

**Search for $\Phi(1860)$
Pentaquark State with
CLAS**

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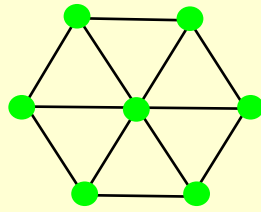
Outline of the Talk

- Introduction to Pentaquarks
- Status Pentaquark Searches
- CLAS experiment to search for $\Phi(1860)$
- Summary and Conclusions

SU(3) Families of Hadrons

Mesons $q\bar{q}$

$$3 \otimes \bar{3} = 8 \oplus 1$$



K

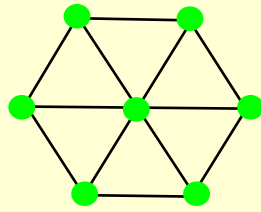
π

\bar{K}

SU(3) Families of Hadrons

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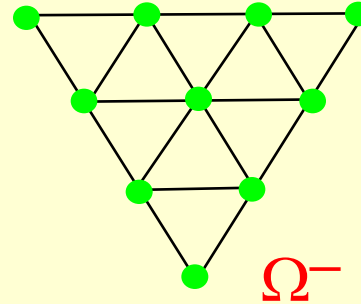
π

\bar{K}

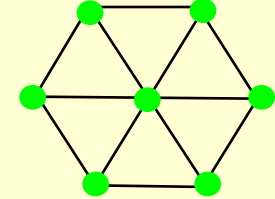
Baryons qqq

$$3 \otimes 3 \otimes 3 = 10 \oplus 8 \oplus 8 \oplus 1$$

Δ



Ω^-



N

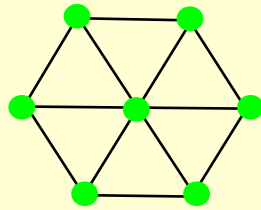
Σ

Ξ

SU(3) Families of Hadrons

Mesons $q\bar{q}$

$$3 \otimes \bar{3} = 8 \oplus 1$$



K

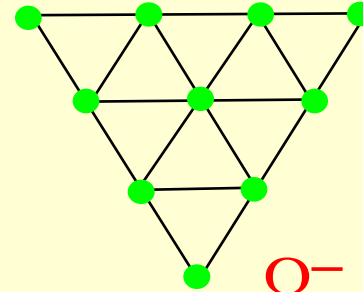
π

\bar{K}

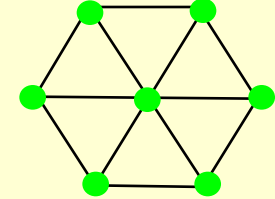
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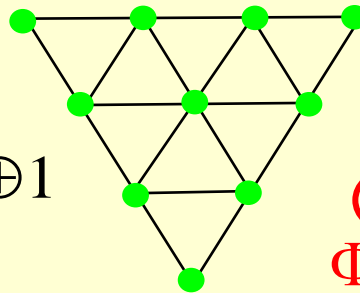
N

Σ

Ξ

Baryons built from meson-baryon, or $qqqq\bar{q}$

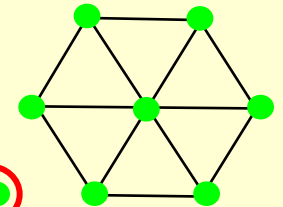
$$8 \otimes 8 = 27 \oplus 10 \oplus \bar{10} \oplus 8 \oplus 8 \oplus 1$$



Θ^+

Φ^{--}

Φ^+

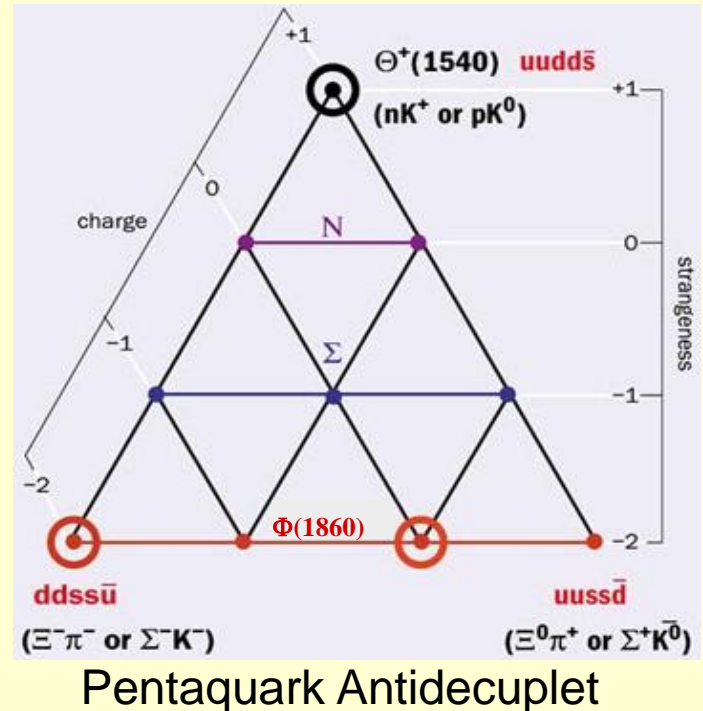


Pentaquarks

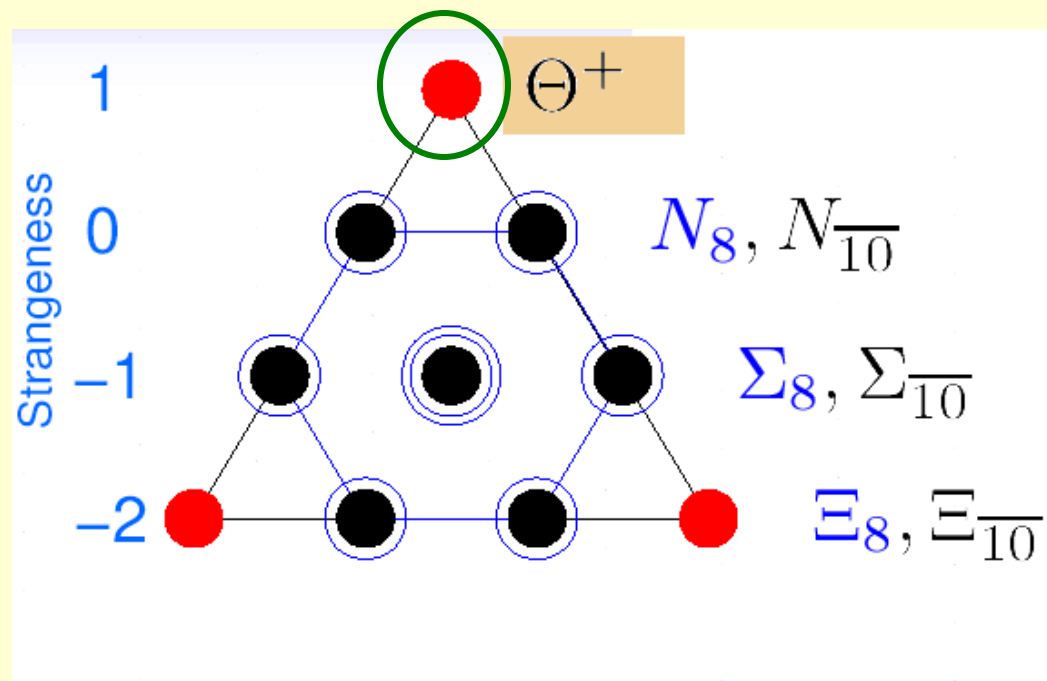
- Considered since mid 70s
 - Masses > 1.7 GeV
 - Wide states if not strongly bound, making their observation difficult

- Predictions in 1990s that the lightest state of the antidecuplet has mass ~ 1.53 GeV and can be **very narrow** < 15 MeV
 - Narrow width significantly increases chances of a particle being observed

- If pentaquarks do exist and they are narrow, then what is their spin, isospin and the parity.



