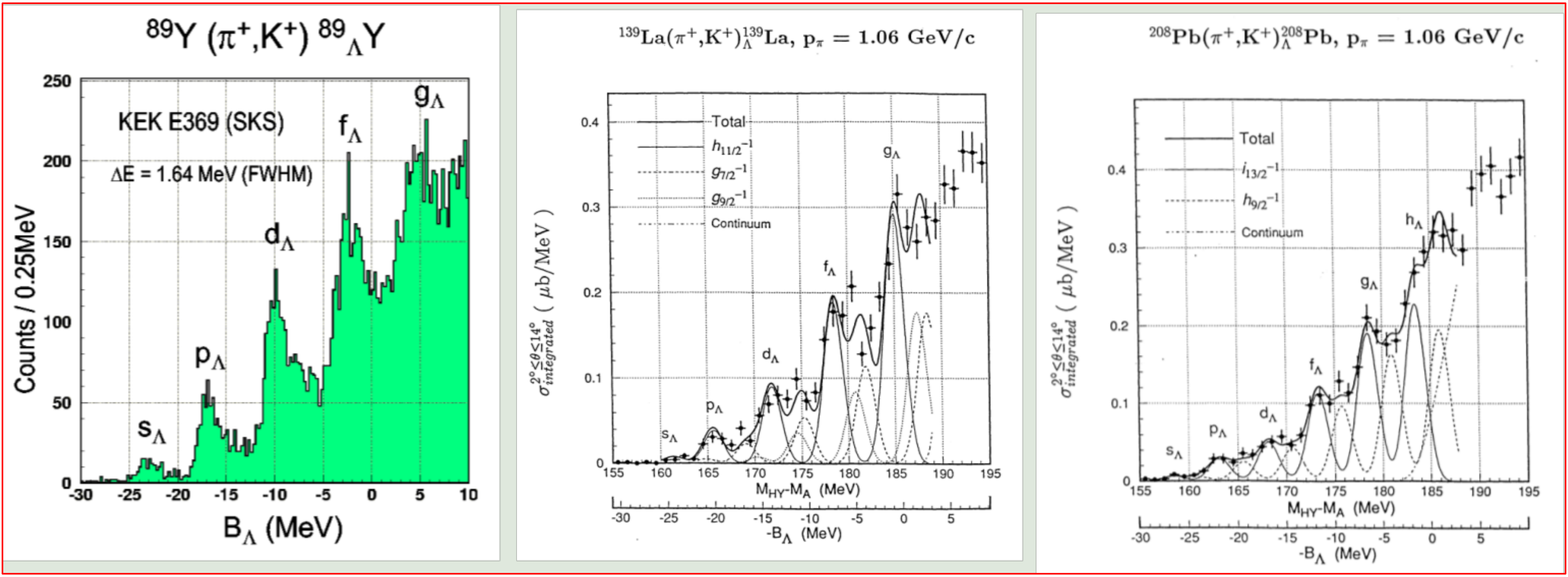
Hyperon in heavy nuclei $^{208}(e,e'K^+)^{208}{}_{\Lambda}Ti$

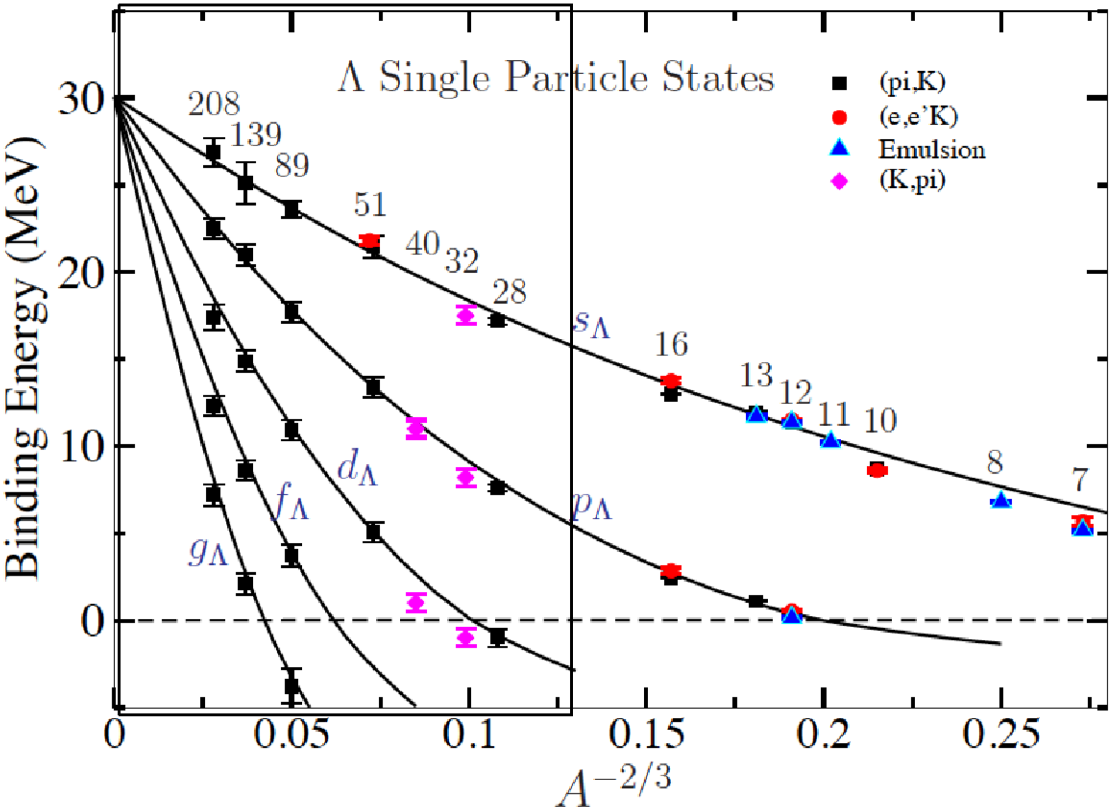
F. Garibaldi – Jlab workshop 15 March 2016



✔(e,e'K) reaction can do much better (a factor of 3 in energy resolution)

Energy resolution → Much more precise Λ single particle energies. Complementarity with (π,k) reaction

Update: Millener, Dover, Gal PRC 38, 2700 (1988)

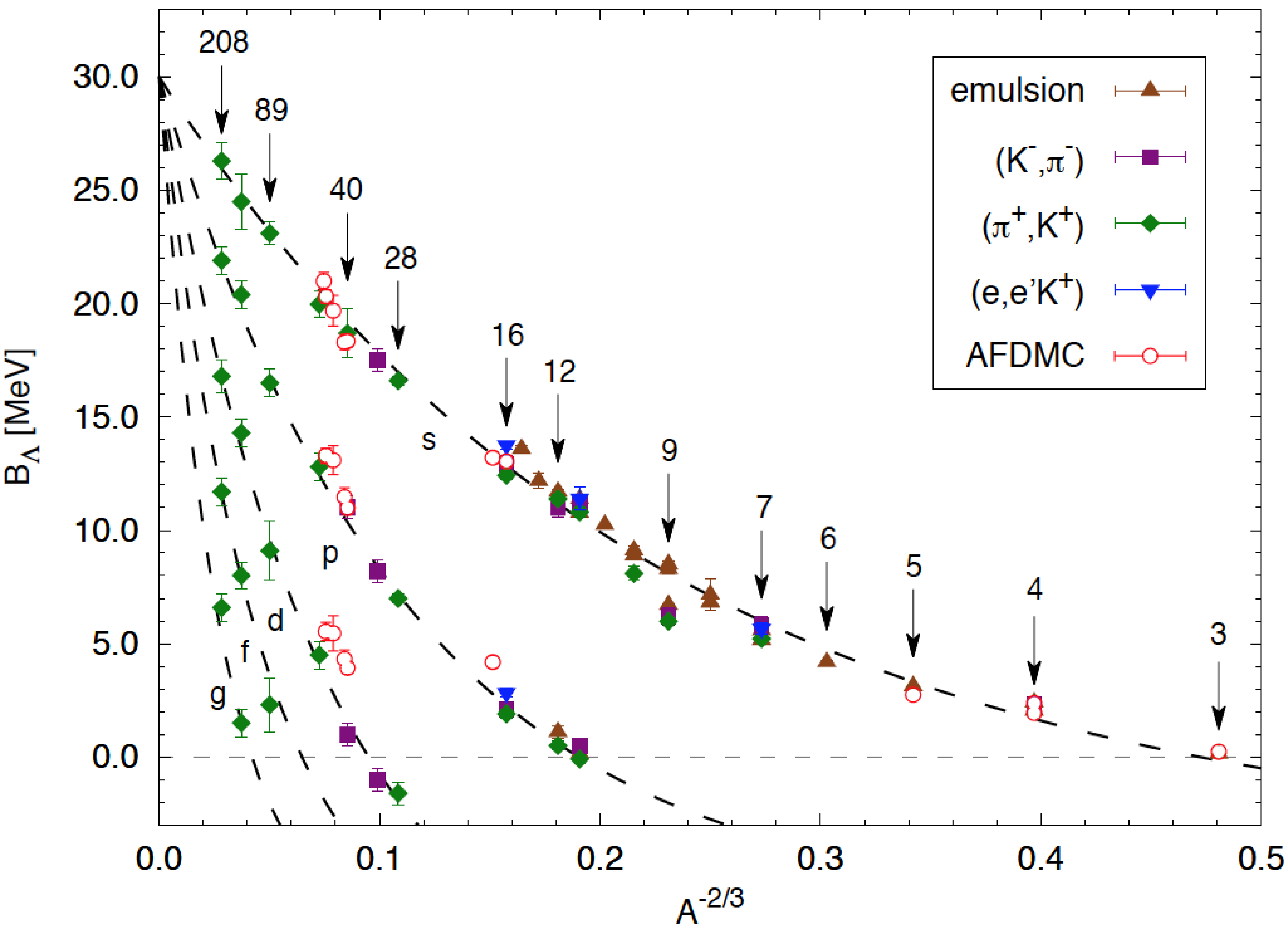


Woods-Saxon $V = 30.05$ MeV, $r = 1.165$ fm, $a = 0.6$ fm

Data to be shifted by 0.54 MeV

Do all data in medium to heavy mass region need this correction ?

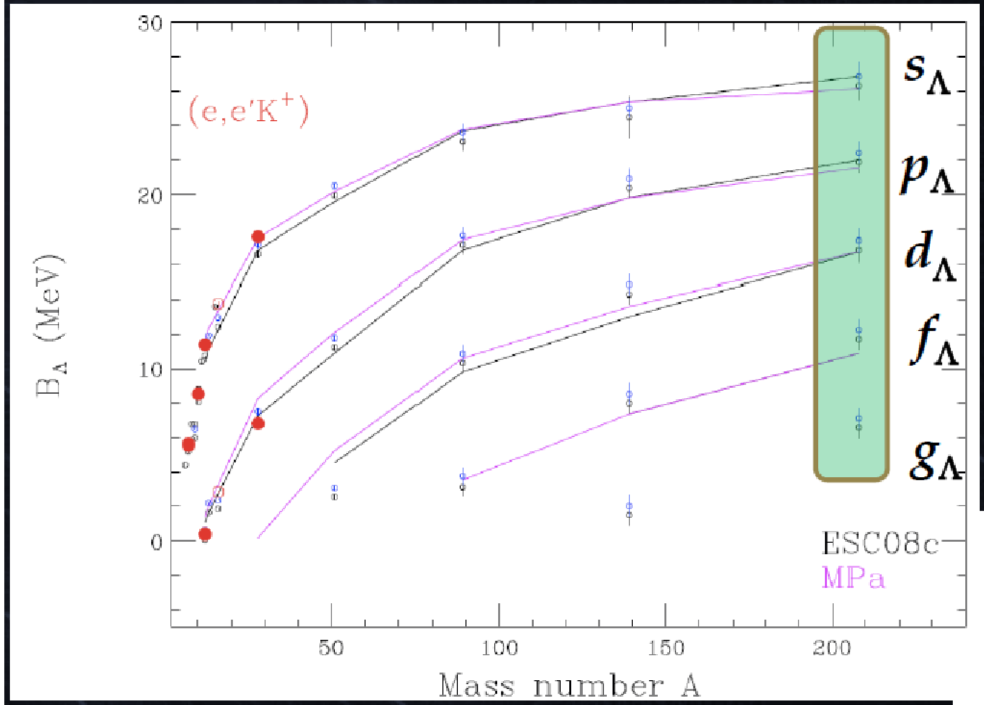
To be confirmed by (e,e'K) experiments

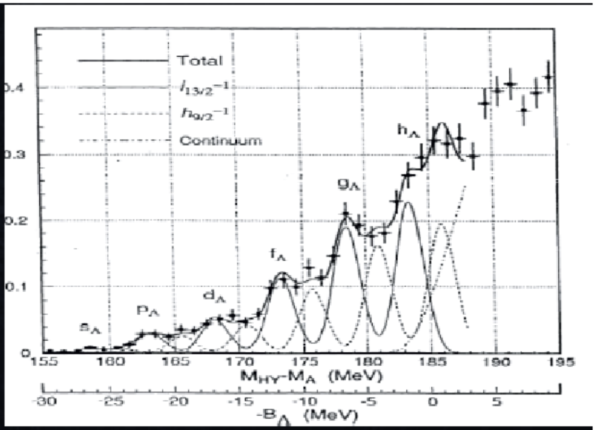

208
89
40
28
16
12
9
7
6
5
4
3
s
p
d
f
g
emulsion
(K⁻,π⁻)
(π⁺,K⁺)
(e,e'K⁺)
AFDMC
B_Λ [MeV]
A^{-2/3}
0.0
5.0
10.0
15.0
20.0
25.0
30.0
0.0
0.1
0.2
0.3
0.4
0.5

