Preliminary Results on Hypernuclear Spectroscopy from the FINUDA Experiment at DAΦNE

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For the FINUDA Collaboration

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The FINUDA Collaboration

- Bari University and I.N.F.N. Bari, Italy
- Brescia University and I.N.F.N. Pavia, Italy
- KEK, Japan
- Laboratori Nazionali di Frascati I.N.F.N., Italy
- Pavia University and I.N.F.N. Pavia, Italy
- Seoul National University, Korea
- Shahid Beheshty University, Teheran, Iran
- Torino University and I.N.F.N. Torino, Italy
- Torino Polytechinc and I.N.F.N. Torino, Italy
- Trieste University and I.N.F.N. Trieste, Italy
- TRIUMF, Vancouver, Canada

50 Years after the discovery of the first hypernucleus, FINUDA has started its production of strange nuclei in Frascati

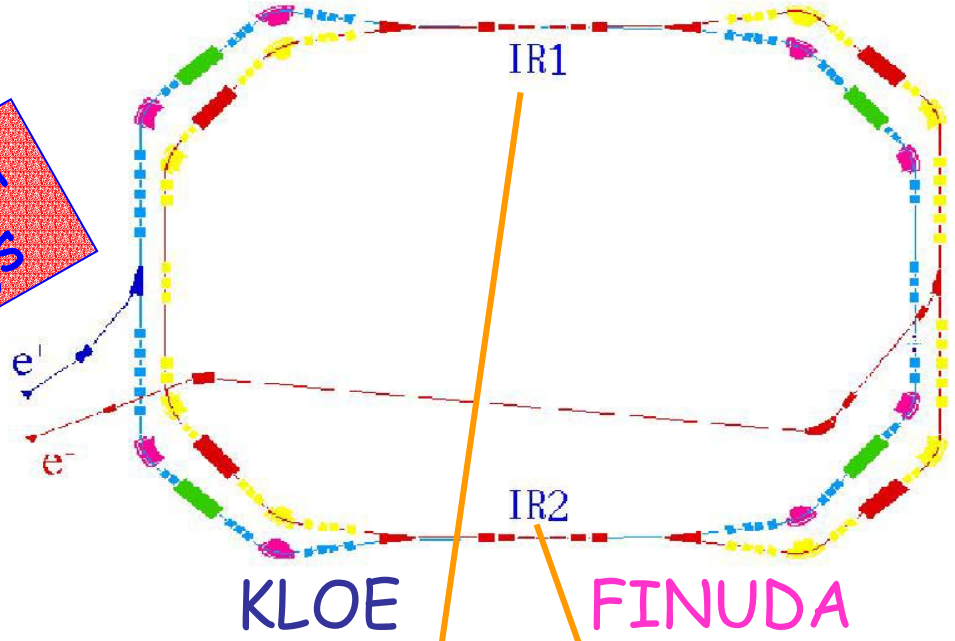
Outline:

- DAΦNE Performances
- FINUDA Physics Program and Apparatus
- First Data Taking Dec.2003-March. 2004
- Finuda Performances
- First Preliminary Results on hypernuclear spectroscopy
- Conclusions

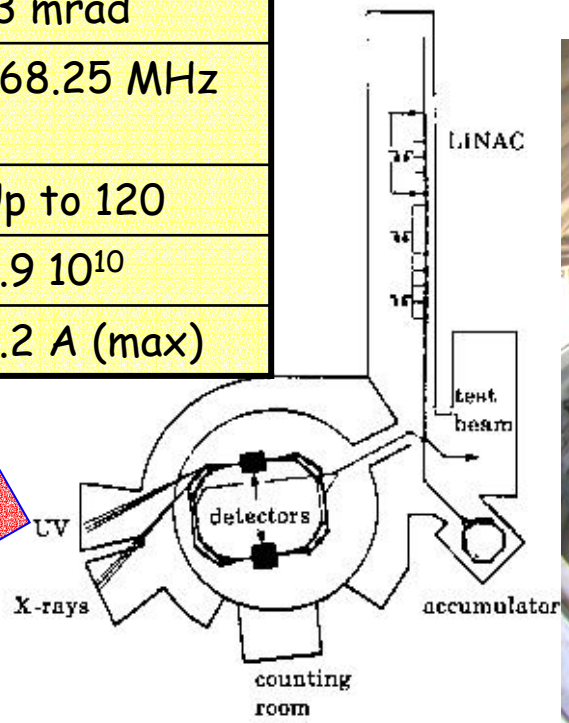
DAΦNE $e^+e^- \rightarrow \phi(1020)$

energy	510 MeV
Design Luminosity	5 10^{32} cm^{-2} 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	13 mrad
Frequency (max)	368.25 MHz
Bunch/ring	Up to 120
Part./bunch	8.9 10^{10}
Current/ring	5.2 A (max)

2 Main Rings



Accelerator Complex



FINUDA

FIsica NUcleare at DAΦNE

$$e^+e^- \rightarrow \phi(1020) \rightarrow K^+K^-(49\%), K_S{}^+K^-{}_L(34\%), \rho\pi(13\%)$$

The ϕ provide a unique "K^- beam" :

1. monochromatic low momentum (127 MeV/c)
2. trigger tagging K^-_{stop} event through the associate K^+
3. no hadronic background

that can be stopped in thin targets to produce hypernuclei :

$$K^-_{stop} + {}^{A}Z \rightarrow {}^{A}_{\Lambda}Z + \pi^-$$

Nuclei with one or more Hyperon bound to the nuclear core

FINUDA Physics Program

- Production of Λ -hyp. : $^{A}Z\,(K^-_{stop}\,,\pi^-)\,^{A}_{\Lambda}Z$

  spectroscopy of hyp. via the π^-_{prompt} momentum

- Decay of Λ-hyp.:

  mesonic decays : $\Lambda \to p\pi^-; \Lambda \to n\pi^0$

  partially Pauli blocked

  non-mesonic decays $\Lambda p \to np; \Lambda n \to nn$

  prevalent

- Lifetime of Λ -hyp.

- Search for neutron rich Λ –hyp.: $^{A}Z\,(K^-_{stop}\,,\pi^+)\,^{A}_{\Lambda}(Z\text{-}1)$

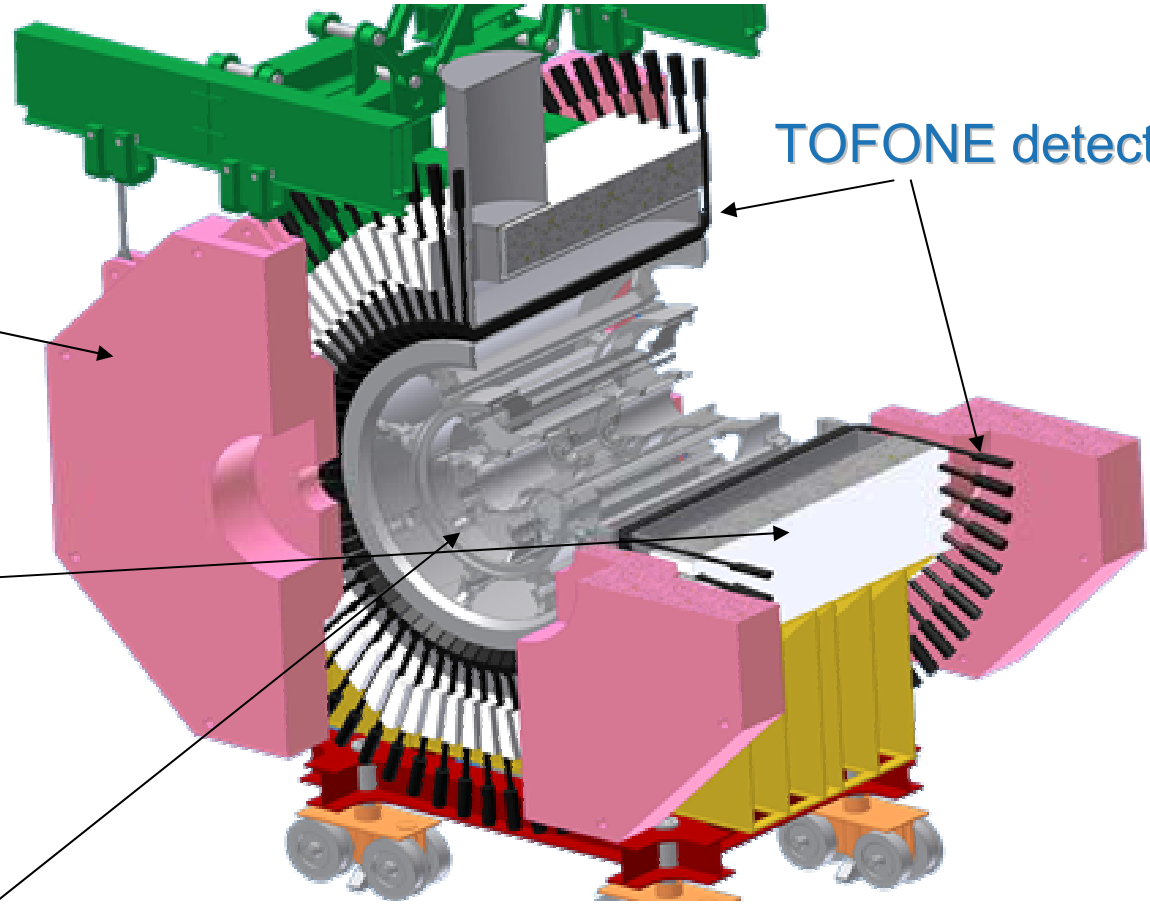
FINUDA physics program

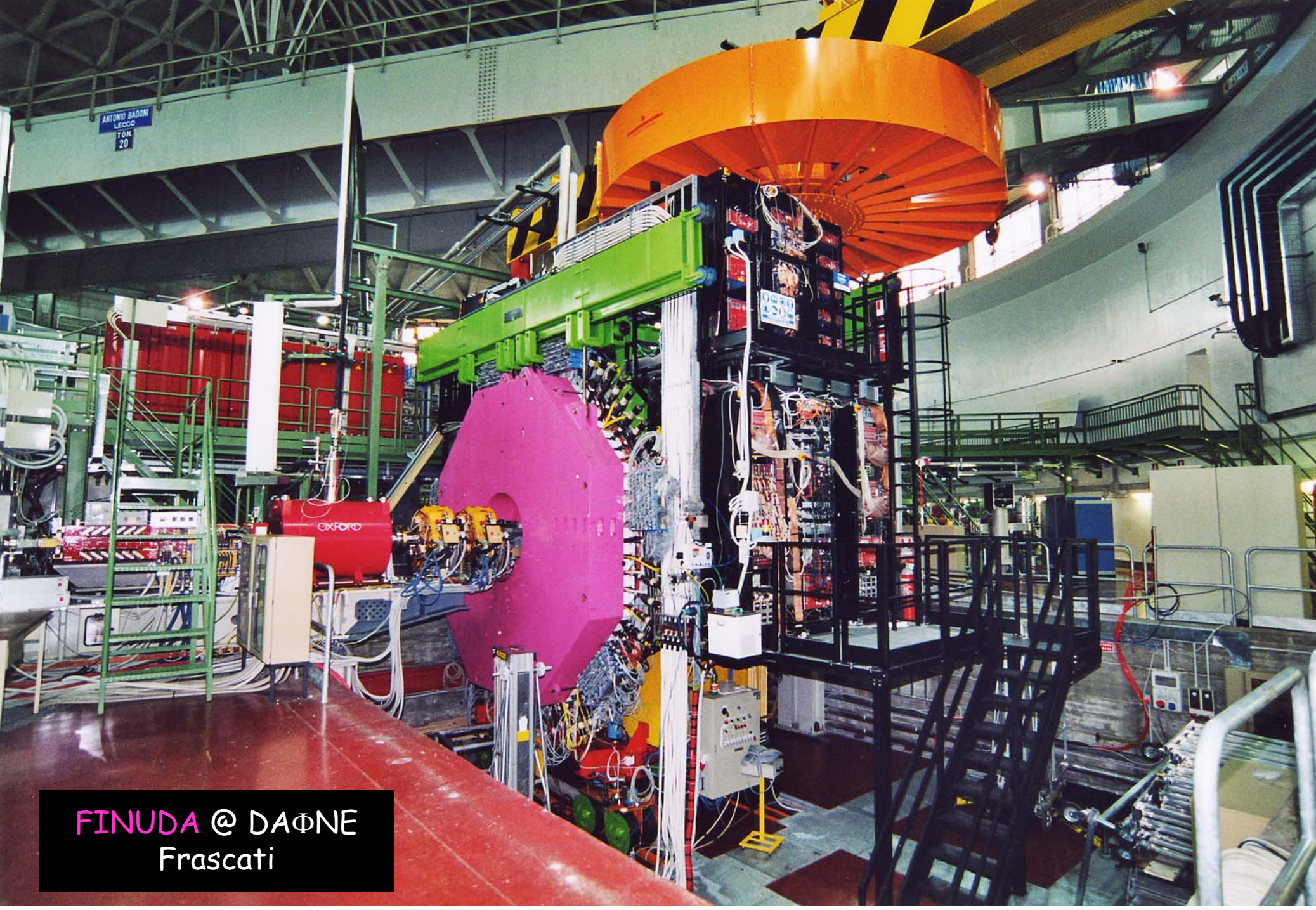
FINUDA can study SIMULTANEOUSLY
hypernuclear spectroscopy and hypernuclear decays

hypernuclear spectroscopy
is an essential tool for testing
theoretical models of Λ-N potentials
and single particle models predictions

hypernuclear decays allows to
study weak processes in nuclear
matter
$\Lambda \rightarrow \pi N$, $\Lambda N \rightarrow NN$ and $\Lambda NN \rightarrow nNN$

