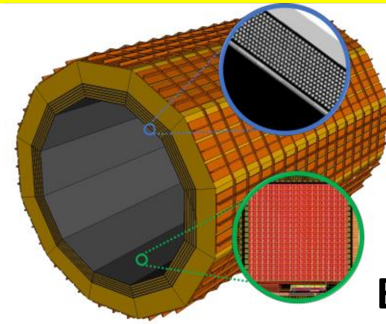
CPAD Summary WG2
Calorimetry

Minfang Yeh, BNL
Friederike Bock, ORNL
Adi Bornheim, Caltech
Stony Brook
02.12.2022

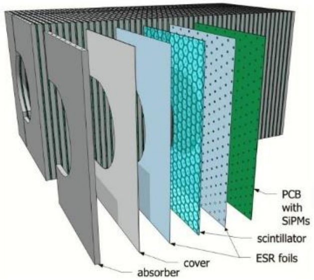
Calorimetry for the Electron Ion Collider
Craig Woody

ePIC Calorimeter Systems

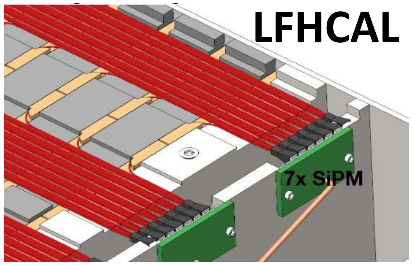
- Electron End Cap EMCAL (EEMC)
  - PWO
- Barrel EMCal (BEMC)
  - Scintillating Glass (Option 1)
  - Pb/SciFi/Si "Imaging" (Option 2)
    (see talk by J.Kim)
- Outer HCal (oHCAL)
  - Fe/Scint tile (sPHENIX re-use)
- Forward EMCAL (FEMC)
  - W/SciFi (similar to sPHENIX)
    (see talk by Z.Ji)
- Longitudinally Segmented Forward HCAL (LFHCAL)
  - Fe/W/Scint tile
  (see talk by N.Novitzky)
- **Forward Insert Calo**
  (see talk by Miguel Arratia)

