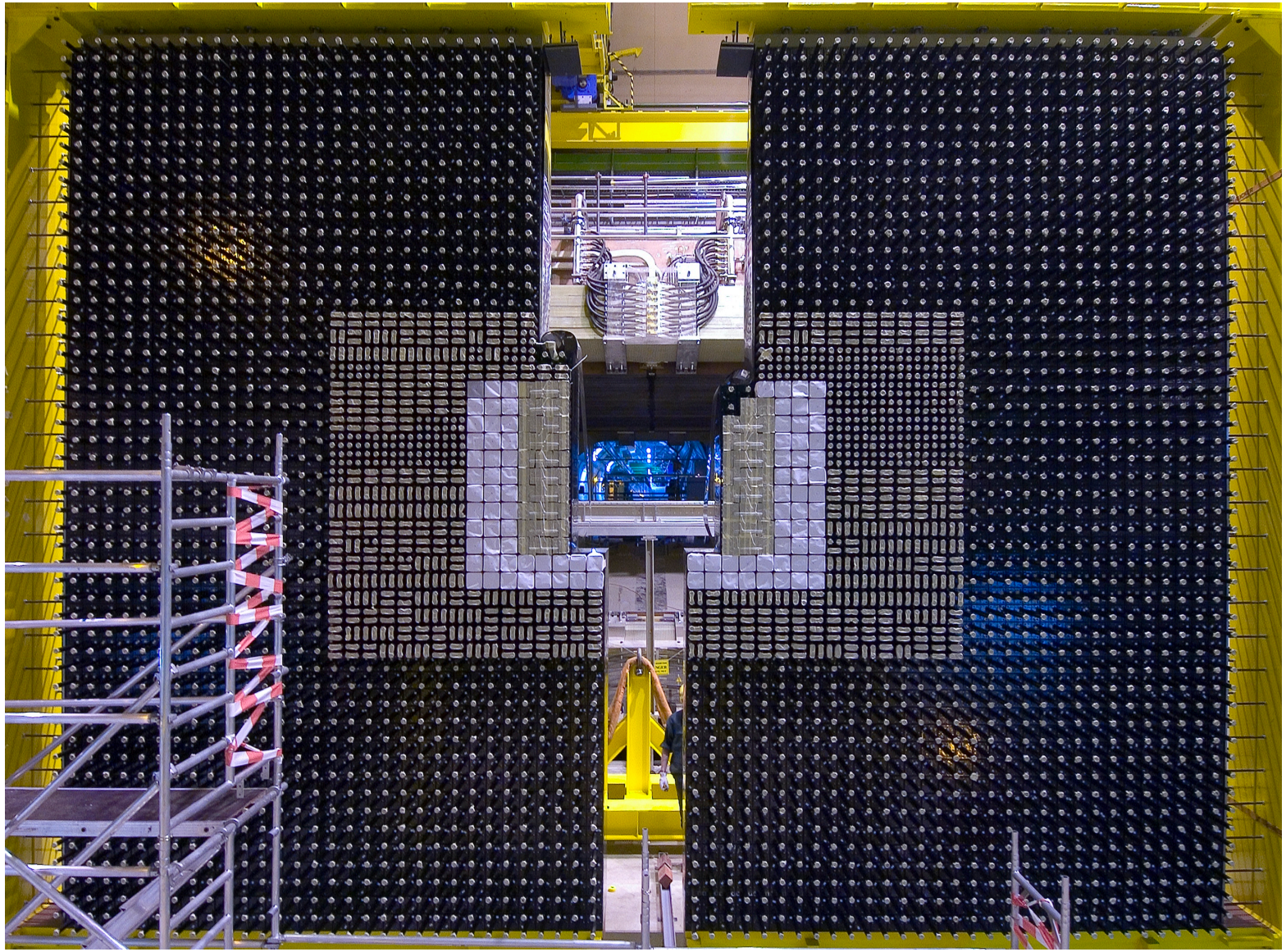
ECAL Overview on Upgrade II requirements with possible LS3 & LS4 configurations

