Opportunity to contribute in the search of the Dark Matter - II

Michela Chiosso, University of Torino and INFN

COMPASS Workshop “Beyond 2020” - CERN
21-22 March 2016

"What we especially like about these theoretical types is that they don't tie up thousands of dollars worth of equipment."

Outline

Dark Matter searches related measurements:
p-He cross section measurements → pbar production in ISM

High Energy Cosmic Rays composition related searches:
particle production in atmospheric showers

Cosmic rays antiprotons

Cosmic ray antiprotons are a remarkable diagnostic tool for astroparticle physics.

The bulk of the measured flux consistent with a purely secondary origin in CR collisions onto interstellar medium gas (ISM)

but additional primary components are not excluded, either of astrophysical origin or of exotic nature, such as dark matter annihilation or decay

More precise measurements of secondary components are needed

Secondary components mainly come from:
p-p; p-He; He-p; He-He

Reactions involving **helium** represent a sizable fraction of the total yield, easily reaching 40% at low energies and **no data are available**

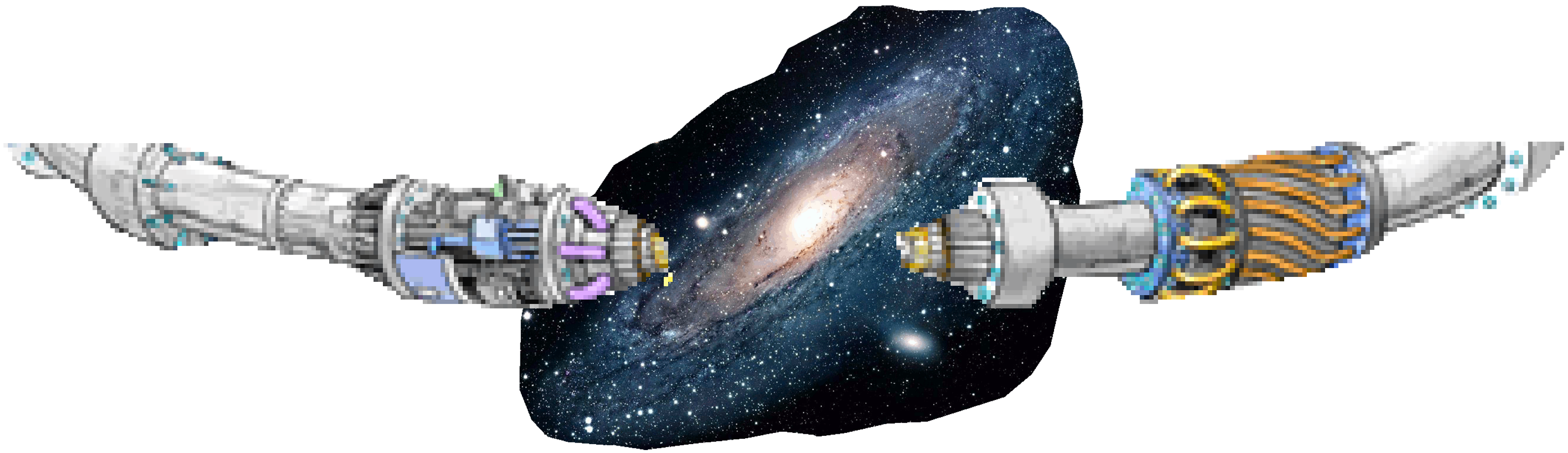
p p: 56%; p He: 24 %; He p: 12 %; He He: 6 %; p N (C, N, O) : 2%

Why not at LHC?

The energy scale relevant for cosmic ray experiments is considerably below the energy scale of operating colliders:

AMS-02 is expected to detect antiprotons up to kinetic energies of several 100 GeV, which descend from primary cosmic rays with energies E ≈ 10 to 10000 GeV.

This corresponds to CM energies sqrt(s) ≈ 4-100 GeV



Existing measurements at accelerators

Most recent data on inclusive **p+p → $\bar{\text{p}}$ + X from NA49** experiment (2010)

NA49: p beam momentum = 158 GeV/c , wide range in P_T (0.10, 1.50) and X_R (0.11,0.44), Lab antiprotons energy from 8 GeV up to 70 GeV

In older experiments critical subtraction of the antiprotons fraction coming from strange hyperons decay (Λ, Σ) → needed precise vertex detection and tracking reconstruction

Experiment	$\sqrt{s}$ (GeV)	p_T (GeV)	x_R
Dekkers *et al*, CERN 1965 [18]	6.1, 6.7	$(0., 0.79)$	$(0.34, 0.65)$
Allaby *et al*, CERN 1970 [19]	6.15	$(0.05, 0.90)$	$(0.40, 0.94)$
Capiluppi *et al*, CERN 1974 [20]	23.3, 30.6, 44.6, 53.0, 62.7	$(0.18, 1.29)$	$(0.06, 0.43)$
Guettler *et al*, CERN 1976 [21]	23.0, 31.0, 45.0, 53.0, 63.0	$(0.12, 0.47)$	$(0.036, 0.092)$
Johnson *et al*, FNAL 1978 [22]	13.8, 19.4, 27.4	$(0.25, 0.75)$	$(0.31, 0.55)$
Antreasyan *et al*, FNAL 1979 [23]	19.4, 23.8, 27.4	$(0.77, 6.15)$	$(0.08, 0.58)$
BRAHMS, BNL 2008 [13]	200	$(0.82, 3.97)$	$(0.11, 0.39)$
NA49, CERN 2010 [14]	17.3	$(0.10, 1.50)$	$(0.11, 0.44)$

These experiments require:

a state-of-the-art spectrometer with high acceptance and high resolution for charged and neutral particles in order to perform measurements of multi-particle final states over a wide kinematic range

Proton beam, variable energy in the range 10 GeV – 1 TeV

Liquid He target

micro vertex detection and precise tracking

Particles identification detectors: antiprotons, positrons, gammas in the final state

Data needed also on:

p+p and p+He $\rightarrow e^+ + X$ at E_e < 50 GeV

p+He $\rightarrow \pi^0 \rightarrow \gamma\gamma$ at E_γ from 500 MeV up to 500 GeV

The goal:

absolute cross-section measurement (with precision better than 10%)

COMPASS facility at CERN

Most important features:

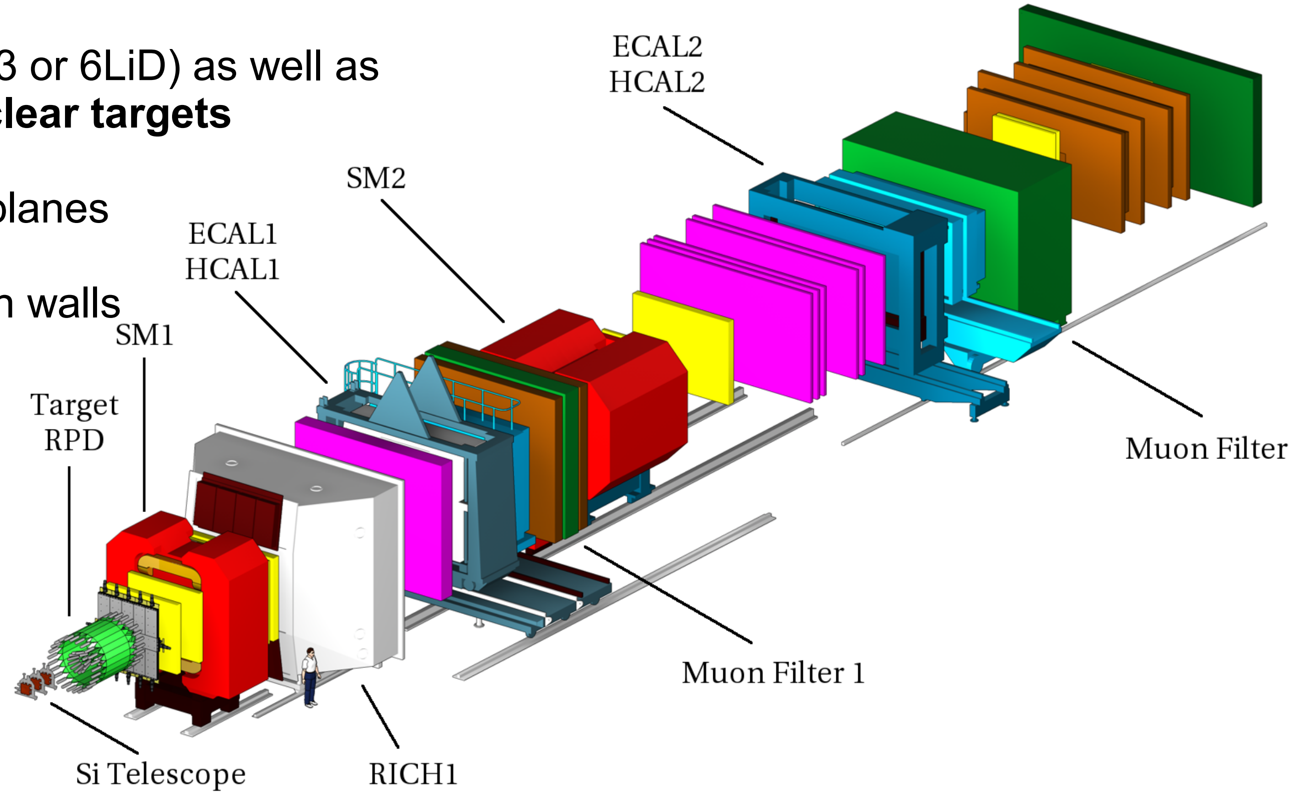
Muon, electron or **hadron secondary beams**

