12 GeV Upgrade
Future Science at Jefferson Lab

EC and SPD Updates

The SoLID EC Working Group

SoLID Collaboration Meeting

May 14-15, 2015

Preshower Test Updates

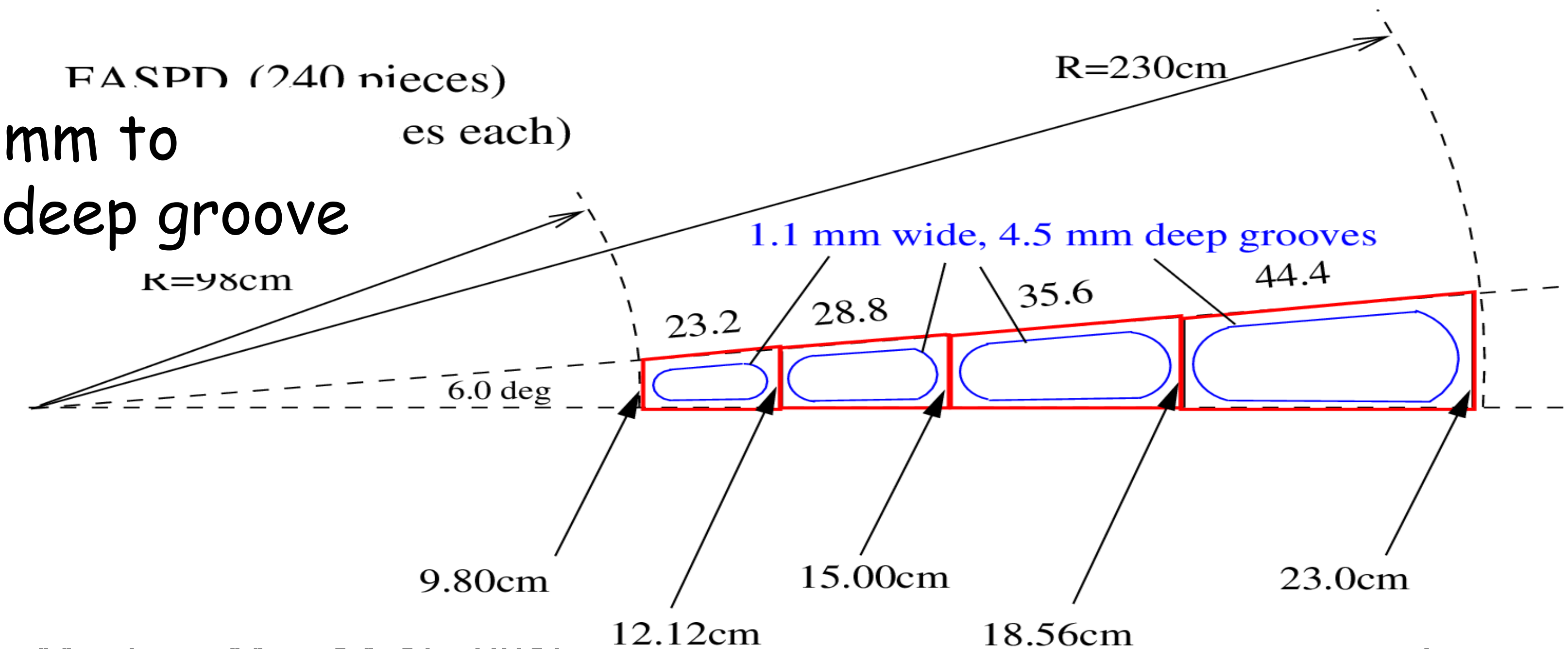
1. Previously test IHEP and Kedi (China) Preshower prototypes, now have compared 4 more Kedi and 4 CNCS (China) preshower modules. All give ~80 p.e. with the same method (2 Y11 fibers, 2.5 turns each). SDU test showed similar results.

FASPD Test Updates

1. Test FASPD prototype (5mm thick, inner-most and out-most modules only). Light yield using 3 turns of single fiber (shorter bar) or 2 turns each of double fiber (longer bar) both give about 9 p.e. This agrees well with estimation and the shorter bar can be improved using double fiber.

2. This gives 5.9 p.e. after fiber connector and clear fiber. With x50 preamp (30ns triangular pulse, 20% of MAPMT max anode current), MIP response is 51mV at peak → seems okay to cut at half MIP.

3. May need 6mm to secure the deep groove



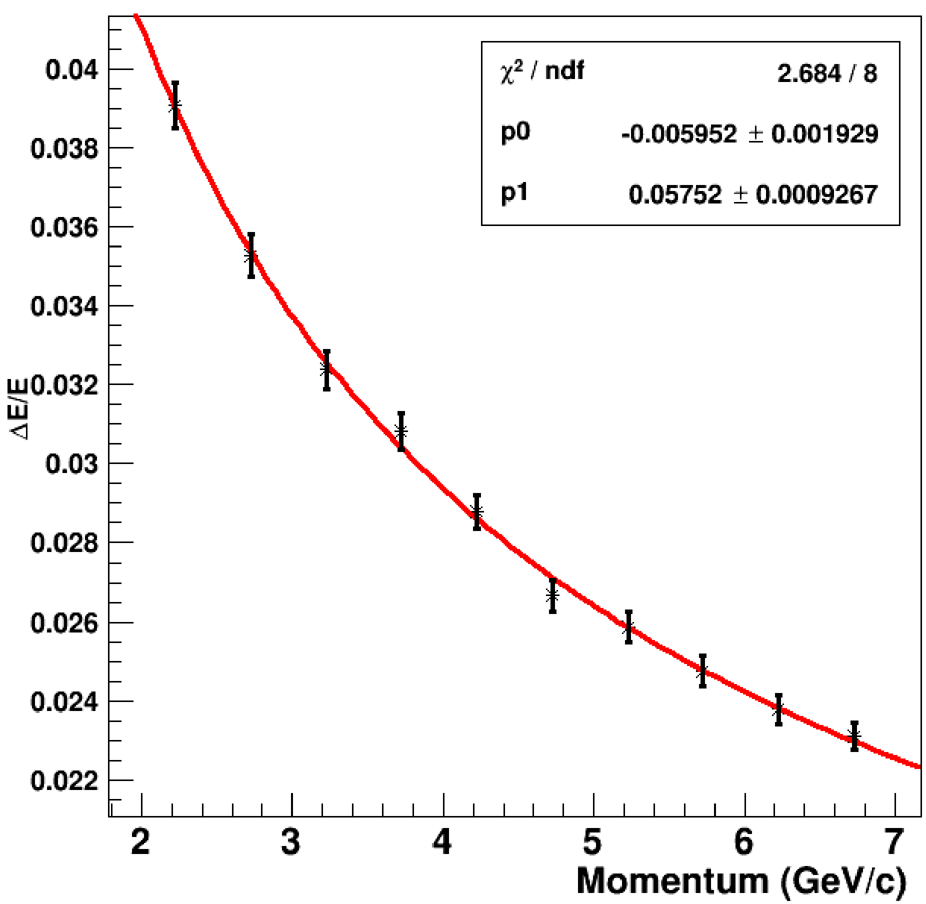
Test Plan

1. FMPMT high field test using FROST magnet (July)
2. FASPD uniformity test with source (June → fine tuning groove design)
3. LASPD timing test with beam.
4. More preshower prototype tests, including radiation resistance.

