SoLID EM Calorimeter Overview

<table>
<thead>
<tr>
<th>SoLID EM Calorimeters</th>
<th>Polar Angle (degree)</th>
<th>P (GeV/c)</th>
<th>Max π/e</th>
<th>Cerenkov Coverage</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVDIS Forward-Angle</td>
<td>22 - 35</td>
<td>2.3 – 6</td>
<td>~ 200</td>
<td>&lt;3-4 GeV/c</td>
<td>~17</td>
</tr>
<tr>
<td>SIDIS Forward-Angle</td>
<td>8-15</td>
<td>1 -7</td>
<td>~ 200</td>
<td>&lt;4.7 GeV/c</td>
<td>~11</td>
</tr>
<tr>
<td>SIDIS Large-Angle</td>
<td>17-24</td>
<td>3 - 6</td>
<td>~20</td>
<td>None</td>
<td>~5</td>
</tr>
</tbody>
</table>
Module Design @ last meeting

- Preshower (PS) – HERMES/LHCb style passive radiator + scintillator
  - 2 $X_0$ Pb radiator + 2 cm scintillator tile w/ WLS readout
- Shower – COMPASS style Shashlyk calorimeter design
  - Layer structure: 0.5 mm lead + 1.5 mm scintillator + 0.12 mm gap (x2); $X_0 = 24$ cm, $R_M \sim 5$ cm, 194 layers, 43 cm total in depth
Updates since last meeting

- Additional Scintillator pad before Preshower for photon background rejection – for FAEC, being discussed for LAEC.

- Module shape changed from $10\times10\text{cm}^2$ square to $100\text{cm}^2$ hexagon ($6.25\text{cm}$/side) due to support design.

- Now include background in the PID and other performance simulation

  - today will report on SIDIS FAEC PID & Trigger;
  - work ongoing for SIDIS LAEC and PVDIS.

- Updates on fiber connection and total EC cost estimate
Photon-rejecting Scintillator Pad

- Scintillator Pad (SPD): 0.5cm, reject high energy photons for electron trigger and hadron trigger at SIDIS forward angle.
- Less segmentation than PS, readout by WLS fiber → clear fiber → PMT.
Simulation
Thin scintillator pad to reject $\gamma$'s at trigger level

- 5mm Sc pad;
- Background dominated by low energy electrons: 20% from end cap of heavy GC, other from more upstream
- Have to be placed before MPRC (which has lots of material for conversion)!

**Graph:**

- Background rate per cm$^2$ in Sc:
  - Electron
  - Low energy $\gamma$
  - All

**Axes:**
- R(cm)
- $10^2$
- $10^4$
Optimizing # Segment

- Photon background dominated by 1-2 GeV.
- A 50ns coin window with corresponding calorimeter (Shower) assumed, will be better at FPGA level.

- Trigger require 5:1 rejection → 120 segments (could be 60 fans divided into 2 sections/fan) → 2MHz MIP rate/segment
Hexagon Calorimeter Simulation

Projection along z

Projection in sideview

3GeV electron shower on hexagon calorimeter grid;
Support Al plates just added, not used in the results of following slides
PID with Hexagons

- Revised with hexagon, no big diff.
- No background yet included

(last meeting: square module 3x3 clustering 94% electron efficiency)

![Graph showing π and e efficiency](image)

- Preshower ID power drop significantly at this bin
- Expect go high w/ higher stat.
Status of Background Simulation

3rd iteration of GEMC + CaloSIM background study
Calorimeter Background Simulation with GEMC + CaloSIM

- GEMC simulate background particles at the front surface of EC (Zhiwen);
- CaloSIM build calorimeter response;
- Combine above two and sum over all contributions (EM, DIS, pi0, pi+, pi-) stochastically within a 50ns coincidental window → background distribution at each trigger
- Embed background into signal simulation (high energy e, pi) and perform analysis (clustering, e/pi separation, etc.)
2X₀ of Pb in preshower reduces photon background from 1GHz/cm² to 10kHz/cm² (MIP signal), still, 1-100MeV photons dominate.

- 3MHz MIP rate / 100cm² PS at inner radius;
- 10x lower at outer radius, could bundle multiple modules for PMT readout.

![SIDIS FAEC Background Graph](image)
Background Energy deposit in Scintillators

- **E_{PS}(MeV)** vs. **E_{SH}(MeV)**
  - *bg vs. e*-
  - significant in preshower

- **Counts per 0.2MeV for 50k events**
  - *bg vs. π*-
  - less significant for shower

- **E_{PS}(MeV)** vs. **E_{SH}(MeV)**
  - *bg vs. π*-
  - vs. e*-

- Signal distribution, Black: background, Red: Electrons
  - signal distribution, Black: background, Red: π

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**Notes:**
- Counting electrons vs. background is significant in preshower.
- Electron background is less significant for shower.
SIDIS FAEC PID w/ background: No change in eff., reduced rejection at low-p

\[ \pi \text{ efficiency} \]

Rejection reduced due to preshower pile up

\[ e \text{ efficiency} \]
Radiation dose prediction now with background – remain stable

- Dose is not a problem for SIDIS configuration.
- Calorimeter design should stand 500krad, now expect 100krad – nice safety margin
- Still missing final PVDIS radiation dose, need final baffle w/o direct line of sight.

