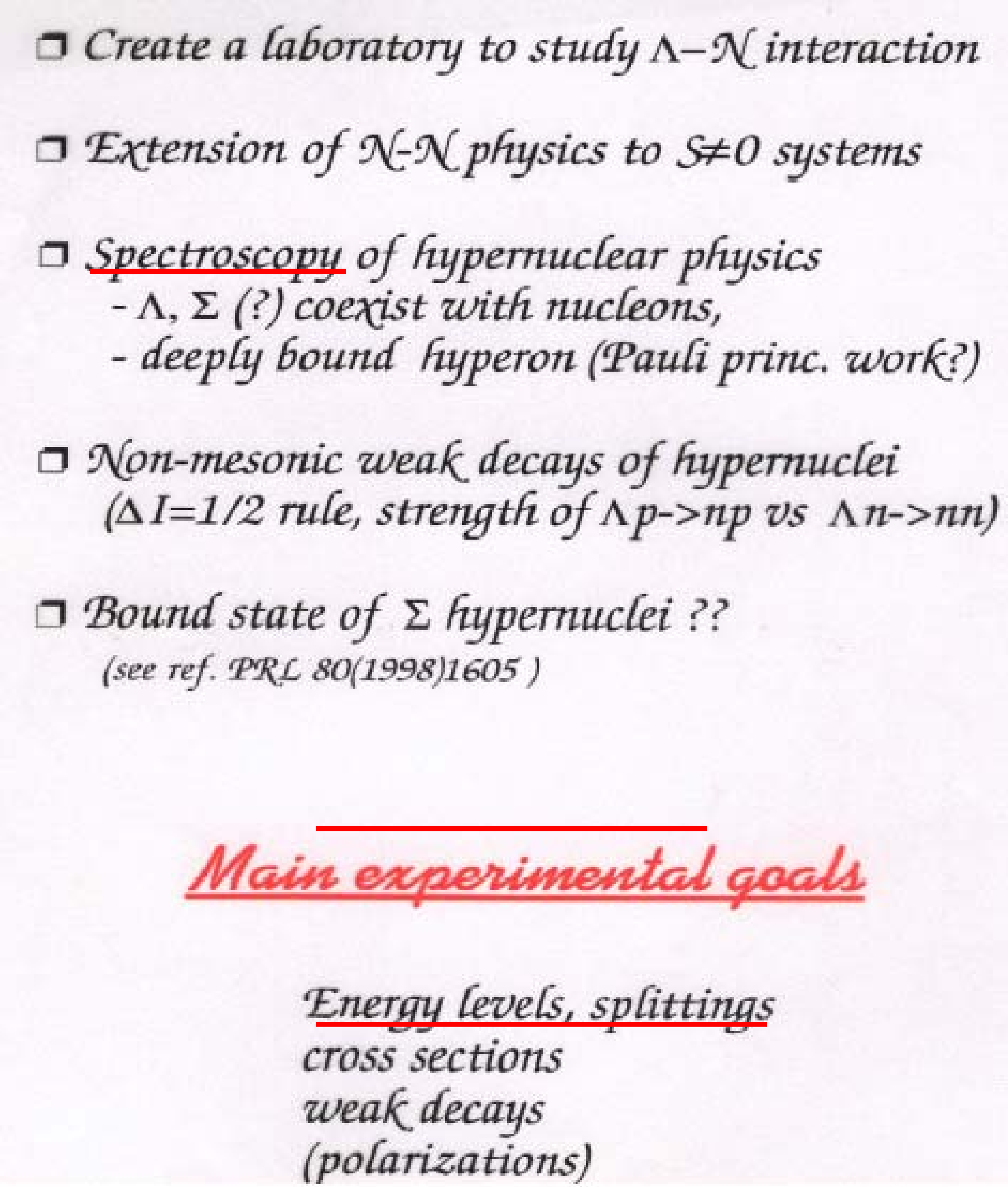
HYP2003- Jefferson Lab - October 03

Future Hypernuclear Program at Hall A

F. Garibaldi-INFN Roma-gr. Coll. Sanita'

- Physics
- Experimental challenge
  - Forward angle - Septum magnets
  - Energy Resolution
  - PID : the RICH
- Targets, expeted rates
- Conclusions

Hypernuclear Phyisics



- Create a laboratory to study Λ–N interaction
- Extension of N-N physics to $S\neq0$ systems
- Spectroscopy of hypernuclear physics
  - Λ, Σ (?) coexist with nucleons,
  - deeply bound hyperon (Pauli princ. work?)
- Non-mesonic weak decays of hypernuclei
  ($\Delta I=1/2$ rule, strength of $\Lambda p \to np$ vs $\Lambda n \to nn$)
- Bound state of Σ hypernuclei ??
  (see ref. PRL 80(1998)1605)

Main experimental goals

Energy levels, splittings
cross sections
weak decays
(polarizations)

- Strange baryons may appear in neutral β-stable matter through processes like

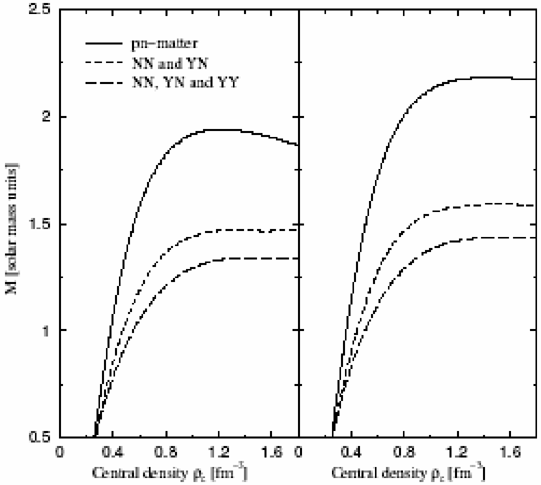
$$n + e^{-} \rightarrow \Sigma^{-} + \nu_{e}$$

as soon as the chemical potentials are such that

$$\mu_{n} + \mu_{e} > M_{\Sigma^{-}}$$

- The presence of strange baryons in neutron stars strongly affects their properties.

  Example: mass-central density relation for a nonrotating (left) and rotating (right) star



- The effect strongly depends upon the poorly known interactions of strange baryons.

- More data needed to constrain theoretical models

There is growing evidence that hyperons appears the first of the strange hadrons in neutron starts at around twice normal density….The onset of the hyperon formation is controlled by the attactive hyperon-nucelon interaction wich can be extracted from hypernucleon scattering data and hypernuclear data (J. Shaffner-Bielich et al: Hyperstars: Phase Transition to (meta)-Stable Hyperonic matter in neutron Stars, arXiv: astroph/0005490

Additional experimental data from hypernuclei will be useful in establishing the foundations of high density matter models. This is especially relevant for the hyperon-nucleon interactions, for which relevant systems are more likely to be produced in current accelerators than for hyperon-hyperon interactions” , in S. Balberg et al: Roles of hyperons in Neutron Stars, arXiv: astro-ph/9810361

recision Λ hypernuclear spectroscopy

Hypernuclear structure vs ΛN interaction

- hypernuclear data well described by weak coupling model

$$\Lambda\ (s\text{-shell}) + J_{\mathcal{A}-1} \dashrightarrow J = J_{\mathcal{A}-1} \pm 1/2$$

(Λ hyperon) (parent nucleus) (created **doublet** state)

(J state)

- many particle shell model :

($|s^4\, p^{\mathcal{A}-5} * s\Lambda; JT>$ configurations)

- Hypernuclear Hamiltonian:

$$\mathcal{H} = \mathcal{H}_{\mathcal{N}} + h_\Lambda + \mathcal{H}_{\mathcal{N}\Lambda}$$

$\mathcal{H}_{\mathcal{N}}$ = hamiltonian for the NUCLEAR CORE

h_Λ = Kinetic term for the hyperon

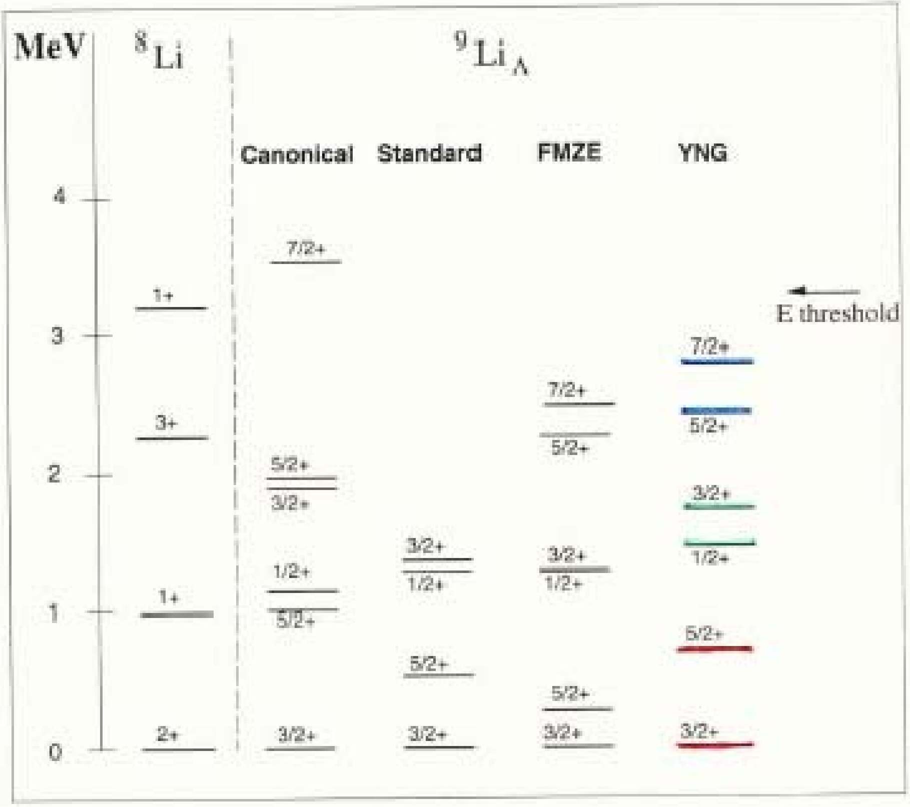
$$\mathcal{H}_{\mathcal{N}\Lambda} = \sum_{i=1}^{A-1} V_{\Lambda N}(\vec{r}_i - \vec{r}_\Lambda)$$ Residual ΛN interaction

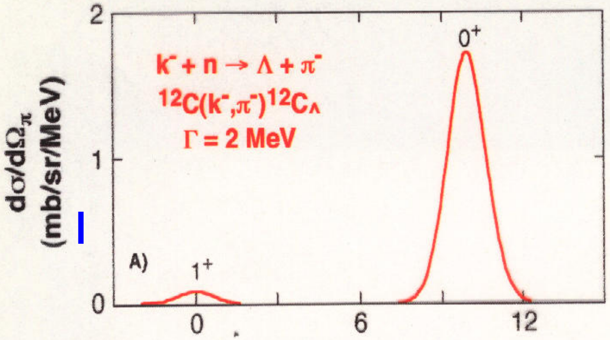
$$\begin{aligned} V_{\mathcal{N}\Lambda} = & V_0(r) && \mathcal{V}\ \text{(central)} \\ & + V_\sigma(r)\, \sigma_{\mathcal{N}} \cdot \sigma_\Lambda && \Delta\ \text{(spin-spin)} \\ & + V_{so}(r)\, \ell_{\Lambda\mathcal{N}} \cdot \sigma_\Lambda && \sigma_\Lambda\ \text{(spin-orbit} \\ & + V_{so}(r)\, \ell_{\Lambda\mathcal{N}} \cdot \sigma_{\mathcal{N}} && \sigma_{\mathcal{N}}\ \text{(spin-orbit} \\ & + V_{\mathcal{T}}(r)\, \mathcal{S}_{12} && \mathcal{T}\ \text{(tensor)} \end{aligned}$$

$$(\ \mathcal{S}_{12} = 3(\sigma_{\mathcal{N}} \cdot r)(\sigma_\Lambda \cdot r) - \sigma_{\mathcal{N}} \cdot \sigma_\Lambda\ )$$

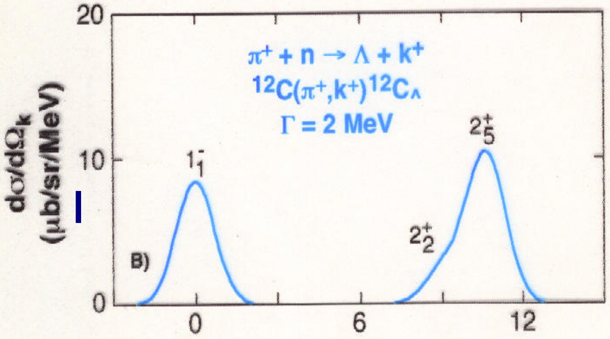
- doublet splitting determined mainly by Δ , σ_Λ , $\mathcal{T}$

