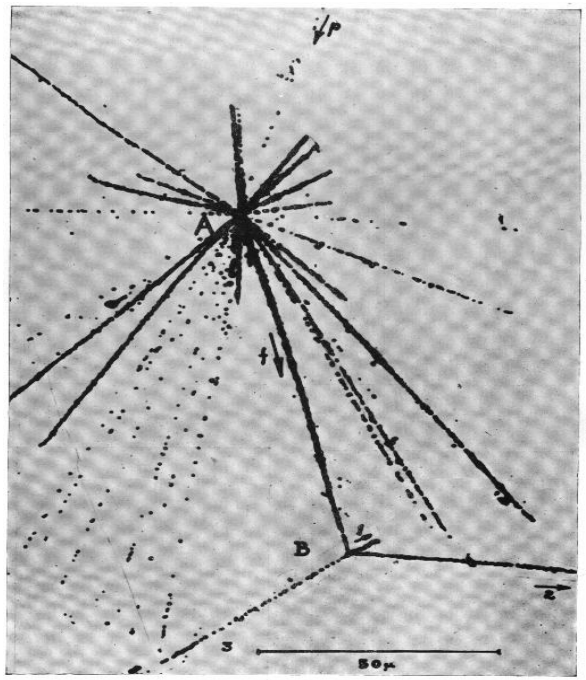
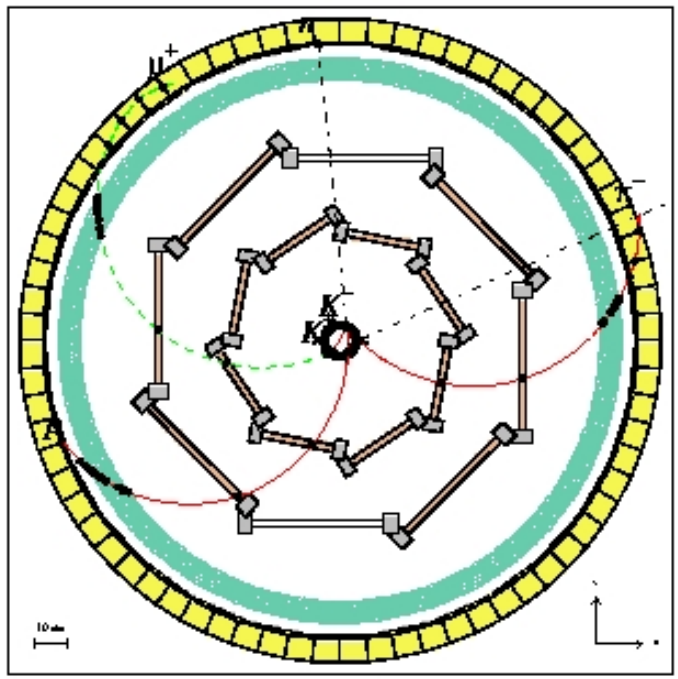
Hypernuclear Physics with FINUDA at DAΦNE





Aldo Zenoni
University of Brescia (Italy)
HYP2003 JLAB, Newport News, October 14-18, 2003

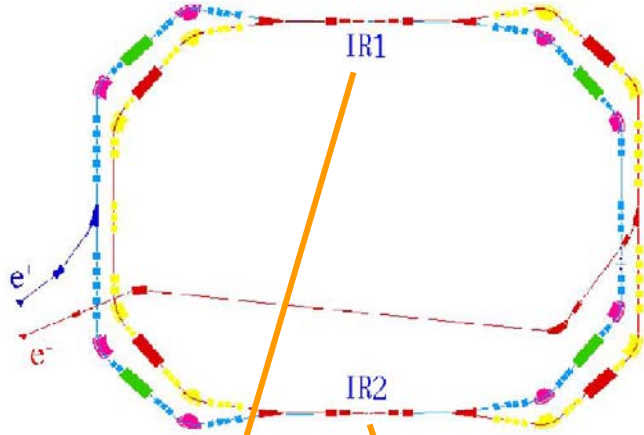
FINUDA is ready and "eager" to start physics

SUMMARY

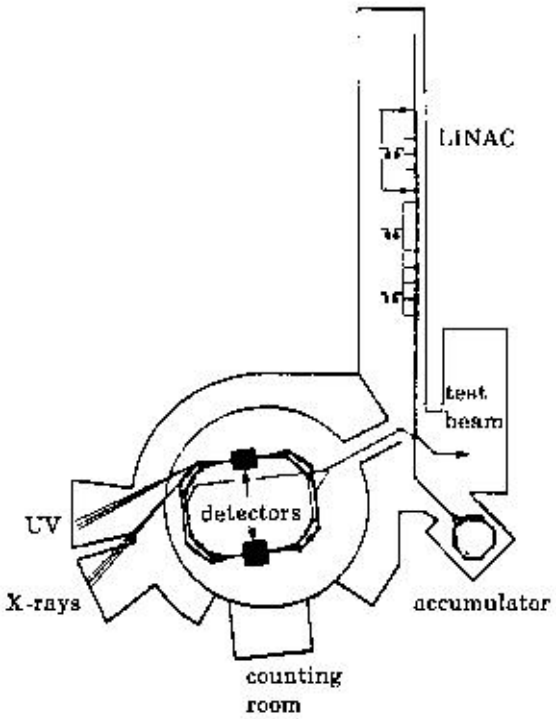
- Status: DAΦNE and FINUDA
- Performances of the detectors
- Targets for 2003 run
- Expected rates
- Highlights on the continuation of the program
- Conclusions

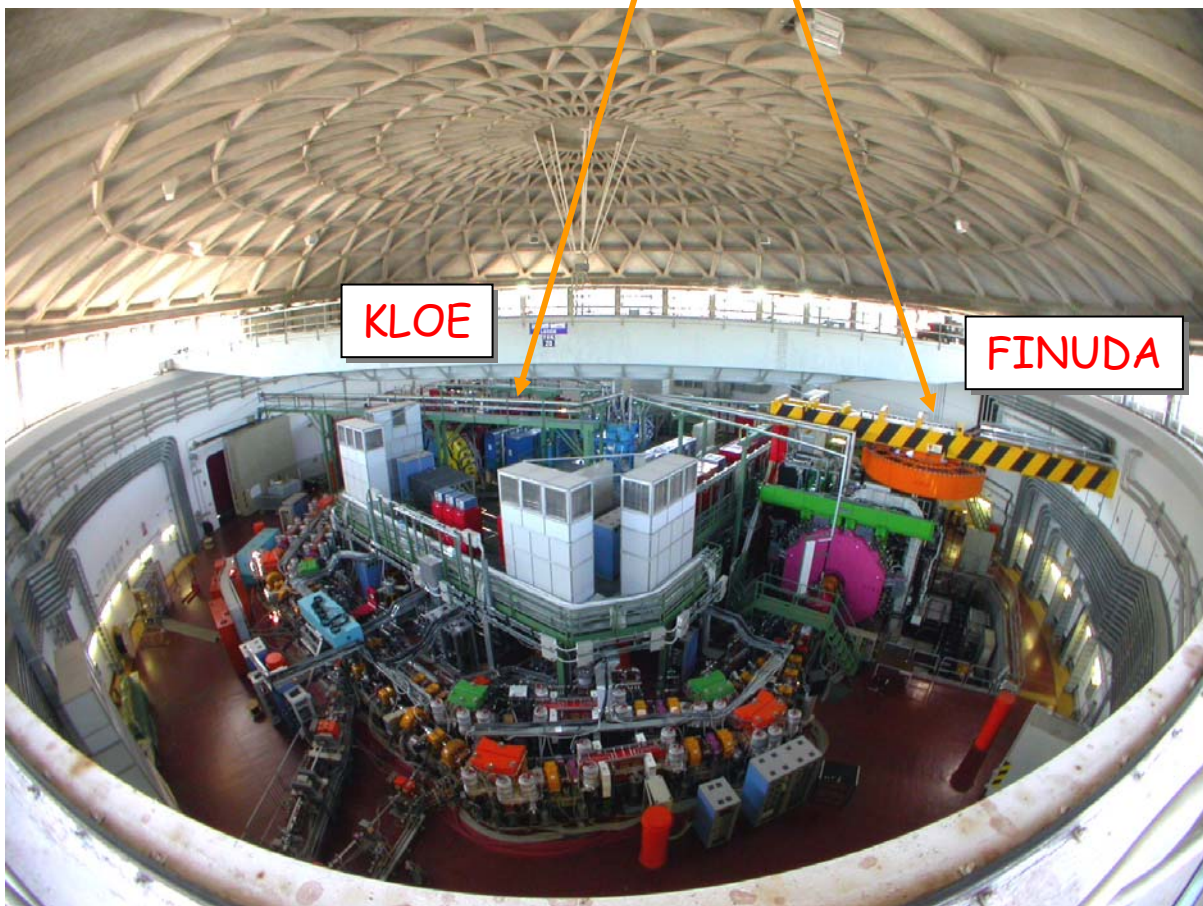
DAΦNE
the Frascati Φ-factory

Main Rings



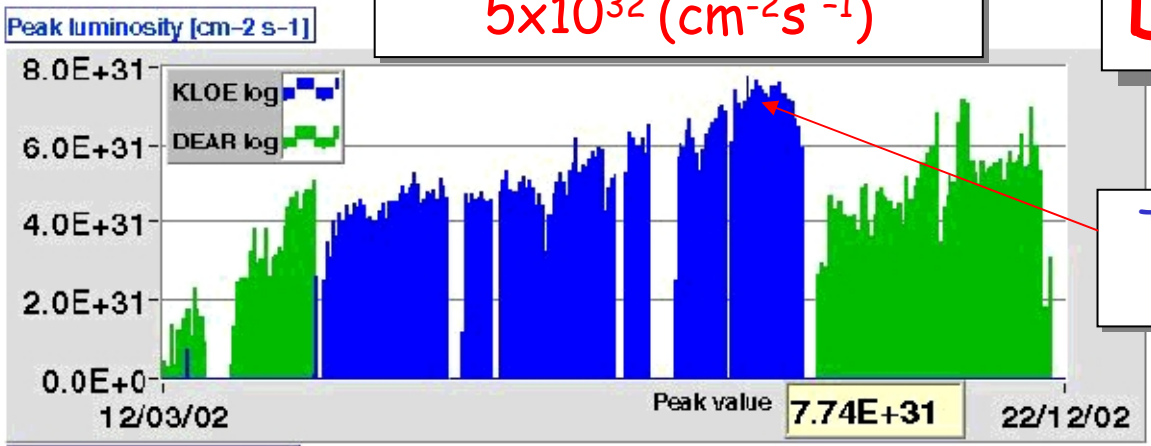
Accelerator complex



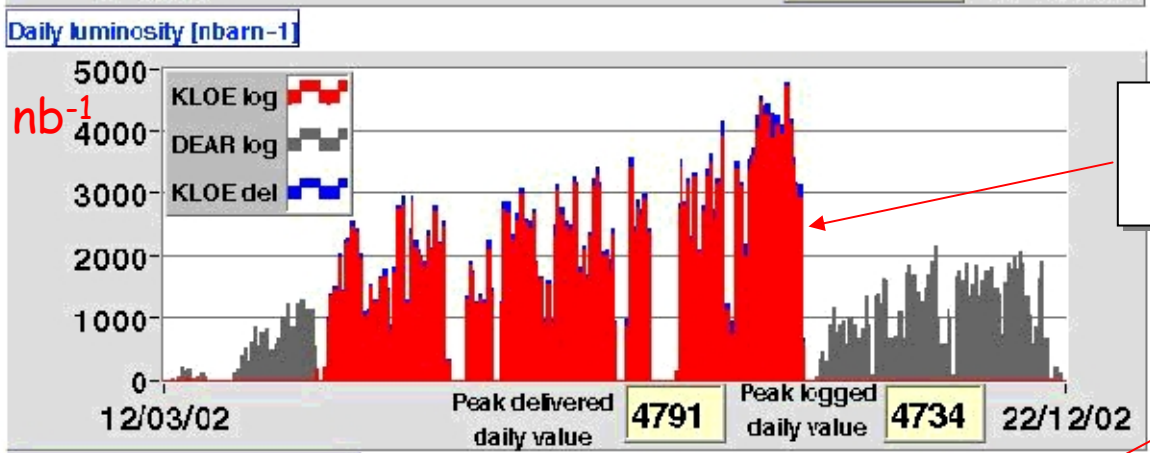


DAΦNE in 2002

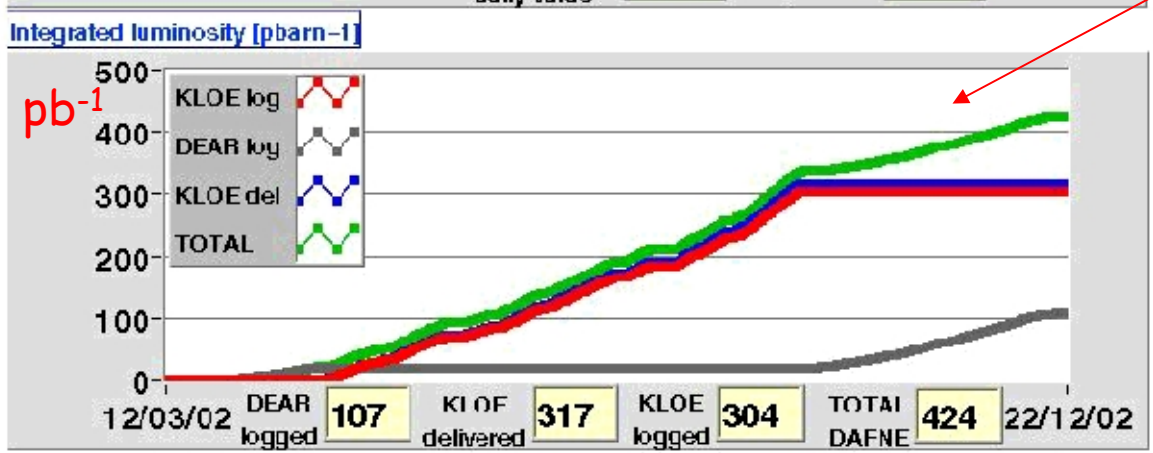
Design top luminosity
5×10^{32} ($cm^{-2}s^{-1}$)



Top luminosity achieved
7.7×10^{31} ($cm^{-2}s^{-1}$)



