BULGARIAN PARTICIPATION IN THE SPS AND PS EXPERIMENTS

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Restricted ECFA Meeting
September 2002, Sofia

Introduction

- Experiments at SPS
  - NA48 – kaon decays
  - NA49 – hadron – nucleus, nucleus – nucleus interactions
  - CHORUS – neutrino oscillations
- Experiments at PS
  - HARP – precise measurement of hadron cross-sections

NA48

- NA 48 detector is designed for measurement of the CP-violation parameters in the K^0 – decays –successfully carried out.
  - NA48 experiment
- Investigation of rare K^0_s and neutral Hyperons decays – 2002
  - NA48/1 experiment
- Search for CP-violation and measurement of the parameters of rare charged Kaon decays – 2003
  - NA48/2 experiment

- Bulgarian participation – trough JINR Dubna since 1999
  - ✓ 2 physicists and 2 PhD students - University of Sofia
  - ✓ Experiment running
  - ✓ Data analysis
  - ✓ Very active but,
  - ✓ Financial support – JINR + BG contribution ~ 1500 $/year

Direct CP-violation

Interference of two decay amplitudes with different final state (strong) interactions needed.

$K \rightarrow \pi\pi$ decays: two amplitudes A_0, A_2 (final state isospin $I = 0, 2$) with strong phases δ_0, δ_2 interfere:

$$\eta_{+-} \equiv \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} \simeq \varepsilon + \varepsilon' \qquad \eta_{00} \equiv \frac{A(K_L \to \pi^0\pi^0)}{A(K_S \to \pi^0\pi^0)} \simeq \varepsilon - 2\varepsilon'$$

$$\varepsilon' \simeq \frac{i}{\sqrt{2}} \mathrm{Im}\left(\frac{A_2}{A_0}\right) \exp[i(\delta_2 - \delta_0)]$$

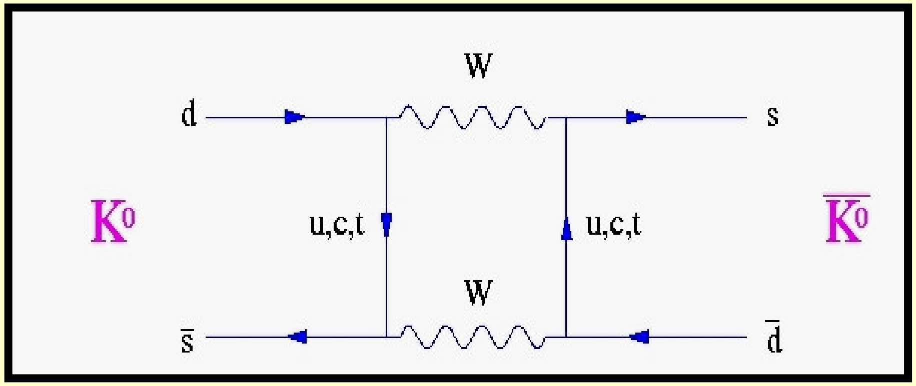
Direct CP violation

The experimental observable is the *double ratio*:

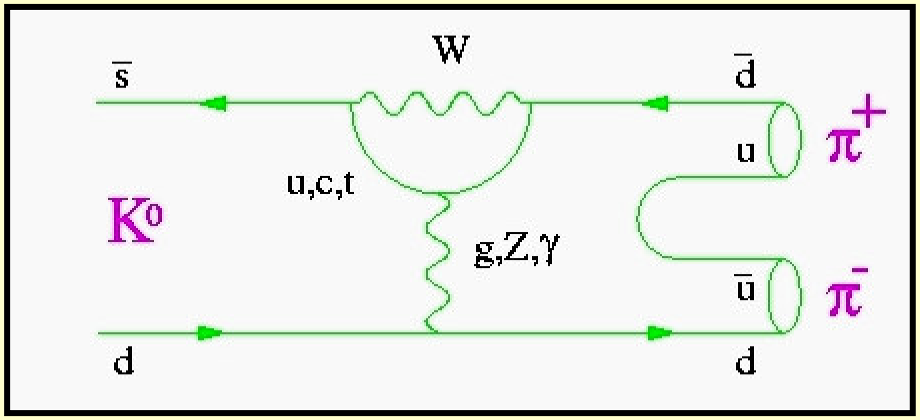
$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \Big/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)} \simeq 1 - 6\,\mathrm{Re}(\varepsilon'/\varepsilon)$$

SM Direct CP-violation

Indirect CP violation through mixing
K^0 / $\overline{K}^0$ oscillation – ε parameter



Direct CP violation through decay
Penguin diagrams – ε' parameter



Theoretical predictions **Re(ε'/ε)** ~ -10^{-4} to ~ $30 \cdot 10^{-4}$
with errors ~ $5\text{-}10 \cdot 10^{-4}$
Very difficult (non perturbative) problem

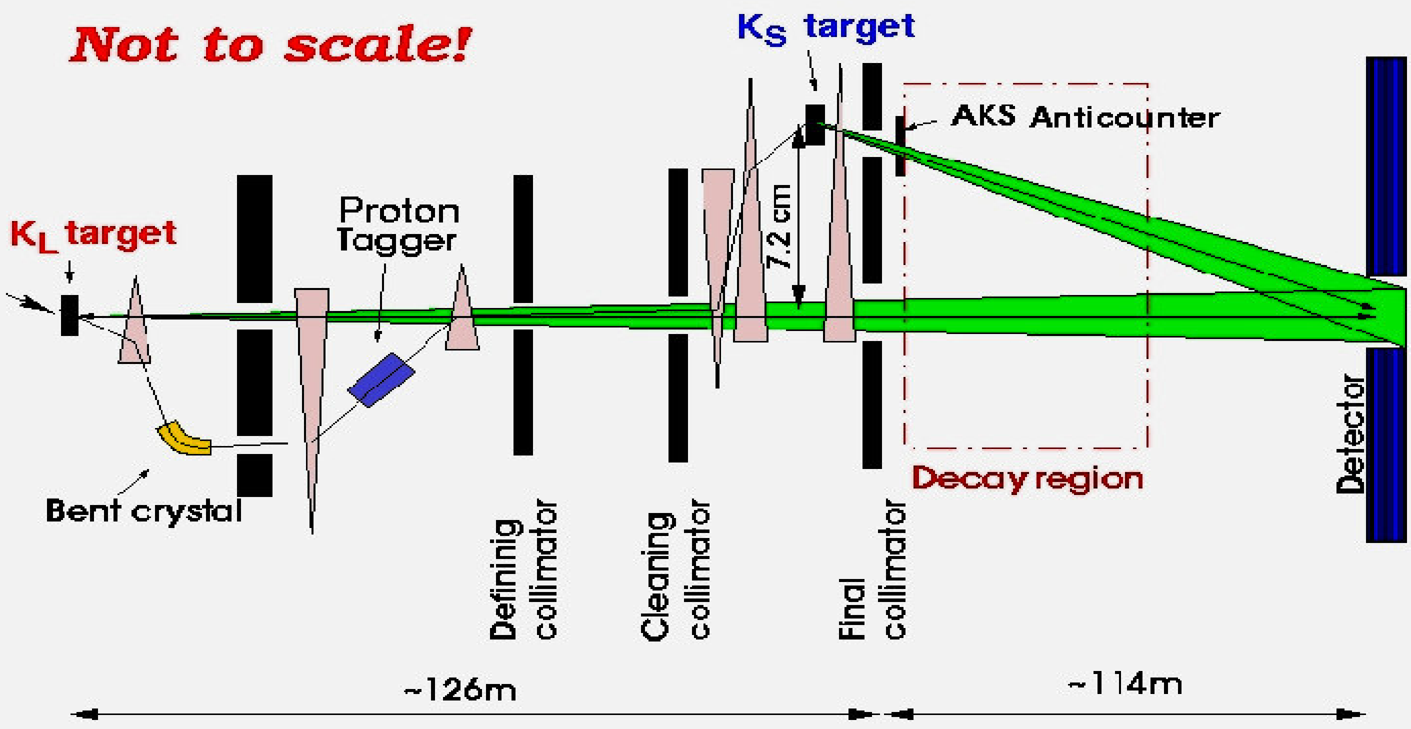
NA48 Direct CP-violation

$$R = \frac{N(K_L \to \pi^0\pi^0)}{N(K_S \to \pi^0\pi^0)} \Big/ \frac{N(K_L \to \pi^+\pi^-)}{N(K_S \to \pi^+\pi^-)} \simeq 1 - 6\, \mathrm{Re}(\varepsilon'/\varepsilon)$$

The NA48 "philosophy" is to fully exploit the reduction of all systematic effects in the double ratio to minimize the size of all corrections:

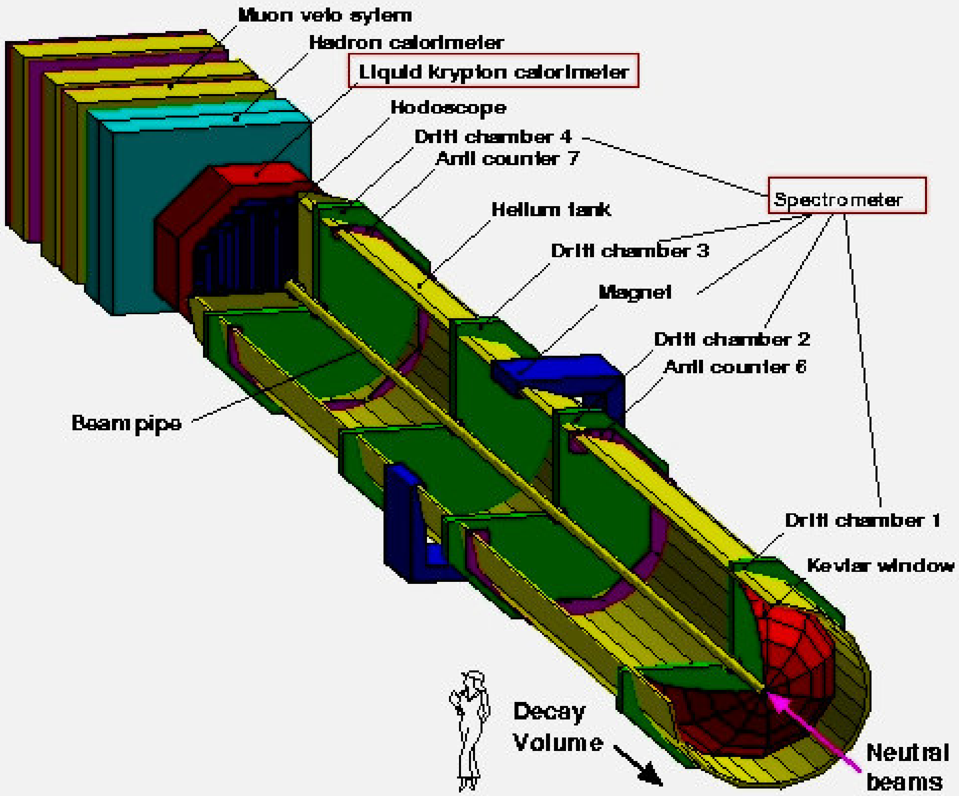
- Simultaneous, almost collinear K_L and K_S beams, allow for concurrent detection of the four modes in the same decay region
  $\Rightarrow$ cancellation of fluxes, inefficiences, dead times, accidental losses;
- K_S identification by time-of-flight proton tagging upstream of K_S production target;
- Detector based on a quasi-homogeneous liquid Krypton calorimeter and a magnetic spectrometer gives high resolutions
  $\Rightarrow$ minimize backgrounds;
- Apply lifetime weighting procedure to equalize K_S and K_L longitudinal decay position distributions
  $\Rightarrow$ minimize acceptance corrections

K_s and K_L simultaneous beams



K_S are distinguished from K_L by tagging the protons upstream of their production target.

NA48 detector



- Magnetic spectrometer to detect $\pi^+\pi^-$ events + scintillator hodoscope for event time measurement
- Quasi homogeneous liquid Krypton calorimeter to detect $\pi^0\pi^0$ events and measure their time
- Anti-counters for photons and muons
- Neutral beams always through vacuum

Direct CP - violation

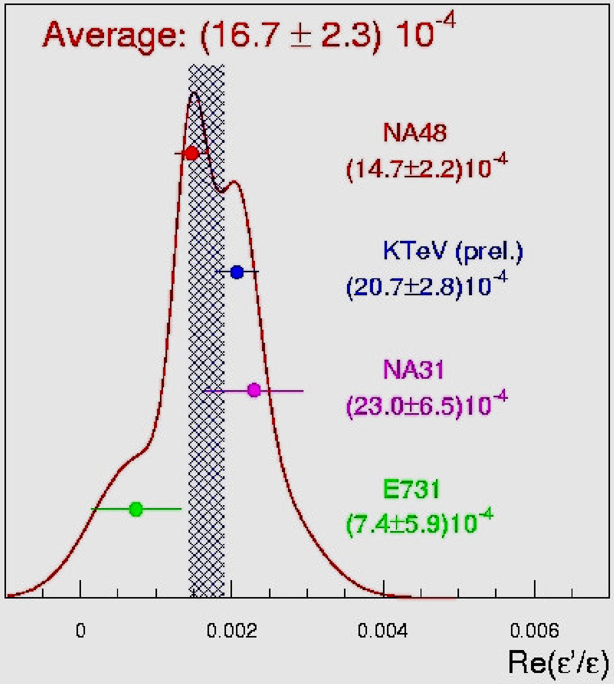
From 2001 data:

$$\varepsilon'/\varepsilon = (13.7 \pm 3.1) \times 10^{-4}$$

Combining with 97+98+99 result $(15.3 \pm 2.6) \times 10^{-4}$

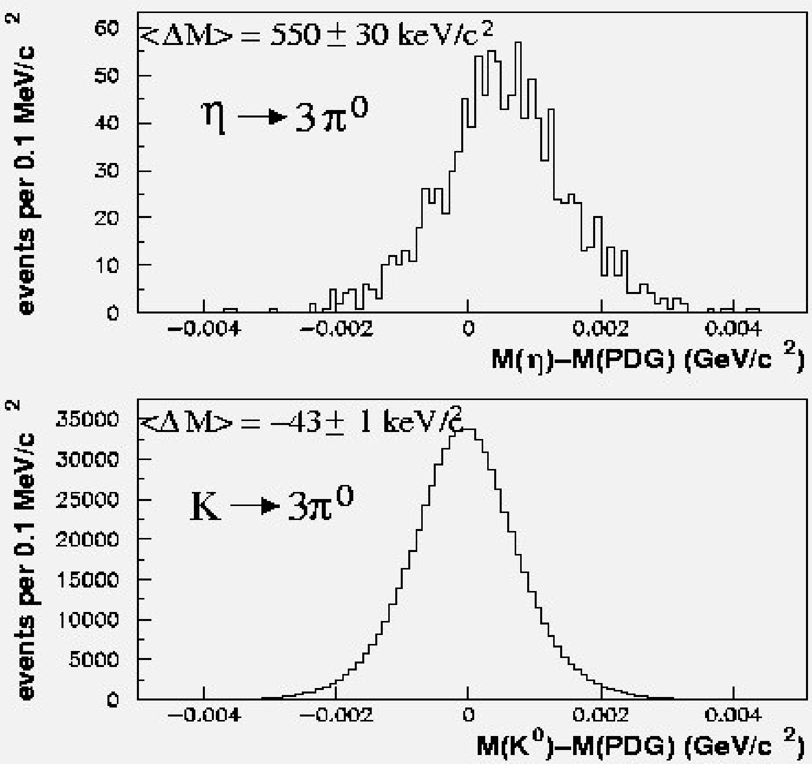
$$\varepsilon'/\varepsilon = (14.7 \pm 2.2) \times 10^{-4}$$

