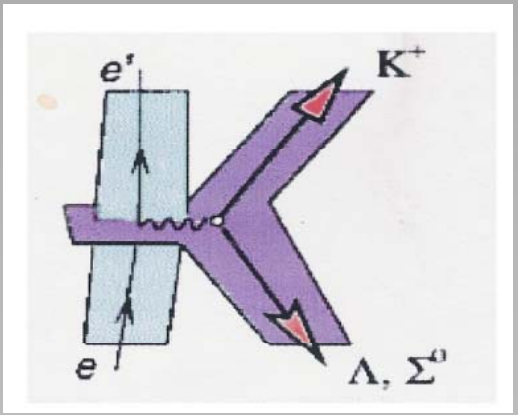
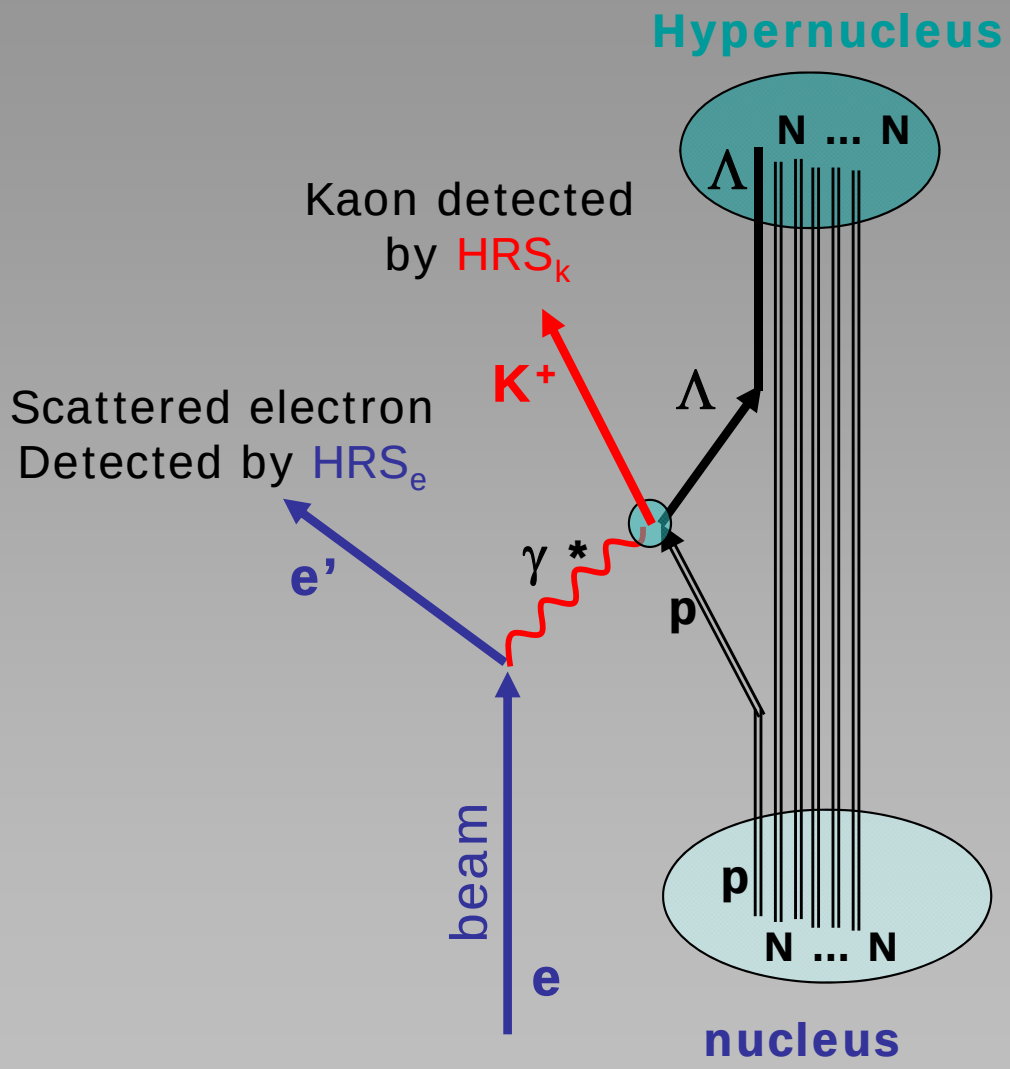
High Resolution (e,e'K$^+$) Spectroscopy at Jefferson Lab, Hall A

Francesco Cusanno, Excellence Cluster Universe, Technische Universitaet Muenchen, Germany
on behalf of Jefferson Lab Hall A Collaboration

- Electroproduction of hypernuclei at Jefferson Lab
- E94-107 Experiment(s) in Hall A
  - Experimental equipment and setup
  - Kaon identification → RICH detector
  - Analysis and results
- Conclusions



Electroproduction of Hypernuclei

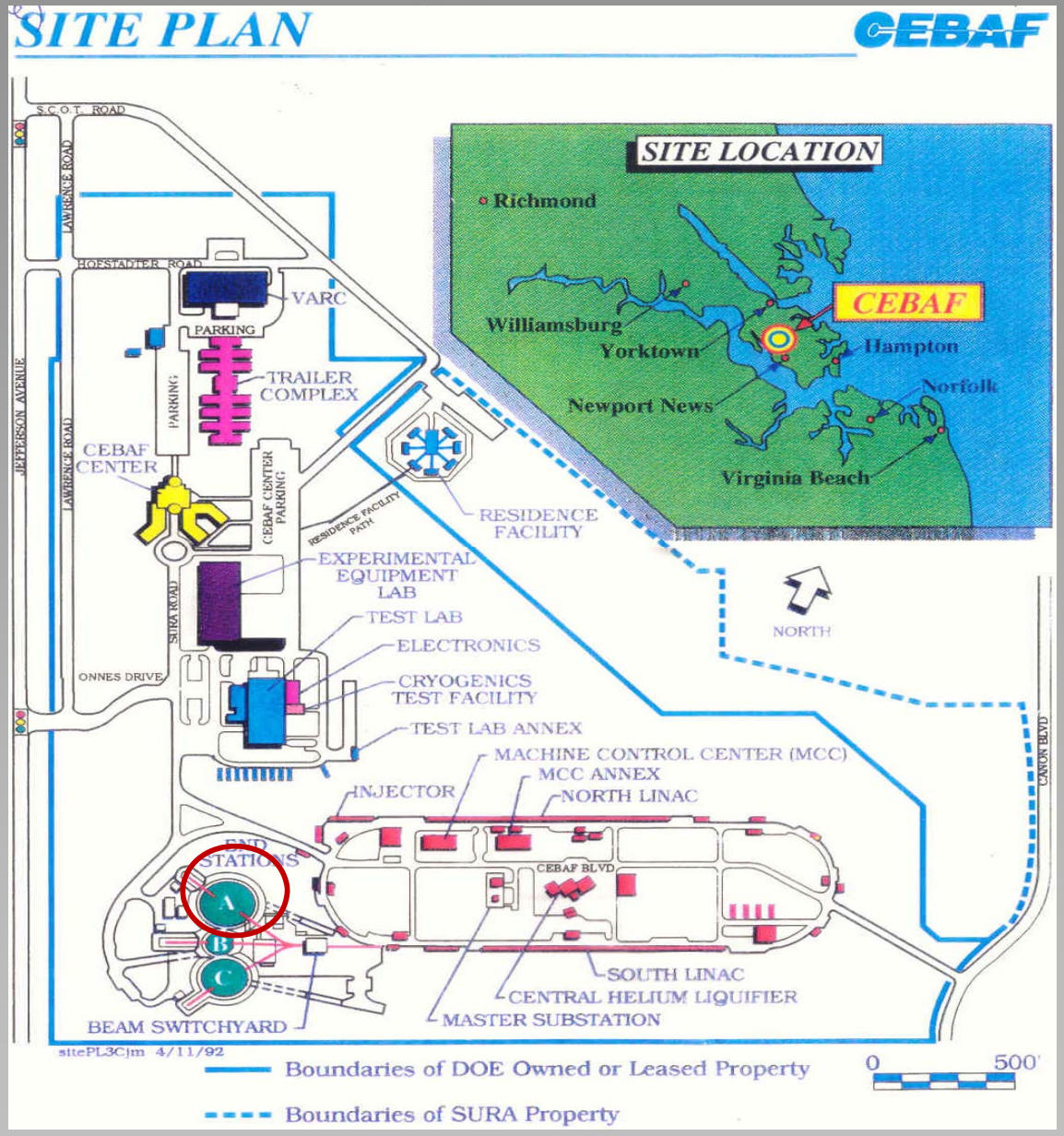


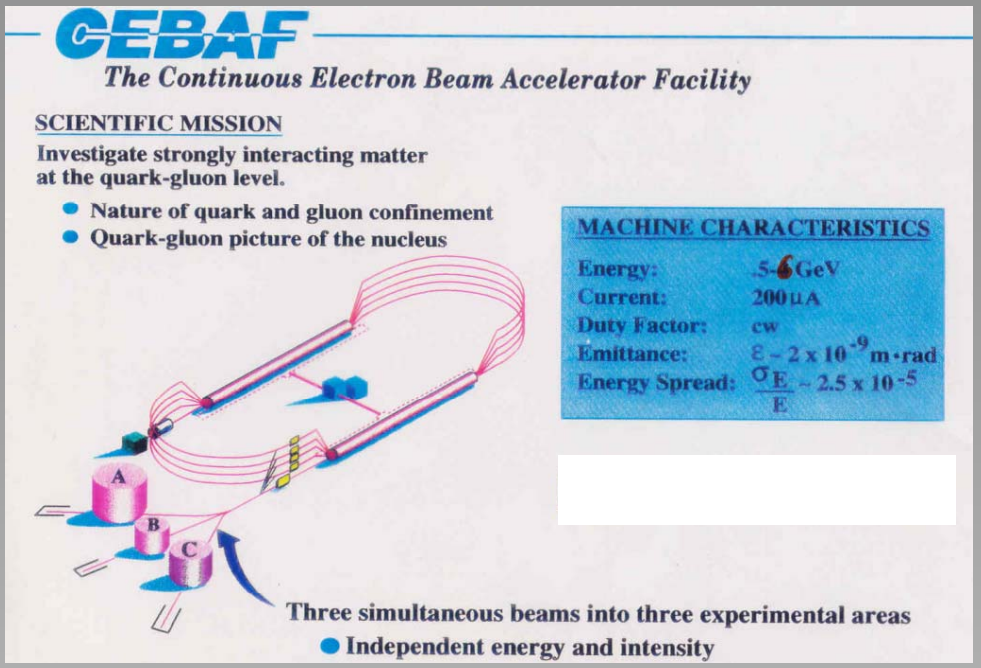
$$e + {}^{A}Z \rightarrow e' + K^{+} + {}^{A}(Z-1)_{\Lambda}$$

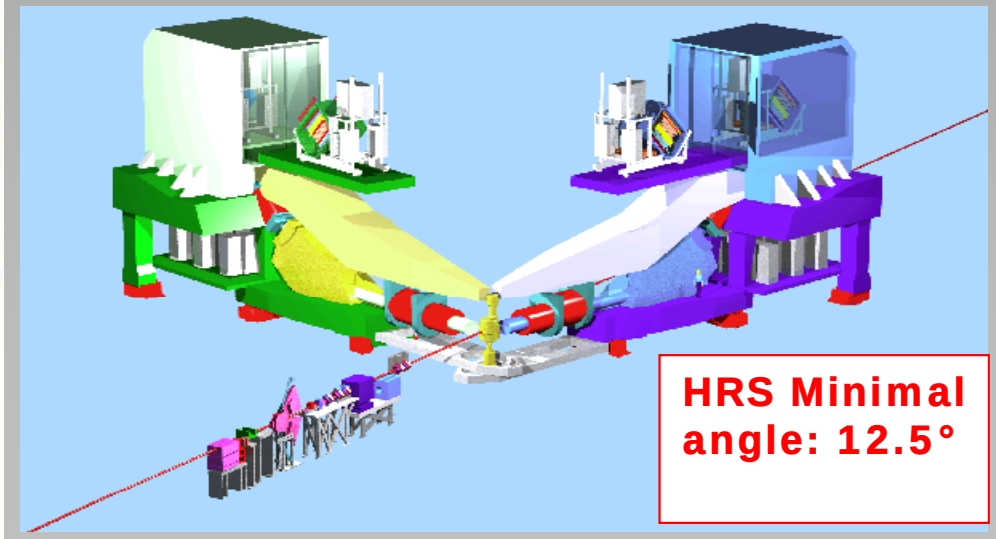
Better energy resolution,
smaller cross section