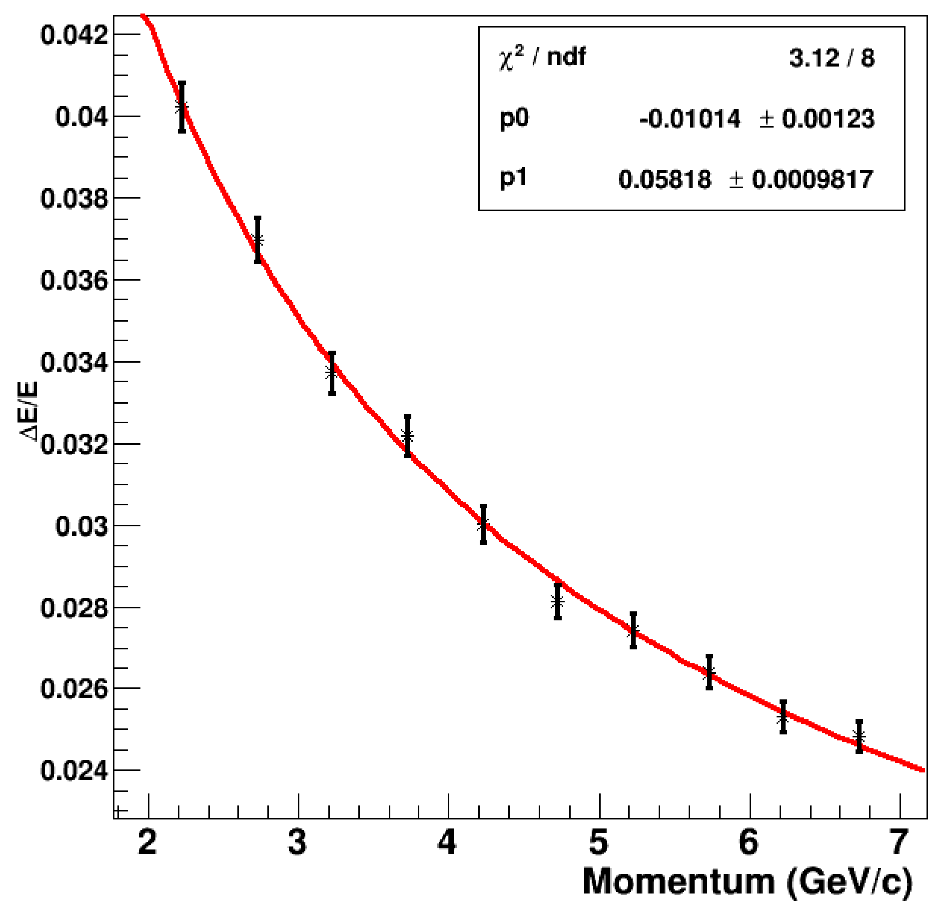
Simulation Updates

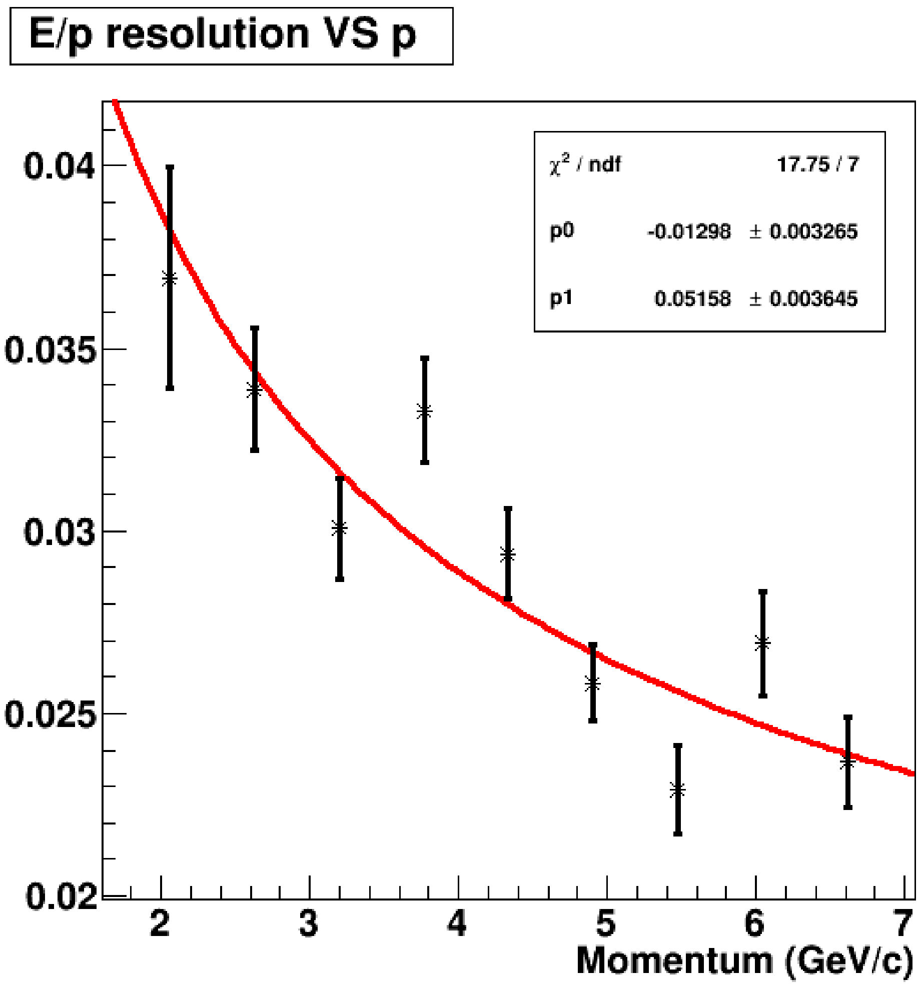
1. Rakitha's simulation now shows similar intrinsic energy resolution for 6+1 cluster (~5.8%/sqrt(E)+1.0%) as Jin's (~5.2%/sqrt(E)+1.3%). Simulation conditions: central area, no radiation in target.

whole EC



6+1 cluster





Jin's (~5.2%/sqrt(E)+1.3%).

