Early thoughts on alternative detectors for MATHUSLA

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SIMONS CENTER FOR GEOMETRY AND PHYSICS **MATHUSLA workshop**

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MATHUSLA

TEL AVIV UNIVERSITY

In The Beginning

- Five detector planes
- Each plane provides space point with ~1 cm resolution in each transverse direction and ~1 nsec time resolution

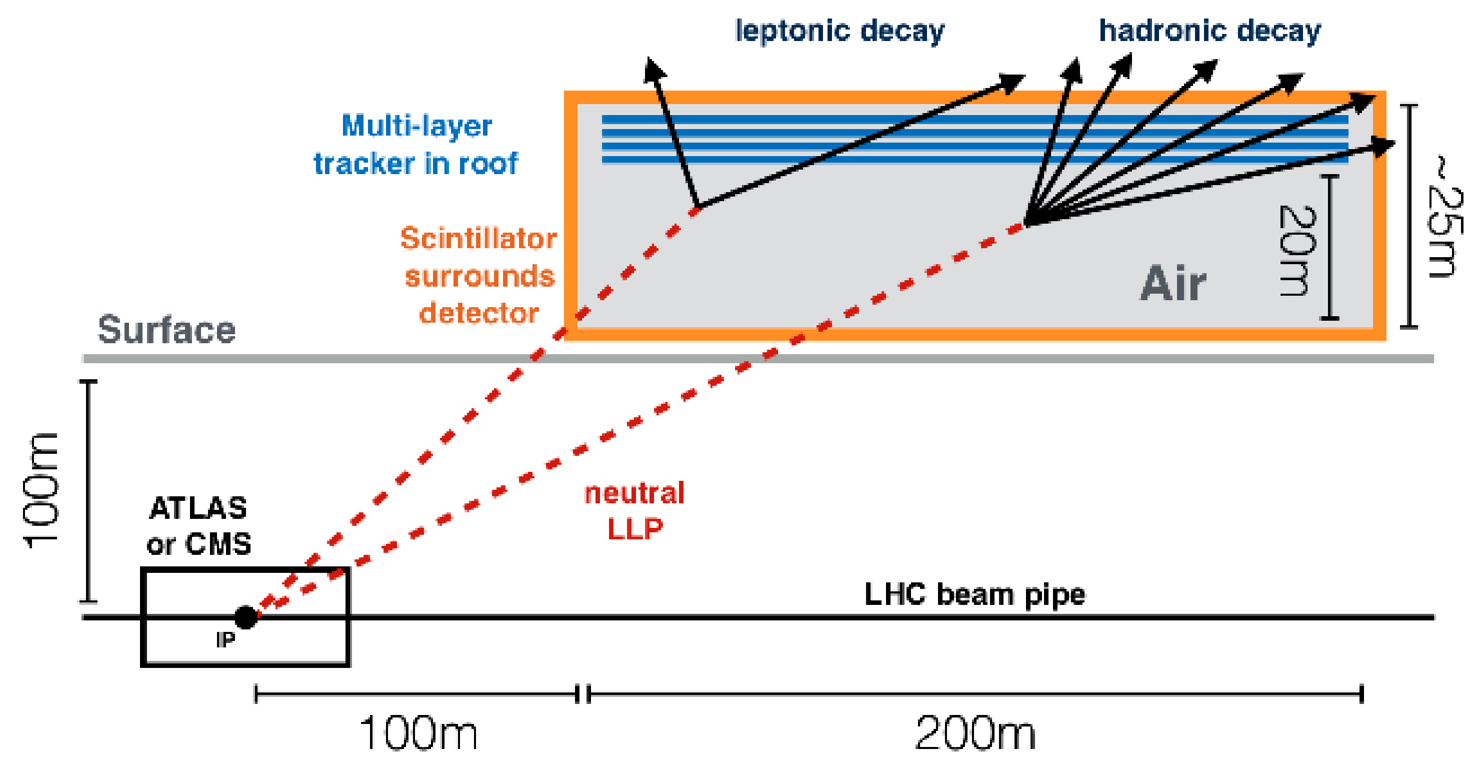
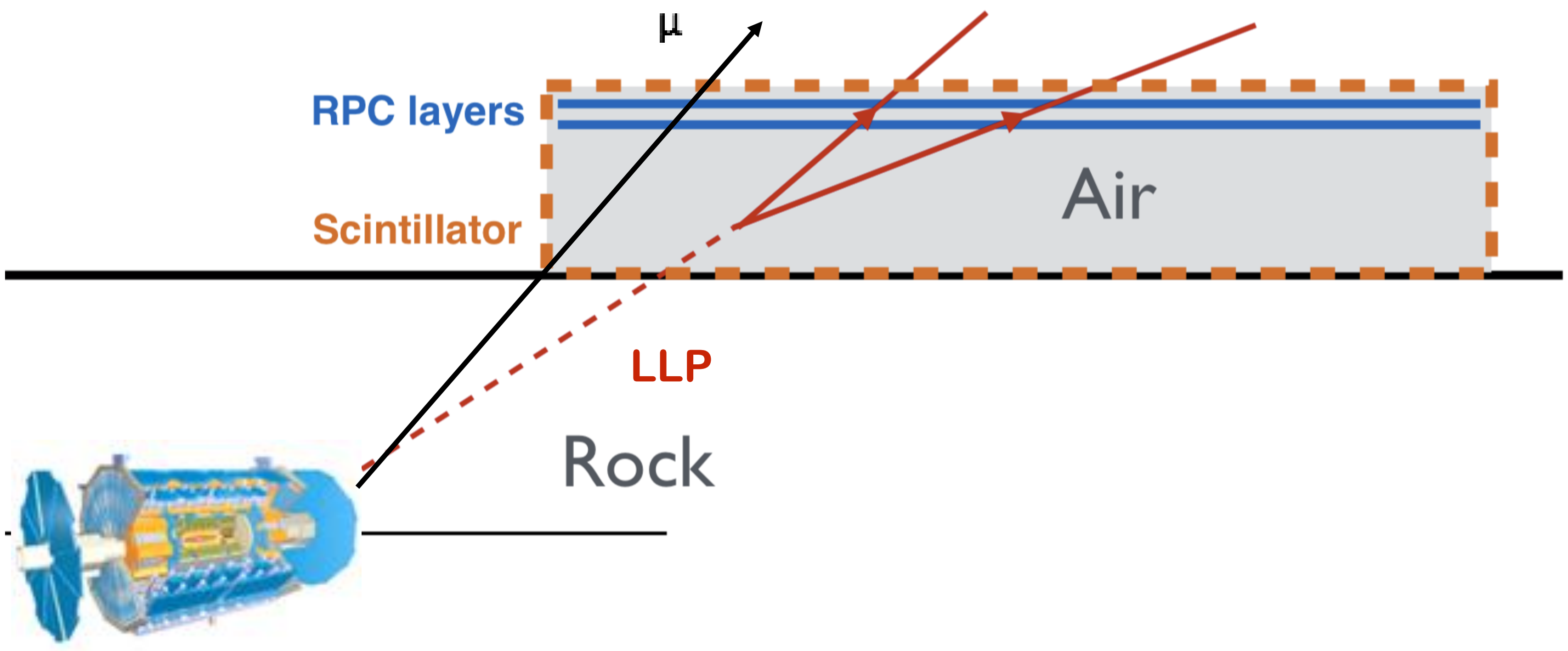


