日本の核物理 / ハドロン物理の将来

Satoshi Yokkaichi
(RIKEN Nishina Center)

- Contents
  - 年表:どういう 20 年か
  -
  - Chiral symmetry around the normal nuclear density
    - この 5 年　：J-PARC E16,　mesic nuclei @RIKEN(π), @J-PARC(E26(ω), E29(ϕ), η),　LEPS　η'
  - QCD phase diagram and finite density QCD'
    - 5 年　　: HADES(SIS18)
    - 10-15 年 : FAIR SIS100 + HADES/CBM
  -

10 years?

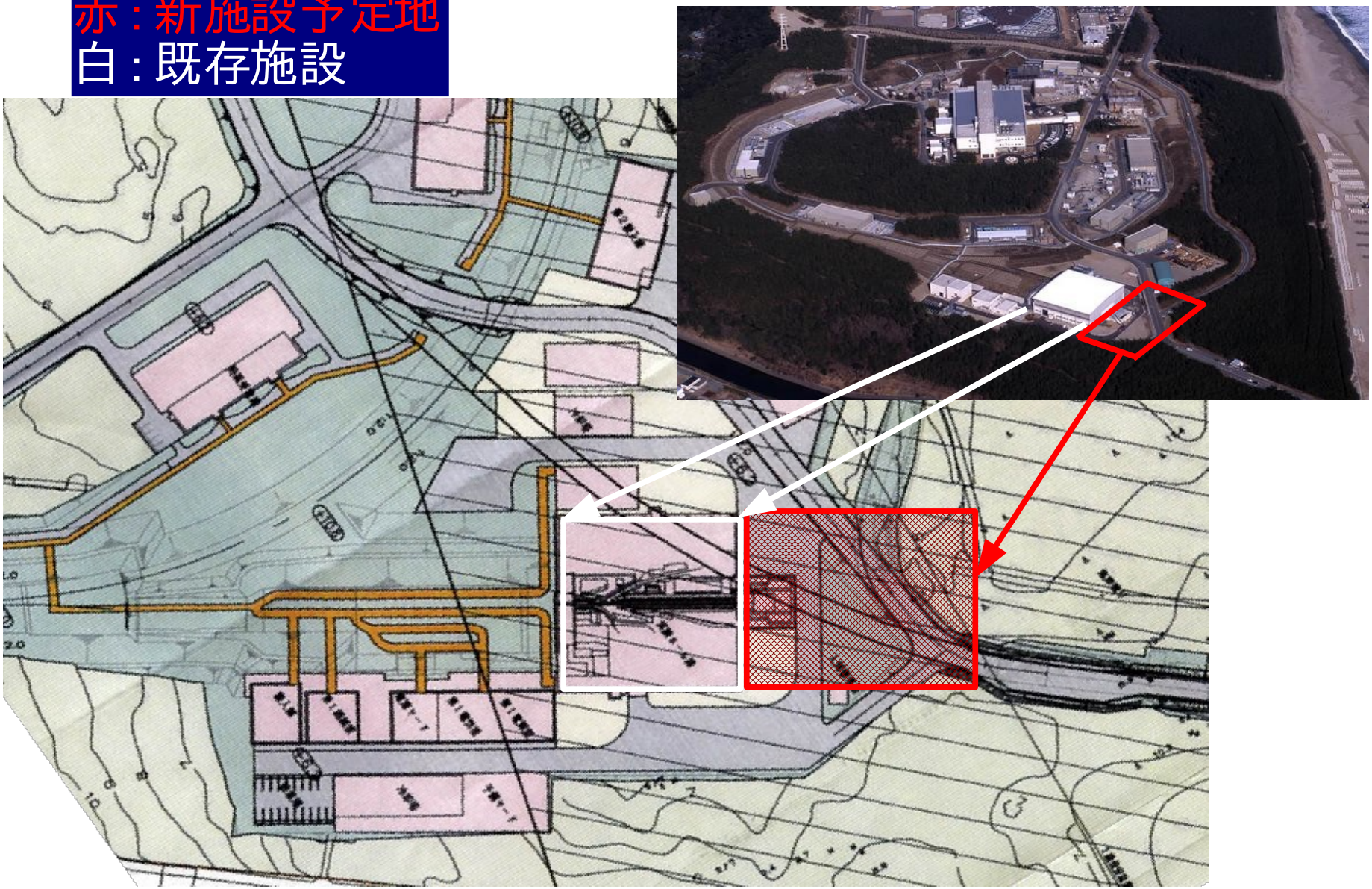
Now

2011-01-21															
						1	2	3	4	5	6	7	8	9	10
		理研2期						理研3期					理研4期		
		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
		H20	H21	H22	H23	H24	H25	H26	H27	H28	H29	H30	H31	H32	
E		51	52	53	54	55	56	57	58	59	60	61	62	63	
Y		41	42	43	44	45	46	47	48	49	50	51	52	53	
				D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	
S		32	33	34	35	36	37	38	39	40	41	42	43	44	
J-PARC hadron			1	2	3	4	5	6	7	8	9	10	11	12	
RJC plan						1	1	2	3	4	5	1	2	3	
RHIC PHENIX		8	9	10	11	12	13	14	15	16					
eRHIC												1?	2	3	
BNL MOU															
LHC ALICE				1	2	3	4	5	6	7	8	9	10	11	
GSI FAIR										1	2	3	4	5	
E16						0	1	2							
				M1	M2	D1	2	3	4	5	6	7	8	9	

HWG 2011Jan12 S.Yokkaichi

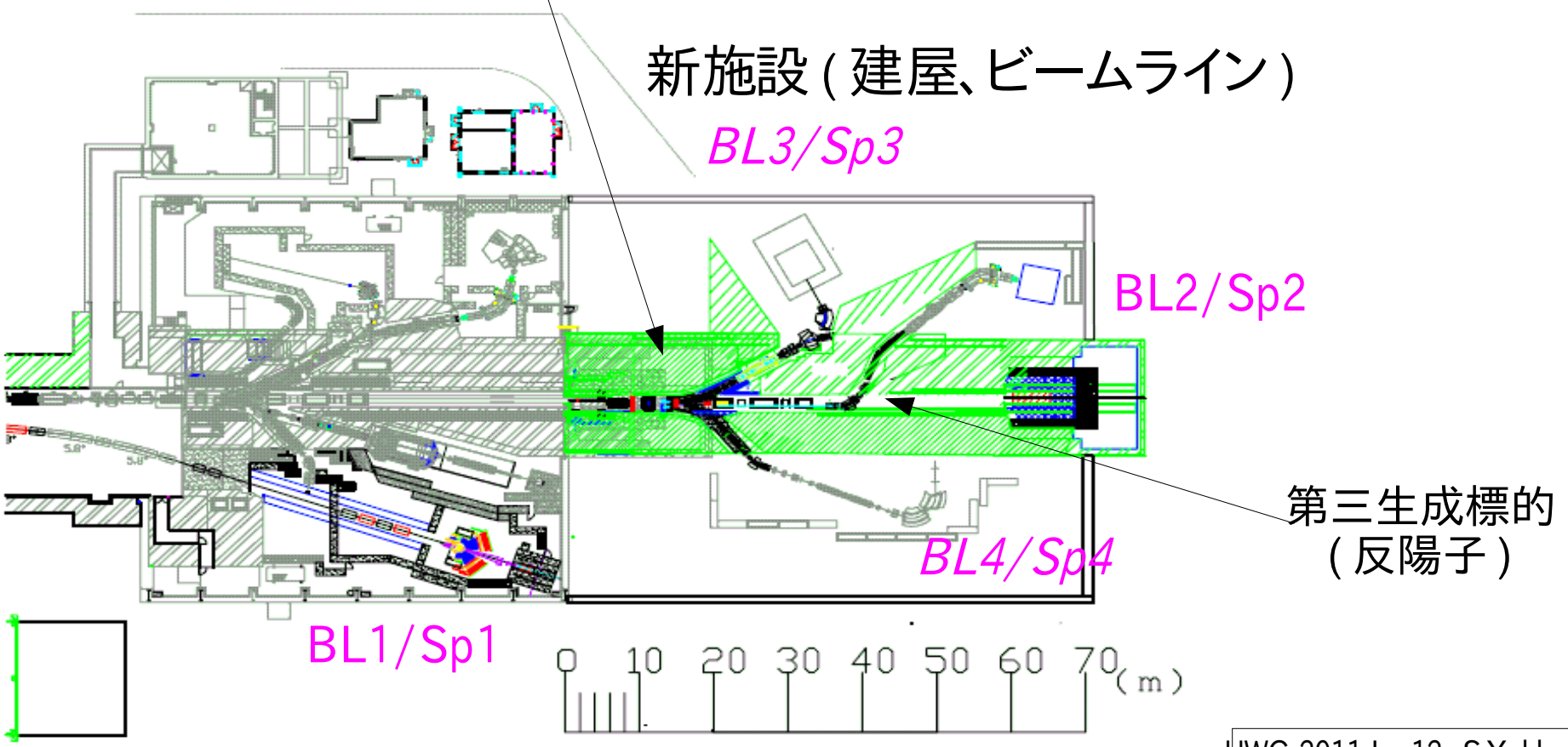
RJC： 新施設建設予定地

赤：新施設予定地
白：既存施設



新実験施設概要図

BL1: High-p 理研
BL2: 反陽子 理研
BL3: 低運動量K 阪大
BL4: 分散整合 阪大



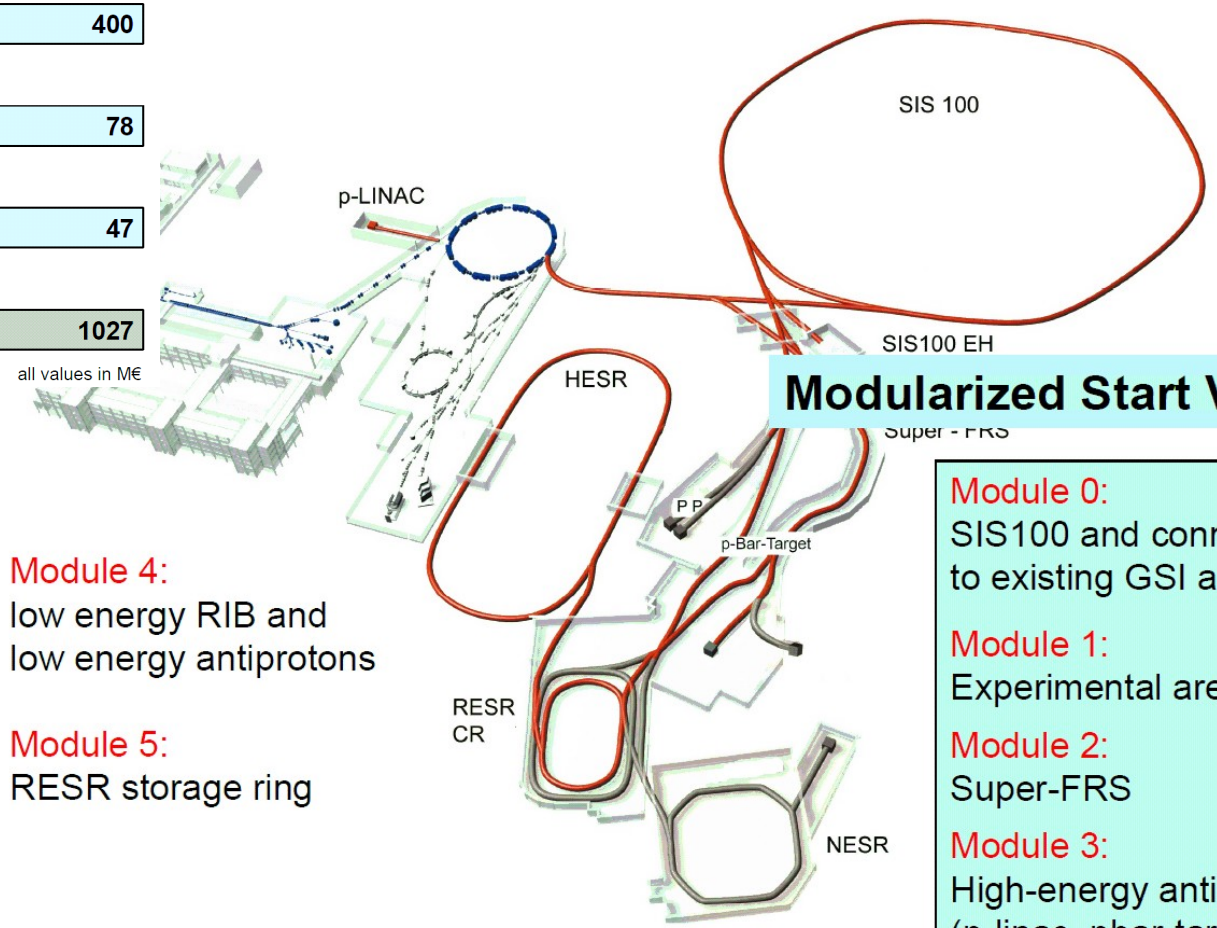
FAIR (slide @ 2010Apr)

Cost Estimate Modules 0-3 (Price Basis 2005)

Total accelerator and personnel Modules 0 - 3	502
Total civil construction Modules 0 - 3	400
Experiment funding	78
FAIR GmbH personnel and running costs	47
Grand Total Modules 0 - 3	1027

all values in M€

Module	Construction time (months)	Ready for installation	
0	72	2015 / 16	+1 year
1	28	2015 / 16	+1 year
2	60	2016	
3	60	2016	+1 year



Modularized Start Version

Module 4:
low energy RIB and
low energy antiprotons

Module 5:
RESR storage ring

Module 0:
SIS100 and connection to existing GSI accel.

