Strange hadrons in nuclei, first results from FINUDA

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Finuda Collaboration

Finuda physics program

- HYPERNUCLEAR SPECTROSCOPY

essential tool for testing :

- theoretical models of Λ-N potentials
- single particle nuclear model predictions
- bound states with strangeness

SIMULTANEOUSLY

- HYPERNUCLEAR DECAYS

- study of baryon-baryon weak processes in nuclear matter

$\Lambda \rightarrow \pi N$, $\Lambda N \rightarrow NN$ and $\Lambda NN \rightarrow nNN$

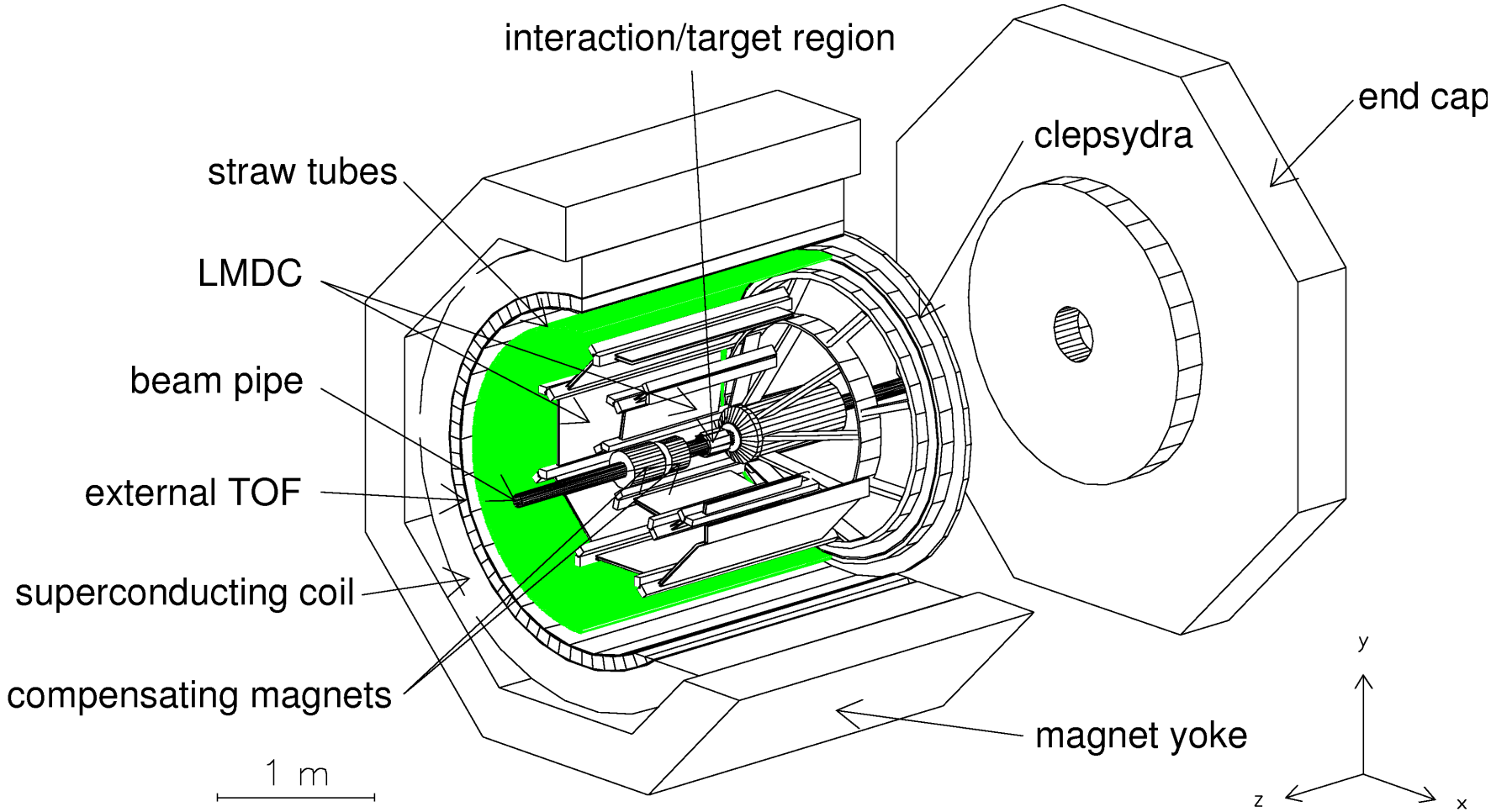
ON DIFFERENT NUCLEI

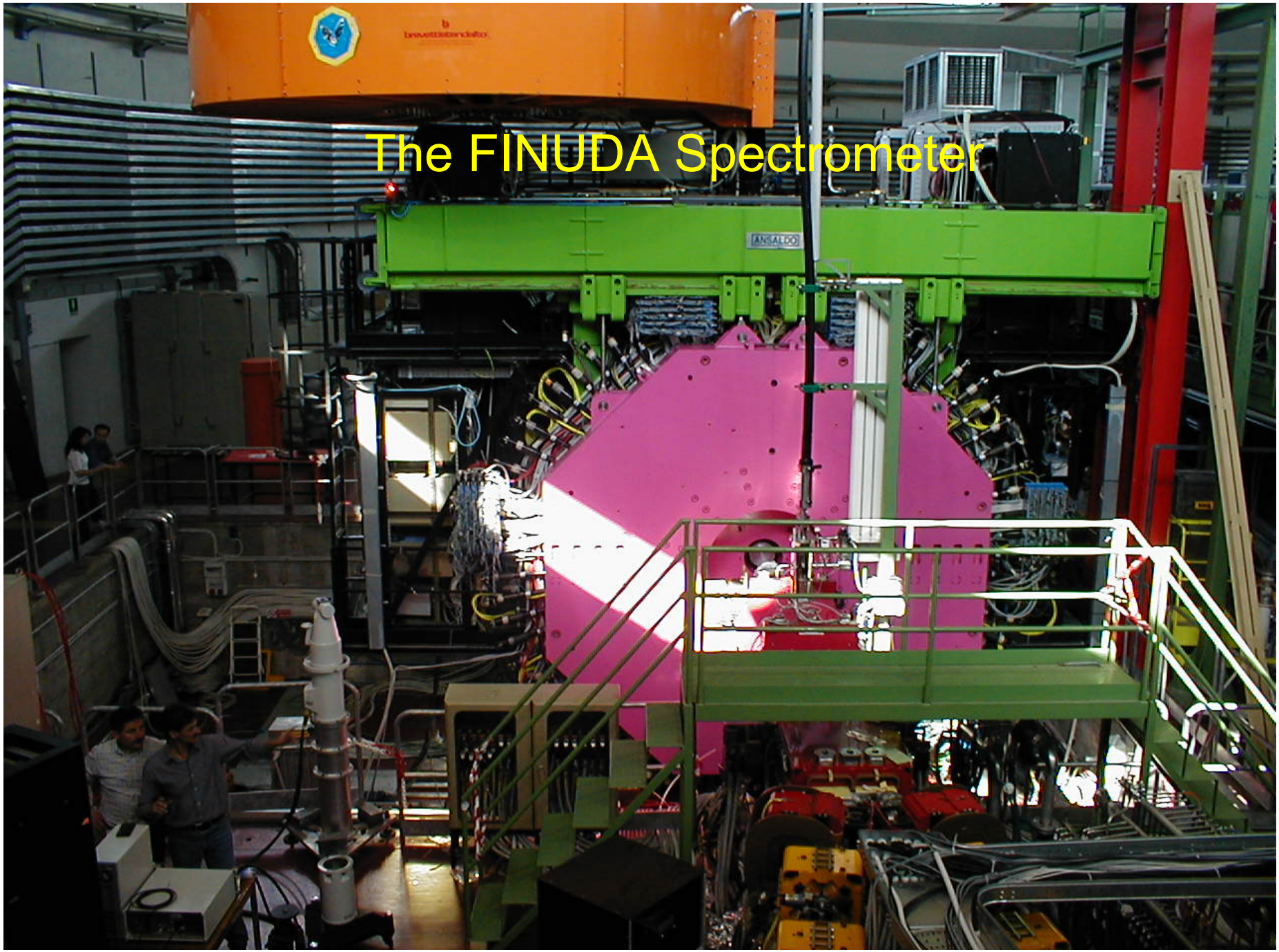
- SEARCH FOR:

- Σ-hypernuclei
- Deeply bound kaonic nuclei
- Neutron-rich hypernuclei
- Rare decays

