Prospects of antideuteron detection with AMS

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1st cosmic ray antideuteron workshop

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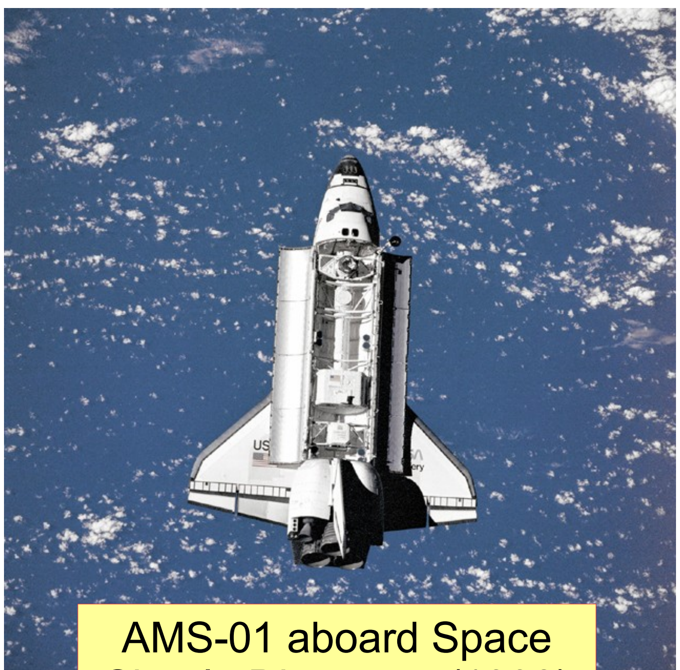
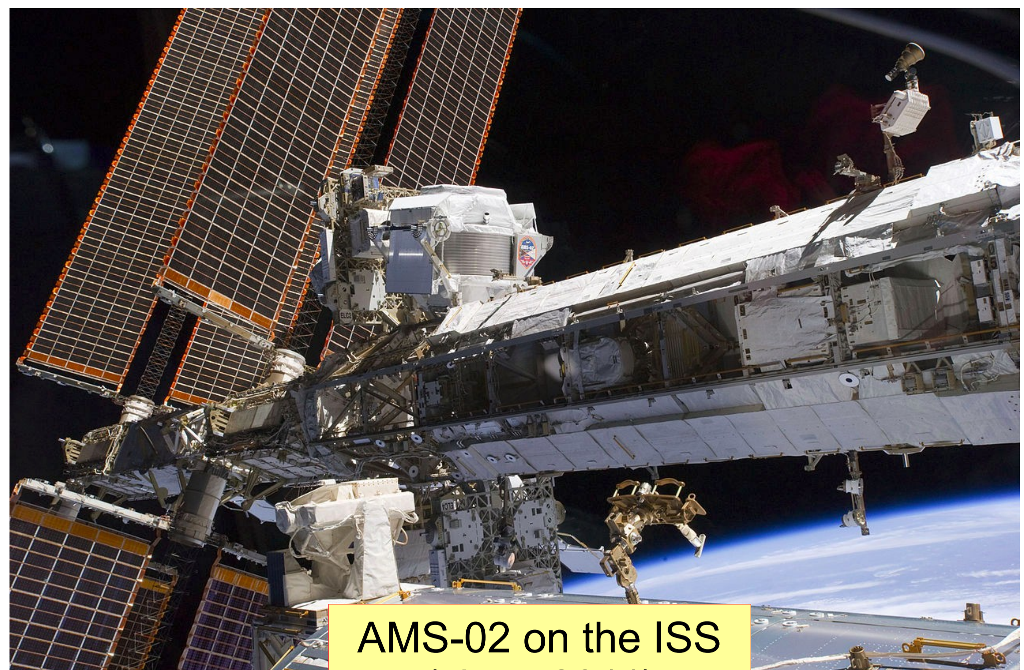
The AMS experiment

- Large international collaboration for detection of cosmic rays in space
- Prototype **AMS-01** flown aboard Space Shuttle in June 1998
  - ~100 hours of data collected
- Final detector **AMS-02** installed on International Space Station in May 2011
  - Data taking ***almost 100% of time***
  - **3 years of data collected** (~50 billion events), ***largest CR sample ever***
  - Expected to continue for ~10 years more



AMS-01 aboard Space Shuttle Discovery (1998)

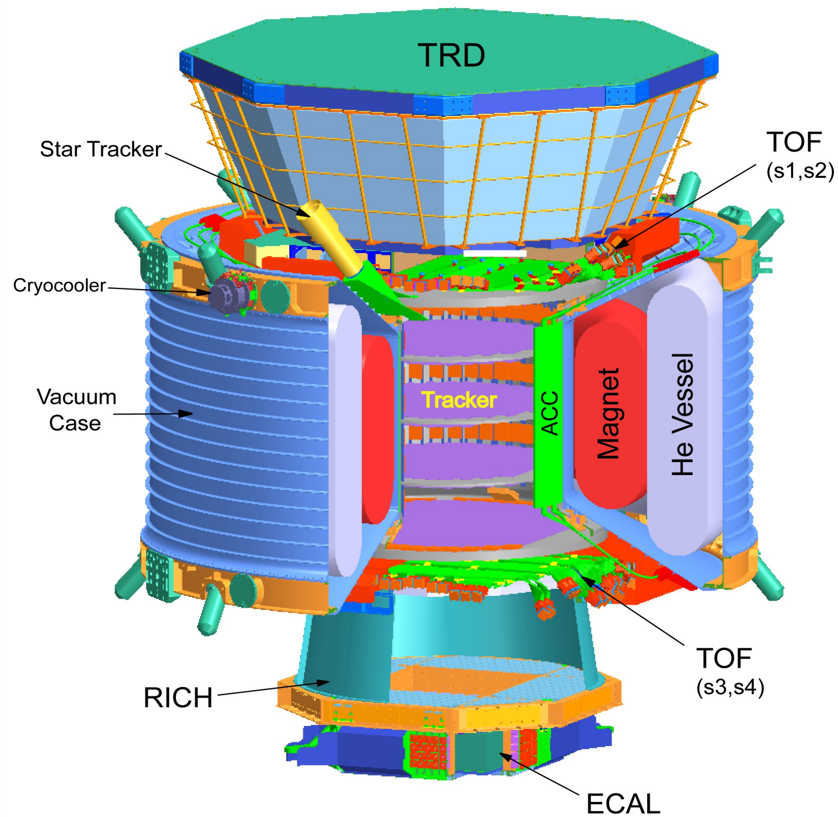


AMS-02 on the ISS (since 2011)

The AMS-02 detector

- A particle physics detector in space
- Has many of the components found in accelerator experiments:
  - ***Permanent magnet*** (B=0.15 T)
  - ***Silicon Tracker***
  - ***Time-of-Flight*** (TOF) detector
  - ***Transition Radiation Detector*** (TRD)
  - ***Ring Imaging Cherenkov Detector*** (RICH)
  - ***Electromagnetic Calorimeter*** (ECAL)
  - ***Anti-Coincidence Counter*** (ACC)

AMS 02
(Alpha Magnetic Spectrometer)



