Hawaii Muon Beamline in detail

Chris Ketter
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Shivang Tripathi
Gary Varner
Salvador Ventura

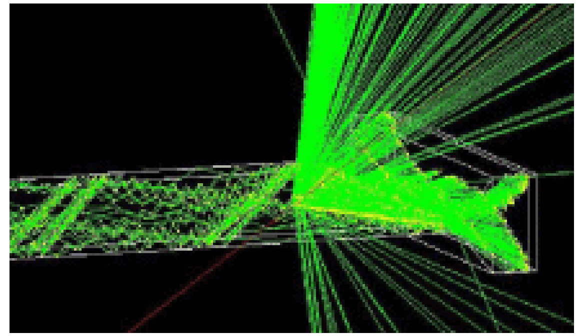
And many former and future members

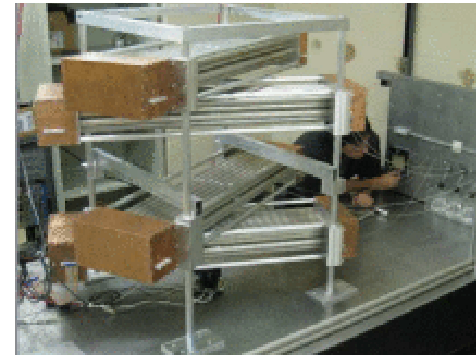
Motivations:

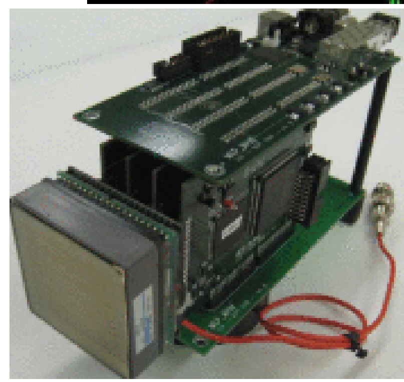
- **Number of beamlines world-wide limited**
- **Want to ensure everything working/tuned before travel**
- **Training platform**

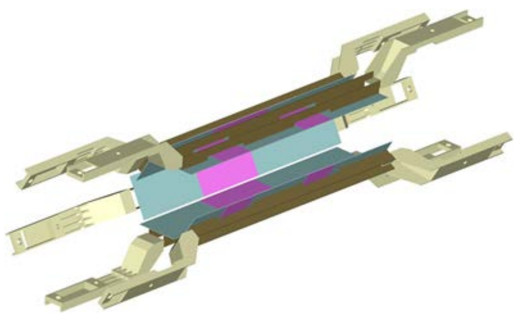
Hawaii Muon Beamline (HMB) v1

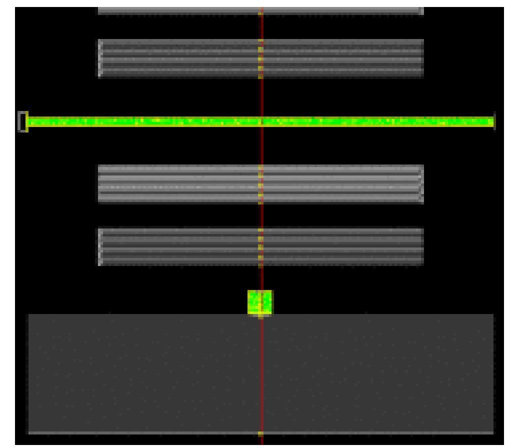
- **Version 1 (drift tubes)**
  - iTOP prototype development
  - Cluster counting
  - Fine-mesh PMTs + scint (T0)
  - Poster on next slide

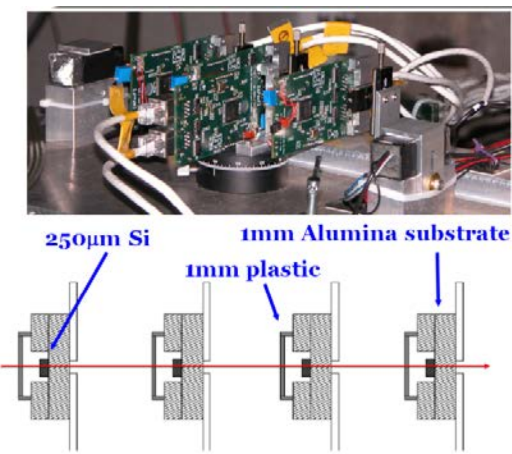


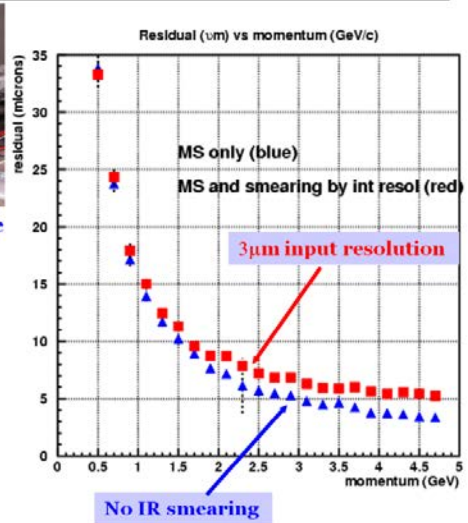


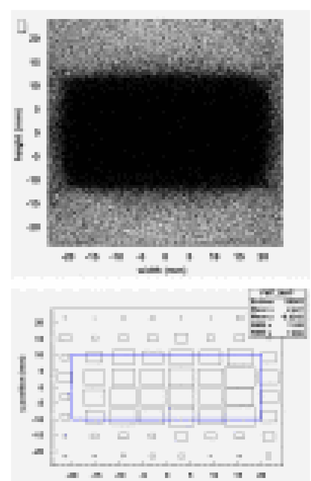


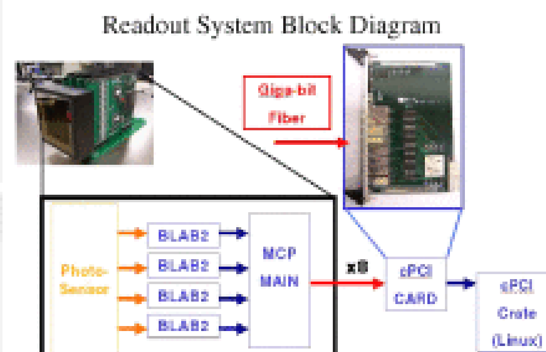


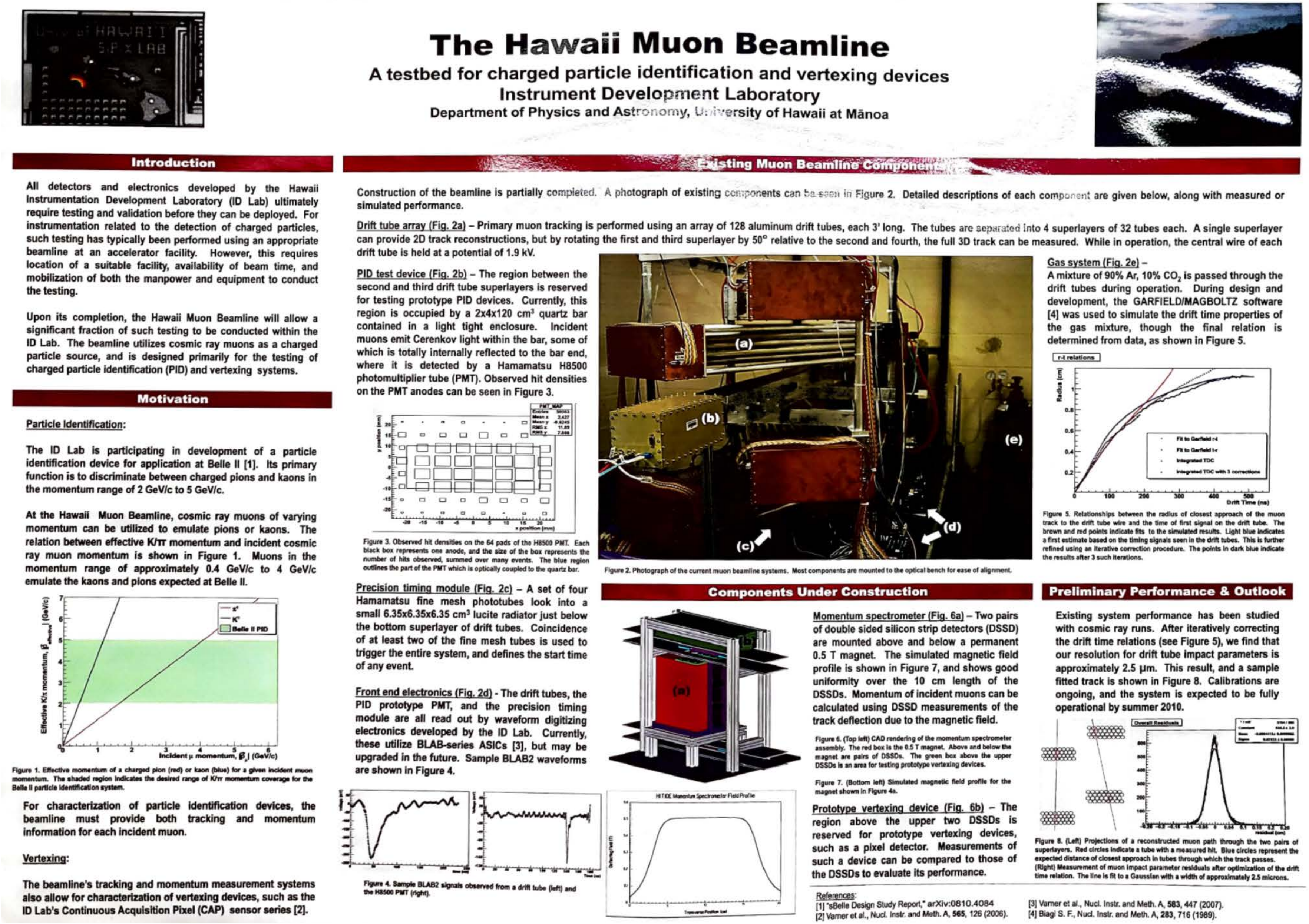












The Hawaii Muon Beamline

A testbed for charged particle identification and vertexing devices

Instrument Development Laboratory
Department of Physics and Astronomy, University of Hawaii at Mānoa

Introduction

All detectors and electronics developed by the Hawaii Instrumentation Development Laboratory (ID Lab) ultimately require testing and validation before they can be deployed. For instrumentation related to the detection of charged particles, such testing has typically been performed using an appropriate beamline at an accelerator facility. However, this requires location of a suitable facility, availability of beam time, and mobilization of both the manpower and equipment to conduct the testing.

Upon its completion, the Hawaii Muon Beamline will allow a significant fraction of such testing to be conducted within the ID Lab. The beamline utilizes cosmic ray muons as a charged particle source, and is designed primarily for the testing of charged particle identification (PID) and vertexing systems.

Motivation

Particle Identification:

The ID Lab is participating in development of a particle identification device for application at Belle II [1]. Its primary function is to discriminate between charged pions and kaons in the momentum range of 2 GeV/c to 5 GeV/c.

At the Hawaii Muon Beamline, cosmic ray muons of varying momentum can be utilized to emulate pions or kaons. The relation between effective K/π momentum and incident cosmic ray muon momentum is shown in Figure 1. Muons in the momentum range of approximately 0.4 GeV/c to 4 GeV/c emulate the kaons and pions expected at Belle II.

Figure 1. Effective momentum of a charged pion (red) or kaon (blue) for a given incident muon momentum. The shaded region indicates the desired range of K/π momentum coverage for the Belle II particle identification system.

For characterization of particle identification devices, the beamline must provide both tracking and momentum information for each incident muon.

Vertexing:

The beamline's tracking and momentum measurement systems also allow for characterization of vertexing devices, such as the ID Lab's Continuous Acquisition Pixel (CAP) sensor series [2].

Existing Muon Beamline Components

Construction of the beamline is partially completed. A photograph of existing components can be seen in Figure 2. Detailed descriptions of each component are given below, along with measured or simulated performance.

Drift tube array (Fig. 2a) – Primary muon tracking is performed using an array of 128 aluminum drift tubes, each 3' long. The tubes are separated into 4 superlayers of 32 tubes each. A single superlayer can provide 2D track reconstructions, but by rotating the first and third superlayer by 50° relative to the second and fourth, the full 3D track can be measured. While in operation, the central wire of each drift tube is held at a potential of 1.9 kV.

PID test device (Fig. 2b) – The region between the second and third drift tube superlayers is reserved for testing prototype PID devices. Currently, this region is occupied by a 2x4x120 cm³ quartz bar contained in a light tight enclosure. Incident muons emit Cerenkov light within the bar, some of which is totally internally reflected to the bar end, where it is detected by a Hamamatsu H8500 photomultiplier tube (PMT). Observed hit densities on the PMT anodes can be seen in Figure 3.

Figure 3. Observed hit densities on the 64 pads of the H8500 PMT. Each black box represents one anode, and the size of the box represents the number of hits observed, summed over many events. The blue region outlines the part of the PMT which is optically coupled to the quartz bar.

Precision timing module (Fig. 2c) – A set of four Hamamatsu fine mesh phototubes look into a small 6.35x6.35x6.35 cm³ lucite radiator just below the bottom superlayer of drift tubes. Coincidence of at least two of the fine mesh tubes is used to trigger the entire system, and defines the start time of any event.

Front end electronics (Fig. 2d) - The drift tubes, the PID prototype PMT, and the precision timing module are all read out by waveform digitizing electronics developed by the ID Lab. Currently, these utilize BLAB-series ASICs [3], but may be upgraded in the future. Sample BLAB2 waveforms are shown in Figure 4.

Figure 4. Sample BLAB2 signals observed from a drift tube (left) and the H8500 PMT (right).

Figure 2. Photograph of the current muon beamline systems. Most components are mounted to the optical bench for ease of alignment.

Gas system (Fig. 2e) – A mixture of 90% Ar, 10% CO_2 is passed through the drift tubes during operation. During design and development, the GARFIELD/MAGBOLTZ software [4] was used to simulate the drift time properties of the gas mixture, though the final relation is determined from data, as shown in Figure 5.

Figure 5. Relationships between the radius of closest approach of the muon track to the drift tube wire and the time of first signal on the drift tube. The brown and red points indicate fits to the simulated results. Light blue indicates a first estimate based on the timing signals seen in the drift tubes. This is further refined using an iterative correction procedure. The points in dark blue indicate the results after 3 such iterations.

Components Under Construction

Momentum spectrometer (Fig. 6a) – Two pairs of double sided silicon strip detectors (DSSD) are mounted above and below a permanent 0.5 T magnet. The simulated magnetic field profile is shown in Figure 7, and shows good uniformity over the 10 cm length of the DSSDs. Momentum of incident muons can be calculated using DSSD measurements of the track deflection due to the magnetic field.

Figure 6. (Top left) CAD rendering of the momentum spectrometer assembly. The red box is the 0.5 T magnet. Above and below the magnet are pairs of DSSDs. The green box above the upper DSSDs is an area for testing prototype vertexing devices.

Figure 7. (Bottom left) Simulated magnetic field profile for the magnet shown in Figure 4a.

Prototype vertexing device (Fig. 6b) – The region above the upper two DSSDs is reserved for prototype vertexing devices, such as a pixel detector. Measurements of such a device can be compared to those of the DSSDs to evaluate its performance.

Preliminary Performance & Outlook

Existing system performance has been studied with cosmic ray runs. After iteratively correcting the drift time relations (see Figure 5), we find that our resolution for drift tube impact parameters is approximately 2.5 μm. This result, and a sample fitted track is shown in Figure 8. Calibrations are ongoing, and the system is expected to be fully operational by summer 2010.

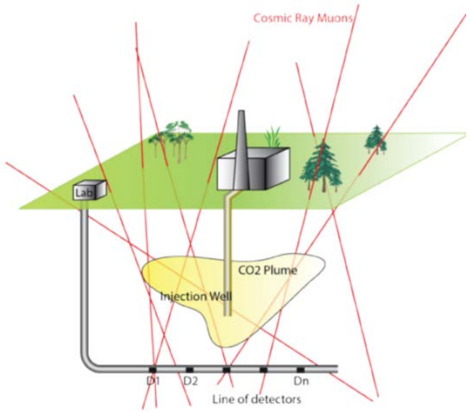
Figure 8. (Left) Projections of a reconstructed muon path through the two pairs of superlayers. Red circles indicate a tube with a measured hit. Blue circles represent the expected distance of closest approach in tubes through which the track passes. (Right) Measurement of muon impact parameter residuals after optimization of the drift time relation. The line is fit to a Gaussian with a width of approximately 2.5 microns.

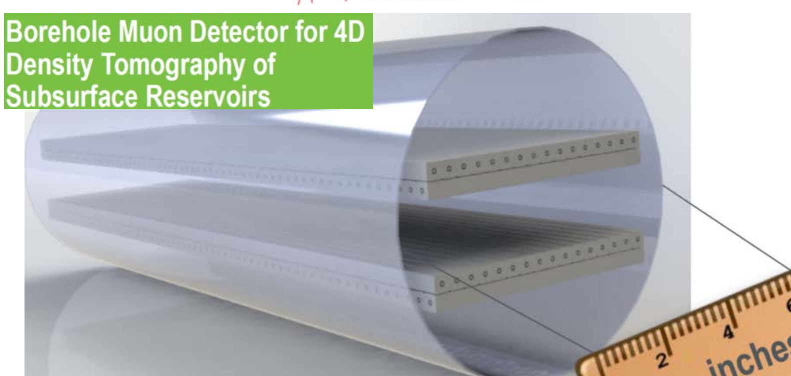
References:
[1] "sBelle Design Study Report," arXiv:0810.4084
[2] Varner et al., Nucl. Instr. and Meth. A, 565, 126 (2006).
[3] Varner et al., Nucl. Instr. and Meth. A, 583, 447 (2007).
[4] Biagi S. F., Nucl. Instr. and Meth. A, 283, 716 (1989).

- Development of an imaging Time-of-Propagation (iTOP) prototype detector, NIM **A623** p. 365 (2010)
- An Imaging time-of-propagation system for charged particle identification at a super B factory, NIM **A623** p. 297 (2010)

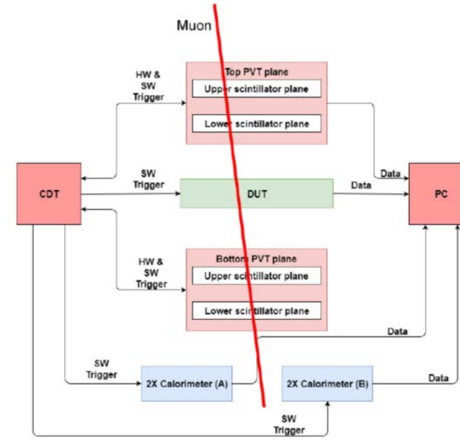
Hawaii Muon Beamline (HMB) v2

- **Version 2 (BMD trackers)**
  - ➢ **Borehole Muon Detector**
  - ➢ **Khahn and James thesis**
  - ➢ **DOE (administration change)**

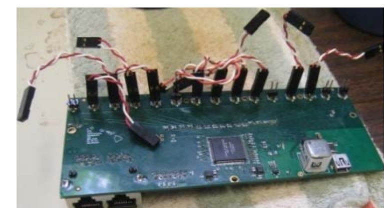


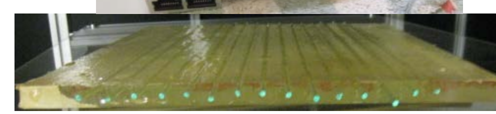


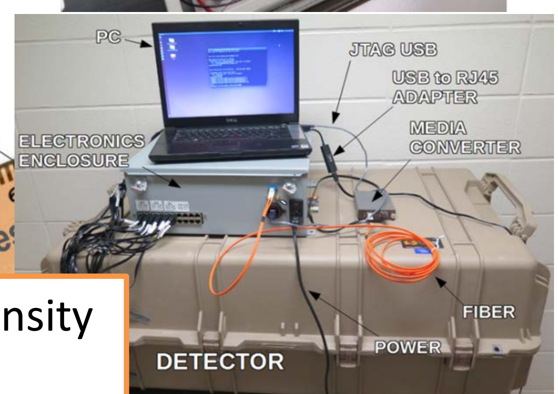
A novel muon detector for borehole density tomography, NIM **A851** p. 108 (2017)



v2 never finished

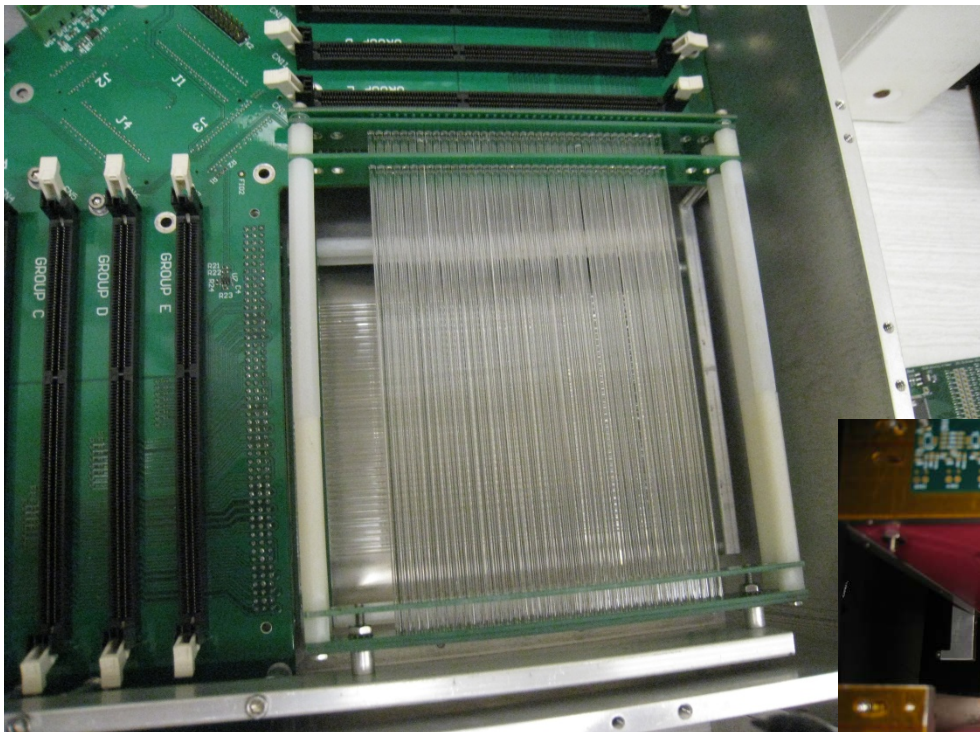


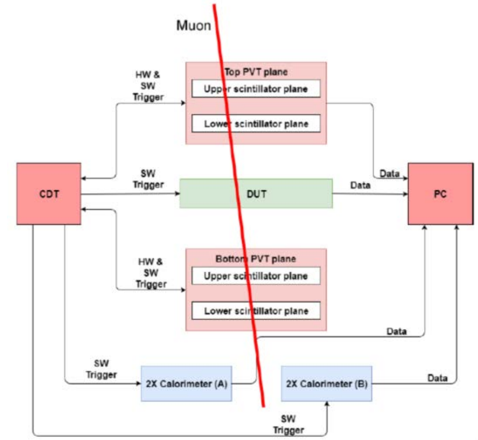




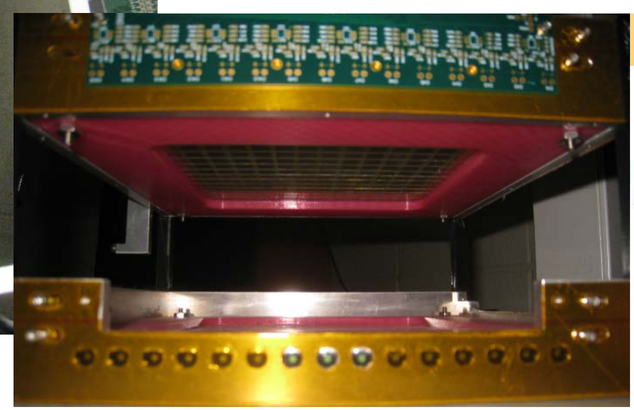
Hawaii Muon Beamline (HMB) v3

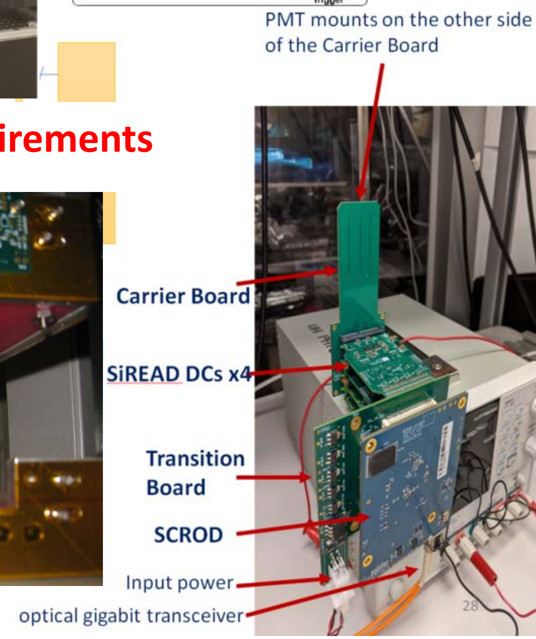
- **Version 3 (scint planes)**
  - **EIC PID readout (Shivang)**





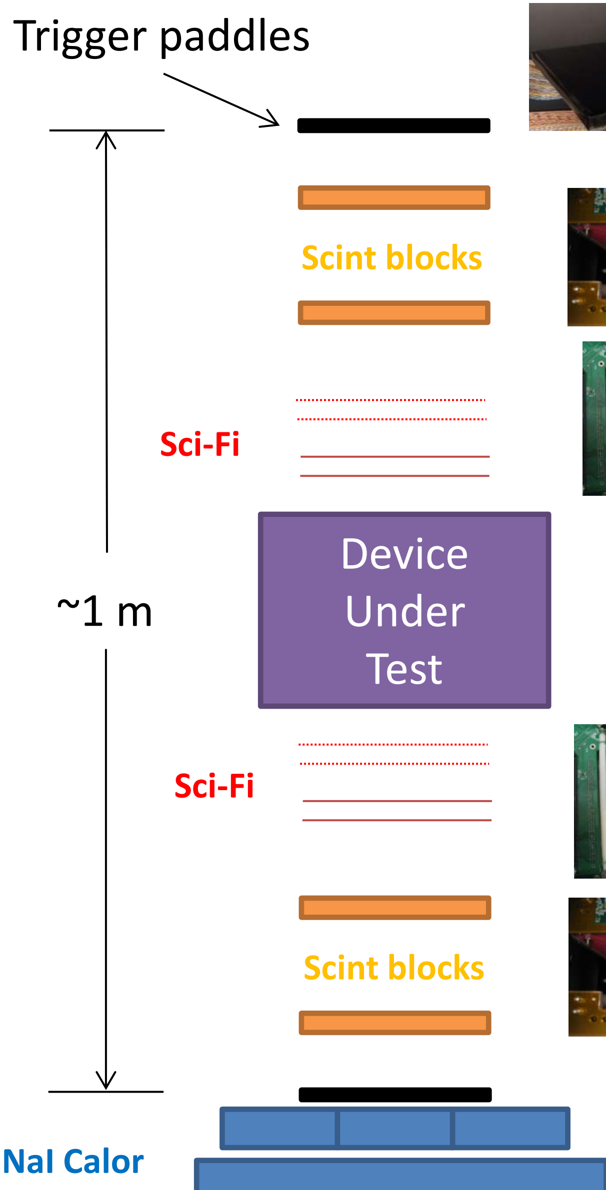
- **Alignment requirements**





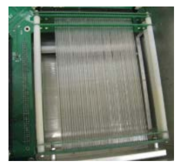
- **Training platform**
  - **Mechanical Design (SolidEdge), Simulation (GEANT4), Pynq (Xilinx/Zynq) python + PL Firmware (Vivado) for DAQ, I/F board (Altium/Allegro), data acquisition (Juptyr notebooks), display (matplotlib), analysis (root)**

General Configuration

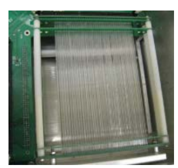


Beam definition (2x)

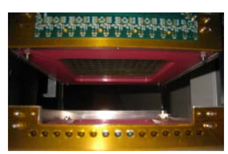
Coarse tracking: 2x 1cm thick plastic scint WLS fiber, both x and y, 1cm pitch (2x2x15 ch.)



Fine tracking: 2mm dia plastic scint fibers, both x and y, ~1.25mm pitch (2x75 ch.)



Fine tracking: 2x 75 channels MPPCs Belle II KLM (ribbon cable) readout



Coarse tracking: 2 x 2 x 15 MPPCs BMD/mRICH hodo (TARGETX) readout

dE/dx for momentum; shower and bremsstrahlung detection

The discovery of radiation

- Discovered by Henri Bequerel in 1896
- Took many years to understand what it was

- Darkening of photographic plate in proximity to a radioactive substance
- **Theme here: whenever a new Instrument is developed, it opens whole new avenues of discovery**
- **Why we are the IDL**

Wulf Electrometer

Electroscopes discharge slowly with time due to weak conductivity in air.

This is caused by ions in the air. Radioactivity produces ions.

How does the ionization of air depend on altitude?

Radioactivity known to occur in materials found in the ground, so …

New Technology For Discovery

What is the nature and origin of natural radioactivity?

Wulf took his electroscope to the top of the Eiffel tower in 1909 and found that the intensity of radiation “decreases at nearly 300 m [altitude to] not even to half of its ground value”. This was too small a decrease to confirm his hypothesis.

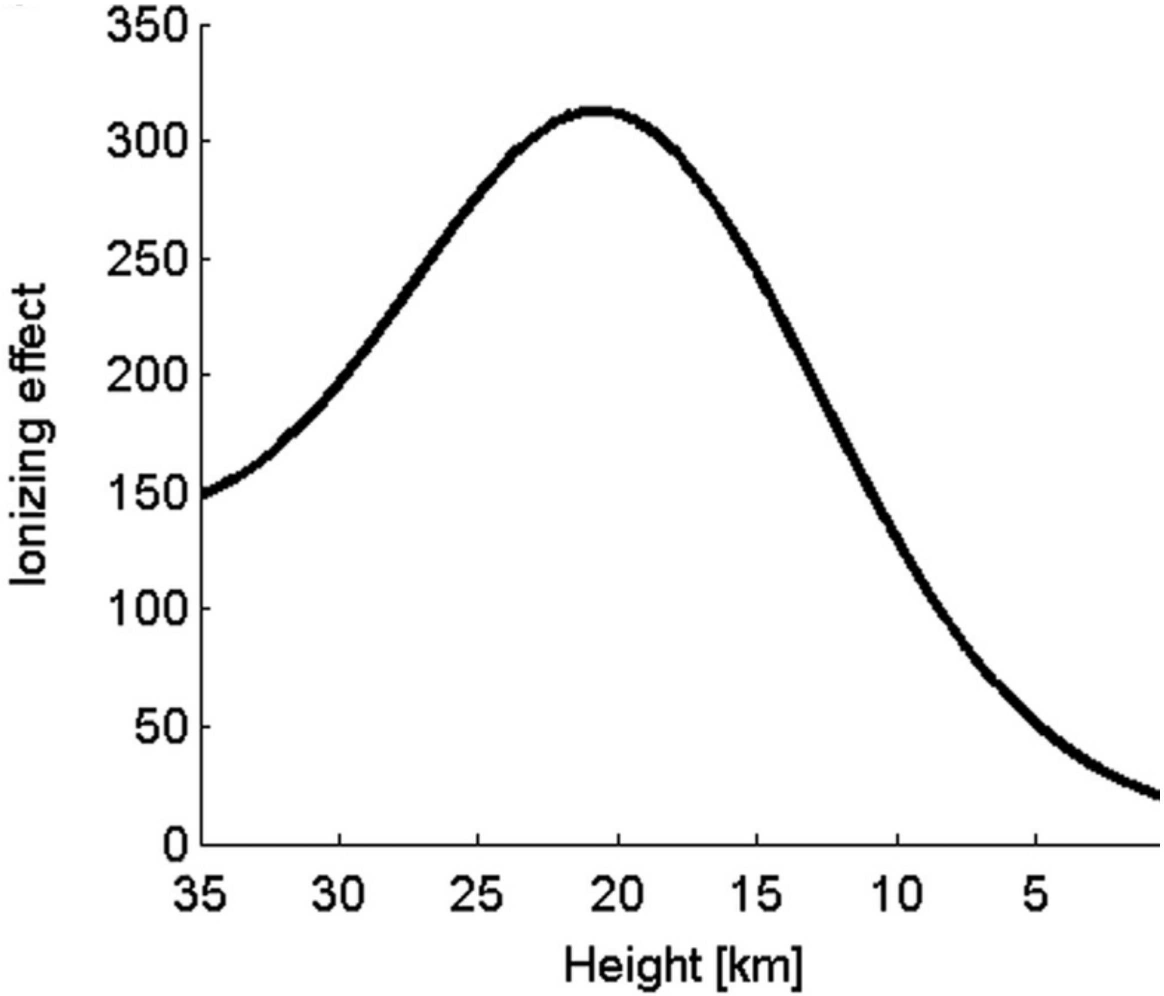
New Technology – Unexpected Results

1912: Hess 5km balloon (improved Wulf {ionizing} chamber)

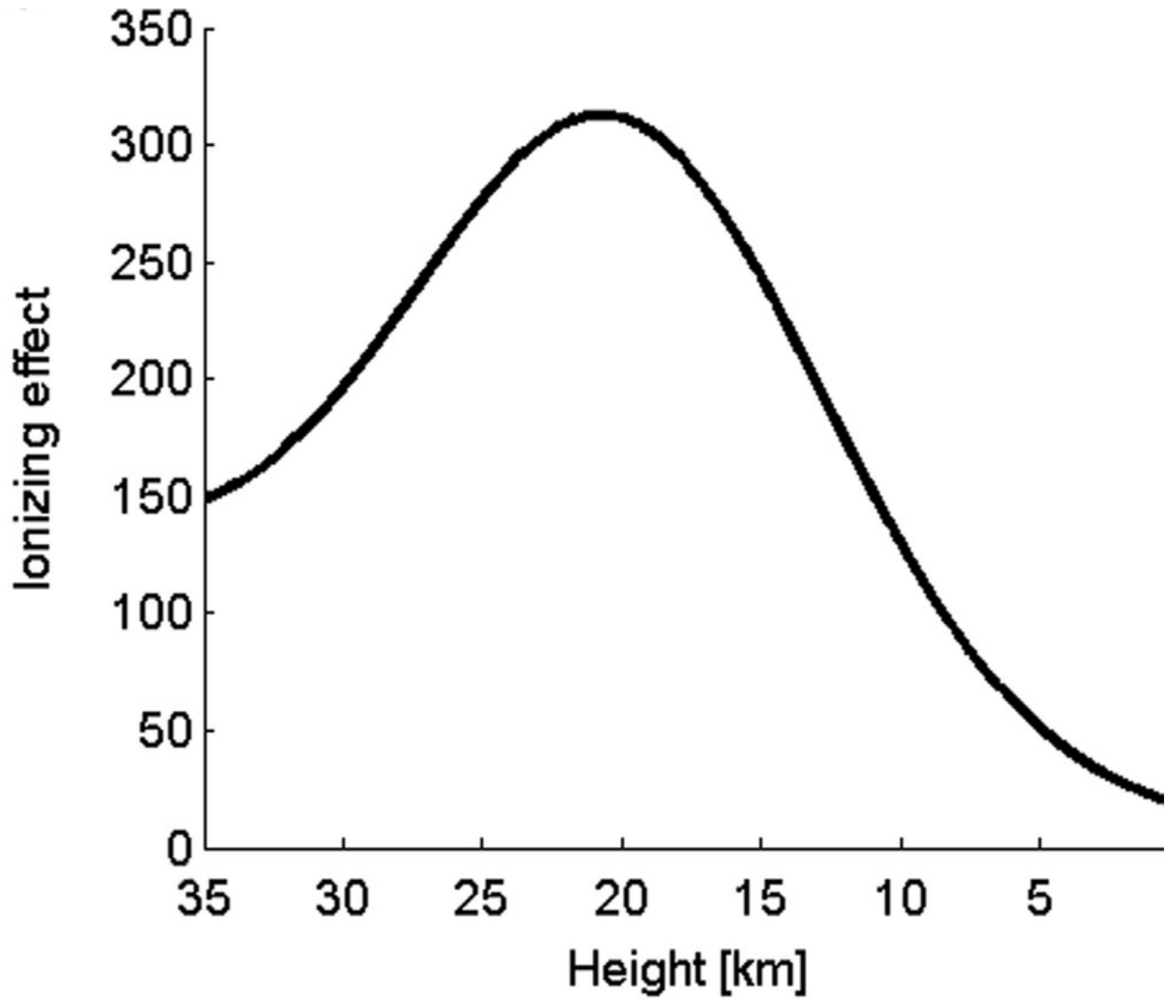
Expectation: “dimunition of ionization as a function of altitude”

– discovers “penetrating radiation”

Ionization Rate vs. Height



Ionization Rate vs. Height



- **Do you know why they are called "cosmic rays" ??**

Origin of the name

The New York Times

VOL. LXXXII....No. 27,370. December 31, 1932

MILLIKAN RETORTS HOTLY TO COMPTON IN COSMIC RAY CLASH

Debate of Rival Theorists Brings Drama to Session of Nation's Scientists.

