Status and plans for Pb(W)-LYSO Shashlik Simulations (DESY Workshop and Beyond)

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intro

This is an attempt to summarize Shashlik simulations for two options Pb-LYSO (4 cm + 2 cm) and W-LYSO (2.5 cm + 2 cm)

- Current understanding
- Work of many people. You may not recognize your plots/results but it is there. It is used to make these plots or cross check these results.
- First goal is to have parameterized performance ready by DESY
- Second goal is to have working and validated configuration for FastSim by DESY
- Time scale for results

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1 Energy Resolution

- Leakage
- Sampling
- Photo-Statistics
- Noise
- Constant

Energy Leakage

Longitudinal leakage

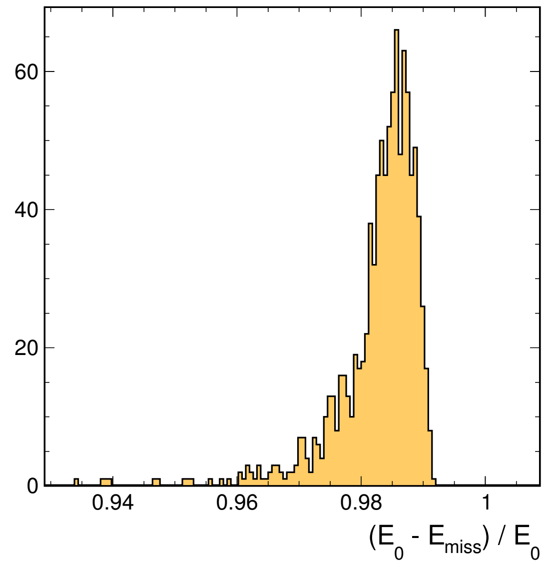
- depends on total length
- same for $PbWO_4$, Pb-LYSO, W-LYSO ($\sim 25X_0$)

Transverse leakage

- depends on clustering algo
- depends on correction algo (MVA)
- assumed zero for now (best case scenario)

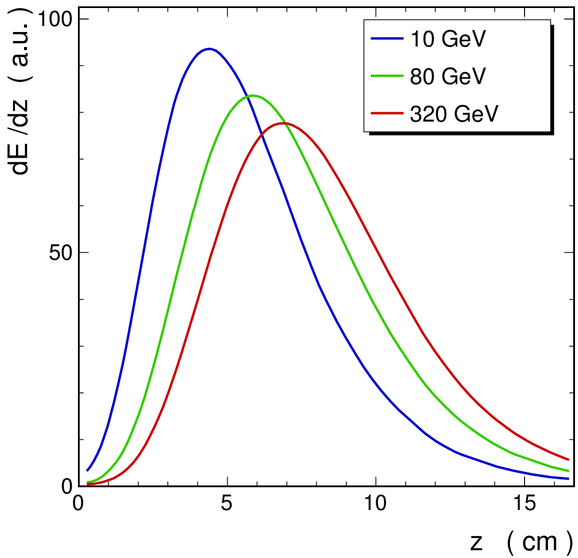
Non-Gaussian

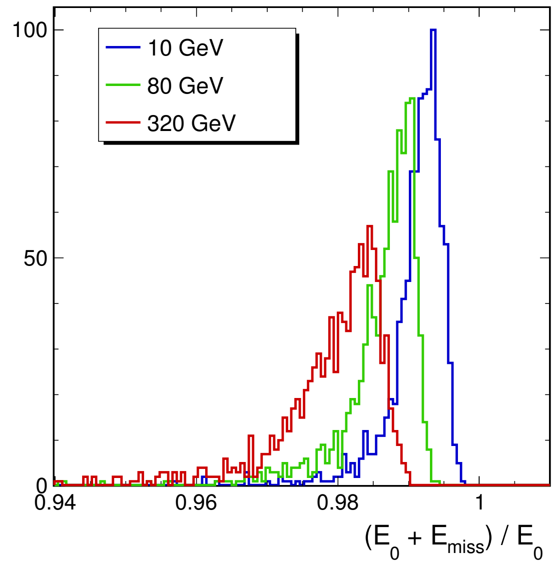
- described by $\sigma_{\rm eff}$ (68% interval)