Rakitha will continue working on PID performance and simulation with background.

Address Recommendations from Director's Review

2a Observations: Other experiments have extensive expertise with scintillating fibers and SiPMs in harsh radiation environments, like LHCb.

2a Recommendations:
The calorimeter group is encouraged to contact other groups (ALICE, LHCb and possibly CMS) to understand the detector design choices these groups have made and resources needed for construction.

1) see LHCb tracker upgrade for the latest development on SiPM and its radiation damage (section 3.5). The tests were done in the LHCb cavern, the neutron irradiation facility at Ljubljana, and with a Pu-Be neutron source. The neutron energy spectrum was simulated to mimic the LHCb running condition, with a peak at 2MeV.

- The noise of SiPM comes from: dark current, pixel cross-talk and after pulsing. The dark count rate (DCR, measured above 0.5 photoelectron) increases strongly after irradiation and is the only radiation damage observed at the level of irradiation required for LHCb. The cross-talk and after-pulsing depend strongly on the detector technology. After-pulsing only occurs after >10ns (pixel recovery time) and is significantly reduced in the latest technology and contributes only a minor fraction to the total noise. Cross-talking can be reduced for new detectors with have so-called "trenches" between pixels.

- Both Hamamatsu and KEKEK have developed customized detectors for LHCb's scifi tracker: trenched, with specific light yield, active area, area efficiency, etc, to fit the SciFi.

- The increase of the DCR was found to depend linearly on the total fluence. For Hamamatsu "no trench" multi-channel arrays (Fig.3.23 left), DCR reaches an increase of factor 20 at 6E11 neq/cm2.

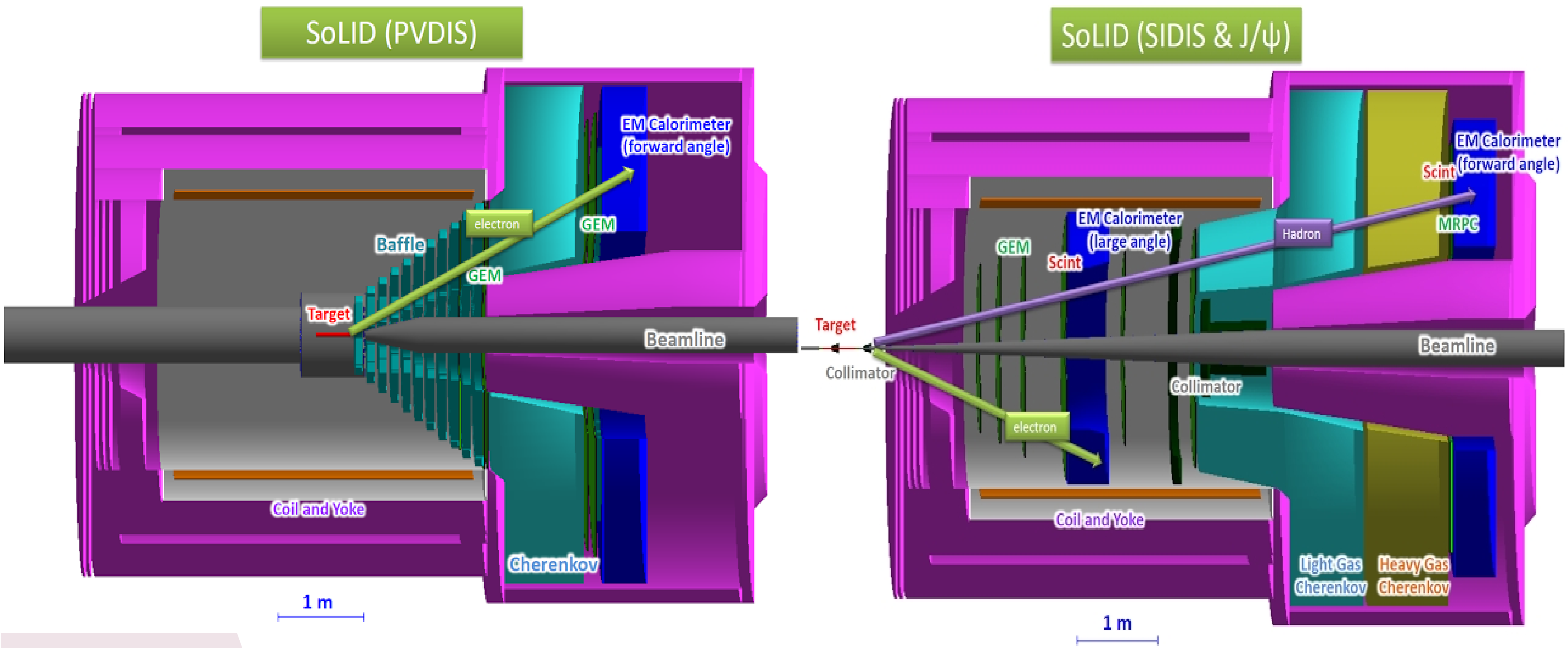
LHCb tracker upgrade (continued)

- Effect of cooling (Fig.3.23 right): cooling by each 10C reduce DCR by factor two. There data were given for fully annealed detectors after slow annealing one week at +40C.