$\Theta(1540)$ Pentaquark



SPRING-8 Result

$$\gamma n \rightarrow K^- \Theta^+ \rightarrow K^- K^+ n$$

- Used plastic (C:H=1:1) as a neutron target source
- Detect K^+ and K^- in the LEPS detector, missing neutron
- Complicated Fermi motion corrections
- Background unknown, estimated from LH_2 data

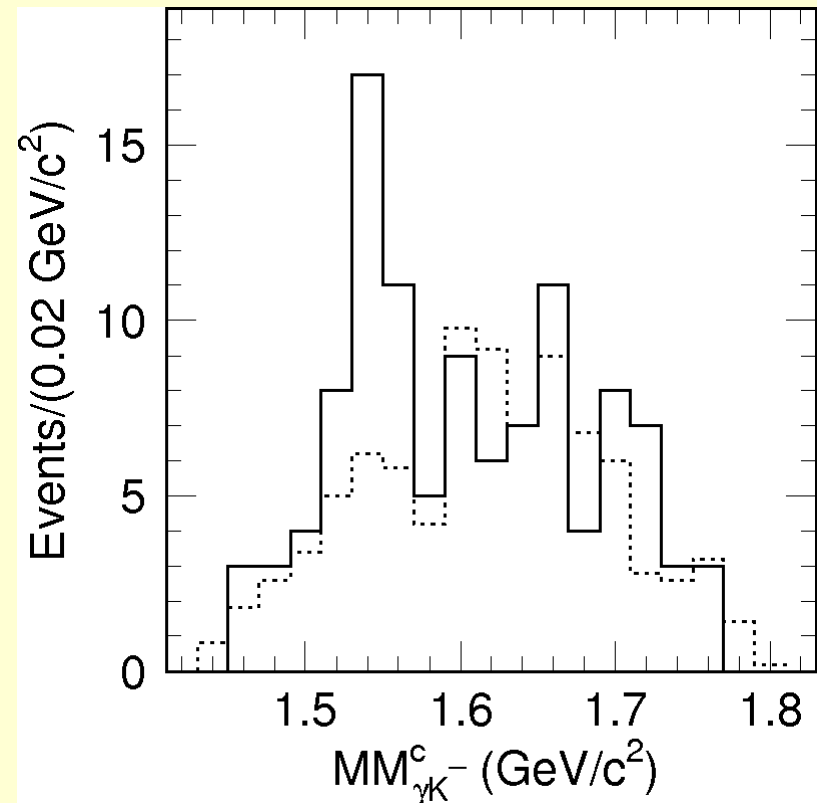
- Found 19 events in a peak near mass of 1.54 GeV

- Statistical significance level

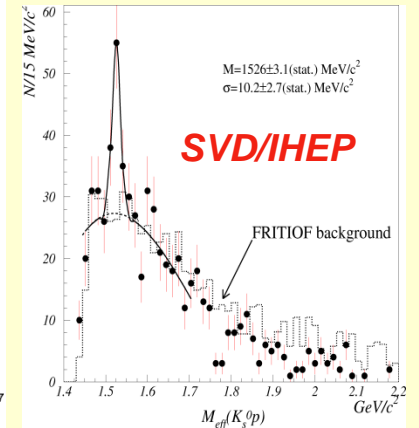
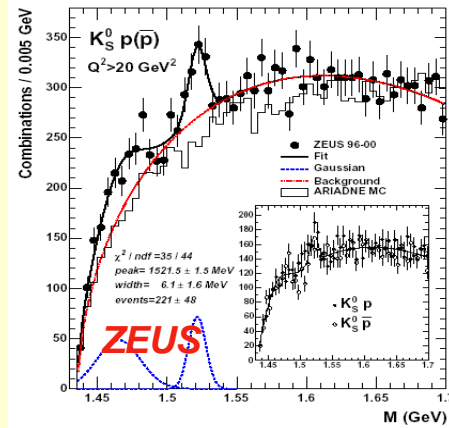
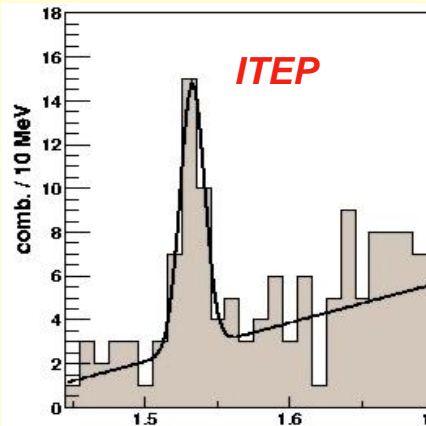
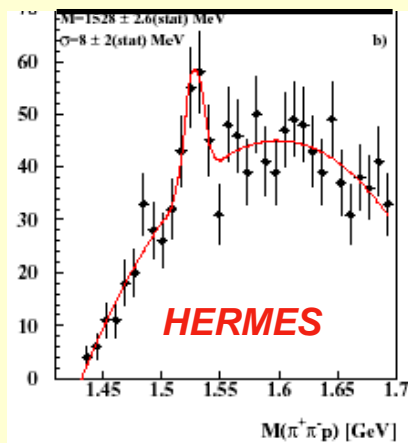
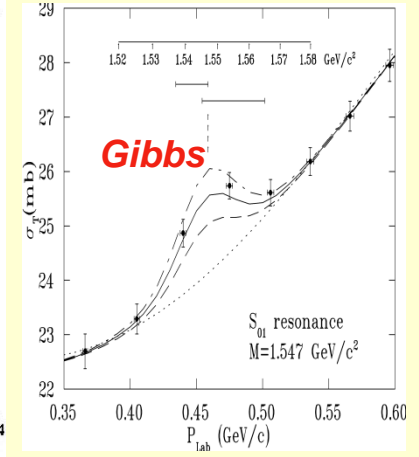
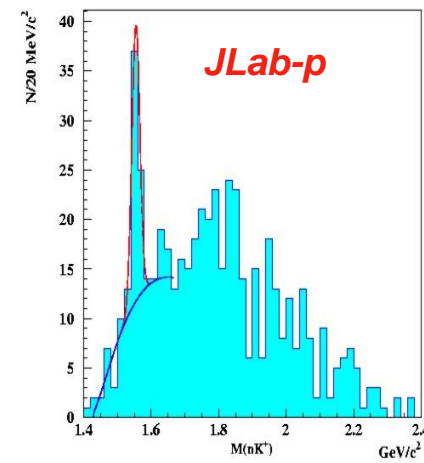
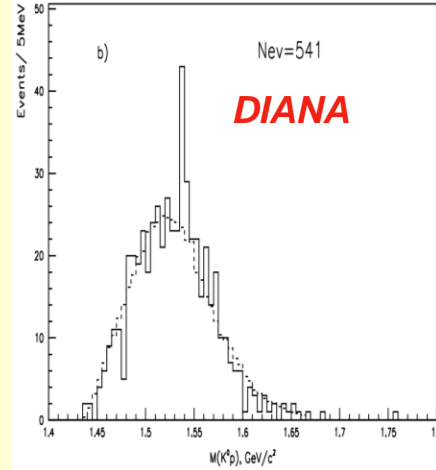
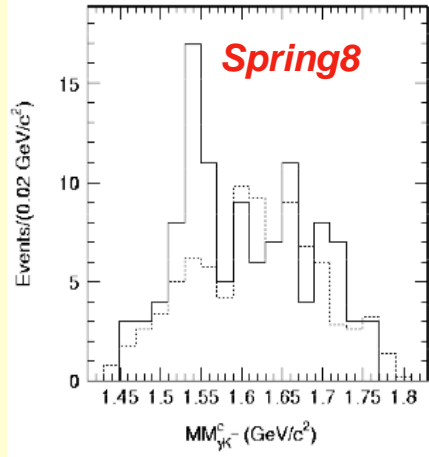
$$\frac{S}{\sqrt{B}} = 4.6\sigma$$

