UNIVERSITÉ
DE GENÈVE

FACULTÉ DES SCIENCES
Département de physique
nucléaire et corpusculaire

The DArk Matter Particle Explorer (DAMPE)

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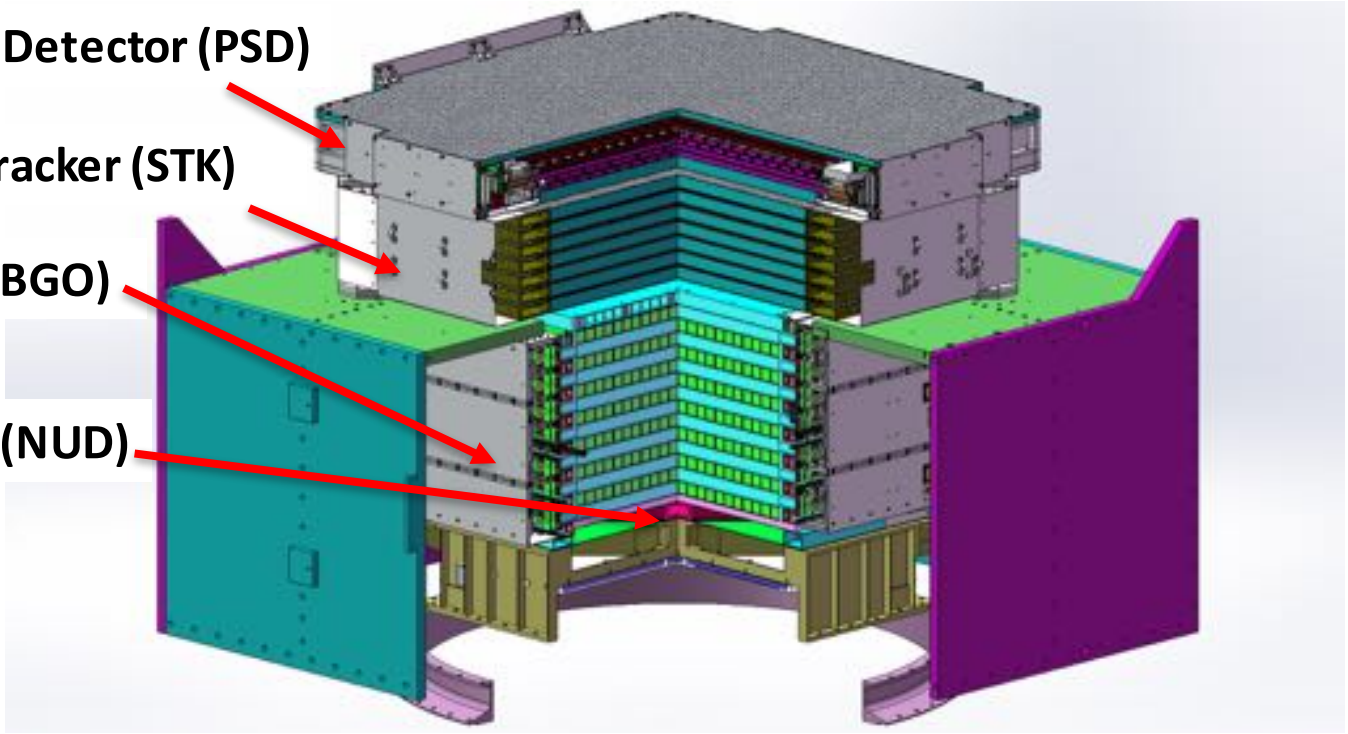
DPNC, University of Geneva, Switzerland

on behalf of the DAMPE Collaboration

TeV Particle Astrophysics 2016
12 -16 September 2016, CERN, Geneva, Switzerland

The DAMPE detector



- ✓ Thick imaging calorimeter (BGO of 32 X_0)
- ✓ Precise tracking with Si strip detectors (STK)
- ✓ Tungsten photon converters in tracker (STK)
- ✓ Charge measurements with PSD and STK
- ✓ Extra hadron rejection with NUD

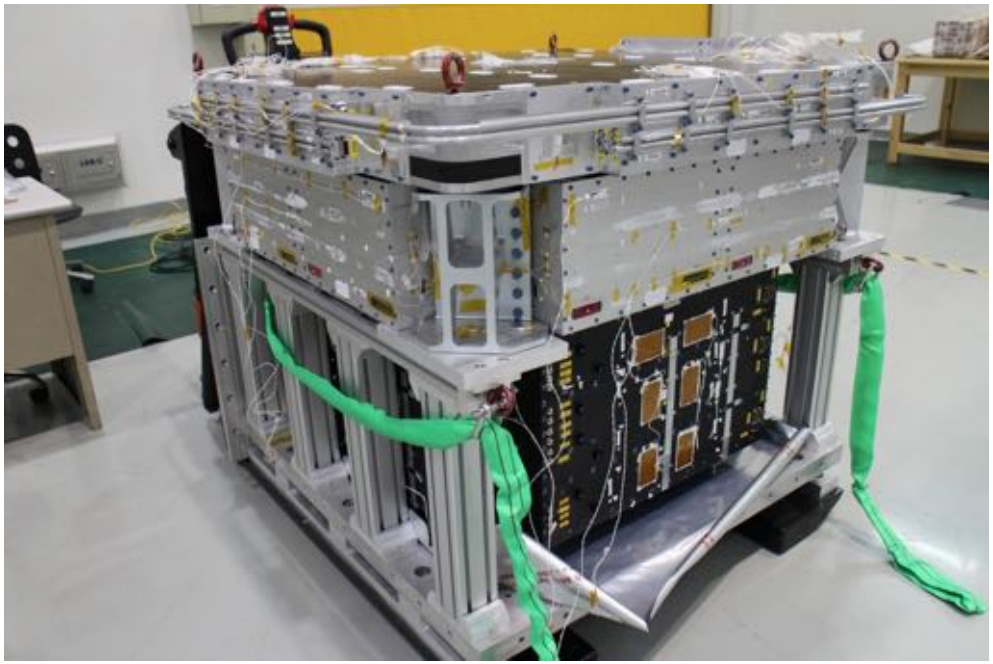
→ high energy γ-ray, electron and cosmic ray telescope

Scientific objectives of DAMPE

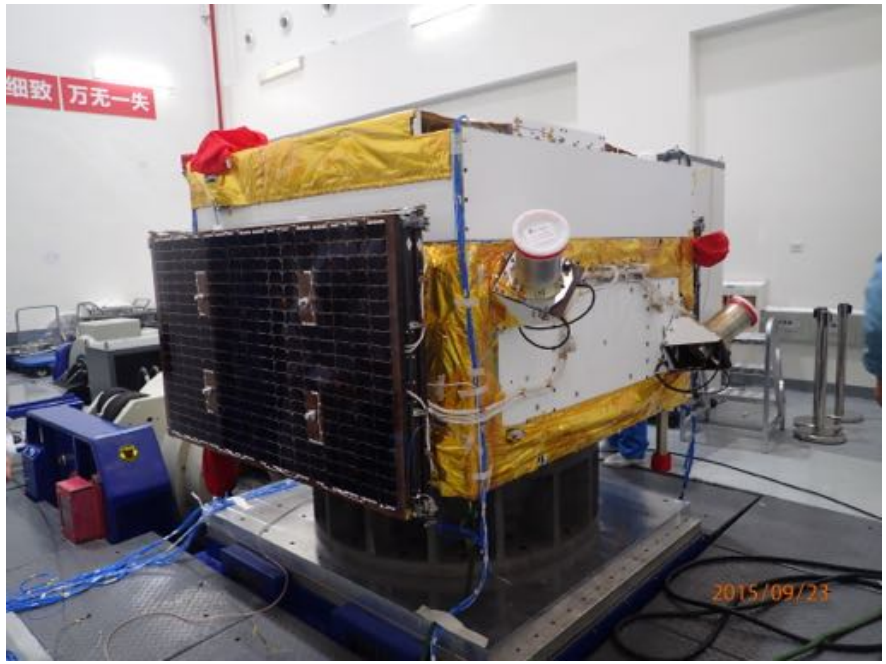
- High energy particle detection in space
  - Measure the high energy cosmic electron and gamma spectra and search for Dark Matter signatures
  - Study of cosmic ray spectrum and composition
  - High energy gamma ray astronomy

Detection of 1 GeV - 10 TeV e/γ, 100 GeV - 100 TeV cosmic rays with excellent energy resolution, direction reconstruction (γ) and charge measurement

The DAMPE detector in real



EQM, Oct. 2014, CERN



Integrated satellite, Sept. 2015, Shanghai

Weight : 1450/1850 kg (payload/satellite)
Power: 300/500 W (payload/satellite)
Readout channels: 75,916 (STK 73,728)
Size: 1.2m x 1.2 m x 1.0 m
Data rate: 16 GB/day

The DAMPE Collaboration

- China
  - Purple Mountain Observatory, CAS, Nanjing
  - University of Science and Technology of China, Hefei
  - Institute of High Energy Physics, CAS, Beijing
  - Institute of Modern Physics, CAS, Lanzhou
  - National Space Science Center, CAS, Beijing

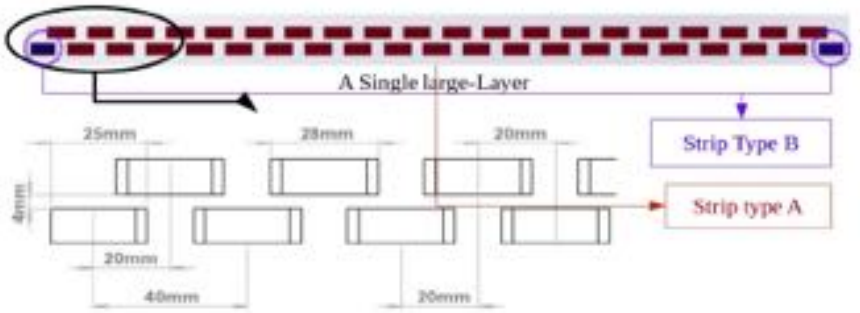
- Switzerland
  - University of Geneva, Switzerland

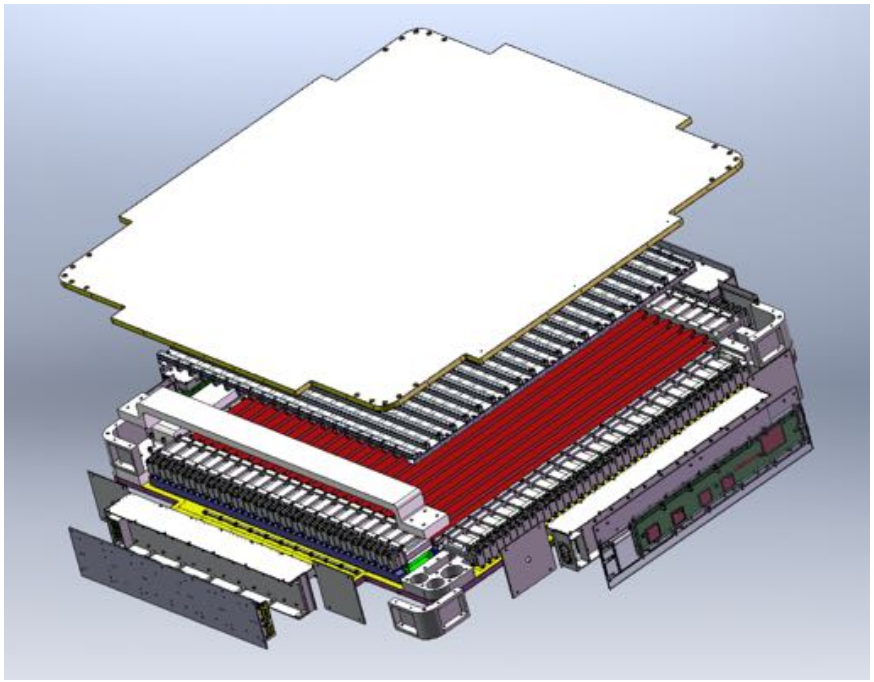
- Italy
  - INFN Perugia and University of Perugia
  - INFN Bari and University of Bari
  - INFN Lecce and University of Salento

First launch of the 5 approved scientific satellites of the Chinese Academy of Sciences

Plastic Scintillator Detector (PSD)

- 2 layers (x, y) of strips 1 cm thick, 2.8 cm wide and 88.4 cm long. Sensitive area 82.5 cm x 82.5 cm, no dead zone
  - Strip staggered by 0.8 cm
- Readout both ends with PMT, use two dynode signals (factor ~40) to extend the dynamic range



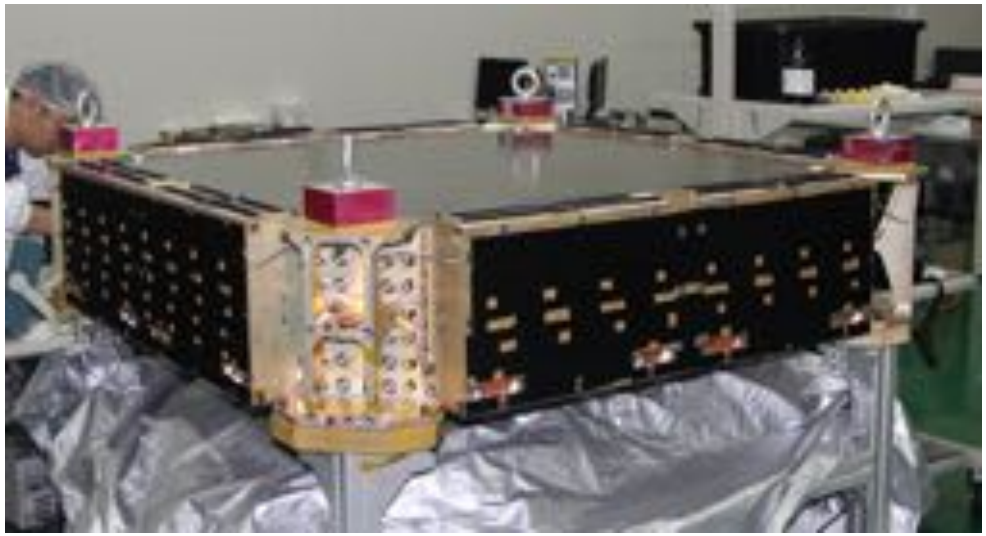


- Expected performance
  - Position resolution ~6 mm
  - Charge resolution 0.25 (Z=1)
  - Dynamic range Z = 1 – 26
  - Efficiency for MIP: >0.9975

Silicon-Tungsten Tracker (STK)

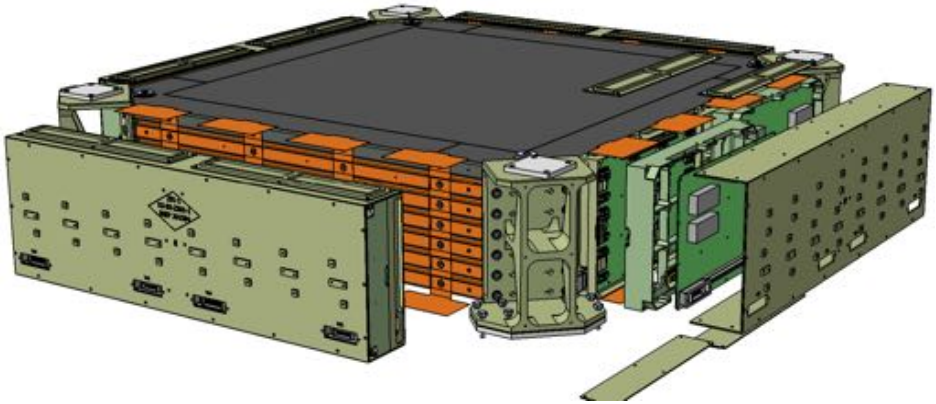
Detection area: 76 x 76 cm^2

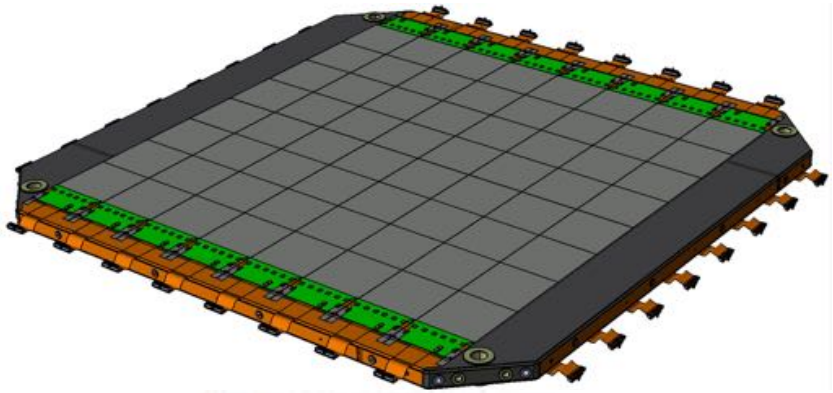
Outer envelope:
1.12 m x 1.12 m x 25.2 cm



- Total weight: 154.8 Kg
- Total power consumption: ~85W

The STK Structure

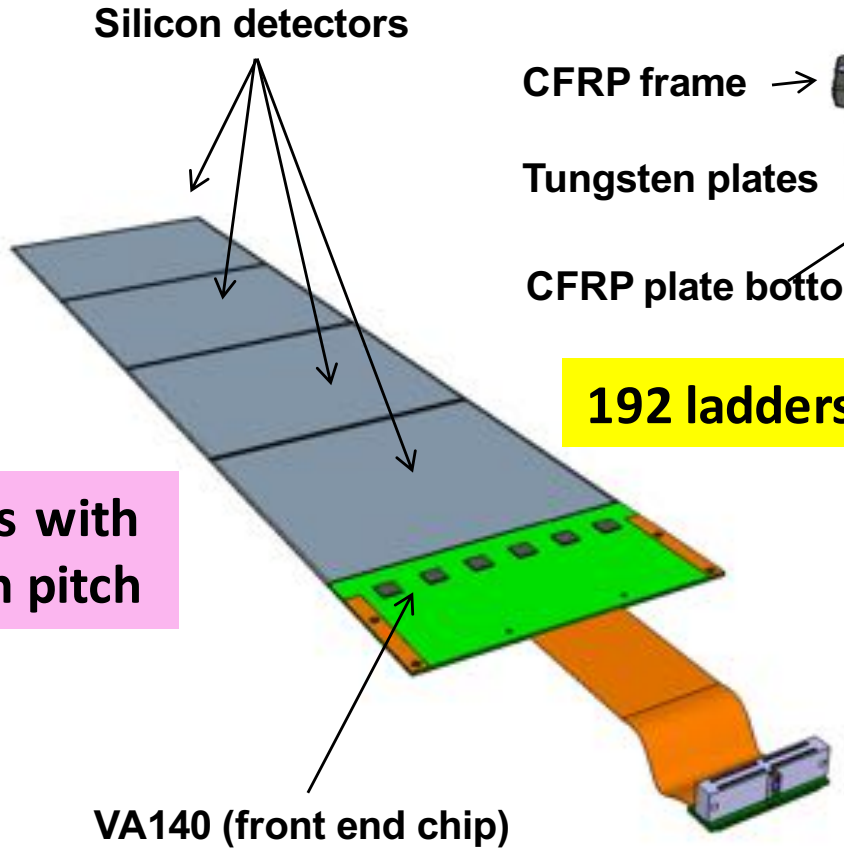


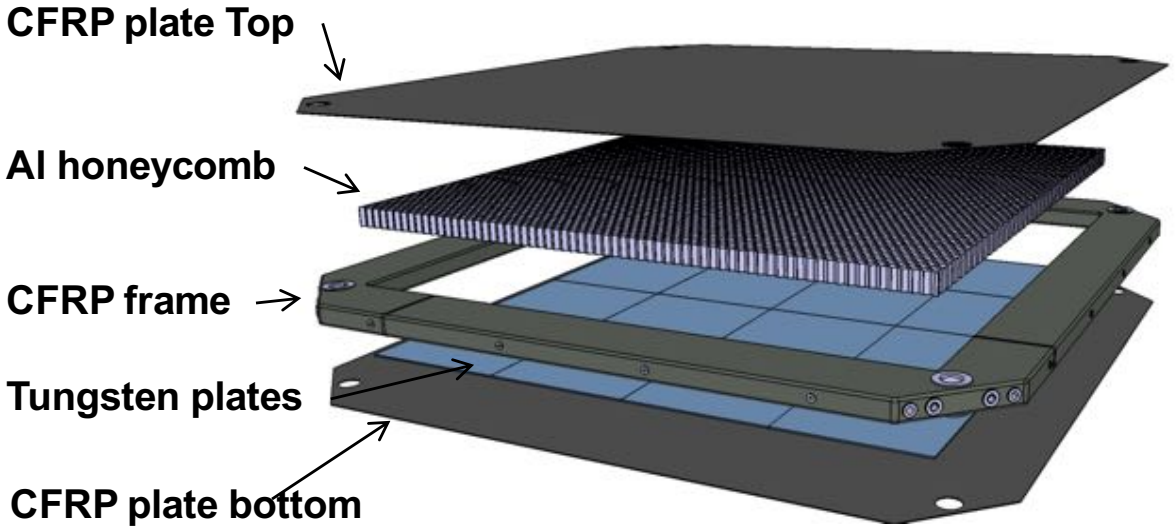


- 12 layers (6x, 6y) of single-sided si strip detector mounted on 7 support trays
  - Tray: carbon fiber face sheet with Al honeycomb core
- Tungsten plates (1mm thick) integrated in trays 2, 3, 4 (from the top)
  - Total 0.85 X_0 for photon conversion
- 8 readout boards on 4 sides
- 4 Al corners to align and support the 7 tracker trays

