Proposal (P16):
Electron pair spectrometer at J-PARC 50-GeV PS to explore the chiral symmetry in QCD
Physics scopes

Satoshi Yokkaichi (RIKEN)

Collaboration

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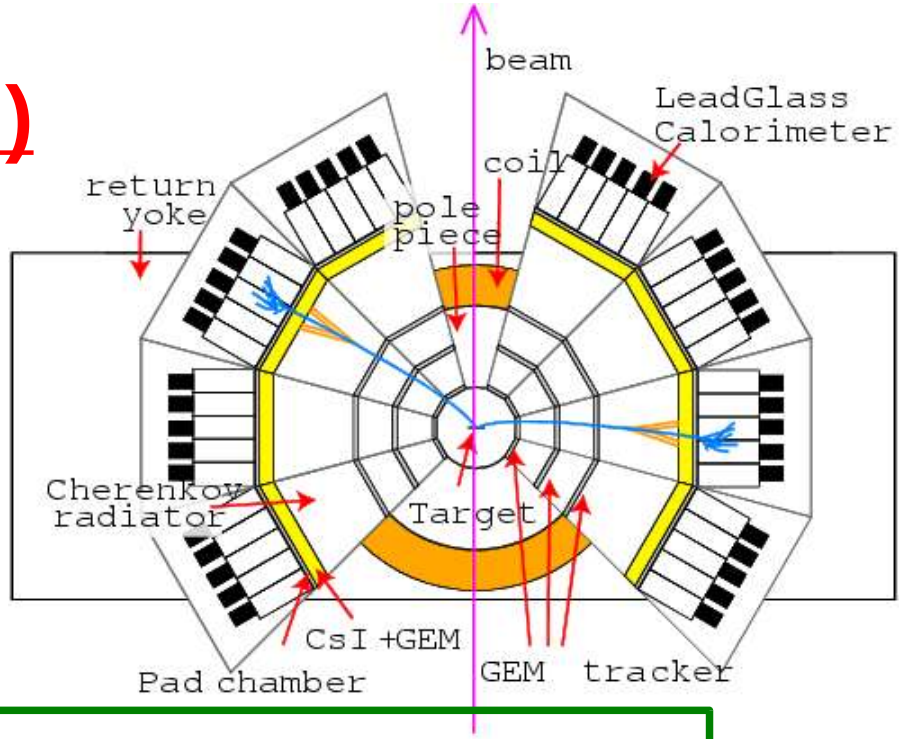


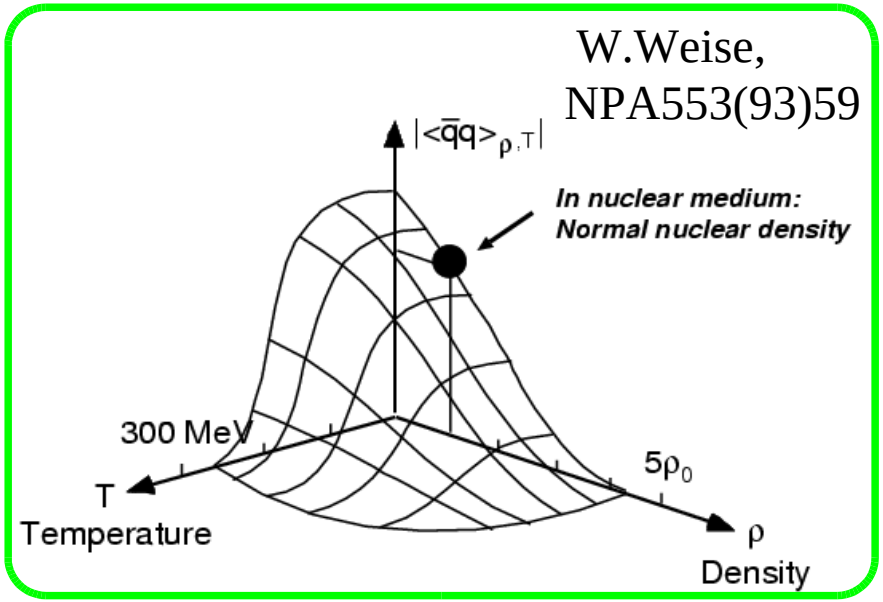
Proposal revised version 1 (2006 June 7) is located on :
http://rarfaxp.riken.go.jp/~yokkaich/paper/jparc-proposal-0604.pdf

Previous PAC : decision is deferred

- The physics addressed by this proposal is considered by the PAC to be important and worth pursuing at J-PARC. However the toy model used by the experimenters for describing the phenomenon of chiral symmetry restoration in p-A interaction appears too simple and unrealistic. To better evaluate the significance of the E325 results and the physics potential of this proposal, it would be extremely helpful to have additional information and clarification on the theoretical model used in the analysis. **The PAC therefore recommends that the decision on this proposal be deferred until more information on the theoretical interpretations becomes available.**
-
- Today I will clarify some possible confusions and address the physics impact of the proposed experiment.

Chiral symmetry restoration in dense matter

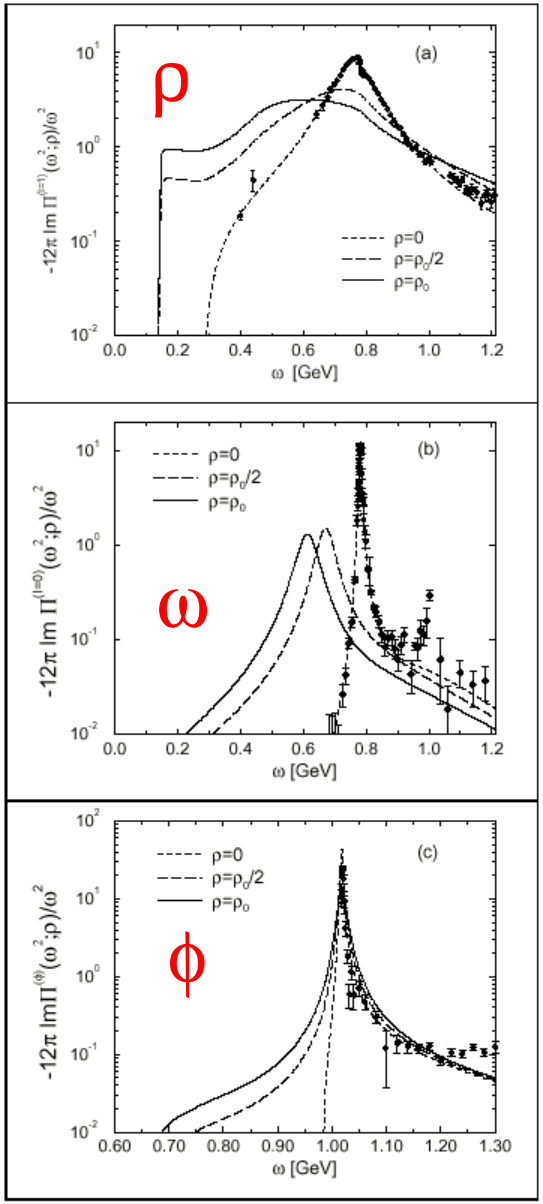
- Origin of hadron mass :spontaneous breaking of chiral symmetry
- In hot/dense matter, chiral symmetry is expected to restore
  - hadron modification is expected
- quark-antiquark condensate (order parameter) : ~2/3 even at the normal nuclear density, T=0
  - could approach by p+A reaction (not A+A)



- 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.

example of the theoretical predictions

effective Lagrangian
(chiral SU(3)+VMD)
Klingle,Kaiser,Weise,
NPA624(97)527



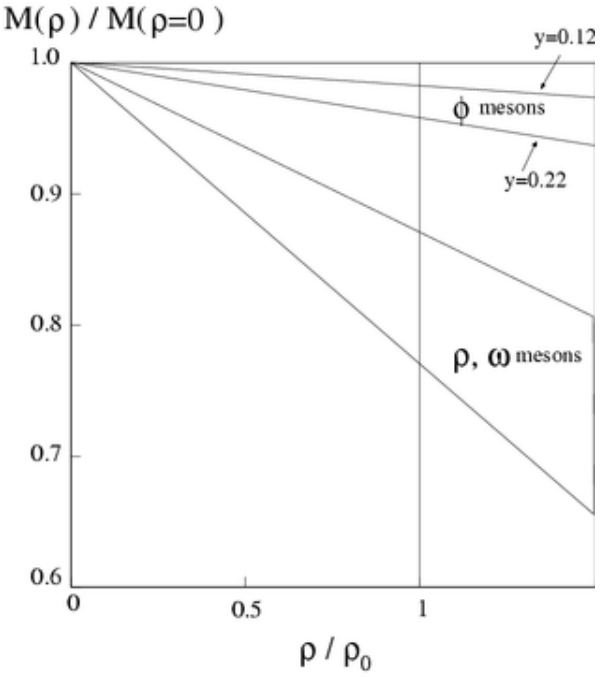
QCD sum rule
Hatsuda and Lee, PRC46(92)R34,PRC52(95)3364