- Mass from fit $1.54 \pm 0.01 \pm 0.05$ GeV
- Upper limit for $\Gamma < 25$ MeV

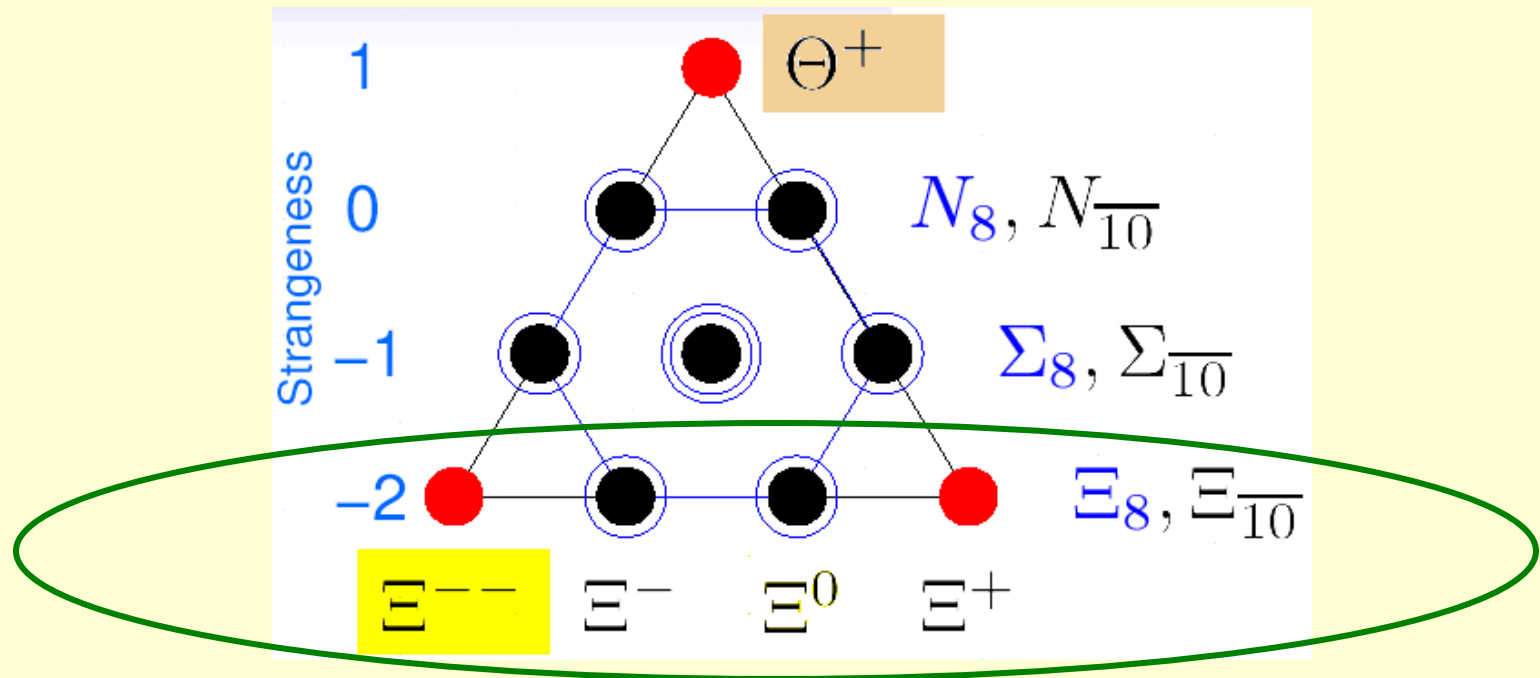
Nakano et al, PRL 91 (2003) 012002



Positive Results for Θ^+



$\Phi(1860)$ Pentaquark

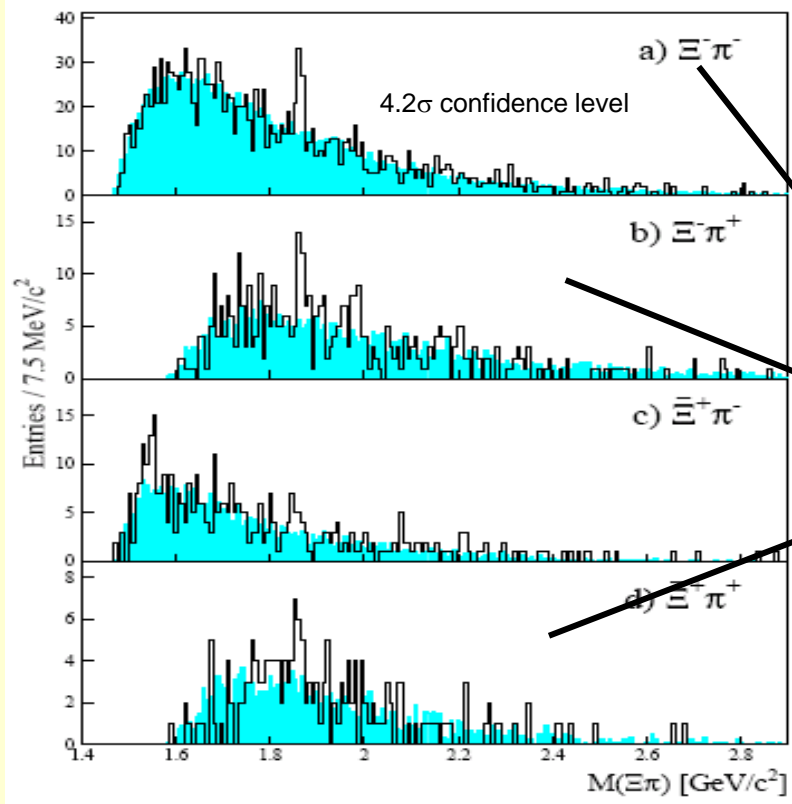


Observation of $\Phi(1860)$

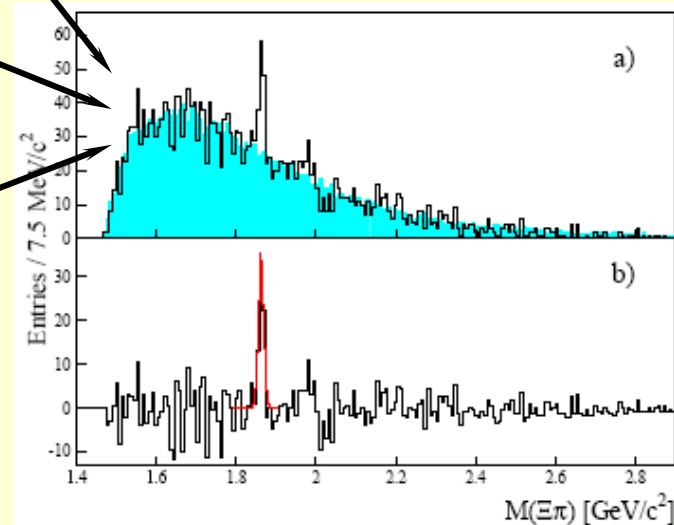
$$pp \rightarrow \Phi(1860) X \rightarrow \pi \Xi(1320) X$$

NA49 CERN SPS

Phys. Rev. Lett. 92 (2004) 042003



- Mass was ~ 1.862 GeV
- Upper limit for $\Gamma < 18$ MeV



Total 69 events in these peaks

5.8 σ confidence level

Photoproduction Limits (HERMES)

- Bremsstrahlung beam from 27.6 GeV positrons
- Deuterium target
- Limits on $M(\Xi^-\pi^-)$ and $M(\Xi^-\pi^+)$

$$\sigma(\Xi_5^0) \times \text{BR} < 1.2 \text{ nb (2.5 nb)} \text{ (90\% CL)}$$

$$\sigma(\Xi_5^{--}) \times \text{BR} < 1.0 \text{ nb (2.1 nb)} \text{ (90\% CL)}$$

A. AIRAPETIAN *et al.*

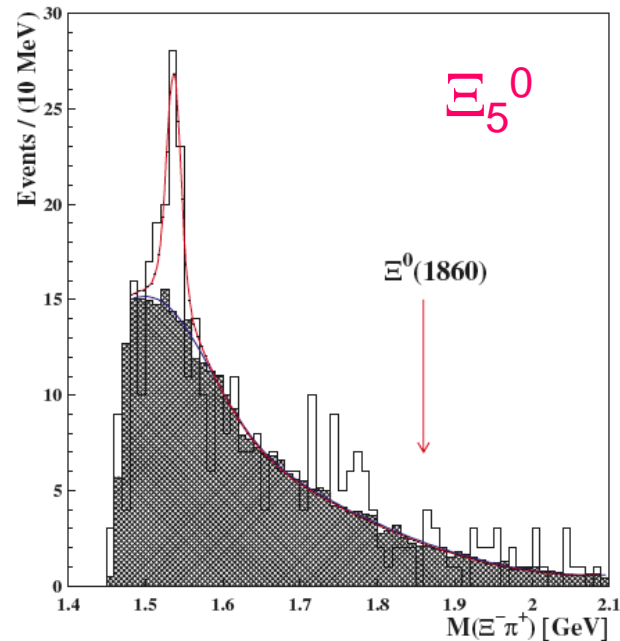


FIG. 3 (color online). Invariant mass distribution of the $p\pi^-\pi^-\pi^+$ (plus c.c.) system, subject to the constraints in event topology discussed in the text. The mixed-event background is represented by the gray shaded histogram, which is normalized to the background component of the fitted curve described in the text. The arrow shows the hypothetical $\Xi_{3/2}^0$ mass. The excess near 1.77 GeV has a statistical significance of only 1.8σ .

