Background Simulations with Geant4 for the General Antiparticle Spectrometer (GAPS) Balloon Experiment

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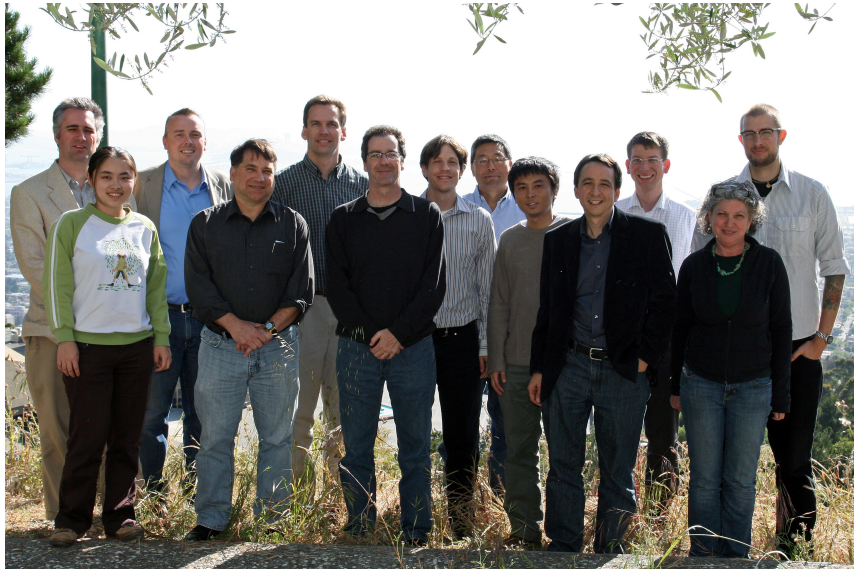

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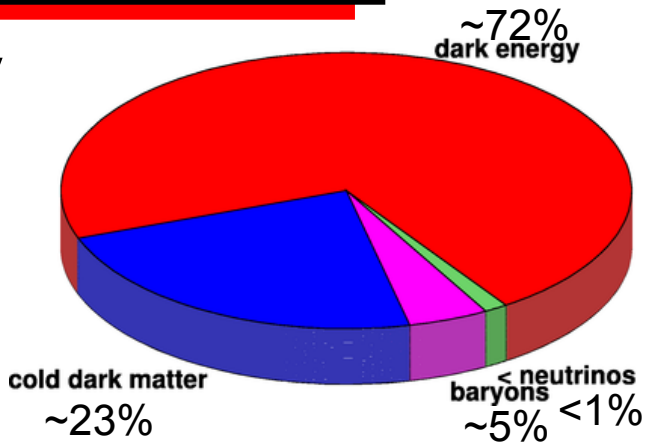
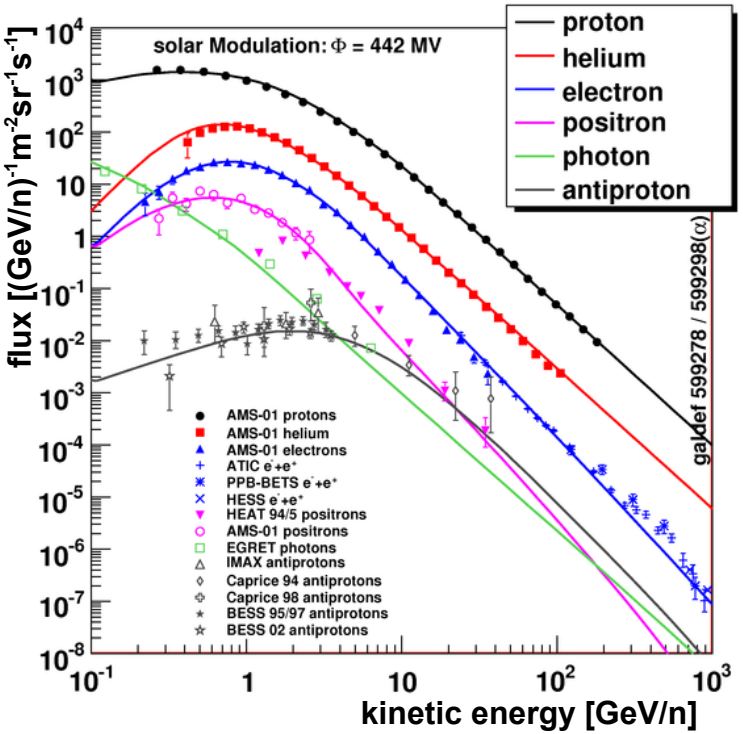
1 Columbia University, 2 Japan Aerospace Exploration Agency, 3 UC Berkeley, 4 Lawrence Livermore National Laboratory, 5 University of Latvia, 6 UC Los Angeles

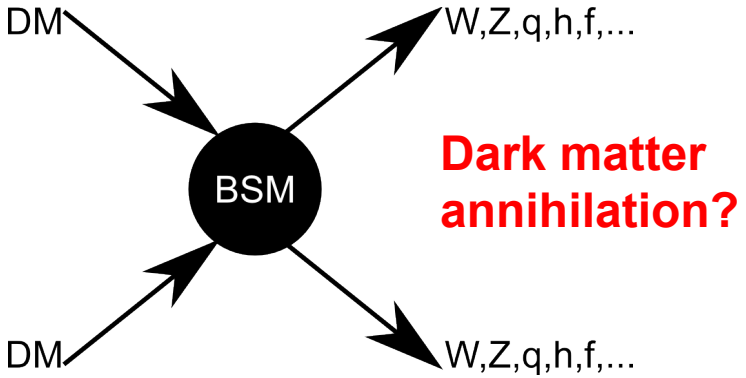
Dark matter search

- evidence for dark matter exists in many different fields
- **BUT** we do not know its nature
- different search approaches: **direct** and **indirect**: here cosmic rays

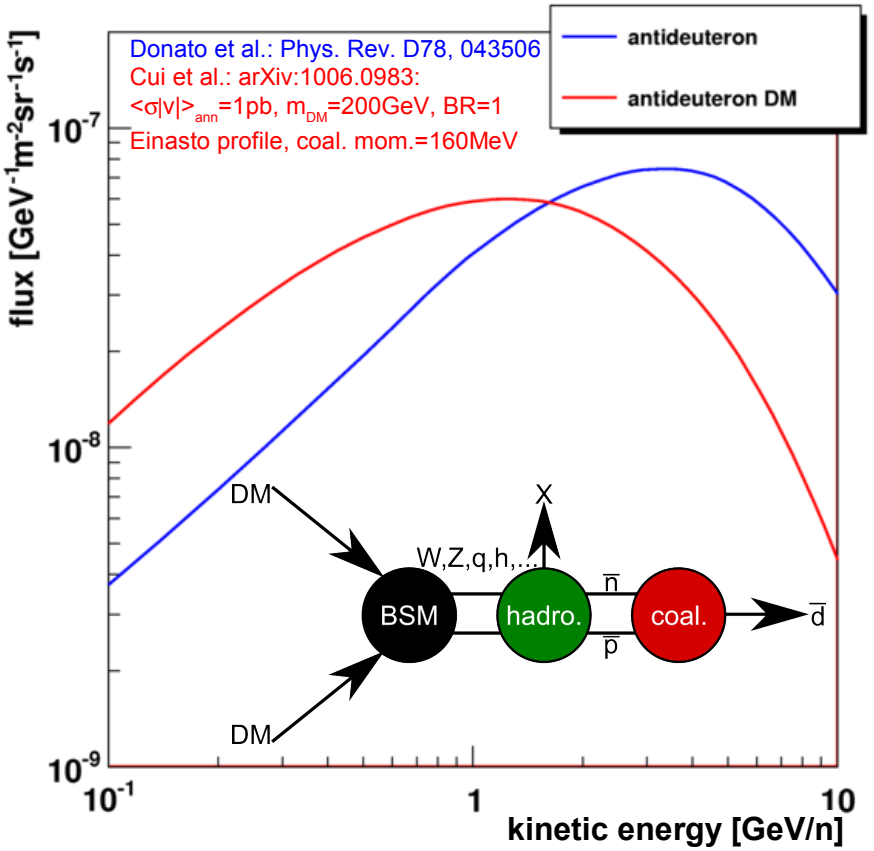


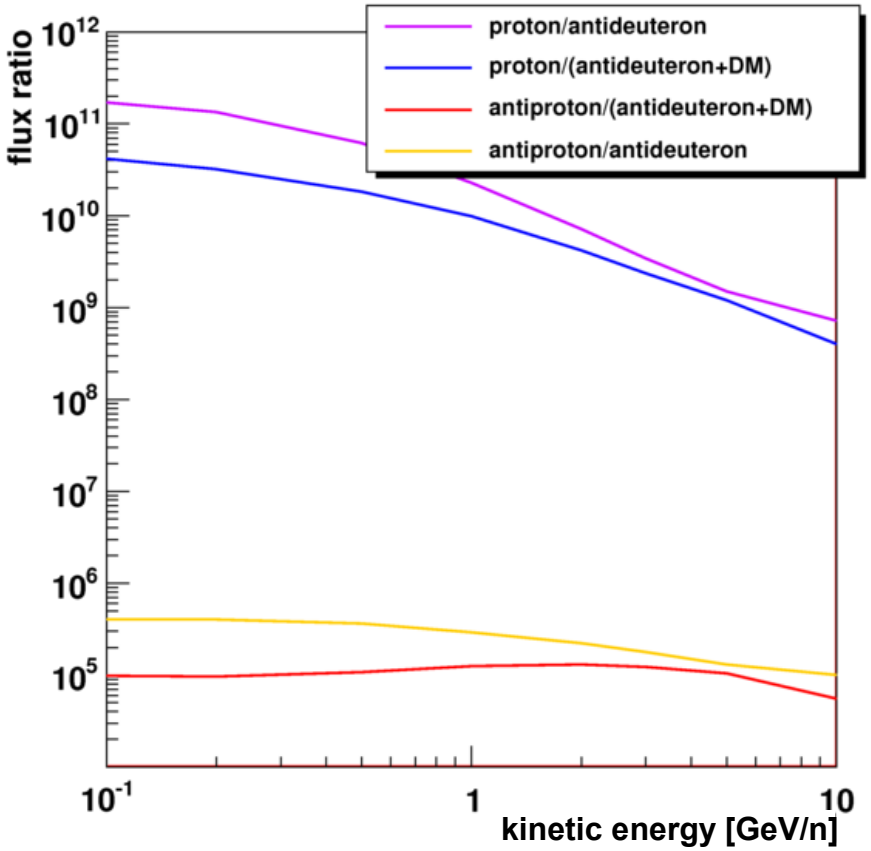


- in general good agreement of cosmic ray flux models with measurements, **but** deviations in **electron** and **positron** data (Fermi, Atic, Pamela)!



