Hawaii Muon Beamline

Chris Ketter
Oskar Hartbrich
Richard Peschke
Harsh Purwar
Shivang Tripathi
Gary Varner
Salvador Ventura

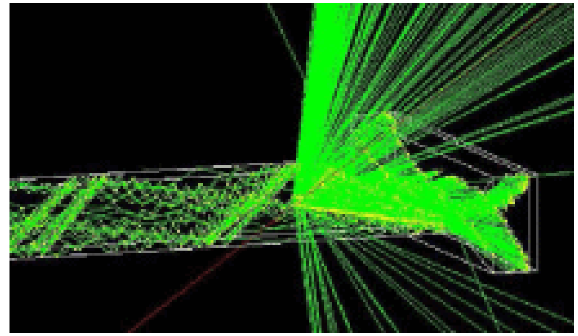
And many former and future members

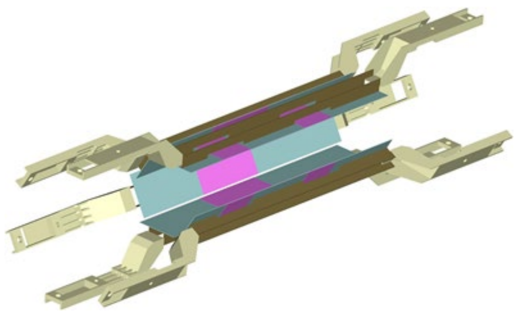
Motivations:

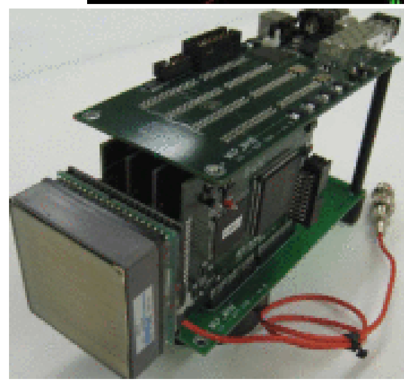
- **Number of beamlines world-wide limited (CF last mRICH run)**
- **Want to ensure everything working/tuned before travel**
- **Training platform**

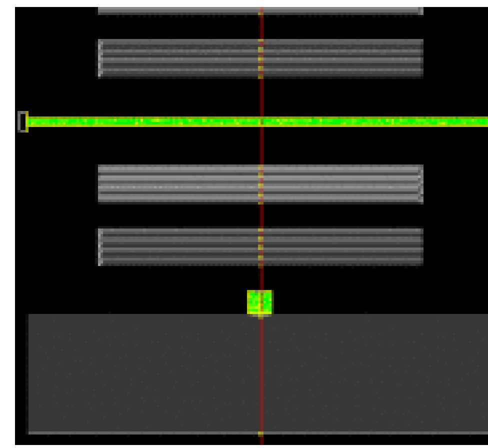
Hawaii Muon Beamline (HMB) v1

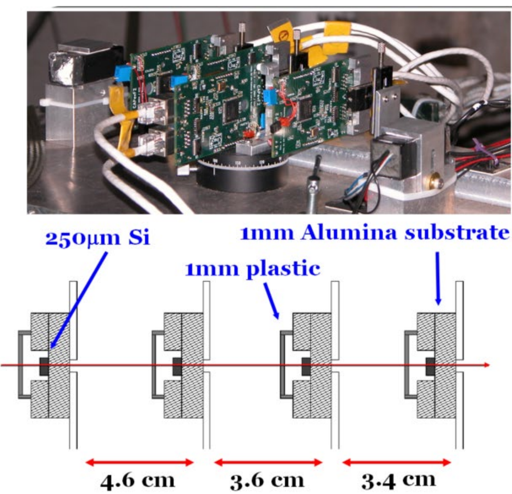
- **Version 1 (drift tubes)**
  - iTOP prototype development
  - Cluster counting
  - Fine-mesh PMTs + scint (T0)
  - Poster on next slide

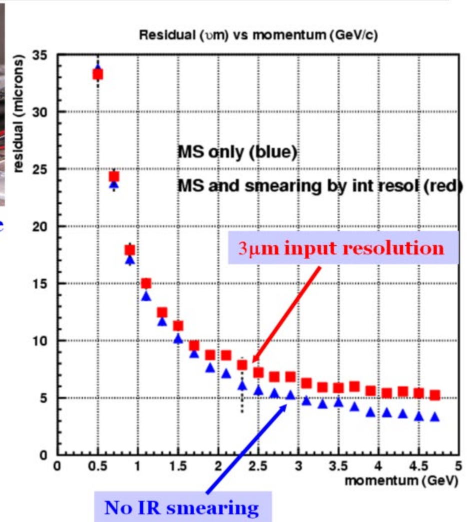


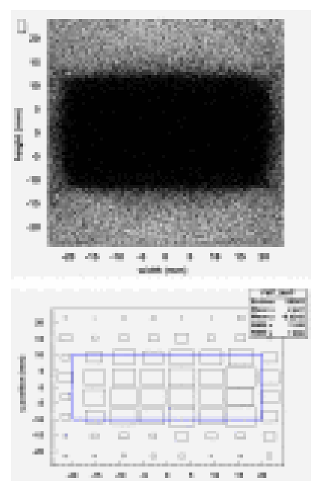


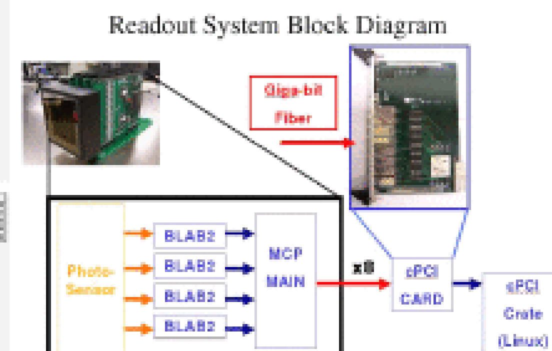


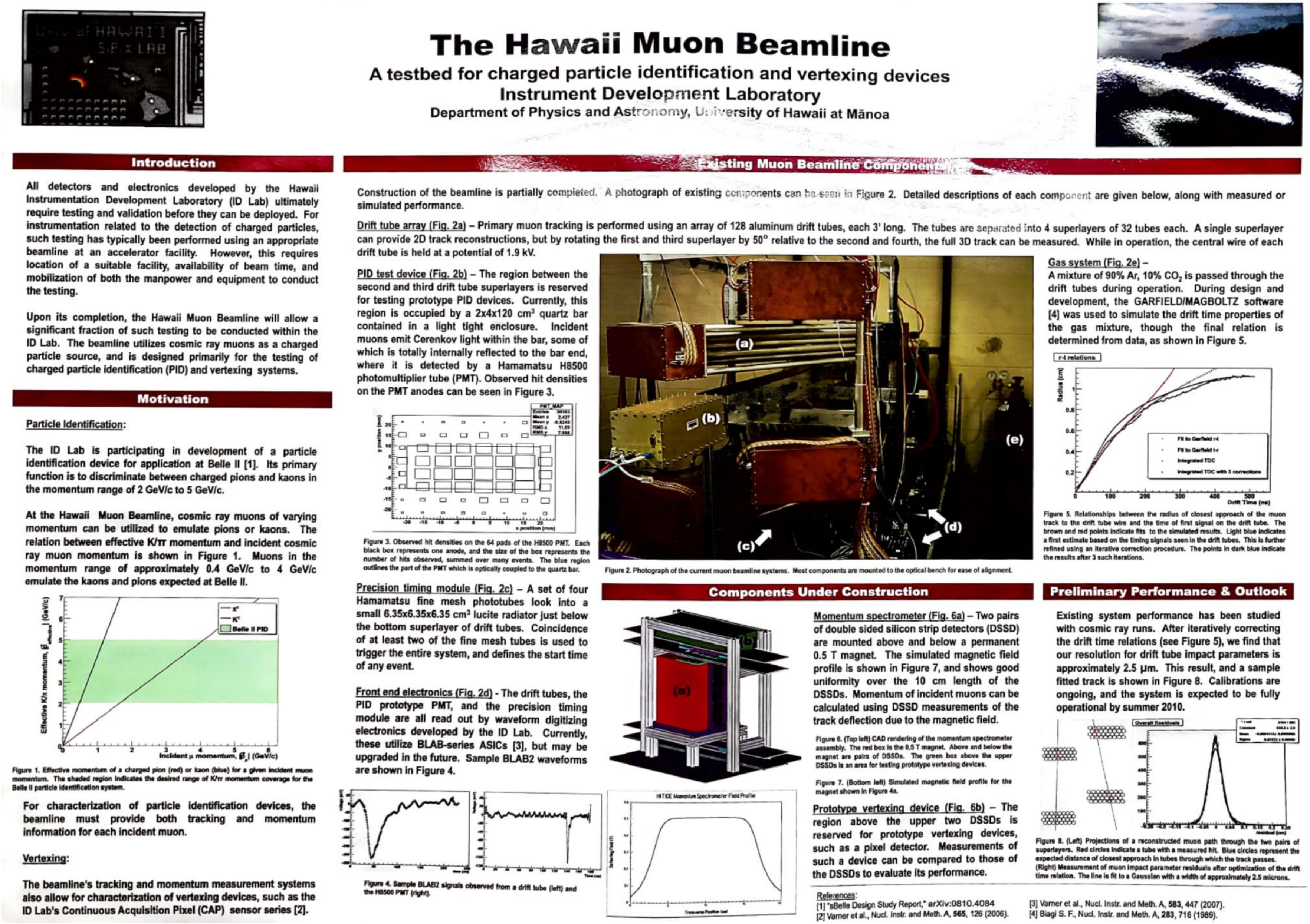








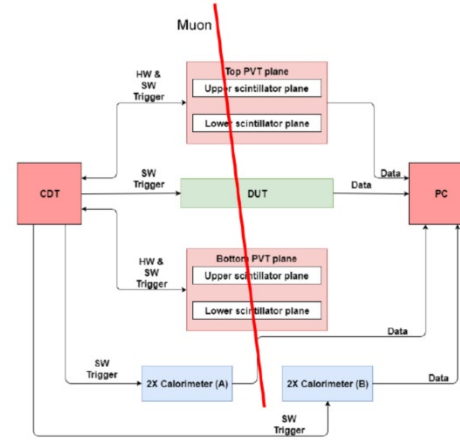




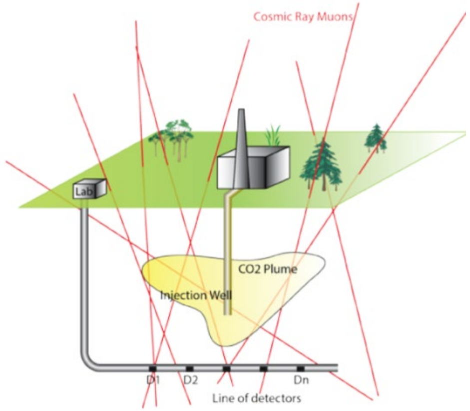
- Development of an imaging Time-of-Propagation (iTOP) prototype detector, NIM **A623** p. 365 (2010)
- An Imaging time-of-propagation system for charged particle identification at a super B factory, NIM **A623** p. 297 (2010)

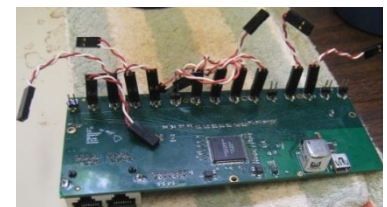
Hawaii Muon Beamline (HMB) v2

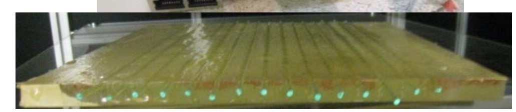
- **Version 2 (BMD trackers)**
  - **Borehole Muon Detector**
  - **Khahn and James thesis**
  - **DOE (administration change)**

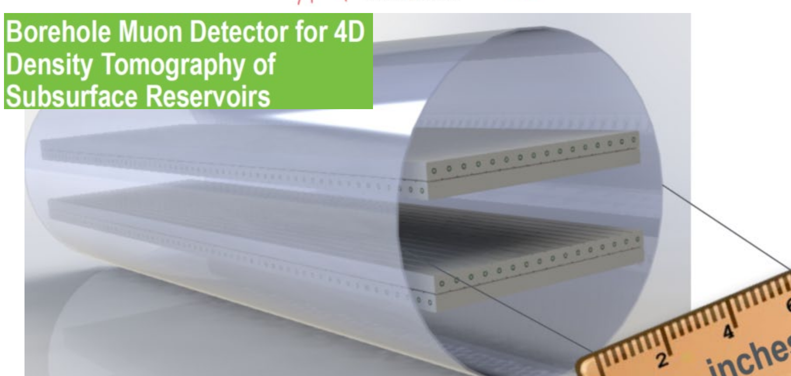


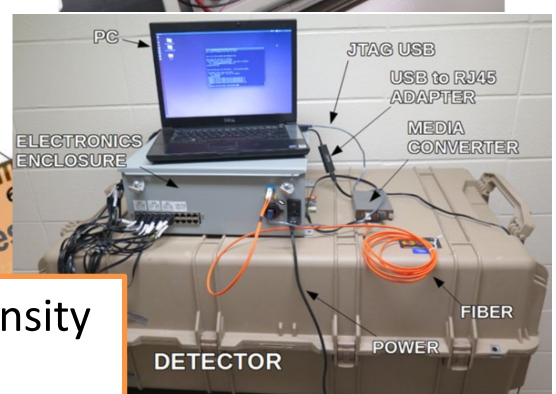
v2 never finished

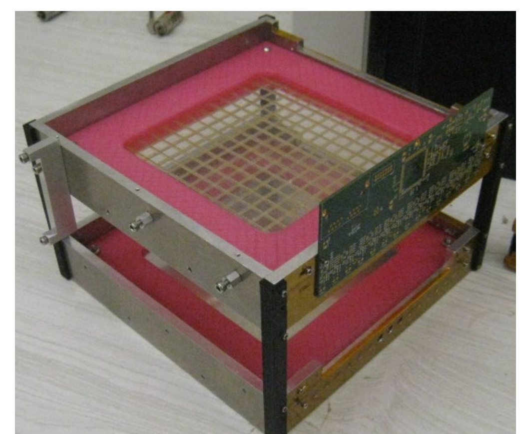








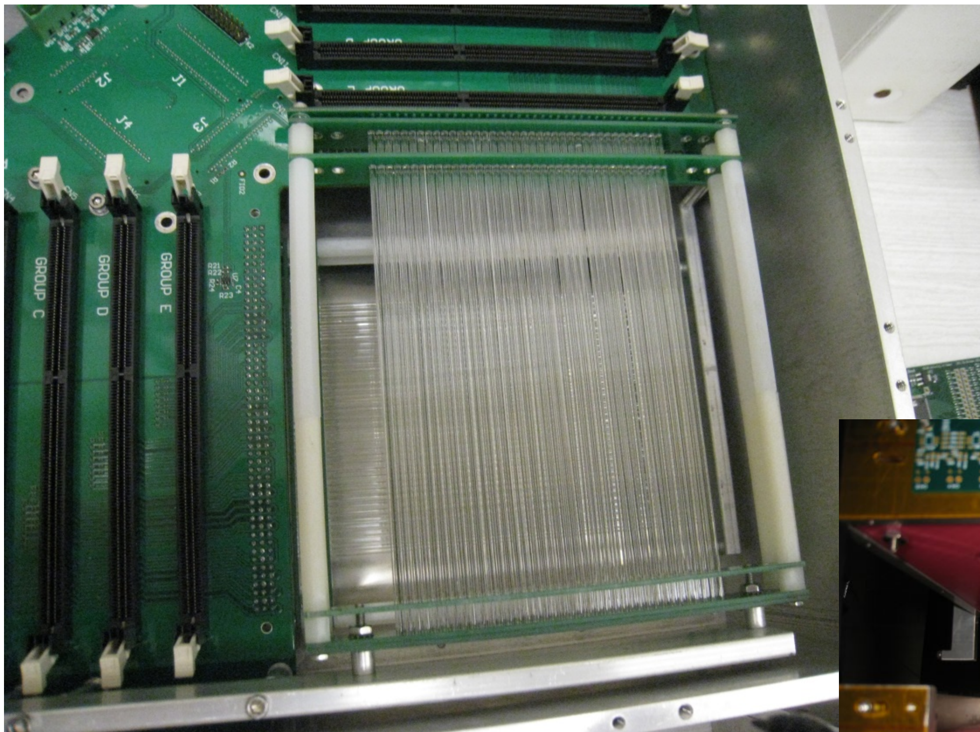


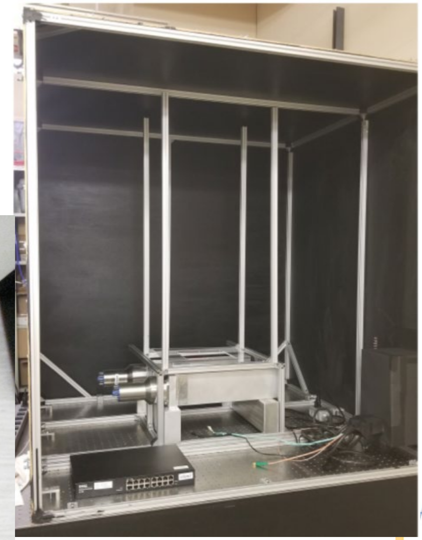


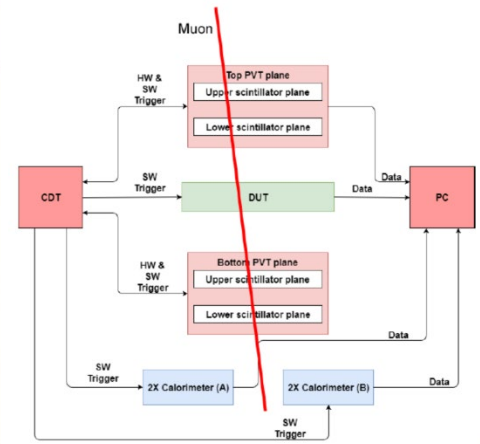
A novel muon detector for borehole density tomography, NIM **A851** p. 108 (2017)

