

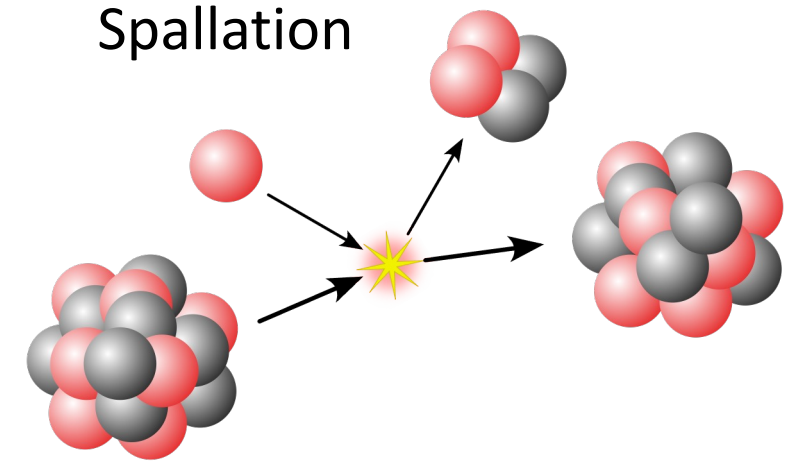
Measurements of cross sections of AstroParticle Physics relevance

P. Zuccon – Trento University & INFN TIFPA

Perugia – June 19th, 2023

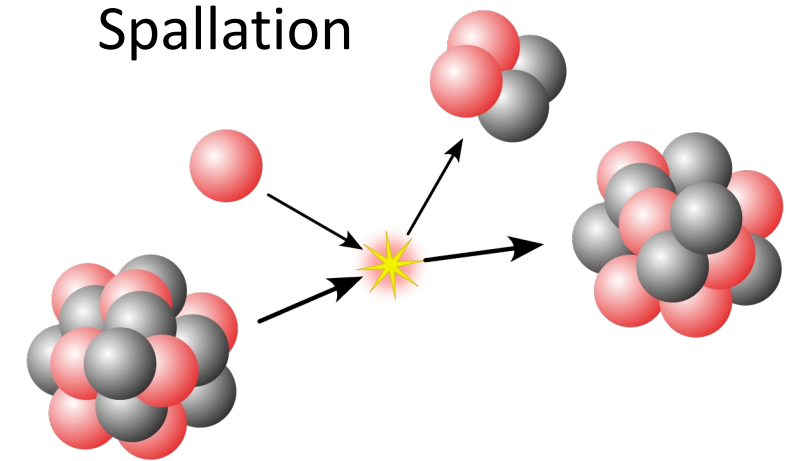
Introduction

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- A similar precision in the knowledge of peculiar cross sections is now requested
- Three kind, maybe four, class of problems
 - For all elements: Isotopic Nuclear fragmentation cross sections on ISM (p and He nuclei)
 - Production of p bar and positrons in dominant CR-ISM interactions (p-p and p-He, He-p)
 - Disappearance cross sections of Nuclei on the CR detectors material (mostly C and Al).
 - Cross section for producing anti-nuclei (D bar, ^3He bar, ^4He bar) in dominant CR-ISM interactions (p-p and p-He, He-p)



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Solve the "cross-pollination" of CR spectra measured in the Heliosphere



Obtain a better sensitivity to signals from exotic physics



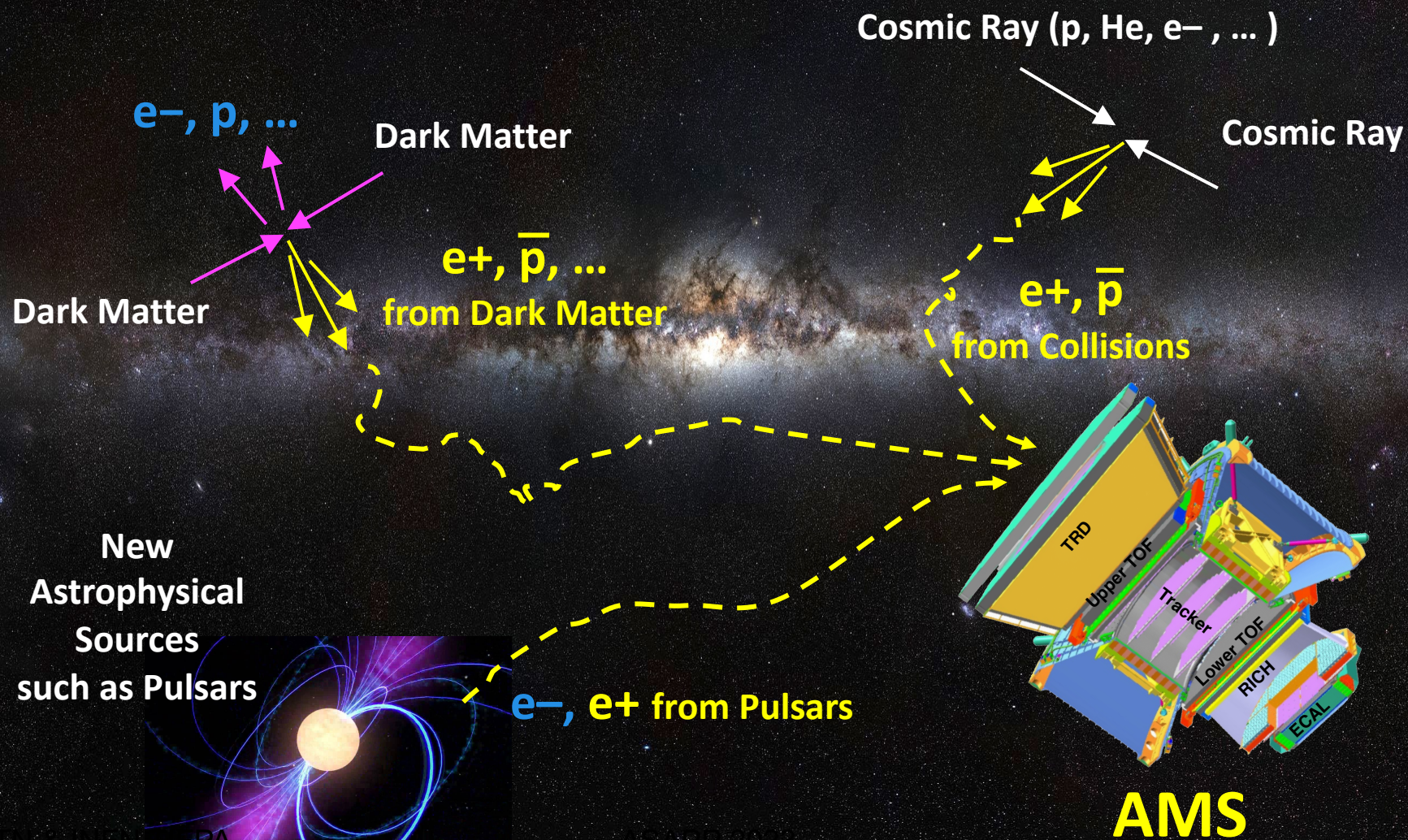
Reduce systematic errors on the measurements



Improve sensitivity to primordial anti-matter and to DM

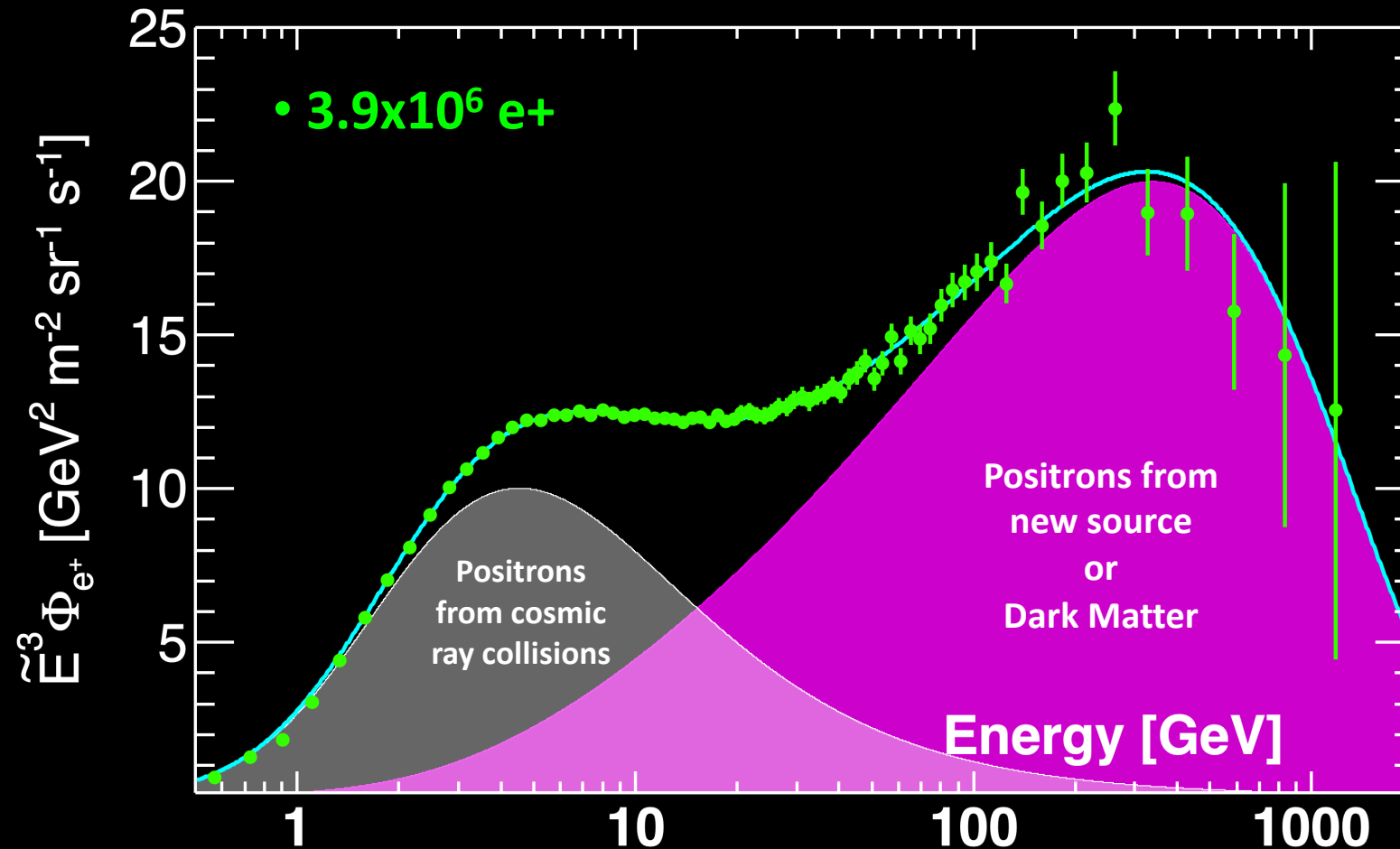
Latest AMS Results on e^+ , e^- , and \bar{p}

Origins of e^+ , e^- , \bar{p}



The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from pulsars or dark matter both with a cutoff energy E_s .