($\sigma_{\mathcal{N}}$ affect the spacing between doublets)

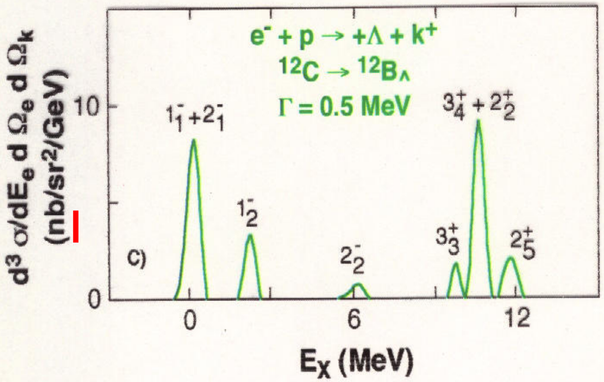




$q \approx 100$ MeV/c --> $\Delta\ell = 0$
---> substitutional states
$\Delta s = 0$ --> no spin flip
---> natural parity
($J = 0^+$)
absorption



$q \approx 300$ MeV/c --> $\Delta\ell = 1,2$
spin flip (weak for $\Theta_K < 10°$)
$\Delta s = 0$ ---> natural parity
($J = 1^-$, $J = 2^+$)
absorption



$q \approx 300$ MeV/c --> $\Delta\ell = 1,2$
--> non substitutional statesd
$\Delta s = 0,1$ (spin flip)
---> unnatural parity
($J = 2^-$, $J = 3^+$)
no absorption

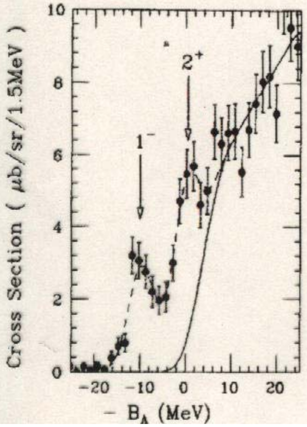
----> *new aspects of hypernuclear structure*

- * production of hypernuclei not available otherwise ($^7He_\Lambda$, $^9Li_\Lambda$)
- * energy resolution ≈ 350 keV

~~* no data~~

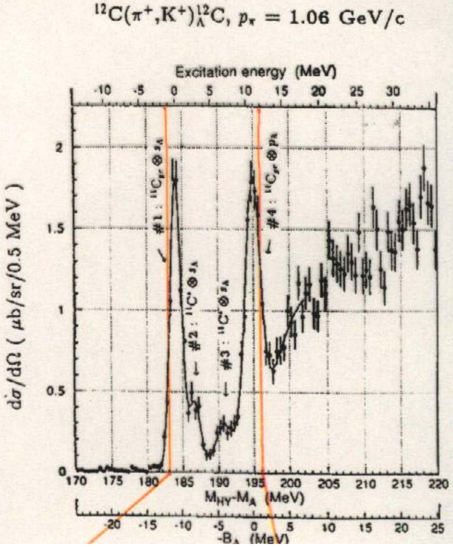
$^{12}C(\pi^+,K^+)^{12}C_\Lambda$ data taken from
M.Akei et al., NP A534 (1991) 478

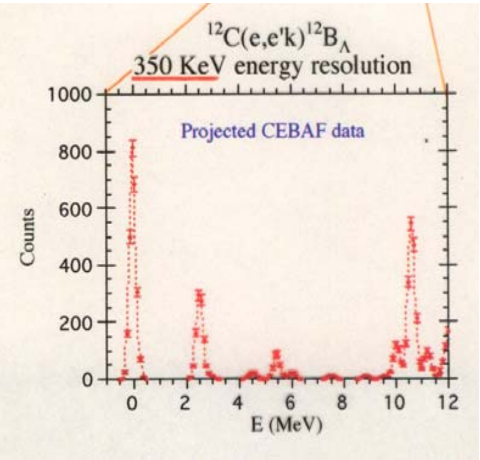
Energy resolution **4 MeV**



More recent **KEK data**
INS-Rep.-1037, Univ. of Tokyo, 1994

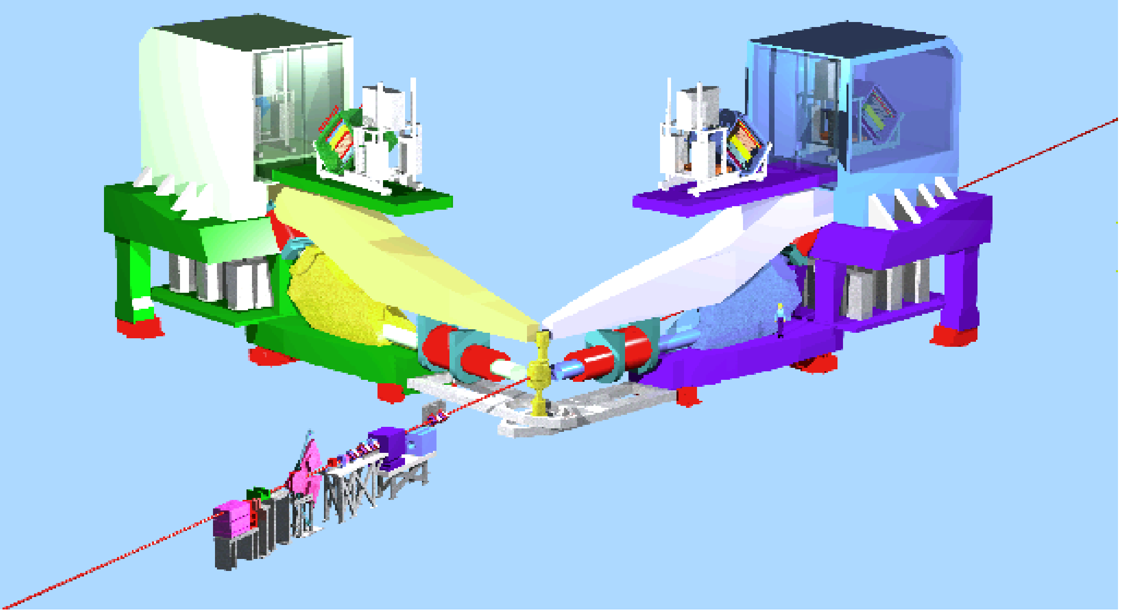
Energy resolution **2 MeV**

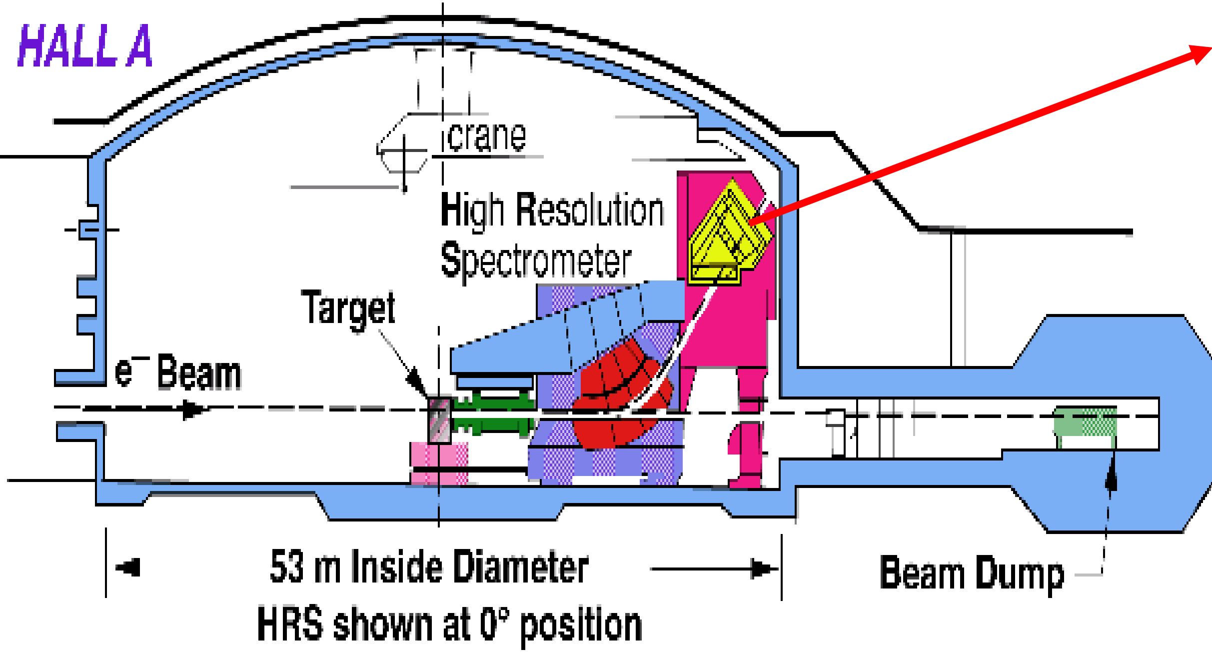


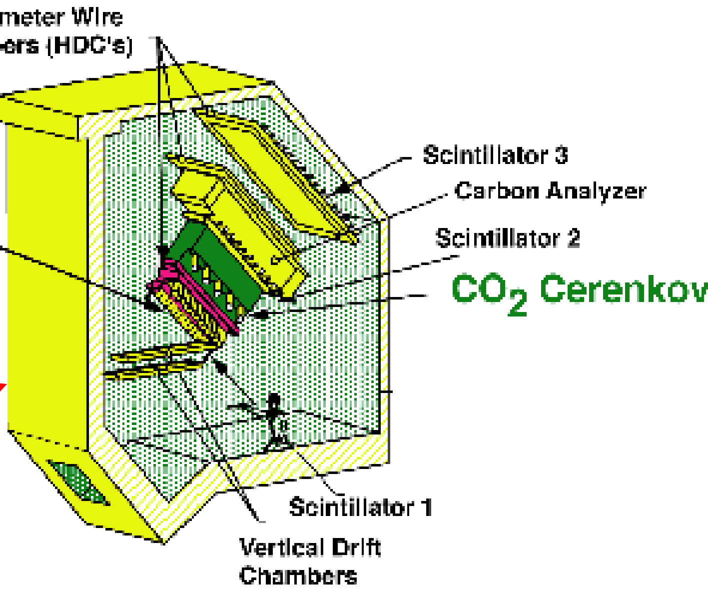


Hall A - Two High Resolution Spectrometers

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



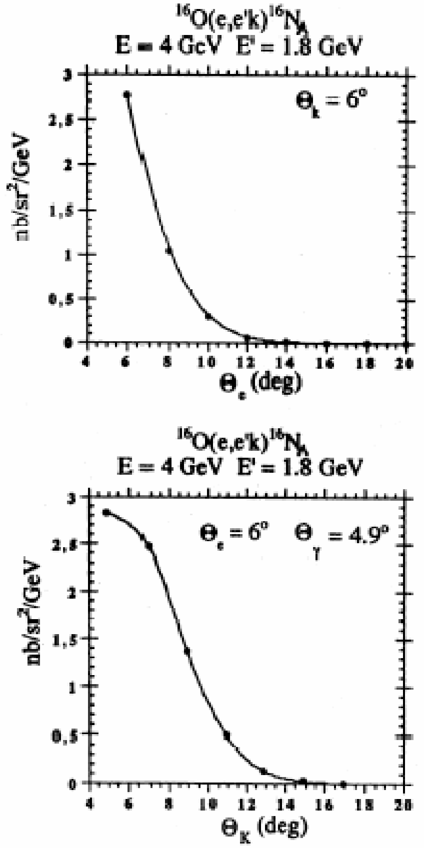


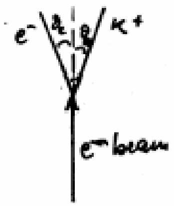


E-94-107 - High Resolution 1p shell Hypernuclear Spectroscopy

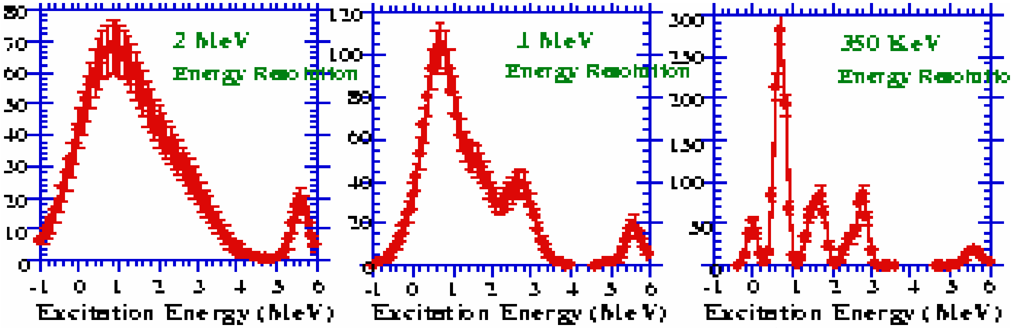
F. Garibaldi, S. Frullani, J. LeRose, P. Markowitz, T. Saito