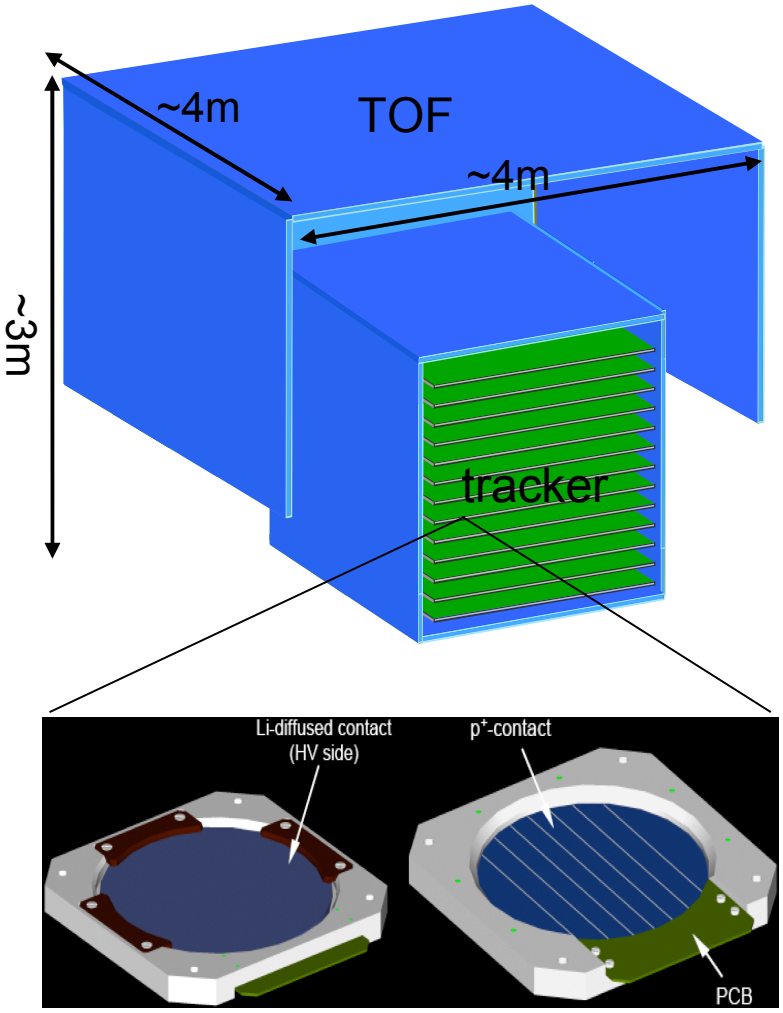
Antideuterons and dark matter





- **antideuteron flux is very small**:
  - challenging to measure the first antideuterons in cosmic rays (secondary interactions of protons with interstellar gas)
  - good source to **study new phenomena**
- theories with **dark matter** self-annihilation predict **"large" low-energy antideuteron signals**

GAPS concept



GAPS consists of two detectors (accep.: ~2.7m²sr):

Si(Li) tracker:

- Si(Li) tracker:13 layers composed of Si(Li) wafers
- relatively low Z material (2/3mm,escape fraction ~20keV) →target and detector
- Lithium doped Silicon detectors for a good x-ray resolution
- circular modules segmented into 8 strips, ~8cm² each →3D particle tracking
- 270 per layer (total: ~3500)
- timing: ~50ns
- dual channel electronics
  5-200keV: X-rays (resolution:~2 keV)
  0.1-200MeV: charged particle

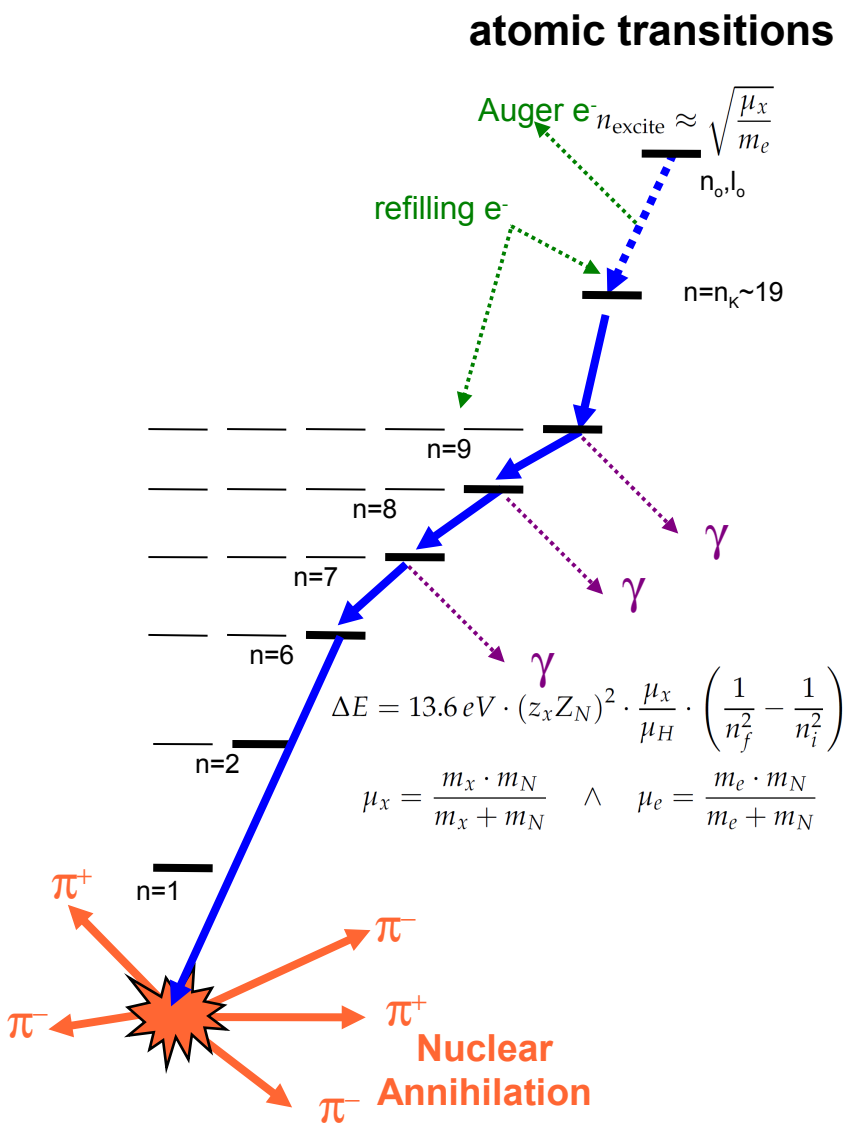
Time of flight and anticoincidence shield:

- plastic scintillator with PMTs surrounds tracker
- track charged particles
- velocity measurement
- anticoincidence for charged particles

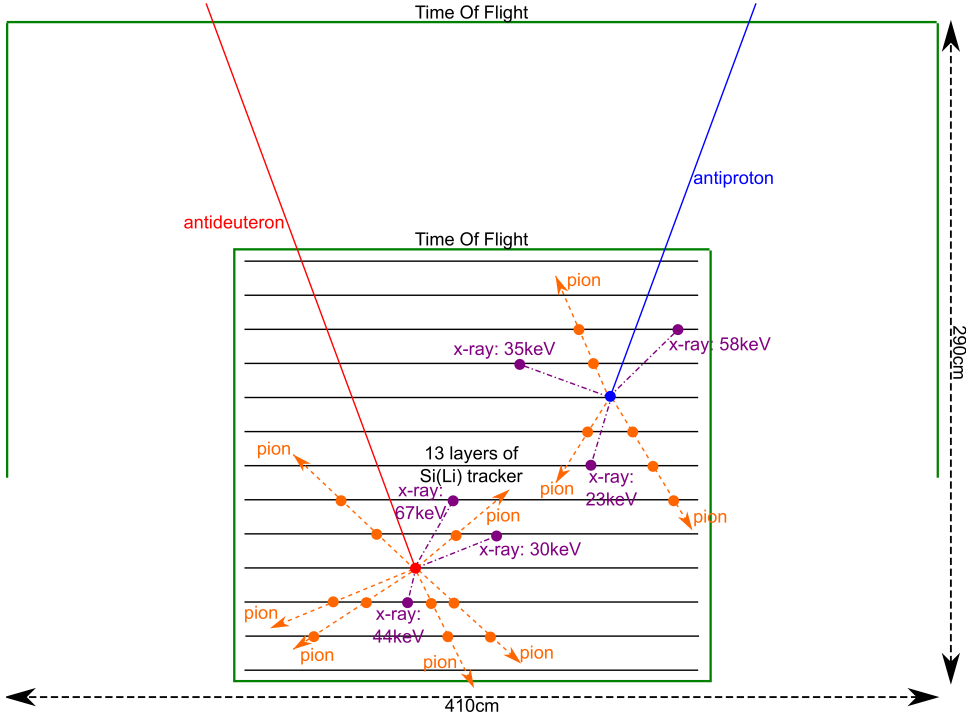
Scientific balloon flights planned from Antarctica in 2014