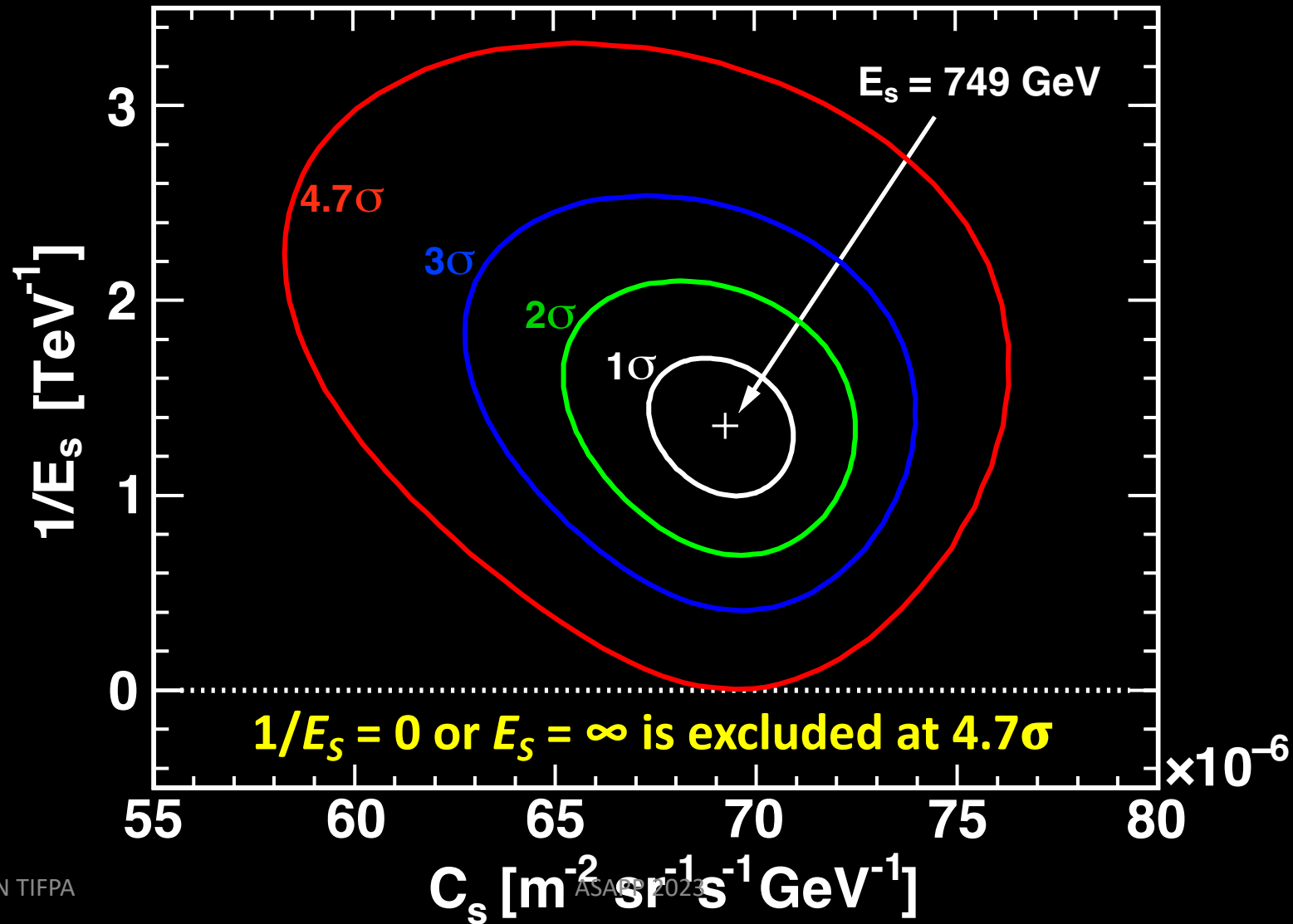
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2} \left[\underbrace{C_d (\hat{E}/E_1)^{\gamma_d}}_{\text{Solar Collisions}} + \underbrace{C_s (\hat{E}/E_2)^{\gamma_s} \exp(-\hat{E}/E_s)}_{\text{Pulsars or Dark Matter}} \right]$$



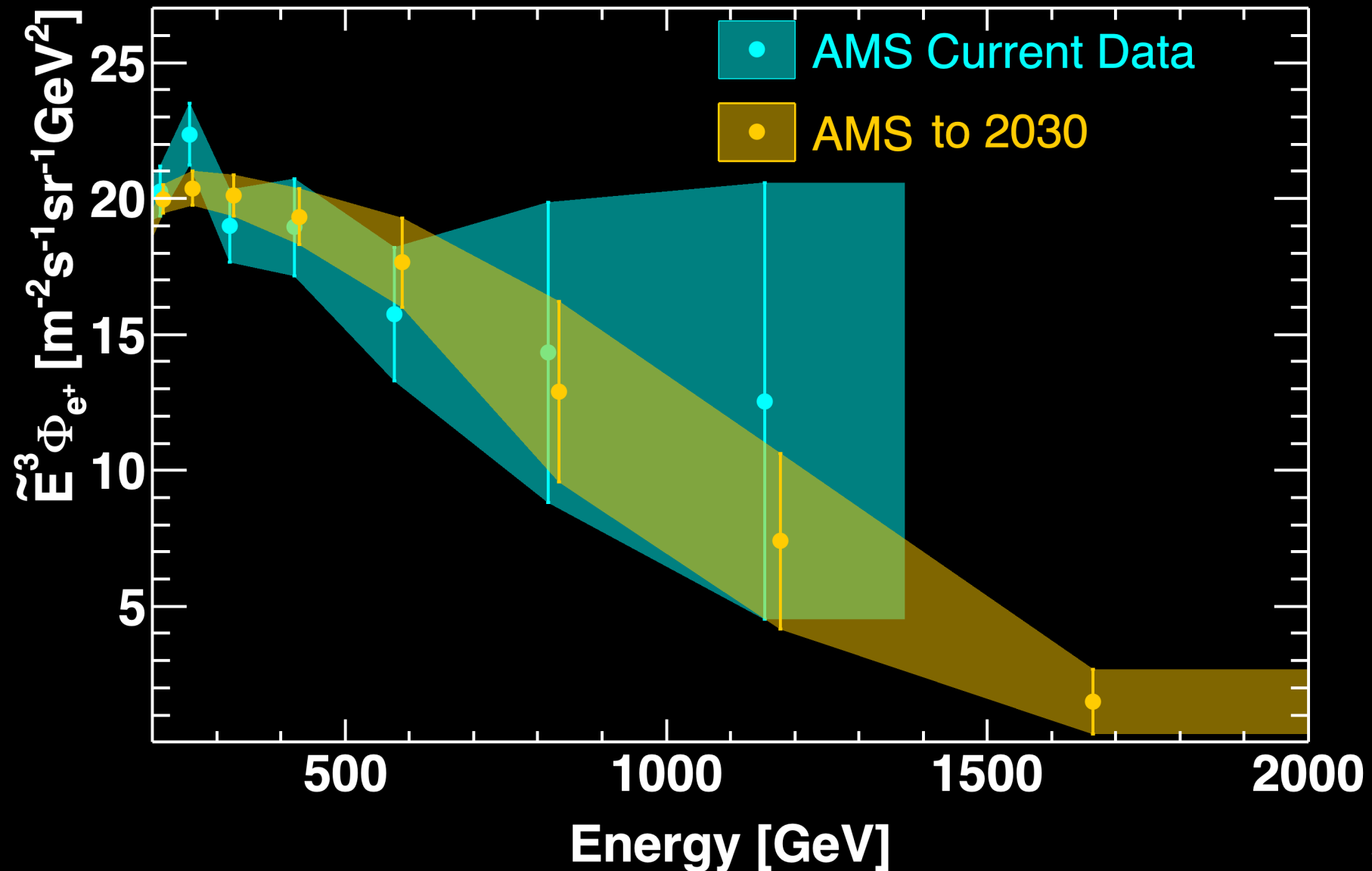
The existence of the finite cutoff energy (4.7σ)
is a new and unexpected observation

Determination of the cutoff energy E_s

$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2} \left[\overset{\text{Collisions}}{C_d (\hat{E}/E_1)^{\gamma_d}} + \overset{\text{New Source or Dark Matter}}{C_s (\hat{E}/E_2)^{\gamma_s} \exp(-\hat{E}/E_s)} \right]$$

