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harp experiment status and prospects for future neutrino beams, K2K and MiniBooNE

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1_ ν beams vs. hadron production

2_ harp

- motivations
- harp detector
- target
- collected data sample (2001)
- present status of analysis
- perspectives on 2002 data taking
- follow-up

(*) for the harp Collaboration

1. ν beams vs. hadron production

Atmospheric & Solar ν data $\rightsquigarrow$ 3 ν mixing oscillations

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = V \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

V: 3×3 mixing matrix

2 mass differences Δm_{ij}^2

3 mixing angles ϑ_{ij}

1 CP: δ

$$\Delta m_{ij}^2 = m_i^2 - m_j^2$$

in order to measure small coupling & mass differences

and to have a large sensitivity on ϑ_{ij}

⇒ neutrino beams with

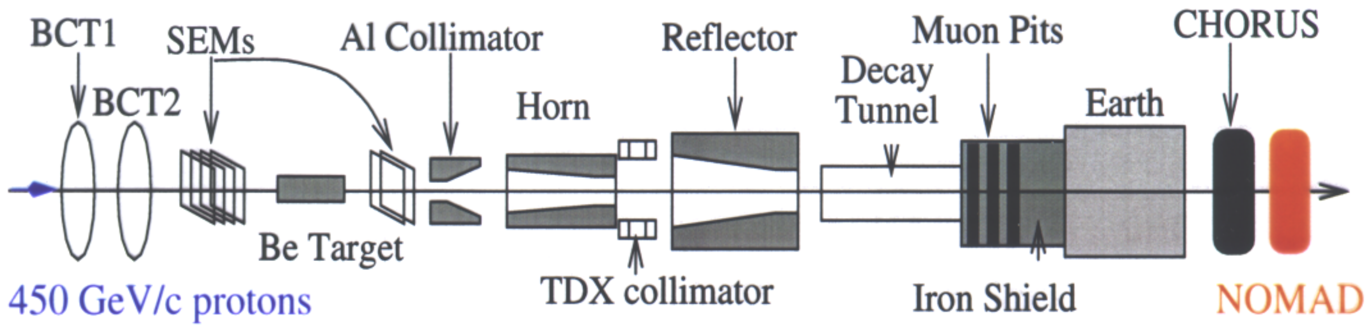
- large intensity
- large L/E , L: propagation distance, E: ν energy
- well known spectra and composition

high energy accelerators provide ν_μ beams by the decay

of π, K produced by high energy protons on light targets:

$\nu_s \leftrightsquigarrow$ hadrons ?

i.e.: the WANF @ CERN SPS



- 450 GeV/c protons on 11 Be rods, $\phi = 3\,mm$, $3 \cdot 10^{13}$ pot/14.4s
- positive (negative) mesons focussed (defocussed) by magnetic horns to CHORUS, NOMAD @ 840 m

$0.95 \cdot 10^{-2}\,\nu_\mu/pot/6.8\,m^2$ $\quad E_{\nu_\mu} \simeq 24.3$ GeV

$\bar{\nu}_\mu/\nu_\mu \simeq 6.9\%$ $\quad \nu_e/\nu_\mu \simeq 1\%$ $\quad \bar{\nu}_e/\nu_\mu \simeq 0.26\%$

- high resolution & granularity of NOMAD detector
  ⇒ study of ν beam with unprecedent accuracy!

  ↳ benchmark for future conventional ν beams

  CNGS, K2K, MiniBooNE, NUMI, ...

to predict ν beam intensity, spectrum & composition:

- precise description of π, K yields by 450 GeV/c protons on Be ($K/\pi \rightsquigarrow \nu_e/\nu_\mu$!)

  - experimental data by 400, 450 GeV/c protons on Be
    Atherton et al. (1980), SPY Collab. (1999)

  - MC hadronic generators: Fluka, 15% of accuracy

  - $K^0_L \sim \dfrac{K^+ + (2n-1)K^-}{2n}$ $\qquad n(x_F) = \dfrac{u}{d}$ in proton

    $\sim 15\%$? $\qquad x_F = \dfrac{p_\ell}{p_{\ell_{max}}}$

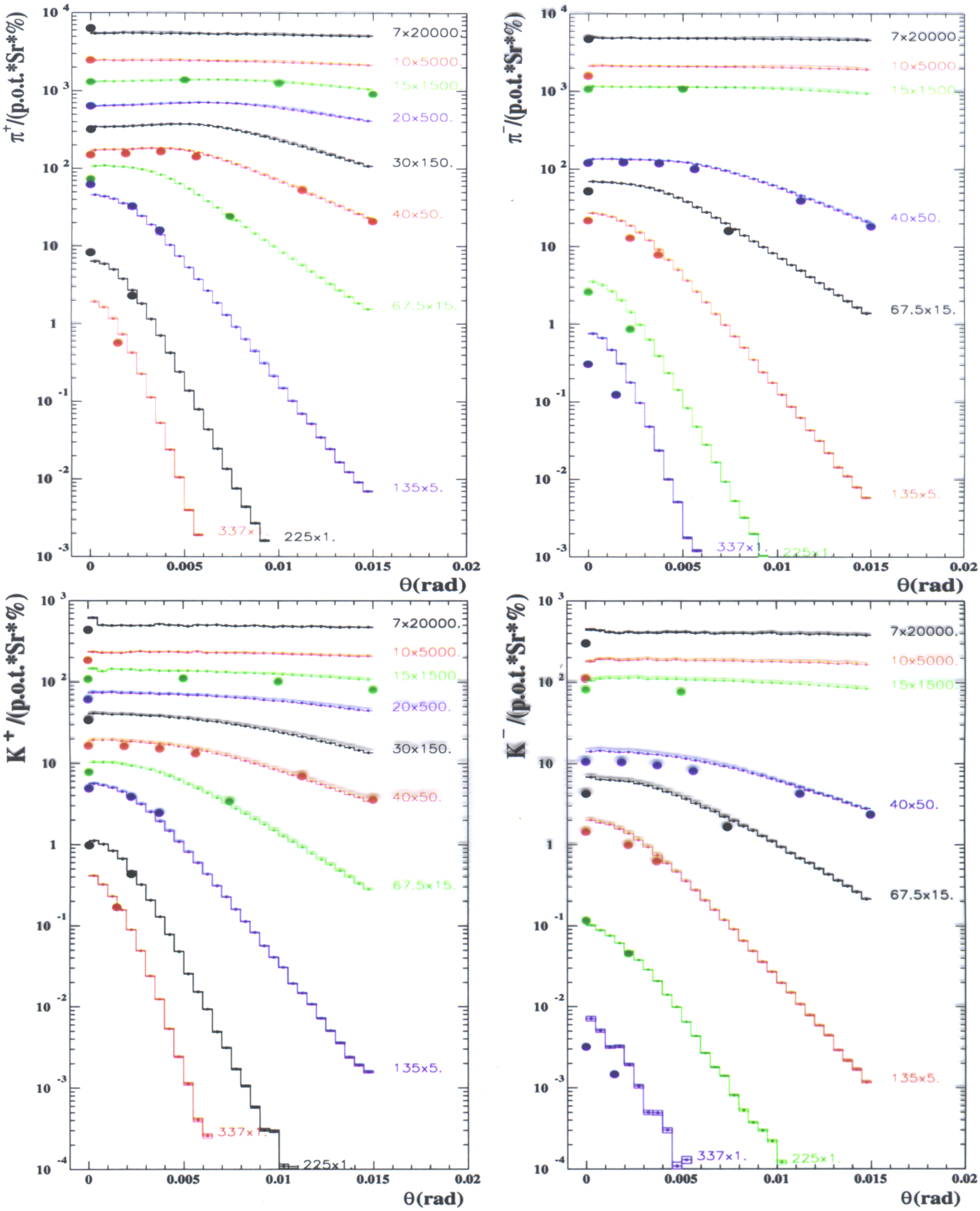
    ↳ limit to sensitivity !!!

    ↳ reweighting functions for $\pi^\pm$, $K^\pm$, p, ...

- accurate description of focussing system

- accurate description of primary proton spot:
  p missing the target will interact in the beam-line
  $\rightsquigarrow$ 30% of $\bar{\nu}_\mu$, ... $\bar{\nu}_e$

- accurate description of particle propagation in the beam-line (reinteractions, ...)



• SPY/Atherton (rescaled) data

—— FLUKA predictions (the best!)

450 GeV/c protons on 10 cm Be

amount of available data : limited

especially as far as the angular scans are concerned

reweighting functions FLUKA → SPY, Atherton data

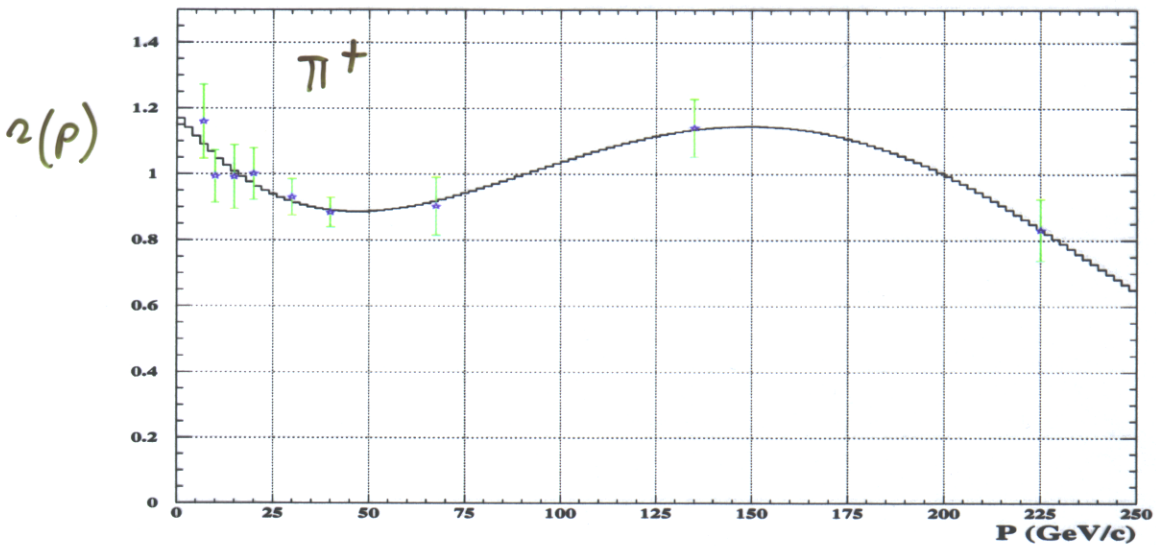
from the ratio, for a selected P, of

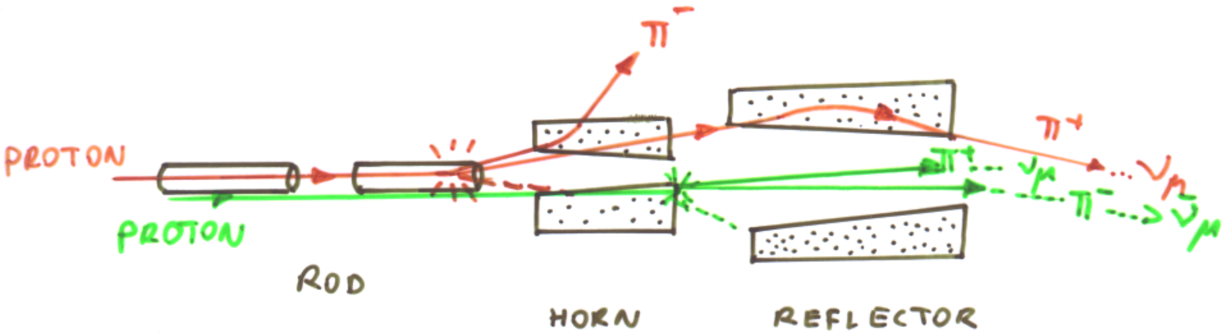
measured and predicted yields, both integrated