PHYSICAL REVIEW D 71, 032004 (2005)

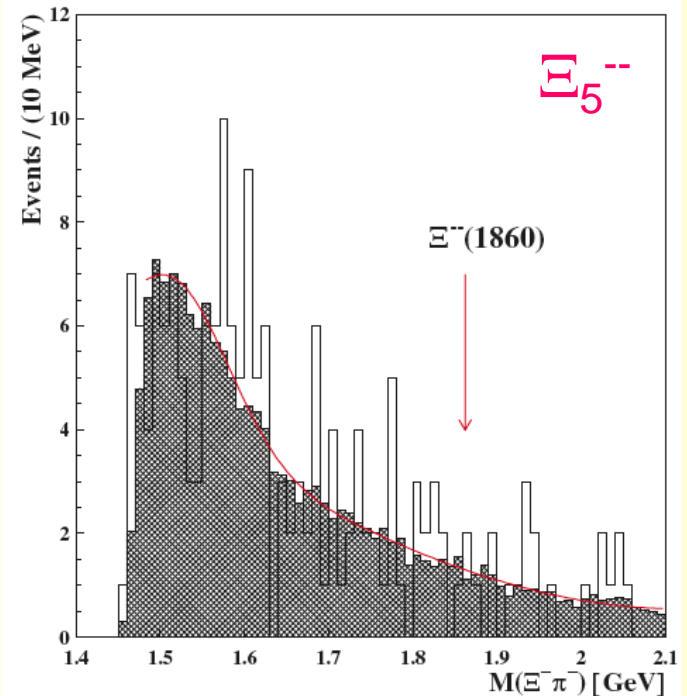


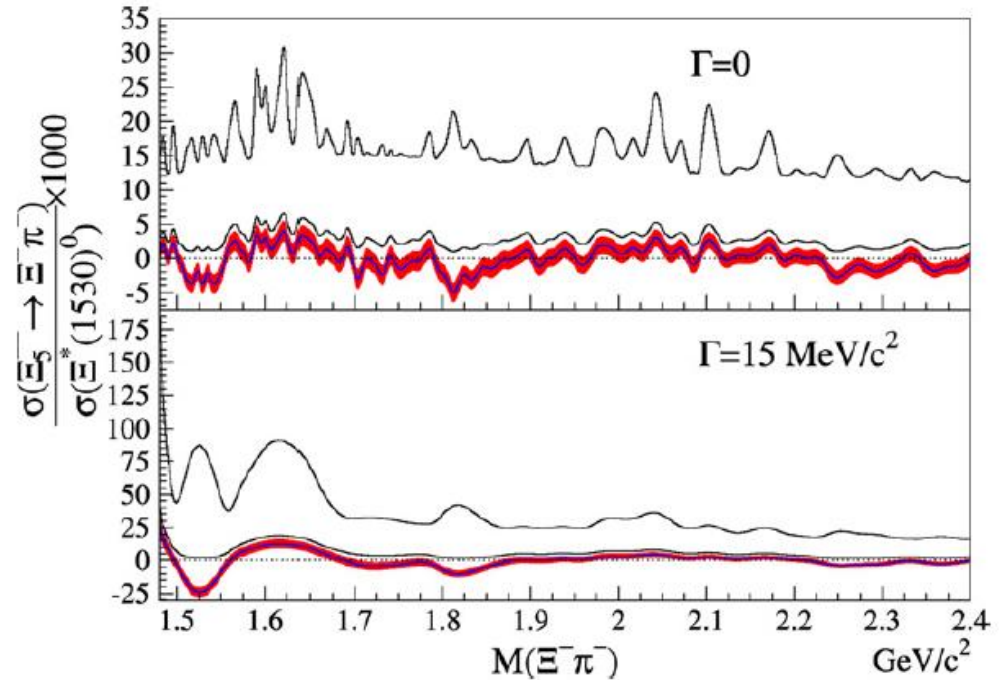
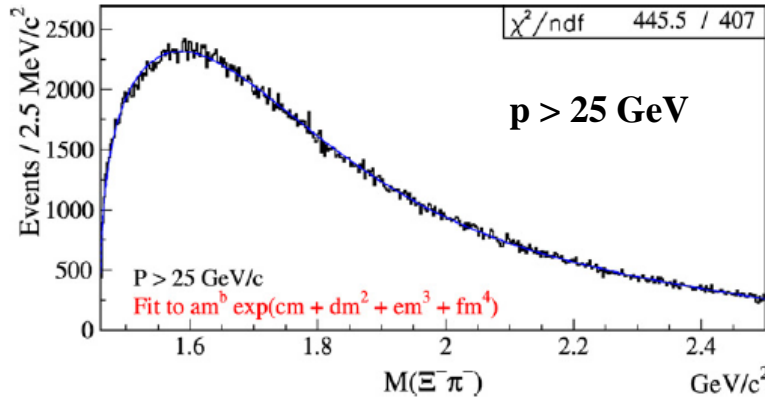
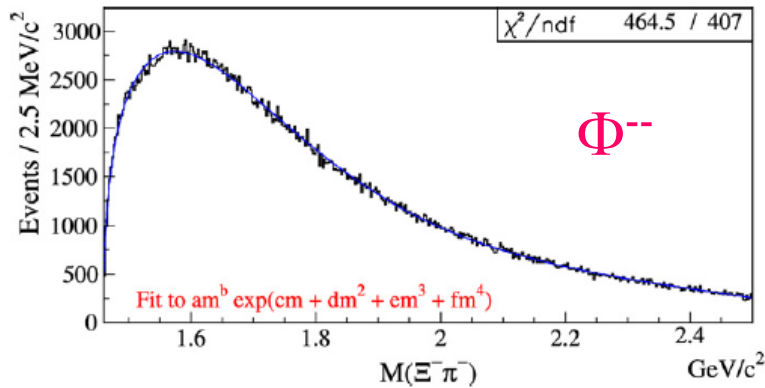
FIG. 2 (color online). Invariant mass distribution of the $p\pi^-\pi^-\pi^-$ system, subject to the constraints in event topology discussed in the text. The mixed-event background is represented by the gray shaded histogram, which is normalized to the background component of the fitted curve described in the text. The arrow shows the hypothetical $\Xi_{3/2}^{--}$ mass.

Photoproduction Limits (FOCUS)

- Bremsstrahlung beam from 300 GeV electrons
- BeO target
- Limits on $M(\Xi^- \pi^-)$ and $M(\Xi^- \pi^+)$

Link PLB661 14 (2008)

$$\sigma(\Phi^{--}) \times \text{BR} / \sigma(\Xi^*(1530)) < 0.032 \text{ (0.091)} \text{ (95\% CL)}$$