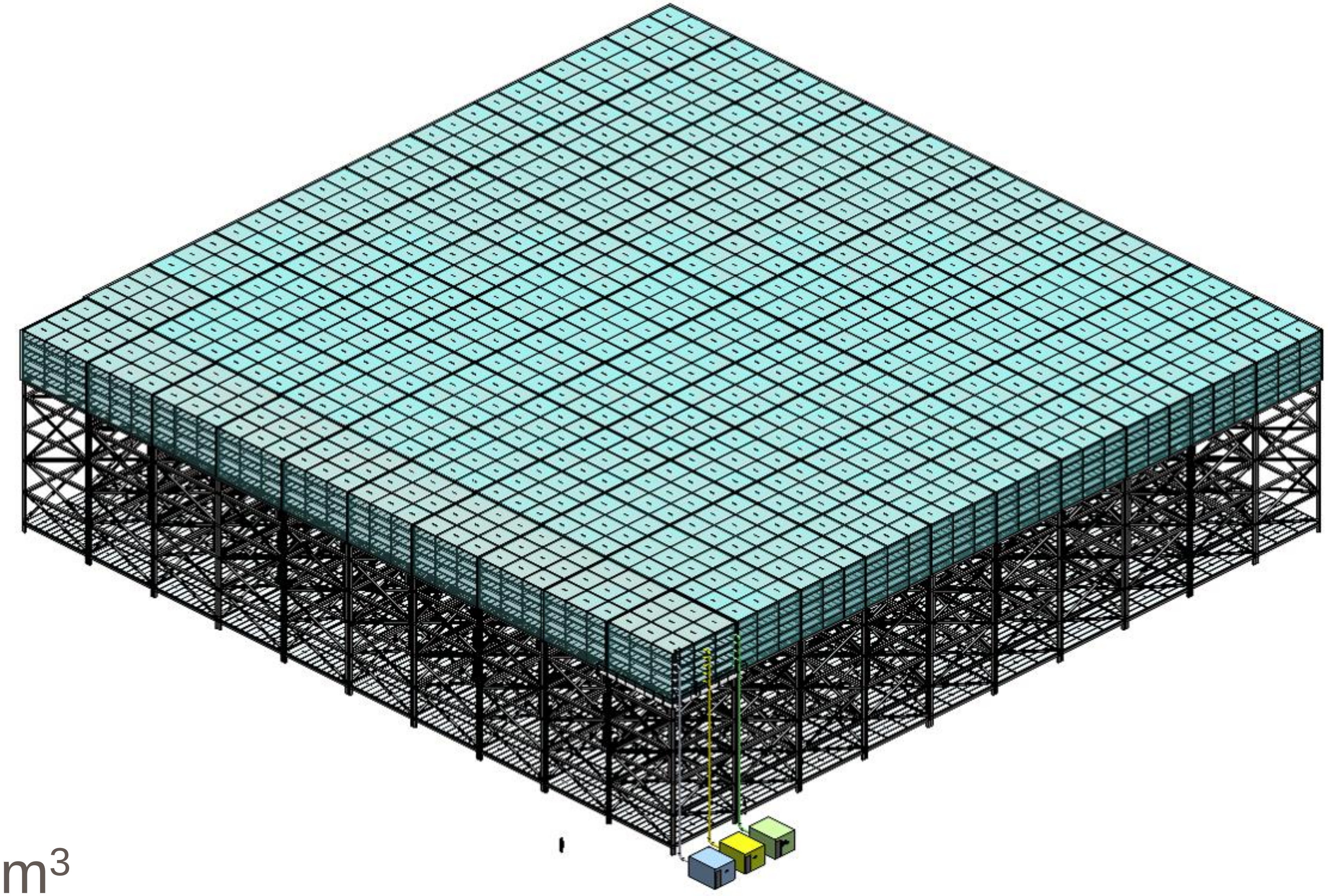
Fig. 1: Simplified detector layout showing the position of the 200 m × 200 m × 20 m LLP decay volume used for physics studies. The tracking planes in the roof detect charged particles, allowing for the reconstruction of displaced vertices in the air-filled decay volume. The scintillator surrounding the volume provides vetoing capability against charged particles entering the detector.

The signal characteristic



- Searching for upward going vertex in the detector volume
  - LLP may decay to jets or lepton pair, signal requires >= two
  - Particles reaching the ground should be relativistically boosted
  - The tracks point toward a common vertex
  - The vertex within a cone from the ATLAS/CMS IP
    - Material could help with particle ID (but induce other BG)
  - Determine speed of charged particles with precision of ~0.05%
  - Use a veto based on bottom scintillator**?**

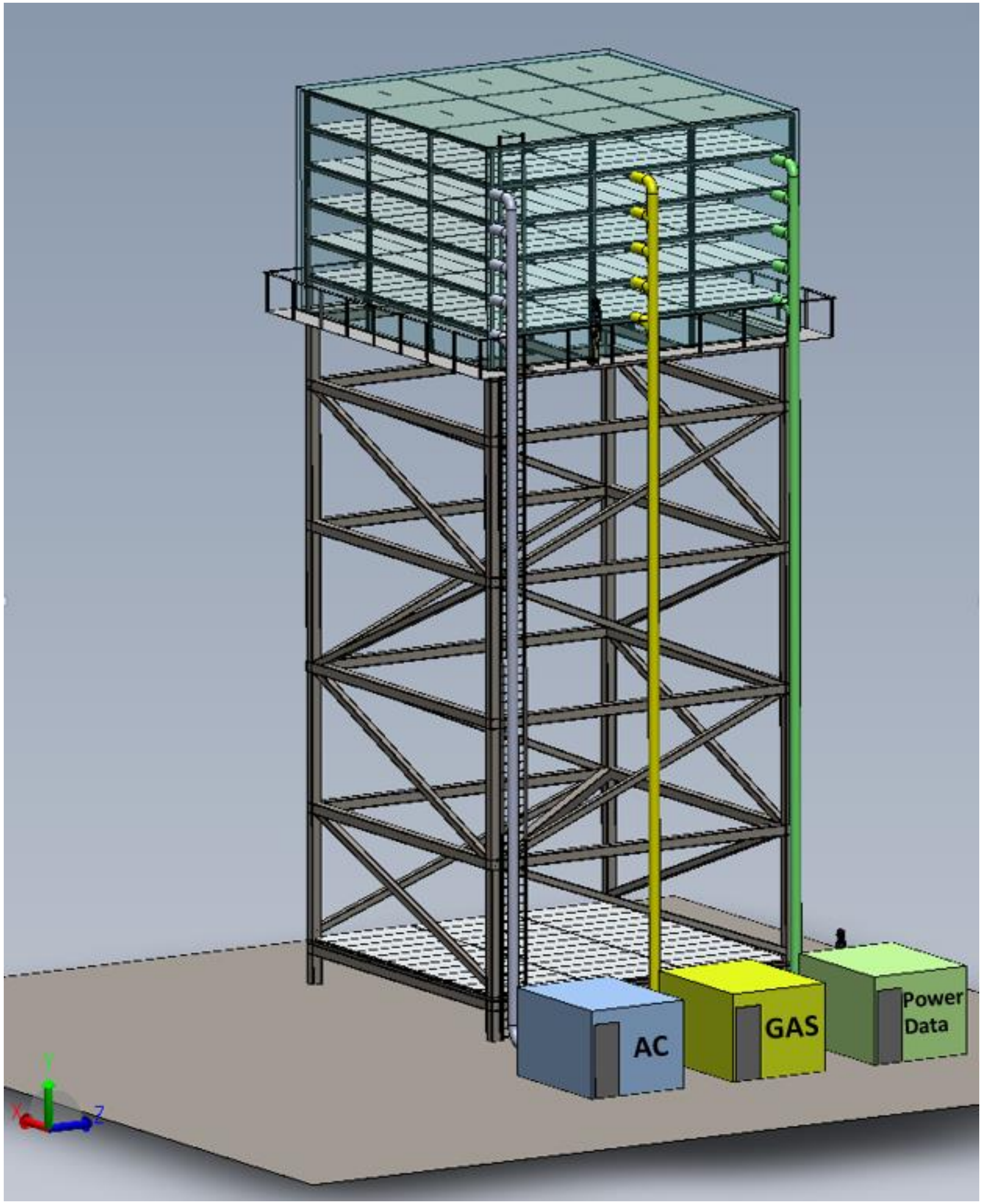
Full size MATHUSLA 100



- 105 x 105 x 25 m^3
- Inter module gap - 1m?