High luminosity, high duty cycle,
excellent beam energy spread

Jefferson LAB, CEBAF Facility

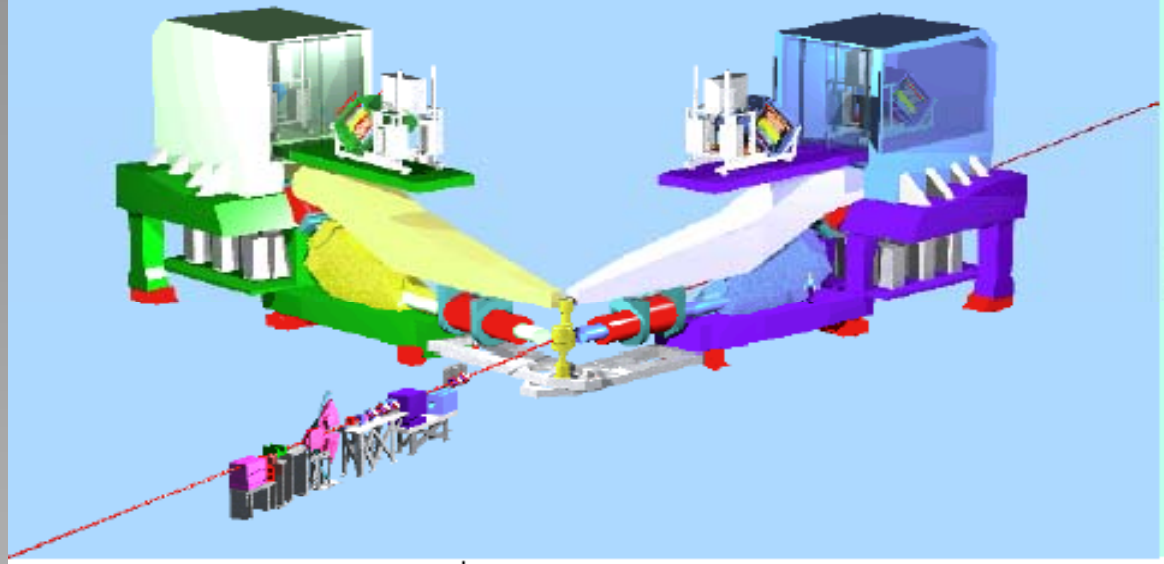


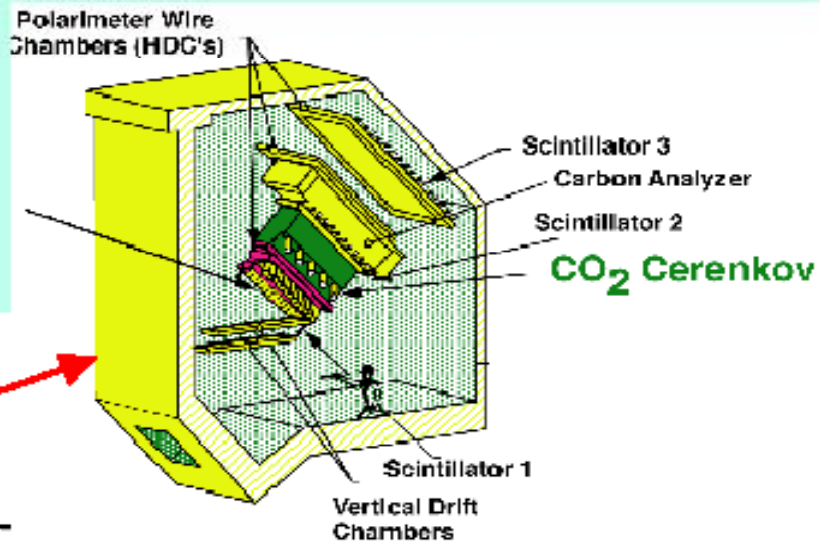


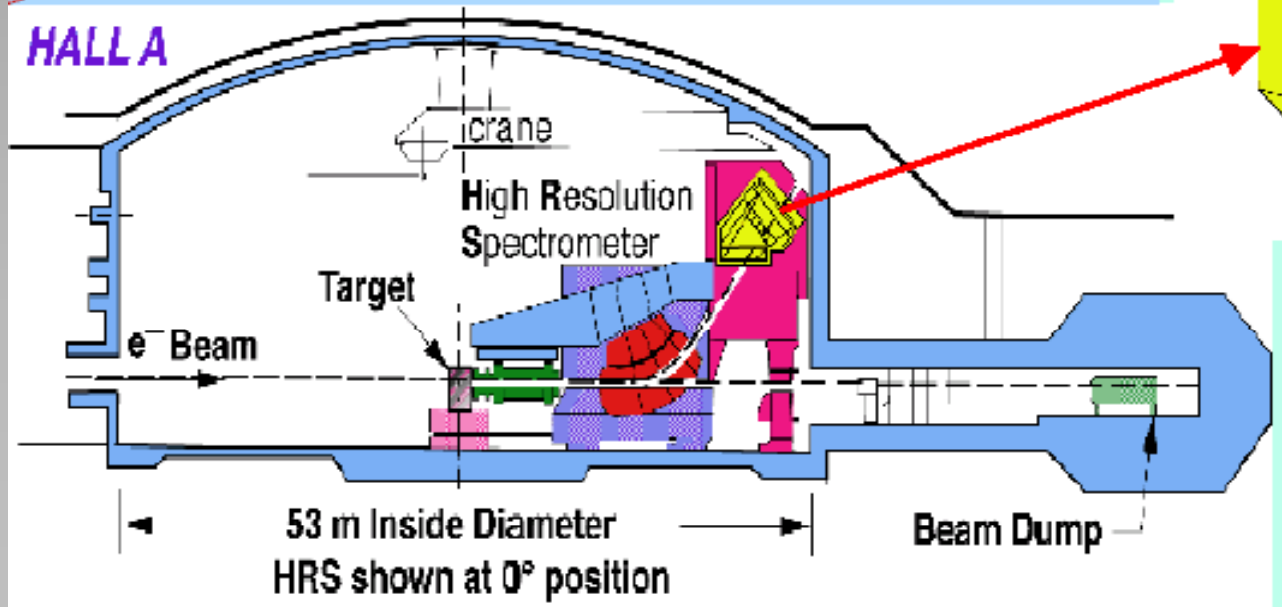


Experimental Hall A – High Resolution Spectrometers HRS

QDQ - Momentum Range: 0.3 –4 GeV/c Δp/p : 1 x 10-4 - Δp = =-5% - ΔΩ = 5 –6 mr







1 (+1) Cherenkov threshold aerogels + RICH in the hadron spectrometer

Experimental Hall A – High Resolution Spectrometers HRS

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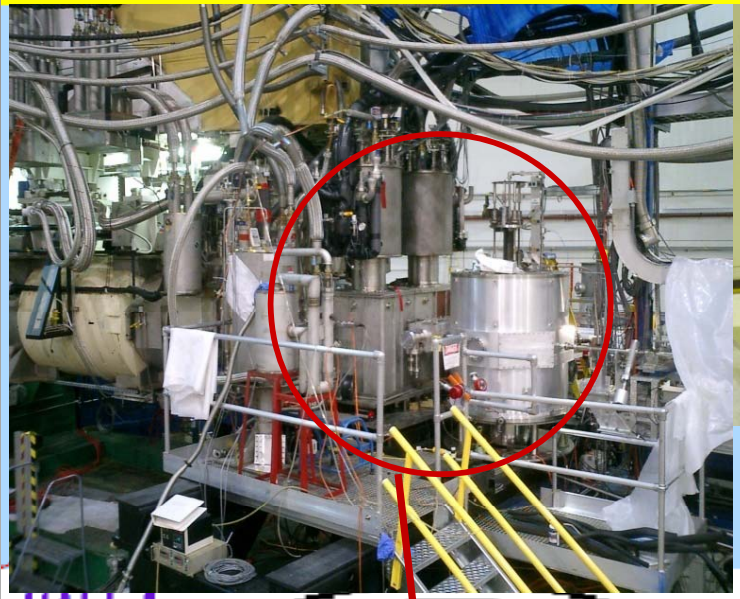
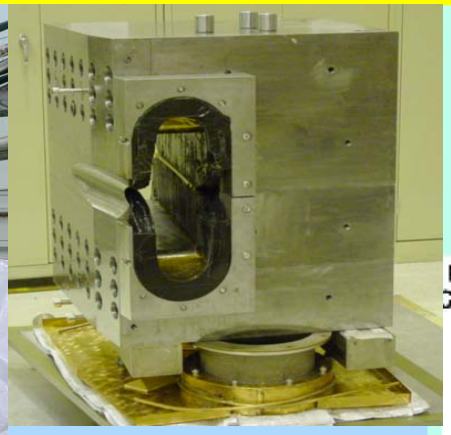
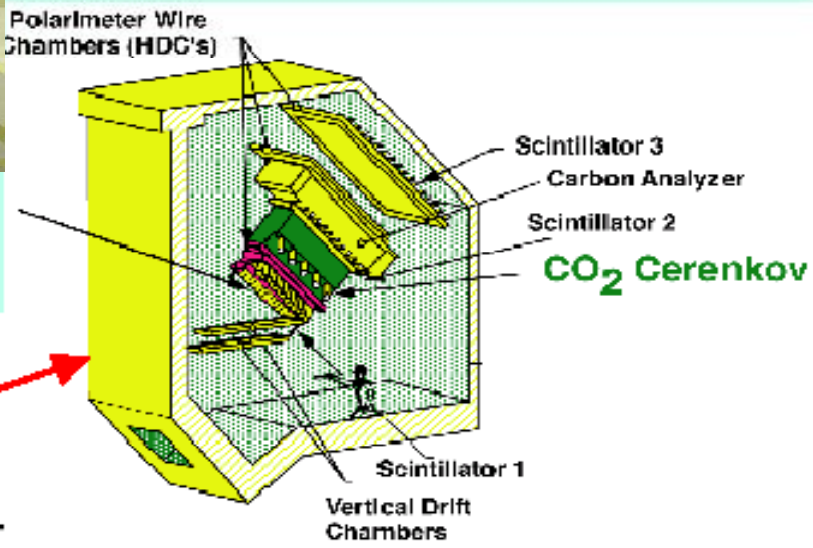
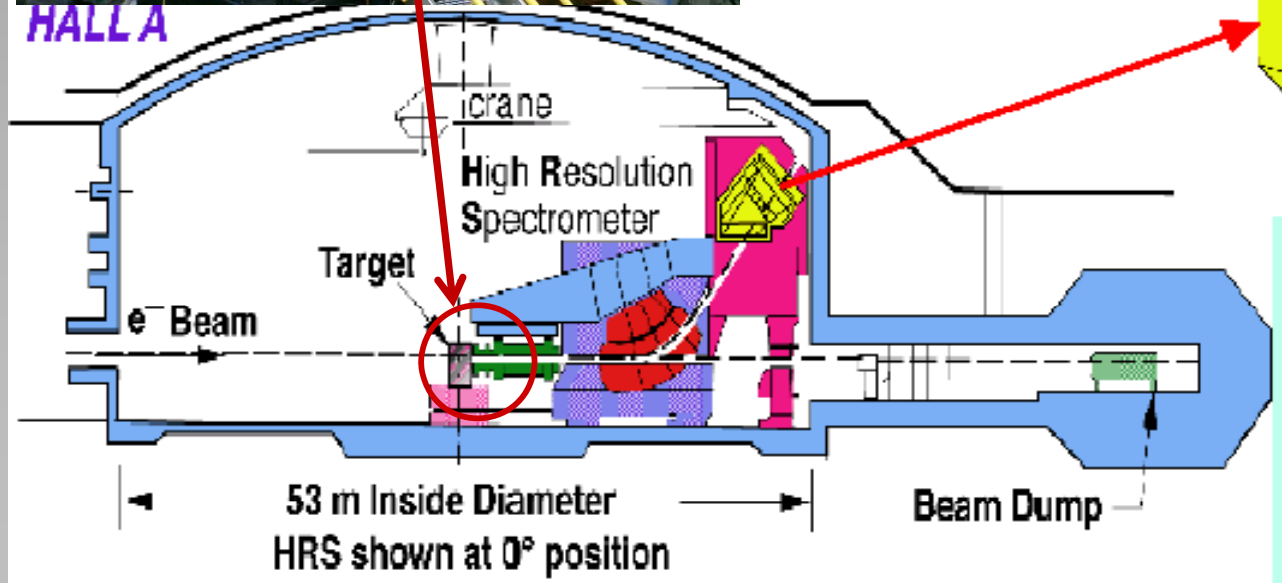








1 (+1) Cherenkov threshold aerogels + RICH in the hadron spectrometer

E94-107 Experiment:

"High Resolution 1p Shell Hypernuclear Spectroscopy"

spokespersons: **F. Garibaldi, S. Frullani, J. Le Rose, P. Markowitz, T. Saito**

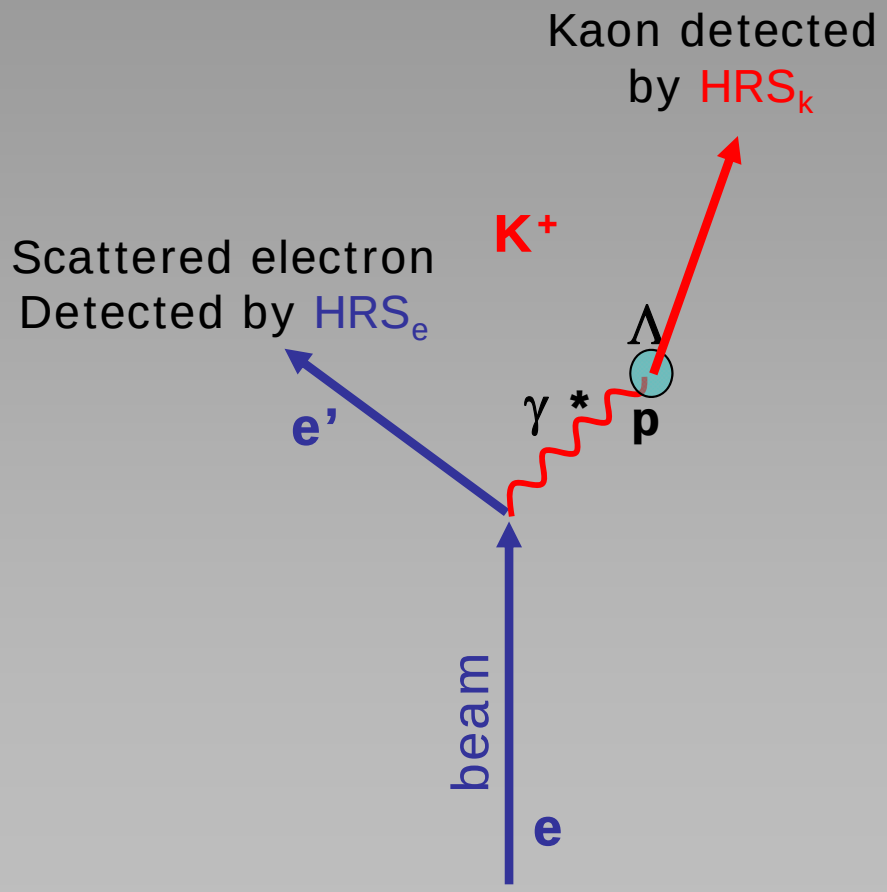
Hall A Collaboration

- **Electroproduction of hypernuclei by the reaction:**

$$e + {}^{A}Z \rightarrow e' + K^{+} + {}^{A}(Z-1)_{\Lambda}$$

- **Nuclear targets and resulting hypernuclei:**
  - ^{9}Be → ^{9}Li$_{\Lambda}$ (**spin doublets**, information on s-s term of Λ-N interaction potential)
  - ^{12}C → ^{12}B$_{\Lambda}$ (comparison with previous data: better understanding of results with hadron probes and Hall C at Jefferson Lab)
  - ^{16}O → ^{16}N$_{\Lambda}$ (precise determination of Lambda binding energy)
- **Experimental requirements:**
  1. **Excellent Energy Resolution**
  2. **Detection at very forward angles** (6° to obtain practical counting rates → **septum magnets**)
  3. **Excellent Particle Identification (PID), unambiguous kaon selection → RICH**

The choise of the Kinematics



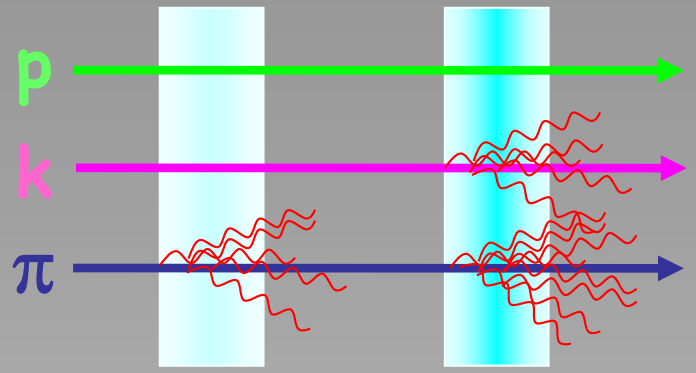
E_{beam} = 4.016 (3.777) GeV
P_k= 1.98 (1.96) GeV/c
P_e= 1.80 (1.56) GeV/c
$\theta_e = \theta_K = 6°$
$\omega = E_\gamma \sim 2.2$ GeV – $Q^2 = 0.079$ (GeV/c)^2
Beam current : 100 μA
Target thickness : 100 mg/cm^2
Counting Rates ~ **2 –25 counts/peak/hour**

Energy resolution

SOURCE	RESOLUTION	Error FWHM (kev)
beam	10^{-4} of 4 GeV (4 σ)	235
e'	10^{-4} of 1.8 GeV	180
k	10^{-4} of 1.9 GeV	190
k straggling	40 KeV	40
Total		≈ 350

Kaon identification using Aerogel Threshold Cherenkov detectors

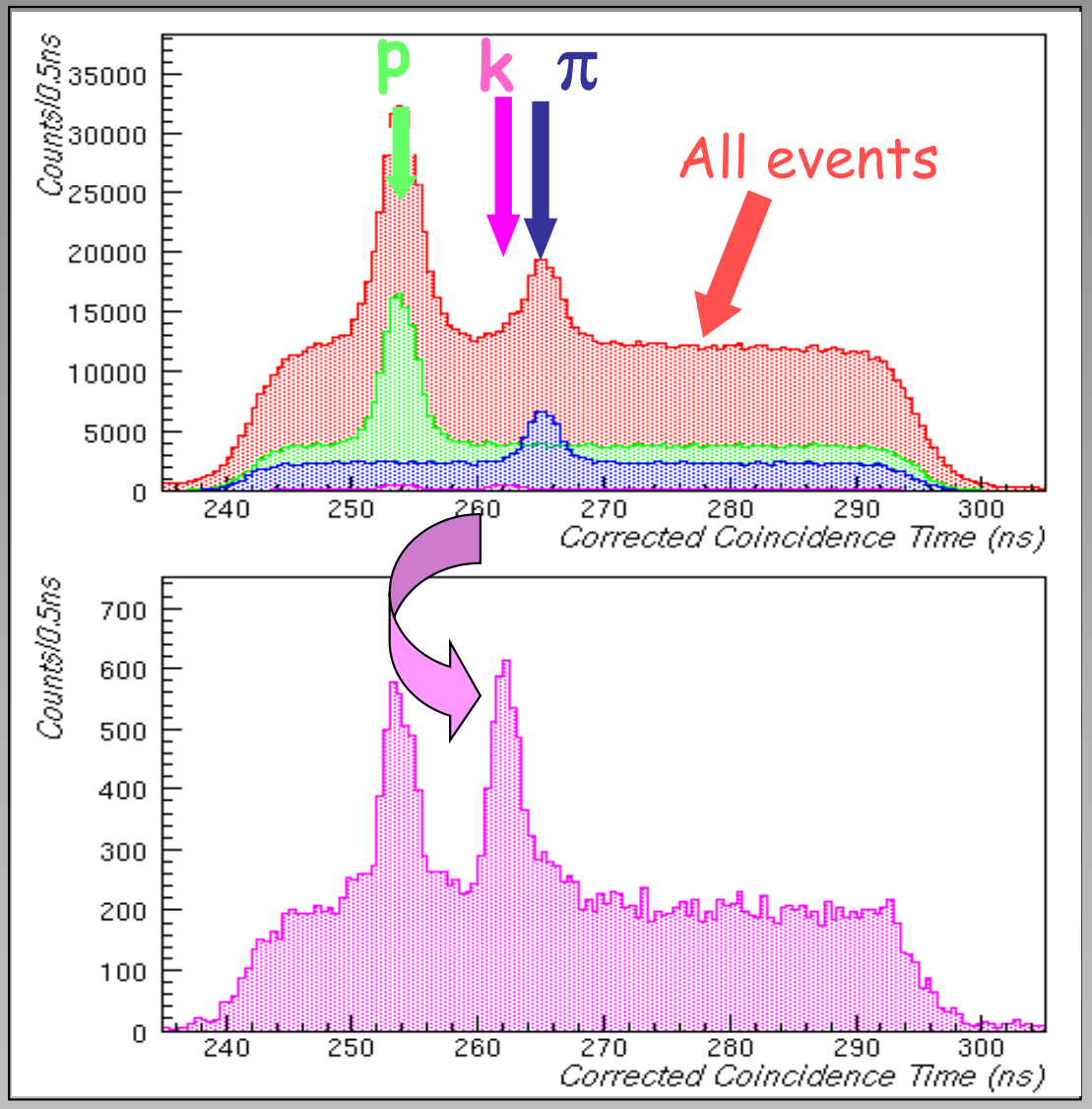
p_h = 1.7 : 2.5 GeV/c



$$\text{Proton} = \overline{\text{AERO1}} \cdot \overline{\text{AERO2}}$$

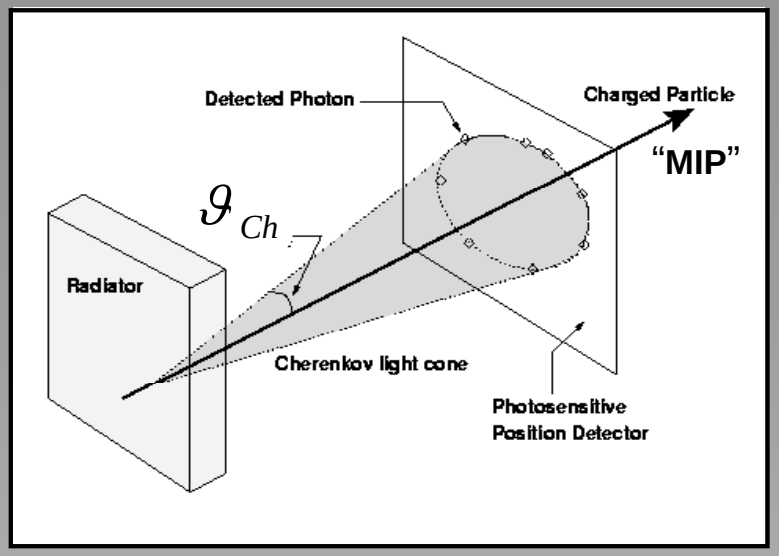
$$\text{Pion} = \text{AERO1} \cdot \text{AERO2}$$