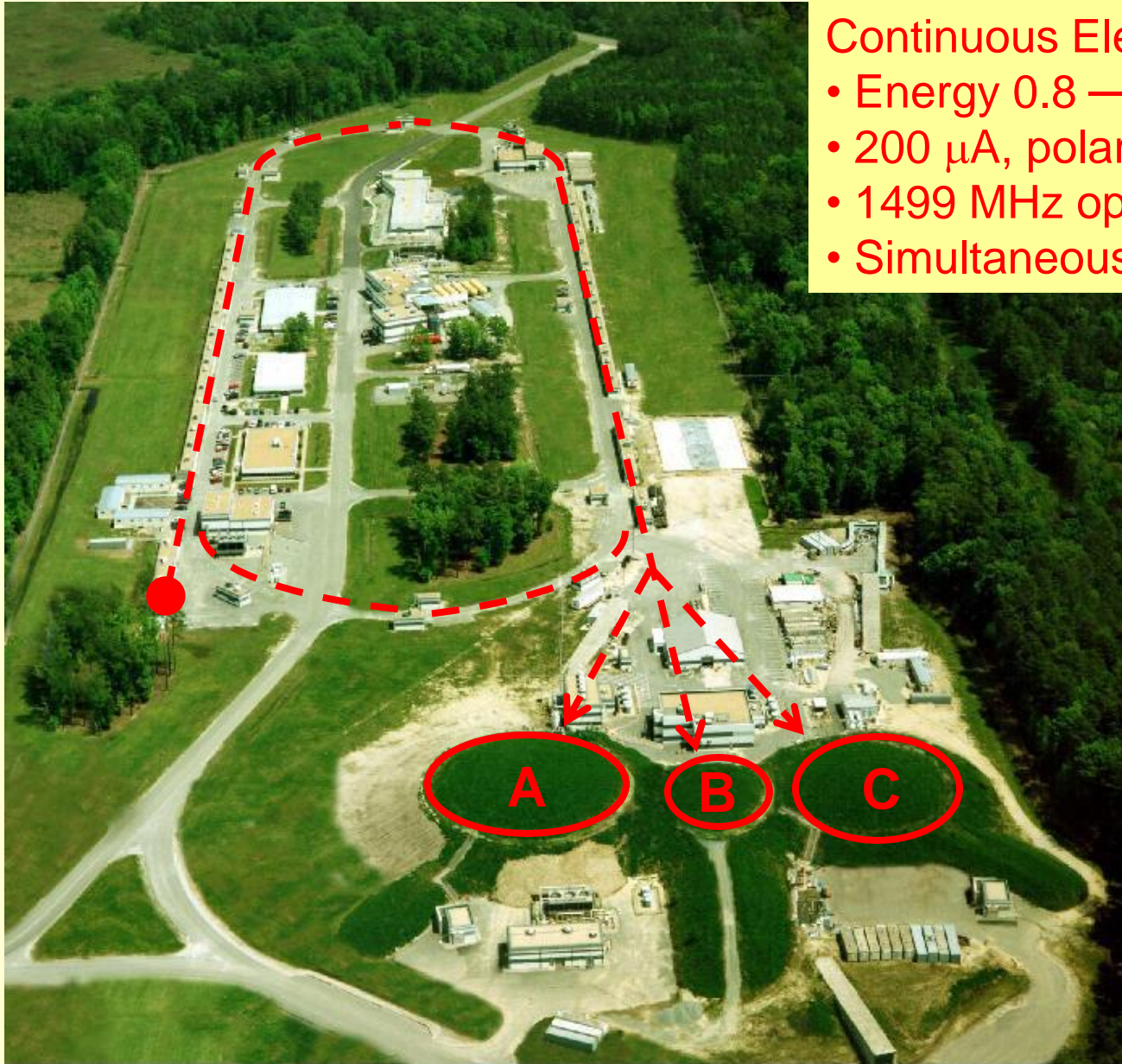


CLAS $\Phi(1860)$ Experiment

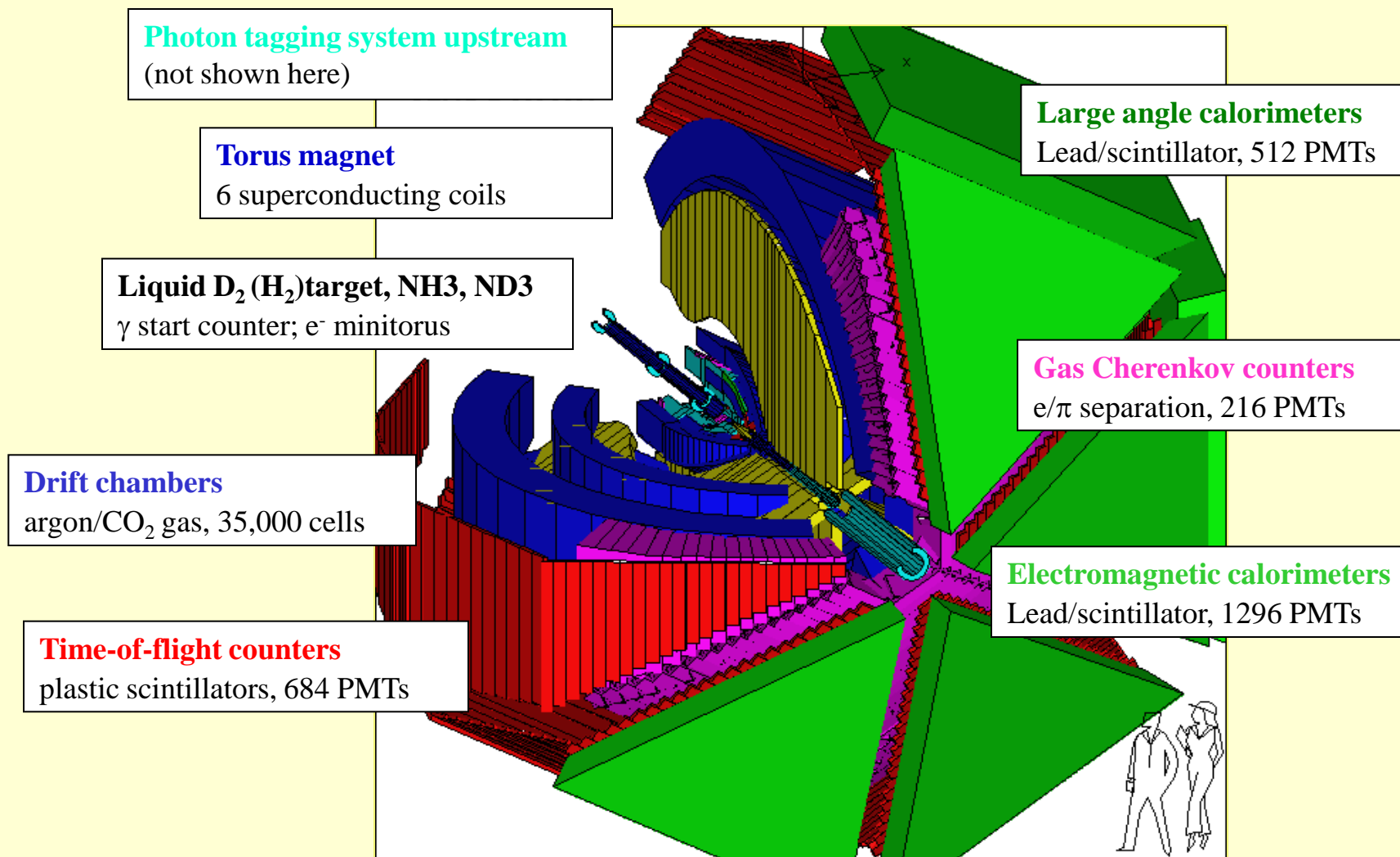
- Systematic searches need to be done to find possible candidates for pentaquark states.
- Dedicated experiments typically have better sensitivity because of the optimized experimental conditions.
- The experimental proposal to do a dedicated experiment to search for $\Phi(1860)$ using CLAS detector at Jefferson Lab was approved in spring of 2004.

JLab Accelerator CEBAF

- Continuous Electron Beam
- Energy 0.8 — 6.0 GeV
 - 200 μA , polarization 85%
 - 1499 MHz operation
 - Simultaneous delivery 3 halls

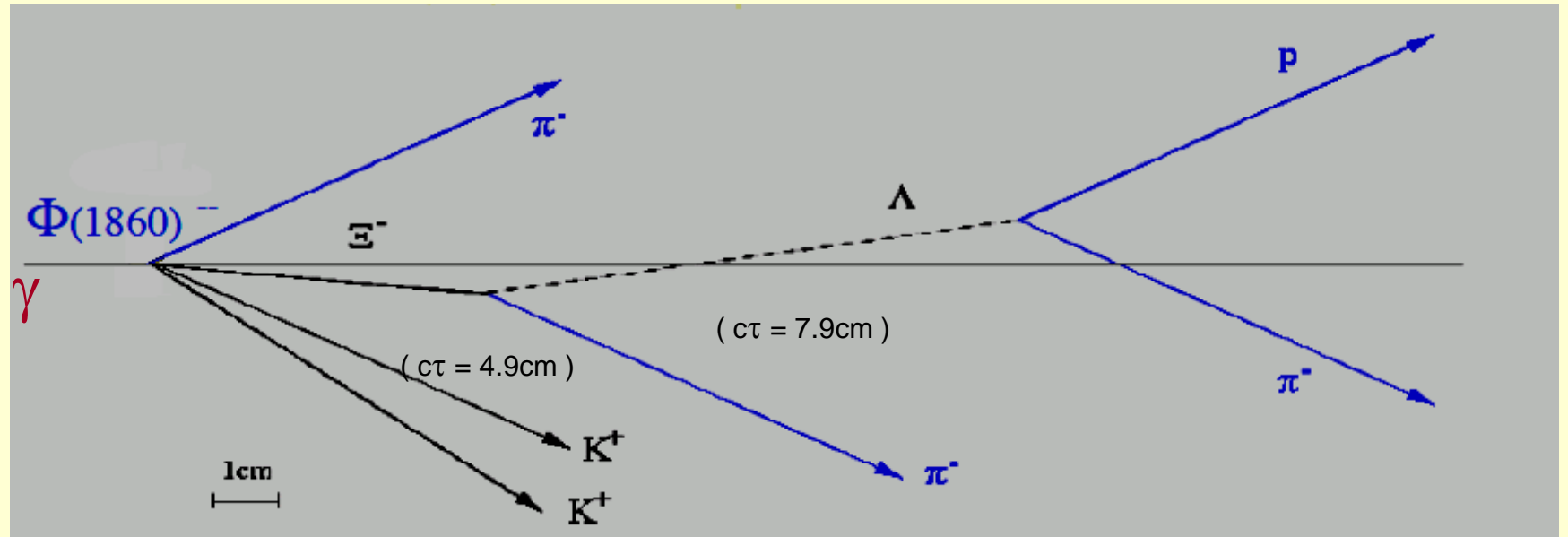


CLAS Detector @ JLab



Schematic of the Experiment

$$\gamma d \rightarrow \Phi^{--} (1860) X \rightarrow \pi^- \Xi^- X \rightarrow \pi^- \pi^- \Lambda X \rightarrow \pi^- \pi^- \pi^- p X$$



- Search for enhancement in $M_{\pi\pi p}$ invariant mass after mass and vertex constraints.
- Detached vertices due to weak decays are crucial for $\Xi^-(1321)$ reconstruction.