Cross section VS. angles

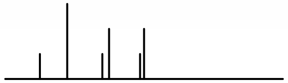




—> very forward angle detection capability is required



$^9Be(e,e'K)^9Li_\Lambda$



very good energy resolution

forward angle reasonable counting rates

very good PID unambiguous kaon identification

E_i = 4 GeV

ω = Eγ ~ 2.2 GeV

p_k = 1.9 GeV

$\theta_e = \theta_k = 6°$

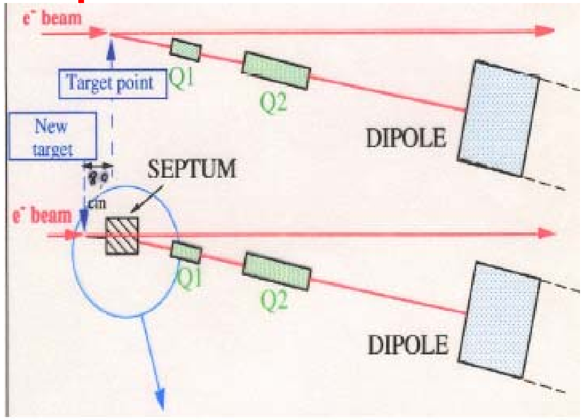
Q^2 = 0.0789 Gev²

Energy Resolution

1. ΔE/E : 2.5 x 10-5
2. ΔP/P (HRS + septum) ~ 10-4
3. Straggling, energy loss…

Forward angle - Septum magnets

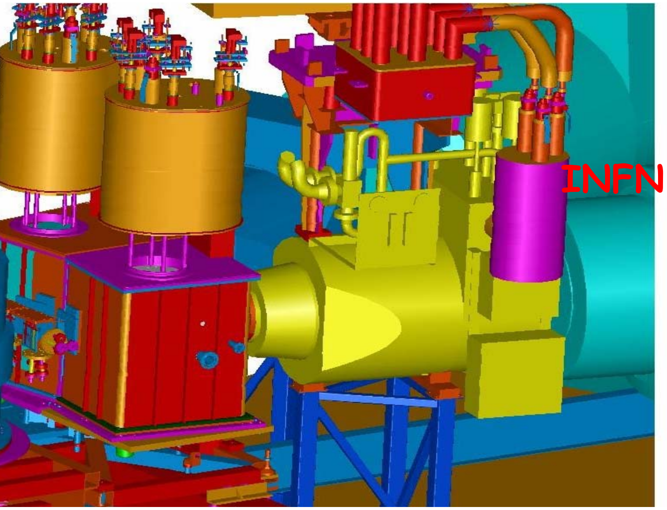
- Meet the requirements of the 94-107 and all “possible” experiments in Hall A

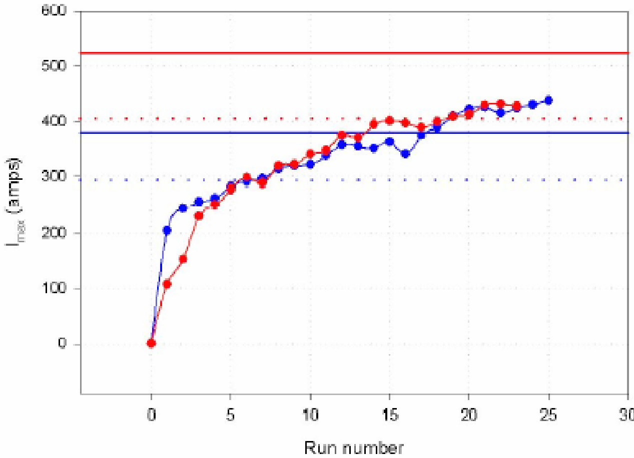


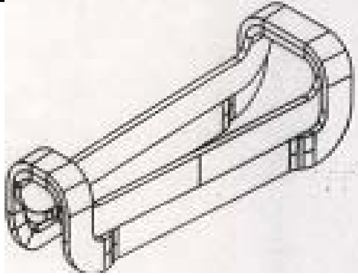
  - Small scattering angle (12.5 --> 6)
  - No degradation in HRS performances
  - General purpose device
    - Continuous covering scattering angles (6 -->12.5)
    - Two independent arms

Length	88 cm
Magnetic length	84 cm
Height of the gap	25 cm
Width of the gap central edge	10.4 cm
Width of the gap exit edge	18.4 cm
Angular acceptance	4.7 mr

p (GeVc)	θ (degrees)	β (degrees)	R (cm)	∫ B. dl (Tesla .m)	B0 (Tesl
2	6	6.5	740.8	0.76	0.9
2	12.5	11.9	404.6	1.39	1.65
4	6	6.5	740.8	1.51	1.8
4	12.5	11.9	4046	2.77	3.3





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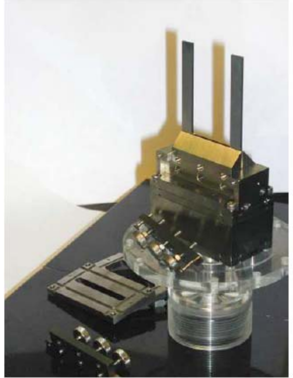
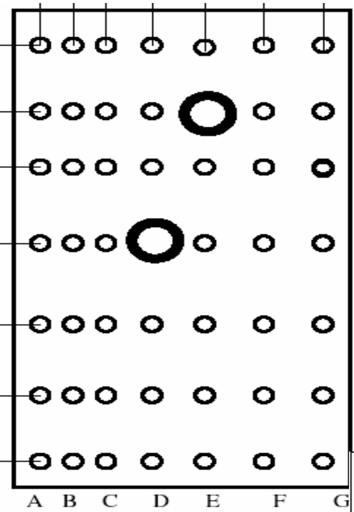
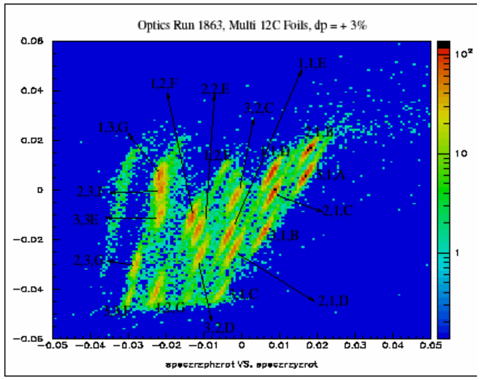


E-97-110
JP. Chen, A. Deur, F. Garibaldi

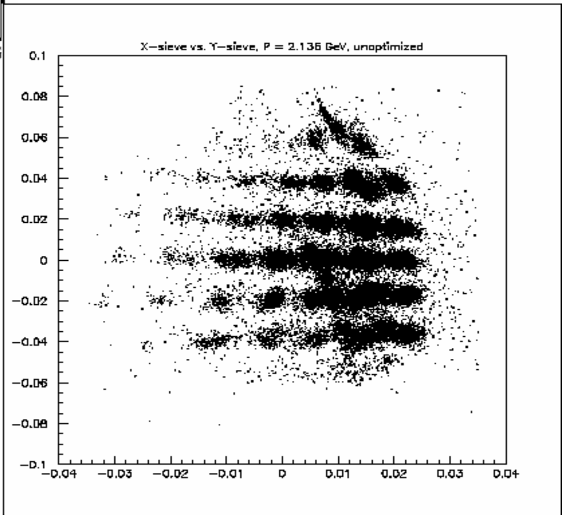
sieve slit



I period



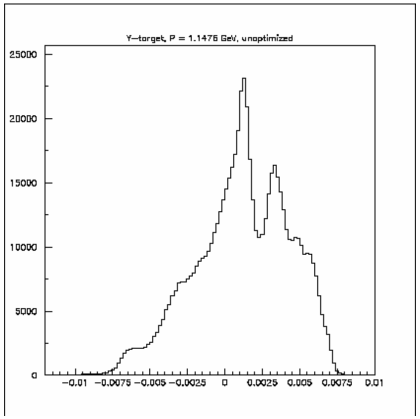
II period

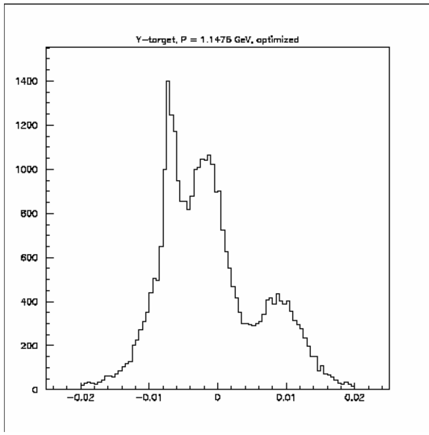


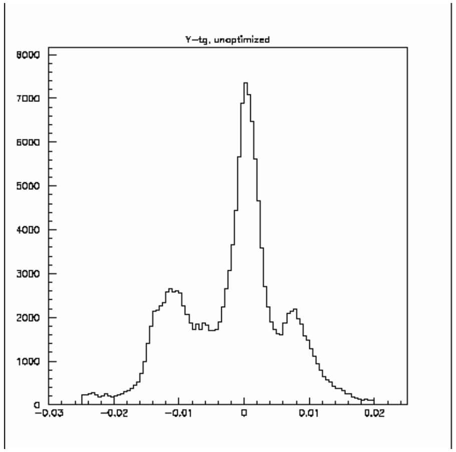
Y target

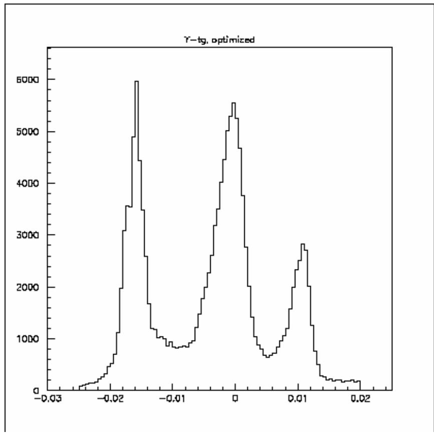
non optimized

optimized







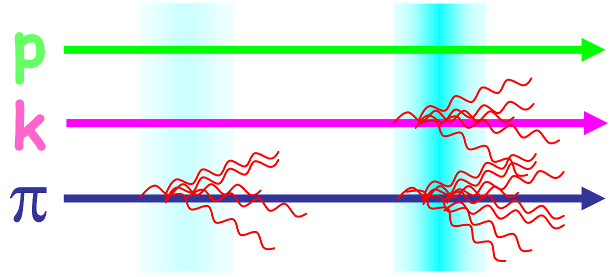


The PID Challenge

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

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

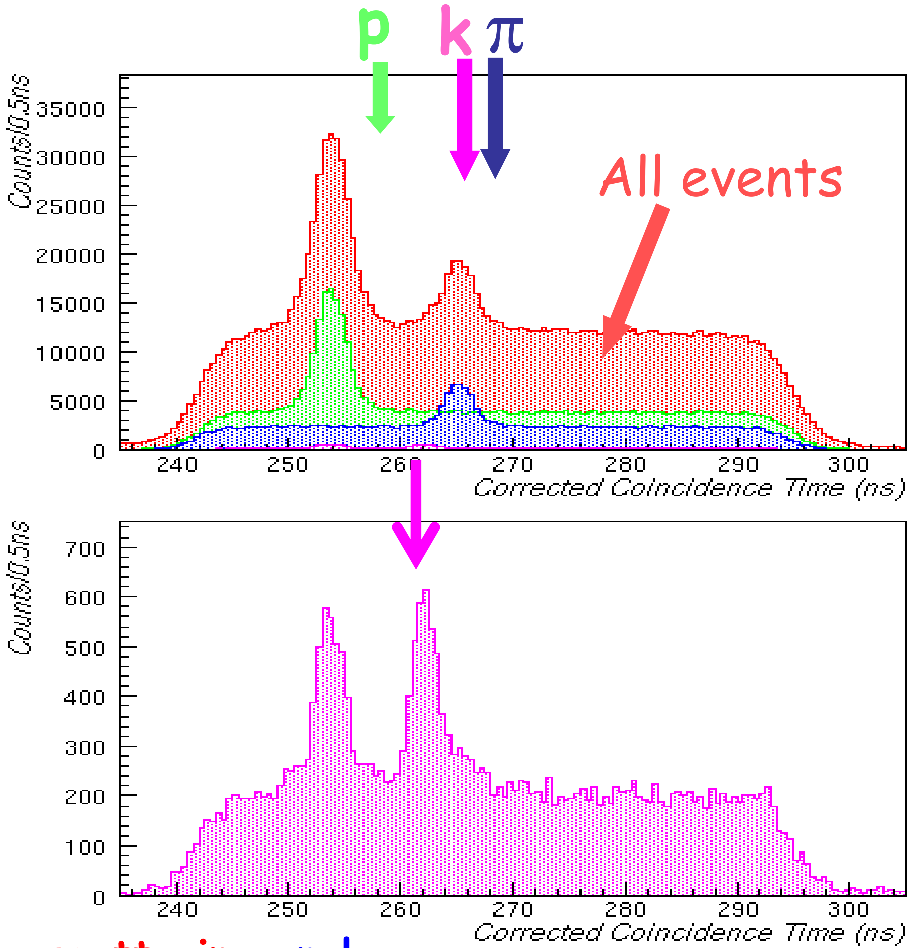
Kaon Identification through Aerogels:



AERO1
n=1.015

AERO2
n=1.055

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



Hypernuclei -> smaller scattering angle

-> higher background --> something else is needed

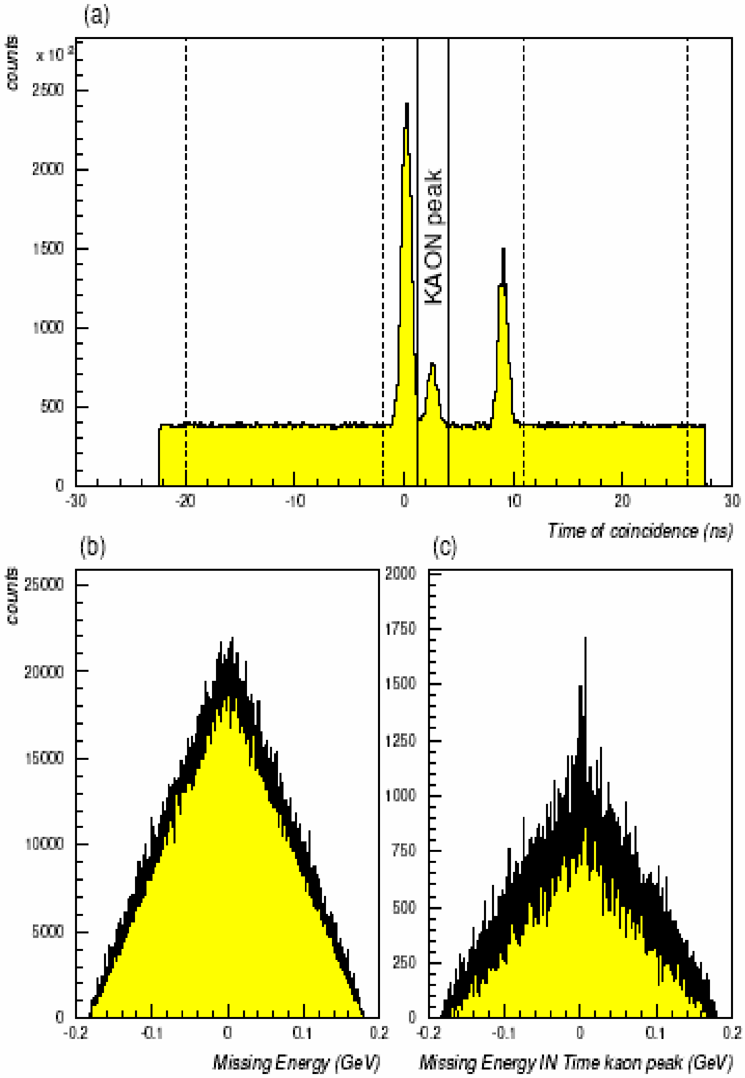


Figure 2: $^{16}O(e,e'K)^{16}N_{\Lambda}$ reaction. (a) Timing spectrum: solid lines se
a cut for events "IN the kaon peak", dashed lines select events "OFF k
peak" used for subtraction. (b) Missing Mass spectrum for all the eve
entering spectrum (a). (c) Missing Mass spectrum for events "IN the k
peak".

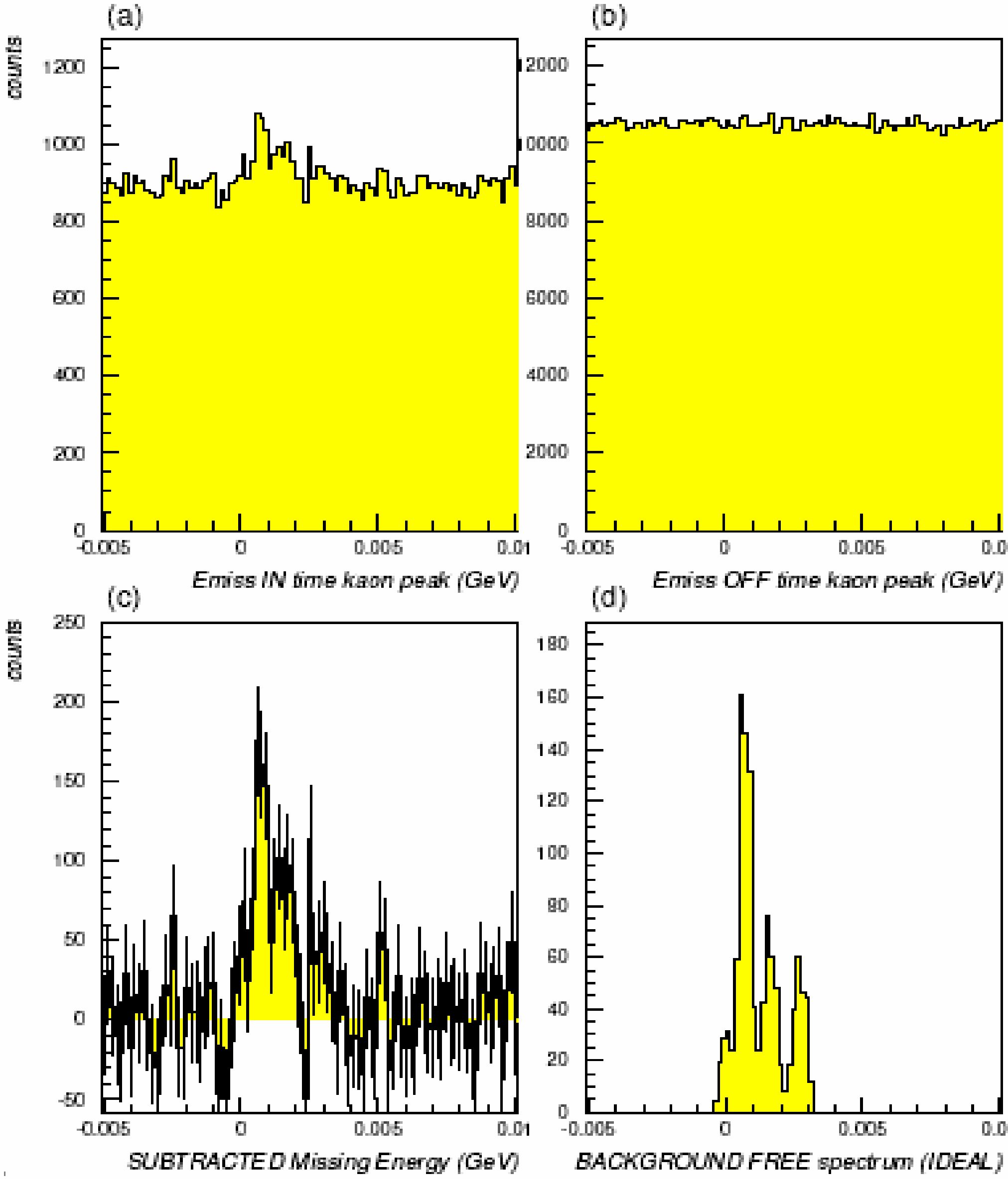
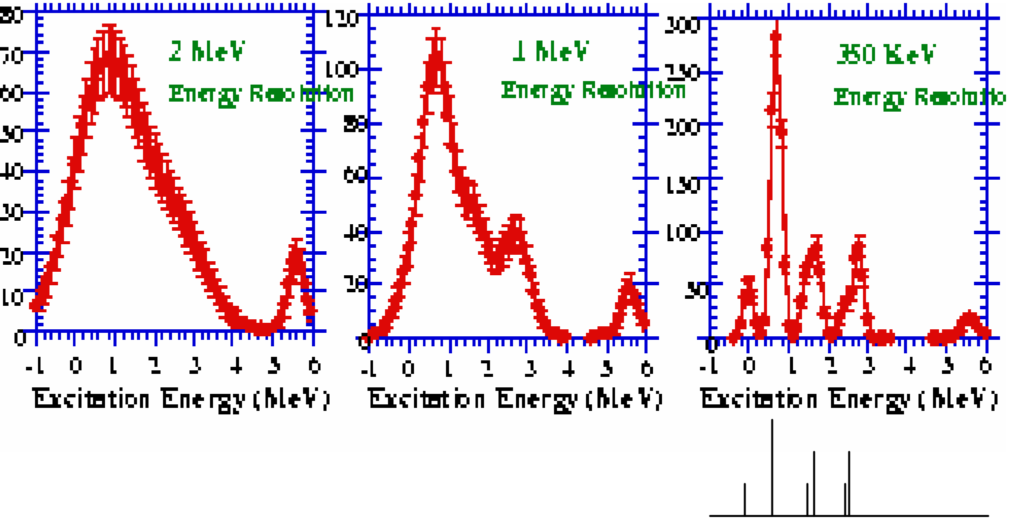


Figure 5: Same as fig 3 for the $^{9}Be(e,e'K)^{9}Li_{\Lambda}$ reaction

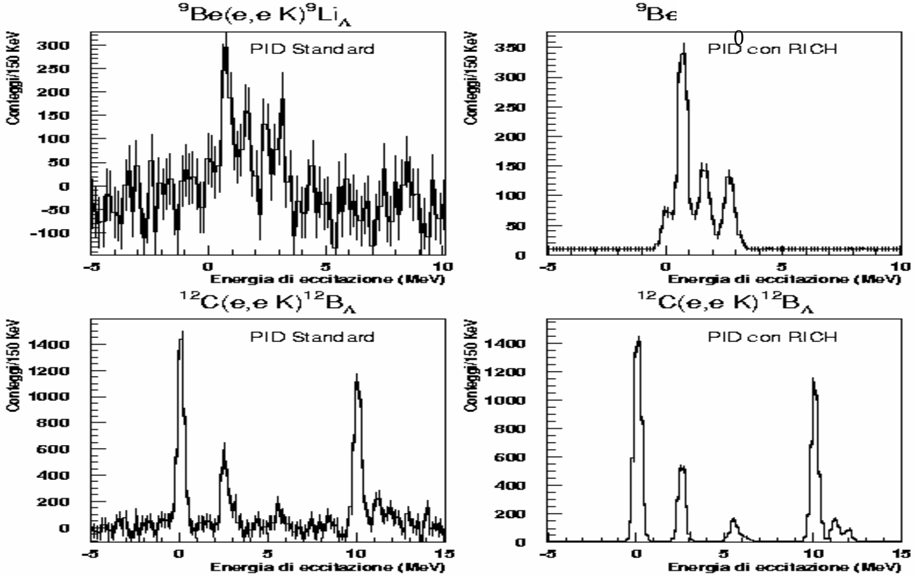
RICH

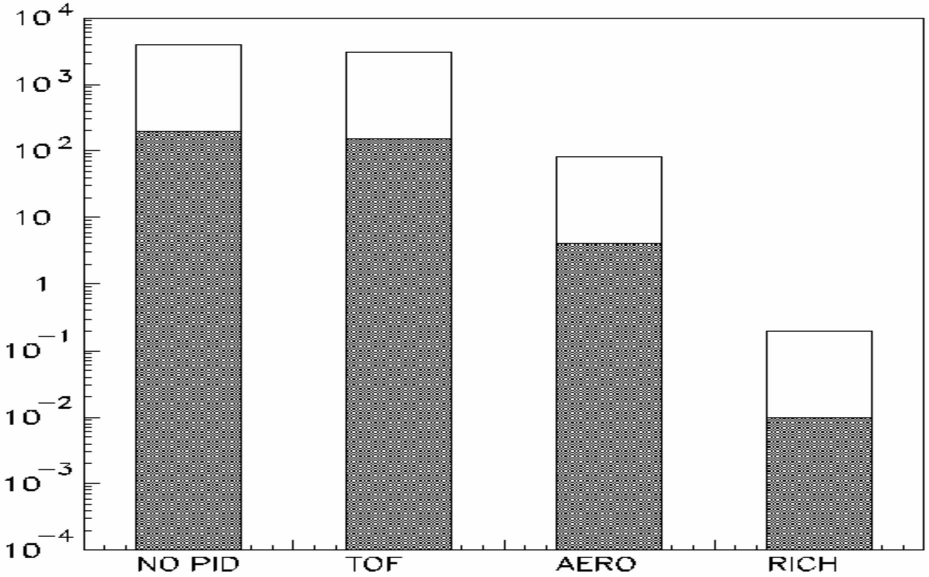


	Process	Rates
signal	(e,e'K)	10^{-4} - 10^{-2}
accidentals	(e,e')(e,pi) (e,e')(e,p) (e,e')(e,k)	100 100 0.1