AMS on ISS for 3 years

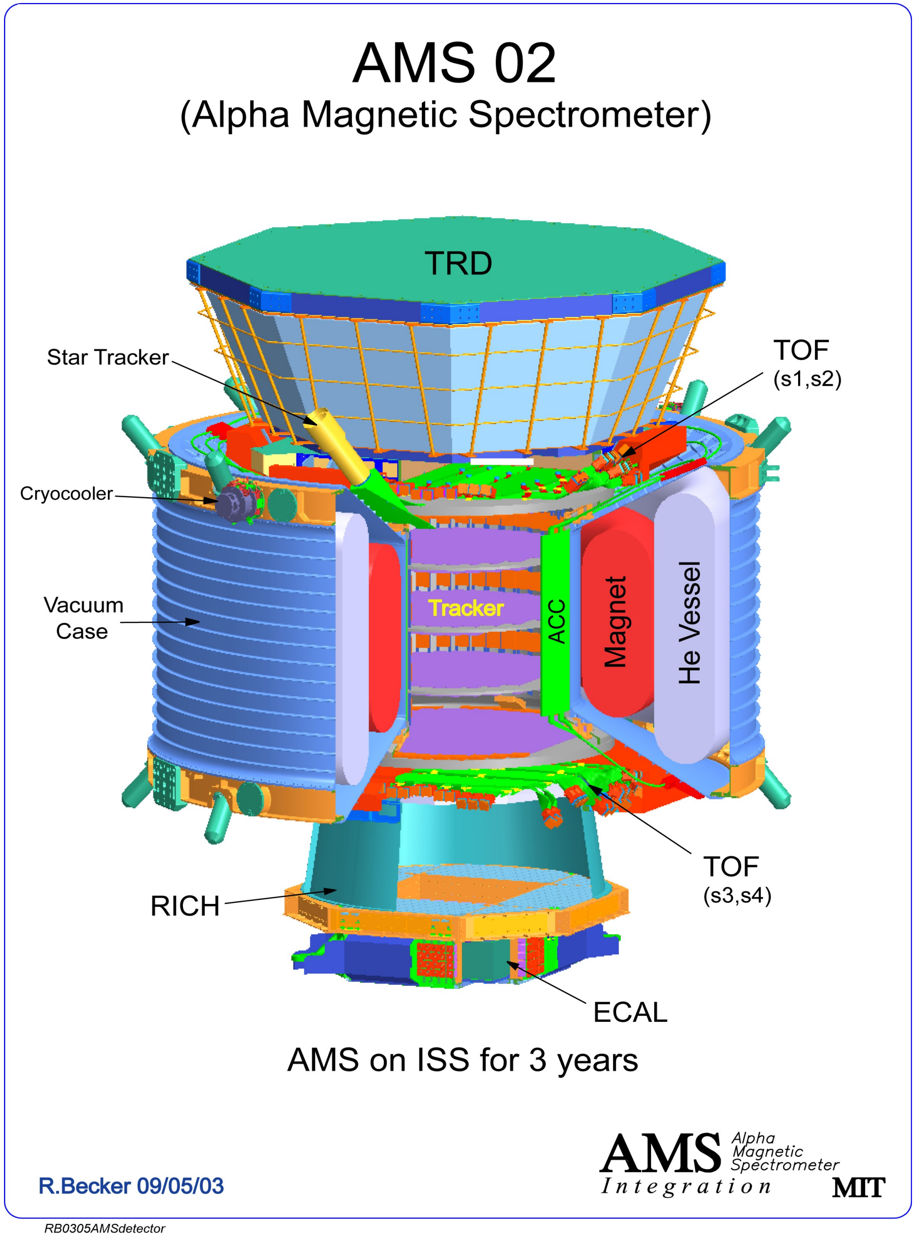
R.Becker 09/05/03

AMS Alpha Magnetic Spectrometer Integration MIT

RB0305AMSdetector

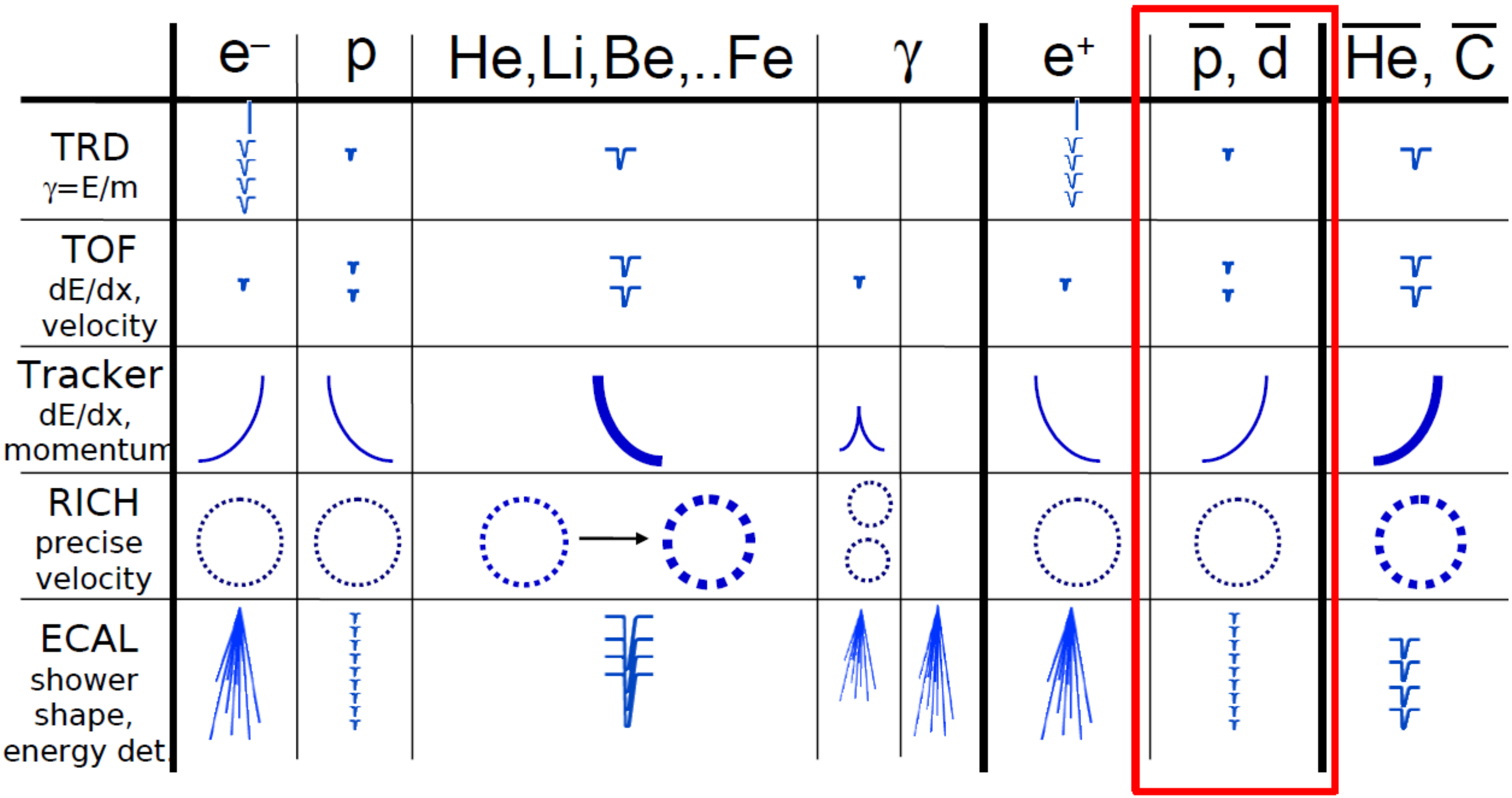
The AMS-02 detector

- Subsystems provide measurements of:
  - ***Velocity/direction***: TOF, RICH, TRD
  - ***Rigidity (p/Z)***: magnet+Tracker
  - ***Charge (absolute)***: TOF, Tracker, RICH, TRD
  - ***Energy***: ECAL
- Particles are detectable at kinetic energies of a few hundred MeV/nucleon or greater



Particle signatures in AMS-02

- **Different particle types may be distinguished by their subdetector signatures**



AMS-02 antideuteron search

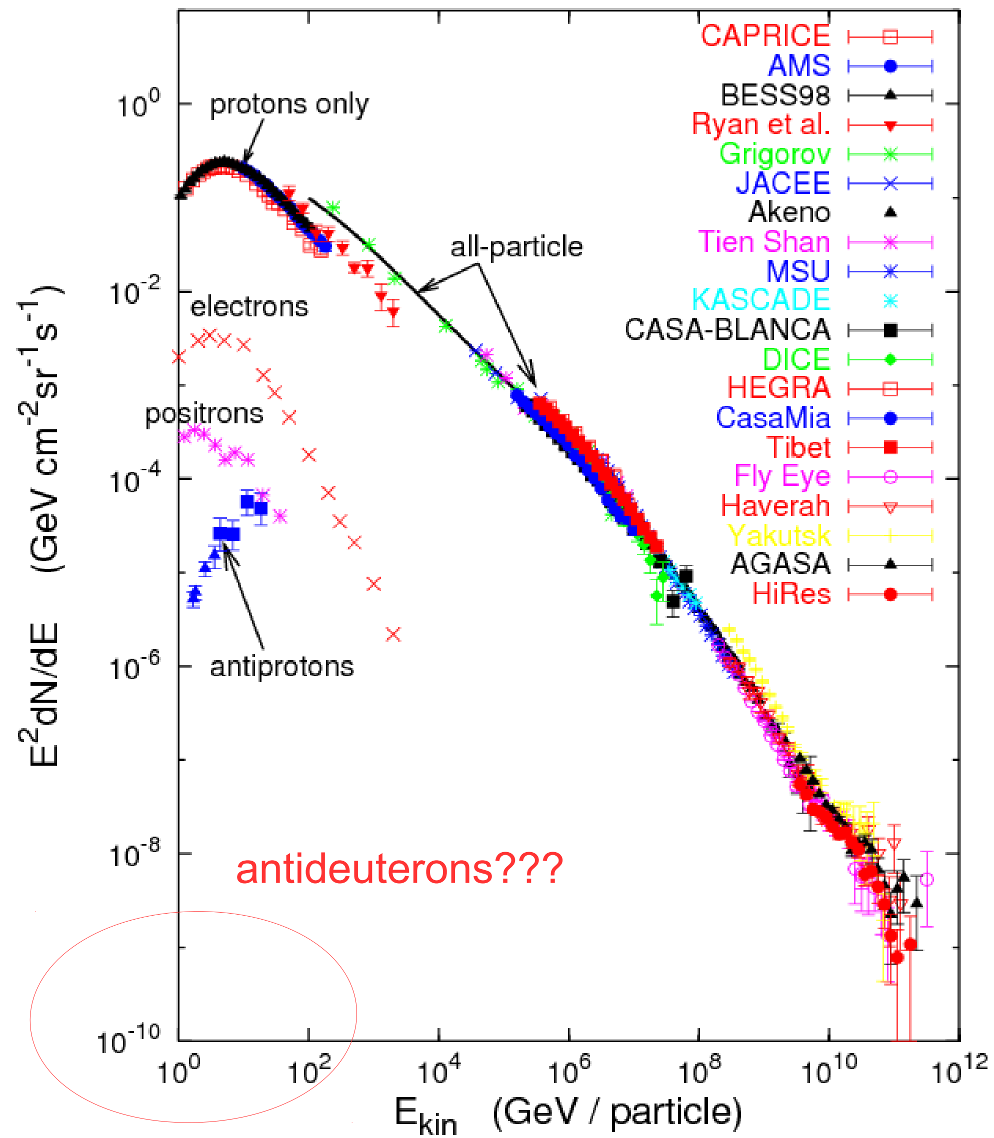
- Antideuteron identification requires reliable measurement of:
  - **Charge** magnitude (=1) & sign (negative)
  - **Mass**, from **velocity/momentum** combination:

$$m = \frac{p}{Z}\frac{\sqrt{1-\beta^2}}{\beta}$$

    - Momentum measured in the form of rigidity (R=p/Z)
    - Methods for velocity measurement:
      - up to ~1 GeV/nuc: **TOF** (directy from Δt between upper/lower planes)
      - at ~1 GeV/nuc: **RICH**, ***NaF radator*** (limited by very small acceptance)
      - at ~5 GeV/nuc: **RICH**, ***aerogel radiator***
        (RICH velocity comes from Cherenkov cone aperture)
- Discreteness of charge, mass values is helpful
  - broad windows may be used
  - closest charges are 100% away, closest masses 50% away
- Existing studies on AMS-02 antideuteron sensitivity were based on superconducting magnet configuration
  - **NEW ANALYSIS NEEDED FOR PERMANENT MAGNET SETUP**

