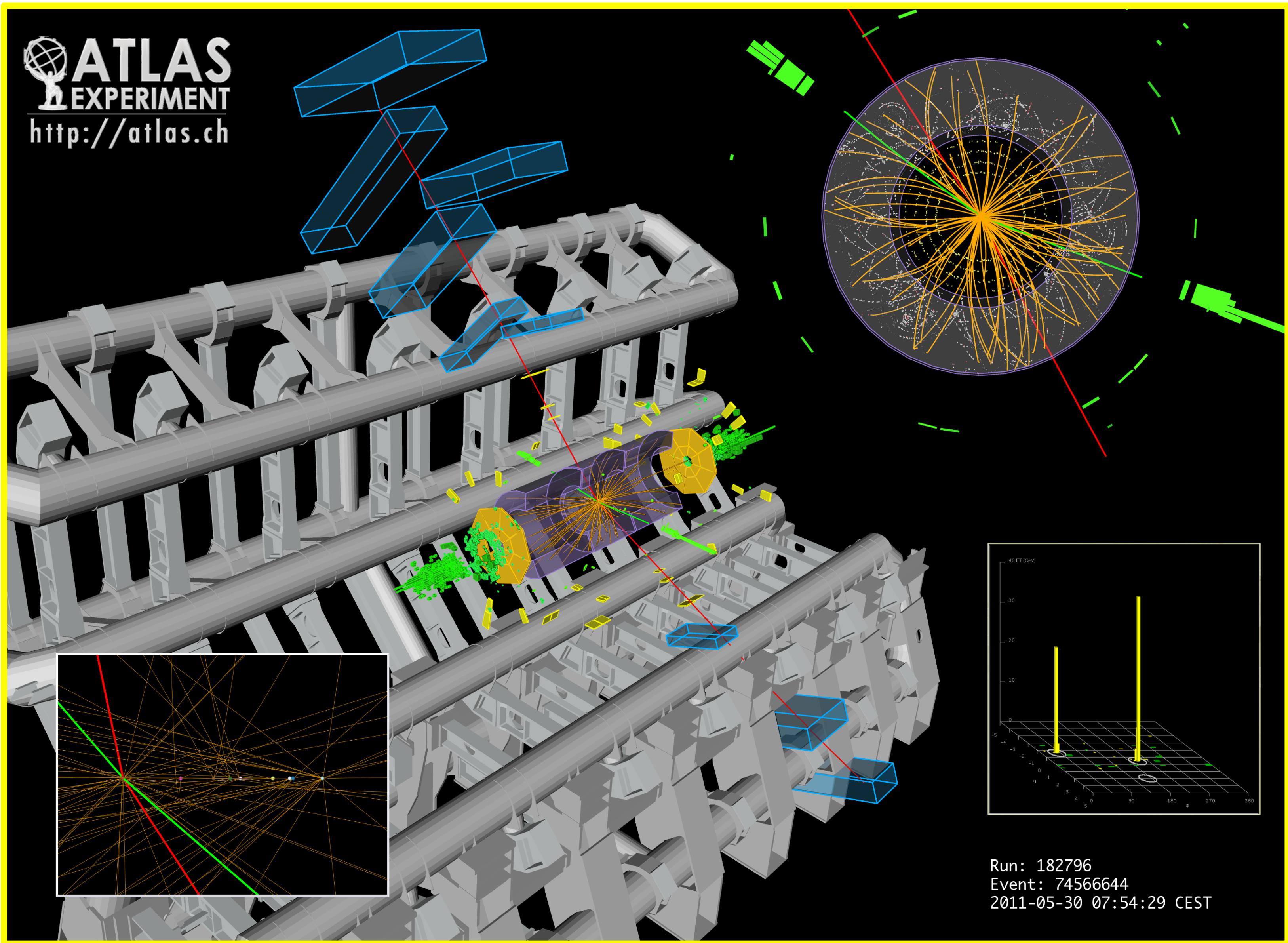




ZZ* -> μμ eeの候補

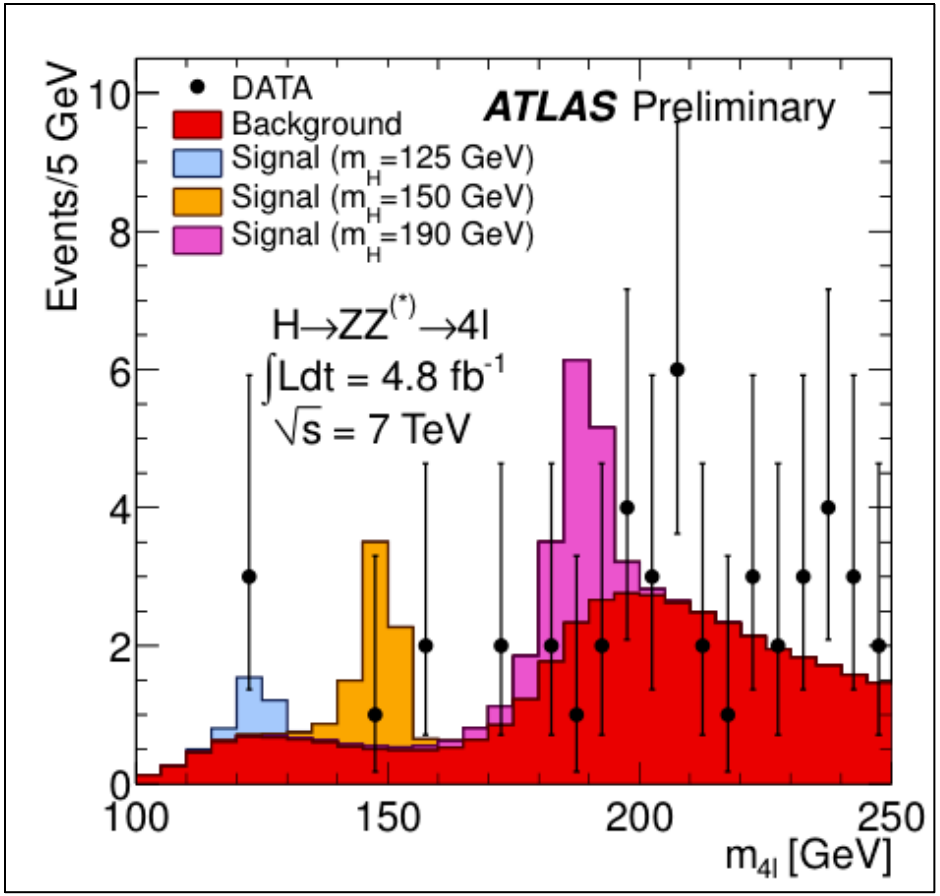
一方 Zは on-shell |Mll-Mz| < 15 GeV

もう一方が off-shell Mll>15GeV

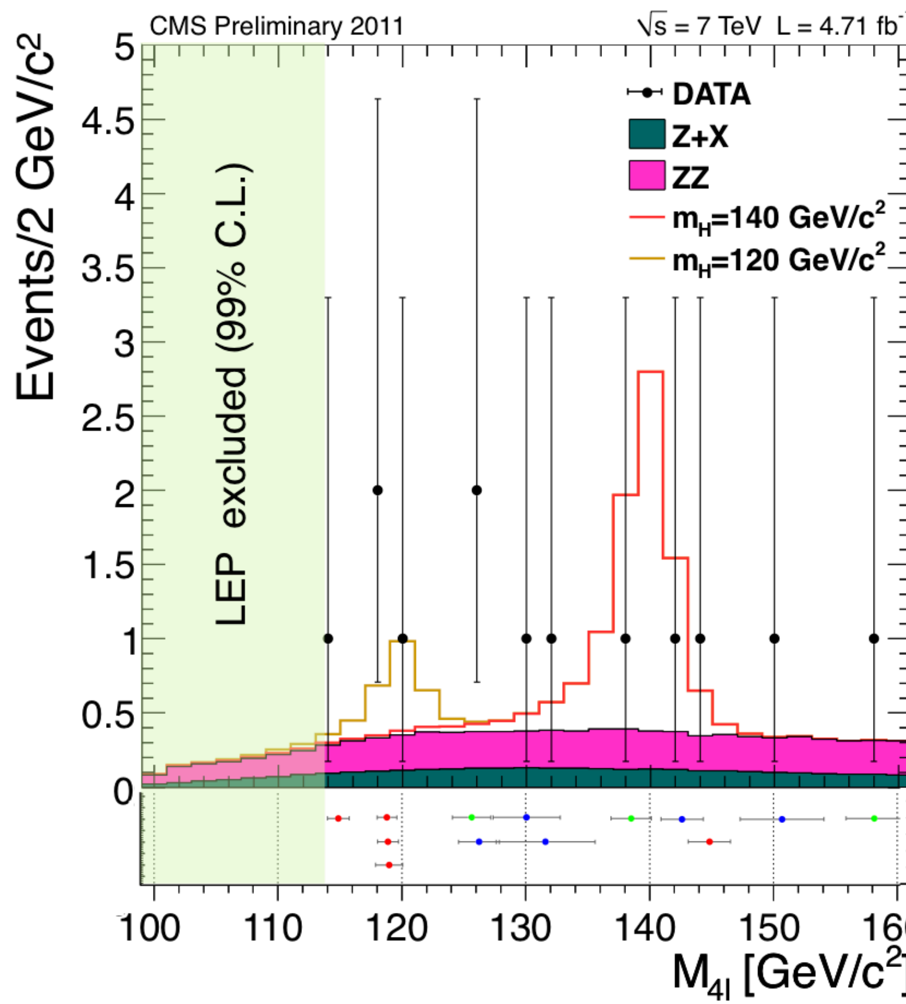


M_{4l} distributions

6 observed



13 observed (9.5+- 1.3 expect)



qq_bar->ZZ production が dominant BG, 閾値 190GeV （それ以下BG少ない）

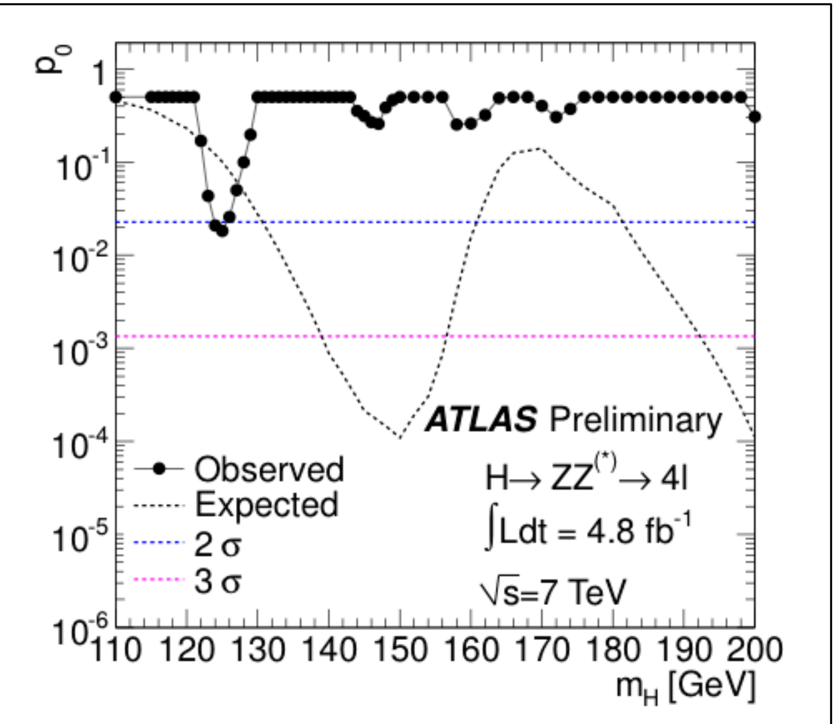
125GeV 付近 ATLAS 3 (4mu 2e2mu 2e2mu) CMS 2 (4e 2e2mu)

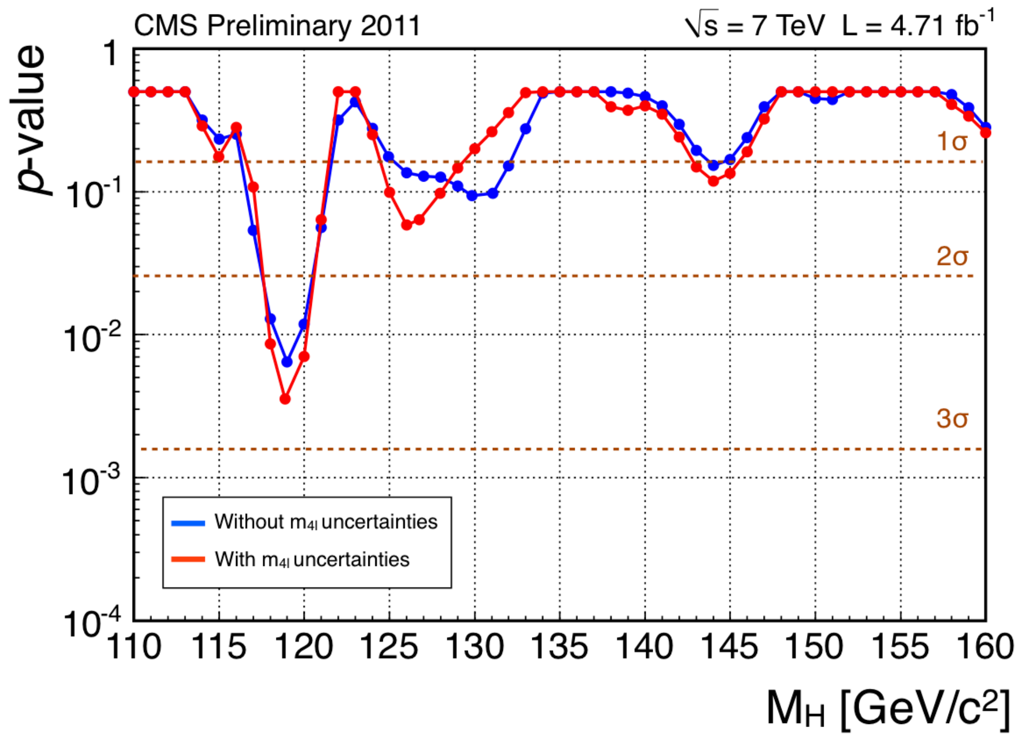
119GeV 付近 CMS 3(4mu)

ATLASの方が leptonの選び方がtight fakeがすくない
Fake lepton 1/3ぐらいある

ATLAS　3発 2.1σ(1.8%)

CMS　3発 0.4% 119GeV
2発 5%　126GeV





注意しなければならない、少数統計の怖さ

「どこでも効果」(Looking Elsewhere effect)

LEE(Looking Elsewhere Effect)「どこでも効果」

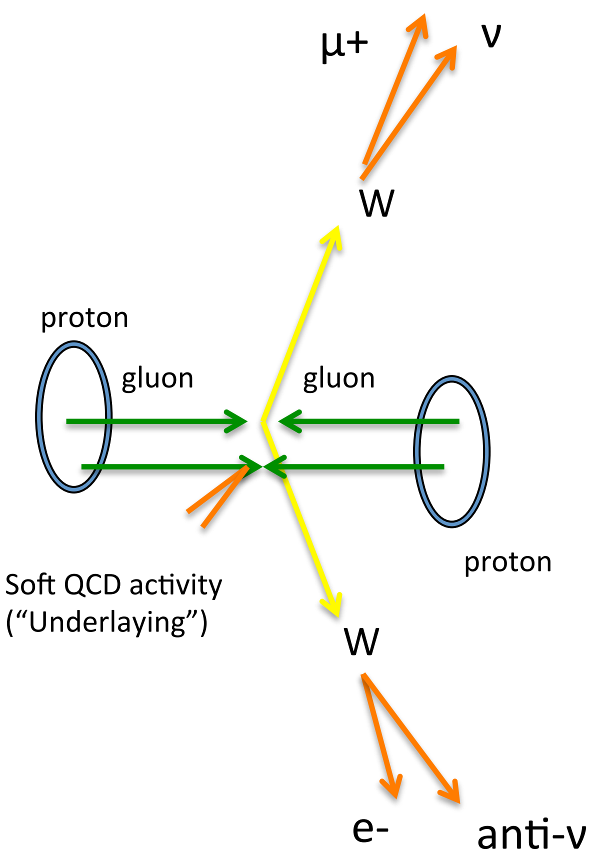
少数統計の際の計算や、複数の解析で 事象超過が見えた時、それをcombineする時に注意が必要

例として誕生日を考えます。1年365日生まれる確率は一定だとします。二人の誕生日がたまたま1月1日で一致する確率は、(1/365)*(1/365)～10^{-6} となり、5σ近い非常に希なことになります。しかし、どこでもいいから一致する確率は 365*(1/365)*(1/365)=1/365 ～ 0.3%(1000回に3回)と結構大きな値になります。どこ日でもいいが、たまたま一致して、この一致した日が1月1日の可能性もあります。このように「どこでも良い」が、たまたま一致する効果をLEEといいます。

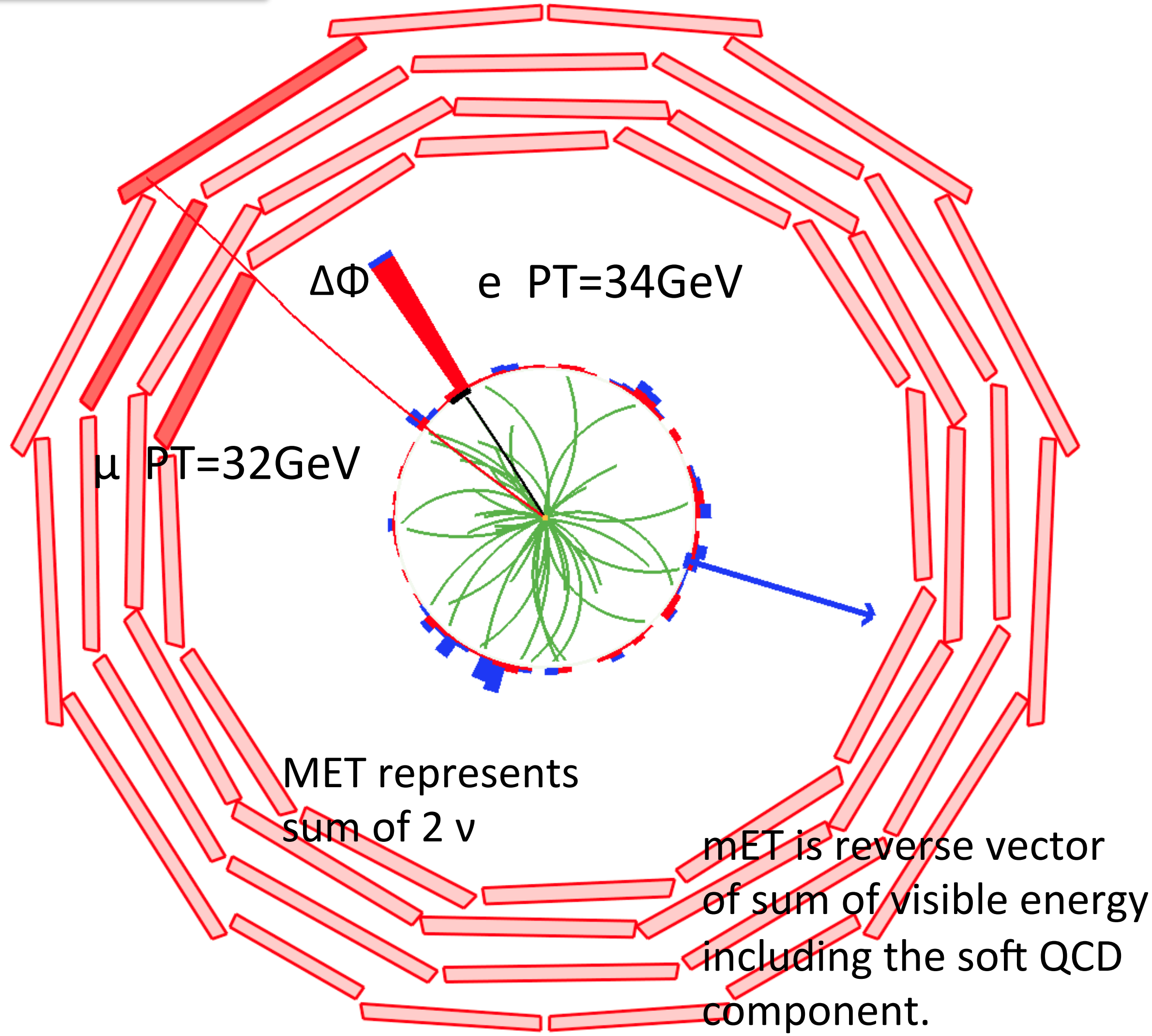
（「どの日でもいい」が　の範囲が鍵：　これを365日まで拡げると、0.3%
1ヶ月　1月の中で一致する　0.03%
1日　1/1まで狭めると、　10^{-6}　で　確率は範囲に依存する）

Higgs ZZ-> 4lにもどると
125GeV(local) のBGがふらついて、たまたま3発観測される確率は　**2.1σ(1.8%)**
115-146GeV(夏までのexcludeされてない領域)の全体（global)でたまたま3発同じ所に観測される確率は　**~ 30%**

[C] H→WW→lνlν

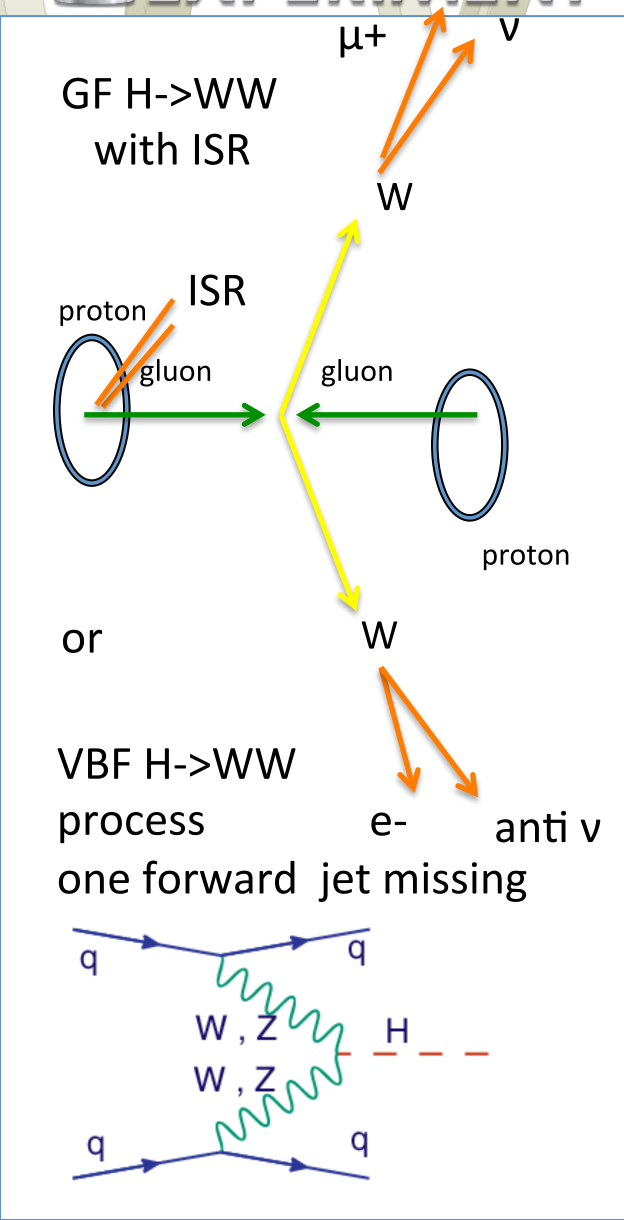


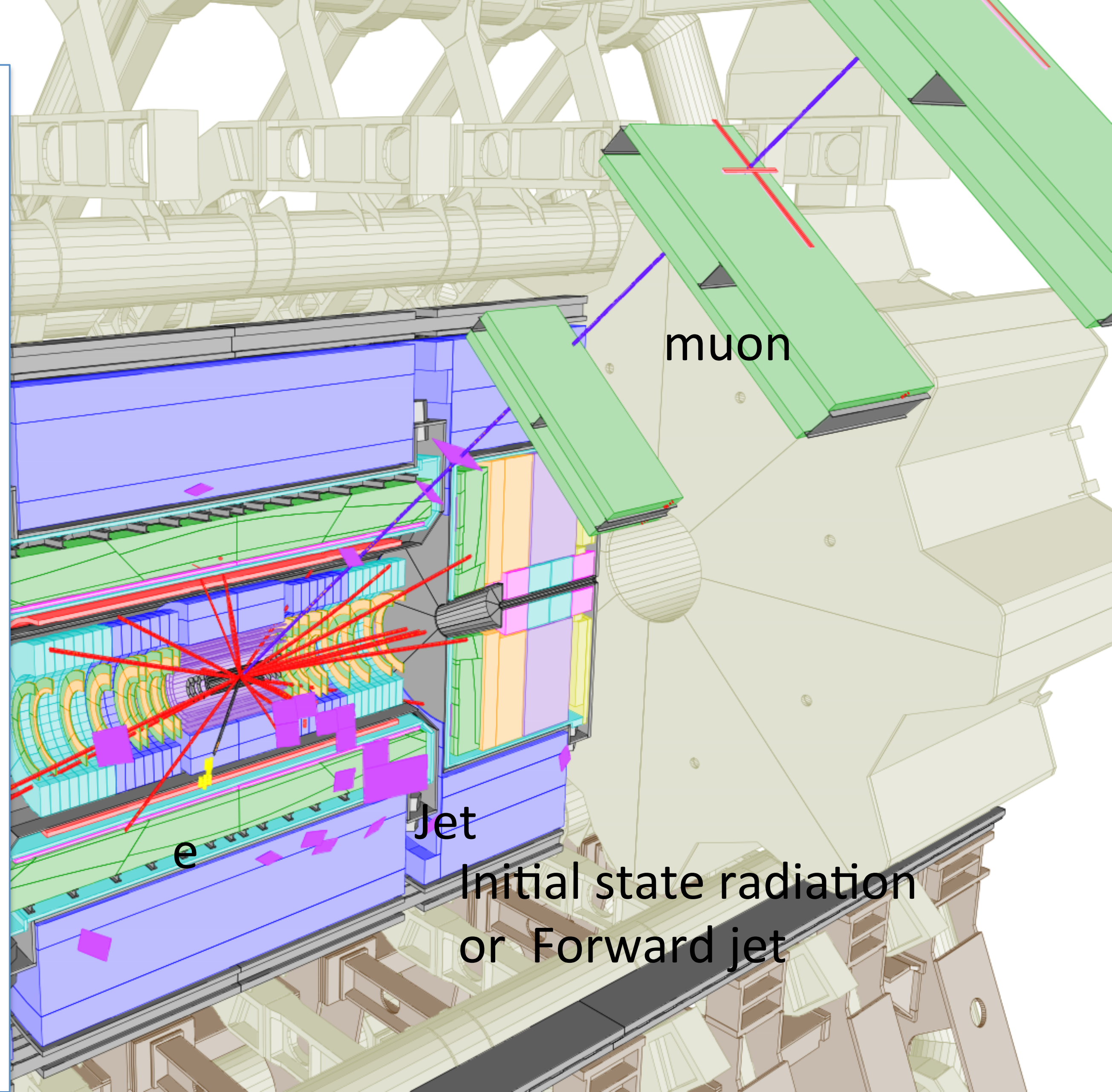
μ+
ν
W
proton
gluon
gluon
proton
Soft QCD activity
("Underlaying")
W
e-
anti-ν



ΔΦ
e PT=34GeV
μ PT=32GeV
MET represents
sum of 2 ν
mET is reverse vector
of sum of visible energy
including the soft QCD
component.

Candidate event in 1 jet category





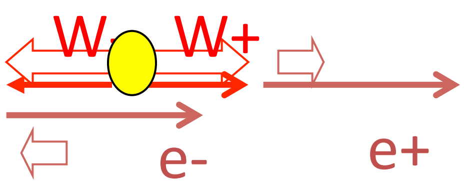
観測されるジェットの数でタイプを3つに分ける

- 0 jet analysis　バックグラウンド　WW
- 1jet(with b-jet veto)　バックグラウンド　tt, WW
- 2jet(Forward jet for VBF)　バックグラウンド　tt

ΔΦ(ll)　Azimuthal angle between dilepton

M_T(Transverse mass)

Higgs Spin0



Higgs spin 0
Wのスピンは反対向き
Wのleptonic decay 100% Parity破っている
leptonは同じ向きにでやすい

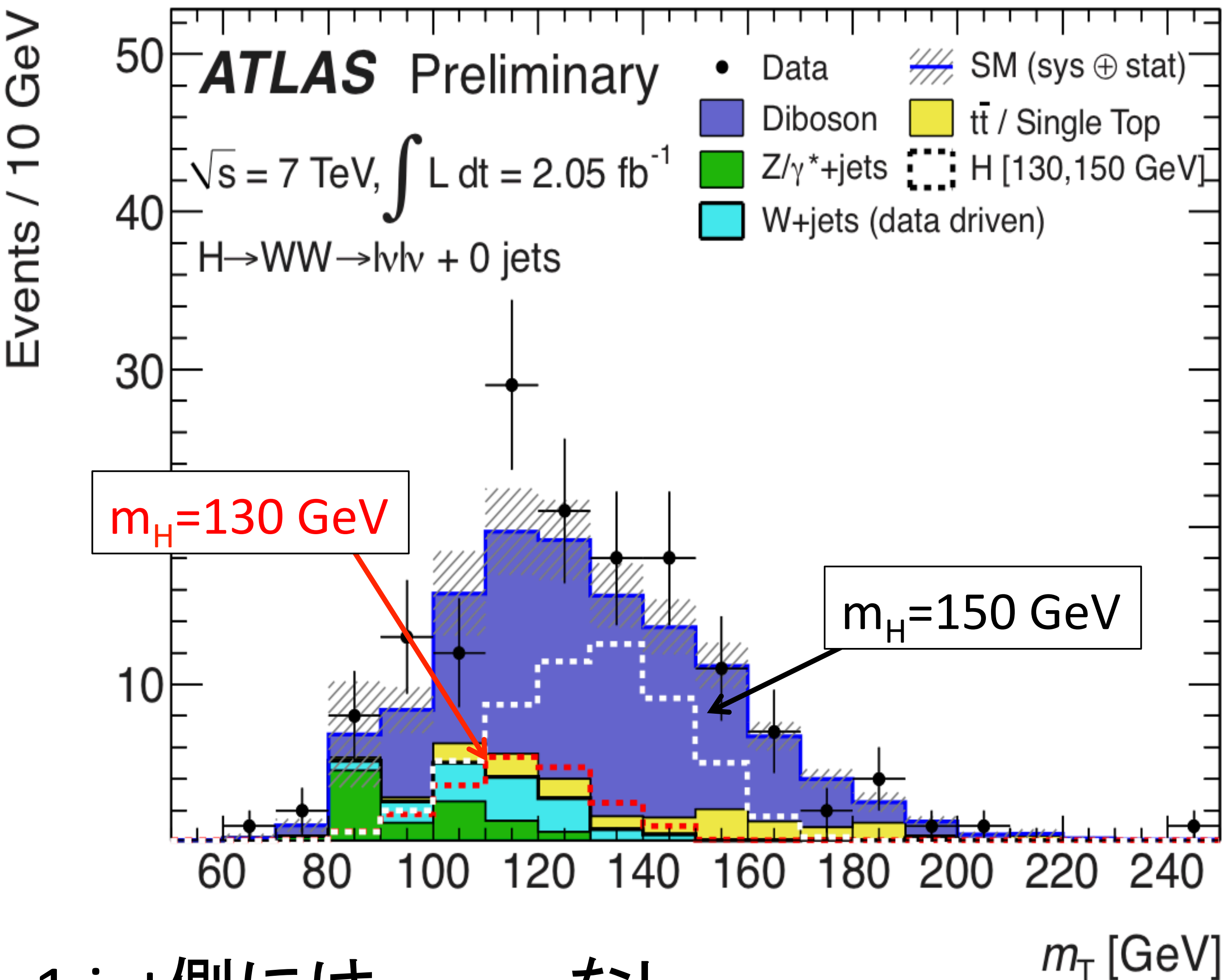
ニュートリノが2発逃げているので
質量が再構成出来ない

$$M_T^2 = (E_T^{ll} + E_T^{missing})^2 - (P_T^{ll} + P_T^{missing})^2$$

Signal $M_T < M_h$

($M_T = M_h$ P_z(Higgs)=0の時)

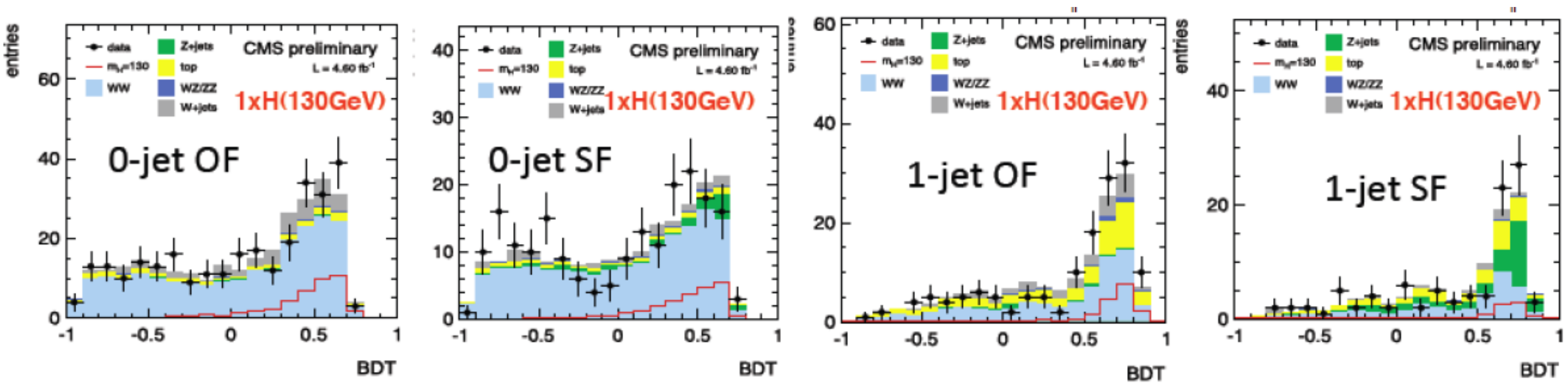
夏までの結果(mETがあるので、なかなか難しい解析）



1 jet側にはexcessなし

CMS: Multivariate analysis

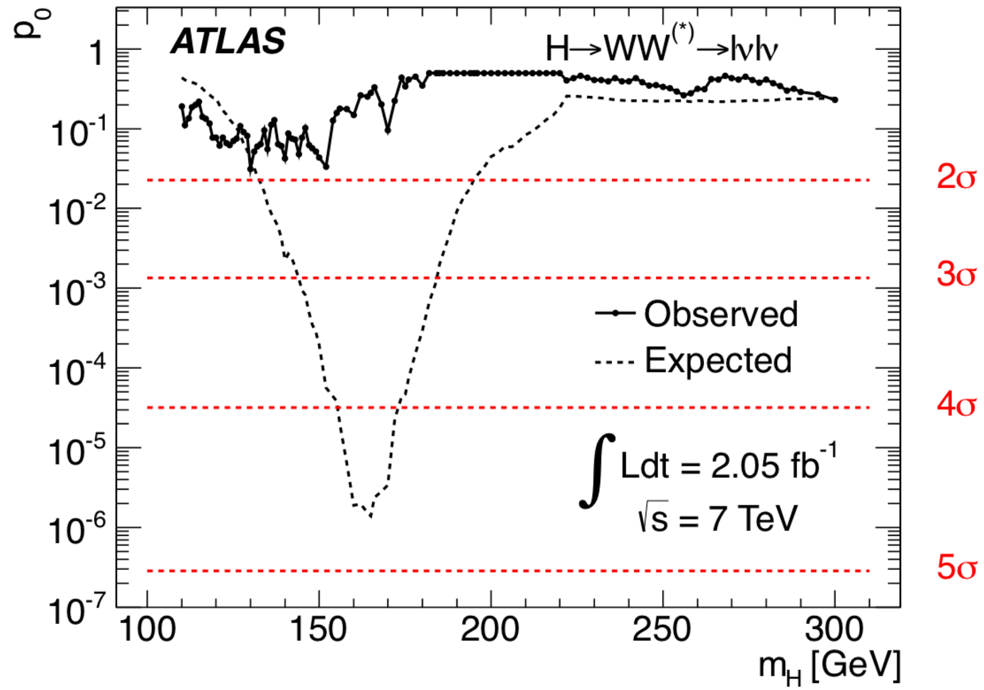
ΔR(ll) とMT分布を使って、BG, Signal　それぞれ“らしさ”を計算して出す