Average daily integrated luminosity: >2 pb^{-1}



Integrated luminosity to experiments in 2002

Total integrated luminosity assigned to FINUDA for 2003 run : 250 pb^{-1}

FI.NU.DA.: FIsica NUcleare a DAΦNE

Main physics idea

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

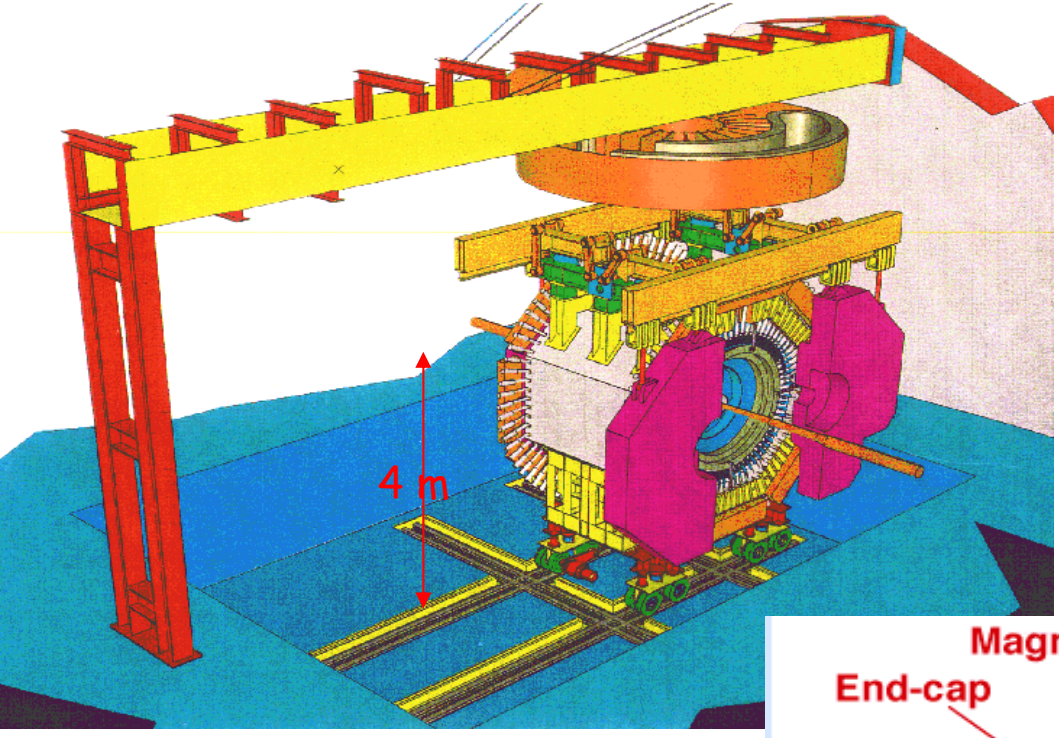
High resolution spectroscopy

Mesonic and Non-mesonic decay

low energy (16 MeV) monochromatic tagged background free

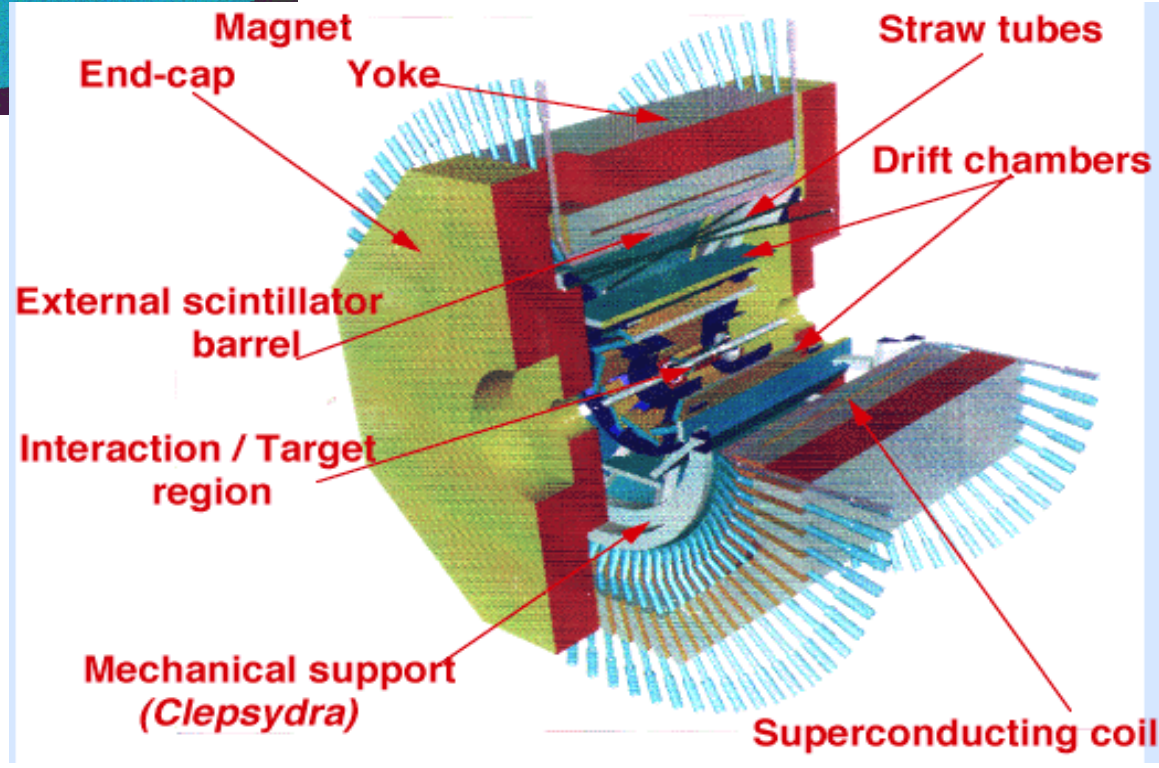
A fixed target experiment carried out at a collider

	DAΦNE K^- beam	K^- extracted beams
K^- beam momentum	Low (127 MeV/c)	Medium-hign (500-600 MeV/c)
K^- beam momentum resolution	Monochromatic and background free	Non-monochromatic and π^- contamination
Target thickness	Very thin (0.2 g/cm^2)	Thick (some g/cm^2)
Resolution on hypernuclear levels	~750 KeV	~1-2 MeV
Detector acceptance	Large (Typical of collider)	Small (Fixed target)
Tagging of K^-	Possible with collinear K^+	Not possible
Rates (event/hour) (10^{-3} capture rate)	400 ($\mathcal{L}$=5 10^{32} cm^{-2}s^{-1})	~10
Study of hypernuclear decay p n in coincidence	Possible pn : 2,5 event/hour nn : 0.7 event/hour mesonic : 8.5 π^-/hour	Difficult or impossible