Solid state polarised targets (NH3 or 6LiD) as well as **liquid hydrogen target and nuclear targets**

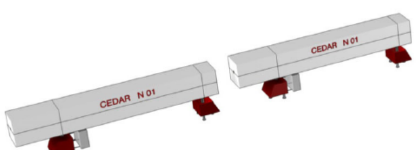
Powerful tracking system – 350 planes

PiD – **Calorimeters, RICH**, Muon walls

Accessible final states
π, κ, p, pbar, gammas



A high momentum resolution for charged particles provided by a two-stage magnetic spectrometer.



CEDARs

2009 data
190 GeV/c proton beam
40 cm long Liquid **H2 target**
Trigger on recoil proton

measurements with nuclear targets:
a target holder can house up to 16 target disks

COMPASS facility at CERN: hadron beam

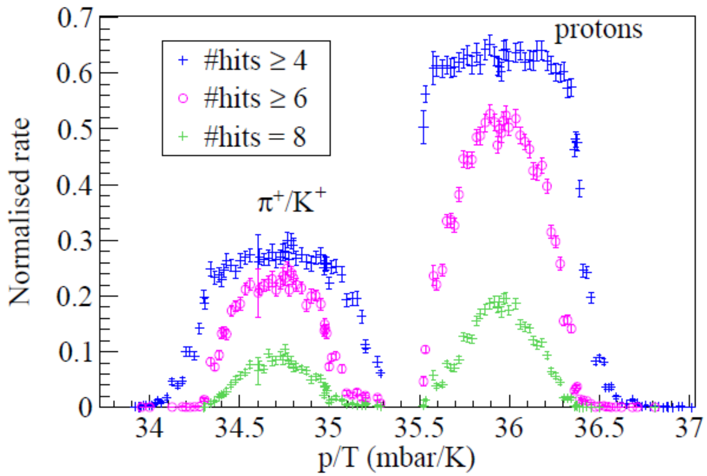
50-280 GeV/c hadron beam
Liquid **H2 target**

Momentum (GeV/c)	Positive beams π^+	K^+	p	Negative beams π^-	K^-	$\bar{p}$
100	0.618	0.015	0.367	0.958	0.018	0.024
160	0.360	0.017	0.623	0.966	0.023	0.011
190	0.240	0.014	0.746	0.968	0.024	0.008
200	0.205	0.012	0.783	0.969	0.024	0.007

Maximum beam momentum (high-energy mode) 280 GeV/c
Maximum beam momentum (normal mode) 250 GeV/c

Two CEDARs designed to provide fast beam particle identification at high rates for particle momenta up to 300 GeV/c

a particle identification efficiency of almost 90% for protons is estimated using a multiplicity of 4 with a high purity of larger than 95% for the chosen working point of the CEDAR