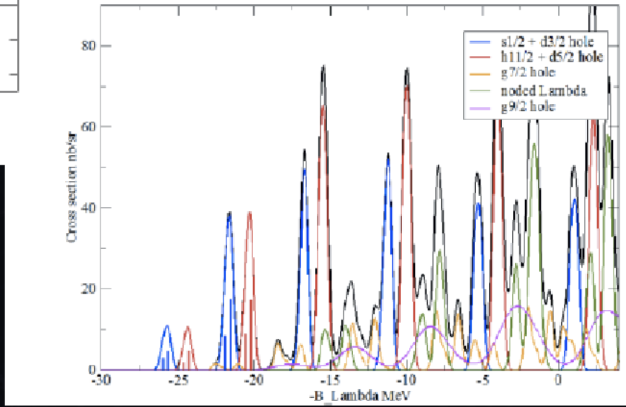
No scattering data exist in the YY sector (a ΣN scattering experiment is currently in preparation at J-PARC)

Therefore, the realistic YN interaction models use the measured binding energies of hypernuclei as constraints

Mass dependence of B_Λ







Lines: Calc. by Yamamoto & Rijken

Nijmegen ESC08c : Commonly used realistic YN

MPa : ESC08c + 3B/4B RF

Millener-Motoba calculations

- particle hole calculation, weak-coupling of the Λ hyperon to the hole states of the core (i.e. no residual Λ-N interaction).

- Each peak does correspond to more than one proton-hole state

- Interpretation will not be difficult because configuration mixing effects should be small

- Comparison will be made with many-body calculations using the Auxiliary Field Diffusion Monte Carlo (AFDMC) that include explicitely the three body forces.

- Once the Λ single particle energies are known the AMDC can be used to try to determine the balance between the spin dependent components of the ΛN and ΛNN interactions required to fit Λ single-particle energies across the entire periodic table.

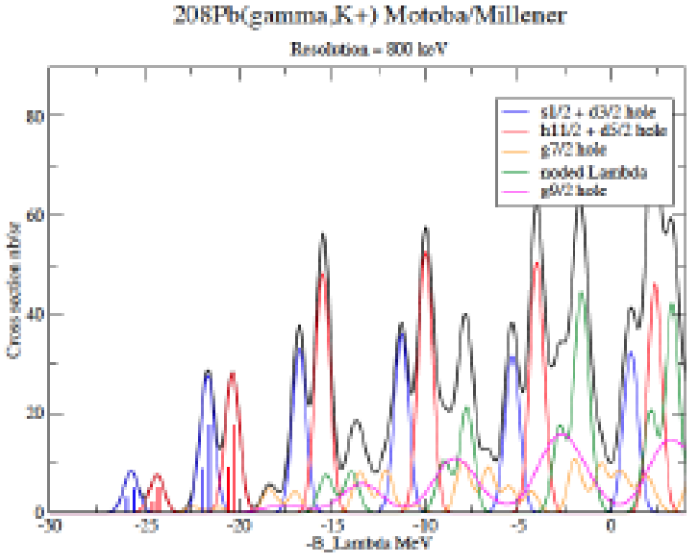


Fig. 5 a Excitation energy plot (Millener Motoba calculation (see text))

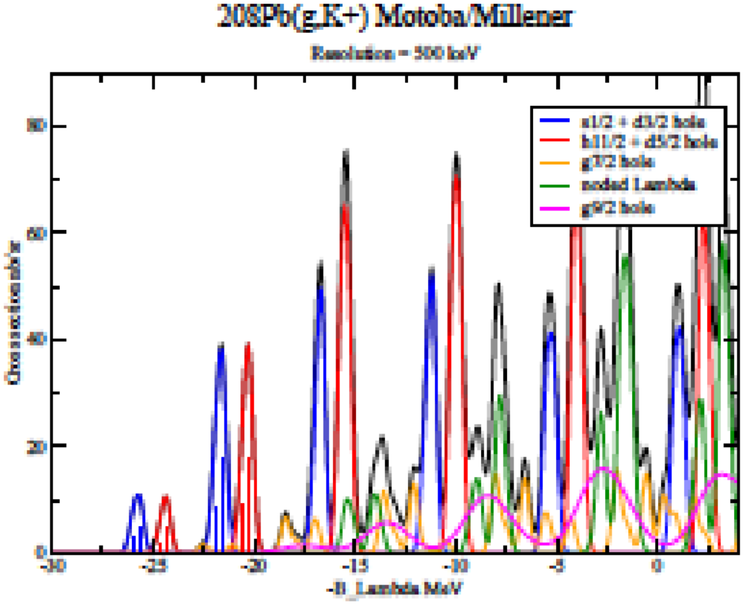


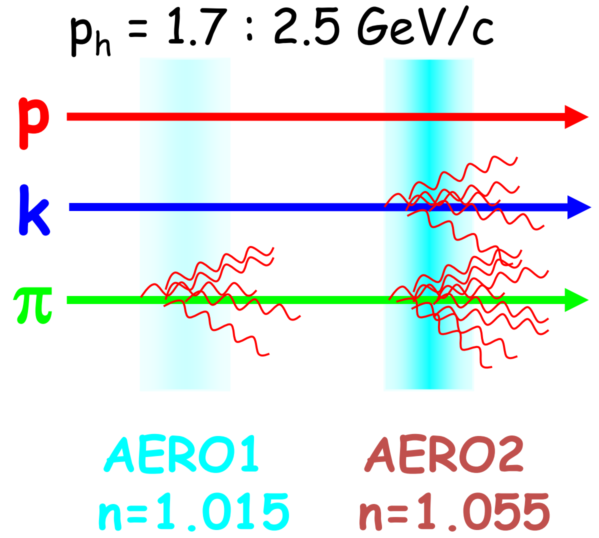
Fig. 5 b Excitation energy plot with 500 keV Energy Resolution

The PID Challenge

Very forward angle ---> high background of π and p

-TOF and 2 aerogel in not sufficient for unambiguous K identification !