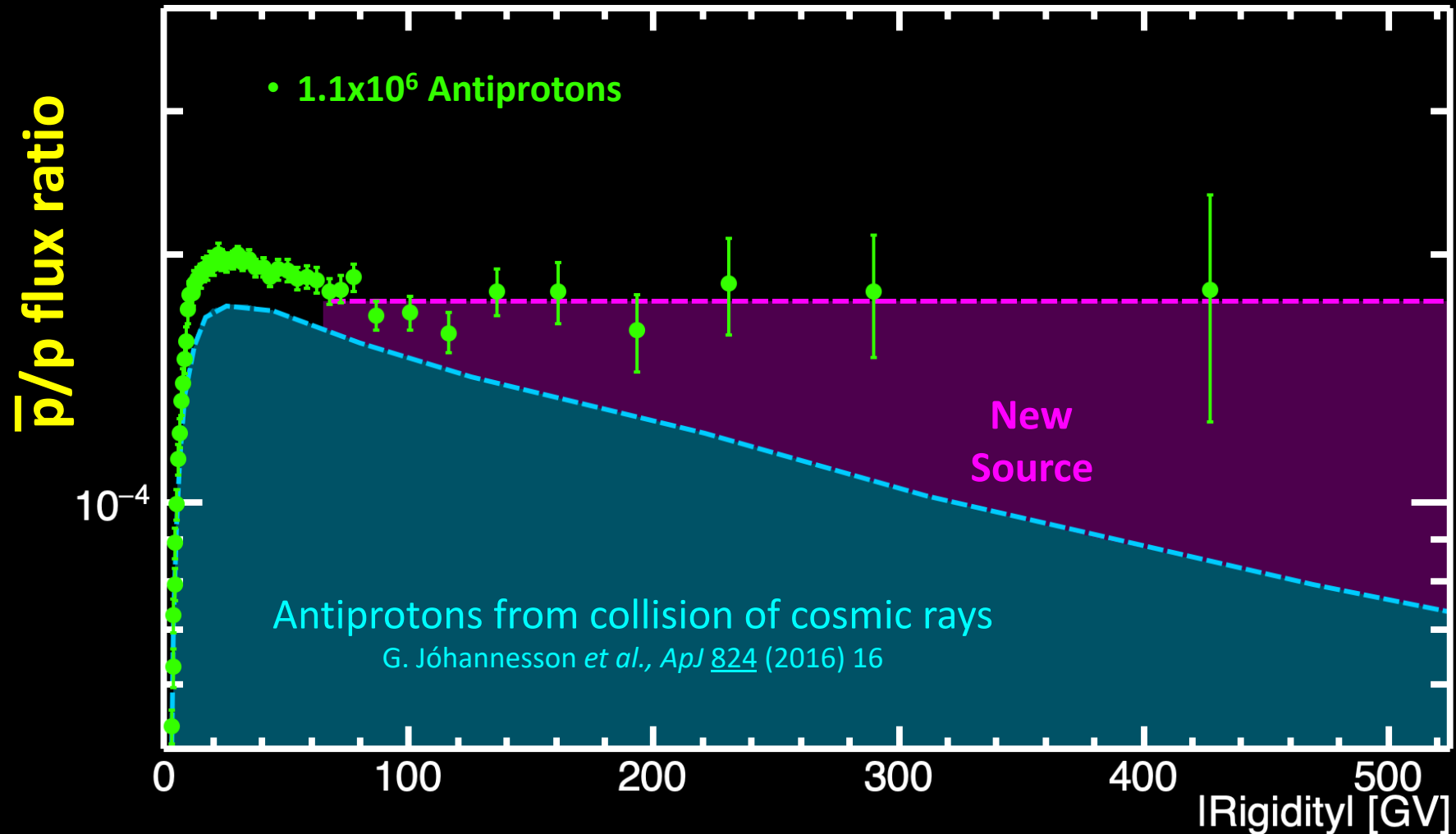


By 2030, AMS will extend the energy range
of the positron flux measurement from 1.4 to 2 TeV
and reduce the error by a factor of two compared to current data

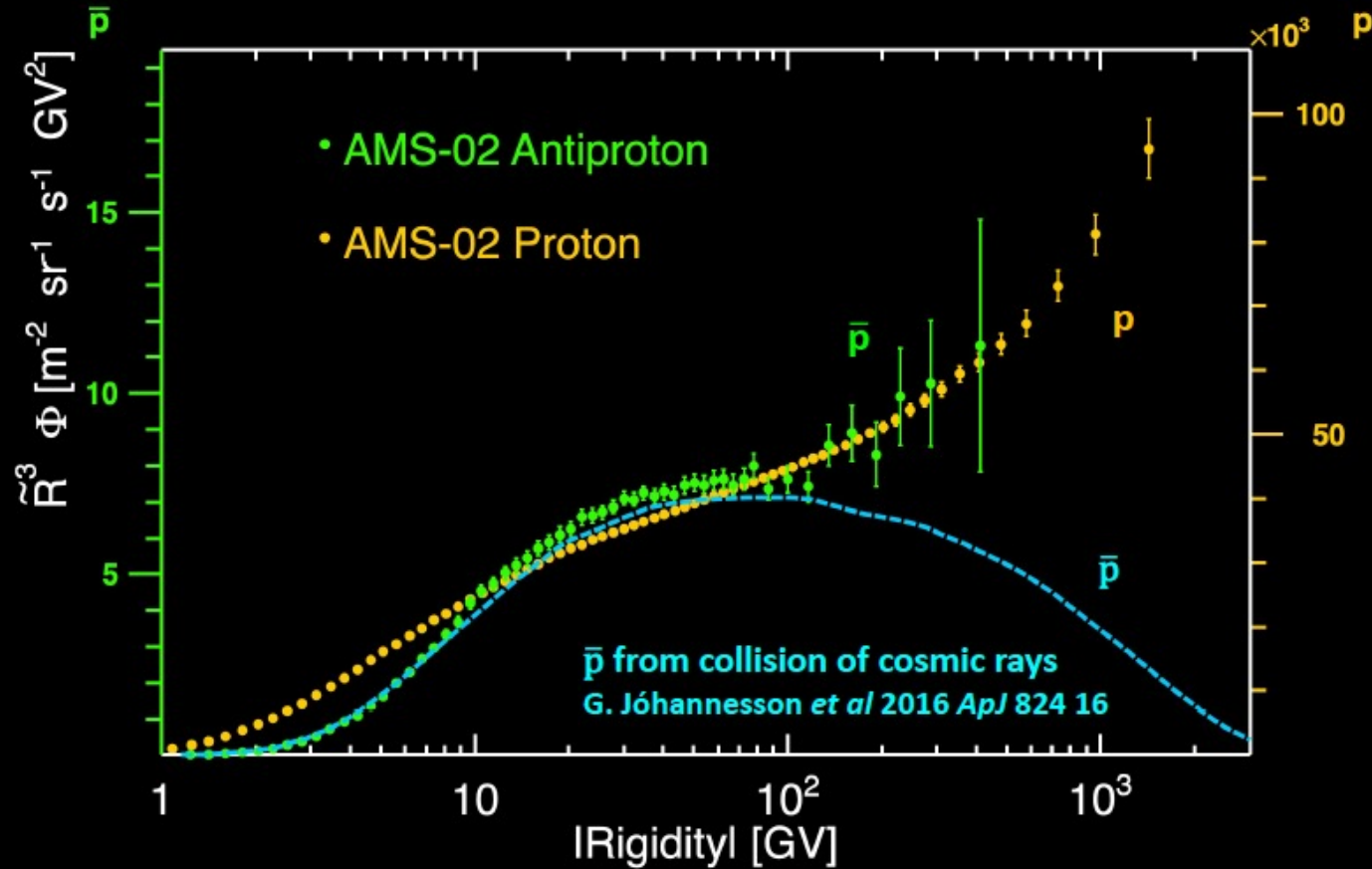


Properties of Cosmic Antiprotons

The antiproton-to-proton flux ratio shows that above 60 GV the ratio is energy independent.



Antiproton and proton spectra



A sample of recent papers on AMS antiproton data

P. Mertsch *et al.*, **Phys. Rev. D** 104 (2021) 103029

M. Boudaud *et al.*, **Phys. Rev. Research** 2, 023022 (2020)

V. Bresci *et al.*, **Mon. Not. R. Astron. Soc.**, 488 (2019), p. 2068

M. Korsmeier *et al.*, **Phys. Rev. D** 97 (2018), 103019

P. Lipari, **Phys. Rev. D**, 95 (2017), 063009

I. Cholis *et al.*, **Phys. Rev. D** 95(2017), 123007

M. Winkler, **JCAP**, 2017(02), 048

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J. Heisig, **Modern Physics Letters A**, (2021), 36, 05