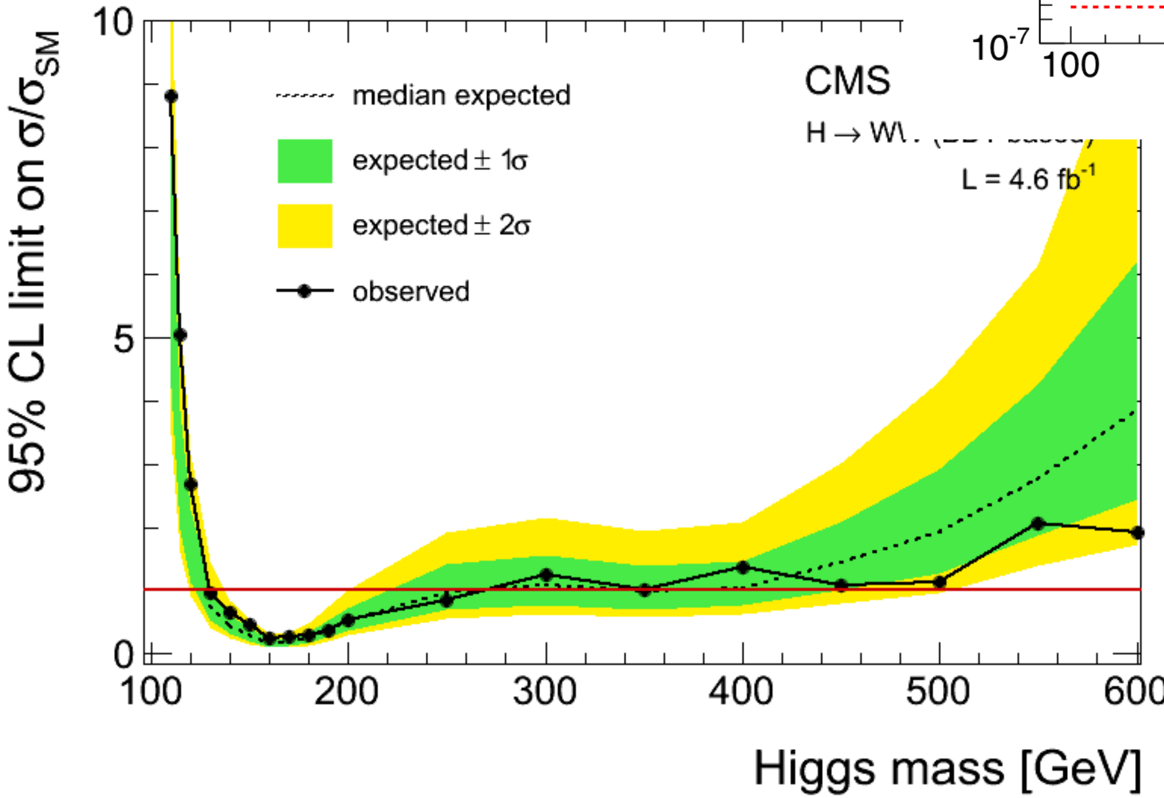


OF　emuの組み合わせ
SF　 ee, mumuの組み合わせ(Zが寄与する)

主に 1 jet側に　excessがみられる。
0jet側はBG consistent

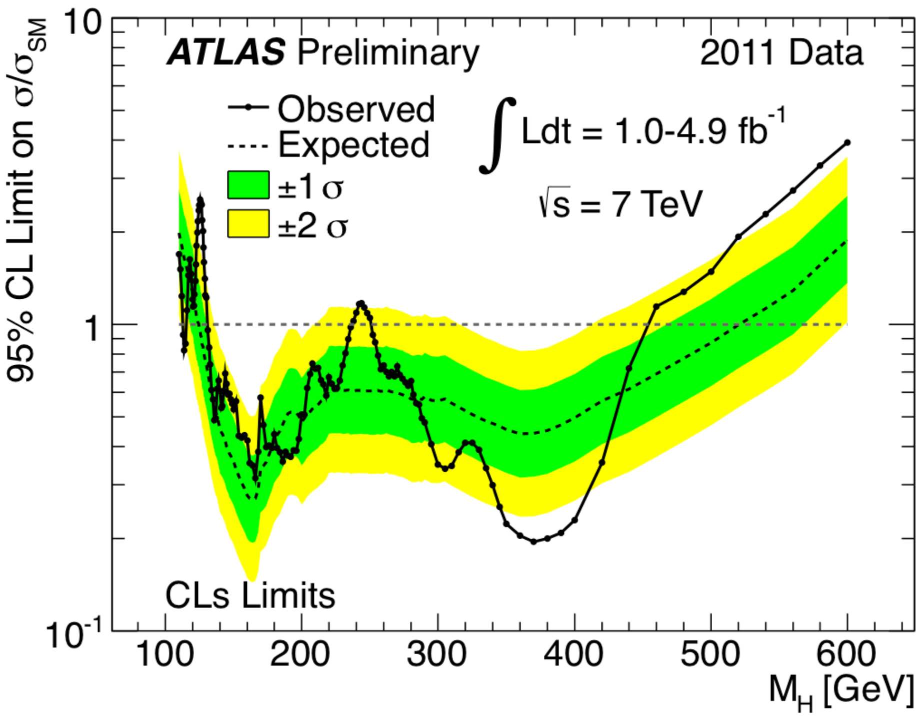
ATLAS　CMS共に
1.9 σ 程度　dataが多い
M_T分布はpeakでないので
massの特定はできない。

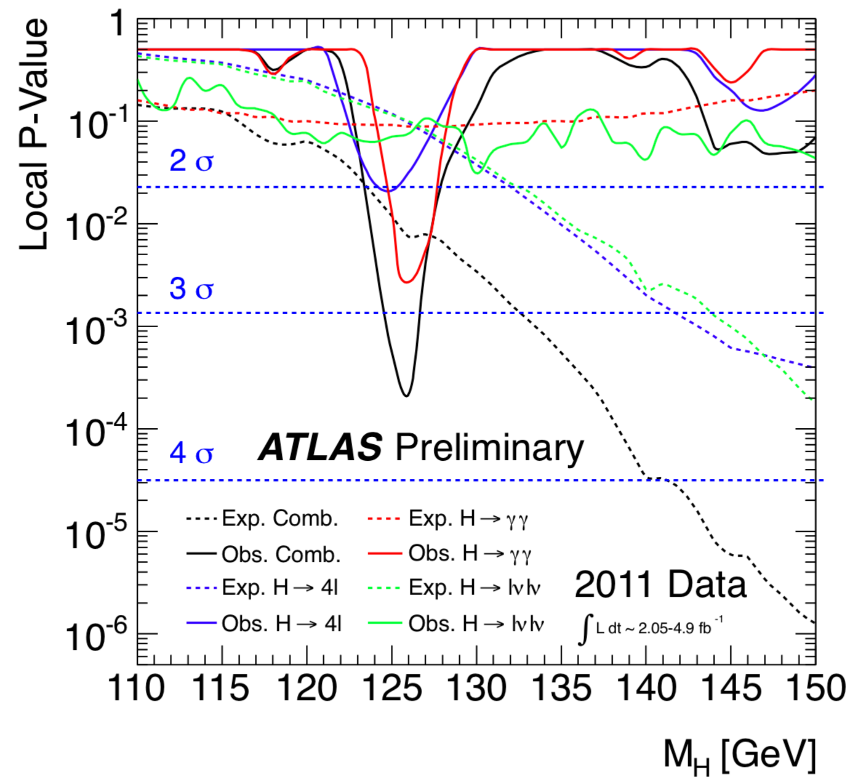




このチャンネルで
CMS　Mh=127-270GeV Higgs棄却
（９５%CL)
ATLAS　145-206GeV exclude

ATLAS combination





Exclude (95% CL)

$112.7 < m_H < 115.5$ GeV (ALEPH Higgs exclude)

$131 < m_H < 453$ GeV

126GeV 3.6σ (0.02%) excess

2.8σ H→ γγ,

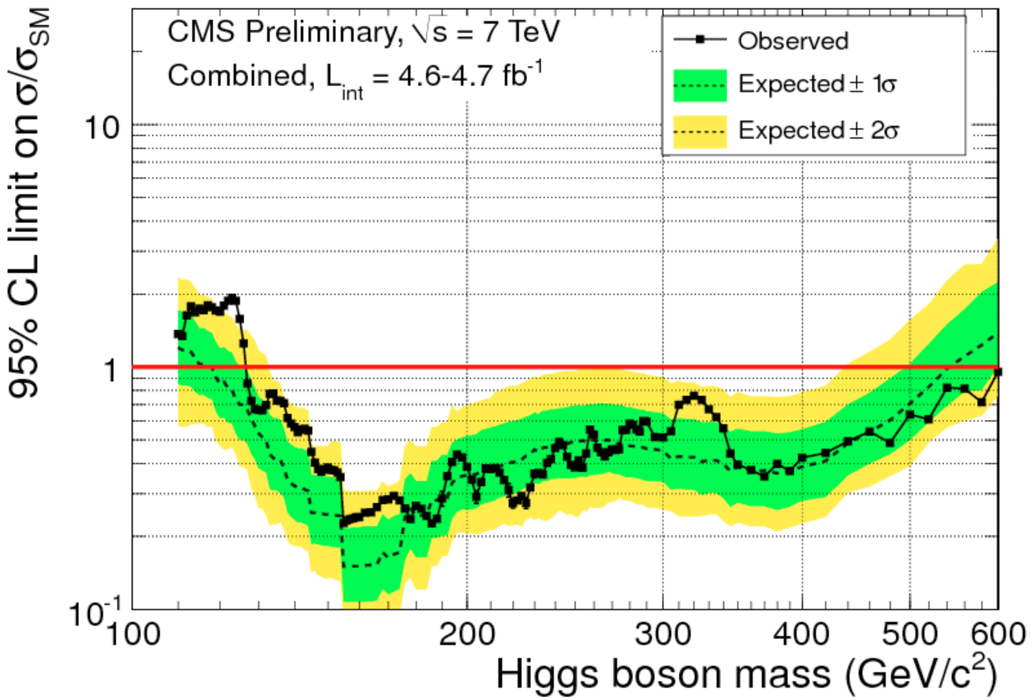
2.1σ H→ 4l,

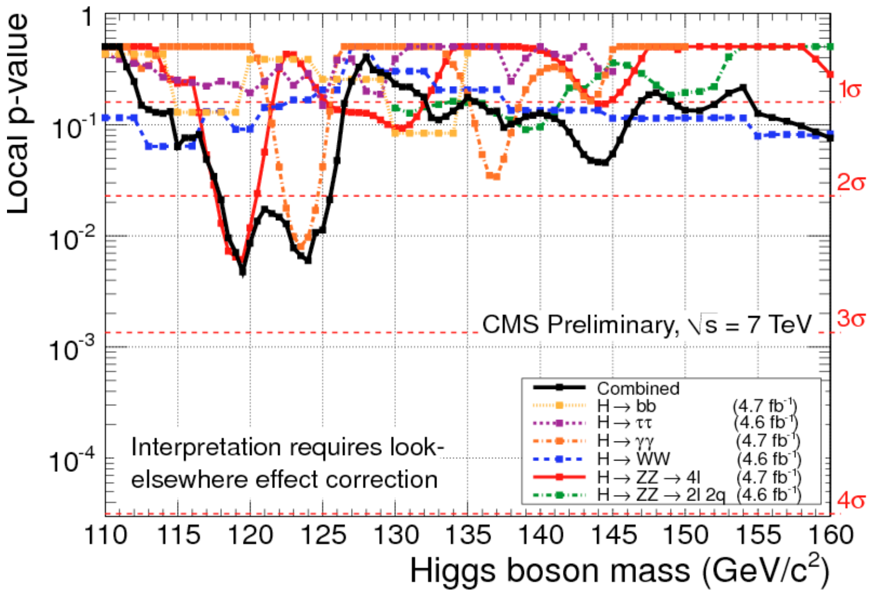
1.4σ H→ lνlν

116-130GeVの領域に絞りこんだ

どこでも効果 **2.5σ（99.4%） 110-146GeV**

CMS combination





Exclude (95% CL)

127 < m_H < 600 GeV

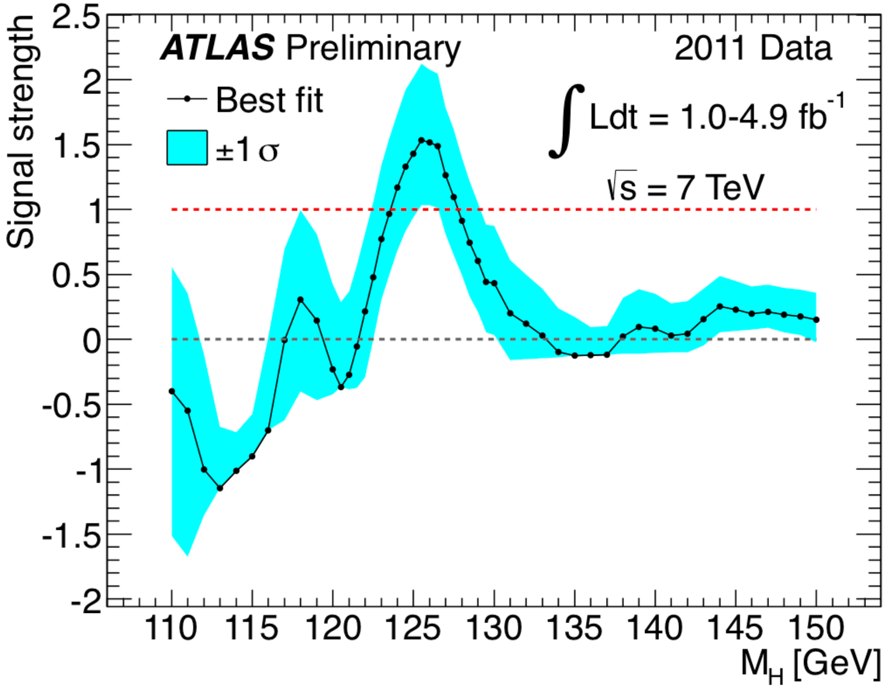
119, 124 GeV 2.6σ (0.5%)

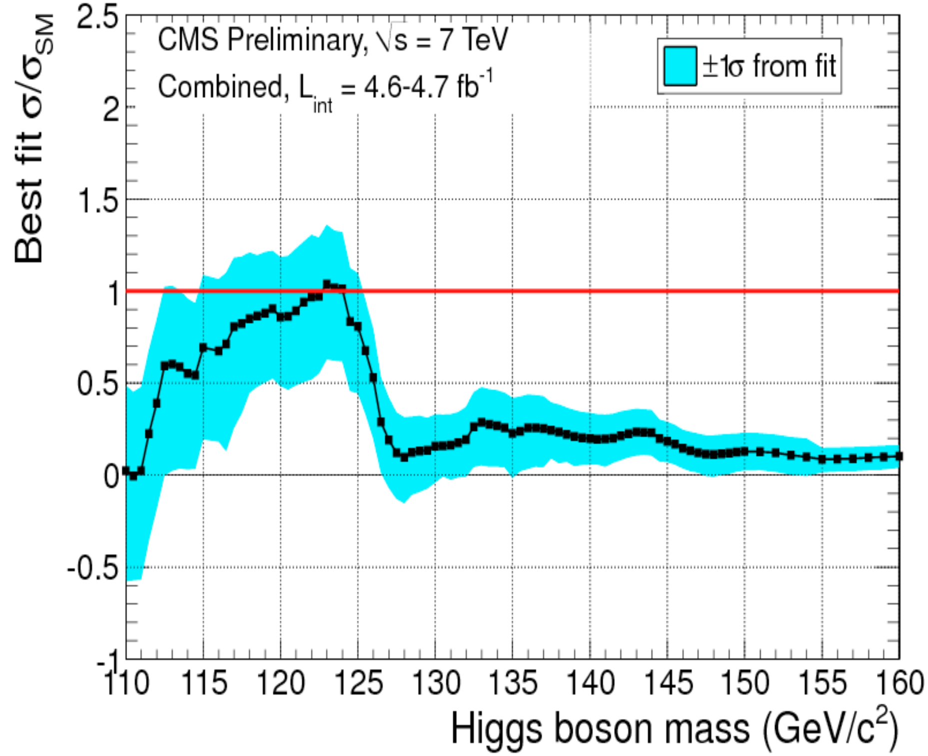
115-127GeVの領域に絞りこんだ

どこでも効果 **1.9 σ** **110-145GeV**

Higgsだと思ってfit

ATLAS　3.6σ　　　(2.5σ　LEE)
CMS　　2.5-2.6σ　(1.9σ　LEE)

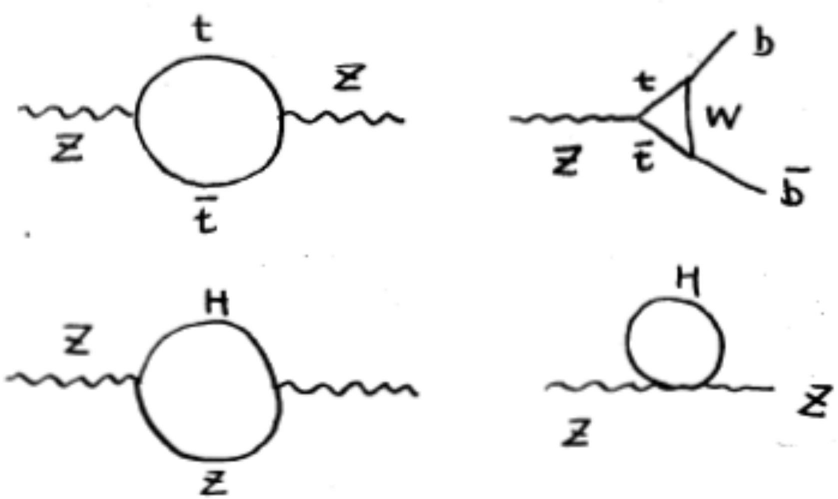




ATLASは126GeV中心
CMSは115-125GeV
のSM Higgsとconsistentな
分布

実験からの制限:(輻射補正からの予言)

LEP実験でZ/Wを0.1%の高い精度で研究
一次の補正が1%弱程度(αEM)なので，直接見えない粒子、top, higgsの効果が見える



$$\rho = \frac{m_W^2}{m_Z^2 \cos^2\theta_W} = 1 \text{ at Tree}$$

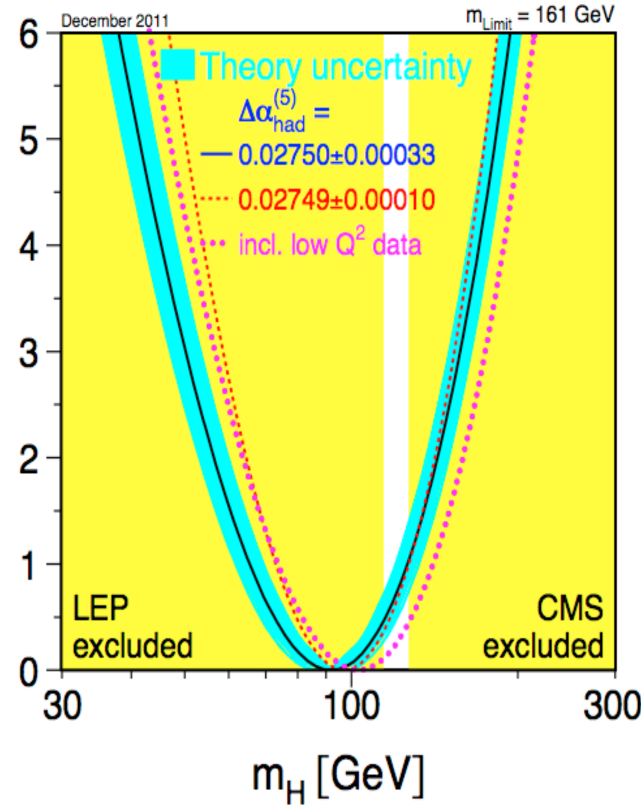
輻射補正(radiative correction) $O(10^{-3})$

topの補正 $\Delta\rho = \frac{3G_F}{8\sqrt{2}\pi^2} m_t^2 \sim 10^{-2}$

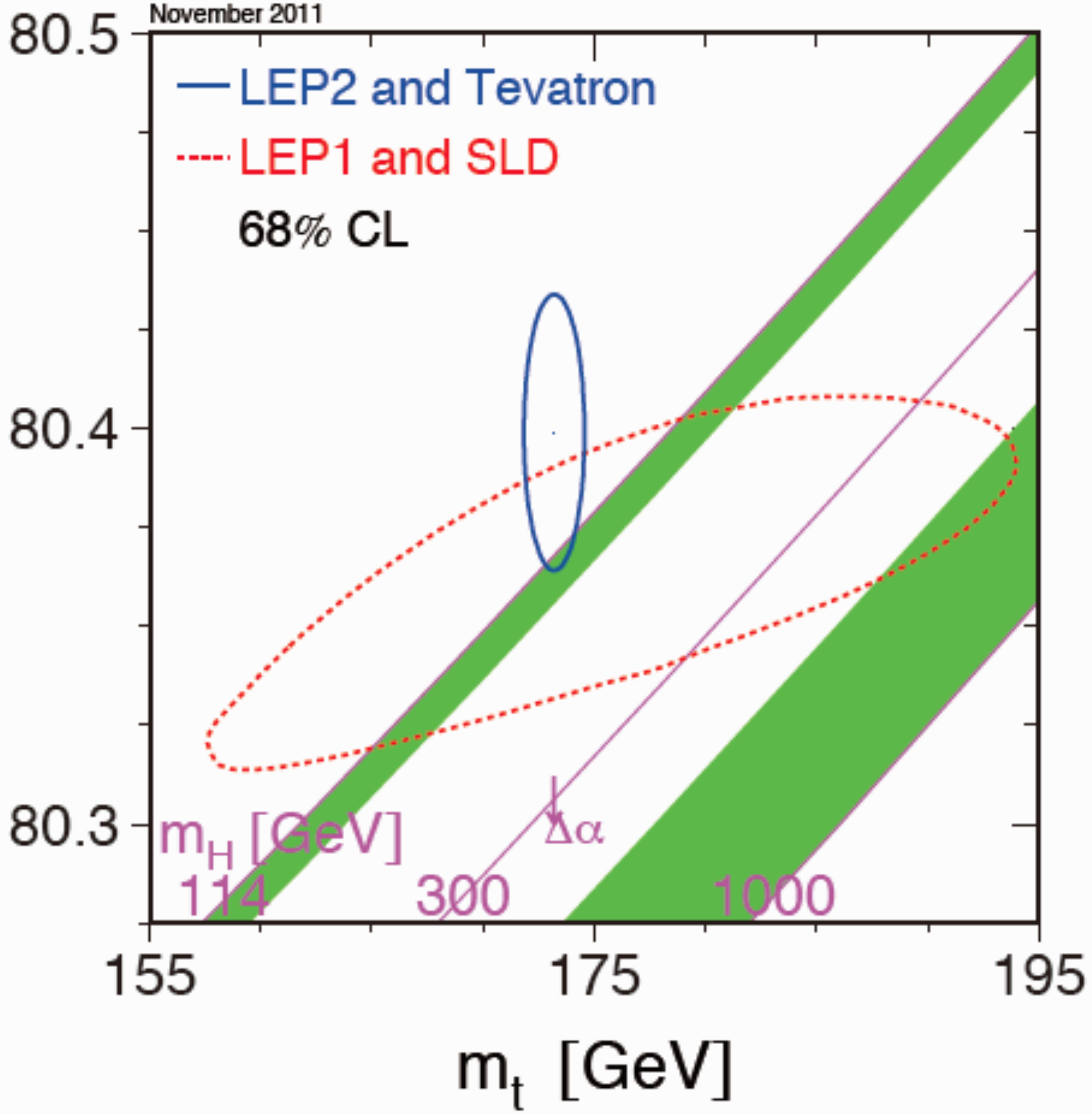
⇩

topのmassを予言 (LEP2-8A)

Higgs $\Delta\rho = \frac{3G_F m_W^2}{8\sqrt{2}\pi^2} \frac{\sin^2\theta_W}{\cos^2\theta_W} \left(\ln \frac{m_H^2}{m_W^2} - \frac{5}{6} \right)$



＜160GeV
(SM-likeなら)



November 2011
80.5
80.4
80.3
LEP2 and Tevatron
LEP1 and SLD
68% CL
m_W [GeV]
m_H [GeV]
114
300
1000
$\Delta\alpha$
155
175
195
m_t [GeV]

125GeVだと思うと

（1）標準模型でHiggsの質量は不安定　すぐに発散する。

何か別の機構　O(10) ＊ 125GeV 〜　TeVにあることの重要な示唆
階層性問題

（2） SUSYだとすると、いろいろ

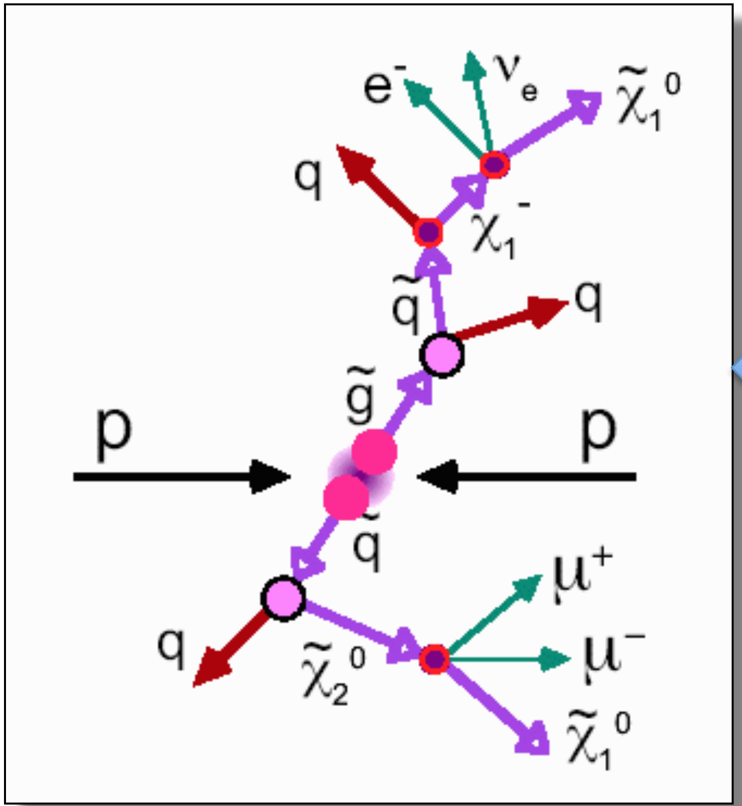
Minimal model
A 〜　√6 mstop　stop mixingが大きくないと　かなりつらくなる

Aが小さいMinimal model
10TeV order のSUSUY mass になり、DM, muon g-2との整合性

NaïveなGMSUSYはたぶん駄目

おまけがあるほうが自然
または　Aがfull mixingになっている。

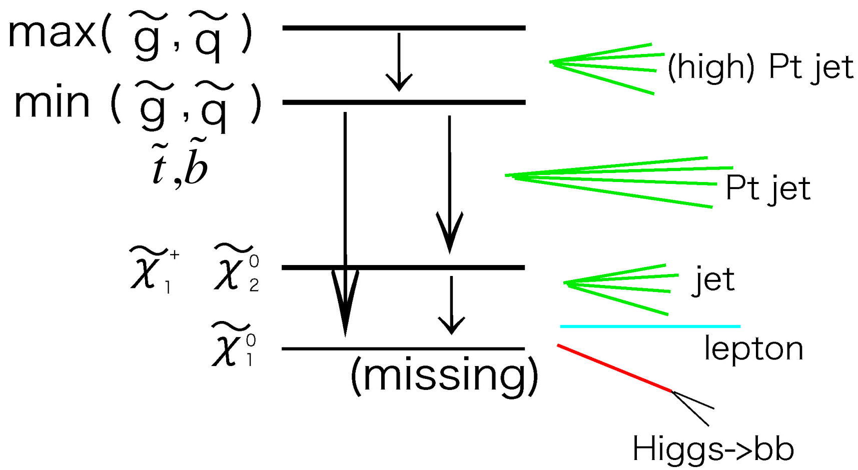
4. SUSY 探索と暗黒物質



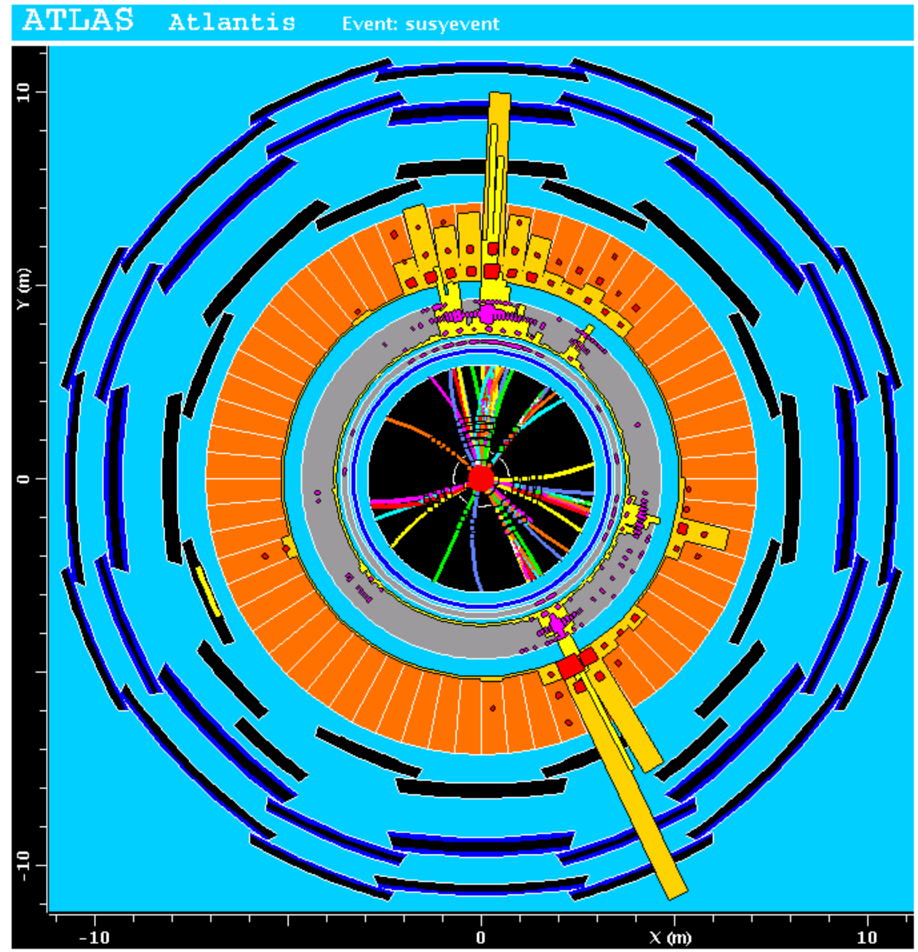
(1)はじめにトポロジーのイントロ
(2)代表的な探索結果と2012年の成果
(3)CMSSM base の limitと暗黒物質
(4)可能な方向性

LHCでのSUSY探索：期待されるトポロジー

Gluino/squarkがはじめに出来て，
カスケード崩壊



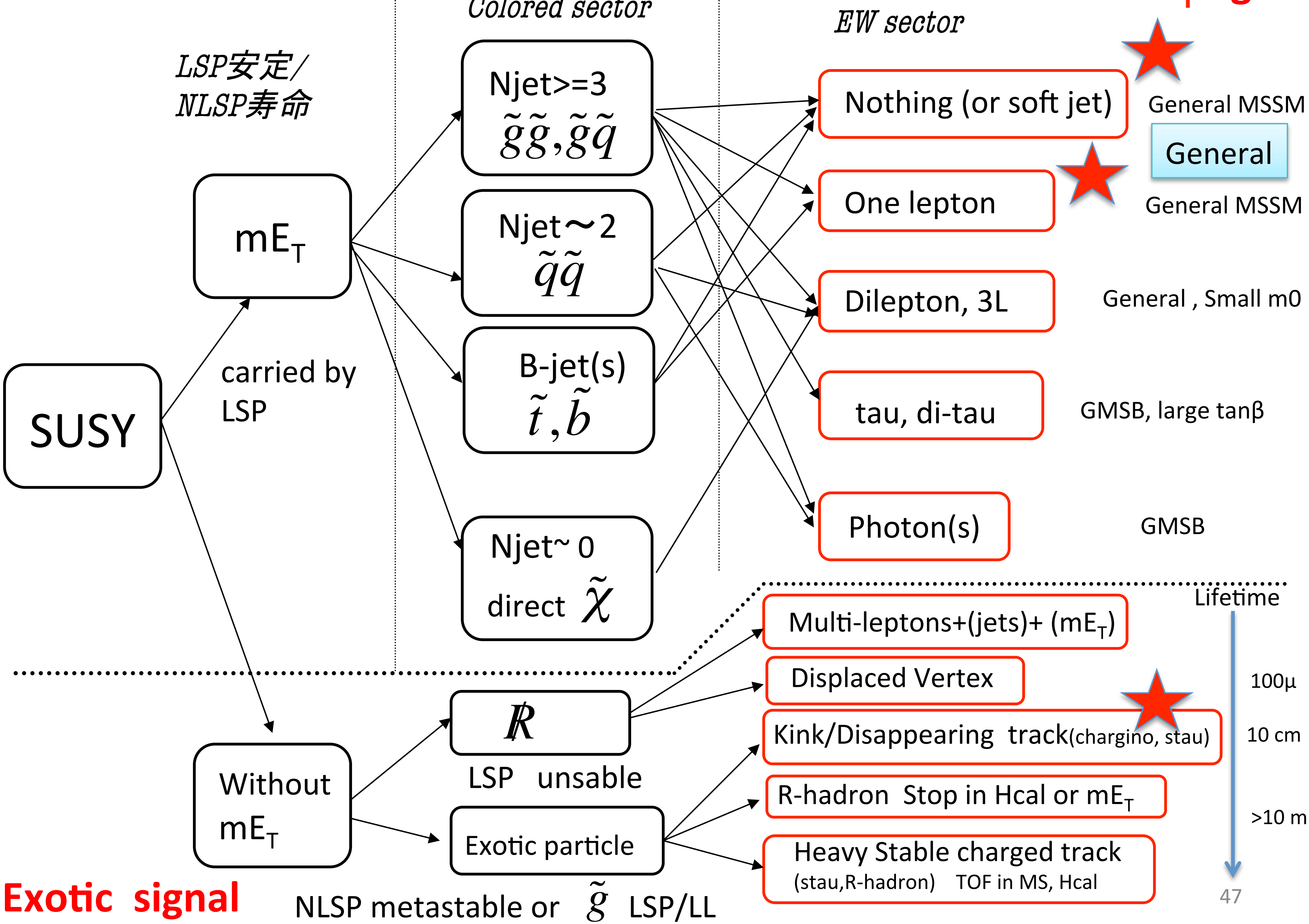
LHC is DM-factory



Event topologies of SUSY

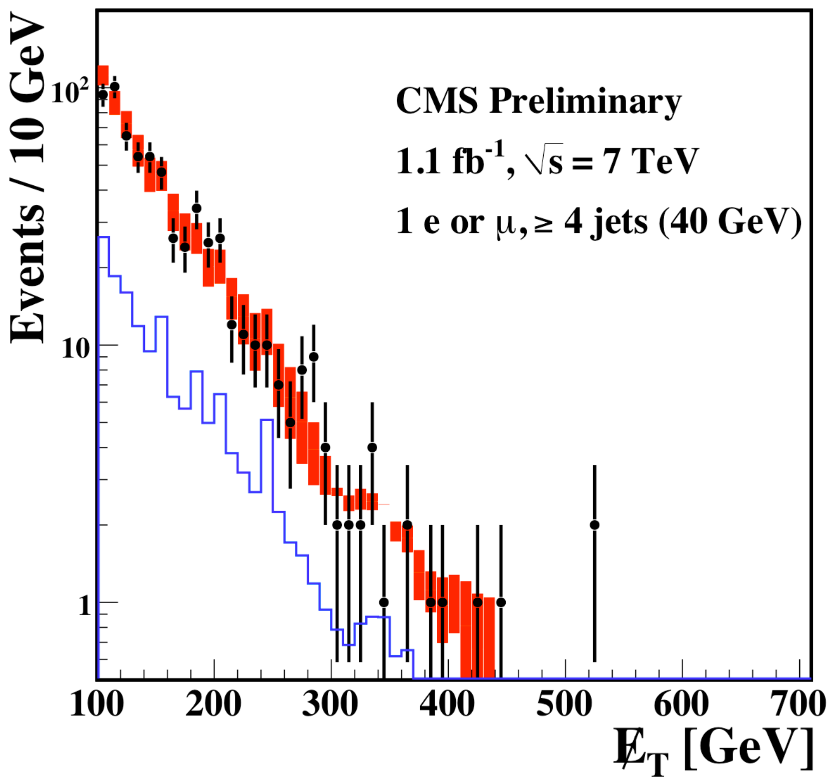
multi leptons
$\not{E}_T$ + High P_T jets + b-jets
τ-jets