FINUDA Apparatus





FINUDA @ DAΦNE
Frascati

FINUDA detectors performances

- S.C. Magnet : B=1.0T homogeneous field within 2% in traking volume
- Interaction/Target region: selection of K+K- pairs production and detection of hypernuclei

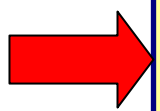
Si VDET σ_z = 30μm ; ΔE 20%FWHM

in TOF σ_t = 250ps

- External tracking device: measurement of trajectories and momenta of charged particles with high precision

LMDC: $\sigma(\rho,\phi)$= 150μm σ_z=1%wire length, STRAW: $\sigma(\rho,\phi)$= 150μm σ_z=500μm

$(\Delta p/p)_{goal}$ = 3.5 x 10^{-3} FWHM



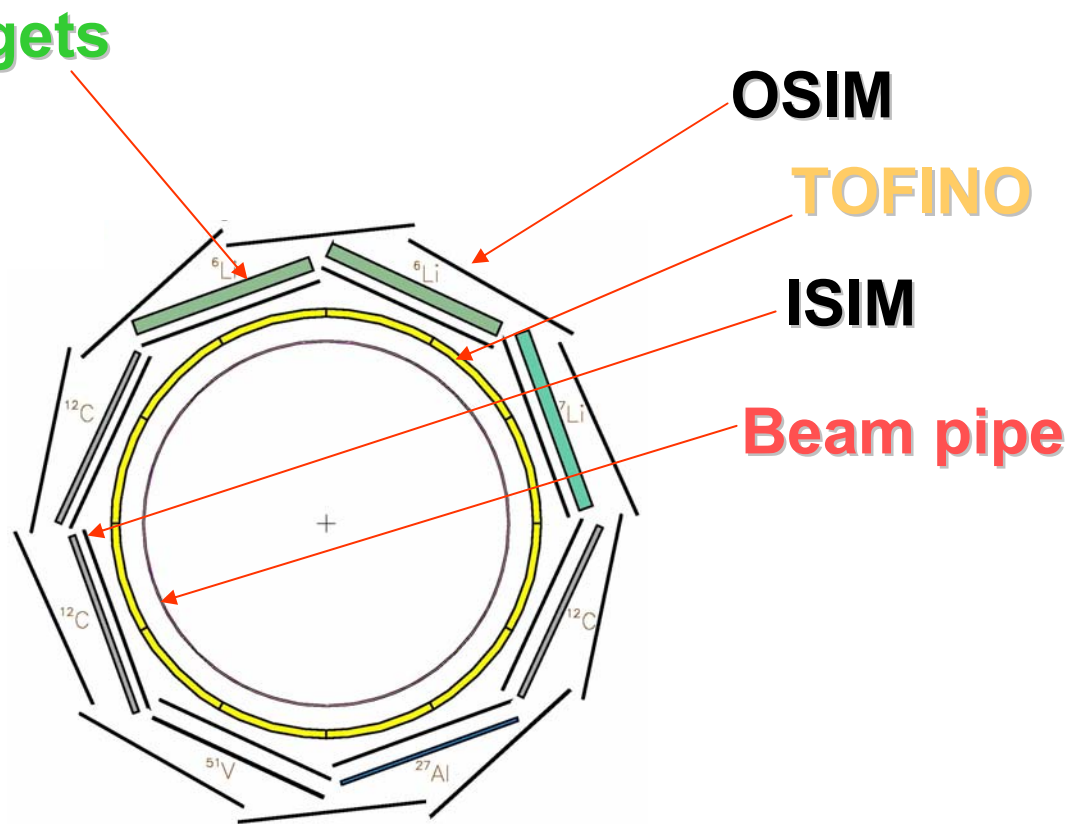
ΔE = 830 KeV FWHM

@ p_{π^-} ~270MeV/c

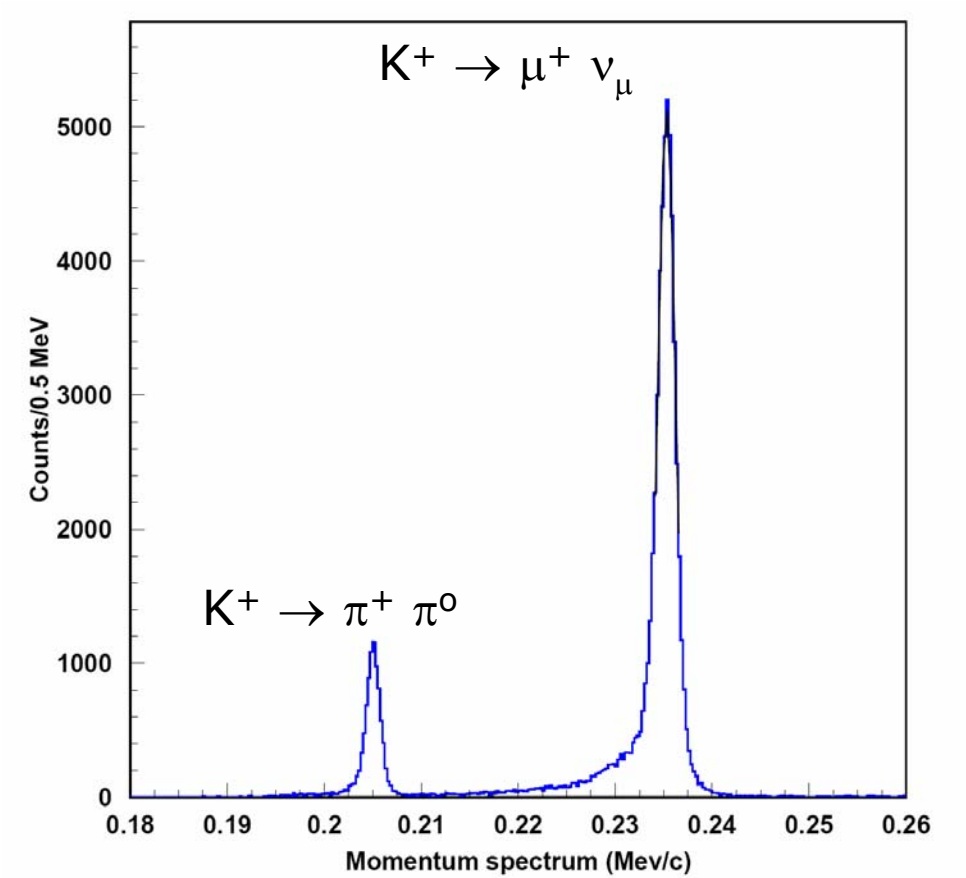
- External scintillator barrel: trigger purposes and neutron detection (10% eff., 8MeV Energy res. at 80MeV, time res. 500ps FWHM
- Helium : $2\Delta p/p=3.5\times10^{-3}$ in He -> 2×10^{-2} in air

Interaction-Target region

3 targets of ^{12}C
2 targets of ^{6}Li
1 target of ^{7}Li
1 target of ^{27}Al
1 target of ^{58}V



Momentum distribution of K^+ charged decay products



$K^+ \rightarrow \mu^+ \nu_\mu$
$K^+ \rightarrow \pi^+ \pi^o$

The width of the μ^+ peak gives a momentum resolution of:

$\Delta p/p < 0.9\%$

(Goal $\Delta p/p < 0.35\%$)

Target Choice

Segmented target: 2x ^{6}Li + 1x ^{7}Li + 3x ^{12}C + 1x ^{27}Al + 1x ^{51}V

^{6}Li: Source of $^{4}_{\Lambda}$He and $^{5}_{\Lambda}$He ($^{6}_{\Lambda}$Li unstable);

Study of the decay of light hypernuclei (~ never examined)

$^{5}_{\Lambda}\mathrm{He} \rightarrow {}^{3}\mathrm{He} + n + p$

$^{5}_{\Lambda}\mathrm{He} \rightarrow {}^{3}\mathrm{H} + n + n$

$^{6}_{\Lambda}\mathrm{He} \rightarrow {}^{4}\mathrm{He} + n + n$ (T = 1/2 still valid ???)

$^{4}_{\Lambda}\mathrm{He} \rightarrow d + d$

$^{4}_{\Lambda}\mathrm{He} \rightarrow p + {}^{3}\mathrm{He}$

$^{4}_{\Lambda}\mathrm{He} \rightarrow \pi^{+} + n + {}^{3}\mathrm{H}$

^{7}Li: Comparison with the ^{6}Li target, available data of poor quality;

^{12}C: Reference target for spectroscopy and weak decays studies,

Search for states weakly excited, $\leq 10^{-5}/K_{stop}$ (present limit $10^{-4}/K_{stop}$)

Weak decays:

$\Gamma p\ (\Lambda p \rightarrow n\ p)$

$\Gamma n\ (\Lambda n \rightarrow n\ n)$

$\Gamma pn\ (\Lambda\ n\ p \rightarrow n\ n\ p)$ New

$\Gamma nn\ (\Lambda\ n\ n\ n \rightarrow n\ n)$ New

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

The results will greatly improve the previous results, factor 3-4 .