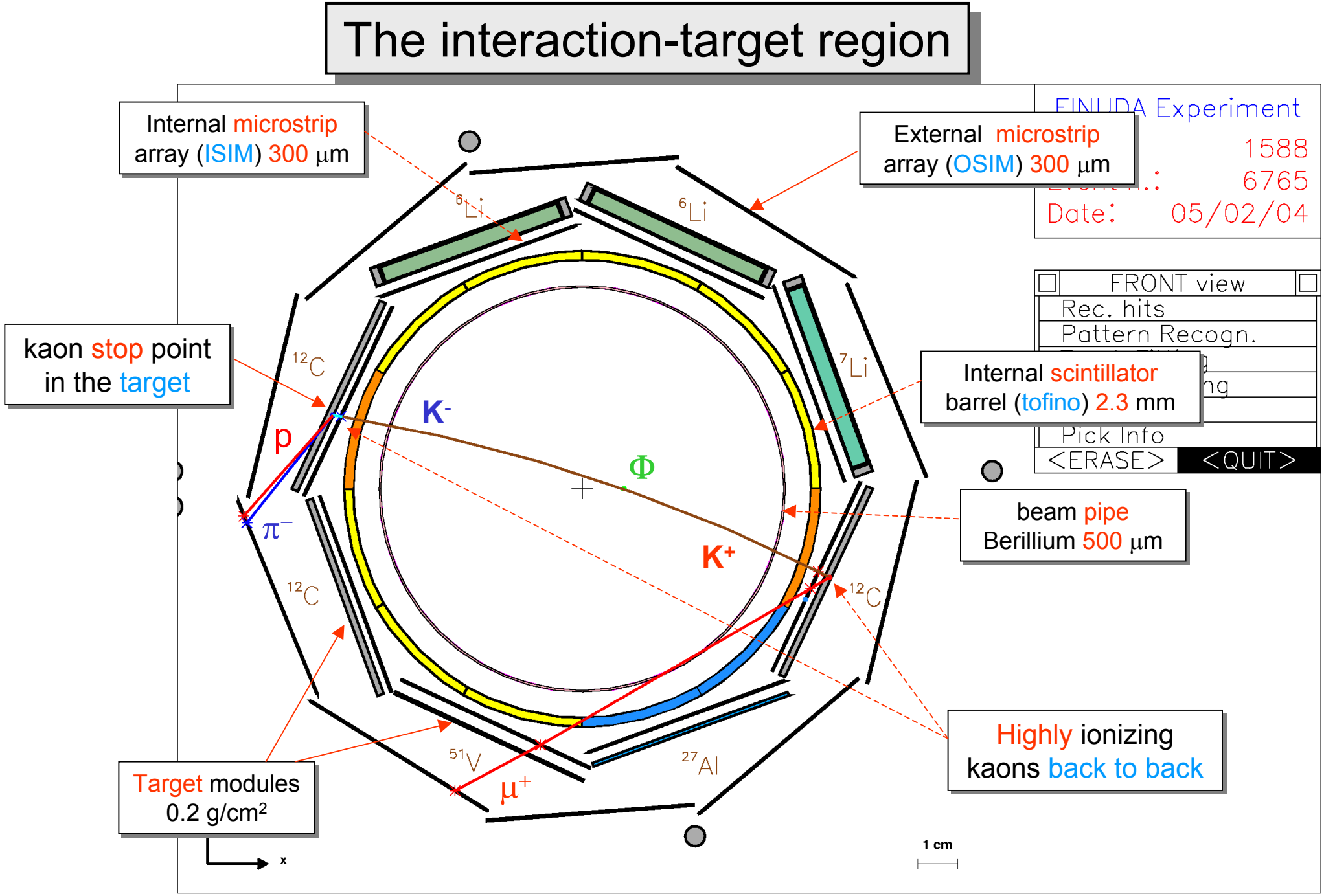
HIGH STATISTICS

The FINUDA Spectrometer

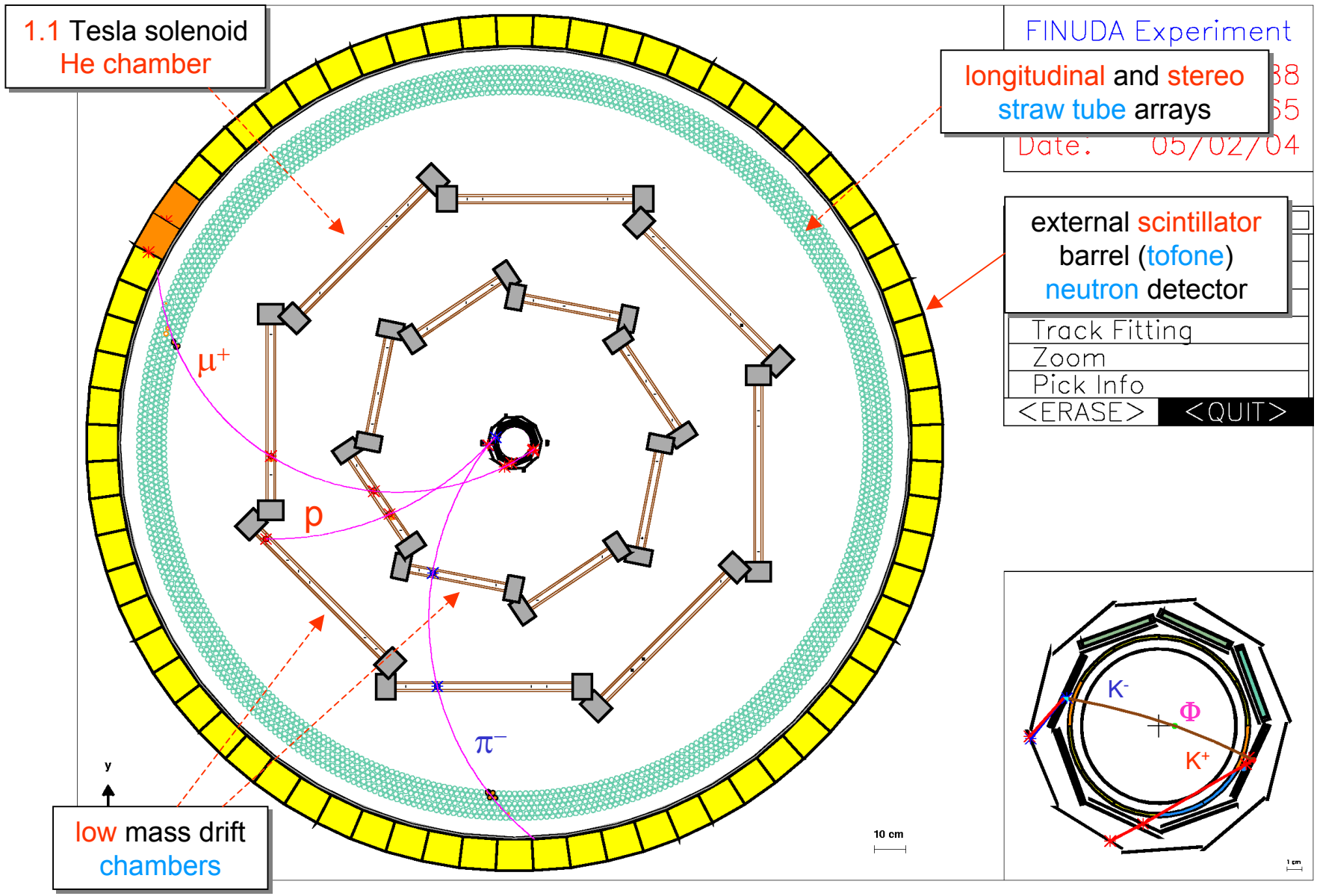



The FINUDA Spectrometer
ANSALDO

The interaction-target region

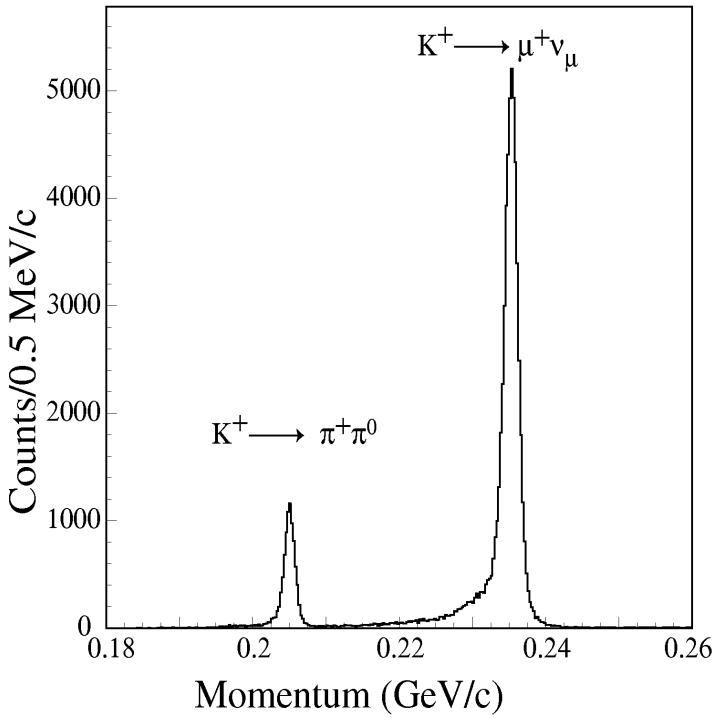


The tracking region and the neutron detector



Positive track momentum coming from the K^+ vertex and momentum resolution

K^+ two body decays: reference for spectrometer calibration



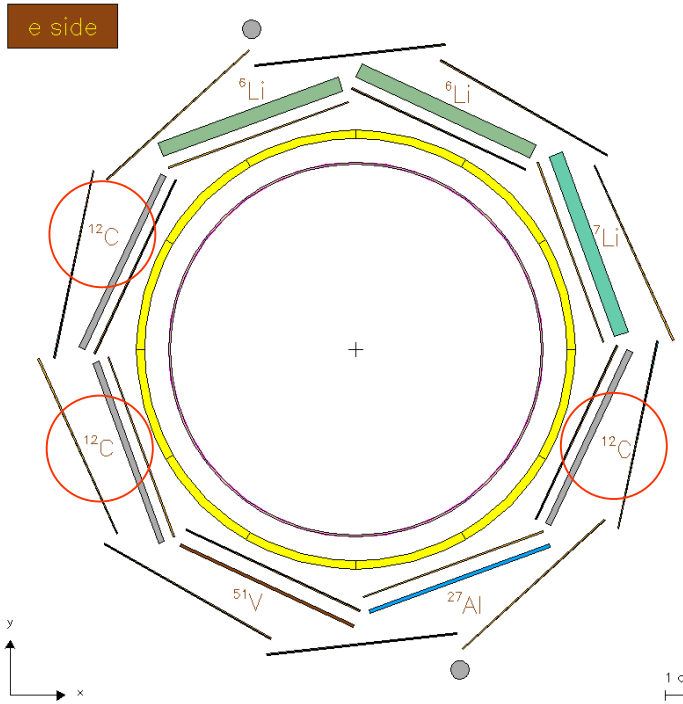
Present Results:
$\Delta p/p \approx 0.6\%$ FWHM
$\Delta M_H = \Delta T_\pi \sim 1.25$ MeV FWHM

FINUDA GOALS:
$p_\pi = 272$ MeV/c and $\Delta p/p \approx 0.38\%$ FWHM
$\Delta M_H = \Delta T_\pi < 0.9$ MeV FWHM

- neglecting the hypernucleus recoil energy : $\Delta M_H = \Delta T_\pi$

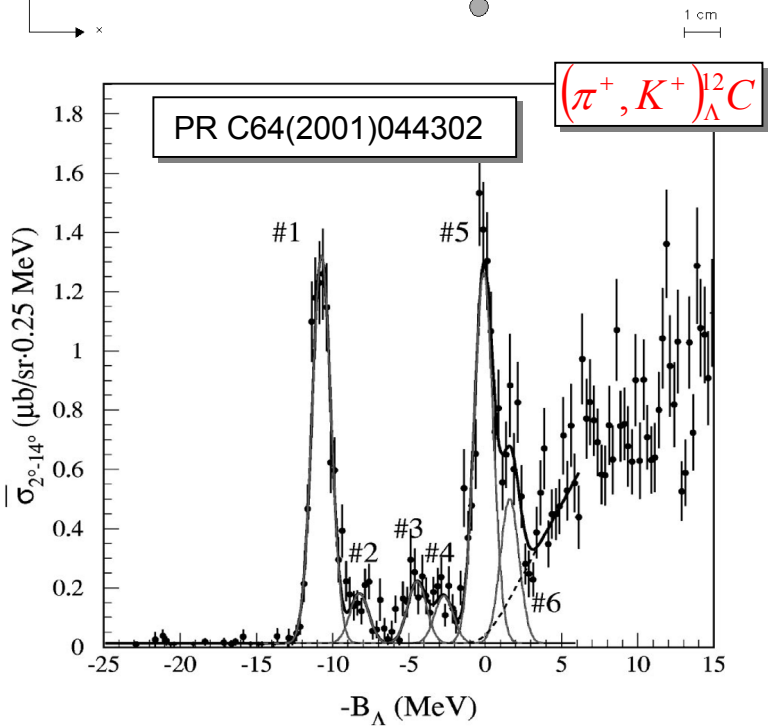
$$\frac{\Delta T_\pi}{T_\pi} = \frac{\sqrt{p_\pi^2 + m_\pi^2} + m_\pi}{\sqrt{p_\pi^2 + m_\pi^2}} \cdot \frac{\Delta p_\pi}{p_\pi}$$

Target: 3 x ^{12}C

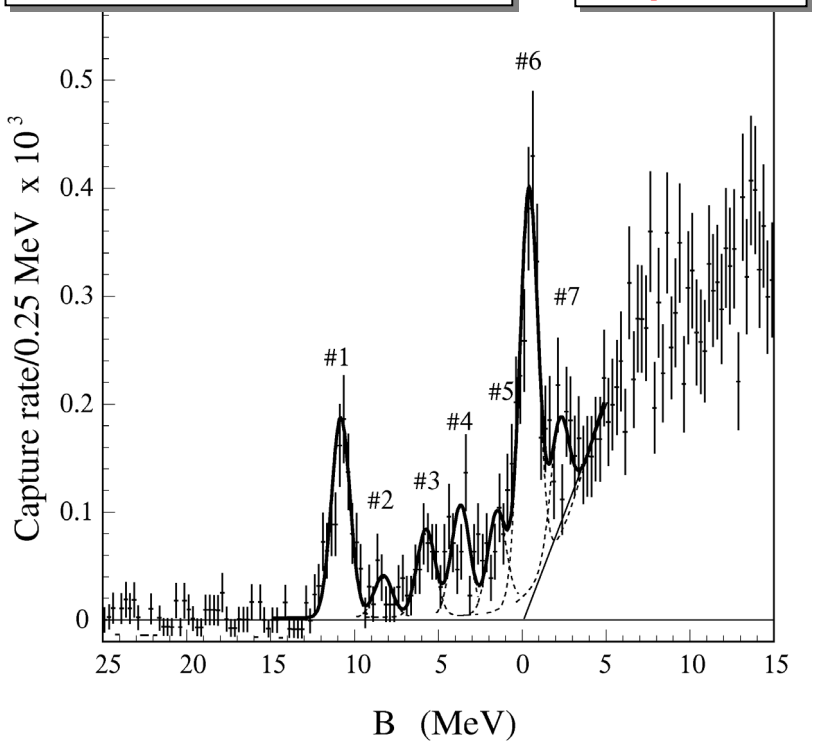


$^{12}_{\Lambda}$C has been extensively studied, therefore the three targets provide:

- data to be compared with previous measurements
- the level of improvement of the quantities observed