Silicon ladder and layers

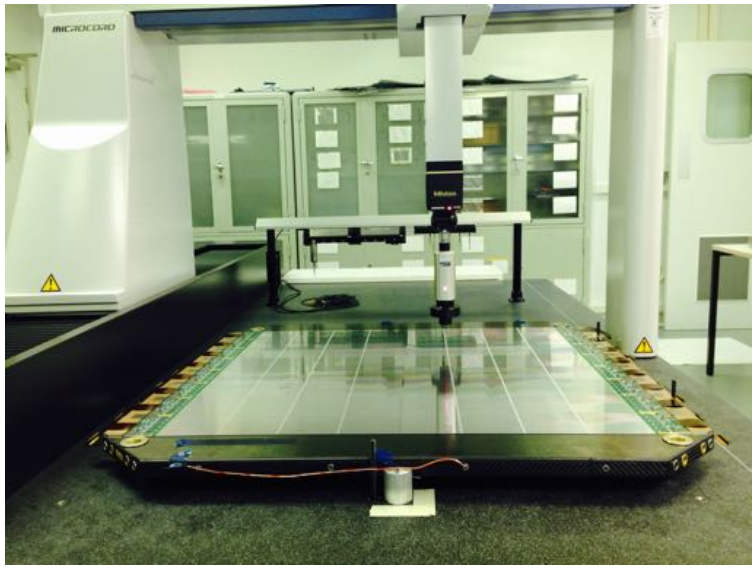
768 silicon sensors
95 x 95 x 0.32 mm^3





192 ladders

Si strips with
121 µm pitch



1152 ASICs: Analog Readout of every other strip

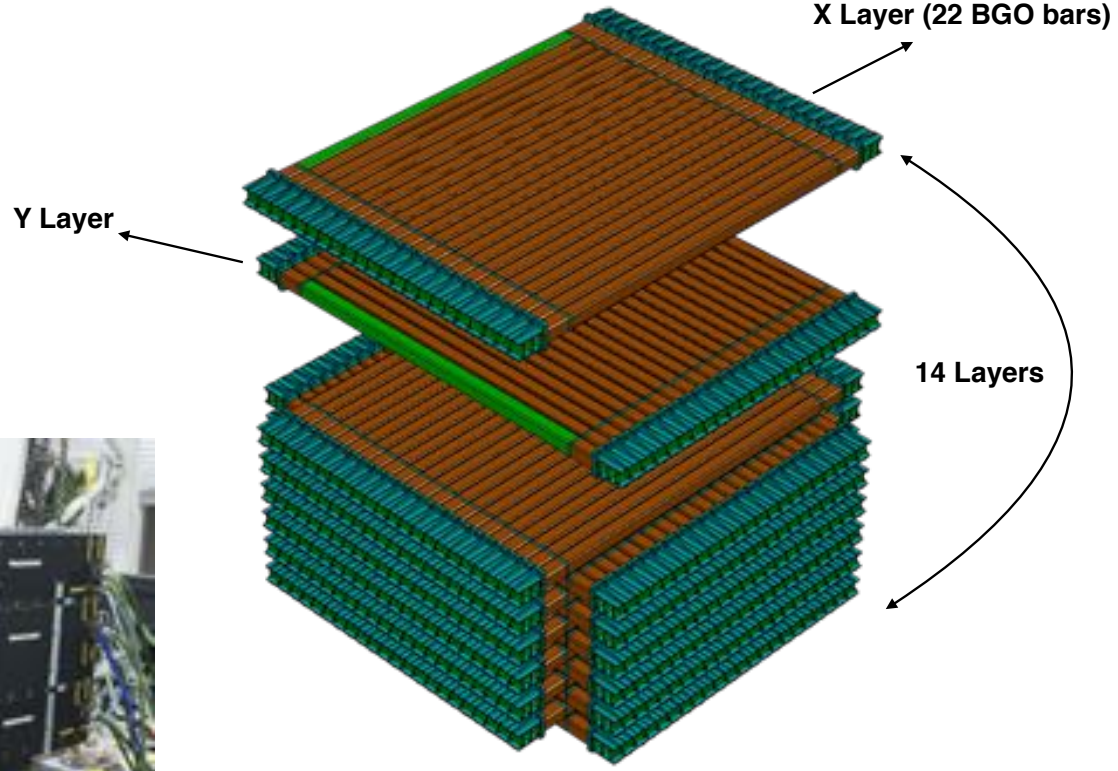
12 layers, 6-x and 6-y

73728 channels

BGO Calorimeter (BGO)

- 14-layer BGO hodoscope, 7 x-layers + 7 y-layers
  - BGO bar 2.5cm × 2.5cm x 60cm, readout both ends with PMT
    - Use 3 dynode (2, 5, 8) signals to extend the dynamic range
  - Charge readout: VA160 with dynamic range up to 12 pC

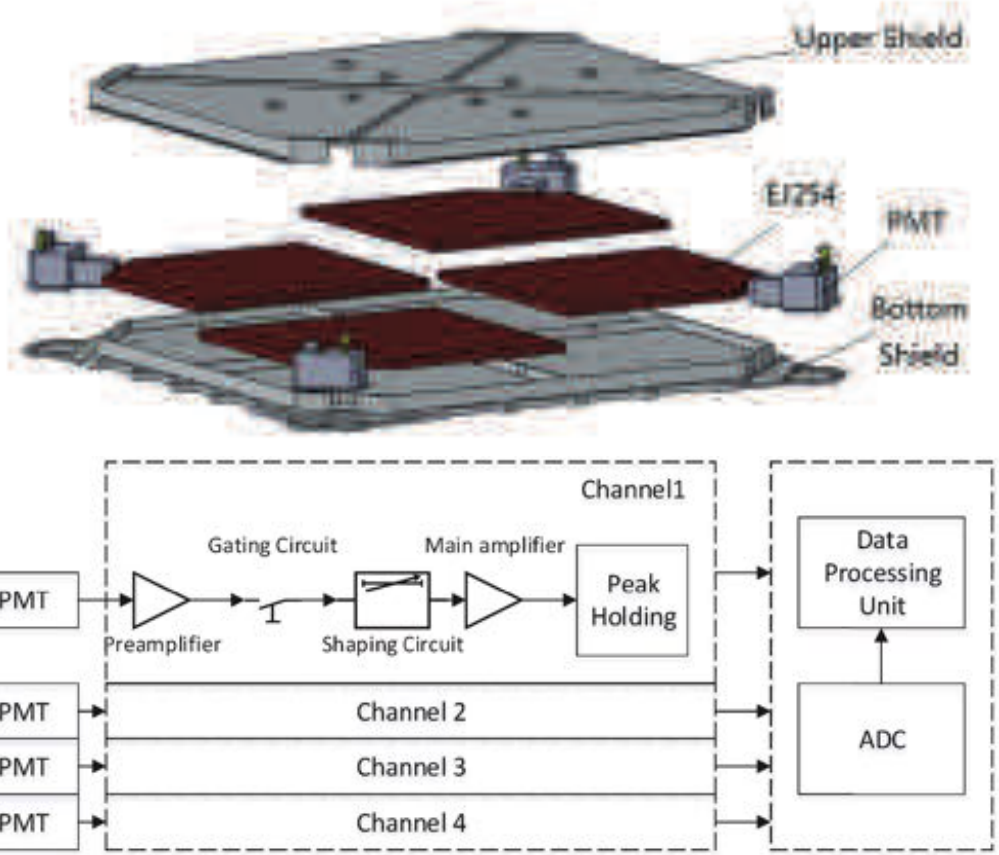
Detection area 60cm × 60cm



Total thickness 32 X_0

Neutron Detector (NUD)

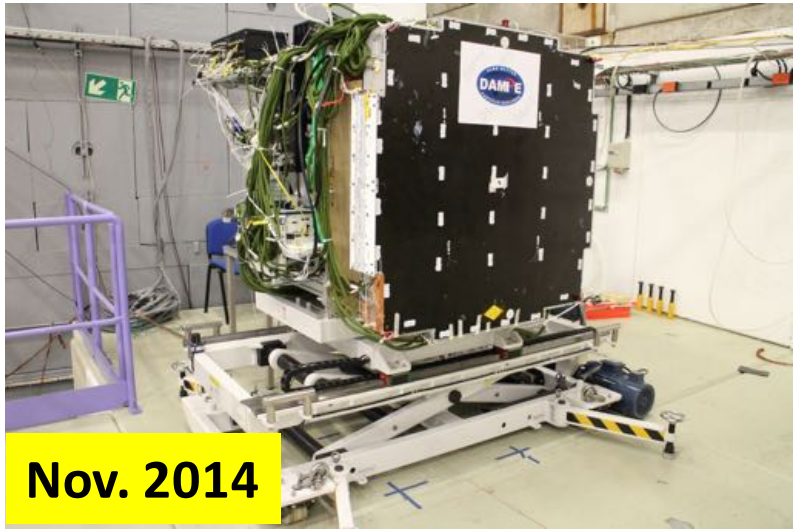
- 4 large area boron-doped plastic scintillators (30 cm × 30 cm × 1 cm)
  - Detect the delayed thermal neutron capture signal to help e/h separation
  - Gating circuit to detect delayed signal with a settable delay (0-20μs) after the trigger from the BGO



On-ground calibration

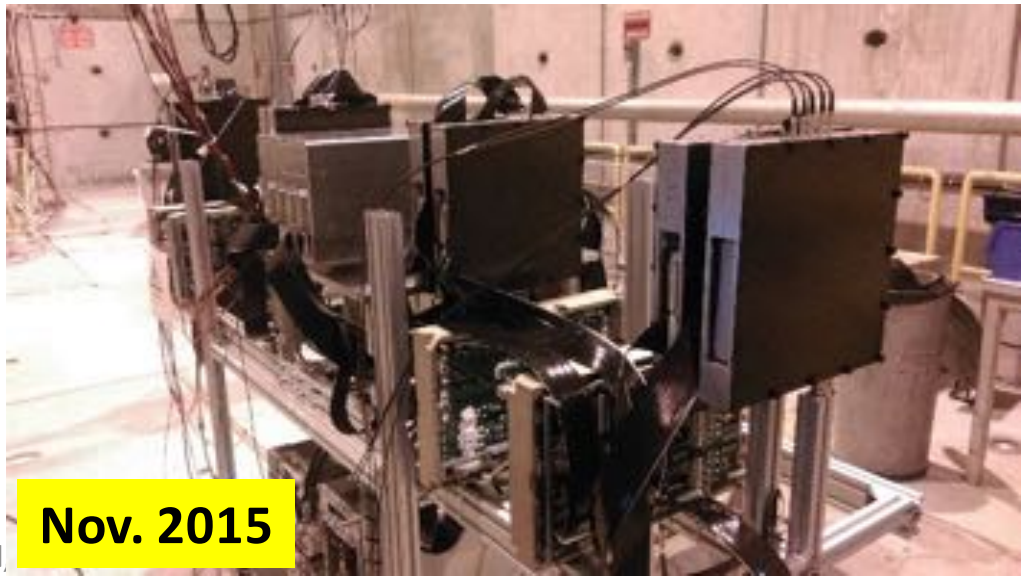
- Many weeks at the CERN PS and SPS beams from Oct. 2012 – Nov. 2015 (EQM)
  - Plus many cosmic muon data (FM)