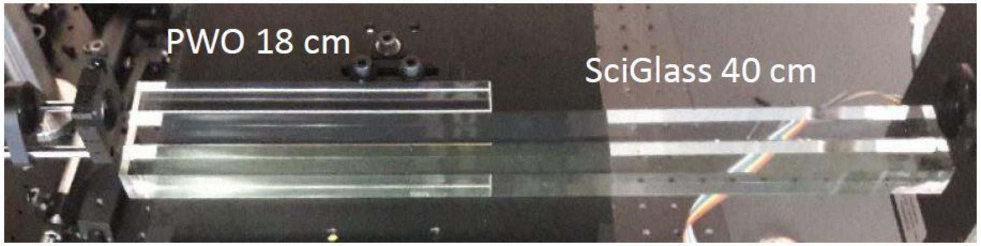


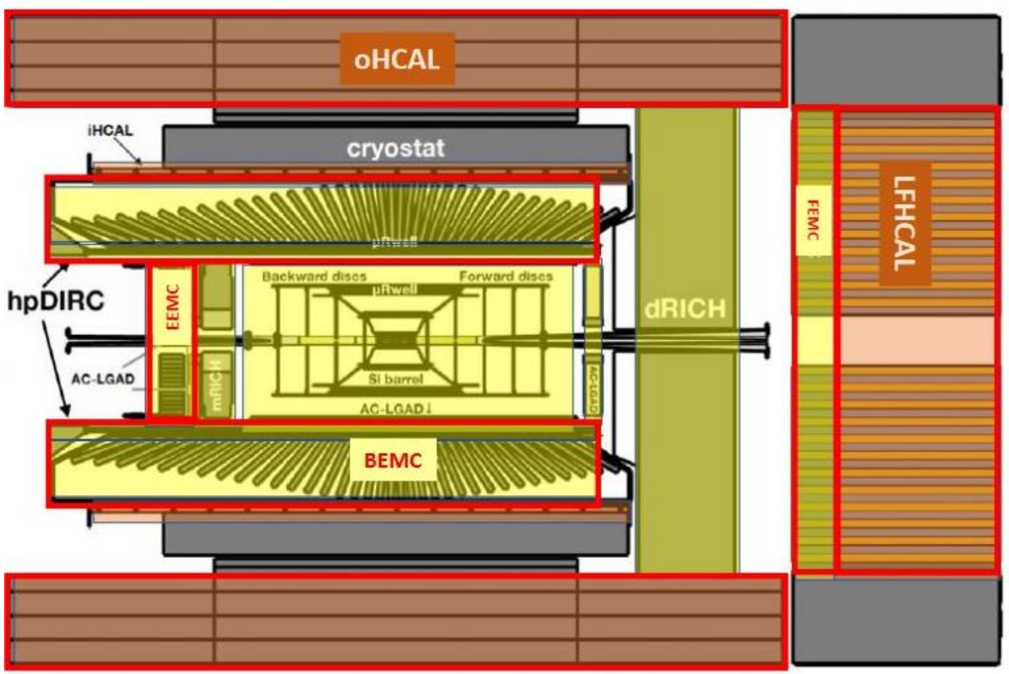
BEMC



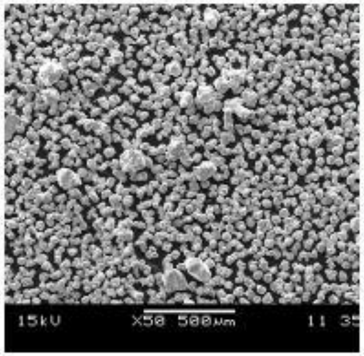
LFHCAL

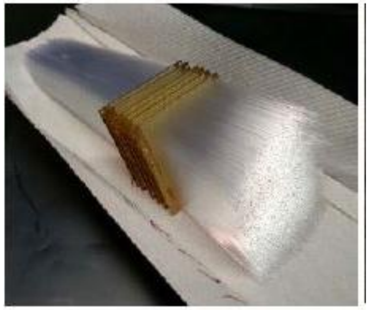






FEMC

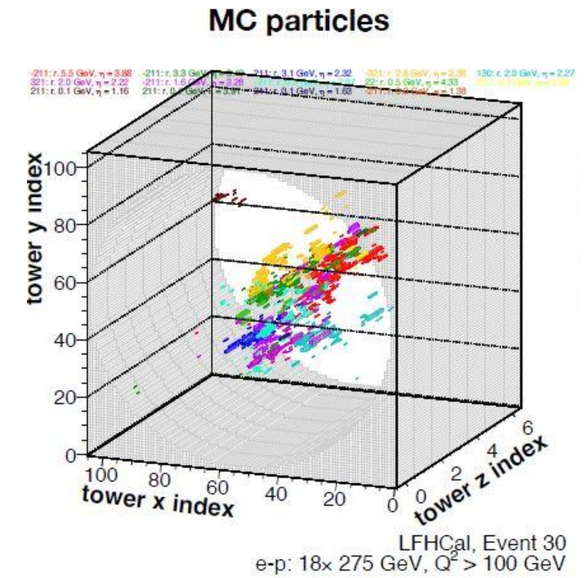


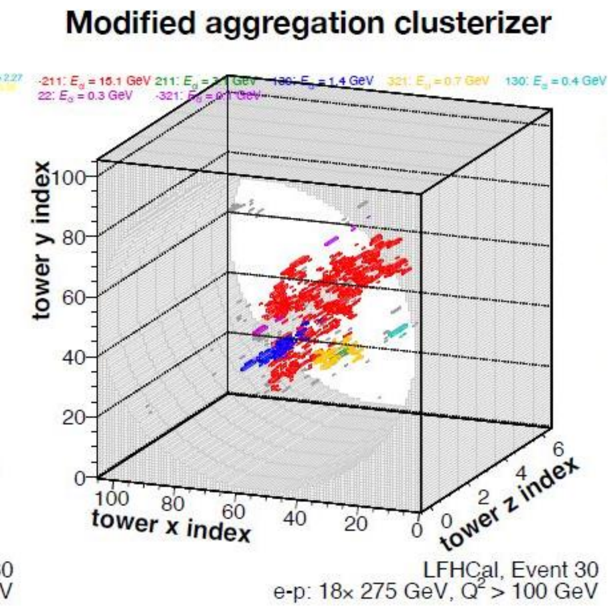


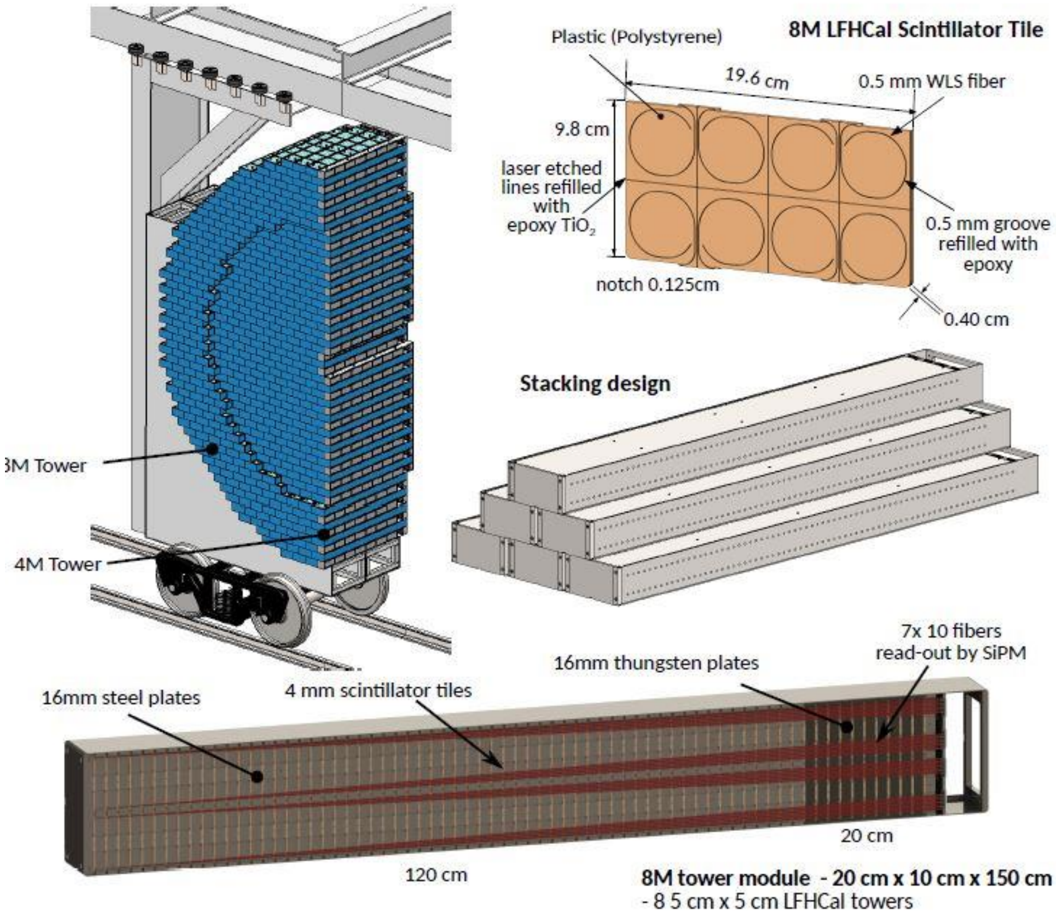
EEMC

The LFHCAL forward hadronic calorimeter for the EPIC detector at the EIC
Norbert Novitzky

LFHCAL : Highly segmented calorimeter
Allows detailed analysis of shower development



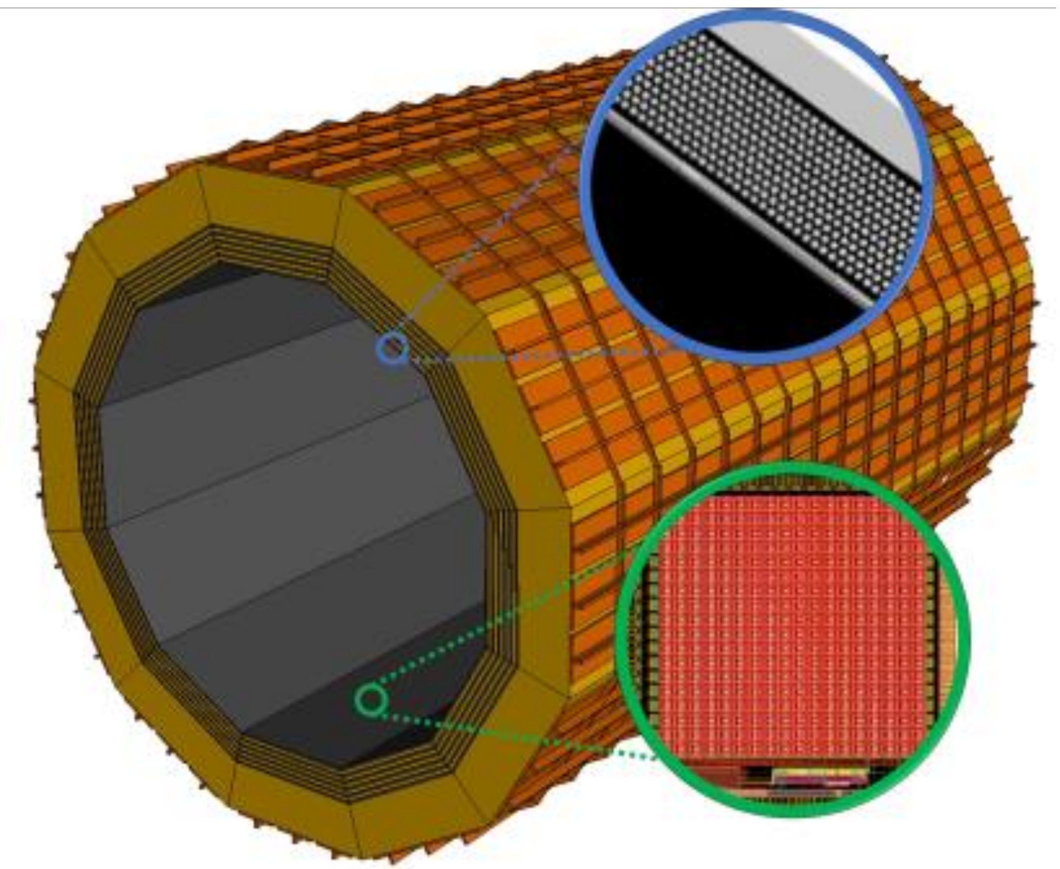


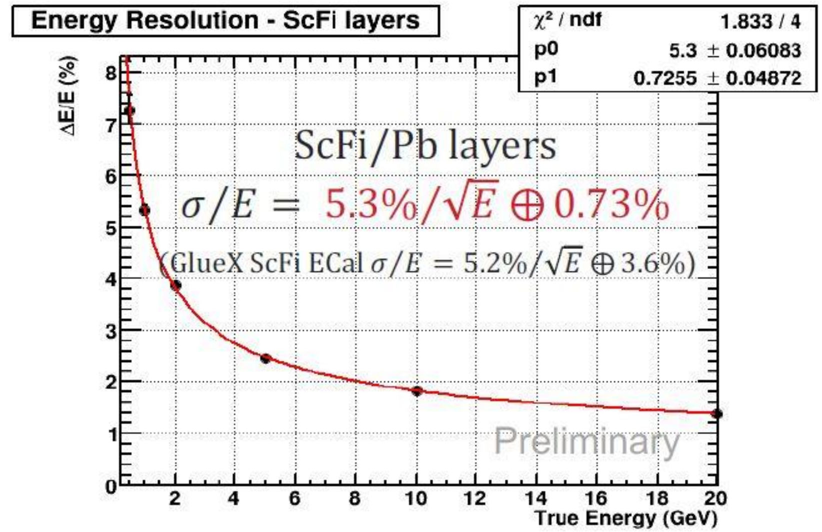


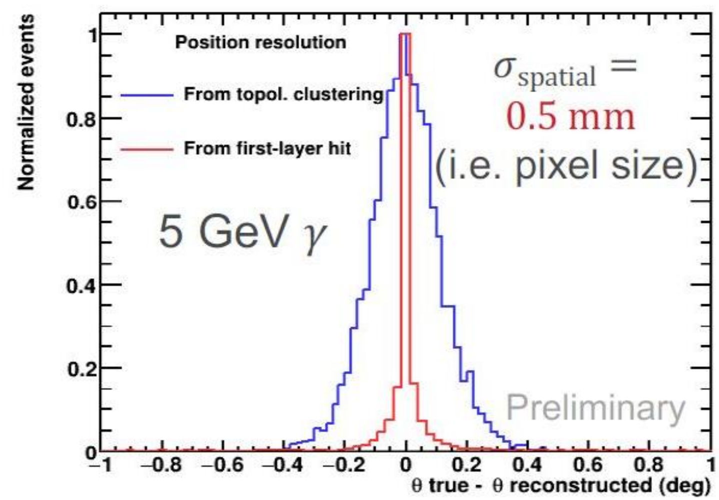
arXiv:2207.09437

Design Concept of Imaging Barrel Electromagnetic Calorimeter for the Electron-Ion Collider
Jihee Kim

Alternative desgin for ePIC barrel calorimeter
Reusing pixelated sensor for postion determination

