Lorentz center

Light Anti-Nuclei as a Probe for New Physics
October 14th to 18th 2019

The COMPASS++/AMBER program for cross-sections measurements

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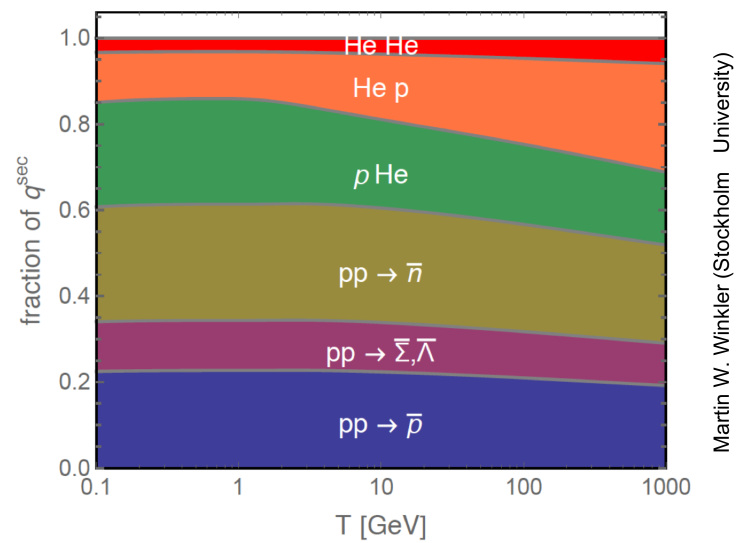
TIFPA

INFN

Introduction

- anti-p production cross section from p-p and p-He interactions is poorly measured and cannot simply constrained from available measurements.
- an accurate prediction of the expected anti-p flux in cosmic rays in the rigidity range from few GeV to several hundreds of GeVs, is interesting to understand cosmic ray and possibly search for signals of new physics
- LHC-b collaboration reported a measurement the anti-p XS from 8 TeV p-He, and foresee a similar measurement with 4TeV protons.
- NA61 published p-p to anti-p at 20, 31, 40, 80, and 158 GeV/c
- we want to investigate the possibility to perform a measurement with the SPS protons between 50 and 280 GeV/c on fixed LH2 and LHe targets, and a magnetic spectrometer

Fraction origin of anti-p from CR interaction with ISM

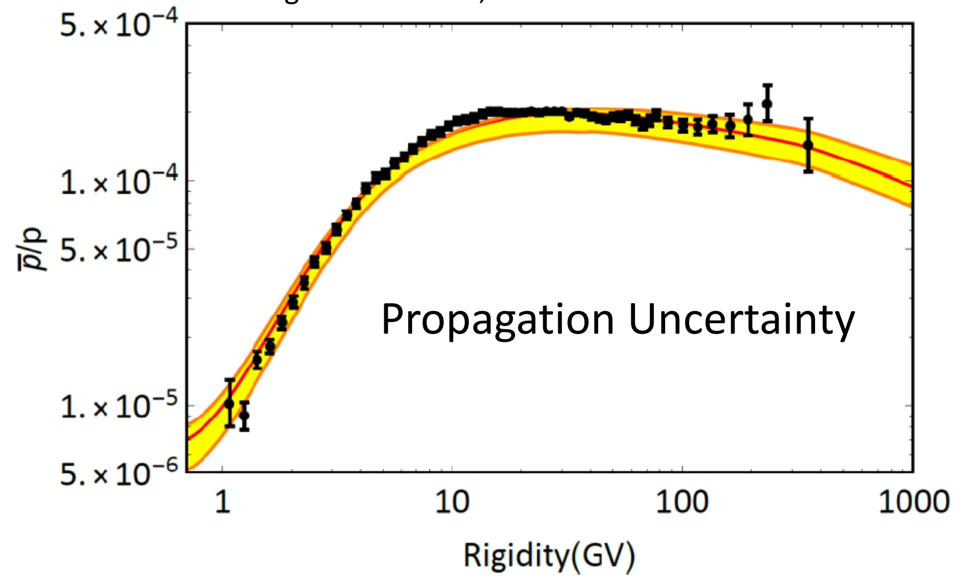


LHCb-CONF-2017-002
Measurement performed at 7 TeV
p-He -> pbar + X

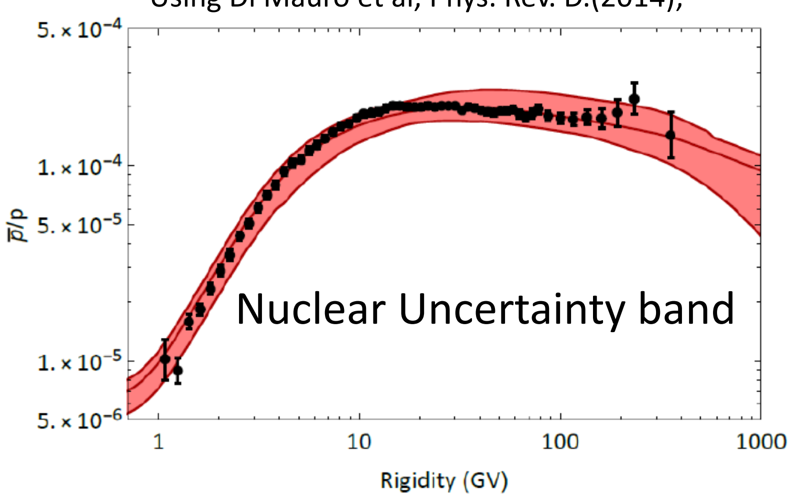
NA61 p+p data beam momenta of 20, 31, 40, 80, and 158 GeV/c
Eur. Phys. J. C 77, 671 (2017)

AMS Data vs Predictions

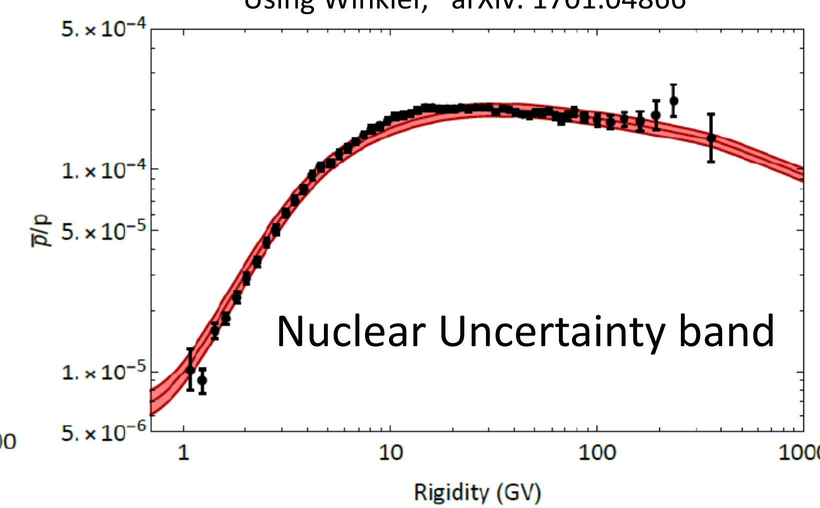
Using Boschini et al, APJ 2018



Using Di Mauro et al, Phys. Rev. D.(2014);