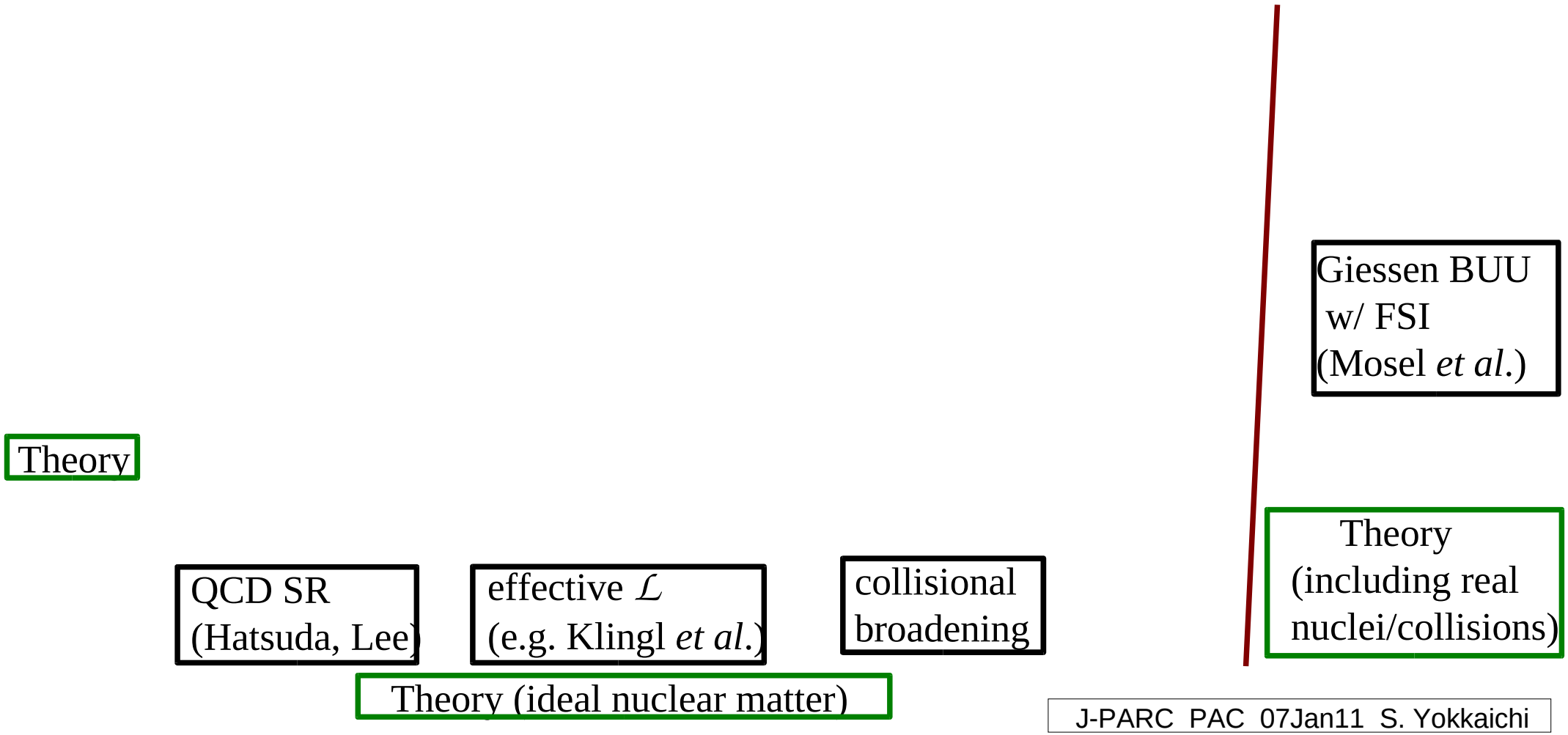
linear dependence on density

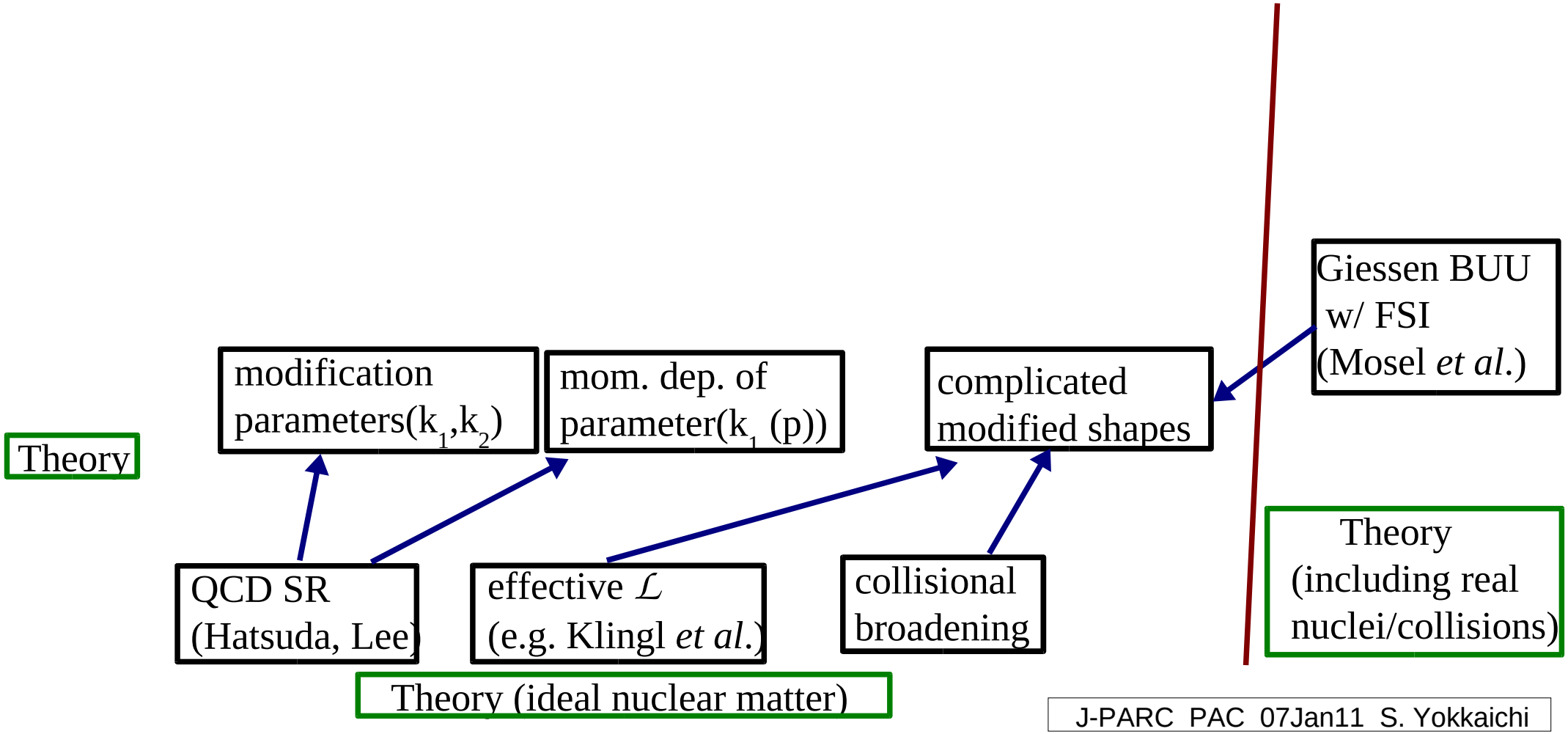
$m^*/m_0 = 1 - k\,\rho/\rho_0$

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




Giessen BUU
w/ FSI
(Mosel *et al.*)
Theory
Theory
(including real
nuclei/collisions)
QCD SR
(Hatsuda, Lee)
effective $\mathcal{L}$
(e.g. Klingl *et al.*)
collisional
broadening
Theory (ideal nuclear matter)