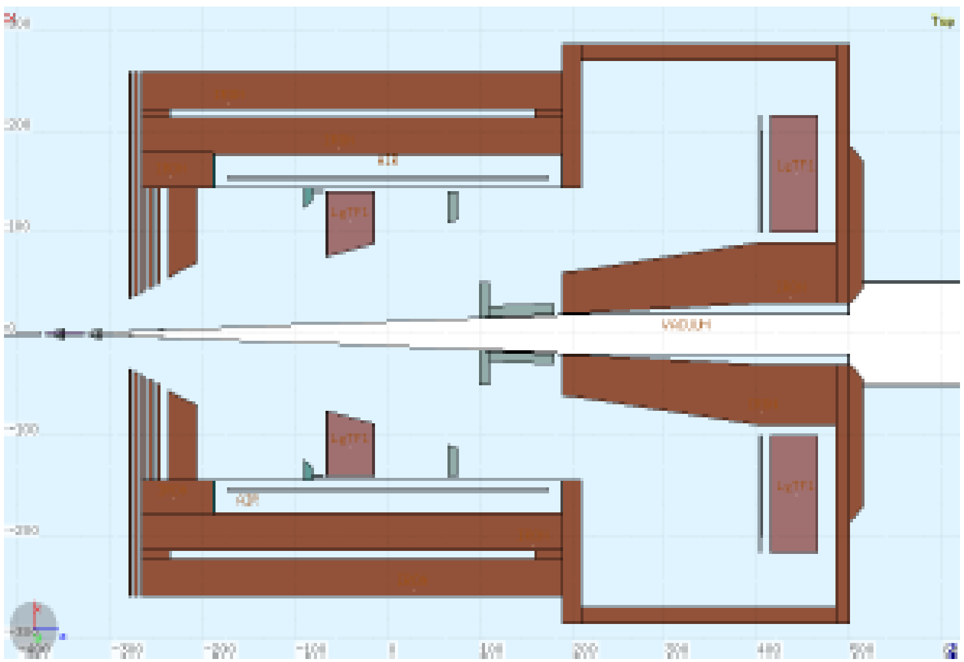
- Comparison between no annealing with with annealing (Fig.3.24 left): DCR with no annealing is about twice the current with slow annealing (one week at +40C), and with fast annealing (80 minutes at +80C) is about mid-way between the two. The effect of annealing is the same for new and standard technology devices.

- Comparison between new and standard technology (Fig.3.24 right): At -40C, trenched detectors have about half DCR of standard detectors.

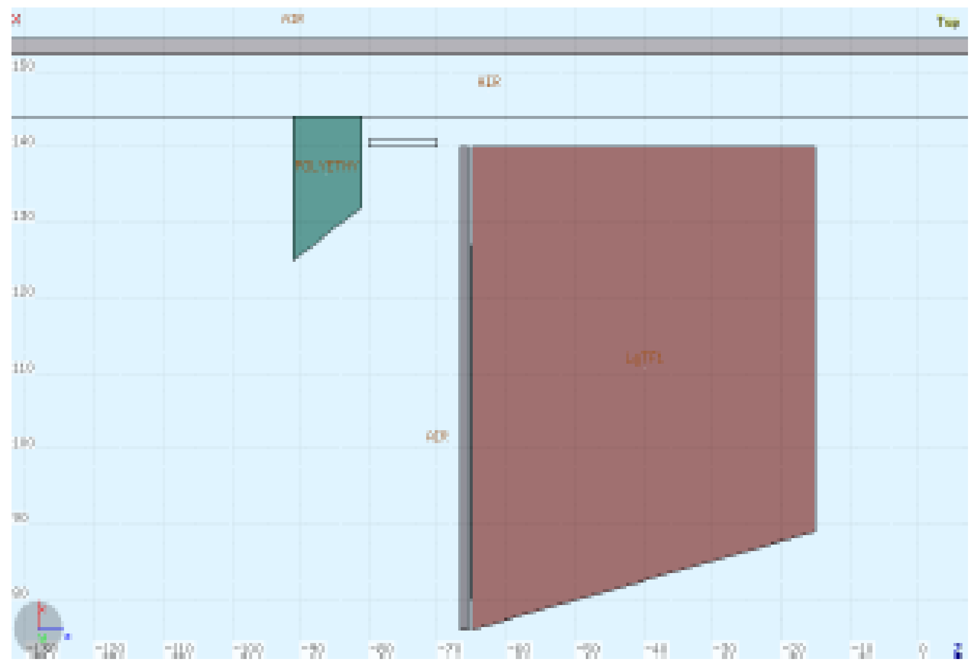
- They need to run at -40C for the SiPM to last the whole duration, at a neutron background of close to 1E12/cm2. So if SoLID is 2E12 neq/cm2, cooling to -50C might work, 4E12-> -60C might work, 8E12-> -70C, 1.6E13 -> -80C, etc. Note that the detector unit must be designed to increase the temperature to 40C for slow annealing or 80C for fast annealing.


SoLID (PVDIS)
EM Calorimeter
(forward angle)
electron
GEM
Baffle
GEM
Target
Beamline
Coil and Yoke
Cherenkov
1 m
SoLID (SIDIS & J/ψ)
EM Calorimeter
(forward angle)
Scint
MRPC
Hadron
EM Calorimeter
(large angle)
GEM
Scint
Target
Collimator
Beamline
Collimator
electron
Coil and Yoke
Light Gas
Cherenkov
Heavy Gas
Cherenkov
1 m

Lorenzo's SIDIS neutron background simulation: Background is reduced by about factor 2 with a small shielding and is (read from color) somewhere between 6E12 and 1E+13n/cm^2. The simulated condition was 3He target, 15uA, 3000 hours. Lorenzo suggested a factor of 3 buffer

