Search for Modification of Vector Meson Properties in Nuclei

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and the CLAS Collaboration

Physics Motivation

High energy, high duty cycle EM machines can probe the properties of individual hadrons in close proximity with other hadronic matter

Take effective Lagrangian at low energy/zero density (free space) with its symmetries: (broken chiral): then allow density to increase

Embedding a hadron in dense hadronic matter is equivalent to changing the vacuum, and quark and gluon condensates will change

Assumption: as the quark and gluon condensates change, the symmetries *remain* intact

Hadronic properties are dependent on the chiral condensate $\langle 0|q\bar{q}|0\rangle$ Changes with ρ & T

QCD sum rules:

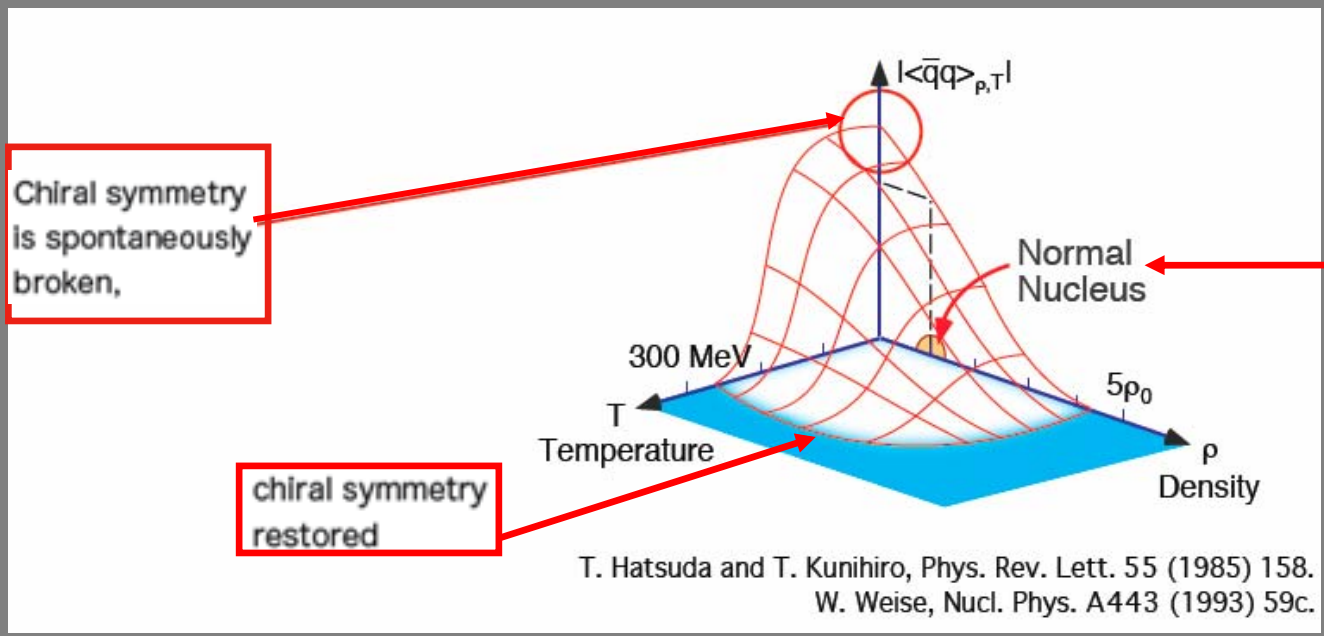
T. Hatsuda and S. Lee ***Phys. Rev. C46 (1992) R34***

$$\frac{m_V^*}{m_V} = 1 - \alpha \frac{\rho_B}{\rho_0} \qquad \alpha \approx 0.16 \pm 0.06$$

Scale invariance in effective Lagrangian:

G.E. Brown and M Rho, ***Phys. Rev Lett. 66 (1991) 2720***

$$\frac{m_V^*}{m_V} = \frac{m_N^*}{m_N} = \frac{f_\pi^*}{f_\pi} \approx 0.8 \quad \text{At } \rho_0$$



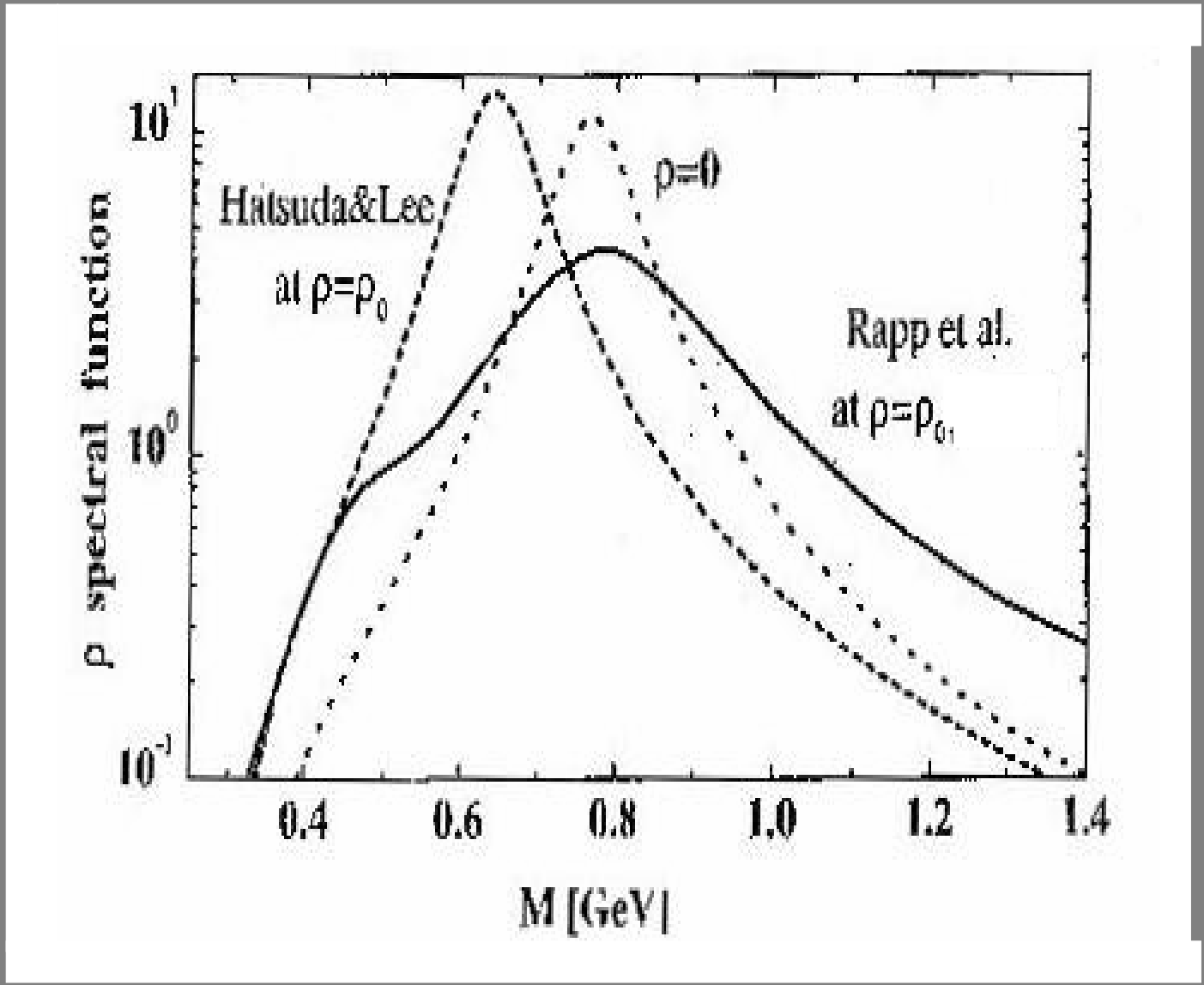
Partial chiral restoration

Present and planned experiments:

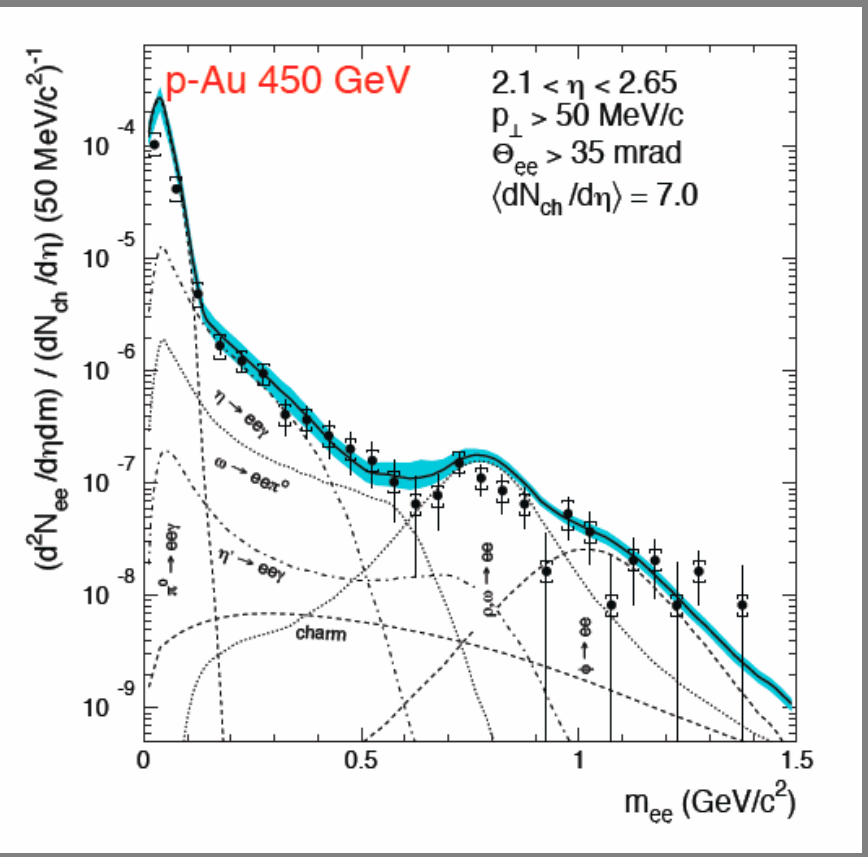
- **Heavy ion reactions:**
- **PHENIX** Au + Au to be published
- **RHIC** p+A, d+A, A+A running
- **LHC** A+A 2008?
- **GSI-HADES** A+A --> VM+A* (VM-->e+e-) running
- **Other reactions:**
- **TAGX** $\gamma+{}^3He \rightarrow \rho+X$ ($\rho \rightarrow \pi+\pi-$) completed
- **KEK** $p+A \rightarrow \rho,\omega,\phi+X$ ($\rho,\omega,\phi \rightarrow e^+e^-$ $\phi \rightarrow K^+K^-$) completed
- **SPring-8** $\gamma+A \rightarrow \phi+A^*$($\phi$--> K+K-) running
- **Bonn-TAPS** $\gamma+A \rightarrow \omega+X$ (ω --> π^0 γ) more stats
- **JLab-g7a** $\gamma+A \rightarrow (\rho,\omega,\phi)+A^*$ (VM-->e^+e^-) completed
-

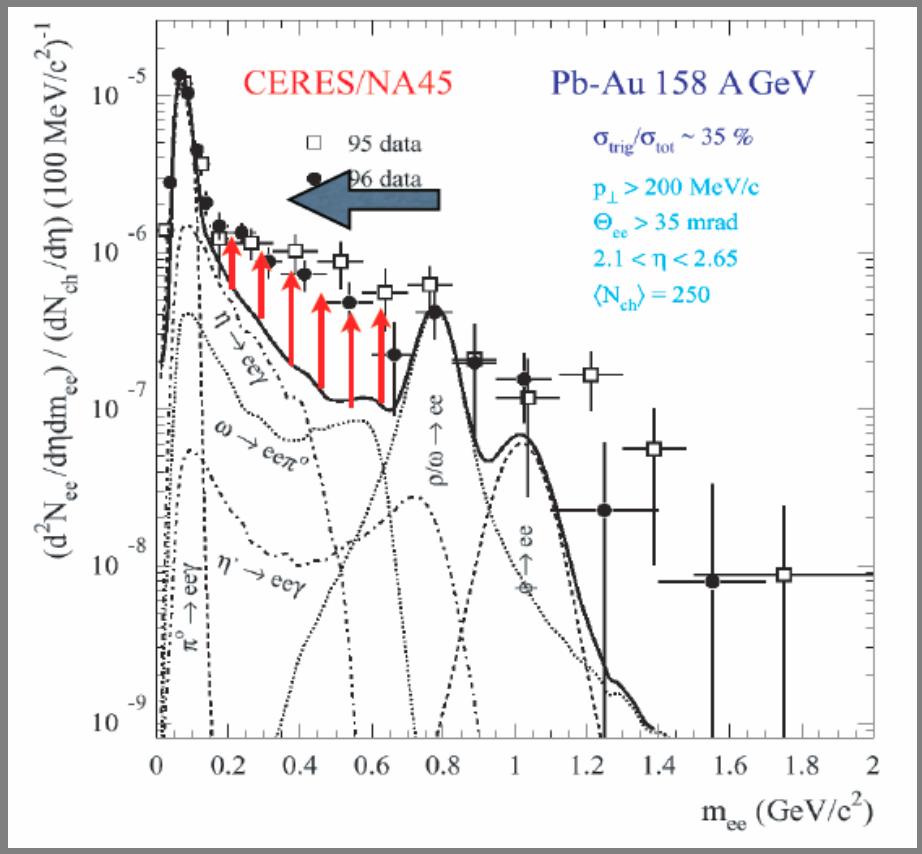
EM probes reduce strong interaction effects

Model Predictions



First evidence in e^+e^- measurements CERES/NA45 @ CERN (1995)