Theory
modification parameters(k_1,k_2)
mom. dep. of parameter(k_1 (p))
complicated modified shapes
Giessen BUU w/ FSI (Mosel *et al.*)
QCD SR (Hatsuda, Lee)
effective $\mathcal{L}$ (e.g. Klingl *et al.*)
collisional broadening
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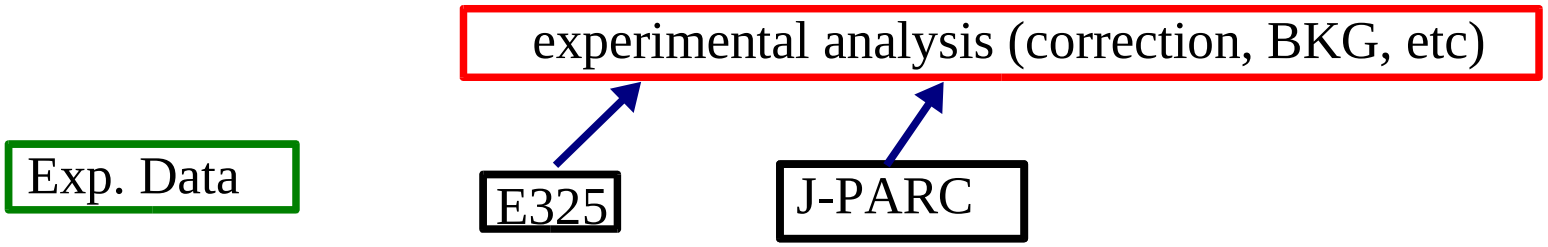
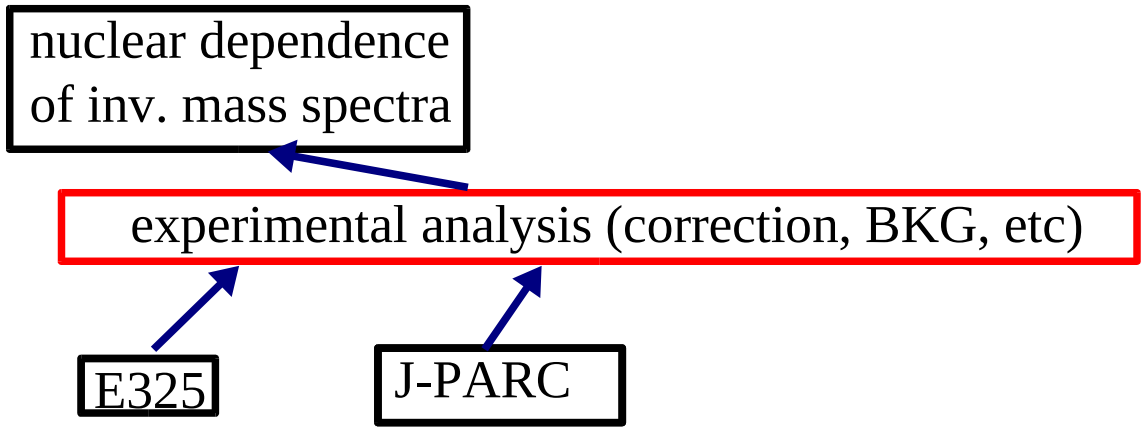
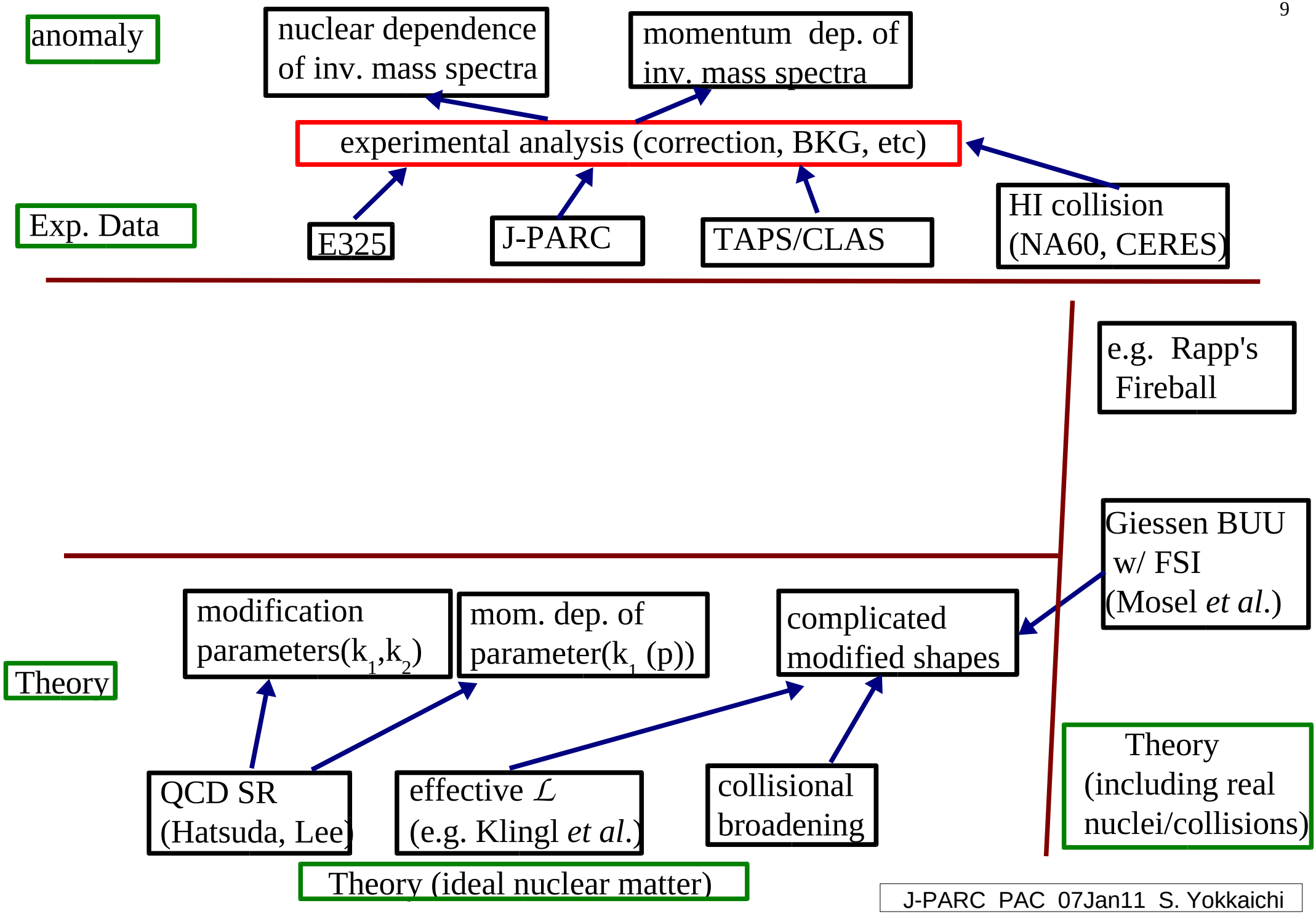

