Mesons in the Medium: Experiments with CLAS

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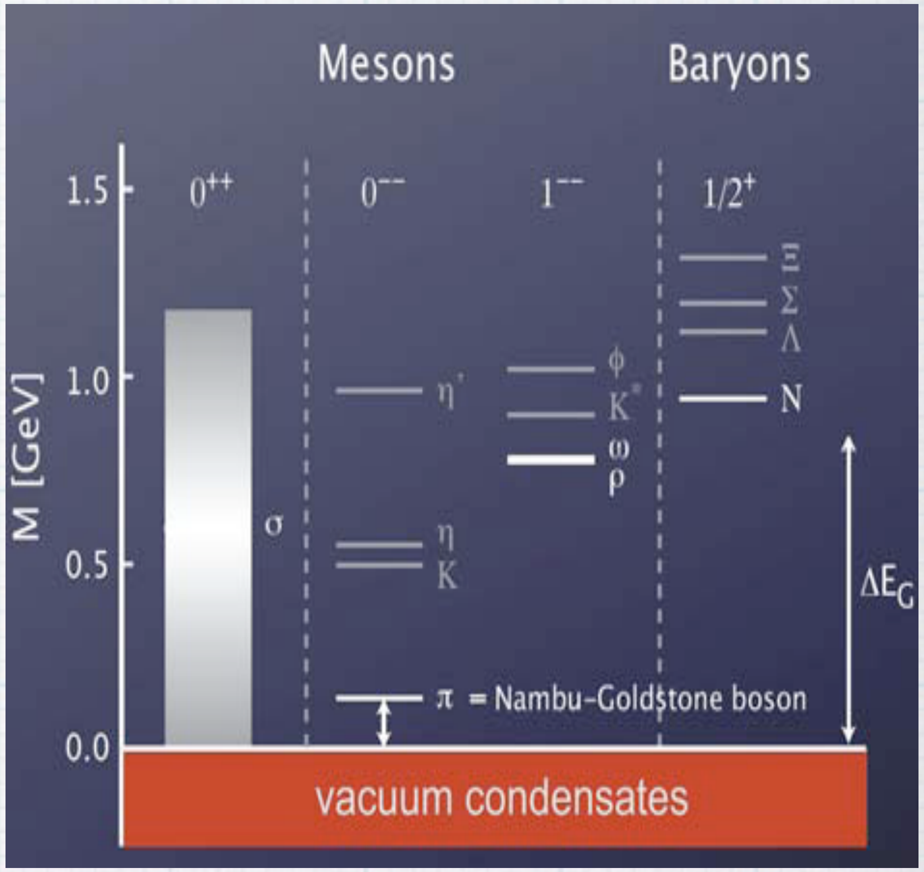
for the CLAS Collaboration

Medium Modifications

Chiral Symmetry Restoration

- 98% of hadron's mass is attributed to spontaneous breaking of chiral symmetry.
- Predictions of chiral symmetry restoration at normal nuclear density (ρ_0=0.16 fm^{-3})
  - Bernard and Meissner, NPA 489, 647 (1988)
  - Brown and Rho, PRL 66, 2720 (1991)
  - Hatsuda and Lee, PRC 46, R34 (1992)
- Consequences are changes to M and Γ of the hadron in the nucleus, such as 20% drop in ρ-meson mass in Pb.



In-medium Hadronic Interactions

In the nuclear medium, the meson-nucleon cross section is modified
Leupold et al., Int. J. Mod. Phys. E19, 147 (2010)

This modification is manifested as collisional broadening or a change to the collisional width.

$$\Gamma = \Gamma_0 + \Gamma_{coll} = \Gamma_0 + \gamma v \rho \sigma^*_{VN}$$

Consequence: increased absorption and reduction in detected yield.

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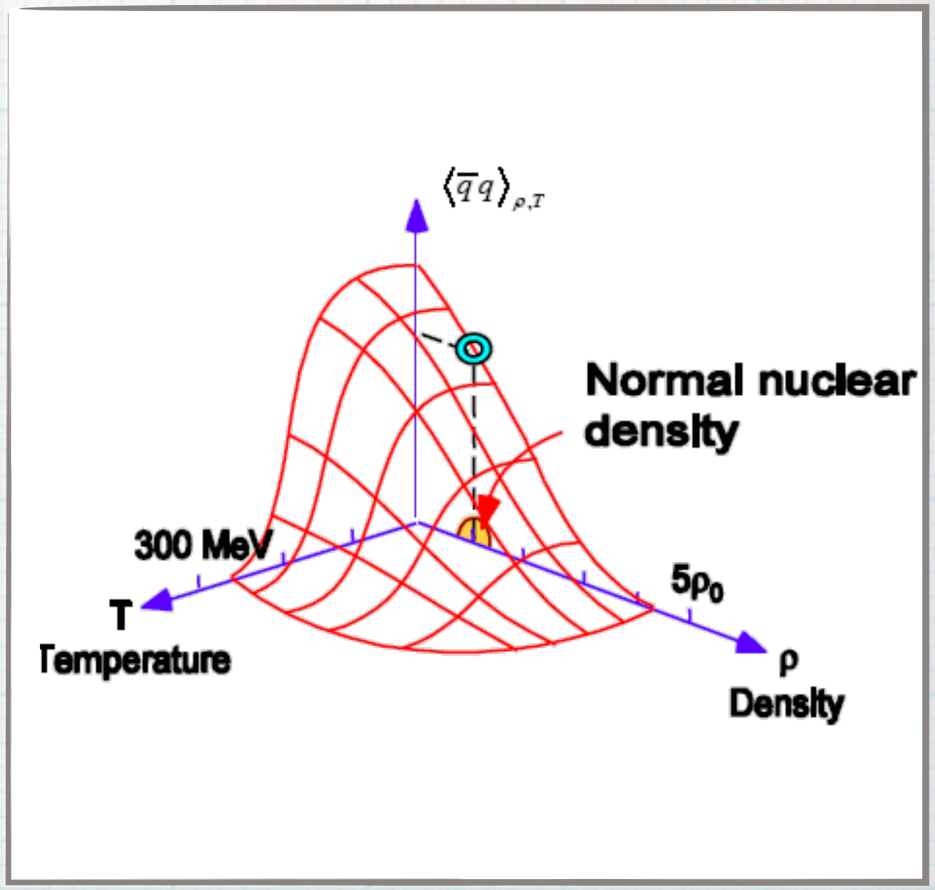

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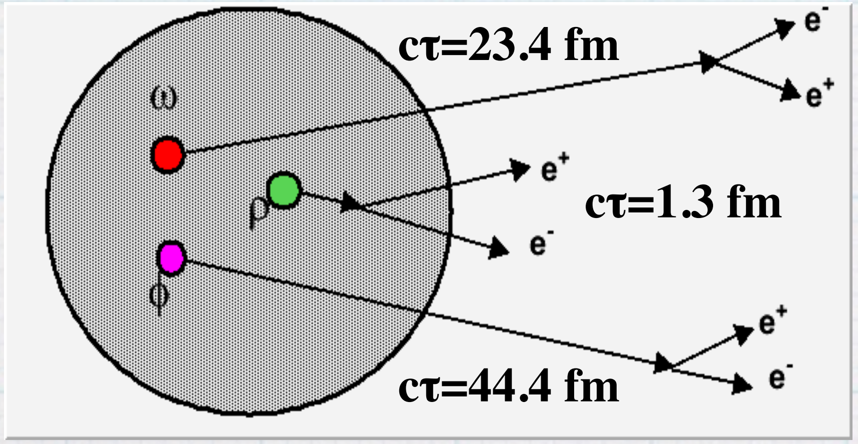
CLAS Experiment

With the g7a experiment at JLab in Hall B, we had access to the in-medium properties of the light vector mesons.

Reaction: $\gamma A \rightarrow VX \rightarrow e^+e^- X$ (no FSI) ($E_\gamma < 4$ GeV)



Meson	Mass (MeV)	Width (MeV)
ρ	768	149
ω	782	8
φ	1020	4

ρ → { R. Nasseripour et al, PRL 99, 262302 (2007)
M. H. Wood et al., PRC 78, 015201 (2008) }

ω and φ → M. H. Wood et al., PRL 105, 112301 (2010)

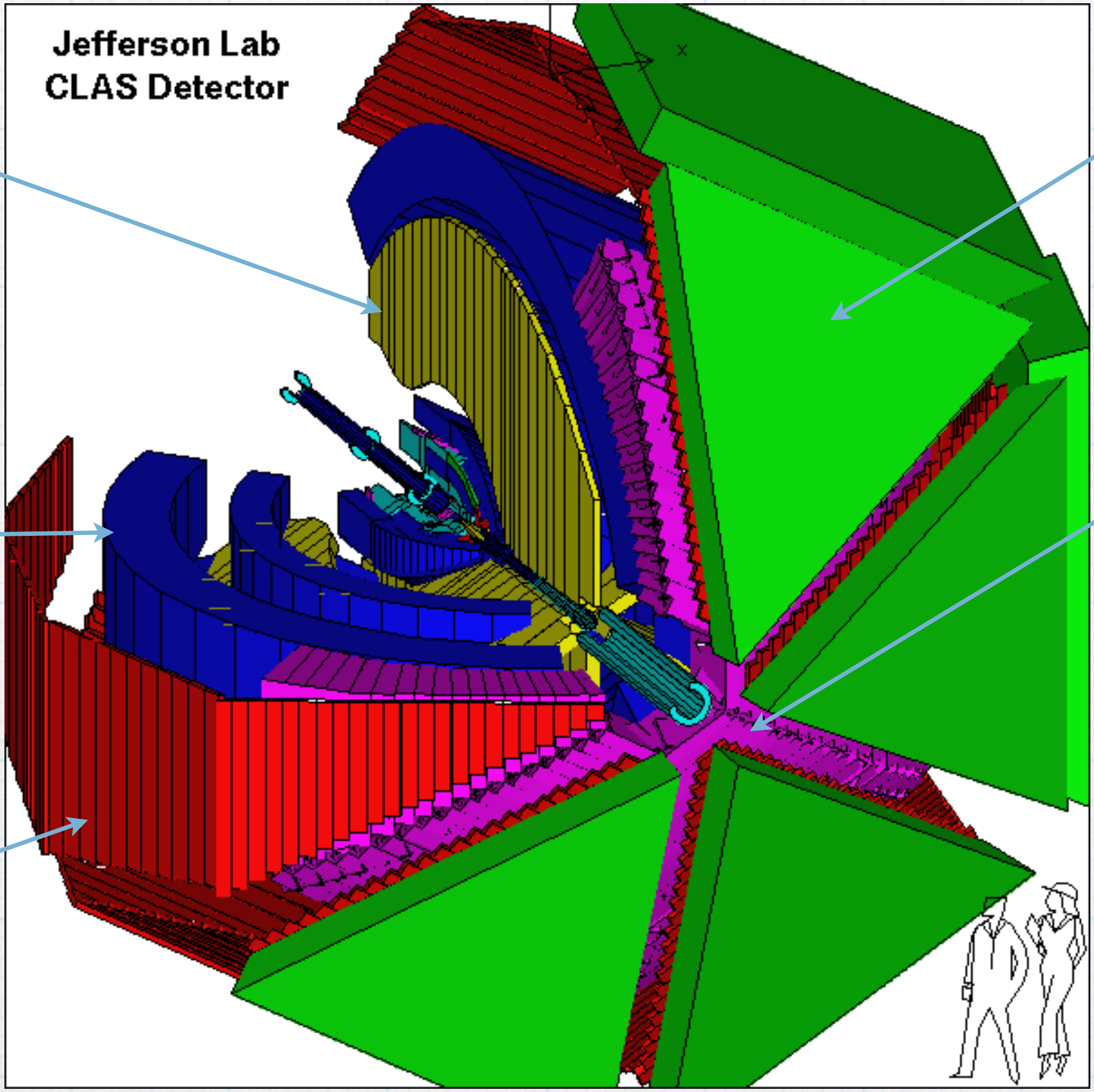
CLAS

Torus Magnet
6 superconducting coils for deflecting charged particles

e- : in-bending tracks
e+ : out-bending tracks

Drift Chambers (Ar-CO_2)
6500 channels/sector to measure the path of a charged particle.