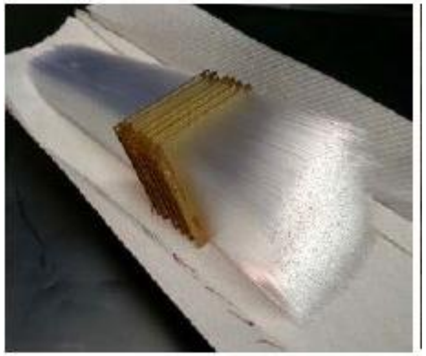


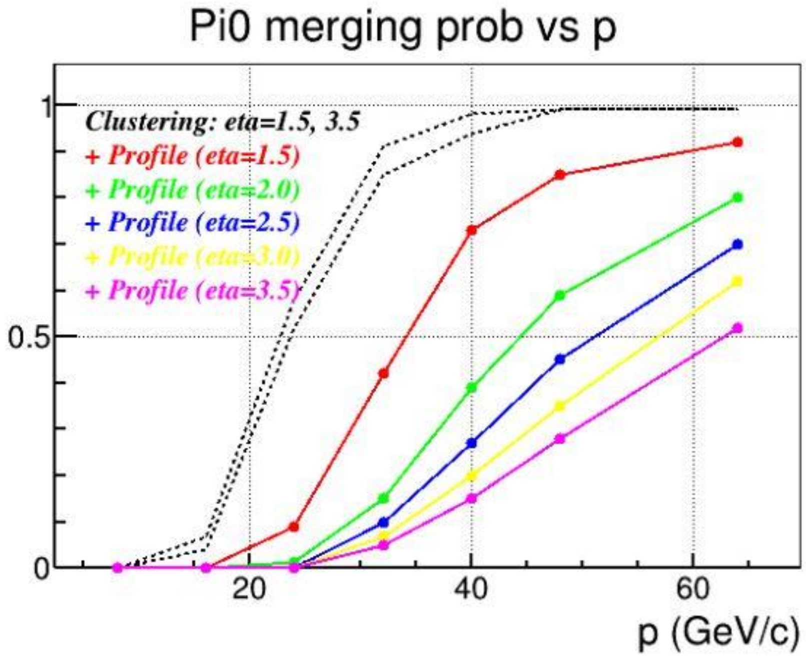




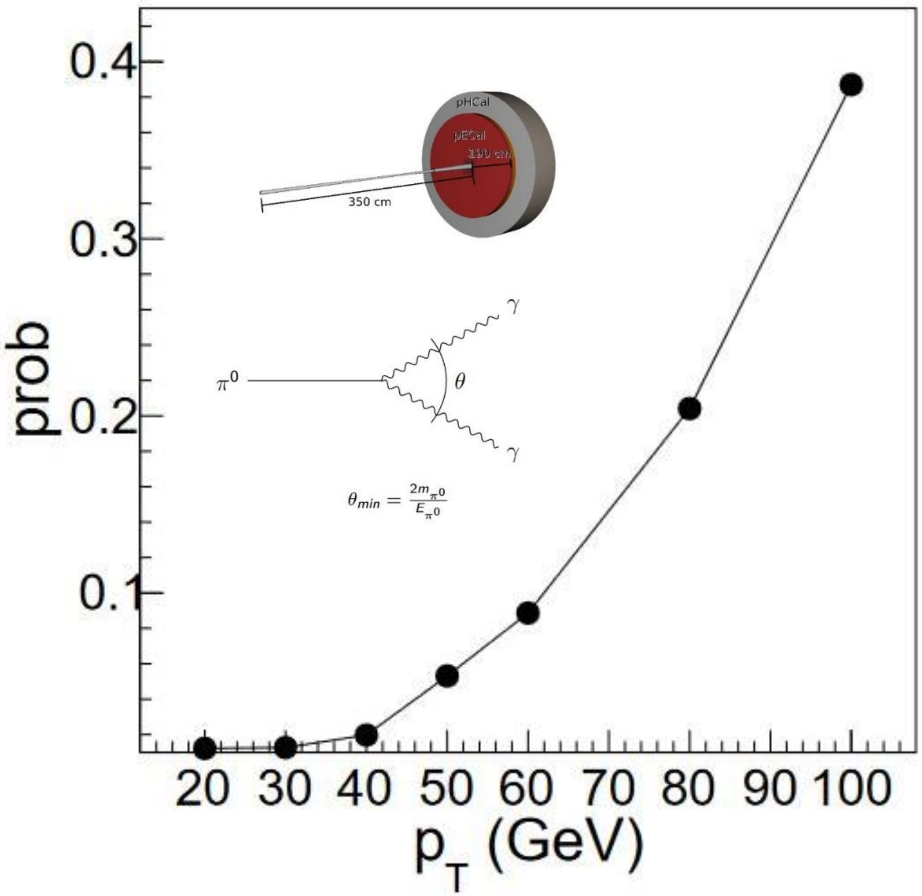
Proton endcap ElectroMagnetic Calorimeter Design and Simulation
Jongling Ji

- Simulation of π^0 separation capabilites
- Comparing various calorimeter variants, show is choice for ePIC detector





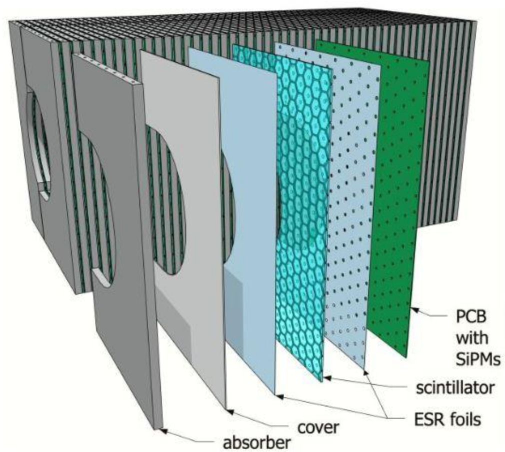
π^0 merging probability - Simulation

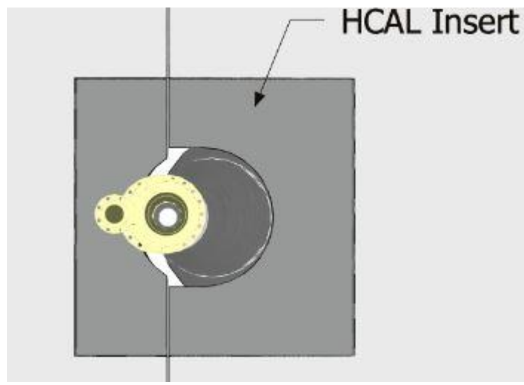


A high-granularity calorimeter insert based on SiPM-on-tile technology for the EIC

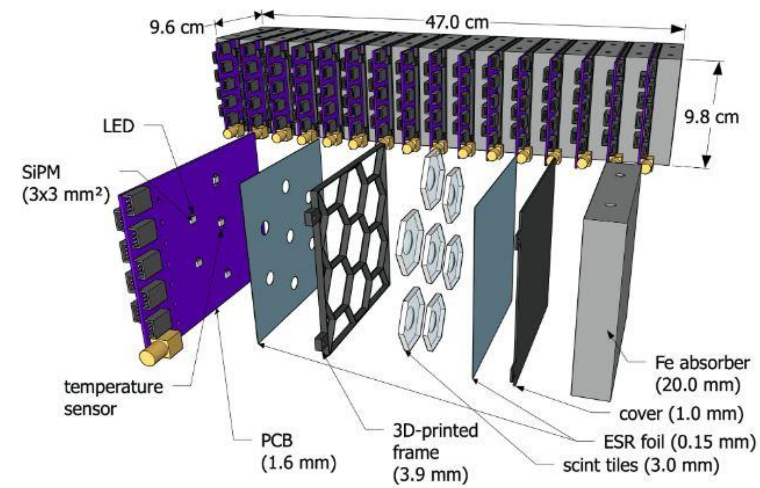
Miguel Arratia

Calorimeter insert surrounding the forward beam pipe

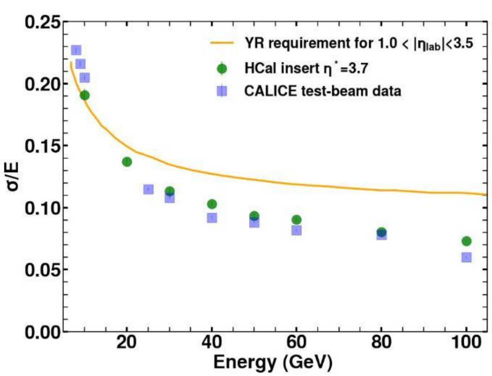




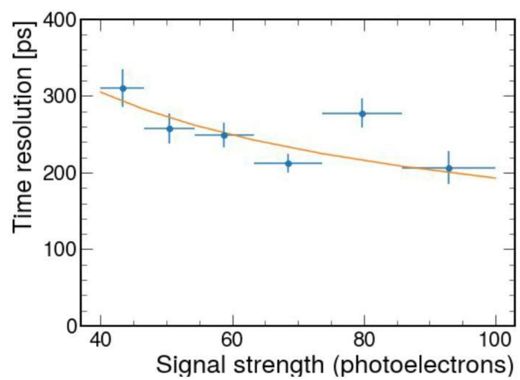
tc.

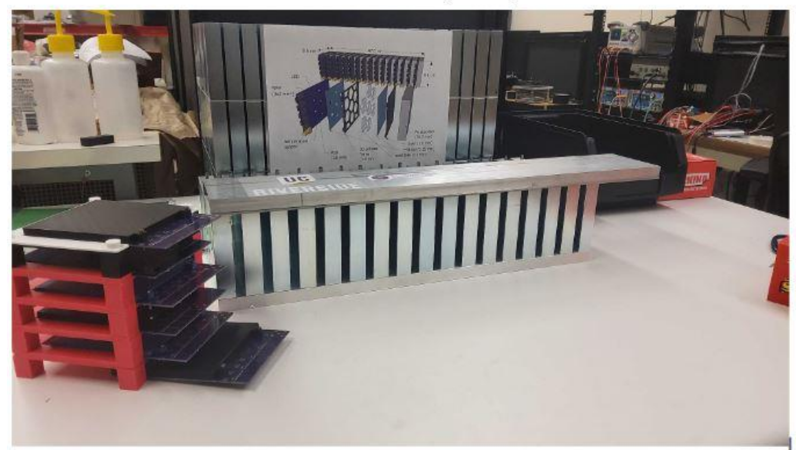


Expected Energy Resolution



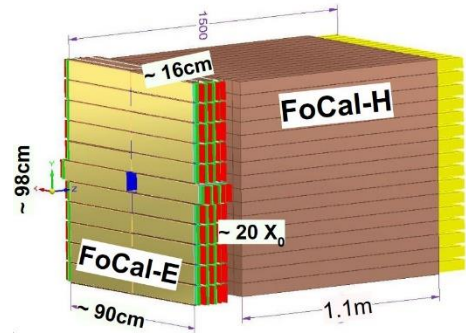
MIP timing resolution 250 ps

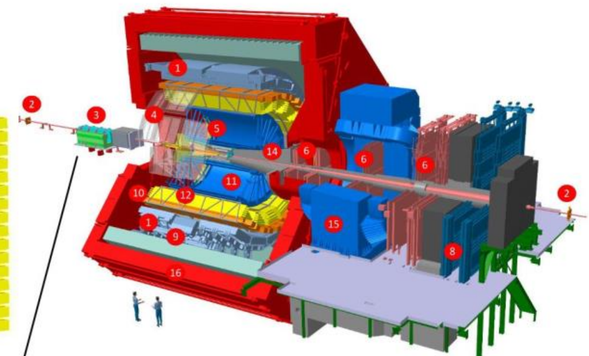




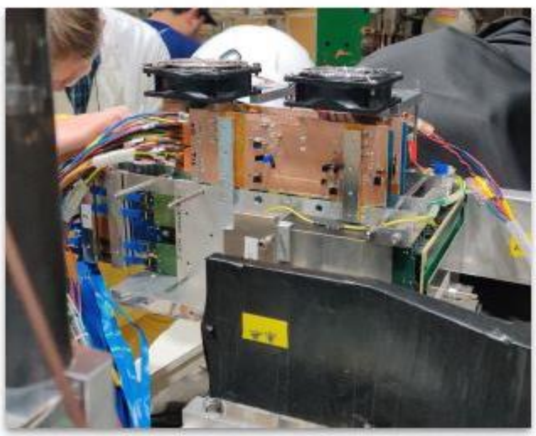
The FoCal detector at the ALICE experiment
Tommaso Isidori

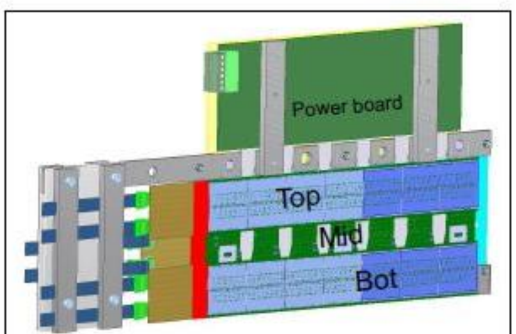
Part of ALICE upgrade (starting 2029)
Molier radius of the calorimeter is 1 cm – spatial resolution of pixels much better.