Module 1:
Experimental areas

Module 2:
Super-FRS

Module 3:
High-energy antiprotons (p-linac, pbar-target, CR, HESR)

- HADES/CBM : 2016/17 installation start

SIS100 (slide @ 2009Oct, K.Sugita, GSI)

- 陽子加速器として比較

	GSI SIS100	J-PARC 50GeV Main ring
Circumference	1083.6 m	1567.5 m
Injection	2.7 GeV	3 GeV
Extraction	29 GeV	50 GeV
Particles/pulse	2.5×10^{13}	3.3×10^{14}
Repetition	0.2 Hz (1 Hz for U)	0.3 Hz
Bending radius	52.632 m	89.831 m
Magnetic field	1.9 T	1.9 T
Magnetic rigidity	100 Tm	170 Tm

27 October 2009 Seminar KEK Cryogenics Science Center 8

20 years?

Now

2011-01-21																												
						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
		理研2期						理研3期					理研4期					理研5期					理研6期					
		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	
		H20	H21	H22	H23	H24	H25	H26	H27	H28	H29	H30	H31	H32	H33	H34	H35	H36	H37	H38	H39	H40	H41	H42	H43	H44	
E		51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	
Y		41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	
				D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30	D31	D32	D33	D34	D35	D36						
S		32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	
J-PARC hadron			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
RJC plan						1	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
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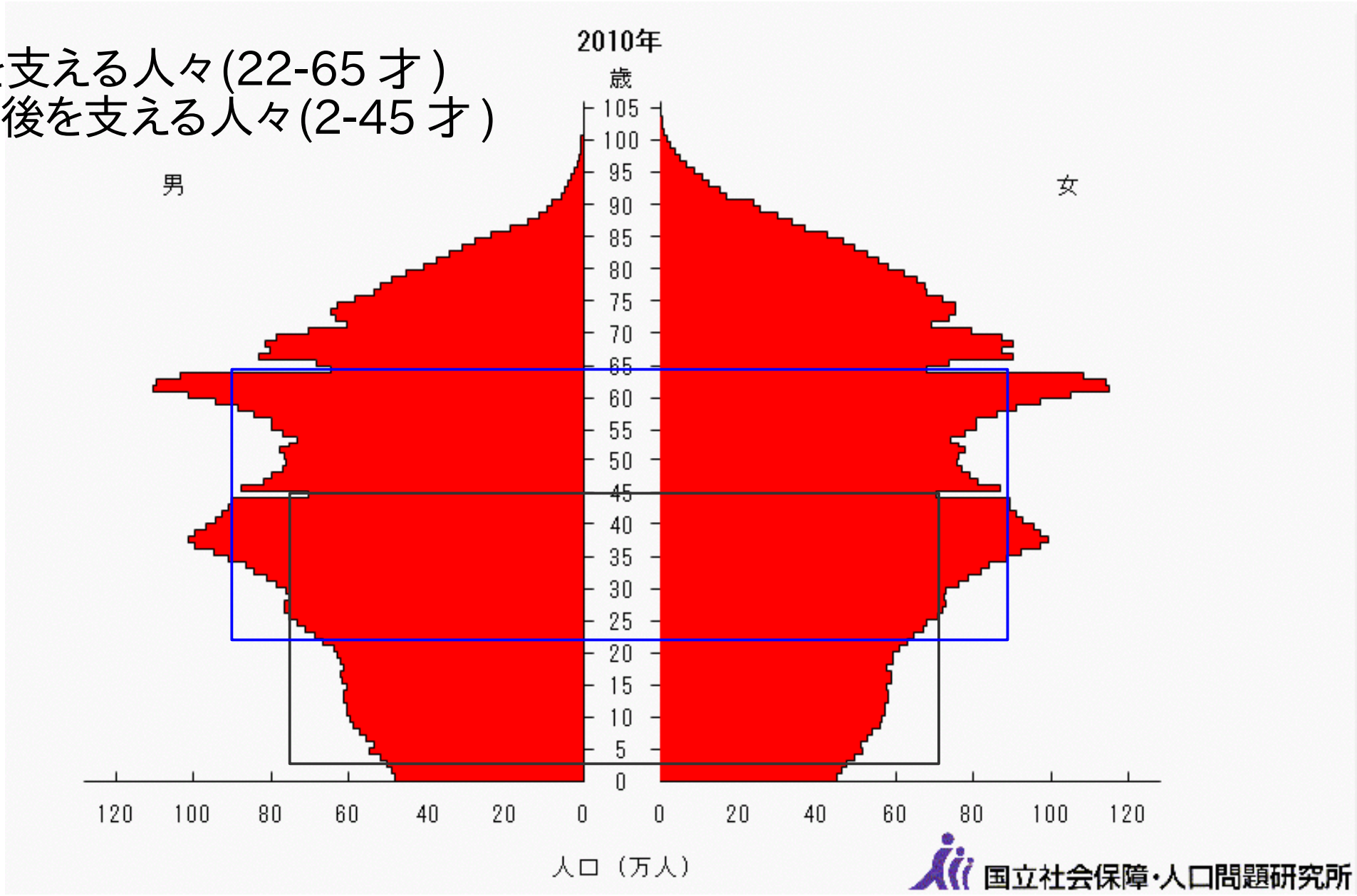
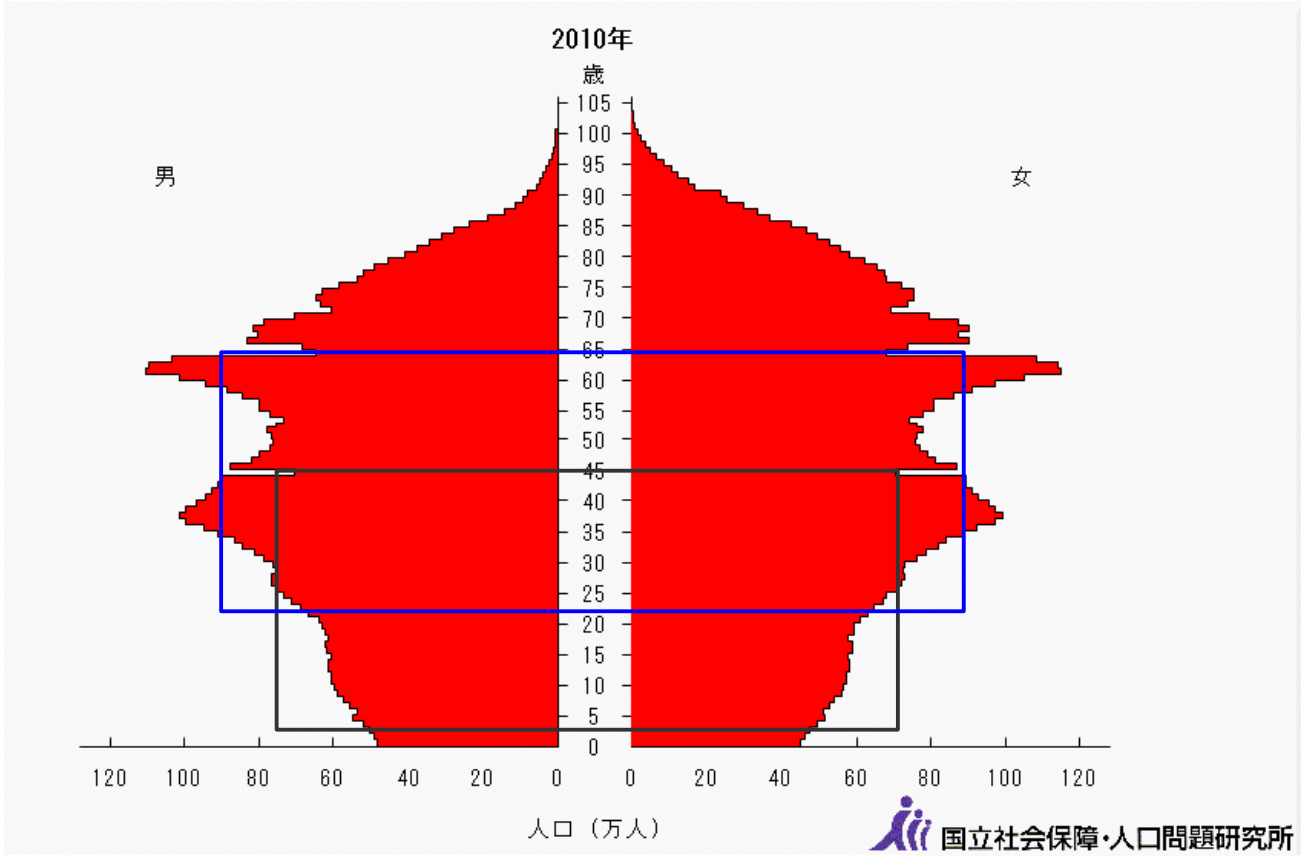
GSI FAIR										1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
E16						0	1	2																			
				M1	M2	D1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19			
日本の人口(推計)				125M					123M					120M					115M					111M			
15ー64才(推計)				80M					76M					72M					69M					66M			
27才人口(max)			1.48	1.49	1.49	1.46	1.41	1.39	1.35	1.30	1.25	1.22	1.21	1.19	1.21	1.21	1.18	1.19	1.19	1.18	1.18	1.16	1.15	1.11	1.09		
22才人口(max)			1.39	1.35	1.3	1.25	1.22	1.21	1.19	1.21	1.21	1.18	1.19	1.19	1.18	1.18	1.16	1.15	1.11	1.09	1.05	1.07	1.08	1.09	1.08		
(年齢@2009)			22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0		

20 年後には人口の母集団 (労働人口、新 M1 、新博士) が 2 割減少
でもまあ 40 年前と同じくらい？

いまを支える人々(22-65 才)
20 年後を支える人々(2-45 才)

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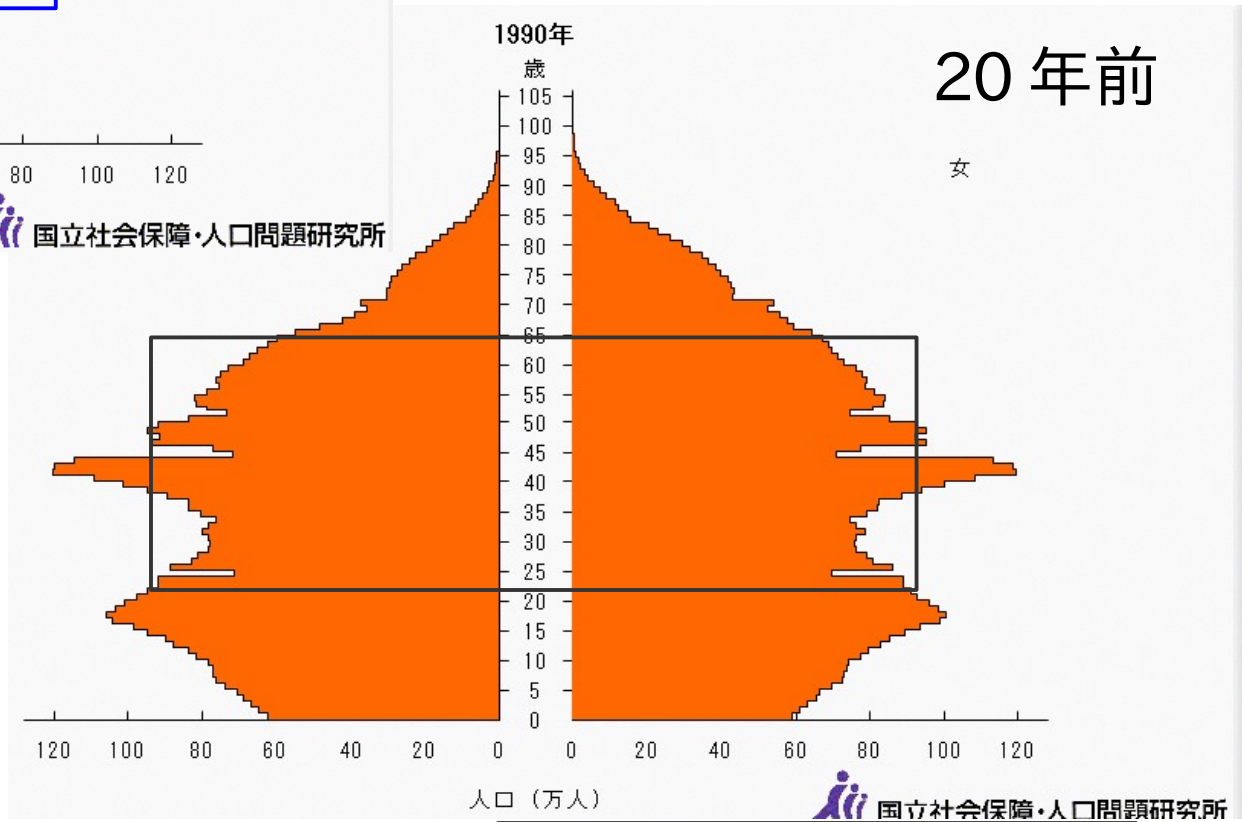
人口（万人）
国立社会保障・人口問題研究所