9.6 x 9.6 unit

- Current benchmark:
  - 5 layers of RPC on the top for triggering and tracking.
  - Layer at the bottom (if at all probably RPC as well)
  - Material could help with particle ID (but induce other BG)
  - Assumed RPC weight 35kg =>1.26 Ton unit)
- Guiding principles
  - Provide the required spatial (O(cm)) and timing (O(ns))
  - Simple
  - One technology if possible
  - Cheap to build (and maintain)

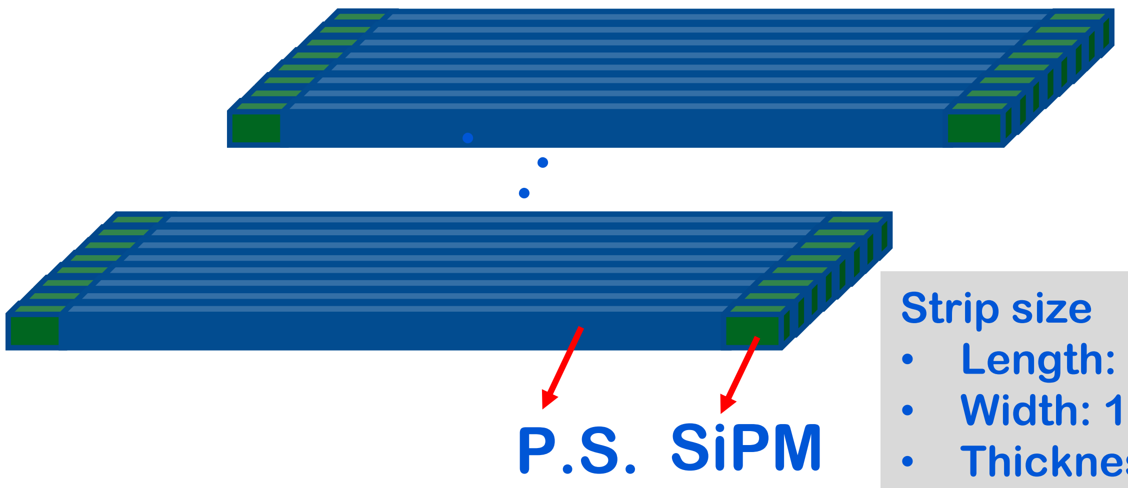


Plastic Scintillators +SiPM

Yuekun Heng, IHEP

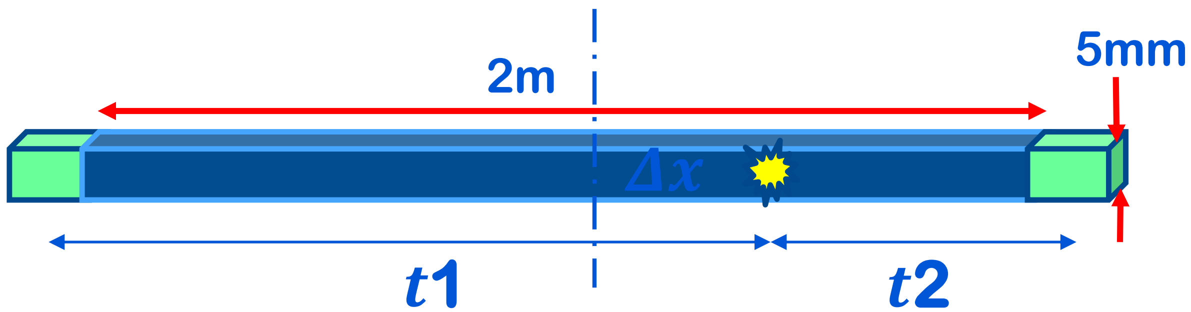
Module

- Size: 2m X 2m
- Plastic scintillator strip: 0.5cmX1cmX200cm
- Vertical muon: 1 MeV deposit energy, ~10000 photons of original light output
- Two end readout: fast SiPM, for example S14160, time resolutionis about 70 ps
- Position resolution
  - Strip width: 1cm
  - Along strip by timing method: ~1cm



Strip size
- Length: 200cm
- Width: 1cm
- Thickness: 0.5cm

Detector Concept



$Positionning: \Delta x = c\, \Delta t/2$

COST Estimate per Module of 4 m^2

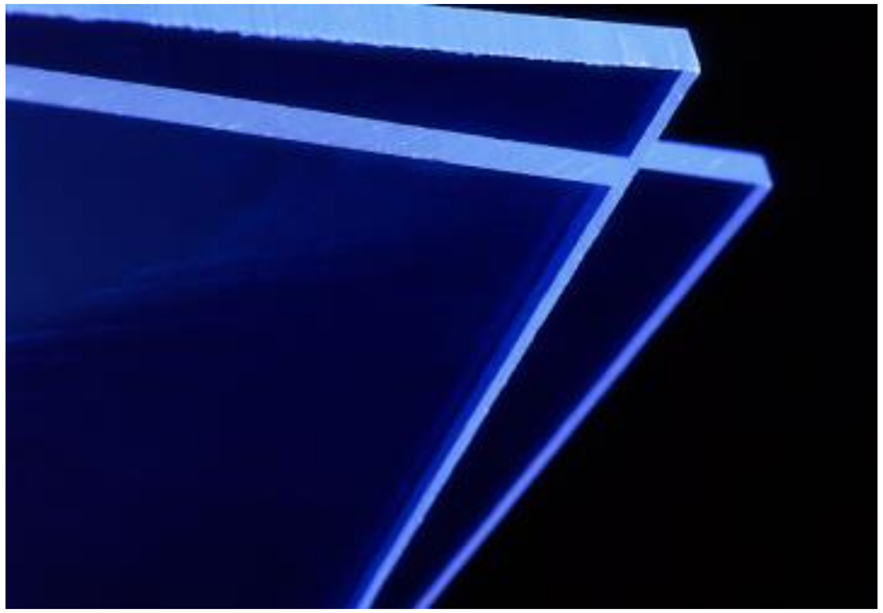
- Box: 100 $
- Plastic Scintillator: 50 $/kg X 20 kg = 1000 $
- SiPM: 400 * 1.5$ = 600 $
- Elec.: ~ 400 channels, sharing? ASIC? Not sure

Total: ~ 1700$ + Elec.

⇒ For 10x10 m
⇒ K$25 + k$15 (SiPMT) + elec

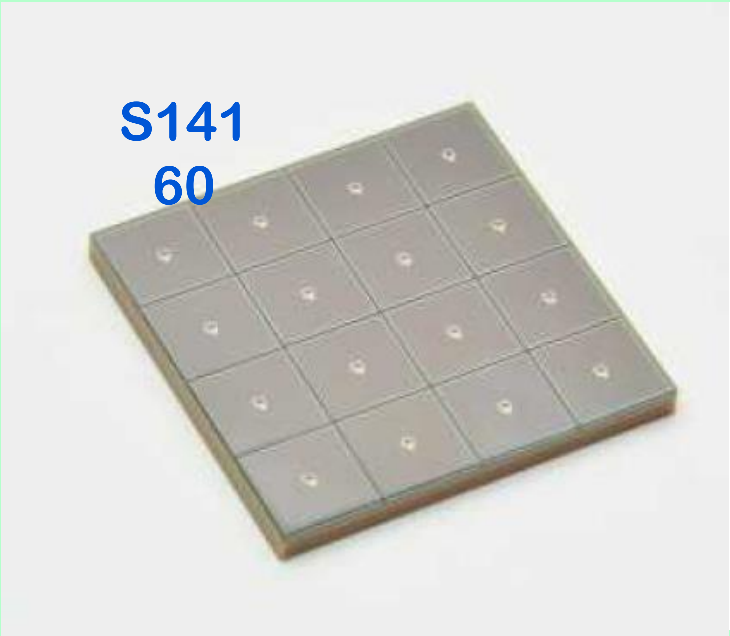
Plastic Scintillators / Fast SiPM

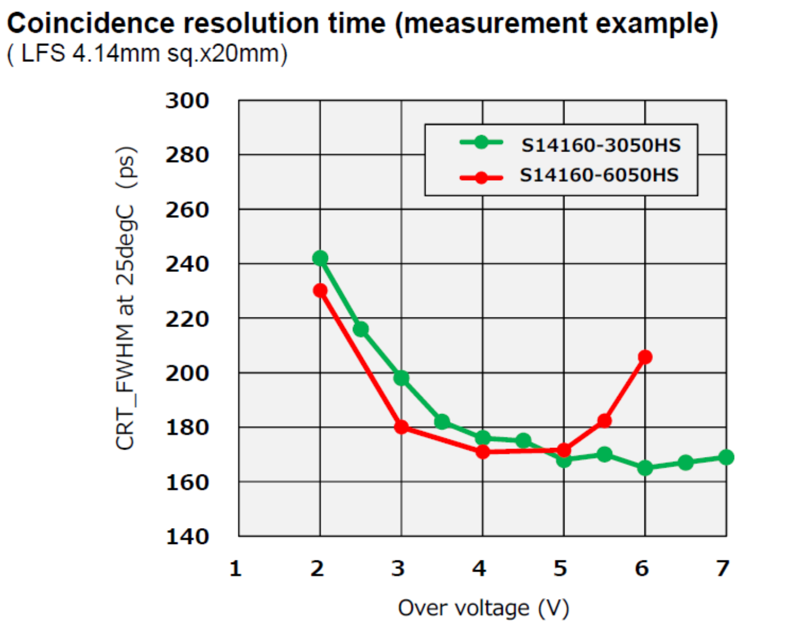
Yuekun Heng, IHEP



SiPM S14160 and its timing performance

Single channel	PDE (Photon Detection Effi)	Gain	CRT(Coincidence resolution time)	peak sensitivity wavelength
3x3 mm^2	50%	2.5*10^6	170ps	450 nm