6.7 σ away from 0 (was 5.9 σ)
2001 result in agreement with previous ones
Paper ready for publication



Naive average: $\mathrm{Re}(\varepsilon'/\varepsilon) = (16.6 \pm 1.6) \cdot 10^{-4}$
$\chi^2/\mathrm{ndf} = 6.2/3$ PDG scaled error $2.3 \cdot 10^{-4}$

Measurement of K^0 and η mass



- Use $\eta \to 3\pi^0 \to 6\gamma$ decays (background free, no K_S beam) from year 2000
- Decay vertex from π^0 mass constraint $\Rightarrow M_{\eta(K)}/M_{\pi^0}$
- Independent of energy scale
- Symmetric decays: reduced non-linearities sensitivity
- Check using $K_L \to 3\pi^0$

4.2 σ shift (0.1%) from PDG on M_η, used to check energy scale with $\eta \to \gamma\gamma$

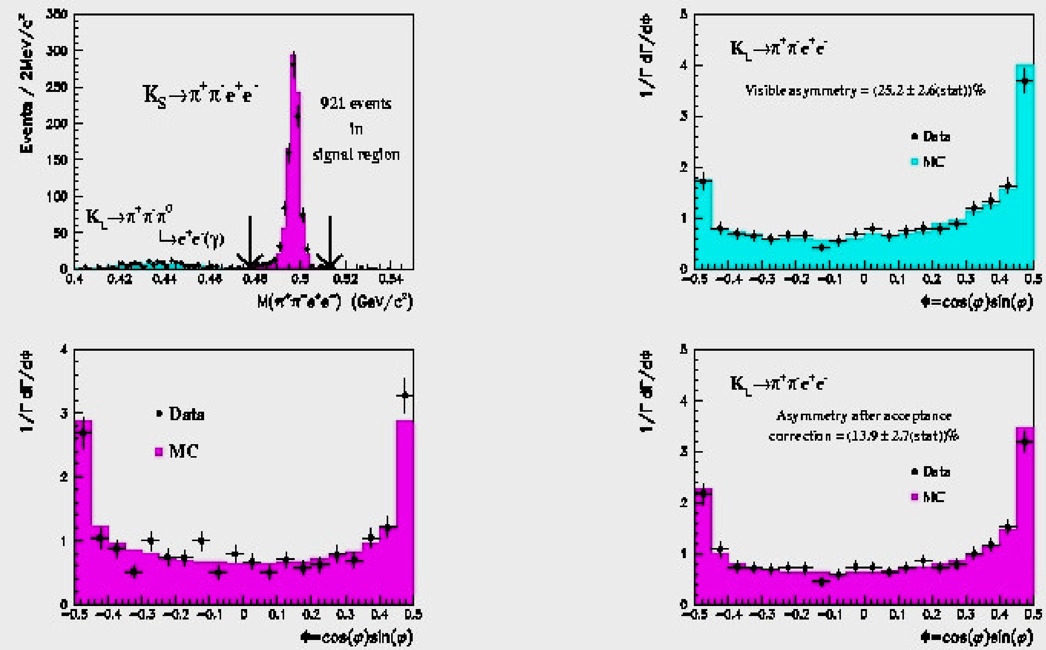
$$M_\eta = 547.843 \pm 0.030_{stat} \pm 0.041_{syst} \text{ MeV}/c^2$$
$$M_{K^0} = 497.625 \pm 0.001_{stat} \pm 0.031_{syst} \text{ MeV}/c^2$$

(Preprint: `hep-ex/0204008`)

$K_S, K_L \rightarrow \pi^+\pi^- e^+e^-$

For K_L, interference between M1 and IB amplitudes gives large T-odd asymmetry in the azimuthal distribution between the $\pi^+\pi^-$ and e^+e^- Decay planes in the CM system

Expected – A(ϕ) ~ 14%



1998+1999 data (921 K_S events, 1337 K_L events):

$$BR(K_S \rightarrow \pi^+\pi^- e^+ e^-) = (4.3 \pm 0.2 \pm 0.3) \cdot 10^{-5}$$

No K_S asymmetry: $A_S(\phi) = (-0.2 \pm 3.4 \pm 1.4)\%$

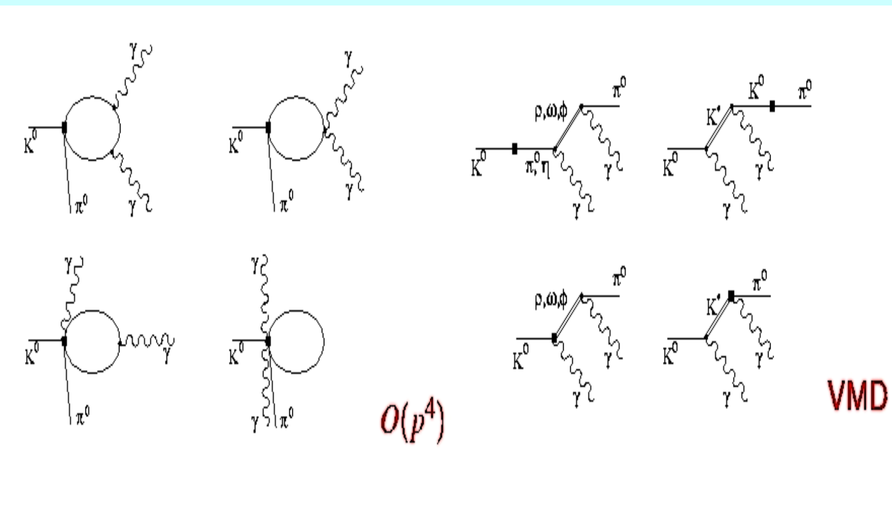
$$BR(K_L \rightarrow \pi^+\pi^- e^+ e^-) = (3.1 \pm 0.1 \pm 0.2) \cdot 10^{-7}$$

K_L asymmetry: $A_L(\phi) = (13.9 \pm 2.7 \pm 2.0)\%$

$K_L \rightarrow \pi^0\gamma\gamma$

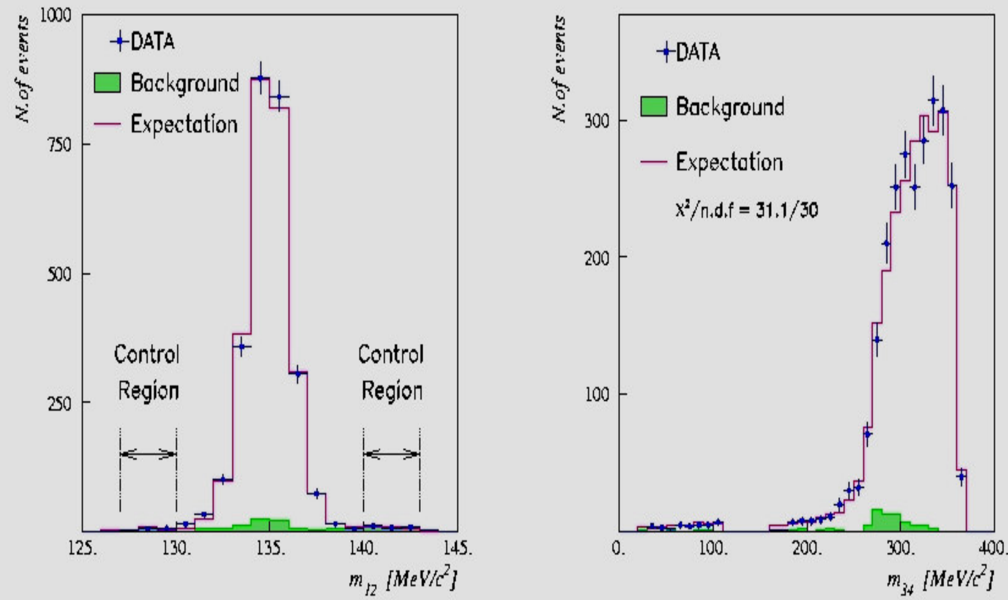
χPT $O(p^4)$ prediction is 1/3 of expt –
Br ~ 0.6 10^{-6}

At $O(p^6)$ including vector meson exchange, can reproduce the rate



VMD contribution parameterized by $\mathbf{a_V}$

To be determined experimentally



Keeping only non-ambiguous events: $a_V = -0.46 \pm 0.03_{stat} \pm 0.04_{syst}$

Using fitted value of a_V and all events:

$$BR(K_L \rightarrow \pi^0\gamma\gamma) = (1.36 \pm 0.03_{stat} \pm 0.03_{syst} \pm 0.03_{norm}) \cdot 10^{-6}$$

Systematics dominated by acceptance and background (hep-ex/0205010)

Implies negligible CP-conserving amplitude in $K_L \rightarrow \pi^0 e^+ e^-$

Present and Future

NA48/1 is a high-sensitivity search for rare K_S decays
No K_L beam, high-intensity (× several hundred) K_S beam.

- 40 h run in 1999:

  Measurement of $BR(K_S \to \gamma\gamma)^a =$
  $(2.78 \pm 0.06_{stat} \pm 0.02_{MCstat} \pm 0.04_{syst}) \cdot 10^{-6}$

  Limit on $BR(K_S \to \pi^0 e^+ e^-)^b < 1.4 \cdot 10^{-7}$ (90%CL)

- Presently running (80 days scheduled)

  Aim at $\sim 3 \cdot 10^{-10}$ SES for $K_S \to \pi^0 e^+ e^-$

  Search for CPV in $K_S \to 3\pi^0$ and $K_S \to \pi^+\pi^-\pi^0$

  Rare hyperon decays

[a] PL B493 (2000) 29
[b] PL B514 (2001) 253

NA48/2 is an approved experiment scheduled for 2003, for the measurement of direct CP violation in $K^\pm$ decays.

- Simultaneous, collinear, momentum-selected $K^\pm$ beams (60 GeV/$c \pm 5\%$)
- Measurement of odd-pion Dalitz plot slope asymmetry in $K^\pm \to \pi^\pm\pi^+\pi^-$ and $K^\pm \to \pi^\pm\pi^0\pi^0$ decays

$$|M(u,v)|^2 \propto 1 + gu + hu^2 + jv + kv^2 + \cdots$$
$$A_g \equiv (g^+ - g^-)/(g^+ + g^-)$$

  Theoretical predictions for A_g in the O(10^{-6} to 10^{-4}) range.

  Experiment: $A_g = (-7 \pm 5) \cdot 10^{-3}$ (Ford, 1970)

  With more than $2 \cdot 10^9 K^\pm \to \pi^\pm\pi^+\pi^-$ decays/year, NA48/2 can measure A_g with a precision $\delta A_g < 2 \cdot 10^{-4}$

- Study low-energy $\pi^+\pi^-$ interaction in $K^\pm \to \pi^+\pi^- e^\pm \nu(\bar{\nu})$ (K_{e4}) decays to extract size of quark condensate $\langle 0|q\bar{q}|0\rangle$ (to understand chiral symmetry breaking mechanism)

  Expect $\delta a_0^0 \simeq 0.007$ (stat) with $10^6 K_{e4}$ events

NA49

❖ Main goal of the experiment

➢ Search for signatures of quark – gluon plasma at SPS energies (20-158 A-GeV)

