DAΦNE hypernuclear physics program

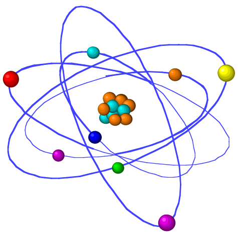
International Workshop
on
the Spectroscopy of Hypernuclei

Tohoku University,
Sendai, Japan,
January 8 - 10, 1998

Alessandro Feliciello / I.N.F.N. - Sezione di Torino

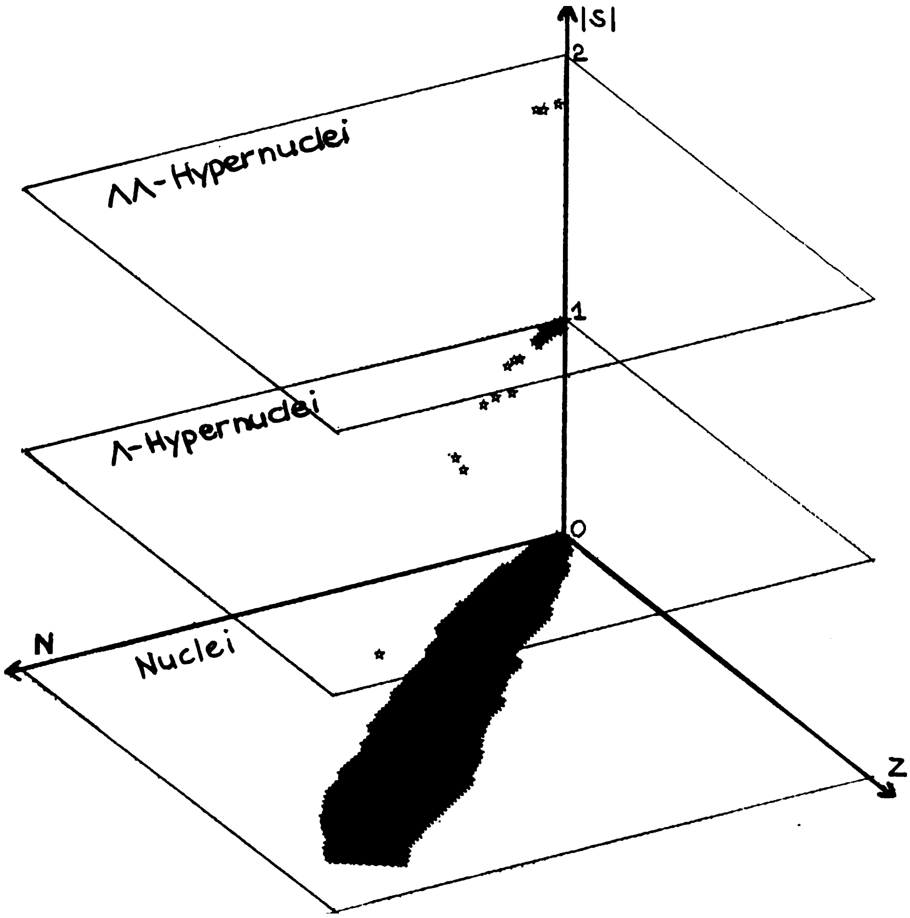
Summary

- Introduction
- The DAΦNE project
- The experiments:
  - KLOE
  - FINUDA
  - DEAR
- The FINUDA apparatus
- The FINUDA physics program
- Conclusions

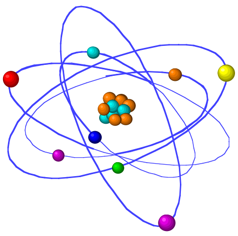


The hypernuclear physics realm

The strangeness adds a new dimension
to the nuclear physics picture



The nucleus can be regarded as a
"clean laboratory" for the
YN interaction study



Present experimental programs

Λ-hypernuclear physics is a field with a considerable and exciting discovery potential

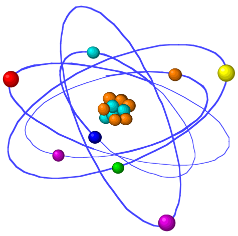
- KEK

  (π^+, K^+), $(K\ , \pi)$
- BNL

  $(K^-_{\text{stop}}, \pi^0)$, (π^+, K^+)
- TJNAF

  $(e, e'K^+)$, (γ, K^+)
- INFN - LNF

  (K^-_{stop}, π)

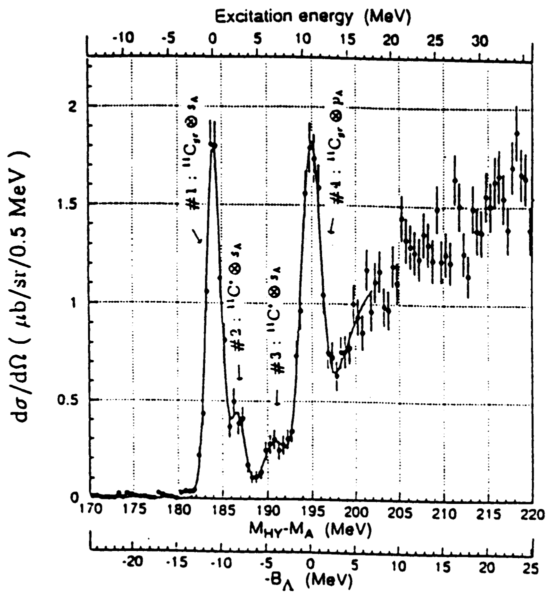


Present experimental limits

✦ limited energy resolution on hypernuclear levels (~ 2 MeV)

(π^+, K^+), (K^-, π^-)

- huge targets used to obtain a reasonable event rate (thickness ~ g/cm^2)



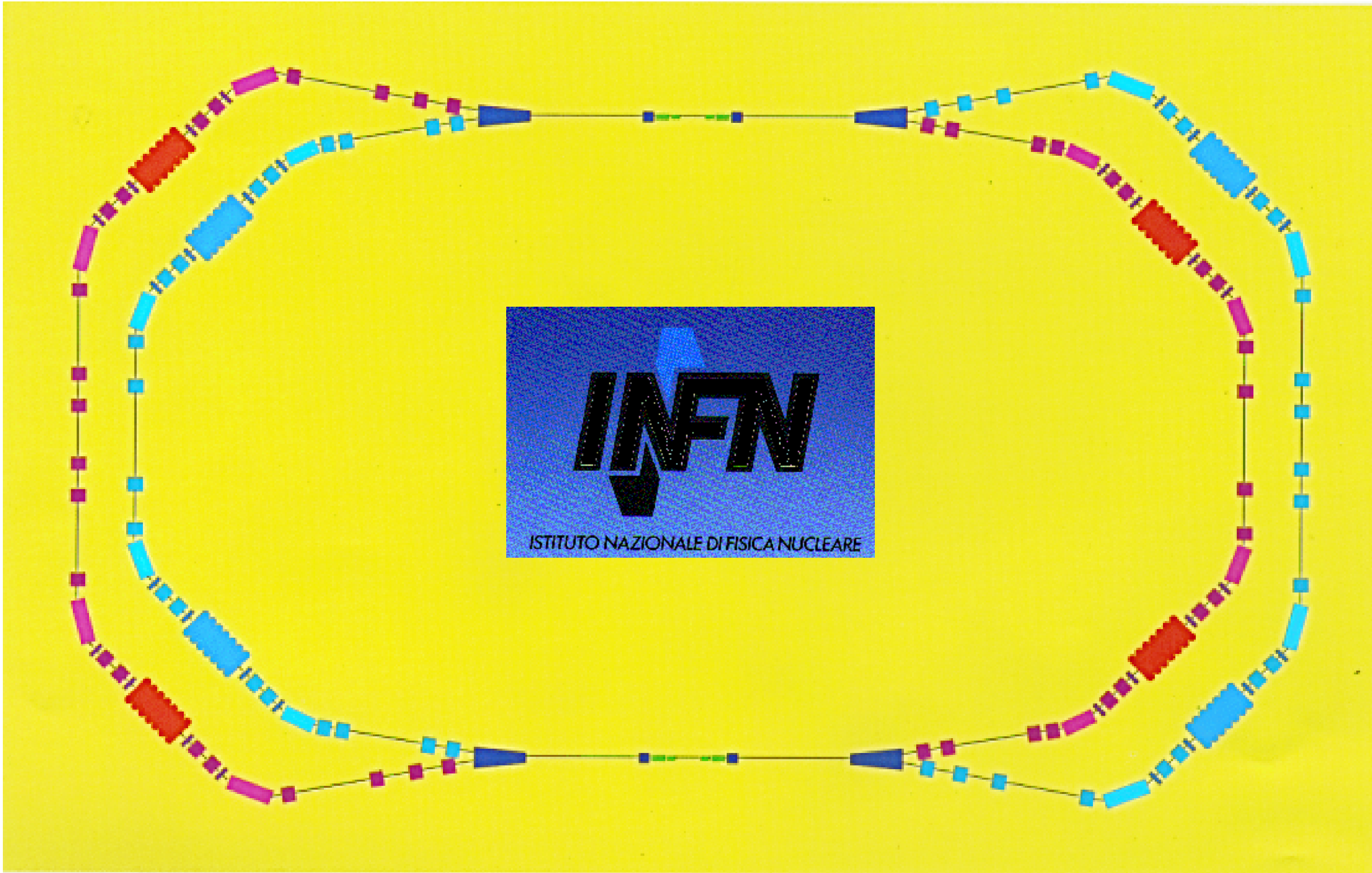
T. Hasegawa *et al.*, INS-Rep. 1037, University of Tokyo, 1994

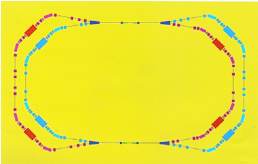
(K^-_{stop} , π^-)

- poor energy resolution of K^- beams ($\Delta p/p$ ~ 5 - 6 % at p 400 - 600 MeV/c)
- huge targets used to stop such "fast" K^- (thickness ~ g/cm^2)