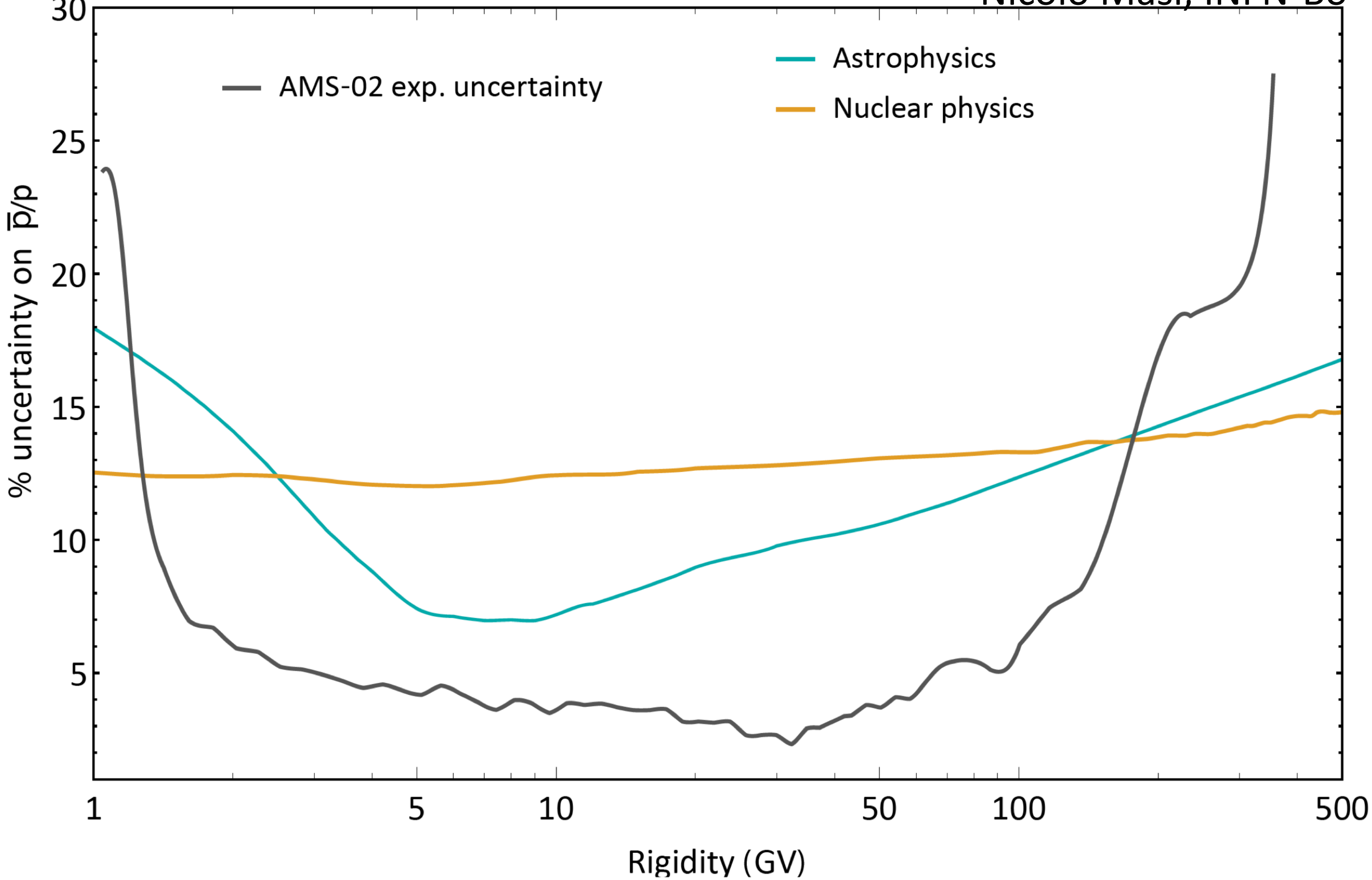


Using Winkler, arXiv: 1701.04866

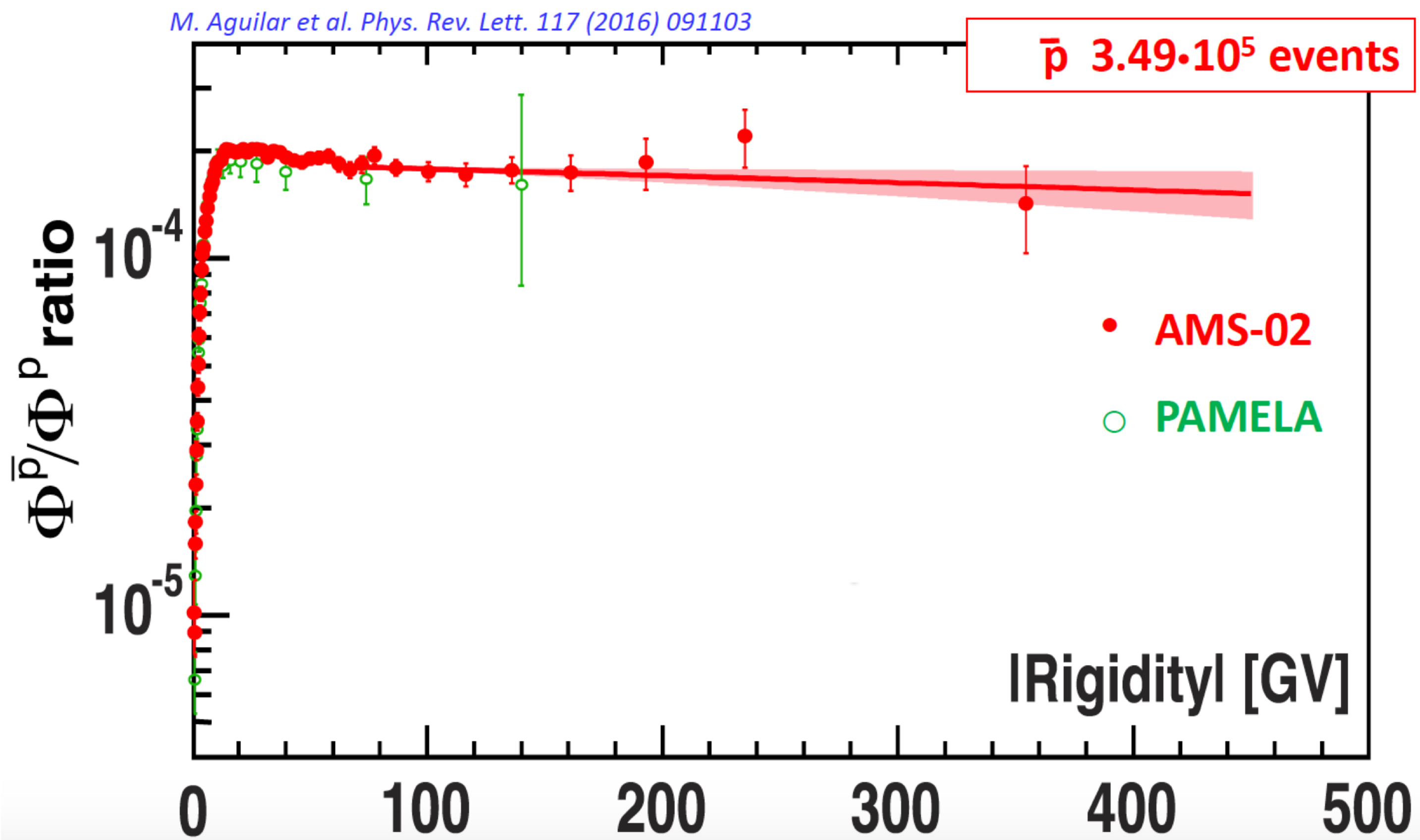


Overall Prediction Uncertainties

Nicolò Masi, INFN-Bo



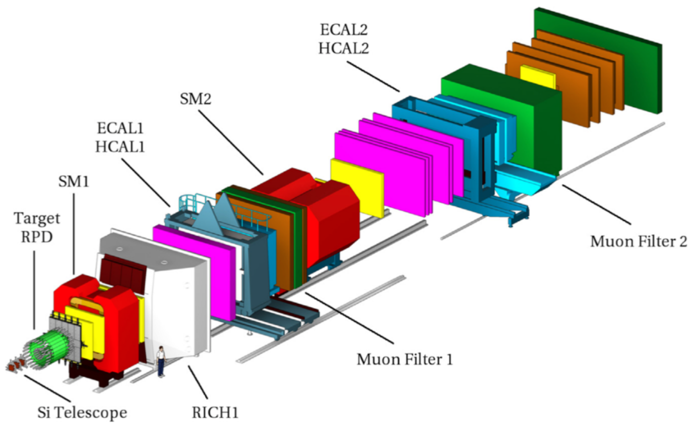
AMS DATA on p-bar/p

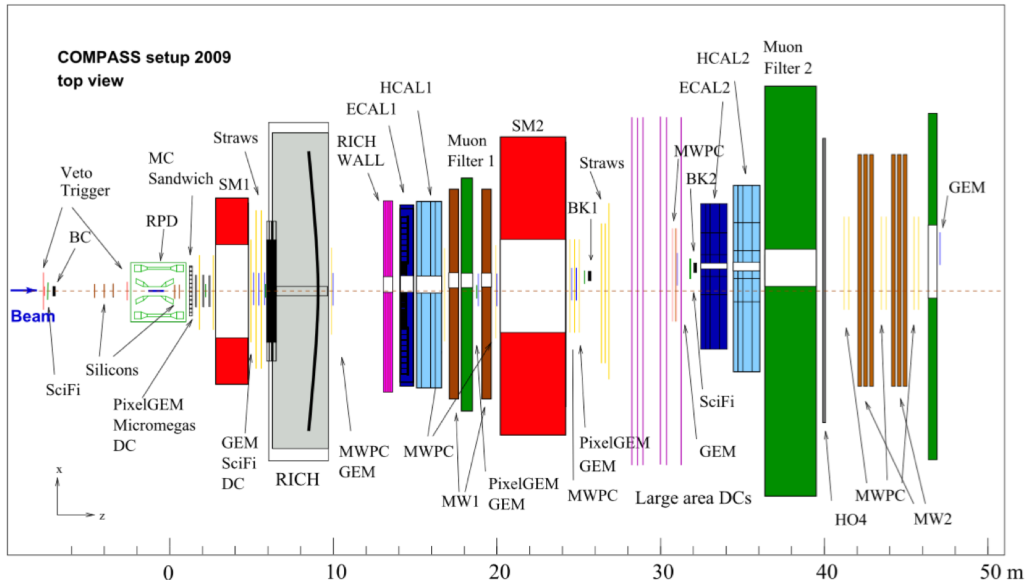


Two major uncertainties limit the prediction of the anti-p flux from CR interaction with ISM

- production cross sections p-p -> pbar +X   p-He-> pbar + X
- CR propagation in the galaxy

COMPASS @ CERN





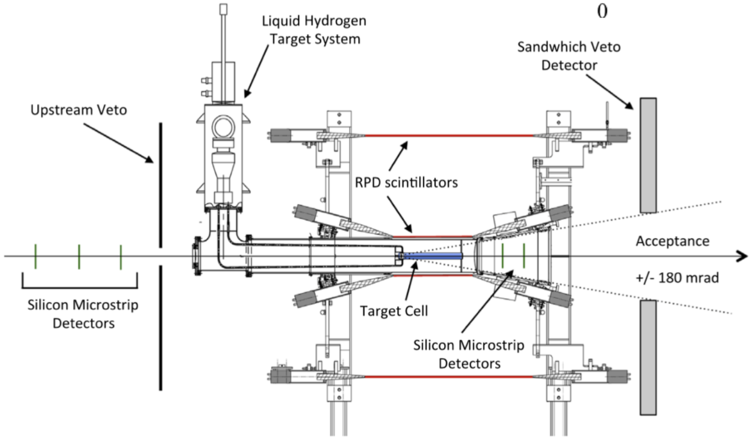


Fig. 4. Side view of the target region with the liquid hydrogen target system.

Acceptance:

+/- 180 mrad

+/- 10 deg

$2.4 < \eta < 6$

New anti-p cross sections with COMPASS++/AMBER

- Use secondary proton beam from SPS
  50, 100, 190, 280 GeV/c
- Use Liquid Hydrogen target and Liquid He target
- Use the COMPASS spectrometer to reconstruct the inelastic event and measure the momentum and charge sign of the tracks attached to the primary vertex
- Use the COMPASS RICH detector to identify anti-p
- Measure the anti-p production cross section for p-p and p-He.

Road to the proposal

- 2017 first contacts between AMS (P.Z., N.Masi) and COMPASS (M.Chiosso, O. Denisov)
- 2018 feasibility study and invite to include the anti-p measurement in the COMPASS-Future 2022-2028 Letter of Intent
- Jan 2019 – Letter of Intent published on arXiv
- Invite form SPSC to submit a proposal for the 2022-2024 program
- Selection of the anti-p measurement for the 3 items to be included in the proposal
- June 2019 proposal submitted to SPSC
- July new collaboration COMPASS++/AMBER is set up
- October 2019 proposal addendum

COMPASS++/AMBER

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SPSC-2019–003
SPSC-I-250
January 28, 2019

Letter of Intent:

A New QCD facility at the M2 beam line of the CERN SPS*

COMPASS++[†]/AMBER[‡]

B. Adams[13,12], C.A. Aidala[1], R. Akhunzyanov[14], G.D. Alexeev[14], M.G. Alexeev[41], A. Amoroso[41,42], V. Andrieux[44], N.V. Anfimov[14], V. Anosov[14], A. Antoshkin[14], K. Augsten[14,32], W. Augustyniak[46],

TION FOR NUCLEAR RESEARCH

CERN-SPSC-2019–022
SPSC-P-360
October 14, 2019

Proposal for Measurements at the M2 beam line of the CERN SPS

– Phase-1 –

COMPASS++*/AMBER[†]

People involved

- UniTN and TIFPA, P. Zuccon, F. Nozzoli
- UniBO and INFN,   N. Masi, L. Quadrani, A. Contin
- UniTO and INFN,   M. Chiosso, O. Denisov, F. Donato, M. Kosmeier
- Nagoya University, N. Horikawa (cryo – targets)

- Support from the COMPASS++/AMBER community at large

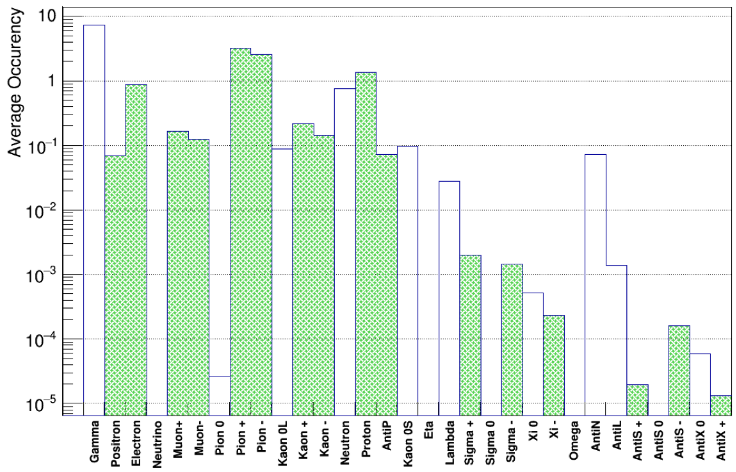
When ?

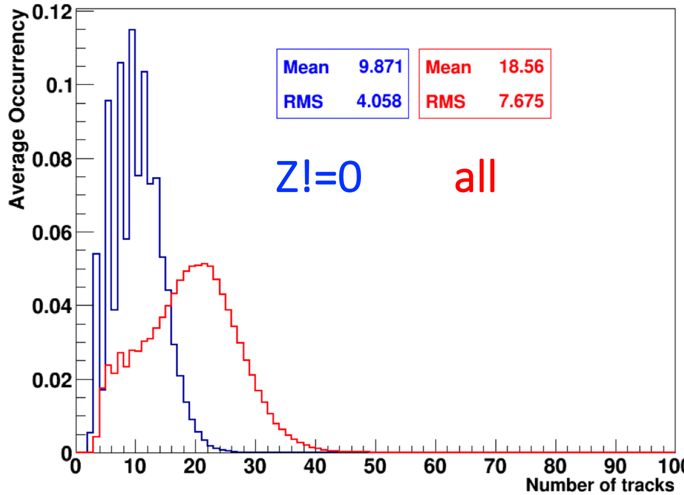
Autumn 2022: commissioning run 10 days
Spring 2023: data taking run 20 days

