12 GeV Upgrade
Future Science at Jefferson Lab

EC and SPD Updates

The SoLID EC Working Group

SoLID Collaboration Meeting

Jan. 7-8, 2021

Outline

1. Overview of Ecal shashlyk prototypes status
2. Fiber and light connection status
3. Current status of light yield and contribution to energy resoltuion
4. FTBF test status

Shashlyk prototype and light yield overview

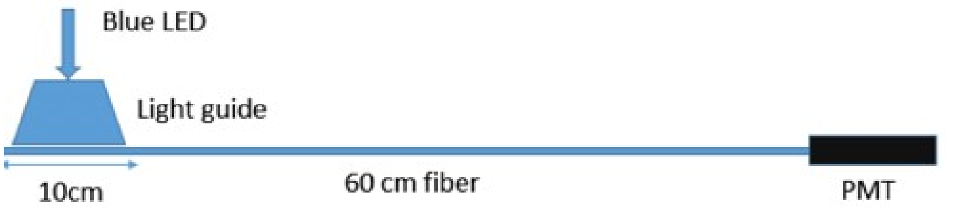
Proto-type	scintillator	lead	reflective layer	WLS fiber	WLS fiber end	module side	cosmic vertical test Npe	cosmic horizontal test Npe	PMT gain method
SDU1	Kedi original	US	printer paper	BCF91A (SC)	none	Tyvek→ TiO_2	254	48	SPE/SDU
SDU2	Kedi new	Chn	printer paper	BCF91A (SC)	Chn silver-plating	Tyvek→ TiO_2	383	83	SPE/SDU
SDU3	Kedi new	US	printer paper	Y11(200) (MC)	Chn silver-plating	TiO_2+glue (1/1)	450	108	SPE/SDU
SDU4	Kedi new	Chn	Powder paint	BCF91A (SC)	ESR	TiO_2+glue+ water	562		SPE/SDU
SDU5	Kedi new	US	Tyvek (0.145mm)	BCF91A (SC)	ESR	BCF91A (SC)	398		SPE/SDU
SDU6	Kedi new	Chn	ESR	Y11(200) MC	ESR (individual)	TiO_2+glue	813		SPE/SDU
THU1	Kedi original	Chn	mirror mylar (reflective)	Y11(200) MC	Italian silver shine	TiO2 (Kedi)	430-470	96	not measured
THU2	Kedi new	Chn	powder paint (diffusive)	BCF91A-SC	Italian silver shine	Tyvek wrapping	748 → 570*	90-103	SPE/IHEP
THU3	Kedi new	Chn	Powder paint	BCF91A-MC					

*re-tested at SDU with better-understood PMT gain

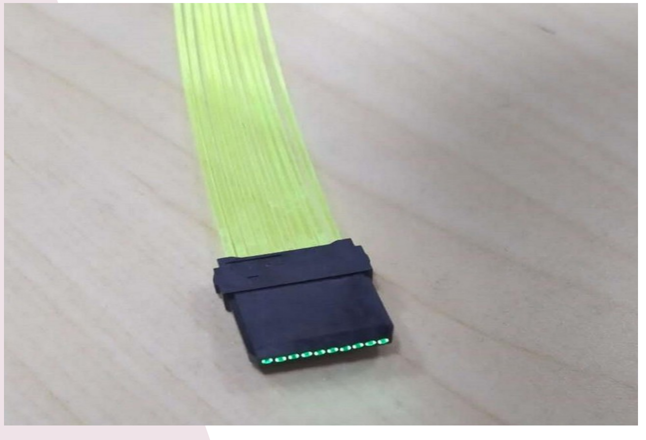
Fiber Status

- In August, met with Saint-Gobain to discuss WLS and clear fiber issues.
- "faulty" BCF91A-MC fiber has been replaced and tested by SDU, now showing 25% higher light yield than BCF91A-SC as expected (note: Y11-MC is 46% higher). Fiber diameter is 1.06mm (vs. 1.00m of SC fibers), but should not be a problem for assembling.