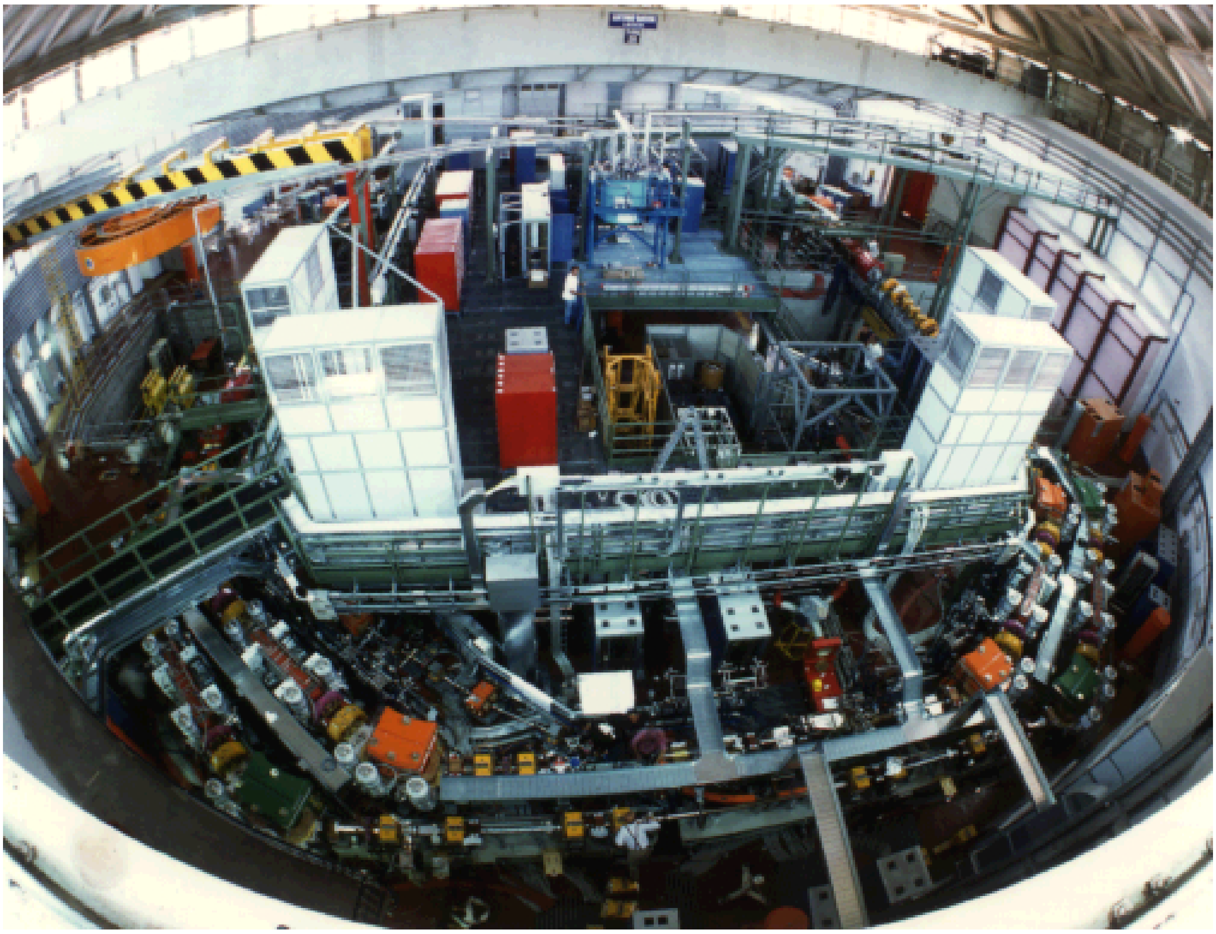
✦ limited statistics

The DAΦNE project

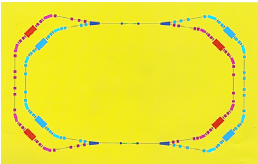




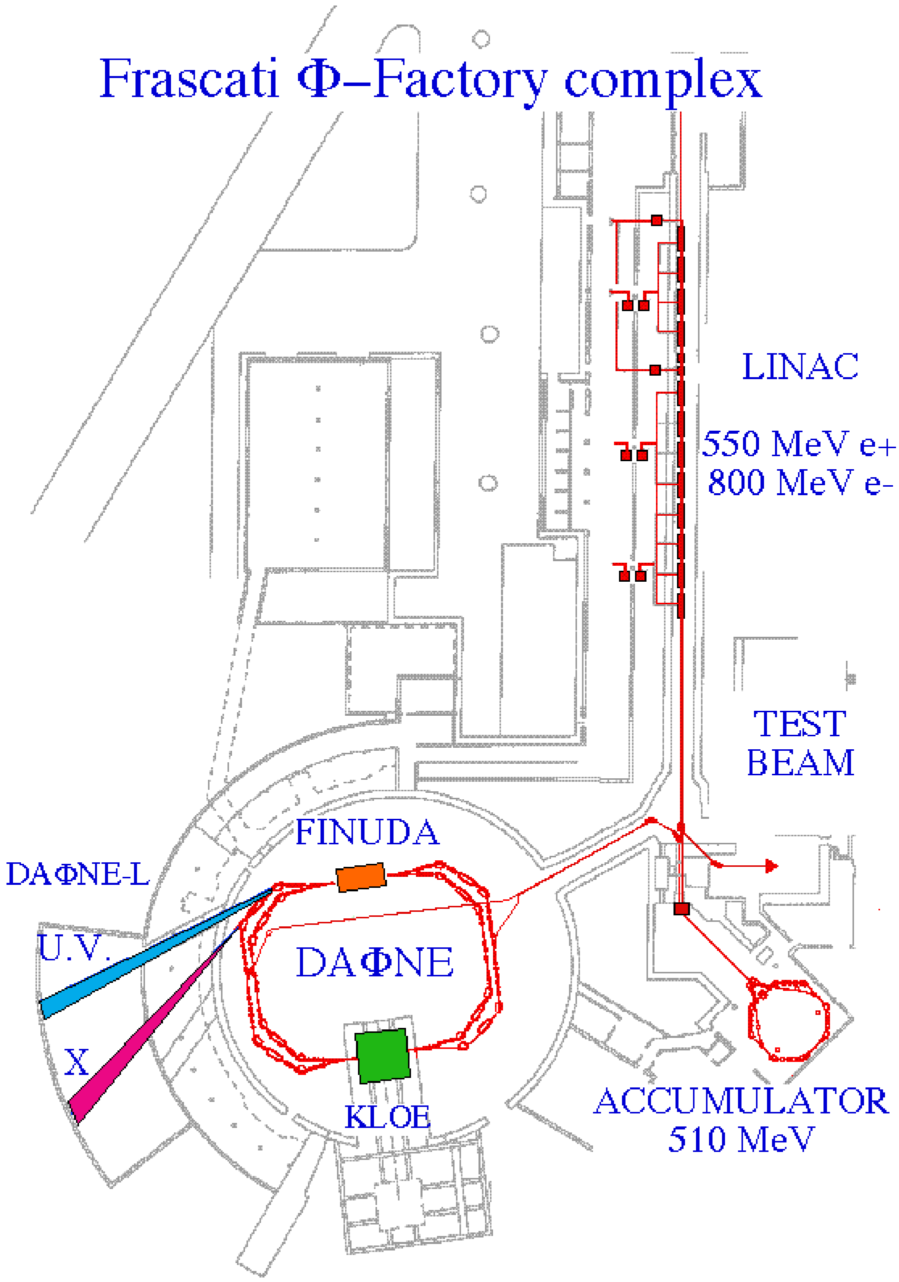
DAΦNE

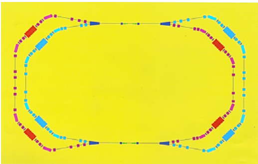


- approved in June, 1990
- first electron beam stored in main ring on October 25, 1997
- first positron beam stored in main ring on November 22, 1997



The DAΦNE machine complex



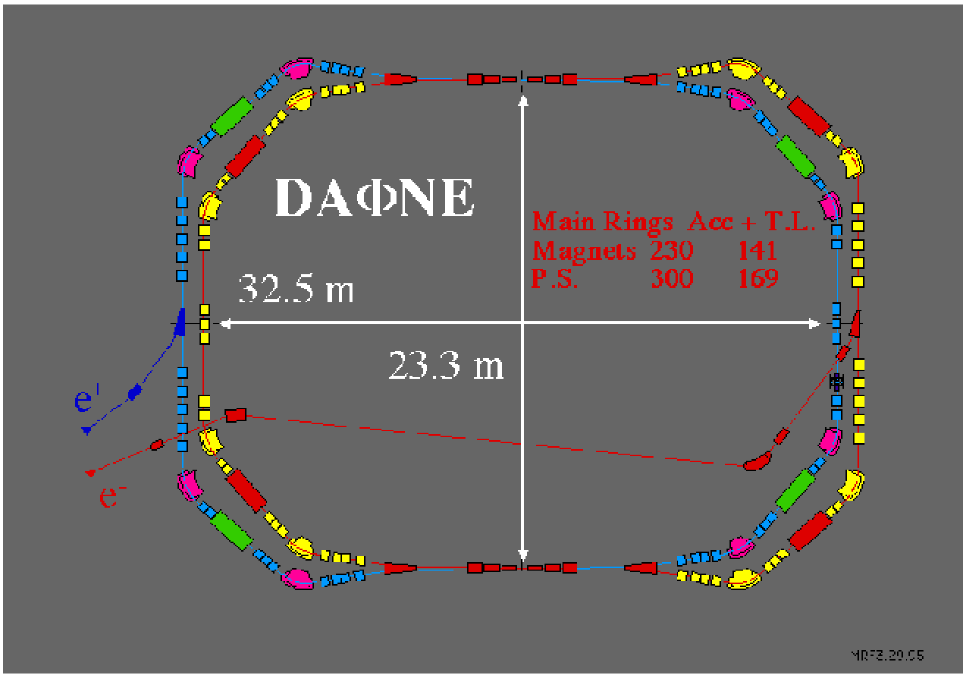


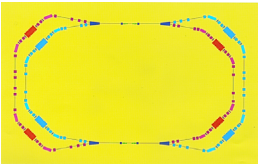
How to reach the goal luminosity $\mathcal{L} \approx 5 \times 10^{32}\ cm^{-2}\ s^{-1}$

2 basic alternatives:

- small ring footprint and few bunches
  - ▲ attractive from the accelerator physics point of view
  - ▲ lower cost
  - ▼ very high single bunch luminosity (!?!)