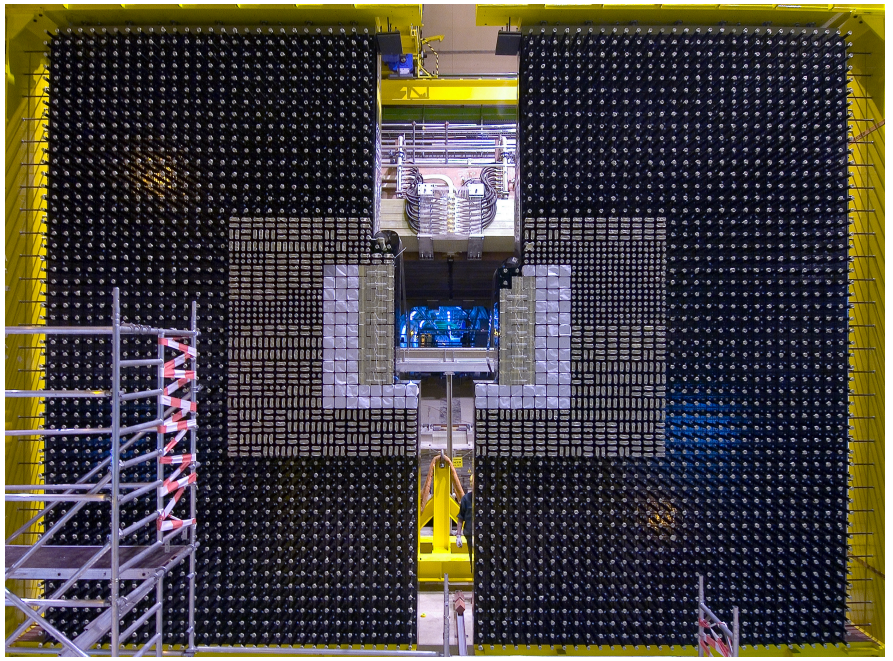


5th LHCb Upgrade II Workshop
31.03.2020

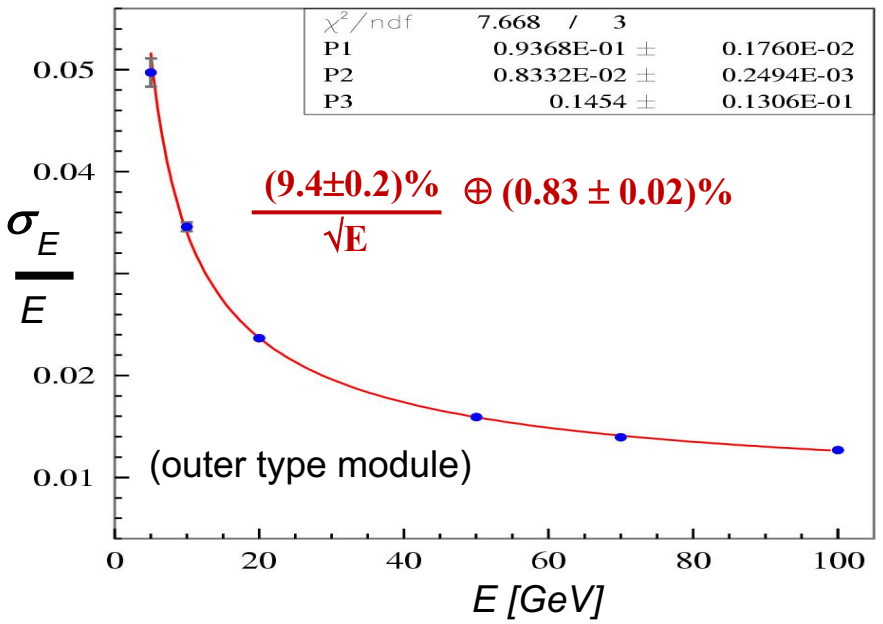
The current LHCb ECAL

Current ECAL optimized for π^0 and γ identification in the few GeV to 100GeV energy range at $L=2\times10^{32}$ cm^{-2}s^{-1}

- radiation resistant **up to 40KGy**
- three sections (Inner, Middle, Outer) of **cell size 4x4, 6x6, 12x12 cm^2**
- **$\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 1\%$**