experimental analysis (correction, BKG, etc)
Exp. Data
E325
J-PARC

anomaly



Exp. Data


anomaly
nuclear dependence of inv. mass spectra
momentum dep. of inv. mass spectra
experimental analysis (correction, BKG, etc)
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E325
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TAPS/CLAS
HI collision (NA60, CERES)
e.g. Rapp's Fireball
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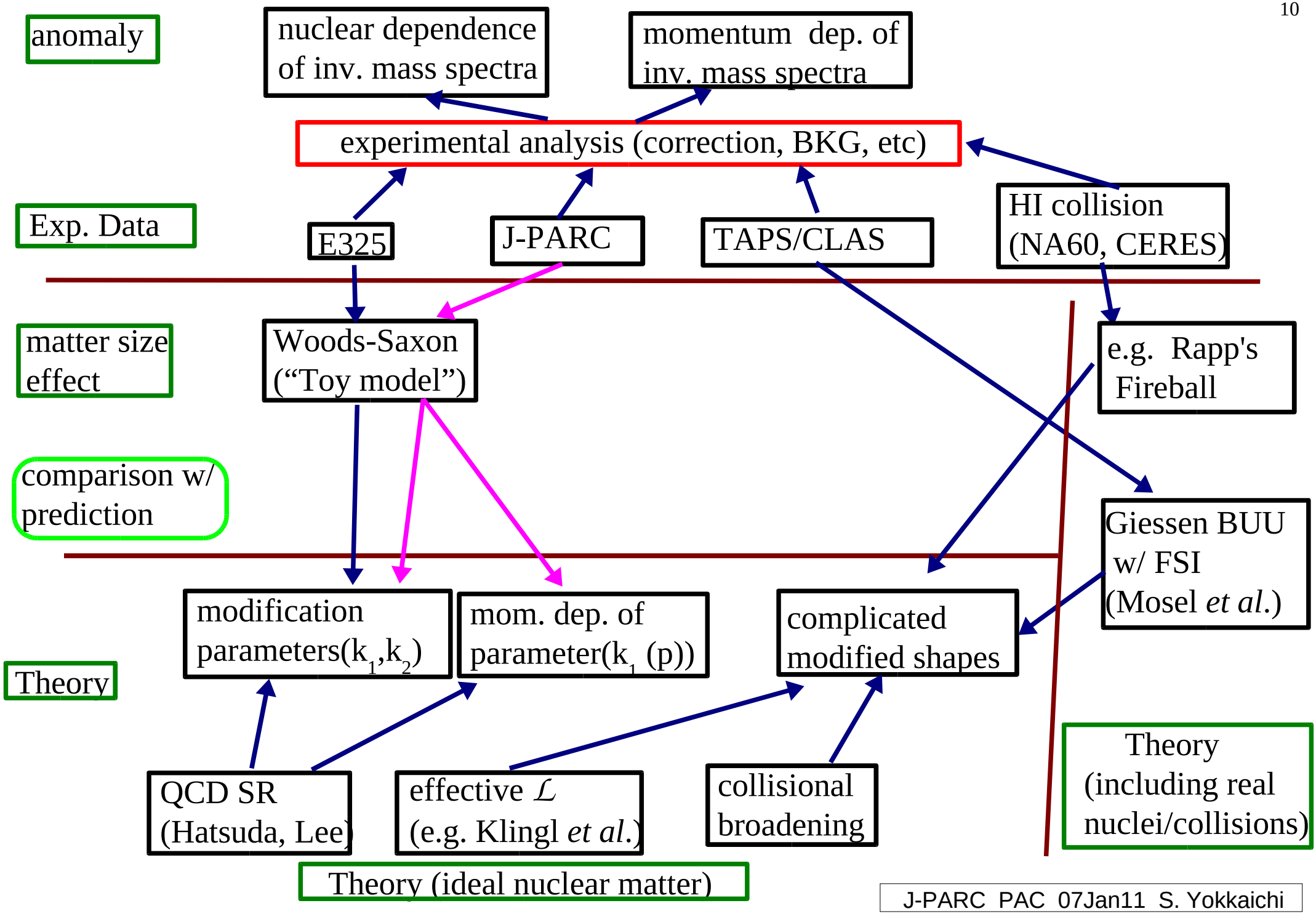
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matter size effect
Woods-Saxon ("Toy model")
e.g. Rapp's Fireball
comparison w/ prediction
Giessen BUU w/ FSI (Mosel *et al.*)
modification parameters(k_1,k_2)
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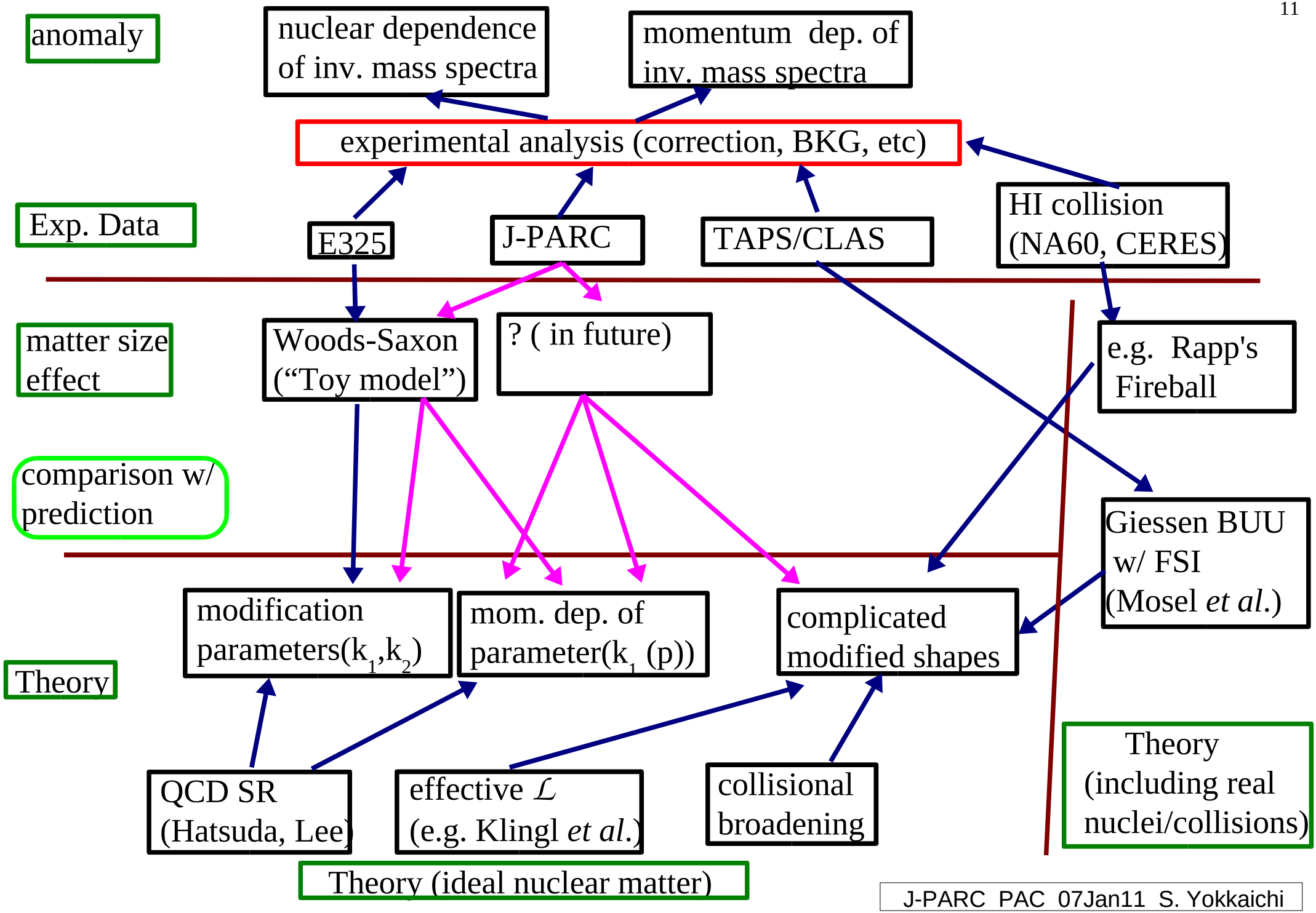
Theory (ideal nuclear matter)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Exp. Data
E325
J-PARC
TAPS/CLAS
HI collision (NA60, CERES)
matter size effect
Woods-Saxon ("Toy model")
? (in future)
e.g. Rapp's Fireball
comparison w/ prediction
Giessen BUU w/ FSI (Mosel *et al.*)
modification parameters(k_1,k_2)
mom. dep. of parameter(k_1 (p))
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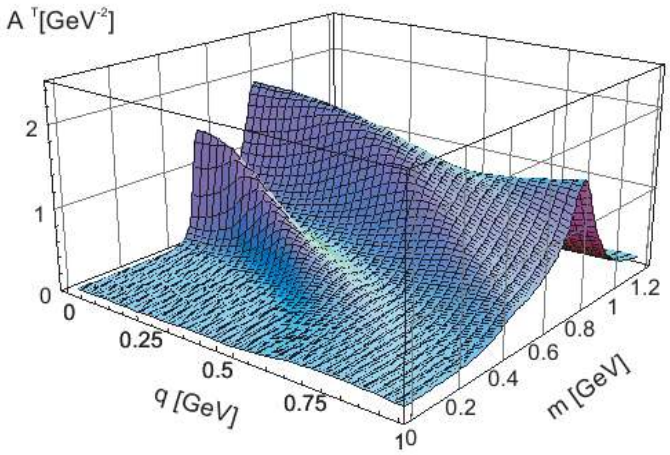
Theory (including real nuclei/collisions)
Theory (ideal nuclear matter)

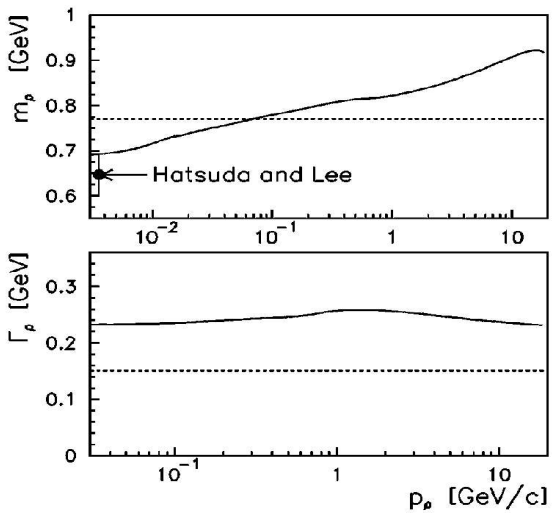
Theoretical approaches for the time being

- QCD sum rule(Hatsuda and Lee) / effective Chiral Lagrangian(Klingl, Kaiser, Weise)/Collisional broadening (Yamazaki and Akaishi, etc.) /...
  - infinite nuclear matter, p=0 or p<1GeV/c
- Giessen BUU (Mosel et al.) ... used by TAPS/CLAS
  - nuclear transport calculation with FSI
  - no modification in more than 1GeV/c
    - contradicts E325 observations, and S.H.Lee's prediction
-
- Connection to the chiral symmetry and observed vector meson spectra in p+A reactions is still an open problem also theoretically.

non-trivial form of the dispersion relation (mass VS momentum)

- S.H.Lee (PRC57(98)927)
  - 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



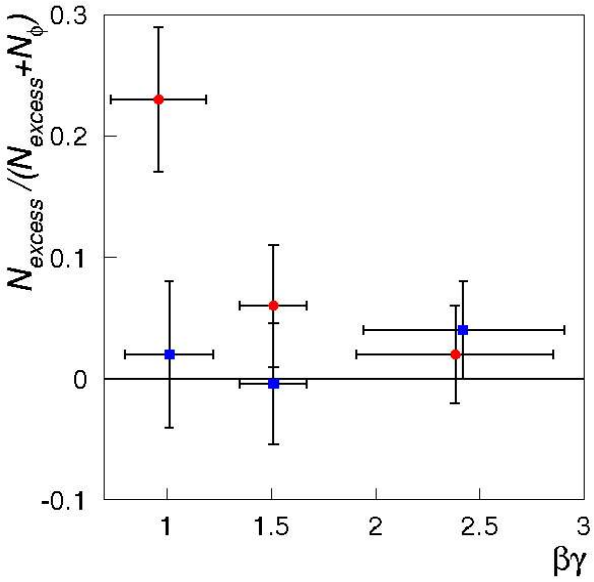


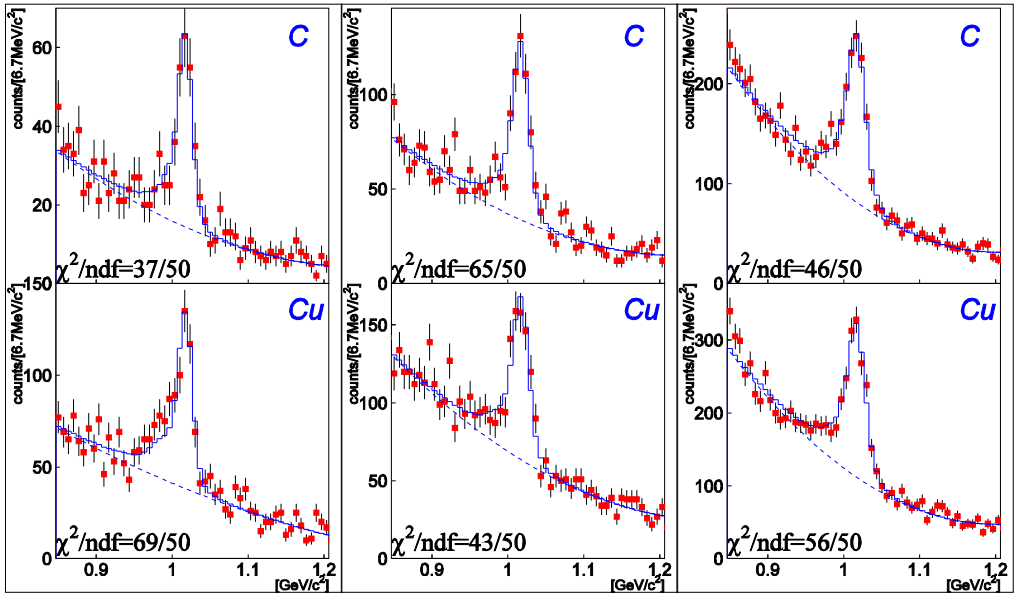
misunderstandings(?)