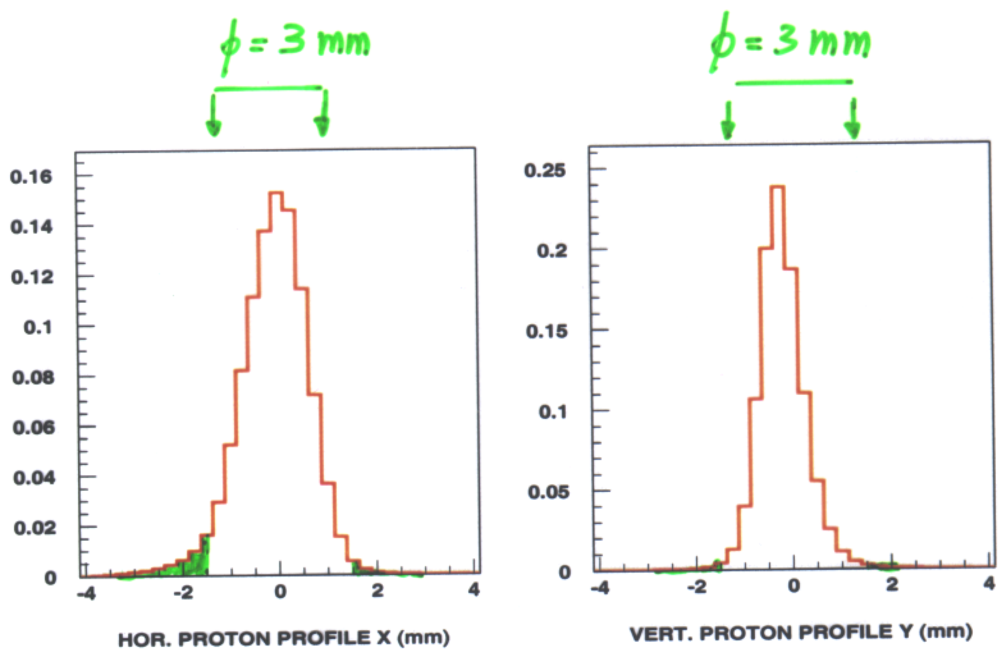
over $\theta \leq 10$ mrad (WANF acceptance)

$$r(p) = \frac{(\Sigma_i \; yield_i \cdot \theta_i \cdot A_i)_{DATA}}{(\Sigma_j \; yield_j \cdot \theta_j \cdot A_j)_{FLUKA}}$$

$A_{i,j}$: acceptance







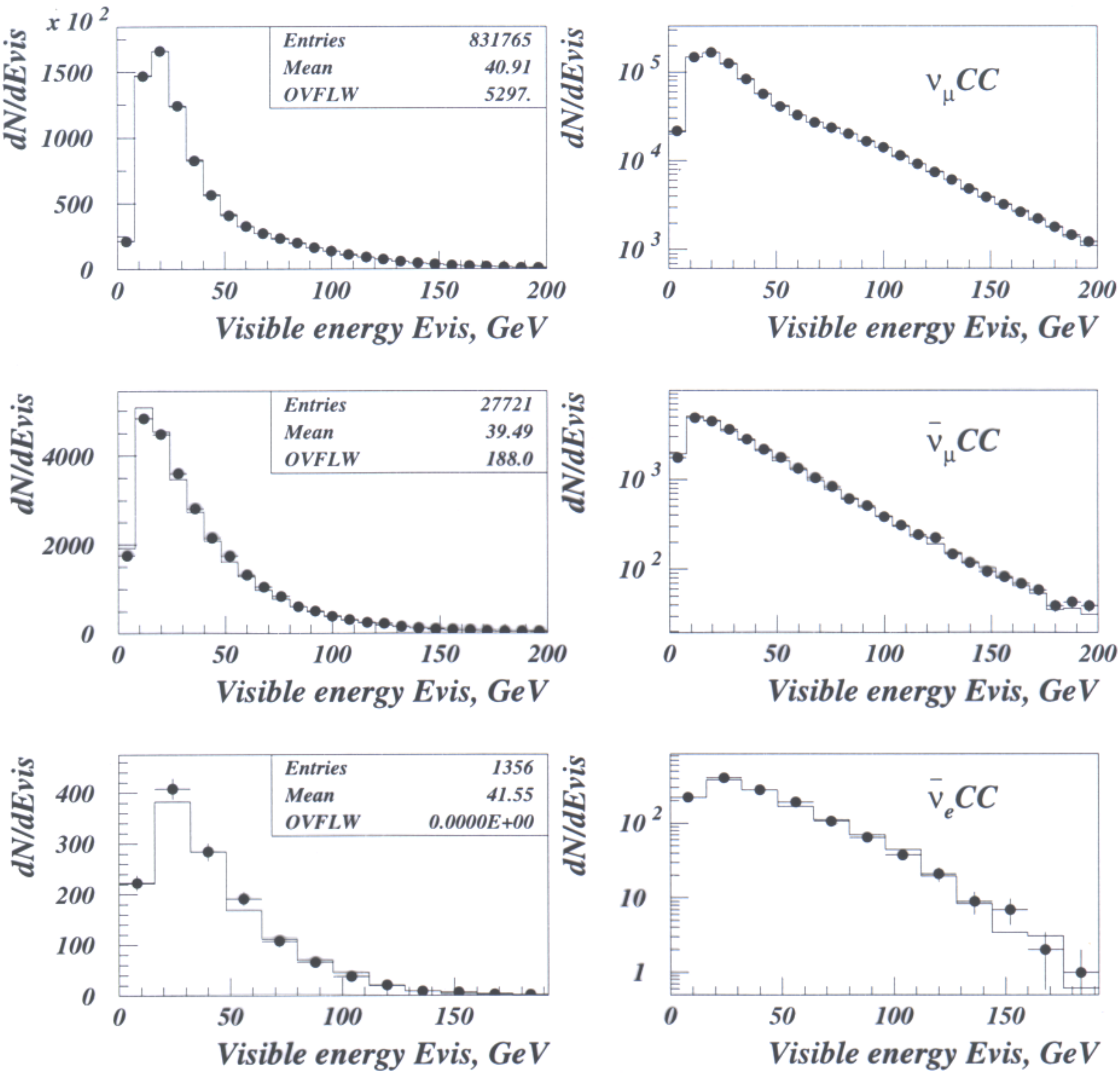
Knowledge of { p-beam profiles / stability
materials in the beam-line

is critical for $\bar{\nu}_\mu$, $\bar{\nu}_e$ fluxes !

⇒ contaminations

↳ background !!!

NOMAD RESULTS

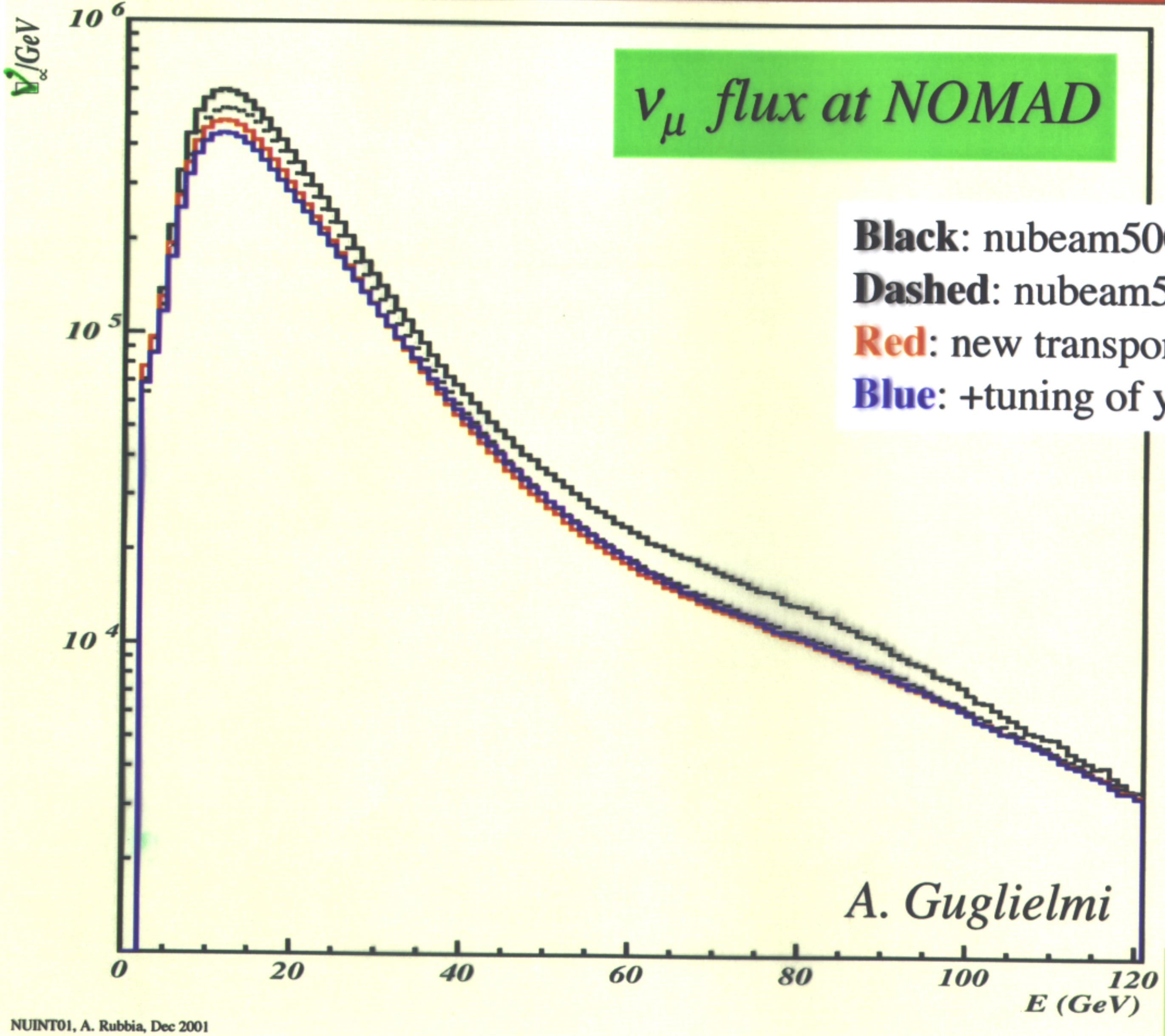


ϕ data

— MC - fluka tuned to SPY/Atherton data
ν_μ CC MC normalized to date (shape)

- agreement MC-ν_μ cc/data @ few % level
- systematics on ν_e/ν_μ ~ 5% (beam)

NOMAD beam MC prediction



Black: nubeam500 + GEANT-FLUKA

Dashed: nubeam500 + FLUKA standalone

Red: new transport + FLUKA standalone

Blue: +tuning of yields to SPY data

A tough job!

E_ν

- Conventional ν beams @ accelerators ($\pi, K \to \nu + \ldots$)

  - not pure ν_μ (ν_e) beams
  - caveat of hadronic cross-sections, particle transport which limit the sensitivity

  $\Rightarrow$ calculation is ~ complicated cascade of physical processes and not just the case of π, K production where mesons decay in a vacuum tunnel ...