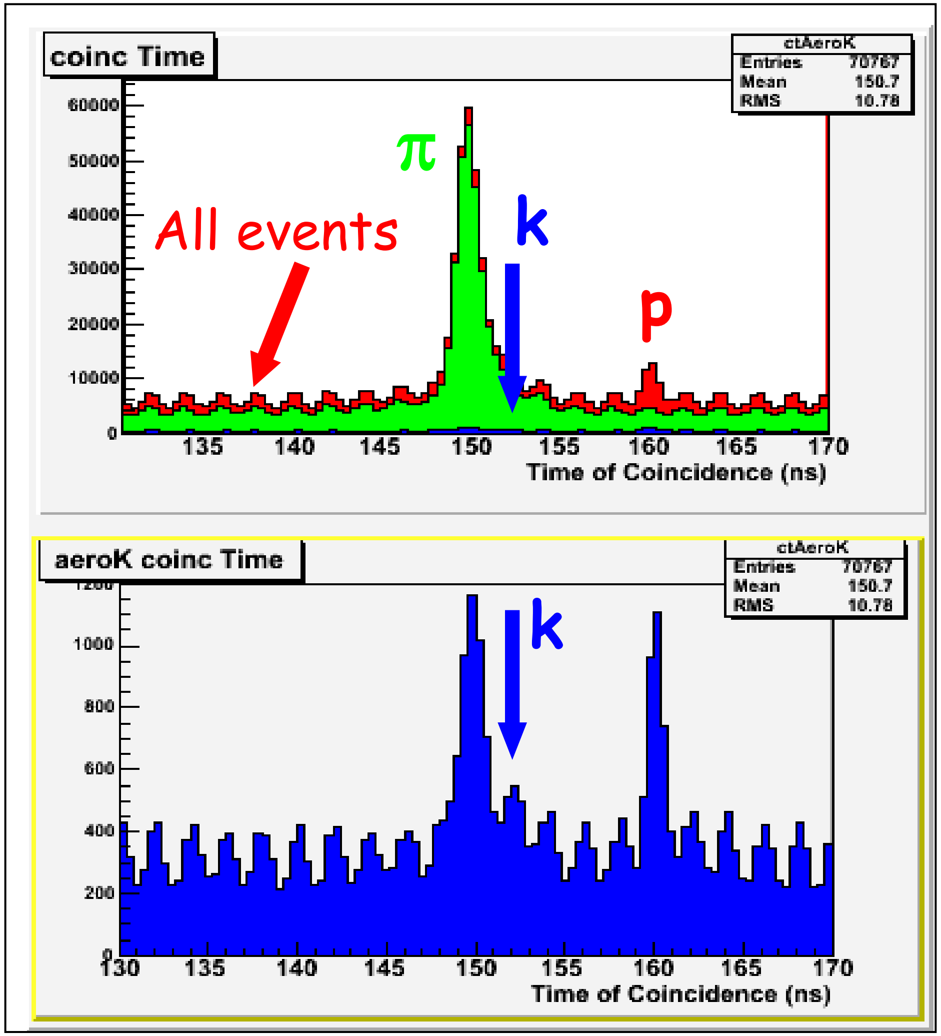
Kaon Identification through Aerogels



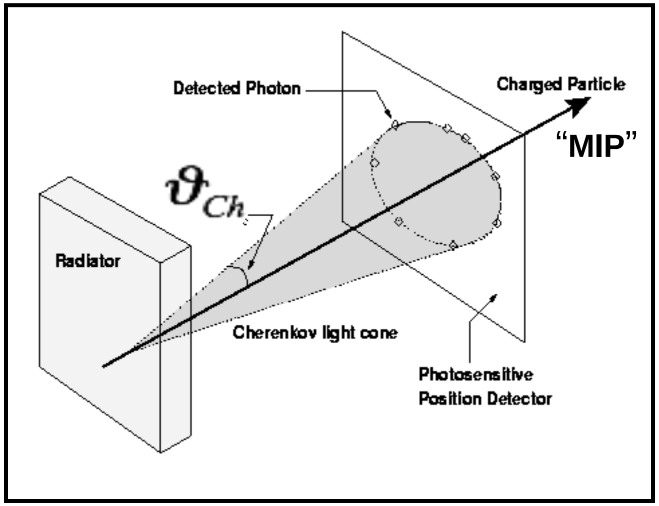
Pions = A1•A2

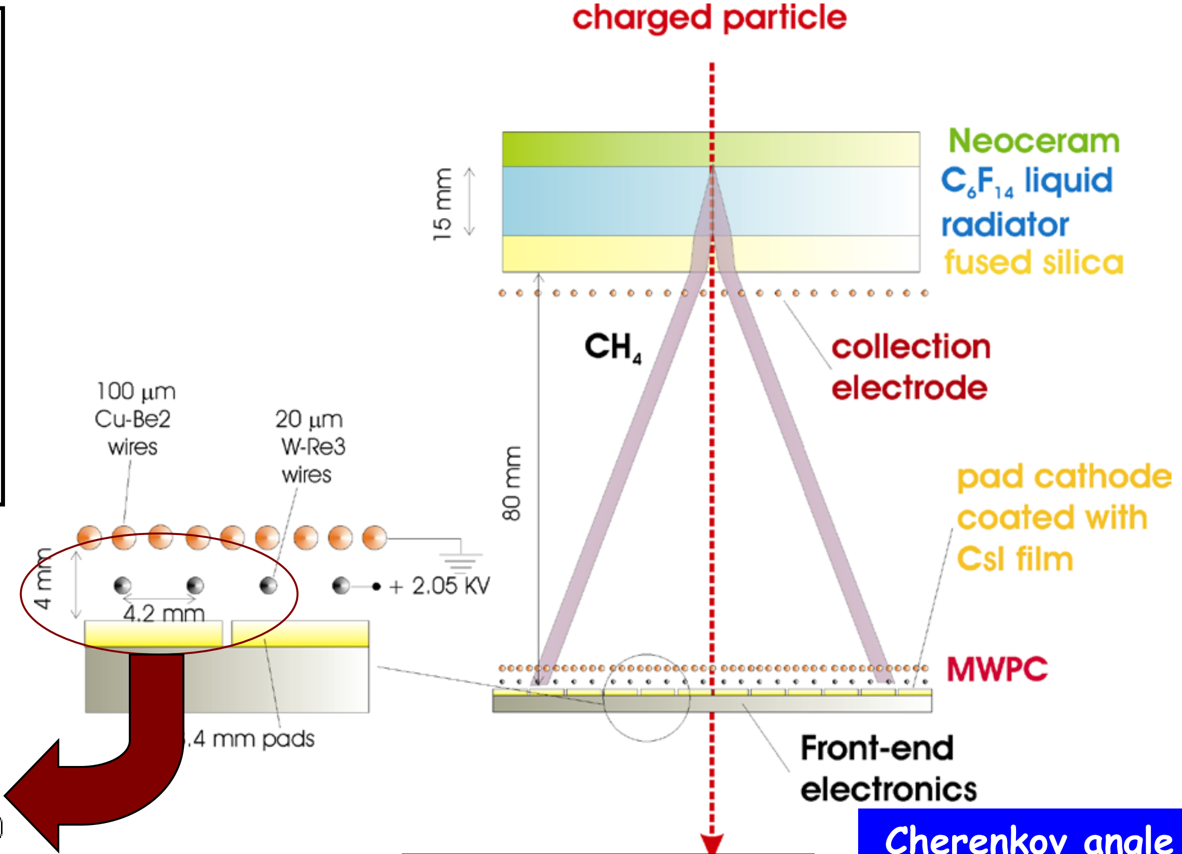
Kaons = $\overline{A1}$•A2

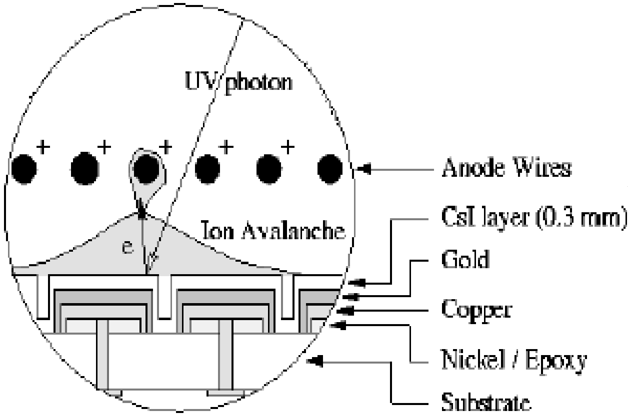
Protons = $\overline{A1}$•$\overline{A2}$



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







Separation Power

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

Cherenkov angle resolution

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

N. of detected photoelectrons

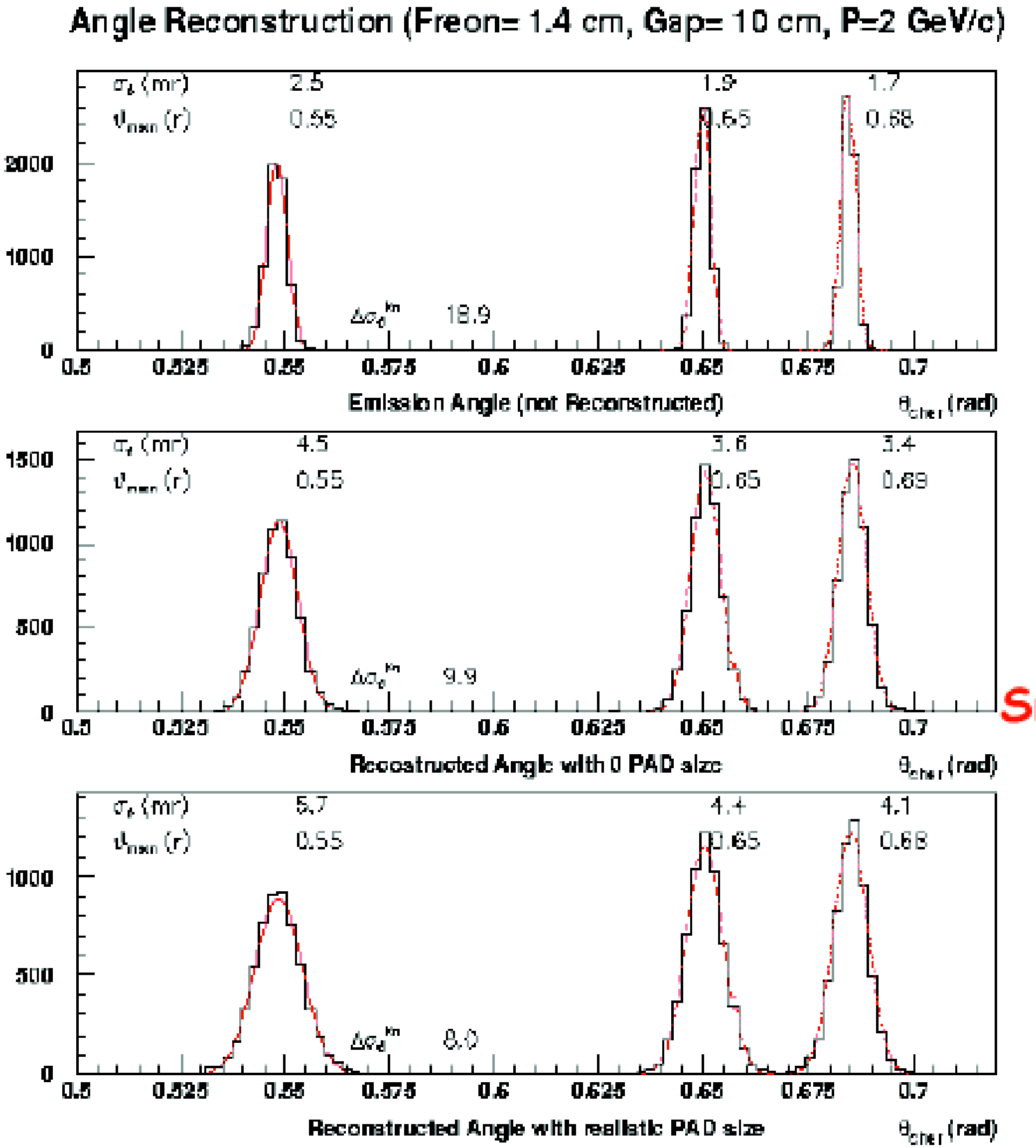
$$N_{p.e.} = 370 L \sin^2 \overline{\vartheta}_c \prod_i \varepsilon_i \Delta E \approx 20-50$$

Performances

- $N_{p.e.}$ # of detected photons(p.e.) ← maximize
- and σ_θ (angular resolution) ← minimizee

N. of detected photoelectrons

$$N_{p.e.} = 370 L \sin^2 \overline{\vartheta_c} \prod_i \varepsilon_i \Delta E \approx 20-50$$



Angle Reconstruction (Freon= 1.4 cm, Gap= 10 cm, P=2 GeV/c)

Separation power

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

Particle mass m_1 **Particle mass m_2**

Cherenkov angle resolution

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

Minimize

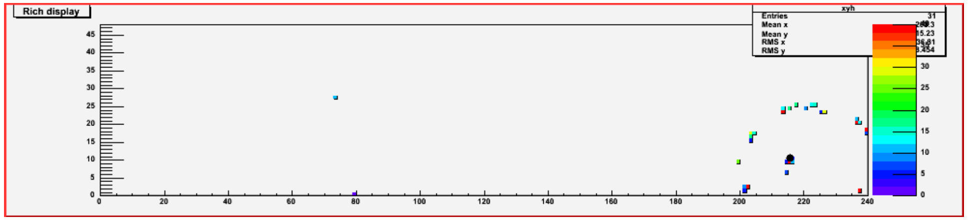
Maximize

π, K separated by 30 mrad

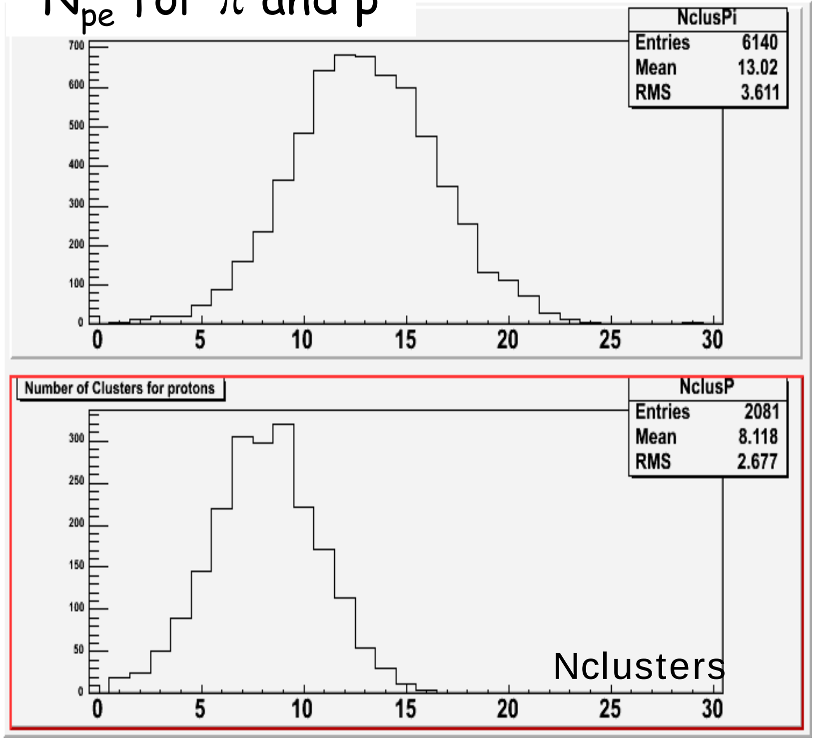
with 3 mrad: 10 σ

Simulation (spectra) done with 5 σ

Rich Performances 'key parameters':



N$_{pe}$ for π and p

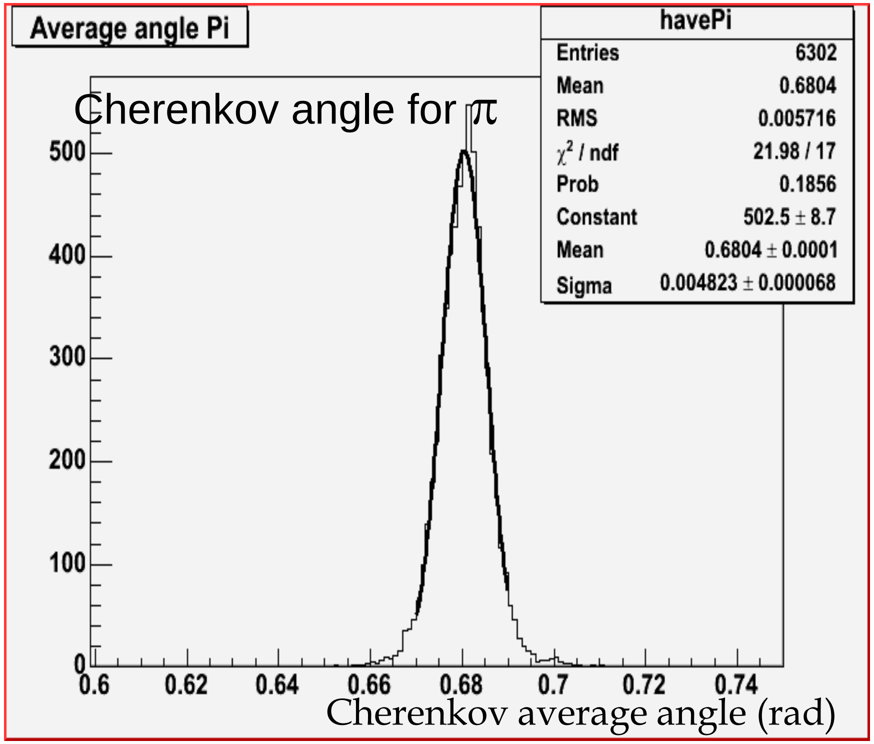


N$_{pe}$ π/p ratio:

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

Mean number of photoelectrons

$$N_\pi = 13$$



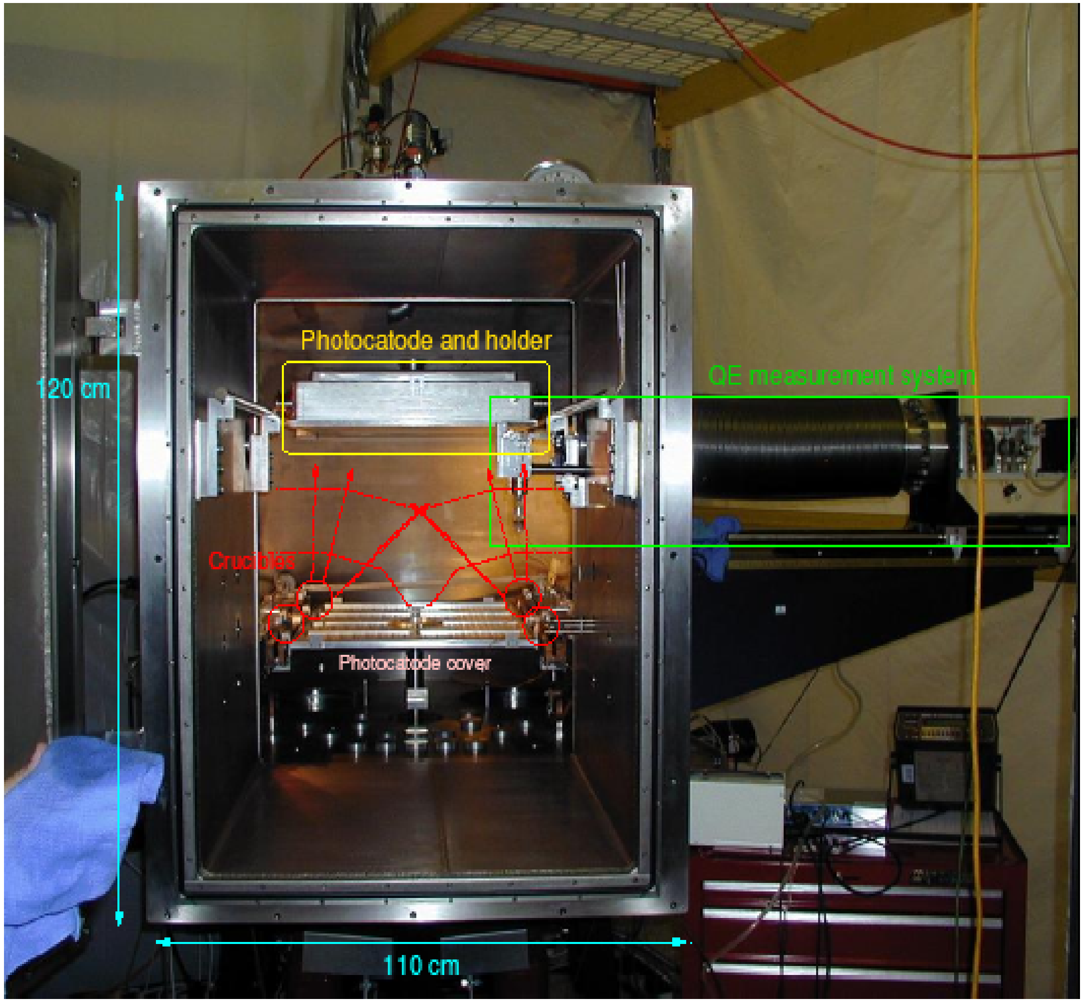
Angular resolution

$$\sigma_{\theta_\pi} = 5 \text{ mrad}$$

$$\Downarrow$$

$$\theta_\pi - \theta_K \sim 6 \cdot \sigma_{\theta_\pi}$$

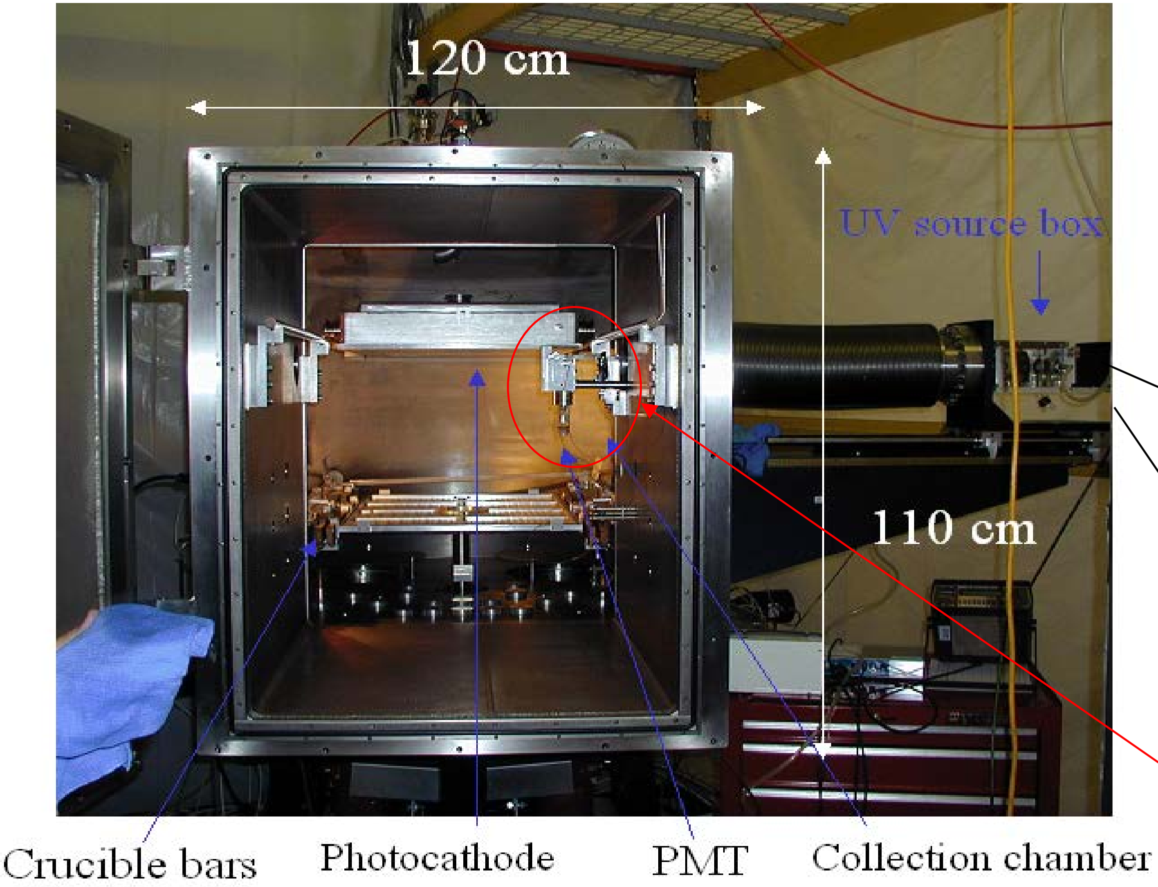
Evaporation Facility for large area photocathode



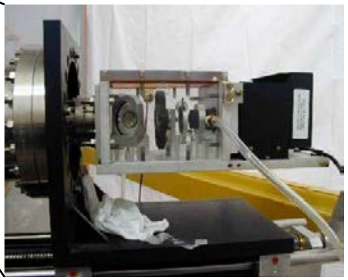
- Stainless steel cylindrical vessel
- 3 pumps (scroll + molecular + cryogenic) provide vacuum of $5 \cdot 10^{-7}$ mbar in < 24 h
- 4 crucibles → thickness uniformity $\sim 10\%$
- CsI powder (from CERN) evaporated at ~ 500 ^{o}C

Evaporation station is temporary moved to Stony Brook University (Long Island) for R&D on GEM

