

Hypernuclear Physics with FINUDA now and in the future



Tullio Bressani
KEK-RIKEN-INFN meeting
Tsukuba, December 13-14, 2004



The FINUDA Collaboration

2

- ■ Bari University and I.N.F.N. Bari
- ■ Brescia University and I.N.F.N. Pavia
- KEK
- ■ L.N.F. / I.N.F.N. Frascati
- ■ Pavia University and I.N.F.N. Pavia
- RIKEN
- ■ Seoul National University
- ■ Teheran Shahid Beheshty University
- ■ Torino University and I.N.F.N. Torino
- ■ Torino Polytechnic and I.N.F.N. Torino
- ■ Trieste University and I.N.F.N. Trieste
- ■ TRIUMF





Outline

1) the FINUDA experiment

- the physics program
- the apparatus

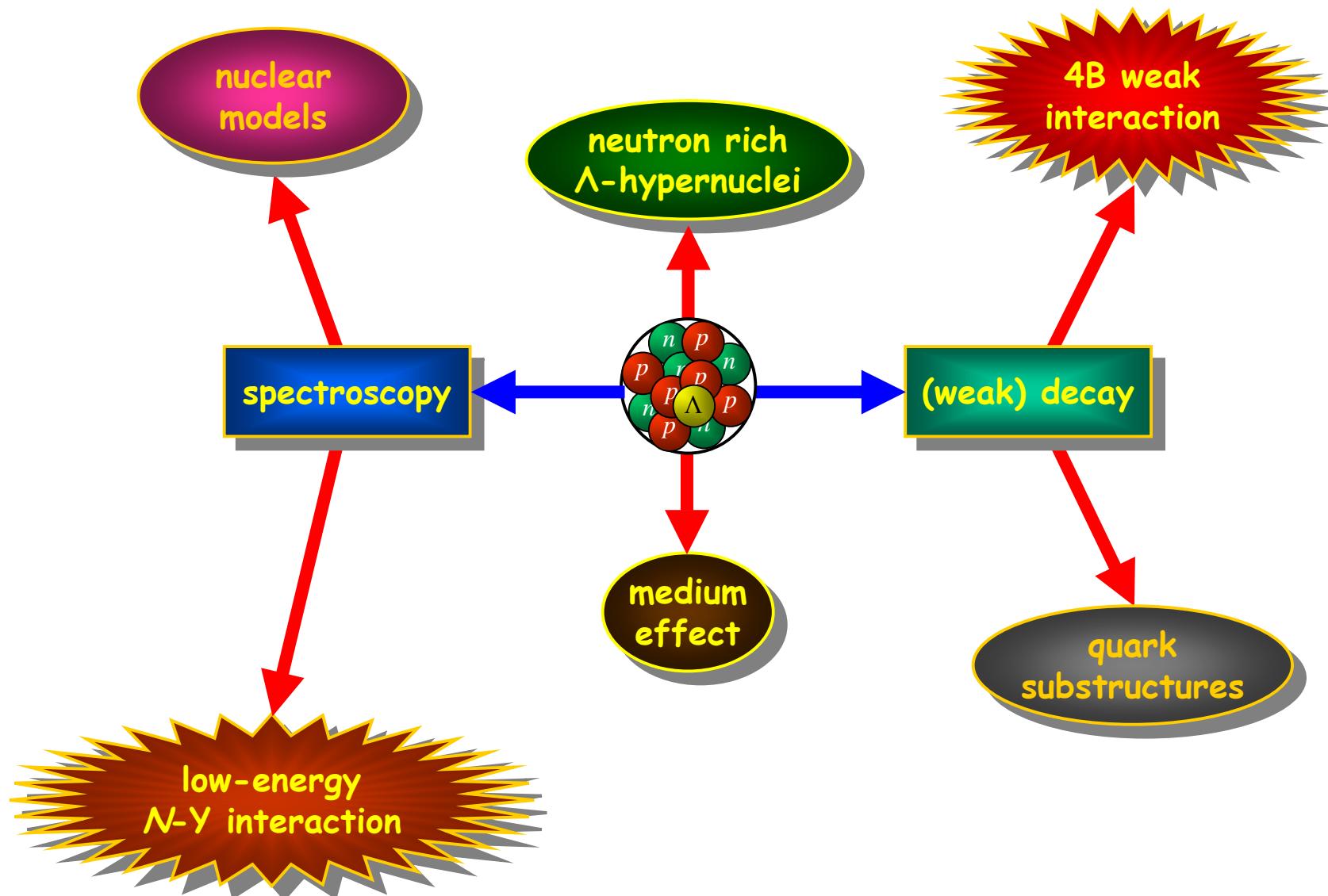
2) the results

- hypernuclear spectroscopy
- search for neutron-rich hypernuclei
- hypernucleus (rare) decays
- Kaon bound state K-pp

3) future plans

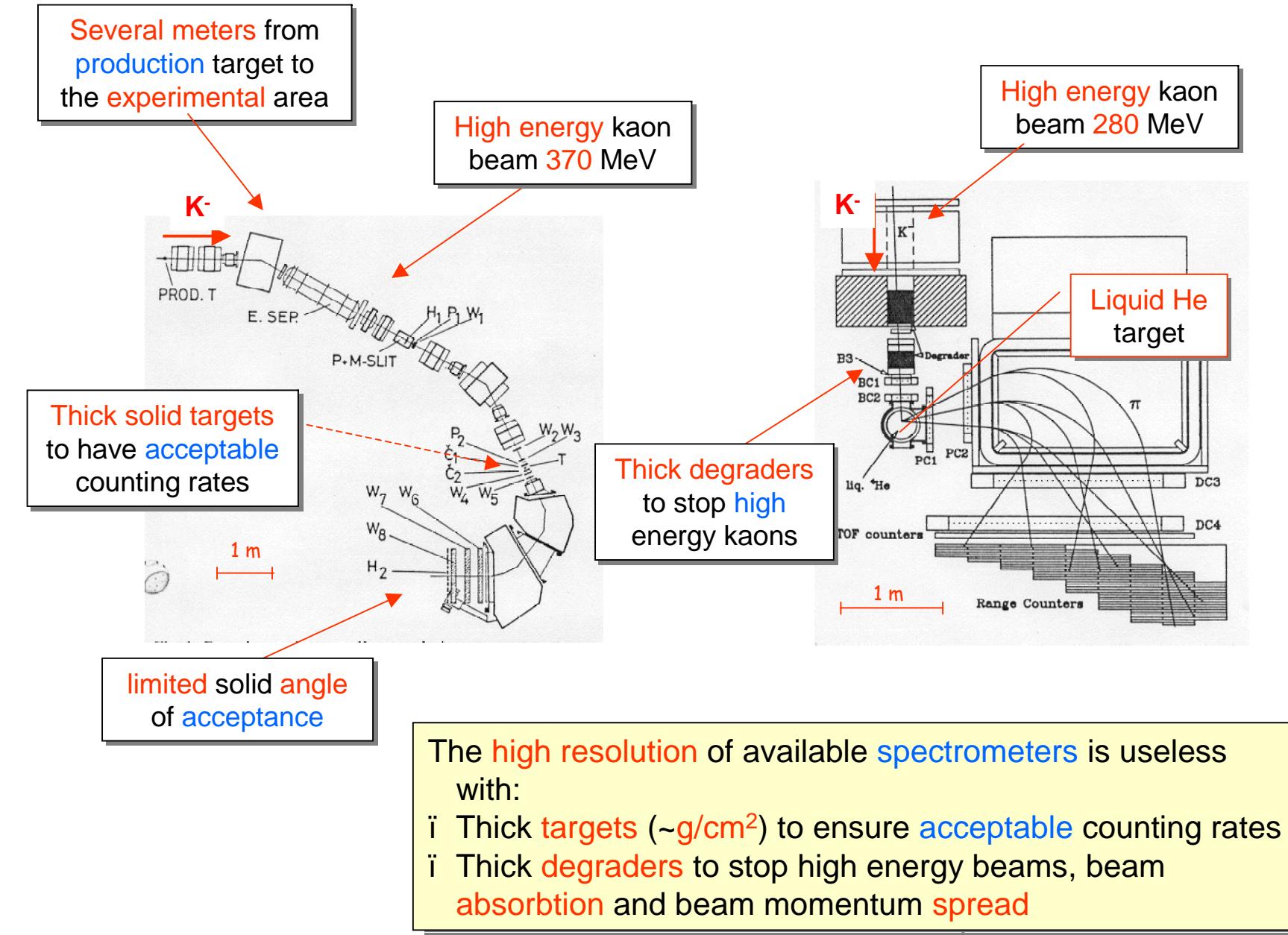


Physics output ($S=-1$)





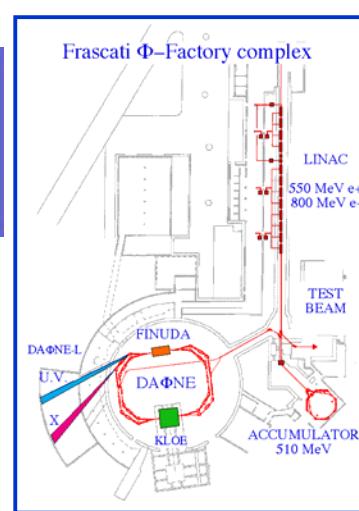
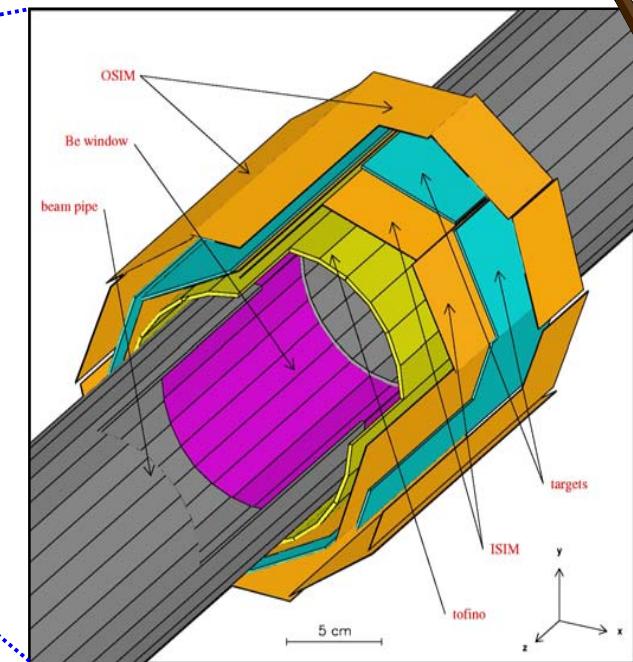
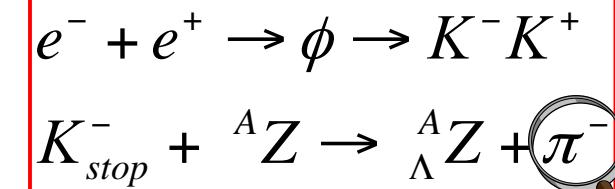
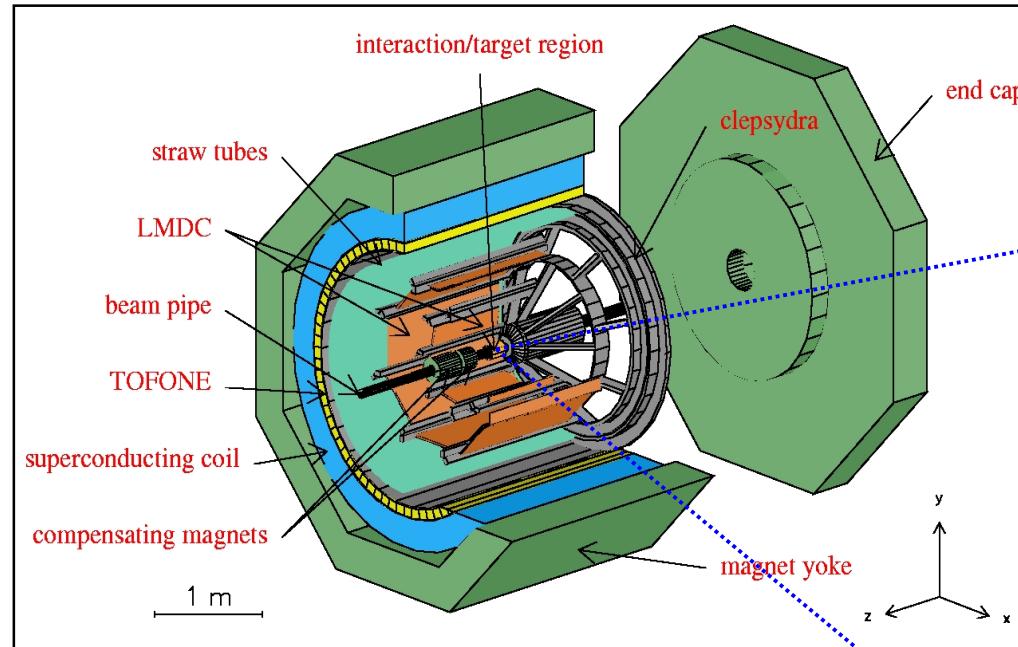
Drawbacks of the secondary beam techniques



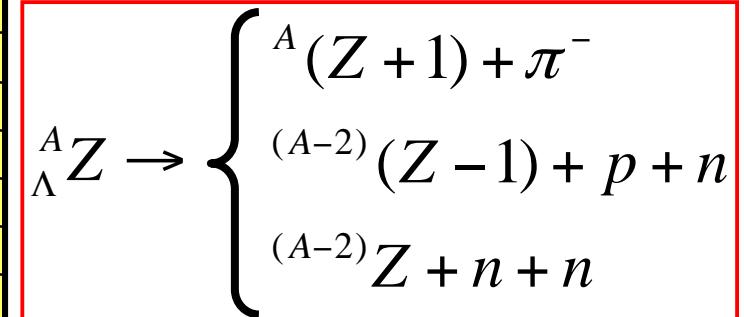


FINUDA @ DAΦNE

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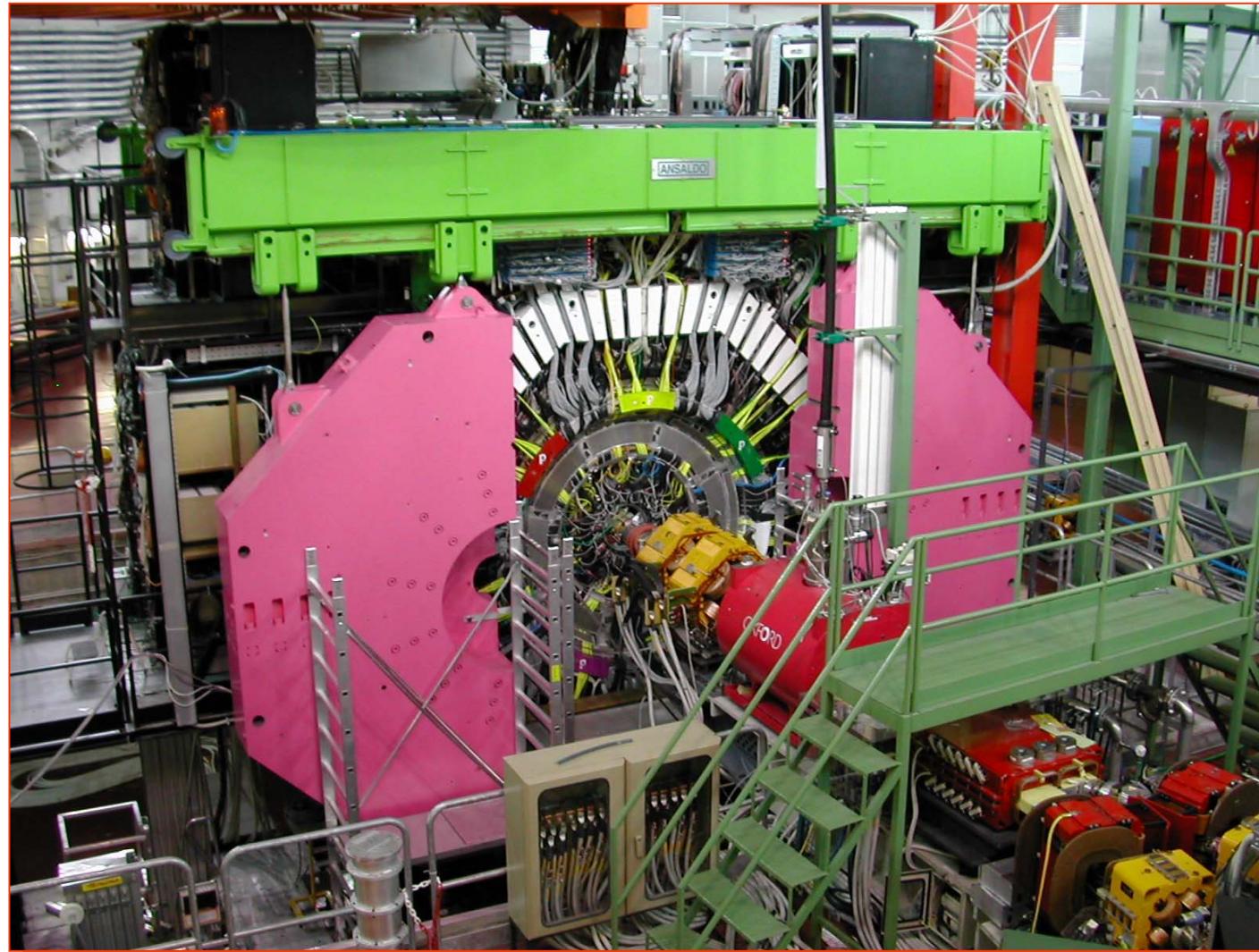


energy	510 MeV
luminosity	$5 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
σ_x (rms)	2.11 mm
σ_y (rms)	0.021 mm
σ_z (rms)	35 mm
bunch length	30 mm
crossing angle	12.5 mrad
frequency (max)	368.25 MHz
bunch/ring	up to 120
part./bunch	$8.9 \cdot 10^{10}$
current/ring	5.2 A (max)