THEIR DATA AT VARIANCE

New Findings of His Ex-Pupil Lead to Thrust by Millikan at 'Less Cautious' Work.

- **A debate raged over the nature of this radiation.**

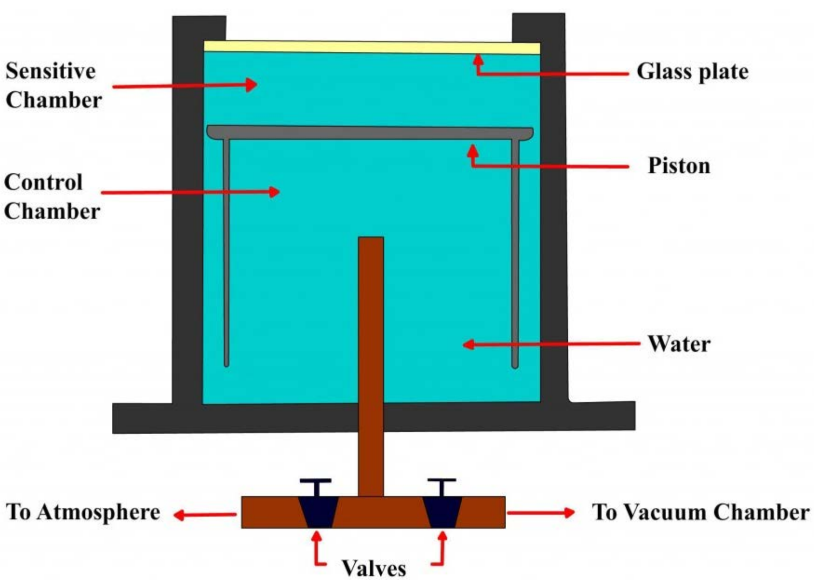
Millikan argued they were γ from space, "cosmic rays"

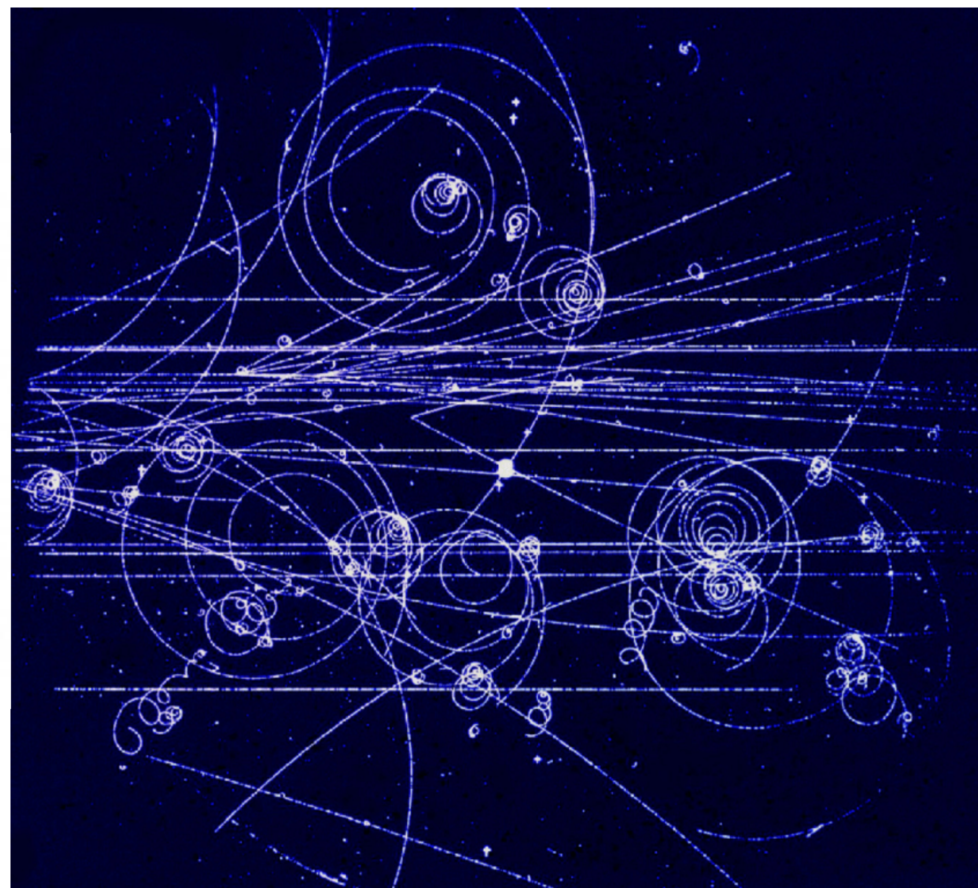
COSMIC RAY RIVALS TO MEET IN DEBATE; Clash of Millikan and Compton Theories to Form High Point at Scientific Convention. 4,500 TO ATTEND SESSIONS Atlantic City Meeting This Week to Hear 1,500 Papers

Next New Technology

1930's: Cloud chamber observations:

- Mounting evidence of energetic particle origin
- Anderson – discovery of the "anti-electron"
- Neddermeyer/Anderson – discovery of the muon



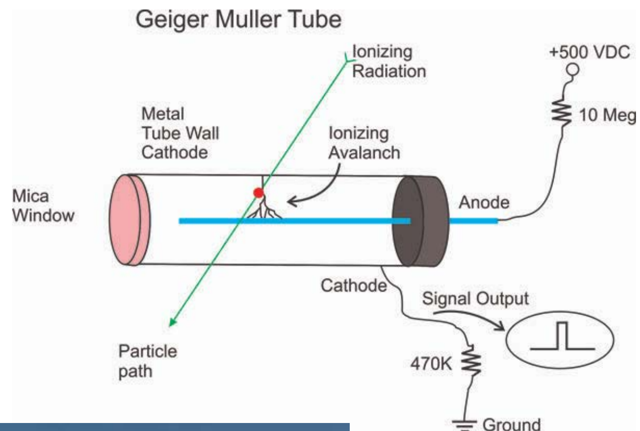


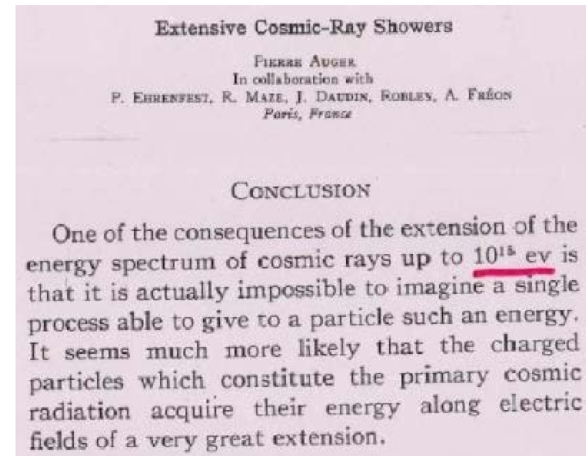
Further technology development

1938: Auger Geiger counter coincidence

- Observation of “extensive air showers”
- Correctly conjectured > 10^{15} eV events

(>10 million times previously observed)

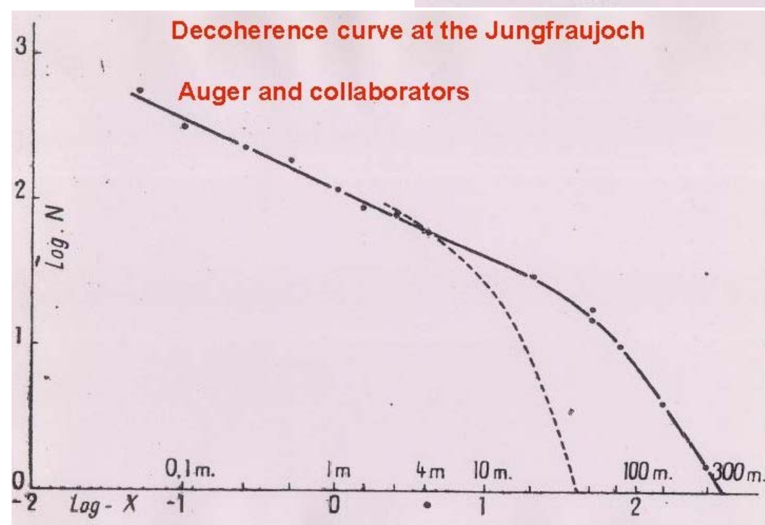



Extensive Cosmic-Ray Showers

Pierre Auger
In collaboration with
P. Ehrenfest, R. Maze, J. Daudin, Robley, A. Fréon
Paris, France

Conclusion

One of the consequences of the extension of the energy spectrum of cosmic rays up to 10^{15} ev is that it is actually impossible to imagine a single process able to give to a particle such an energy. It seems much more likely that the charged particles which constitute the primary cosmic radiation acquire their energy along electric fields of a very great extension.



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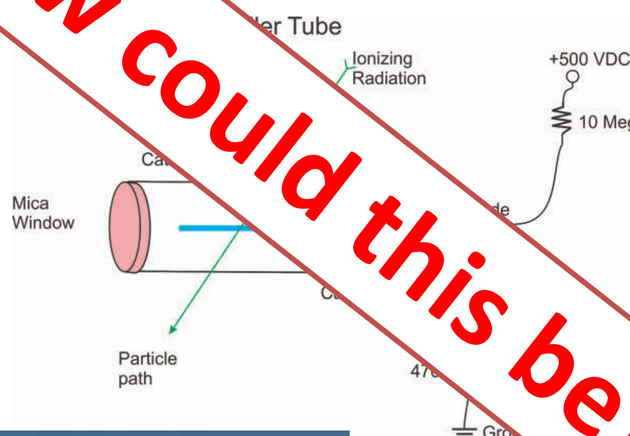
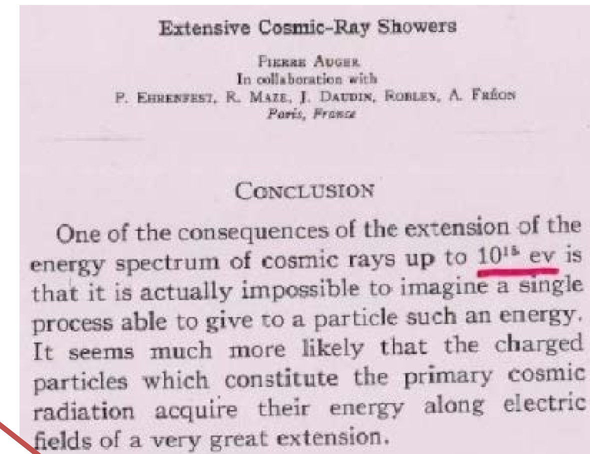
How could this be????

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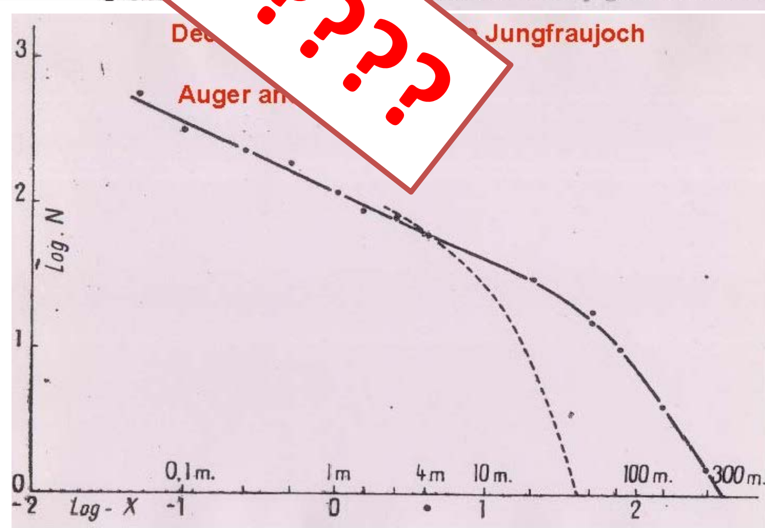


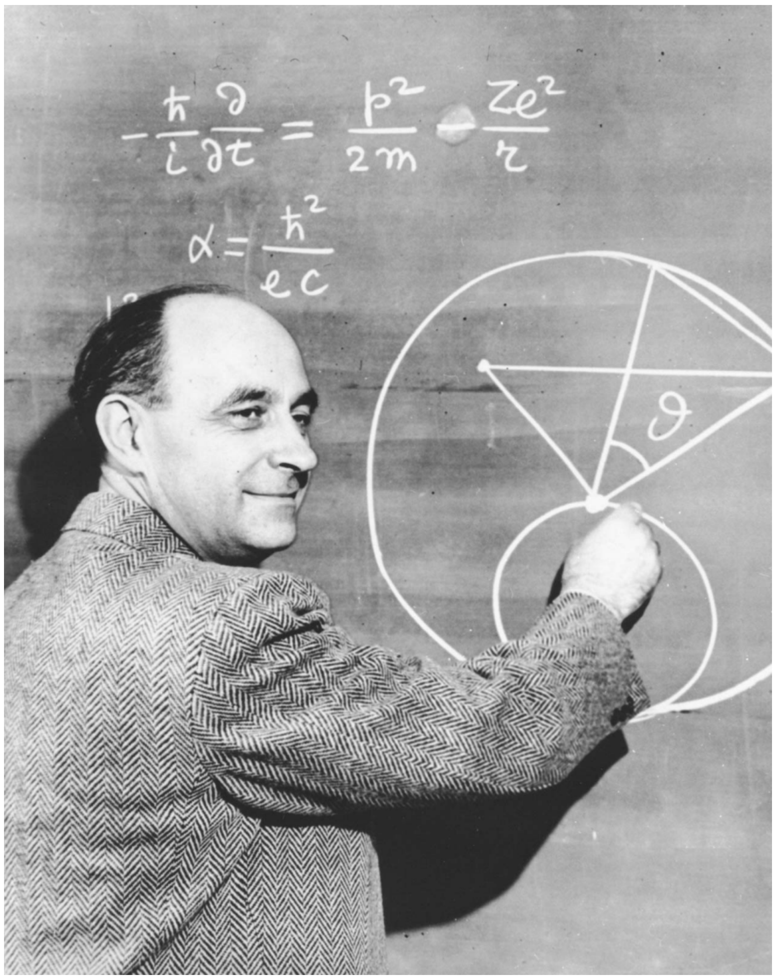
Experimental mysteries ➔ Discovery

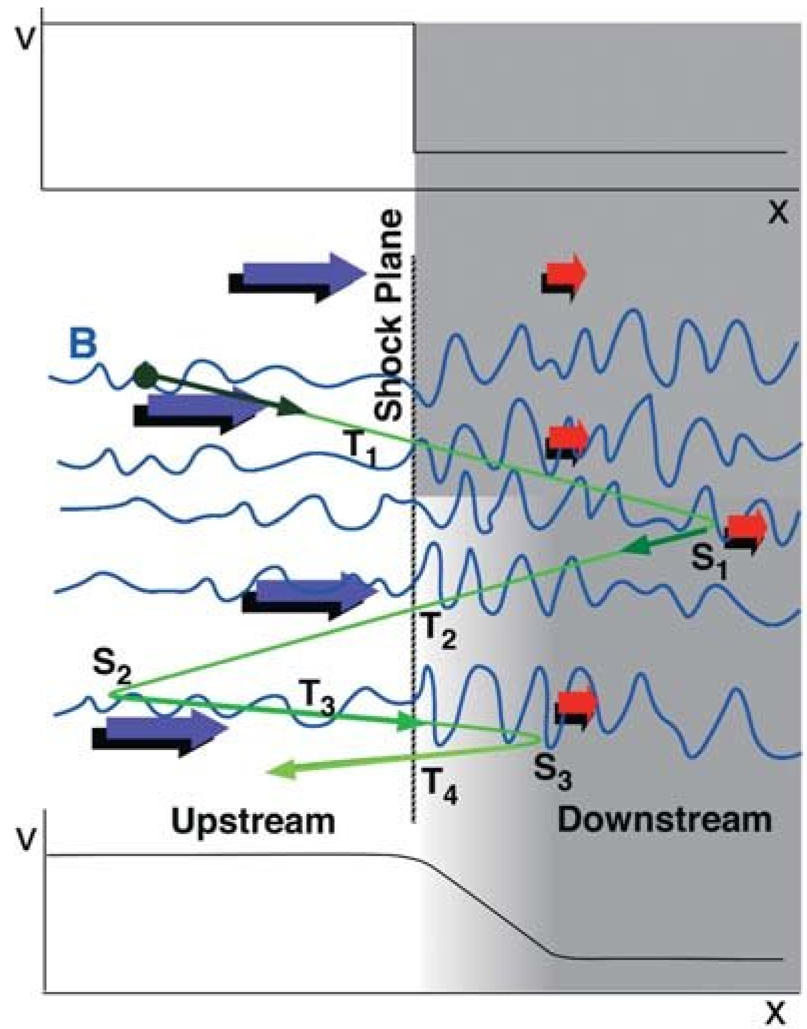
A decade passed without an acceptable solution…

Experimental mysteries ➔ Discovery

A decade passed without an acceptable solution…

1949 Fermi – proposes shock acceleration



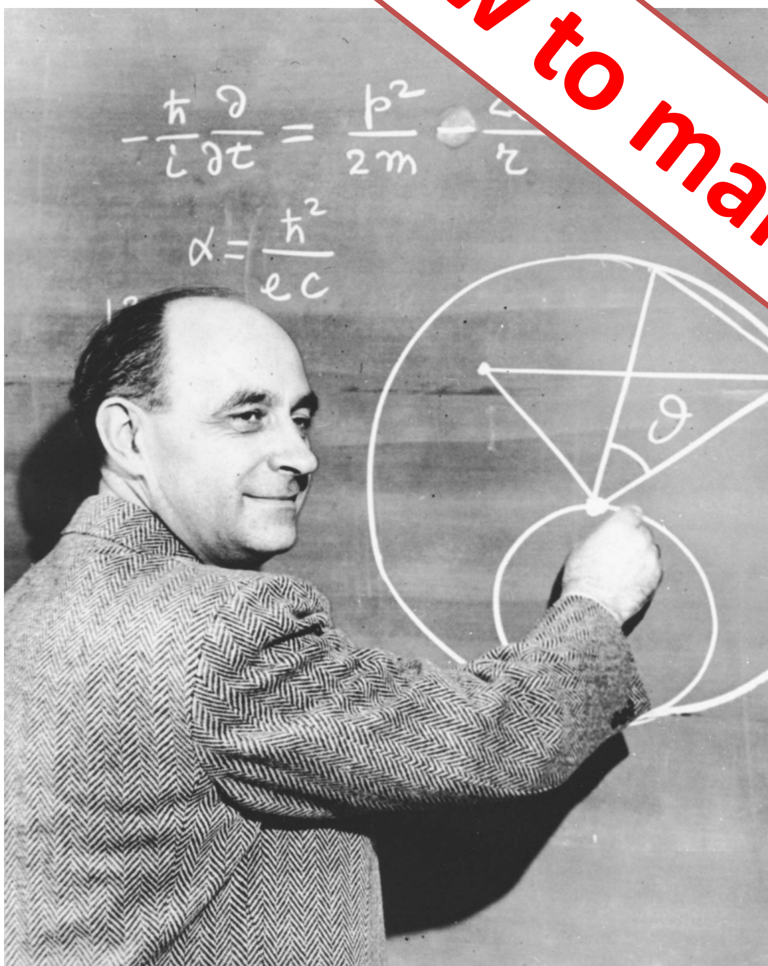


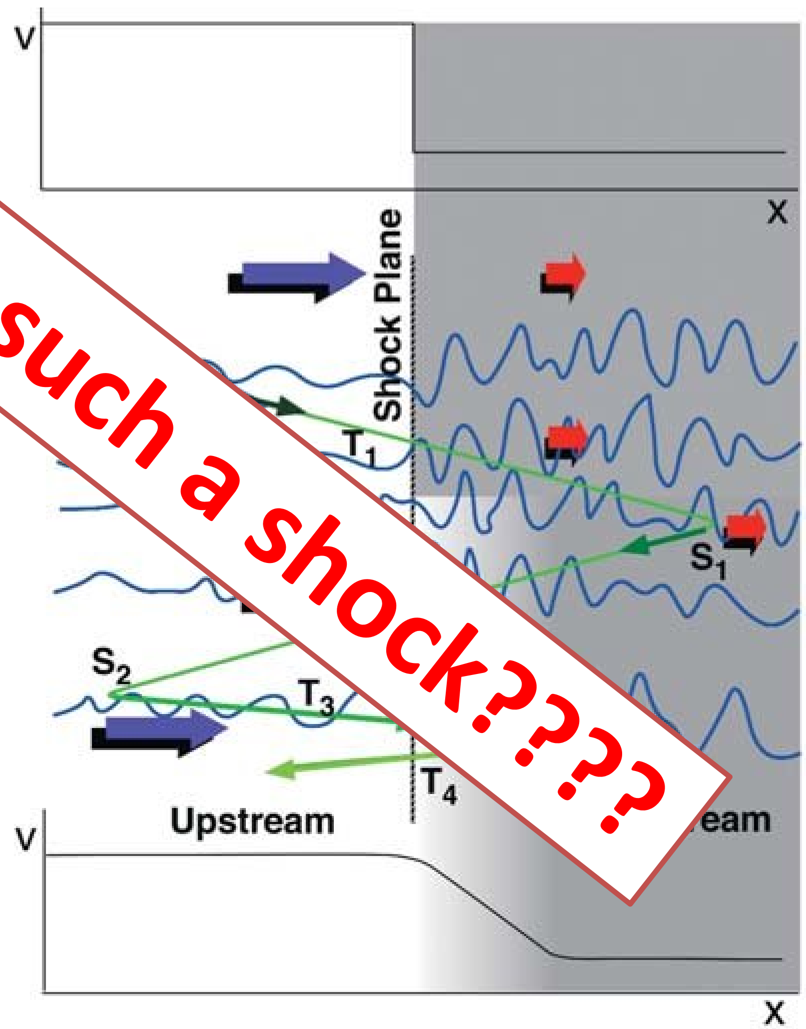
Experimental mysteries ➔ Discovery

But how to make such a shock????

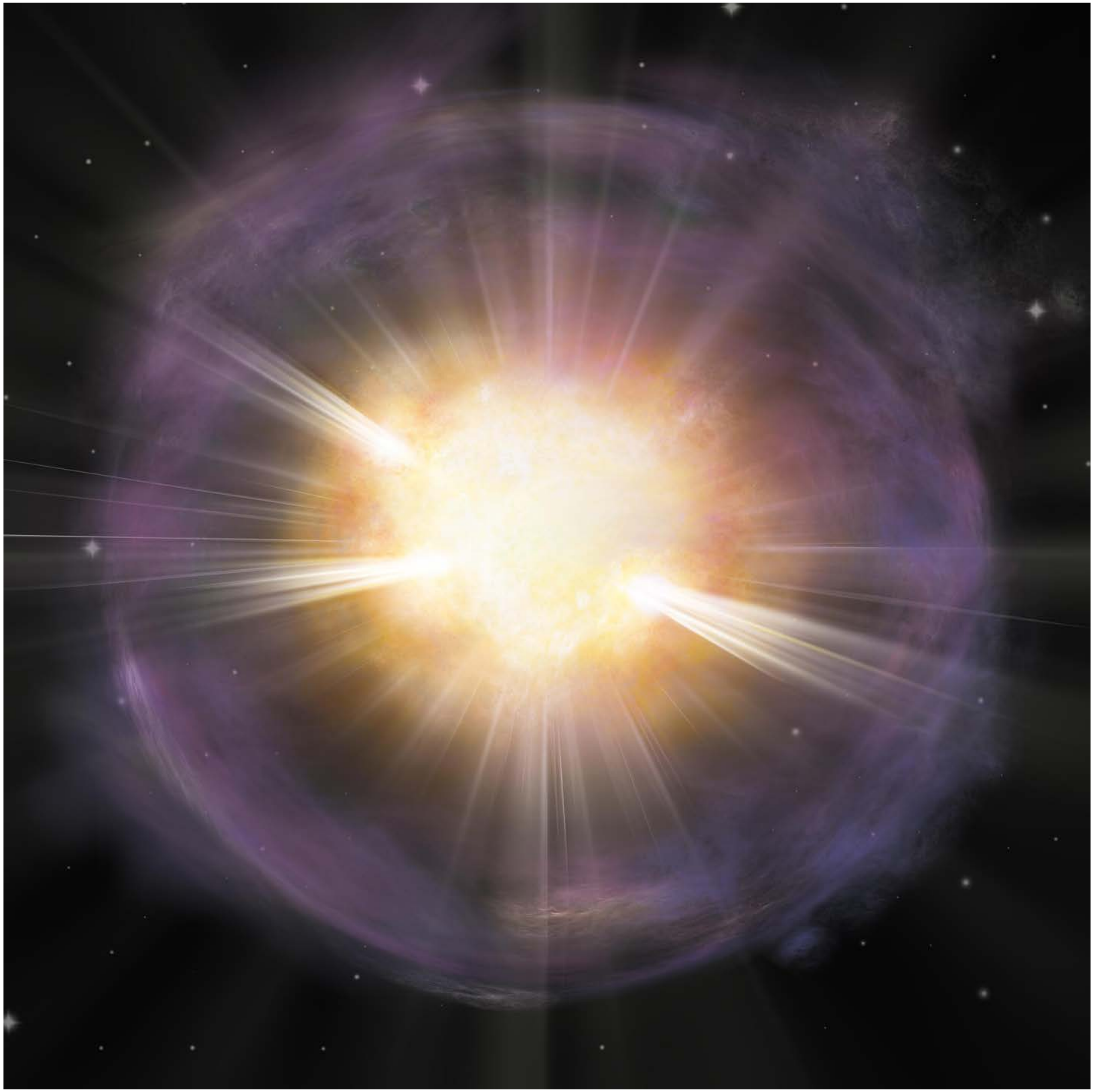
…le passed without an acceptable solution…

…proposes shock acceleration





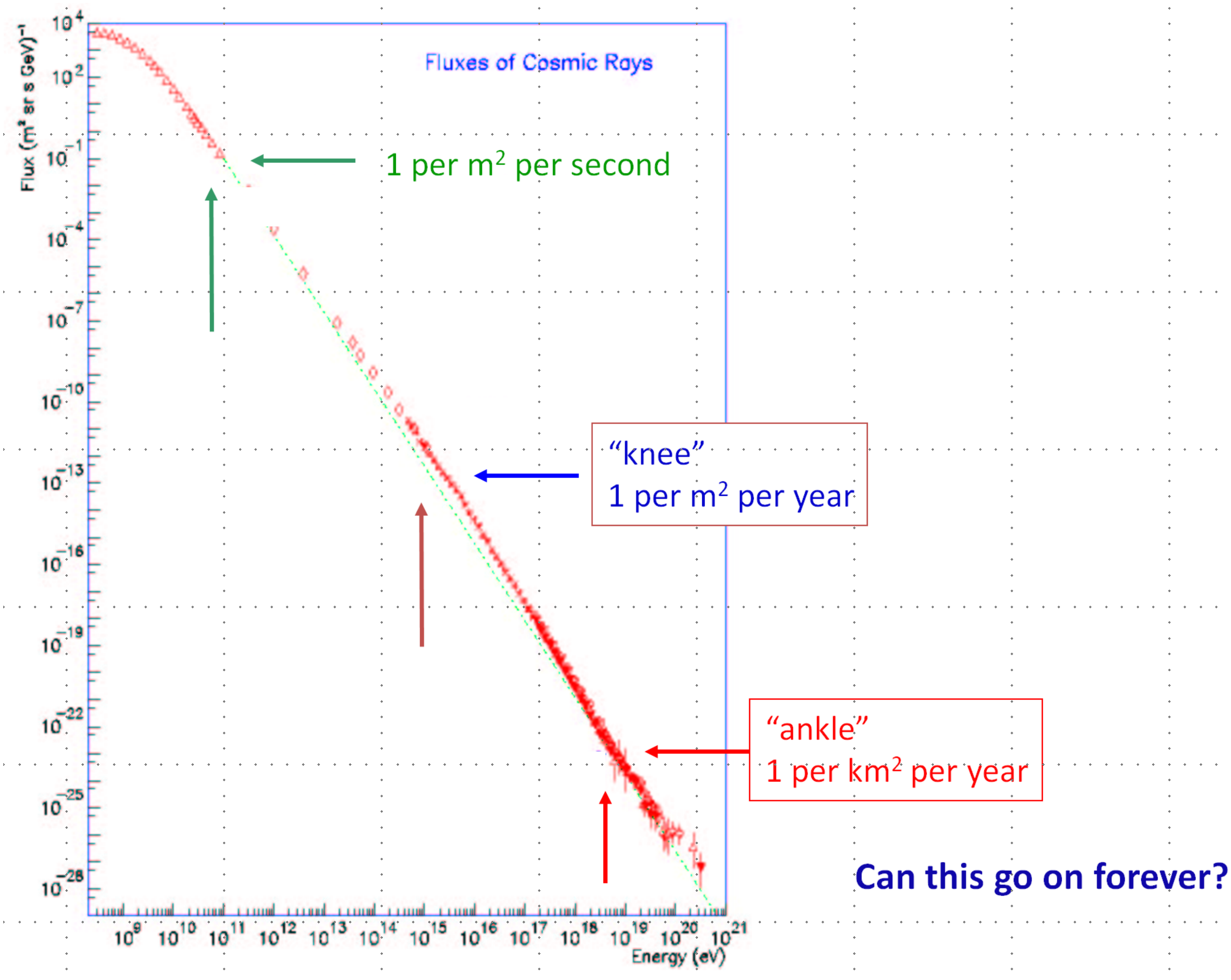
Again, a complicated story…



Supernova can do the trick (with caveats)

Know there must be other processes, since core-collapse can't get beyond iron, so where do the heavier elements come from?

The spectrum



Can this go on forever?