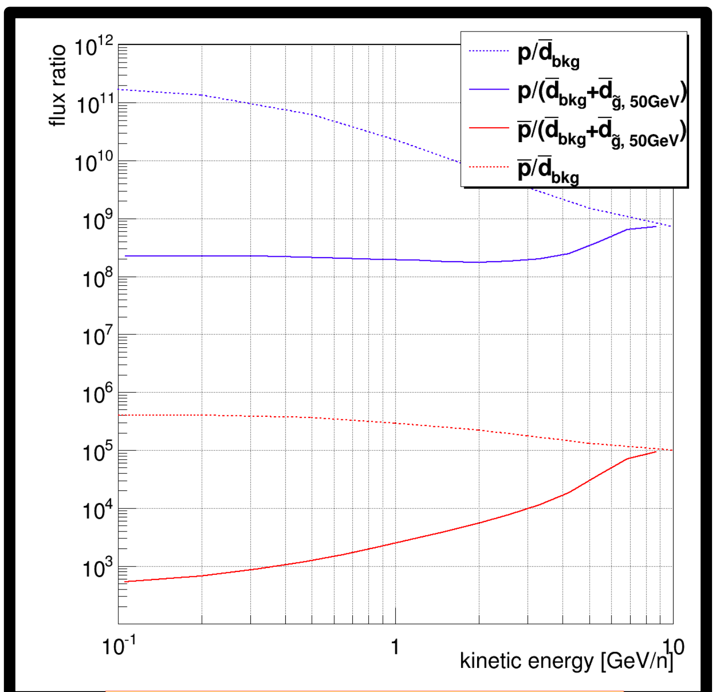
Cosmic-ray spectrum

- Particles in cosmic rays include:
  - **protons** (~90%)
  - **He-4** (~10%)
  - **other nuclei** (~1%)
  - **electrons** (~1%)
  - **positrons** (~10^{-3})
  - **antiprotons** (~10^{-4})
- Antideuterons have never been observed in CR (as expected from low statistics)
- The spectrum observed by AMS-02 is affected by solar modulation and geometric effects
  - Of particular importance at the GeV region

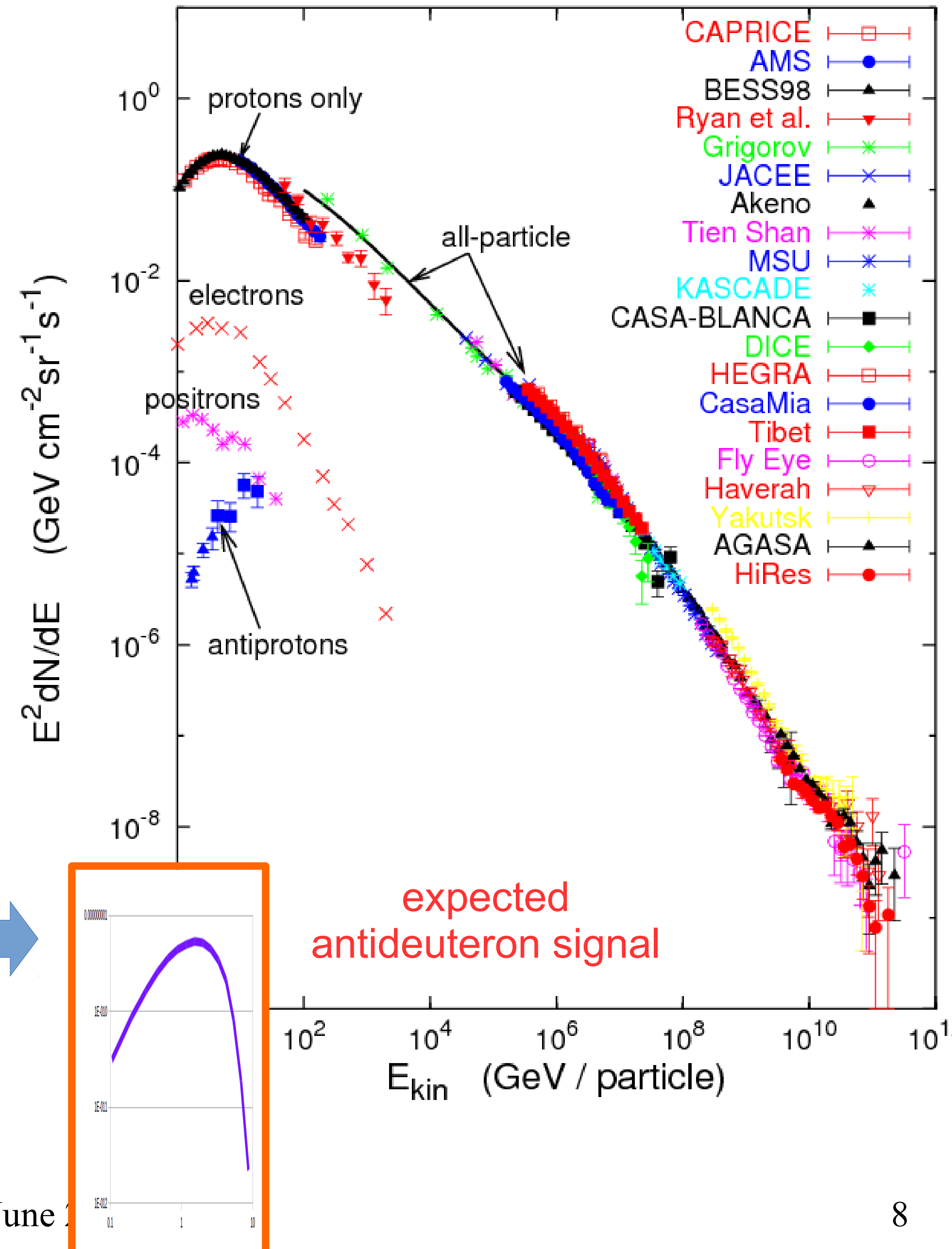


Cosmic-ray spectrum

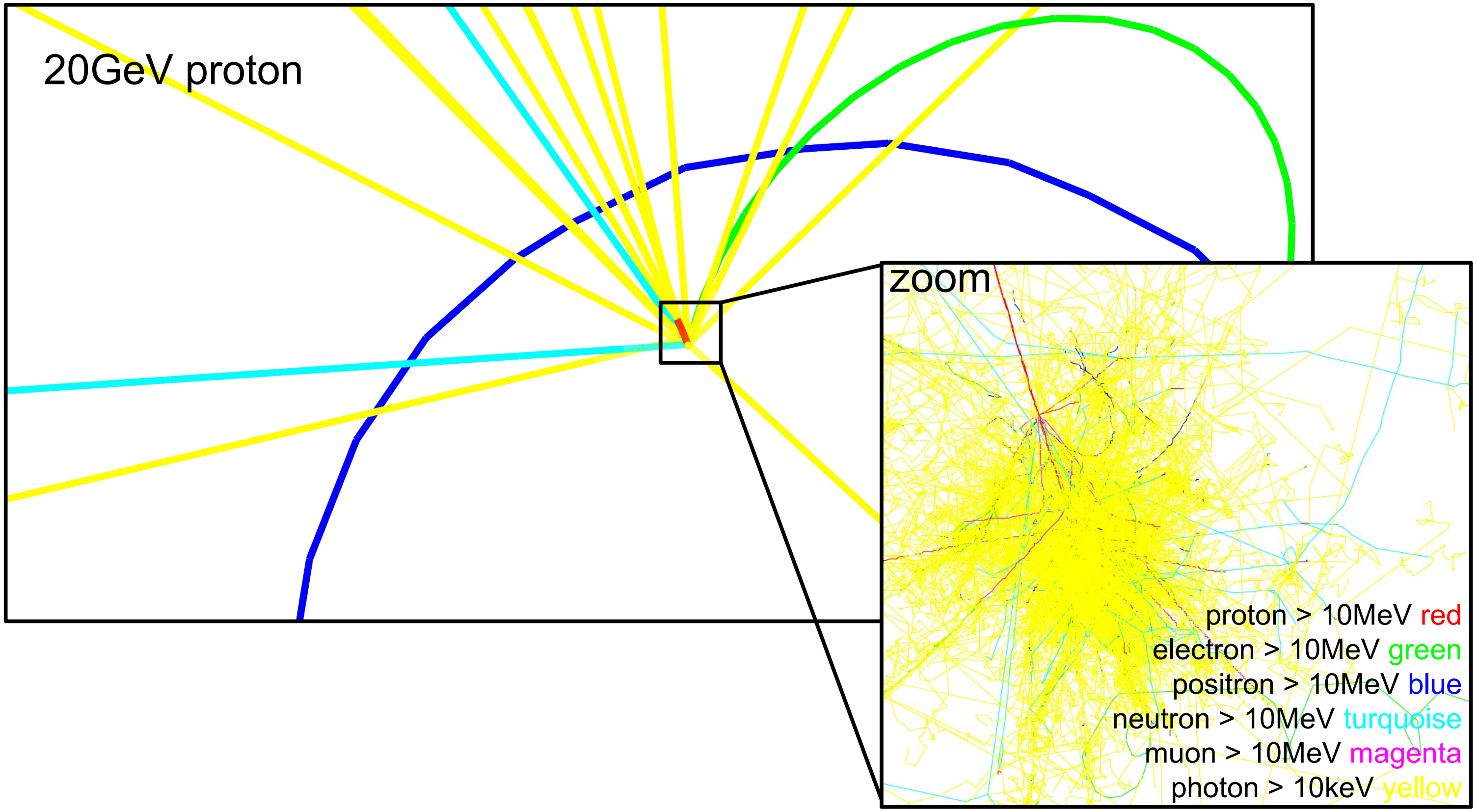
- Required rejections for antideuteron detection:
  - **protons**: > 10^8 - 10^{10}
  - **He-4**: > 10^7 - 10^9
  - **electrons**: > 10^6 - 10^8
  - **positrons**: > 10^5 - 10^7
  - **antiprotons**: > 10^4 - 10^6