Y. Genolini *et al.*, **arXiv:2103.04108** (2021)

I. Cholis *et al.*, **Phys. Rev. D**, 99 (2019), 103026

A. Cuoco *et al.*, **Phys. Rev. D**, 99 (2019), 103014

M. Carena *et al.*, **Phys. Rev. D**, 100 (2019), 055002

A. Reinert *et al.*, **JCAP**, 01 (2018), p. 055

A. Cuoco *et al.*, **Phys. Rev. Lett.**, 118 (2017), 191102

M. Cui *et al.*, **Phys. Rev. Lett.**, 118 (2017), 191101

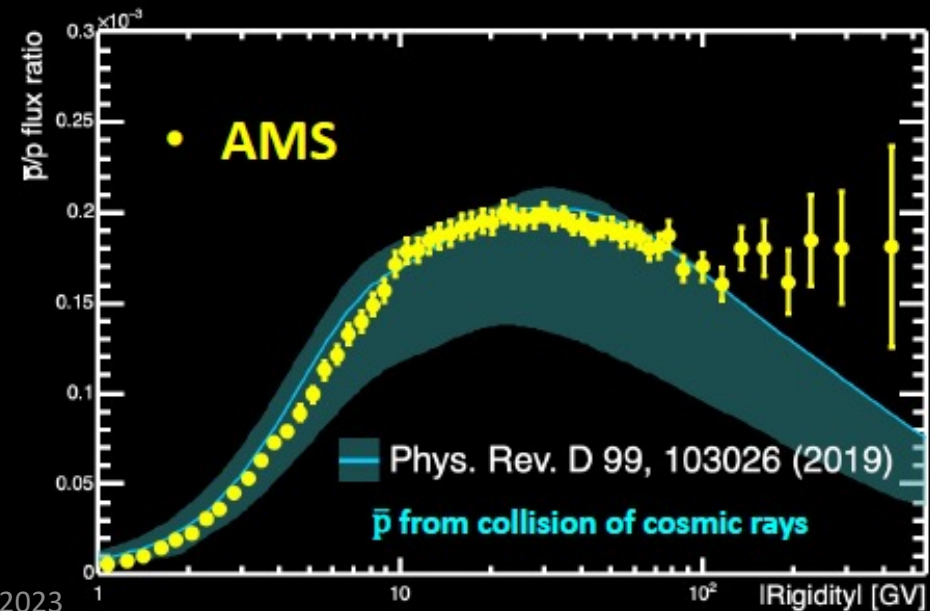
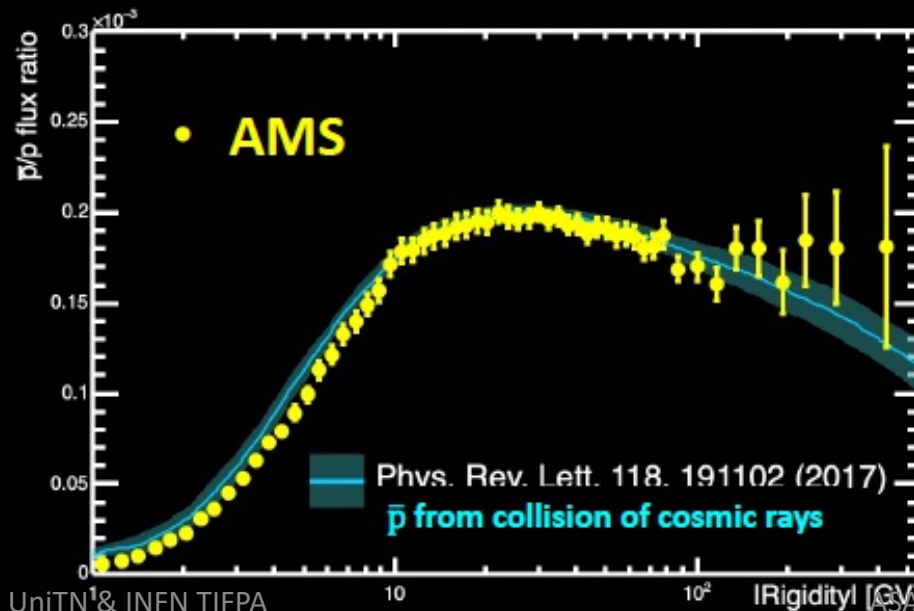
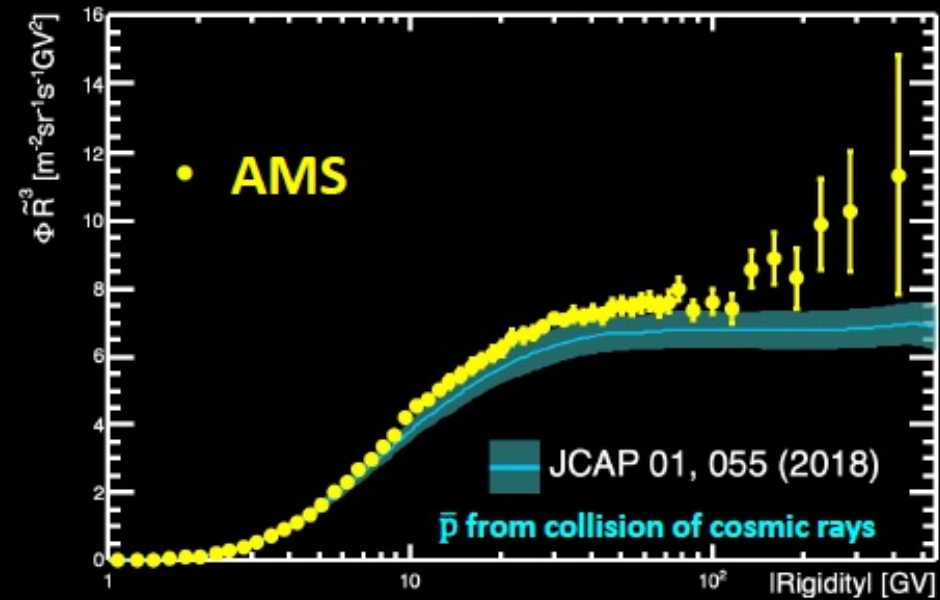
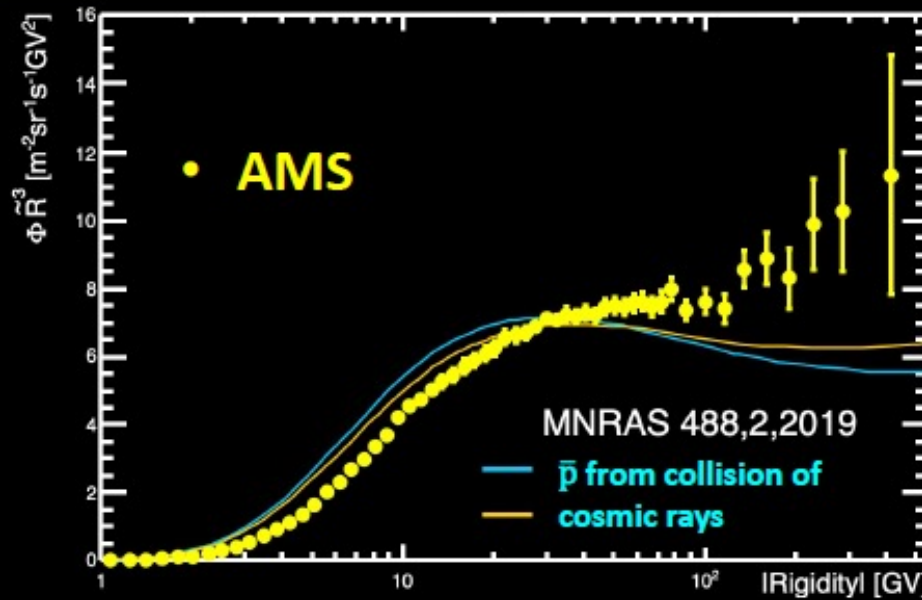
Y. Chen *et al.*, **Phys. Rev. D**, 93 (2016), p. 015015

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**Antiproton
production
and
propagation**

**Antiprotons
from
Dark Matter**

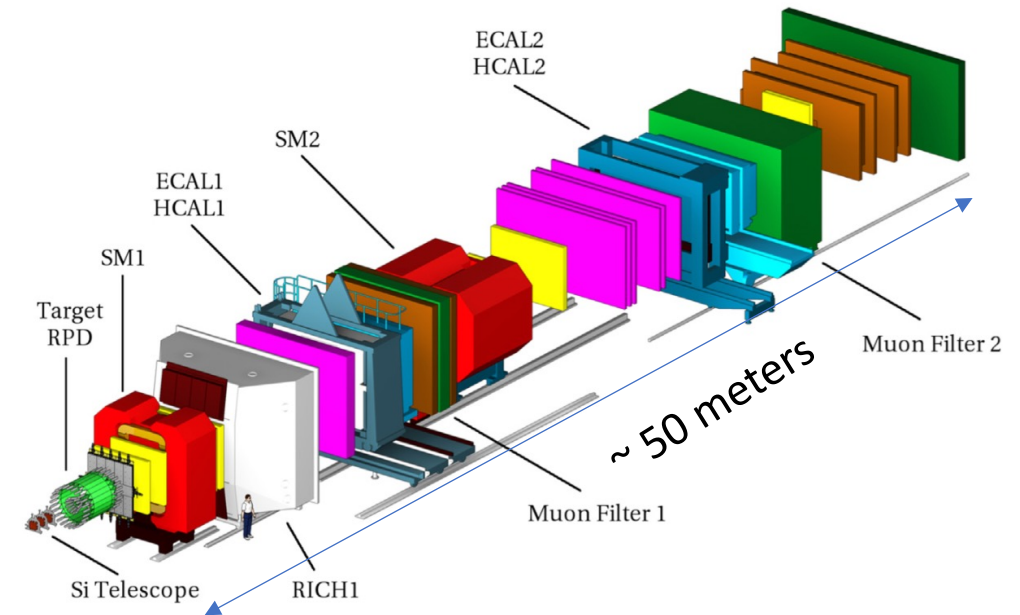
Example: AMS Antiproton Results compared with Cosmic Ray Models Based on AMS Data



The AMBER experiment at CERN



- The AMBER experiment (NA66) is a fixed target experiment at CERN SPS.
- It has been approved for three measurements
 - $p\bar{p}$ production cross section in p -He interaction
 - Proton radius measurement through muon-hydrogen scattering
 - Drell Yan processes to study form factors and emergence of the hadron mass
- A proposal for a AMBER phase2 to be done after the LHC long shutdown is in preparation

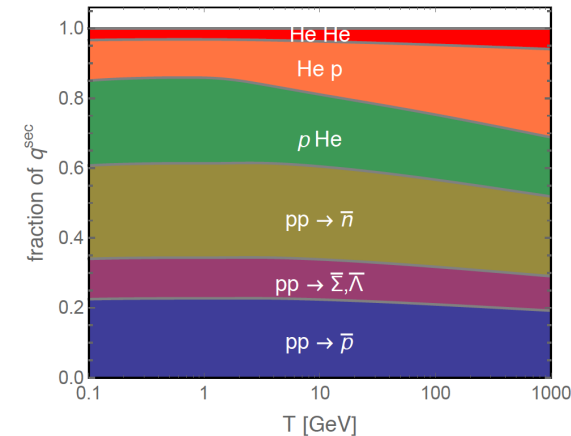


(the AMBER/COMPASS spectrometer)

Existing anti-p cross section

- anti-p production cross section from p-p and p-He interactions is poorly measured and cannot simply be 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 of the anti-p XS from 8 TeV p-He, and foresees a similar measurement with 4 TeV 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 \rightarrow pbar + X

NA61 p+p data beam momenta of 20, 31, 40, 80, and 158 GeV/c

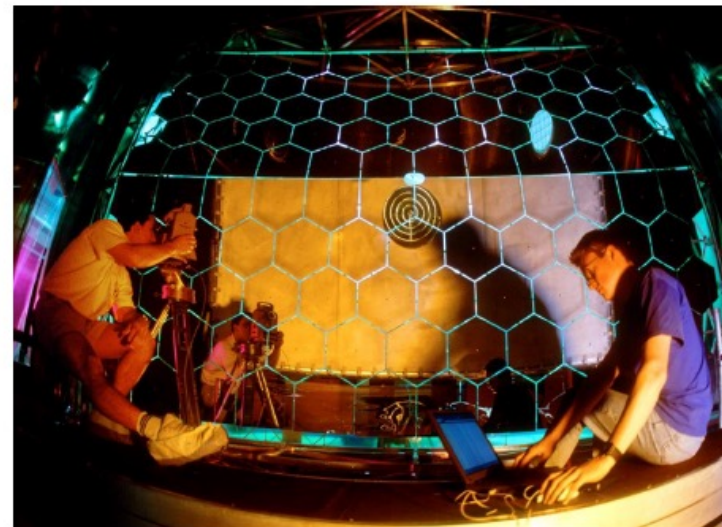
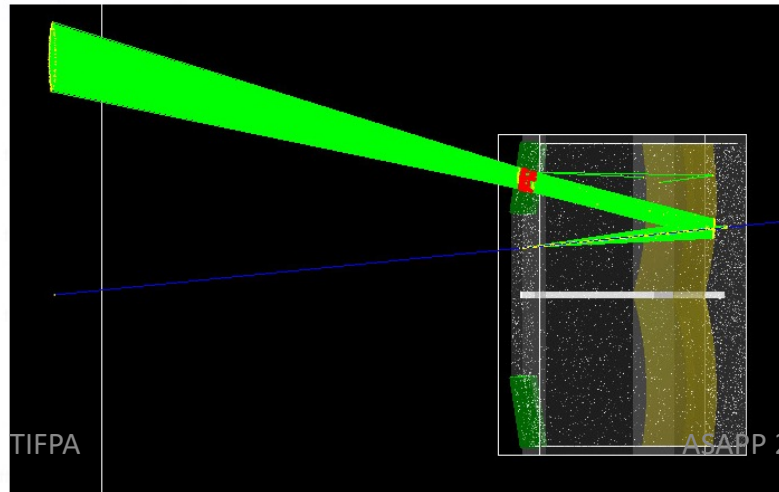
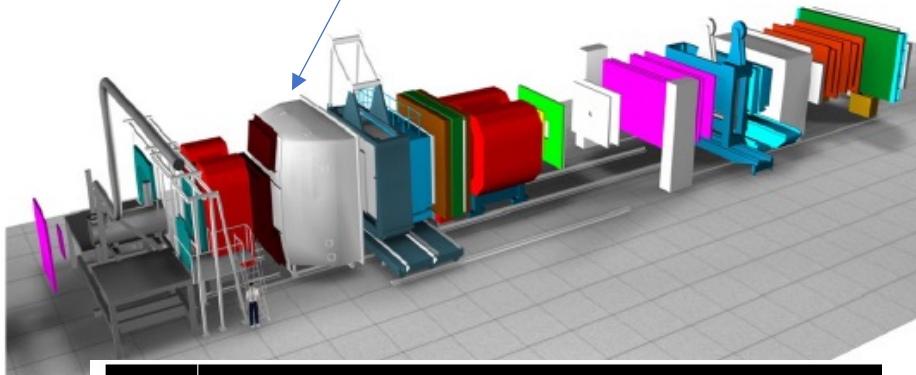
Eur. Phys. J. C 77, 671 (2017)