Hawaii Muon Beamline (HMB) v3

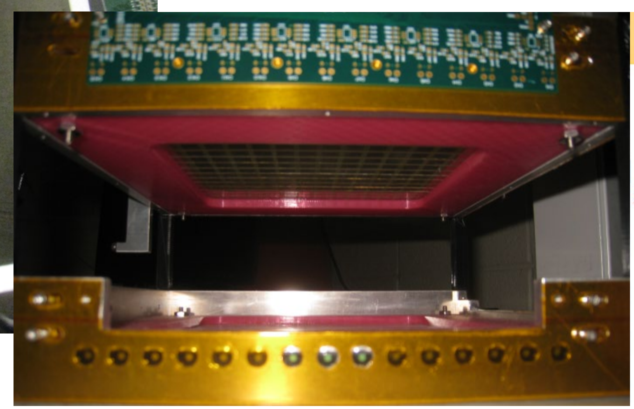
- **Version 3 (scint planes)**
  - **EIC PID readout (Shivang)**

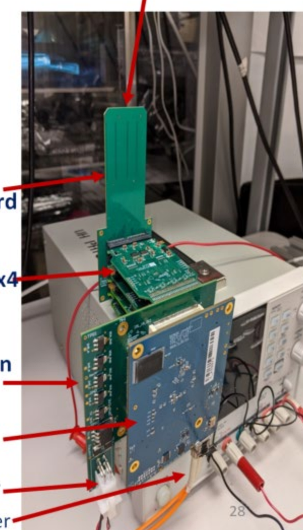






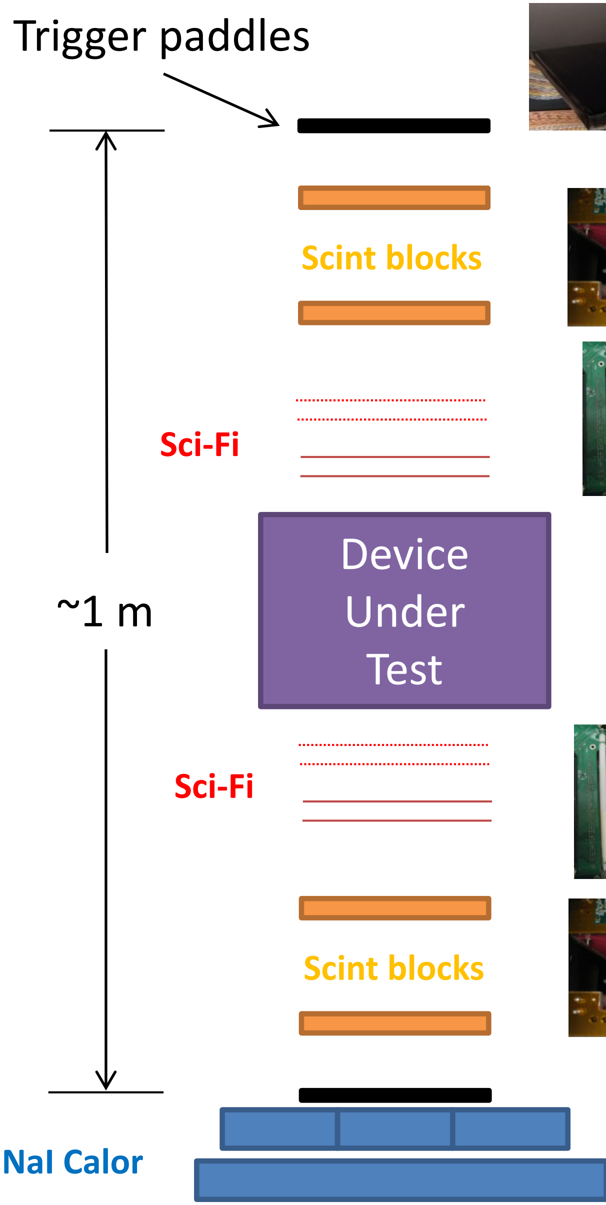
- **Alignment requirements**



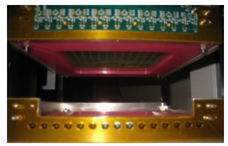


- **Training platform**
  - **Mechanical Design (SolidEdge), Simulation (GEANT4), Pynq (Xilinx/Zynq) python + PL Firmware (Vivado) for DAQ, I/F board (Altium/Allegro), data acquisition (Juptyr notebooks), display (matplotlib), analysis (root)**

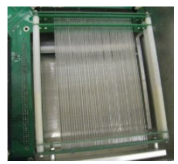
General Configuration



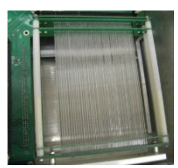
Beam definition (2x)



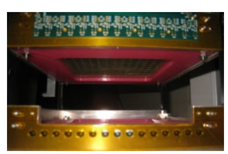
Coarse tracking: 2x 1cm thick plastic scint
WLS fiber, both x and y, 1cm pitch (2x2x15 ch.)



Fine tracking: 2mm dia plastic scint fibers
WLS fiber, 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

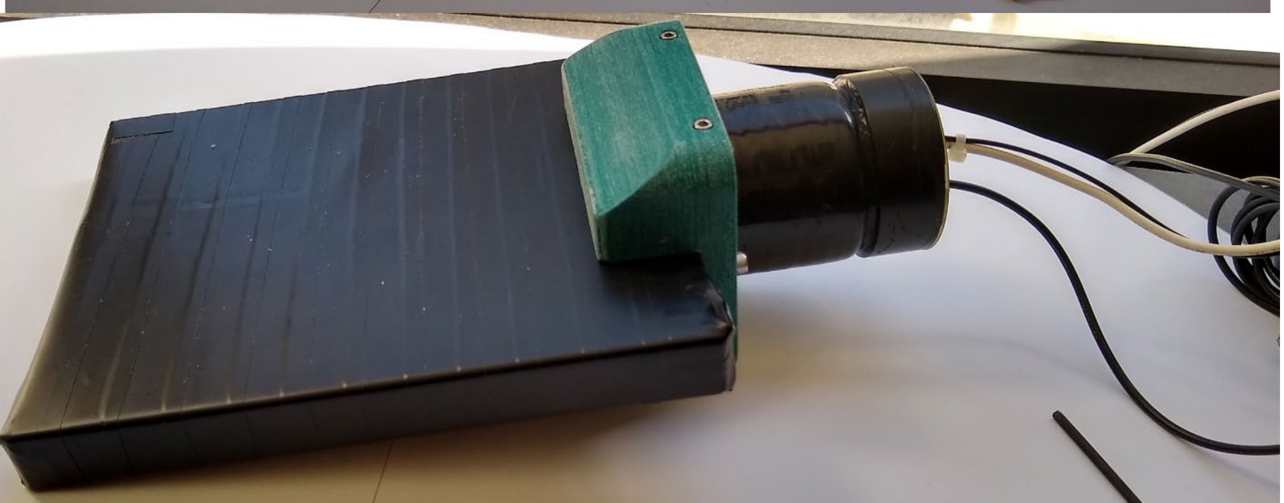
dE/dx for momentum; shower and bremsstrahlung detection

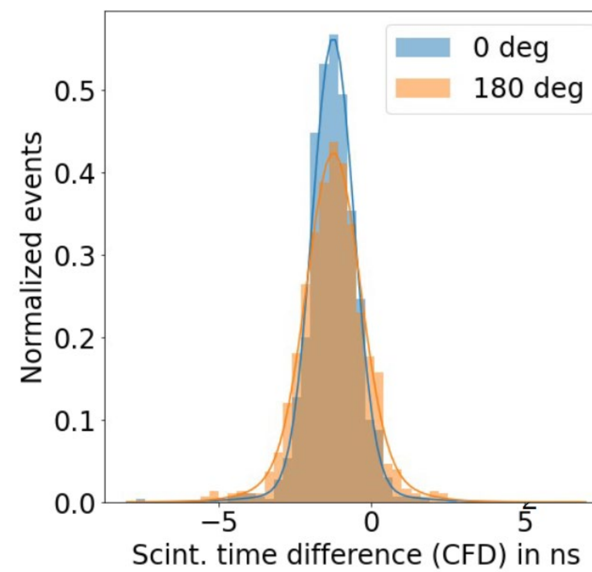
Beam definition counters

Note:

Oskar Hartbrich

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

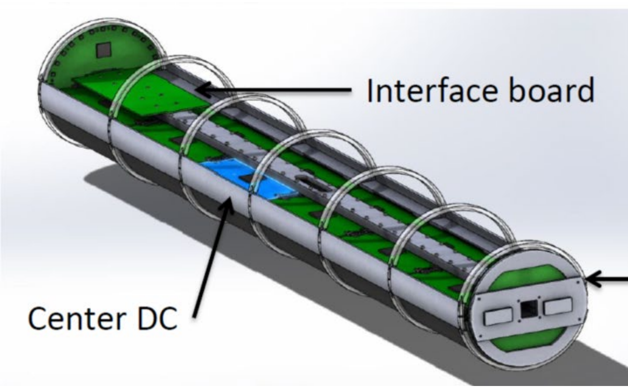


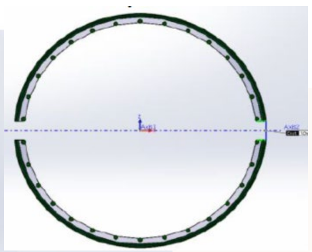


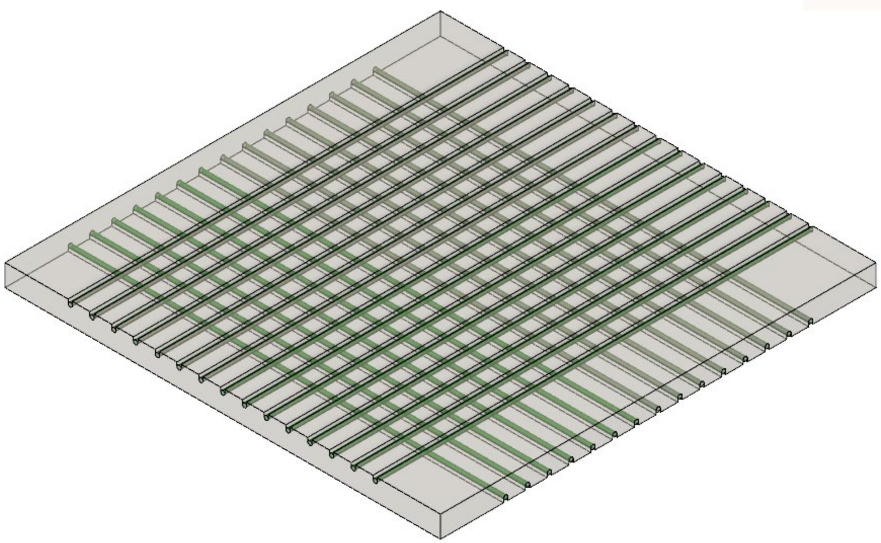
Scint block trackers

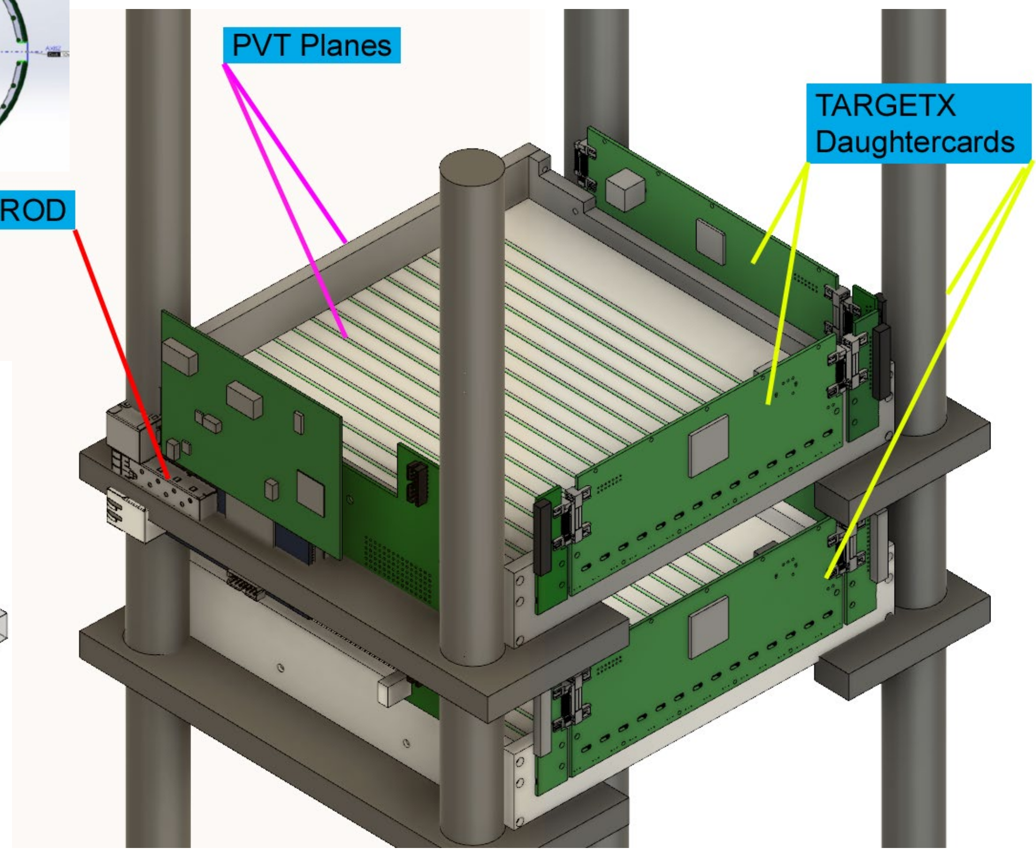
Notes:

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

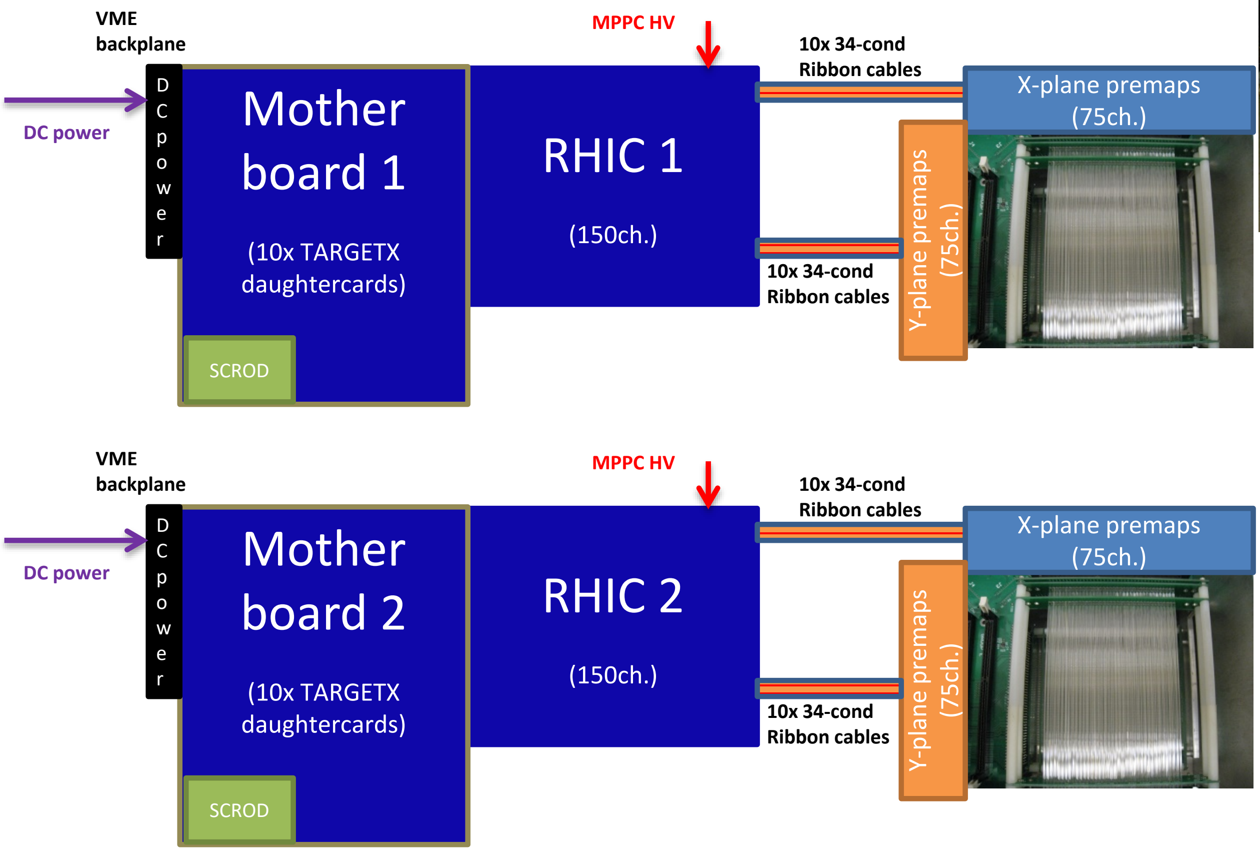


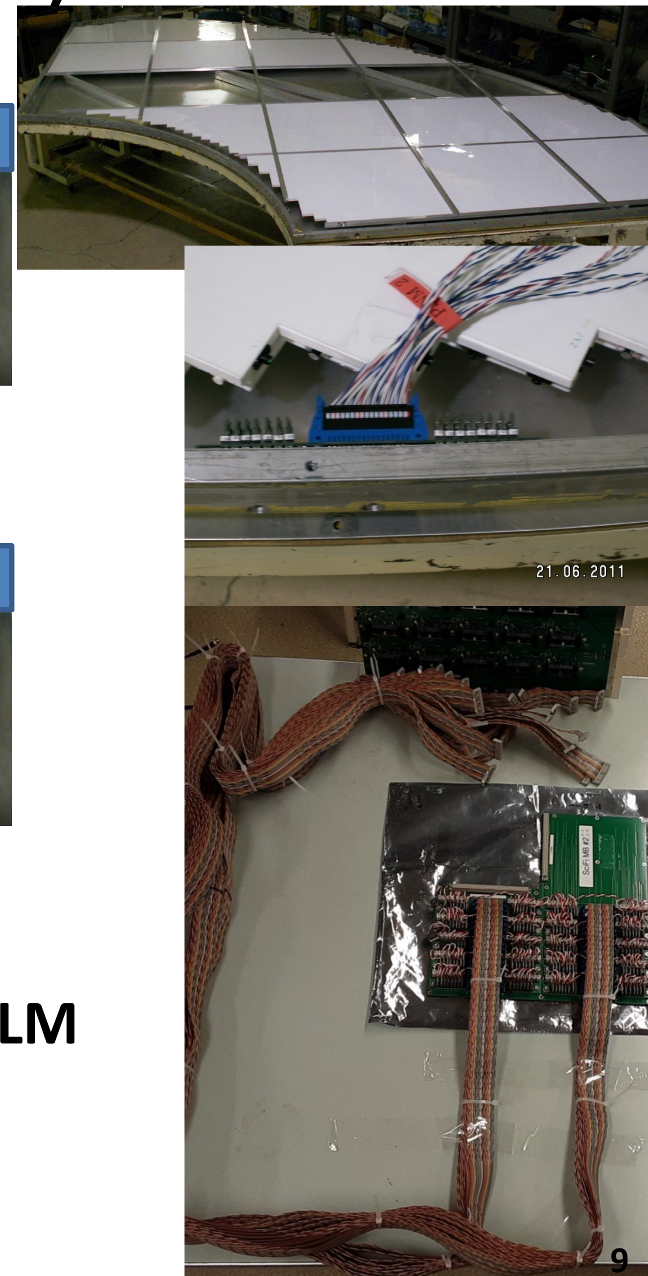






Scintillating Fiber (Sci-Fi) Trackers





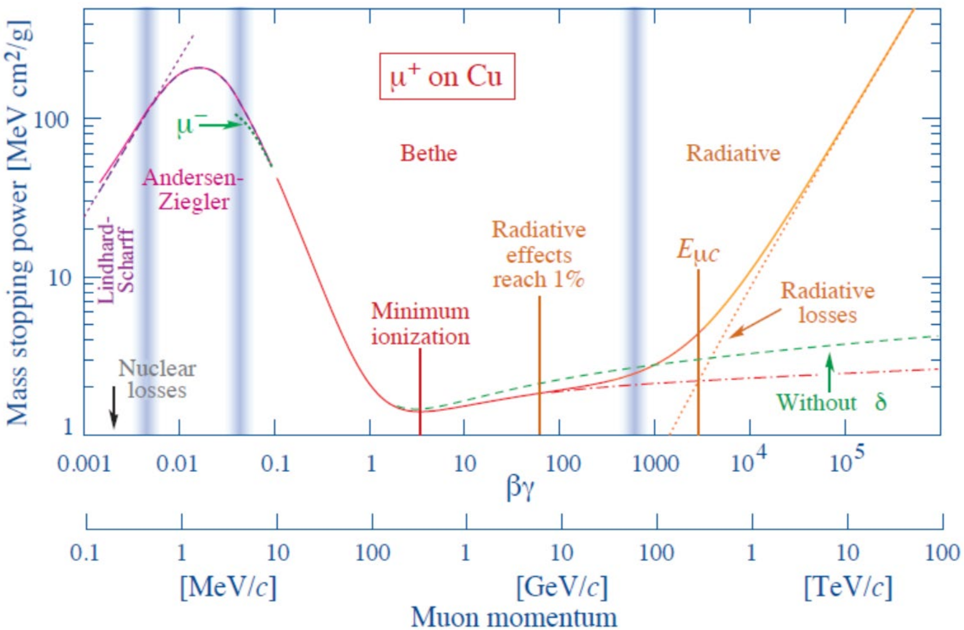
Notes:

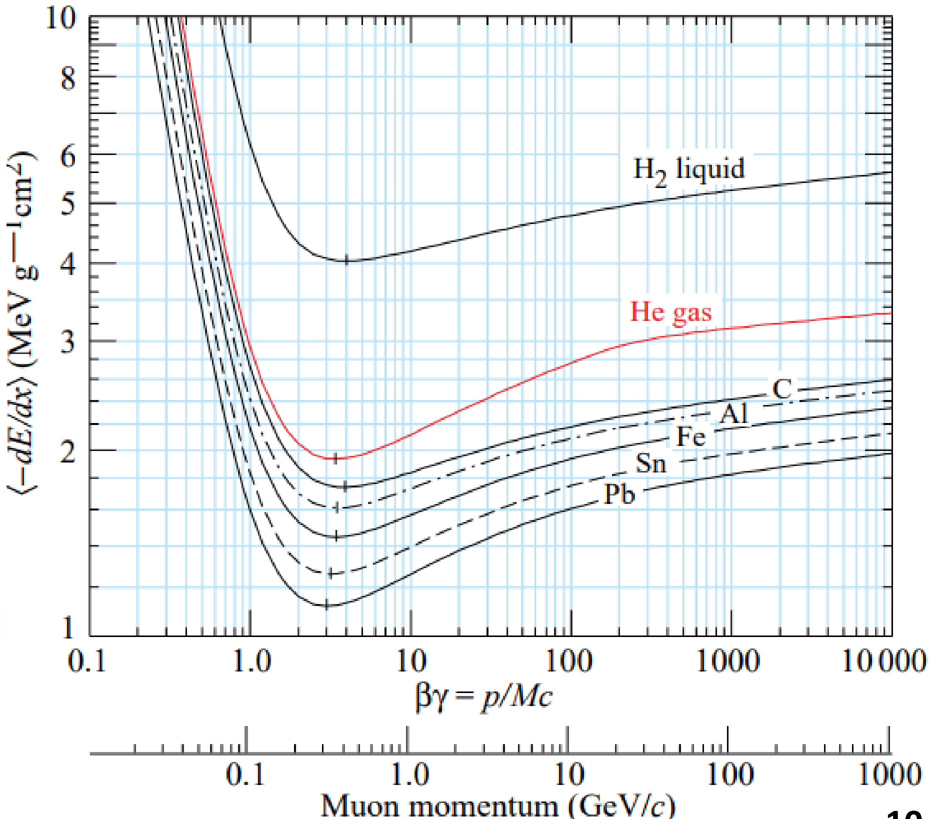
- **Basically a scaled down version of Belle II KLM**
- **4cm x 1cm strips → fibers**
- **Cables! (Chris Ketter)**

Calorimeter

Note:

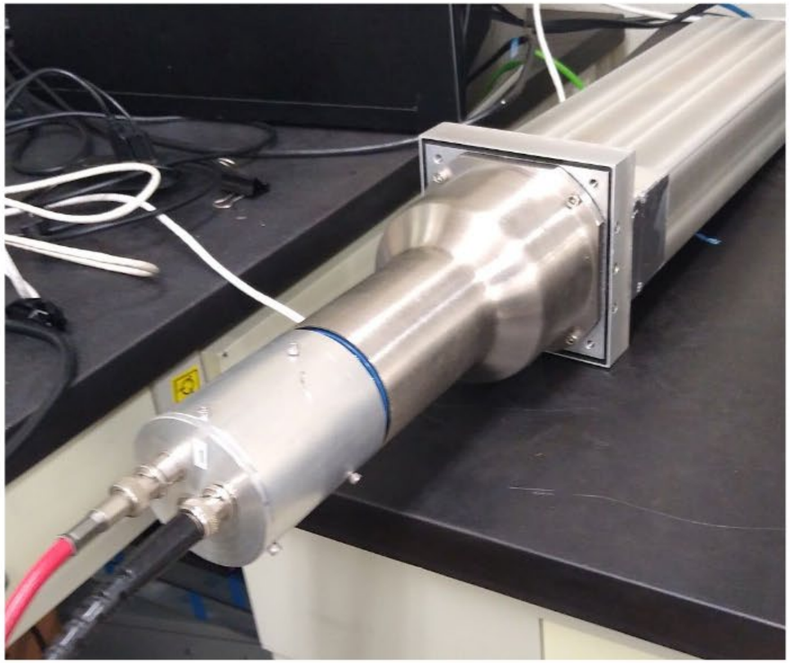
- **Limited space for a magnet (see upgrade slide later)**
- **Use dE/dx to reject low-p muons, relativistic rise for high-p tag**
- **Useful to have shower and bremsstrahlung detection**

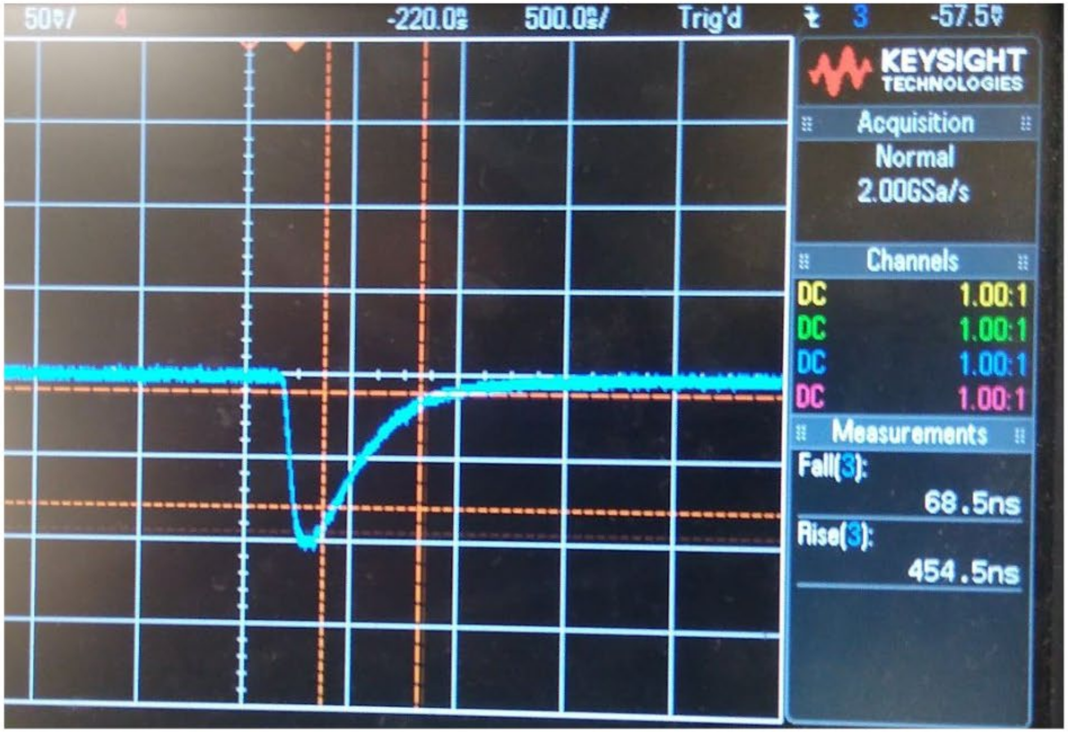




Calorimeter (1 of 6)

- HV = 1000 V

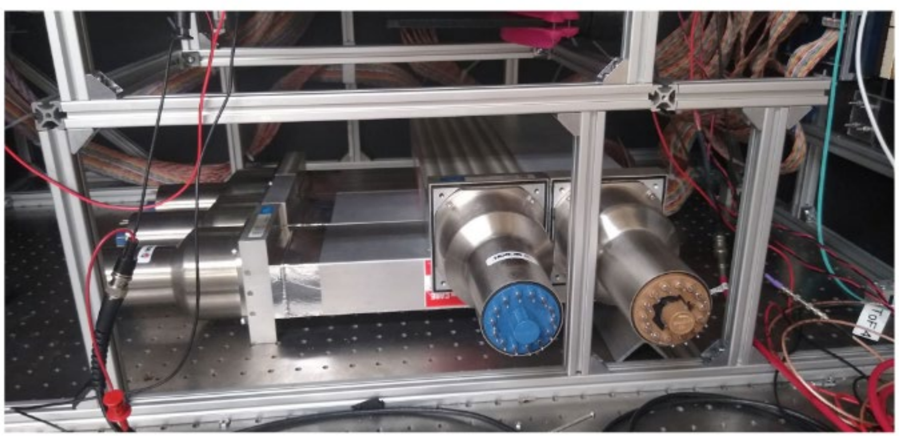




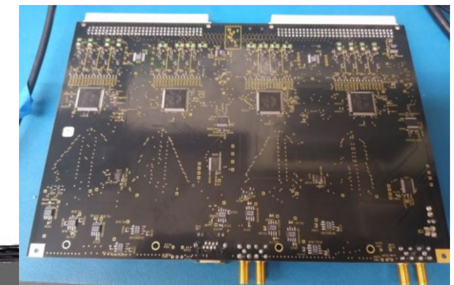
St. Gobain s600-8565 NaI counters

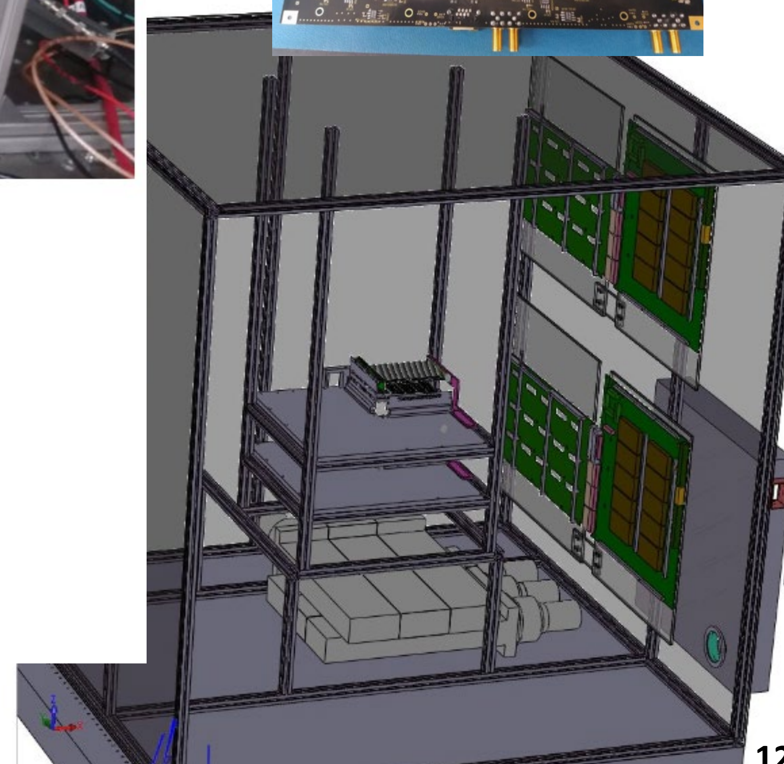
Scintillator	Light yield (photons/ keV)	Light ouput (%) of NaI(Tl) bialkali pmt	Temperature coefficient of light output (%/C) 25°C to 50°C	1/e Decay time (ns) (10-3µs)	Wavelength of maximum emission γm (nm)	Refractive index at γm	Thickness to stop 50% of 662 keV photons (cm)	Thermal expansion (°/C) x 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