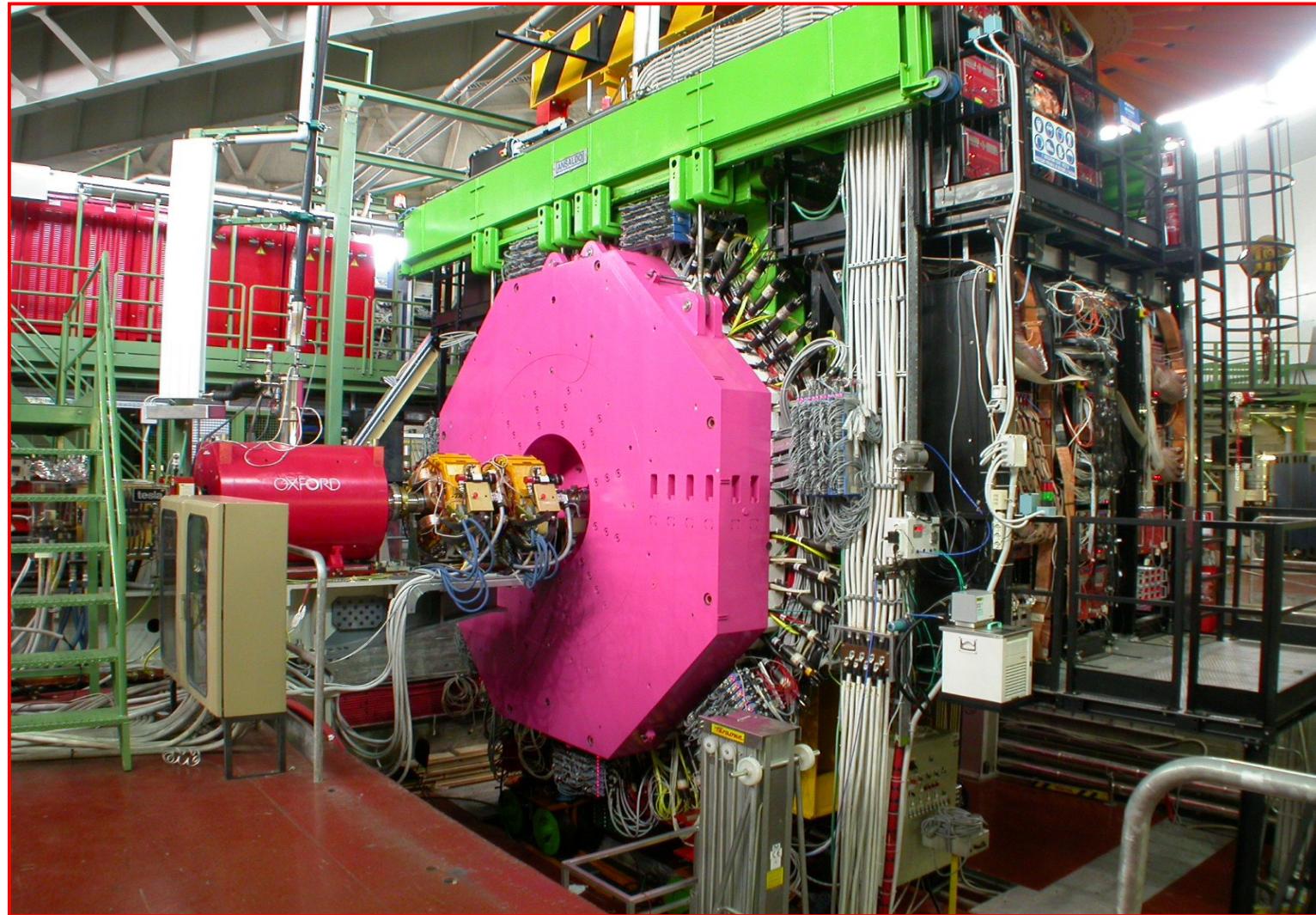


FINUDA @ DAΦNE



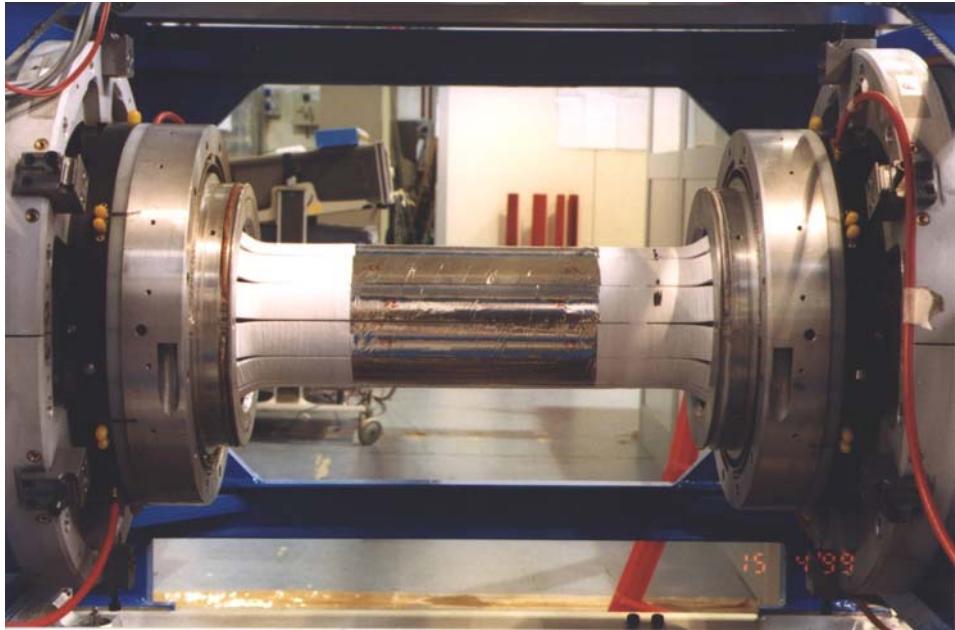


FINUDA @ DAΦNE





Detectors of the internal region



internal scintillator barrel
mounted (tofino)

silicon microstrips arrays
ISIM/OSIM





FINUDA detectors performances

❖ s.c. solenoid: $B = 1.0 \text{ T}$; field homogeneity within 2%

❖ interaction/target region: K^+ / K^- identification,
hypernucleus production and detection

ISIM/OSIM: $\sigma_z = 30 \mu\text{m}$; $\Delta E = 20\% \text{ FWHM}$
 TOF_{in} : $\sigma_t = 250 \text{ ps}$

❖ tracking devices: measurement of trajectories
and momenta of charged particles ($\Delta p/p = 3.5\%$)

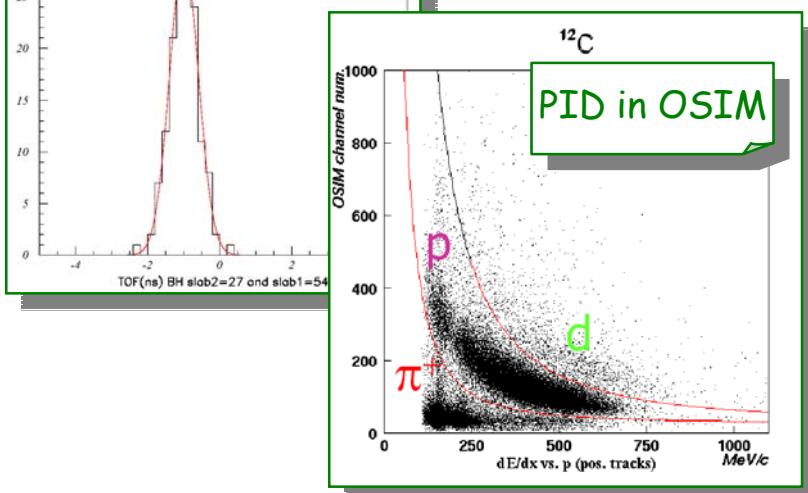
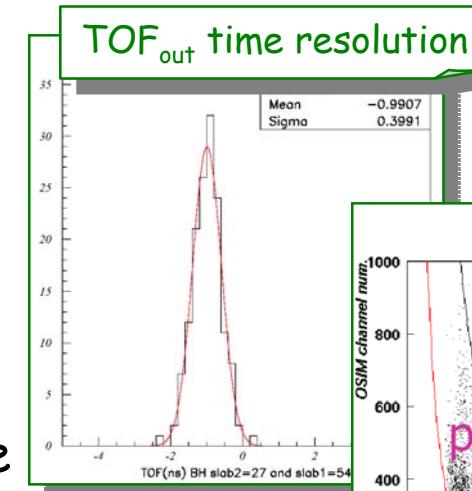
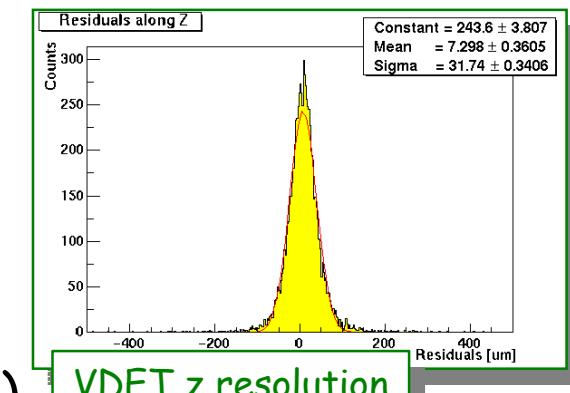
LMDC: $\sigma(\rho, \phi) = 150 \mu\text{m}$; $\sigma_z \leq 1\%$ wire length
STB: $\sigma(\rho, \phi) = 150 \mu\text{m}$; $\sigma_z = 500 \mu\text{m}$

❖ external scintillator barrel: trigger
and neutron detection

TOF_{out} : $\sigma_t = 500 \text{ ps FWHM}$
efficiency $\geq 10\%$; $\Delta E = 8 \text{ MeV}$

❖ He chamber: minimization of particle
multiple scattering

$\Delta p/p$: He atmosphere = 3.5%
air = 2%

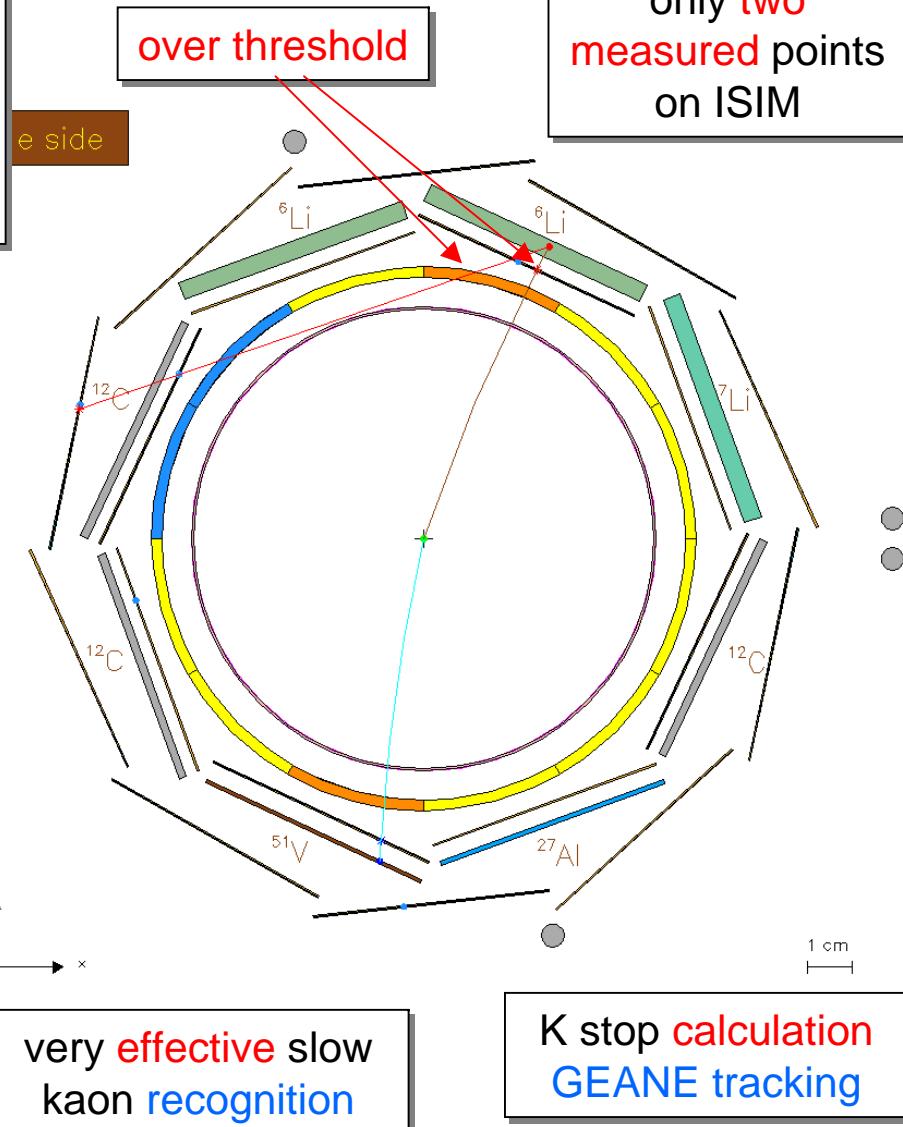
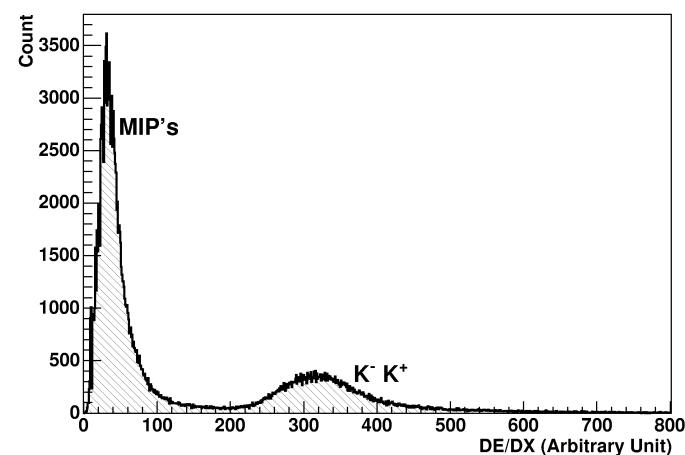
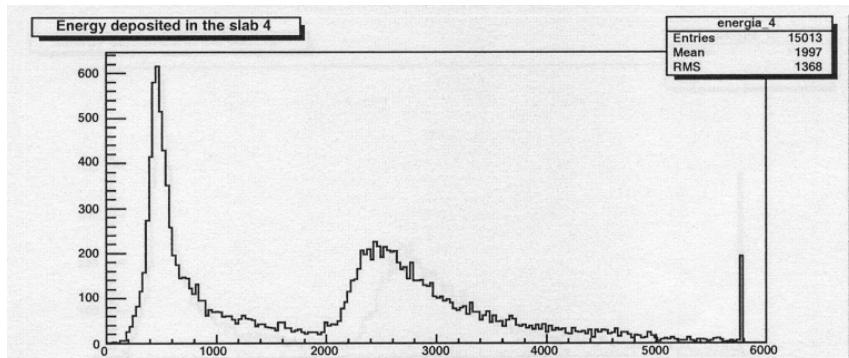




K^+ / K^- identification

Hypernuclear trigger:

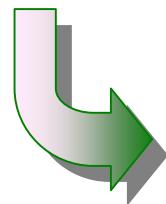
- ii 2 hits on tofino over threshold (kaon)
- ii extended back to back
- ii multiplicity (>2) on tofone
- ii Time correlation tofino-tofone (<10ns)





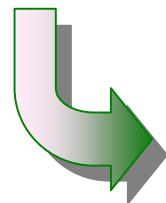
FINUDA key features

- 👉 very thin nuclear targets ($0.1 \div 0.3 \text{ g/cm}^2$)



high resolution spectroscopy

- 👉 coincidence measurement with large acceptance



decay mode study

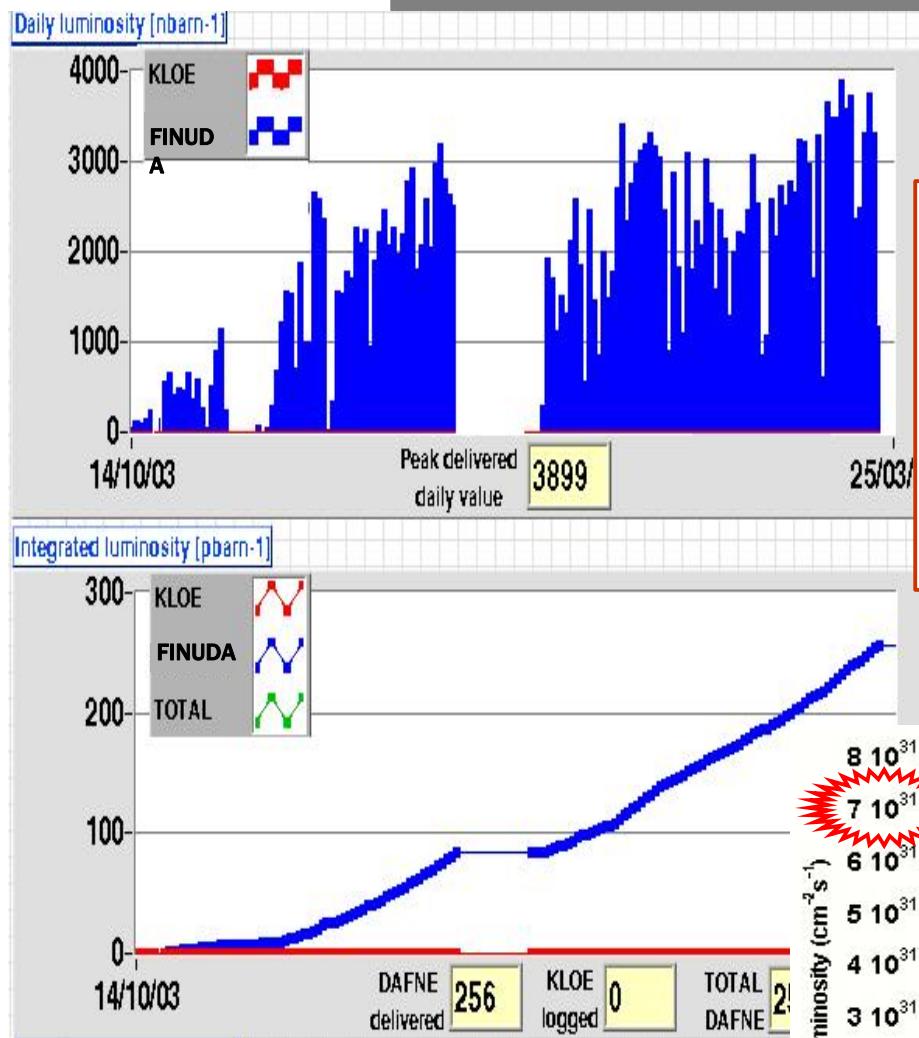
- 👉 irradiation of different targets in the same run