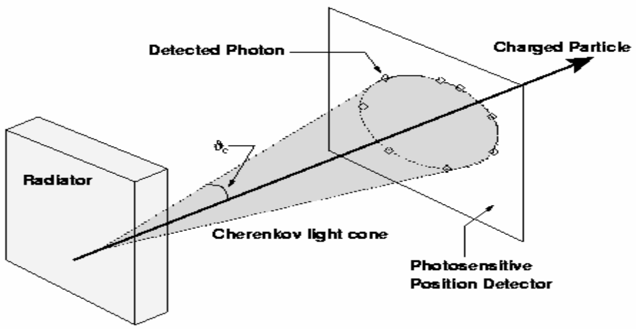
Contamination of pion and proton on the K signal with different PID systems, for the counting rates of two levels (10-2 Hz and 10-4 Hz)

without RICH with RICH





Ring Imaging CHerenkov Detector



Detect single photon positions to reconstruct the Cherenkov angle:

$\cos\theta = 1/n\beta$ $\Delta\beta/\beta = tg\ \Delta\theta$

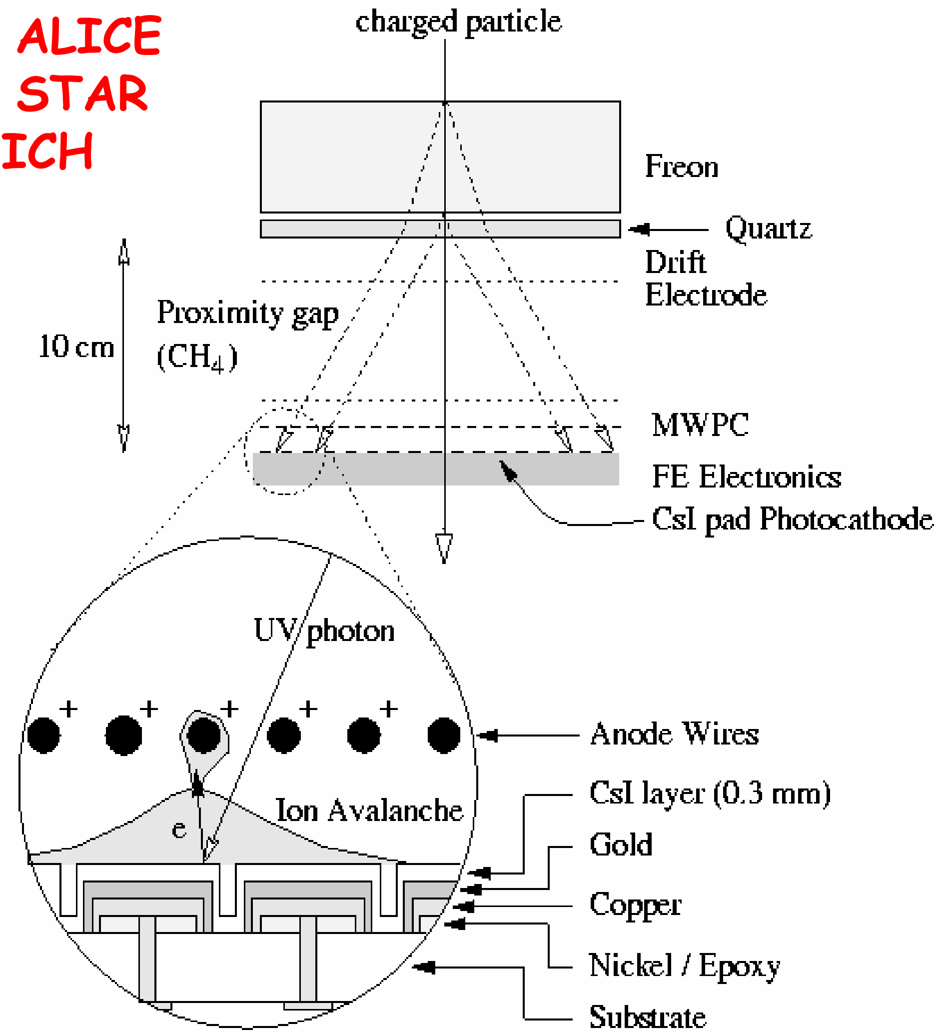
N = p.e. per ring

$\Delta\theta \rightarrow \Delta\theta/\mathrm{sqrt}(N)$

- *n* fixed by the momentum(2GeV/c)

  C6 F14, transparent down to 160 nm
- compact (~ 50 cm)
- relatively thin (18% X0)
- $310 \times 1820\ mm^2$
- quarz window 5 mm

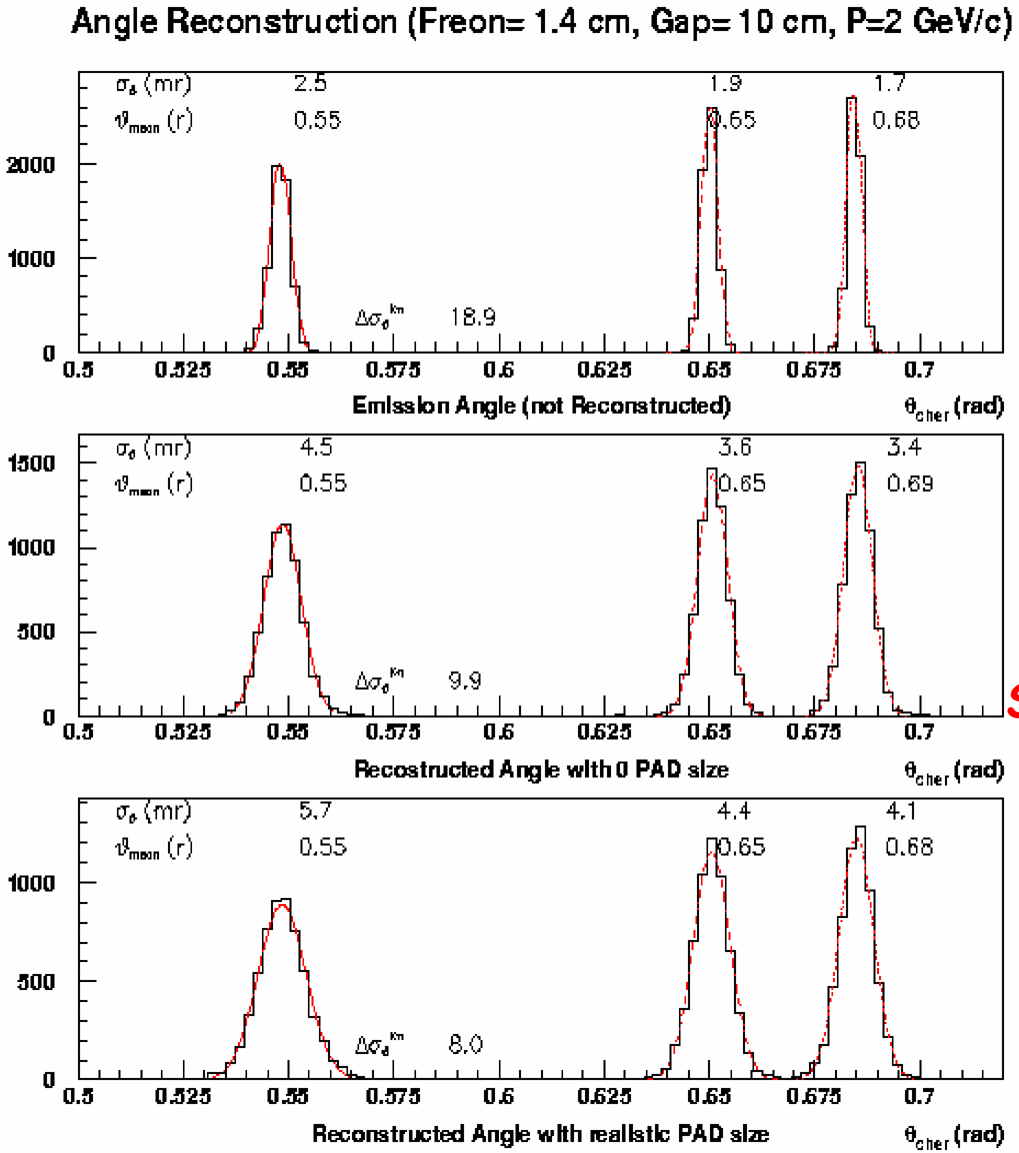
Like ALICE and STAR RICH



Optics	Proximity Focusing	
Radiator	Liquid Freon (C_6F_{14}, n=1.28)	15 mm
Photo converter	CsI film coated on a Pad Plane	300 nm
Position Detector	Multi Wire and Pad Proportional Chambe filled with Methane at STP	
FE Electronics	11520 analog chs, multiplexed S&H	

N. of detected photoelectrons

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



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 6 σ

5 mrad good enough

check the # p.e.

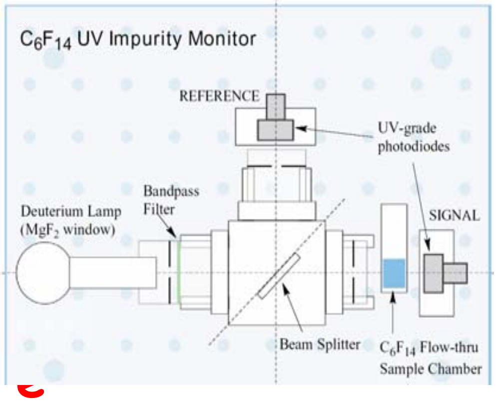
check the sinlge photon ang. res.

(FPP tracking would help)

Many parameters affect the detector performances (# p.e.)

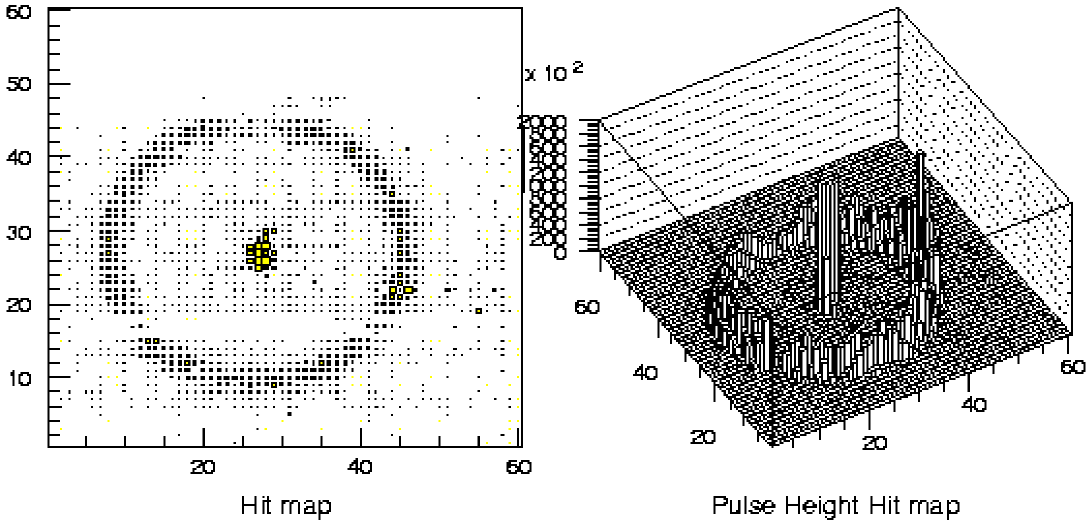
- quartz transparency in the v.w. region of interest (160 - 220 nm)

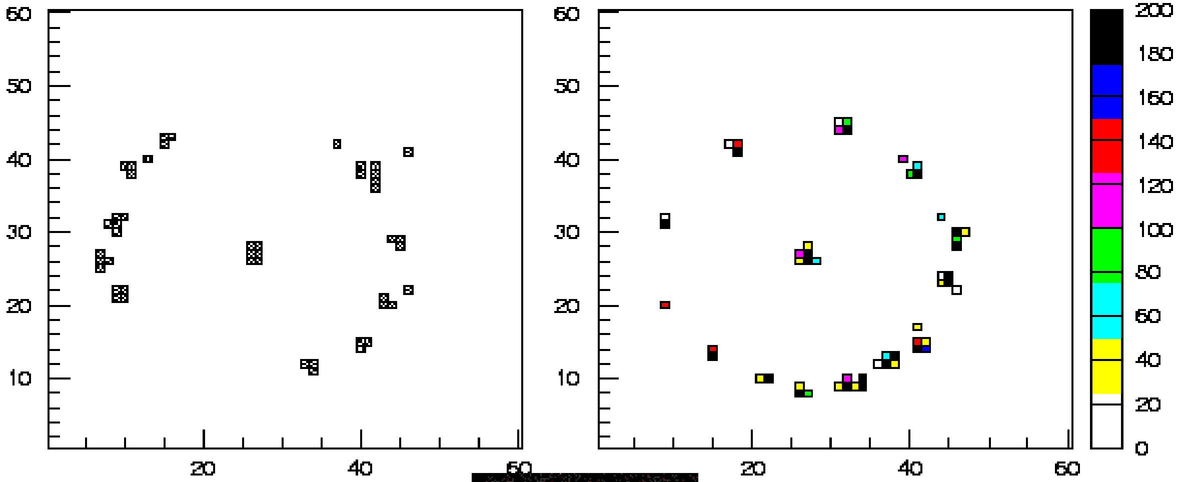
- freon purity to not absorb the emitted Cherenkov light
  - freon purity circuit + continuously monitoring