FINUDA PRESENT RESULTS $\left(K^-_{stop}, \pi^-\right)^{12}_{\Lambda}C$



#	-B$_\Lambda$ (MeV)
1	-10.94±0.06
2	-8.4±0.2
3	-5.9±0.1
4	-3.8±0.1
5	-1.6±0.2
6	0.27±0.06
7	2.1±0.2

Search for Σ bound states with FINUDA

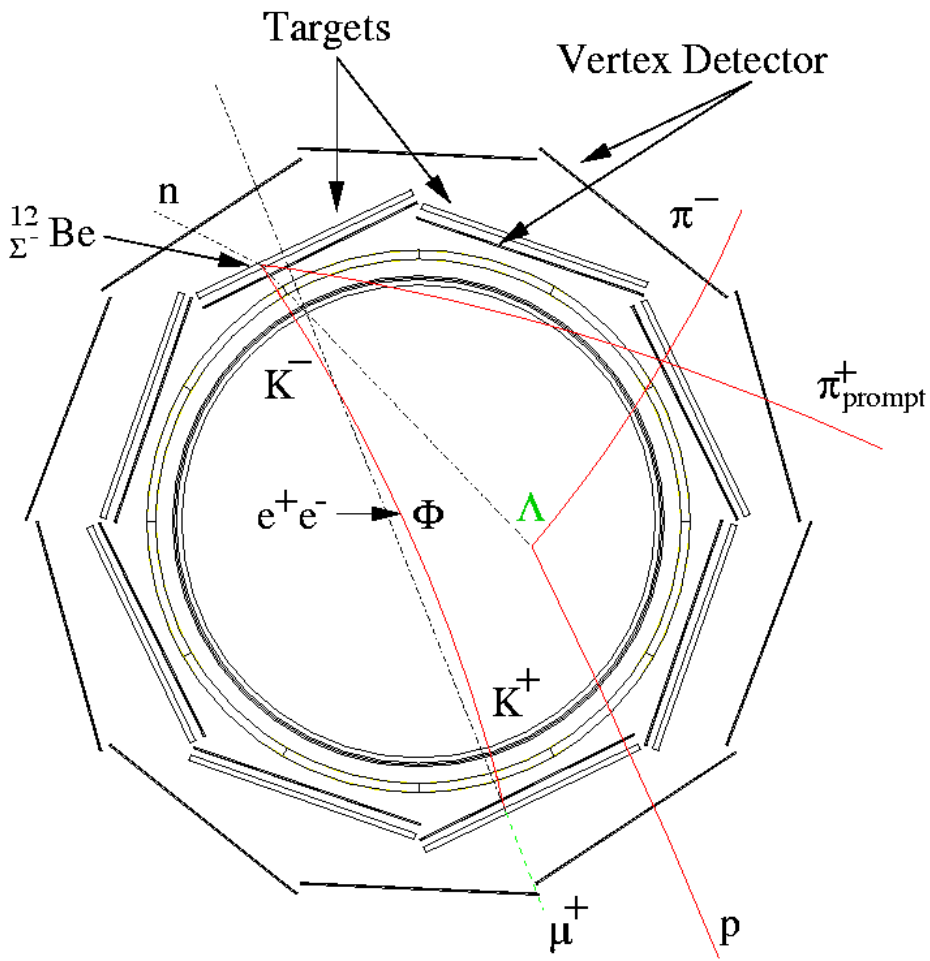
Reaction steps

$$K^-_{stop} + A \rightarrow {}_{\Sigma}B + \pi^{\pm}_{prompt}$$

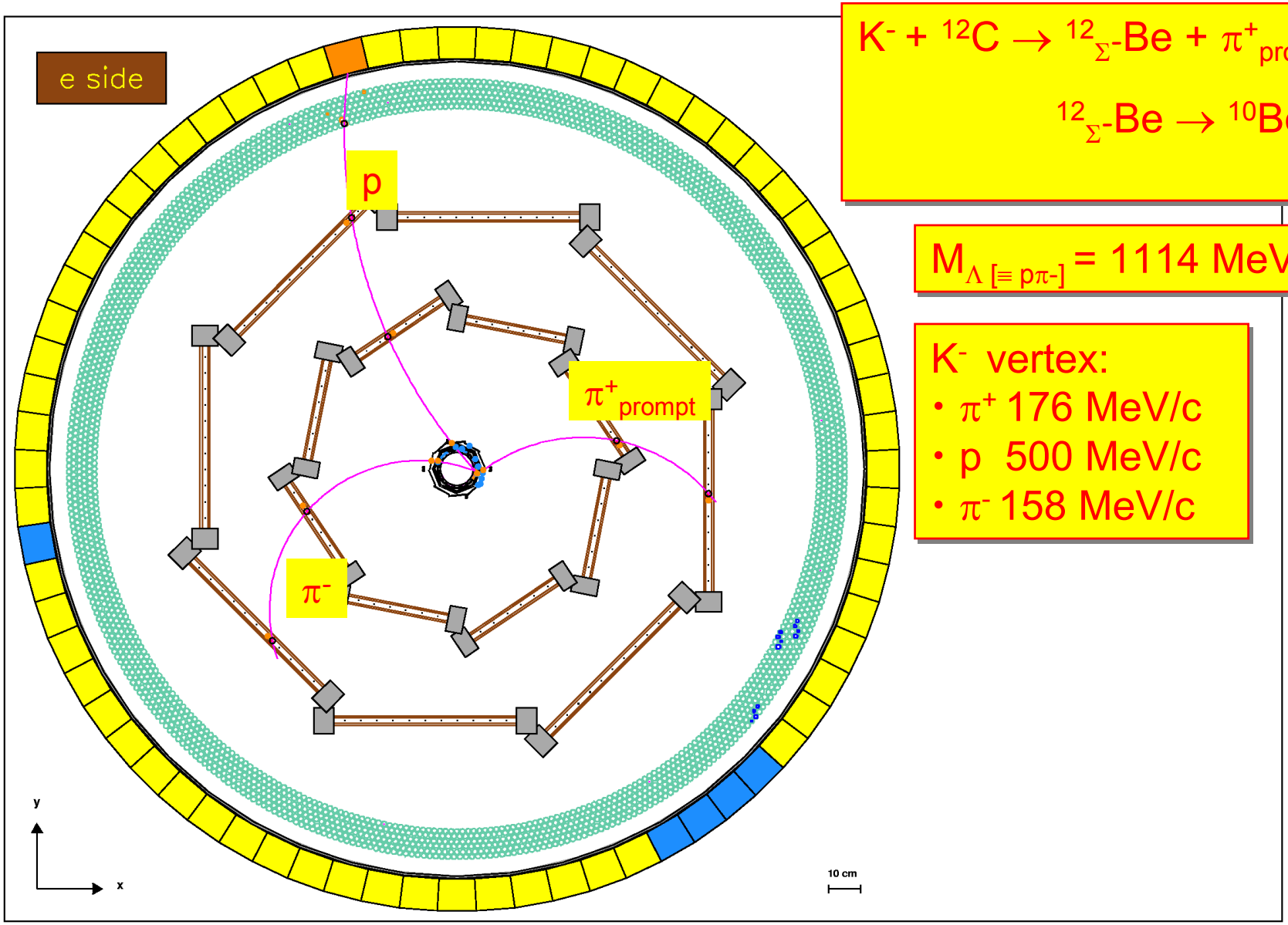
$$\Sigma + N \rightarrow \Lambda + N$$

$$K^-_{stop} + {}^{12}C \rightarrow \begin{cases} {}^{12}_{\Sigma^-}Be + \pi^+_{prompt} \\ \quad {}^{12}_{\Sigma^-}Be \rightarrow {}^{10}Be + \Lambda + n \\ {}^{12}_{\Sigma^+}C + \pi^-_{prompt} \\ \quad {}^{12}_{\Sigma^+}C \rightarrow {}^{10}B + \Lambda + p \\ {}^{12}_{\Sigma^0}C + \pi^-_{prompt} \\ \quad {}^{12}_{\Sigma^0}C \rightarrow {}^{10}C + \Lambda + n \\ \quad {}^{12}_{\Sigma^0}C \rightarrow {}^{10}B + \Lambda + p \end{cases}$$

Σ-hyp simulated event



^{12}C , reconstructed topology of a Σ-hyp event



$K^- + {}^{12}C \rightarrow {}^{12}_{\Sigma}\text{-Be} + \pi^+_{prompt}$

${}^{12}_{\Sigma}\text{-Be} \rightarrow {}^{10}Be + \Lambda + n$

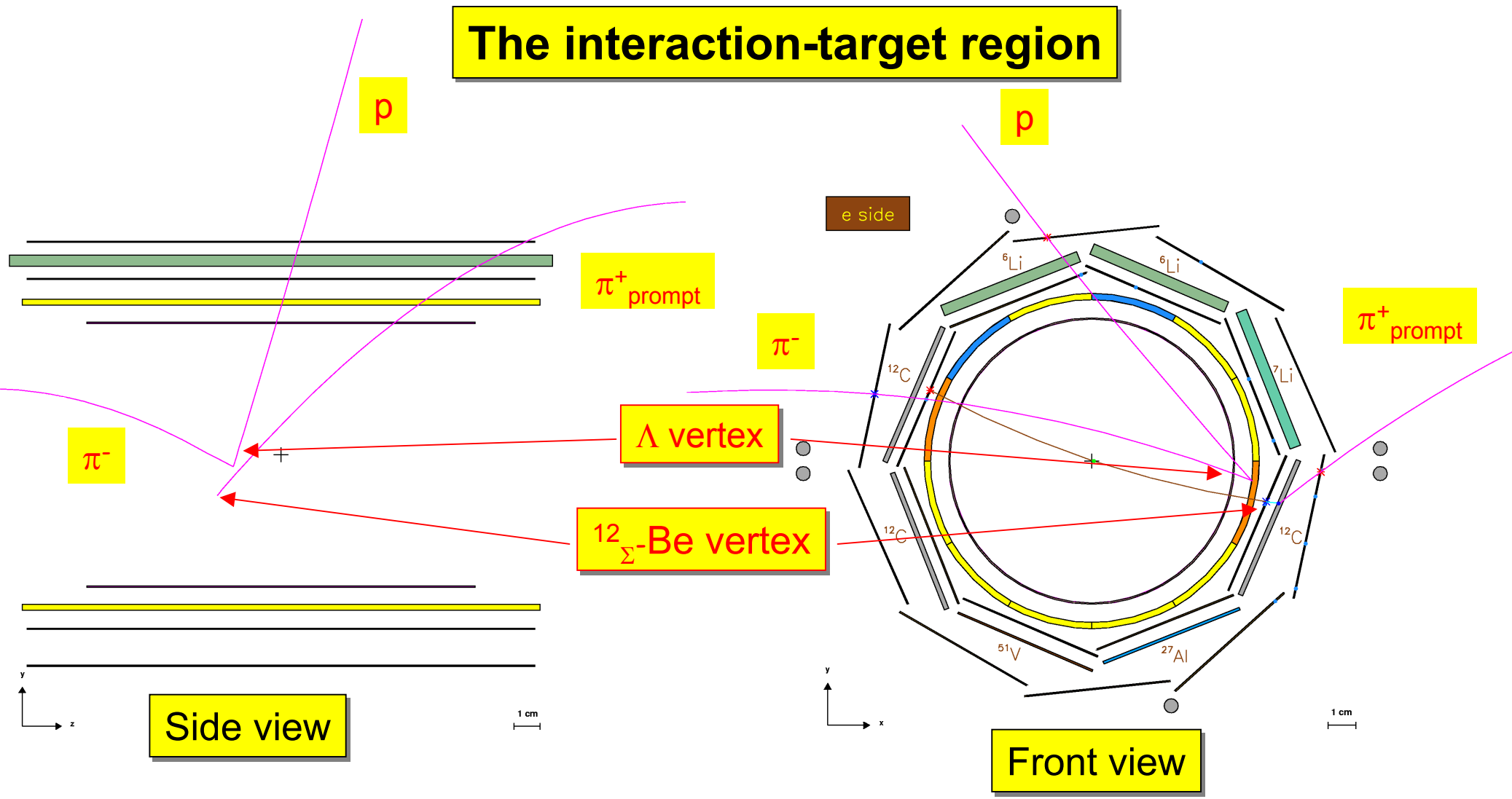
$\Lambda \rightarrow \pi^- + p$

$M_{\Lambda\,[\equiv p\pi^-]} = 1114\ MeV/c^2$

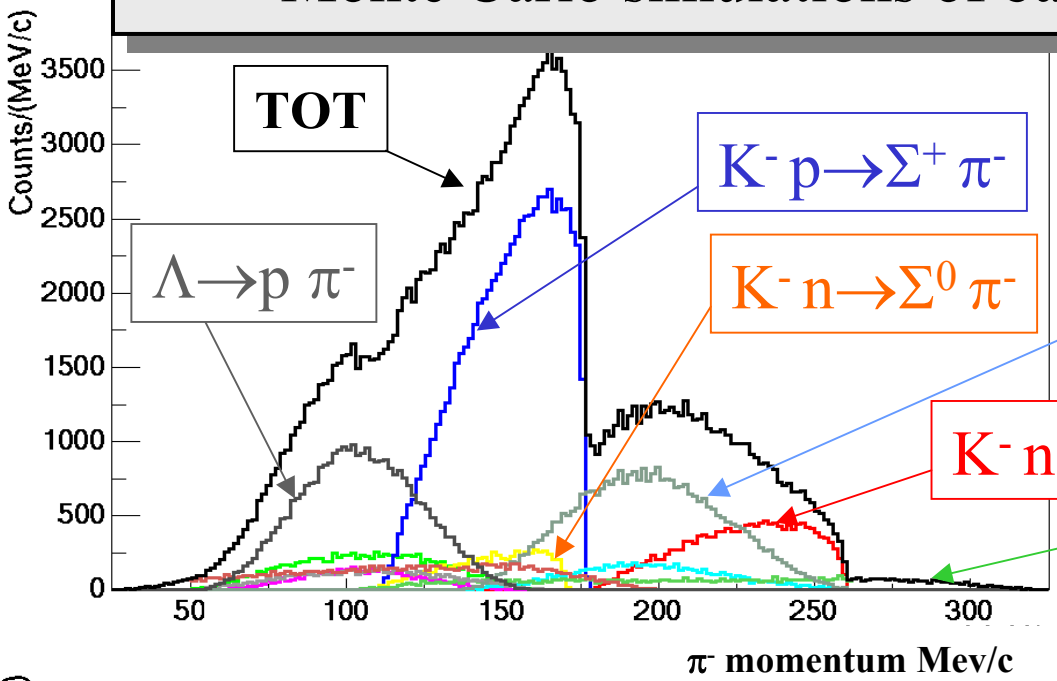
K^- vertex:

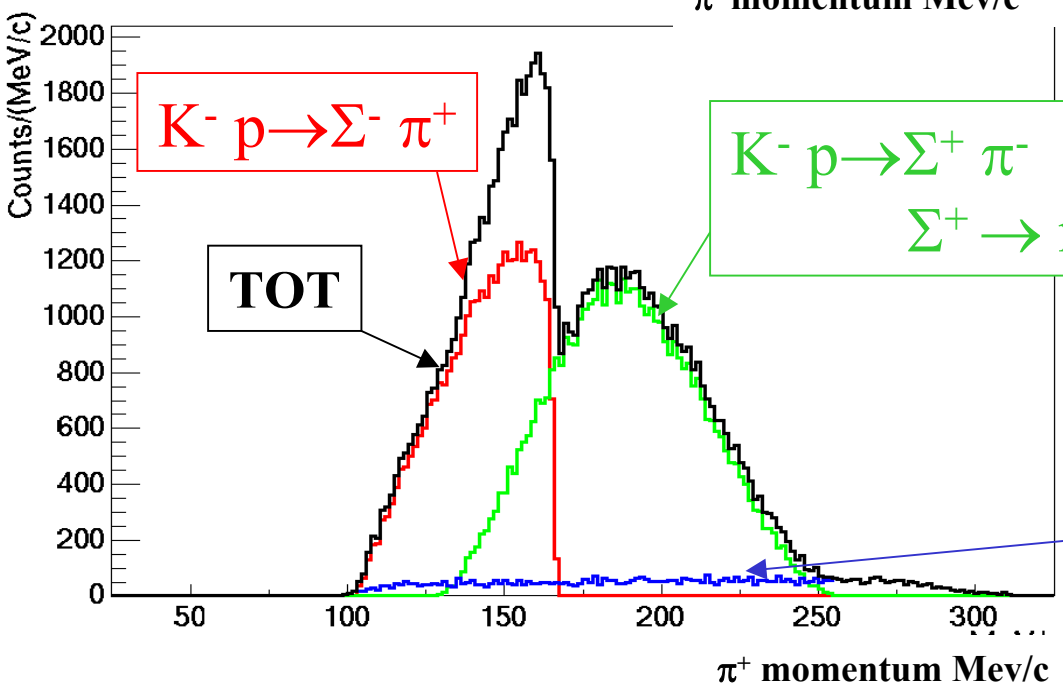
- π^+ 176 MeV/c
- p 500 MeV/c
- π^- 158 MeV/c