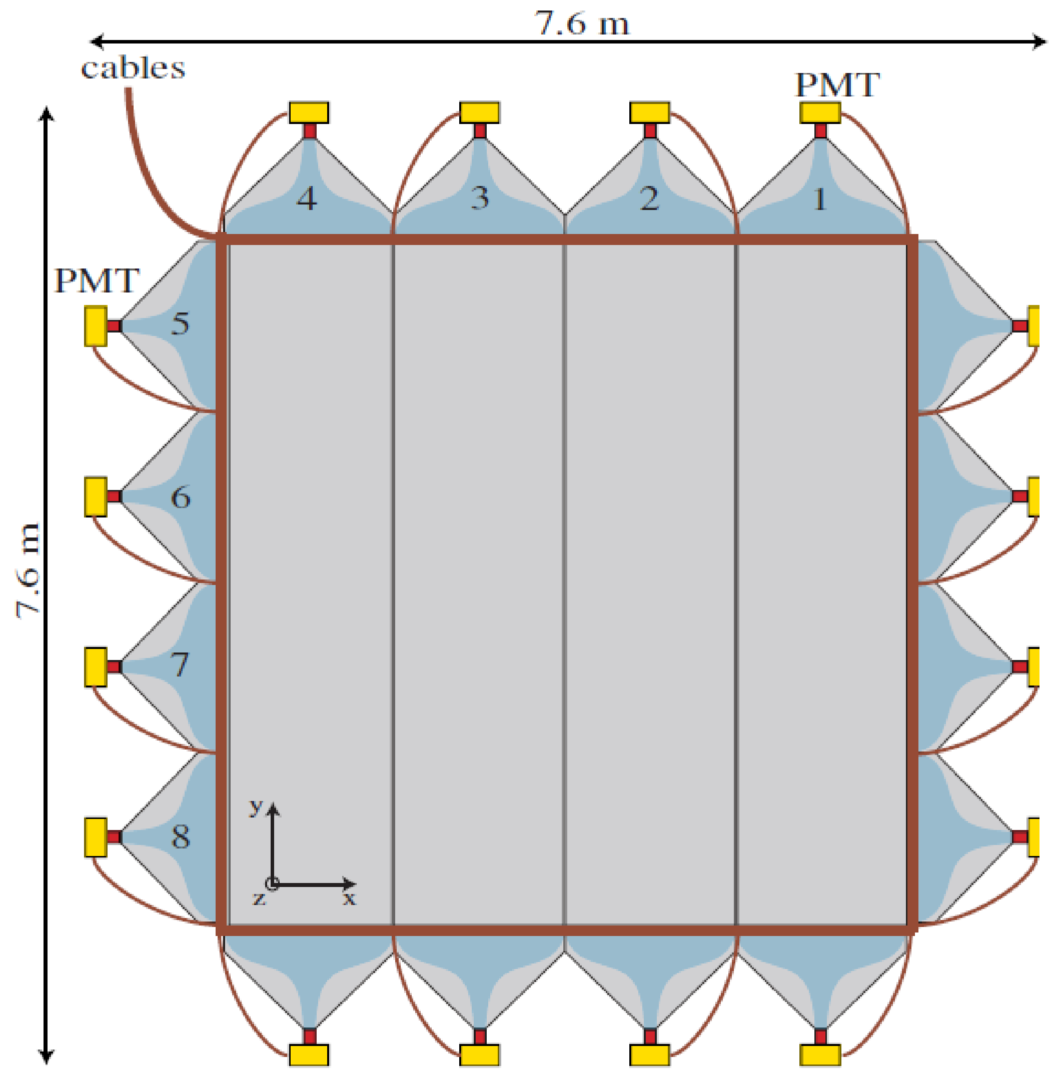


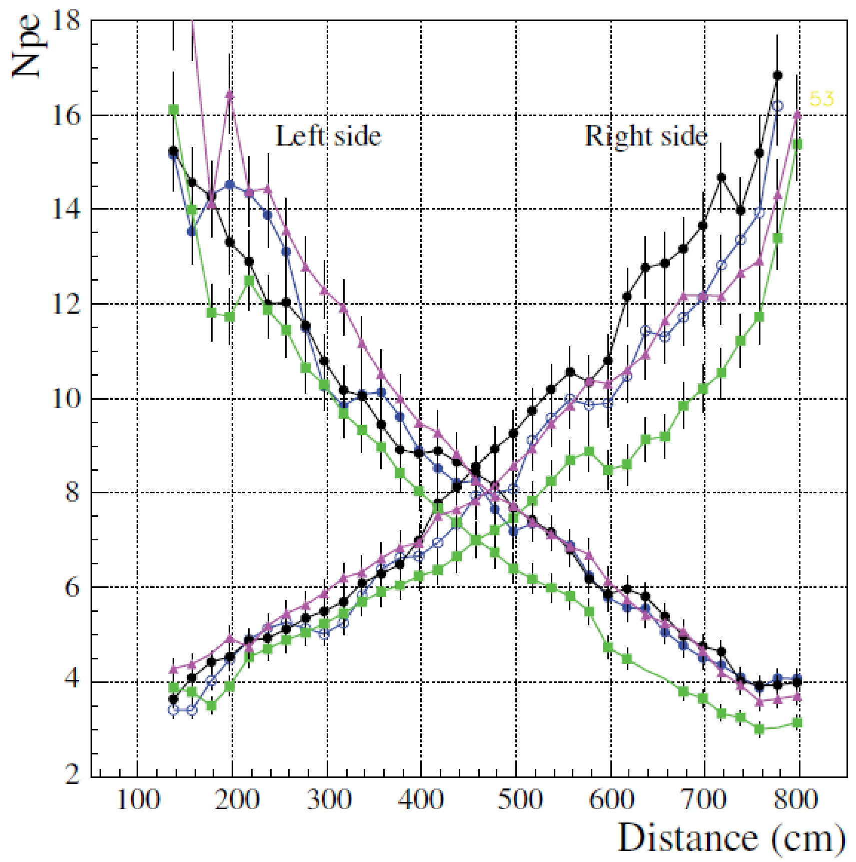
Fast plastic scintillator performances

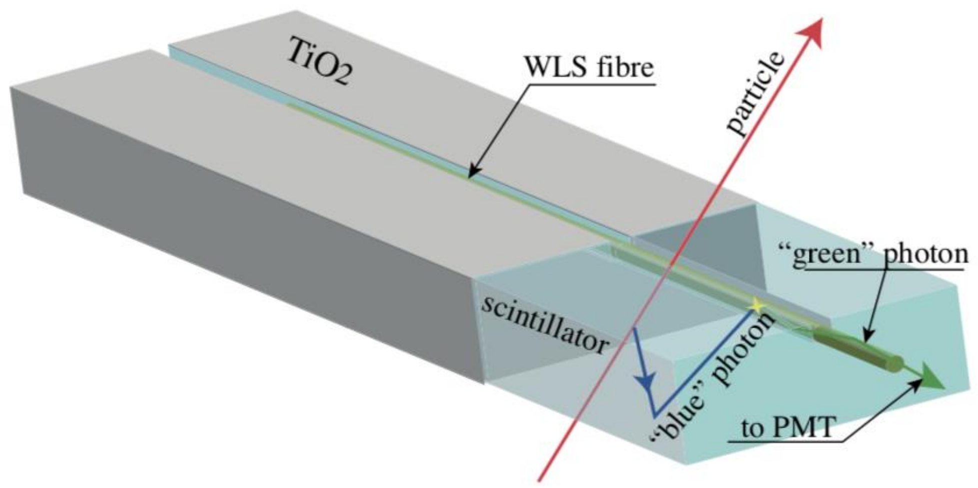
Scintillator	Light Output % Anthracene[1]	Wavelength of Maximum Emission, nm	Decay Constant, ns	Bulk Light Attenuation Length, cm
BC-400	65	423	2.4	250
BC-404	68	408	1.8	160
BC-408	64	425	2.1	380
BC-412	60	434	3.3	400
BC-416	38	434	4.0	400
BC-418	67	391	1.4	100
BC-420	64	391	1.5	110