- CsI photocathode
  - evaporation + on line QE absolute measurement
  - QE is strongly affected by oxygen and moisture
    - Careful handling of photocathodes after evaporation
    - Continuous monitoring of gas “purity”

CERN tests 11/01





CERN tests

7 GeV/C p bear

Argon CH4 (25/75)

2 photocathodes

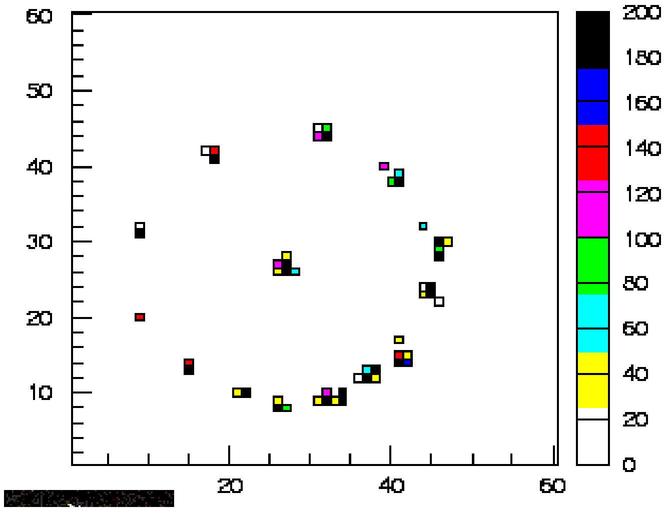
Rome and CERN

Equal performances

N = ~ 12

Can be be extrapolated to ~ 14 with CH

CERN November 2000



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Rome and CERN

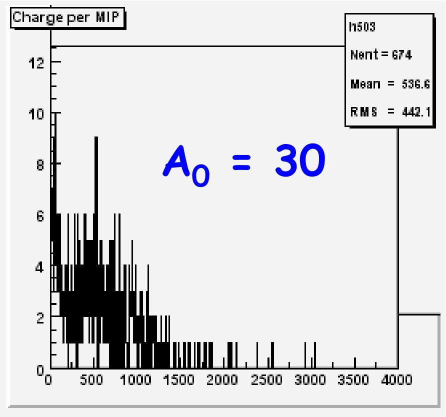
Equal performances

N = ~ 12

Can be be extrapolated

to ~ 14 with CH4

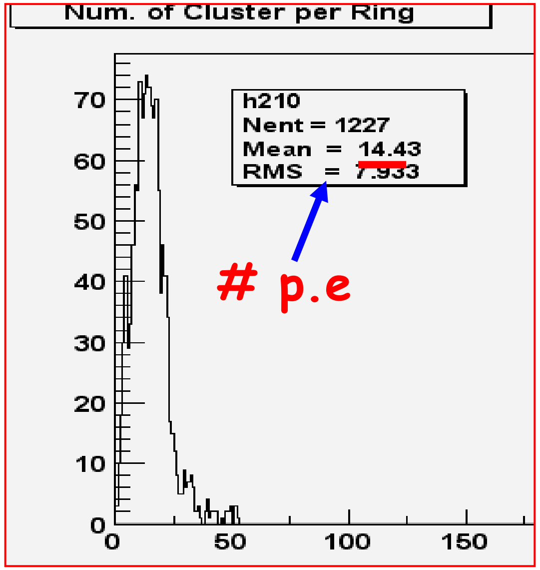
Cosmics Jlab September 2003



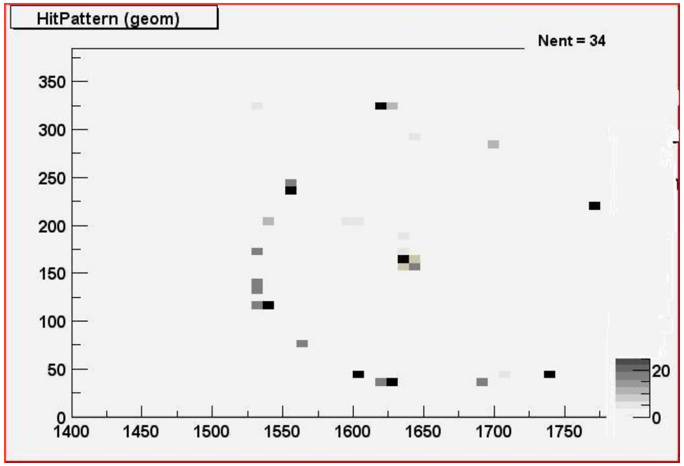
$A_0 = 30$

MIP peak=550

$G \sim 8 \times 10^4$

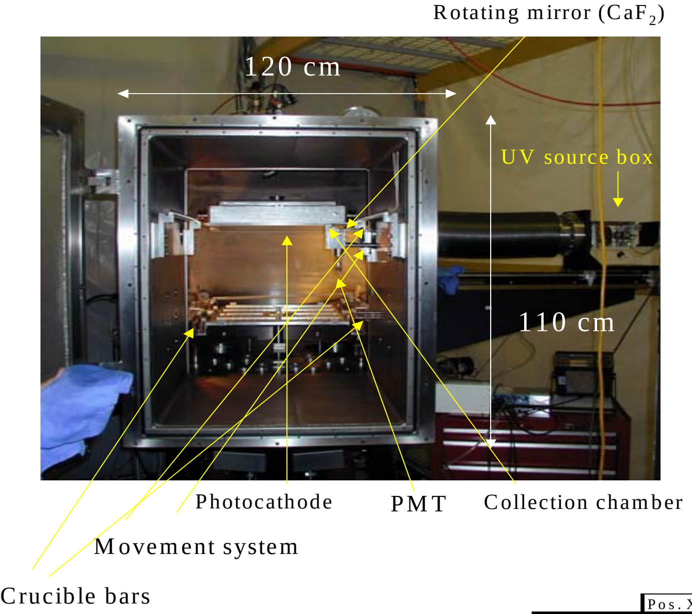


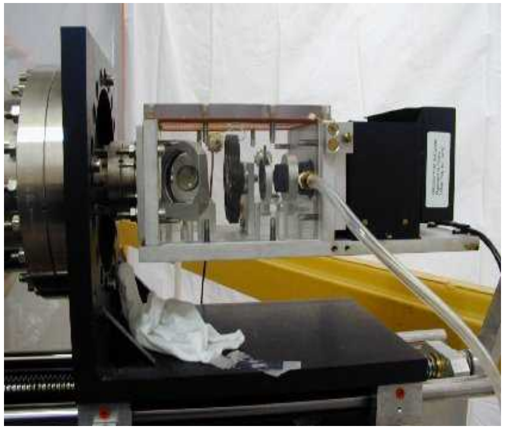
p.e

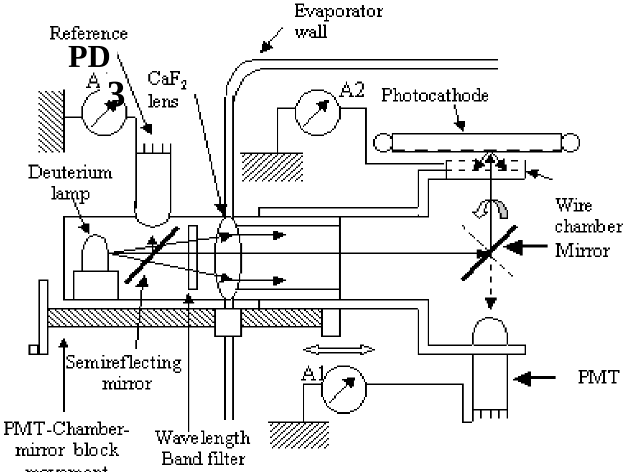


Evaporation system

10^{-6} mbar vacuum, 2 nm/s CsI deposition at T = 60 °C (CERN experts indications). Vacuum - heating conditions start 15 - 24 h before evaporation. A post-evaporation heat treatment s done for 12 hours.



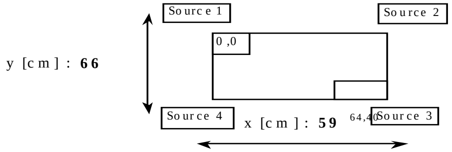




Evaporation layout

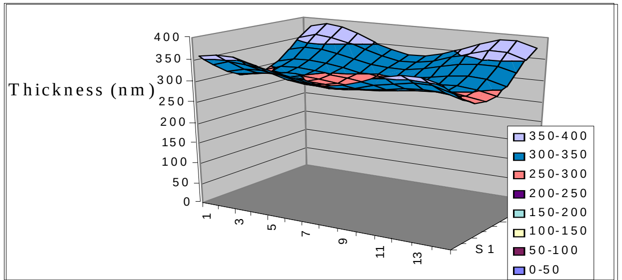
Crucibles positions

	Pos. X	Pos .Y
Source #1 :	2.5	53.15
Source #2 :	61.5	53.15
Source #3 :	61.5	-12.85
Source #4 :	2.5	-12.85

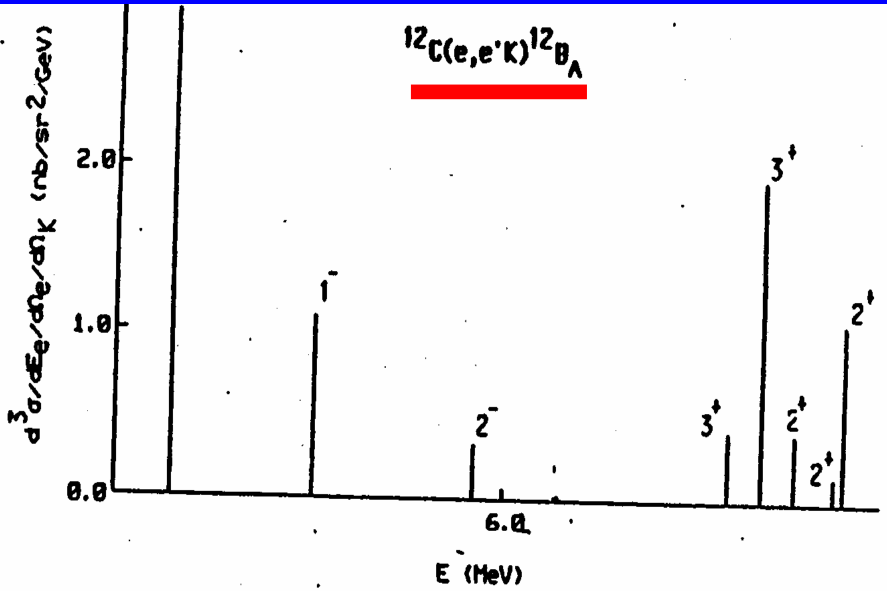


- PhotoCathode - crucibles plane distance: 42 cm
- 4 μm Ni - 1 μm Au support
- crucible quantity: 0.8 g weight each one, corresponding to ~ 320 nm thickness (expected and measured)