Time-of-Flight Hodoscope
48 scintillators/sector for measuring a particle's travel time



Electromagnetic Calorimeter for detecting electrons.

EC e/π rejection factor: 10^{-2}

Gas Cherenkov Counter for e/π separation.

CC e/π rejection factor: 10^{-1}

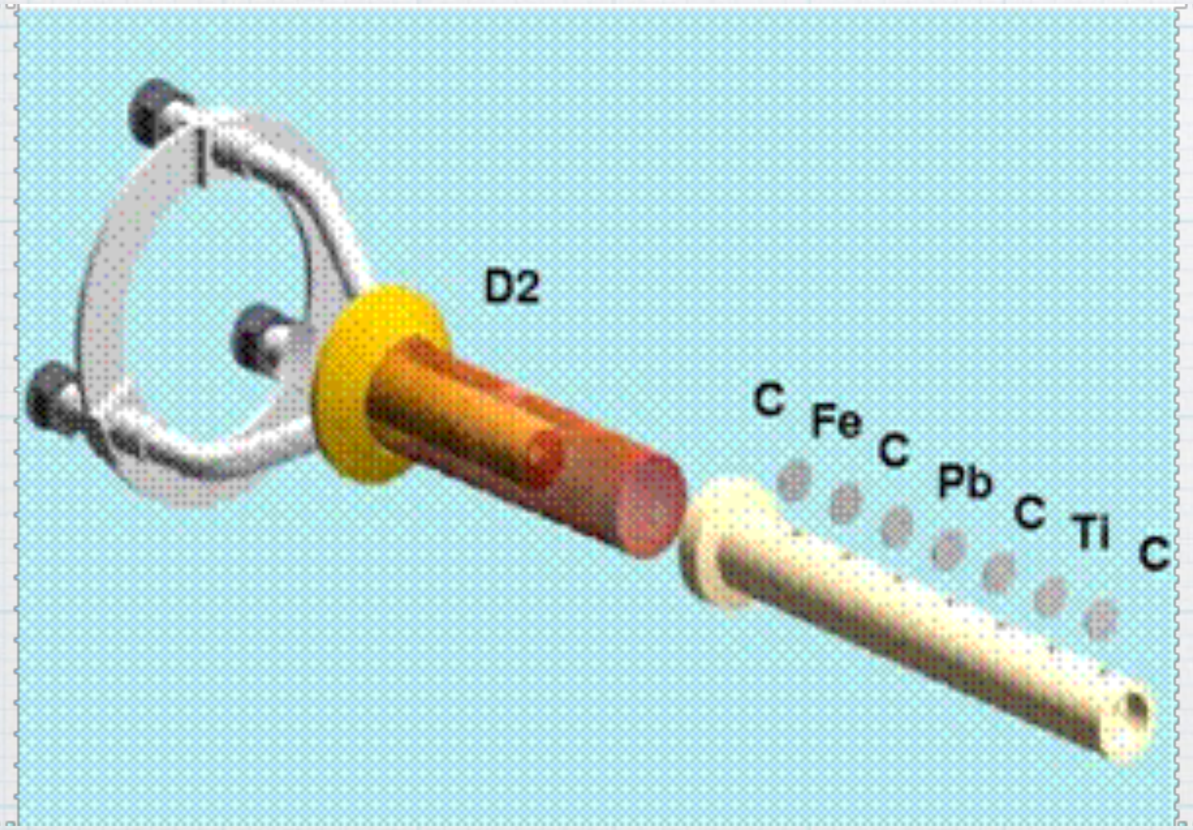
EC/CC rejection factor: 10^{-3}

Rejection factor for e^+e^- : 10^{-6}

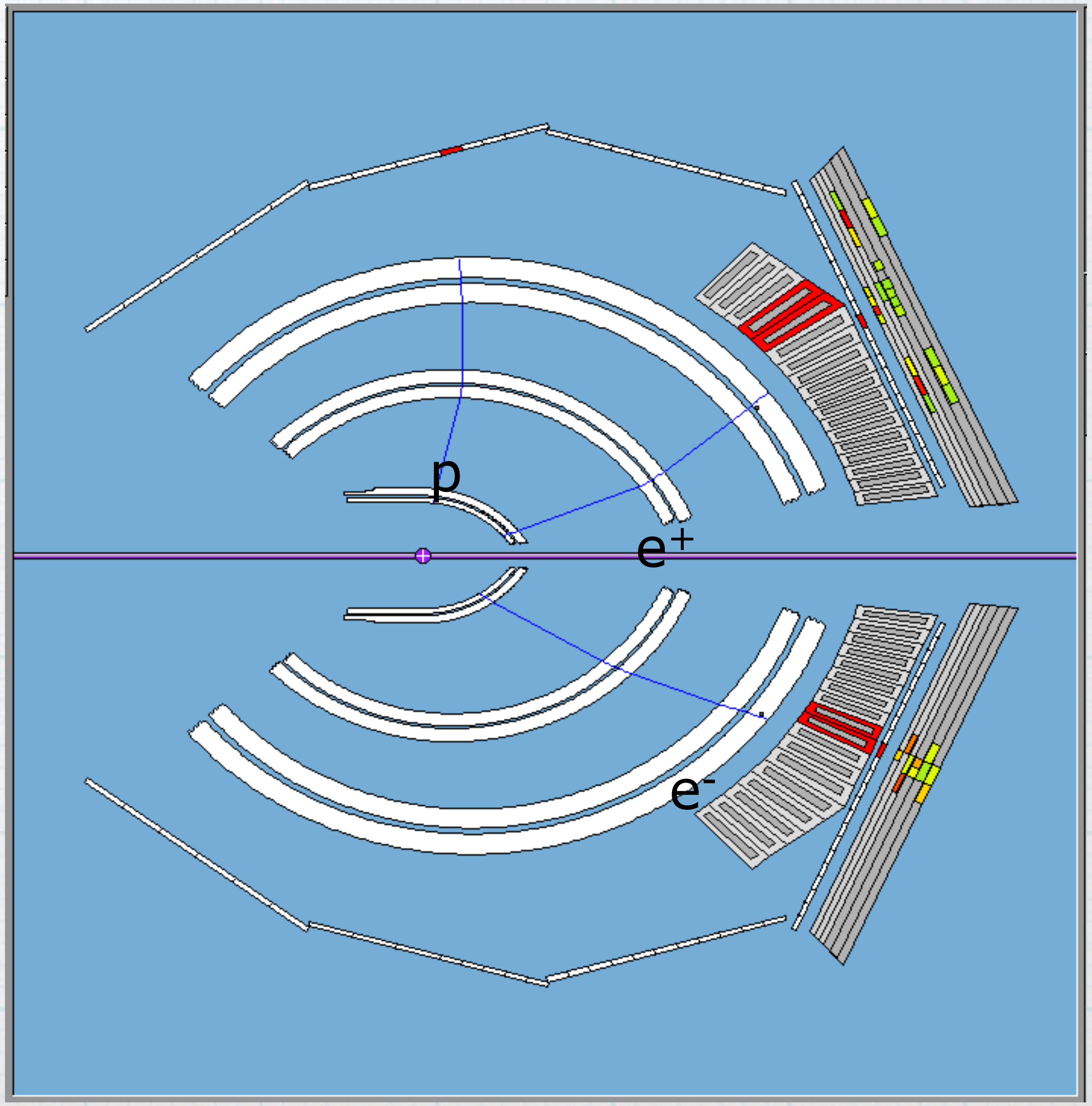
Event Selection

Segmented Target

Foils of carbon, iron, titanium, lead.
Cell of LD_2 as a control.