^{27}Al: Never studied before;

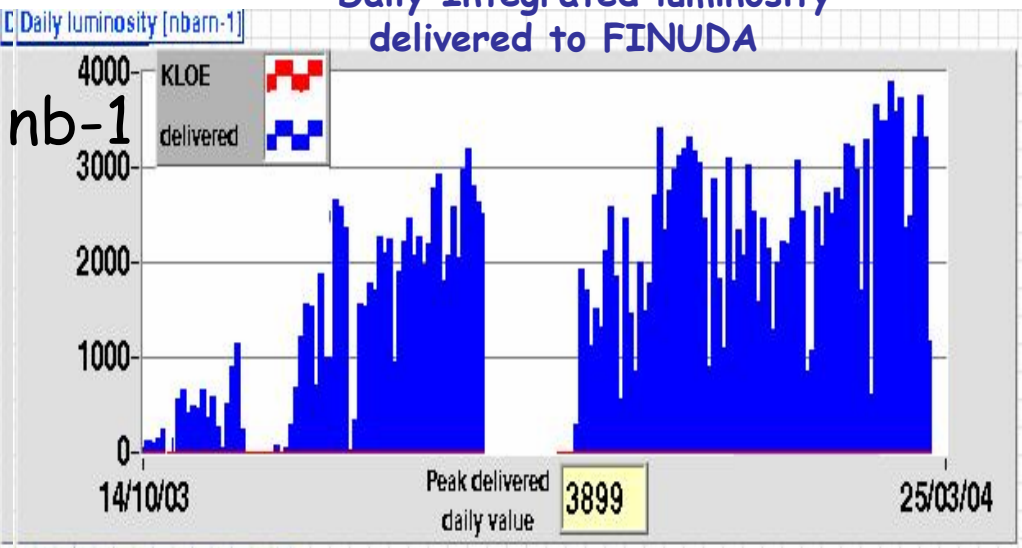
Measurement of the capture rate in the medium hypernuclei

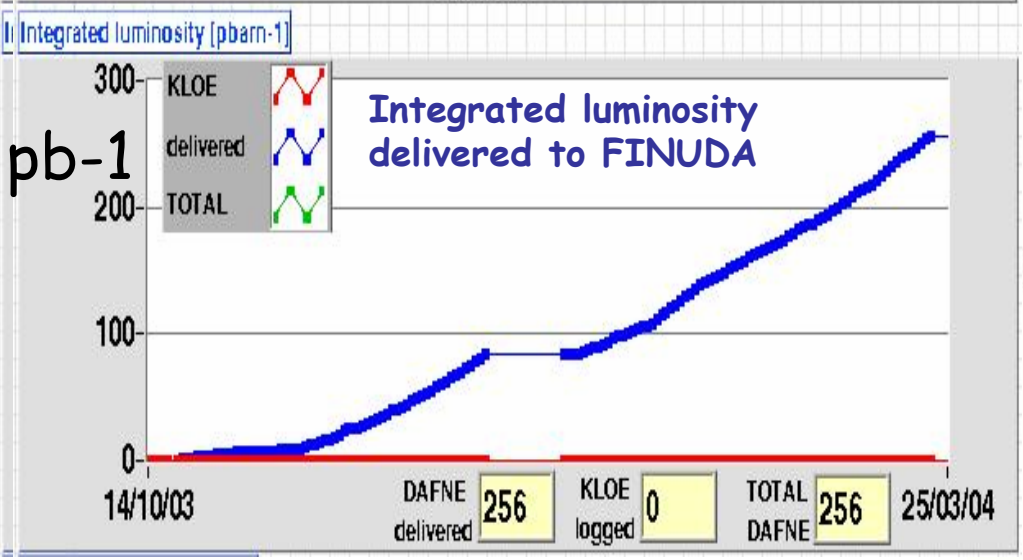
^{51}V: No measurements available with K^- at rest, useful for weak decay studies;

Important to assess the capture rate for the medium and heavy hypernuclei

DAΦNE Performance : Oct.2003-March2004

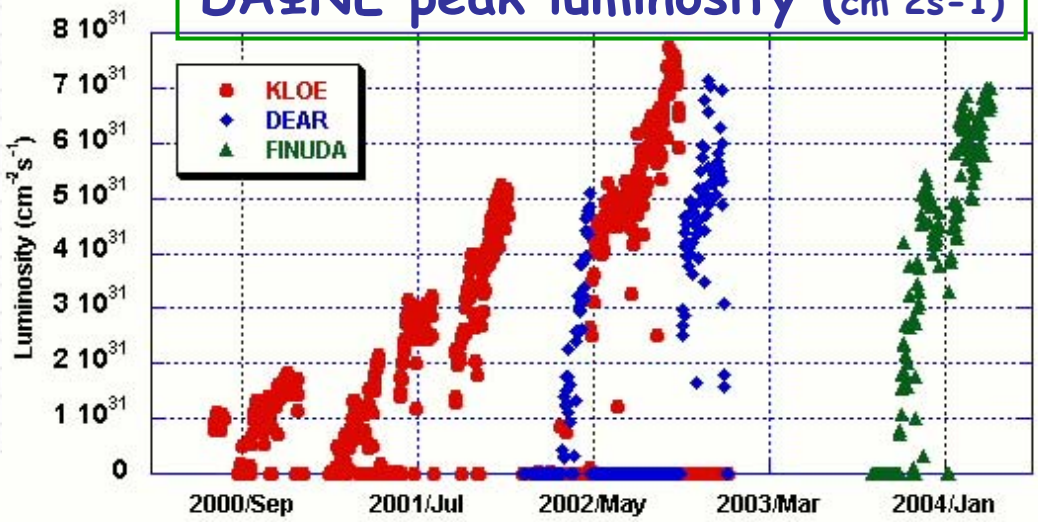
Daily Integrated luminosity
delivered to FINUDA





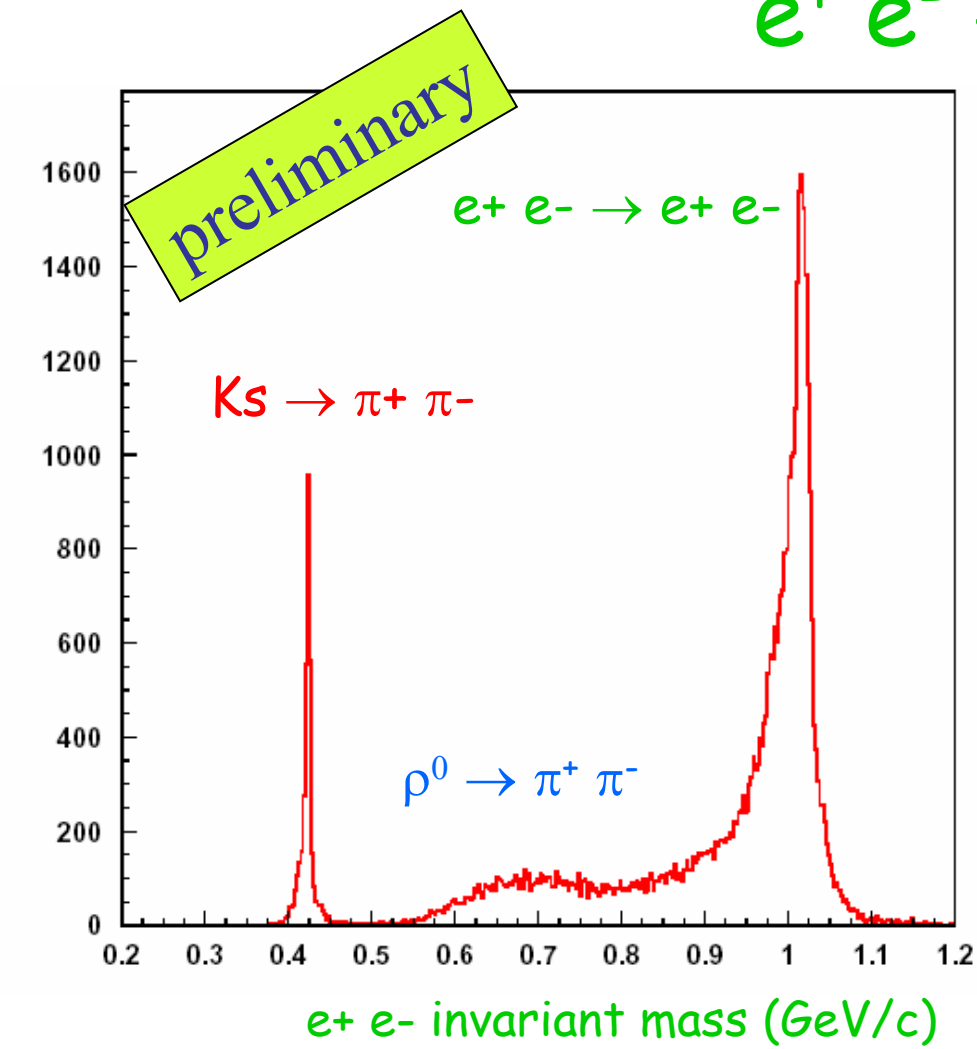
From October 14th 2003 to March 22nd 2004 DAΦNE delivered: 250pb-1 total integrated luminosity. Of this 33pb-1 used for machine tuning, 10 pb-1 for FINUDA detector debug. FINUDA useful data period:
Dec. 1st - March 22nd
corresponding to 190pb-1 excluding data-taking dead time

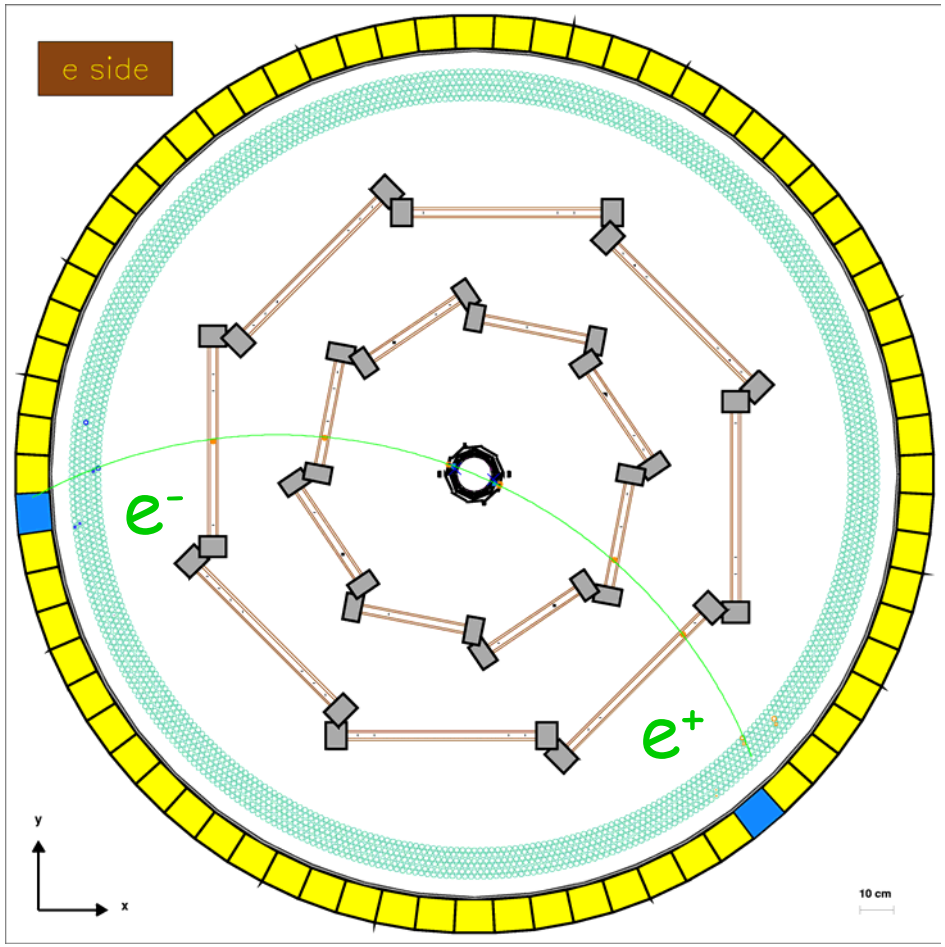
DAΦNE peak luminosity ($cm^{-2}s^{-1}$)