❖ Data taking - till 2002

❖ Data analysis – one – two more years

➢ Bulgarian participation

✓ 2 physicists 2 PhD student and 2 students - University of Sofia

✓ 3 physicists – INRNE of BAS

✓ dE/dx calibration of TPC

✓ Experiment running

✓ Software development and Data analysis

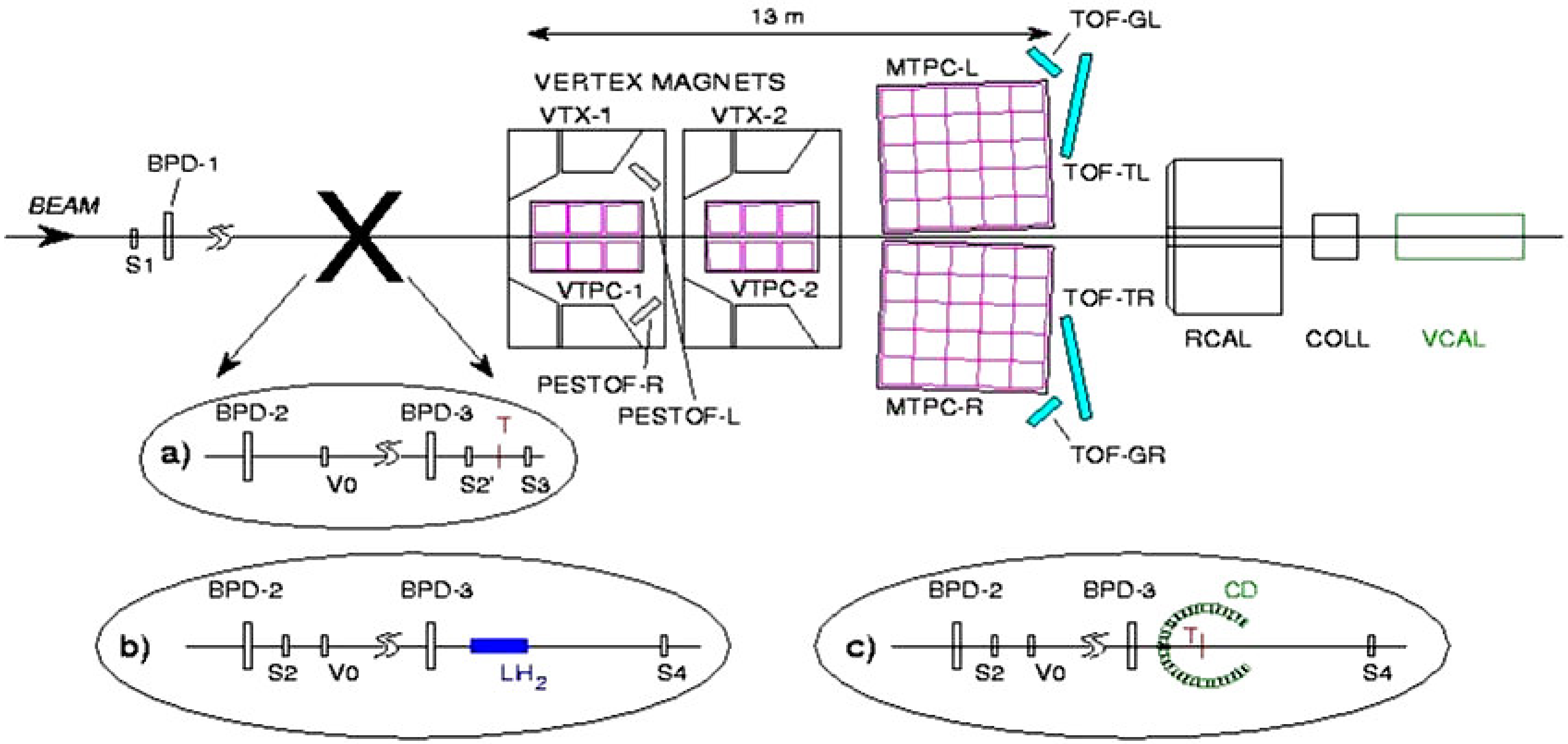
✓ Financial support – only by collaboration, debt 5000 CHF

NA49

- The aim:
- To localize and investigate the properties of the transition region from confined matter to quark gluon plasma
- Existing data suggest – transition take place at low SPS energies
- For this purpose:
- Energy dependence of hadronic observables
- System size dependence of hadronic observables
- Investigation of event to event fluctuations (charge , mean p_t)
- Better understanding of pp and pA interactions

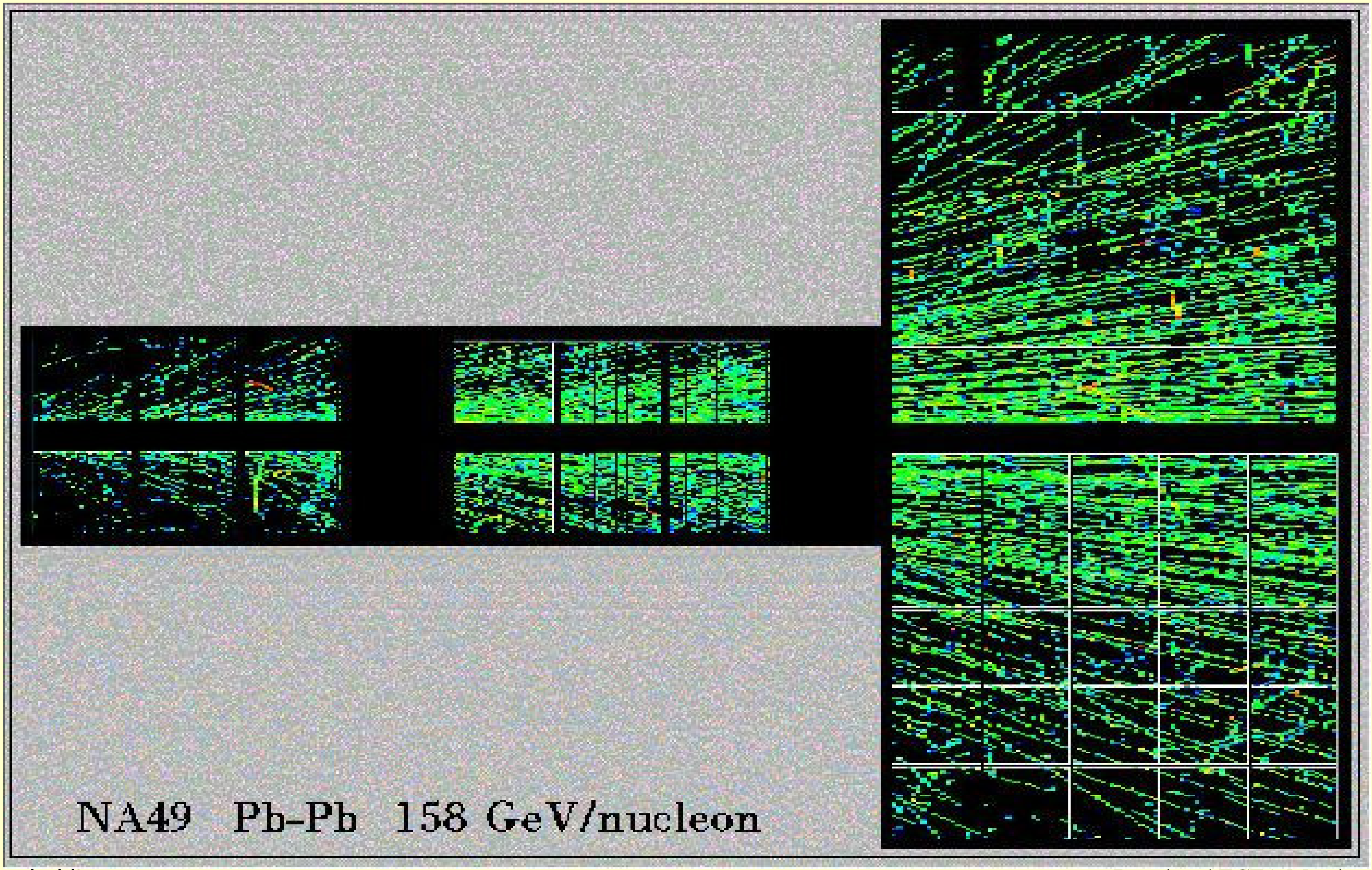
- Experimental setup
  - Good momentum resolution
  - Good two track resolution – huge number of tracks in AA collisions
  - Good particle identification

NA49 setup

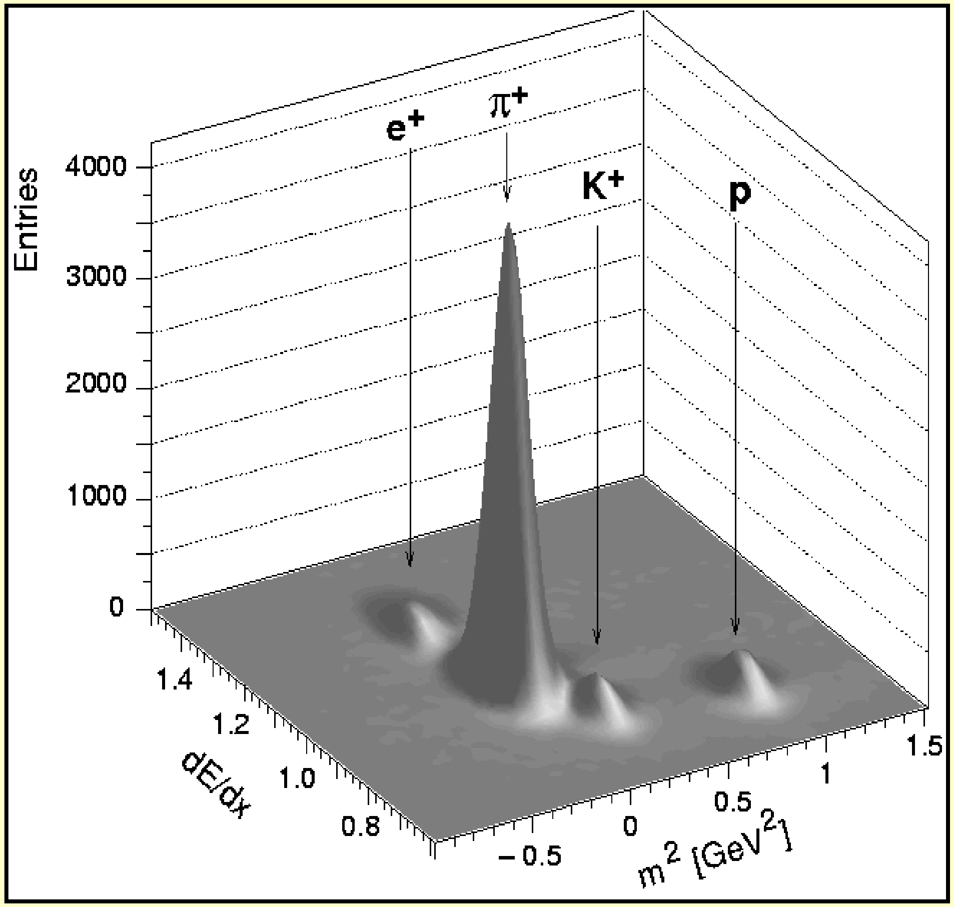


- Large acceptance hadron detector
- Three different target stations

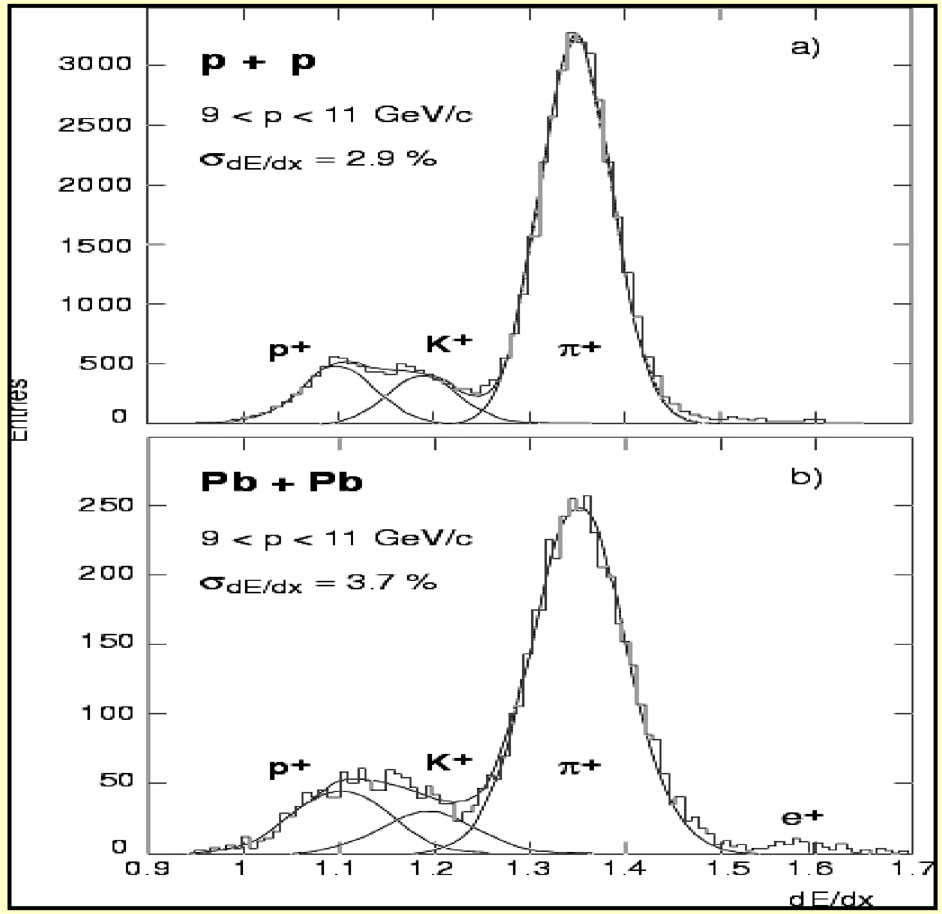
NA49 PbPb event



NA49 Particle Identification

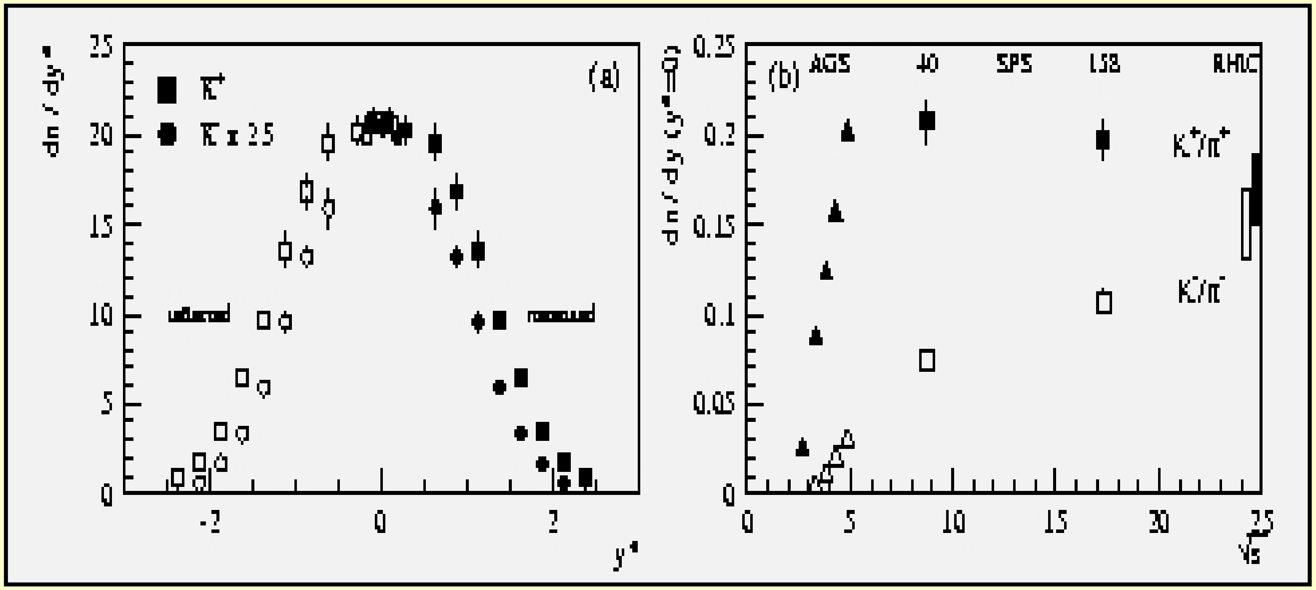


High energy particles - dE/dx



Low energy particles – TOF & dE/dx

Energy dependence – K, Λ



K/π ratio as function of s

K^-/π^- ratio – monotonic

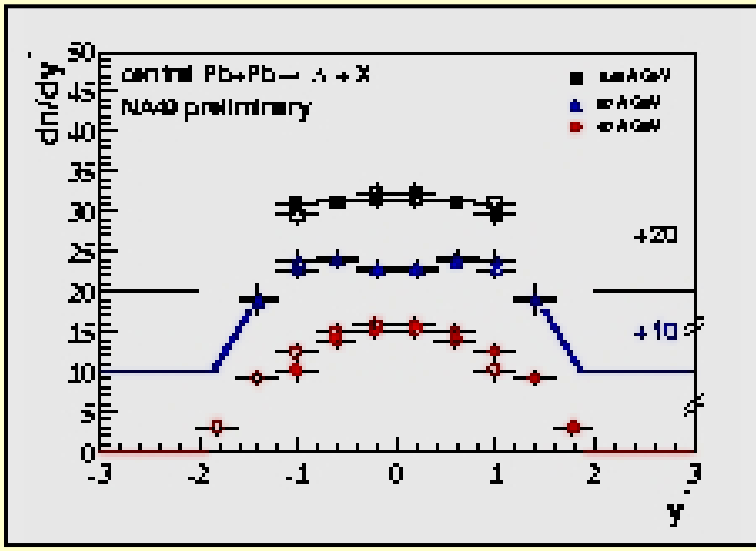
K^+/π^+ ratio – reach maximum at 30 -40 GeV