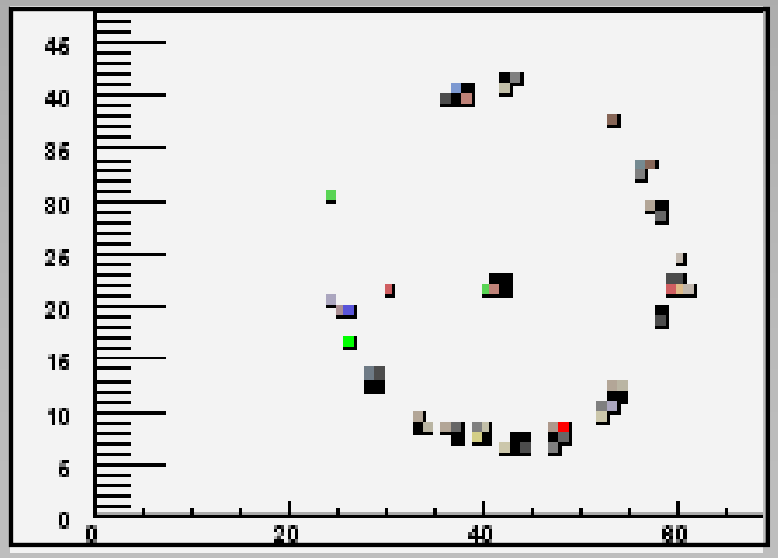
$$\text{KAON} = \overline{\text{AERO1}} \cdot \text{AERO2}$$

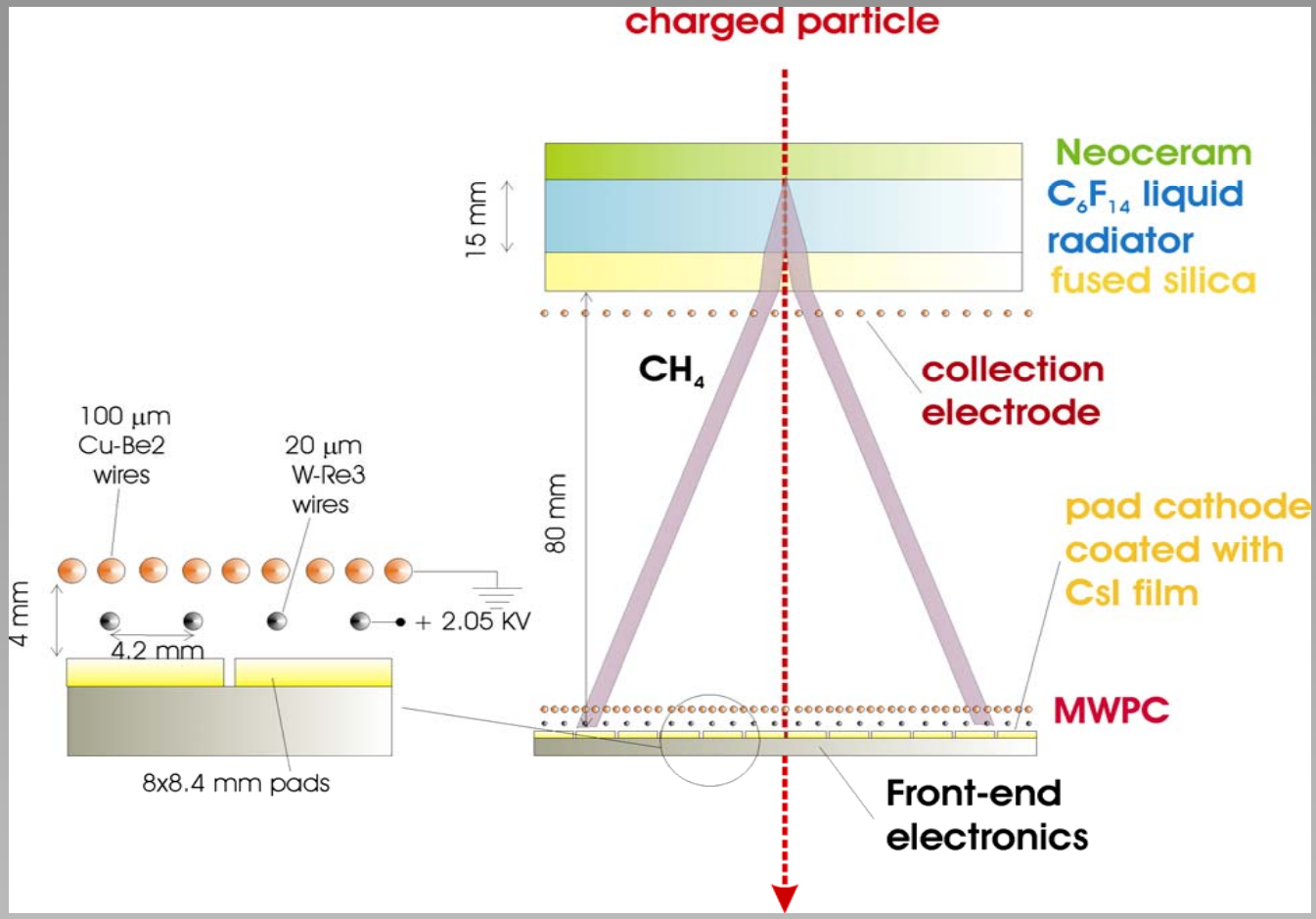


Small acceptance → forward angles – Higher background

RICH detector –C_6F_{14}/CsI proximity focusing RICH







Performances:

$N_{p.e.}$ **# of detected photons (p.e.) and σ_θ (angular resolution)**

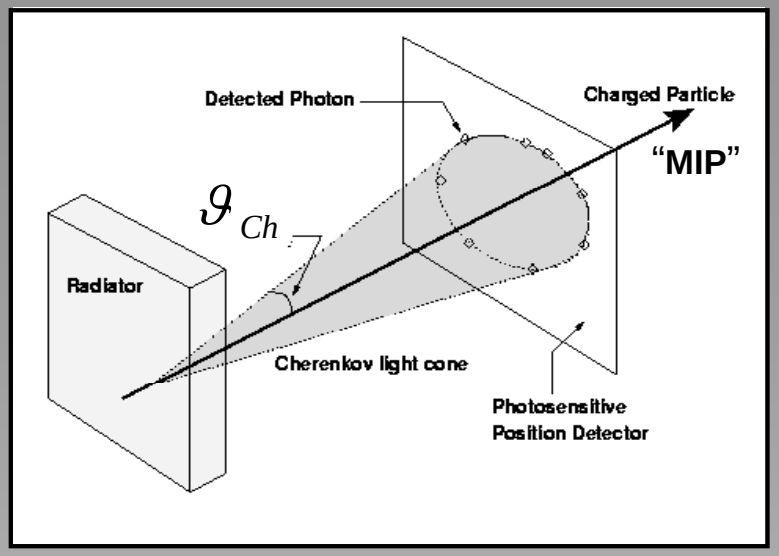
Separation Power

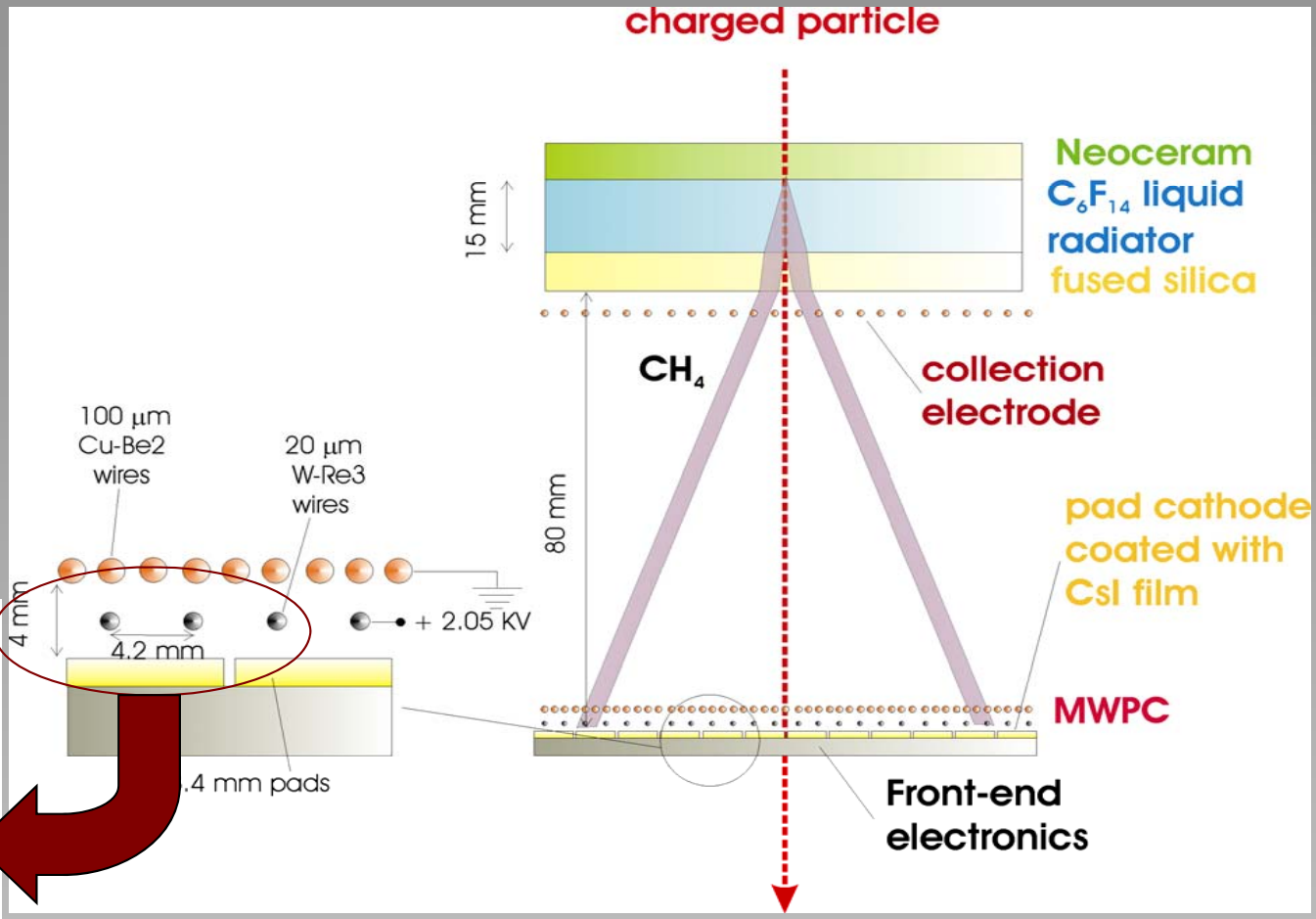
$$\vartheta_2 - \vartheta_1 = n_\sigma \sigma_{\vartheta_c}$$

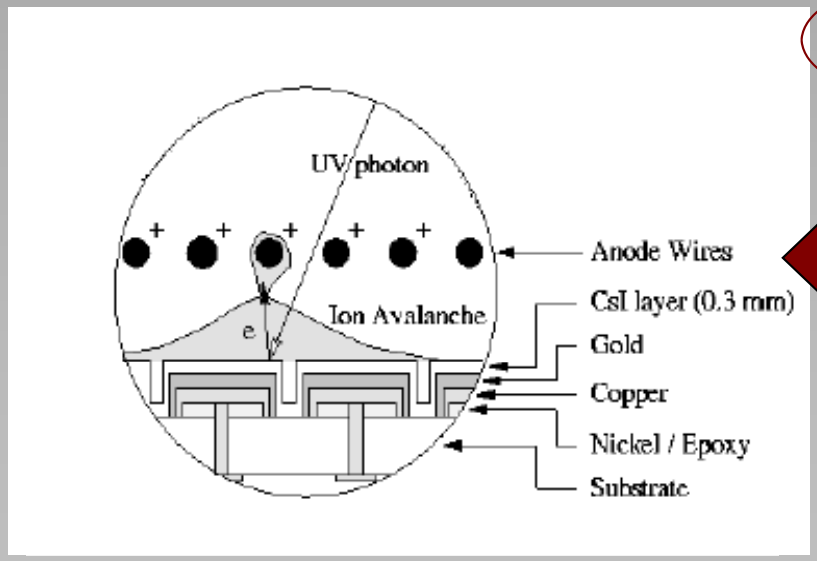
Cherenkov angle resolution

$$\sigma_{\vartheta_c} = \frac{\sigma_\vartheta^{p.e.}}{\sqrt{N_{p.e.}}}$$

RICH detector –C_6F_{14}/CsI proximity focusing RICH







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Cherenkov angle resolution

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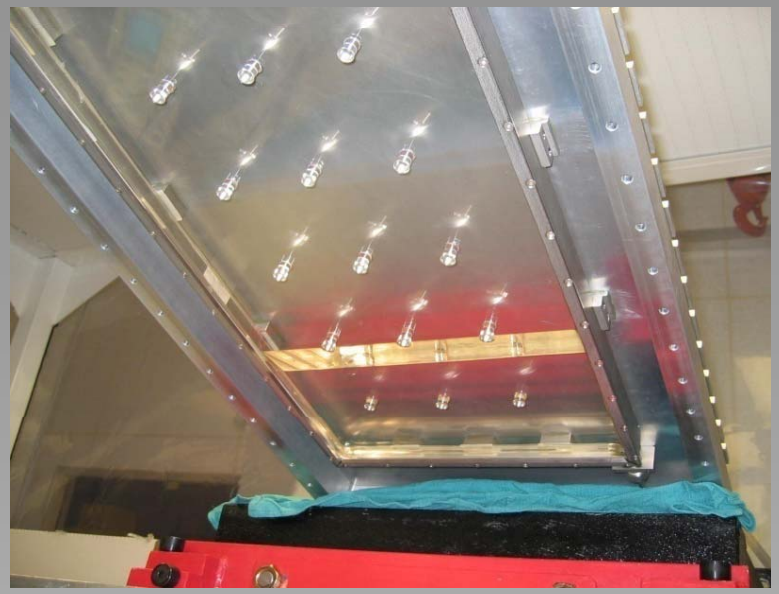
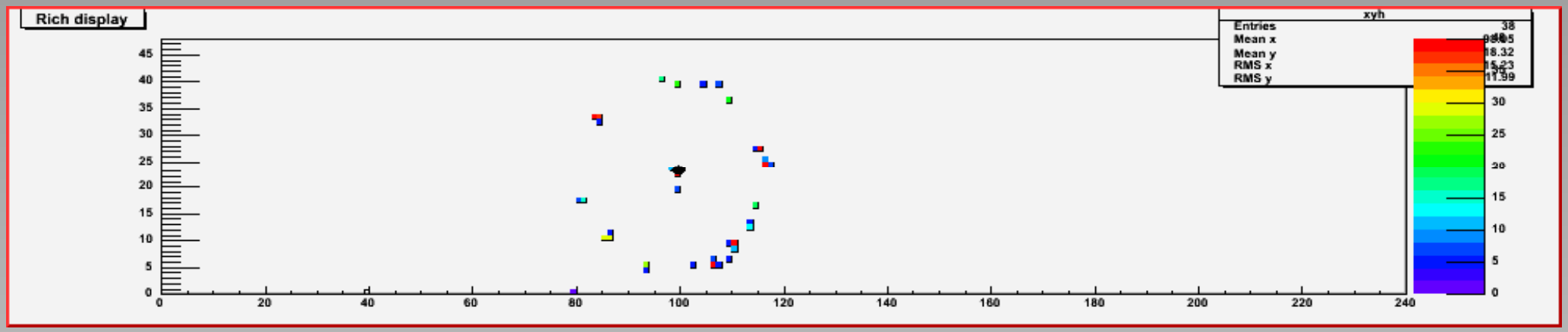
The RICH detector at Jefferson Lab



