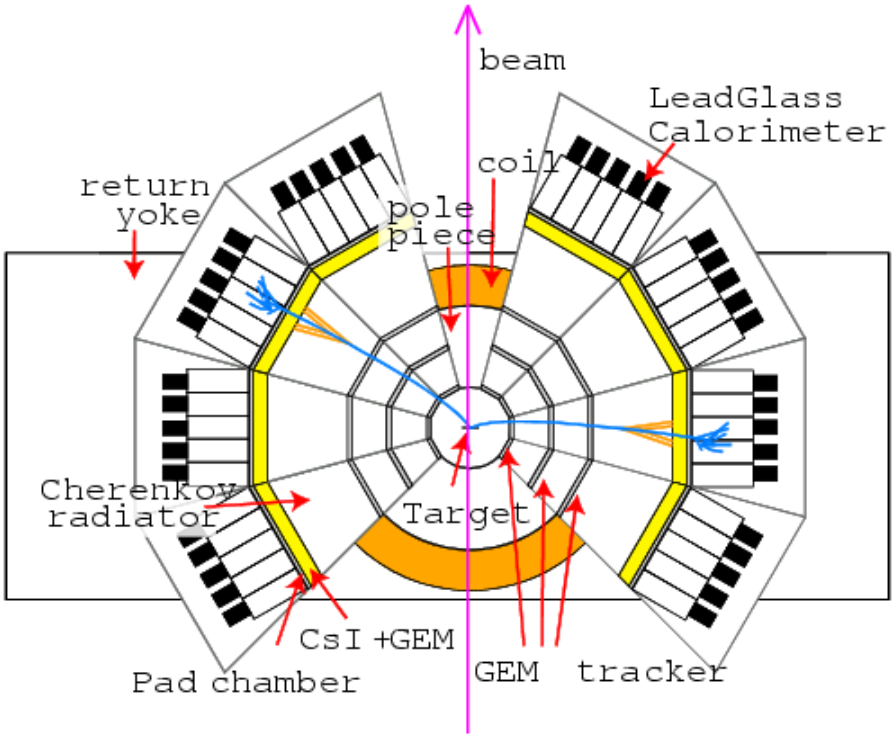
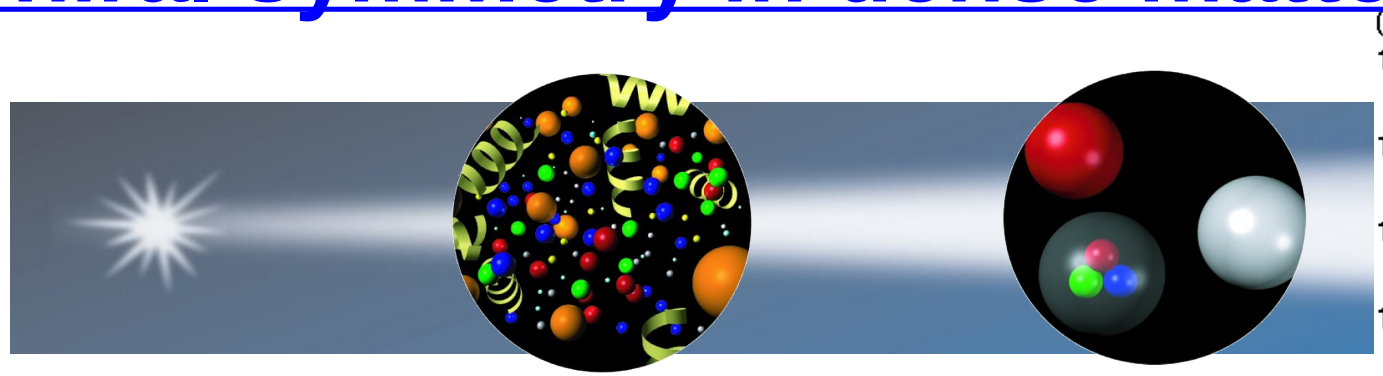
Measurements of the low mass dielectron spectra at J-PARC

Satoshi Yokkaichi
(RIKEN Nishina Center)

- Physics : chiral symmetry in matter
- results of KEK-PS E325
- J-PARC E16 experiment
  - goal
  - Key issues of design
  - R&D status

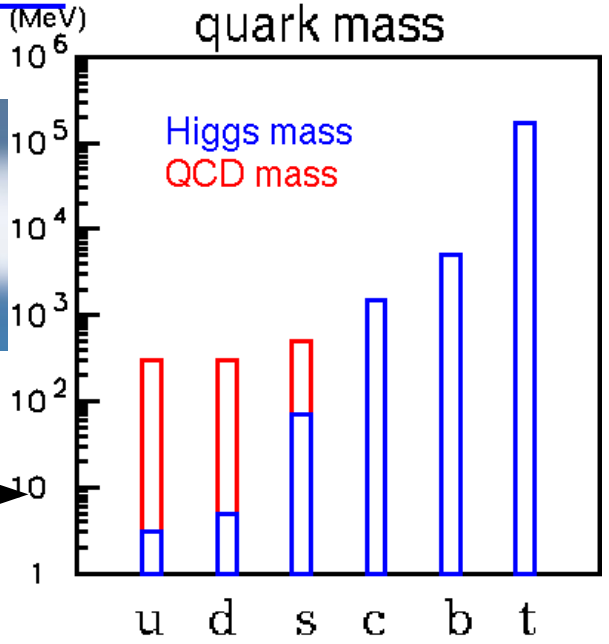


Chiral symmetry in dense matter

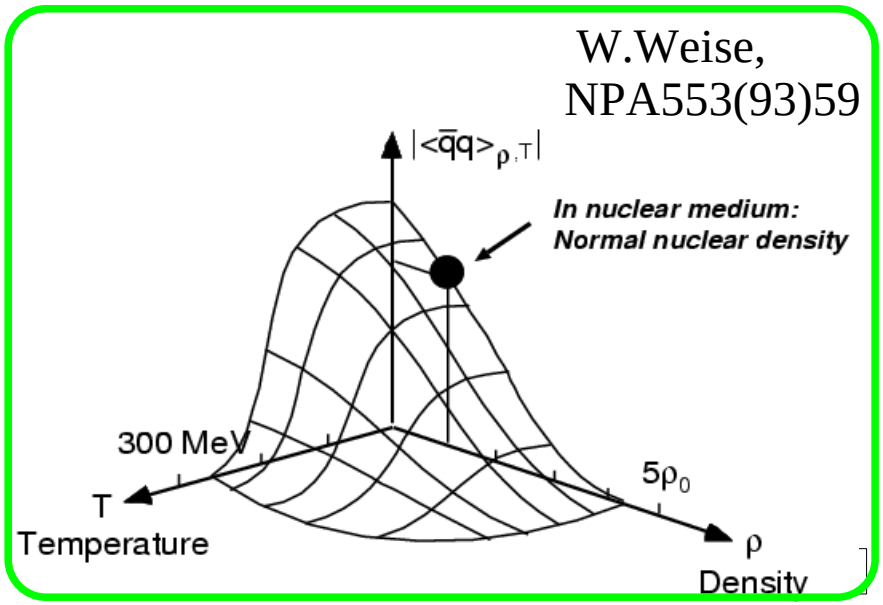


big bang　10psec　0.1msec

quark mass　0MeV　3MeV from Higgs　300MeV from chiral condensate $\langle \bar{q}q \rangle$



- Origin of hadron mass : spontaneous breaking of chiral symmetry
- In hot/dense matter, chiral symmetry is expected to be restored
  - hadron modification is also expected
  - many theoretical predictions...



Hatsuda and Lee, PRC46(92)R34,PRC52(95)3364

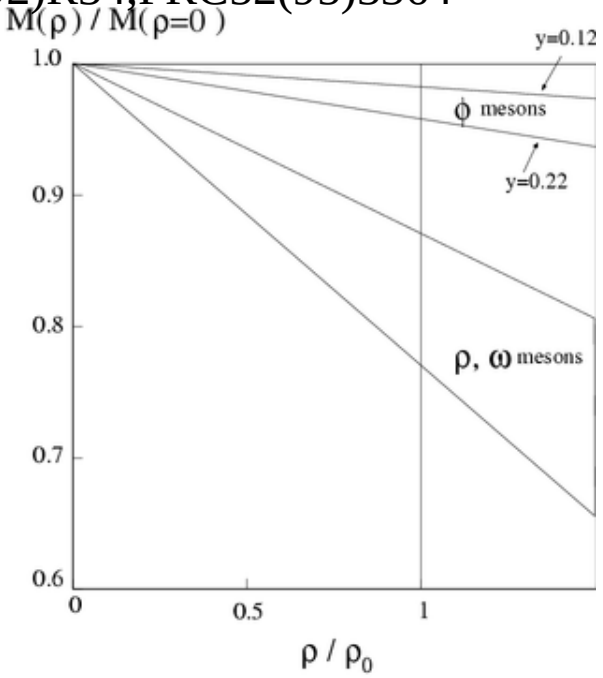
linear dependence on density

$m^*/m_0 = 1 - k\,\rho/\rho_0$

mass decreasing

- 16(±6)% for ρ/ω
- 0.15(±0.05)*y
  =2~4% for ϕ
  (for y=0.22)