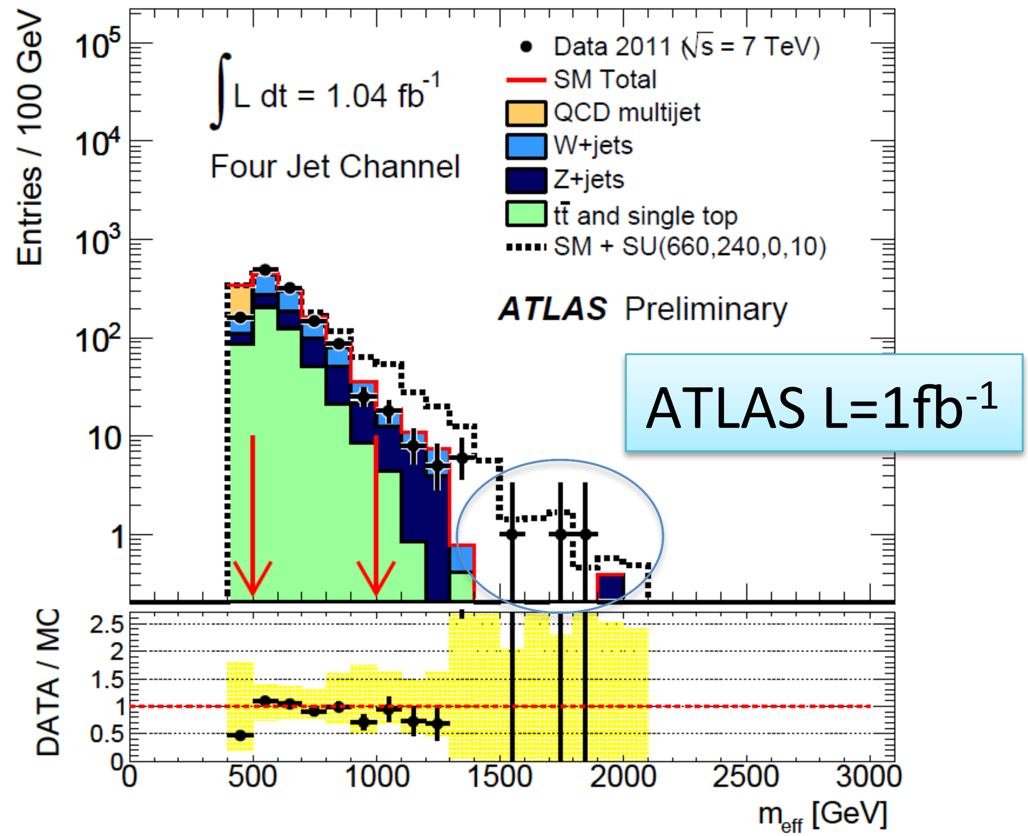
もう少し詳しくトポロジー見ると



No Lepton モード

high PT >= 4 Jets & Large mET & mET は jetの方向でない





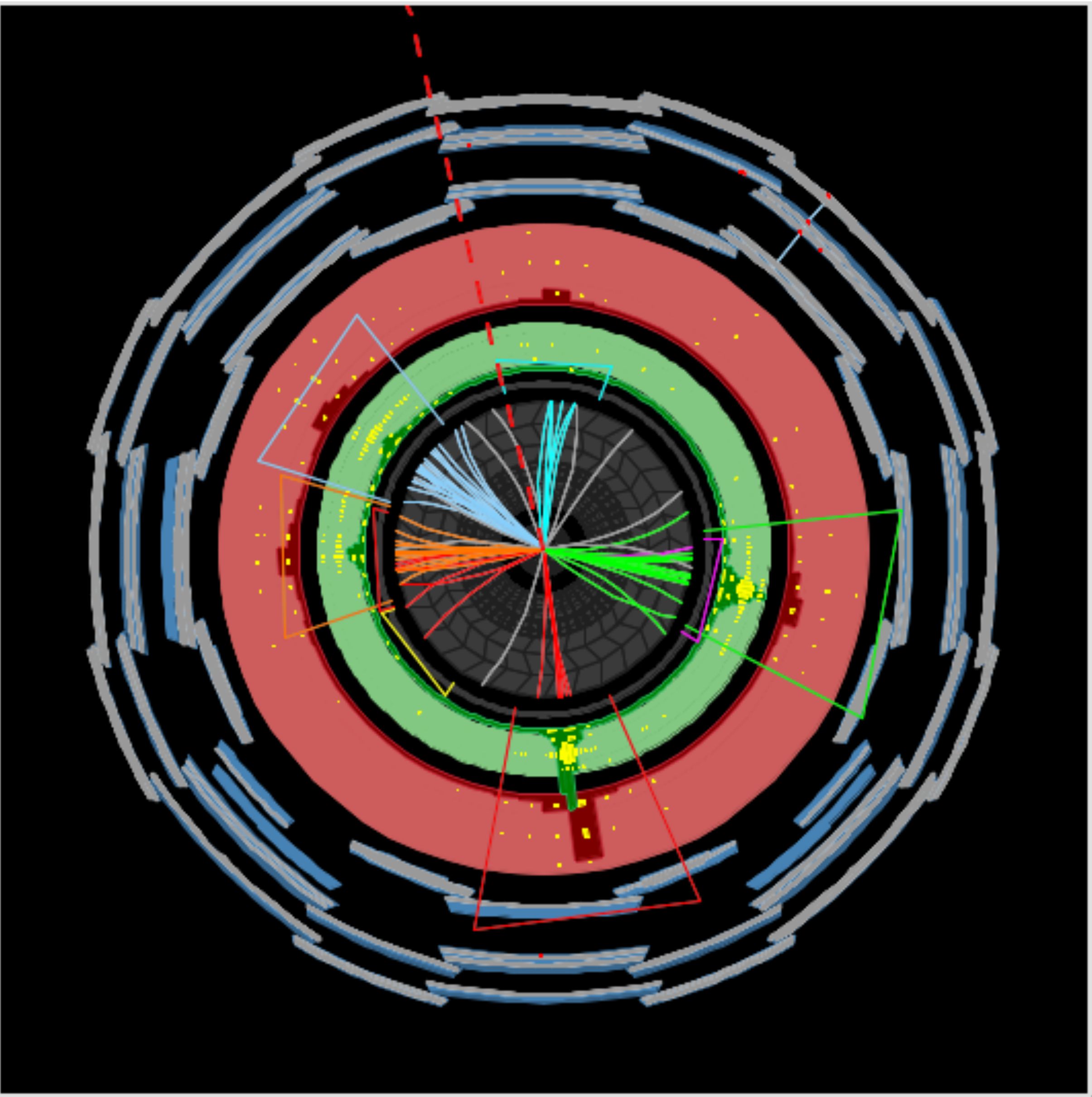
Neutrino from W/Z もけっこう高いPT
まで行く mETだけではだめ
Scalar sum of Jet activity(HT)
CMSは HT
ATLASは Meff= mET+ Σ PT (jet)

Meff >1000GeV (mET/Meff>0.25 mET>250GeV)

Data 40 events
BG 33.9+-2.9+-6.2 (**Z 16 W 13** t 4)

3 candidates in high Meff region ！！！

Candidate event (Hardest)



Run=183021 #66383304

Meff(4j) = 1810 GeV
MET = 460 GeV phi=1.8

4 high PT (>150GeV) Jets
- pT=528 GeV eta=0.58 phi=-1.45
- pT=418 GeV eta=0.83 phi=-0.19
- pT=233 GeV eta=-0.91 phi=2.54
- pT=171 GeV eta=-0.47 phi=-3.11
- pT=42 GeV eta=0.47 phi=1.52

good candidate

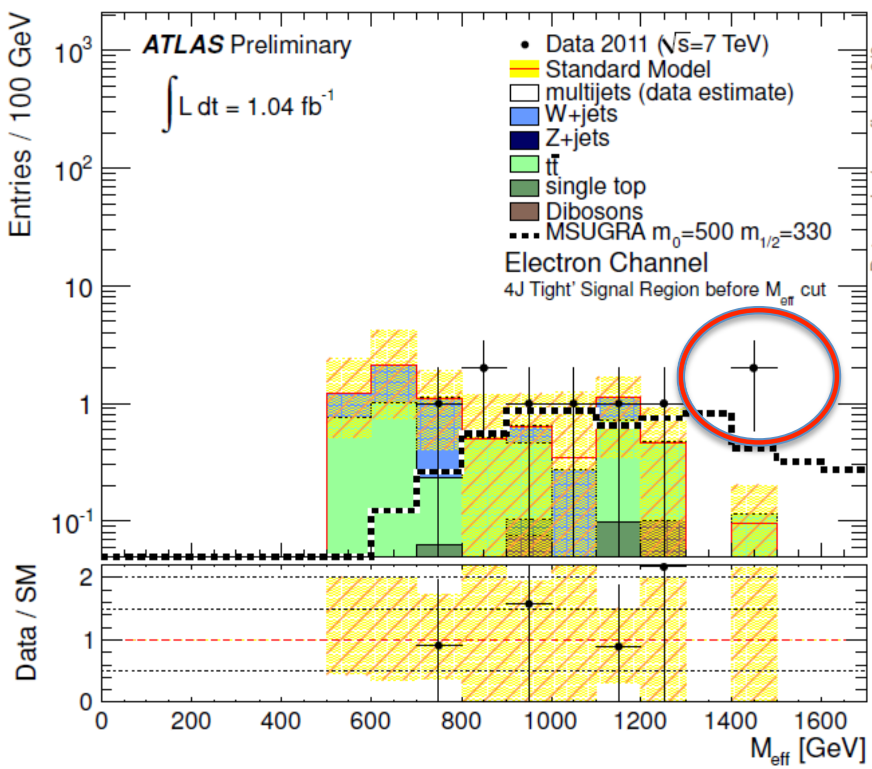
Meff ～ 1.5 * M(squark, gluino)

If it is Sugra-like candidate
gluino,squark ~ 1.3-1.5TeV

One lepton Mode

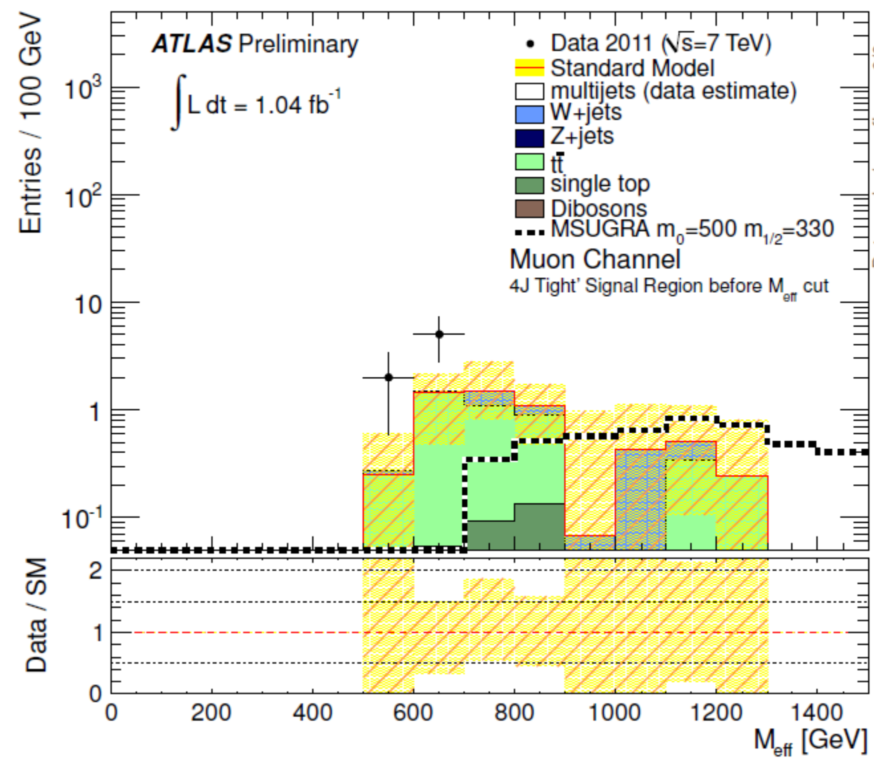
Electron (PT>25GeV)　 muon (PT>20GeV) で　trigger
4jets以上　(PT>60,40,40,40 GeV)　MET>200GeV　 MT>100GeV　Meff>500GeV

electron



Data 9 events
BG 8 +-3.7 (W/Z 4 t 4)

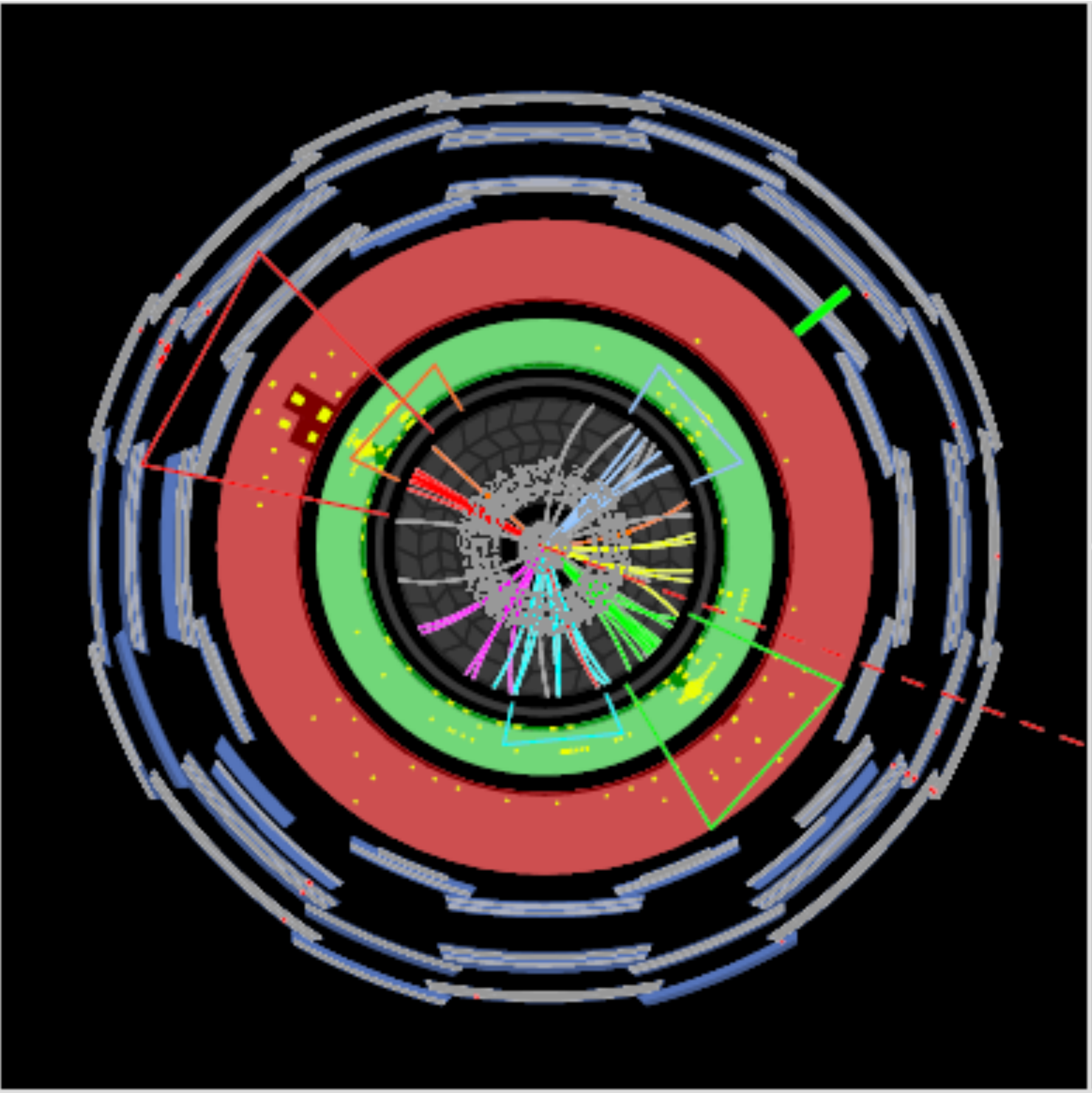
muon



Data 7 events
BG 6 +-3 (W/Z 2 t 5)

バックグラウンドと無矛盾
2事象 Meff > 1400GeV

Candidate events



Run=183391 #61816156

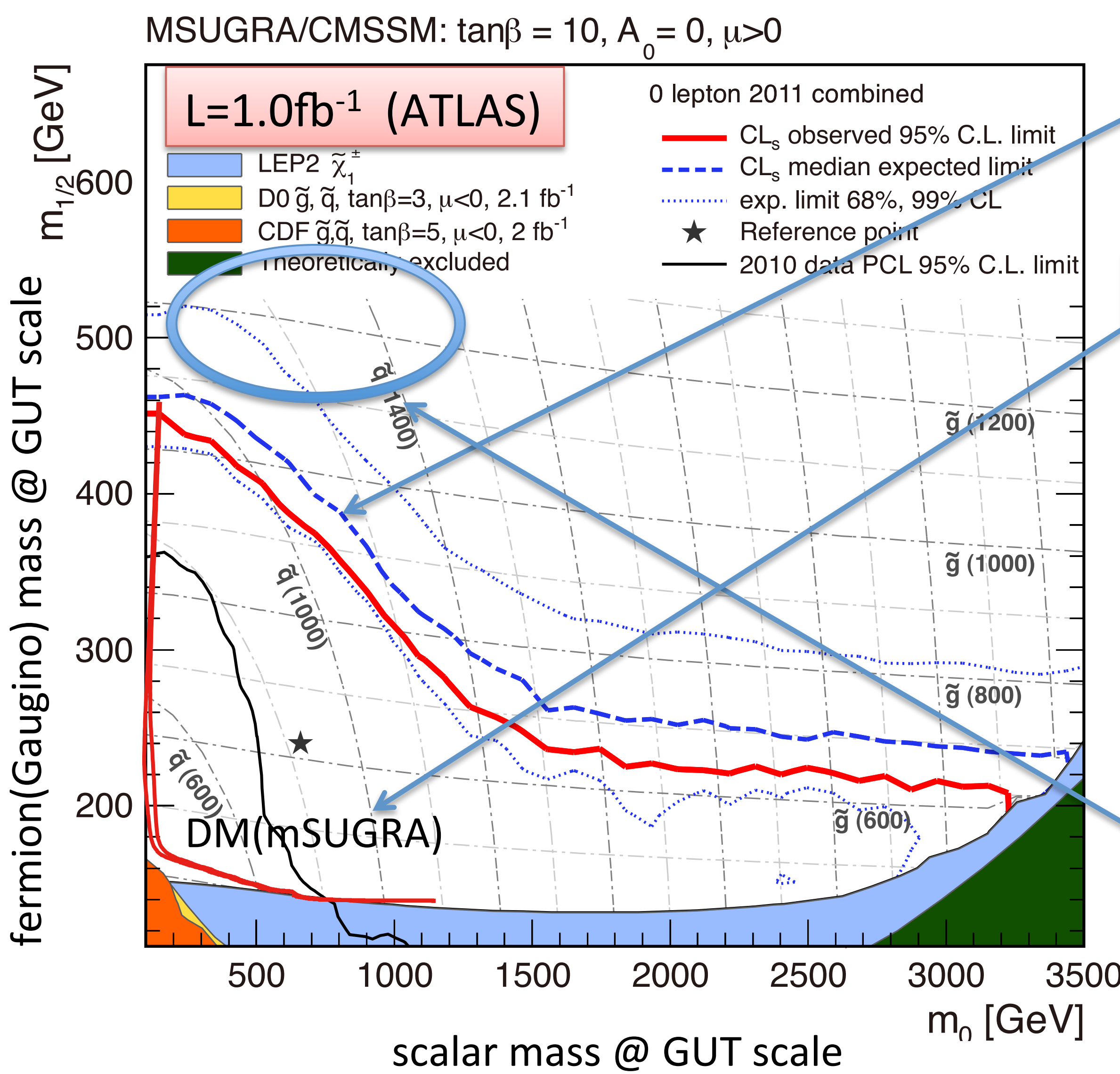
Meff(4j) = 1453 GeV
MET = 317 GeV phi=-0.34
Jets
pT=654 GeV eta=-0.07 phi=2.64
pT=305 GeV eta=-0.24 phi=-0.74
pT=70 GeV eta=-0.10 phi=0.71
pT=64 GeV eta=-1.44 phi=2.41
pT=51 GeV eta=-1.18 phi=-1.48

Electron
pT=42.8GeV eta=-1.4 phi=2.4

Nvtx = 4 with 103,19,10,4 tracks

W+ jets とも矛盾なし

CMSSMで NaïveなGUTを仮定して gluino/squark productionへ制限



squark/gluino 〜
1.1TeV (squark 〜gluino)
750GeV (heavy squark)

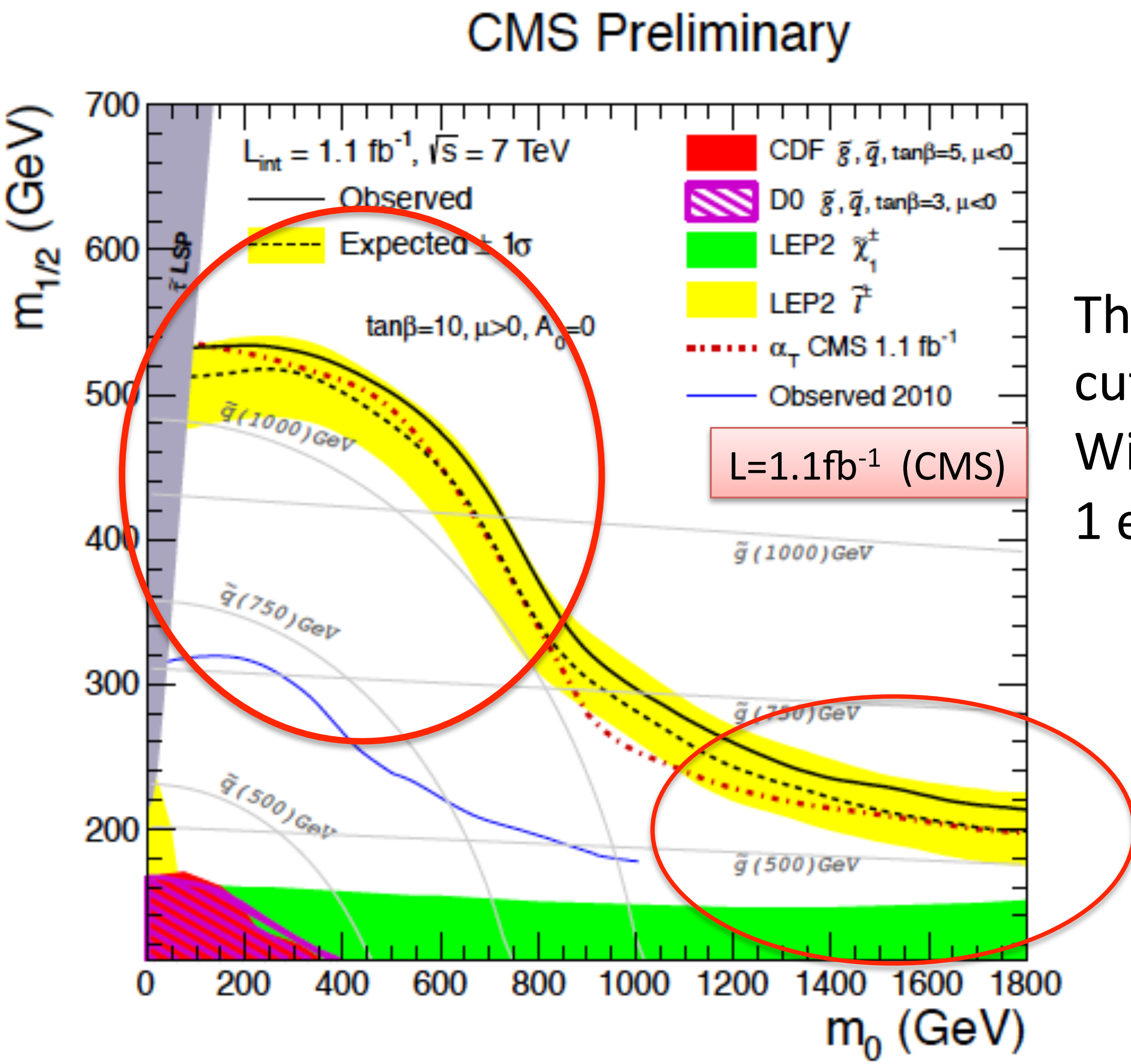
Dark matterで期待される 領域

(1) Bulk region
(2) Focus Point (Large m0)
(3) small m0 coannihilation

gluino ~ 1.3-1.5TeV
muon (g-2) がいいところ
これは今年checkできる

Naïve DM over-close our Universe(Ω>>1) !! Bino DMはかなりきつい

CMS has obtained the similar results. No excess was found and gluino ～ 1.2 TeV, squark ～ 1.1 TeV are obtained.

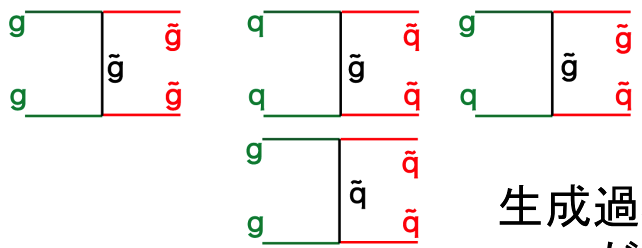


They applied tight cut (Best limit is obtained With tight selection. 1 event obs. 1.5 expect.)

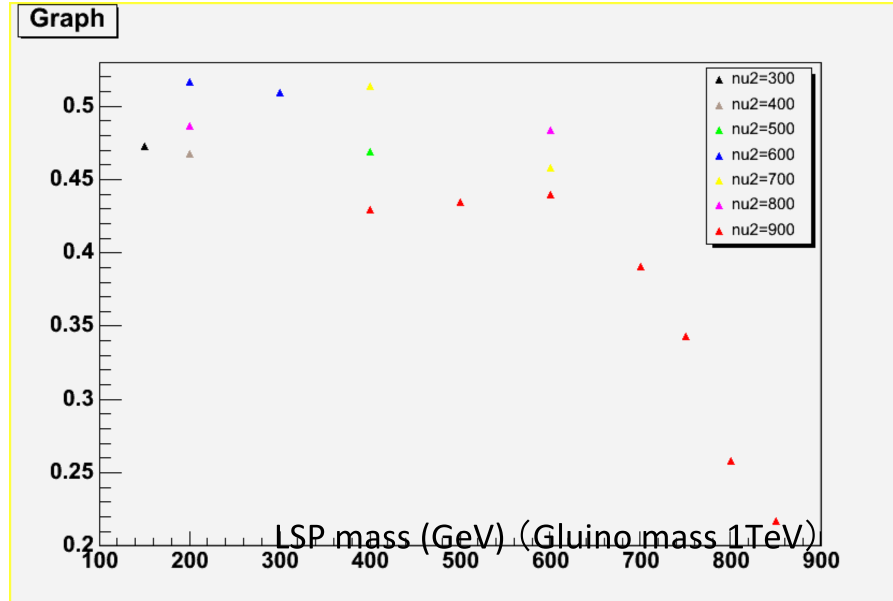
At Large m0
gluino ~ 600GeV
gluino only
3body decay
high Jet multiplicity
s mall mET

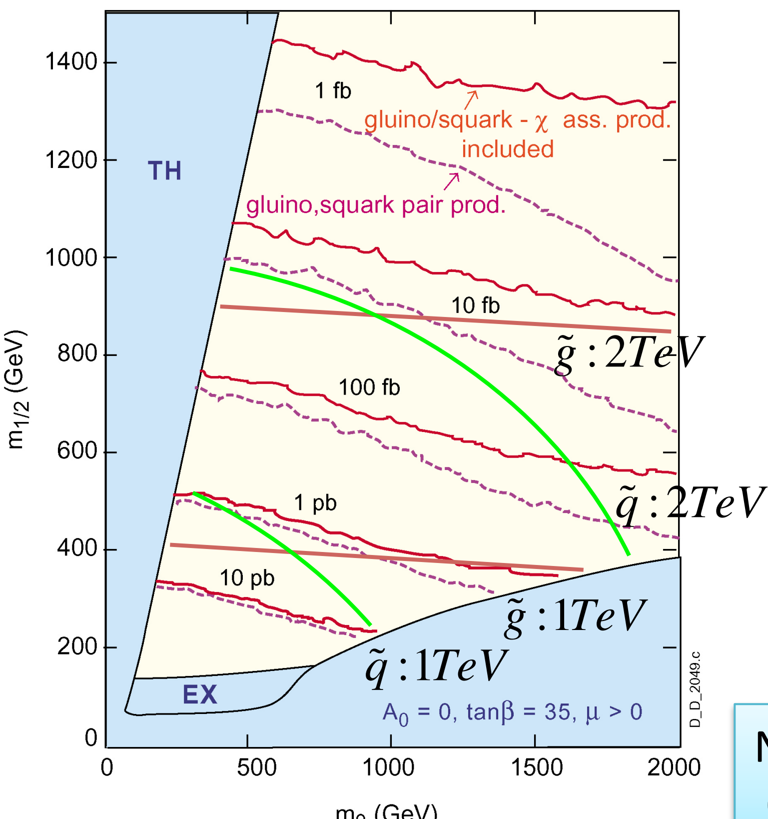
この結果の適用限界？　モデル依存性

g̃g̃対生成　q̃q̃対生成　q̃g̃随伴生成



生成過程は strong
massだけできまる





いろんな分布は、Modelにそんなに依存しない。

一番効くのは、ΔM（colored とLSP) ΔM (coloured vs LSP)=400GeV (@ 14TeV)

これがLHCでクルーシャル
ΔM < 300GeV（@7TeV)

No SUSY found @ LHC (1) heavy colored (2) degenerate (3) NoSUSY @ TeV scale.