^{12}C , reconstructed topology of a Σ-hyp event



Monte Carlo simulations of background reactions for ^{12}C





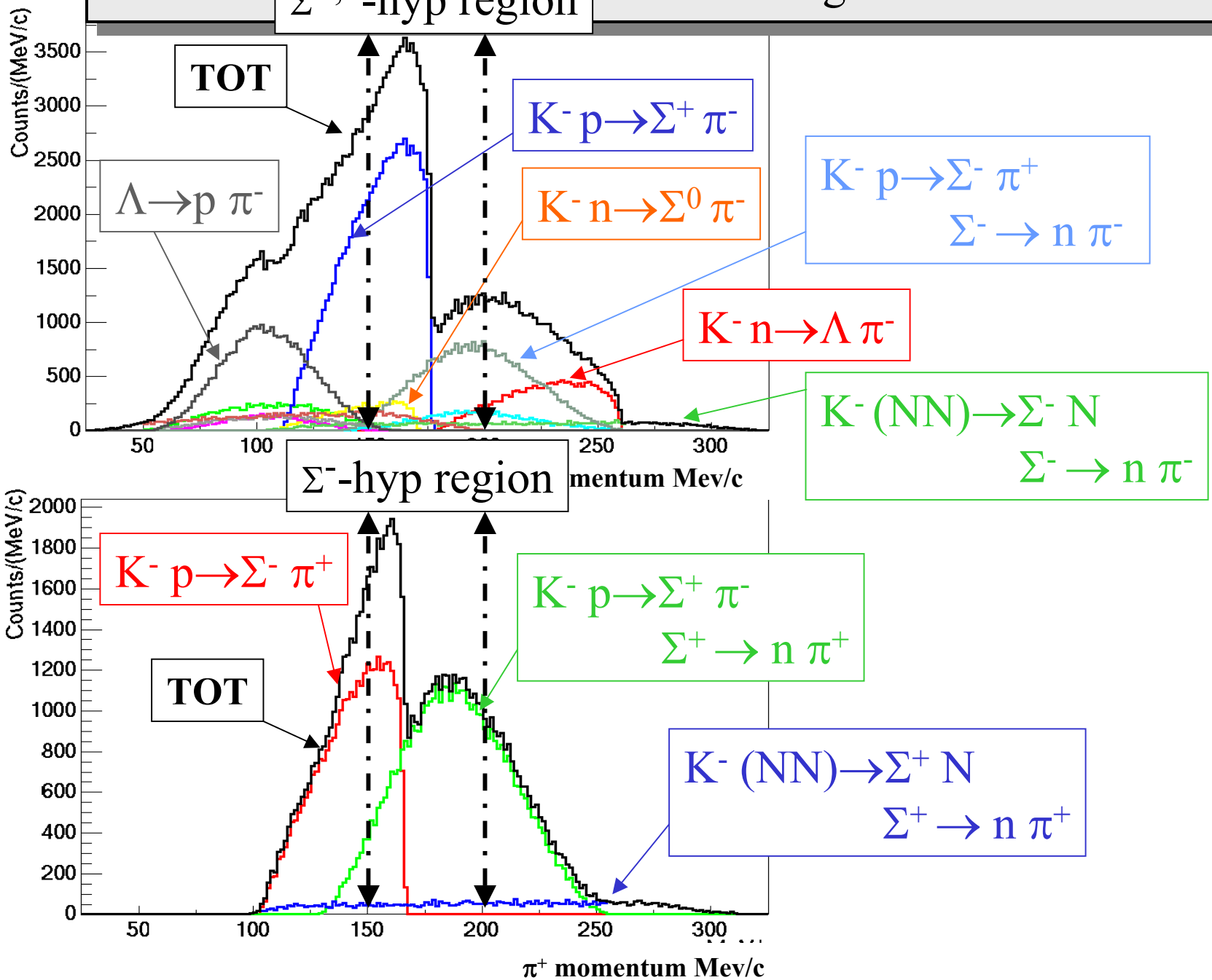
Conversion Reaction:

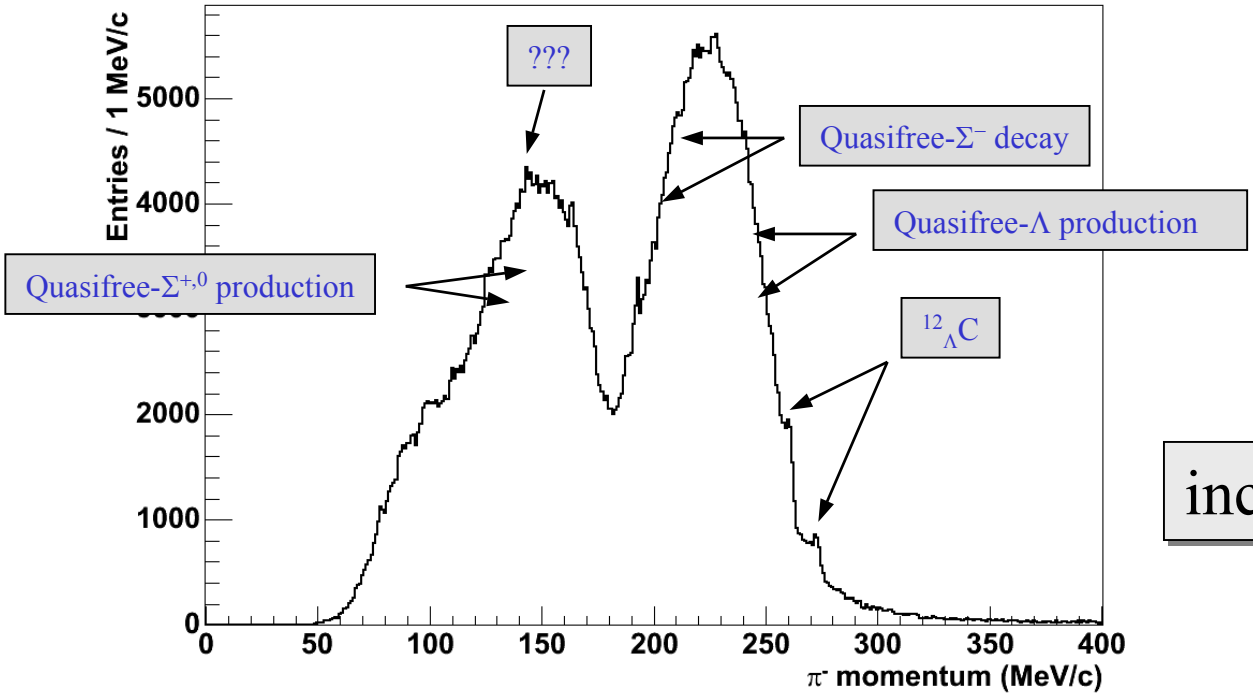
$\Sigma N \rightarrow \Lambda N$

Final π's q.f. scattering:

$\pi N \rightarrow \pi N$

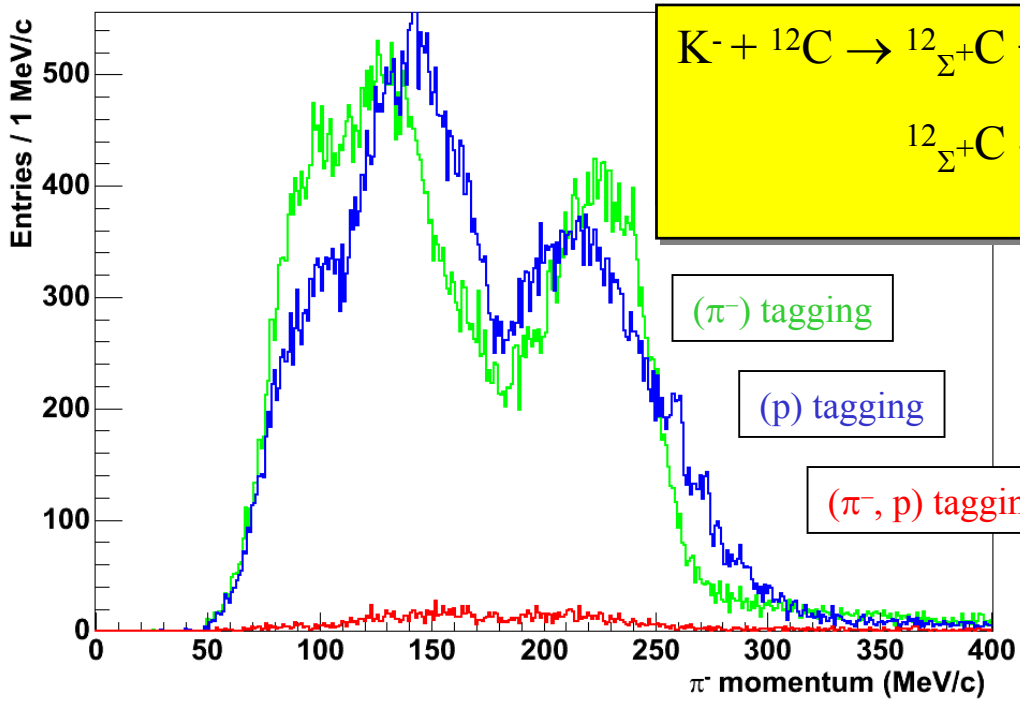
Mo ions of background reactions for ^{12}C





$$K^-_{stop} + {}^{12}C \Rightarrow \pi^- + X$$

inclusive spectrum



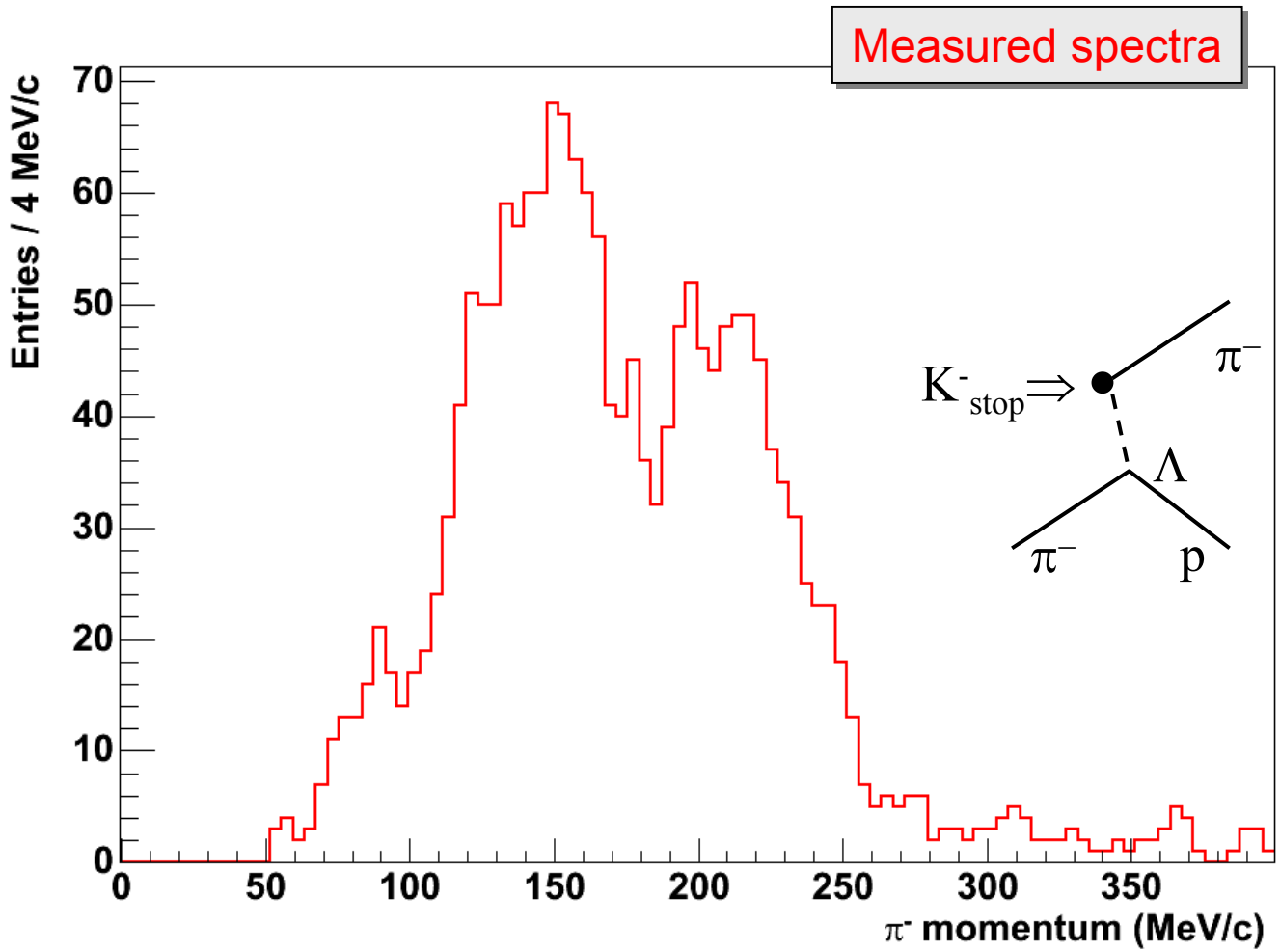
$$K^- + {}^{12}C \rightarrow {}^{12}_{\Sigma^+}C + \pi^-_{prompt}$$