Test Beam results - FoCal-E pixels

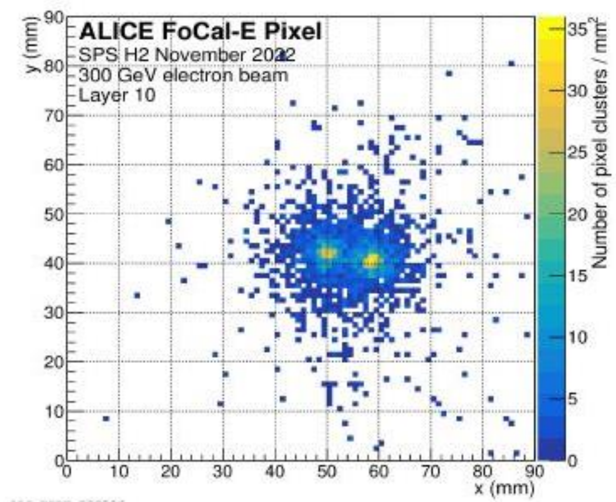


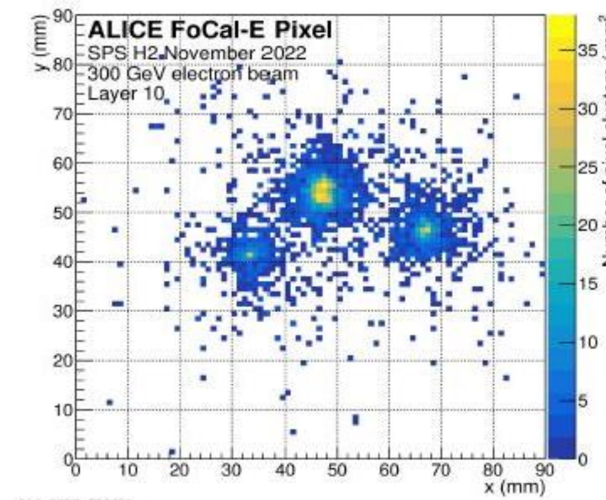


Successful commissioning of the HICs

| Global hitmaps monitored using O2 QC

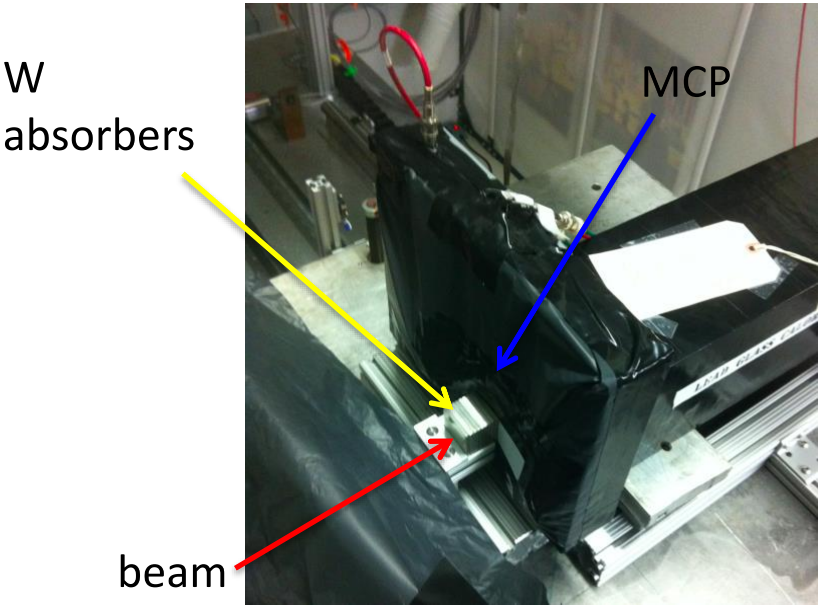
| Double and triple electron signature identified in preliminary analysis

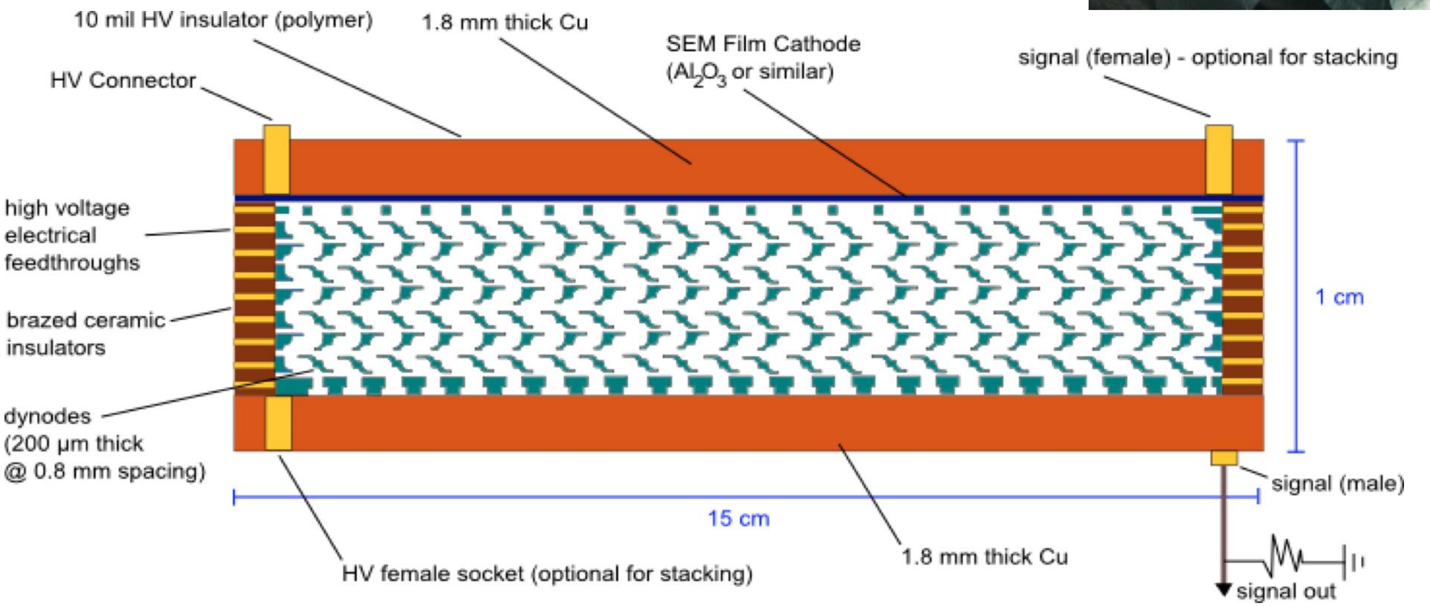




Secondary Emission Calorimetry
David Winn

- Secondary emission calorimetry provides potentially very fast and radiation hard calorimetry option.
- Beam tests with conceptual setups demonstrate prove of principle.
- Beam tests with MCP demonstrate very fast timing response.

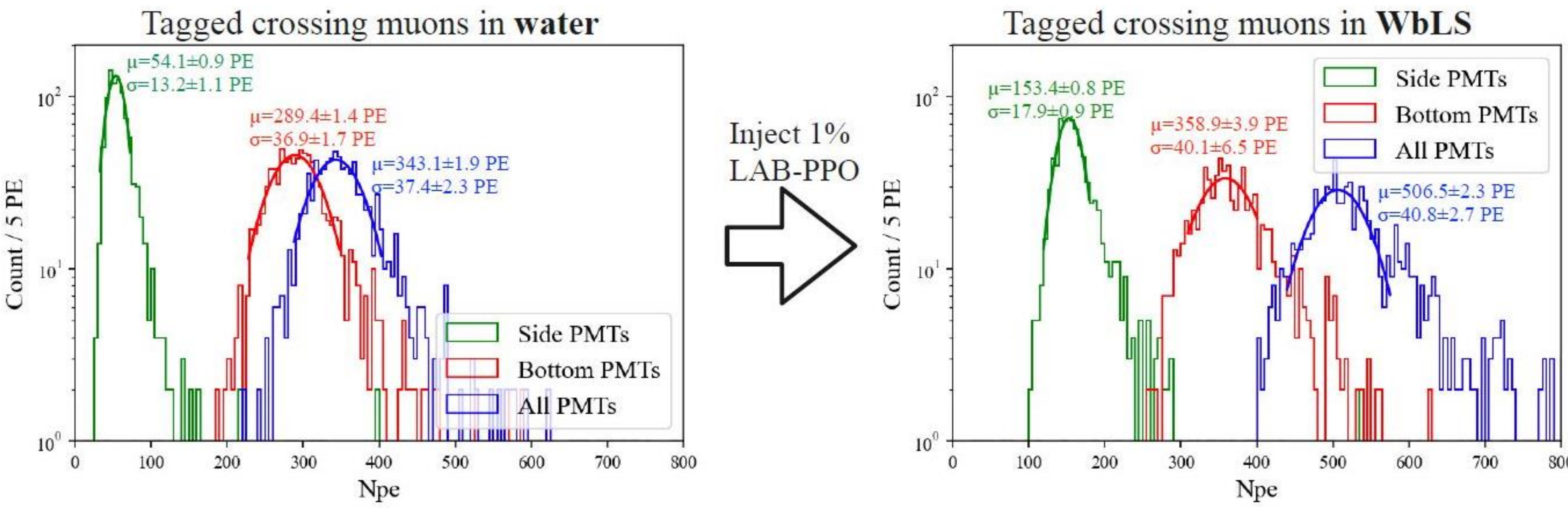




Status and Results of the Water-based Liquid Scintillator R&D facility at Brookhaven National Lab

Xin Xang

- Improvement of light yield with WbLS measured.
- Improved scintillation and Cherenkov component



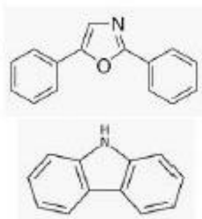
- Much enhanced light production from the tagged crossing muons with merely 1% injection of LAB-PPO.
- Data is consistent with scintillation LY of ~100-200 pe/MeV
- Detailed analysis of light yield is in progress (to account for reflections, and attenuation using a detailed *ratpac* MC).