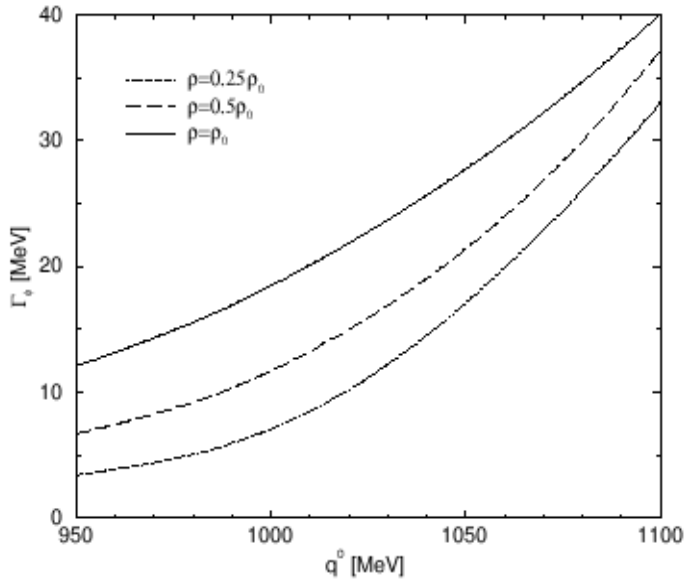
at the normal nuclear density



Oset and Lamos

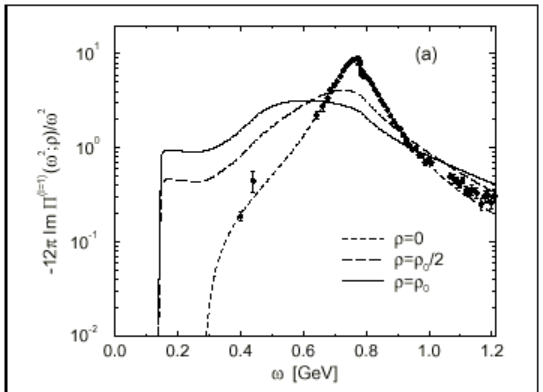
NPA 679 (01) 616

ϕ mass shift
< 1%
width broadening
x5 (22MeV)
at 1020MeV, at ρ_0

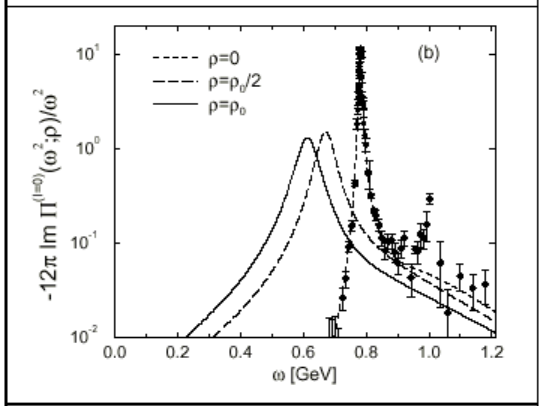


Klingle,Kaiser,Weise,
NPA624(97)527

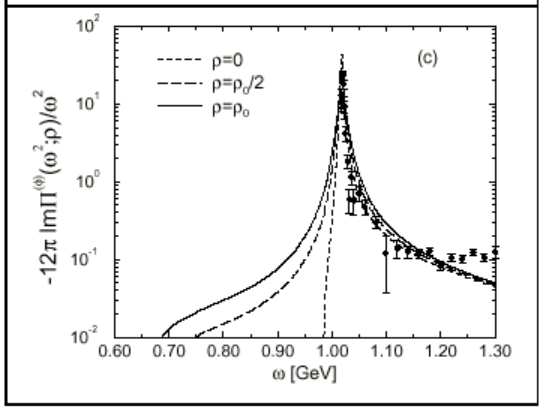
ρ



ω

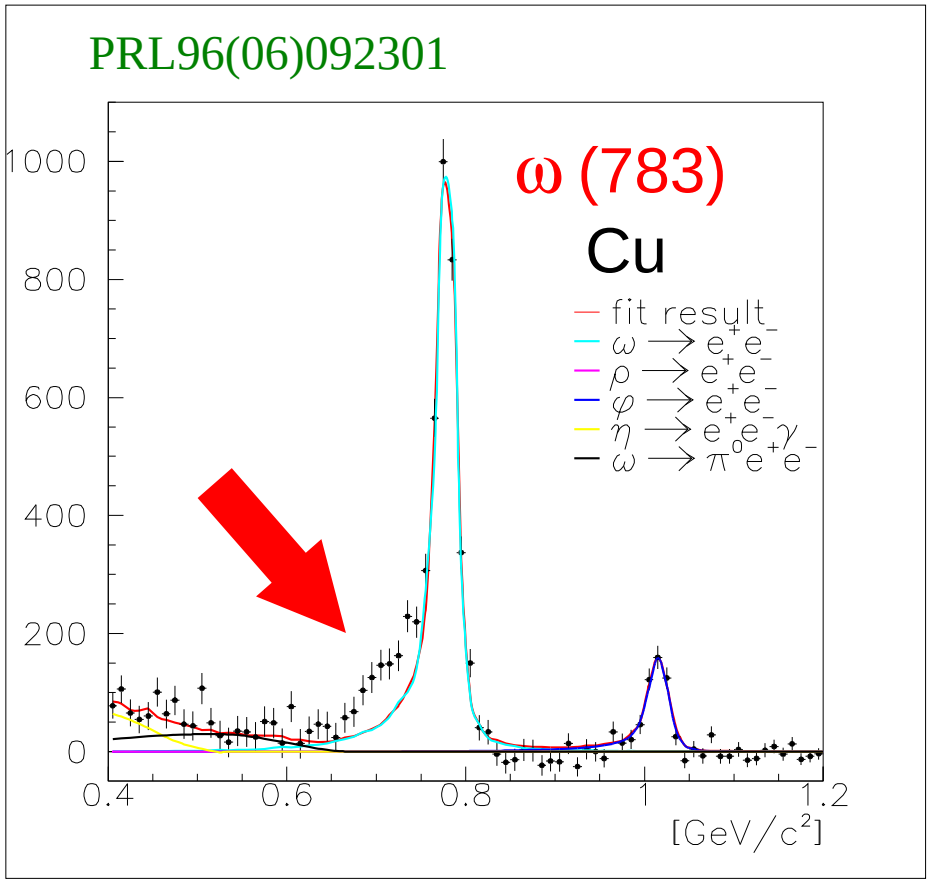


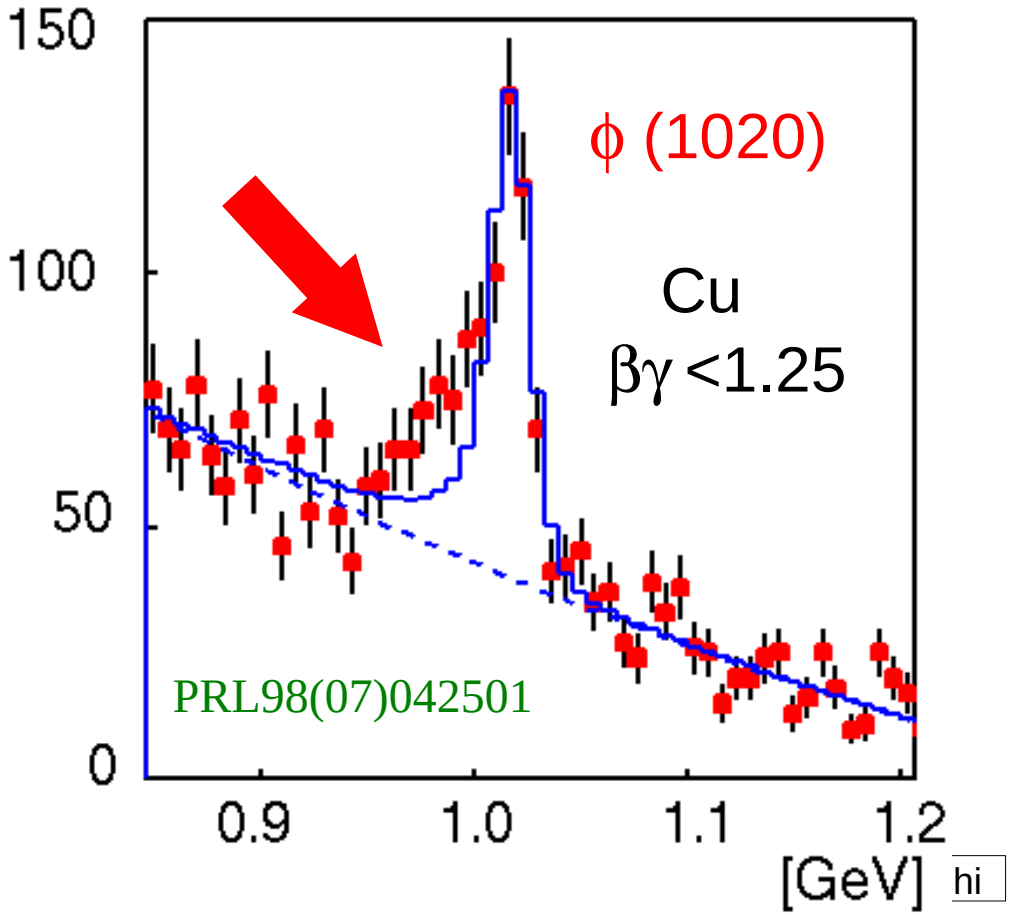
ϕ



E325 observed the meson modifications

- in the e^+e^- channel
- below the ω and ϕ ,statistically significant excesses over the known hadronic sources including experimental effects

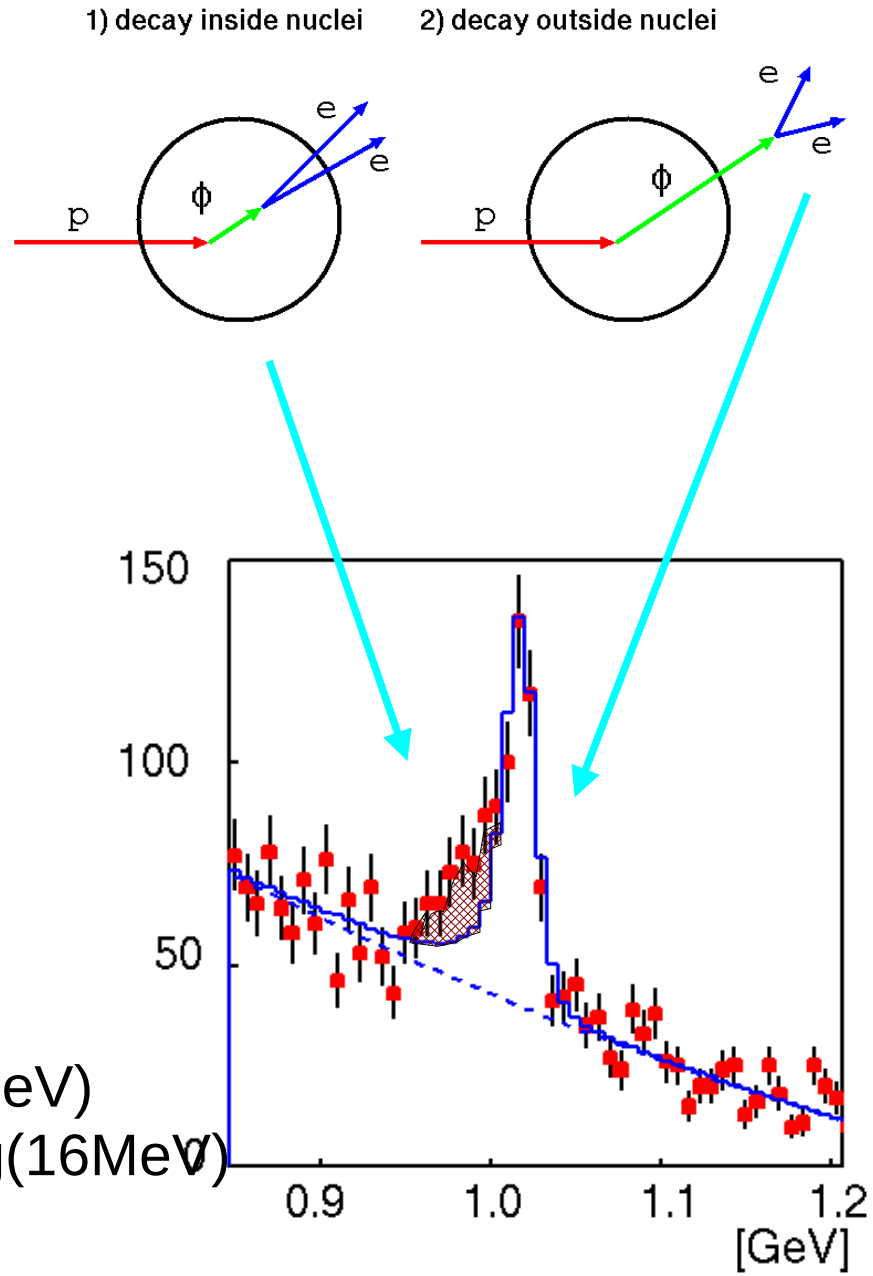




hi

E325 : interpretation

- MC type model analysis to include the nuclear size/meson velocity effects
  - generation point : uniform for ϕ meson
    - from measured A-dependence
  - measured momentum distribution
  - Woods-Saxon density distribution
  - decay in-flight : linearly dependent on the density of the decay point
    - dropping mass: $M(\rho)/M(0) = 1 - k_1(\rho/\rho_0)$
    - width broadening: $\Gamma(\rho)/\Gamma(0) = 1 + k_2(\rho/\rho_0)$
- consistent with the predictions



$$k_1 = 0.034^{+0.006}_{-0.007}$$

$$k_2^{tot} = 2.6^{+1.8}_{-1.2}$$

3.4% mass reduction (35MeV)
3.6 times width broadening(16MeV)
at ρ_0

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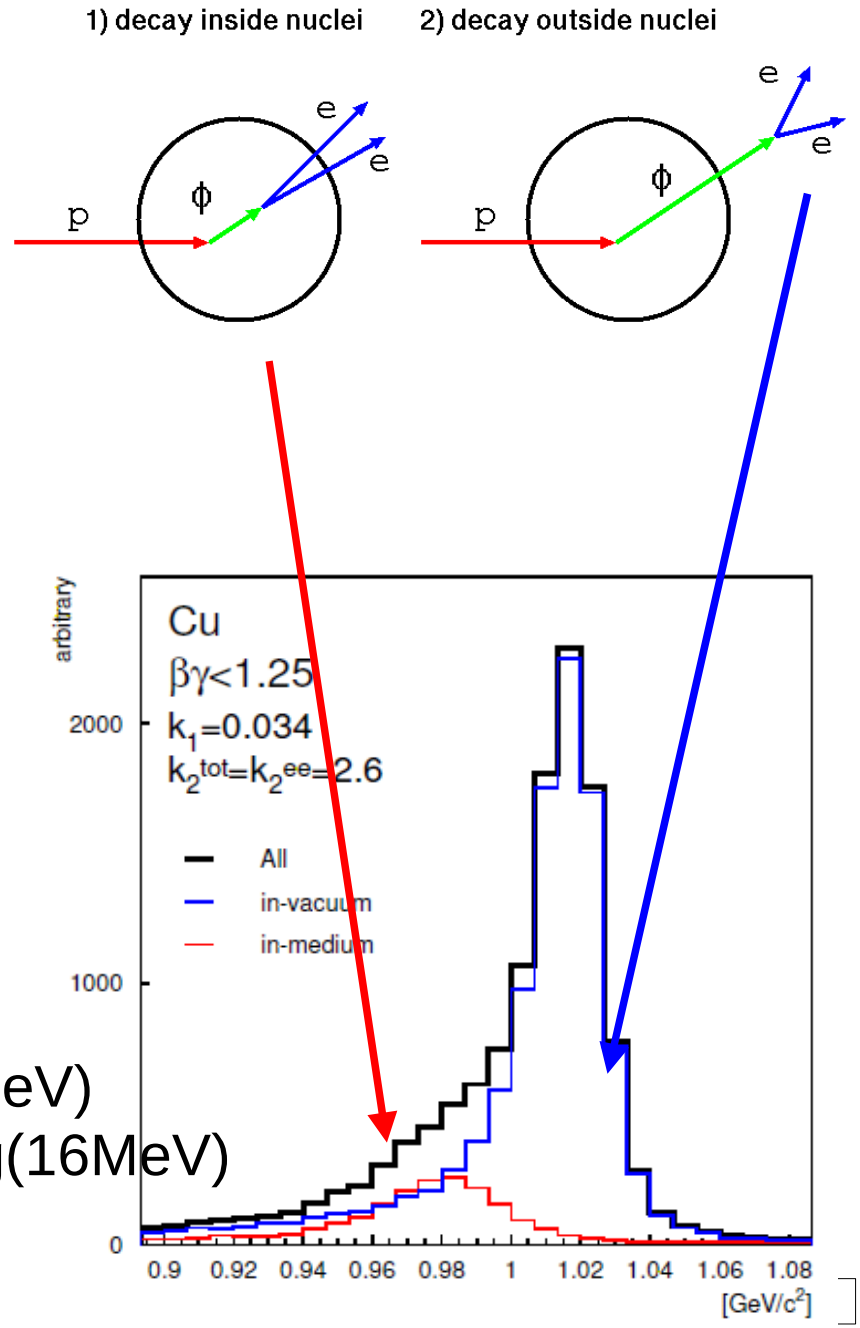

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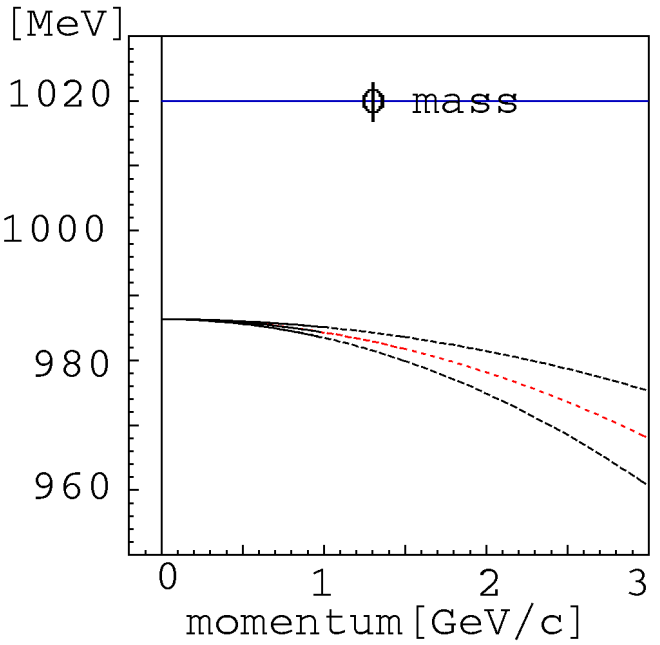
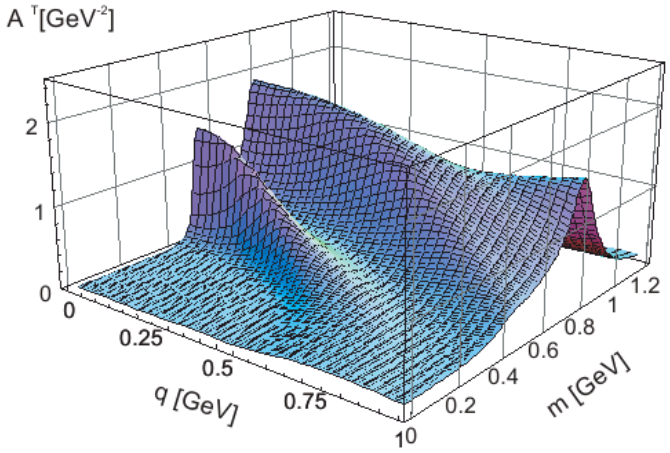
From “mass modification” to physics

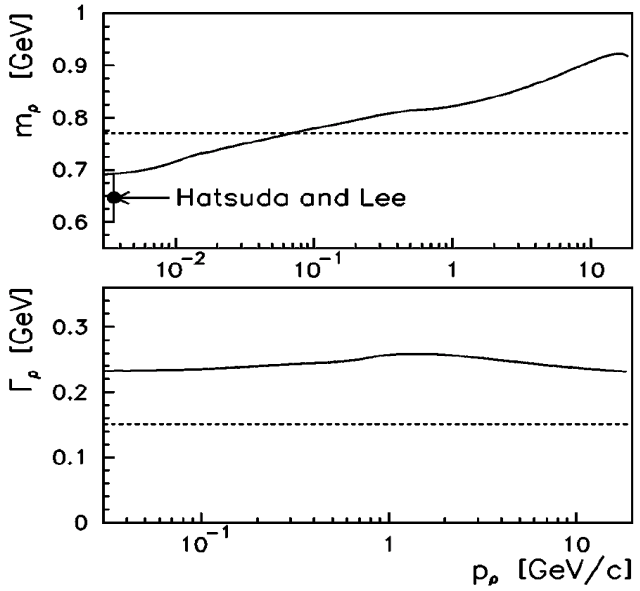
- Mass shape modification of vector mesons in medium looks to be established by many experimental results (E325/CLAS-G7/TAPS at the lower energy, NA60/CERES in HI collision)
  - statements contradict each other
    - mass dropping and/or width broadening
    - depending on the interpretation models to include the matter size effect
  - physics
    - only hadronic effects ? or chiral restoration ?
- Next step in the invariant-mass approach
  - put an emphasis on $\phi \rightarrow e^+e^-$: less ambiguous
    - ρ's complicated shape, ρ–ω interference, ρ/ω ratio, etc.
  - systematic study of the shape modification
    - nuclear matter size dependence : larger/smaller nuclei, collision geometry
    - momentum dependence : predicted, but not measured yet
  - check the validity of the interpretation models

dispersion relation (mass VS momentum)