$${}^{12}_{\Sigma^+}C \rightarrow {}^{10}B + \Lambda + p$$

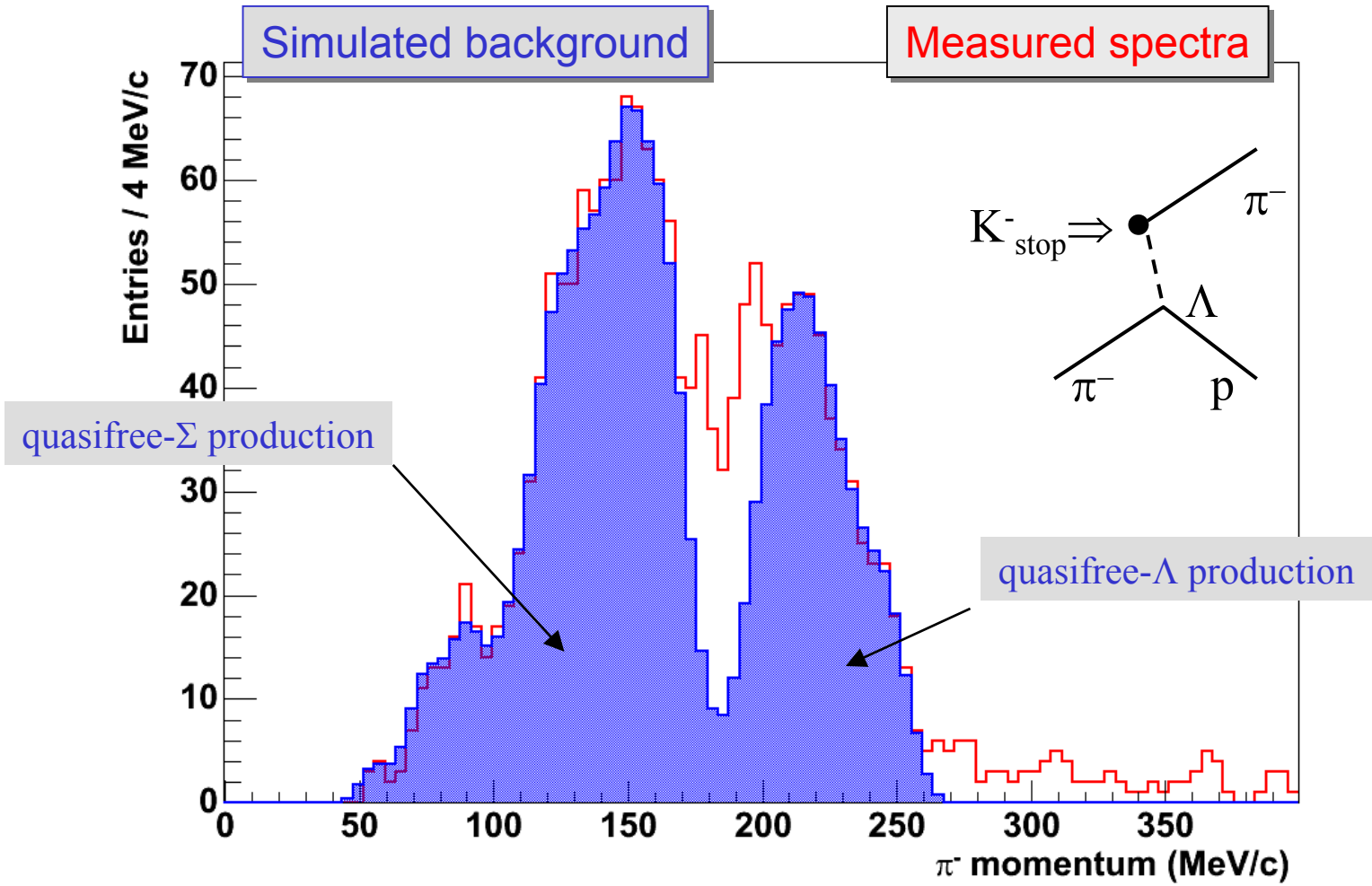
$$\Lambda \rightarrow \pi^- + p$$

coincidence spectra

$$K^-_{stop} + {}^{12}C \Rightarrow \pi^- + \Lambda\,(\pi^-,p) + X$$



$$K^-_{stop} + {}^{12}C \Rightarrow \pi^- + \Lambda\,(\pi^-,p) + X$$

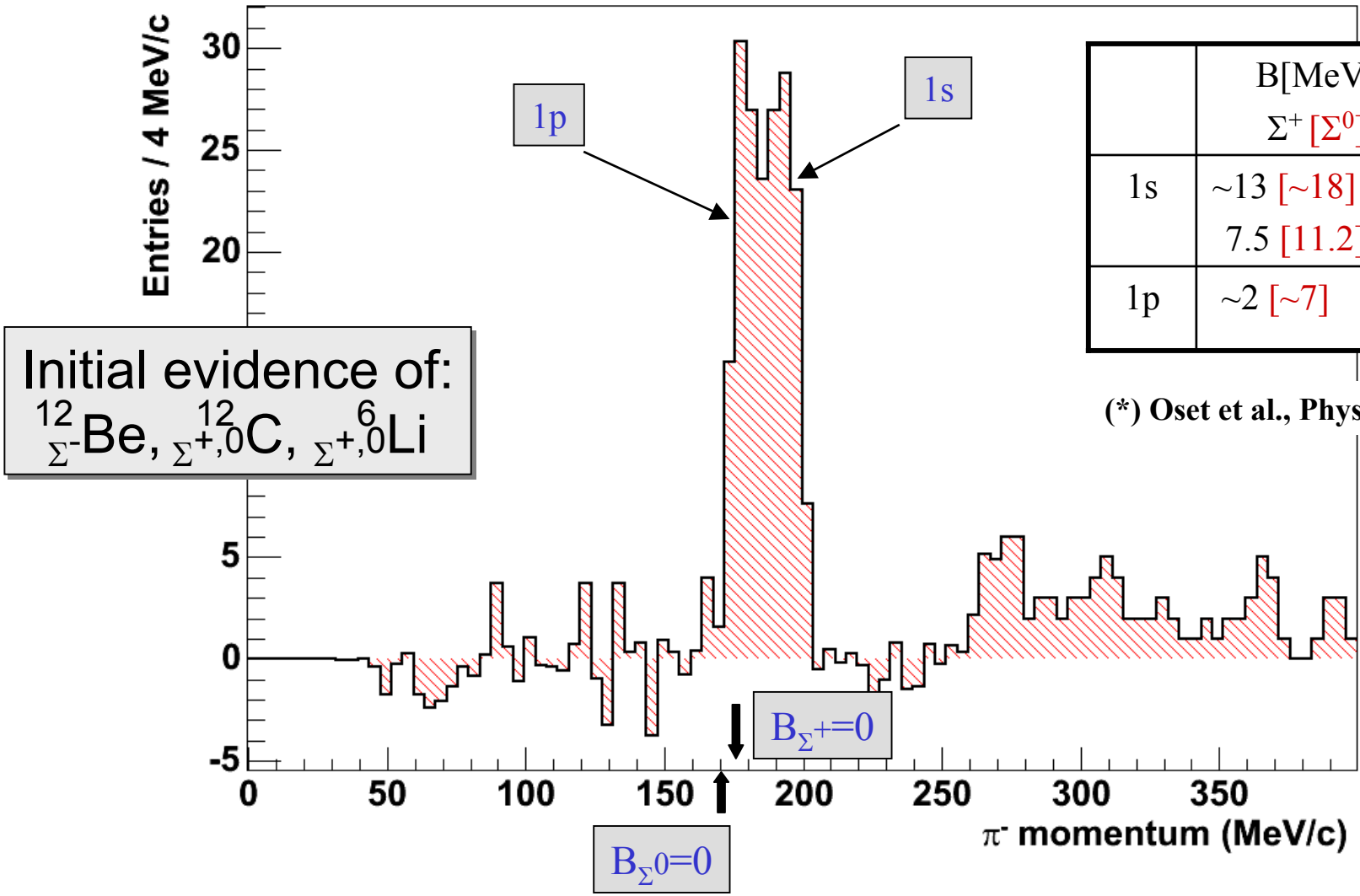


$$K^-_{stop} + {}^{12}C \Rightarrow \pi^- + \Lambda + X$$

Γ determined by ΣN→ΛN

	B[MeV] Σ^+ [Σ^0]	Γ[MeV] Σ^+ [Σ^0]
1s	~13 [~18] 7.5 [11.2](*)	~7 6.7 [6.8](*)
1p	~2 [~7]	~7

(*) Oset et al., Phys.Rep.,188(1990)79



Initial evidence of:
$^{12}_{\Sigma^-}$Be, $^{12}_{\Sigma^{+,0}}$C, $^{6}_{\Sigma^{+,0}}$Li

Search for kaon bound states

- Missing-mass spectroscopy
  - (K^-_{stop}, n or p) … KEK-PS E471/E549, **FINUDA**
    - ^{4}He(K^-_{stop}, n)$S^+(3140)$ …K^-ppn ? (169MeV bound)
    - ^{4}He(K^-_{stop}, p)$S^0(3115)$ …K^-pnn ? (193MeV bound)
- Invariant-mass spectroscopy
  - K^- absorption at rest in nuclei … **FINUDA**

$$K^- pp \rightarrow \Lambda + p \quad \Lambda \rightarrow p + \pi^-$$

three final particles to be detected

$$K^- pn \rightarrow \Lambda + n \ , \ \Sigma^- + p$$

$$K^- ppn \rightarrow \Lambda + d$$

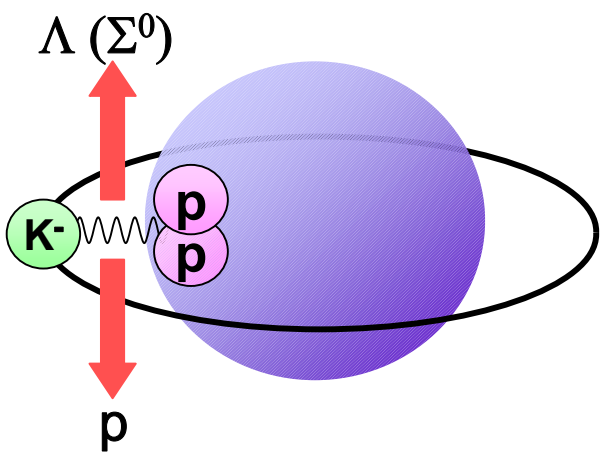
Λ-p coincidence events

- About 5% of the Λ events are associated with a proton.

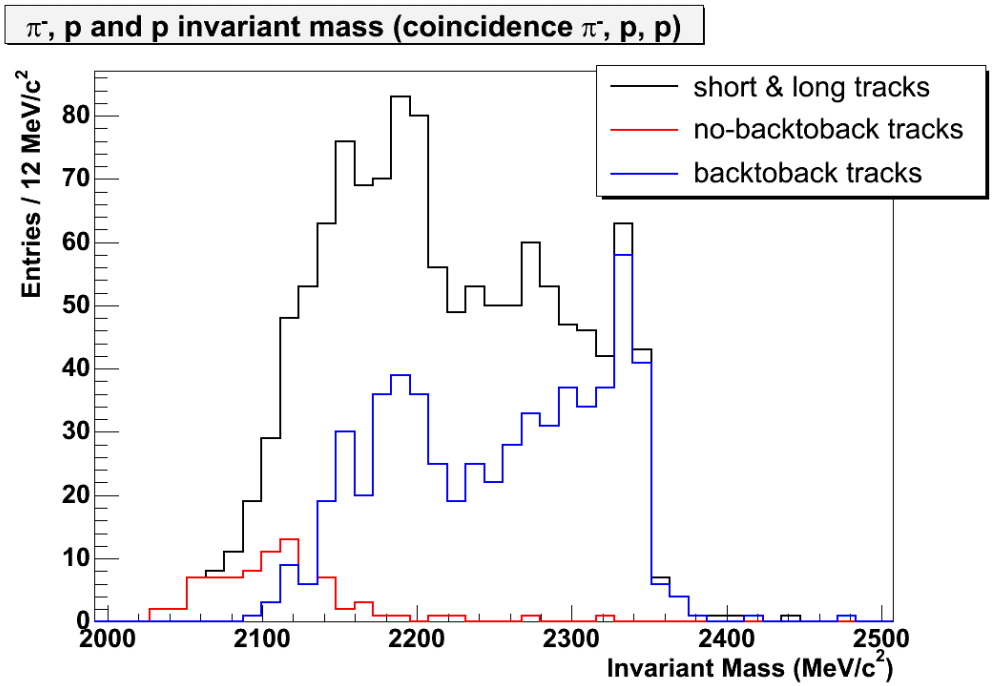
Two-proton absorption ?

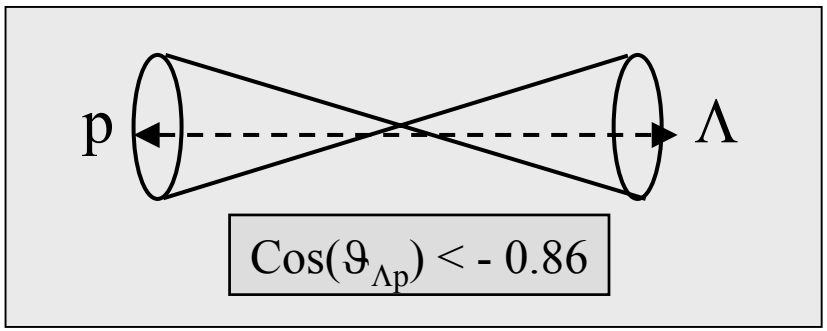
$$K^- + \text{“}pp\text{”} \rightarrow \underbrace{\Lambda + p}$$

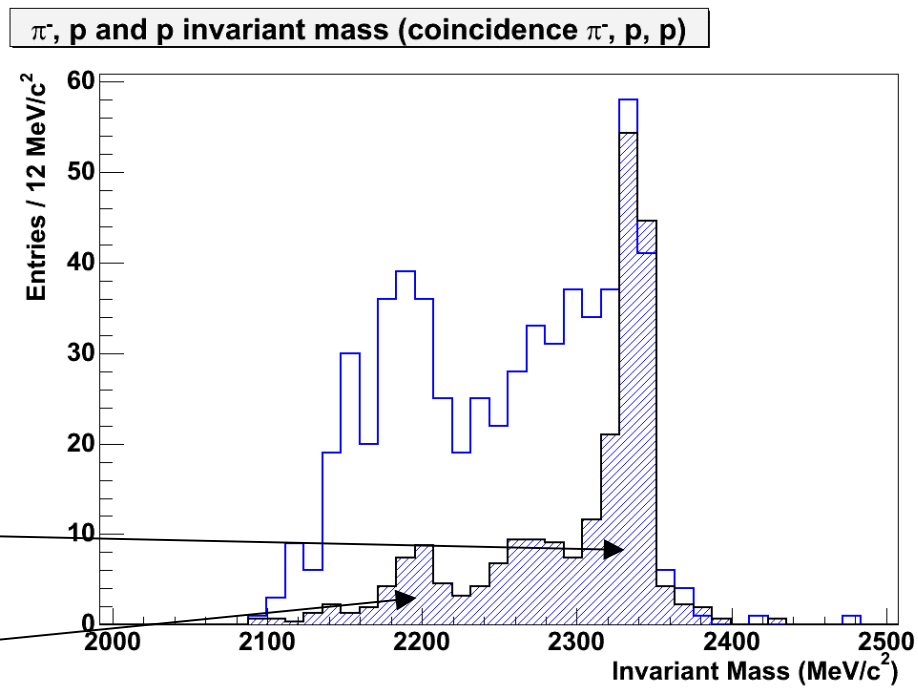
Back-to-back correlation is expected.