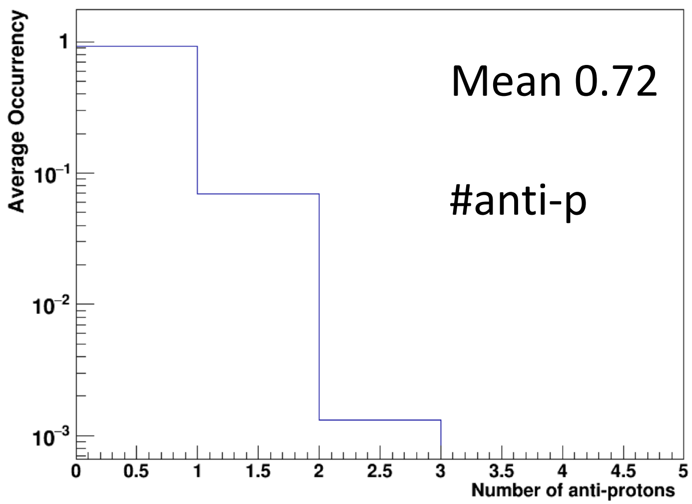
Expected performances

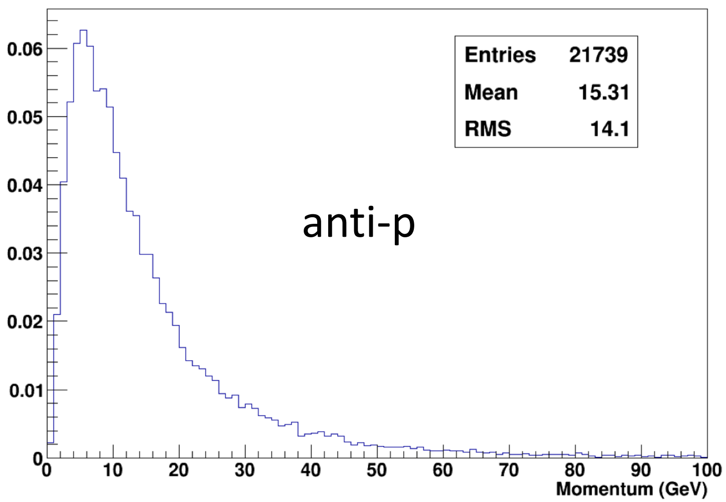
p-LH2 event features @ 190 GeV/c

3.05 10^5 interacting events



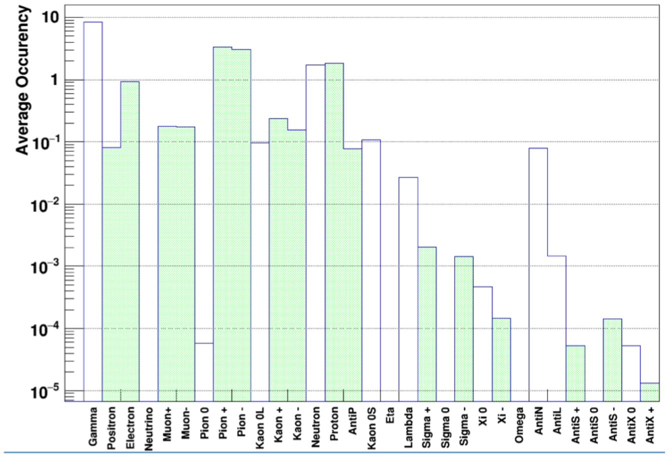


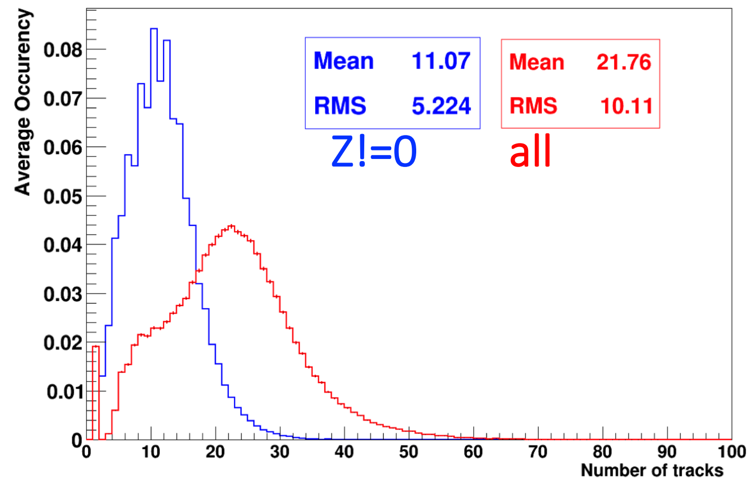


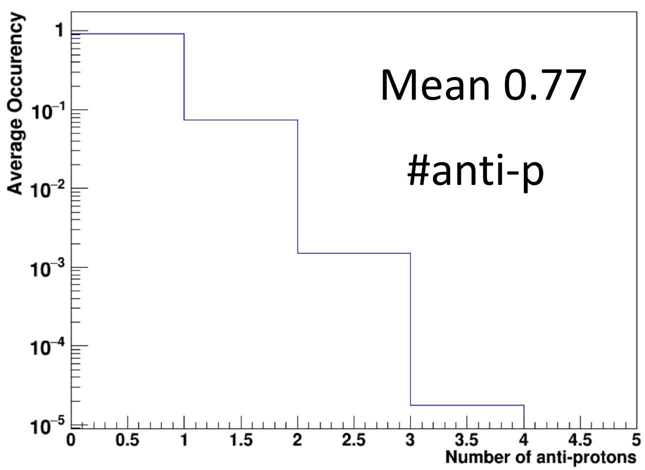


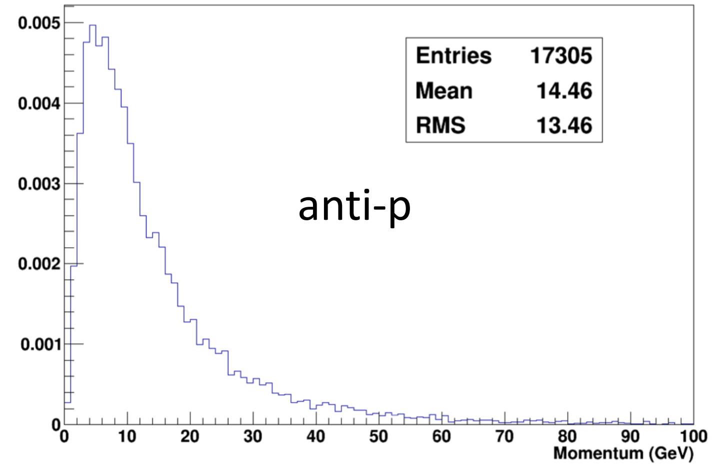
p-LHe event features @ 190 GeV/c

2.25 10^5 interacting events



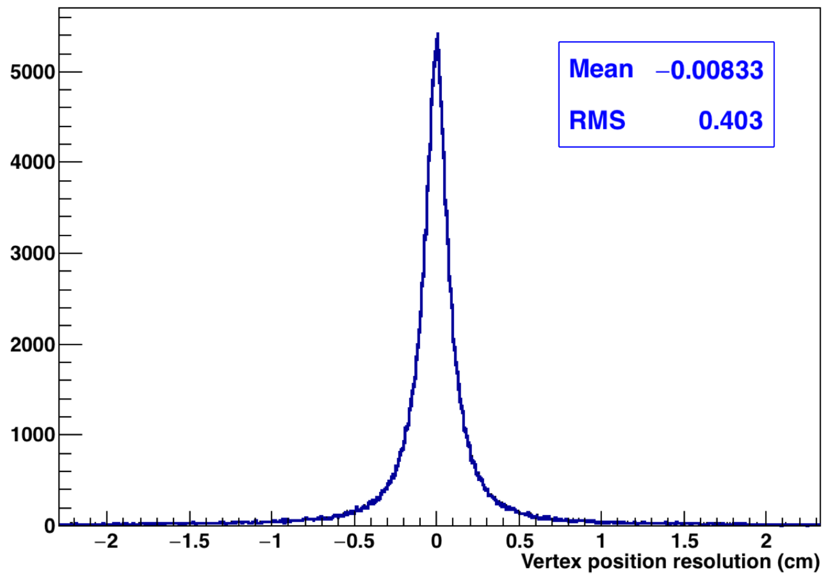




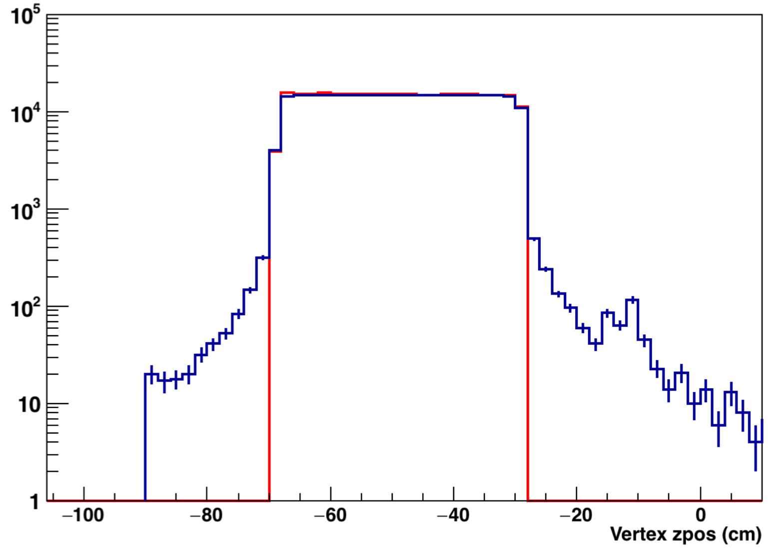


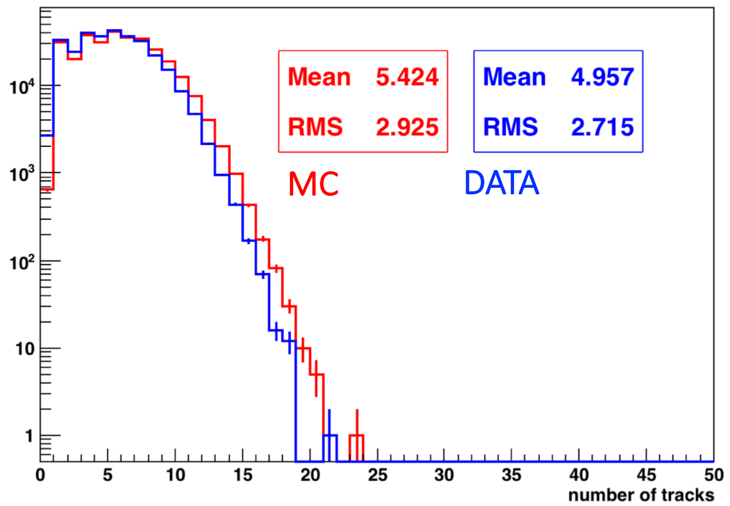
COMPASS simulation (p-p 190GeV)