Fiber type	ADC channel
BCF91A-SC	2588
BCF91A-MC faulty	2577
BCF91A-MC new	3219



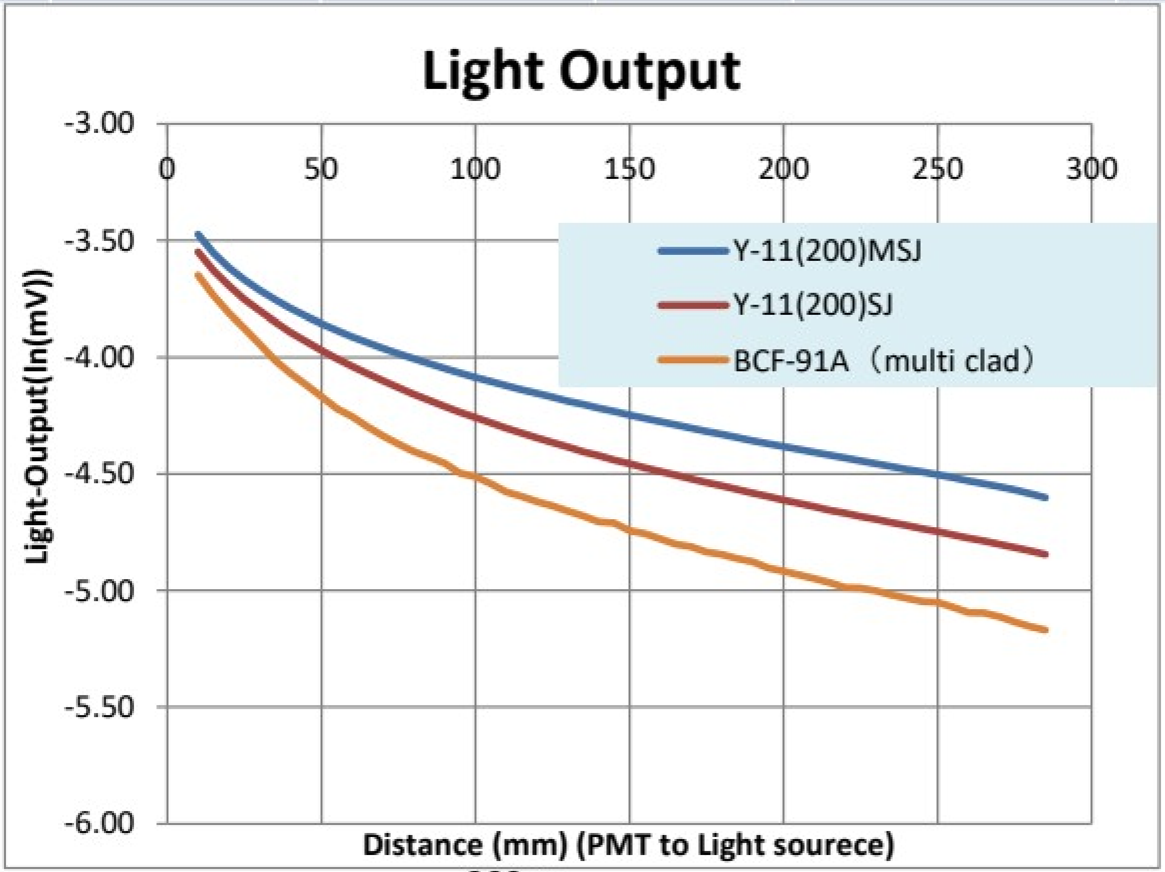
- Chunhui PMMA fiber tested by SDU with attenuation length ~20m, but **radiation hardness is questionable.**
- DDK fibre connectors tested by SDU repeatedly, ~22% light loss, small variation depending on polishing quality.

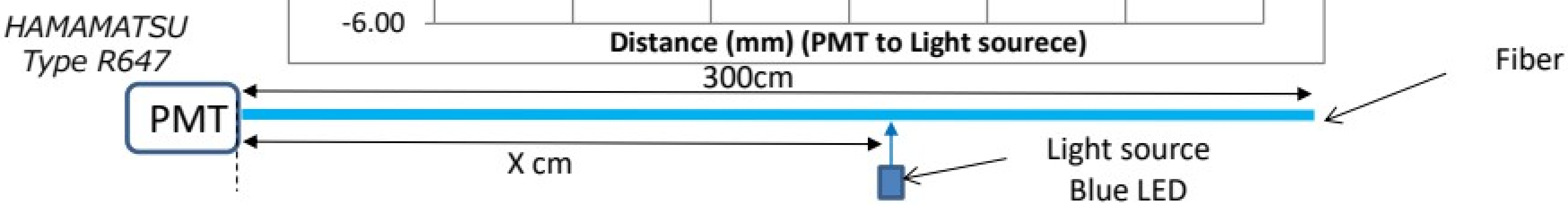


Chunhui PMMA fiber

Comparison Y-11 and BCF-91A

	Clad type	Diameter(mm)	ATT.L(cm)	V_10cm (mV)	V_285cm (mV)
Y-11(200)MSJ	Multi	1.0	373	30.9	10.0
Y-11(200)SJ	Single	1.0	328	28.7	7.9
BCF-91A	Multi	1.0	296	26.0	5.7