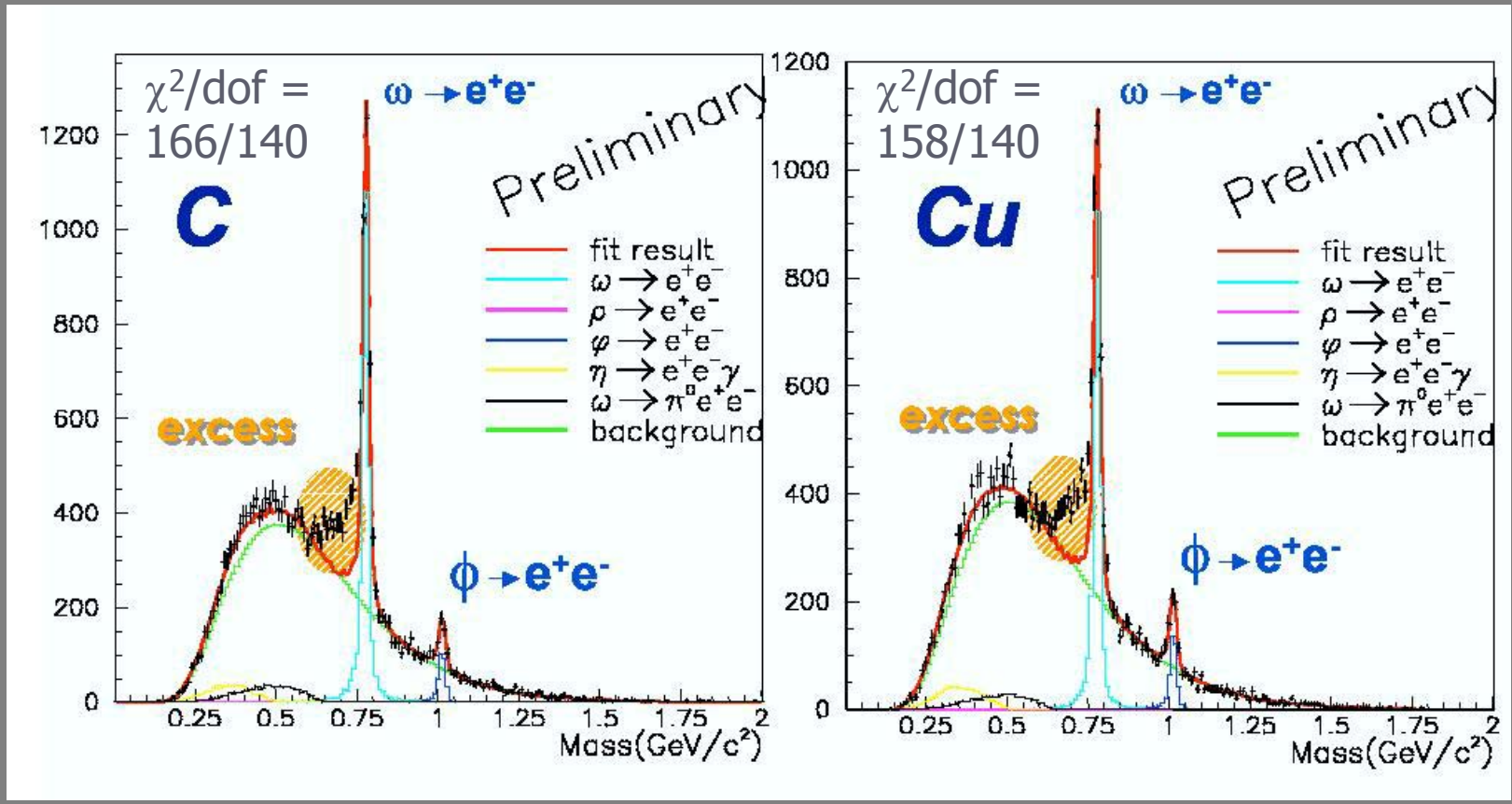
p+Au understood in terms of p+p superposition

Large excess observed in Pb+Au below 0.7 Gev/c^2

- ρ/ω mass shift??

Other Experiments: KEK-PS E325

p+A->ρ,ω,ϕ+X (ρ,ω,ϕ->e+e-. ϕ->K+K-)

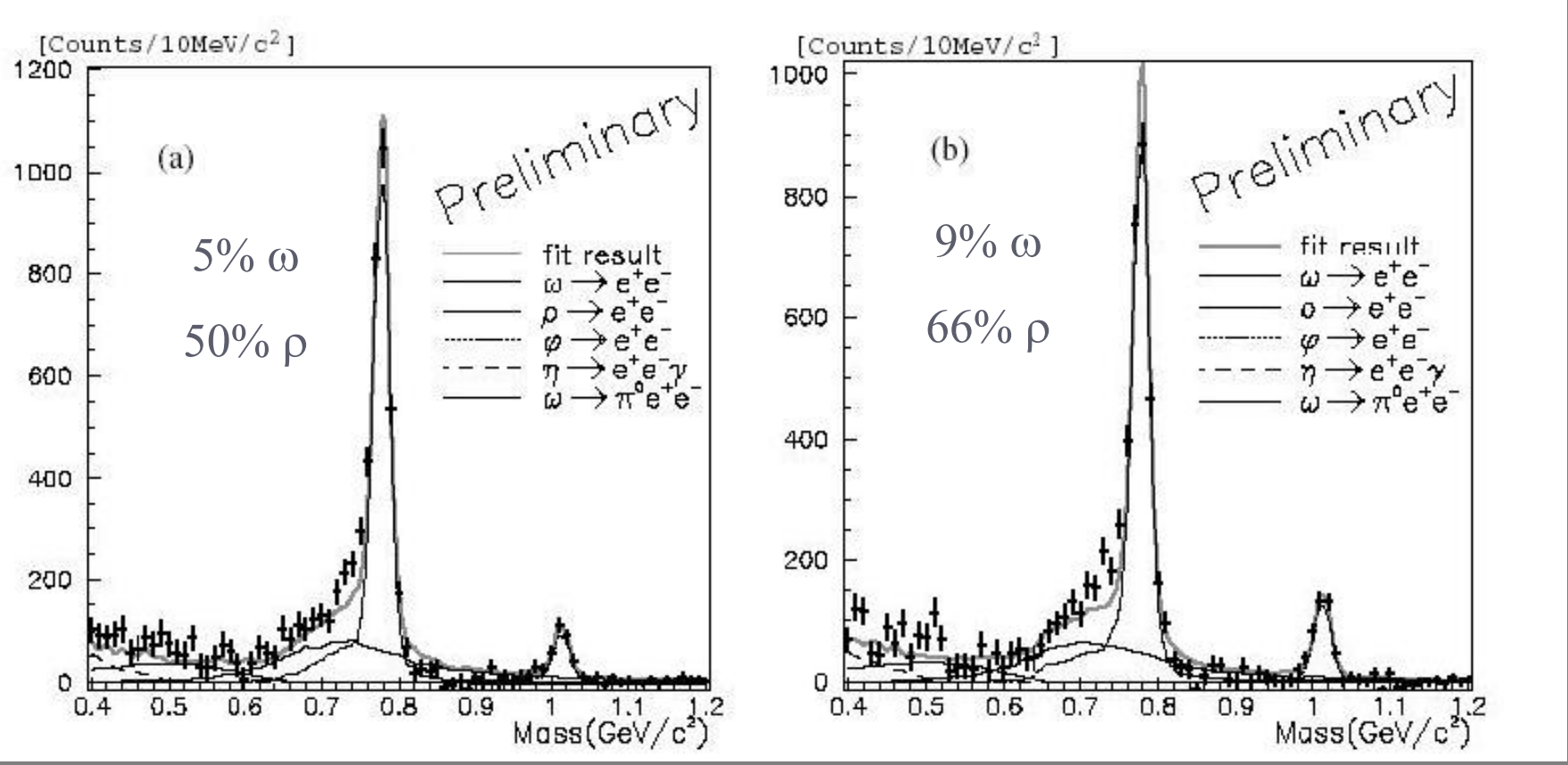


Invariant Mass Spectrum of e+e- ('02 Data)

R. Muto et al., J. Phys. G 30, S1023 (2004)

KEK-PS E325 cont.

$\rho = \omega$



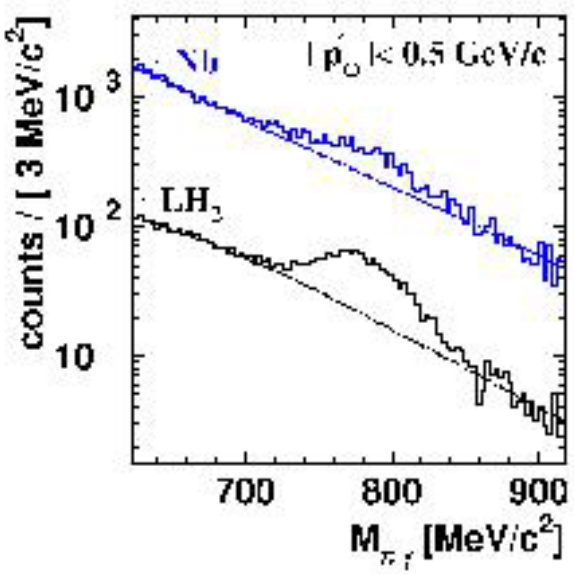
"the fit … reproduces the data qualitatively well"

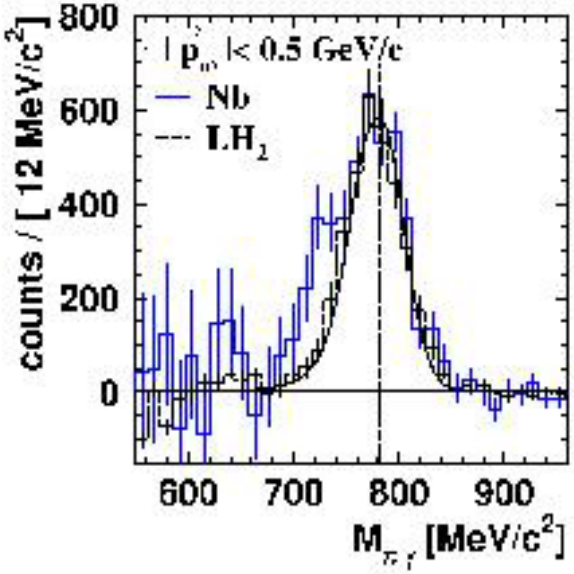
$m = m_0 (1 - 0.16\ \rho/\rho_0)$

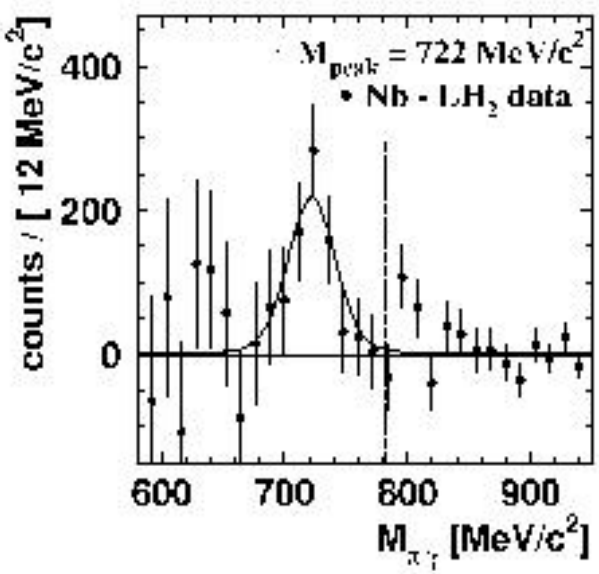
Other Experiments: TAPS results (Bonn-ELSA)

Crystal Barrel

γ+A-->ω+X (ω --> π^0 γ) , clean channel, but possible rescattering of π^0 within nuclear medium.







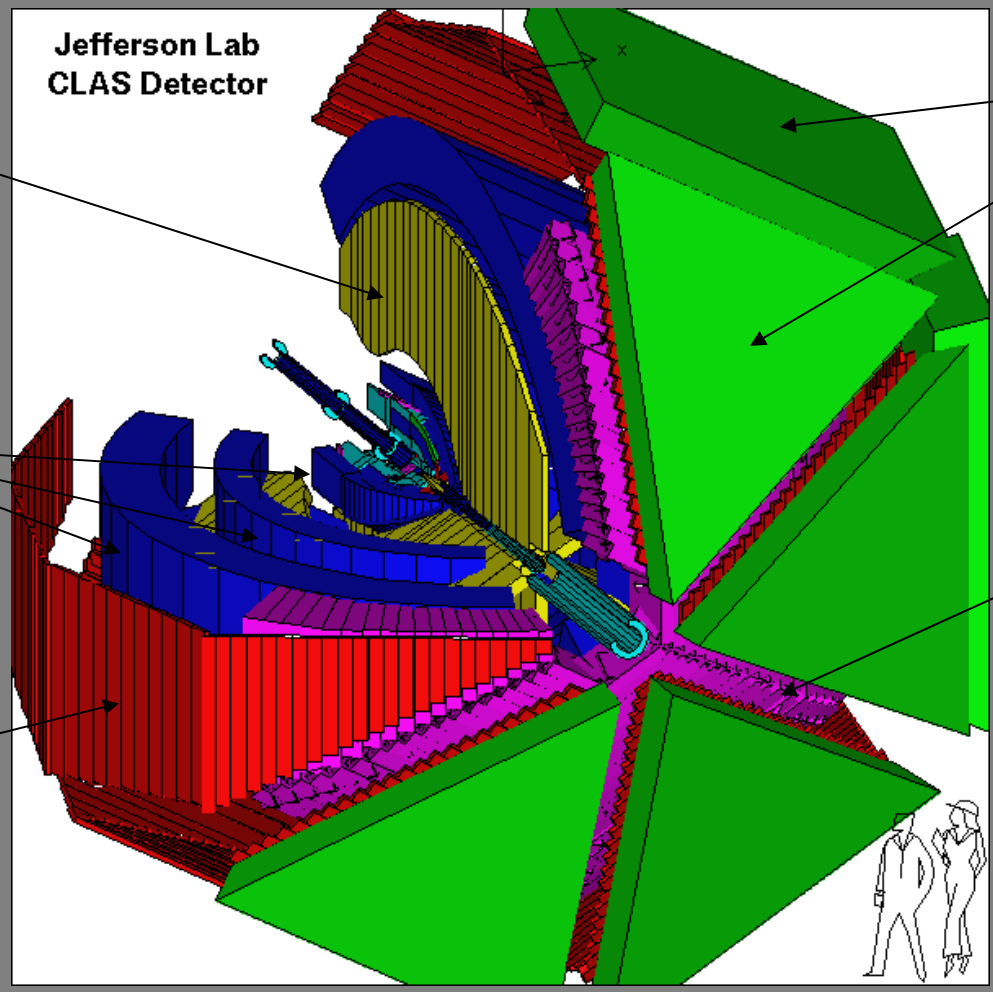
D. Trnka et al., Phys.Rev.Lett. 94 (2005) 192303

$m = m_0 (1 - \alpha \rho/\rho_0)$

$\alpha \sim 0.14$

Second run (to get more statistics) is planned.

g7 Cebaf Large Acceptance Spectrometer (CLAS)



Superconducting Torus Magnet
6 Superconducting coils

Electromagnetic Calorimeter
Lead-Scintillator

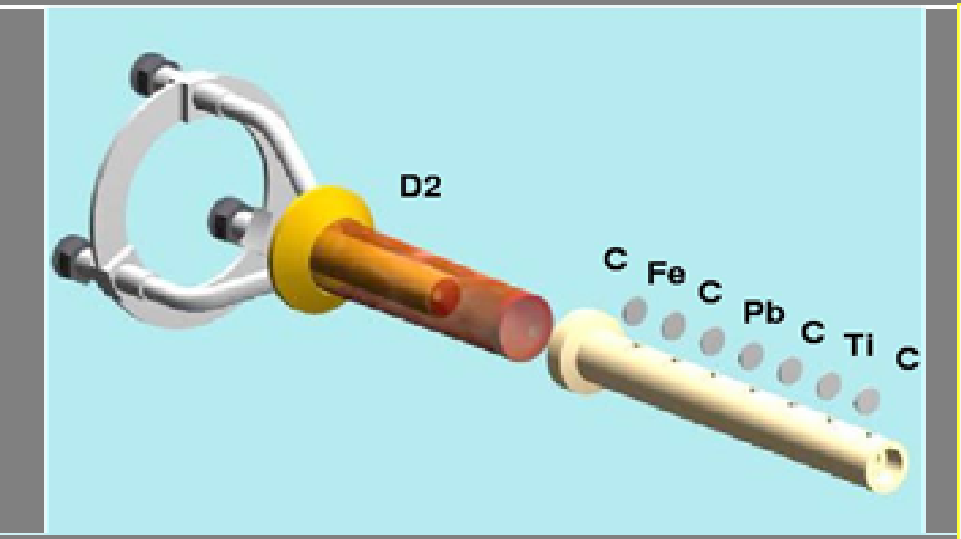
Drift Chambers
Ar-CO_2
6500 channels/sector