Vertex resolution



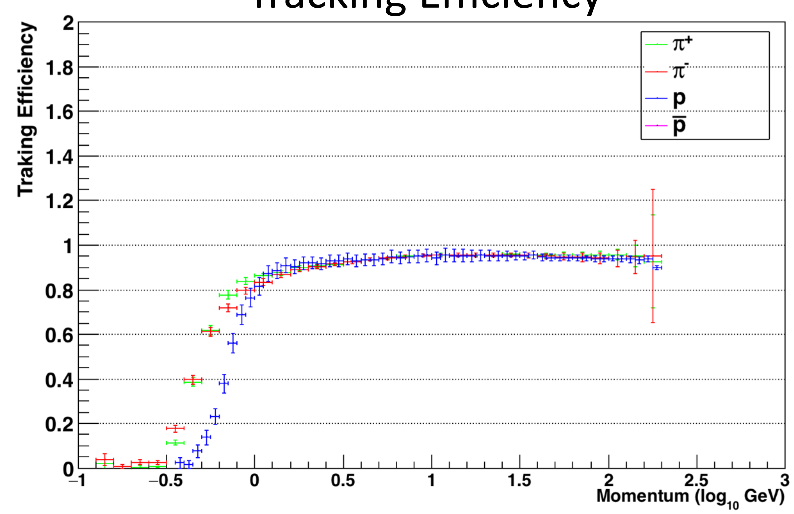
Vertex position



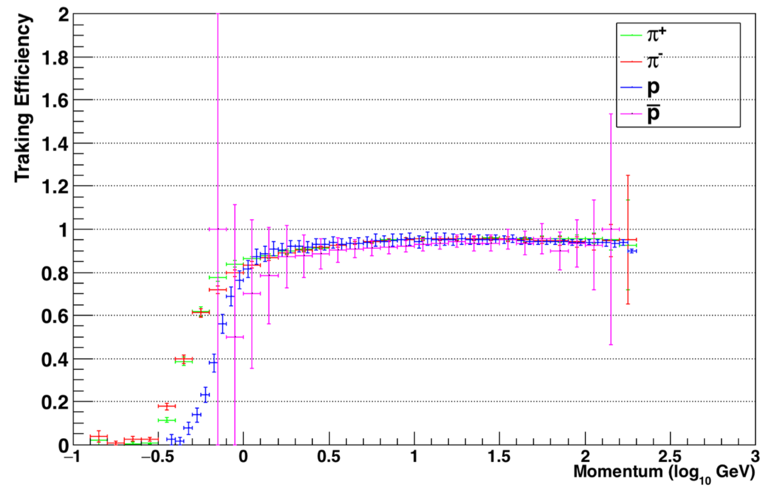


COMPASS Rec accuracy

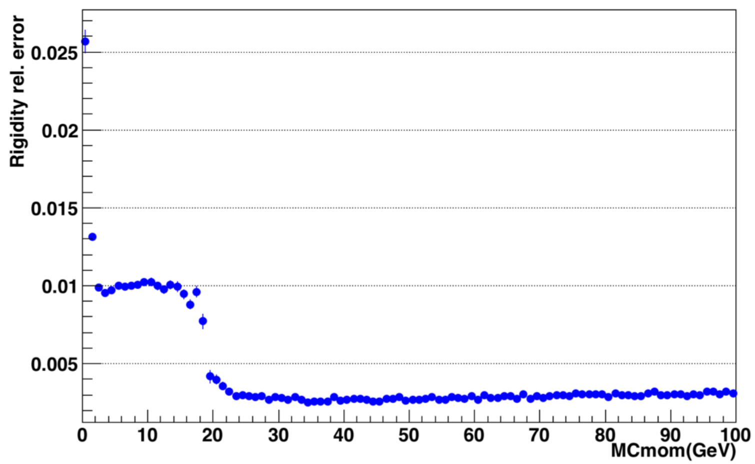
Tracking Efficiency



Tracking Efficiency



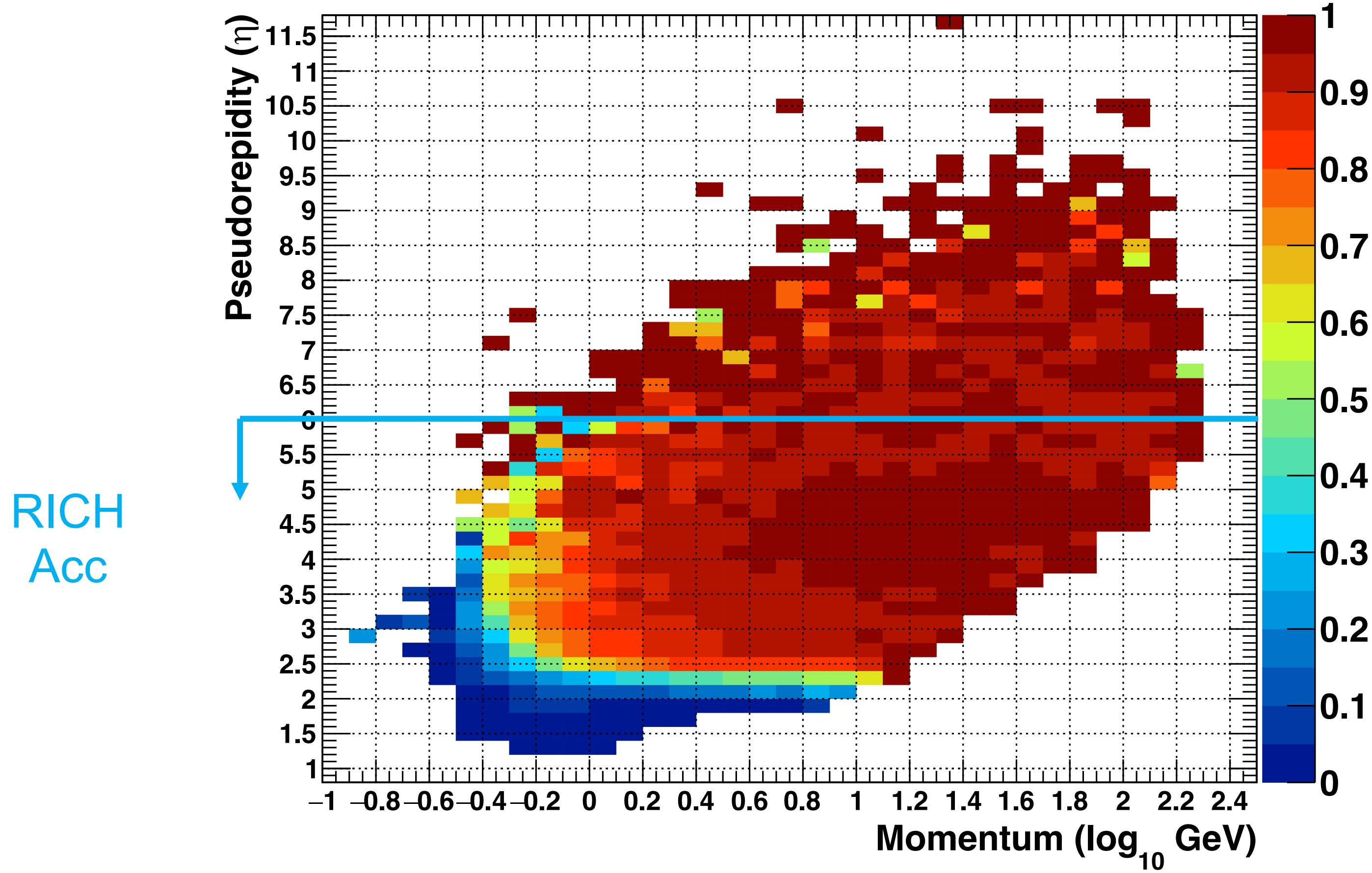
Momentum resolution



COMPASS simulation (p-p 190GeV)

Antiproton tracking efficiency

Pseudo-rapidity vs log_{10}(momentum)



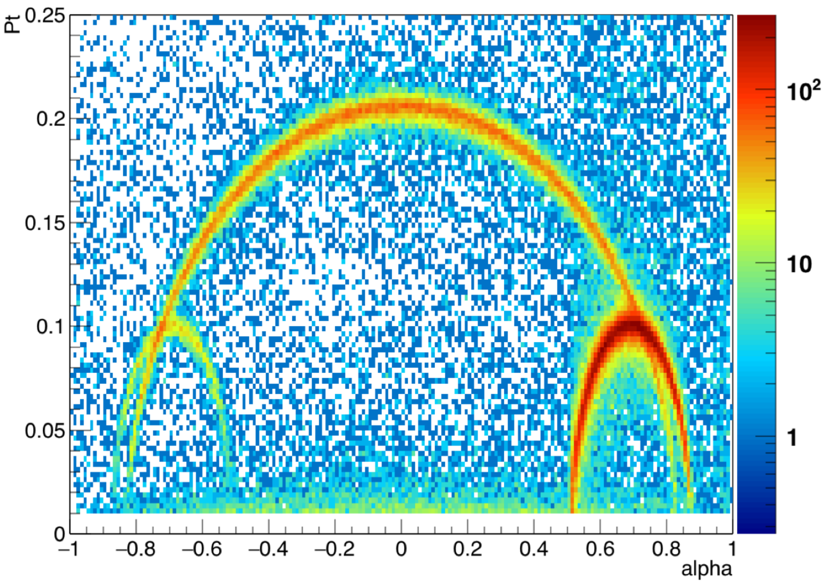
Estimate RICH particle identification performance from p-p data already collected at 190 GeV

Select pure samples of p, pbar, π+ and π-

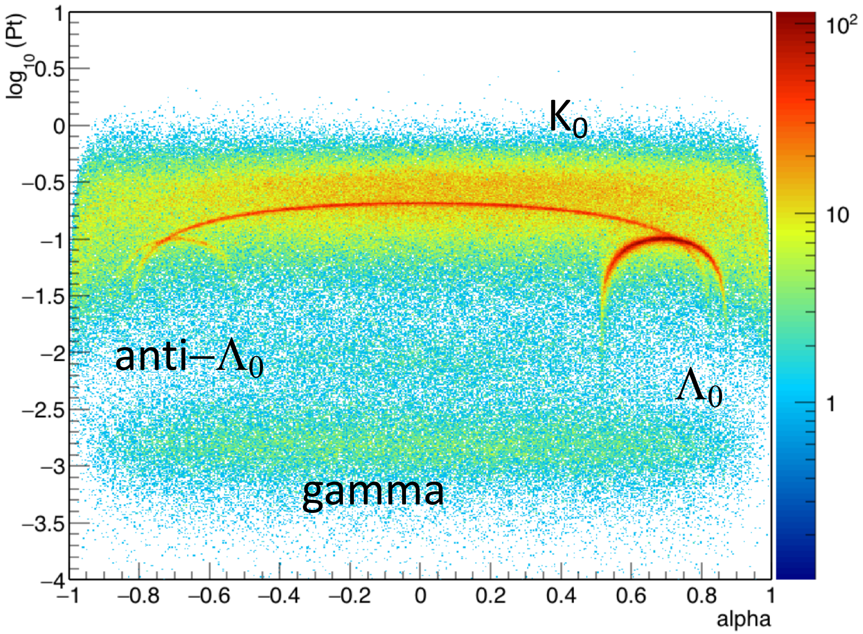
DATA SET collected in 2009 (p-LH2)

Select a sample of V0
- two tracks forming a vertex
- p=p1+p2 points to the primary vertex

After clean up (min dist, prim ang)

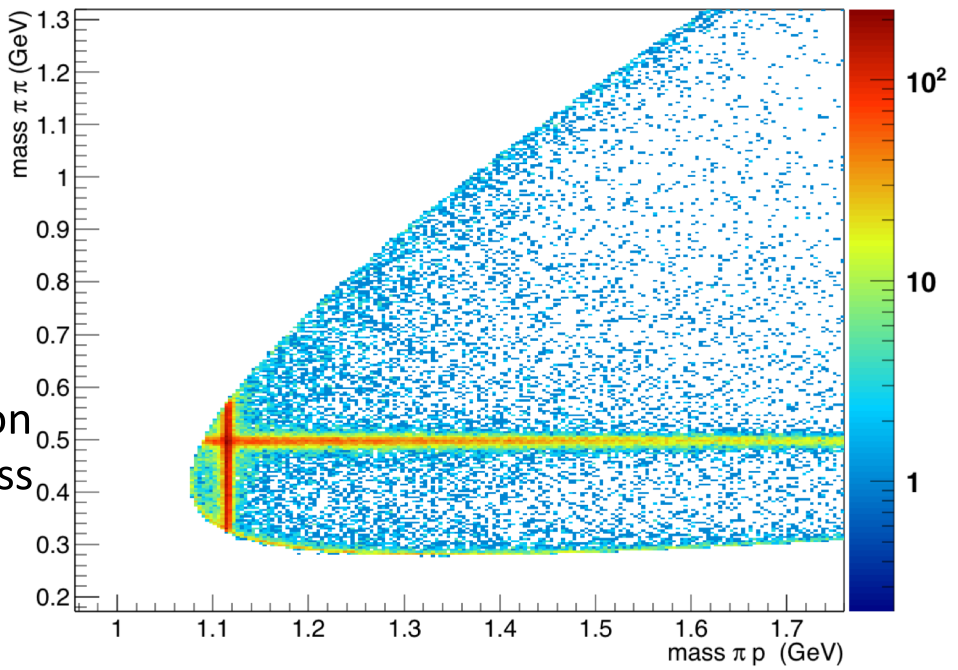


Armenteros plot



alpha = pl1-pl2/(pl1+pl2)