Again new tools, completely unexpected discovery

Early 1960s: Penzias and Wilson, studying radio emissions from the Milky Way using ultra-sensitive microwave receiving system found an unexpected background of radio noise with no obvious explanation.

They spent hours searching for and removing the pigeon dung. Still the noise remained, and was later identified with the Big Bang -- 3K microwave background

"The discovery of the cosmic microwave background by Penzias and Wilson transformed cosmology from being the realm of a handful of astronomers to a 'respectable' branch of physics almost overnight." – Michael Turner

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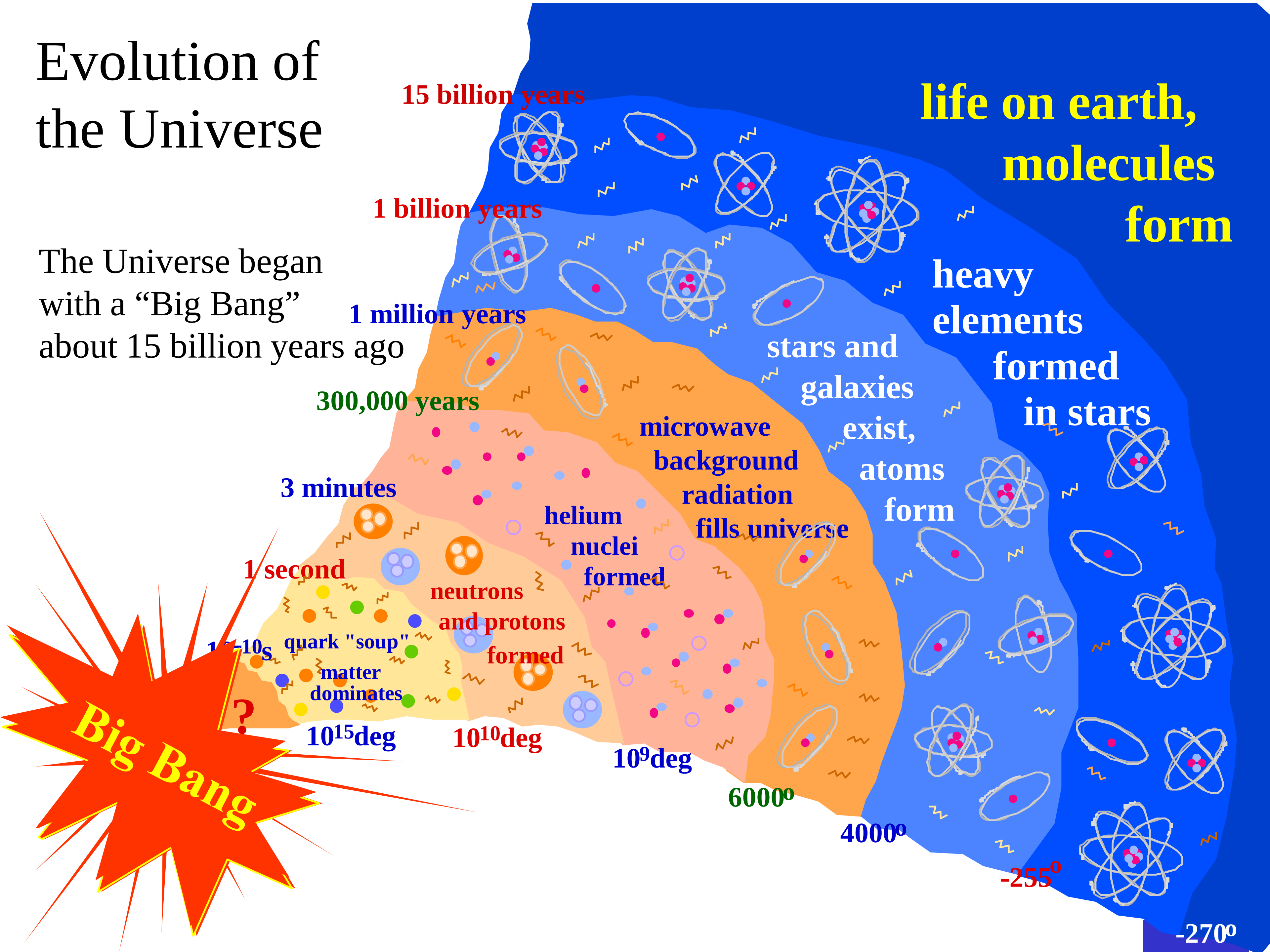
"Thus, they looked for dung but found gold…" – Ivan Kaminow

Evolution of the Universe

The Universe began with a “Big Bang” about 15 billion years ago



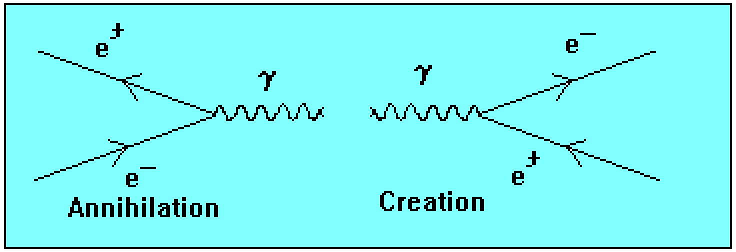
Profound Implications

- The Universe is awash in 3K microwave background

→ Impacts Directly on what we can observe

- Why are we here ??

→ From $E=mc^2$, how to get a stable Universe?



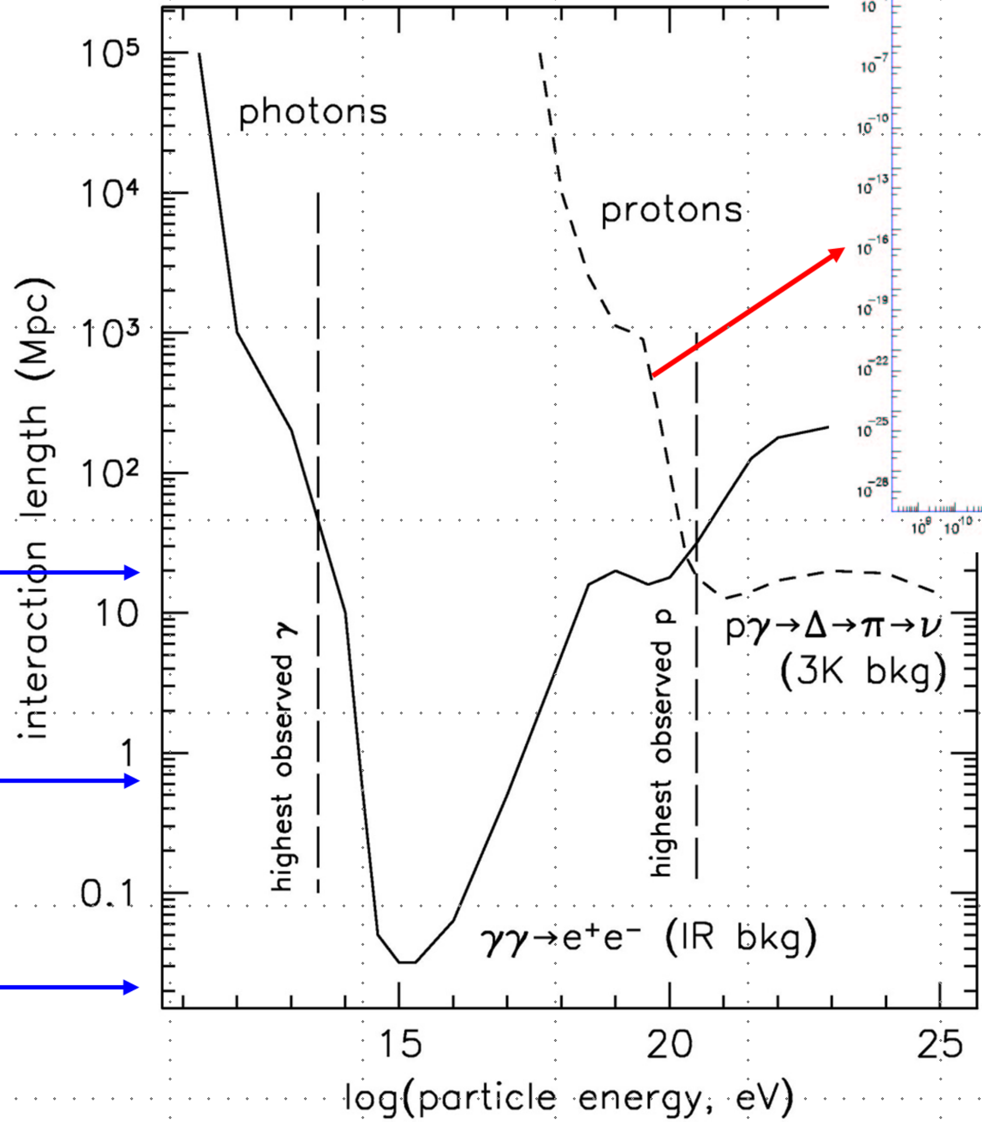
What about these background γ ?

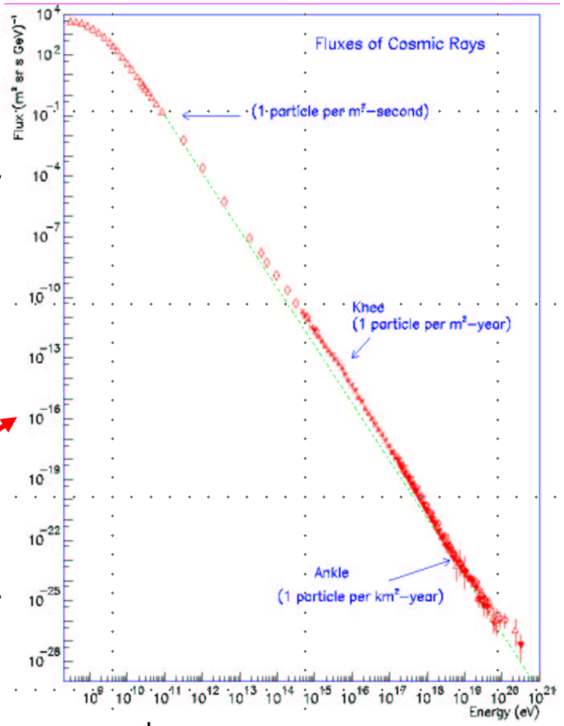
"Far out"

Virgo Cluster

Andromeda

Milky Way dia.





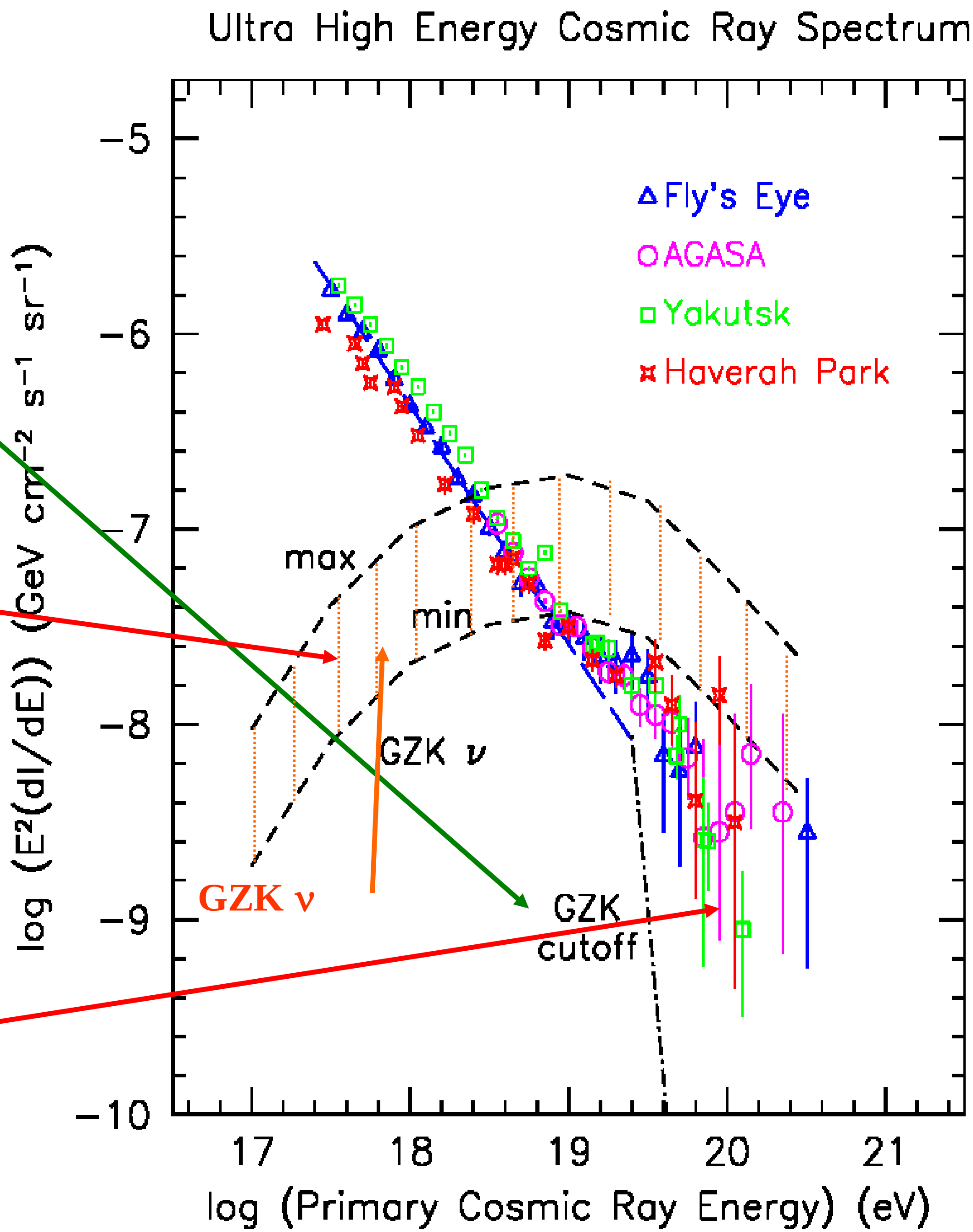
Expectations:

1. Greisen, Zatsepin, Kuzmin (GZK) calculated a cutoff:

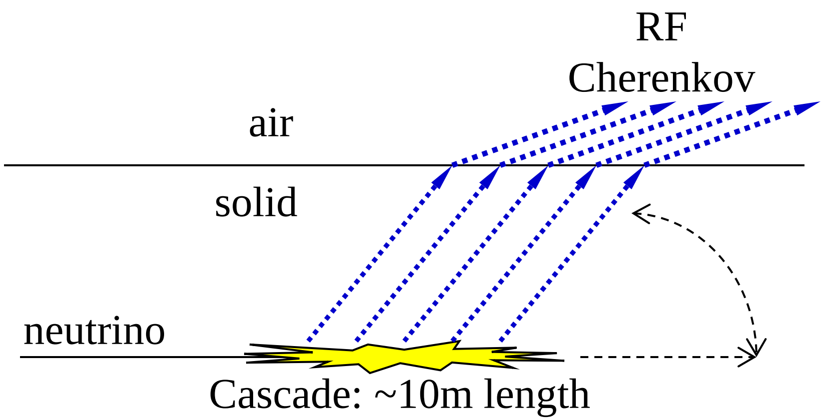
$p * \gamma \rightarrow \Delta \rightarrow n + \pi \rightarrow \nu$

2. These interactions produce a corresponding neutrino flux

3. Provides a handle on what is going on for these "extra-GZK" events



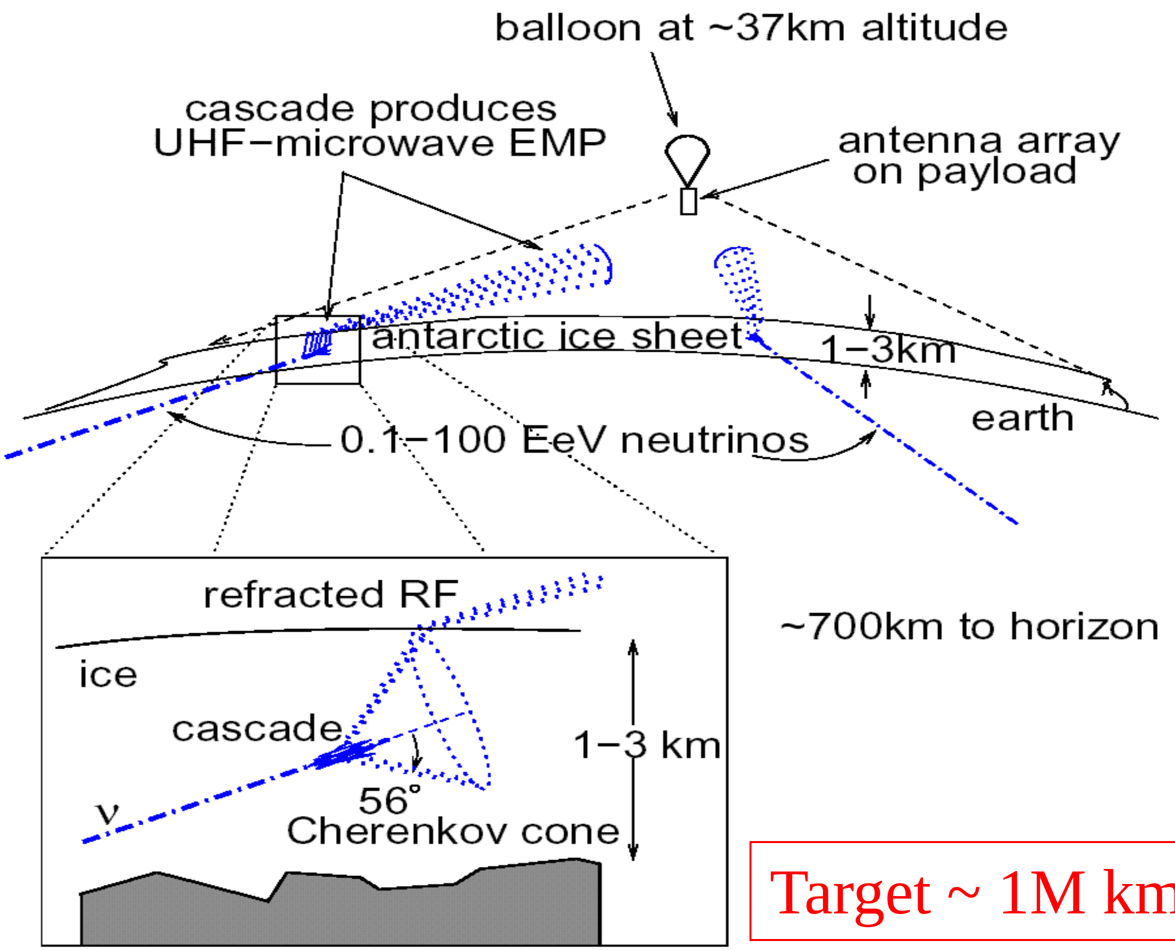
How to Observe?



1960's: Askaryan predicted that the resultant compact cascade shower (1962 JETP **14**, 144; 1965 JETP **21**, 658):

- would develop a local, relativistic net negative charge excess
- would be coherent ($P_{rf} \sim E^2$) for radio frequencies
- for high energy interactions, well above thermal noise
- detectable at a distance (via antennas)
- polarized – can tell where on the Cherenkov cone

ANITA concept

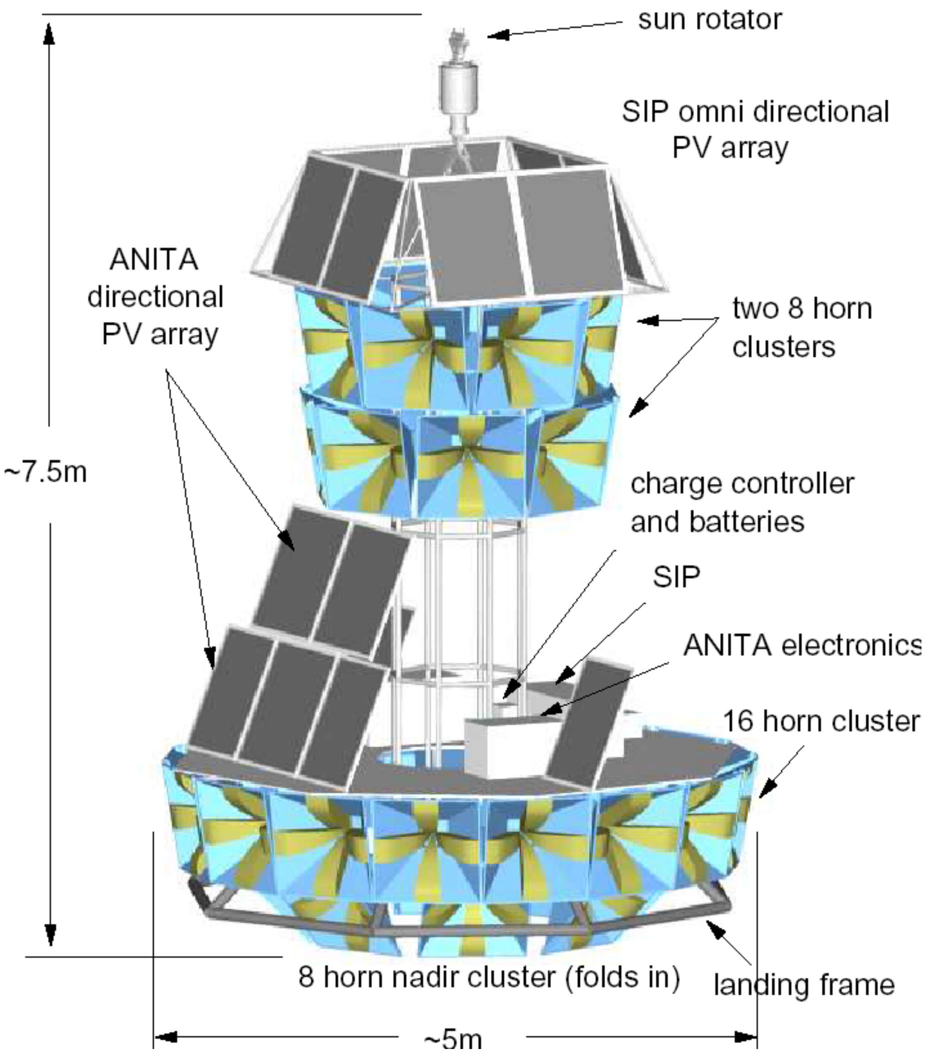


Target ~ 1M km^3

Antarctic Ice at f<1GHz, T<-20C :

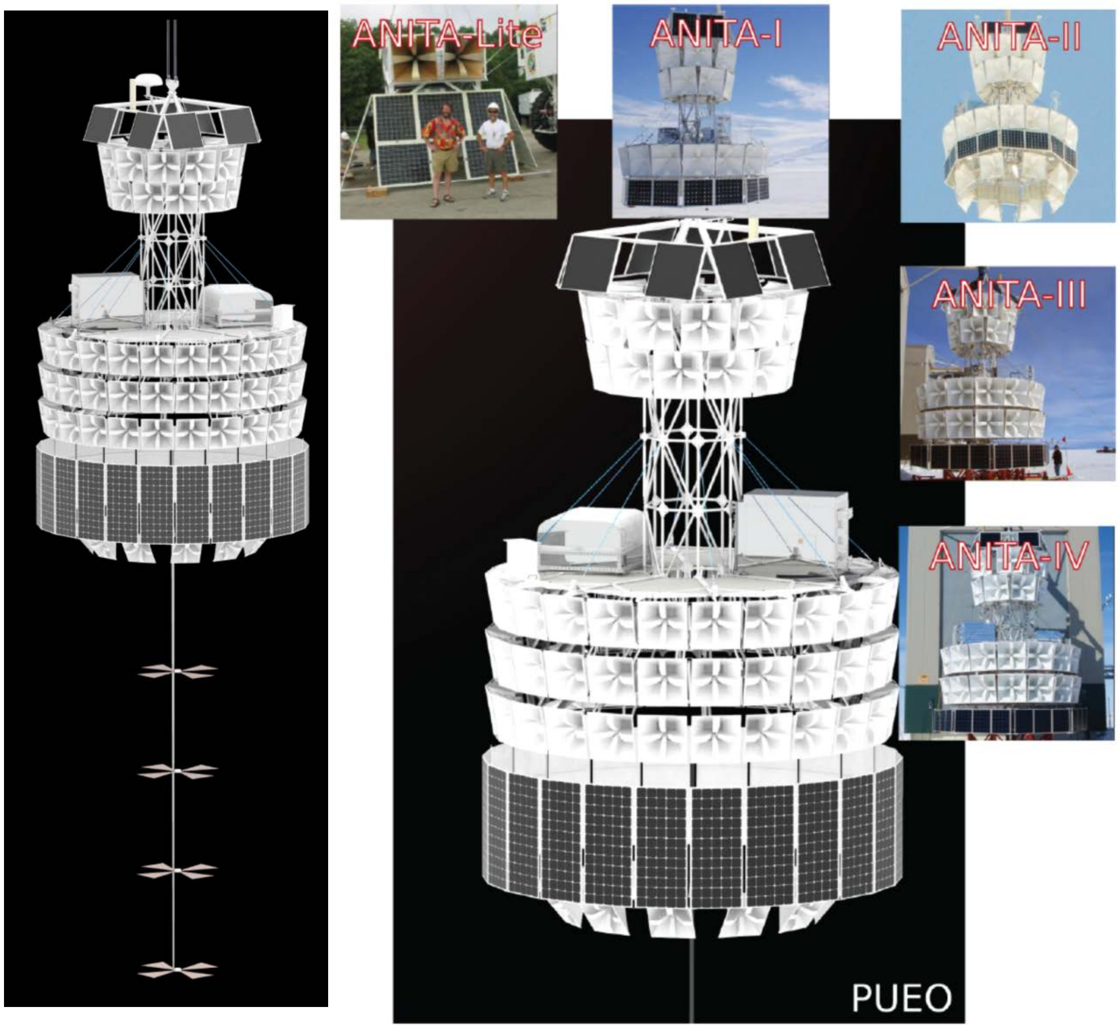
- ~Lossless RF transmission
- Minimal scattering
- largest homogenous, RF-transmissive solid mass in the world
- RF quiet!

Antarctic Impulsive Transient Antenna (ANITA)



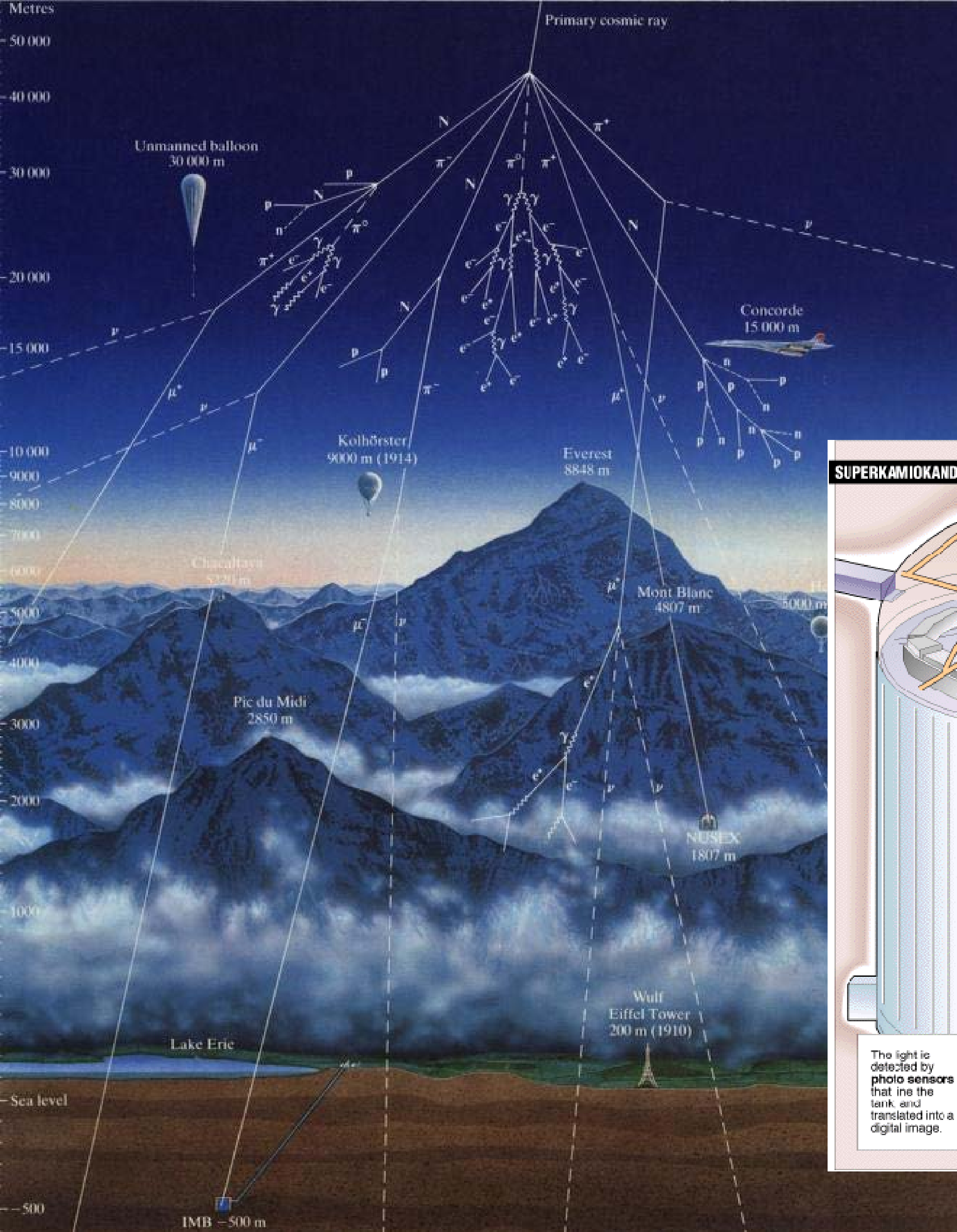
The discovery of radiation

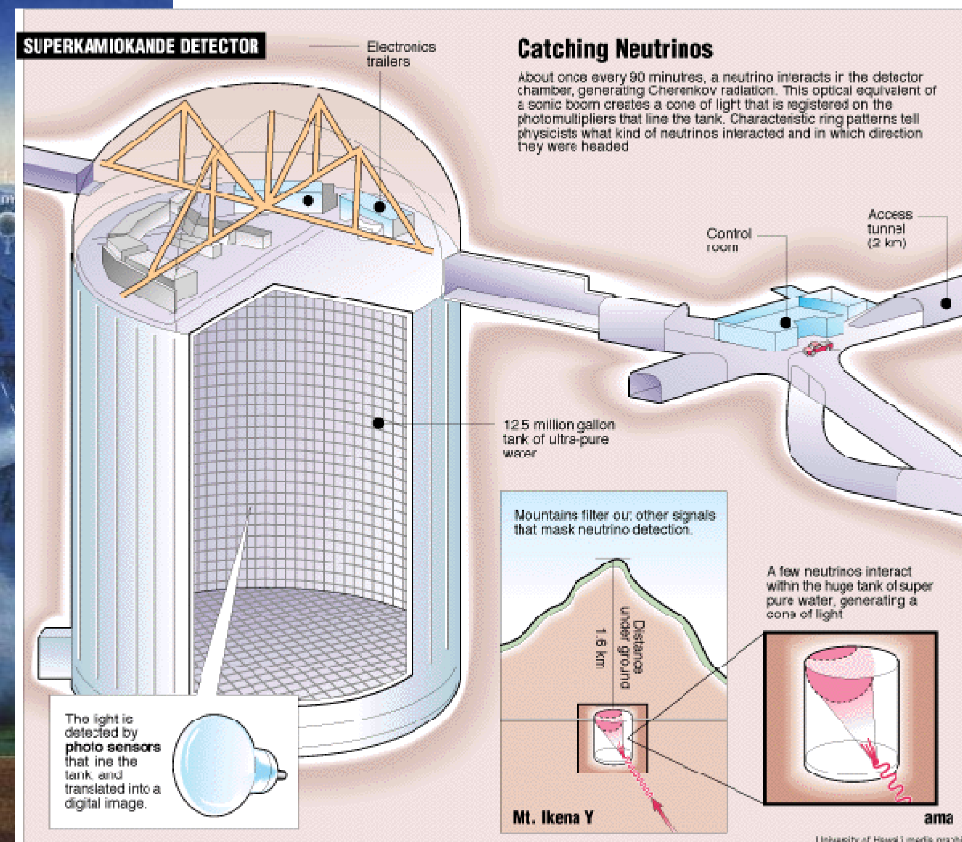
- **One of 2 UH 2024 Antarctic balloon flights**