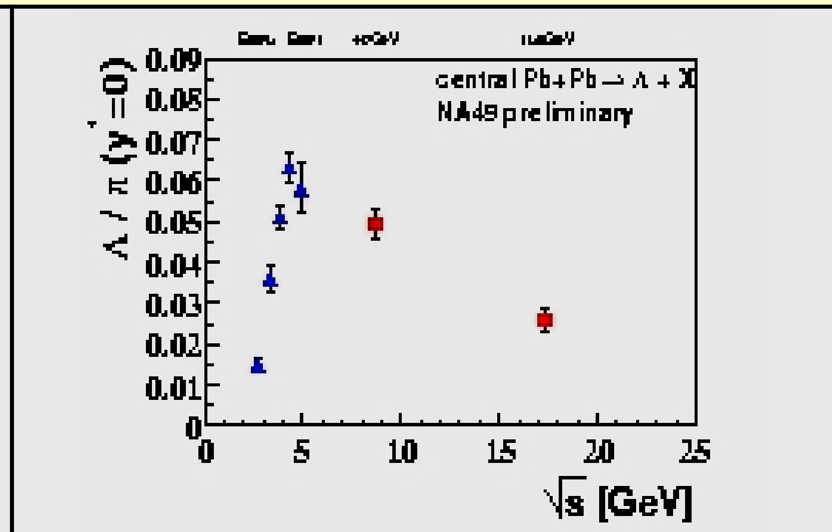
The same for Λ/π ration

The explanation – if assume a phase transition at ~ 40 GeV

Rapidity distribution for K and Λ at 40 GeV,

The same behavior at other energies





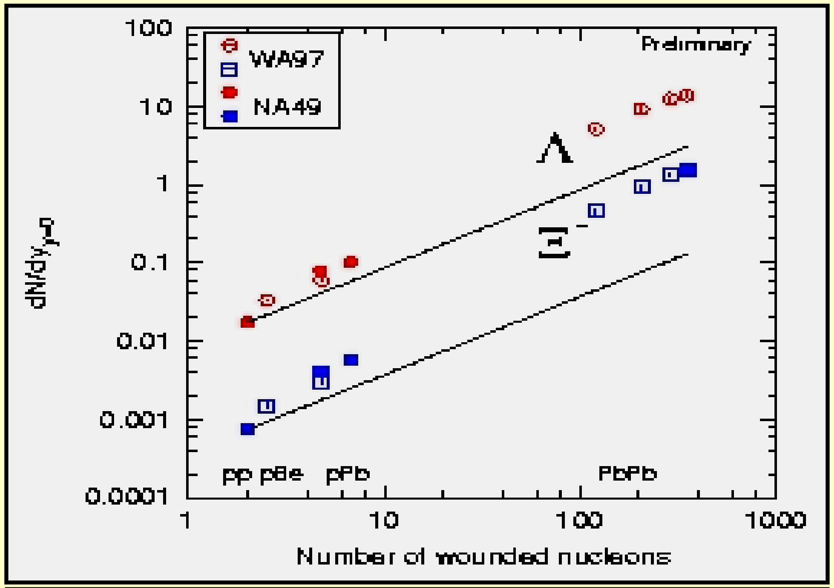
Hyperon Yields in pp, pA and AA collisions

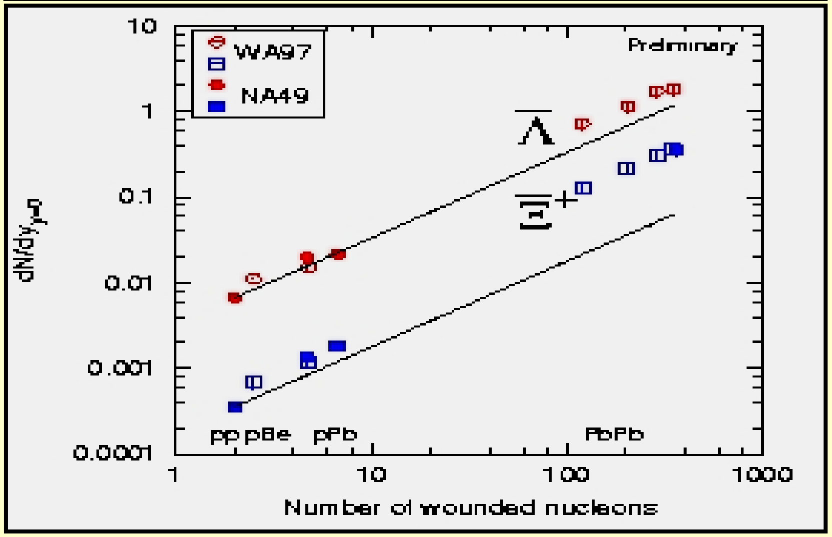
The enhancement of hyperon production per participant in A + A collisions compared to p+A collisions is clearly visible

However almost the same effect in p+A collisions comparing to p+p collision

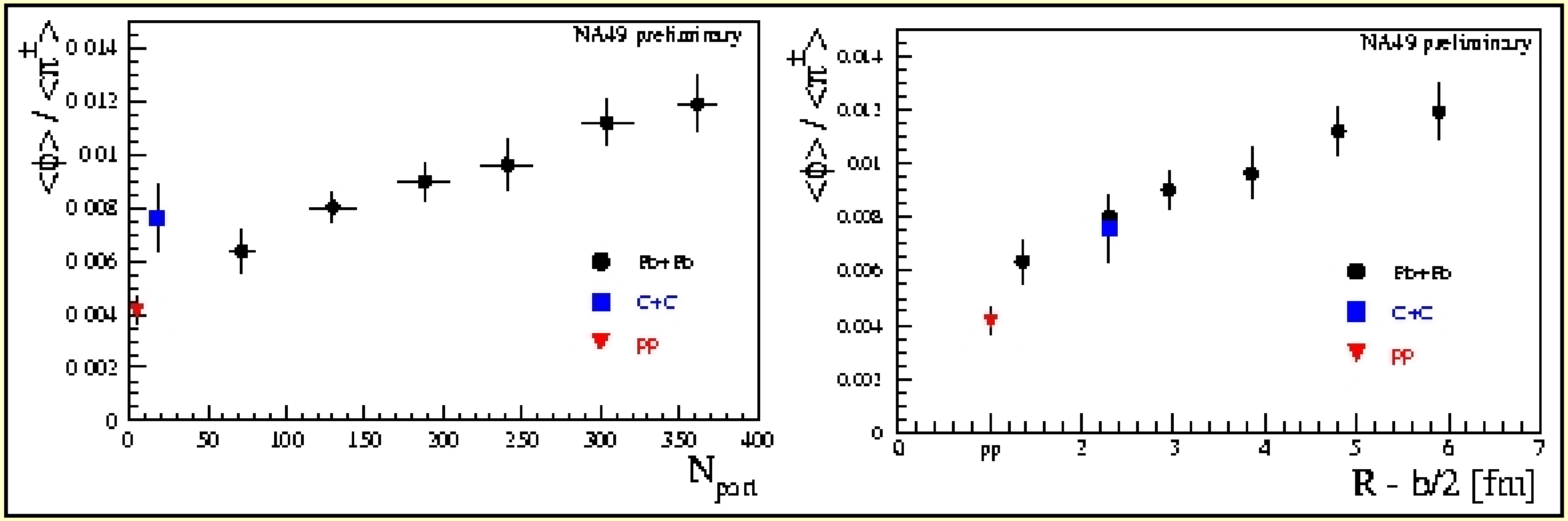
Important – isospin effects – should be clarified

(pp and pn data)





System size dependence of ϕ production



Comparing the Φ/π ratio of central collision of light ions to that of peripheral collision of heavy nuclei

The number of participants may be not the right variable to characterize the reaction

Does not take into account the collision geometry

R – nuclear radius, b – the impact parameter of the collision

Variable R-b/2 – thickness of the interaction region

NA49

More than 28 . 10 ^{6} events collected at different energies and targets

Need for low energy data (20 – 30 GeV)

October 2002 – Pb+ Pb run

data	energy	years	events
p + p	158 GeV	1996, 1999, 2000, 2001, 2002	8.9 mln.
	100 GeV	1998	640 000
	40 GeV	1998, 1999	410 000
p + Al	158 GeV	1997	355 000
p + C	158 GeV	2002	570 000
p + C	100 GeV	2002	200 000
p + Pb	158 GeV	1997, 1999, 2001	3.4 mln.
	100 GeV	2001	470 000
	250 GeV	1997	100 000
$\pi^{\pm}$ + p	158 GeV	2000	2.18 mln.
π^{+} + Pb	158 GeV	1997, 1999, 2001	910 000
π^{-} + Pb	158 GeV	2001	770 000
d + p	158 GeV	2000	980 000
d + p	40 GeV	1999	650 000
C + C	158 GeV	1998	560 000
C + C	40 GeV	1999	250 000
Si + Si	158 GeV	1998	410 000
Si + Si	40 GeV	1999	140 000
Pb + Pb	158 GeV	1996, 2000	5 mln.
	80 GeV	2000	381 000
	40 GeV	1999	1.55 mln.

CHORUS

- Main goal of the experiment
  - Observation of neutrino oscillation $\nu_\mu \rightarrow \nu_\tau$
  - **Observation of** ν_τ
  - Wide range investigation of charmed physics
- Data taking 1994 – 1997
- Currently – data analysis 1 or 2 years more

- Bulgarian participation
  - ✓3 physicists and 1 PhD student - Univ. of Sofia
  - ✓Experiment running
  - ✓Software development and Data analysis
  - ✓Financial support – only by collaboration

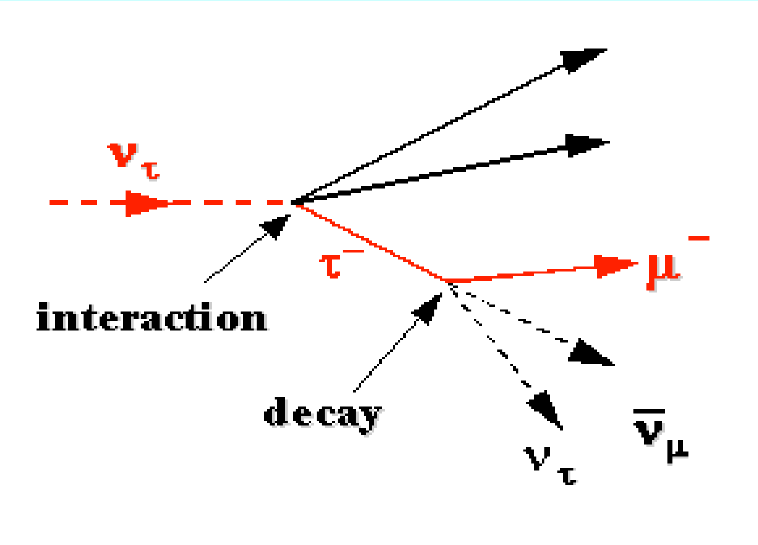
CHORUS Main objective

ν_τ appearance in the SPS WBB ν_μ beam via oscillation

$P(\nu_\mu \rightarrow \nu_\tau)$ down to $1 \cdot 10^{-4}$ for $\delta m^2 \sim 10\ eV^2$