Mass selection

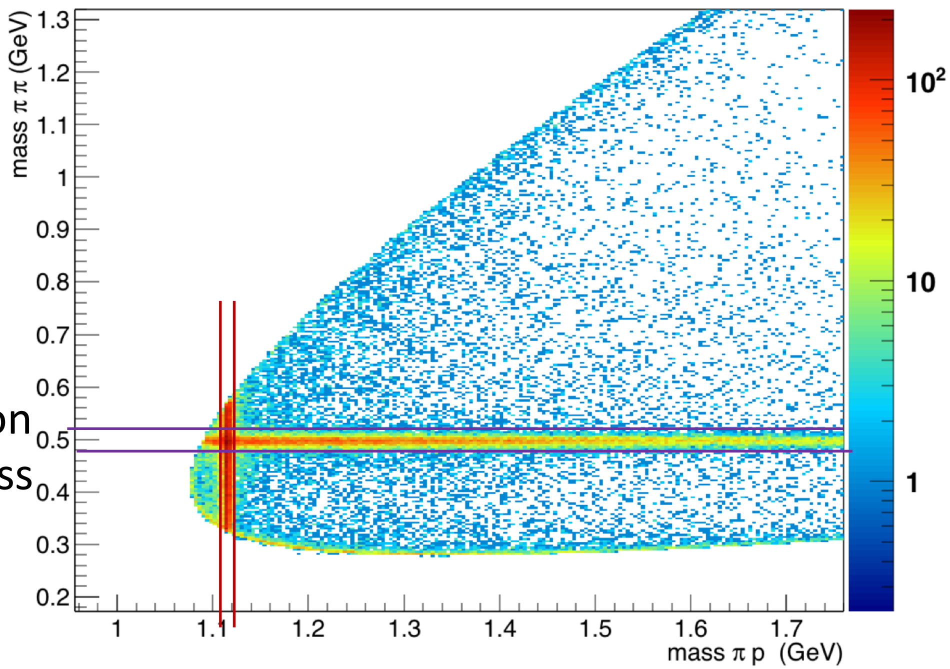


Kaon mass

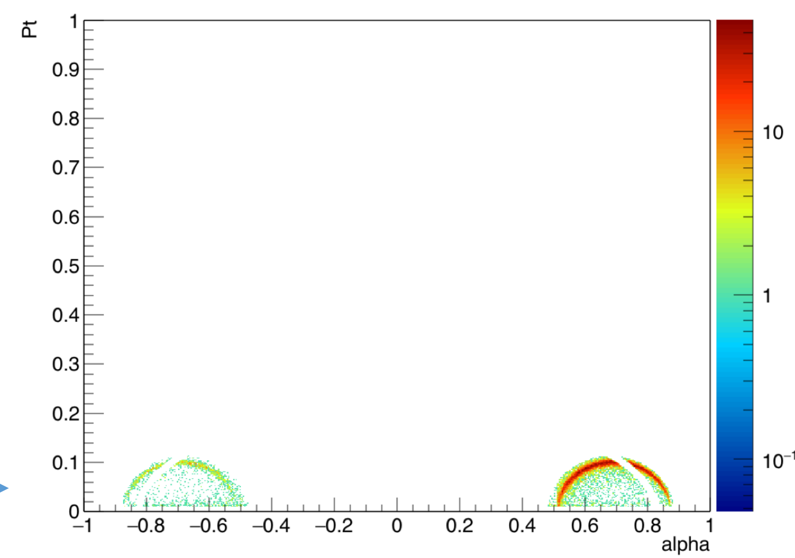
Lambda Mass

Mass selection

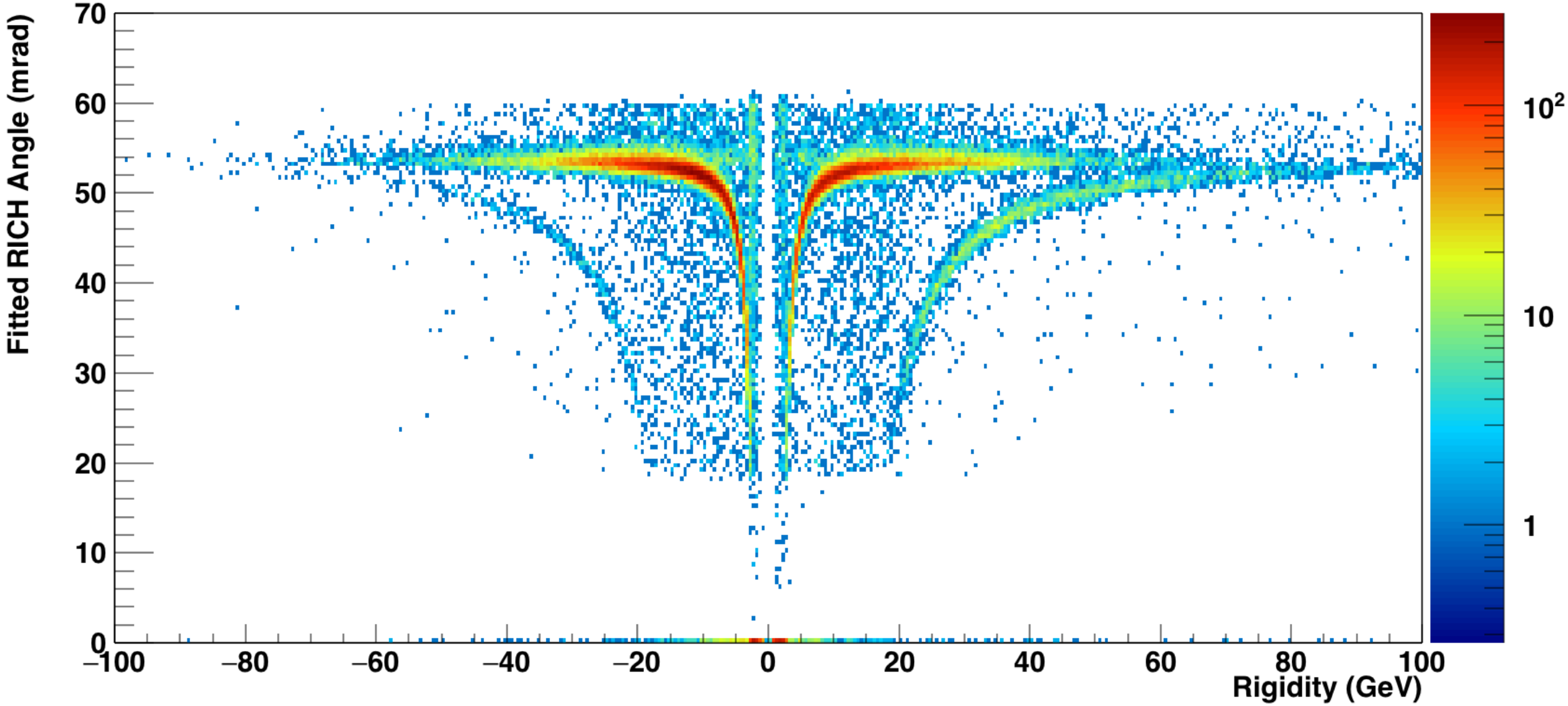
Kaon mass



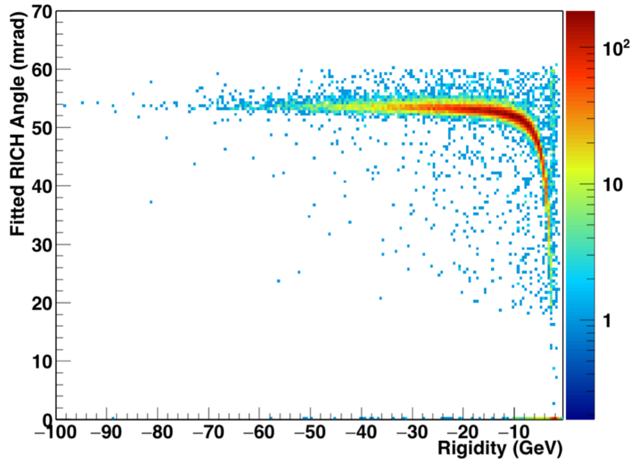
Lambda Mass



Selected Tracks from K_0 and Λ_0

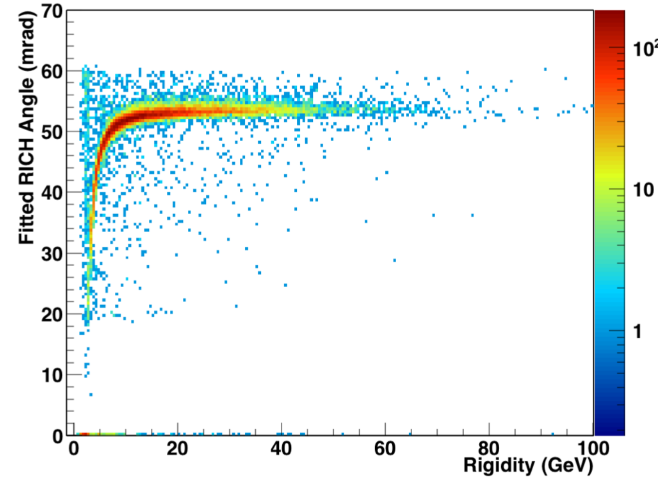


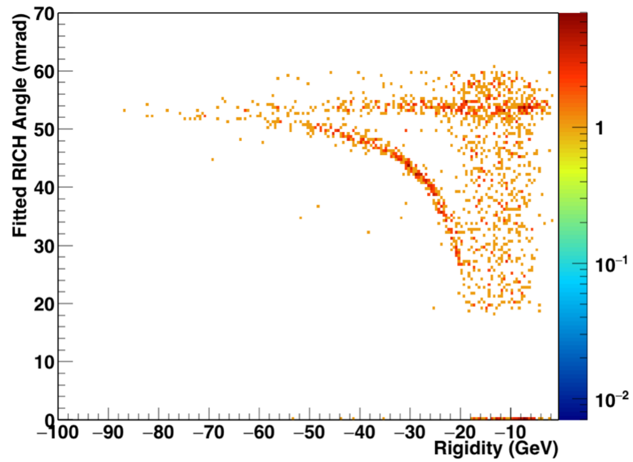
Individual “pure” samples



pi-

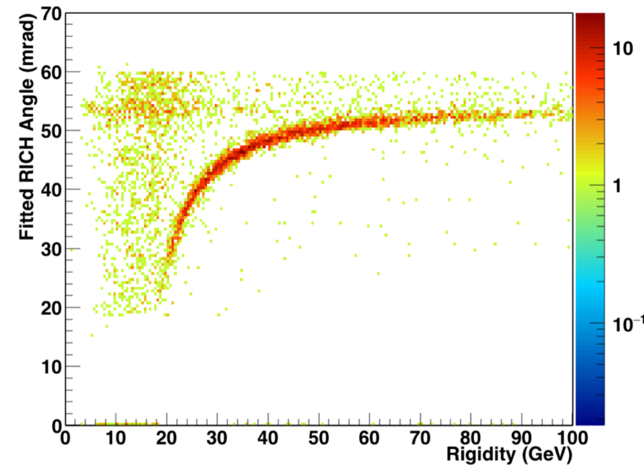
pi+



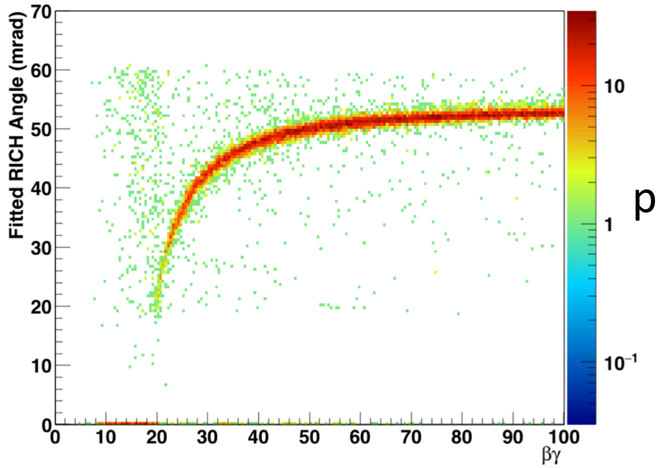


pbar

p

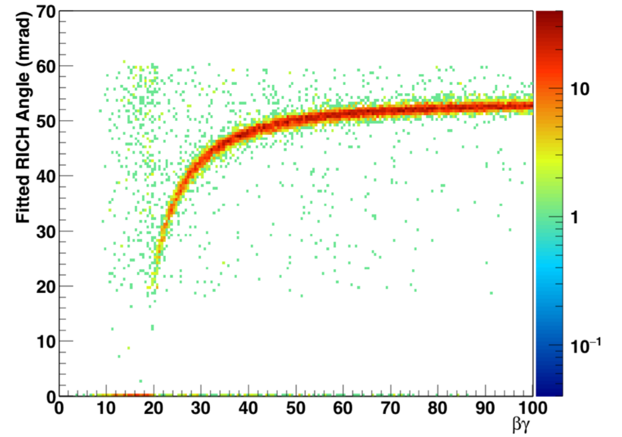


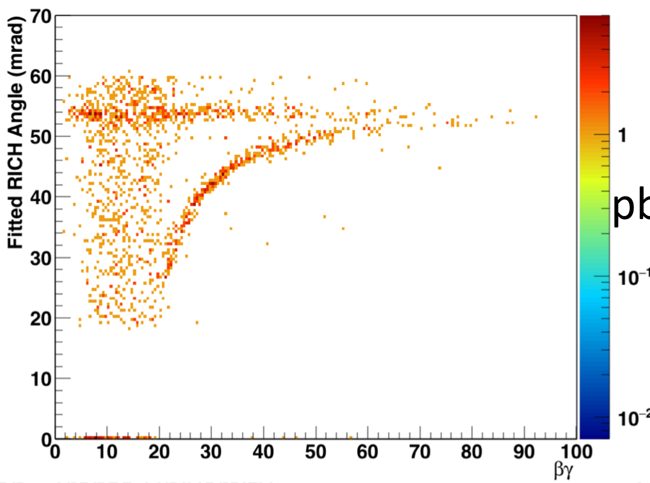
RICH angle vs βγ



pi-

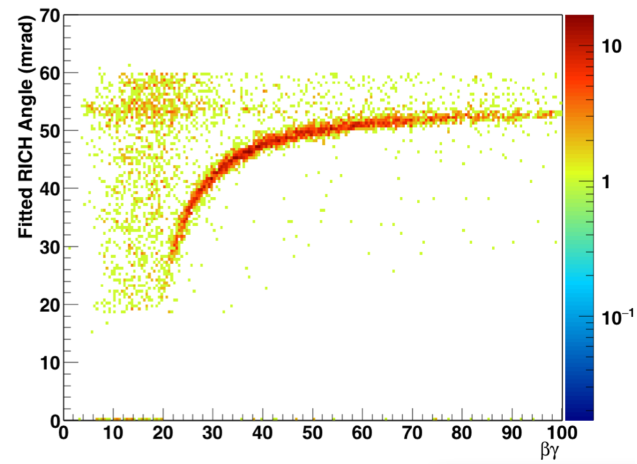
pi+





pbar

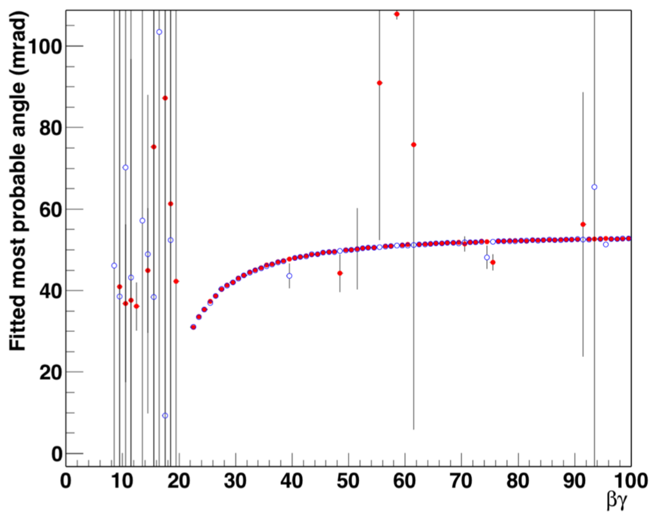
p



Gaussian Fit of the RICH angle

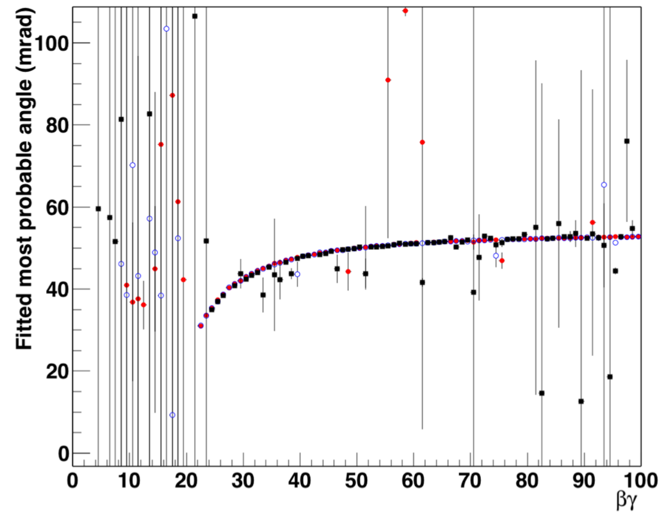
MPV

pi+
pi-

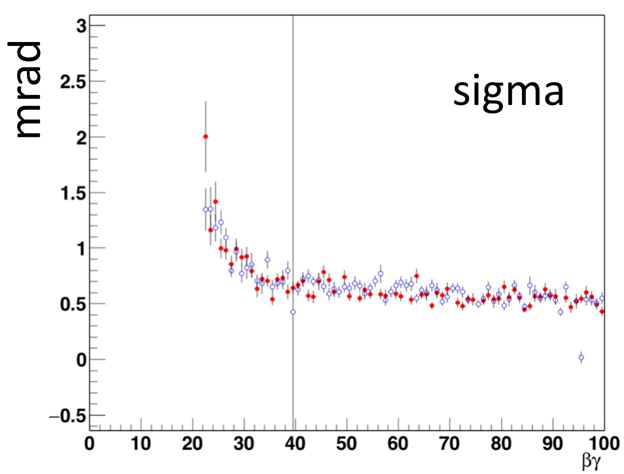


MPV

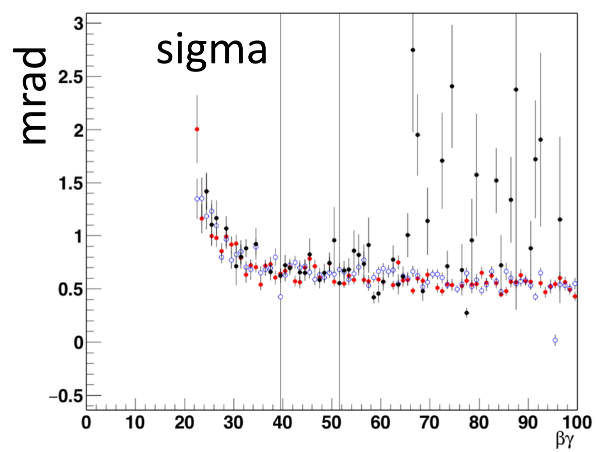
pi+
pi-
p



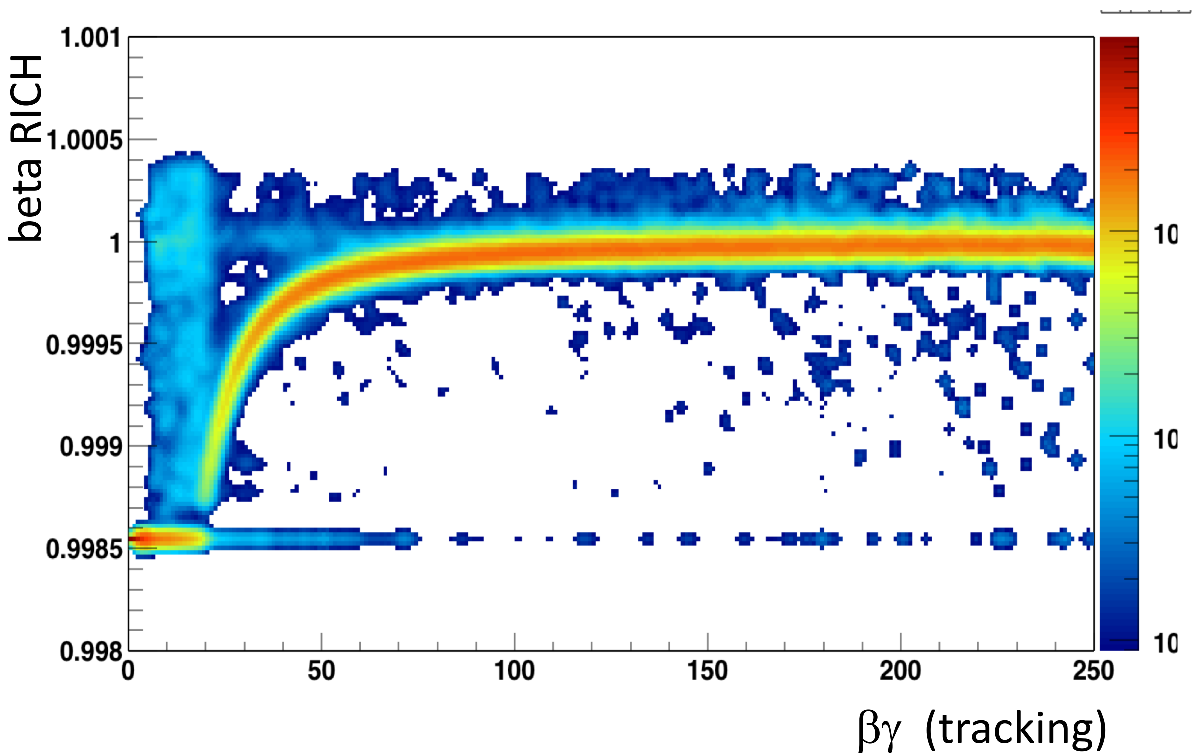
pi+
pi-



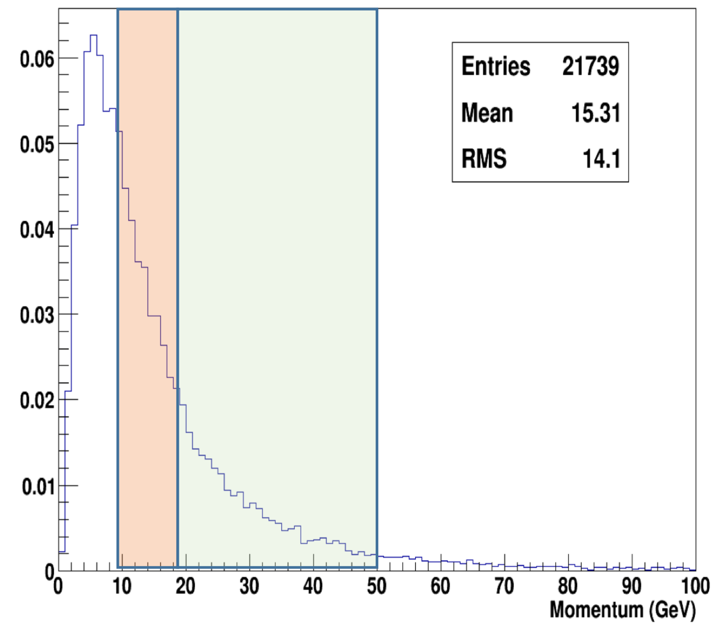
pi+
pi-
p



Universal RICH response function



anti-p spectrum @190 GeV/c



anti-p and p are identified above threshold (~18 GeV/c) with an efficiency >95% up to ~60 (GeV/c)