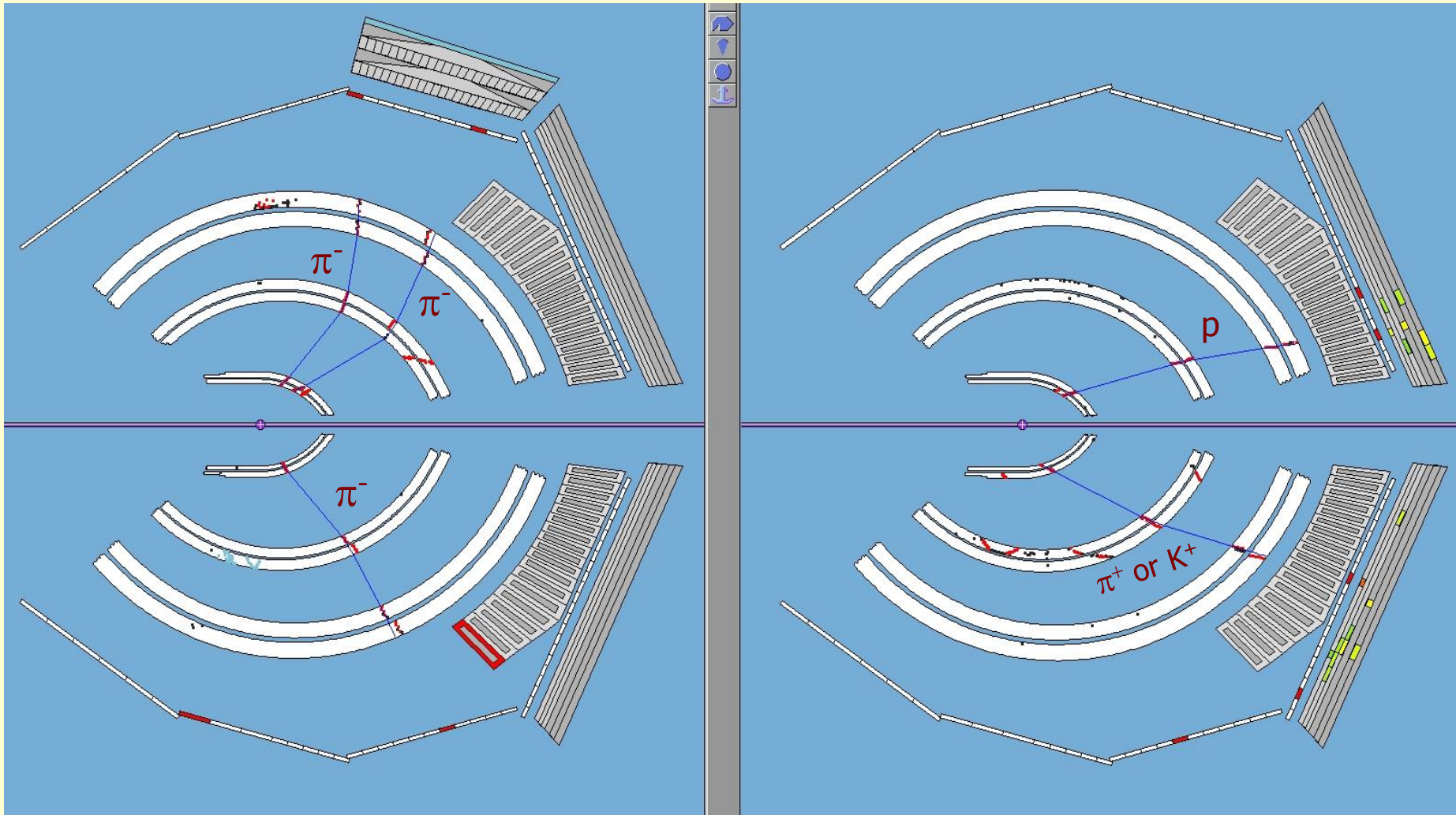
CLAS Data

- Data taking is completed in February of 2005 (eg3 run).

- 29 days of running on 40cm long LD2
 - ✓ Primary electron beam at energy 5.77 GeV, 30nA current, incident on a 5×10^{-4} r.l. EM radiator.
 - ✓ Secondary γ beam with energy range $4.5 < E_\gamma < 5.5$ GeV in the DAQ trigger system.
 - ✓ Photon-deuteron integrated luminosity 25 pb^{-1} .

- Physics analysis is complete.

Sample Event in CLAS

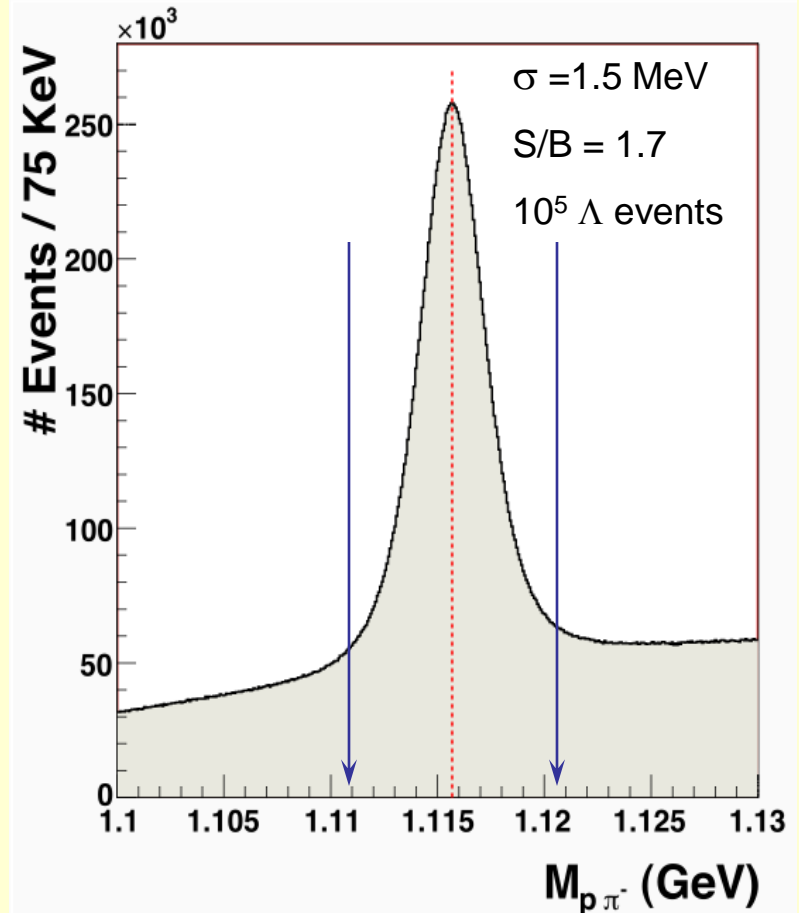
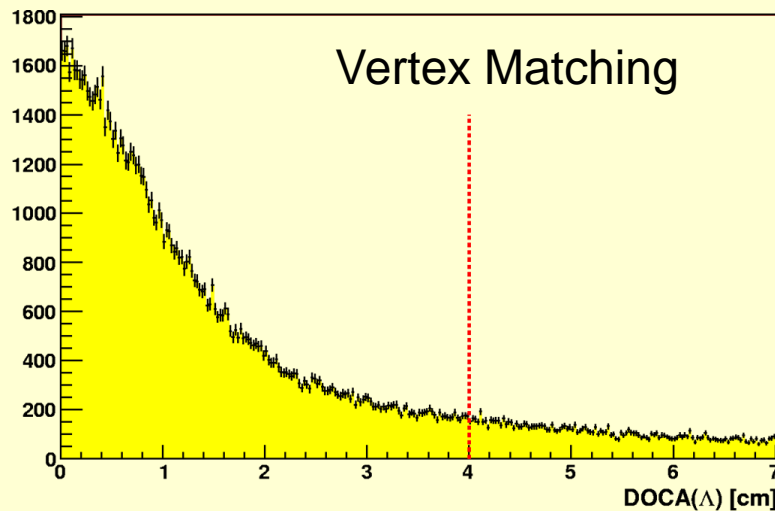