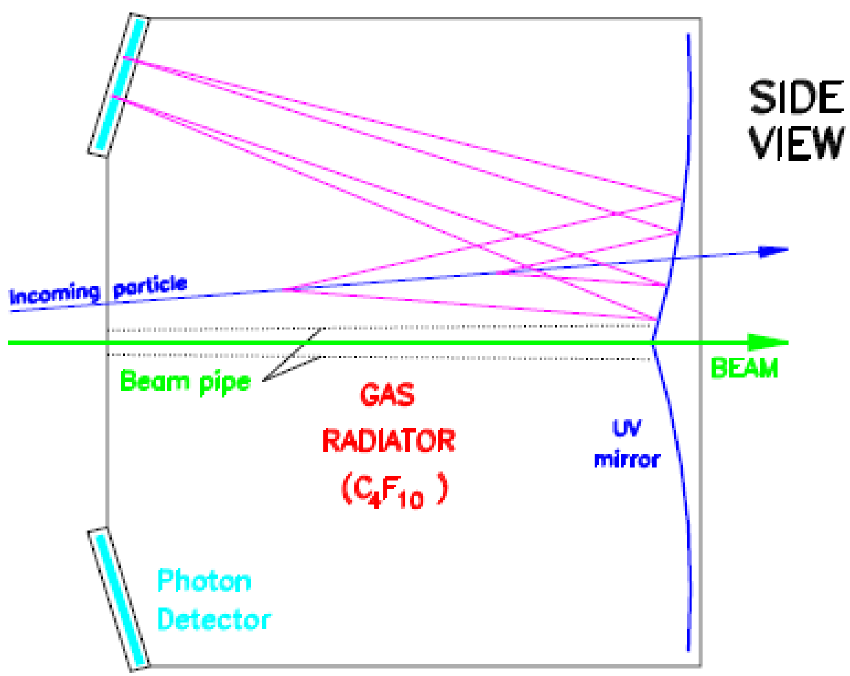


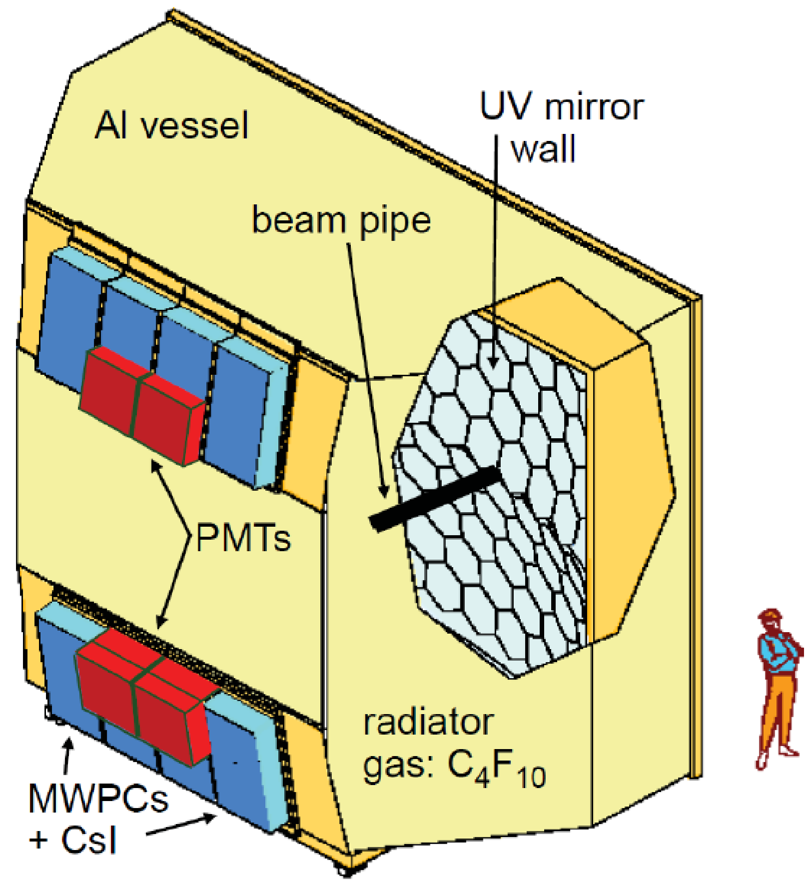
Antiproton Identification

The RICH Detector

3m long vessel filled with $C4F10$ gas as a radiator

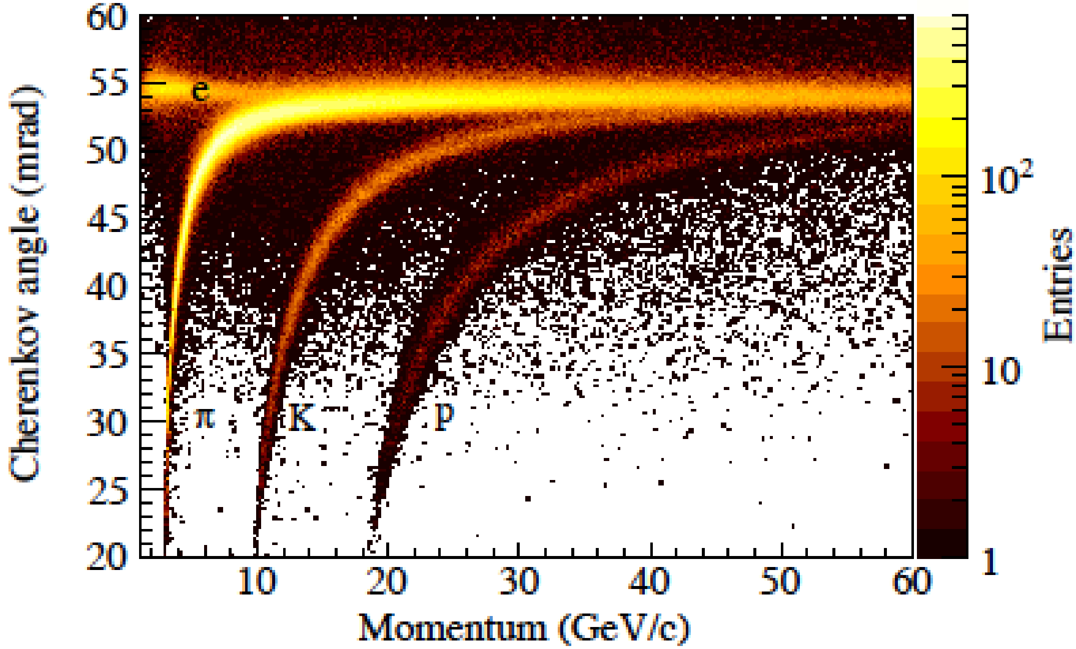
The refractive index of the radiator material ($n \approx 1.0015$) corresponds to **Cherenkov thresholds** of about **2.5, 9, and 17GeV/c for pions, kaons, and protons**, respectively.

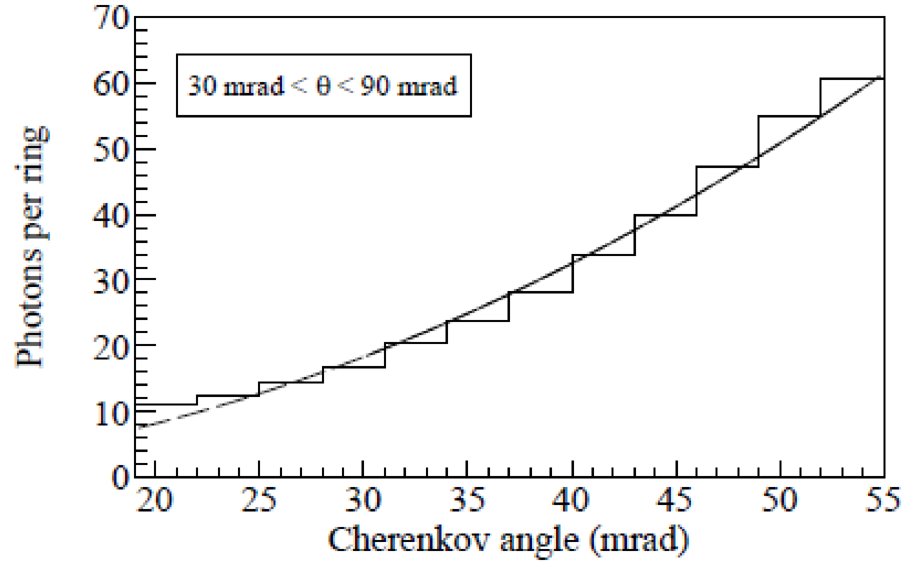




Antiproton Identification

pion-kaon separation at 95% confidence level for momenta up to 45GeV/c.
Average number of photons per ring at saturation, i.e. for $\beta=1$ is 56 in the central and 14 in the peripheral region.





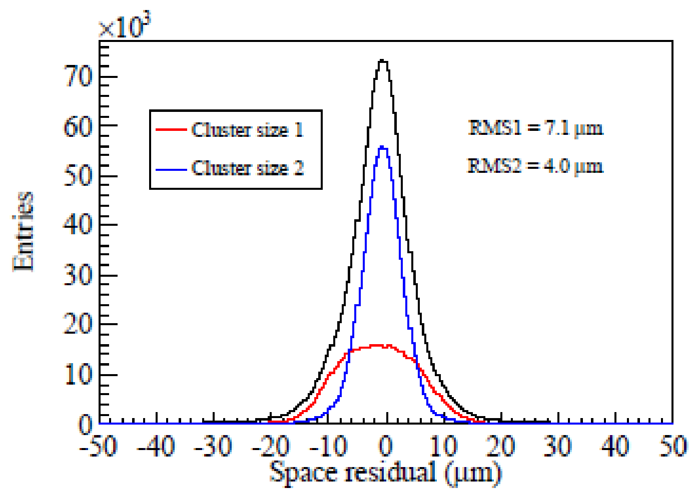
Precise vertex reconstruction and tracking

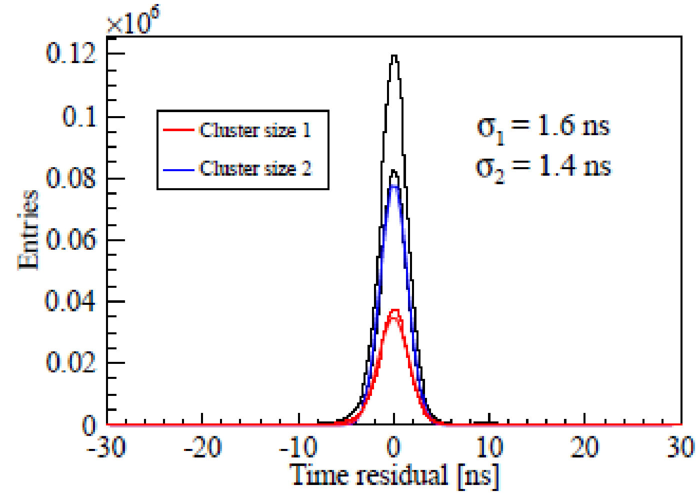
high resolution of the primary vertex position and tracking to reject hyperons decay.