From the Kaon threshold (~9 GeV/c) to the p threshold, p and anti-p are identified using RICH in veto mode.

Combine the elements to obtain a cross section measurement

Cross section measurement

- Strategy
  - Count all the p-p (or p-He) interaction in the target (R_i)
  - Identify events with one (or multiple) anti-p vs reconstructed momentum and angle ($R_s\ (p, \theta)$)
  - Calculate the double differential cross section as

$$\frac{d\sigma_{\overline{p}}}{dp\ d\theta} = \frac{R_s(p, \theta)}{R_i}$$

- Several possible pitfalls and sources of systematic errors!

Summary of the expected errors

Systematic

	efficiency	est sys error
Track Recon	95%	~1%
Rich Efficiency	~ 99%	~0.5 %
RICH PID	99 to 75 %	0.1 to 4%
Trigger		1%
Vertex error	98%	0.5%
Beam Purity	99.9%	0.5%
TOTAL		4 to 6 %

Considering 2 targets (LHe and LH2, each 50 cm long),
The estimated acceptance and efficiency from the full COMPASS MC.
20 bins in momentum from [10, 50] GeV/c and 20 bin in Pt
75% beam purity at 5E5 p/s beam intensity
We expect to reach 1.7(1.0) % statistical error in most of the 400 differential cross section bins with 4(12) hours of beam time for each energy point.