Dal & Raklev (2014), arXiv:1402.6259

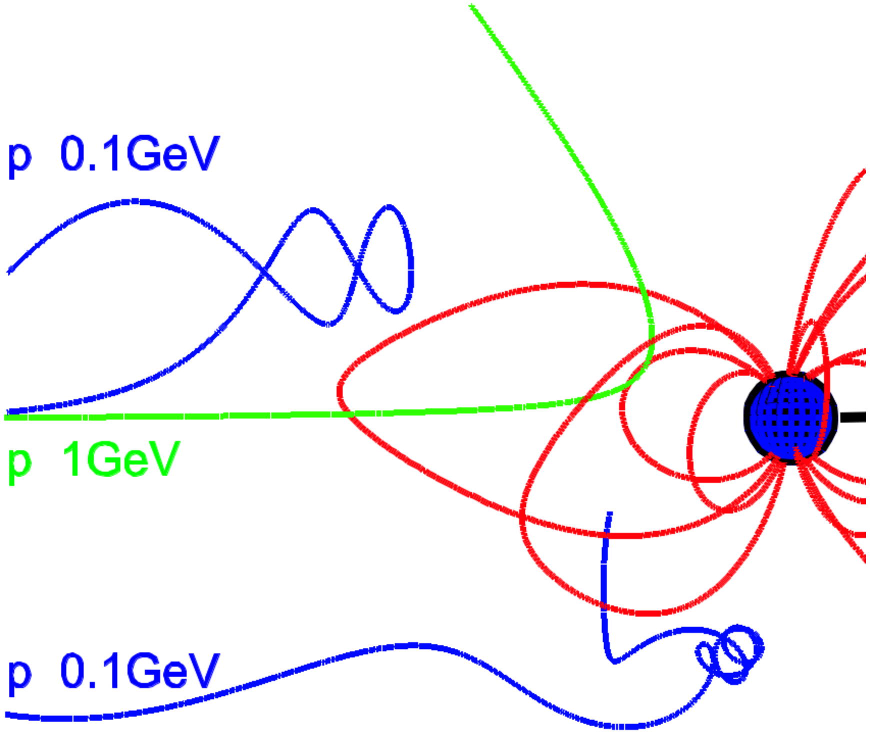


Geomagnetic and atmospheric influence

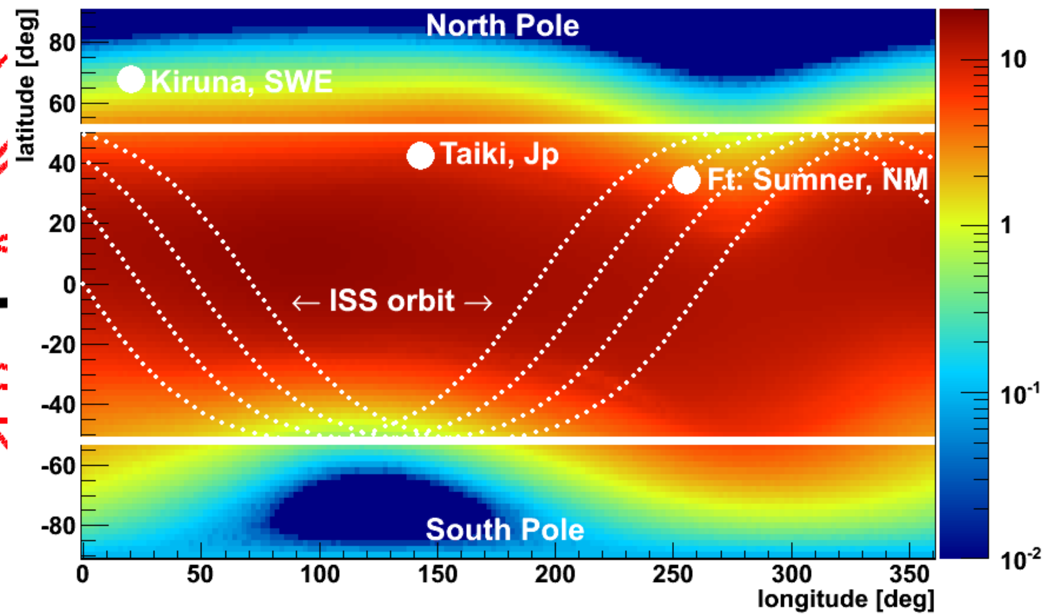


- atmosphere is important source of background for GAPS and AMS (backscatter)
- validated atmospheric/geomagnetic simulation approach based on PLANETOCOSMICS and GEANT4

Cutoff: perpendicular tracks



Geomagnetic cutoff rigidity [GV] for perpendicular protons

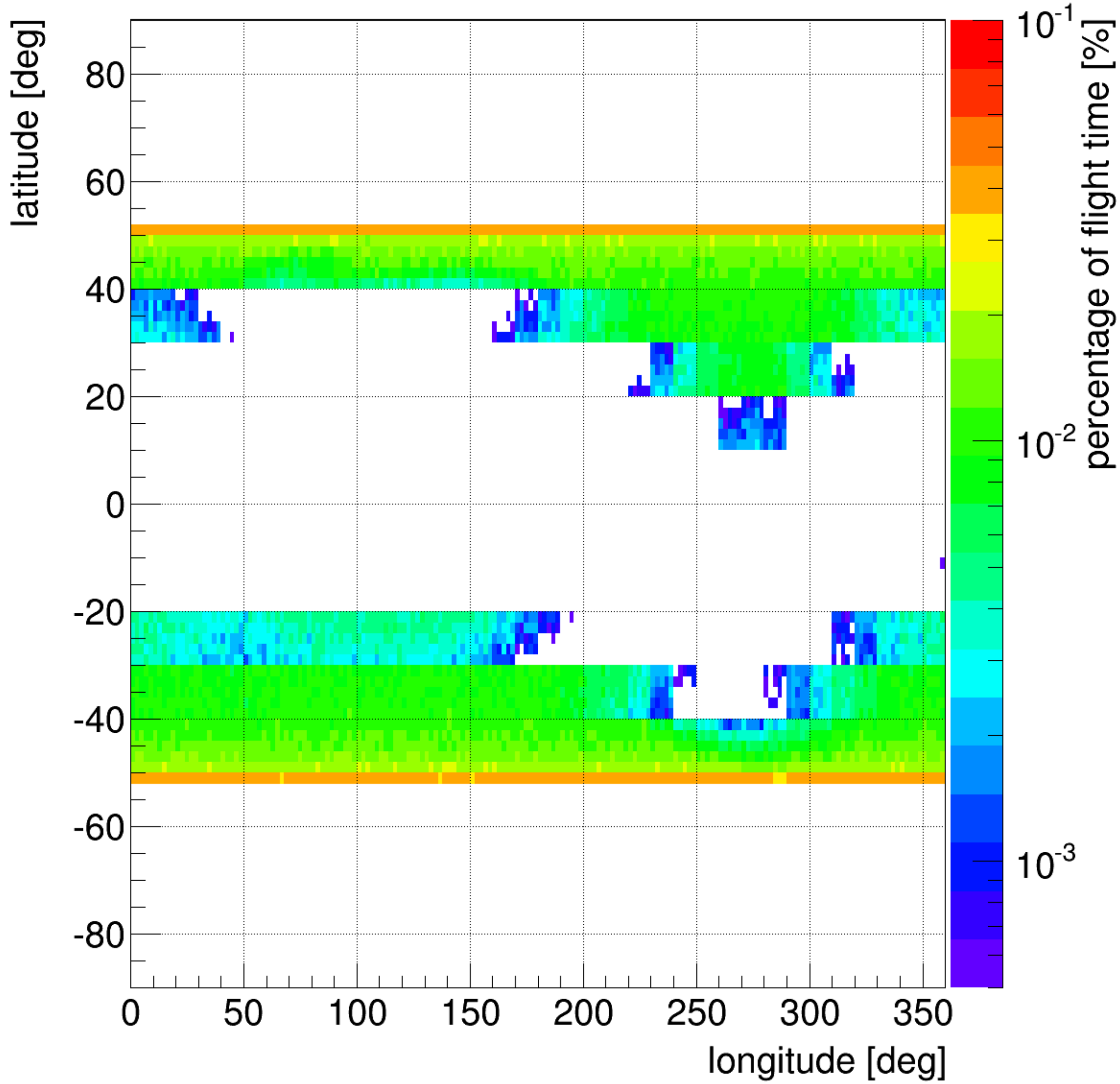


- geomagnetic field shields especially low-energy charged particles
- effect depends on the position