- E325 results : existence of the spectral modification of vector mesons in nuclear matter
  - is not “model-dependent”.
    - obtained data cannot be reproduced by the vacuum shape
  - “toy model” is only used to deduce the modification parameters considering the relation of the nuclear-size and $\beta\gamma$.
    - statistics are not enough to determine many parameters
      - momentum dependence, formation times, etc.
  - For the time being, there is no “established nuclear model” to reproduce the E325 results anyway. -> see later
- Connection to the chiral symmetry is still an open question.
  - even if the modification parameters are not “model-dependent”

E325 Model fitting : parameter k_1 and k_2

- Excess is observed in the ϕ spectrum
- To determine the shift parameters...
  - $m^*/m_0 = 1 - k_1 \rho/\rho_0$
  - $\Gamma_{tot}^*/\Gamma_{tot}^0 = 1 + k_2 \rho/\rho_0$
- We fit the observed 6 mass spectra (C/Cu, slow/mid/fast) with modified MC shapes and calculate the χ^2 as the sum of 6 spectra





Best Fit Value:

(nucl-ex/0511019, PRL in press)

$k_1 = 0.034 + 0.006 - 0.007$

(3.4 % mass decreasing at ρ_0)

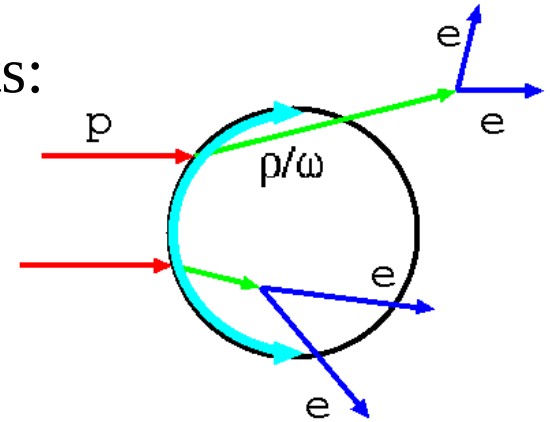
$k_2 = 2.6 \quad +1.8 \; -1.2$

(3.6 times width broadening at ρ_0)

Toy model used E325

- Assumptions to include the nuclear size effect in the fitting shape
  - mesons fly through the nucleus, decay with modified mass if the decay point is inside nucleus
    - meson production point : from our measurements:
      - measured $\alpha \sim 2/3$ for ω , ~ 1 for ϕ [PRC]
      - surface for ω, volume for ϕ
    - meson momentum :
      - measured distribution in our experiment
        - $\sim 0.8(1.0)\ \mathrm{GeV} < p < \sim 2.4\ (3.0)\ \mathrm{GeV}$ for $\omega(\phi)$
    - nuclear density distribution : Woods-Saxon type
    - ρ & ω meson modification form : $m^*/m_0 = 1 - k\ \rho/\rho_0$

(k=0.16±0.06 in Hatsuda & Lee, '92,'96)



“Toy model” is enough

- based on some experimental observations
  - meson momentum distribution is observed one
    - absorption is effectively counted
  - generation point distributions are estimated by the observed nuclear dependence of the production CS
  - WS density distribution is also based on the exp.data
- hadronic effect (e.g. collisional broadening) are neglected to avoid the double counting
  - QCDSR prediction includes all QCD-originated effects in principle.
- momentum dependence of the shift is neglected in E325 analysis : too small statistics to determine it from the data
  - can be determined at J-PARC by fine binning in momentum

another “model” to include the nuclear size?

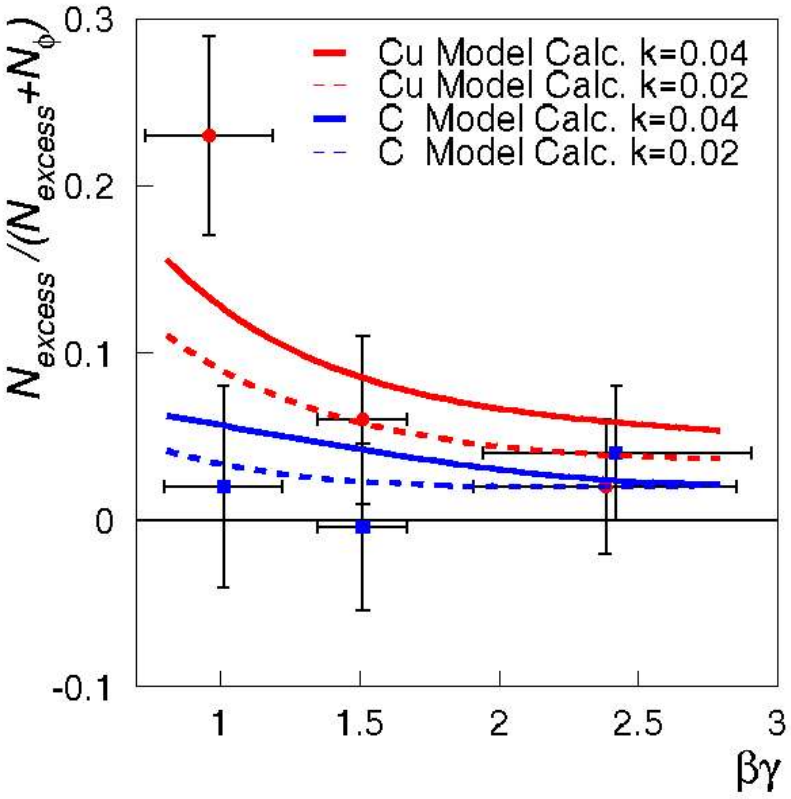
- There is no calculation for the mass modification in finite size real nuclei, except for the Giessen BUU.
- They are trying to explain the real spectra, including “final state interactions (FSI)”. However, for the time being they say no modification over p=1GeV/c, while E325(and J-PARC)mean meson p=1.6~2 GeV/c ($\beta\gamma$=2) , and it looks inconsistent E325 observation.
- In E325 three PRL papers (two is already published or accepted) which were mentioned the 'toy' model, no referee criticized the model itself.
- Thus we don't adopt the BUU for the time being.

Experimental approach: What can we reveal by the proposed experiment?

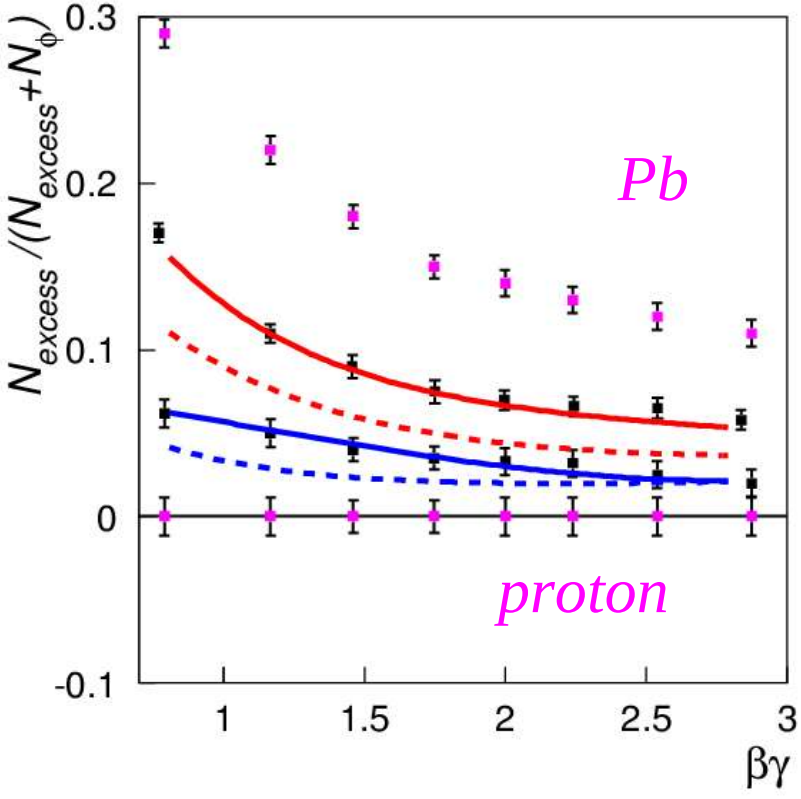
- At J-PARC,
  - High statistics & new nuclear targets & collision geometry
- Establish the existence of ϕ mass modification
  - using not only Cu but smaller/larger nuclei
  - model independent
- determine the shift parameters, shape analysis : comparison with various spectra
  - model (for nuclear size effect) dependent, in principle

(proposed experiment at J-PARC)

- Main goal : collect ~1x10^5 $\phi \rightarrow$ ee for each target in 5 weeks
  - 100 times as large as E325
    - velocity dependence of excess (model independent quantity)
    - new nuclear target as Pb, H
    - stat. error bars can be shrunk to the size of current syst.err.



x 100 stat.