- large ring footprint and many bunches
  - ▲ conventional technologies
  - ▲ more reliable



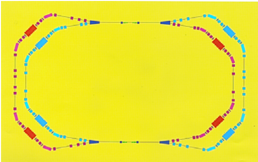


DAΦNE features

- e^+ and e^- circulate in 2 separate rings, ~ 100 m long, and collide at a horizontal half-angle

$$\vartheta_x = 10 - 15 \text{ mrad}$$

- high collision frequency, without parasitic crossing
- 4-period modified Chasman-Green type lattice
- crab-crossing option
- "low β" insertions carefully designed, because of 2 constraints:
  - large, unencumbered solid angle around the interaction point (IP)
  - horizontal separation required at short distance from IP, to allow for short bunch-to-bunch longitudinal distance



DAΦNE potentialities

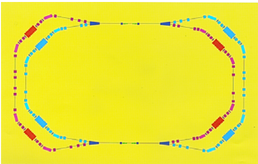
At $\mathcal{L} = 5 \times 10^{32}\ \mathrm{cm^{-2}s^{-1}}$,
in a 10^7 s year, we will have
a production of $\sim 22 \times 10^9\ \phi$

Considering the ϕ decay,
with their branching ratios, we will obtain:

decay mode	B.R.	events per year
$\phi \to K^+K^-$	0.495	1.1×10^{10}
$\phi \to K_L K_S$	0.344	7.6×10^9
$\phi \to \gamma\eta$	0.012	2.8×10^8
$\phi \to \gamma\eta'$	$< 10^{-3}$	—

Hence DAΦNE can be regarded also as:

- a remarkably good *K*-factory
- a good η-factory
- an interesting source of η' and *gluons* (hopefully)



Possible high-statistics and high-precision "nice experiments"

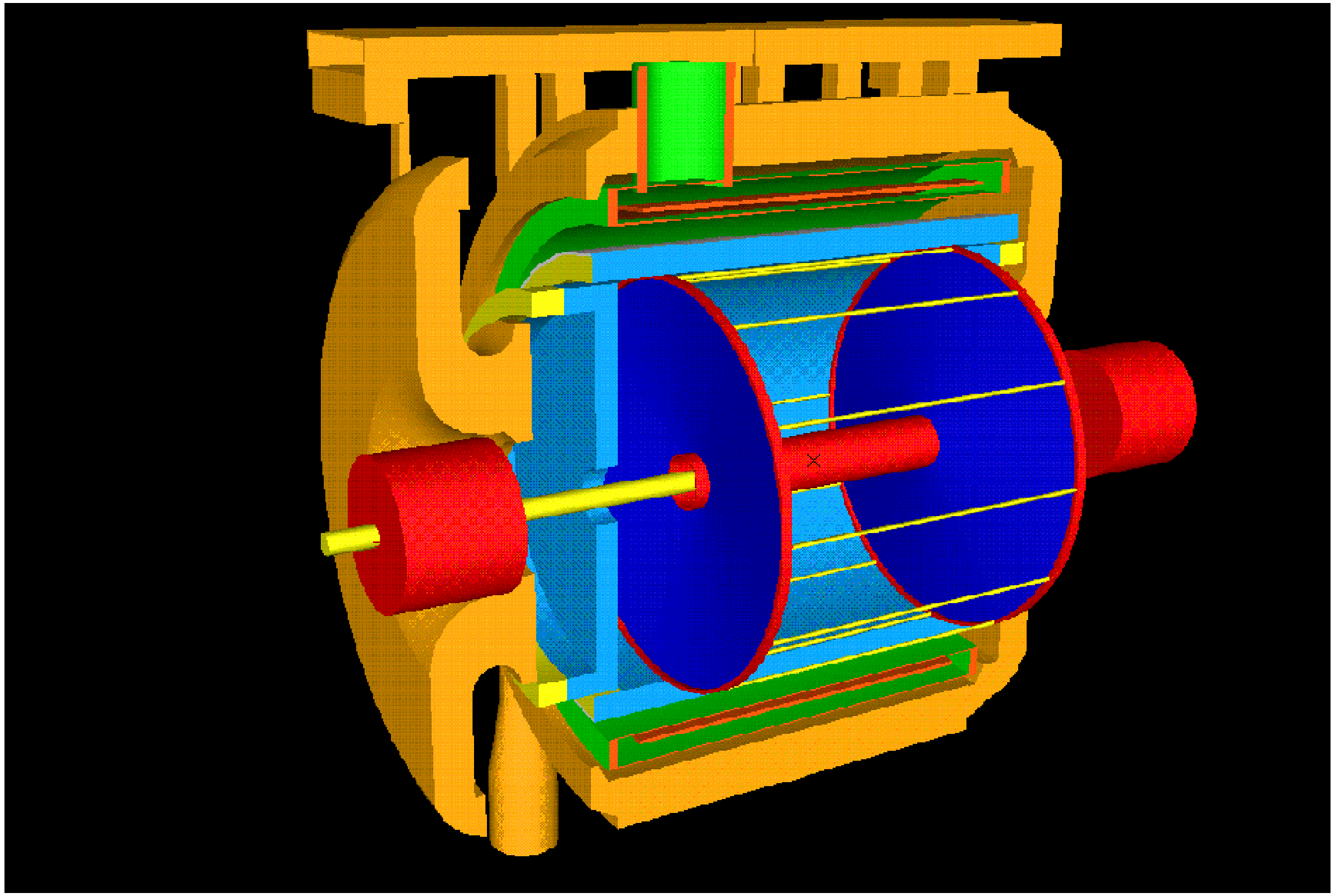
- CP, CPT physics
- hypernuclear physics
- *K* decays
- ϕ decays and quantum mechanics
- one photon processes
- radiative ϕ decays
- low energy *KN* interaction
- spectroscopy issues above ϕ
  (in the prospect of an energy upgrade of the machine)

Double
Annular
Φ-factory for
Nice
Experiments

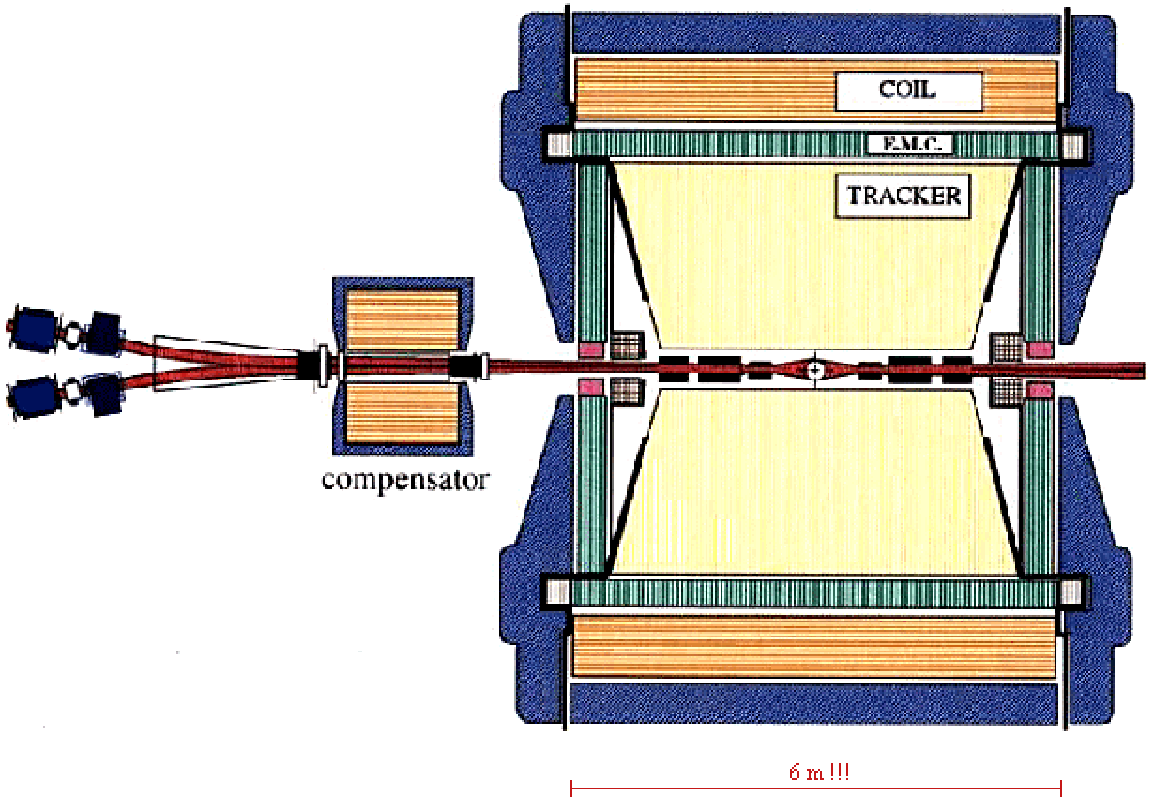
The KLOE experiment

- ★ *Bari University and I.N.F.N.*
- ★ *Roma Istituto Superiore di Sanità and I.N.F.N.*
- ★ *I.N.F.N. Frascati National Laboratories*
- ★ *Lecce University and I.N.F.N.*
- ★ *Napoli University and I.N.F.N.*
- ★ *Pisa University and I.N.F.N.*
- ★ *Roma "La Sapienza" University and I.N.F.N.*
- ★ *Roma "Tor Vergata" University and I.N.F.N.*
- ★ *Roma III University and I.N.F.N.*
- ★ *Trieste University and I.N.F.N.*
- ★ *Udine University and I.N.F.N.*
- ★ *Columbia University, New York*
- ★ *IEKP, Universität Karlsruhe*
- ★ *IHEP, Institute of High Energy Physics, Academia Sinica*
- ★ *ITEP, Institute of Theorethical and Experimental Physics, Moscow*
- ★ *SUNY, at Stony Brook*
- ★ *Tel Aviv University, School of Physics and Astronomy*
- ★ *Ben Gurion University*
- ★ *University of Virginia, Physics Department*