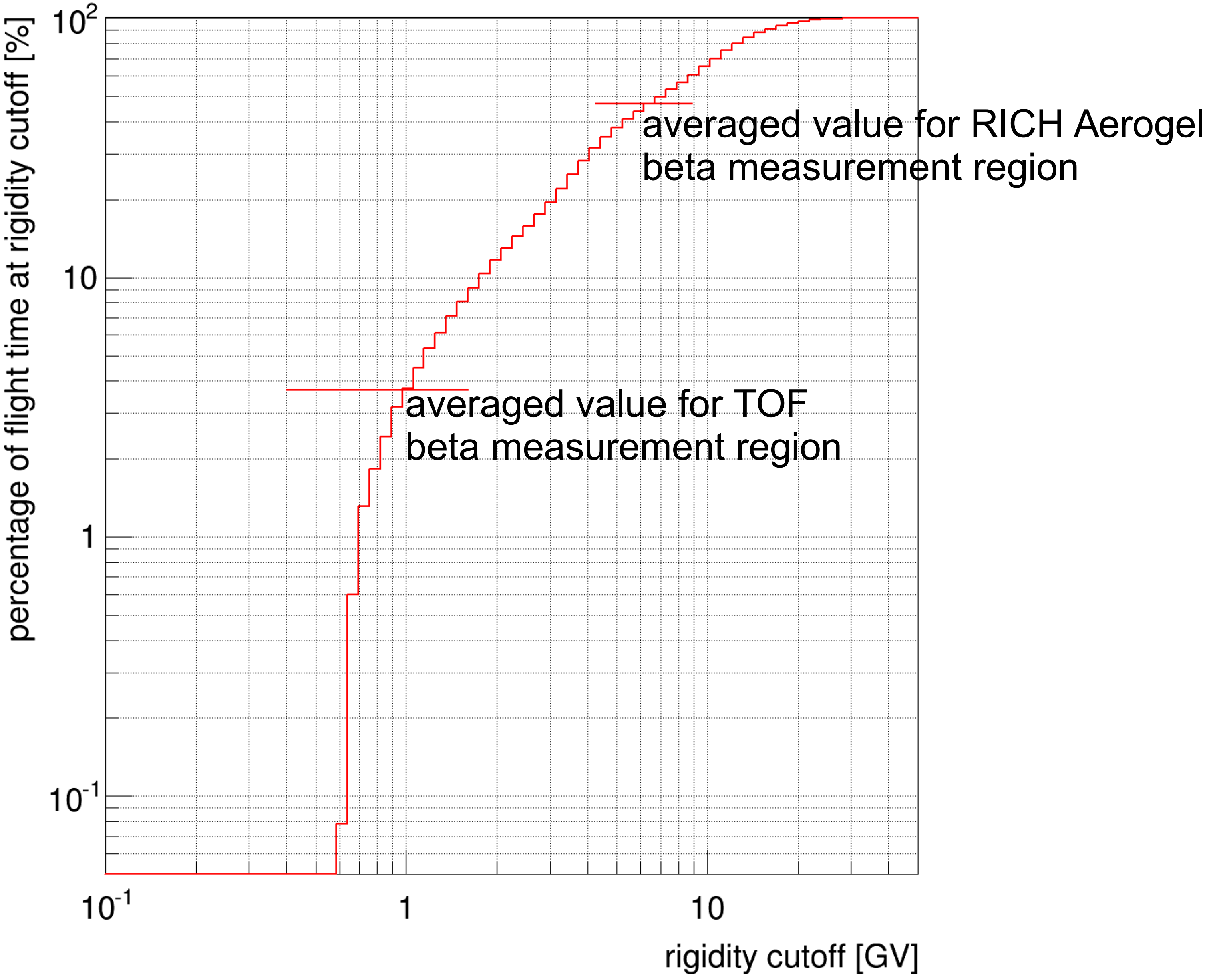
- **precise understanding is needed for systematic corrections**

Locations for antideuteron measurement

- Simulations with IGRF geomagnetic field and Tsyganenko 2001 magnetosphere
- Percentage of flight time spent at a certain geomagnetic location where
  - the rigidity cutoff is below 7GV for protons
  - the zenith angle with respect to the instrument z-axis is $\cos(\theta)>0.6$
  - Polar regions of ISS are scanned with 2deg grid, other regions with 10deg
  - Cutoff value is interpolated



Average time spent at low rigidity cutoffs



The current work

- A number of different particle species may mimic antideuterons in AMS-02 data
- Most obvious candidates are particles with similar mass, charge or mass/charge ratio
- All abundant CR particle species must be considered - even small contamination fractions may be important if contaminant's flux is large

- Current work: ***study simulated AMS-02 data to evaluate contamination from different particle species***

Some possible contaminants for antideuteron region

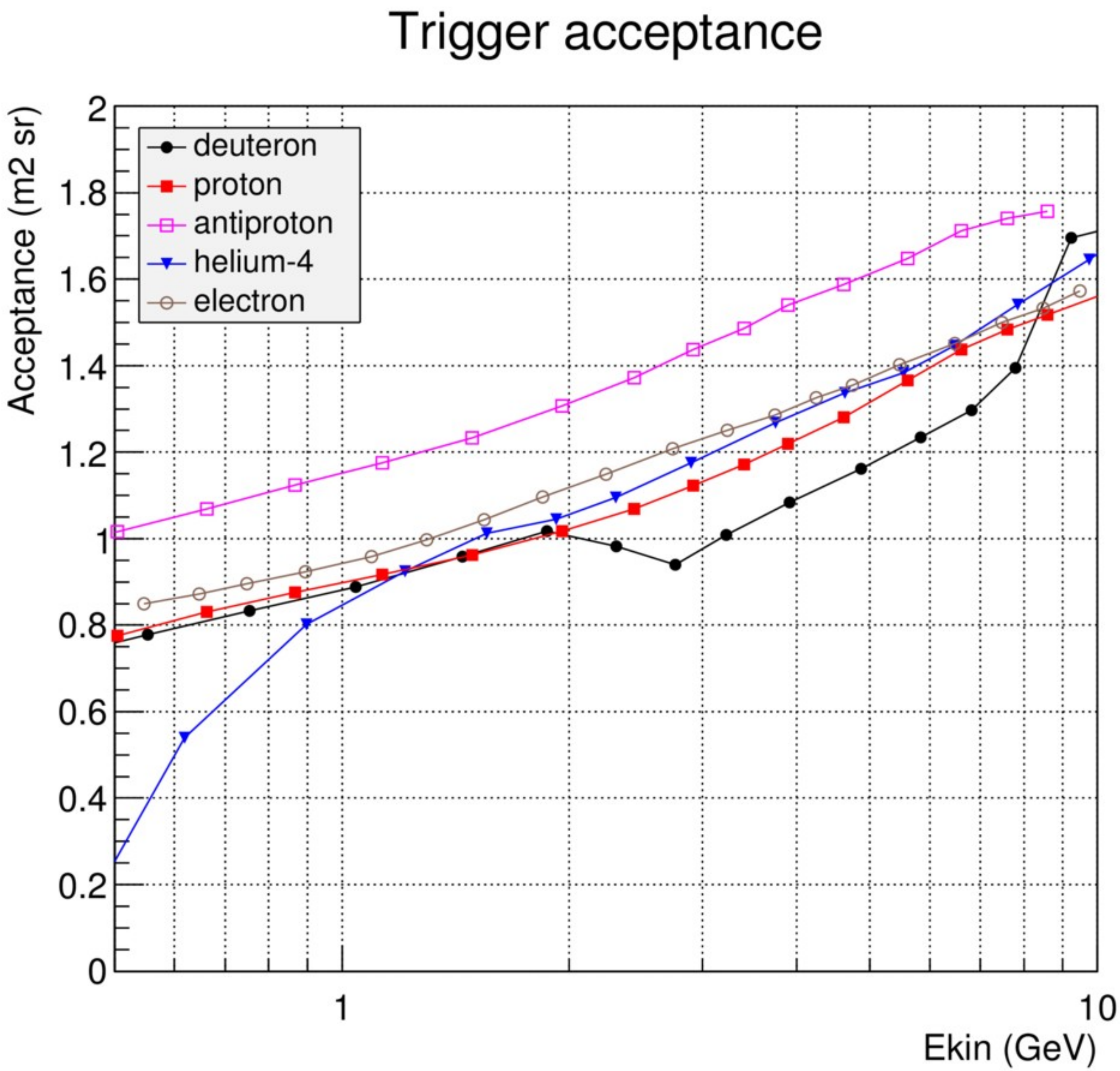
- **Protons**: right charge, wrong sign, wrong mass by factor 2, but extremely abundant
- **Deuterons**: right charge, wrong sign, right mass, very abundant - dangerous especially if upgoing
- **Antiprotons**: potentially one of the most difficult to deal with - same charge sign as antideuterons, also hadronic, several orders of magnitude more abundant
- **Electrons**: most abundant CR component with negative charge, but non-hadronic and with very different mass
- **Positrons**: same as electrons but less abundant and with wrong charge sign - if electrons are handled positrons will also be solved
- **Helium-4**: extremely abundant, same mass/charge ratio, but wrong sign; frequently fragments into deuterons in AMS-02 - dangerous if upgoing (the He ion itself or its fragments)

MC samples used

- MC samples used in contamination studies are **Geant4** simulations performed by the AMS collaboration
- Simulated samples used (all uniform in log p):
  - **deuterons** (6.2×10^{7} particles, 1.5×10^{6} triggers, p = 1-20 GV)
    - models used: Glauber-Gribov, BLIC (<5GeV/nuc) + DPMJET2.5 (>5GeV/nuc)
  - **protons** (1.24×10^{10} particles, 3.82×10^{8} triggers, p = 0.5-200 GV)
  - **antiprotons** (1.00×10^{8} particles, 2.7×10^{6} triggers, p = 0.5-10 GV)
  - **electrons** (1.00×10^{9} particles, 1.5×10^{7} triggers, p = 0.5-10 GV)
  - **helium-4** (6.9×10^{8} particles, 2.5×10^{7} triggers, p = 1-400 GV)
- Geant4 versions: **4.9.6** (d, p, ^{4}He), **4.9.4** (p-bar, e^{-})
- Deuteron simulations currently used as reference for antideuteron studies
  - Antideuteron simulations currently being planned
  - Ongoing work in Hawaii on standalone studies with Geant4, experimenting with different physics lists
- Study so far focused on downgoing particles with inclinations up to 45°
  - Upgoing particles are also important

