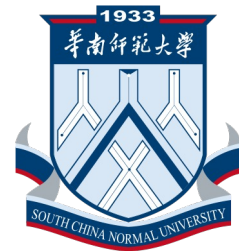




CLHCP2025 新乡

第十一届中国LHC物理会议

The 11th China LHC Physics Conference



LHCb Upgrades

Hengne Li (李衡讷)

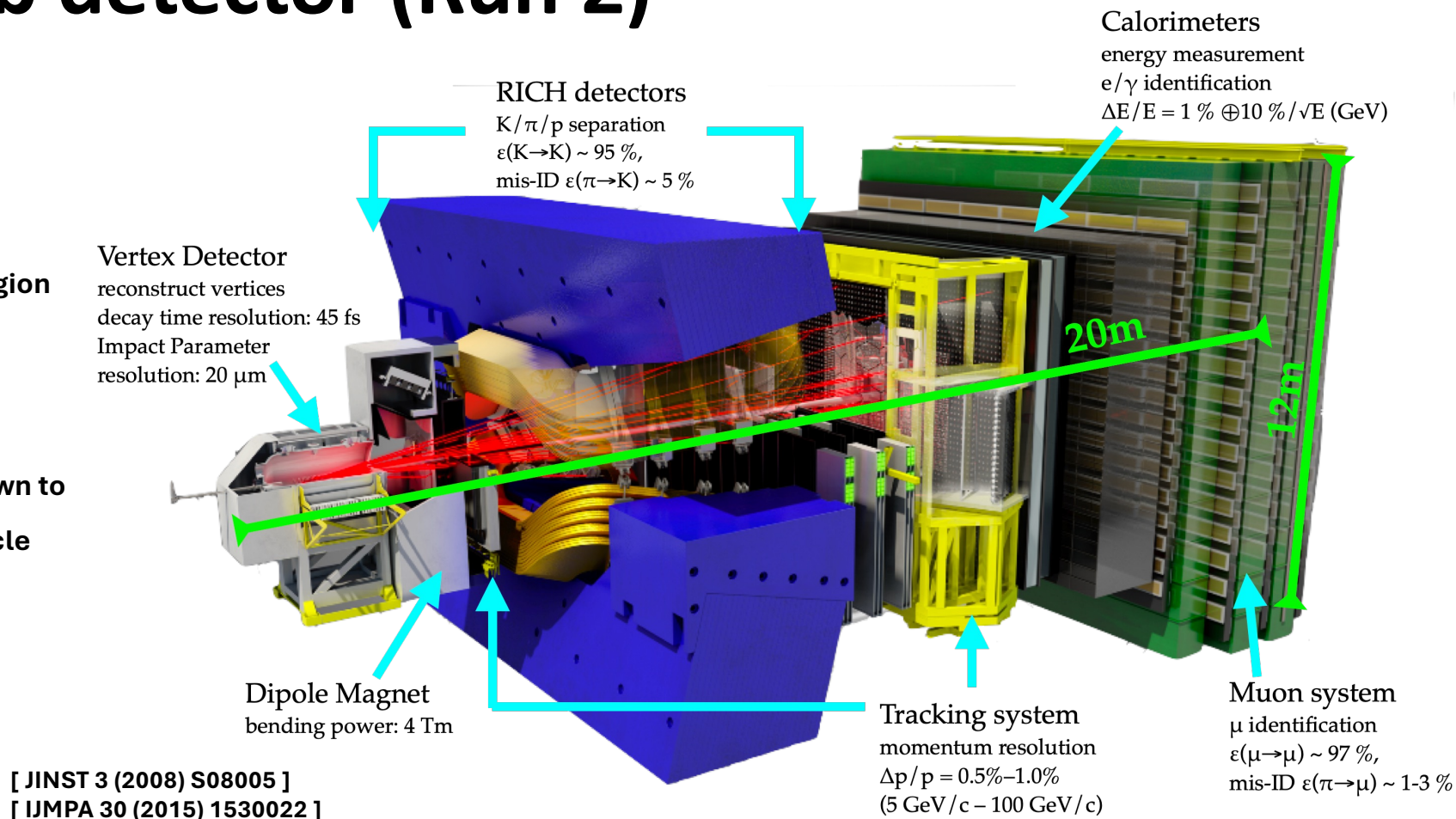
South China Normal University (华南师范大学)

On behalf of the LHCb collaboration

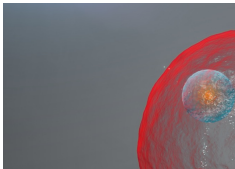
2 Nov. 2025, Xinxiang

The LHCb detector (Run 2)

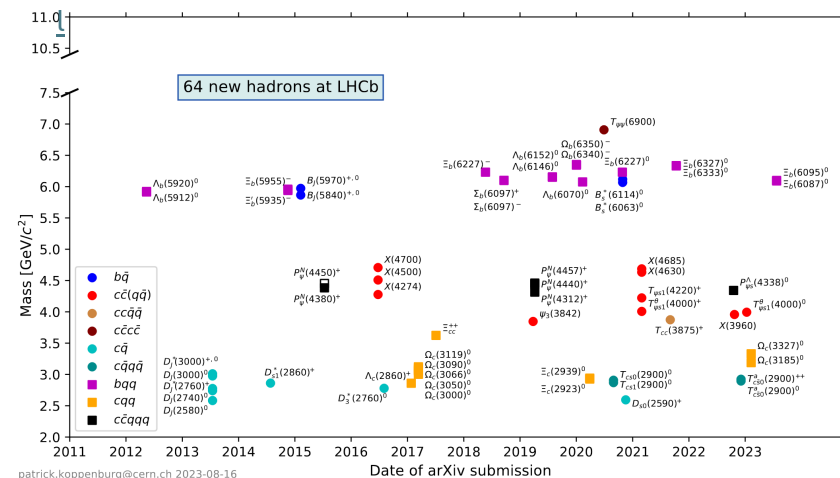
- LHCb is the only dedicated detector (at LHC) fully instrumented in forward region
- Unique kinematic coverage
 $2 < \eta < 5$
- A high precision device, down to very low- p_T , excellent particle ID, precise vertex and track reconstruction.