Reconstruction of $\Lambda(1116)$

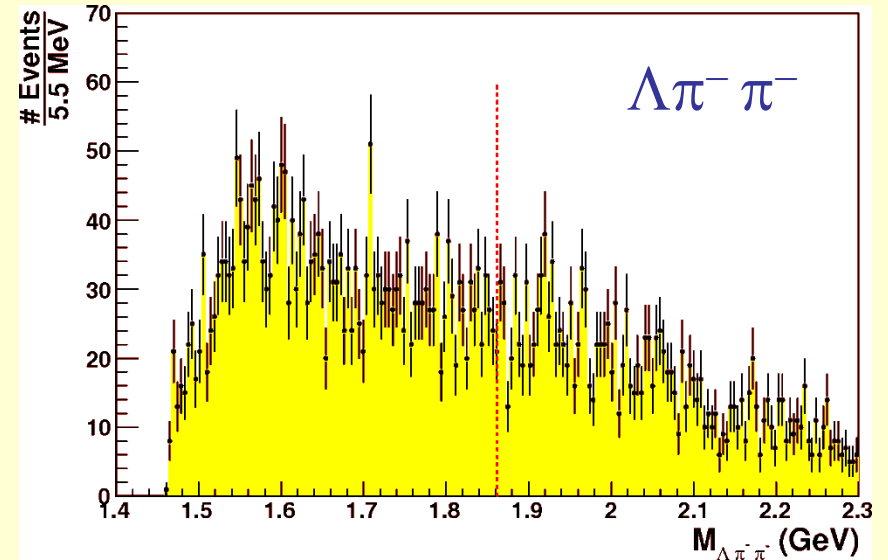
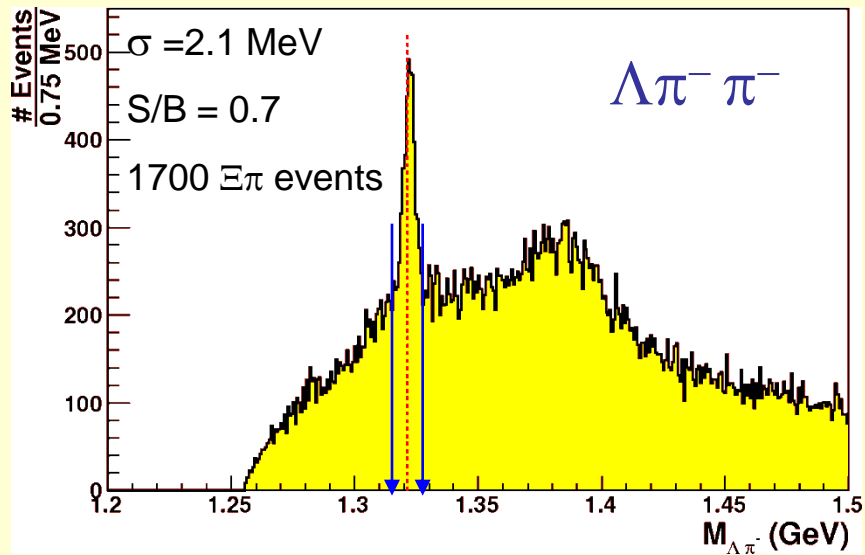
- Require a positive and a negative track.
 - Common decay vertex
 - Common time at the vertex

$\Lambda(1116) \rightarrow \pi^- p$

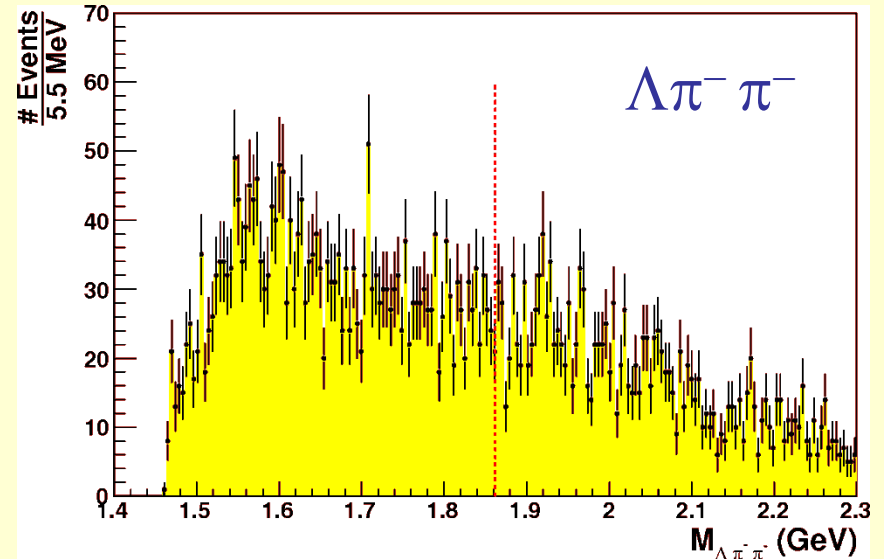
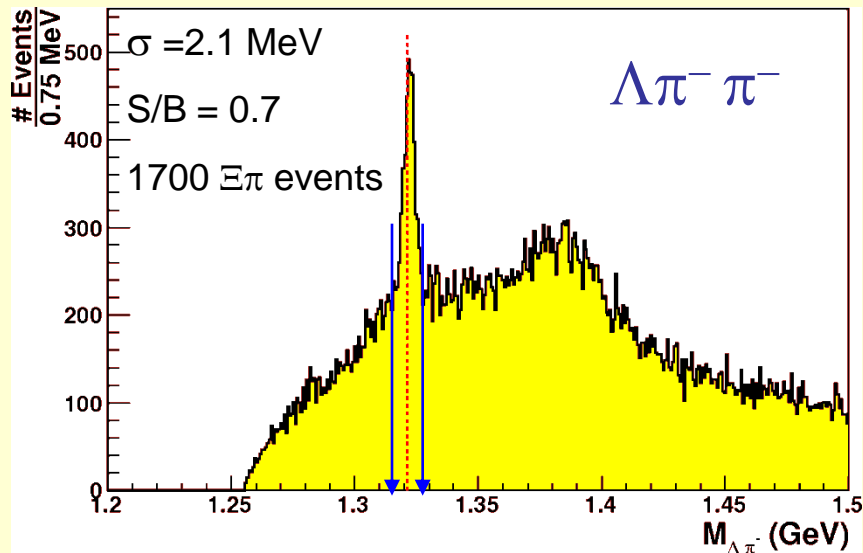
- Select the pair most consistent with $\Lambda(1116)$



Invariant Mass Distributions

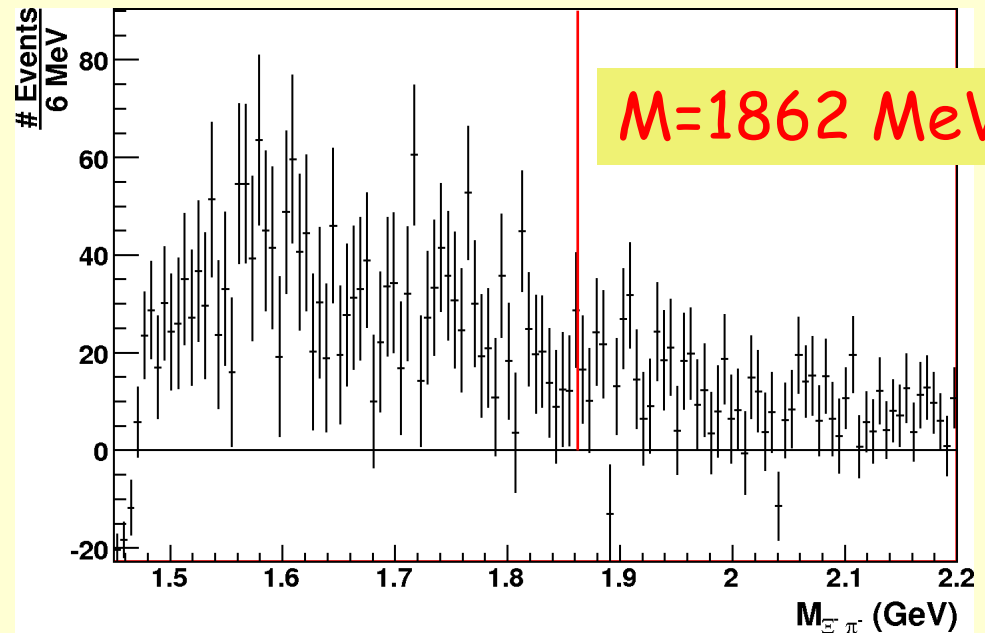


Invariant Mass Distributions



Side-band subtraction
Mass spectrum ($\Xi^-\pi^-$)