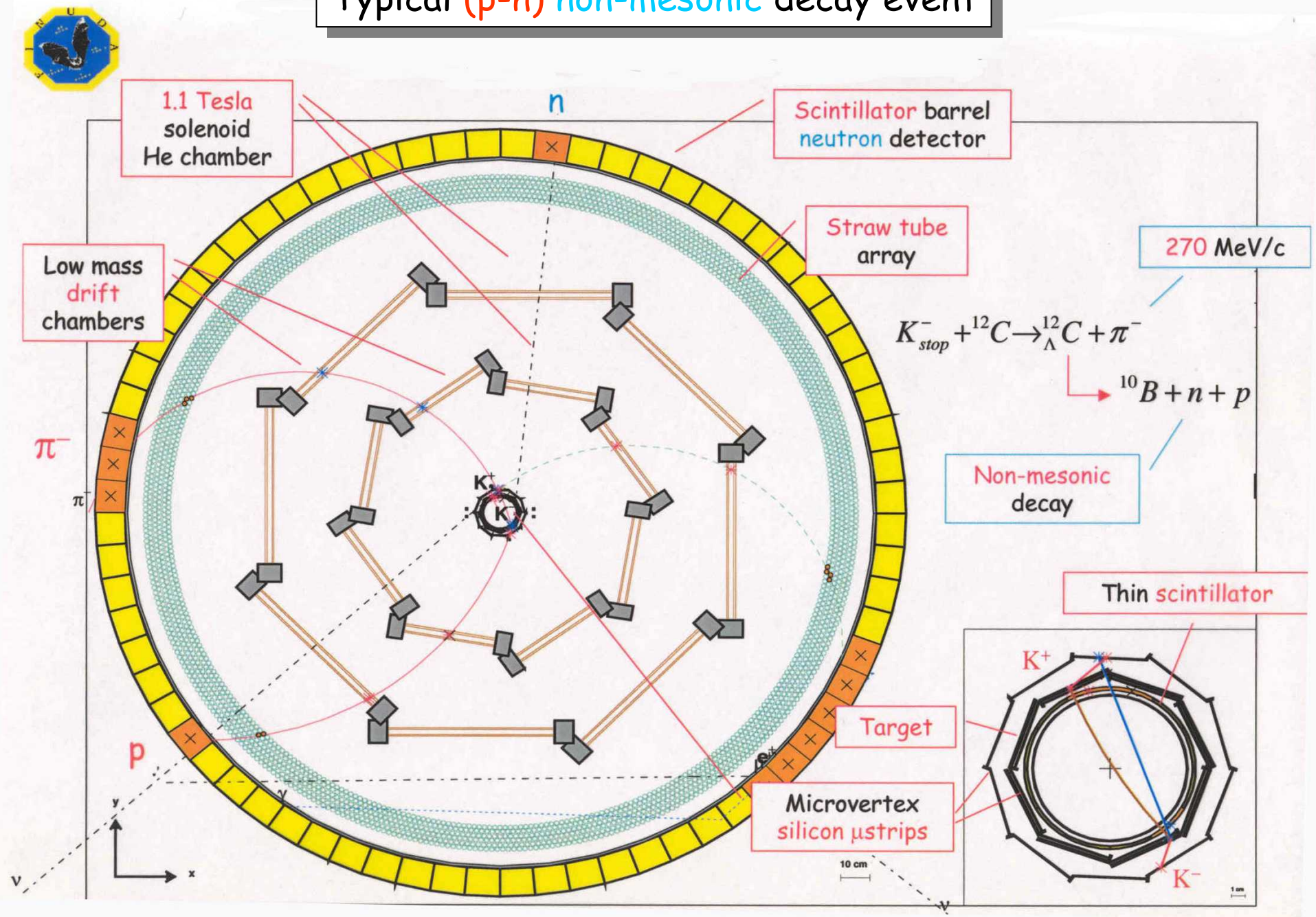


FI.NU.DA:
a detector for
hypernuclear physics

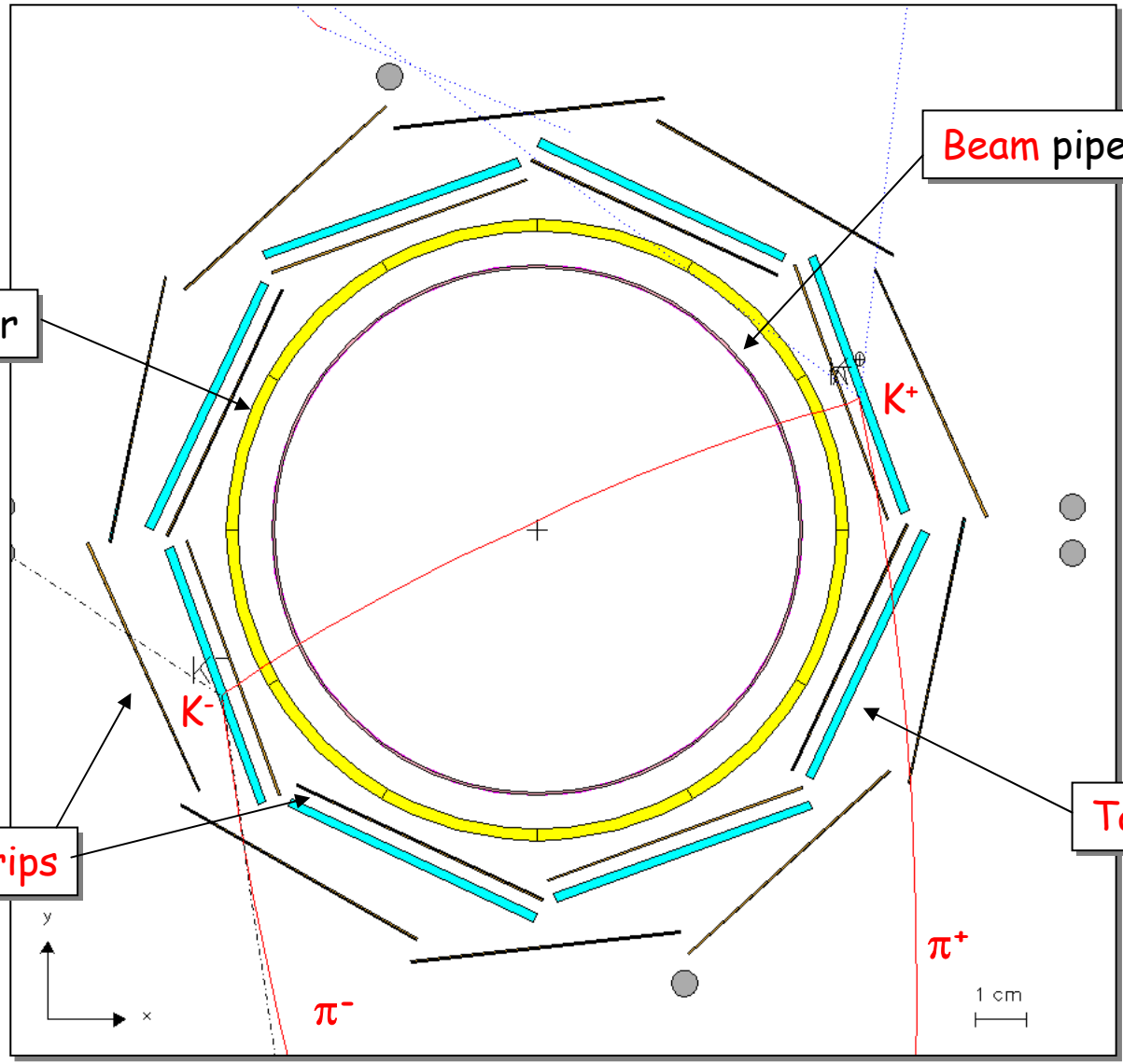
The structure of a
collider experiment

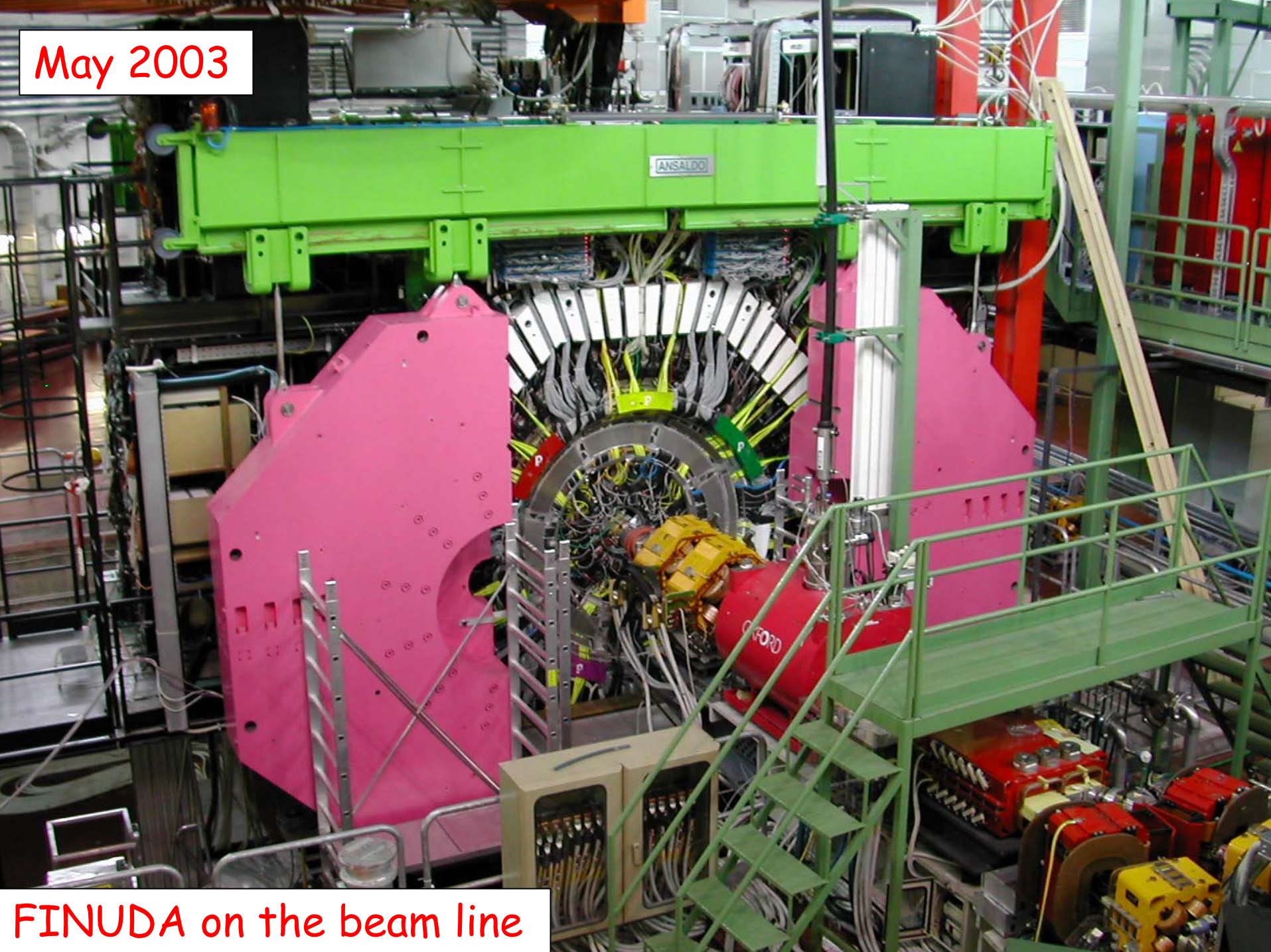


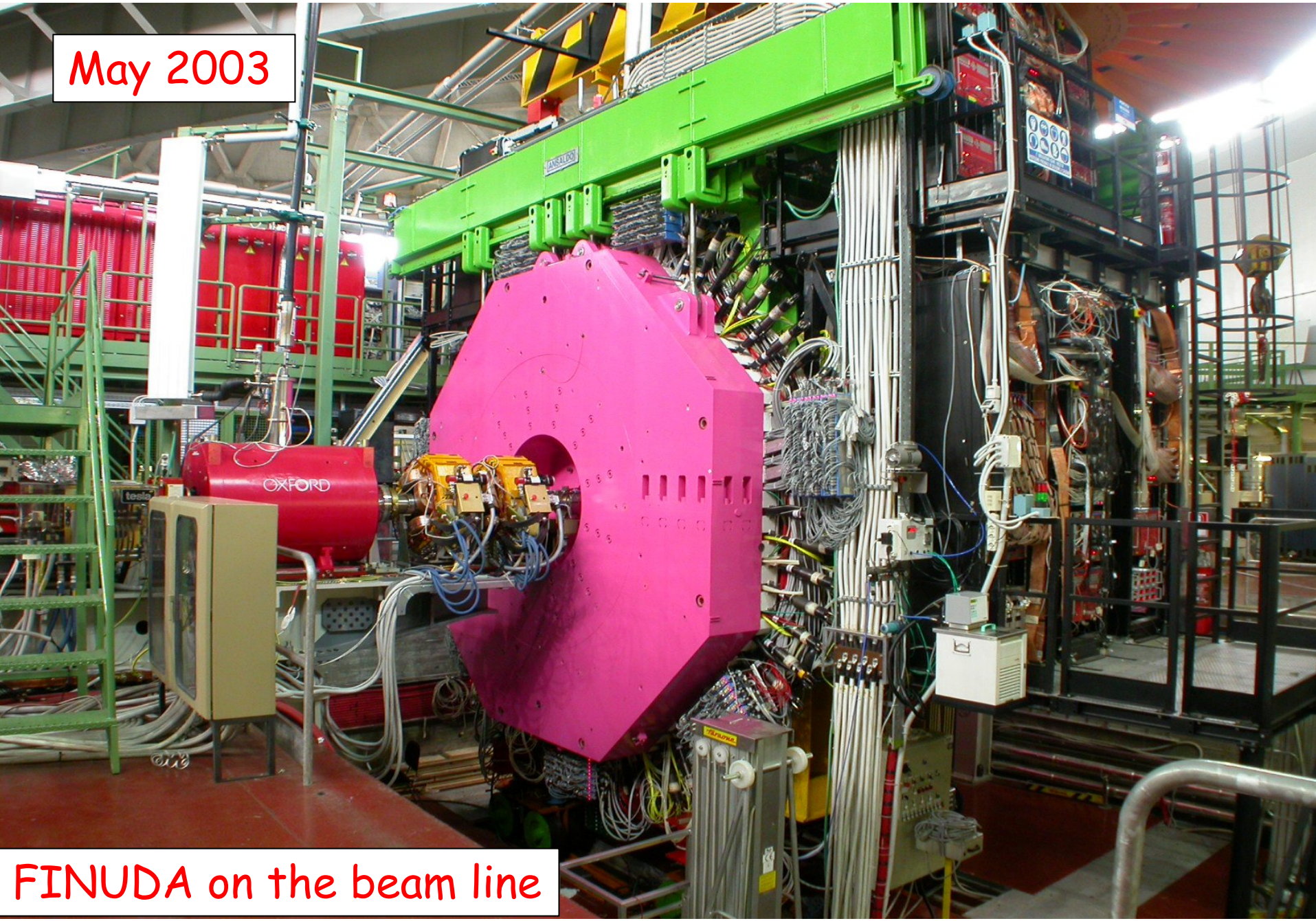
Typical (p-n) non-mesonic decay event



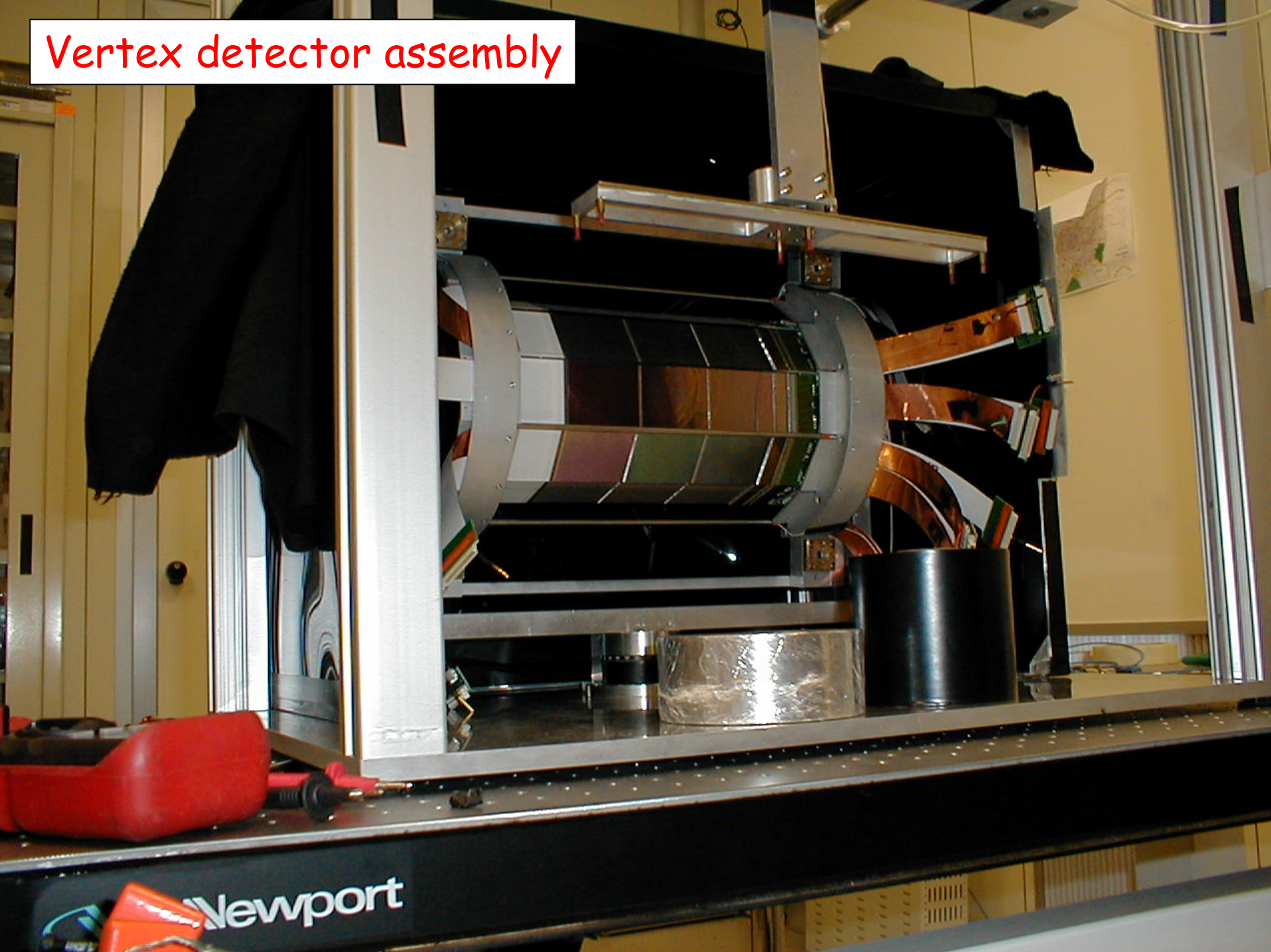
The interaction-target region

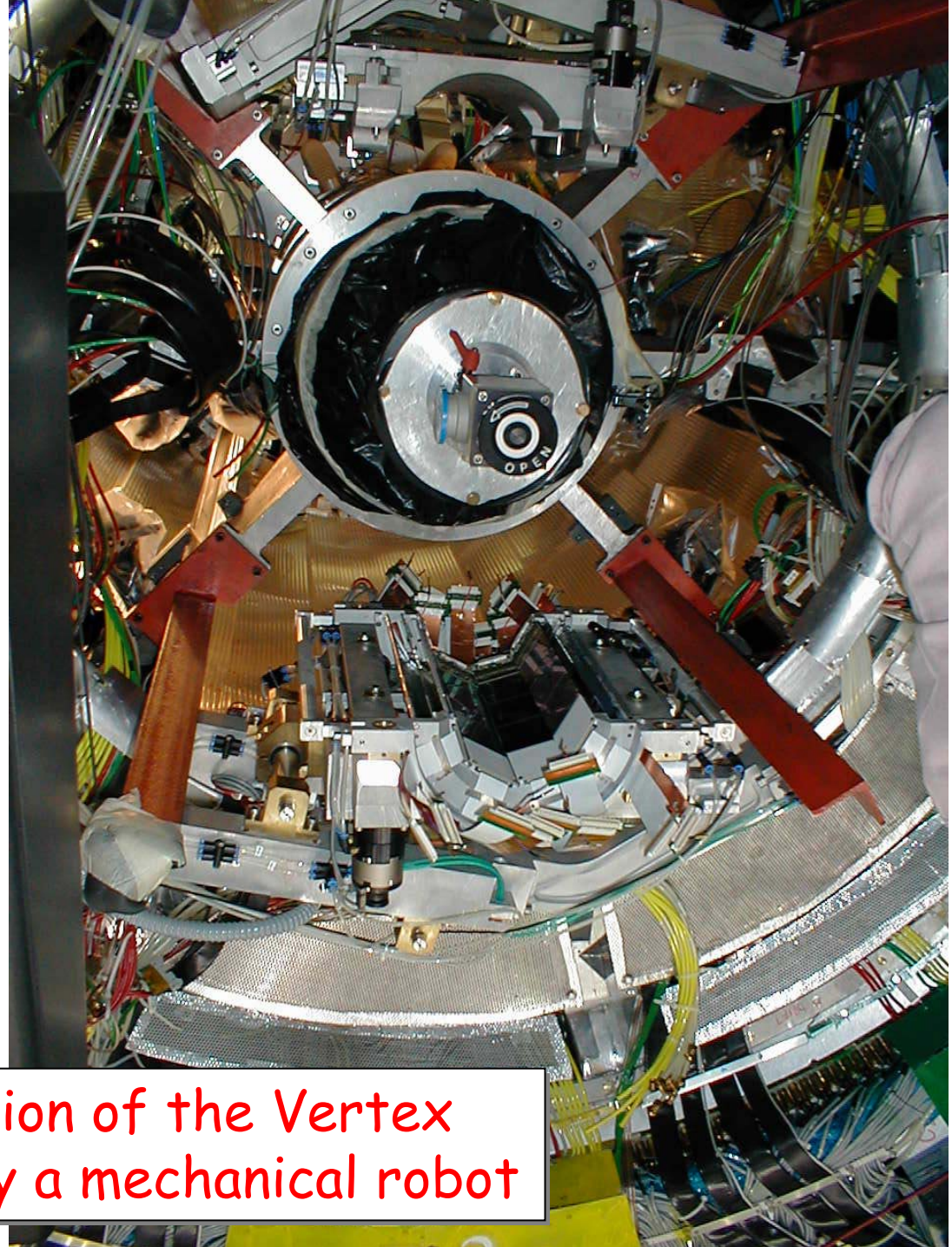



May 2003
ANSALDO
FINUDA on the beam line


May 2003
OXFORD
FINUDA on the beam line

Vertex detector assembly





Installation of the Vertex detector by a mechanical robot

FINUDA detector performances

- **S.C. Magnet:** B = 1.1 T homogeneous field within 2% inside the tracking volume.
- **Interaction/Target region:** selection of K^+- K^- pairs production and detection of hypernuclei.

InTOF σ_t = 250 ps

Si VDET: σ_z = 30 μm ; en. res. 20% FWHM

- **External tracking device:** measurement of trajectories and momenta of charged particles with high precision $\Delta p/p$ = 0.3%.

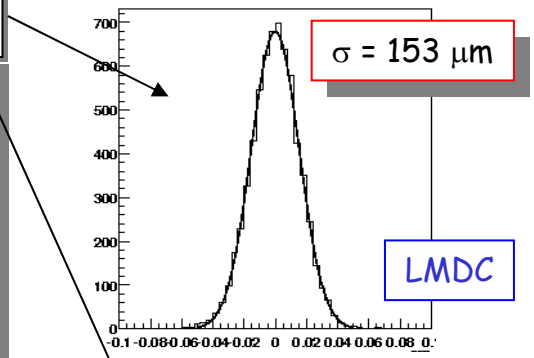
LMDC: $\sigma(\rho,\phi) \approx$ 150 μm; σ_z 1% wire length

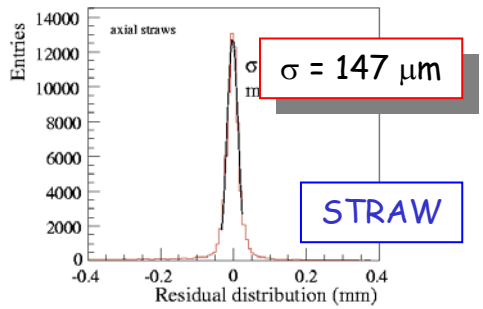
STRAW: $\sigma(\rho,\phi) \approx$ 150 μm; σ_z = 500 μm

- **External scintillator barrel:** trigger purposes and neutron detection (10% eff. , 8 MeV energy Res. at 80 MeV, time resolution 500 ps FWHM)
- **Helium gas chamber:** multiple scattering reduction.