RICH photocathode installation




JLAB Hall A on-line RICH Event Display



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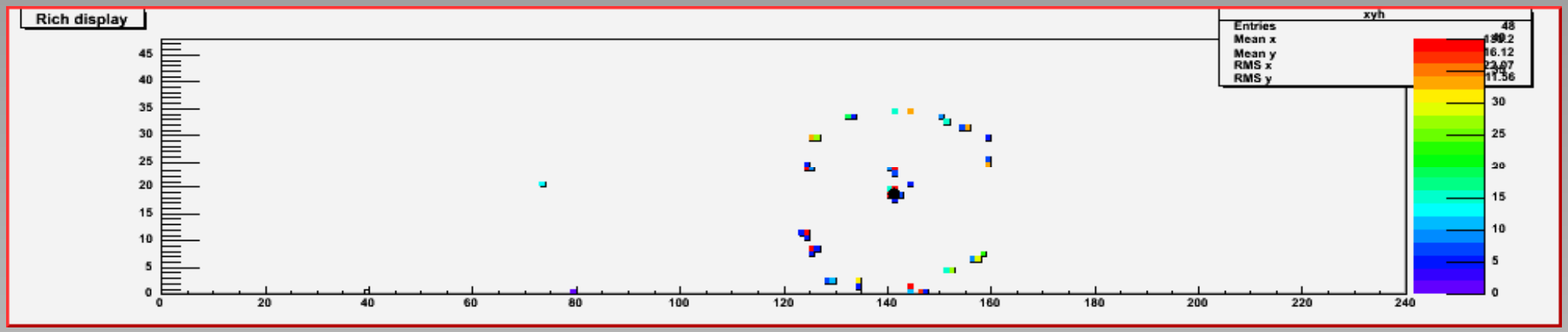

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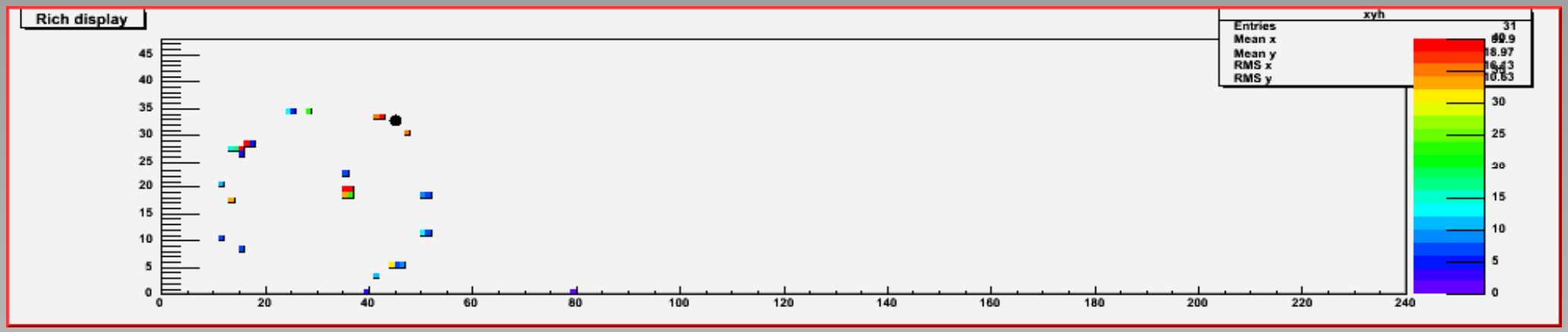

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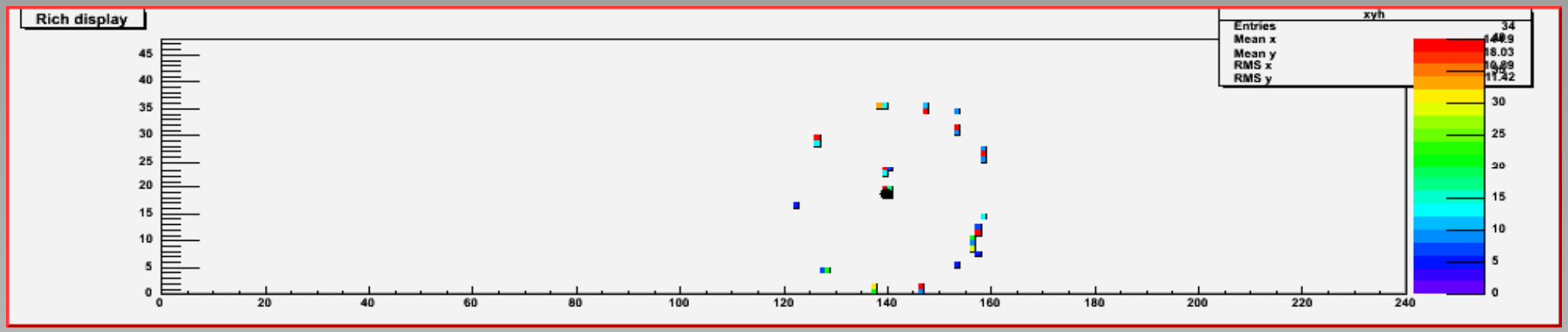

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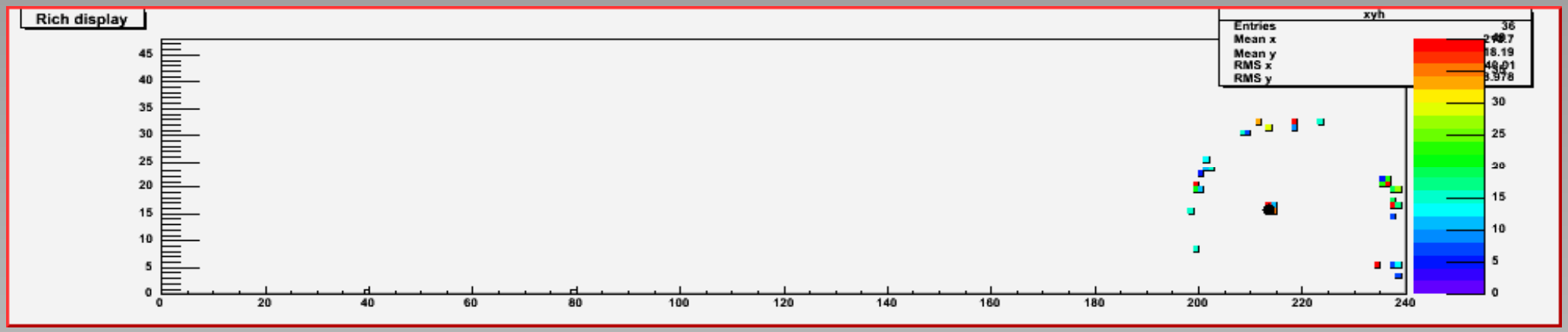

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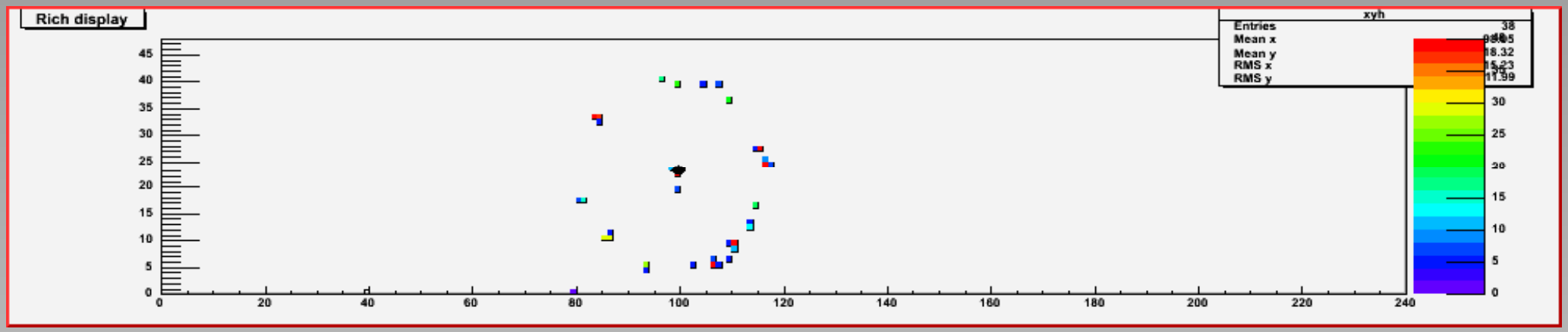

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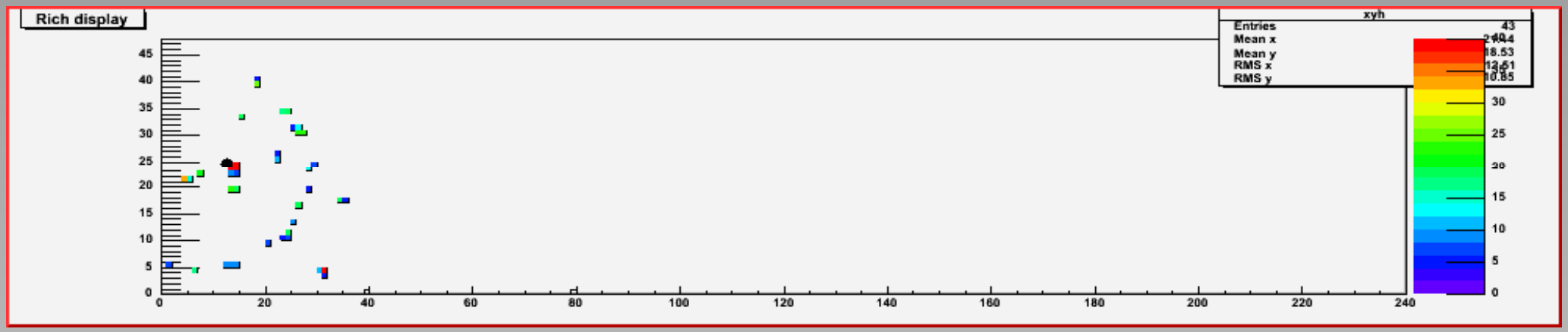
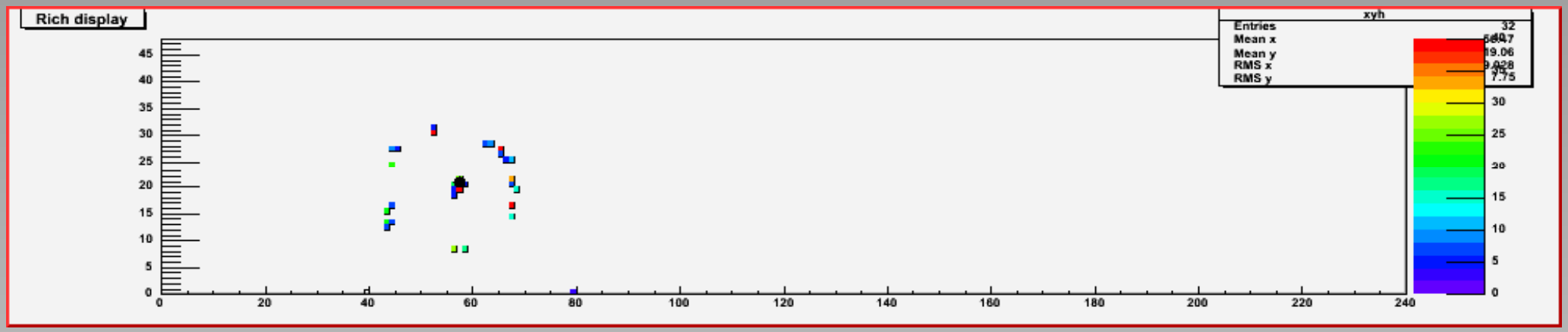


JLAB Hall A on-line RICH Event Display



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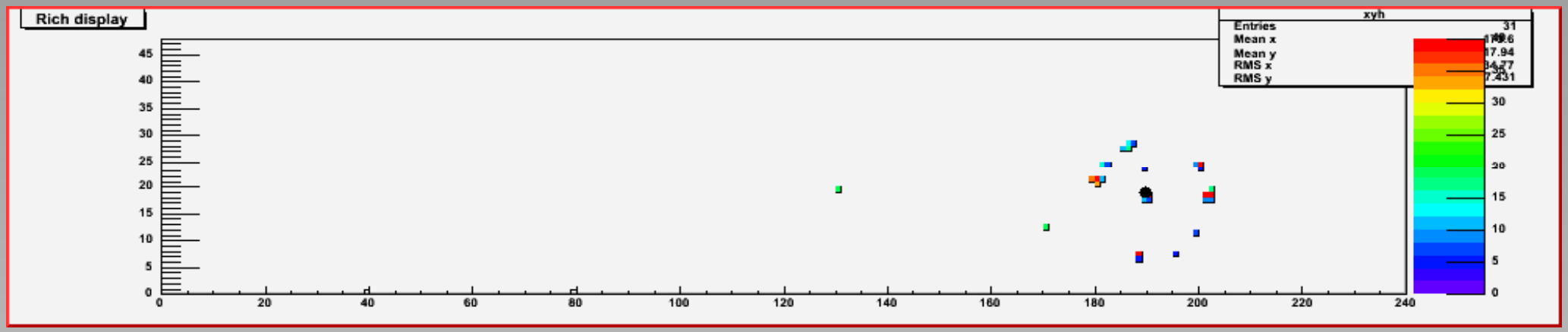

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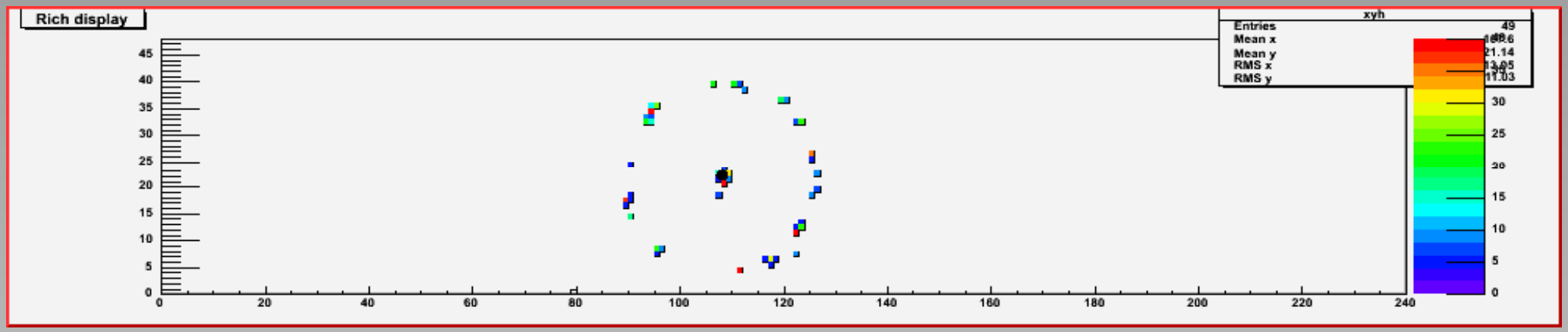

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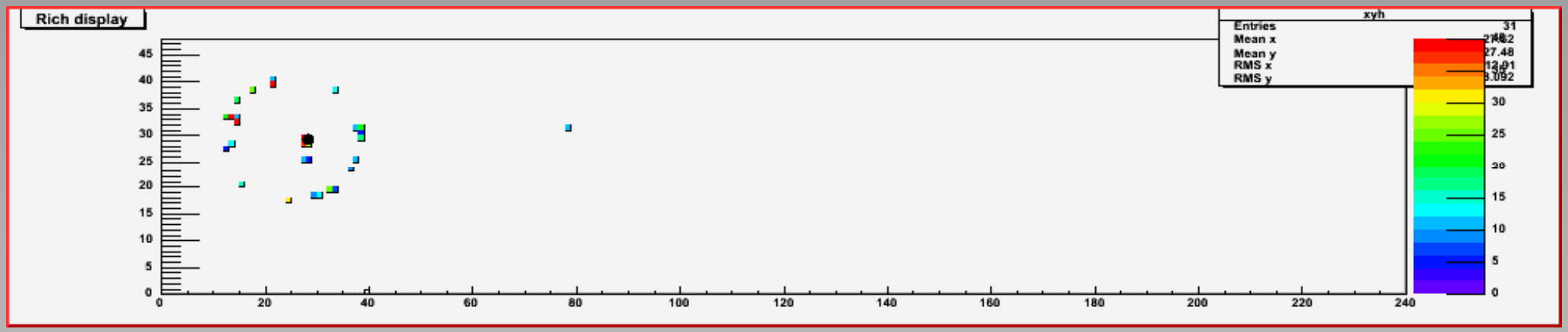