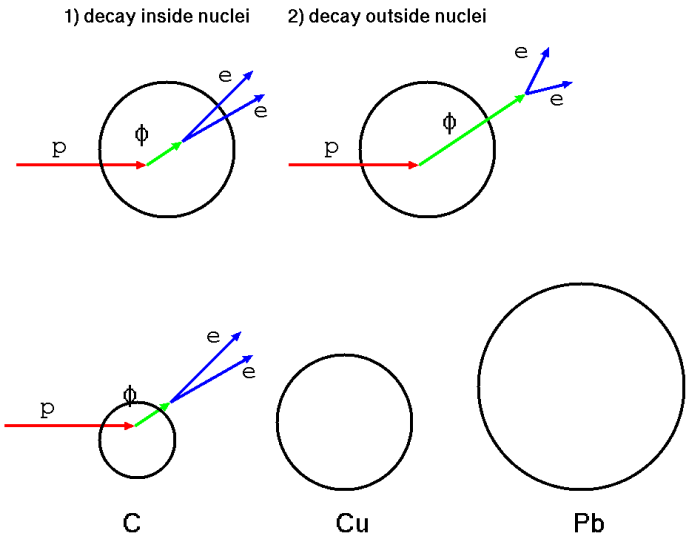


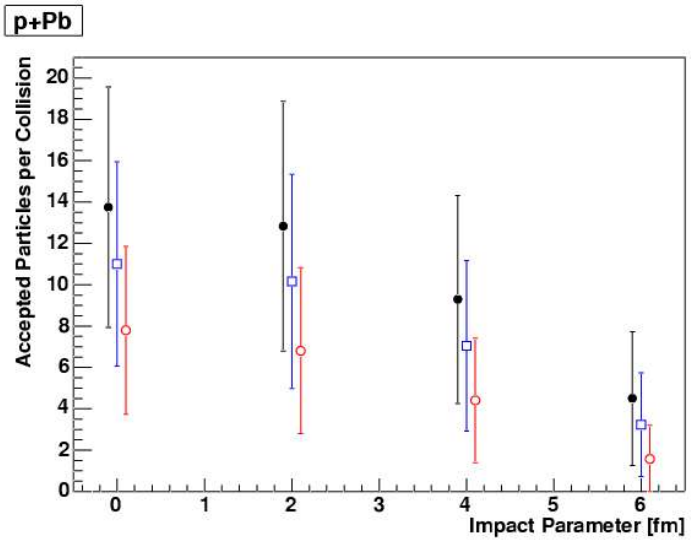
(proposed experiment at J-PARC)

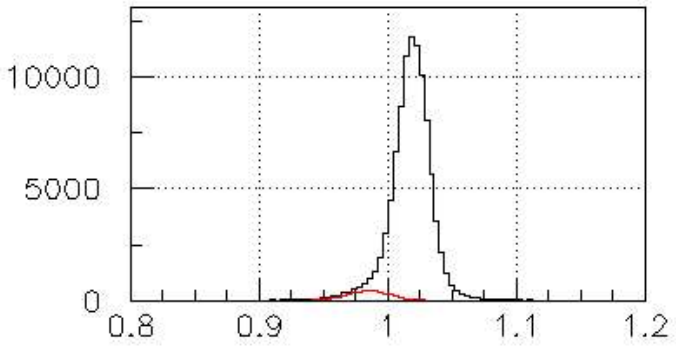
- new nuclear targets: Pb, H → *next*
- velocity dependence of the spectra
  - can be converted to the momentum dependence of the mass in medium for the first time :
    - $k_1(p)$, $k_2(p)$ common to nuclear size
- very slow ϕ s : 1000~3000 of $\beta\gamma<0.5$, 100~200 of $\beta\gamma<0.2$
  - same stat. as current E325 statistics
  - detector acceptance is enough for such slow mesons
  - kinematical distribution (in the very low stat. region) is taken from JAM

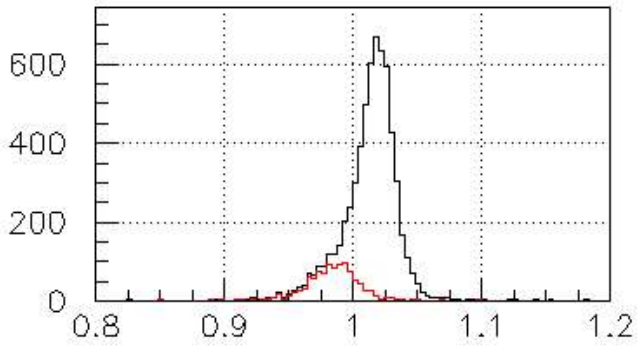
New nuclear targets with larger statistics

- Smaller nuclear target :
  - proton as reference(CH_2 -C subtraction)
  - LH target cannot be used because of the materials
- Larger nuclear target as Pb
  - larger nuclear matter
  - collision geometry (“impact parameter”) study using multiplicity (PRC60 024902 (18GeV p+A))
    - can be divided to at least two regions
    - another type of the matter size effect
  - larger radiation length for heavier target
    $\rightarrow$ more thiner foil target to keep S/N
    - high statistics capability is required.

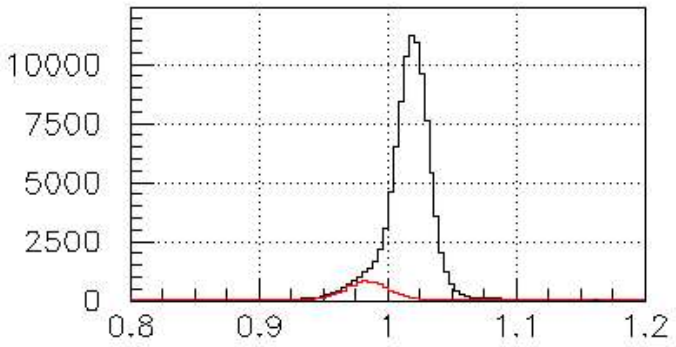


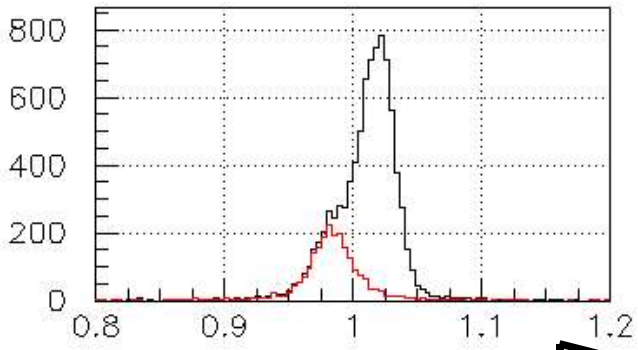






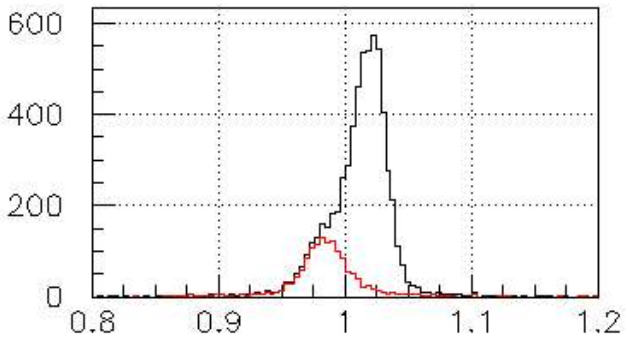
Cu

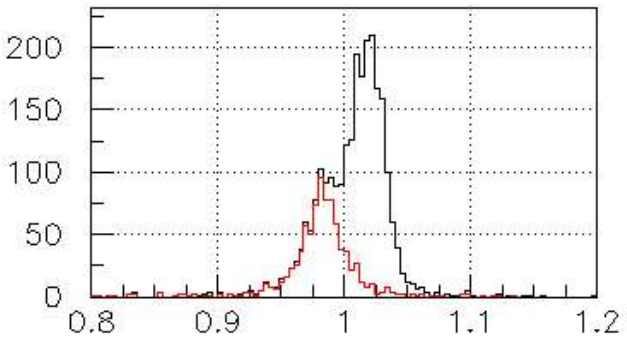




Pb

Pb central





Vector meson measurements in the world

dilepton mesurement

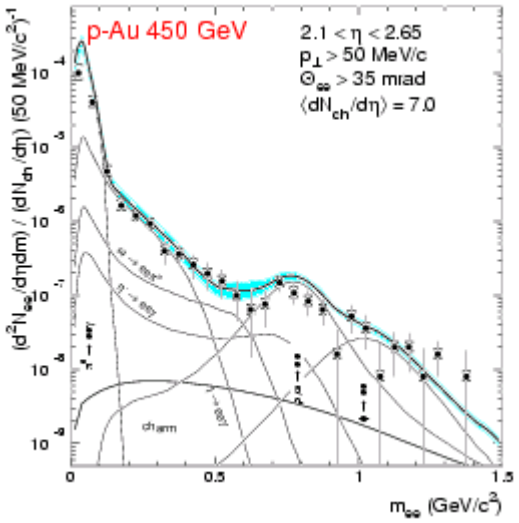
- HELIOS (ee, μμ) 450GeV p+Be / 200GeV A+A
- CERES (ee) 450GeV p+Be/Au / 40-200GeV A+A
- E325 (ee,KK) 12GeV p+C/Cu
- NA60 (μμ) 400GeV p+A/158GeV In+In
- PHENIX (ee,KK) p+p/Au+Au
- HADES (ee) 4.5GeV p+A/ 1-2GeV A+A
- CLAS-G7(ee) 1~2 GeV γ+A
- *J-PARC* (ee) 30/50GeV p+A/ ~20GeV A+A
- *CBM/FAIR* (ee) 20~30GeV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