Sample Event



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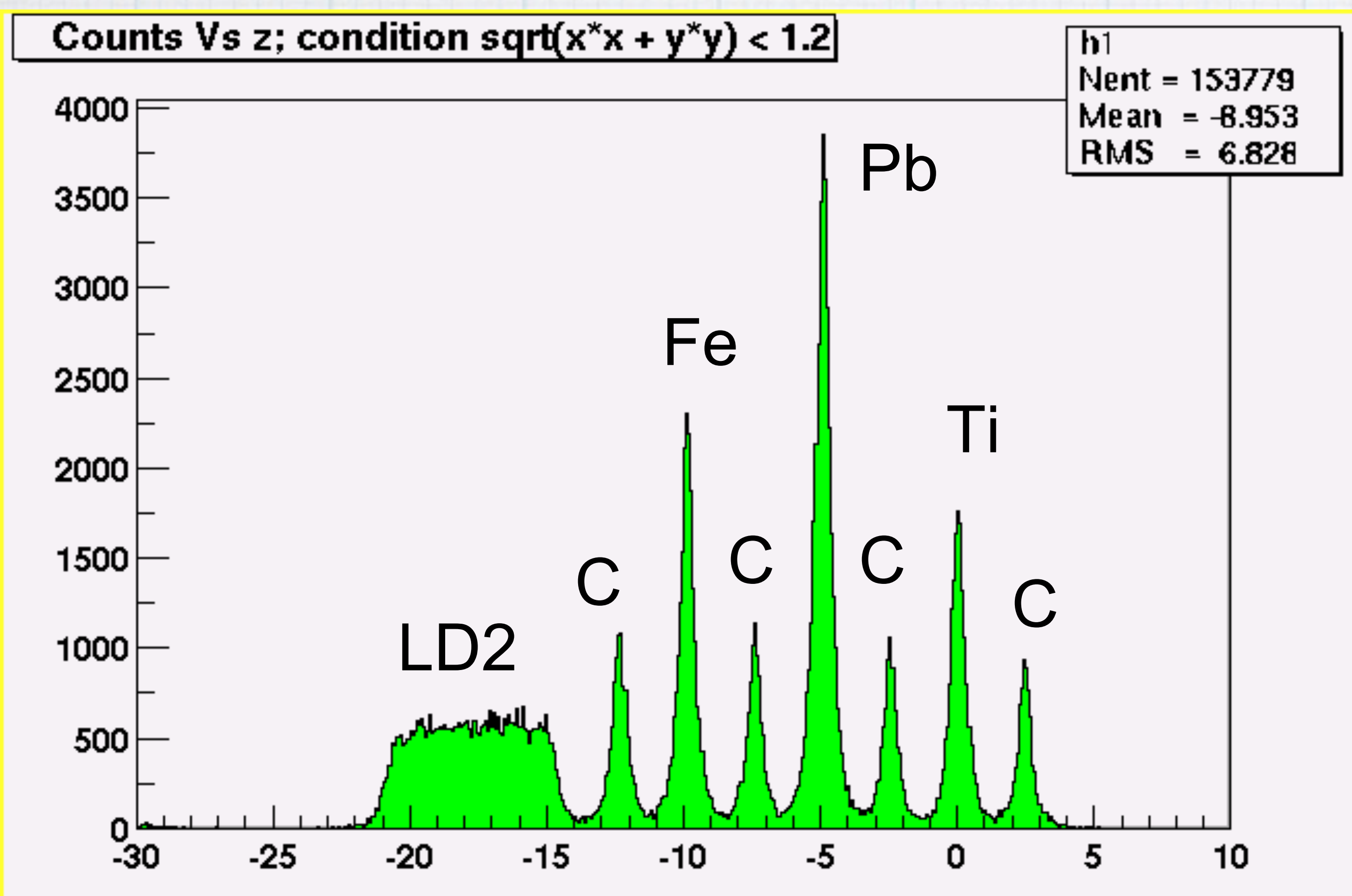

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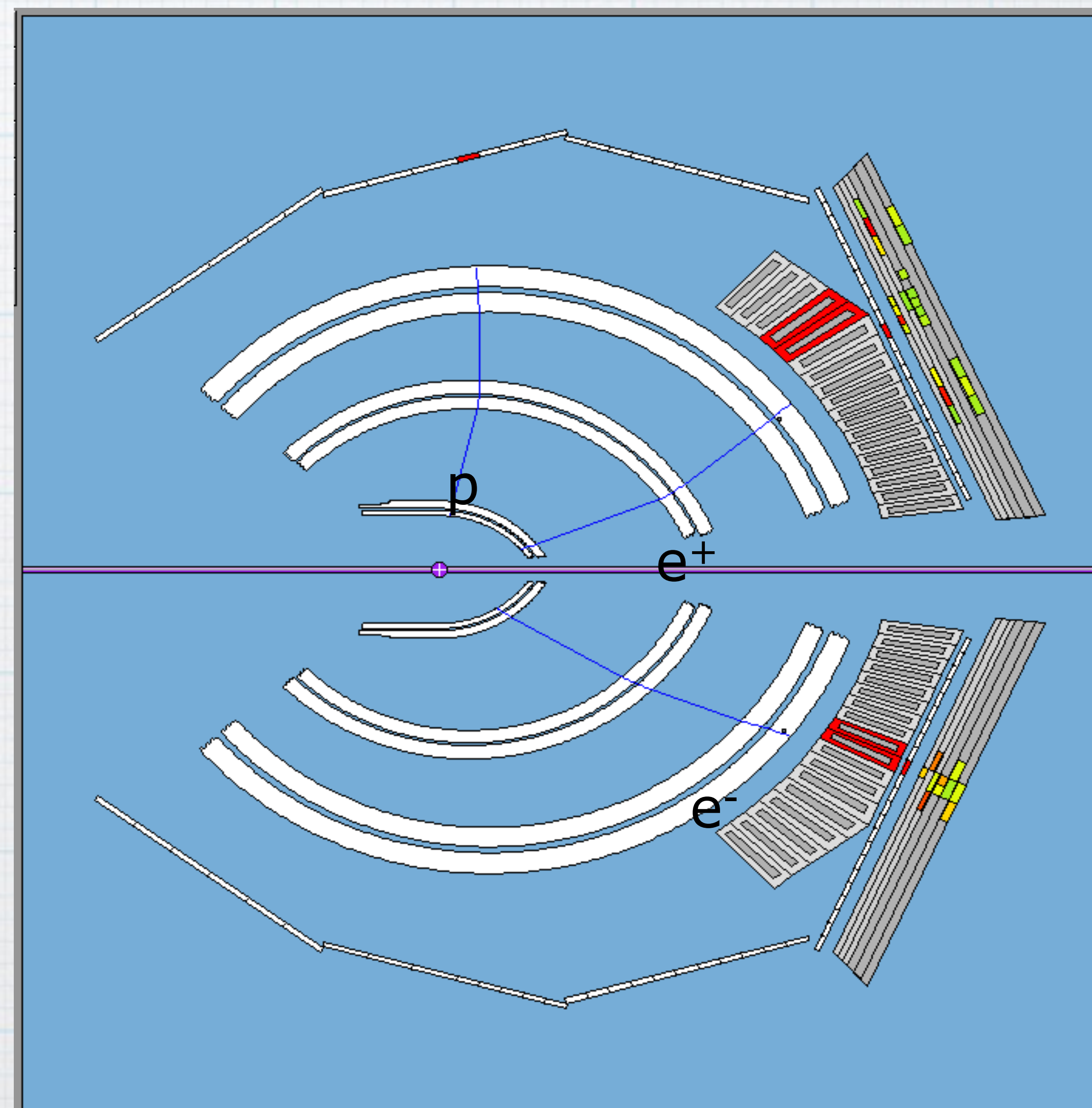
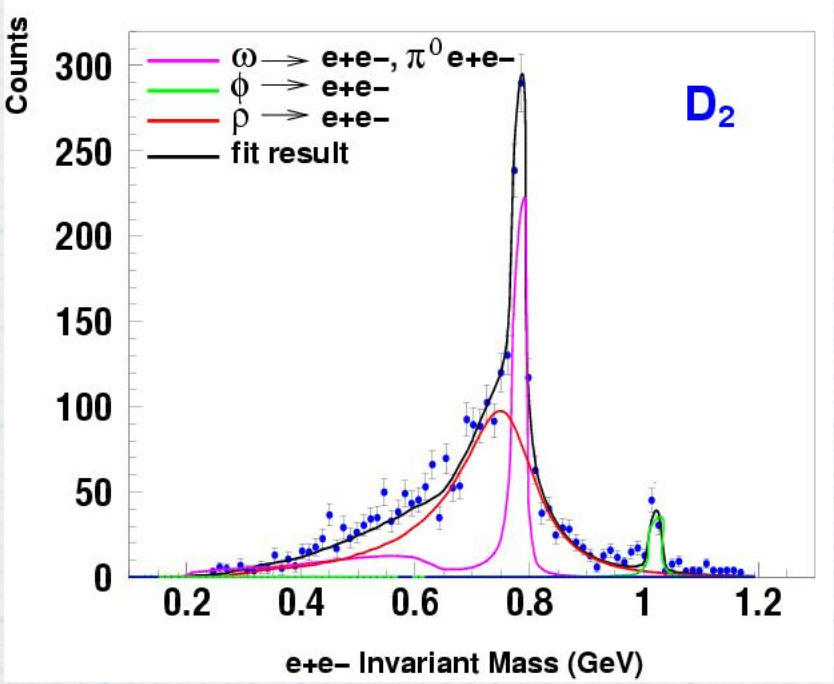
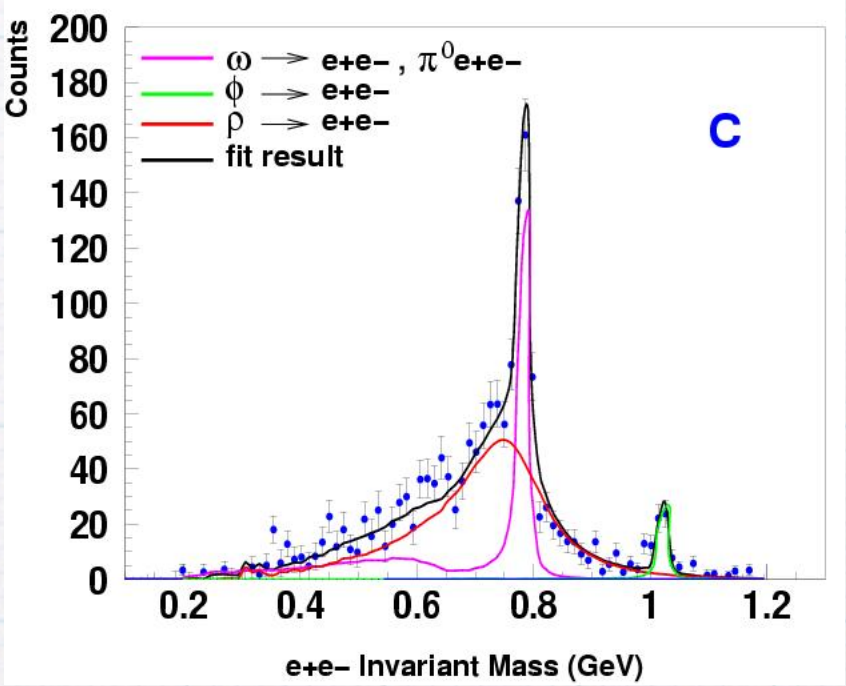
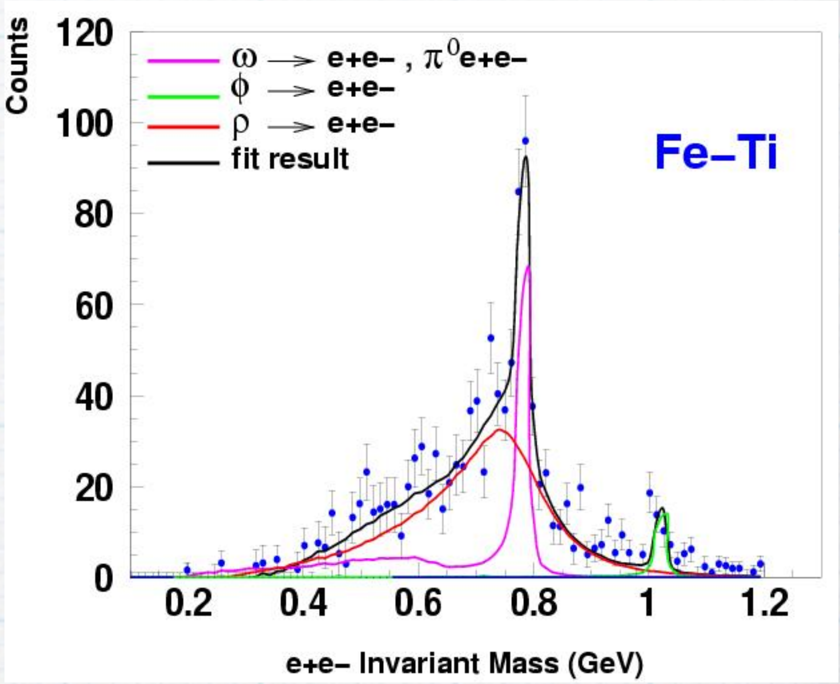