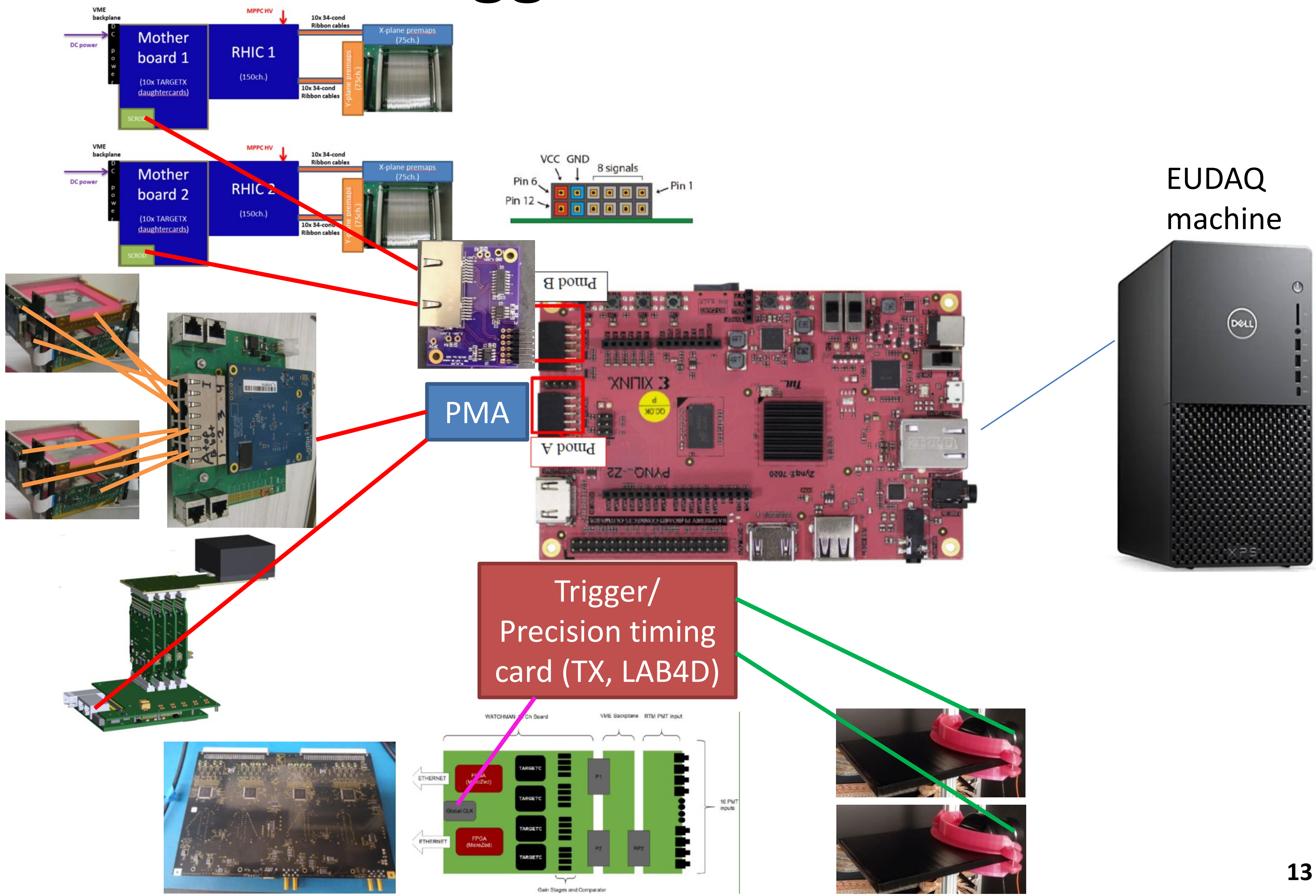
- **NaI Calorimeter**
  - **6U VME board (WATCHMAN)**





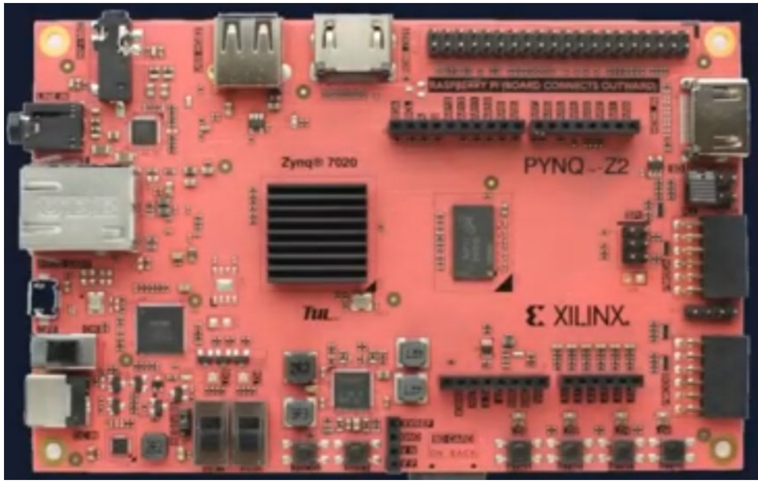
Salvador Ventura

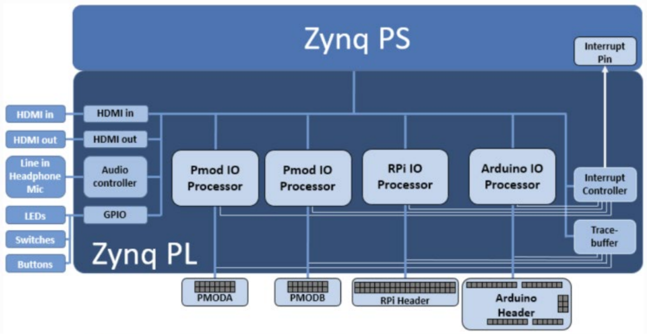
Trigger Overview

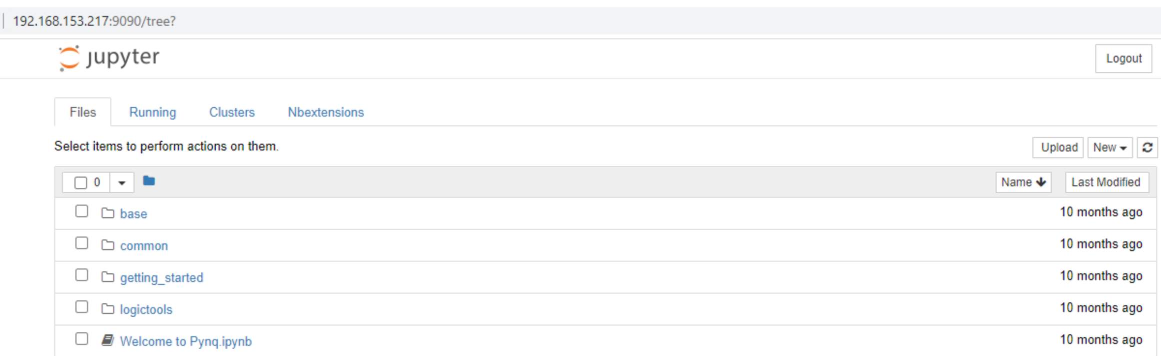


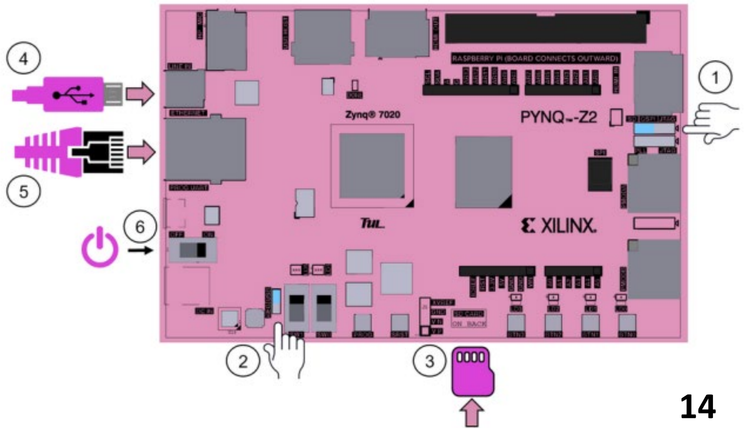
Python productivity for Zynq (Pynq)