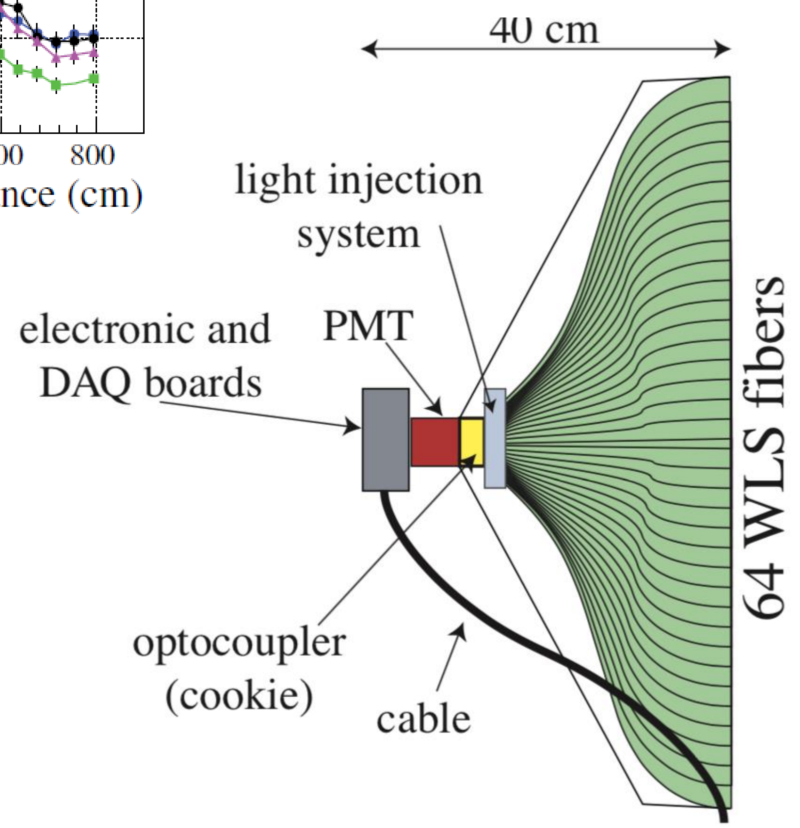
OPERA

arXiv:physics/0701153v1 [physics.ins-det] 12 Jan 2007







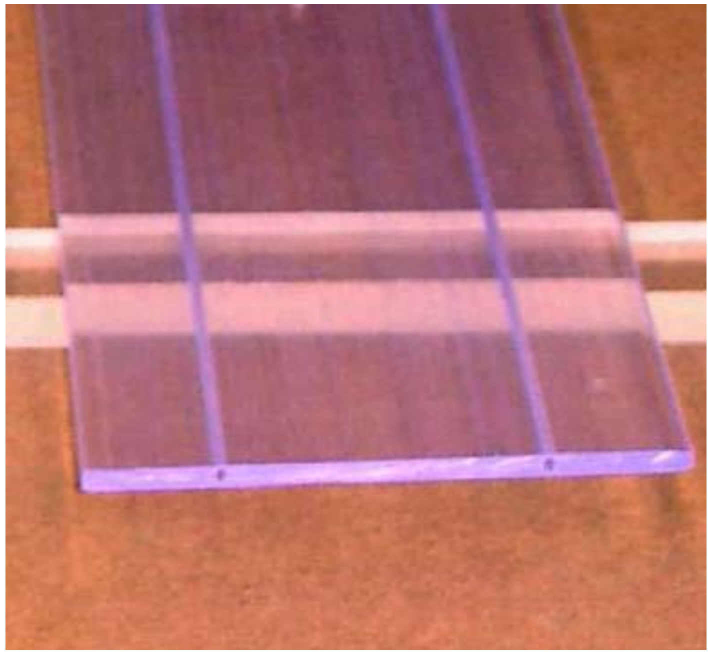


Extruded Scintillators

- A slightly cheaper version of plastic scintillator is the extruded scintillators. Studies at Fermilab (FERMILAB-PUB-05-344) show they reach ~75% of of the light yield of BC408 or similar to Kuraray SCSN-81.
- To increase the light yield one can insert WLS fibers to holes prepared during the extrusion process.
- Cast plastic scintillators cost $50 per kg
- MINOS extruded scintillators (300 tons!) was around $10 per kg, Fermilab claim to $5-8 per kg
- D0 experiment use extruded strips for the Central and Forward Preshower detectors

FERMILAB-PUB-05-344

FERMILAB-Conf-03-318-E



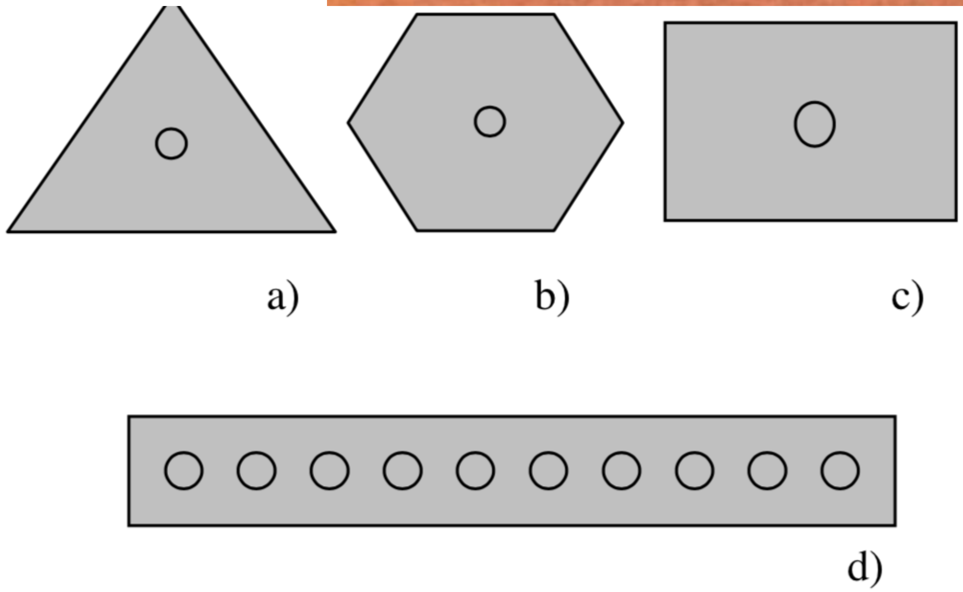
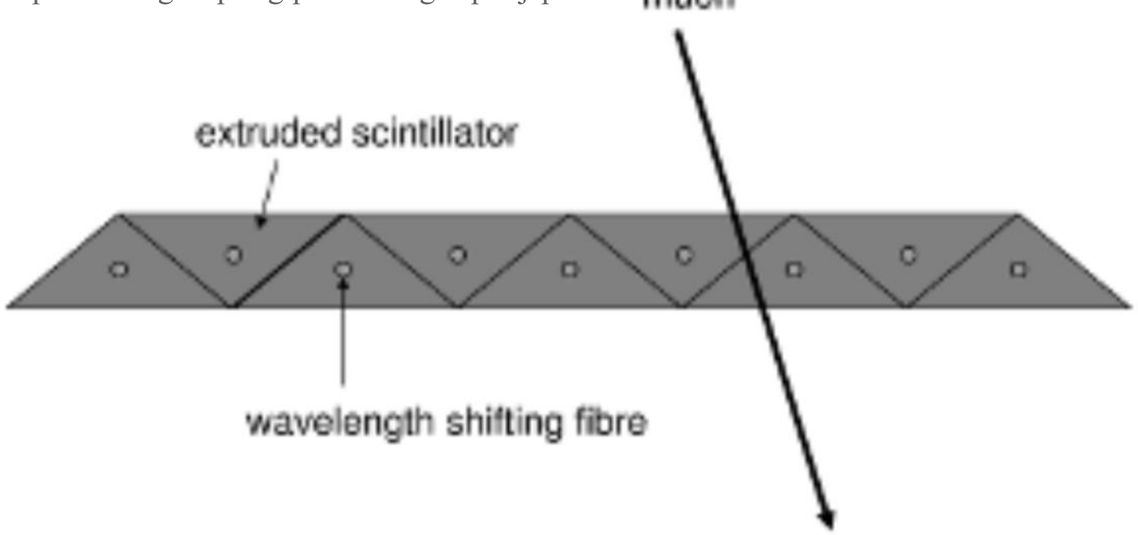