SIDIS – He3– Large Angle Calorimeter

SIDIS – He3– Forward Calorimeter
Hexagon Calorimeter Trigger with Full Background

6+1 cluster contains ~96% of shower energy
Hexagon Calorimeter Electron Trigger Using 6+1 cluster energy

- Do observe very high electron efficiency in simulation.
- However, shower cut must be low to accept low-p electrons. This limits the rejection for high-p pions. See next slide.

Possible solution:
- From DAQ group (Xin, Alex): use position dependent threshold,
- consider including preshower trigger.
HEX1+6 Trigger
> 0.95GeV

HEX1+6 Trigger
> 1.95GeV

π efficiency with cut

E/p vs. p

Accepted

All
Hexagon Calorimeter Pion Trigger Efficiency

- Trigger cut: HEX1+6 trigger raw signal > 85% MIP (which is MIP – 2σ = 220MeV calibrated)
- Background passes this cut: rate ~20Mhz, dominated by photon.
- With a 5:1 photon suppression from scintillator, we get ~4MHz total trigger rate, which fit in the DAQ limit (PR12-10-006)
- Will join global DAQ study for final verification
Design Updates – Fiber connectors
@ last meeting

LHCb shower
Now: Fiber connector conceptual design from LEONI Fiber

- 100 fibers/connector:
  - made of Al
  - 35% light loss at worst
  - $100/each

- fiber bundle to PMT connector, estimate $25/module (Leoni)
- 1-1 fiber for PS: $10 each (other companies)
Budget @ last meeting

<table>
<thead>
<tr>
<th></th>
<th>Per module cost ($)</th>
<th>All module cost (M$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module material</td>
<td>700(L)/250(S)</td>
<td>1.26</td>
</tr>
<tr>
<td>Module production</td>
<td>800(L)/500(S)</td>
<td>1.49</td>
</tr>
<tr>
<td>Clear fiber</td>
<td>260(L)/65(S)</td>
<td>0.46</td>
</tr>
<tr>
<td>Fiber connectors</td>
<td>150</td>
<td>0.27</td>
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<tr>
<td>PMTs</td>
<td>600*2</td>
<td>2.34</td>
</tr>
<tr>
<td>Labor</td>
<td>5 tech and 5 student years</td>
<td>1.3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7.12</td>
</tr>
<tr>
<td>Total + 30% contingency</td>
<td></td>
<td>9.26</td>
</tr>
</tbody>
</table>

- + Prototyping ~ 0.3 M$
- + Support ~
Budget Update (no new Sc Pad yet)

- IHEP (not including fibers) for 1700 PS+SH
  - Preshower: $112k-$120k
  - Shower: $549k-$651k
  - Structure+assembly: $255k-$340k
  - IHEP total: ($1.22-$1.51)M + 24% overhead (2012 rate) = ($1.51-$1.87)M

- Fiber connectors+tubing (Leoni+other): ~$300k

- WLS+clear fibers(?): $703k (S.G.) - $2.47M (Kuraray)

- PMTs: $600x2x(~1900) = $2.28M

- Total from above (no contingency): ($4.8M-$5.2M) if using S.G.; $(6.6-7.0)M if using Kuraray

- Labor? Shipping? Overhead? Contingency?
Plan

- PID and Trigger study with background for SIDIS LAEC and PVDIS;
- Discussing overlapping module readout with DAQ group;
- Ongoing studies to reduce PMT cost:
  - Multi-anode PMTs ($100/channel) to read out Preshower, but there are gain matching issues.
  - Smaller PMTs to read out Preshower
  - Need solid quotes for PMTs
backup
Simple illustration of timing pileup vs. 
# segments – using only 1MIP events

30 sectors
8 MHz MIP
(40%)

60 sectors
4 MHz MIP
(20%)

240 sectors
1 MHz MIP
(5%)
Online: Trigger with background

Hadronic shower which introduce a pion contamination, usually spread into larger area compared to EM shower. A localized trigger, e.g. HEX1+6 trigger can significantly suppress the hadron response, while maintaining high eff. for electrons.
Shower – quick review