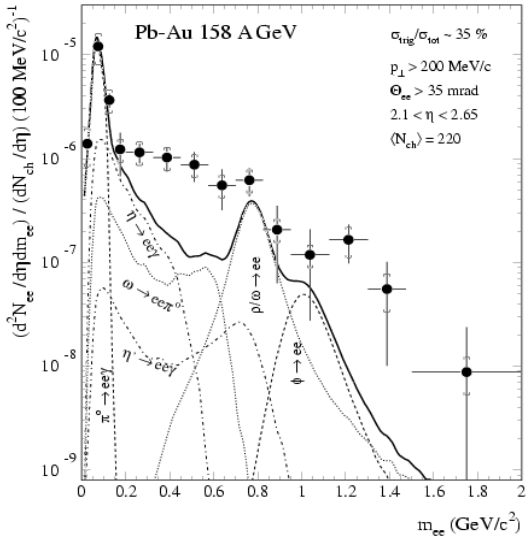
- TAGX (ππ) ~1 GeV γ+A
- STAR (ππ,KK) p+p/Au+Au
- LEPS (KK) 1.5~2.4 GeV γ+A
- CBELSA ($\pi^0\gamma$) 0.64-2.53 GeV γ + p/C/Nb

already state 'modified'
running/in analysis
future plan

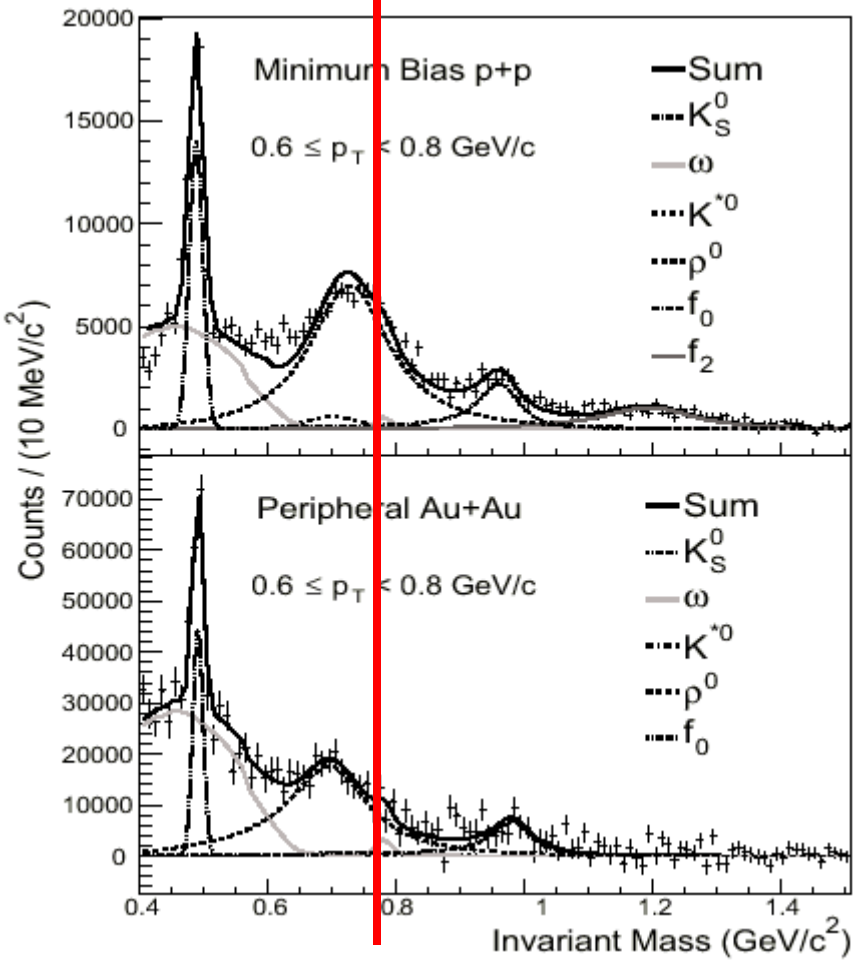
(Vector meson measurements)

- 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
  - recently stated the 'broadening' (nucl-ex 0611022)
- STAR : $\rho \rightarrow \pi^+\pi^-$ (PRL92('04)092301)
  - 'shift' in p+p & A+A peripheral
    - relative abundance is free parameter/ shape is BWxPS



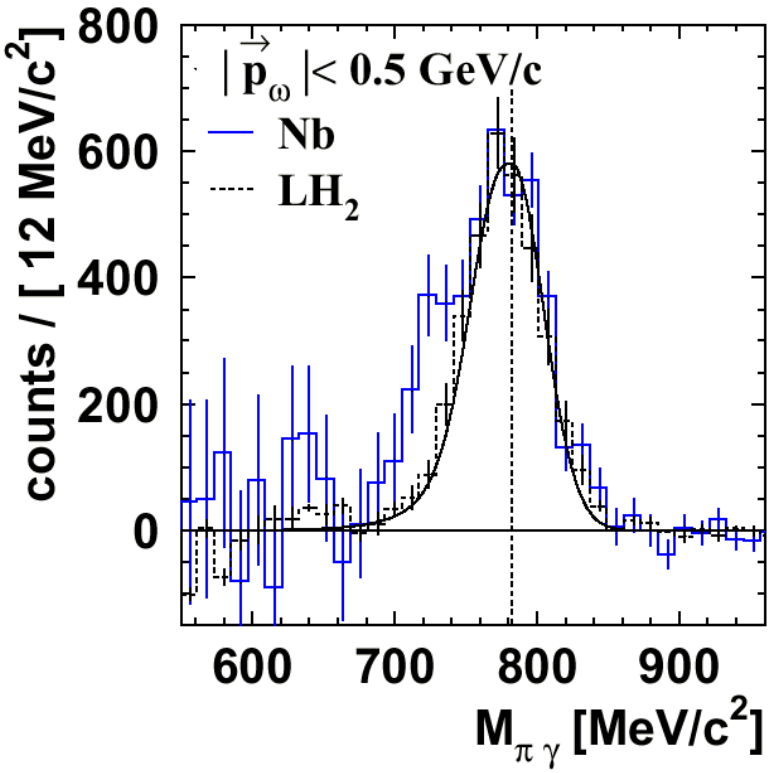


~770MeV

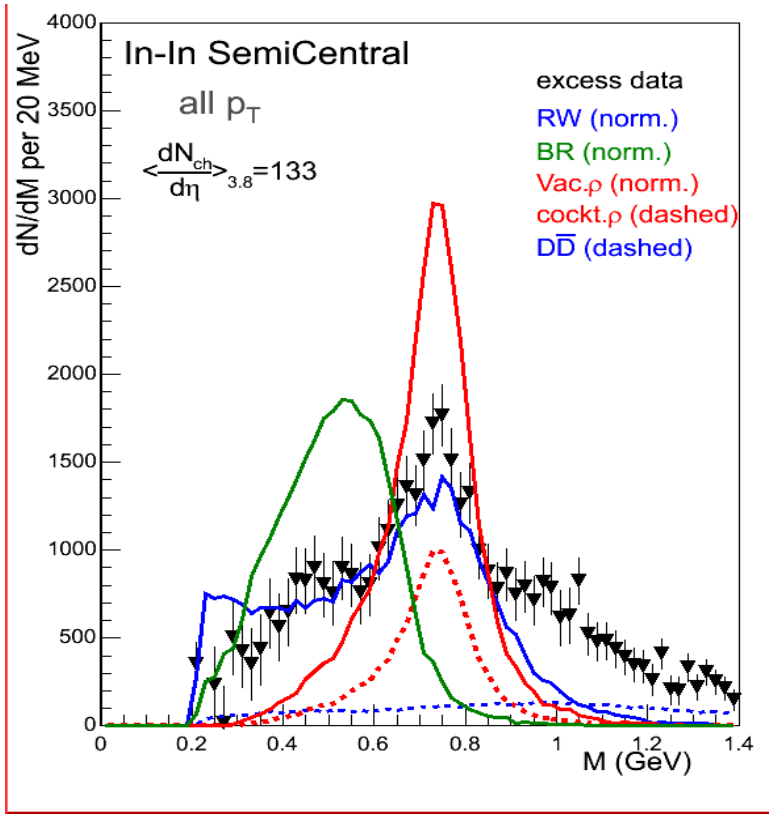


(Vector meson measurements)

- 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 statistics< 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