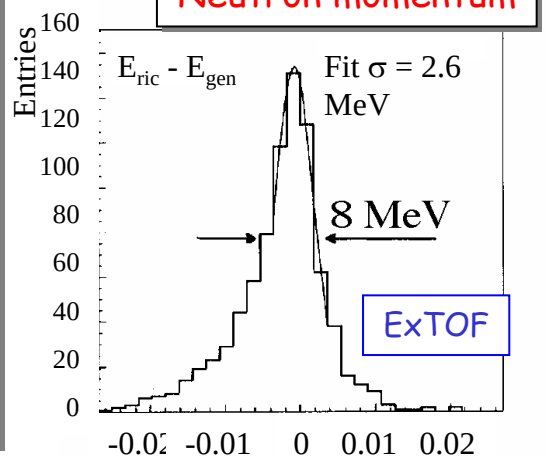
FINUDA momentum resolution $\Delta p/p$ is: 0.3% in He → 1.5% in air

Test beam

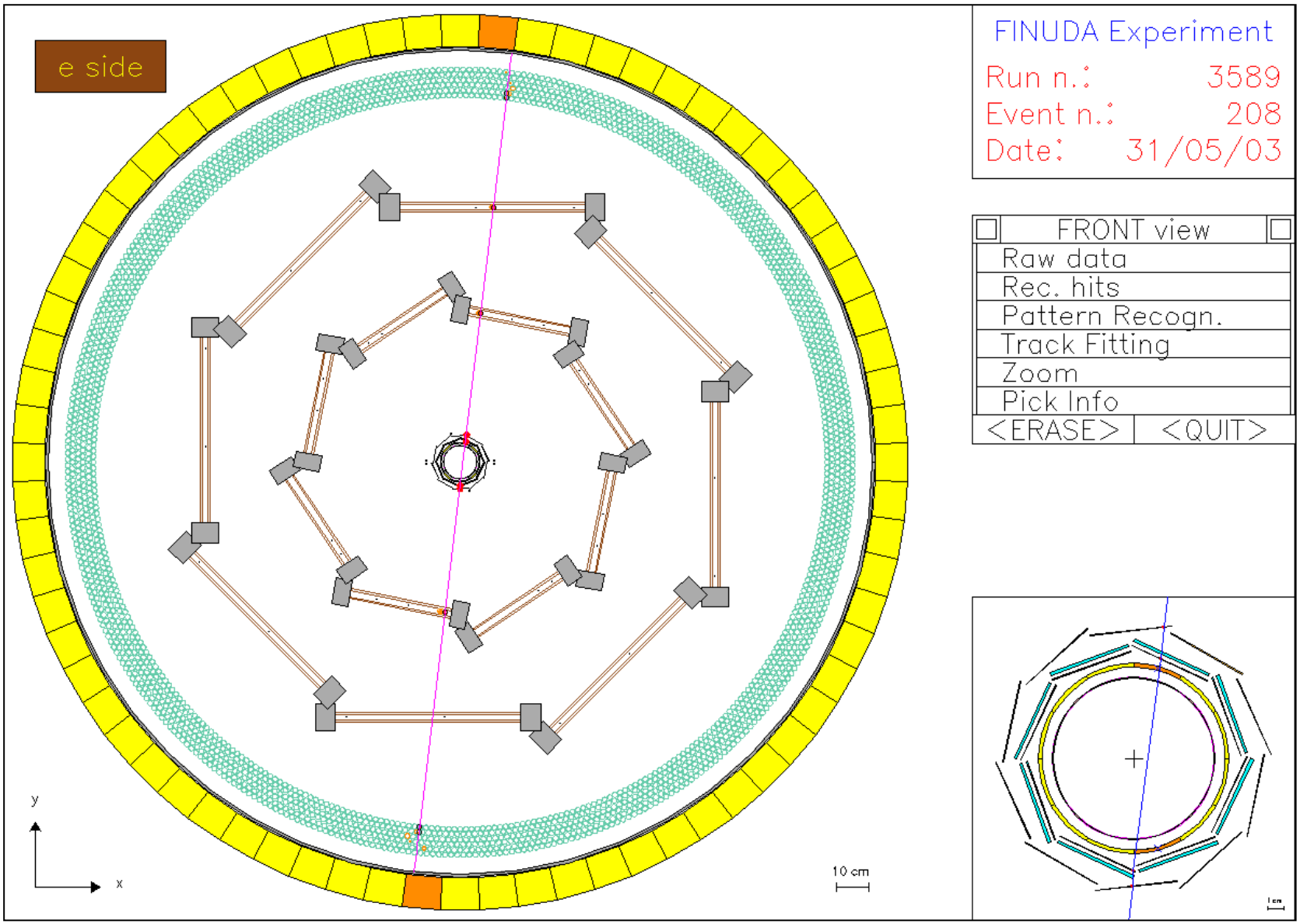




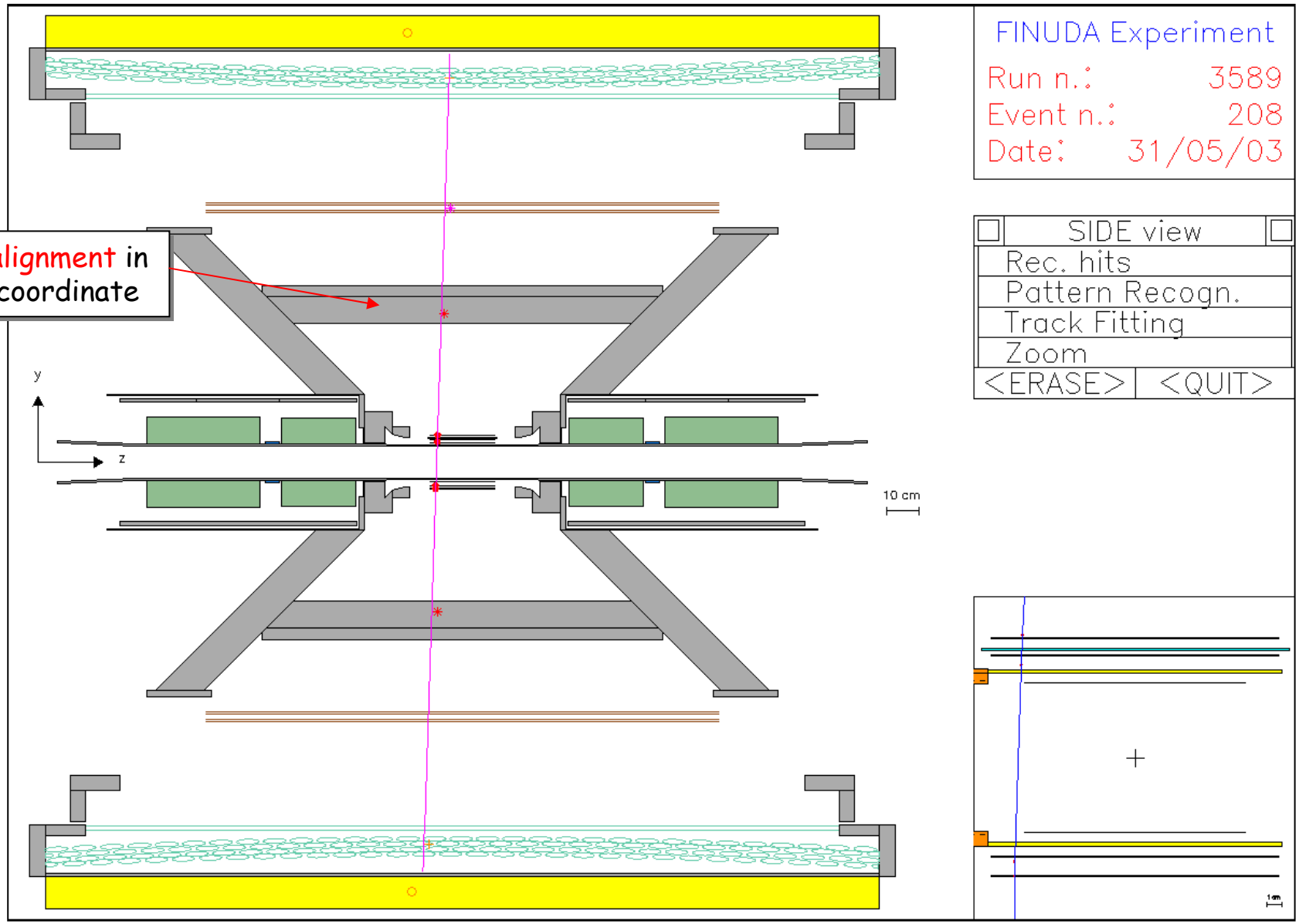
Neutron momentum



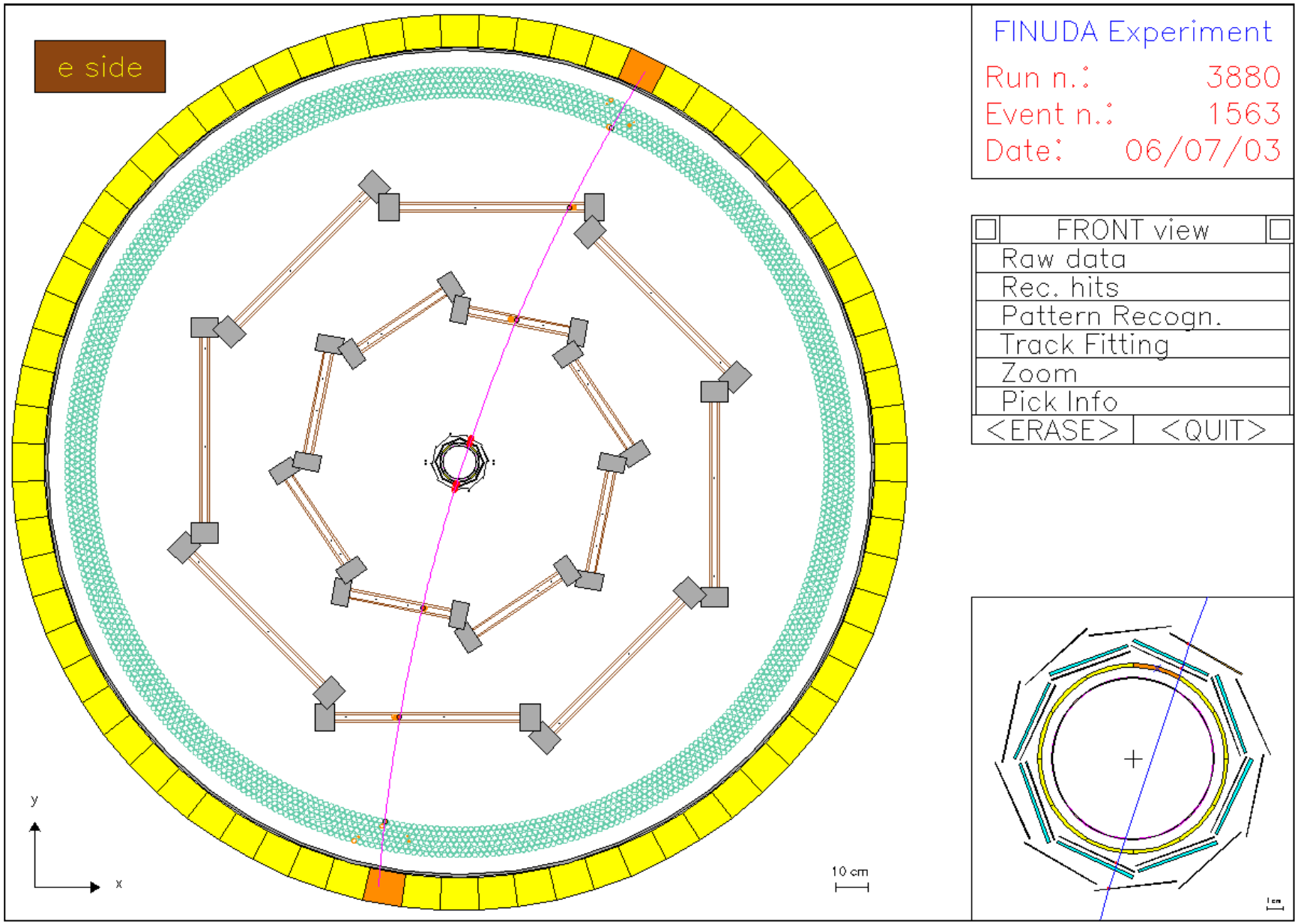
Cosmic rays with B= 0 T



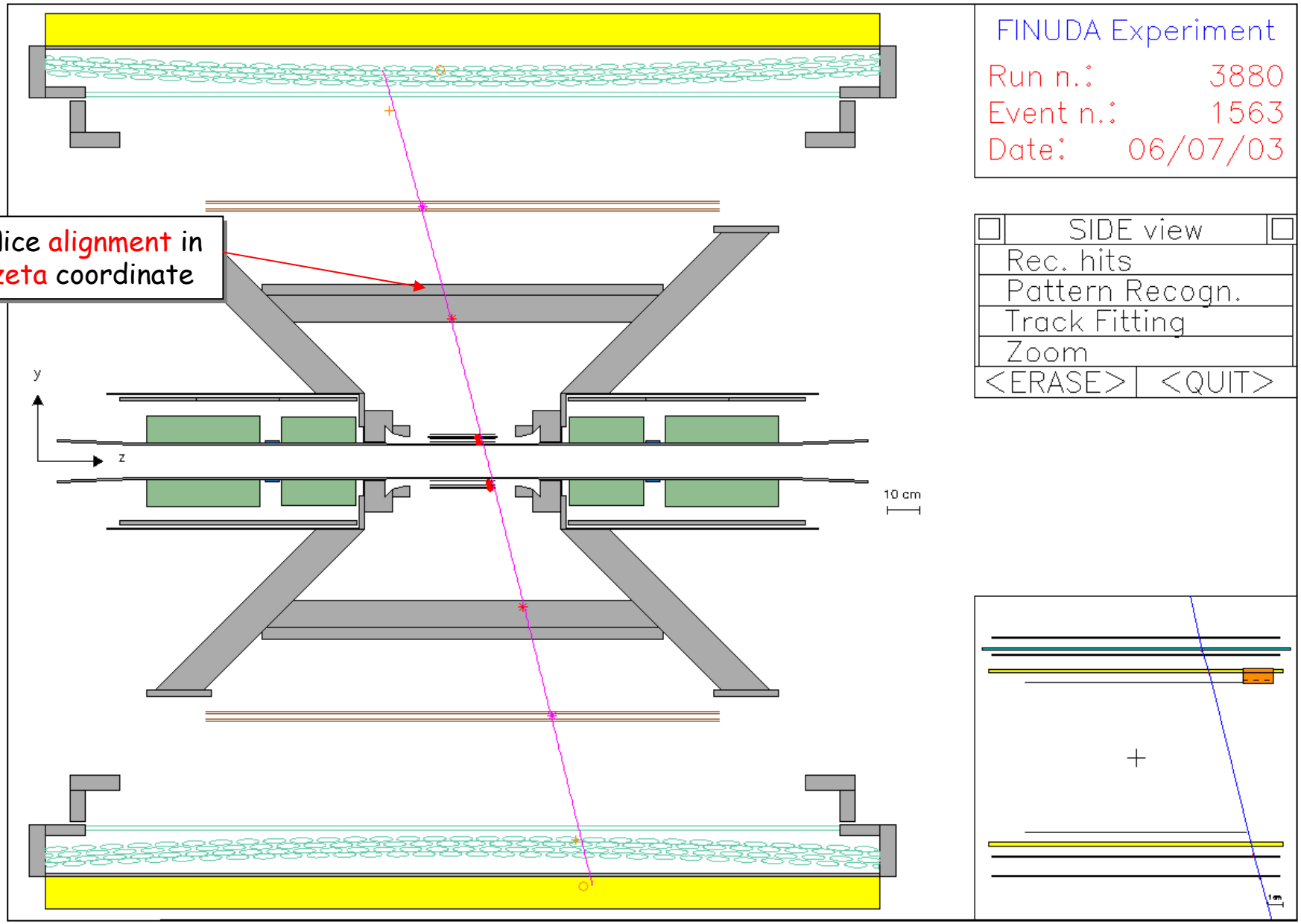
Cosmic rays with B= 0 T



Cosmic rays with B= 1.1 T

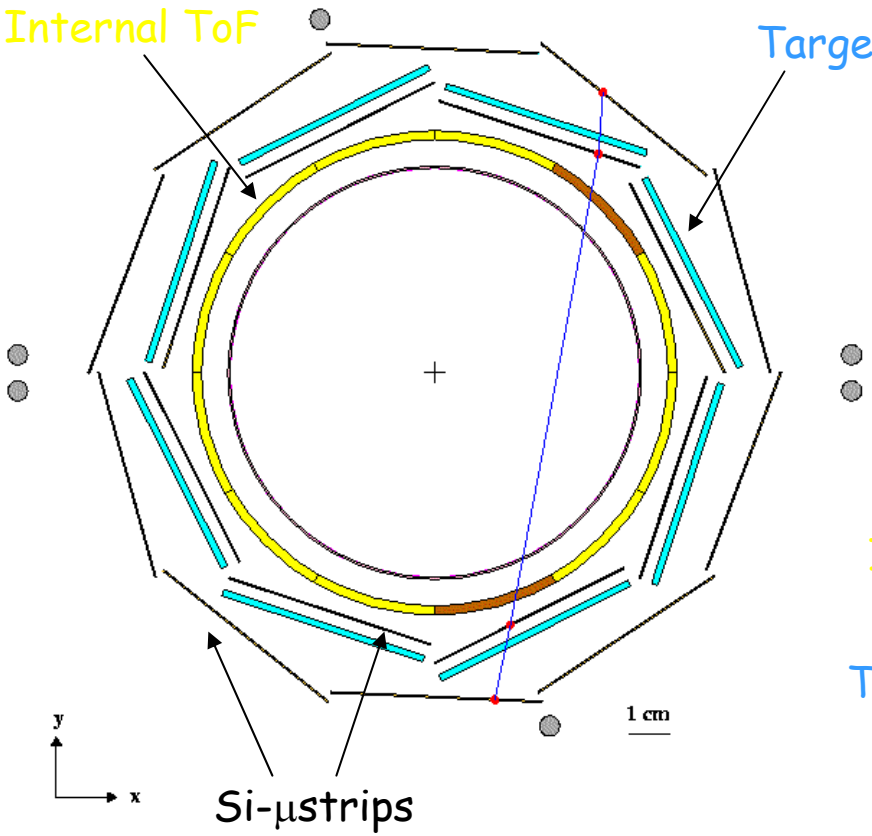


Cosmic rays with B= 1.1 T

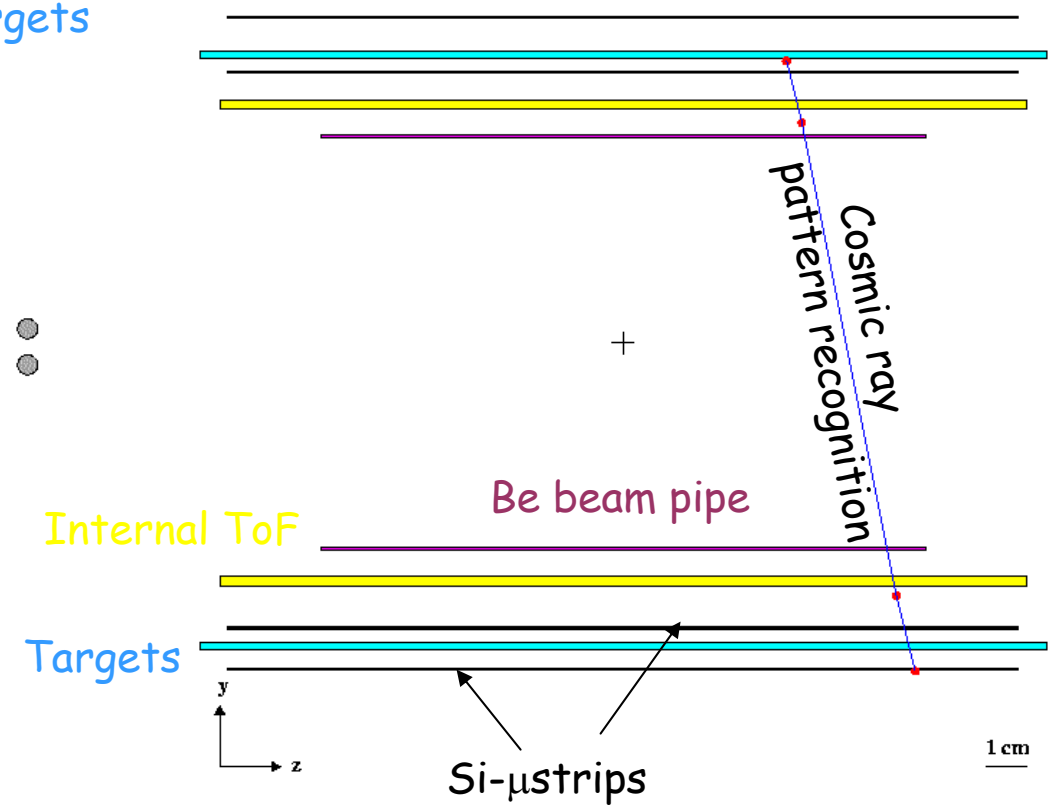


Interaction vertex region