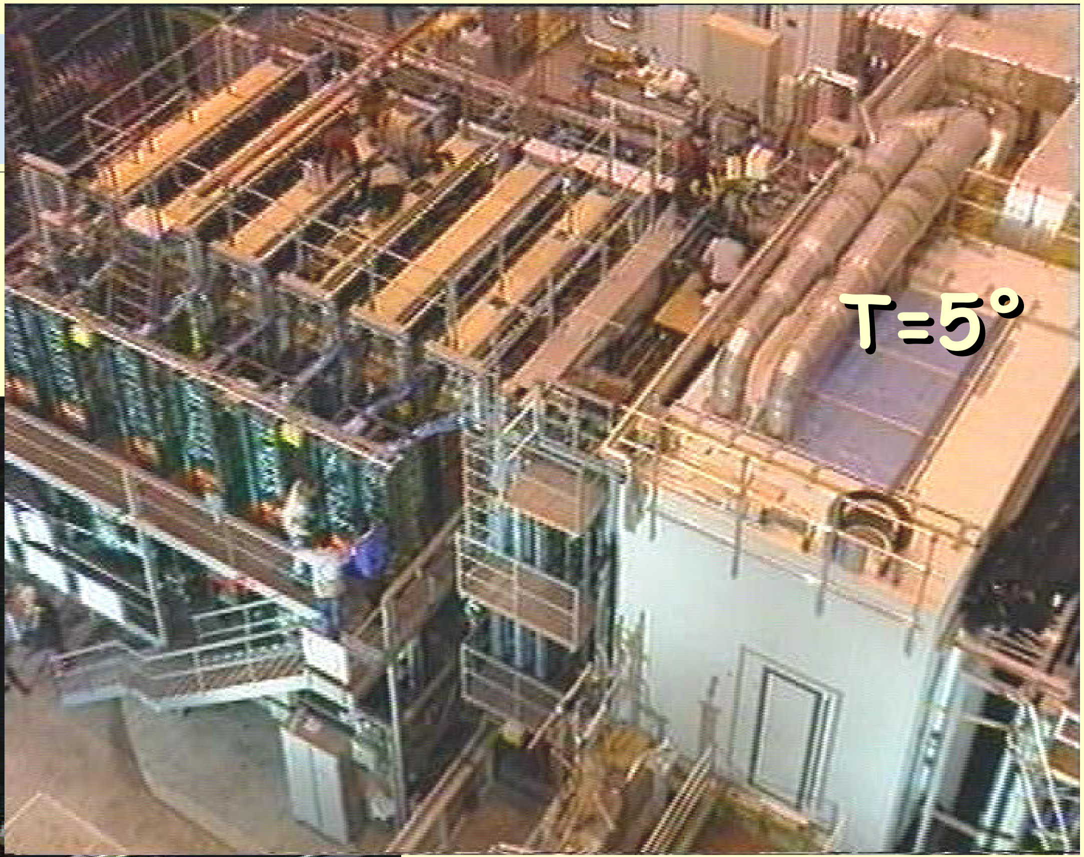
ν_τ direct detection in 770 kg nuclear emulsion target

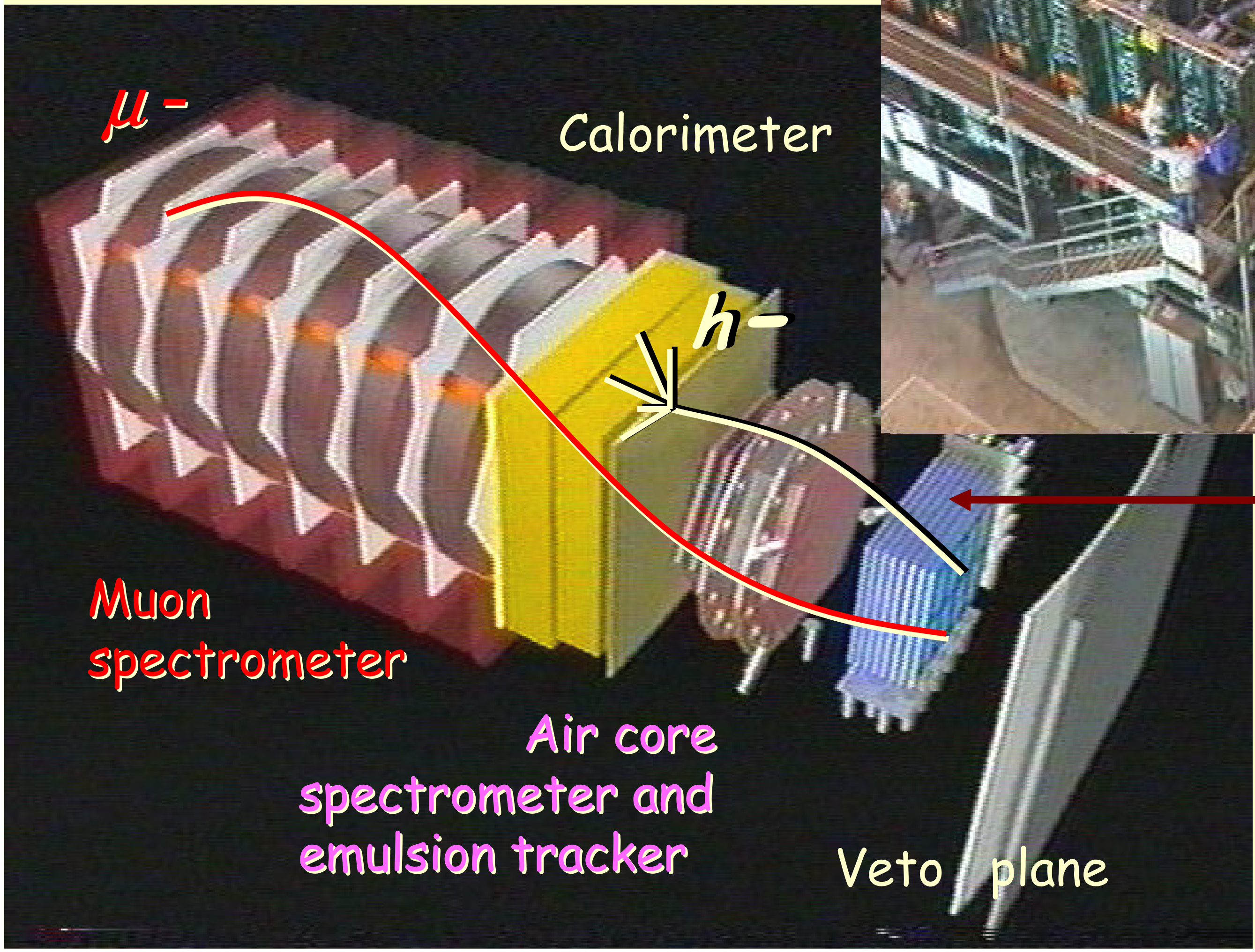
Tag: visible 1- and 3- prongs decay of primary τ-lepton (decay path ~1.5 mm)



CHORUS detector

Nucl. Instr. Meth A 401 (1997) 7





770 kg emulsion target and scintillating fibre tracker

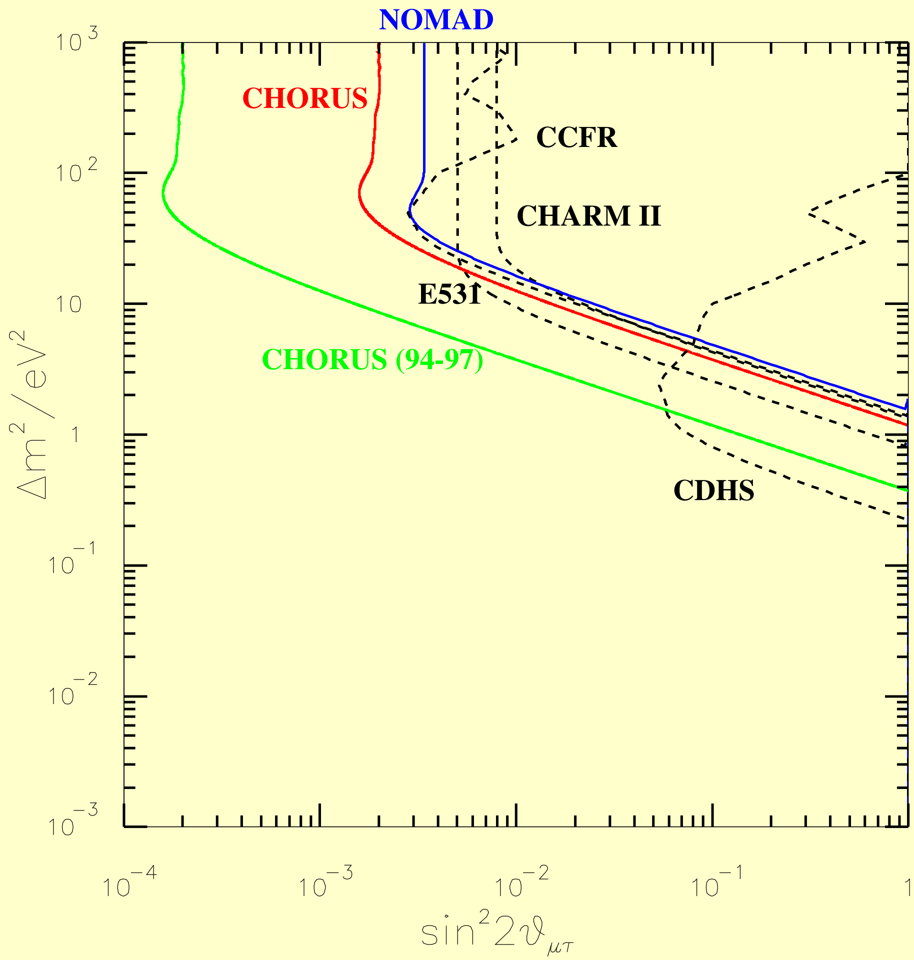
Restricted ECFA Meeting,
Sofia, September 2002

Limit on $\nu_\mu \rightarrow \nu_\tau$ oscillation

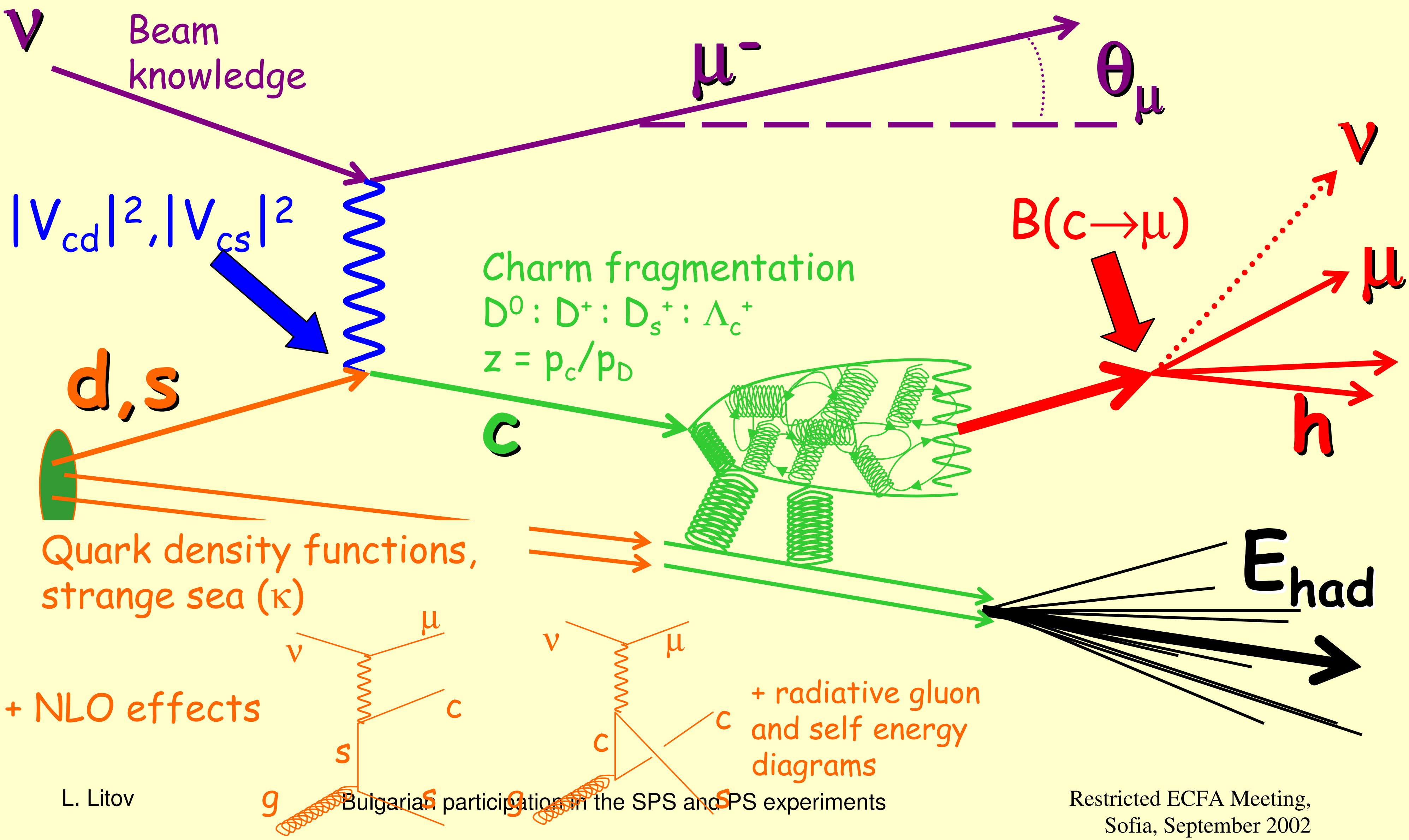
ν_τ interactions ware not observed

$$P_{\mu\tau} = \sin^2 2\theta_{\mu\tau} \cdot \sin^2\left(\frac{1.27 \cdot \Delta m^2_{\mu\tau} \cdot L}{E}\right)$$

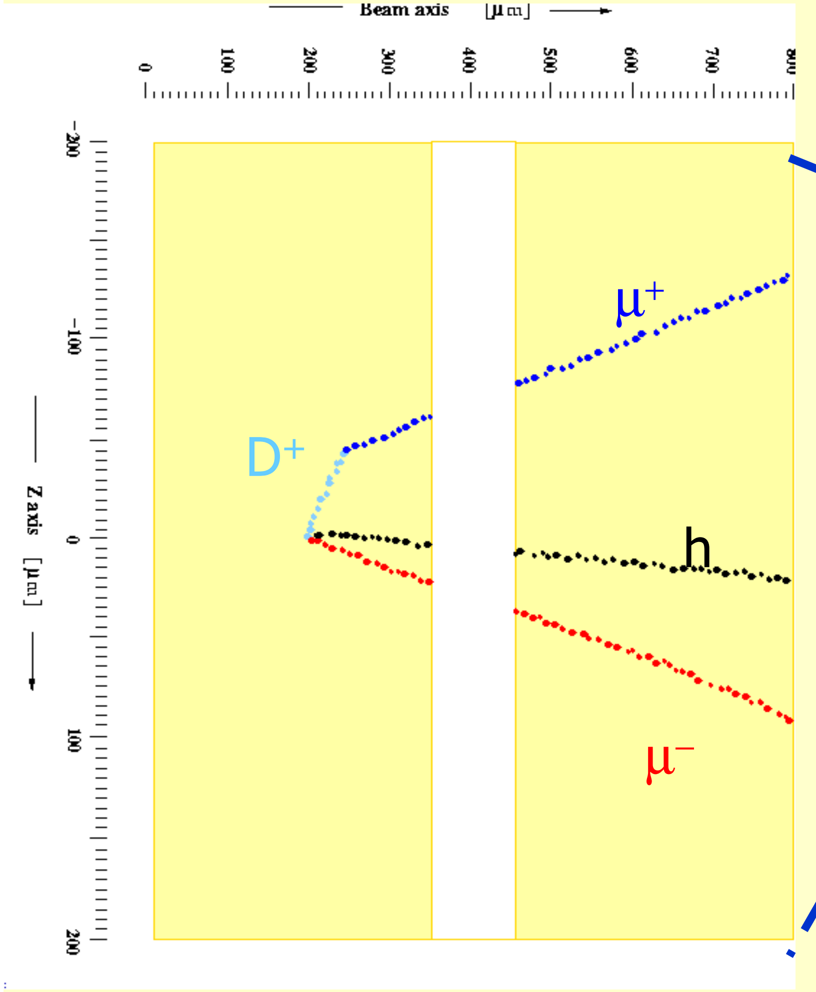
Upper limit for the probability for $\nu_\mu \rightarrow \nu_\tau$ oscillations