Measuring $p\bar{p}$ cross section with AMBER

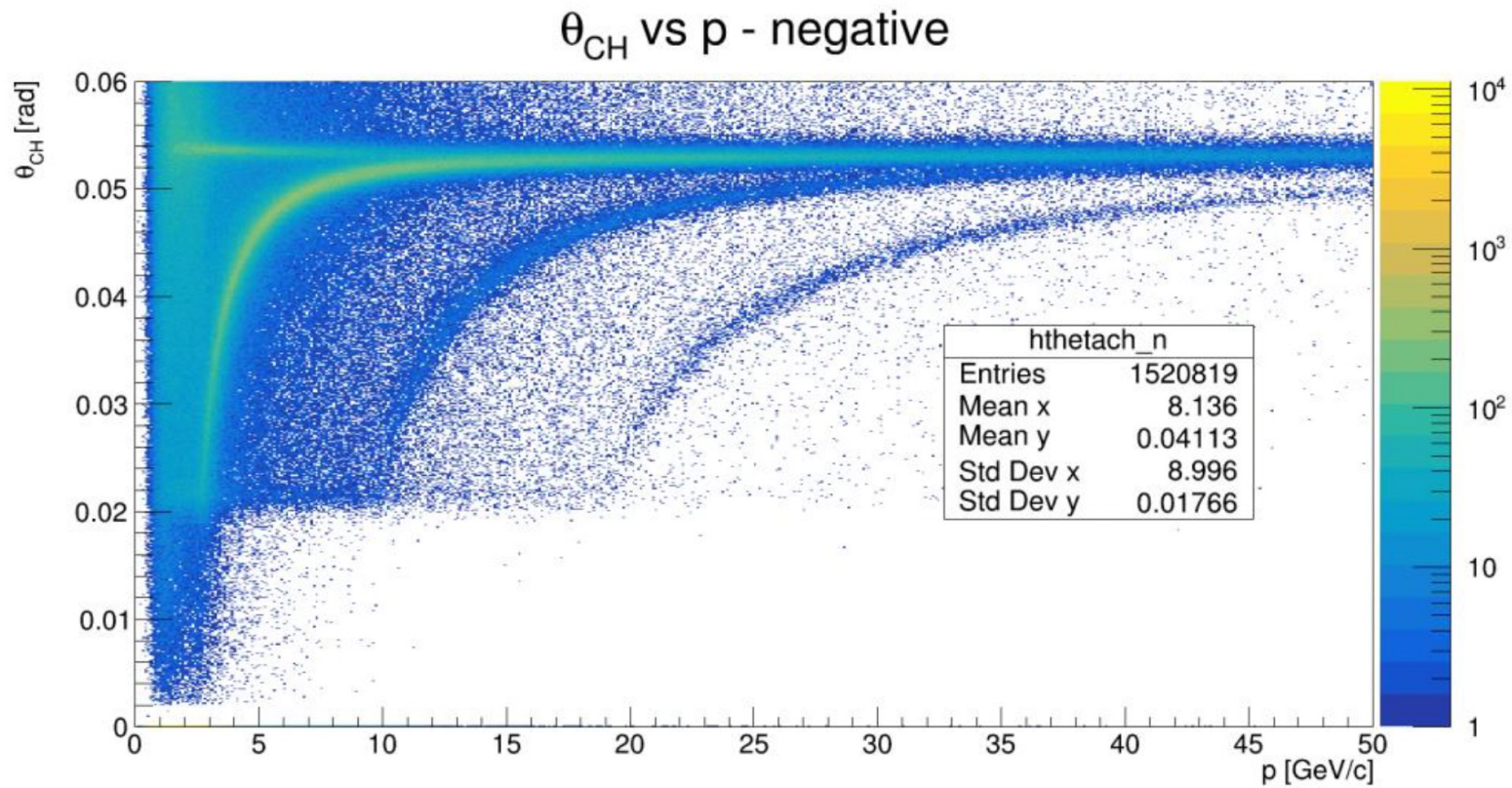
- Target: Liquid ^4He cylinder 1.2 m long for 10 cm of diameter
- Precise beam telescope measuring the incoming particle trajectory
- Two stages spectrometer (50m long) with typical momentum resolution ranging from 1% to 0.1%
- Large gas RICH detector for Particle identification
- Use secondary hadron beams from primary SPS proton on a Be target.
- Explore 6 proton momenta: 60, 80, 100, 160, 190, 250 GeV/c
- Use 2 long CEDARs (threshold Cerenkov) to identify protons in the hadron beam

Non Tracking detectors

- Two sets of ECAL and HCAL
- One of the largest RICH detectors ever operated.



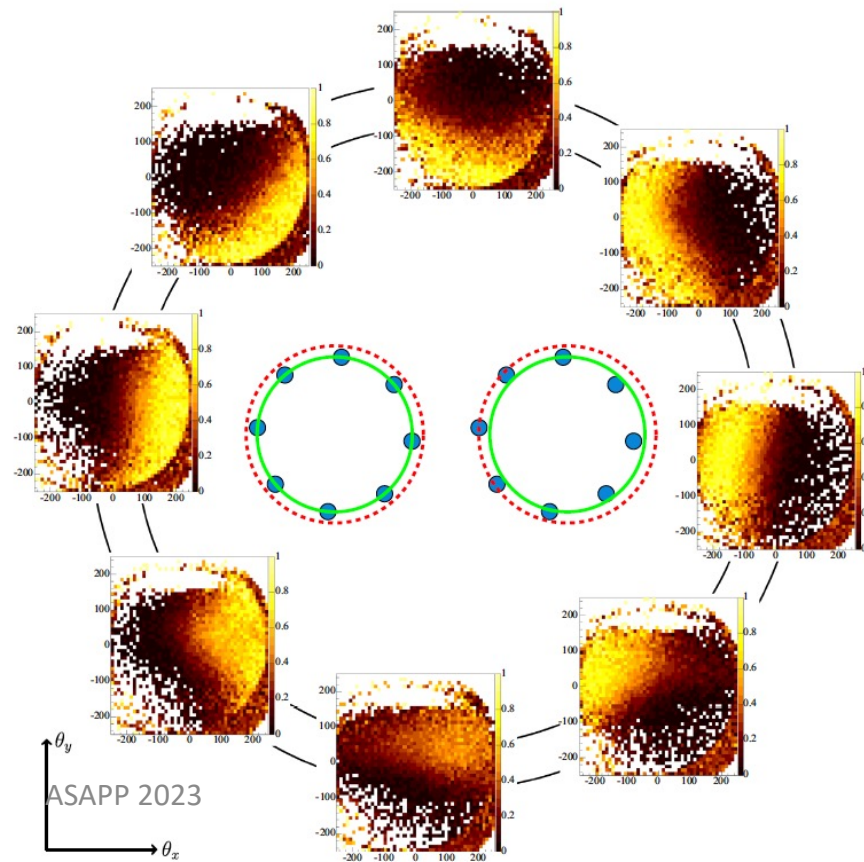
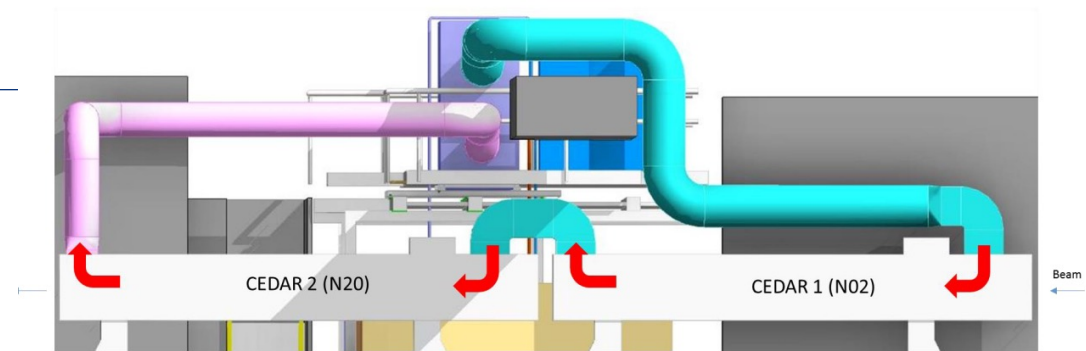
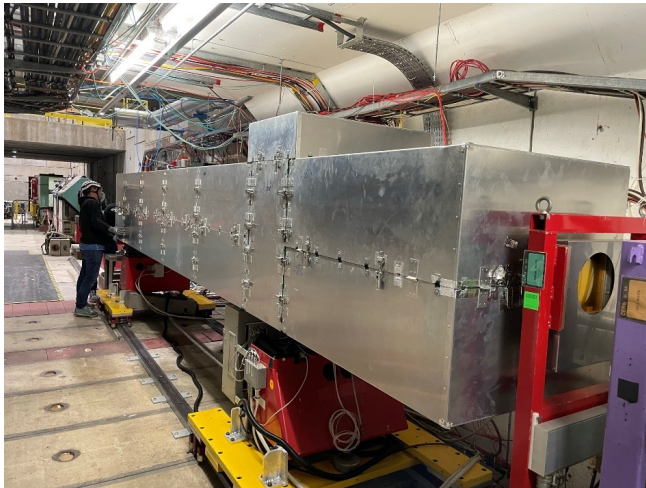
RICH Measurement example