- **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)**

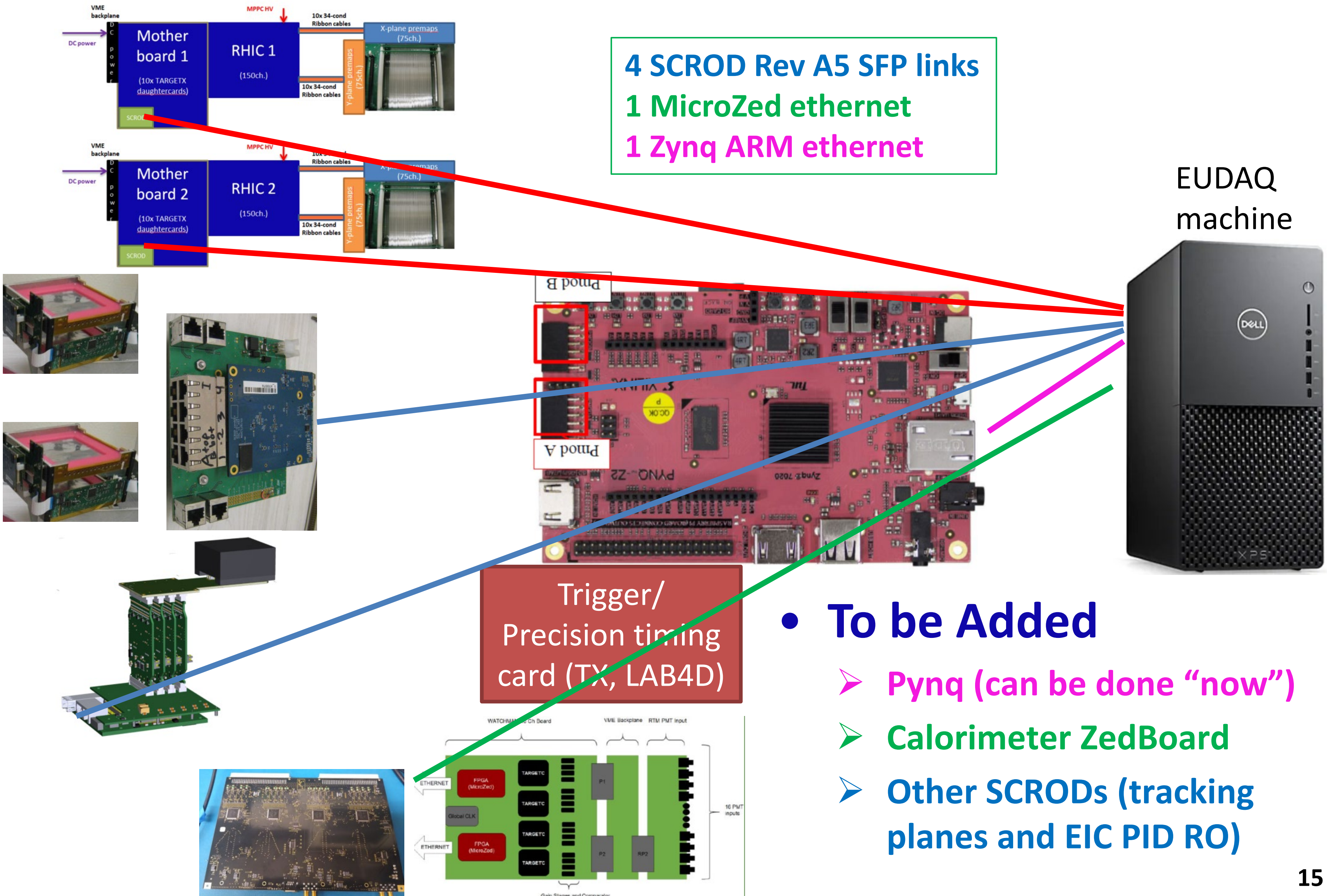








Data Collection Overview

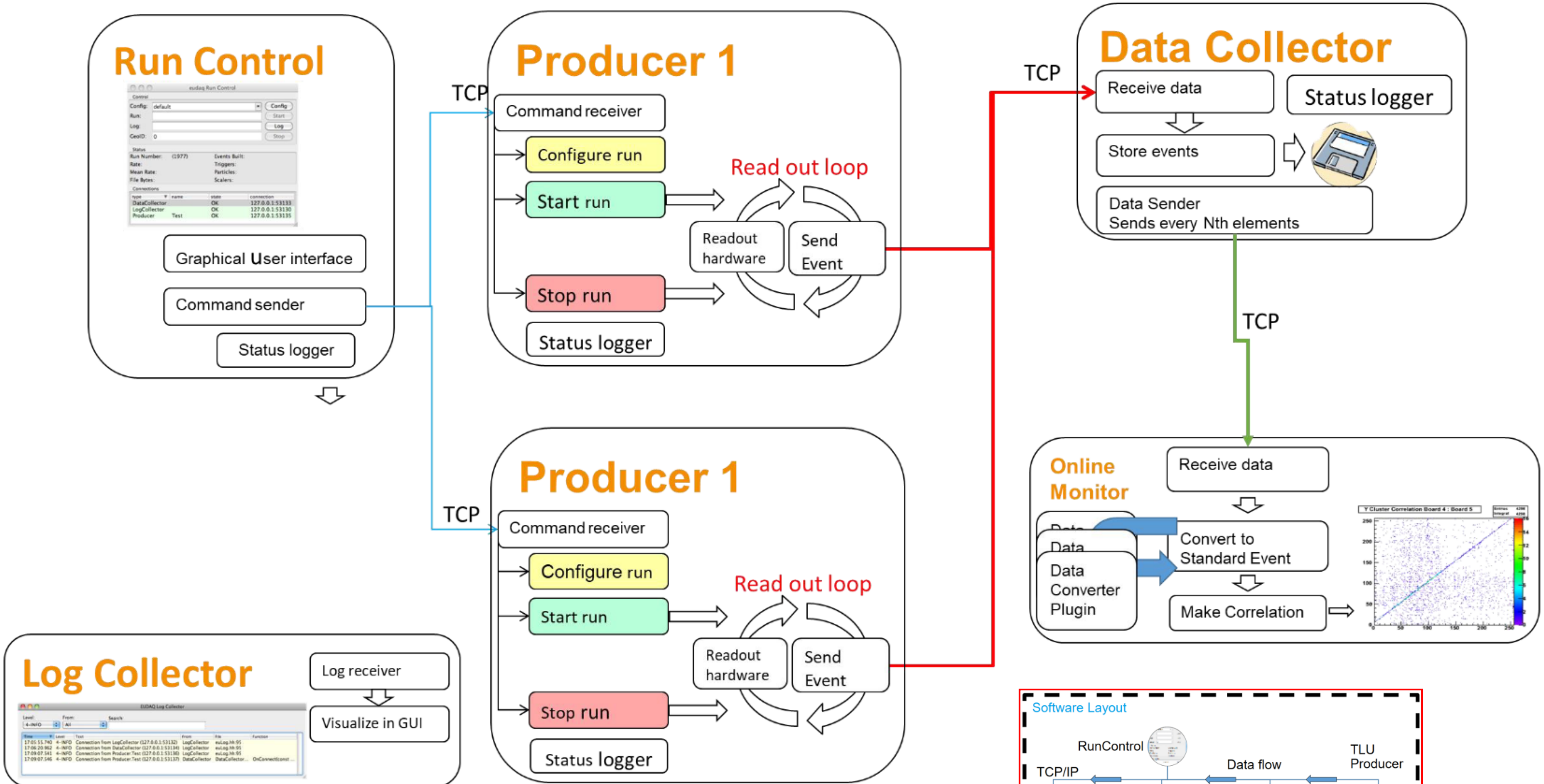


4 SCROD Rev A5 SFP links
1 MicroZed ethernet
1 Zynq ARM ethernet

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

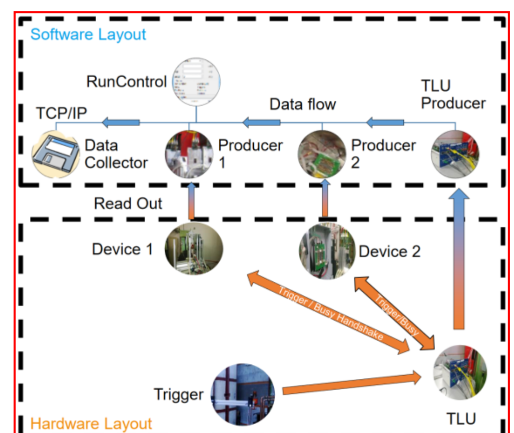
Richard Peschke

EUDAQ

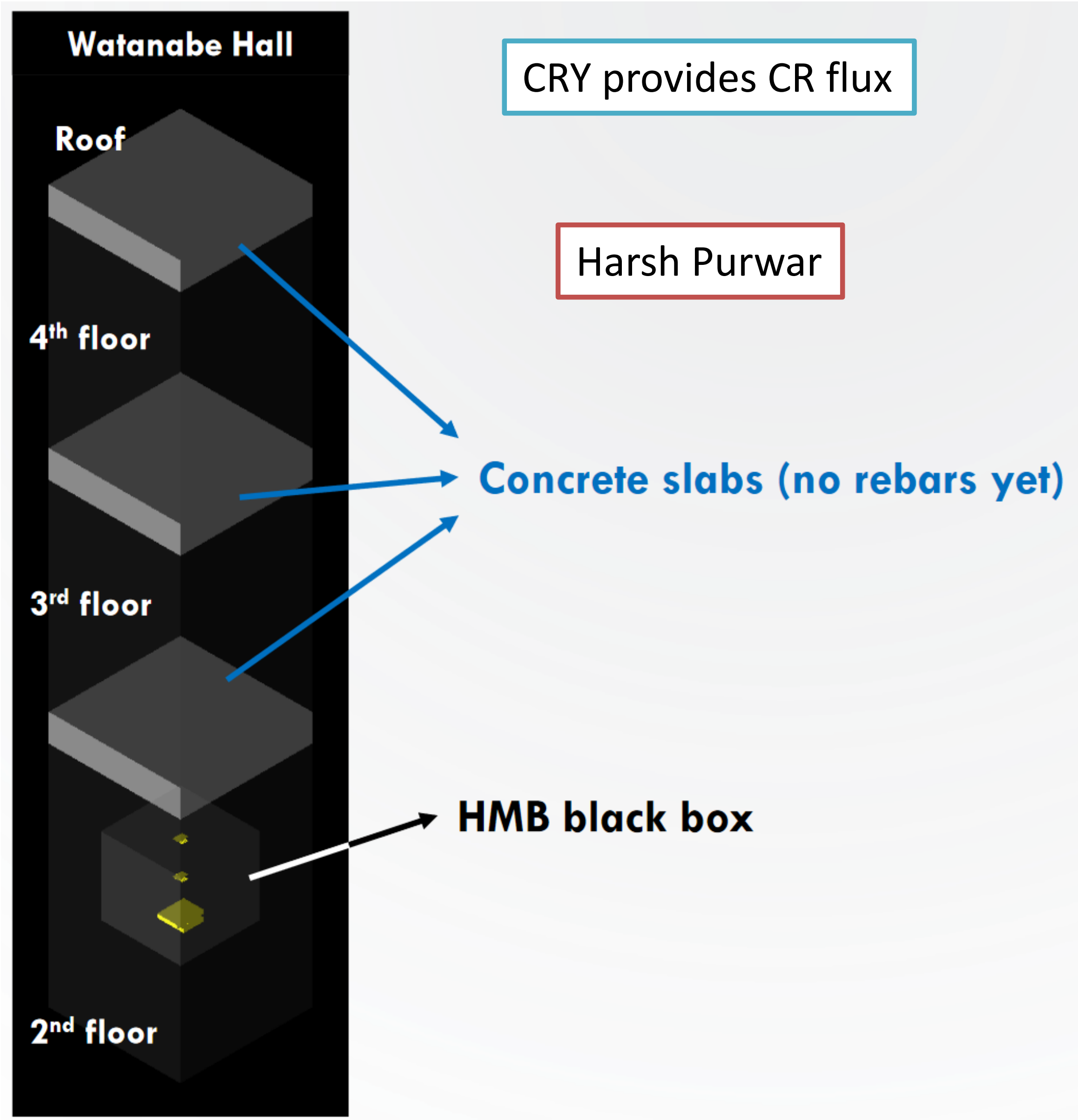


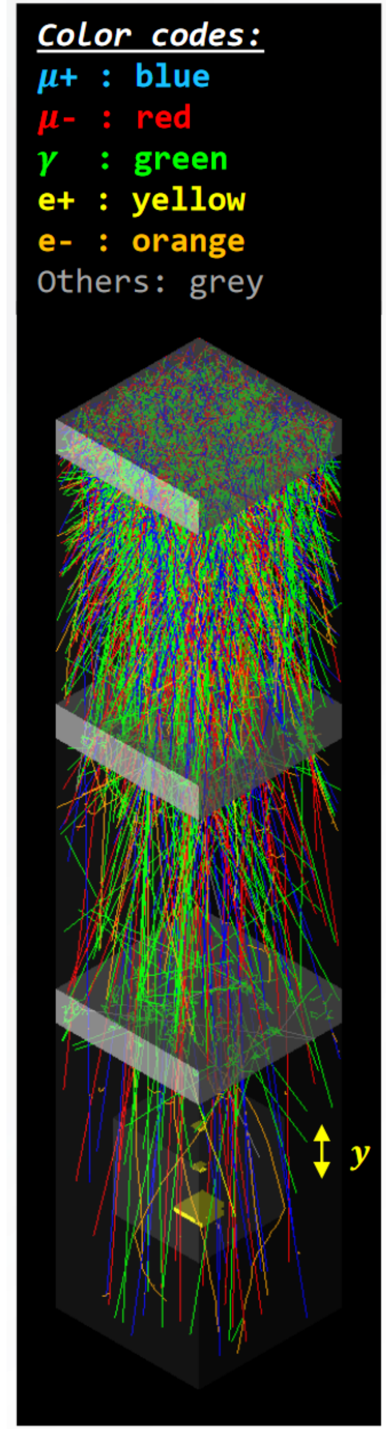
EUDAQ2 – A Flexible Data Acquisition Software Framework for Common Test Beams

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

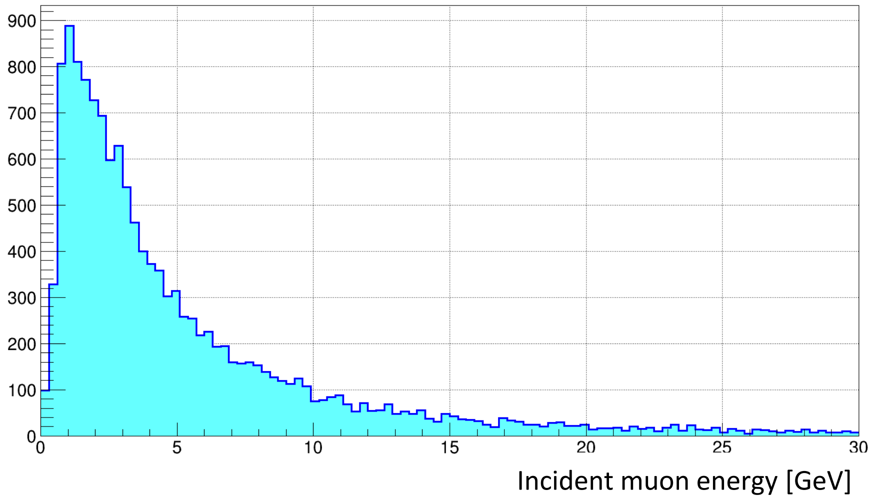




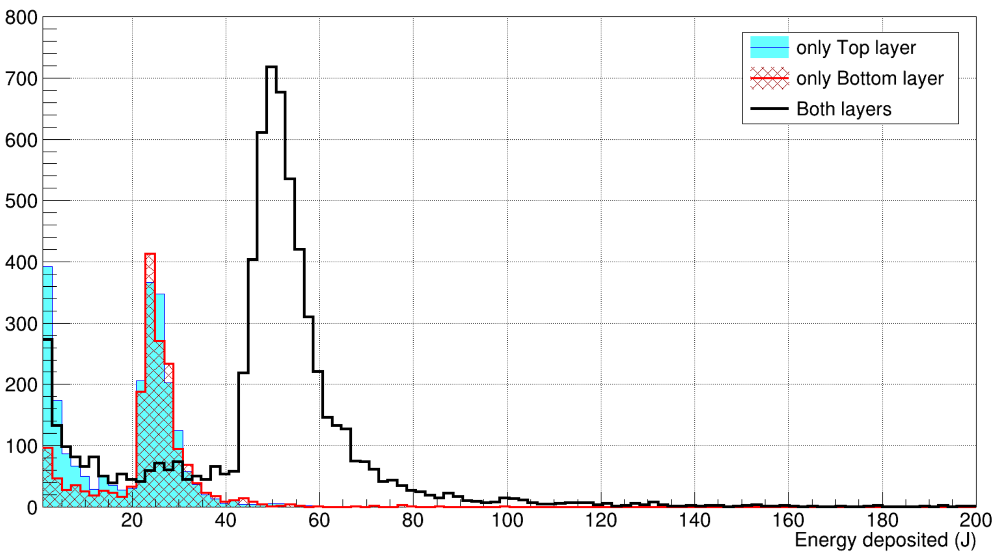
GEANT4+CRY simulation

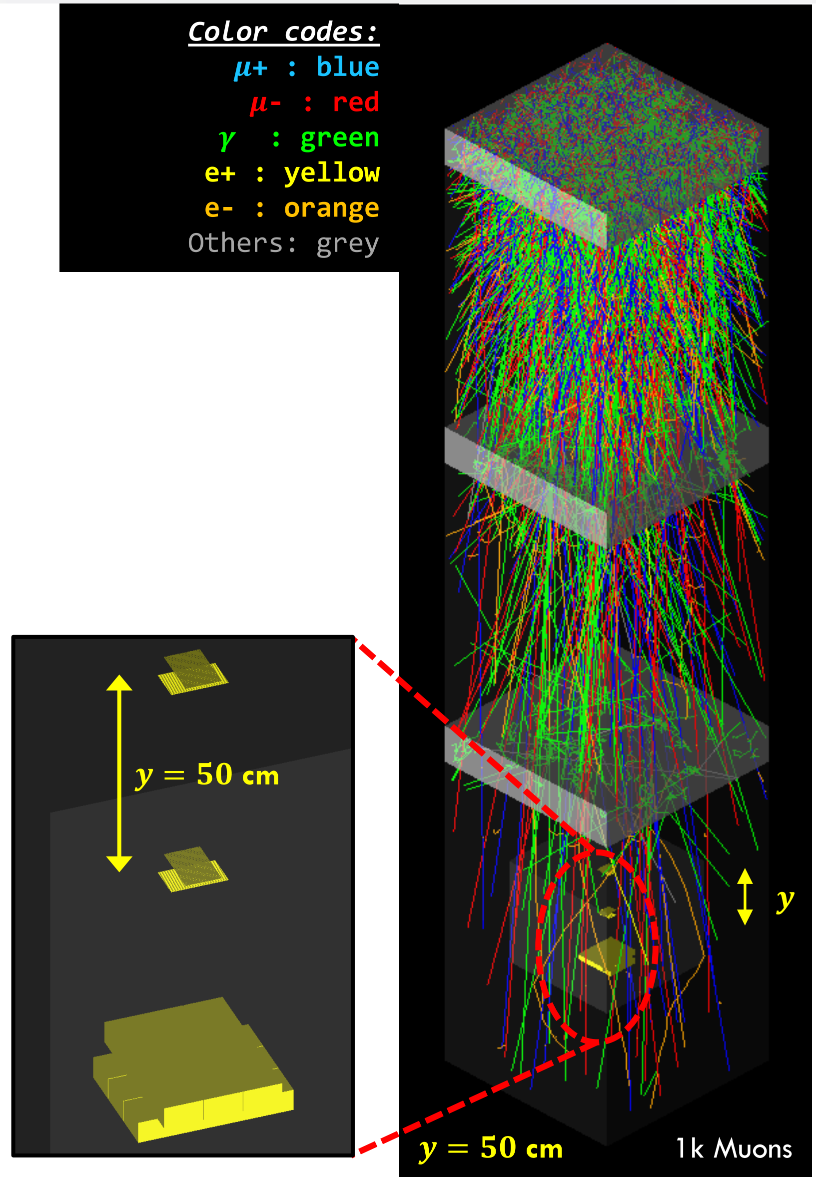
- Avg. Muon incident rate: 2175 hits per hour (~36 hits/min on NaI slab)

Muon energy spectrum



Total energy deposited on HMB calorimeter





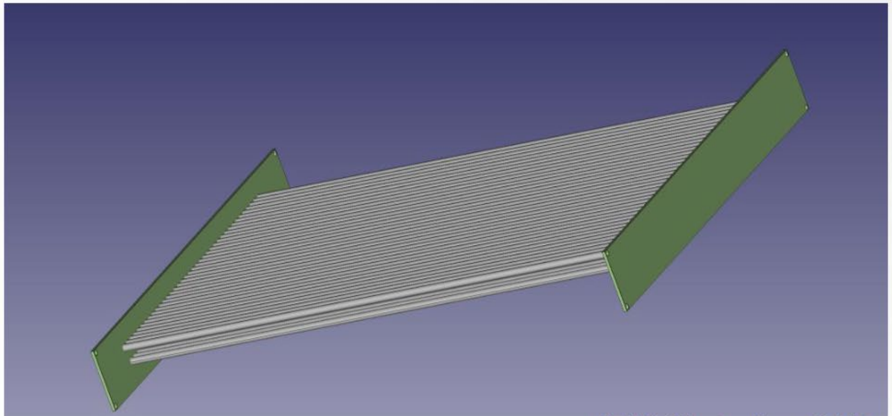
DD4hep

Importing CAD geometry in DD4hep

Shivang Tripathi

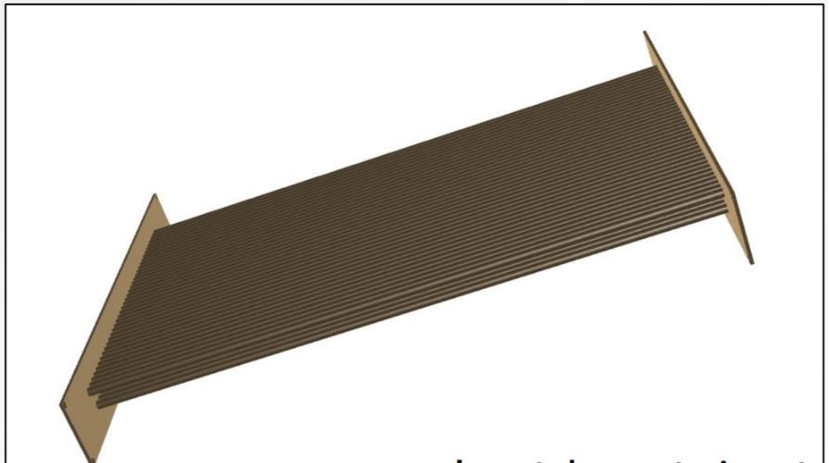
- Open .STEP file in FreeCAD software and export selected parts to a Collada .dae file.
- Import this .dae file (detector assembly) in DD4hep with DDCAD and then, ***root*** may be used for visualization.

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



STEP file in FreeCAD

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



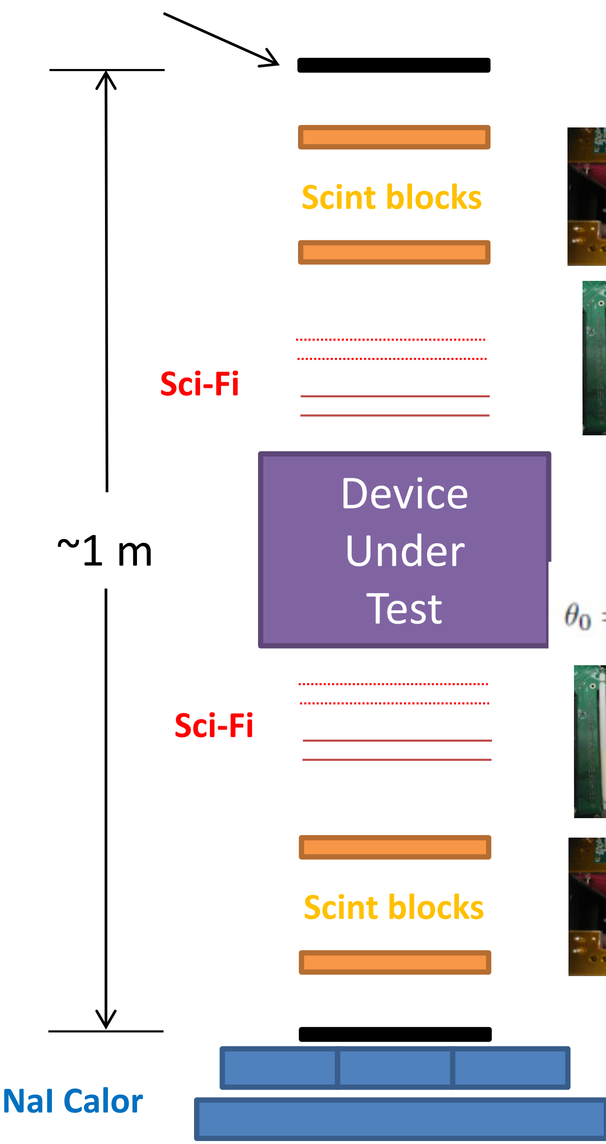
Imported geometry in root

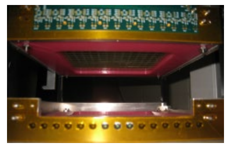
Notes:

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

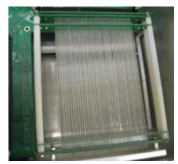
Tracking Resolution Estimates

Toy Monte Carlo



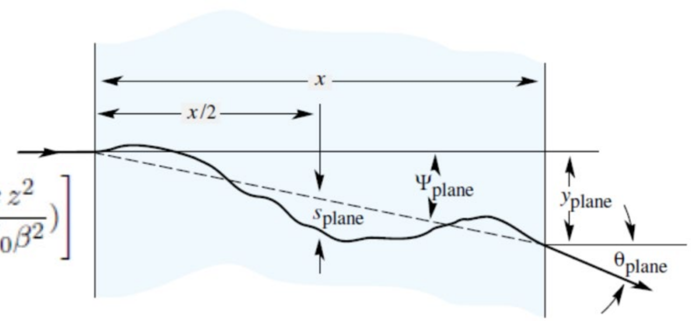


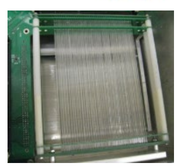
10mm/sqrt(12)



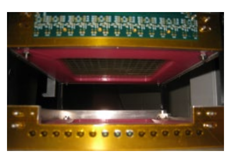
1.25mm/sqrt(12)

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





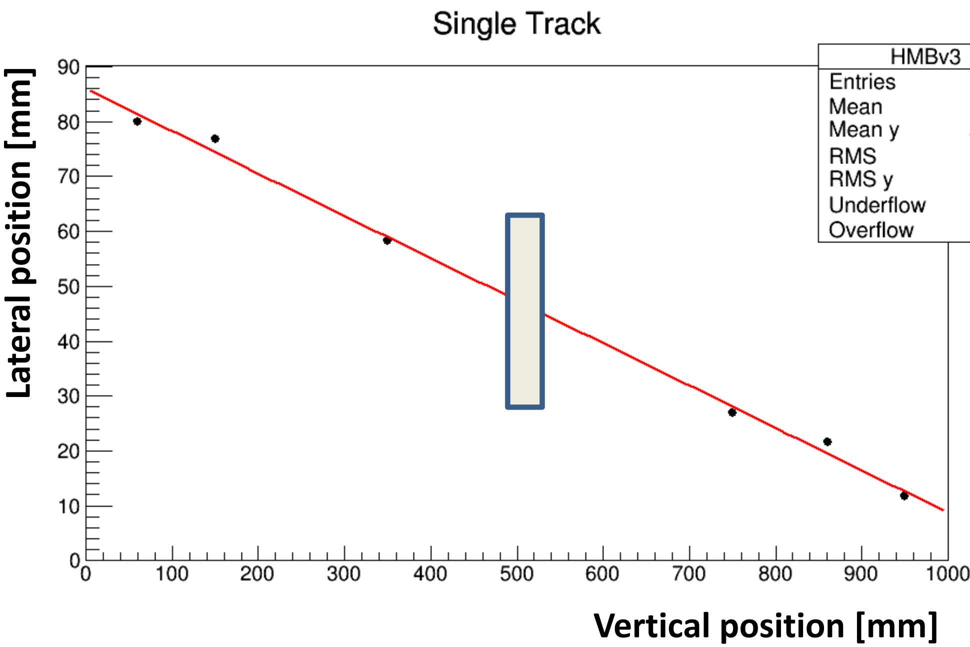
1.25mm/sqrt(12)