- **Still awaiting that first neutrino!**

The big picture of extensive air showers

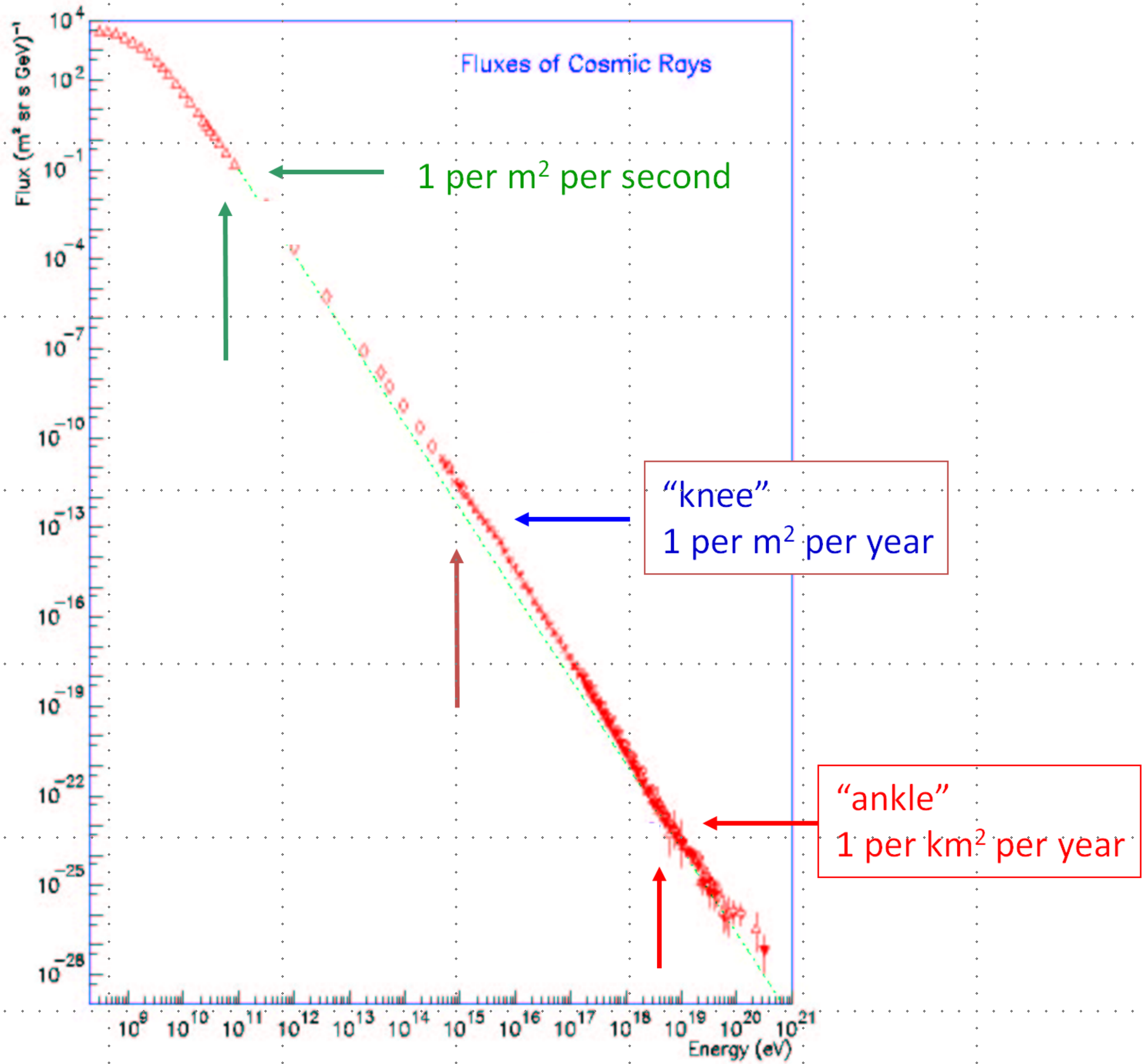




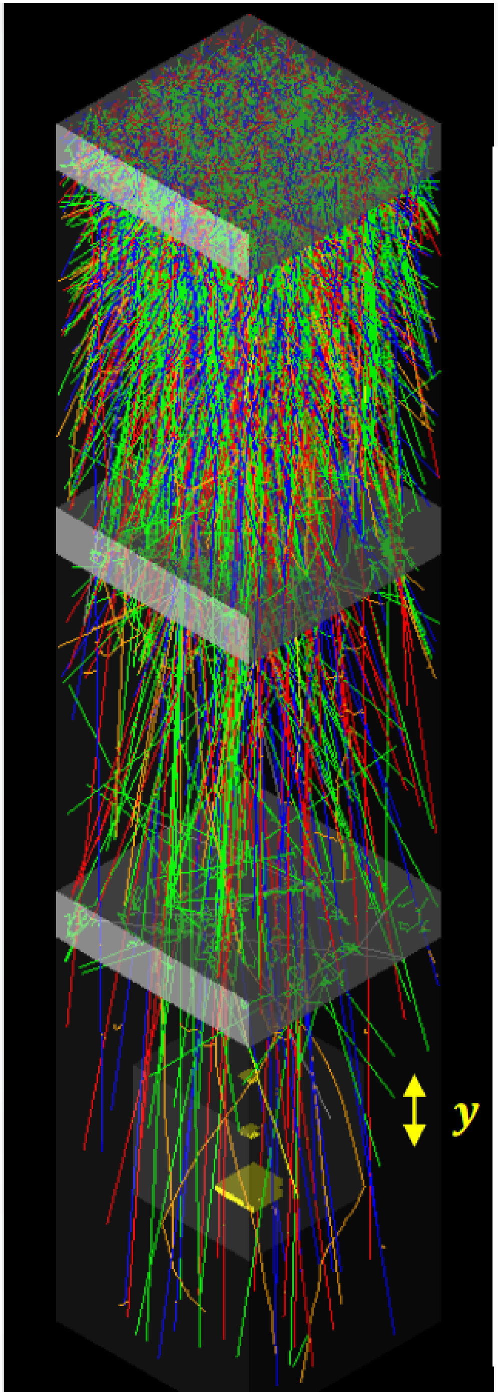
Why so Hard?? The Flux Problem

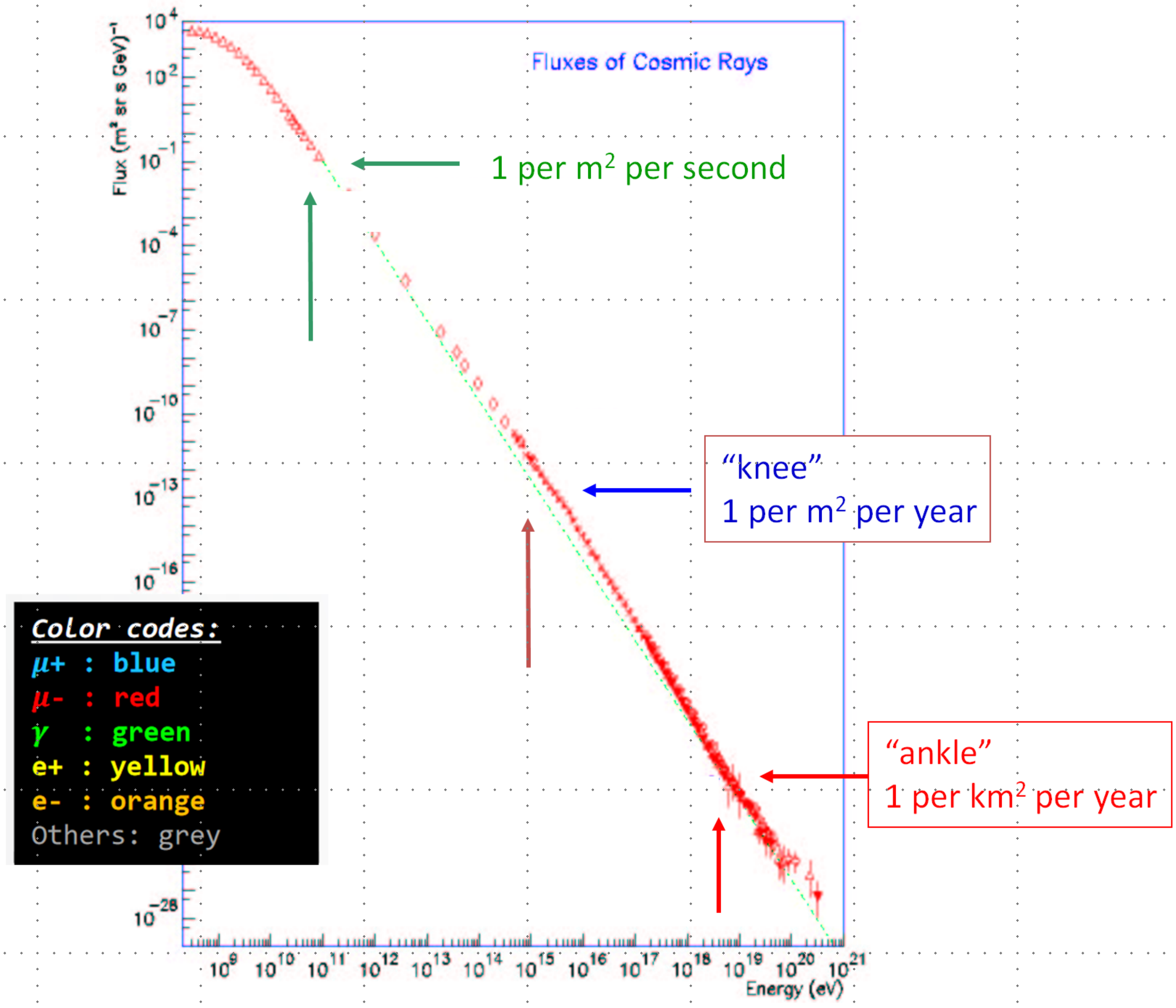
- At E>10^20…

$$\boxed{\iiint_{r,\phi,\theta} dr\,d\phi\,d\theta}$$

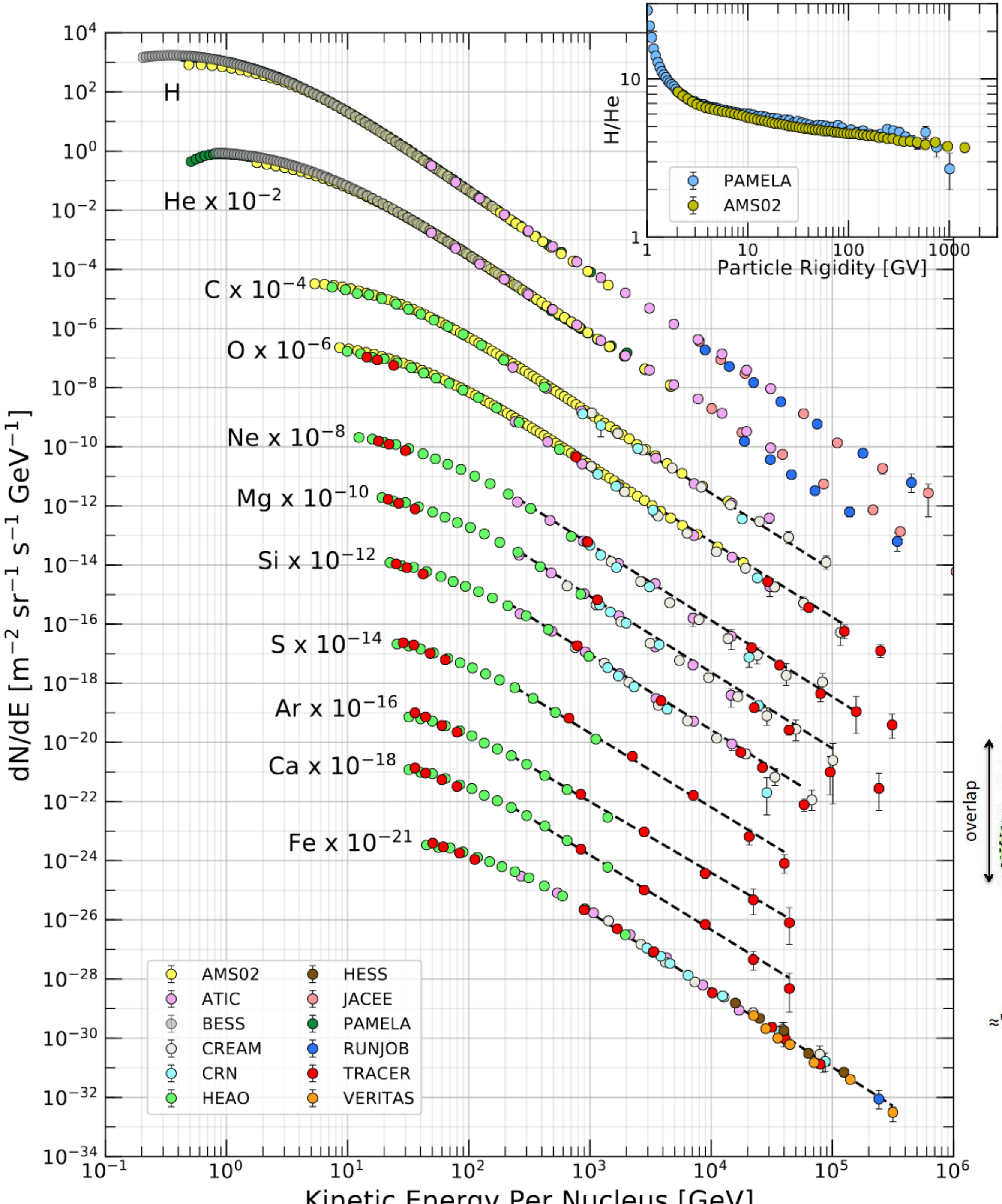


HMB: not a problem

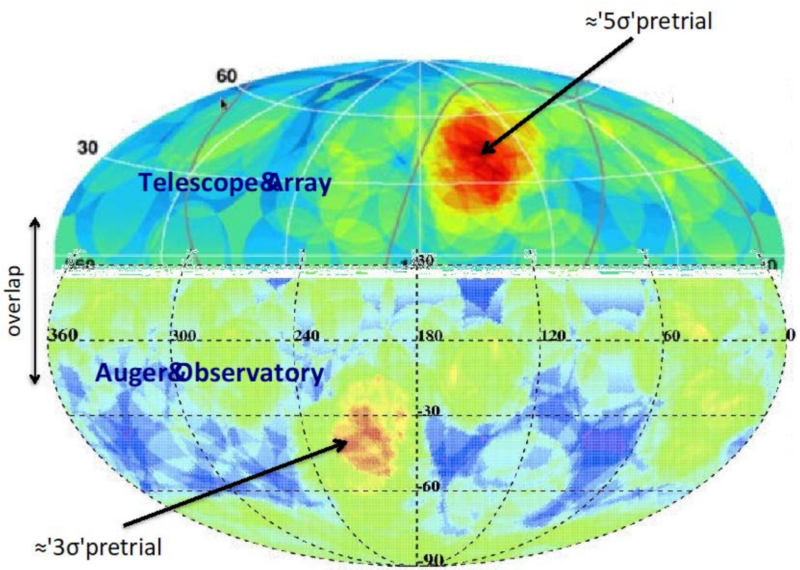




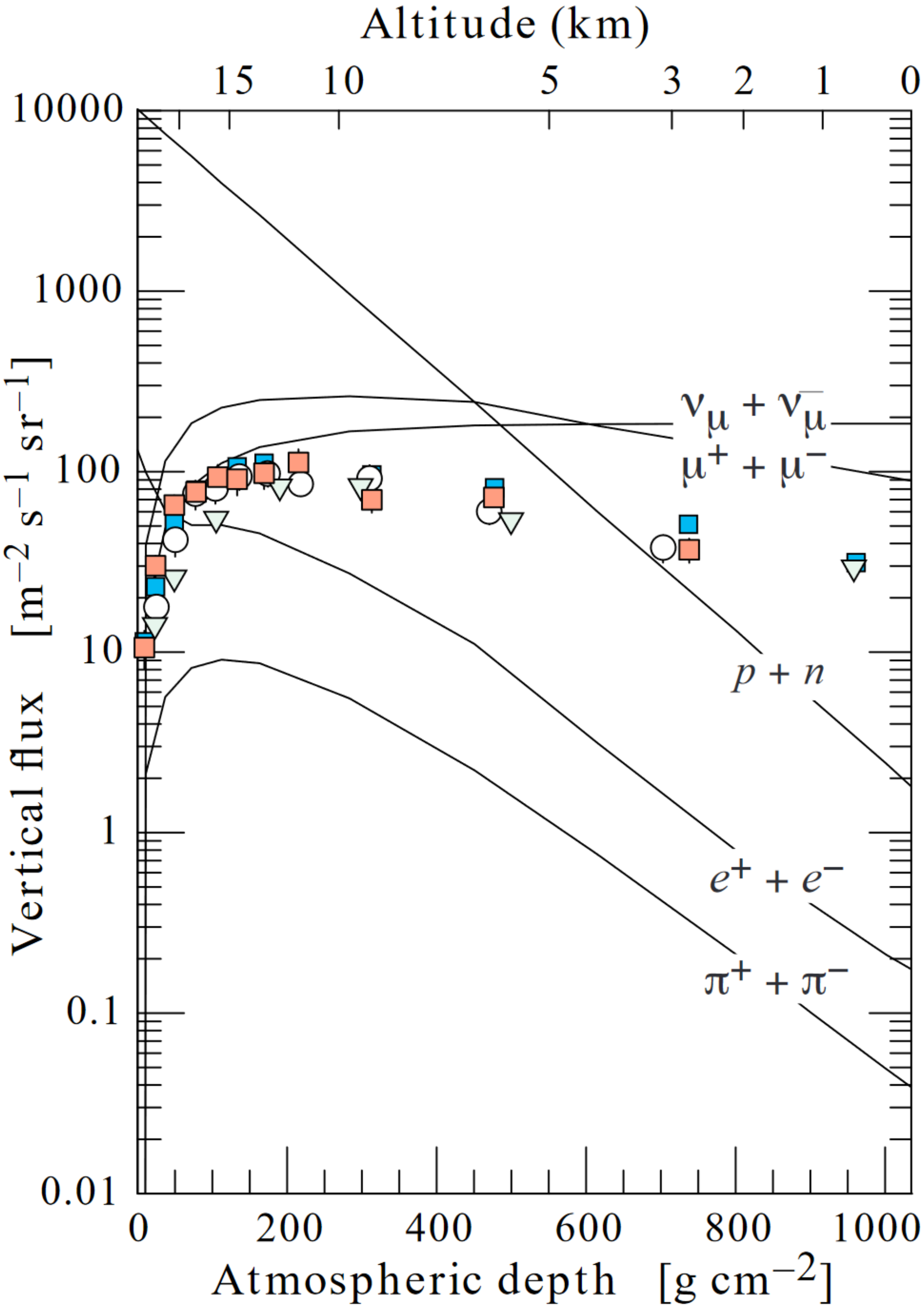
Composition and Direction



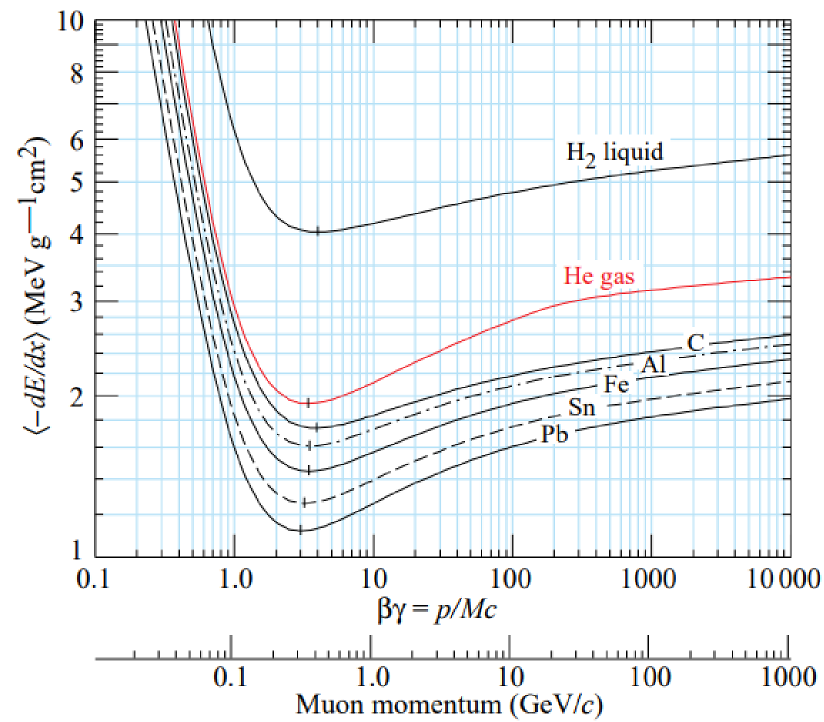
$$R = \frac{p\,c}{Z\,e} = r_L B$$



What Streams Through the Atmosphere



$$I_\pi(E_\pi, X) \approx \frac{Z_{N\pi}}{\lambda_N} I_N(E_\pi, 0)\, e^{-X/\Lambda} \frac{X E_\pi}{\epsilon_\pi}$$



What Makes it to the surface

$$\frac{dN_\mu}{dE_\mu d\Omega} \approx \frac{0.14\, E_\mu^{-2.7}}{\text{cm}^2\ \text{s sr GeV}} \times \left\{ \frac{1}{1 + \frac{1.1 E_\mu \cos\theta}{115\,\text{GeV}}} + \frac{0.054}{1 + \frac{1.1 E_\mu \cos\theta}{850\,\text{GeV}}} \right\}$$

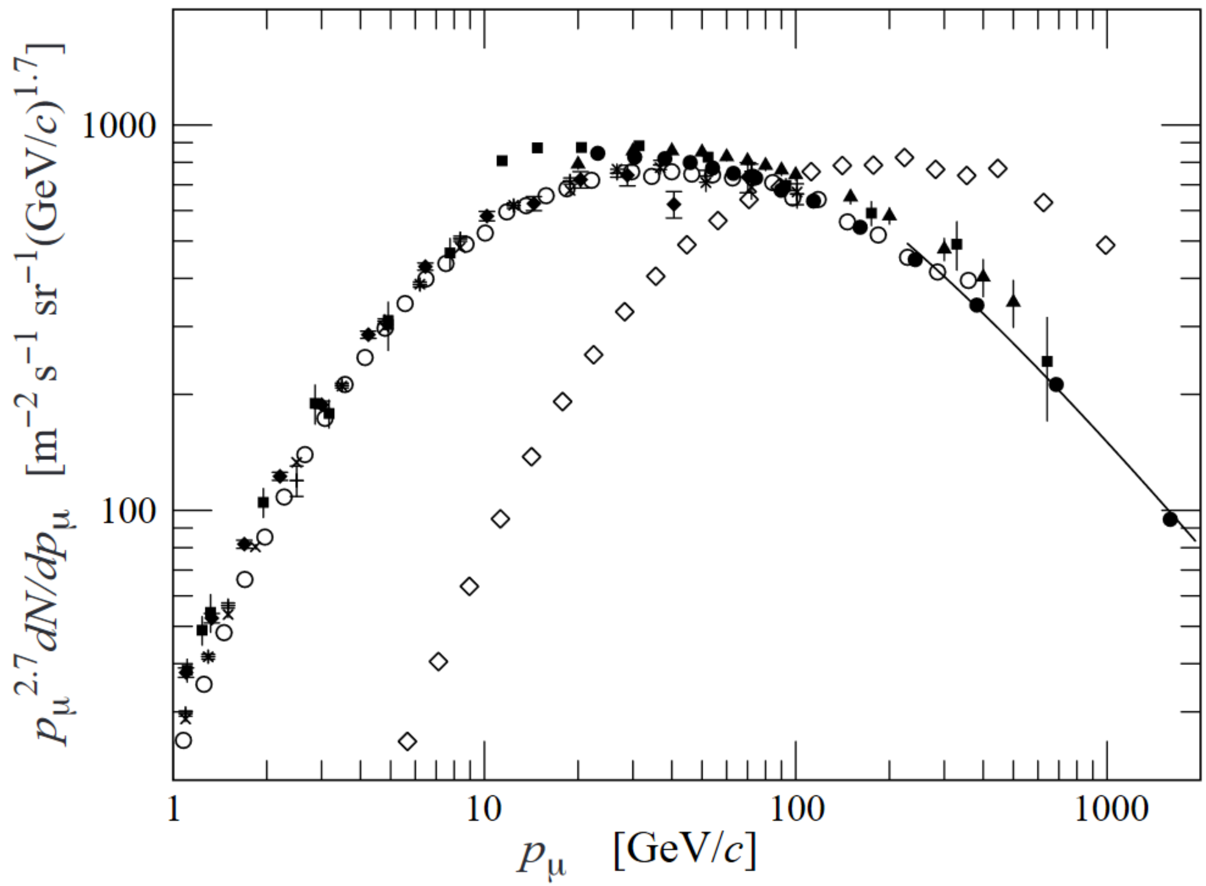
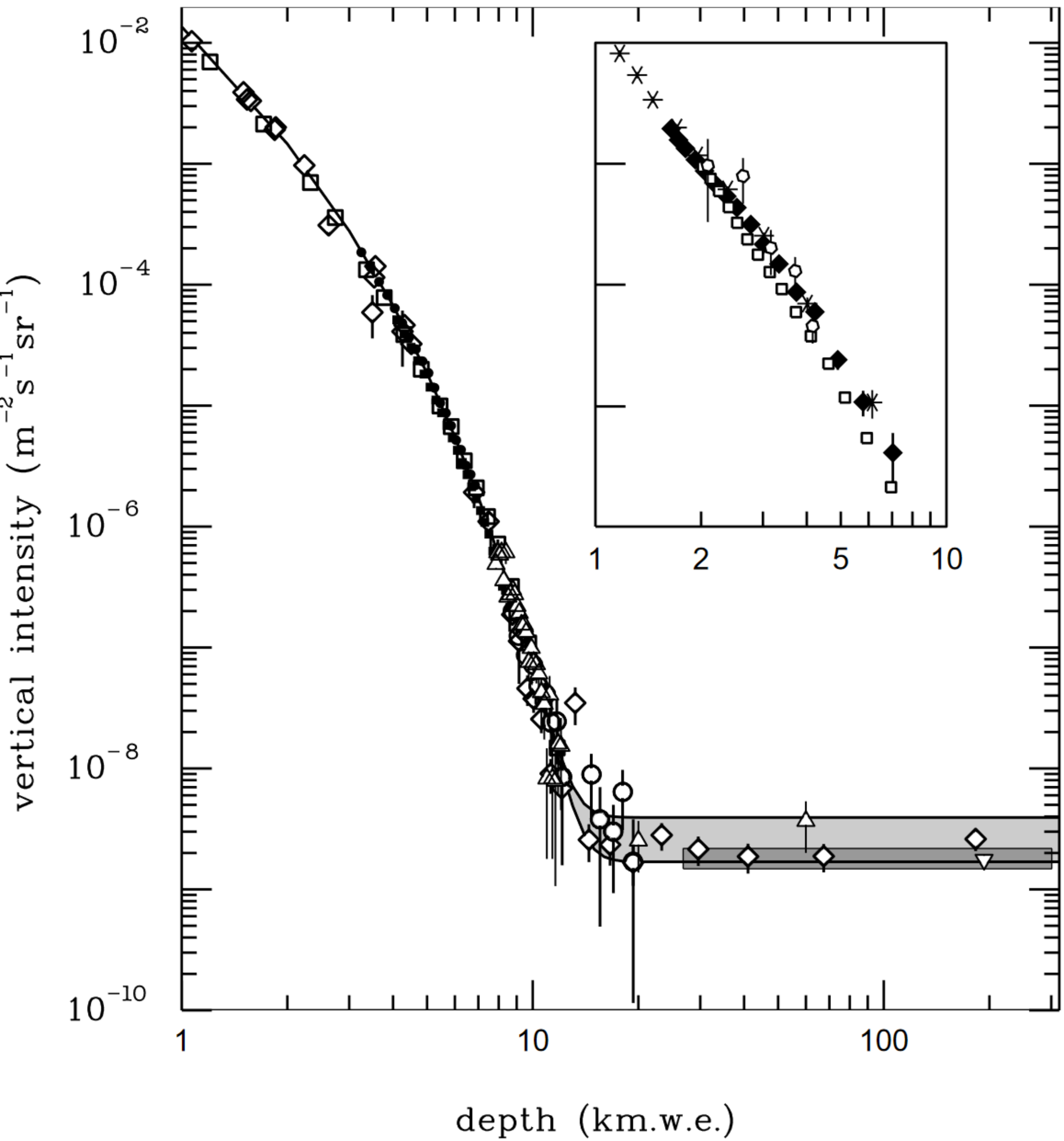


Figure 29.5: Spectrum of muons at $\theta = 0°$ (♦ [56], ■ [60], ▾ [61], ▲ [62], ×, + [58], ∘ [51], and • [59] and $\theta = 75°$ ◊ [63]). The line plots the result from Eq. (29.4) for vertical showers.



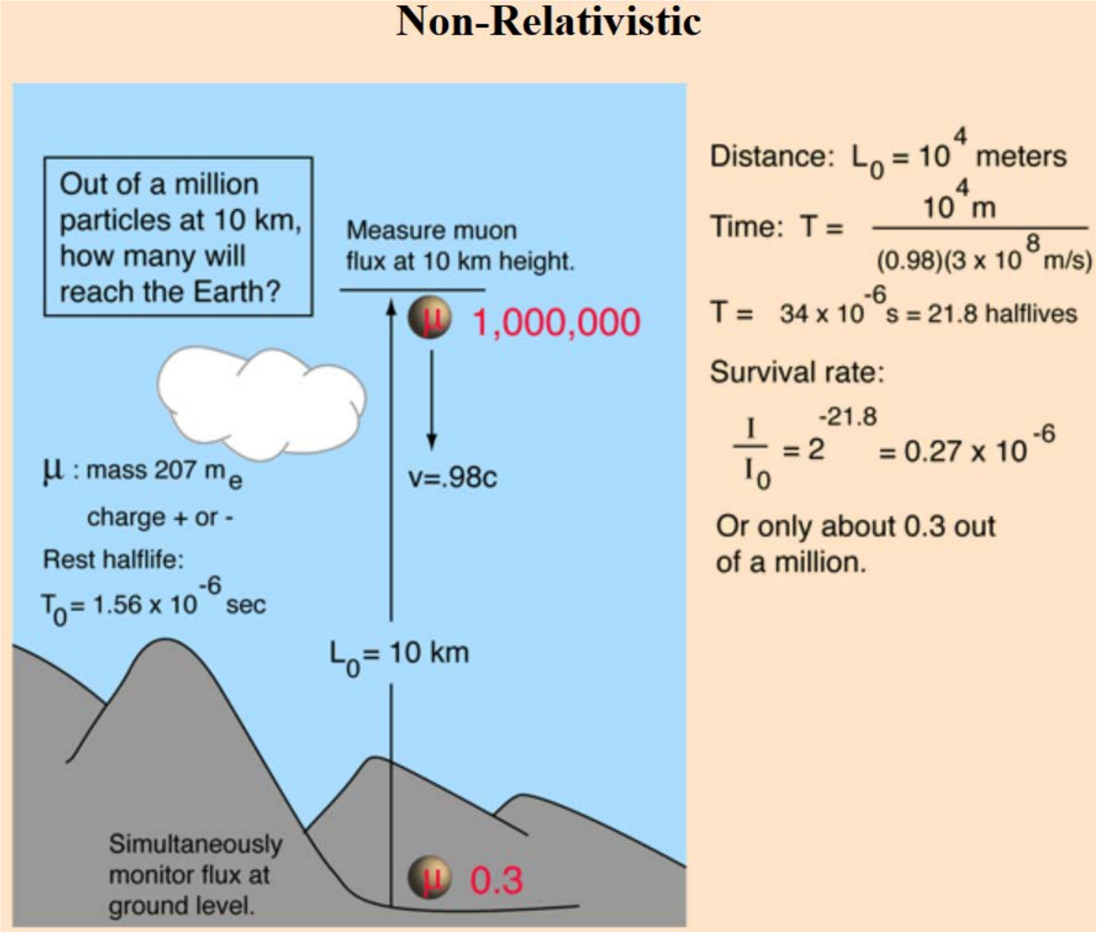
What if I want to shield?

Cull direct muons, but neutrinos unstoppable!