Choice of technology
Shashlyk design was chosen based on advantage of radiation resistance + cost + ease of readout
Features
Pb/Scint ratio 1:3 (V) : chosen to reach $<5\%/\sqrt{E}$ energy resolution and $\sim100:1$ pion rejection
Scintillator thickness of 1.5mm: based past designs to balance sampling fineness VS lateral light transmission loss
Total length of 20 $X_0$: contain 98% of shower and maximize pion-electron difference
→ MIP = 270 MeV (real) / 320 MeV (reconstructed)
Lateral size of 10x10 cm²: max size allowed (to reduce $$) before position resolution significantly deteriorates ($\sigma\sim1$ cm after cor.)
Choice of technology
HERMES/LHCb style VS full Shashlyk design, former is much easier to readout and high in radiation resistance

Features

Absorber of 2 X0 lead:
- Thinner – loose preshower rejection
- Thicker – loose shower resolution
- Scanned for 1.5, 2 and 3 X0;
- 2 X0 serve SoLID best

Scintillator of 2 cm:
- MIP = 4 MeV, electron cut ~ 3 MIP
Simulation setup with hexagon calorimeter modules
Back up 1/2 for previous slides

Electron eff. for SIDIS large angle calorimeter

- All events
- Accepted events w/ 3D cut
Back up 2/2 for previous slides

Pion eff. for SIDIS large angle calorimeter

- All events
- Accepted events w/ 3D cut
Backup - Simulated efficiency & rejection

- Electron
- Pion
- Photon

Energy range: 1-7 GeV, flat phase space for SIDIS-forward ~1.7 γ-rej

Cut on energy dep.
Most photon focus on lower energy side ($\pi^0$ decay)
And lower energy photon produce less back scattering
Therefore, do the study again with $1 < E_\gamma < 2$ GeV
Design Updates
- Shape
Change from square to hexagon

Main reason from supporting structure and layout (see Paul Reimer’s talk)
Physics feature should be similar to square shape and we will go through test and prototyping
Design Updates
- Layout Update
SIDIS and PVDIS FAEC (beam view)

Both can share supporting structure, only need to move along beam direction to change configuration.

Supporting structure needs to be made from 100cm to 261cm.
Ideas to minimize SIDIS LAEC Acceptance gap

We want to cover full azimuthal angle and leave no gap between modules, so module can not be tilted and need to be along Z axis.

Prefer having short outer module so that the outer module area can cover more and inner module area can cover less.

Inner module need to be special shape to avoid blocking acceptance. One way to solve it is to have smaller 5x5cm (like COMPASS) module with various length.

Assume 600mm full module length

Blue: LAEC acceptance angle
Orange: angle between inner and outer
Yellow: angle between inner and outer

Reviewed using G4 simulation next few pages
SIDIS LAEC (beam view)

Type I (10x10cm) module in blue, type II (5x5cm long) module in green, type III (5x5cm short) module in purple. Supporting structure needs to be made from 75cm to 140cm.
Design Updates
- Edge effects for LAEC
LAEC layout in G4 Simulation
LAEC in full standalone G4 Simulation
Track transportation provided by GEMC, CLEO field
How much does inner modules help?

- LAEC catch 80% of shower
- Go freely to forward acceptance
Design Updates
- Shower cluster size cut
Previously showed pion rejection.

PID selection used 3-D cut on PS, e/p and momentum
PS and e information come from sum signal in all non-zero modules
Enemy here is very specific: almost fully absorbed hadronic shower with high energy deposition

94% electron eff.
Shower area difference

Electron shower

Hadronic shower (e/p > 80%)

R spread (mm)

Φ - spread (mm)

Notice the difference in color scale
Apply additional cut to limit max size of cluster around track projection

Limit cluster to be no larger than 3x3 modules around track projection to
shower central depth

Minor cut on EM shower but effectively removed hadronic showers of very high
energy deposition

w/ >= 94% electron eff.

Flat phase space in PVDIS acceptance

BIG improvement @ high p end
Can it be further improved?

Further limit cluster to be not larger than 2x2 modules around track projection to shower central depth
Now loose ~5% of EM shower, but hadron shower cuts faster

Change cut and maintain >=94% electron eff.
All hadron rej. better than 100:1

Flat phase space in PVDIS acceptance
Design Updates
- Radiation dose
What’s new

LHCb/HERMES preshower, instead full Shashlyk preshower
As shown before, the preshower scintillator receive most of the radiation, due to the low energy backgrounds
This part radiation dose are now absorbed in 2X0 absorber, and we just see its EM tail now
Especially, lead absorber effectively kill all low energy electron background
New background distribution updated by Zhiwen
SIDIS:
  - With target collimator (suppress background by 4)
  - First large angle simulation
PVDIS: have option to remove direct photon sight (expected to be removed in the final baffle design)
Dominating background, photons 1-10 MeV
After preshower, which attenuate them a lot, they still penetrate ~10 layers in Shashlyk
PVDIS - current baffle (with direct $\gamma$)

$\gamma$ dominate
But attenuated quickly
PVDIS - preview for a baffle w/o direct $\gamma$