The evaporator system



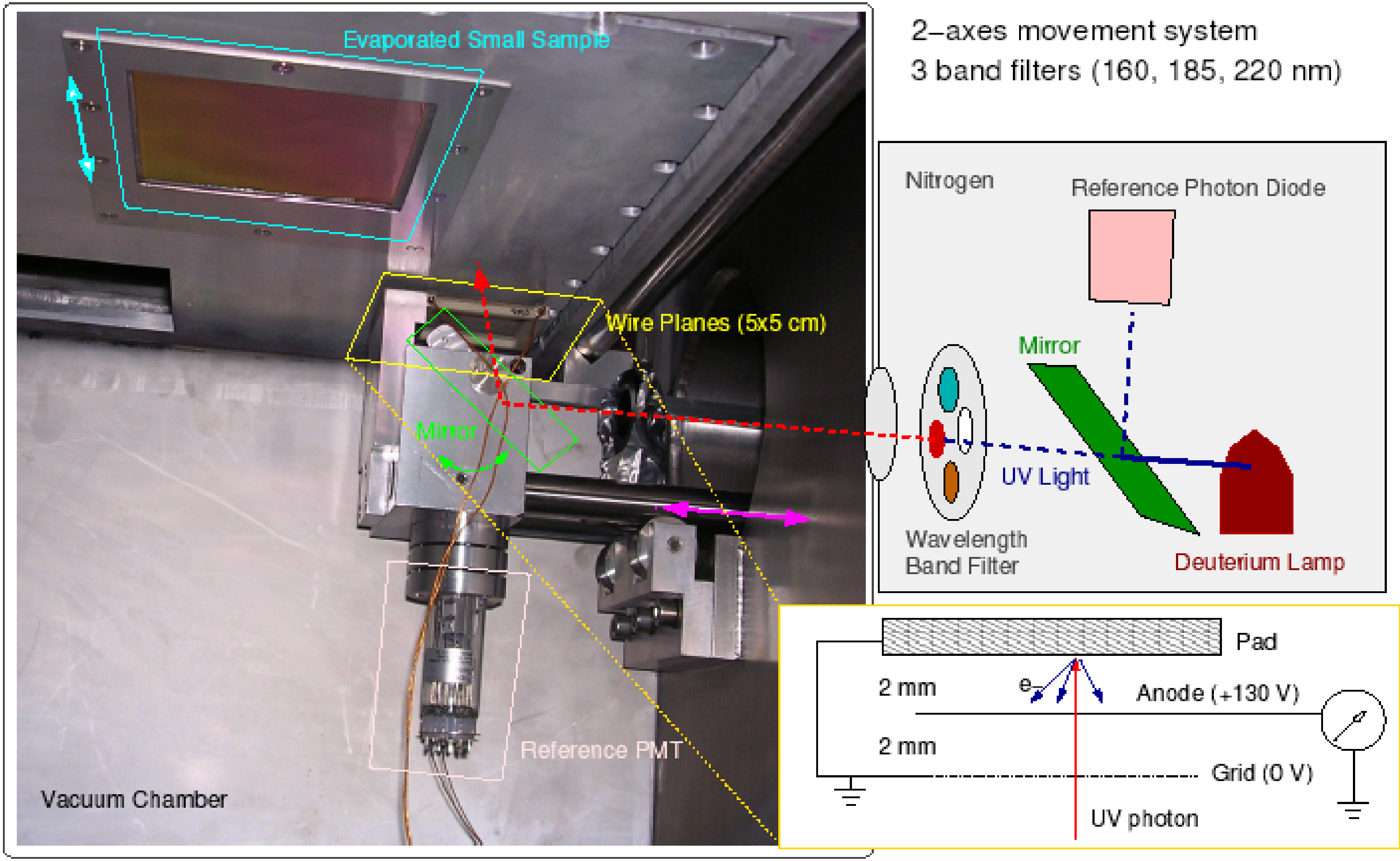
UV source and optical system



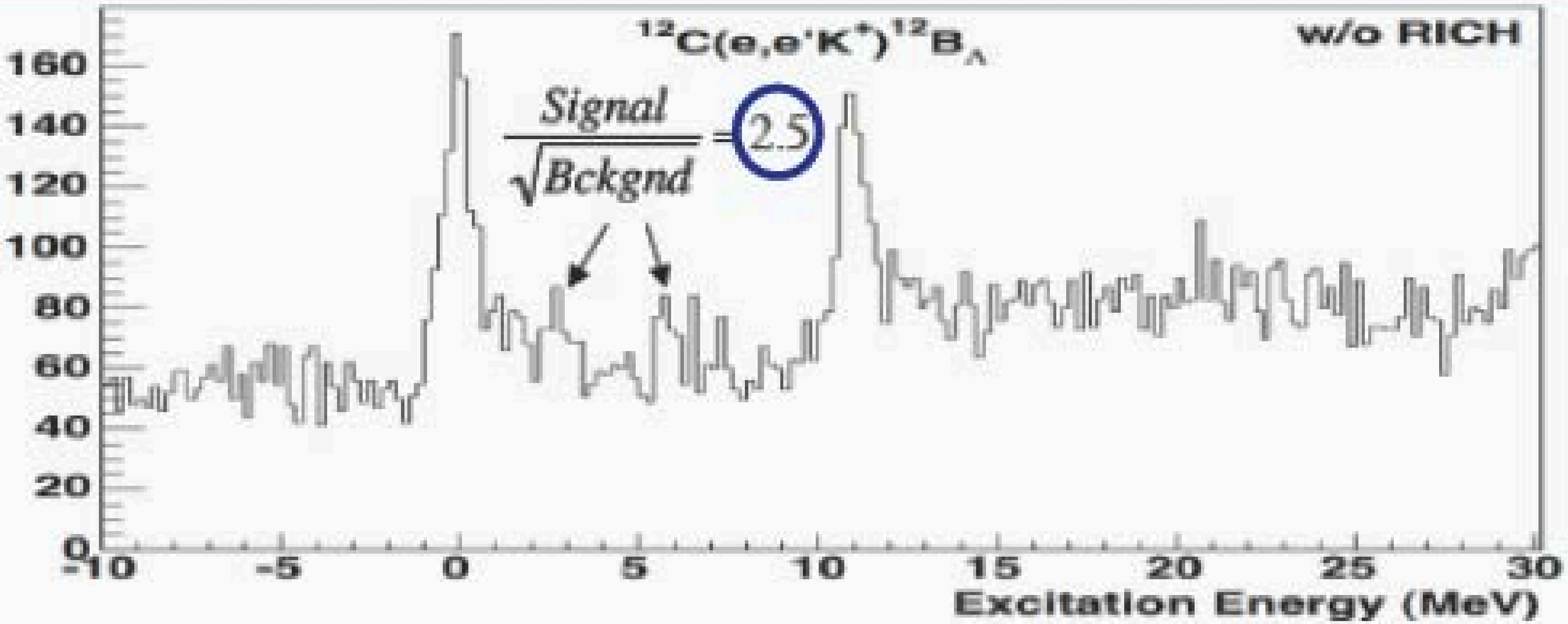
Quantum Efficiency measurement system

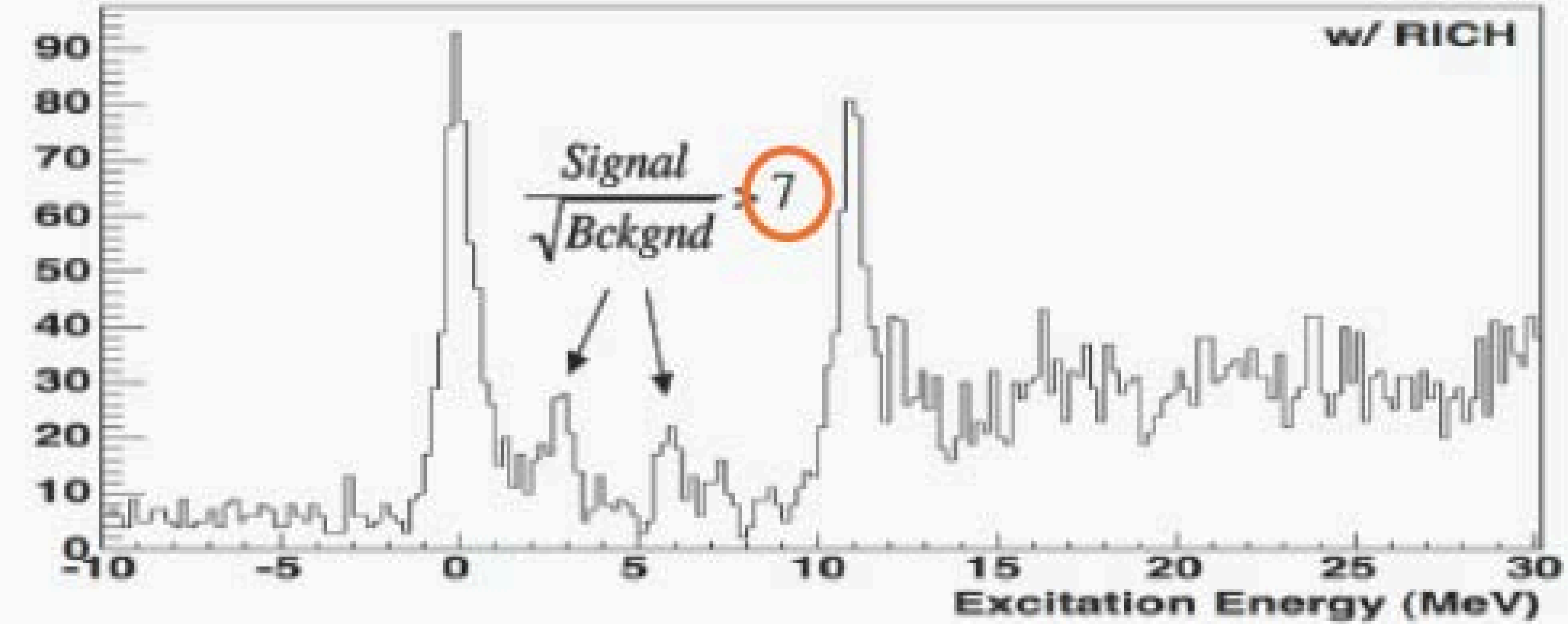
2–axes movement system

3 band filters (160, 185, 220 nm)

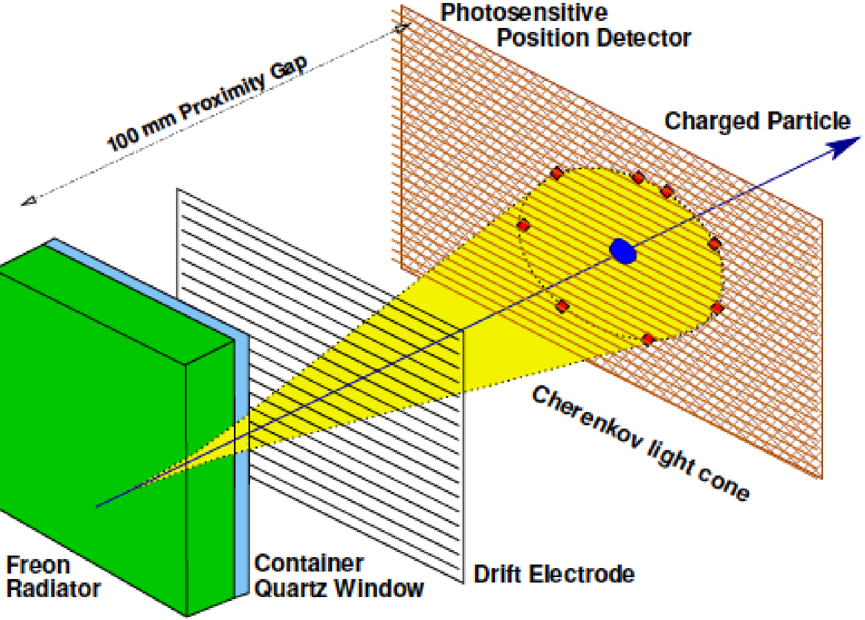


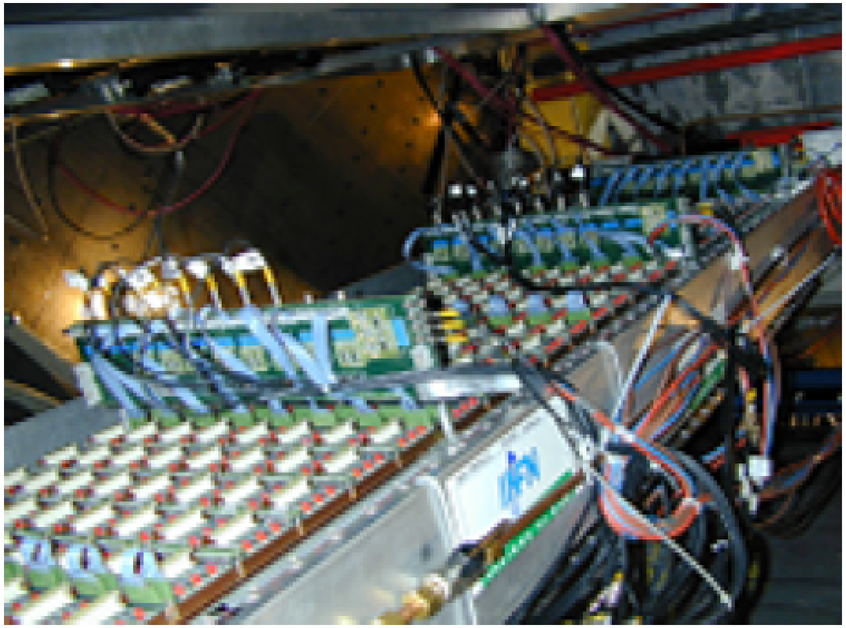
$$QE = \frac{I_{chamber}}{I_{PMT}} \cdot QE_{PMT}$$


$^{12}C(e,e'K^+)^{12}B_\Lambda$
w/o RICH
$\frac{Signal}{\sqrt{Bckgnd}}$ = 2.5
160
140
120
100
80
60
40
20
0
-10
-5
0
5
10
15
20
25
30
Excitation Energy (MeV)


w/ RICH
$\frac{Signal}{\sqrt{Bckgnd}}$ = 7
90
80
70
60
50
40
30
20
10
0
-10
-5
0
5
10
15
20
25
30
Excitation Energy (MeV)

π/K PID: Proximity Focusing RICH





Radiator	15 mm thick Liquid Freon (C_6F_{14}, n=1.28)
Photon converter	300 nm CsI film coated on Pad Planes
Position Detector	1940×403 mm^2 - Multi Wire/Pad Proportional Chamber filled with Methane at STP, HV= $1050 \div 1100$ V
FE Electronics	11520 analog chs, multiplexed S&H