high degree of flexibility

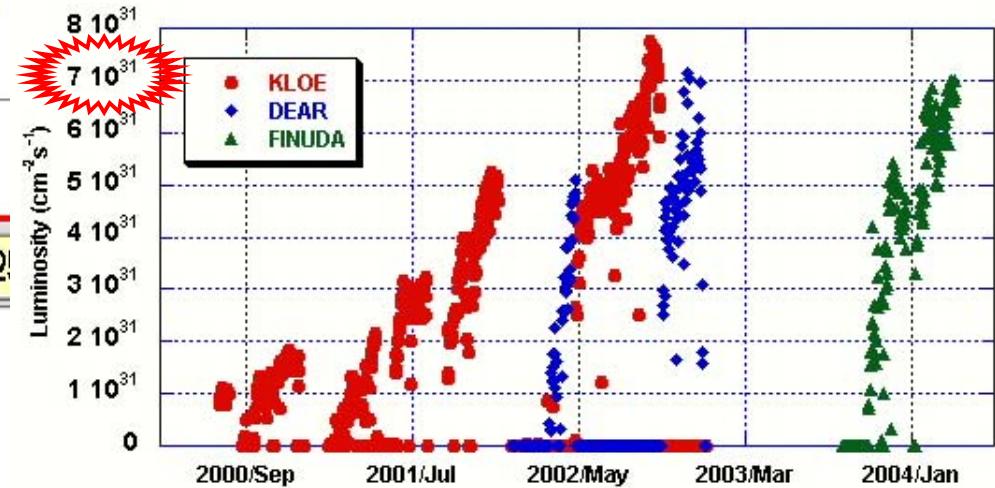


FINUDA first run



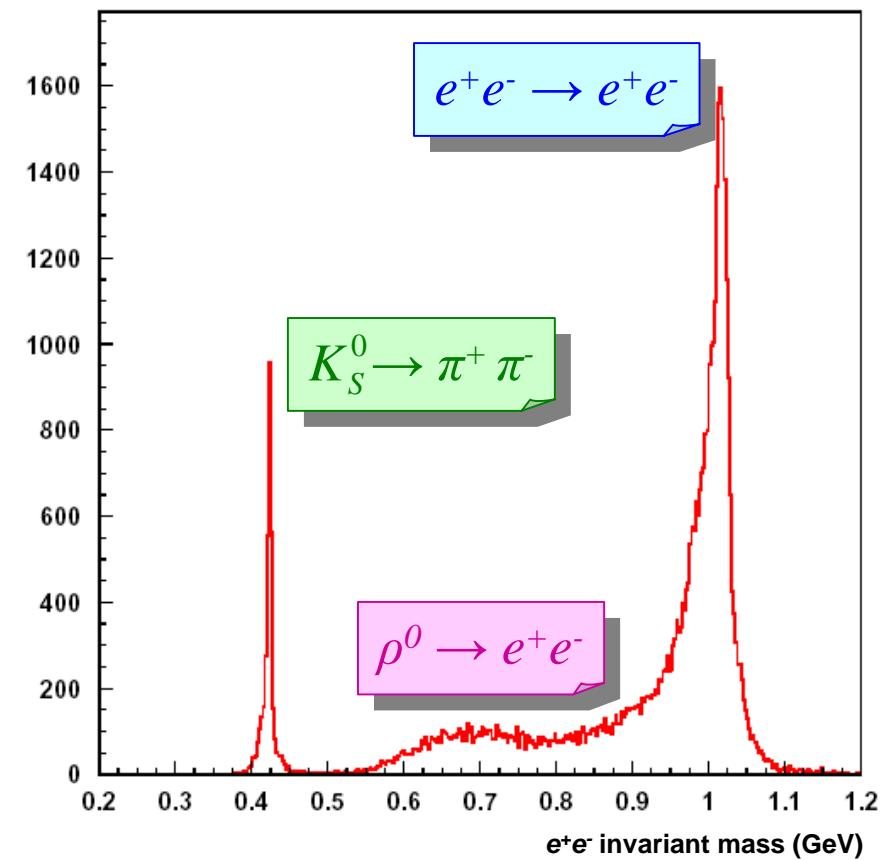
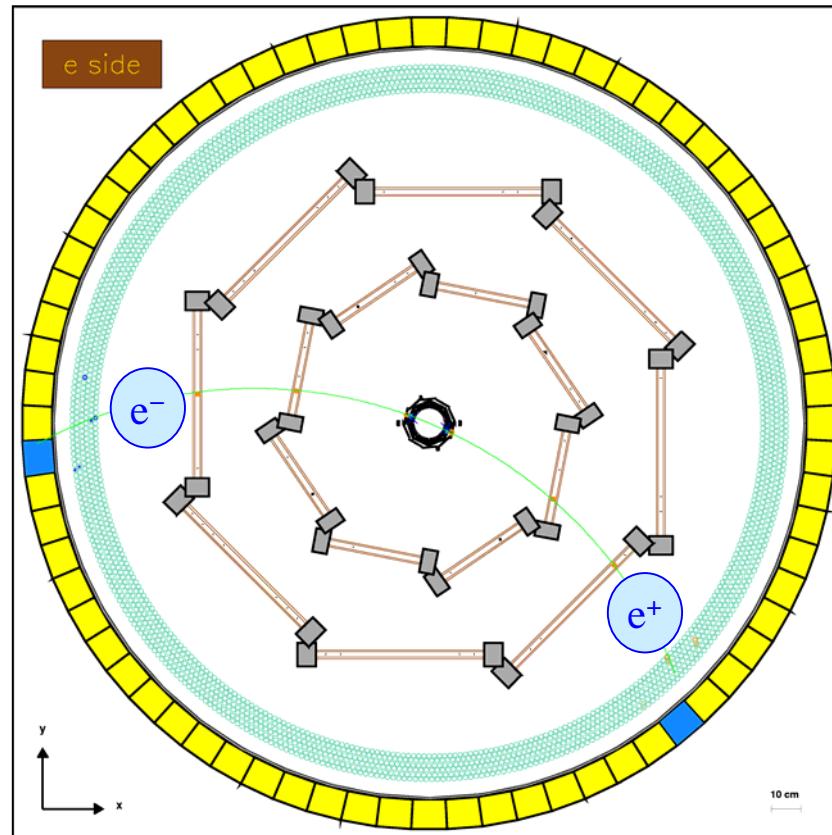
14-Oct-2003 to 22-Mar-2004:

- 250 pb⁻¹ delivered to IP2
 - 33 pb⁻¹ machine tuning
 - 10 pb⁻¹ FINUDA debugging
 - 190 pb⁻¹ useful data taking



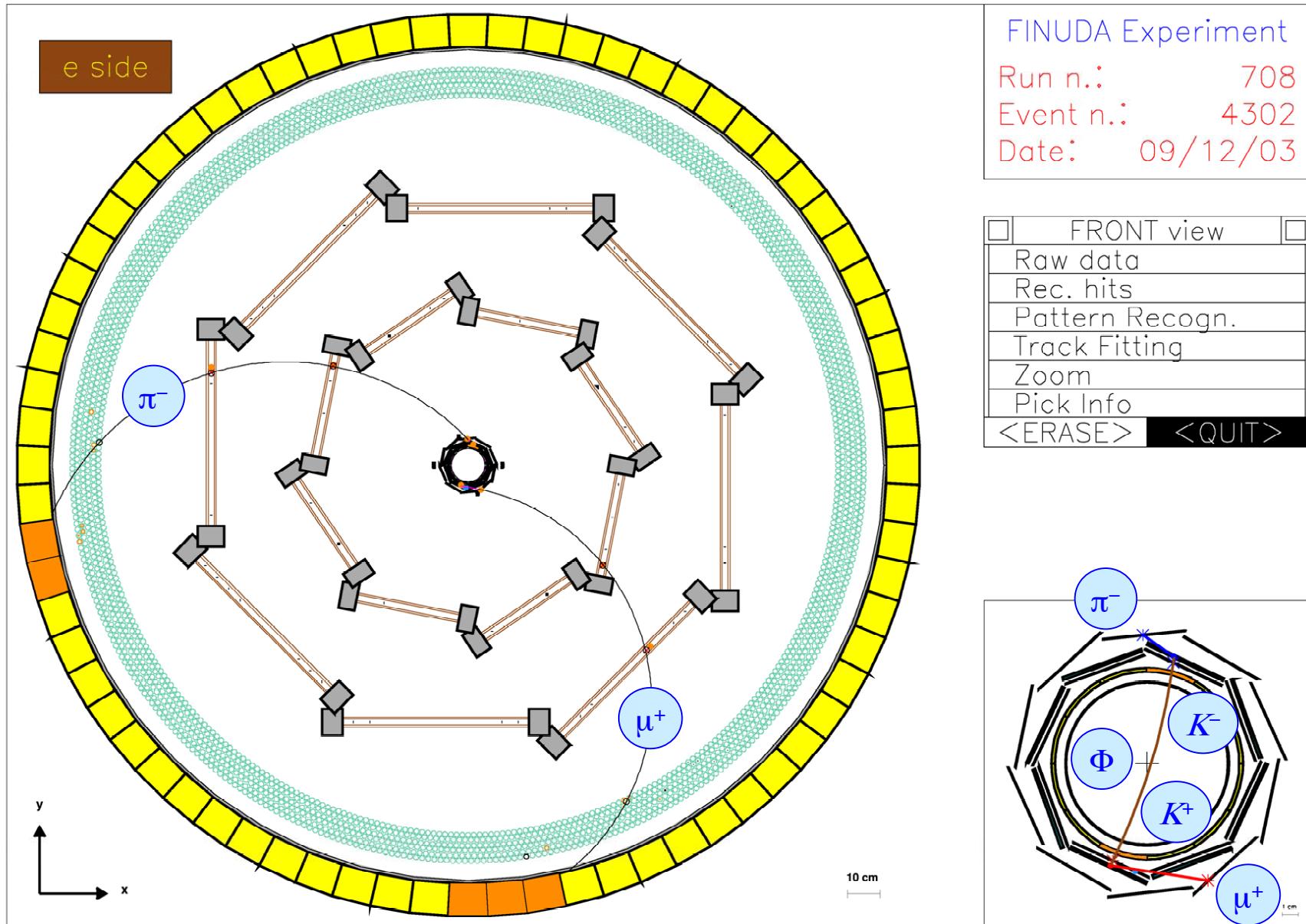


Bhabha event



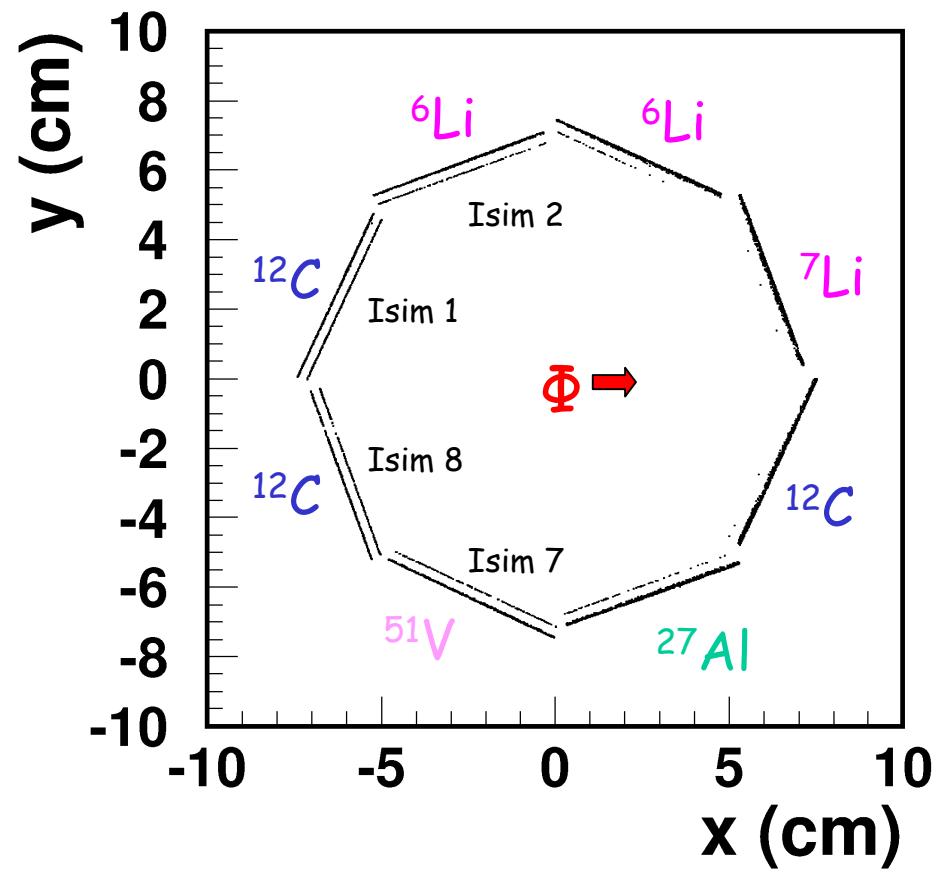
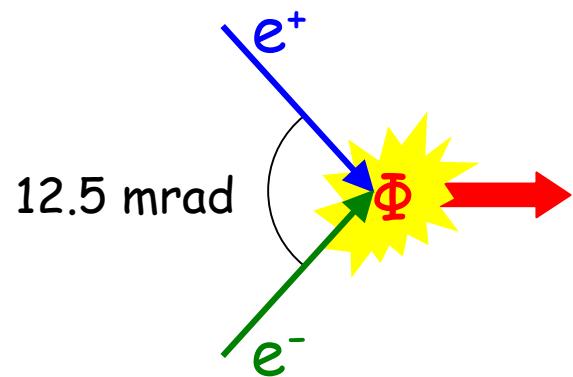
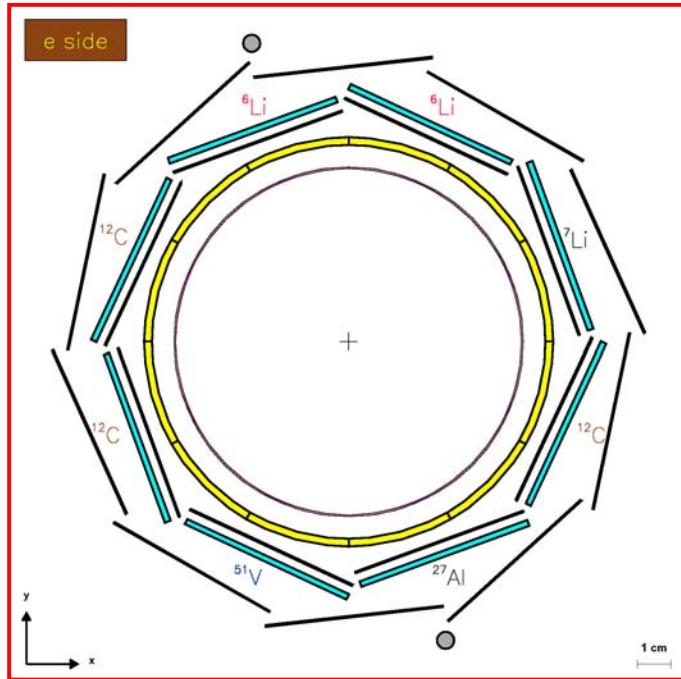