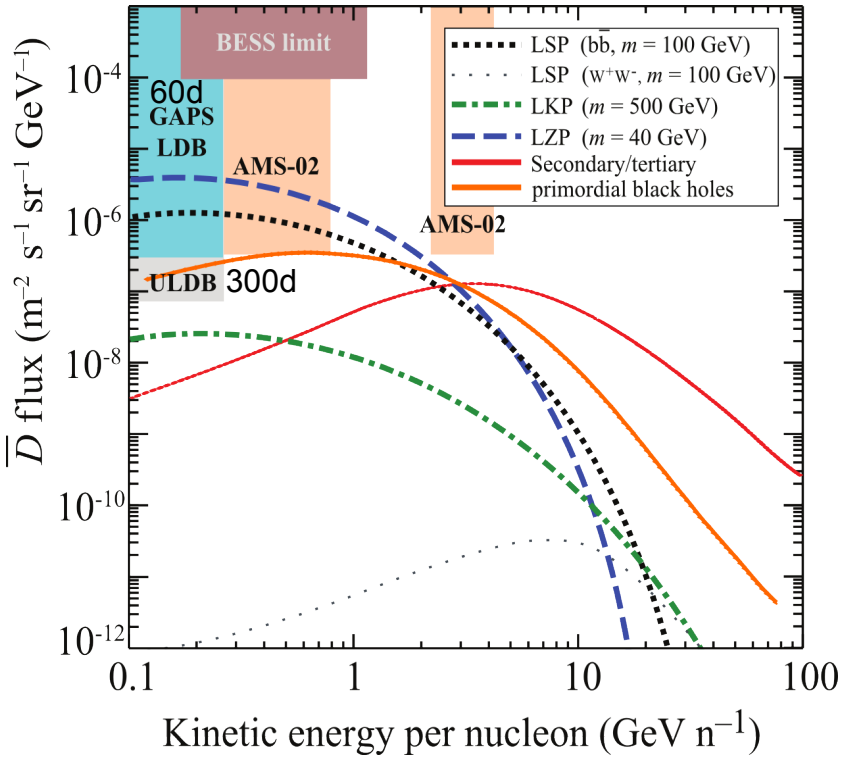
Antideuteron identification

- antideuteron slows down and stops in material
- large chance for creation of an excited exotic atom (E_{kin}~E_I)
- deexcitation:
  - fast ionisation of bound electrons (Auger)
    →complete depletion of bound electrons
  - Hydrogen-like exotic atom (nucleus+dbar) rad. deexcitation: **characteristic x-ray transitions**
- nucleus-antideuteron annihilation: **pions**
- exotic atomic physics quite well understood (tested in KEK 2004 testbeam)



Background & sensitivity





Identification uses:

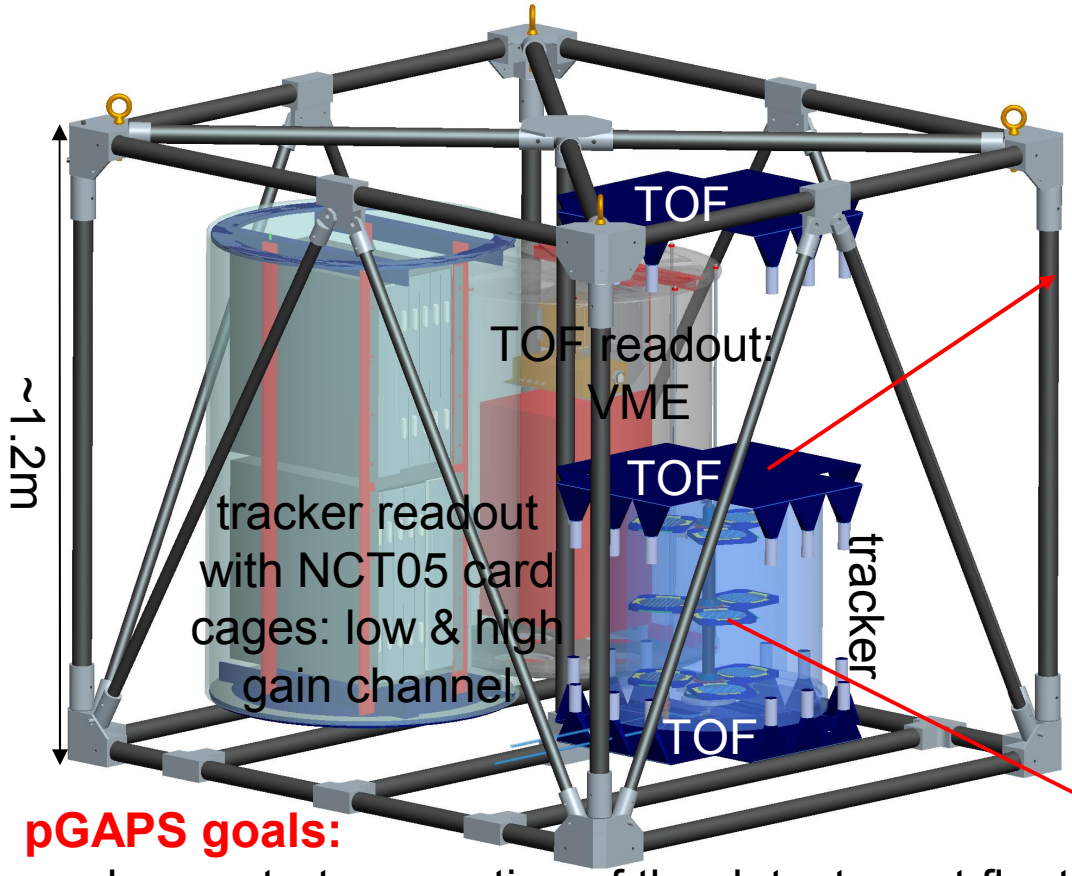
- TOF velocity and track, depth in tracker, x-rays and pions from annihilation

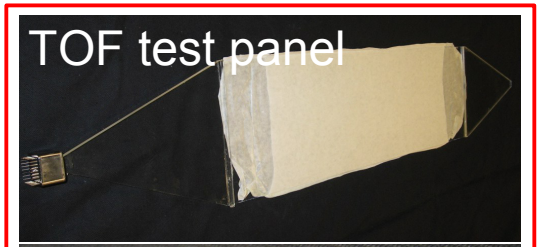
Background sources:

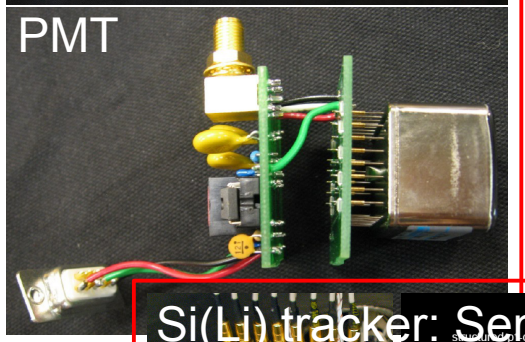
- Antiprotons, protons,/electrons in coincidence with cosmic x-rays, atmospheric production of antideuterons

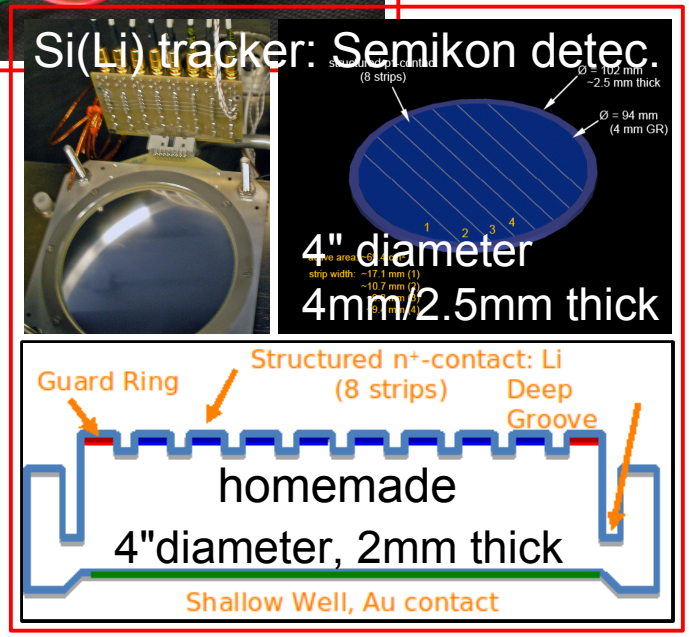
- reasonable antideuteron fluxes within sensitivity:
  Supersymmetry, Kaluza-Klein UED, Warped extra dimensions, primordial black holes
- synergy with direct searches and neutrino telescopes

Prototype experiment (pGAPS)









pGAPS goals:

- demonstrate operation of the detectors at float
- measure incoherent background
- Time of Flight: 3 layers, 18 panels, 36 PMTs
- Si(Li) tracker: 3 layers, 9 modules
- 2011 flight from Taiki, Japan

Simulation roadmap

Aspects of the simulations

Cosmic fluxes	Atmospheric simulation	Detector simulation	Exotic atomic physics

Final goals of these efforts:

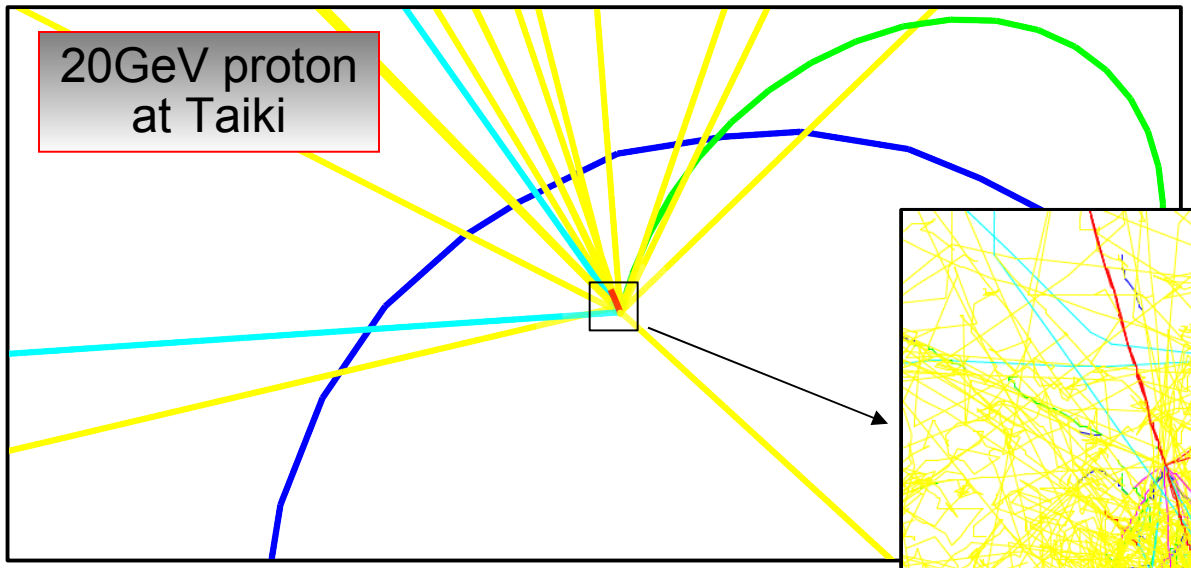
Analysis
- Test of analysis chain from flight computer format to reconstructed objects.
- Comparison with MC information to improve/understand analysis cuts.

Backgrounds
- Study backgrounds due to cosmic particles.
- Study backgrounds due to atmospheric particles.
- Study backgrounds due to particles produced in interactions of cosmic/atmospheric with inactive detector material.

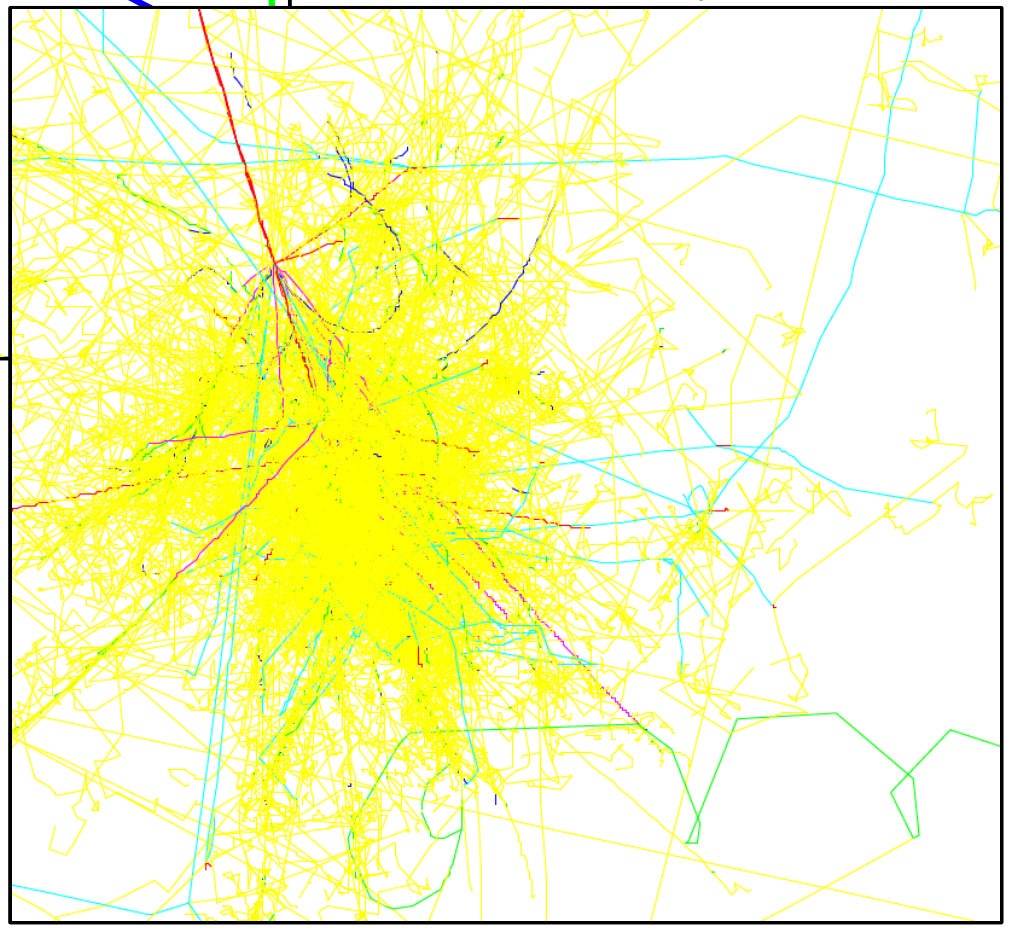
Instrument Design
- Use these studies to determine the hardware requirements.
- Study trigger requirements.
- Final set of physics/full detector simulation should so flexible that it can be used for bGAPS designing.

Science Goal
- Test capability and implications for creation/deexcitation of muonic atoms? Good demonstration of GAPS concept?

Air shower & geomagnetic field



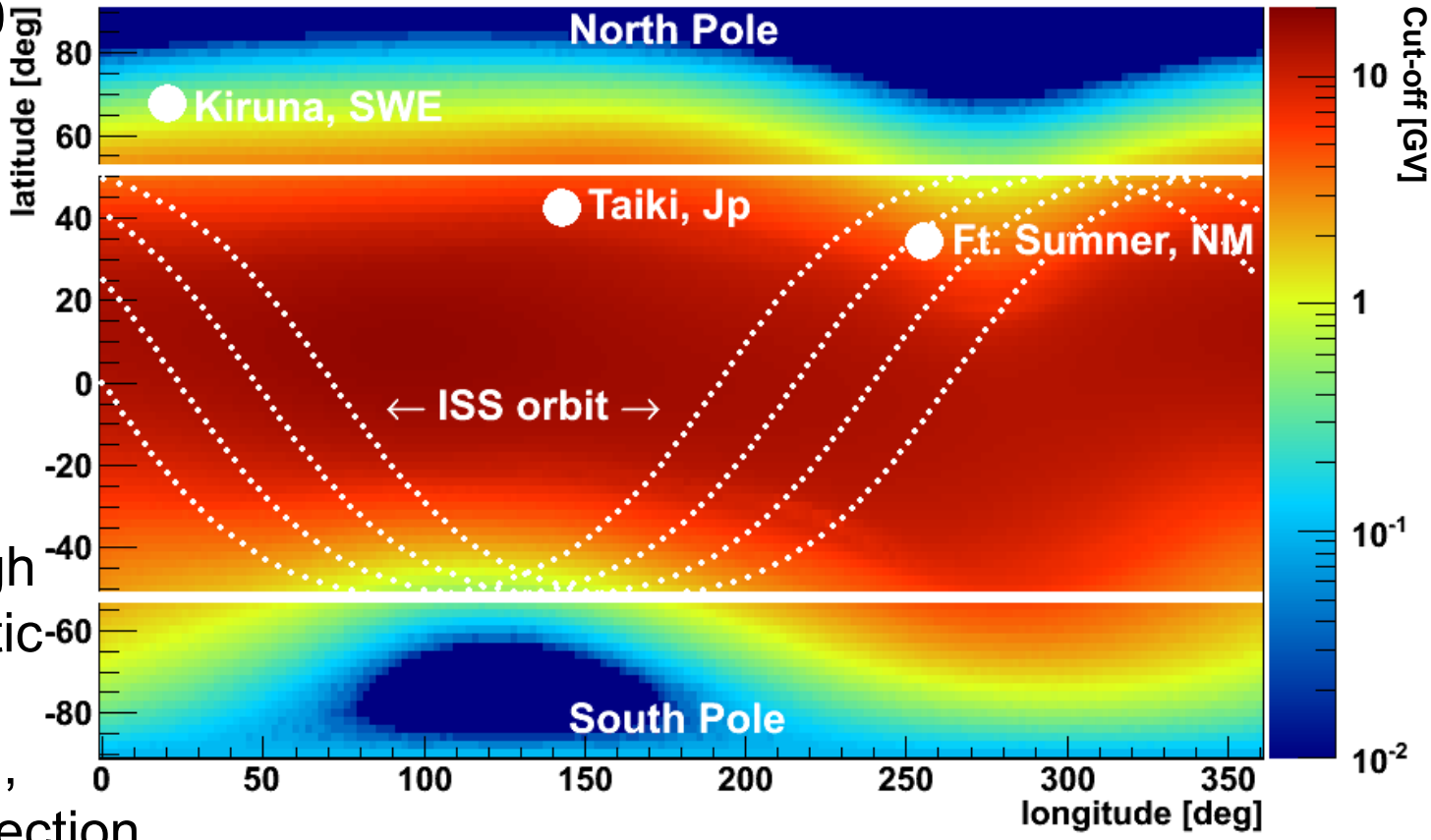
proton > 10MeV (red)
electron > 10MeV (green)
positron > 10MeV (blue)
neutron > 10MeV (turquoise)
muon > 10MeV (purple)
photon > 10keV (yellow)



Atmospheric and geomagnetic simulations with PLANETOCOSMICS (Desorgher, Universitaet Bern) based on GEANT 4.9.2 modified to match specific requirements!

