December 5 LHCC Follow-up

CMS Site

- C. Alpigiani, A. Ball, H. Lubatti and C. Young meet with CERN civil engineer Johnathan Gall to discuss MATHUSLA100 at P5. Specifically we asked about excavating 10 to 20 meters and the CMS site, which would have several advantages. Slight improvement in solid angle (acceptance), results in a less obstructive structure and may help with thermal stability.
- We gave Johnathan a basic overview of the MATHUSLA footprint and need for services. Johnathan will look into detail, but did not immediately see a major problems with excavation to some, to be determined depth, below the surface or with providing services (power, gas etc.) to the area.
- We asked Johnathan to look into costs for a building to cover MATHUSLA that would include space for constructing the ~10mX10m detector units and installing them as they are completed
- We will continue to interact with Johnathan and other CERN civil engineers familiar with Point5 to explore in more detail the civil engineering work.

Correlating With Main Detector

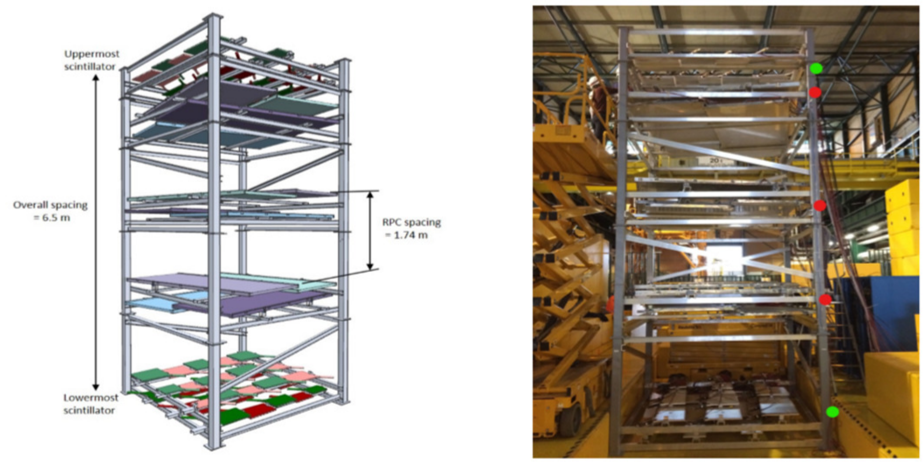
- We verified with ATLAS and CMS trigger groups the feasibility of reading out the main detector using a trigger from MATHUSLA
- Need to readout multiple bunches in the main detector in order to cover the range of time correlation possible between a MATHUSLA event and the corresponding one in ATLAS or CMS,.
- Not a problem for either LHC detectors give the long trigger latencies foreseen for HL-LHC operation.

Demonstrator Unit

- The MATHUSLA100 base line envisages 10mX10mX25m units that have a 10mX10mX20m decay volume with a 10mX10mX5m comprised of tracking stations at the top and a tracking layer at the bottom.
- For tracking layers we are evaluating both RPCs and extruded scintillator bars with wave length shifting fibers coupled to SiPM that operates with order 60 V bias.
  - Extruded scintillator bars have been used to replace RPCs for forward muon detectors by Bell-II
  - Extrusion facilities at FNAL are capable of producing 200 tons of extruded bars per year with rwo-shift operation.
  - A commercial factory in Illinois is also available.
  - Scintillator tracking units remove need for a gas system, high voltages and are relatively insensitive to temperature and pressure variations.
- Given the large area we need to cover reducing unit costs is a necessity.
  - We are investigating low cost front-end electronic options that could work with either scintillators or RPCs.
  - The low rate environment (biggest rate are from cosmic rays) allows for the possibility of low-cost frontend electronics.
- Our plan is to build a ~10mX10mX5m demonstrator unit of the tracking volume to test various options and define fabrication and assembly processes tailored to large unit volume production.
- For RPCs we intend to work on developing new fabrication techniques to significantly reduce unit costs
- We are preparing a request to the Simons foundation for funds to build the demonstrator unit.