Eos: a prototype for next-generation neutrino detectors
Gabriel Orebi Gann

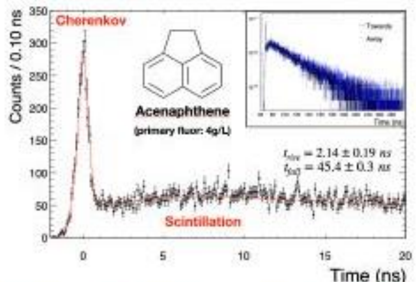
- Customizing time constants of scintillators to optimize detector peformance
- Optical decoupling of scintillation and Cherenkov components

Engineering WbLS properties: Bourret (LBNL)

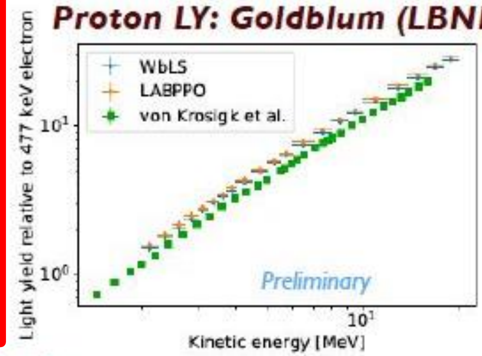
Example:
slowing down decay time
- Standard PPO → 2ns
- New carbazole → 15ns



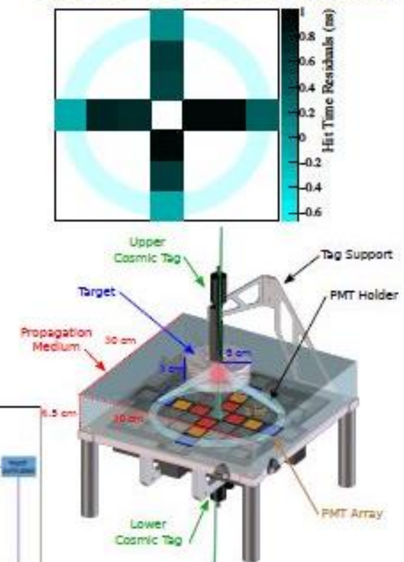
Slow LS: Oxford, Mainz



Proton LY: Goldblum (LBNL)



CHESS detector: LBNL

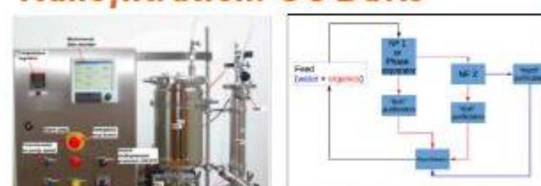


Extensive international effort in Germany (Mainz, Munich), UK, China

Additional work on: slow LS, alternative fluors, alternative surfactants

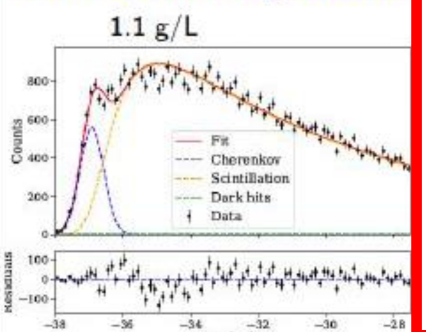
Scattering & attenuation: UC Davis, UC Berkeley+LLNL

Nanofiltration: UC Davis

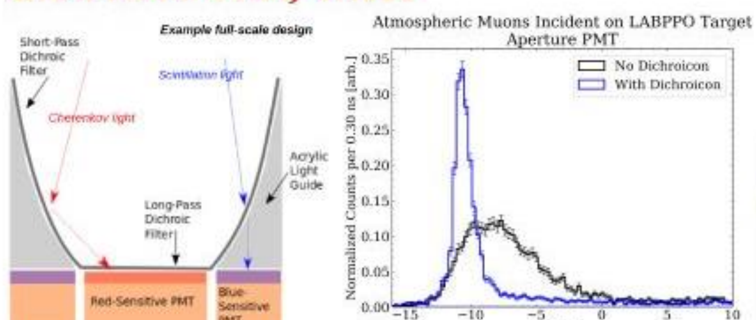


Preliminary design for a two-staged nanofiltration concept for large scale WbLS purification.

LAPPDs: ANNIE, CHESS



Dichroicon: Penn, CHESS

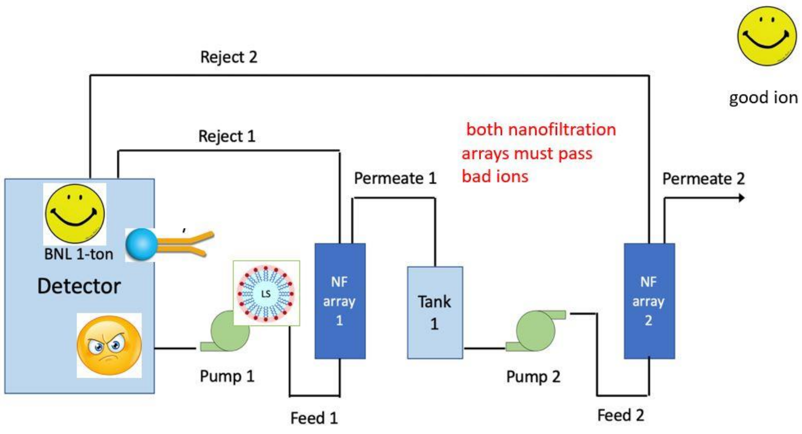


NIMA 889 69 (2018); JINST 14 T05001 (2019); Phys. Rev. D 105 (7) 2022; Phys. Rev. C 95 055801 (2017); Eur. Phys. Jour. C 80 867 (2020); Mat. Adv. 1 71 (2020); Eur. Phys. Jour. C 82 169 (2022); NIMA 947, 162604 (2019); arXiv:1902.06912; JINST13 P07005 (2018); JINST9 P06012 (2014); NIMA 943 162420 (2019); Eur. Phys. Jour. C 77 811 (2017); arxiv:1908.03564; arXiv:1502.01132; arXiv:1707.08222; NIMA 972 164106 (2020); Astropart. Phys. 109 33 (2019); NIMA 852 15 (2017); NIMA 712 162 (2013); Phys. Rev. D 97 052006 (2018); JINST14 I (2019); Phys. Rev. D 101 072002 (2020); arXiv:2006.00173

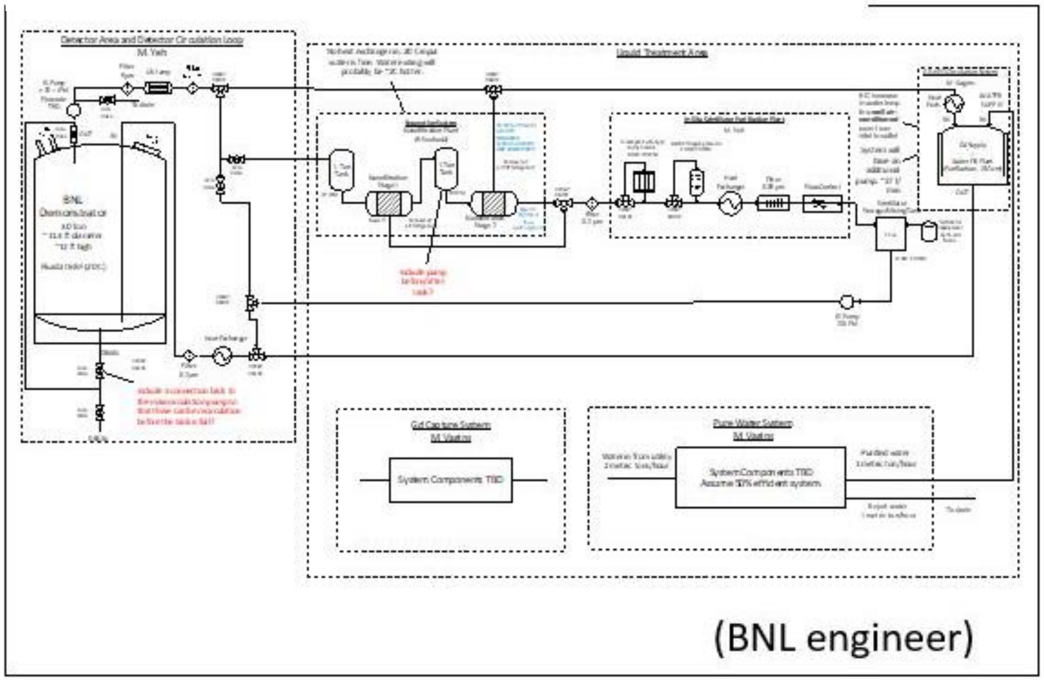
SLIPS concept: Oxford, UK

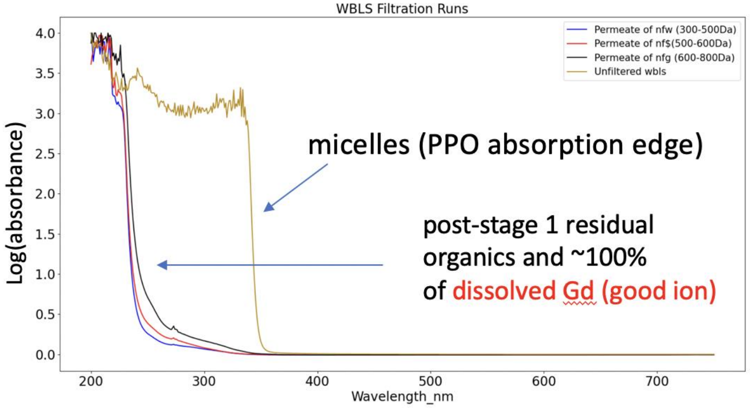
Removing optical and radiological contaminants from Water-based Liquid Scintillator
Robert Svoboda

- Practical implementation of a WbLS detector requires careful control of LS and contaminations.
- Method established, scaling up of demonstrator setup.