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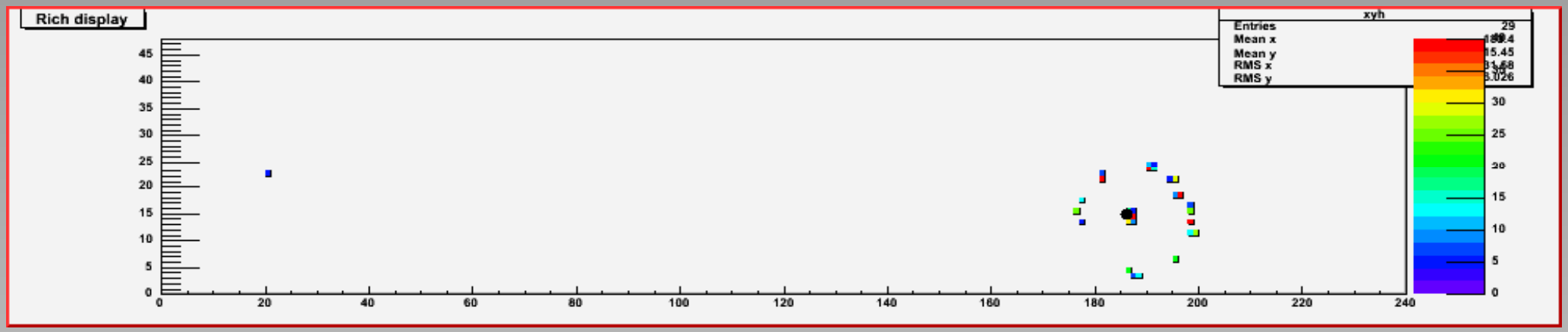

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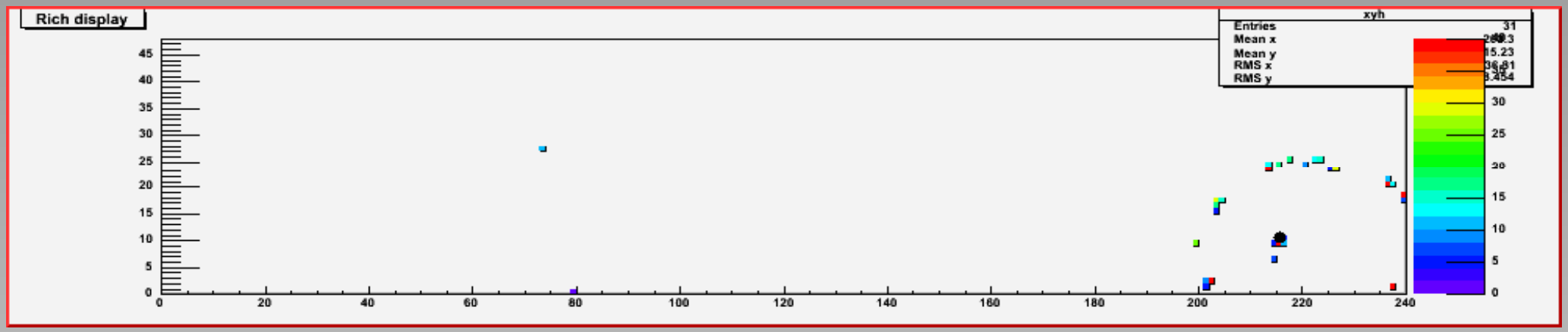
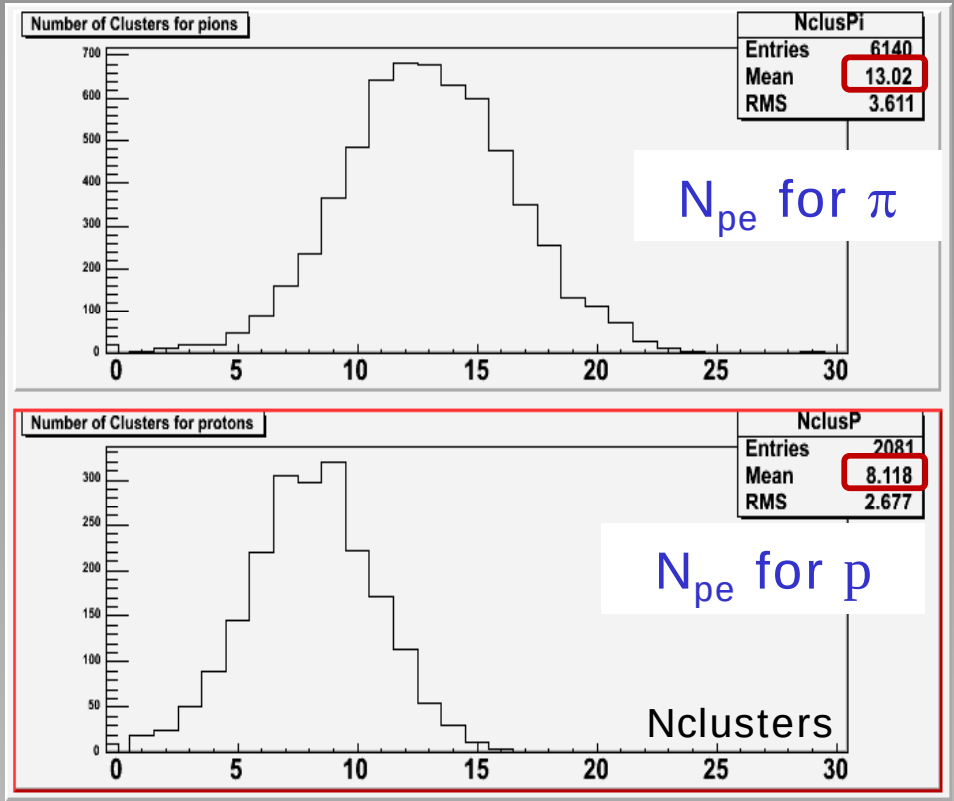
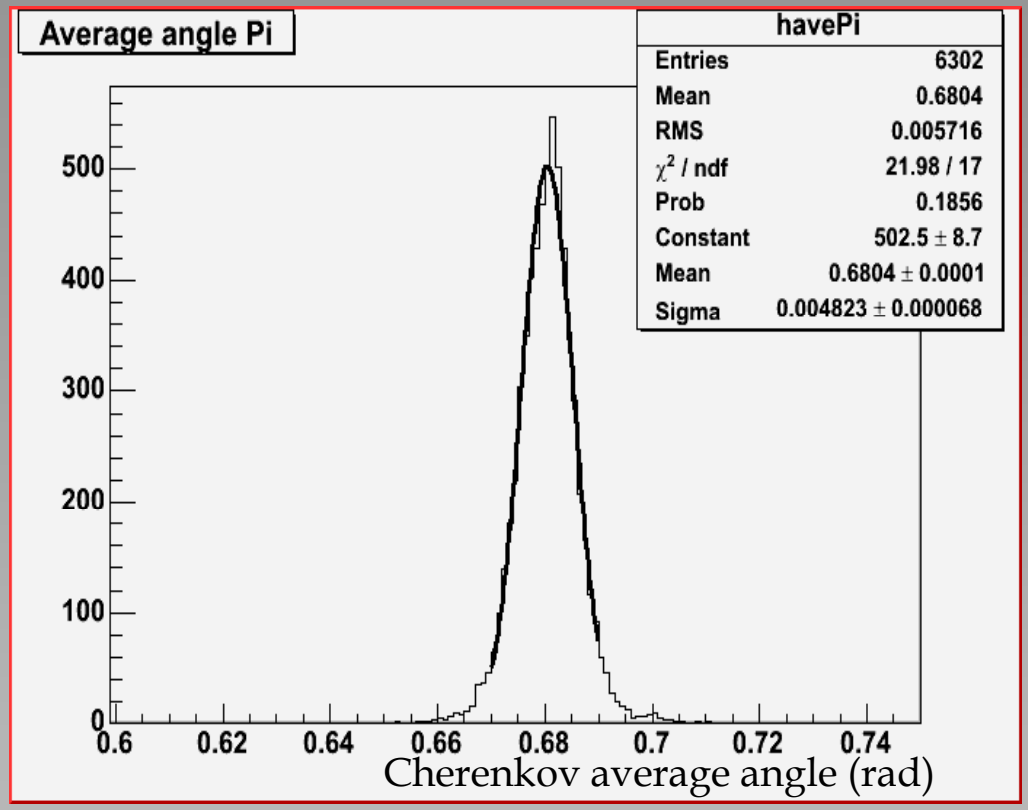


Rich Performances – 'key parameters':

Cherenkov angle for π





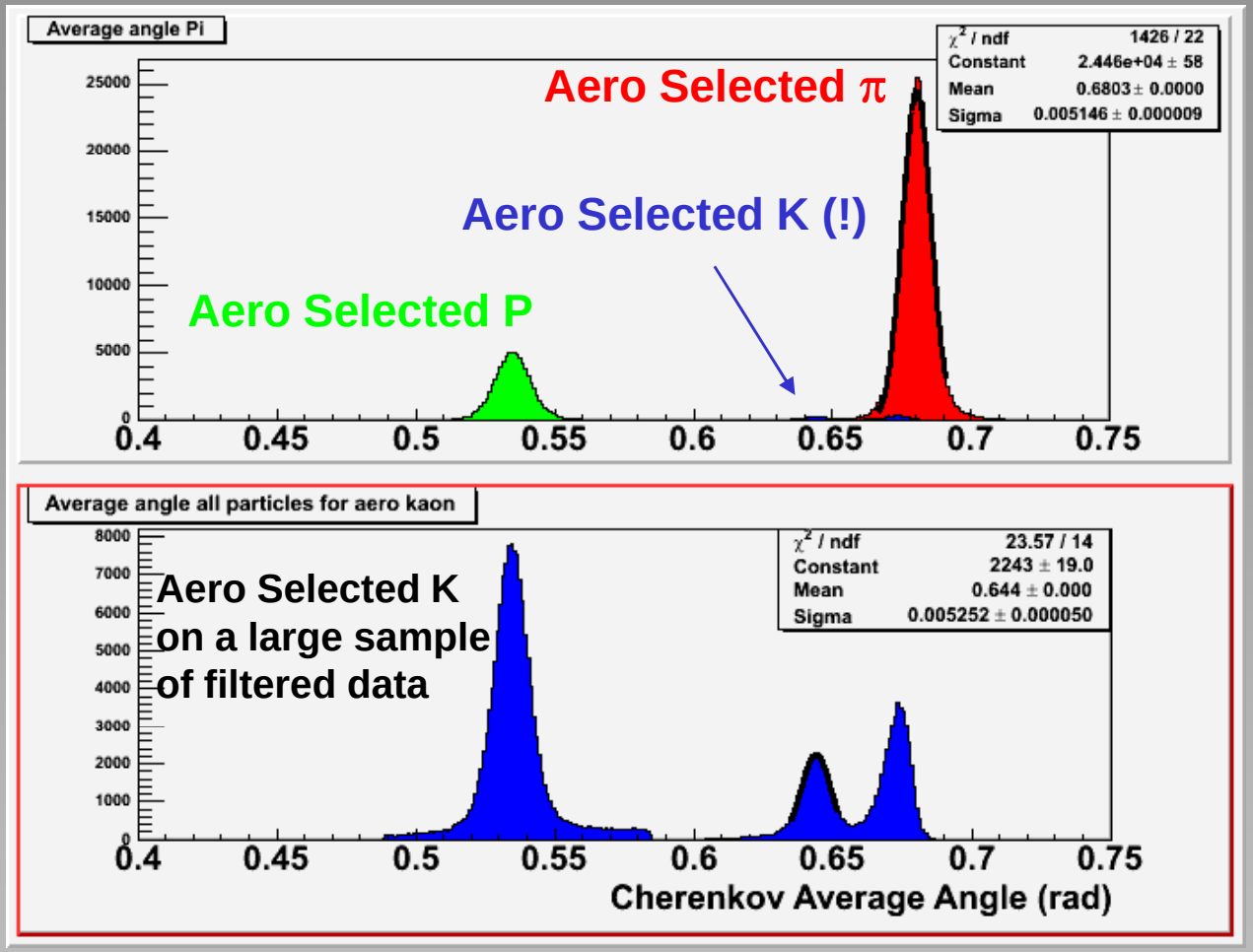
N_{pe} π/p ratio:

$$\frac{N_{clus}^{P}}{N_{clus}^{\pi}} = \frac{1-\beta_P^2 n^2}{1-\beta_\pi^2 n^2} = 0.66$$

Angular resolution:

$$\sigma_{\vartheta_c} \approx 5\,mrad$$

Rich Performances – Particle Identification (PID):



π/K population ratio

$$\approx 100$$

Angular resolution

$$\sigma_{\vartheta_c} \approx 5\,mrad$$

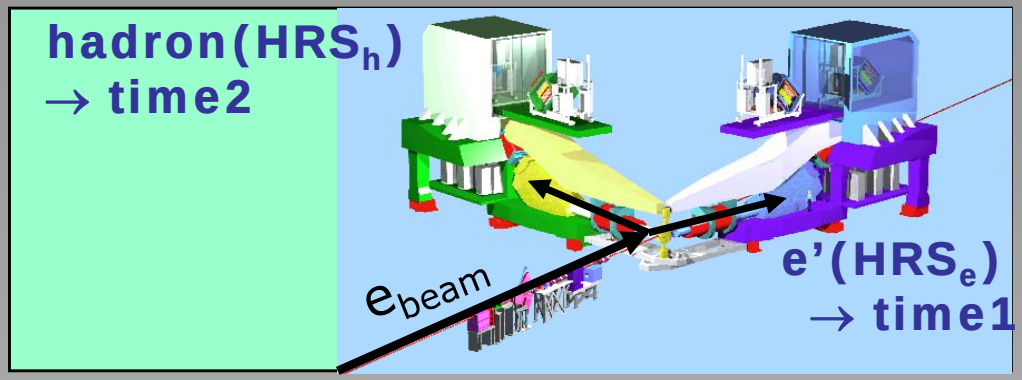
Separation Power

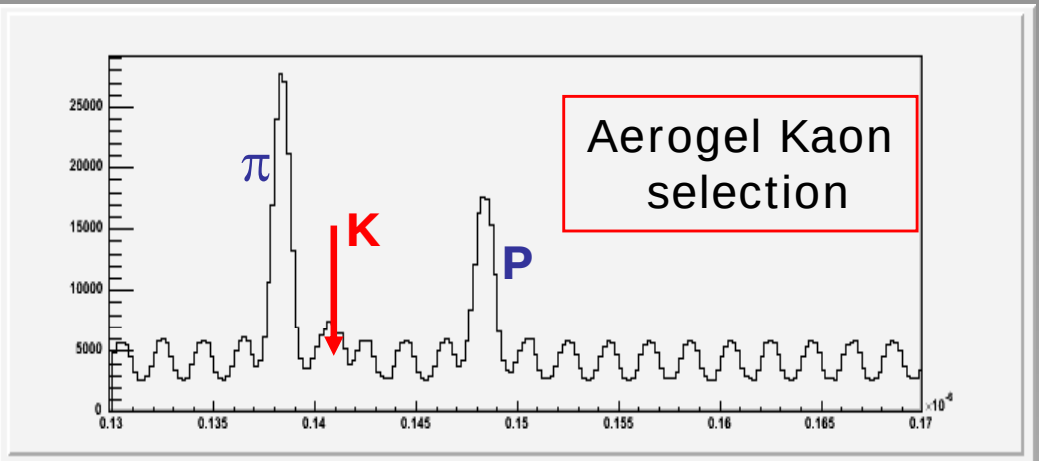
$$\vartheta_\pi - \vartheta_K \approx 7\sigma_{\vartheta_c}$$

