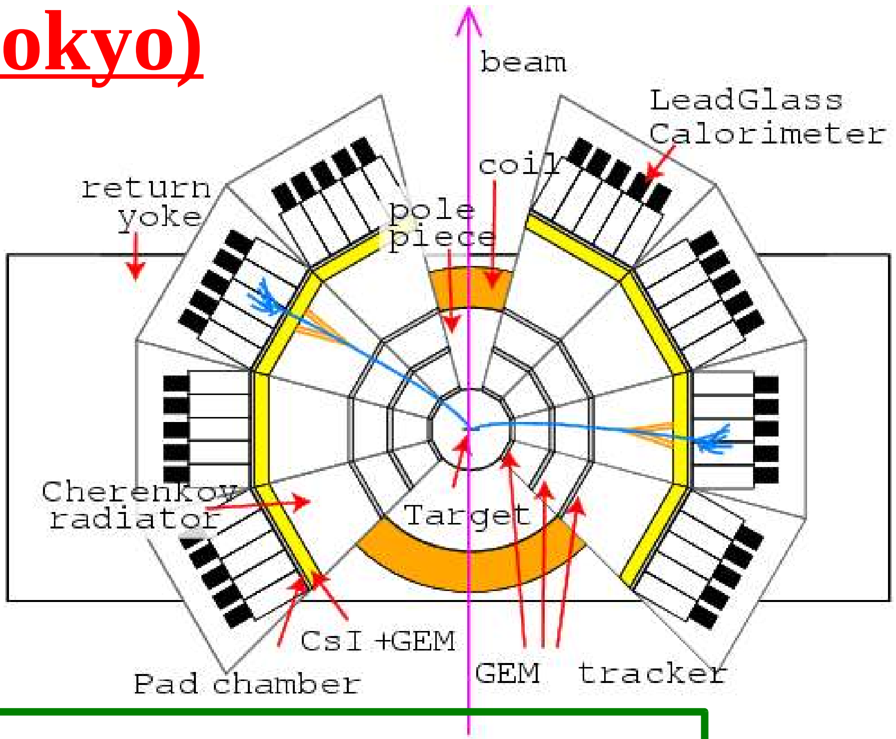
Proposal : Electron pair spectrometer at J-PARC 50-GeV PS to explore the chiral symmetry in QCD

Satoshi Yokkaichi (RIKEN)
Kyoichiro Ozawa (CNS, U-Tokyo)



Collaboration

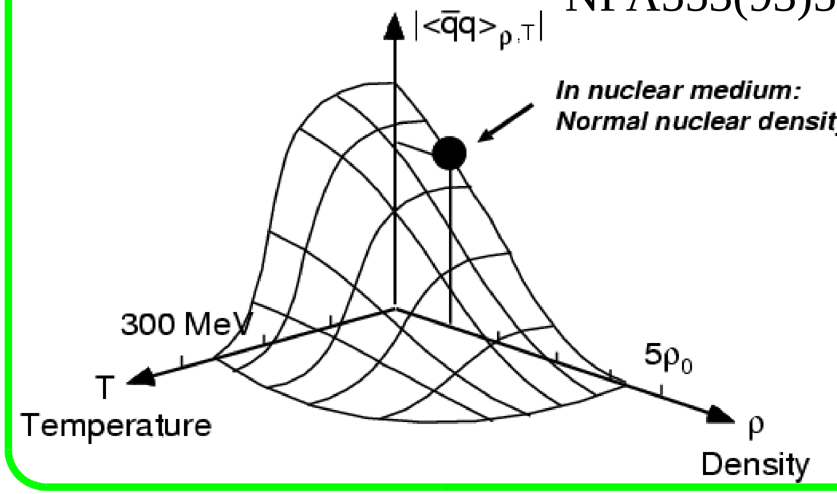
RIKEN	S.Yokkaichi, H. En'yo, M. Naruki, R.Muto, T. Tabaru
CNS, U-Tokyo	K. Ozawa, H. Hamagaki
Hiroshima-U	K. Shigaki
KEK	S. Sawada, M. Sekimoto
Kyoto-U	F. Sakuma, K. Aoki

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

Chiral symmetry restoration in dense matter

- Origin of hadron mass :spontaneous breaking of chiral symmetry
- In hot/dense matter, chiral symmetry is expected to restore
  - hadron modification is expected
- quark-antiquark condensate (order parameter) : ~2/3 even at the normal nuclear density, T=0
  - could approach by p+A reaction (not A+A)

W.Weise, NPA553(93)59



- Many theoretical predictions of vector meson (mass/width) modification in dense medium, related (or not related) with CS
  - Brown & Rho ('91) : $m^*(\rho)/m_0 \sim f_\pi^*/f_\pi \sim 0.8$ *at* $\rho=\rho_0$
  - Hatsuda &Lee ('92) , Klingle, Kaiser &Weise ('97), Muroya, Nakamura & Nonaka('03), etc.

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

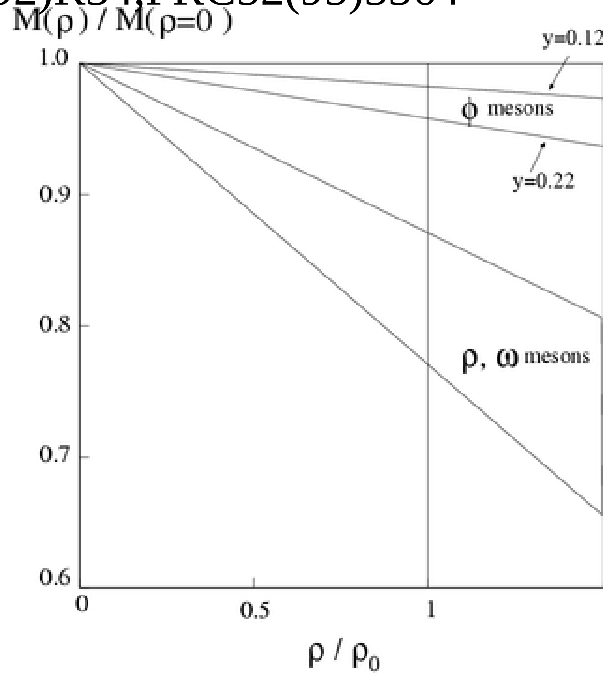
linear dependence on density

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

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

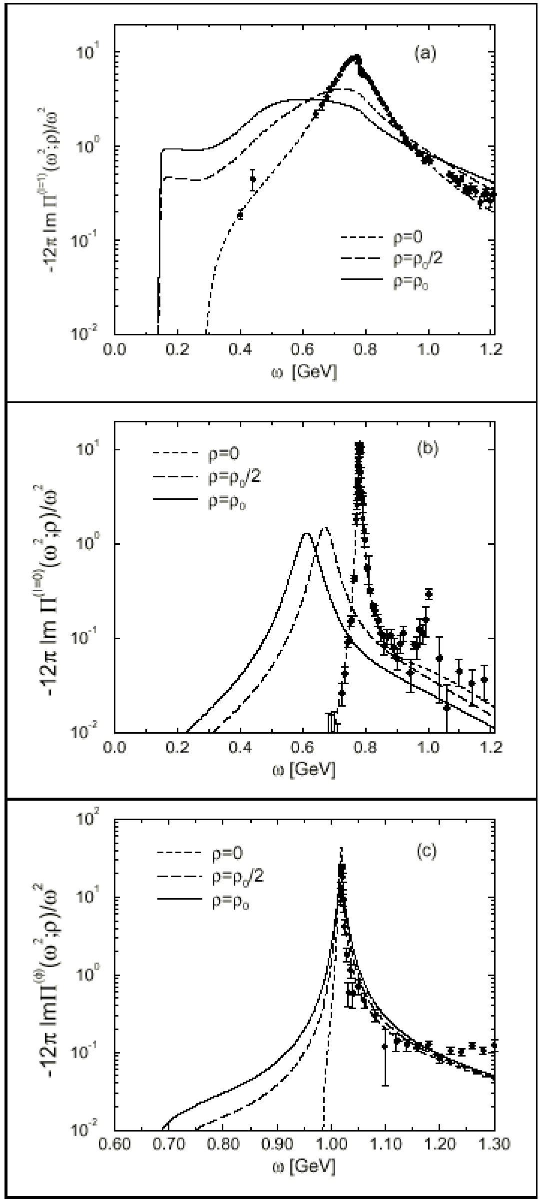


Klingle,Kaiser,Weise, NPA624(97)527

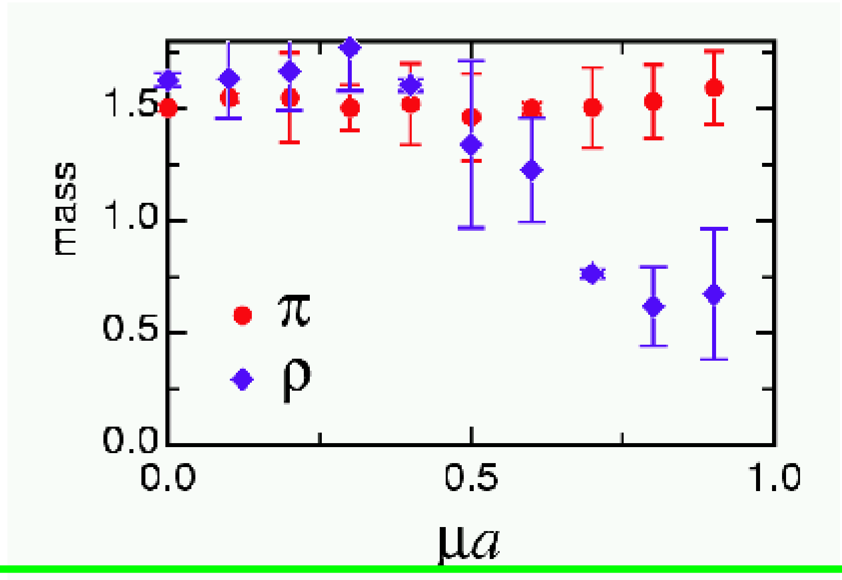
ρ

ω

φ

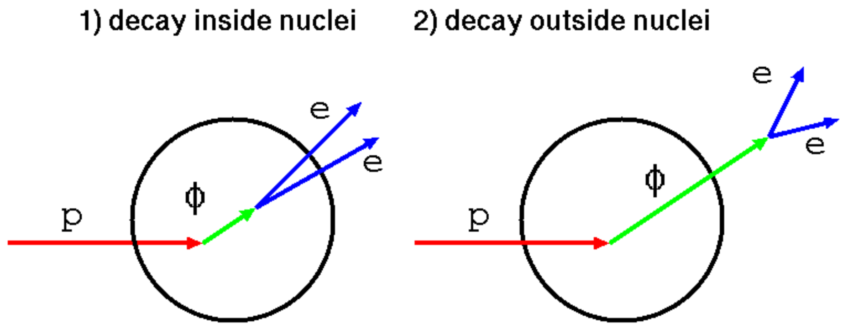


Muroya, Nakamura, Nonaka, PLB 551 (03) 305



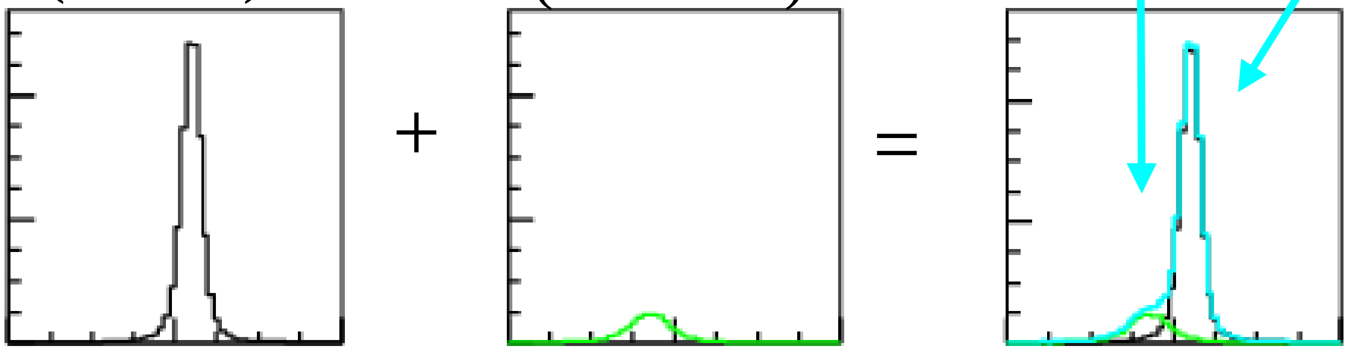
Expected Invariant mass spectra in e^+e^-

- 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

outside decay (natural) + inside decay (modified) = expected to be observed



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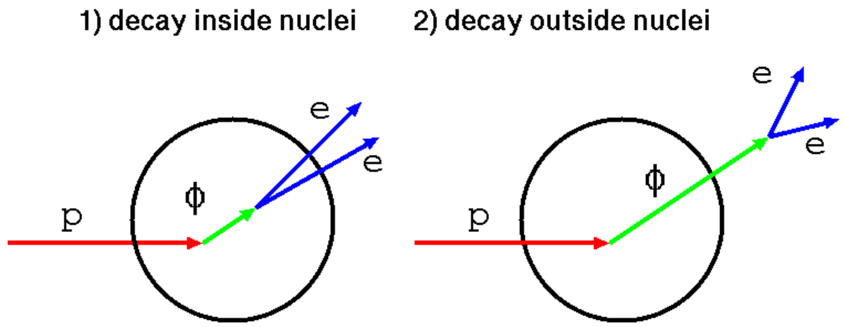
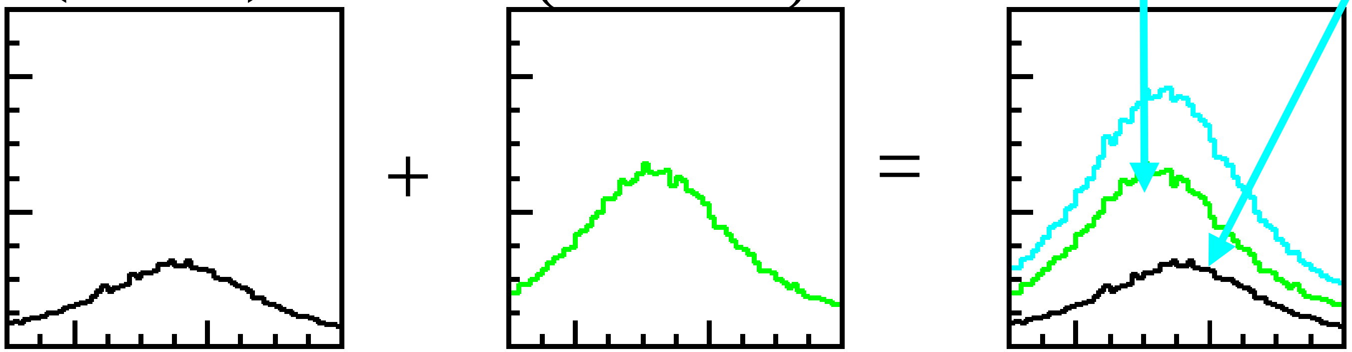


shorter-life meson(ρ) cases : Schematic picture

outside decay (natural) + inside decay (modified) = expected to be observed



Experiment KEK-PS E325

- 12GeV p+A $\rightarrow \rho/\omega/\phi$ +X ($\rho/\omega/\phi \rightarrow e^+e^-$, $\phi \rightarrow K^+K^-$)
- Experimental key issues:
  - Very thin target to suppress the conversion electron background (typ. 0.1% interaction/0.2% radiation length of C)
  - To compensate the thin target, high intensity proton beam to collect high statistics (typ. 10^9 ppp $\rightarrow$ 10^6Hz interaction)
  - Large acceptance spectrometer to detect slowly moving mesons, which have larger probability decaying inside nuclei (1<$\beta\gamma$<3)