Some discussions with Raytum Photonics

- Suggested using liquid light guide. Large ones (11mm in dia) is not commercially available but some companies may be interested in developing it → Chunhui/SDU, see next slide
- Raytum will get some DDK connector samples and study the polishing technique. However, polishing for SoLID is technically tedious and we do not know how much they will charge us.

Some discussions with Chunhui (through SDU)

- Confirmed they also have two types of clear fibers:
  - PS-core: loss 25%/m, radiation hardness is “good”;
  - PMMA-core: ligh loss 5%/m, radiation hardness is “normal”;
  - Both types are single-cladding from Chunhui

- Willing to develop two methods. The light loss for both plans are expected to be worse than our current DDK connector method (but may reduce manpower cost of polishing 97 fibers)
  - All 97 WLS fibers from a module to a lens then → 2-3mm diameter fiber;
  - All 97 WLS fibers from a module to a liquid light guide.

Shashlyk Prototype Modules – Light yield analysis and plan

- Best light yield is SDU6, 800 p.e. with Y11(200)MC; scale to 680 p.e. for BCF91A-MC (so far SoLID cost estimate is using BCF91A-MC);
- With 800 p.e. for cosmic (~60MeV), scaling up to 1 GeV electron with 20% sampling ratio gives 2666 p.e./GeV electron. Compare to LHCb 2.6-3.5 p.e./MeV, 4-4.4p.e./MeV;
- Using BCF91A-MC we expect 2265 p.e./GeV.
- Adding factor of 2-3 for light loss to PMT (fiber connector 25% and 1.5m=71%*0.75=0.53, 2.5m=57% *0.75=0.43, 3.5m=46% *0.75=0.35 clear fiber of type BCF98, with attenuation length 4.5m), we get 1/sqrt(1333)=2.7% or 1/sqrt(888)=3.4% contribution to energy resolution due to photon statistics. This is pushing the margin considering the intrinsic resolution is (5-6)%. Ideally the effect of photoelectron statistics should be negligible. – simulation needed to study impact on PID/triggering

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- LHC collaboration contacted me for our method of light readout under high radiation…
- Ultimately depends on the current energy resolution of the modules → see FTBF test

- Consider other vendors – CERN tested Kuraray PSM clear fiber to have 8m attenuation (vs. BCF98's 4.5m); Y11(200)SC has higher light yield than BCF91A-MC

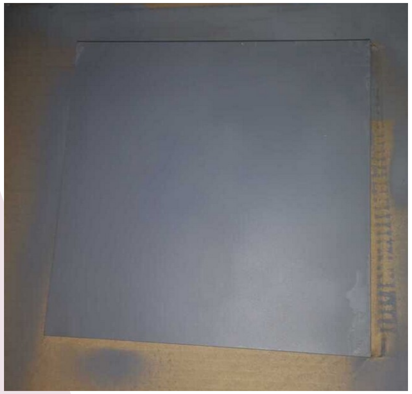
- ?? Would like to order 8 IHEP prototypes to (1) measure their light yield; (2) study their material and structure; but need funding ($70-80k).

Some other remaining issues

- Connector of fiber → PMTs
- MAPMT use for Preshower and FASPDs (purchased two MAPMT assemblies from Hamamatsu)
- Support structure design