Oct. 2012

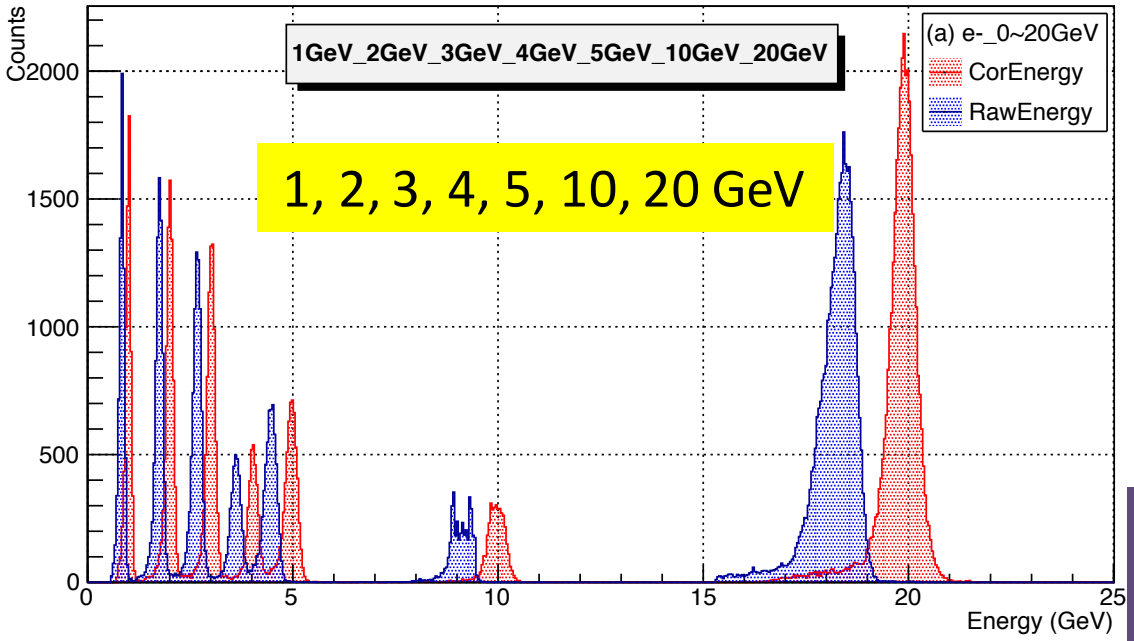


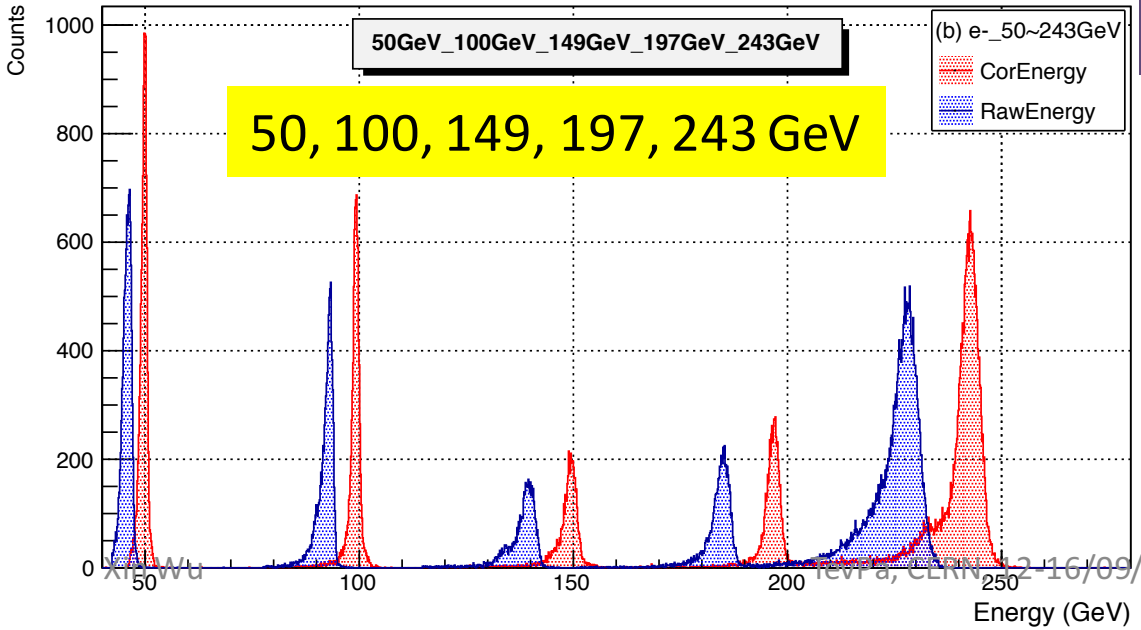
Nov. 2014

March 2015


Nov. 2015

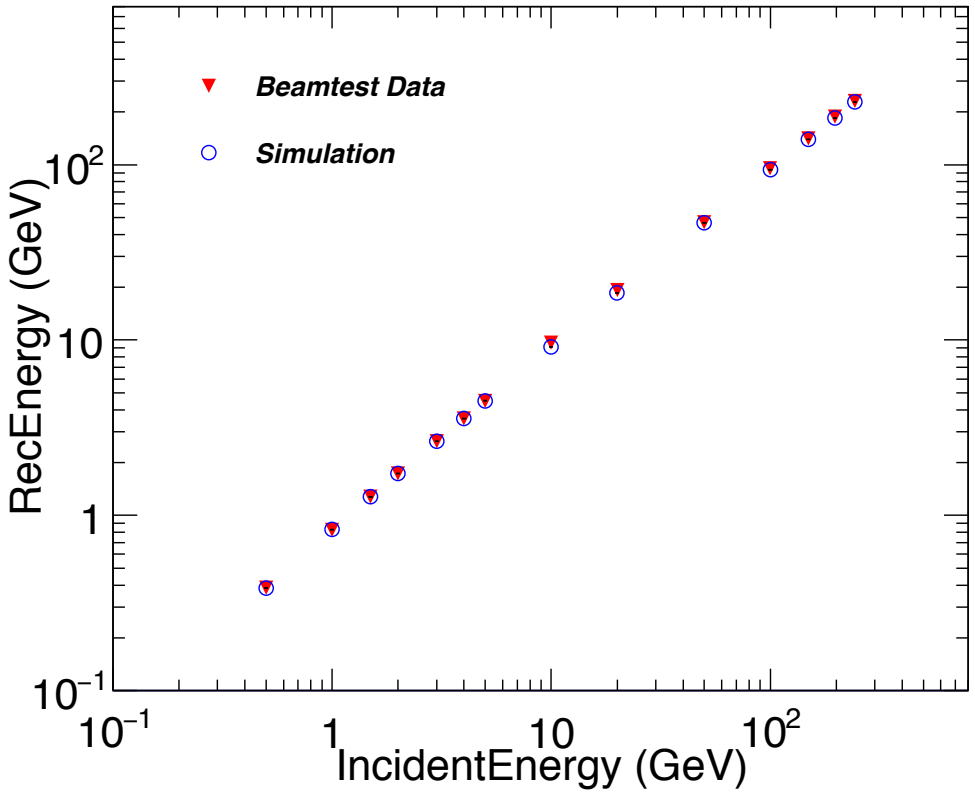
Energy calibration with electrons beams

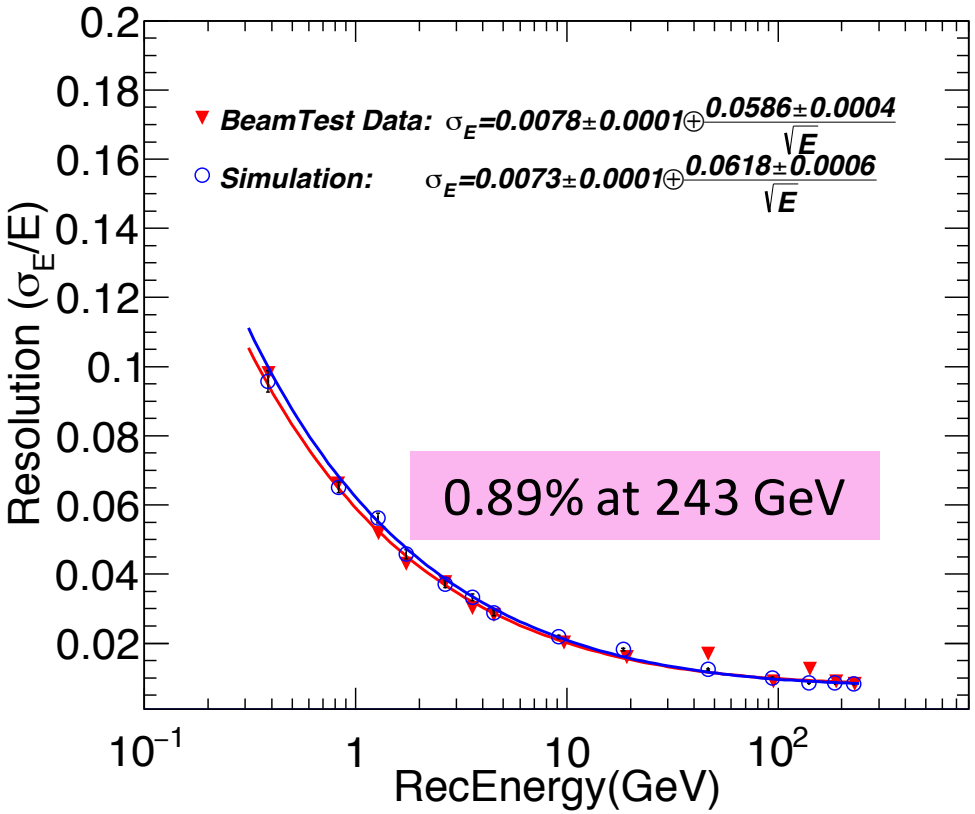




Energy scan of the full-size EQM with electrons from 0.5-243 GeV from PS and SPS

Energy linearity and resolution

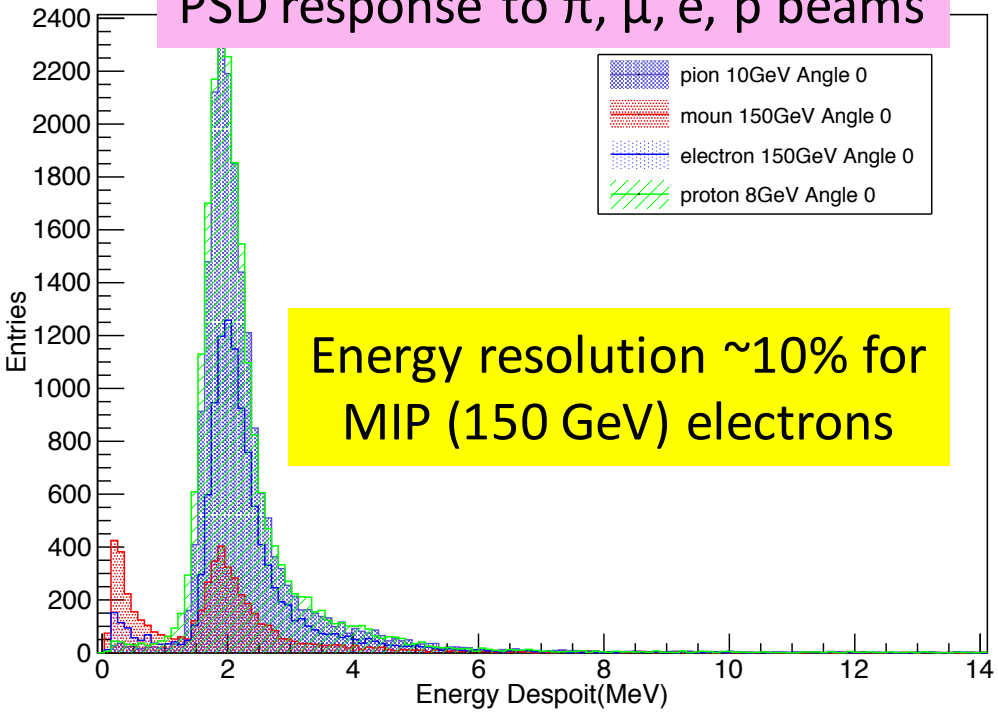




Good linearity and resolution, agree with full detector simulation

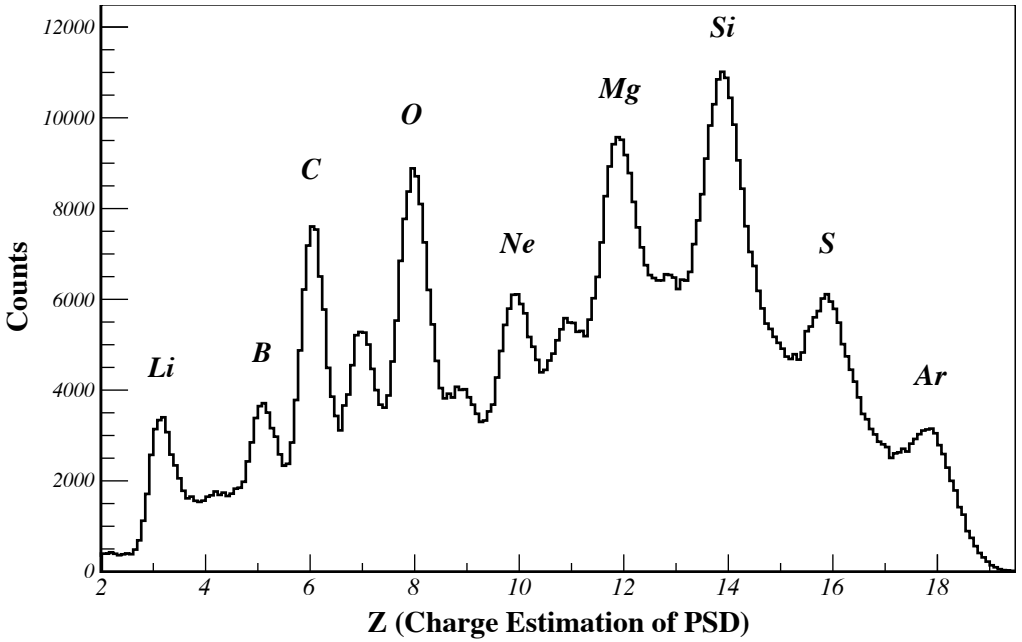
PSD calibration

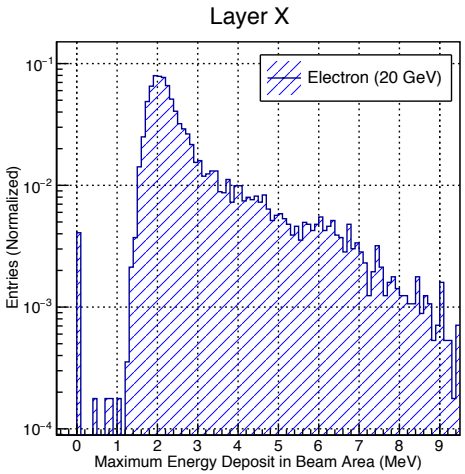
PSD response to π, μ, e, p beams

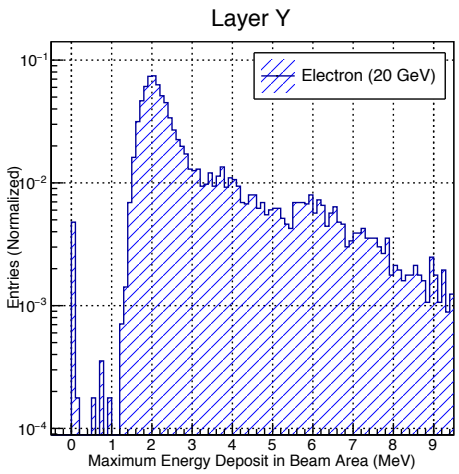


Energy resolution ~10% for MIP (150 GeV) electrons

PSD Z measurement with nuclear fragments from the Ar beam



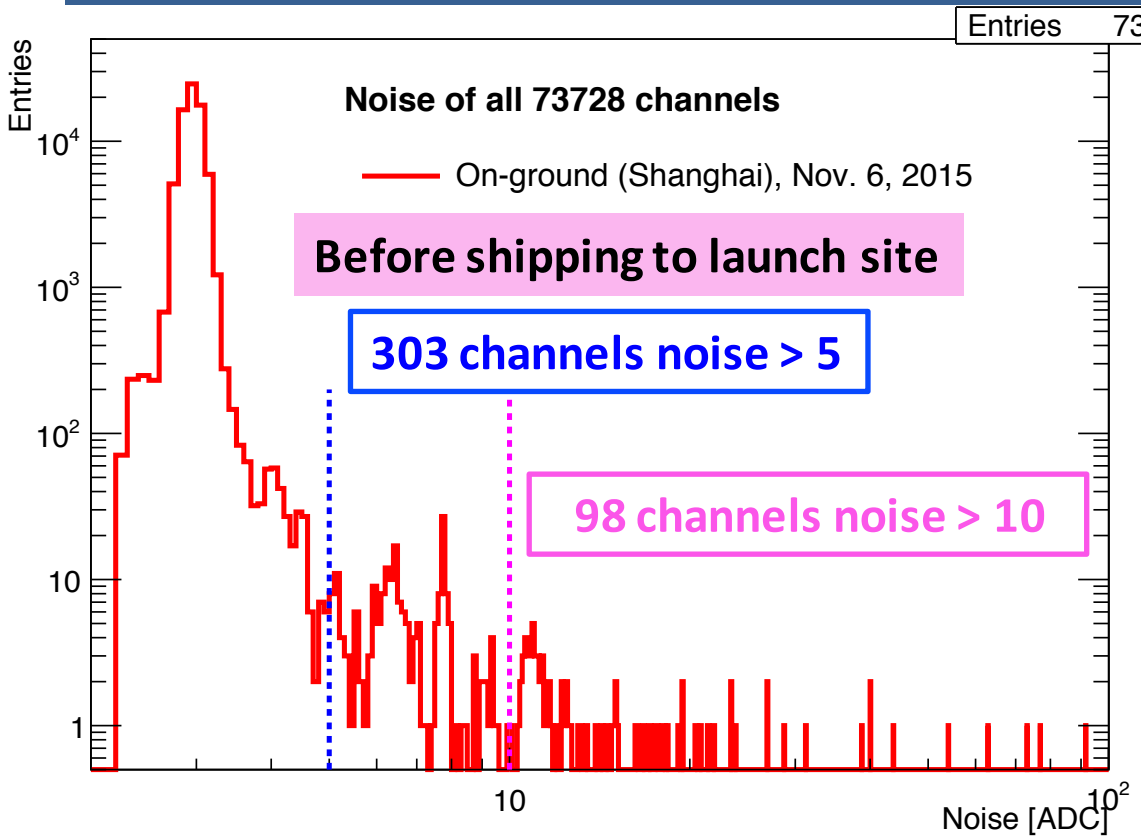




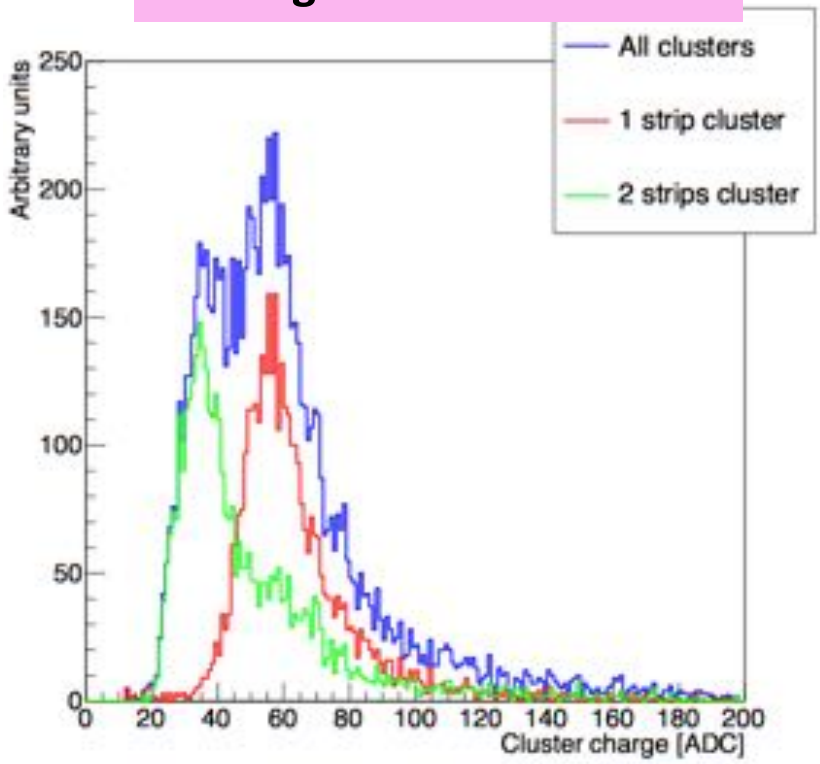
PSD response to 20 GeV electron: single layer detection efficiency > 0.994 for a 0.5 MIP cut

PRELIMINARY

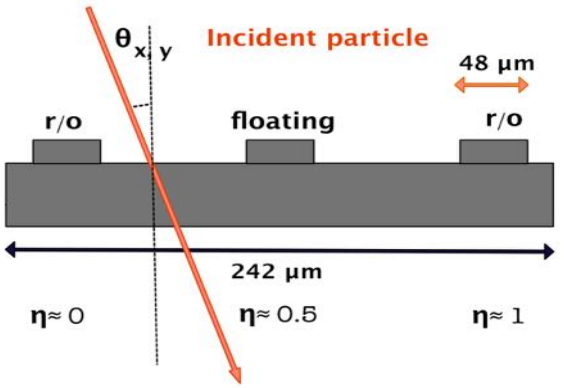
STK signal and noise before launch



MIP signal from test beam



- Bulk of noise ~3 ADC
  - Only ~0.4% noisy (>5 ADC) channels
  - Only ~0.13% very noisy (bad) channels

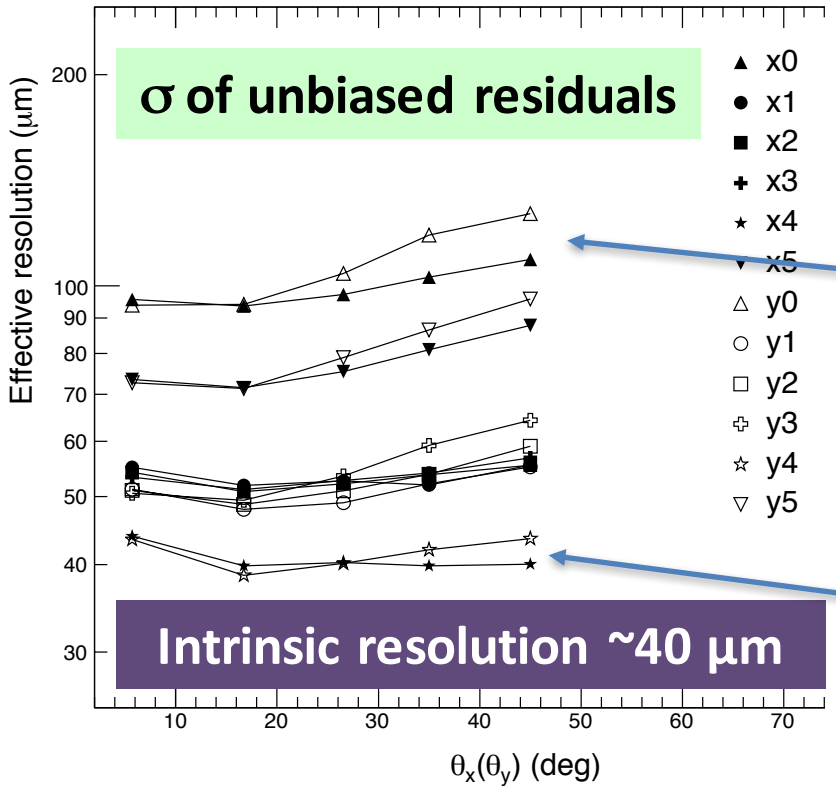


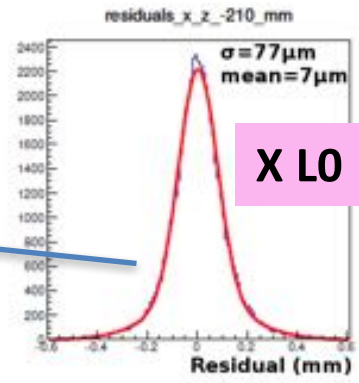
MIP signal ~18-60 ADC → S/N ~6-20

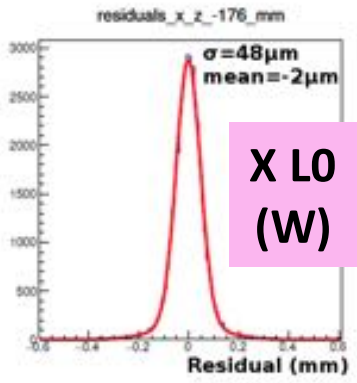
STK on-ground alignment

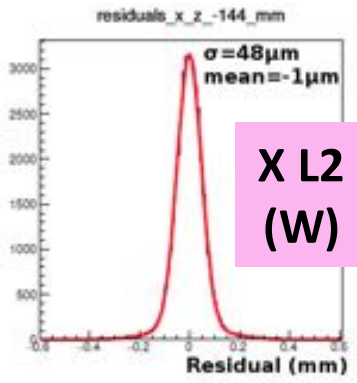
- 4 sets of alignment done with cosmic muons from April-November 2015
  - April 2015, Geneva, after STK construction completion
  - May 2015, Shanghai, after satellite integration
  - August-September 2015, Shanghai, after thermo-vacuum tests
  - October-November 2015, Shanghai, after vibration tests

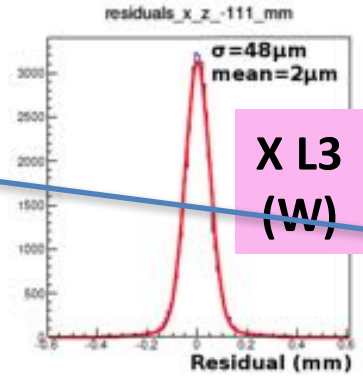
changes of alignment < 40 µm!

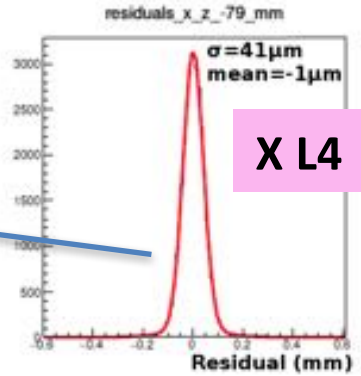


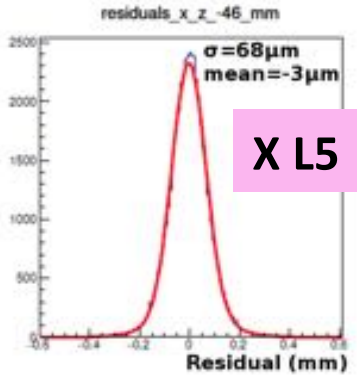






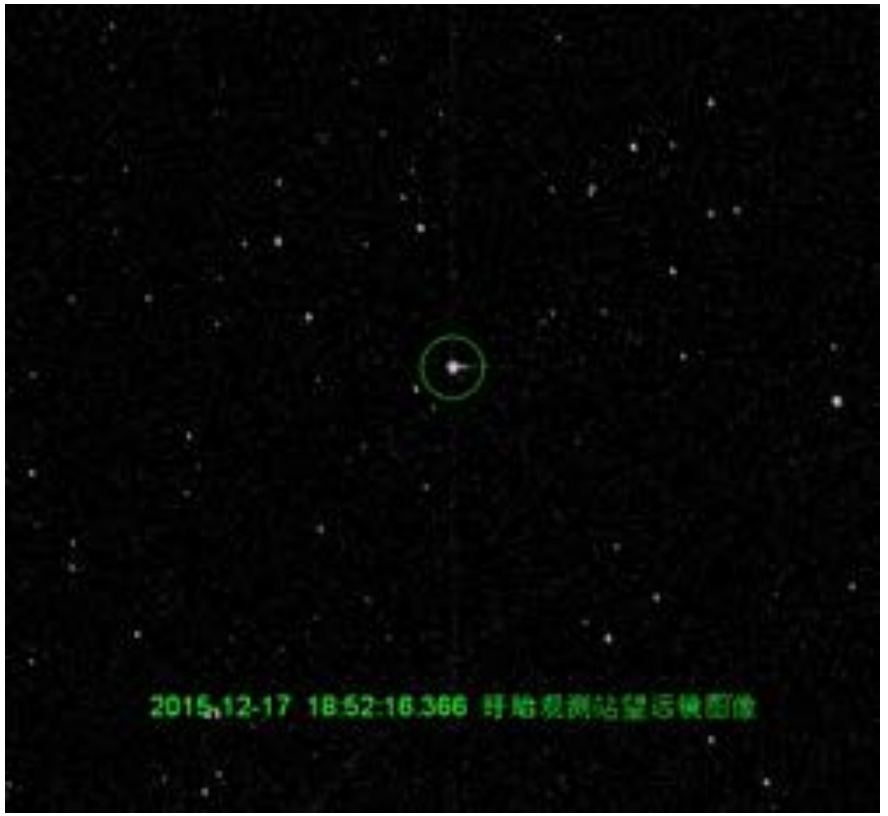


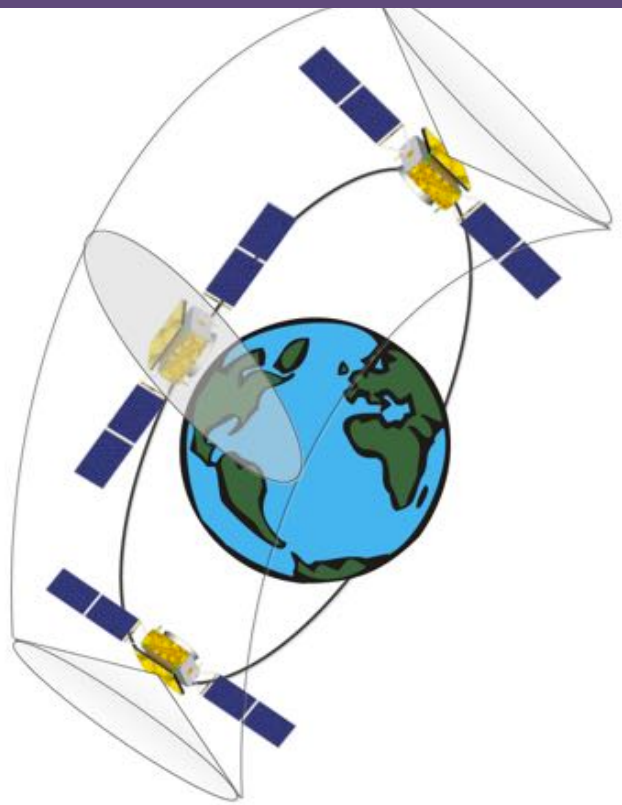




Successfully launched on Dec. 17 2015!

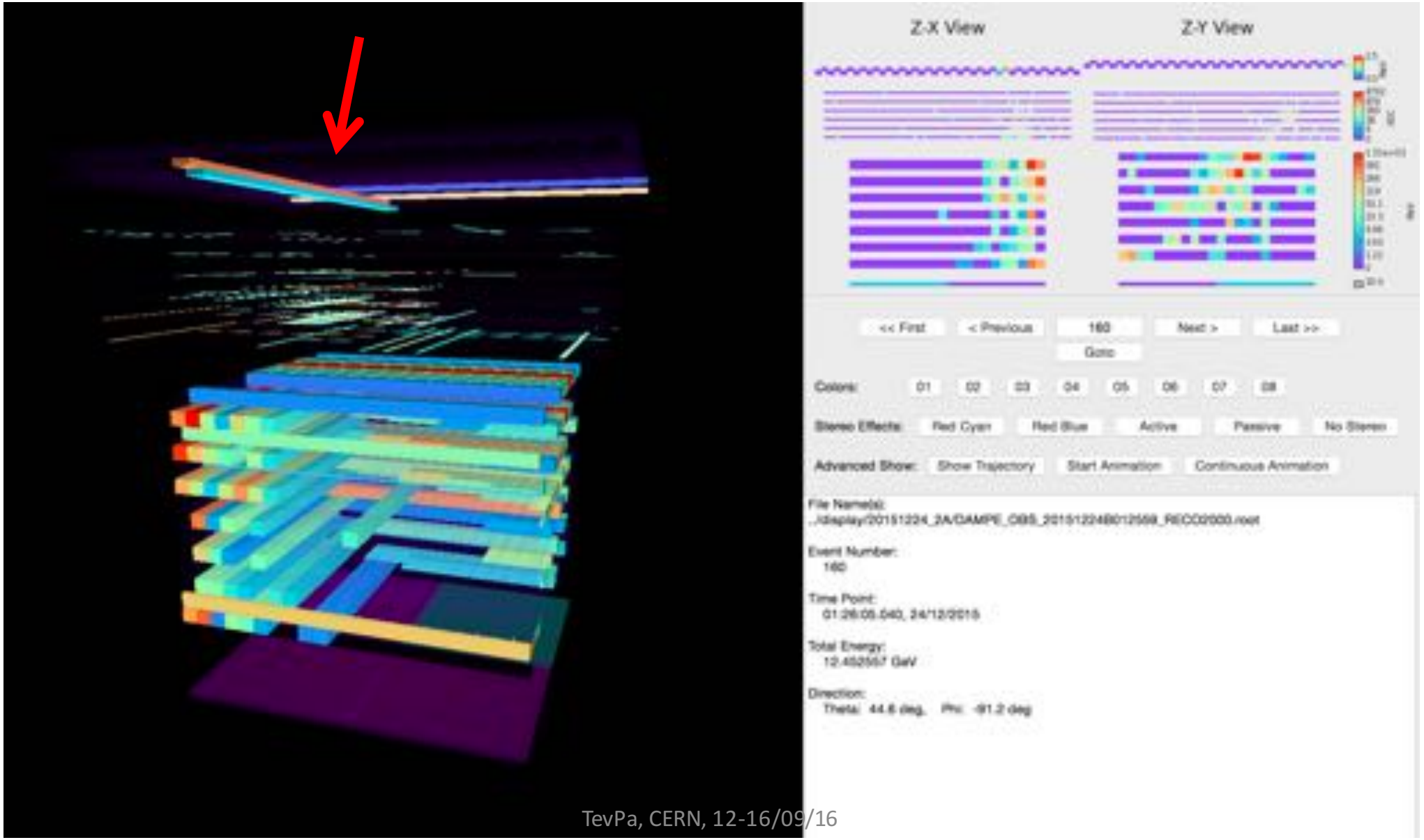
- Altitude: 500 km
- Inclination: 97.4065°
- Period: 95 minutes
- Orbit: sun-synchronous
- Pointing precision 0.005°



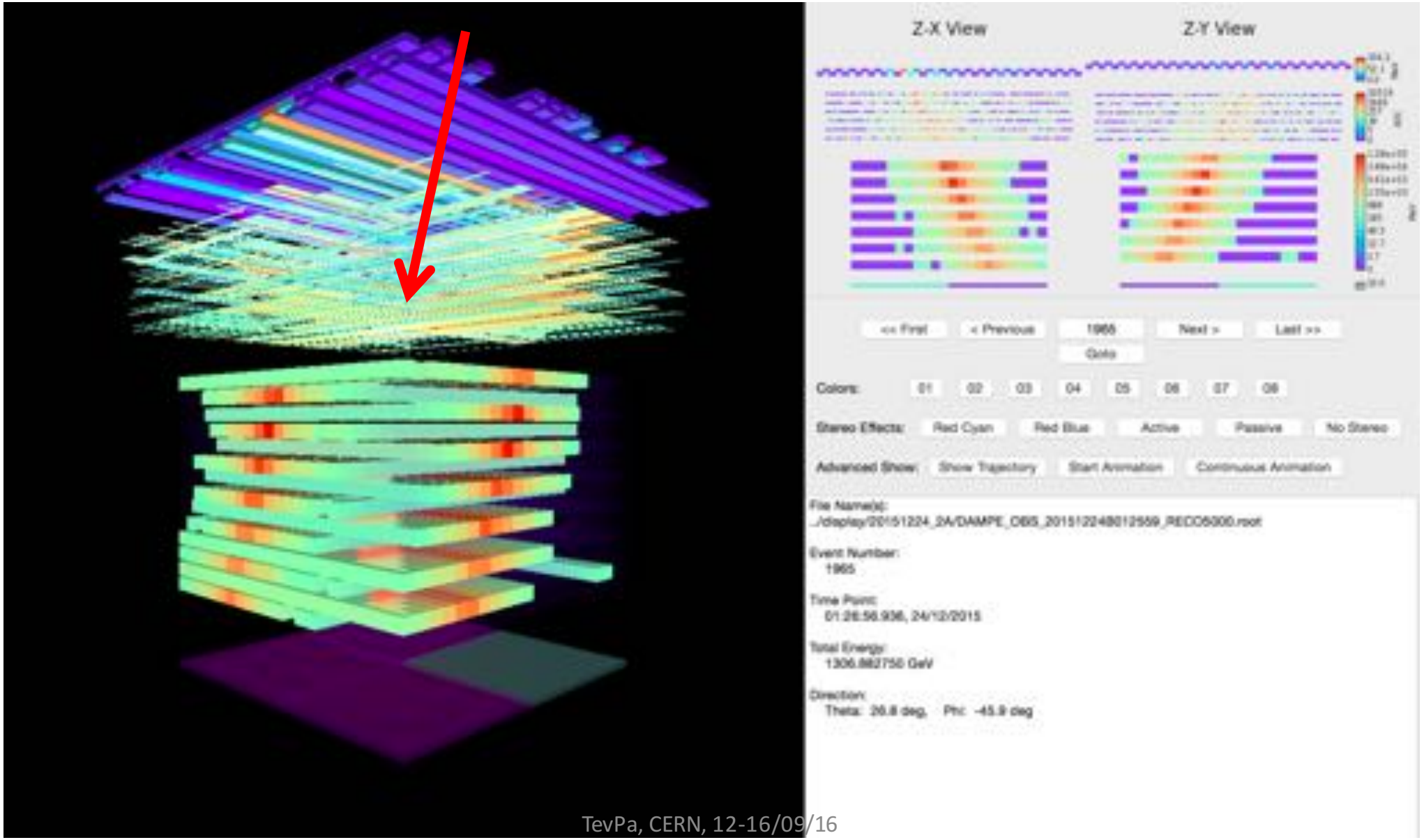


- Dec. 20: all detectors powered on, except the HV for PMTs
- Dec. 24: HV on!
- Dec. 30: stable trigger condition
- Smooth operation since!