Energy resolution with electrons

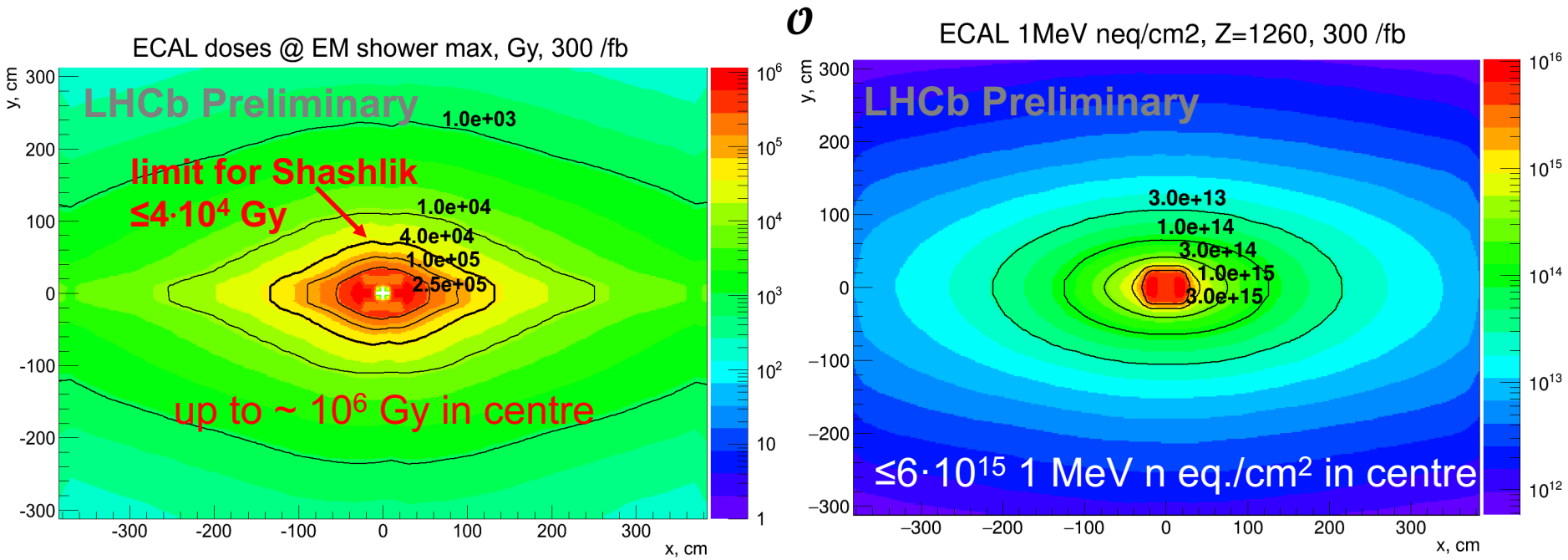


- ✓ Large Shashlik array ~50 m^2 with **3312 modules** and **6016 channels**
- ✓ Modular wall-like structure of ~8x7m^2, two halves open laterally

Basic ECAL requirements for Upgrade II

Overall requirements:

- ✓ sustain **radiation doses** of up to ~1MGy and ≤6·10^{15}cm^{-2} for 1MeV neq/cm^2 at 300 fb^{-1} (1MGy = 100Mrad)
- ✓ include a **very fast timing component** of $\mathcal{O}$(10) picoseconds for pile-up mitigation
- ✓ keep good **energy resolution** of order σ(E)/E ~ 10%/√E ⊕ 1%
- ✓ handle **increased occupancy** by increasing granularity
- ✓ respect dimensional **constraints of a module**: 12 x 12 cm^2 outer dimension



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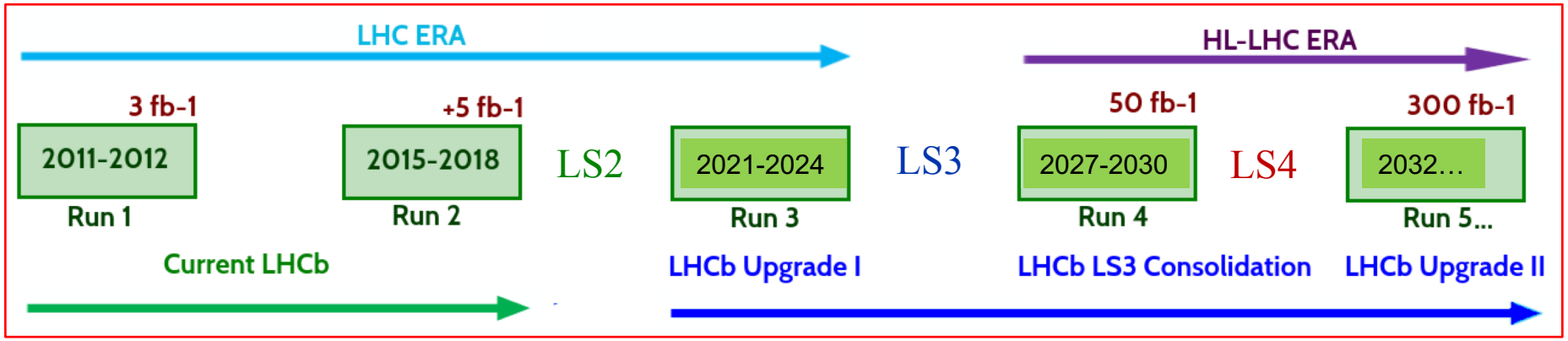
LHCb ECAL Upgrade II

Updated Schedule 12.12.2019



After LS2 in 2021-2024:

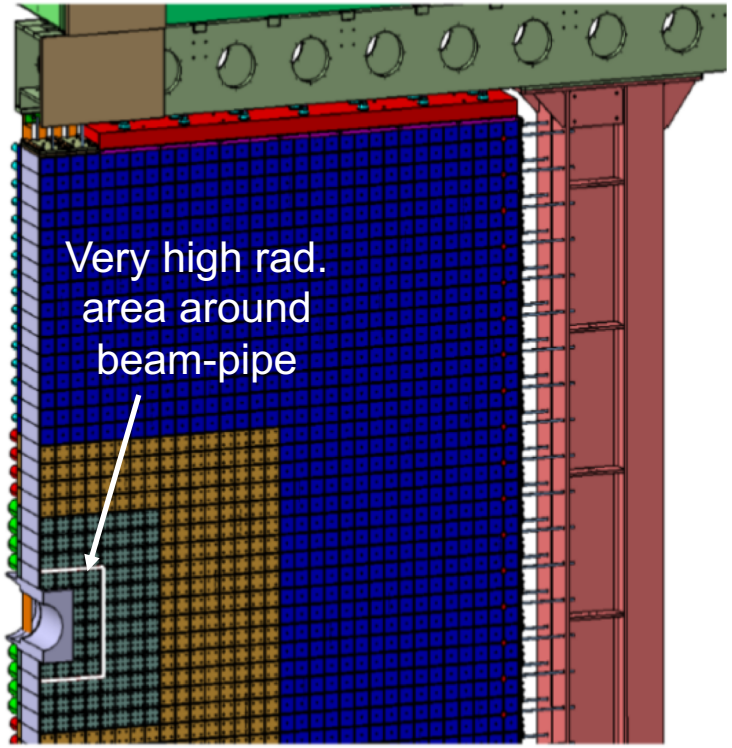
- Run with unmodified ECAL shashlik modules at L=**2**x10^{33} $cm^{-2}s^{-1}$