π^-pp Invariant Mass on ^{6}Li





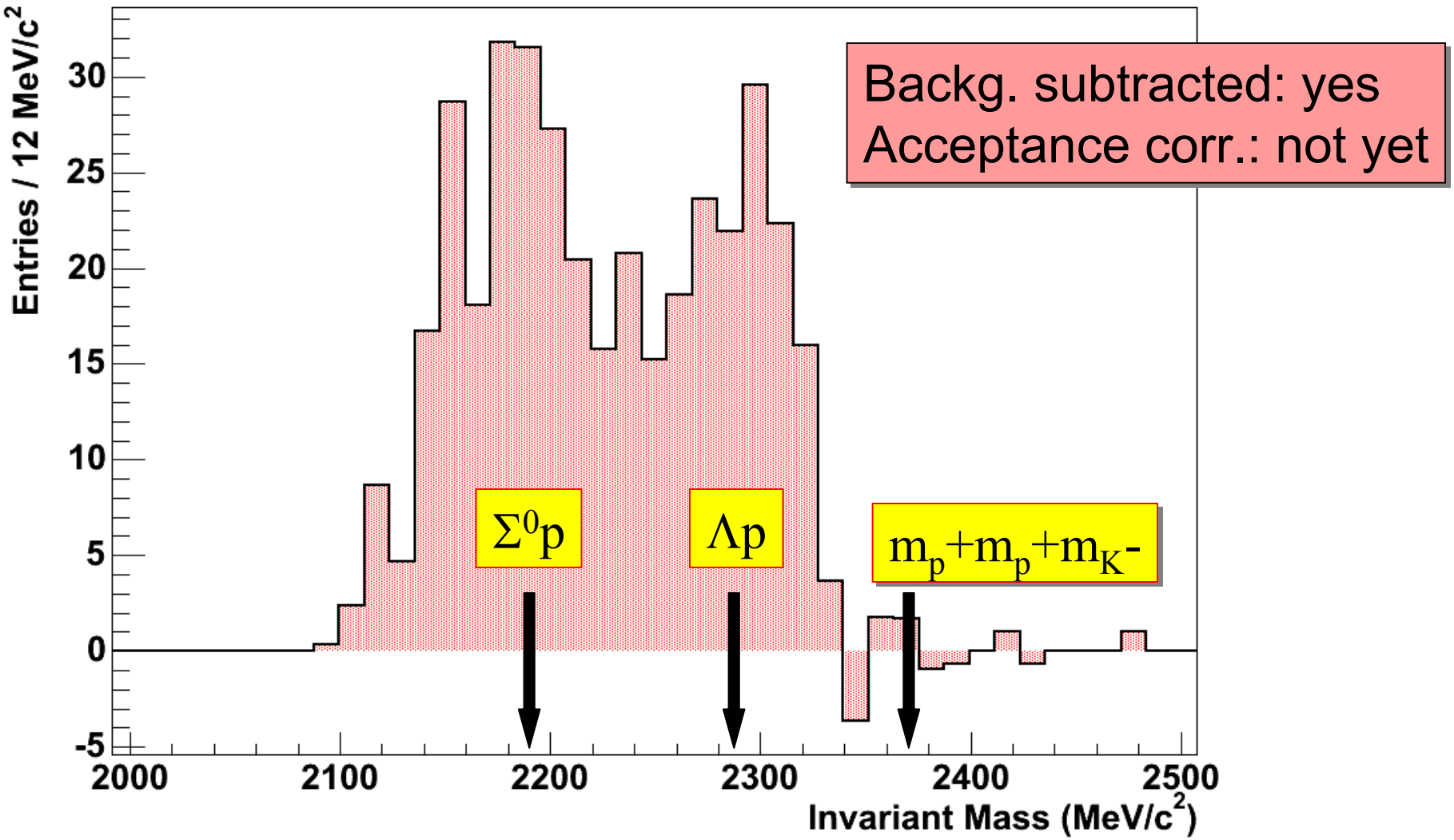


Background: the two proton absorption is the only process emitting a Λ and a proton back-to-back, except for the quasi-free reactions on two protons:

$$K^- pp \rightarrow \Lambda + p$$

$$\Sigma^0 + p$$

π^-pp Invariant Mass on ^{6}Li :
Evidence for a kaon deeply-bound state (K^-pp)$\rightarrow\Lambda$p or Σ^0p



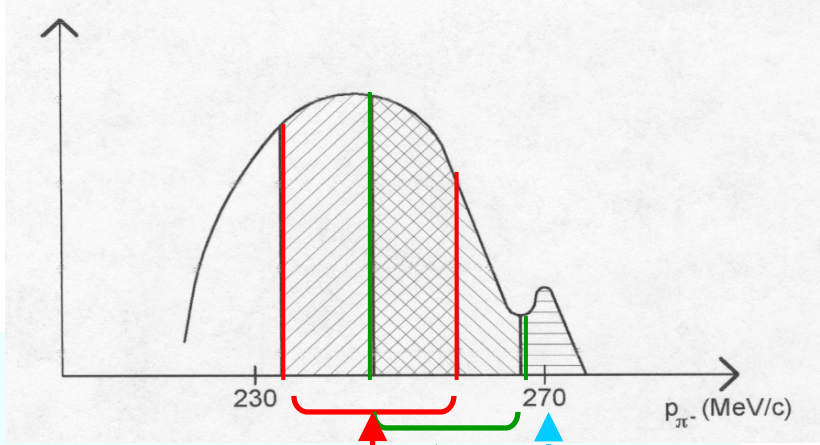
Summary

- FINUDA/DAFNE a unique facility for Λ and Σ hypernuclear studies
- Spectroscopy and Λ hypernuclear decays (mesonic, non-mesonic, rare decays)
- Initial analysis indicates bound $_{\Sigma}$B states beyond A=4
- We observed back-to-back Λ-p coincidence events in K^- absorption at rest, for the first time.
- The Λ-p invariant-mass distribution suggests the existence of a K^-pp deeply-bound system.

Targets: 2 x ^{6}Li

Spectroscopized

π^-



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

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

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

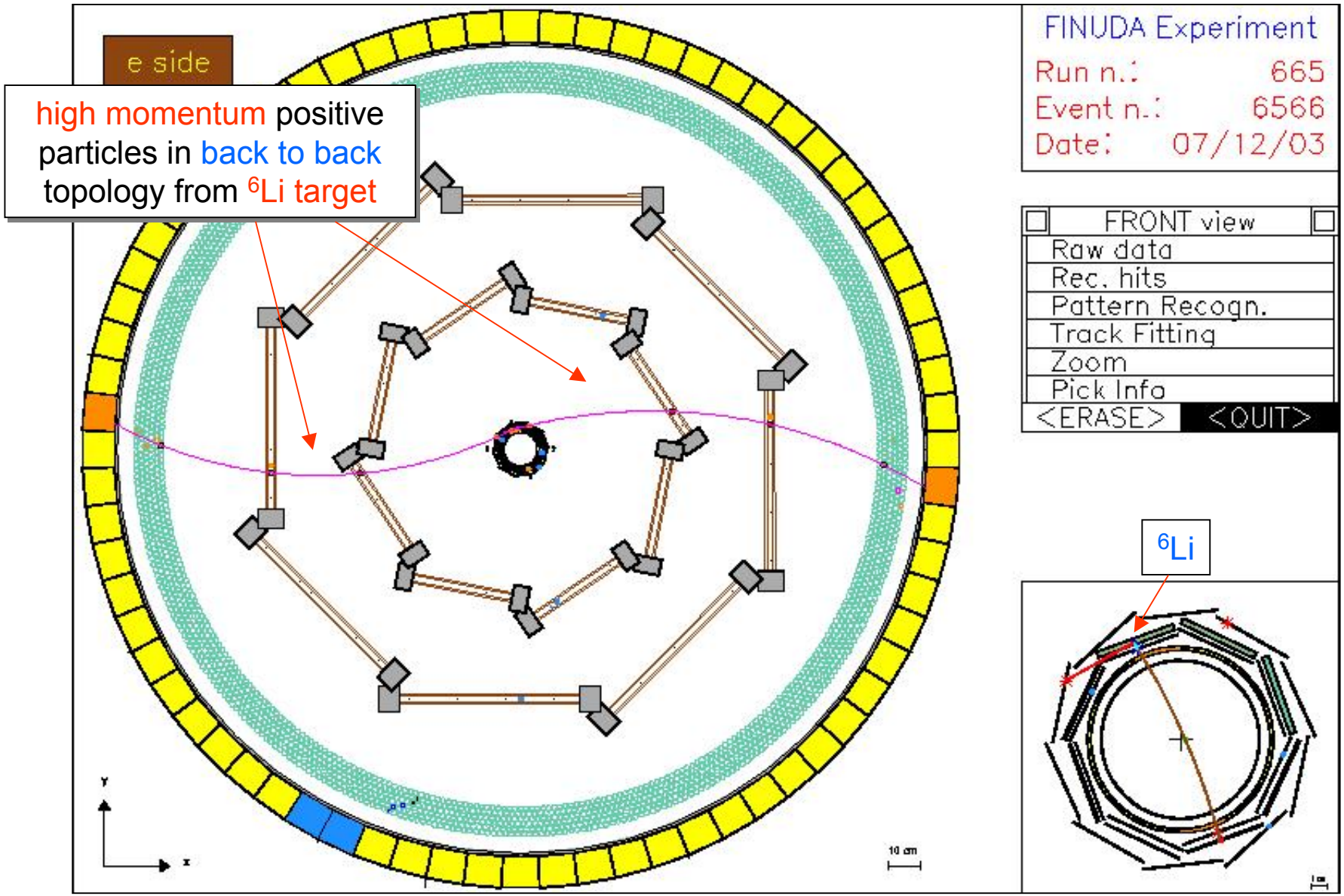
$^{4}_{\Lambda}He + p + n$

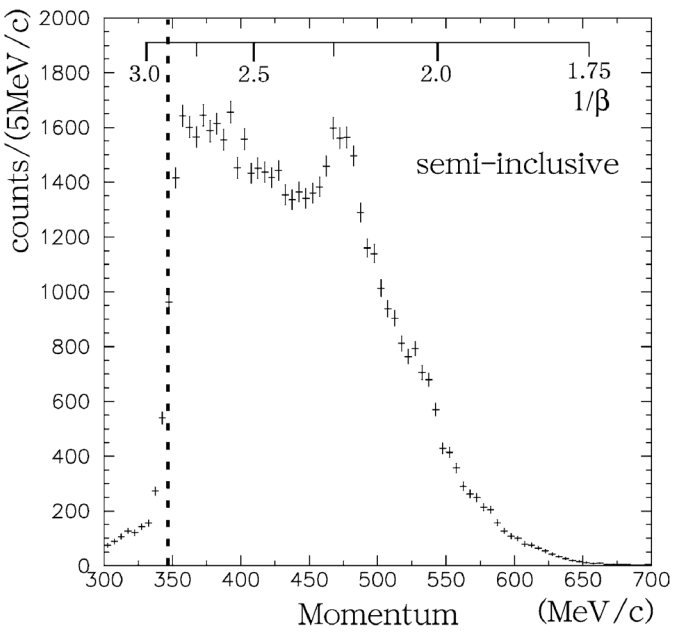
- d+d **spectr.** (~0.3/pb^{-1} if B.R. ~10^{-3})
- p+ ^{3}H **spectr.**(0.2/ pb^{-1} if B.R. ~10^{-3})
- π^++n+^{3}H many events (~ 10^2/pb^{-1})