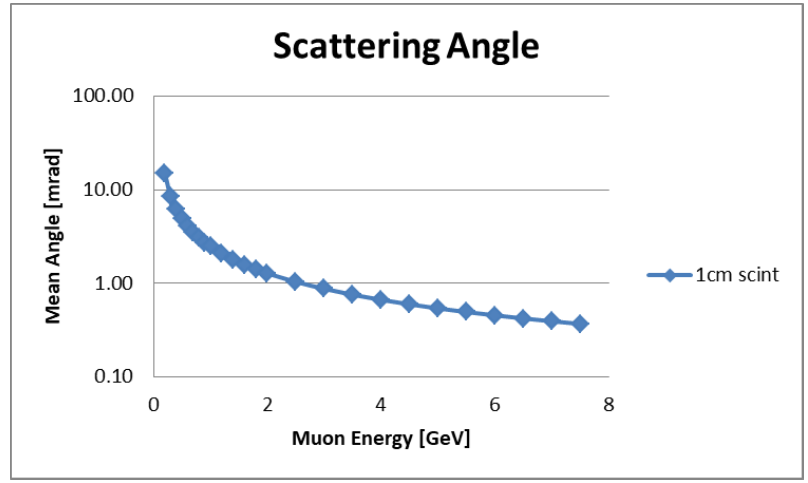


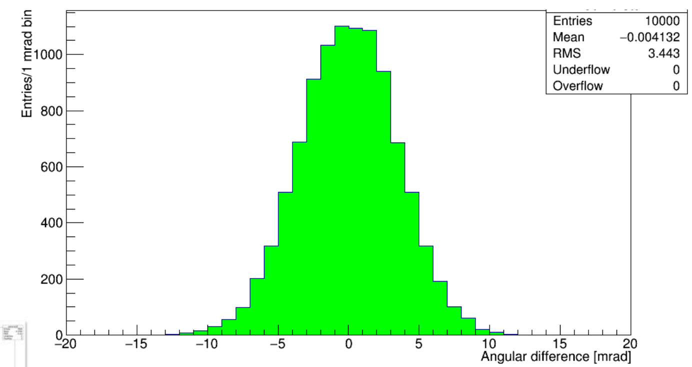
10mm/sqrt(12)

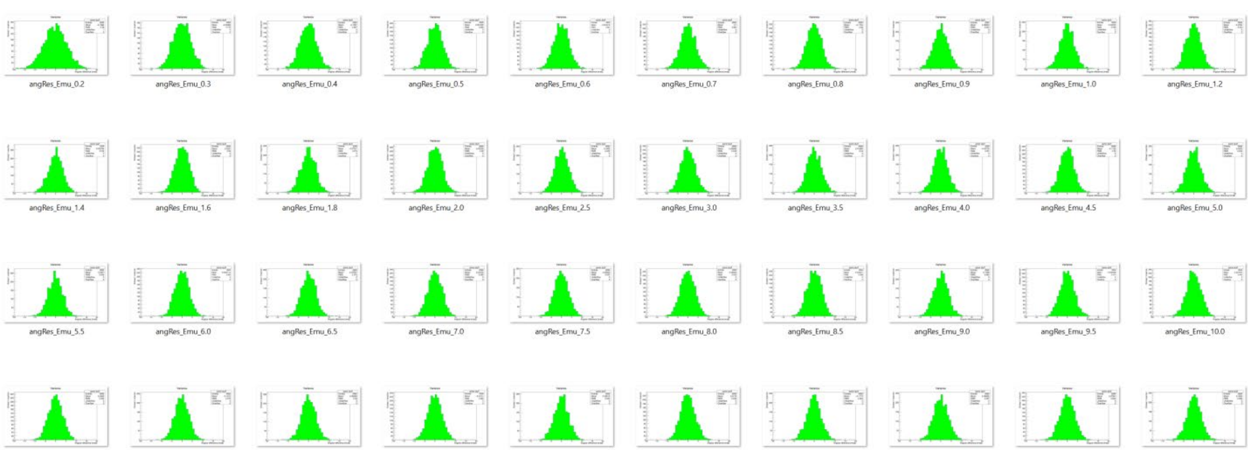
Tracking Resolution Estimates

At reference plane of center of DUT





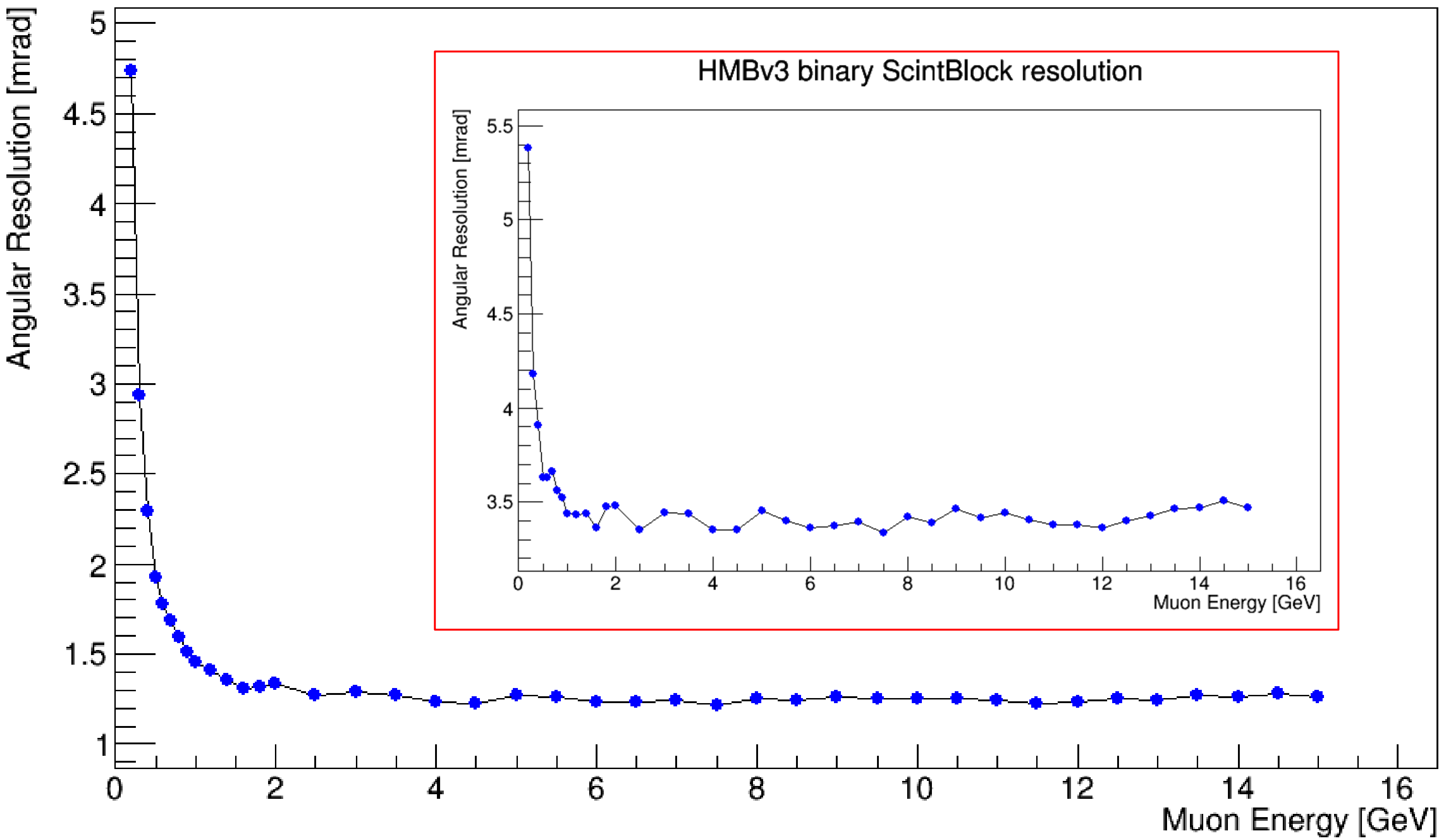




- **Typically 3.5 mrad resolution**
- **Dominated by scint block resolution**

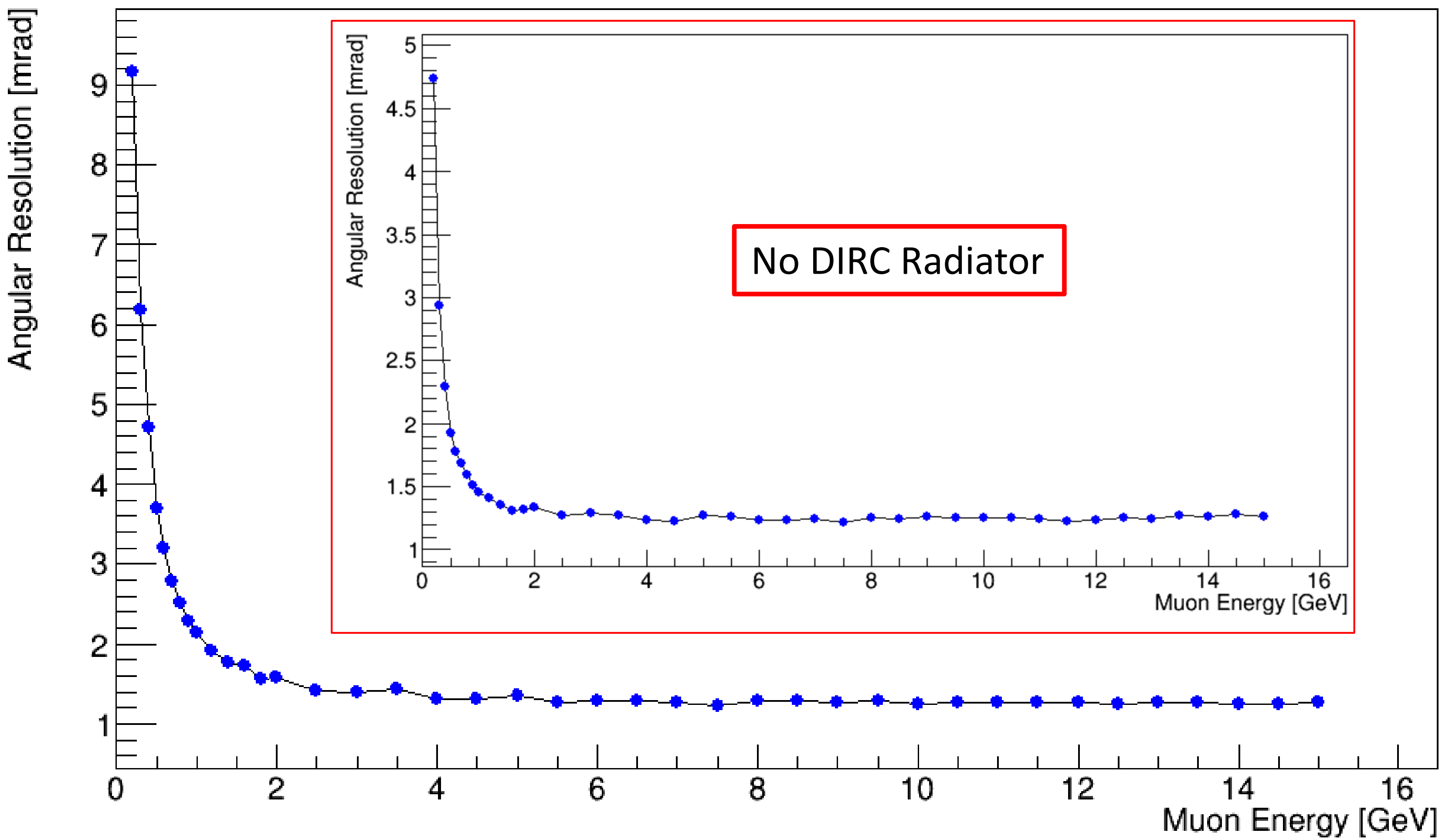
Tracking Resolution Estimates

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



Tracking Resolution Estimates

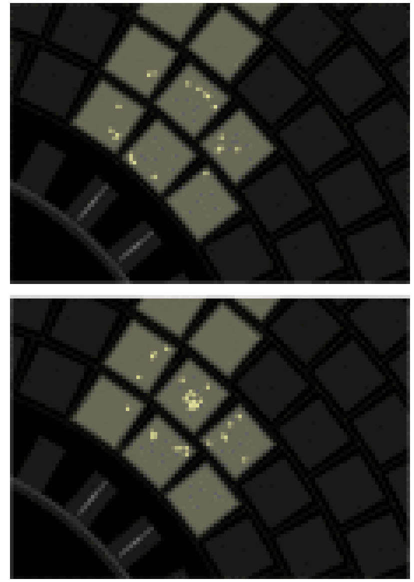
With 17.25 mm thick fused silica radiator at DUT center

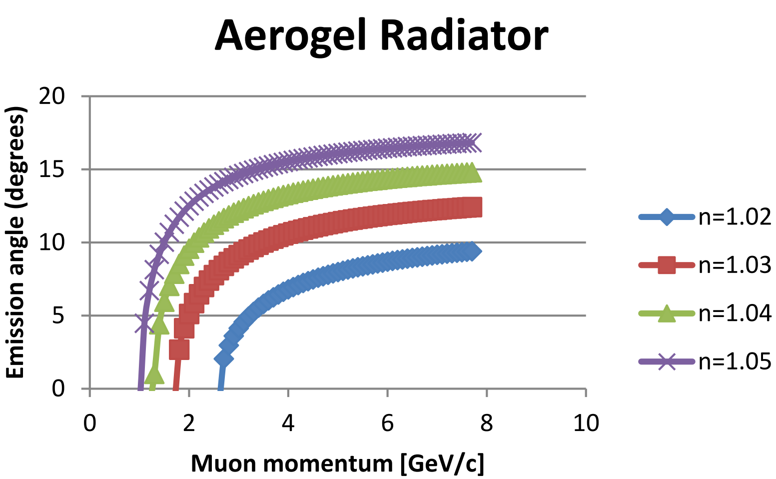


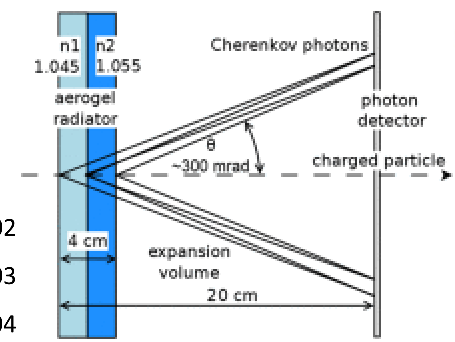
Only 1D, sanity-check of final GEANT result

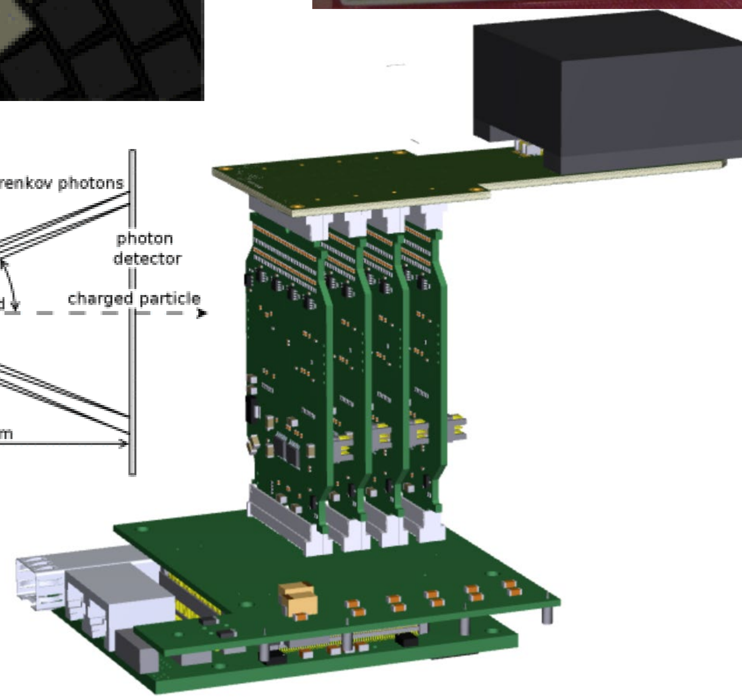
DUT:
Aerogel Ring Imaging Cherenkov (ARICH)