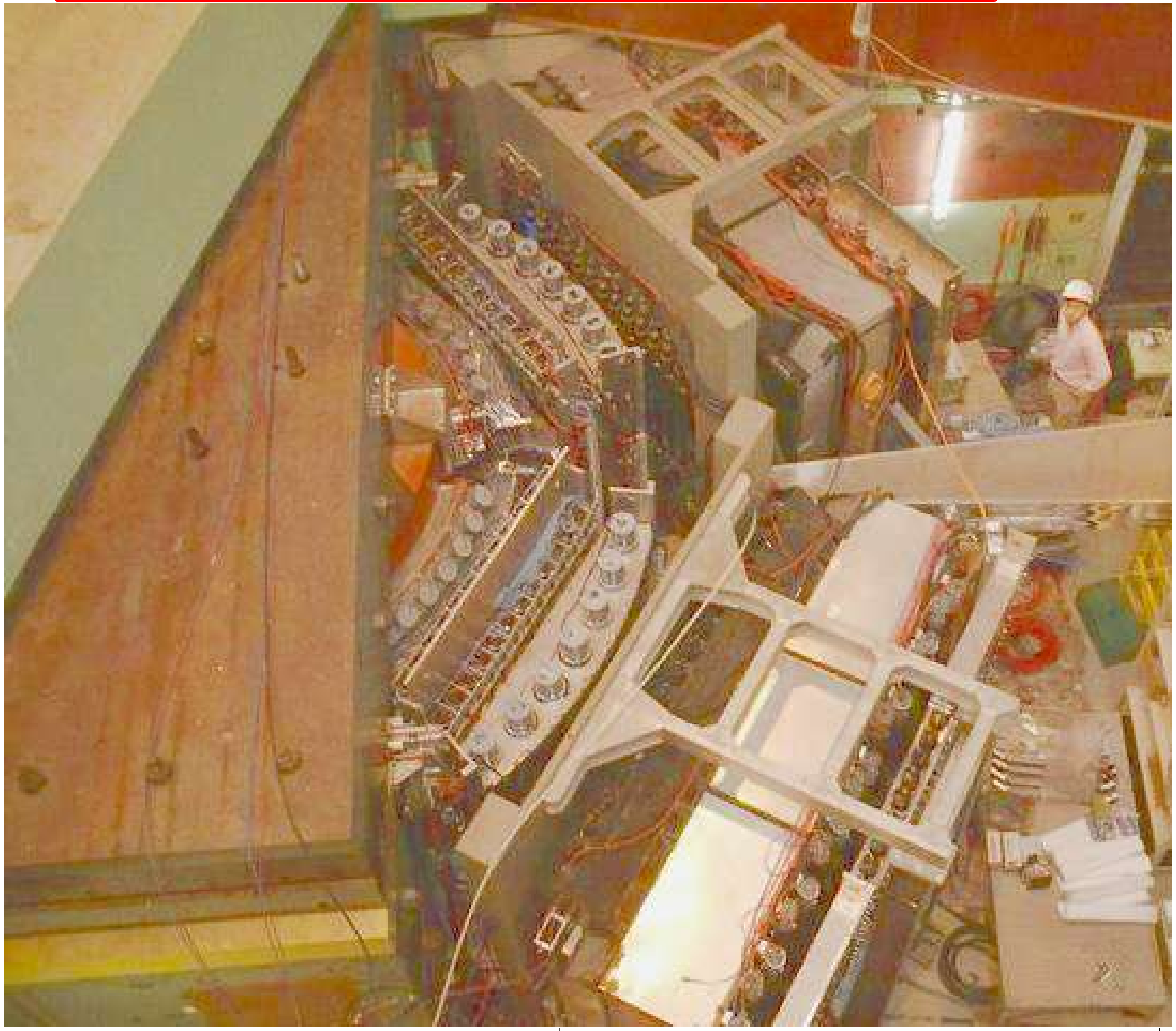
Collaboration

J. Chiba, H. En'yo, Y. Fukao, H. Funahashi, H. Hamagaki, M. Ieiri, M. Ishino, H. Kanda, M. Kitaguchi, S. Mihara, K. Miwa, T. Miyashita,T. Murakami, R. Muto, T. Nakura, M. Naruki, K.Ozawa, F. Sakuma, O. Sasaki, H.D.Sato, M.Sekimoto, T.Tabaru, K.H. Tanaka, M.Togawa, S. Yamada, S.Yokkaichi, Y.Yoshimura
(Kyoto Univ. , RIKEN, KEK, CNS-U.Tokyo, ICEPP-U.Tokyo, Tohoku-Univ.)

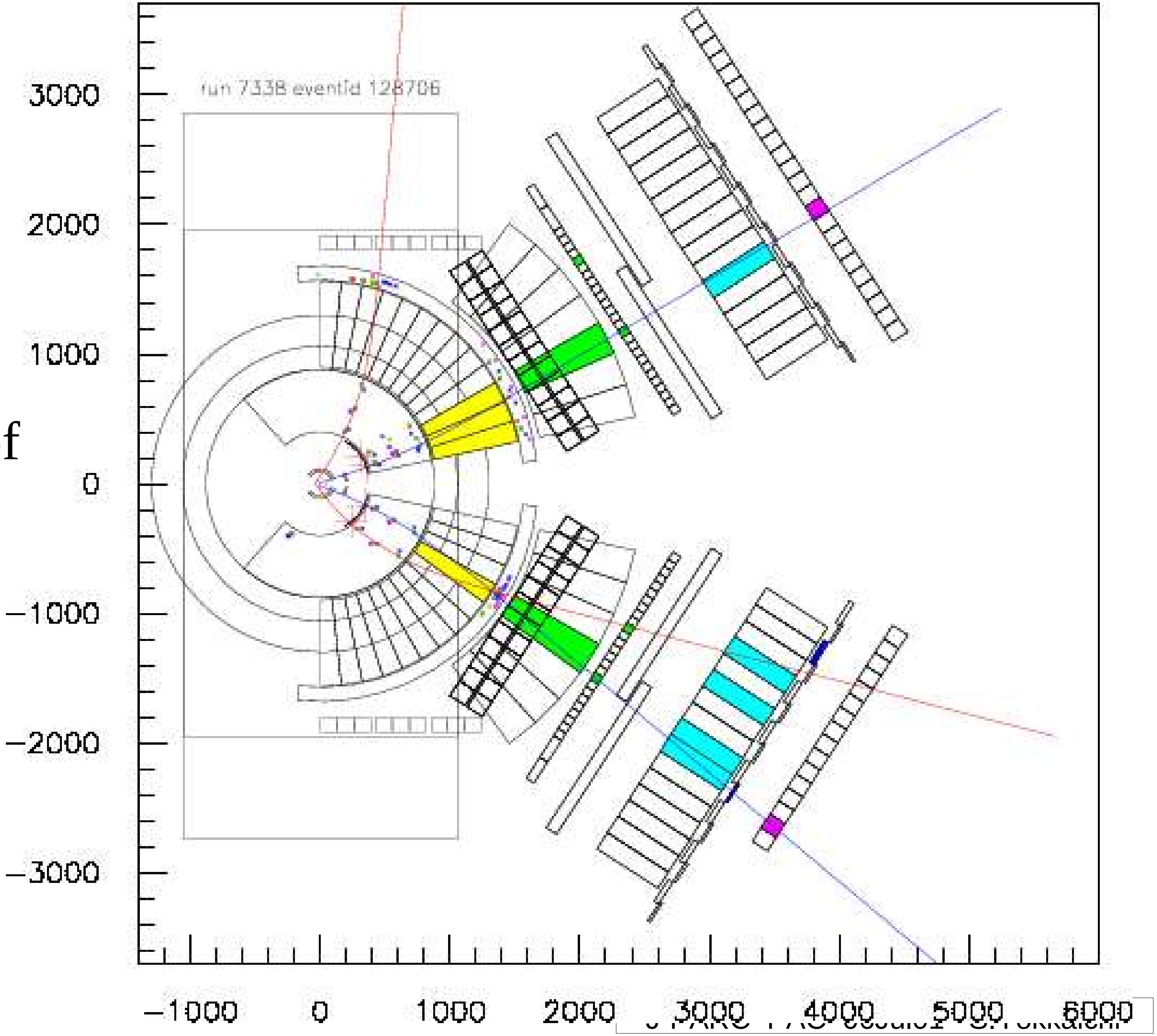
History of E325

- 1993 proposed
- 1996 const. start
- '97 data taking start
- '98 first ee data
  - PRL86(01)5019
- 99,00,01,02....
  - x100 statistics
  - PRL96(06)092301
  - nucl-ex/0511019
  - nucl-ex/0603013(PRC accepted)
  - nucl-ex/0606029
- '02 completed
- spectrometer paper
  - NIM A457(01)581
  - NIM A516(04)390

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



- Typical e^+e^- Event
  - blue:electron
  - red : other
  - invariant mass and momentum of mother particle can be calculated

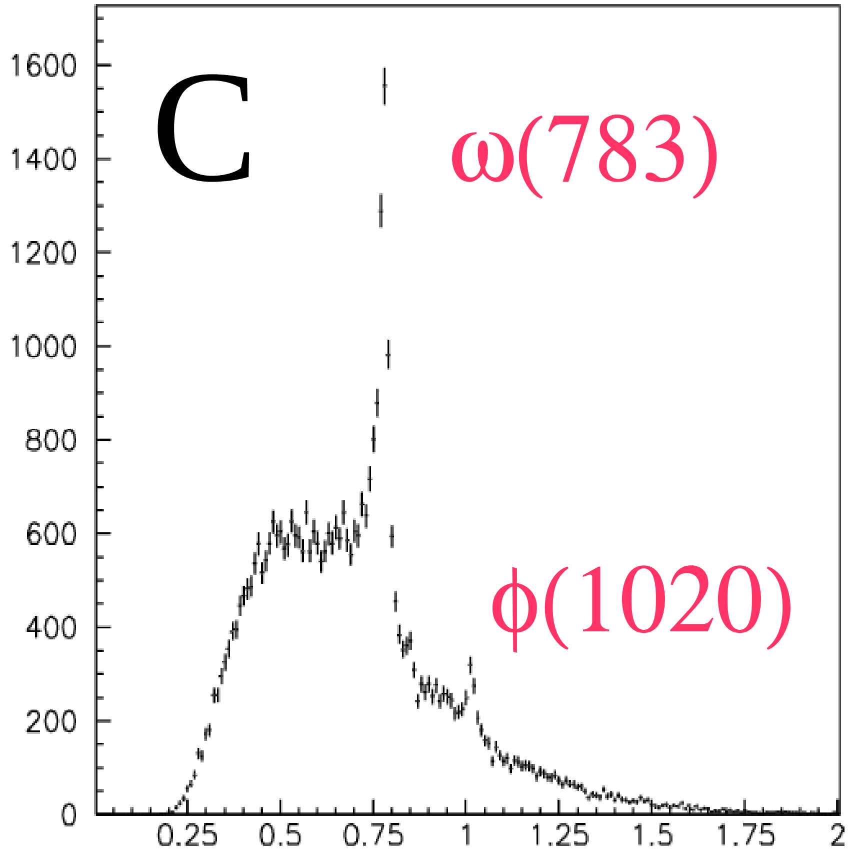


Result of E325

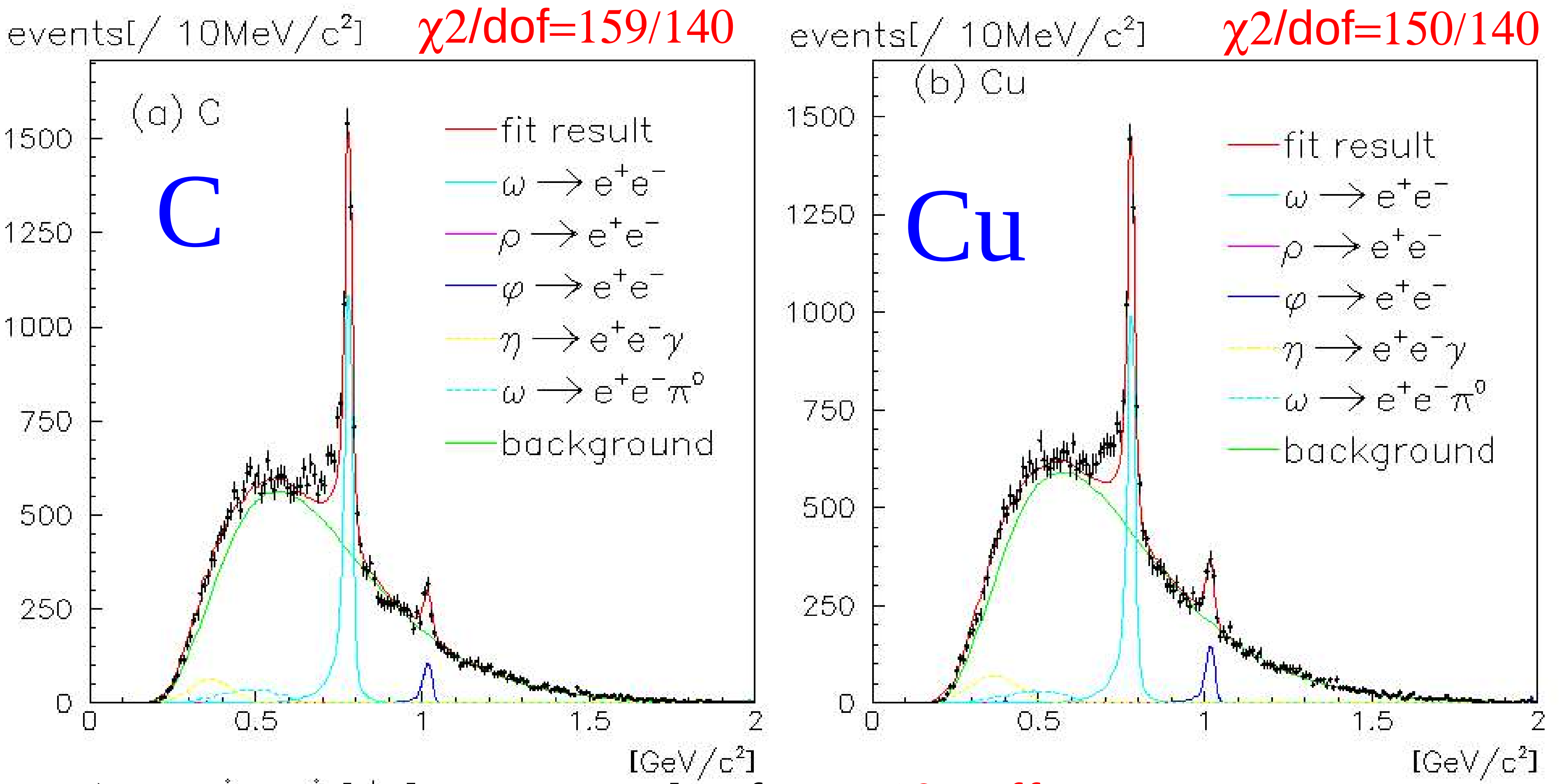
hadron modification in dense matter is detected in

$\rho/\omega \rightarrow e^+e^-$, $\phi \rightarrow e^+e^-$

PRL 96 (2006) 092301, nucl-ex/0511019



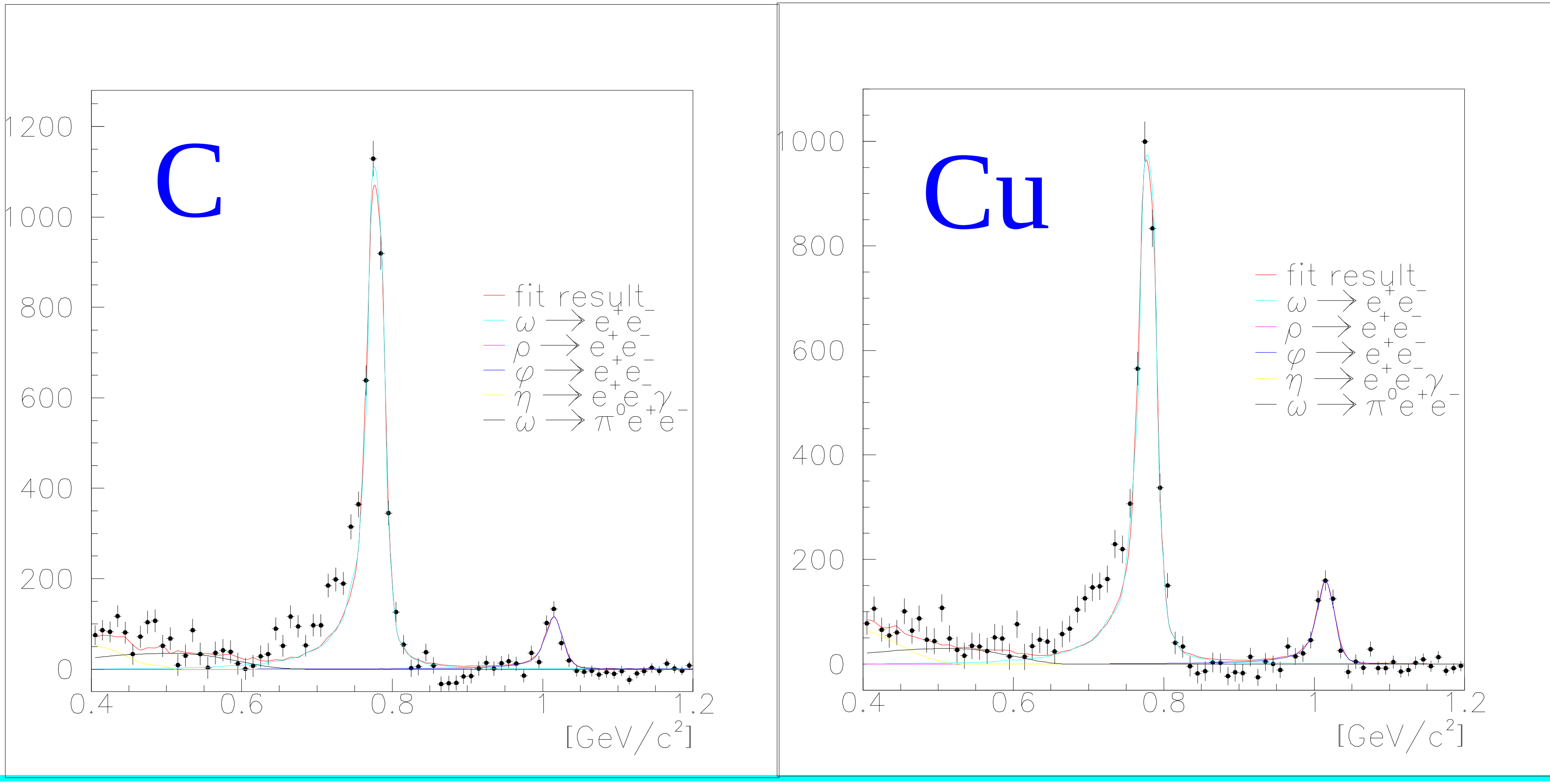
Fitting results w/ known hadronic sources



- 1) excess at the low-mass side of ω (~10σ effect)
  - To reploduce the data by the fitting, we have to exclude the excess region : 0.60~0.76 GeV
- 2) ρ–meson component seems to be vanished !