Fig. … n have the ext… ERνA, b) sci… d in R&D stu…

⇒ For 10x10 m (same configuration of 2x2)

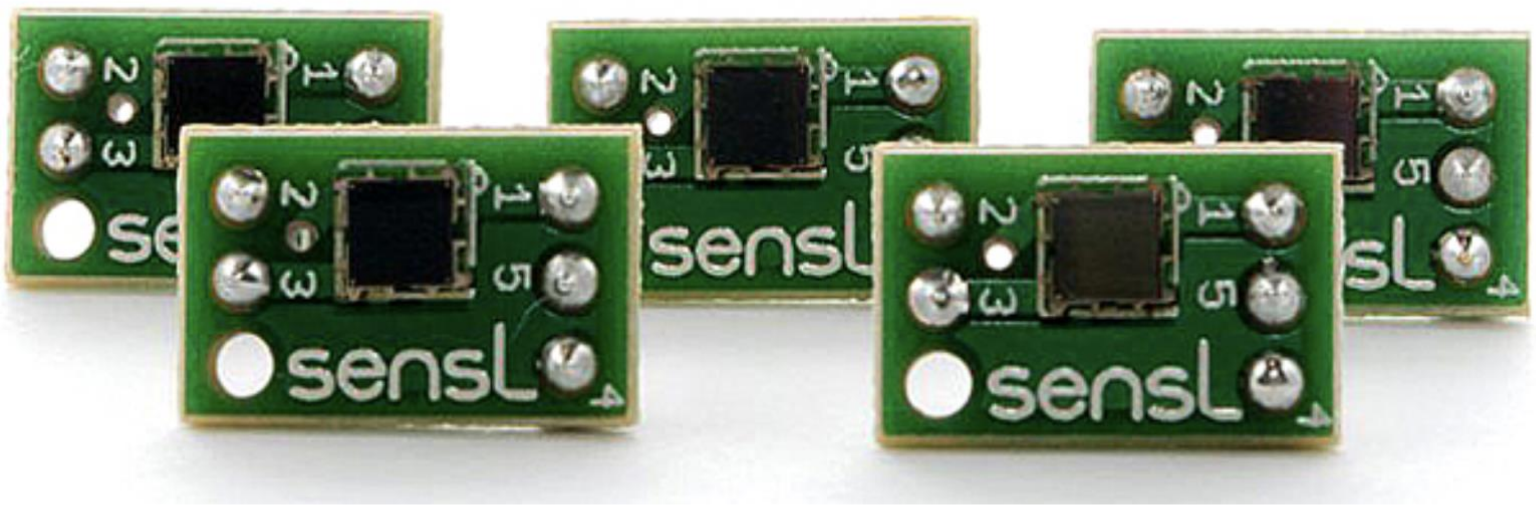
⇒ K$5 + k$15 (SiPMT) + elec

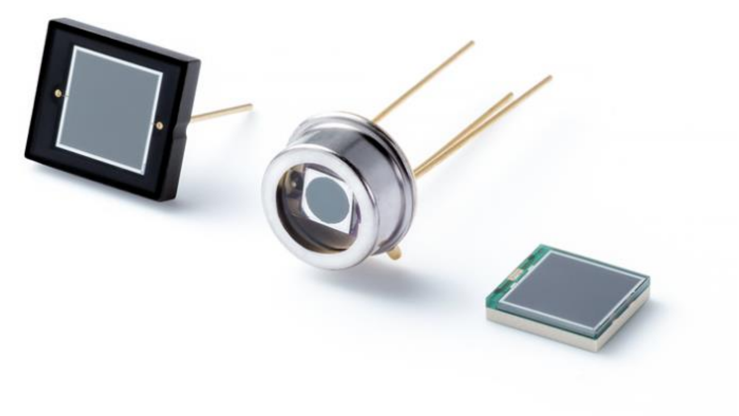
http://proceedings.aip.org/proceedings/cpcr.jsp



PMT versus SiPMT

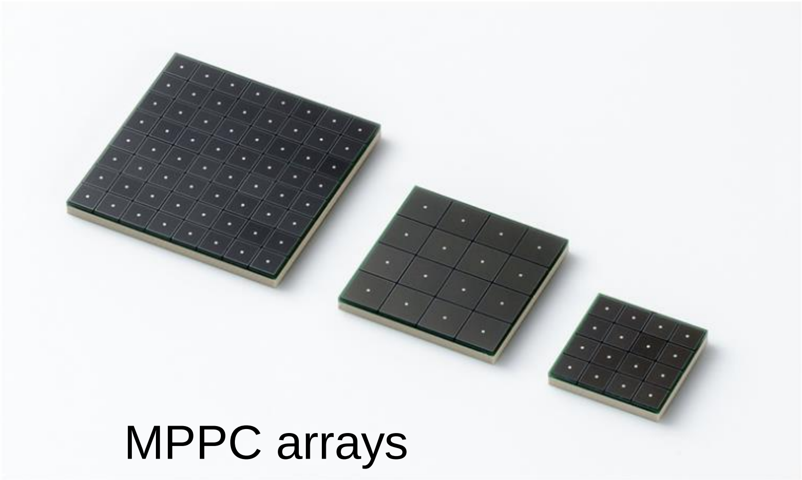
- SiPMT – low cost, high performance alternative.
- Bias voltage ~30-35V
- Sensors available in several sizes   (1-6mm)
- Single units an arrays





Single-element MPPCs (SiPMs)

HAMAMATSU MPPCs (Multi-Pixel Photon Counters)



