Introduction: benchmarking and global optimisation

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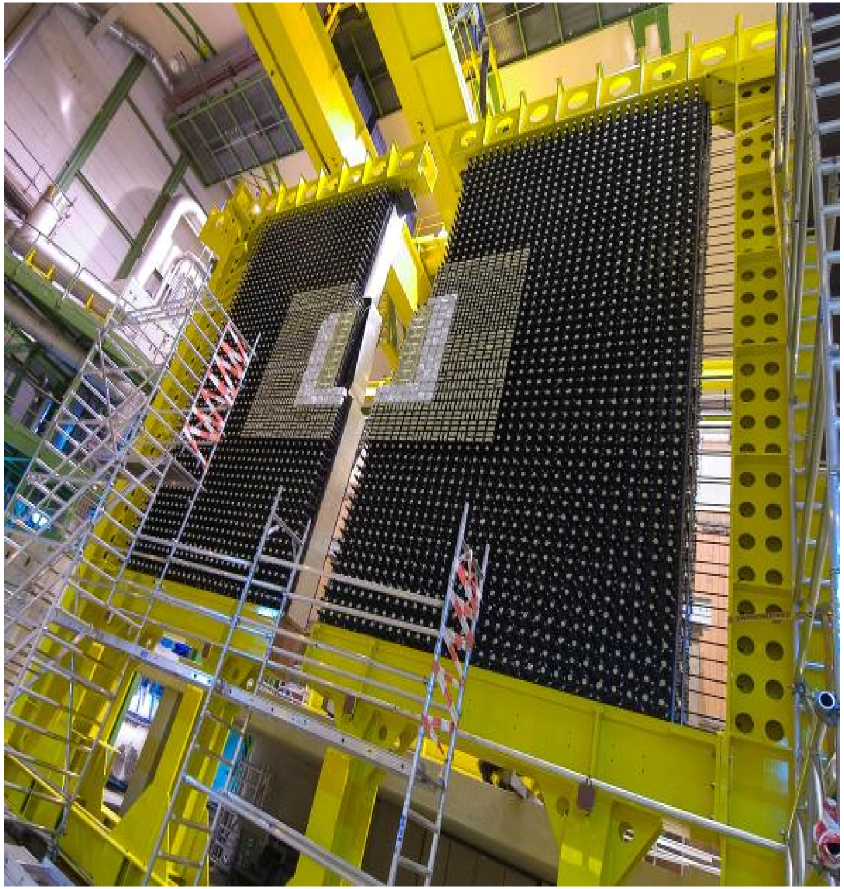
on behalf of the LHCb ECAL Upgrade II R&D group

CERN LHCb CRYSTAL CLEAR EP R&D

ECAL Upgrade II Workshop
Orsay, 13/12/2022



Introduction to benchmarking and global optimisation

• Physics benchmark studies for the FTDR have used stand-alone simulations of the ECAL: detailed Hybrid Monte Carlo approach (reminder on next slide) or faster, but more approximate simulations (e.g. talk by Daniele Manuzzi)

• Full simulation of the Run 3 detector upstream of the ECAL

• This approach was also extended to the LS3 detector configuration

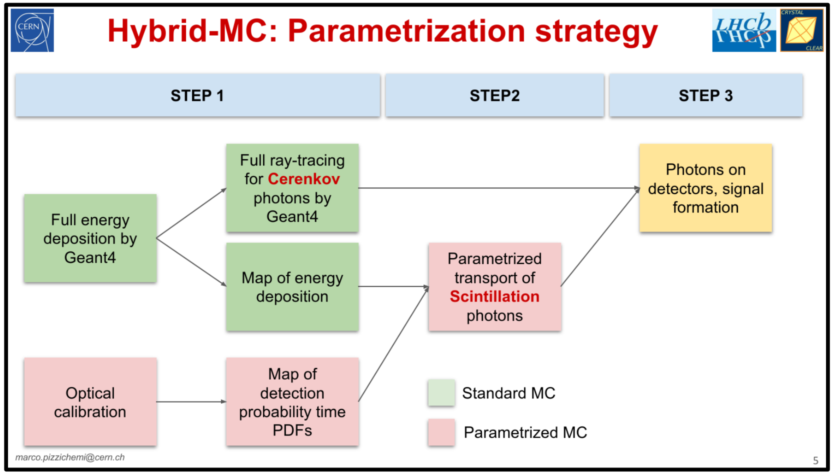
• Several physics benchmark analyses are ongoing, also in view of the TDR on the LS3 consolidation → following talks in this session