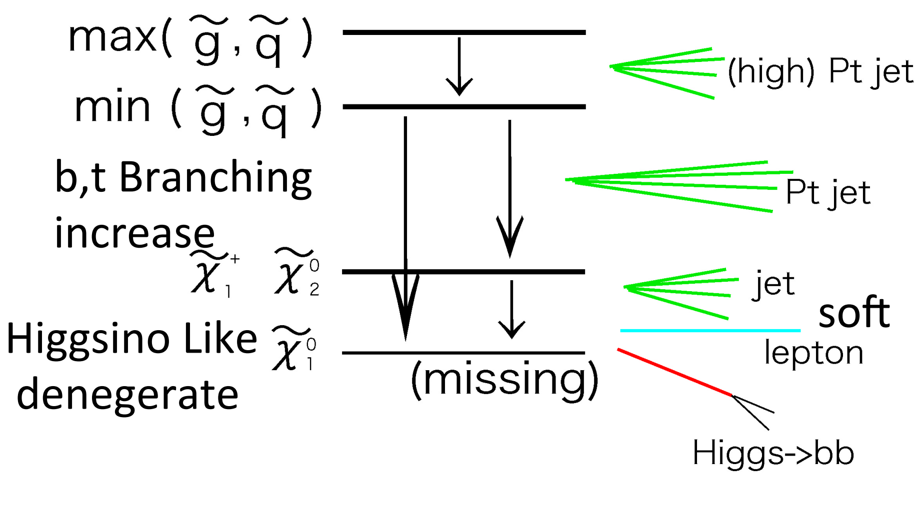
Dark Matter (1)

Higgsino/Wino DM

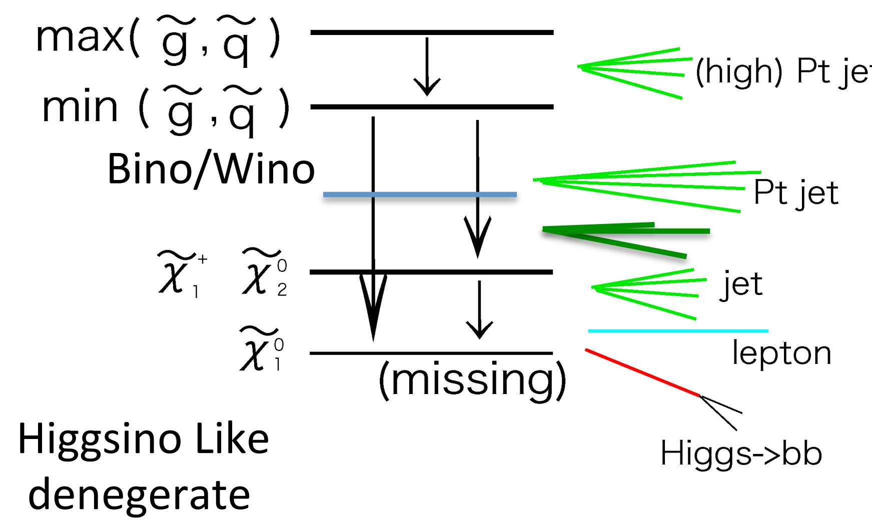
Higgsino Dark matter case: In mSugra Higgsino mass (μ) is calculated &
|μ| ∼ m1/2 except for Focus point. (but it is over-constrained)
μ is smaller than 0.4*m1/2 -> Higgsino like LSP dark matter

higgsino DM can annihilate much more,
also |μ| can be small in more relaxed model

LHC phenomenology (A) jets + mET + bjets (Higgsino coupling)
(B) Long cascade high jet multiplicity & less mET



No excess



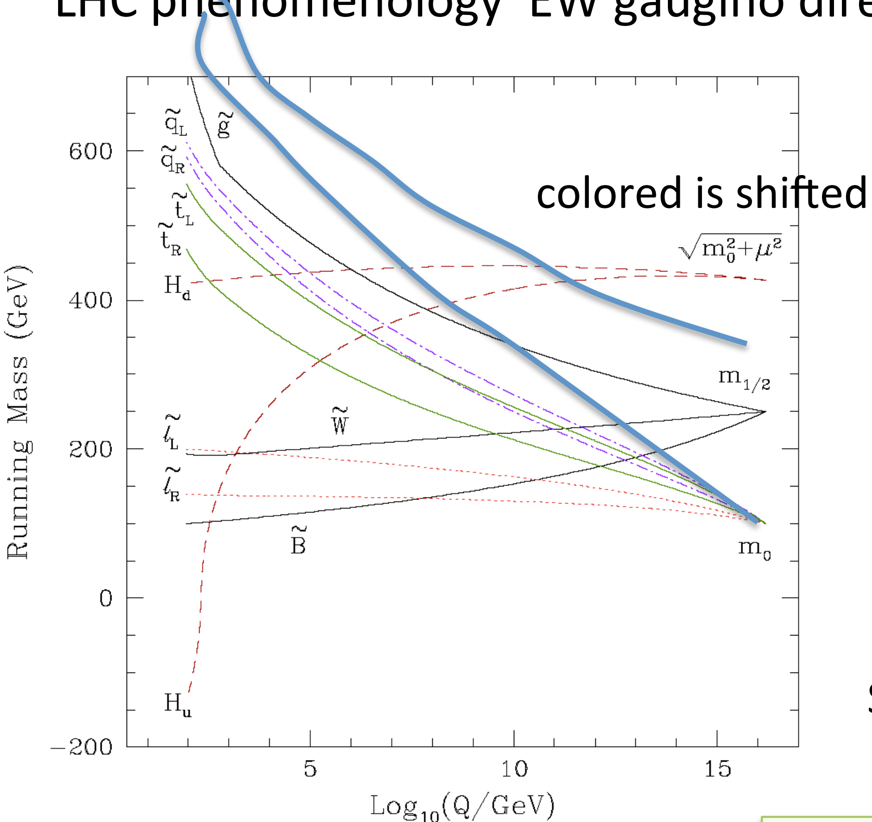
No excess

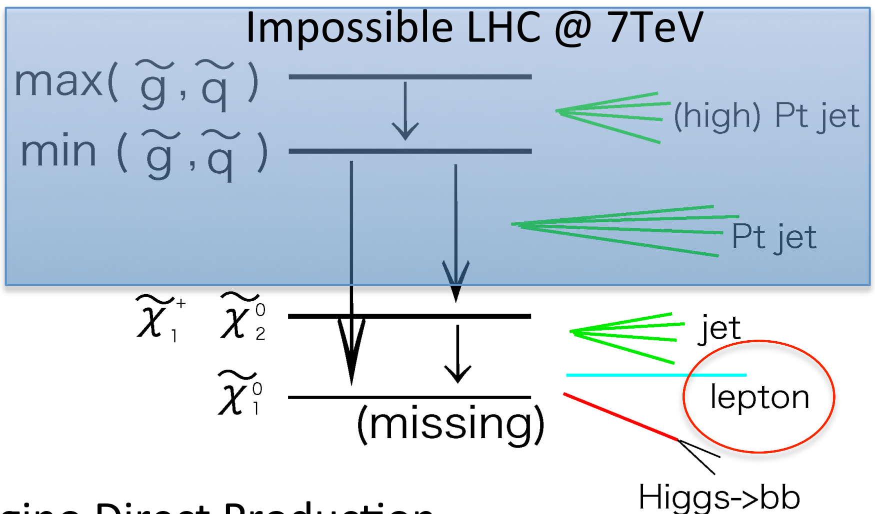
Dark Matter (2)

If GUT relation is assumed
M1(Bino) = M2(Wino) = M3(Gluino)
Limit on Bino mass is 180GeV

(2) Heavy Colored particle. @ GUT M3(gluino) > M2(Wino)=M1(Bino)
Colored particles are too heavy to be produced @ LHC , but Bino is still about 100GeV

LHC phenomenology EW gaugino direct production





Gaugino Direct Production is only possible signal.

SS di-lepton or 3L
but still not yet have enough sensitivity.

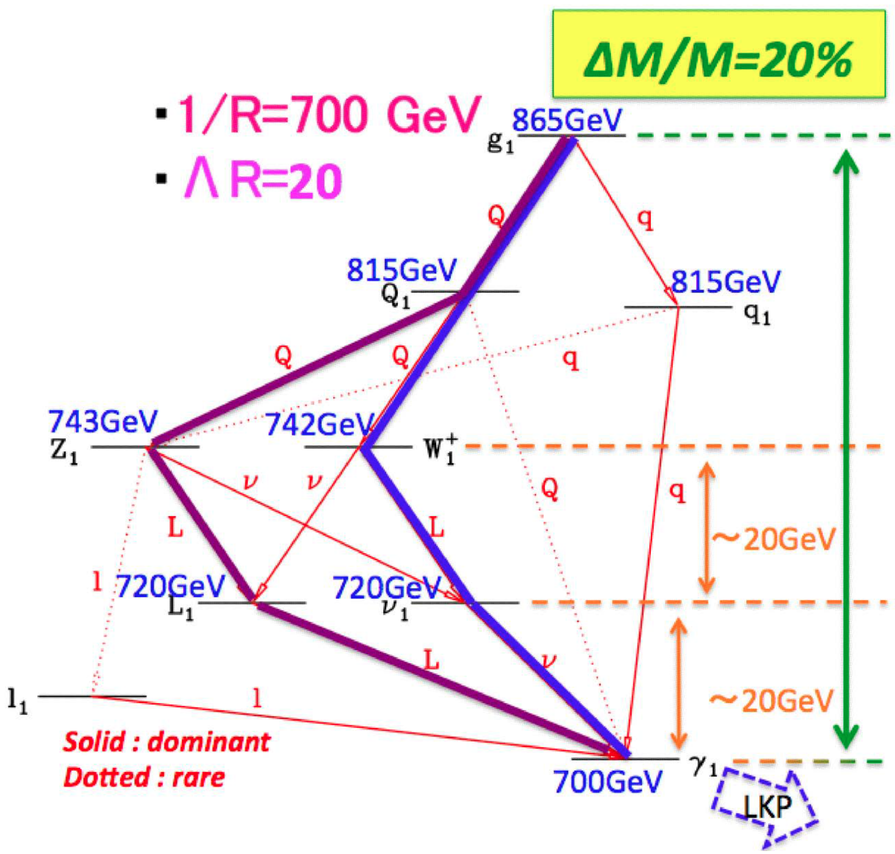
Sensitivity should be up, tight LID + ISR + optimization

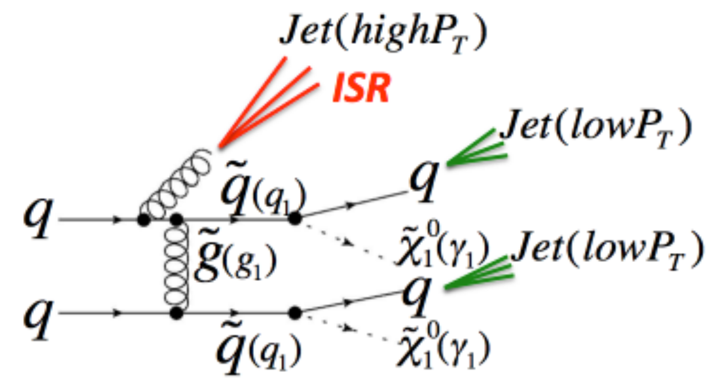
Dark Matter (3)

If GUT relation is assumed
M1(Bino) = M2(Wino) = M3(Gluino)
Limit on Bino mass is 180GeV

(3) If all SUSY particles are degenerate same as UED:
jets emitted from the cascade becomes soft.

LHC phenomenology: ISR jet + soft object

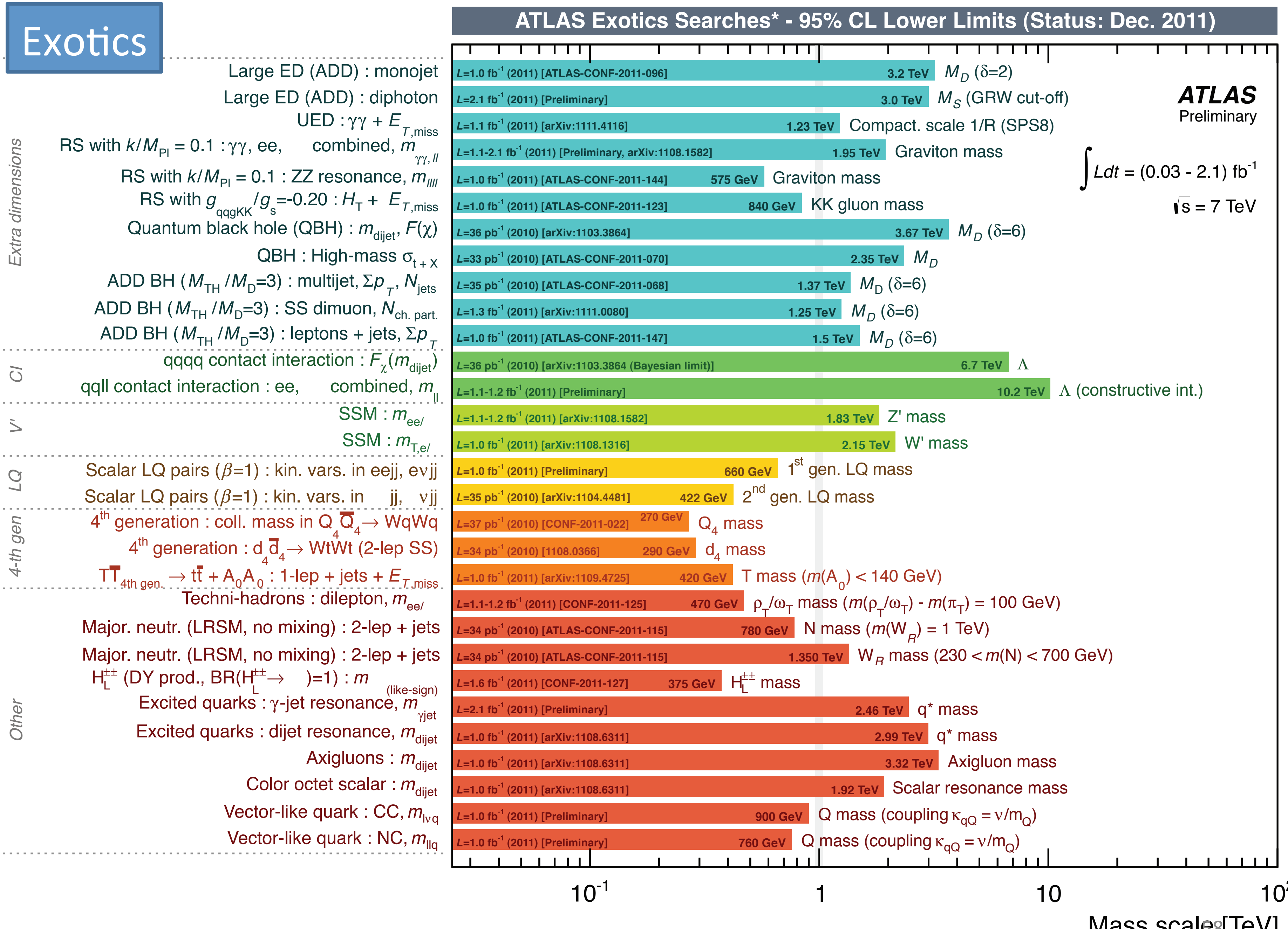




ISR Trigger is low efficiency
(~5%)

soft-lepton combined trigger
(1) multi soft leptons
(2) soft lepton + jets

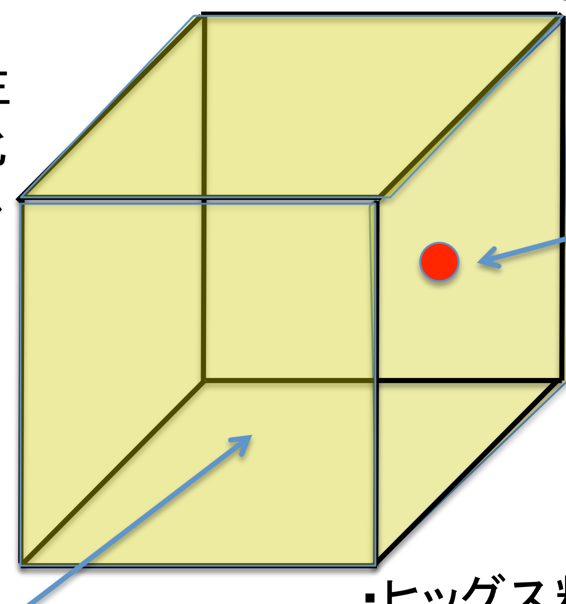
Exotics



*Only a selection of the available results leading to mass limits shown

まとめ

ヒッグス、SUSYの発見　→　容れ物の科学



素粒子をプローブとして
時空や真空をさぐること

まとめ 2

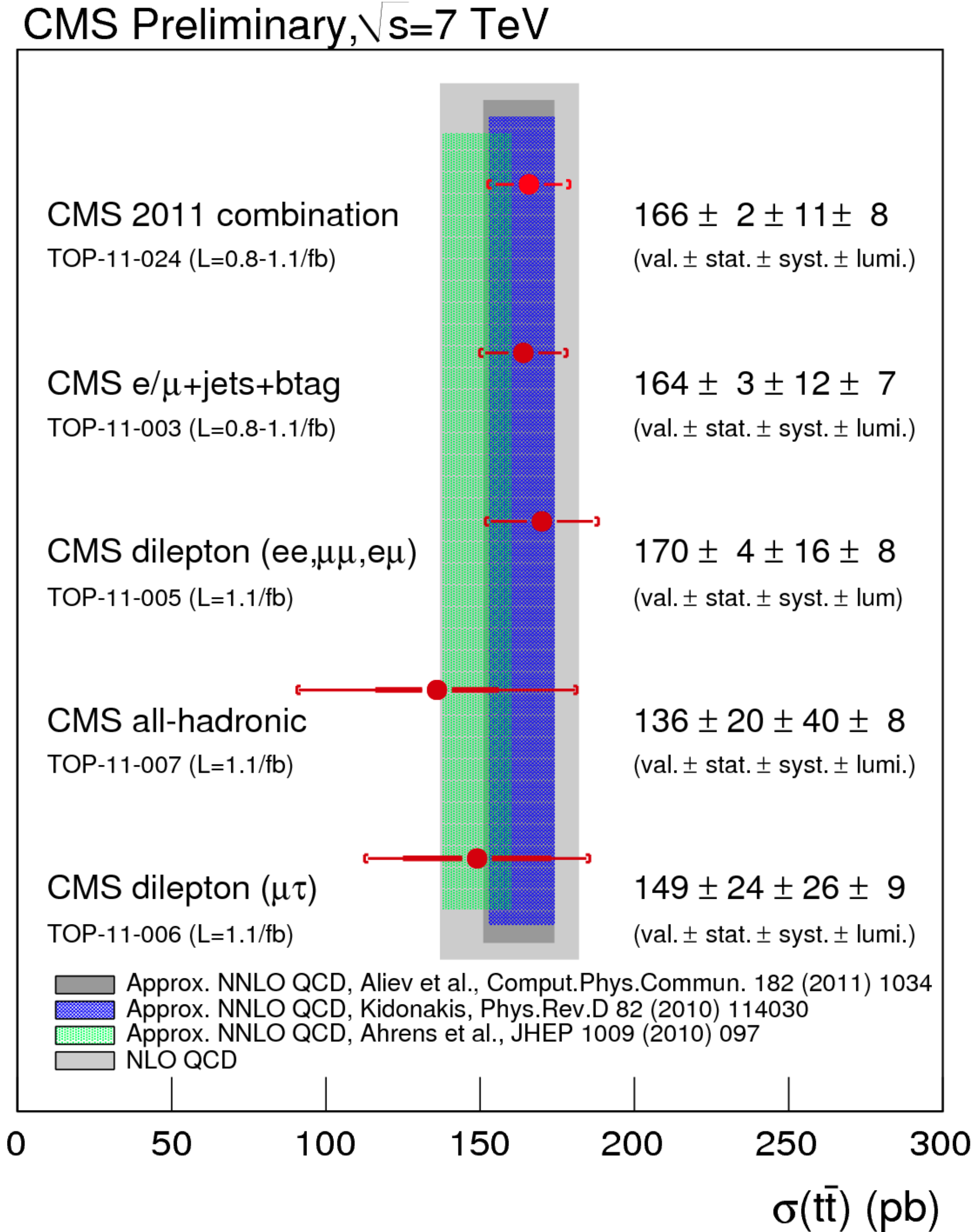
おたのしみに

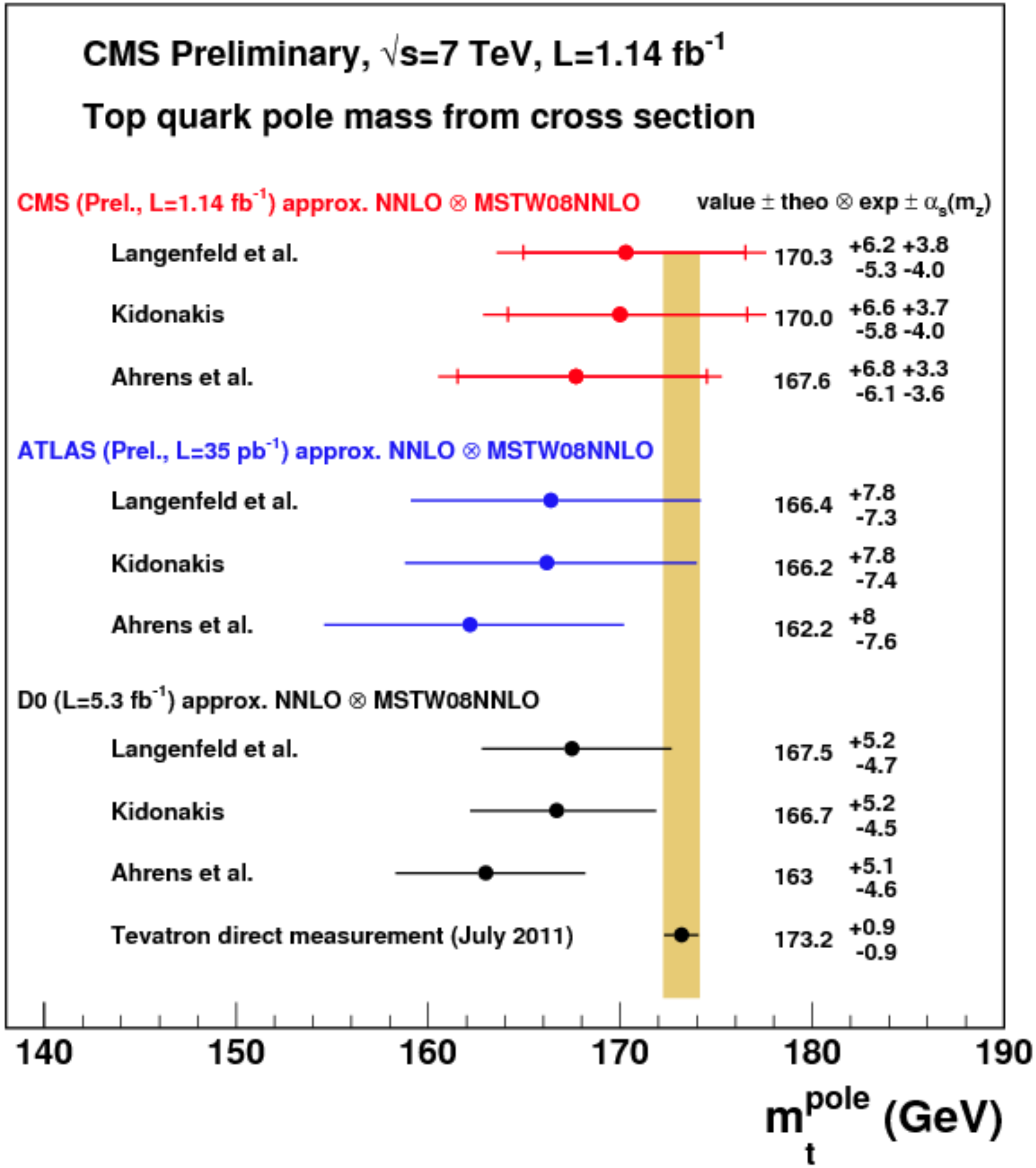
おまけ

2011 Physics Proton Trigger Menu (end of run L = 3.3 10^{33} $cm^{-2}s^{-1}$)

	Offline Selection	Trigger Selection		L1 Rate (kHz) at 3e33	EF Rate (Hz) at 3e33
		L1	EF		
Single leptons	Single muon > 20GeV	11 GeV	18 GeV	8	100
	Single electron > 25GeV	16 GeV	22 GeV	9	55
Two leptons	2 muons > 17, 12GeV	11GeV	15,10GeV	8	4
	2 electrons, each > 15GeV	2x10GeV	2x12GeV	2	1.3
	2 taus > 45, 30GeV	15,11GeV	29,20GeV	7.5	15
Two photons	2 photons, each > 25GeV	2x12GeV	20GeV	3.5	5
Single jet plus MET	Jet pT > 130 GeV & MET > 140 GeV	50 GeV & 35 GeV	75GeV & 55GeV	0.8	18
MET	MET > 170 GeV	50 GeV	70GeV	0.6	5
Multi-jets	5 jets, each pT > 55 GeV	5x10GeV	5x30GeV	0.2	9
TOTAL				**<75**	**~400 (mean)**

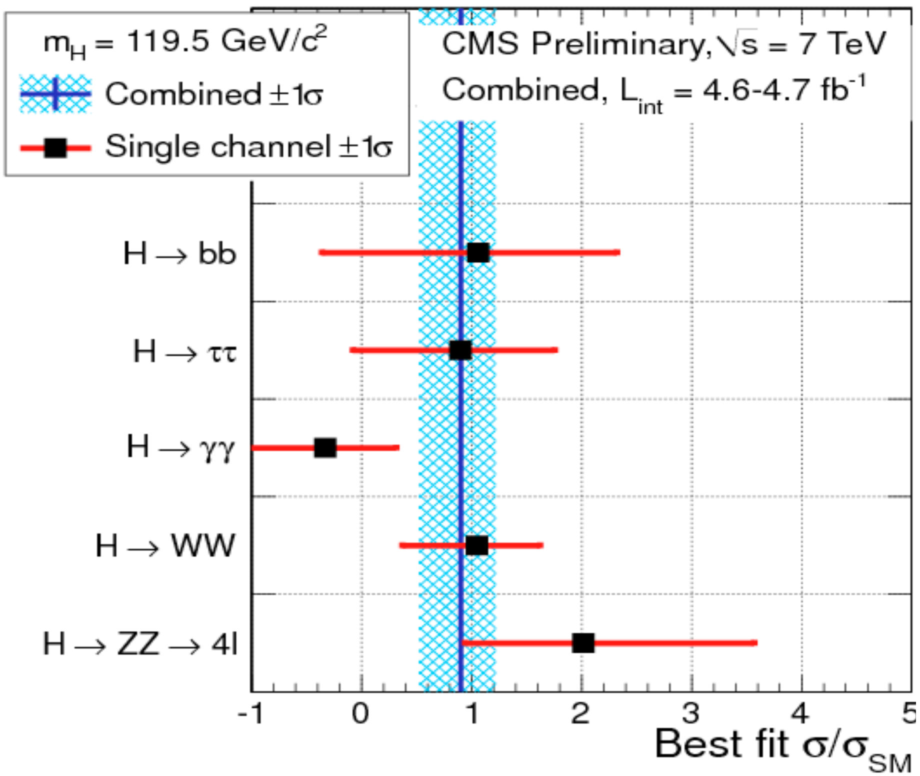
- Some increase in L1 thresholds needed in 2012 (other measures need upgrade)
  - Many triggers have rate ~ E_t^{-3}, raising thr. 20% gives 50% rate reduction
- Isolated single lepton triggers ready in 2011, but not yet used in physics
  - Factor of 2 to 3 available from tracking isolation alone at EF
- Expect to keep 25 GeV single lepton offline thresholds in 2012


CMS Preliminary, √s=7 TeV
CMS 2011 combination
TOP-11-024 (L=0.8-1.1/fb)
166 ± 2 ± 11 ± 8
(val. ± stat. ± syst. ± lumi.)
CMS e/μ+jets+btag
TOP-11-003 (L=0.8-1.1/fb)
164 ± 3 ± 12 ± 7
(val. ± stat. ± syst. ± lumi.)
CMS dilepton (ee,μμ,eμ)
TOP-11-005 (L=1.1/fb)
170 ± 4 ± 16 ± 8
(val. ± stat. ± syst. ± lum)
CMS all-hadronic
TOP-11-007 (L=1.1/fb)
136 ± 20 ± 40 ± 8
(val. ± stat. ± syst. ± lumi.)
CMS dilepton (μτ)
TOP-11-006 (L=1.1/fb)
149 ± 24 ± 26 ± 9
(val. ± stat. ± syst. ± lumi.)
Approx. NNLO QCD, Aliev et al., Comput.Phys.Commun. 182 (2011) 1034
Approx. NNLO QCD, Kidonakis, Phys.Rev.D 82 (2010) 114030
Approx. NNLO QCD, Ahrens et al., JHEP 1009 (2010) 097
NLO QCD
0
50
100
150
200
250
300
σ(tt̄) (pb)

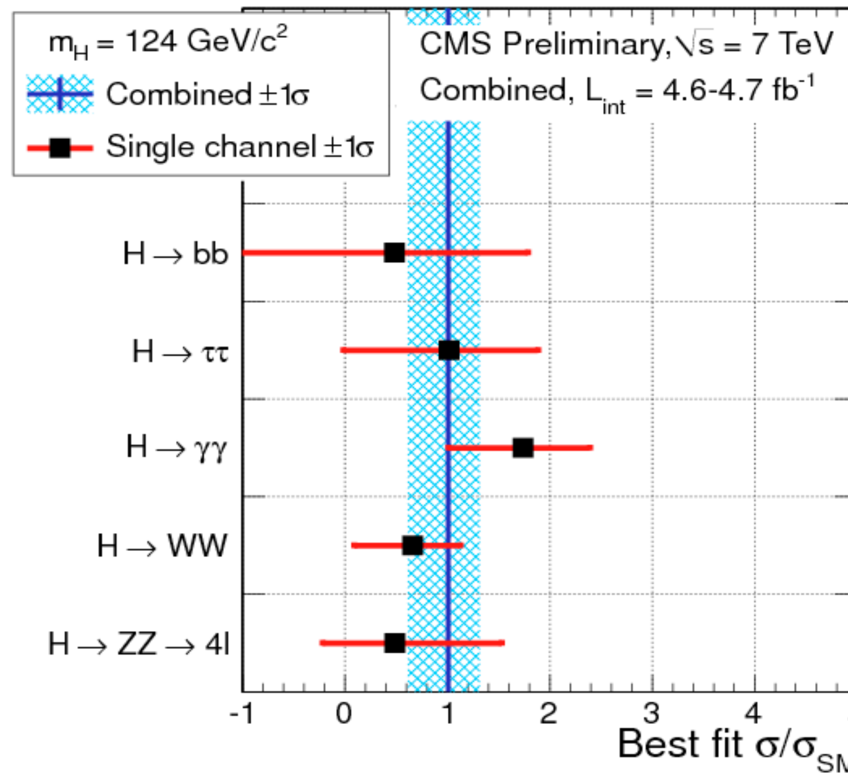


CMS Preliminary, √s=7 TeV, L=1.14 fb-1
Top quark pole mass from cross section
CMS (Prel., L=1.14 fb-1) approx. NNLO ⊗ MSTW08NNLO
value ± theo ⊗ exp ± αs(mz)
Langenfeld et al. 170.3 +6.2 +3.8 -5.3 -4.0
Kidonakis 170.0 +6.6 +3.7 -5.8 -4.0
Ahrens et al. 167.6 +6.8 +3.3 -6.1 -3.6
ATLAS (Prel., L=35 pb-1) approx. NNLO ⊗ MSTW08NNLO
Langenfeld et al. 166.4 +7.8 -7.3
Kidonakis 166.2 +7.8 -7.4
Ahrens et al. 162.2 +8 -7.6
D0 (L=5.3 fb-1) approx. NNLO ⊗ MSTW08NNLO
Langenfeld et al. 167.5 +5.2 -4.7
Kidonakis 166.7 +5.2 -4.5
Ahrens et al. 163 +5.1 -4.6
Tevatron direct measurement (July 2011) 173.2 +0.9 -0.9
140 150 160 170 180 190
m_t^pole (GeV)

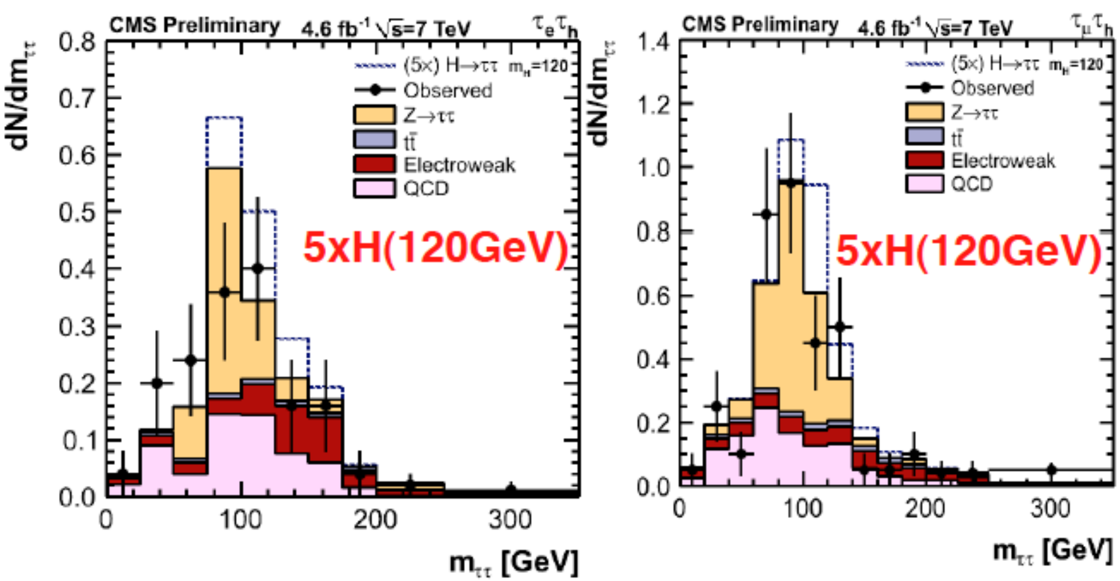
119GeV

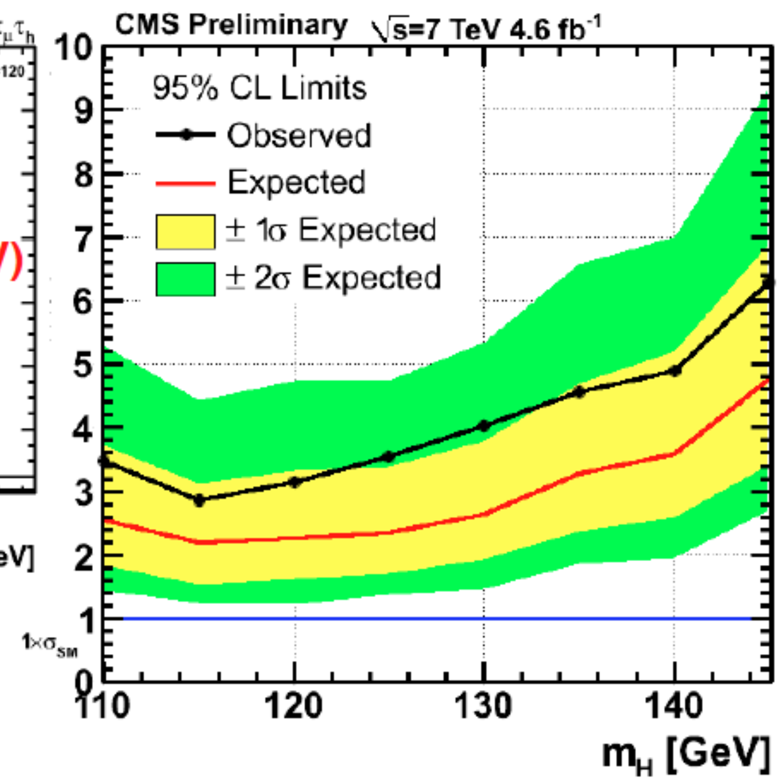


124GeV



[D] H→tautau



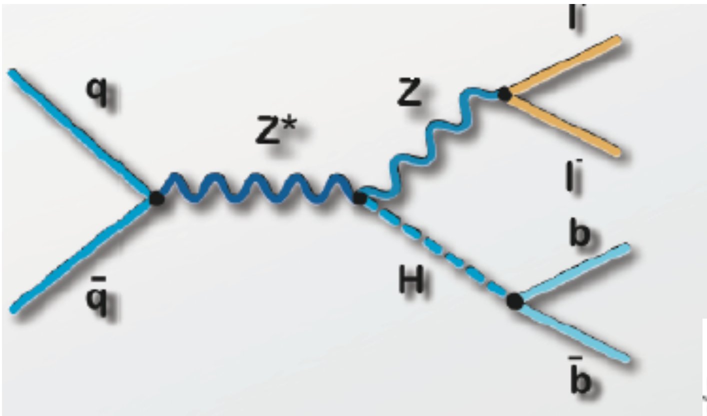


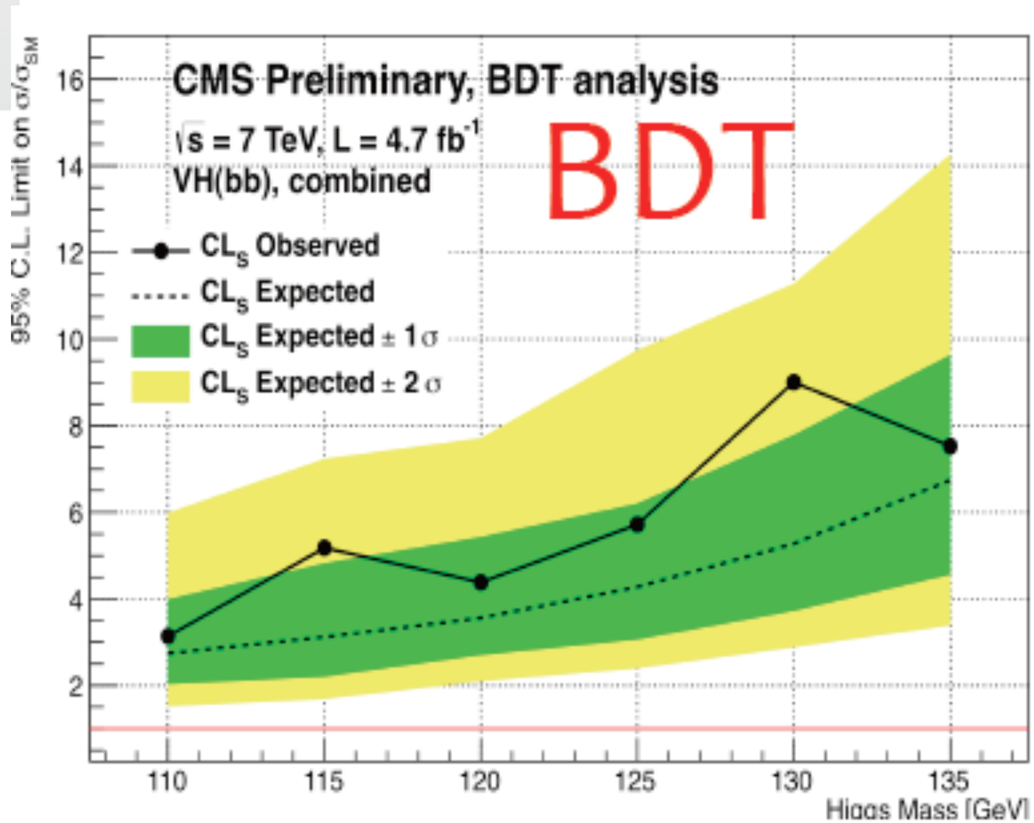
Examples of data in VBF Channels

tautau 1 σ　レベルだけど　zeroともconsistent

[E] H→bb

HZ(ll,nunu) HW(lnu)





1σ　レベルだけど
zeroともconsistent

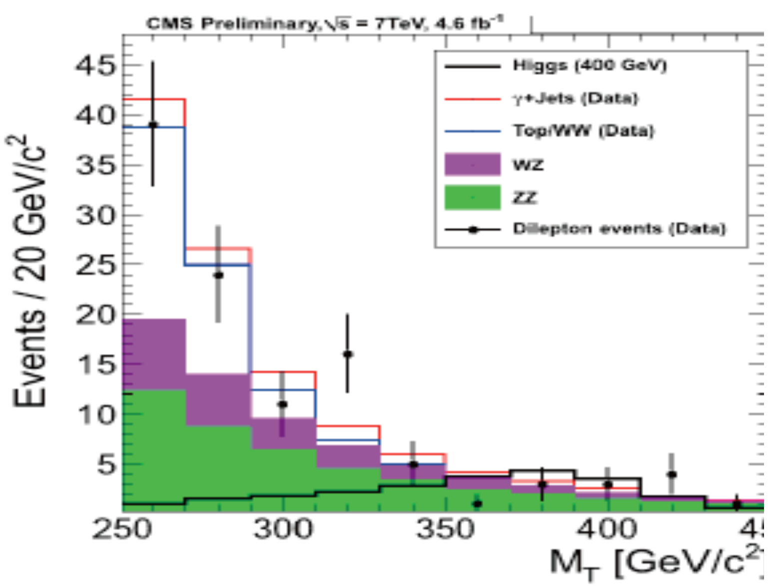
[F] Heavy Higgs (ZZ→llqq, llνν)

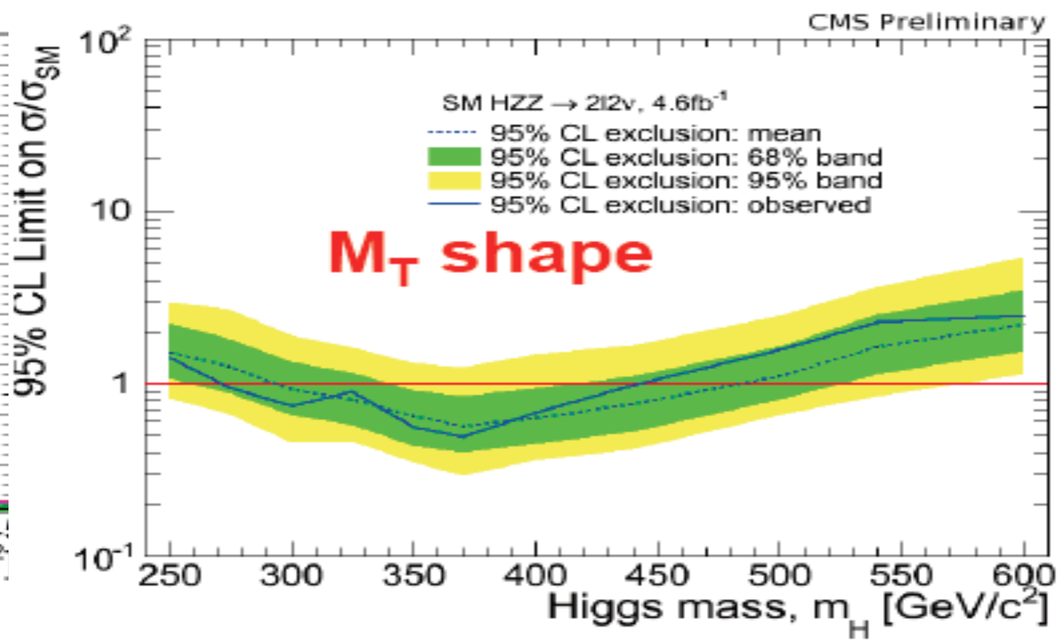
(1) $\Gamma \sim M_h^3$ becomes wide for a heavy higgs, the benefit using “lepton” becomes less.
(2) Br(Z->ee,mumu)*σ is too small for heavy Higgs

H→ZZ→llνν and llqq help the sensitivity for the heavy Higgs.