At Earths surface (depends on lattitude)

The integral intensity:

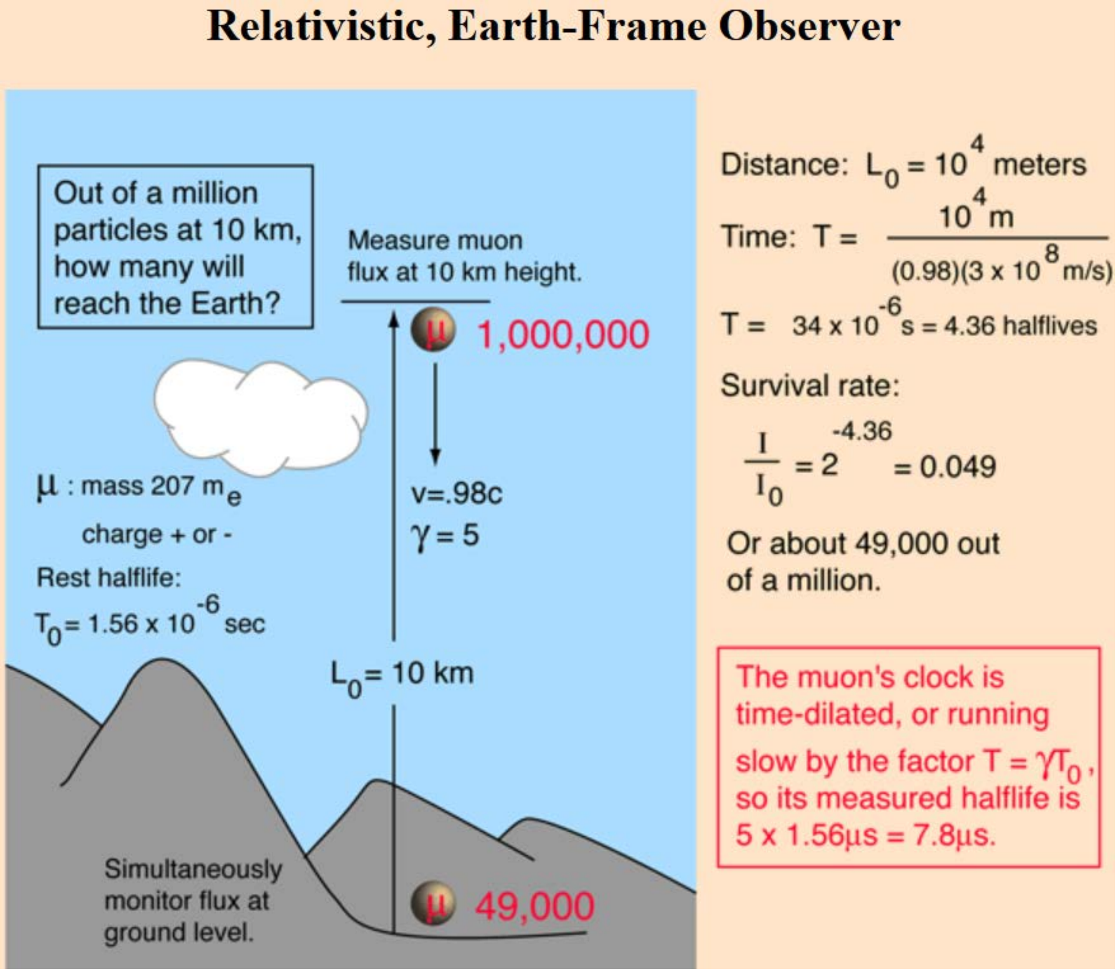
vertical muons above 1 GeV/c at sea level is $\approx 70\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$



At Earths surface (depends on lattitude)

The integral intensity:

vertical muons above 1 GeV/c at sea level is $\approx 70\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$

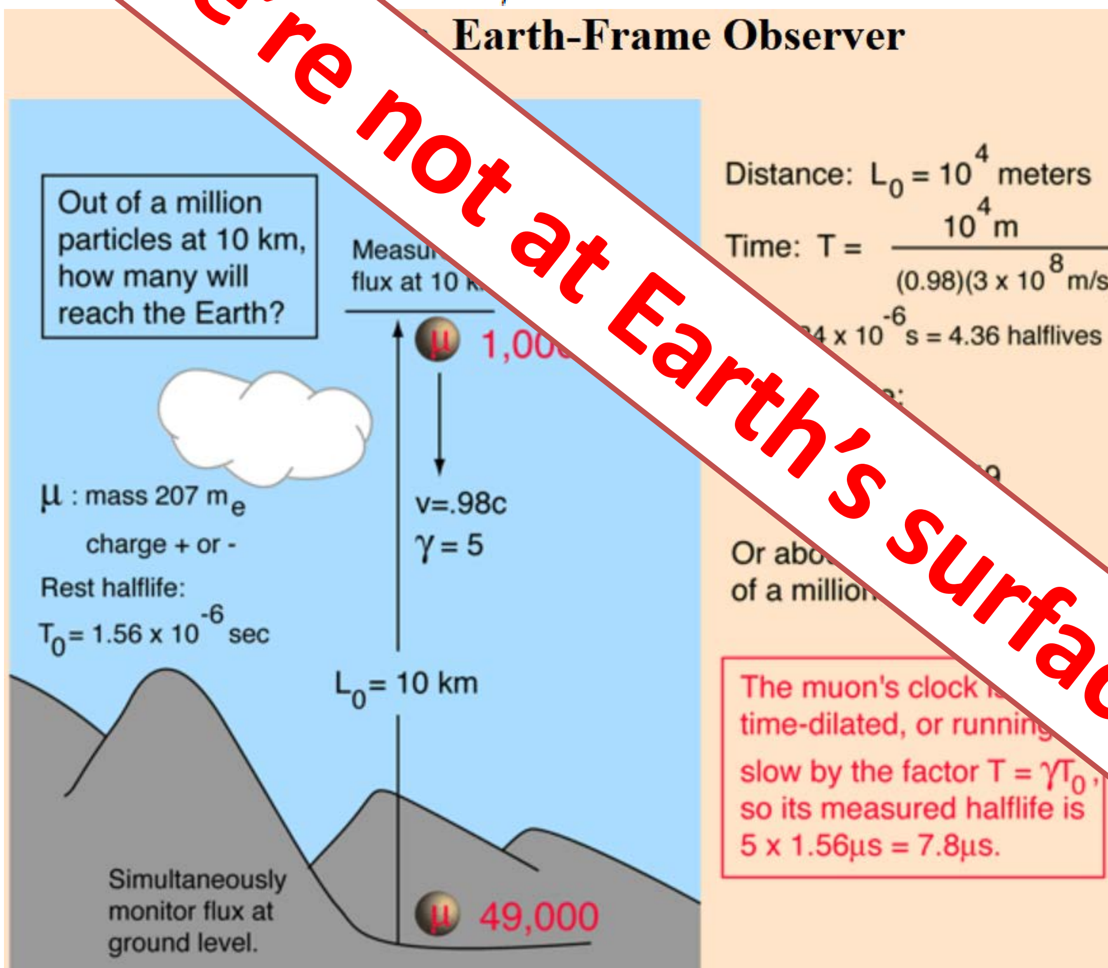


At Earths surface (depends on lattitude)

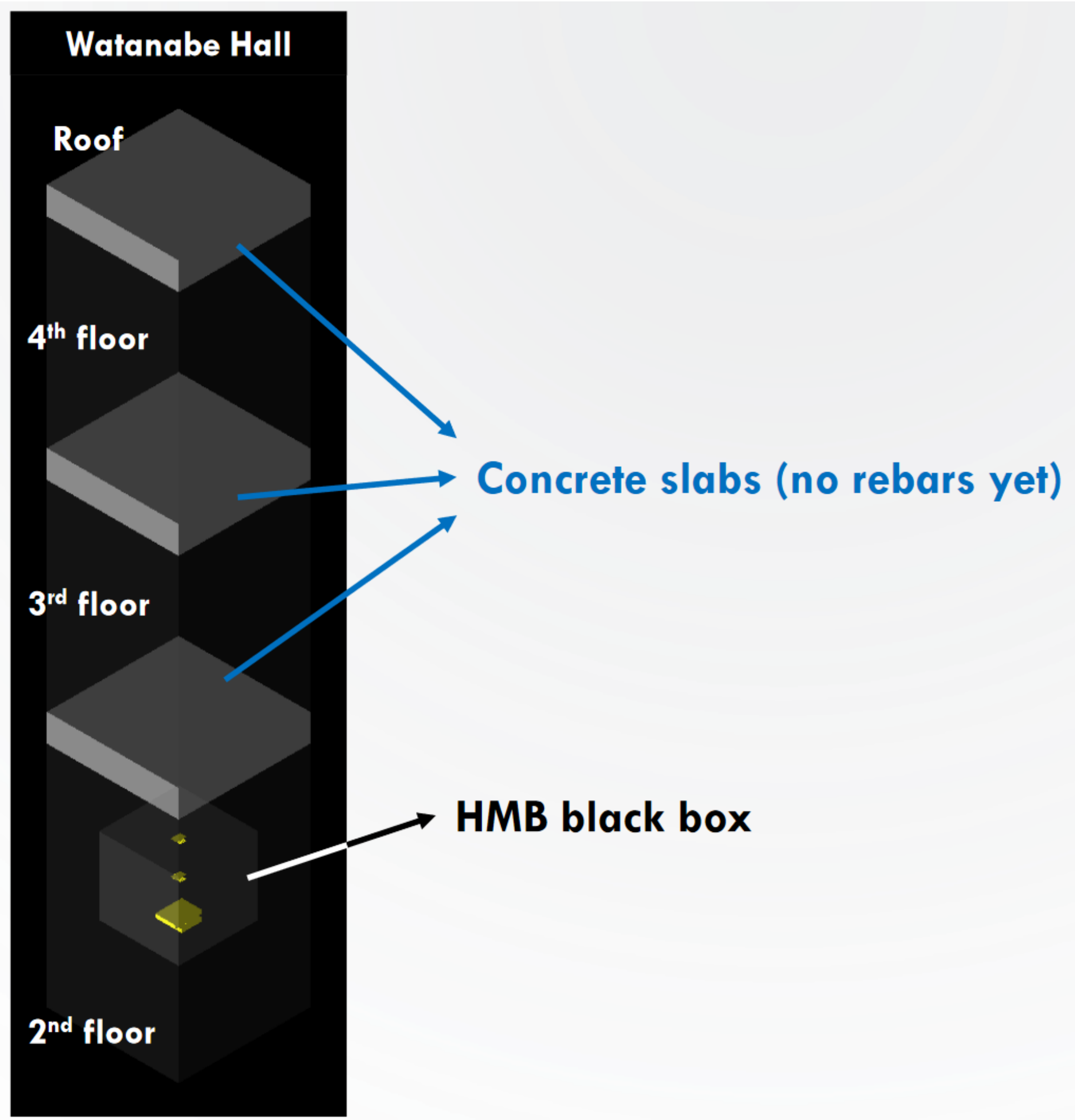
Alas, we’re not at Earth’s surface

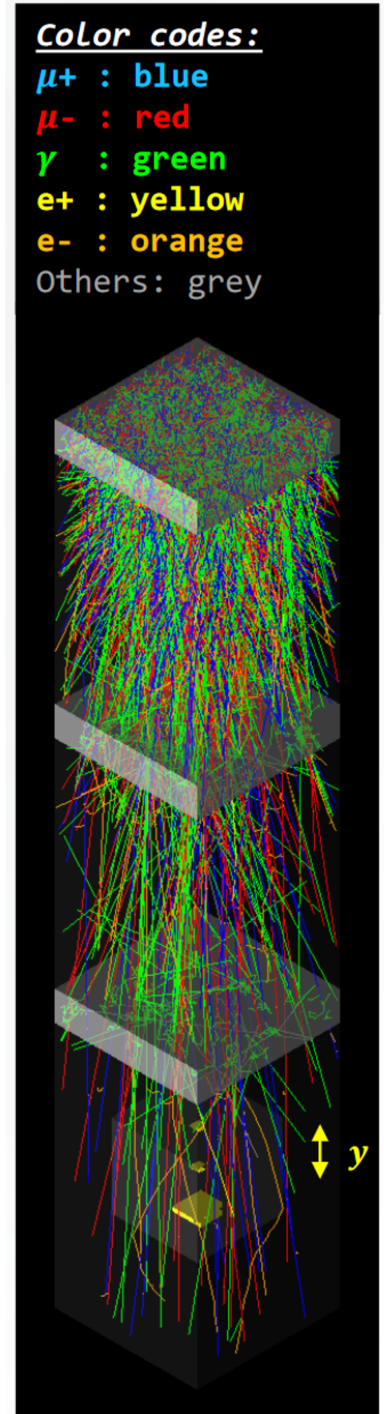
The integral intensity:

vertical muo 1 GeV/c at sea level is $\approx 70\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$



GEANT4+CRY simulation

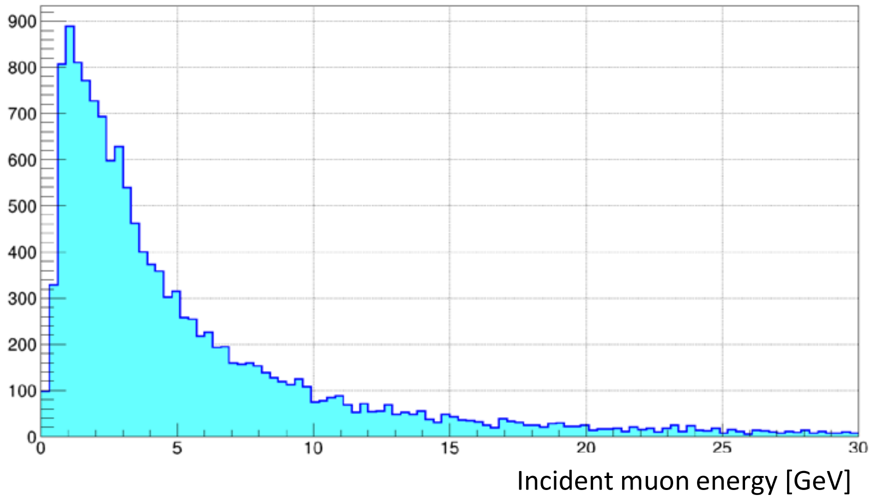


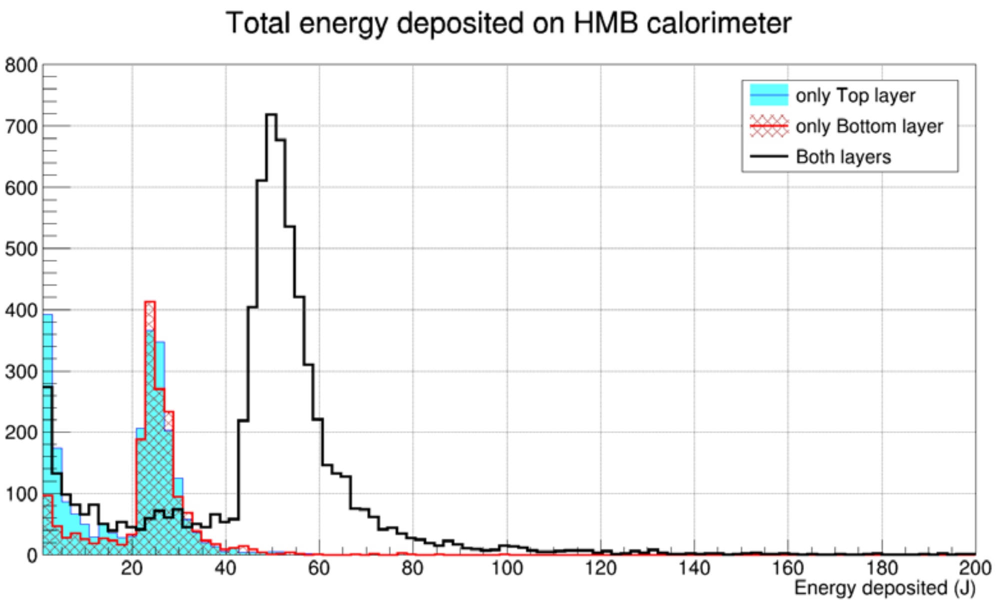


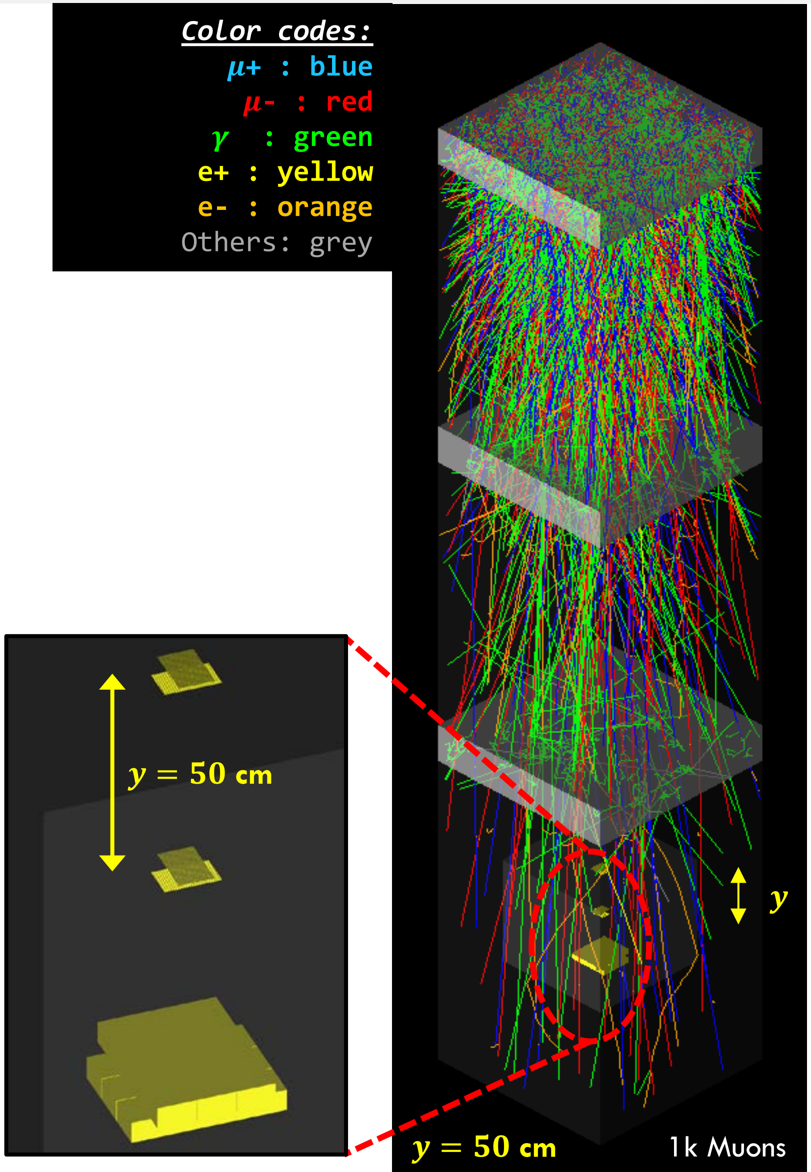
GEANT4+CRY simulation

- Avg. Muon incident rate: 2175 hits per hour (~36 hits/min on NaI slab)

Muon energy spectrum







Summary – So this is our beam

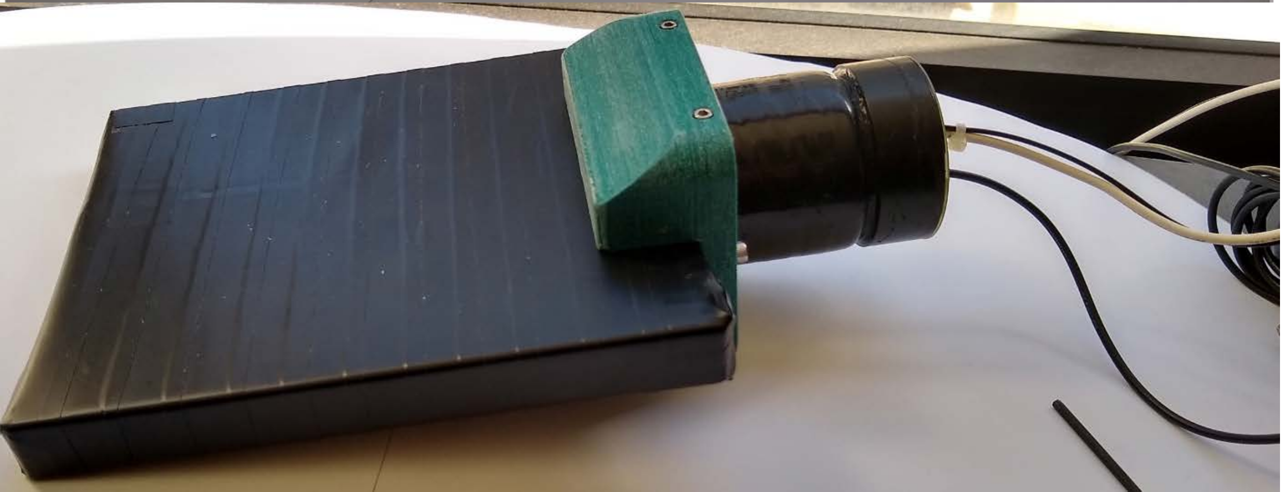
- **Muons are a very nice beam**
  (minimal "multiple scattering")
- **Diffuse, so need good tracking system and to <u>be patient</u>**
- **Rule of thumb is about 1 muon per square centimeter per minute**
  (~0.5 Hz within HMB acceptance limits)
- **Typical "overnight" run is perhaps 16 hours**
- **So ~30k muons per nightly run**
  (perhaps 100k muons over weekend)
- **Next time we'll talk about details of how we'll measure their direction and energy**

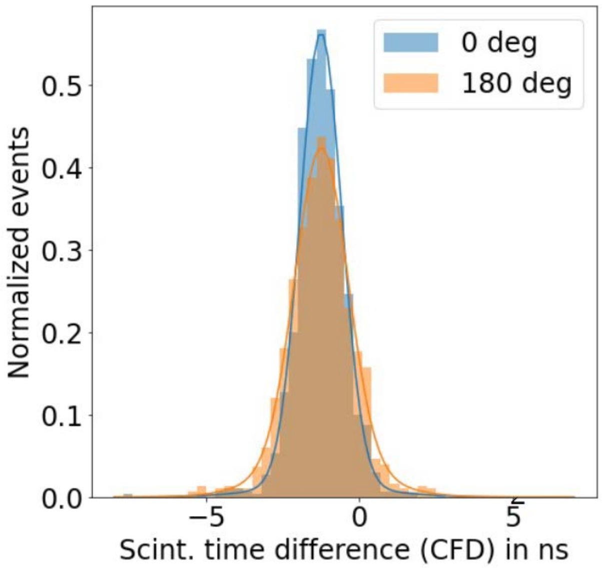
Beam definition counters

Note:

Oskar Hartbrich

- **Re-use Belle Time of Flight fine-mesh PMTs**
- **Newly fabricated**



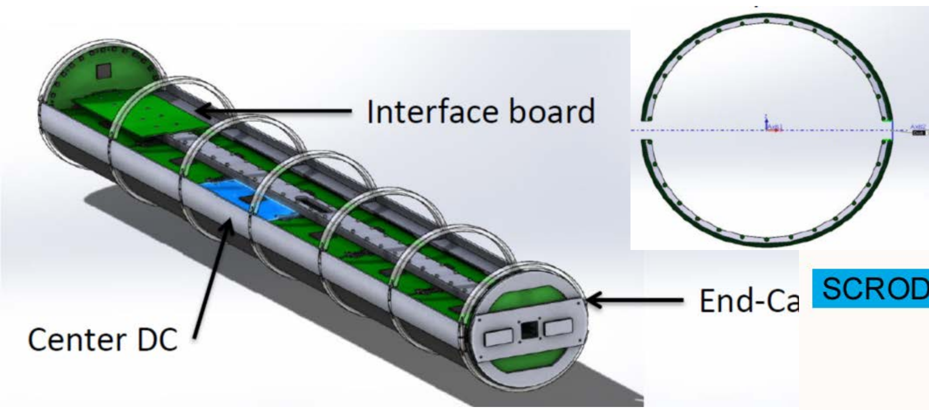


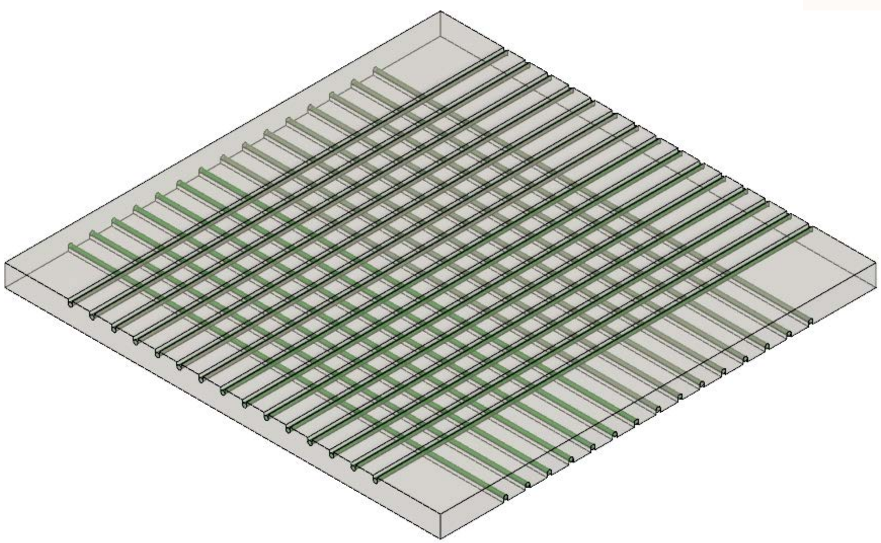
Scint block trackers

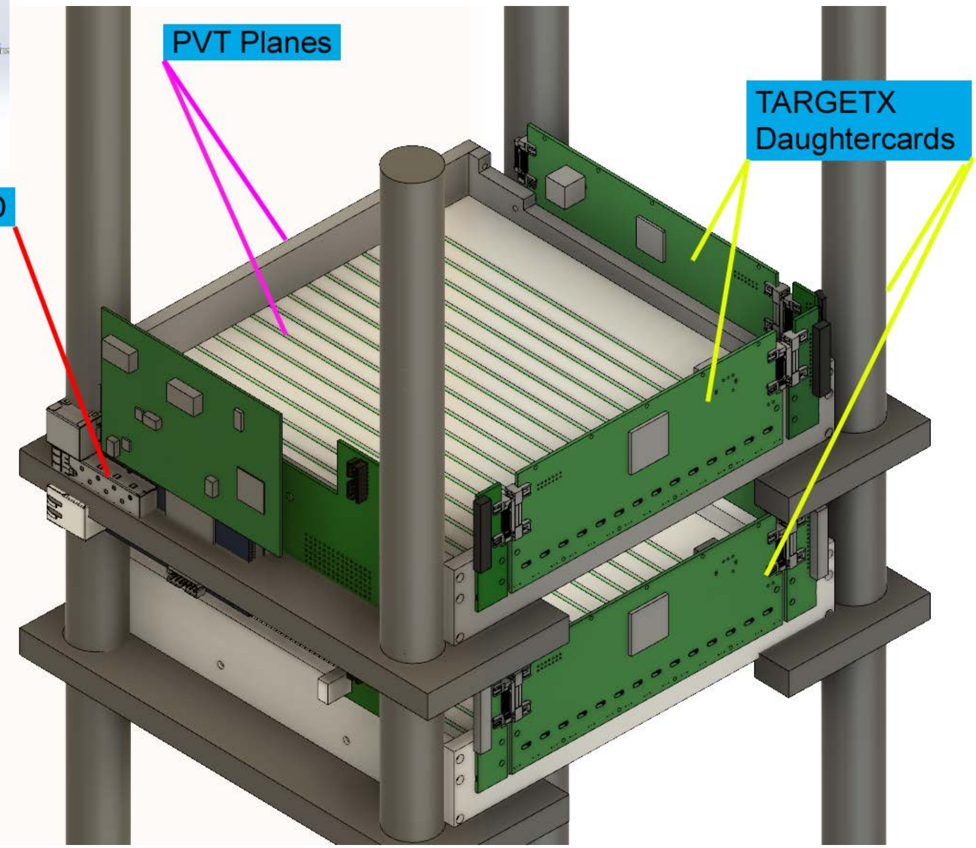
Notes:

Henry/Zander

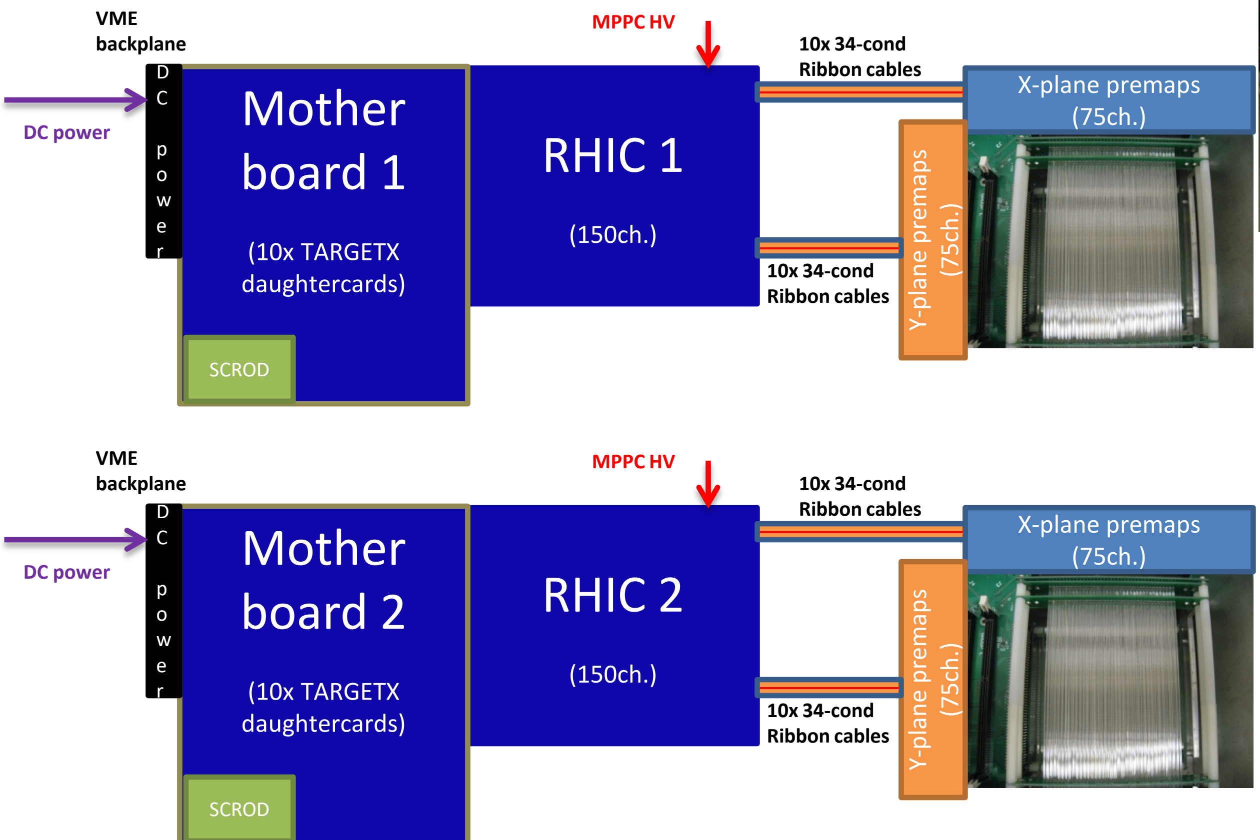
- **Originally prototype for Borehole Muon Detector**
- **Explore gradiometry in position reconstruction**

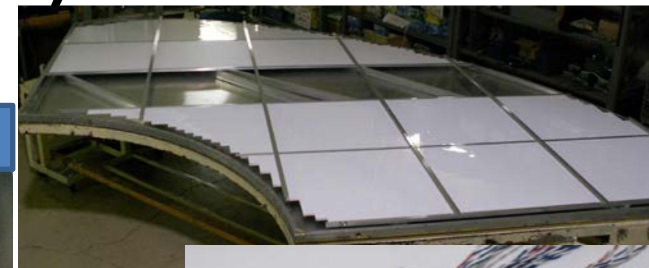


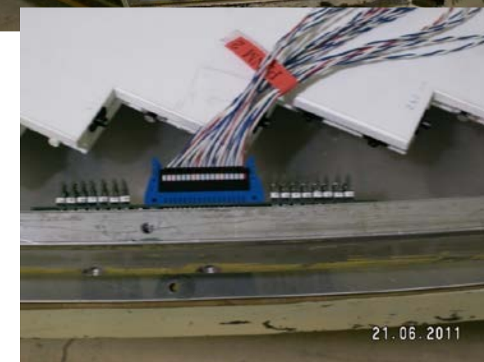




Scintillating Fiber (Sci-Fi) Trackers







Chris/Ethan/Richard

Notes:

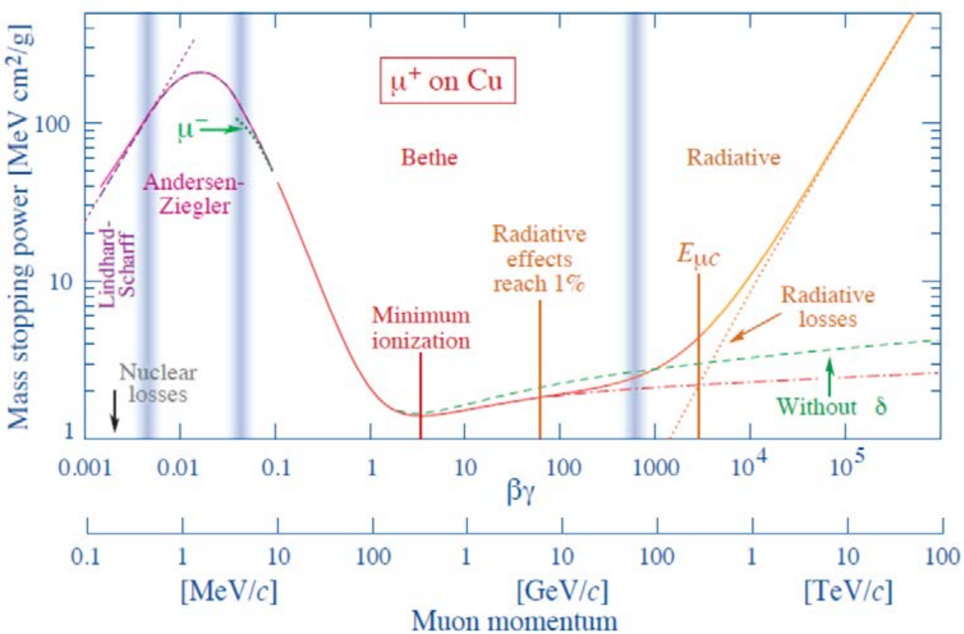
- **Basically a scaled down version of Belle II KLM**
- **4cm x 1cm strips → fibers**
- **Cables! (Chris Ketter)**