Analysis framework developed

- Developed a test-stand analysis frame work that allows access RPC and scintillator data.
- Includes geometry information and good run list.
- Timing calibrations performed and integrated into framework
- Tracking algorithms have been written.
  - Algorithm fits space points and time.
  - More testing in progress
- Event display written and being tested.

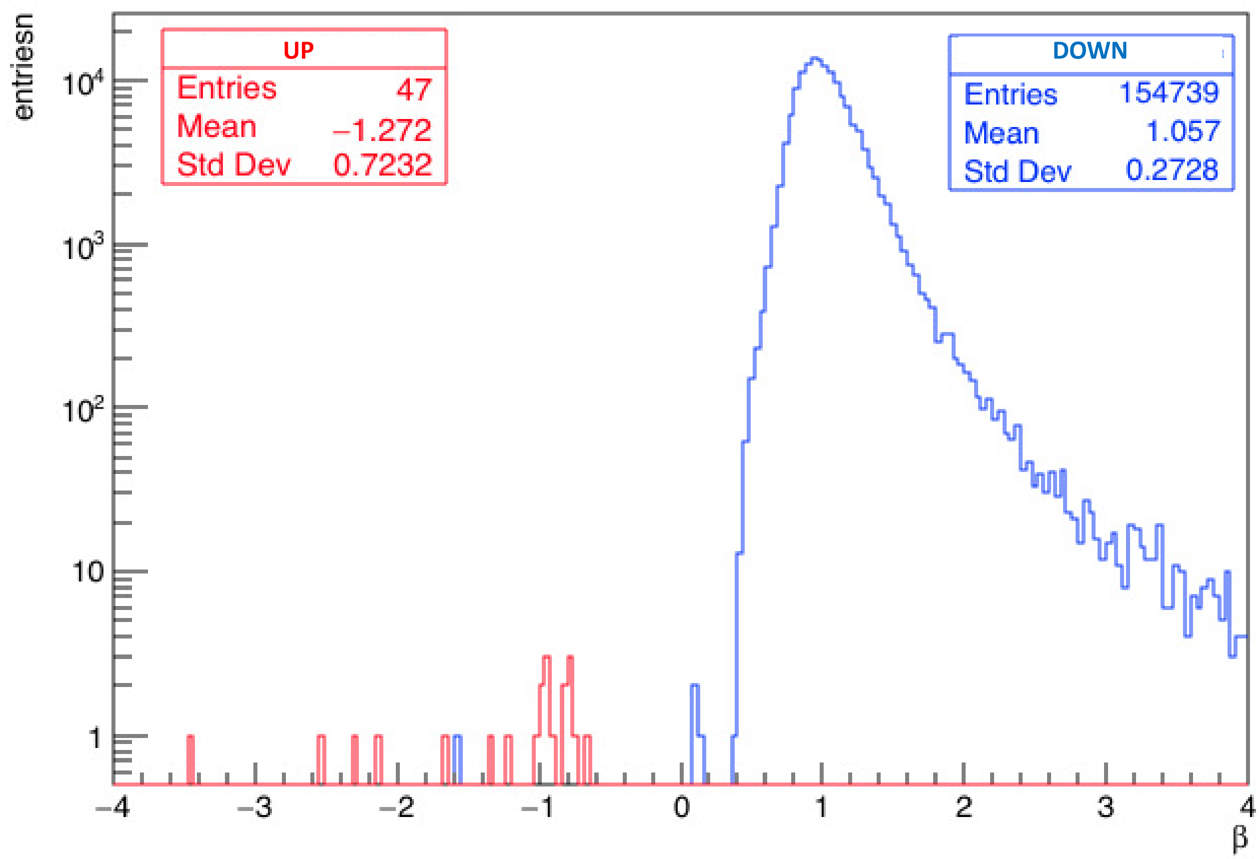


(a) (b)

MATHUSLA Test Stand. a) shows the layout of the DZERO scintillators art top and bottom) of the test stand and the Argo-YBJ RPCs in 3 layers in between. The size of the test stand Covers 2.5 m^2, and is about 6.5 m tall. b) shows a picture of the test stand installed in the ATLAS SX1 building. The green and reds dots indicate scintillator planes and RPC stations, respectively.