LS3 in 2025/26:

- **Replace modules around beampipe** to improve performance at L=**2**(4)x10^{33} $cm^{-2}s^{-1}$ (minimal consolidation: ~32 rad. hard modules compliant with Upgrade II conditions)

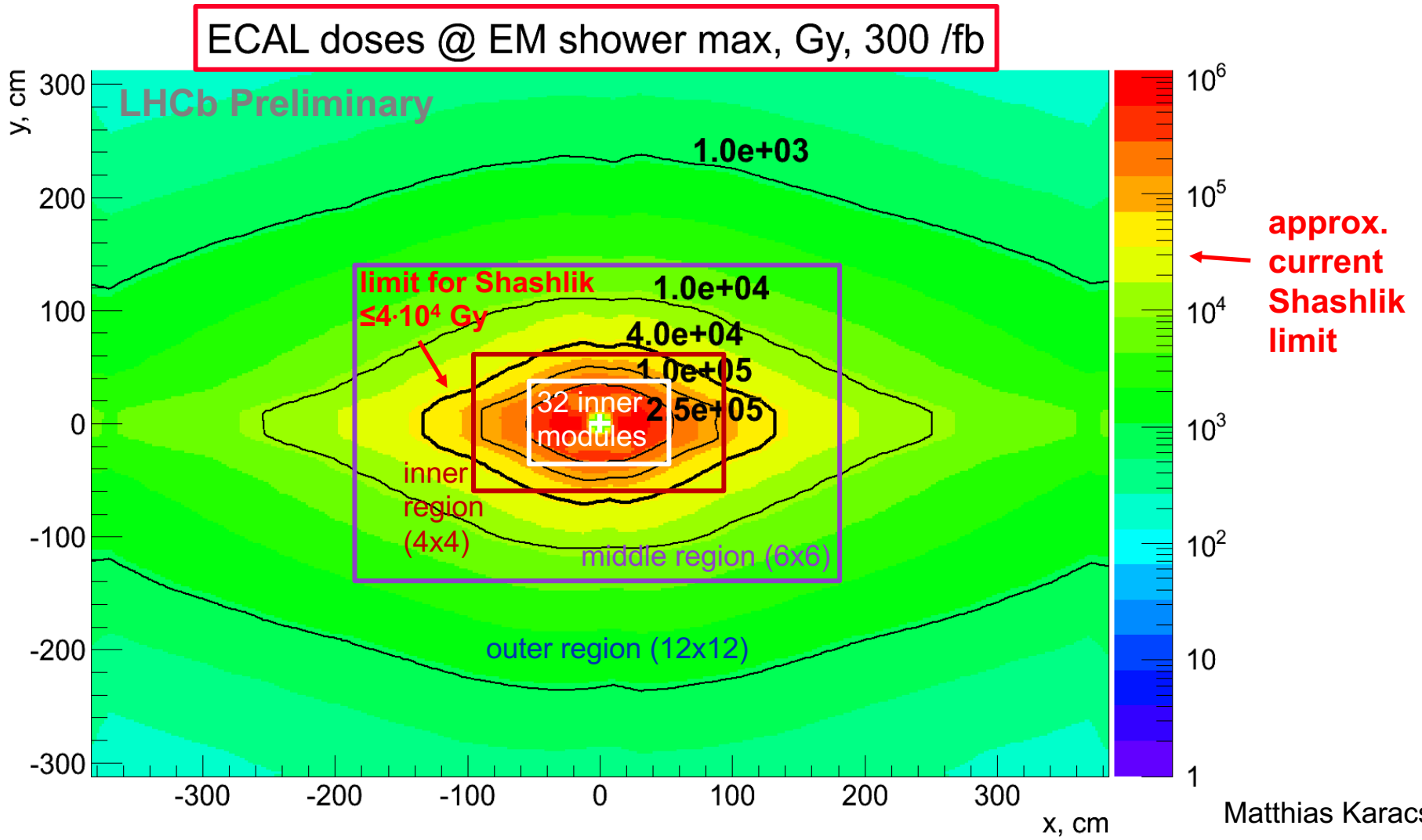
LS4 in ≥2031:

- **Rebuild ECAL with new radiation tolerant modules and (refurbished) old modules** compatible with occupancies for a luminosity of up to L=**15**x10^{33} $cm^{-2}s^{-1}$
- **Include timing information** to mitigate pile-up