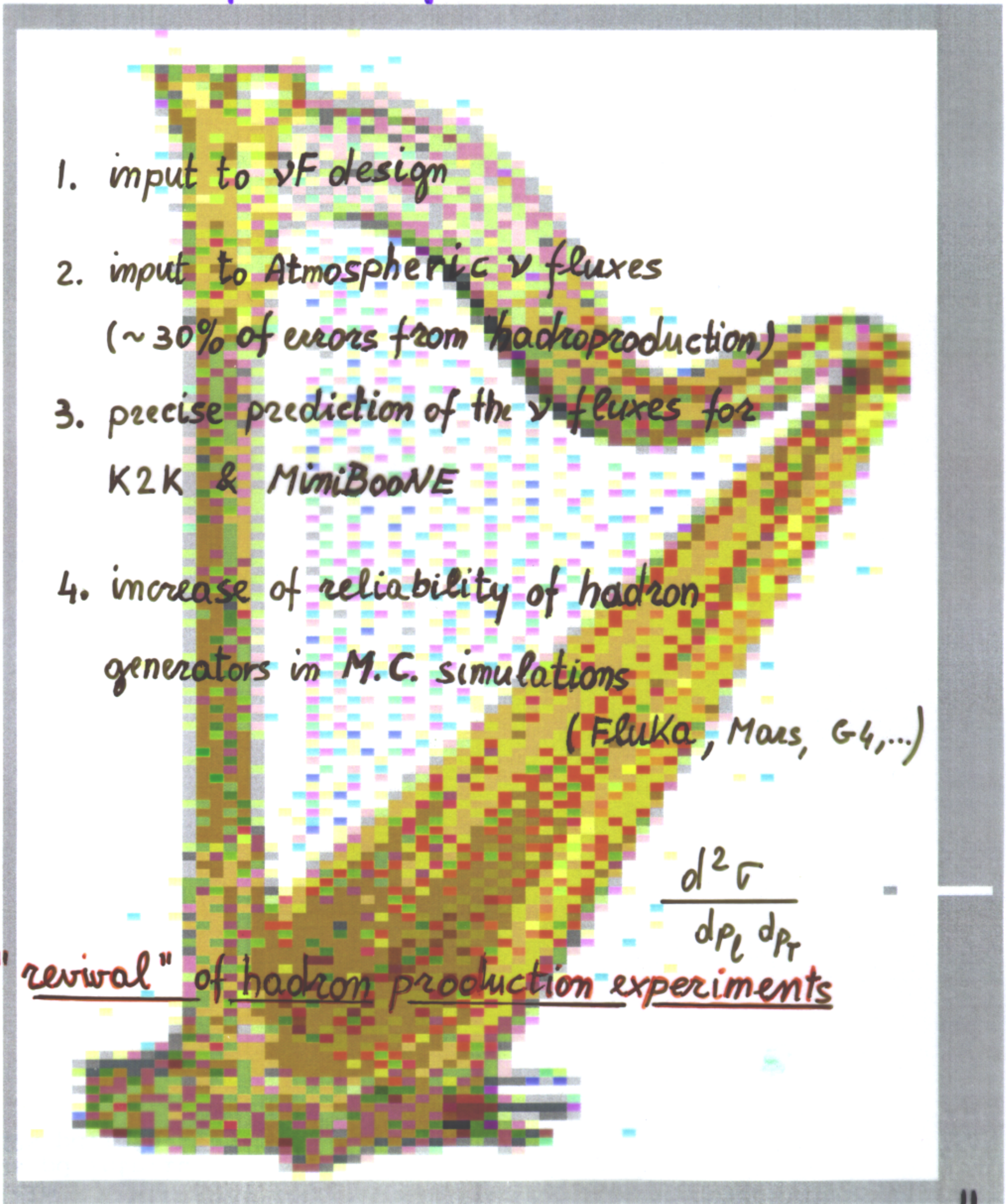
  ↳ • good MC hadronic generator (~ fluka)
  • tuning to hadr. production data

- new more intense, better defined ν beams than the conventional-ones!

  - Super beam
  - ν-factory! $\to \mu \to e \, \nu_\mu \, \nu_e$!
  - β-beam

2. harp:

a hadron production experiment
for the ν factory and
the atmospheric ν flux



1. input to νF design
2. input to Atmospheric ν fluxes (~30% of errors from hadroproduction)
3. precise prediction of the ν fluxes for K2K & MiniBooNE
4. increase of reliability of hadron generators in M.C. simulations (FluKa, Mars, G4,...)

$$\frac{d^2\sigma}{dp_l\, dp_T}$$

"revival" of hadron production experiments

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134 physicists, 24 institutions, 10 countries

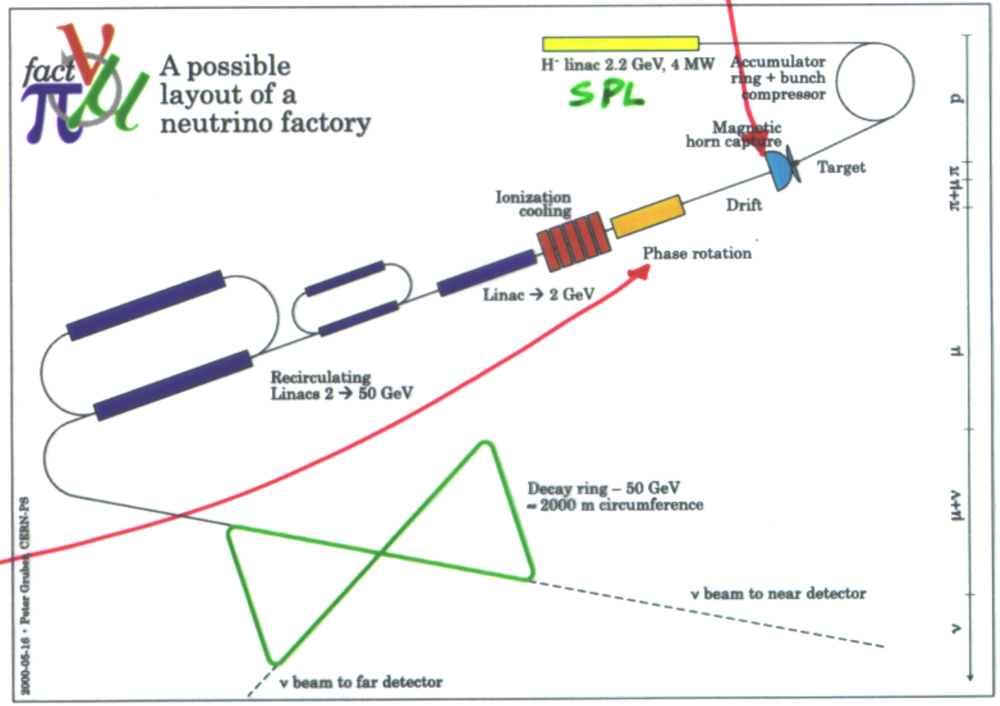
2.1 Motivations

1. the ν-factory design

Primary energy, target material & geometry, collection scheme

- maximizing π^+, π^- production rate / pot / GeV
- Knowing with high precision (< 5%) the p_T-distribution

CERN scenario: 2.2 GeV/c proton linac



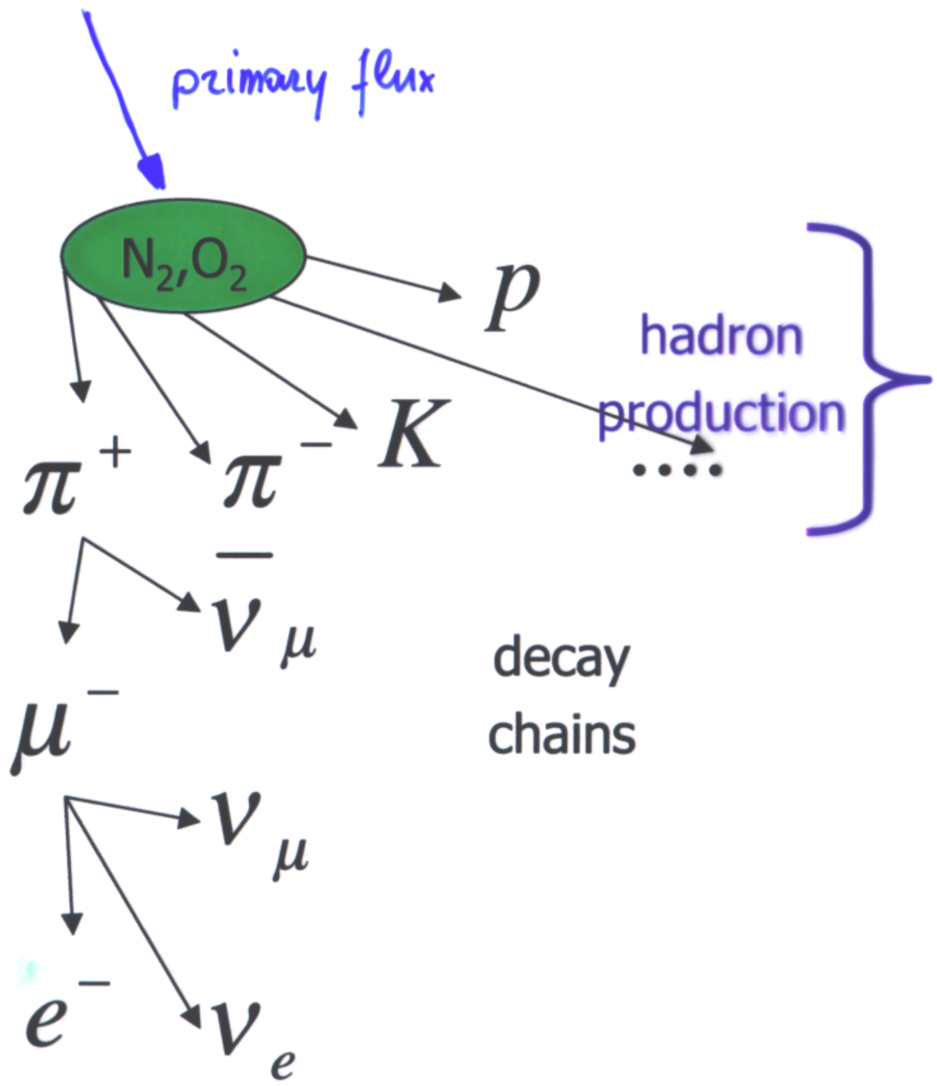
Phase rotation:

- longitudinally freeze the beam: slow down earlier particles, accelerate later ones.
- need good knowledge also of P_L-distribution

SPL: $1.1 \cdot 10^{16}$ p/s → 10^{23} p/year

$0.3 \cdot 10^{21}$ μ-decay/year → ν!

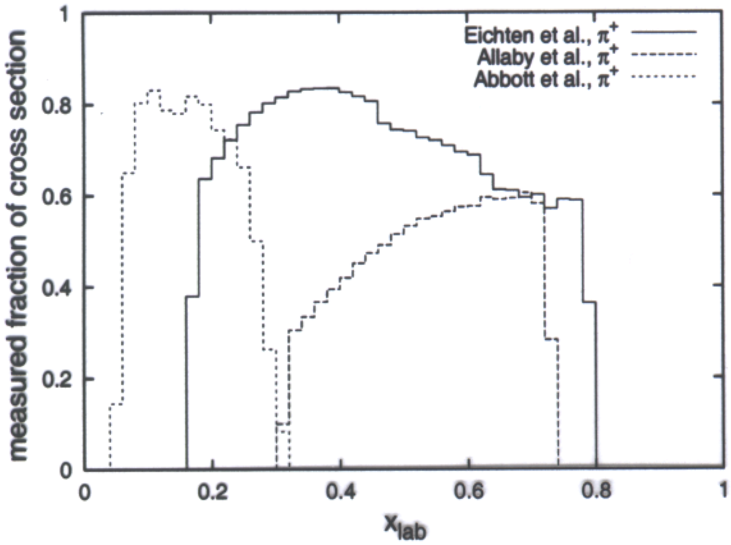
2 Atmospheric ν fluxes



- primary flux : known to better than 10%
- most of the uncertainty comes from the lack of data to construct and calibrate a reliable hadron interaction model
- model-dependent extrapolations from the limited set of data ⇒ 30% uncertainty in atmospheric fluxes !

lack of data!