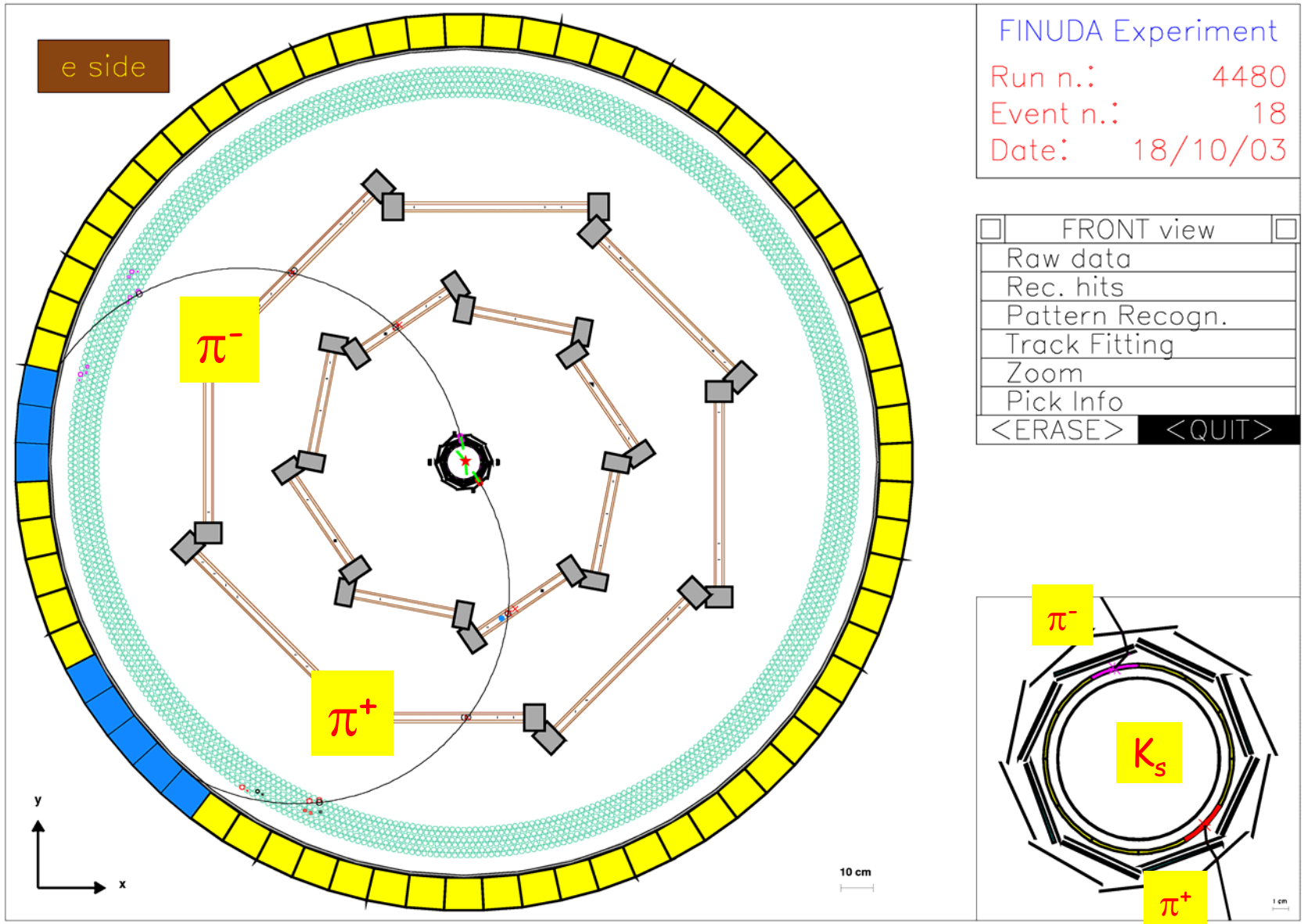
M.Berta

Bhabha event:
$e^+ e^- \rightarrow e^+ e^-$

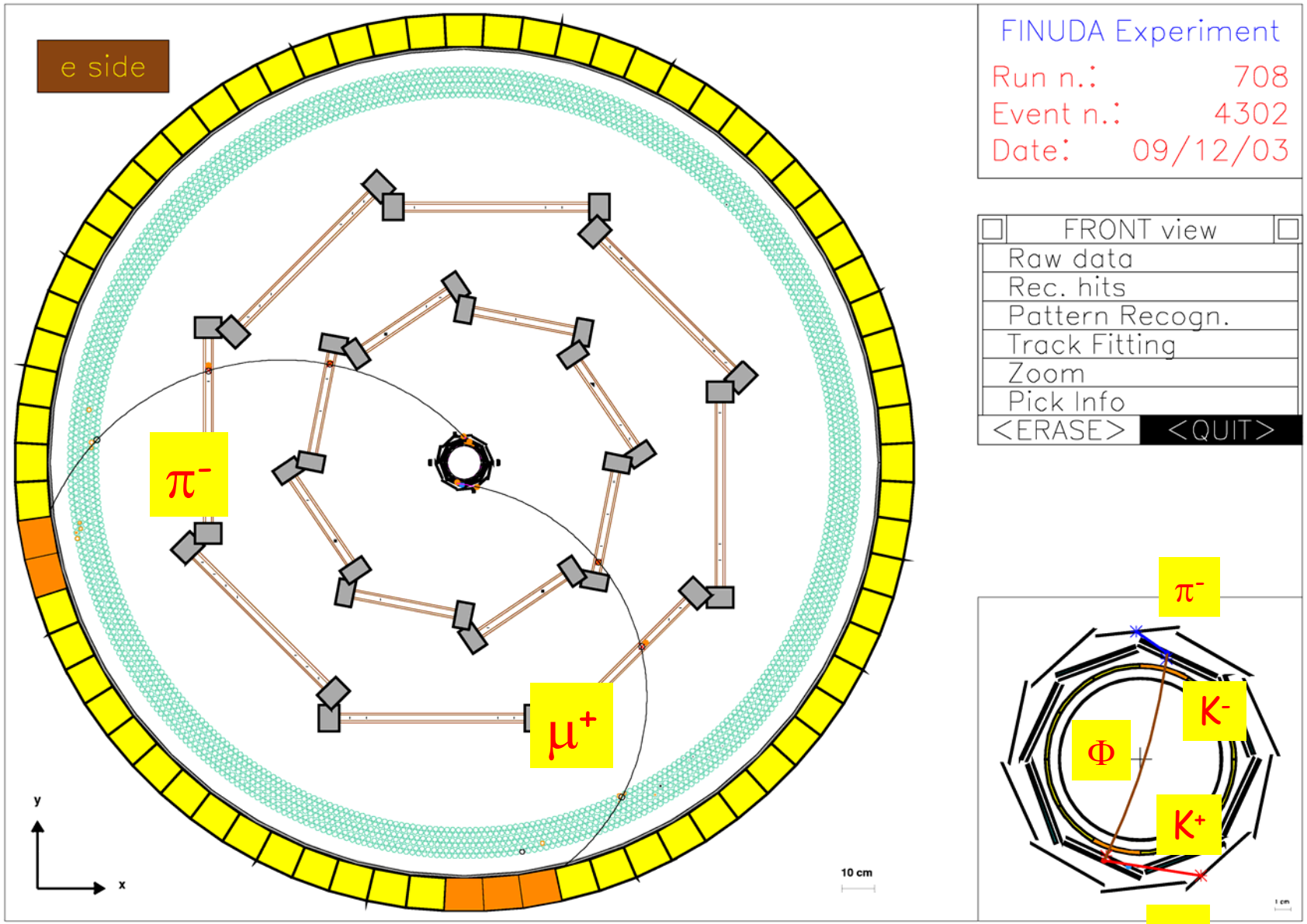




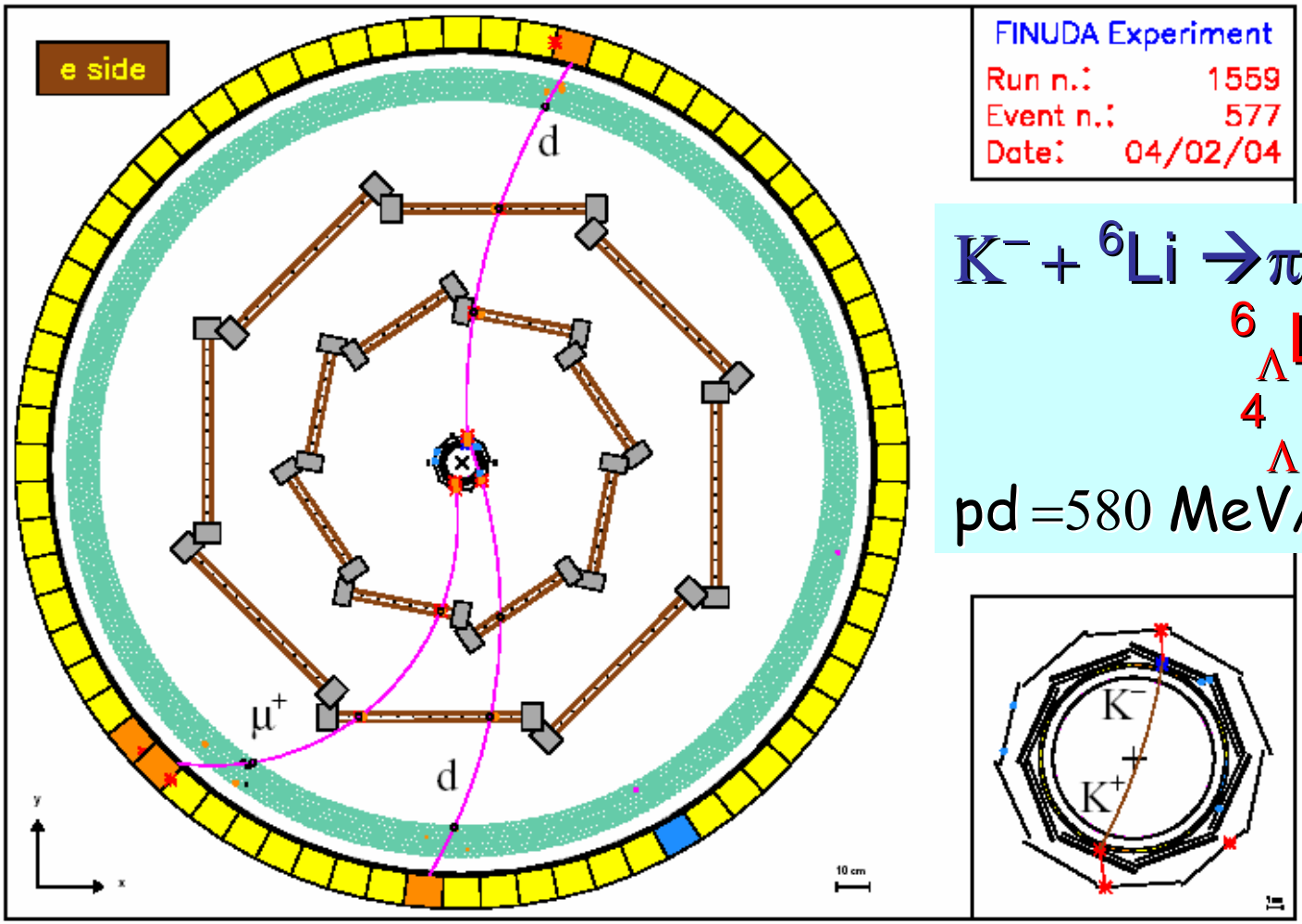
$K_s \rightarrow \pi^+ \pi^-$ event



Hypernuclear formation event $K^-_{stop} + {}^{A}Z \rightarrow {}^{A}_{\Lambda}Z + \pi^-$



Rare Hypernuclear decay event:



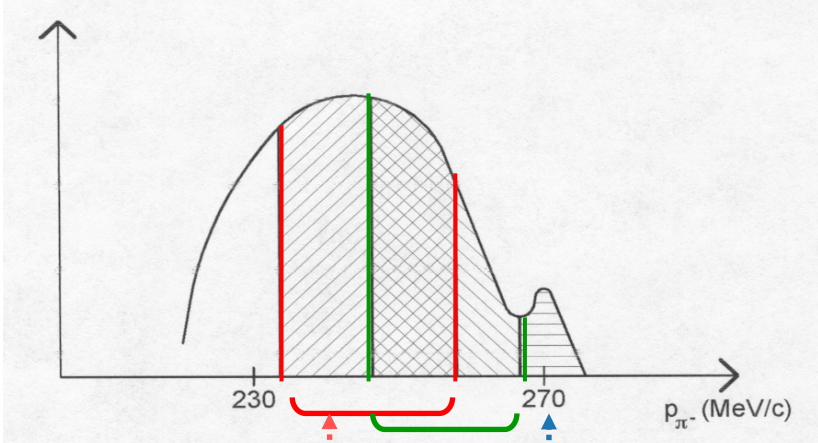
$K^- + {}^6Li \rightarrow \pi^- + {}^6_\Lambda Li$

${}^6_\Lambda Li \rightarrow {}^4_\Lambda He + p + n$

${}^4_\Lambda He \rightarrow d + d$

pd = 580 MeV/c

Light hypernuclei spectroscopy



Spectroscopized

π^-

$K^- + {}^6Li \rightarrow \pi^- +$

${}^5_\Lambda He + p$

- τ
- Γ_p (in coinc.) about 10/pb^{-1}
- Γ_n (in coinc.) a few/pb^{-1}
- $\Gamma_{\pi-}$ about 10^2/pb^{-1}