Successfully operated at 2 GeV/c in Hypernuclear Experiment with

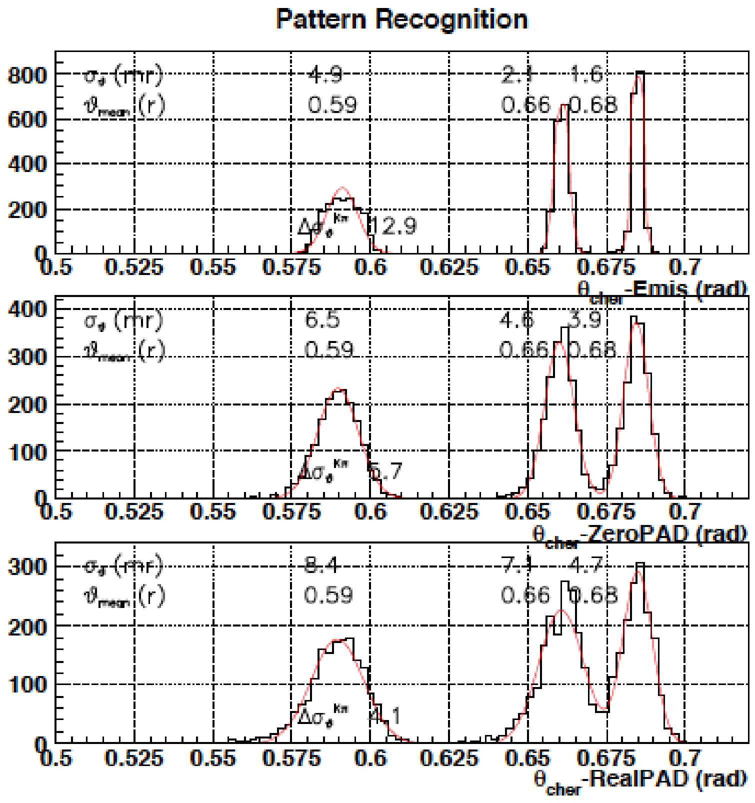
π/K rejection $<$ 1:1000

RICH upgrade for 2.4 GeV/c

- add a inox frame spacer to increase the proximity gap of ∼ 2 cm

GEANT3 MonteCarlo prediction, normalized to Hypernuclear Experiment data

$n_\sigma \sim 4.1 \Rightarrow \pi : K \sim 1 : 140$



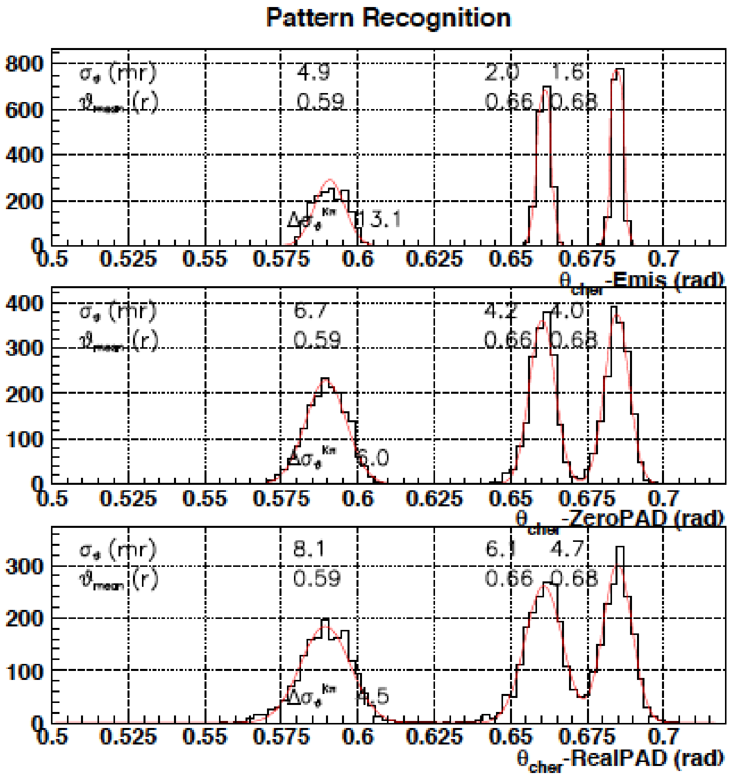
RICH upgrade for 2.4 GeV/c

- add a inox frame spacer to increase the proximity gap of ~ 2 cm
- move closer to the VDC (from 280 cm to ~ 170 cm)

GEANT3 MonteCarlo prediction, normalized to Hypernuclear Experiment data

$n_\sigma \sim 4.4 \Rightarrow \pi : K \sim 1 : 500$

better light collection (smaller charge particle phase-space)
compatibility with A1 and A2 to be confirmed



RICH upgrade for 2.4 GeV/c

- add a inox frame spacer to increase the proximity gap of ∼ 2 cm
- move closer to the VDC (from 280 cm to ∼ 170 cm)
- new radiator: use a lower refractive index (C_5F_{12})

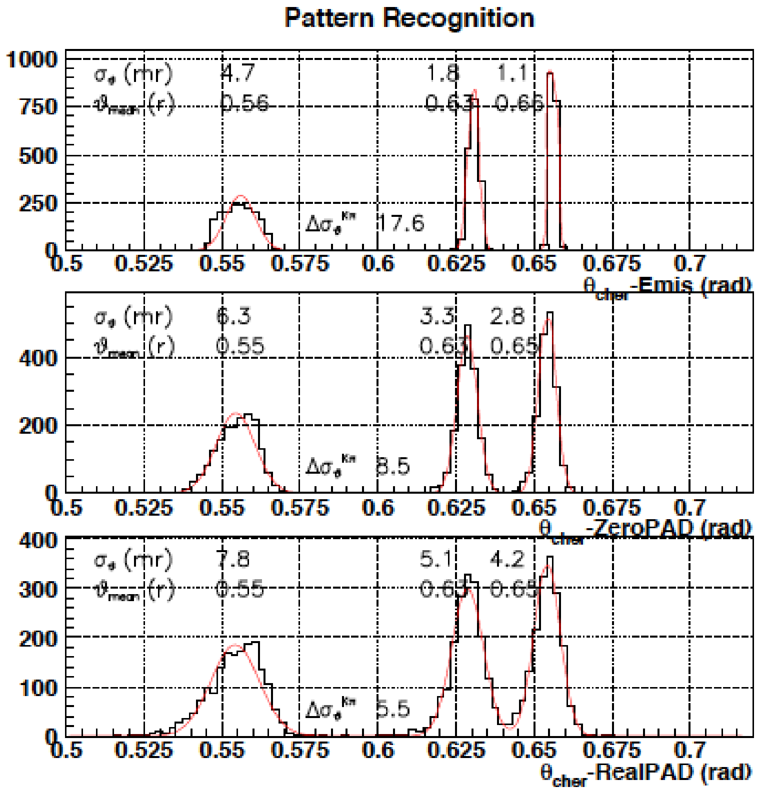
GEANT3 MonteCarlo prediction, normalized to Hypernuclear Experiment data

$n_\sigma \sim 5.5 \Rightarrow \boxed{\pi : K \sim 1 : 1000}$

C_5F_{12} boils at 30°C

cooling system required

this is the current direction of the upgrade



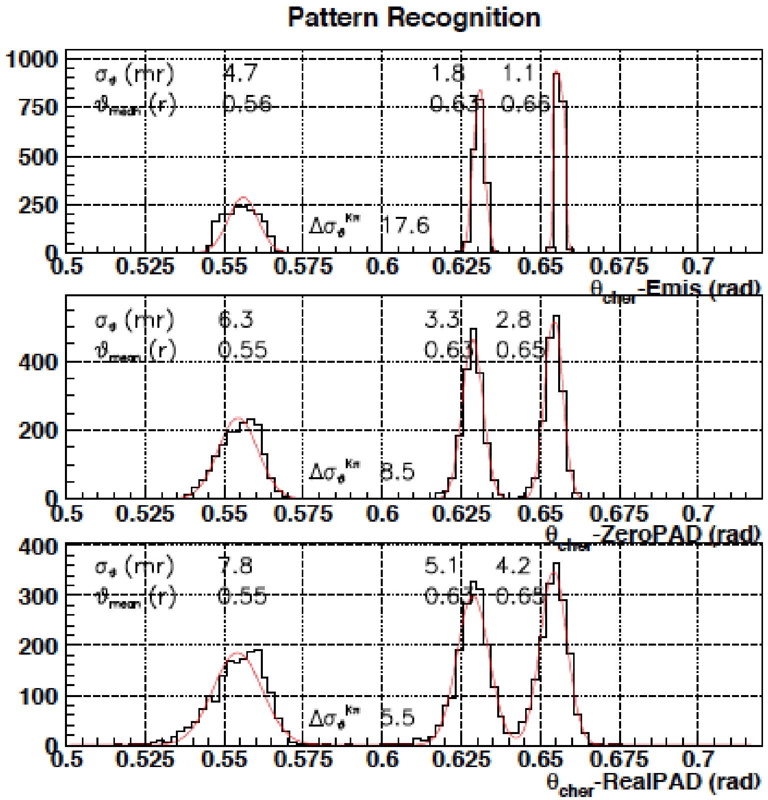
RICH upgrade for 2.4 GeV/c

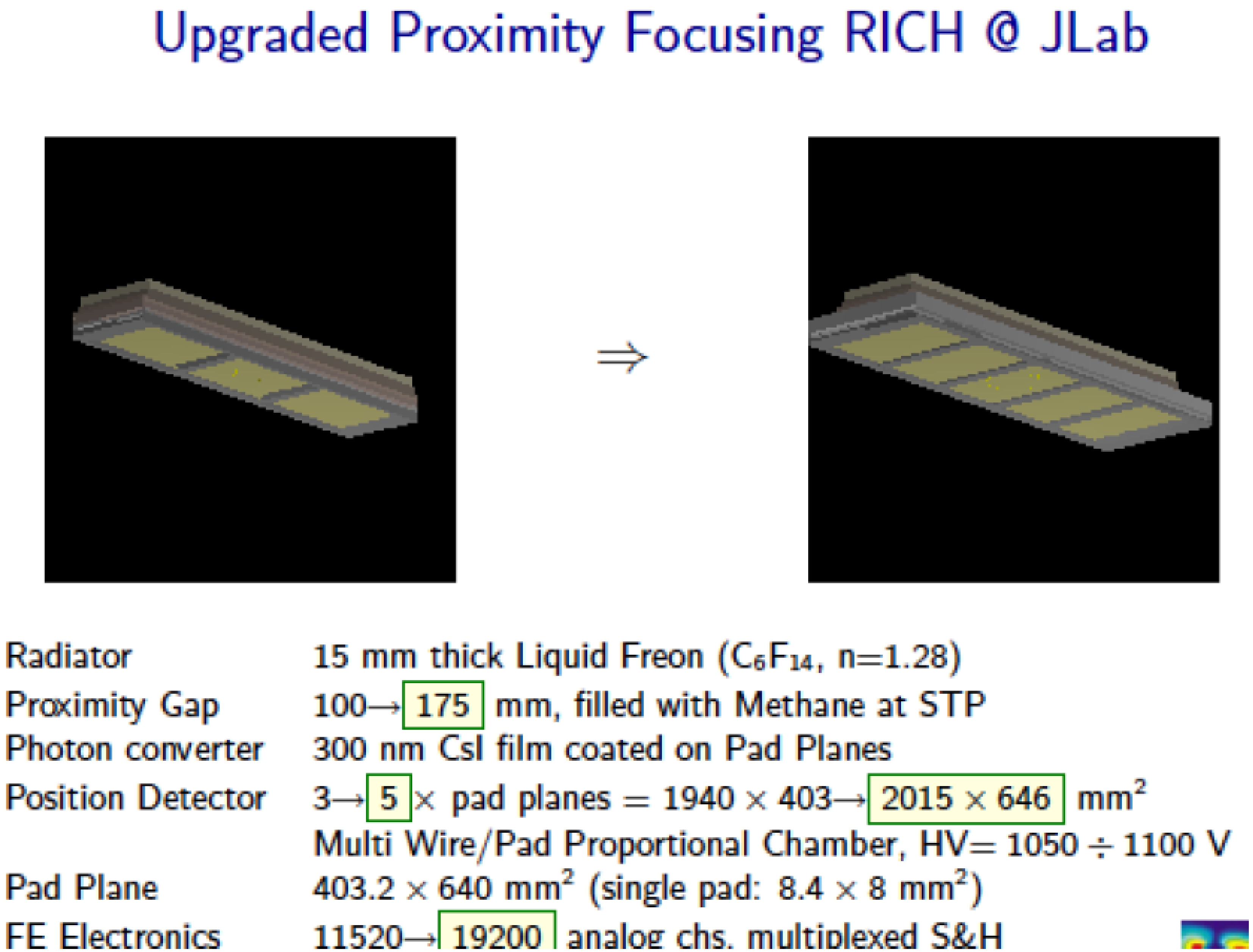
- add a inox frame spacer to increase the proximity gap of ∼ 2 cm
- move closer to the VDC (from 280 cm to ∼ 170 cm)
- new radiator: use a lower refractive index (C_5F_{12})
- other options considered but rejected (cost/performance)

GEANT3 MonteCarlo prediction, normalized to Hypernuclear Experiment data

$n_\sigma \sim 5.5 \Rightarrow \boxed{\pi : K \sim 1 : 1000}$

C_5F_{12} boils at 30°C
cooling system required
this is the current direction of the upgrade





Upgraded Proximity Focusing RICH @ JLab

⇒

Radiator	15 mm thick Liquid Freon (C_6F_{14}, n=1.28)
Proximity Gap	100→ $\boxed{175}$ mm, filled with Methane at STP
Photon converter	300 nm CsI film coated on Pad Planes
Position Detector	3→ $\boxed{5}$ × pad planes = 1940 × 403→ $\boxed{2015 \times 646}$ mm^2
	Multi Wire/Pad Proportional Chamber, HV= 1050 ÷ 1100 V
Pad Plane	403.2 × 640 mm^2 (single pad: 8.4 × 8 mm^2)
FE Electronics	11520→ $\boxed{19200}$ analog chs. multiplexed S&H

Fig. 9. Old and new upgrated RICH layout

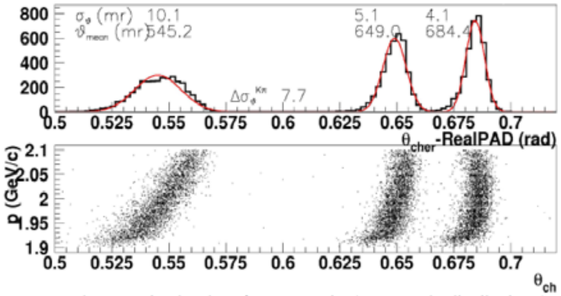


Fig. 11. Upgrated RICH simulated performance. Pion/Kaon angle distribution (equal hadrons populations) at 2 GeV/c momentum, in the HRS acceptance. The Mcarlo is tuned on Hall A hypernuclear experimental data.