The KLOE apparatus



The KLOE apparatus



The KLOE detector

standard, 4π, general purpose collider apparatus

- large (~ 6 × 6 ×6 m^3) cylindrical structure
- high resolution
- minimum bias

tracking device ➡ drift chamber (Ø = 4 m, L = 3.5 m)

- large fiducial volume for K_L decays

  30 cm < r < 150 cm   -150 cm < z < 150 cm

  (35% of all K_L are expected to decay in it)

- very light mechanical structure:

  8 mm Carbon fiber

- operated with a Helium-based gas mixture
- good spatial resolution:
  $\sigma_{\rho,\phi} \approx 200\ \mu m, \sigma_z \approx 3$ mm
- high *p* resolution: $\Delta p_t/p_t \approx 2.5\ 10^{-3}$

  (at 220 MeV/*c*)

- high reconstruction efficiency: ≥ 98%

The KLOE detector

e.m. calorimeter ➡ lead-scintillator sampling

- exceptional timing ability $\sigma_t = 50\ \mathrm{ps}/\sqrt{E_{[GeV]}}$
- good efficiency (> 99%) and
  good energy resolution $\sigma_E/E = 4.5\%/\sqrt{E_{[GeV]}}$
  for γ down to 20 MeV
- good space resolution:
  $\sigma_{x,y} \approx 0.5\ \mathrm{cm}/\sqrt{E_{[GeV]}}$, $\sigma_z \approx 2$ cm
- true hermetic device: $\Delta\Omega/4\pi = 0.99$
- good particle identification

magnetic field ➡ superconducting solenoid

- 0.6 T uniform field in a ~ 76 m^3 volume

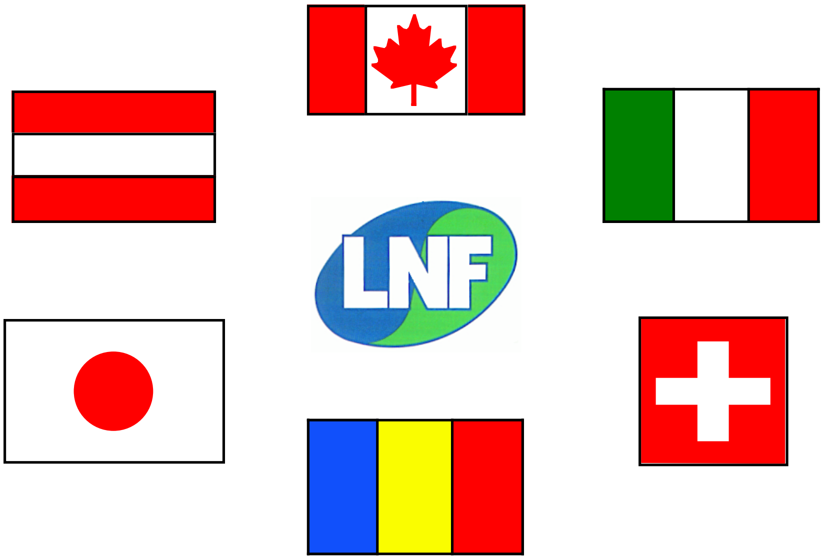
beam pipe ➡ beryllium (0.5 mm)

- low mass to minimise: multiple scattering
  $K^{\pm}$ energy loss
  K regeneration
- proper design to define a fiducial region
  for K_s decays

... other physics topics

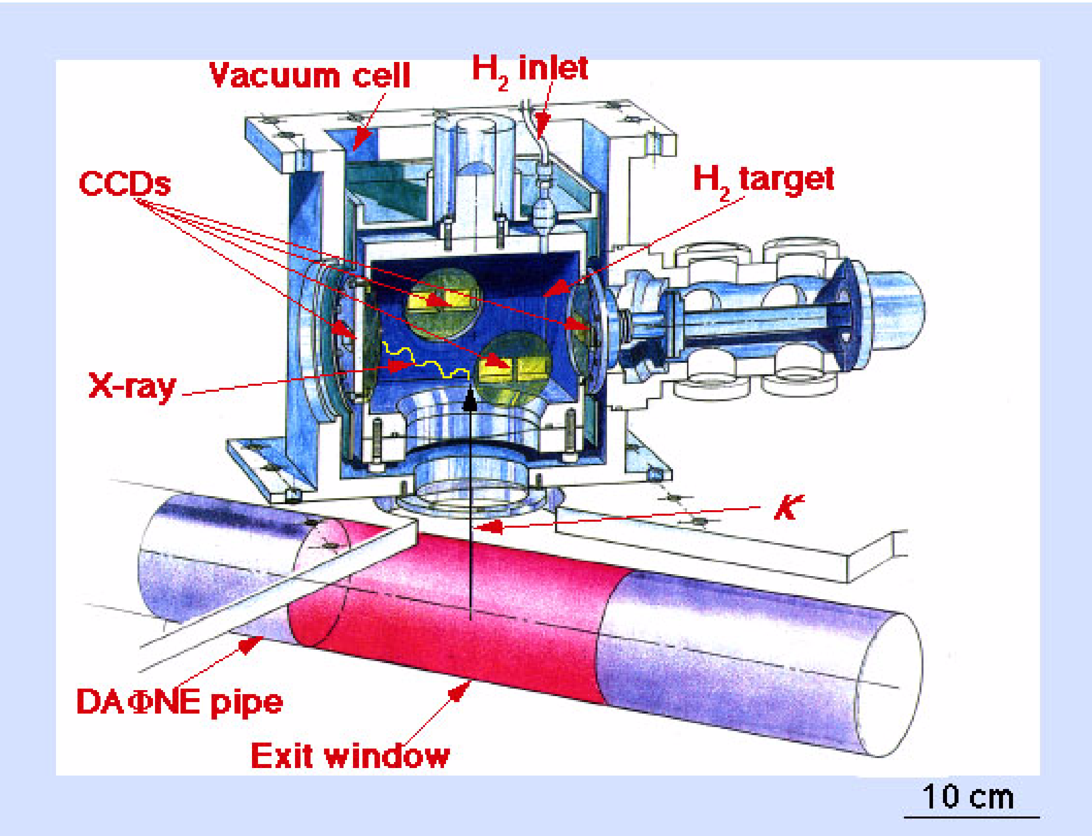
- searches for CP violation in $K_s \to 3\pi^0$
- radiative ϕ decays
  ($a_0(980)$ and $f_0(970)$ puzzle)
- e^+e^- annihilation into hadrons
  from threshold to 1.5 GeV
- rare K decays
- K^- mesons and the Chiral Lagrangian
- rare η and π^0 decays
- test of Quantum Mechanics

The DEAR experiment



- I.N.F.N. Frascati National Laboratories
- Trieste University and I.N.F.N.
- Fribourg University
- Neuchatel University
- Institute for Medium Energy Physics, Vienna
- Institute of Physics and Nuclear Engineering "Horia Hulubei", Bucharest
- Institute of Physical and Chemical Research (RIKEN), Saitama
- Hokkaido University
- Tokyo University
- Tokyo Institute of Technology
- KEK, High Energy Accelerator Research Organisation, Tokyo
- Victoria University

The DEAR experiment



"The most important experiment to be carried out in low energy K-meson physics today is the definitive determination of the energy level shift in K p and K d atoms, because of their direct connection with the physics of the KN interaction and their complete independence of all other kind of measurements which bear on this interaction"

R.H. Dalitz

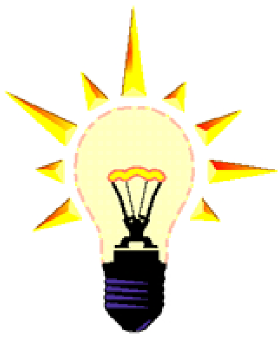
The FINUDA experiment

- ★ ***Bari University and I.N.F.N.***
- ★ ***Brescia University***
- ★ ***I.N.F.N. Frascati National Laboratories***
- ★ ***Pavia University and I.N.F.N.***
- ★ ***Torino University, Politecnico, C.N.R. and I.N.F.N.***
- ★ ***Trieste University and I.N.F.N.***
- ★ ***TRIUMF, Vancouver***
- ★ ***Victoria University***
- ★ ***Shahid Beheshty University, Teheran***

Why a nuclear physics experiment at a collider?

The K^- from ϕ decay present
a series of unique properties:

- nearly monochromatism ($p \sim 127$ MeV/c)
- no contamination
- low energy (~ 16 MeV)
  - range ~ 1 g/cm^2
  - straggling on range ~ 50 mg/cm^2
- possibility of tagging by means of K^+



They represent an ideal tool for
high-resolution hypernuclear
spectroscopy with stopped K

Hypernuclei production

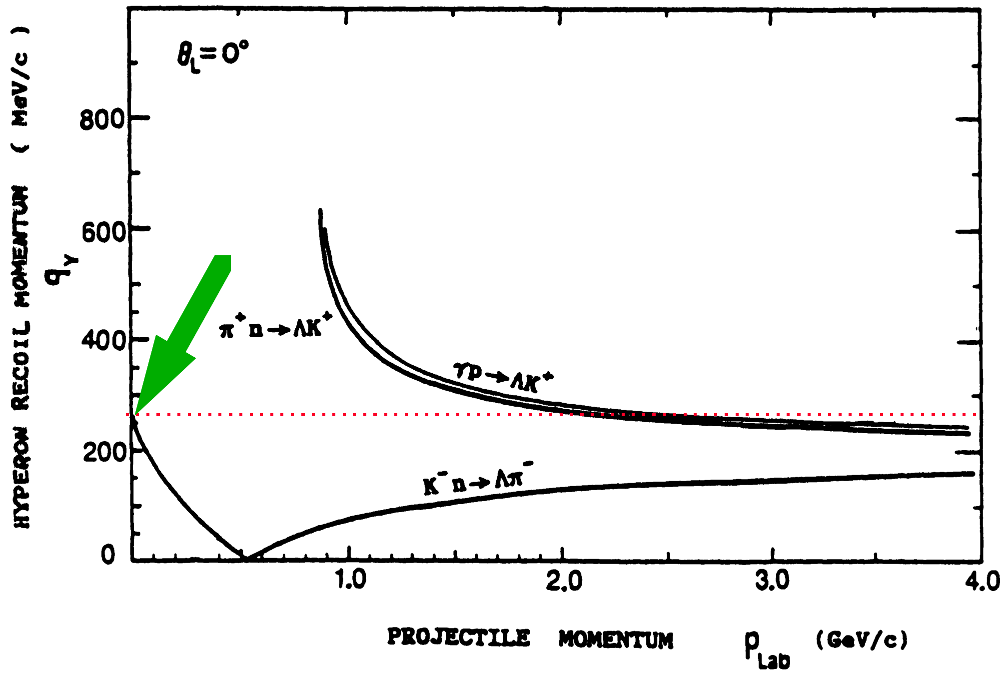
The formation reaction allows to combine the advantages of strangeness exchange and associated production reactions:

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

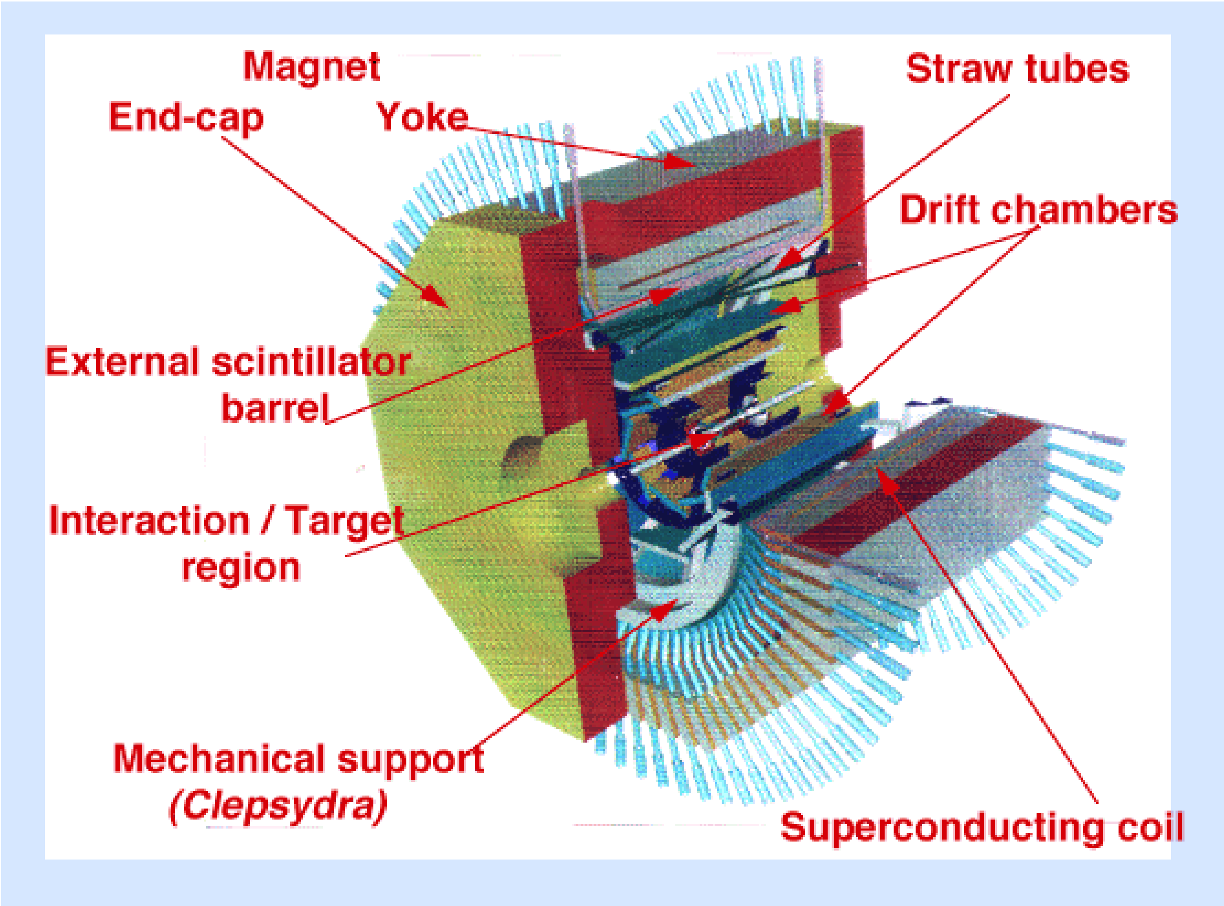
($250\ \mathrm{MeV}/c \le p_\pi \le 280\ \mathrm{MeV}/c$)

▲ same momentum transfer to Λ of associated production

▼ reasonable hypernuclear final state rate production: 10^{-3}/stopped K^-



The FINUDA apparatus



FINUDA
figures of merit

(the answer of FINUDA)

- high resolution,
  non focusing, spectrometer:
  $\Delta E \sim 700$ keV
  ($\Delta p/p \sim 3$ ‰ @ $p \sim 270$ MeV/c)

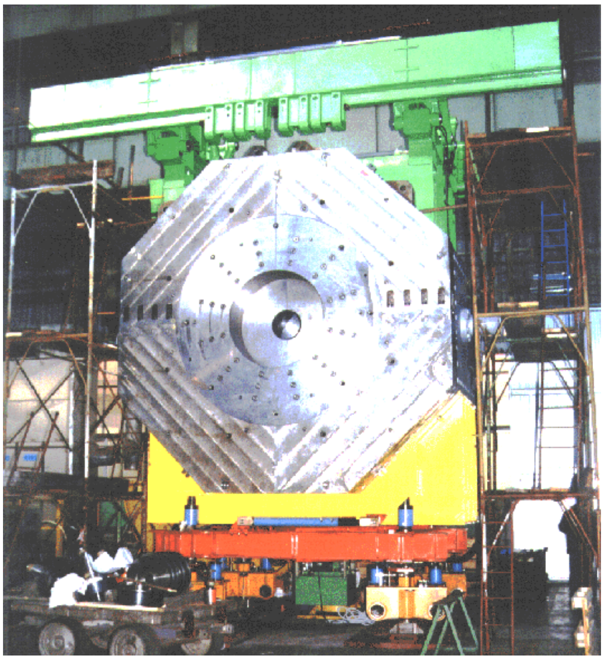
- very thin stopping targets for incident K (~ 0.2 - 0.3 g/cm^2)

- minimum amount of material along the particle trajectory
  (in order to minimise multiple Coulomb scattering)

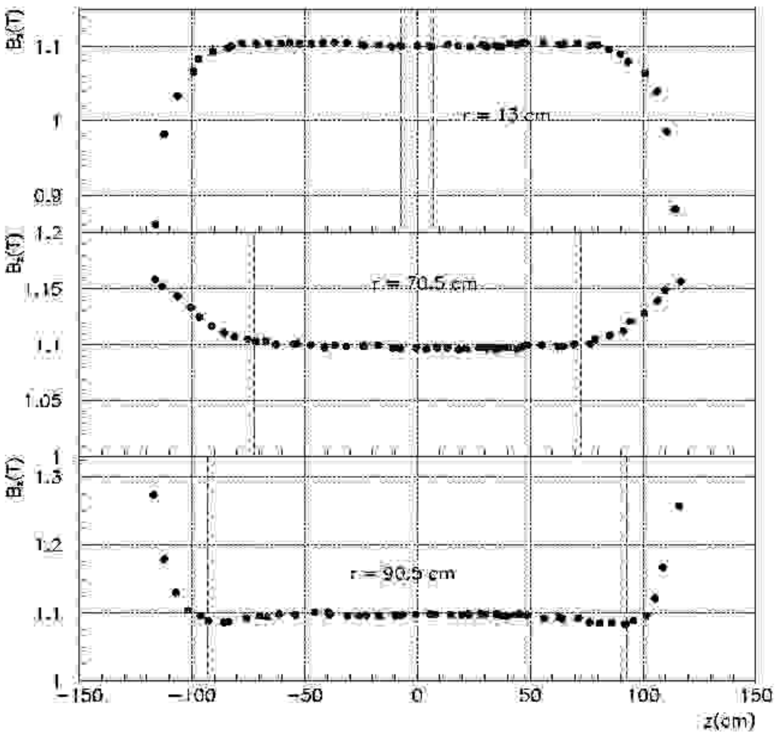
- large solid angle of acceptance for hypernuclei production: $\sim 2\pi$ sr

- large solid angle of acceptance also for mesonic and non mesonic decay products: $\sim 2\pi$ sr

The FINUDA apparatus



The apparatus is immersed into a 1.1 T solenoidal magnetic field, uniform within 1% over the tracking volume



The FINUDA apparatus

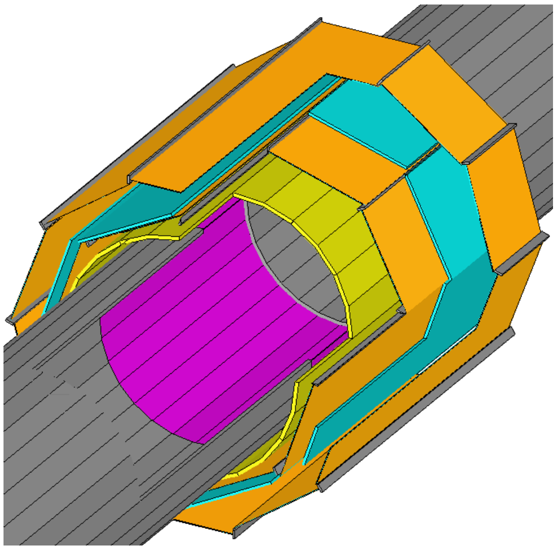
The apparatus is characterised by a
cylindrical symmetry
(like a typical collider detector)
and
it can be subdivided in
3 “logical units”:

❶ an interaction/target region

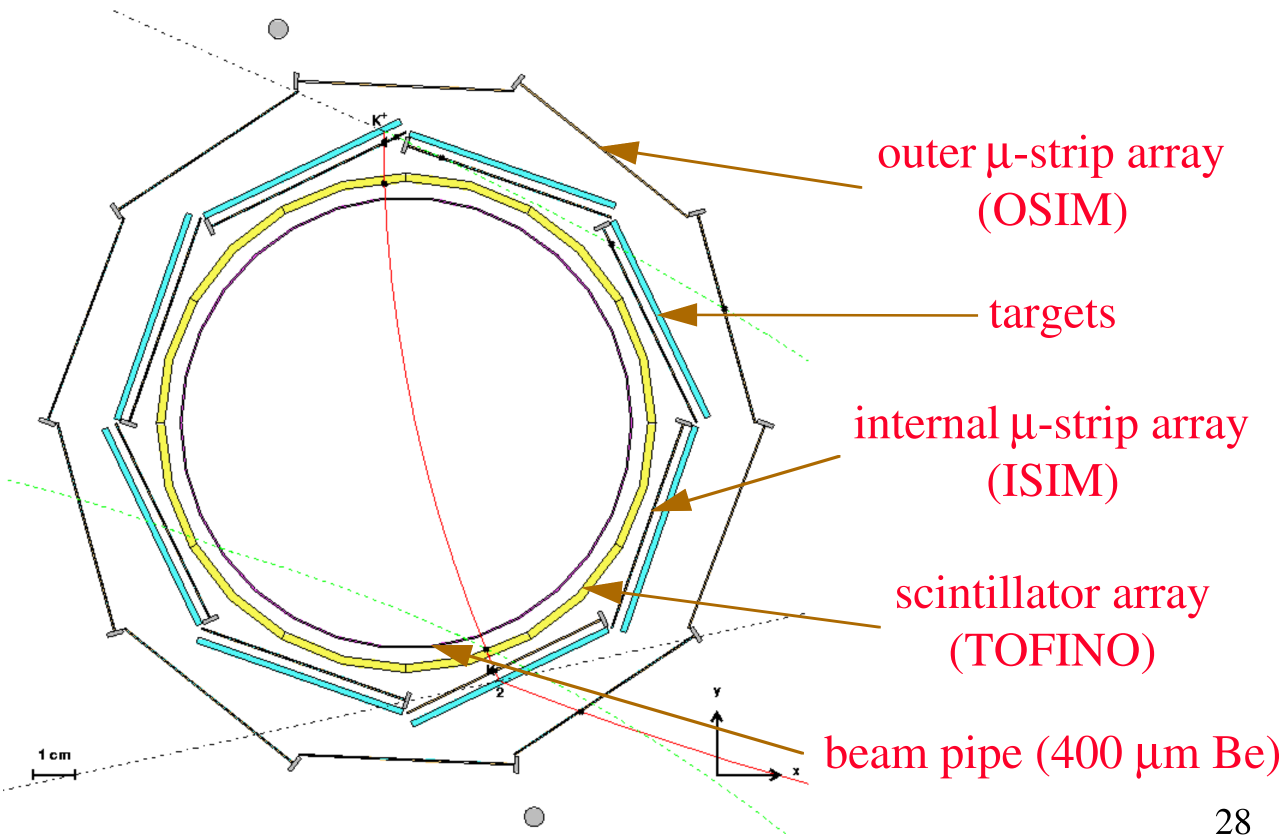
❷ a complex tracking system

❸ an outer scintillator array

The interaction / target region

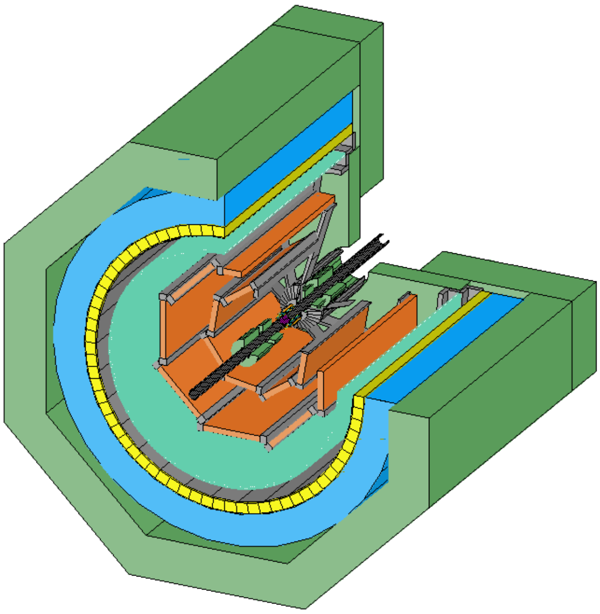


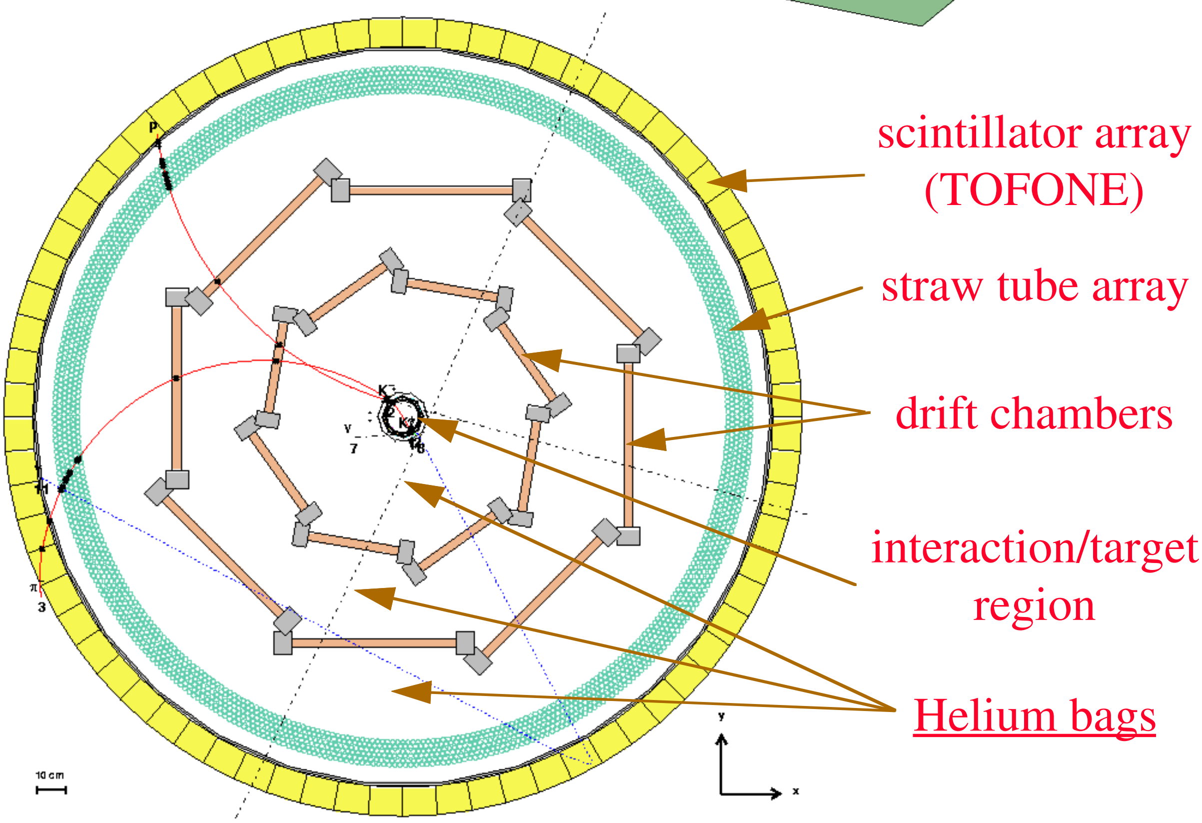
- first level trigger (based on ΔE in TOFINO)
- $K^{\pm}$ trajectories determination (ISIM)
- $K^{\pm}$ stop inside nuclear targets
- indirect determination of the K^{-} stopping point (based on ΔE in ISIM)



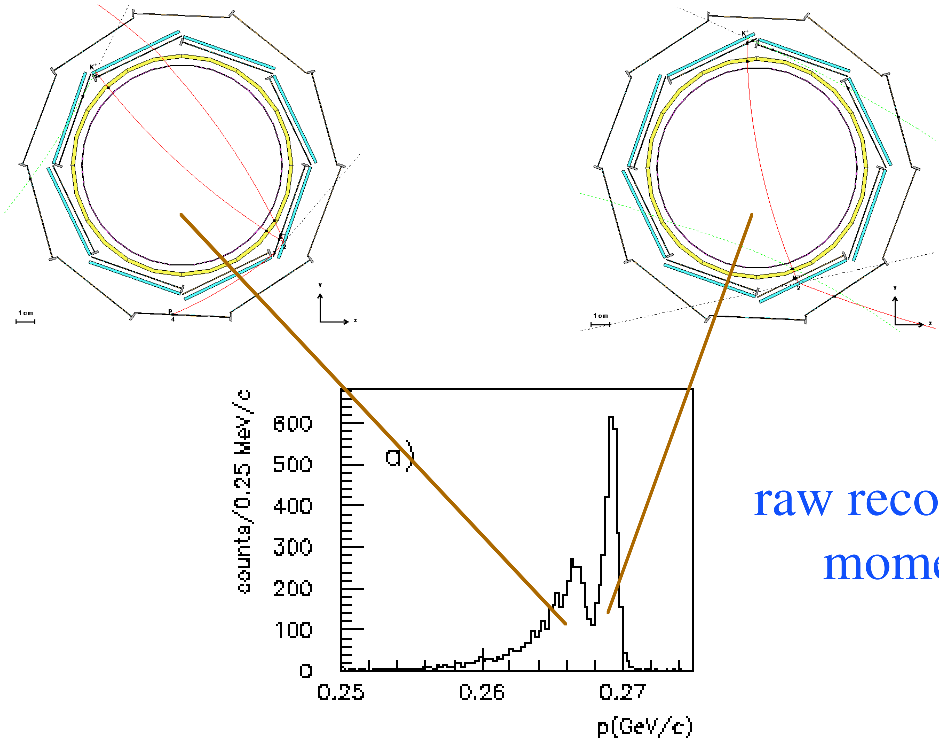
The tracking system and the outer scintillator array