Test-Stand Analysis

- Dominant rate is downward-going cosmic rays.
- Noise and other fakes are minor perturbation on this rate.
- True upward-going rate is expected to be small.
- Fakes are not necessarily a small contribution and not trivial to reject with only three RPC planes.
- Strong evidence of upward-going tracks.
  - Velocity distribution from one run (~1 hour) on next page.
- Rate scales with luminosity.
- Need to understand acceptance and efficiency before we can make meaningful comparison with expectations.



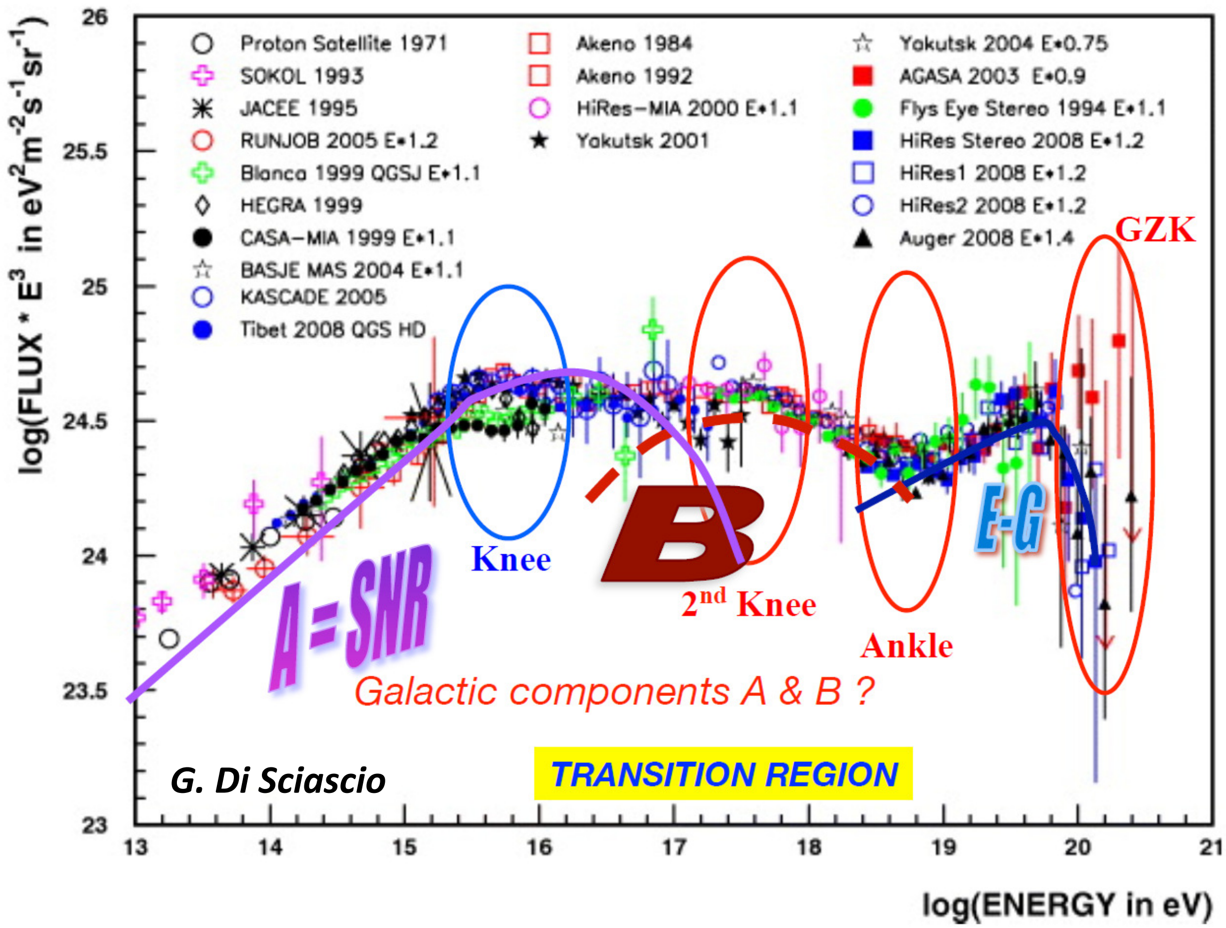
entriesn
UP
Entries 47
Mean −1.272
Std Dev 0.7232
DOWN
Entries 154739
Mean 1.057
Std Dev 0.2728
10^4
10^3
10^2
10
1
−4
−3
−2
−1
0
1
2
3
4
β