ρ meson

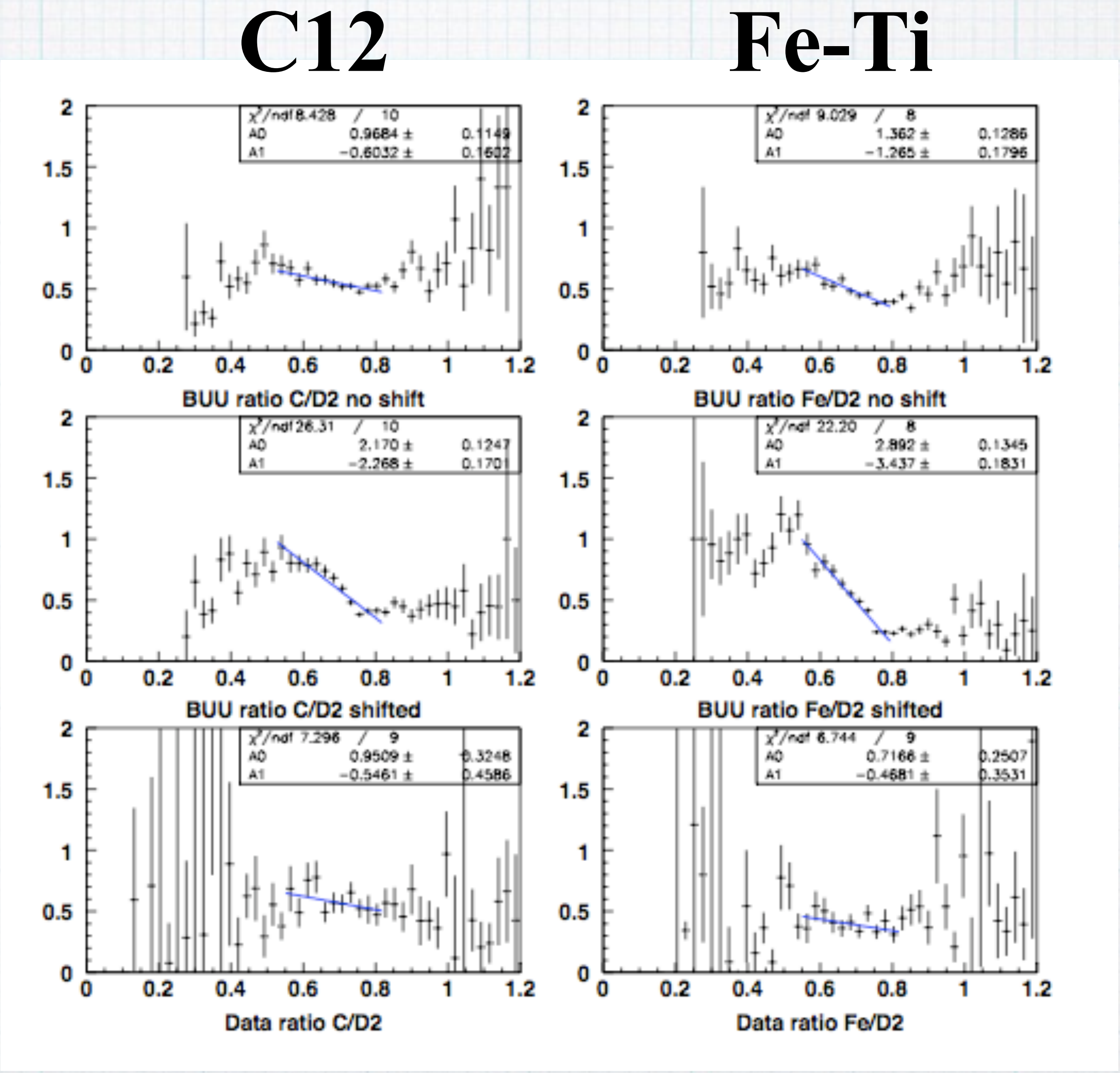






- Combinatorial Background subtracted
- Line shapes were simulated by GiBUU
- Lines shapes were fit to the mass spectra. Centroids and widths were fixed. The relative scale for each line was varied.
- All contributions except the ρ meson were subtracted.

ρ meson



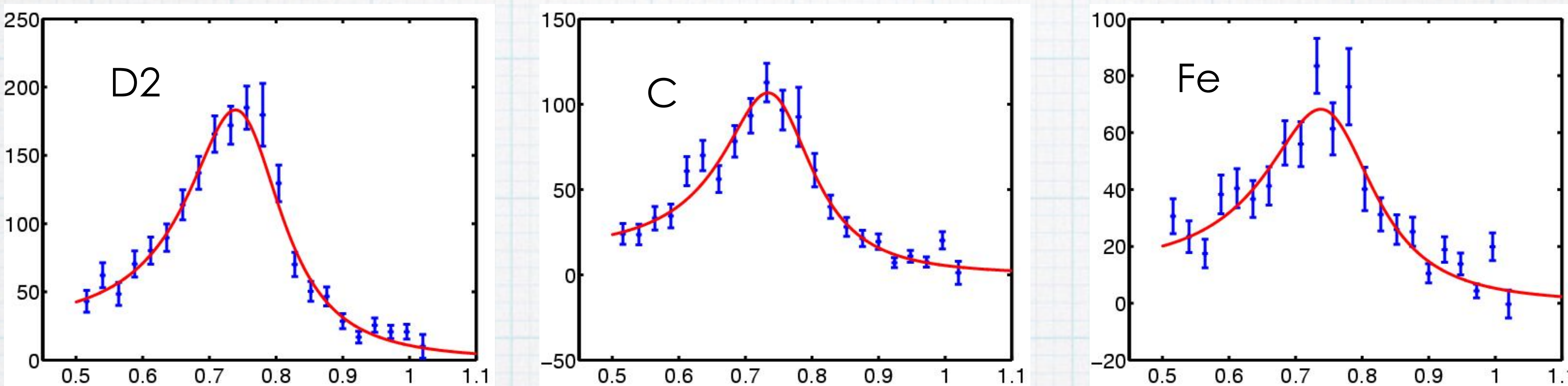
Simulation with no mass shift

Simulation with mass shift

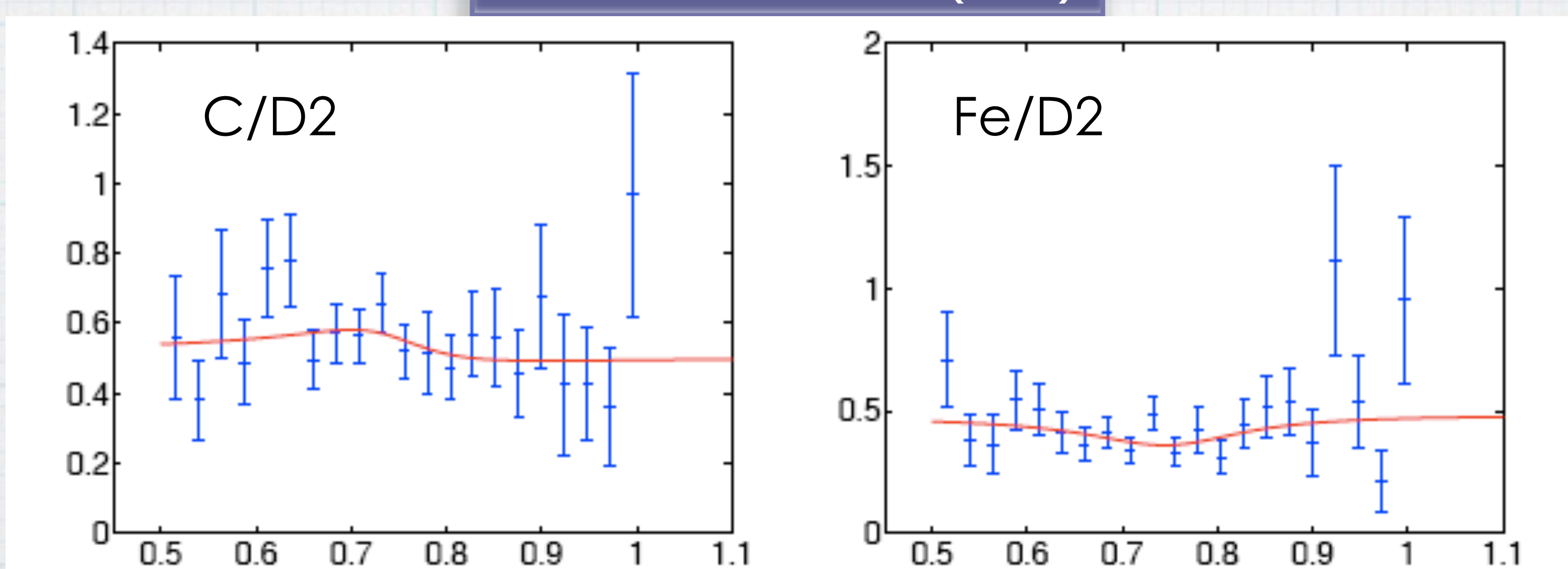
JLab data

Visually the ratio of masses are consistent with no mass shift.