Energy dependence of Leakage

Left: Longitudinal shower profile in Pb-LYSO
Right: Energy deposited in Pb-LYSO





Energy Leakage Parameterization

Grindhammer and Peters parameterize longitudinal EM shower profiles

$$\langle\frac{1}{E}\frac{dE(t)}{dt}\rangle = f(t) = \frac{(\beta t)^{\alpha-1}\beta exp(-\beta t)}{\Gamma(\alpha)}$$

Good description of Geant4 simulation with additional 0.24% resolution term.
Leakage resolution in %

$$\frac{\sigma_E}{E} = f \oplus 0.24\%$$

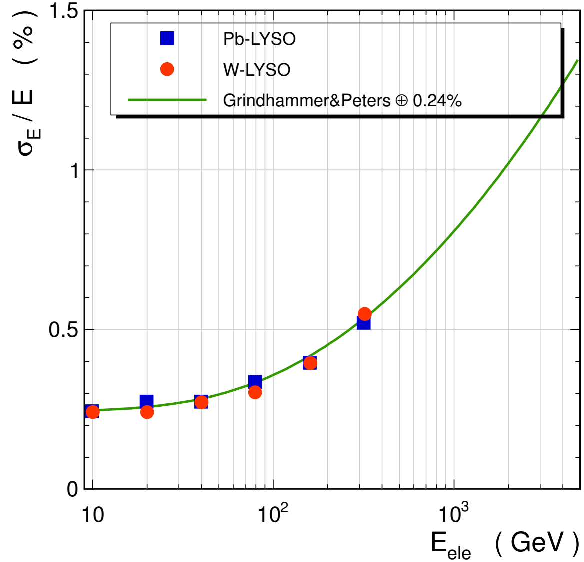
$$f = p_0 + p_1 \cdot lnE + p_2 \cdot (lnE)^2 + p_3 \cdot (lnE)^3$$

$$p_0 = 0.101349$$

$$p_1 = -0.0621358$$

$$p_2 = 0.0176115$$

$$p_3 = 7.87208e - 04$$



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MIP Sampling Fraction

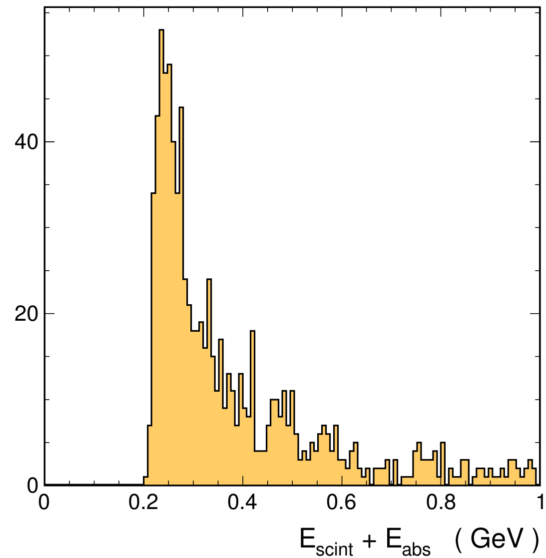
Sampling fraction

$$f_{mip} = \frac{E_{scint}}{E_{abs} + E_{scint}}$$

Use muons
Not all muons are MIP!
Apply $E < 300$ MeV

MIP Sampling fraction does not depend on energy of muons

	10 GeV	320 GeV
Pb-LYSO	0.268	0.264
W-LYSO	0.259	0.257



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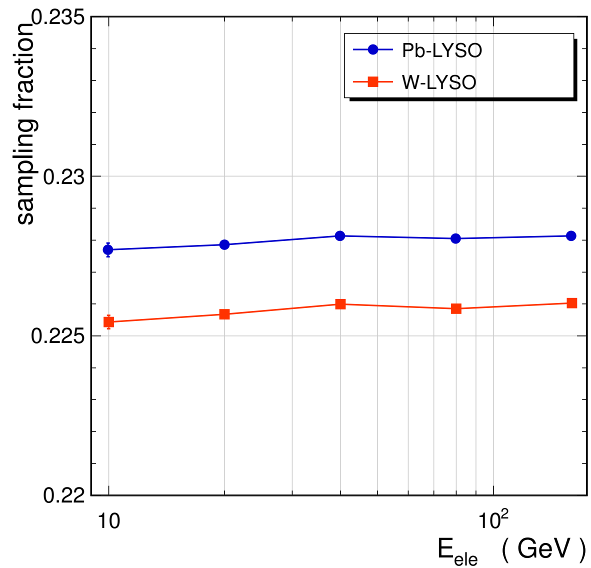
Electron Sampling Fraction