Testing at Fermilab Test Beam Facility

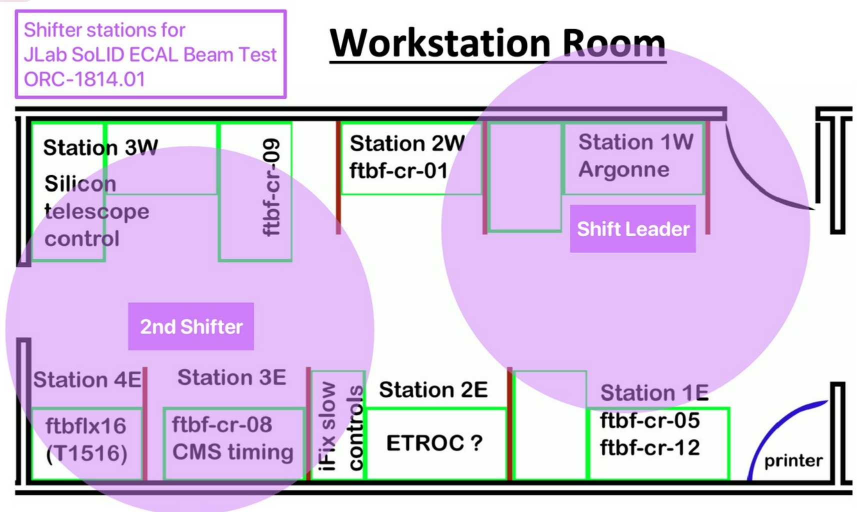
- Beam scheduled for Jan. 13-27 (daytime during 1st week, night time 2nd week);
- Lead by Jixie Zhang, Xinzhan Bai (UVA)/ Alexandre Camsonne, David Flay (JLab)/ with local help from Paul Reimer, Manoj Jadhav, Junqi Xie (ANL)
- Using 3 shashlyks (SDU4,SDU5,THU2), 3 preshowers, and 2 scintillators for triggering. 2X0 prelead and a 1(2?)cm Al plate are also in place. Main goal is to characterize energy resolution for GeV-level electrons.



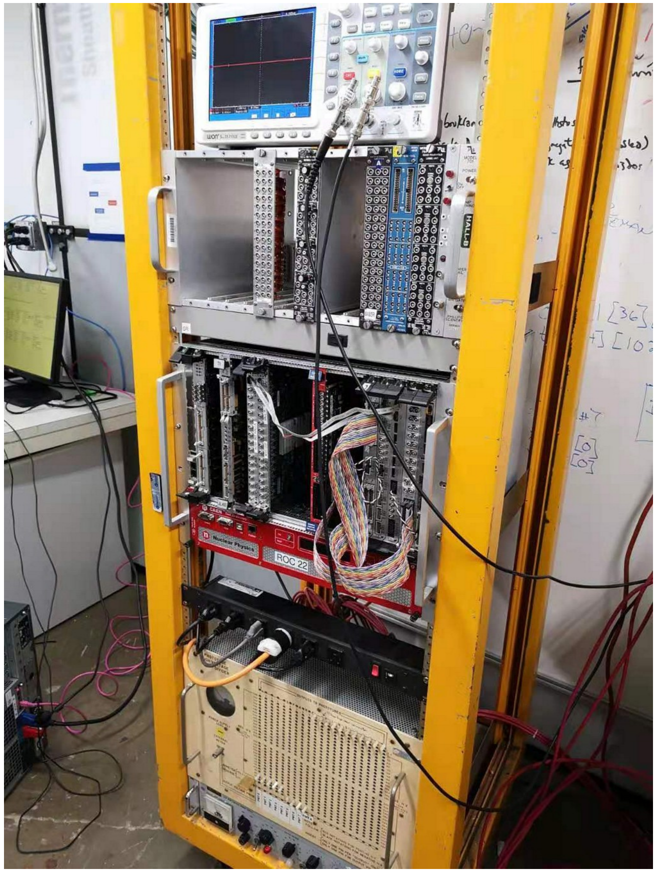
Test lab pictures

Testing at Fermilab Test Beam Facility

- UVA team arrived at FTBF on Wed. Jan.6th
- getting badge, training, hazard analysis, shift prep (2 in-person, 1 remote, 6-hr rotation), installation underway.