Fitting results (BKG subtracted)

ρ/ω <0.06 +0.09(syst.) , <0.08 + 0.21(syst.) (95%CL)

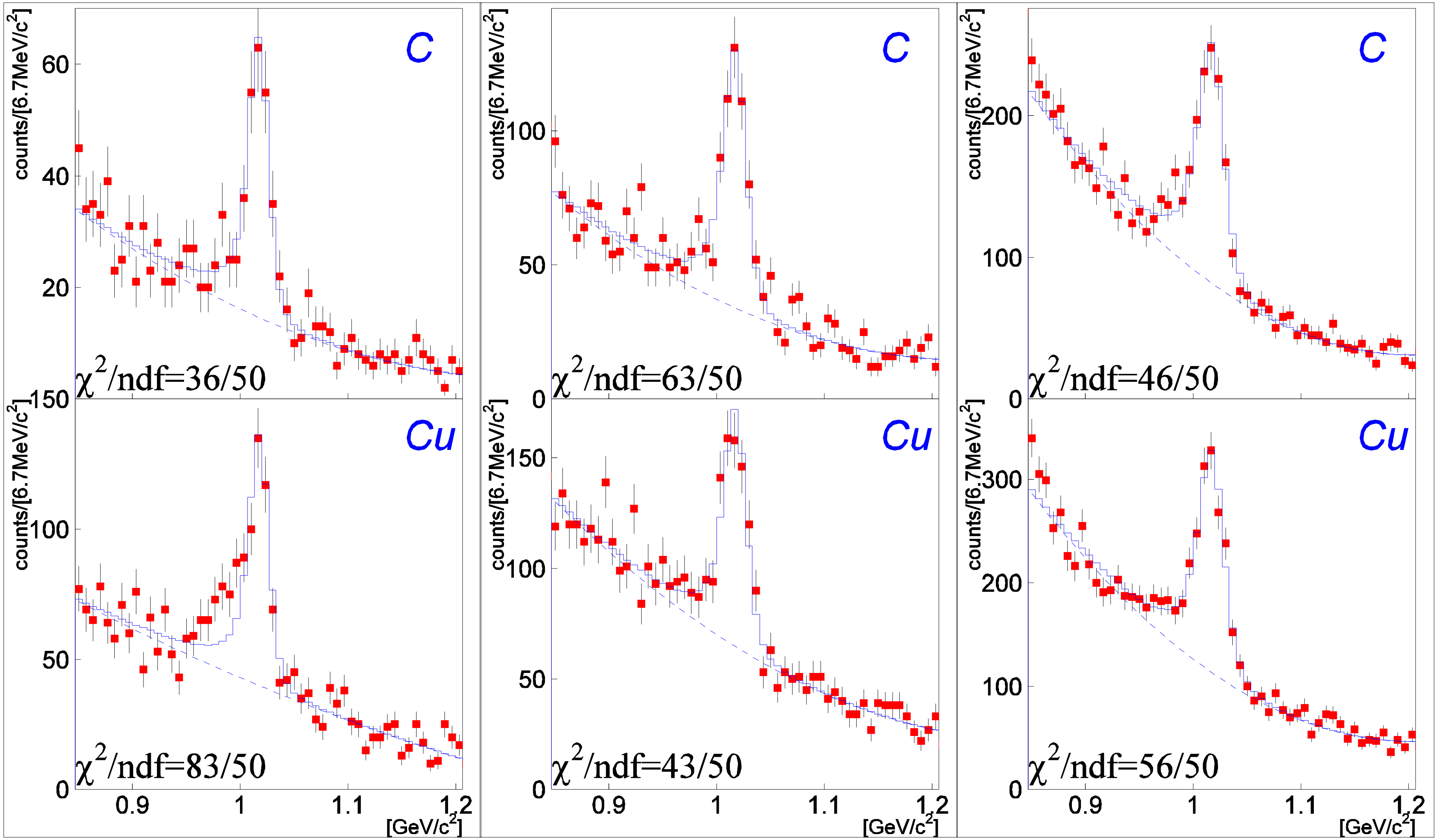


- However, ρ/ω =1.0±0.2 in former experiment (p+p, 1974)

  ...suggests that the origin of excess is modified ρ mesons.

e^+e^- spectra of ϕ meson (divided by $\beta\gamma$)

$\beta\gamma$<1.25 (Slow)	1.25<$\beta\gamma$<1.75	1.75<$\beta\gamma$ (Fast)



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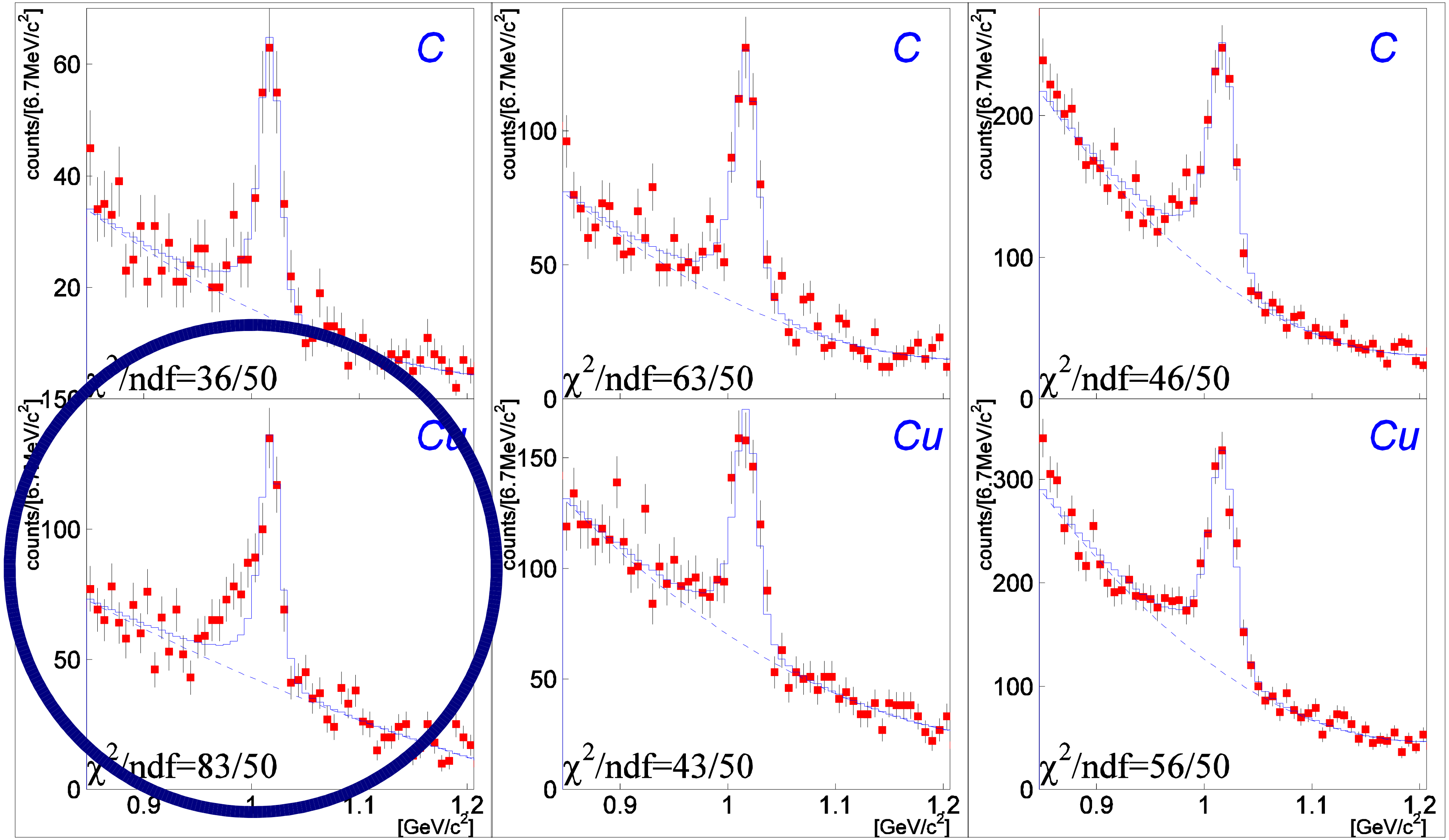
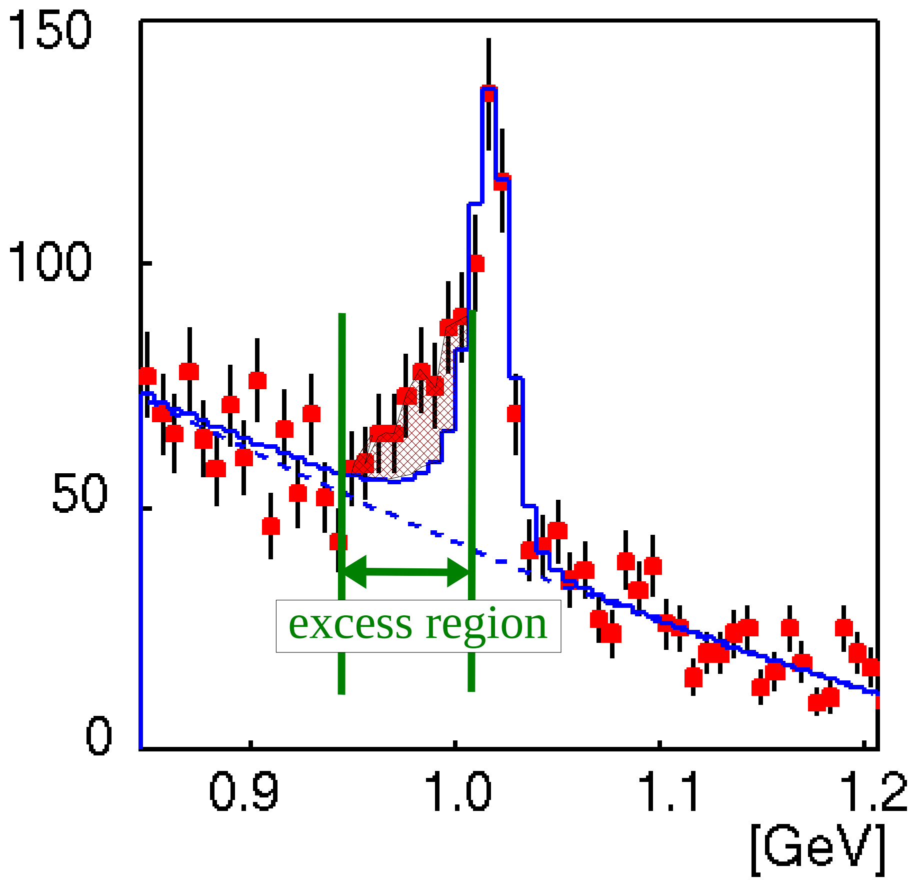


only slow/Cu is not reproduced in 99% C.L.

Amount of excess

- To evaluate the amount of excess (N_{excess}), fit again excluding the excess region (0.95~1.01GeV) and integrate the excess area.