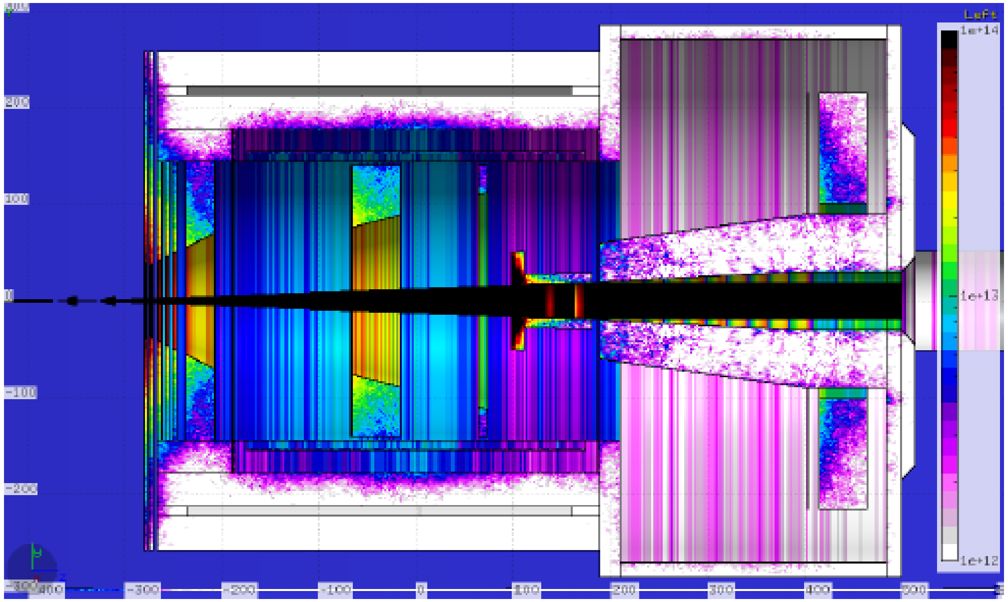


ZOOM on shielding and location of APD

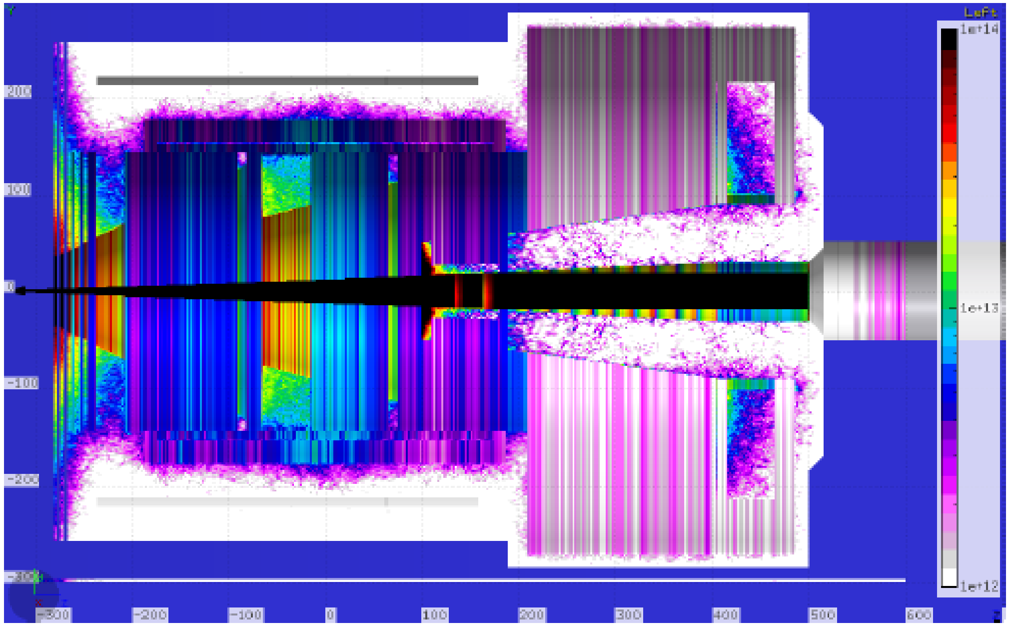


Lorenzo's SIDIS neutron background simulation: Background is reduced by about factor 2 with a small shielding and is (read from color) somewhere between 6E12 and 1E+13n/cm^2. The simulated condition was 3He target, 15uA, 3000 hours. Lorenzo suggested a factor of 3 buffer

NO SHIELDING



WITH SHIELDING



2) Craig Woody's talk on EIC eRD1, Jan 2015, shows:

- SiPM tested up to 0.3E9 n/cm^2 at BNL (14MeV neutrons), DCR increases by factor 10-50 (10-20 for Hamamatsu, 45 for SensL, 45-50 for KETEK), pixel-size-dependent, with Hamamatsu 15um shows the least increase;

- tested up to 7E10 n/cm^2 (>6MeV neutrons) at LANCE, DCR increases by 100-1000, can reach milli-Amp, also observed some loss of pixels.

3) Also gathered information from Carl Zorn and Ardarvan from Hamamatsu. Ardavan referred to Carl as the expert, and below is Carl's reply:

- Carl: "The estimated high energy fluence for Hall D is 3 x 10^8 n/cm^2 for 1 MeV equivalent. At that level, the noise would rise to unacceptable levels within 3-4 years (dark rate increases by a factor of x10). By cooling down the SiPMs to 5°C during operation, the lifetime is expected to be the full 10 years of GlueX. (The dark rate is reduced by x1/3 during cooling.)"

4) CMS (talked to Brad Cox): CMS calorimeter upgrade will use W (inactive) +LSO (active), very small size (the module is about the size of a finger). The advantage of the small size is the small attenuation in the optical elements, so with radiation damage the damage in the signal is not severe. For readout, the background next to the calo is about 1E14-E15 but the SiPM is located far away, "get down to about 1E12". Is also studying galium-based PM (larger gap than silicon). He had some experience with FMPMT, some tests found that the residual gas in the tube gets ionized and the ions deposited on the cathode, causing the gain to drop by 15-50% over ~2 years of period.

Address Recommendations from Director's Review

2a Findings

• The plan to rely on an outside international laboratory to produce EM calorimeter modules seems risky, considering difficulties with communication observed so far.

Recommendations:

The calorimeter group is encouraged to contact other groups (ALICE, LHCb and possibly CMS) to understand the detector design choices these groups have made and resources needed for construction.

– Prof. Onel from U. of Iowa – received a supporting email, I need to follow up on this after I come back from CIPANP

– Tom Cormier ORNL (previously Wayne State U.) – Thanks to Nilanga and Bolek I managed to have a phone call with him (details next slide). Have requested to give a colloquium in the Fall and will visit their (now decommissioned) calorimeter lab.

Information from Tom Cormier (ORNL/WSU)

- WSU built 16,000 modules for ATLAS, forming 4,000 towers (4 mod/tower). It took 3 years although most of the construction was done within two years. At the peak the lab had 10 people working. These are partly technicians (more experience, hired "from the street"), and partly graduate students (both Phys and engineering, both MS and PhD, some were willing to work full-time at minimal wage $10/hr for a full semester or a full year). The important factor is most of people should be full-time since the whole procedure is like a factory-assembly line. They had 10 assembly stations at $20k cost each. Tom had one Russian/IHEP person who had been working with him for a long time and it really helped. Some of the techs are from Russia too.

- Fiber density was 100/tower. The shape is semi-projective.

- They obtained scintillator tiles from a Russian company (had also a Russian contractor to oversee the production and quality control). Used injection molding with fixed shape/size. Upon receiving the scintillator tiles WSU machined them down to 76 different sizes to form the projective shape of the module.

- They used Vulcan GMS (http://vulcangms.com/) for the lead sheets. Lead sheets were produced at 76 different sizes directly using an adjustable die. (the hole positions were fixed but the outer size of the die can be adjusted).