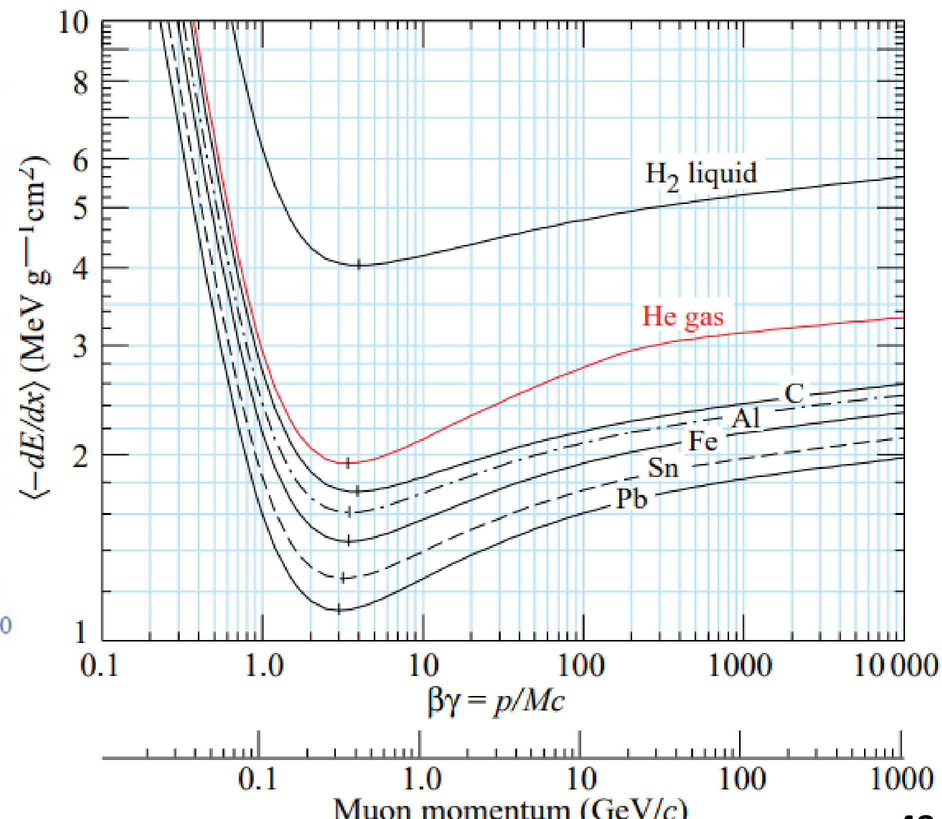
Calorimeter

Salvador/Shivang

Note:

- **Limited space for a magnet (see upgrade slide later)**
- **Use dE/dx to reject low-p muons, relativistic rise for high-p tag**
- **Useful to have shower and bremsstrahlung detection**

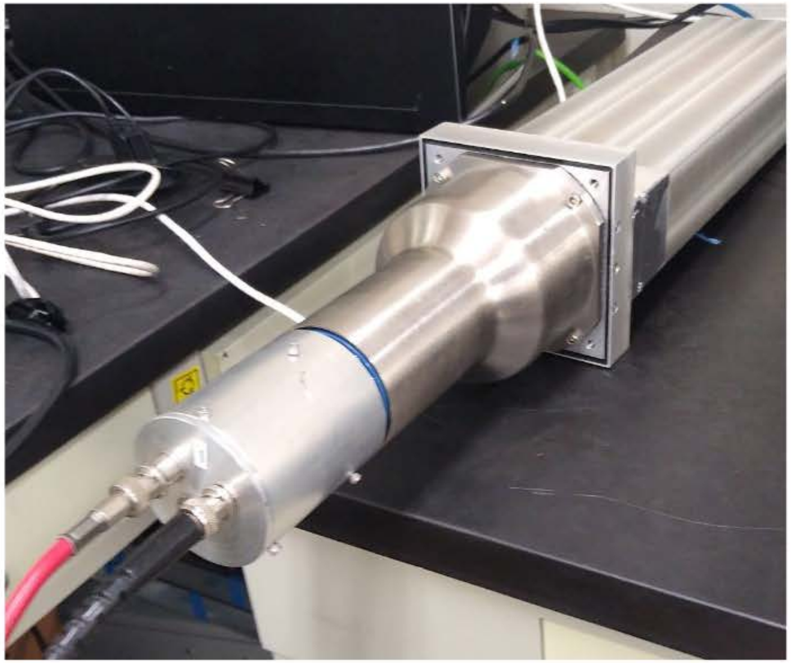




Calorimeter (1 of 6)

PMTs bases
Henry/Zander

- HV = 1000 V

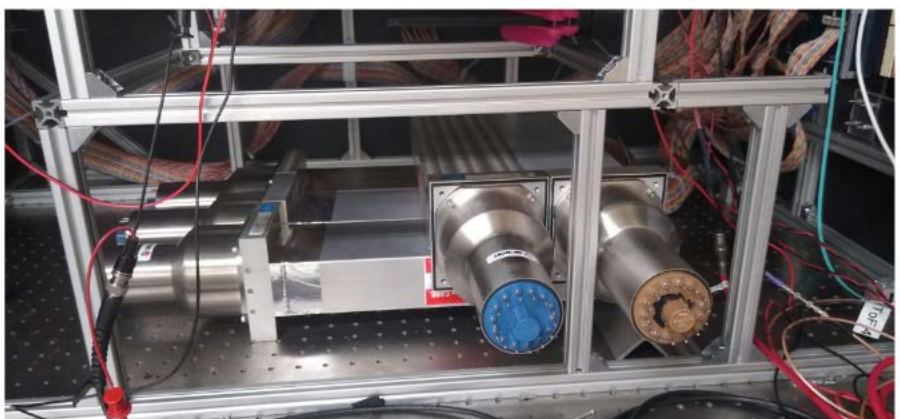


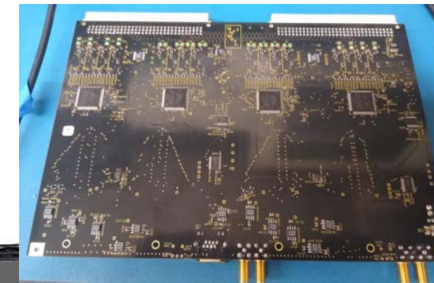
St. Gobain s600-8565 NaI counters

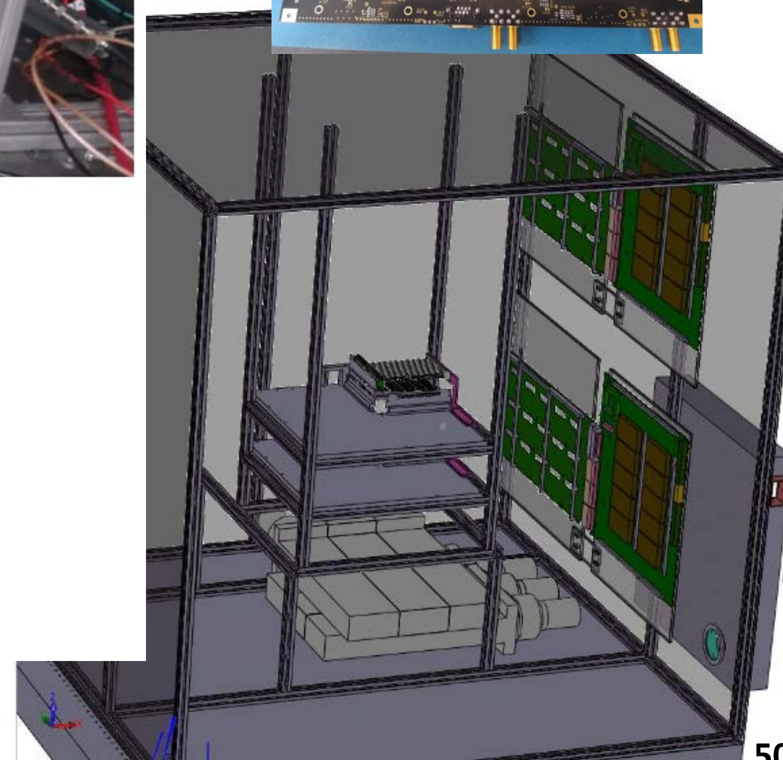
Scintillator	Light yield (photons/ keV)	Light ouput (%) of NaI(Tl) bialkali pmt	Temperature coefficient of light output (%/C) 25°C to 50°C	1/e Decay time (ns) (10-3μs)	Wavelength of maximum emission ym (nm)	Refractive index at ym	Thickness to stop 50% of 662 keV photons (cm)	Thermal expansion (°/C) x 10^{-6}	Cleavage plane	Hardness (Mho)	Density g/cm³	Hygroscopic	Comments
NaI(Tl)	38	100	-0.3	250	415	1.85	2.5	47.4	<100>	2	3.67	yes	General purpose, good energy resolution

Calorimeter Configuration

- **NaI Calorimeter**
  - ➢ **6U VME board (WATCHMAN)**

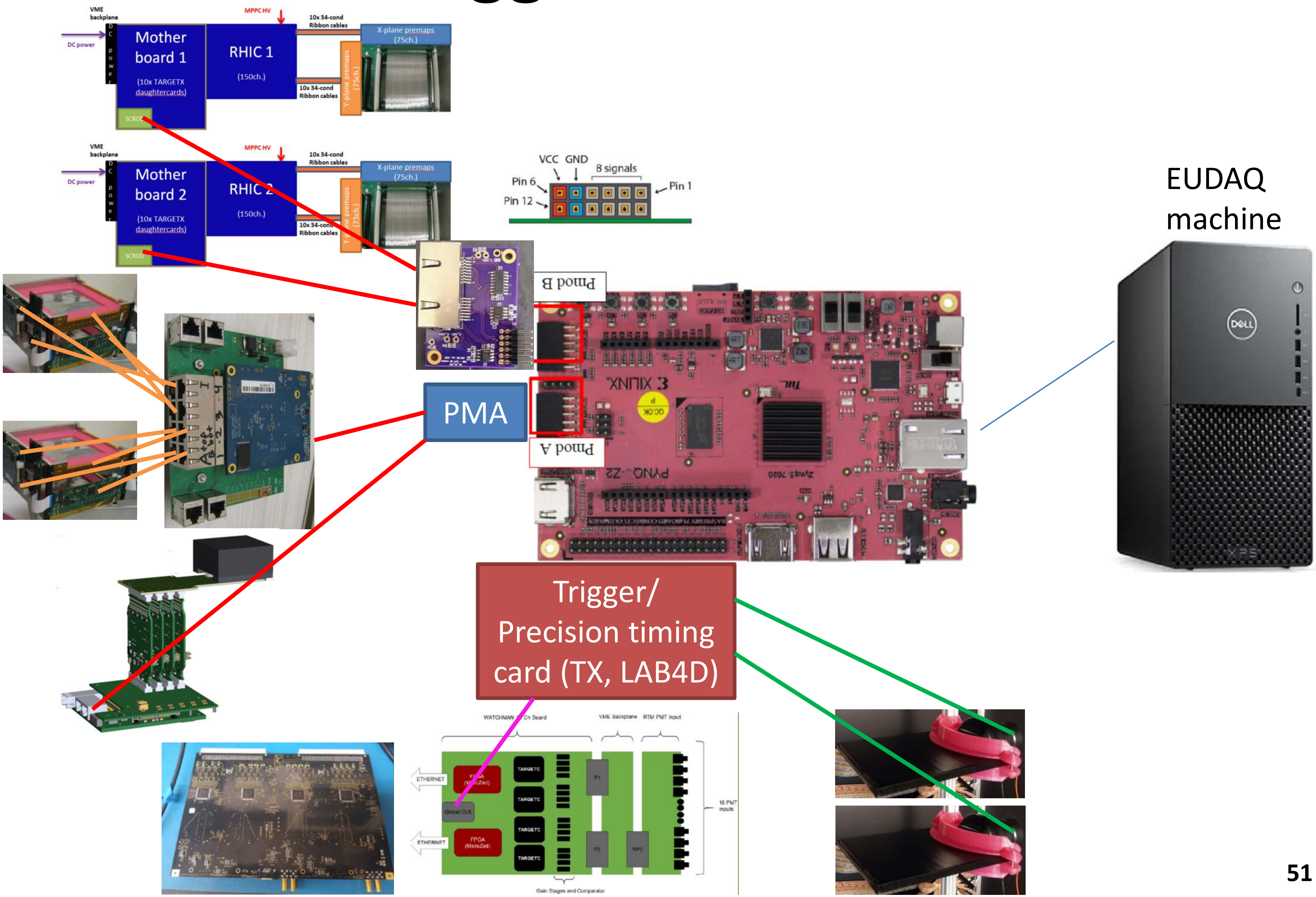






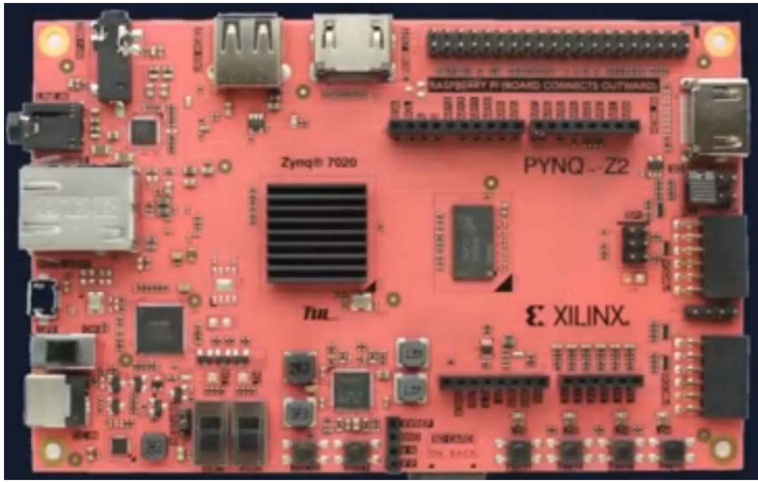
Salvador Ventura

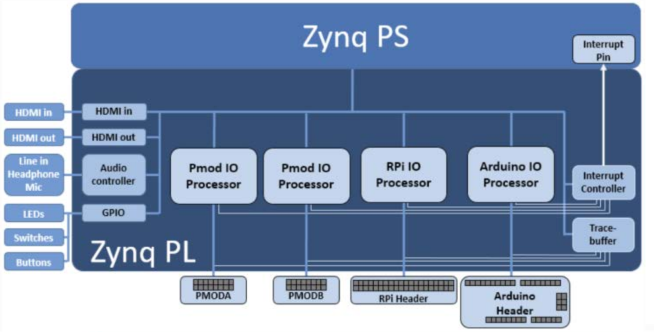
Trigger Overview

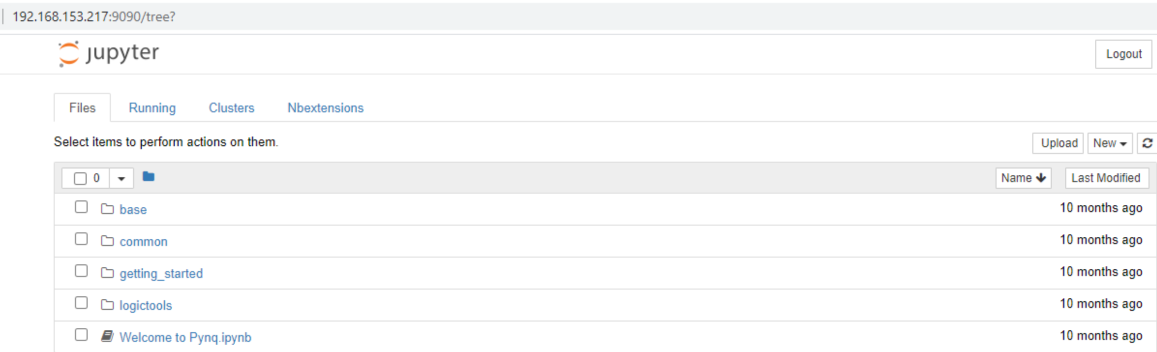


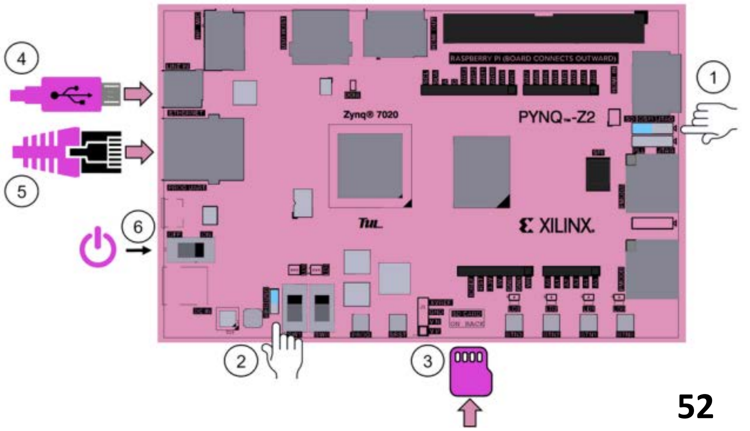
Python productivity for Zynq (Pynq)

- **Pynq architecture**
  - Python Zynq (PYNQ) Jupyter Notebook
  - Other languages/kernels available
  - Hardware (PL) overlays
  - SD card for filesystem, DDR3 RAM
  - Proper (Arm-9 dual-core), with hardware assist
  - HDMI in/out (object recognition)
  - Hardware computation assist (DSPs)

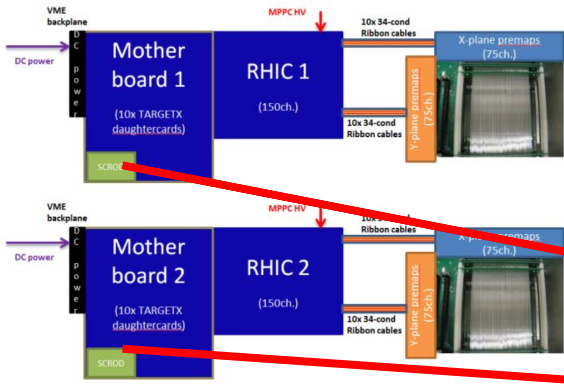






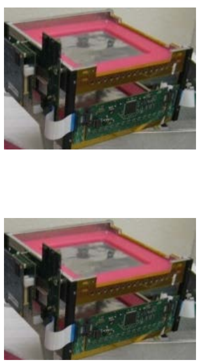


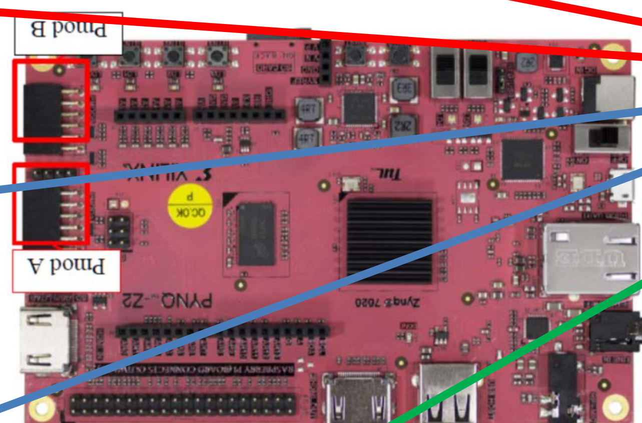
Data Collection Overview

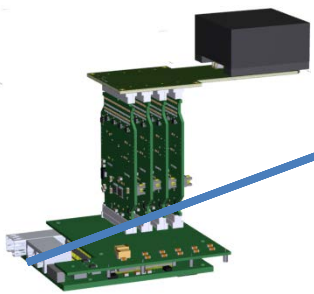


4 SCROD Rev A5 SFP links
1 MicroZed ethernet
1 Zynq ARM ethernet

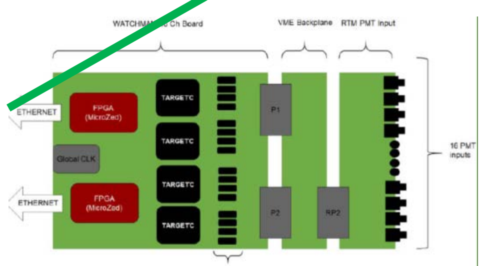
EUDAQ machine







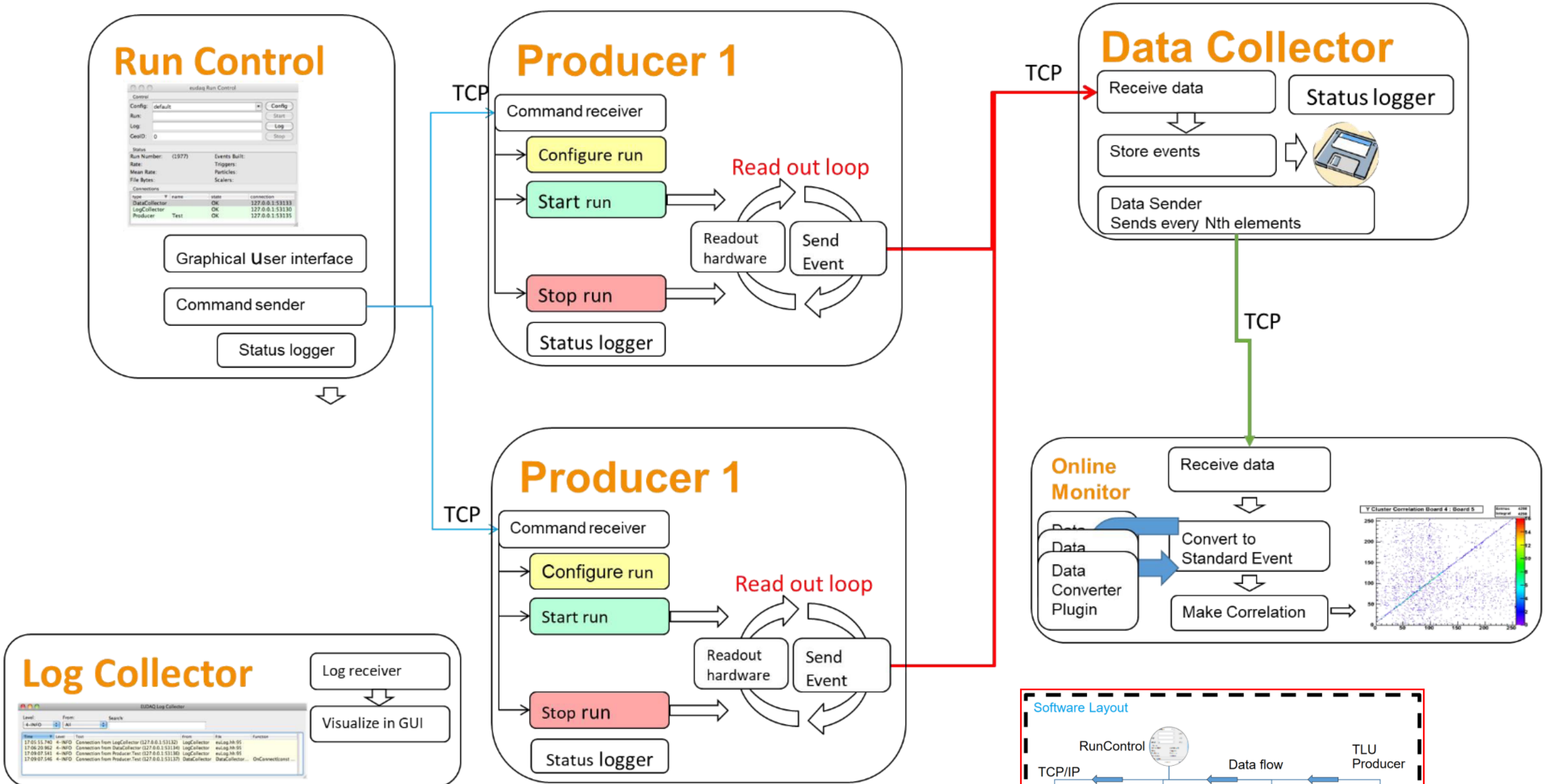
Trigger/ Precision timing card (TX, LAB4D)



- **To be Added**
  - ➢ Pynq (can be done “now”)
  - ➢ Calorimeter ZedBoard
  - ➢ Other SCRODs (tracking planes and EIC PID RO)

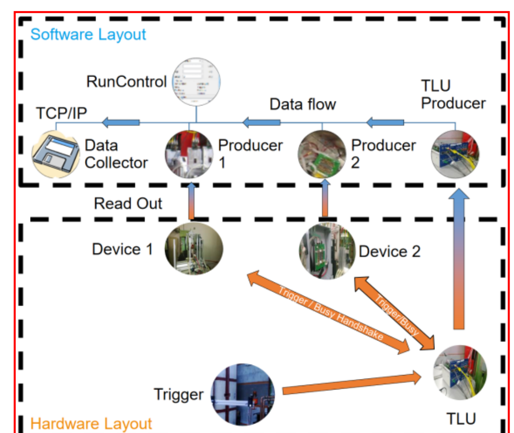
Richard Peschke

EUDAQ

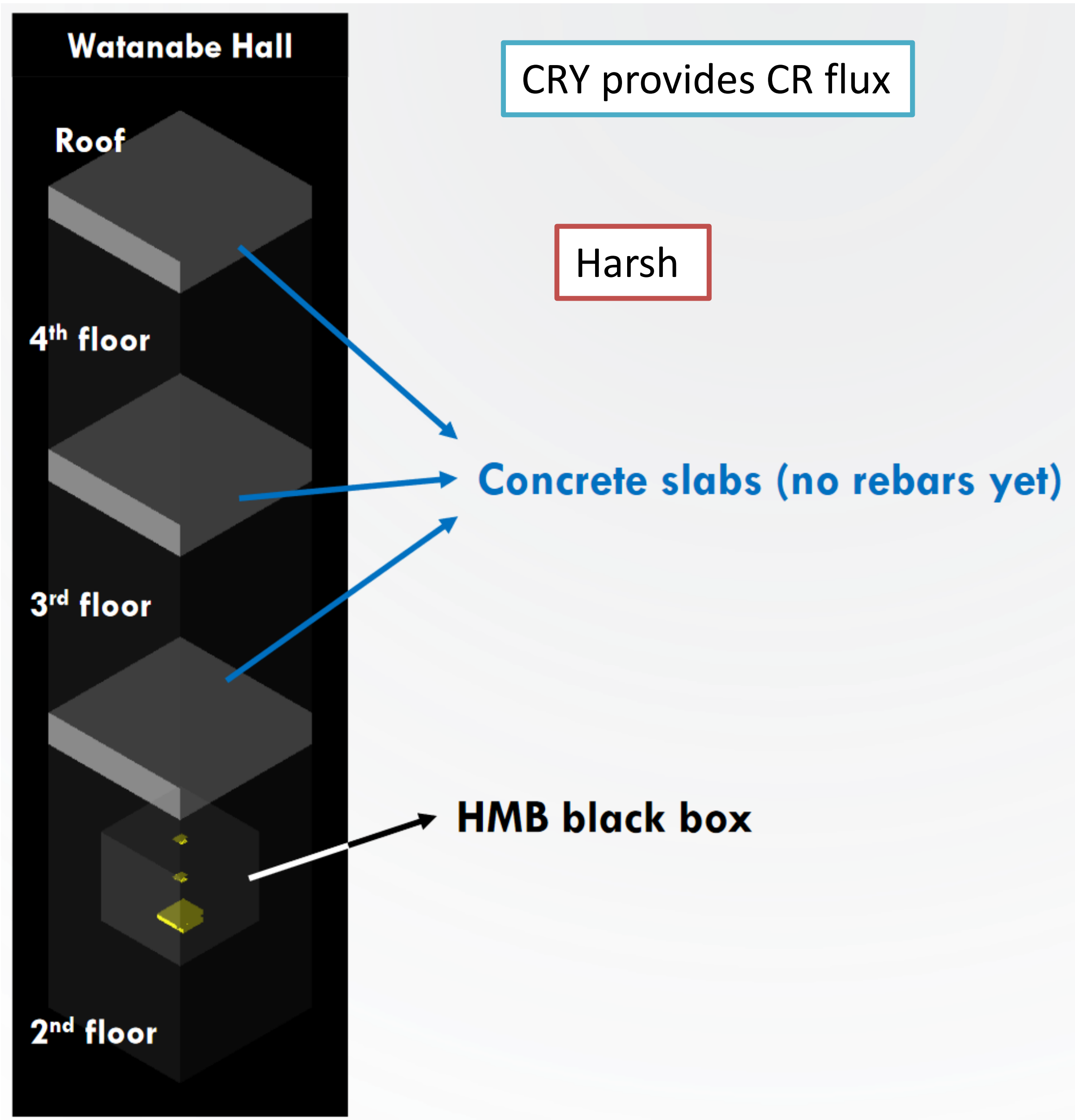


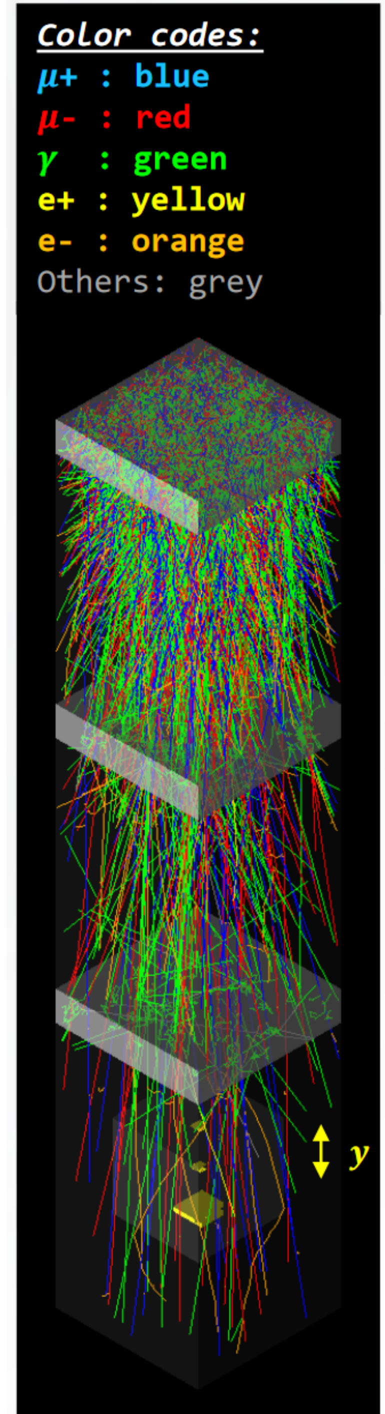
EUDAQ2 – A Flexible Data Acquisition Software Framework for Common Test Beams

Y. Liu[a,1] M. S. Amjad[b] P. Baesso[c] D. Cussans[c] J. Dreyling-Eschweiler[a] R. Ete[a] I. Gregor[a] L. Huth[a] A. Irles[d] H. Jansen[a] K. Krueger[a] J. Kvasnicka[e,a] R. Peschke[a,f] E. Rossi[a] A. Rummler[g] F. Sefkow[a] M. Stanitzki[a] M. Wing[b,a] M. Wu[a]



GEANT4+CRY simulation

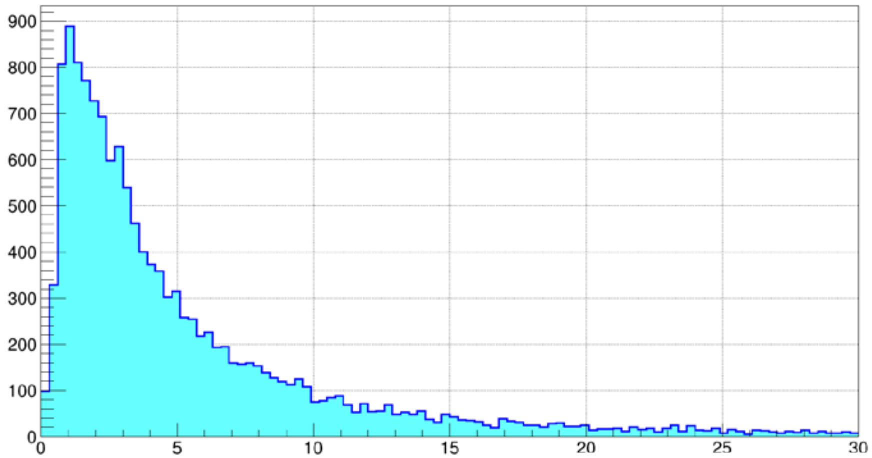




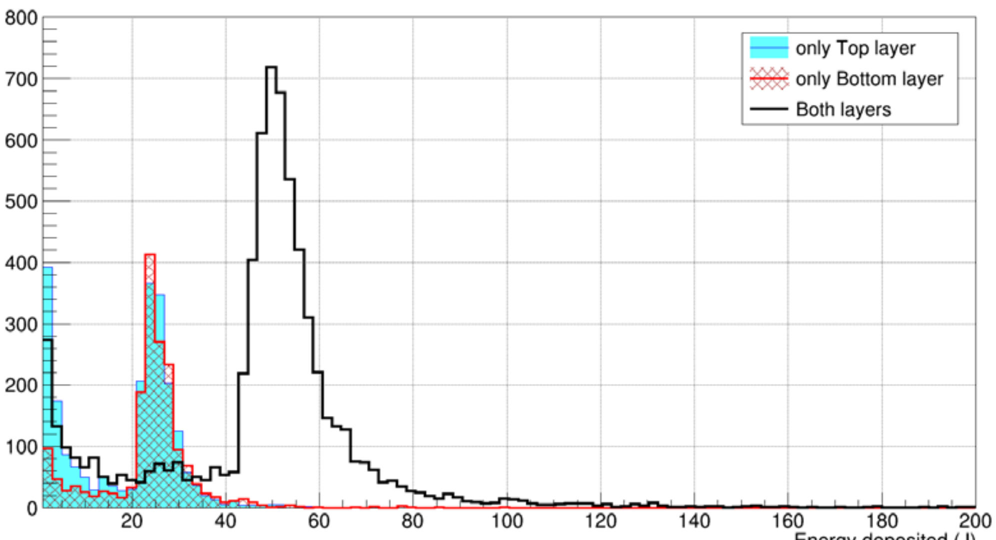
GEANT4+CRY simulation

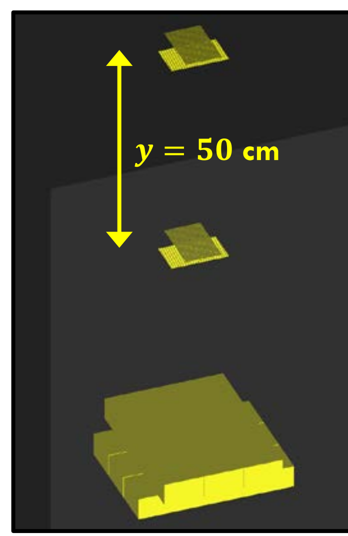
- Avg. Muon incident rate: 2175 hits per hour (~36 hits/min on NaI slab)

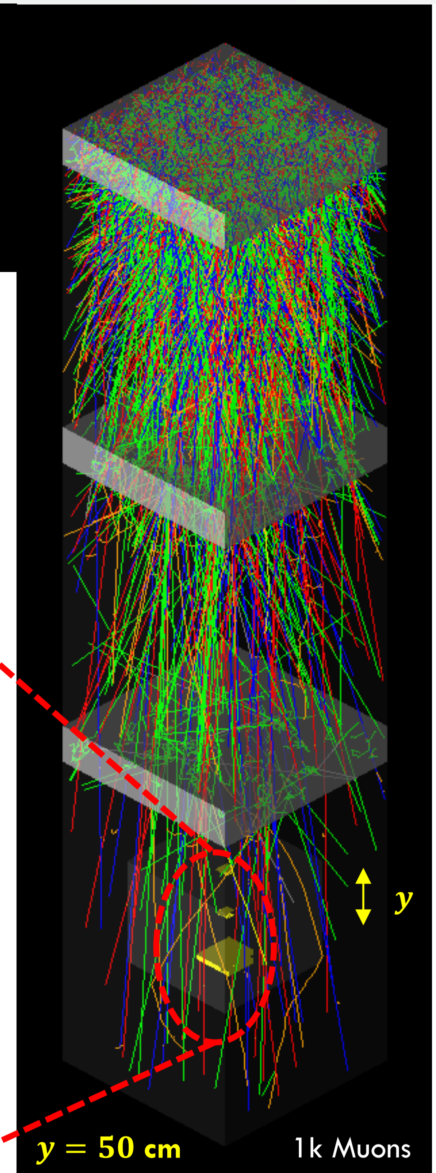
Muon energy spectrum



Total energy deposited on HMB calorimeter







DD4hep

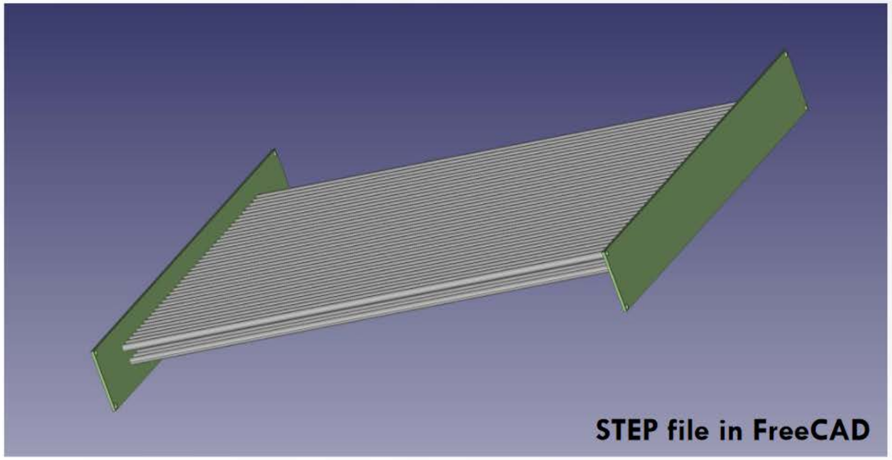
Importing CAD geometry in DD4hep

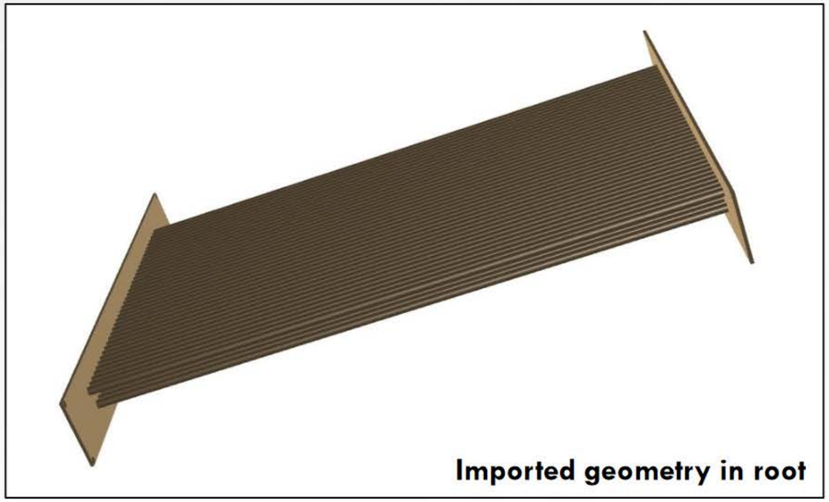
Shivang

- Open .STEP file in FreeCAD software and export selected parts to a Collada .dae file.
- Import this .dae file (detector assembly) in DD4hep with DDCAD and then, ***root*** may be used for visualization.