Radiation requirements for Upgrade II

3 regions of ECAL



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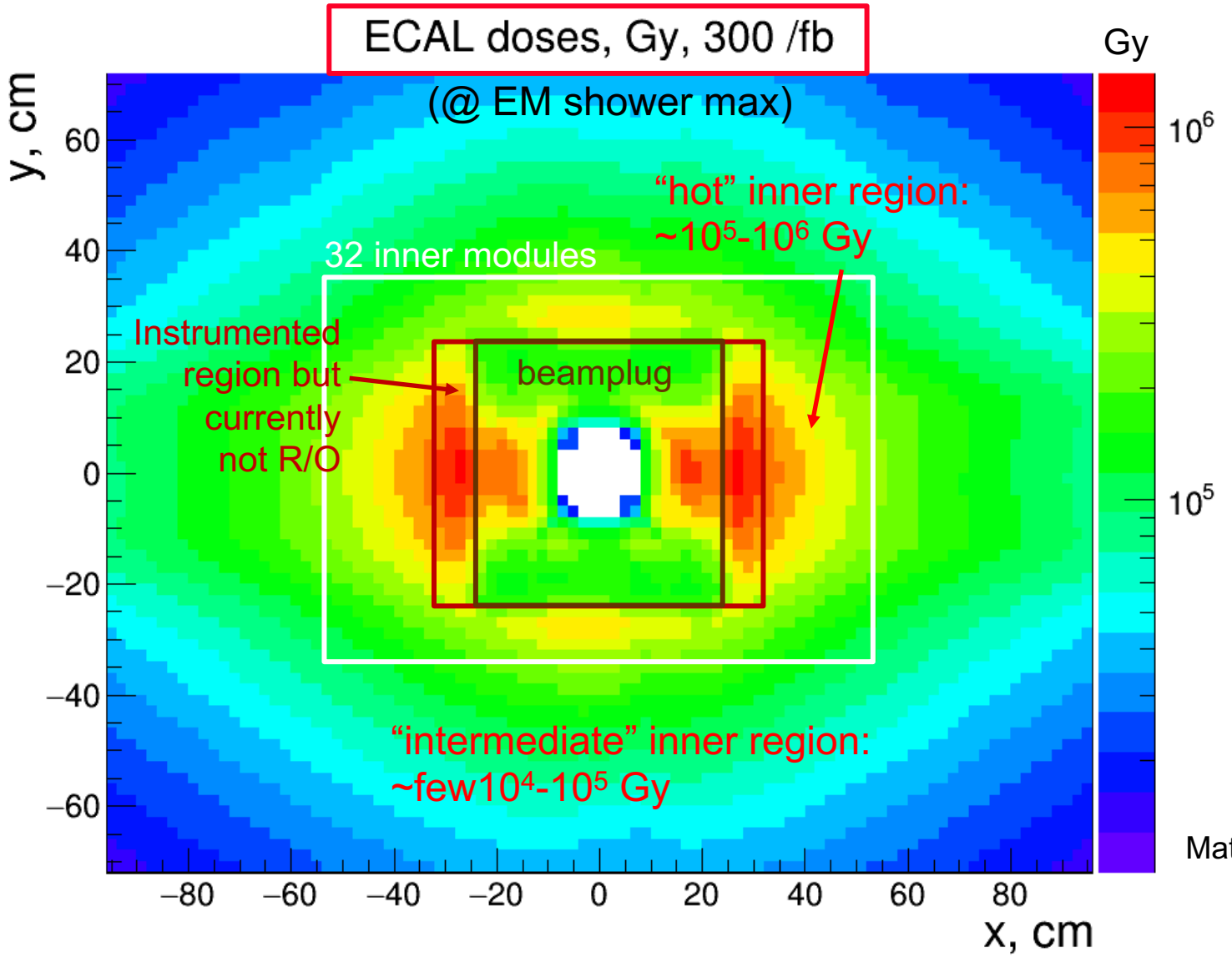
Radiation requirements for Upgrade II

inner region



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ECAL requirements for Upgrade II

Radiation resistance requirements to modules:

- ✓ in **"hot" inner region** need of very rad. hard modules sustaining up to ~ **1000kGy**
- ✓ in **"intermediate" inner region** need of modules sustaining between ~50kGy to **200kGy**
- ✓ big part of **middle region** and all of **outer region** compatible with current shashlik type modules resisting up to **~40kGy**

From radiation point of view: (not taking into account cell size requirements due to occupancy)

- ➢ need **32 new modules** for extreme conditions **up to ~1MGy**
- ➢ need another **144 new modules** with "moderate" radiation requirements **up to ~200kGy**
- ➢ can "reshuffle" inner-type modules (**176 modules with 4x4cm^2** cells) to middle region
- ➢ can "re-shuffle" middle-type modules (**448 modules with 6x6cm^2** cells) to outer region
- ➢ out of a total of 3312 modules **2688 modules** are of outer-type **with 12x12cm^2** cells

From physics and reconstruction point of view:

- ✓ 5D ECAL requirements (**E, x, y, z, t**) to be determined from reconstruction and physics performance studies for:
  - ➢ "hottest" and "intermediate" inner region to define E-resol., cell size, M_R, Z-segmentation, timing resol., …
  - ➢ middle and outer region to optimize "re-shuffling strategy"
  - ➢ note: no need anymore of square regions (no L0) → better match to irradiation map