Precise tracking immediately upstream and downstream of the target is performed by **silicon microstrip detectors:**

three stations upstream of the target, which are used as a **beam telescope**, and two stations downstream of the target, which are used for **vertex reconstruction**

Spatial resolution: along the beam axis varies from 0.75 to 4.7mm, across the beam axis lies in the 13 to 16 μm





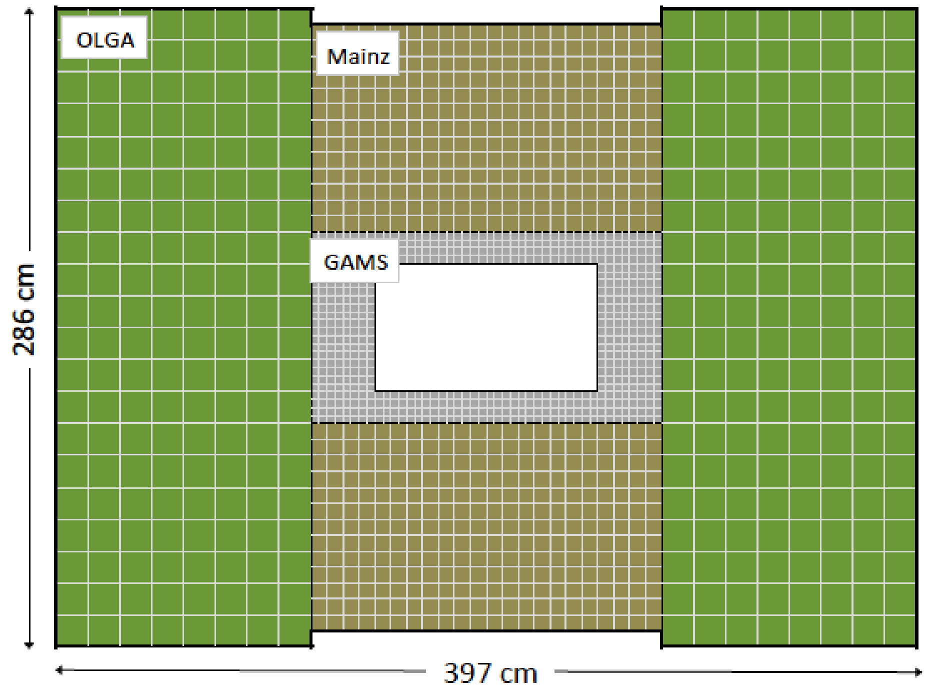
For the tracking in the beam region: pixelised Gas Electron Multiplier (GEM) detectors with a minimised material budget along the beam

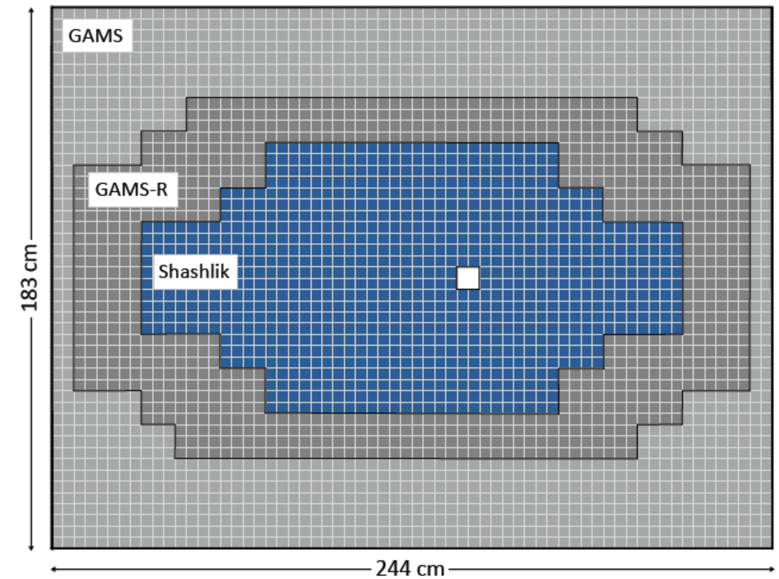
For the tracking at small angles: Micromegas trackers

Electromagnetic calorimetry

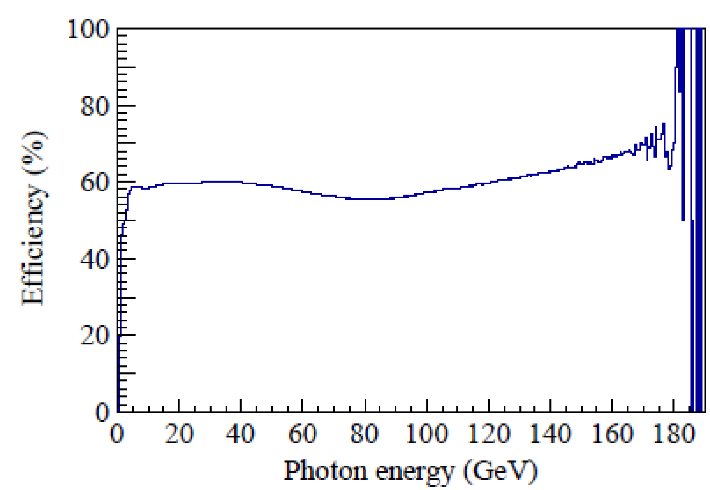
ECAL1: the dynamic range is set to detect energies of up tp 60 GeV in GAMS cells, 30 GeV in MAINZ cells and 20 GeV in OLGA cells.

ECAL2: the dynamic range of the central cells is set to a maximum energy of 150 GeV and to 60 GeV for the outermost two rows and lines for diffractive data taking.





γ, $e^{+/-}$, π^0 separation capability in the final state



Trigger (COMPASS 2009)

Table 5: Overview of trigger subsystems, vetos and physics triggers used for data taking.

Trigger subsystem	Logical composition	
Beam trigger (BT)	SciFi1 $\wedge$ beam counter	
Beam killer veto	beam killer 1 $\wedge$ beam killer 2	
Veto	Sandwich $\vee$ veto hodoscopes $\vee$ beam killer	
Proton trigger	see Eq. 3	
Multiplicity trigger MT1	1 (later 2) el. of outer ring counter	
Multiplicity trigger MT2	amp. inner disk $>$ 1.6 MIPs (later 2.5 MIPs)	
Calorimeter trigger	$\sum_{12\times 12}$ cell amplitude $>$ threshold	
CEDAR trigger	CEDAR1 multiplicity $\wedge$ CEDAR2 multiplicity	
Physics trigger	**Logical composition**	**Rate / 10 s spill**
Diffractive trigger DT0	BT $\wedge$ proton trigger $\bar{\wedge}$ veto	180k
Low-t trigger LT1	BT $\wedge$ MT1 $\bar{\wedge}$ veto	370k (140k)
Low-t trigger LT2	BT $\wedge$ MT2 $\bar{\wedge}$ veto	620K (260K)
Primakoff trigger Prim1	BT $\wedge$ calorimeter trigger ($>$ 60 GeV) $\bar{\wedge}$ veto	260k
Primakoff trigger Prim2	BT $\wedge$ calorimeter trigger ($>$ 40 GeV) $\bar{\wedge}$ veto	450k
Kaon trigger KT	BT $\wedge$ CEDAR trigger$\bar{\wedge}$ veto	30k

p + p -> pbar + X + p

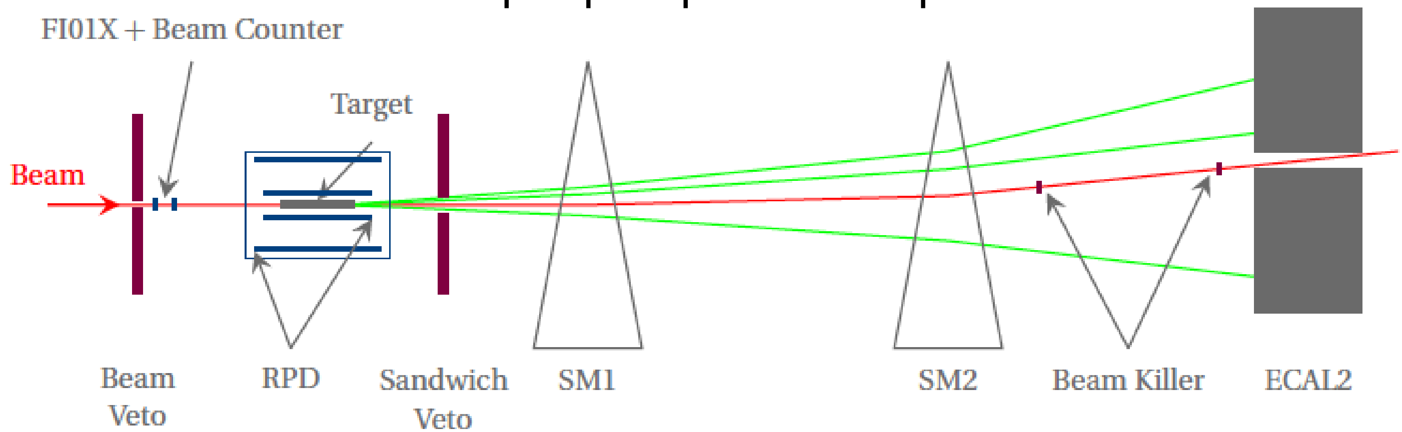


Figure 3.1: DT0 trigger scheme: Trigger (blue) and Veto (purple) components [59]. In the spectrometer, a non-interacting beam track (red) and an event with three charged tracks (green) is drawn for illustration.