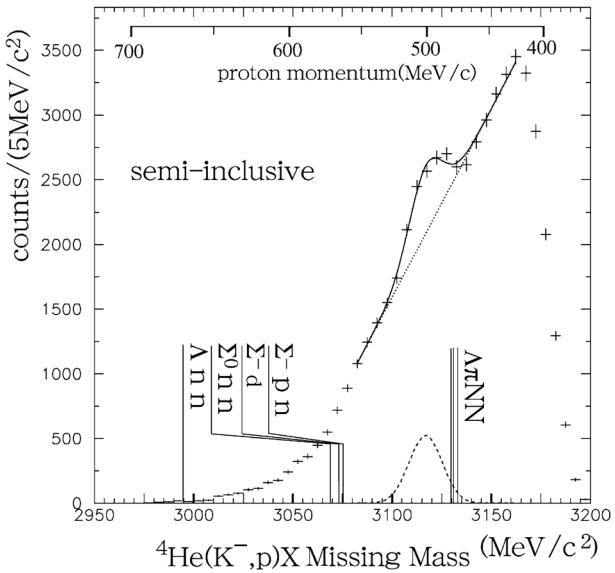
$^{4}_{\Lambda}H + p + p$

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

Candidate for rare decays of $^{4}_{\Lambda}$He





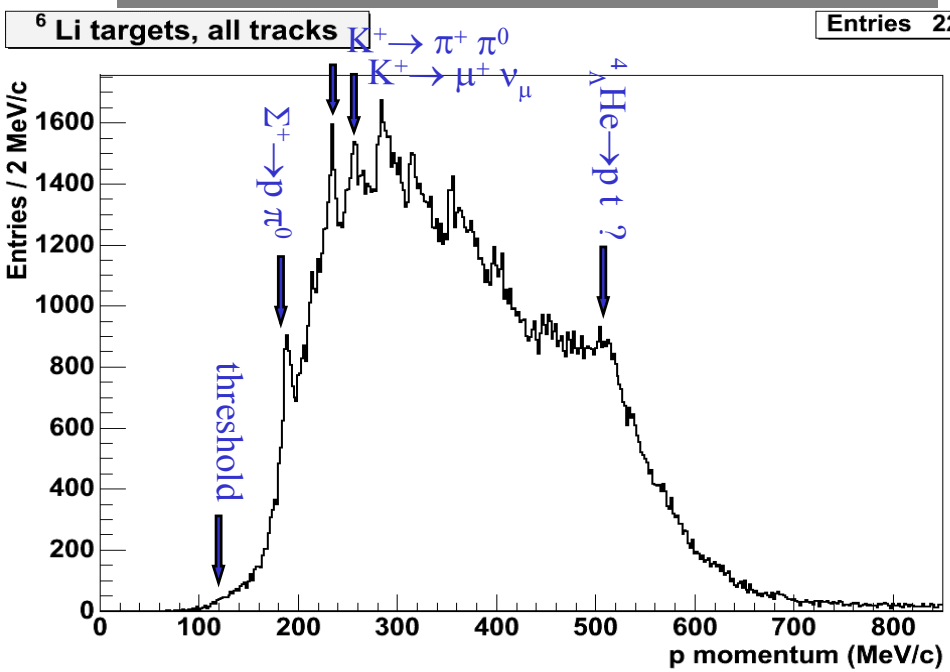


$K^-_{stop} + {}^4He \Rightarrow p + X$

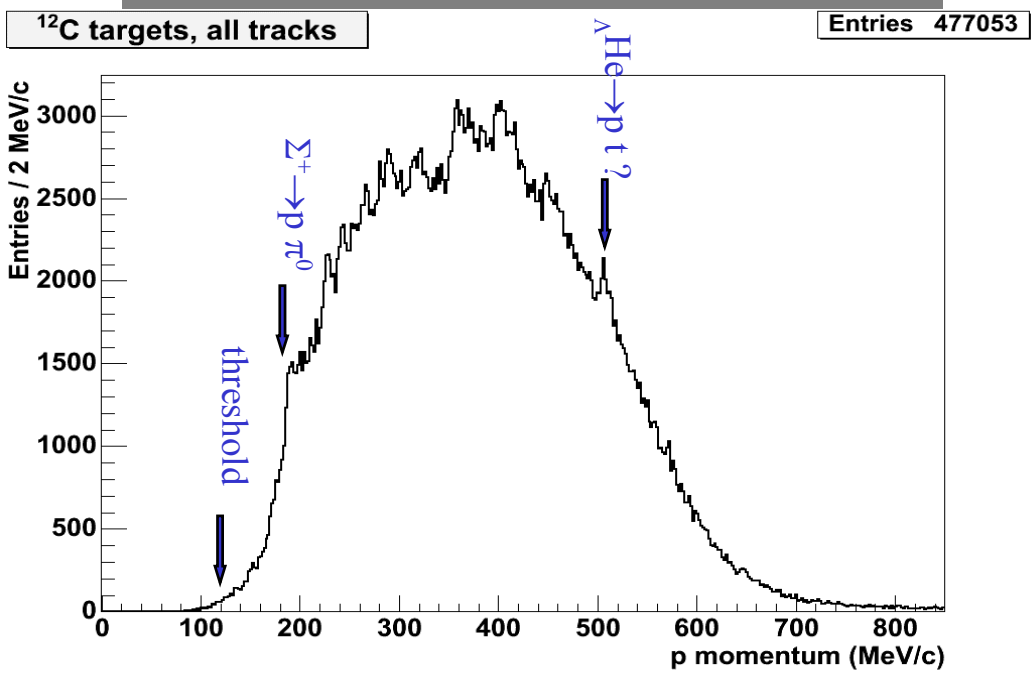
$S^0(3115) \rightarrow \Sigma NN$

Suzuki, P.L.,B597(2004)263

$K^-_{stop} + {}^6Li \Rightarrow p + X$

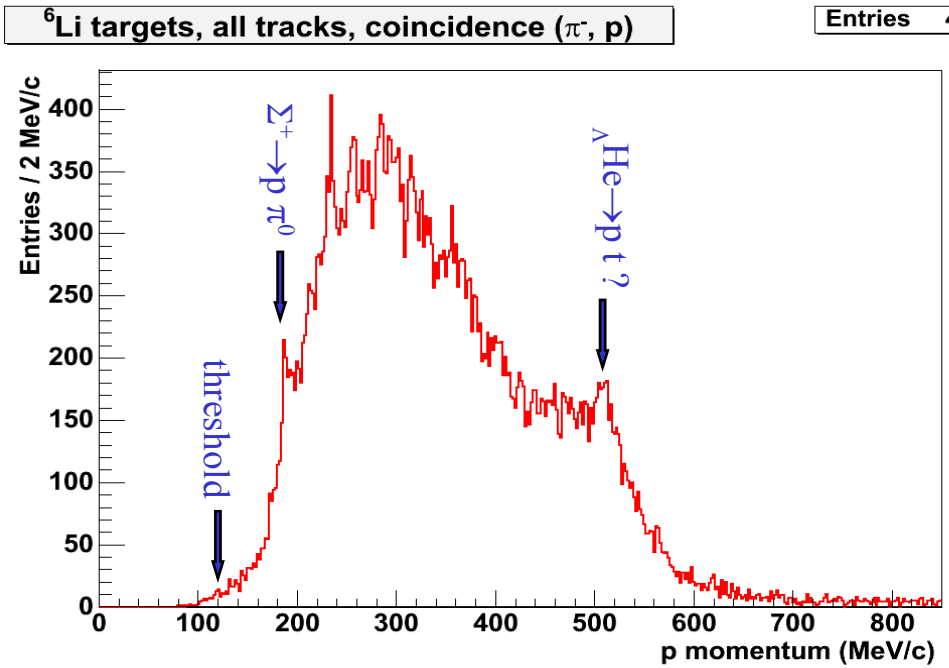


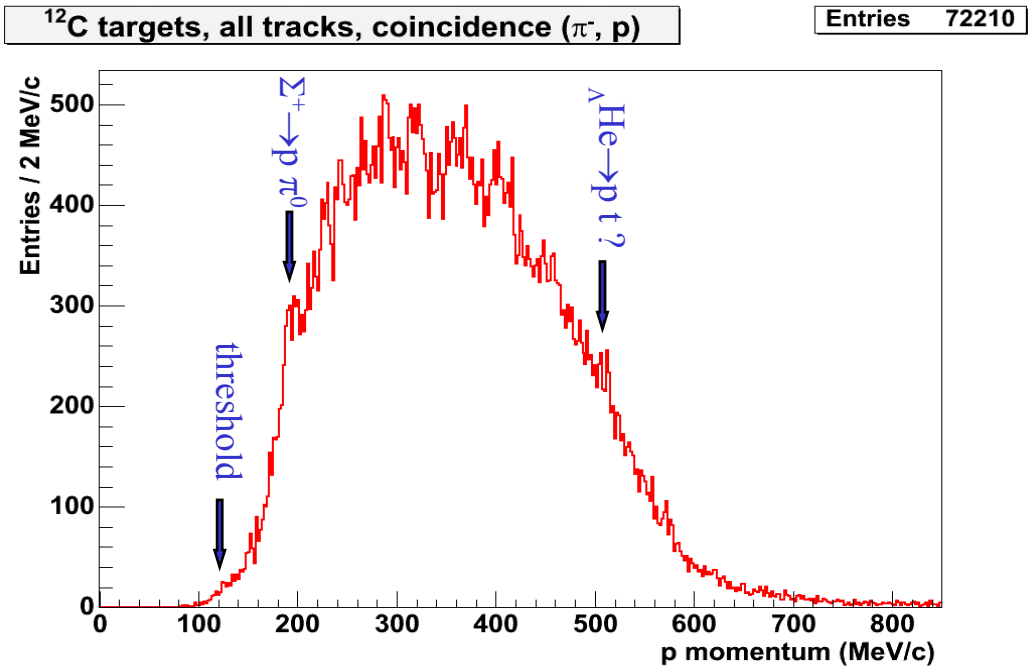
$K^-_{stop} + {}^{12}C \Rightarrow p + X$



$$K^-_{stop} + {}^6Li \Rightarrow p + \pi^- + X$$

$$K^-_{stop} + {}^{12}C \Rightarrow p + \pi^- + X$$





^{6}Li: the peak gets enhanced !

^{12}C: the peak nearly disappears !

$^4_\Lambda$He :

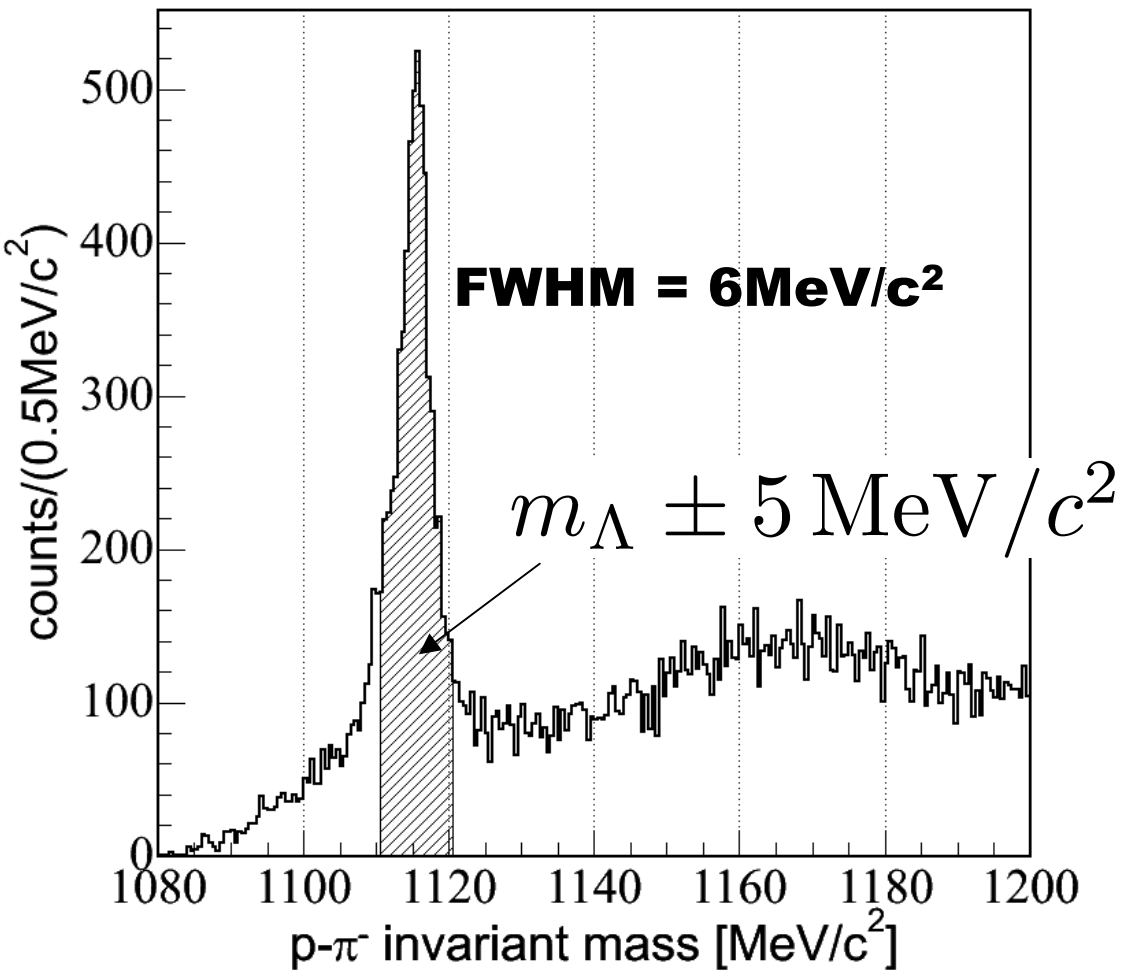
$K^- + {}^4He \rightarrow {}^4_\Lambda He + \pi^-$ (255 MeV/c)

$^4_\Lambda He \rightarrow p\ t$ (500 MeV/c)

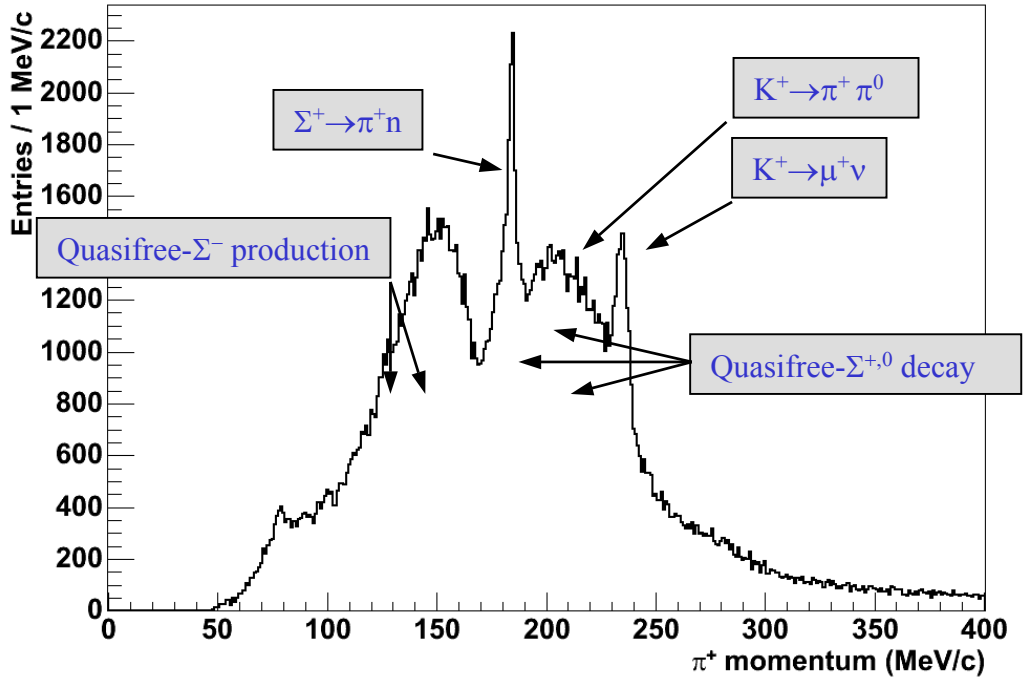
t ←back-to-back→ p

At $p_t \approx p_p$ no t-peak is found, the proton peak is not to be correlated to any triton