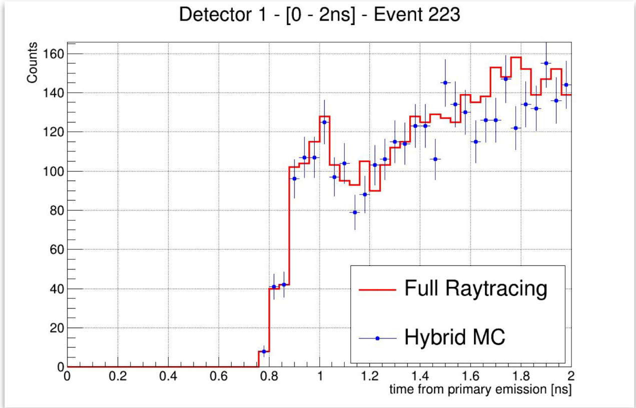
• The long-term goal is a global optimisation of the Upgrade II LHCb detector, recent common ECAL/VELO effort is a first step in this direction
→ see talk by Laurent Dufour

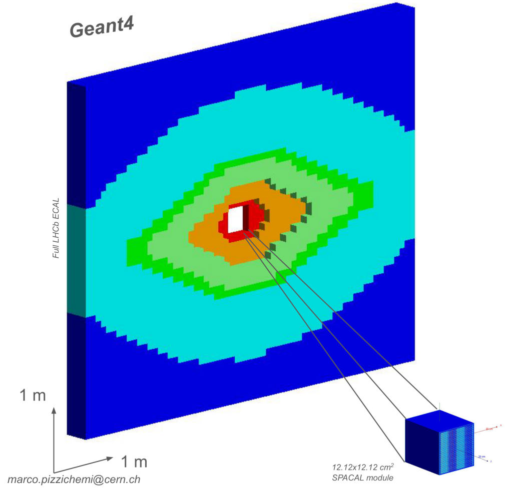
Overview

- Current developments in simulation and reconstruction
- Preparations for the LS3 TDR
- Preparations for the Upgrade II scoping document

Reminder: Hybrid MC simulations







- Geant4 simulation of energy deposition and parametrised transport of scintillation photons
- Different module types implemented: SpaCal, Shashlik
- Used from single modules (test beam) to full ECAL options (e.g. “Run4_rotated”, “Run5_rotated”, ...)
- Particle flux from full LHCb simulation can be included
- Parametrised response of photon detector (e.g. Hamamatsu R7600U-20, R7899-20, ...)

