

Next steps towards the PicoCal

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

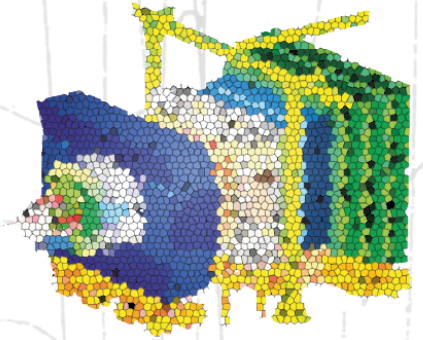


LHCb in collaboration with Crystal Clear,
supported by EP R&D (WP 3.2.0 and 3.2.1)



**6th Workshop on the
LHCb Upgrade II**
Barcelona, 30/03/2023

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Upgrade II**



29.03.2023-31.03 2023

Barcelona



Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA

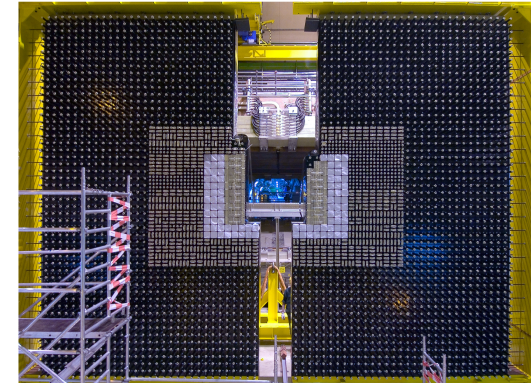
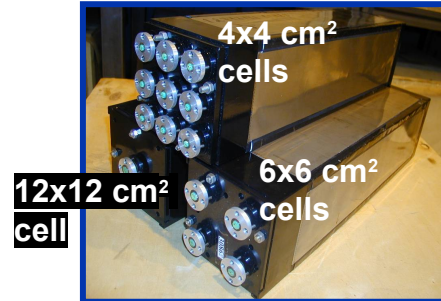
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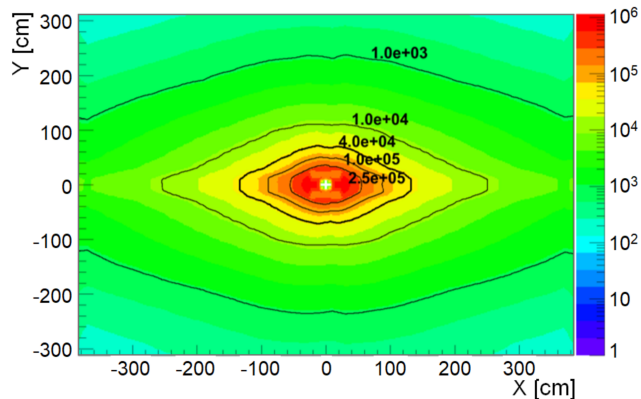
The current ECAL and motivation to upgrade

Current LHCb ECAL:

- Optimised for π^0 and γ identification in the few GeV to 100 GeV region at $2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- Shashlik technology with 4x4, 6x6 and 12x12 cm² cell size
- Radiation hard up to **40 kGy**
- Energy resolution: $\sigma(E)/E \approx 10\%/\sqrt{E} \oplus 1\%$
- Large array of $\approx 50 \text{ m}^2$ with 3312 modules and 6016 channels



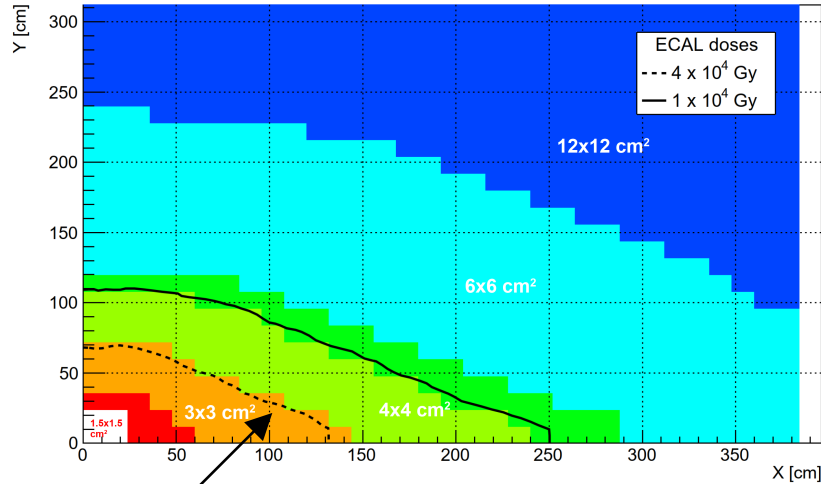
Accumulated radiation dose [Gy] after 300 fb⁻¹