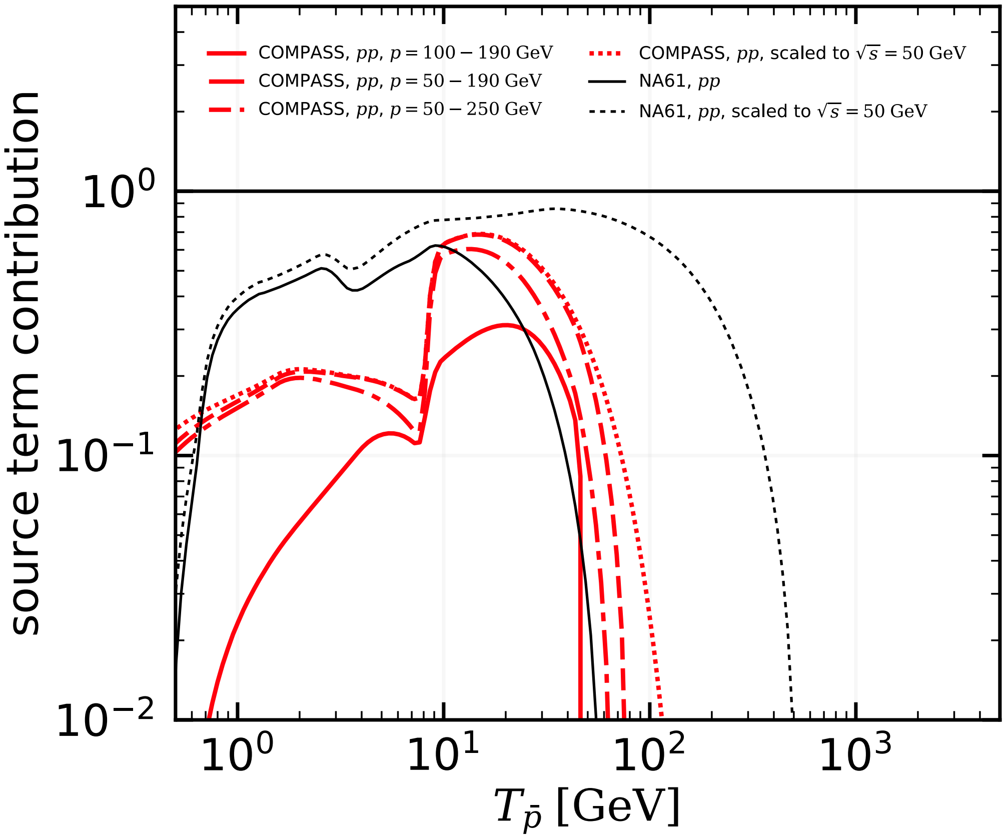
Relevance of the measurement

p-p source term coverage

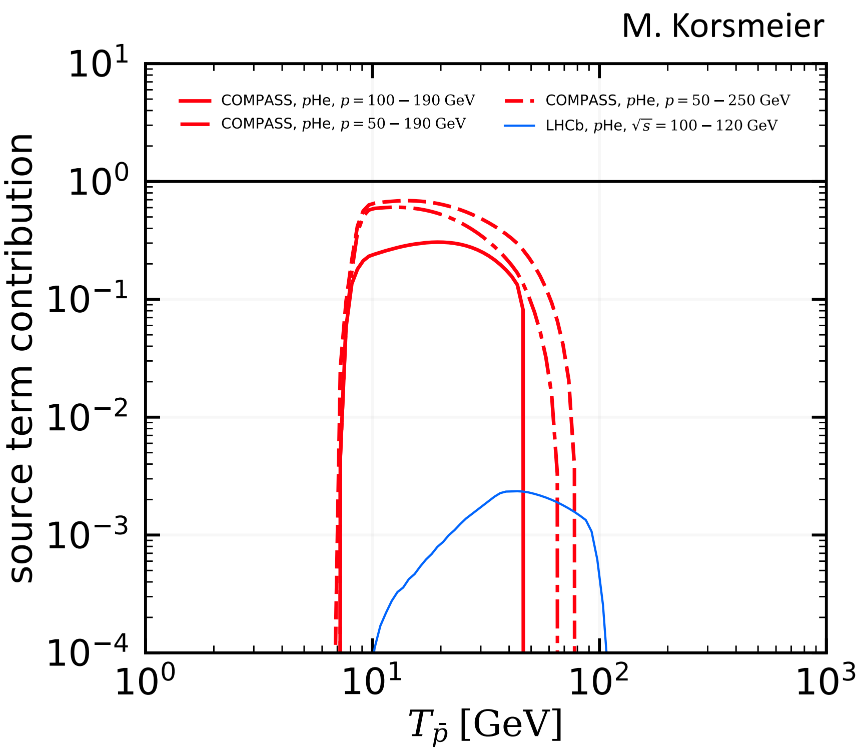
Red AMBER

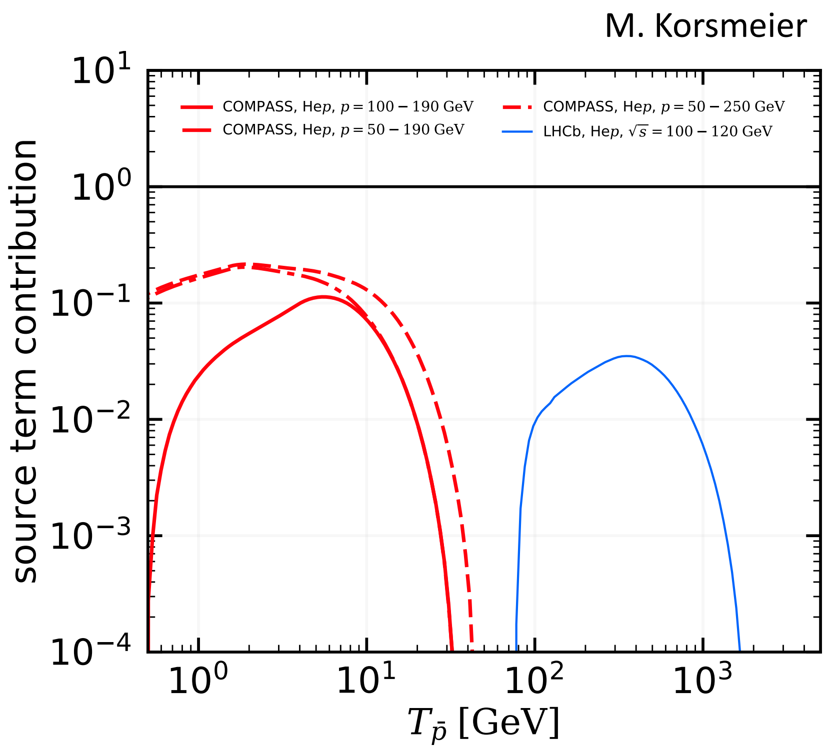
Black NA61

M. Korsmeier



p-He He-p Source term coverage

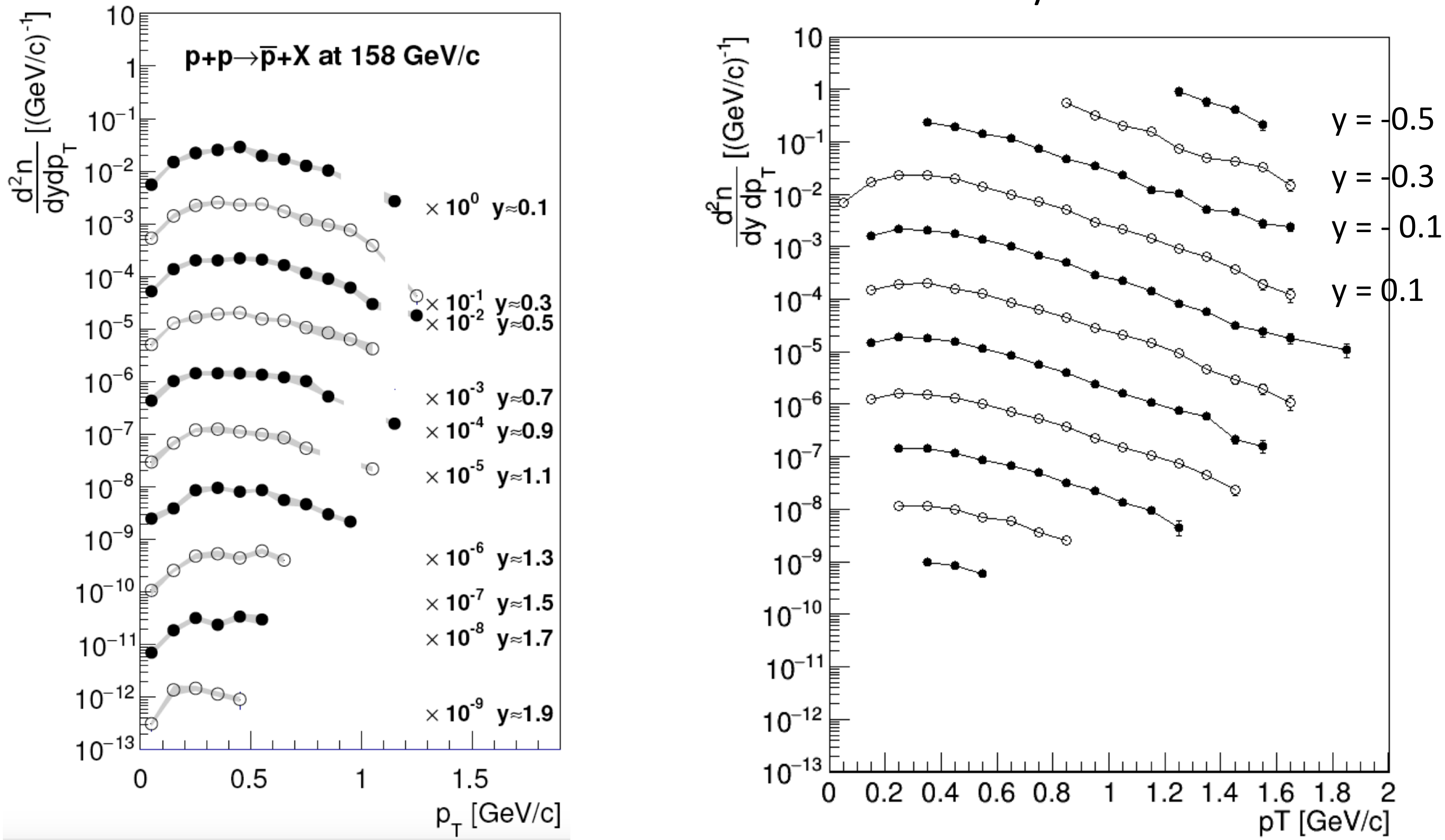




Comparison of p-p -> bar-p +X with NA61

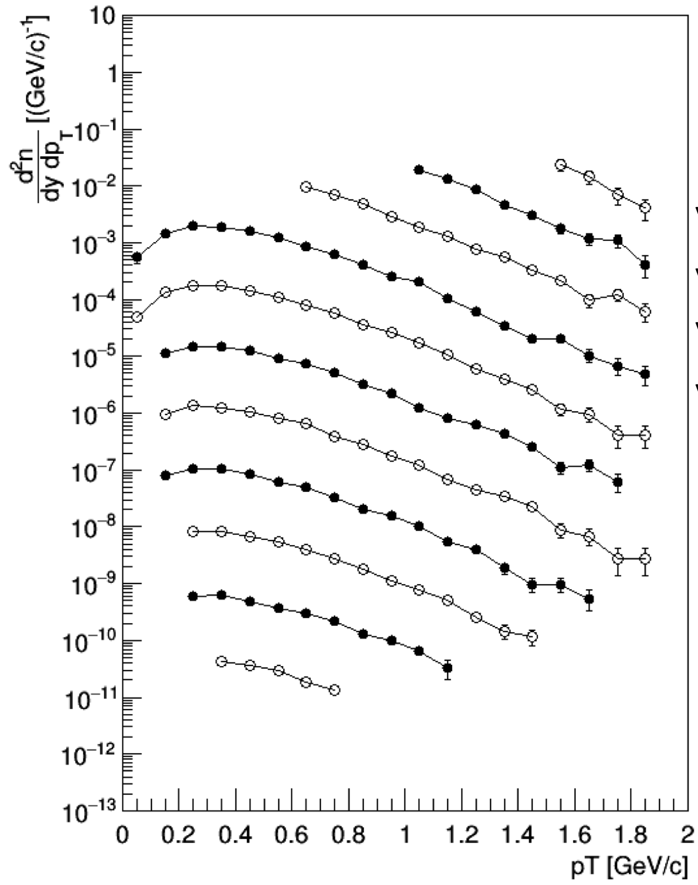
NA61
158 GeV p on LH2

COMPASS++/AMBER
190 GeV/c on LH2



Expected cross section measurement p-He -> bar-p + X

p 190 GeV/c



y = -0.5

y = -0.3

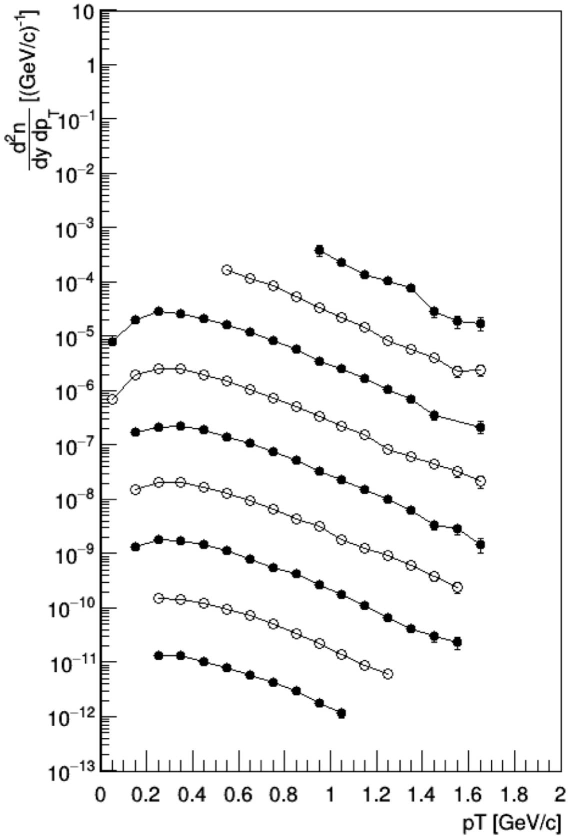
y = - 0.1

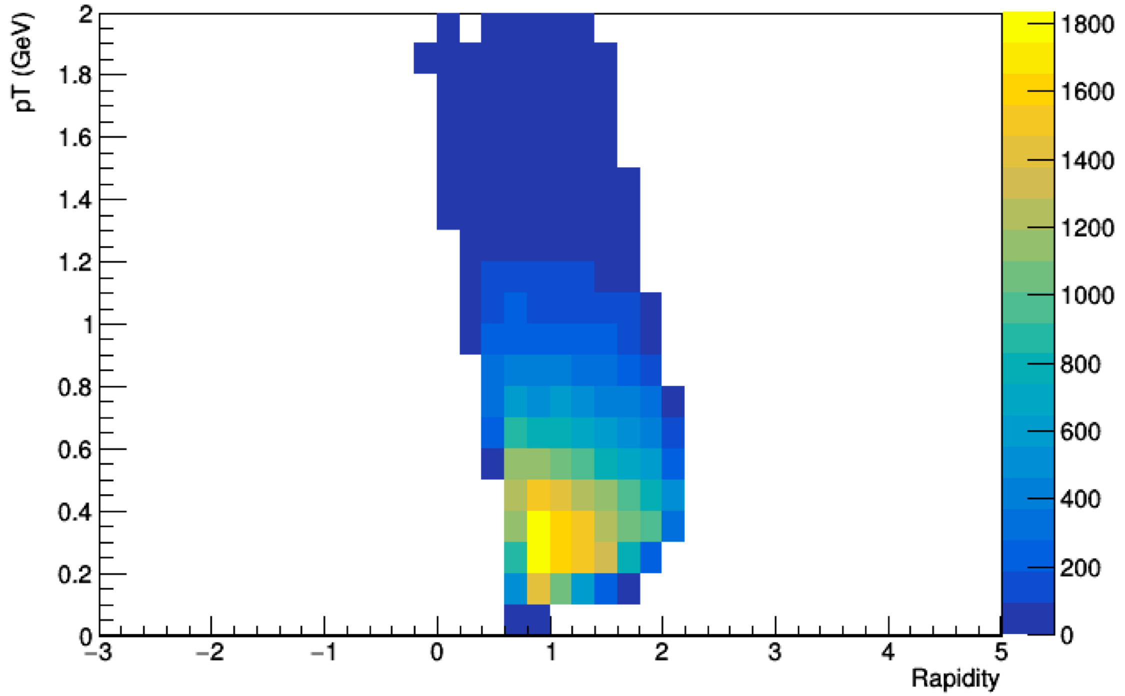
y = 0.1

Summary

- CR antimatter data sensitivity to exotic sources is degraded by the poor knowledge of the pbar production cross sections
- We have shown that a measurement of
  p-p->pbar + X
  and
  p-He-> pbar + X
  can be performed at CERN with the COMPASS++/AMBER spectrometer at momenta ranging from 50 GeV/c to 280 GeV/c
- A new collaboration is being set up and a proposal to SPSC has been submitted
- The new COMPASS++/AMBER data might have an impact on the DM sensitivity on the CR p-bar channel