In FreeCAD (STEP file) → Collada (.dae)

Imported in DD4hep → Visualize with ***root***



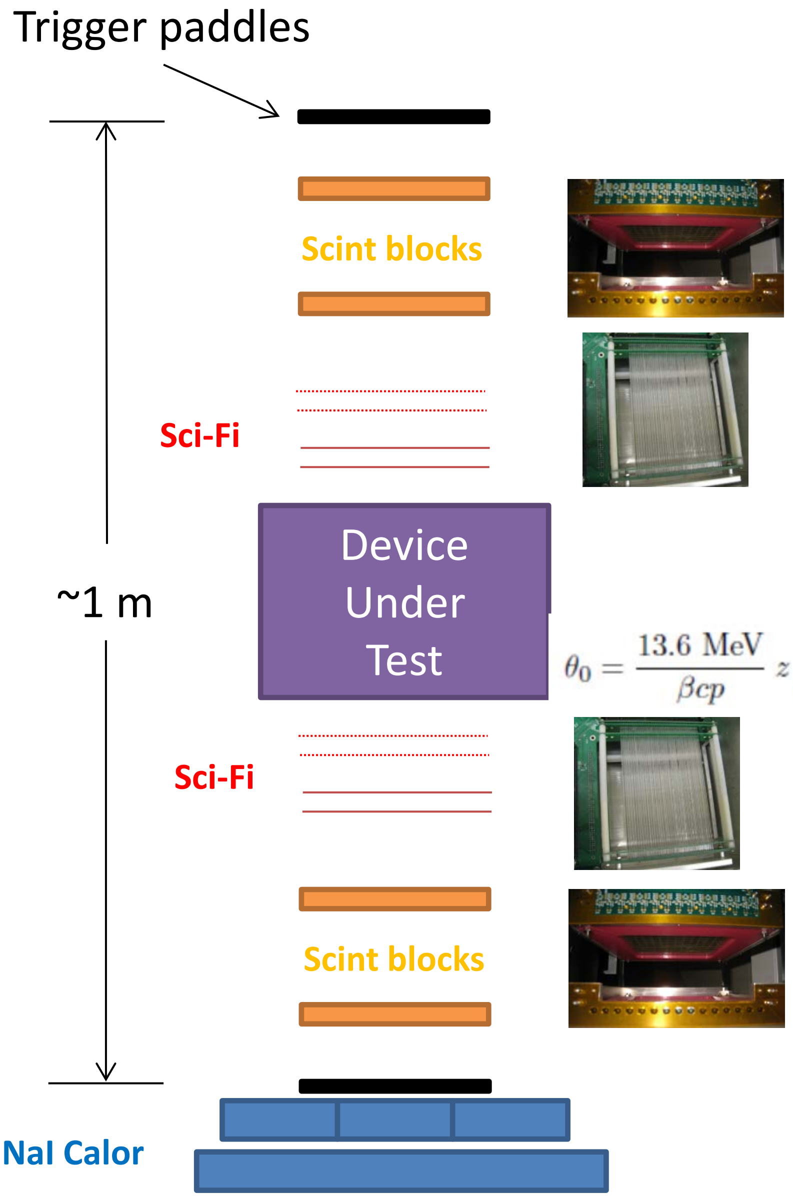


Notes:

- **Unified description of mechanics (construction) and simulation**

Tracking Resolution Estimates

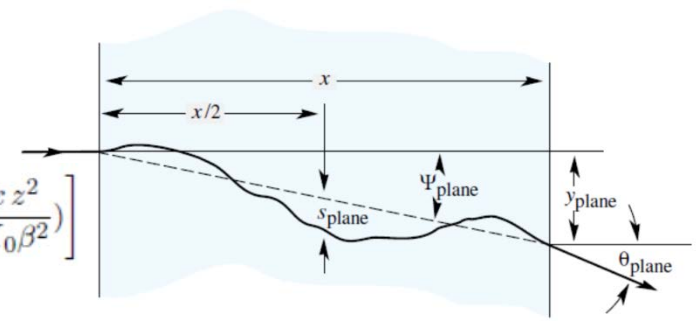
Toy Monte Carlo



10mm/sqrt(12)

1.25mm/sqrt(12)

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p} z \sqrt{\frac{x}{X_0}} \left[1 + 0.088 \log_{10}\left(\frac{x\, z^2}{X_0 \beta^2}\right)\right]$$

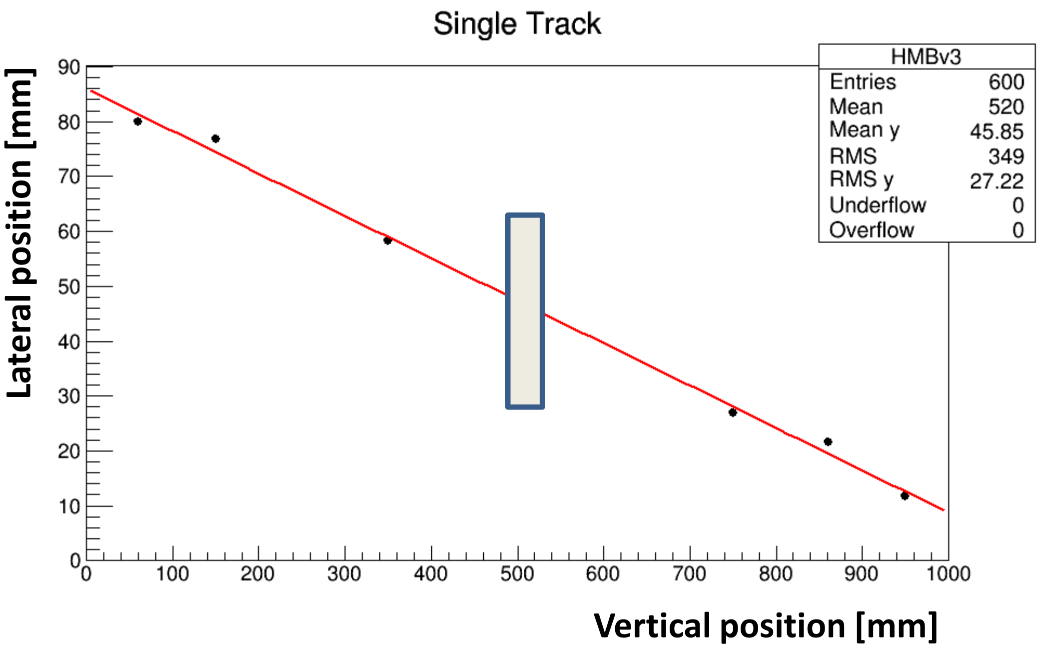


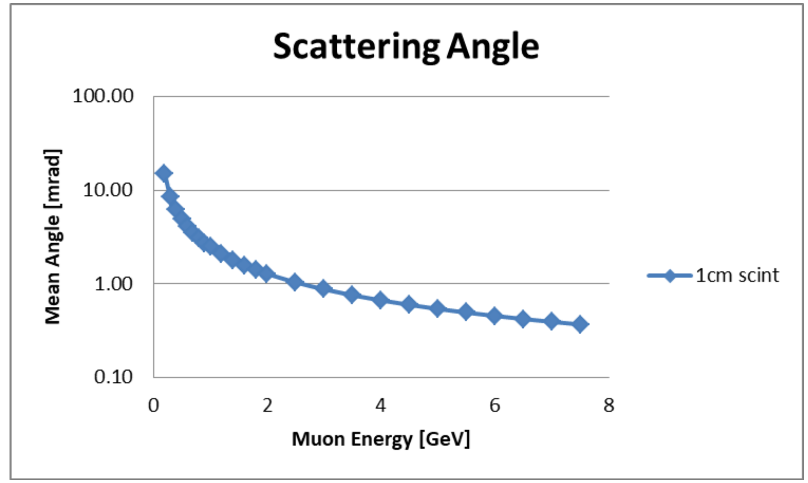
1.25mm/sqrt(12)

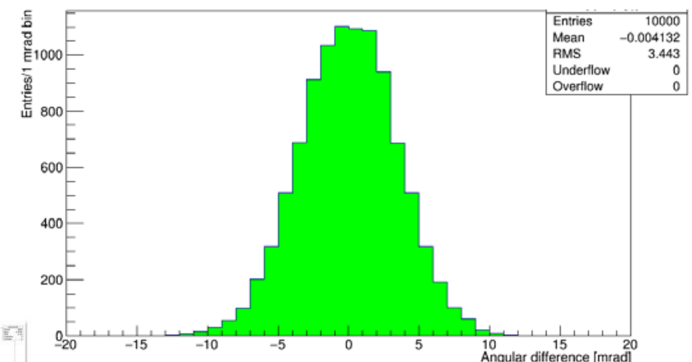
10mm/sqrt(12)

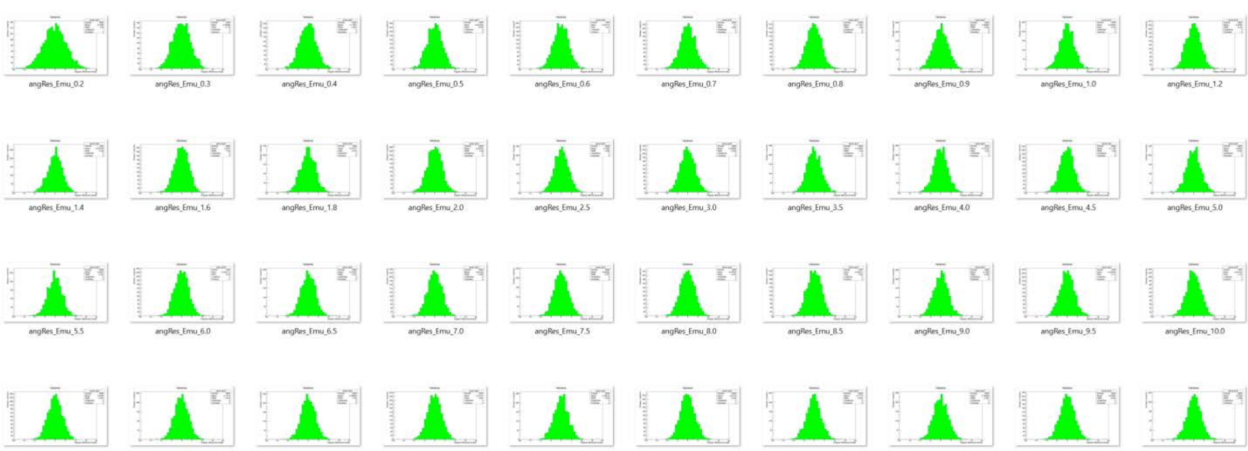
Tracking Resolution Estimates

At reference plane of center of DUT





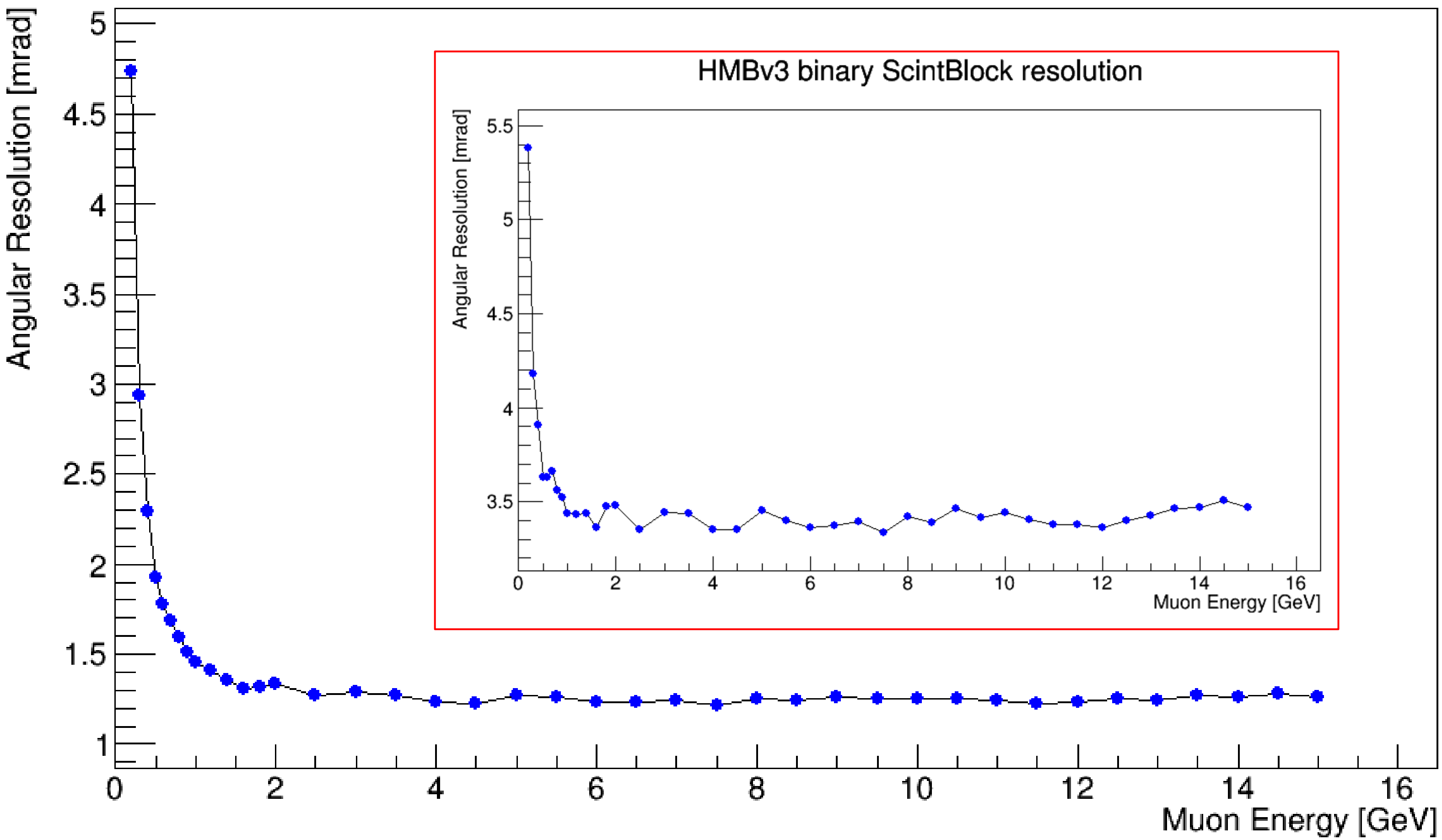




- **Typically 3.5 mrad resolution**
- **Dominated by scint block resolution**

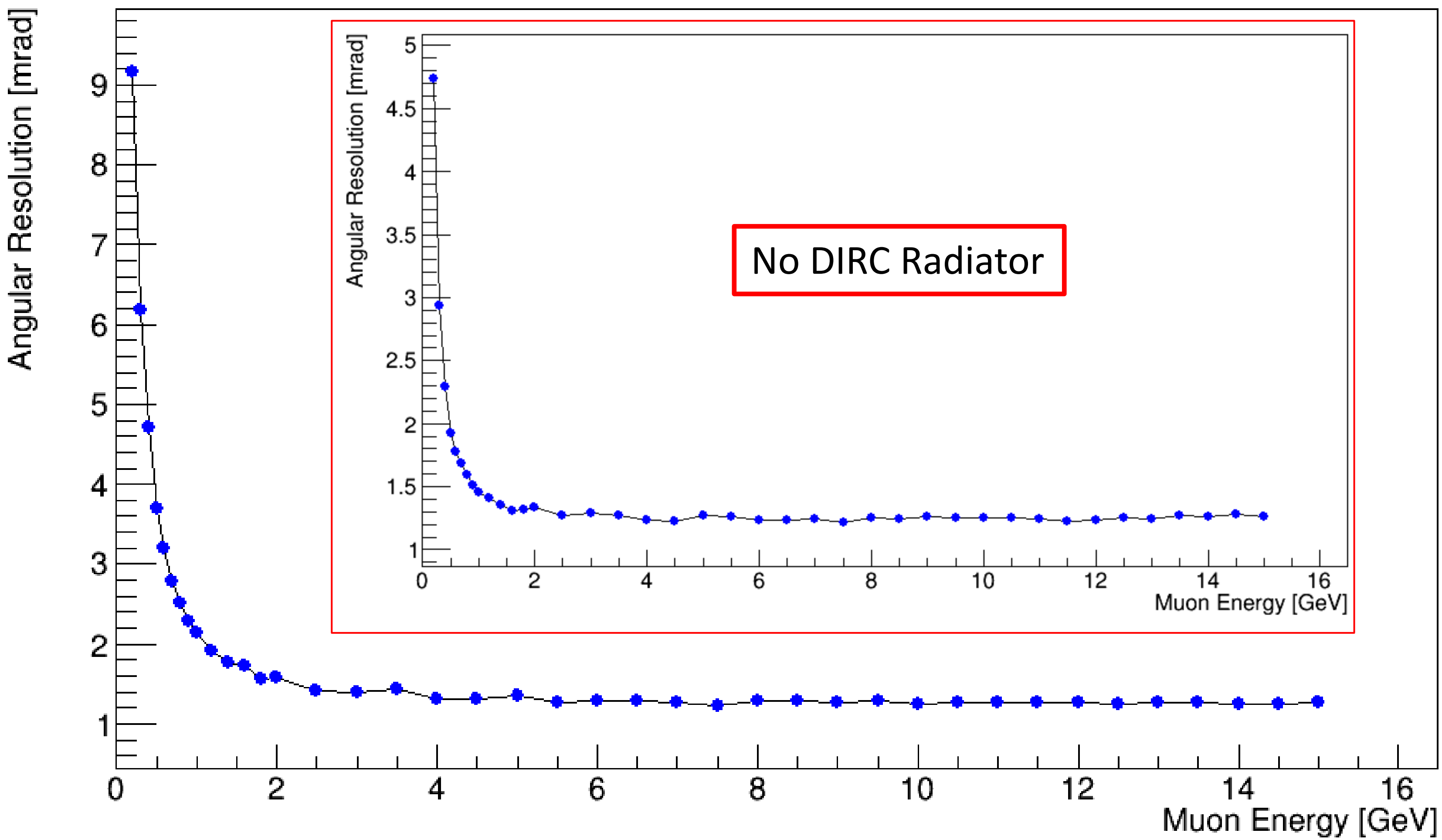
Tracking Resolution Estimates

If can improve from 10mm/sqrt(12) → 10mm/10



Tracking Resolution Estimates

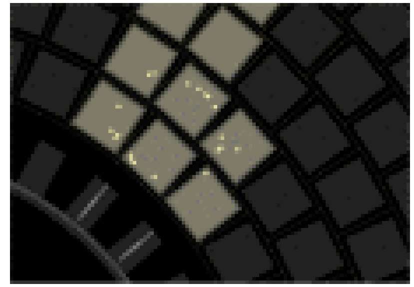
With 17.25 mm thick fused silica radiator at DUT center

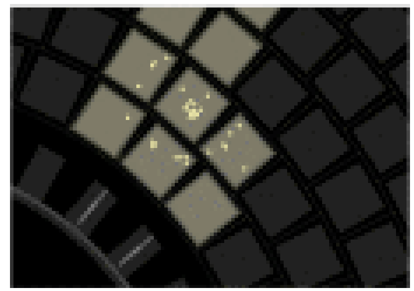


Only 1D, sanity-check of final GEANT result

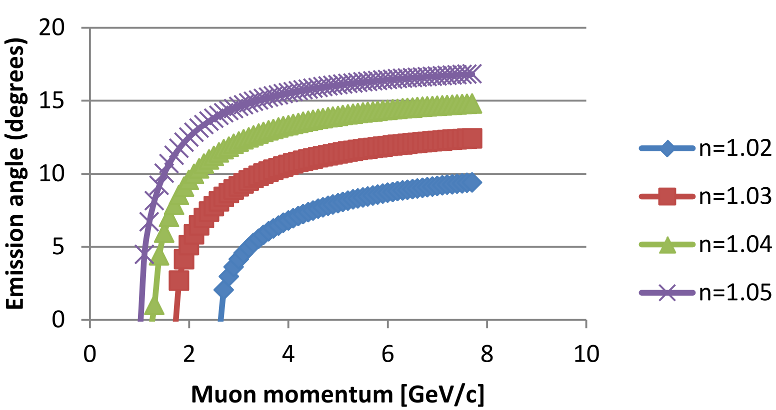
DUT:
Aerogel Ring Imaging Cherenkov (ARICH)

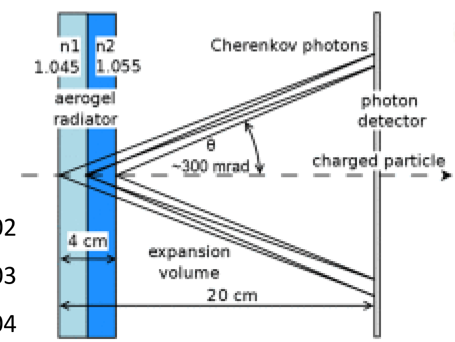
- **mRICH using ARICH technique**
  - **Proximity focus**
  - **Can measure ring image to determine muon momentum**

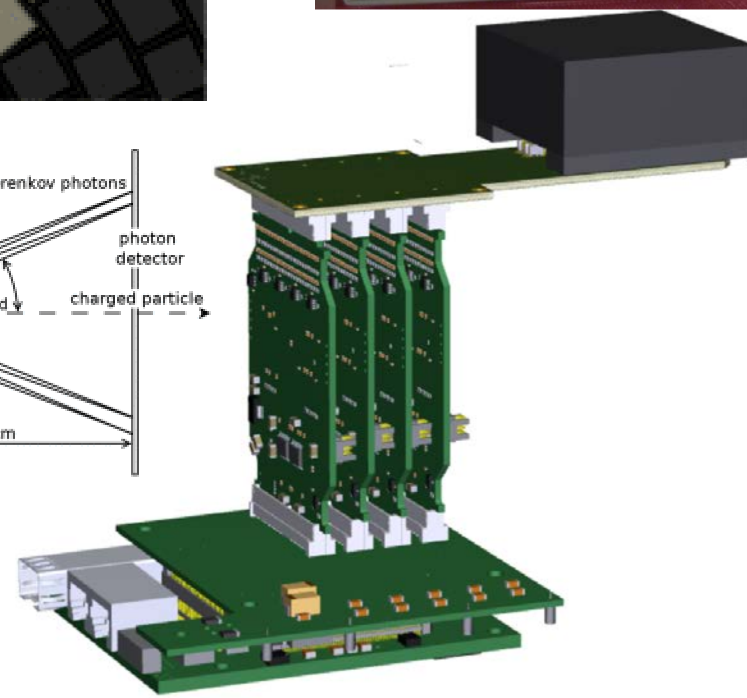




Aerogel Radiator

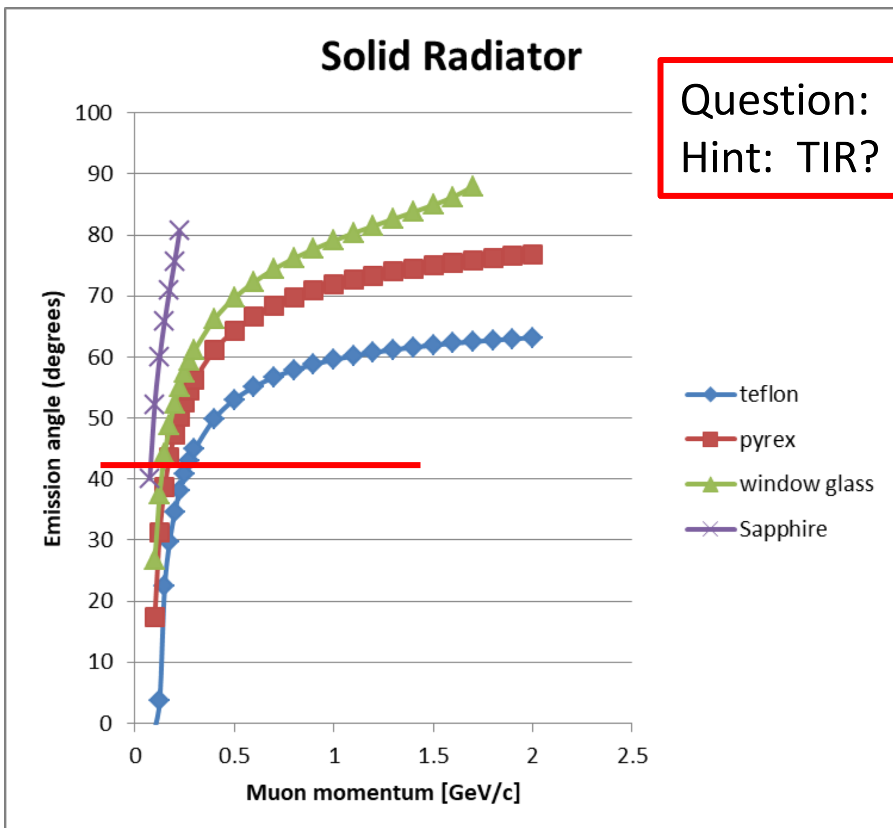




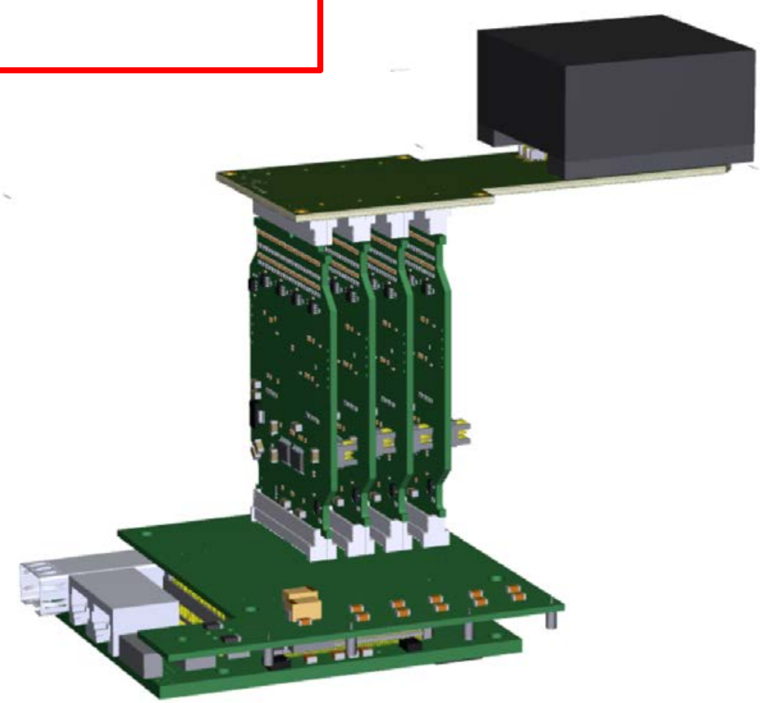


DUT:
compact Ring Imaging Cherenkov (cRICH)

- **ARICH technique**
  - **Works well at high p, but many atmospheric muons at lower momentum**
  - **Can make compact if use dense, thin material**



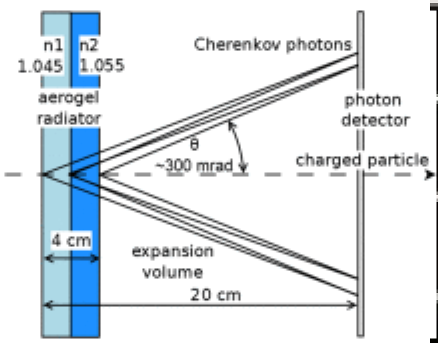
Question: will we see these?
Hint: TIR?