→ see talk by Marco Pizzichemi

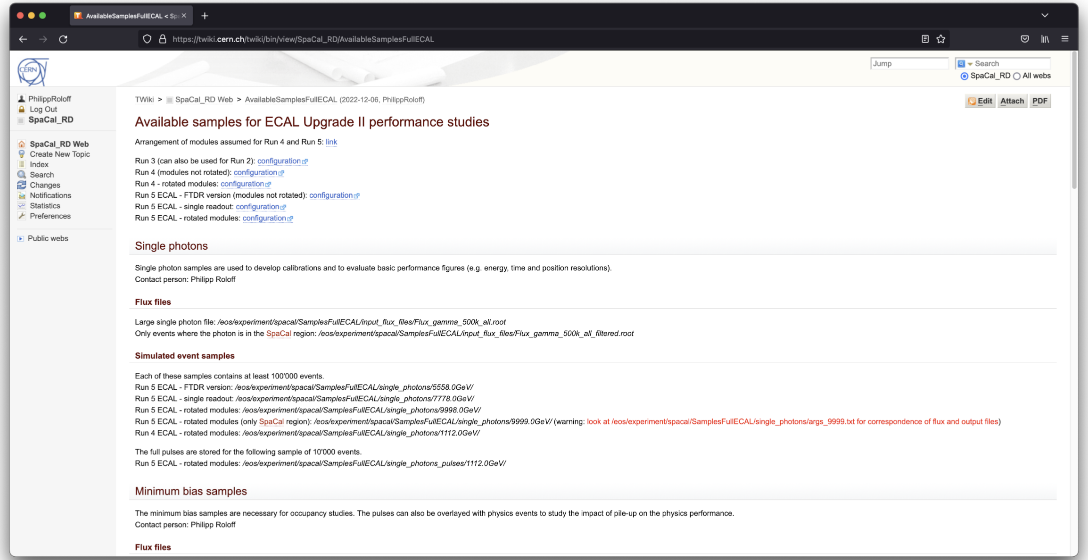
Available Monte Carlo samples

Available samples from Hybrid MC documented on wiki page:

- General-purpose (e.g. single photons, minimum bias) for the development of corrections, resolution / occupancy studies

- Physics samples (also with overlay of minimum bias) from the studies shown in this session

- Available at /eos/experiment/spacal
→ let me know in case you wish to have access



https://twiki.cern.ch/twiki/bin/view/SpaCal_RD/AvailableSamplesFullECAL

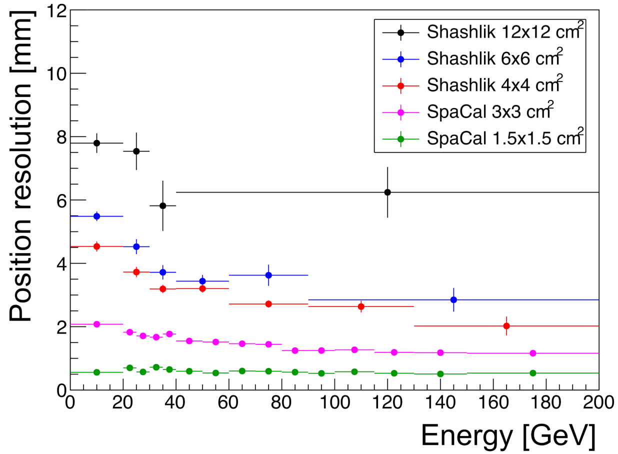
A few comments on reconstruction

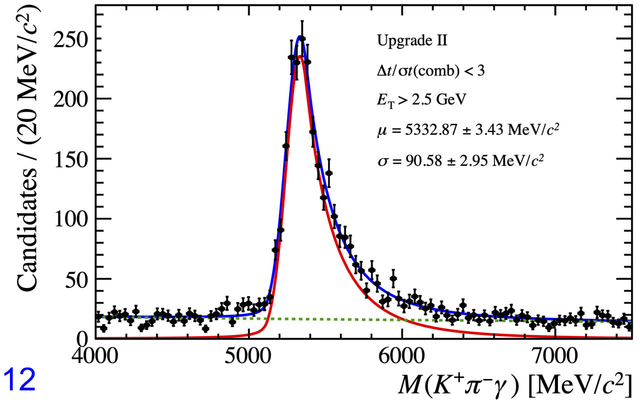
- Local reconstruction from current ECAL adapted for FTDR simulations
→ Including L, S and E corrections

- (Simplified) algorithms for Bremsstrahlung recovery and π^0 reconstruction exist
→ see talks by Federico Betti, Sasha Stahl and Daniele Manuzzi

- Potential for improvement from using longitudinal segmentation and timing in the clustering

- Effort ongoing to use regressors for position, energy and time reconstruction
→ see talk by Alexey Boldyrev





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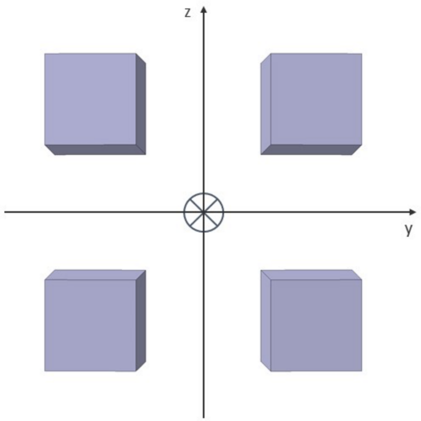
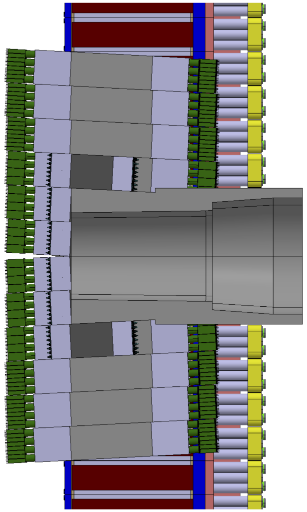
New: Tilted SpaCal modules