- few old experiments
- small acceptance
- poor data in particular @ low energy
- ~ Be target used, $p = 14.6, 12.5, 19.2$ GeV/c

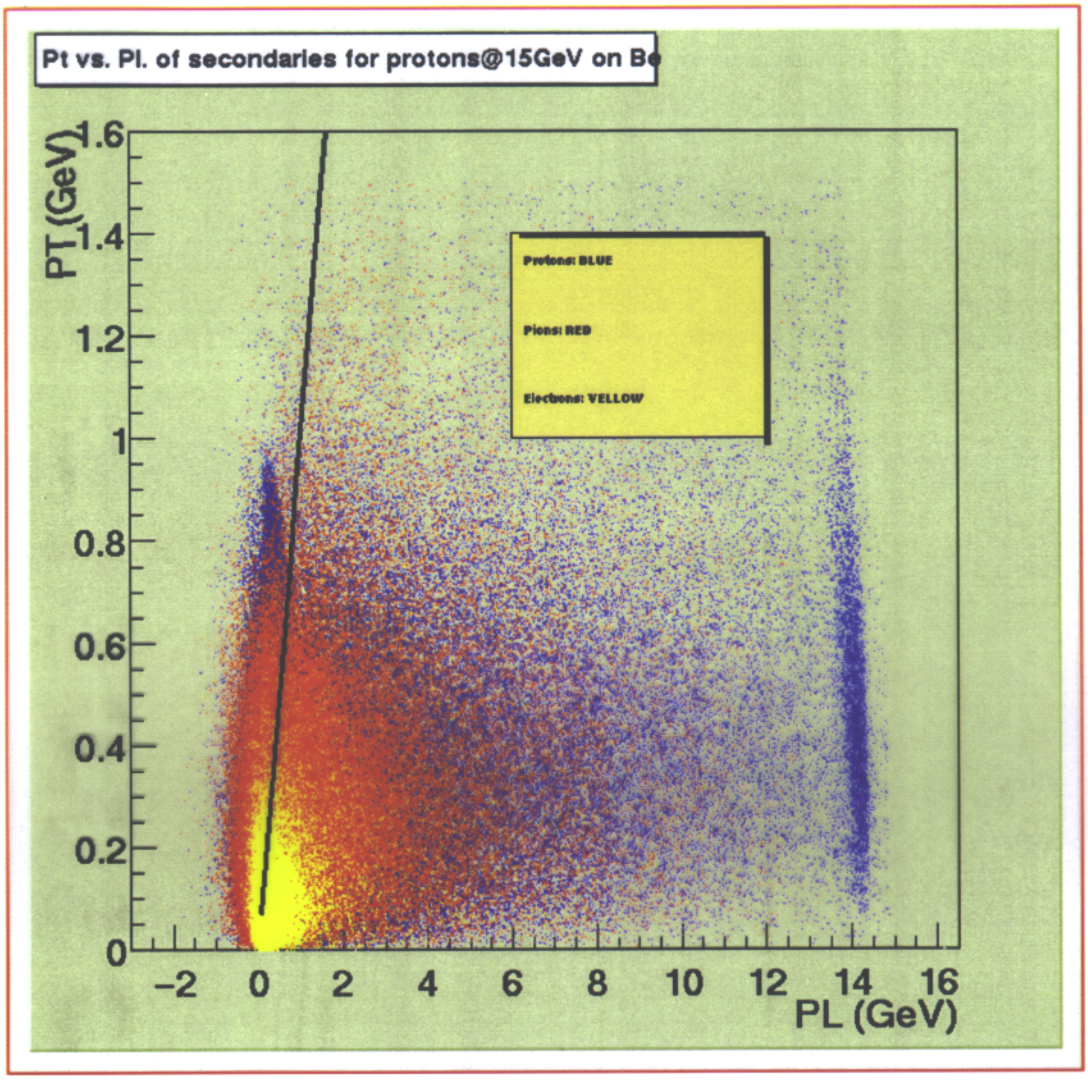


- some data could be already exploited: E910

aim of harp:

- hadronic $d^2\sigma/dp_T/dp_L$ various beams & targets
- high statistics ($\sim 10^6$) per setting, low systematics
  ↳ 2% accuracy over all phase space
- proton/pion beams, $2 \div 15$ GeV/c, T9 beam @ PS
  $\Delta p/p \lesssim 1\%$
- additional (cryo-) target + { 60 cm Al rod K2K; 65 cm Be rod MiniBooNE replica

15 GeV/c protons on Be

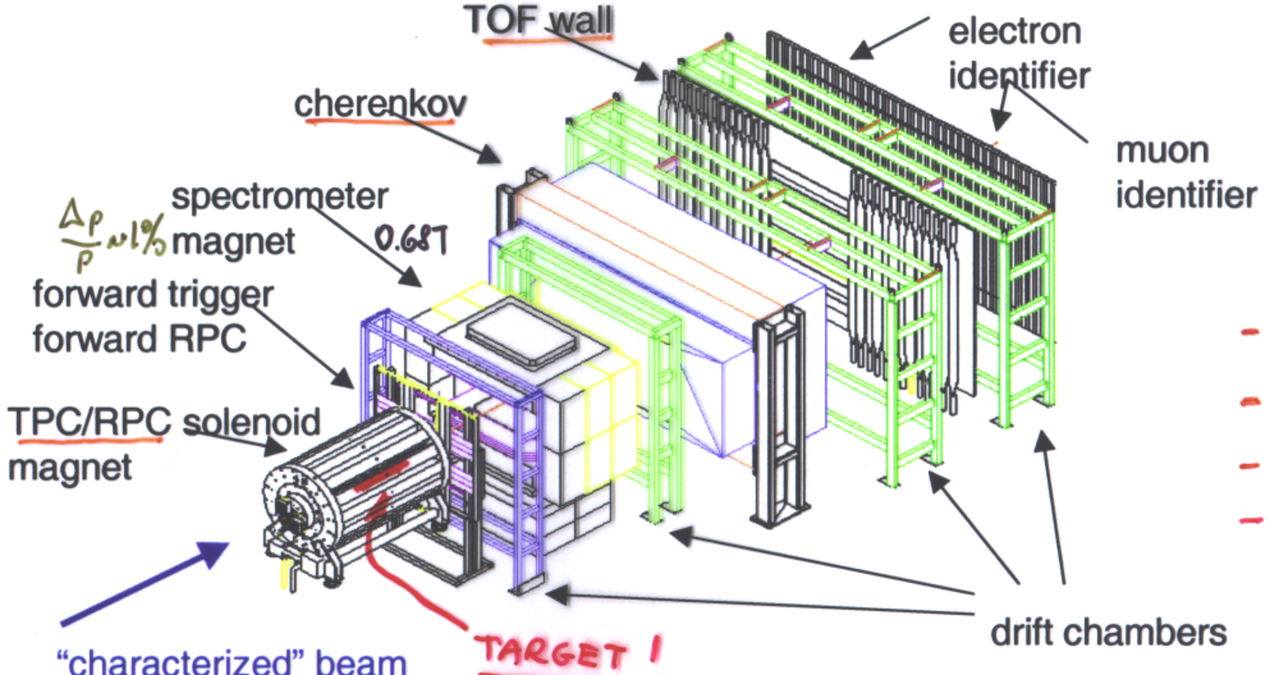


the experimental exploitation requires:

- momentum evaluation in 100 MeV/c – 10 GeV/c range
- large acceptance
- p/π, K/p, e/p separation

2.2 HARP detector

harp: large Acceptance and Particle I.D.



$\check{C}$, TOF (21m), MWPCs

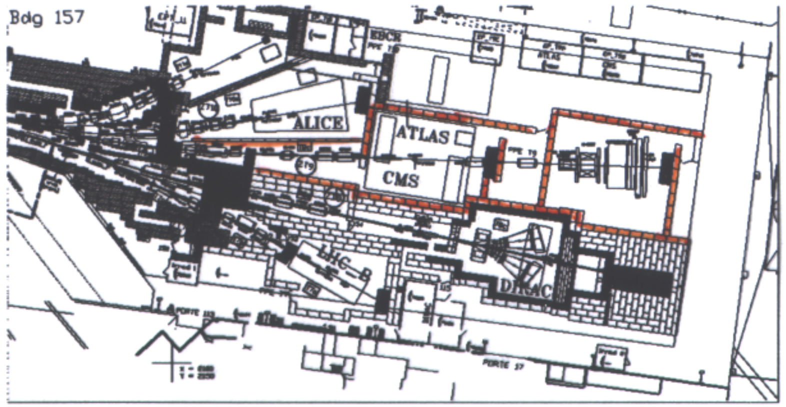
+ ITC trigger

NOMAD 90% Argon
9% carbon dioxide
1% methane

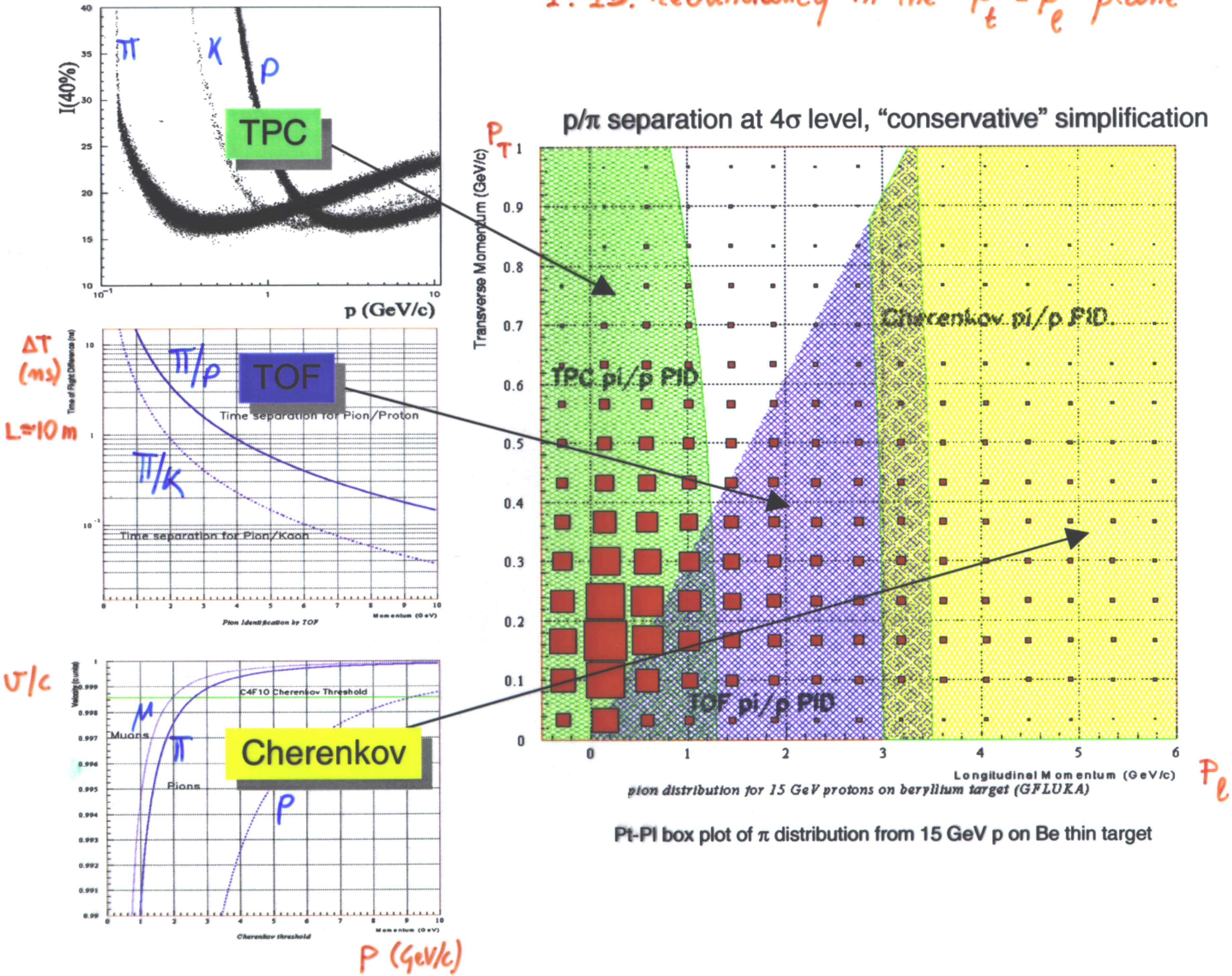
- TPC/RPC
- cherenkov
- TOF wall
- TARGET