Sampling fraction

$$f_e = \frac{E_{scint}}{E_{abs} + E_{scint}}$$

Very slight dependence on energy

	f_e
Pb-LYSO	0.228
W-LYSO	0.226



e/mip

	f_e / f_{mip}
Pb-LYSO	0.857
W-LYSO	0.876

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Sampling Resolution for Electrons

Sampling fraction

$$f_e = \frac{E_{scint}}{E_{abs} + E_{scint}}$$

Sampling resolution

$$\frac{\sigma_f}{\langle f \rangle}$$

- Gaussian distributions of f
- Perfect $1/\sqrt{E}$
- Both options (Pb and W) have almost identical sampling by construction

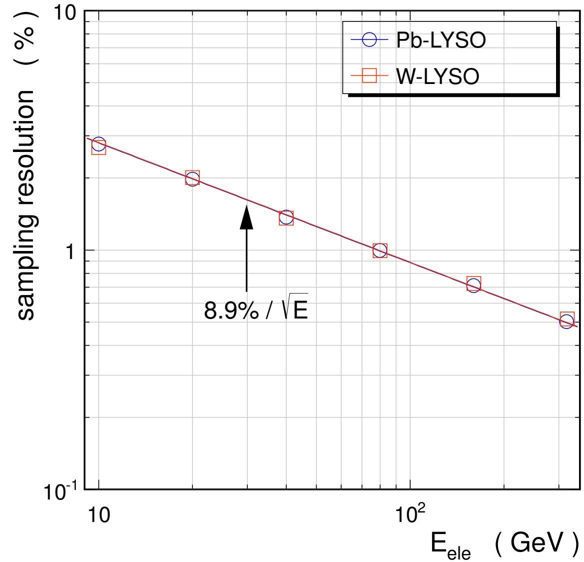

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Photo Statistics (LY)

We have Renyuan's measurements that include:

- LYSO tile 2.5×2.5 cm^2
- Four WLS fibers of 40 cm long
- Photo-Detetor is PMT with $\sim 10\%$ QE

This is very realistic and conservative setup. The direct measurement of $LO_{test} =\sim 20$ p.e. per MeV of deposited energy in LYSO

Assuming

- Final choice of fibers will provide collection as good as WLS
- Final choice of photo-detector will provide QE as good as PMT

...the expected light output is

$$LO = LO_{test} \times f_e = 20\ p.e. \times 0.227 = 4.5\ p.e./MeV$$

Photo Statistics (LY)

Pb-LYSO (W-LYSO) Light Output of 4.5 p.e. per MeV of incident electron results in photo-statistic term of energy resolution

$$\frac{\sigma_E}{E} = \frac{1.5\%}{\sqrt{E}}$$

EE undamaged as measured in TestBeam has stochastic term for energy resolution

$$\frac{\sigma_E}{E} = \frac{5.4\%}{\sqrt{E}}$$

Expected Light Output for Pb-LYSO (W-LYSO) is $\times 13$ higher than $PbWO_4$ EE before radiation damage. This has been achieved already.

Birks law: Do we need to apply it for $PbWO_4$ and LYSO?

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Noise (choice of Photo Detector and Front End)

We don't have direct measurements for the Strawman option
We don't know what are the options yet

We can use realistic scenario

- Photo-detector is VPT with photo-cathode similar to PMT in Renyuan's tests
- VPTs are the same as in EE in any other aspect
- Front End is identical to current EE
- Performance is very well known!