- The SpaCal region with tilted modules has been implemented in the hybrid Monte Carlo for the LS3 and LS4 configurations
→ see talk by Marco Pizzichemi

- L, S and E corrections adapted to rotated modules
→ more special cases needed for cells close to gaps
→ validated for Run5_rotated

- ML regressors also adapted to this case





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Next step: treatment of radiation damage

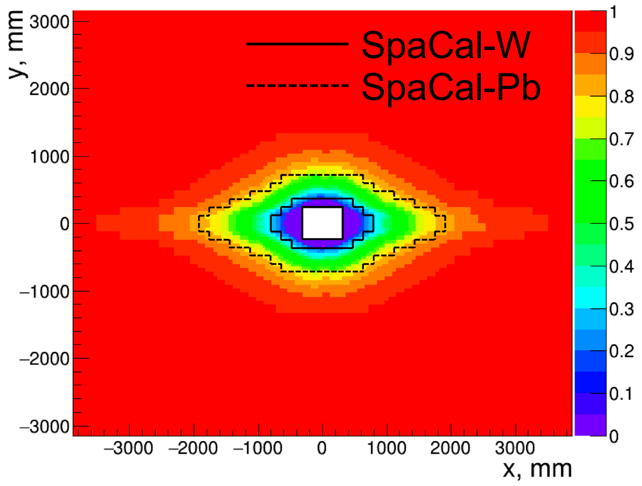
Example: significant radiation damage expected after Run 3

Strategy: scale attenuation length in Geant4 using measurements of irradiated material

• Scintillating fibres in SpaCal modules (already done for single modules)
→ see talk by Marco Pizzichemi yesterday

• Scintillator tiles and WLS fibres in Shashlik modules (implementation easy, needed for LS3 consolidation TDR)

ECAL cell light output after 2025 (48 fb^{-1})



Overview

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- Preparations for the LS3 TDR
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Considerations in view of the LS3 TDR

- LS3 configuration with rotated SpaCal modules available, assuming L = 2 x 10^{33} $cm^{-2}s^{-1}$
→ Processing time / computing resources no major problem
→ Simulation of full events (without merging signal + minimum bias afterwards) feasible

- No longitudinal segmentation
→ Reconstruction code inspired by current ECAL usable, can also benefit from new developments of ML-based reconstruction

- Need to fully understand if the timing in the SpaCal region (and also parts of the Shashlik) is relevant
→ Impact on $K^*\gamma$ and Bremsstrahlung recovery is small, but could be different for other cases (e.g. lower-energy π^0)

- How to deal with the neutron shield?
→ Leads to non-negligible increase of occupancy (most problematic for final states with π^0)
→ More photon conversions (e.g. increase from ≈ 50% to ≈ 60% in $K^*\gamma$ events)
→ So far included in all simulations (as part of the Run 3 detector)

Proposed program for LS3 benchmarking

Aim to have a few physics benchmark studies comparing the significance per fb for following configurations:

- Run 2: For comparison with published results
- Run 3: Skip if schedule too tight?
- Run 3 detector with radiation damage: crucial to illustrate what happens if we do noting during LS3
- LS3 detector: including rotated SpaCal modules

There is freedom to use the favourite decay modes of the analysers

→ However, the investigated channels ideally cover neutral pions, electrons and single photons at low and high energy!

Overview

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What do we need for the LS4 scoping document?