In Fig. 9 we show the old and new (upgrated) layout. The photon detection plane was doubled (3 more pad panels added). This would have allowed the detectors to separate kaons, in the E-94-107 kinematical conditions (at a kaon momentum ~ 2 GeV/c) with a higher rejection ratio, an additional ~ 1.5 sigma (Fig.10,11) corresponding to a pion:kaon rejection better than 1:10000 at 2.0 GeV/c, with improved efficiency.

In our experiment the central momentum of the detected kaons will be 1.2 GeV/c. For this reason even better performances to separate kaons from pions will be obtained. Easy calculation [37] bring to ~ 7.8 sigma the pion – kaon separation angle. Adding, conservatively 1.5 sigma, we would obtain a separation ~ 9.3 sigma. This would correspond, assuming a factor ~ 100 for pion-kaon particle population, to a ~ 10^6 power rejection

Convoluting the threshold Cherenkov and the RICH power rejection we would have a pion-kaon power rejection ~ 10^{12}

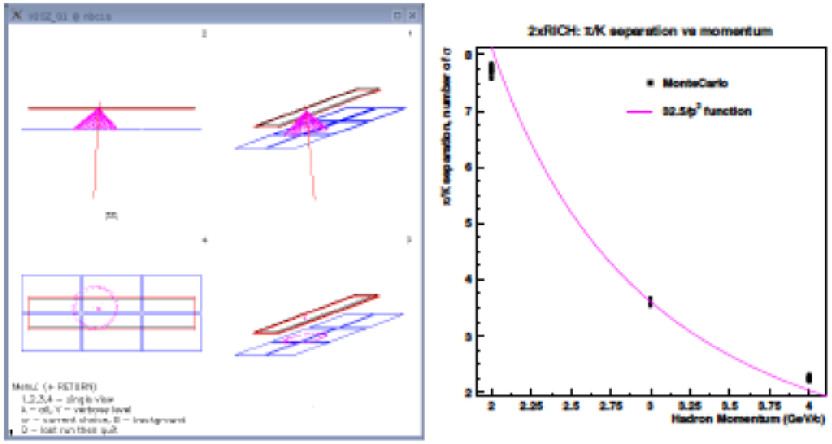


Fig. 10 Upgraded RICH simulation events (left panel) and expected performance (right panel): pion-kaon separation (number of sigmas) at different hadron momenta. The simulation is tuned to the E-94-107 hypernuclear experimental data.

Target

a. A 0.5 mm of Lead has to be sandwiched between two 0.15 mm of diamond that is pure ^{12}C as don by the PREX experiment [31] (see Fig. 6). This would allow us to run with ~ 70 µA on a 100 mg/cm^2 (or thicke but degradation of energy resolution would happen). The major drawback of this option would be the Excitatio Energy spectrum highly contaminated by the Carbon spectrum.

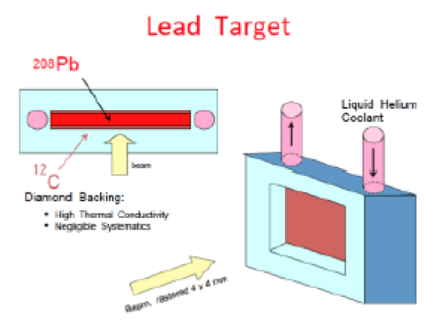
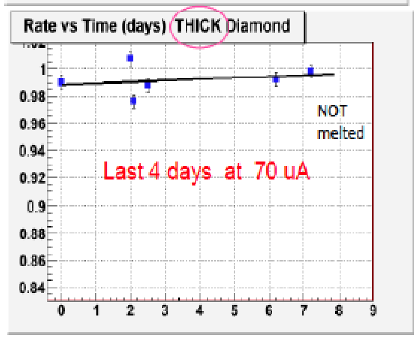


Fig. 6. The PREX Lead target.



Performance of one of the PREX targets

b. The setup used at NIKHEF for (e,e'p) experiment [Ref. 6, and C. Marchand, personal communication]. This would allow us to run safely with 10 µA of beam current and 100 mg/cm2 (or thicker) of pure ^{208}Pb target

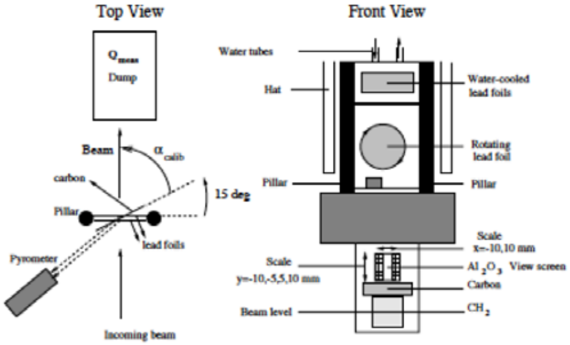
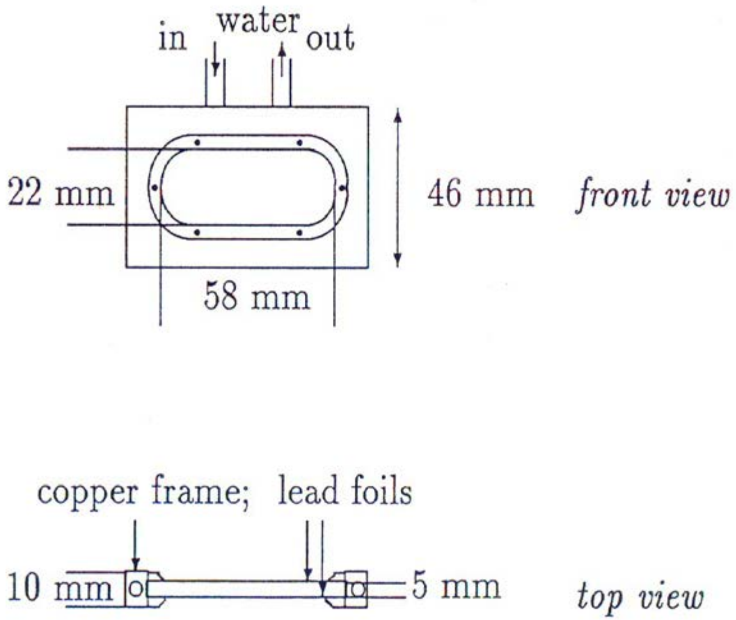


Fig. 7 The NIKHEF ^{208}Pb target layout

Nikhef target

Water - 15^{o} - 60—70 l/h



Heath transfer calculation show that the conduction cooling becomes competitve as compared to increase radiation cooling by rotating the target for thick target

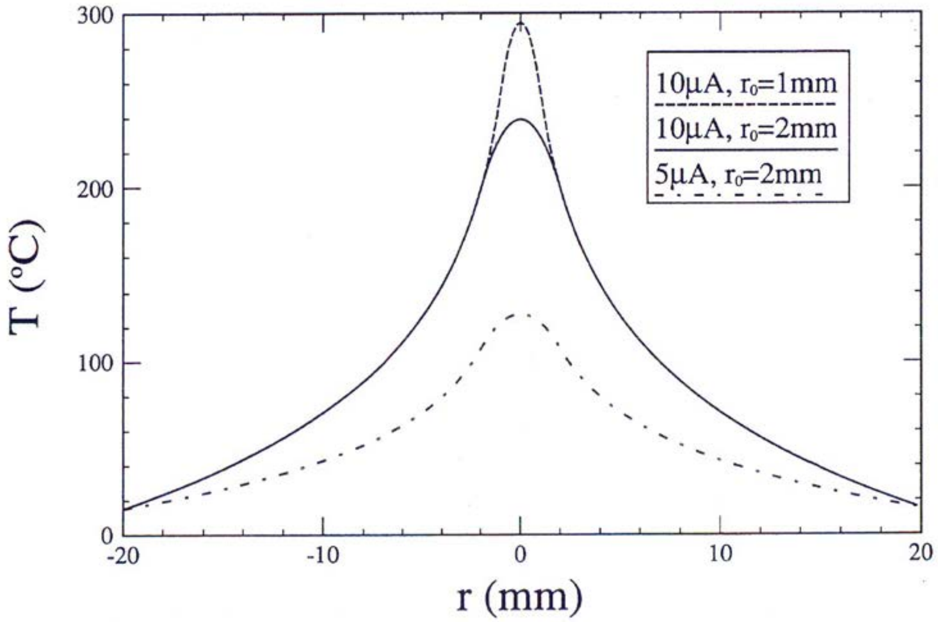
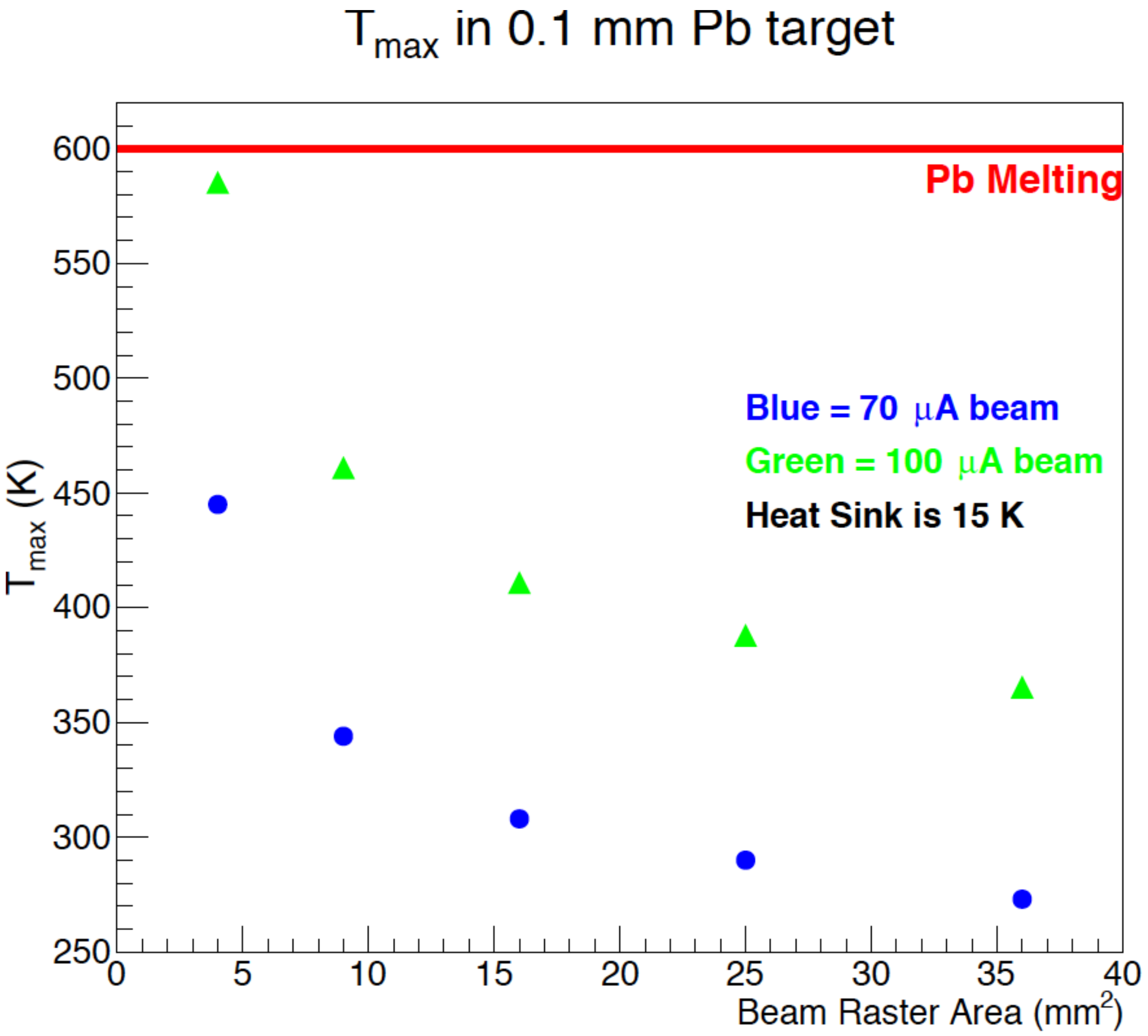