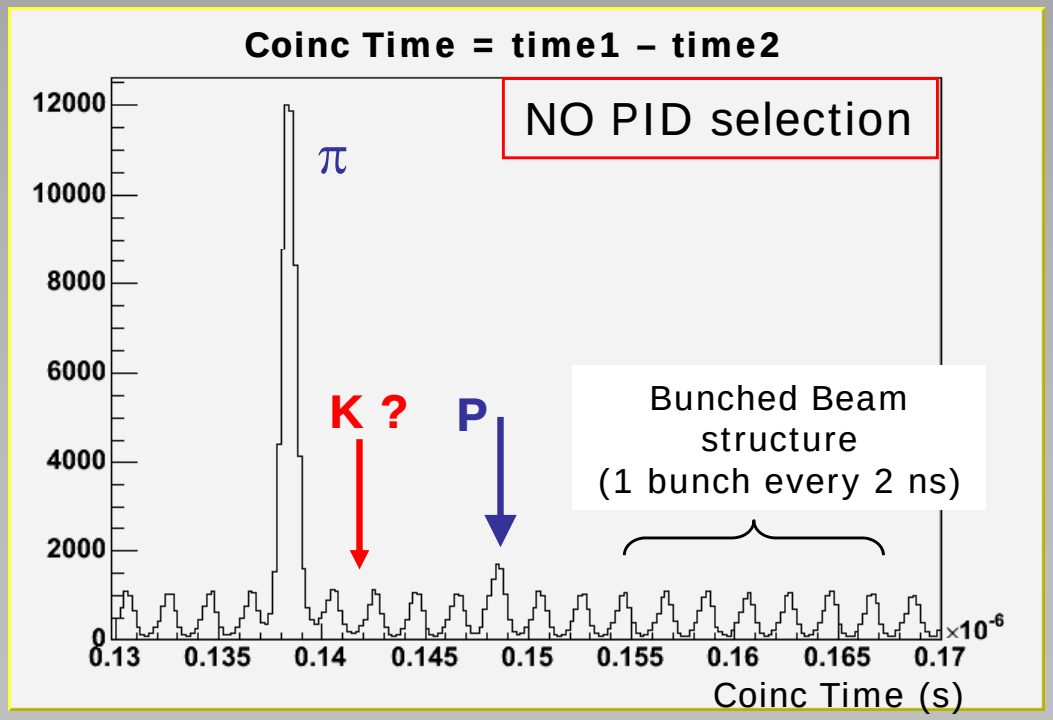
'Kaon selection': $\vartheta_K \pm 3\sigma_{\vartheta_c}$

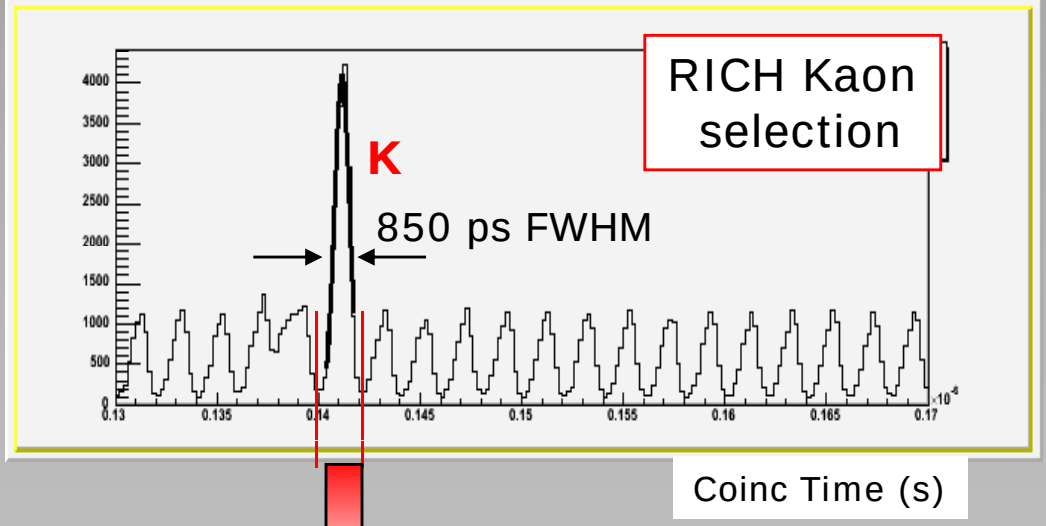
JLAB Hall A E94-107: Results on ^{12}C target

e-arm Vs hadron-arm "Time of Coincidence" spectrum and K selection









Missing Energy Spectra

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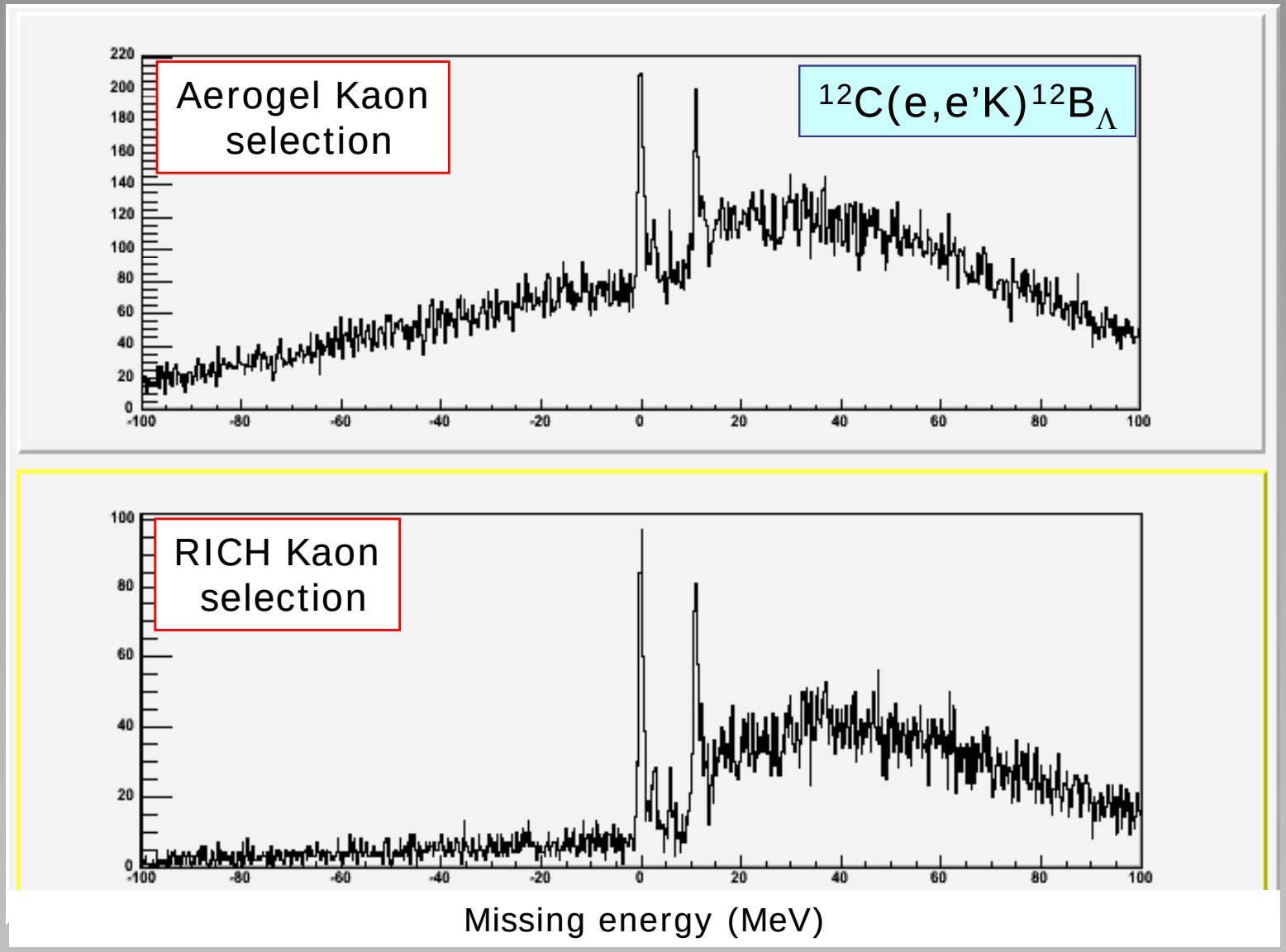
JLAB Hall A E94-107: Results on ^{12}C target

Missing Energy Spectra

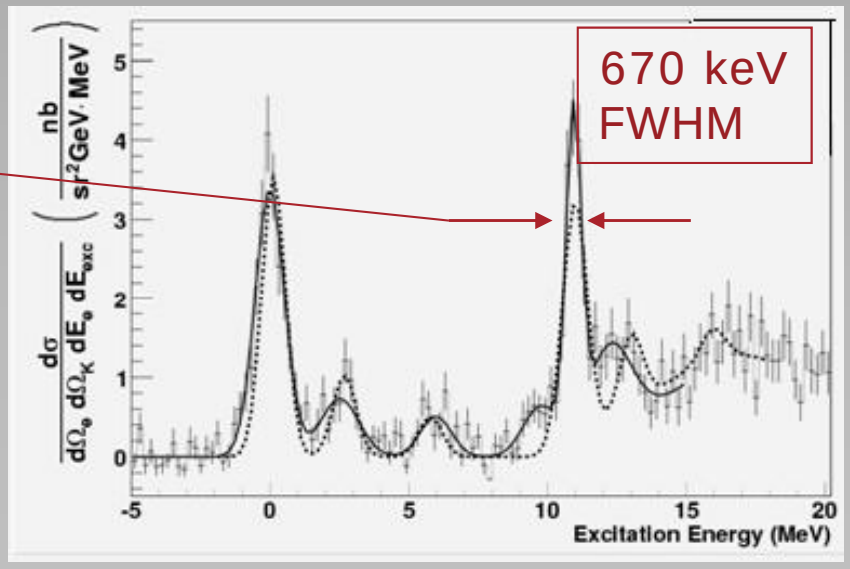


Results on ^{12}C target – Hypernuclear Spectrum of $^{12}B_\Lambda$

Experimental data			
Position (MeV)	Width (FWHM, MeV)	SNR	Cross section (nb/sr^2/GeV)
0.0 ± 0.03	1.15 ± 0.18	19.7	4.48 ± 0.29(stat) ± 0.63(syst)
2.65 ± 0.10	0.95 ± 0.43	7.0	0.75 ± 0.16(stat) ± 0.15(syst)
5.92 ± 0.13	1.13 ± 0.29	5.3	0.45 ± 0.13(stat) ± 0.09(syst)
9.54 ± 0.16	0.93 ± 0.46	4.4	0.63 ± 0.20(stat) ± 0.13(syst)
10.93 ± 0.03	0.67 ± 0.15	20.0	3.42 ± 0.50(stat) ± 0.55(syst)
12.36 ± 0.13	1.58 ± 0.29	7.3	1.19 ± 0.36(stat) ± 0.35(syst)

Narrowest peak is doublet at 10.93 MeV
⇒ experiment resolution < 700 keV

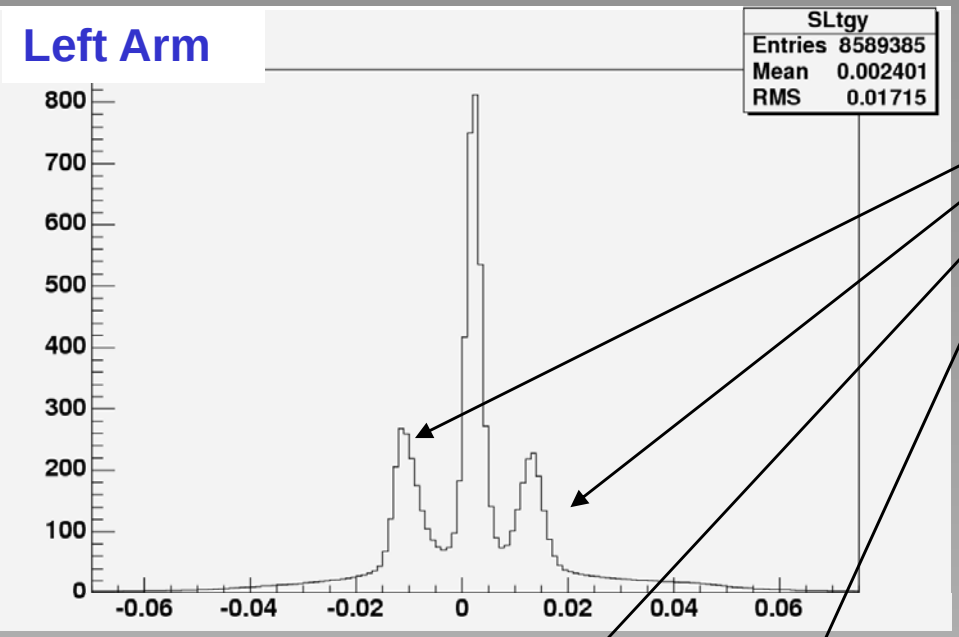
Precise detection of core-excited states, strong indication of a mixture state



M.Iodice et al., Phys. Rev. Lett. 99 (2007) 052501

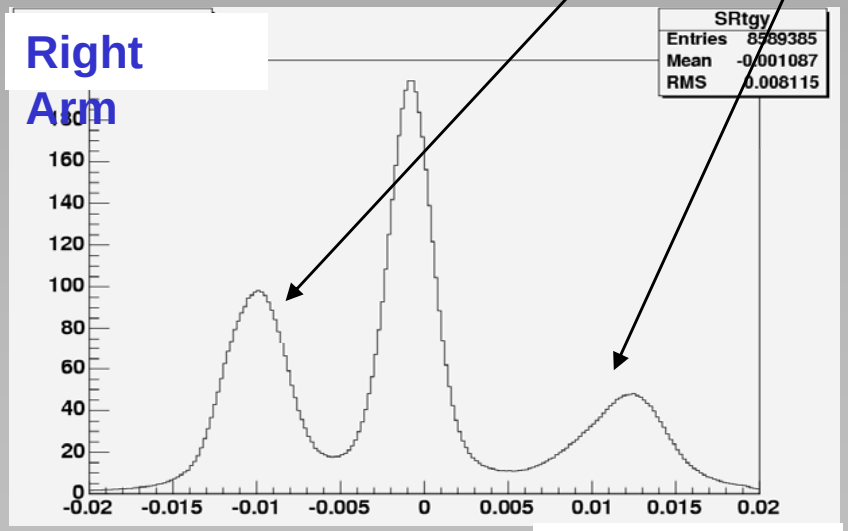
JLAB Hall A E-94107: Results on waterfall target