} ⇒

PS East Area beams: 2 – 15 GeV/c

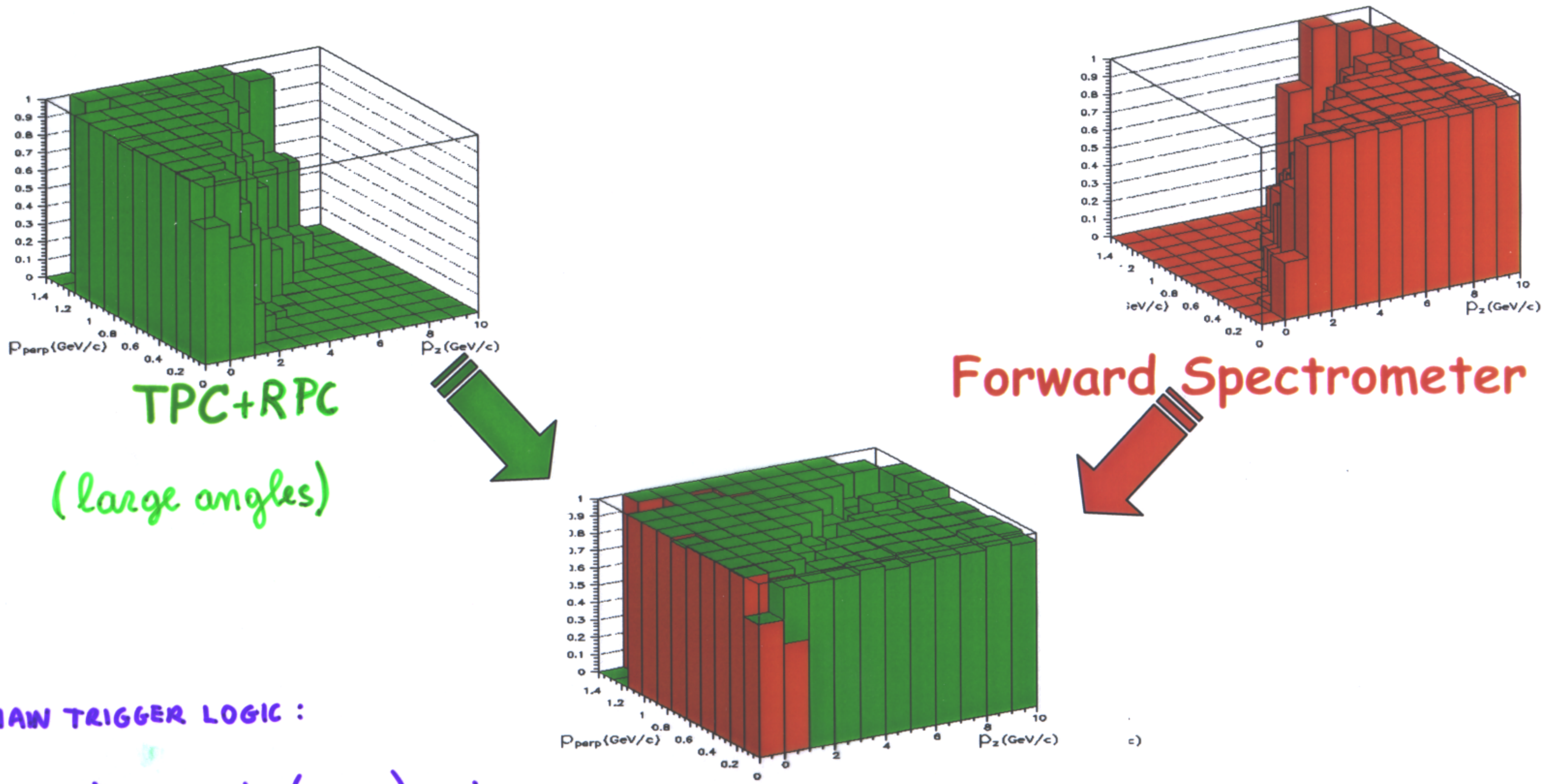


P. ID. redundancy in the $P_t - P_\ell$ plane



Pt-Pl box plot of π distribution from 15 GeV p on Be thin target

Acceptances * Pid Efficiencies

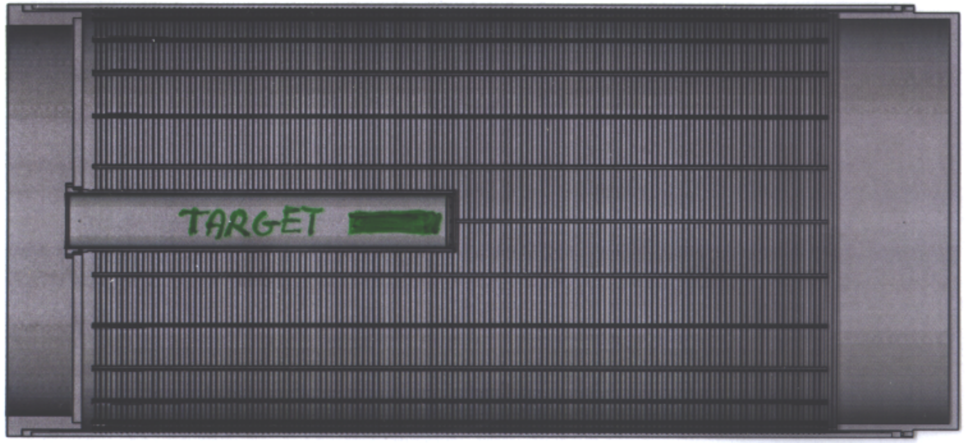


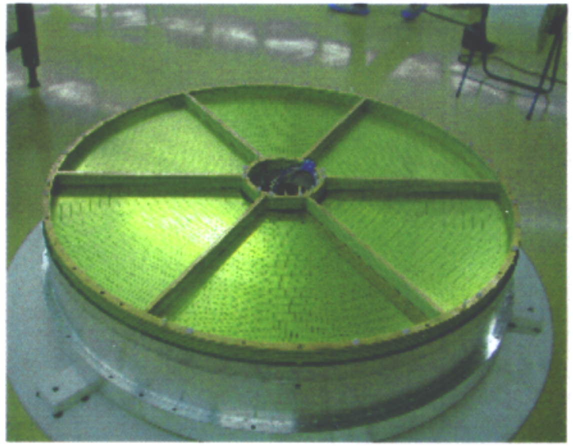
MAIN TRIGGER LOGIC :

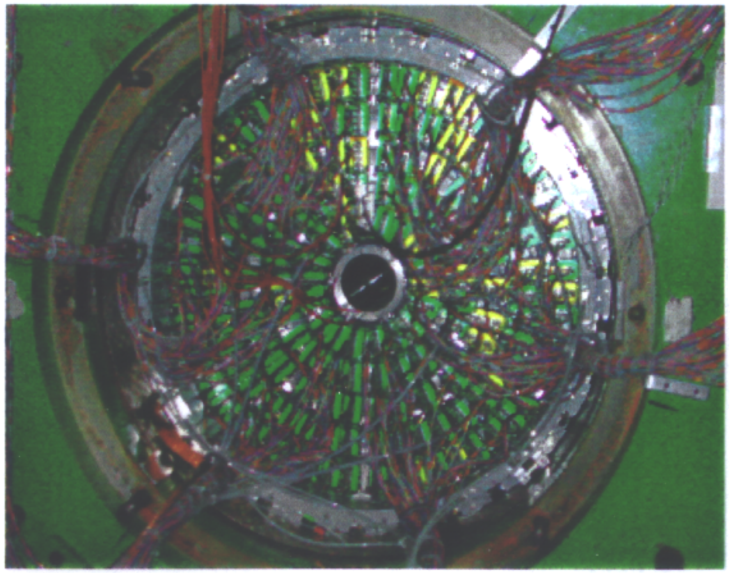
Forward (FTP) Trigger
OR
Large-angle (ITC) Trigger

large-angle detectors : TPC

→ beam



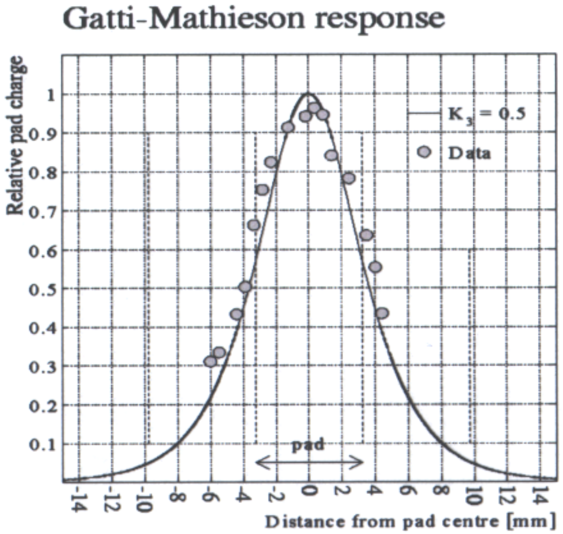


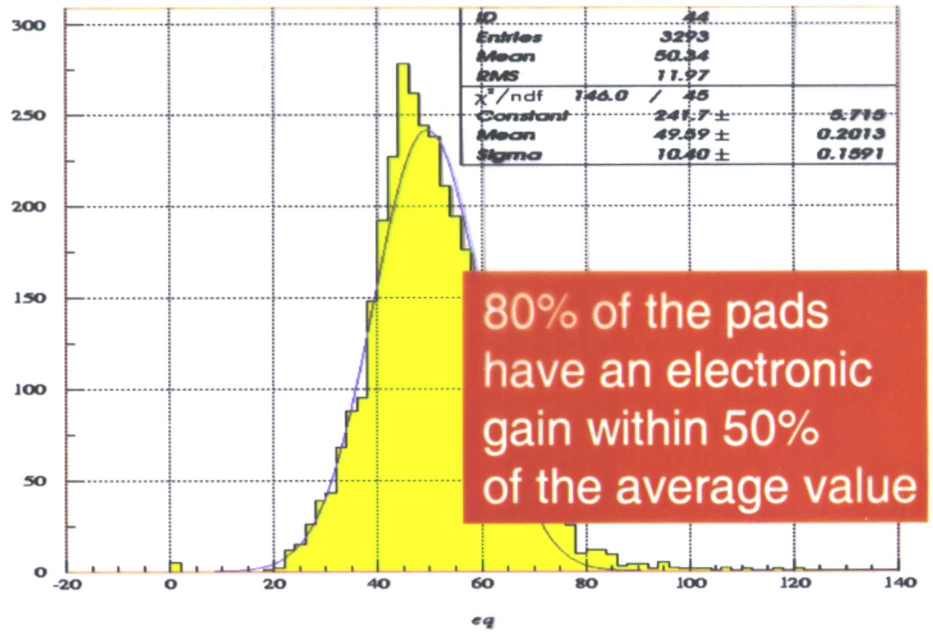


- 1.5 m long, 0.8 m diameter, 90% Argon, 10% methane
- 0.7 T solenoidal magnetic field, $\frac{\Delta p_T}{p_T} \sim 0.033 \cdot p_T$
- 12 KV/m $v_{drift} = 5$ cm/μs
- 3972 readout pads arranged in 20 concentric rows
- ionization level sampled on each pad in 0.1μs

- design mostly inspired by existing detectors or designed (Aleph, NA49, Alice). Readout from Alice/NA45

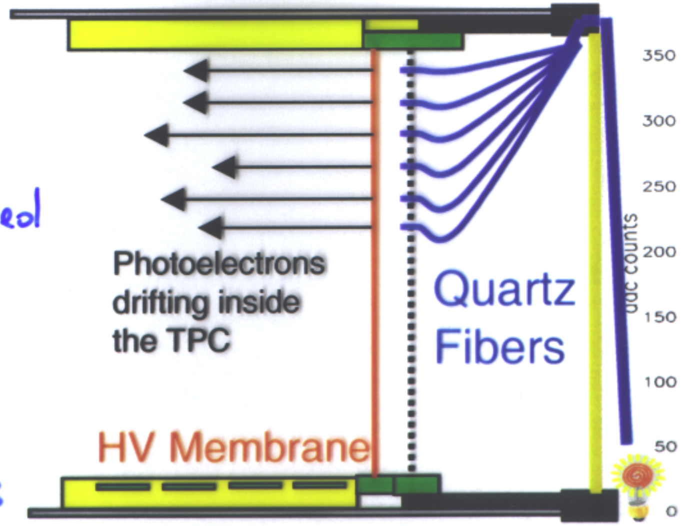
...