Direct observation of a Λ hyperon



$$K^-_{stop} + {}^{12}C \Rightarrow \pi^+ + X$$

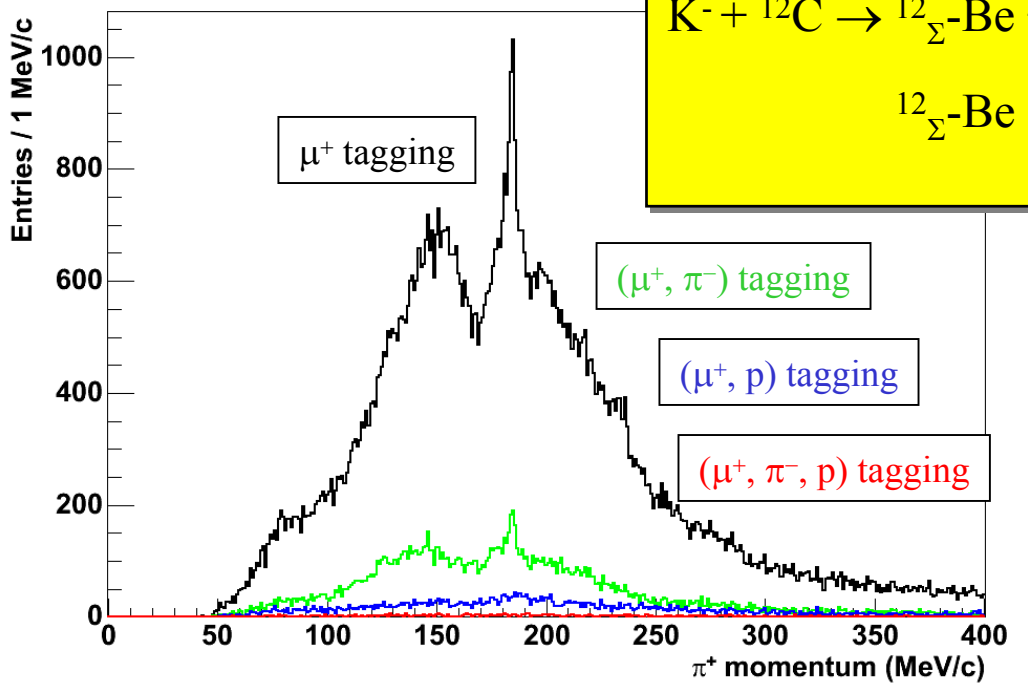


inclusive spectrum

$$K^- + {}^{12}C \rightarrow {}^{12}_{\Sigma}\text{-Be} + \pi^+_{prompt}$$

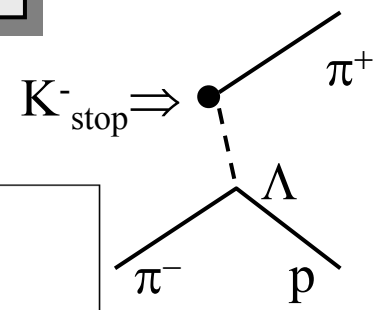
$$^{12}_{\Sigma}\text{-Be} \rightarrow {}^{10}Be + \Lambda + n$$

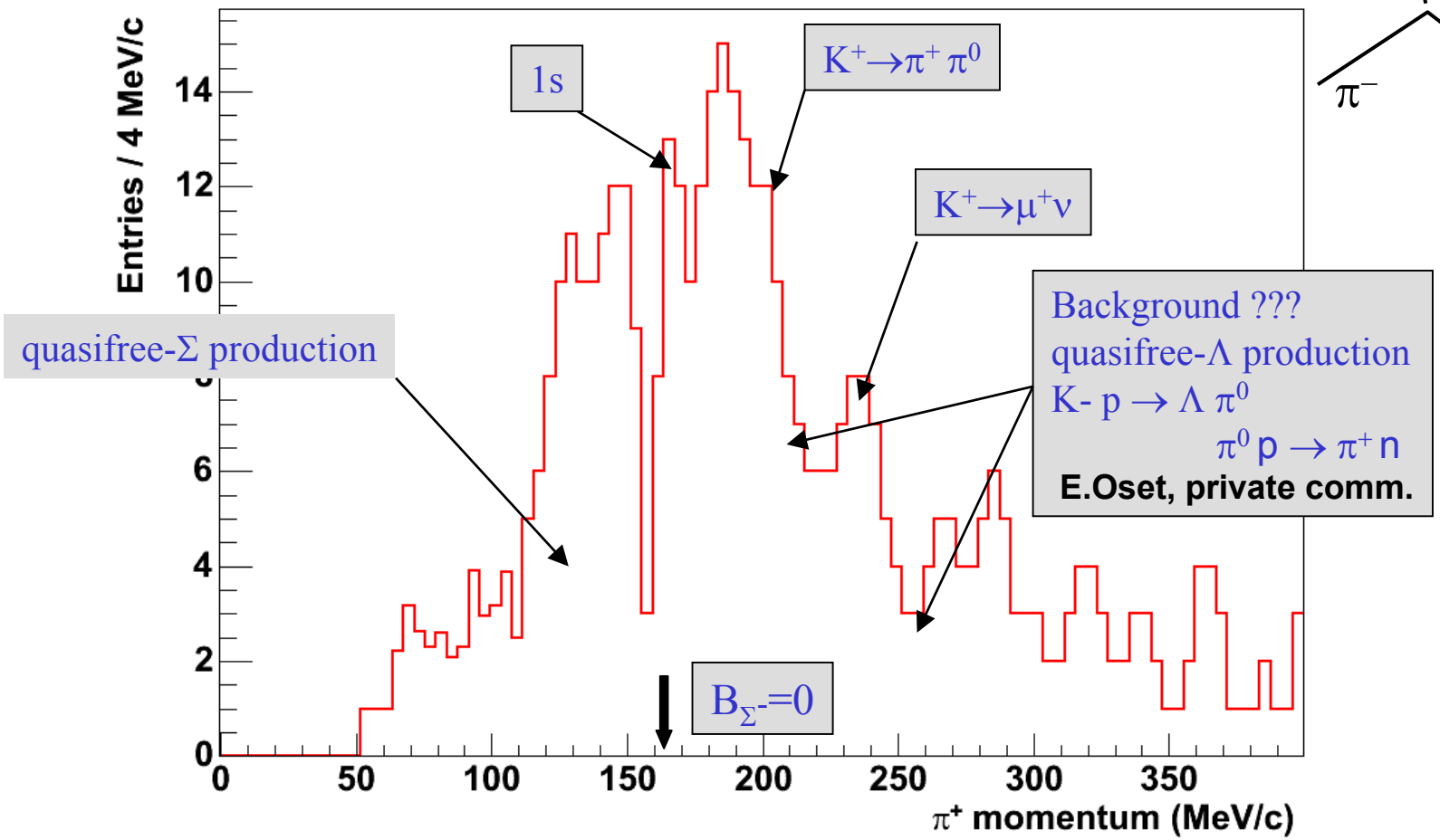
$$\Lambda \rightarrow \pi^- + p$$



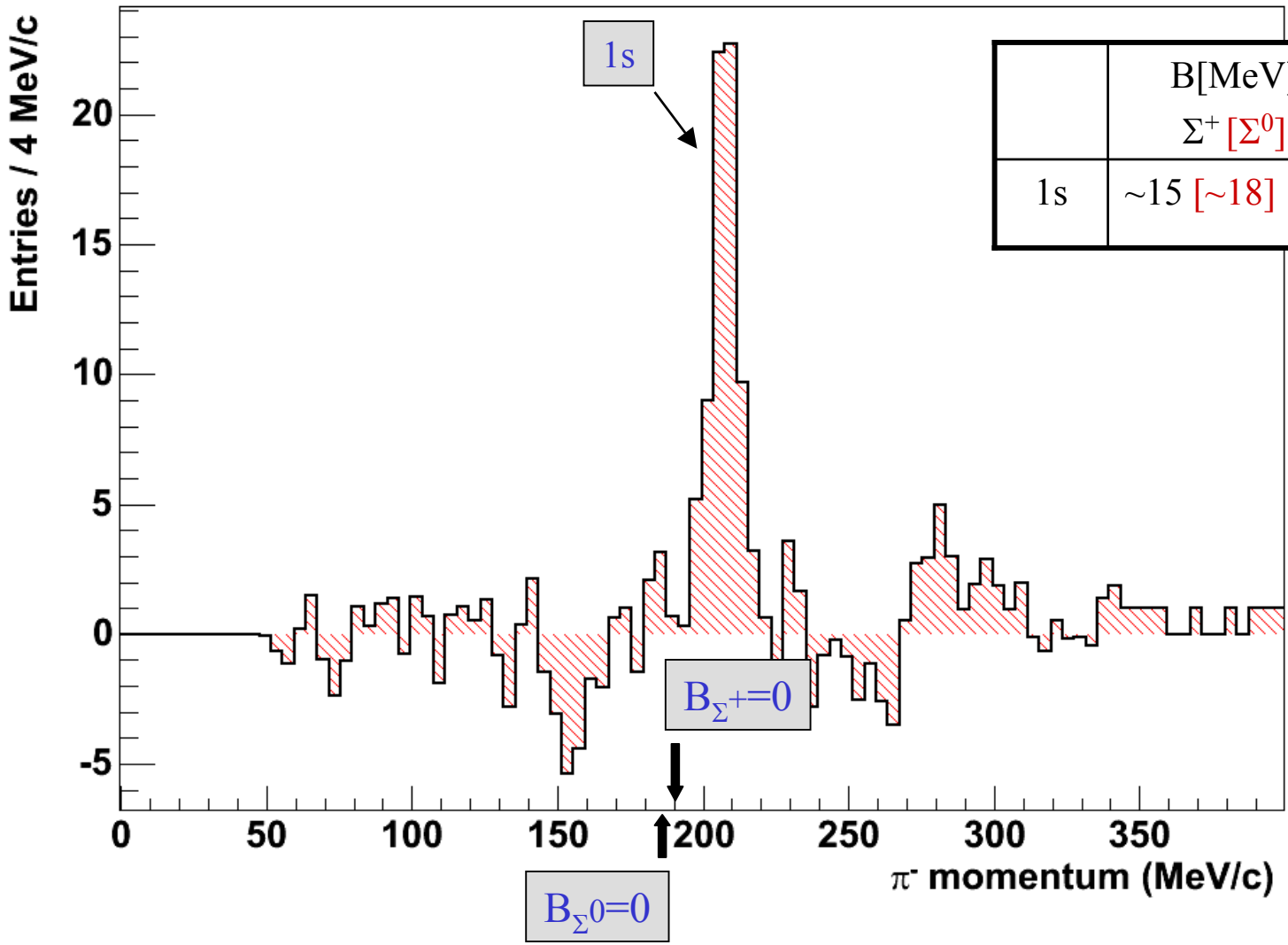
coincidence spectra

$$K^-_{stop} + {}^{12}C \Rightarrow \pi^+ + \Lambda\,(\pi^-,p) + X$$





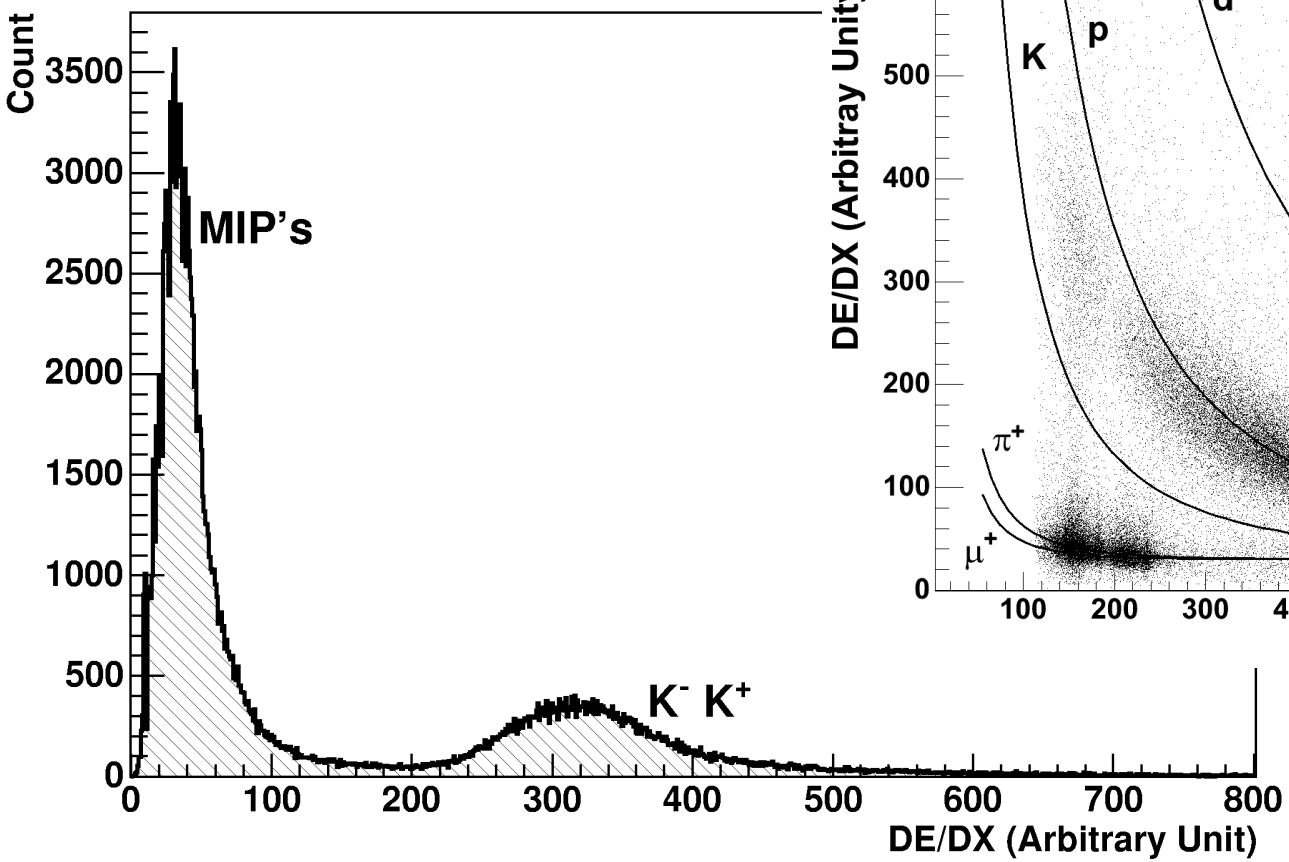
$$K^-_{stop} + {}^6Li \Rightarrow \pi^- + \Lambda\,(\pi^-,p) + X$$



	B[MeV] Σ^+ [Σ^0]	Γ[MeV](^{0}) Σ^+ [Σ^0]
1s	~15 [~18]	~7

Silicon Vertex Detector PID

Inner microstrip layer



Outer microstrip layer