Information from Tom Cormier (ORNL/WSU) (continued)

- Fiber mirrors: after inserting of fibers, fibers were gathered and diamond-polished, then were inserted into a sputtering machine (1000 at a time) for sputtering with aluminum. The finish is "rugged" so can't be easily peeled off or damaged. Can't use thermal evaporation of aluminum because it's not structurally solid enough. I asked about attaching a single mirror to the module end. Answer is that's possible. Can also just neglect mirrors but the longitudinal (energy) nonlinearity may increase. Can use cosmic or source tests to easily characterize the energy linearity (ray hits transversely through the module, and moving the source along the module to see the variation in response).

- Engineering support is partly from LBL (paid) and partly from other collaborators (free). The biggest concern was for the projective shape of the ATLAS hcal, all modules had to be supported ONLY from the back and nothing from the front. This was all designed by contracted engineers and built at WSU. ATLAS was the only experiment that has shashlyk modules within the solenoid, in contrast to fixed target experiments where one can support the modules from both front and back.

- All modules were cosmic-tested to provide the starting HV, which turned out to be good to 2-3%. With the cosmic test, pi0 appeared right away without further tuning.

- The WSU group is now involved in a new project and the calo lab is not used (assembly stands recycled). Equipment that I will try to ask for loan, if working, are fiber cutter, sputtering machine, scintillator cutter(?).

scintillator cutter

fiber cutter

sputtering

assembly stations (what's left)

Address Recommendations from Director's Review

2a Findings

• The simulations do not seem to include the support structures and inactive material.

Recommendations:

The collaboration is strongly encouraged to develop an end-to-end realistic simulation and reconstruction to further optimize cost and physics reach and derive clear performance requirements for the individual subdetectors.

Answer: We can develop the full-scale simulation including nuts bolts rods and endcaps, but we need manpower – 0.5 postdoc.

Staged R&D Plan

Priority A: design-related tasks, must be completed during pre R&D because they may affect basic design of the detectors

Priority B – performance evaluation: preferrably to be completed in the pre-R&D but can also be completed in the R&D stage. These tasks are usually related to the fine-tuning of the subsystem design

Priority C – final design work: preferrably to be completed by the end of the R&D stage but can also be completed in the early (few) months of the construction stage. These tasks are usually related to the mass production or evaluation of the subsystem.

Staged R&D Plan

Priority A: design-related tasks, must be completed during pre R&D because they may affect basic design of the detectors

Priority	Subsystem	Task	Material cost	Manpower cost per year (already existing)
A	Preshower, FASPD, LASPD, Shower	simulation and design	N/A	0.5 postdoc (0.3 postdoc)
	Preshower, FASPD, Shower	fiber connector and clear fiber light loss study	$1k connectors, 400 meters BCF98 clear fiber $5k	(0.5 postdoc), two half-time grad student
	Preshower, FASPD	MAPMT base design	3× MAPMT H12445-100MOD, $11k	
	Preshower, FASPD, LASPD, Shower	LED control system		
	FASPD	prototype testing	FASPD prototype $5.3k (3 sets, 4 sizes per set)	
	LASPD	fine-mesh PMT high field test		
	LASPD	in-beam test with tracking		
	Preshower, Shower	support design		0.1 physicist, 0.15 engineer
	Shower	prototyping at UVa	$3k for 10× R11102 PMTs, $55k for module parts, $3k for WLS fiber, $20k assembly stand, $4k HV, total $82k	0.2 engineer, 0.5 postdoc, part-time tech, 1 grad student, 3 undergrad

Staged R&D Plan

Priority B – performance evaluation: preferably to be completed in the pre-R&D but can also be completed in the R&D stage. These tasks are usually related to the fine-tuning of the subsystem design

B	Preshower, FASPD	MAPMT test		0.5 postdoc, 0.5 grad student
	Preshower, FASPD, LASPD, Shower	radiation resistance test		
	FASPD	uniformity in light yield		
	Preshower, Shower	support design		0.33 physicist, 0.25 engineer
	Shower	procure prototypes from IHEP and test in-beam	\$78k including 30% IHEP overhead (\$4k HV)	N/A

Staged R&D Plan

Priority C – final design work: preferably to be completed by the end of the R&D stage but can also be completed in the early (few) months of the construction stage. These tasks are usually related to the mass production or evaluation of the subsystem.

C	Preshower	design and building testing and assembly stands at the production scale		0.2 tech, 0.25 grad student
	Shower	design and building testing stands at the production scale		0.2 tech, 0.25 grad student
	Shower	design of assembly stands at the production scale		0.25 engineer
	Shower	building of assembly stands at the production scale		1 tech, 0.1 engineer
	Preshower, Shower	PMT testing at the production scale		0.5 tech, 1 grad student