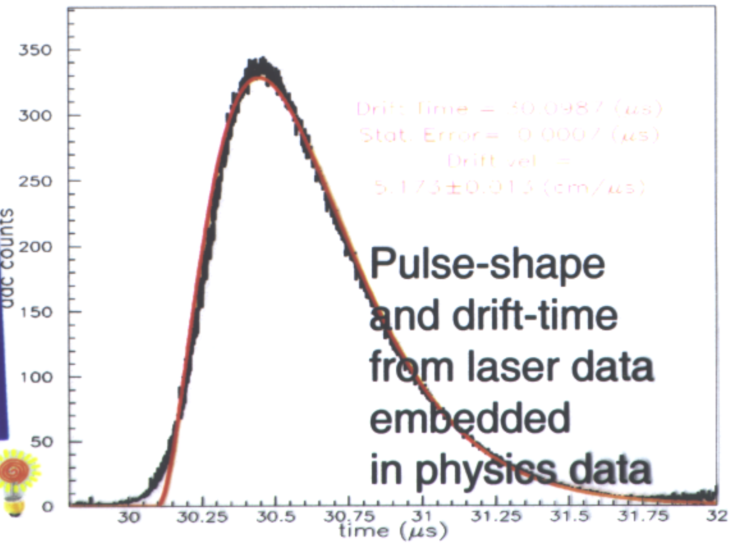




- pad's equalization and calibration (^{83}Kr) data collected, analysis in progress

- laser calibration system: photoelectric emission from Al sputtered quartz fibers illuminated by UV light.
  - drift-time & stability
  - space-charge & distances
  - pulse-shape analysis

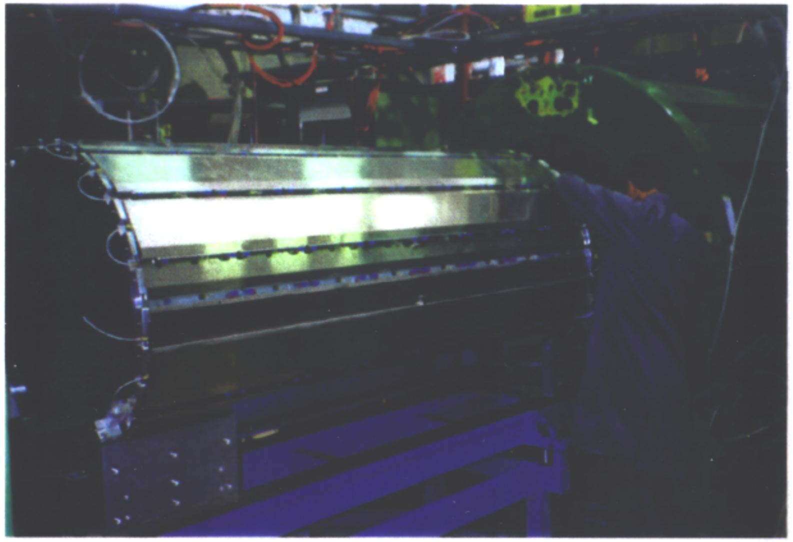


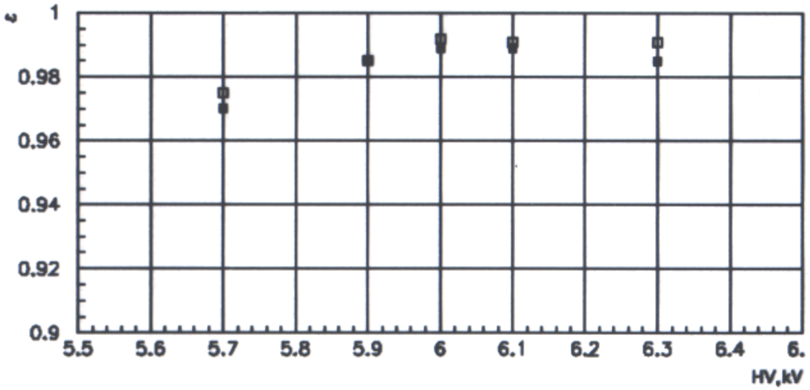


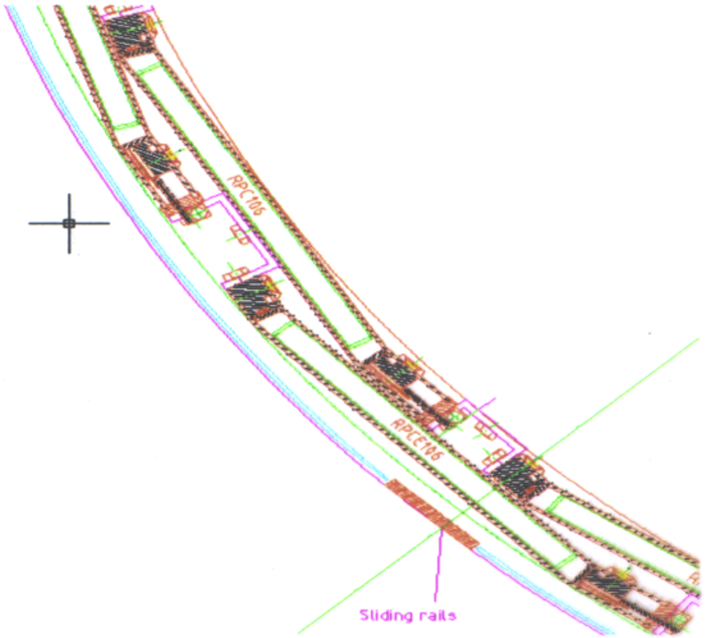
large angle detectors : RPC

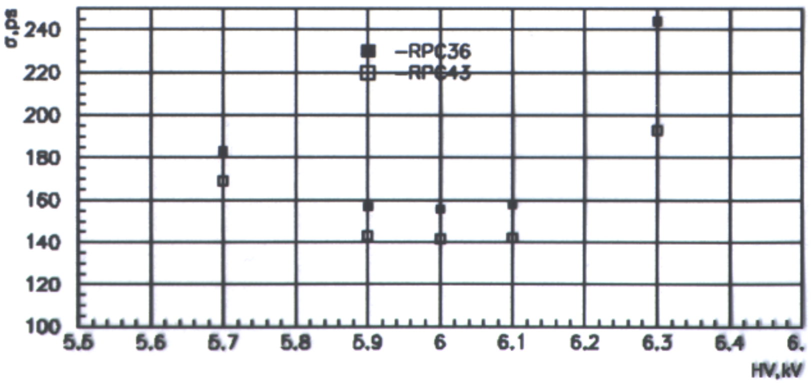
- separation of large-angle e/π $p < 300$ MeV/c
- $\sigma_t < 200$ ps needed resolution

  - 30 barrel RPCs, 16 forward
  - 150 ps resolution
  - 99% efficiency

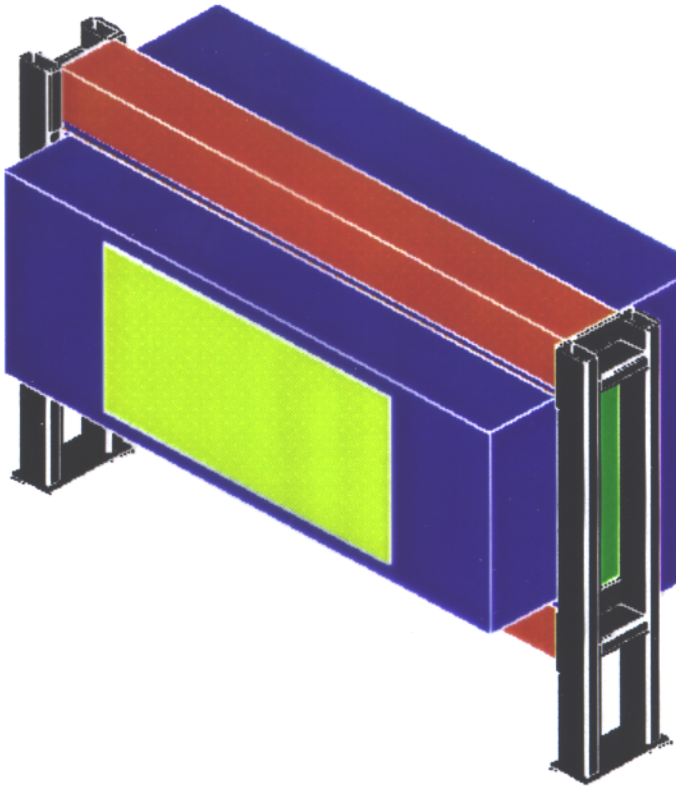








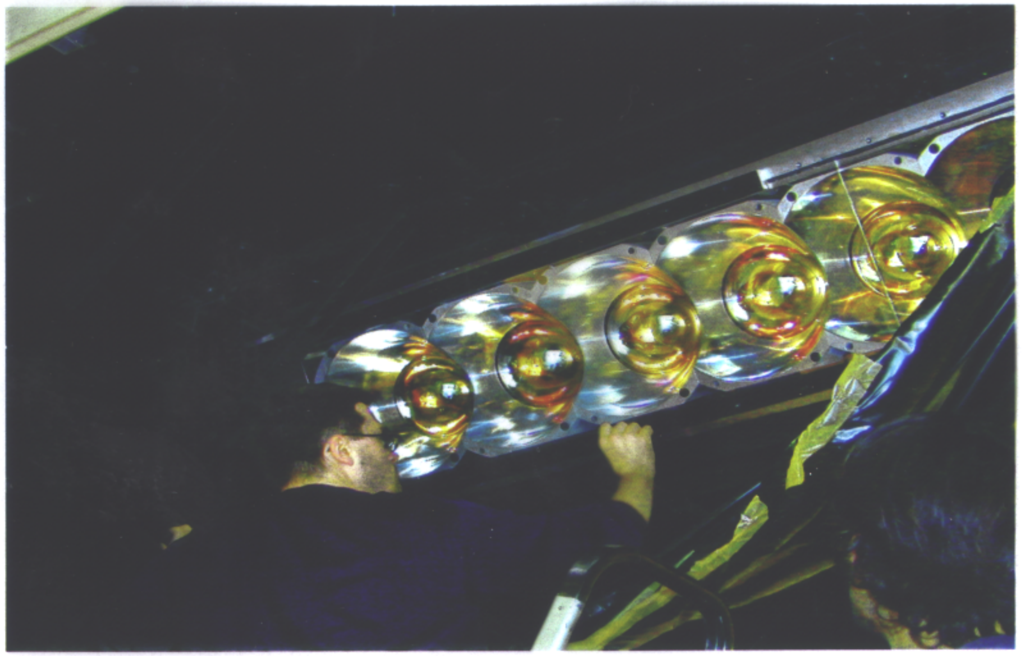
forward spectrometer : Cherenkov



- cylindrical mirrors in a 35 m^3 vessel filled with C_4F_{10}
- CHOOZ 8" PMTs

	3 GeV	5 GeV	12 GeV
Eff π	89. ± 10. %	> 93%	> 97%
Eff μ	97.5 ± 10. %		

data based on beam particles identified through Beam Cherenkov, Beam TOF and muon identifier