Fit to Mass Spectra



e⁺e⁻ Invariant Mass (GeV)



Results of the ρ meson search:

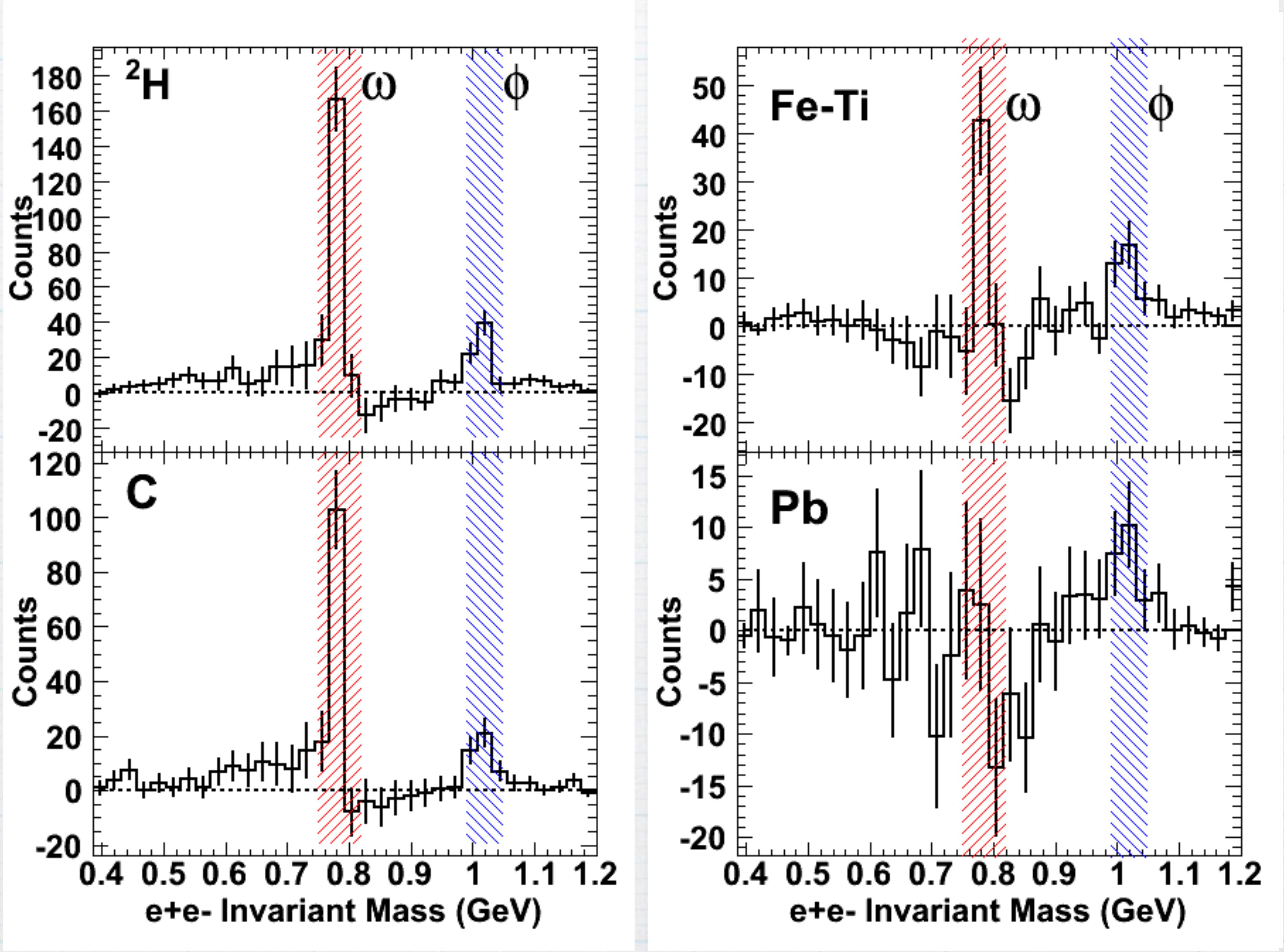
- consistent with no mass shift (upper limit Δm < 21 MeV)
- width broadening consistent with many-body effects (~40%) (predicted by GiBUU)

ω and ϕ mesons

Mass Spectra with ρ, ω, and ϕ mesons

— simulation

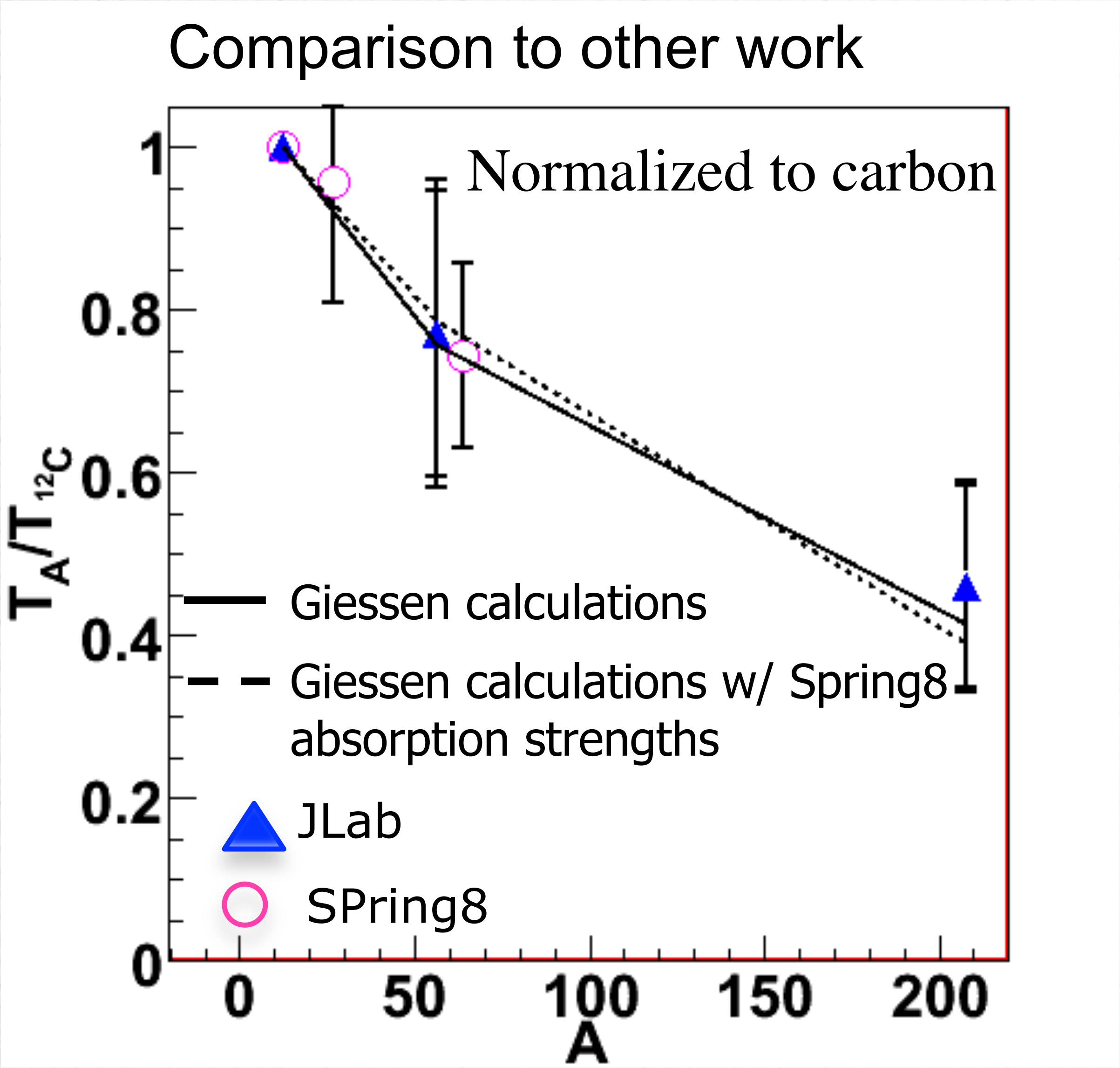
Mass Spectra after subtraction of the ρ-meson contribution

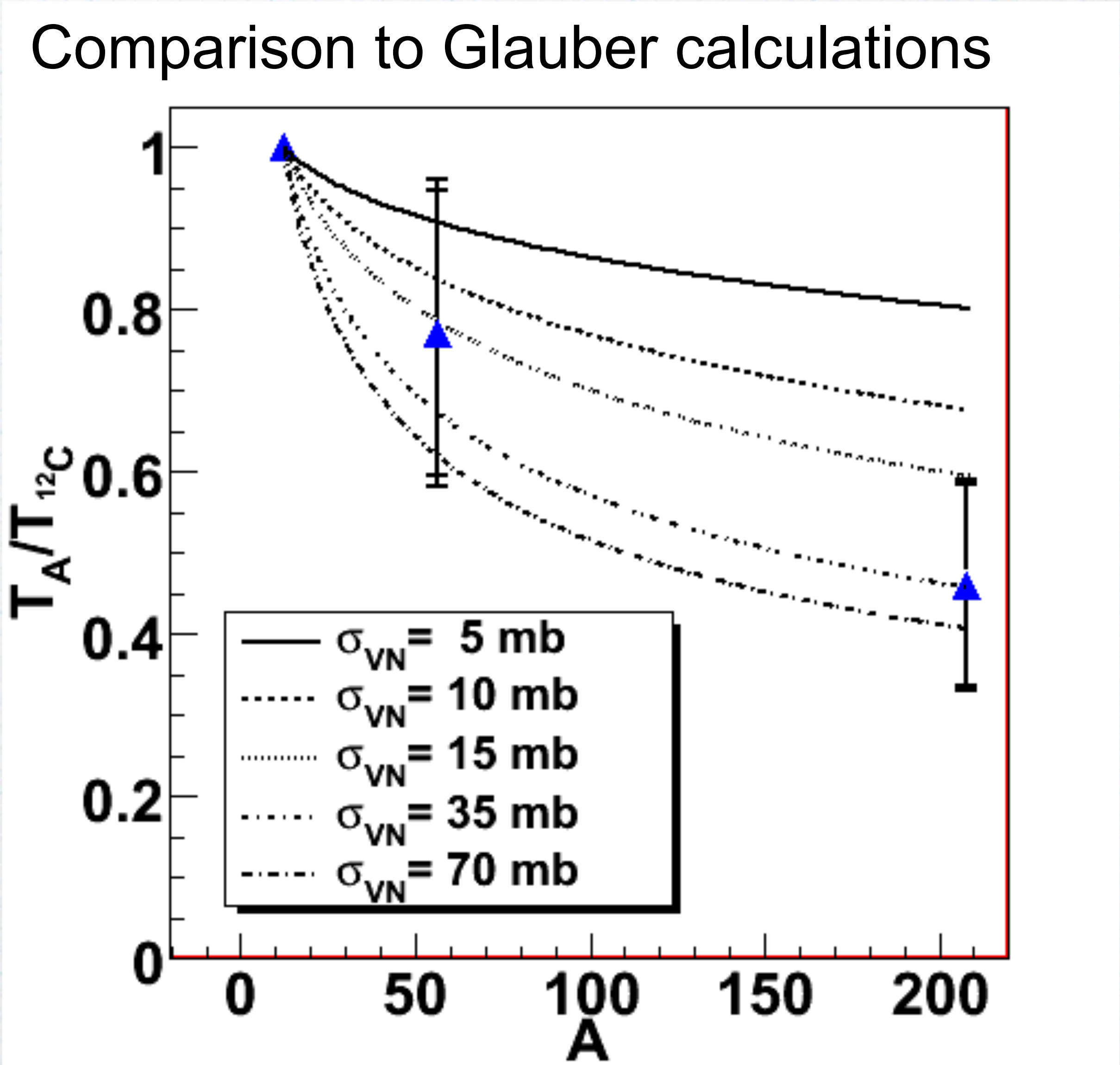


Measured Quantity

$$T_A = \frac{\sigma_{VA}}{A\sigma_{VN}}$$

ϕ Meson Absorption





SPring8: $\gamma A \rightarrow \phi X \rightarrow K^+K^-X$
E_γ=1.5-2.4 GeV
T. Ishikawa et al., Phys. Lett. B 608, 215 (2006)