- S.H.Lee (PRC57(98)927) $m^*/m_0 = 1- k\ \rho/\rho_0$
  - ρ/ω : $k=0.16\pm0.06+(0.023\pm0.007)(p/0.5)^2$
  - ϕ : $k=0.15(\pm0.05)*y + (0.0005\pm0.0002)(p/0.5)^2$
    - for p<1GeV/c
- Kondratyuk et al. (PRC58(98)1078) : ρ meson
- Post & Mosel(NPA699(02)169) : ρ meson





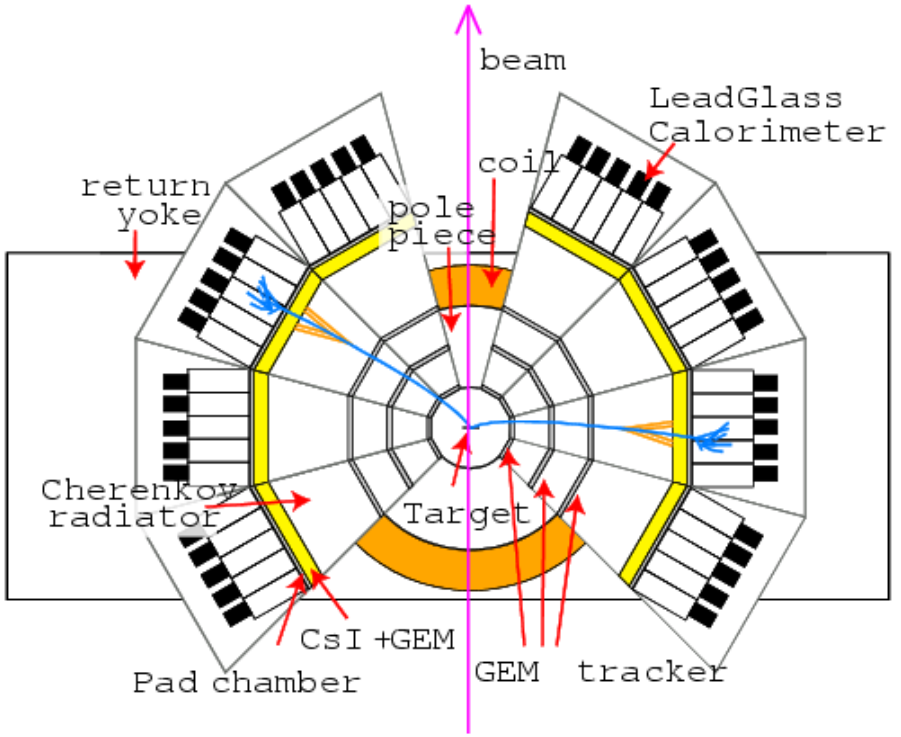


---J-PARC E16 experiment---
Low-mass dielectron measurement

- 2007/3 : stage1 (physics) approval
- Detector R&D is on going

Collaboration

RIKEN	S.Yokkaichi, H. En'yo, F. Sakuma
U-Tokyo	K. Ozawa
CNS, U-Tokyo	H. Hamagaki
Hiroshima-U	K. Shigaki
KEK	A.Kiyomichi, M. Naruki, R.Muto, S. Sawada, M. Sekimoto
Kyoto-U	K. Aoki

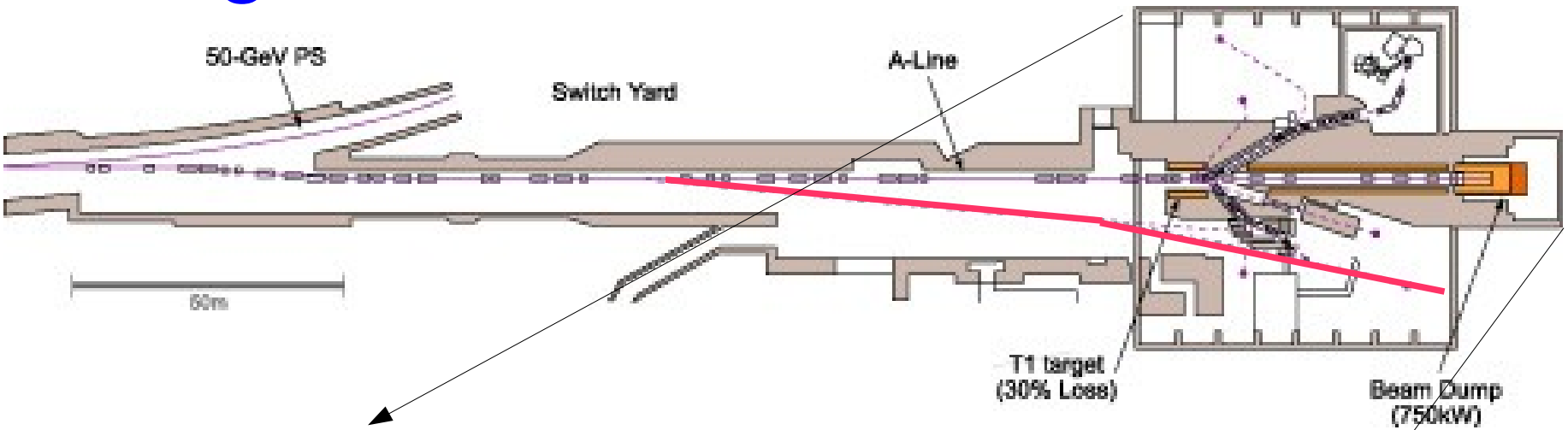


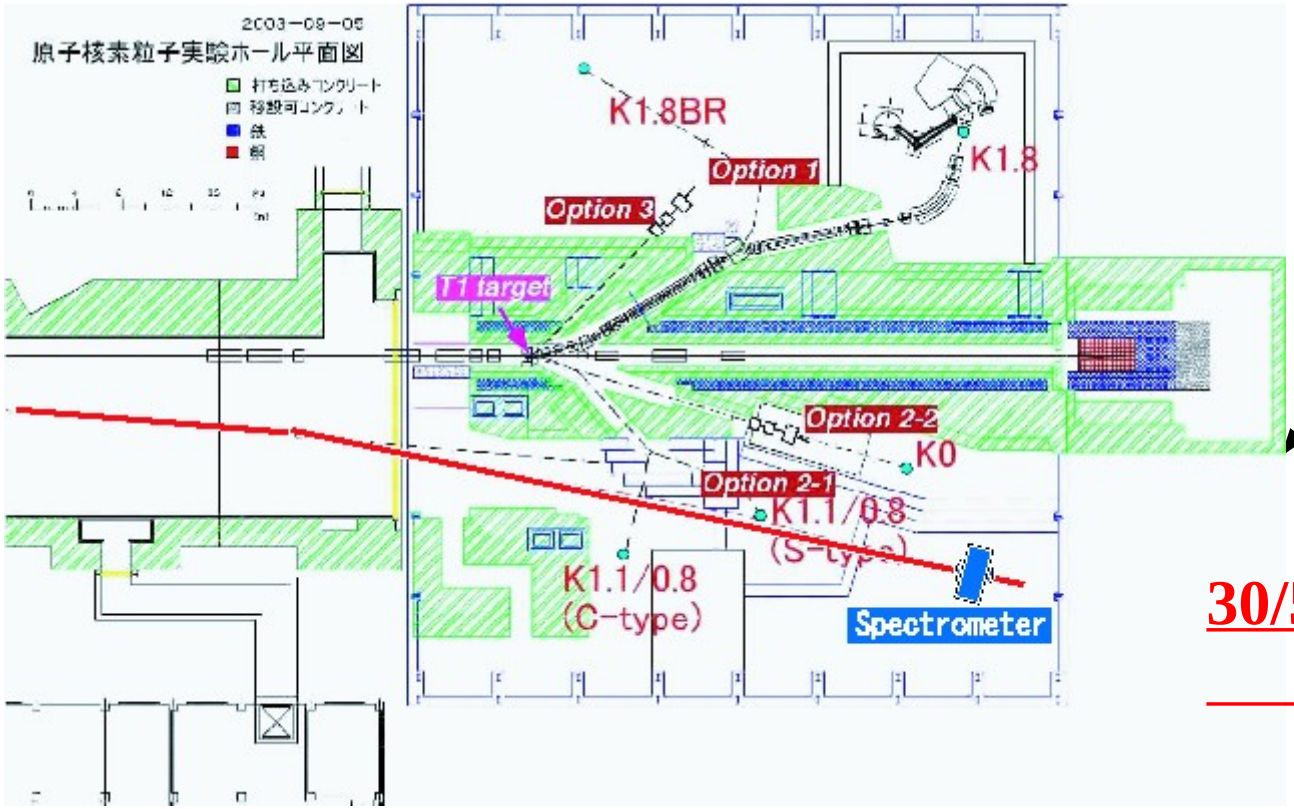
Proposal revised version 1 (2006 June 7) is located on :
http://ribf.riken.jp/~yokkaich/paper/jparc-proposal-0604.pdf

J-PARC E16 experiment

- Same concepts as KEK-PS E325
  - thin target (0.1% interaction) / primary beam (~10^{10} /sec)/ slowly moving vector mesons in the ee channel
- Main goal : collect ~1-2 x 10^5 $\phi \rightarrow$ ee for each target in 5 weeks
  - ~100 times as large as E325
    - new nuclear targets : proton (CH_2 -C subtraction), Pb
    - collision geometry for Pb target (by multiplicity)
  - **systematic study** of the velocity & nuclear size dependence of excess ('modified' component)
    - check the interpretation models
    - extract the dispersion relation (momentum dependence of mass)
  - mass resolution : keep ~ 10 MeV
- ρ ,ω and J/ψ can be collected at the same time

High momentum Beamline

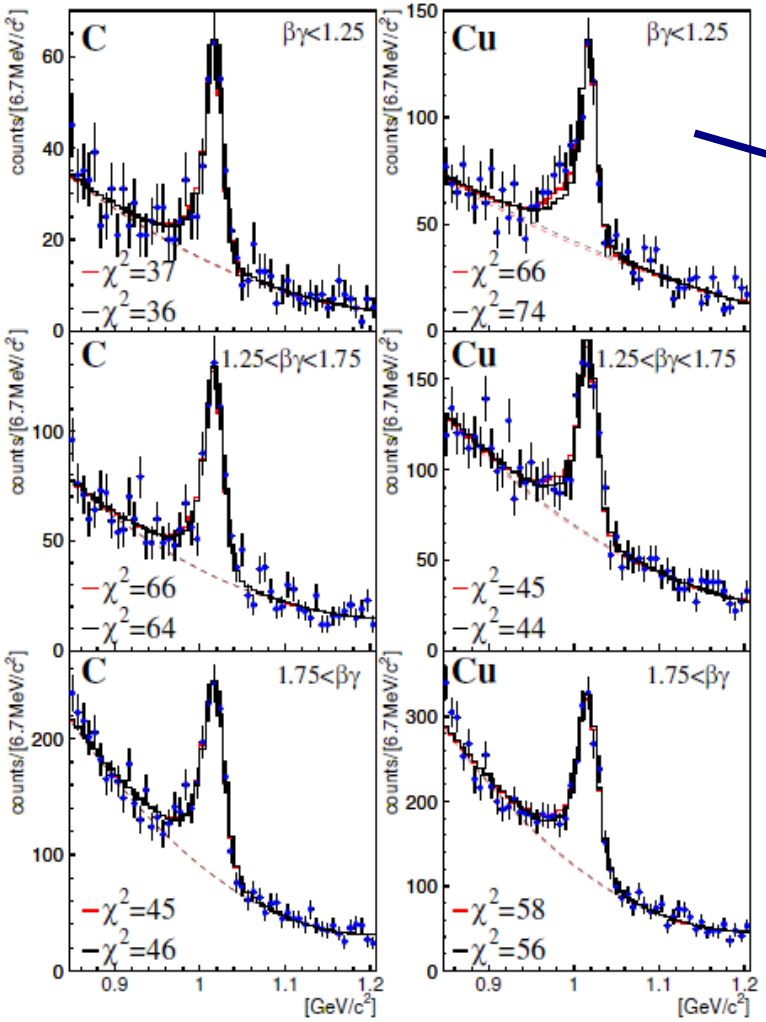


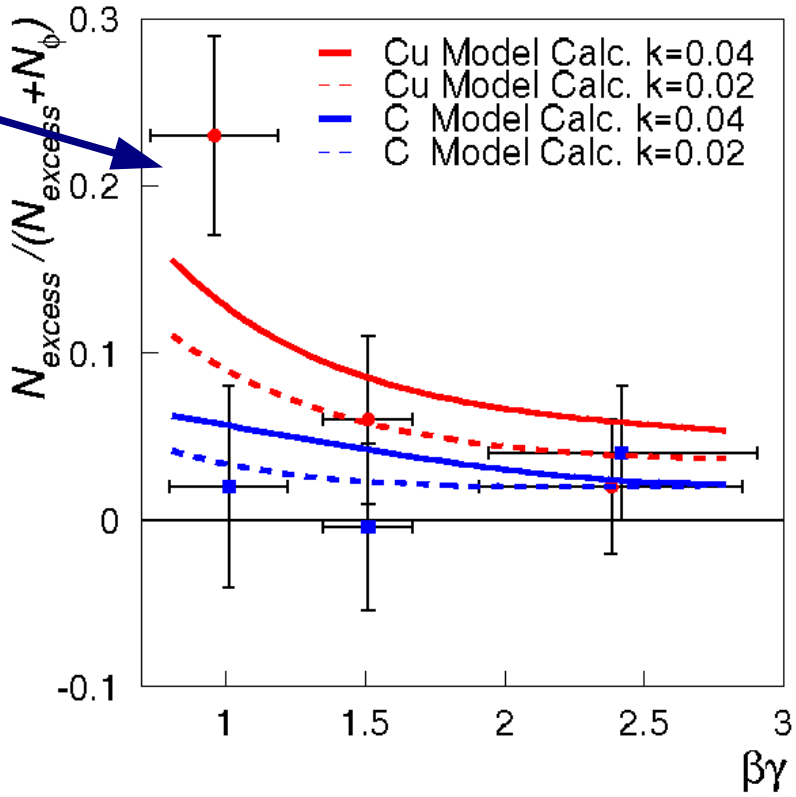


30/50GeV proton beam
(upto 10^{12} /sec)

velocity and nuclear size dependence

- velocity dependence of excesses ('modified' component)
- E325 only one data point for ϕ (slow/Cu) has significant excess