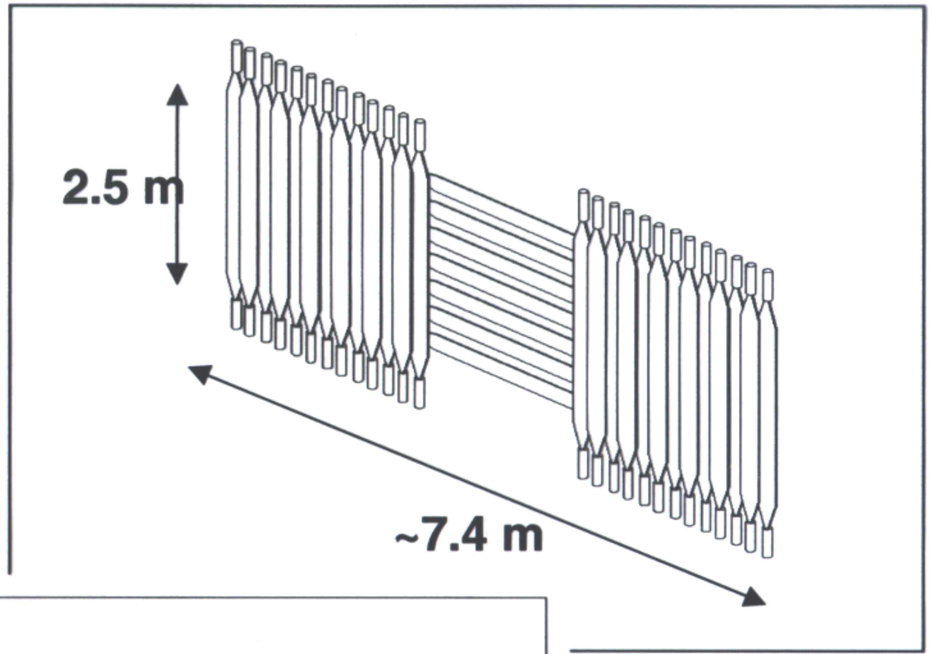
forward spectrometer : TOF wall

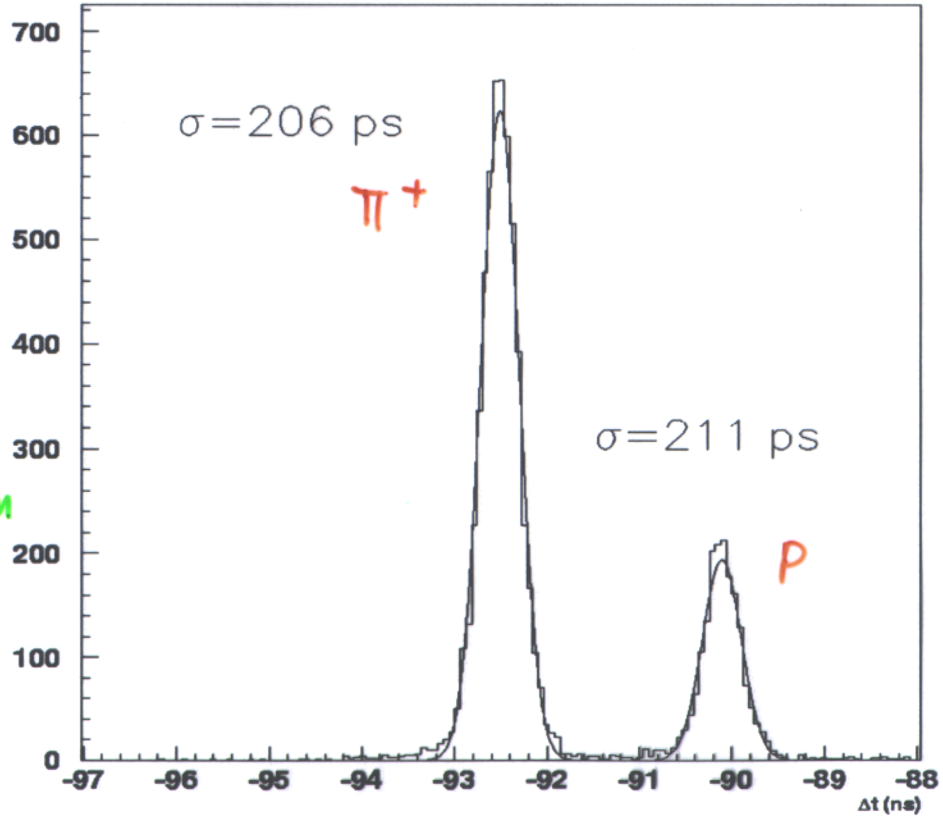
- 40 scintillation counters, BC-408 equipped with XP2020 PMTs.
- expecially designed electronic chain, 35ps resolution, cross-talk, good stability
- continuos laser, c-rays and pulse calibration used for time-walk corrections and stability monitors

↳ intrinsic time resolution

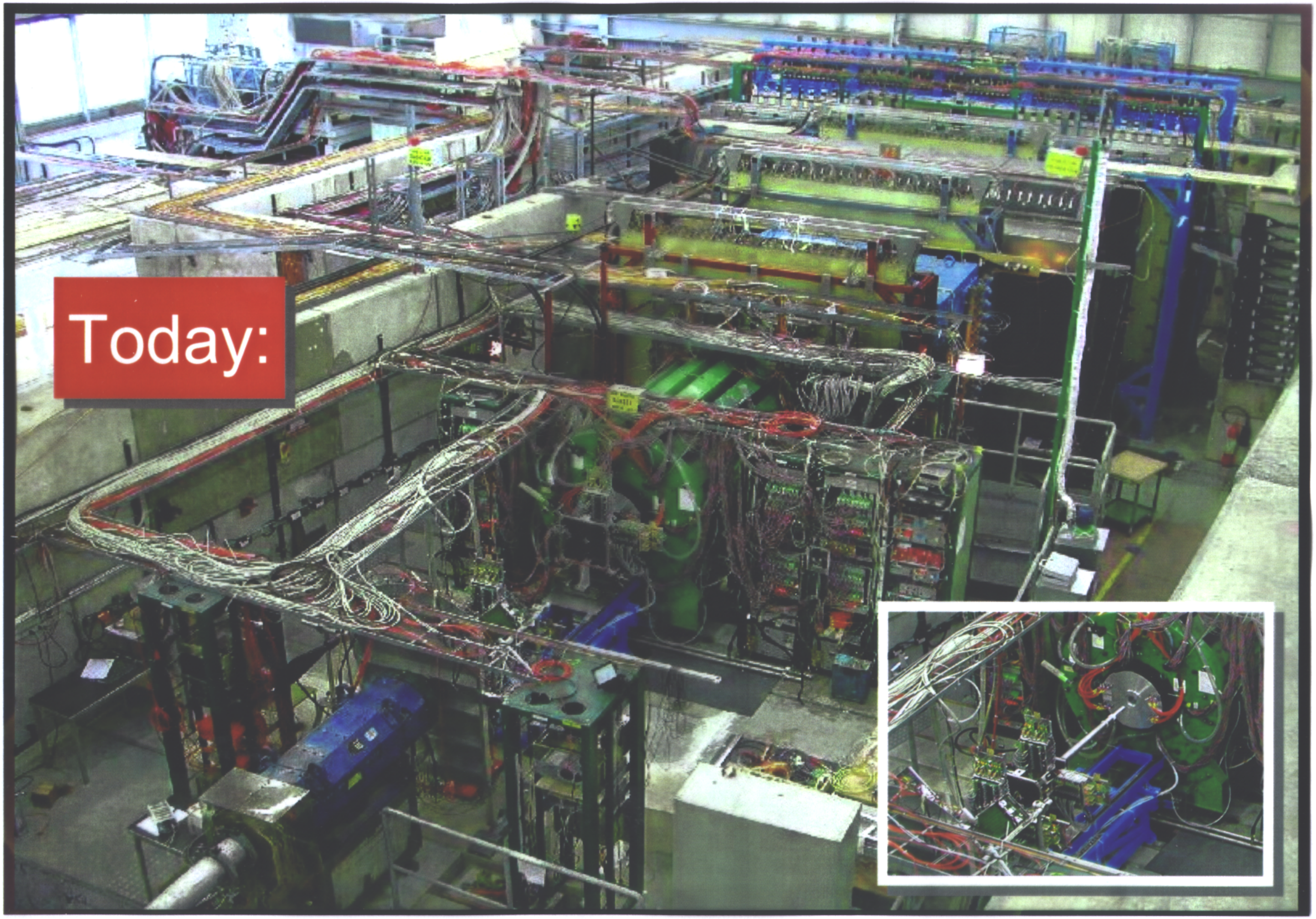
$\sigma_t \sim 150$ ps

$\Rightarrow \sigma_{TOF} \sim 210$ ps

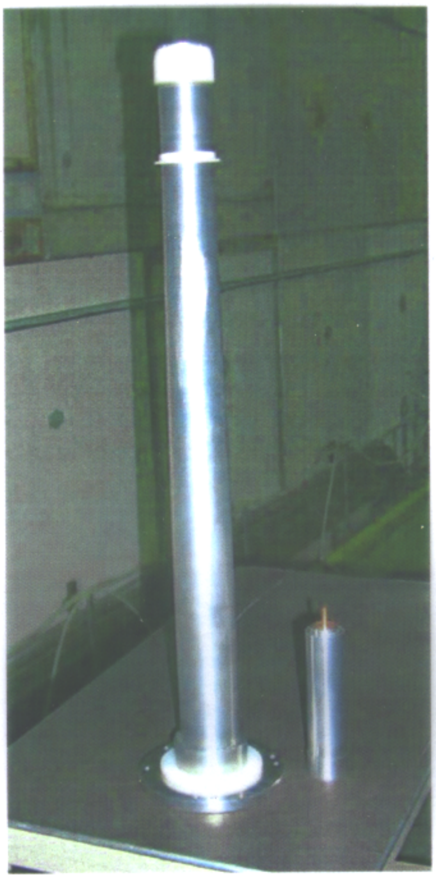




3 GeV/c protons


Today:

2.3 targets



target tube and standard target holder

Solid targets

target	Z	thin 0.02 λ (cm)	thick 1λ (cm)
Be	4	0.81	40.5
C	6	0.76	38.1
Al	13	0.79	39.4
Cu	29	0.30	15
Sn	50	0.45	
Ta	73	0.22	11.14
Pb	82	0.34	17.1