Commission, Calibration, and Integration of EC

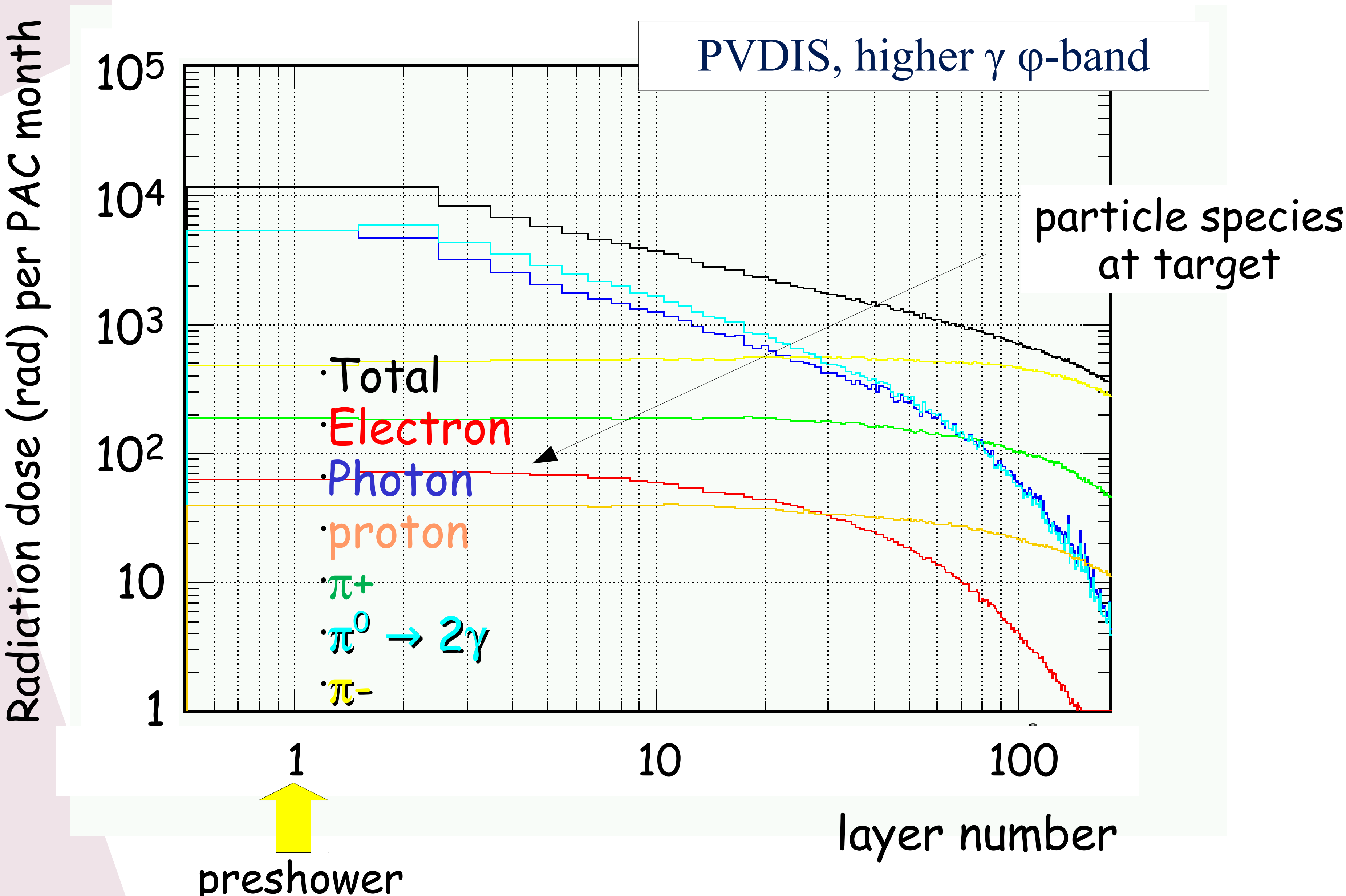
- Cosmic test, LED test – before beam – this should be good to 10-20%.
- A rough fit based on the fact that the energy deposit should be smooth function of R and should be repetitive in phi – with beam, fast, can be done with only EC running
- Using MIP at very low beam current – If set electron max at 1.5V, MIP peak (60MeV) should be seen at around 40mV with dE/E=20% or +/- 8mV. The FADC full scale is 2 V and 12 bit, so resolution is 2/4096=0.5mV which correspond to +/-16 bins, plenty for a clear identificiation (if we are not messed up by very low-E background) – with beam, not so fast, can be done with only EC running -- could be good to 2-5%;

Commission, Calibration, and Integration of EC

(continued)

- Using elastic electrons at low beam energy – with beam, commissioning, slow, coverage in momentum and angle won't be large (probably can only use 2.2 GeV beam), precision will be high if done with tracking, can be done with only EC running but precision limited by the knowledge of scattering angle (EC position resolution divided by drift distance, also lack of vertex position);
- Using electrons with known tracking/momentum – with beam, commissioning, slow, must be done with GEM, high precision.
- pi0 reconstruction: need 2-cluster triggers – with beam, can be done with EC only, can be done continuously and non-intrusive, can potentially reach high precision.

Design Consideration 3: Radiation Dose



Fiber Choice

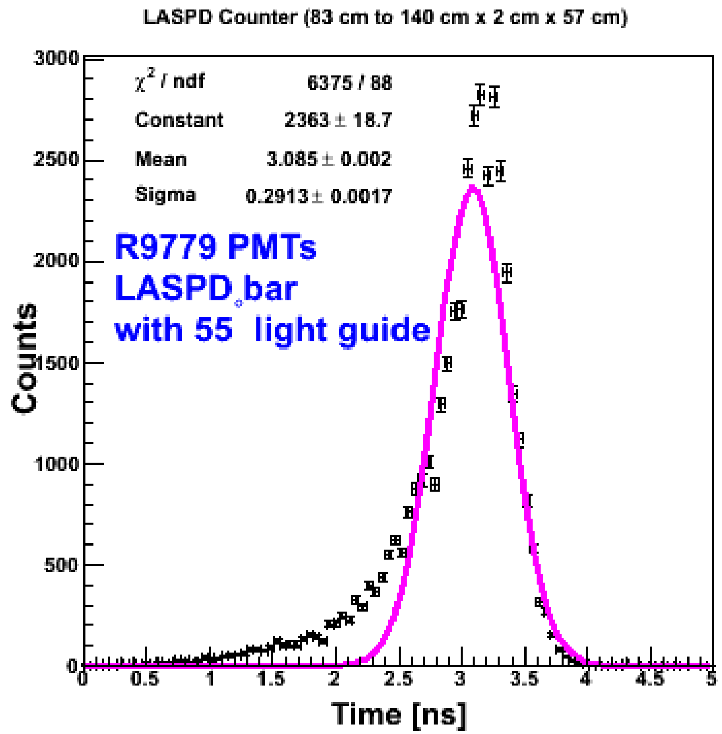
WLS fibers	Kuraray Y11	Saint Gobain BCF91A, BCF92 (faster)
wavelength	~420 → 494nm	~430 → 476nm
1/e length	>3.5m	>3.5m
mechanical property	less bending loss	
radiation hardness	13% light loss at 100krad (30% at 700krad)	15% light loss at 100krad (50% at 700krad)
light yield		2-3 times less than Y11
Clear fibers	Kuraray clear-PSM	Saint Gobain BCF98
cost	$$$	$

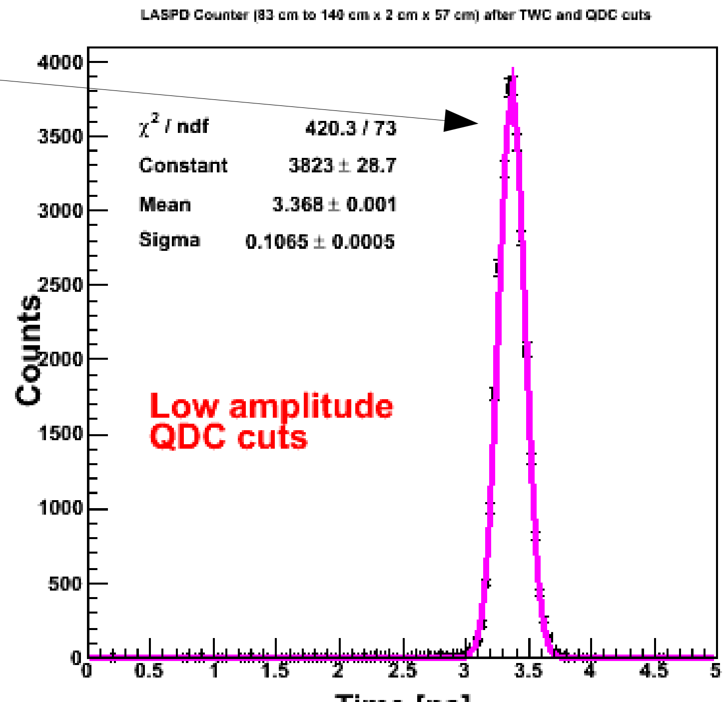
Will use Y11 for Preshower and FASPD, BCF91A for Shower; Clear fiber yet to be tested.