Left Arm

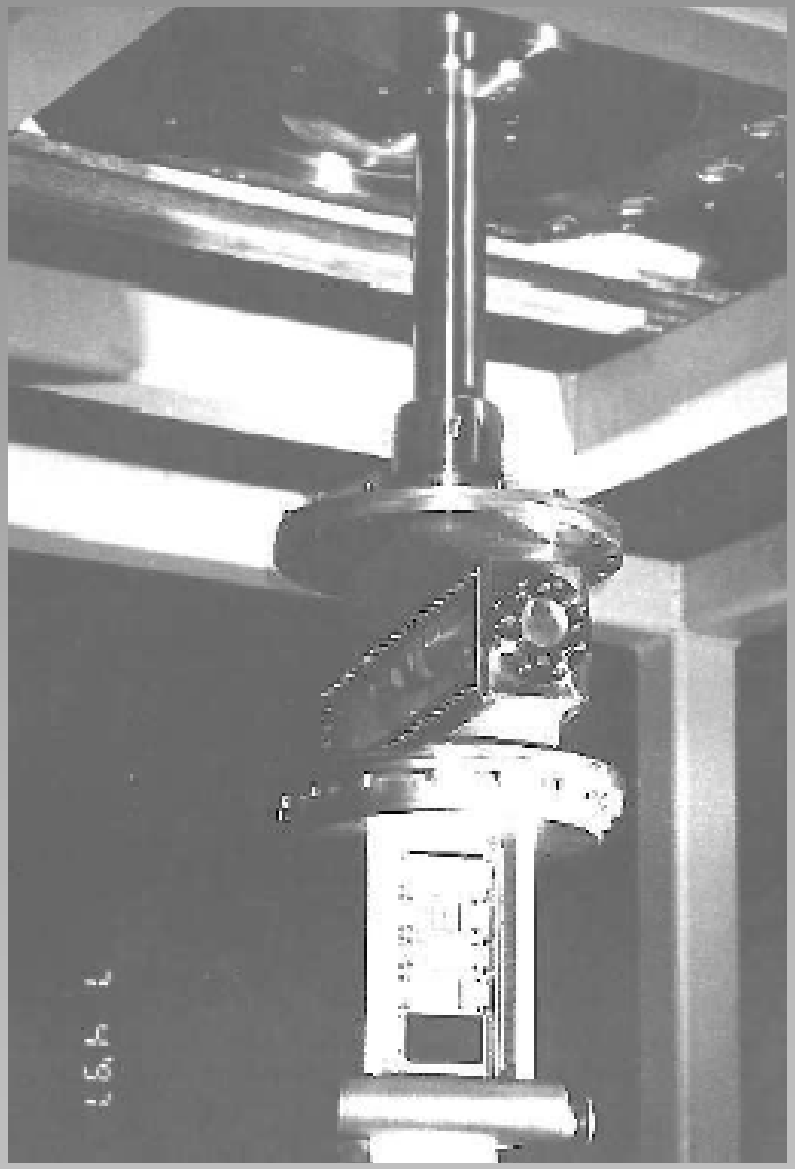


Be windows

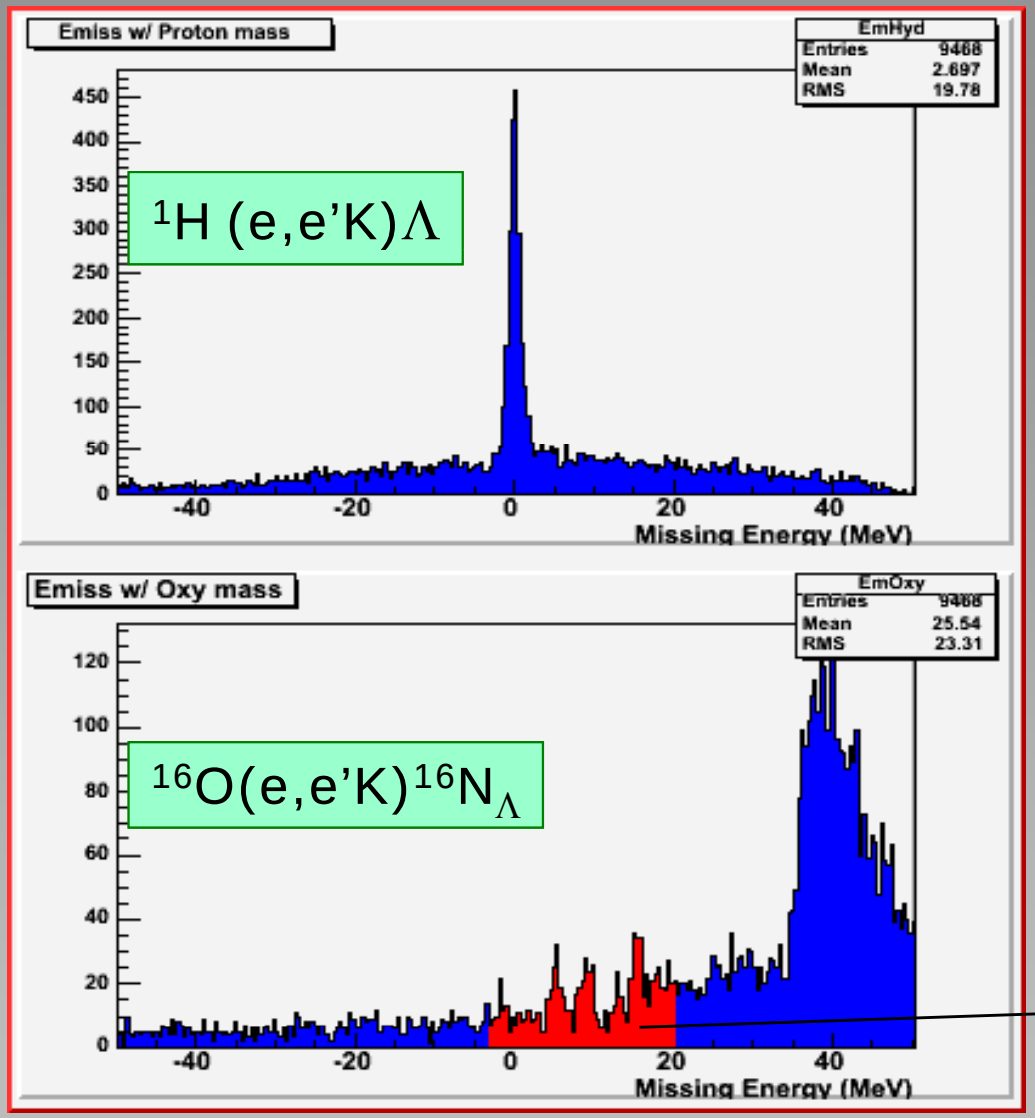
Right Arm

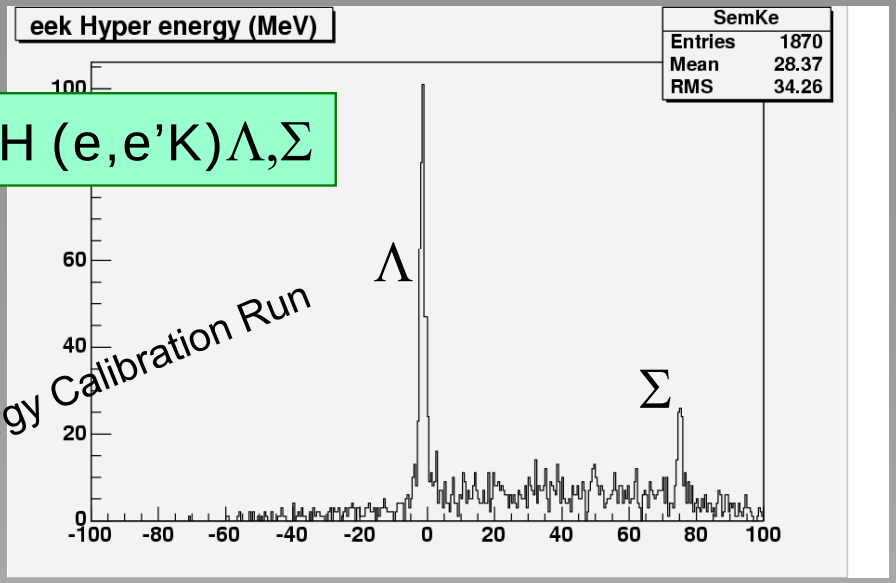


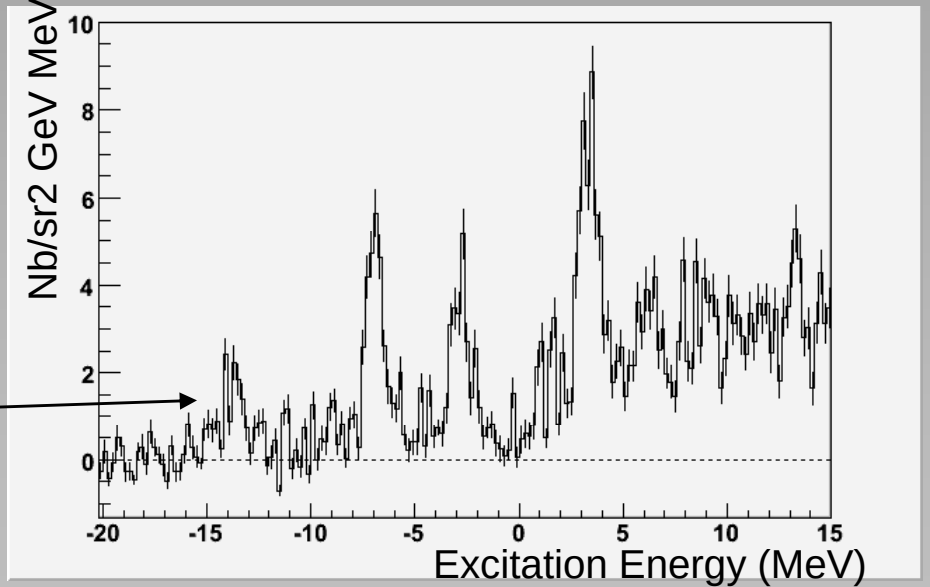
Y- Target (m)



JLAB Hall A E-94107: Results on waterfall target

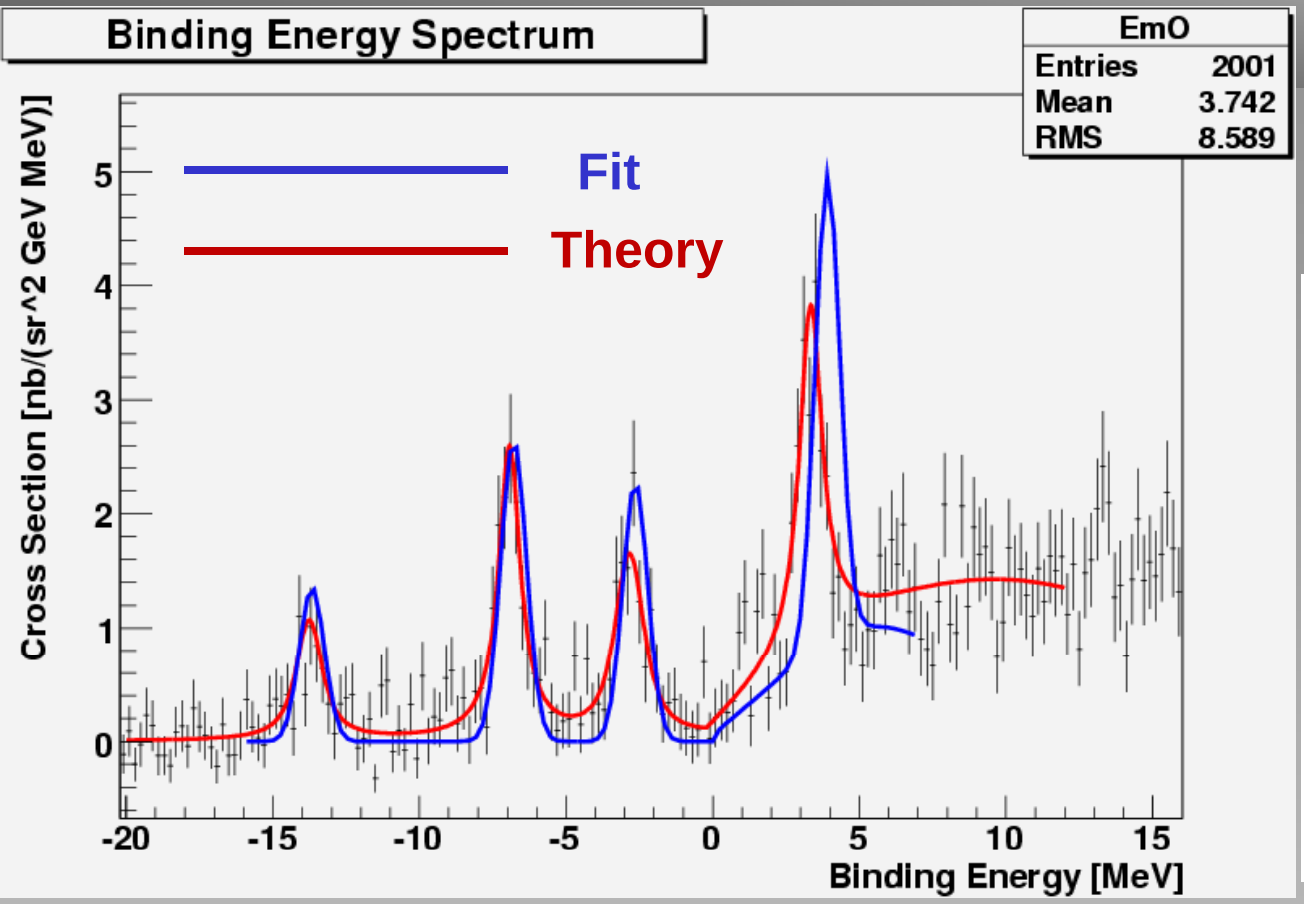






- Water thickness from elastic cross section on H
- Fine determination of the particle momenta and beam energy using the Lambda peak reconstruction (resolution vs excitation energy)

Results on ^{16}O target – Hypernuclear Spectrum of $^{16}N_\Lambda$



E_x (MeV)	Width (FWHM, MeV)	Cross section ($nb/sr^2/GeV$)
0.00 / 13.76 ±0.16	1.71 ± 0.70	1.45 ± 0.26
6.83 ± 0.06	0.88 ± 0.31	3.16 ± 0.35
10.92 ± 0.07	0.99 ± 0.29	2.11 ± 0.37
17.10 ± 0.07	1.00 ± 0.23	3.44 ± 0.52

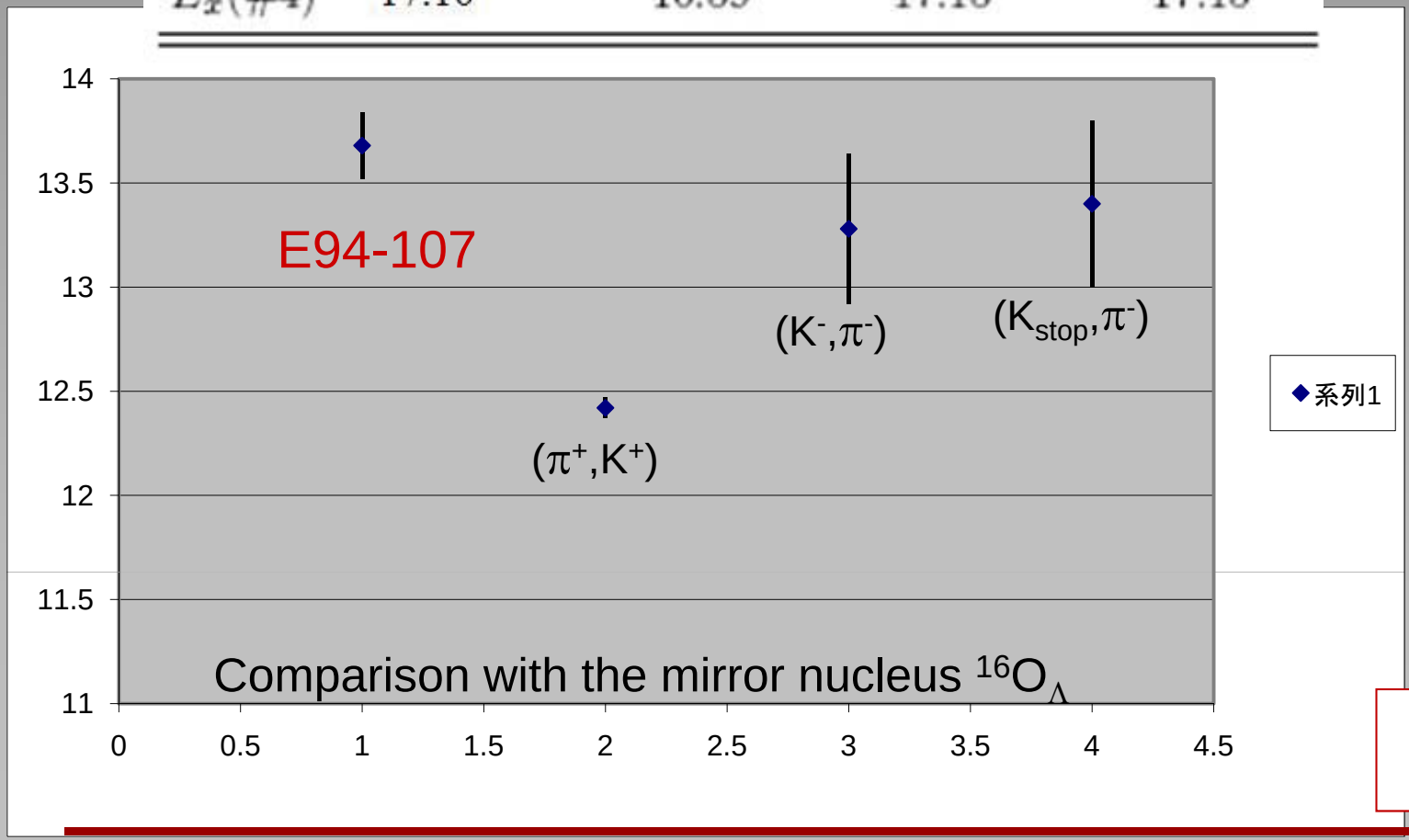
- Fit to the data (red line): Fit 4 regions with 4 Voigt functions $\Rightarrow$ $\chi^2_{/ndf} = 1.19$
- Theoretical model (blu line) based on :
  - i) SLA p(e,e'K+)Λ (elementary process)
  - ii) ΛN interaction fixed parameters from KEK and BNL $^{16}_{\Lambda}O$ spectra (J. Millener)

Binding Energy B_Λ=13.76 ± 0.16 (stat) ± 0.05 (sys) MeV

Measured for the first time with this level of accuracy

Results on ^{16}O target – Hypernuclear Spectrum of $^{16}N_\Lambda$

	$(e,e'K^+)$ This expt.	(π^+,K^+) KEK [1]	(K^-,π^-) CERN [2]	(K^-_{stop},π^-) KEK [3]
B_Λ (#1)	13.76(16)	12.42(5)	13.28(36)	13.40(40)
E_x (#2)	6.83	6.23	5.96	6.39
E_x (#3)	10.92	10.57	10.62	10.84
E_x (#4)	17.10	16.59	17.15	17.15



[1] O. Hashimoto, H. Tamura, Part Nucl Phys 57, 564 (2006)