MPPC arrays

Extrusion at Fermilab

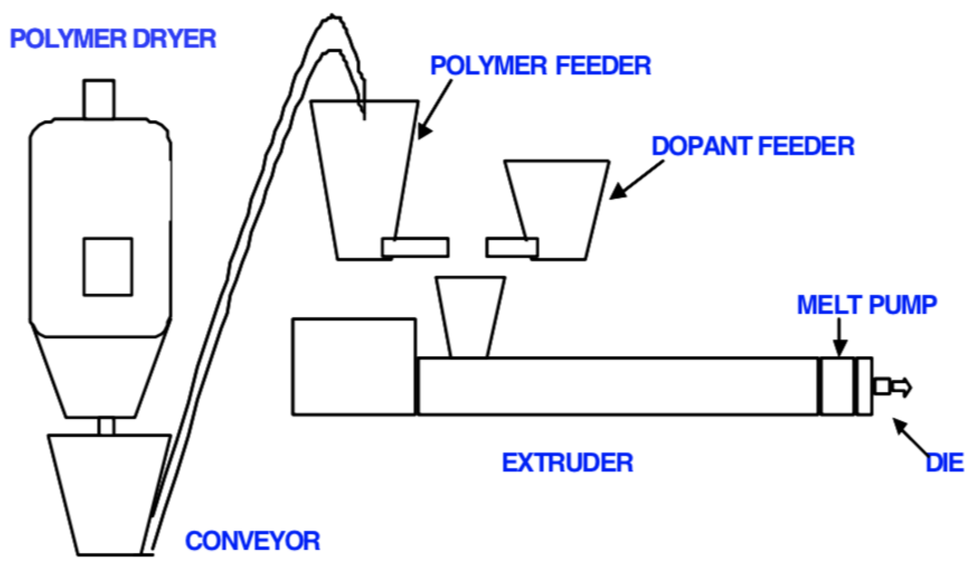
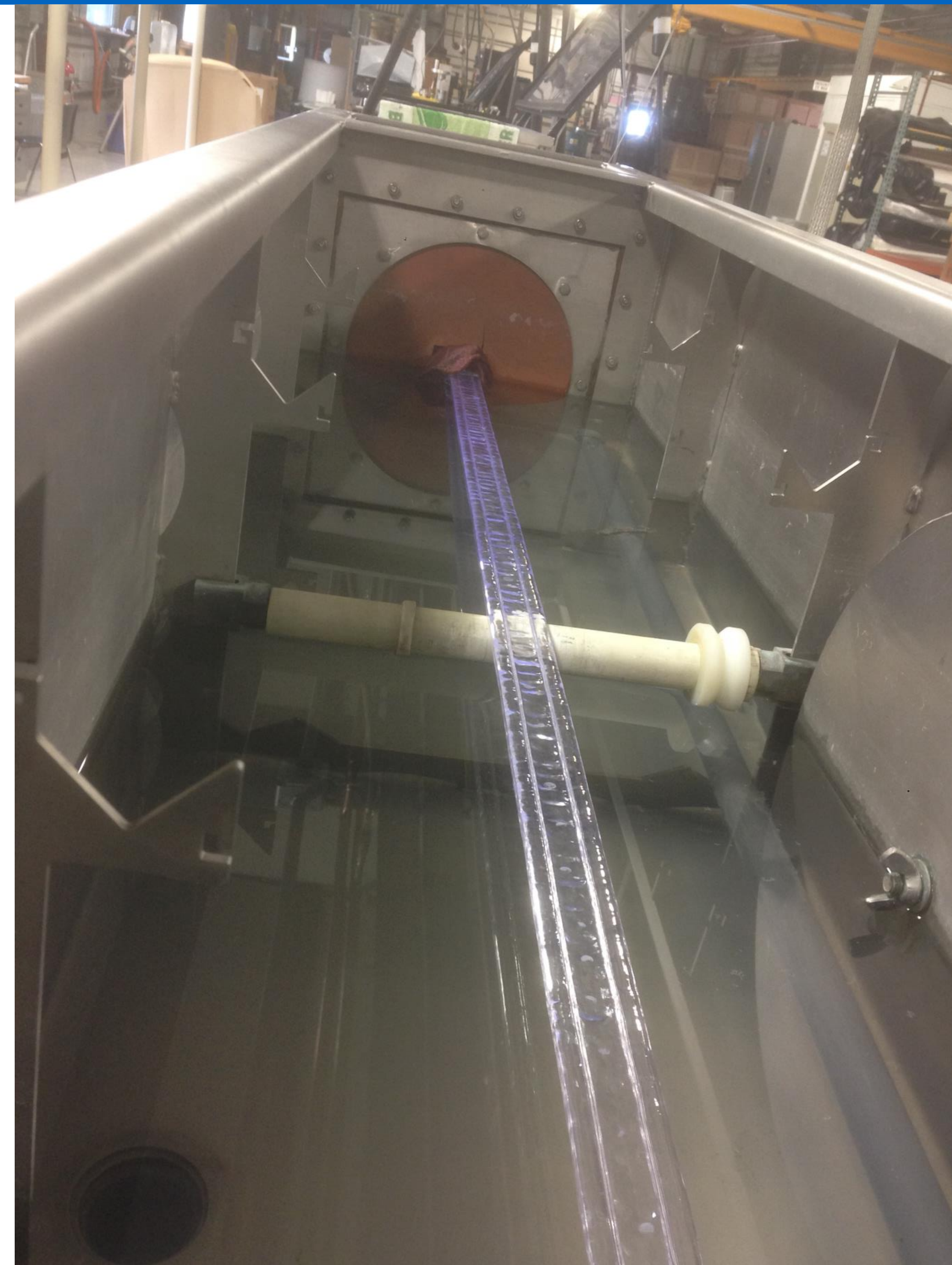


Fig. 3. Schematic diagram of the FNAL/NICADD continuous extrusion line for plastic scintillator.

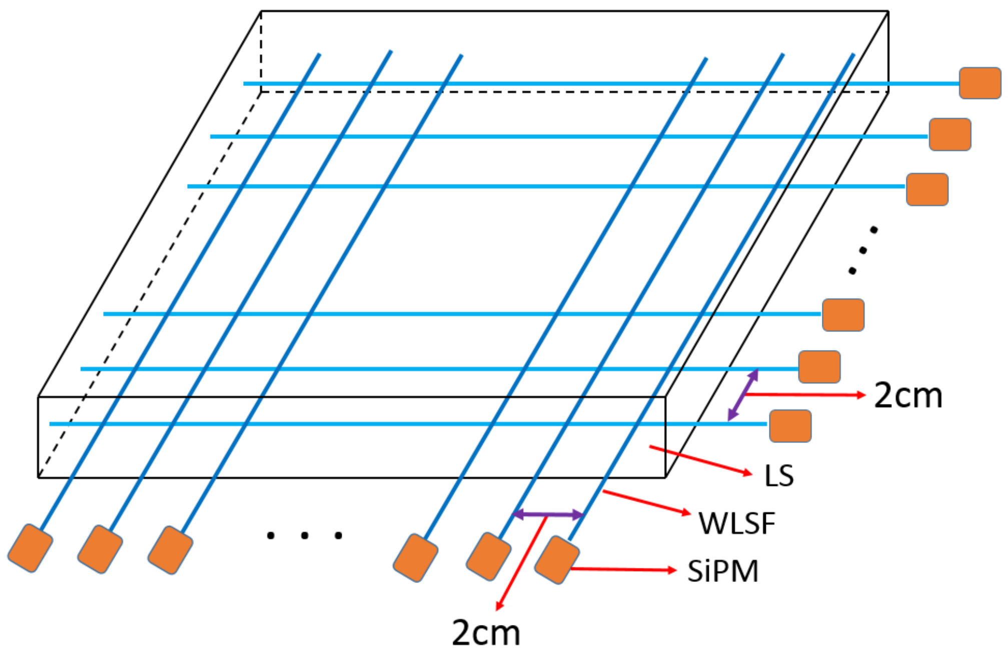


Liquid Scintillators

- Endless combination see e.g. Cocktails for LS, Ronald Edler.
- Requirements: good uptake, high transition for photons, high quantum yield, safe cocktail, low price, low content of 14C
- Contains: solvent, scintillating material (5-12 g/liter), surfactant, sample
- Many studies of materials, and performance, and shapes (e.g. CERN-EP/2000-069), Good summary: “Principles and Applications of Liquid Scintillation Counting”, National Diagnostics
- A single container of liquid scintillator segmented by optical separators can provide a granularity of a few centimeters over a large volume.

Liquid Scintillators+WLS+SiPM

Yuekun Heng, IHEP



Detector Concept

Module Box

- Filled with LS: 2m X 2m X 1 cm
- Vertical muon deposit energy: ~ 2MeV, ~20000 photons of original light output

WLSF+ SiPM

- Fiber Type: Kuraray Y-11
  - Light transportation ability: 4.2%
  - Attenuation length ~1.5m
  - Fibers: 2 cm span, X: 100, Y: 100
- Readout: SiPM + Front end elec.
  - Photoelectron number: ~10
  - Charge measurement: Center gravity method to get position precision of ~1cm
  - Time measurement: ~1ns

COST Estimate per Module of 4 m^2

- Box and fiber feedthrough: 500 $
- Liquid Scintillator: 2000 $/$m^3$ X 0. 04 m^3 = 80 $
- WLSF 400m* 2 $/m = 800 $
- SiPM 200 * 1.5$ = 300 $
- Elec.: ~ 200 channels, sharing? ASIC? Not sure

Total: ~ 1700$ + Elec.

”Ice cubes”