LS3 ECAL configuration options

Light red: new 1MGy modules
Green: keep existing modules

Current ECAL: **6'064** cells (6016 ch. readout)

LS3: 32 modules 1MGy region

- with 2.0 cm cells: **8'080 ch.**
- with 1.5 cm cells: **9'872 ch.**
- ✓ note: assuming dual R/O (twofold Z-segmentation)

LS3 new 1MGy region 1.5 cm cells								
ECAL regions			mod./region	#ch./region	#cells/mod.	size (cm)	Z-segments	# channels
1MGy region			32	2048	64	1.5	2	4096
200 kGy region			144	1296	9	4.0	1	1296
middle			448	1792	4	6.0	1	1792
outer			2688	2688	1	12.0	1	2688
		Totals	**3312**	**7824**				**9872**
LS3 new 1MGy region 2cm cells								
ECAL regions			mod./region	#ch./region	#cells/mod.	size (cm)	Z-segments	# channels
1MGy region			32	1152	36	2.0	2	2304
200 kGy region			144	1296	9	4.0	1	1296
middle			448	1792	4	6.0	1	1792
outer			2688	2688	1	12.0	1	2688
		Totals	**3312**	**6928**				**8080**
current ECAL								
ECAL regions			mod./region	#ch./region	#cells/mod.	size (cm)	Z-segments	# channels
1MGy region			32	288	9	4.0	1	288
200 kGy region			144	1296	9	4.0	1	1296
middle			448	1792	4	6.0	1	1792
outer			2688	2688	1	12.0	1	2688
		Totals	**3312**	**6064**				**6064**

LS3 ECAL configuration options

Light red: new 1MGy modules
Dark red: new 200kGy modules
Green: reuse existing modules

LS3 new 1MGy and 200kGy region							
ECAL regions		mod./region	#ch./region	#cells/mod.	size (cm)	Z-segments	# channels
1MGy region		32	2048	64	1.5	2	4096
200 kGy region		144	2304	16	3.0	2	4608
middle 1		176	1584	9	4.0	1	1584
middle 2		272	1088	4	6.0	1	1088
outer 1		176	704	4	6.0	1	704
outer 2		2512	2512	1	12.0	1	2512
	Totals	**3312**	**10240**				**14592**

LS3 new 1MGy region 1.5 cm cells							
ECAL regions		mod./region	#ch./region	#cells/mod.	size (cm)	Z-segments	# channels
1MGy region		32	2048	64	1.5	2	4096
200 kGy region		144	1296	9	4.0	1	1296
middle		448	1792	4	6.0	1	1792
outer		2688	2688	1	12.0	1	2688
	Totals	**3312**	**7824**				**9872**

LS3: 32 modules in 1MGy region

- 1MGy region:1.5 cm cells
- 200kGy region: 4.0 cm cells (old)

➢ **9'872 channels**

LS3: 32 modules in 1MGy region and 144 modules in 200kGy region:

- 1MGy region: 1.5 cm cells
- 200kGy region: 3.0 cm cells and dual R/O
- move existing 4 cm and 6 cm cells further out into middle and outer region

➢ **14'592 channels**

LS4 ECAL configuration options

- Equip high radiation regions with new rad. hard modules with cells of 1.5, 3, 4cm
- Reshuffle as many existing Shashlik modules with 4, 6, 12cm cells into 40kGy region
- Produce new 40kGy modules to compensate lack of modules with 4 and 6cm cells

Light red: new 1MGy modules
Dark red: new 200kGy modules
Blue: rebuilt or refurbish (dual R/O) existing 40kGy modules
Green: reuse existing 40kGy modules (without modification)

LS4 with partlial dual R/O:

- About half of ECAL with dual R/O (Z-segmentation)

➢ **21'904 channels**

LS4 with full dual R/O:

- Entire ECAL with dual R/O (Z-segmentation)