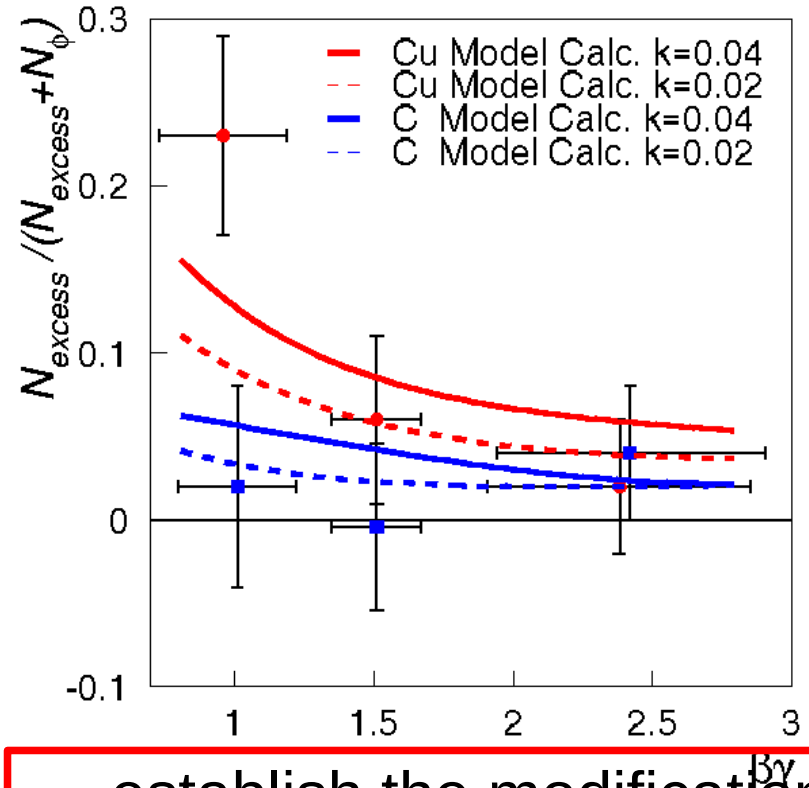




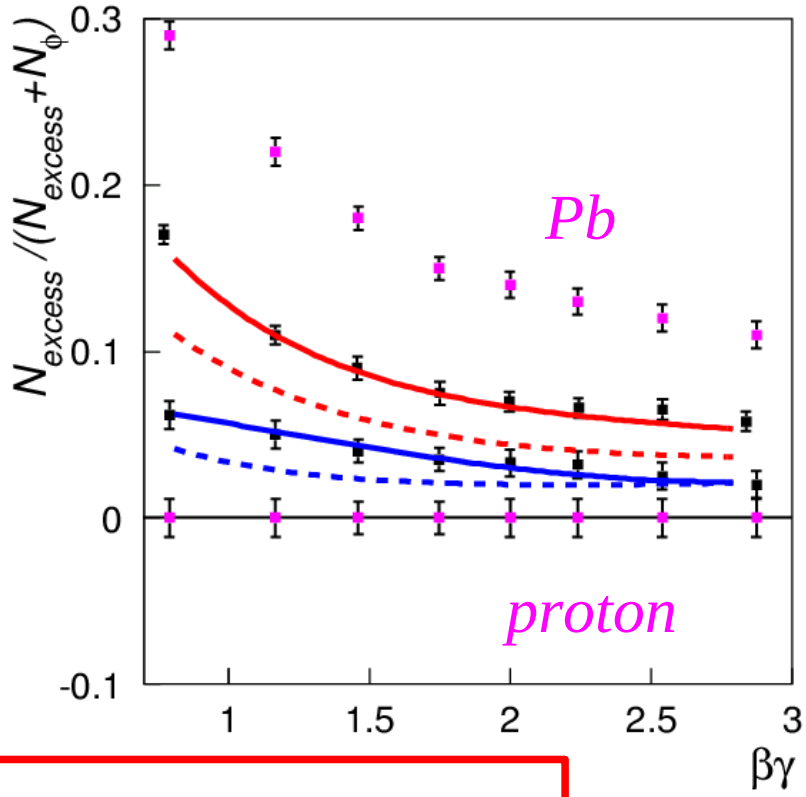
NP08 08Mar06 S.Yokkaichi

velocity and nuclear size dependence

- velocity dependence of excesses ('modified' component)
- E325 only one data point for ϕ (slow/Cu) has significant excess
- systematic study : all the data should be explained the interpretation model



x 100 stat.



- establish the modification
-

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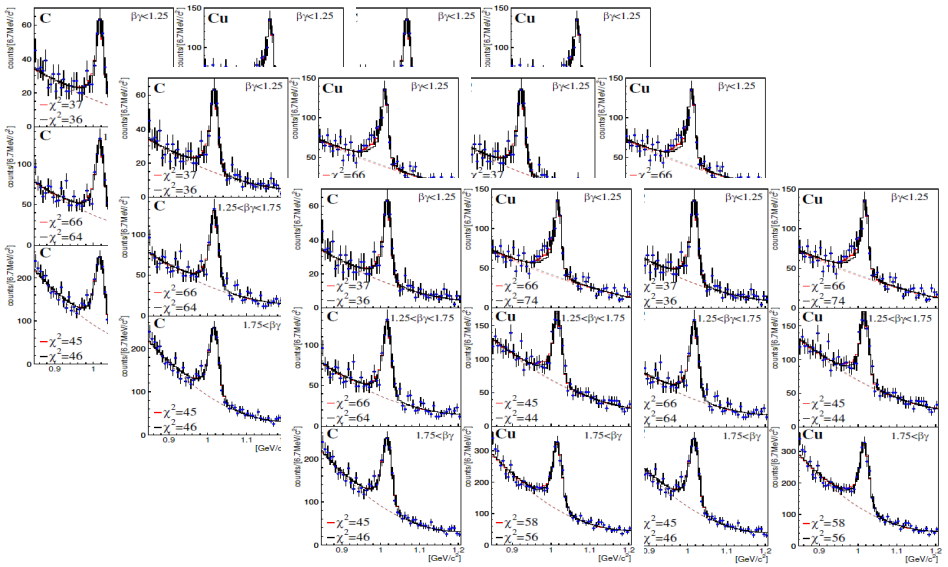
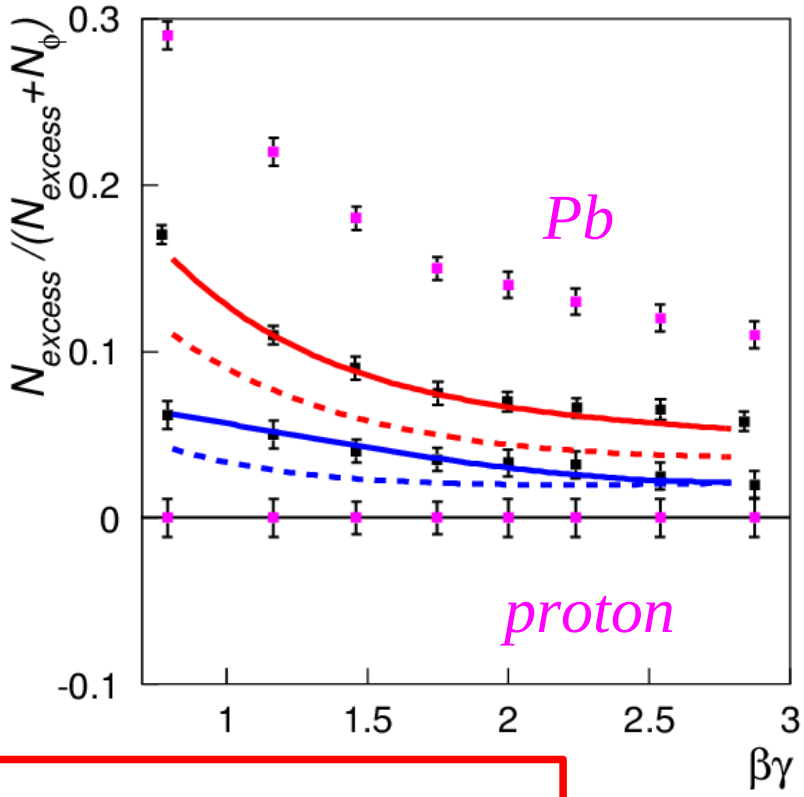
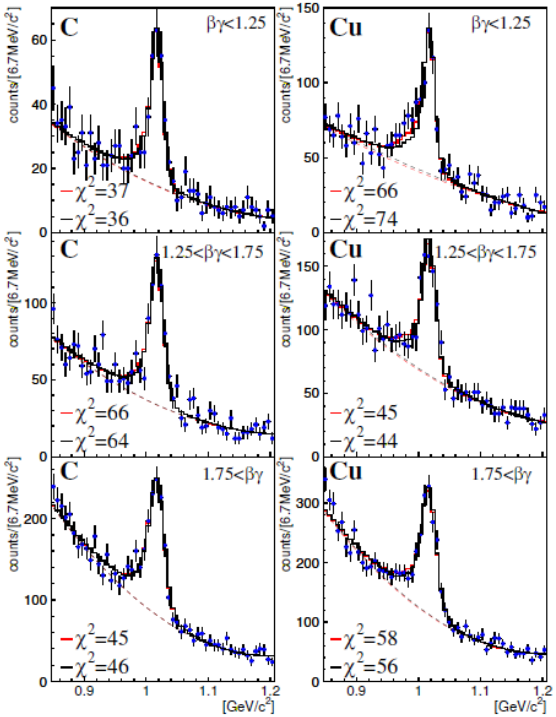


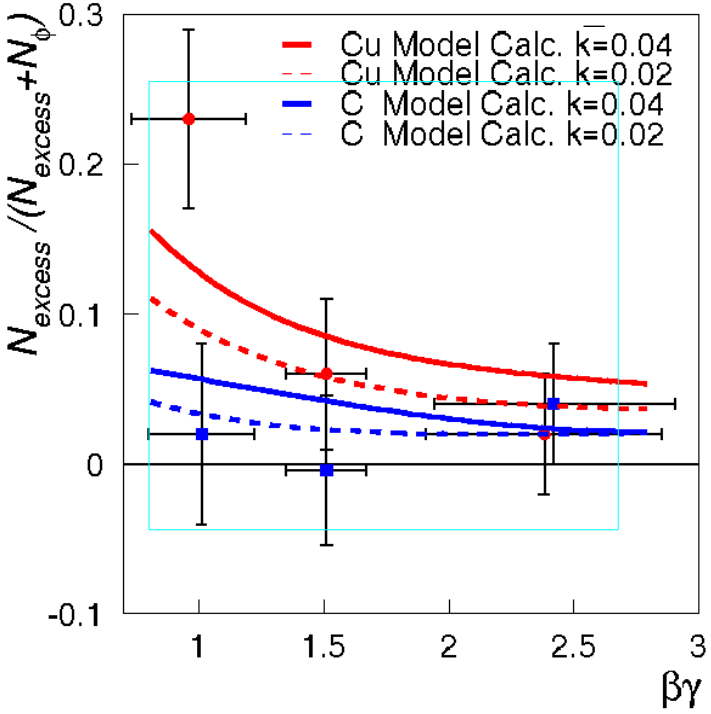


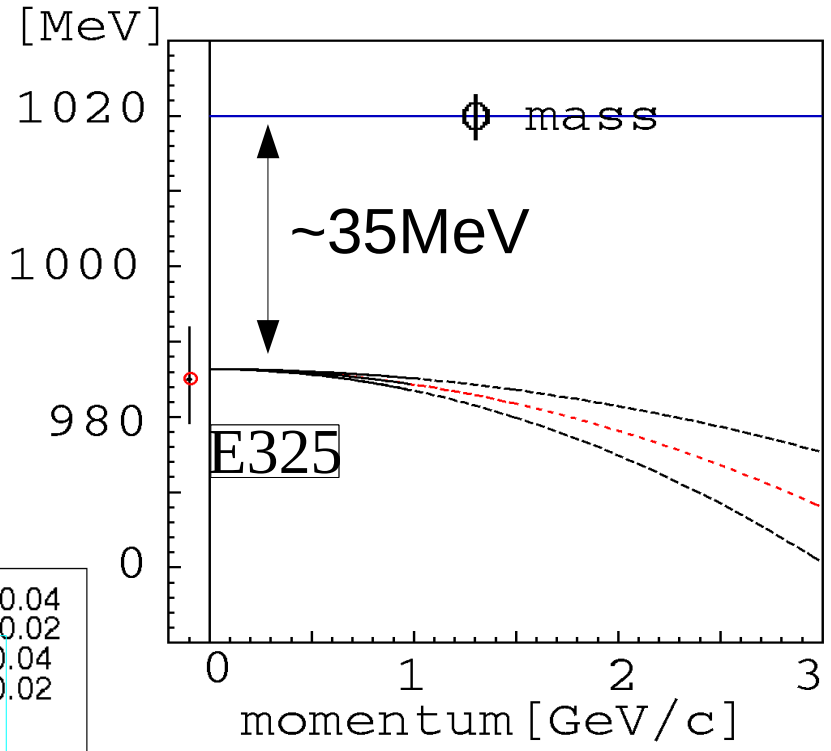
- establish the modification
- check the interpretation model with shape analysis for each histogram

dispersion relation(mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV)
- current E325 analysis neglects the dispersion (limited by the statistics)