Proton identification in the Secondary hadron beam

CEDARs

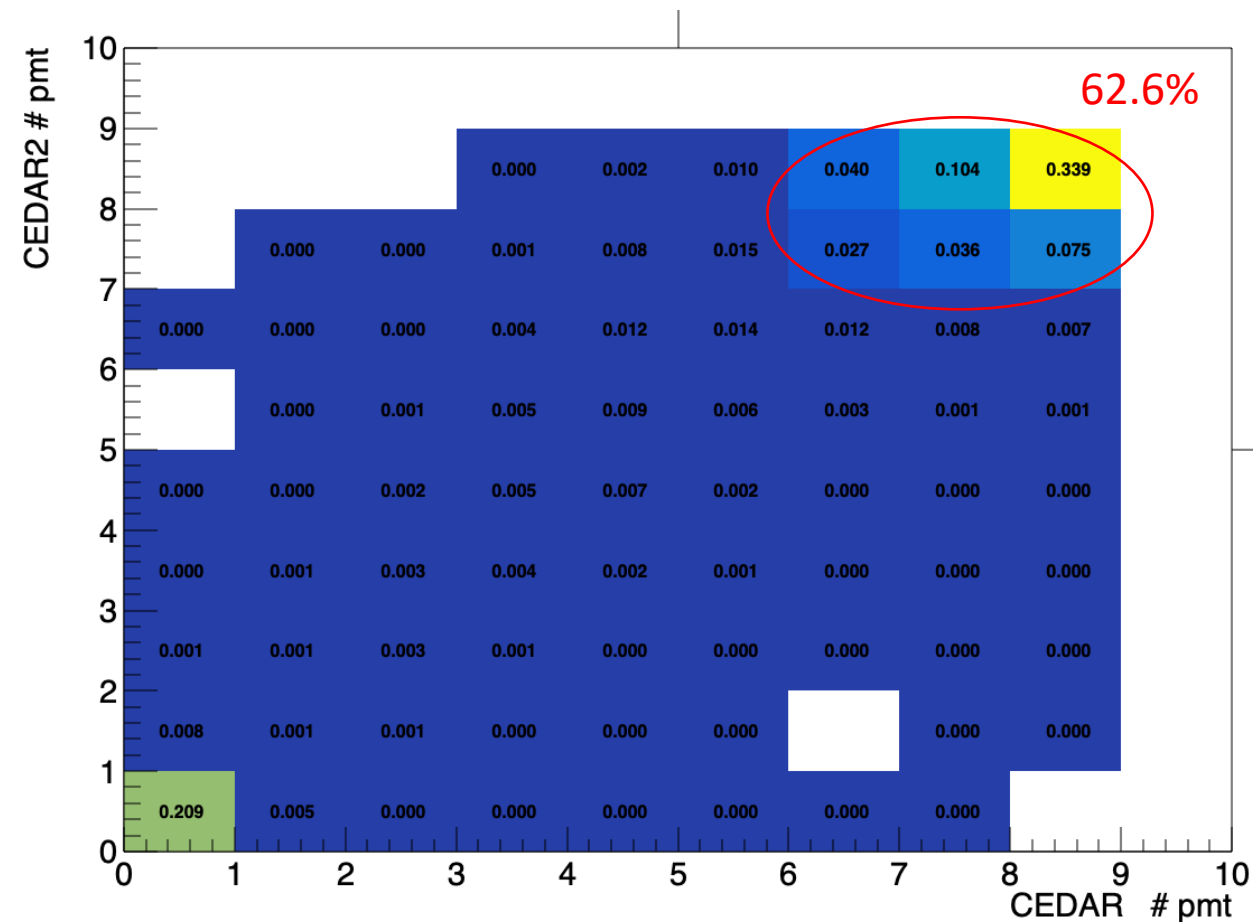
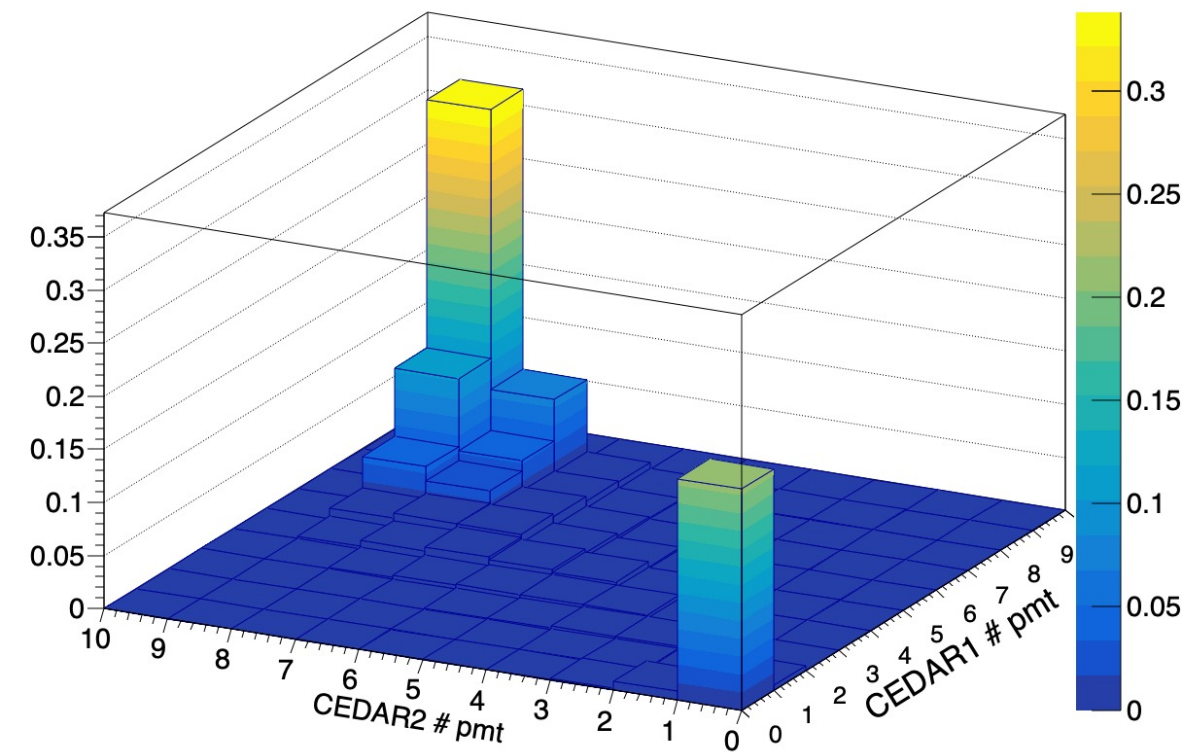
CErenkov **D**ifferential counters
with **A**chromatic **R**ing focus