Fig. 2. *Temperature profile of a circular water cooled lead target of radius 20 mm. The dashed curve corresponds to a 10 µA beam spot of 1 mm radius, the solid curve to a 10 µA beam spot of 2mm radius and the dot-dashed curve to a 5 µA beam spot of 2mm*

For our experiment we plan to use cryogenic fluid to cool the target. The maximum current one can use without melting the target can be calculated by the formula

$$< i_{max} > = 2\pi k\,(T_{melting} - T_0)/\{[\ln(r_1/r_0) + \tfrac{1}{2}]\,\rho dE/dx\}$$

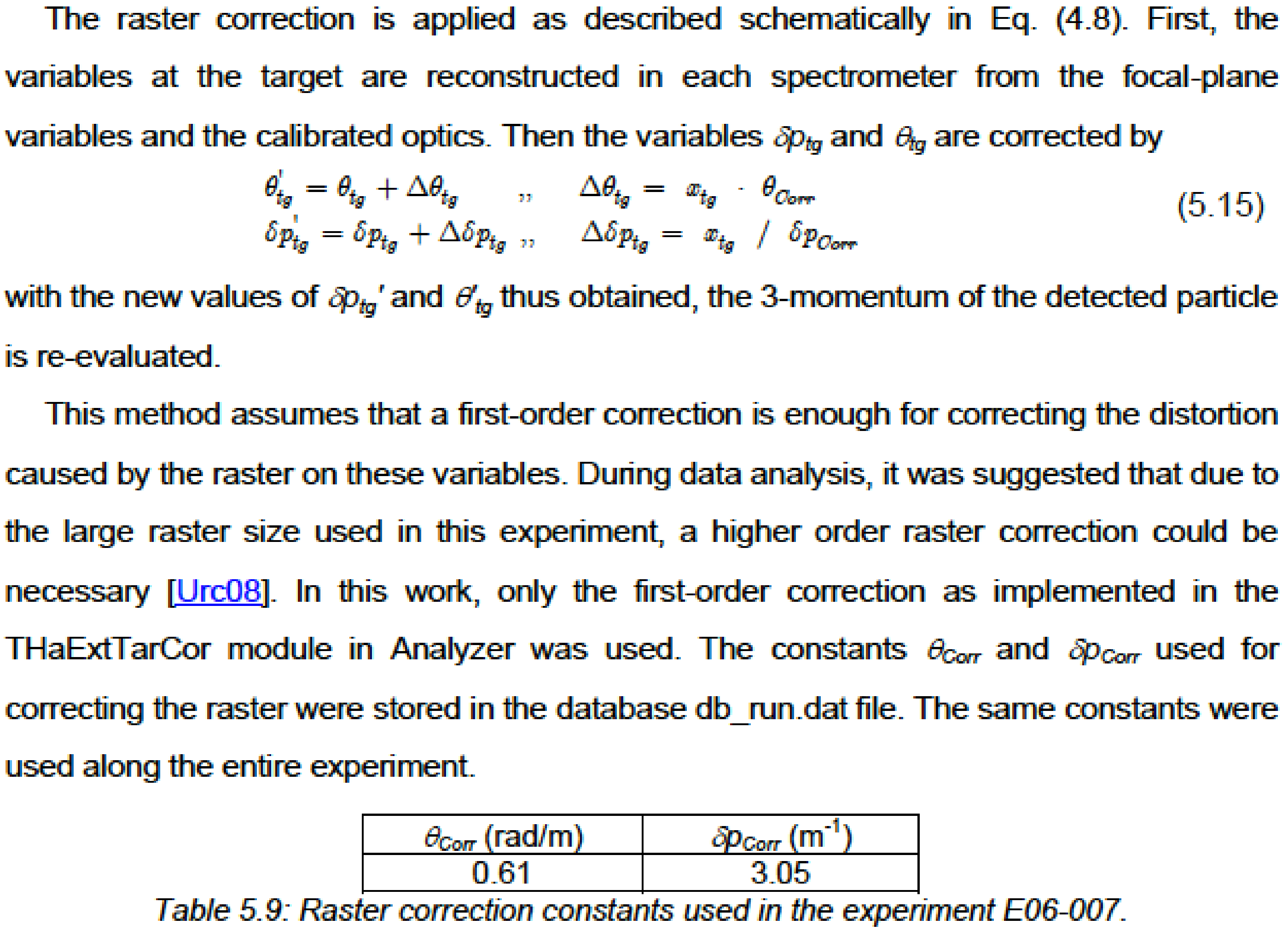
where $<i>$ is the beam current, $k \sim 35.3 W.K^{-1}.m^{-1}$, $\rho \sim 11.35\ g.cm^{-3}$ for lead, $T_{melting}$ is 601K for lead. This shows that using cryogenic cooling we can use a beam current of ~ 35 µA. However, the actual shape of the target is not circular, neither is the exact shape and size of the beam spot known. Therefore what shown in the Fig. 8 gives only a first order estimation of the expected heat dissipation performance. For this reason we assume, conservatively, that we can run with 25 µA. Tests will be performed to check if a current as high as 35 µA could be used.



T_{max} in 0.1 mm Pb target

We will have to raster the beam...

Raster correction (from the experiment E06-007)



The raster correction is applied as described schematically in Eq. (4.8). First, the variables at the target are reconstructed in each spectrometer from the focal-plane variables and the calibrated optics. Then the variables δp_{tg} and θ_{tg} are corrected by

$$\begin{aligned} \theta'_{tg} &= \theta_{tg} + \Delta\theta_{tg} \quad ,, \quad \Delta\theta_{tg} = x_{tg} \cdot \theta_{Corr} \\ \delta p'_{tg} &= \delta p_{tg} + \Delta\delta p_{tg} \quad ,, \quad \Delta\delta p_{tg} = x_{tg} \ / \ \delta p_{Corr} \end{aligned} \qquad (5.15)$$

with the new values of $\delta p_{tg}'$ and θ'_{tg} thus obtained, the 3-momentum of the detected particle is re-evaluated.

This method assumes that a first-order correction is enough for correcting the distortion caused by the raster on these variables. During data analysis, it was suggested that due to the large raster size used in this experiment, a higher order raster correction could be necessary [Urc08]. In this work, only the first-order correction as implemented in the THaExtTarCor module in Analyzer was used. The constants θ_{Corr} and δp_{Corr} used for correcting the raster were stored in the database db_run.dat file. The same constants were used along the entire experiment.

θ_{Corr} (rad/m)	δp_{Corr} (m^{-1})
0.61	3.05

Table 5.9: Raster correction constants used in the experiment E06-007.

As it is shown in Figure 5.19, when the raster is properly taken into account, simil energy resolution is obtained both with and without it.

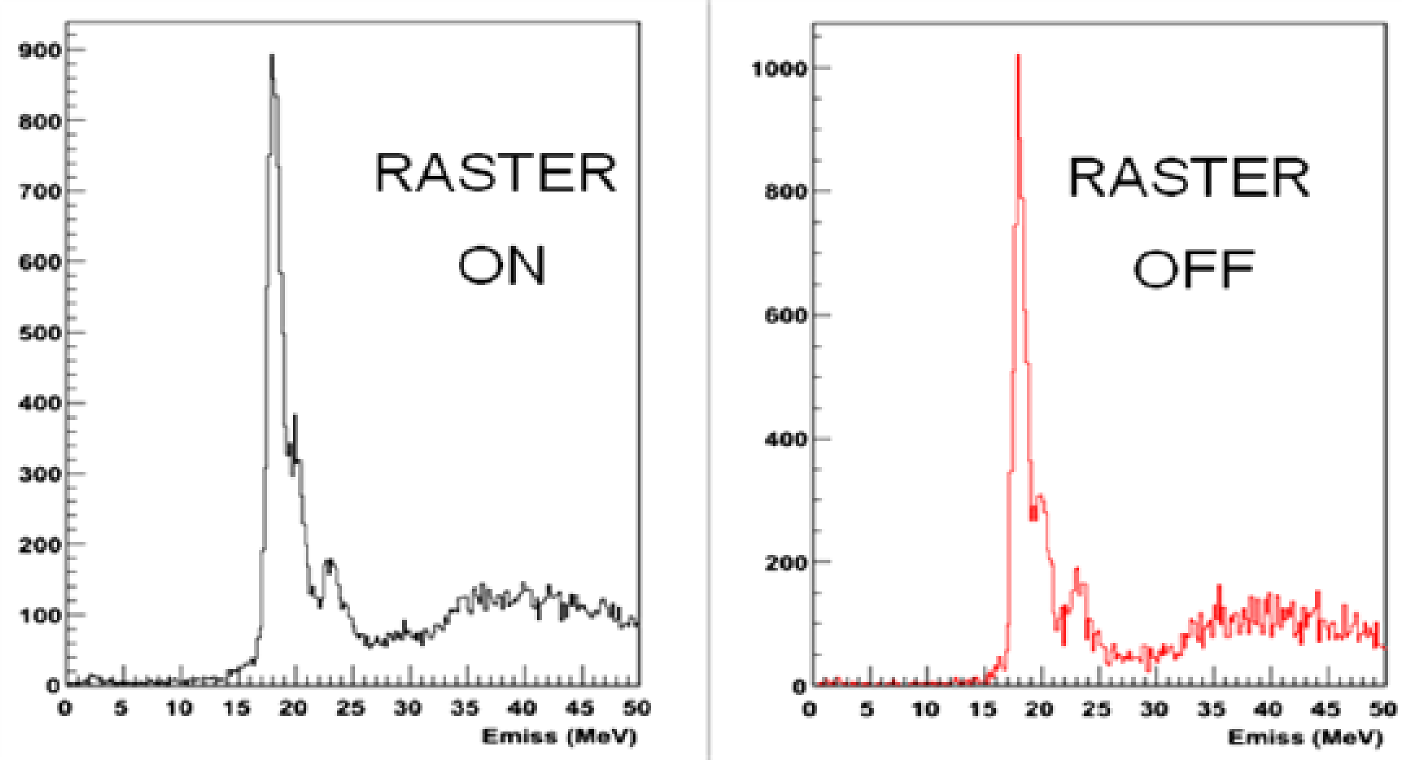


Figure 5.19: ^{12}C(e,e'p) E_{miss} spectrum acquired with unrastered and properly corrected rastered beam. Similar energy resolution is obtained in both cases.

c. The same setup but cooling with a cryogenic liquid to allow us to use with higher beam currents (~ 25 μA) to be able to increase the counting rate so improving the "detectability" of the small peaks.

After considering the options b and c and discussing with JLab target group, we decided to adopt the solution c.

d. the same layout but using a rotating target (see Silvius talk)

This would allow us to operate at 70 μA with a ~ 4 σ peak significance

840 hours (5 weeks)

<I> (mA)	Target thickness (mg/cm^2)	Peak significance	shell
25	100	3.6	S
70	100	4.0	S
100	100	4.2	S