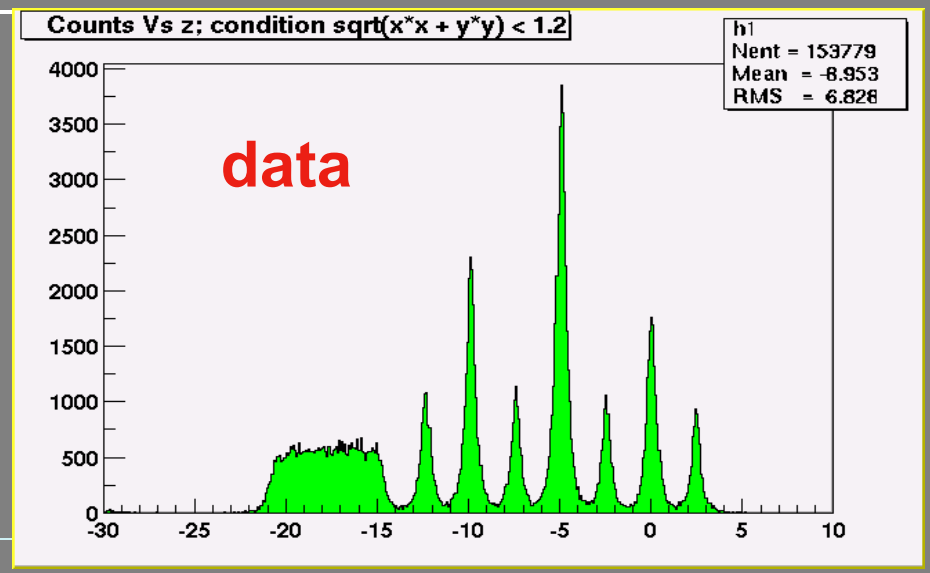
Gas Cherenkov Counter
e/π separation

Time-of-Flight Hodoscope
48 Scintillators/sector

Multi-segmented Nuclear Target

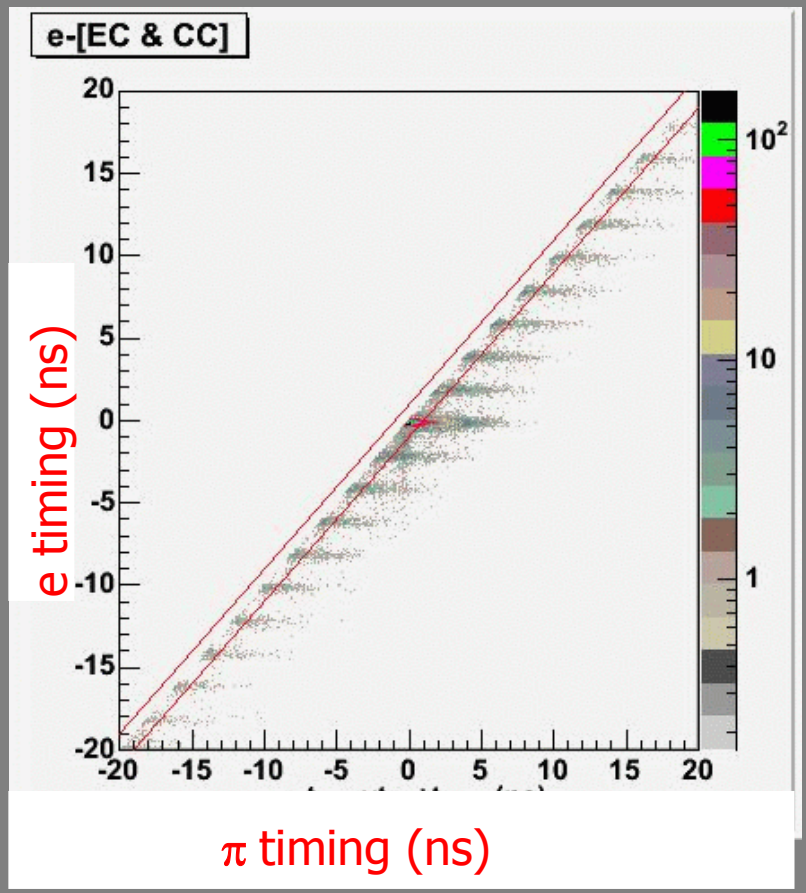
- Contains materials with different average densities.
- LD2 and seven solid foils of C, Fe, Pb, and Ti.
  Each target material 1 g/cm^2 and diameter 1.2 cm

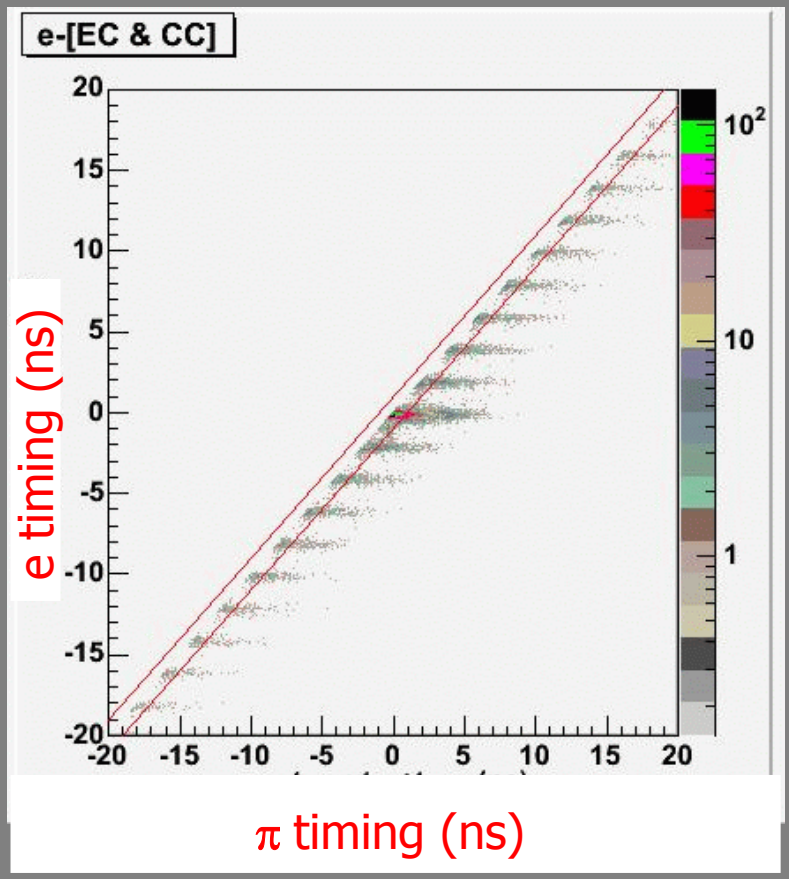




- Proper spacing 2.5 cm to reduce multiple scattering
- D2 target as reference, small nucleus, no modification is expected.