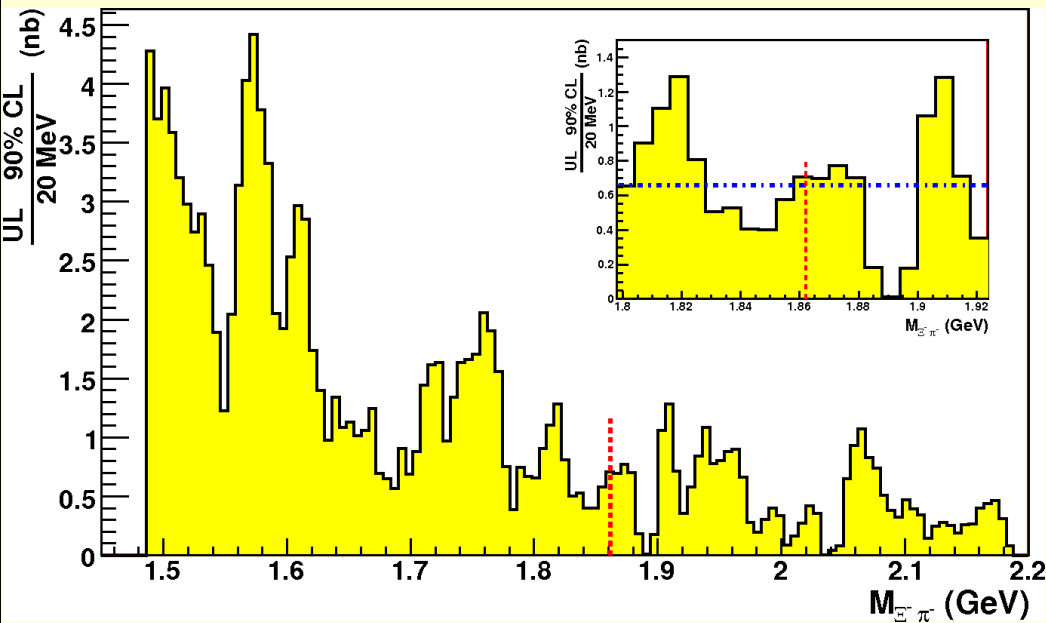
NO Narrow structure
Visible



Main Experimental Uncertainties

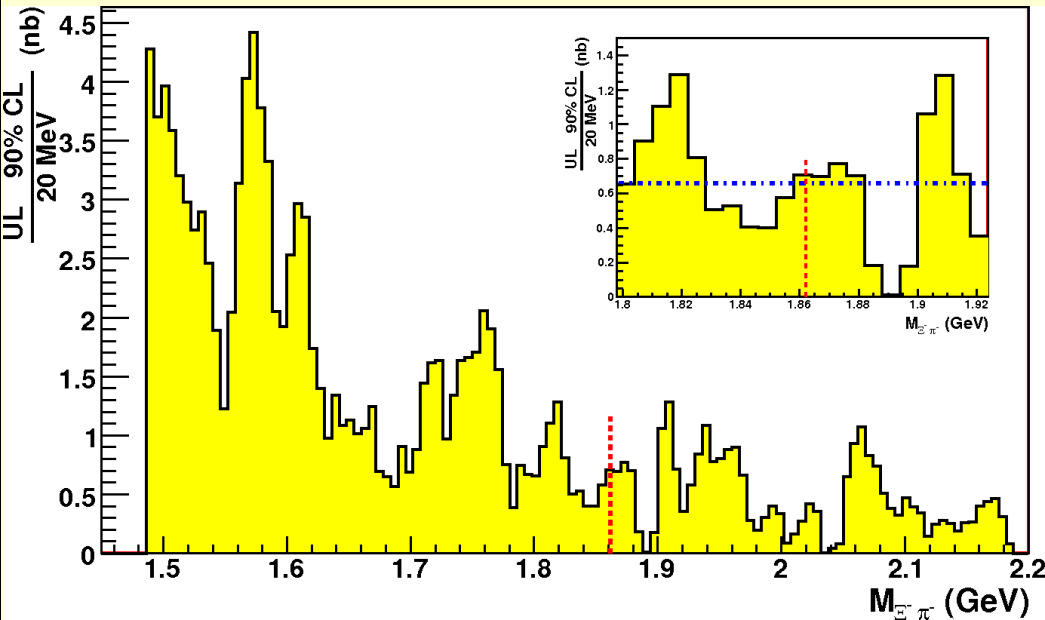
- The eg3 experiment used higher than nominal photon flux to achieve higher statistical accuracy.
- Trigger efficiency estimates produced ~20% systematic uncertainty in the estimation of upper limits.
- Various events distributions were used to estimate the CLAS acceptance for the reaction.
 - ✓ We assigned ~20% uncertainty to the CLAS acceptance and efficiency.
- All other systematic uncertainties were negligible compared to these two.

Results for Upper Limit



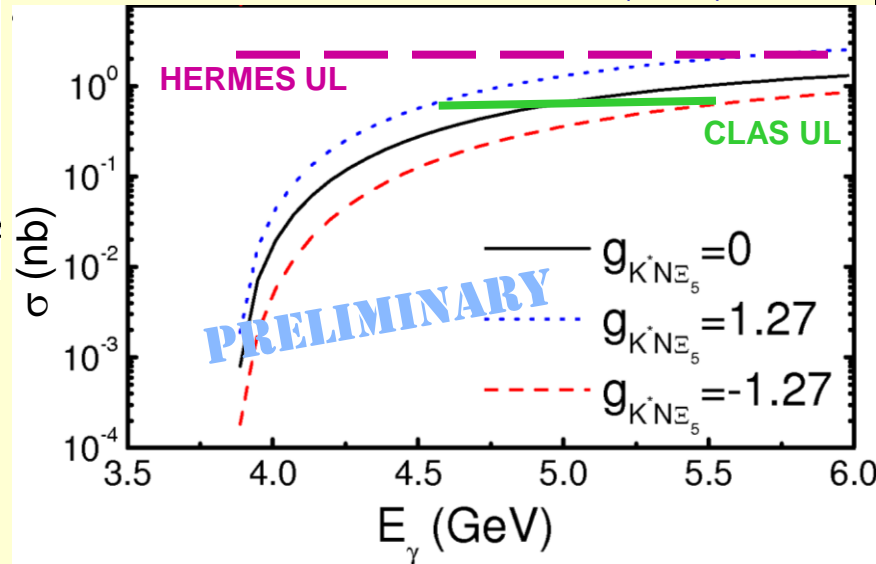
Upper limit for $\gamma d \rightarrow \Phi^- X \rightarrow \Xi^- \pi^- X$ cross section at $M \sim 1.862$ GeV is ~ 0.62 nb (90% CL)

Results for Upper Limit



- Compare to hadronic model which include couplings to $\Sigma \bar{K}^*$ and $\Sigma \bar{K}$

Liu, Ko, PR C69 (2004)



Upper limit for $\gamma d \rightarrow \Phi^- X \rightarrow \Xi^- \pi^- X$ cross section at $M \sim 1.862$ GeV is ~ 0.62 nb (90% CL)

- Reduced the upper limit on the cross section ~ 2 nb from HERMES by factor of ~ 3 .

Conclusions

- The CLAS experiment to search for $\Phi^{--}(1860)$ is complete.
- Mass spectrum $M_{\Xi\pi}$ DOES NOT show significant enhancements near $M_{\Xi\pi}=1.862$ GeV.
- Preliminary upper limit for cross section is ~ 620 pb.

- If $\Phi^{--}(1860)$ exists then **either**:
 - JLab energy was too low to produce it, **or**
 - CLAS acceptance may not match the kinematics, **or**
 - The production and $\Xi\pi$ decay cross section near threshold is less than 620 pb.

- **Preparing data for publication**

The END

Thank You !