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



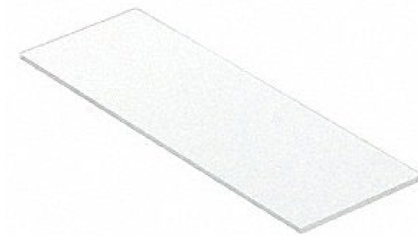


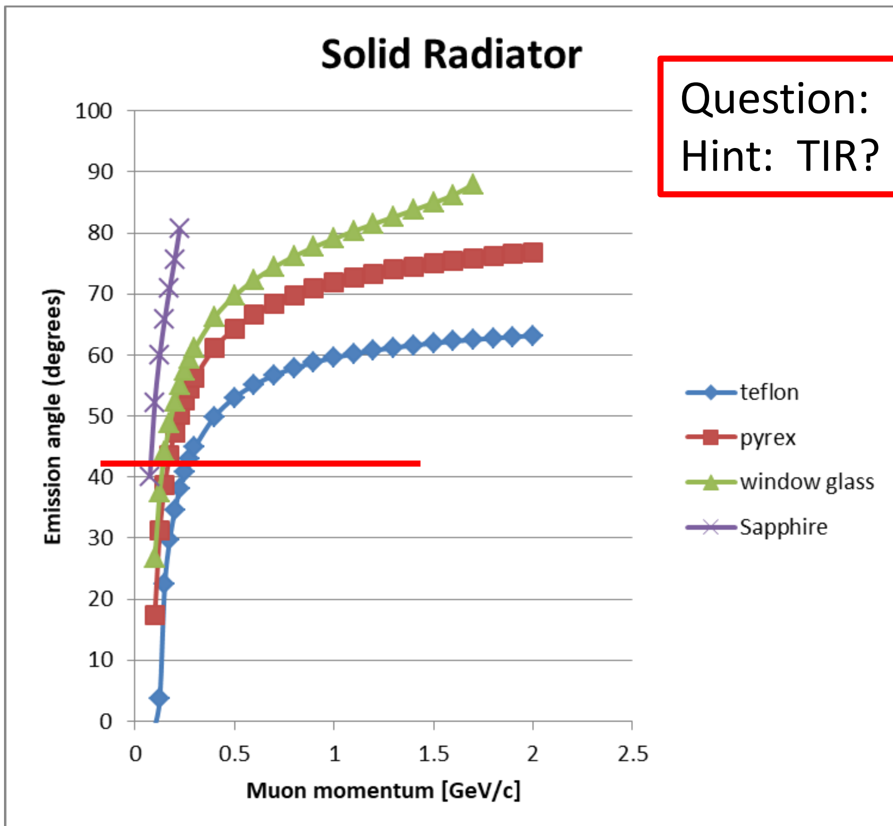




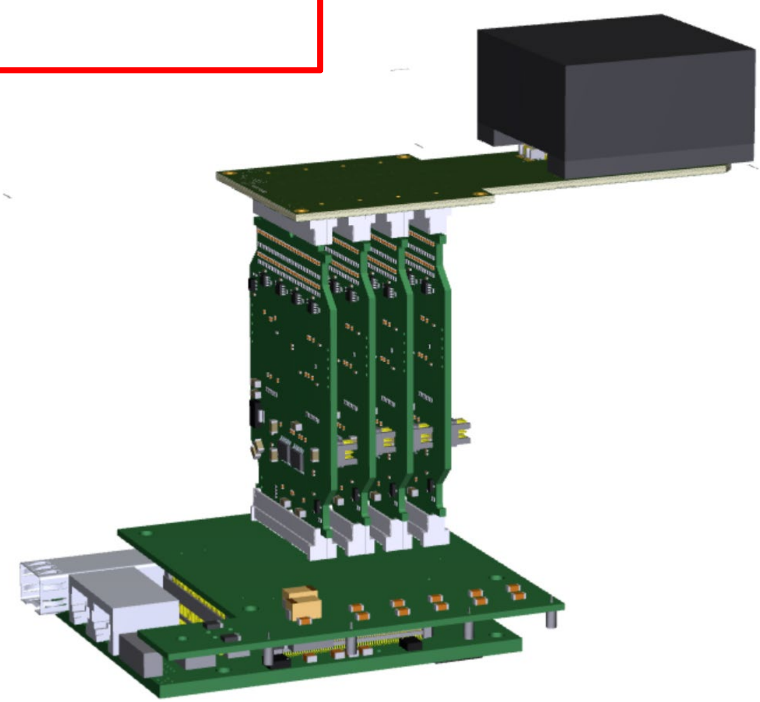
DUT:
compact Ring Imaging Cherenkov (cRICH)

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



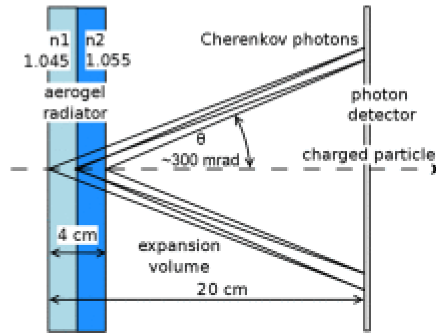


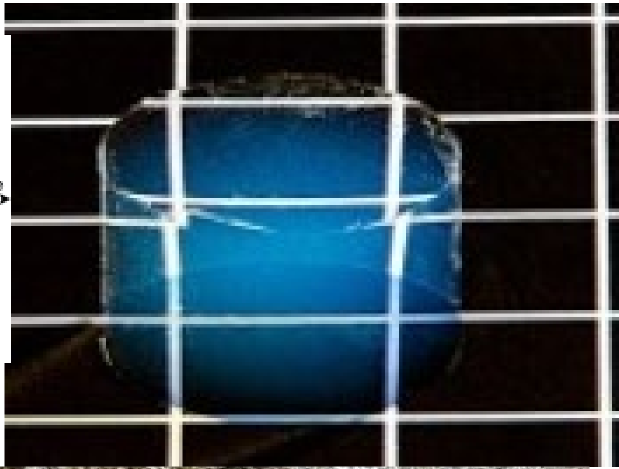
Question: will we see these?
Hint: TIR?

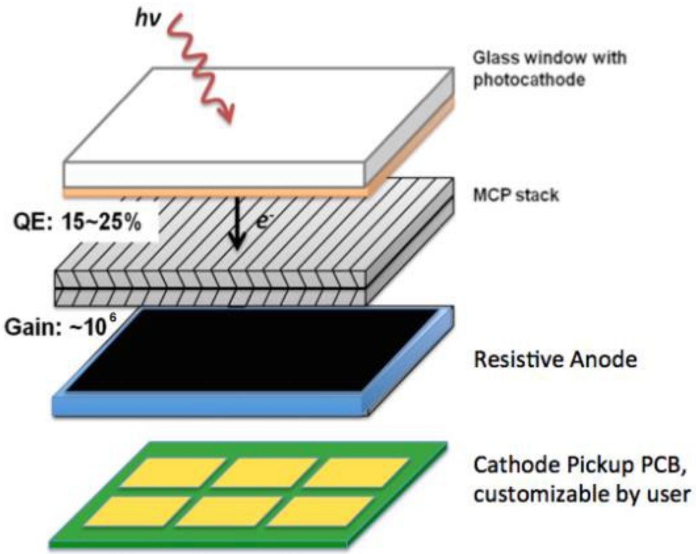


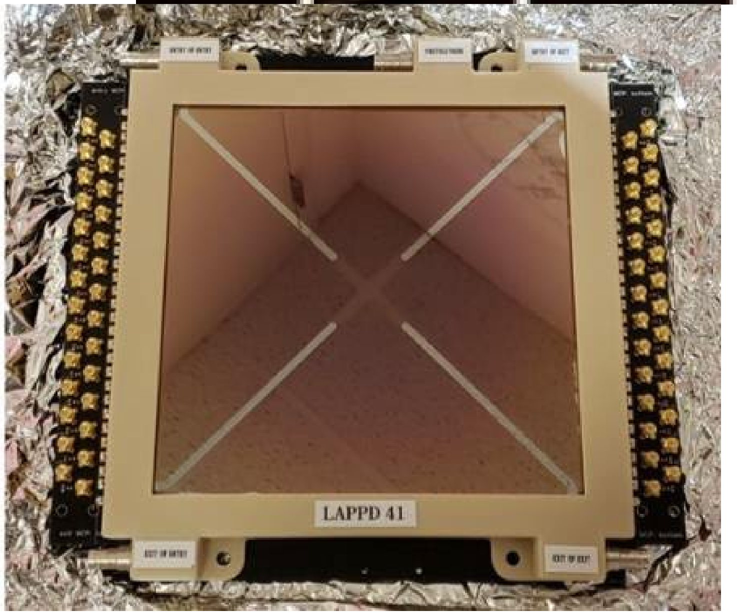
DUT
Large Area Picosecond PhotoDetector (LAPPD)

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





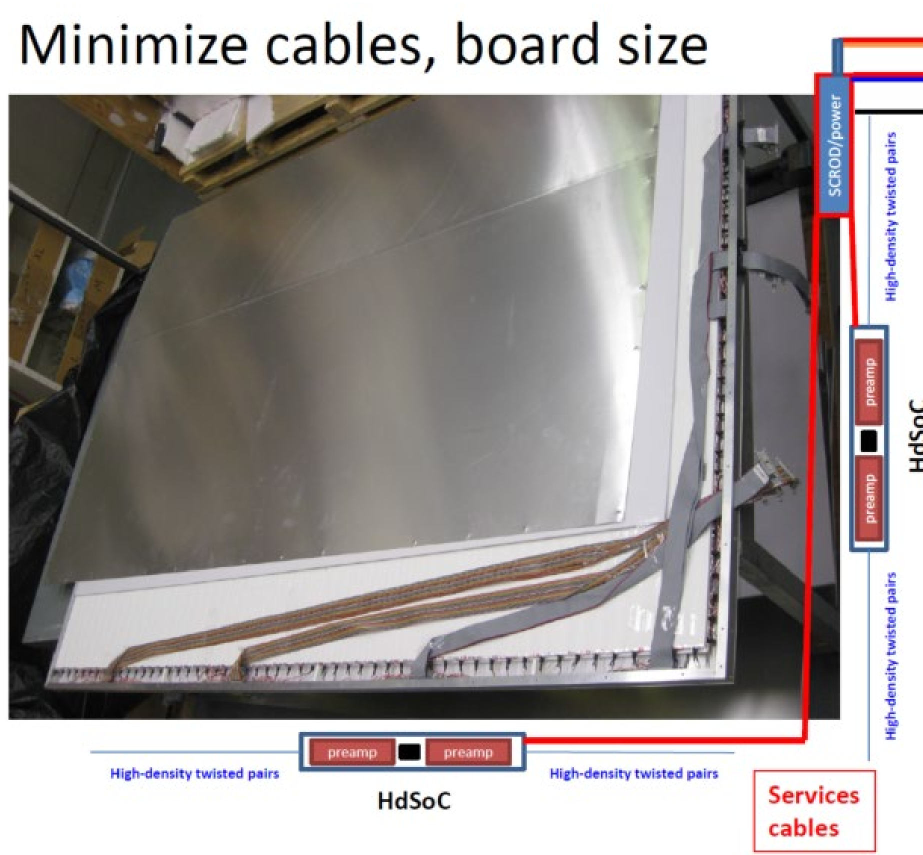




HMB v3

Other tests

- Minimize cables, board size

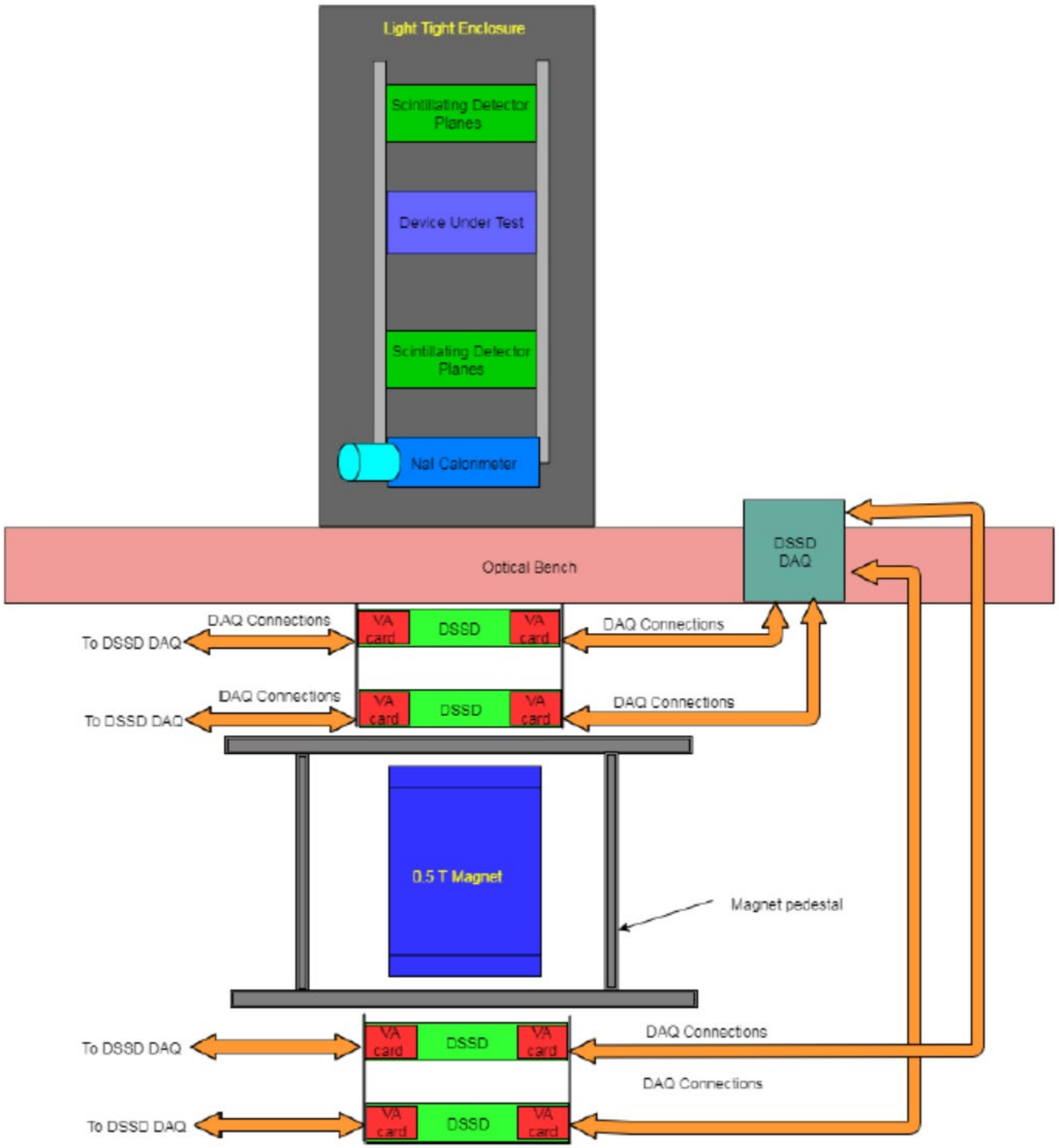


- 2 separate ASIC cards
- #z channels always same; wrap phi channels as needed
- 8 sectors * 15 layers * 2 FW/BW * 2 ASICs = 480 ASICs, ASIC cards
- 240 SCROD

- **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 "2026" 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

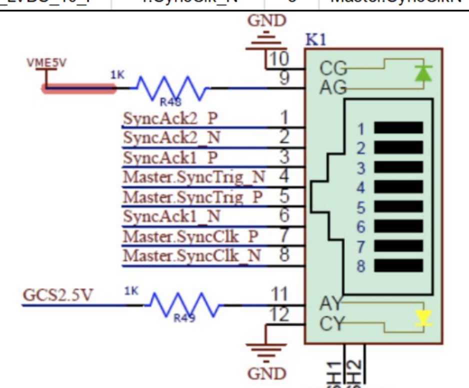
- **Nobody working on full-time**
- **Pynq readout to EUDAQ**
- **Pynq PMOD-B trigger**
  - ➢ Trigger distribution FW
    - ❑ Trigger data format definition (added to spreadsheet)
    - ❑ Variants for SCROD and Calor ➔ make the same