Pre-R&D: LASPD prototype testing

- Setup: "3-bar" setting (Ref FTOF12 testing), 5x5x30cm EJ200 reference bars, PMT R9779
- Results: 58ps for reference bars, 98ps for 2-cm LASPD (two-side readout). [Single-side readout expected to be ~(84-170)ps, looking for further testing with tracking.]

$(t_{left}+t_{right})/2-t_{event,ref}$





Plan

By summer 2015

- Preshower: CHN#1 prototype, SDU/UVa parallel testing;
- LASPD: FMPMT using FROST magnet (UVa)
- FASPD: test prototypes (UVa)
- DDK fiber connector custom design; (UVa ↔ Fujikura)
- PMT pre-amp and HV divider design (JLab ↔ UVa)

summer 2015 - 2016

- Shower: look for prototype funding ~$100k, engineering support (UVa)

Long term:

- Support structure design (ANL)

Long term construction:

- SDU(China): Preshower+FASPD construction/testing, PMT testing, possibly Shower construction
- UVa: LASPD, and Preshower+FASPD construction/testing, possibly Shower construction, general installation
- W&M: MAPMT testing, general construction and installation
- LANL: general construction and installation

Commissioning

For all components: Preshower, Shower, LASPD, FASPD, two methods to test/calibrate/commissioning in situ (in addition to cosmic):

1. LED system – check on fibers, fiber connections, PMT, DAQ, electronics
2. Using MIP at low luminosity: general calibration of PMT gain.

Manpower Cost Breakdown (pre-CDR)

1. Construction/Testing: 7 tech FTE, 2 postdoc FTE, 5 student-year, 2 supporting JLab FTE.
2. pre R&D years 1 and 2 (per year): 1 undergrad, 2.5 graduate students, 1.3 postdoc, 0.3 technician, 0.1 physicist, 0.1 engineer

Design Consideration 1: Pb/scintillator ratio

Experiment	COMPASS	PANDA	KOPIO
Pb Thick/Layer (mm)	0.8	0.3	0.28
Sci Thick/Layer (mm)	1.5	1.5	1.5
Energy Res. a/sqrt(E)	6.5%	~3%	~3%
Rad. length, X_0 (mm)	17.5	34	35
Total rad length in X_0	22.5	20	16
Moliere radius (mm)	36	59	60
Typical Detecting Energy	10^1~10^2GeV?	<10GeV	<1GeV
Lateral Size (cm)	~4x4	11x11	11x11
Active depth(cm)	400	680	555

- Thinner Pb layers give better energy resolution, but requires more layers → Balancing between energy resolution and module length

Preshower Prototyping and Production

Vendor	polymer base	light yield anthracene	Price for mass production (20mm)
IHEP	polysterene	40% from CERN data	$216k tot + 30%, or $156 each
Chn #1 高能科迪科技有限公司？		40% from UVa data	$100*1800=$180k
Chn#2 中核控制系统工程有限公司	ST401 phenylethene	40%	$100*1800=$180k
Eljen Technology	EJ200 polyvinyltoluene	64%	[$77 (no groove)/$204 (grooved)] *1800; or $212/$418x3
Saint Gobain Crystal	BC408 polyvinyltoluene	64%	$430x2 no groove

Chinese: subject to 20% transverse (横向) overhead

LASPD Prototyping and Production

Vendor	polymer base	light yield % anthracene	Price for mass production (20mm)
IHEP (material only)	polysterene	40% from CERN data	$10k total, 5mm, no light guide, +30%
Chn #1 高能科迪科技有限公司 ?		40% from UVa data	$533*60, $32k tot (1/3 SPD, 2/3 l.g.)
Chn#2 中核控制系统工程有限公司	ST401 phenylethene	40%	$420EA, $25k total, no l.g.(?)
Eljen Technology	EJ200 polyvinyltoluene	64%	$578*60, $35k tot (1/3 SPD, 2/3 l.g.)
Saint Gobain Crystal	BC408 polyvinyltoluene	64%	$1062*60, no groove, no l.g.

? Chinese: subject to 20% transverse (横向) overhead or not?

FASPD Prototyping and Production

Vendor	polymer base	light yield % anthracene	Price for mass production (20mm)
IHEP (material only)	polysterene	40% from CERN data	$40k total, 5mm; +30%
Chn #1 高能科迪科技有限公司？		40% from UVa data	
Chn#2 中核控制系统工程有限公司？	ST401 phenylethene	40%	($1500)*60=, $90k total
Eljen Technology	EJ200 polyvinyltoluene	64%	$1160*60=$66k tot
Saint Gobain Crystal	BC408 polyvinyltoluene	64%	$1062 EA, no groove, no l.g.

? Chinese: subject to 20% transverse (横向) overhead or not?

Shashlyk Production (IHEP)

- Mold: $30k x 2 (scintillator), $15k (lead); plus
- $1270 per module, see below
- Same prototyping and mass production
- Not including 30% overhead

Component	Cost per module
Scintillator	$200
Lead	$240
flanges, nuts	$230
assembly	$320
add fiber mirror, testing	$110

Prototyping (8 modules): $55k+30%, plus fiber ($2,961)

Mass production: $2,361k + 30% = $3,069k, plus fiber

Shashlyk Production (Alternate)

Component	3 modules	8 modules	1800 modules
scintillator (CHN#1)	$10k	$27k	$1kx1800=$1.8M
lead (Kolgashield)	$7,776	$17k	$488k
paper (Kolgashield)	$1,152	$2.5k	$130k
flanges, nuts, rods	$600	$1.6k	$150x1800=$270k
fiber mirror, testing	?		
Total w/o assembly	$19.5k	$48.1k	$2,688k

fiber not included in table.

CHN: only #1 can do injection molding