Feasibility studies

NA49 (2001: 13 days of data taking)
p+p at 160 GeV/c: 1 100 000 events → 550 000 events on DST (special spill)

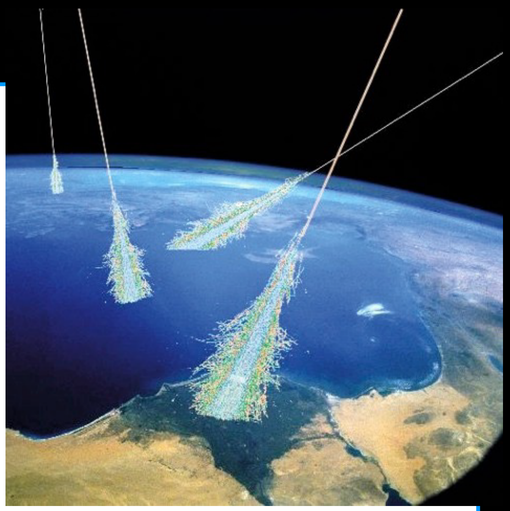
42.000 events/day

Beam Intensity: 1x10^4 p/s
LH target: 20.29 cm long

COMPASS:
Beam Intensity: 5x10^6 p/s
LH target: 40 cm long

≈ Factor 1000 more events/day

Cosmic rays studies



Elemental composition at high energy is still unknown → essential to:
solve finally the puzzle of high energy cosmic rays sources

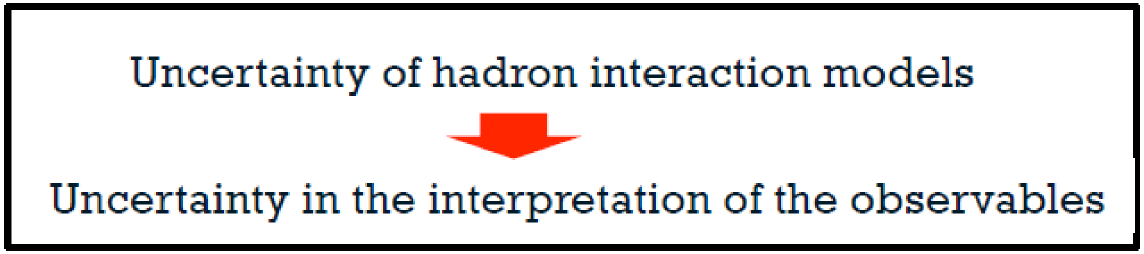
understand the transition from galactic to extra-galactic cosmic rays

understand change in the power-law of the cosmic rays fluxes, like the “knee”, at 3×10^6 GeV

Cosmic rays measurements above 10^5 GeV are based on detection at ground of secondary particle showers (EAS) which they produce in the Earth Atmosphere

The uncertainty of the extrapolation of the hadronic production cross section in extensive air shower is a major problem for the interpretation of existing cosmic ray data for example in terms of the primary mass composition

Relevant measurements for cosmic rays physics: pion-carbon and proton-carbon from 50 GeV beam energy up to a few hundreds of GeV



FUTURE DIRECTIONS

Direct measurements

The next challenge will be to extend direct measurements up to 1000 TeV with the same level of accuracy reached so far.

- ✓ New "ideas" on Calorimetry : increase acceptance, good resolution with reasonable size/weight (e.g. Calocube).
- ✓ Gain one energy decade in anti-matter detection: warm superconducting magnets, μm tracking on large surface with low-consumption electronics

Opportunities are around the corner: e.g. China space programs (HERD)

Indirect measurements:

Next challenges: better determination of chemical composition and higher exposures with, at the highest energies, a full sky coverage (north/south observations)

- ✓ LHAASO – Cosmic rays in the region of the transition galactic extra-galactic.
- ✓ Auger Prime – Muon content to better address composition at the highest energies.
- ✓ Ground based detection of ultra high energy cosmic rays with full sky coverage.
- ✓ Space based detection of ultra high energy cosmic rays (EUSO concept).

Not only CR:

- ✓ p-He cross section measurements → pbar production in ISM (LHCB-SMOG? COMPASS?)
- ✓ particle production in atmospheric showers → TOTEM, LHCF.....SAS?

Cosmic rays and accelerator physics
(Alessia Tricomi, Paolo Lipari)

Overview on cosmic rays and accelerators: Ralph Engel

Cosmic ray phenomenology - low energy: Fiorenza Donato

Cosmic ray phenomenology - high energy: Andrea Chiavassa

Cosmic ray and accelerators, experiment: Lorenzo Bonechi

Cosmic ray, future: Oscar Adriani

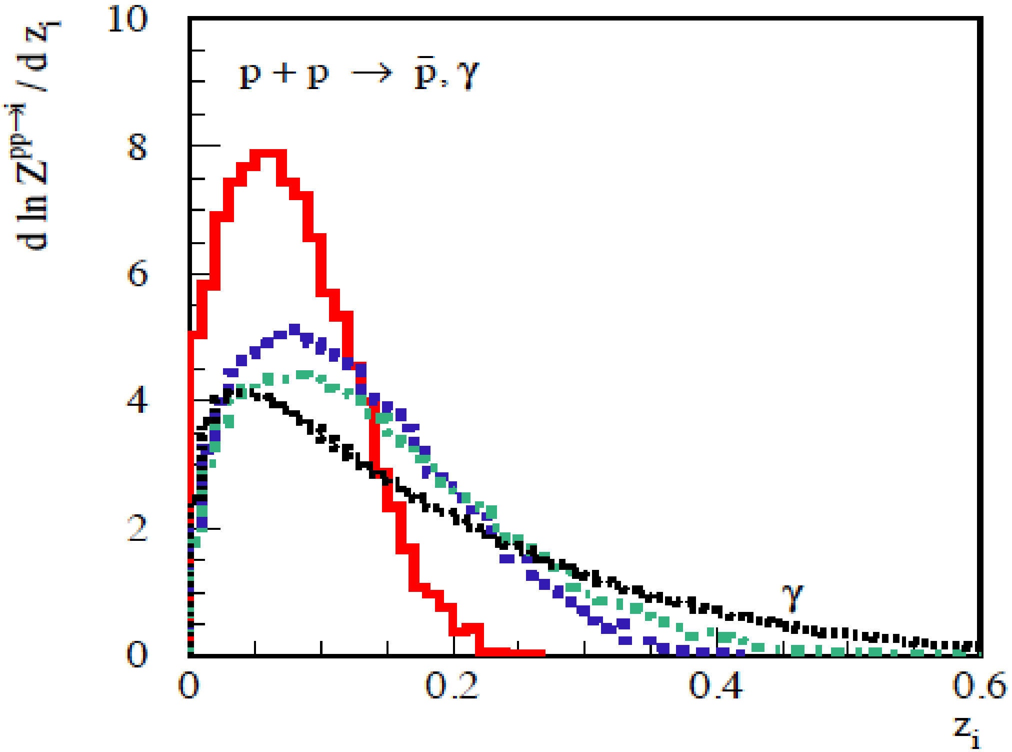
+ A new idea!