Single channel noise in EE is $\sim$140 MeV.
Using stochastic term of 5.4%/$\sqrt{E}$ one can express 140 MeV = 48 p.e.
Single channel noise in Strawman 48 p.e / 4.5 p.e/MeV = 10.7 MeV ($\times$13 lower than EE!)

Assume one needs 9 channels (3$\times$3) to reconstruct EM shower,
noise term in energy resolution

$$\frac{\sigma_E}{E} = \frac{0.032\ GeV}{E}$$

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Can we see muons?

- MIP is $\sim$250 MeV
- Sampling fraction f_{mip} = 0.262 (average)
- MIP in p.e = 250 MeV $\times$ 0.262 $\times$ 20 p.e/MeV = 1310 p.e
- Single channel noise = 48 p.e.
- MIP is $\times$27 larger than noise

Yes, we can see muons clearly!

Total Energy Resolution

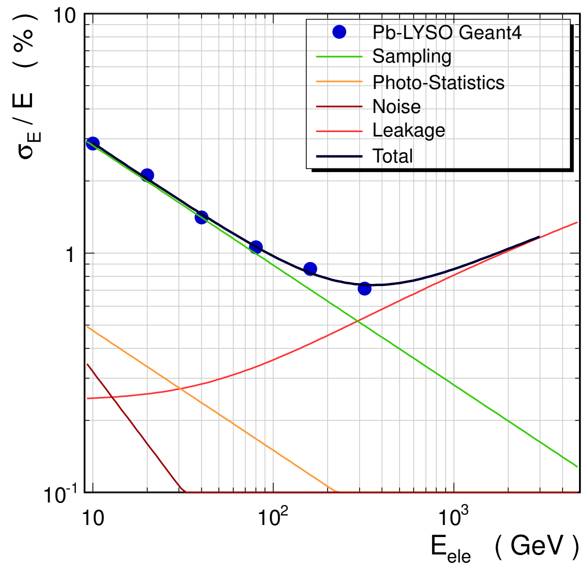
- Similar values for Pb-LYSO and W-LYSO
- Dominant terms: sampling and leakage

What's next? Additional terms due to light collection non-uniformity (longitudinal and transverse)

- Can estimate it with Litrani/Geant4
- If effect is large, it can be mitigated by modifying the configuration
- Should be kept as low as possible
- **Catch:** what is possible can be determined by R&D only!
- For now, assume ZERO. Proceed with Litrani/Geant4

For Standalone:

- Photo-Statistics: 20 pe/MeV in LYSO
- Noise: 48 p.e. per channel



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Radiation Damage in Shashlik

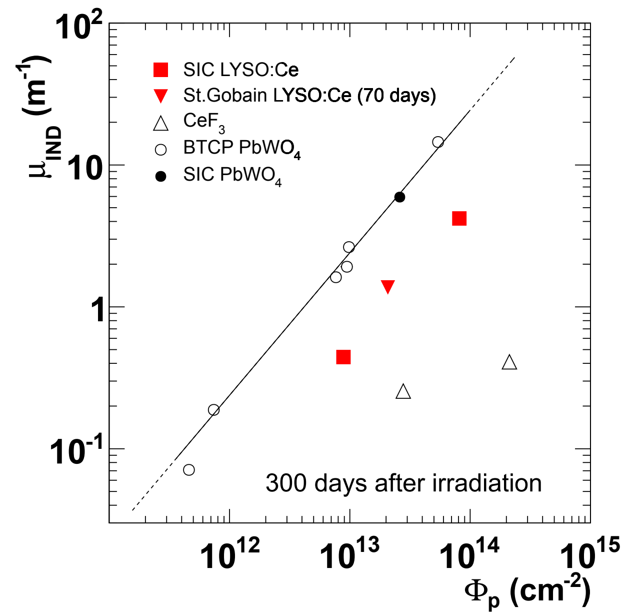
Degradation of efficiency for light collection can be simulated with Litrani.