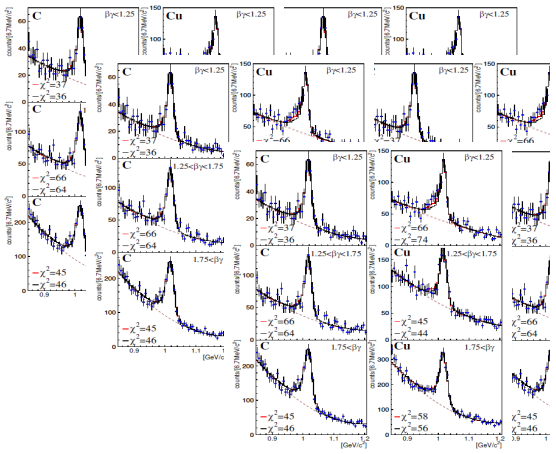


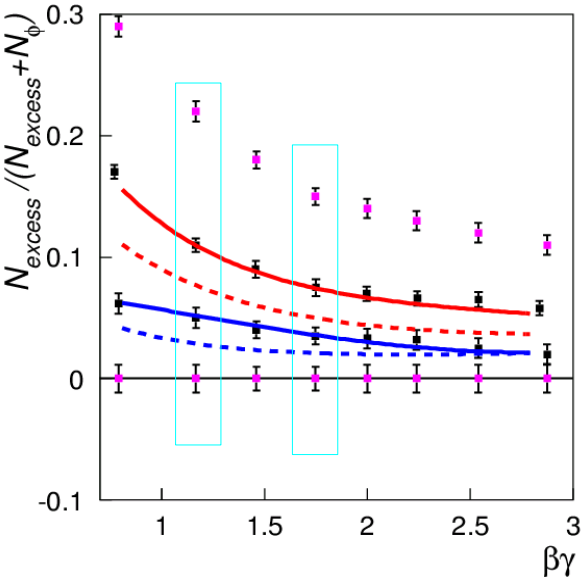


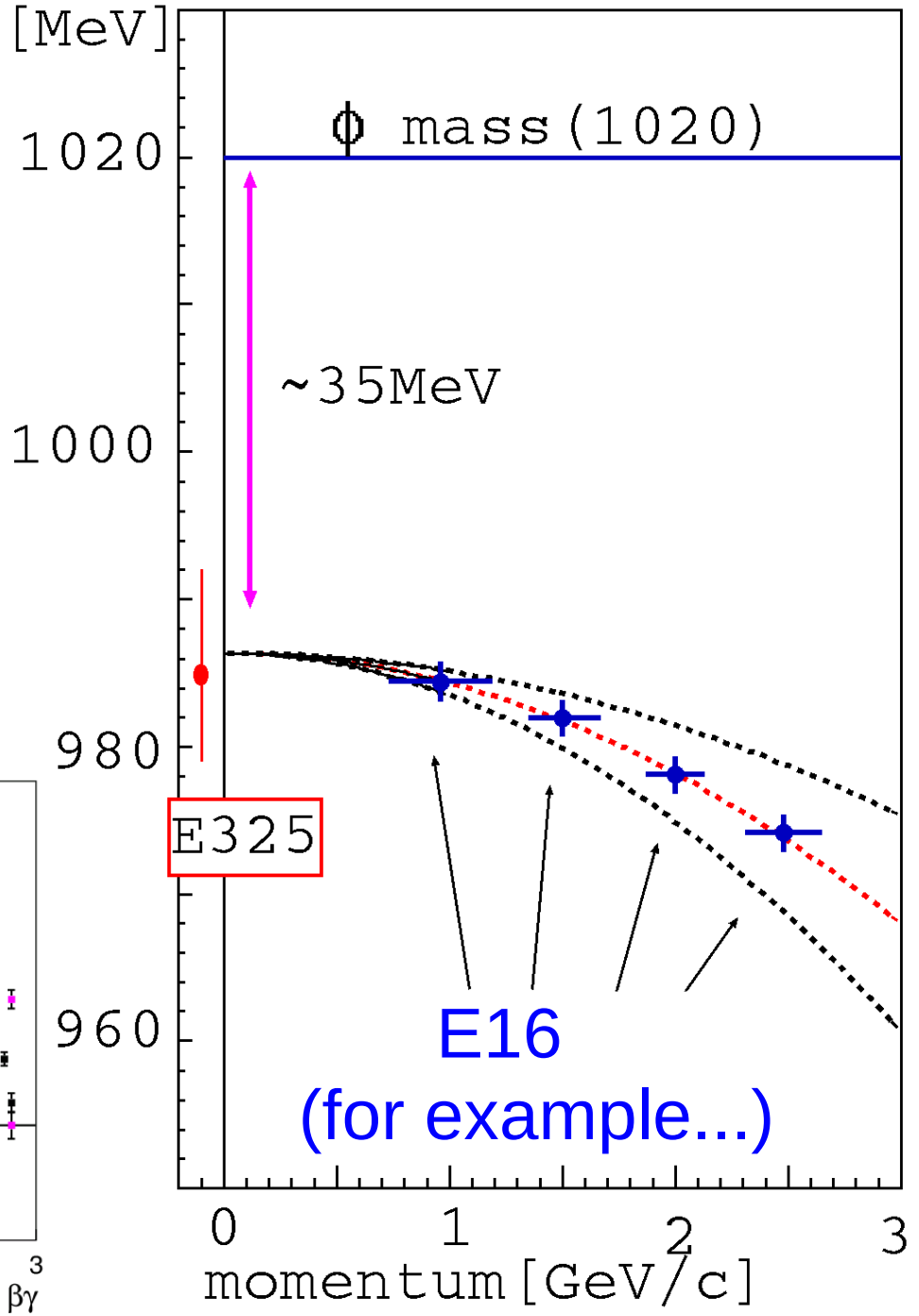


dispersion relation(mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV)
- current E325 analysis neglects the dispersion (limited by the statistics)
- fit with common shift parameter $k_1(p)$, to all nuclear targets in each momentum bin





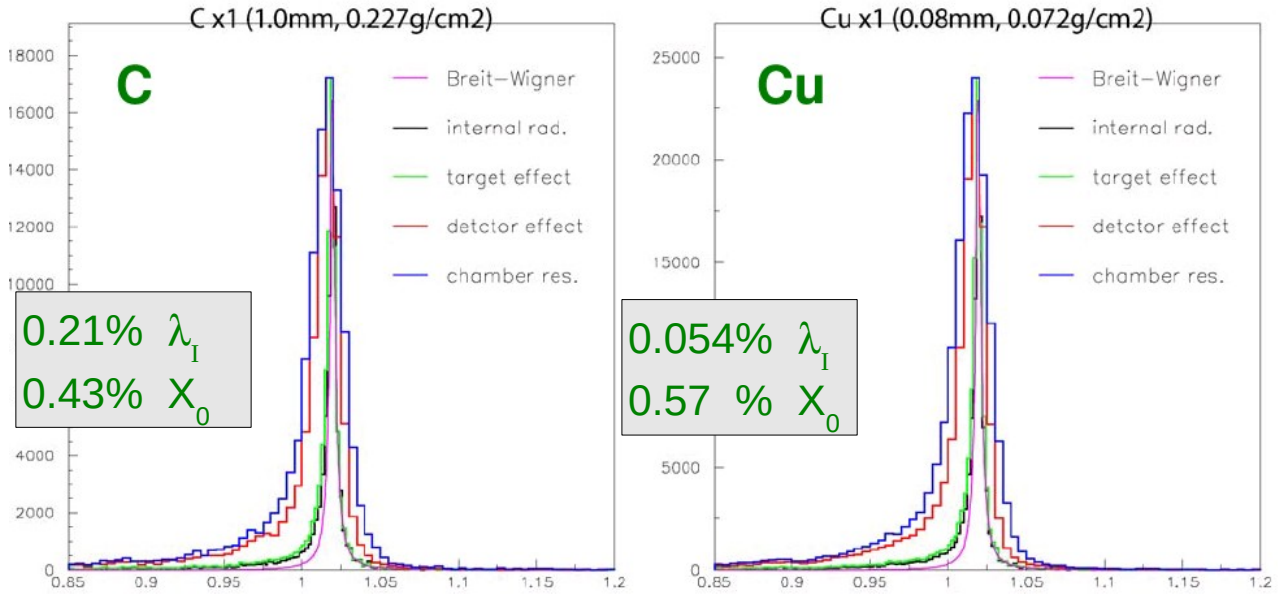


Key issues/digits for the spectrometer design

- electron ID : 10^{-4} π rejection
  - suppress the trigger rate and the background from miss-identified pions
- low material: 0.5% X_0 for each target, 4% X_0 for trackers
  - suppress the background from the conversion electron pairs, reduce a tail due to the bremsstrahlung
- high rate capability: 10MHz interactions at targets
  - to collect high statistics in use of primary beam (~10^{10} /sec)
- high mass resolution: less than 10 MeV (rms)
  - to see the modification
  - less than 200um of position resolution of the trackers

experimental effects on the BW shape (E325)

- E325 Detector Sim.
  - target material is negligible for ~0.5% radiation length (X_0)
  - detectors :up to 4.5 % X_0 in the tracking region



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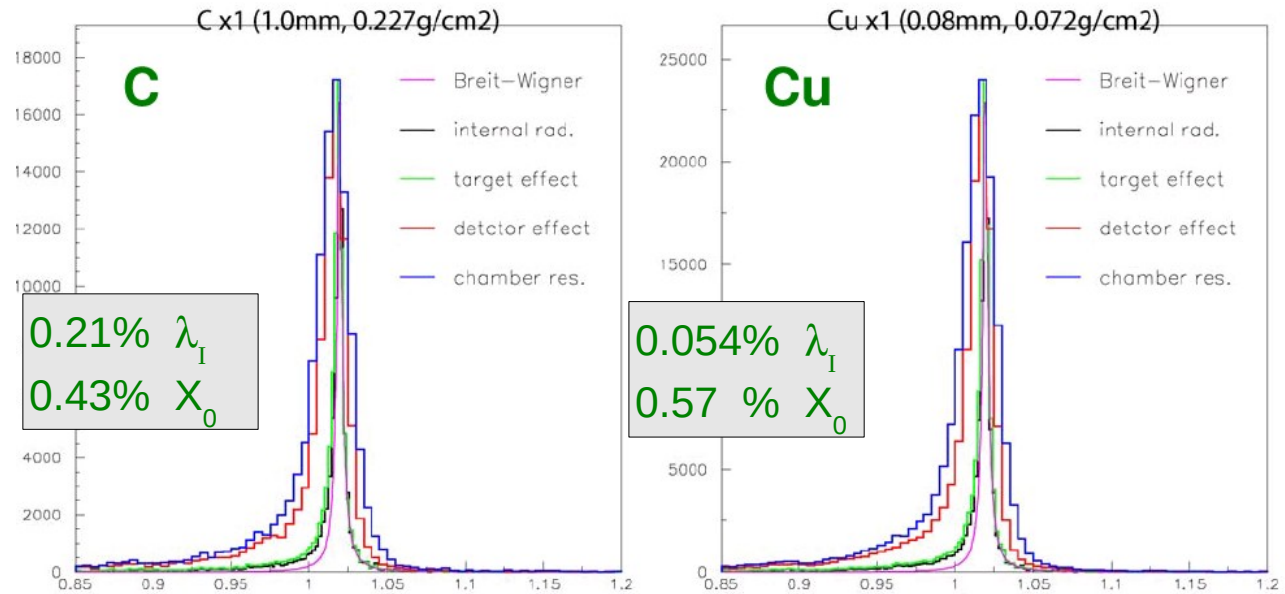
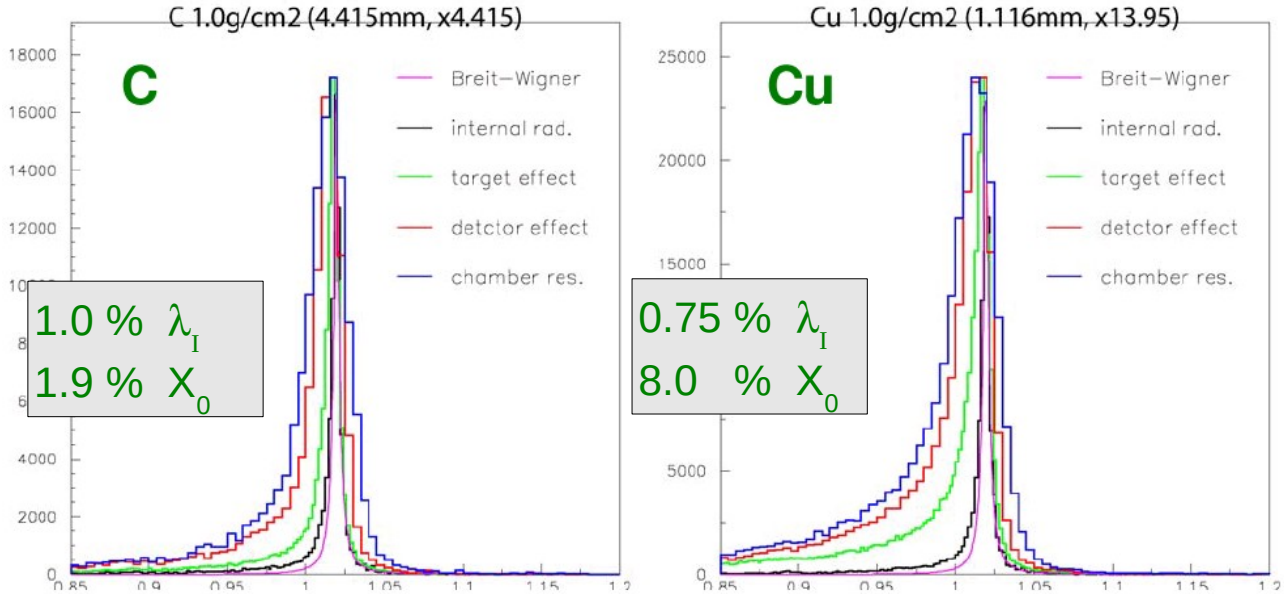


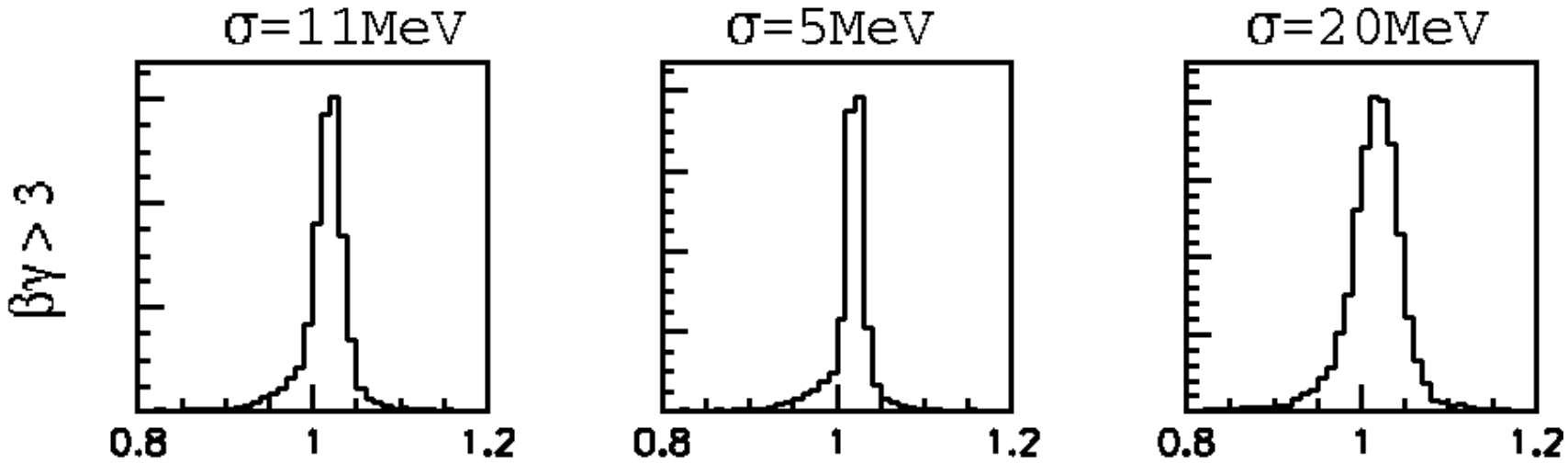
- In the case of the thick targets : 1g/cm^2
  - bremsstrahlung in target is so large for the Cu case