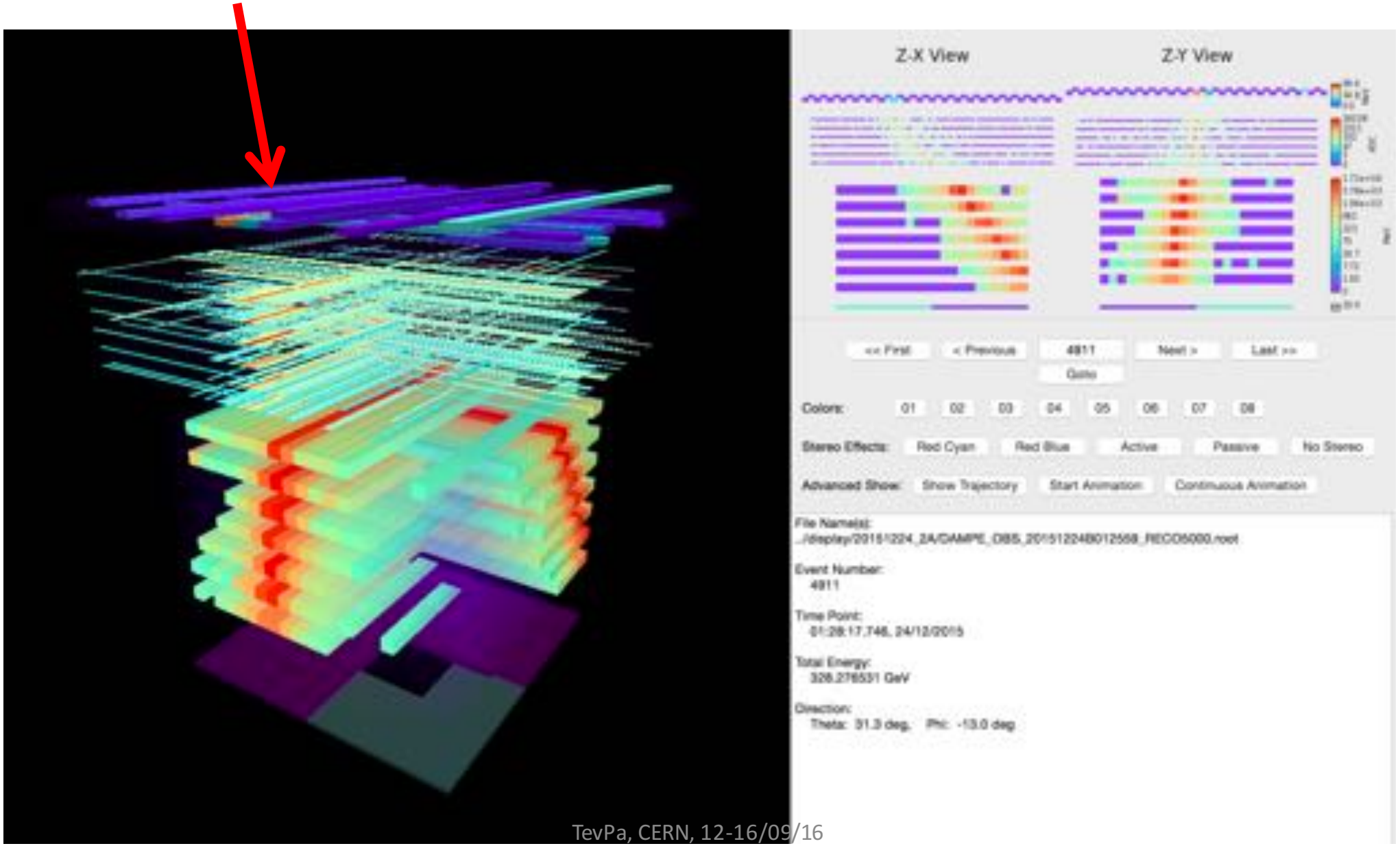
Dec. 24: 12 GeV proton



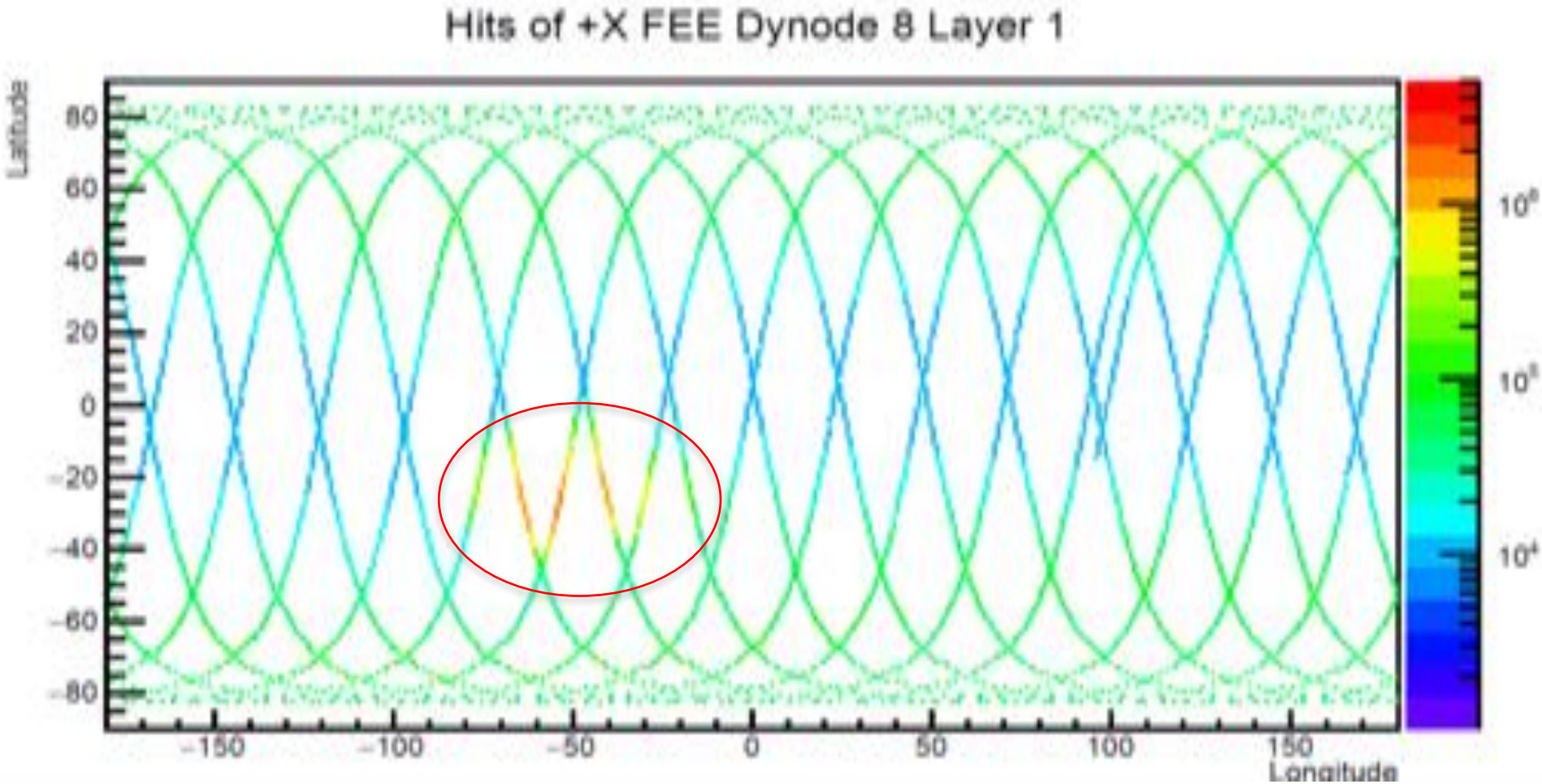
Dec. 24: 1.3 TeV carbon



Dec. 24: 328 GeV electron

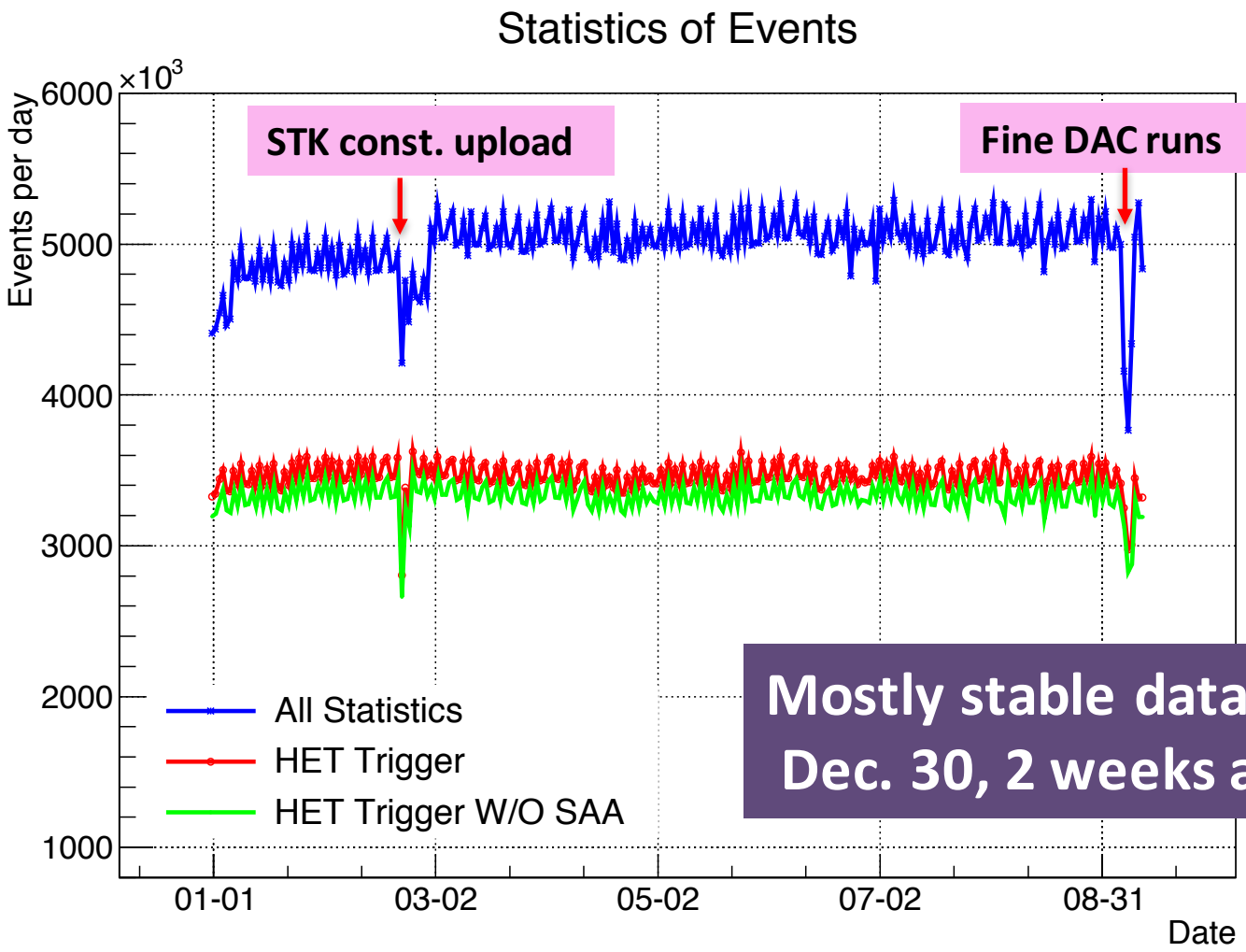


Particle hit counts vs orbit



- 15 orbits/day
- ~50 Hz average trigger rate
  - Main high energy trigger and prescaled low energy and MIP triggers

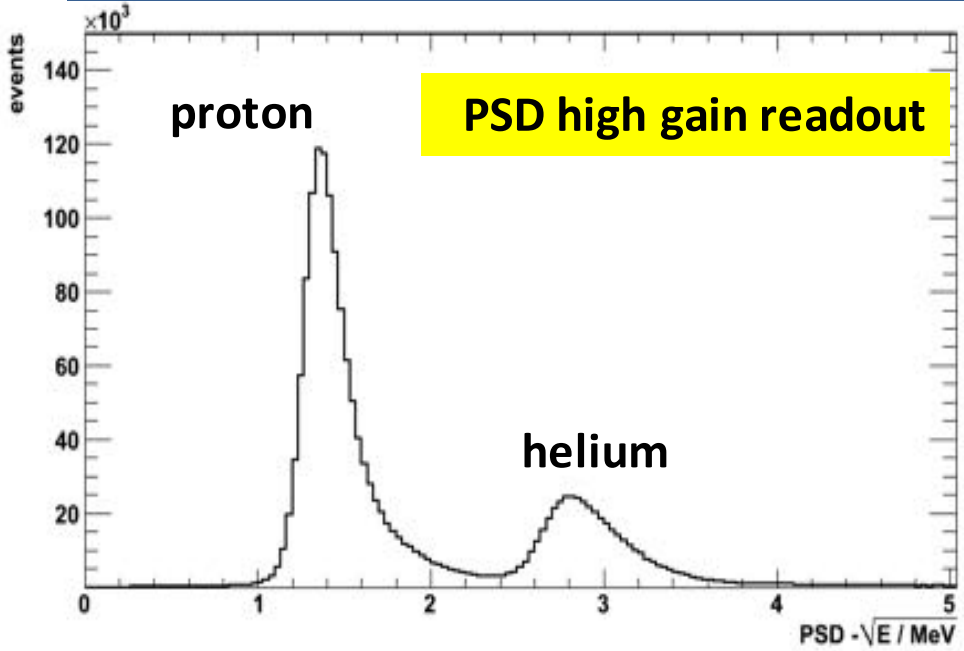
Number of events recorded per day

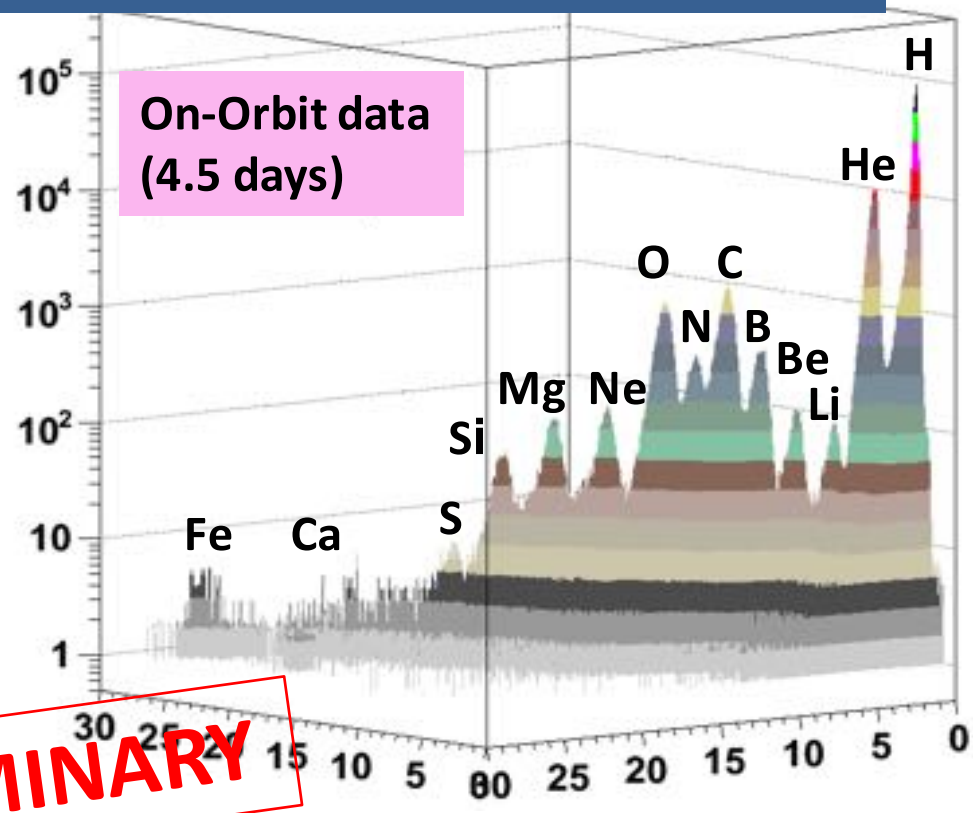


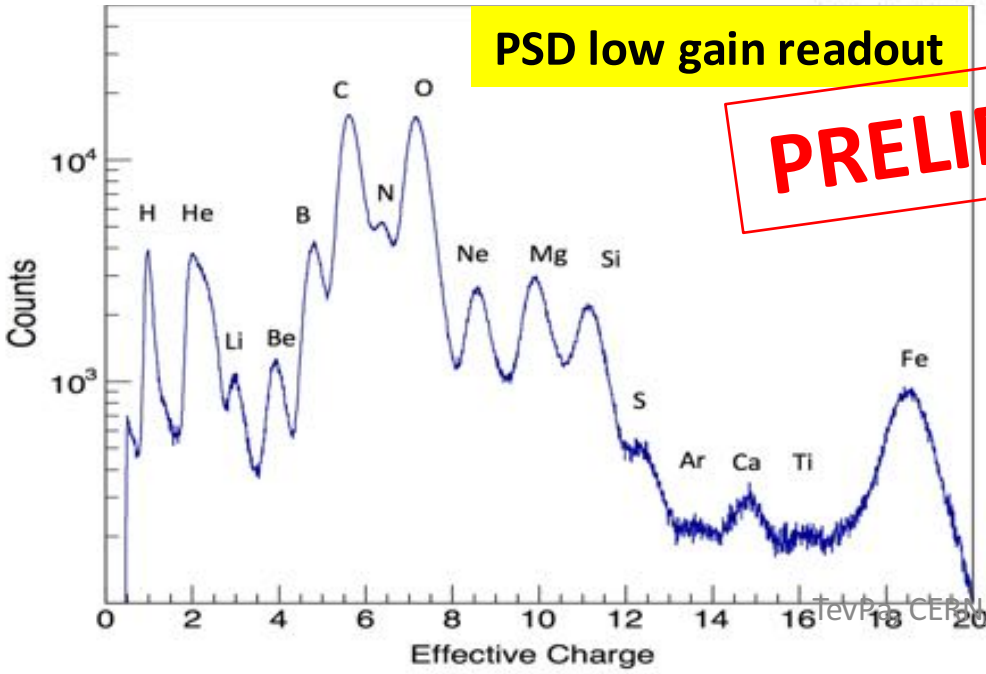
Mostly stable data-taking since Dec. 30, 2 weeks after launch!