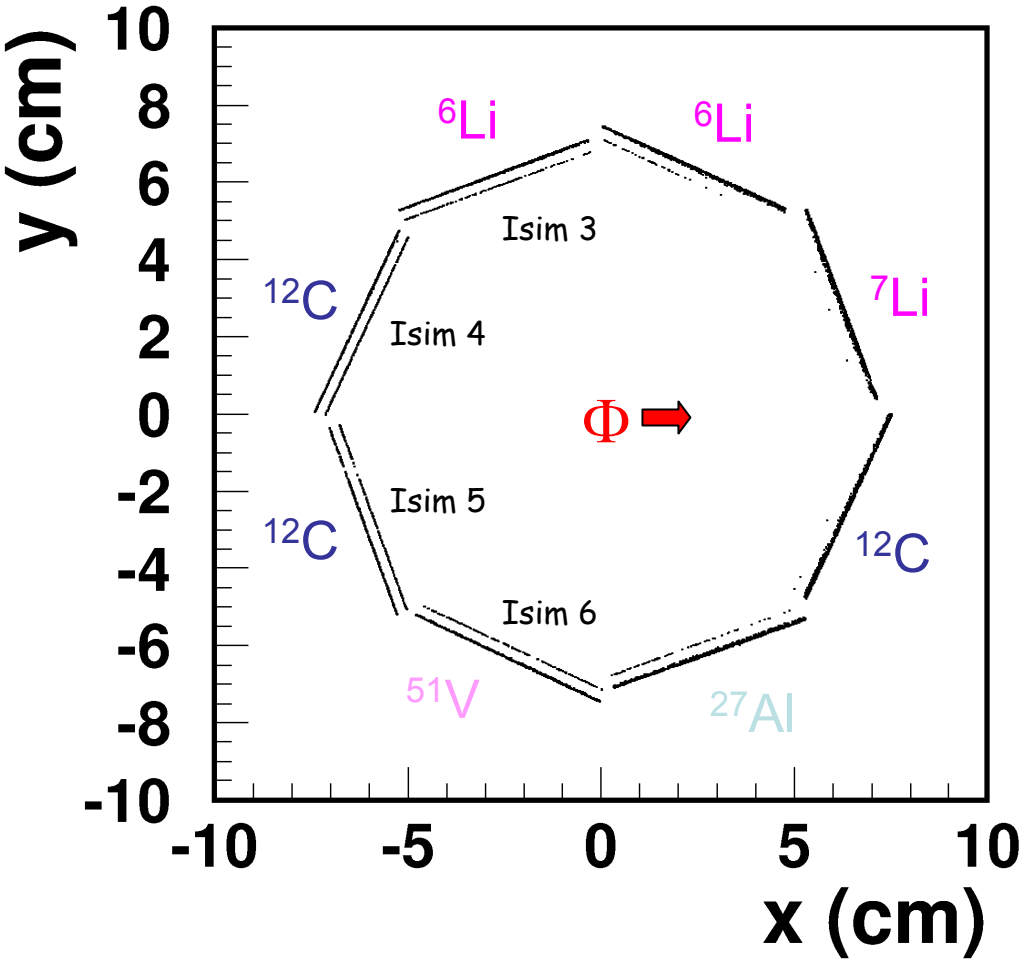
${}^4_\Lambda He + p + n$

- d+d spectr. (~1/pb^{-1} if B.R. ~10^{-3})
- p+ ^{3}H spectr.(0.5/ pb^{-1} if B.R. ~10^{-3})
- π^++n+^{3}H many events (~ 10^2/pb^{-1})
  how distinguishable?

${}^4_\Lambda H + p + p$

- ^{4}He+ π^+ spectr. (10^2/pb^{-1}) calibration

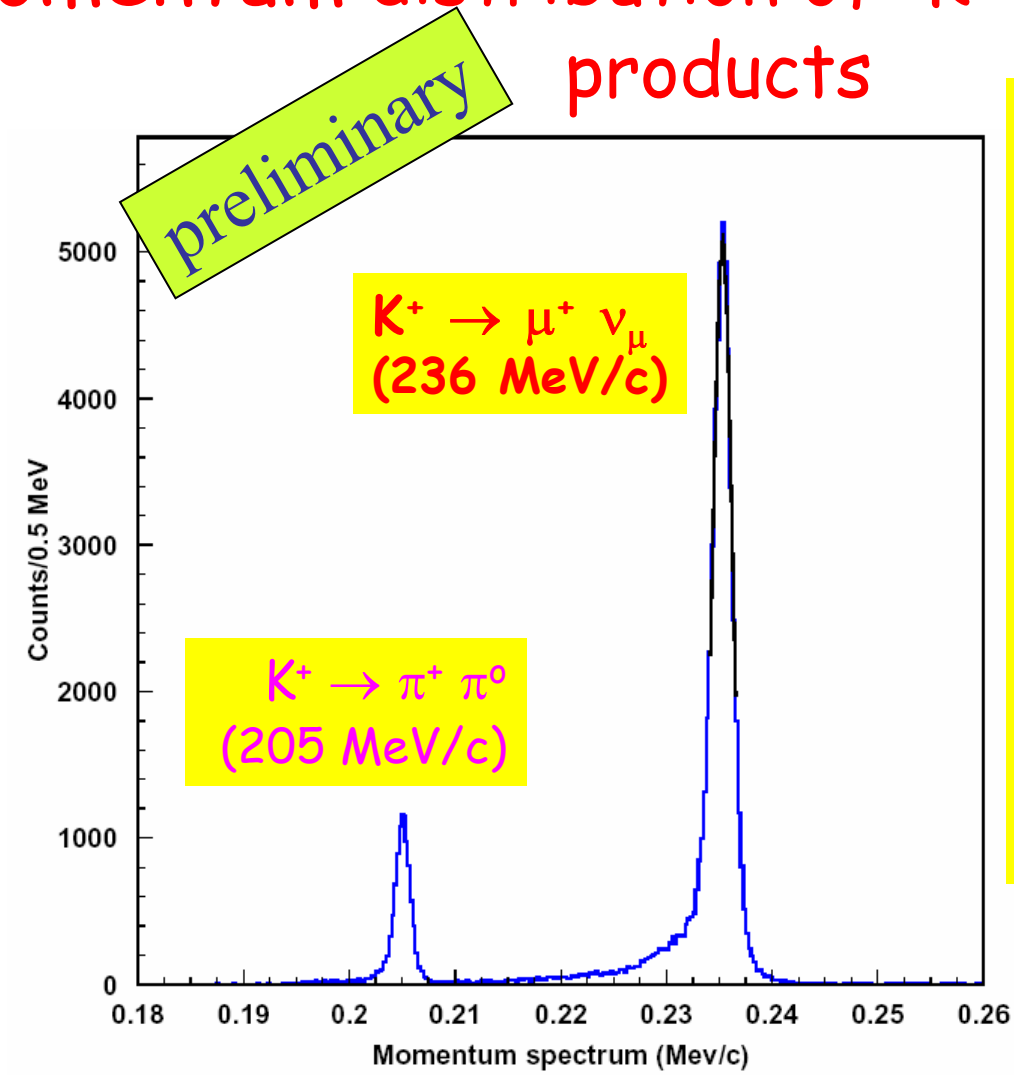
Target envelope by K^- stop



Scatter plot of the reconstructed y vs x coordinates of the K^- stopping points:

- -most external octagon: 8 target modules, where most of the K^- stop.
- -Inner layers: stops on the microstrip ISIM modules
  - •they correspond to about 10% of the total stops, due to (e^+e^-) beam boost, directed in the positive x versus

Momentum distribution of K^+ charged decay products



$K^+ \rightarrow \mu^+ \nu_\mu$, $\pi^+\pi^o$

From the width of the μ^+ peak the actual preliminary momentum resolution is:

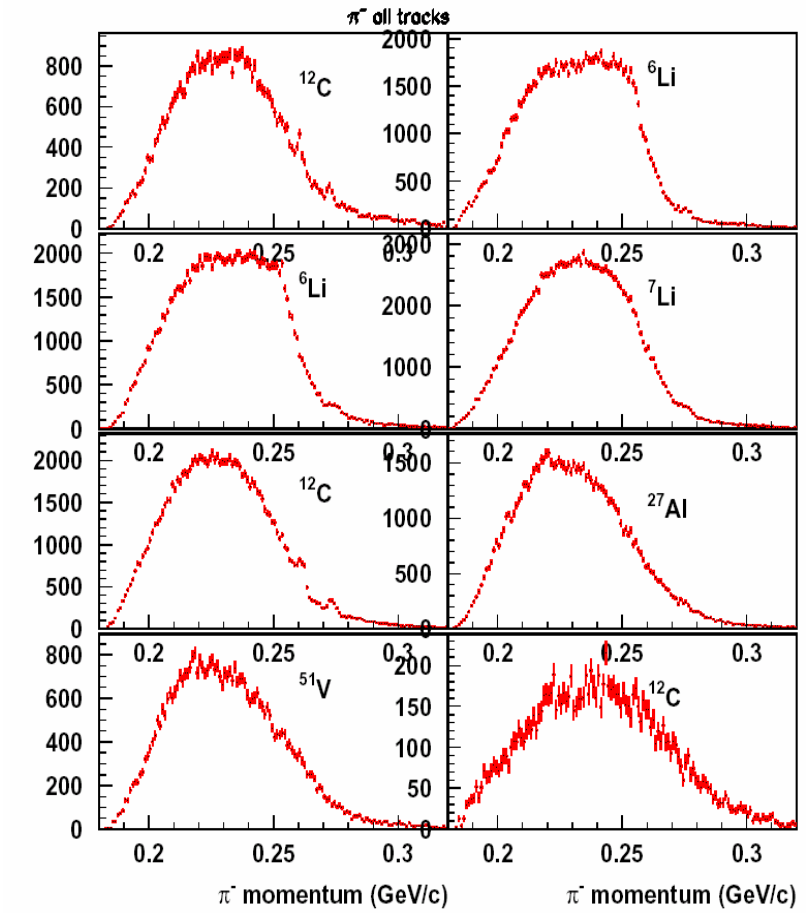
$\Delta p/p \approx 0.9\%$ FWHM

DATA analysis : Event Selection

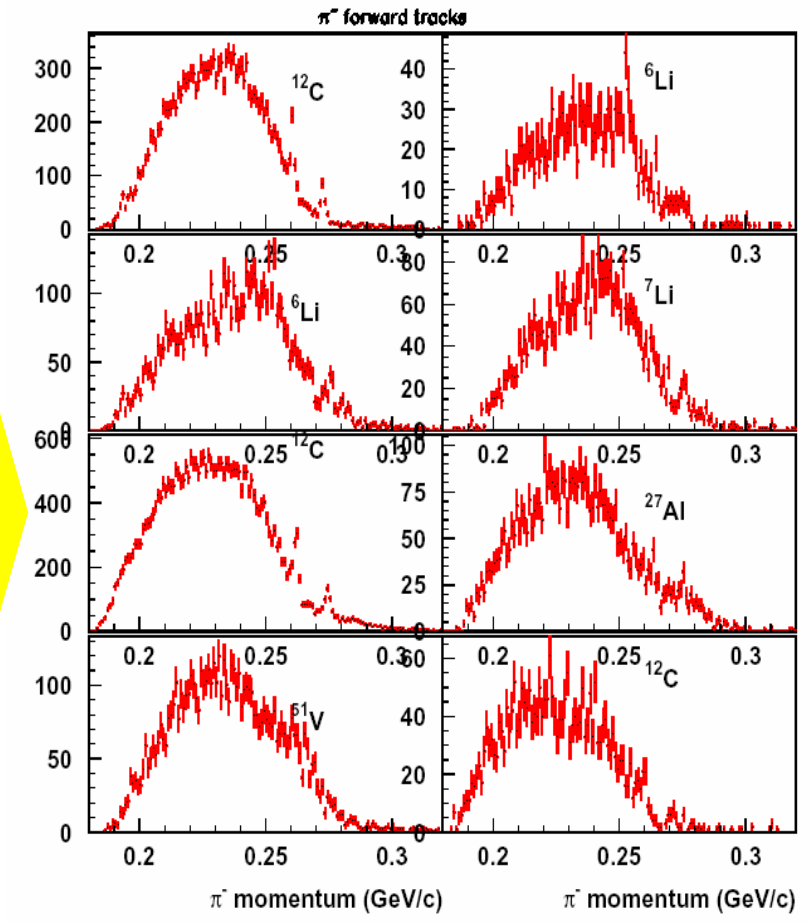
1) Global Event Pattern Recognition
2) Selection criteria for π^- Candidates from hypernuclear formation:

- negative track from K^- vertex
- 4 points/track, in detectors:
  1. Outer microstrip OSIM
  2. first layer LMDC
  3. second layer LMDC
  4. Straw Tubes triplet
- forward track (not crossing backward the interaction/target region): angle w.r.t. target 10^o -> 170^o
- momentum corrected for the energy loss in the target material crossed
- Quality cuts on track fitting

Clean hypernuclear structures present in all targets



sel. cuts



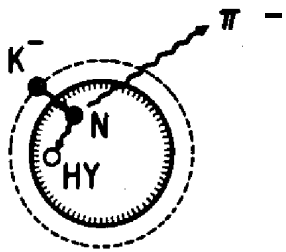
π- reconstructed momentum spectrum in the 8 nuclear targets – NO selection

applying selection cuts: forward w.r.t. target, quality fit

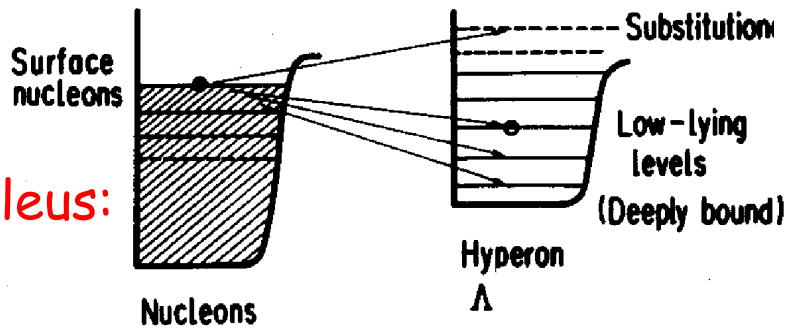
π^- spectra following the hyp. formation

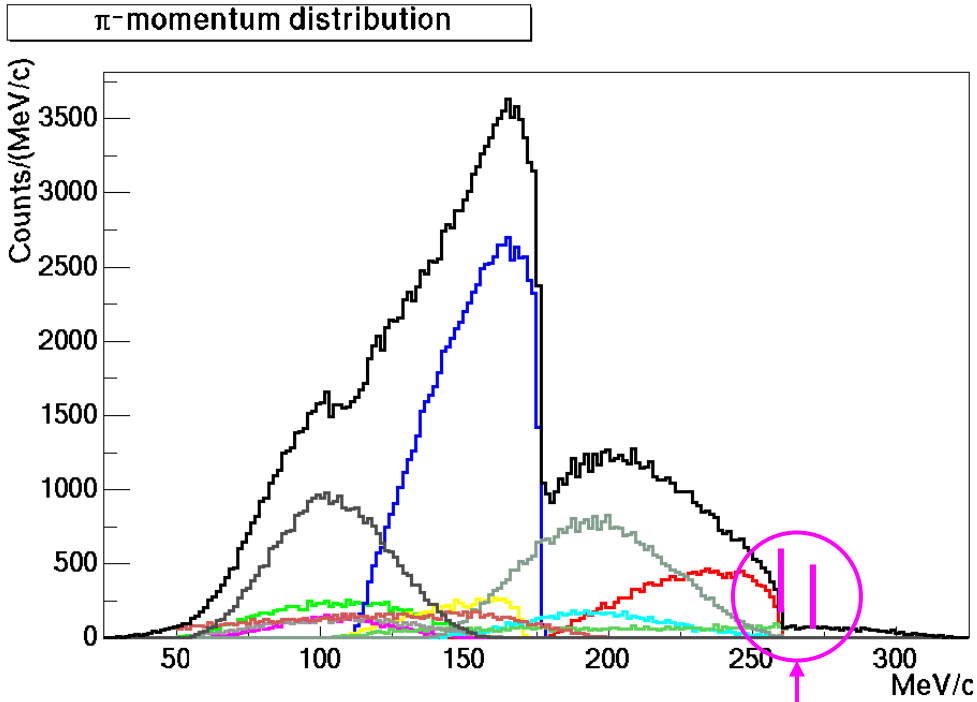
$$K^-_{stop} + {}^{A}Z \rightarrow {}^{A}_{\Lambda}Z + \pi^-$$

a) atom:



b) nucleus:





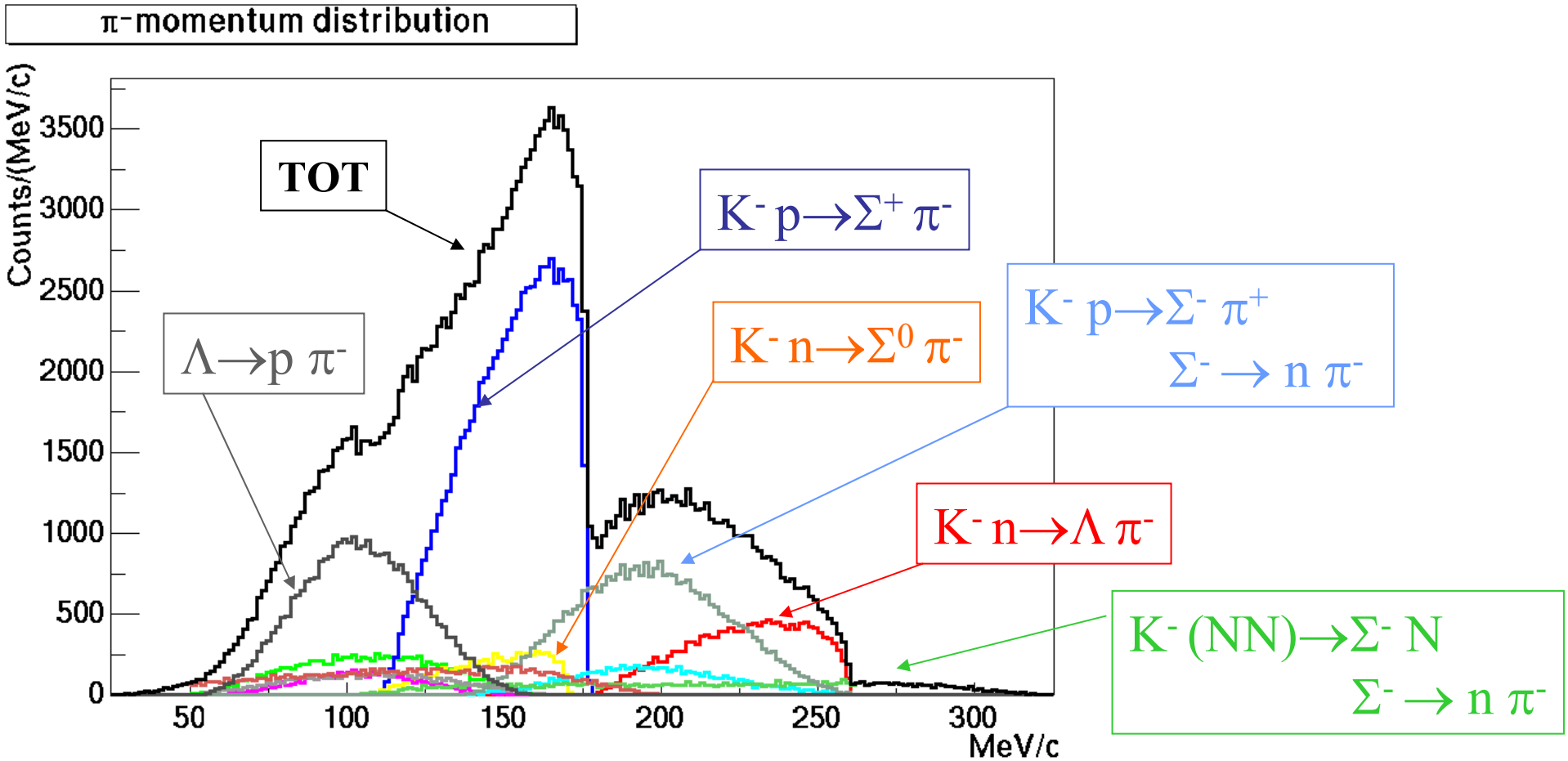
Λ - hyp

$$B_\Lambda = M_{A-1} + M_\Lambda - M_A - M_K + M_\pi + T_\pi$$

T.Yamazaki., Nucl. Phys. A434 (1985) 363c-372c

Background reactions: π- spectra

Background reactions giving a π- following K- Nucleus interactions have been simulated in the apparatus with FINUDA Monte Carlo :



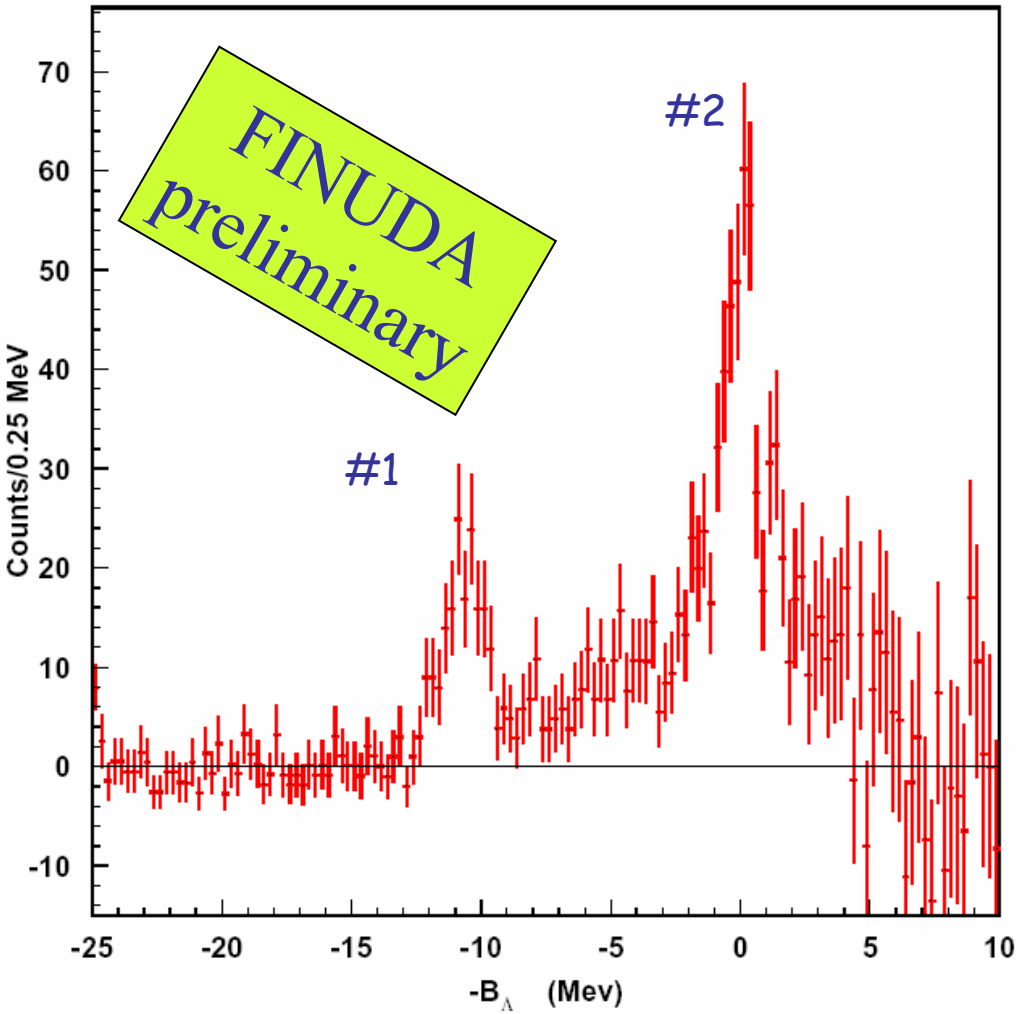
^{12}C Target N.1

- ^{12}C is the reference Nucleus
- In the following I'll refer to ^{12}C target N.1, about 20% of the available statistics for ^{12}C

  Different targets have different systematic mainly due to the geometrical alignment of the detectors, that are currently being improved.
- The measured π- momentum is transformed intothe binding energy B_Λ of the lambda:

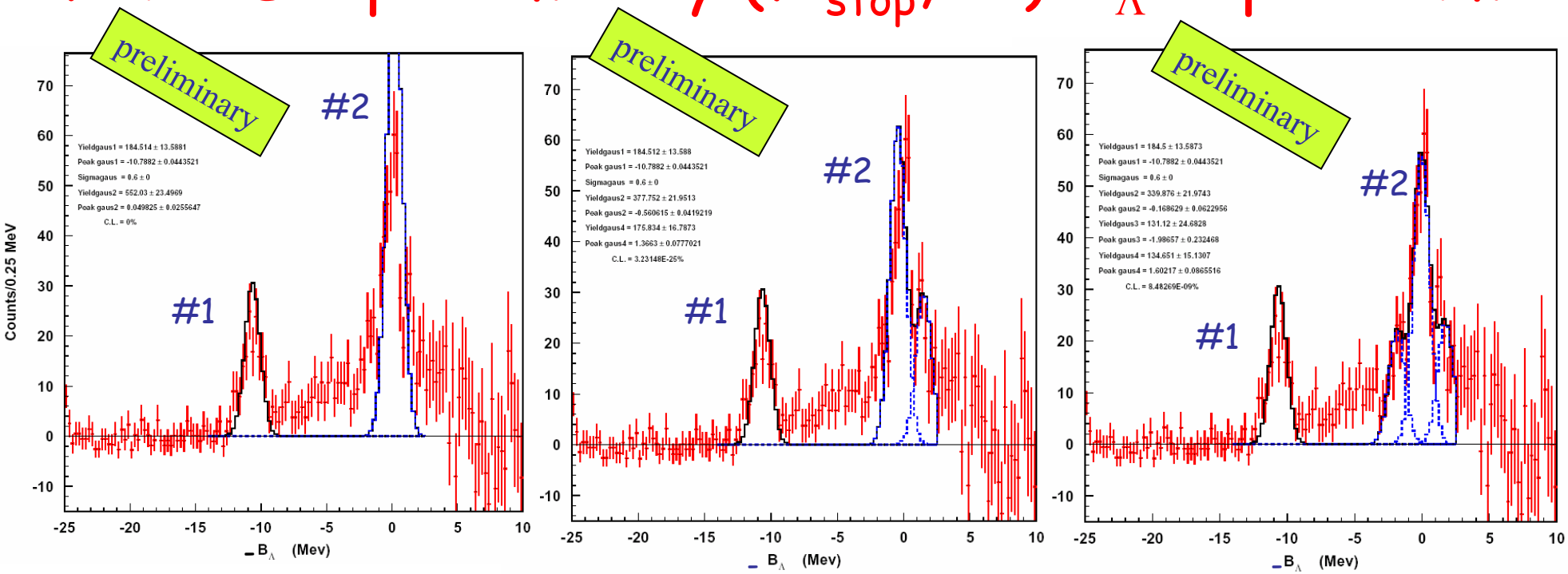
$$B_\Lambda = M_{A-1} + M_\Lambda - M_A - M_K + M_\pi + T_\pi$$

Clean $(K^-_{stop}, \pi^-)\ ^{12}_{\Lambda}C$ spectrum



- Simulated background particles have been reconstructed and π^- selected following the same selection criteria as for the hypernucleus formation π^- candidates
- The shape of the background simulated and reconstructed spectrum is parameterized by a simple curve and subtracted from the experimental spectrum.
- Resolution (σ_E =600KeV) set by peak #2 at B_Λ = 0 ($\Delta p/p \approx$ 0.6% FWHM)

FINUDA preliminary (K^-_{stop}, π^-) $^{12}_{\Lambda}C$ spectrum



STEP 1

- Exclude region between peaks #1 , #2
- Fit with 2 gauss with σ_E =600KeV fixed
- Does not work there is more than 1 object in #2 (?)…

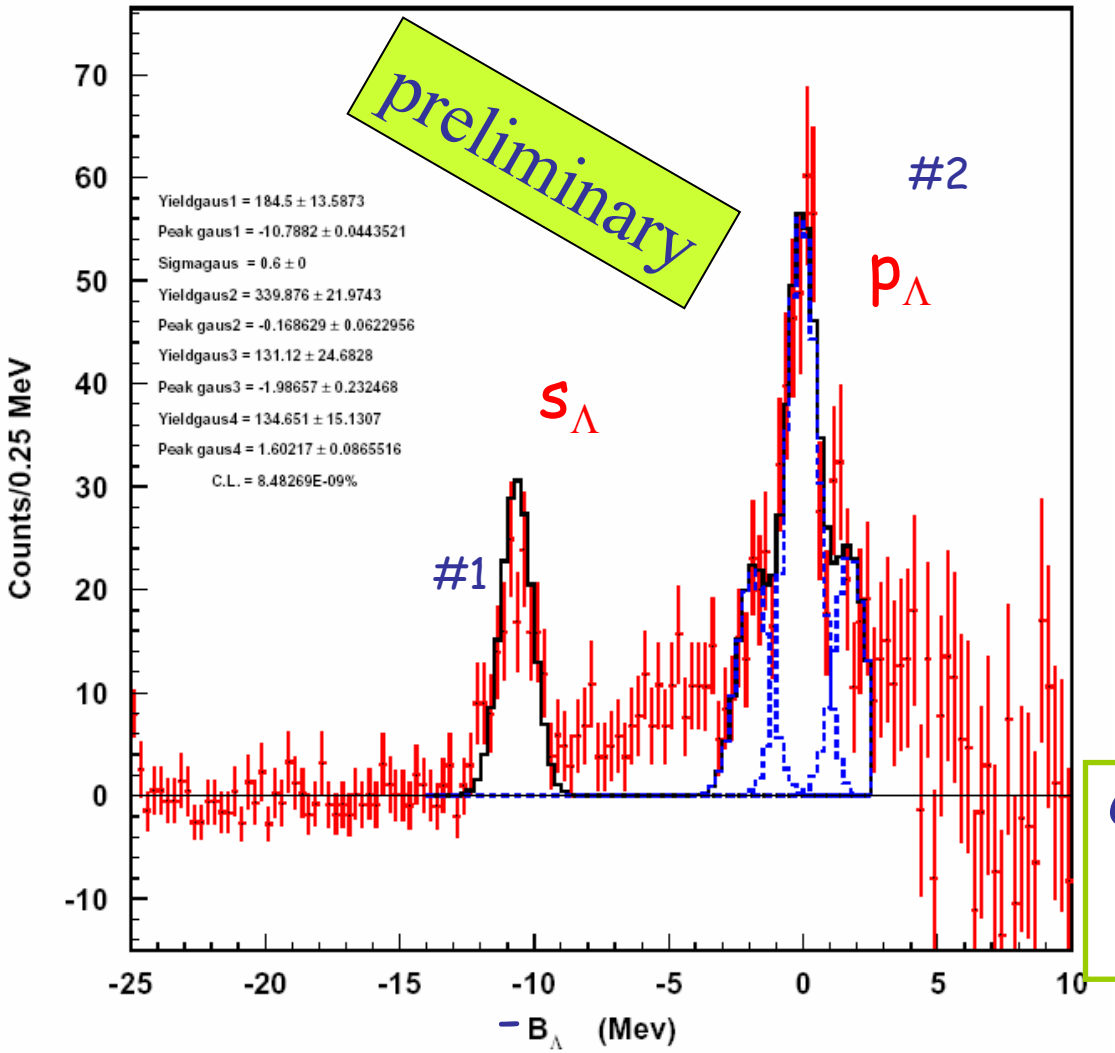
STEP 2

- …try to fit peak #2 with 2 gauss …. Seems better but…

STEP 3

- …add a third gauss for the peak #2
- Now better fit.

FINUDA preliminary $^{12}_{\Lambda}C$ spectrum



- Partial statistics, only one of the three 12C targets
- Best fit with the sum of 4 gaussian distributions, 1 for the ground state peak (#1), 3 needed to describe the p_Λ state peak (#2)
- Region between main peaks excluded from fit.

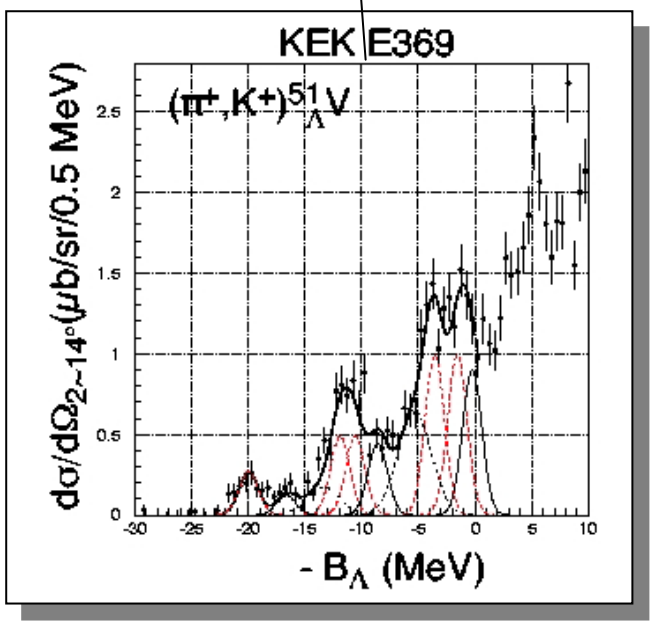
Capture Rates:
#1 ground state: ~ $1.8\times10^{-3}/K^-_{stop}$
#2 excited state: ~ $3.3\times10^{-3}/K^-_{stop}$