- After the talk of F. Donato yesterday a new idea came to my mind
- The SMOG system has already been tested in 2012 in LHCb
  - Injection of noble gas atoms inside the beam pipe to:
    - Measure the beam profile
    - Measure the luminosity
- Why don't use SMOG to measure cross section relevant for Cosmic Ray Physics???
  - P-He→Antiprotons+X
- We could make use of 'perfect' Particle Identification Detectors
- We could make use of the highest possible energies
  - Direct access to protons in the most interesting energy region

Spare Slides

Michela Chiosso, University of Torino and INFN

These experiments require:



$Z_i = E_{pbar}/E_p$ or E_γ/E_p

Epbar = **1**, **3**, **10** GeV

Eγ = 10 GeV

The bulk of antiprotons is produced by proton with kinetic energy 10-20 times larger
AMS energies ~ **1-500 GeV in Epbar → beam proton energies with ~ few GeV – 10 TeV**

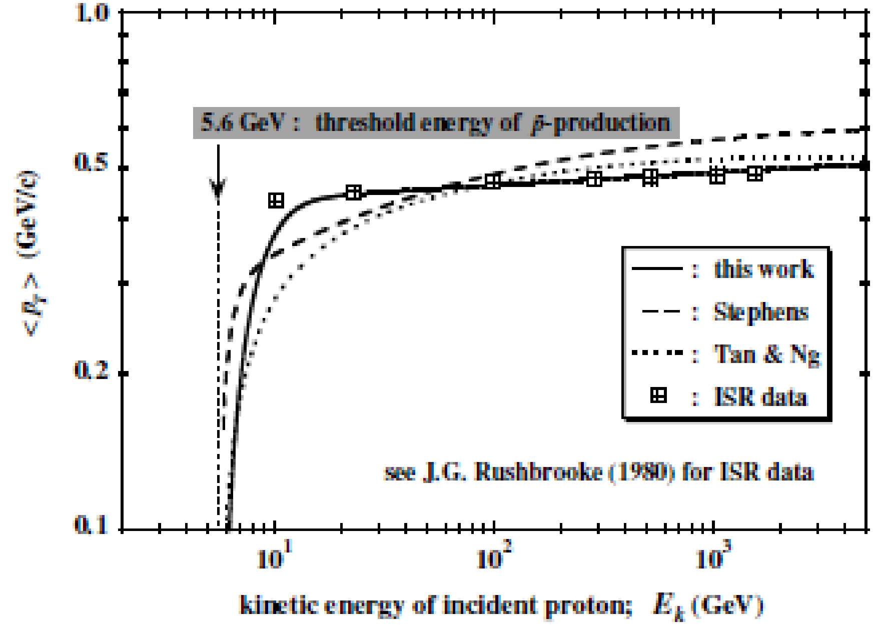


Figure 1: Average transverse momentum of $\bar{p}$

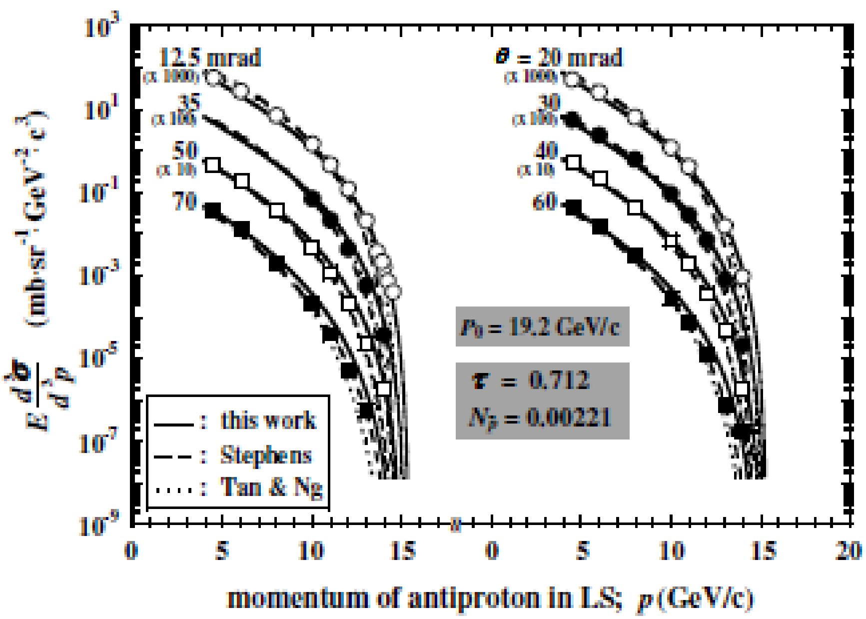


Figure 2: Cross section against momentum.

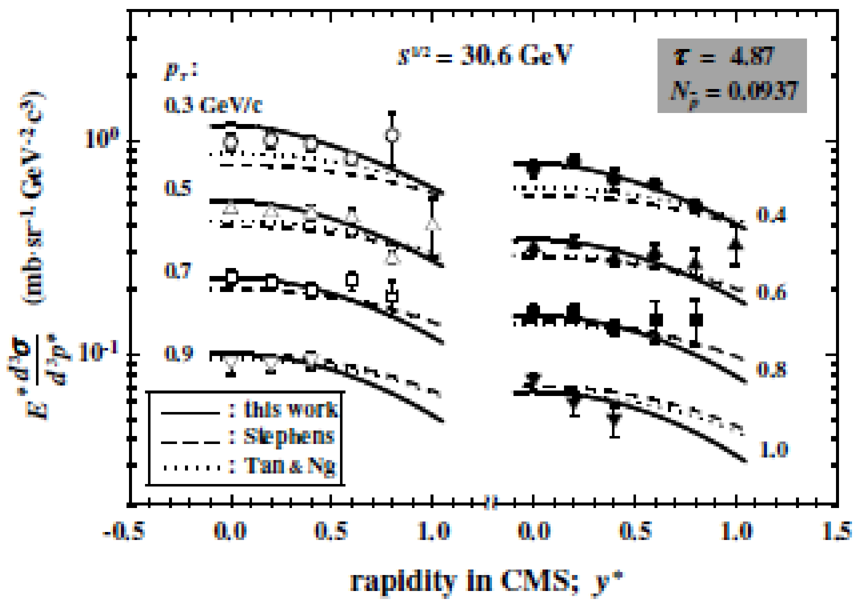


Figure 3: Cross section against rapidity.

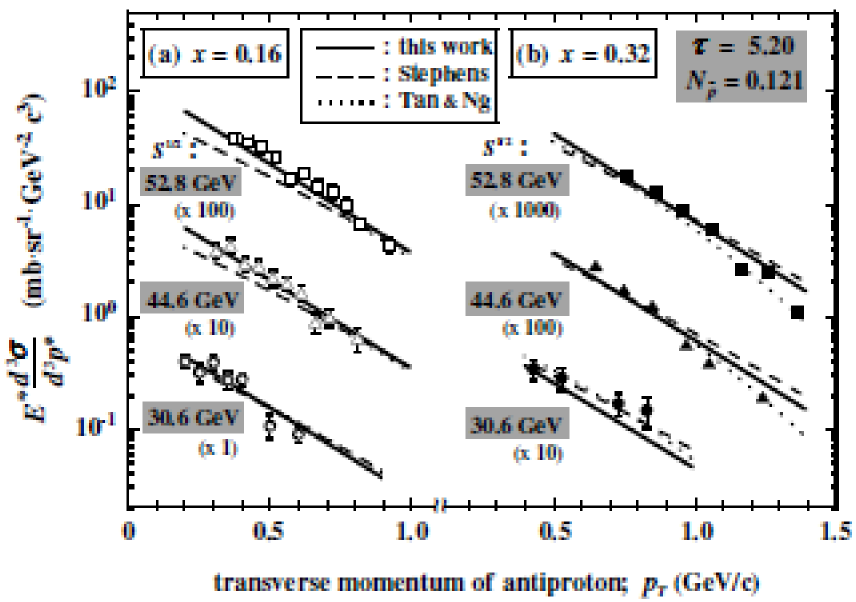
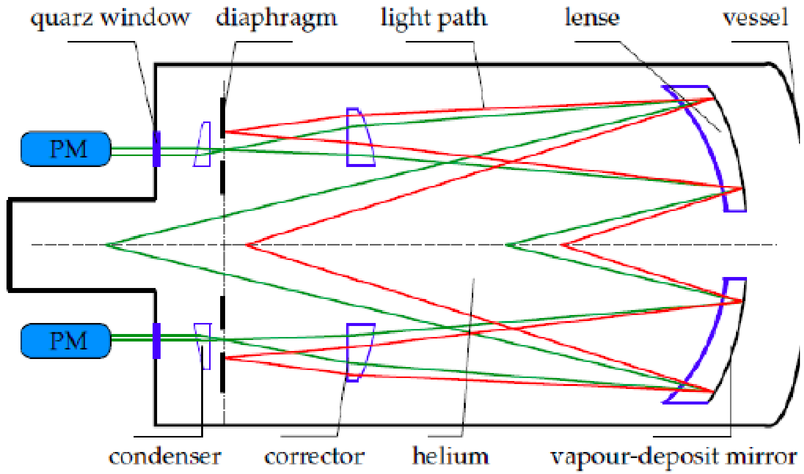
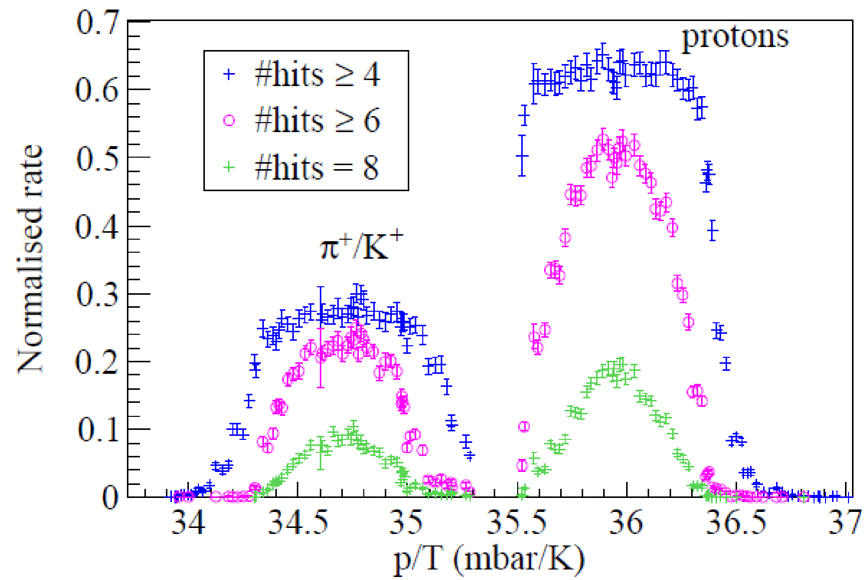