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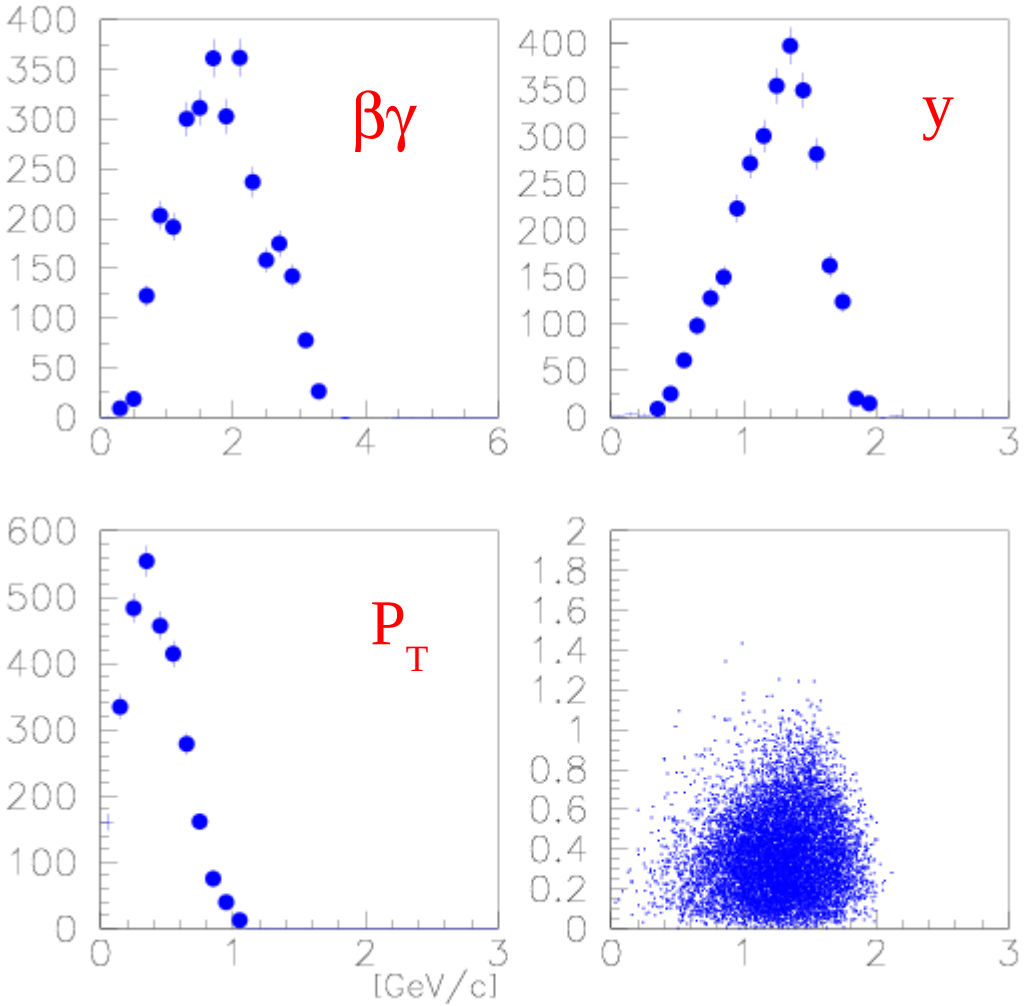
running/in analysis
future plan

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)
  - especially collect ~10^5 $\phi \rightarrow e^+e^-$ for each target in 100 shift (~5weeks) operation : 100 times as large as E325's statistics
- New spectrometer using new technology (GEM tracker/HBD)
- Impact of the proposed experiment
  - vector meson modification in various size (0~10fm) of dense matter
  - "momentum dependence of in-medium mass"
  - check the predictions of various theories : which is better to describe the data?
    - based on the chiral symmetry, effective theory, just FSI, etc
  - new theoretical calc. would be developed to interpret the current & future data
    - momentum dependence, nuclear size effect, etc.

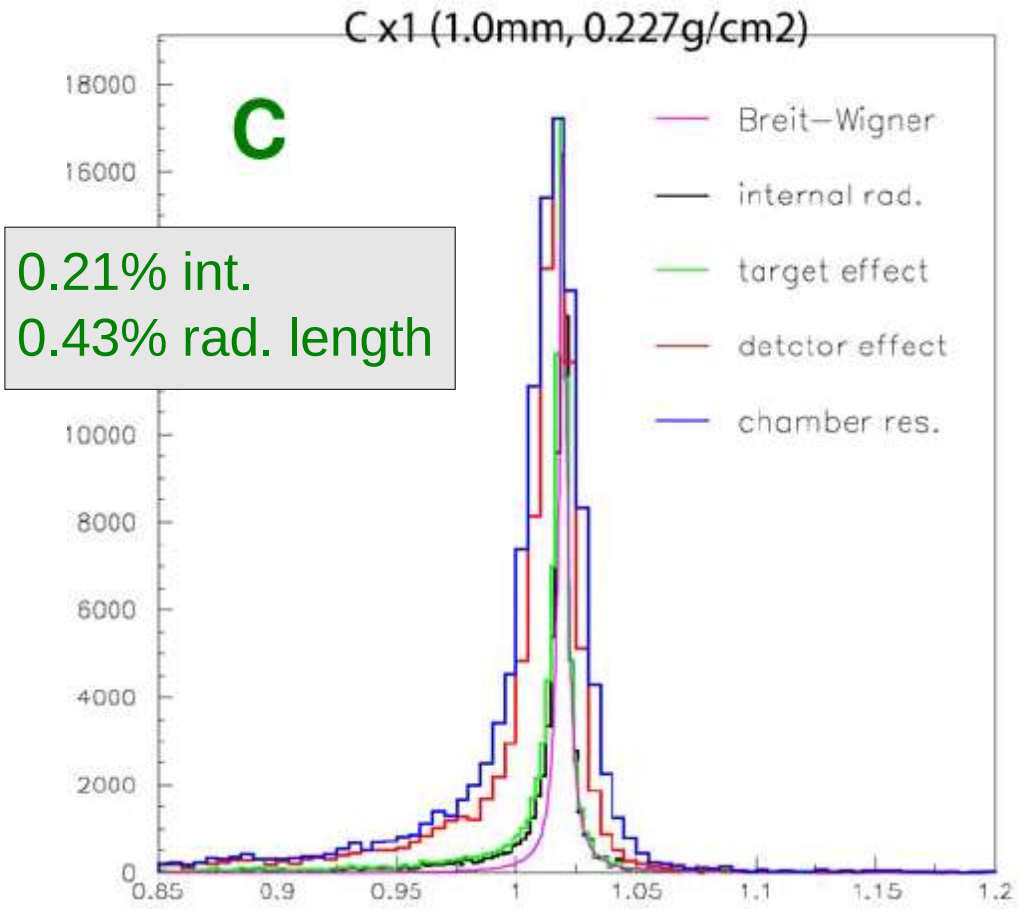
measured kinematic distribution of $\phi \rightarrow e^+e^-$

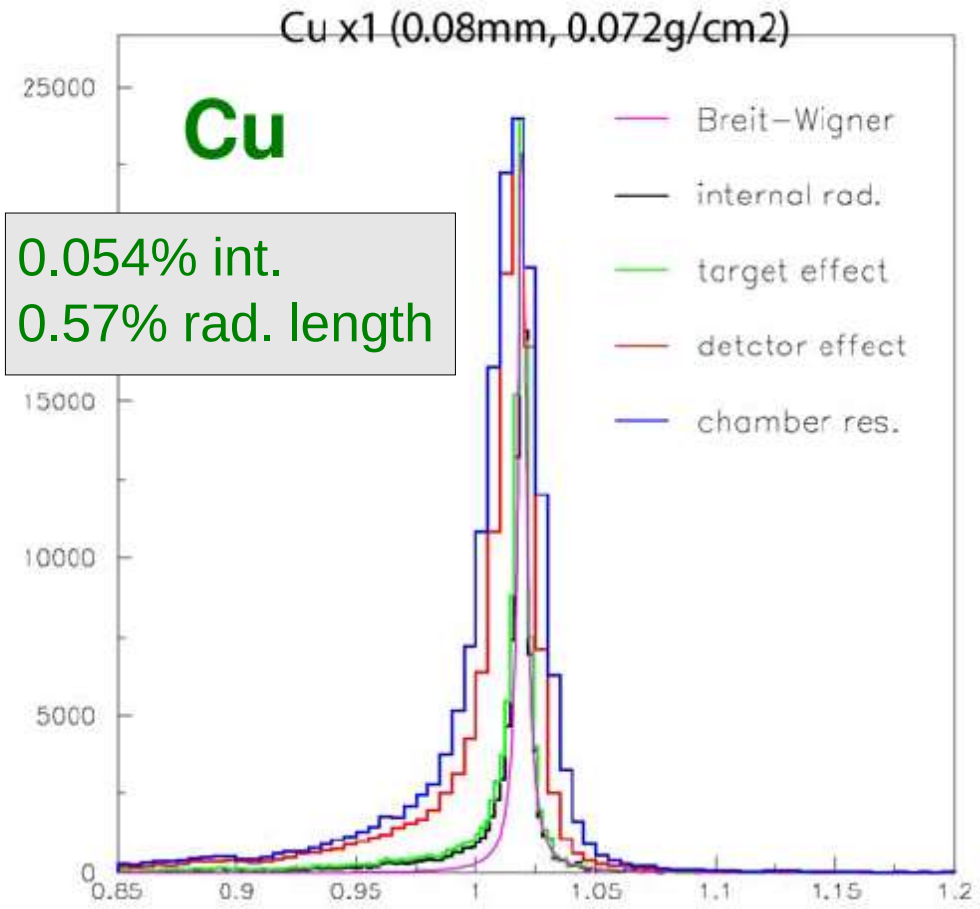
- $0.5 < y < 2$
- $1 < \beta\gamma < 3$
  - (1<p<3 GeV/c)
- $0 < P_T < 1$



experimental effects on the BW shape

- target material is negligible for ~0.5% radiation length
- detectors :up to 4.5 % rad. length for the tracking region





(experimental effects on the BW shape)

- thick target effect : 1g/cm^2