$\gamma$ get reduced by $\sim 5$

$\pi$- become important here
SIDIS - Forward

γ dominate
But attenuated quickly
SIDIS - Large-Angle

γ dominate
But attenuated quickly

Layer #1 is 2cm preshower scint.
Light Readout
WLS fiber in scintillator pad

Drill on scintillator and glue WLS in
Used by LHCb etc.
Will use by CLAS12 FT-Hodo
Fiber

WSL fiber in shower, 100/module
Bicron BCF-91A
- multi-clad, 1/e length >3.5m
- 1mmD, bend 20cmD (?)
- $0.87/m
- less rad hard

WLS fiber in preshower pad, 1-2/module
KURARAY Y-11(200)MS
- multi-clad, 1/e length >3.5m
- 0.5mmD, bend 5cmD
- $1/m
- more rad hard

Clear fiber for both, 101-102/module
Bicron BCF-98
- $1/m
Fiber connection

- fiber bundle to PMT connector, cost estimate $25/module
Readout

PMT option - Hamamatsu R3998-02
28mmD Bialkali Photocathode
$600 each
Used by CLAS TPE calorimeter which has COMPASS module
As our baseline design
APD/SiPM option
High resistance to magnetic field
Need to be careful due to high neutron background
Contacting vendor for high radiation resistance designs (sensor + amp.)
Estimating neutron background @ photon detectors
Budget Update
## Budget table - calorimeter group

<table>
<thead>
<tr>
<th>Component</th>
<th>Per-module cost($)</th>
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</tr>
<tr>
<td>Labor</td>
<td>5 tech years, 5 student years</td>
<td>0.75</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>6.7</strong></td>
</tr>
<tr>
<td>Total+ 30% contingency</td>
<td></td>
<td><strong>8.7</strong></td>
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</table>

+ Prototyping ~ 0.3 M$
Lab estimate : 5.7 (base)+3.8 (Labor)
JP : 6.2 (base) + 1.3 (Labor)
Budget Update
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+ Prototyping ~ 0.3 M$
Lab estimate : 5.7 (base)+3.8 (Labor)
JP : 6.2 (base) + 1.3 (Labor)
What we need
What we need

Engineering support (Zhiwen)
Support structure
How to do maintenance and install it back
Inquiries
IHEP (Xiaochao)
Fiber connection (Mehdi)
Photon detectors (Zhiwen)
Background effect (Jin)
Event mixing with signal and background simulation
Prototyping
Support structure ideas

Overview
One support for LAEC, one support for FAEC
Only a few cm gap between outer radius of SIDIS LAEC and inner radius of cryo, is it enough?
Only a few cm gap between outer radius of FAEC and inner radius of nose cone, is it enough?
Need to consider the supporting with overall magnet cryo and yoke structure.

“super” Modules
Group 1-3 row of modules into supermodule
shift supermodule’s horizontal position to make layers
backup
WLS radiation hardness

Table 1
Optical properties of each type of WLS fibers before the irradiation. Average light output at 140 cm and RMS, average attenuation length ($L_{att}$) and RMS, for ten fibers of each type. The values are normalized to $I_{140}$ of the Y11(200)MSJ fibers.

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>$I_{140}$</th>
<th>RMS (%)</th>
<th>$L_{att}$ (cm)</th>
<th>RMS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCF91A MC</td>
<td>0.98</td>
<td>9.6</td>
<td>280</td>
<td>9.5</td>
</tr>
<tr>
<td>Y11(200)MSJ</td>
<td>1.00</td>
<td>1.8</td>
<td>280</td>
<td>1.6</td>
</tr>
<tr>
<td>S250-100</td>
<td>0.81</td>
<td>5.7</td>
<td>230</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Table 2
Relative light output at $x = 140$ cm, for total doses of 1.16 and 6.93 kGy.

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>$\frac{R(140)}{R(30)}$ for 1.16 kGy</th>
<th>$\frac{R(140)}{R(30)}$ for 6.93 kGy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 days 1 day 10 days</td>
<td>0 days 1 day 10 days</td>
</tr>
<tr>
<td>BCF91A MC</td>
<td>0.83 0.86 0.85</td>
<td>0.54 0.56 0.56</td>
</tr>
<tr>
<td>Y11(200)MSJ</td>
<td>0.87 0.92 0.91</td>
<td>0.71 0.72 0.74</td>
</tr>
<tr>
<td>S250-100</td>
<td>0.60 0.70 0.81</td>
<td>0.52 0.55 0.64</td>
</tr>
</tbody>
</table>
Fiber splicing

Robust connection and excellent transmission (2%) CLAS12 Forward Tagger Hodoscope will fuse WLS and clear fiber. Commercial vendor has been contacted and They are also developing their own method. We will collaborate with them to examine the labor and cost requirement.