➢ **30'208 channels**

LS4 full dual R/O

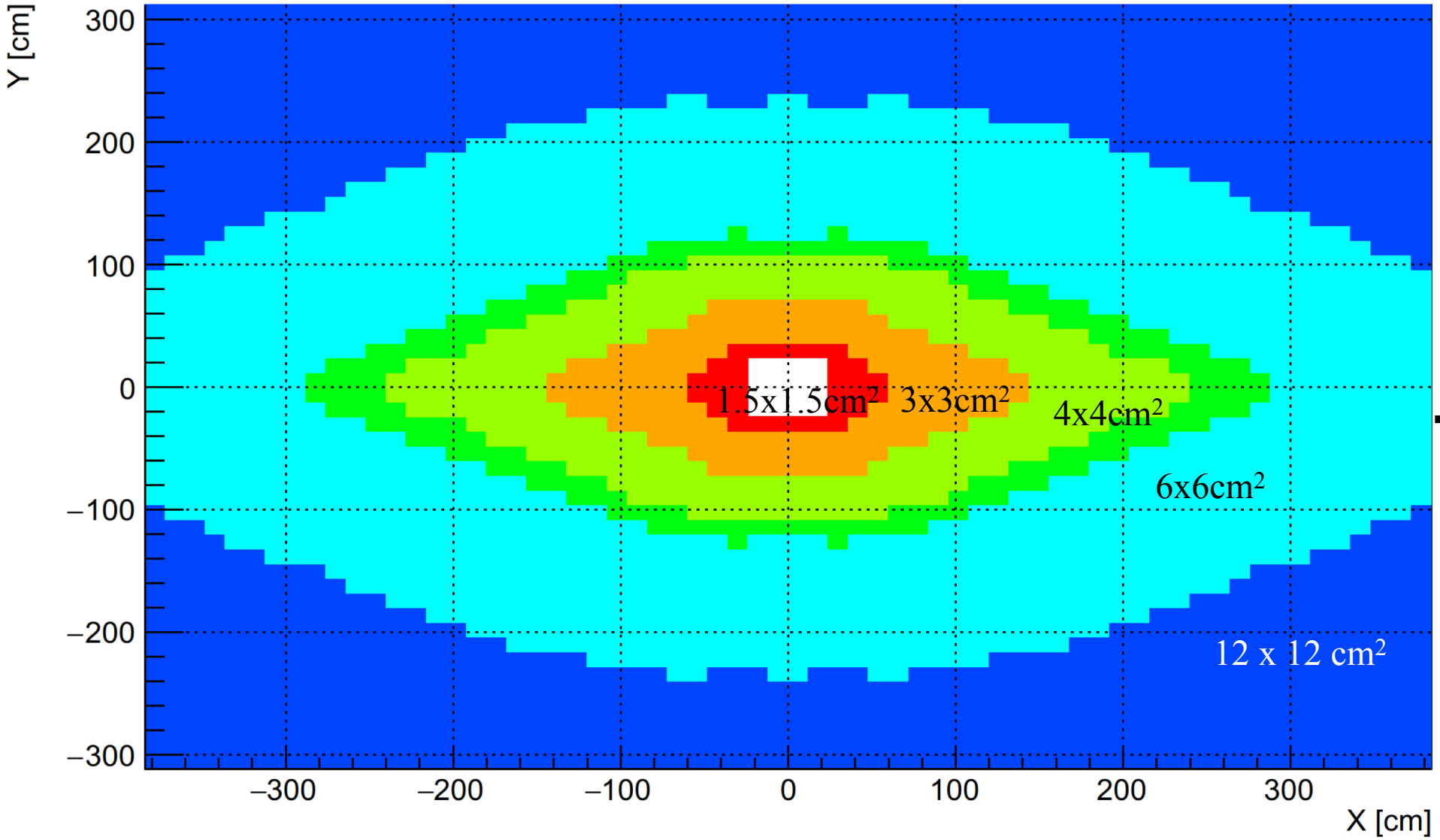
ECAL regions		mod./region	#ch./region	#cells/mod.	size (cm)	Z-segments	# channels
1MGy region		32	2048	64	1.5	2	4096
200 kGy region		144	2304	16	3.0	2	4608
middle 1		272	2448	9	4.0	2	4896
middle 2		176	1584	9	4.0	2	3168
outer 1		1344	5376	4	6.0	2	10752
outer 2		1344	1344	1	12.0	2	2688
	Totals	**3312**	**15104**				**30208**

LS4 partly dual R/O

ECAL regions		mod./region	#ch./region	#cells/mod.	size (cm)	Z-segments	# channels
1MGy region		32	2048	64	1.5	2	4096
200 kGy region		144	2304	16	3.0	2	4608
middle 1		272	2448	9	4.0	2	4896
middle 2		176	1584	9	4.0	1	1584
outer 1		896	3584	4	6.0	1	3584
outer 2		448	1792	4	6.0	1	1792
outer 3		1344	1344	1	12.0	1	1344
	Totals	**3312**	**15104**				**21904**