The typical event



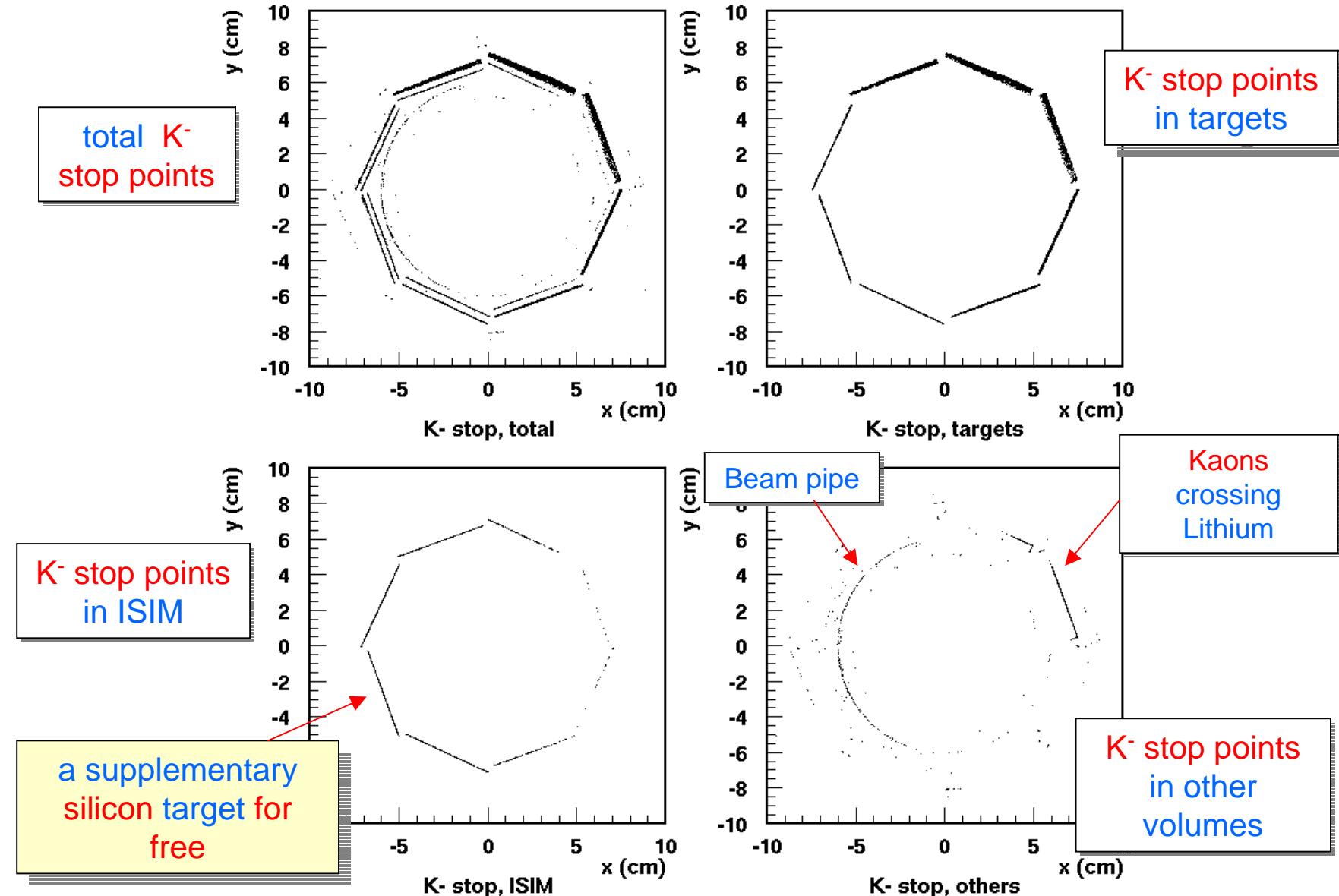


Target envelope by K^- stopping points



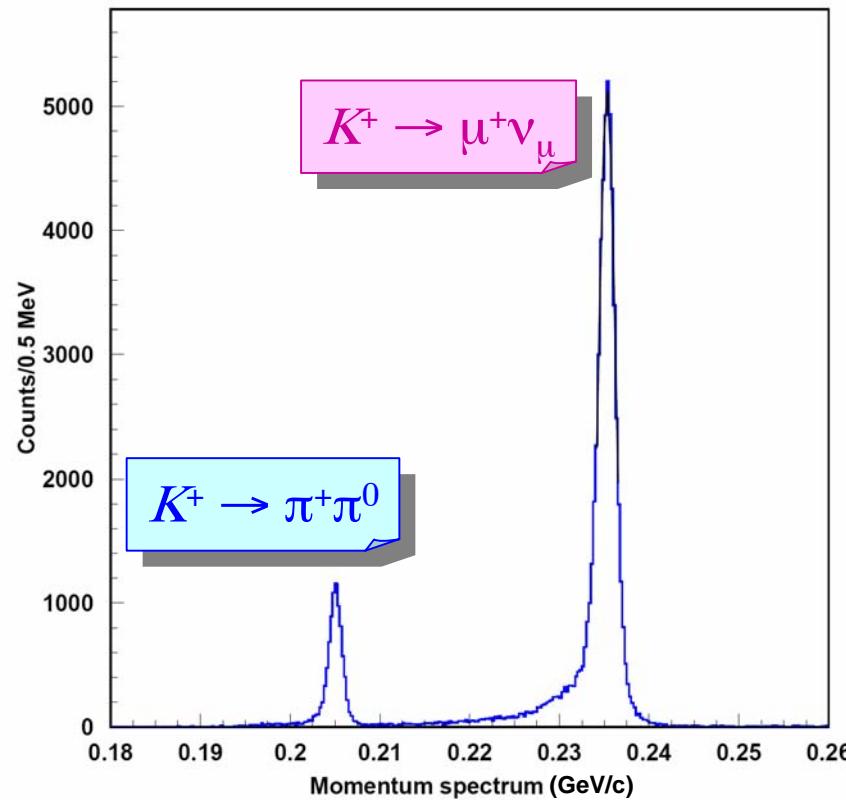


K^+ / K^- stopping points

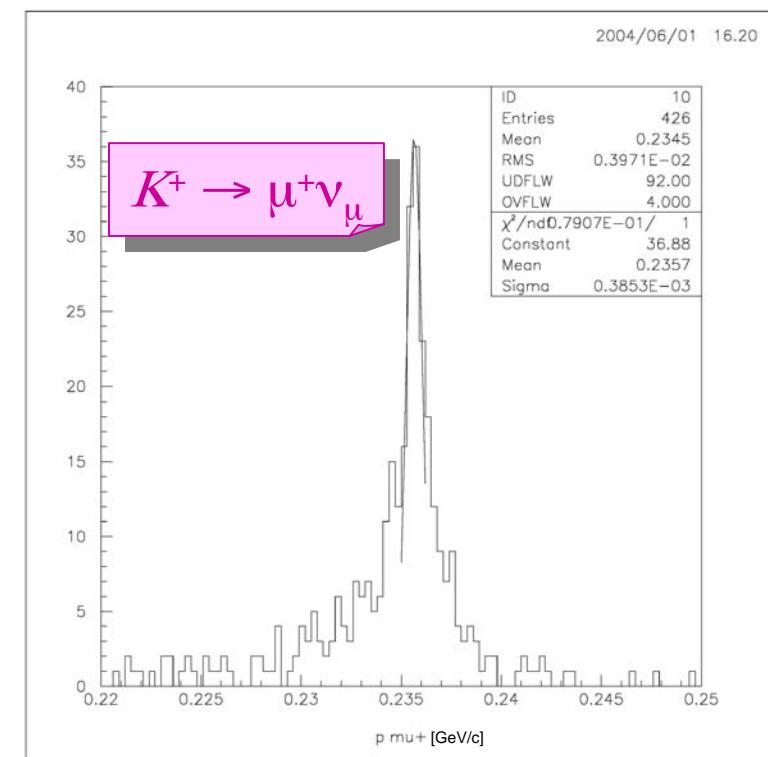




Improvement in momentum resolution

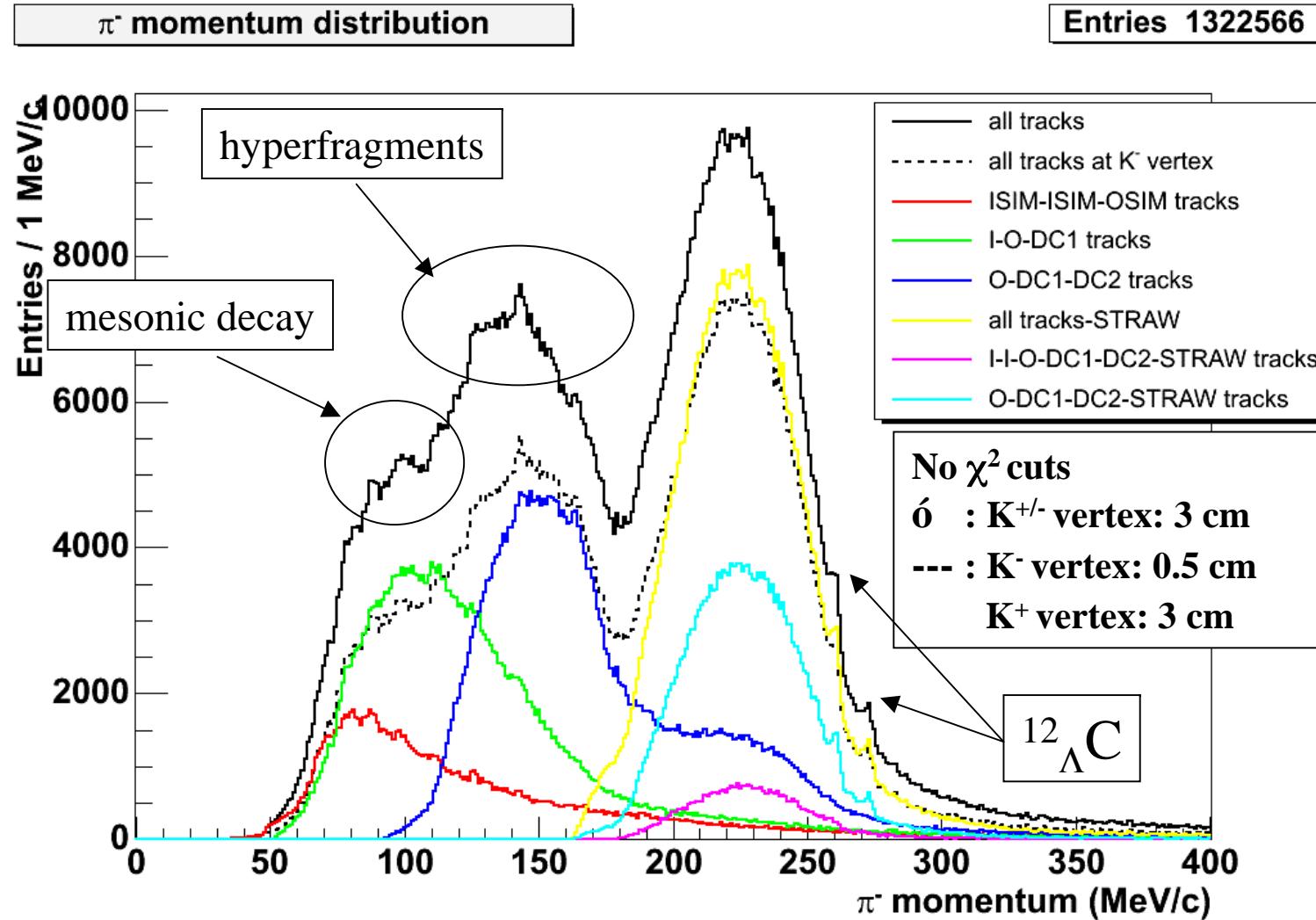


$\Delta p/p \sim 0.6\%$



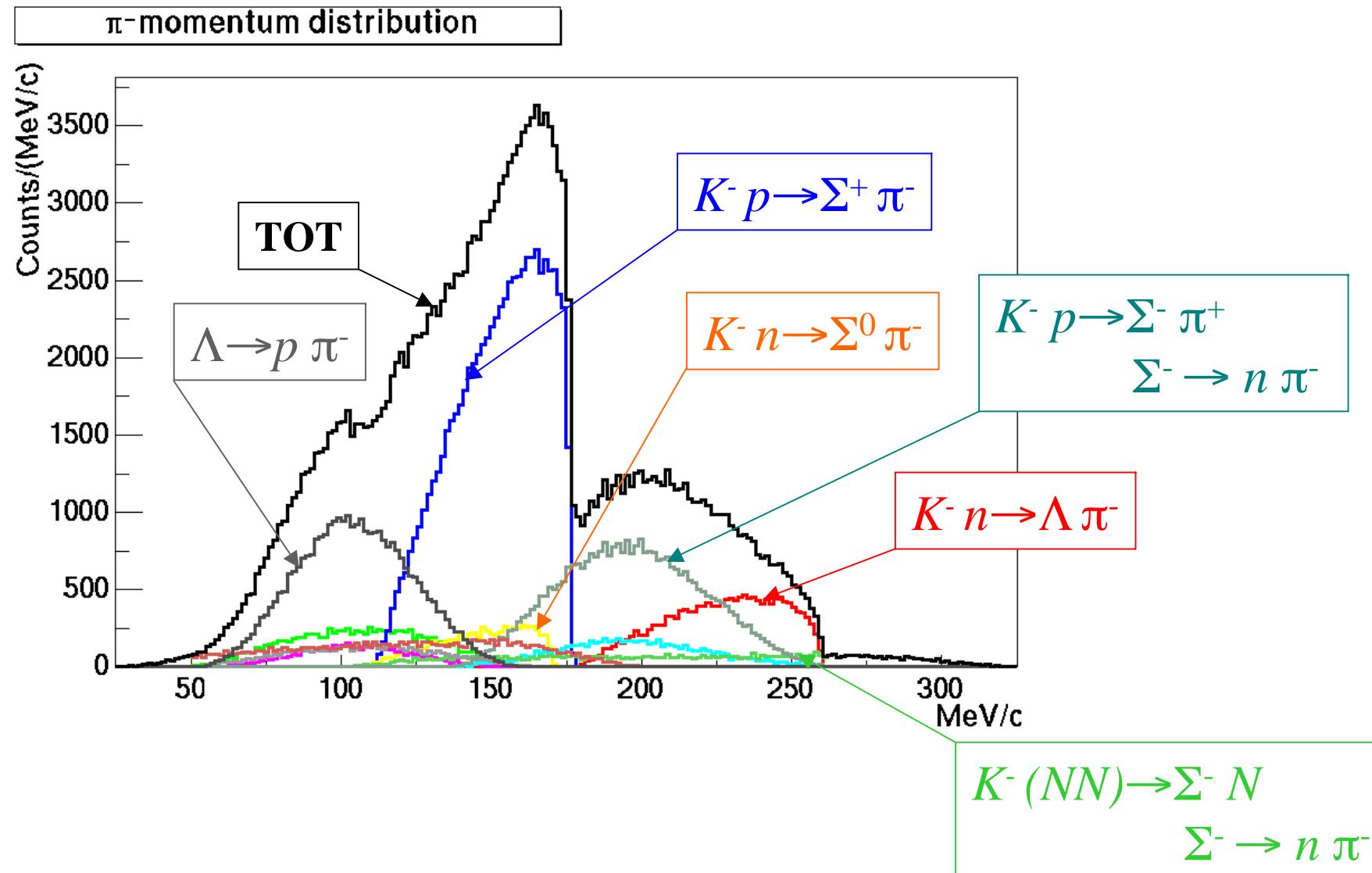


$K^- {}^{12}C \Rightarrow \pi^- X$ inclusive spectra



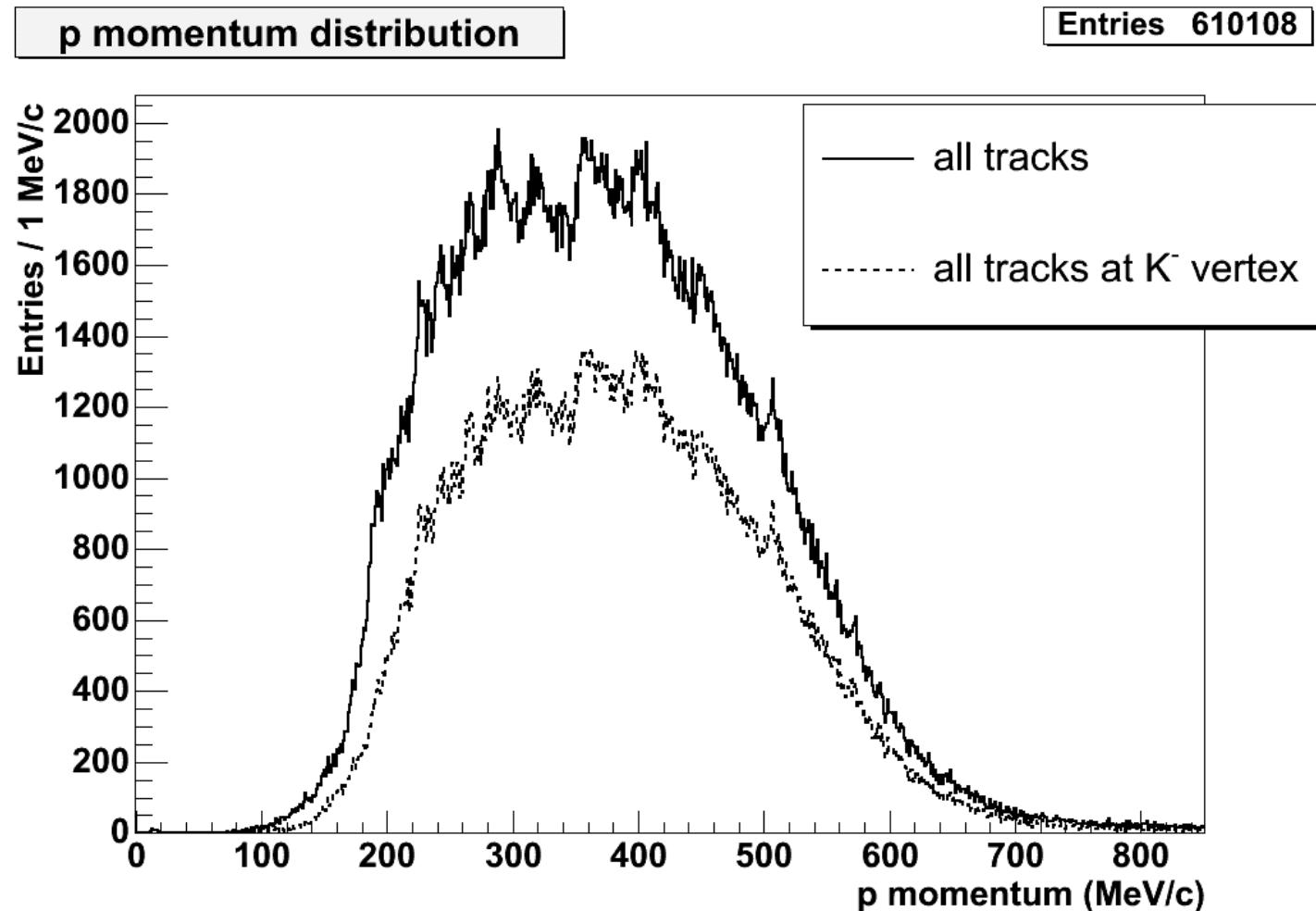


Background reactions: π^- spectrum



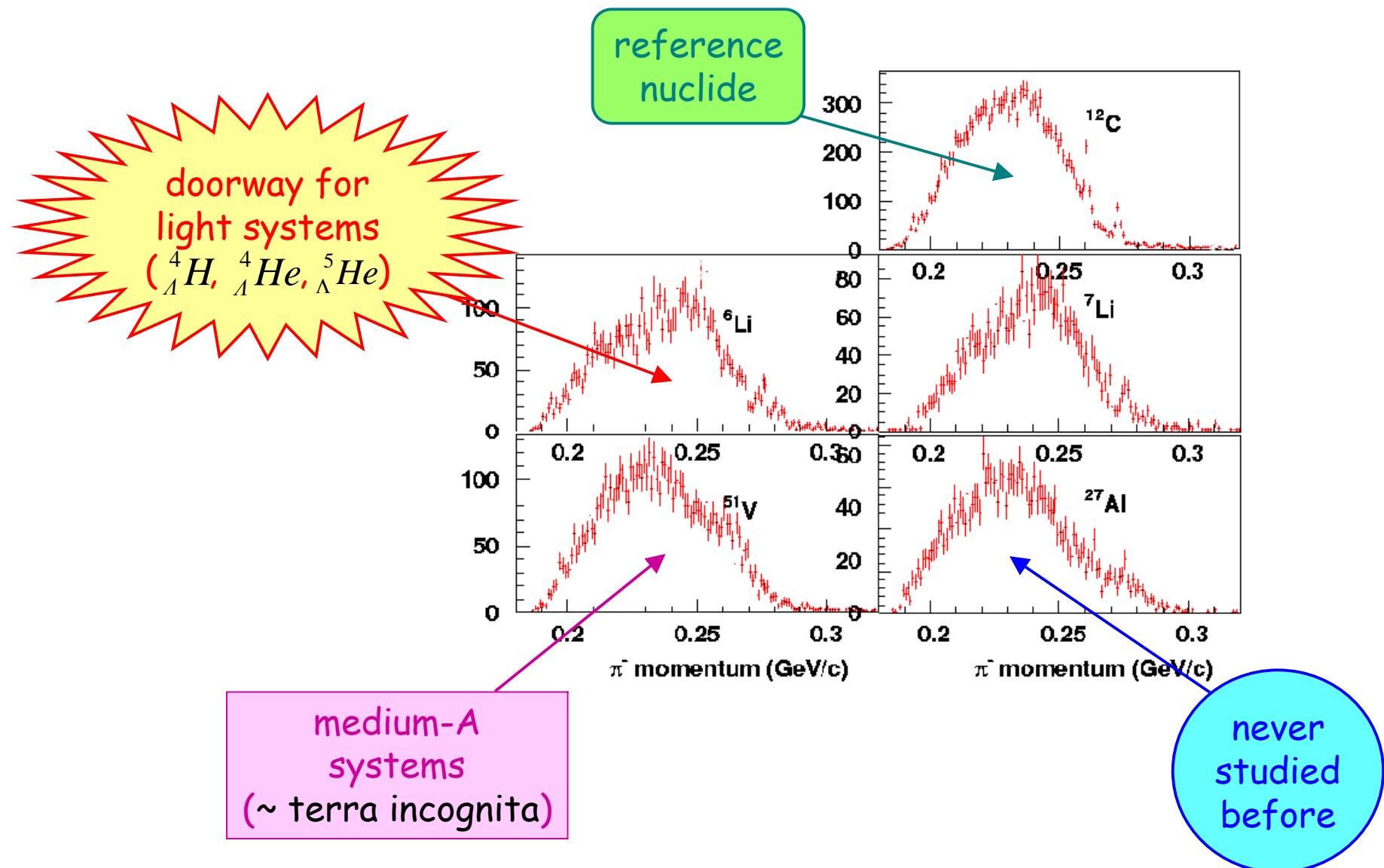


$K^- {}^{12}C \Rightarrow p X$ inclusive spectrum



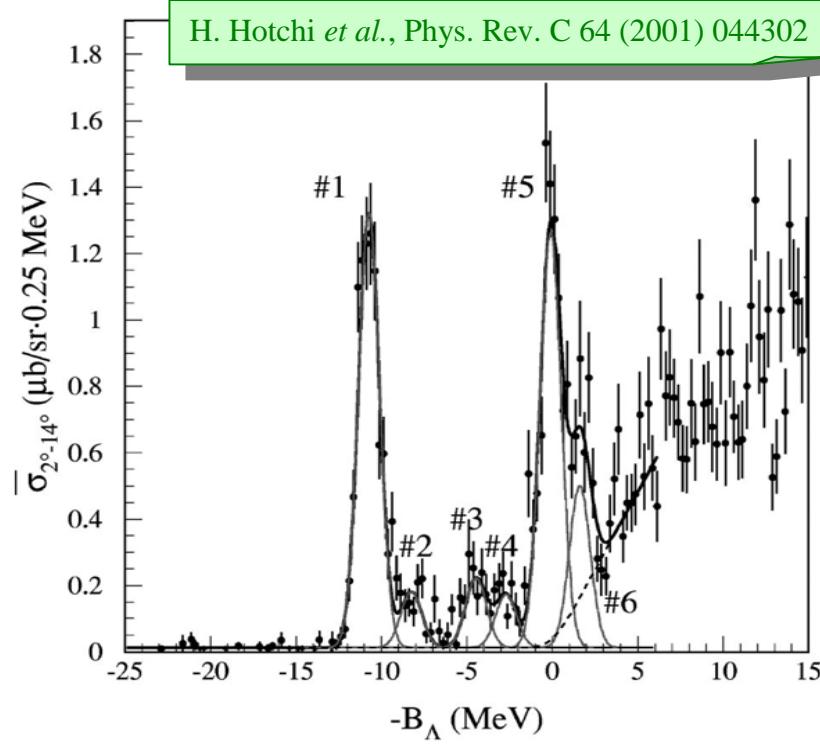


Spectroscopy



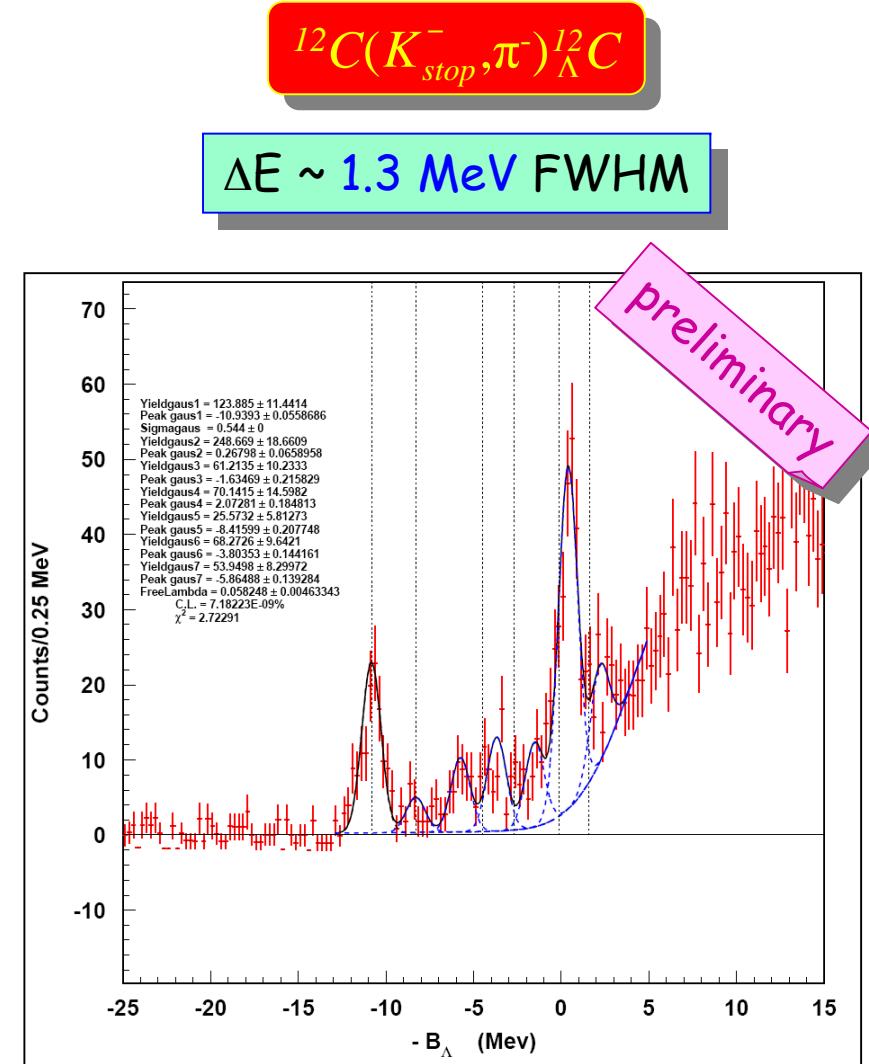


FINUDA vs. KEK-E369



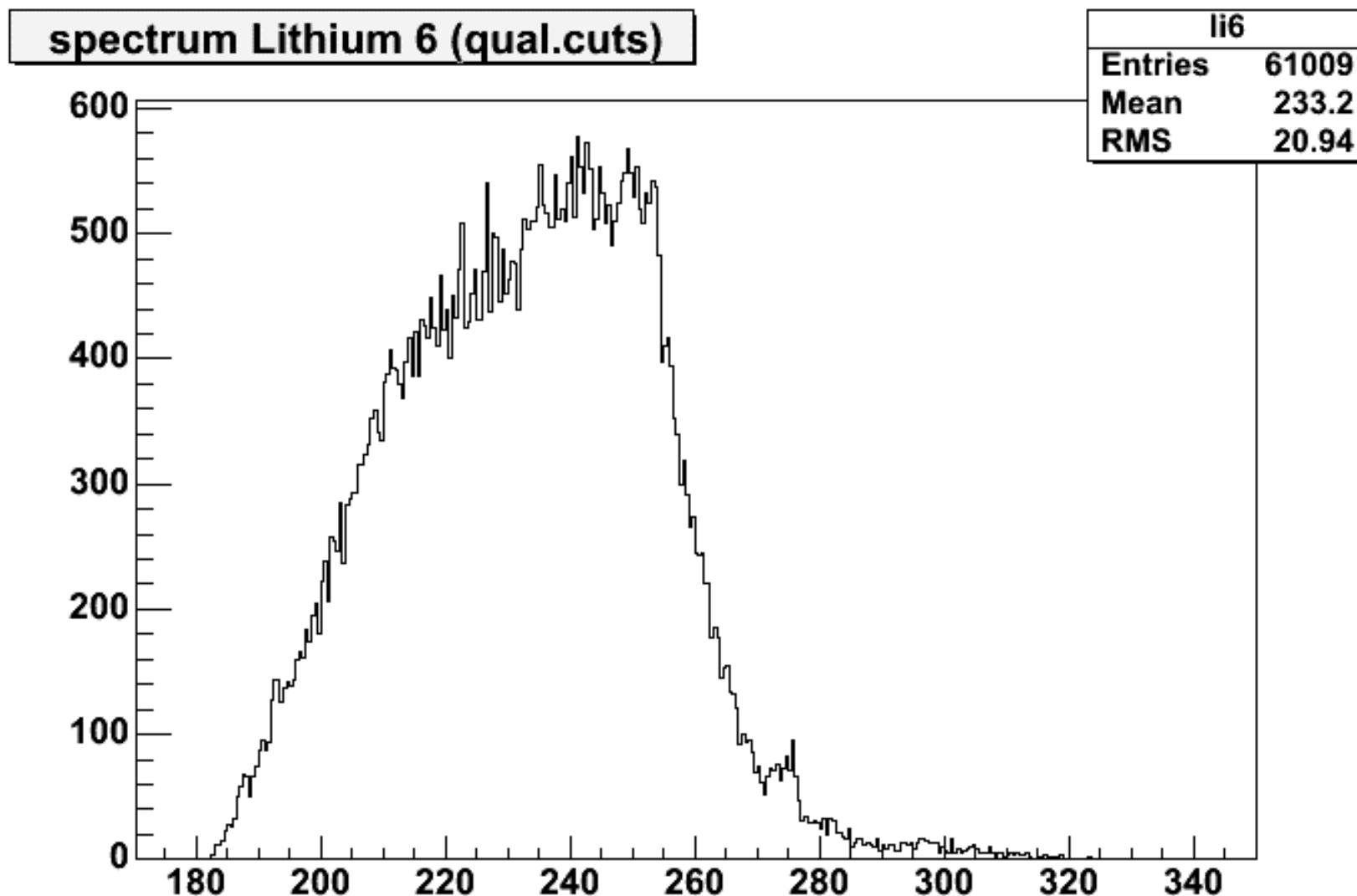
$^{12}\text{C}(\pi^+, K^+) \Lambda^{12}\text{C}$

$\Delta E \sim 1.5 \text{ MeV FWHM}$