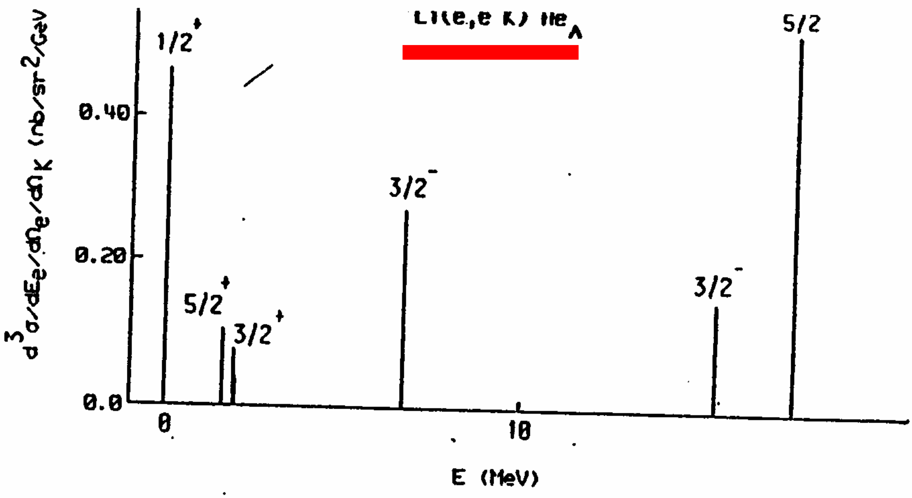
Expected thickness



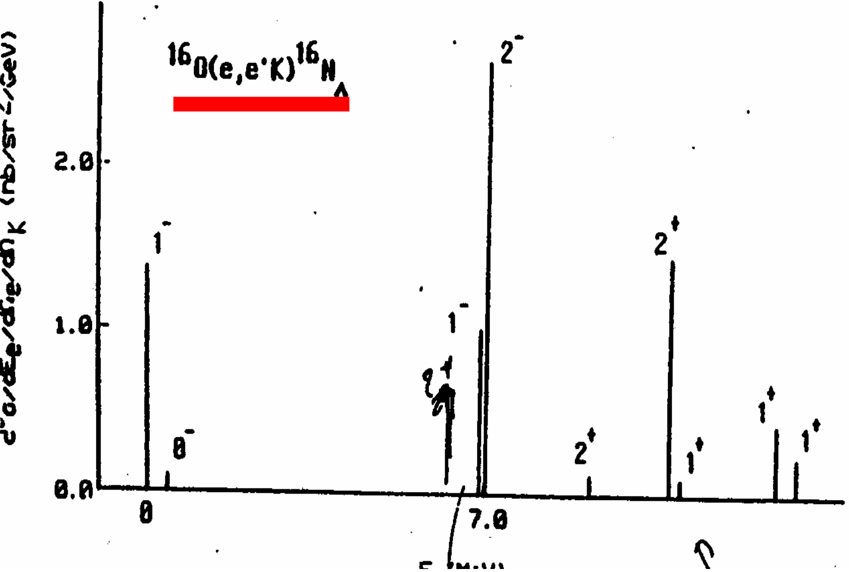
Targets



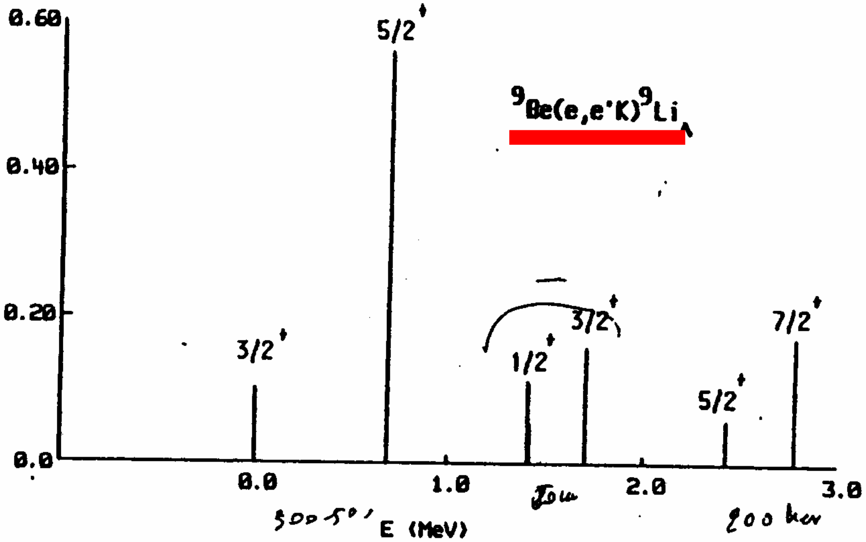
12C(e,e'K)12B_Λ
d3σ/dEe/dΩe/dΩK (nb/sr2/GeV)
2.0
1.0
0.0
1-
2-
3+
3+
2+
2+
2+
6.0
E (MeV)



Li(e,e K) He_Λ
d3σ/dEe/dΩe/dΩK (nb/sr2/GeV)
0.40
0.20
0.0
1/2+
5/2+
3/2+
3/2-
3/2-
5/2
0
10
E (MeV)

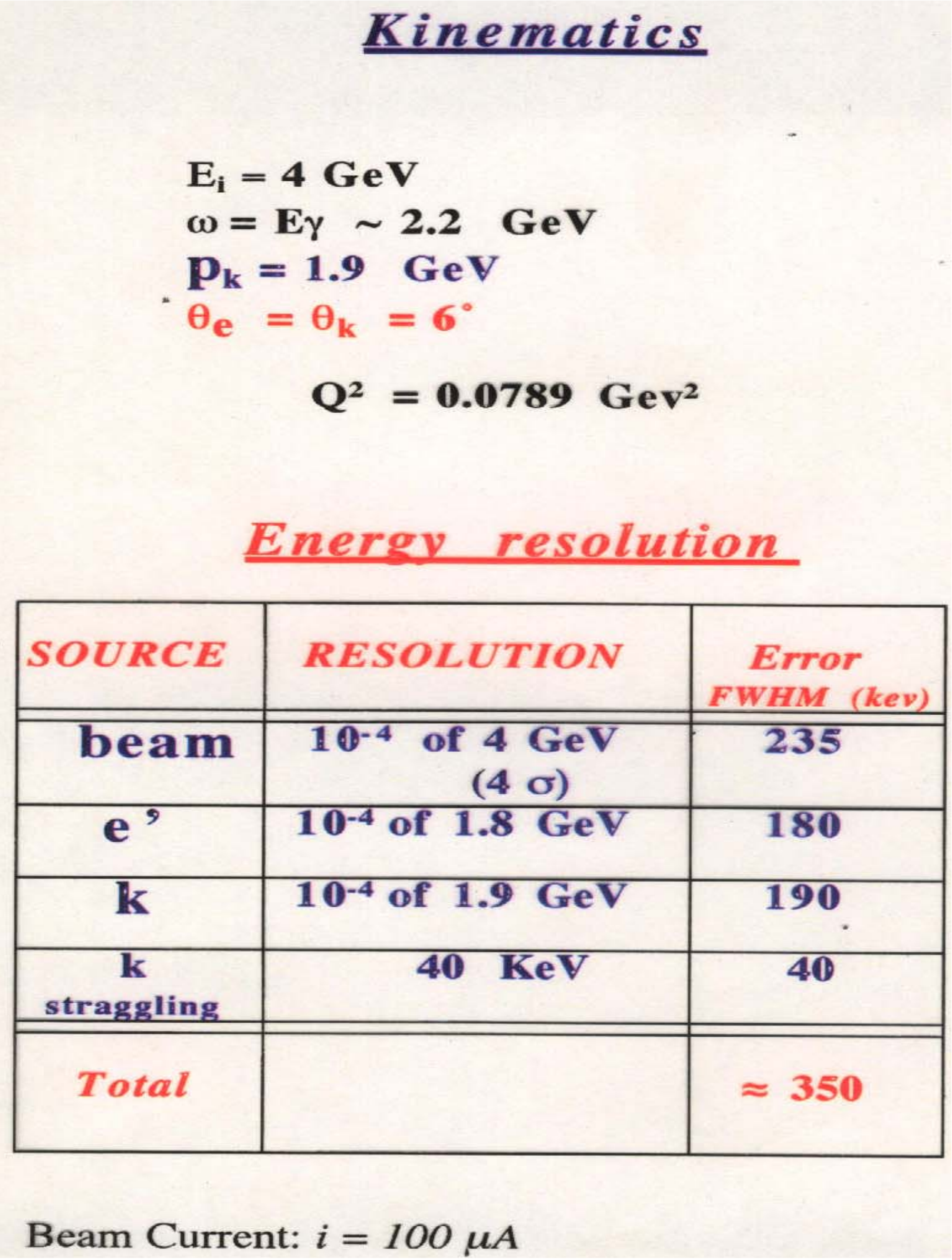


16O(e,e'K)16N_Λ
d3σ/dEe/dΩe/dΩK (nb/sr2/GeV)
2.0
1.0
0.0
1-
0-
9+
1-
2-
2+
2+
1+
1+
1+
0
7.0
E (MeV)



9Be(e,e'K)9Li_Λ
0.60
0.40
0.20
0.0
3/2+
5/2+
1/2+
3/2+
5/2+
7/2+
0.0
1.0
2.0
3.0
E (MeV)
500-50'
Jou
200 kev

Counting rates



Kinematics

$E_i = 4$ GeV

$\omega = E\gamma \sim 2.2$ GeV

$p_k = 1.9$ GeV

$\theta_e = \theta_k = 6^\circ$

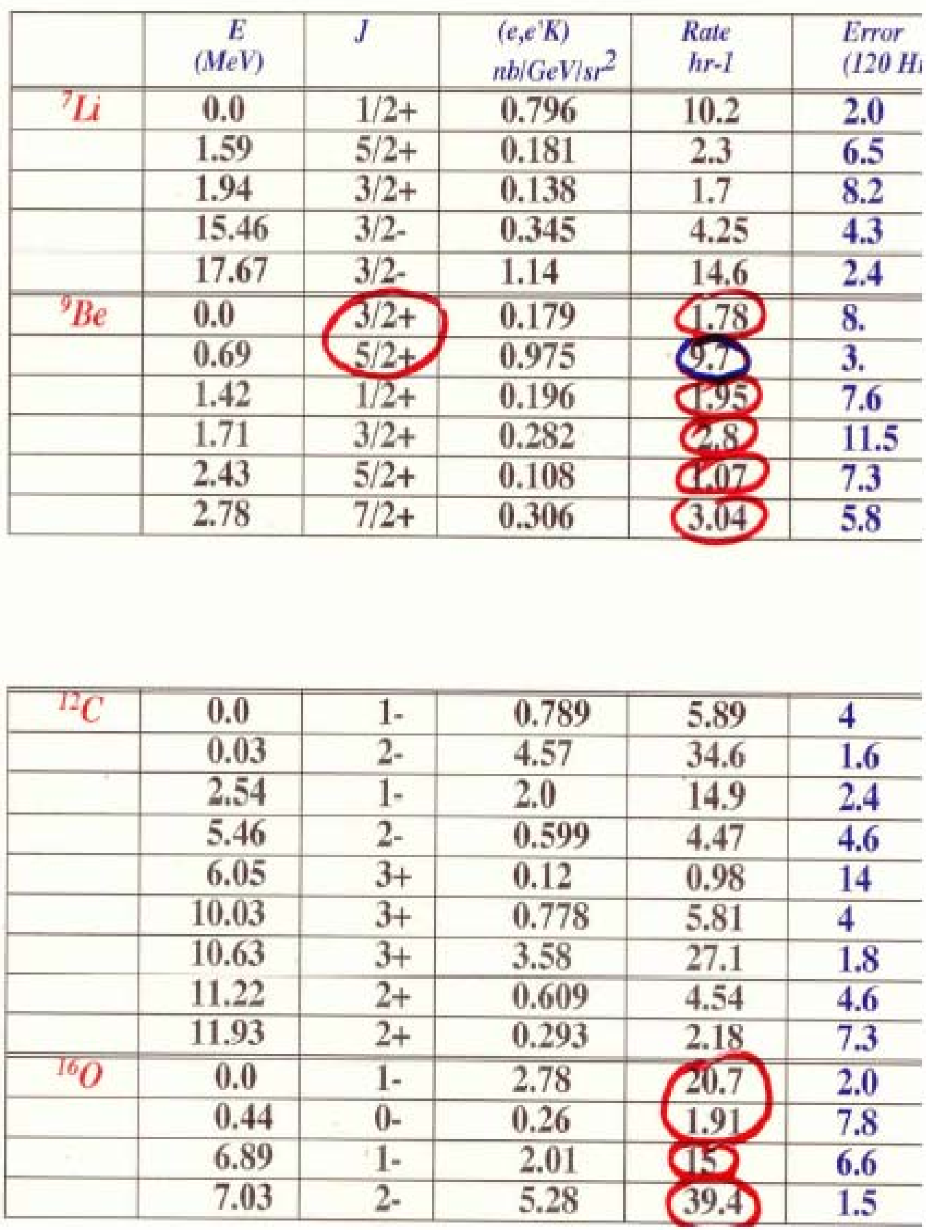
$Q^2 = 0.0789$ Gev^2

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

Beam Current: $i = 100\ \mu A$

Target thickness = 100 mg/cm^2



	E (MeV)	J	(e,e'K) nb/GeV/sr^2	Rate hr-1	Error (120 H
^{7}Li	0.0	1/2+	0.796	10.2	2.0
	1.59	5/2+	0.181	2.3	6.5
	1.94	3/2+	0.138	1.7	8.2
	15.46	3/2-	0.345	4.25	4.3
	17.67	3/2-	1.14	14.6	2.4
^{9}Be	0.0	3/2+	0.179	1.78	8.
	0.69	5/2+	0.975	9.7	3.
	1.42	1/2+	0.196	1.95	7.6
	1.71	3/2+	0.282	2.8	11.5
	2.43	5/2+	0.108	1.07	7.3
	2.78	7/2+	0.306	3.04	5.8

^{12}C	0.0	1-	0.789	5.89	4
	0.03	2-	4.57	34.6	1.6
	2.54	1-	2.0	14.9	2.4
	5.46	2-	0.599	4.47	4.6
	6.05	3+	0.12	0.98	14
	10.03	3+	0.778	5.81	4
	10.63	3+	3.58	27.1	1.8
	11.22	2+	0.609	4.54	4.6
	11.93	2+	0.293	2.18	7.3
^{16}O	0.0	1-	2.78	20.7	2.0
	0.44	0-	0.26	1.91	7.8
	6.89	1-	2.01	15	6.6
	7.03	2-	5.28	39.4	1.5

1. **^{12}C**: comparison with present data, better understanding of the data with hadronic probes (additional peaks found with respect to the predictions).