Goals in view of the scoping document:

• Fully illustrate the benefit of longitudinal segmentation with physics benchmarks (not foreseen for Shashlik region in downscoped option of the FTDR)

• Further optimisation of the baseline LS4 ECAL configuration, e.g. benefit of more SpaCal modules, additional SpaCal-W/Poly region
→ see my presentation from yesterday

• First steps towards global optimisation of the Upgrade II detector (minimum is to address common timing issues with the VELO group)

• Proper inclusion of luminosity decay in all studies

Important technical work needed:

• Improved clustering to make use of longitudinal segmentation and timing

• The detailed simulation is already an order of magnitude faster compared to FTDR times, but even more increase needed

This session

09:00 → 11:20	**Physics benchmarking of the baseline** Chair: Hassan Jawahery	200/0-Auditorium - Auditoriu...	
09:00	**Introduction: benchmarking and global optimisation** **Speaker**: Philipp Roloff (CERN)		20m
09:20	**Analysis report: K* gamma** **Speaker**: Liupan An (CERN)		15m
09:35	**Analysis report: electron-positron final states (B->Kee and Z->ee)** **Speaker**: Federico Betti (CERN) 2022_12_13_U2_CA...		15m
09:50	**Analysis report: neutral pions in D-meson decays** **Speaker**: Sascha Stahl (CERN)		15m
10:05	**Analysis report: B->J/psi pi0** **Speaker**: Alexey Boldyrev (NRU Higher School of Economics (Moscow, Russia))		15m
10:20	**Analysis report: B->pi+ pi- pi0** **Speaker**: Daniele Manuzzi (Universita e INFN, Bologna (IT))		15m
10:35	**Physics impact of VELO timing** **Speaker**: Laurent Dufour (CERN)		15m
10:50	**Plans of the simulation project** **Speaker**: Dr Mark Peter Whitehead (University of Glasgow (GB))		15m
11:05	**Discussion**		15m

Summary and conclusions

- Physics benchmarks using detailed simulations important:

- To demonstrate the capabilities the Upgrades we are proposing
- Comparison of different detector configuration options and further optimisation of our baseline designs

- The most urgent topic is to illustrate the physics potential of LS3 consolidation (32 + 144 new SpaCal modules with potential for timing, rearrangement of all ECAL modules in rhomboidal geometry)
→ More volunteers would be very welcome!

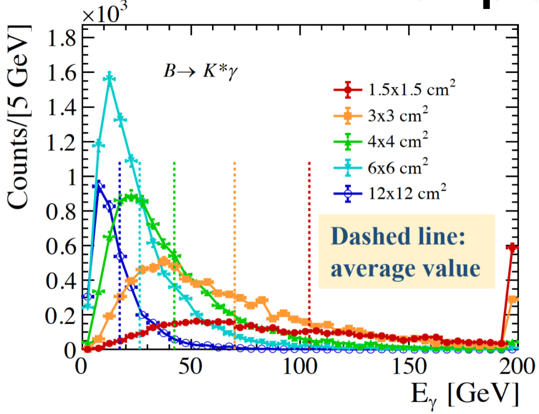
- Long-term goal is to port the geometry, digitisation and reconstruction to the full LHCb software framework for global optimisation of the Upgrade II detector-

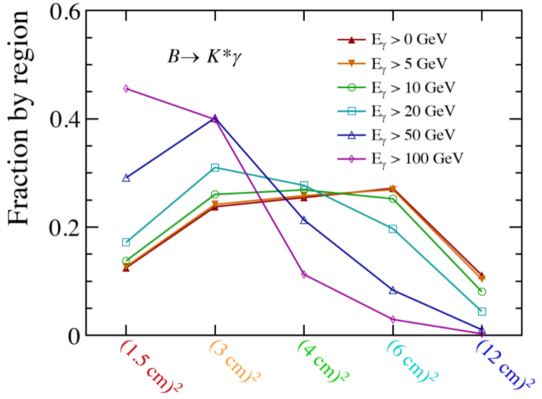
Thank you!