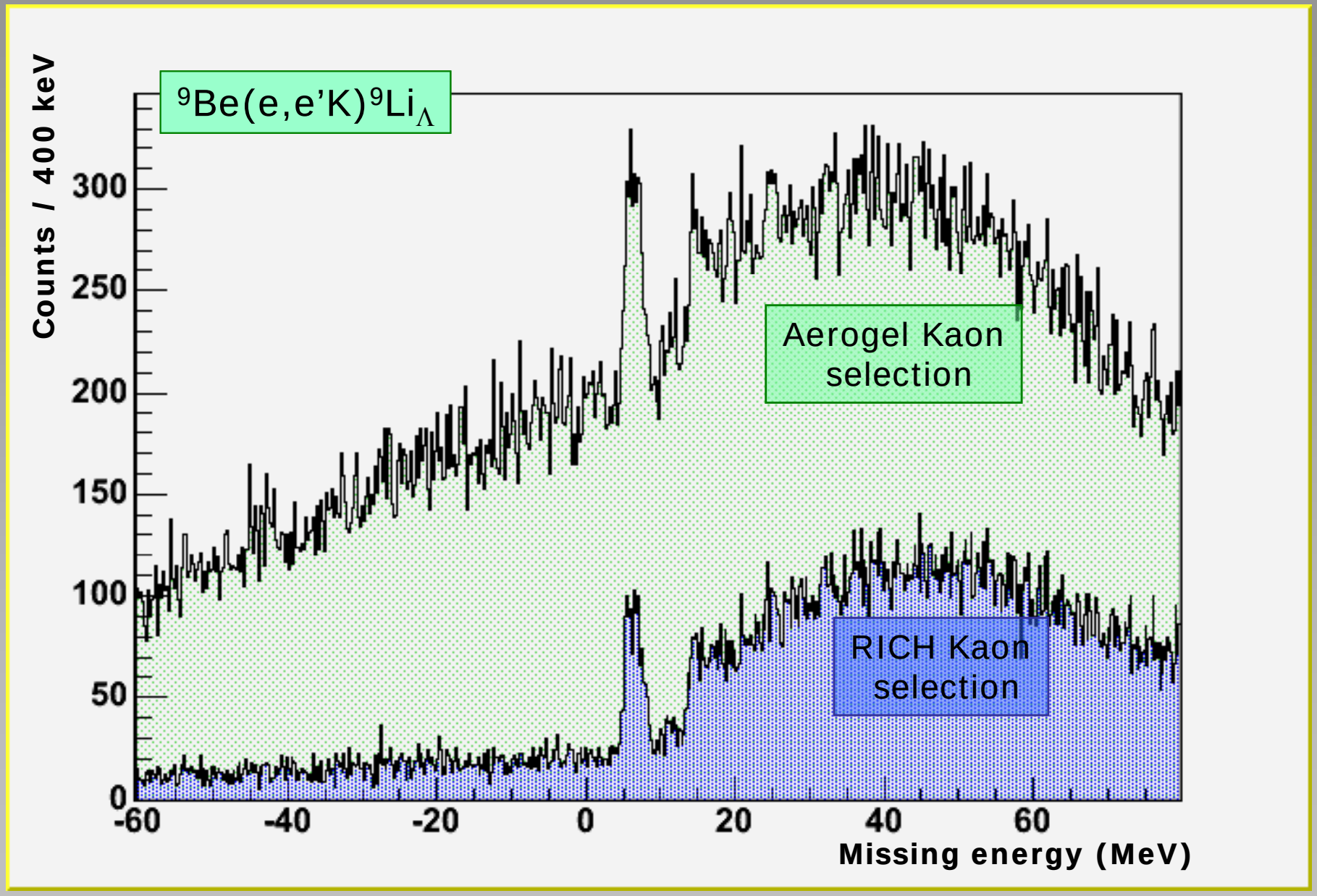
[2] private communication from D. H. Davis, D. N. Dovee, fit of data from Phys Lett B 79, 157 (1978)

[3] private communication from H. Tamura, erratum on Prog Theor Phys Suppl 117, 1 (1994)

Difference expected with respect to mirror nucleus: 400 – 500 keV (M. Sotona)

Paper (re)submitted to Phys Rev Lett

JLAB Hall A E-94107: Preliminary Results on ^{9}Be target

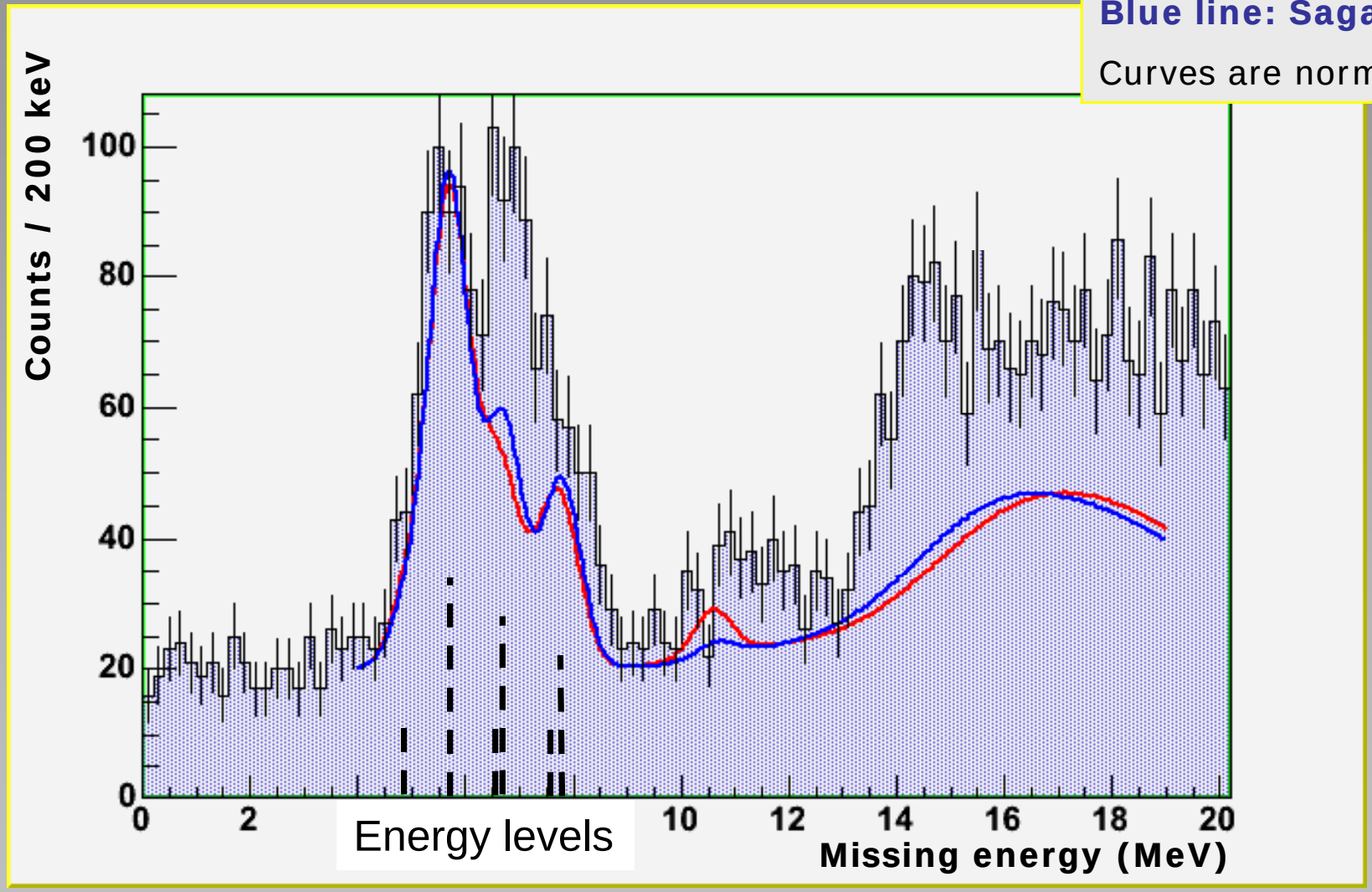


JLAB Hall A E-94107: Preliminary Results on ^{9}Be target

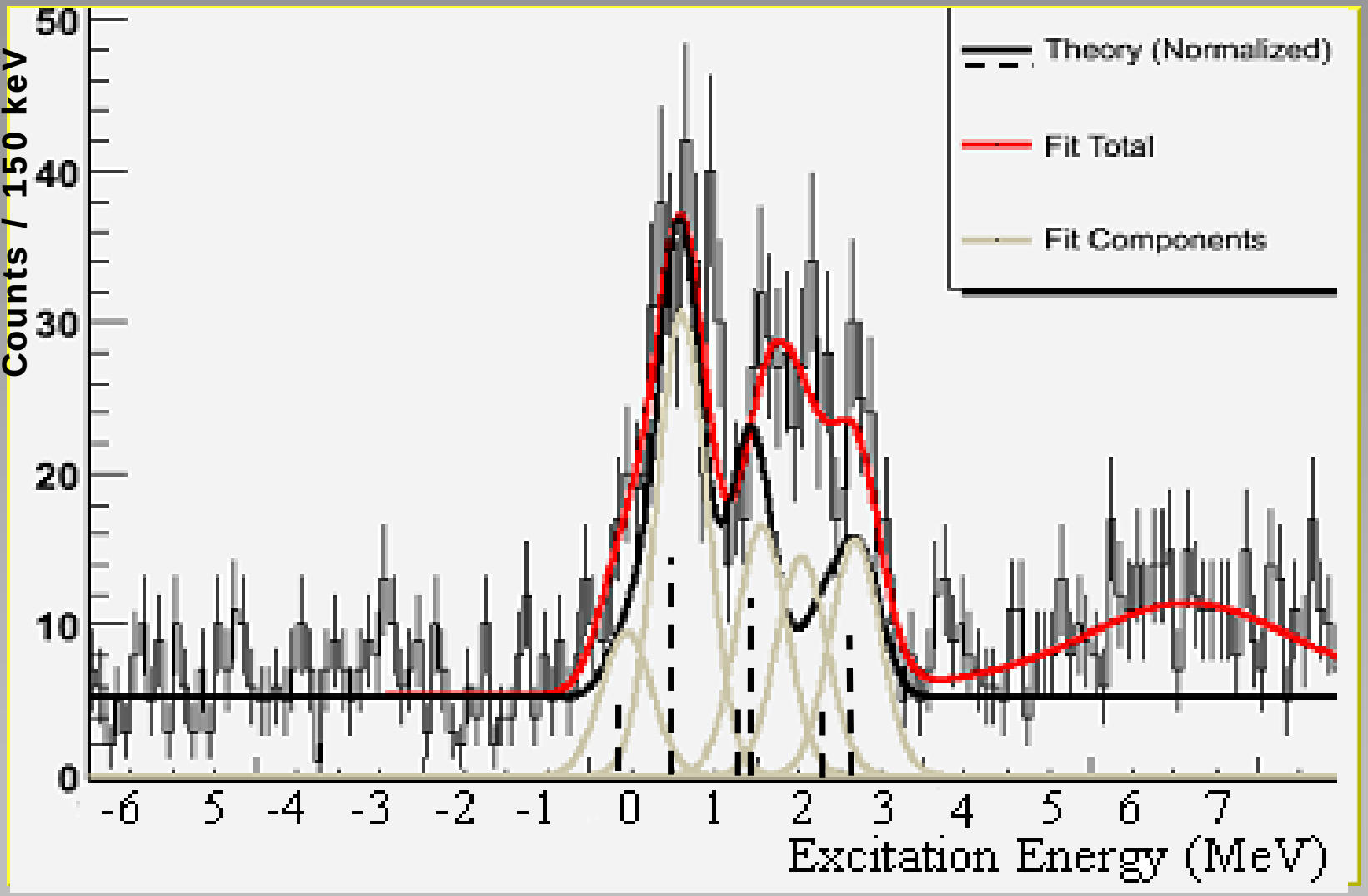
Red line: Bennhold-Mart (K MAID)

Blue line: Sagay Saclay-Lyon (SLA)

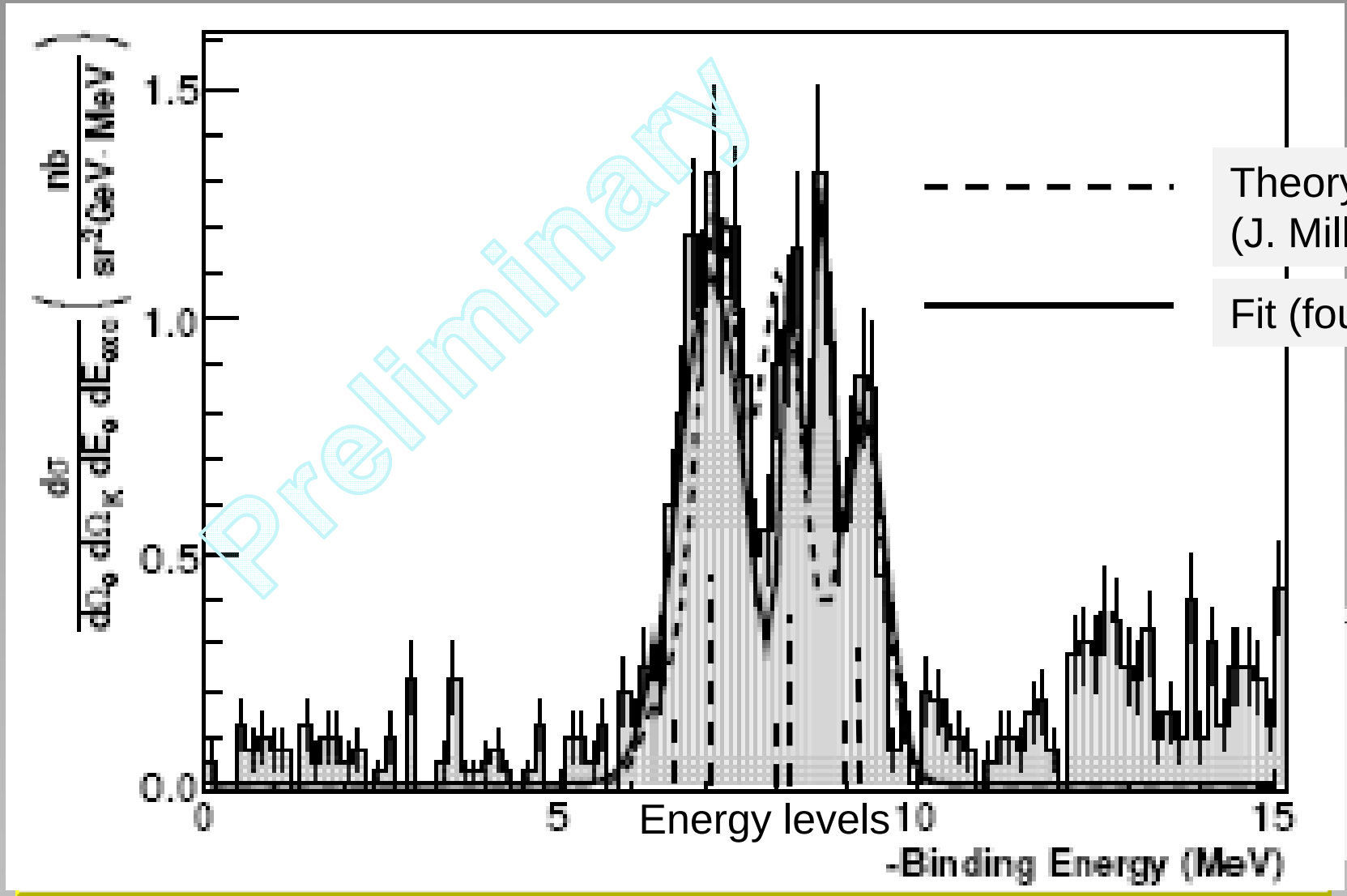
Curves are normalized on g.s. peak.

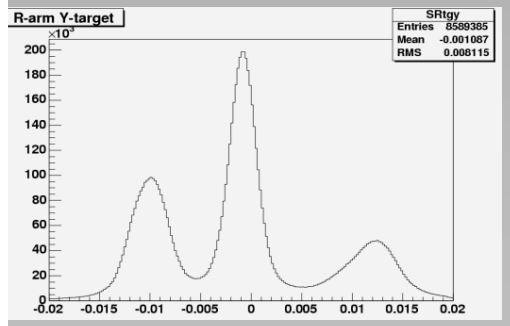


JLAB Hall A E-94107: Preliminary Results on ^{9}Be target



JLAB Hall A E-94107: Preliminary Results on ^{9}Be target





Conclusions:

- **Experiment E94-107 at Jefferson Lab: systematics study of light hypernuclei (shell-p)**
- **The experiment required important modifications on the Hall A apparatus**
- **Good quality data on ^{12}C, ^{9}Be and ^{16}O targets (^{12}B$_\Lambda$ and ^{9}Li$_\Lambda$ and ^{16}N$_\Lambda$)**
- **New experimental equipments showed excellent performances**
- **The RICH detector performed as expected and it is crucial in the kaon selection**
- **Experiment E07-012 on angular dependence of ^{16}O(e,e'K)^{16}N$_\Lambda$ scheduled in Hall A on Spring 2012**
- **Joined Hall A / Hall C hypernuclear-spectroscopy program is important part of the 12-GeV program at Jefferson Lab**

Acknowledgements

Thanks to:

- **Hyp-X Organizers, and O. Hashimoto and F. Garibaldi for their kind invitation**
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- **finally**

THANK YOU for your attention!