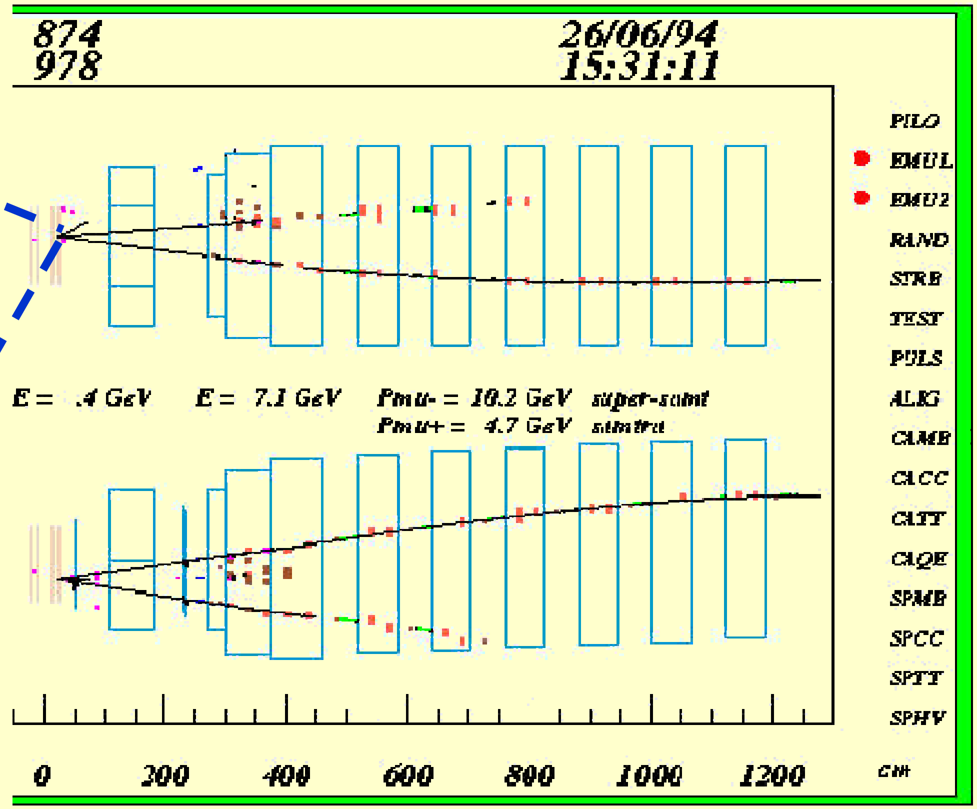
Neutrino charm production



Charm physics



Zoom



Diffractively produced D_s event

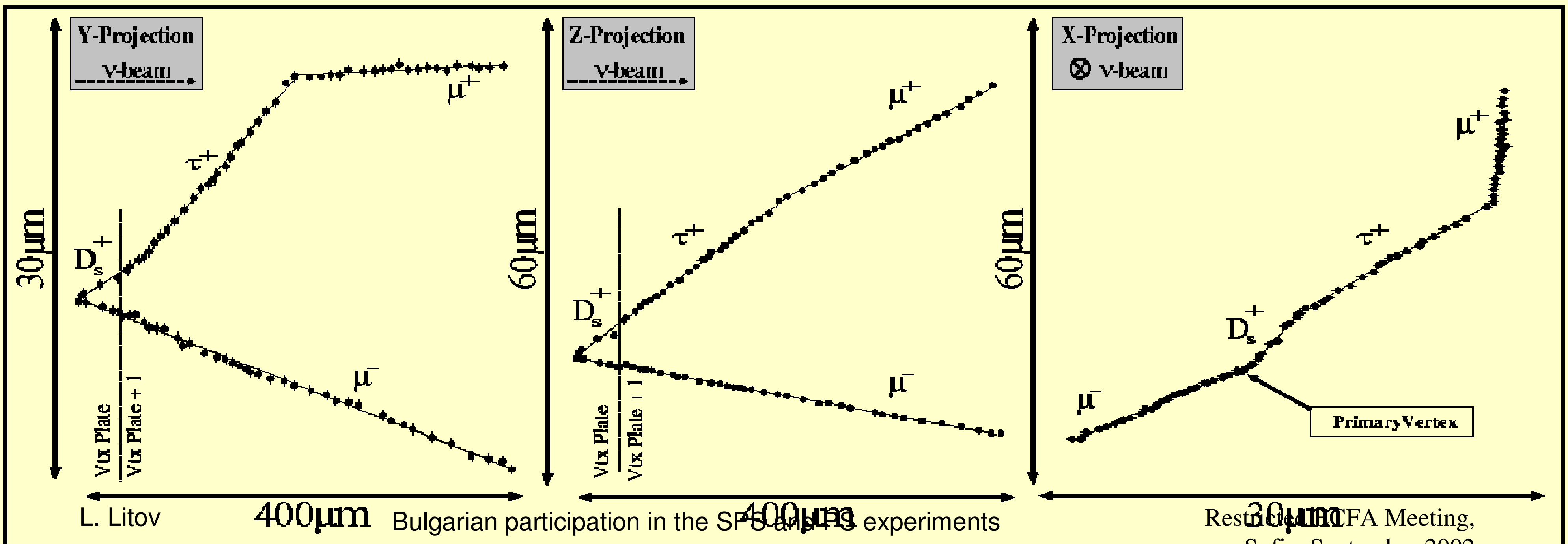
$$\nu_\mu N \rightarrow D_s^* \mu^- N'$$

$$\hookrightarrow D_s^+ \gamma$$

$$\hookrightarrow \tau^+ \nu_\tau$$

$$\hookrightarrow \mu^+ \nu_\mu \nu_\tau$$

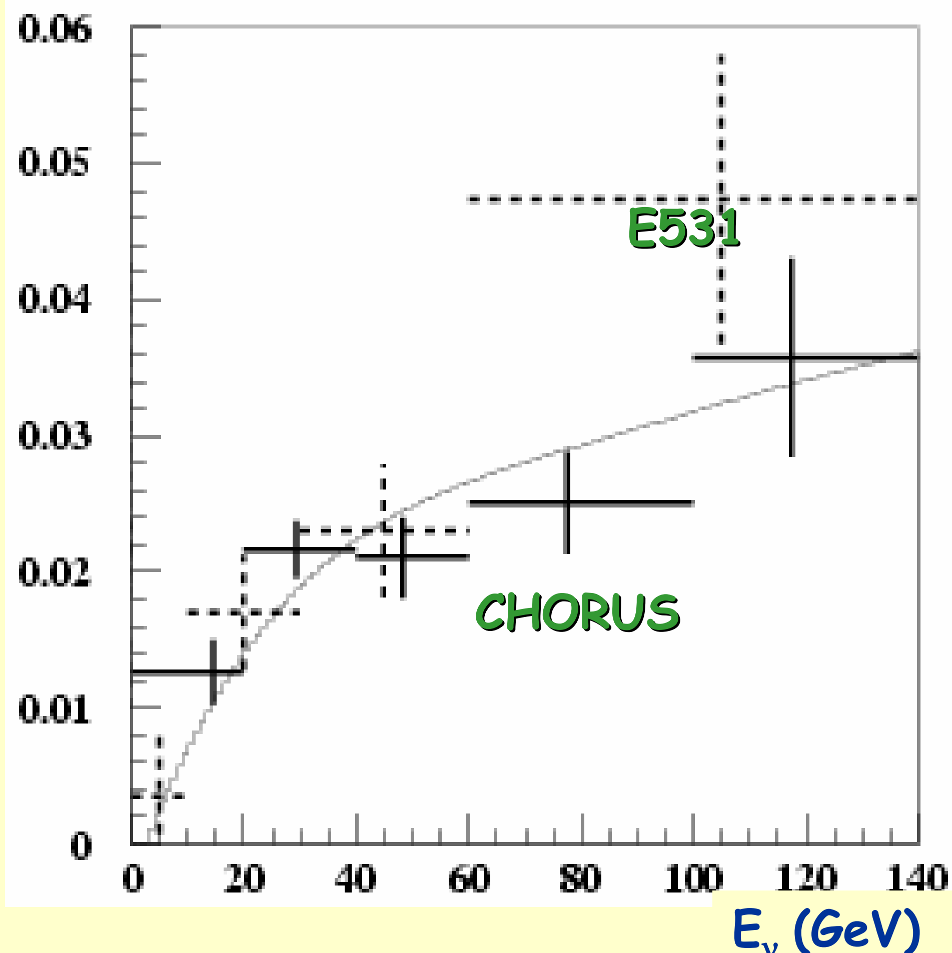
Phys. Lett. B 435 (1998) 458-464



D^0 production rate

$\sigma(D^0) / \sigma(CC) = 1.99 \pm 0.13$ (stat.) ± 0.17 (syst.) %

$\langle E_\nu \rangle = 27$GeV, $P_\mu < 30$GeV/c



$D^0 \rightarrow V4 / D^0 \rightarrow V2$
$= 23.1 \pm 4.0$ %

♦ $(D^0) / \sigma$ (charm)
$= 53 \pm 11$ %

Slow rescaling model
$m_c = 1.3$ GeV/c^2

Phys.Lett.B 527 (2002) p.173

HARP

- Main goal of the experiment
  - Measurement of hadron production in different materials
  - Better understanding of atmospheric ν flux
  - Optimization of pion production for future neutrino factory/muon collider projects
  - Wide range investigation of charmed physics
- Data taking 2001 -2002

- Bulgarian participation
  - ✓6 physicists, 1 engineer and 1 PhD student - Univ. of Sofia
  - ✓4 physicists – INRNE of BAS
  - ✓Construction, calibration and exploitation of RPC
  - ✓Ultrasound system for gas quality control (Cherenkov Counter)
  - ✓Trigger system - ~ 100 VME active splitters
  - ✓Experiment running
  - ✓Software development and Data analysis
  - ✓Financial support – no, but 30000 CHF debt to Collaboration

HARP – Primary Goal

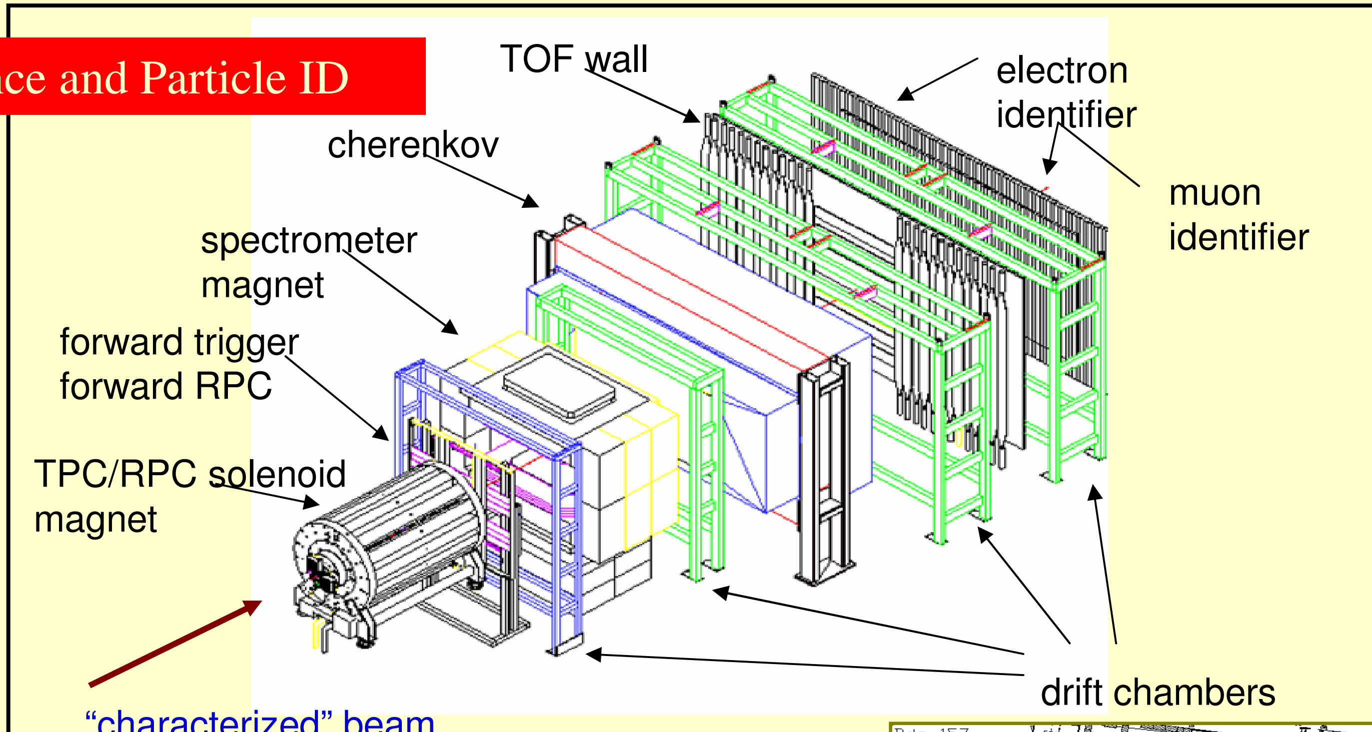
- Precise measurement (< 5%) of pion yeld

$$
\begin{array}{l}
p + T \rightarrow \pi + X \\
\qquad\quad\;\; \downarrow \\
\qquad\quad\;\; \mu + \nu_\mu \\
\qquad\quad\;\; \downarrow \\
\qquad\quad e + \nu e + \nu_\mu
\end{array}
$$