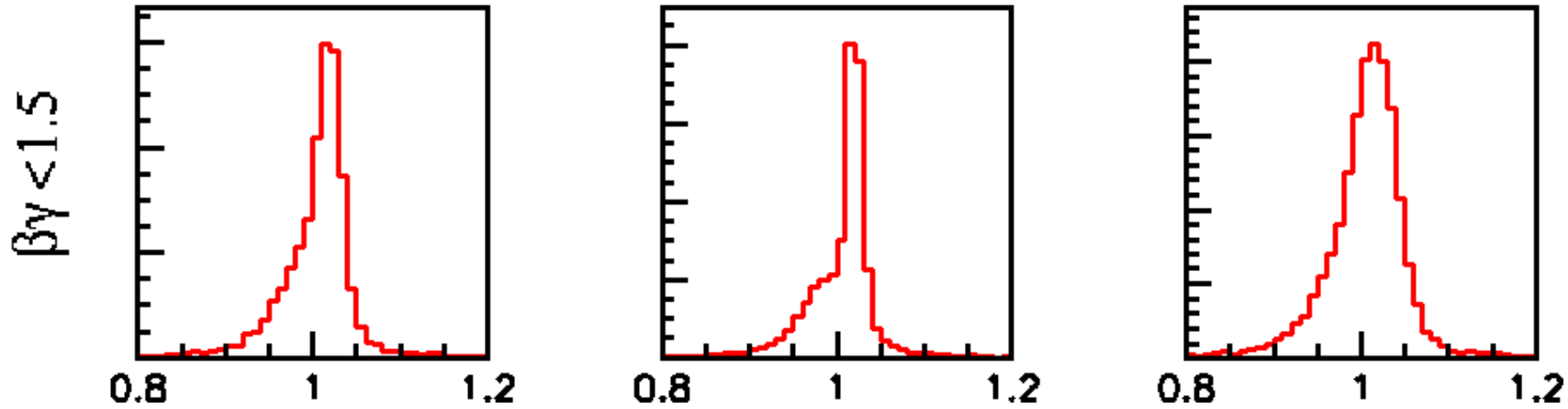
mass resolution requirement

- mass resolution should be kept less than ~10MeV

Fast



Slow

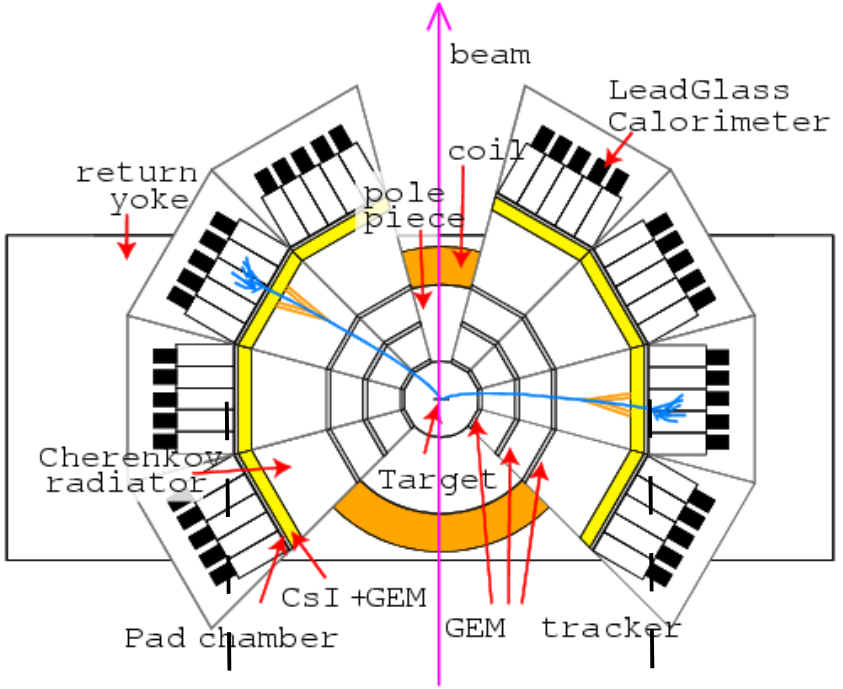


(model calc. for the Cu target)

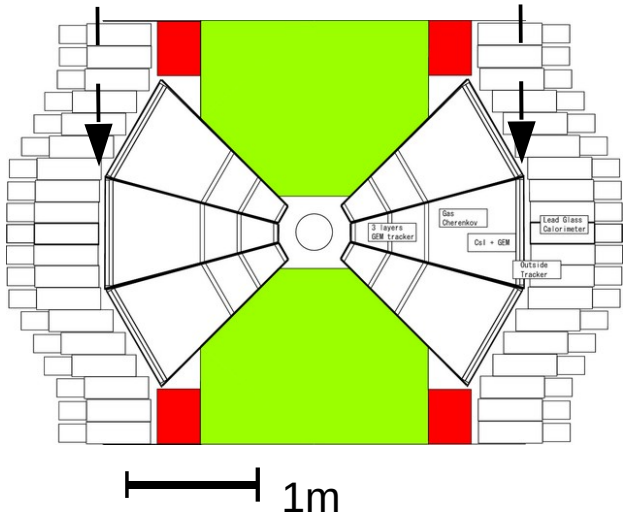
Proposed spectrometer

- Spectrometer Magnet : reuse E325 's
  - remodeling the pole / repairing the coil
  - stronger field for compact detector size
- GEM(Gas electron multiplier) Tracker
    - 0.7mm pitch strip readout
- Two-stage Electron ID (10^{-4} π rejection)
  - Hadron Blind Detector (Gas Cherenkov)
    - GEM+CsI photocathode
    - hexagonal pad readout (~30mm ϕ)
  - Leadglass EMC: reuse of TOPAZ
- ~70K Readout Channels (in 26 segments)
  - cf. E325: 3.6K, PHENIX:~300K
- Cost : ~$5M (including ~$2M electronics)
  - cf. E325: $2M not including electronics

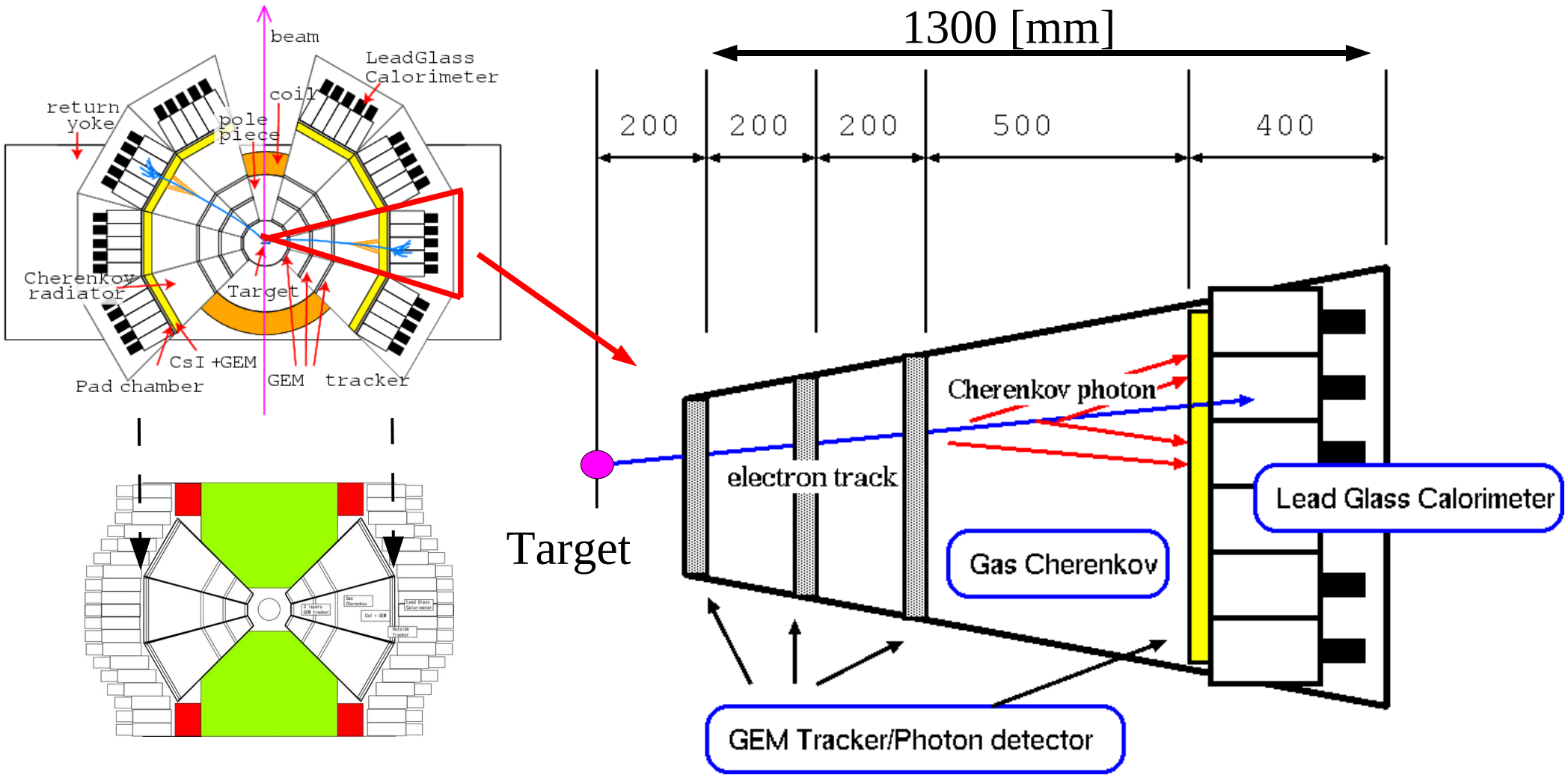
Plan view



Beam view



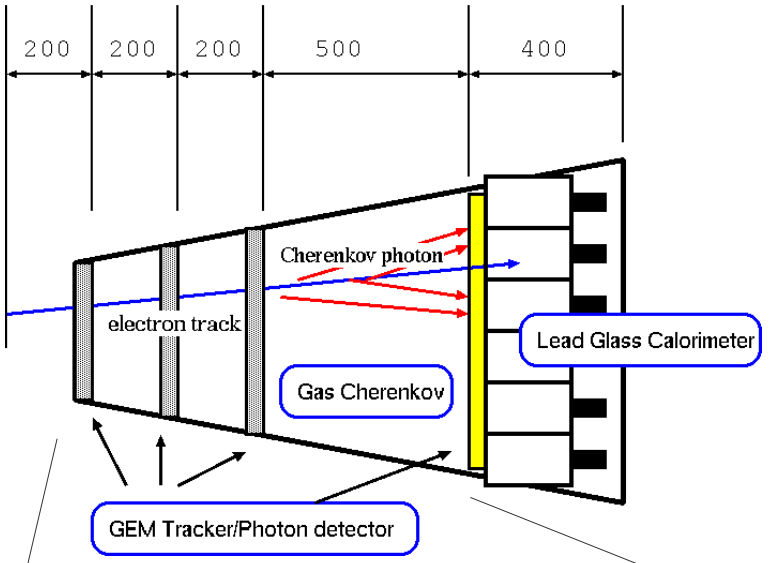
Prototype module is under construction

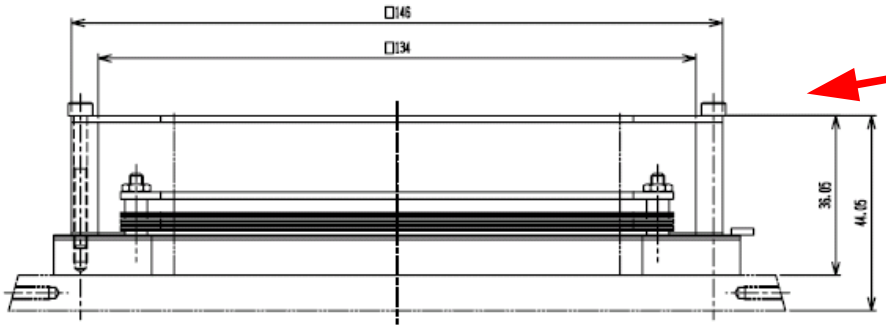


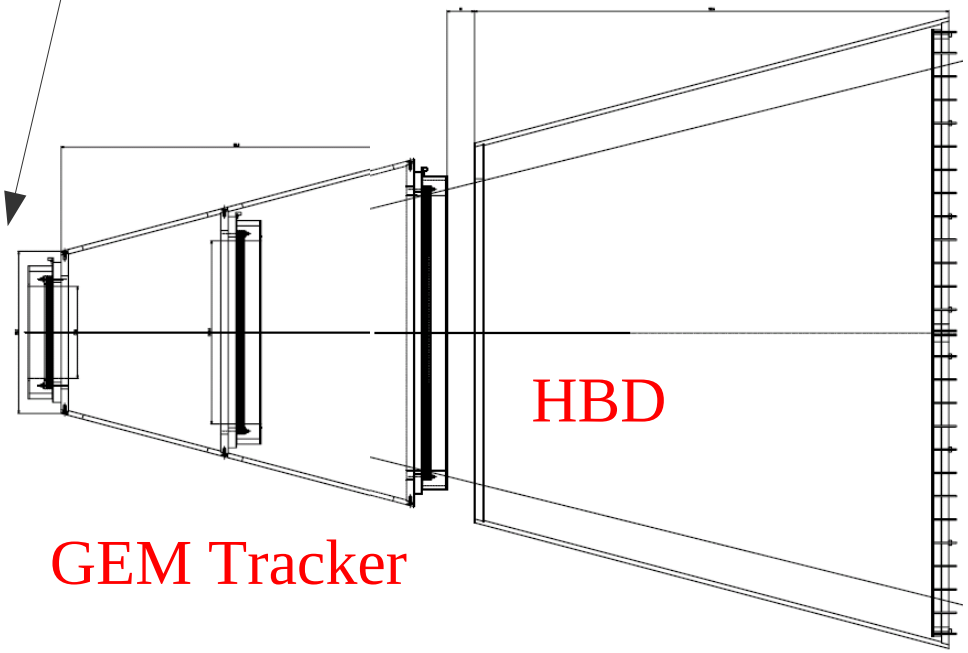
- the spectrometer consists of 26 modules in the conceptual design

Prototype module is under construction

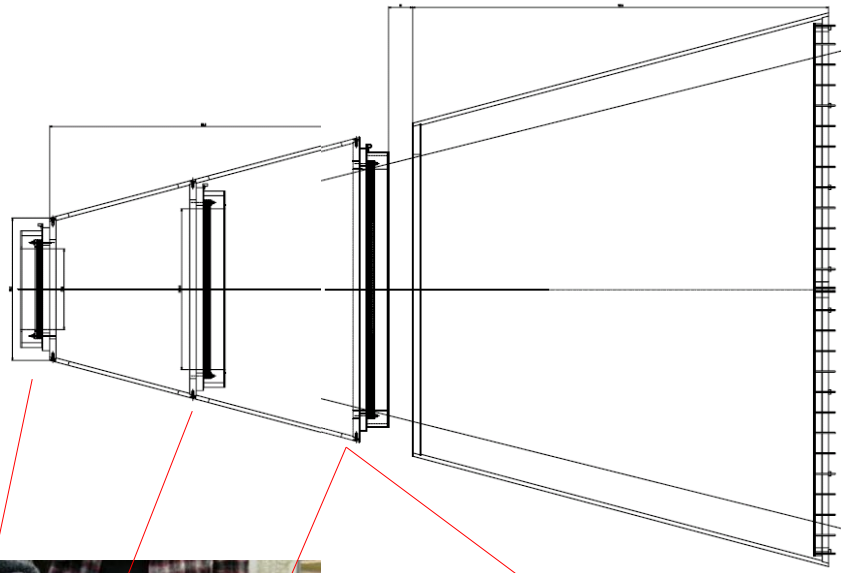
- Items should be tested
  - thin readout boards :
    - Kapton 25um, Cu 4um
    - double sided (x,y) 350um pitch
  - domestic large GEM (300mm x 300mm)
  - alignment of the three GEM chambers
- Parts will be delivered till March 31, test will start in April