	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

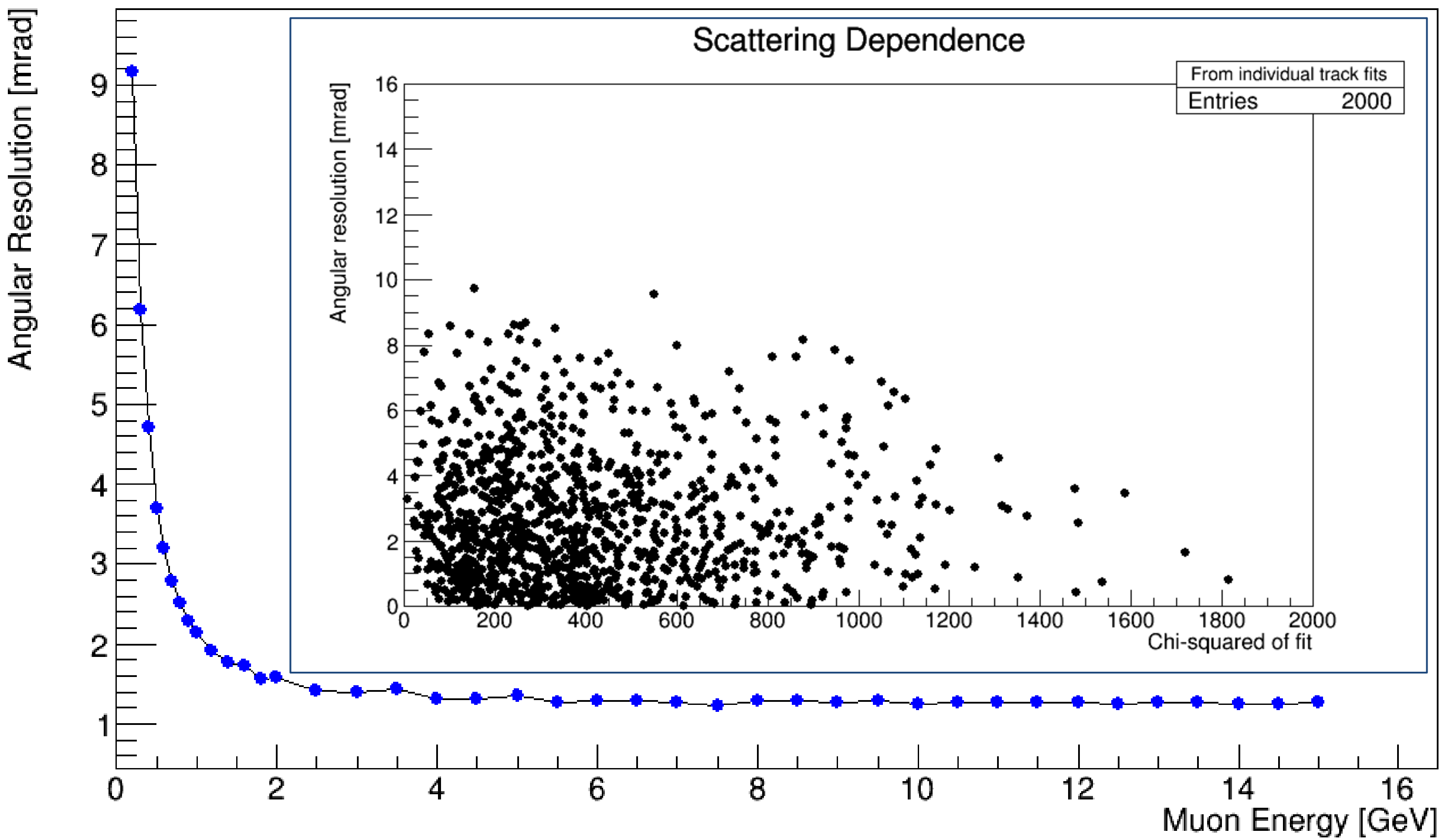
- **Calorimeter trigger**
  - ➢ Use PMOD-B board
- **Scint block trigger/readout**
  - ➢ Trigger input card design (with LAB4D readout for Scint paddles) ['final' Calorimeter trigger solution]
  - ➢ Modify scint plane daughtercards for direct SiPM attach
  - ➢ Light cones for optical coupling (?)
  - ➢ Daughtercard firmware (4x window TARGETX)



Backup

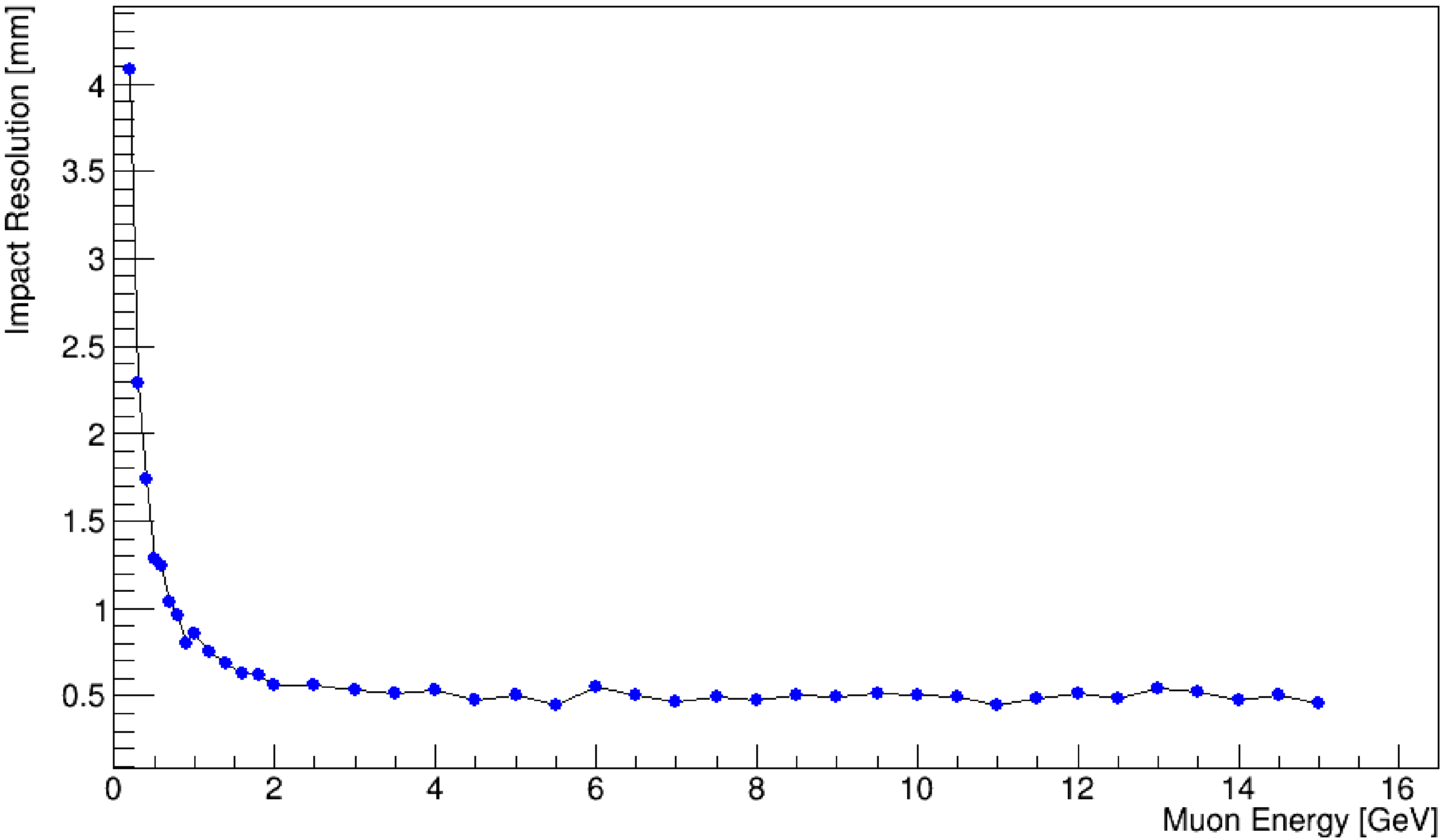
Tracking Resolution Fits

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

Scheduled delivery:
Tuesday 9/22/2020 by 5:00 pm

IN TRANSIT

At destination sort facility

HONOLULU, HI

GET STATUS UPDATES

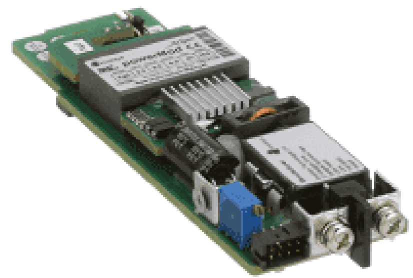
FROM
THIEF RIVER FALLS, MN US

TO
HONOLULU, HI US
MANAGE DELIVERY

Travel History | Shipment Facts

Local Scan Time

Sunday , 9/20/2020			
	9:12 pm	HONOLULU, HI	At destination sort facility
		Expand History	
Friday , 9/18/2020			
	10:52 pm		Shipment information sent to FedEx

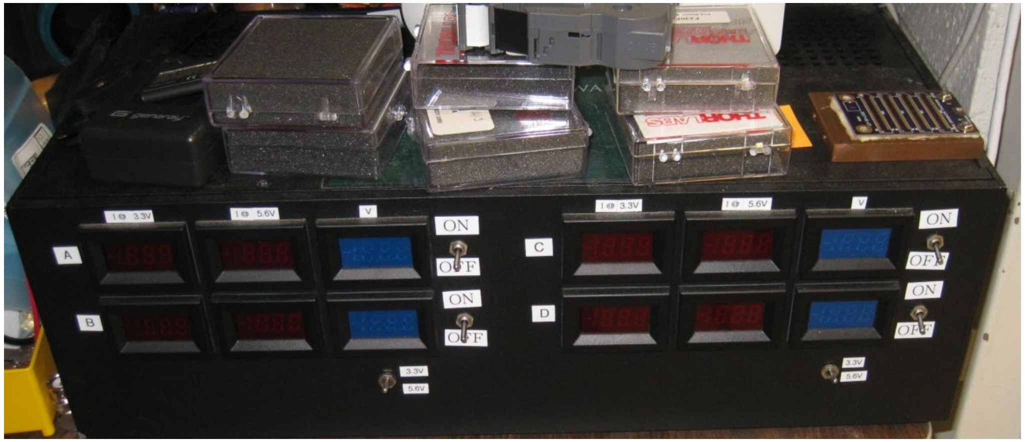


Excelsys power
Adjustable 3 – 6 V
40A per module

Ordered 2 chassis, 5 XG2

Repurposed power module from iTOP prototype

Based upon compact DC-DC



Nomenclature: HMB 3.abcd

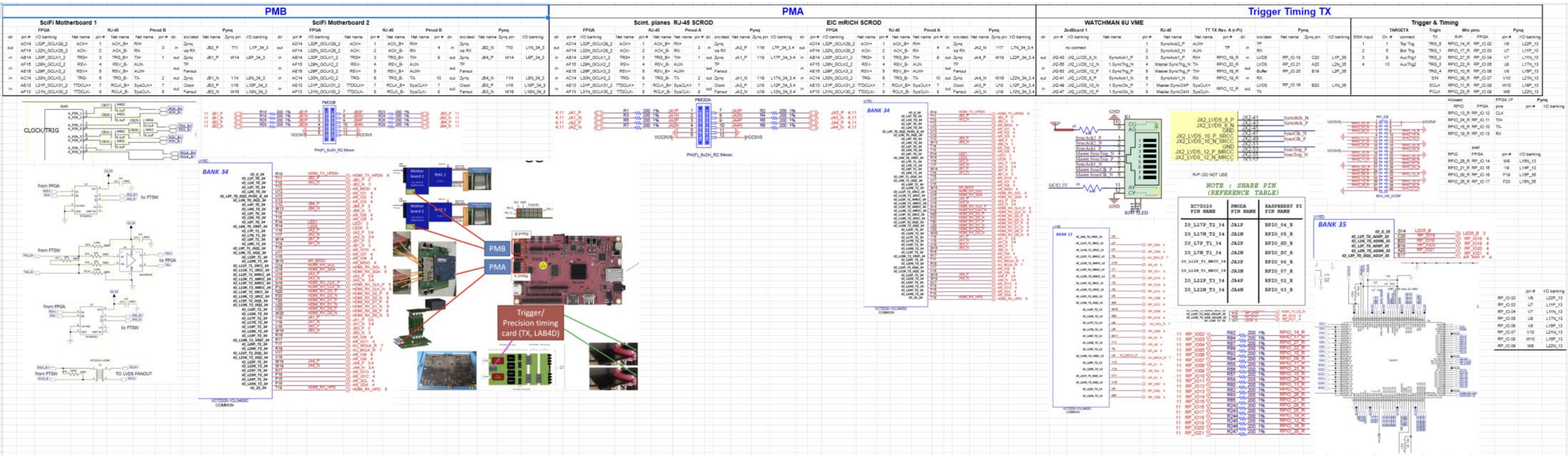
1. **Version 3. is without semiconductor tracker/magnet (v4)**
   a. **Tracker configuration**
   b. **Calorimeter configuration**
   c. **RICH configuration**
   d. **DUT configuration**

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

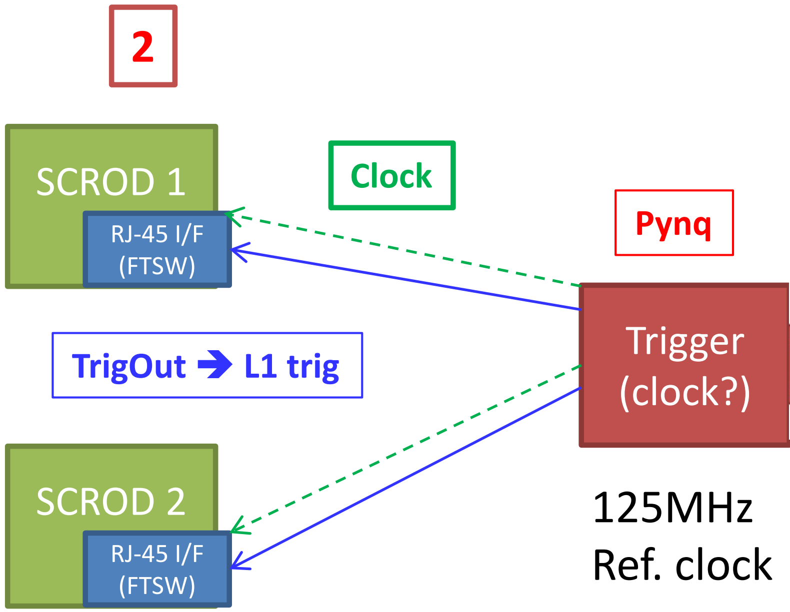
Will switch to 3.2xxx when scint planes ready (could be 3.2100 or 3.2011 or … depending upon which other systems ready first)

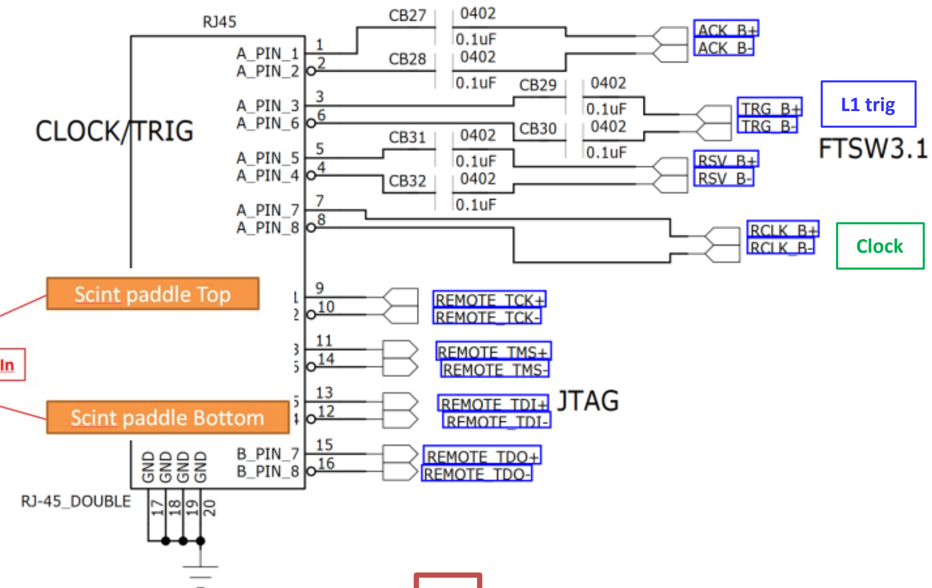
Interconnect Document (google doc)



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

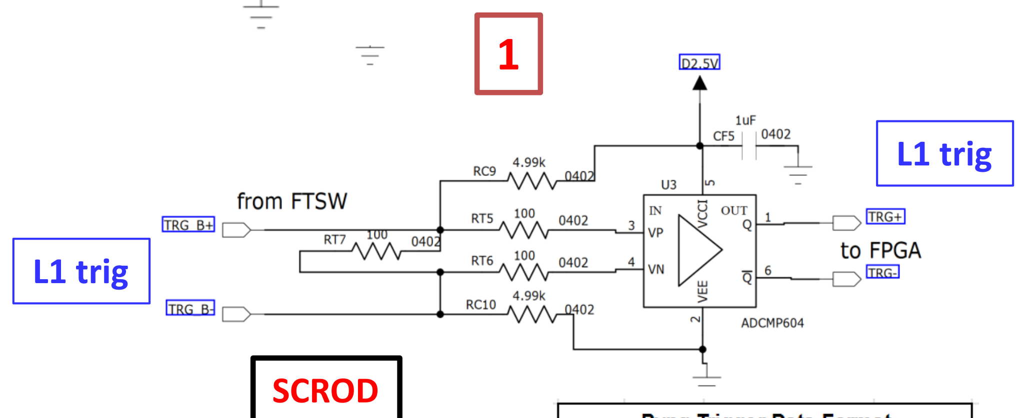
Trigger Details

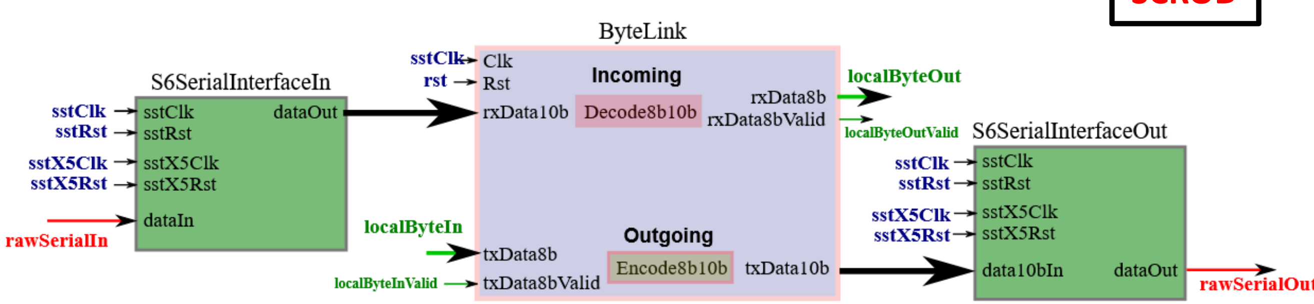




3

- **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)