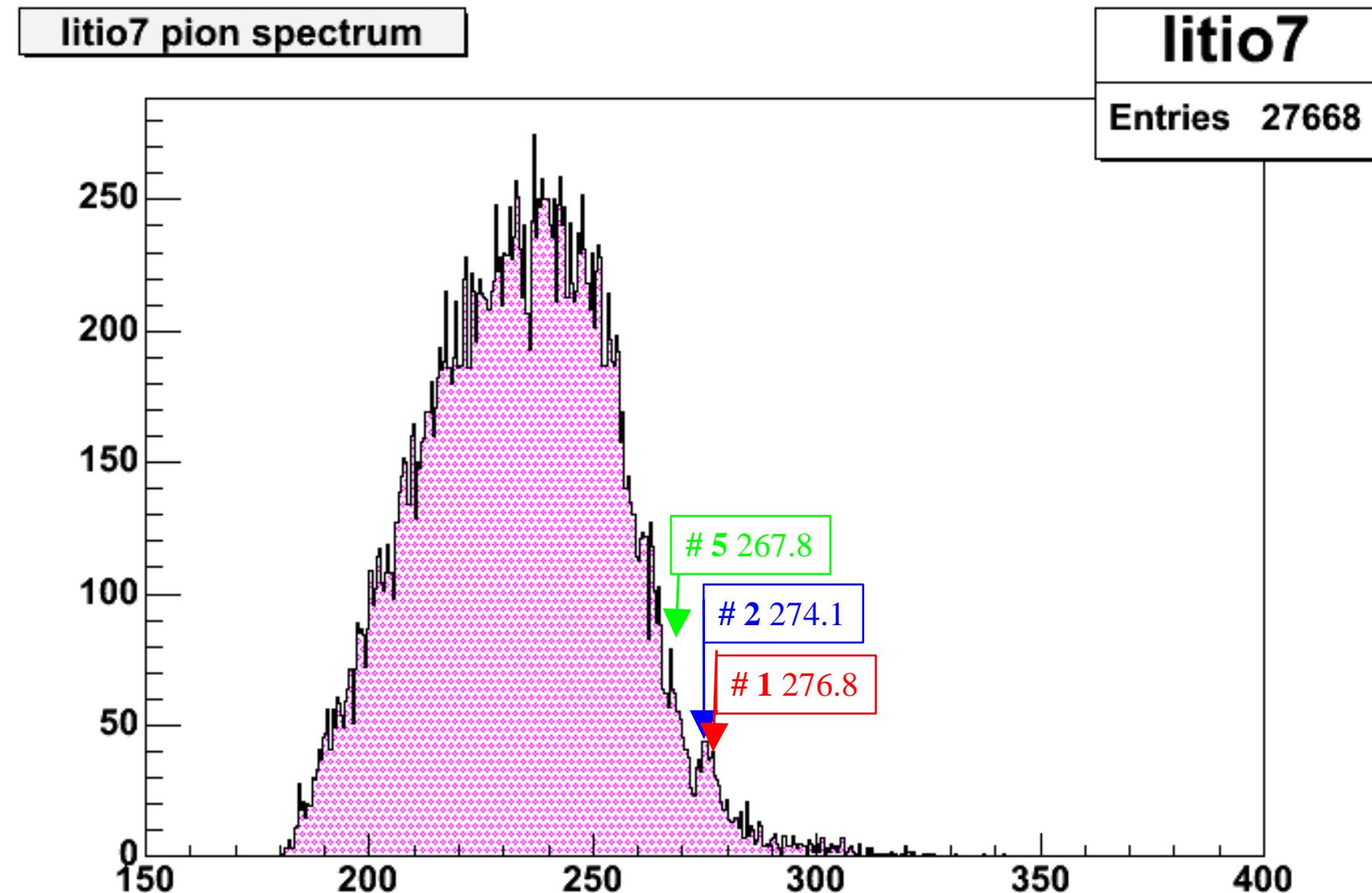


${}^6\text{Li}$ target: π^- spectrum





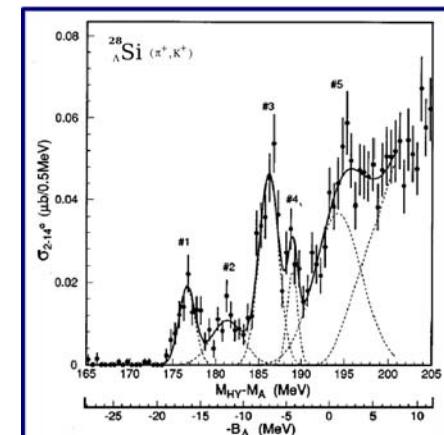
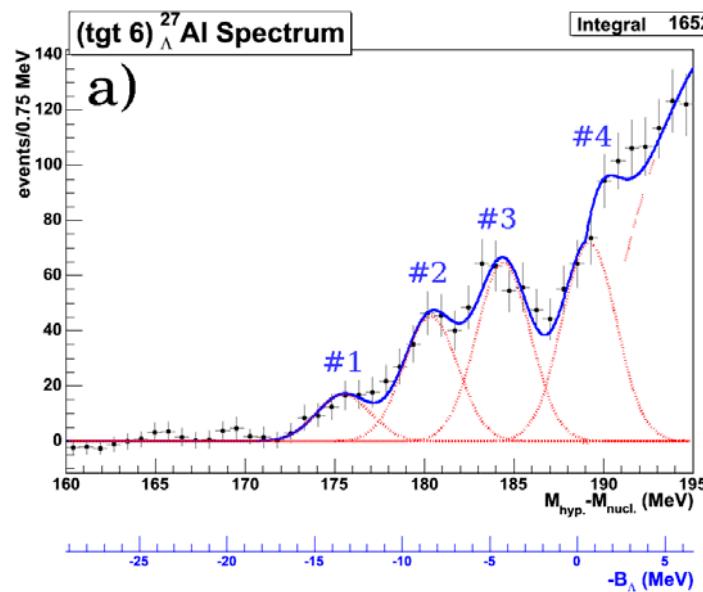
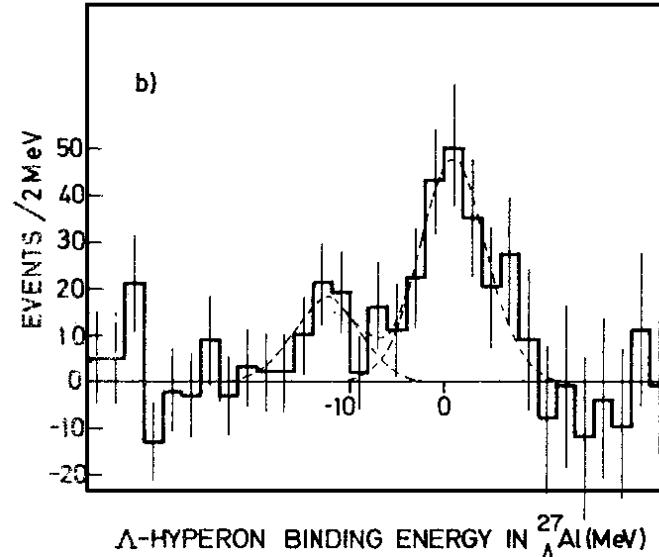
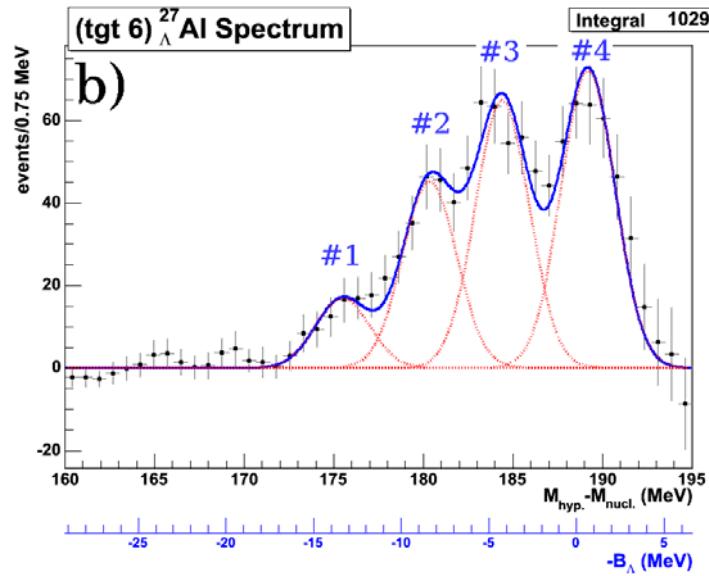
^7Li target: π^- spectrum





$^{27}\Lambda Al$ and $^{28}\Lambda Si$: excitation spectra

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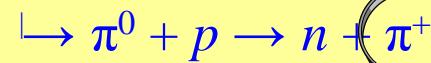
B_{Λ} (MeV)	E_x (MeV)	$m_{\text{hyp.}}$ (MeV)	p_{π} (MeV/c)
16.6	0	26229.88309	282.89833
11.9	4.7	26234.58309	277.71012
7.0	9.6	26239.48309	272.27922
4.3	12.3	26242.18309	269.27666
-0.1	17.6	26247.48309	263.36096



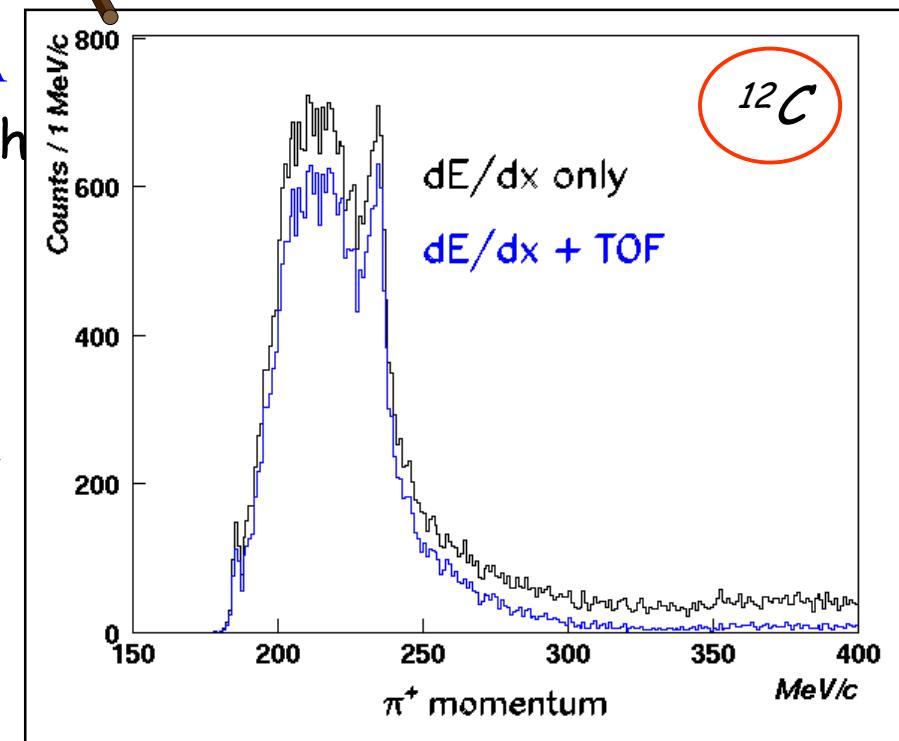
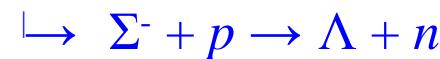
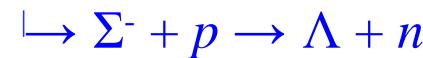
neutron-rich hypernuclei

2 production mechanisms:

1) **strangeness + double charge exchange**

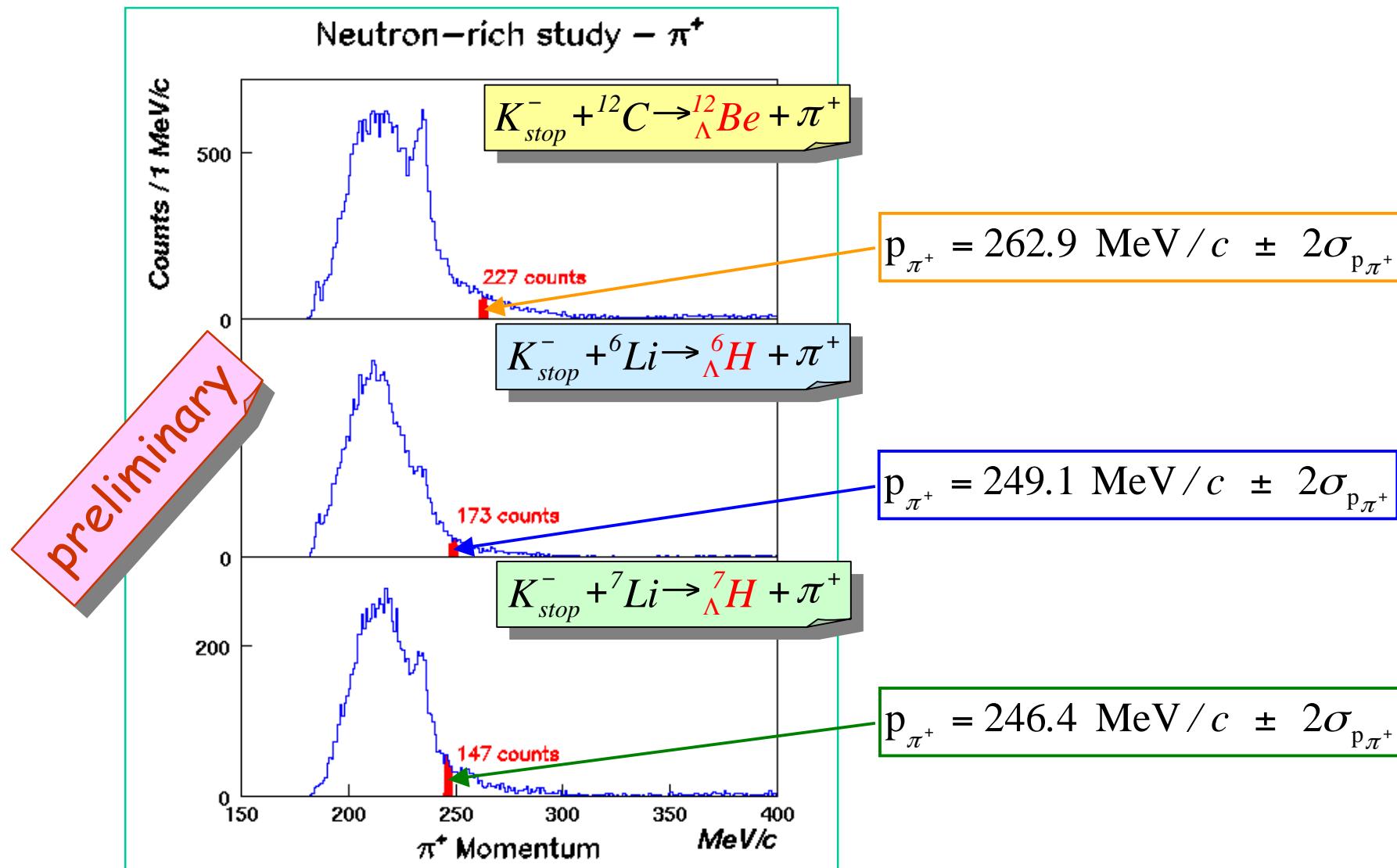


2) **Strangeness exchange with**





neutron-rich hypernuclei





Upper limit for NRH formation probability

P_{NRH} UPPER LIMIT ($\cdot 10^{-5}$)	90% C.L.		2 σ C. L.		3 σ C.L.	
	dE/dx PID	$dE/dx +$ TOF PID	dE/dx PID	$dE/dx +$ TOF PID	dE/dx PID	$dE/dx +$ TOF PID
Present Momentum Resolution (0.9%)	2.6 3.5 4.9	2.1 2.9 4.3	3.2 4.3 6.1	2.6 3.6 5.3	4.9 6.6 9.4	4.0 5.6 8.3
Nominal Momentum Resolution (0.35%)	1.6 2.1 3.3	1.3 1.8 2.8	2.0 2.6 4.1	1.6 2.2 3.5	3.1 4.1 6.5	2.5 3.5 5.6

PRELIMINARY



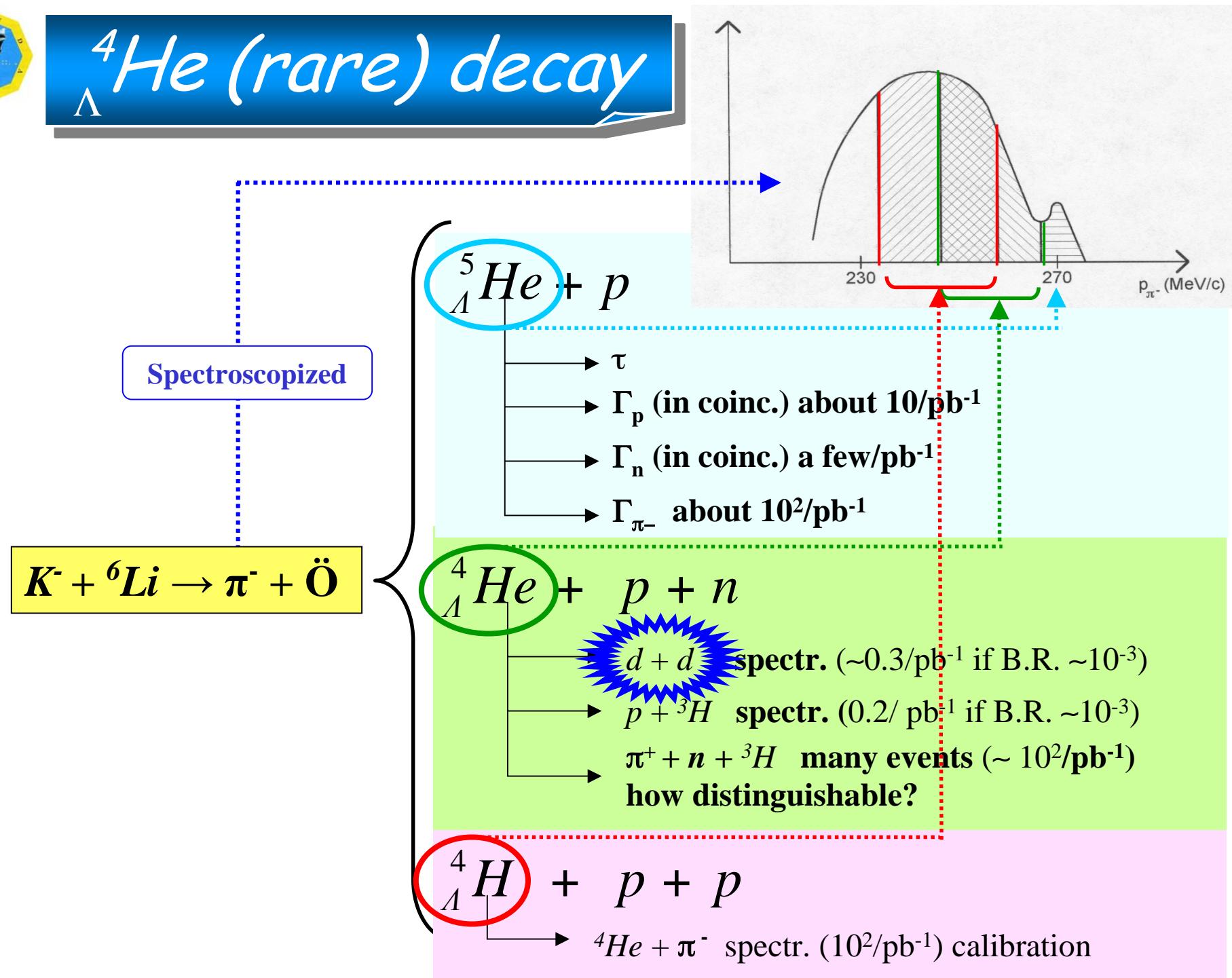
Uncertainties dominated by the error on the μ^+ time gate efficiency ($\approx 10\%$)

KEK result for $^{12}_{\Lambda}\text{Be}$:
 $6.1 \cdot 10^{-5}$ (90% C.L., no error given)

new results

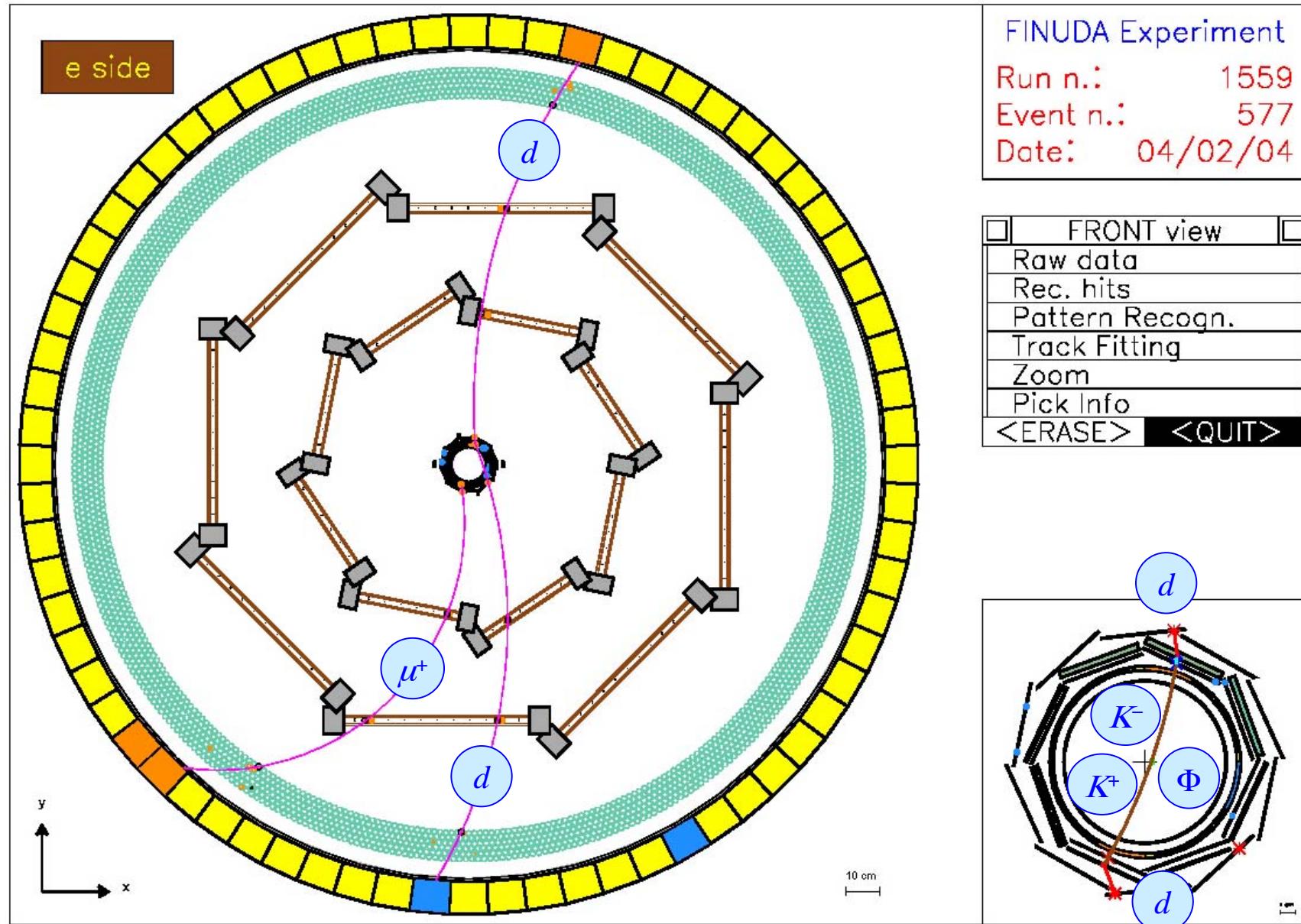


$^4\Lambda He$ (rare) decay





$\Lambda^0 \rightarrow d + d$ (rare) decay



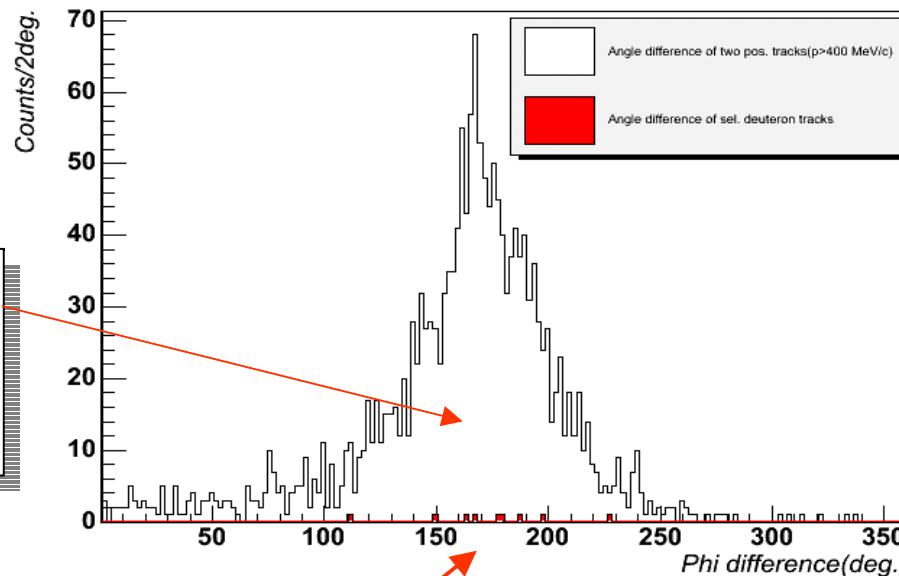


$\Lambda^4He \rightarrow d + d$ (rare) decay

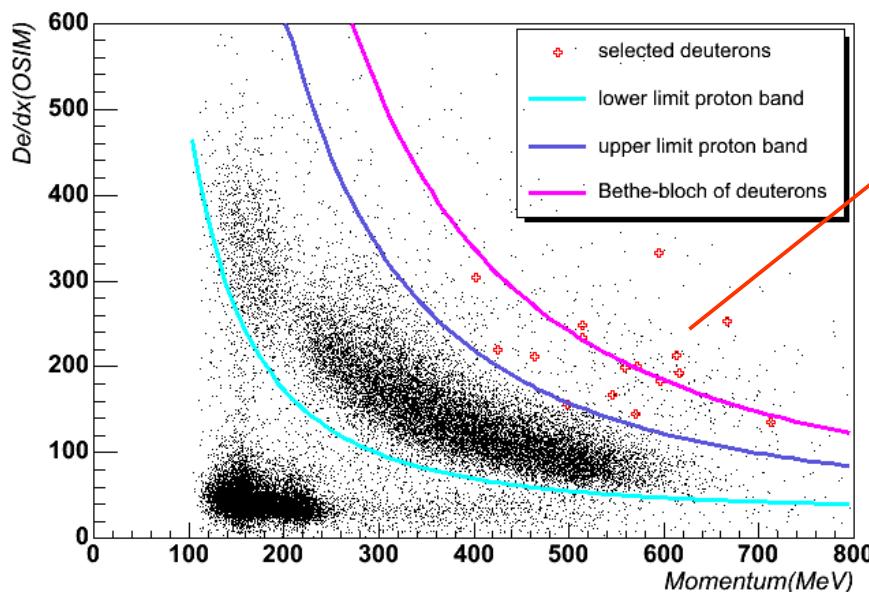
events with two positive tracks from ${}^6\text{Li}$ targets with momentum > 400 MeV/c

interesting events to be recognized
 ${}^4\Lambda\text{He} \rightarrow d+d$
 ${}^4\Lambda\text{He} \rightarrow d+p+n$

Phi difference of a pair of positive tracks($p>400\text{MeV}/c$)