Cosmic Ray Physics

- MATHUSLA100 located at an altitude corresponding to an atmospheric depth of about 1000 g/cm^2 has high efficiency for cosmic ray events in the interval 10^{15} - 10^{18} eV.
- MATHUSLA100 standalone measurements of arrival times, individual trajectories and the spatial distributions of charged particles in the extended air shower (EAS) front.
  - Provides estimate of the shower core, the direction of the shower axis (zenith, and azimuth), slope of the radial distribution of particle densities (also known as shower age, s) and the total number of charged particles (shower size) of the EAS event.
  - The shower size is connected to the energy of the cosmic ray primary and the shower age is sensitive to the type of primary nuclei.
  - Only the ARGO-YBJ detector and the KASCADE detectors, neither of which are active, provided muon tracking and measurements of the temporal/spatial-structure of the front of air showers.
  - ARGO-YBJ detector had only one plane of detectors
  - KASCADE, a surface detector, covered only 1-2% of the 40,000 m^2 area with detectors.
  - The MATHUSLA100 good granularity and ~ 80% coverage of the 10,000 m^2 area allows us to measure the shape of the lateral density distribution of EAS at the shower front, which is new information.
- MATHUSLA100 measurements combined with the LHC underground detector measurements provides important information about the muon component of the EAS
  - EAS information on high-energy muons in the range 50 to 70 GeV for vertical incidence is an important observable for the analyses of cosmic ray composition.
  - KASCADE, also a surface detector, covered a larger area than MATHUSLA100 (40,000 vs 10,000 m2) but had <2% coverage to be compared with about 80% active coverage for MATHUSLA100
- The range 10^{14} - 10^{18} eV crucial for understanding origin of Galactic Cosmic Rays and the transition from Galactic to extra-galactic CRs.

The all-particle energy spectrum measured by many detectors

- Lots of structure in current measurements
- Good measurements in the energy range 10^{15} to 10^{17} eV necessary for understandin[g] where contributions from Galactic cosmic r[ays] (CR) end and extra Galactic contributions b[egin]
- Our cosmic ray experts claim that understanding the origin of the knee at 3-4 PeV may be the main open problem in cosmic ray (CR) physics.
  - could be due to the end of the galactic compo[nent] or the maximum energy from a single class of sources for example, supernovae.
  - Or another class of galactic CR sources that ca[n] accelerate particles up to about 10^{17} eV.
  - Sorting this out requires high statistics and go[od] measurements to establish the chemical com[position of] source radiation and the distribution of direct[ions of] incident particles.