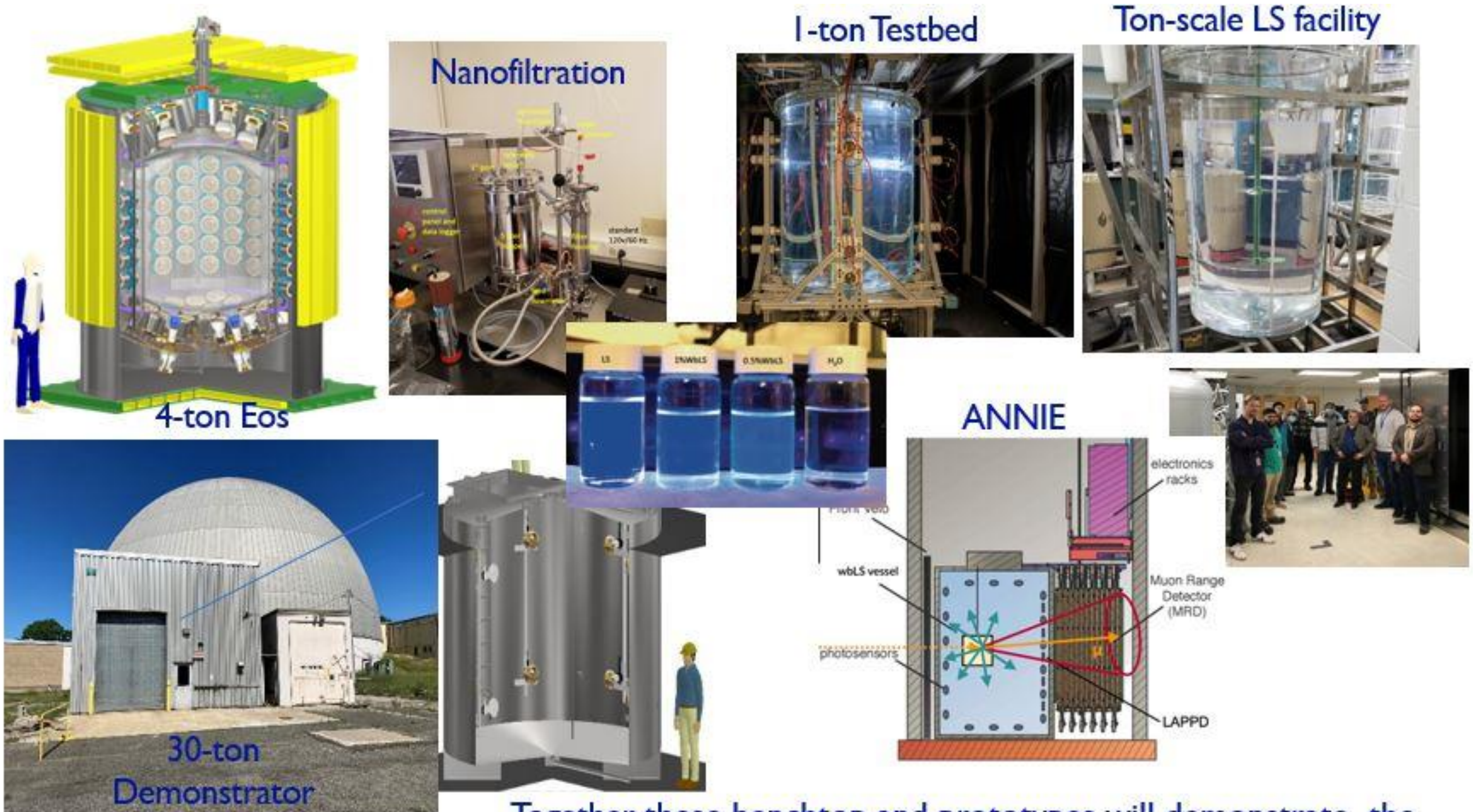


(university physicist)





Scaling up WbLS detector demonstrators



Together these benchtop and prototypes will demonstrate the feasibility and capabilities of hybrid detectors for fundamental physics

Adding new detection channels

- Electron antineutrinos can be detected in scintillators using using inverse beta decay
  - Electron antineutrinos interact with hydrogenous materials
  - Neutron can then be captured using a dopant with a high neutron capture cross section
    - ^{6}Li, ^{10}B, Gd
- ^{6}Li is an ideal candidate
  - Recent formulations makes it relativity simple to added to a scintillator
  - Reaction products do not experience lower scintillation quenching compared to ^{10}B
- Metal loading also possible
  - Bismuth loading for improved gamma-ray sensitivity
- *Other interesting dopants???*

$$\overline{\nu_e} + p^{+} \rightarrow e^{+} + n$$

Prompt (e^{+})

Delayed: $^{6}Li(n,t)^{4}He$

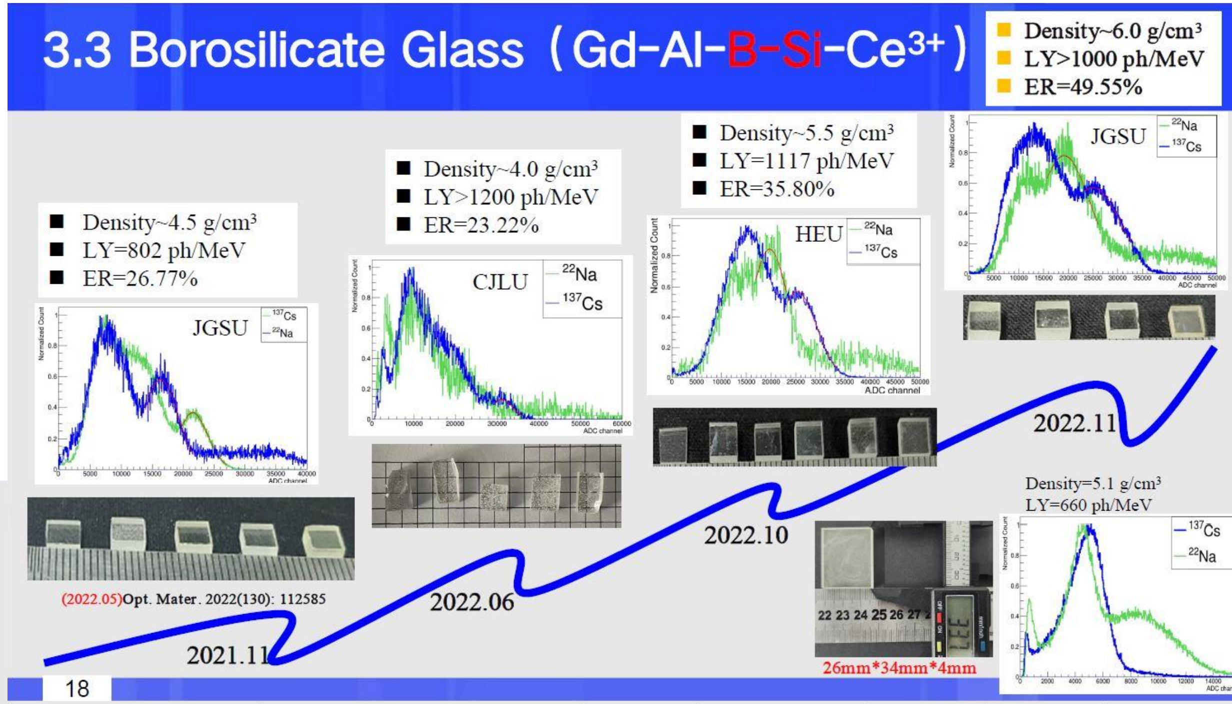
Standard light curable | Bismuth - loaded

12 OAK RIDGE National Laboratory

The R&D of the New Glass scintillator with high density and high light yield

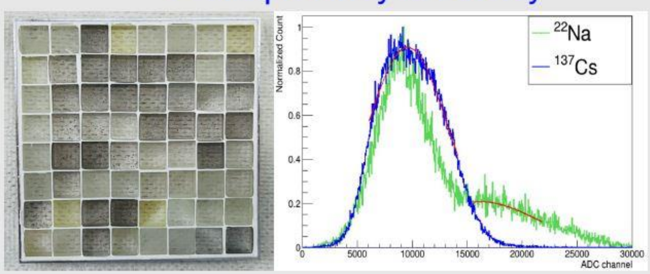
Sen Qian

- R&D on glass scintillators for future experiments very promising.
- Improving LY and density.
- Working with industry to explore mass production.
- See also table in RYZ talk p19.