Figure 4: Cross section against p_T.

Proton tagging with CEDARs

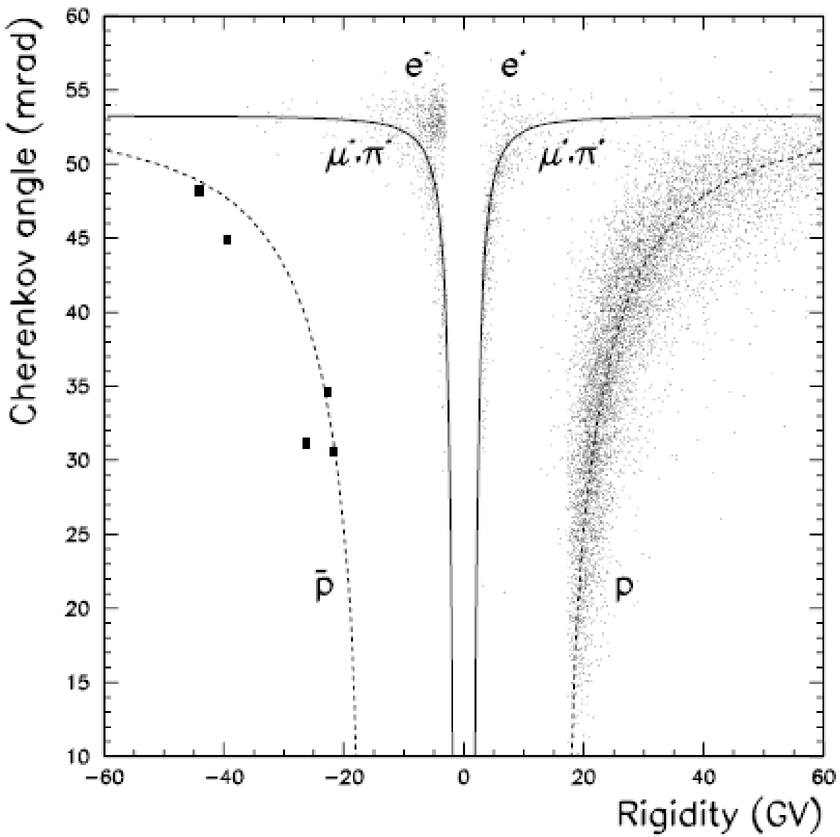




Nominal Beam intensity: of **5 x 10^6 s^{-1} (2009)**
If one assume 70% efficiency of the CEDARs proton tagging
we can expect up to ≈ 2.5 x 10^6 p s^{-1}

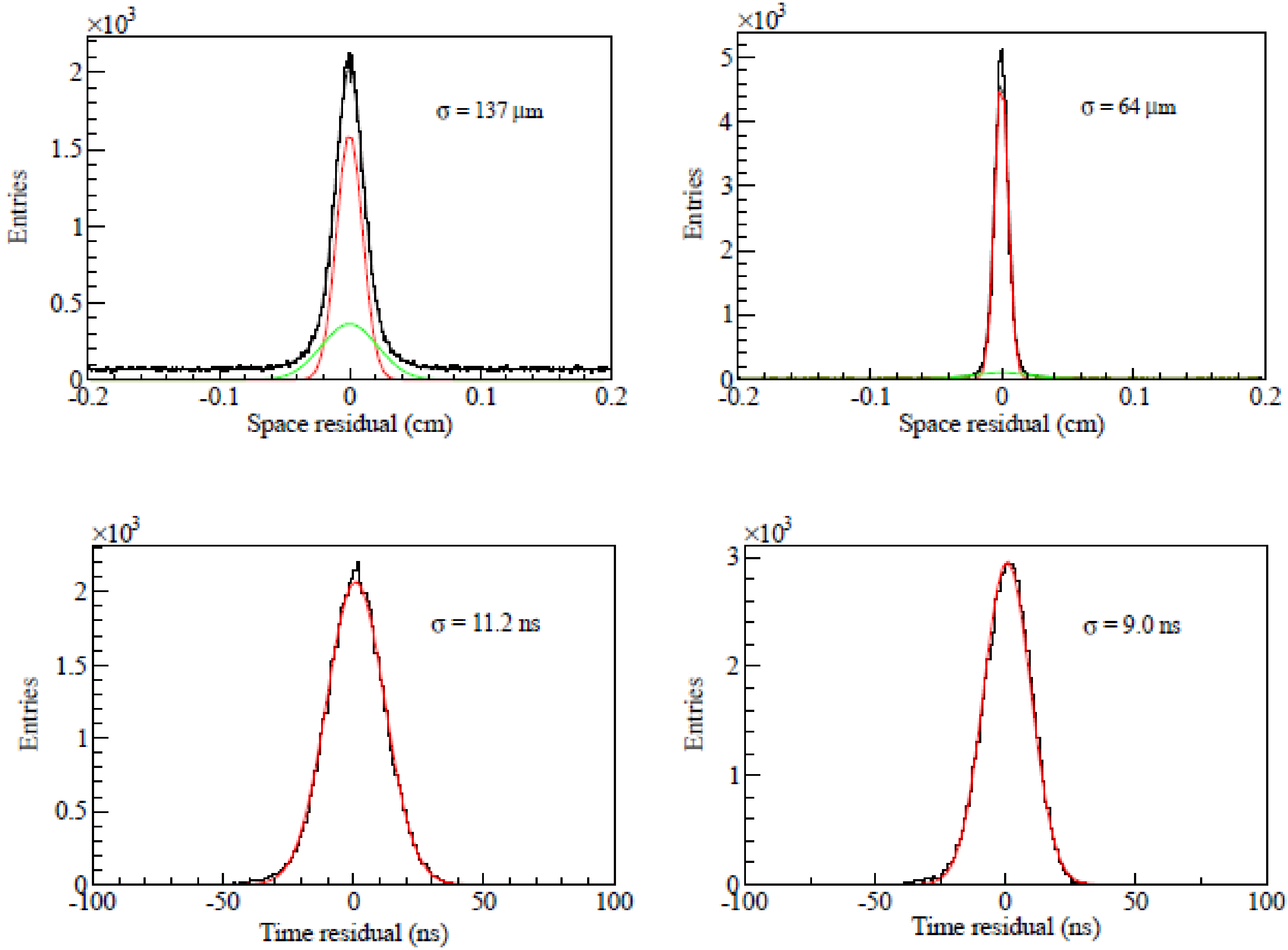
Caprice RICH Detector

Superconductive magnet with tracking system, RICH with C4F10 gas radiator, imaging silicon-tungsten calorimeter