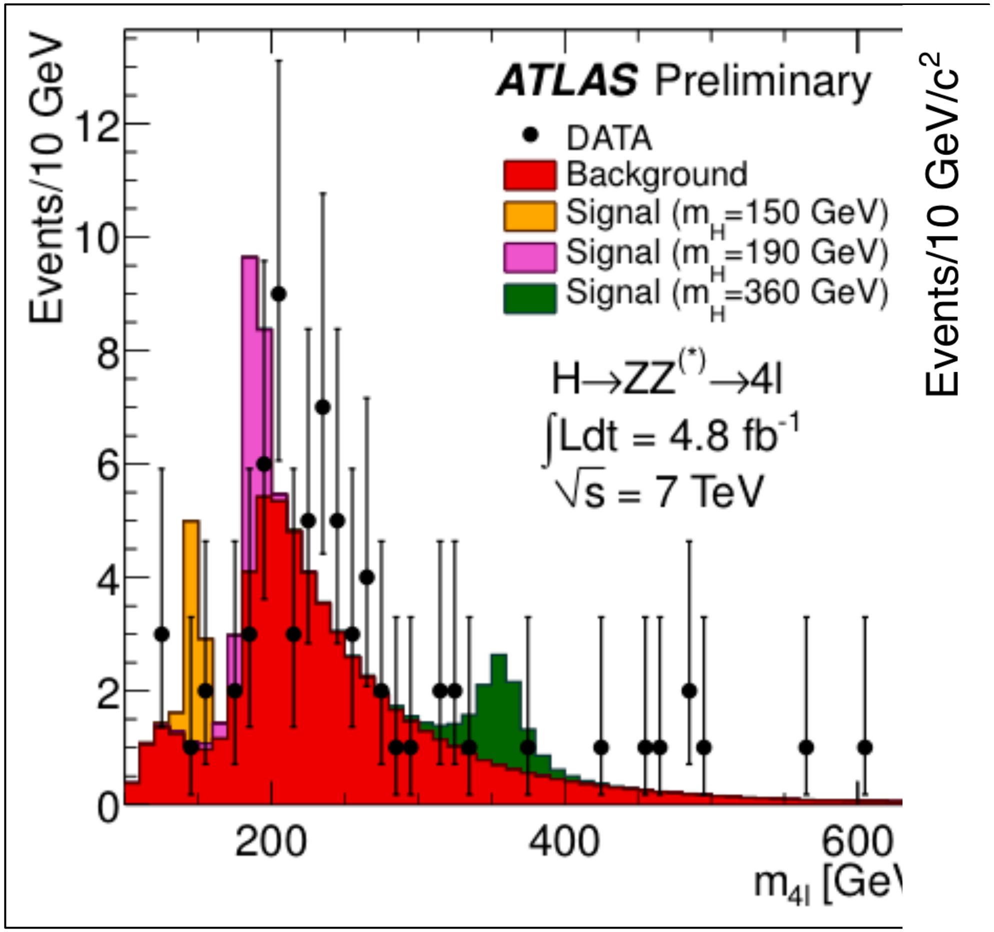
H→ZZ→llνν : OS lepton pair whose invariant mass is Mz, and large mET
MT is calculated as follow, (MT < Mh, but there is Jacobian broad peak near Mh)

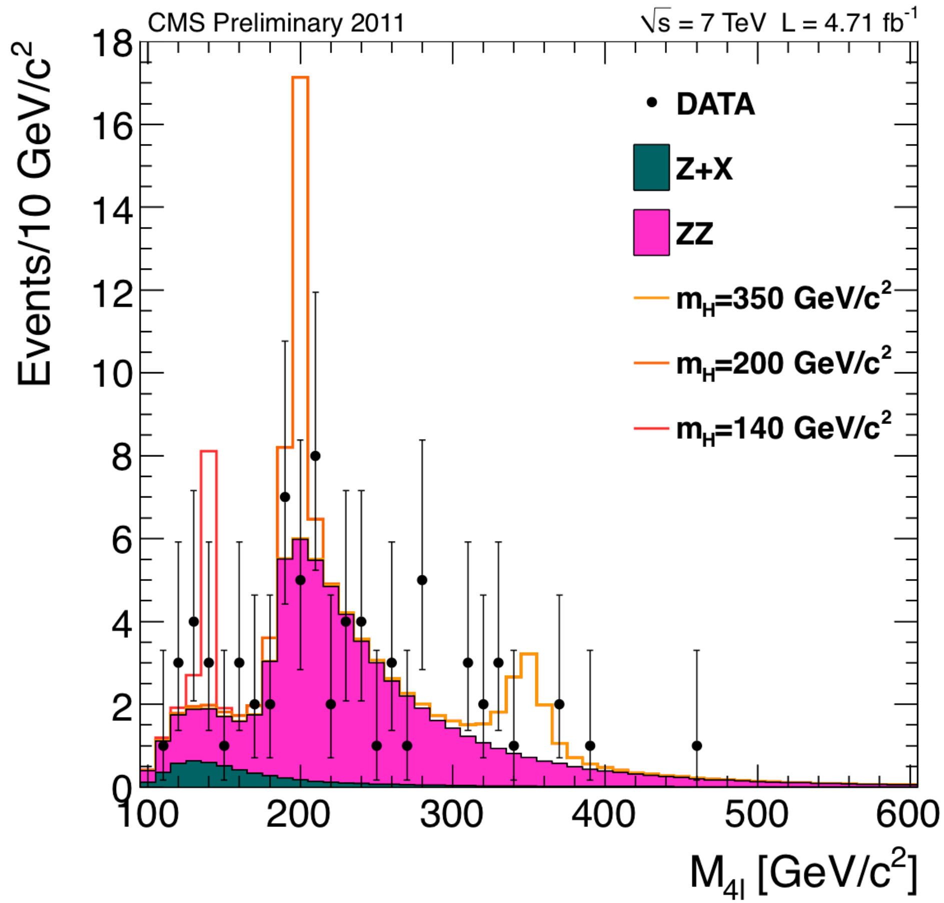
$$m_T^2 \equiv \left[\sqrt{m_Z^2 + |\vec{p}_T^{\,\ell\ell}|^2} + \sqrt{m_Z^2 + |\vec{p}_T^{\,\mathrm{miss}}|^2}\right]^2 - \left[\vec{p}_T^{\,\ell\ell} + \vec{p}_T^{\,\mathrm{miss}}\right]^2$$





[F] ZZ→llll


ATLAS Preliminary
DATA
Background
Signal (m_H=150 GeV)
Signal (m_H=190 GeV)
Signal (m_H=360 GeV)
H→ZZ(*)→4l
∫Ldt = 4.8 fb-1
√s = 7 TeV
Events/10 GeV
m_4l [GeV]


CMS Preliminary 2011
√s = 7 TeV L = 4.71 fb-1
DATA
Z+X
ZZ
m_H=350 GeV/c2
m_H=200 GeV/c2
m_H=140 GeV/c2
Events/10 GeV/c2
M_4l [GeV/c2]

General comments on BG processes

BG estimation is crucial for SUSY hunting, since no peak is expected.

Main BG is W/Z+jets,

top pair production and QCD multijet processes.

(diboson also contributes to EW gaugino direct production)

Control regions are defined to enhance these SM BG processes and check the various distributions.

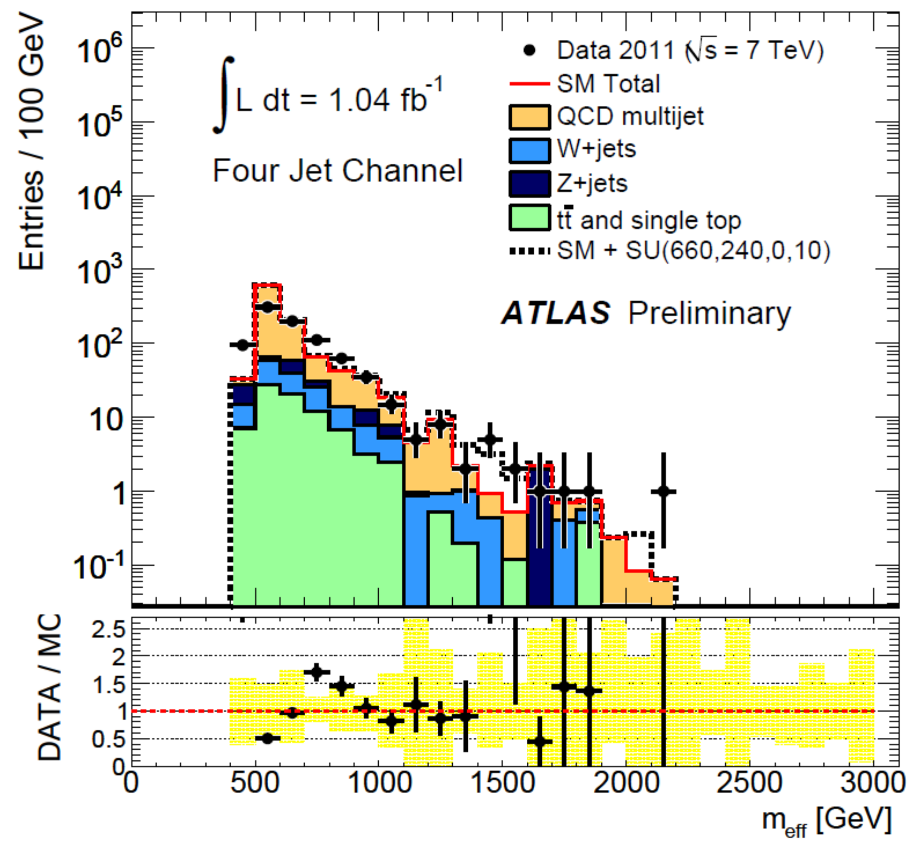
BG1: Control regions (QCD)

QCD multi-jets processes contribute to BG for many SUSY searches, when ν emits in a heavy flavor jet or when jet energy is miss-measured (Fake mET) .

Large mET is useful variable for SUSY.
Also Scalar sum of Jet activity(HT) is useful.
Sum of them, Meff= mET+ Σ PT (jet) is used in ATLAS.

Data is harder than PYTHIA prediction.
PYTHIA is parton shower scheme,
To produce high PT jet, Q^2 of shower evolution is set high, still not enough,
On the other hand, Q^2 is high
then too many jets are produced in PYTHIA and there is discrepancy.
QCD BG is estimated with real data using this CR

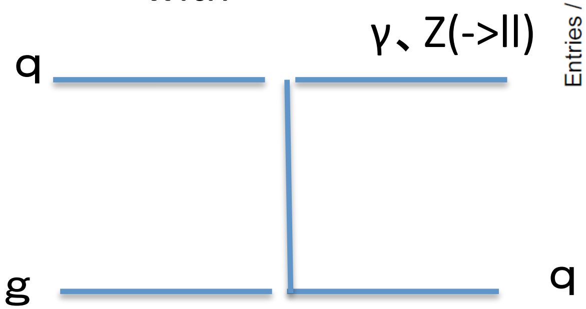
ΔΦ(jet vs mET) <0.4 is required to obtain QCD sample



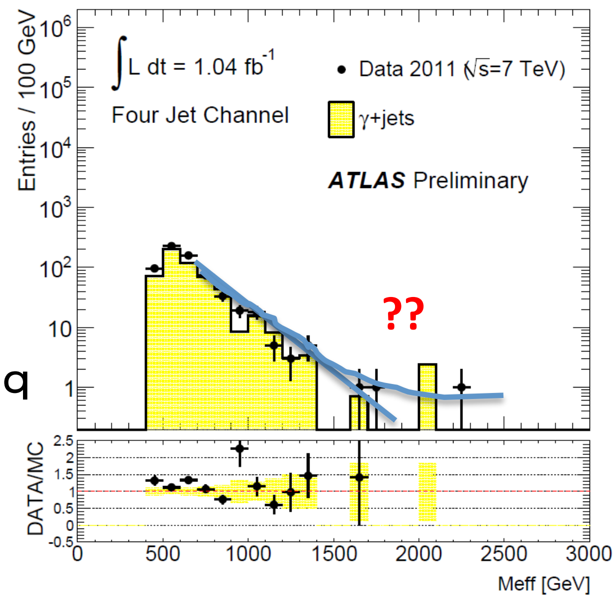
Meff= mET+ Σ PT (jet)

BG2: Control regions (Z)

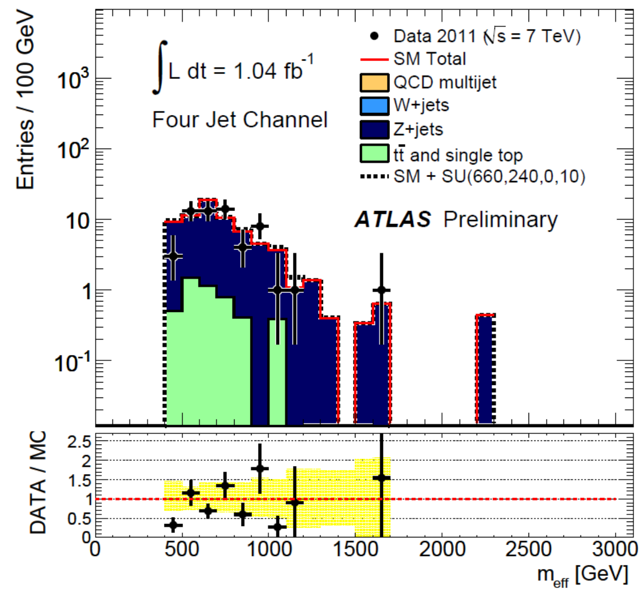
BG (Z->νν)+Jets can be estimated with



Gamma + jets



Z(ll) + jets



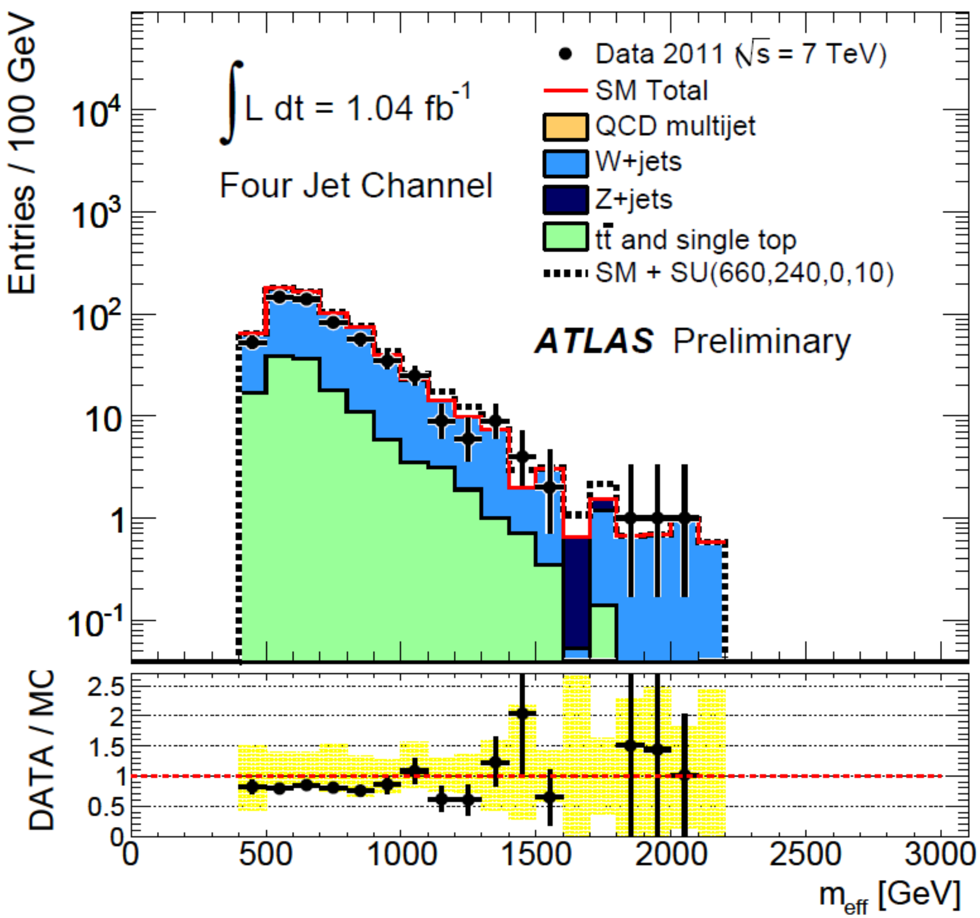
Events with high PT jet are expected.

Yellow and blues show the simulated distribution of γ+jets and Z(ll)+jets
Currently MC produced by ALPGEN are used and
Normalization has been performed using data. There are two serious problems:

(1) Statistic of both Data & MC are limited in the interesting regions.
    No body believes MC for such a high end of the kinematics.
    Linear extrapolation or asymptotic?
(2) If use use MC information, JES uncertainties (~10%) will contributes. still high.

BG3: Control regions (W)

W + jets (1lep without b)



$M_T < M_W$ & no bjets are selected to obtain W+jets sample.
Blue shows the simulated W+jets BG.

MC is produced with ALPGEN.

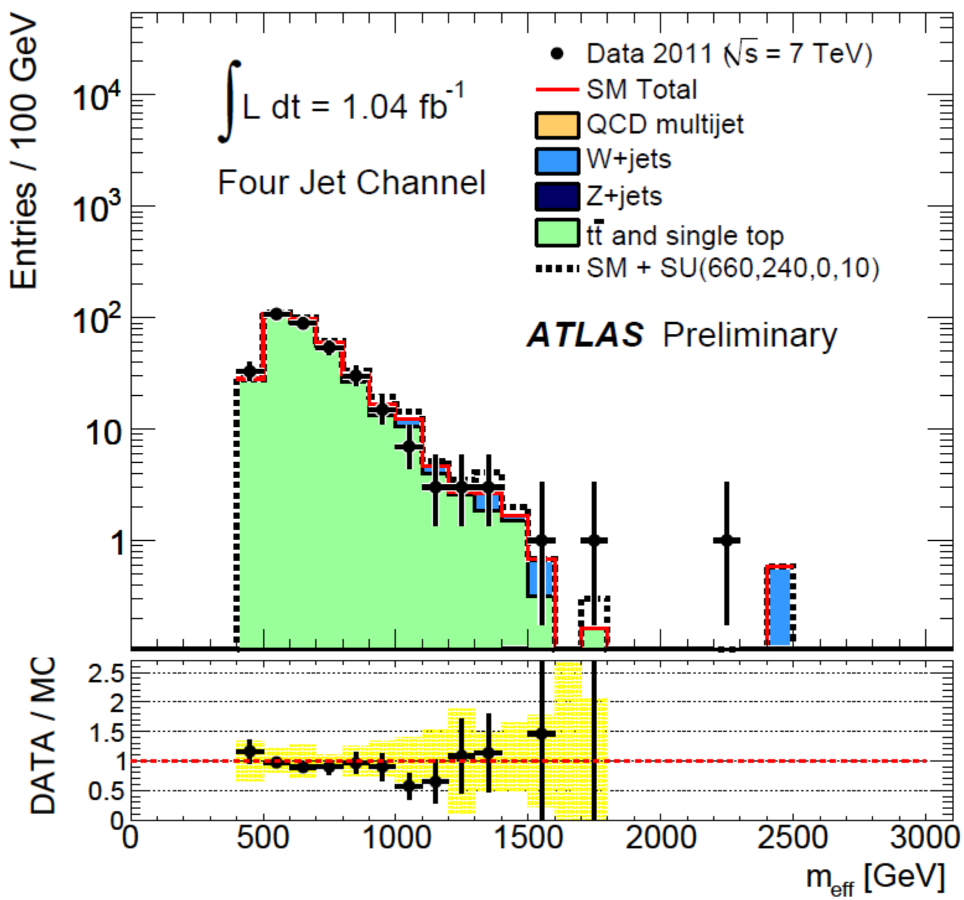
Statistic is high comparing to Z+jets
Slop is slightly different?
Data is harder ?

Currently
Normalization is determined by data
& shape predicted by ALPGEN is used.

Linear extrapolation ?
some structure asymptotically ?
This becomes key I will show later.

Prediction (W+jets BG in high Meff region) is most urgent & important,
otherwise we can not conclude even if we have an excess, (the same as H->WW)

BG4: Control regions (tt)



$M_T < M_W$ & bjets are selected to obtain tt sample and the pure tt sample can be selected.

tt is not dominant BG except for mET+bjet analysis, since σ at 7TeV is 170pb.

It becomes serious at ECM=14TeV (830pb)

Now basically We use MC even with normalization.

But tt+Njets, high meff regions still need more data and study. Different kinematic regions are used in top WG and SUSY WG

Selectionの概論

m1/2

squark pair　squark->qχ (2body)
(A) 2jet-like
(B) 特にm0小さいと lepton Br
BG落とす為に Large mET

gluino/squark
(A) 3～4 jet-like（最低 2 本はハード）」
(B)g->bb,ttなど　b, leptonic

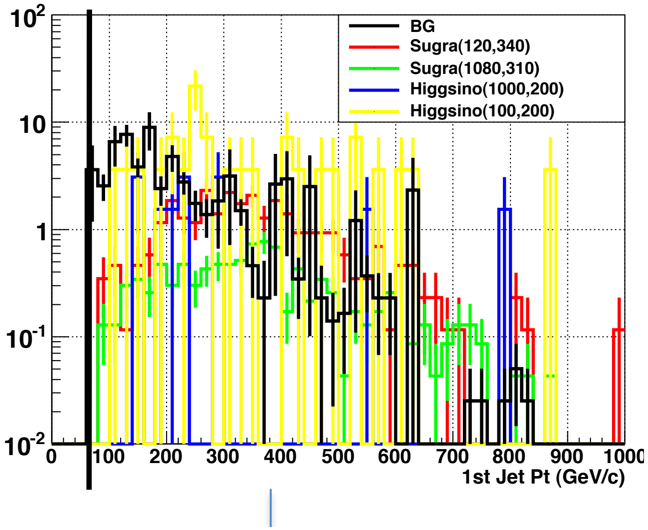
gluino pair　Gluino->qqχ (3body)
(A) 4jet-like
(B) 特にm0 大きいとき　σ小
hard >= 4jets (small mET)
(C) sbottom, stop　Br　bの解析
BG落とす High PT jets多数 or b

m0

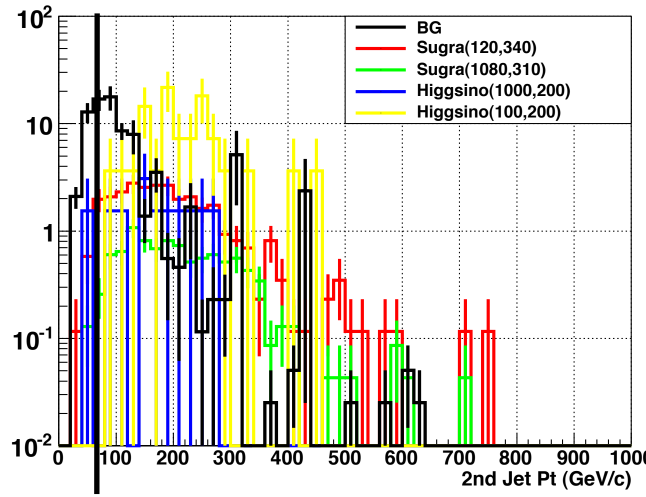
Main BG　W(lnu)+jets,　Z(nunu)+jets,　top,　QCD(2jets以外は効かない)
mETを厳しくしても W/Zは結構 最後まで残る。
ECM 7TeV なので top　σ=830pb -> 160pb （断面積 1/5)　W/Z が 1,2,3 で主

Jet PT of W+jets process comparing with signal

< 1st Jet Pt >

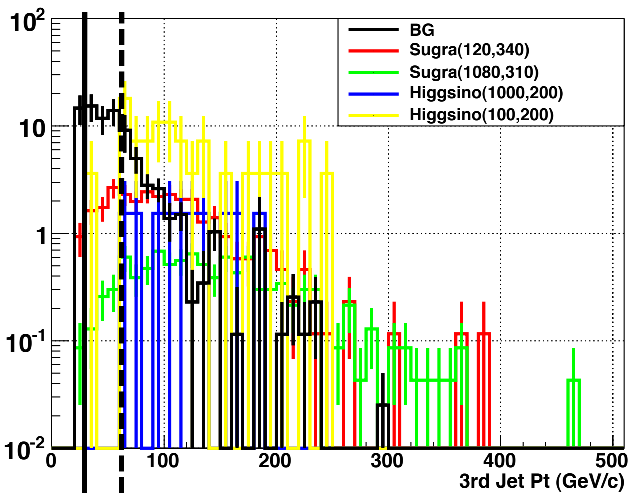


< 2nd Jet Pt >

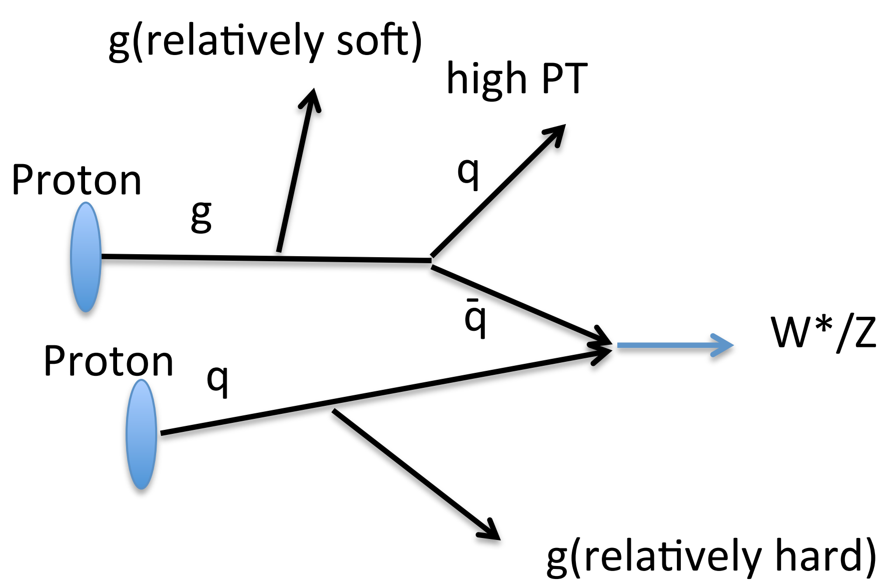


2nd is still hard

< 3rd Jet Pt >

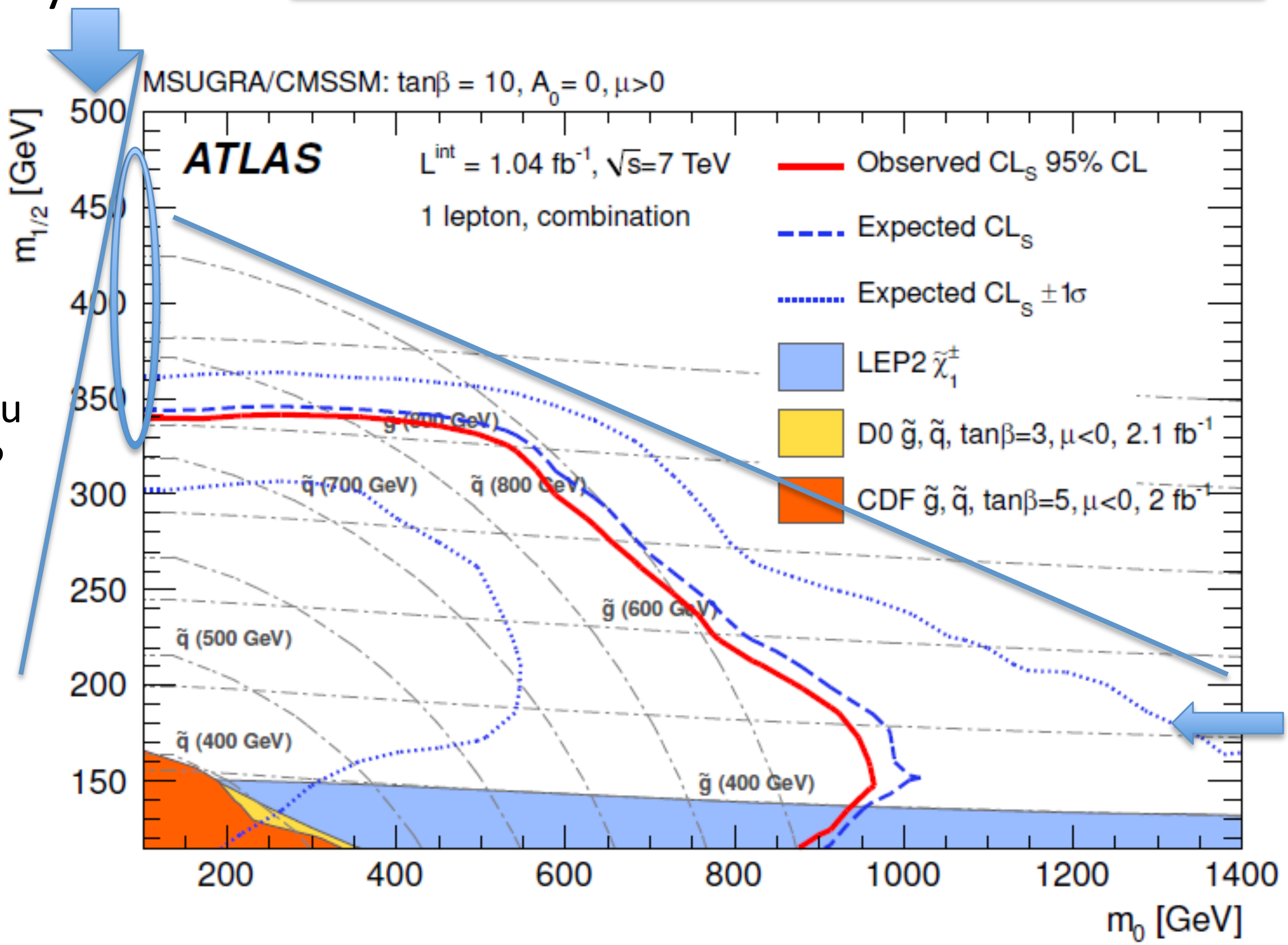


3rd becomes softer



constrained on CMSSM

Dilepton analysis



Stau LSP

excluded by No lepton channel

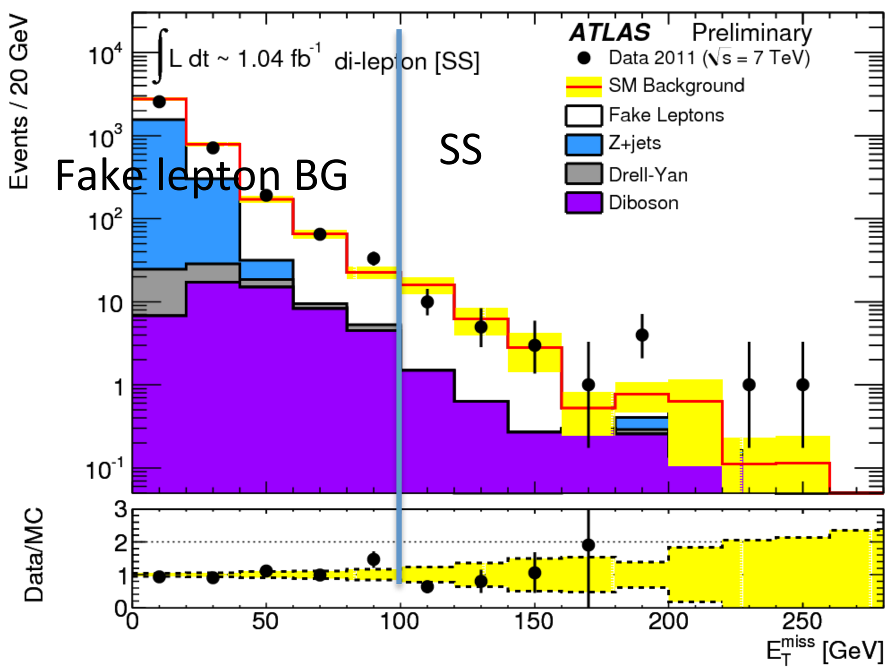
Squark, gluino ~ 800GeV

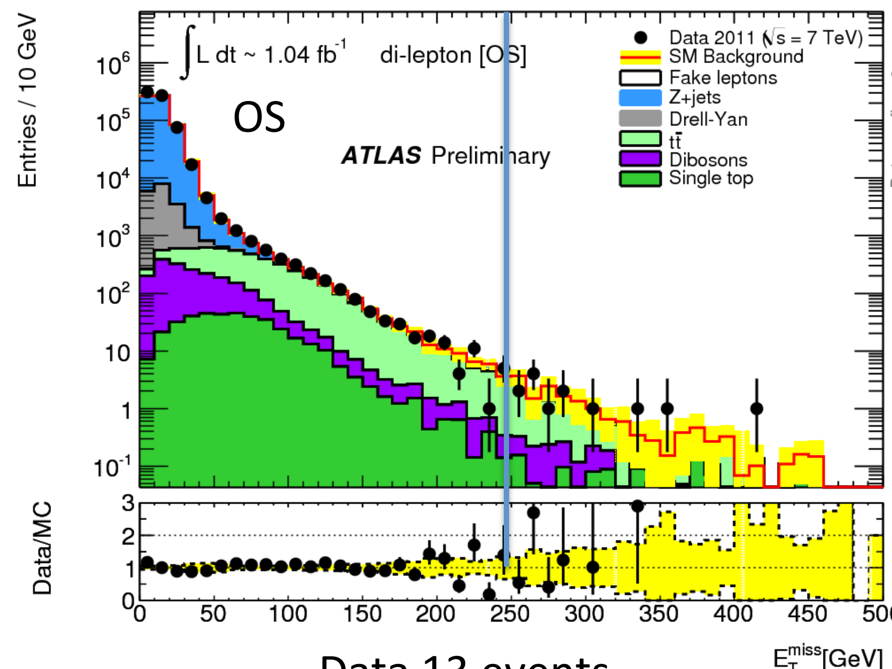
This channel is crucial for "discovery"