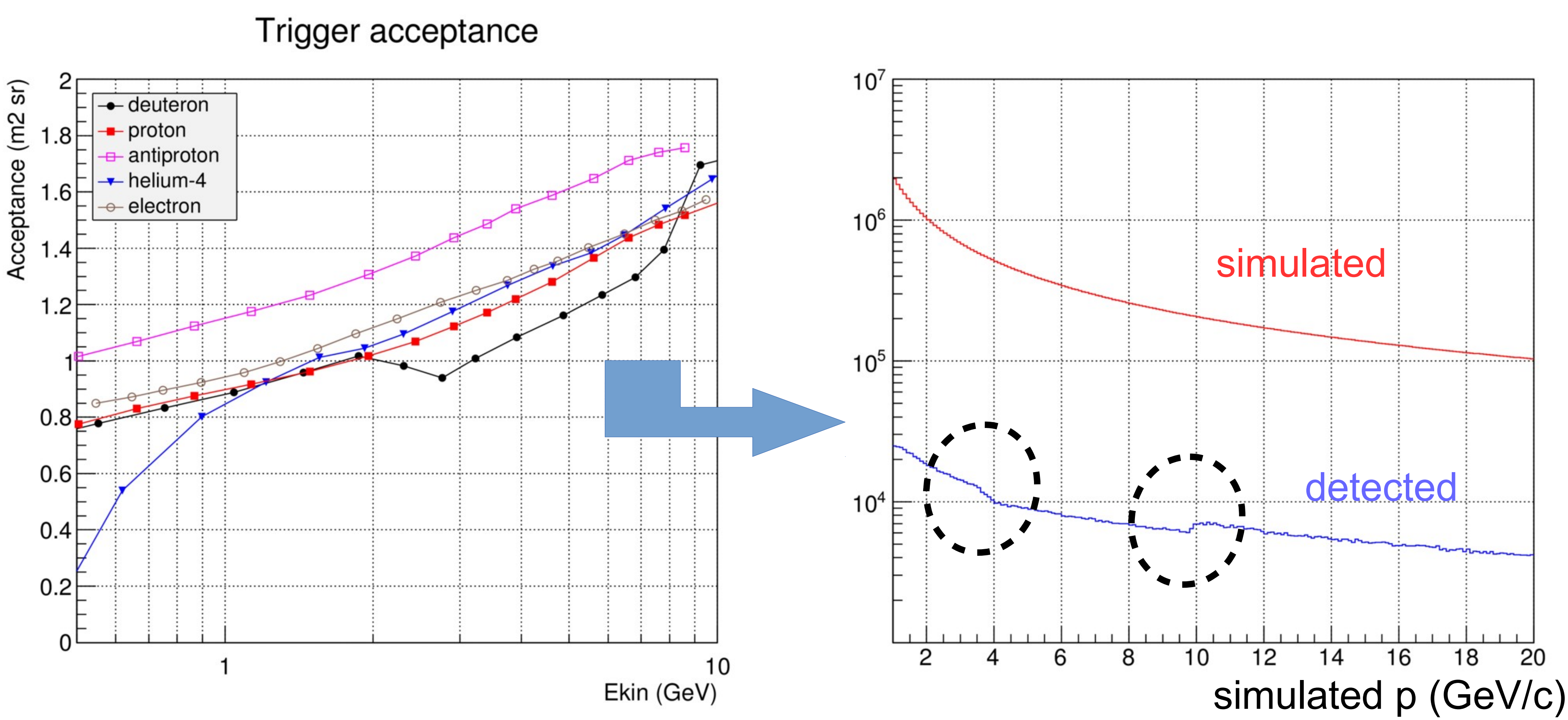
AMS-02 trigger acceptance

- Results obtained from simulations, no cuts applied
  - Fast AMS trigger
- Trigger acceptance in AMS-02 is ~1 m^2sr around GeV region
  - Increases with particle energy
  - Similar for e^-, p, d, ^4He
  - ~30% higher for antiprotons (due to e.g. annihilations)



AMS-02 trigger acceptance

- Features of deuteron curve, with decrease at 2-3 GeV and increase at 10 GeV, may be artifacts of simulation (change of interaction model as function of energy)
  - This reflects large uncertainties in cross-section knowledge

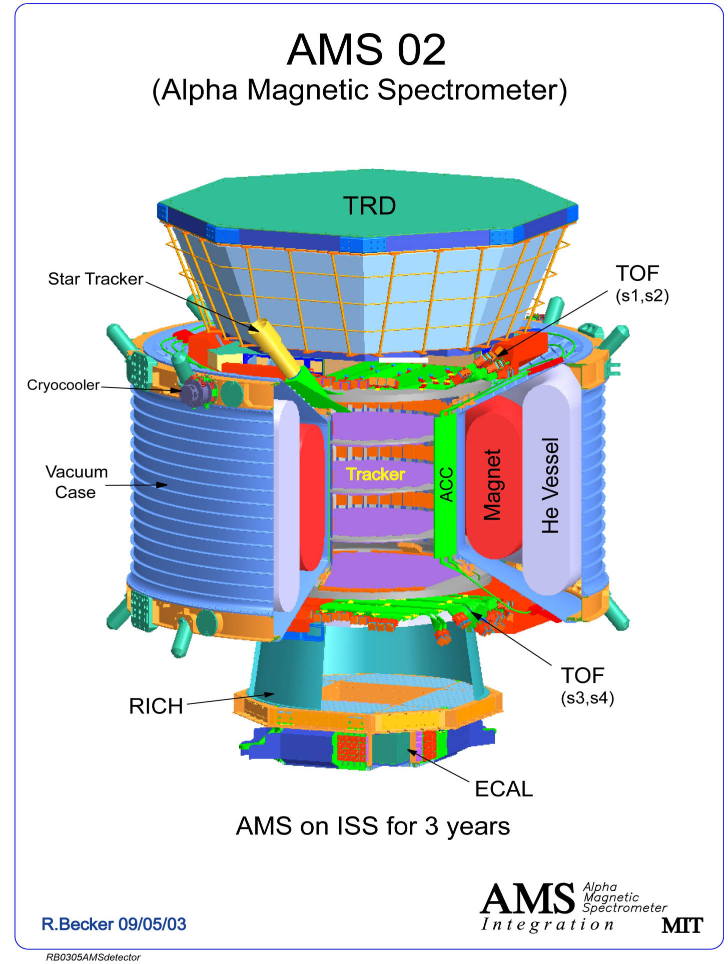


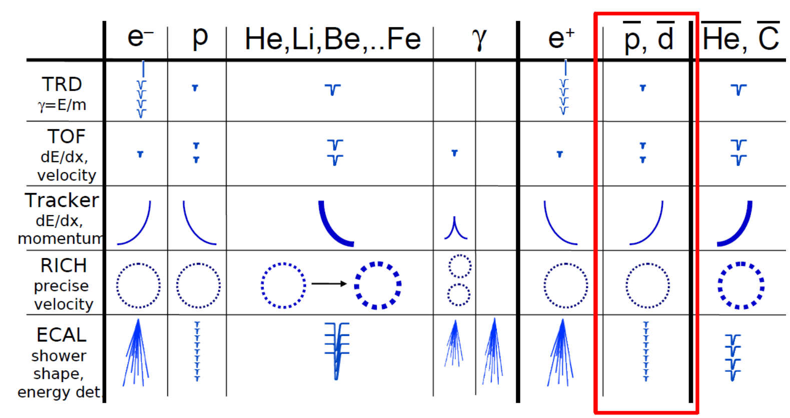
Quality cuts

- Set of cuts originally developed to exclude (anti-)proton contamination in (anti-)deuteron region
  - Hadron/hadron case, so no TRD and ECAL cuts considered
  - Deuteron simulations became available recently, will be considered in future cut upgrades
- Optimized for kinetic energy around 1 GeV
  - Velocity measurement based on TOF data
- Phase space of different variables explored to maximize ratio of "signal"/"noise" events
  - ***Signal***: protons reconstructed as protons
  - ***Noise***: protons reconstructed as deuterons
  - Wide mass range allowed in each case ($m_p \pm 20\%$, $m_d \pm 20\%$), exact range will be tuned in the future to optimize event selection
- Specific cuts chosen to preserve high fraction of "signal" events and limit "noise" events

Quality cuts used

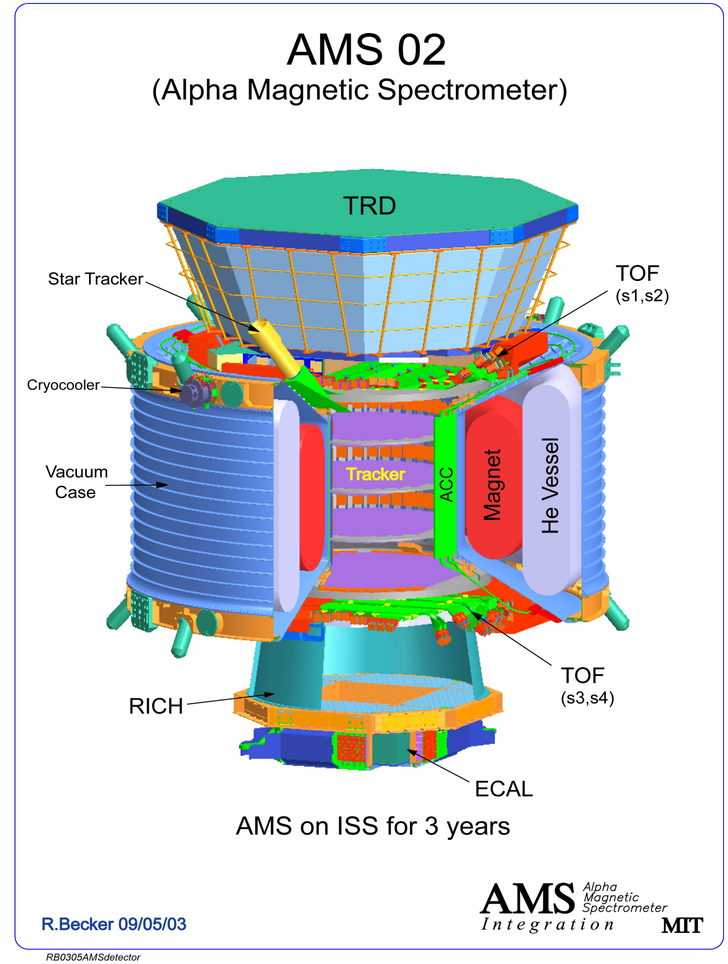
- **Currently used for MC samples**:
  - Exactly 1 particle in event, with Tracker & TOF data
  - No more than 1 ACC cluster
  - Rigidity uses all 7 inner Tracker planes, ≥ 4 having XY hits
  - Rigidity measurement robustness:
    - Alternative algorithm gives 0.95x-1.03x of standard algorithm
    - Upper planes give 0.85x-1.25x, lower planes give 0.88x-1.04x
  - TOF: $0.3 < \beta < 1$, and ≥ 3 (of 4) planes used, ≤ 2 non-used clusters, energy deposited within 3-10 MeV (upper), 0-10 MeV (lower)
  - [continues...]