FTBF (1/7/21) pictures

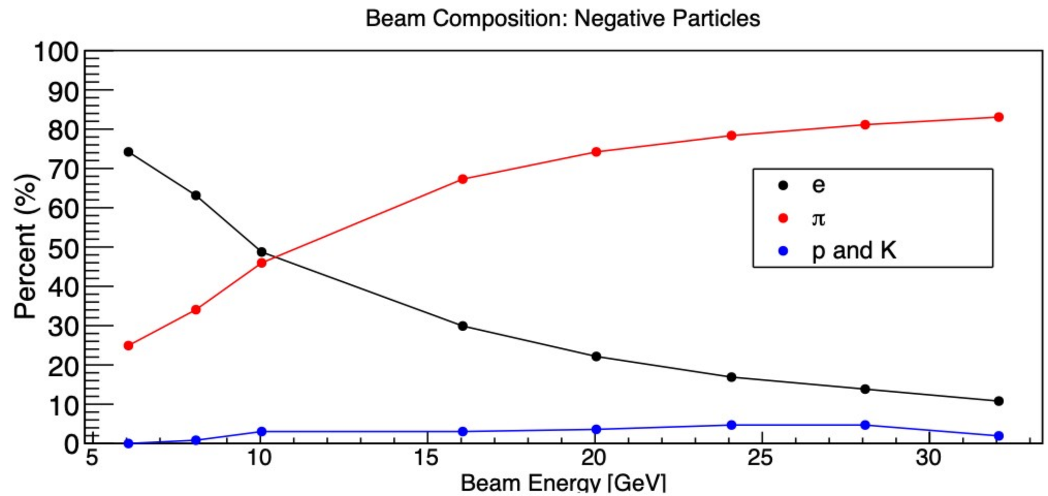


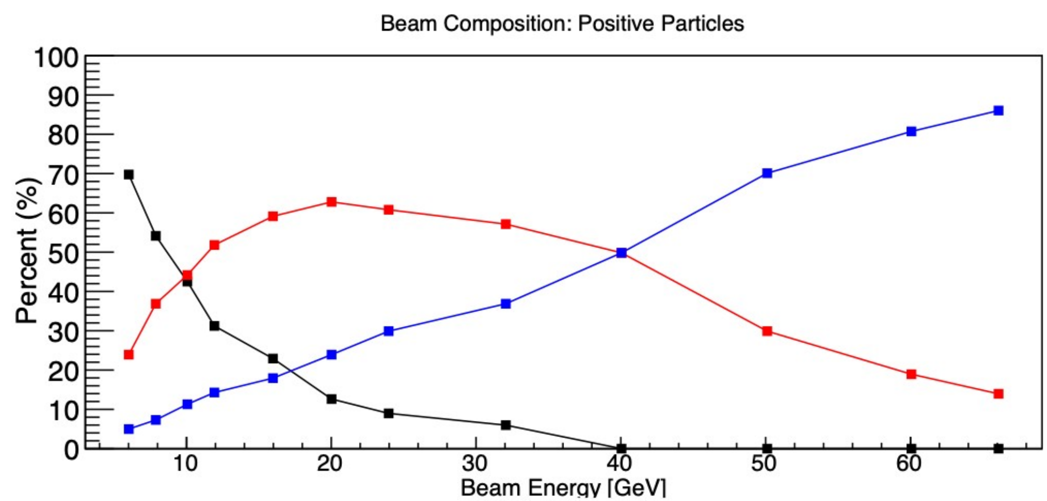
FTBF Beam Intensity and Composition

From FTBF

Energy	Mode[1]	Protons	Pions[2]	Highest Intensity[3]	Muons	Kaons	electrons	Spot Size[4]	Δp
120 GeV	Protons	100%	0	5E5	0	0	0	6mm	2%
60 GeV	pions +								
50 GeV	pions +								
40 GeV	pions +								
32 GeV	pions +/-			500,000					
30 GeV	pions +/-			500,000					
25 GeV	pions +/-			600,000					
20 GeV	pions +/-			500,000					
16 GeV	LEπ +/-		87%	1,000,000	100%			10mm	<4.5%
15 GeV	LEπ +/-								
12 GeV	LEπ –			500000					
10 GeV	LEπ +/-								
8 GeV	LEπ +/-		55%	750,000	98%			12mm	2.3%
6 GeV	LEπ +								
4 GeV	LEπ +/-		31%	400,000	74%			13mm	2.7%
3 GeV	LEπ +/-								2.7%
2 GeV	LEπ +/-		<30%	450,000				13mm	2.7%
1 GeV	LEπ +/-		<30%	69,000					2.7%

- Will use FTBF Cherenkov for PID, and MWPC for positioning info.





- Note: Beam intensity = particles/spill
- Length of spill = 4.2 sec

Revised Run Plan for 12 Shifts — Electrons Only

- Rates now account for duty factor f = (spill = 4.2 sec)/(rep time = 60 sec) = 0.07
- **NOTE:** This is for e^- only!