Assumptions under current scenario

- Similar η dependence of dose, hadron fluence as in current EE
- Similar VPT degradation
- $\times$5 rad-harder than $PbWO_4$
- Evolution of Photo-Statistics
- Evolution of Noise
- Sampling and Leakage stay the same

Not known:

- EM damage
- Transport (fiber) damage



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Plans for Radiation Damage in Shashlik

Within about 1 week

- Model for Standalone
- Evolution of EM amplitude degradation vs η vs $\int L dt$
- Compare EE and Shashlik EM resolutions vs $\int L dt$
- Compare EE and Shashlik $H \to \gamma\gamma$ resolutions vs $\int L dt$

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Shashlik in FastSim

- Release
- Configs
- Validation

General status of Shashlik in FastSim

- Default CMSSW 61X has it
- Prepared config files for Pb-LYSO and W-LYSO based on G. Grindhammer and S. Peters *"The Parameterized Simulation of Electromagnetic Showers in Homogeneous and Sampling Calorimeters"*

Effective values

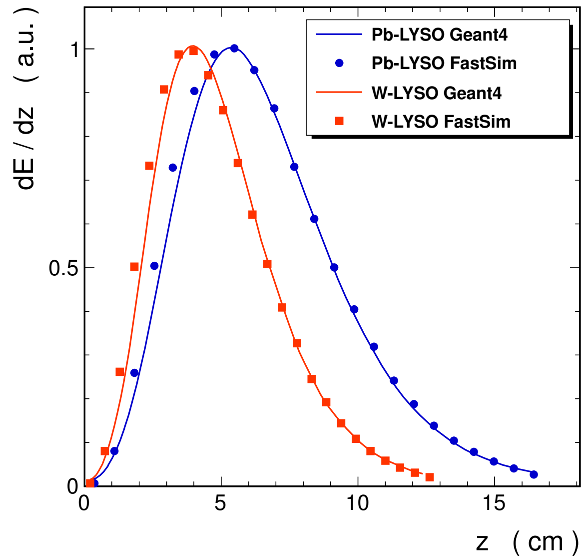
	Pb-LYSO	W-LYSO
A	189.46	172.21
Z	75.44	69.55
Density [g/cm^3]	9.99	13.94
Radiation Length [g/cm^2]	6.80	7.12
Molière Radius [cm]	1.75	1.08
Critical Energy [MeV]	7.99	8.51
Sampling Frequency (FS)	1.13	1.14
ê	0.84	0.88

Validation of Longitudinal Shower Shape

FastSim vs Geant4 for shower shapes for electrons with E=40 GeV

Tuning of effective radiation length

	X_0 [cm]
Pb-LYSO	0.73
W-LYSO	0.57



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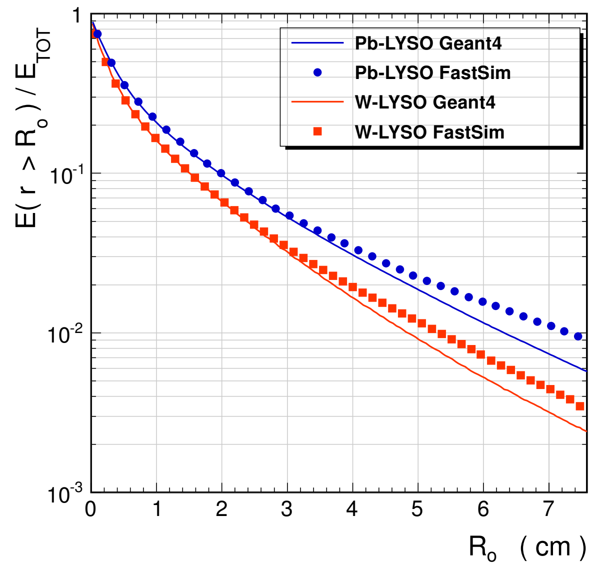
Validation of Transverse Shower Shape

FastSim vs Geant4 for shower shapes for electrons with E=40 GeV

Tuning of effective Molière Radius

	R_M [cm]
Pb-LYSO	2.10
W-LYSO	1.51



Plans for Shashlik in FastSim

Within about 1 week

- Validate shower shapes for low and high energy of electrons

Within about 2 weeks

- Validate sampling, photo-statistics and noise
- Total Resolution should agree between Geant4 and FastSim

Longer time scale

- Implement radiation damage in FastSim 61X for EE ($PbWO_4$) and Shashlik