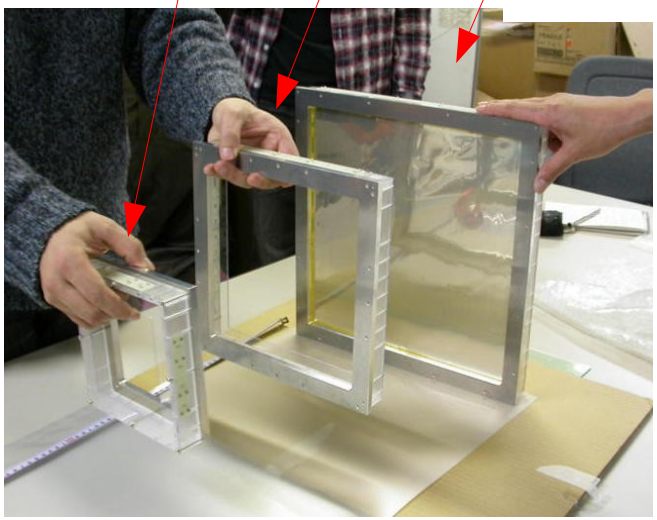




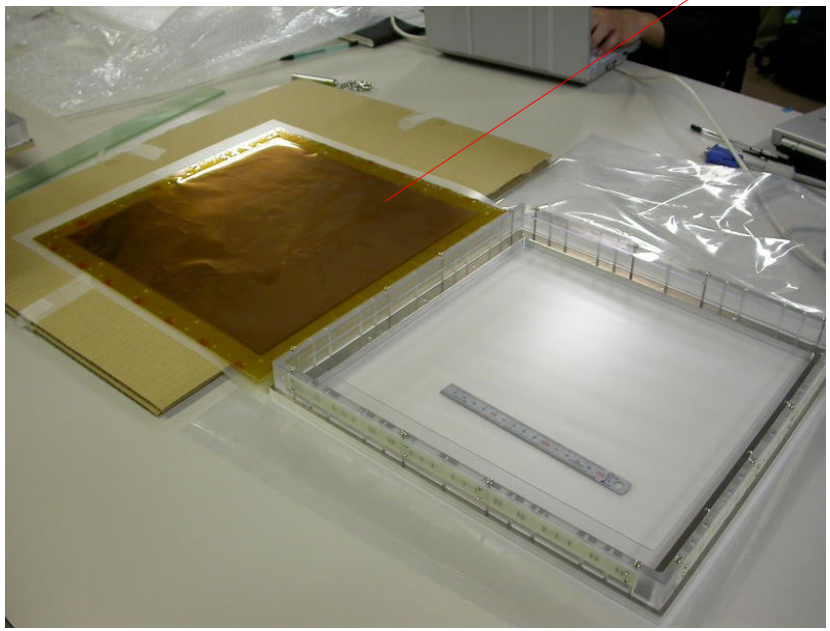


Delivered parts (Feb.29)





chamber frames



largest thin read-out board (300x300mm)

Detector R&D status

- GEM : domestic products works well
  - high gain GEM / larger size (300mm x 300mm)
- HBD (Gas Cherenkov using GEM + CsI photocathord)
  - PHENIX prototype / working model
  - In Japan:
    - CsI photocathord (Hamamatsu)
    - CF_4 operation
    - Beam test @ HiSOR (Hiroshima-U)
    - long term operation

already tested
on going
construction -> test in JFY2008
(2007/08 Grant-in-Aid)

- GEM Tracker for high rate
  - Triple GEM w/ 2D double-sided strip read-out board (@U-Tokyo)
  - low material strip read-out board
- prototype module of the spectrometer
  - Tracker + HBD in real-size

Summary

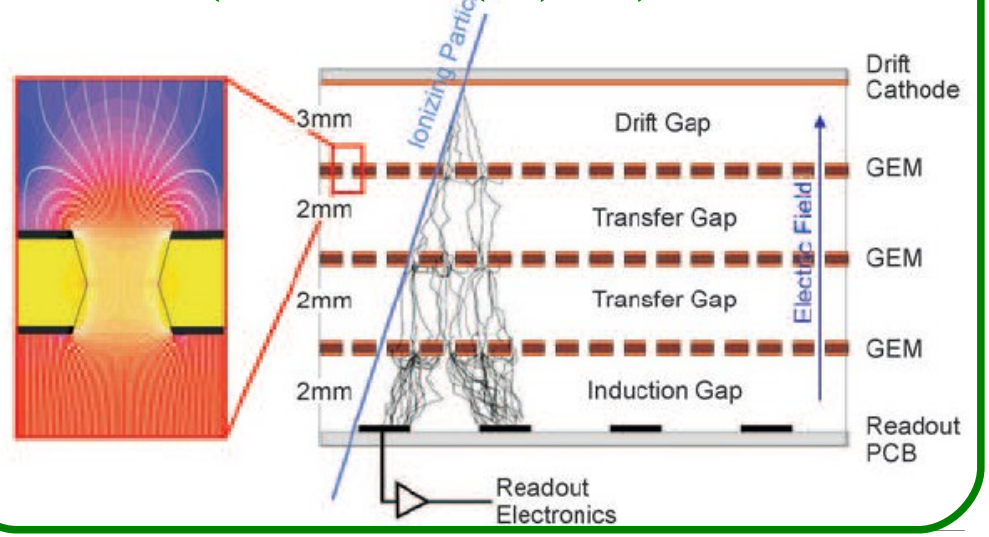
- Vector meson measurements in e^+e^- channel at J-PARC E16
  - to investigate the chiral symmetry in dense hadronic matter
- 30 (or 50) GeV primary proton beam (~$1x10^{10}$ /sec)
  - especially collect ~10^5 $\phi \rightarrow e^+e^-$ for each target in ~5weeks (800 hours) operation : 100 times as large as KEK-PS E325's statistics
- New spectrometer using new technology (GEM tracker/HBD)
  - R&D is on going at U-Tokyo and RIKEN w/ grant-in-aid
  - Spectrometer design should be finalized in 2008
- Impact of the experiment
  - systematic study of the vector meson mass modification in various size (0~10fm) of dense matter (nuclear matter)
  - momentum dependence of in-medium mass (dispersion relation)
  - provide the systematic data which motivate to develop new theoretical calculations, including interpretation in the real nuclear matter

Backup slides...

GEM Tracker to cope with high rate

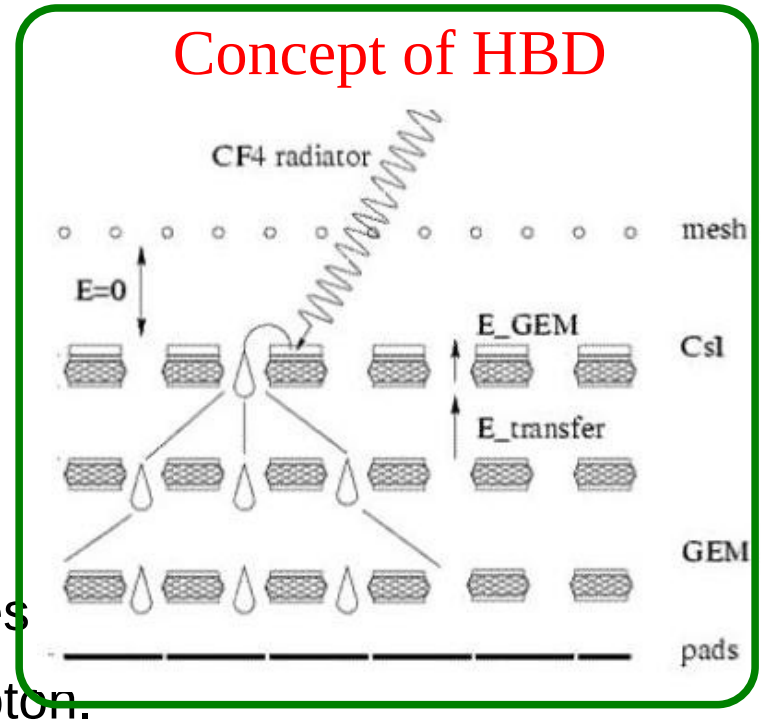
- Expected single rate is too high to use DC
  - origin : beam halo and/or from the interactions at the target
- E325 experience x 10 times
  - 1.8 MHz @ 6° (20mm from the beam) /3.5mm x100mm cell of DC @r=200mm
    - 5KHz/mm^2 → GEM tracker can be operated (cf. COMPASS exp.)
  - 400KHz @ 60° /4mm x100mm @r=200mm
    - marginal rate for DC operation
- E16
  - Fine segment to cope with the high rate
  - position resolution 0.2mm to keep the mass resolution
  - → **GEM Tracker w/ 0.7mm pitch readout**

COMPASS GEM Tracker
(NIM A577(07)455)



HBD (Hadron Blind Detector)

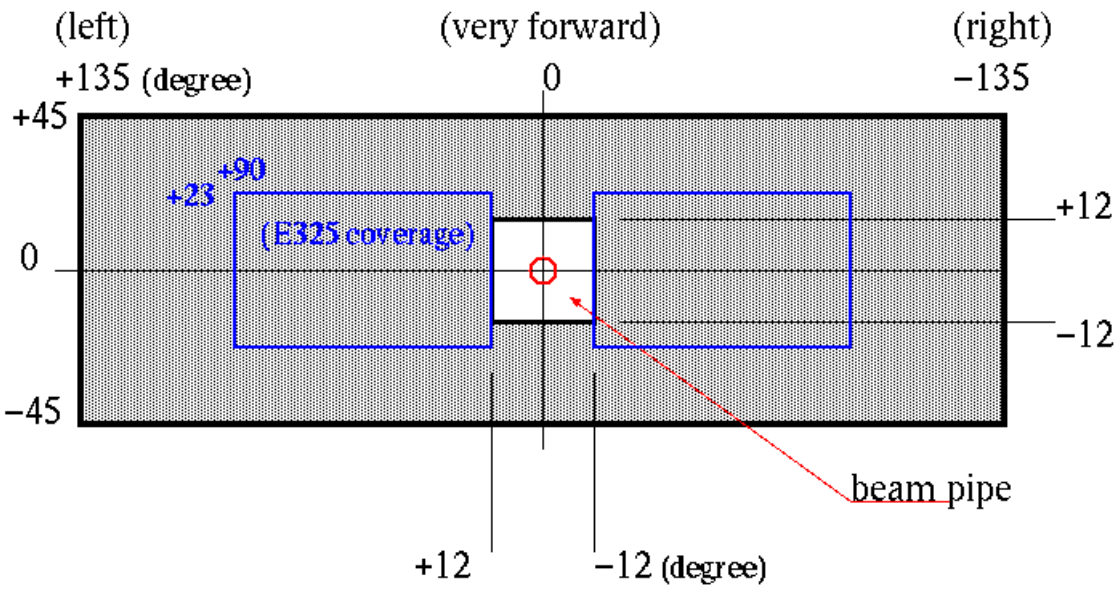
- HBD : Thr. type Gas Cherenkov Counter
  - CsI photocathode : UV photon sensitive
  - Triple GEM with pad readout
  - CF_4 is a radiator and amplification gas
  - Ionized electrons are collected by mesh
    - photoelectrons are amplified by 3 stages
    - ionized electrons are amp. by only last 2 stages
    - $\rightarrow$ can detect only particles with cherenkov photon.
      - (1/100 of pion rejection)
- Joint development with Weitzman Institute
  - originally for PHENIX upgrade plan
- Cover large area with no mirror
- 10cm x 10cm of Trigger tile : effectively fine segmented
  - essential to trigger the e^+e^- pair from the vector meson



To collect high statistics

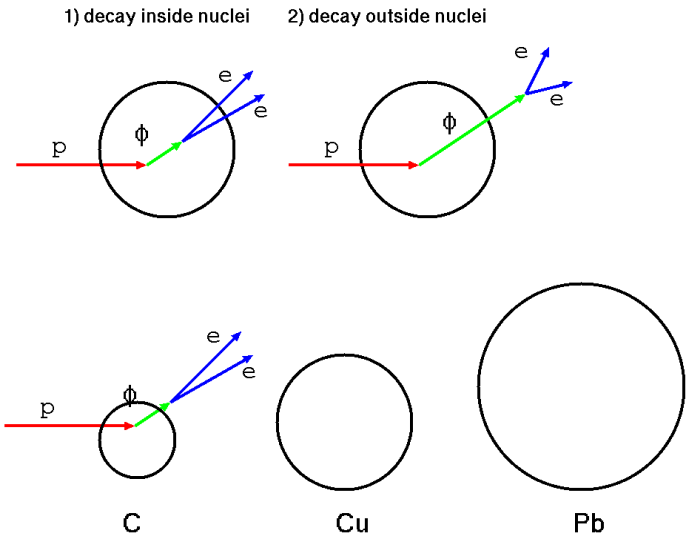
- For the statistics 100 times as large as E325, new spectrometer is required.
  - To cover larger acceptance : x~ 5
  - Higher energy beam (12 → 30/50 GeV) : x ~2 of production
  - Higher intensity beam (10^9 → 10^{10} /spill (1sec)) : x 10 (→ 10MHz interaction on targets)

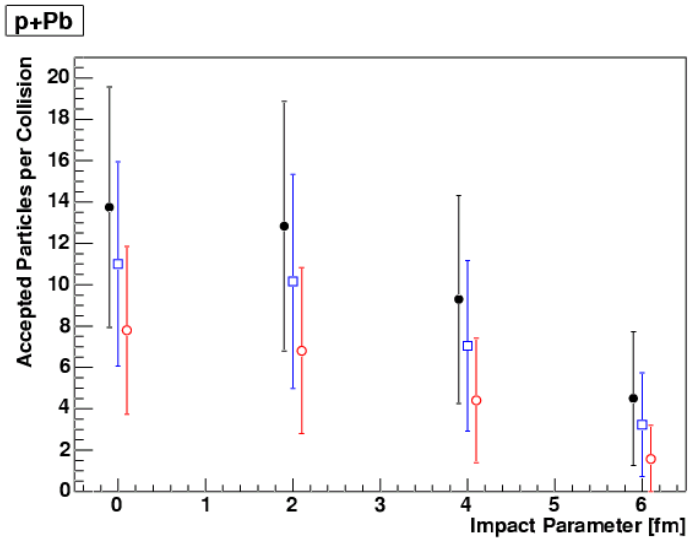
Geometrical (horizontal & vertical) coverage of the spectrometer



New nuclear targets with larger statistics

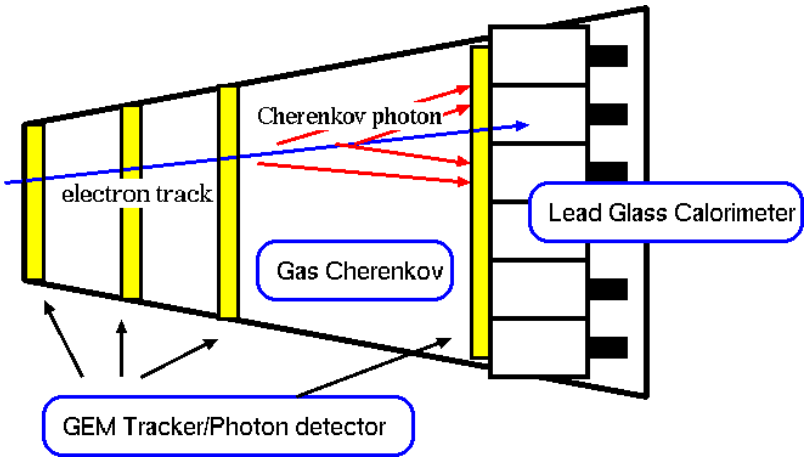
- Smaller nuclear target :
  - proton as reference(CH_2 -C subtraction)
  - LH target cannot be used because of the materials
- Larger nulcear target as Pb
  - larger nuclear matter
  - collision geometry(impact paramter) study using multiplicity
  - larger radiation length for heavier target
    $\rightarrow$ more thiner foil target to keep S/N
    - high statistics capability is required.