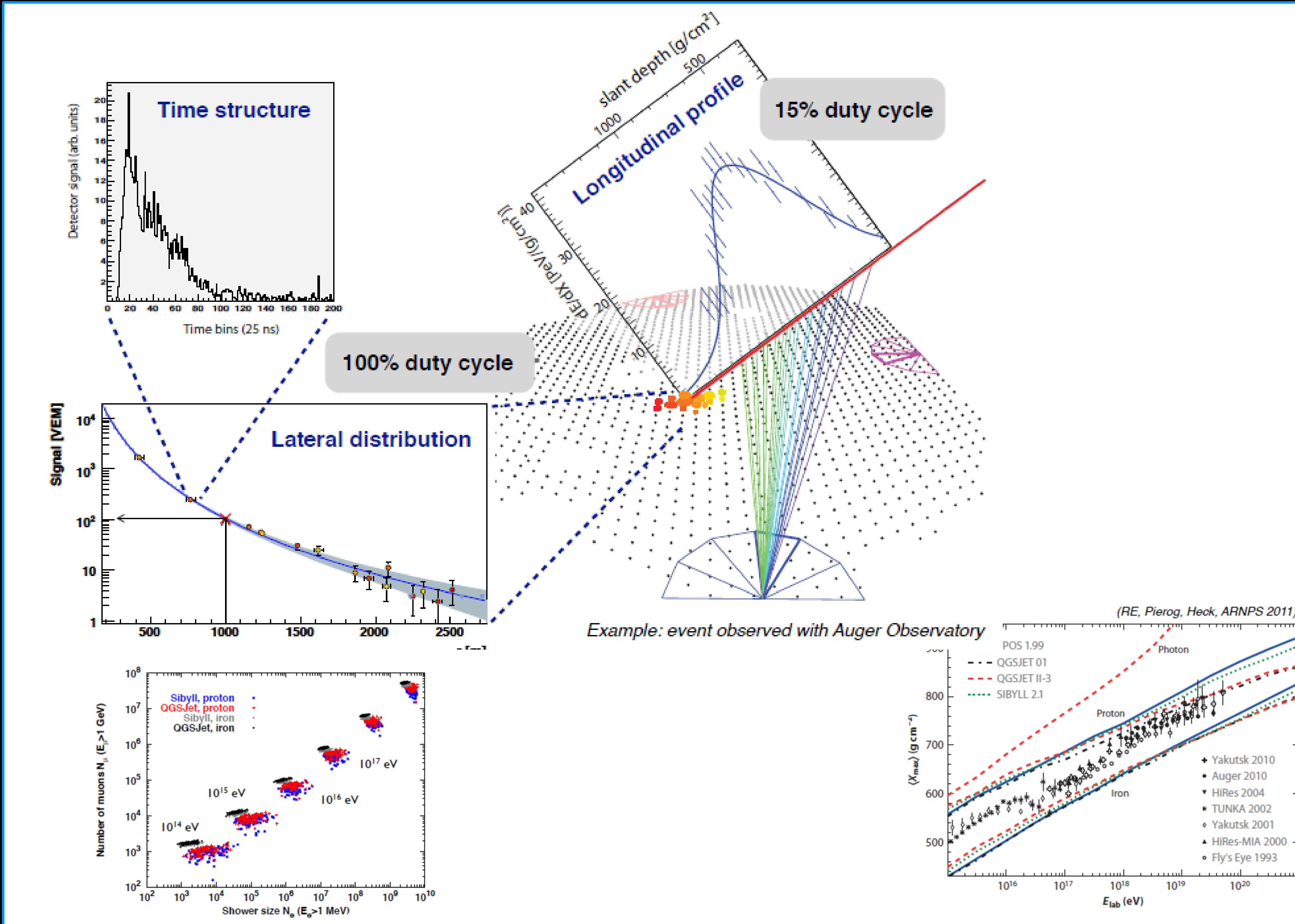


Tracking

Pixel-GEMs detectors with pixel readout in the central region for precise tracking in the beam region, able to cope with the high particle fluxes in the beam centre, and to separate individual hits close to the beam



Cosmic rays studies



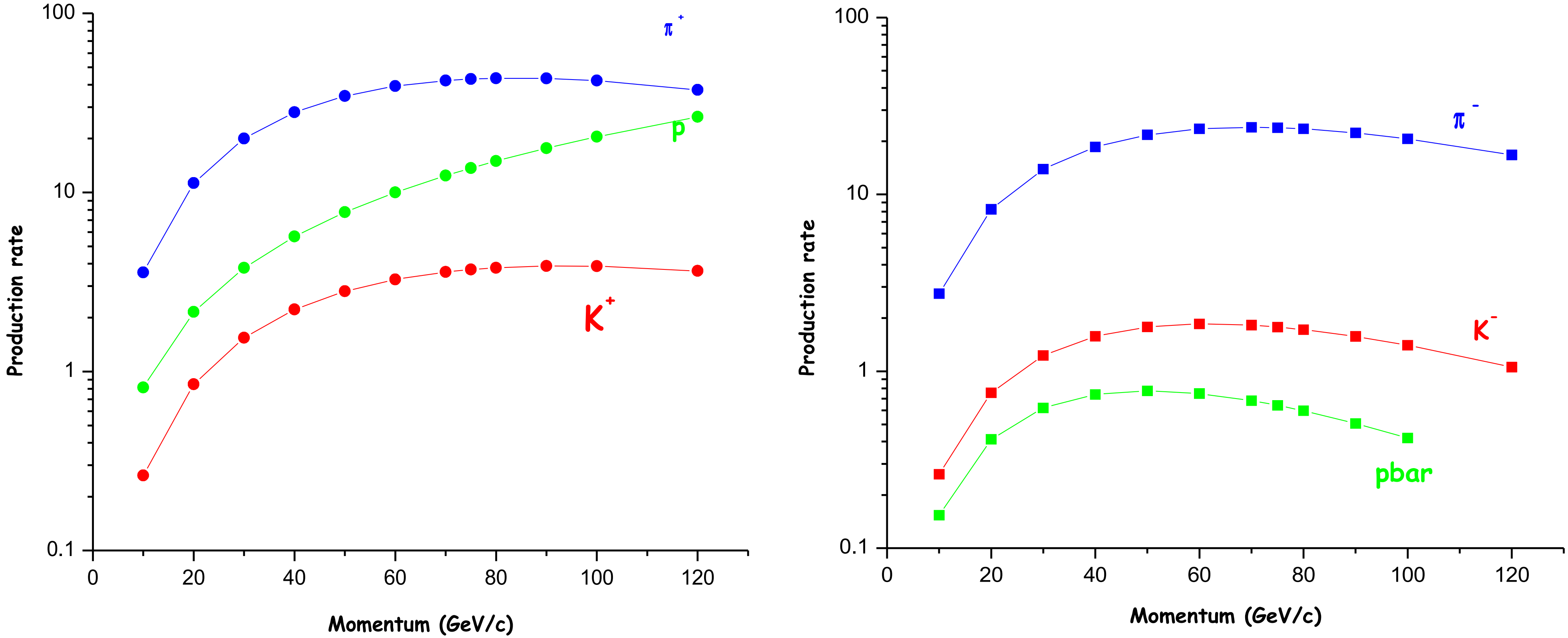
AMS RICH Detector

AMS
mattoni di aerogel con un indice di rifrazione n di 1.05 e
mattoni fluoruro di sodio (NaF) nella parte centrale, con indice di rifrazione 1.33, per estendere in basso il range di velocita misurabili e garantire che i fotoni siano raccolti nel piano di rivelazione

Sigma_beta/beta = 0.1%/Z

M2 beam line secondary beams

Particle production at 0 mrad



Antiproton Identification

For each event the RICH-1 data are decoded, the MAPMT hits are selected on the basis of the time information and the MWPCs hits are selected on the base of the time and amplitude information and clustered; all accepted particles, namely tracks within the RICH angular acceptance and having a momentum between 1.8 and 180 GeV/c, are then correlated to the RICH reconstructed coordinates.

These resolutions allow pion-kaon separation at 95% confidence level for momenta up to 45GeV/c.

The average number of photons per ring at saturation, i.e. for $\beta=1$ is 56 in the central and 14 in the peripheral region.