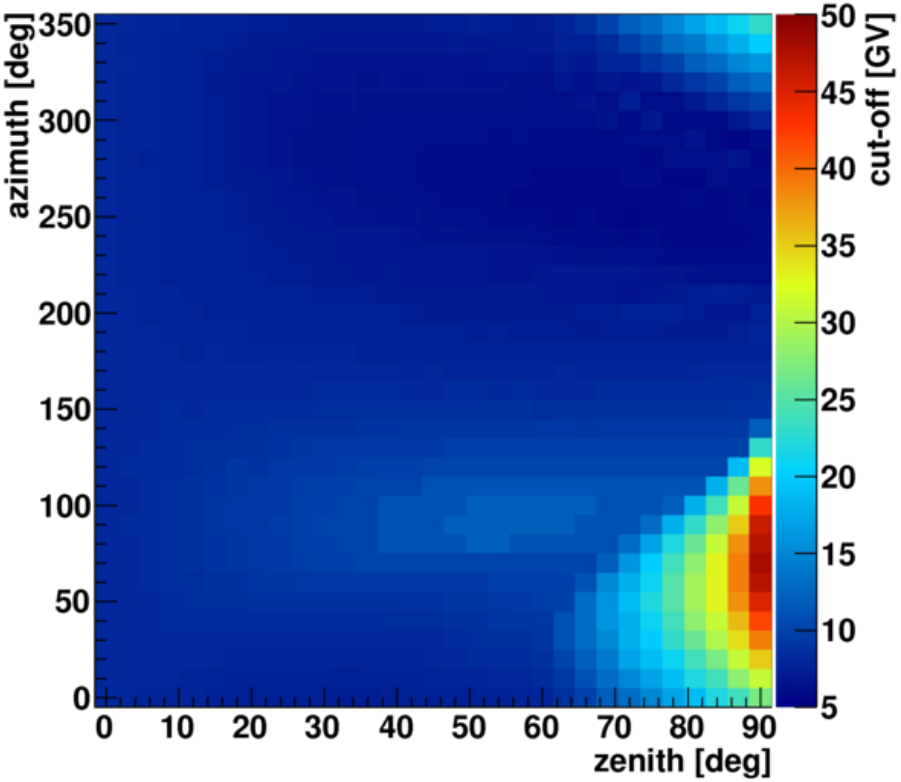
Geomagnetic cut-off

- use IGRF 2010 magnetic field (mathematical description of Earth's main magnetic field)
- trace charged particles (here protons) through Earth‘s magnetic field starting at certain position, altitude and direction

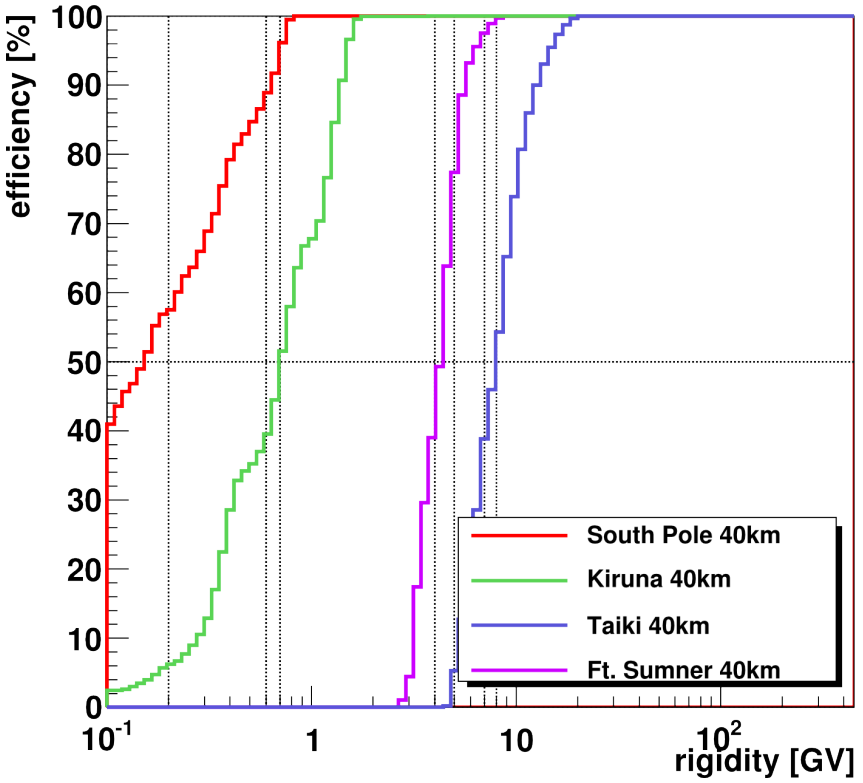


- check if particle escapes the magnetic field
- cut-off for perpendicular incidence with respect to Earth‘s surface

Cut-off and particle direction



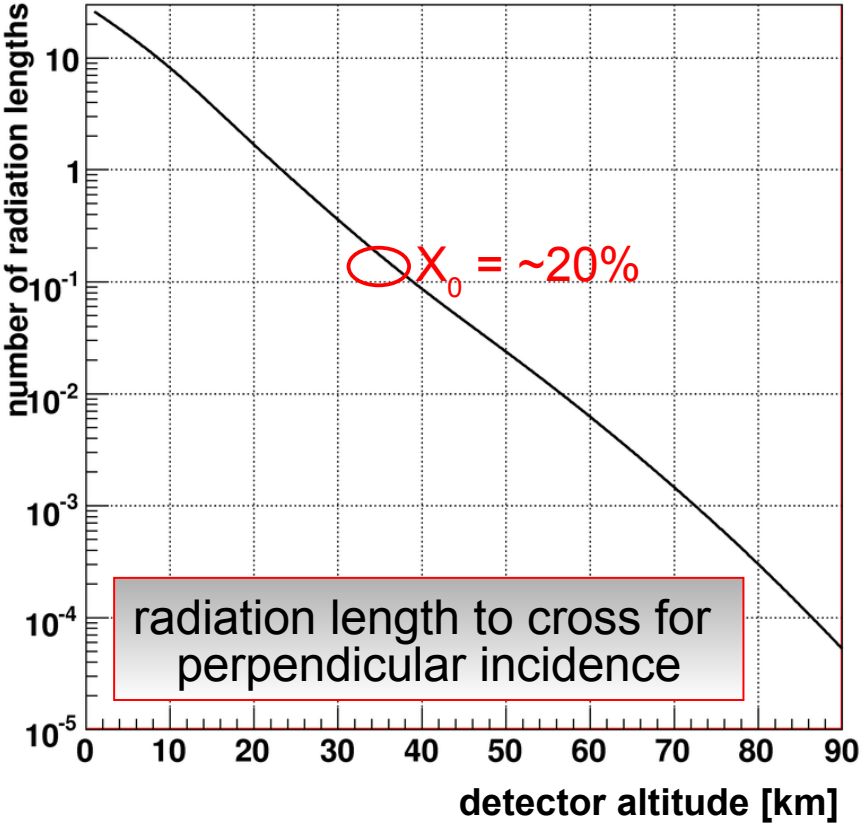
cut-off in Taiki as function of direction

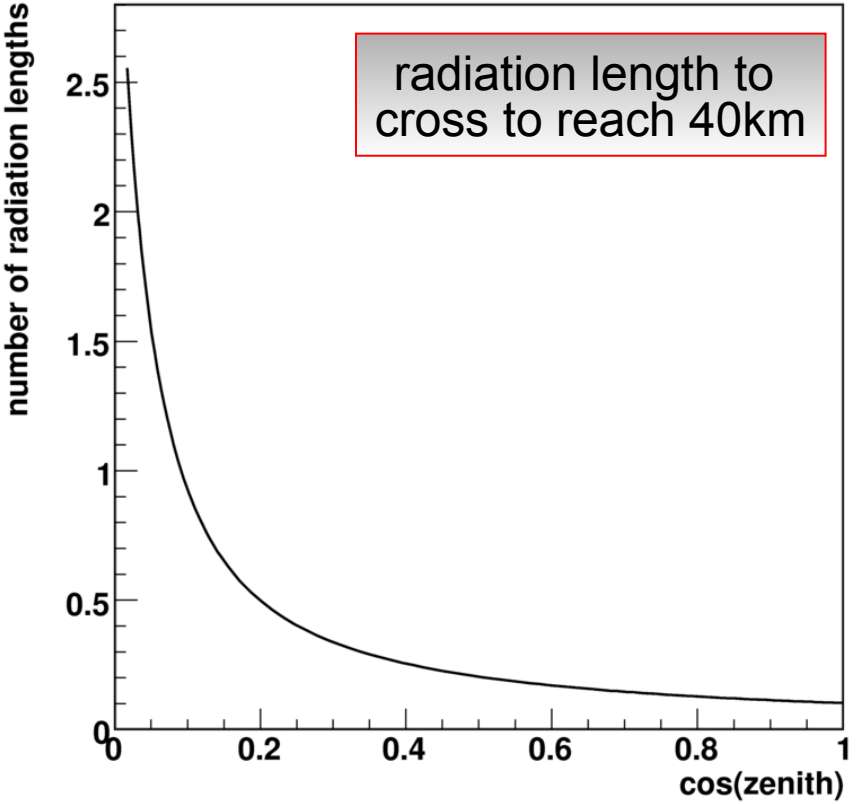


cut-off averaged over isotropic distribution at different positions:

50% of cosmic rays with ~8GV get through to balloon altitude in Taiki

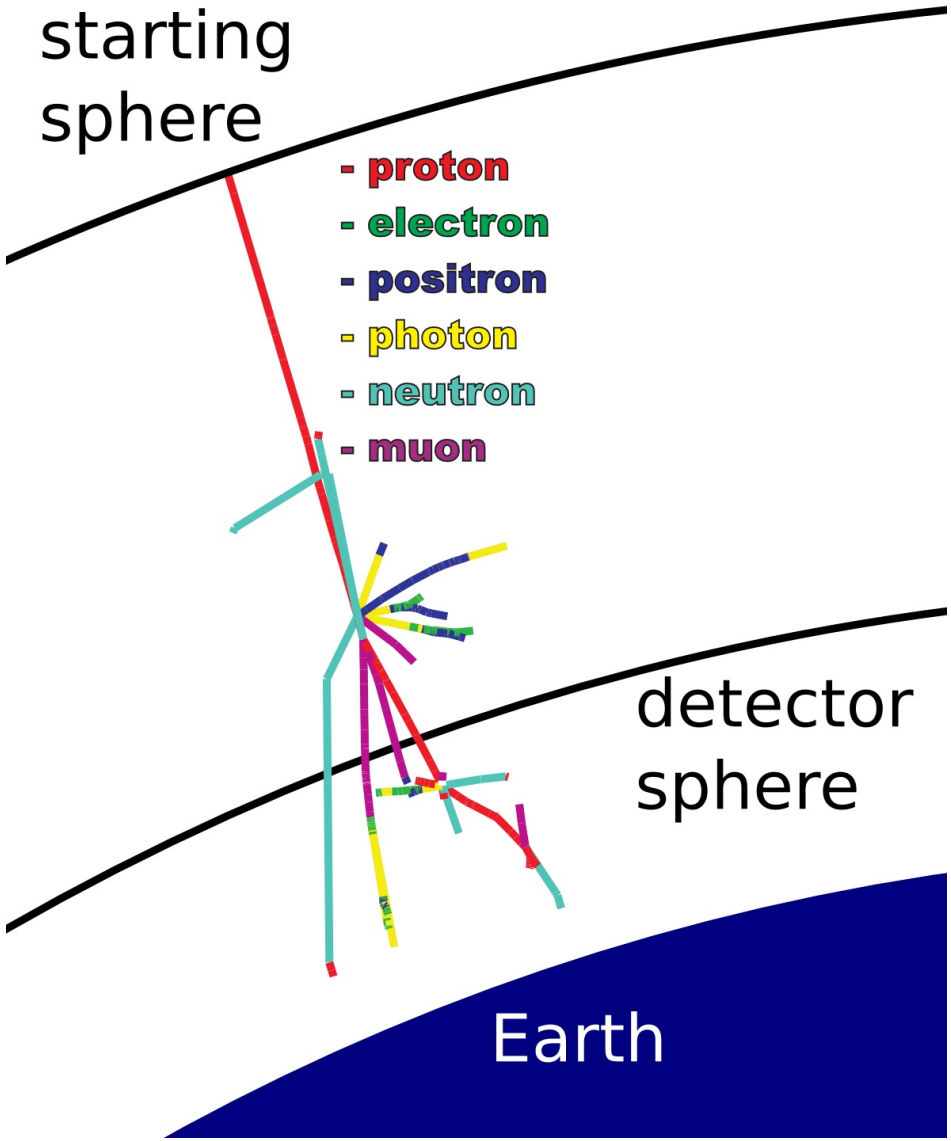
Atmospheric influence





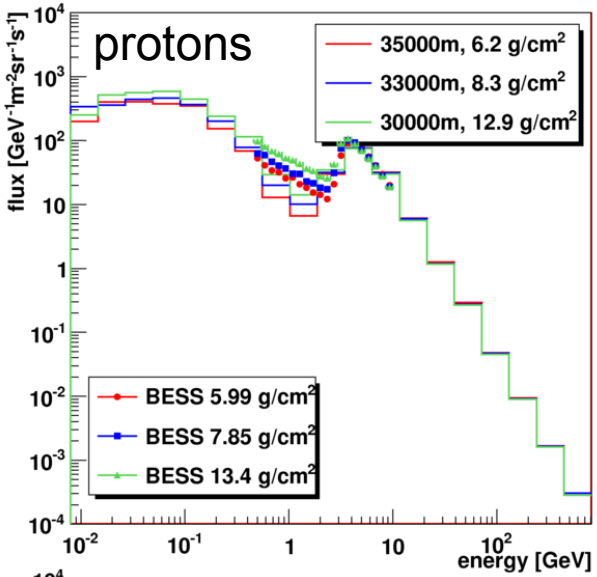
- use of **NRLMSISE-00** atmospheric model: models the temperatures and densities of the atmosphere's components.
- grammage of matter in front of 33km: ~8.4g/cm^2 (Space: 6-10g/cm^2)
- on average ~20% of a radiation length (nuclear mean free pathlength ~10%) before 33km: **Atmospheric background has to be calculated!**

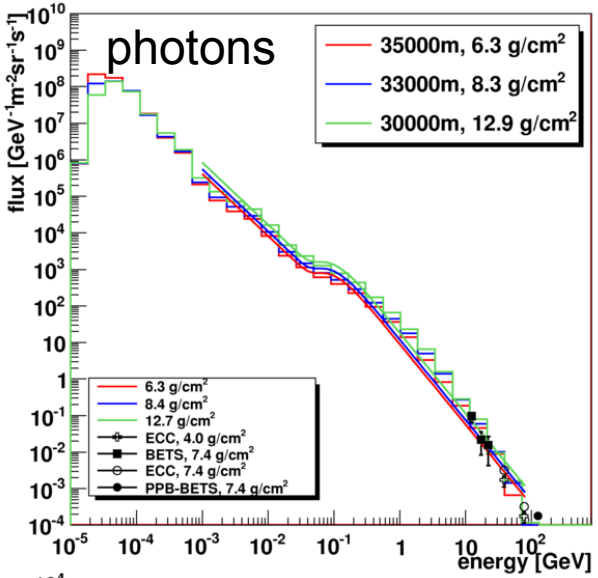
Particle gun

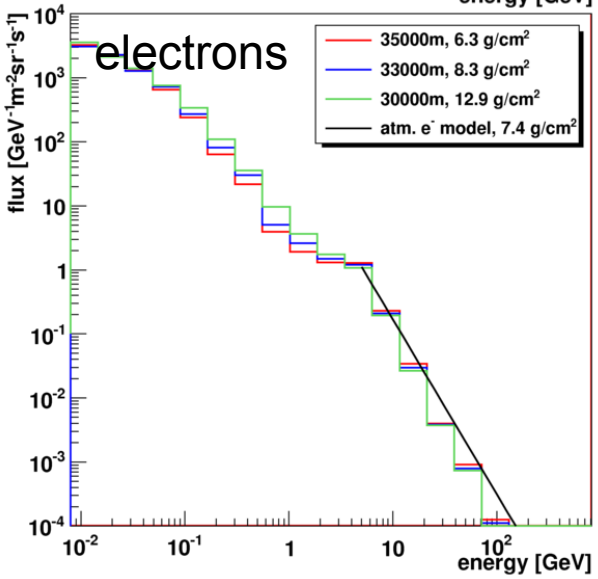


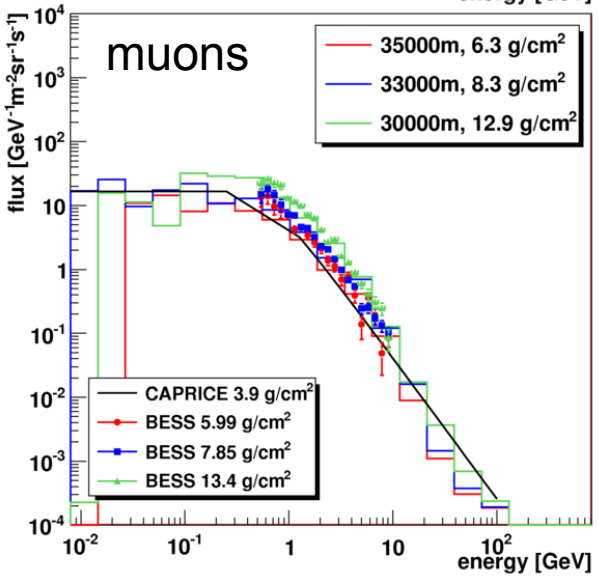
- start particles at **500km altitude above Earth** and detect particles in **spherical shells around the Earth**
- choose starting positions such that the trajectories of undisturbed particles result in an isotropic distribution at detection altitude
- switch on atmosphere and magnetic field for the simulation
- **physics models:**
  - em.: standard
  - hadronic: QGSP, BIC, HP Neutron
  - ion: BIC