20 年前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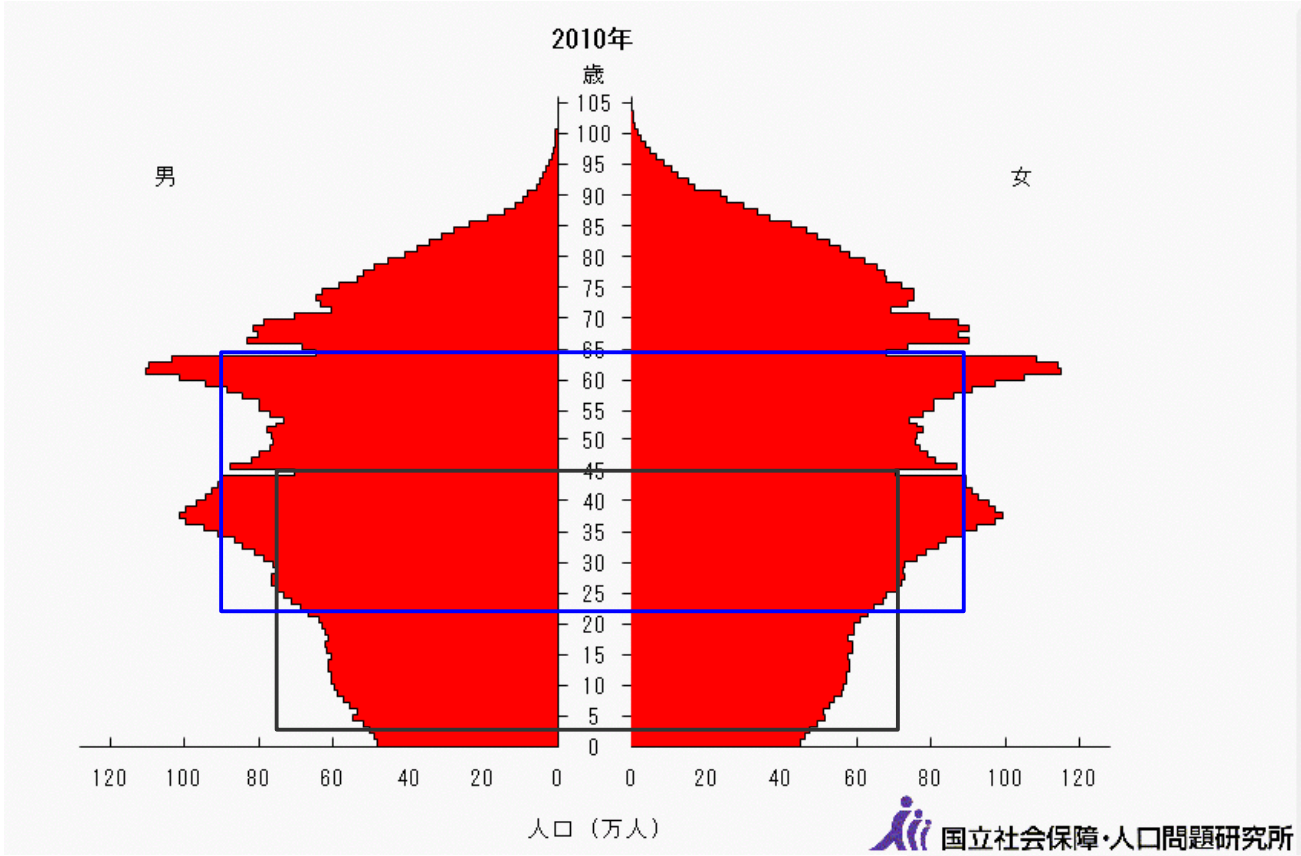
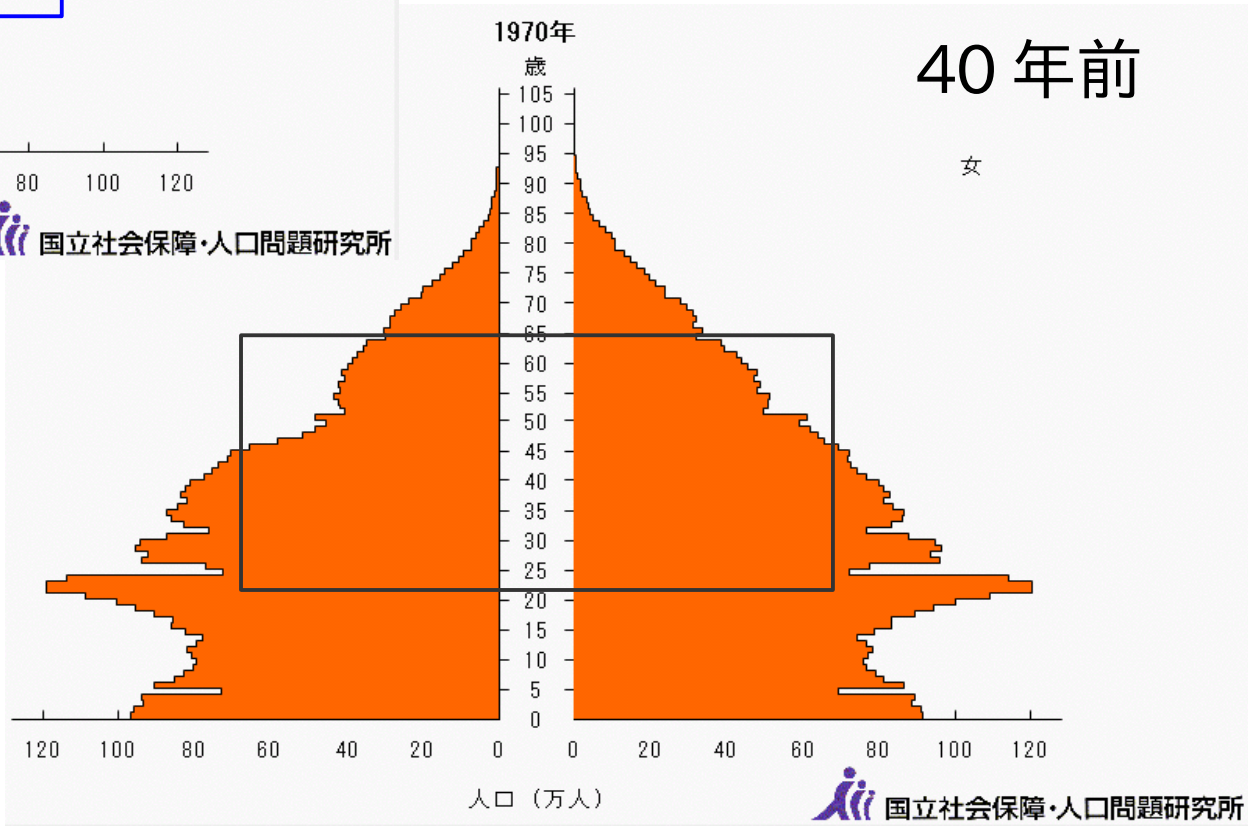
人口（万人）
国立社会保障・人口問題研究所



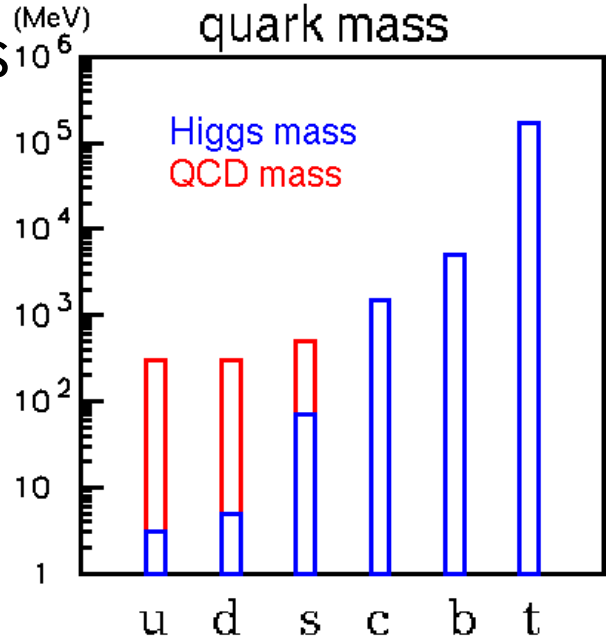


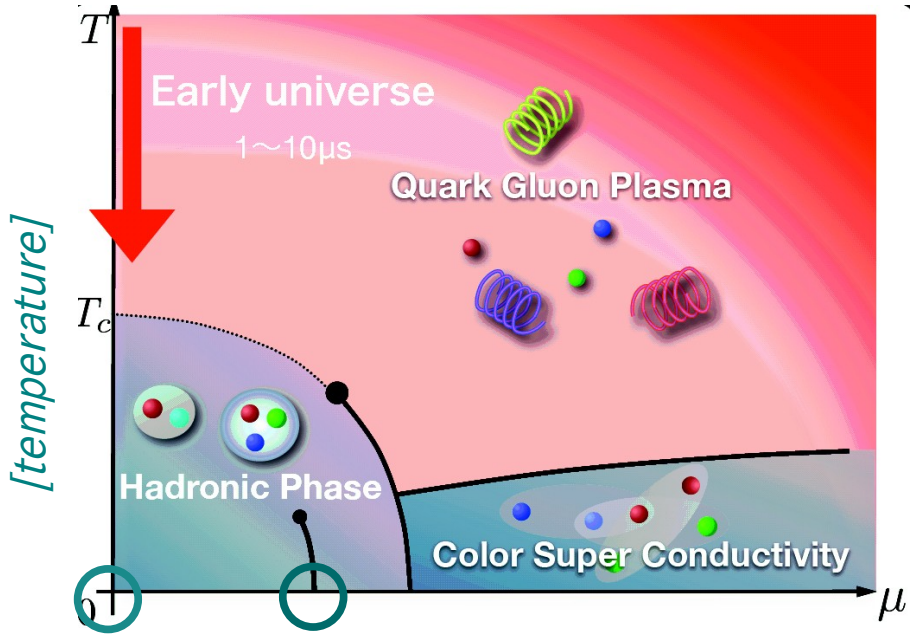
40 年前

HWG 2011Jan12 S.Yokkaichi

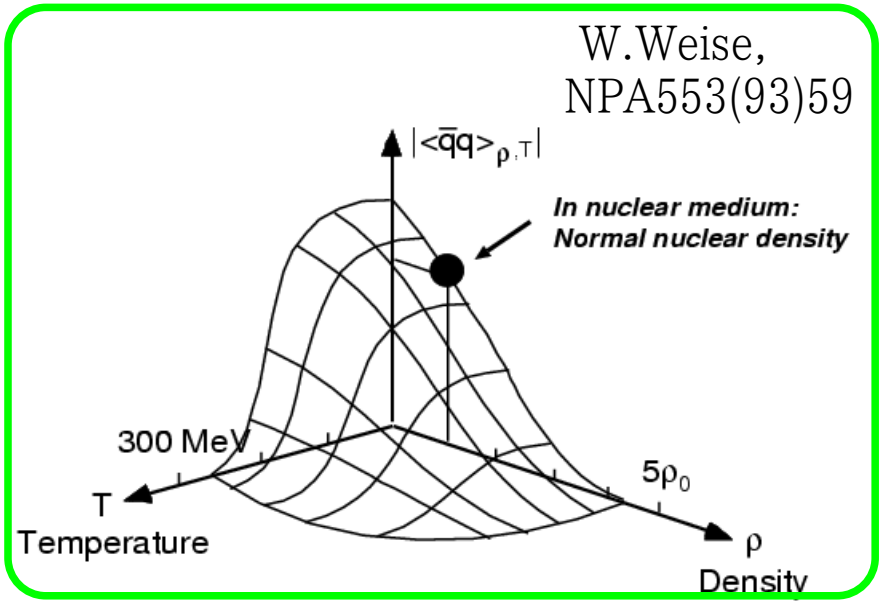
Mass and chiral symmetry in nuclear matter

- Origin of quark and 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...