Coverage of 190 GeV/c p on LHe

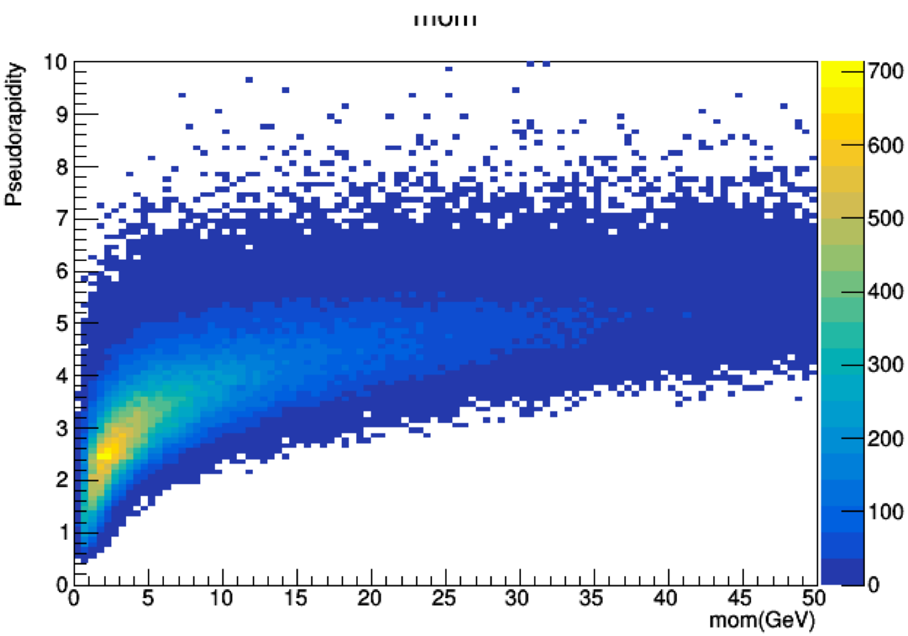


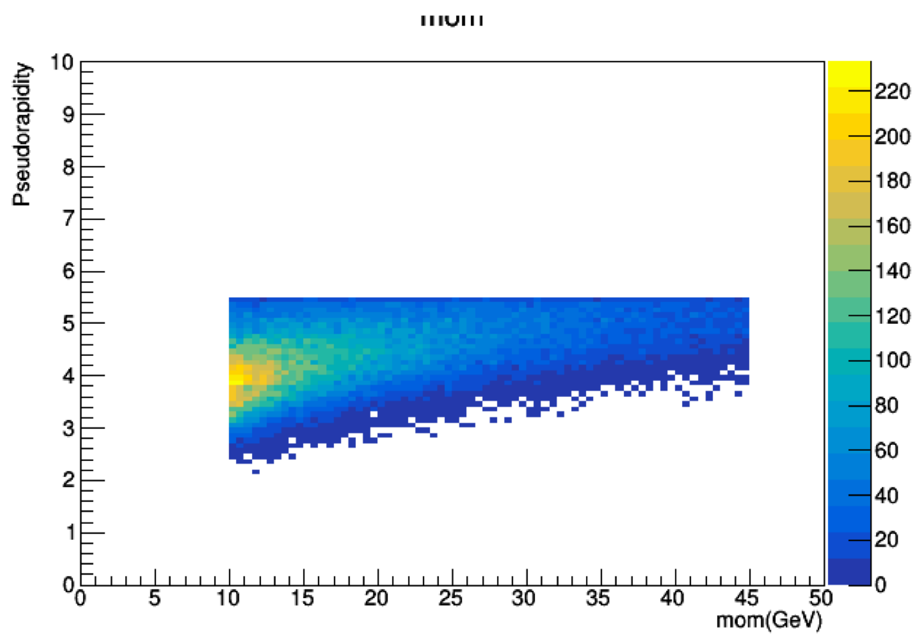


Particle range at 50 GeV/c momentum

MC_PID	Name	range	Mass	Charge	Lifetime		Energy	Beta	gamma
		m	GeV/c2		s		GeV		
20	SIGMA 0	9.31E-10	1.19E+00	0	7.40E-20		5.00E+01	1.00E+00	42
28	ANTISIGMA 0	9.31E-10	1.19E+00	0	7.40E-20		5.00E+01	1.00E+00	42
17	ETA	1.50E-08	5.48E-01	0	5.49E-19		5.00E+01	1.00E+00	91
7	PION 0	9.33E-06	1.35E-01	0	8.40E-17		5.00E+01	1.00E+00	370
24	OMEGA -	7.38E-01	1.67E+00	-1	8.22E-11		5.00E+01	9.99E-01	30
32	ANTIOMEGA +	7.38E-01	1.67E+00	1	8.22E-11		5.00E+01	9.99E-01	30
27	ANTISIGMA -	1.01E+00	1.19E+00	-1	7.99E-11		5.00E+01	1.00E+00	42
19	SIGMA +	1.01E+00	1.19E+00	1	7.99E-11		5.00E+01	1.00E+00	42
21	SIGMA -	1.85E+00	1.20E+00	-1	1.48E-10		5.00E+01	1.00E+00	42
29	ANTISIGMA +	1.85E+00	1.20E+00	1	1.48E-10		5.00E+01	1.00E+00	42
23	XI -	1.86E+00	1.32E+00	-1	1.64E-10		5.00E+01	1.00E+00	38
31	ANTIXI +	1.86E+00	1.32E+00	1	1.64E-10		5.00E+01	1.00E+00	38
16	KAON 0 SHORT	2.69E+00	4.98E-01	0	8.93E-11		5.00E+01	1.00E+00	100
22	XI 0	3.31E+00	1.32E+00	0	2.90E-10		5.00E+01	1.00E+00	38
30	ANTIXI 0	3.31E+00	1.32E+00	0	2.90E-10		5.00E+01	1.00E+00	38
18	LAMBDA	3.54E+00	1.12E+00	0	2.63E-10		5.00E+01	1.00E+00	45
26	ANTILAMBDA	3.54E+00	1.12E+00	0	2.63E-10		5.00E+01	1.00E+00	45
12	KAON -	3.76E+02	4.94E-01	-1	1.24E-08		5.00E+01	1.00E+00	101
11	KAON +	3.76E+02	4.94E-01	1	1.24E-08		5.00E+01	1.00E+00	101
10	KAON 0 LONG	1.56E+03	4.98E-01	0	5.17E-08		5.00E+01	1.00E+00	100
9	PION -	2.80E+03	1.40E-01	-1	2.60E-08		5.00E+01	1.00E+00	358
8	PION +	2.80E+03	1.40E-01	1	2.60E-08		5.00E+01	1.00E+00	358
6	MUON -	3.12E+05	1.06E-01	-1	2.20E-06		5.00E+01	1.00E+00	473
5	MUON +	3.12E+05	1.06E-01	1	2.20E-06		5.00E+01	1.00E+00	473
13	NEUTRON	1.42E+13	9.40E-01	0	8.87E+02		5.00E+01	1.00E+00	53
25	ANTINEUTRON	1.42E+13	9.40E-01	0	8.87E+02		5.00E+01	1.00E+00	53
46	TRITON	5.35E+24	2.81E+00	1	1.00E+15		5.01E+01	9.98E-01	18
45	DEUTERON	8.00E+24	1.88E+00	1	1.00E+15		5.00E+01	9.99E-01	27
15	ANTIPROTON	1.60E+25	9.38E-01	-1	1.00E+15		5.00E+01	1.00E+00	53
14	PROTON	1.60E+25	9.38E-01	1	1.00E+15		5.00E+01	1.00E+00	53
3	ELECTRON	2.94E+28	5.11E-04	-1	1.00E+15		5.00E+01	1.00E+00	97847
2	POSITRON	2.94E+28	5.11E-04	1	1.00E+15		5.00E+01	1.00E+00	97847
49	HE3	5.35E+24	2.81E+00	2	1.00E+15		5.01E+01	9.98E-01	18
47	ALPHA	4.04E+24	3.73E+00	2	1.00E+15		5.01E+01	9.97E-01	13

p-p 190 GeV/c LH2





Compass Trigger system

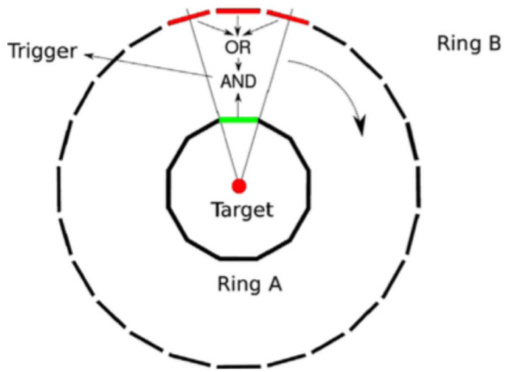


Fig. 54. Allowed combinations for target pointing in the RPD part of the proton trigger.

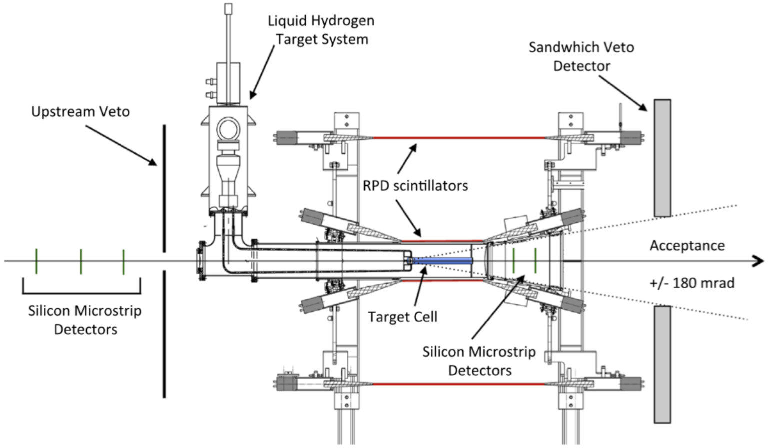


Fig. 4. Side view of the target region with the liquid hydrogen target system.

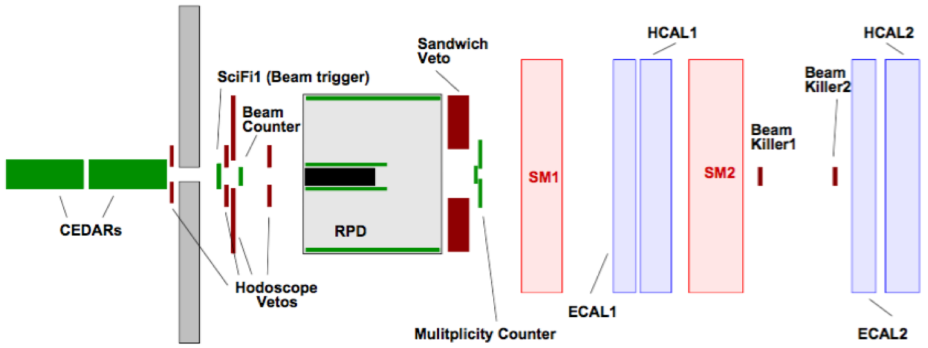


Fig. 51. Arrangement of trigger elements in the spectrometer (schematic side view, not to scale).

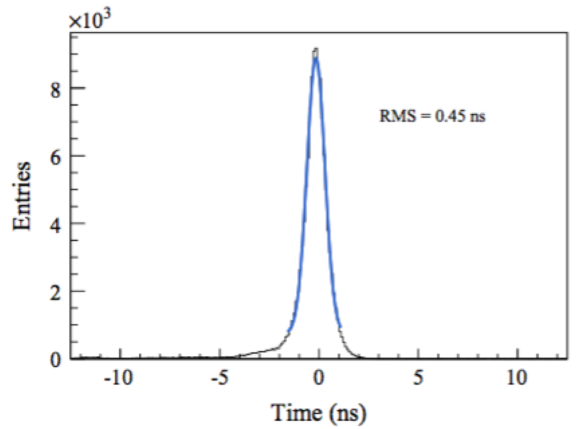


Fig. 53. Time residual of the beam trigger.

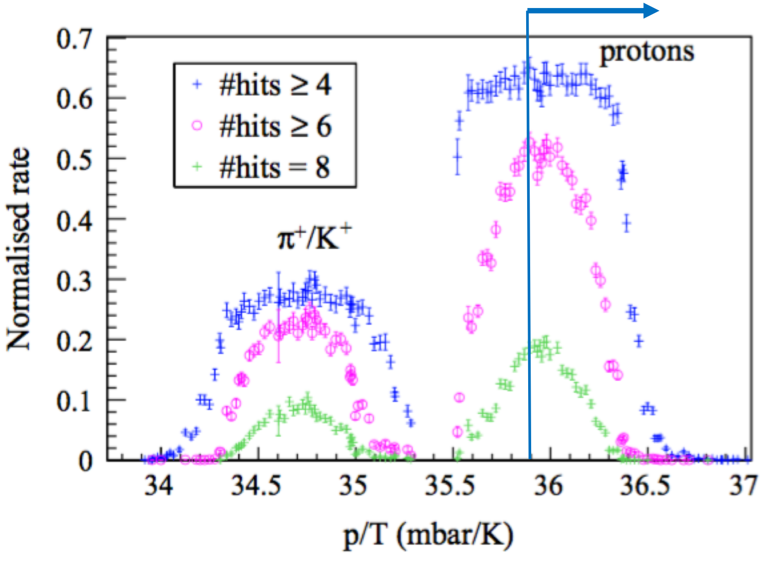
Rate statistics and pileup

- Typical beam intensity is 5 10^7 p for a 9.8s spill
- We expect ~ 5.4 % of the protons to interact with the 40cm LH2 target → ~ 270k interaction/s
- Compass standard trigger DT0 is $BT \,\&\, \overline{BK} \,\&\, \overline{Sandwich\,Veto} \,\&\, RPD$
- This reduce the trigger rate to 33 kHz which can be handled by the COMPASS DAQ
- For the future measurements we will ask to reduce the beam intensity to 5 10^6 and plan to use the trigger

$$BT \,\&\, \overline{BK} \,\&\, \overline{Sandwich\,Veto}$$

- This will provide an expected rate of 25 kHz

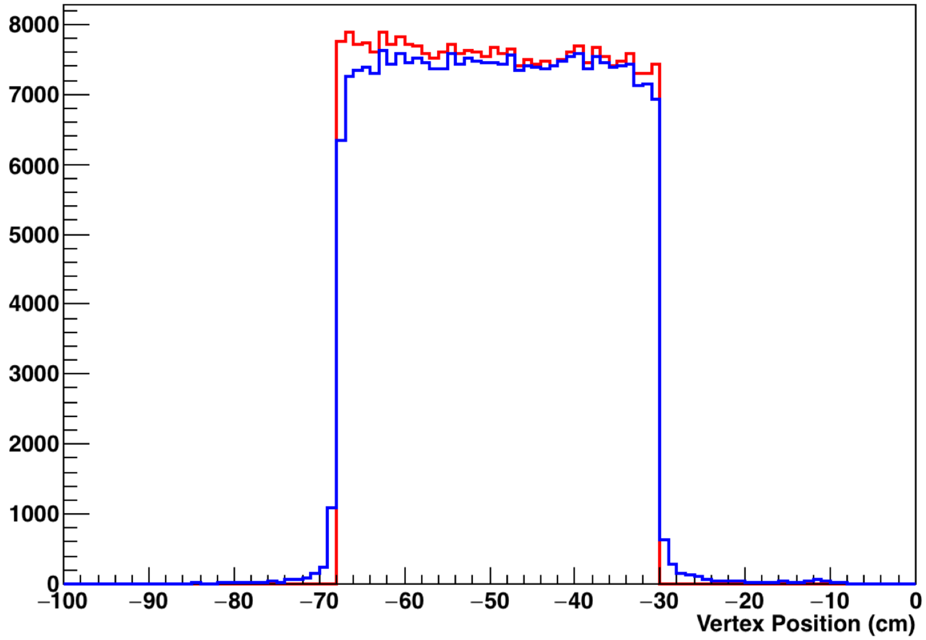
Upstream Threshold Cherenkov counter



Beam and Trigger error ~ 0.5%

Lost Interaction events

- Select a fiducial volume on the target [-68,-30] cm
- Look how many events have a reconstructed vertex within the fiducial volume



MC events: 288312
No Vertex: 2753 (0.95%)
Vtx outside: 2856 (0.99%)

Thanks to the Recoil Detector no-vertex events can be cross-checked with data

Vertex error 0.5%