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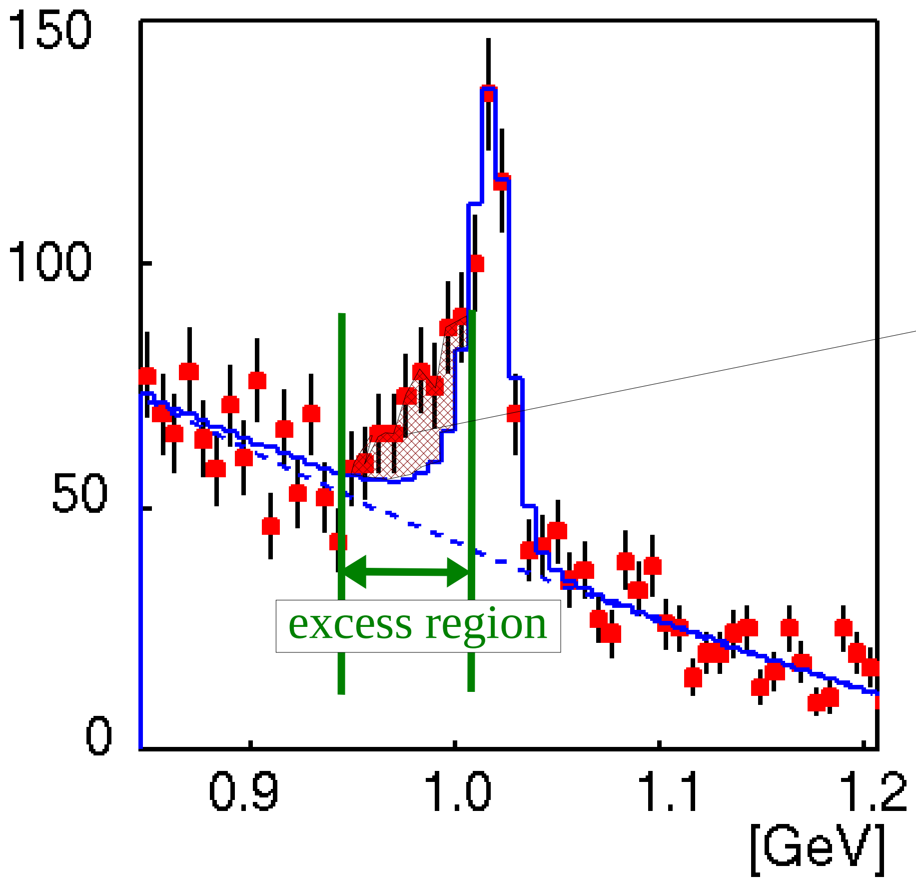
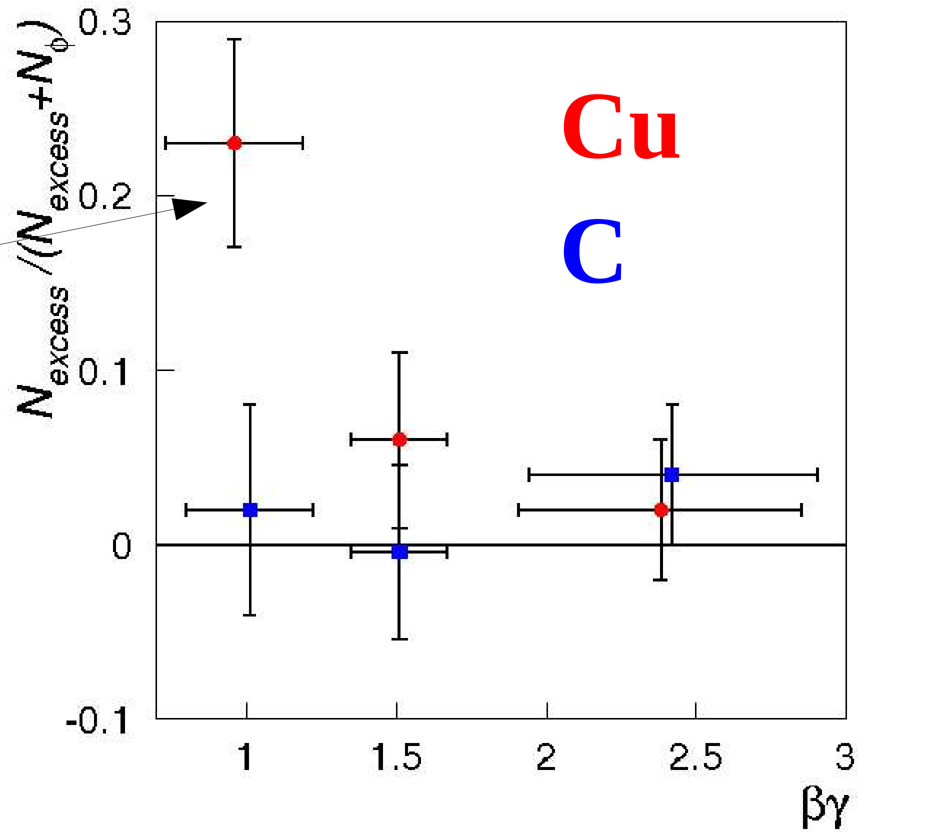
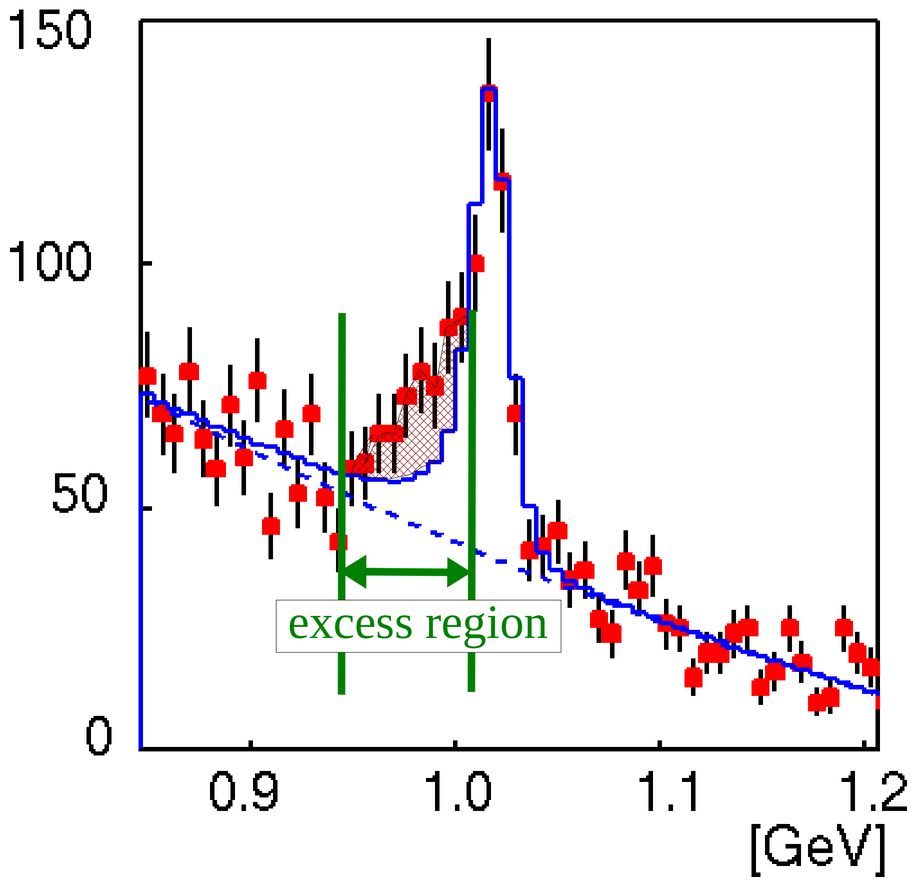
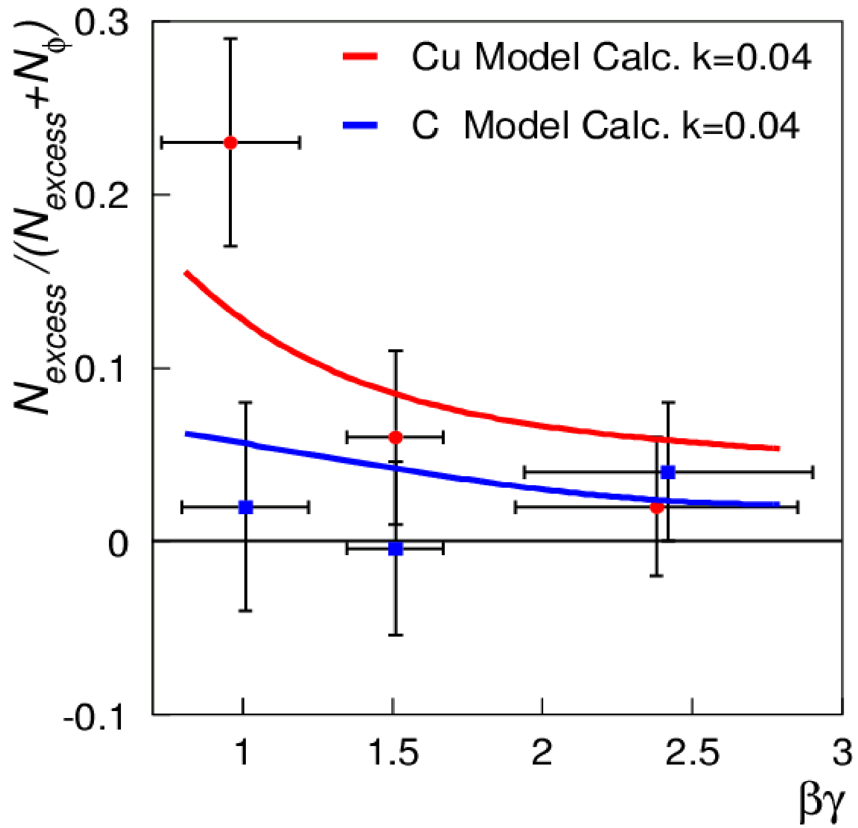




Amount of excess

- To evaluate the amount of excess (N_{excess}), fit again excluding the excess region (0.95~1.01GeV) and integrate the excess area.
- Model calculation reproduces the tendency of N_{excess} / (N_{excess} + N_{ϕ})

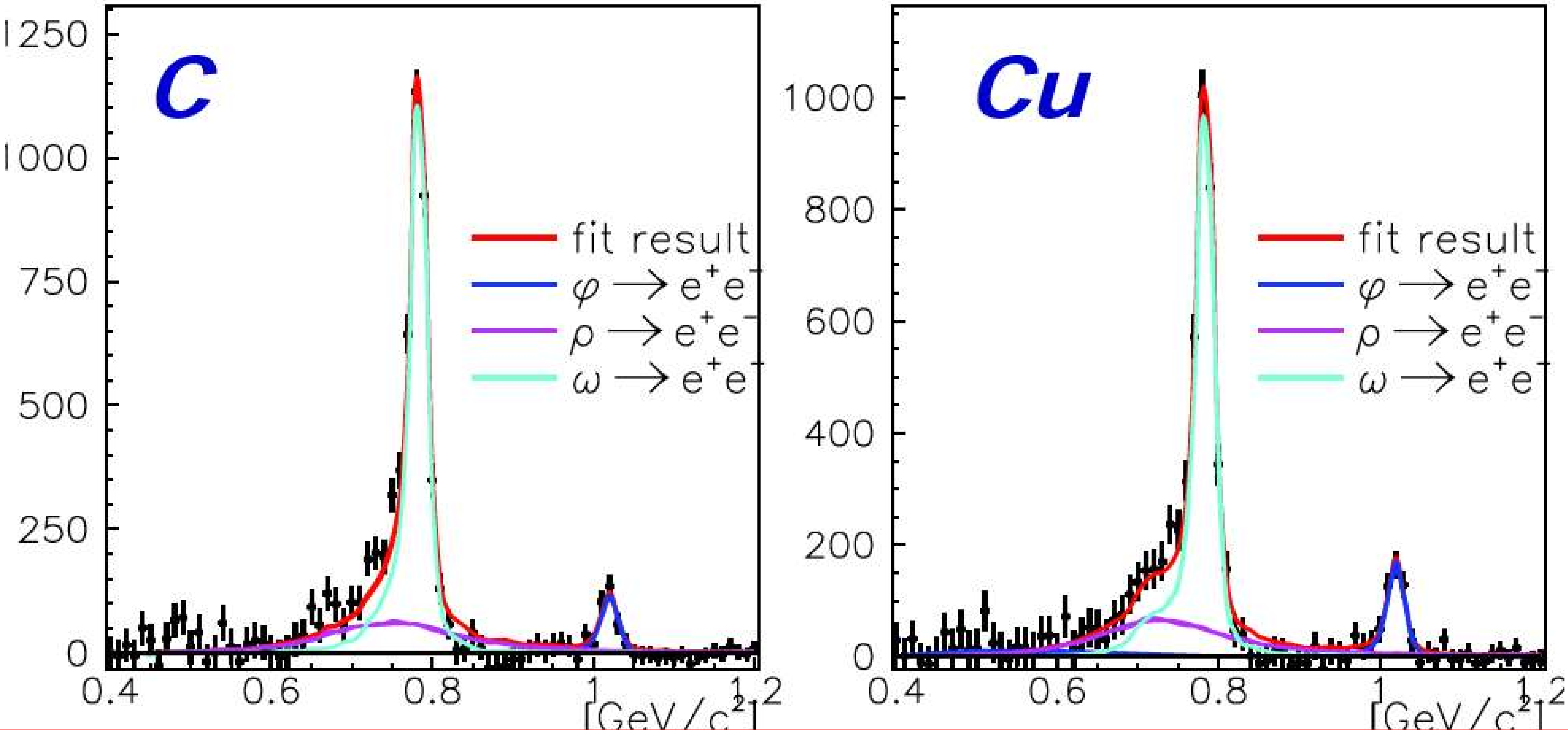




Fitting results by the toy model

Free param.: - scales of background and hadron components for each C & Cu

- modification paramter k for ρ and ω is common for C & Cu



From the fit : k=0.092 ± 0.002 : ~ 9 % reduced at normal nuclear density

ρ/ω ratio : 0.7± 0.1 (C), 0.9±0.2 (Cu) : ... ρ meson returns.

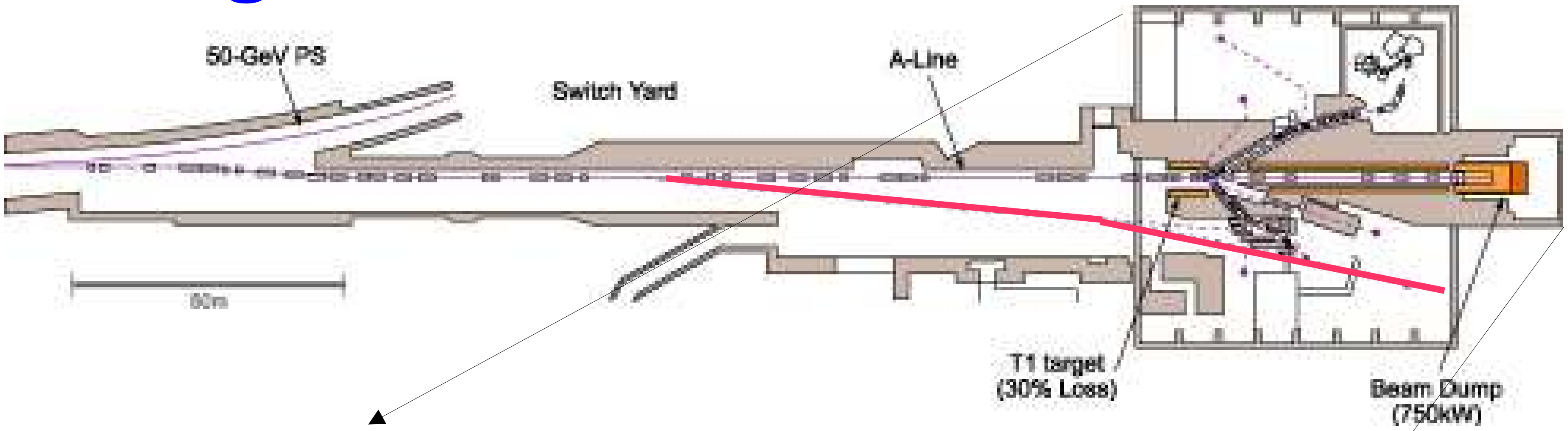
E325 detected the mass modification in the invariant mass spectra...

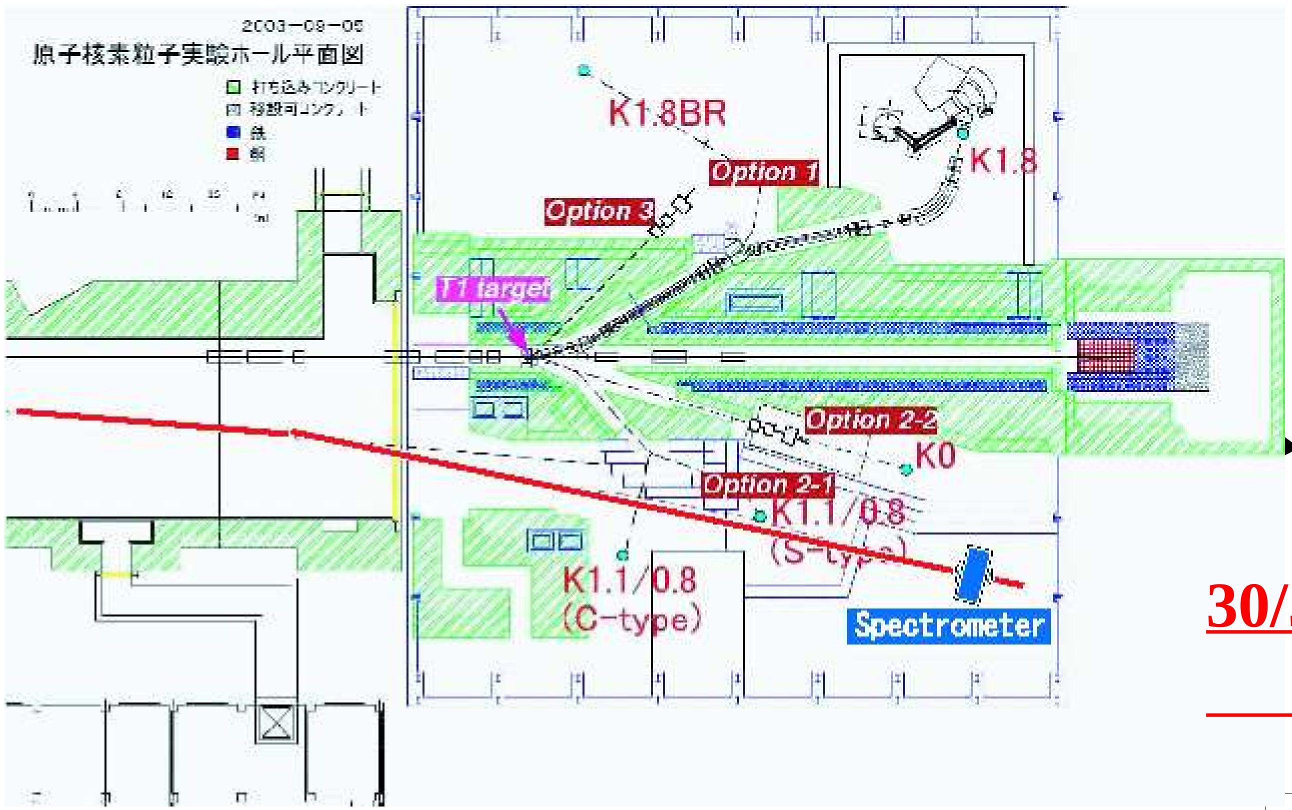
- Some predictions like upward mass-shift can be excluded
- Toy model is consistent with the data
  - Ignored effect :
    - finite-size nuclei <-> infinite nuclear matter
    - Possible time evolution of the density of nuclei in the reaction
    - momentum dependence of 'mass shift' & 'witdh broadening'
- For further discussion to approach the chiral restoration:
  - precise experimental data comparable the predictions
    - $\beta\gamma$ dependence (especially slow region), matter size dependence, etc.