Dedx vs p



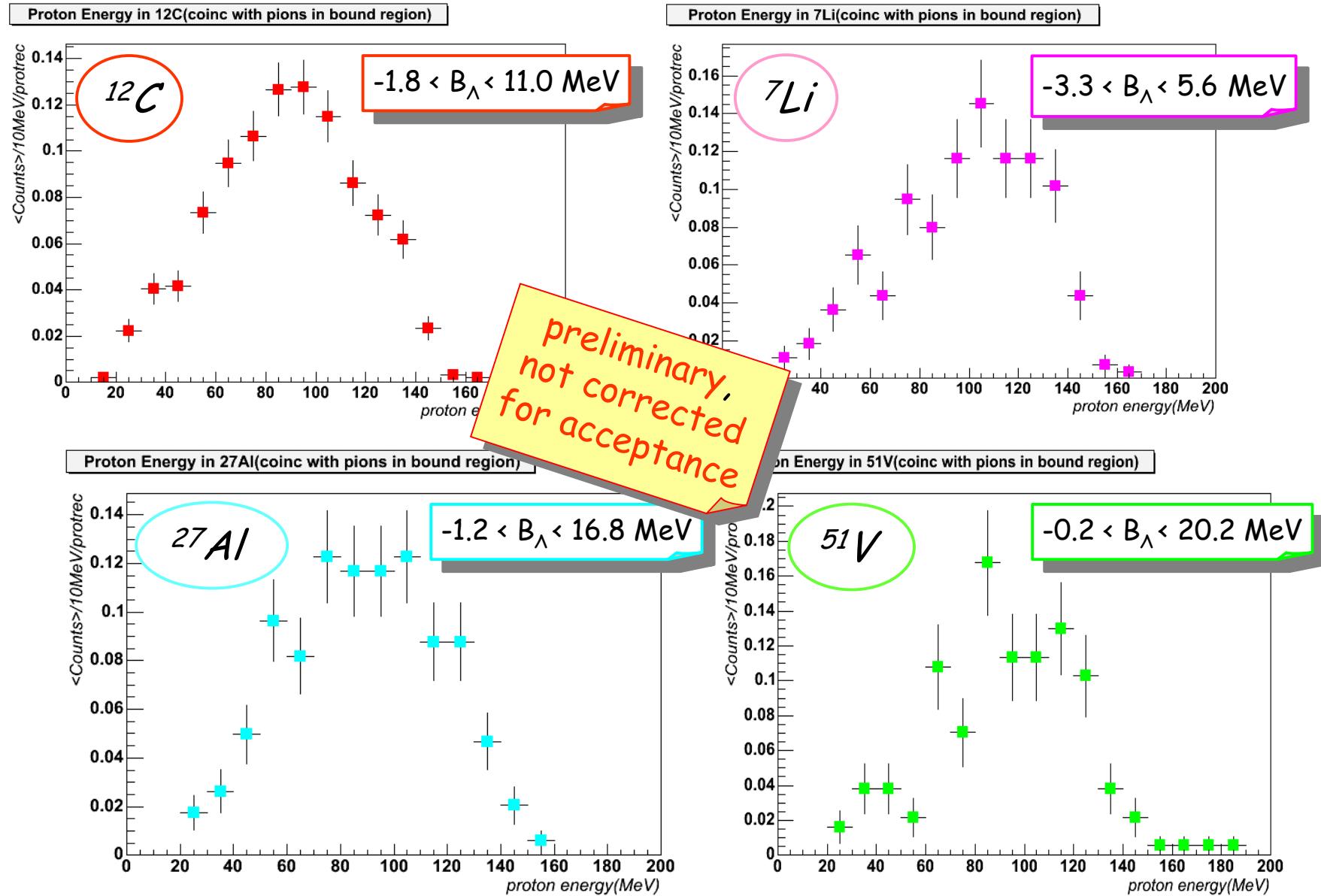
azimuthal angle difference

candidates ${}^4\Lambda\text{He} \rightarrow d+d$

accurate backtracking and kinematic analysis needed

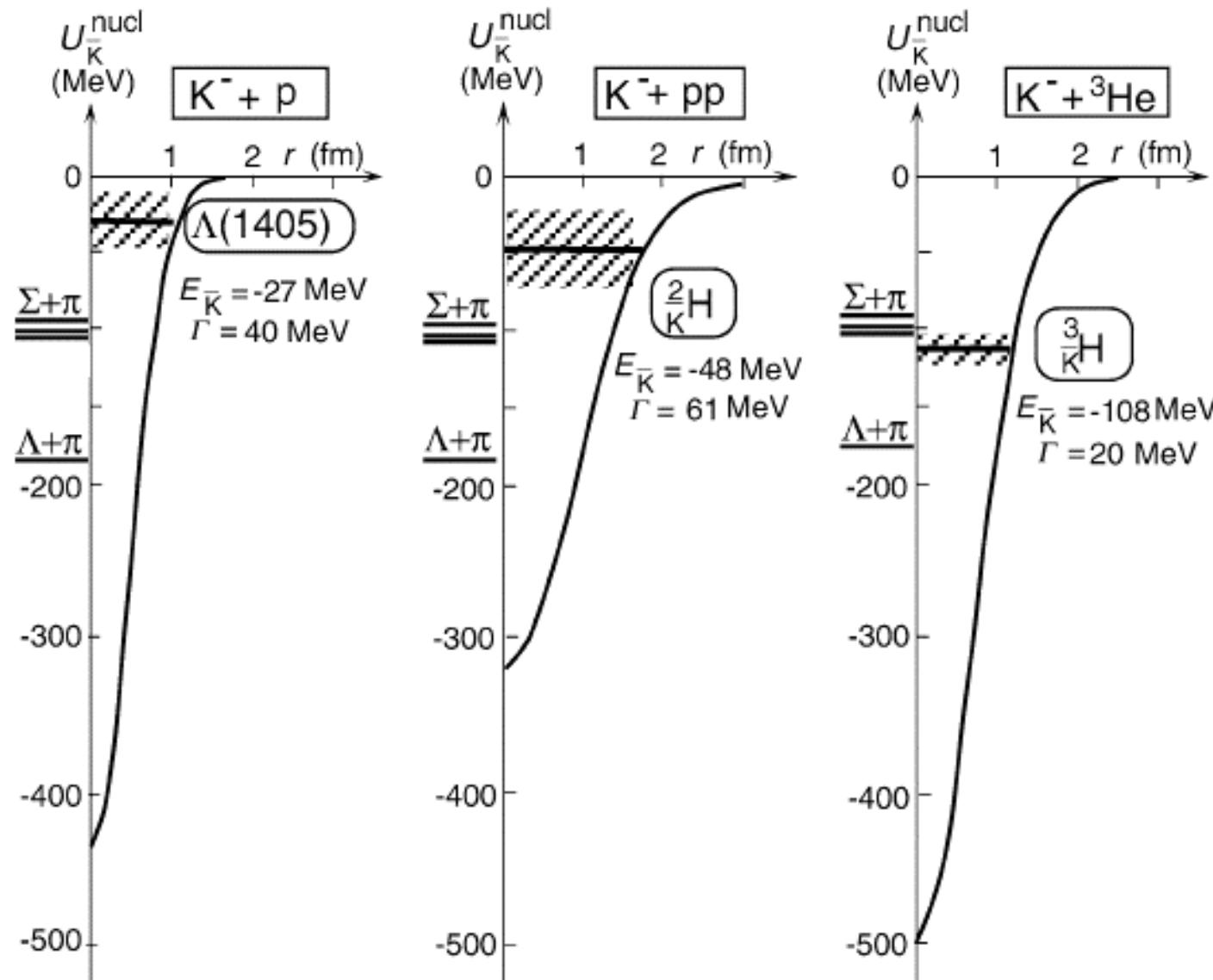


NM proton stimulated decay





K-pp state: theoretical calculations

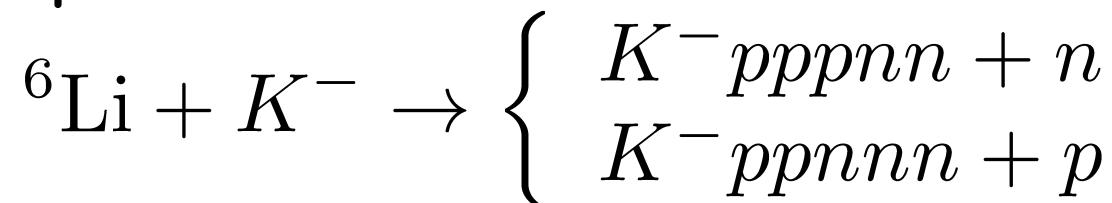




Kaonic nuclei search with Λ tagging

- Missing-mass spectroscopy

- Example:



- A kaonic nucleus emits a **hyperon** in its decay.

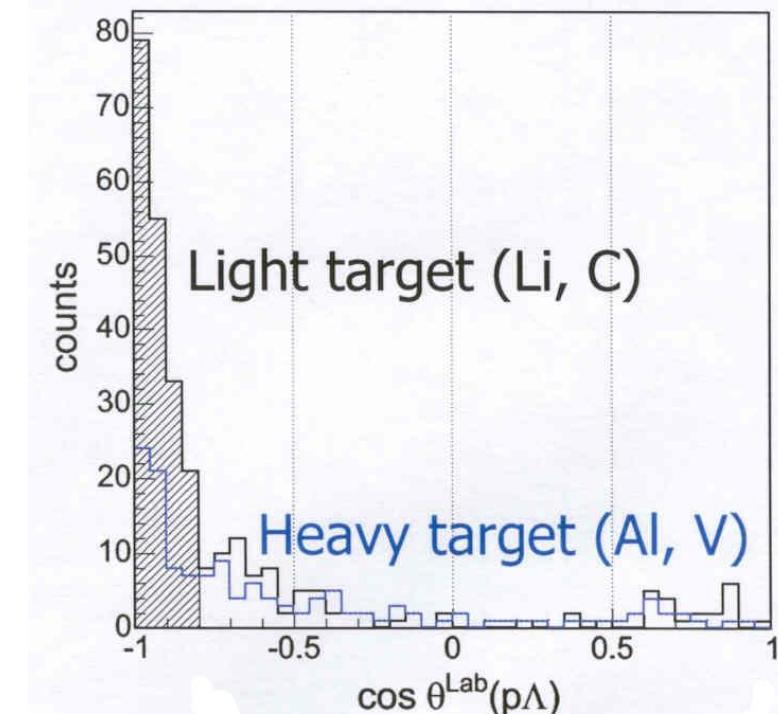
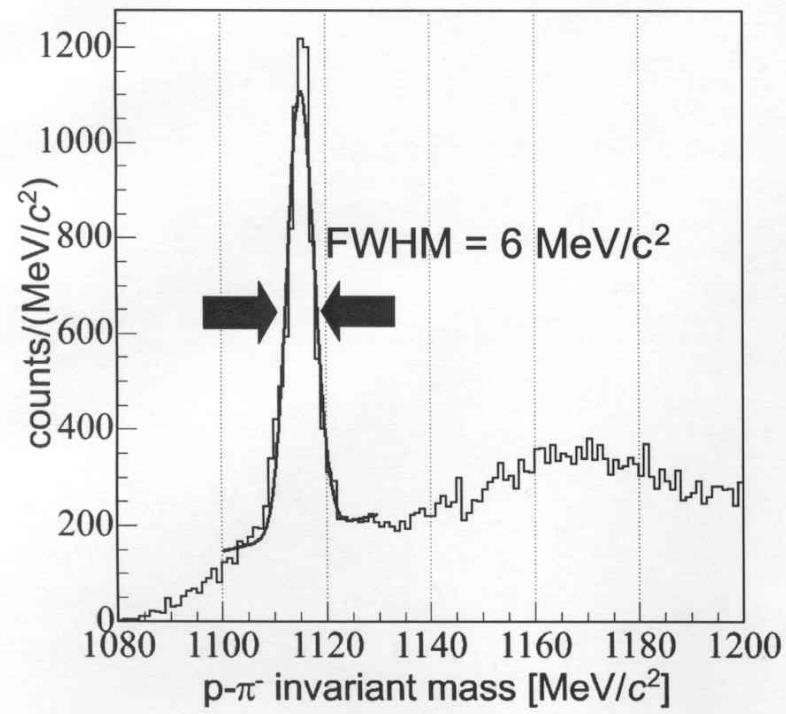
- Invariant-mass spectroscopy

- Example:





Λ momentum distribution and back-to-back correlations



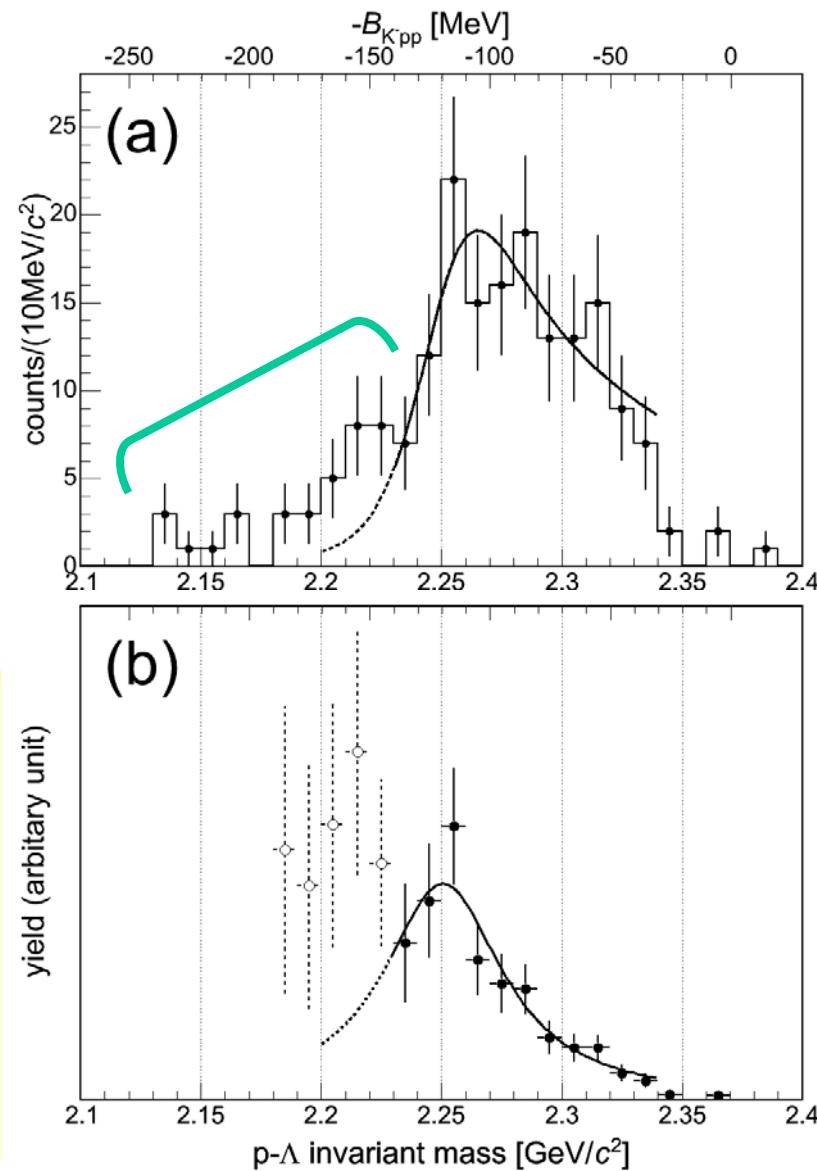


Before / after acceptance correction (fit 2)

Contribution from
 $\Sigma^0 + p$ decay are seen
in low mass region

No other background exists !

$B = 120^{+7}_{-5}$ MeV
 $\Gamma = 58^{+10}_{-8}$ MeV
Very preliminary !!
(systematic error to be added)

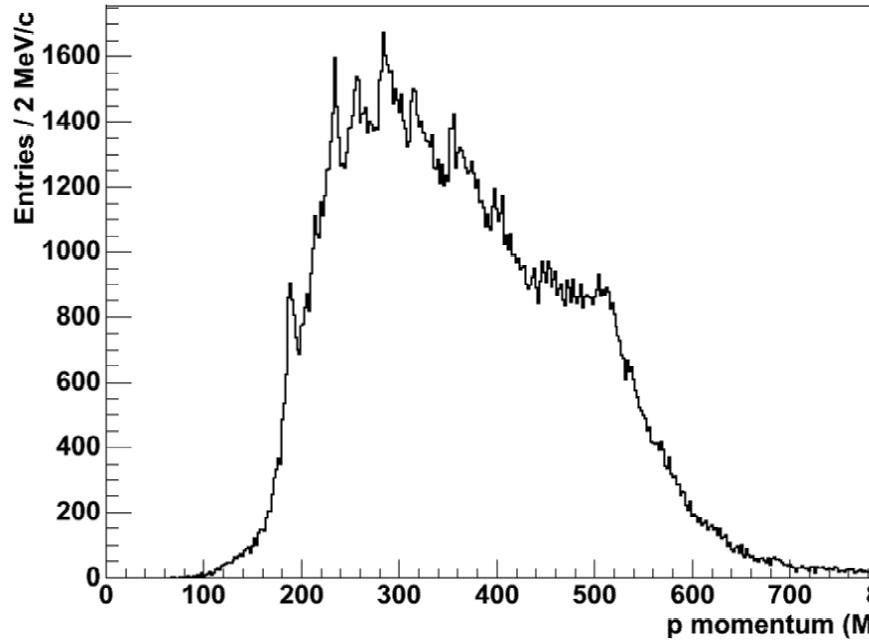




$K^- {}^6Li \Rightarrow p X$ inclusive spectrum

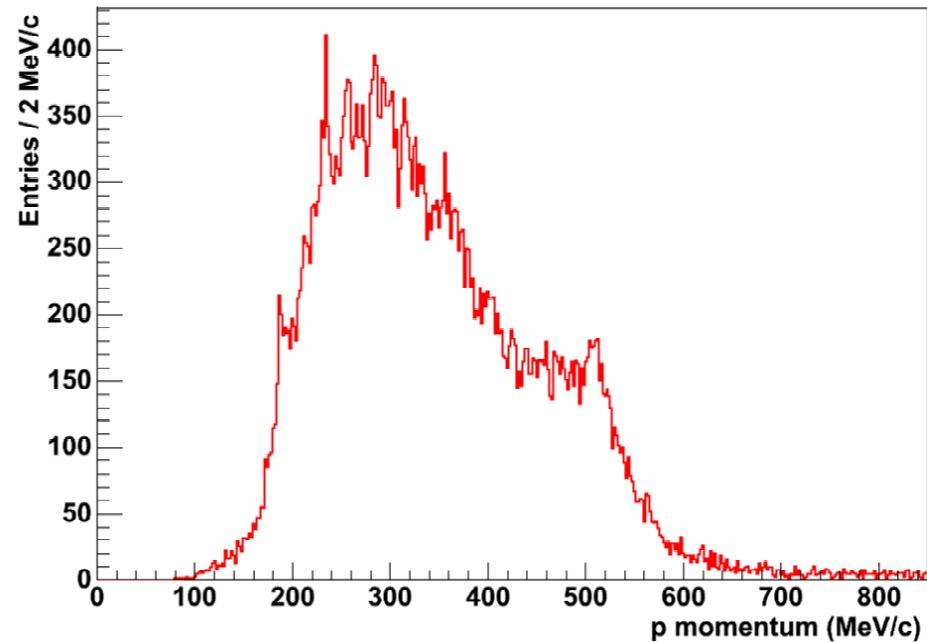
${}^6\text{Li}$ targets, all tracks

Entries 224574



${}^6\text{Li}$ targets, all tracks, coincidence (π^-, p)

Entries 46720

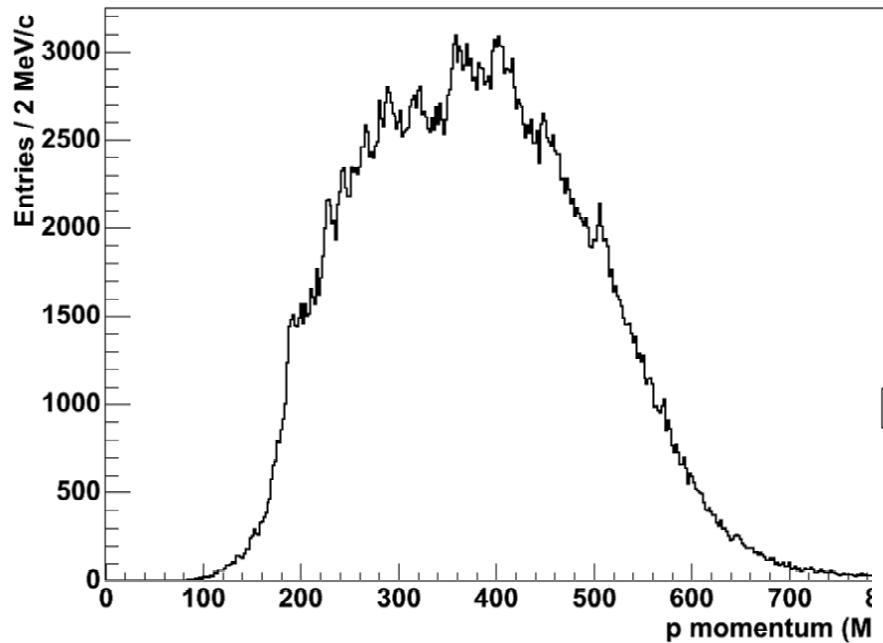




$K^- {}^{12}C \Rightarrow p X$ inclusive spectrum

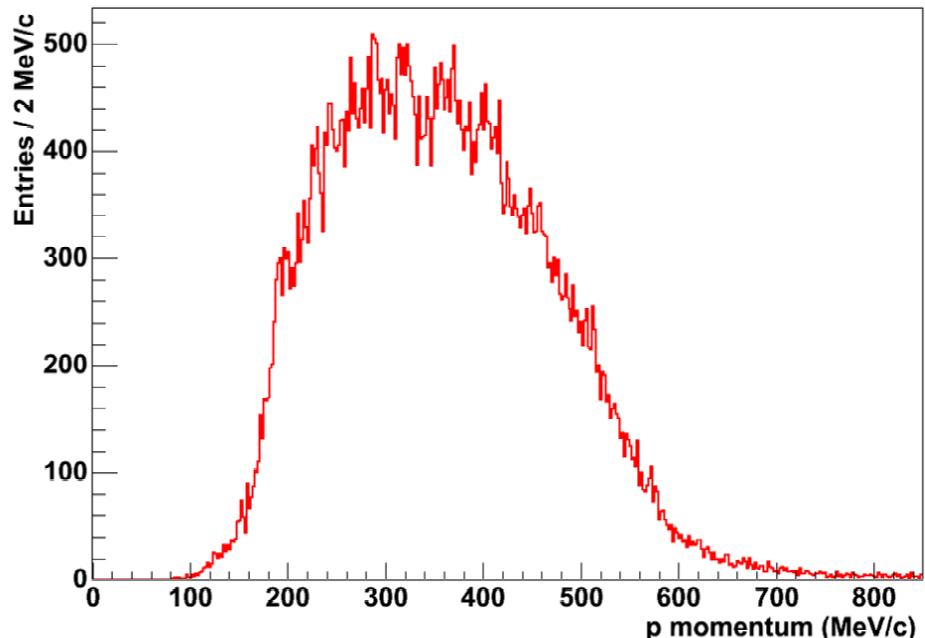
${}^{12}\text{C}$ targets, all tracks

Entries 477053



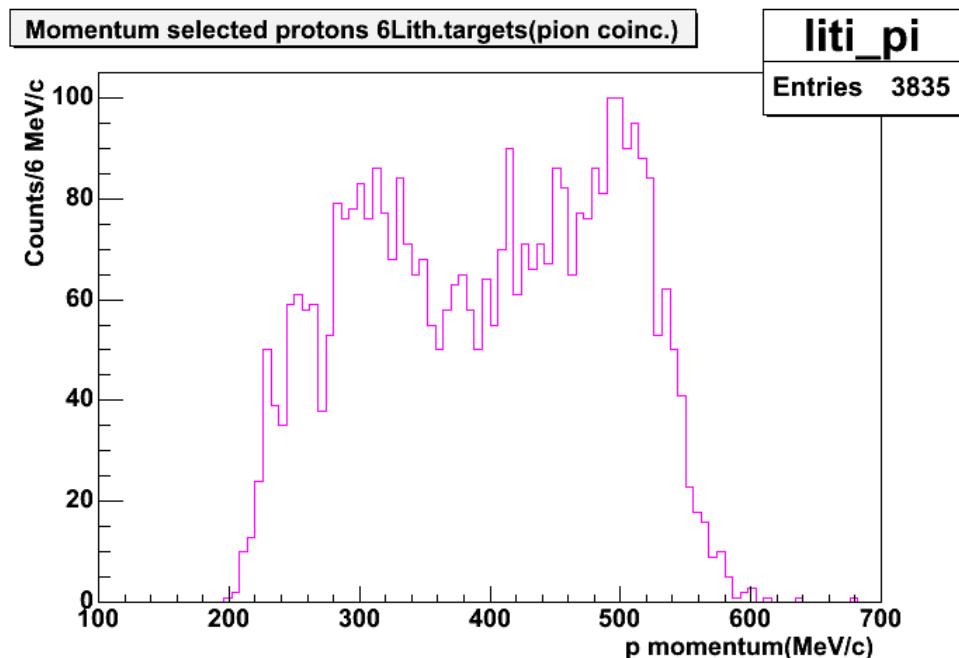
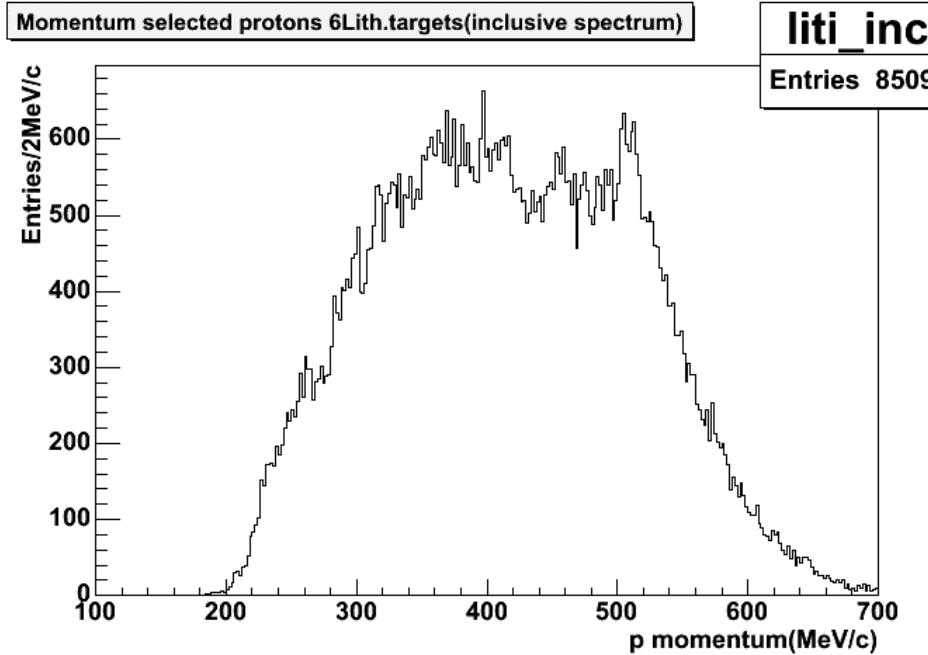
${}^{12}\text{C}$ targets, all tracks, coincidence (π^- , p)