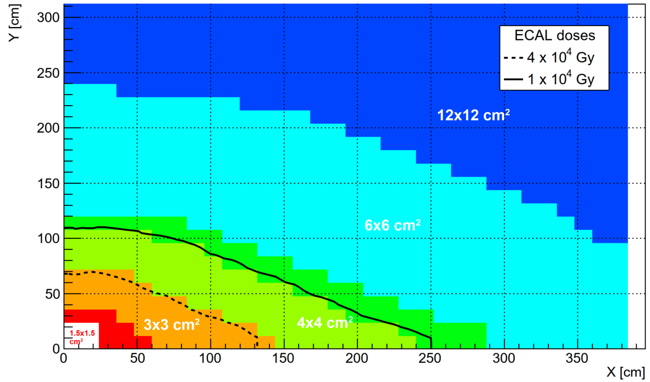
Backup slides

Comparison of different regions

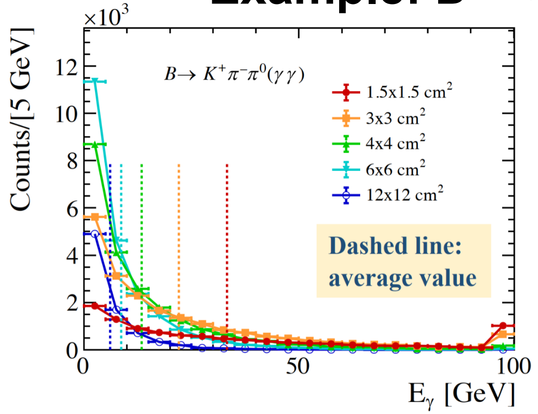
Example: $B^0 \rightarrow K^*\gamma$

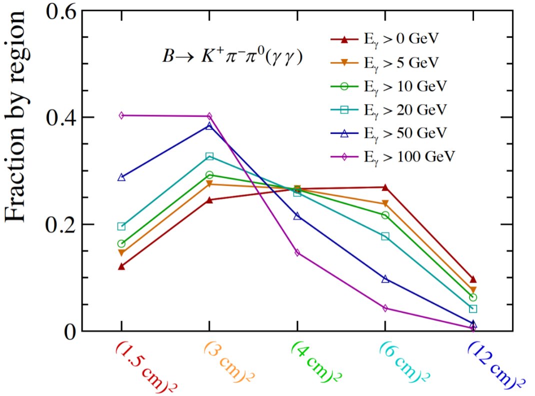






Example: $B^0 \rightarrow K^+\pi^-\pi^0;\ \pi^0 \rightarrow \gamma\gamma$

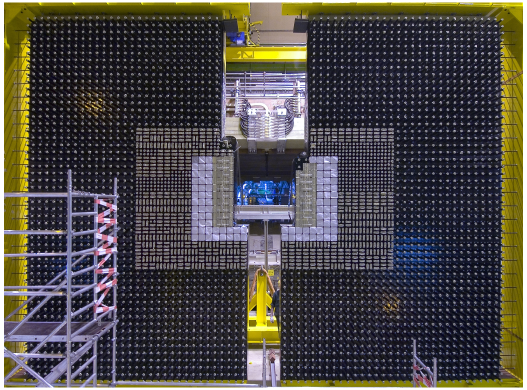


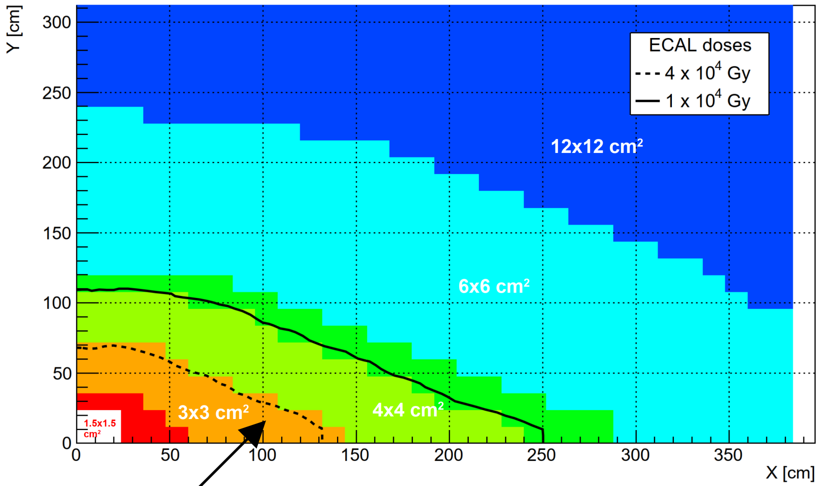


Fractions of photons in the different detector regions for 2 physics channels

→ The two inner regions are important for physics

Reminder: SpaCal/Shashlik ECAL for Upgrade II





Radiation limit of current Shashlik technology

Requirements for the Upgrade II:

- Sustain radiation doses up to 1 MGy and ≤ 6 x 10^{15} 1 MeV neq / cm^2 in the centre
- Keep current energy resolution of $\sigma(E)/E \approx 10\%/\sqrt{E} \oplus 1\%$
- Pile-up mitigation crucial

→ Timing capabilities with O(10) ps precision, preferably directly in the calorimeter modules

→ Increased granularity in the central region with denser absorber

SpaCal technology for inner region:

- Innermost modules with scintillating crystal fibres and W absorber

→ Development of radiation-hard scintillating crystals

→ 1.5x1.5 cm^2 cell size

- 40-200 kGy region with scintillating plastic fibres and Pb absorber

→ Need radiation-tolerant organic scintillators

→ 3x3 cm^2 cell size

Shashlik technology:

- Timing with new WLS fibres, long. segmentation (double-sided readout)

→ Cost optimisation by refurbishing ≈2000 existing modules for timing

→ Adapt to the required cell sizes by adding ≈1300 new modules

LS3 consolidation: W absorber for innermost modules equipped with scintillating plastic fibre for 2x2 cm^2 cell size

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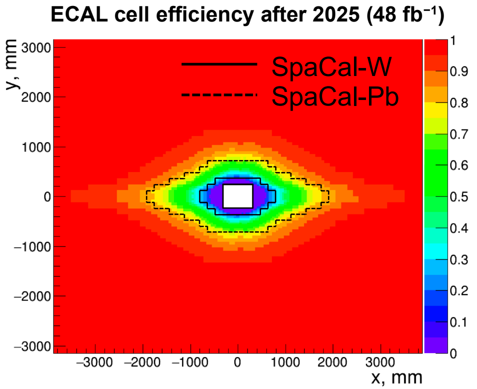
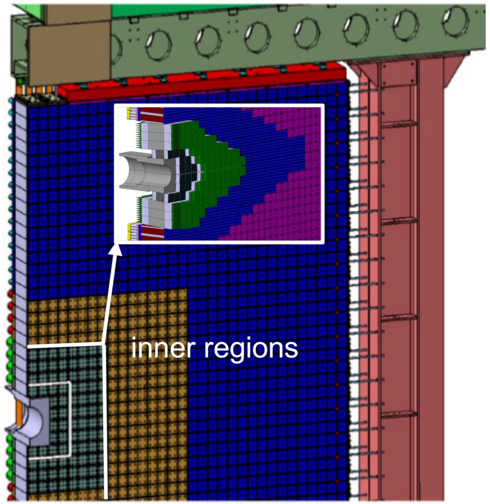
Reminder: LHCb ECAL upgrade strategy



Run 3 in 2022-2025:
Run with unmodified ECAL Shashlik modules at L = 2 x 10^{33} $cm^{-2}s^{-1}$

LS3 consolidation in 2026-2028:
Introduce single-section rad. tolerant SpaCal (2x2 and 3x3 cm^2 cells) in inner regions and rebuilt ECAL in rhombic shape to improve performance at L = 2(4) x 10^{33} $cm^{-2}s^{-1}$
→ 32 SpaCal-W & 144 SpaCal-Pb modules with plastic fibres compliant with Upgrade II conditions
→ Could include timing information with single-sided readout to inner regions