Proposed Experiment at J-PARC

presice investigation of hadron modification in dense matter

High momentum Beamline





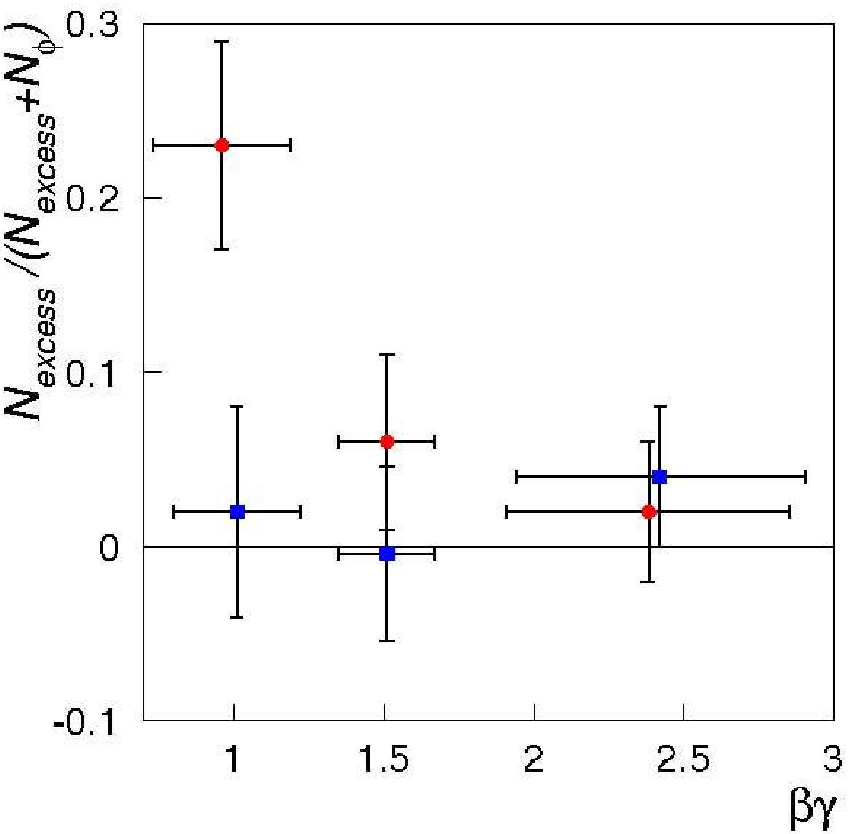
30/50GeV proton beam (~10^{10} /sec)

Next generation experiment at J-PARC

- Same concept as E325
  - thin target / primary beam (~10^{10} /sec)/ slowly moving mesons
- Main goal : collect ~1 x 10^5 $\phi \rightarrow ee$ for each target in 5 weeks
  - ~100 times as large as E325
    - velocity dependence of 'modified' component
    - new nuclear targets : proton (CH_2 -C subtraction), Pb
    - collision geometry for larger nucleus target
  - mass resolution : ~ 10 MeV
- ρ ,ω and J/ψ can be collected at the same time
  - higher statistics of ρ and ω than E325 with different nuclear targets
  - 100-1000 J/ψ are expected in 50GeV operation
- Normal nuclear density (p+A)
  - but also high matter density (A+A, ~20GeV/u)

high statistics

- Main goal : collect ~1x10^5 $\phi \rightarrow ee$ for each target in 5 weeks
  - 100 times as large as E325
    - velocity dependence of 'modified' component



high statistics

- Main goal : collect ~1x10^5 $\phi \rightarrow ee$ for each target in 5 weeks
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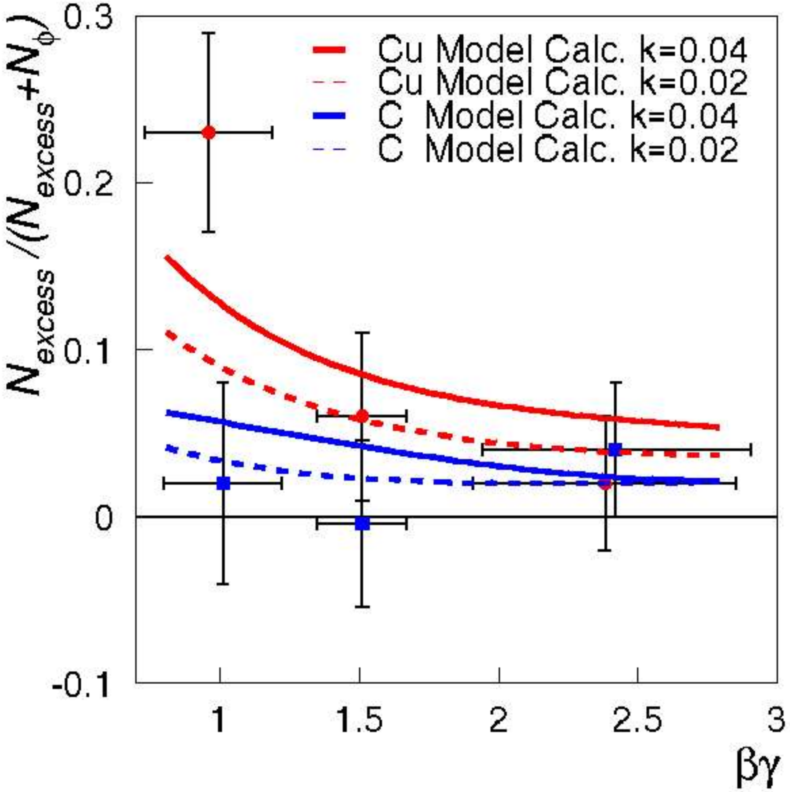

difficult to compare with the prediction

high statistics

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  - 100 times as large as E325
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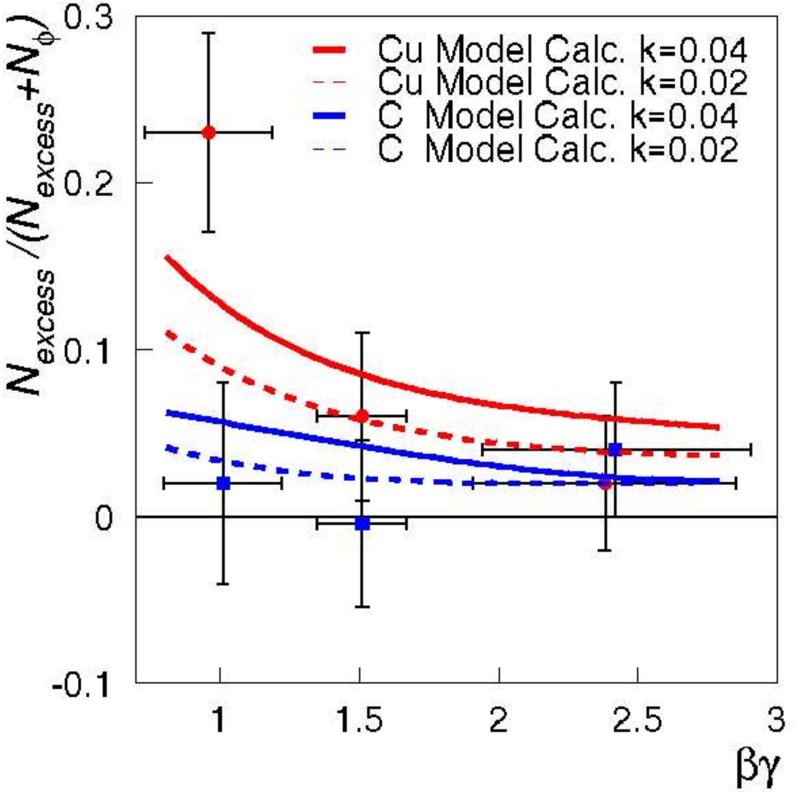
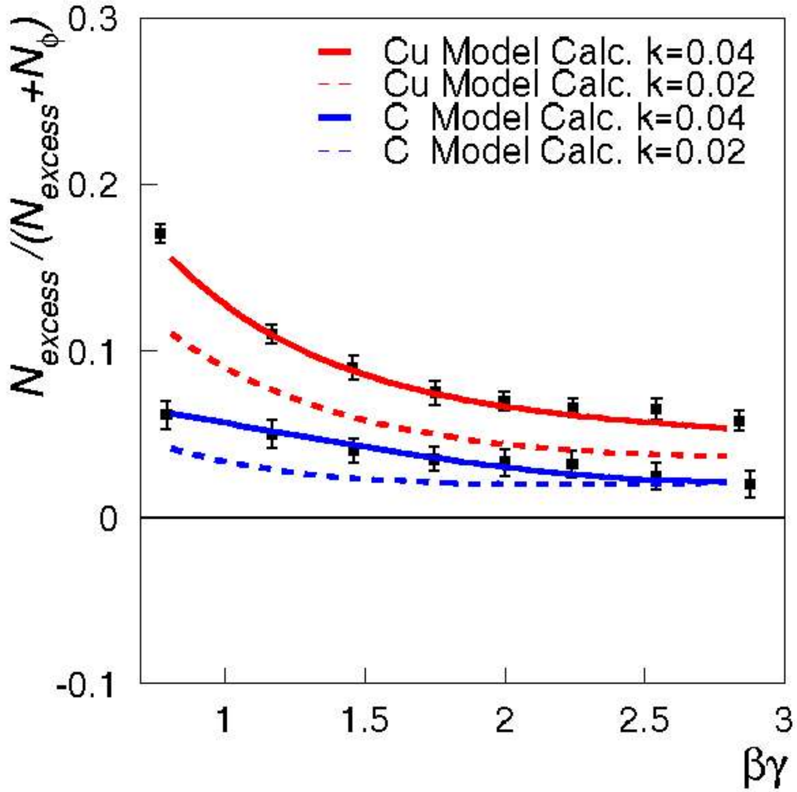


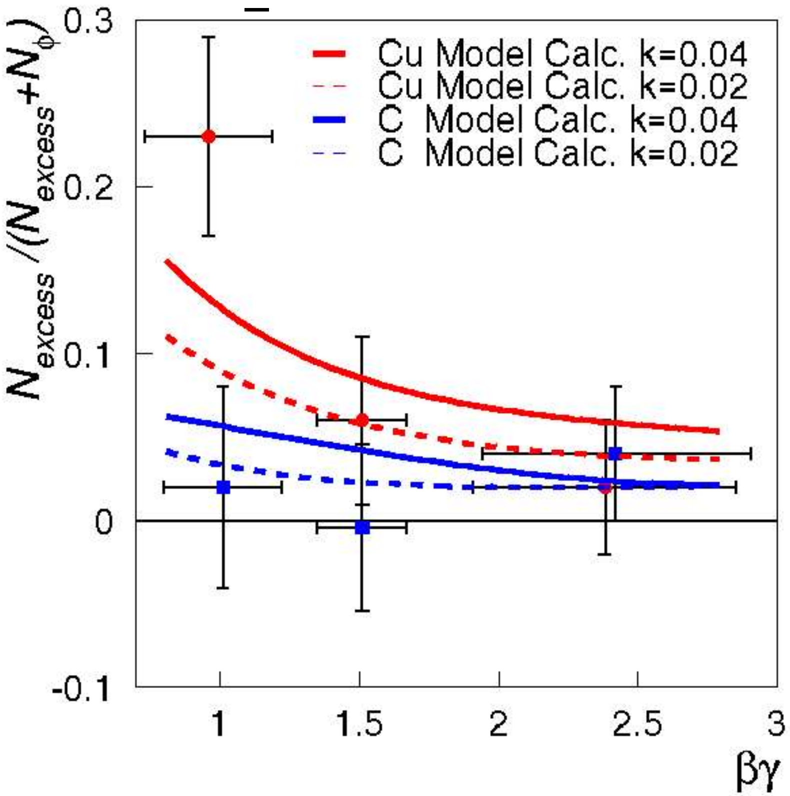
x 100 stat.



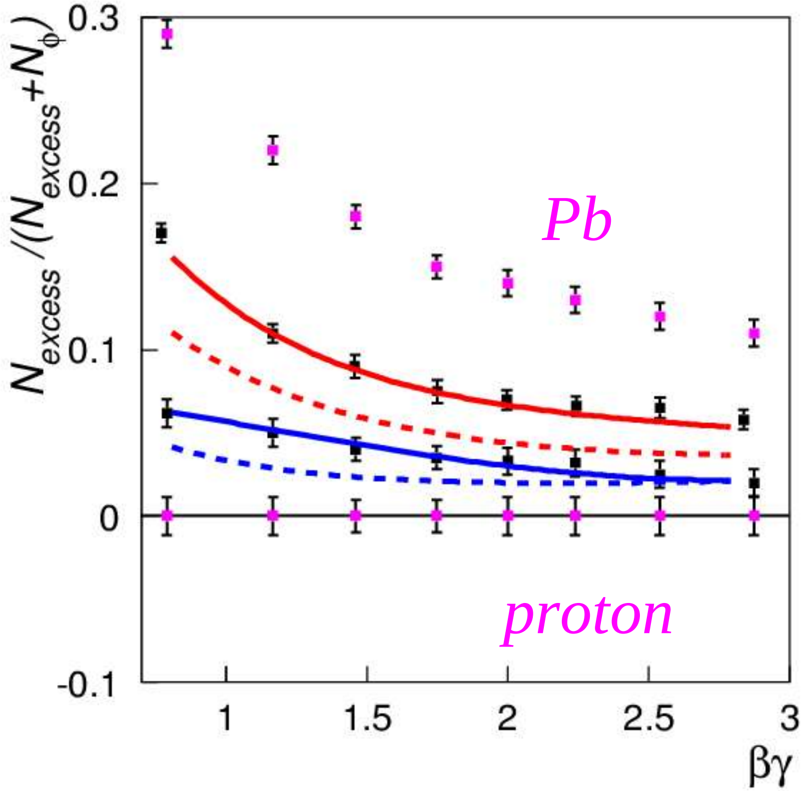
error bars are shrunk and βγ bin can be divided

high statistics

- Main goal : collect ~1x10^5 $\phi \rightarrow ee$ for each target in 5 weeks
  - 100 times as large as E325
    - velocity dependence of 'modified' component / new nuclear targets



x 100 stat.