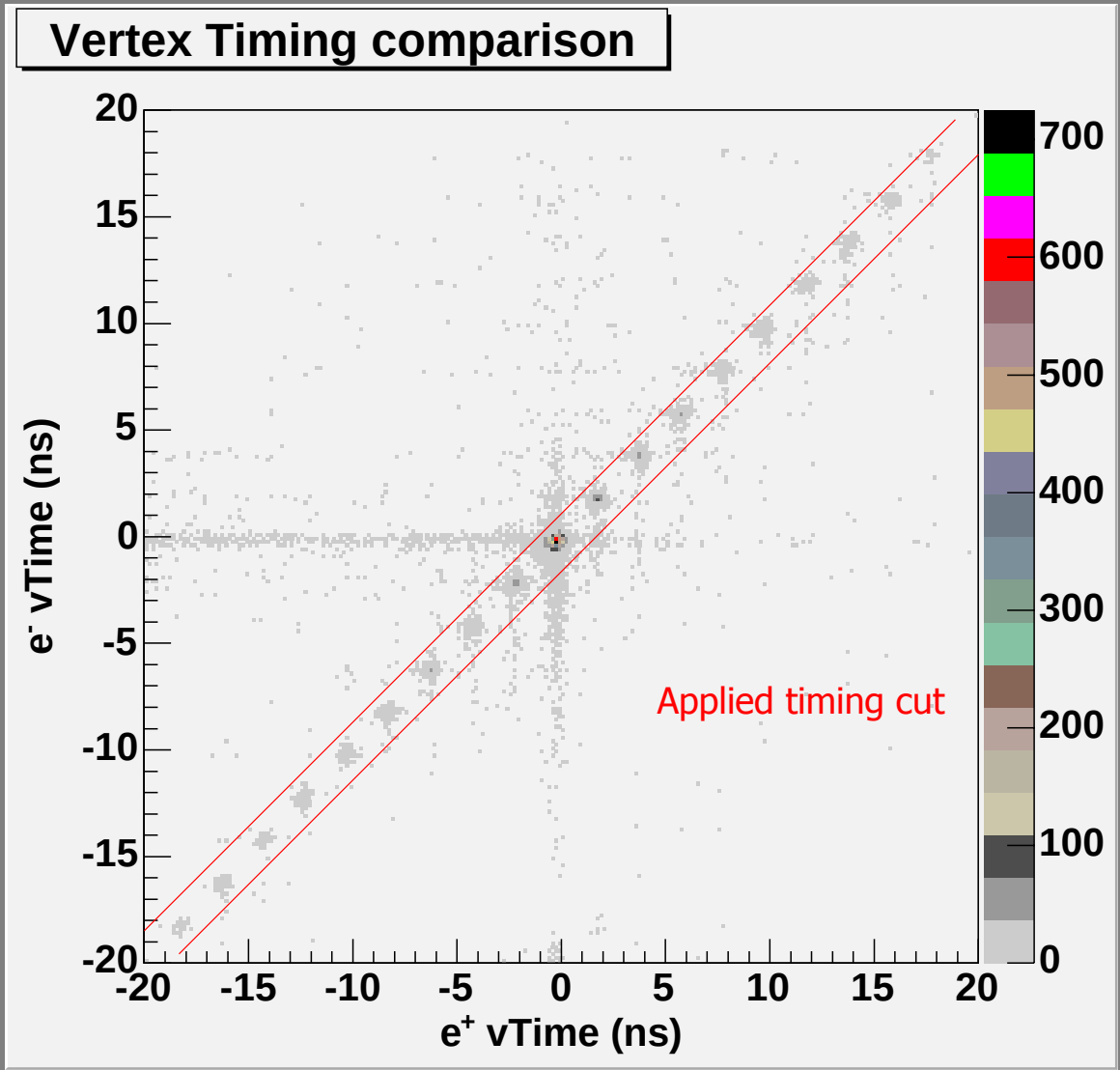
Pion Rejection



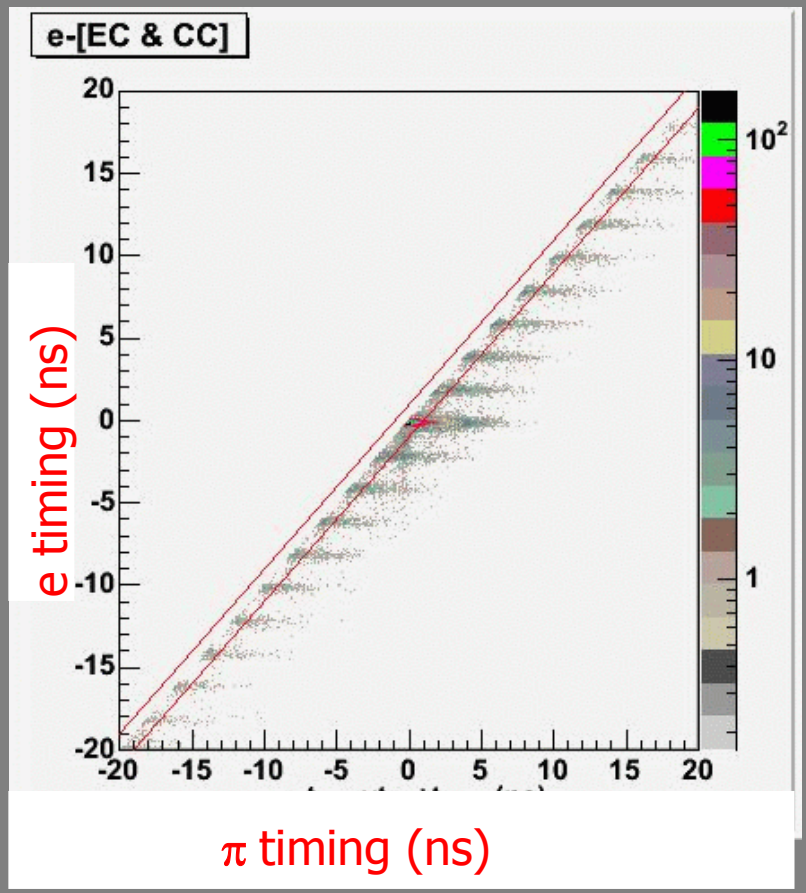


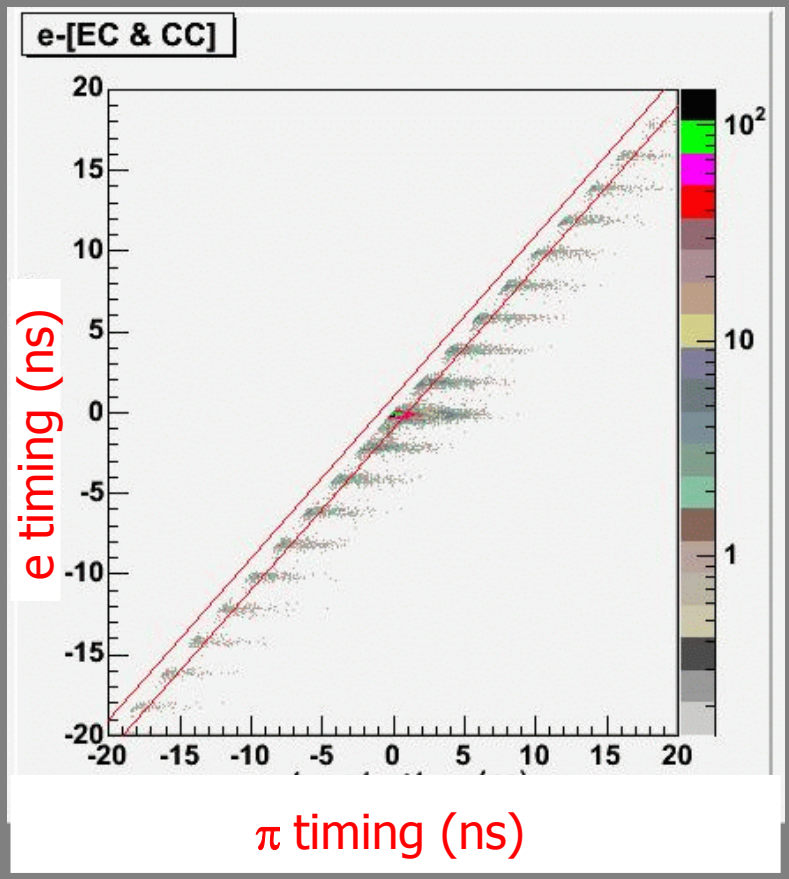
BR→ e^+e^- ρ:5e-5,ω:7e-5,ϕ:3e-4

Pion Rejection ~10^7



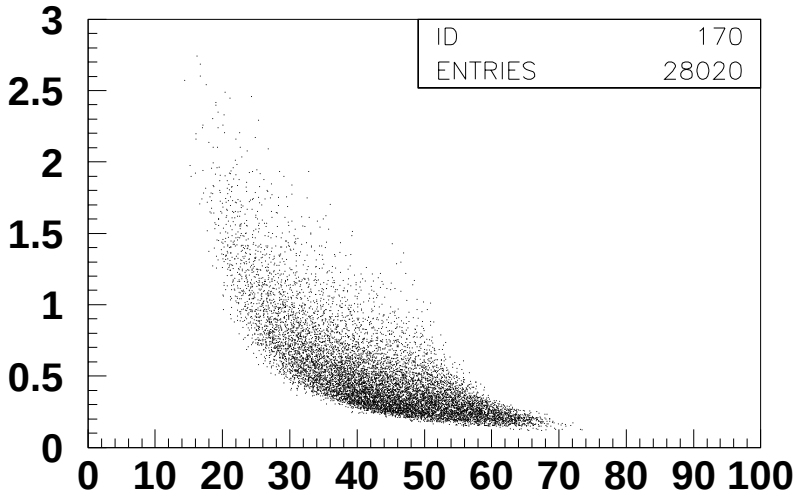
Pion Rejection



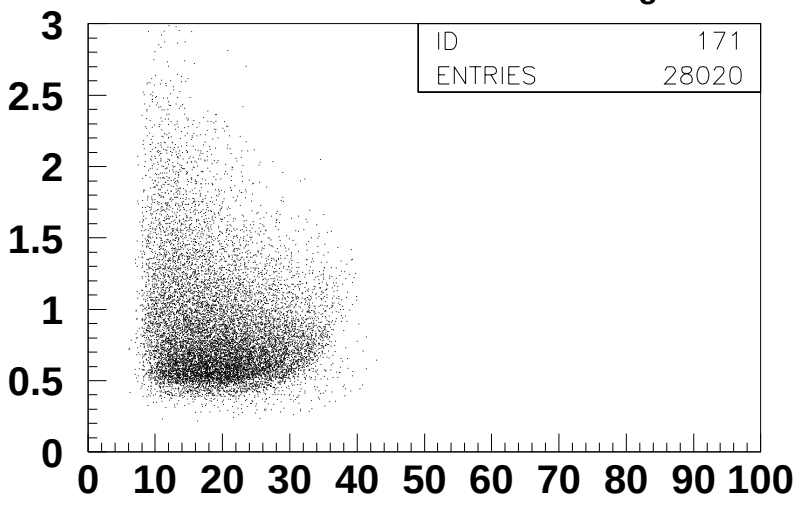


BR→ e^+e^- ρ:5e-5,ω:7e-5,ϕ:3e-4

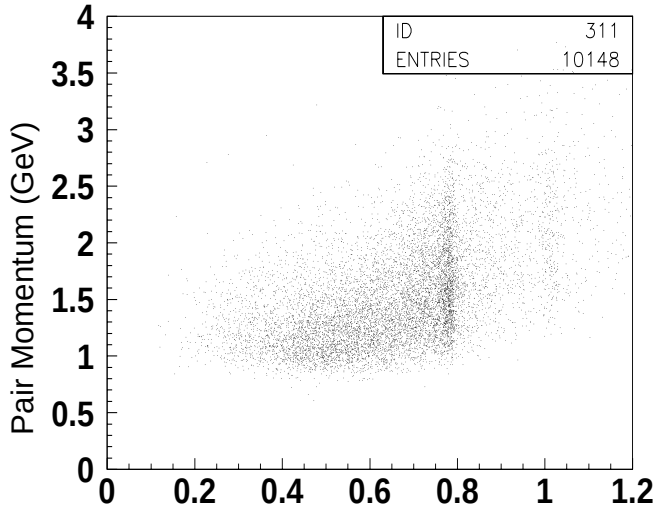
Electron/Positron Acceptance



Electron momentum versus angle

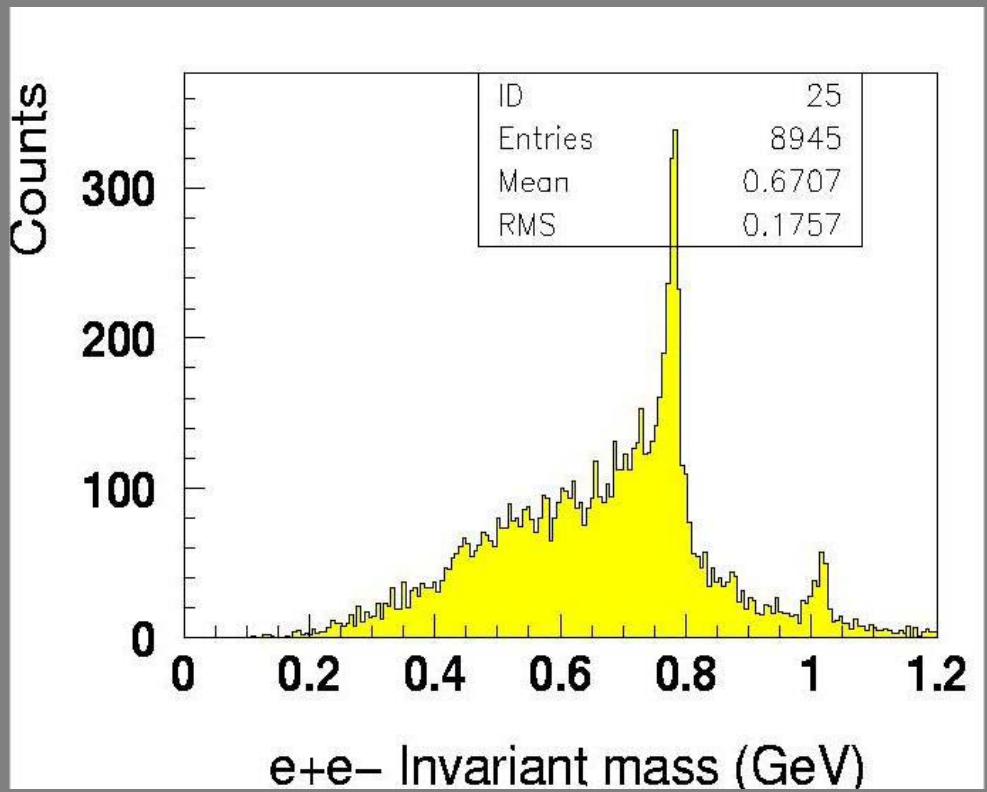


Positron momentum versus angle

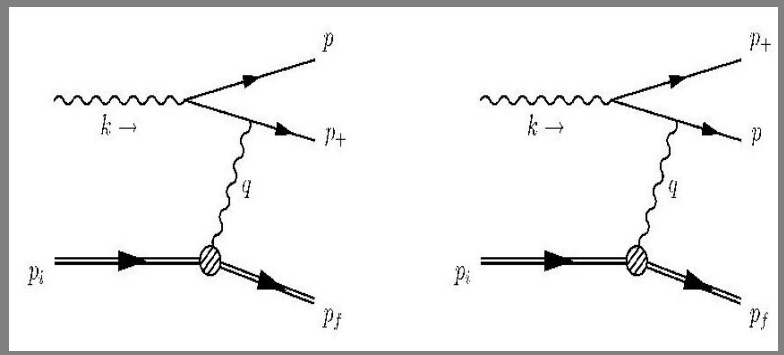


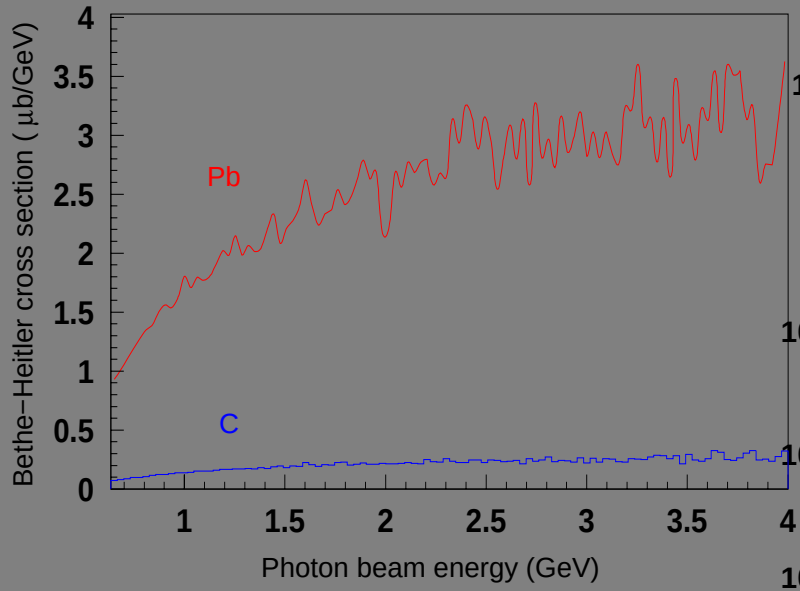
Running Conditions

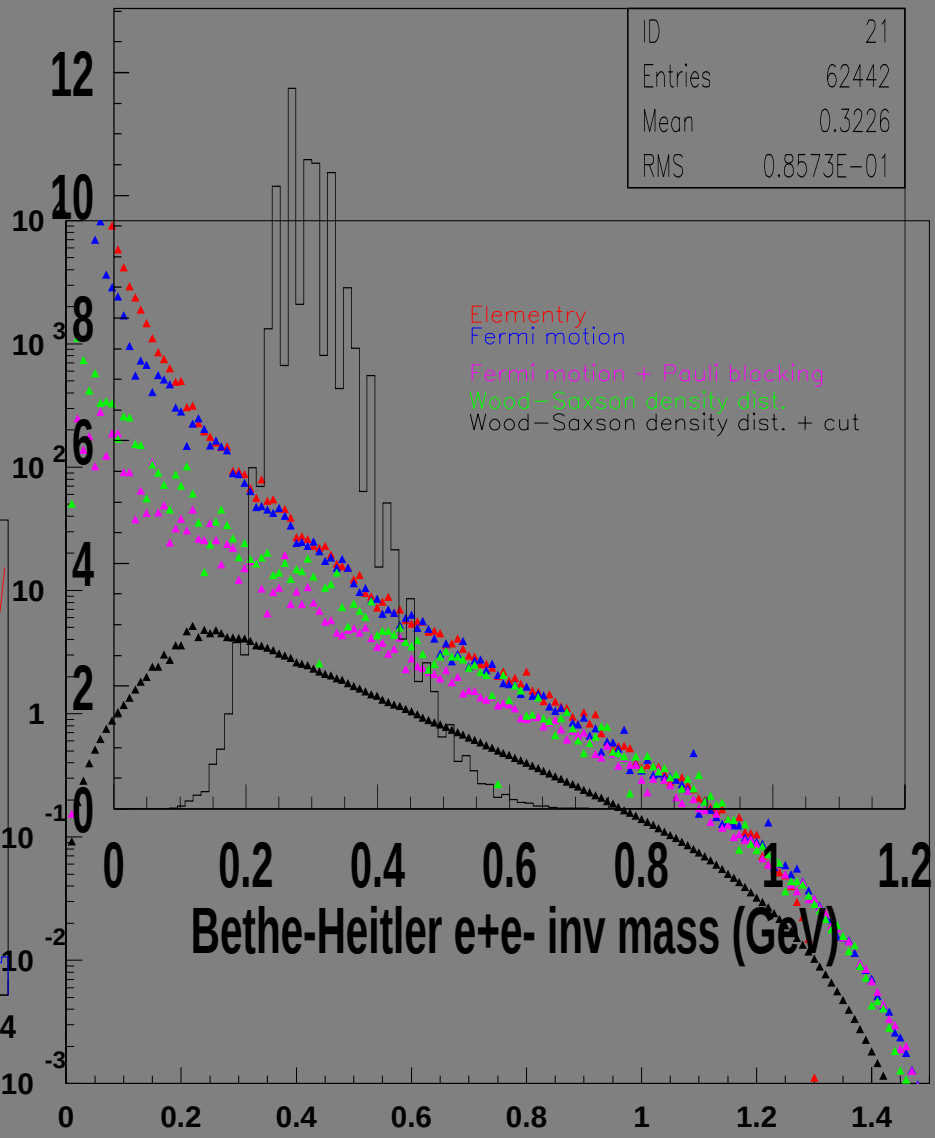
g7a:
Electron Energy: 3 GeV Photon Flux: 5 X 10^7/s L: 10^{32} cm^{-2}/s
Trigger Rate: Double Electron: 150 Hz Single Electron: 660 Hz
Targets: D_2 C (Fe & Ti) Pb 1 g/cm^2 each
Drift Chamber Occupancy: 1.2% Time: 18 days Integrated L: 150 pb^{-1}