vacuum normal nuclear density *[density]*



Vector meson mass spectra in dense matter

Bronwn-Rho scaling
PRL 66(91)2720, etc

$$m_\rho^*/m_\rho \sim (\langle\bar{q}q\rangle^*/\langle\bar{q}q\rangle)^{1/2}$$

effective Lagrangian (chiral SU(3)+VMD)
Klingle,Kaiser,Weise,
NPA 624(97)527

QCD sum rule
Hatsuda and Lee, PRC 46(92)R34, PRC 52(95)3364

linear dependence on density

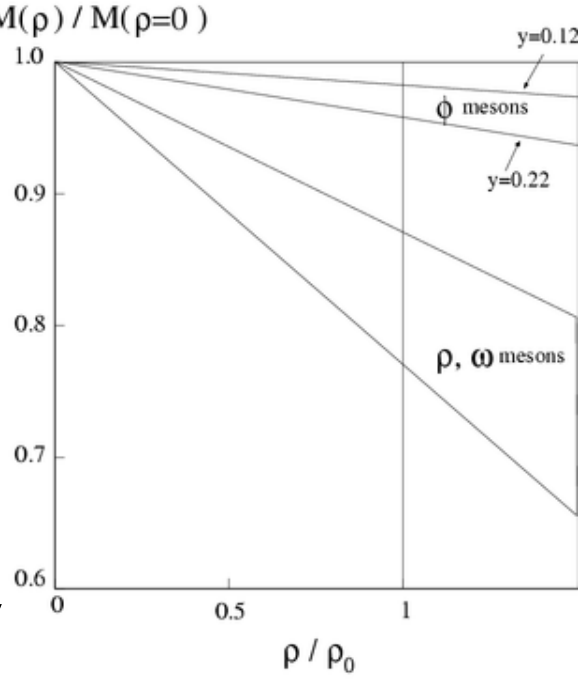
$m^*/m_0 = 1 - k\ \rho/\rho_0$

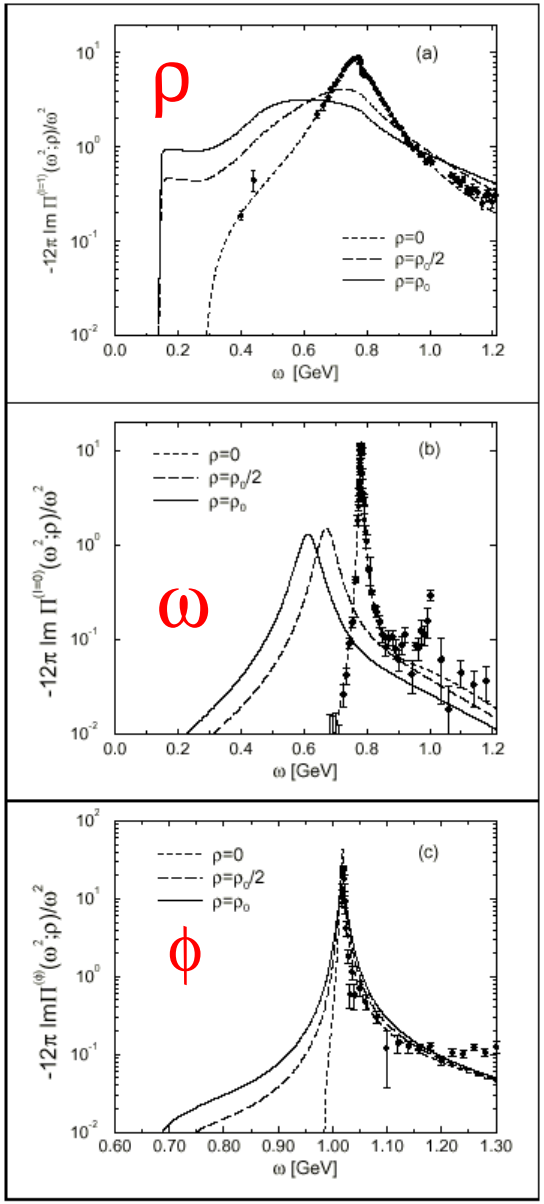
mass 'dropping'

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

for y=0.22

at the normal nuclear density





Vector meson measurements in the world

dilepton measurement

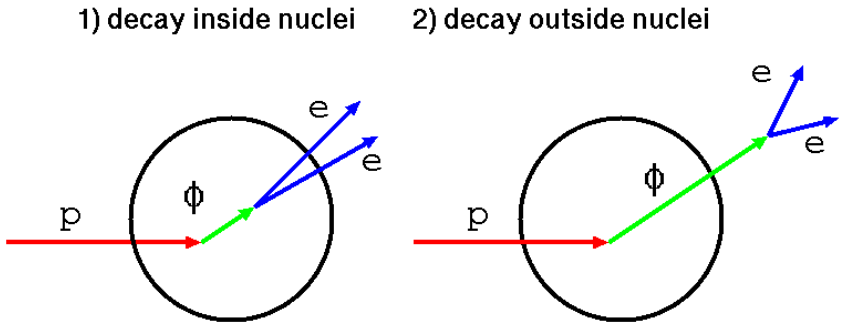
- HELIOS/3 (ee, μμ) 450GeV p+Be / 200GeV A+A
- DLS (ee) 1 GeV A+A
- CERES (ee) 450GeV p+Be/Au / 40-200GeV A+A
- E325 (ee,KK) 12GeV p+C/Cu
- NA60 (μμ) 400GeV p+A/158GeV In+In
- PHENIX (ee,KK) p+p/Au+Au
- HADES (*) (ee) 4.5GeV p+A/ 1-2GeV A+A
- CLAS-G7 (*) (ee) 1~2 GeV γ+A
- *J-PARC E16* (ee) 30/50GeV p+A / ~20GeV A+A ?
- *CBM/FAIR* (ee) 20~30GeV A+A

published/ 'modified'
published/ 'unmodified'
running/in analysis
future plan
as of 2010/Dec

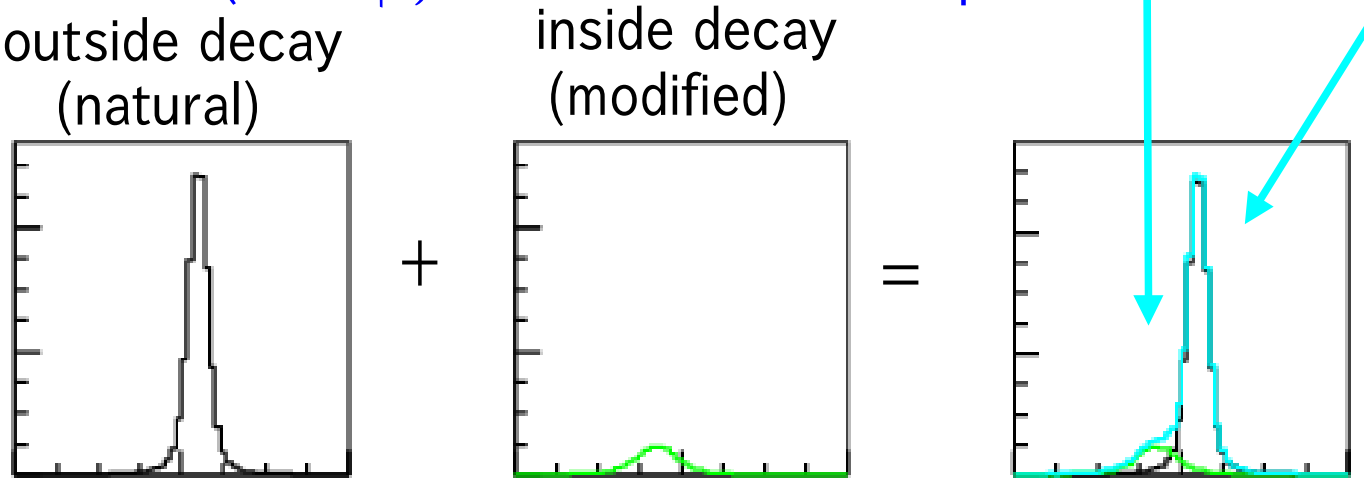
- TAGX (ππ) ~1 GeV γ+A
- STAR (ππ,KK) p+p/Au+Au
- LEPS (KK) 1.5~2.4 GeV γ+A
- CBELSA/TAPS(*) ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/Nb

Expected Invariant mass spectra in e^+e^-

- smaller FSI in e^+e^- decay channel
- double peak (or tail-like) structure :
  - second peak is made by inside-nucleus decay (modified meson) : amount depend on the nuclear size and meson velocity
    - could be enhanced for slower mesons & larger nuclei



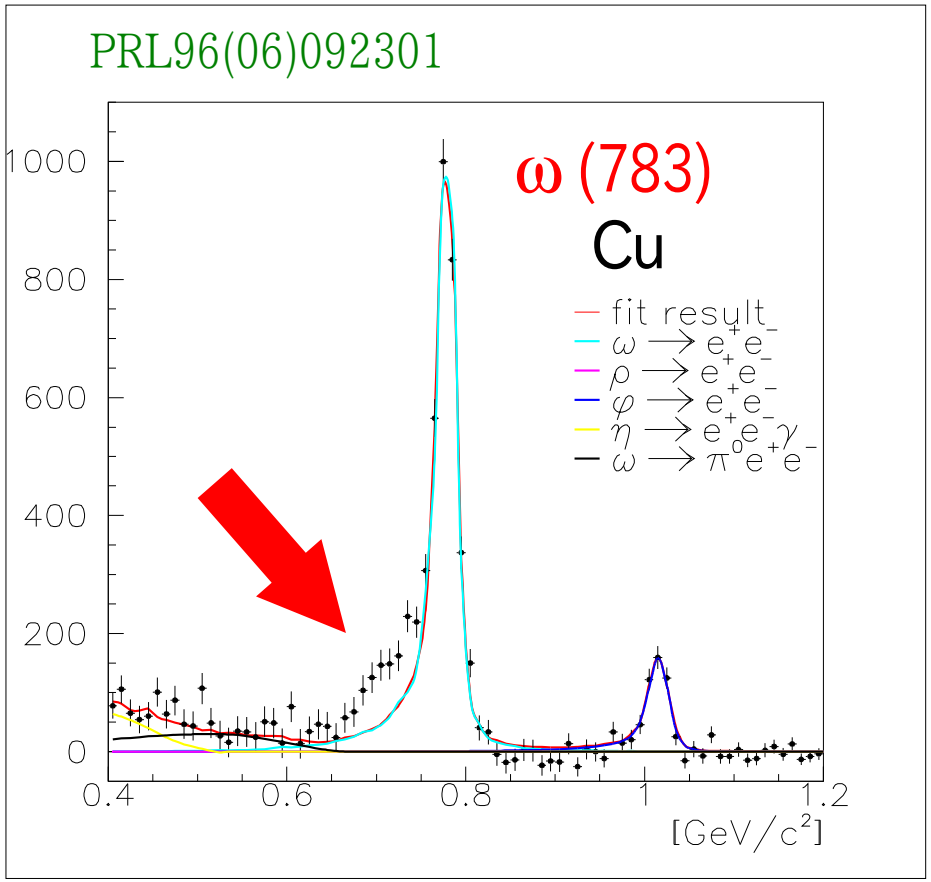
longer-life meson(ω & ϕ)cases : Schematic picture