Example of large LS - MACRO

Astroparticle Physics 6 (1997) 113- 128

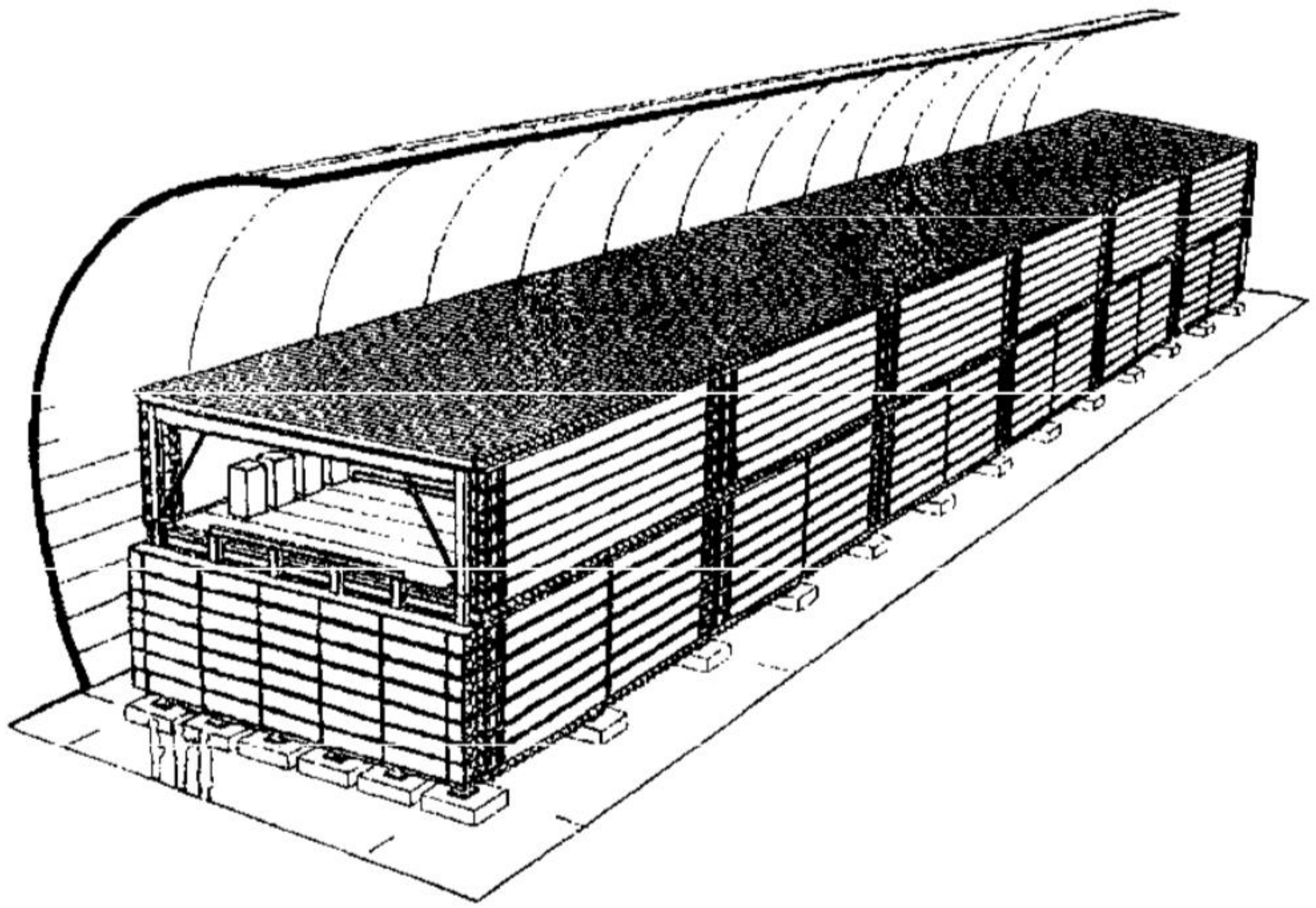
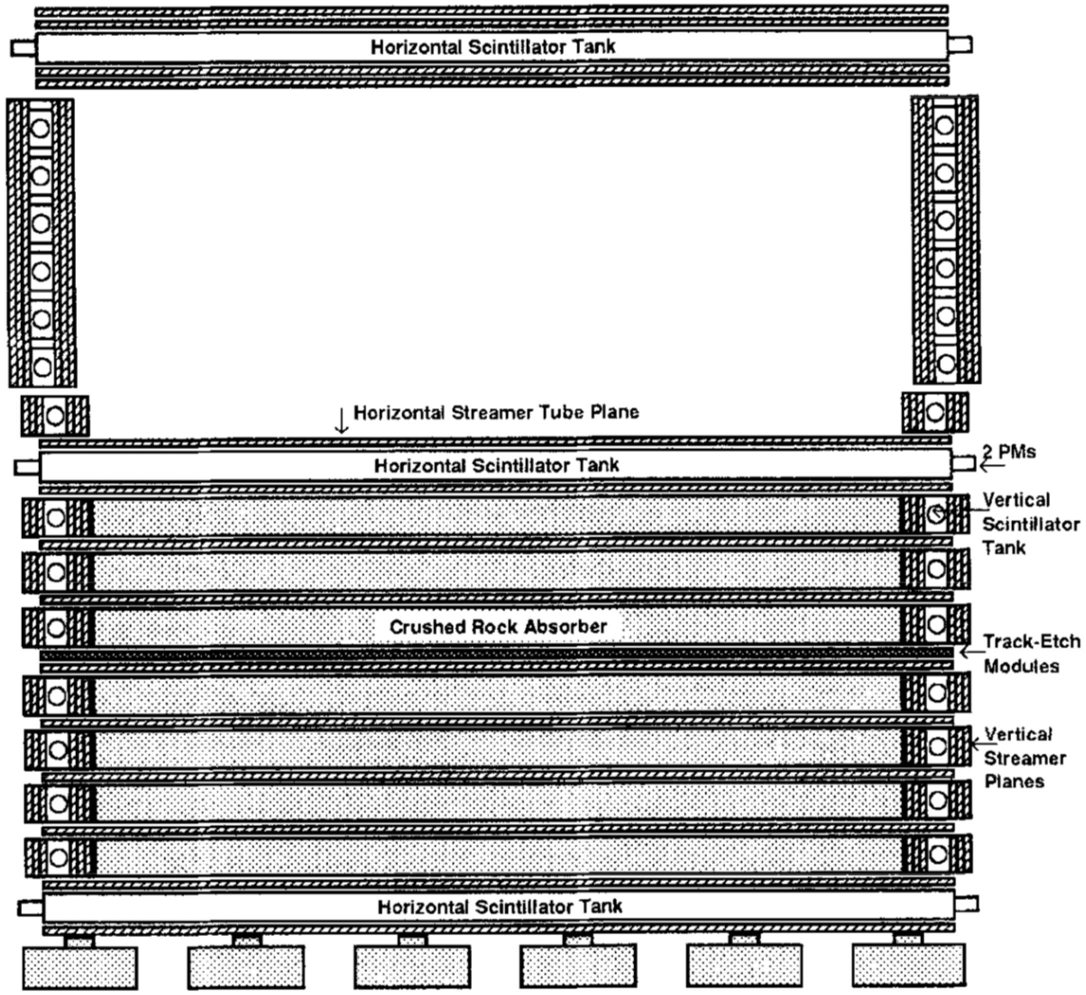


Fig. 1. The complete MACRO detector in perspective view. It is 76.5 m long, 12 m wide and 9.6 m high.



. 2. A single MACRO supermodule in cross sectional view. It is 12.6 m long, 12 m wide and 9.6 m high.

- 49 x (11.9 x 0.75 x 0.25 m3) horizontal scintillators
- 28 x(12 x 0.25 x 0.5 m3) vertical scintillators
- 96.4% mineral oil 3.6% pseudocumence + 1.4 g/liter PPO 1.4 mg/liter bis-MSB (WLS)
- Position resolution 11 cm, energy 1 MeV, time of flight 700 ps.
- PMTs 20 cm

Tests of LS at TAU

- Initiated test of LS bars in various shapes, aiming at ~ 3 m bars, squares or triangles

Concluding comments

- No conclusions… just early thoughts
- RPC is a clear strategy which will provide the desired spatial resolution and timing
- There are other options such as plastic scintillators, mainly extruded ones (Minos, D0)
- Benefit from the low price of SiPMT compared to PMT
- Enhance the length with WLS fibers
- Attractive alternative Liquid Scintillator in a large container with WLS fibers readout, or long tubes with WLS fibers.
- Additional pros for scintillators:
  - Not sensitive to weather (temperature, humidity..)
  - No need for gas system, maintenance, gas leaks..)
  - For SiPMT run on LV
- Should consider also weight for each option
- The advantage of modular MATHUSLA – can work on several solution in parallel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PROMISE

Additional reading

- Beckman Instruments, LS 1801, 3801, 5801 Series Liquid Scintillation Systems Operating Manual, 1985.
- Packard Instrument Company, Liquid Scintillation Analysis; Science and Technology, Rev C, 1986.
- Packard Instrument Company, Tri-Carb Liquid Scintillation Analyzers: Models 2100TR/2300TR, Operations Manual, 1995.
- University of Wisconsin - Madison, Radiation Safety for Radiation Workers Handbook, 199
- Nationa Diagnostics, Principles and Applications of Liquid Scintillation Counting

- MACRO Collaboration, Astroparticle physics *6 (1997) 113-128*
- Ronald Edler, Cocktails for Liquid Scintillation Counting and references there.
- S. Mufson et al., Liquid scintillator production for the NOvA experiment, NIM, arXiv:1504.04035 [hep-ex]
- Anna Pla -Dalmau et al., Extruding Plastic Scintillator at Fermilab, FERMILAB-Conf-03-31 E
- D. Beznosko et al., FNAL-NICADD Extruded Scintillator, FERMILAB-PUB-05-344
- *Saint-Gobain Ceramics & Plastics, Inc.* Premium Plastic Scintillators
- …..