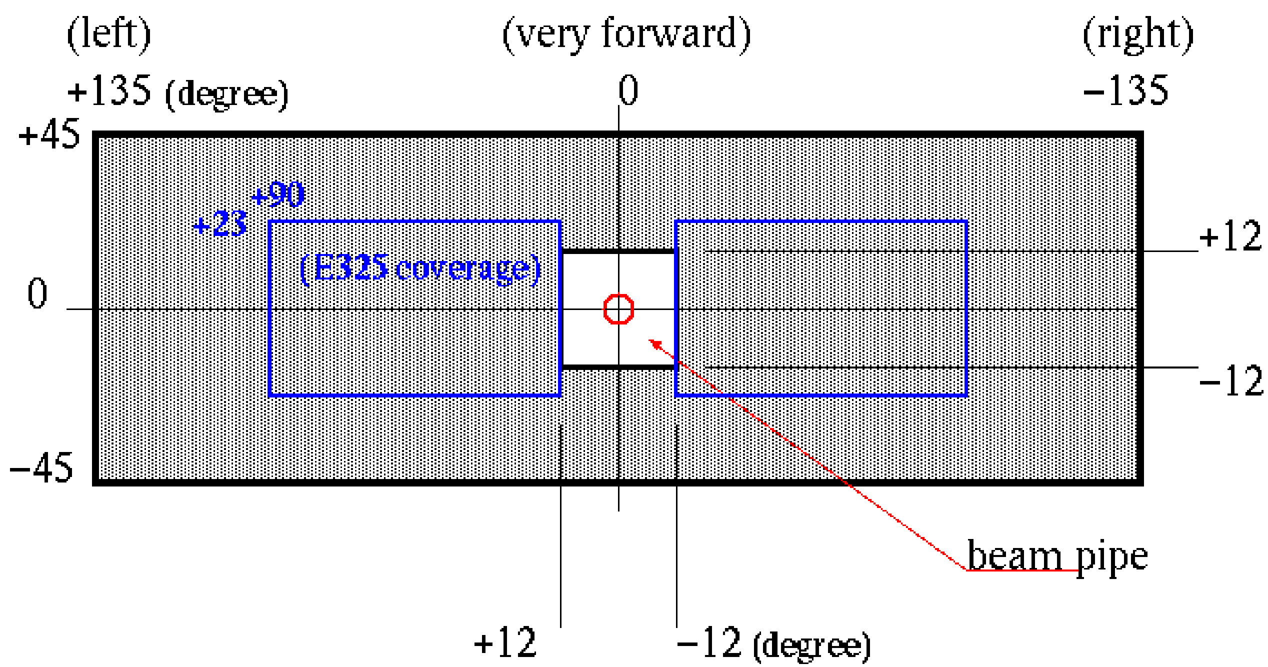


error bars are shrunk and βγ bin can be divided

To collect high statistics

- For the 100 times as large as E325:
  - To cover larger acceptance : x~ 5
  - Higher energy beam (12 → 30/50 GeV) : x ~2 of production CS
  - Higher intensity beam ($10^9 \rightarrow 10^{10}$ /spill (1sec)) : x 10

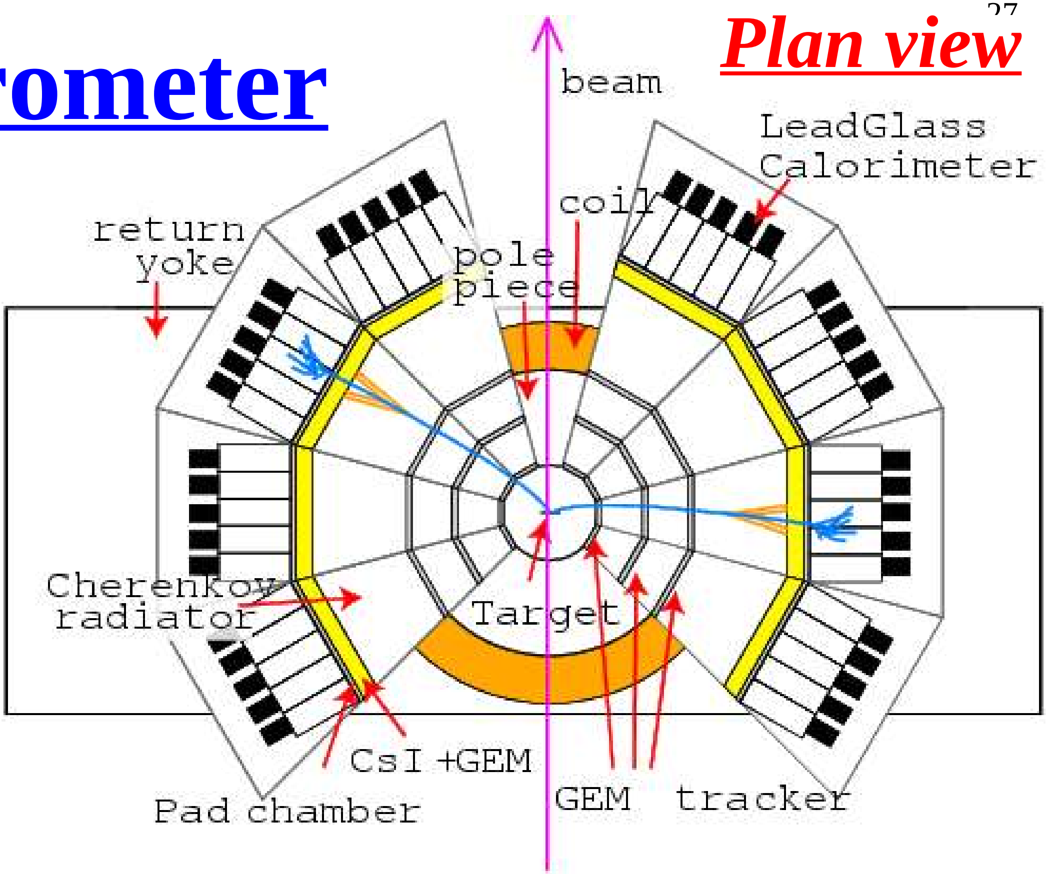
Geometrical (horizontal & vertical) coverage
of the spectrometer



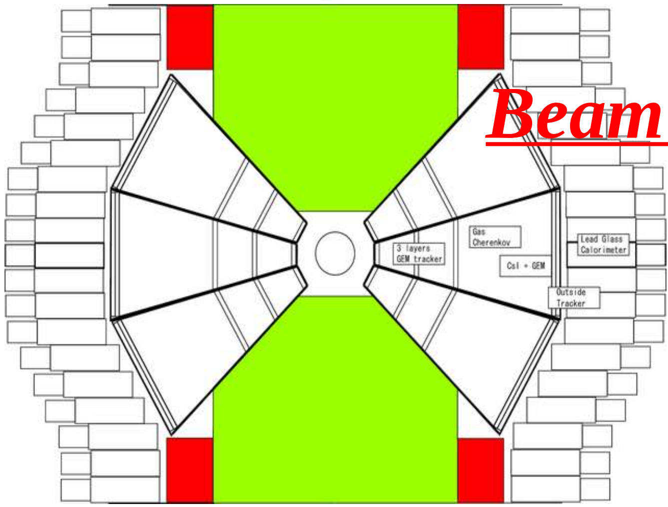
Proposed spectrometer

- 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)
  - Gas Cherenkov(*HBD*)
    - GEM+CsI photocathode
    - hexagonal pad readout (~30mm ϕ)
  - Leadglass EMC: reuse of TOPAZ
- ~70K Readout Channels (in 27 segments)
  - cf. E325: 3.6K, PHENIX:~300K
- Cost : ~$5M (including ~$2M electronics)
  - cf. E325: $2M not including electronics

Plan view



Beam view



Detector R&D status

- GEM : domestic products works well
  - high gain GEM / larger size
- HBD (GC using GEM + CsI photocathord)
  - PHENIX prototype has worked
  - In Japan:
    - CsI photocathord : worked
    - gas system for 10 ppm-impurity
    - CF_4 operation

already done
test is on going/scheduled
using CNS and RIKEN budget
would make a tryal product
(applying to Grant-in-Aid)

- GEM Tracker for high rate
    - low material strip read-out board / read out circuit
- prototype module of the spectrometer:
    - Tracker and HBD in real-size

Schedule

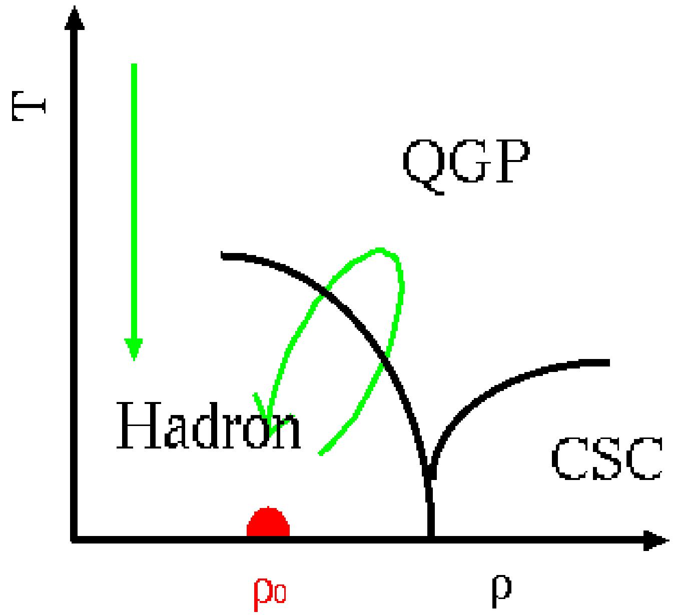
- *(If funding and construnction of the primary beam line are ideal,)*
- 2006 :
  - bench test completion
- 2007 -8:
  - prototype spectrometer module test/design finalize
- 2008-9 :
  - production
- 2009-10
  - spectrometer construnction at the counter hall
- 2010
  - ready for 30GeV proton beam

Summary

- Vector meson measurements in e^+e^- channel at J-PARC
  - to investigate the chiral symmetry in dense hadronic matter
- 30 or 50 GeV primary proton beam (~1×10^{10} /sec)
  - on thin targets (~0.1% int.length) to reduce electron background
  - especially collect ~10^5 $\phi \to e^+e^-$ in p+A reaction in 100 shift (~5weeks) operation
    - 100 times as large as E325's statistics
- New spectrometer using new technology (GEM tracker/HBD)
  - to cope with high rate (10MHz interaction on target)
  - mass resolution : less than 10 MeV/c^2
  - larger incident energy/larger acceptance $\to$ 10 times larger statistics.
  - higher rate capability $\to$ more 10 times stat. using x10 higher intensity beam
- Detector elements with new technology are being developed and tested.

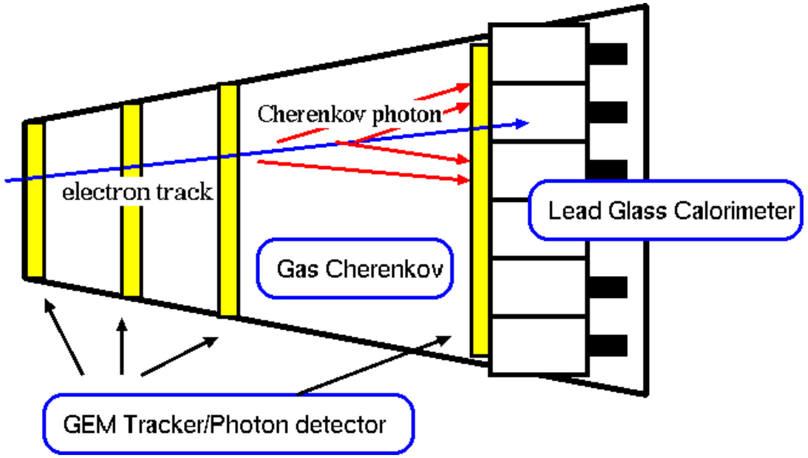
(Summary)

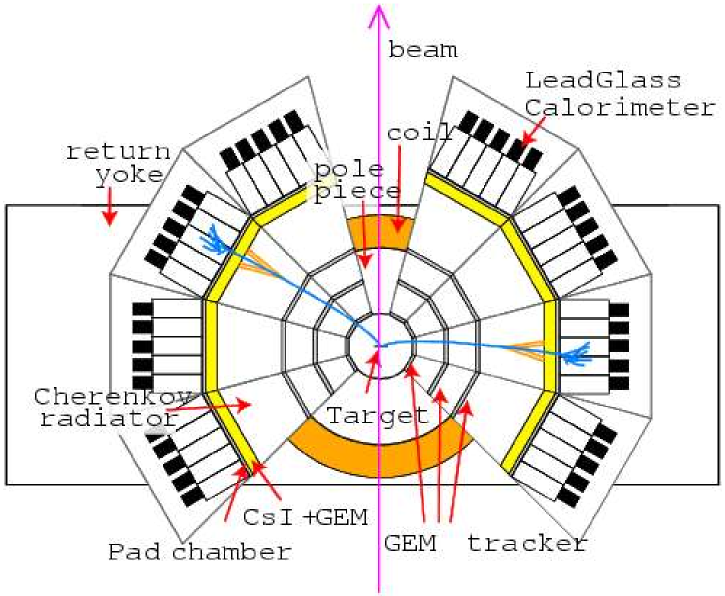
- High statistics of modified ϕ (and ρ/ω) $\rightarrow e^+e^-$
  - 100 times as large as E325's statistics
  - test in various matter size (0 ~ 10 fm)
-
-
- unique and world highest-quality experimental data
  - We can compare precisely with theoretical predictions based on the QCD in dense matter
  - Understanding the nature of hadrons and QCD vacuum via the chiral symmetry
- Future
  - $\sigma \rightarrow \gamma\gamma$ in p+A
  - A+A collision for highest matter density



Backup slides...

Cost estimation





Detector	element	description	cost[Yen] (/segment)	cost [M Yen]
GEM Tracker	Frame			50
	GEM foil	20 k ×(1+4+9) ×3	820k	23
	(10×10[cm^2] foil)			(1134 foils)
	readout strip board	100 k ×14	1.4M	38
	(10×10[cm^2])			(378 boards)
	electronics	3 k/ch ×(860 ×2)chs	5.2M	140
				(46440 chs)
Cerenkov Counter	Frame			50
	GEM foil	20 k ×25 ×3	1.5M	41
	(11×11[cm^2])			(2025 foils)
	CsI coat	40 k ×25 foils	1M	27
				(675 foils)
	readout pad board		500k	14
	electronics	3 k/ch ×460 chs	1.4M	38
				(12420 chs)
Outside Tracker	Frame			20
	readout strip board		500k	14
	electronics	3 k/ch ×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

Vector meson measurements in the world

dilepton mesurement

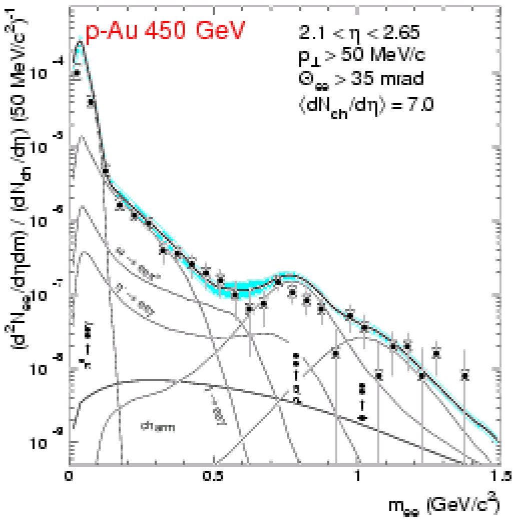
– HELIOS	(ee, μμ)	450GeV p+Be / 200GeV A+A
– CERES	(ee)	450GeV p+Be/Au / 40-200GeV A+A
– E325	(ee,KK)	12GeV p+C/Cu
– NA60	(μμ)	400GeV p+A/158GeV In+In
– PHENIX	(ee,KK)	p+p/Au+Au
– HADES	(ee)	4.5GeV p+A/ 1-2GeV A+A
– CLAS	(ee)	1~2 GeV γ+A
– *J-PARC*	(ee)	30/50GeV p+A/ ~20GeV A+A
– *CBM/FAIR*	(ee)	20~30GeV A+A
– TAGX	(ππ)	~1 GeV γ+A
– STAR	(ππ,KK)	p+p/Au+Au
– LEPS	(KK)	1.5~2.4 GeV γ+A
– CBELSA	($\pi^0\gamma$)	0.64-2.53 GeV γ + p/C/Nb

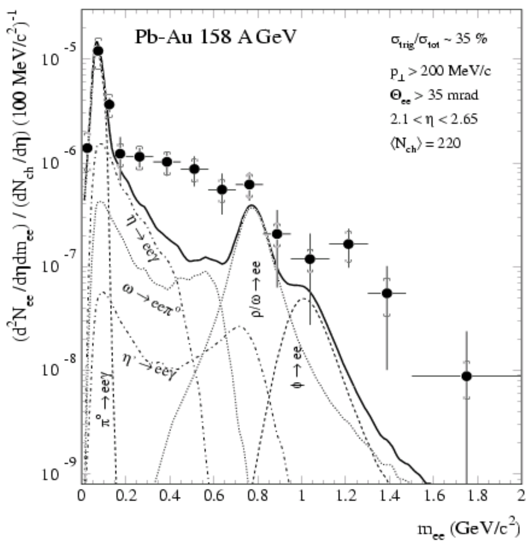
already state 'modified'
running/in analysis
future plan