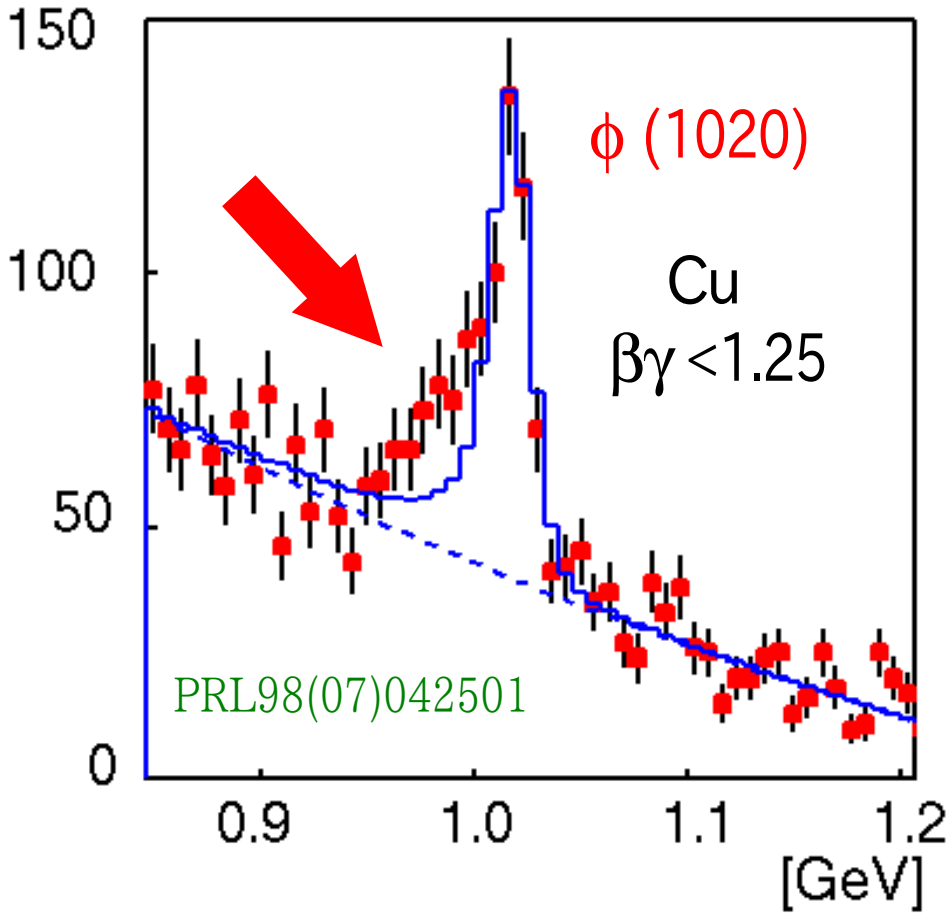


expected to be observed

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





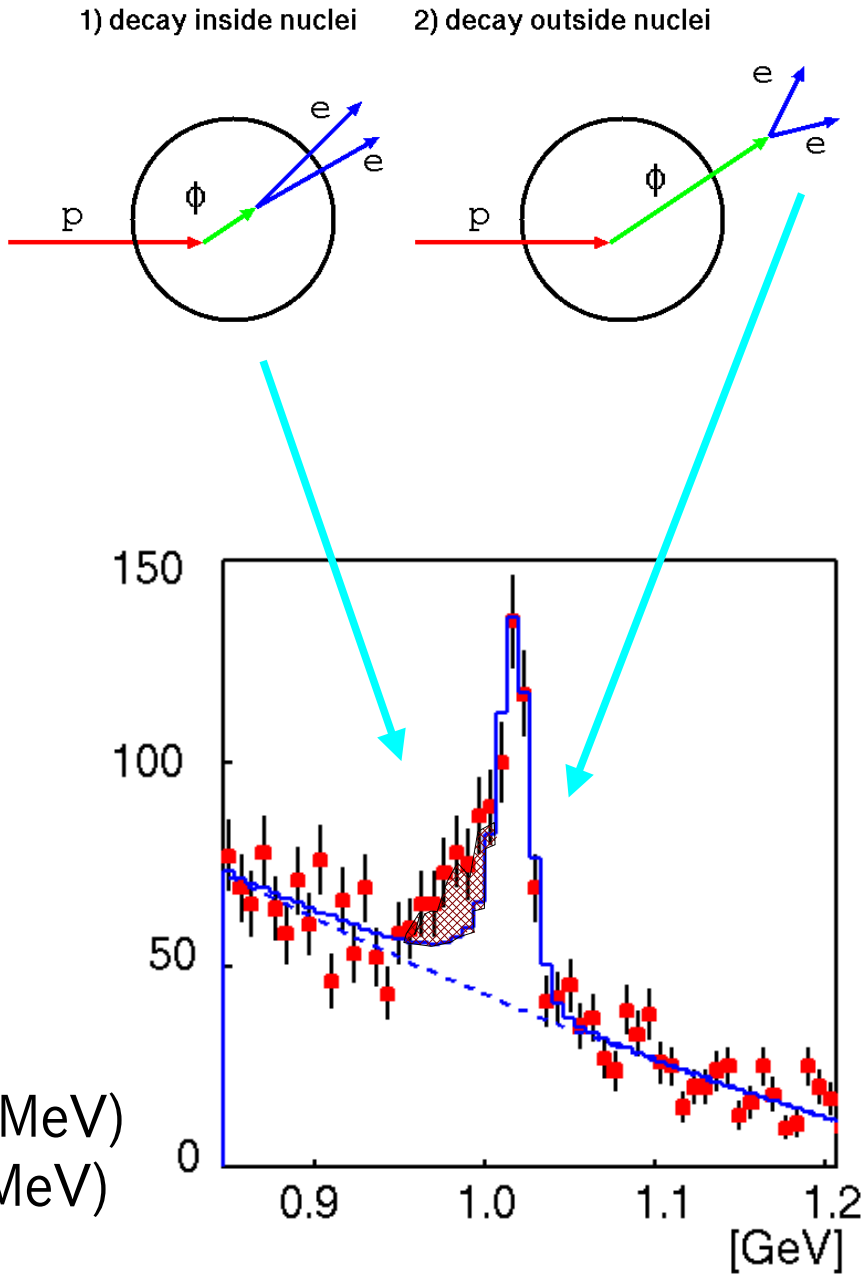
Discussion : modification parameters

- MC type model analysis to include the nuclear size/meson velocity effects
  - generation point : uniform for ϕ meson
    - from the 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 result with the predictions by Hatsuda & Lee (k_1) , Oset & Lamos (Γ)

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

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

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



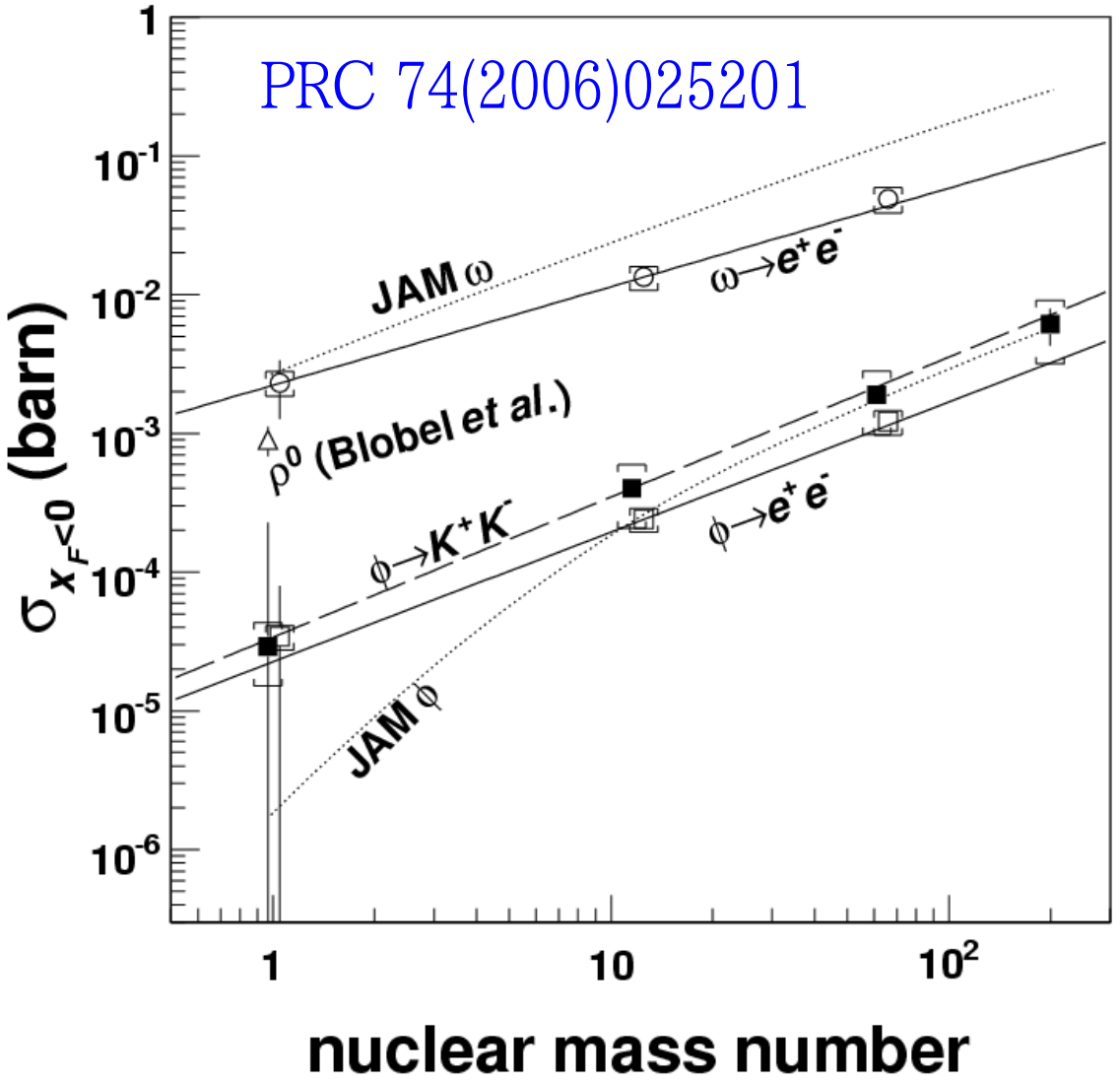
Recent status in the world

- mass modification of vector mesons in nuclear matter exist (E325/CLAS-G7/(TAPS) at the lower energy, NA60/CERES/PHENIX in HI collision)
  - interpretations are not converged
    - mass dropping and/or width broadening?
    - interpretation model dependence ?
      - space-time evolution of the (T, ρ) of matter in the real world
  - physics
    - hadronic many-body effect? chiral symmetry restoration?
- Next step in the invariant-mass approach
  - $\phi \rightarrow e^+e^-$: less uncertain than the ρ/ω case
    - ρ's broad and complicated shape, ρ–ω interference, ρ/ω ratio, etc.
  - systematic study of the mass modification
    - matter-size dependence: larger/smaller nuclei, impact parameter
    - momentum dependence : never measured
  - check the interpretation models

meson production cross sections:E325

- values for the CM backward
- consistent w/ the former measurement for ρ meson by Blobel (PLB48(1974)73)
- Nuclear dependence α_ϕ = 0.937 corresponds to about $\sigma_{\phi N}$=3.7mb (cf. Sibirtsev et.al. EPJA 37(2008)287)

  additional Γ=12 MeV for 2 GeV/c ϕ (β=0.9) : consistent with Γ=16 MeV (i.e. k_2=2.6)
- Remark: Γ_ϕ =16MeV at m_ϕ=985MeV is consistent with Oset & Ramos et.al (NPA679(2001)616)



J-PARC E16 experiment

Systematic study of the modification of vector meson spectra in nuclei to approach the chiral symmetry restoration

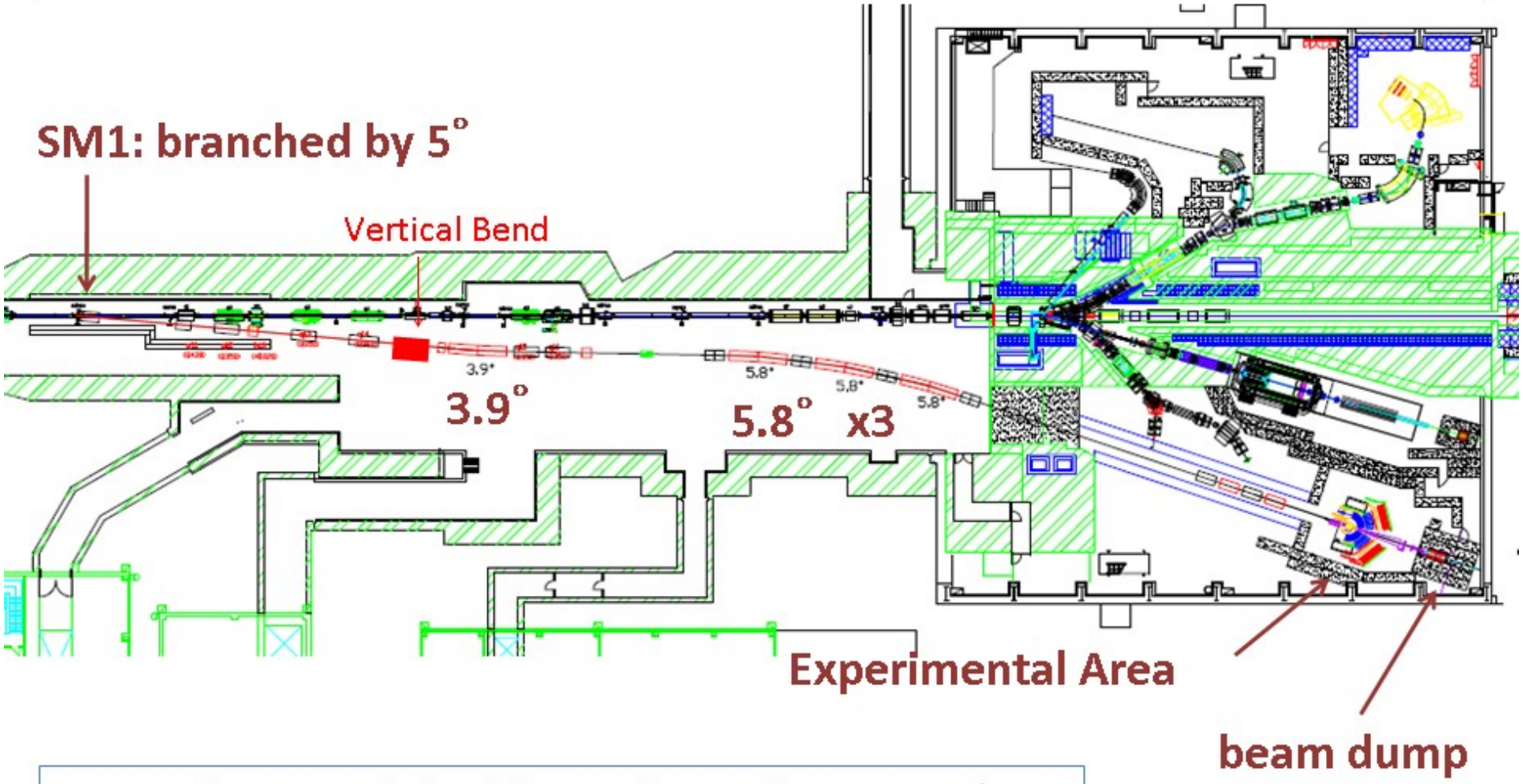
Collaboration

RIKEN S.Yokkaichi, H. En'yo, F. Sakuma, K. Aoki, J. Kanaya
U-Tokyo K. Ozawa, K. Utsunomiya, Y. Watanabe, Y.Komatsu, S.Masumoto
CNS, U-Tokyo H. Hamagaki Hiroshima-U K. Shigaki
KEK A.Kiyomichi, M. Naruki, R. Muto, S. Sawada, M. Sekimoto