- accurate measurements of the momentum of the π^- from the hypernuclei formation reaction
- accurate measurements of the particles (n, p) from hypernuclei decay

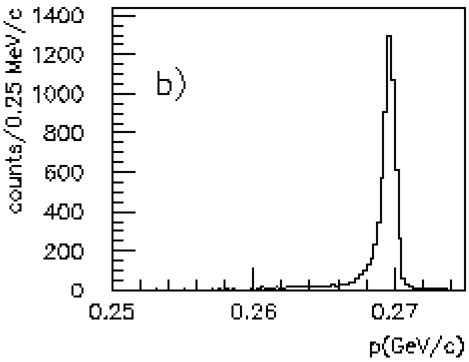




Design performances: momentum resolution



raw reconstructed momentum



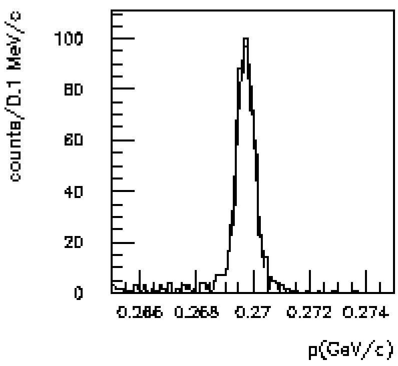
ΔE corrected momentum

$\Delta p/p$ = 3.3‰ FWHM

ΔE corrected momentum

for forward π^-

$\Delta p/p$ = 2.6‰ FWHM

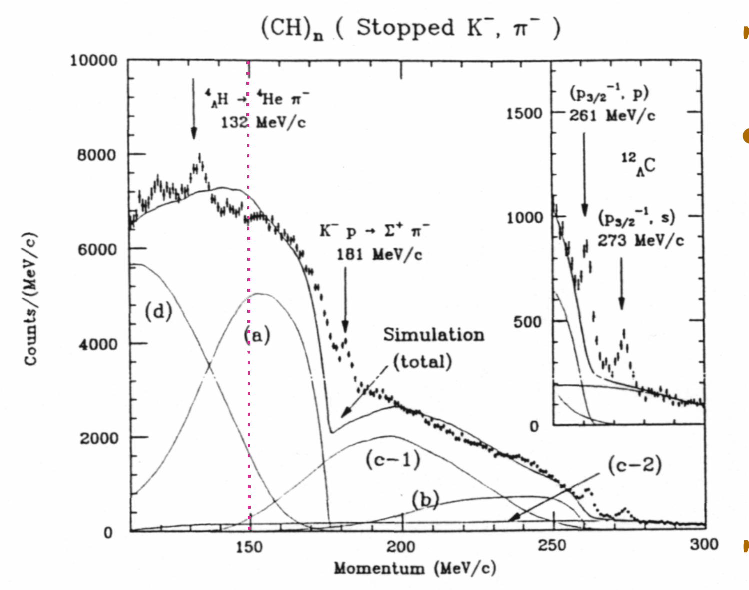


The FINUDA physics program

- High resolution Λ-hypernuclei spectroscopy
- Λ-hypernuclei lifetime
- Study of hypernuclei decays and possible violation of the $\Delta I = 1/2$ rule
- Production of hyperfragments through two-body decays
- Production of Λ-hypernuclei with a large neutron excess
- Study of K^--N scattering at low energies
- Measurement of the $K_{\mu 2}$ decay
- Search for π^+ decay mode of hypernuclei

Background suppression

(H. Tamura et al., Phys. Lett. 160 B (1985) 32)



$K^- + n \to \Lambda + \pi^-$ (b)

$\Lambda \to p + \pi^-$ (d)

$K^- + p \to \Sigma^+ + \pi^-$ (a)

$\Sigma^+ \to n + \pi^+$

$\Sigma^+ \to p + \pi^0$

$K^- + n \to \Sigma^0 + \pi^-$ (a)

$\Sigma^0 \to \Lambda + \gamma$

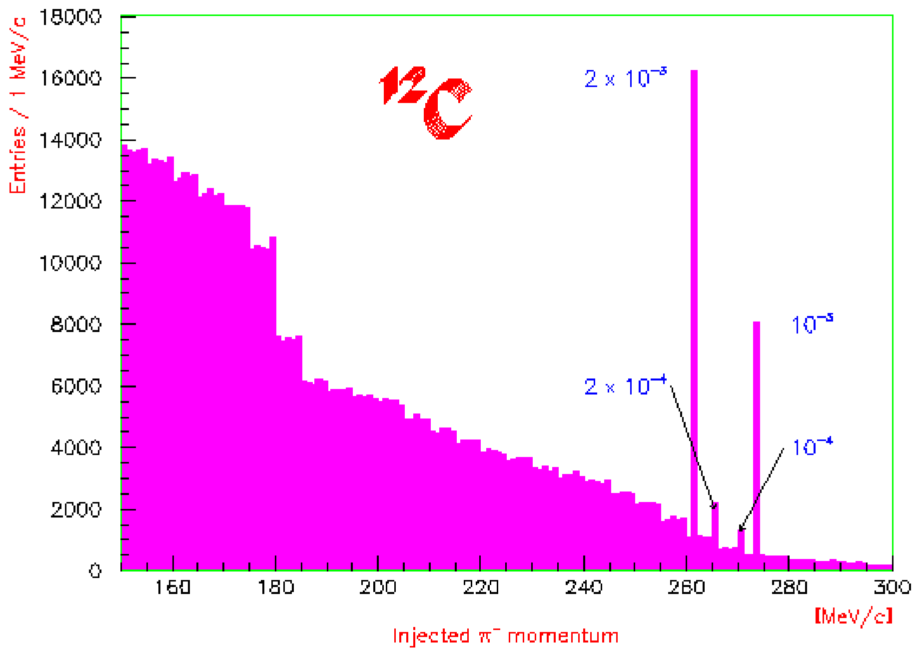
$\Lambda \to p + \pi^-$ (d)

$K^- + n \to \Sigma^- + \pi^0$

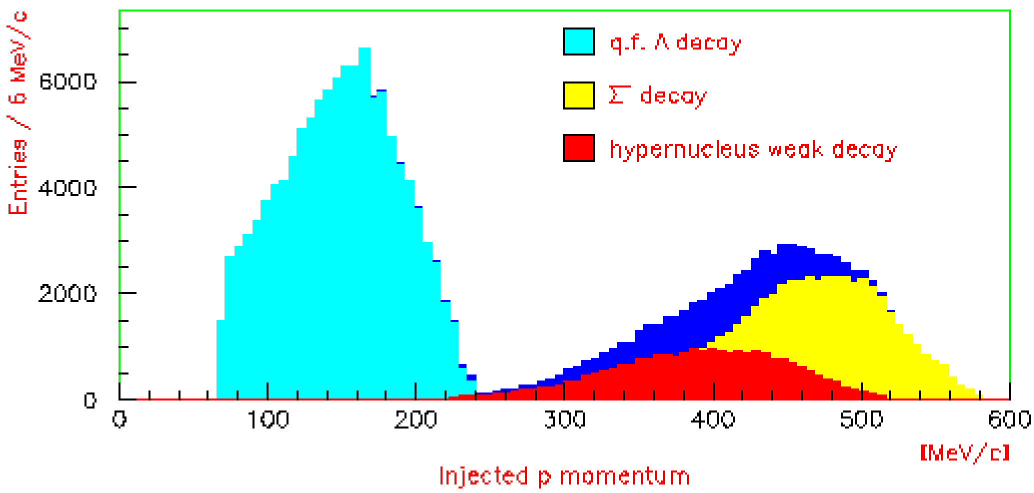
$\Sigma^- \to n + \pi^-$ (c-1)

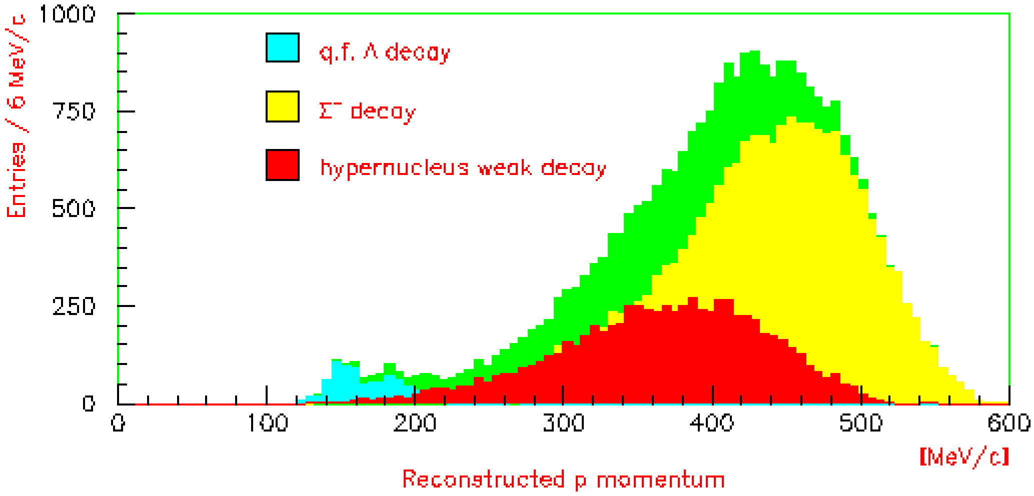
$K^- + (np) \to \Sigma^- + p$

$\Sigma^- \to n + \pi^-$ (c-2)