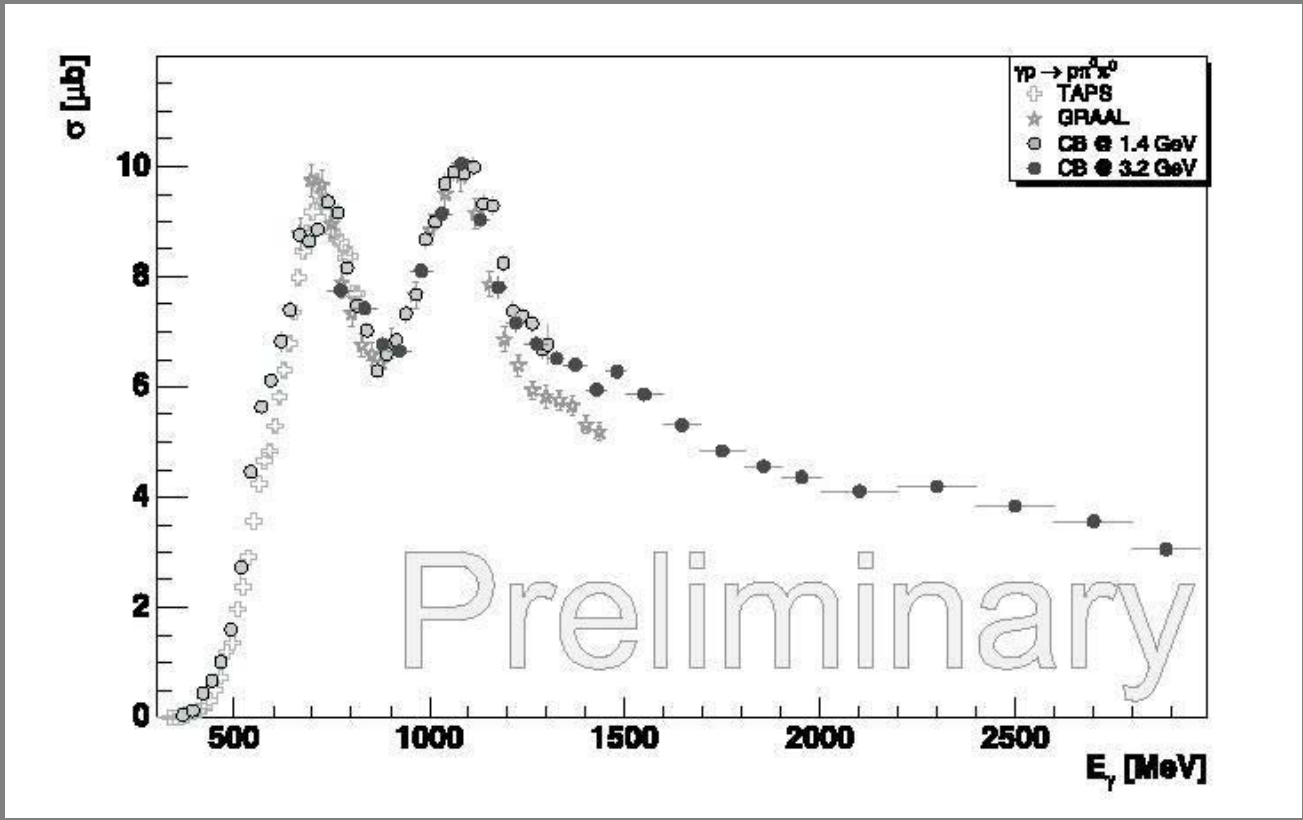
Background Bethe-Heitler





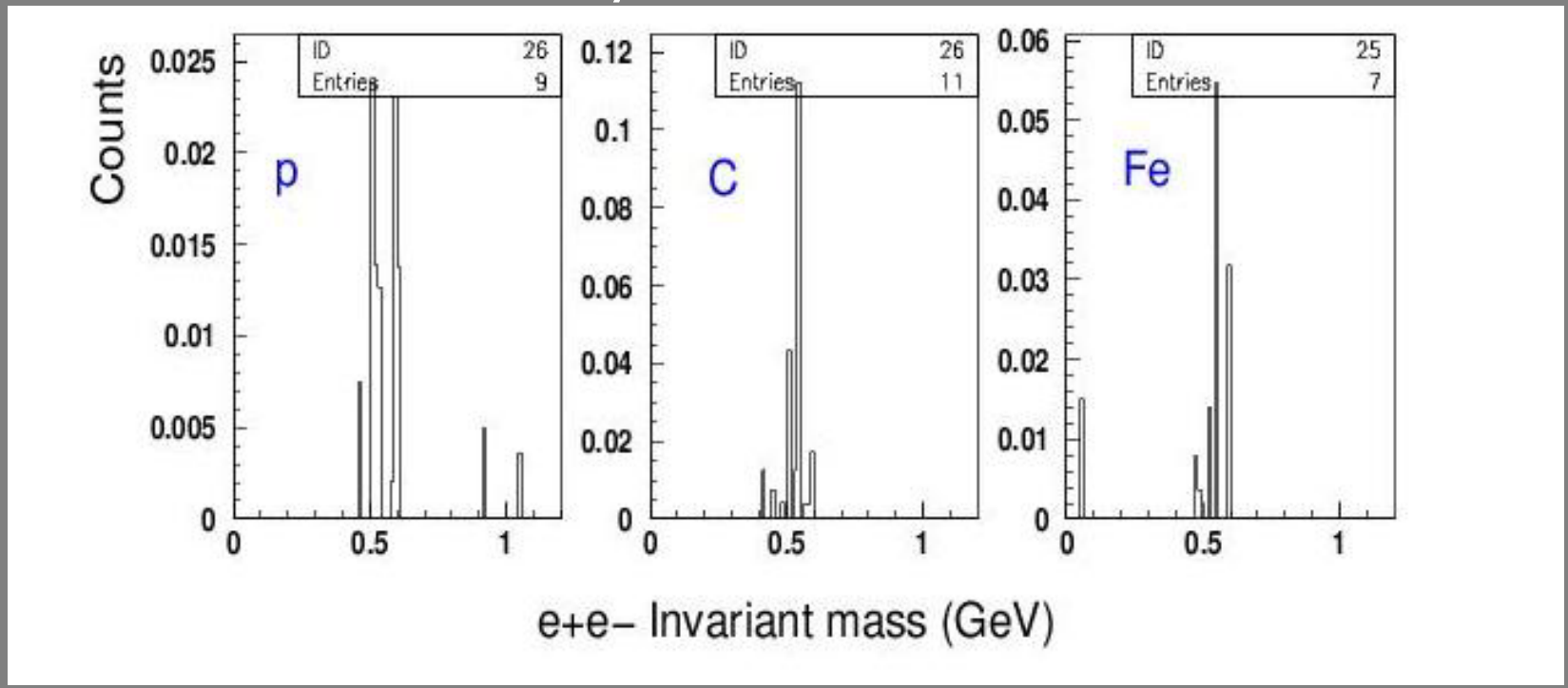


$\pi^0 \pi^0$ double Dalitz decay



Backgrounds

π^0 π^0 double Dalitz decay



Uncorrelated 'Mixed' Event Background

The combinatorial background is the random combination of pairs (e+e-, e-e-, and e+e+) due to the uncorrelated sources.

$\gamma \rightarrow$ **e+ e-**

$\pi^0 \rightarrow \gamma$ **e+ e-**

$\gamma \rightarrow$ **e+ e-**

$\pi^0 \rightarrow \gamma$ **e+ e-**

$\gamma \rightarrow$ **e+ e-**

$\pi^0 \rightarrow \gamma$ **e+ e-**

$\gamma \rightarrow$ **e+ e-**

$\pi^0 \rightarrow \gamma$ **e+ e-**

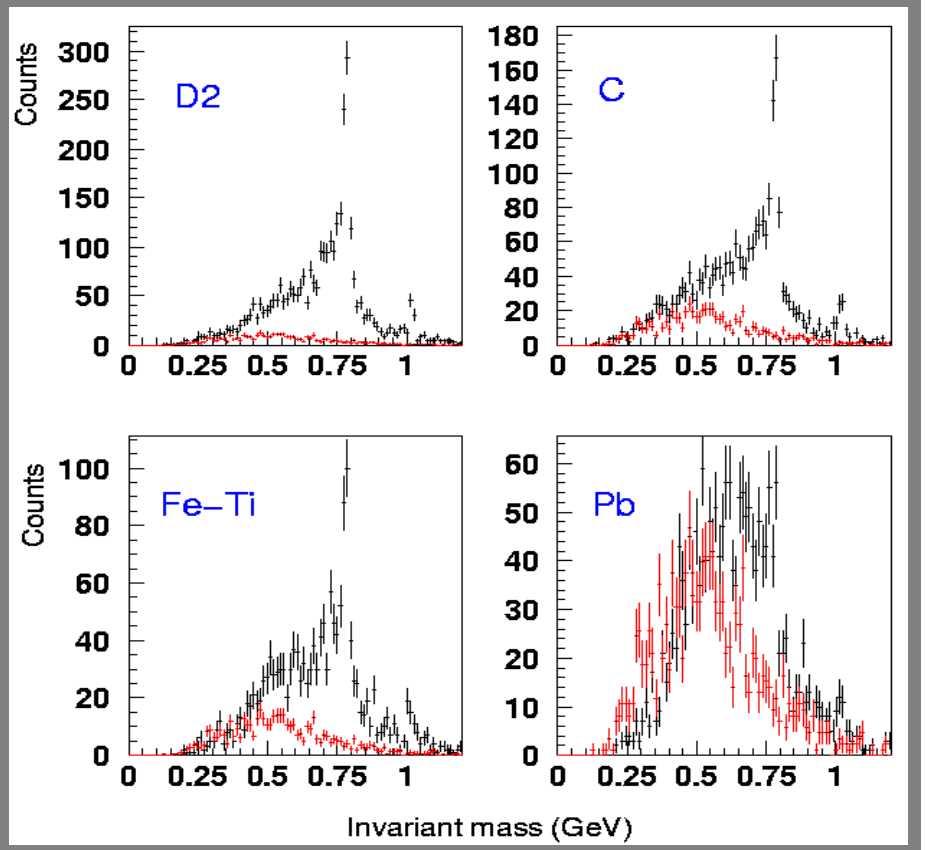
Assume N_+, and N_- obey Poisson statistics

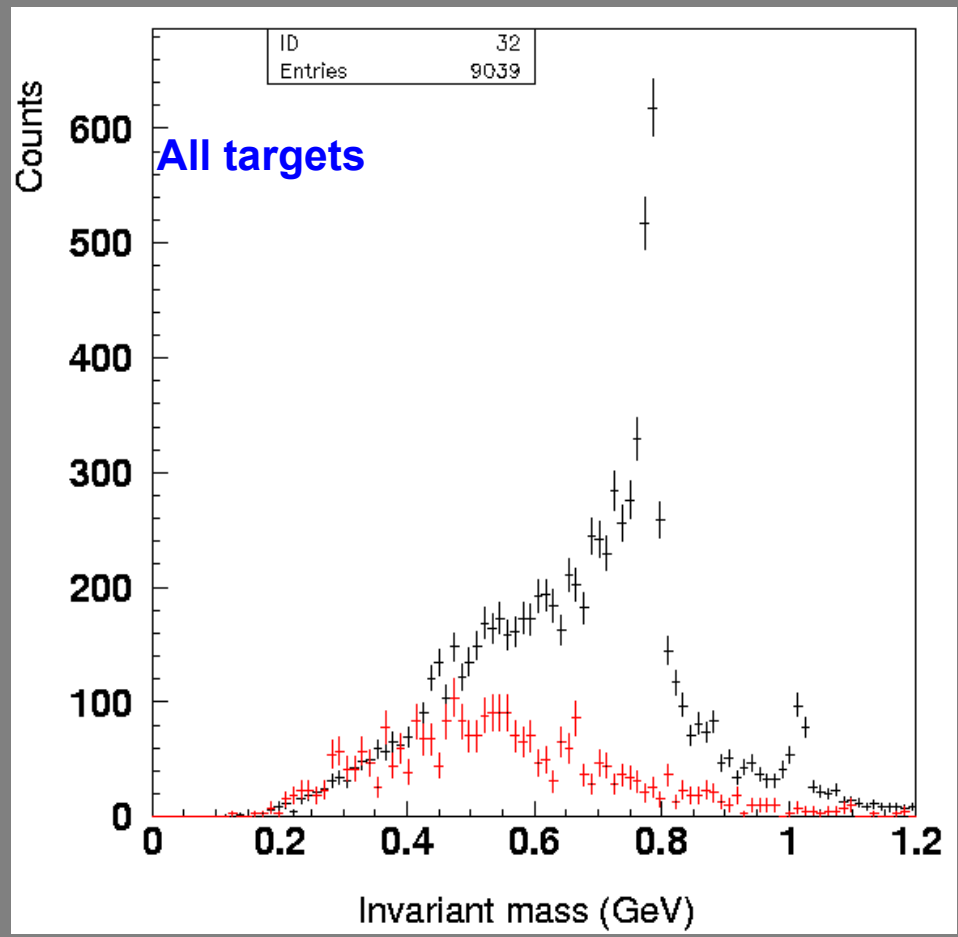
$$N_{+-} = 2\sqrt{N_{++}}\sqrt{N_{--}}$$