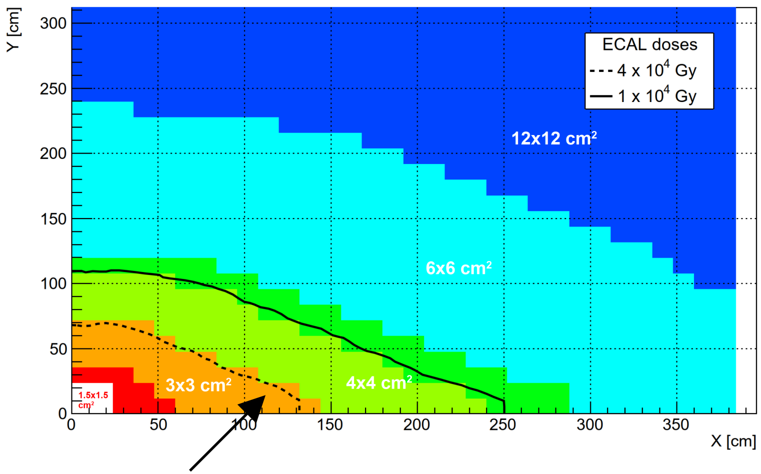
LS4 Upgrade II in ≥2035:
Introduce double-section rad. hard SpaCal (1.5x1.5 & 3x3 cm^2 cells) and improve timing of Shashlik modules for a luminosity of up to L = 1.5 x 10^{34} $cm^{-2}s^{-1}$
→ Innermost SpaCal-W modules equipped with crystal fibres
→ Include timing information and double-sided readout to full ECAL for pile-up mitigation



Reminder: Baseline configuration for Upgrade II

5 ECAL regions matching the radiation maps:

Cell size:	Modules:
1.5 x 1.5 cm^2	32 *new* modules for extreme conditions of up to 1 MGy
3 x 3 cm^2	144 *new* modules with "moderate" radiation requirements of up to ≈ 200 kGy
4 x 4 cm^2	272 *new* modules + 176 refurbished existing modules (add long. segmentation?)
6 x 6 cm^2	896 rebuilt + 448 refurbished existing modules (add long. segmentation?)
12 x 12 cm^2	1'344 refurbished existing modules (add long. segmentation?)



Radiation limit of current Shashlik technology

Number of channels:
Current ECAL: 6'064 cells (6'016 channels read)
Full double-sided readout (long. segmentation):
30'208 channels

The SpaCal modules need to be tiled to meet the energy resolution target

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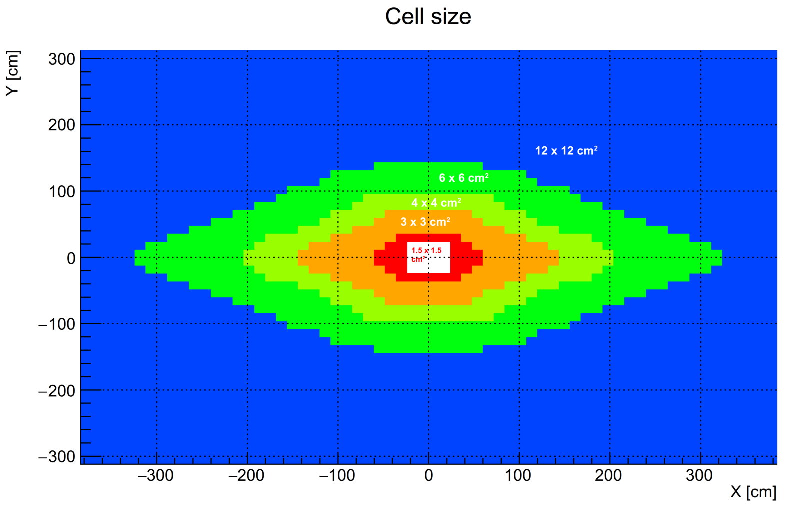
<u>Reminder:</u> LS3 configuration



- 9’344 cells (compared to 6’064 in current ECAL)

- Timing will be implemented for SpaCal region
→ requires new electronics for ≈ 3’300 cells

- Existing modules will be rearranged
(4x4 cm^2 Shashlik modules moved out to avoid too much radiation damage, WLS fibres could be easily replaced)

<u>Cell size:</u>	<u>Modules:</u>
2 x 2 cm^2	32 *new* SpaCal-W modules
3 x 3 cm^2	144 *new* SpaCal-Pb modules
4 x 4 cm^2	176 existing modules in rhombic configuration
6 x 6 cm^2	448 existing modules in rhombic configuration
12 x 12 cm^2	2’512 existing modules in rhombic configuration