Elementary: $\sigma_{\phi N} < 10$mb
In-medium: $\sigma^*_{\phi N}$ = 35mb (SPring8)
$\sigma^*_{\phi N}$ = 15-70mb (JLab)

ω-Meson Absorption

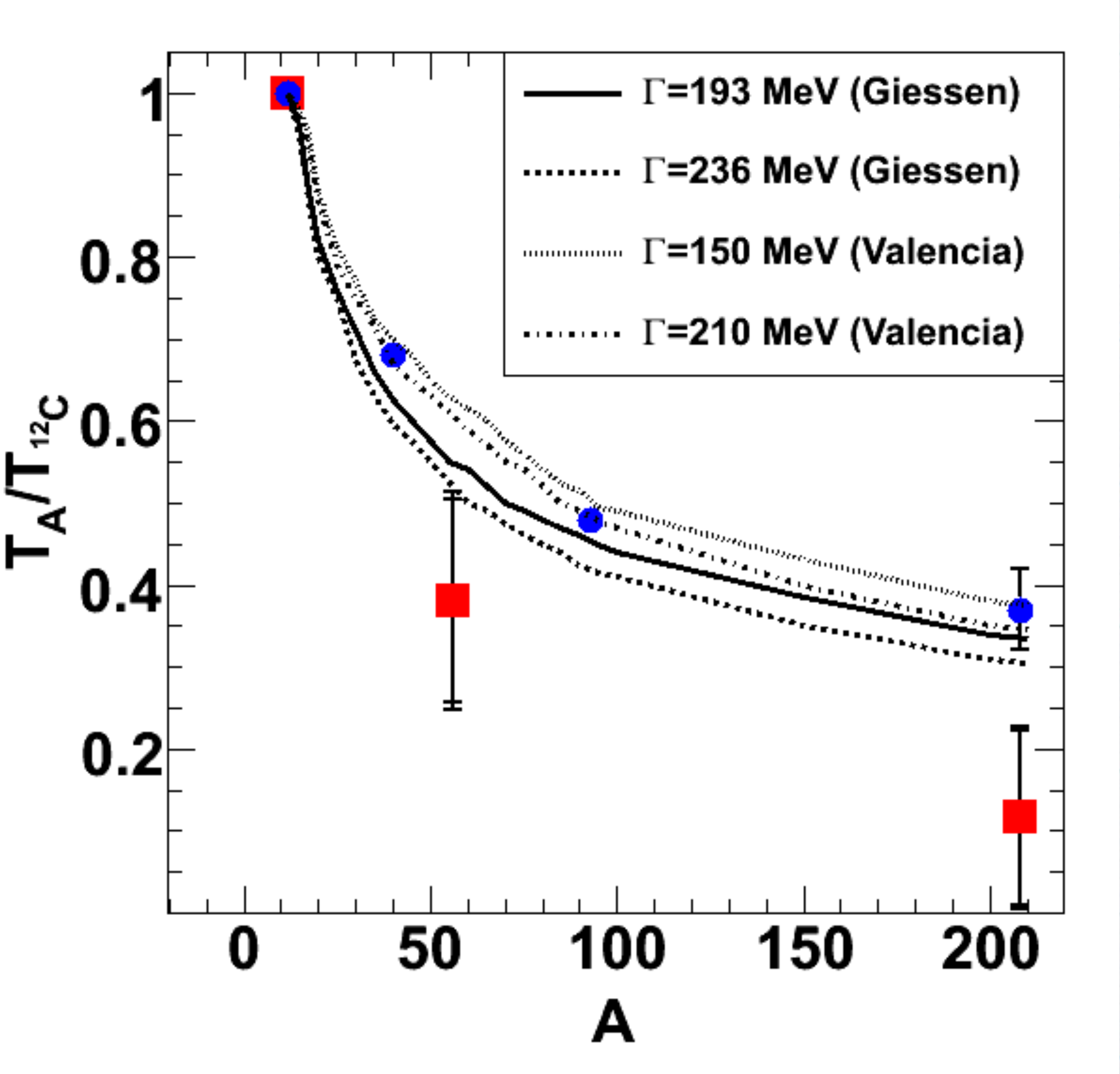
- JLab
- CBELSA-TAPS
  M. Kotulla et al., PRL 100, 192302 (2008)

Giessen Calculations

P. Muhlich and U. Mosel, NPA 773, 156 (2006)

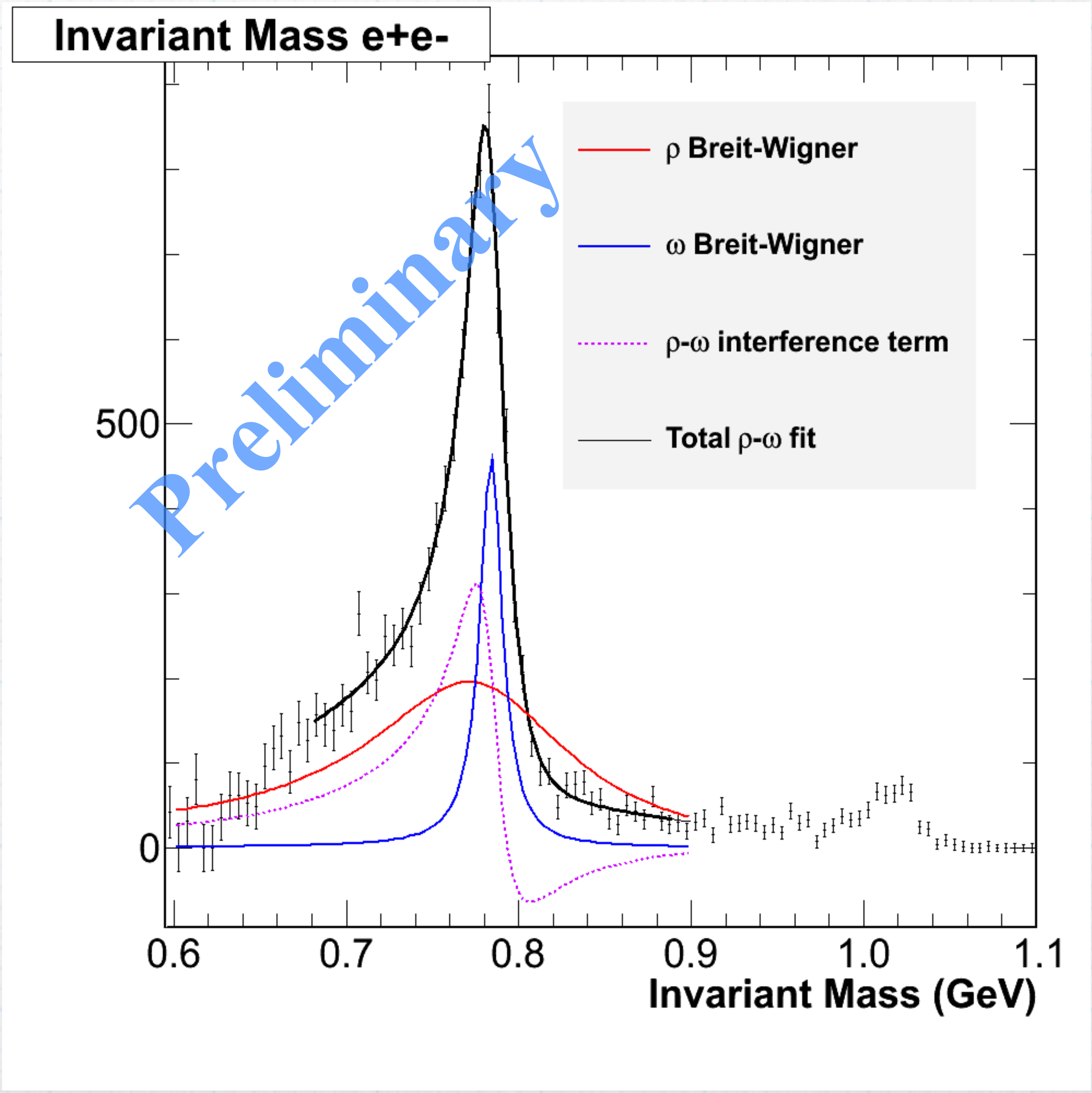
Valencia Calculations

Kaskulov et al., EPJA 31, 245 (2007)



g12: Measurement of the Elementary Process

* Data Data collected in Hall B in 2008.
* Bremsstrahlung photon beam on a LH2 target (E_γ < 5.5 GeV).
* Work conducted by Michael Paolone while at Univ. of South Carolina (now at Temple University).
* Fit: ρ BW + ω BW + interference term
* In preparation for analysis review.



Summary

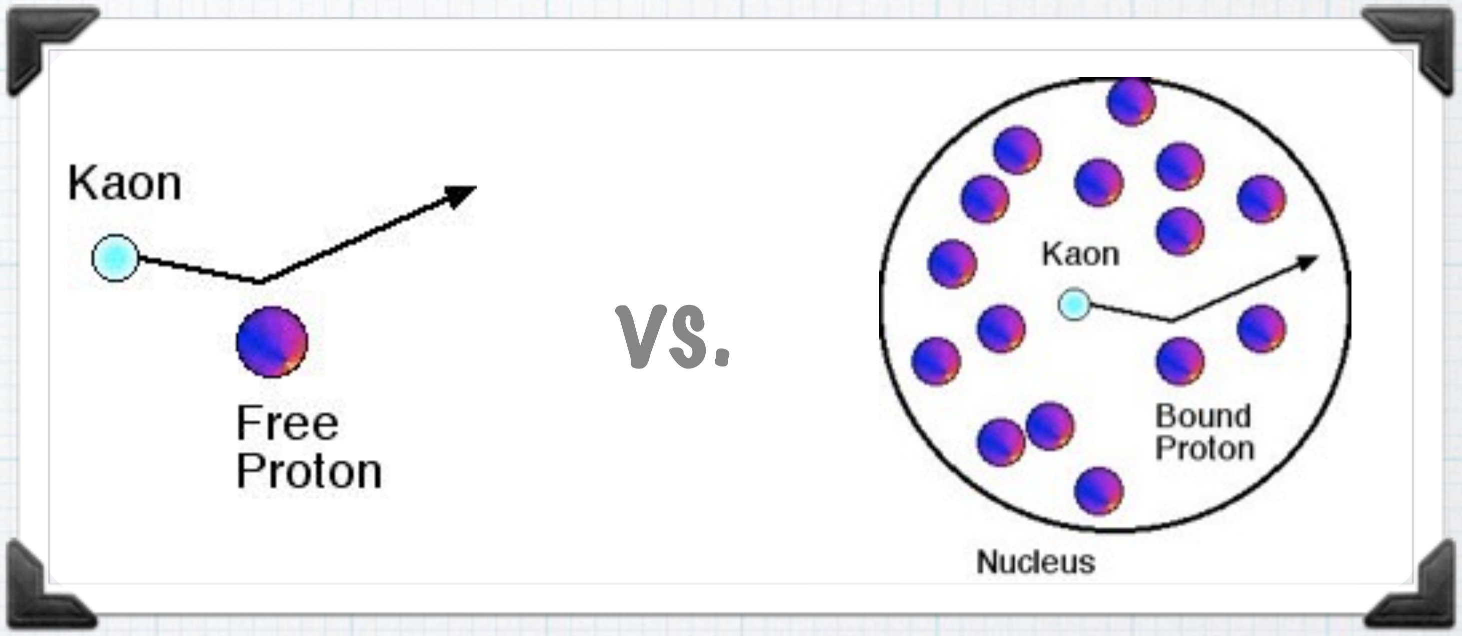
* The CLAS experiment with γ beam made valuable contributions to the field of in-medium meson modifications.
  - ⭐ **ρ meson**: consistent with no mass shift in cold nuclear medium at JLab kinematics
  - ⭐ **ϕ meson**: consistent with Spring8 result. The in-medium cross section is 2-3 times greater than the elementary cross section.
  - ⭐ **ω meson**: large absorption (collisional width > 200 MeV).
* How can the program continue?
  - ✓ Follow-up Hall B experiment (conditionally-approved by PAC) was canceled before the upgrade.
  - ✓ increase the statistics
  - ✓ Momentum dependence of in-medium modifications for the vector mesons
  - ✓ Improved target: replace Pb with Nb and increase the target spacing for absorption studies.
  - ✓ In-medium Kaon-Nucleon potentials