2leptons Mode

chargino1 + neutralino2 -> lepton pairs + mET   (no requirement on jet)

2lepton   electron (medium: PT>25GeV for leading   >20GeV for 2nd)
muon (combined: PT>20GeV for leading   >10GeV for 2nd)



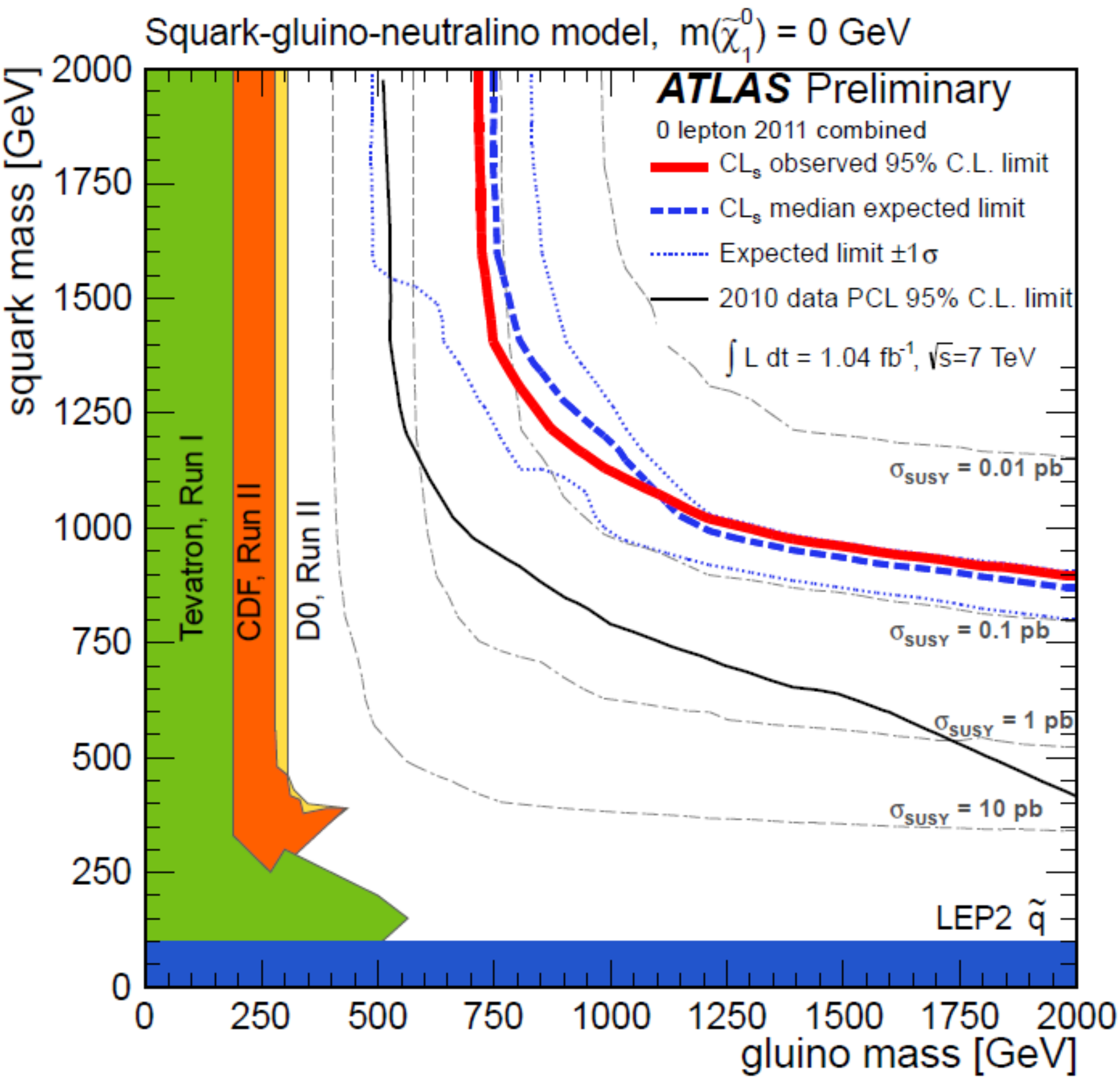


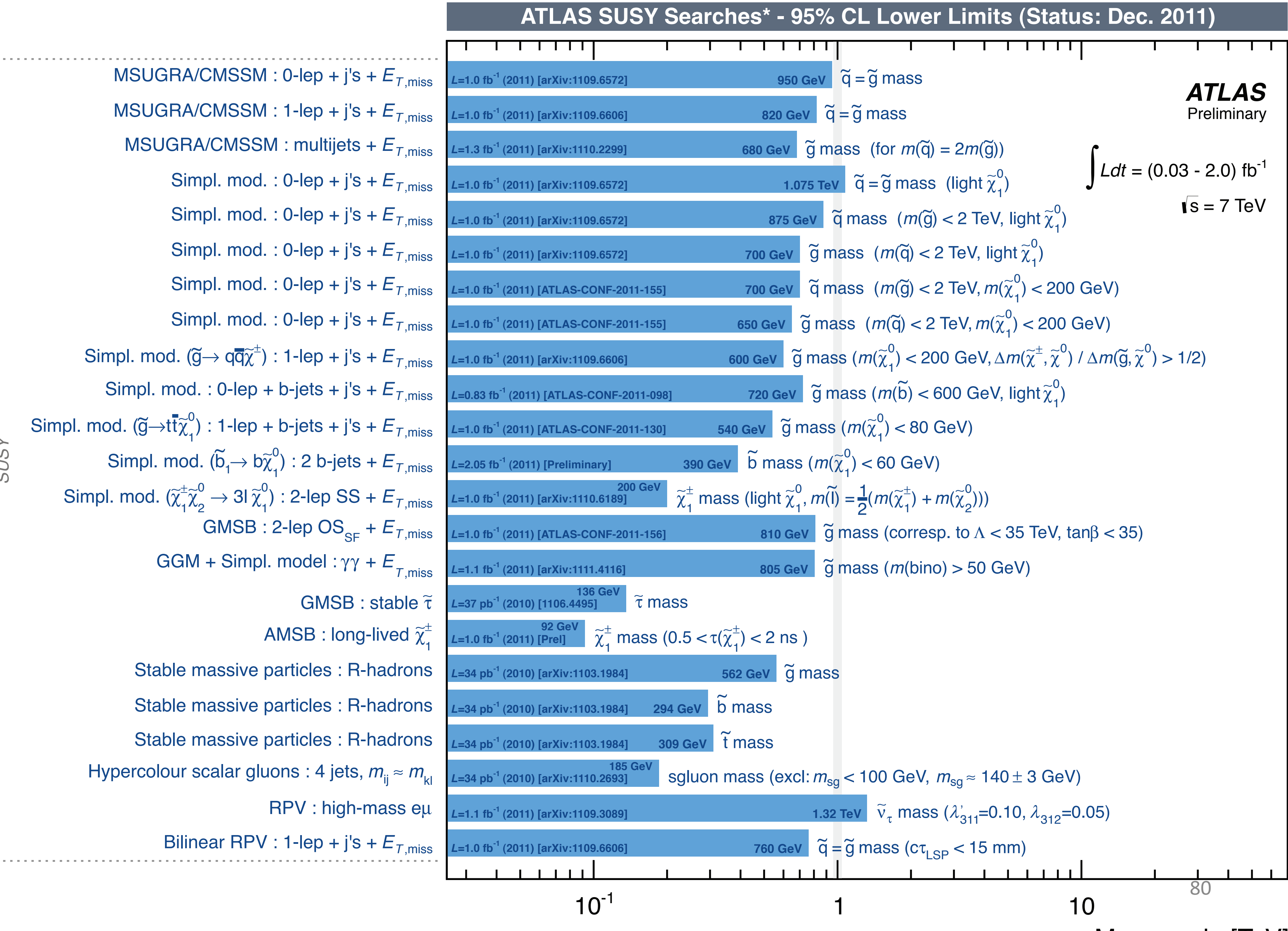
Data 25 events
BG 33+- 4+-4

Data 13 events
BG 15+-1+-4

No excess was found -> still sensitivity is less than 100GeV(Bino) for direct production
Lepton ID should be more tight to reduce fake contribution.

極端なケースでの制限

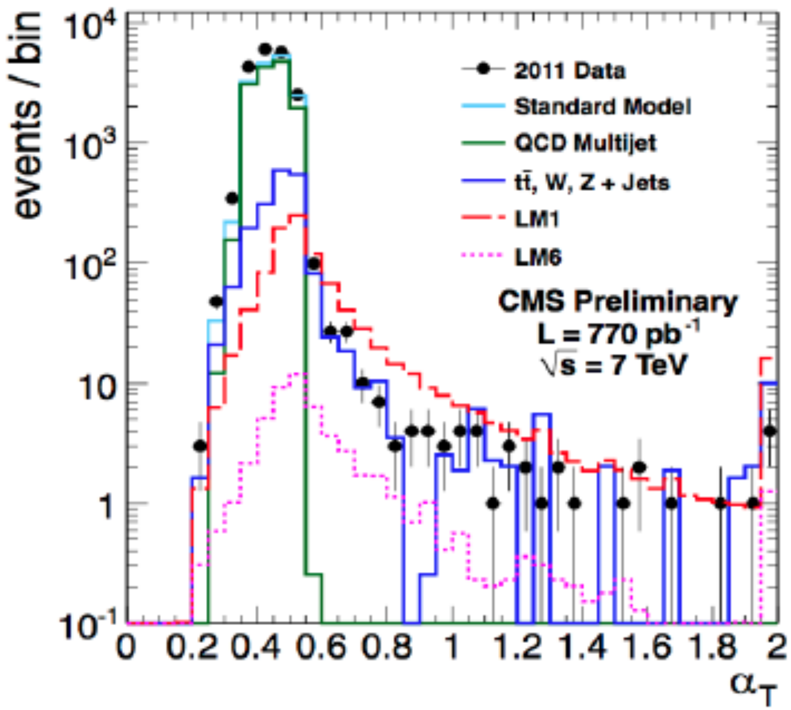

Squark-gluino-neutralino model, $m(\tilde{\chi}_1^0)$ = 0 GeV
ATLAS Preliminary
0 lepton 2011 combined
CL_s observed 95% C.L. limit
CL_s median expected limit
Expected limit ±1σ
2010 data PCL 95% C.L. limit
$\int L\,dt$ = 1.04 fb^{-1}, $\sqrt{s}$=7 TeV
σ_{SUSY} = 0.01 pb
σ_{SUSY} = 0.1 pb
σ_{SUSY} = 1 pb
σ_{SUSY} = 10 pb
Tevatron, Run I
CDF, Run II
D0, Run II
LEP2 $\tilde{q}$
squark mass [GeV]
gluino mass [GeV]
0
250
500
750
1000
1250
1500
1750
2000

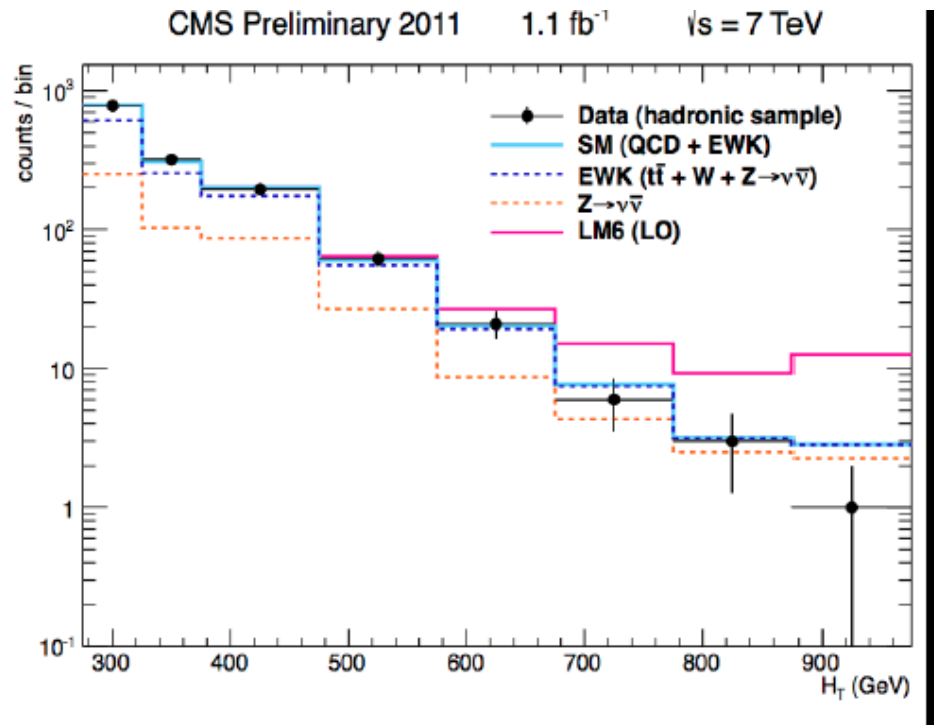

ATLAS SUSY Searches* - 95% CL Lower Limits (Status: Dec. 2011)
ATLAS
Preliminary
$\int L dt = (0.03 - 2.0)\ fb^{-1}$
$\sqrt{s} = 7$ TeV
MSUGRA/CMSSM : 0-lep + j's + $E_{T,miss}$
L=1.0 fb-1 (2011) [arXiv:1109.6572] 950 GeV $\tilde{q} = \tilde{g}$ mass
MSUGRA/CMSSM : 1-lep + j's + $E_{T,miss}$
L=1.0 fb-1 (2011) [arXiv:1109.6606] 820 GeV $\tilde{q} = \tilde{g}$ mass
MSUGRA/CMSSM : multijets + $E_{T,miss}$
L=1.3 fb-1 (2011) [arXiv:1110.2299] 680 GeV $\tilde{g}$ mass (for $m(\tilde{q}) = 2m(\tilde{g})$)
Simpl. mod. : 0-lep + j's + $E_{T,miss}$
L=1.0 fb-1 (2011) [arXiv:1109.6572] 1.075 TeV $\tilde{q} = \tilde{g}$ mass (light $\tilde{\chi}^0_1$)
Simpl. mod. : 0-lep + j's + $E_{T,miss}$
L=1.0 fb-1 (2011) [arXiv:1109.6572] 875 GeV $\tilde{q}$ mass ($m(\tilde{g}) < 2$ TeV, light $\tilde{\chi}^0_1$)
Simpl. mod. : 0-lep + j's + $E_{T,miss}$
L=1.0 fb-1 (2011) [arXiv:1109.6572] 700 GeV $\tilde{g}$ mass ($m(\tilde{q}) < 2$ TeV, light $\tilde{\chi}^0_1$)
Simpl. mod. : 0-lep + j's + $E_{T,miss}$
L=1.0 fb-1 (2011) [ATLAS-CONF-2011-155] 700 GeV $\tilde{q}$ mass ($m(\tilde{g}) < 2$ TeV, $m(\tilde{\chi}^0_1) < 200$ GeV)
Simpl. mod. : 0-lep + j's + $E_{T,miss}$
L=1.0 fb-1 (2011) [ATLAS-CONF-2011-155] 650 GeV $\tilde{g}$ mass ($m(\tilde{q}) < 2$ TeV, $m(\tilde{\chi}^0_1) < 200$ GeV)
Simpl. mod. ($\tilde{g} \to q\bar{q}\tilde{\chi}^{\pm}$) : 1-lep + j's + $E_{T,miss}$
L=1.0 fb-1 (2011) [arXiv:1109.6606] 600 GeV $\tilde{g}$ mass ($m(\tilde{\chi}^0_1) < 200$ GeV, $\Delta m(\tilde{\chi}^{\pm}, \tilde{\chi}^0) / \Delta m(\tilde{g}, \tilde{\chi}^0) > 1/2$)
Simpl. mod. : 0-lep + b-jets + j's + $E_{T,miss}$
L=0.83 fb-1 (2011) [ATLAS-CONF-2011-098] 720 GeV $\tilde{g}$ mass ($m(\tilde{b}) < 600$ GeV, light $\tilde{\chi}^0_1$)
Simpl. mod. ($\tilde{g} \to t\bar{t}\tilde{\chi}^0_1$) : 1-lep + b-jets + j's + $E_{T,miss}$
L=1.0 fb-1 (2011) [ATLAS-CONF-2011-130] 540 GeV $\tilde{g}$ mass ($m(\tilde{\chi}^0_1) < 80$ GeV)
Simpl. mod. ($\tilde{b}_1 \to b\tilde{\chi}^0_1$) : 2 b-jets + $E_{T,miss}$
L=2.05 fb-1 (2011) [Preliminary] 390 GeV $\tilde{b}$ mass ($m(\tilde{\chi}^0_1) < 60$ GeV)
Simpl. mod. ($\tilde{\chi}^{\pm}_1\tilde{\chi}^0_2 \to 3l\,\tilde{\chi}^0_1$) : 2-lep SS + $E_{T,miss}$
L=1.0 fb-1 (2011) [arXiv:1110.6189] 200 GeV $\tilde{\chi}^{\pm}_1$ mass (light $\tilde{\chi}^0_1$, $m(\tilde{l}) = \frac{1}{2}(m(\tilde{\chi}^{\pm}_1) + m(\tilde{\chi}^0_2))$)
GMSB : 2-lep OS_{SF} + $E_{T,miss}$
L=1.0 fb-1 (2011) [ATLAS-CONF-2011-156] 810 GeV $\tilde{g}$ mass (corresp. to $\Lambda < 35$ TeV, $\tan\beta < 35$)
GGM + Simpl. model : $\gamma\gamma$ + $E_{T,miss}$
L=1.1 fb-1 (2011) [arXiv:1111.4116] 805 GeV $\tilde{g}$ mass (m(bino) > 50 GeV)
GMSB : stable $\tilde{\tau}$
L=37 pb-1 (2010) [1106.4495] 136 GeV $\tilde{\tau}$ mass
AMSB : long-lived $\tilde{\chi}^{\pm}_1$
L=1.0 fb-1 (2011) [Prel] 92 GeV $\tilde{\chi}^{\pm}_1$ mass ($0.5 < \tau(\tilde{\chi}^{\pm}_1) < 2$ ns)
Stable massive particles : R-hadrons
L=34 pb-1 (2010) [arXiv:1103.1984] 562 GeV $\tilde{g}$ mass
Stable massive particles : R-hadrons
L=34 pb-1 (2010) [arXiv:1103.1984] 294 GeV $\tilde{b}$ mass
Stable massive particles : R-hadrons
L=34 pb-1 (2010) [arXiv:1103.1984] 309 GeV $\tilde{t}$ mass
Hypercolour scalar gluons : 4 jets, $m_{ij} \approx m_{kl}$
L=34 pb-1 (2010) [arXiv:1110.2693] 185 GeV sgluon mass (excl: $m_{sg} < 100$ GeV, $m_{sg} \approx 140 \pm 3$ GeV)
RPV : high-mass eμ
L=1.1 fb-1 (2011) [arXiv:1109.3089] 1.32 TeV $\tilde{\nu}_{\tau}$ mass (λ'_{311}=0.10, λ_{312}=0.05)
Bilinear RPV : 1-lep + j's + $E_{T,miss}$
L=1.0 fb-1 (2011) [arXiv:1109.6606] 760 GeV $\tilde{q} = \tilde{g}$ mass ($c\tau_{LSP} < 15$ mm)
10^{-1}
1
10
SUSY

CMSの解析

$$\rightarrow \alpha_T = \sqrt{\frac{p_{T,j2}/p_{T,j1}}{2(1-\cos\Delta\phi)}}$$

バランス　　分子 1　　分母 4　　½
アンバランス　　分母　小さい ＞ 1/2





基本的に QCD jet を　α Tで落とす
W/Z/top　　HT Σ　ET jet

High HT cut　candidate 1, a few
感度が高くなる

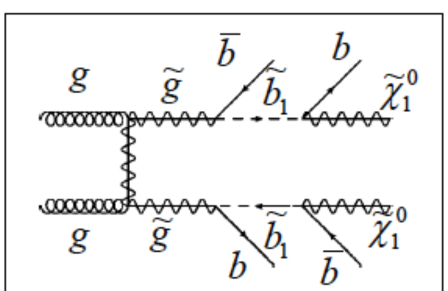
mET + jets with B jet (Stop search)

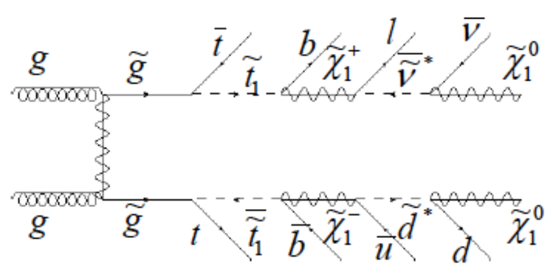
Stop is crucial for naturalness (Only Higgs mass and Higgsino mass)
+Br increases when Higgsino component in LSP increase

(A) No Lepton + multijets(>=3) + mET + b-jet (at least 1 or 2)
gluino pair production
and gluino -> top stop
(gluino → b sbottom also contributes this stopology)

（B）One Lepton + multijets(>=3)+mET+bjet(at least 1)
gluino pair production
gluino -> btop stop & lepton is emitted from top decay or chargino

(C) No lepton + 2 b jets + mET (stop pair sbottom pair)
direct productio of stop/sbotom
stop/sbotom -> b + chargino/neutralino (chargino -> LSP+soft)

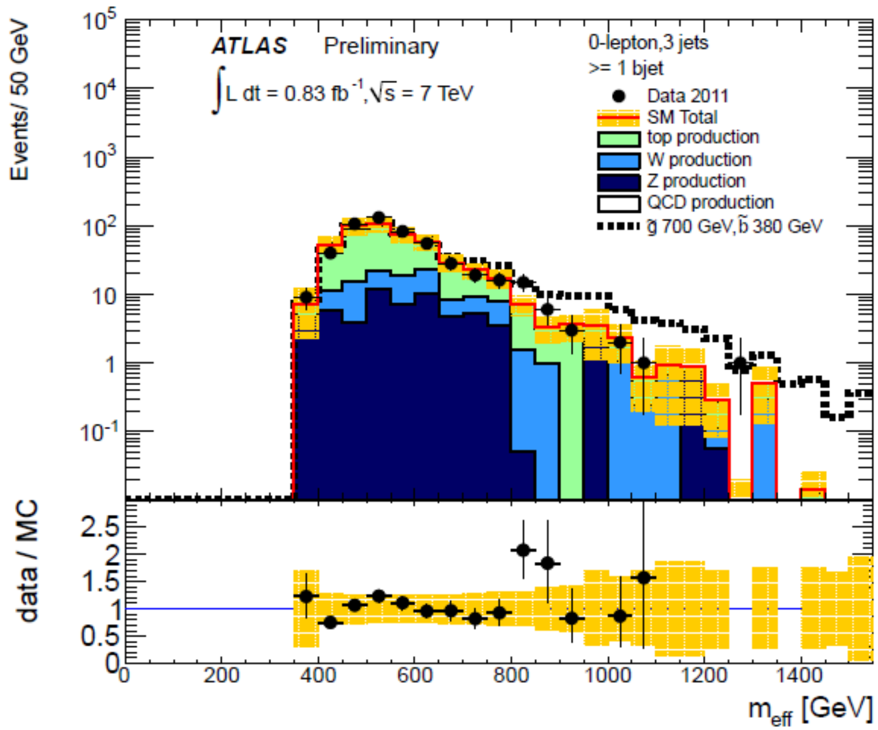




Results of Topology A (bjet +No lepton)

At least 3jets(PT>130,50,50) MET>130GeV MET/Meff>0.25 Δϕ>0.4 Meff>700GeV

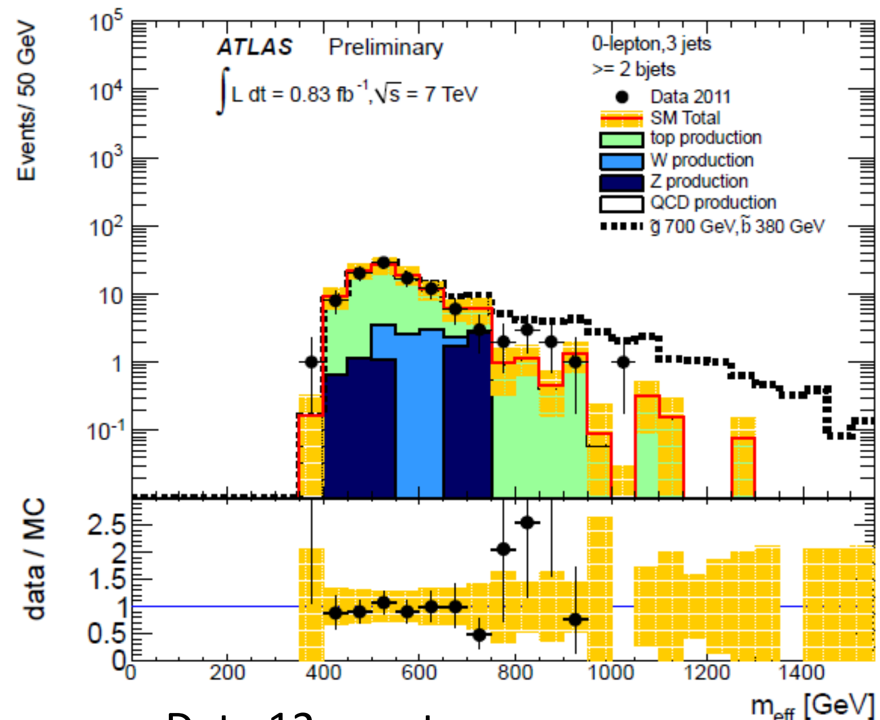
Bjet>=1



Data 63 events

BG 70 +24 -22 (**t 37 W/Z 31** QCD 2)

Bjet>=2



Data 12 events

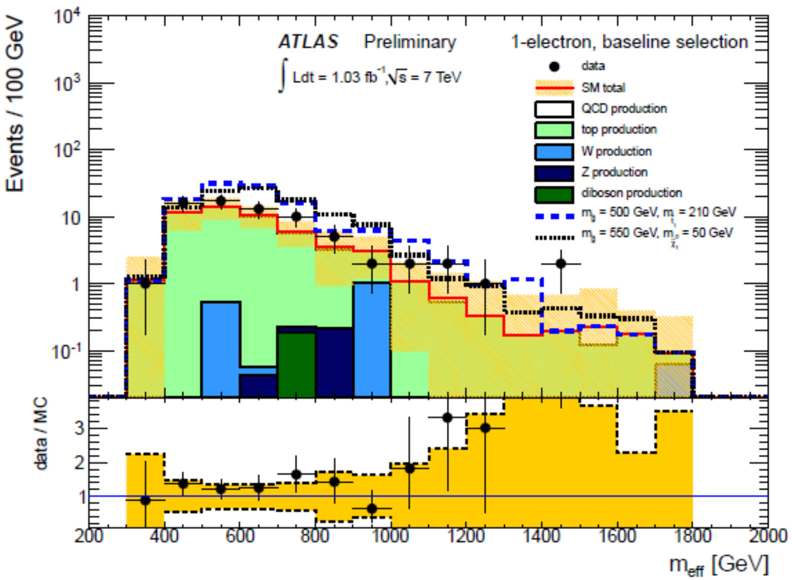
BG 13 +- 5 (**t 8 W/Z 5** QCD 0.5)

Green shows the tt BG(Leading contribution), data is consistent with SM BG
No excess was found in both topology. N>=2bjets is useful to suppress W/Z+bb BG since g->bb has relatively small angle and can not be distinguish for high Pt region.