Requirements for the Upgrade II:

- Sustain radiation doses up to **1 MGy** and $\leq 6 \times 10^{15} \text{ 1 MeV neq / cm}^2$ 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
- Better time resolution, less impact of radiation damage, more information for event reconstruction and particle identification from **longitudinal segmentation**

Technologies for the Upgrade II



Radiation limit of current Shashlik technology

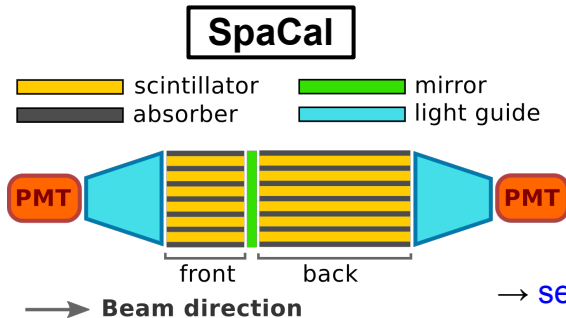
SpaCal technology for inner region:

- Innermost modules with scintillating crystal fibres and W absorber
 - Development of **radiation-hard scintillating crystals**
 - **1.5x1.5 cm²** cell size
- 40-200 kGy region with scintillating plastic fibres and Pb absorber
 - Need radiation-tolerant organic scintillators
 - **3x3 cm²** cell size

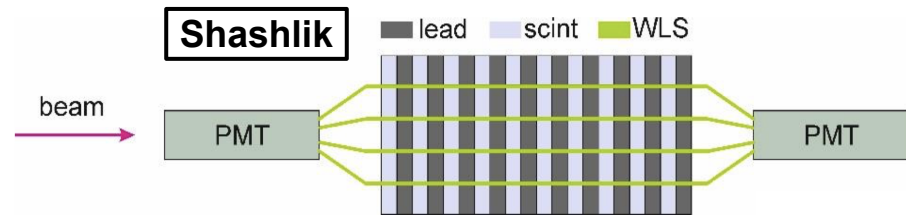
Shashlik technology:

- **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

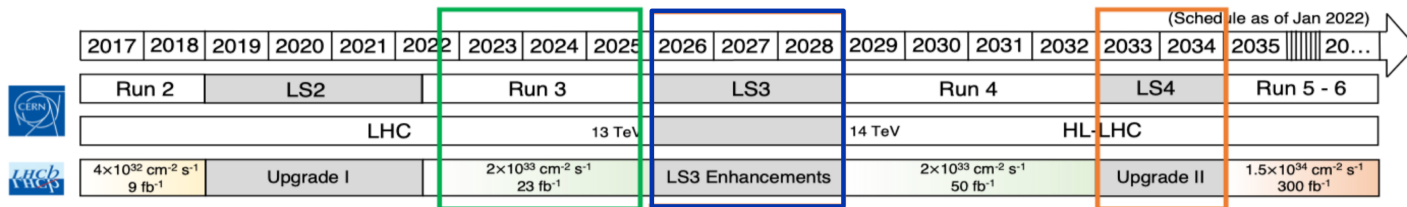
LS3 consolidation: W absorber for innermost modules equipped with scintillating plastic fibre for **2x2 cm²** cell size



→ see presentation by [Loris Martinazzoli](#)



LHCb ECAL upgrade strategy



Run 3 in 2022-2025:

Run with unmodified ECAL Shashlik modules at $L = 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
(new 40 MHz readout)

LS3 consolidation in 2026-2028:

Introduce **single-section rad. tolerant SpaCal** (2x2 and 3x3 cm² cells) in inner regions and rebuilt ECAL in **rhombic shape** to improve performance at $L = 2(4) \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