Data

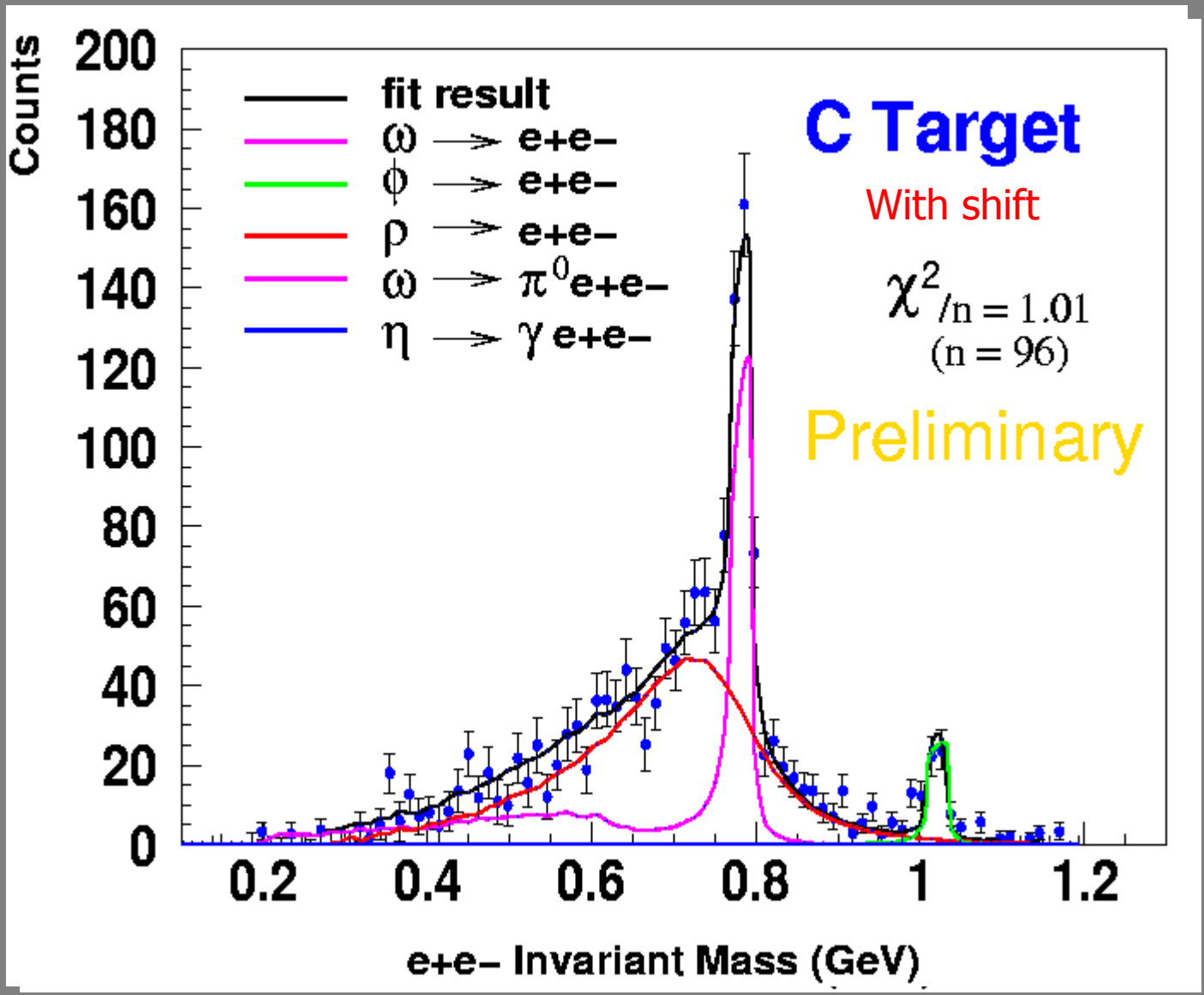
Normalized background

$$N_{+-} = 2\sqrt{N_{++}}\sqrt{N_{--}}$$

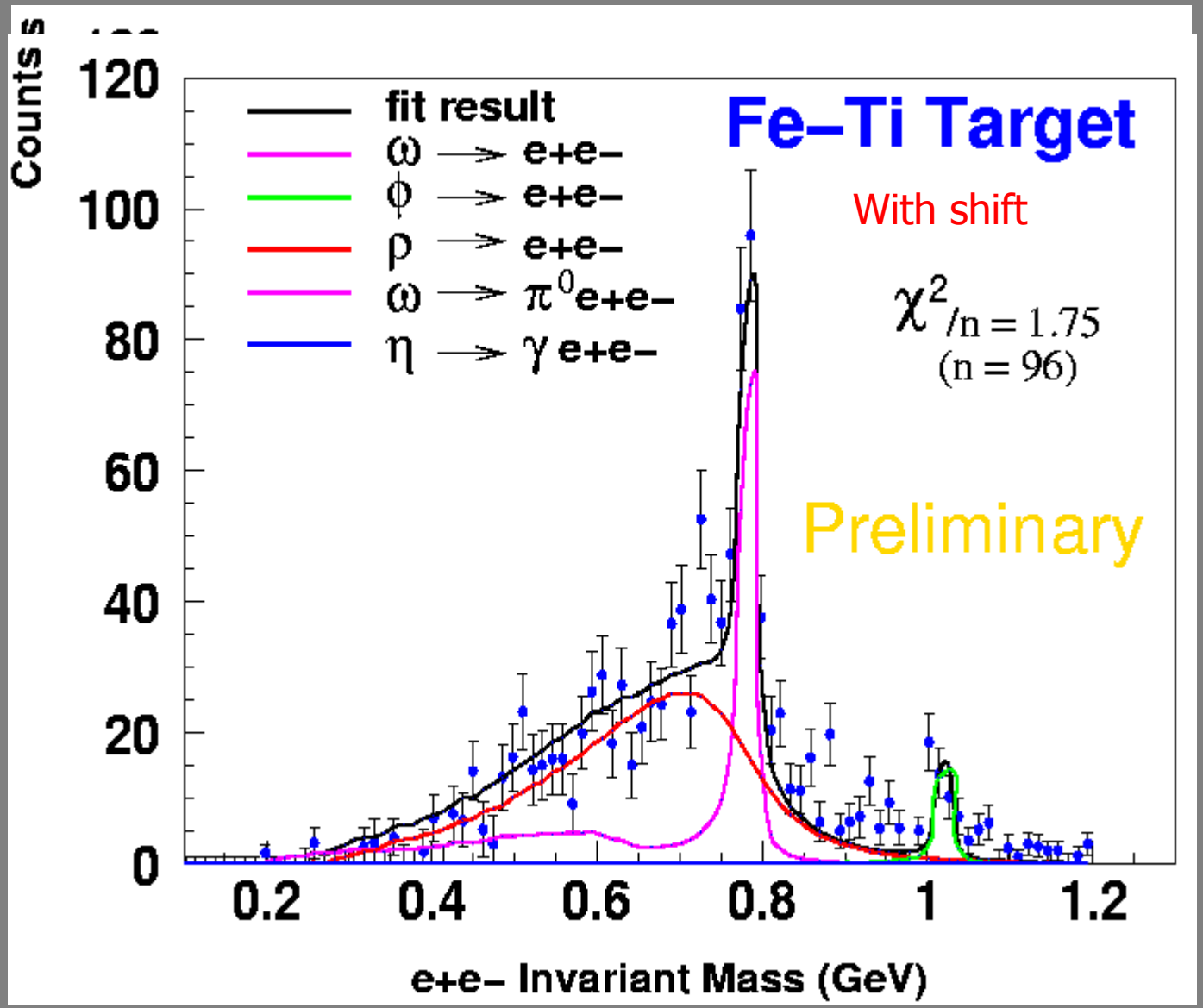




g7a Results Carbon

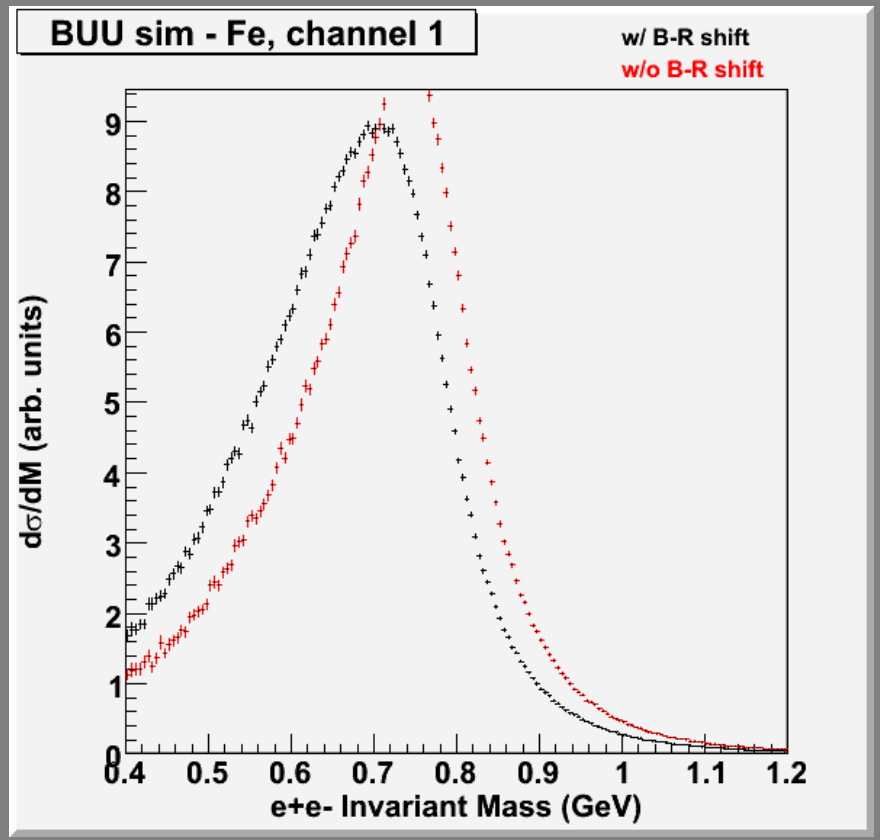


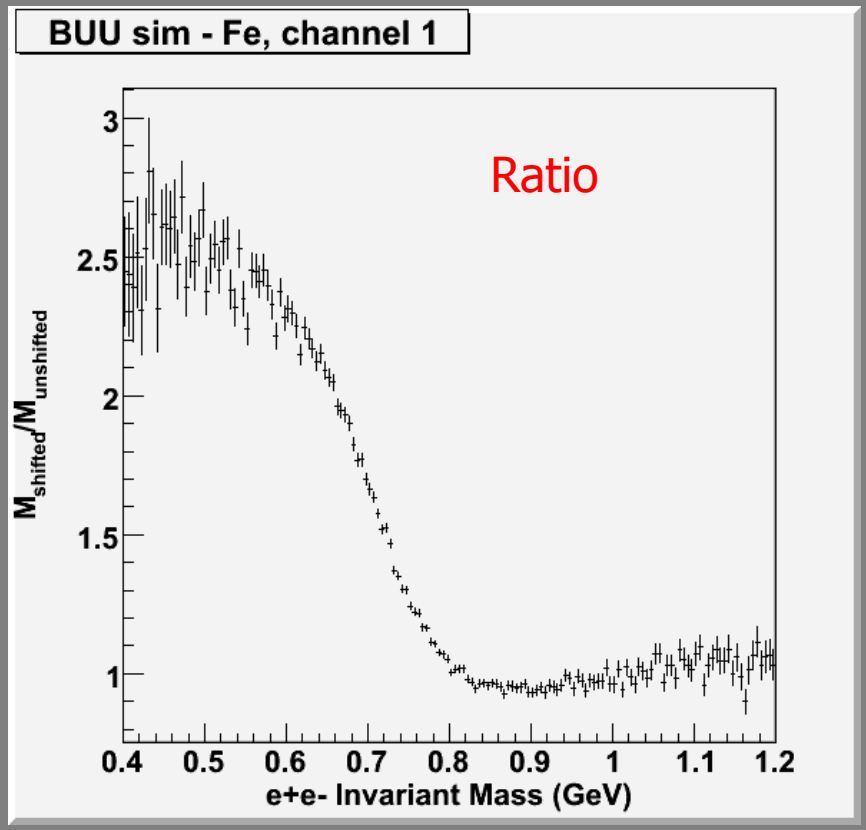
g7a Results: Fe/Ti



BUU Simulation: ρ meson in Iron

With /without Brown-Rho scaling

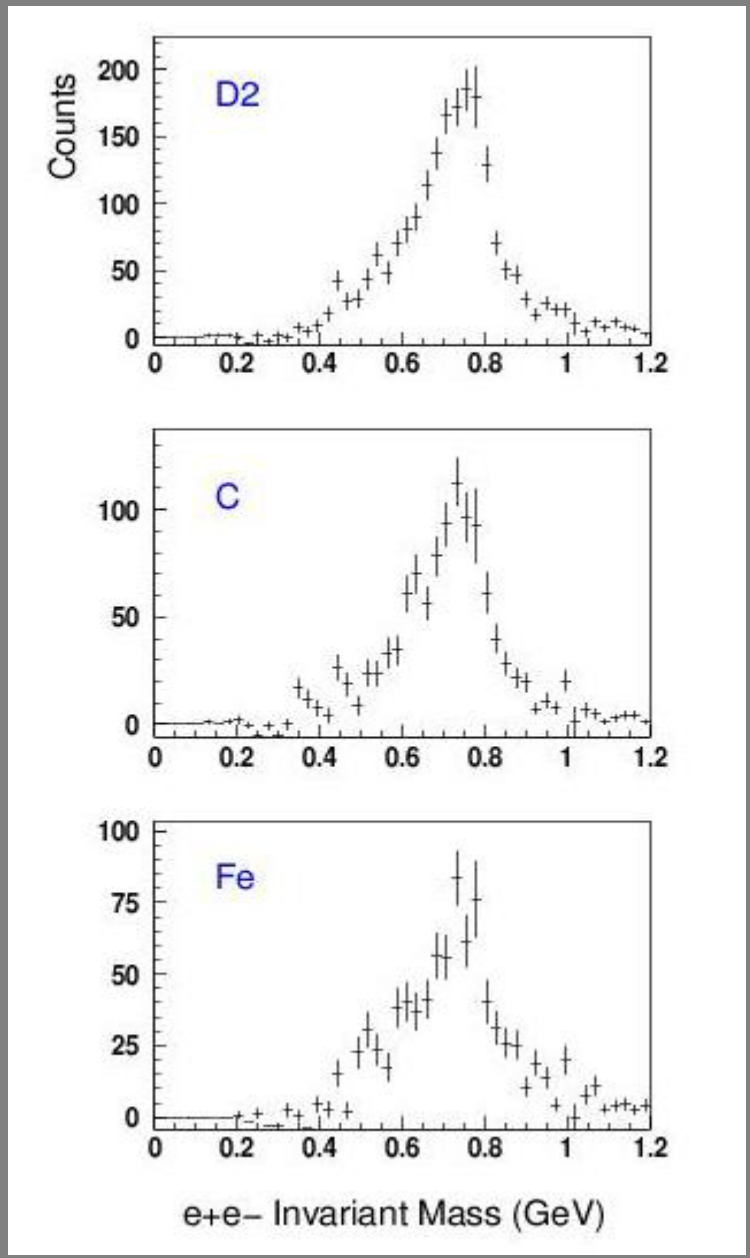


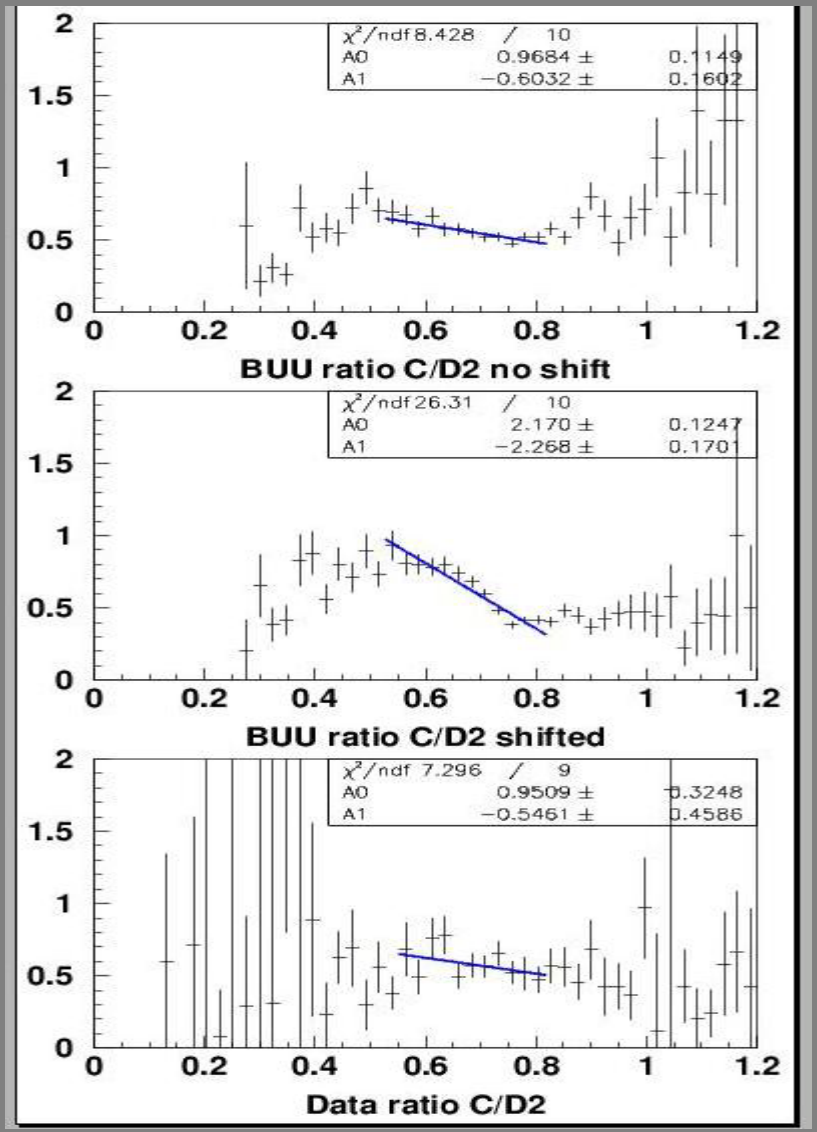


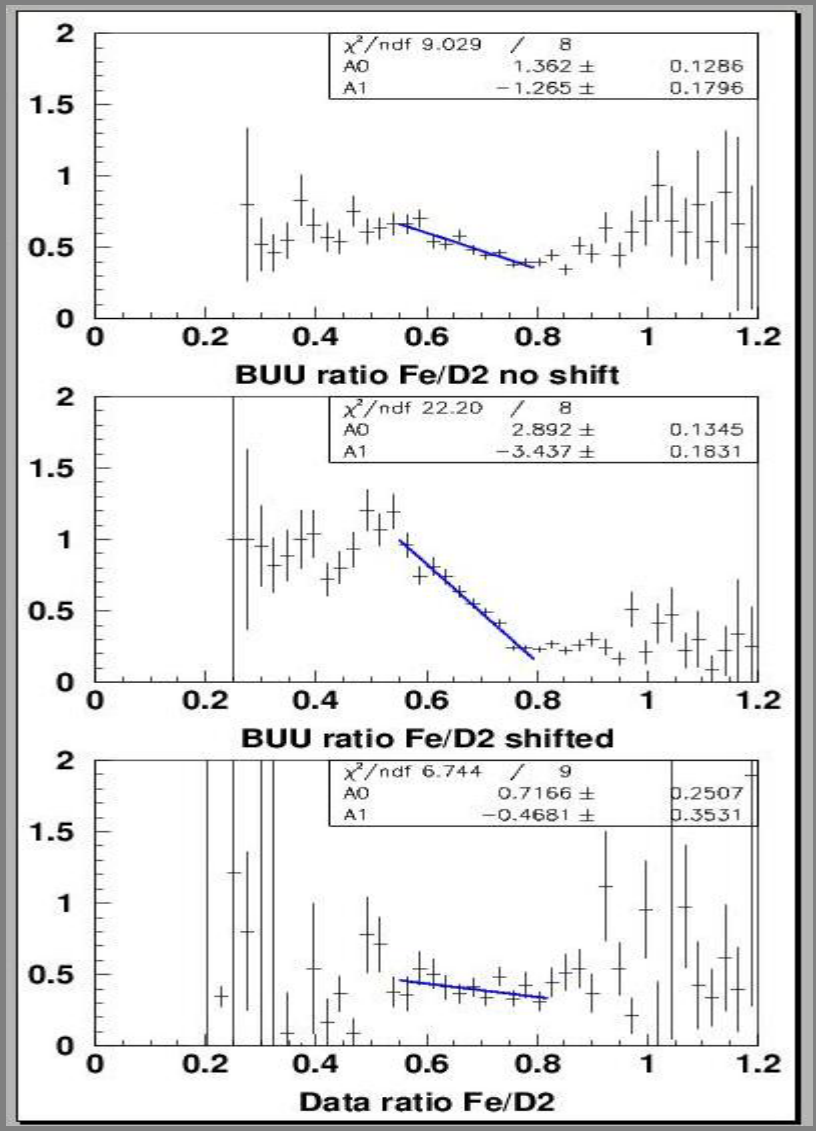
g_7 Data

extracted ρ mass distribution

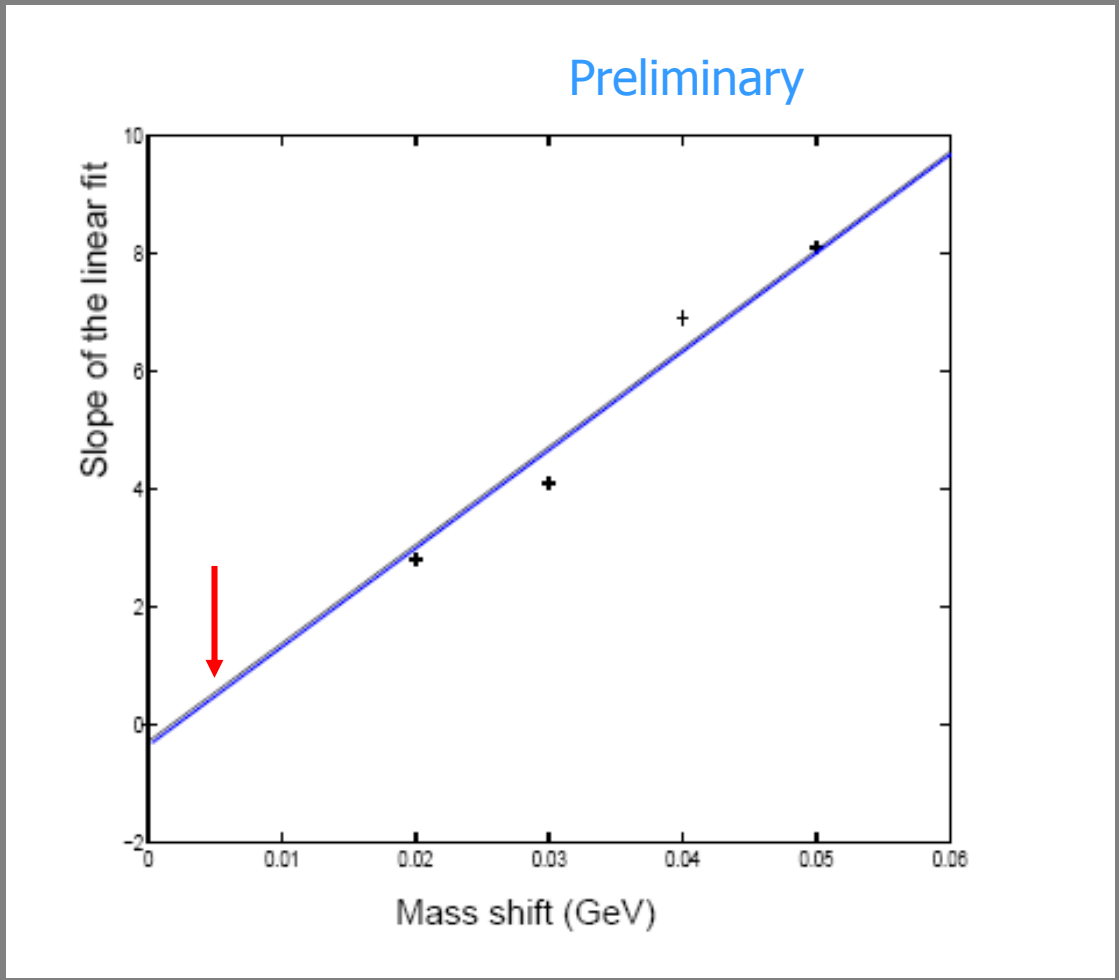
from data




χ²/ndf 8.428 / 10
A0 0.9684 ± 0.1149
A1 −0.6032 ± 0.1602
BUU ratio C/D2 no shift
χ²/ndf 26.31 / 10
A0 2.170 ± 0.1247
A1 −2.268 ± 0.1701
BUU ratio C/D2 shifted
χ²/ndf 7.296 / 9
A0 0.9509 ± 0.3248
A1 −0.5461 ± 0.4586
Data ratio C/D2


χ²/ndf 9.029 / 8
A0 1.362 ± 0.1286
A1 −1.265 ± 0.1796
BUU ratio Fe/D2 no shift
χ²/ndf 22.20 / 8
A0 2.892 ± 0.1345
A1 −3.437 ± 0.1831
BUU ratio Fe/D2 shifted
χ²/ndf 6.744 / 9
A0 0.7166 ± 0.2507
A1 −0.4681 ± 0.3531
Data ratio Fe/D2