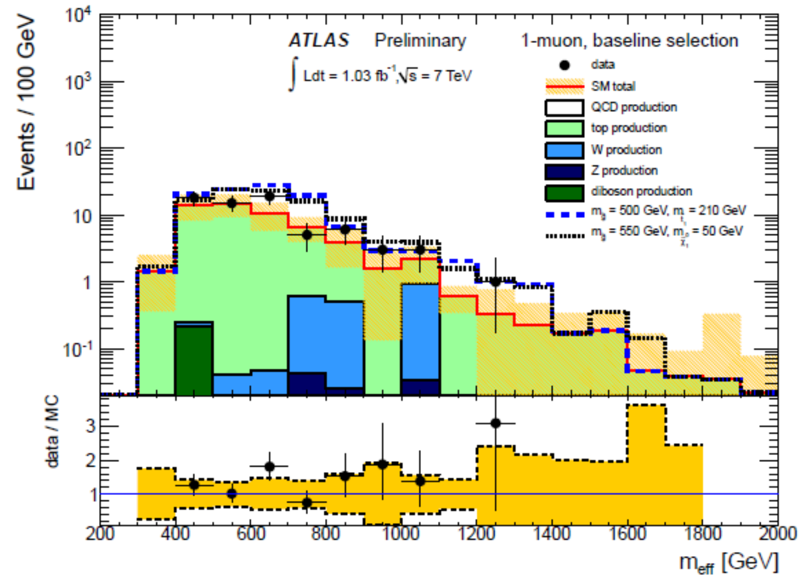
Results of Topology B(bjets+lepton)

Exactly One lepton PT>25GeV (electron) PT>20GeV(muon)
At least 4jets(PT>50GeV) MET>180GeV MT>100GeV Meff>600GeV
At least 1 b jet

Electron



Muon

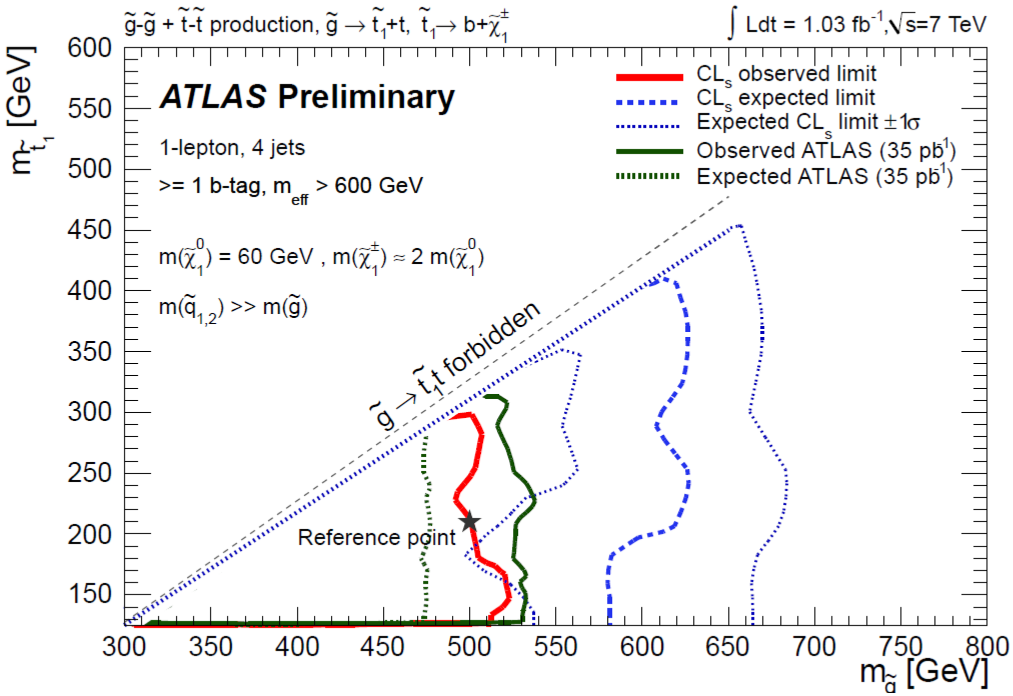


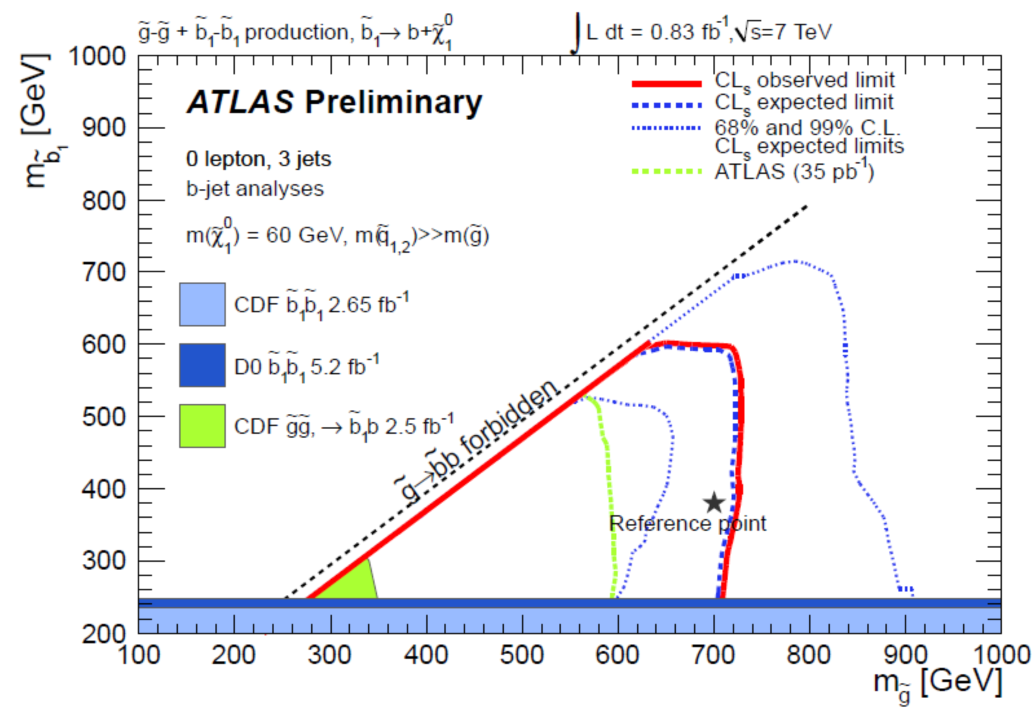
Data37 events
BG 28 +- 8 (t 23 W/Z 1 QCD 1)

Data37 events
BG 27 +- 5 (t 24 W/Z 2)

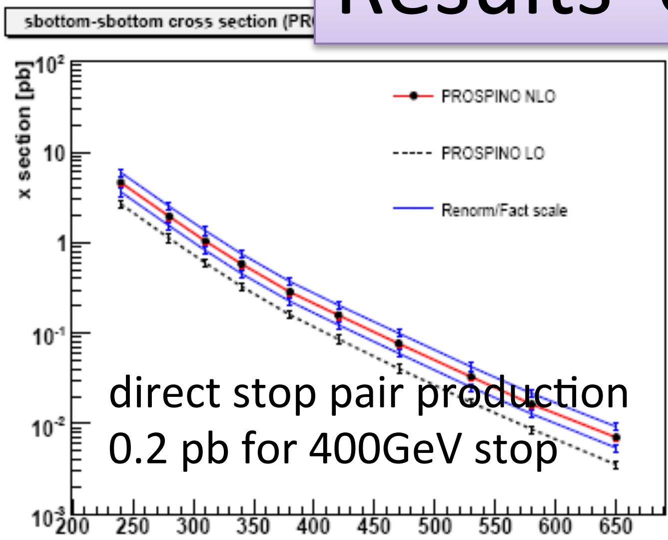
Top is main BG(green) , yellow band shows the systematic error of the estimation.
JES error and b-tag error are dominant.

small excess (< 2σ) was found : tt+Njets is need to be understood.


g̃-g̃ + t̃-t̃ production, g̃ → t̃1+t, t̃1→ b+χ̃±1
∫ Ldt = 1.03 fb-1,√s=7 TeV
ATLAS Preliminary
1-lepton, 4 jets
>= 1 b-tag, meff > 600 GeV
m(χ̃01) = 60 GeV , m(χ̃±1) ≈ 2 m(χ̃01)
m(q̃1,2) >> m(g̃)
CLs observed limit
CLs expected limit
Expected CLs limit ±1σ
Observed ATLAS (35 pb-1)
Expected ATLAS (35 pb-1)
g̃ → t̃1t forbidden
Reference point
mt̃1 [GeV]
mg̃ [GeV]
600
550
500
450
400
350
300
250
200
150
300
350
400
450
500
550
600
650
700
750
800


g̃-g̃ + b̃1-b̃1 production, b̃1→ b+χ̃01
∫L dt = 0.83 fb-1,√s=7 TeV
ATLAS Preliminary
0 lepton, 3 jets
b-jet analyses
m(χ̃01) = 60 GeV, m(q̃1,2)>>m(g̃)
CLs observed limit
CLs expected limit
68% and 99% C.L.
CLs expected limits
ATLAS (35 pb-1)
CDF b̃1b̃1 2.65 fb-1
D0 b̃1b̃1 5.2 fb-1
CDF g̃g̃, → b̃1b 2.5 fb-1
g̃→b̃b forbidden
Reference point
mb̃1 [GeV]
mg̃ [GeV]
1000
900
800
700
600
500
400
300
200
100
200
300
400
500
600
700
800
900
1000

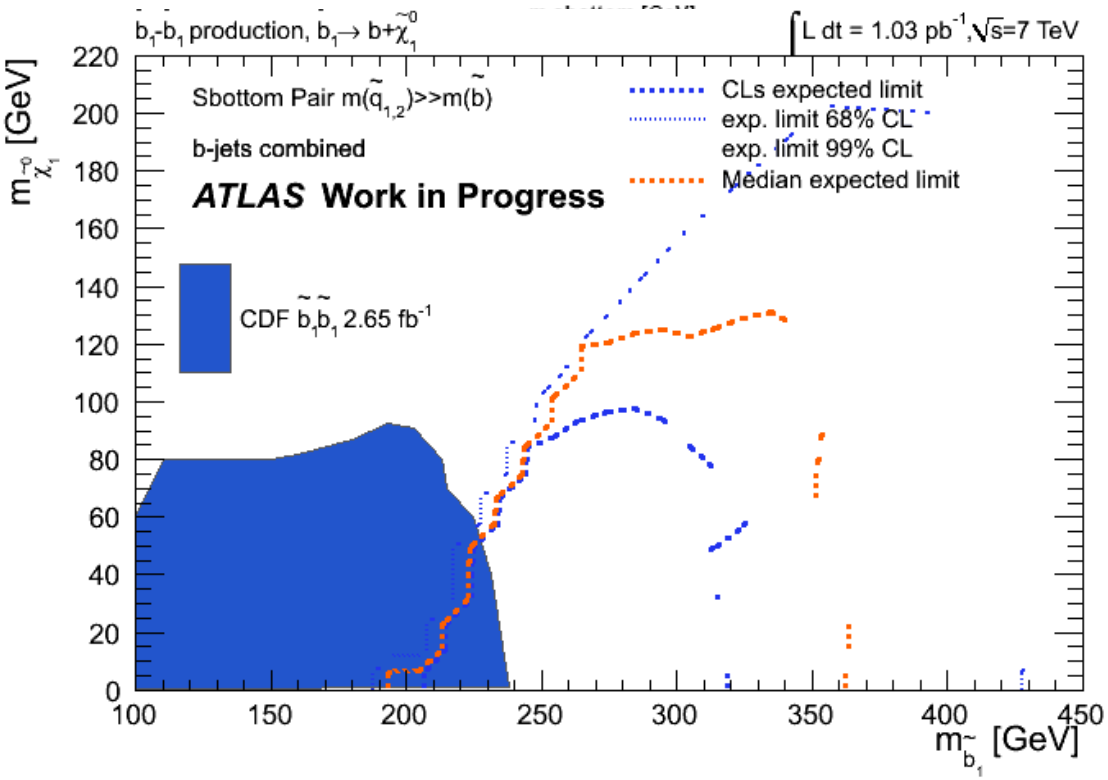
Results of Topology C (2bjets)



direct stop pair production
0.2 pb for 400GeV stop

Stop->b+chargino
(Higgsino/Wino lighter)
In both case ΔM(charhino-neutralino) becomes smaller

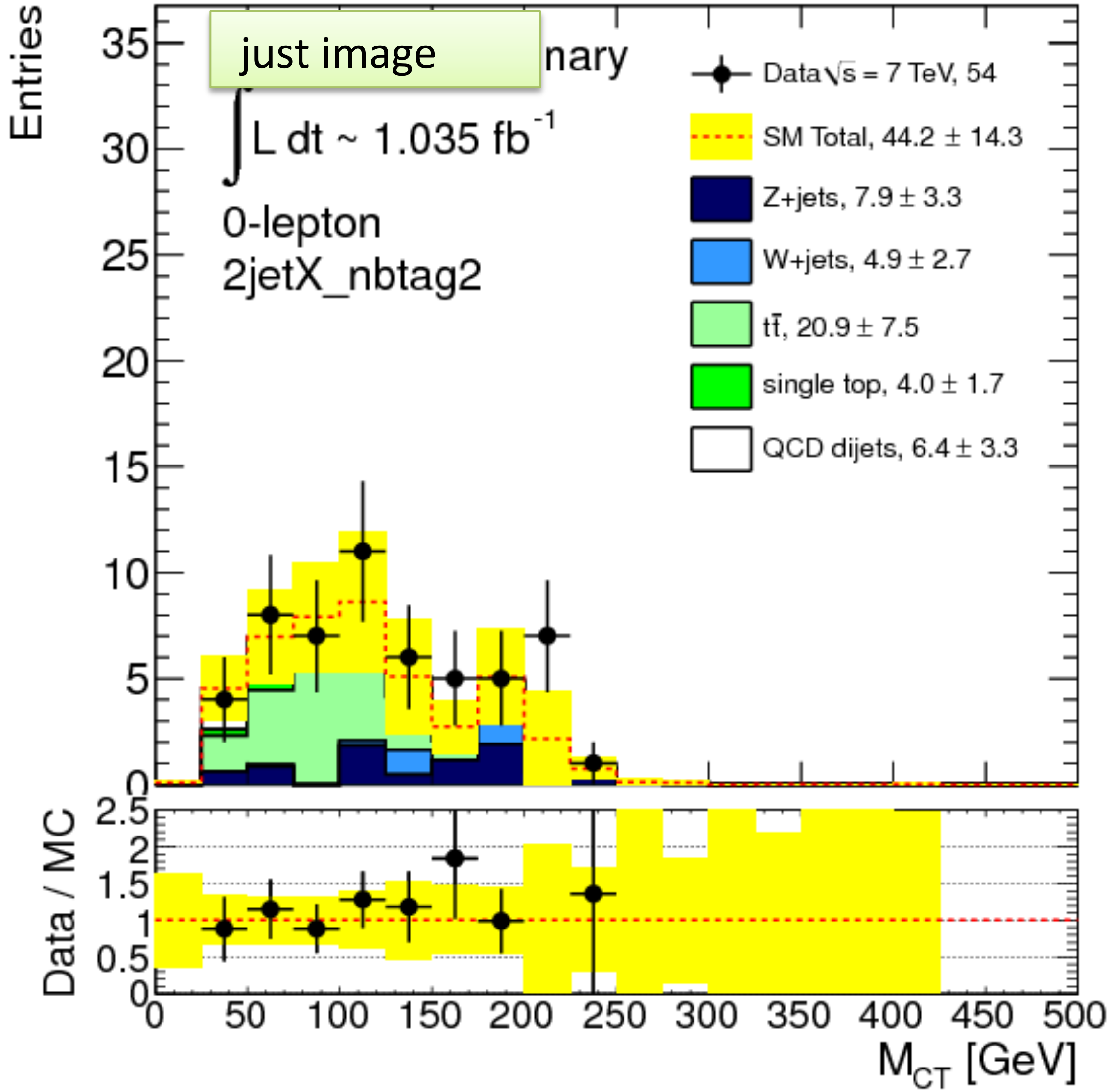
2bjet+mE_T is event-toplogy



PT>130,50GeV (no 3rd jet > 50)
MET>130GeV
Δϕ/MET/MET (standard susy)
good 2b jet
MCT > 150GeV

Trigger is crucial
ΔM < 200GeV is not triggered

tt -> bbWW is main BG
both W decays leptonically,
lepton(tau) PT is soft.



$$M_{CT}^2 \equiv [E_T(q_1) + E_T(q_2)]^2 - [\overrightarrow{P_T}(q_1) - \overrightarrow{P_T}(q_2)]^2$$

$$M_{CT}^{\max} = 2p_T^{\max} = \frac{m^2(q_R) - m^2(\chi)}{m(q_R)}$$

Large contraverse mass
is expected for signal.
End point is almost stop mass
if ΔM(stop wino) is large.

MCT>150GeV is signal region
18events observed
10.9+- 4.5 BG expect
Slight excess (< 2σ)

Still investigating BG

edge of MCT is 250GeV

-> ΔM >> 0
m(stop)=250GeV
inconsistent with σ

→ ΔM ~ 150GeV
m(stop)~350GeV

5 SUSY with Exotic signature

Motivation

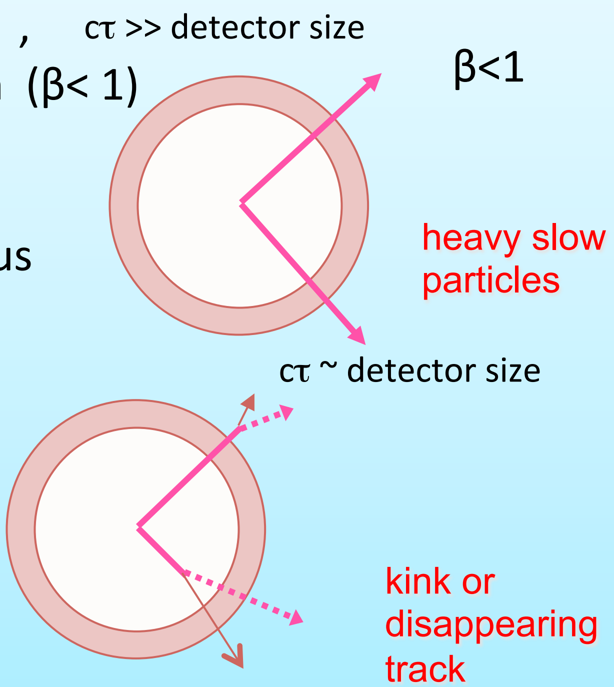
(1) AMSB Wino LSP chargino life cτ= 1-10 cm Wino Ω<<1
(2) GMSB stau NLSP stable in detector or decay in ID Gravitino DM
(3) SPLIT SUSY (m0>1000TeV) gluino → R-hadron
(4) R-parity violation If coupling is small displaced vertex

Signatures

(A) Heavy charged particles (GMSB stau, R-hadron)
- (A1) dE/dx energy loss in the semiconductor ,
- (A2) TOF information in Cal. or muon system (β< 1)

(B) Decay in flight (AMSB wino, GMSB stau)
- (B1) Kink/Disappearing track in the continuous tracking system (ATLAS)
- (B2) neutralino decay with long-life displaced vertex is found

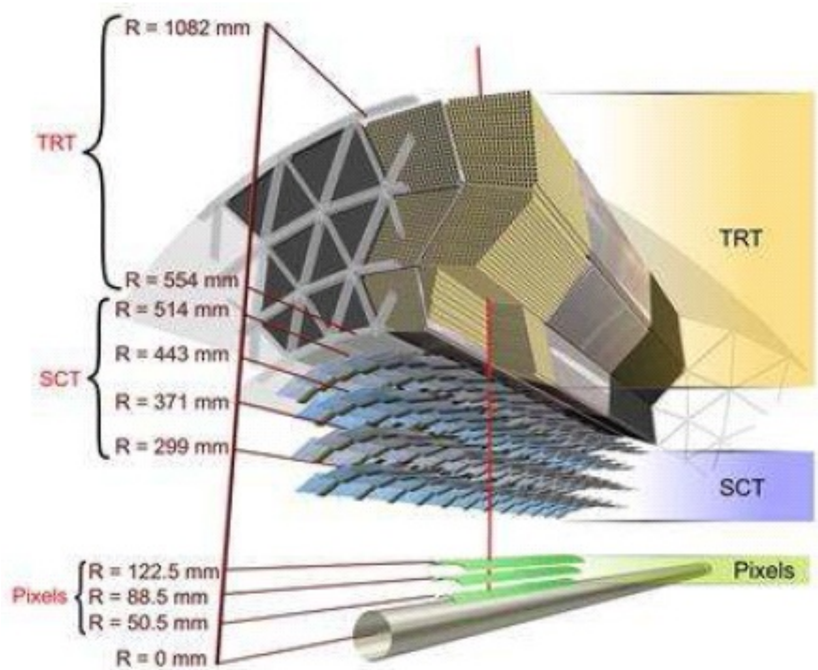
(C) stau and R-hadron(both neutral and charged) stop in the dense material (Hadron calorimeter) dedicated trigger is necessary to catch decay.



methods as function of lifetime

cτγ 0.1mm 100mm 1000mm ∞ →

	Displaced Vertex	dE/dx in Pixel	Kink / Disappearing	dE/dx in TRT	Time of Flight In Calorimeter	Time Of Flight In Muon Spectrometer	Stop in Calorimeter
RPV	✓		✓				
AMSB		✓ ?	✓ ★				
Stau LL		✓ ★	✓		✓	✓ ★	✓
Stau SL	✓ ?						
R-had		✓			✓	✓	✓

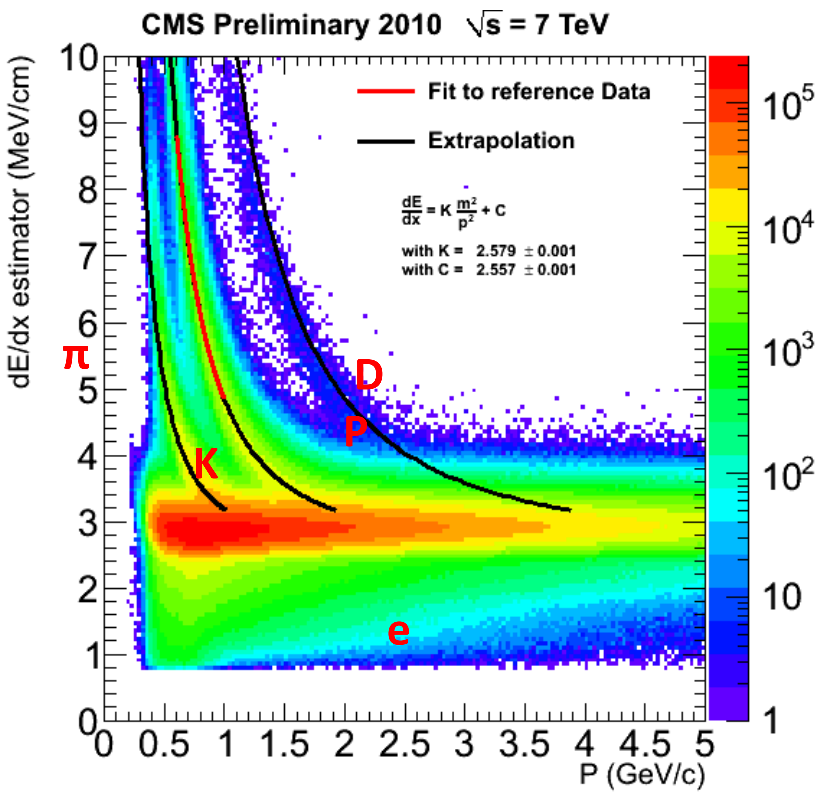


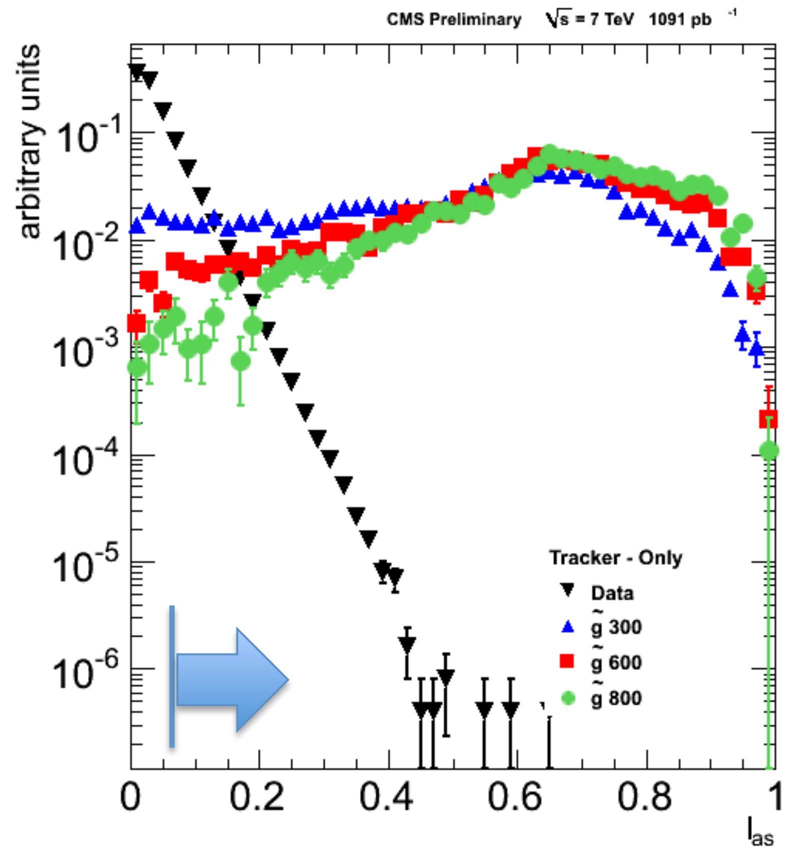
Radius of each detector

	ATLAS	CMS
Vertex	0.1mm	0.1mm
Pixel(dE/dx)	5-10cm	5-100cm
TRT	50-100cm	No
Hcal	2-4m (Δ t~1nsec)	1.5-2.5m
μ	5-10m(Δ t~1nsec)	4-6m

Hadronic calorimeter Fe or cu
Depth 1m time resolution ～1nsec

(A1) dE/dx in Si tracker



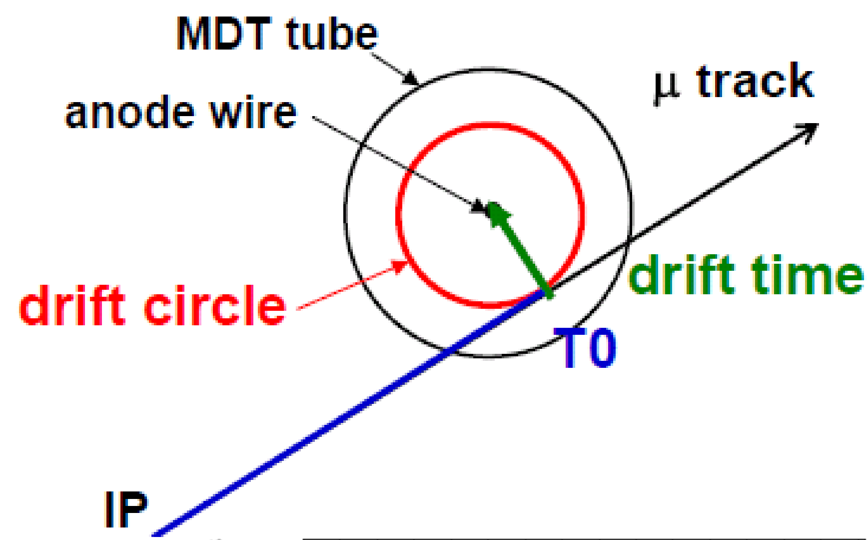


$$I_{as} = \frac{3}{N} \times \left(\frac{1}{12N} + \sum_{i=1}^{N} \left[P_i \times \left(P_i - \frac{2i-1}{2N} \right)^2 \right] \right),$$

Ionization energy loss dE/dX ~$1/\beta^2$
We can use this information to search for heavy stable particles.

Pi is the probability
for a minimum–ionizing particle (MIP) to produce a charge smaller or equal to the **i**–th
charge measurement for the observed path length in the detector

(A2) TOF information using muon



drift time = TDC output time
- T_0(flight time from IP)

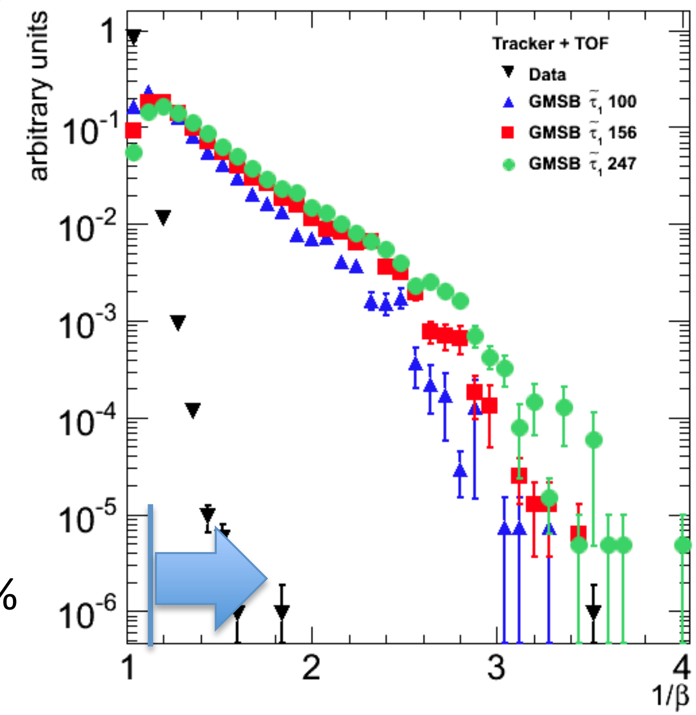
drift circle = function(drift time)

Then the position is determined.

But $\beta=1$ is assumed for this calculation.
For the particle with $\beta<1$,
drift circle become wrong.

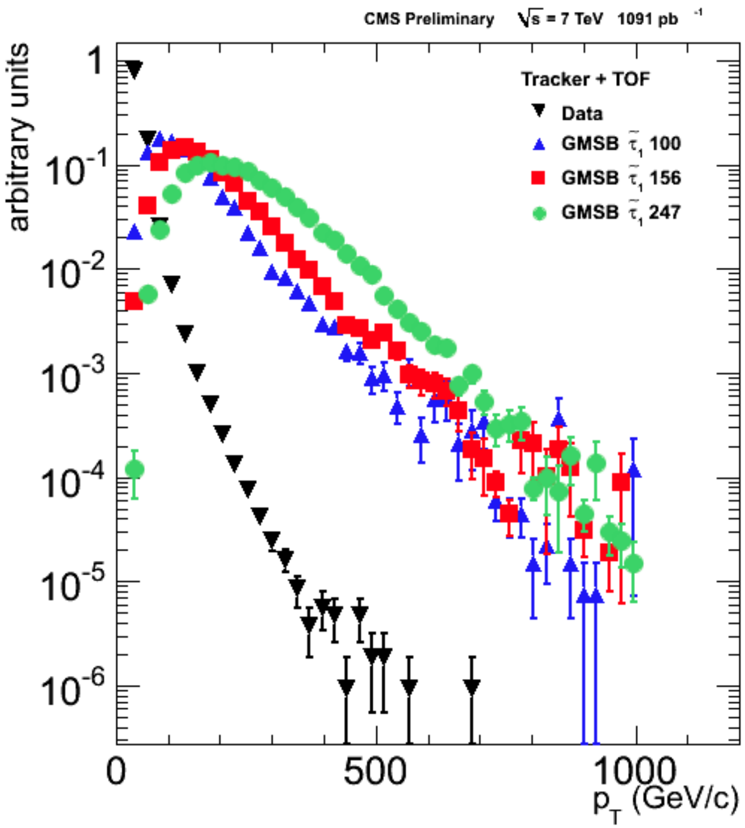
Then the chi^2 becomes worse, since the calculated drift is worse.
T0 is fitted to obtain best chi^2

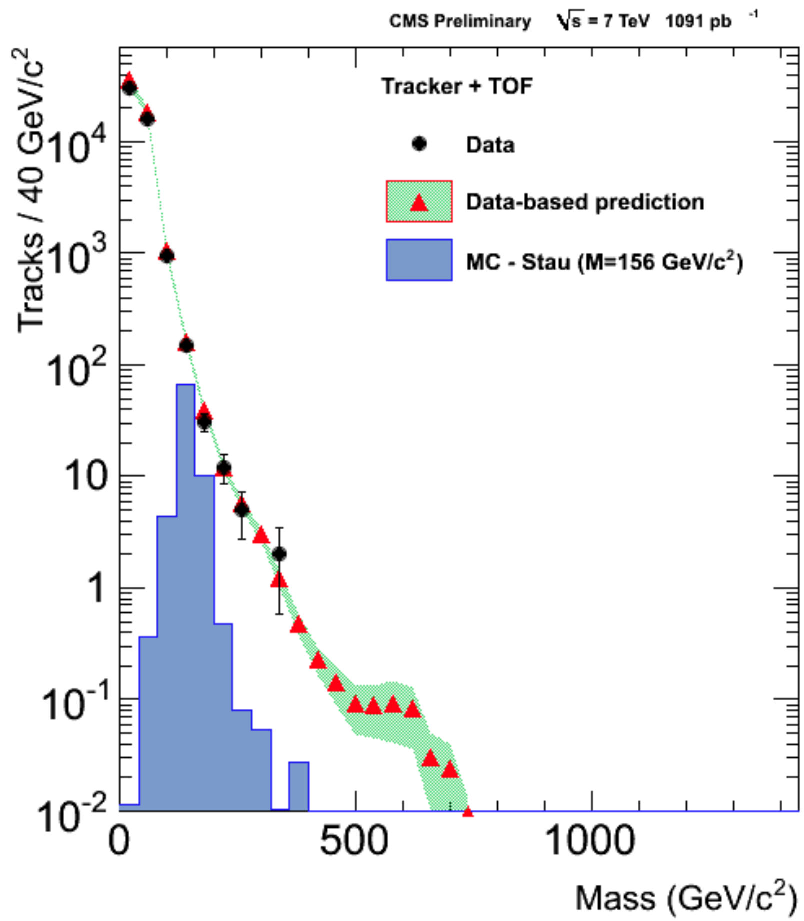
$\beta = 0.3\text{-}0.95$



β resolution ~ 7%

(A1) dE/dx in ID + (A2) muon TOF (I)





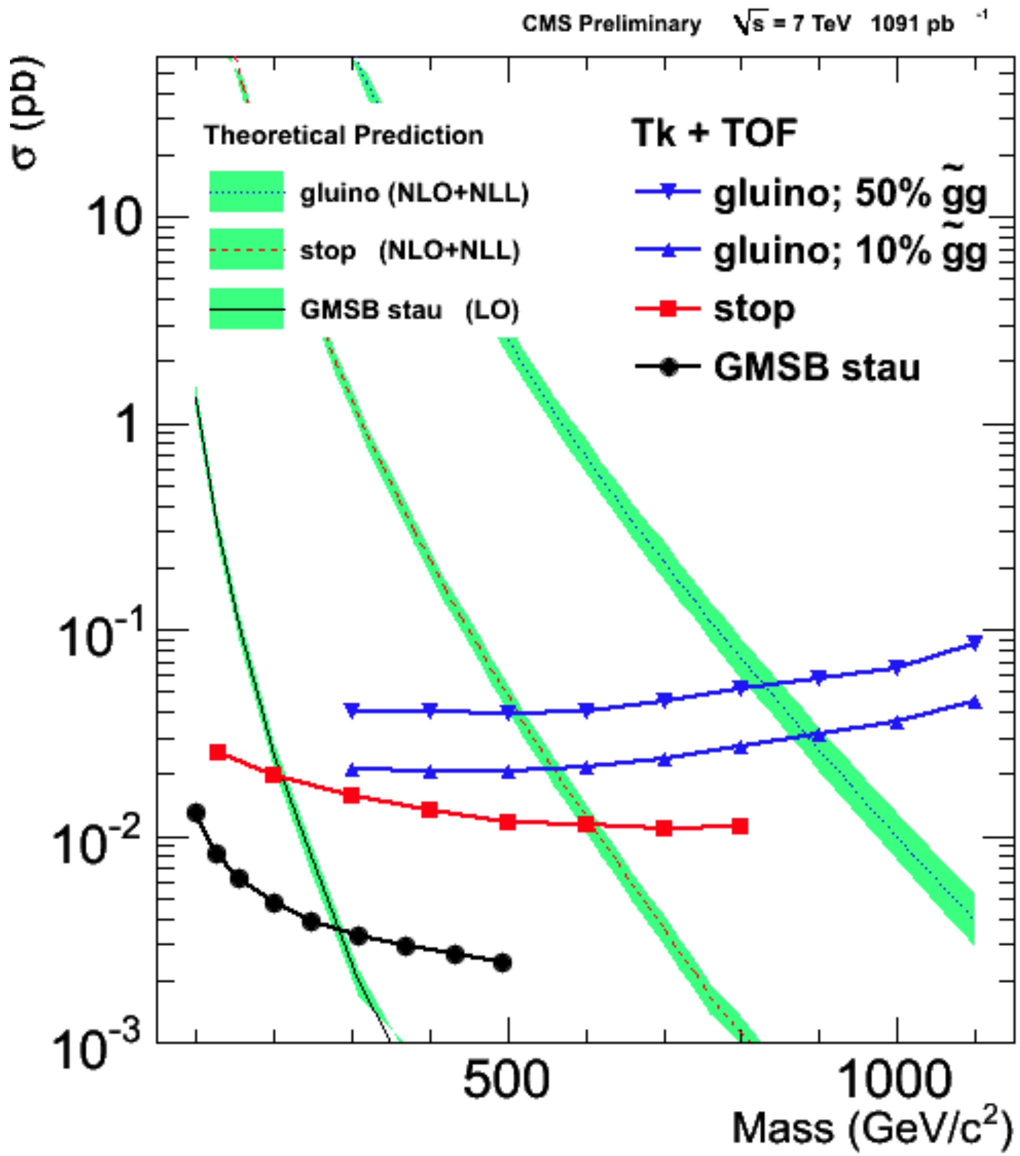
PT>40GeV
Ias>0.05
1/β> 1.05

Data 10562 events
BG 12662+- 1269(sys) event

$$m = p\frac{\sqrt{1-\beta^2}}{\beta}$$

BG is estimated assuming that PT, dE/dx and 1/β are independent

(A1) dE/dx in ID + (A2) muon TOF (II)