Entries 72210





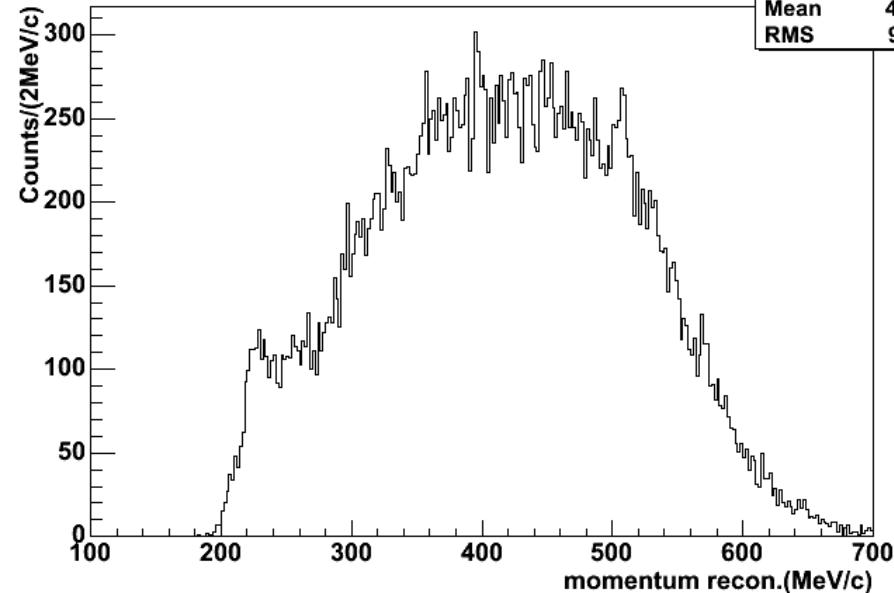
Some preliminary data: 6Li



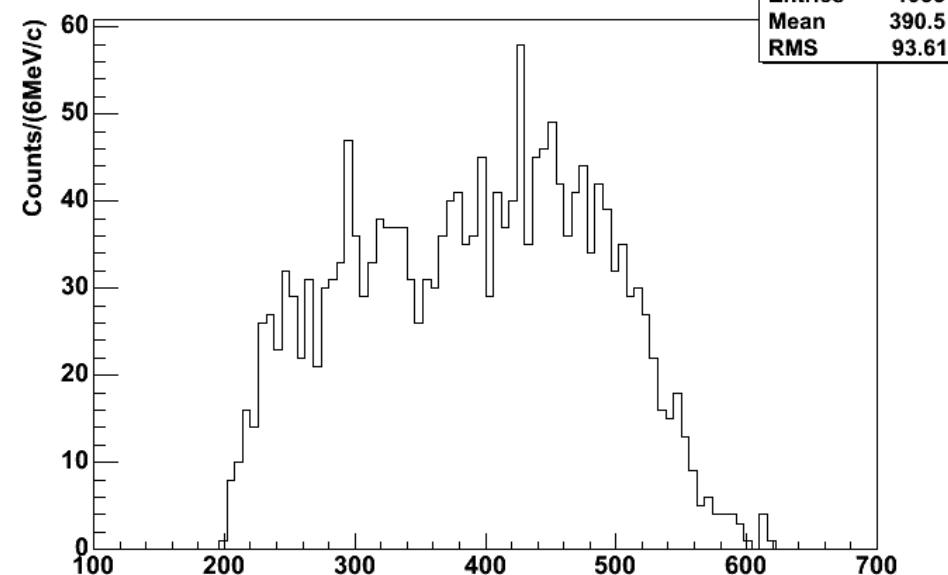


Some preliminary data: ^7Li

Momentum selected protons targ 4(inclusive spectrum)

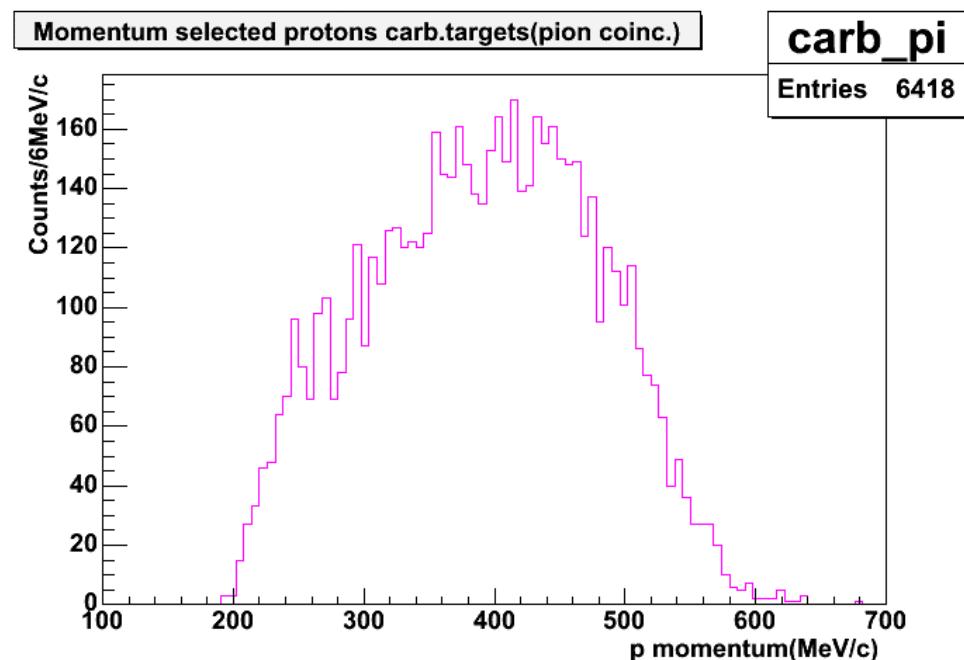
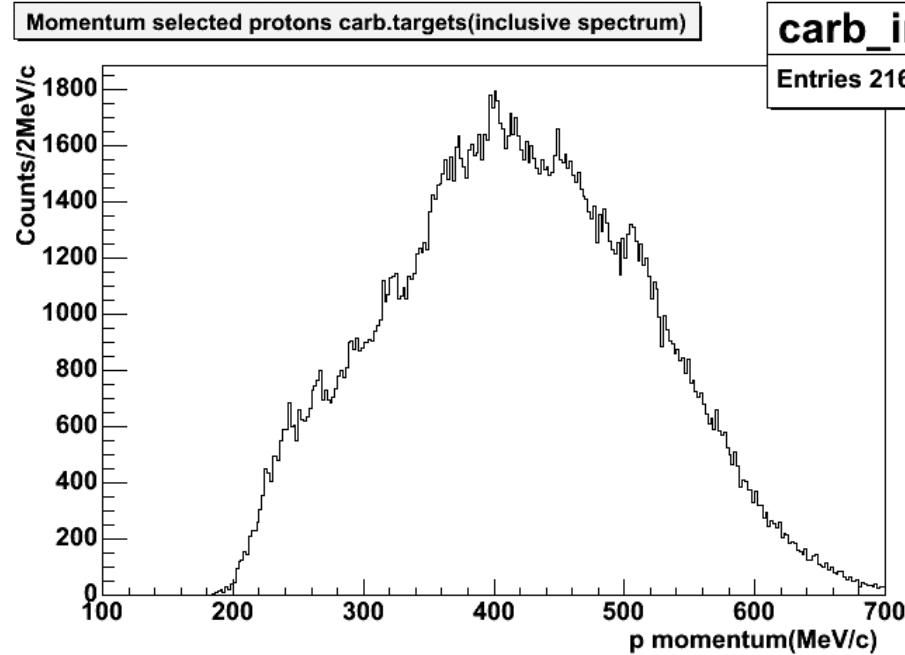


Momentum selected protons targ 4(coinc with pion)



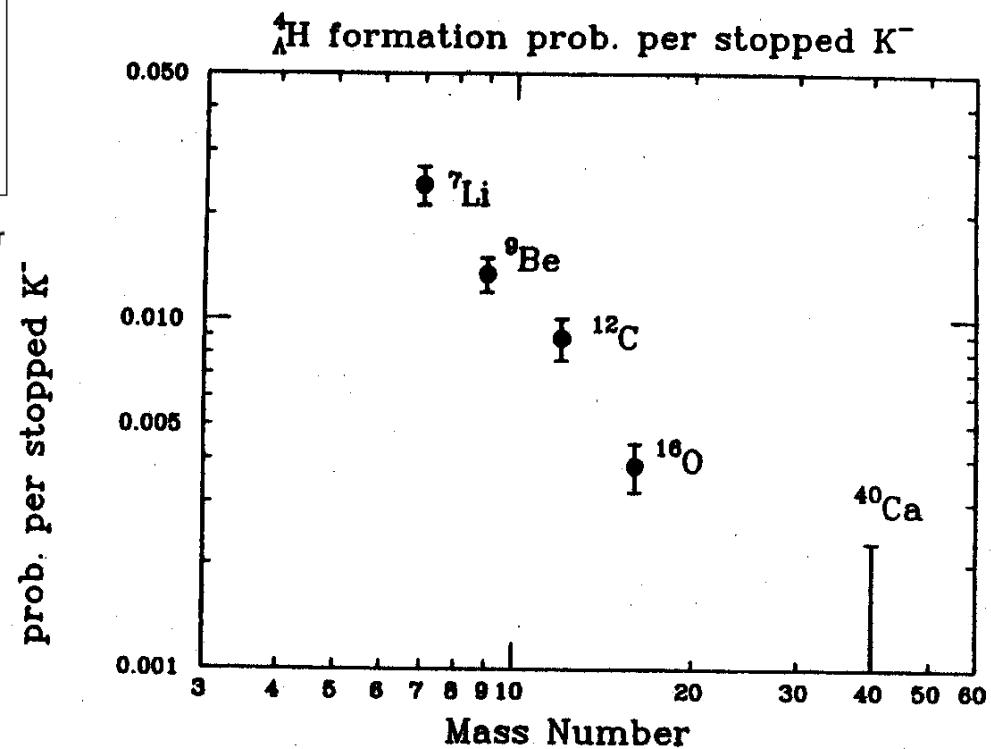
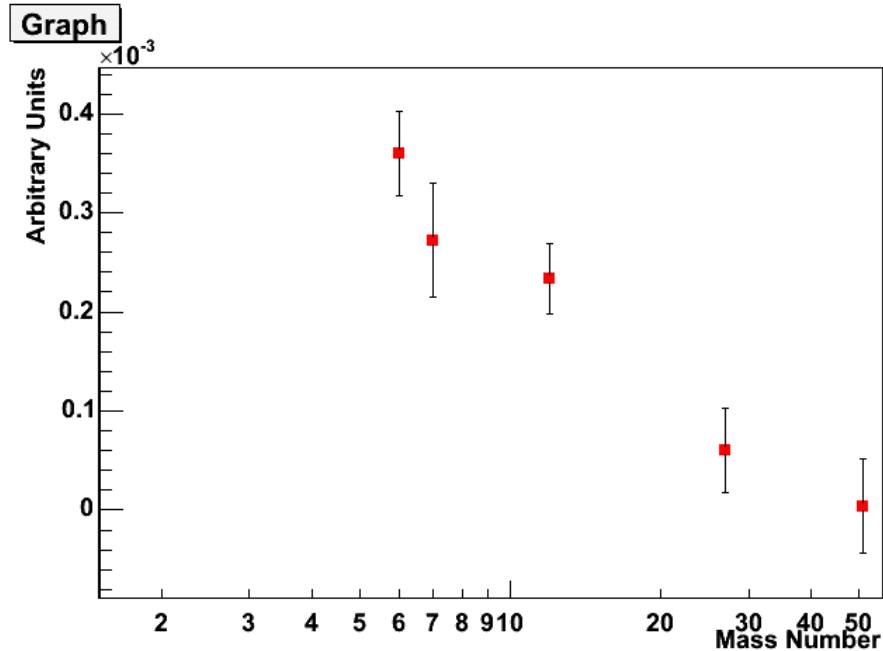


Some preliminary data: ^{12}C





Some preliminary data





Summary

- ❑ First data taking period successfully carried out (30×10^6 events on tape)
- ❑ Preliminary and partial results on spectroscopy are competitive with world published data
- ❑ Experimental upper limit for the NRH production:
 - ✓ better than published one for ${}_{\Lambda}^{12}Be$
 - ✓ measured for the first time for ${}_{\Lambda}^6H$ and ${}_{\Lambda}^7H$
- ❑ First observation of ${}_{\Lambda}^4He$ non mesonic (rare) decay
- ❑ Observation of K-pp bound state



Short term plans

1 Next data-taking period scheduled in the 2nd half of 2005

v effort focused on light-medium targets (^6Li , ^7Li , ^9Be , ^{16}O , ...)

⚠ Increase by a factor 4 of the DAQ rate

⚠ Replacement of the internal TOF detector (KEK)

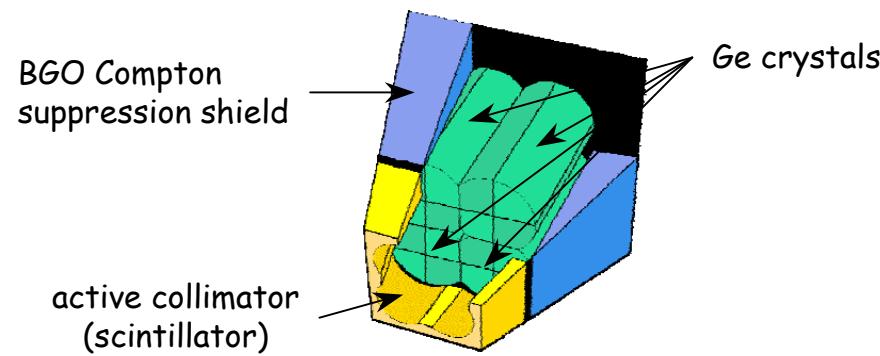
⚠ Improvement of the reconstruction program

- ☛ geometrical alignment
- ☛ detector calibration
- ☛ pattern recognition strategy
- ☛ selection criteria



Long term plans

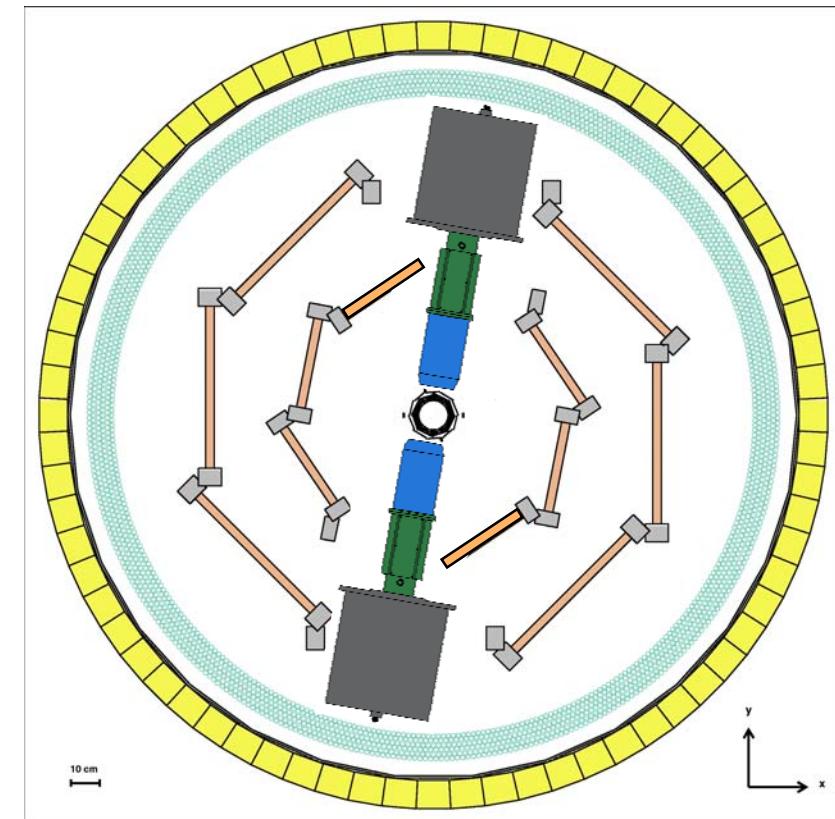
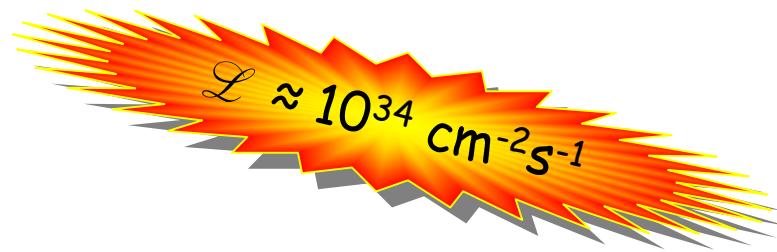
The Segmented Clover Detector



BGO Compton suppression shield

active collimator (scintillator)

Geometrical acceptance reduced to 72%





(K^-, p, p) invariant mass

(π^-, p, p) invariant mass

$\text{Cos}(\vartheta_{\Lambda p}) < -0.86$