NOTE: Still need to account for DAQ dead time

E (GeV)	Particle Rate (kHz)	Weight (~ 1/rate)	Time (hrs)	Number of Shifts (1 shift = 12 hrs)	Number of Particles
1.0	12.7	0.08	11.5	1.0	5.3E+08
2.0	12.1	0.08	12.2	1.0	5.3E+08
4.0	10.7	0.10	13.7	1.1	5.3E+08
6.0	9.3	0.11	15.8	1.3	5.3E+08
8.0	7.9	0.13	18.5	1.5	5.3E+08
10.0	7.2	0.14	20.4	1.7	5.3E+08
12.0	6.5	0.16	22.7	1.9	5.3E+08
16.0	5.0	0.20	29.3	2.4	5.3E+08
TOTAL	—	1.00	144.0	12.0	4.2E+09

Revised Run Plan for 12 Shifts — All Particles

- Rates now account for duty factor f = (spill = 4.2 sec)/(rep time = 60 sec) = 0.07
- **NOTE:** This includes e^-, π^-, p^- and K^-

NOTE: Still need to account for DAQ dead time

E (GeV)	Particle Rate (kHz)	Weight (~ 1/rate)	Time (hrs)	Number of Shifts (1 shift = 12 hrs)	Number of Particles
1.0	12.9	0.13	18.6	1.5	8.6E+08
2.0	12.8	0.13	18.7	1.6	8.6E+08
4.0	12.6	0.13	19.0	1.6	8.6E+08
6.0	12.4	0.13	19.3	1.6	8.6E+08
8.0	12.3	0.14	19.6	1.6	8.6E+08
10.0	13.4	0.12	17.9	1.5	8.6E+08
12.0	14.5	0.12	16.6	1.4	8.6E+08
16.0	16.7	0.10	14.4	1.2	8.6E+08
TOTAL	—	1.00	144.0	12.0	6.9E+09

Backup Slides

ECal + SPD cost overview

Item		Note on duration, uncertainties, risks
Shashlyk	SDU: 2,953k	- Minimum 90 weeks construction, Shower scintillators can be delivered ~13 months; IHEP possible
Preshower	SDU; 395k	- IHEP, Eljen both possible + US $40k lead (material only, estimate)
SPD (Eljen)	FA: $62.1k (4.5mm grooves) LA: $39.7k	can deliver within 3 months. Can start deliver in batches in month 2.
HV/CAEN	see DAQ	
PMT/Hamamatsu	$714.7k (Hamamatsu + JLab in-house design bases)	shipping rate can be 1/12 of full quantity per month
Fiber (Saint Gobain)	192km BCF91A-MC at $1.8/m; 520km BCF98-SC at 1.25/m; total $995.6k (March 2017)	2019 update to $1.91/m and $1.33/m → $1,056k, may need BCF98-MC → $1,235k delivery will be 12-18 months
Fiber (Kuraray)	6800m Y11(200)MC at $4.67/m, total $31.8k	subject to currency exchange rate, awaiting for delivery schedule
Fiber connectors	WLS clear using Fujikura ($220k), Fiber PMT est $200k	need Fiber PMT design
Supporting frame	$884.5k	very preliminary design for Shower, scaled by area; no design for SPD and Preshower
Total	$6.5M	+ 220k (~3.4%)

Anything I may be forgetting?

- IHEP shashlyk prototyping (~$65-70k estimate in 2014);

- Lead sheet for Preshower (50k$? I can estimate this using Kolga quote for the lead sheet with holes, scale by mass);

- need confirm PMT base cost + contingency code;

- better estimate for fiber PMT connector? (got drawing from Hall B PCAL);

- MAPMT shielding?

- PMT frame?

- SDU construction manager?? (GlueX BCAL had one)

- misc: light-tight wrapping???