Background suppression





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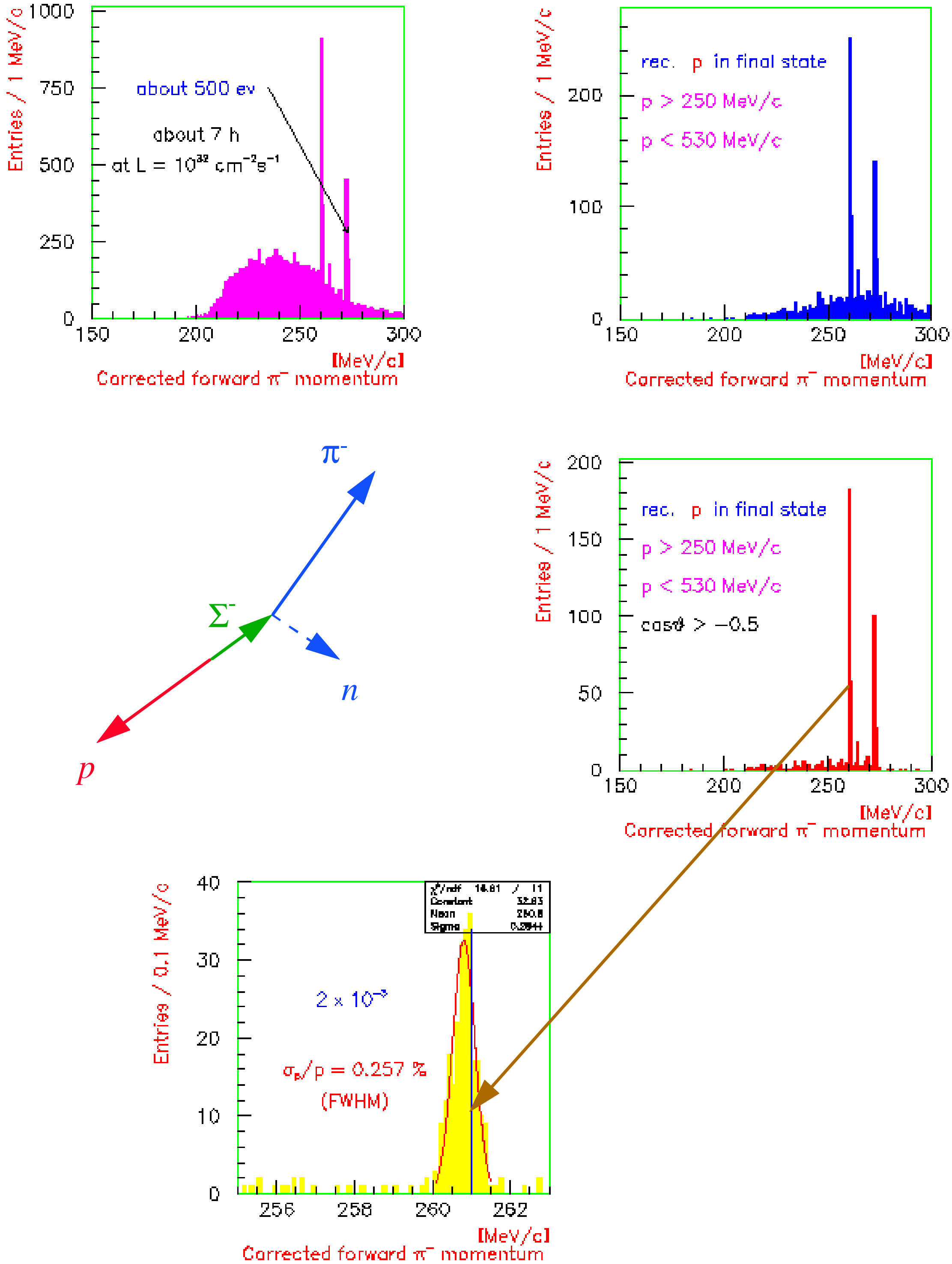
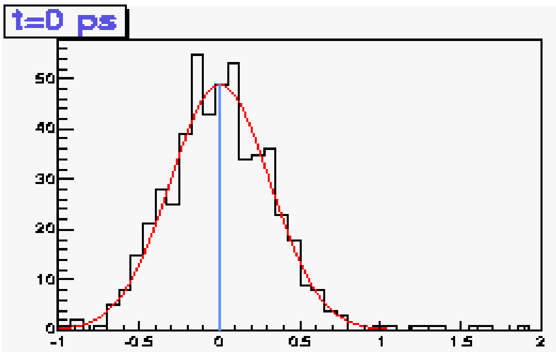
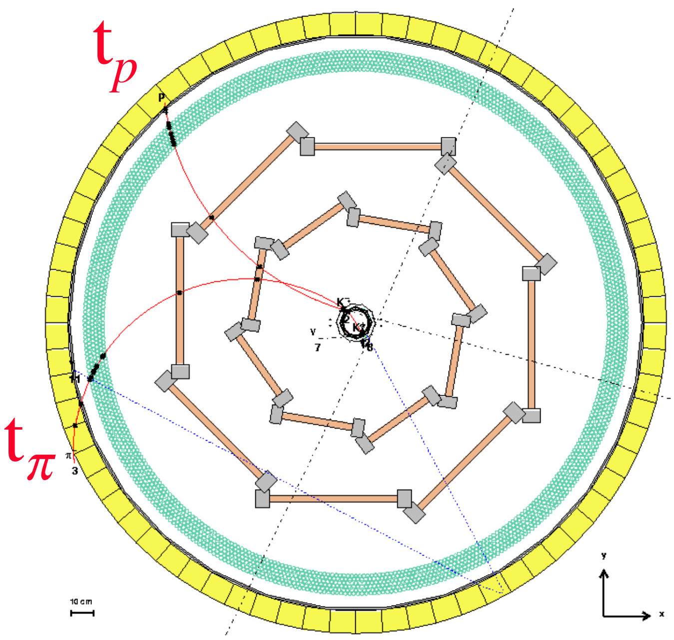


Measurement of Λ-hypernuclei lifetime

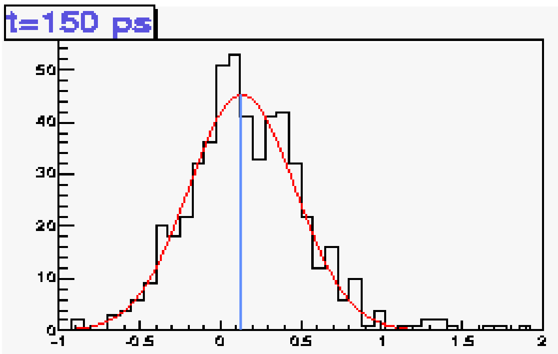
$\Delta T = t_p - t_\pi$

$\sigma_t = 240$ ps

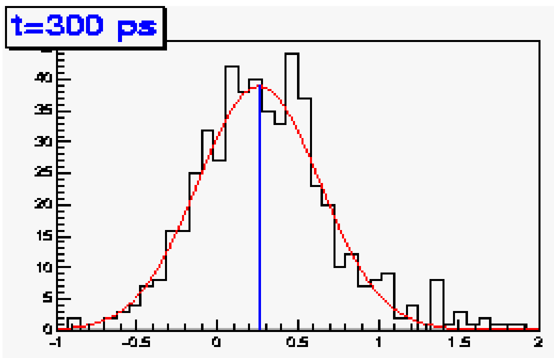




Simulated: 0 ps
Reconstructed: 5 ± 17 ps



Simulated: 150 ps
Reconstructed: 143 ± 14 ps



Simulated: 300 ps
Reconstructed: 307 ± 20 ps

We need ≈ 2000 events in order to measure τ with a statistical error of 10%

FINUDA
figures of merit

(the answer of FINUDA)

- high rates* for:
  - hypernuclear spectroscopy:

    ~ 80 ev/h

  - non mesonic decay:
    - *np*: ~ 2 ev/h
    - *nn*: ~ 0.4 ev/h

    } in coincidence!!!

  - Λ-hypernuclei lifetime:

    ~ 14 ev/h

* at $\mathcal{L} = 10^{32}$ cm^{2}s^{-1} and
K capture rate = 10^{-3}

Conclusions

- FINUDA is ready to be installed!

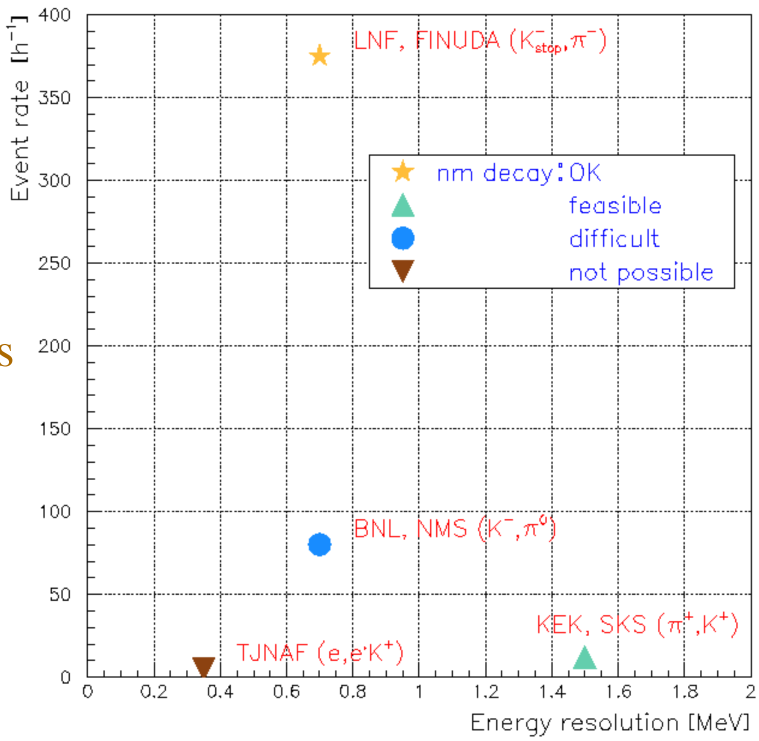
  June →September '98

- Start of data taking:

  December '98

FINUDA perspectives

accelerator's capabilities



physicist's skill

4 months of data-taking (~ 1000 h):

20000	events for H.R. spectroscopy
625	*np* n.m. decays
150	*nn* n.m. decays
3500	events for τ measurement

on 4 different target nuclei

The FINUDA typical event