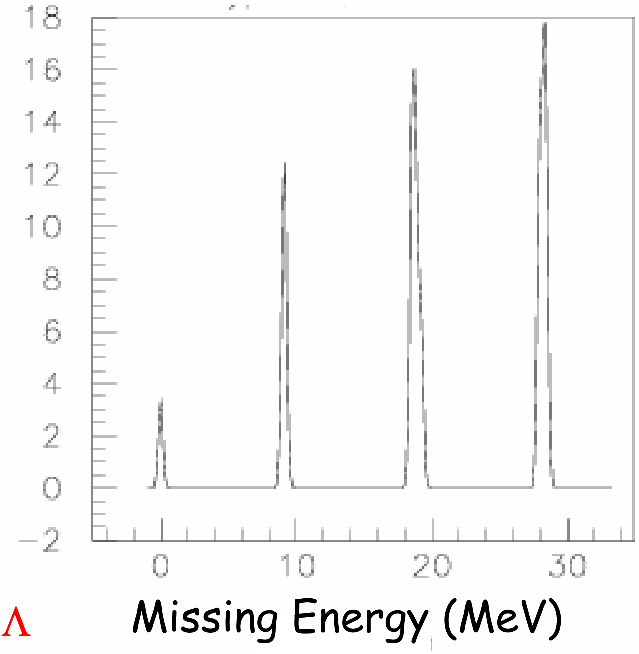
2. **^{9}Be**: spin doublets, s-s potential parameter clarification.

3. **^{7}Li**: large neutron excess

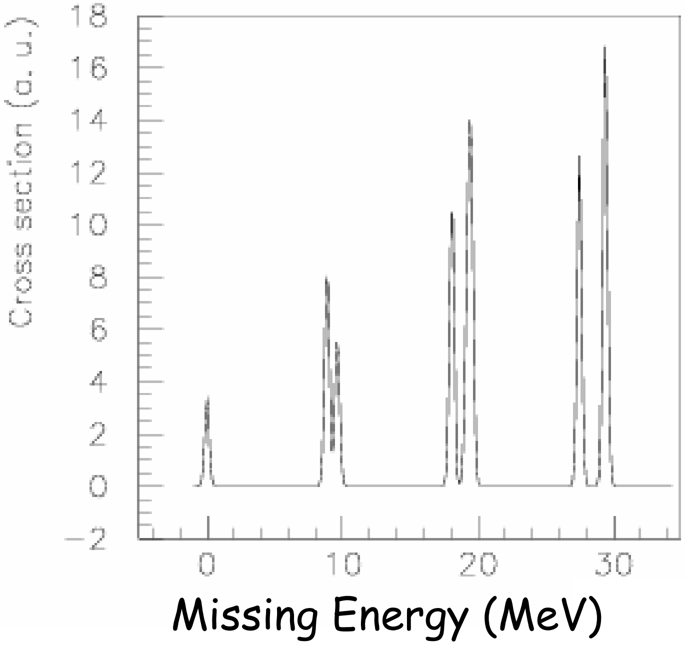
4. **^{16}O**: "simple" structure, ground state doublet investigation

^{52}Cr ? : due to the stability of ^{51}V core, the **level structure** should be rather **simple**. Expectation supported by **spectroscopy on ^{51}V**. Tipically the **cross section** for heavier target are **lower**. It is observed that this **suppression is dependent to 2J+1**. **For this reason** the cross section for elettroproduction of $^{52}V_{\Lambda}$ should be **comparable with ^{12}C -> $^{12}B_{\Lambda}$** or ^{9}Be -> $^{9}Li_{\Lambda}$ cases

Expected spectra for ^{52}Cr



$^{52}Cr \rightarrow {}^{52}V_{\Lambda}$

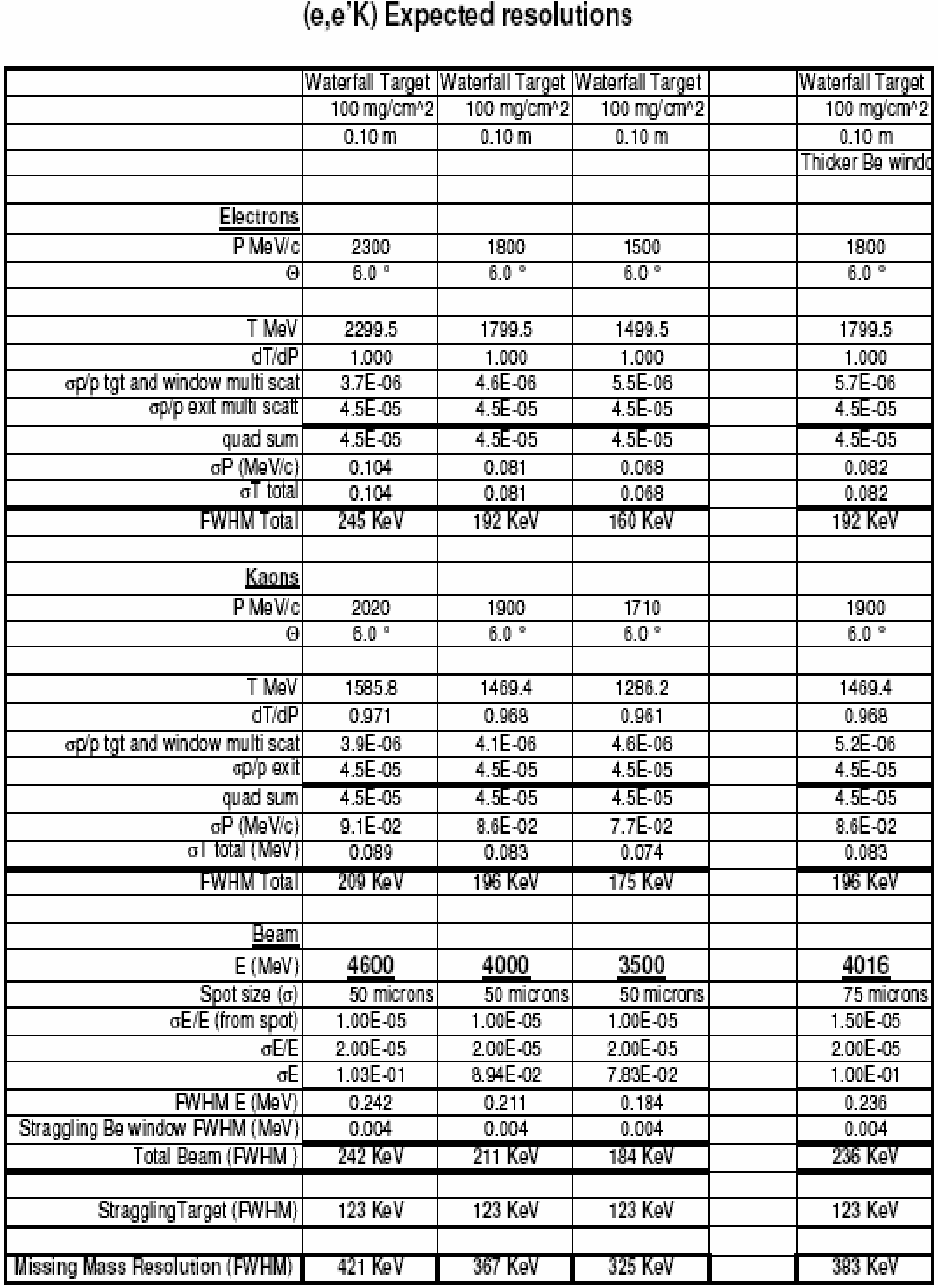


Calculations (M. Sotona) from Woods-Saxon potential with two different hypotesis:

1. V_{LS} = 0.4 MeV, to fit splitting measured in γ spectroscopy
2. V_{LS} = 2.0 MeV, to fit widening of d peak in $^{51}V_{\Lambda}$ found by hadronic probes (Hotchi et al., Phys. Rev. C64, 2001, 044302).

Note: this 2-nd **widening** may be **partially** attributed to other **structure effects**

June 2002 optics tests



(e,e'K) Expected resolutions

	Waterfall Target	Waterfall Target	Waterfall Target		Waterfall Target
	100 mg/cm^2	100 mg/cm^2	100 mg/cm^2		100 mg/cm^2
	0.10 m	0.10 m	0.10 m		0.10 m
					Thicker Be windo
Electrons					
P MeV/c	2300	1800	1500		1800
Θ	6.0 °	6.0 °	6.0 °		6.0 °
T MeV	2299.5	1799.5	1499.5		1799.5
dT/dP	1.000	1.000	1.000		1.000
σp/p tgt and window multi scat	3.7E-06	4.6E-06	5.5E-06		5.7E-06
σp/p exit multi scatt	4.5E-05	4.5E-05	4.5E-05		4.5E-05
quad sum	4.5E-05	4.5E-05	4.5E-05		4.5E-05
σP (MeV/c)	0.104	0.081	0.068		0.082
σT total	0.104	0.081	0.068		0.082
FWHM Total	245 KeV	192 KeV	160 KeV		192 KeV
Kaons					
P MeV/c	2020	1900	1710		1900
Θ	6.0 °	6.0 °	6.0 °		6.0 °
T MeV	1585.8	1469.4	1286.2		1469.4
dT/dP	0.971	0.968	0.961		0.968
σp/p tgt and window multi scat	3.9E-06	4.1E-06	4.6E-06		5.2E-06
σp/p exit	4.5E-05	4.5E-05	4.5E-05		4.5E-05
quad sum	4.5E-05	4.5E-05	4.5E-05		4.5E-05
σP (MeV/c)	9.1E-02	8.6E-02	7.7E-02		8.6E-02
σT total (MeV)	0.089	0.083	0.074		0.083
FWHM Total	209 KeV	196 KeV	175 KeV		196 KeV
Beam					
E (MeV)	4600	4000	3500		4016
Spot size (σ)	50 microns	50 microns	50 microns		75 microns
σE/E (from spot)	1.00E-05	1.00E-05	1.00E-05		1.50E-05
σE/E	2.00E-05	2.00E-05	2.00E-05		2.00E-05
σE	1.03E-01	8.94E-02	7.83E-02		1.00E-01
FWHM E (MeV)	0.242	0.211	0.184		0.236
Straggling Be window FWHM (MeV)	0.004	0.004	0.004		0.004
Total Beam (FWHM)	242 KeV	211 KeV	184 KeV		236 KeV
StragglingTarget (FWHM)	123 KeV	123 KeV	123 KeV		123 KeV
Missing Mass Resolution (FWHM)	421 KeV	367 KeV	325 KeV		383 KeV

(Target (^{12}C): 114 mg/cm^2)

Kinematics:

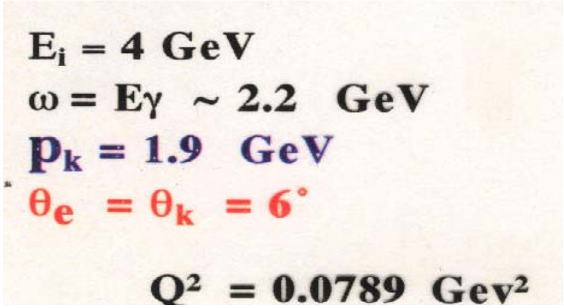
E_i= 4.7 GeV

P_e= 3.8 GeV/c

P_{hadr}=1.5 GeV/c

Resolution 720 KeV

with our setup (no windows) and kinematics



E_i = 4 GeV

ω = Eγ ~ 2.2 GeV

p_K = 1.9 GeV

$\theta_e = \theta_K = 6^\circ$

Q^2 = 0.0789 Gev²

~ 350 keV

Conclusions

- very good energy resolution hypernuclear spectroscopy experiment on 1p shell nuclei will be performed in Hall A

- first septum magnet used for GDH: performances as expected

- second septum being installed

- challenging PID
  - aerogel and RICH performing as expected

- we are ready!