Irradiated Preshower Results

1. Students: Margaret Doyle, Sam Blum
2. Optical grease is from 2014, expired. We tested the preshower "as is", after replacing grease, and after replacing the fiber. All NPE lower than before radiation but could be partly due to mechanical (not radiational) damage to fiber

Tile #	location in Hall A	Before Radiation	Radiation Dose (krad)	With Old Grease "as is"	After replacing grease	After replacing fiber
Kedi 1	Beam Right lumis	87.1	161-164	56.6	74.4	73.3
Kedi 2	Upstream of scattering chamber	85.4	185-189	57.6 (fiber had a kink)	67.3	68.0
Kedi 3	Beamline grider	87	31-38	66	69.7	77.3
Kedi 4	Compton chicane	91	9-17	55(?)*-74 (fiber broken)	86.5	
CNCS 1	beam left lumis	83.4	156-172	56.2	49.7	70.0
CNCS 2	Beam Right scattering chamber	84.7	43-53	61.6	71.0	74.5
CNCS 3	Beam Left scattering chamber	81.8	20-24	62.5	69.3	
CNCS 4	Hall A dump	83.4	230-286	41.2	47.2	54.0

Green numbers are updated results after replacing a loose-wire PMT
Red numbers were performed with a PMT that behaved inconsistently.

http://hallaweb.jlab.org/experiment/PVDIS/SoLID/EC/meetings/2014-test/2016-test/Documents/PSH_rad_tests_02Jan2017.pdf

More background information

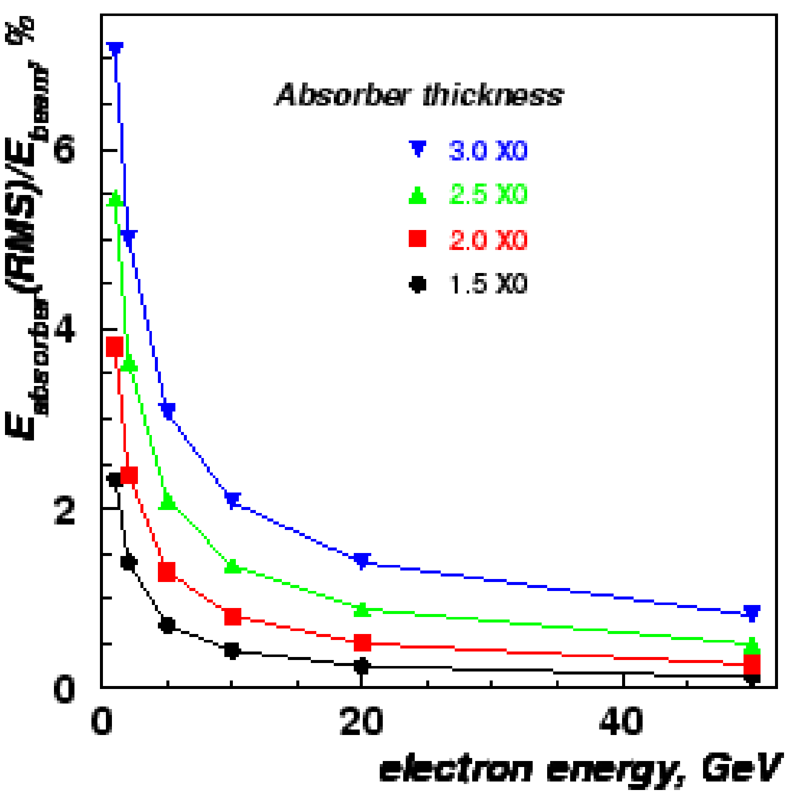
1. LHCb tracker upgrade (scifi tracker) reported irradiation test of fibers and 4 models to extend to higher doses. Light loss starts to be visible at 0.5kGy or 50krad, and drops by factor two at roughly 2-3kGy or 200-300krad. These are plastic fibers where radiation damage affects mostly the clarity (attentuation length) and the scintillating efficiency and the two are similar. Thus damage is expected to be more visible for longer fibers. For WLS fibers, there can be additional damage to the WLS dye/fluor that is not applicable to the LHCb scifi tracker.
2. Radiation dose expected for SoLID (see ECal meeting minutes from 3/26/14, maybe outdated), and the run duration corresponding to 200krad dose: SPD 2krad/month (100 months); Preshower 10krad/month (PVDIS?, 20months); Shashlyk 2krad/month (PVDIS?, 100 months).