- ~5 M events recorded per day, trigger rate very stable
  - ~3.5 M are high energy (efficiency turn-on ~2-10 GeV) triggers

PSD charge measurement





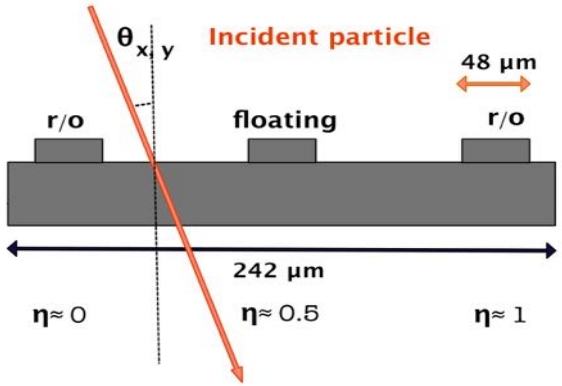


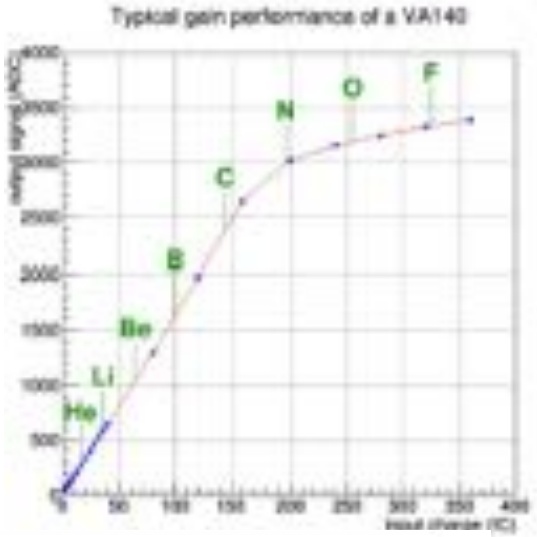
PRELIMINARY

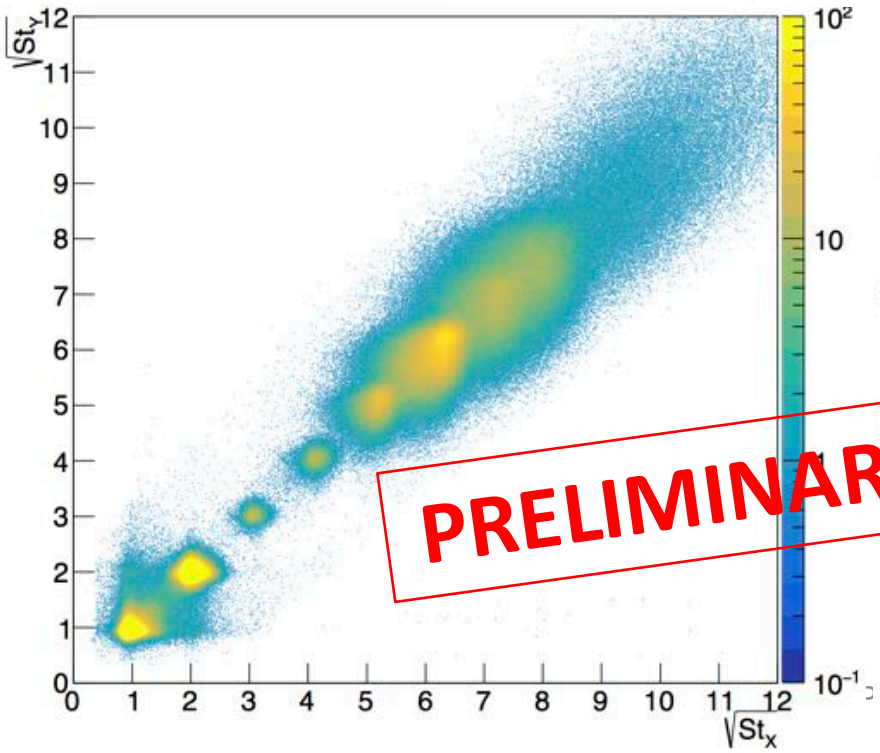
Charge resolution ~20-30% depending on Z

STK charge measurement

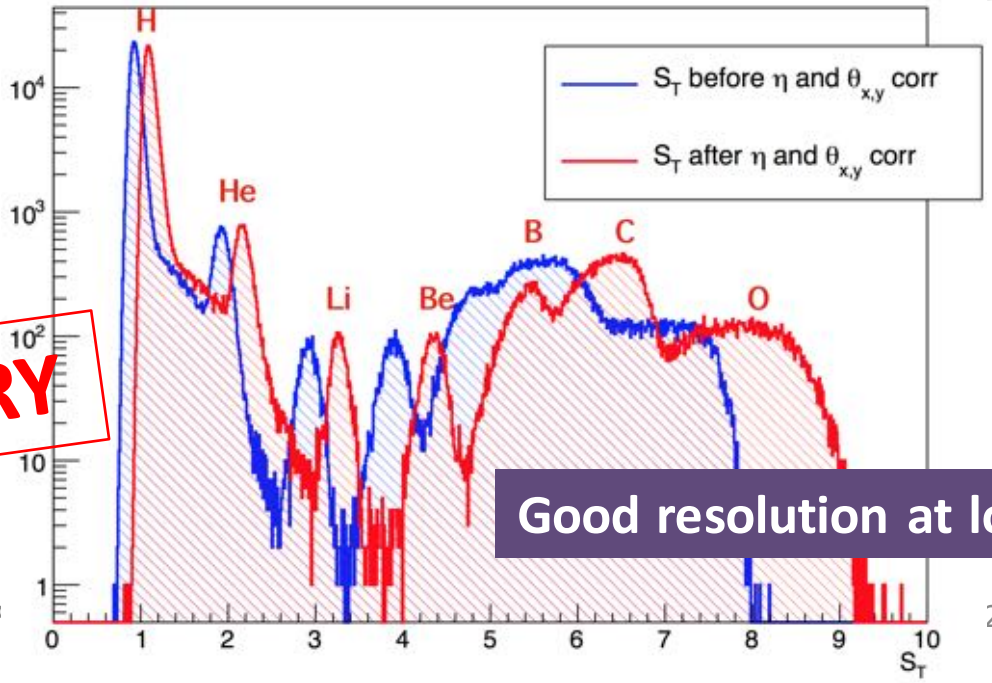
- STK charge measurement : need to correct for floating strip readout scheme, also the saturation effect for high Z (>8)





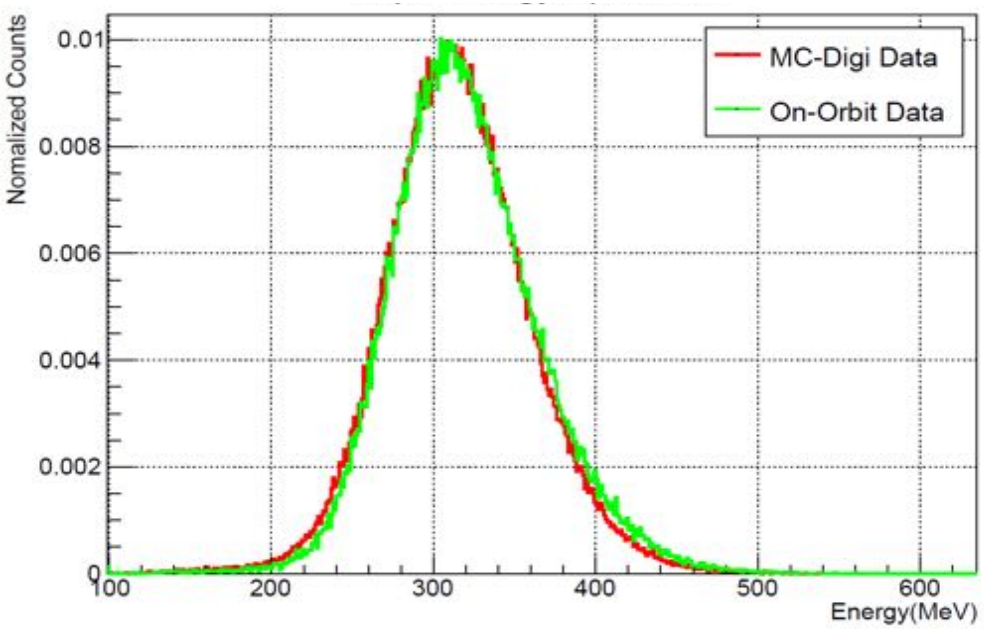


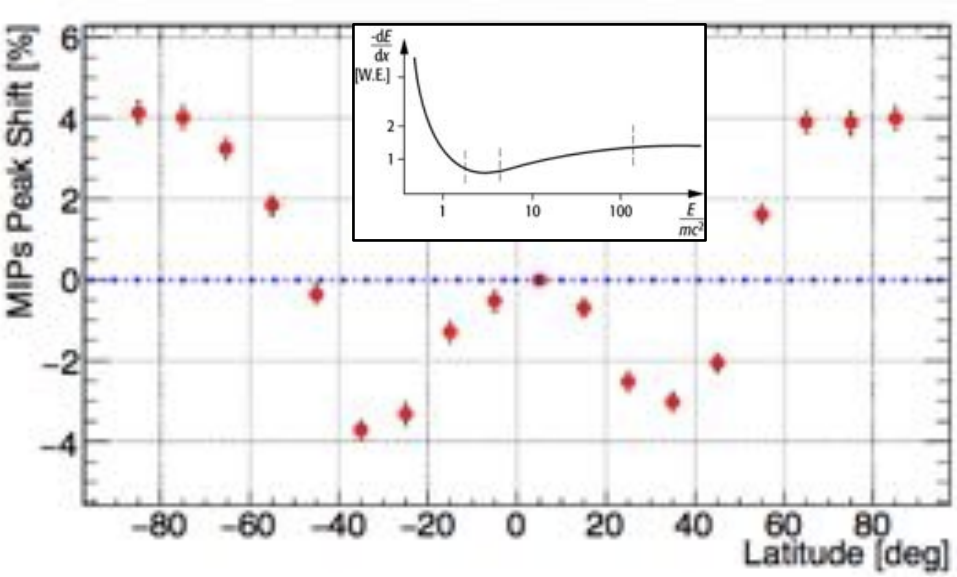
PRELIMINARY



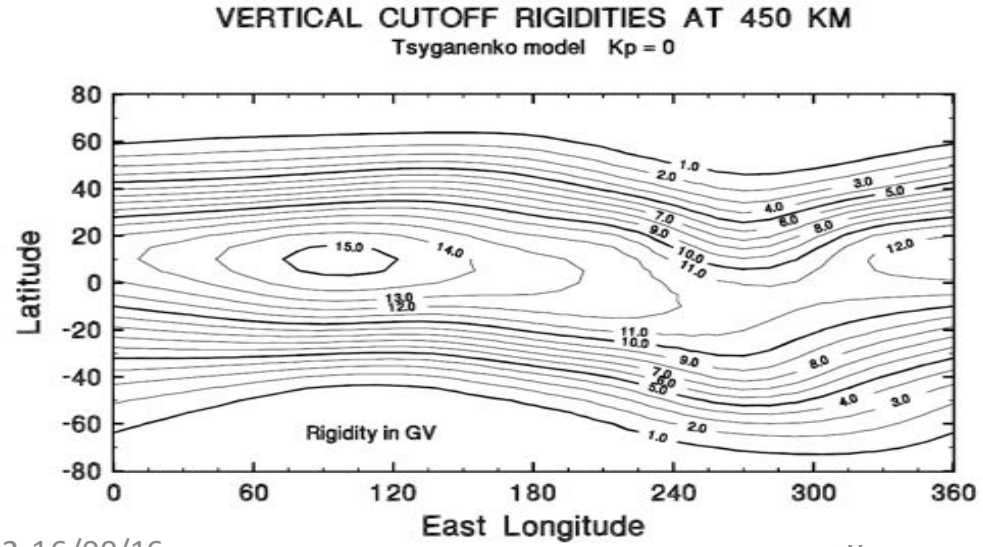
Good resolution at low Z

BGO MIP calibration

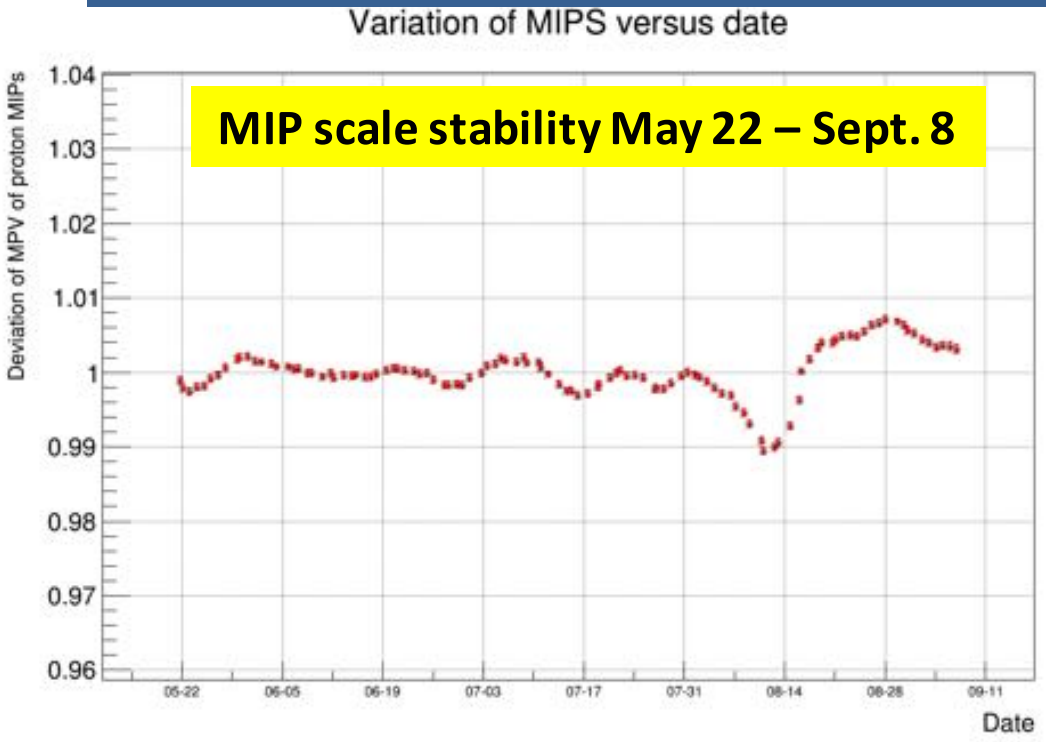




MIP calibration (2x per orbits) needs to take geomagnetic cutoff effect into account



BGO temperature effect

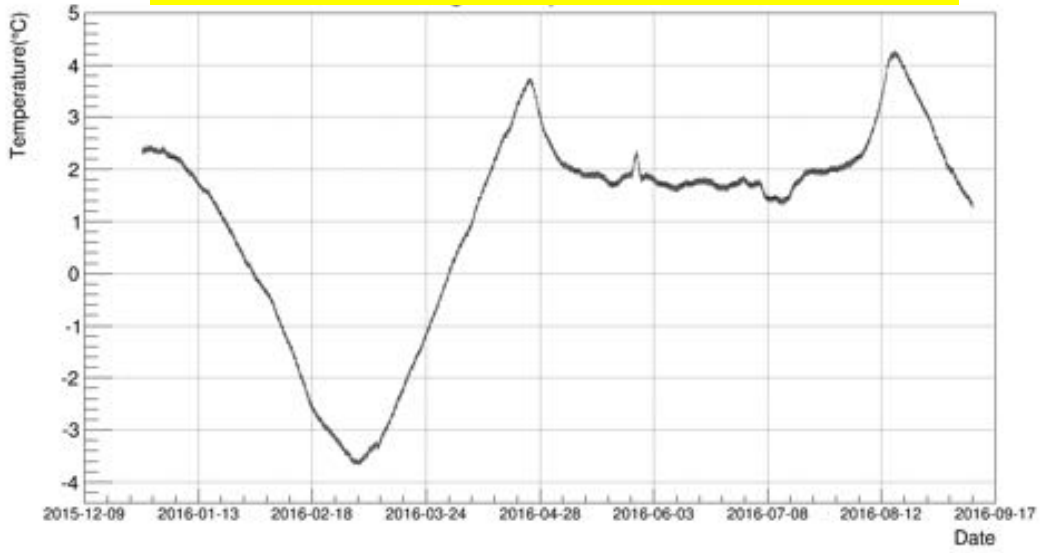


MIP scale stability May 22 – Sept. 8

MIP scale stability ~1% before temperature correction

Further correction will be done in data reprocessing to achieve 0.5% stability

BGO temperature Dec 24 – Sept. 10

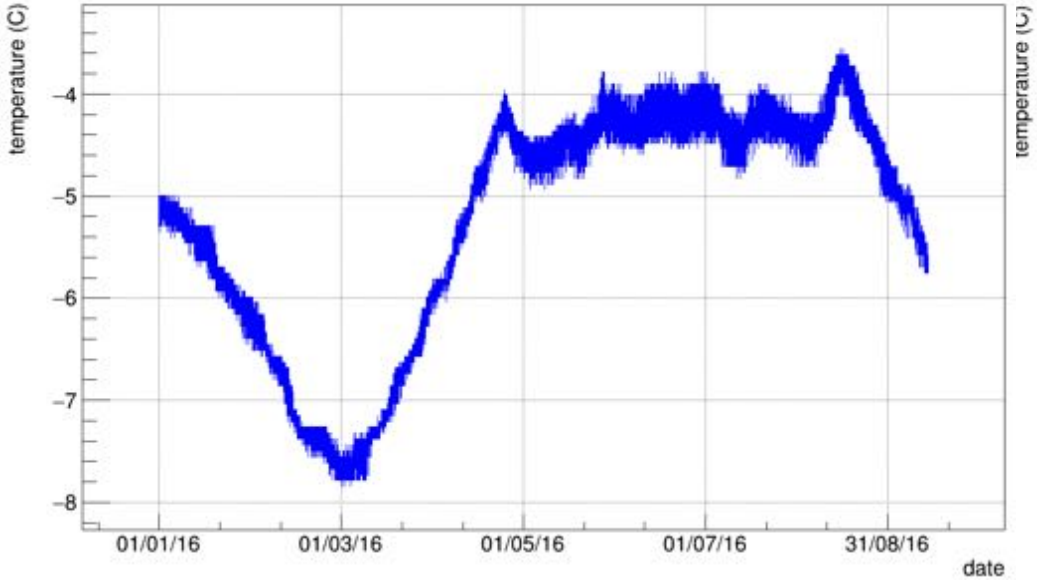


Temperature:

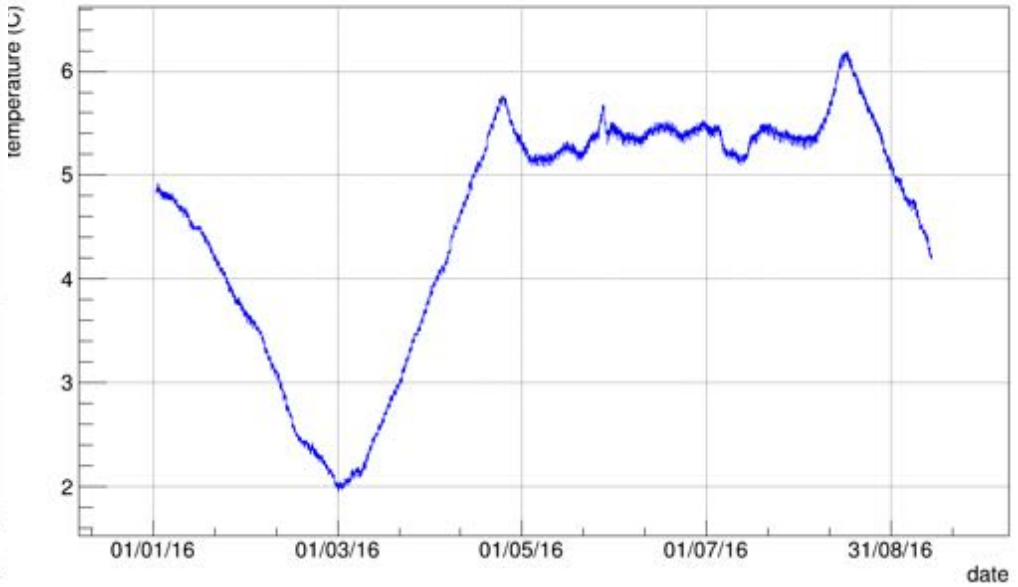
- Short term very stable
  - day to day change (<<1° C)
- Long term variation $\lesssim 8^{o}$ C

Thermal Stability of the STK

Ave. radiator temperature since launch



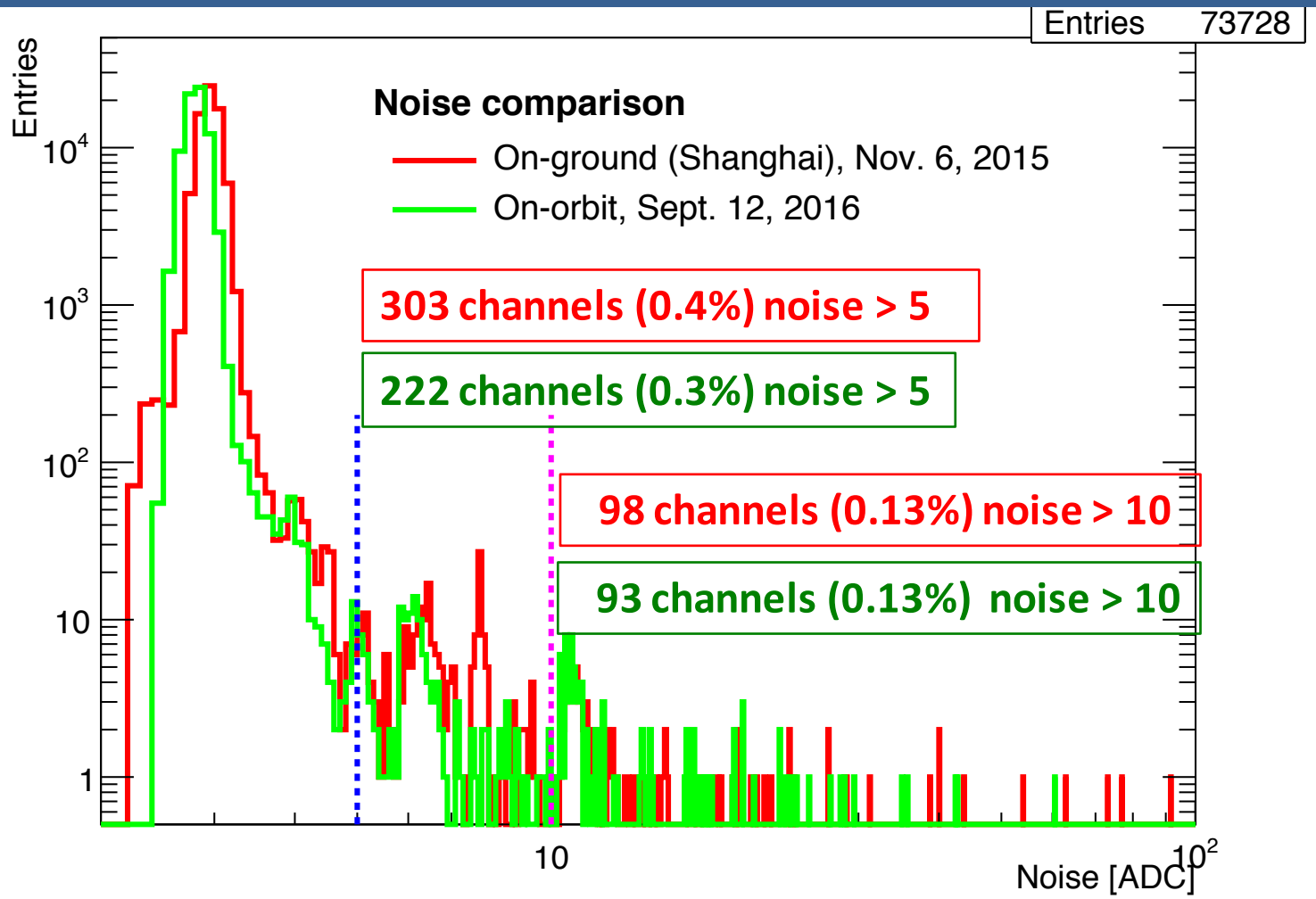
Ave. Si ladder temperature since launch



- STK is constantly 10° higher than the radiators
- Day to day variation much less than 1°
- Max. monthly variation ~2.5°
- Max. variation since launch ~6°
- Max. difference between ladders ~2°

The thermal management system for 73k readout channels works very well!