CEDAR Selection p 190 GeV/c

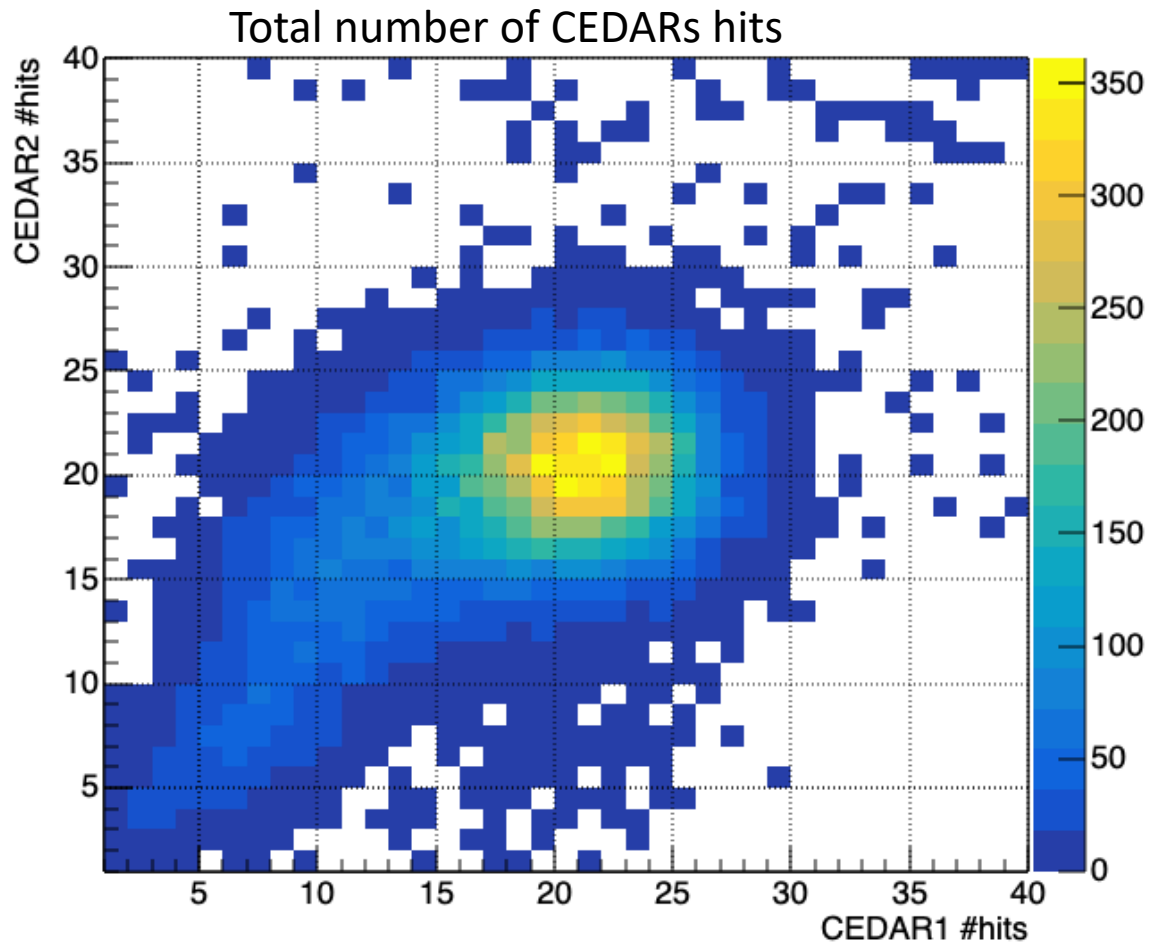
CEDAR1 ≥ 6 pmts

CEDAR2 ≥ 7 pmts

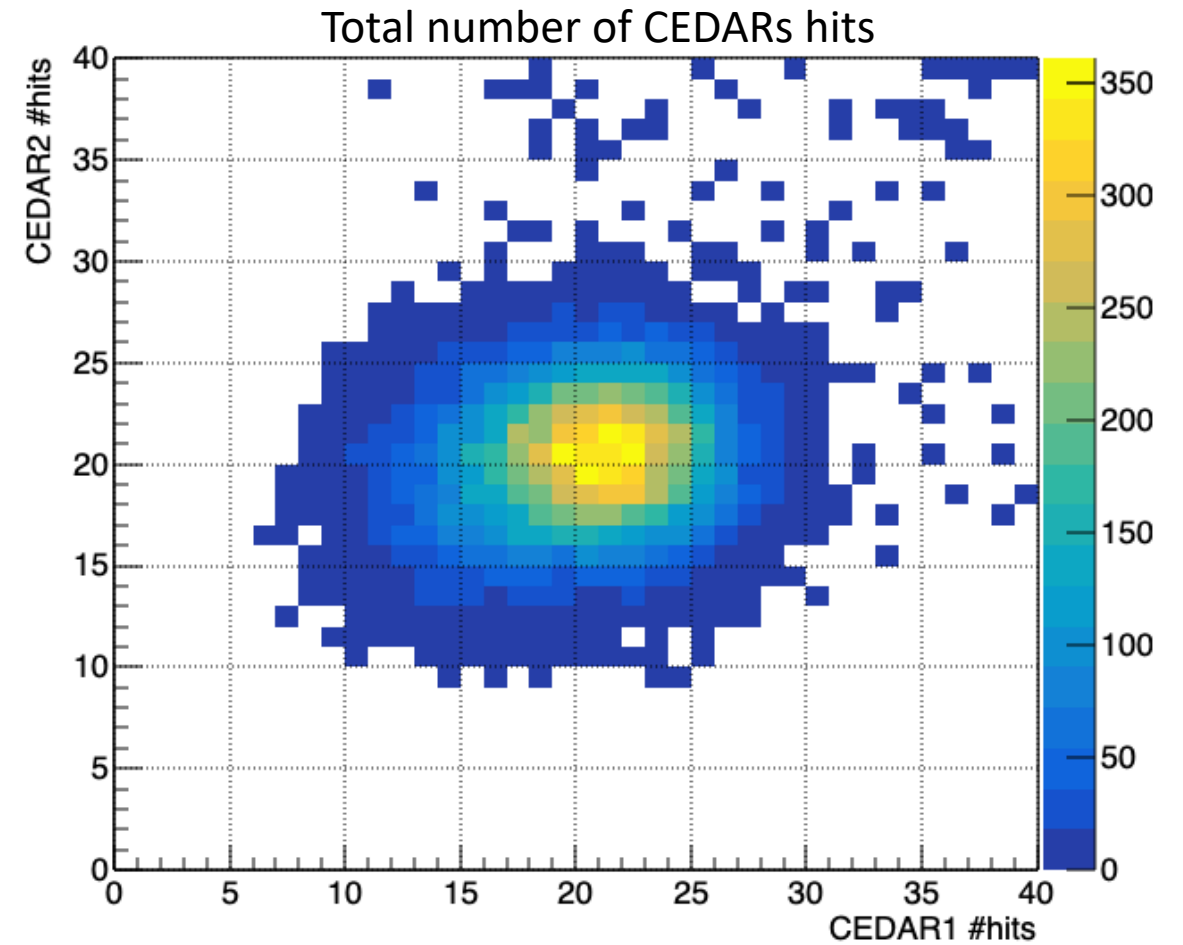


Effect of the CEDAR selection cut

Before N pmt cut



After N pmt cut



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

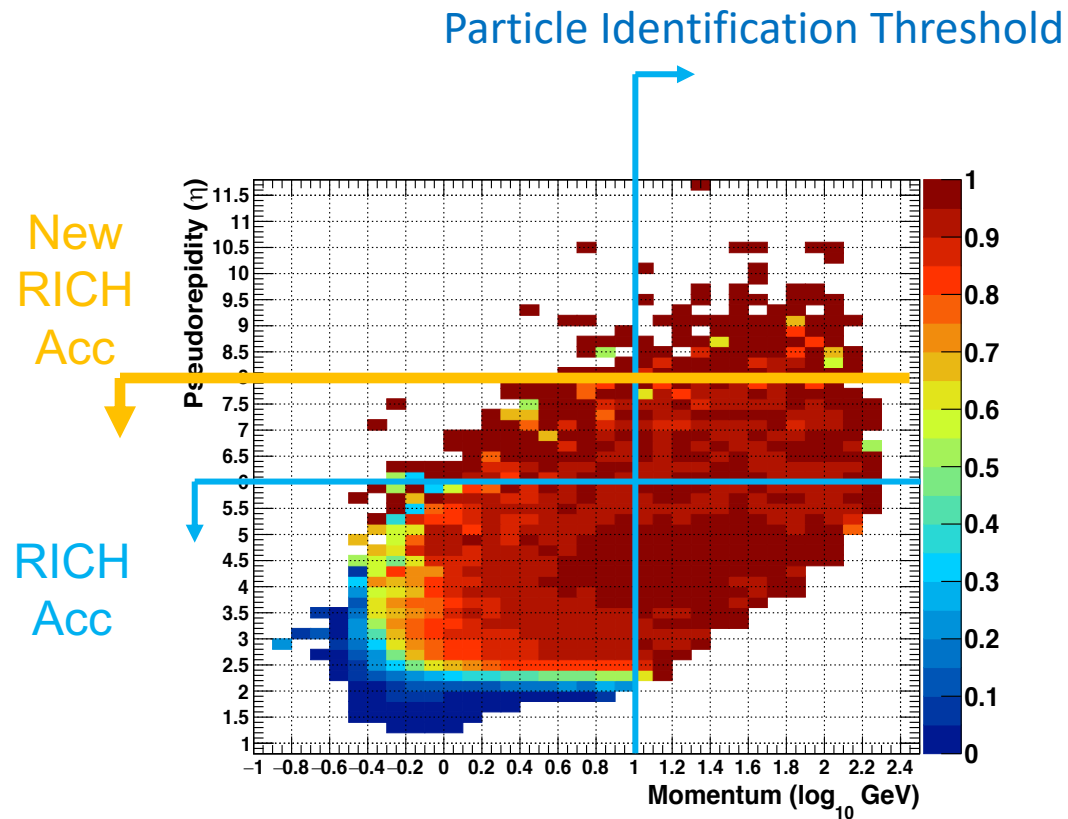
$$\frac{d\sigma_{\bar{p}}}{dp d\theta} = \frac{R_s(p, \theta)}{R_i}$$



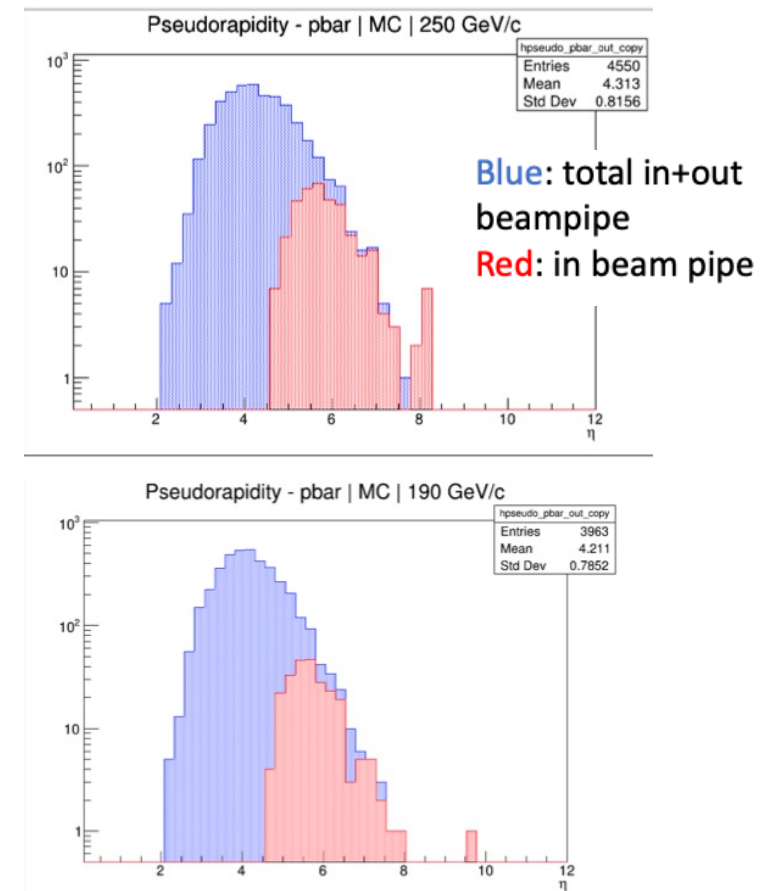
Explored phase space for anti-p production

Antiproton tracking efficiency

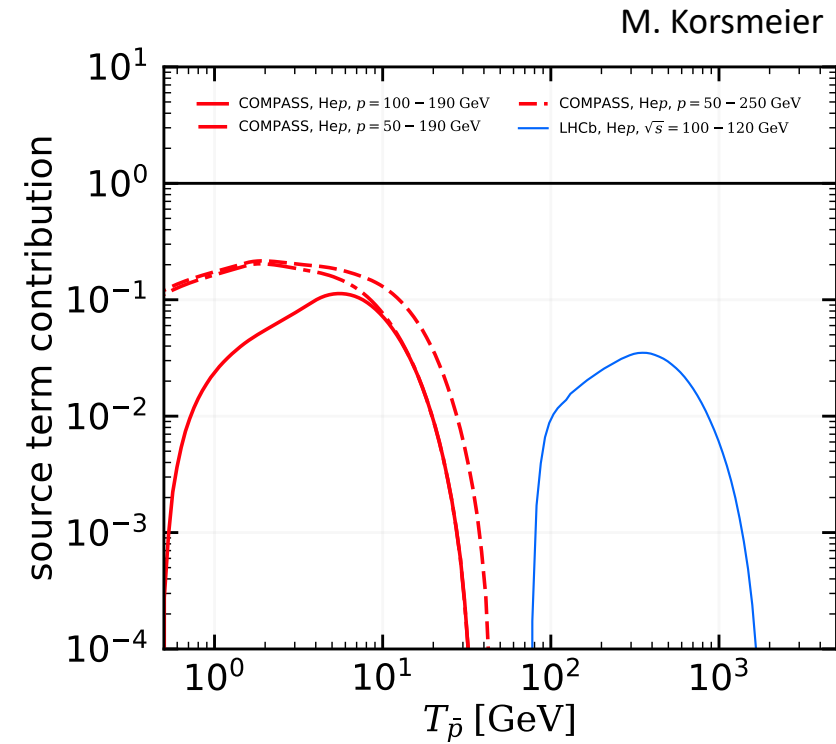
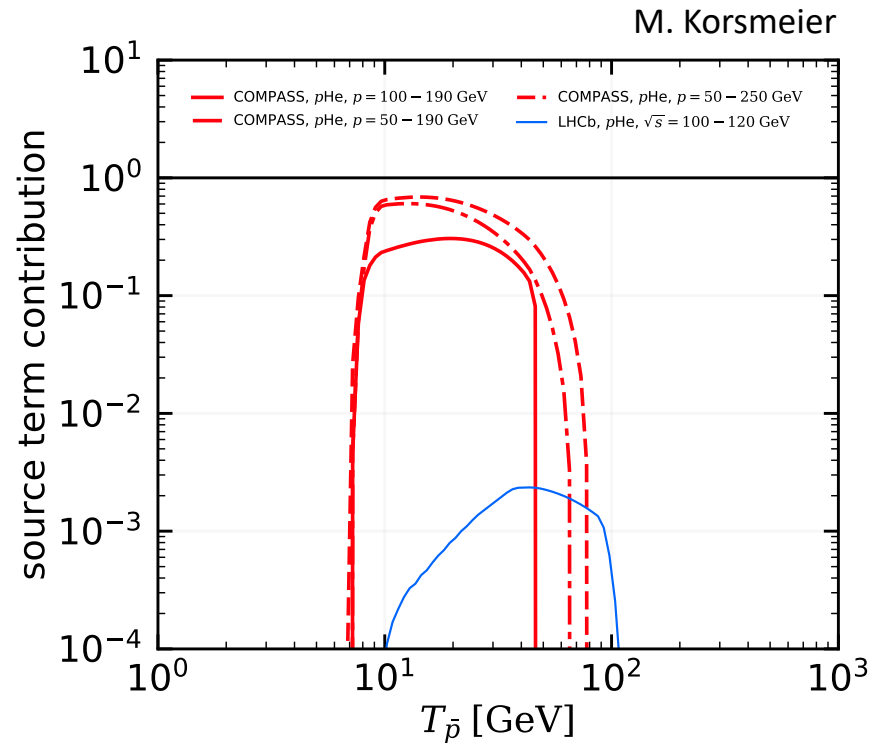
Pseudo-rapidity vs $\log_{10}(\text{momentum})$