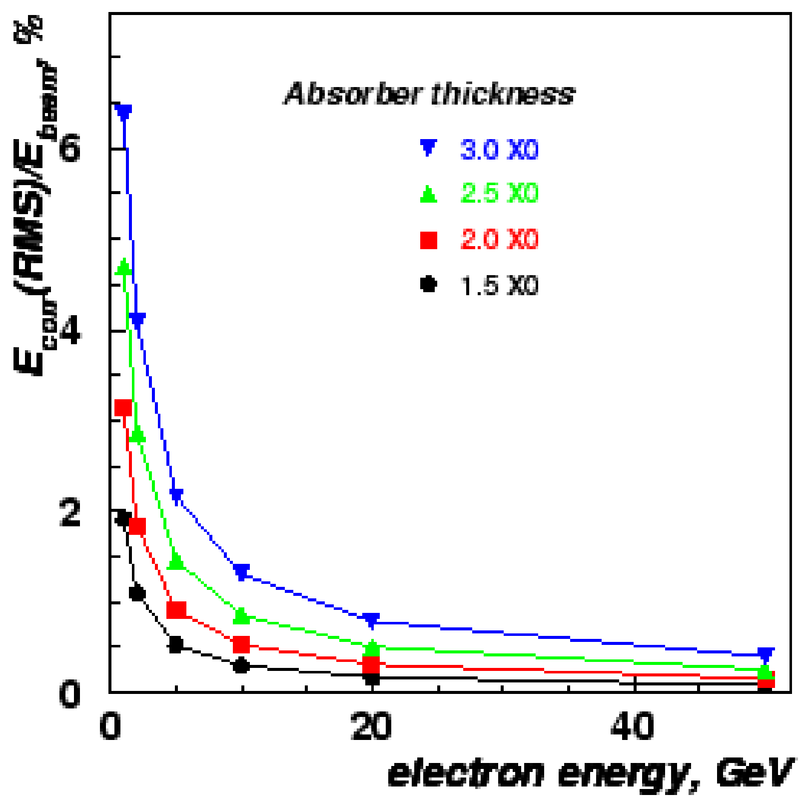
Ecal Simulation (Ye Tian/Syracuse)

1. Then try to separate the effect of incident angle (PVDIS), the 2cm Al support between the preshower and the shower, and the 2Xo of pre-lead before the preshower
2. In fact this is consistent with LHCb's study:

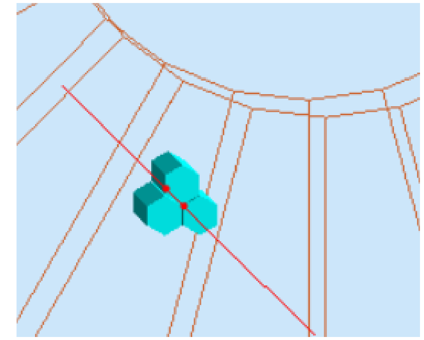
Ecal configuration	1 GeV e- dE/E
1748 modules, 25 deg, 2cm Al, no pre-lead	4.03 ± 0.03
1748 modules, 25 deg, 2cm Al, 2Xo pre-lead	6.20 ± 0.05
1748 modules, 25 deg, no Al, 2Xo pre-lead	5.84 ± 0.05

Figure 3.3 from LHCb Cal TDR: Simulation of the energy lost in lead by electrons. On the left plot the relative error on the energy measurement is shown. This should be compared with the design ECAL module resolution of 10%/sqrt(E) plus 1% constant. On the right shown is with correction of the prelead Edep using preshower signal.





Beam test module simulation



1. 100 MeV/c, e+ and π+
2. 200 MeV/c, e+ and π+

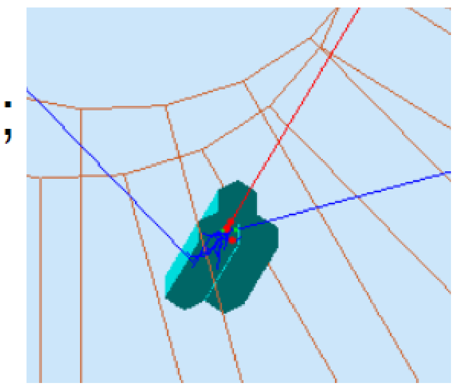
No field, straight hit the center module.

Beam size: 3cm radius

1) 1 module: Y= - 120.984cm, X= - 39.116cm;

2) 3 modules: Y= - 117.575-1cm, X= - 44.704+1cm;

3) 7 modules: Y= - 120.984cm, X= - 39.116cm;



Each above setup has 2 configurations:

a) Full ECAL without 2cm Al support structure
b) Full ECAL with 2cm Al support structure

Modified configurations:

1) Add 6mm Al at front of the shower
2) Replace 0.12mm Mylar to 0.07mm TIO_2 painting.