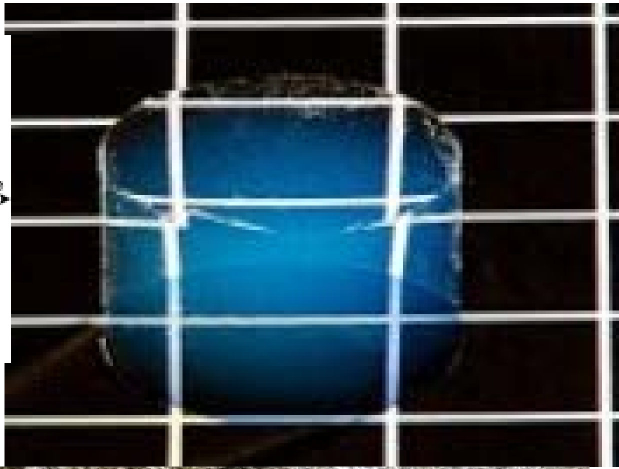


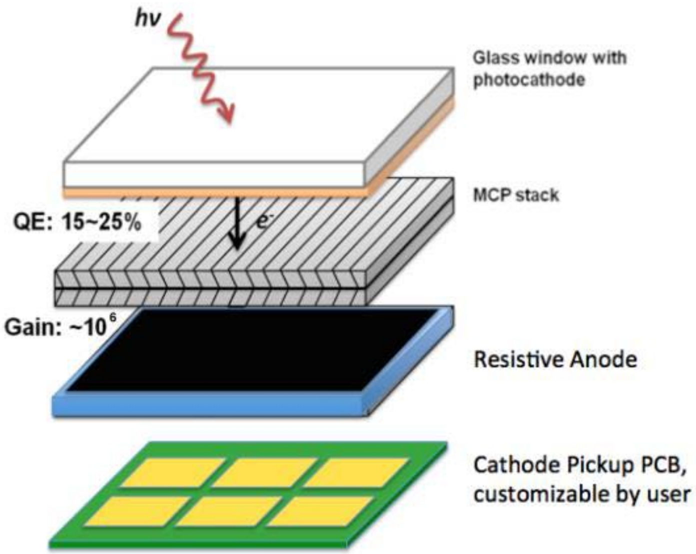
DUT

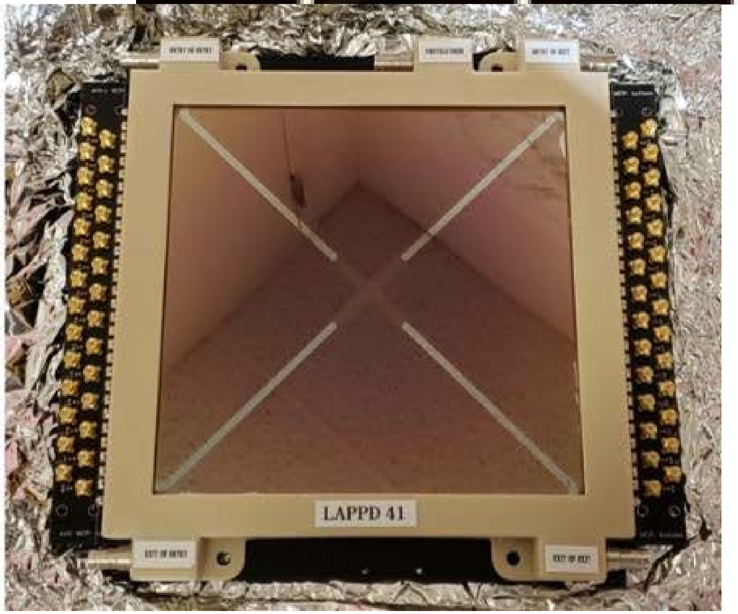
Large Area Picosecond PhotoDetector (LAPPD)

- **In addition to laser testing, can also image Cherenkov rings**
  - ➢ **Initially DRS4 readout**
  - ➢ **Transition to AARDVARC readout**





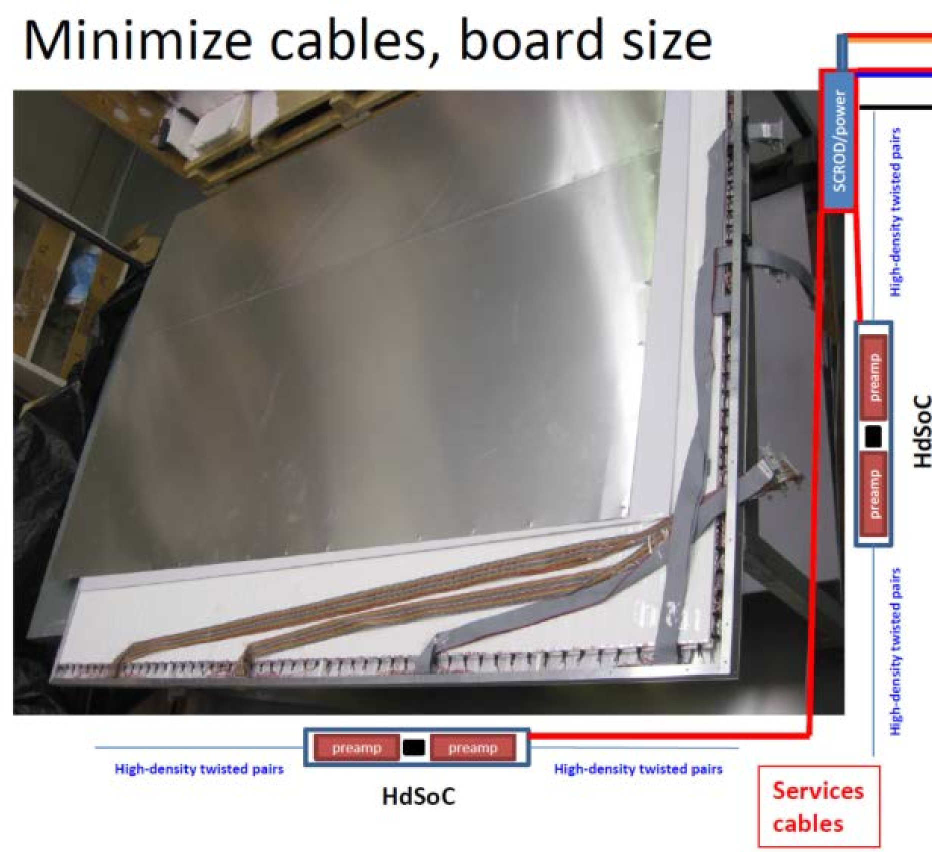




HMB v3

Other tests

- Minimize cables, board size

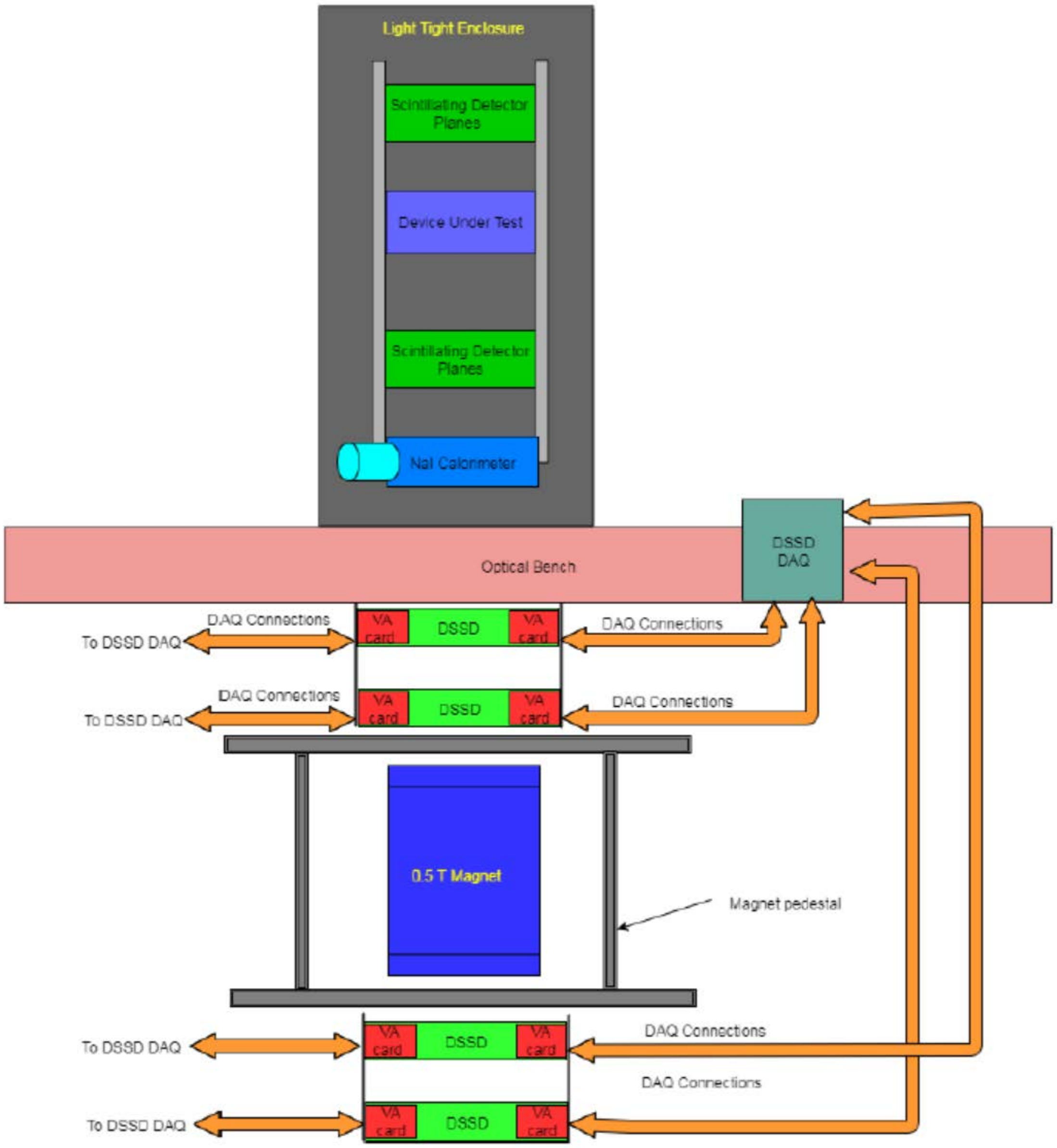


- 2 separate ASIC cards
- #z channels always same; wrap phi channels as needed
- 8 sectors * 15 layers * 2 FW/BW * 2 ASICs = 480 ASICs, ASIC cards
- 240 SCROD

- **Timing of long scintillator strips with WLS fibers (KLM scint upgrade)**
- **mRICH test?**
- **Spatial/timing resolution comparisons between BMD and SciFi Trackers**

HMB v4

- **Belle II "LS2" upgrades**
  - ➢ **Number of beamlines worldwide very limited, resource under great duress**
  - ➢ **Want to be *certain* prototype works properly before (or if) doing beamtest**
  - ➢ **Improved tracking**
  - ➢ **Silicon strip sensors (Belle I SVD)**
  - ➢ **Permanent magnet to form spectrometer**
  - ➢ **Momentum select to mimic K/pi of different velocities**

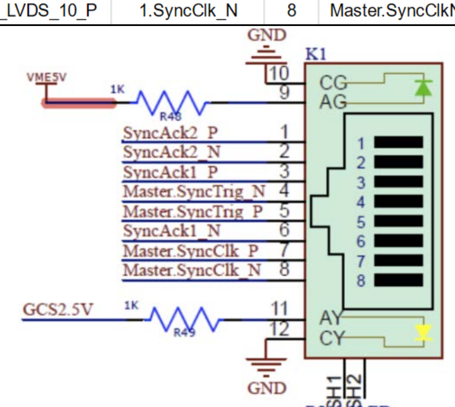


Summary -- Prioritized List

- **Nobody working on full-time**
- **Pynq readout to EUDAQ**
- **Pynq PMOD-B trigger**
  - Trigger distribution FW
    - Trigger data format definition (added to spreadsheet)
    - Variants for SCROD and Calor → make the same
- **Calorimeter trigger**
  - Use PMOD-B board
- **Scint block trigger/readout**
  - Trigger input card design (with LAB4D readout for Scint paddles) ['final' Calorimeter trigger solution]
  - Modify scint plane daughtercards for direct SiPM attach
  - Light cones for optical coupling (?)
  - Daughtercard firmware (4x window TARGETX)

	RJ-45		Pmod B			
Net name	pin #	Net name	Net name	pin #	dir.	src/dest
ACK+	1	ACK_B+	RX+	3	in	Zynq
ACK-	2	ACK_B-	RX-			via RX
TRG+	3	TRG_B+	TX+	1	out	Zynq
RSV-	4	RSV_B-	AUX-		out	TP
RSV+	5	RSV_B+	AUX+			Fanout
TRG-	6	TRG_B-	TX-	2	out	Zynq
TTDCLK+	7	RCLK_B+	SysCLK+	7	out	Clock
TTDCLK-	8	RCLK_B-	SysCLK-	8		Fanout

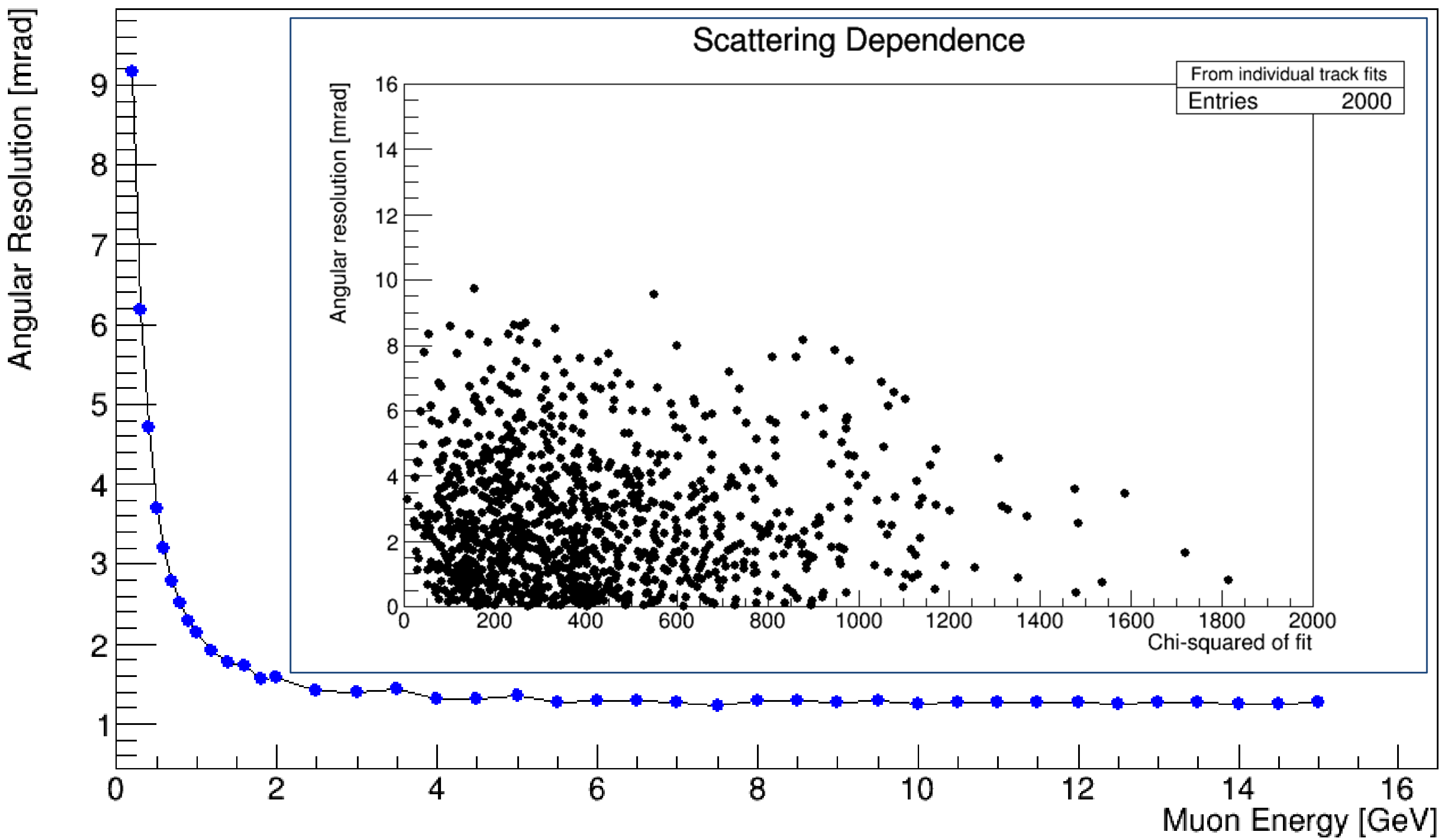
WATCHMAN 6U VME					
	ZedBoard 1			RJ-45	
dir	pin #	I/O banking	Net name	pin #	Net name
	no connect			1	SyncAck2_P
				2	SyncAck2_N
out	JX2-43	JX2_LVDS_8_N	SyncAck1_P	3	SyncAck1_P
in	JX2-55	JX2_LVDS_12_N	1.SyncTrig_N	4	Master.SyncTrig_N
	JX2-53	JX2_LVDS_12_P	1.SyncTrig_P	5	Master.SyncTrig_P
out	JX2-41	JX2_LVDS_8_P	SyncAck1_N	6	SyncAck1_N
in	JX2-49	JX2_LVDS_10_N	1.SyncClk_P	7	Master.SyncClkP
	JX2-47	JX2_LVDS_10_P	1.SyncClk_N	8	Master.SyncClkN



Backup

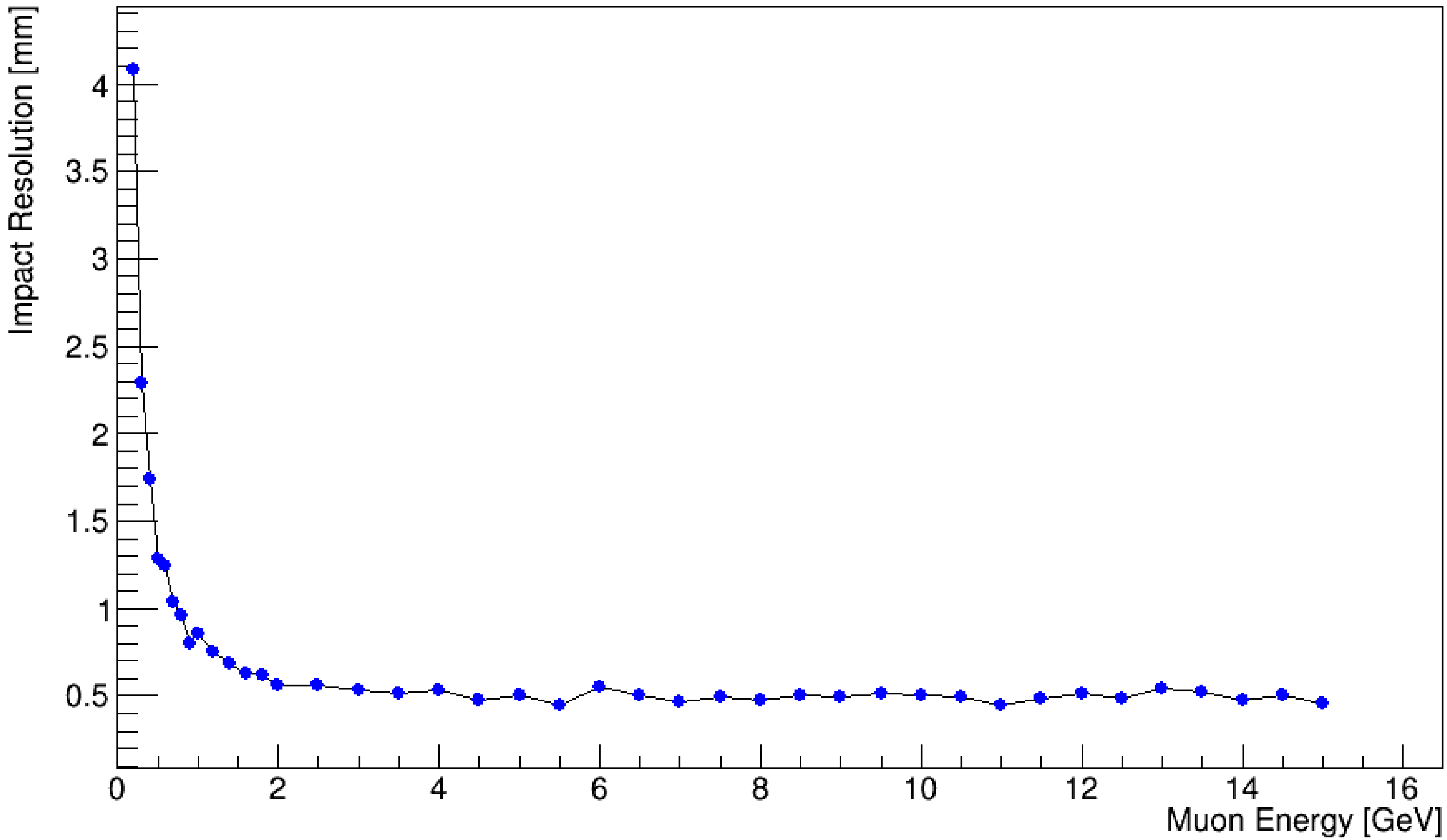
Tracking Resolution Fits

With 17.25 mm thick fused silica radiator at DUT center

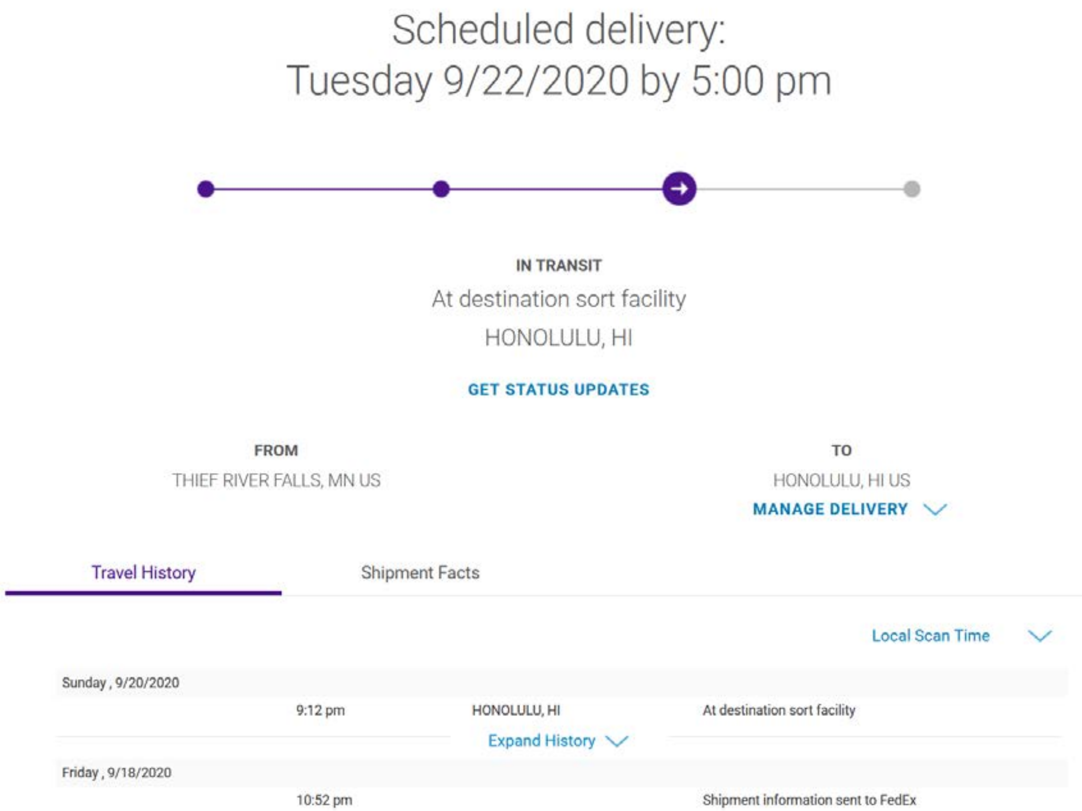


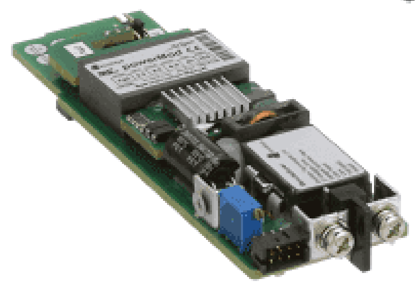
Impact Resolution Estimates

While did measurement, could have just related to angle by geometry



HMB 3.1000 power



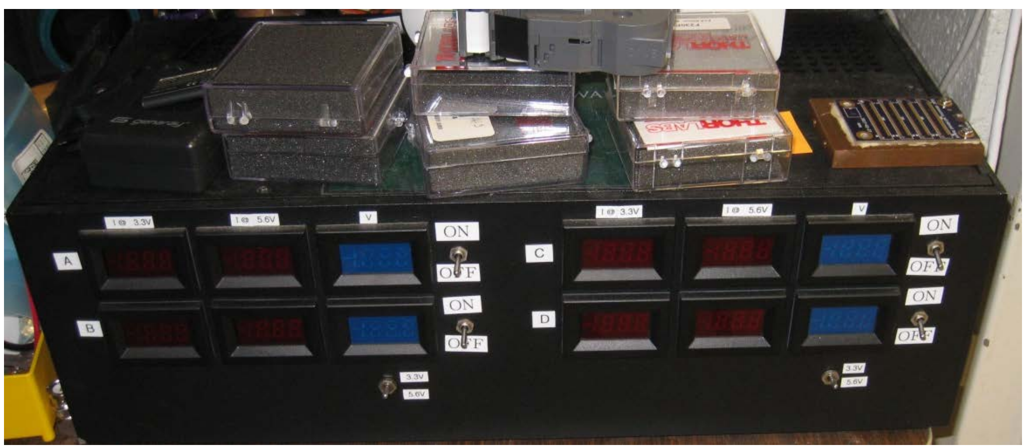


Excelsys power
Adjustable 3 – 6 V
40A per module

Ordered 2 chassis, 5 XG2

Repurposed power module from iTOP prototype

Based upon compact DC-DC



Nomenclature: HMB 3.abcd

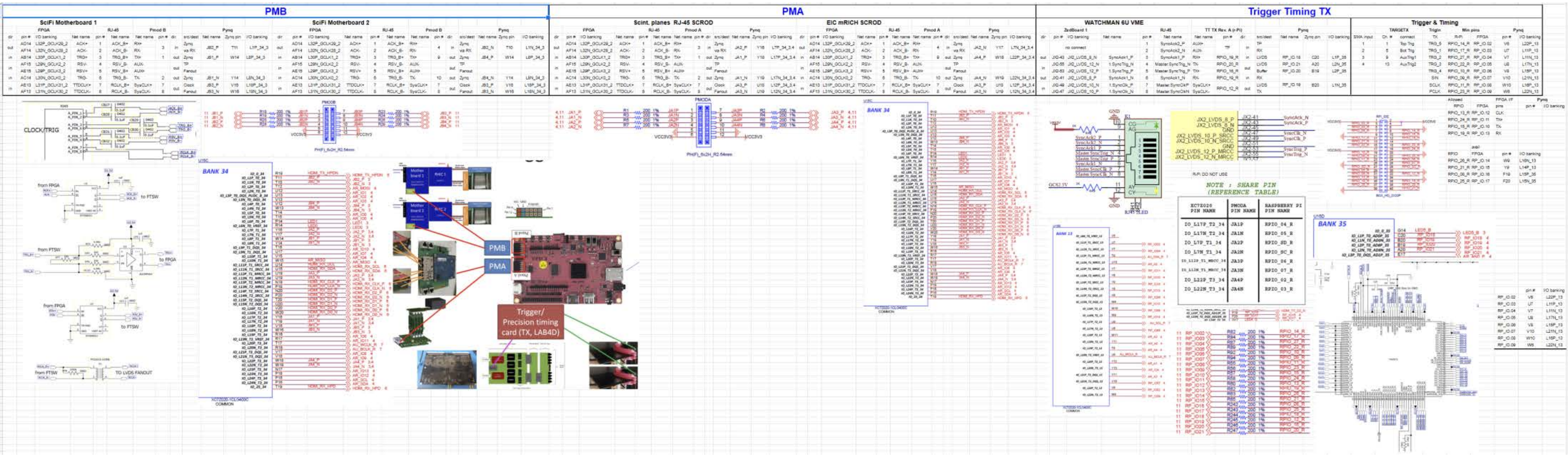
1. **Version 3. is without semiconductor tracker/magnet (v4)**
   a. **Tracker configuration**
   b. **Calorimeter configuration**
   c. **RICH configuration**
   d. **DUT configuration**

So for example: HMB 3.1000

Will be the first set-up (just 2 existing layer pairs) with KLM Motherboard and pre-amp/cable readout

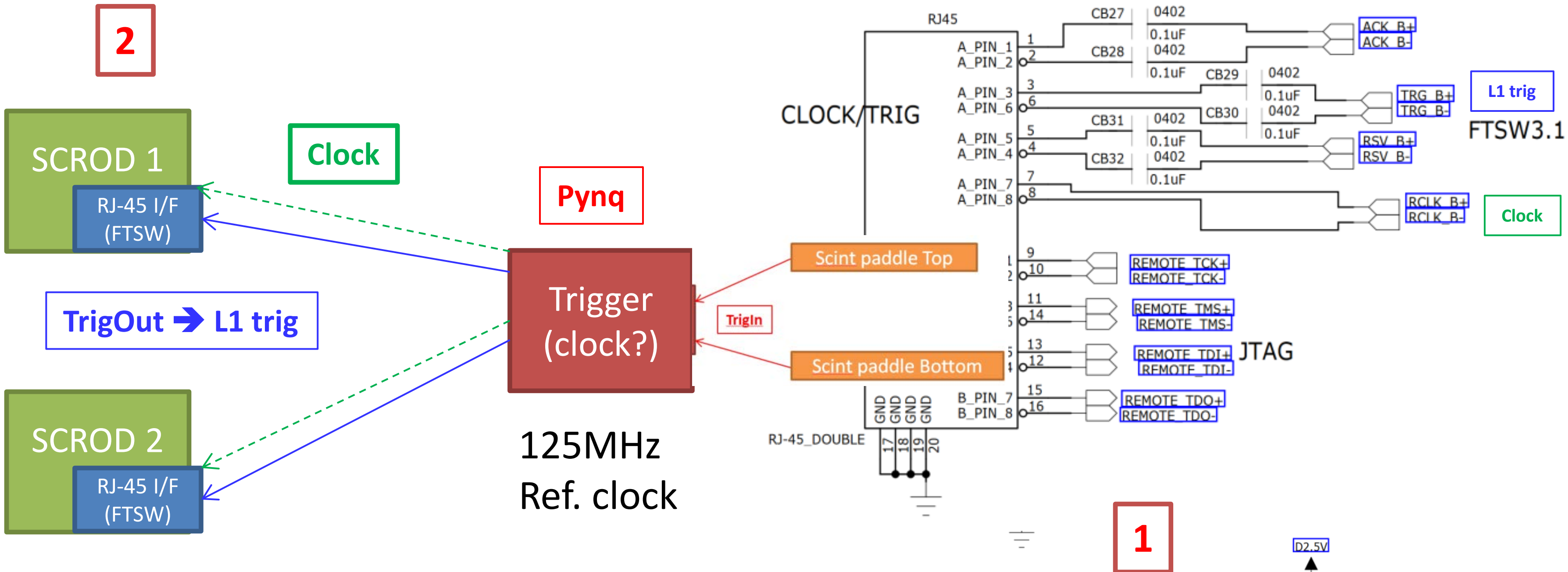
Will switch to 3.2xxx when scint planes ready (could be 3.2100 or 3.2011 or … depending upon which other systems ready first)

Interconnect Document (google doc)

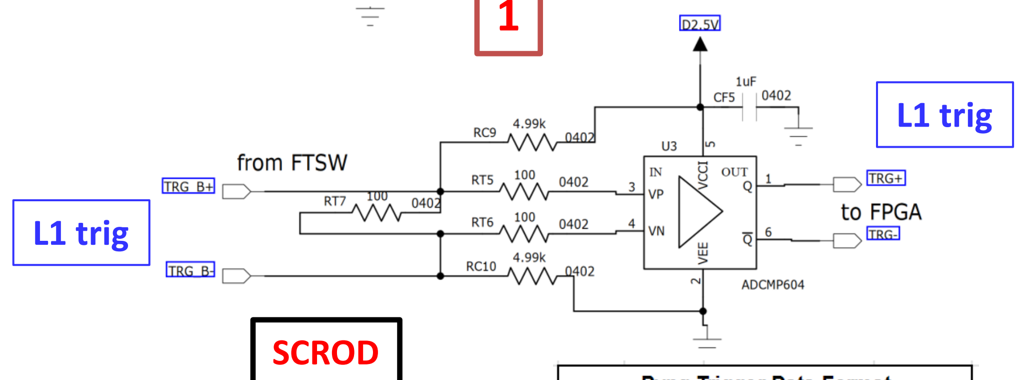


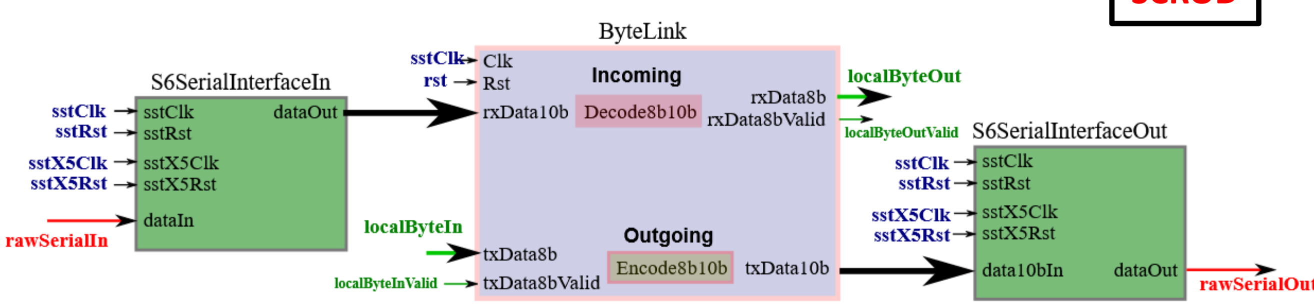
https://docs.google.com/spreadsheets/d/1n2BbW0DX0ElCNCiPCY2XMOYuf8mqHJAXCbxMYiiGm7U/edit?usp=sharing

Trigger Details



3
- **Use “byte-link” protocol**
- **Clock (25MHz), 125Mbps (DDR)**
- **Trigger latency ~ 10’s of ns**





Pynq Trigger Data Format		
Word	8-bit	
#	Word	Word
1	0x50	Trigger!
2	0xXX	Trigger #
3	0xXX	Coarse Time [31:24]
4	0xXX	Coarse Time [23:16]
5	0xXX	Coarse Time [15:8]
6	0xXX	Coarse Time [7:0]
7	0xXX	Phase (offset)