Validation of simulation



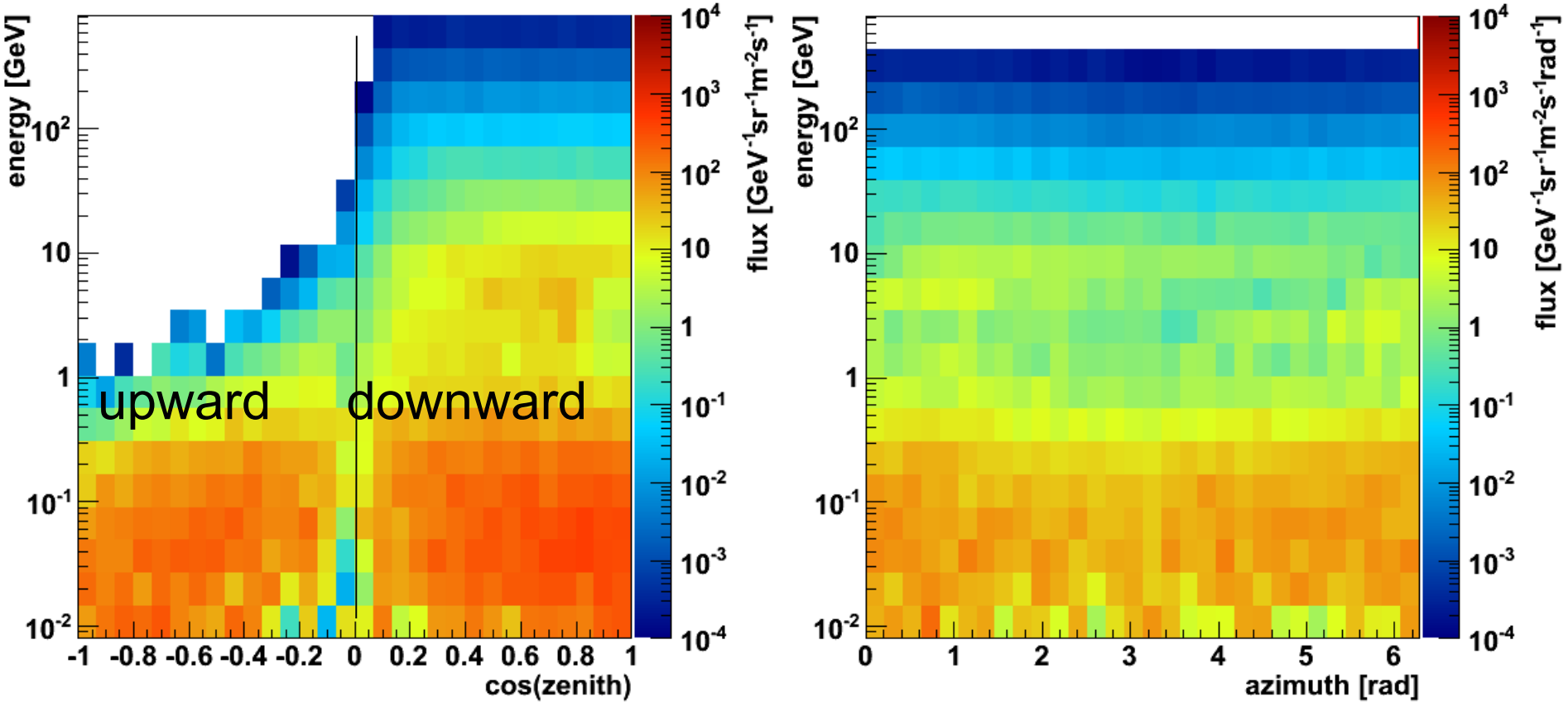






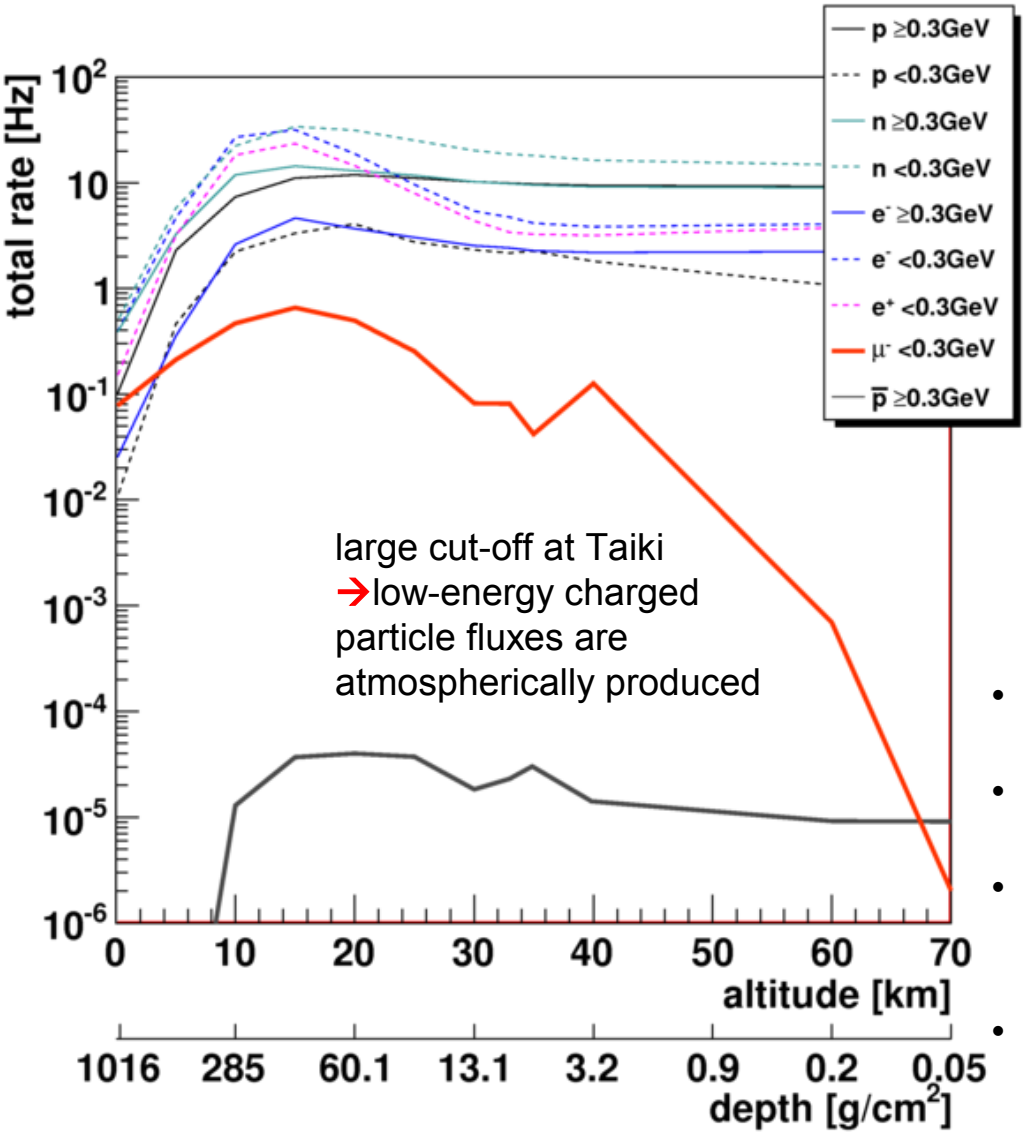
- particle fluxes (ATM+CR) for certain particle types at different altitudes
- comparison of atmospheric simulations shows **good agreement** with BESS, ECC, BETS, PPB-BETS, CAPRICE measurements and models
- simulations need check for light ion physics

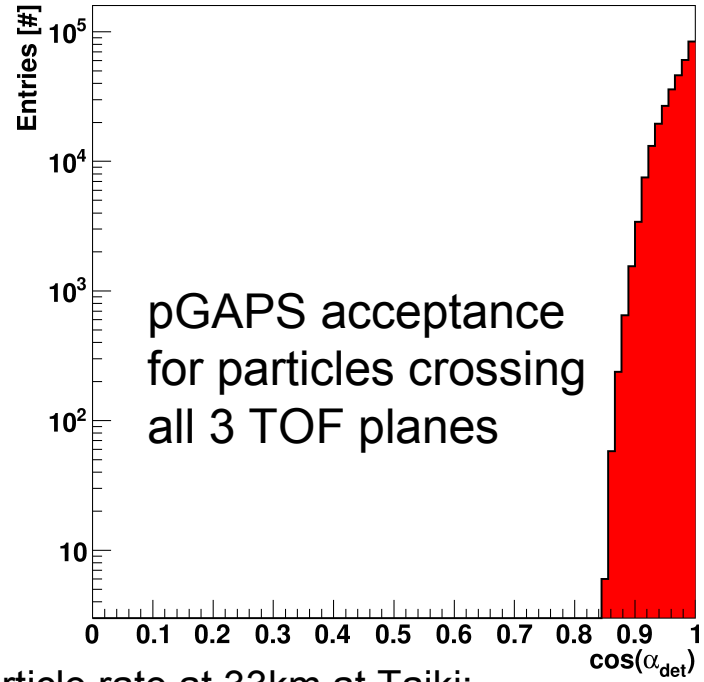
Proton fluxes at Taiki



- total proton fluxes (cosmic + atmospheric) at 33km altitude
- upward fluxes have smaller energies
- no dependence on azimuth angle