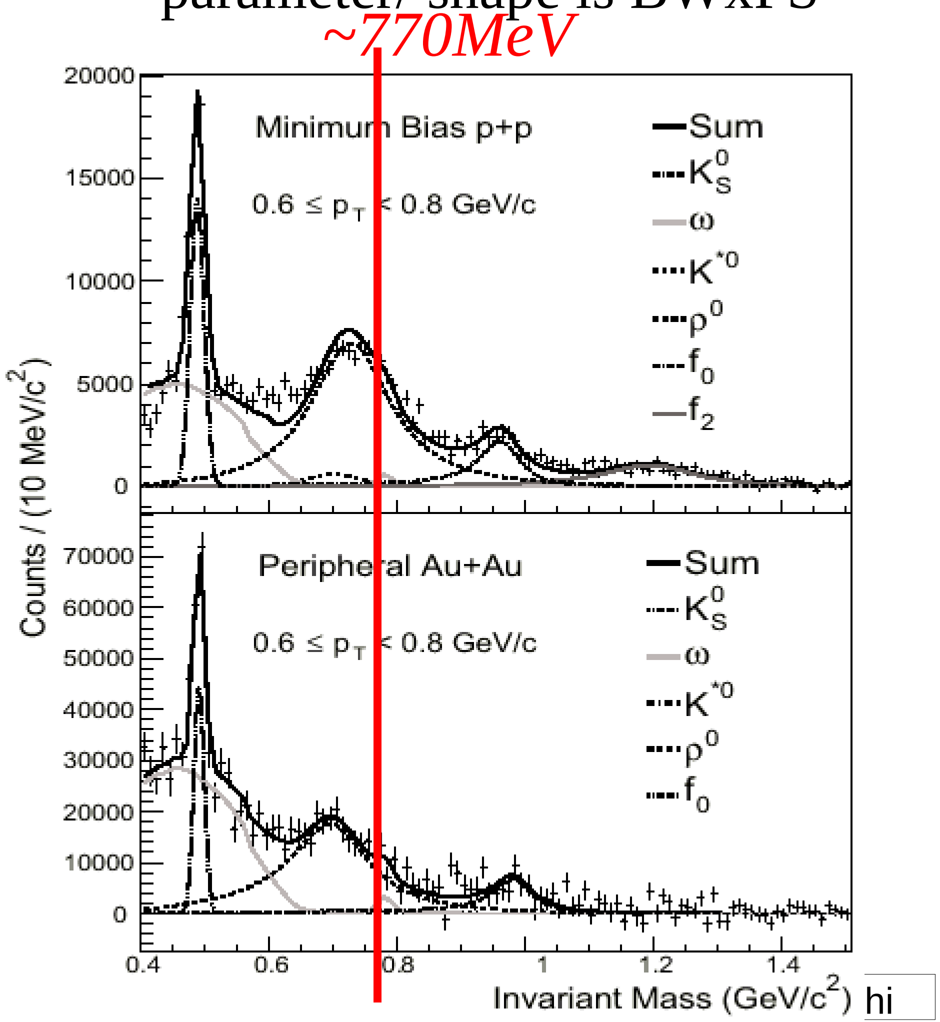
(Vector meson measurements)

- CERES : e^+e^- (EPJC 41('05)475)
  - anomaly at lower region of ρ
    - in A+A, not in p+A
  - relative abundance is determined by their statistical model

- STAR : $\rho \rightarrow \pi^+\pi^-$ (PRL92('04)092301)
  - 'shift' in p+p & A+A peripheral
    - relative abundance is free parameter/ shape is BWxPS

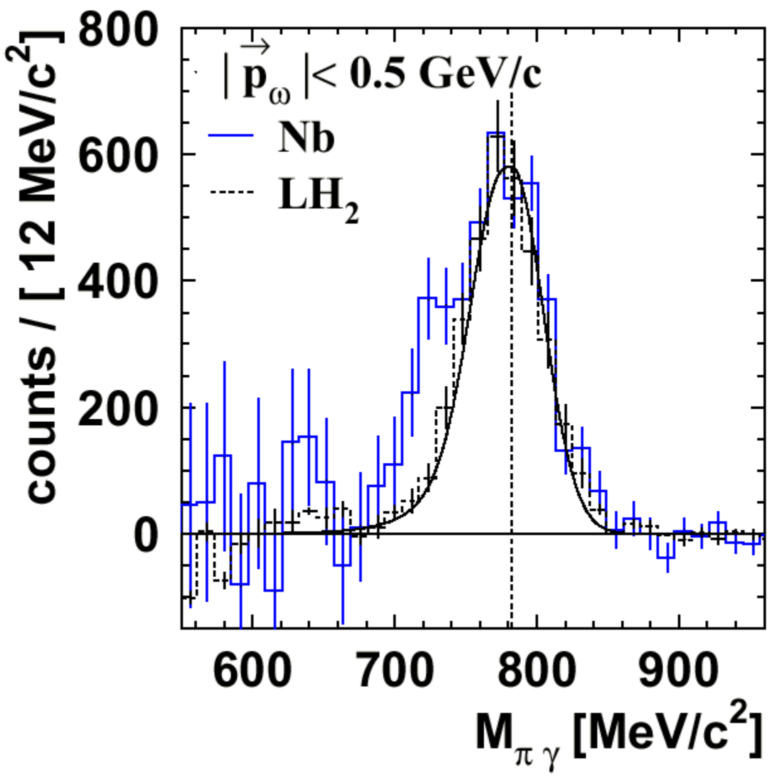




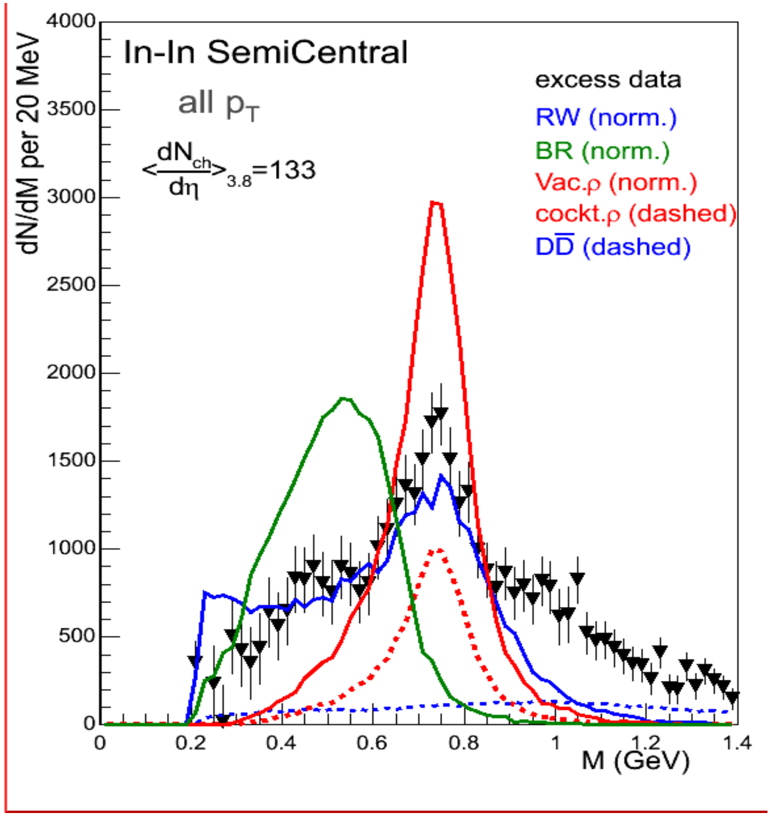


(Vector meson measurements)

- CBELSA/TAPS :(PRL94(05)192303)
  - $\omega \rightarrow \pi^0\gamma\ (\rightarrow \gamma\gamma\gamma\ )$
  - anomaly in γ+Nb, not in γ+p
    - direct comparison within the data
    - momentum dependence is seen



- NA60 : (nucl-ex/0510044)
  - $\rho \rightarrow \mu^+\mu^-$:
  - 'BR scaling is ruled out'



competitivity w/ dilepton measurements

HI/higher energy

- HELIOS (ee, μμ) 450GeV p+Be / 200GeV A+A
- CERES (ee) 450GeV p+Be/Au / 40-200GeV A+A statistics<E325
- NA60 (μμ) 400GeV p+A/158GeV In+In resolution>E325
- PHENIX (ee,KK) p+p/Au+Au
-
- E325 (ee,KK) 12GeV p+C/Cu stat.< J-PARC
- HADES (ee) 4.5GeV p+A/ 1-2GeV A+A stat.<~(?) E325
- CLAS (ee) 1~2 GeV γ+A stat. <\ (?) E325
-
- *J-PARC* (ee) 30/50GeV p+A/ ~20GeV A+A
- *CBM/FAIR*(ee) 20~30GeV A+A /p+A stat. of slow component < J-PARC
-

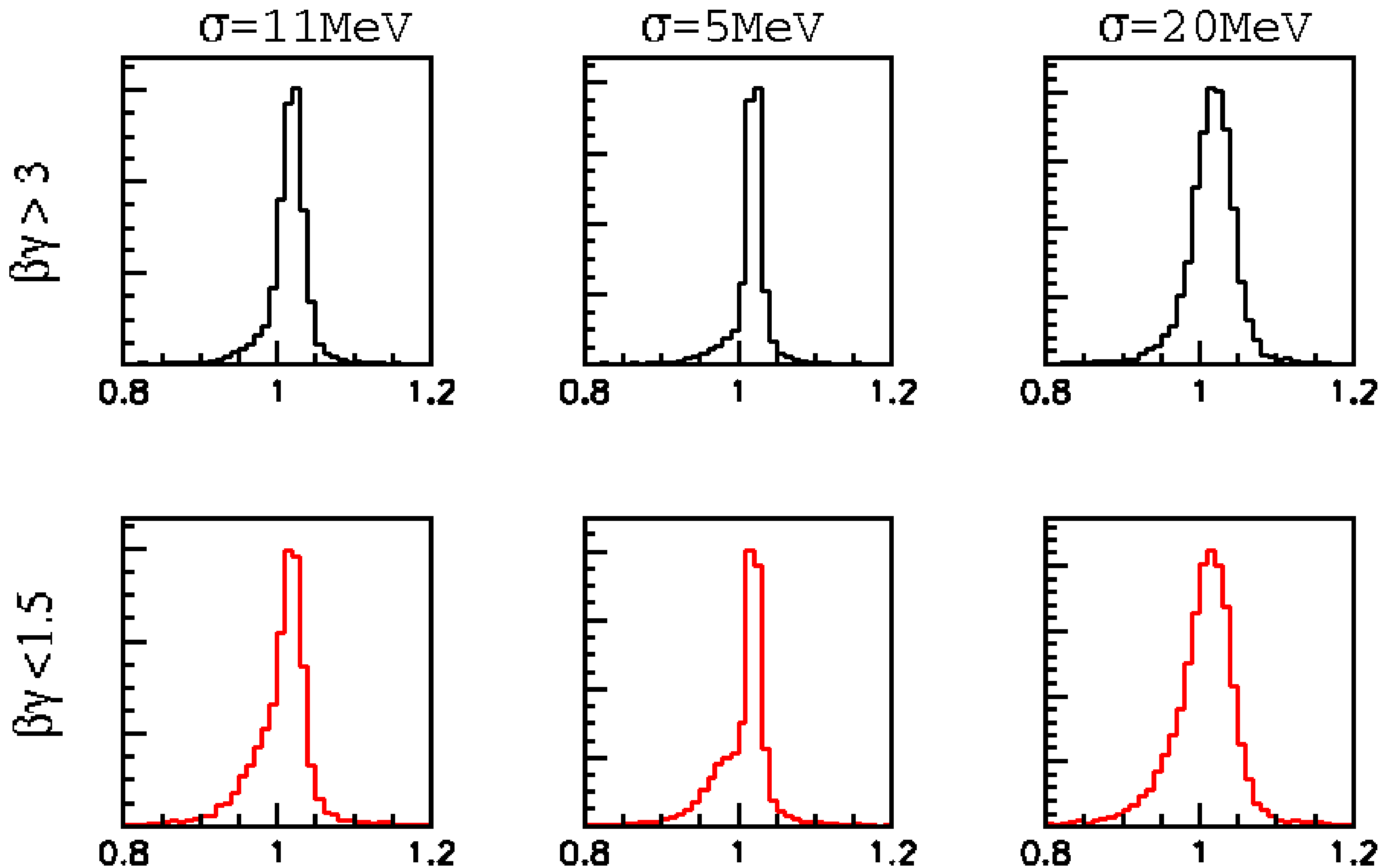
already state 'modified'
running/in analysis
future plan

mass resolution requirement

- mass resolution should be kept less than ~10MeV

Fast

Slow



(model calc.)

spectrometer acceptance

A) Reuse of E325 spectrometer

or

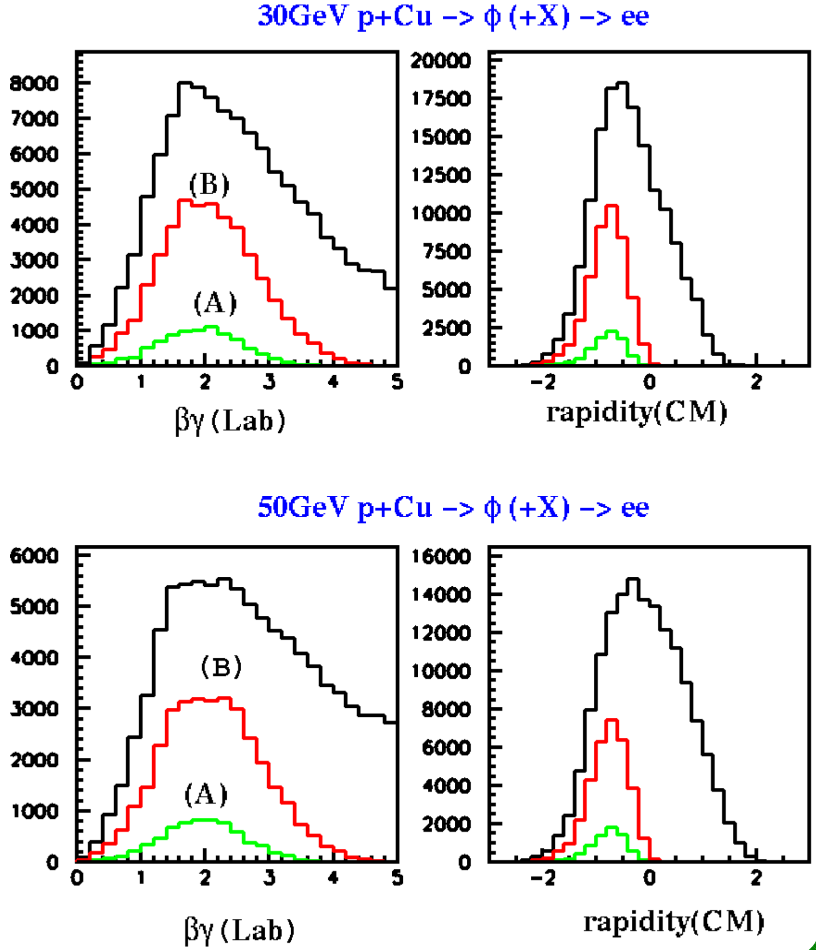
B) Proposed larger acceptance spectrometer

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 ϕ–>ee

(estimated by JAM)

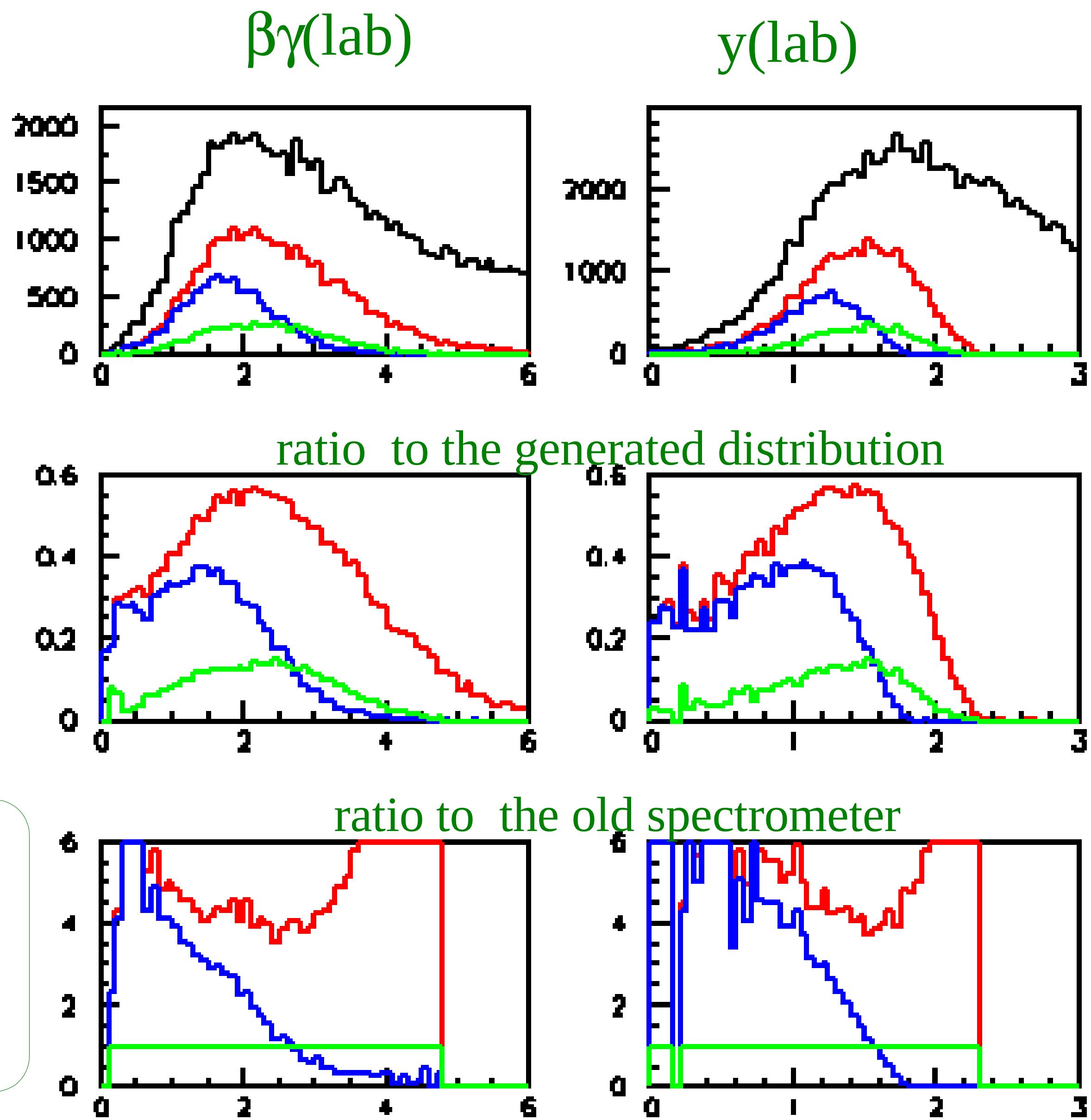


10 times can be collected by larger acceptance and beam energy (both 30 and 50 GeV are acceptable)