ECAL segmentation with LS4 options

→ 5 ECAL regions matching the radiation maps

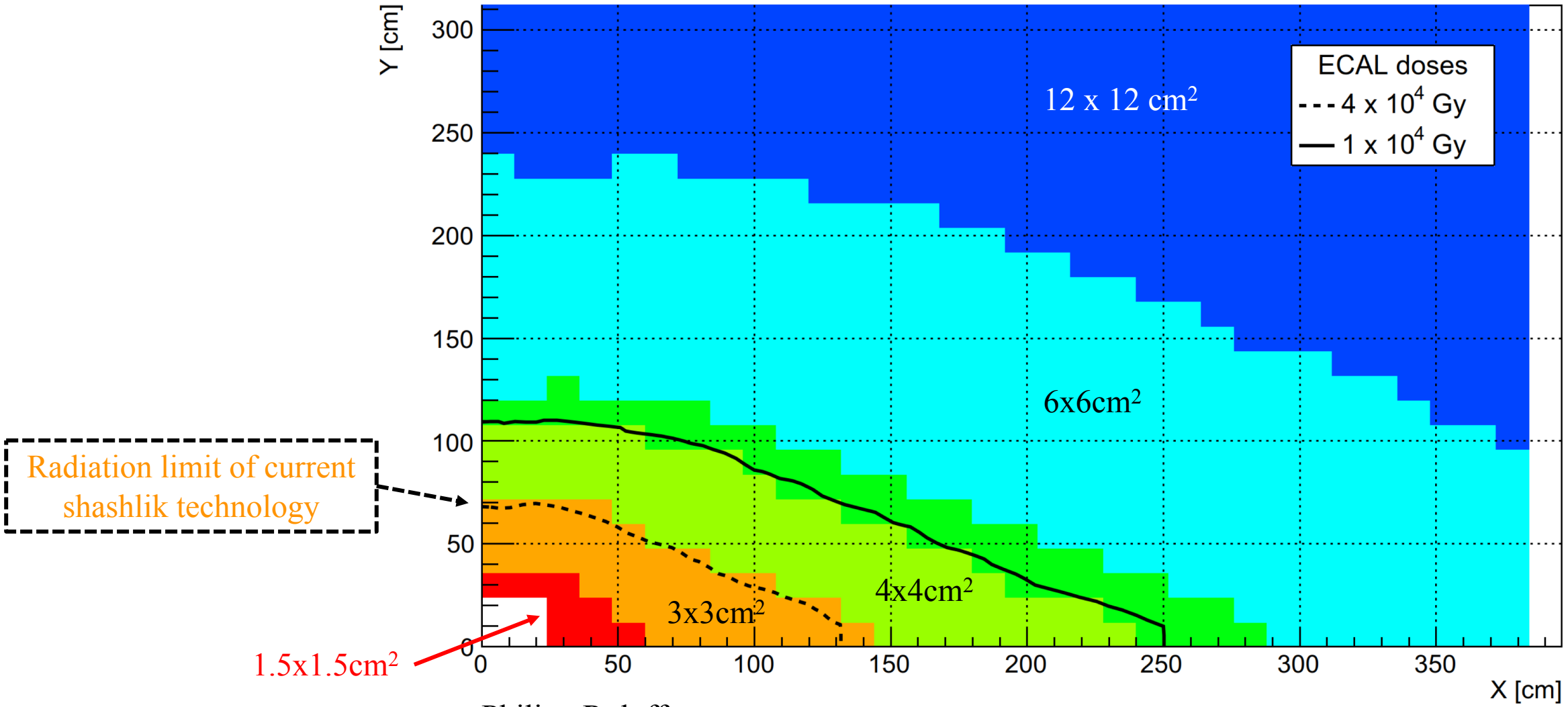


Cell size:	# of modules
1.5x1.5cm²:	32
3x3cm²:	144
4x4cm²:	272+176
6x6cm²:	896+448
12x12cm²:	1344

Light red: rebuild 1MGy modules
Dark red: rebuild 200kGy modules
Blue: rebuild 40kGy modules
Green: reuse existing modules
(refurbish if double R/O)

Philipp Roloff

ECAL segmentation with LS4 options



Philipp Roloff

Conclusions and steps towards the FTDR

- The ECAL in its current configuration cannot cope with neither the radiation nor the occupancy conditions of Upgrade II
- If we want to keep the ability to reconstruct π^0 and γ at Upgrade II conditions, the ECAL has to undergo a *major* upgrade
- Upgrade II radiation and occupancy conditions have to fulfill the following (probably minimal) requirements:
  - ✓ Energy resolution as current ECAL of order $\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 1\%$, adding $\mathcal{O}(10)$ picoseconds timing capability
  - ✓ 32 new radiation hard (1MGy) modules in hottest region with very high granularity (cell size of $\leq$1.5cm)
  - ✓ 144 new radiation tolerant (200kGy) modules in inner region with high granularity (cell size of $\leq$3cm)
  - ✓ ~1200 new modules possibly of Shashlik type (40kGy) with medium granularity (cell size of $\leq$4 and $\leq$6cm)
  - ✓ Reuse of ~2000 existing Shashlik modules (possibly after some refurbishment) with 4,6,12cm cell size (out of 3300)
- Next steps towards the FTDR:
  - ✓ Optimize reconstruction algorithm and determine ECAL 5D (E,x,y,z,t) performance requirements from physics simulation
  - ✓ Finalize R&D on 1MGy SPACAL sampling technology fulfilling required 5D performance (for implemention in LS3)
  - ✓ Start R&D on 200kGy sampling technology (SPACAL, Shashlik,…) fulfilling required 5D performance
  - ✓ Optimize current 40kGy Shashlik technology for timing performance and possibly z-segmentation
  - ✓ Pursue R&D on timing plane at shower maximum (see next talk)
  - ✓ Investigate possible options of photodetectors (PMT, MaPMT, SiPM, …)
  - ✓ Define readout architecture and intensify R&D on R/O electronics with picosecond capability (“prototypes” in LS3?)
  - ✓ Define “minimal” and “optimal” ECAL configurations for LS3 & LS4 and provide realistic cost estimate