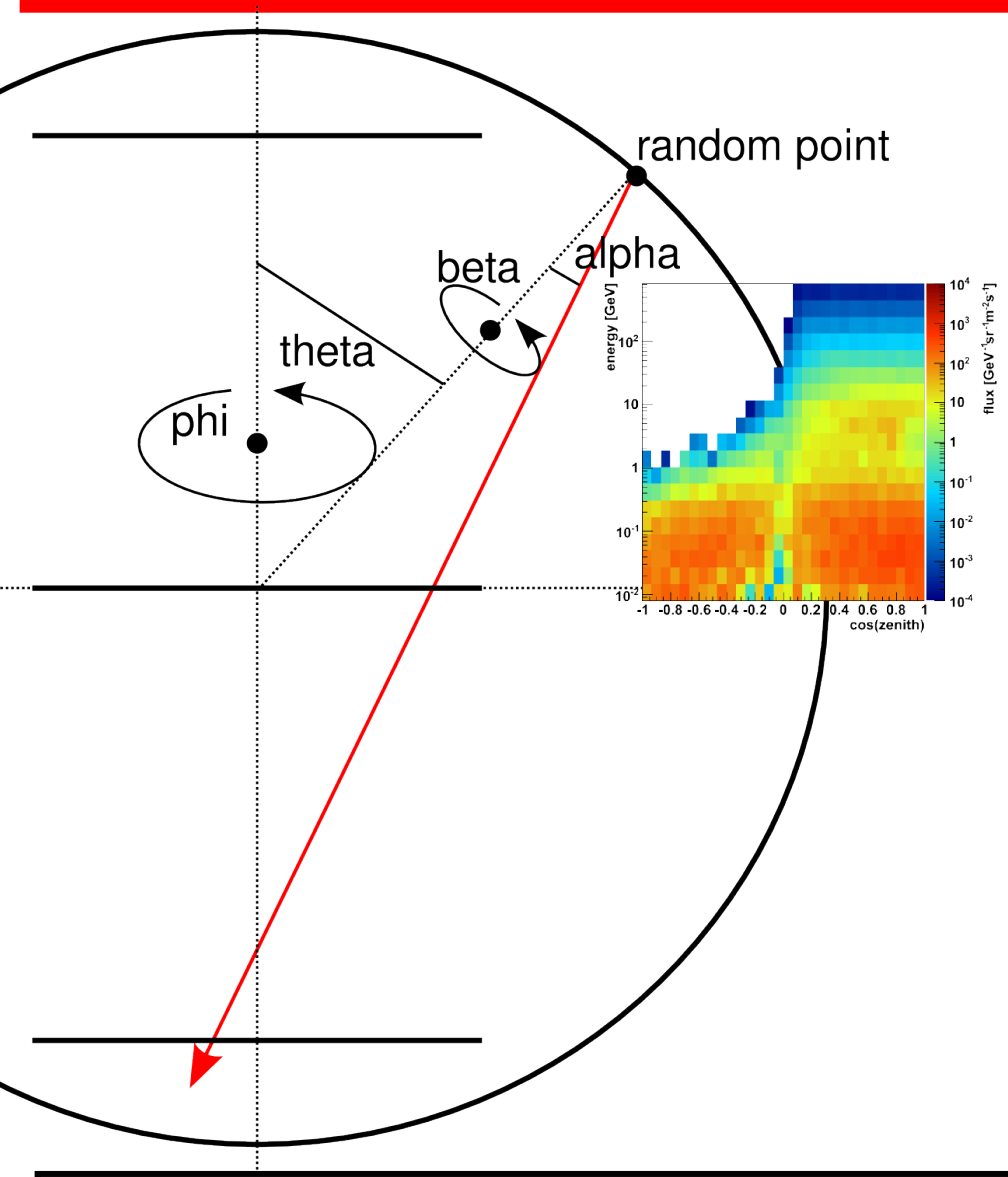
Particle rates for pGAPS





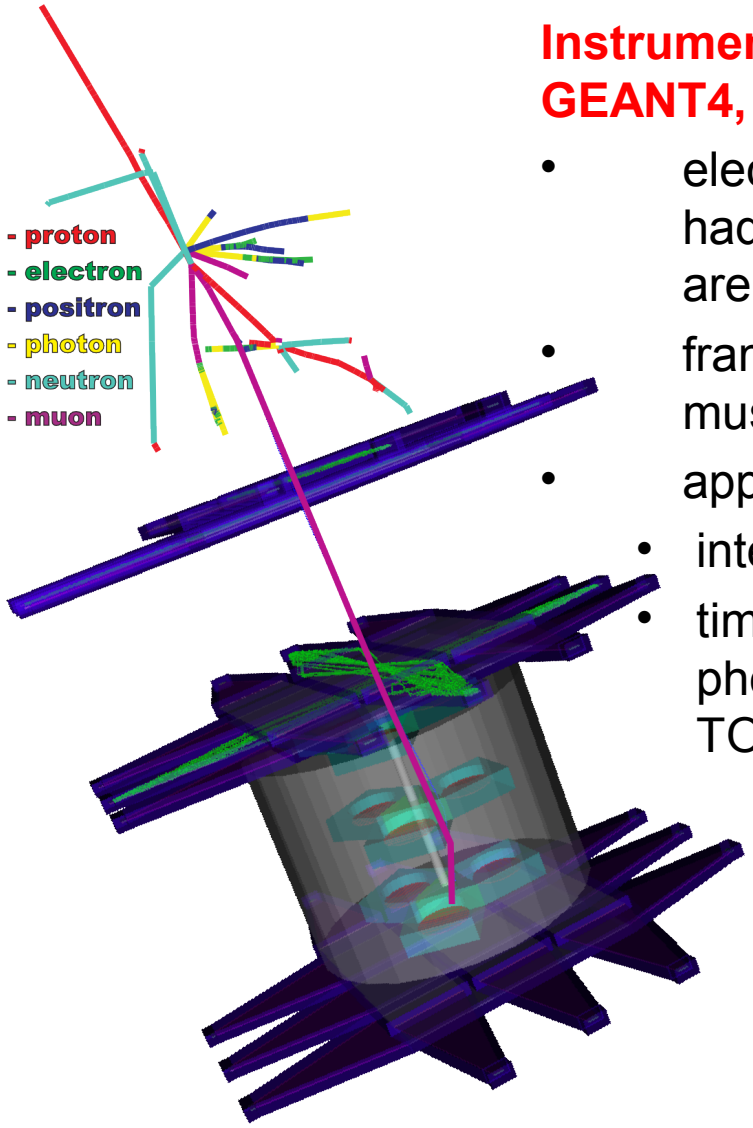
- particle rate at 33km at Taiki: **total ~10-50Hz** (accep.: 0.054m²sr)
- strongest backgrounds by neutrons, protons, electrons, positrons
- no antiprotons will be measured, but muons might be used to create muonic atoms to study exotic physics at flight
- exotic atomic events faked by x-ray coincidences with cosmic rays in the detector need to be studied **carefully!**

Particle gun for detector simulation



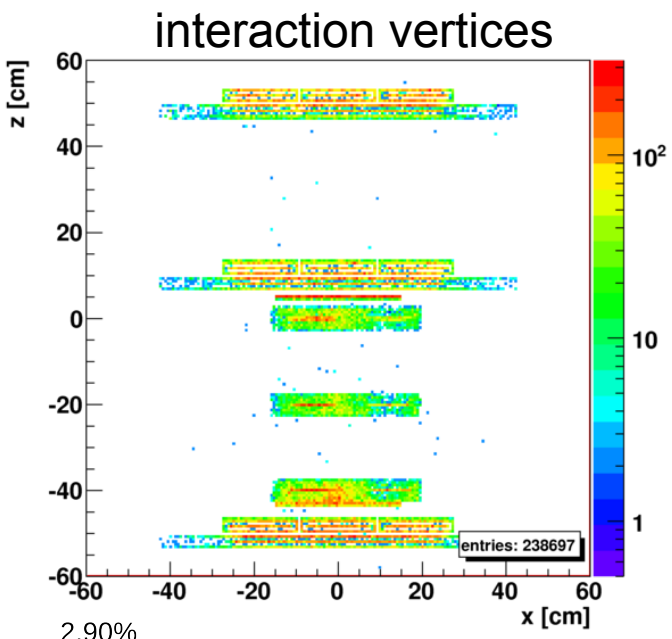
- distribute random starting points homogeneously on sphere around detector
- random zenith angle (alpha) according to atmospheric simulation
- random azimuth angle (beta) uniformly distributed between 0-360°
- start particle from surface with random energy according to atmospheric simulation

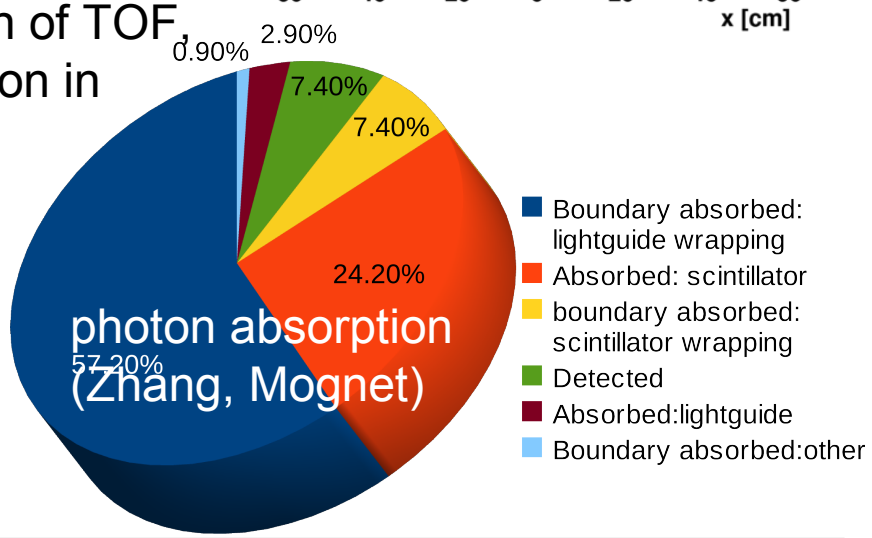
Detector simulation



Instrument simulation with GEANT4, ROOT output:

- electromagnetic, hadronic, optical physics are running
- frames and structures must be added
- application:
  - interaction vertices
  - timing resolution of TOF, photon absorption in TOF scintillator





Conclusion & outlook

- GAPS is specifically designed to measure low-energetic **antideuterons** which are a promising way for **indirect dark matter search** using the creation of **exotic atoms**
- antideuteron flux is very small → understanding of **backgrounds** is **essential**

- modified **PLANETOCOSMICS** showed **good agreement with measurements**
- prototype experiment is currently under construction and a flight is scheduled for **Summer 2011 from Taiki, Japan**:
  - detailed simulation of particle fluxes in atmosphere and detector: light ion, antideuteron and exotic physics need to be improved/implemented/developed
  - hardware development: Si(Li), TOF, readout, structure, thermal model