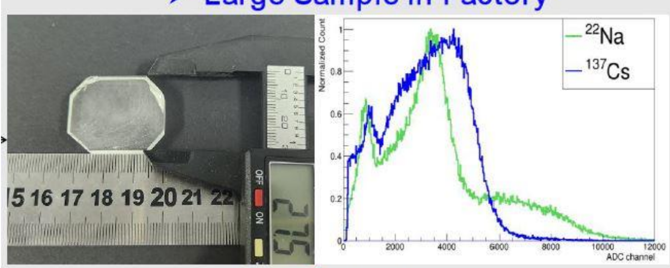
Typy	Composition	Density (g/cm³)	Light yield (ph/MeV)	Decay time (ns)	Emission peak(nm)	Price/1 c.c（RMB）
Glass Scintillator in Paper	Ce-doped high Gadolinium glass[1]	4.37	3460	522	431	~10
	Ce-doped fluoride hafnium glass[2]	6.0	2400	23.4	348	150
Plastic Scintillator	BC408[3]	~1.0	5120	2.1	425	60
	BC418[3]	~1.0	5360	1.4	391	80
Crystal	GAGG:Ce[4]	6.6	50000	50	560	2400
	LYSO:Ce[5]	7.1	30000	40	420	1200
	BGO[6]	7.3	8000	300	480	800
Glass Scintillator for CEPC（preliminaryl target）	?	>7	>1000	<100	350-500	~1
Stuaus of Glass Scintillator	?	>6	>1000	<200	350-500	~?

➢ Sample Array in Factory



LY=346 ph/MeV

➢ Large Sample in Factory

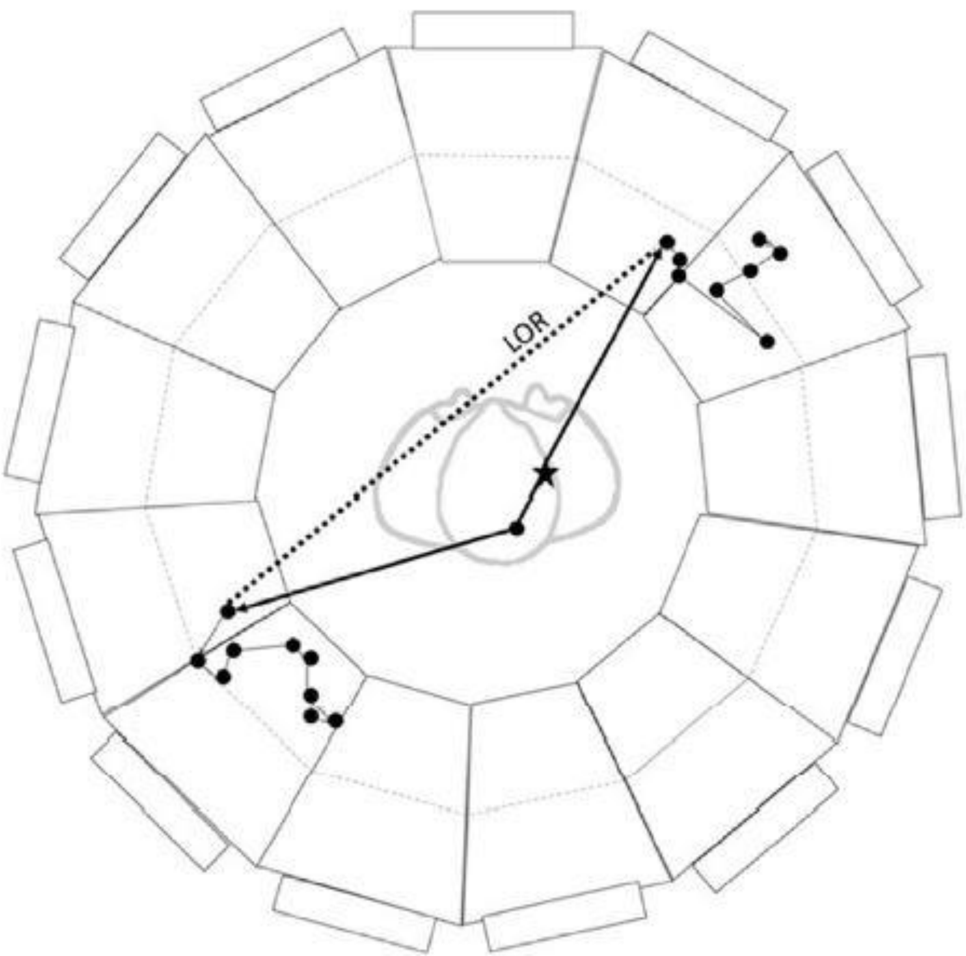


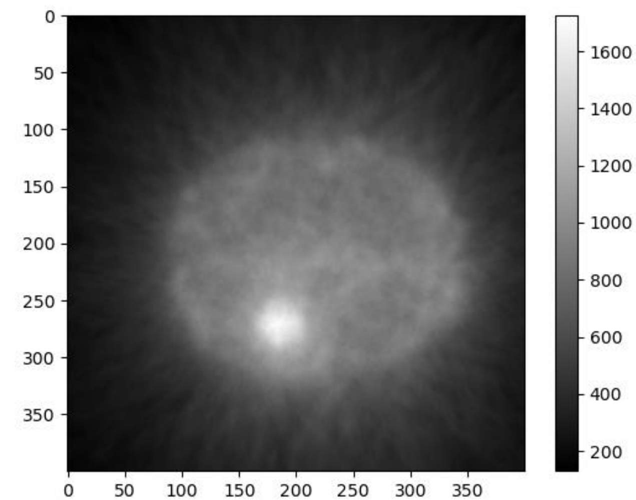
LY=466 ph/MeV

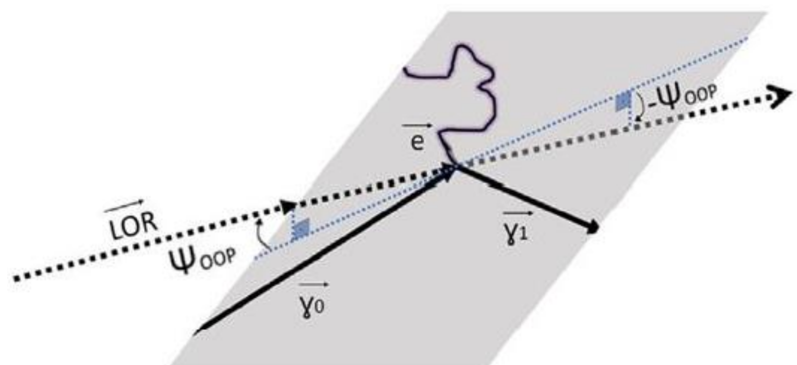
A TOPAS Simulation of Low-Dose High-Resolution Low-Z-Medium Whole-Body TOF-PET
Kepler Domurat-Sousa

- Improve PET scanner performance by better measurement of the vertex.
- Conceptually very relevant for precision timing in collider experiments.

Assumed performace : 100 um spatial resolution, 1 switched dye molecule per keV, and 212 ps time resolution (500 ps FWHM)
required dose 1/1000 of current PET







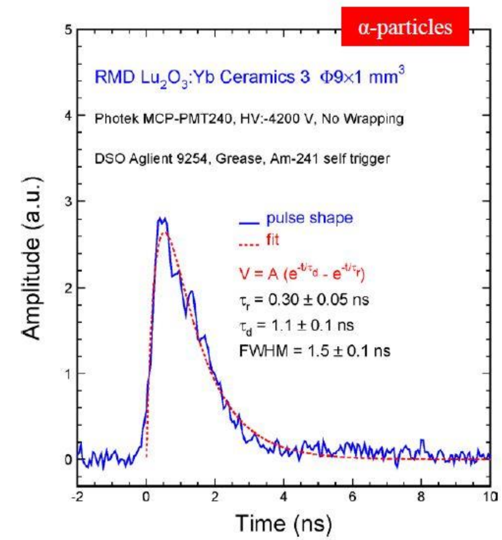
Recent Progresses of Inorganic Scintillators for Future High Energy Physics Experiments

Renyuan Zhu

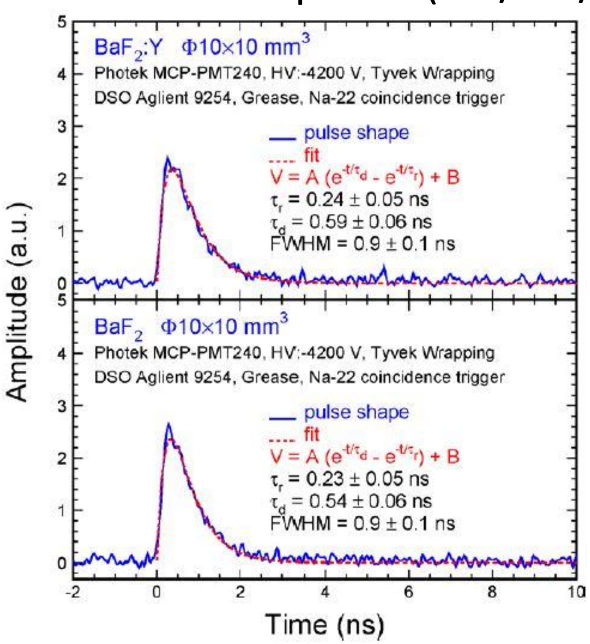
	BaF_2	BaF_2:Y	Lu_2O_3:Yb	YAP:Yb	YAG:Yb	ZnO:Ga	β-Ga_2O_3	LYSO:Ce	LuAG:Ce	YAP:Ce	GAGG:Ce	LuYAP:Ce	YSO:Ce
Density (g/cm^3)	4.89	4.89	9.42	5.35	4.56	5.67	5.94	7.4	6.76	5.35	6.5	7.2[f]	4.44
Melting points (°C)	1280	1280	2490	1870	1940	1975	1725	2050	2060	1870	1850	1930	2070
X_0 (cm)	2.03	2.03	0.81	2.59	3.53	2.51	2.51	1.14	1.45	2.59	1.63	1.37	3.10
R_M (cm)	3.1	3.1	1.72	2.45	2.76	2.28	2.20	2.07	2.15	2.45	2.20	2.01	2.93
λ_I (cm)	30.7	30.7	18.1	23.1	25.2	22.2	20.9	20.9	20.6	23.1	21.5	19.5	27.8
Z_{eff}	51.0	51.0	67.3	32.8	29.3	27.7	27.8	63.7	58.7	32.8	50.6	57.1	32.8
dE/dX (MeV/cm)	6.52	6.52	11.6	7.91	7.01	8.34	8.82	9.55	9.22	7.91	8.96	9.82	6.57
λ_{peak}[a] (nm)	300 220	300 220	370	350	350	380	380	420	520	370	540	385	420
Refractive Index[b]	1.50	1.50	2.0	1.96	1.87	2.1	1.97	1.82	1.84	1.96	1.92	1.94	1.78
Normalized Light Yield[a,c]	42 4.8	1.7 4.8	0.95	0.19[d]	0.36[d]	2.6[d] 4.0[d]	6.5 0.5	100	35[e] 48[e]	9 32	190	16 15	80
Total Light yield (ph/MeV)	13,000	2,000	280	57[d]	110[d]	2,000[d]	2,100	30,000	25,000[e]	12,000	58,000	10,000	24,000
Decay time[a] (ns)	600 0.5	600 0.5	1.1[d]	1.1[d]	1.8[d]	3.0[d] 1.0[d]	110 5.3	40	820 50	191 25	570 130	1485 36	75
LY in 1st ns (photons/MeV)	1200	1200	170	34[d]	46[d]	980[d]	43	740	240	391	400	125	318
LY in 1st ns /Total LY (%)	9.0	64	60	60	43	49	2.0	2.5	1.2	3.3	0.7	1.4	1.3
40 keV Att. Leng. (1/e, mm)	0.106	0.106	0.127	0.314	0.439	0.407	0.394	0.185	0.251	0.314	0.319	0.214	0.334