Cryogenic targets 6 cm long

H_2	D_2	N_2	O_2

Special targets

K2K target	~60 cm Al + λ/2
MiniBooNE target	~65 cm Be + λ/2

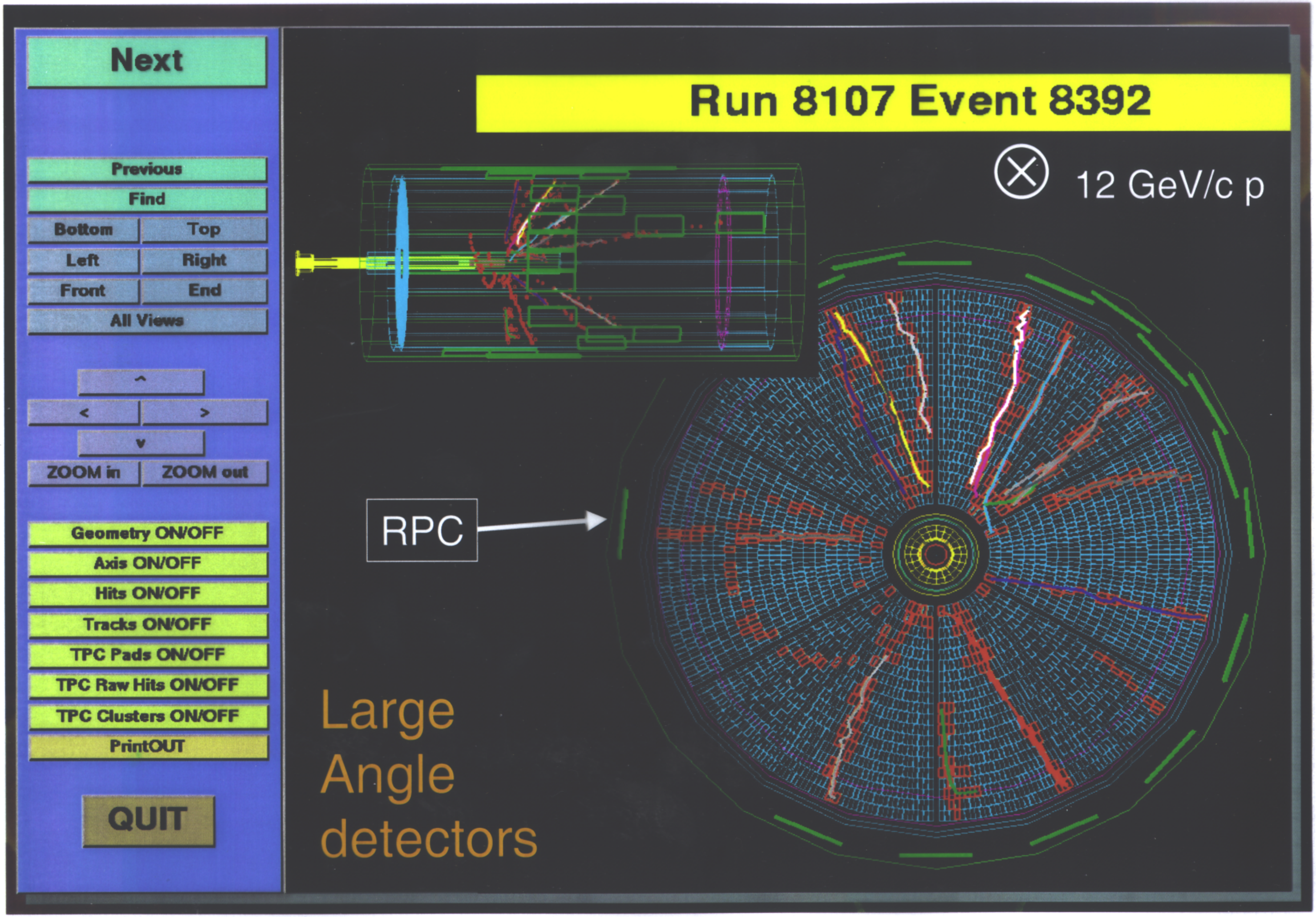
2.4 Collected data sample (2001)

- ~ 100 million physics triggers, event rate ~ 2.5 KHz (~10^6 event/day)
- thin Be, Al, Ta, Pb target P = 3, 5, 12, 15 GeV/c, +, −
- some K2K target measurements @ 12.9 GeV/c, +
  " MiniBooNE " " @ 8 GeV/c, +
- special runs for calibrations, empty target, c-rays, ...

2.5 Present status of the analysis

- low energy, 3 GeV/c ✓
- beam particle compositions ✓
- detector calibration ✓
- large angle analysis: - TPC clustering, track finding and fitting, RPC
  - particle ID (e, π, K, p)

⇒ first $d^2n/dp\,d\eta$ within 5% error by the end of March 2002 ?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All Views
ZOOM in
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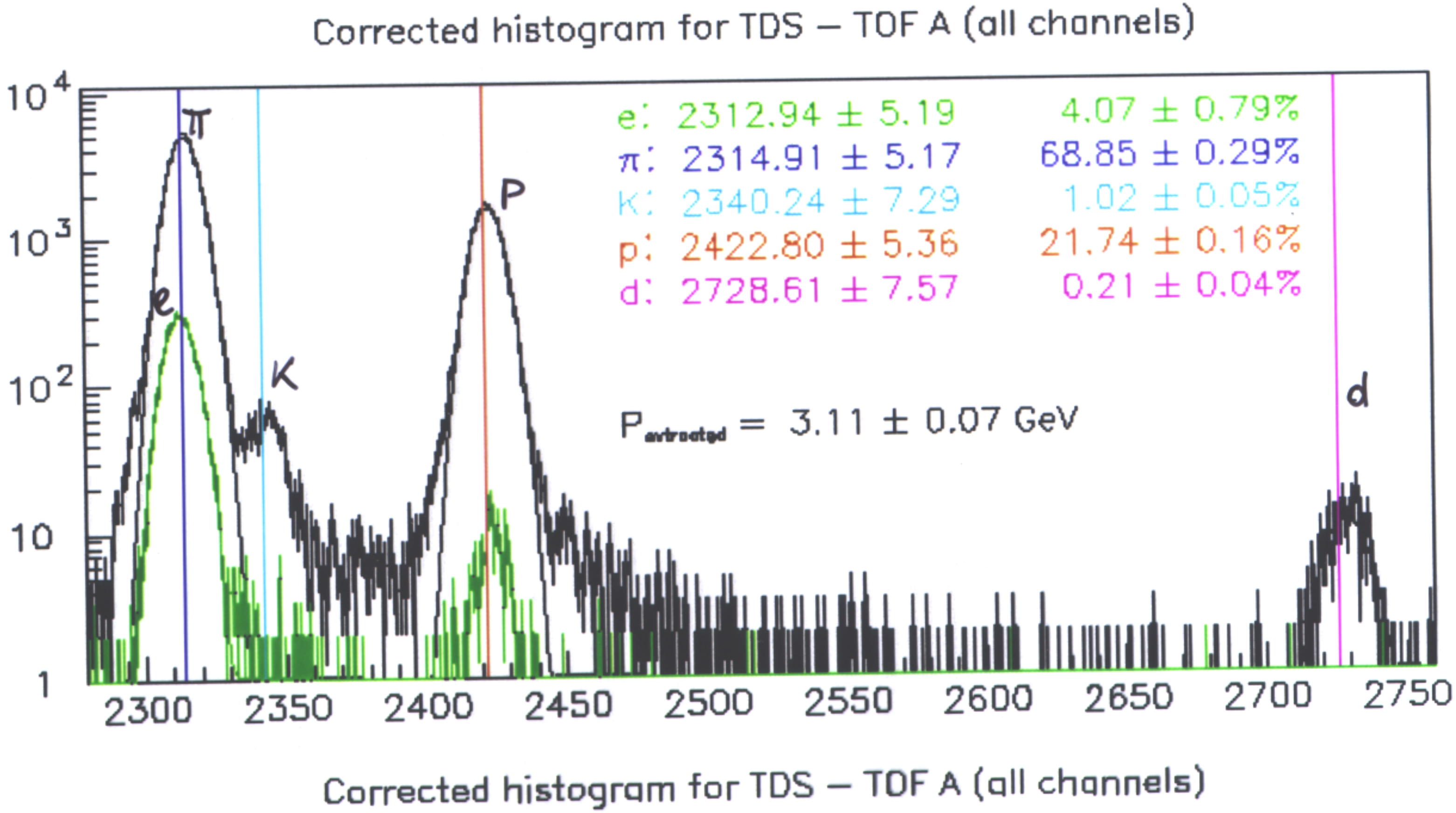
Geometry ON/OFF
Axis ON/OFF
Hits ON/OFF
Tracks ON/OFF
TPC Pads ON/OFF
TPC Raw Hits ON/OFF
TPC Clusters ON/OFF
PrintOUT
QUIT
Run 8107 Event 8392
12 GeV/c p
RPC
Large Angle detectors

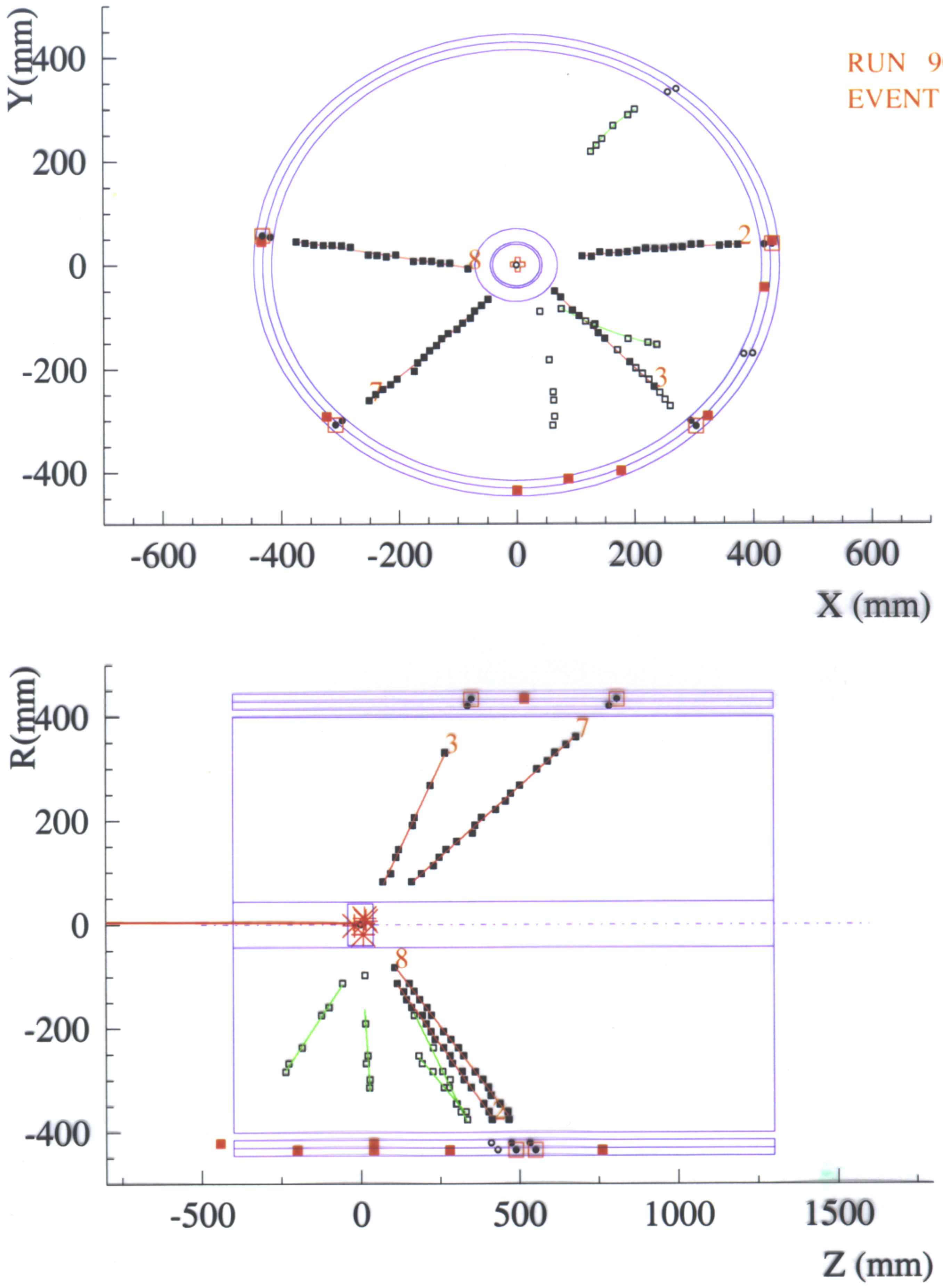
- beam shape and composition on a particle-by-particle basis
  - Time-of-Flight (~21 m): hadron PID $p \lesssim 5$ GeV/c
  - 2 Cherenkov counters: e^+e^- tagging ≤ 3 GeV/c
    - π tagging ≥ 3 GeV/c
  - 4 MWPC, $\sigma \sim 0.7$ mm on target impact-point
  - 6.44 λ μ identifier

$p = 3$ GeV/c

expected peak positions allow to calibrate and cross-check the beam-line momentum



Large Angle Analysis



2.6 Perspectives on 2002 data taking

PS beam will restart in May

→ cryogenic targets (H_2, D_2, N_2, O_2)

→ final K2K & MiniBooNE statistics

→ complete the measurements on standard targets with all beam momenta & both polarities

2.7 Follow-up

Complement the HARP measurements with higher momenta for:

- higher energy ν-fact proton drivers
- " " region of hadroproduction for atmosph. ν
- study the beam composition for NUMI (120 GeV/c) and JHF Super beam (50 GeV/c)

→ HARP/NA49 project @ CERN SPS using the NA49 apparatus

→ interesting option : E907 @ FNAL

This talk is dedicated

to the memory of my mother Giulia,

a very special woman which greatly

contributed to many events of my life

grazie mamma

A.