In-medium Kaons

Density dependence predictions of the KN potential

- K- effective mass decreases
- K+ effective mass increases

Brown et al, NPA567, 937 (1994)
Weise, NPA610, 35c (1996)
Li et al, NPA625, 372 (1997)



FOPI Collaboration at GSI

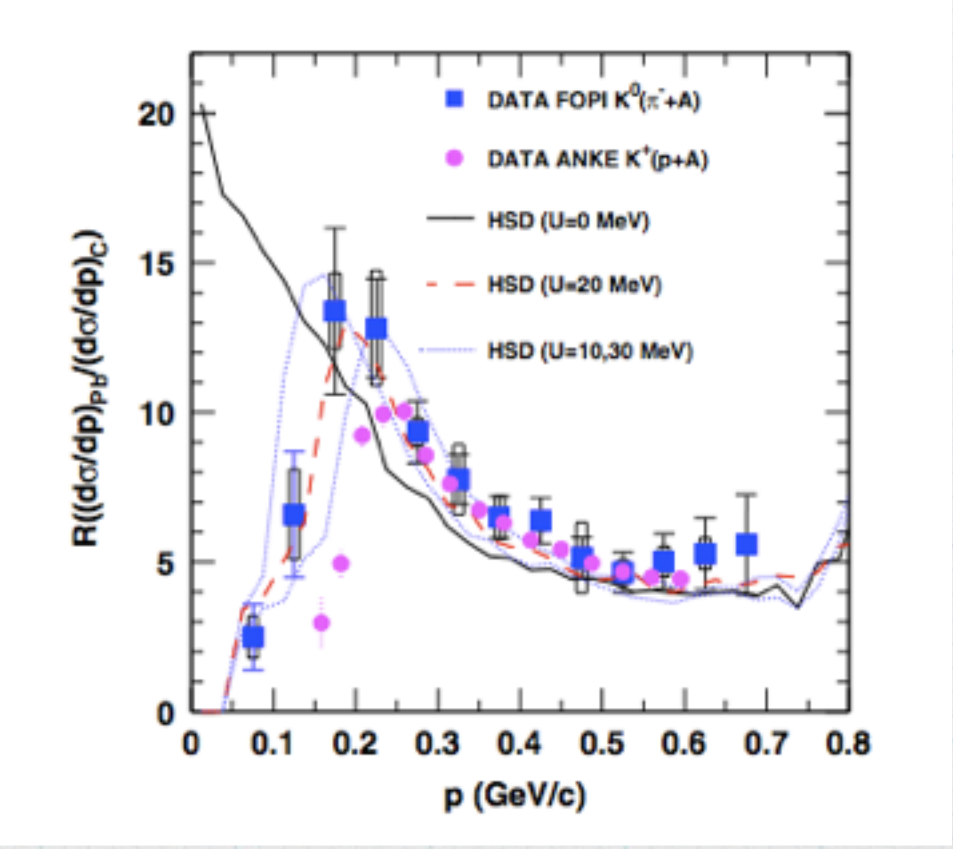
Benabderrahmane et al., PRL 102, 182501 (2009)

- K^0 production in C and Pb with 1.15 GeV π^- beams
- Data suggests a 20 MeV repulsive potential in Pb
- Increase in in-medium potential : low momentum Kaons are accelerated to higher exit momenta.