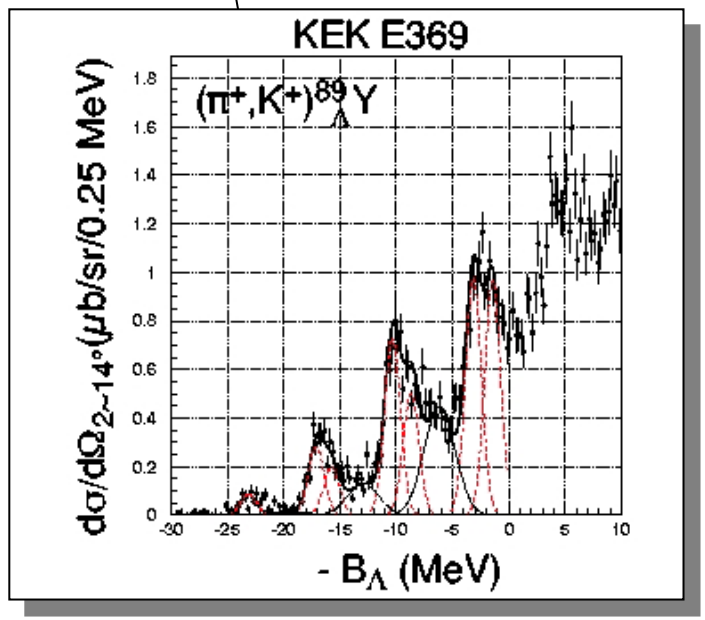
Spectroscopy: pre-Finuda data

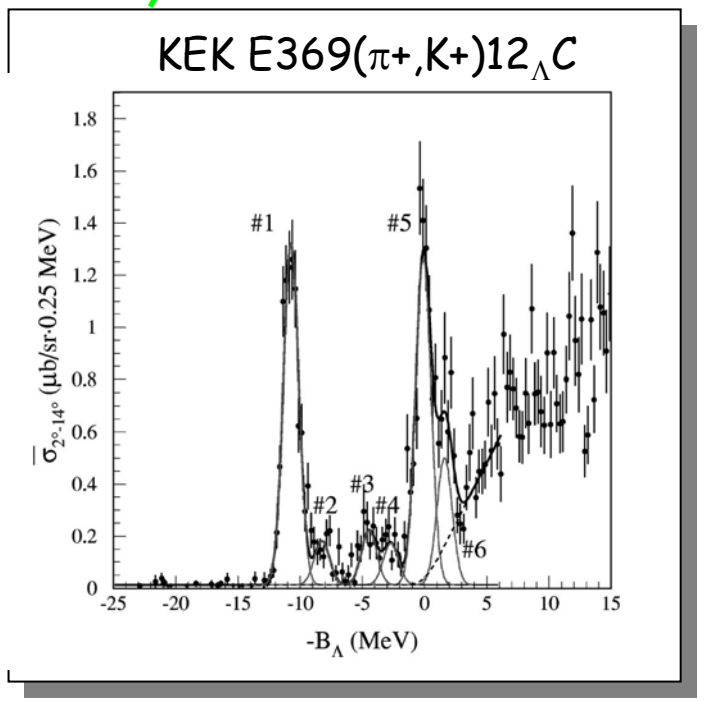
1.93 MeV

1.65 MeV

1.45 MeV





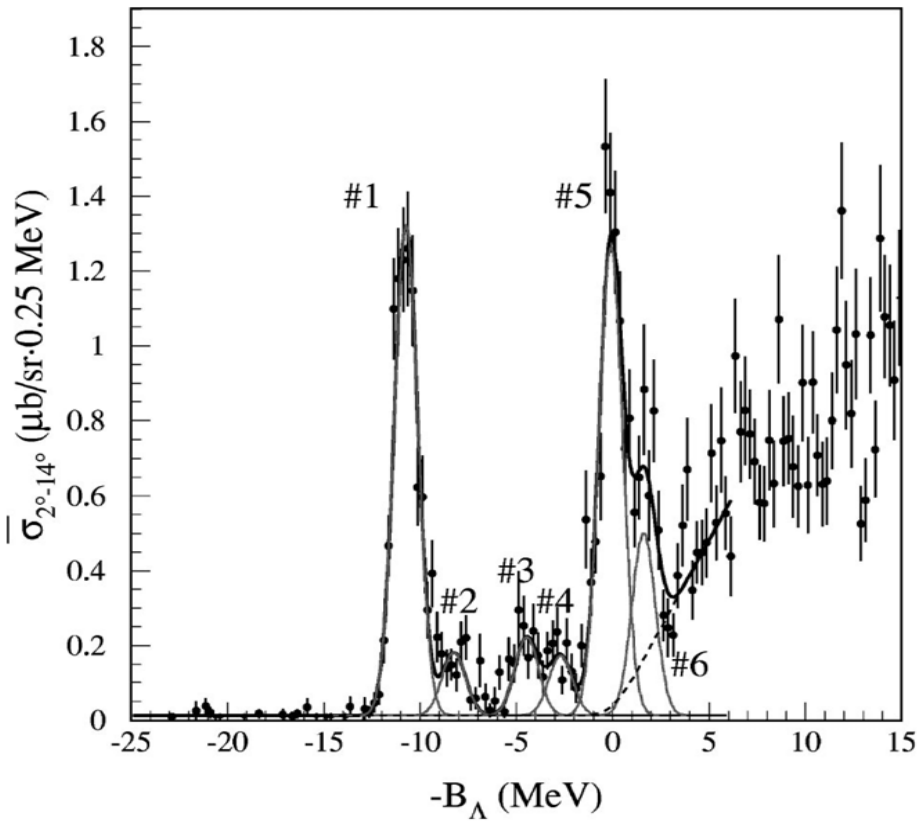


H.Hotchi, Phys.Rev. C 64 (2001) 044302

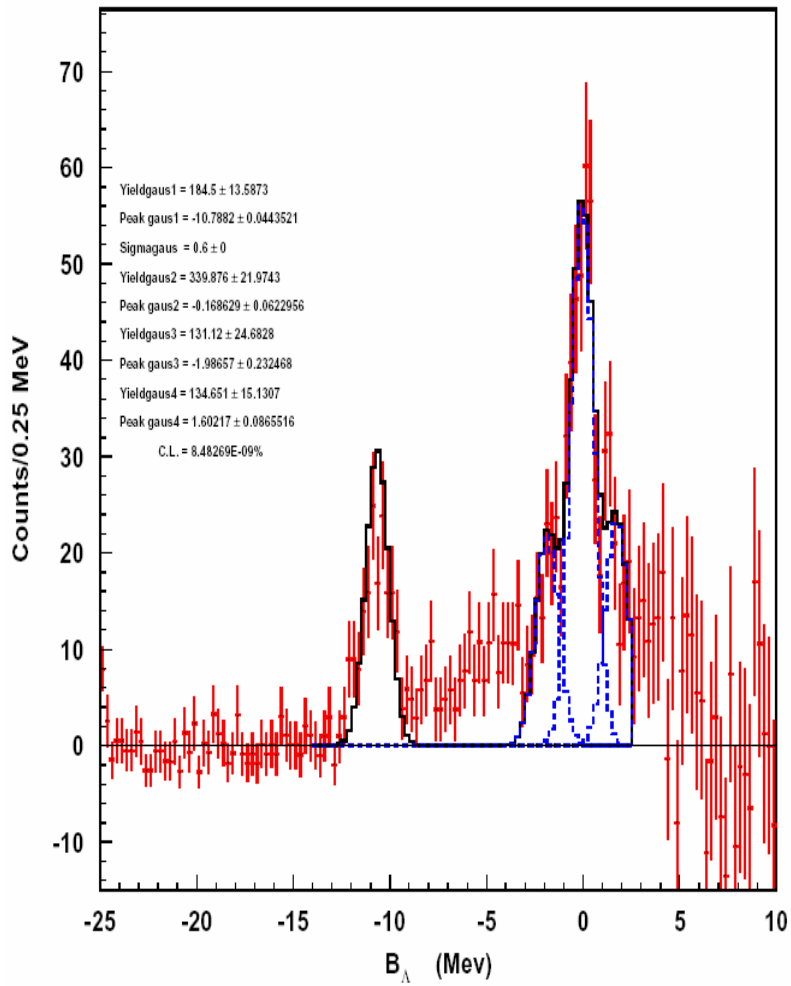
$^{12}_{\Lambda}C$ spectroscopy: FINUDA vs KEK-E369

Previous results: KEK E369
En.Res.≈ 1.45 MeV FWHM
(π^+, K^+)

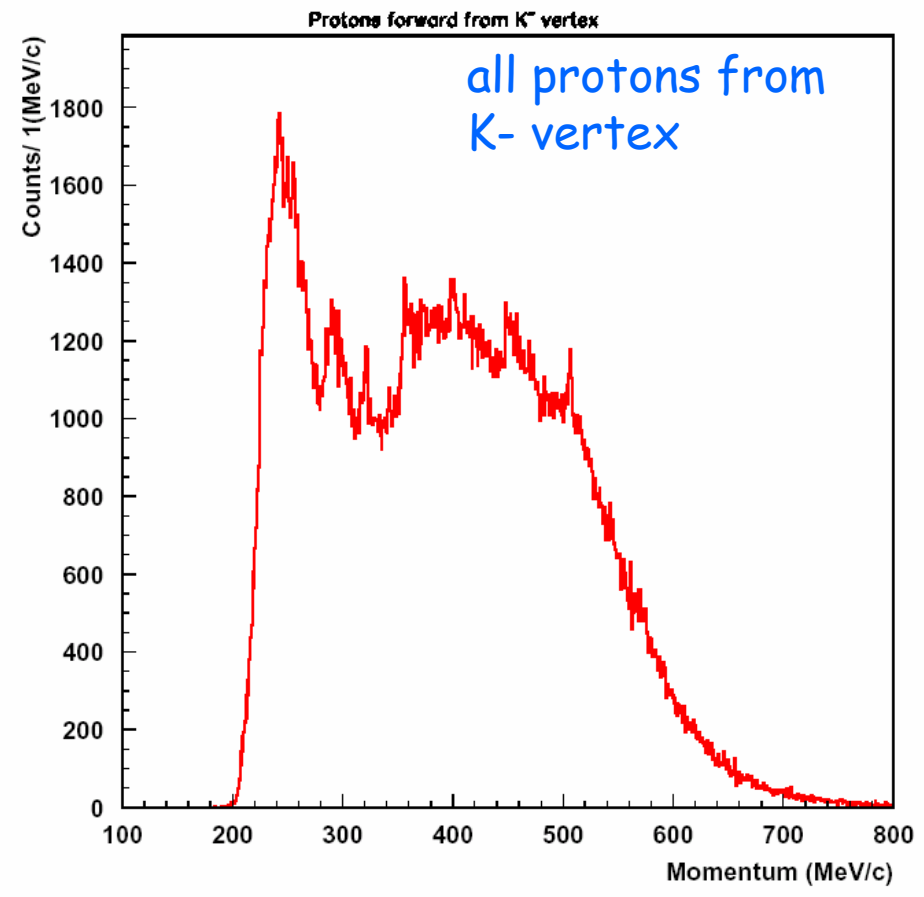
FINUDA preliminary
En. Res. ≈ 1.4 MeV FWHM
(K^-_{stop}, π^-)

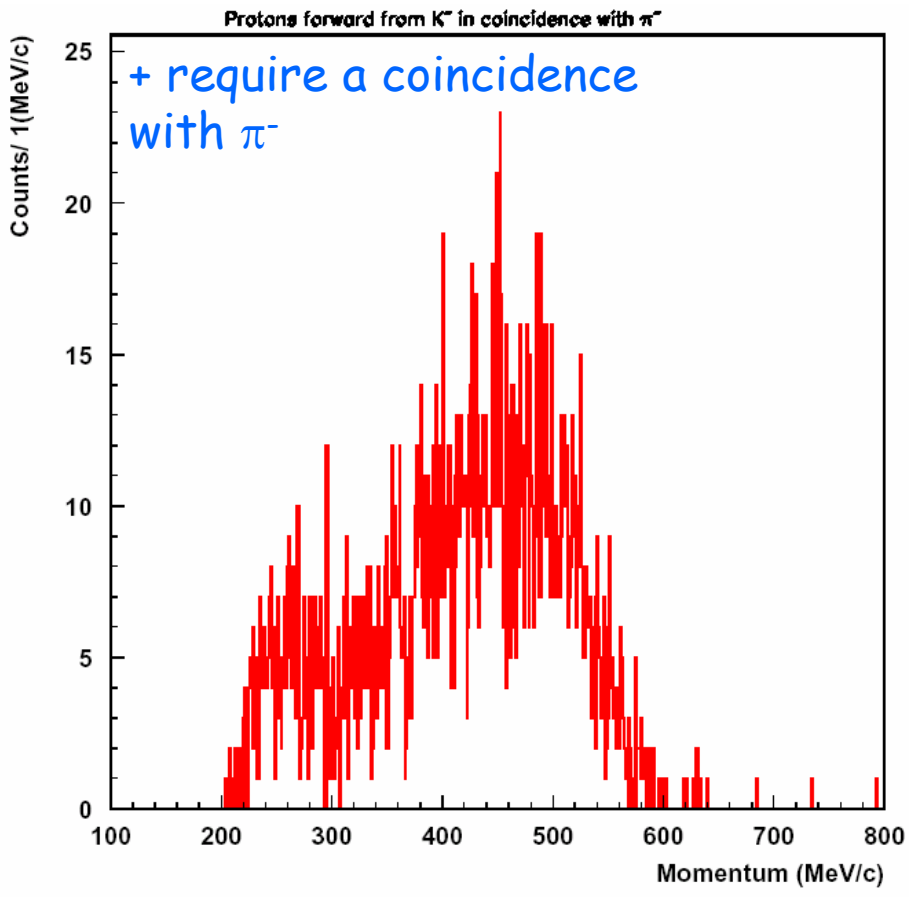


H.Hotchi, Phys.Rev. C 64 (2001) 044302



Looking for protons from the Non Mesonic Λ decay





- Protons coming from background processes and hypernucleus decays
- forward tracks without and with the coincidence of π^- from hyp. formation (protons mainly from hyp. decay)

Conclusions

- FINUDA HAS SUCCESSFULLY ENDED ITS FIRST DATA TAKING PERIOD COLLECTING $30X10^6$ EVENTS
- PRELIMINARY RESULTS ALREADY SHOW COMPETITIVE WITH WORLD RESULTS AND PROVE THE VALIDITY OF THE NOVEL IDEA OF USING A Φ-FACTORY AS A SOURCE OF SLOW KAONS FOR HYPERNUCLER PRODUCTION
- WE ARE ON THE WAY TO GREATLY IMPROVE ENERGY RESOLUTION AND STATISTICAL ERROR