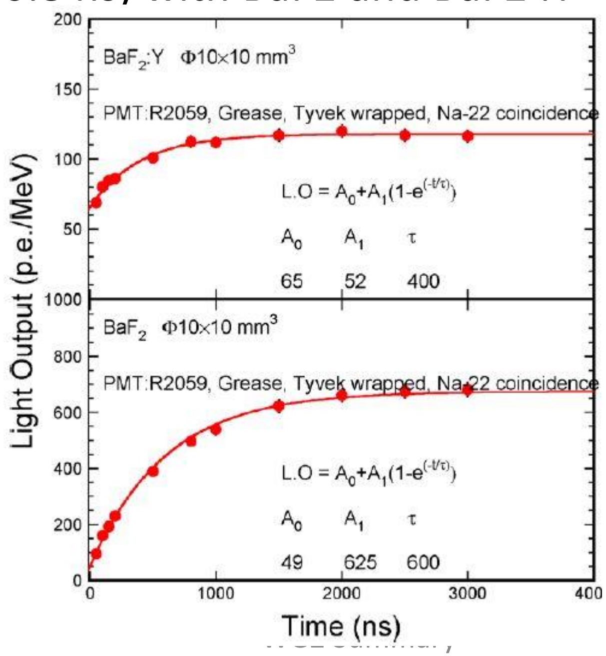
[a] top/bottom row: slow/fast component; [b] at the emission peak; [c] normalized to LYSO:Ce; [d] excited by Alpha particles; [e] 0.3 Mg at% co-doping; [f] $Lu_{0.7}Y_{0.3}AlO_3$:Ce.

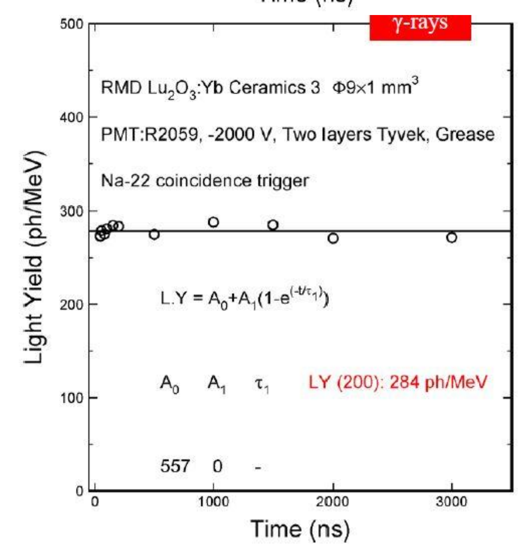
Lu2 O 3 :Yb (9.4 g/cc) shows an ultrafast decay time of 1.1 ns with negligible slow component



Ultrafast response (0.2/0.6/0.8 ns) with BaF2 and BaF2 :Y



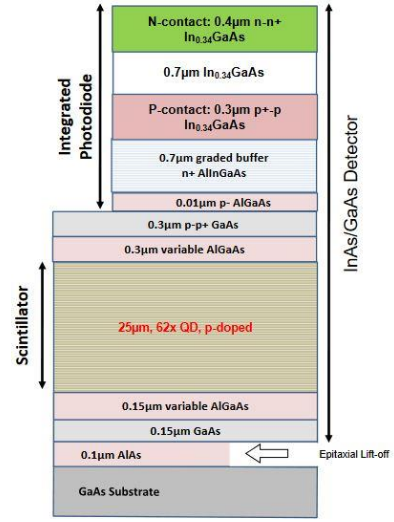


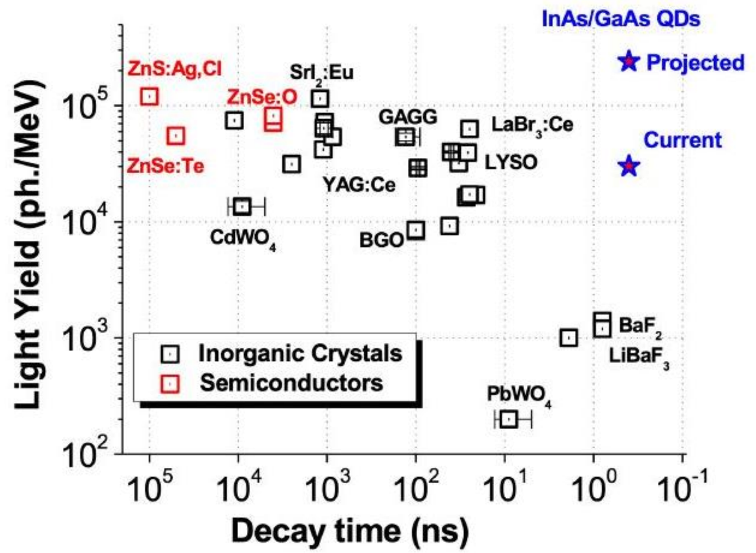


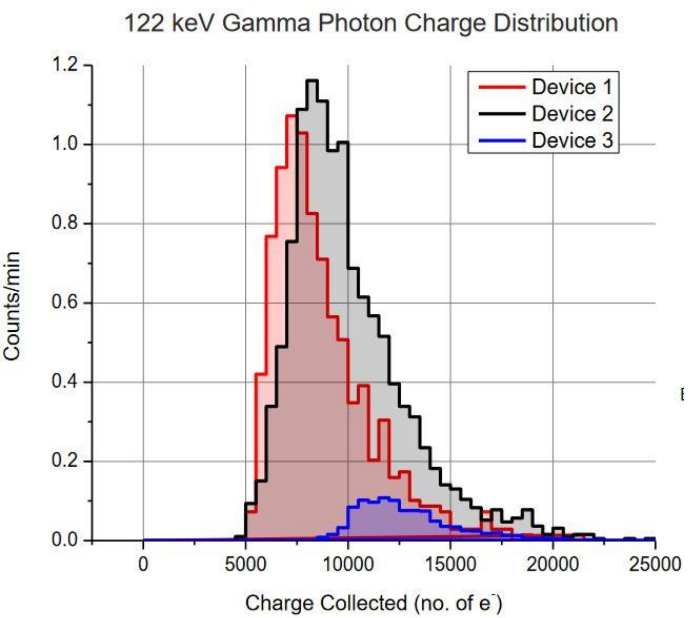
Study of the Properties of Quantum Dot InAs/GaAs

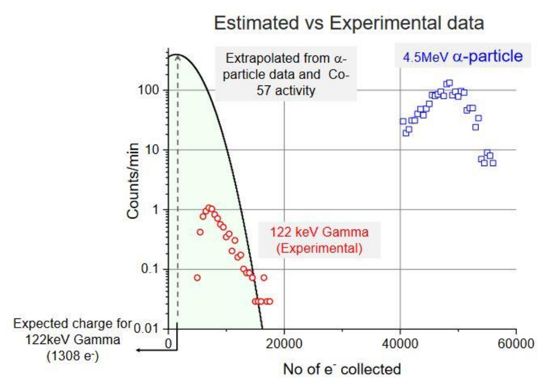
Tushar Deepak Mahajan

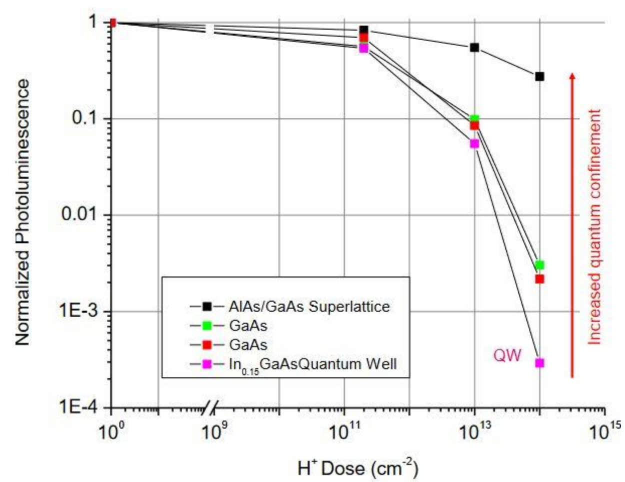
- GaAs QD scintillator :
- Very large light yield
- Integrated design
- Radiation hardness











Summary

- Calorimeters become 5D detectors – measuring energy, postion and time.
- Wide range of activities to achieve this goal : Combining technologies, uzing proven technologie and enhance with new approaches.
- New materials, production methods and adopting technologies from industry.
- I learned a lot.