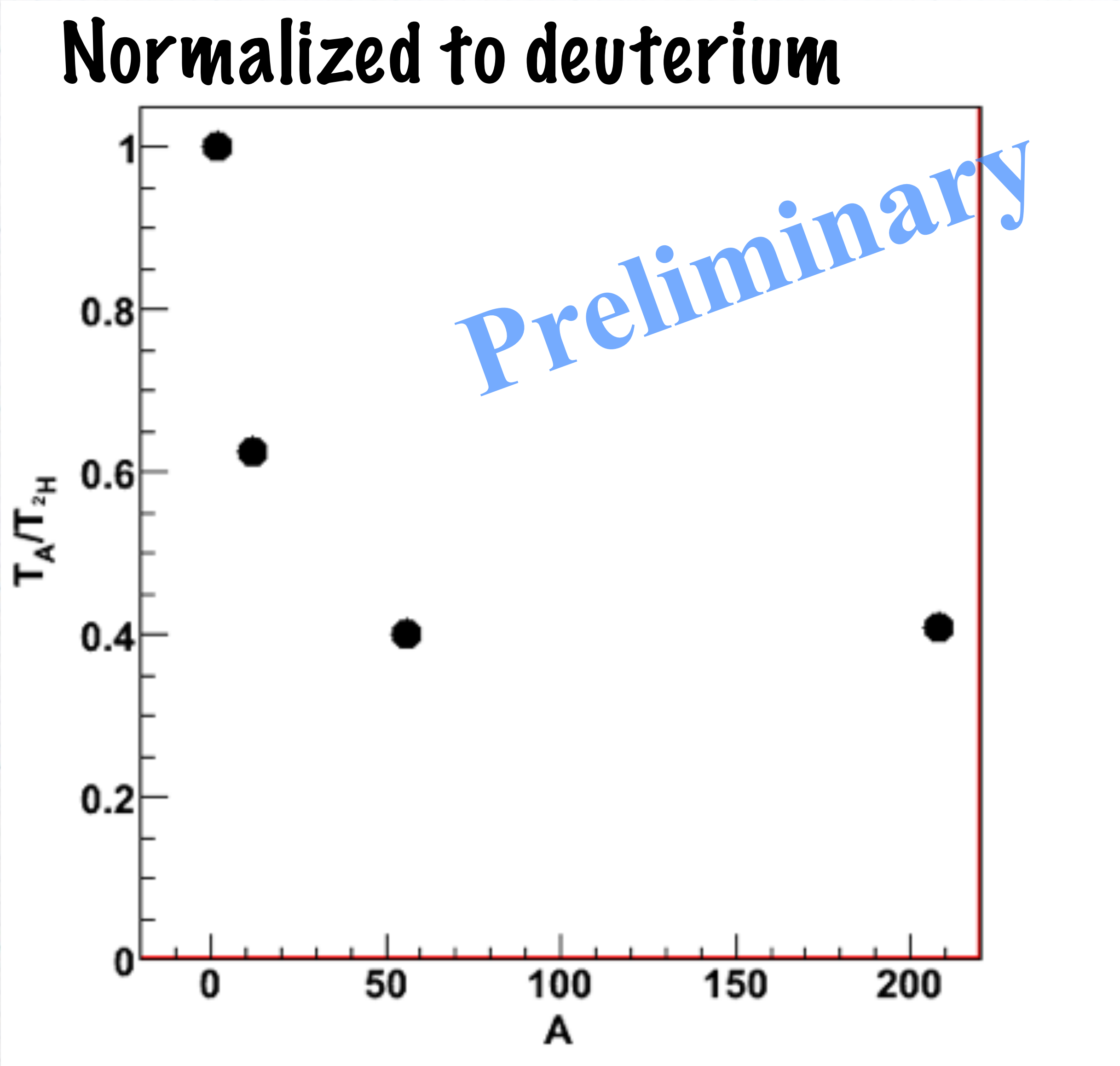
ANKE Spectrometer at COSY

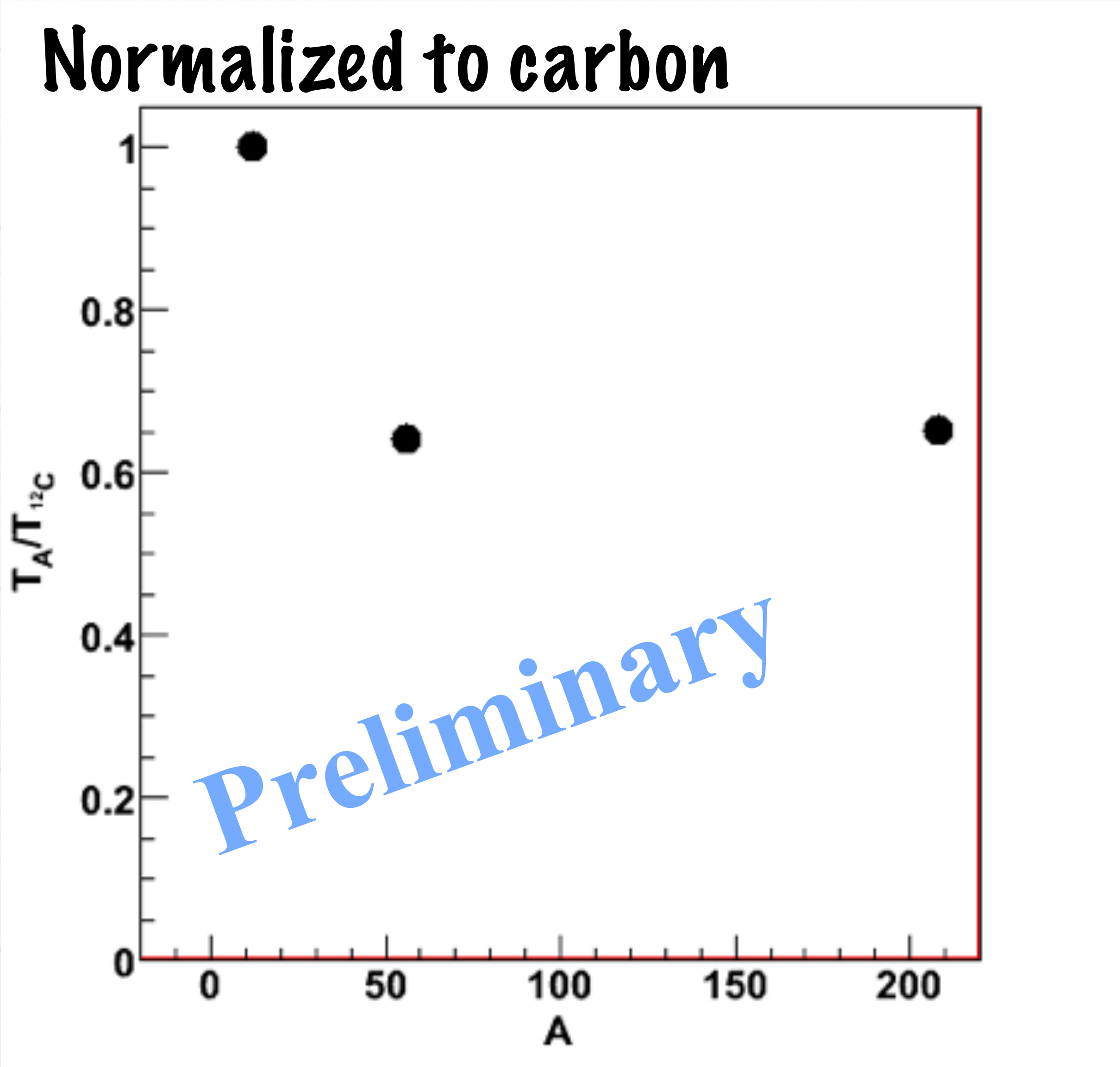
Buescher et al., EPJA 22, 301 (2004)

- K^+ production in D, C, Cu, Ag, and Au with 1-2.3 GeV proton beams
- Data show similar momentum dependence.



K_s Meson Absorption





- Analysis is a work in progress
- Simulations are needed for detector acceptance and vertex reconstruction
- Possible target contamination ($c\tau$ = 2.68 cm and target spacing = 2.5 cm)
- Analysis of meson momentum dependence is underway

Hall D

Advantages

- High-intensity photon beam
- Multi-particle final state
- Forward detector (meson-nucleus bound states?)
- Measure both ω rare decays.

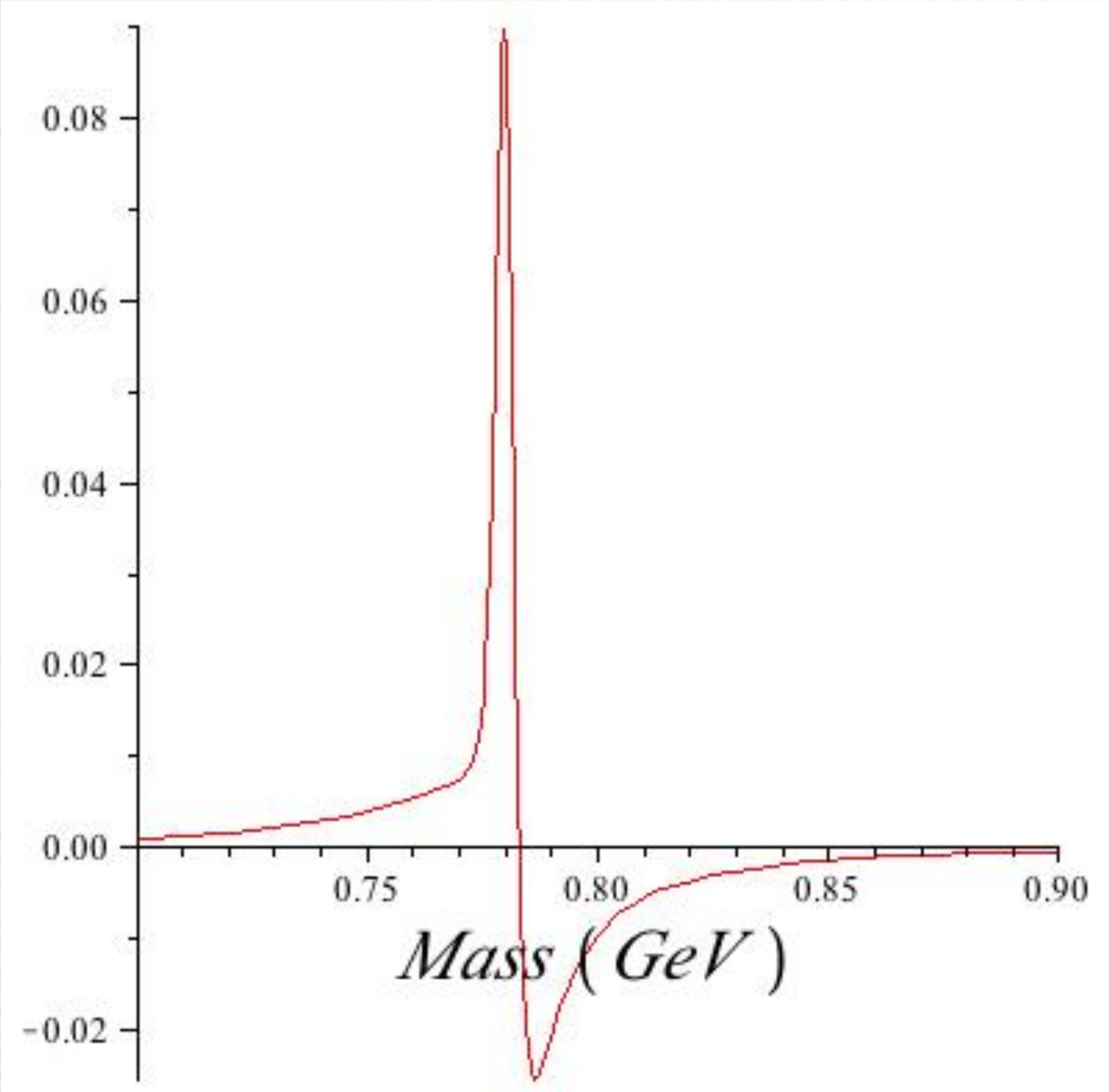
Questions

- Low momentum?
- electron/pion discrimination?
- positron acceptance?
- Target vertex reconstruction?
- Kaon acceptance?

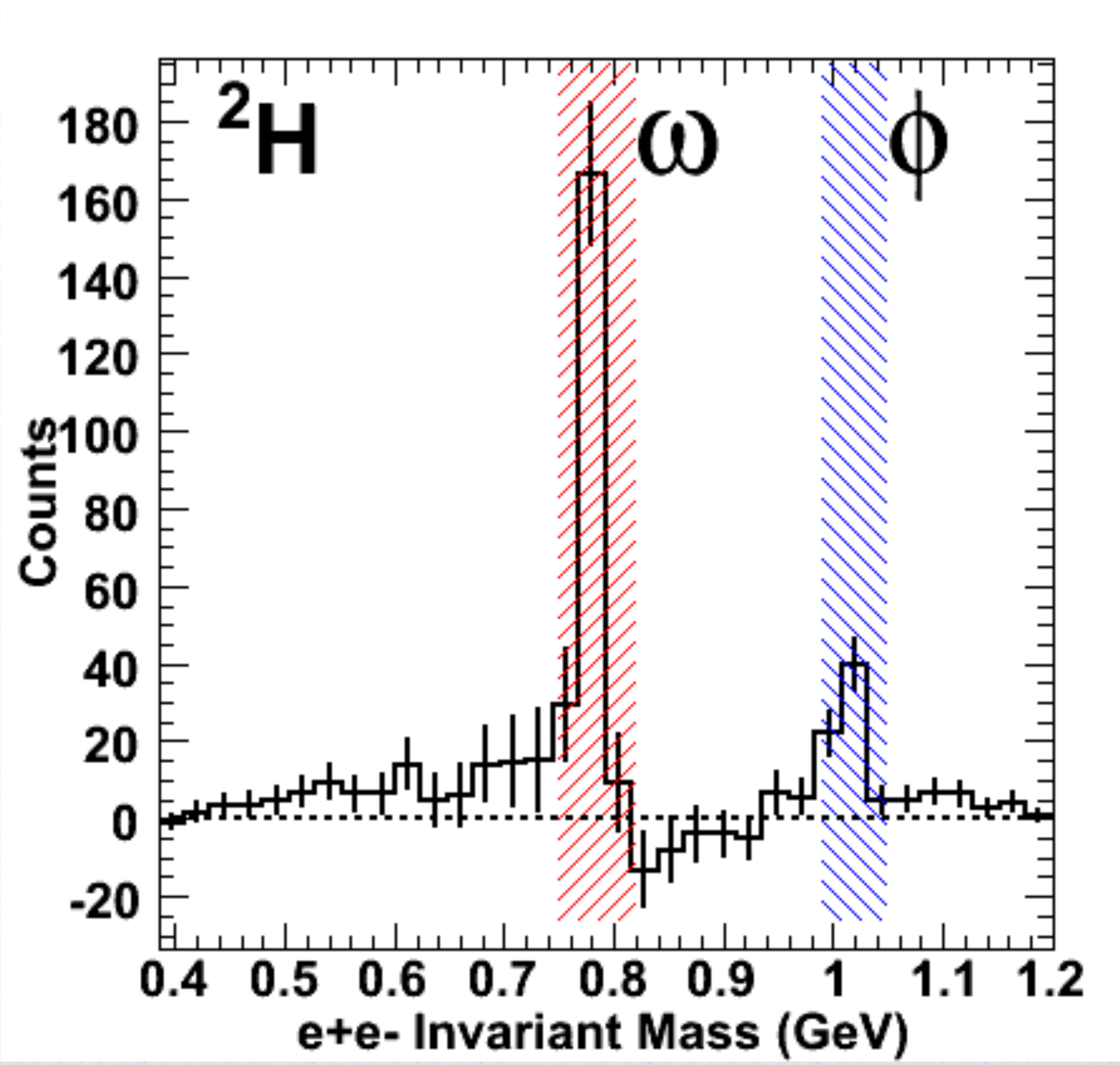
Backup Slides

ρ-ω Interference

Interference contribution after ρ-meson subtraction



Data from the ^2H Target



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$K_s \rightarrow \pi^+\pi^-$ is a good candidate for JLab analysis

- $\pi^+\pi^-$ events are plentiful
- Photon beam illuminates the entire nucleus
- Target spacings are 2.5 cm
- For K^0, $c\tau$ = 2.68 cm