Front view

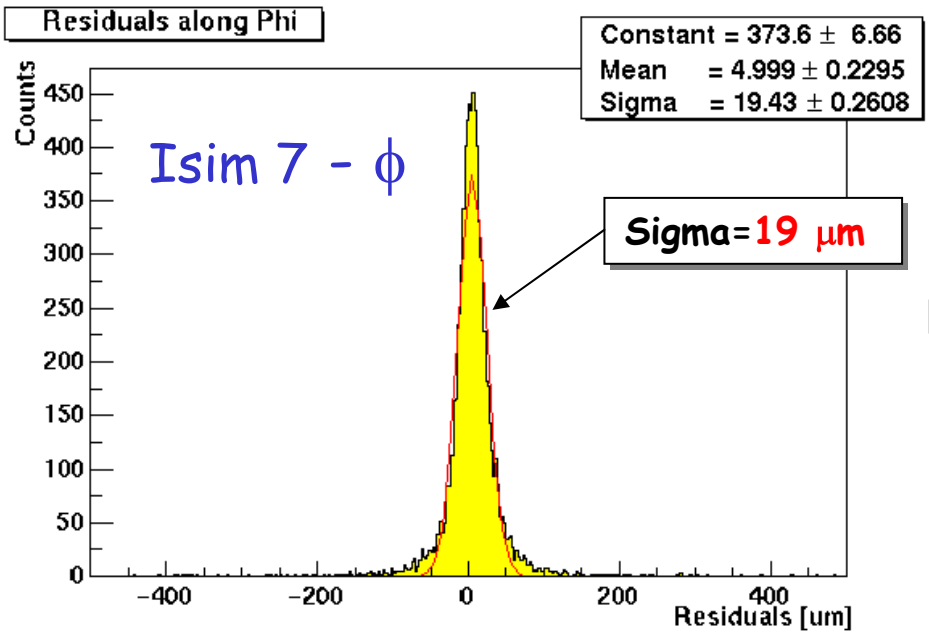


Side view



Alignment of Silicon VDET with cosmic rays

Results after 1st order correction

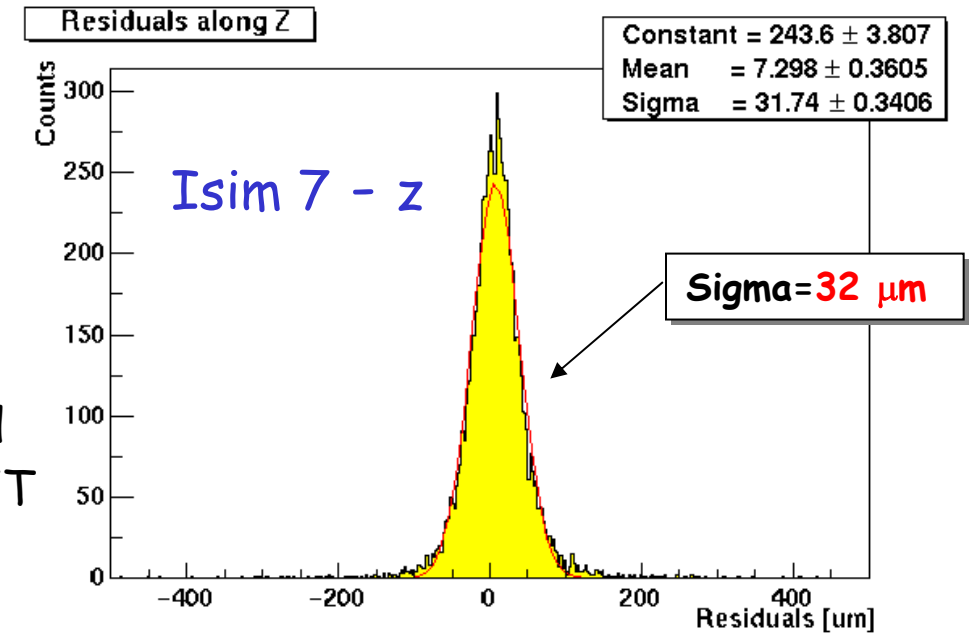


- ~ 20.000 good cosmic rays required
- ~ 3 Hz of cosmic rays crossing VDET

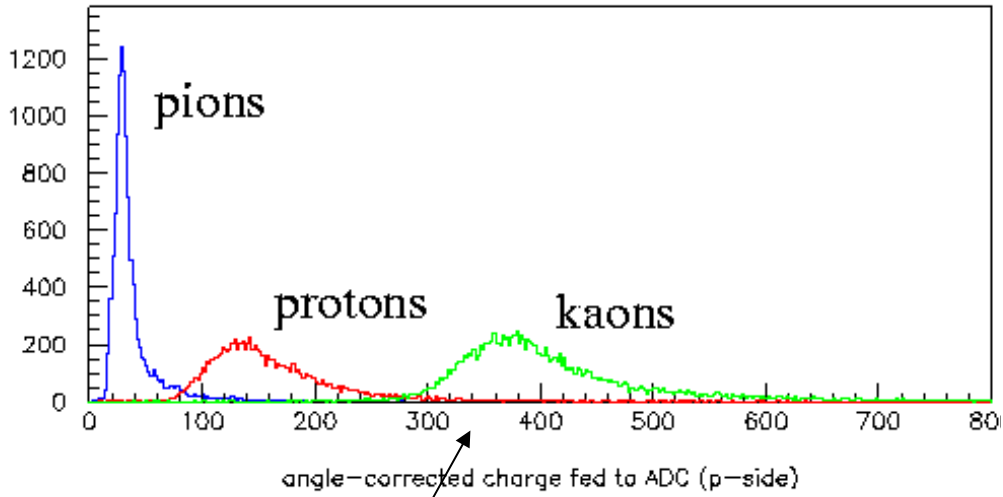
⇒ ~ 3 weeks of data taking

Expected results:

- σ_{int} : pitch/$\sqrt{12}$ = ϕ ~ 15 μm, z ~ 30 μm
- $\sigma^2 = \sigma^2_{int} + \sigma^2_{MS} + \sigma^2_{sag}$
- average efficiency of a module > 97%