Mass Shift Sensitivity



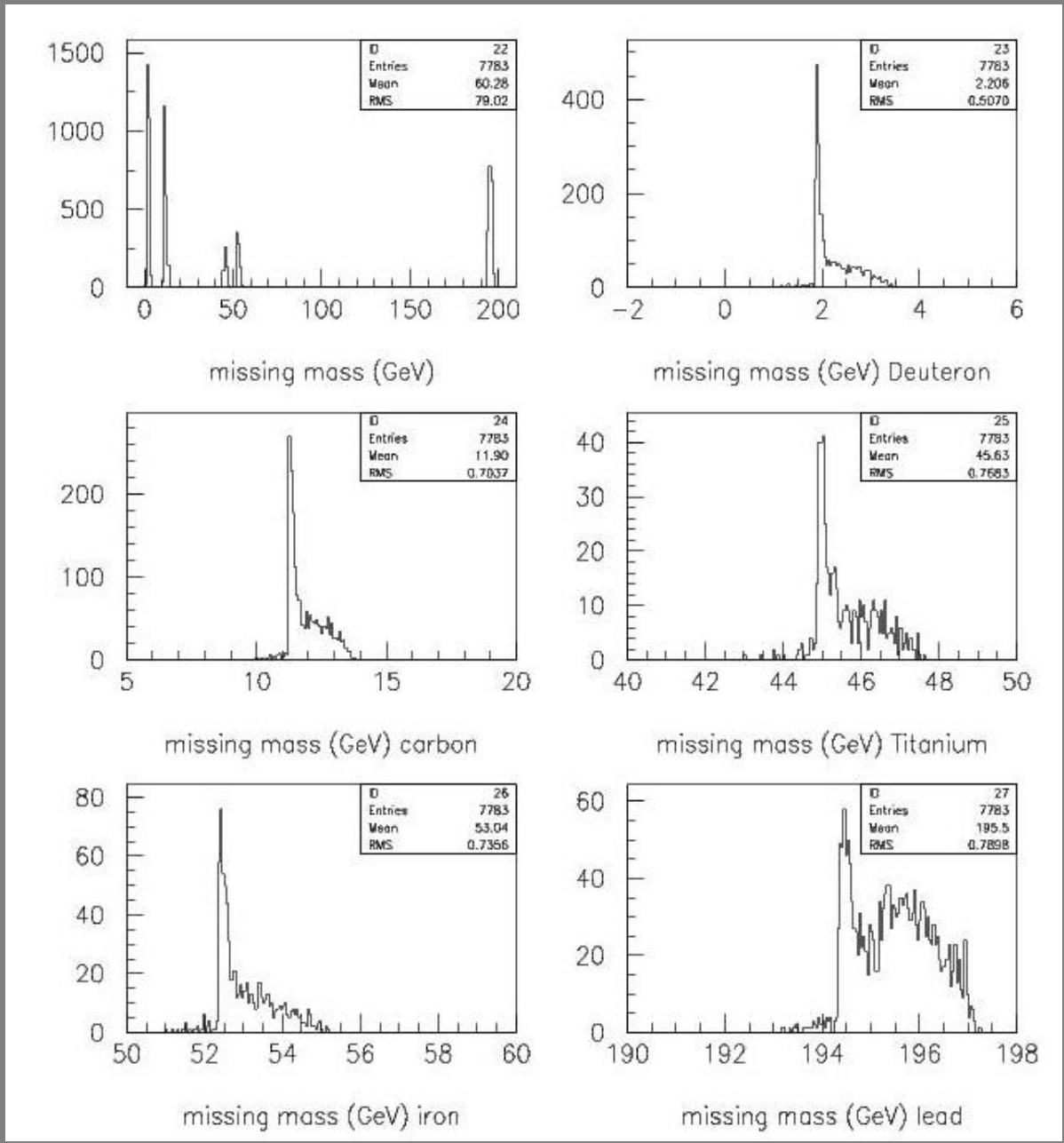
Summary and Conclusions

- e+e- from rare leptonic decay of light vector mesons are identified.
- Clear ρ, ω and ϕ signals in the invariant mass spectrum.
- "Mixed events" technique for the combinatorial background works giving both shape and normalization!
- Full Monte-Carlo simulation for Bethe-Heitler and pion dalitz decay show negligible contribution in the region of the vector mesons.
- Preliminary results are not compatible with substantial increase of width or the predicted mass shift (α~0.16). If any mass shift, it should be much smaller. Work is in progress to determine an upper limit on α with the current statistics.

- , *Medium modification studies continue to be a hot topic!*
- Need follow up experiment to increase statistics (D,C,Fe and Nb)

Our group would like to thank U. Mosel and P. Muehlich for providing us with the model calculations, theoretical support and participating in several meetings and discussions during this work.