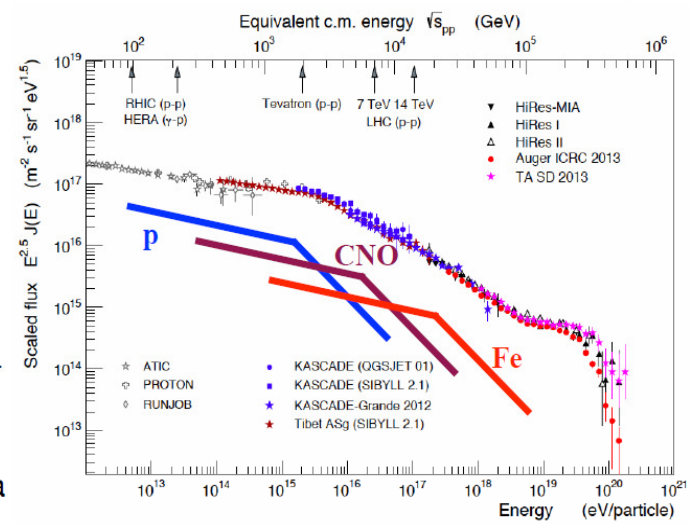
Cosmic Ray Physics with MATHUSLA

- The nearly full coverage of MATHUSLA100 has several advantages
  - males possible a lower energy threshold energy ~100 GeV compared to KASCADE who's threshold was ~ 1 PeV.
  - With lower threshold can eventually compare to satellite measurements (CREAM, Calet, HERD)
  - WE need to quantify how well we can determine the number of charged particles in order to extract the energy.
  - Obtain good measurement the lateral distribution of showers, which gives another parameter for estimating the energy and separate contributions of primary masses based on topological distribution of secondary particles as was done by ARGO.
- With the ability to measure several different parameters it should be possible to separate with decent statistics p+He, intermediate mass nuclei and Fe up to 10^{16} eV.
  - NB KASCADE-Grande was only able to extract light and heavy nuclei information
- MATHUSLA' S multiple tracking layers may help to understand the energy spectrum.
- MATHUSLA may be able to measure shower energies above a PeV (~10^{17} eV) provided we can extend the linearity of analog measurements by a factor of 10 greater than ARGO, which would allow us to reach ~ 50 PeV – this needs to be verified by careful simulation studies

Approaching the '*knee*'

The standard model (mainly driven by KASCADE results):

- Knee attributed to light (proton, helium) component
- Rigidity-dependent structure (Peters cycle): cut-offs at energies proportional to the nuclear charge $E_Z = Z \times 4$ PeV
- The sum of the flux of all elements with their individual cut-offs makes up the all-particle spectrum.
- Not only does the spectrum become steeper due to such a cutoff but also heavier.



Determining elemental composition in the 10^{14} - 10^{18} eV range is crucial to understand where Galactic CR spectrum ends

If the mass of the knee is *light* according to the standard model
➜ Galactic CR spectrum is expected to end around 10^{17} eV

If the composition at the knee is *heavier* due to CNO / MgSi
➜ we have a problem !

G. Di Sciascio

BACKUP

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KASCADE and KASCADE-Grande

- Large surface array study the cosmic ray primary composition and the hadronic interactions in the energy range of 10^{16}–10^{18} eV and
- High threshold energy complicated the energy-size calibration of the shower because they did not overlap with satellite measurements
- They used muons to study the elemental composition, but muon measurements were made with relatively small area detectors.

Cosmic Ray Physics

- The range 10^{14} - 10^{18} eV crucial for understanding origin of Galactic Cosmic Rays and the transition from Galactic to extra-galactic Cosmic Rays.
- The 10^{16} - 10^{18} eV range is a transition region with different spectral features: elemental composition crucial
- KASCADE: model-dependent results, at the knee results are in conflict with other experiments (ARGO, CASA-MIA, Tibet Array, BASJE-MAS). Above the knee: low statistics.
    - We note that the surface detector KASCADE had four times the area of MATHUSLA100, but only a 2% of the area was instrumented.
- Based on the ARGO-YBJ results, the RPC charge readout crucial to study hadronic interactions in the very forward region and to investigate elemental composition with a nearly-model independent technique (NO muons!).
- MATHUSLA is important for checking the ARGO approach at sea level and to investigate unknown systematic uncertainties associated to shower measurements.