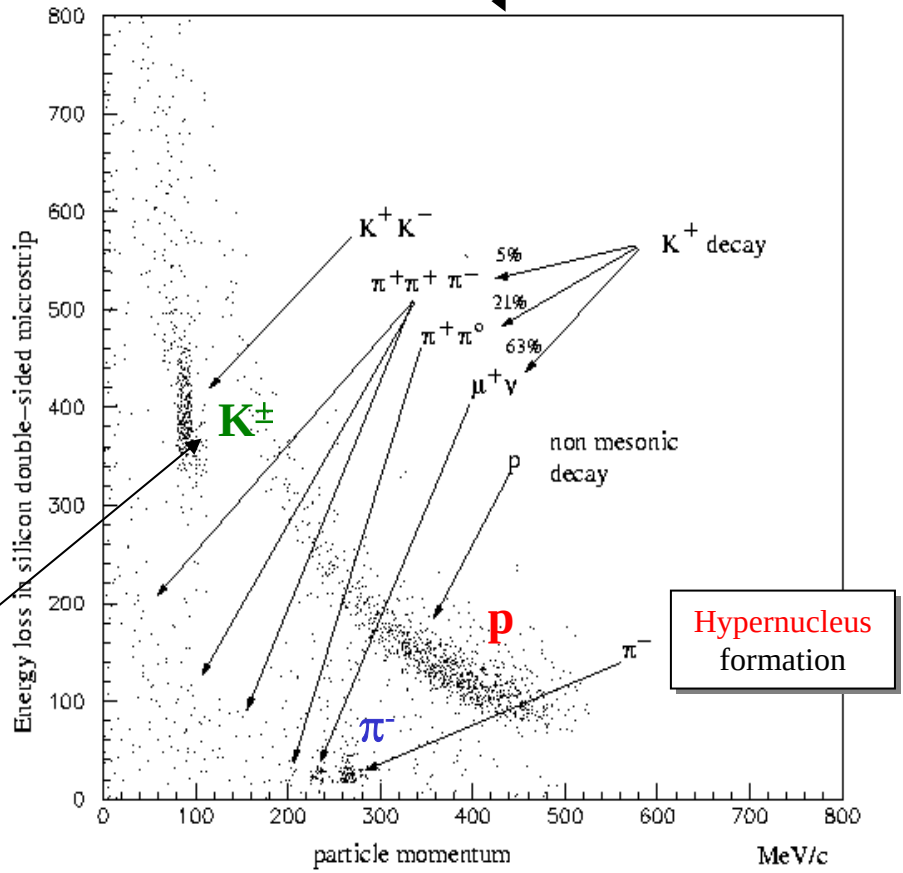


PID with VDET x FINUDA



Measured PID in μstrips at π^- p $K^{\pm}$ momentum at a test beam

Simulated PID in FINUDA

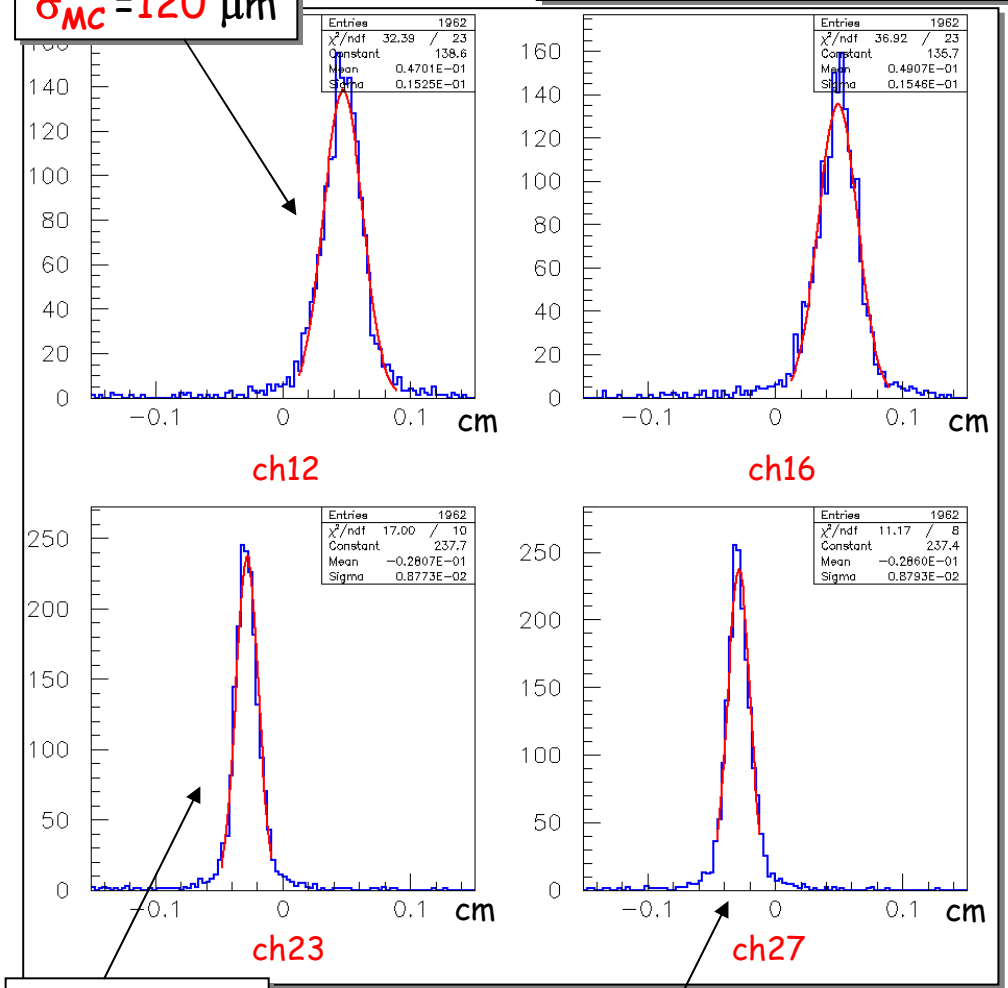


Essential for $K^{\pm}$ beam recognition

LMDC resolution and alignment

σ_{exp}=150 μm
σ_{MC} =120 μm

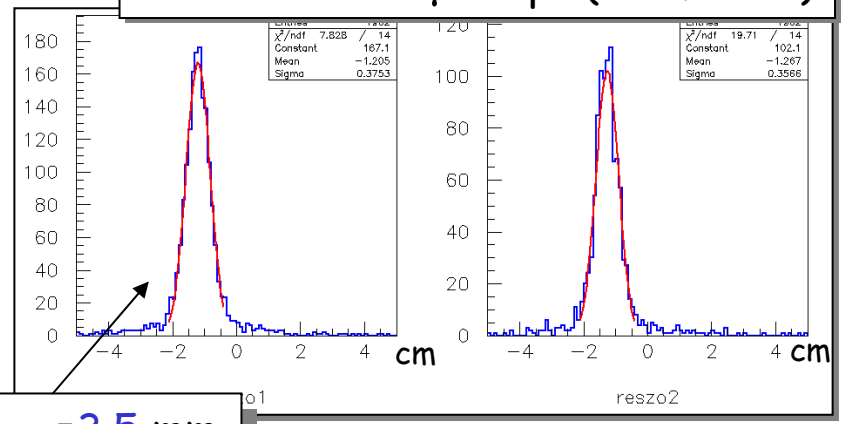
Fit residuals on drifts



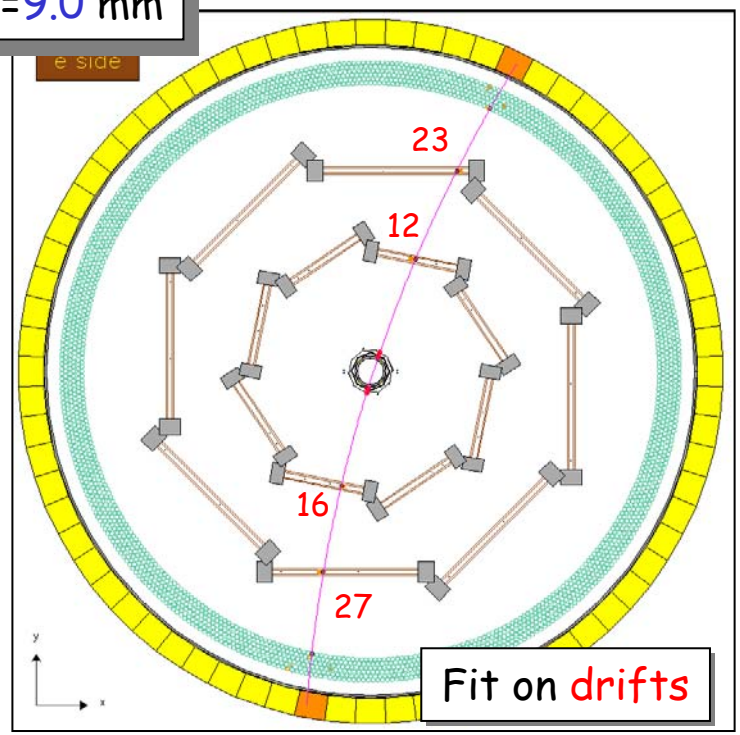
σ_{exp}=87 μm
σ_{MC} =70 μm

Chamber displacement
Δy=-280 μm

Residuals on z μstrips (not fitted)



σ_{exp}=3.5 mm
σ_{MC} =9.0 mm

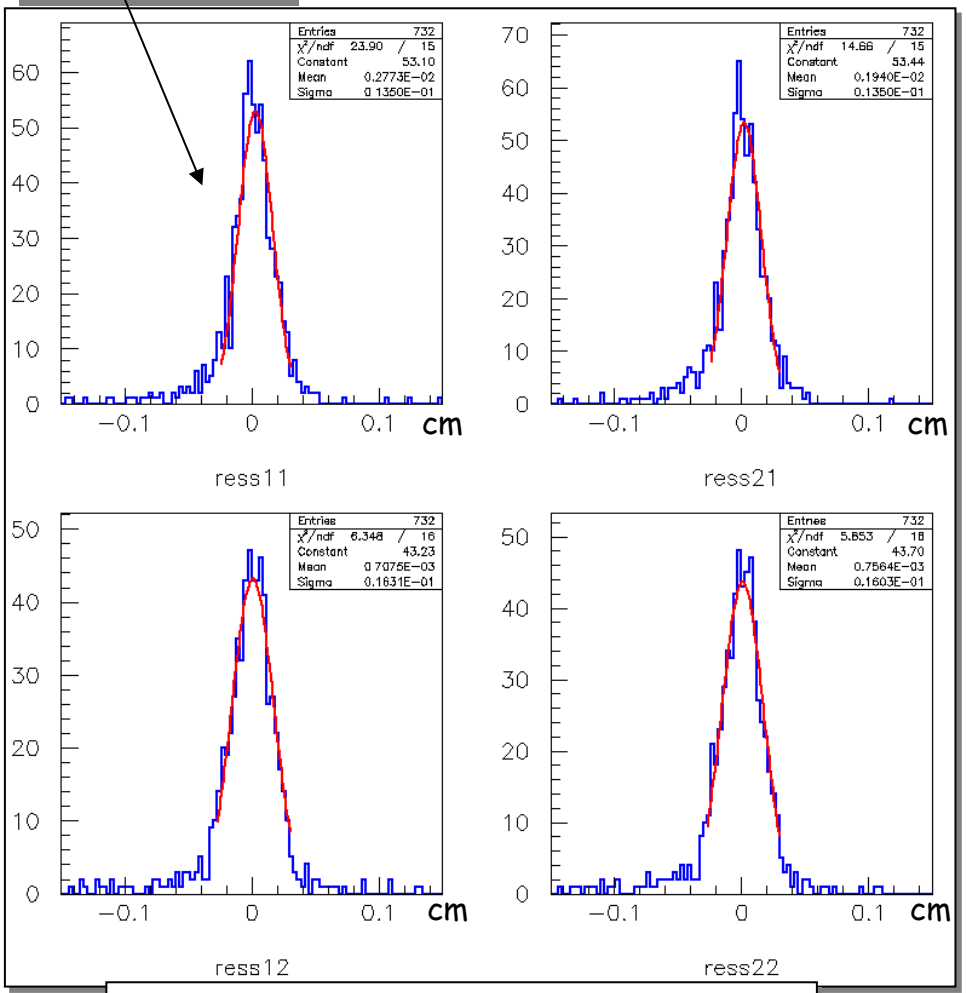


Fit on drifts

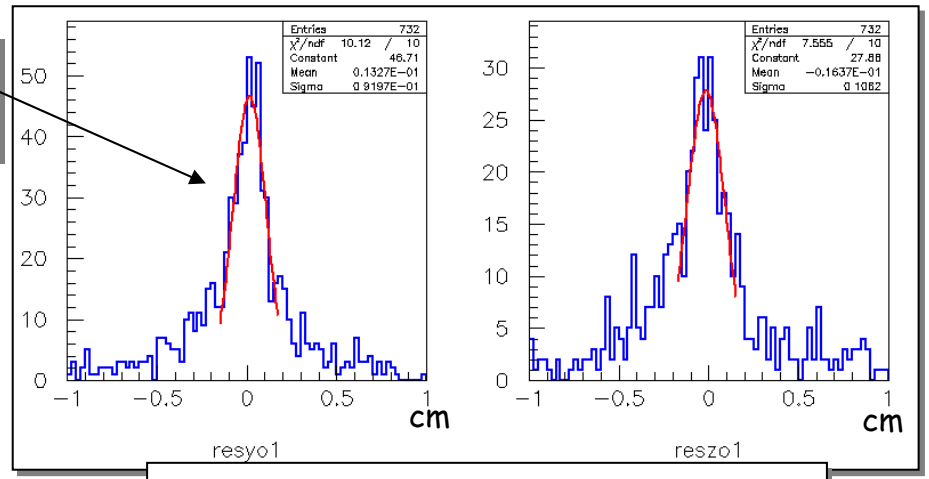
Straw tubes detector resolution

σ_{exp}=140 μm
σ_{MC} =110 μm

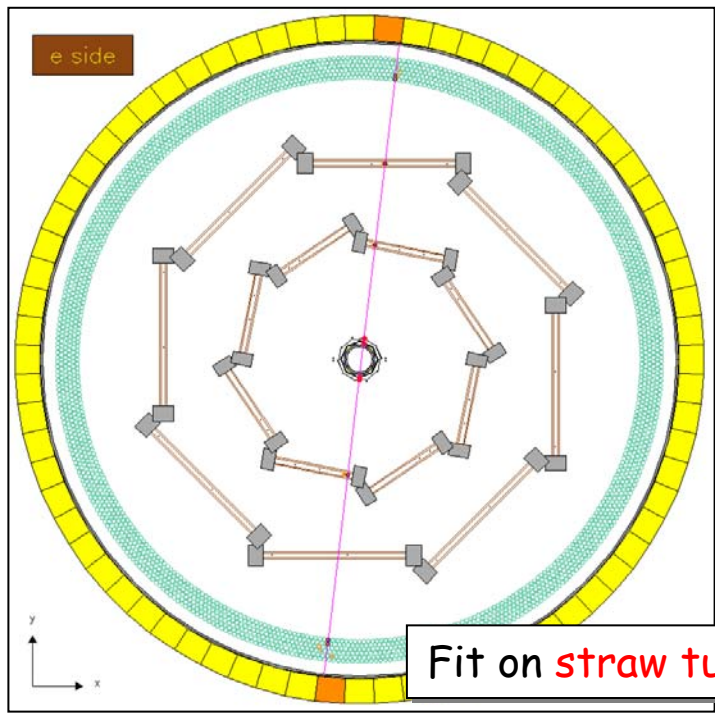
σ_{exp}=0.90 mm
σ_{MC} =0.75 mm



Fit residuals on longitudinal tubes



Residuals on μstrips (not fitted)



Fit on straw tubes

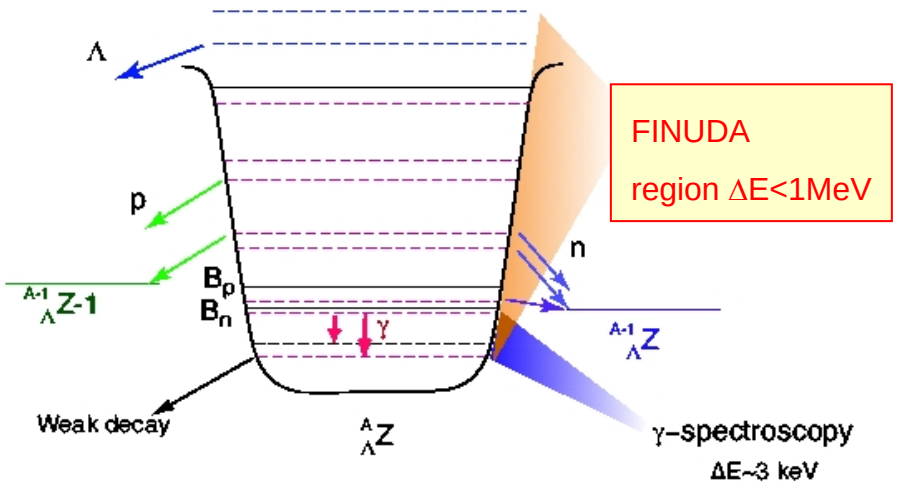
FINUDA physics program

- HYPERNUCLEAR SPECTROSCOPY
  is an essential tool for testing
  theoretical models of Λ-N potentials
  and single particle model predictions

- HYPERNUCLEAR DECAYS
  allows to study weak processes
  in nuclear matter $\Lambda \rightarrow \pi N$
  $\Lambda N \rightarrow NN$ and $\Lambda NN \rightarrow nNN$

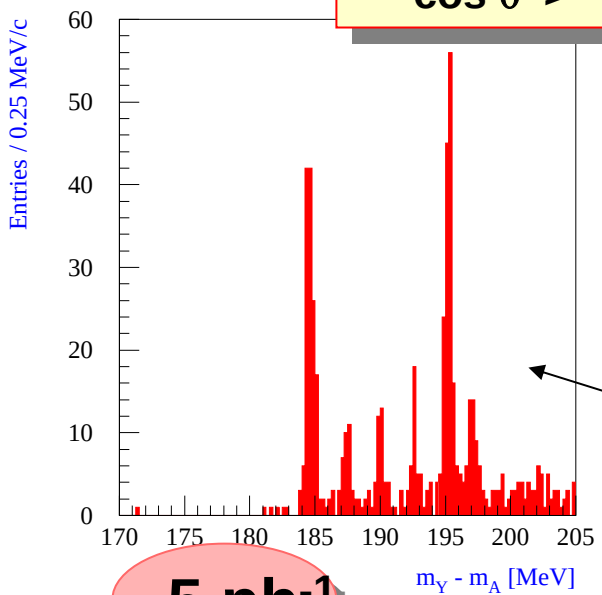
SIMULTANEOUSLY

Spectroscopy



The high energy region of excitation in heavy Λ-hypernuclei cannot be explored with γ spectroscopy.