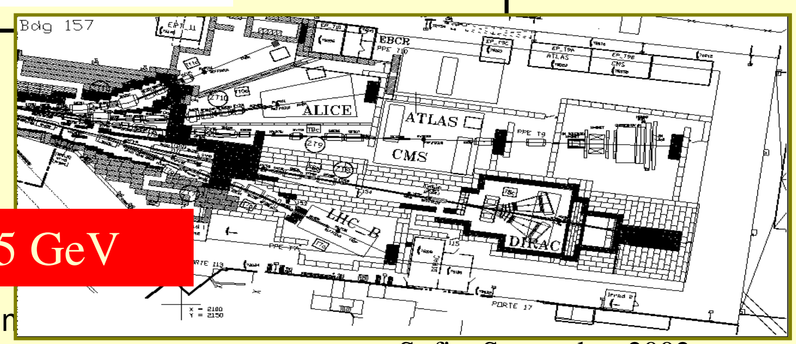
- Cross-section measurement precision < 2%
- Detector requirements
  - ✓ Good momentum resolution
  - ✓ Particle identification for primary and secondary particles

The HARP Detector

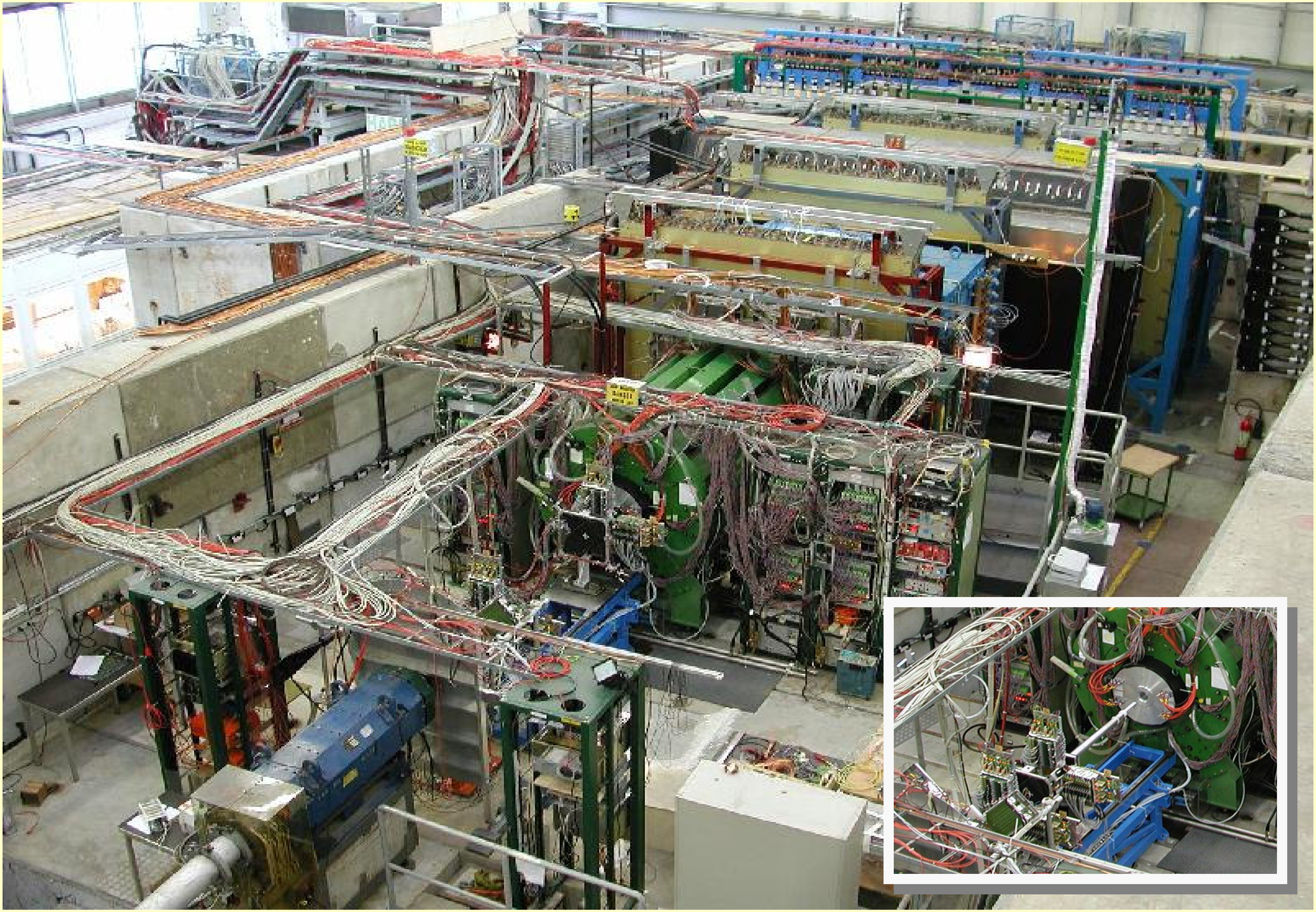
Large Acceptance and Particle ID



Neutrino Factory: ~2-24 GeV
Atmospheric meson flux: 2-100 GeV



PS East Area beams: 2-15 GeV



Beam and Trigger Instrumentation

- **Time-of-Flight (~21.3 m):**
  hadron PID ≤ 5 GeV/c

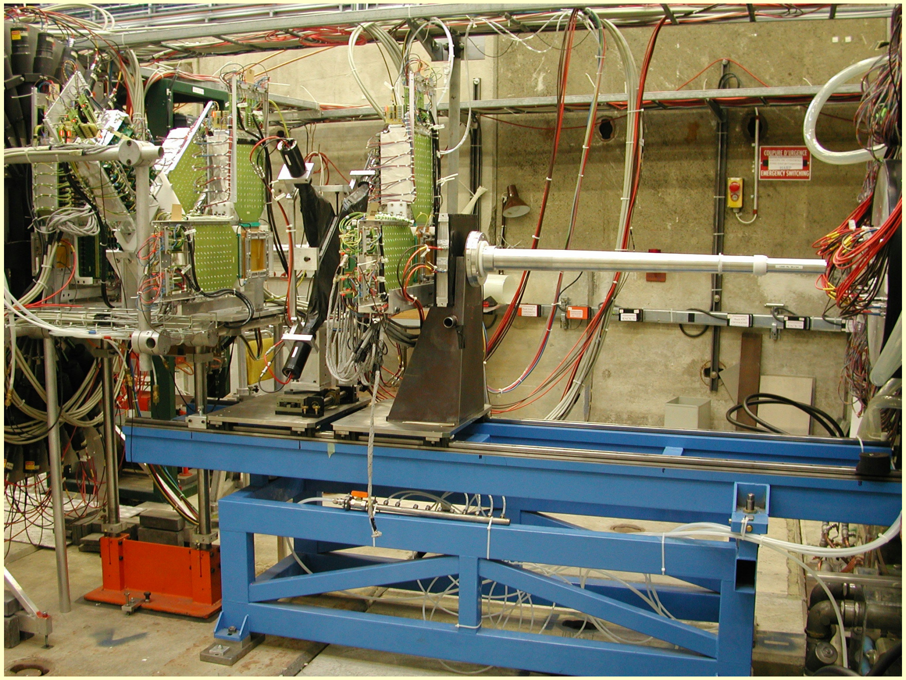
- **Two Cherenkov Counters**:
  e^+e^- tagging ≤ 3 GeV/c
  p tagging ≥ 3 GeV/c

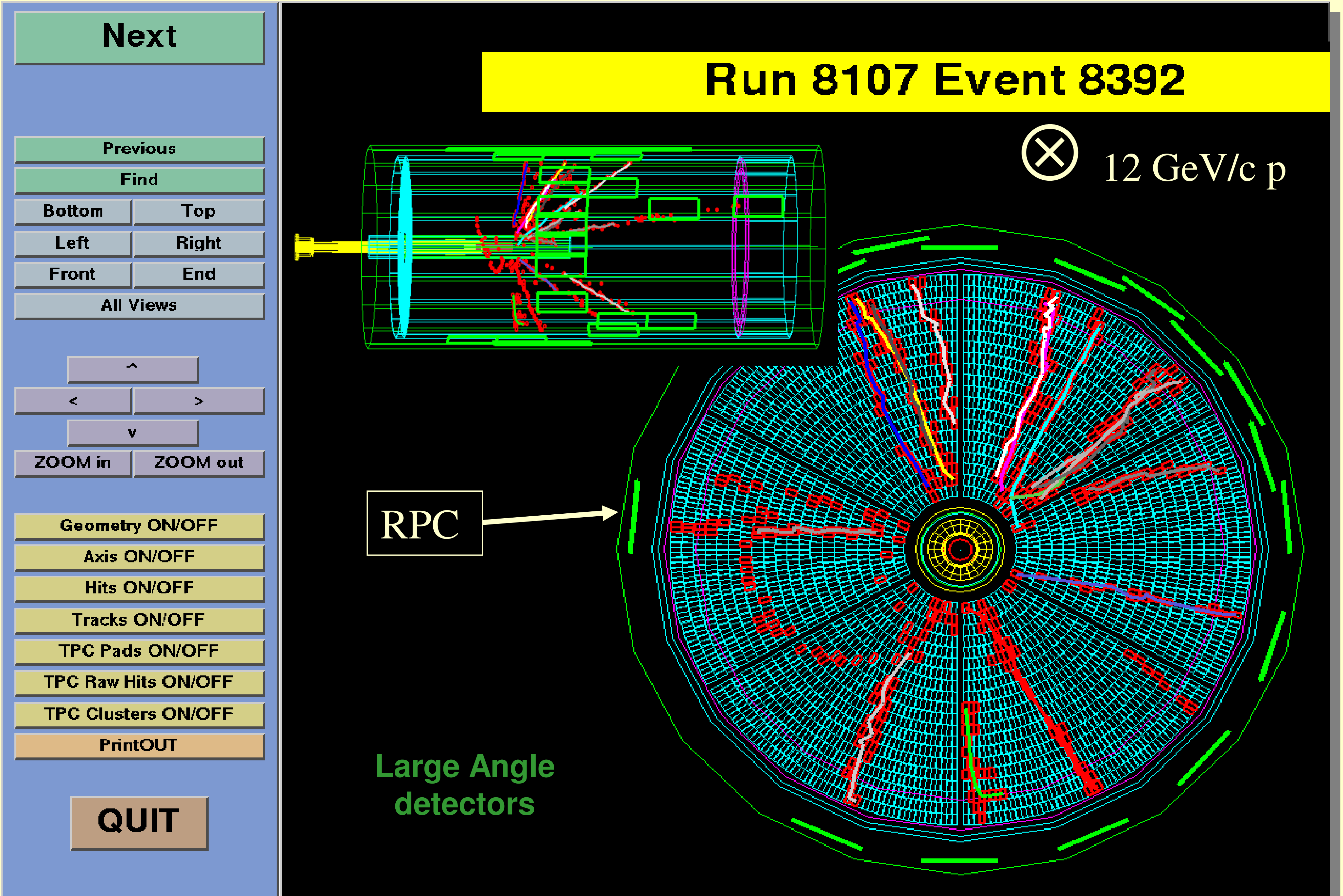
- **Four MWPC**:
  0.7 mm accuracy on target impact point

- **6.44 l muon identifier**

Main Trigger logic:

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

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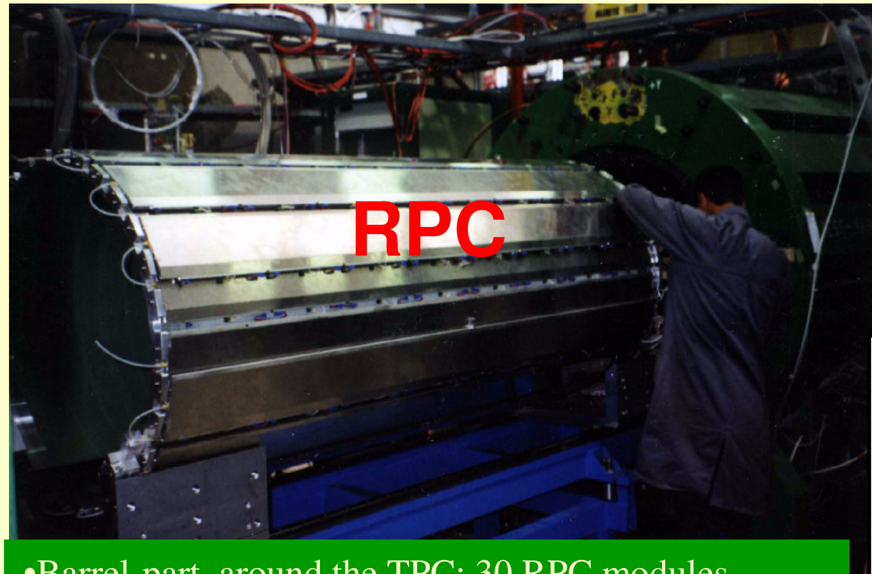
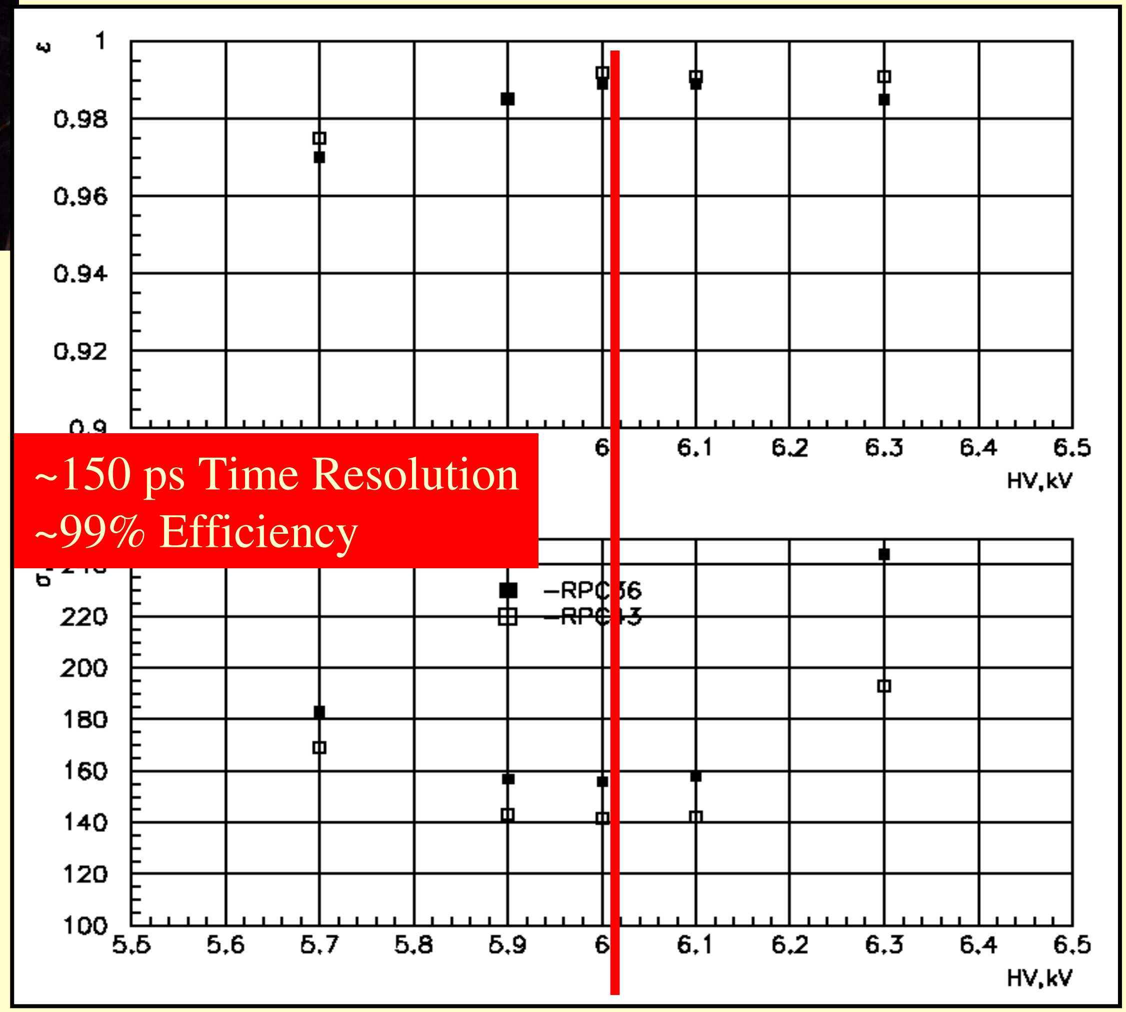
Left
Right
Front
End
All Views
^
<
>
v
ZOOM in
ZOOM out
Geometry ON/OFF
Axis ON/OFF
Hits ON/OFF
Tracks ON/OFF
TPC Pads ON/OFF
TPC Raw Hits ON/OFF
TPC Clusters ON/OFF
PrintOUT
QUIT
Run 8107 Event 8392
12 GeV/c p
RPC
Large Angle detectors



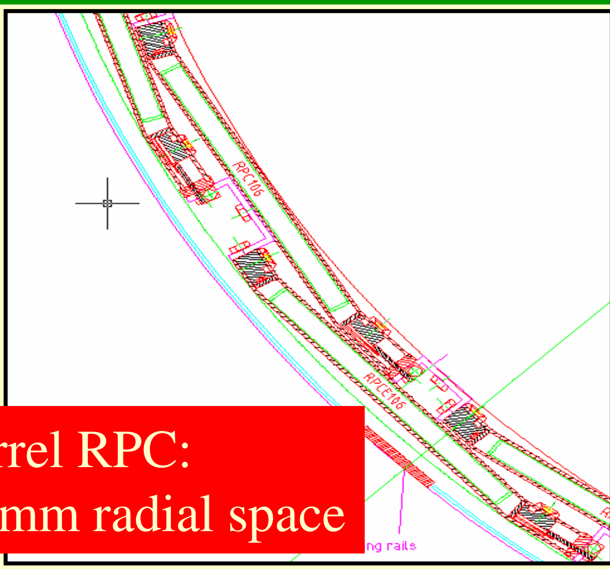
e–π separation at low momentum (<300 MeV) and large angles imply <200 ps time resolution.
Achieved with 4 gaps glass RPC of 0.3 mm gap thickness

- Barrel-part, around the TPC: 30 RPC modules
- Forward part, at the TPC exit: 16 RPC modules

368 readout channels, ~8 m^2 double layer.
Also participating to trigger definition

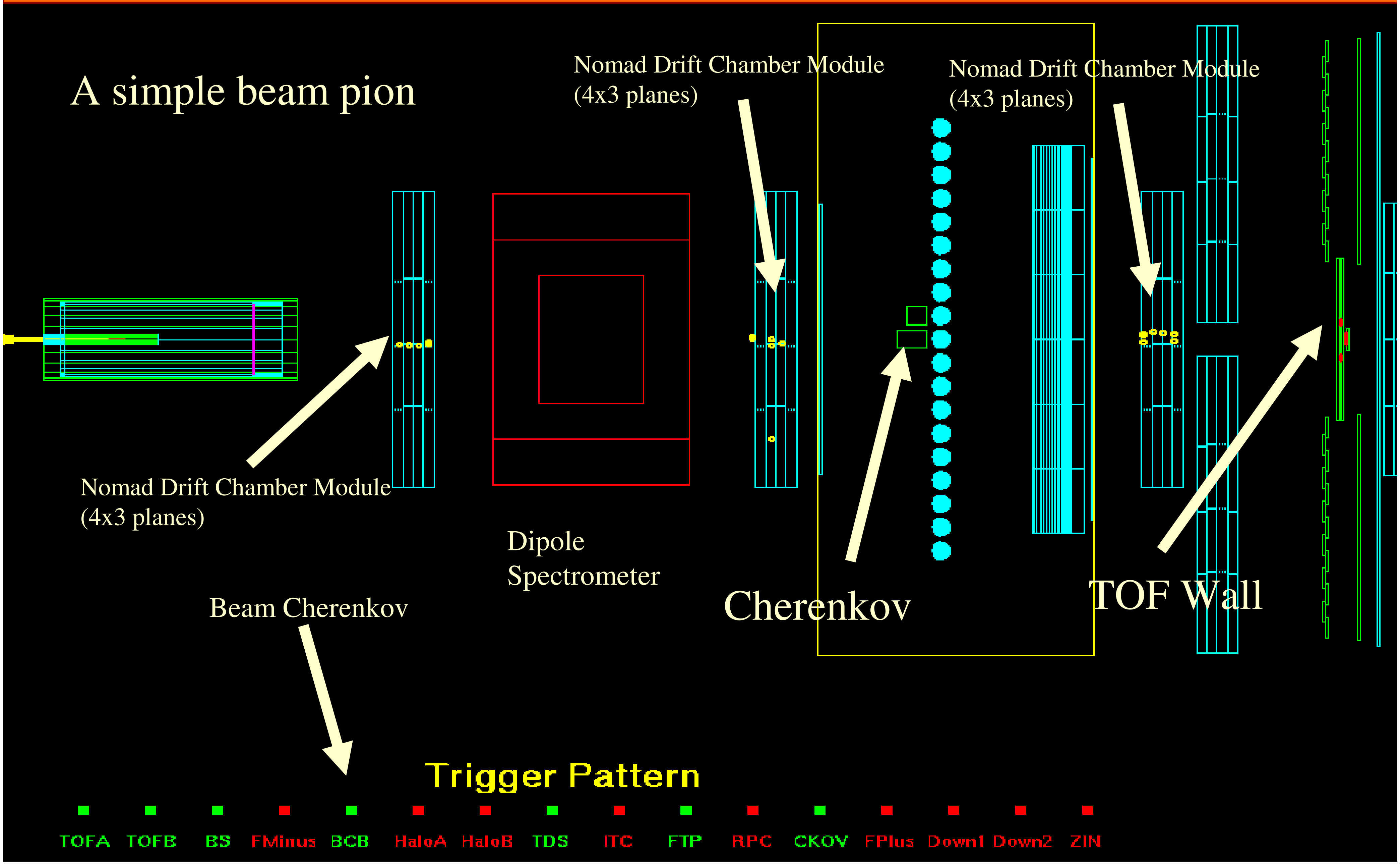


~150 ps Time Resolution
~99% Efficiency



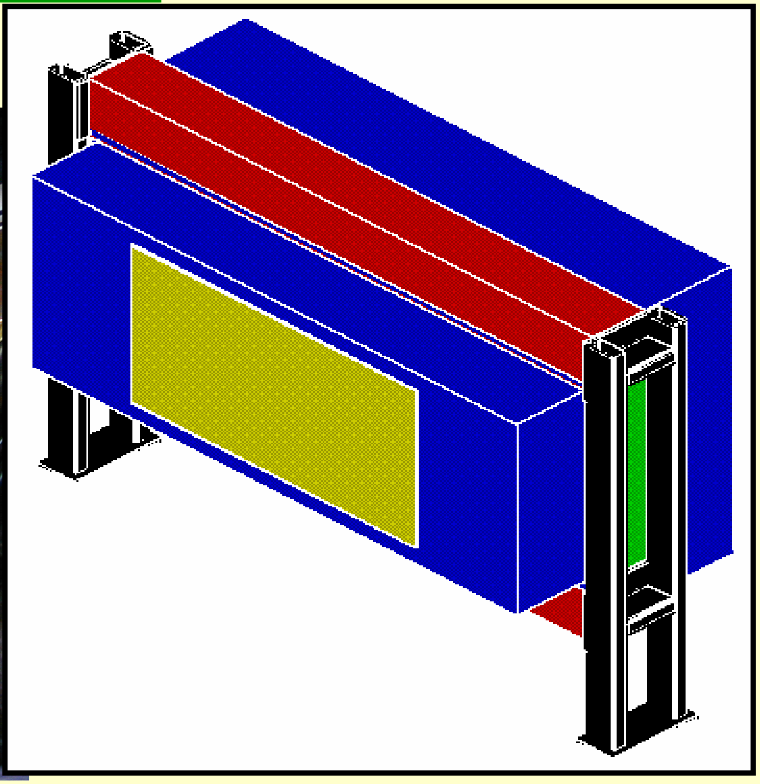
Barrel RPC:
24 mm radial space

Forward Spectrometer



Cherenkov detector

8” photomultipliers
C_4F_{10} “Threshold” operations
Cylindrical mirror optical design
35 m^3 vessel

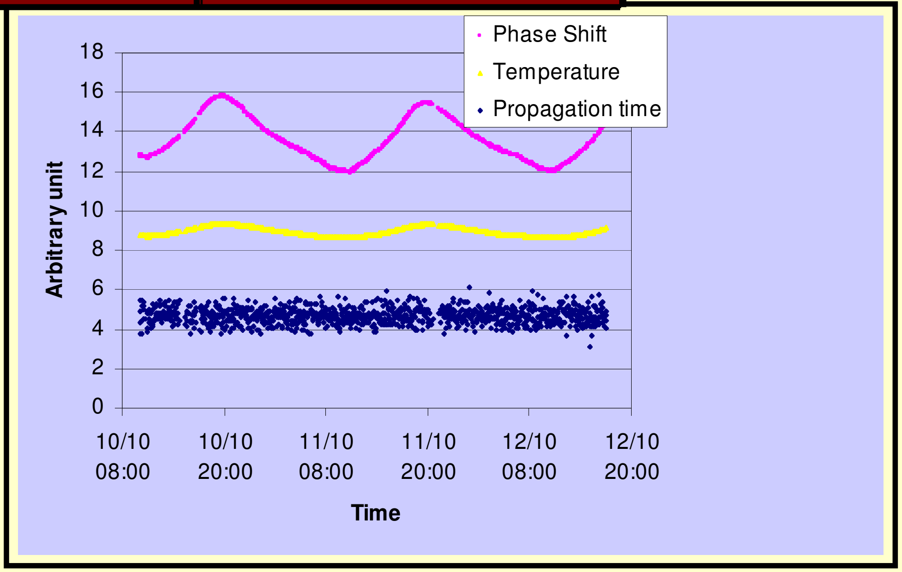


Cherenkov performance

Data based on beam particles identified through Beam Cherenkovs , beam TOF and muon identifier.

	3 GeV	5 GeV	12 GeV
Eff pions	89. ± 10. %	>93% @95% C.L. 113/113	>97% @ 95% C.L.(40/40)
Eff muons	97.5 ± 10. %		---

Density monitored by sonar techniques (acustic wave phase shift) <1% precision.



2001 Data

⌘ 85 millions physics-triggers concentrated on thin targets and positive beam momenta

⌘ 5 target elements (out of 7+4)

⌘ 4 beam momenta (out of 6)

⌘ partial thick target data (K2K)

⌘ In addition, ~5M calibration events.

HARP data-taking plan (version 29/10/2001)

Negative Particle Beams, thin targets

	Be	C	Al	Cu	Sn	Ta	Pb	empty
-3	18		17			16	15	14
-5	19		20			21	22	23
-12								
-15		0.54	0.9	0.7	1.15	2.1	1.37	

Positive Particle Beams, thin targets

	Be	C	Al	Cu	Sn	Ta	Pb	empty	empty no TPC
+3	2.20	2.41	2.43	3.59	1.34	4.35 11	4.83 10	0.89(****) 9(**)	
+5	2.26		2.12	1.53 3		1.53 2	1.46 1	1.19	
+12	5.93		3.79	1.96		1.56	2.50	1.40	
+15	2.09	2.70	2.30	3.00	2.24	2.60	2.33		

For K2K, at P=12.9 GeV/c

	thin	medium	thick
+12.9	1.51 8	2.21 5(***)	1.37 4(***)

For MiniBoone, at P=8 GeV/c

	thin Be	empty
+8	3.20	

Thick targets

	Ta	Pb
+3	1.13 6(***)	1.0 7(*) (**)

Special targets

	Cu "button"	Cu "skew"
+12	1.45	not available

Conclusions

- Active participation in a number of fixed target experiments
- Practically there is no financial support for this investigations
- Participation in the preparation of LHC experiments is important and we work hard, however
- We consider extremely important the participation in running experiments especially for young people
  - ✓ The only way to obtain experience in real conditions
  - ✓ To learn and do physics
  - ✓ PhD – problem – in Bulgaria the requirement is 4-5 good publications