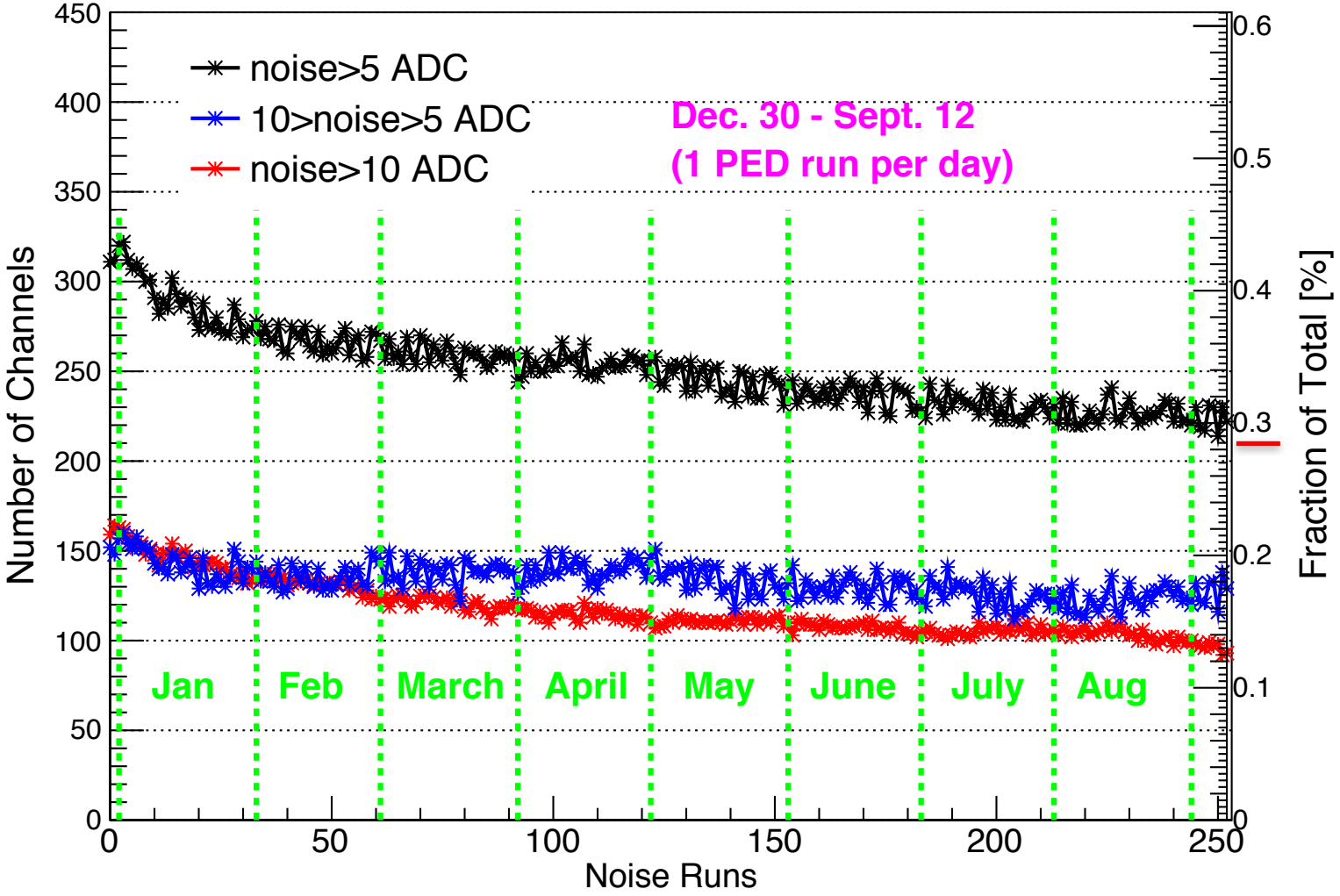
STK noise: Sept. 12 vs on-ground



- Noise improved because of lower temperature in space and stabilization
  - Bulk of noise ~2.8 ADC (vs 3 ADC on ground)

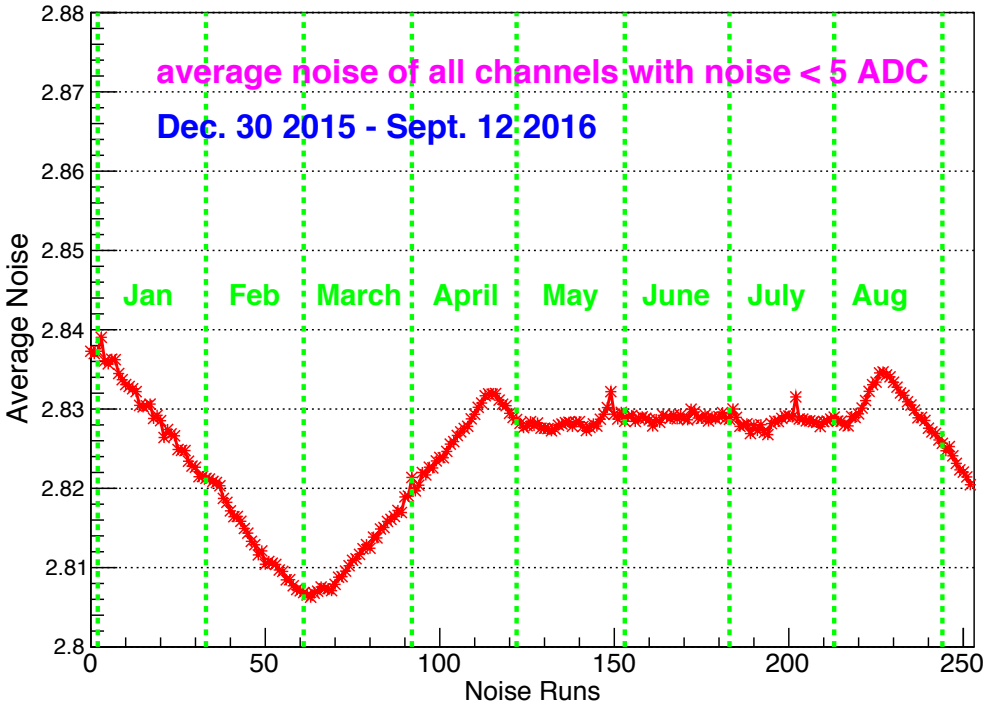
Similar good performance on-orbit and on-ground!

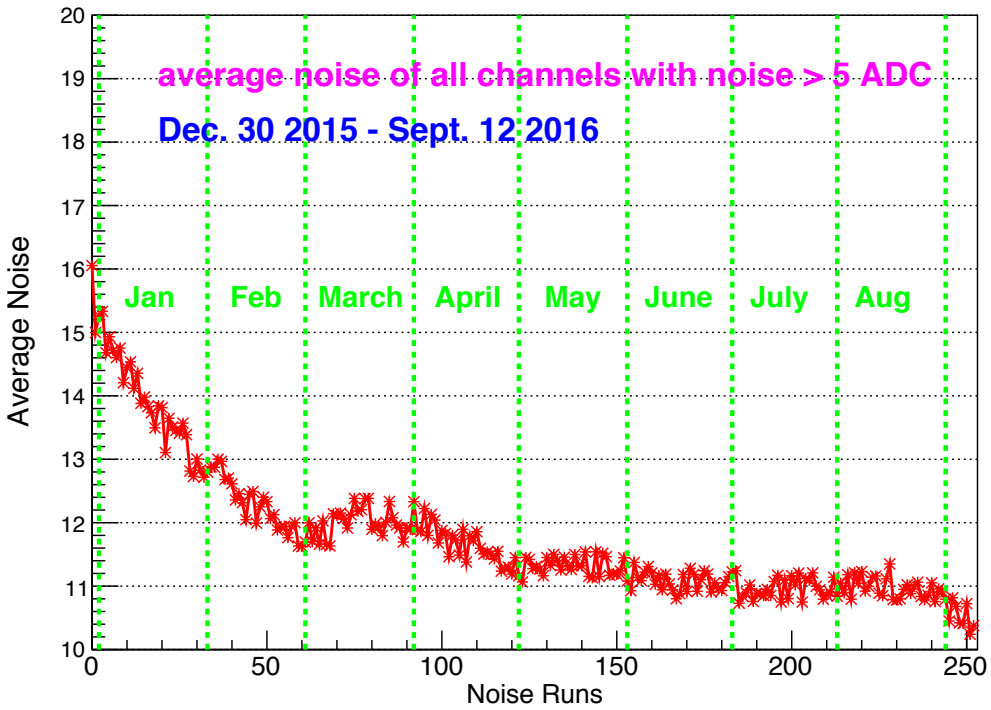
Noise category since Dec.30 (stable trigger condition)



- STK in excellent condition, noisy channels ~0.3%
  - In space silicon detector can actually improves with time!

Evolution of average noise : bulk and noisy channels

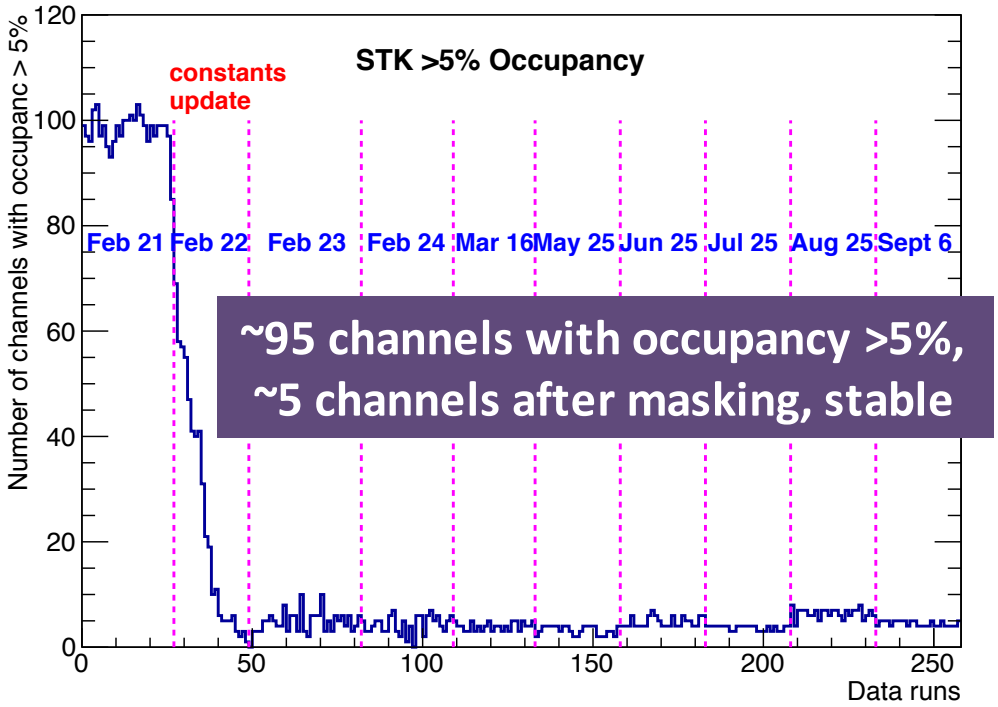




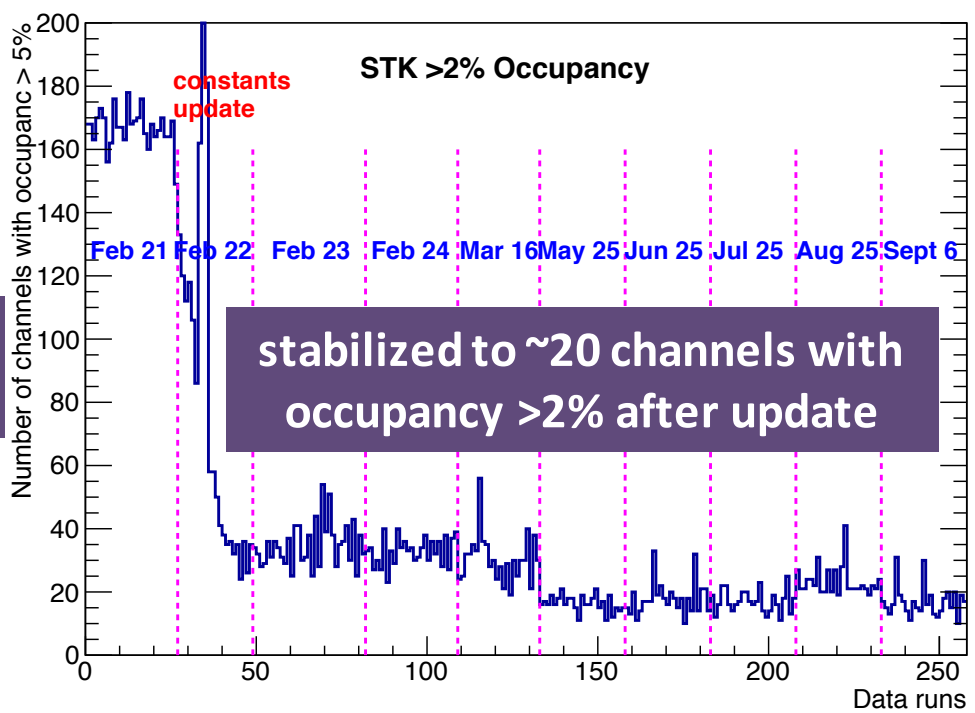
- Bulk of noise correlated with temperature
  - Very small temperature coefficient
    - ~0.01 ADC per 2°
  - Simplification for operation
    - online data compression only updated once of Feb. 22 using average noise of Feb. 13-17

- Noisy channels stabilized to lower noise values
  - Very small temperature effect

STK channel occupancy

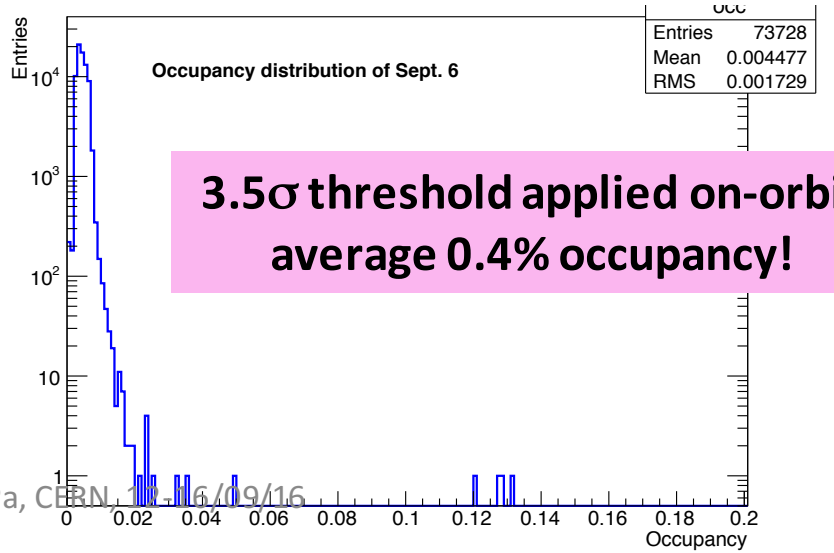


~95 channels with occupancy >5%, ~5 channels after masking, stable



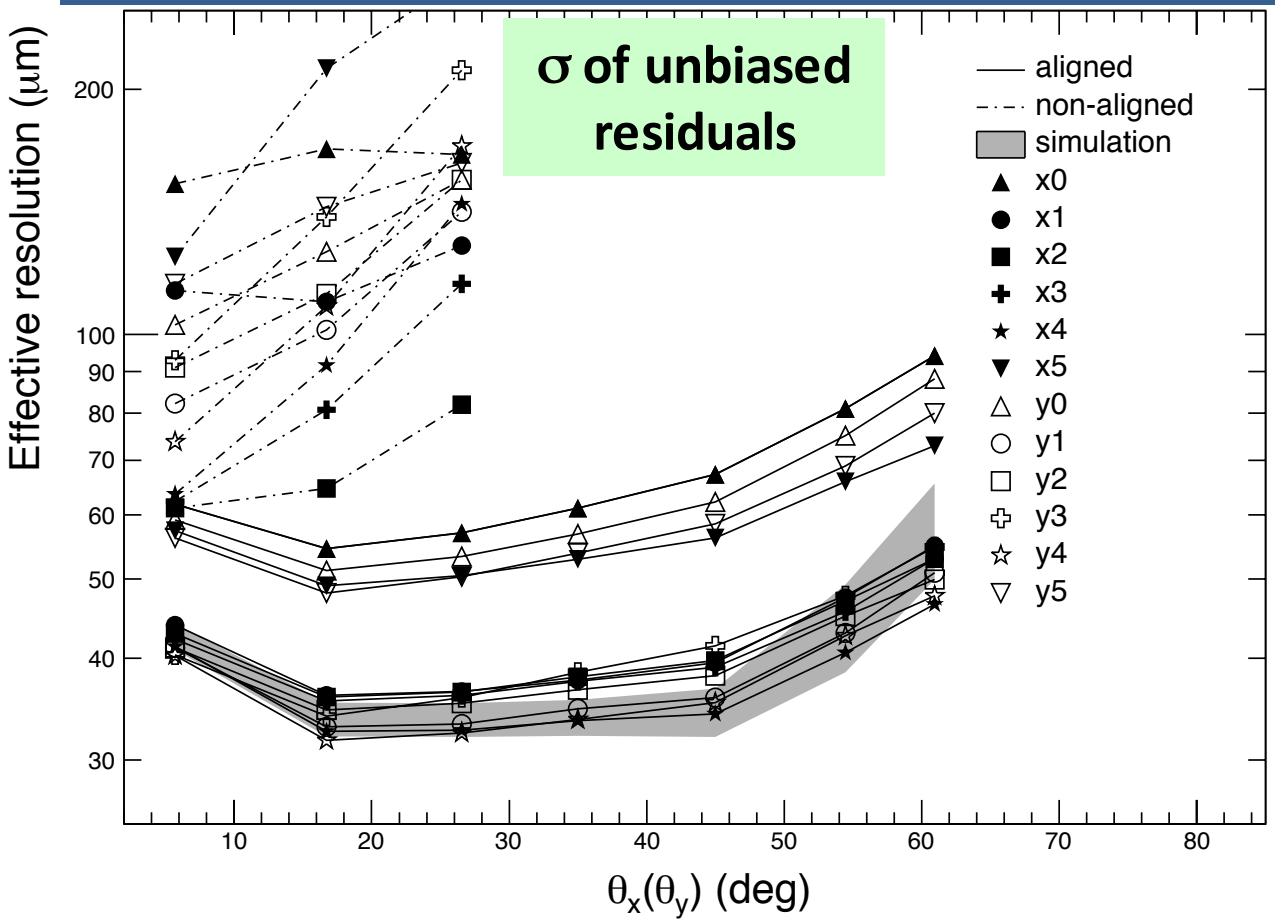
stabilized to ~20 channels with occupancy >2% after update

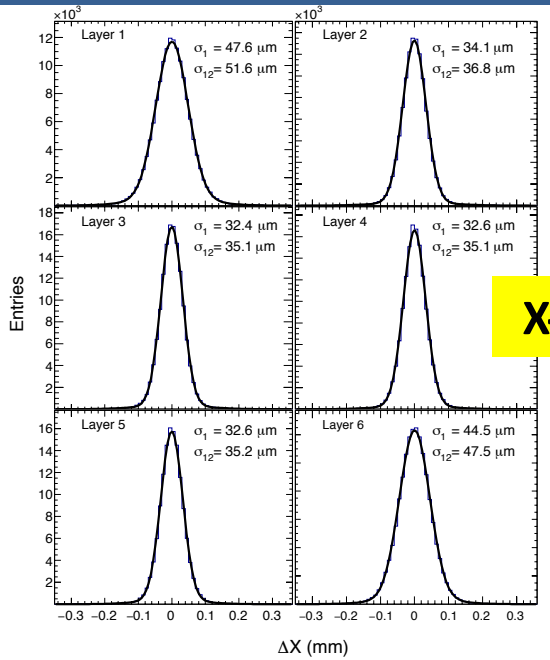
Noise thresholds and bad channels list updated on-orbit on Feb. 22



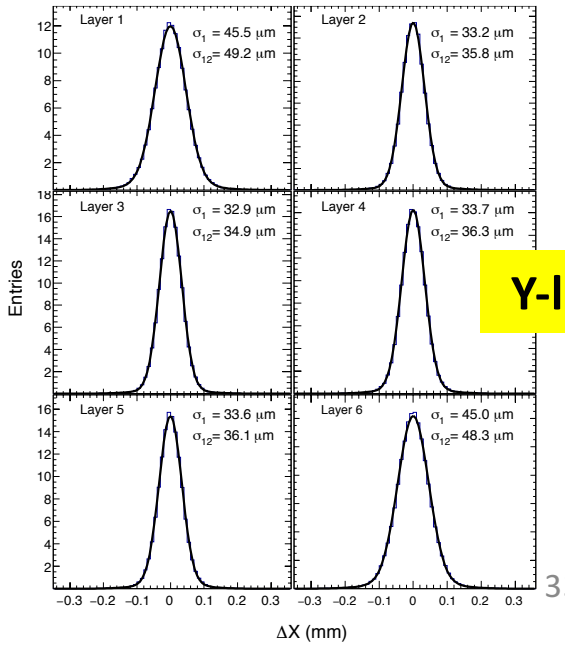
3.5σ threshold applied on-orbit average 0.4% occupancy!