Proposal http://ribf.riken.jp/~yokkaich/paper/jparc-proposal-0604.pdf

Scientific approval : 2007/3
... Detector R&D ...
Ready for beam : 2012/autumn

Location of E16 : High-momentum beam line



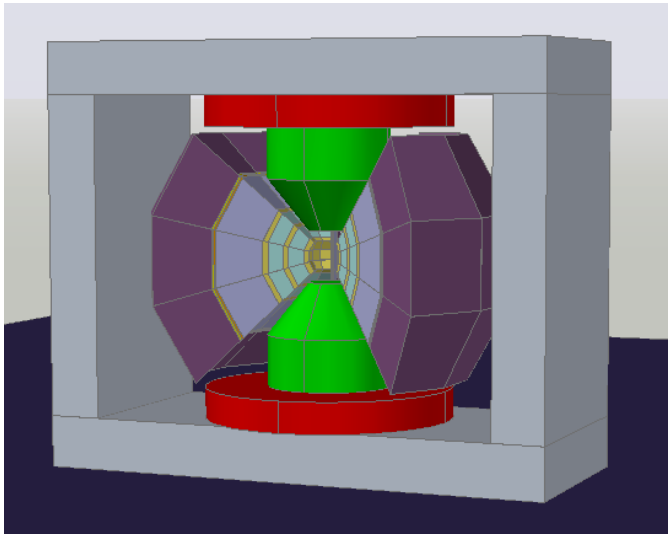
Beam dump and shields are for 10^{10} protons/s

by R. Muto

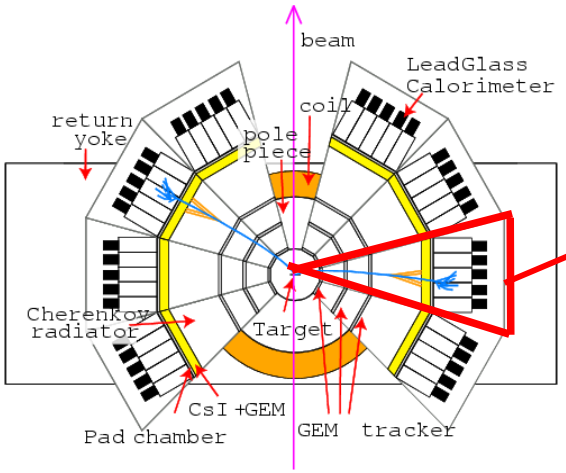
To collect high statistics

- 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)

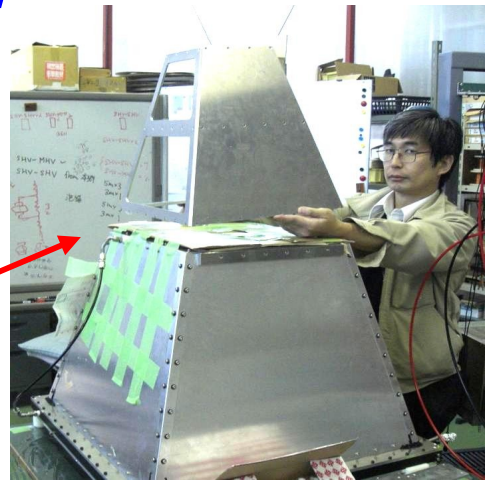
Proposed Spectrometer



Plan View



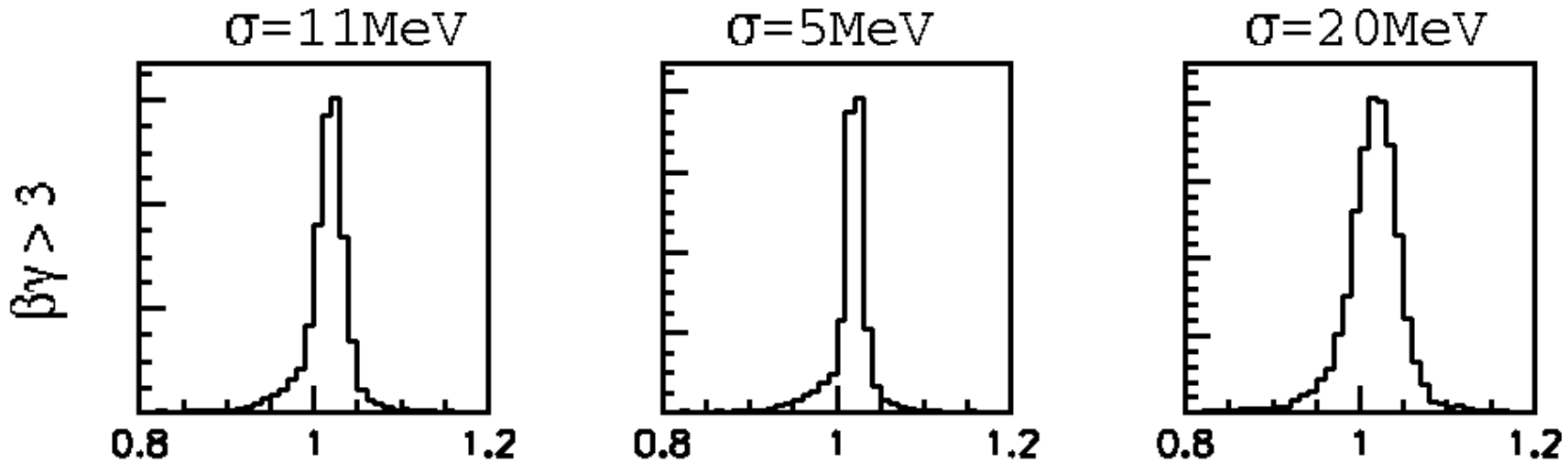
Prototype Module



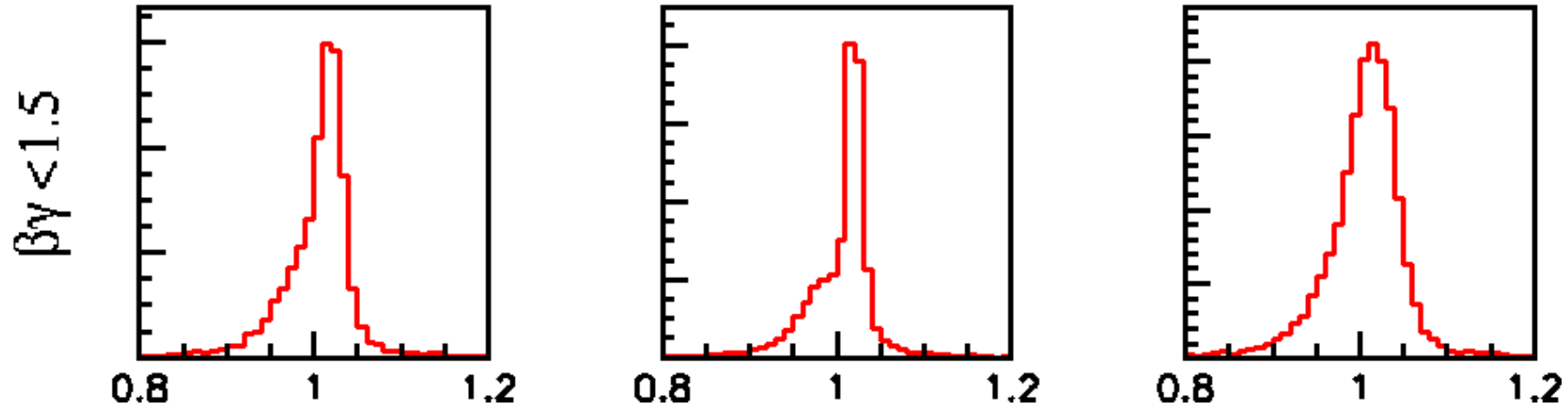
mass resolution requirement

- mass resolution should be kept less than ~10MeV

Fast



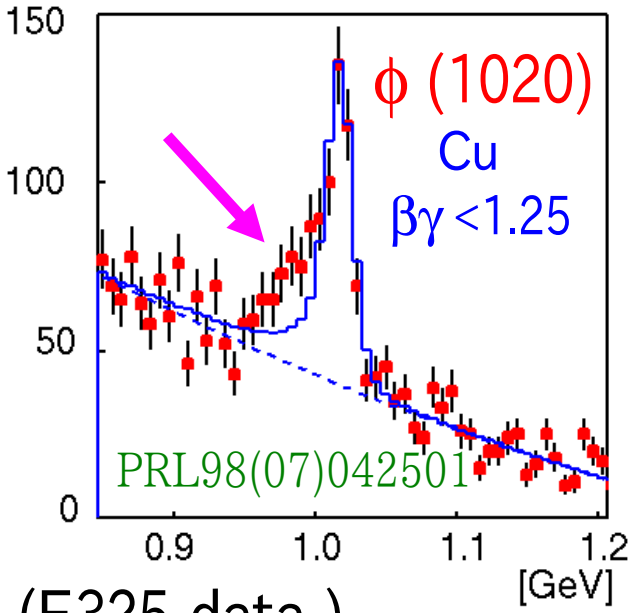
Slow



(model calc. for the Cu target)

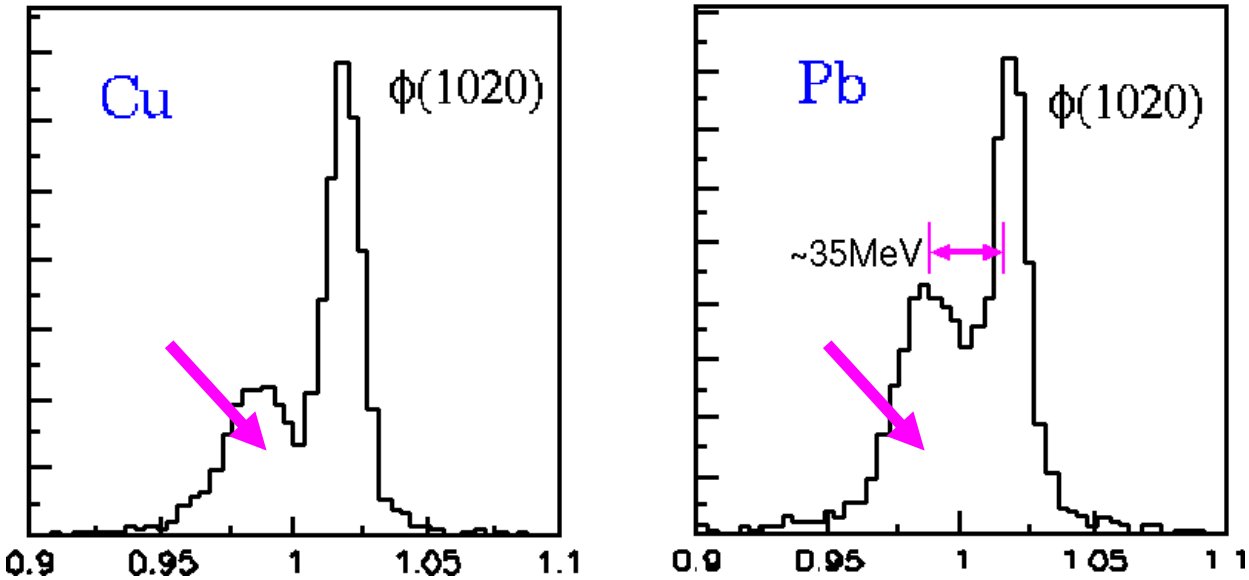
mass resolution requirement

- mass resolution should be kept less than ~10MeV
- Very ideal case : very slow mesons w/ best mass resolution:



(E325 data)