250<p_p<530 Mev/c
cos θ > - 0.5



~ 5 pb^{-1}

- FINUDA energy resolution will be ΔE~ 750 keV still better than any experiment up to now.
- In competition only with JLab experiment

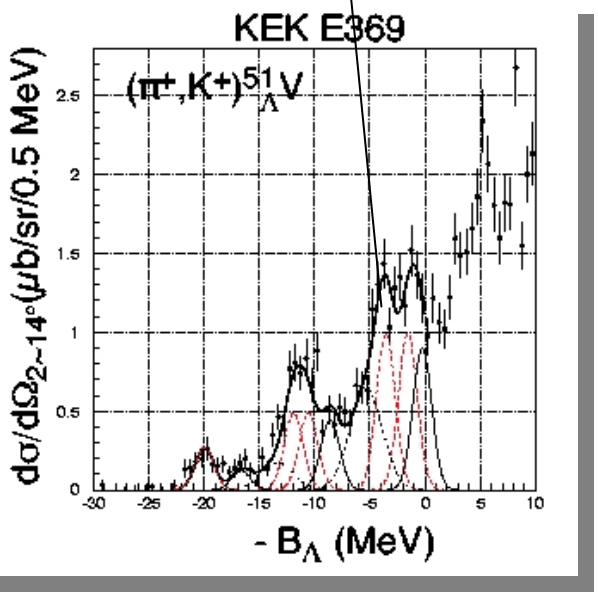
Simulation with 8 $^{12}_{\Lambda}C$ targets
Backward proton in coincidence to reduce background from

$$K^-(np) \rightarrow \Sigma^- p \rightarrow n\pi^- p$$

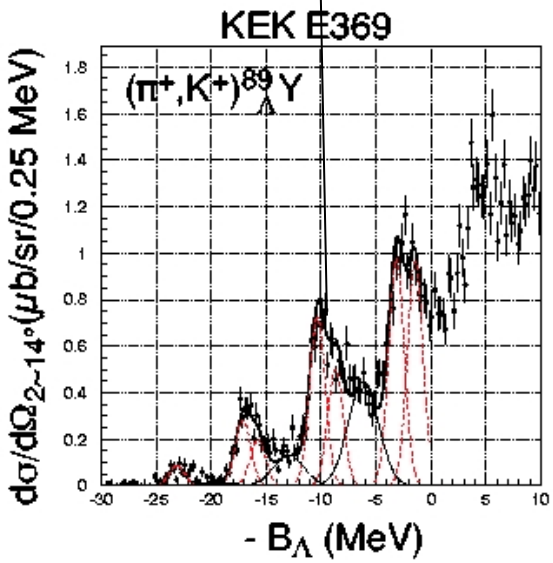
Best present spectroscopic data

Up to now SKS at KEK has collected nice data

1.93 MeV

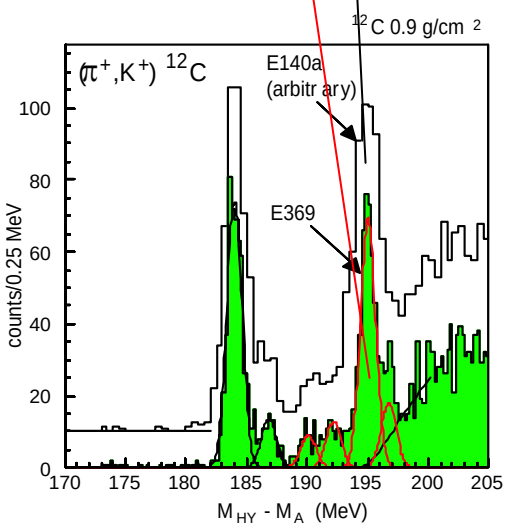


1.65 MeV



1.9 MeV

1.45 MeV



Hypernuclear decays

Mesonic Λ decay in the nucleus

$$\begin{cases} \Lambda \rightarrow p + \pi^- & \Gamma_{\pi^-} \\ \Lambda \rightarrow n + \pi^0 & \Gamma_{\pi^0} \end{cases}$$

Suppressed by Pauli blocking in medium-heavy nuclei

$\Gamma_m = \Gamma_{\pi^-} + \Gamma_{\pi^0}$

Non-mesonic Λ decay

$$\Lambda N \rightarrow NN \quad \begin{cases} p + n & \Gamma_p \\ n + n & \Gamma_n \end{cases}$$

$$\Lambda NN \rightarrow nNN\ (15\%) \quad n + N + N \quad \Gamma_{NN}$$

Dominant in medium-heavy nuclei (A≥12)

$\Gamma_{nm} = \Gamma_p + \Gamma_n + \Gamma_{NN}$

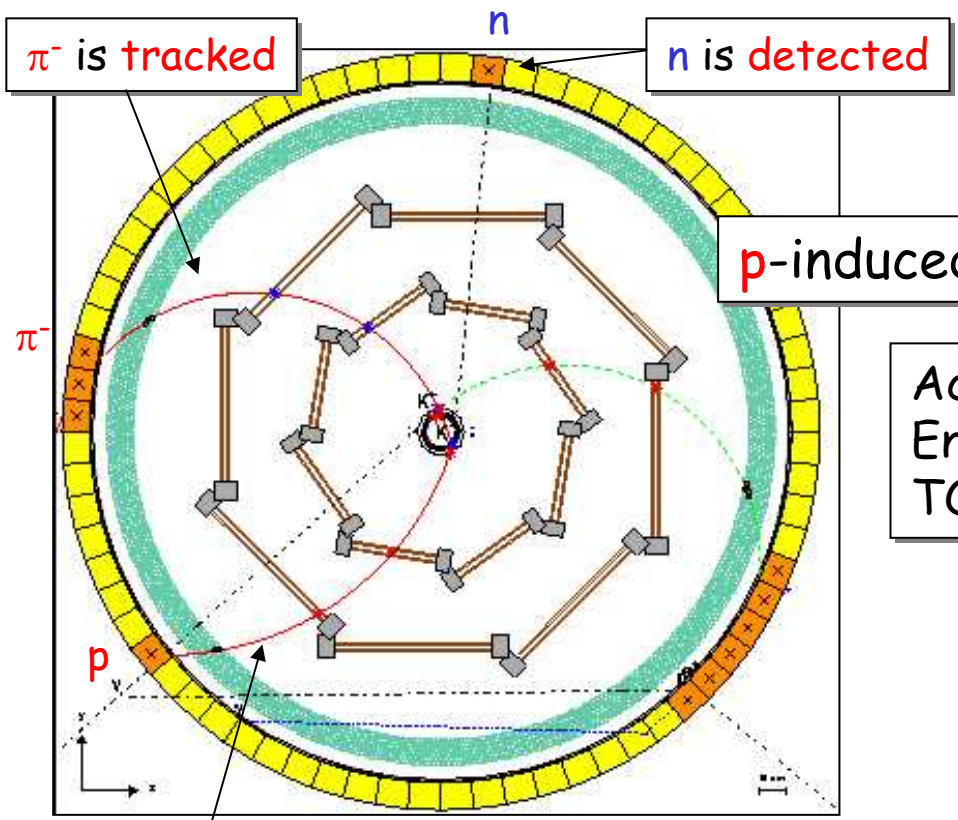
Gives the only experimental access to the four-baryon, strangeness changing weak interaction

Hypernucleus lifetime

$\tau = h / \Gamma_{tot}$

$\Gamma_{tot} = \Gamma_{\pi^-} + \Gamma_{\pi^0} + \Gamma_p + \Gamma_n + \Gamma_{NN} = \Gamma_m + \Gamma_{nm}$

Non mesonic decay

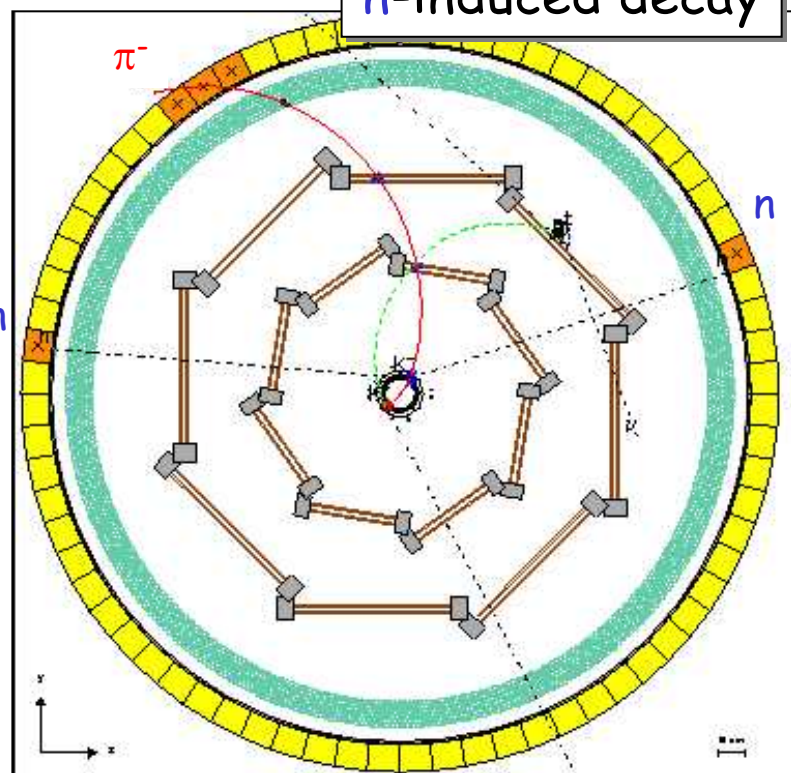


p-induced decay

proton

Acceptance 30%
Energy resolution 1.3 MeV (at 80 MeV)
TOF resolution 500 ps (fwhm)

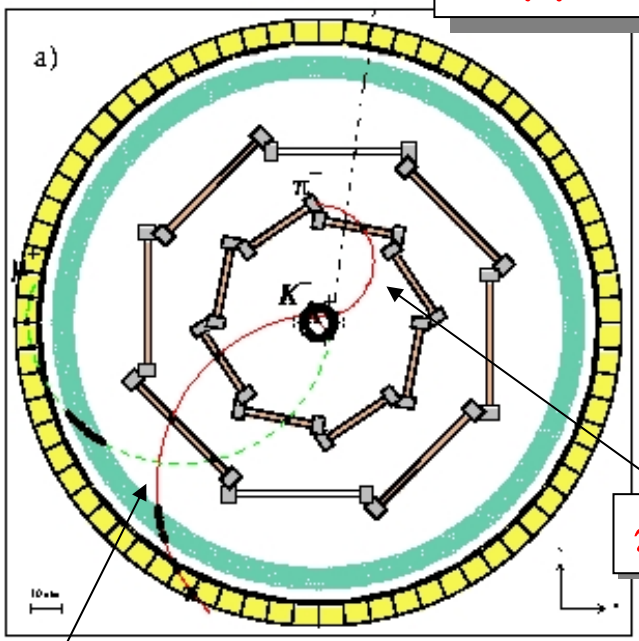
n-induced decay



neutron

Acceptance 71%
Energy resolution ~ 8 MeV (at 80 MeV)
Efficiency ~10%
TOF resolution 500 ps (fwhm)

Hypernucleus mesonic decay

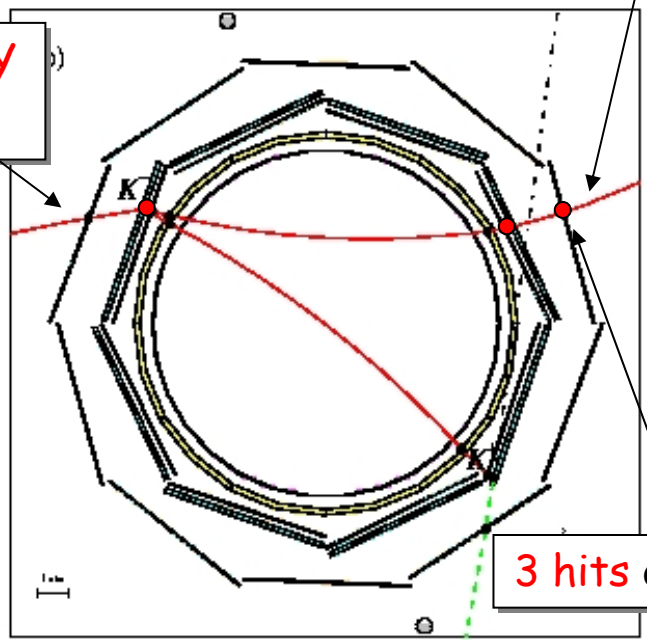


- Acceptance 20% (3 hits on μstrips)
- Momentum resolution 40% (100 MeV/c)
- Both π^- are measured in coincidence