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.

spectrometer acceptance for $\phi \rightarrow e^+e^-$

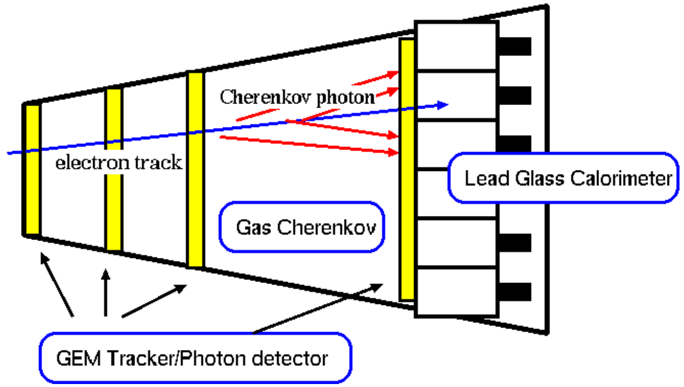
acceptance for the slow component ($\beta\gamma < 2$) is kept w/ forward cut



black : generated ϕ in 50GeV p+Cu
red : accepted by new spectrometer
(blue : new sp. but forward 20° cut)
green : old E325 spectrometer

GEM Tracker to cope with high rate

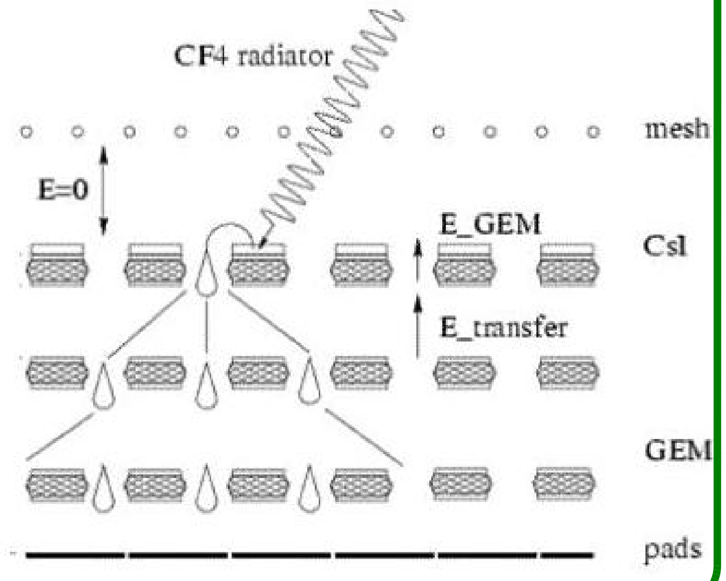
- Expected single rate is too high to use DC
  - origin : beam halo and/or from the interactions at the target
- E325 experience x 10 times
  - 1.8 MHz @ 6^{o} (20mm from the beam) /3.5mm x100mm cell of DC @r=200mm
    - 5KHz/mm^2 $\rightarrow$ GEM tracker can be operated (cf. COMPASS exp.)
  - 400KHz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



HBD (Hadron Blind Detector)

- HBD : Thr. type Gas Cherenkov Counter
  - CsI photocathode : UV photon sensitive
  - Triple GEM with pad readout
  - Ionized electrons are collected by mesh
    - photoelectrons are amplified by 3 stages
    - ionized electrons are amp. by only last 2 stages
    - → can detect only particles with cherenkov photon.
      - (1/100 of pion rejection)

Concept of HBD



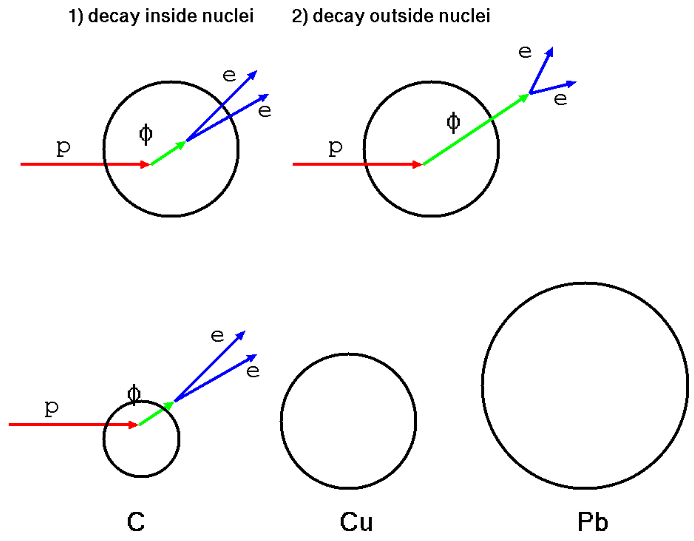
- Joint development with Weitzman Institute
  - originally for PHENIX upgrade plan
- Cover large area with no mirror
- 10cm x 10cm of Trigger tile : effectively fine segmented
  - essential to trigger the e^+e^- pair from the vector meson

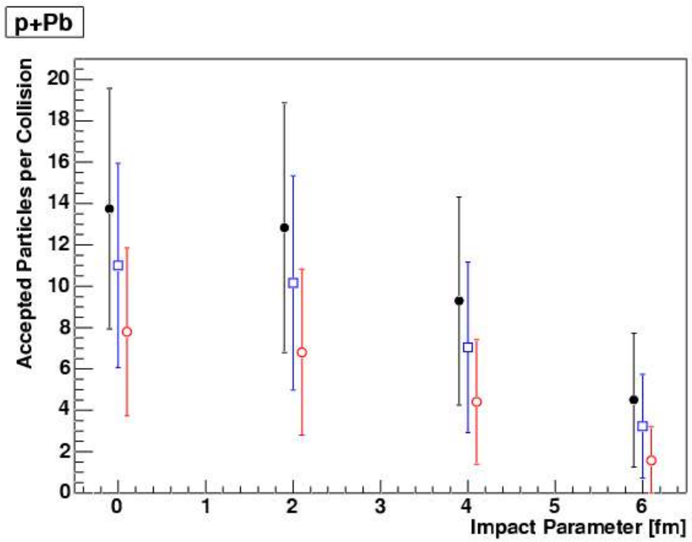
Trigger and S/N

- Main trigger background
  - E325: 1~2 KHz of 1st level-trigger rate [(GC * LG) x 2]
    - electron from upstream, accidental coincidence of two EID counters
  - Goal : same order of 1st level-trigger rate [(GC * LG * 3rd Tracker) x 2]
    - x10 beam : x100 accidental fake single electron
    - x5 fake accidental pair in larger acceptance
    - finer segmentation of trigger counters
      - GC(HBD) : x10 , LG : x4 , Tracker x10
      - GC-Tracker position matching : from the target
- Main offline background
  - combinatorial e^+e^- pair from π^0 Dalitz and γ conversions
  - simulation : 50GeV p+Cu (10M interaction/spill)
    - x 150 fake pair for x100 ϕ : S/N ~ 1/1.5 of E325
    - also trigger background (200/spill) : not so significant
  - ~4 $\phi \rightarrow e^+e^-$ & ~40 $\rho/\omega \rightarrow e^+e^-$/spill in the detector acceptance

New nuclear targets with larger statistics

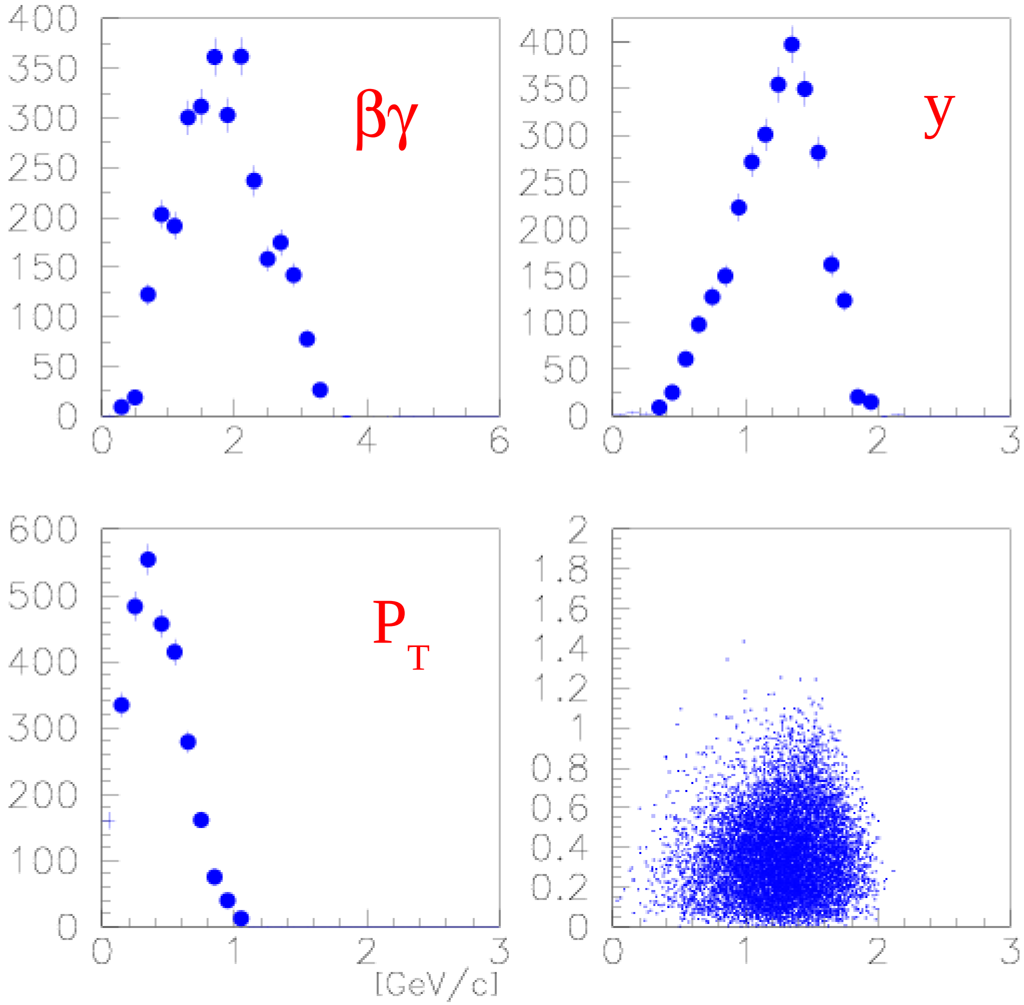
- Smaller nuclear target :
  - proton as reference(CH_2 -C subtraction)
  - LH target cannot be used because of the materials
- Larger nulcear target as Pb
  - larger nuclear matter
  - collision geometry(impact paramter) study using multiplicity
  - larger radiation length for heavier target
    $\rightarrow$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





measured kinematic distribution of $\phi \to e^+e^-$

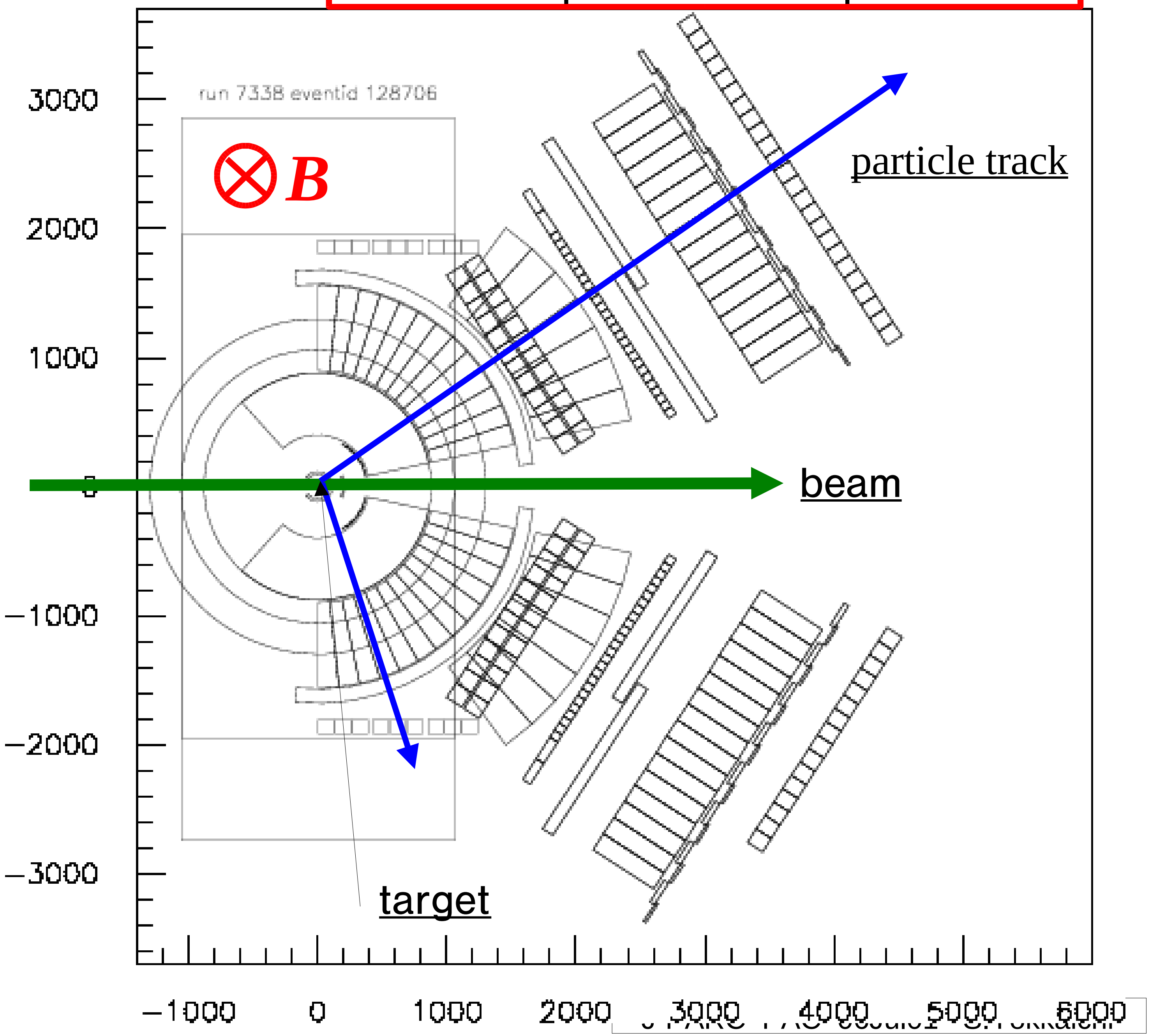
- $0.5 < y < 2$
- $1 < \beta\gamma < 3$
  - (1<p<3 GeV/c)
- $0 < P_T < 1$



Experimental setup

- Spectrometer Magnet
  - 0.71T at the center
  - 0.81Tm in integral
- Targets
  - at the center of the Magnet
  - C & Cu are used typically
  - very thin: ~0.1% interaction length
- Primary proton beam
  - 12.9 GeV/c
  - ~1x10^9 in 2sec duration, 4sec cycle

schematic plan view of spectrometer



Experimental setup - Detectors

Electron ID counters

Gas Cherenkov &

Lead Glass EMC

total 3×10^{-4} π rejection

with 78% e efficiency

in two-stage operation

Tracker

Three Drift Chambers

Kaon ID counters

Aerogel Cherenkov

& TOF