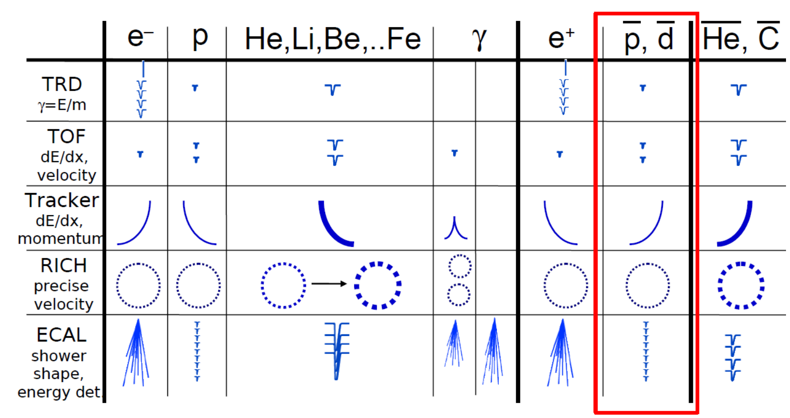




Quality cuts used

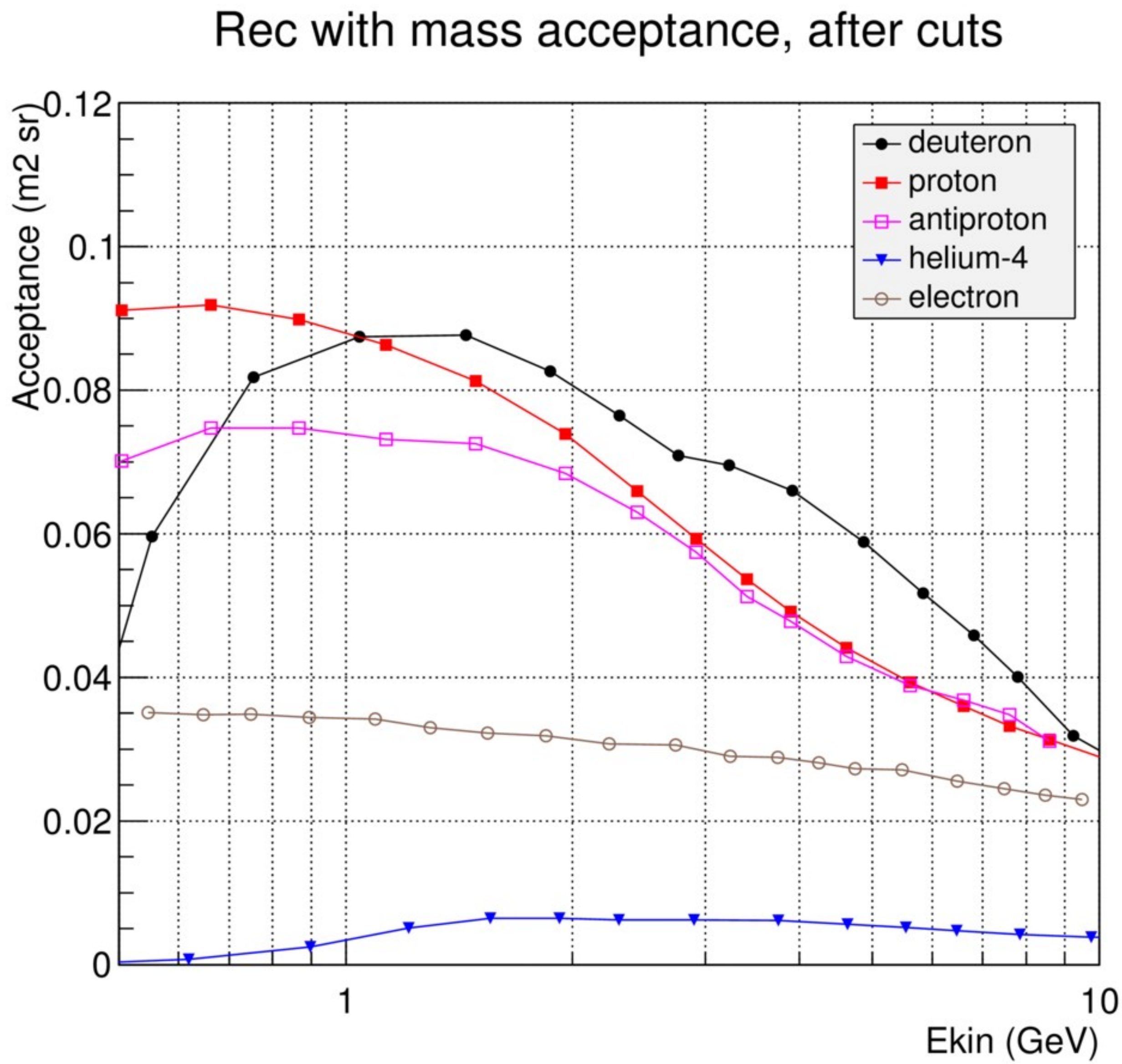
- **Currently used for MC samples**:
  - [continued]
  - Reconstructed charge compatible with Z = 1:
    - AMS global: 0.7-1.4; Tracker: 0.7-1.3; TOF: 0.7-1.4 (all), 0.5-2.0 (upper & lower)
  - Limits on χ^2 in Tracker, TOF reconstructions
- **Ongoing work**
  - Cuts to be refined, TRD/ECAL data added, multivariate analysis also planned
  - DAQ-related cuts (geographical position, orientation, detector status...) to be introduced in analysis of ISS data





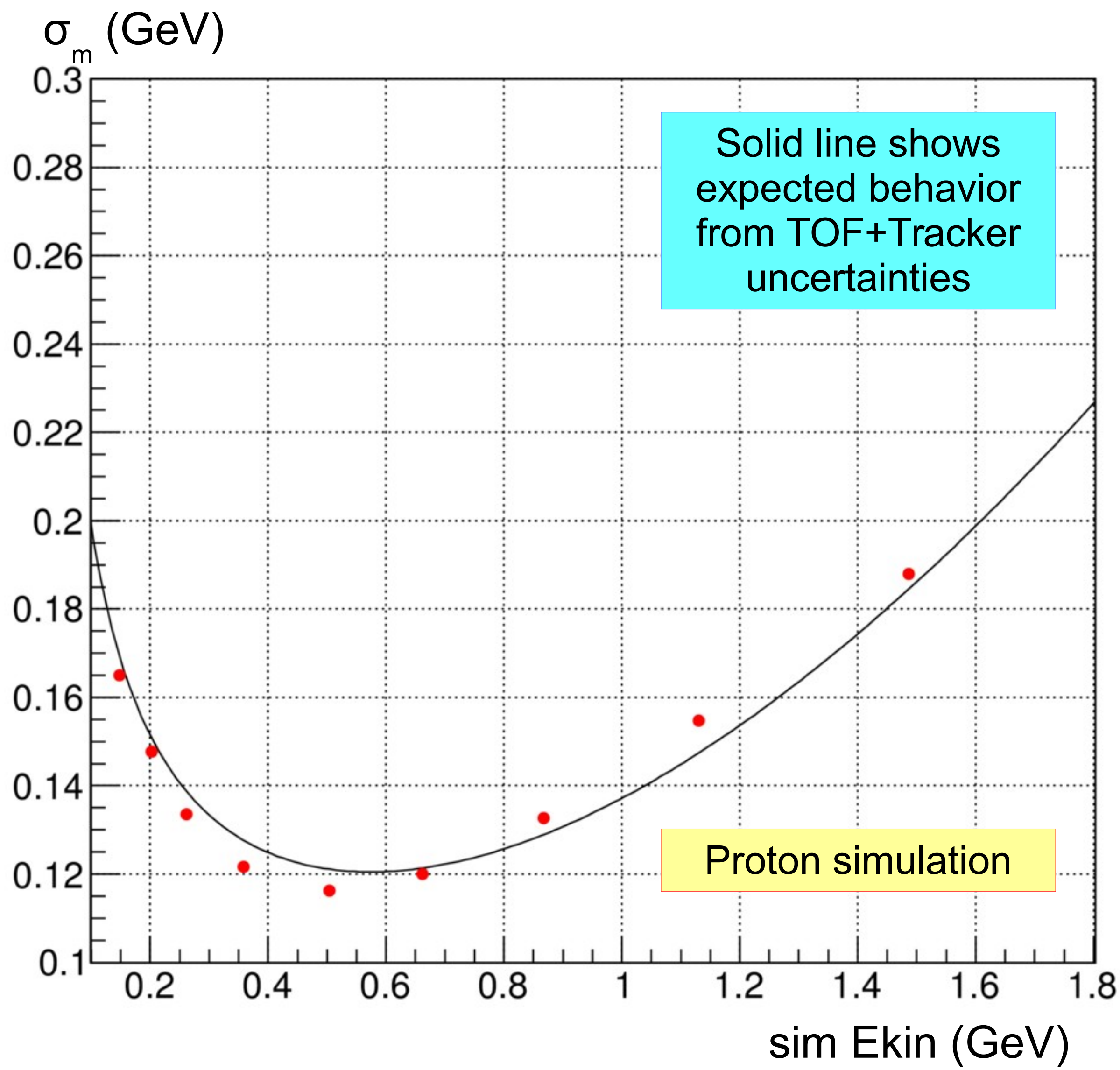
Acceptance after cuts

- Acceptance after cuts at 1 GeV:
  - ~0.08 m²sr for hadrons
  - ~0.03 m²sr for electrons
  - Large electron fraction excluded due to β > 1 reading
- Much smaller value for helium
  - restriction to Z = 1 included in quality cuts
- Quality cuts tend to exclude noisy events (detected as ACC clusters, extra TOF clusters...)
  - higher energy means more interactions
  - also explains why antiprotons (where annihilation is possible) are clearly below protons at low energy