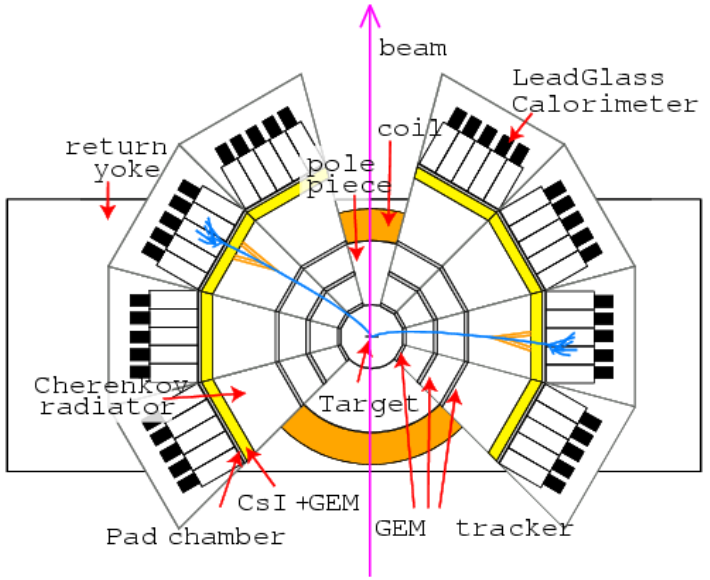




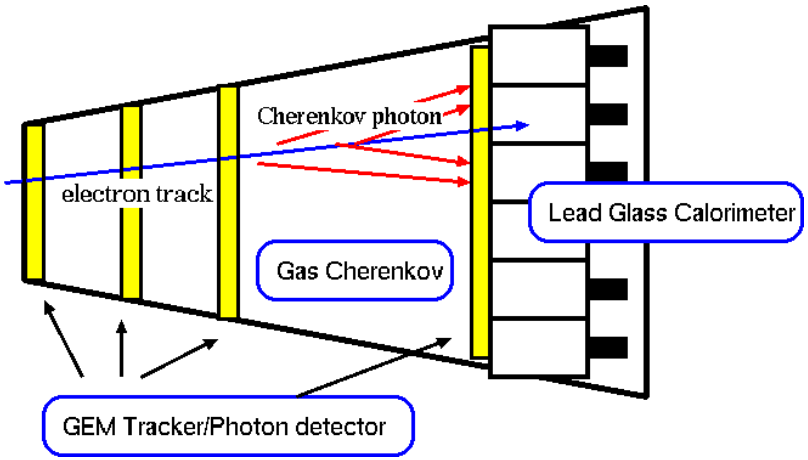
Schedule

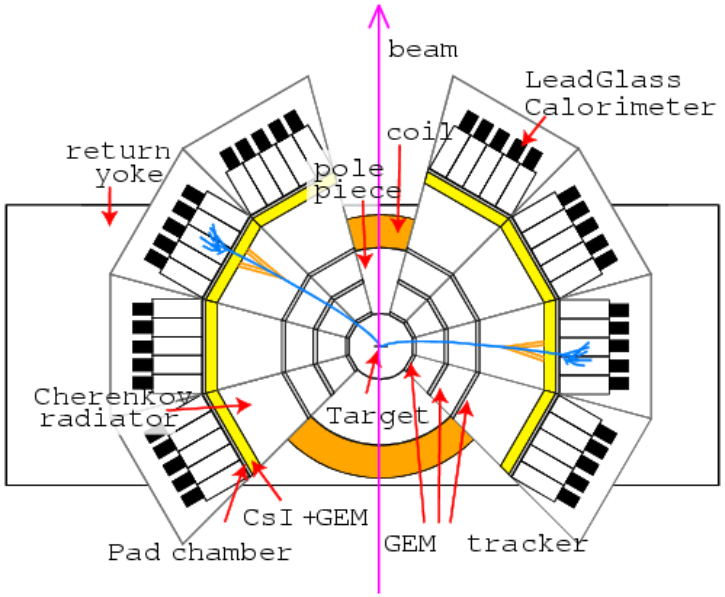
- (already funded ~ $ 0.15M)
  - 2007 -8:
    - prototype spectrometer module test/design finalize
- (budget dependent ~ $5M)
  - 2008-9 :
    - production start
  - 2009-10
    - spectrometer construction at the counter hall
  - 2011
    - ready for 30GeV proton beam





Cost estimation





Detector	element	description		cost [M Yen]
			cost[Yen] (/segment)	
GEM Tracker	Frame			50
	GEM foil ($10\times10[cm^2]$ foil)	20 k $\times$(1+4+9) $\times$3	820k	23 (1134 foils)
	readout strip board ($10\times10[cm^2]$)	100 k $\times$14	1.4M	38 (378 boards)
	electronics	3 k/ch $\times$(860 $\times$2)chs	5.2M	140 (46440 chs)
Cerenkov Counter	Frame			50
	GEM foil ($11\times11[cm^2]$)	20 k $\times$25 $\times$3	1.5M	41 (2025 foils)
	CsI coat	40 k $\times$25 foils	1M	27 (675 foils)
	readout pad board		500k	14
	electronics	3 k/ch $\times$460 chs	1.4M	38 (12420 chs)
Outside Tracker	Frame			20
	readout strip board		500k	14
	electronics	3 k/ch $\times$400 chs	1.2M	33 (10800 chs)
subtotal			13.5M	
EM Calorimeter	lead glass and PMT	reuse from TRISTAN/TOPAZ		0
	Frame			20
	electronics	3 k/ch		2 (650 chs)
Magnet	Return yoke	reuse from E325		0
		transfer from KEK		30
	Pole piece	modification		20
	Coil	repair		30
Total				590

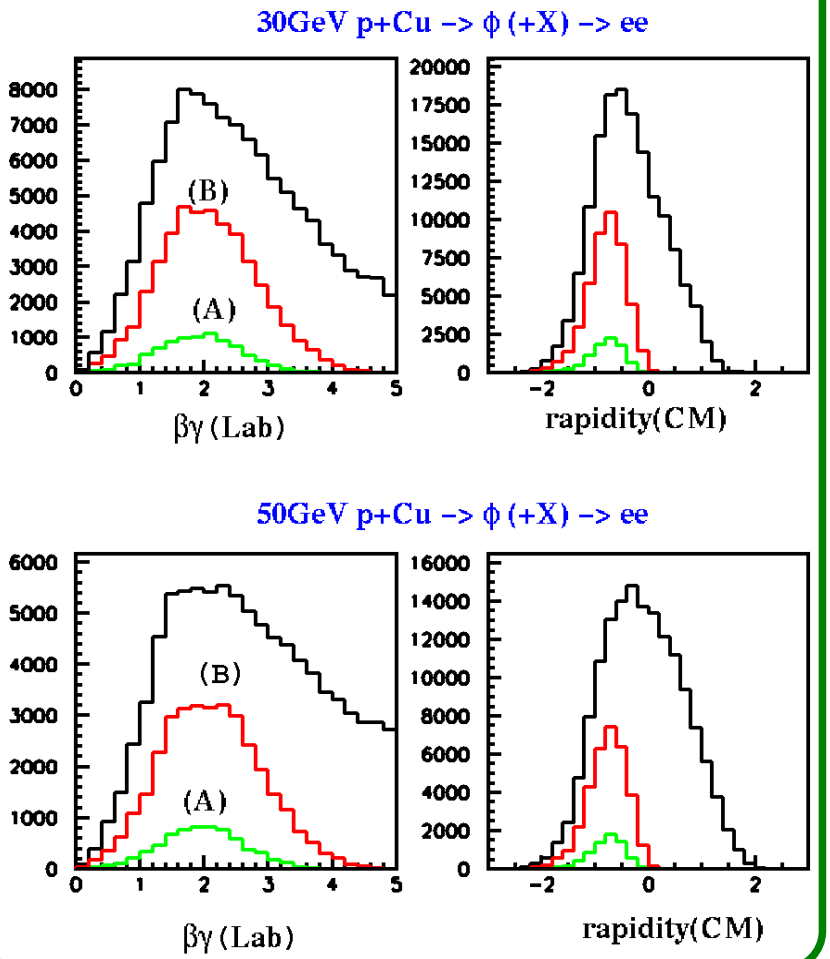
beam energy and spectrometer acceptance

A) Reuse of E325 spectrometer
B) Proposed larger acceptance spectrometer

expected ϕ yield for two options (using JAM)

beam energy		12 GeV	30 GeV	50 GeV
ϕ production CS (p+Cu)		1.0 mb	3.0 mb	5.1 mb
detector acceptance	case A	8.8%	6.0%	4.5%
	case B	45%	31%	23%
normalized yield by E325	case A	1	2.0	2.6
	case B	5.1	10.0	12.7

spectrometer acceptance $\phi \rightarrow e^+e^-$ (estimated by JAM)

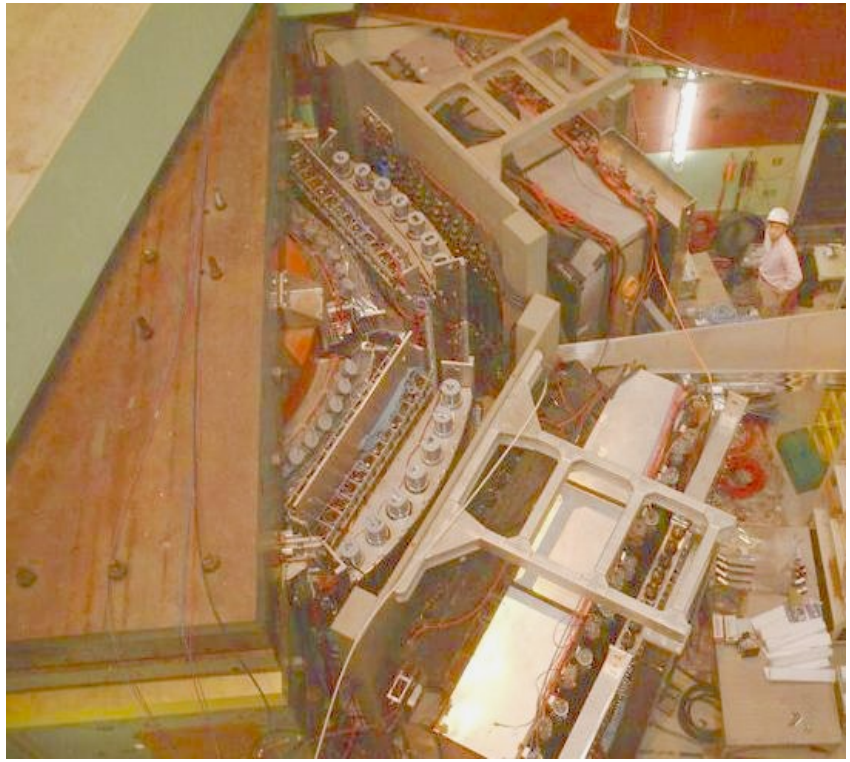


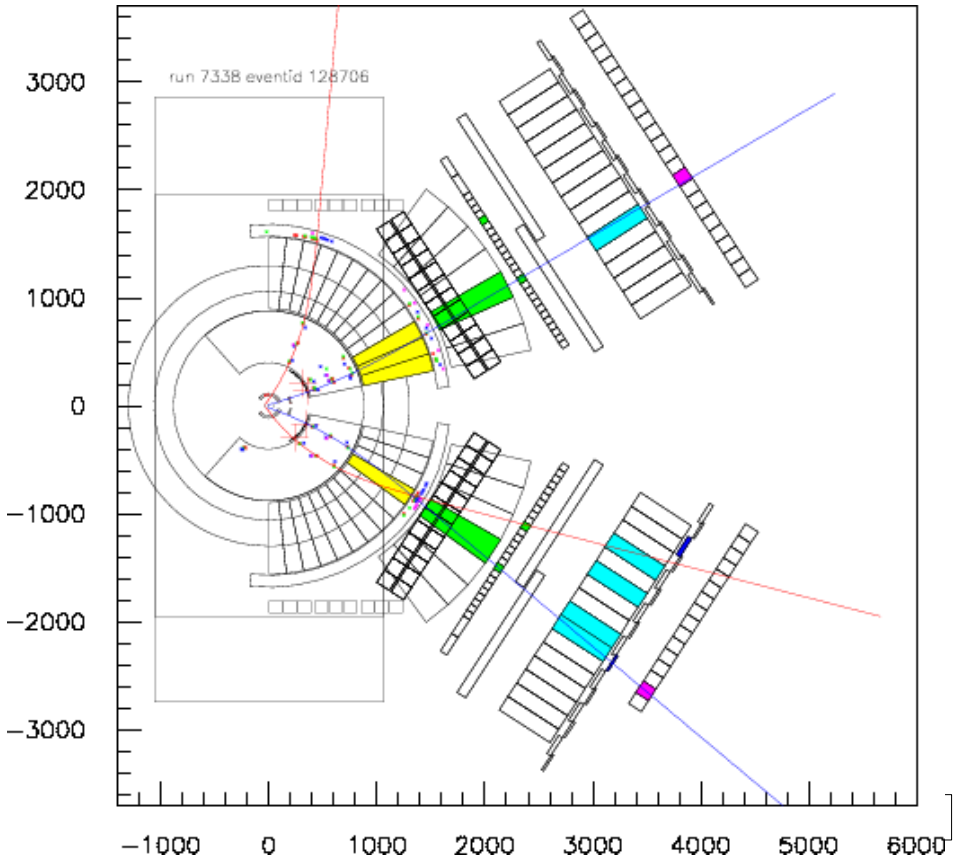
10 times can be collected by larger acceptance and beam energy (both 30 and 50 GeV are acceptable)

Further, for 10 times higher intensity beam (10^{10})
(i.e. high interaction rate : 10MHz)
to collect higher statistics (10^5 ϕ =100 times of E325),
new spectrometer is required.

KEK-PS E325

- to observe the vector meson modification in the cold nuclear matter at the normal nuclear density
- 12GeV p+C/Cu $\rightarrow \rho/\omega/\phi$ +X ($\rho/\omega/\phi \rightarrow e^+e^-$, $\phi \rightarrow K^+K^-$) , 1<p<3GeV/c for ϕ
- run 1997-2002





History of E325

- 1993 proposed
- 1994 R&D start
- 1996 construction start
- '97 data taking start
- '98 first ee data
  - PRL86(01)5019 ρ/ω (ee)
- 99,00,01,02....
  - x100 statistics
  - PRL96(06)092301 ρ/ω (ee)
  - PRC74(06)025201 α (ee)
  - PRL98(07)042501 φ (ee)
  - PRL98(07)152302 φ (KK),α
- '02 completed
- spectrometer paper
  - NIM A457(01)581
  - NIM A516(04)390

E325 spectrometer
located at KEK-PS EP1-B primary beam line