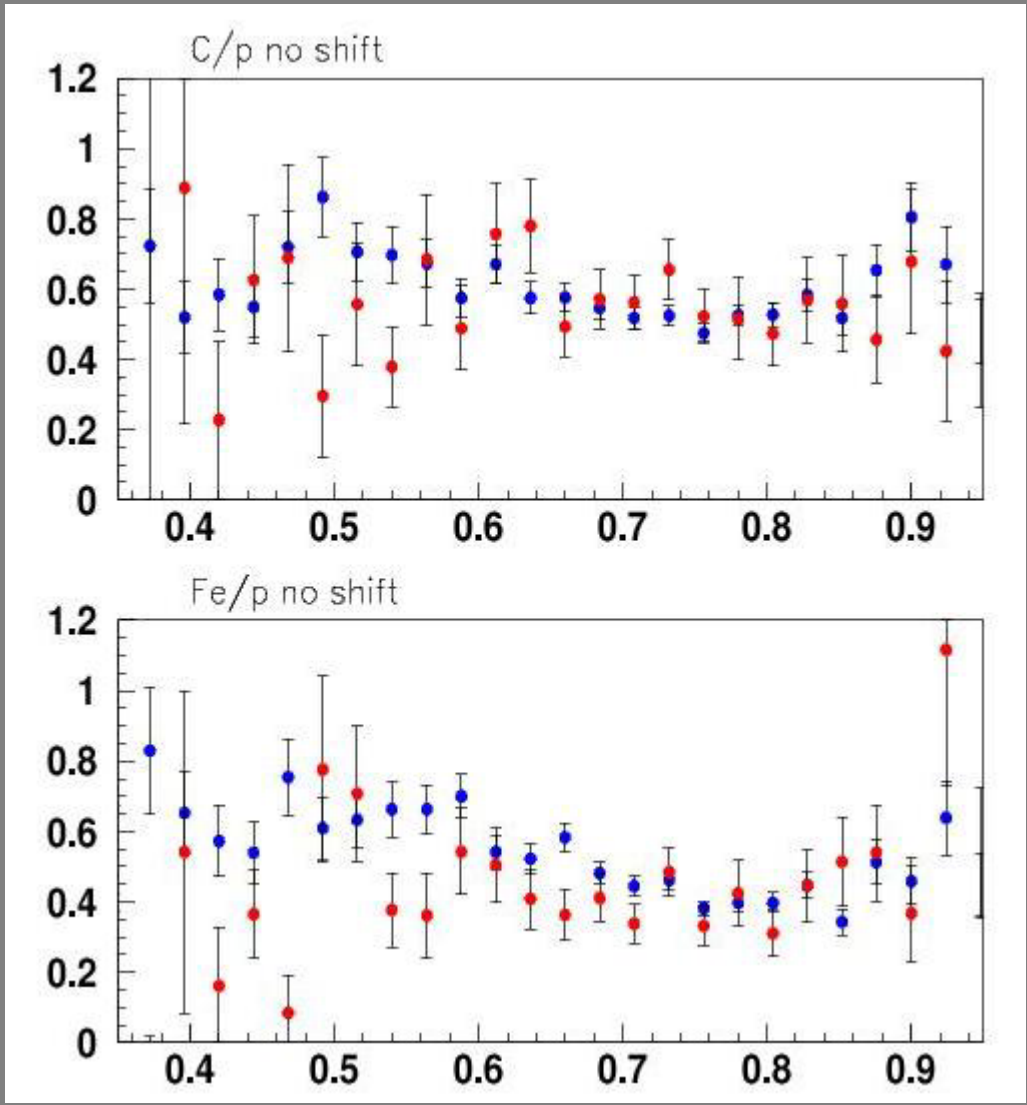
Coherent/Incoherent Production



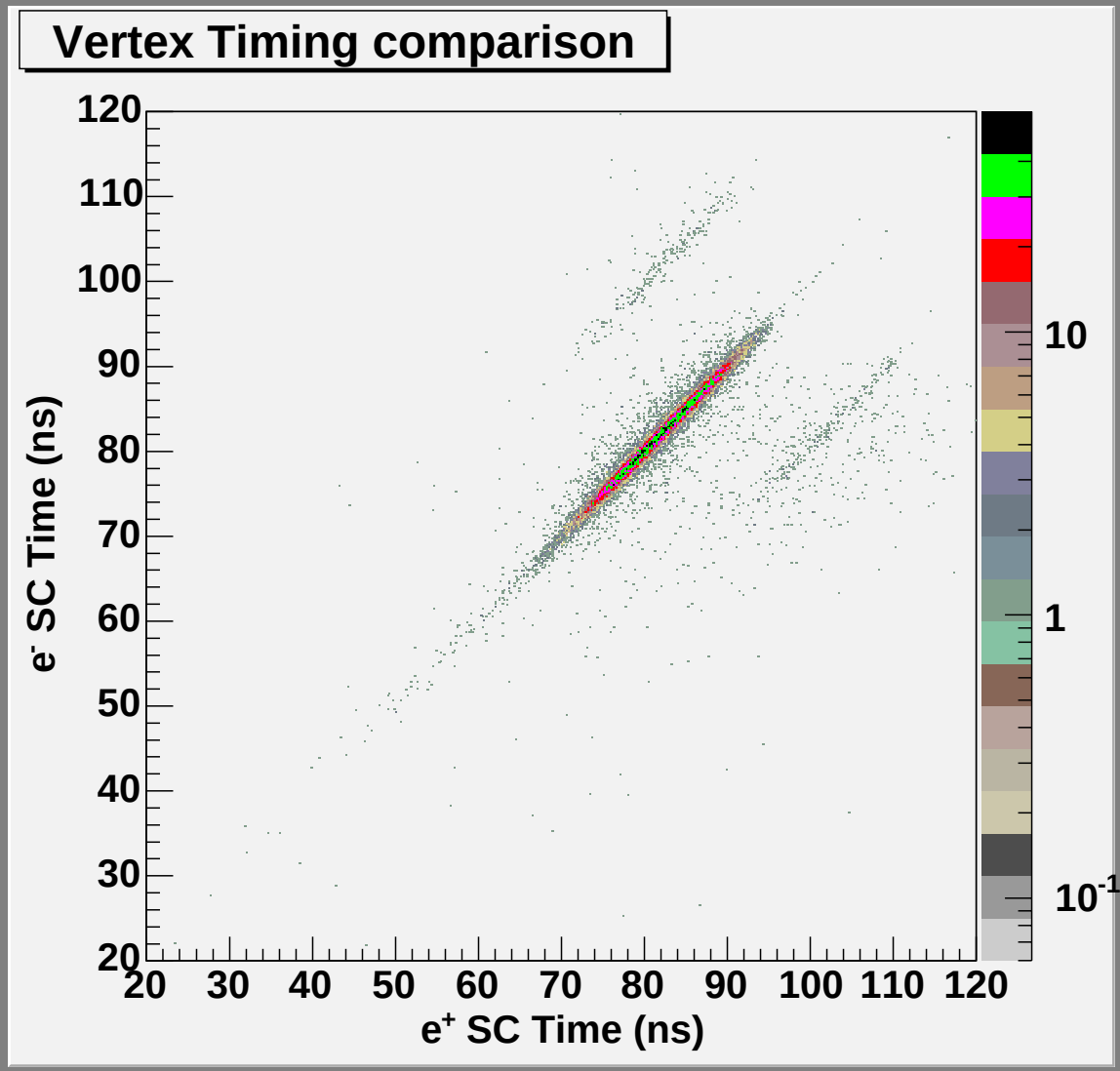
g7 Data

Blue x BUU simulation

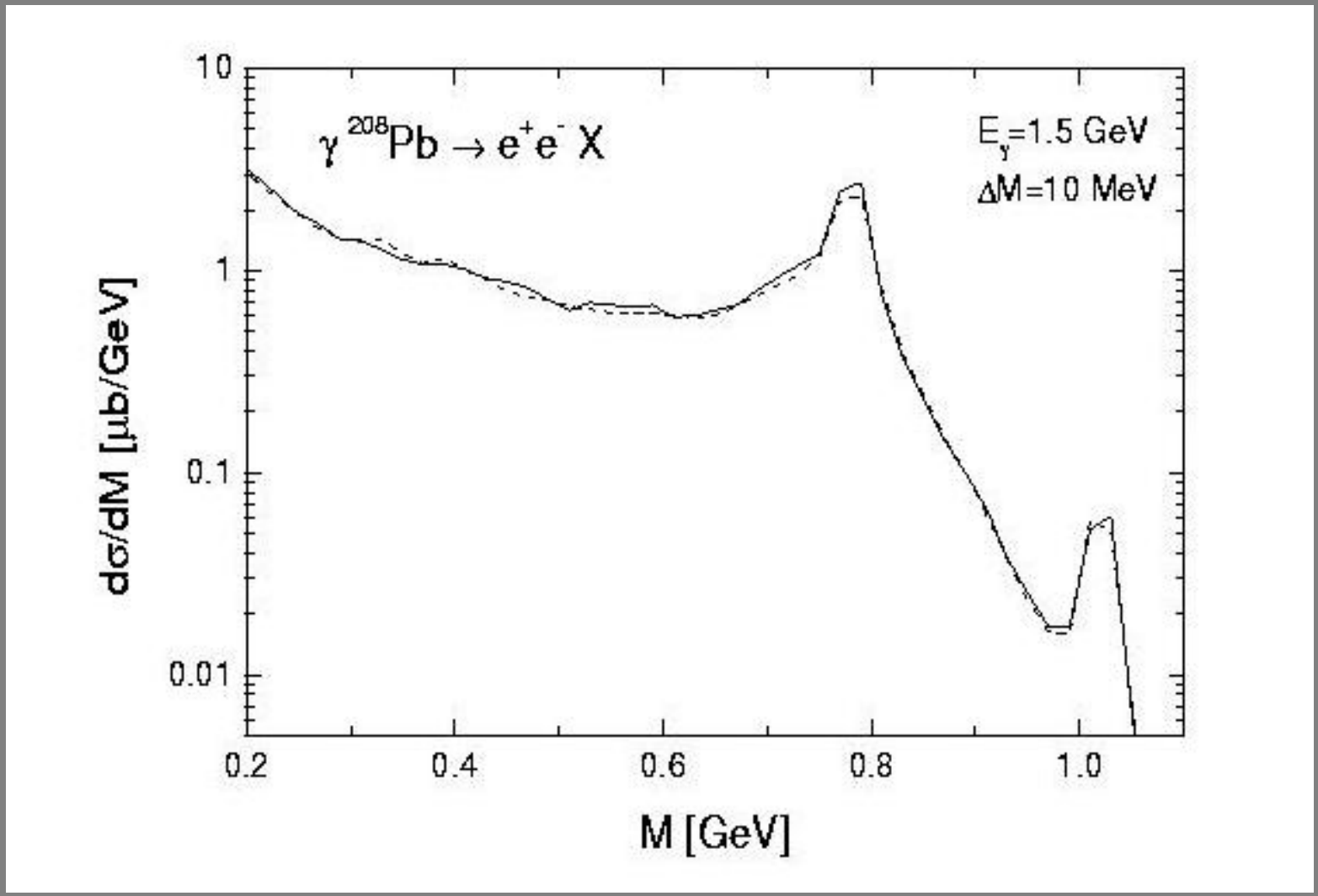
Red Data



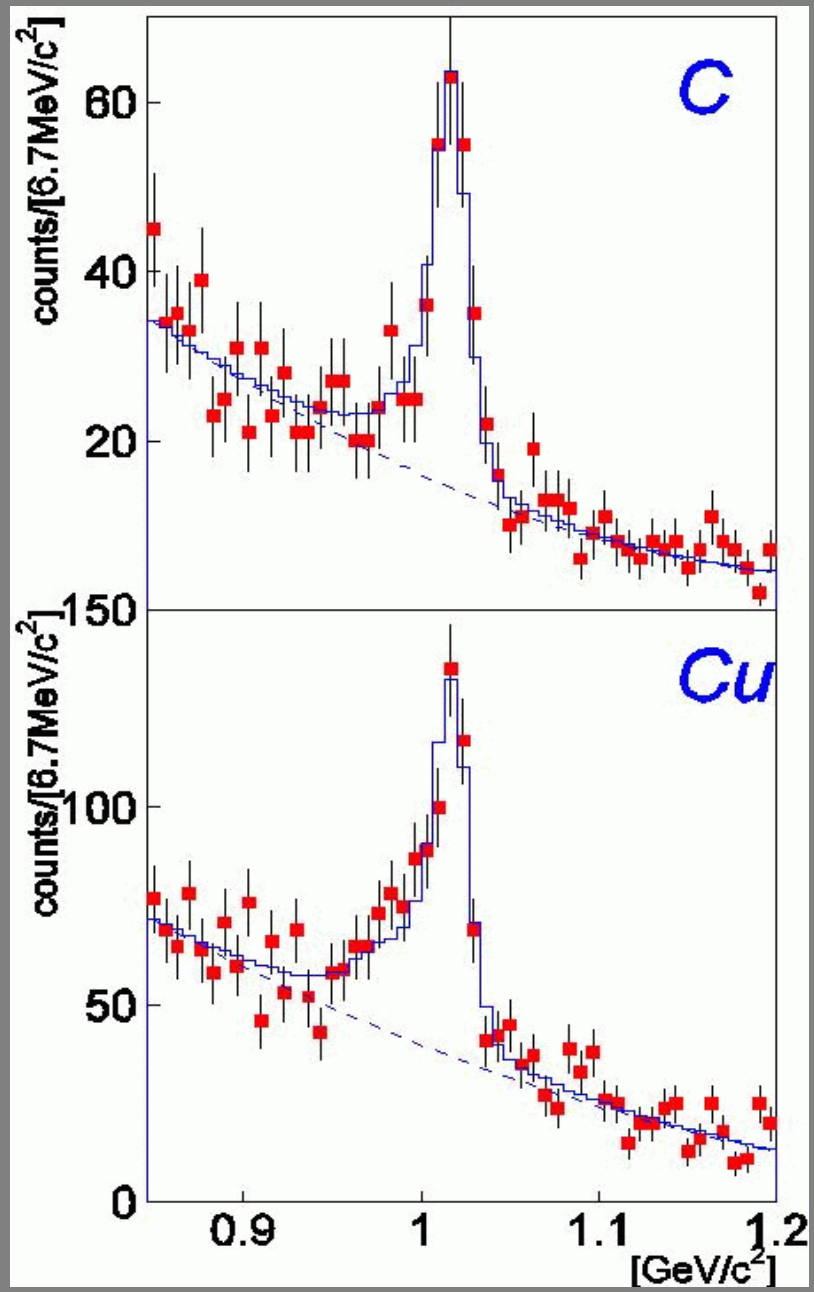
Pion Rejection



Coulomb Effects



KEK Result on the ϕ



Iron

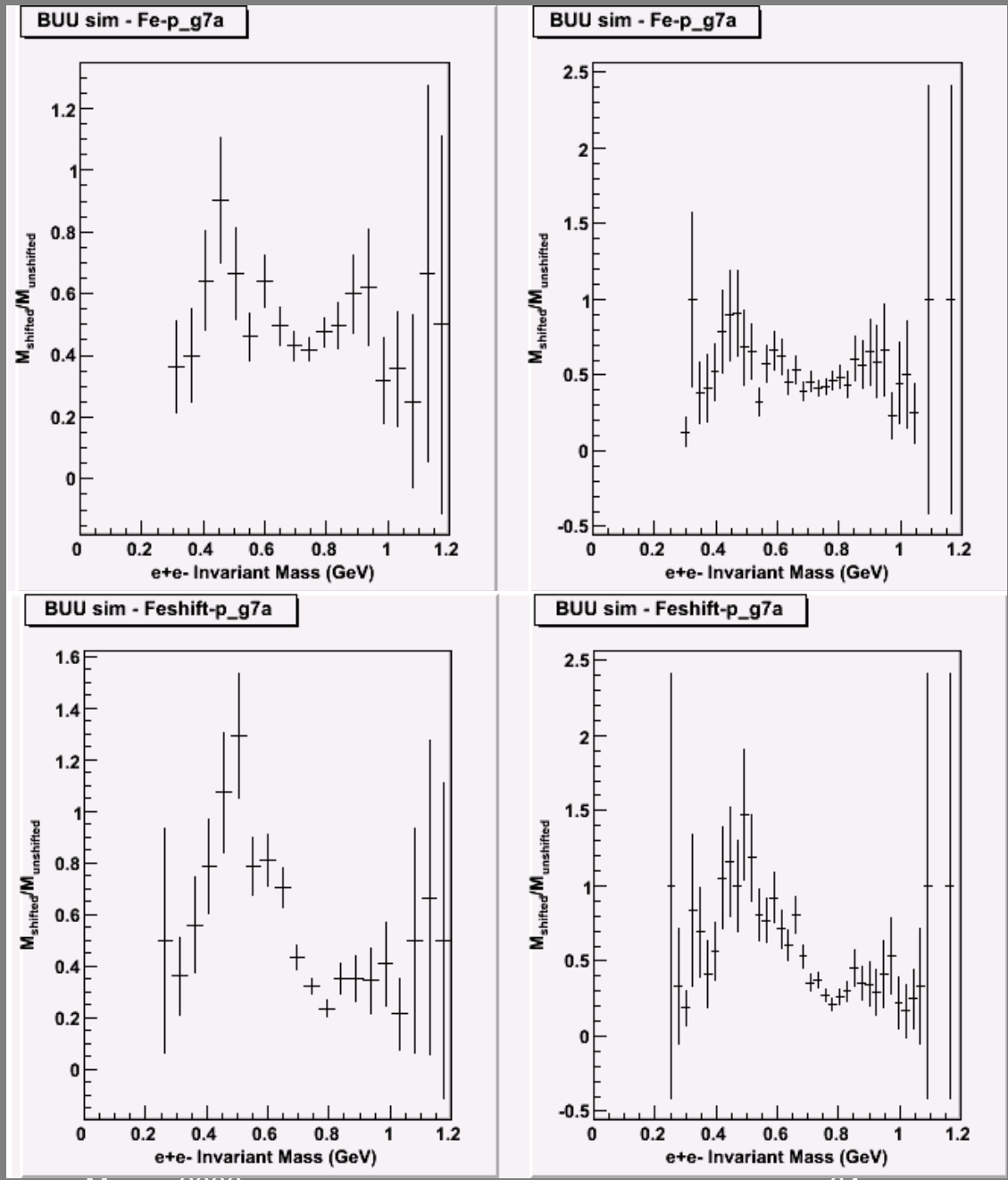
Simulation

Ratio of Iron

To

Hydrogen

g_7 Statistics



Carbon

Simulation

Ratio of Carbon

To

Hydrogen

g_7 Statistics