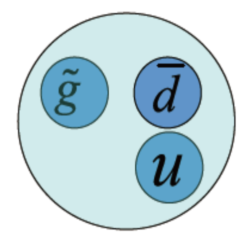


Obtained limits

293GeV is excluded (95%CL) for stable stau.
direct production

899, (839) GeV for stable gluino

R-hadron: $R^{\pm}$



Stable R-hadron

(B1) Kink/displaced track (I)

event display of AMSB event

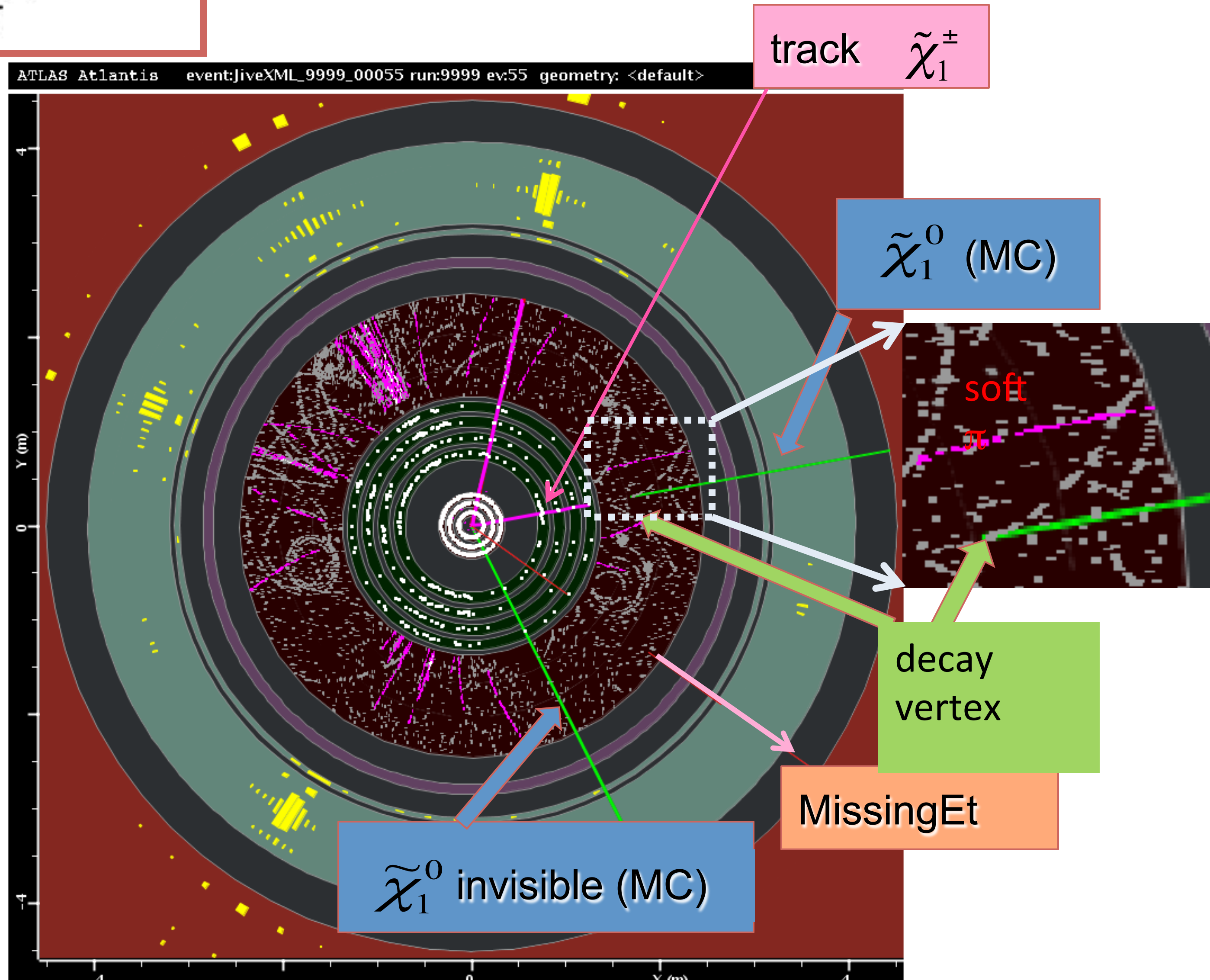
$$\tilde{g}\tilde{g} \rightarrow q\bar{q}'\tilde{\chi}_1^- \, q\bar{q}'\tilde{\chi}_1^-$$
$$\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \pi^-, \quad \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \pi^-$$

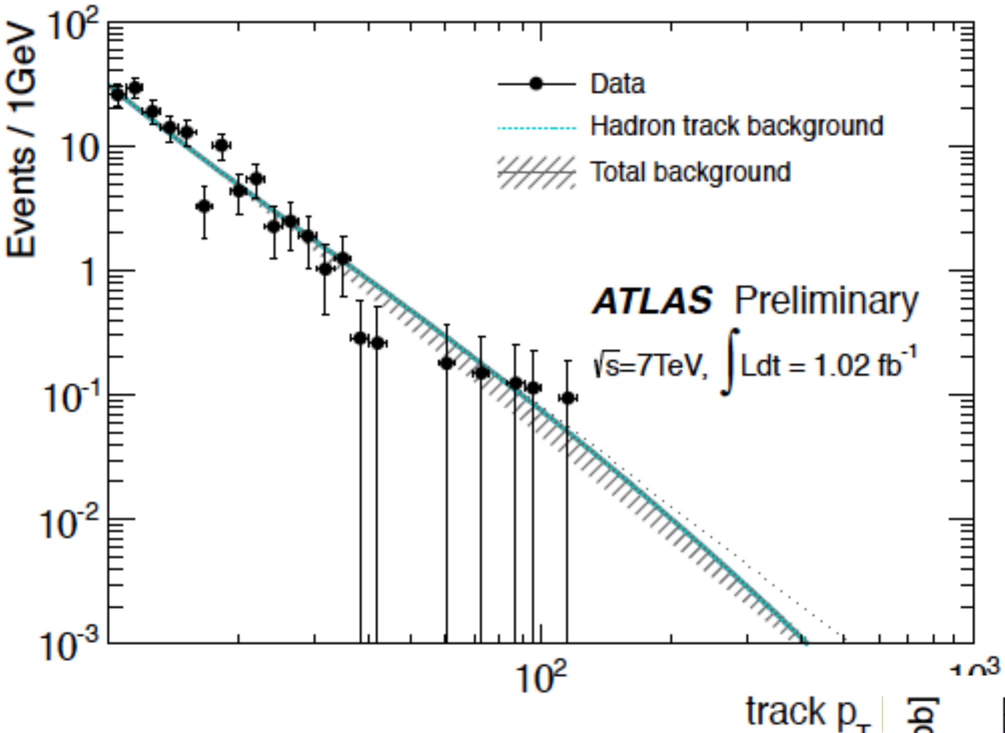
AMSB:
Wino is LSP

Chargino Wino$^+$
Neutralino Wino^0
Mass degenerate
Long-lived chargino

mass ($\tilde{g}$)= 1TeV
mass ($\tilde{q}$)= 1TeV

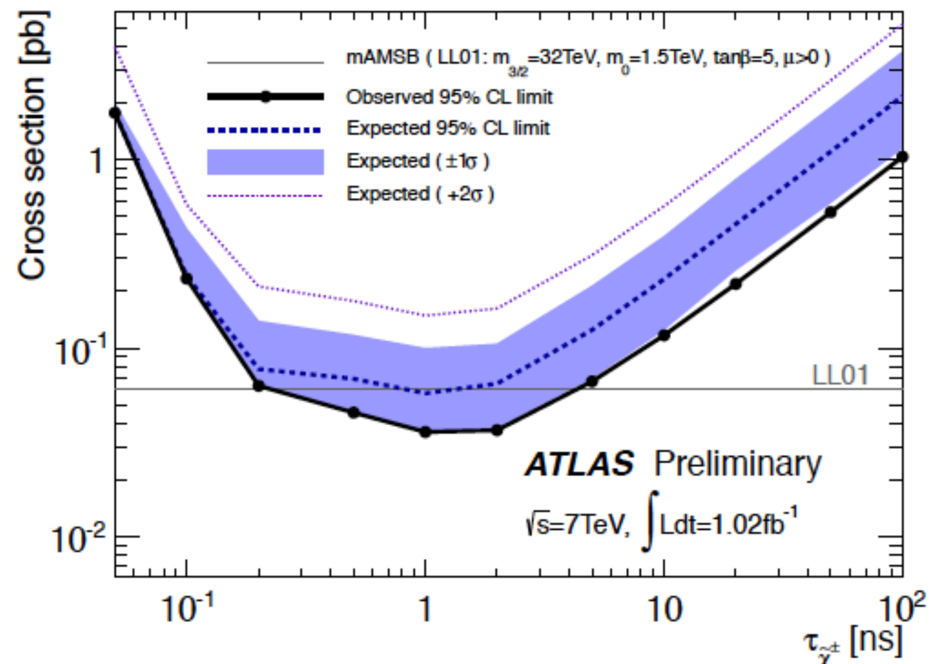
Br($\tilde{g} \rightarrow qq'\chi$) = 1
mass(chargino)
= 100.157GeV
mass(neutralino)
= 100.000GeV
cτ of chargino = 300mm
cross section : 170 fb



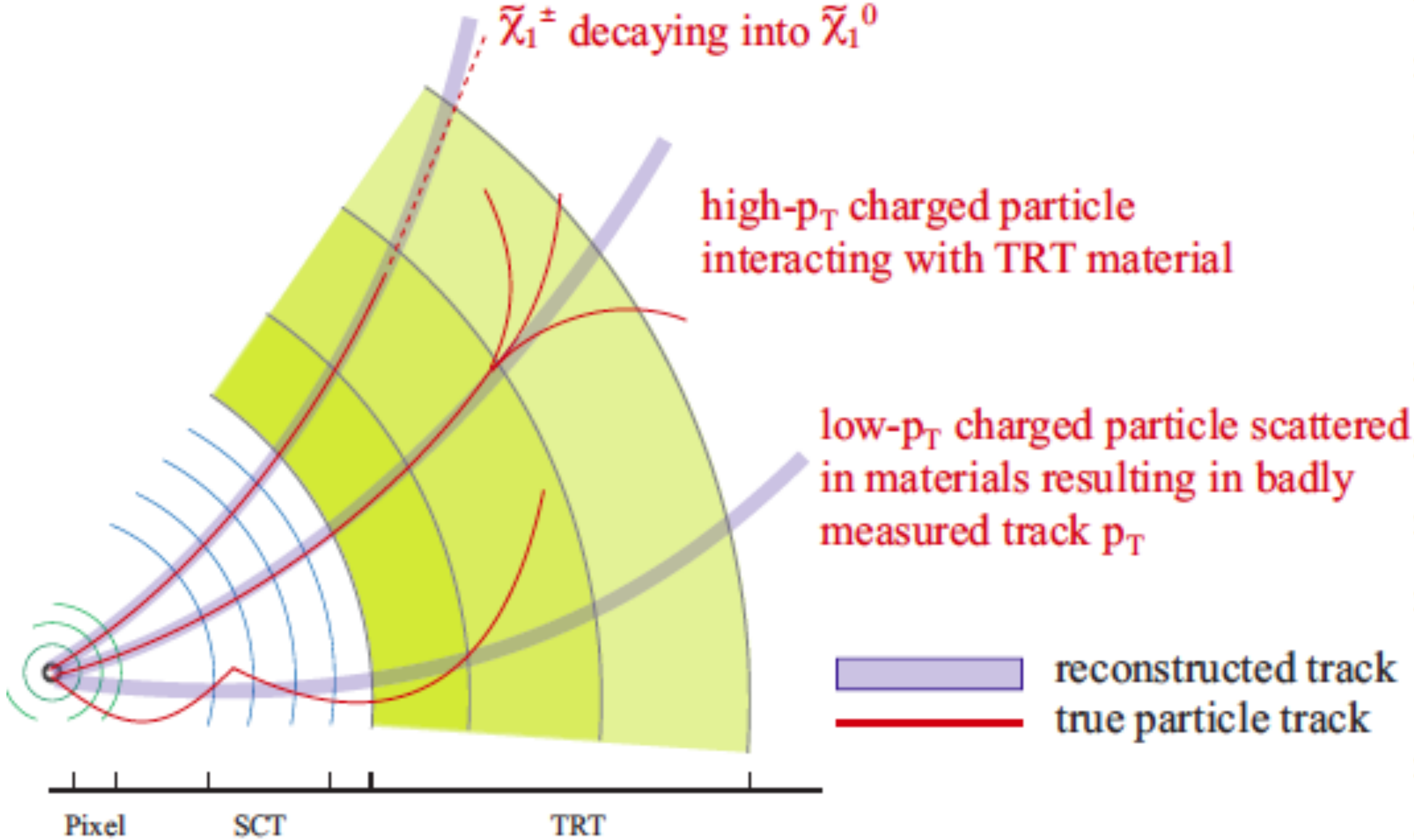


Current Limit on Wino is 90GeV obtained at OPAL.
Now We have exceed this limit using disappearing track search.
New Lower limit is for tau= 0.2-5 nsec.
Wino > 92GeV for tau~1nsec

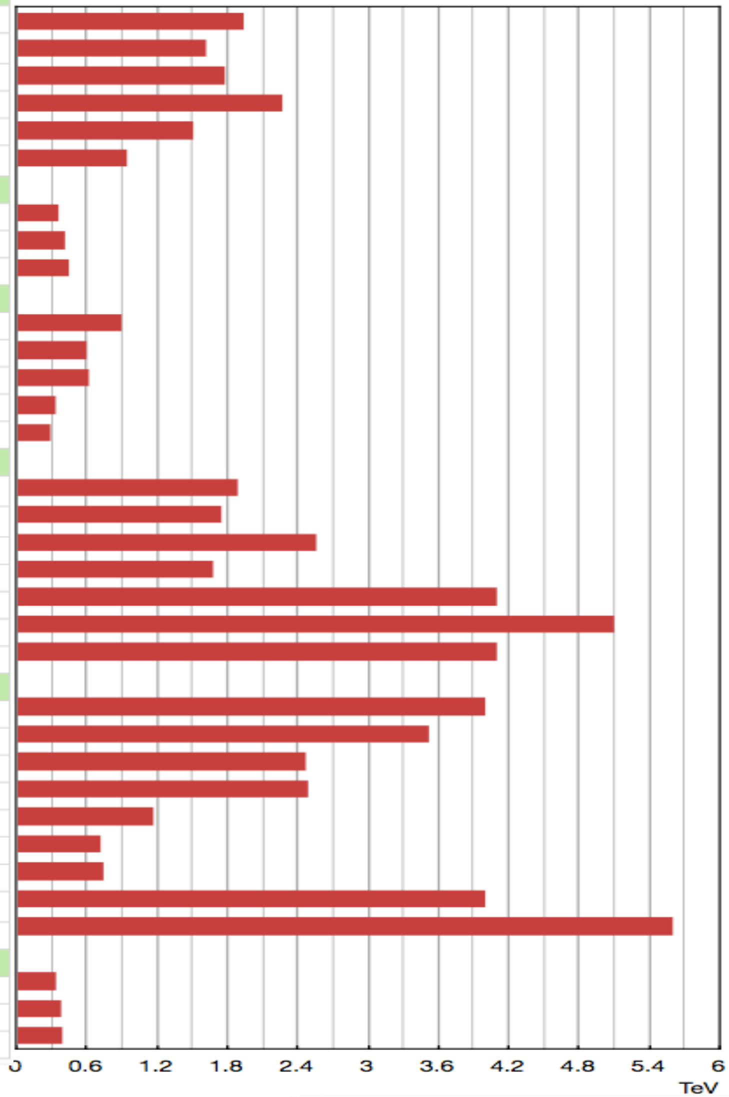
PT distribution for disappearing track in TRT



mAMSB model
M0 >> 1TeV m3/2>32GeV is obtained.
It is first limit on AMSB with (large m0)

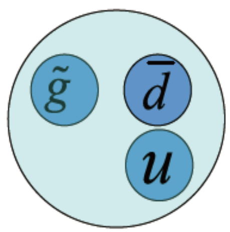

$\tilde{\chi}_1^{\pm}$ decaying into $\tilde{\chi}_1^0$
high-p_T charged particle interacting with TRT material
low-p_T charged particle scattered in materials resulting in badly measured track p_T
reconstructed track
true particle track
Pixel
SCT
TRT

	Limits in TeV		
	Heavy Bosons		
Z'_{SSM} ll	1.94	2011	
Z'_{Ψ} ll	1.62	2011	
G_{KK} ll k/M = 0.1	1.78	2011	
W' lv	2.27	2011	
W' dijet	1.51	2011	
G_{KK} $\gamma\gamma$ k/M = 0.1 (2010)	0.945	2010	
	4th Generation		
$M_{b'}$, b' ⇒ tW (2010)	0.361	2010	
$M_{t'}$, t' ⇒ tZ (100%)	0.417	2011	
$M_{t'}$, t' ⇒ bW (100%), l+jets	0.45	2011	
	Heavy Stable Particles		
M_{gluino}, HSCP	0.899	2011	
M_{gluino}, Stopped Gluino	0.601	2011	
M_{stop}, HSCP	0.620	2011	
M_{stop}, Stopped Gluino	0.337	2011	
M_{stau}, HSCP	0.293	2011	
	Large Extra Dimensions		
M_s, $\gamma\gamma$, GRW (2010)	1.89	2010	
M_s, $\mu\mu$, GRW (2010)	1.75	2010	
M_D, monojet, n_{ED} = 2 (2010)	2.56	2010	
M_D, monojet, n_{ED} = 6 (2010)	1.68	2010	
M_{BH}, rotating, M_D=3.5 TeV, n_{ED} = 2	4.1	2011	
M_{BH}, non-rot, M_D=1.5 TeV, n_{ED} = 6	5.1	2011	
String Ball M, M_D=2.1, M_s=1.7, g_s=0.4	4.1	2011	
	Compositeness and Contact Interactions		
String Resonances	4.0	2011	
E_6 diquarks	3.52	2011	
Axigluon/Coloron	2.47	2011	
q* , dijet	2.49	2011	
q* , boosted Z	1.17	2010	
e*, Λ = 2 TeV	0.720	2010	
μ*, Λ = 2 TeV	0.745	2010	
C.I. Λ , dijet mass (3 pb^{-1})	4.0	2010	
C.I. Λ , X analysis	5.6	2010	
	LeptoQuark		
LQ1, β=0.5 (2010)	0.340	2010	
LQ1, β=1.0 (2010)	0.384	2010	
LQ2, β=1.0 (2010)	0.394	2010	



(A1) dE/dx in Pixel + (A2) muon TOF (I)

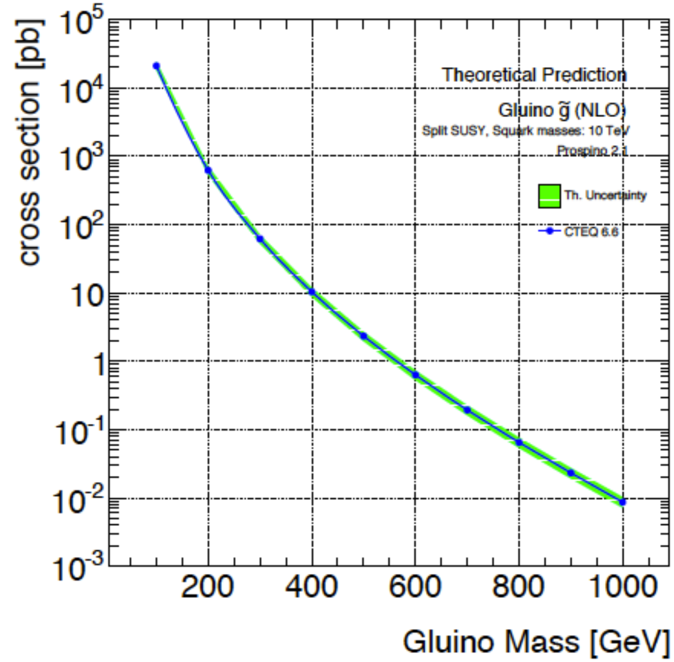
R-hadron: $R^{\pm}$

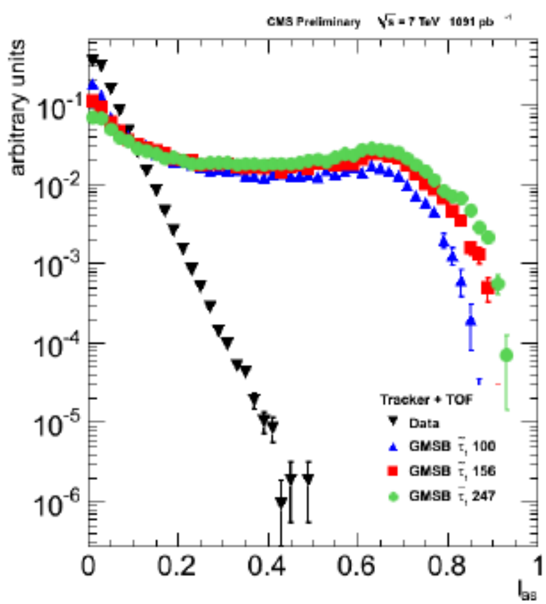


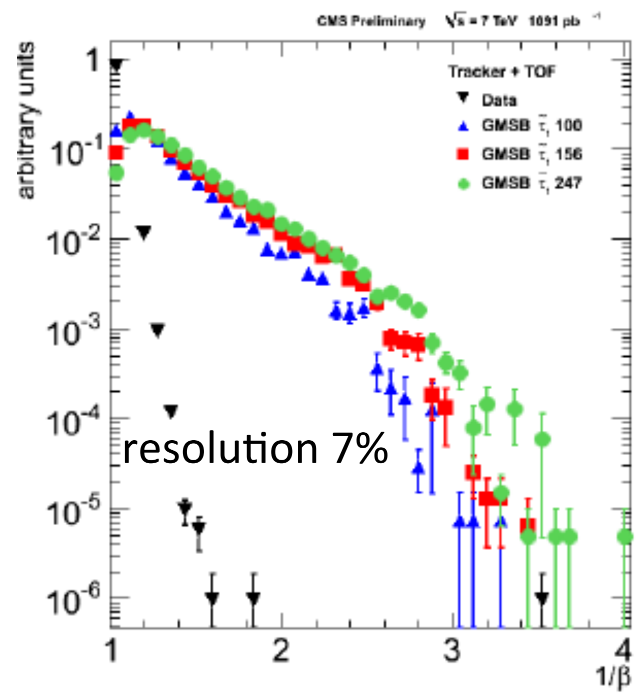
Stable R-hadron

・ionize dE/dx ~ $1/\beta^2$ (Beth-bloch)

・Hadronic
Gluino interaction becomes smaller in high energy.
Spectator quark interacts hadronically.
momenta of them are small
→ small dE/dx is expected.



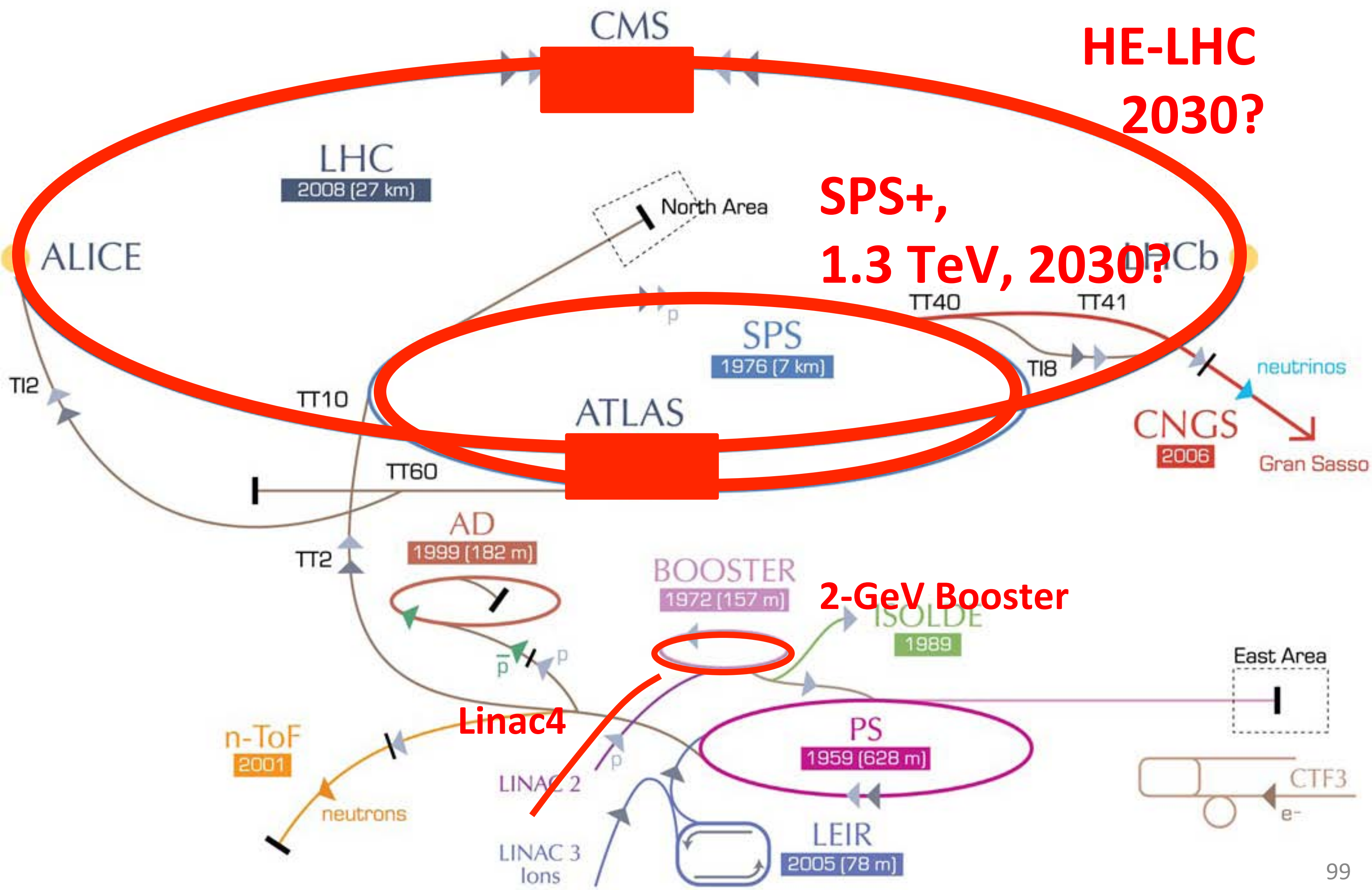




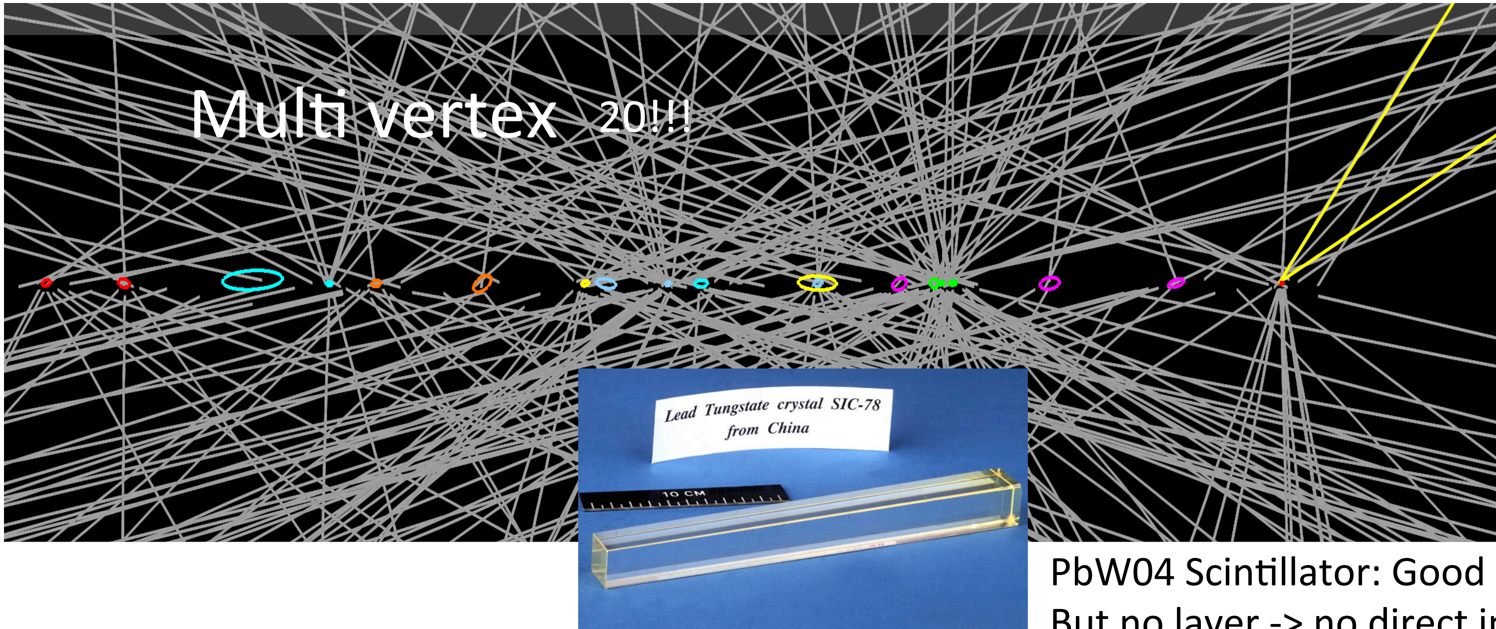
resolution 7%

$\beta<0.85$

HE-LHC – LHC modifications

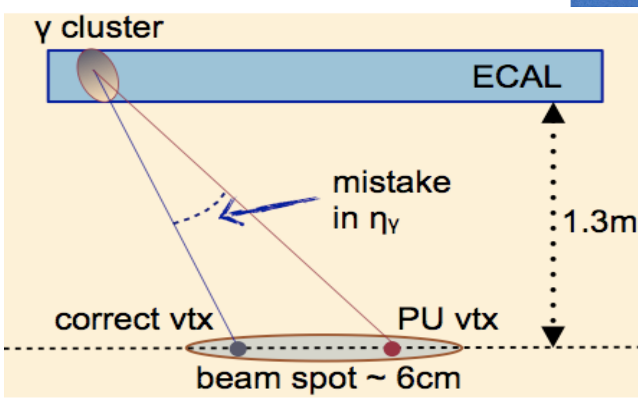


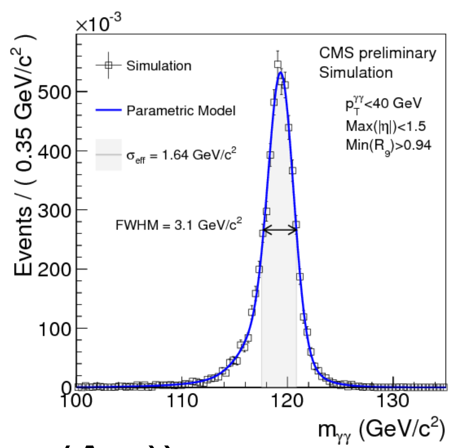
many proton crossing in one bunch crossing:
MB cross-section is as large as 70 mb, many hadronic collision are superimposed



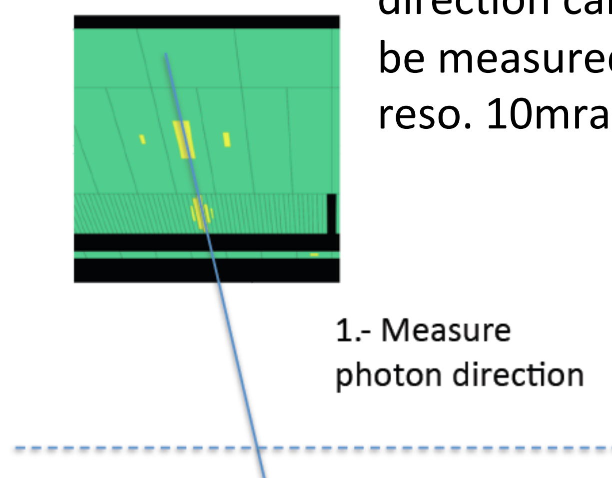
"pile-up"
mean
14

PbW04 Scintillator: Good energy resolution
But no layer -> no direct information.



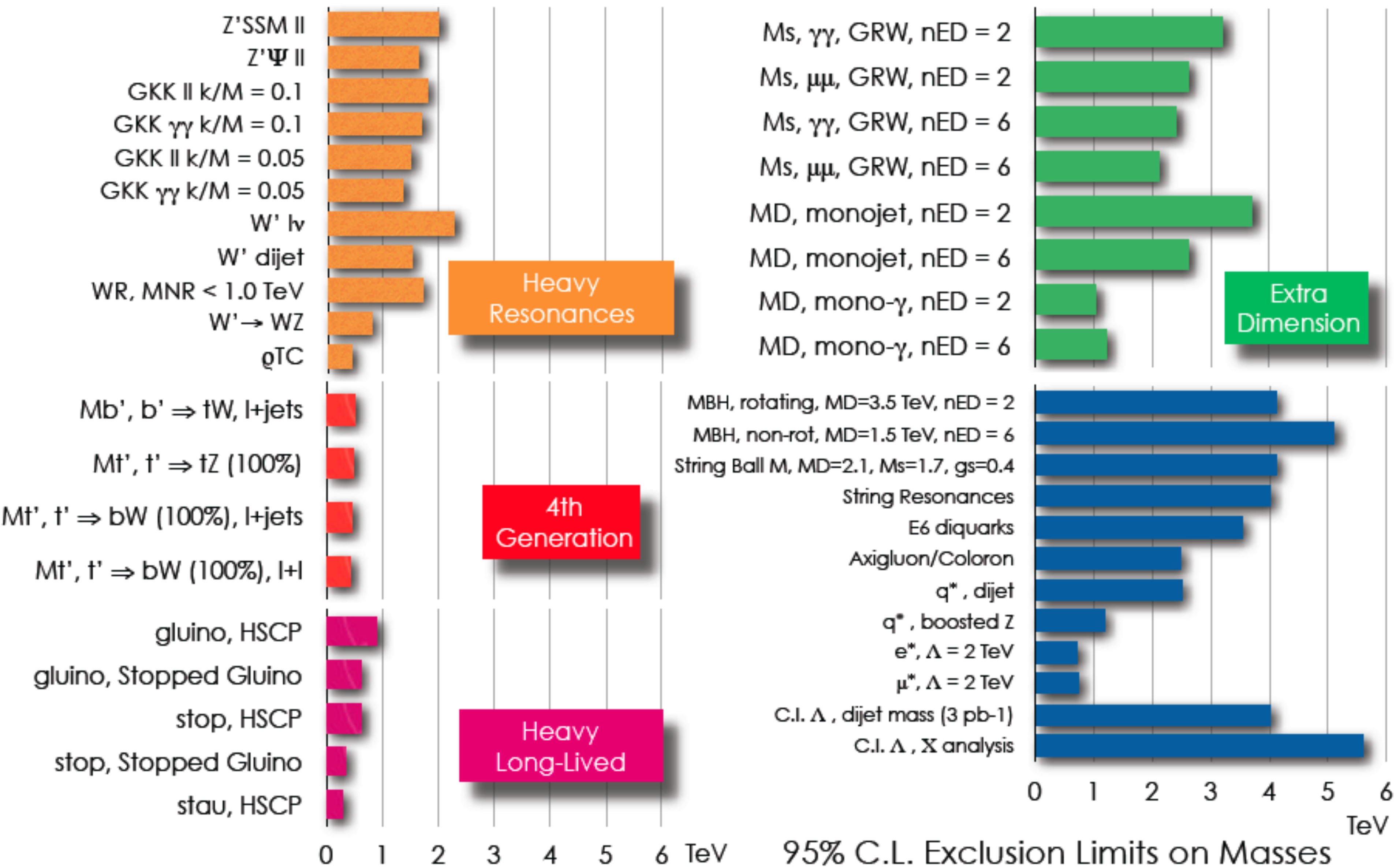


ATLAS L.Ar 3 layer
direction can
be measured
reso. 10mrad



γγ: $m^2 = 2E_{T1}E_{T2}(\cosh(\Delta\eta) - \cos(\Delta\varphi))$

error on $\Delta\eta$ is also propagated to mass resolution



Z'SSM ll
Z'Ψ ll
GKK ll k/M = 0.1
GKK γγ k/M = 0.1
GKK ll k/M = 0.05
GKK γγ k/M = 0.05
W' lν
W' dijet
WR, MNR < 1.0 TeV
W'→ WZ
ρTC
Heavy Resonances
Mb', b' ⇒ tW, l+jets
Mt', t' ⇒ tZ (100%)
Mt', t' ⇒ bW (100%), l+jets
Mt', t' ⇒ bW (100%), l+l
4th Generation
gluino, HSCP
gluino, Stopped Gluino
stop, HSCP
stop, Stopped Gluino
stau, HSCP
Heavy Long-Lived
0 1 2 3 4 5 6 TeV
Ms, γγ, GRW, nED = 2
Ms, μμ, GRW, nED = 2
Ms, γγ, GRW, nED = 6
Ms, μμ, GRW, nED = 6
MD, monojet, nED = 2
MD, monojet, nED = 6
MD, mono-γ, nED = 2
MD, mono-γ, nED = 6
Extra Dimension
MBH, rotating, MD=3.5 TeV, nED = 2
MBH, non-rot, MD=1.5 TeV, nED = 6
String Ball M, MD=2.1, Ms=1.7, gs=0.4
String Resonances
E6 diquarks
Axigluon/Coloron
q*, dijet
q*, boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
C.I. Λ, dijet mass (3 pb-1)
C.I. Λ, X analysis
0 1 2 3 4 5 6
TeV
95% C.L. Exclusion Limits on Masses