Removal of RICH BeamPipe



p-He He-p Source term coverage



AMBER -2023 Physics run

- April 24th: Detector and beam commissioning starts
- May 20th: Data taking starts with p at 190 GeV/c
- May 25th : switch for the long run with p at 60 GeV/c
- June 6th : Switch to p at 100 GeV/c
- June 11th : switch to 250 GeV/c
- June 14th : switch to 160 GeV/c
- June 18th : switch to 80 GeV/c
- June 25th : Last day with liquid He target
- June 26-28th: Empty target runs
- June 29th-30th: Drell Yan high intensity test
- July 1st : CEDAR PID efficiency runs

NOTE: SM1 and SM2 currents have been scaled such that the primary beam at different momenta follows the same path within the spectrometer as the 190 GeV one

We added to additional energy points (80 and 160 GeV), because p-p measurements at those energies are available and it is interesting to compare

Reconstruction + alignment

align spectrometer
mass reconstruction
optimization of reco
options

Bad spill/run

Bad spill/run selection.

Bad runs will be
analyzed at further
stage

Correction estimation

detector efficiencies
Acc. corrections -> MC
RICH efficiency and purity
estimation
CEDAR efficiency/purity
tracking efficiency
DAQ dead time

...

Selection criteria studies

Cuts to be applied are
studied and optimized.
e.g. vertex position,
good track selection,
RICH cut, CEDAR cuts....

Systematics

Systematics studies
(e.g. RICH, CEDAR,
tracking...)
luminosity

Final steps

having the pbar phase space corrected for every
factor -> normalize the number of pbar produced
per event and scale the total cross section p+He

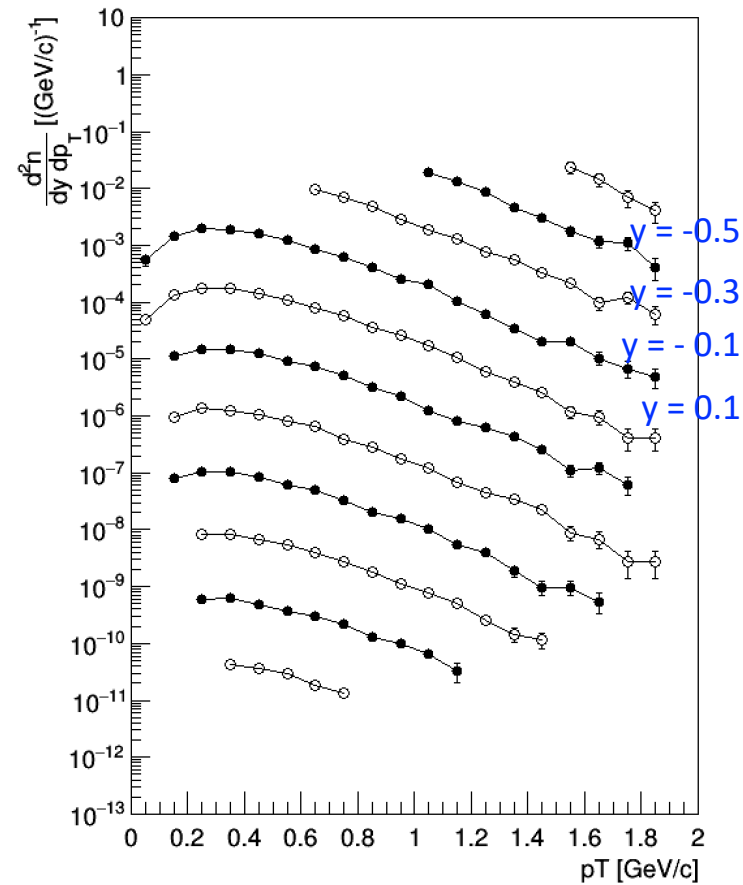
80 and 160 GeV/c
interesting for p+p cross
section scaling (measured
by NA61)

Main goal: measure **double differential (momentum and polar angle (or pseudorapidity)) cross section of antiproton produced in p+He⁺ collision** at many data point possible over the range available (in our case: 60, 80, 100, 160, 190, 250 GeV/c of incident proton).

→ Fundamental detectors: RICH (for pbar in final state) and CEDAR (for tagging proton in beam mixture) + tracking

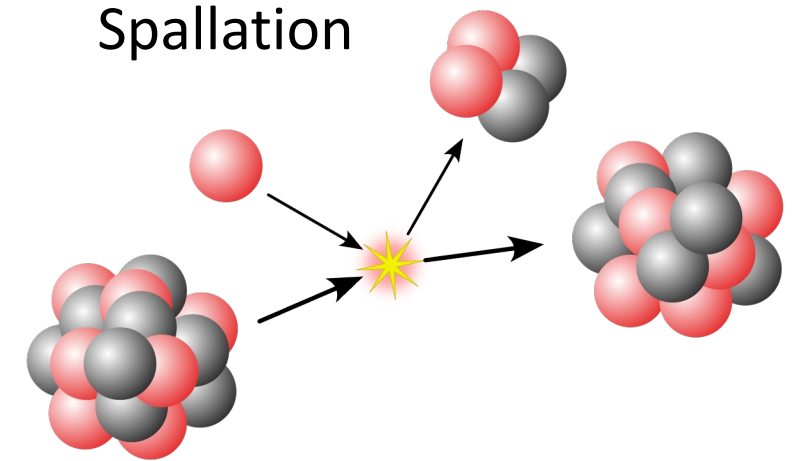
Expected cross section measurement p-He -> bar-p + X

p 190 GeV/c



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Obtain a better sensitivity to signals from exotic physics

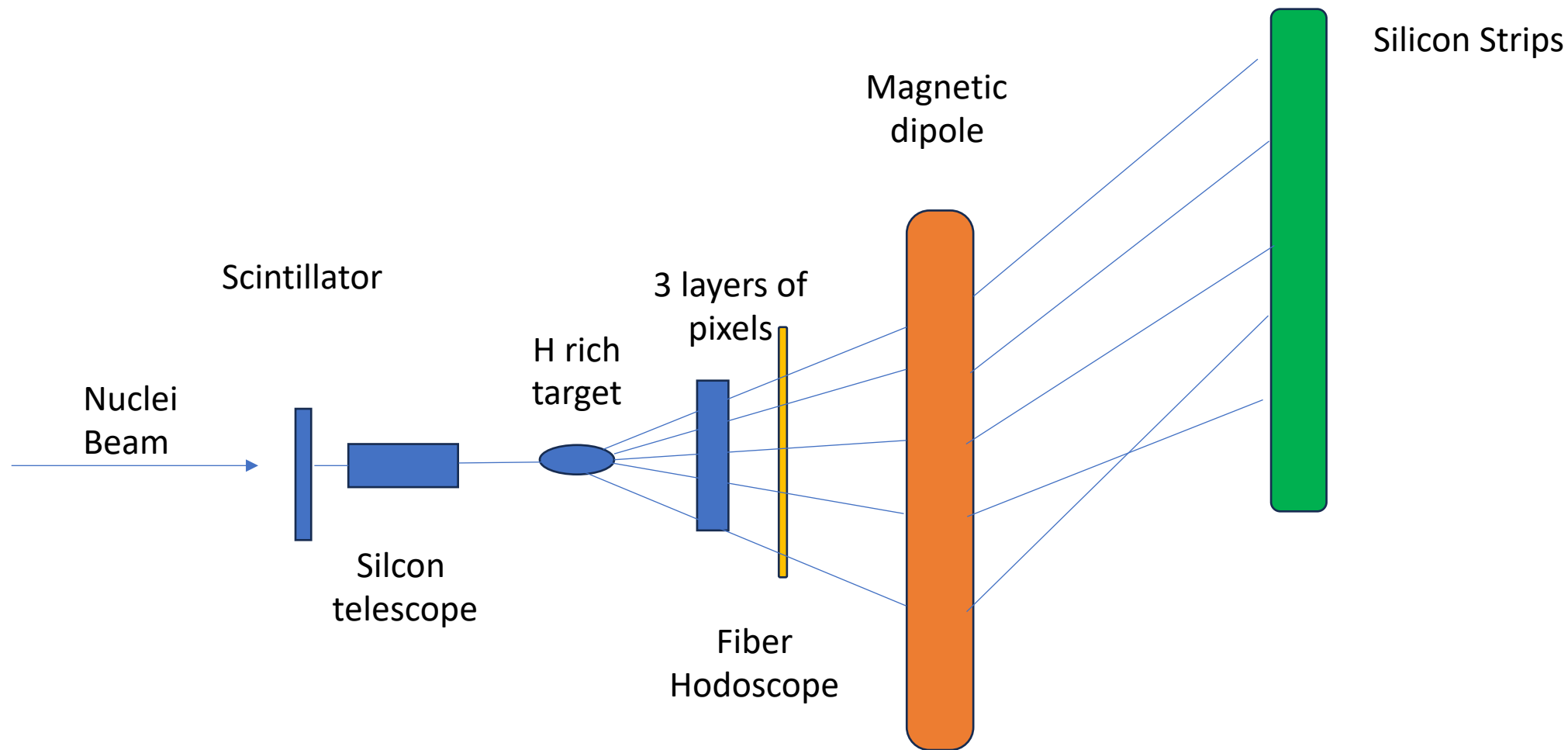


Reduce systematic errors on the measurements



Improve sensitivity to primordial anti-matter and to DM

Example setup



Conclusions

- Cross sections measurements are needed
 - To understand better current measurements
 - To develop better propagation models and investigate on CR origin
 - To reduce systematic errors in the data
 - To improve sensitivity signals of new Physics.
- Some of them are already available, some other will arrive soon
- In general an experimental effort must be put on the ground to fill the gaps that may unlock future discoveries.