STK on-orbit alignment





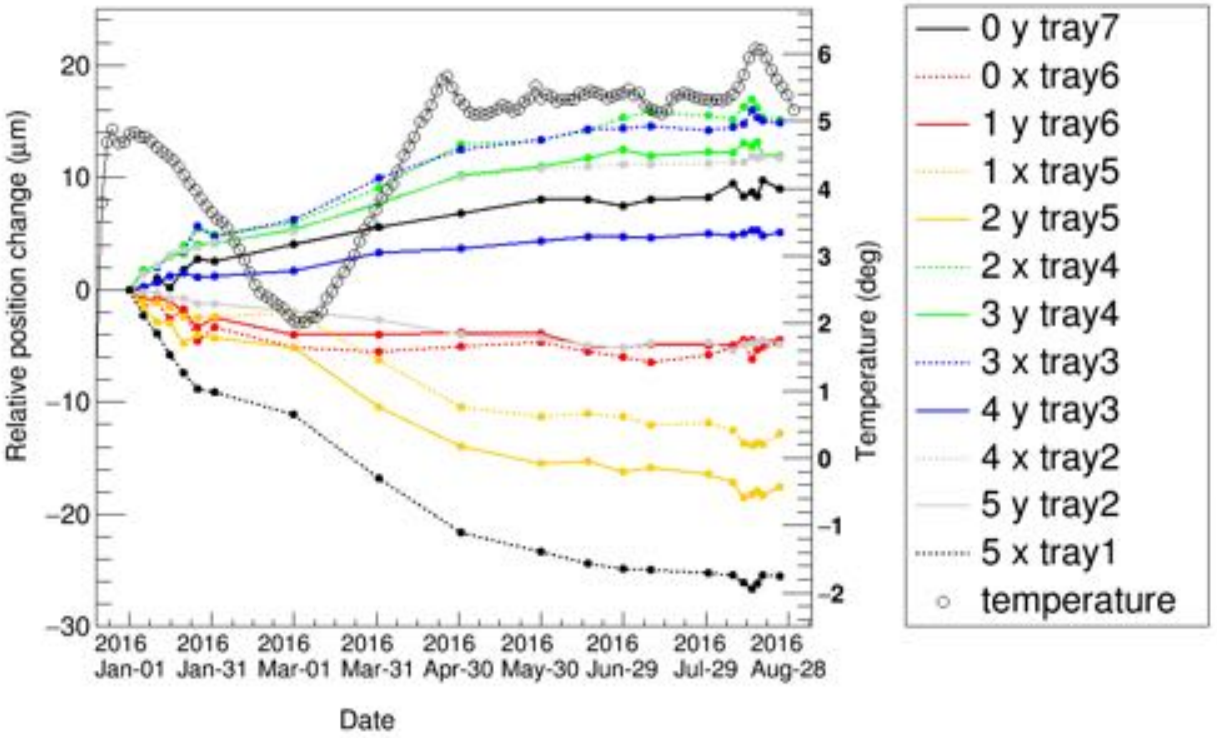
X-layers

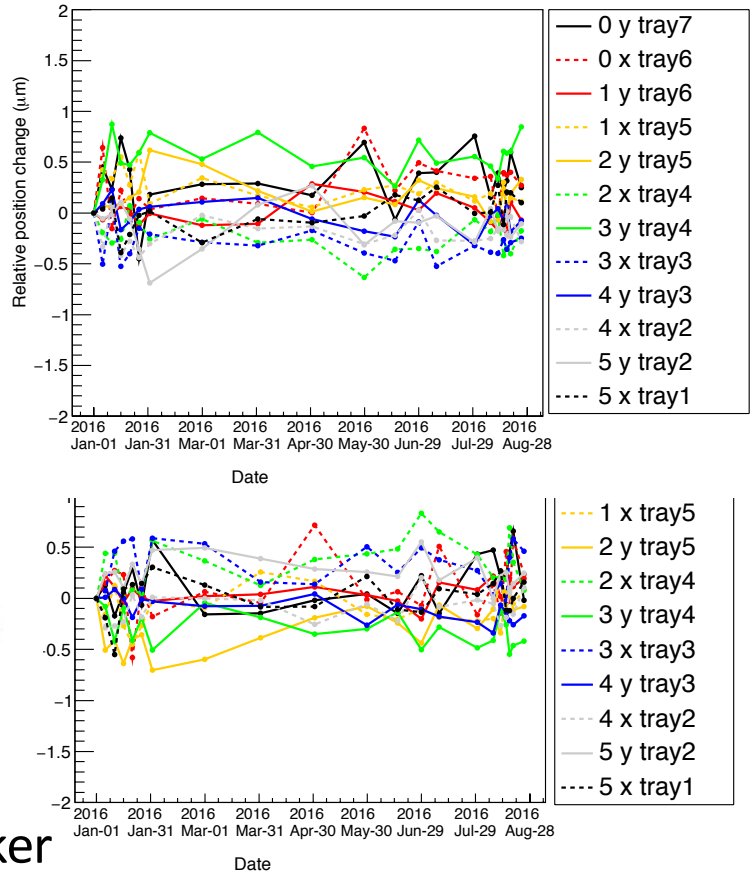


Y-layers

- Achieved ~40 intrinsic position resolution after on-orbit alignment
  - Good agreement with perfect aligned MC and test beam measurements

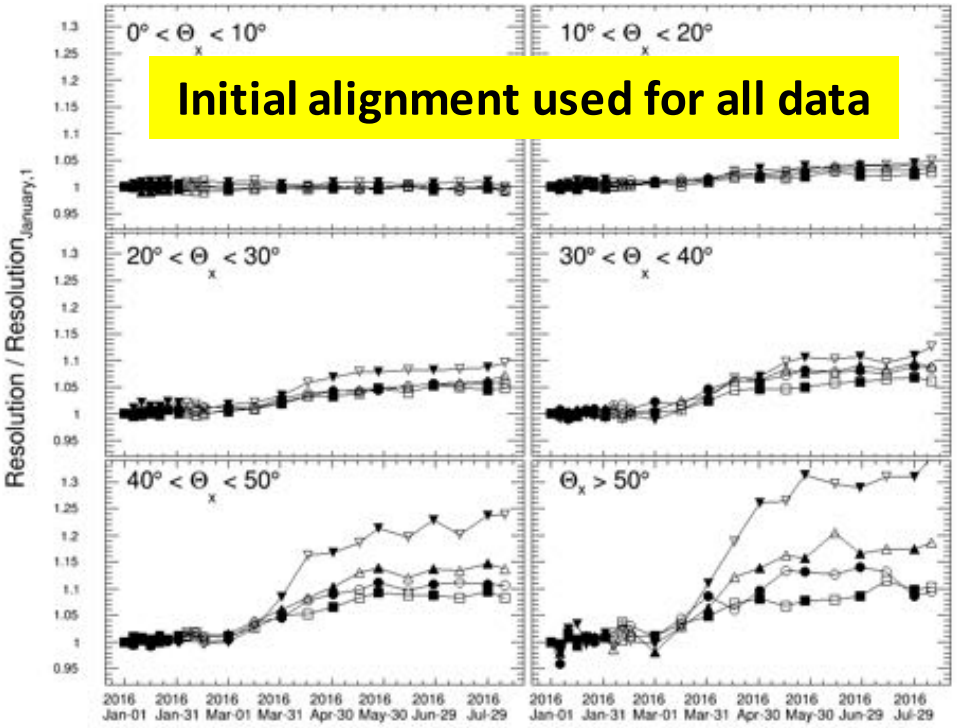
STK mechanical stability

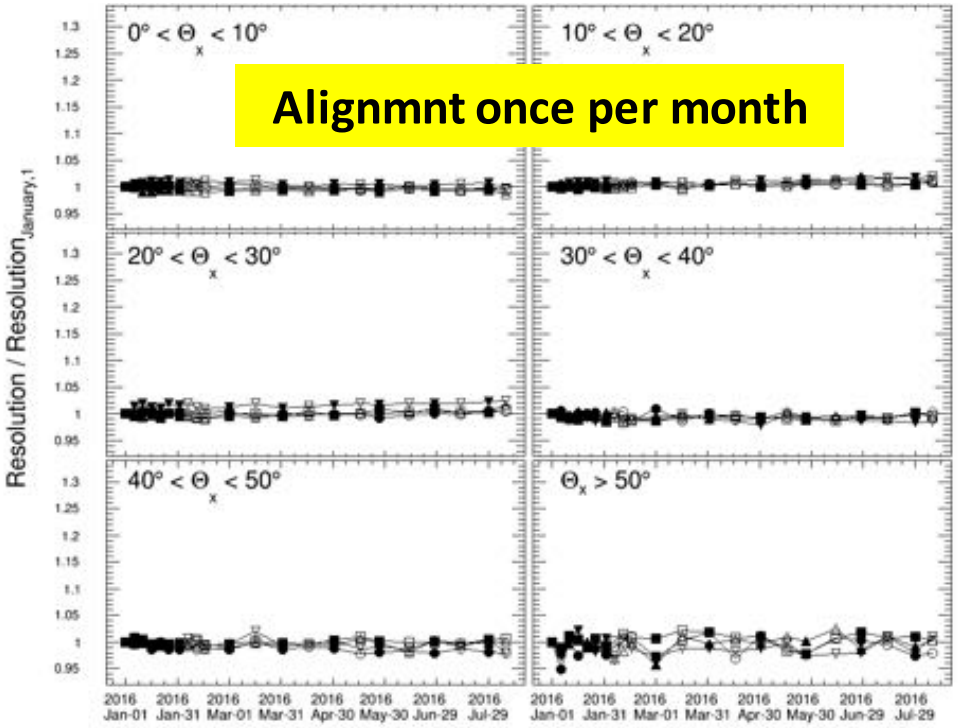




- Mechanical stability is vey important for a tracker
  - STK stability is monitored by alignment constants
- Negligible movement in x-y since launch, very small movement in z
  - Max. ~25μm in Z-direction, no effect on tracking efficiency
  - Some level of correlation with temperature

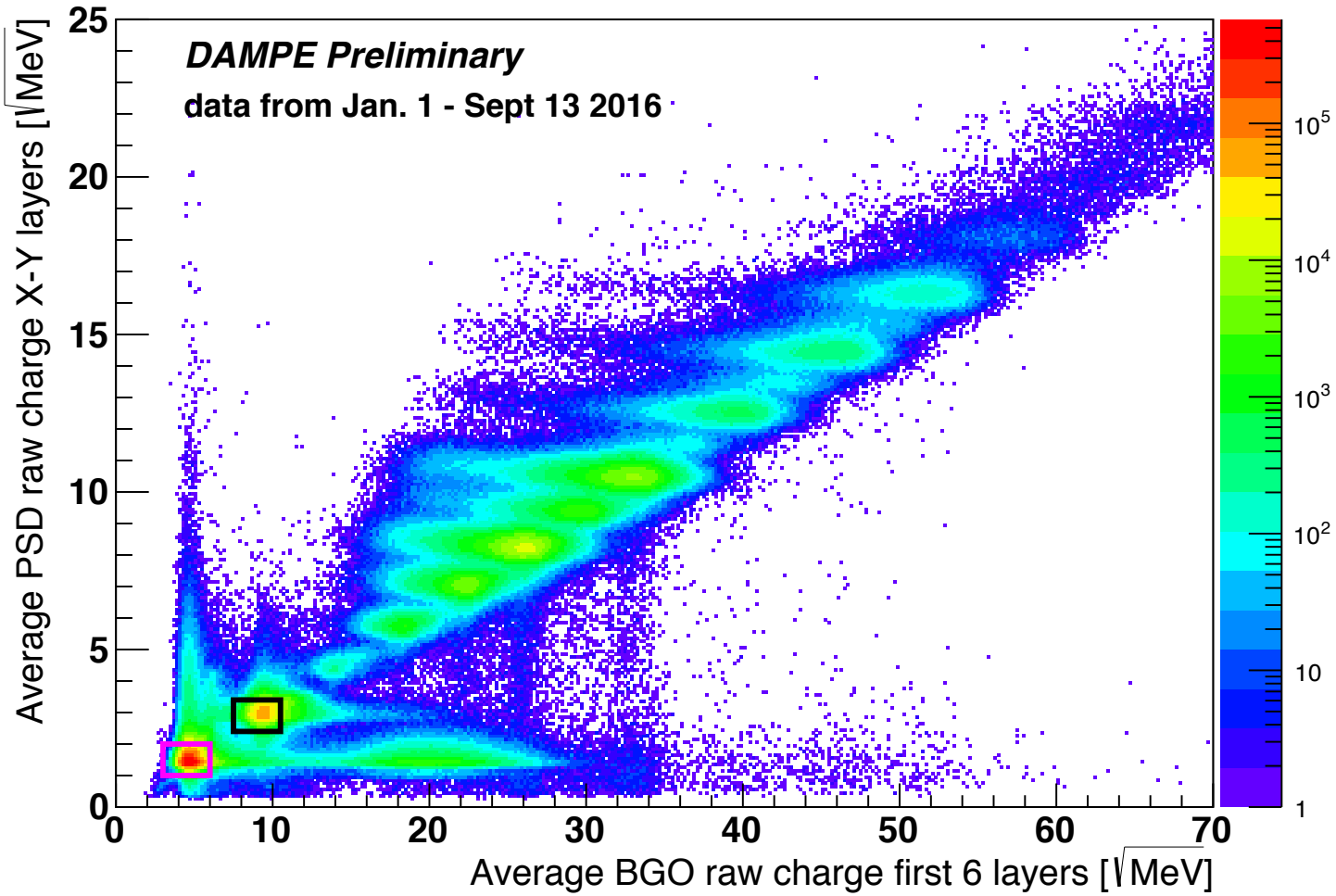
Position resolution with alignment update





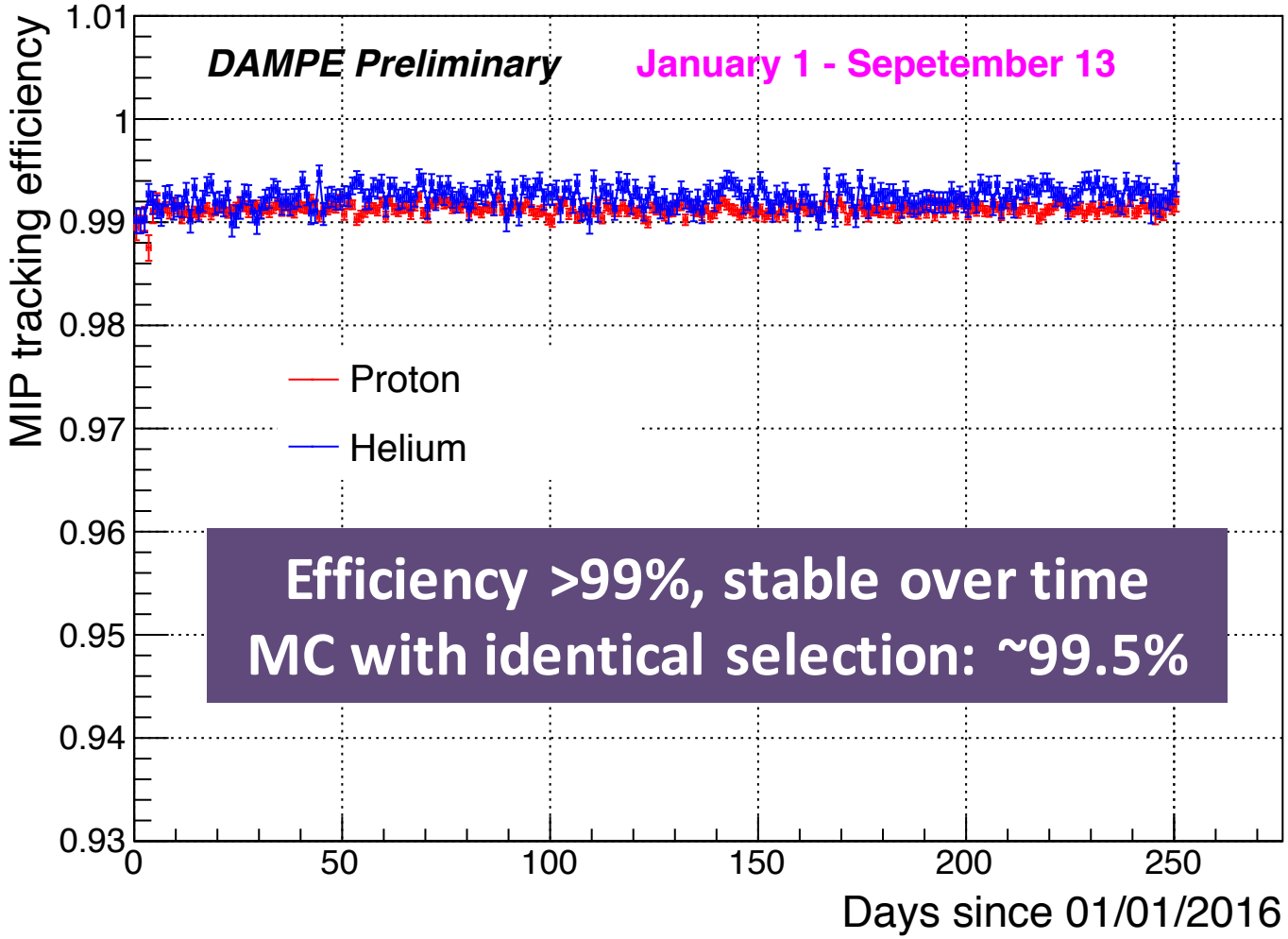
- Movement in z affect the position resolution of inclined tracks (up to 30% for >40° incidence angle)
  - Can be fully recovered with more frequent alignment updates

Selecting MIP for tracking efficiency study



- Selection of a sample of proton and helium MIP events
  - No showering before the first 6 layers of BGO
  - Selection based on PSD and BGO quantities only

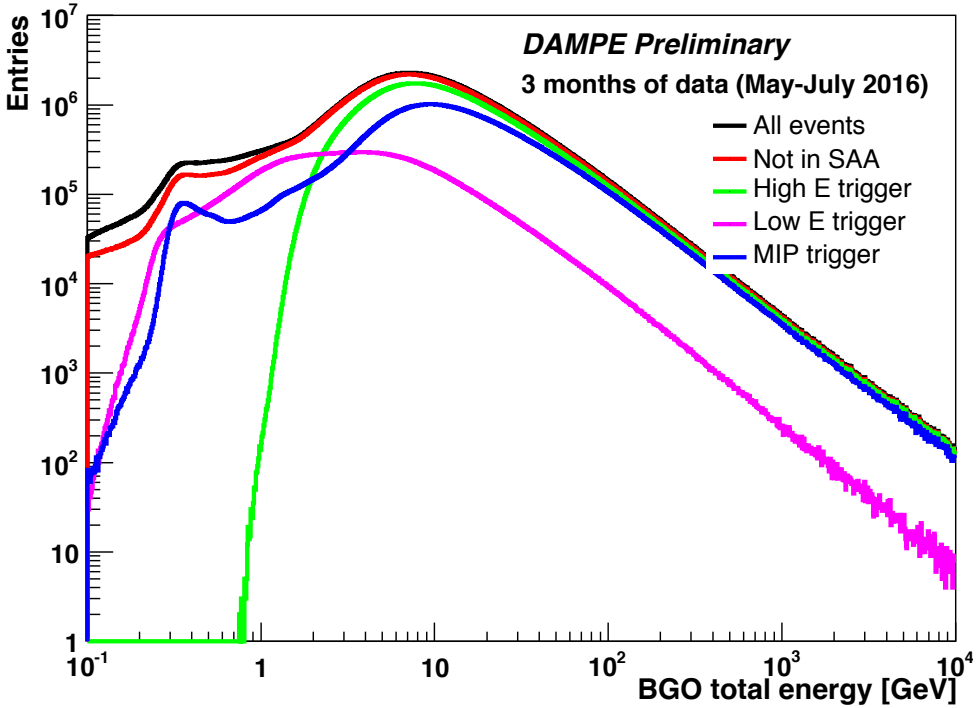
MIP tracking efficiency

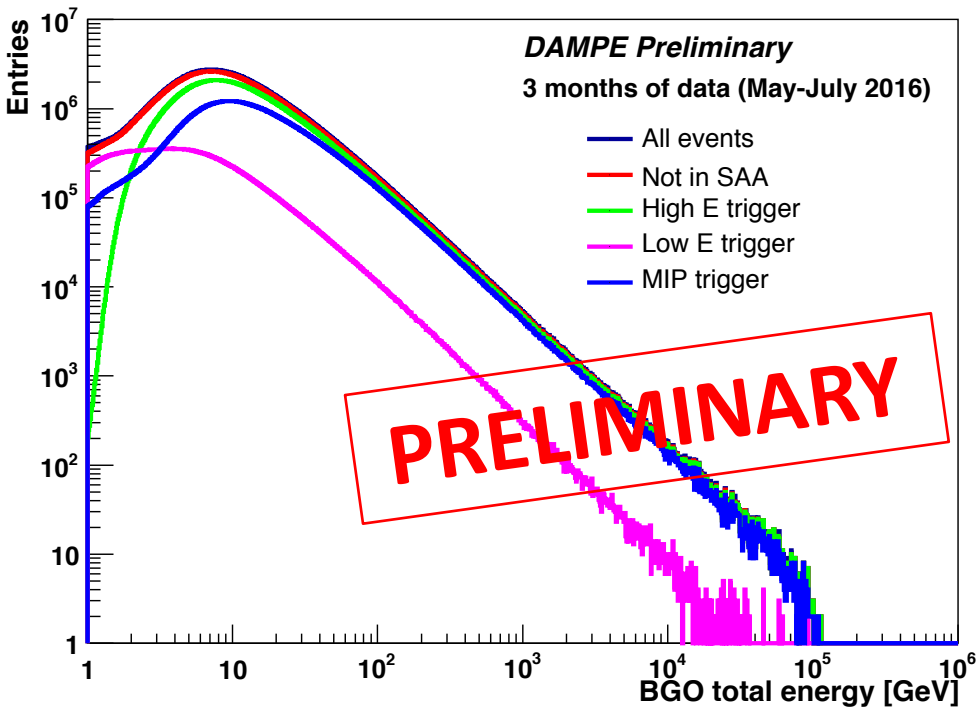


- Use a sample of proton and helium MIP events
  - No showering before the first 6 layers of BGO
  - Selection based on PSD and BGO quantities only

The tracker is in excellent condition!

Raw energy distribution, data of 3 month





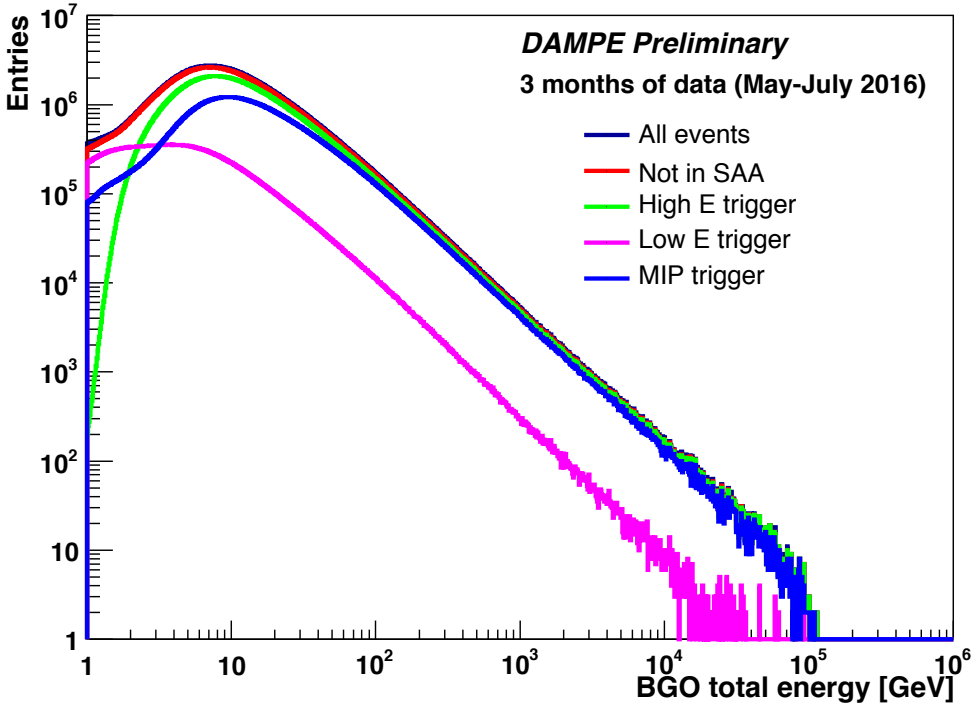
- ~465 M events for 3 months!
  - ~9.4% in SAA, mainly <1 GeV
  - Bulk of data collected by high E trigger, efficient for > 10 GeV
  - Also collect large amount of low E (for γ) and MIP (for calibration) data

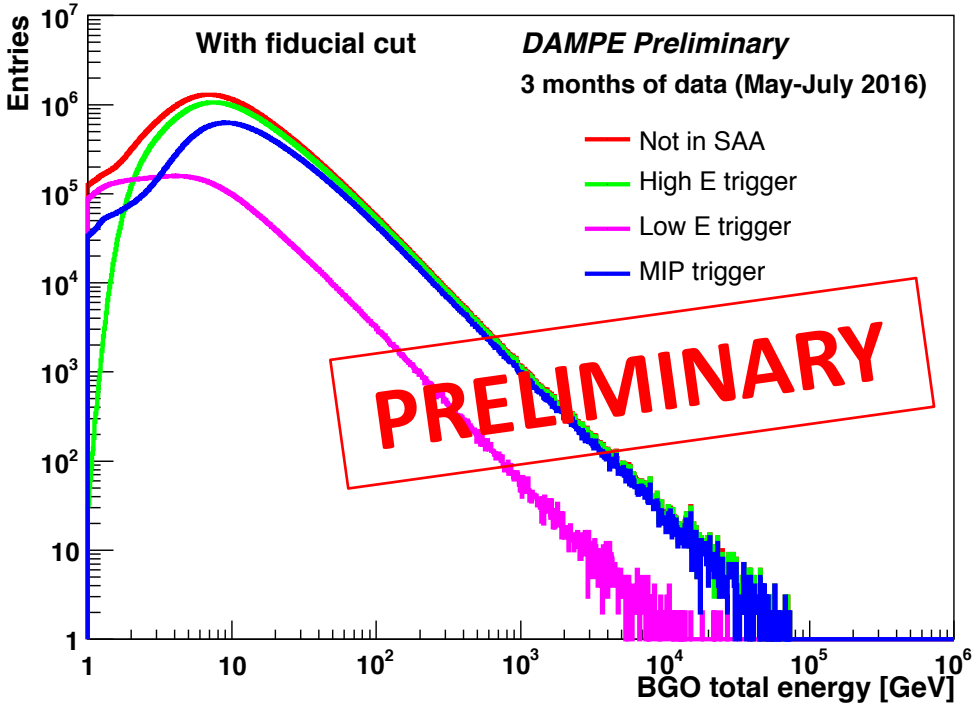
- ~250 k events with raw E > 1 TeV
  - ~5% in SAA

~1 Million TeV events/year!