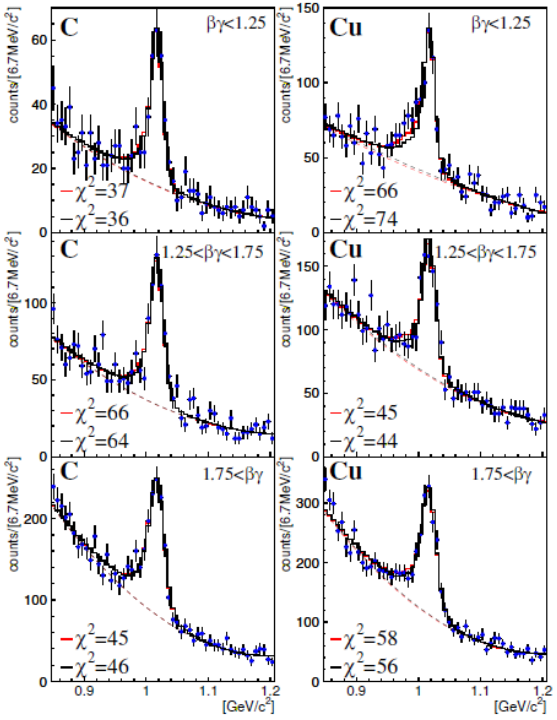
βγ<0.5, σ=5 MeV

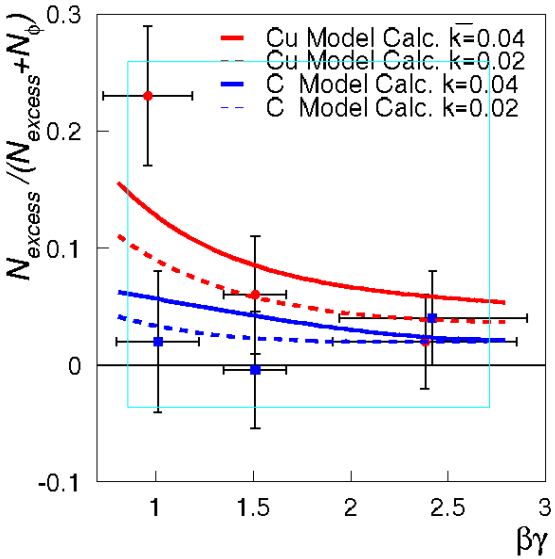


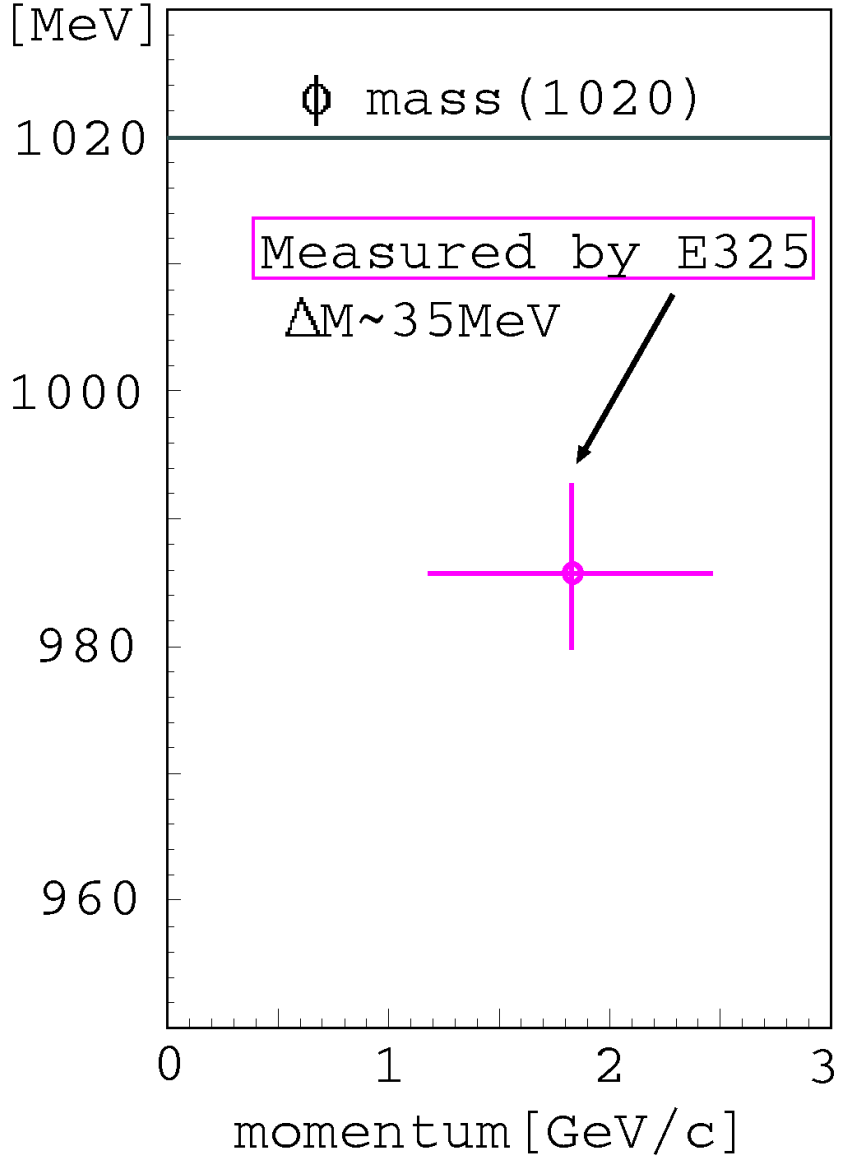
(model calc.)

dispersion relation (mass VS momentum)

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

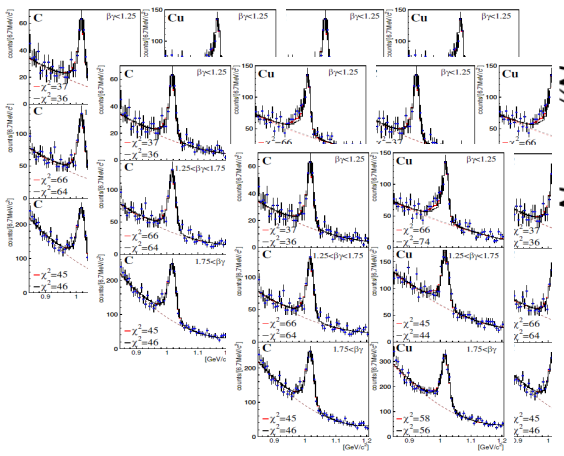


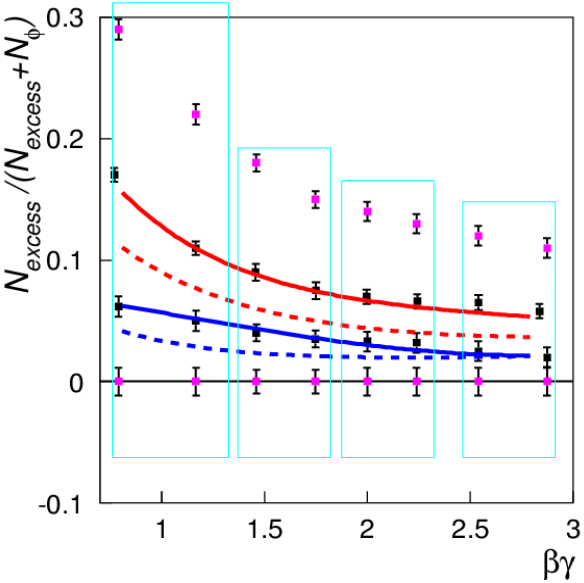


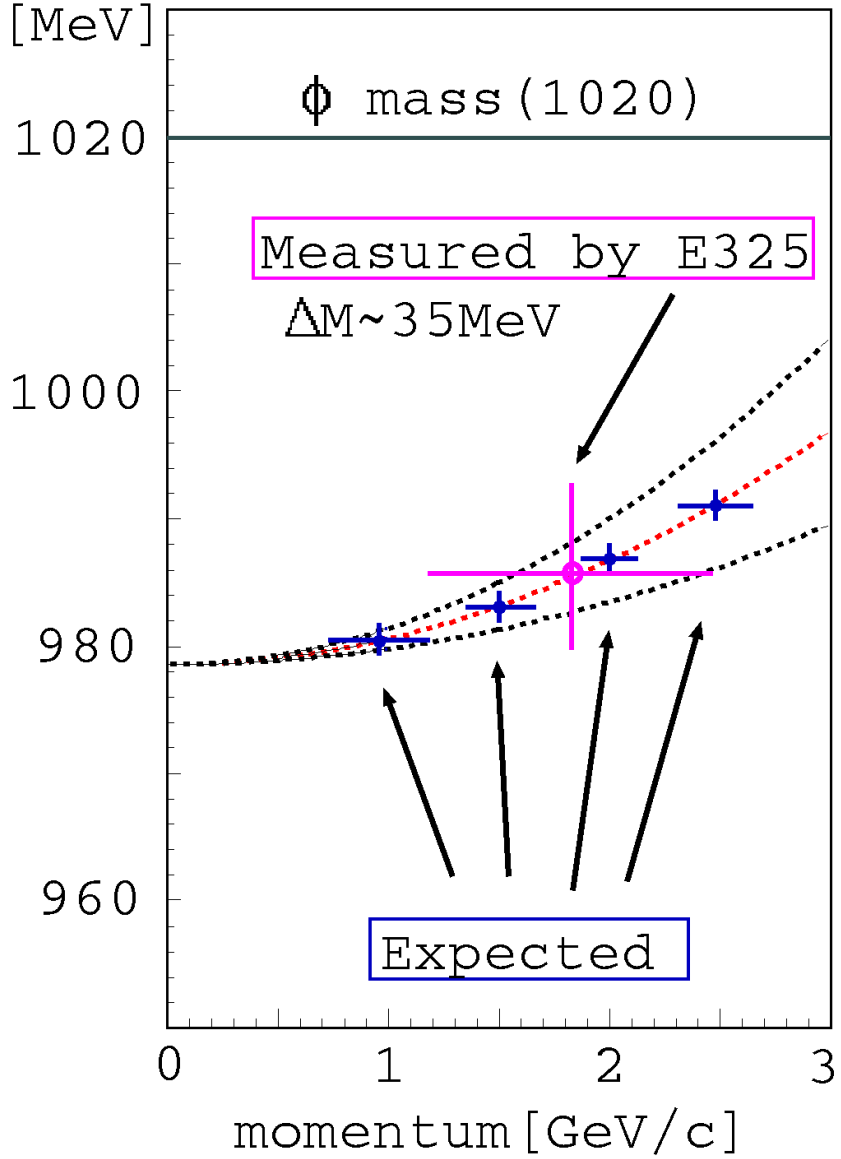


dispersion relation (mass VS momentum)

- prediction for ϕ by S.H.Lee(p<1GeV/c)
- 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



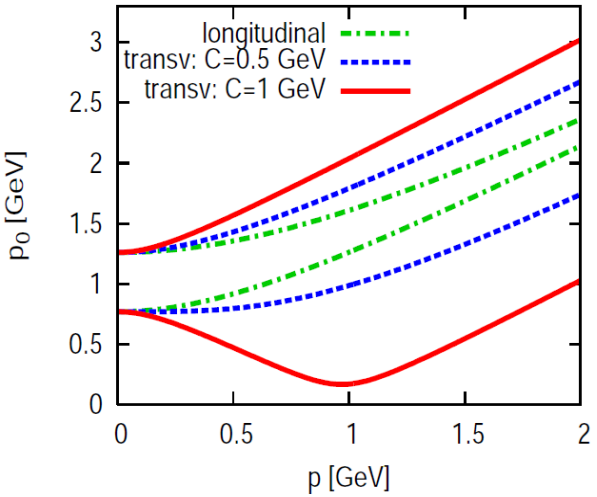




dispersion (mass VS momentum) in dense matter

- 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

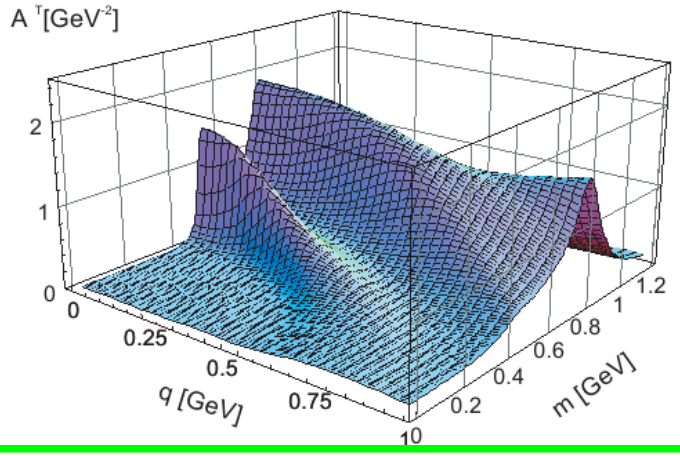
- Harada & Sasaki (arXiv:0902.3608v1)



a_1

ρ

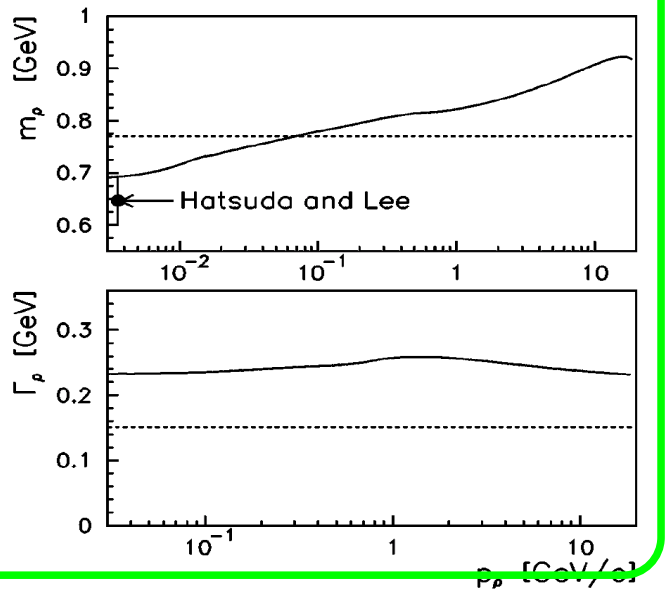
- Post & Mosel (NPA699(02)169)



ρ

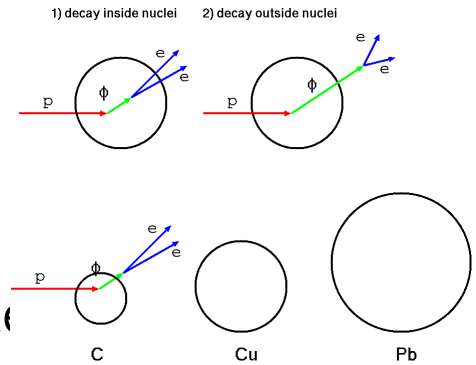
- Kondratyuk et al. (PRC58(98)1078)