π^-

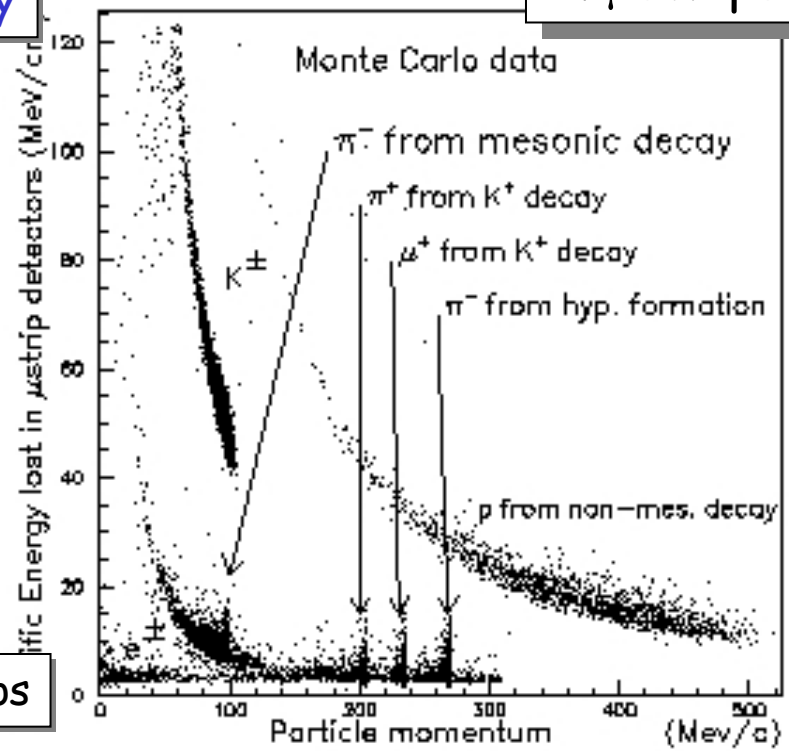
π^- from HY decay

π^- from HY formation



3 hits on μstrips

good PID in μstrips

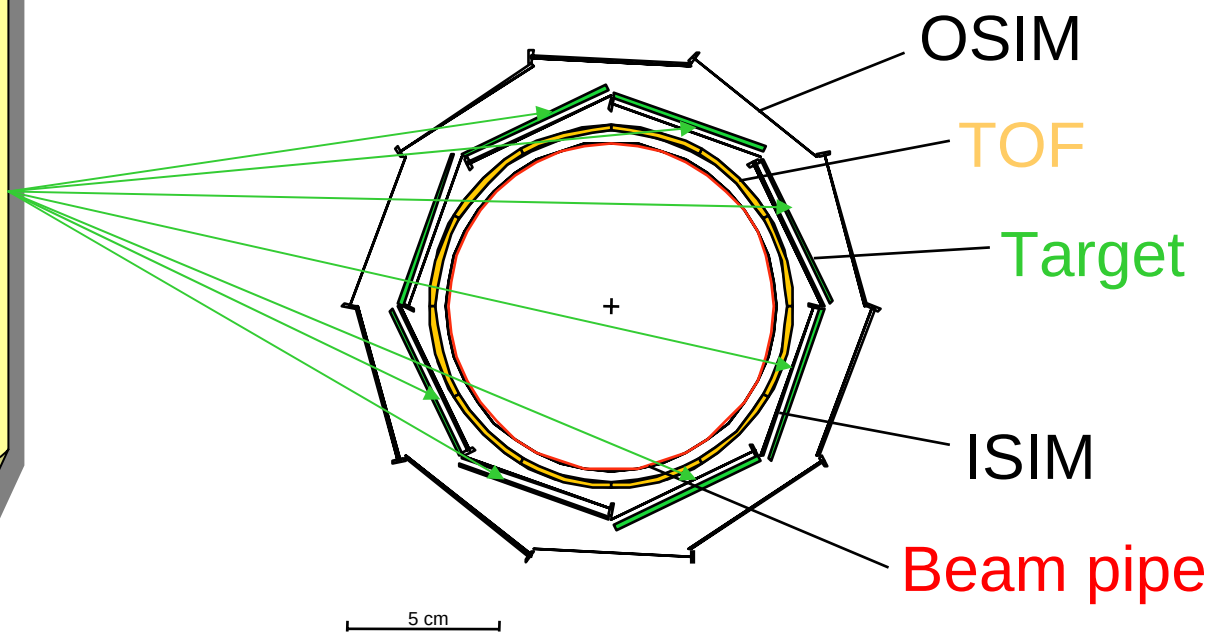


Target set-up

2003 Data Taking
250 pb^{-1} assigned

FINUDA

- 2 ^{6}Li
- 1 ^{7}Li
- 3 ^{12}C
- 1 ^{27}Al
- 1 ^{51}V



^{12}C targets are necessary for detector performance tuning and decay mode studies.

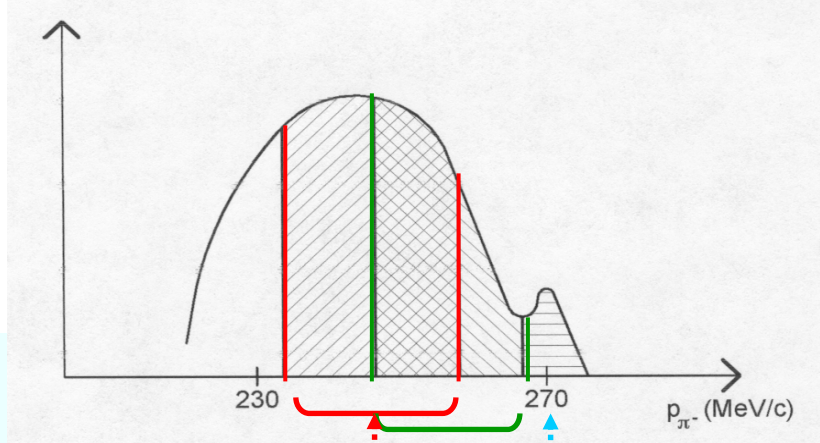
^{27}Al and ^{51}V are medium-heavy nuclei that will be used for spectroscopic studies

^{6}Li and ^{7}Li are source of light hypernuclei

Light hypernucleus spectroscopy

Spectroscopized

π^-



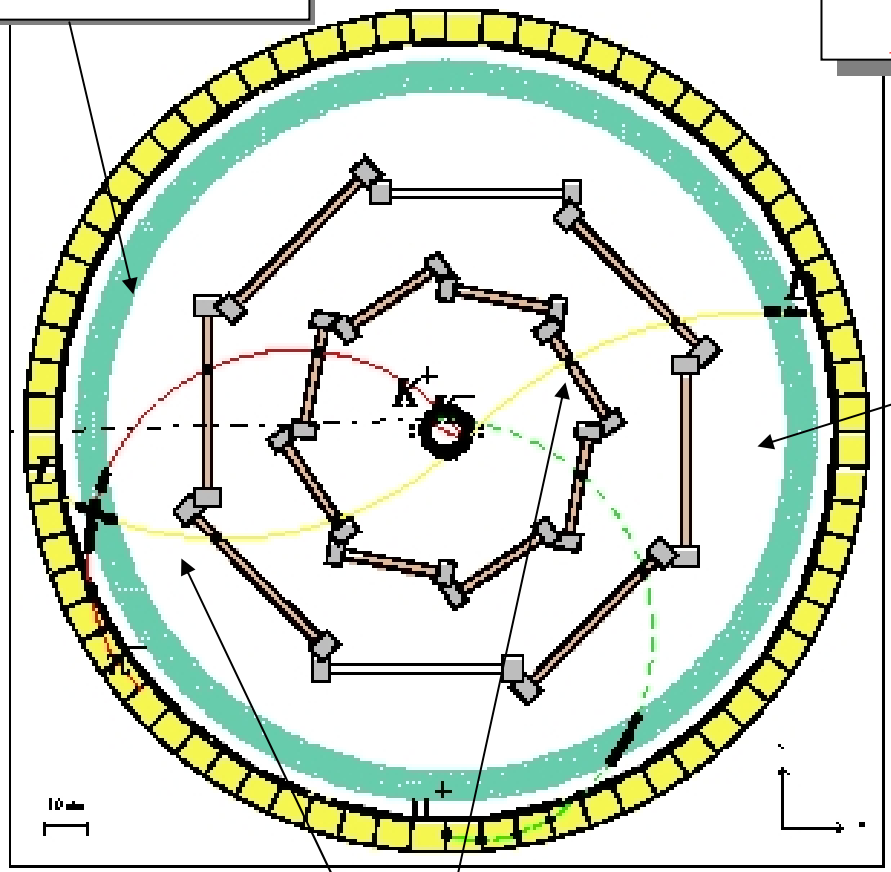
$K^- + {}^6Li \rightarrow \pi^- +$

- ${}^5_\Lambda He + p$
  - 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.** (~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}**) **how distinguishable?**
- ${}^4_\Lambda H + p + p$
  - ^{4}He+ π^- spectr. (10^2/pb^{-1}) calibration

${}^6_\Lambda Li$ is unstable by nucleon emission

π^- is tracked

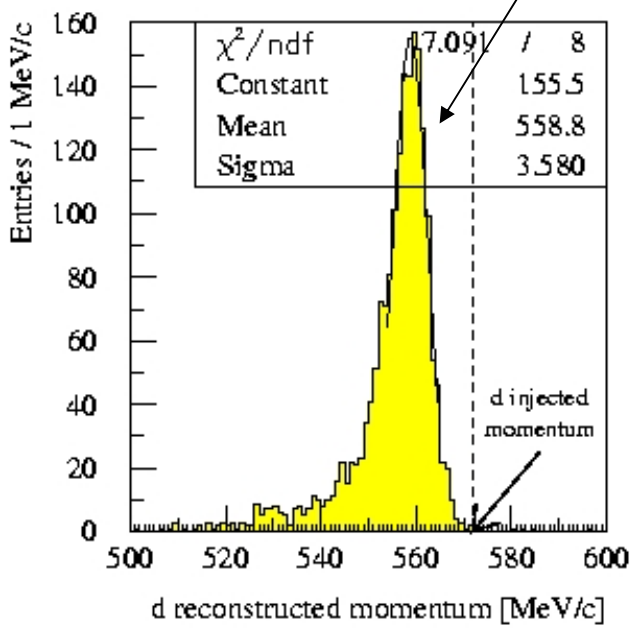
${}^{4}_{\Lambda}\mathrm{He} \longrightarrow \mathrm{d} + \mathrm{d}$ decay



π^- and 1(2) d are measured in coincidence

both d are tracked

forward d



Acceptance 32%
Momentum resolution 2% (at 570 MeV/c)
TOF resolution 500 ps (fwhm)

Neutron rich hypernuclei

by product

$K^-_{stop} + p \rightarrow \Lambda + \pi^0$

$\pi^0 + p \rightarrow \pi^+ + n$

two steps

$K^-_{stop} + p \rightarrow \Sigma^- + \pi^+$

$\Sigma^- + p \rightarrow \Lambda + n$

FINUDA can detect the π^+

KEK

only upper limits were set for neutron rich production

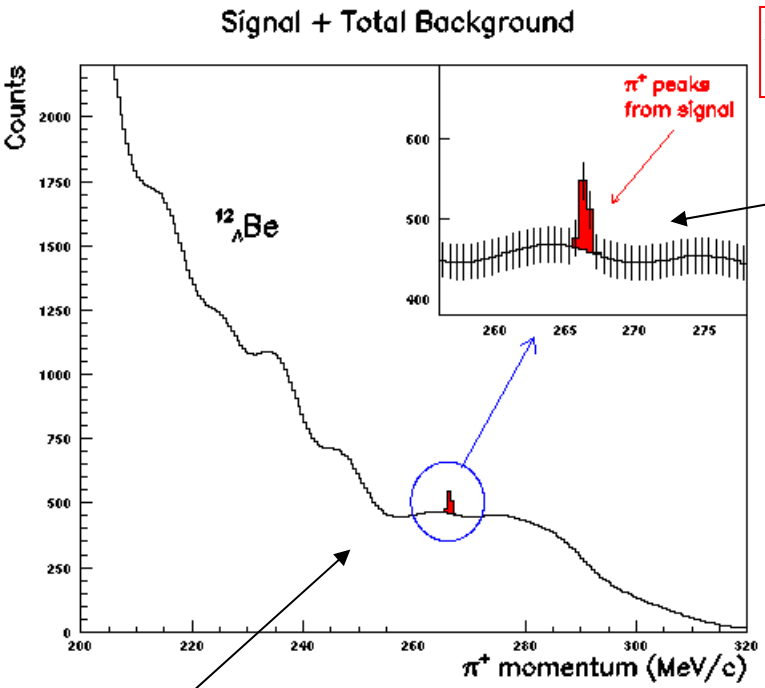
in the ground state

Targets	Hypernuclei	Probability per K^-_{stop}
^{9}Be	$^{9}_{\Lambda}$He	$< 2.3\times10^{-4}$
^{12}C	$^{12}_{\Lambda}$Be	$< 6.1\times10^{-5}$
^{16}O	$^{16}_{\Lambda}$C	$< 6.2\times10^{-5}$

Main background from $K^- p \rightarrow \Sigma^+ \pi^-$

$\rightarrow n \pi^+$

Neutron rich hypernuclei in FINUDA

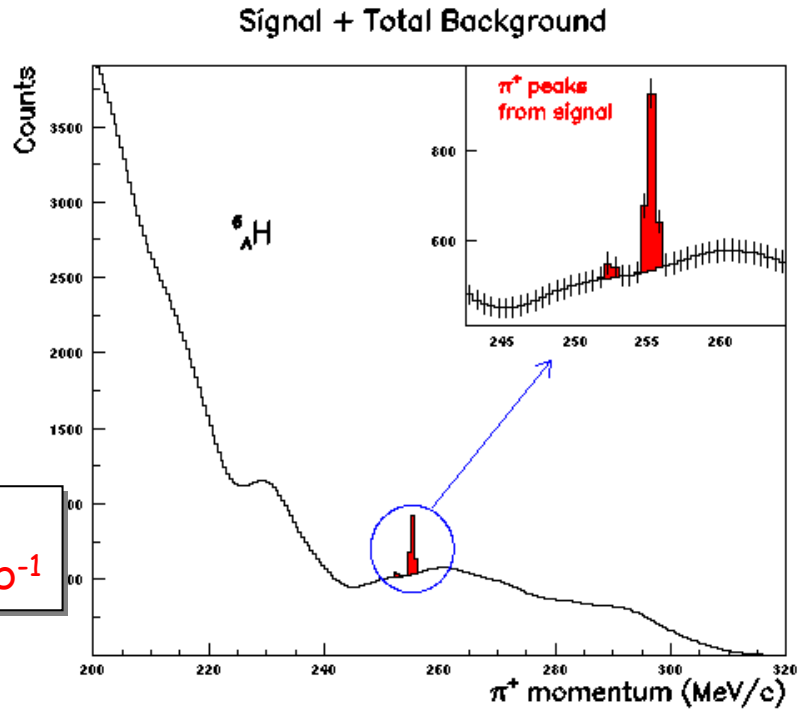


$^{12}C\left(K_{stop},\pi^{+}\right)^{12}_{\Lambda}Be$

Formation probability[1]: 1.8 10^{-5}
80 events with 3 ^{12}C targets: 55 pb^{-1}

(1) Nucl.Phys. A691 (2001) 51c

Σ^{+} decay background



$^{6}Li\left(K_{stop},\pi^{+}\right)^{6}_{\Lambda}H$

Formation probability[2]: 1. 10^{-4}
500 events with 2 ^{6}Li targets: 90 pb^{-1}

(2) Not unreasonable guess

Rates and integrated luminosity

Expected integrated luminosity from DAΦNE : >2 pb^{-1}/day

High resolution hypernuclear spectroscopy

54 $Hz_{[K^+ K^-]}$ • 0.13 $_{[\text{trig. and forward } \pi^- \text{ rec. eff.}]}$ • 10^{-3} $_{[\text{cap. rate}]}$ = 25 ev/h

Good spectroscopic studies on ^{12}C, ^{27}Al, ^{51}V and ^{7}Li can be performed with ~50 pb^{-1} ~30 days

Non mesonic decay

- 10^{-3} ground level capture rate with 8 targets
- pn and nn events in coincidence escaping FSI

0.15 pn detected events/h
0.04 nn detected events/h

To get a statistical error of 10% on Γ_{np} and Γ_{nn} on $_{\Lambda}{}^{5}He$ with 2 ^{6}Li targets we need
100 pn events ~ 75 pb^{-1}
80 nn events ~ 250 pb^{-1}

Highlights for the continuation of the program beyond 2003

Expected beam allocation in 2004 and 2005:
$\mathcal{L}_{int}$ = 500-700 pb^{-1}

Continuation on the survey of spectroscopy and decays with targets:

^{9}Be ^{16}O ^{28}Si ^{40}Ca (^{48}Ca) ^{55}Mn
^{89}Y ^{98}Nb ^{133}Cs ^{139}La ^{165}Ho ^{209}Bi

- probably not all of them, but a ''reasonable'' selection, following the results of the 2003 run, in particular for the medium-A targets

and/or

- strong effort on particular targets if exciting results will be found (like neutron-rich $^{6}_{\Lambda}$H and $^{7}_{\Lambda}$H with ^{6}Li and ^{7}Li targets)
- The decision will depend also on the expected increase in luminosity, from ~10^{32} cm^{-2} s^{-1} to ~ 5 10^{32} cm^{-2} s^{-1}

Conclusions

We wish that the strong effort made at
DAΦNE on Hypernuclear Physics
with the ambitious research program of the
FINUDA experiment,
could properly celebrate the
50th anniversary
of the discovery of Hypernuclei

The FINUDA Collaboration

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