Caution: raw visible energy and raw counts!

Raw energy distribution, with fiducial cut



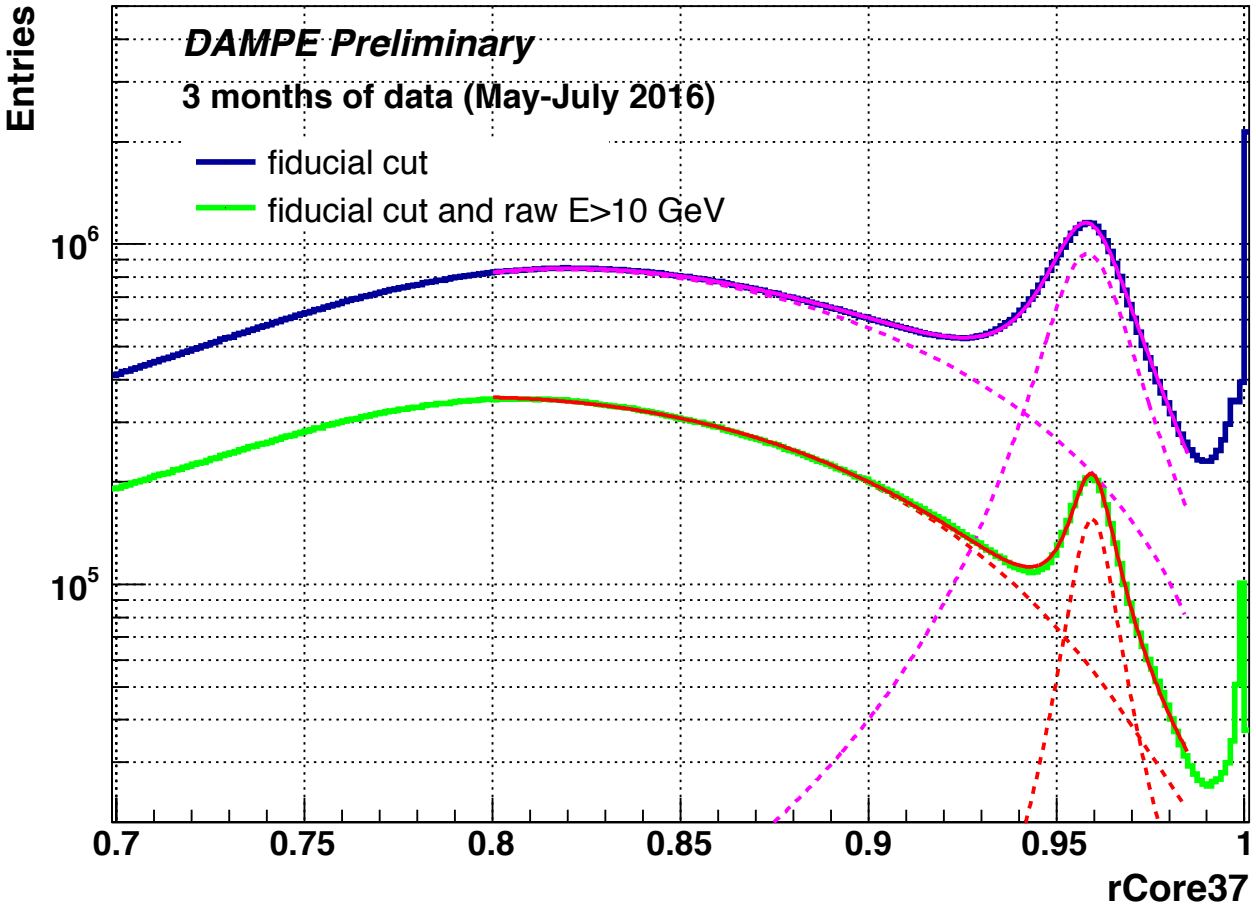


- Pile-up at the tail removed by simple fiducial cut
  - Direction reconstructed in BGO points to the top of the BGO and PSD
  - BGO bar with highest energy is at least 2 bars away from the 4 sides

~200k TeV (raw) fiducial events/year!

Mostly p and nuclei, for high energy CR physics

Do we see electrons/photons?



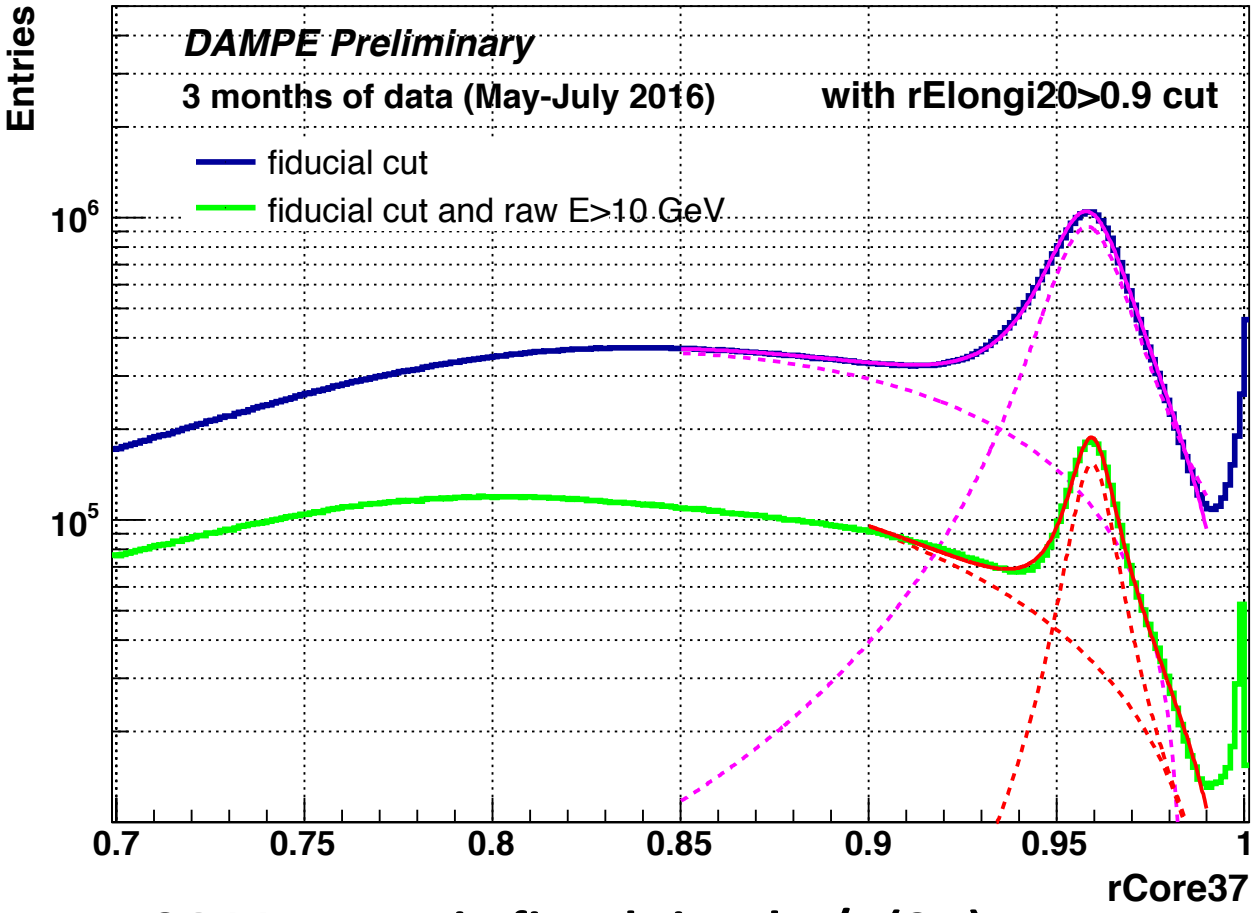
Simple lateral shower shape variable: rEcore37 = ratio of energy in 3 bars/7 bars around the shower axis

PRELIMINARY

- **~24 M events in fitted e/γ signal (2σ) in full energy range**
  - **~2.2 M events in e/γ signal region above 10 GeV**

Will collect ~9 M e/γ with energy >10 GeV per year!

Add longitudinal shower shape cut



Simple longitudinal shower shape variable: rElongi20 = ratio of energy in shower max+20 X_0 to total energy

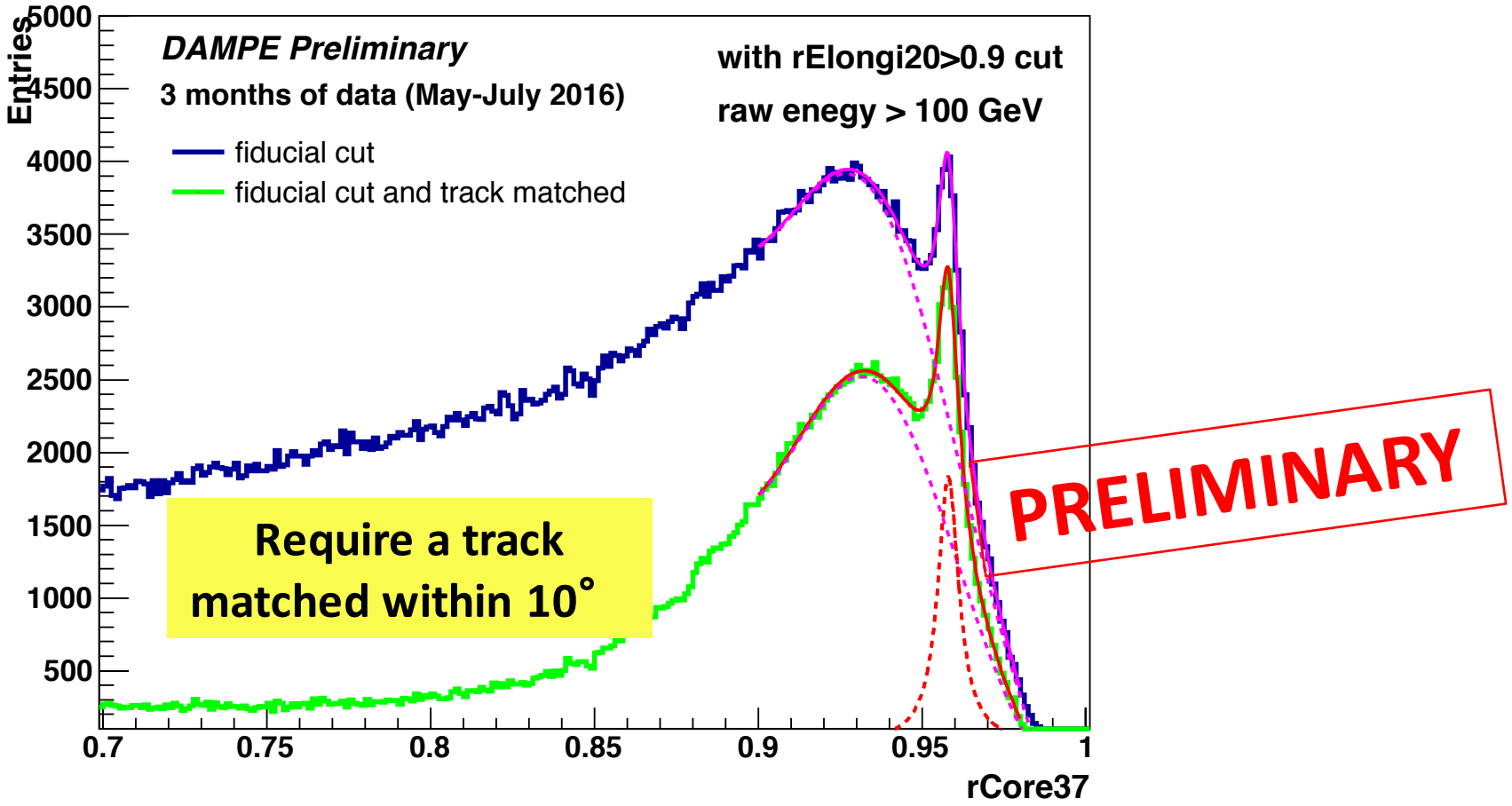
PRELIMINARY

- **~24 M events in fitted signal e/γ (2σ) in full energy range**
  - **~2.2 M events in e/γ signal region above 10 GeV**

Signal stable, s/b improved

But the challenge is at high energy!

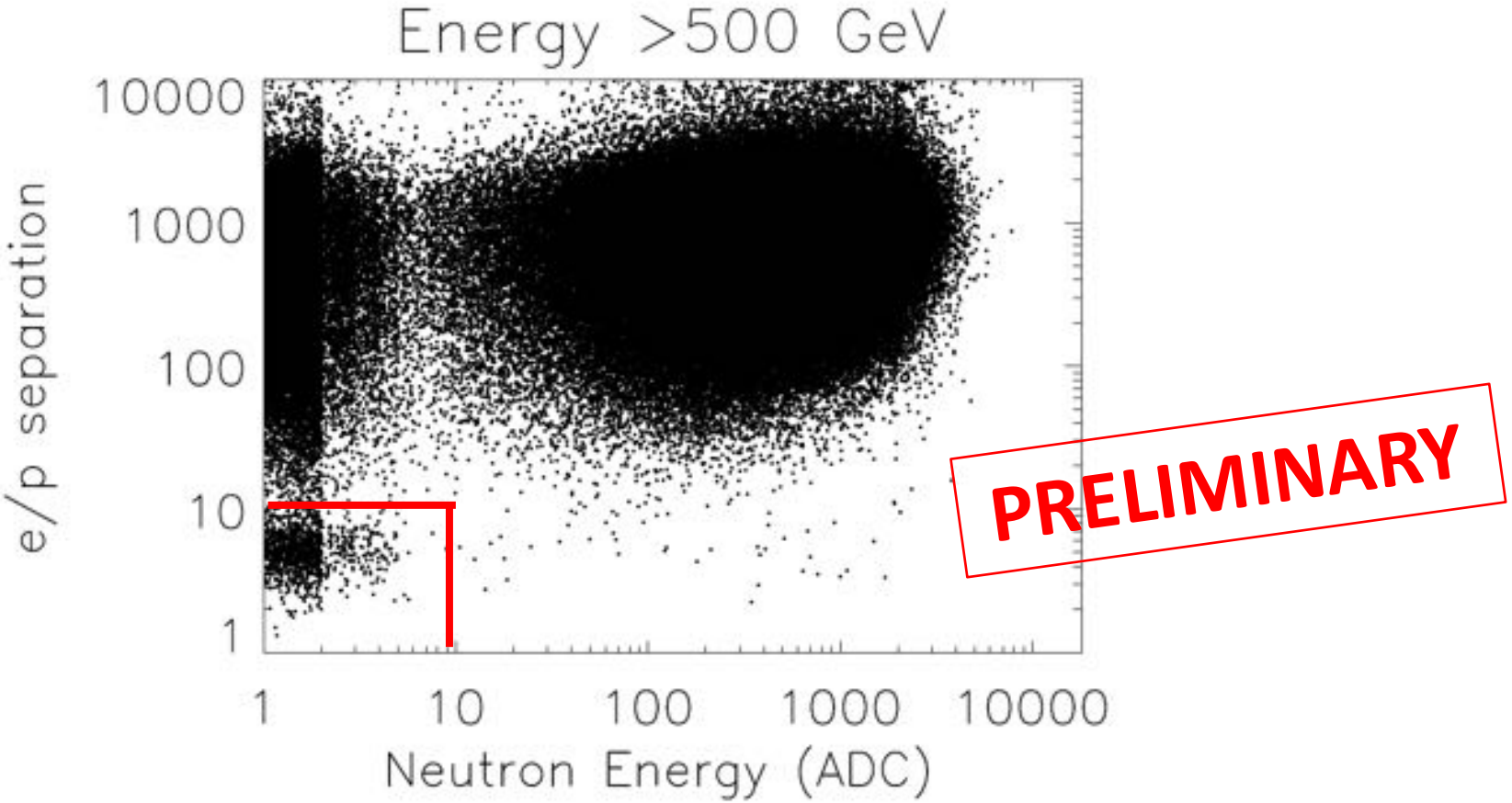
Improvement of s/b with STK



- ~15k events in fitted signal (2σ) with E>100 GeV in 3 months
  - Signal stable with track match cut, s/b improved

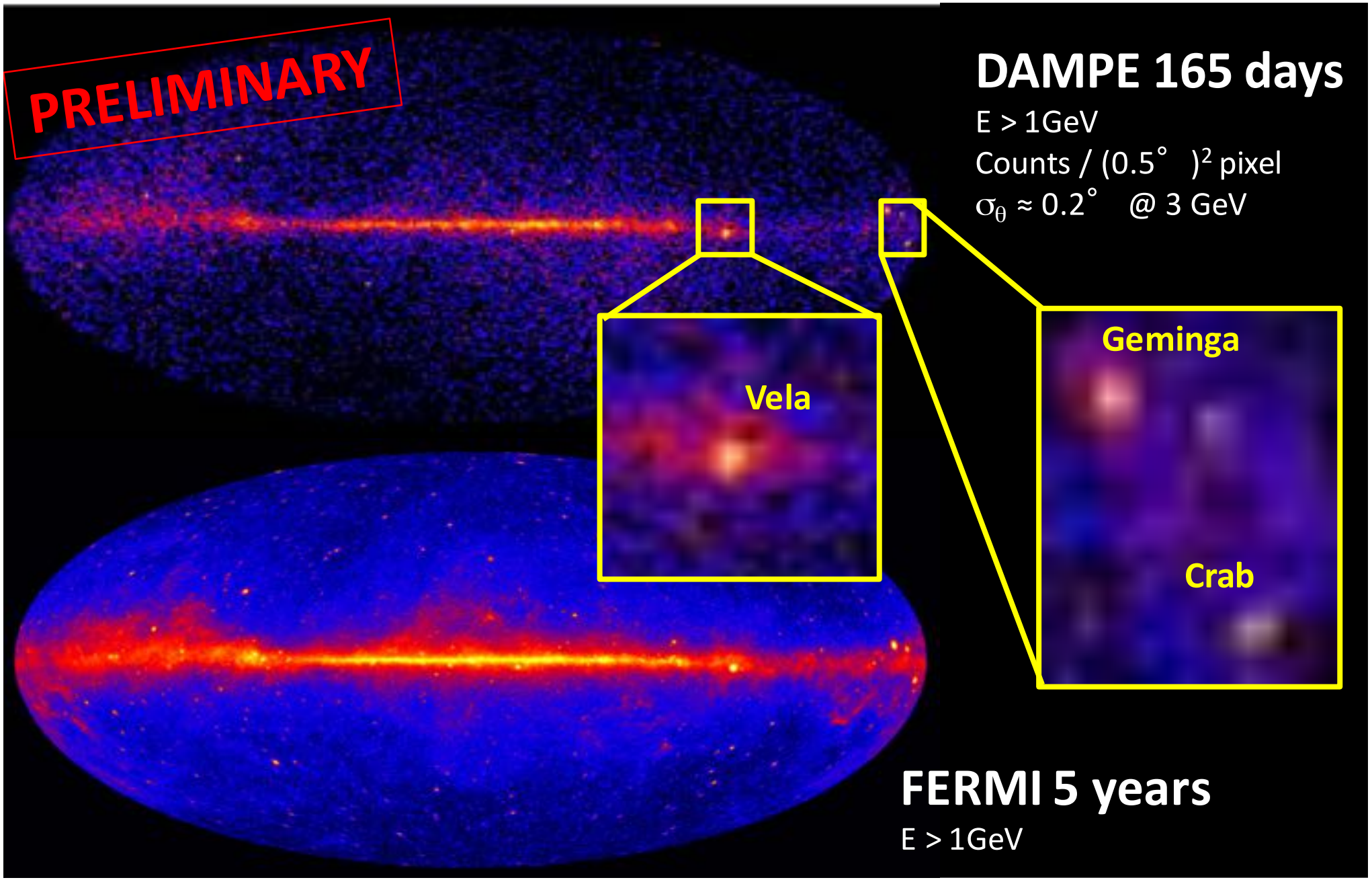
More powerful methods exploiting the full detector capability have been developed and being tested

Improvement of e/p with NUD



Neutron Detector has a factor ~10 proton rejection power at high energy

Gamma rays observed!



Conclusions

- DAMPE is a powerful space telescope for high energy electron, γ-ray, and cosmic rays, in operation!
  - Detector has been well calibrated before launch
- On-orbit commissioning has completed
  - A short commissioning period thanks to the robust detector technologies and the high quality of construction
- Smooth continues and a large amount of good quality data is being collected
- First pass calibration and event reconstruction software is in place
  - Electrons, gamma rays and nuclei are observed
  - TeV particle identification in space is a new challenge and dedicated algorithms are being developed

Please stay tuned for exciting results with "TeV particles" from DAMPE, hopefully soon!