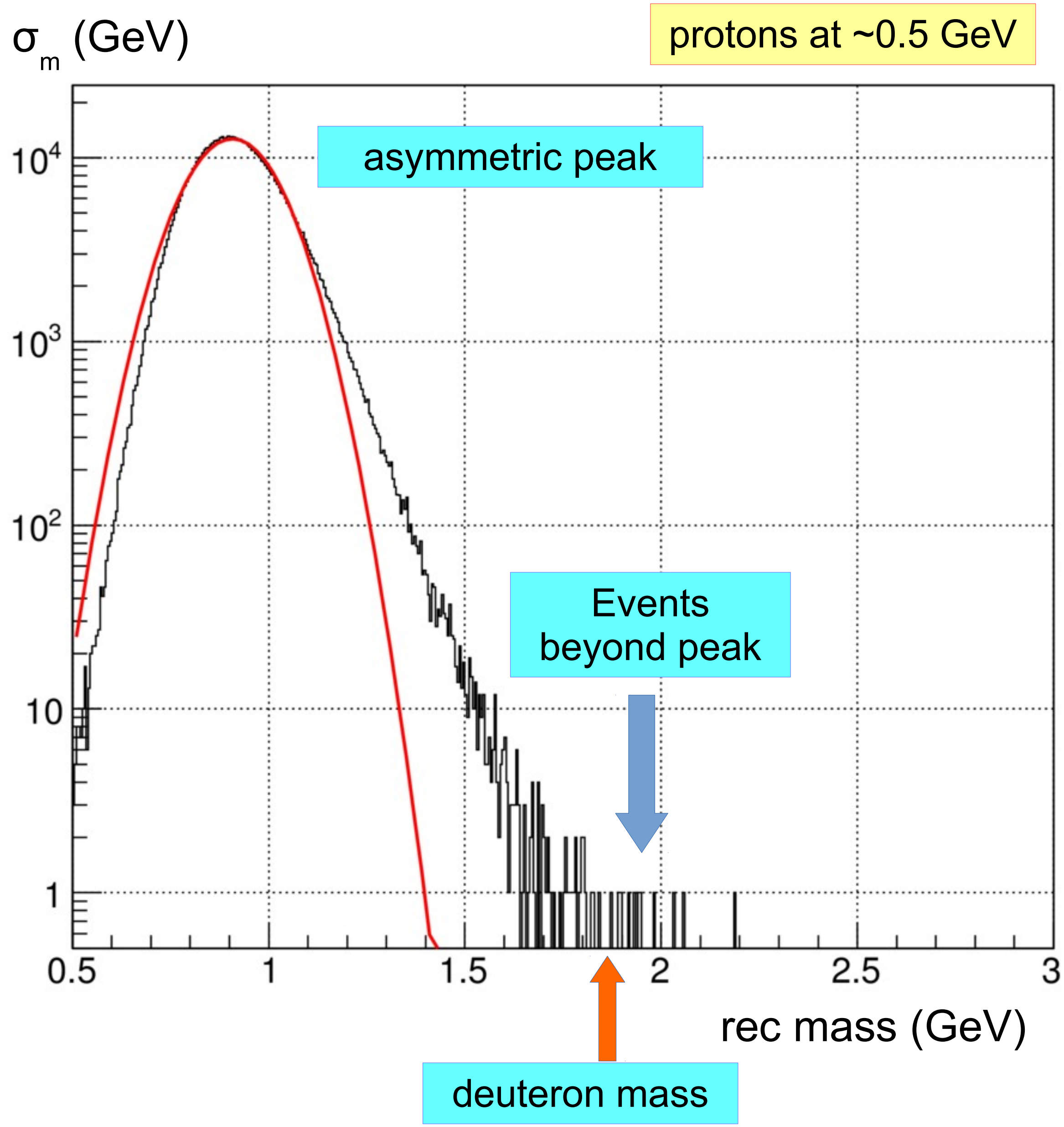
Mass resolution

- Proton results show mass resolution of 12% at ~0.5 GeV after quality cuts are applied
  - Should be enough for good d/p separation if tails were fully Gaussian...



Mass resolution

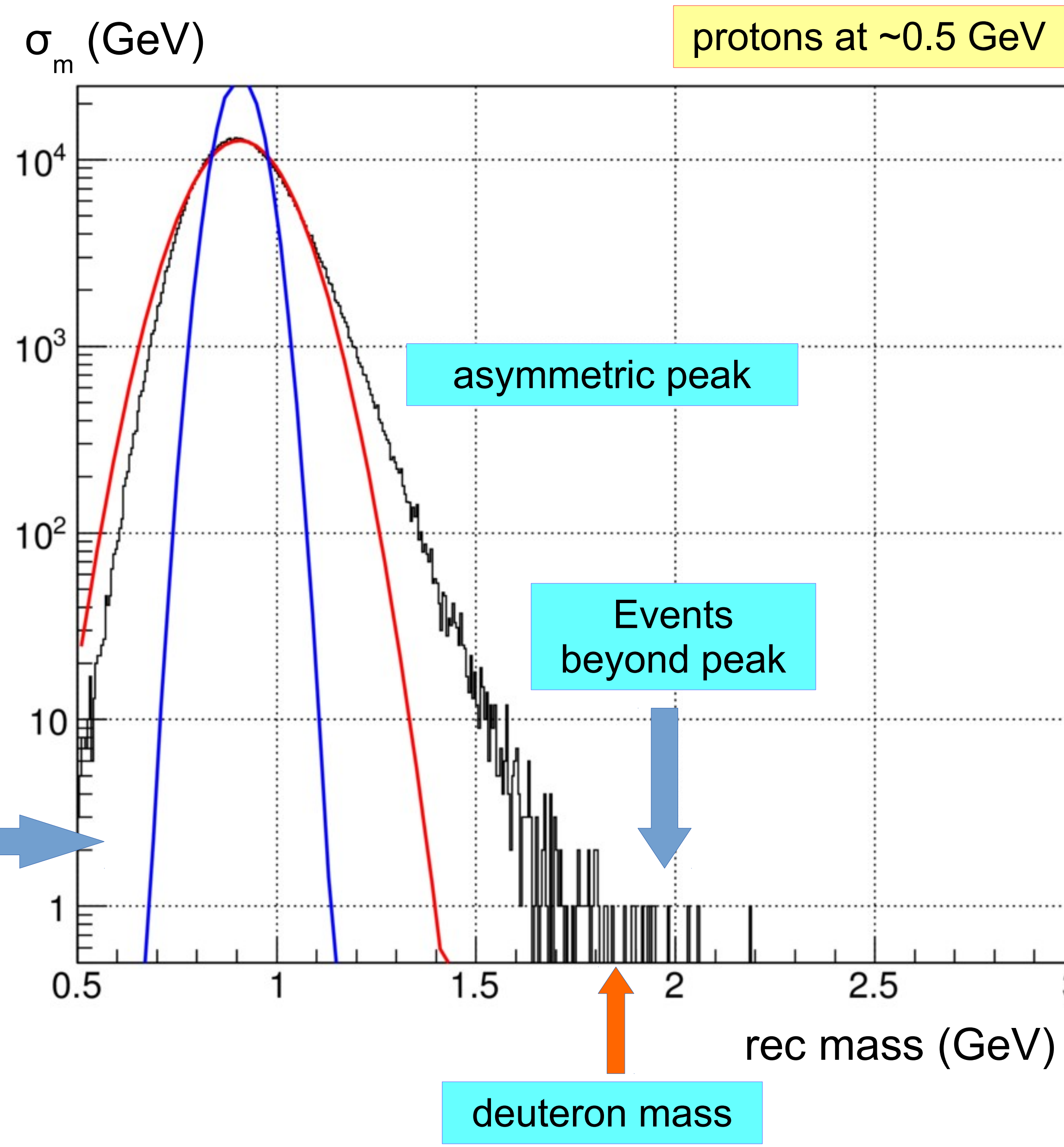
- Unfortunately, as expected, that is not exactly the case
  - Gaussian curve shown matches top of mass peak
  - Mass peak is slightly asymmetric, with larger tail on the right
  - A tiny, but non-zero fraction of events lies beyond the peak
- Ongoing work to improve reconstruction results



Mass resolution

- Superconducting magnet configuration would have been better
  - Example for ~0.5 GeV: mass resolution would be 5% instead of 12%

with superconducting magnet



Next steps

- **This is a work in progress**
- More studies needed to use the capabilities of AMS-02 in full
  - Further simulations should be performed
  - Expand study to RICH-based region (~5 GeV): smaller geometrical acceptance but greater exposure time due to reduced geomagnetic effects
  - Study upgoing particles
- Improve knowledge of antideuteron cross-sections and detector response
  - Deuteron data may give some insight - AMS-02 can help!
  - ... but remember there are significant differences between particles and antiparticles (see e.g. proton/antiproton)
  - Dedicated antideuteron simulations will be performed - input welcome