ρ



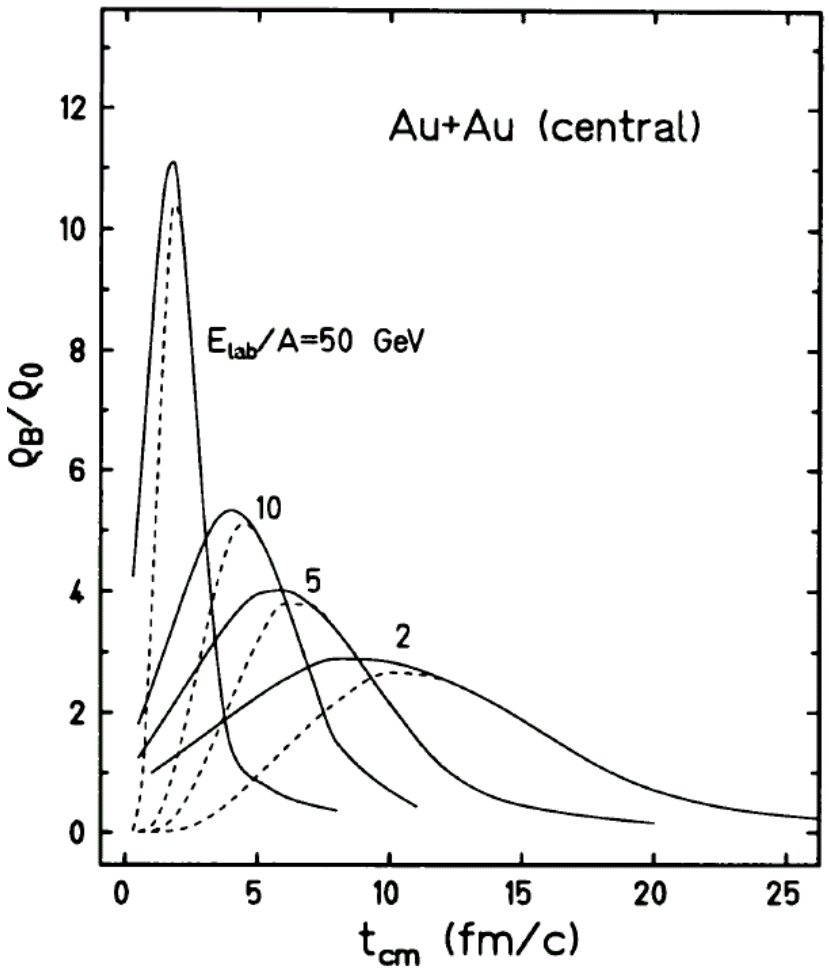
Summary of E16 experiment

- Main goal : collect ~1-2 x 10^5 $\phi \rightarrow e^+e^-$ for each target in 5 weeks
  using 30 (or 50) GeV p +A (C/CH_2/Cu/Pb) reactions
  - statistics : ~100 times as large as E325
  - **systematic study of the modification**
    - velocity & nuclear size (0~10 fm) dependence
      - proton/Pb targets / collision geometry (impact parameter)
    - momentum dependence (dispersion relation)
  - mass resolution : σ < 10 MeV (E325 : 10.7 MeV for ϕ)
    - double peak structure can be seen w/ $\beta\gamma$ < 0.5, σ ~5-6 MeV
  - ρ, ω, J/ψ 's also can be measured at the same time
  - Confirm the modification observed in E325, and provide new information about the mass of hadrons

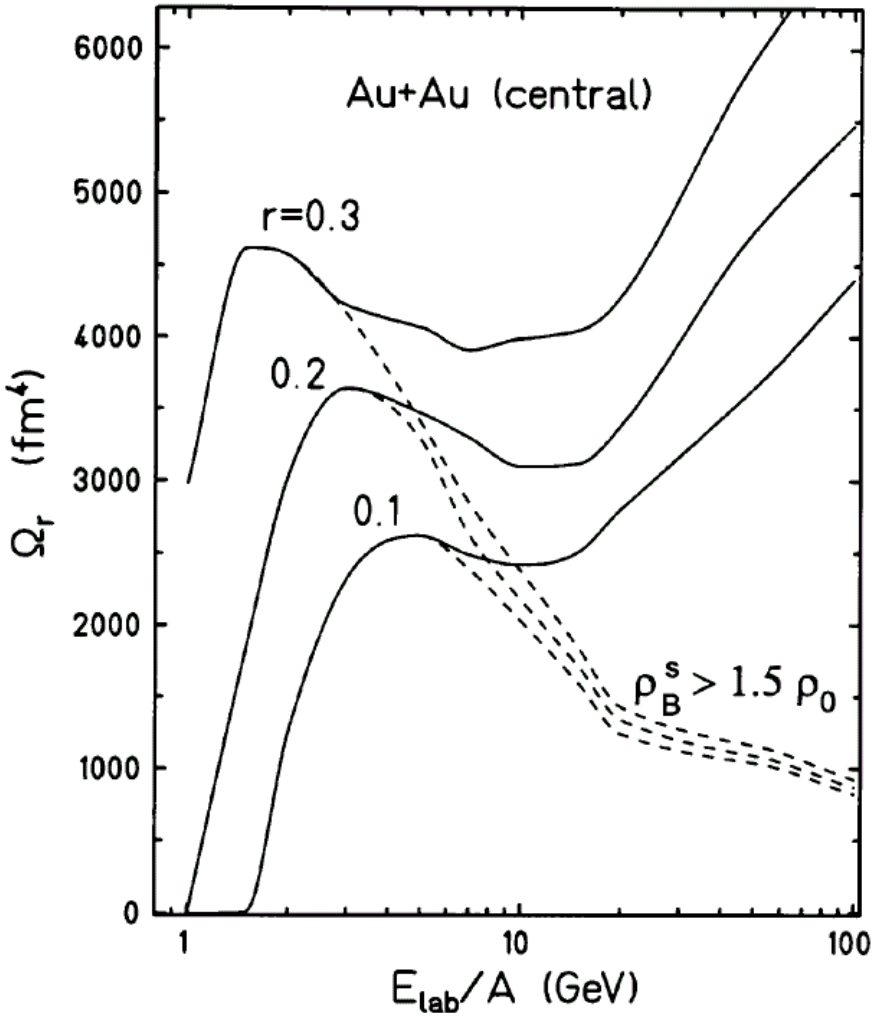


density & chiral condensate in HIC

- Friman et.al (EPJA 3(98)165)

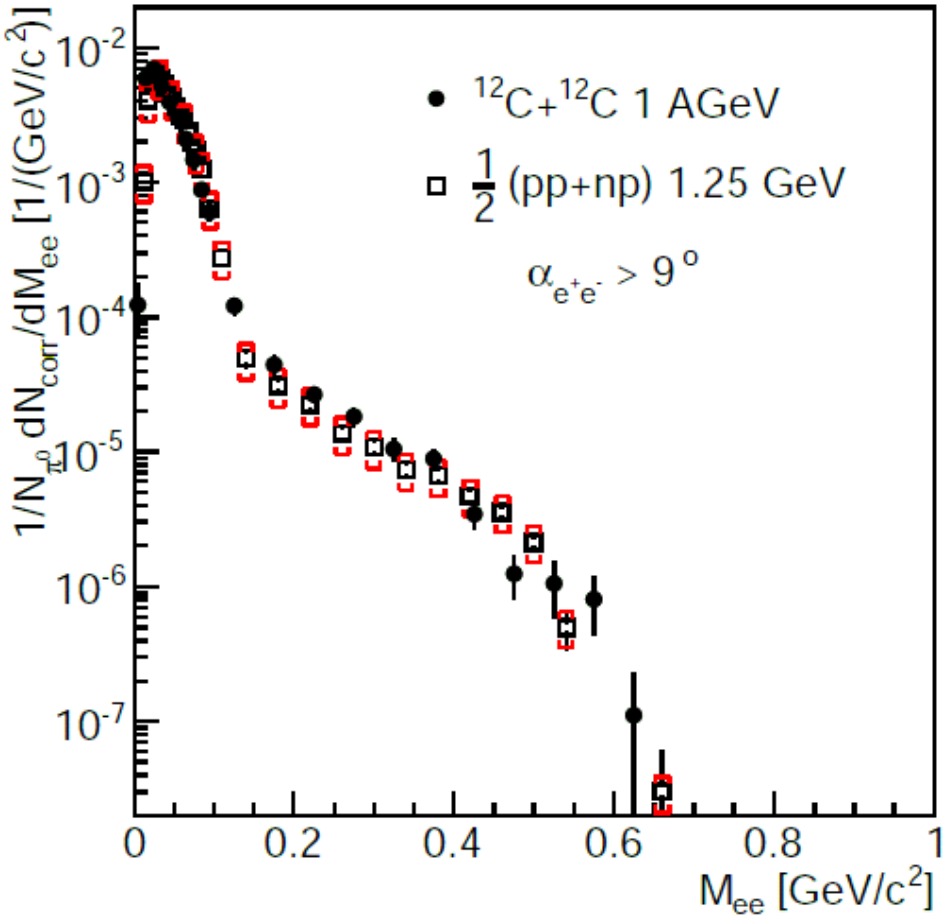


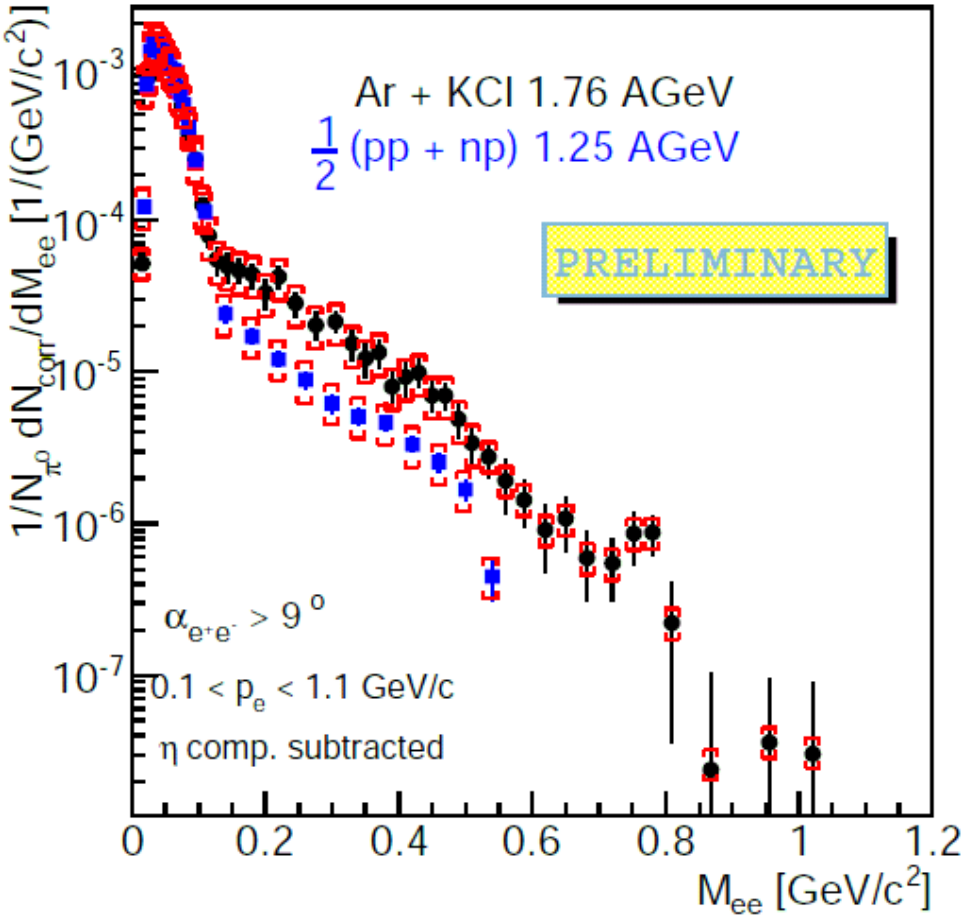
where $\langle\bar{q}q\rangle/\langle\bar{q}q\rangle_0$ is smaller than r



HADES

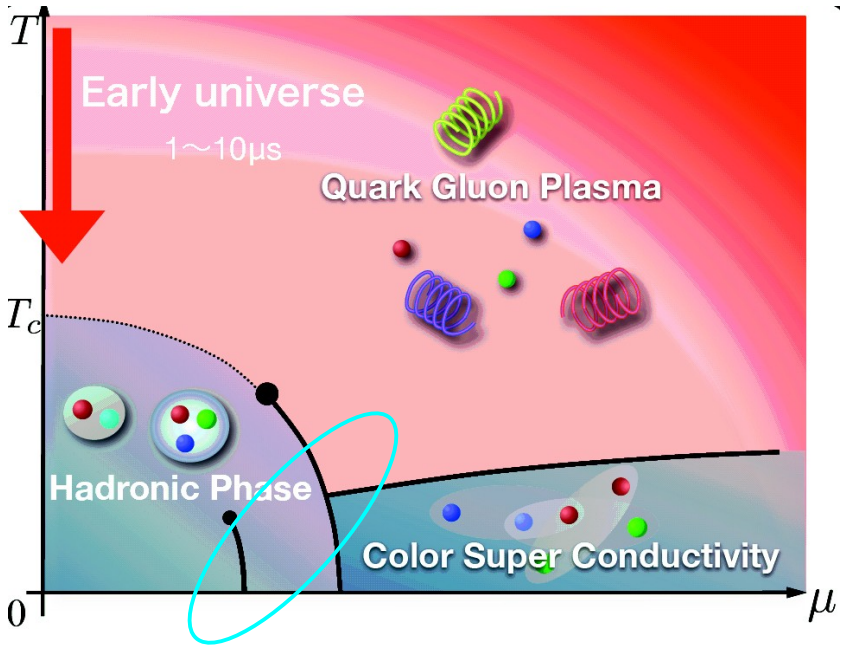
- dielectron arXiv:1011.5424v2
- DLS data is confirmed, and the puzzle in C+C is resolved by (pp+np)
- However, Ar+KCl have enhancement over (pp+np)
- Next Au+Au run : approach the high-density region?





Summary

- Study of the nature of QCD vacuum
  - spontaneous breaking of chiral symmetry as a major origin of mass
  - hadrons (as a probe) in finite density
    - hadrons in nuclei : measurements of invariant mass and/or meson bound state
      - chiral condensate, gluon condensate, baryon representation...
    - ...and more dense QCD matter using Heavy Ion Collisions (1-50 GeV/u in Lab.system)



Summary

- Study of the nature of QCD vacuum
  - Next frontier of QCD is the dense matter