→ 32 SpaCal-W & 144 SpaCal-Pb modules with plastic fibres **compliant with Upgrade II** conditions

→ Option to include timing information with single-sided readout to inner regions

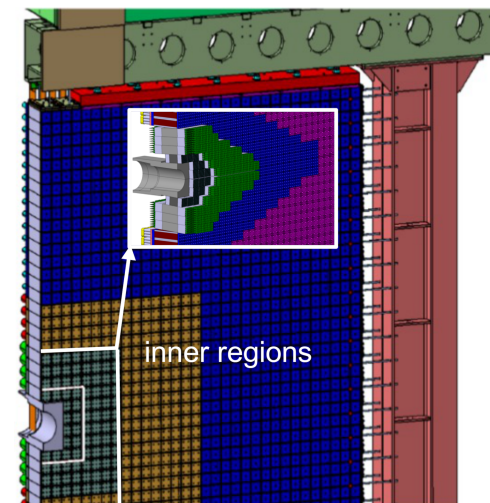
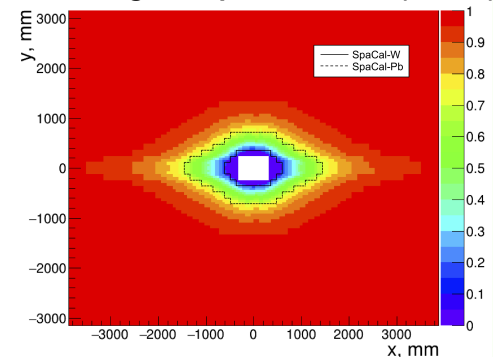
LS4 Upgrade II in 2033/2034:

Introduce **double-section radiation hard SpaCal** (1.5x1.5 & 3x3 cm² cells) and improve timing of Shashlik modules for a luminosity of up to $L = 1.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

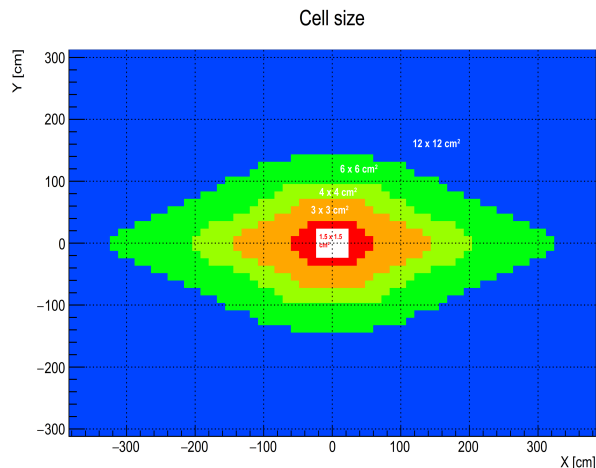
→ Innermost SpaCal-W modules equipped with **crystal fibres**

→ Include **timing** information and double-sided readout to full ECAL for pile-up mitigation

ECAL light output after 2025 (48 fb⁻¹)



Baseline LS3 configuration



No longitudinal segmentation

Cell size:

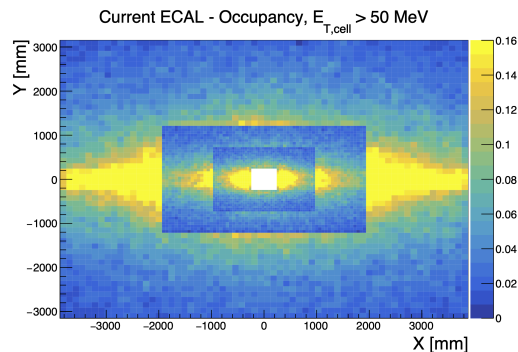
- 2 x 2 cm²
- 3 x 3 cm²
- 4 x 4 cm²
- 6 x 6 cm²
- 12 x 12 cm²

Modules:

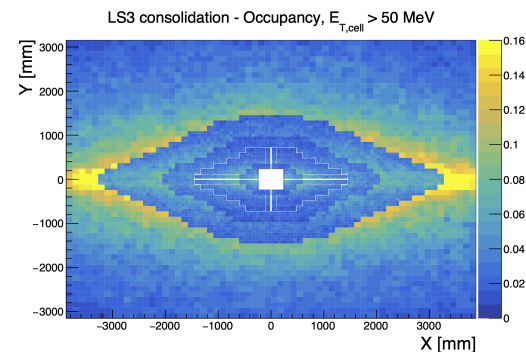
- 32 *new* SpaCal-W modules
- 144 *new* SpaCal-Pb modules
- 176 existing modules in rhombic configuration
- 448 existing modules in rhombic configuration
- 2'512 existing modules in rhombic configuration

- 9'344 cells (compared to 6'064 in current ECAL)
- Modules tilted in the SpaCal region
- Existing modules will be **rearranged** (4x4 cm² Shashlik modules moved out to avoid too much radiation damage, WLS fibres could be easily replaced)
- **Timing** could be implemented for SpaCal region
→ requires new electronics for up to ≈ 3'500 cells

Occupancy at $L = 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$



Run 3



Run 4

Planning for 2023 and 2024

Light-weight LHCb-internal review by U2PG on LS3 consolidation:

- Scheduled for **May 3 and 4** (to be followed by official agreement from TB to proceed with TDR)
- Main reviewers: Hassan Jawahery, Guy Wilkinson, Tim Gershon (+ ad-hoc experts: Ken, Renaud, Niko, Eric)
- Should include: physics opportunities, technology readiness, schedule, availability of person-power and resources

Light-weight TDR for LS3 consolidation:

- Submission to LHCC planned by **September 2023** (combined PID TDR with RICH)
- Physics performance gain as compared to Run 3 configuration
- Demonstration of required technological performance (R&D and prototyping) for proposed consolidation
- Infrastructure requirements for LS3 and LS4 (new platform)
- Institute responsibilities
- Planning, schedule (personnel loaded) and cost

Scoping document (for LS4 Upgrade II):

- Towards the end of **2024** (exact date to be decided by the collaboration)
- Comparison of physics performance for key channels between baseline and descoped option
- Realistic estimate of cost for baseline and descoped options

Schedule for LS3 consolidation and Upgrade II during LS4



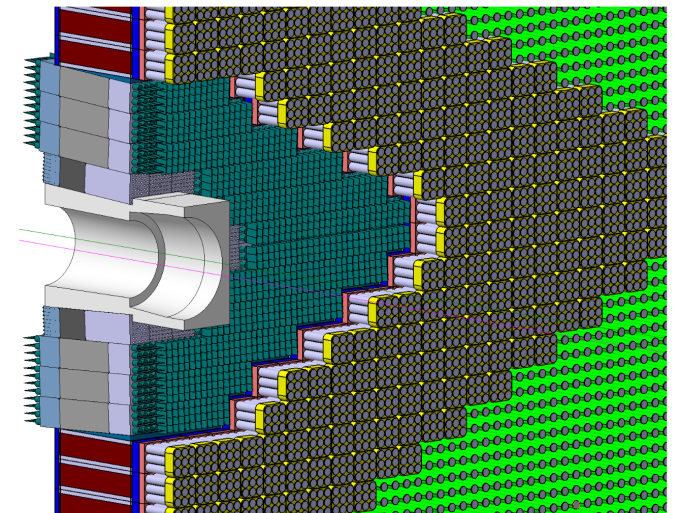
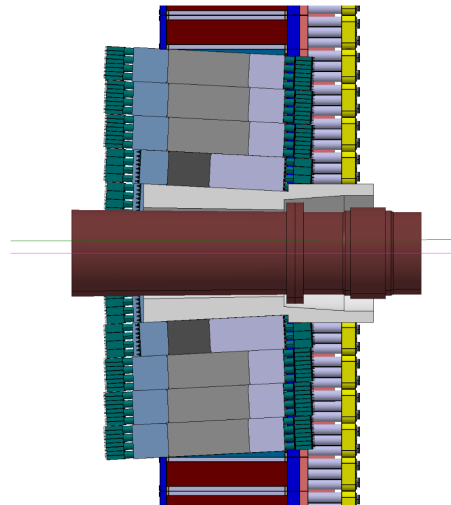
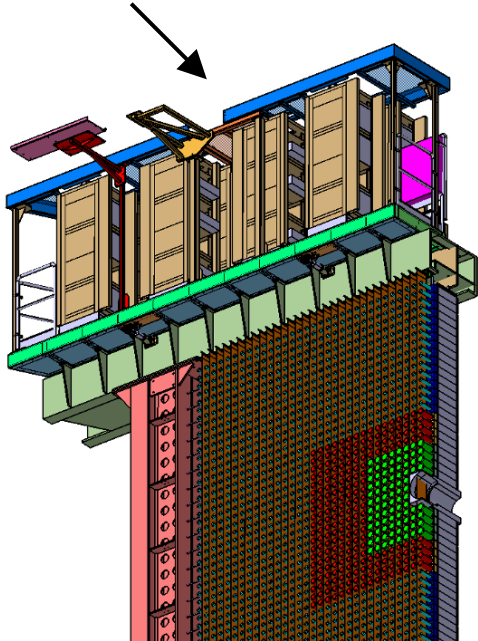
Schedule summary:

- **May 2023:** Light-weight internal U2PG review to approve ECAL LS3 consolidation (LHCb-internal)
- **September 2023:** Light-weight PID TDR to LHCC for LS3 consolidation (ECAL & RICH)
- **End of 2024:** Scoping document for Upgrade phase IIb in LS4 (including ECAL)
- **2025-2027:** Production of 176 SpaCal modules, 3'500 new electronics channels and PCIe400 for the Run 4 ECAL
- **2026-2028:** Infrastructure modifications (platform) and ECAL re-build (new modules, rhombic arrangement) during LS3
- **2026:** TDR for ECAL Upgrade phase IIb in LS4
- **2028-2032:** Production/refurbishment of Shashlik modules, production of SpaCal/GAGG, introduction of double-sided readout
- **2033-2034:** Re-building of ECAL with addition of new modules during LS4

Modification of the infrastructure during LS3

- Increased number of **electronics channels** (up to factor 5 in LS4)
 - Platform on top of the ECAL needs to be modified to provide more rack space
- SpaCal modules need to be **rotated** by $3^\circ+3^\circ$ to achieve energy resolution goal
 - New beam plug to be adapted
- **Cable management** will be more challenging
- Dedicated infrastructure meetings have started recently

Platform
to be modified



Preparation of TDR for LS3

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- General structure defined
- **Benchmark studies** comparing Run 3 configuration (also with expected radiation damage!) to LS3 consolidation ongoing
→ [see presentation by Liupan An](#)
- **Updated cost estimate** ongoing based on today's knowledge

Scoping document and cost

ECAL Upgrade II baseline and options defined in FTDR:

- Baseline: SpaCal & Shashlik with **double-sided readout**
 - 30208 channels, cost \approx 35 MCHF
- Downscoped: SpaCal with double-sided readout, Shashlik with single-sided readout
 - 19456 channels, cost \approx 22 MCHF
- **Physics loss of downscoped version still to be evaluated** (needs work on reconstruction!)
 - Intermediate option not excluded

Scoping document aims at three LHCb Upgrade II cost options:

- FTDR baseline option: cost \approx 175 MCHF
 - Intermediate option: cost reduction of order 15%
 - Minimal option: cost reduction of order 30%
- **ECAL downscoped option already well within the minimal upgrade option!**
(with FTDR costing and assuming flat cut everywhere)

Summary and conclusions

ECAL upgrade strategy:

- Baseline **technologies** and configurations for LS3 and LS4 defined in FTDR
- **LS3** consolidation with additional 3'500 channels and rhombic shape of ECAL
- Upgrade II during **LS4** introduces dual readout with 30'000 channels

Upcoming milestones:

- Light-weight U2PG review and LS3 TDR in 2023
- Scoping document in 2024, Upgrade II TDR in 2026
- No show stoppers identified,
but tight schedule for **LS3 consolidation** (including infrastructure)!

More details in the following talks:

- [Liupan An](#): PicoCal simulations and benchmarking
- [Loris Martinazzoli](#): PicoCal technologies
- [Patrick Robbe](#): PicoCal electronics

Thank you!

Backup slides