LHCb: a history of success

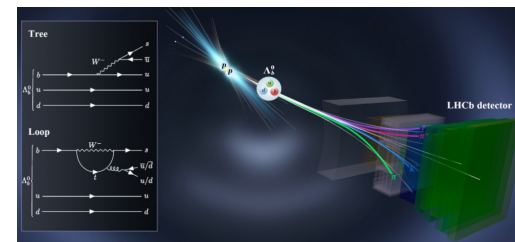
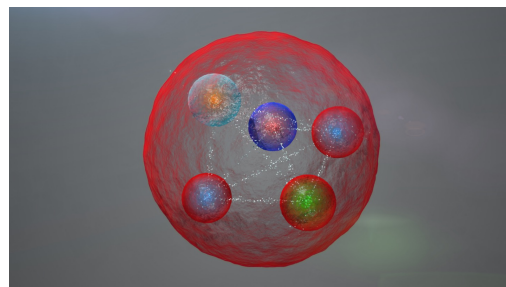
- 887 papers, 81781 citations (inspirehep)
 - Series of significant discoveries
 - Rare decays
 - CPV in charm and beauty
 - Spectroscopy
 - Physics program well beyond designed
 - Fixed-target
 - Heavy-ions
 - Dark sector
 - Electroweak
- Observation of
- 

<https://www.nikhef.nl/~pkoppenb/particles.htm>



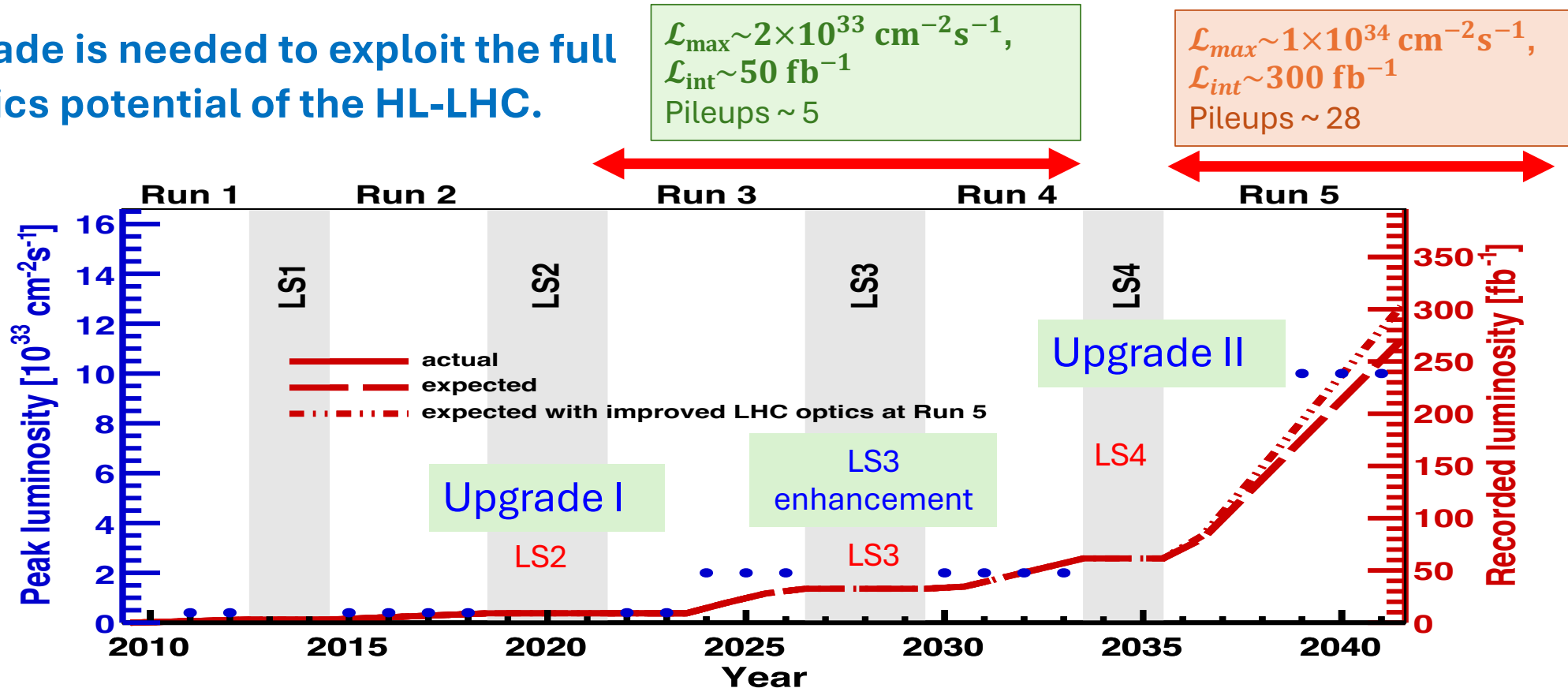
patrick.koppenburg@cern.ch 2023-08-1

First observation of CP violation in baryon decays



The LHCb upgrades

Upgrade is needed to exploit the full physics potential of the HL-LHC.



- Upgrade I (2019 - 2023)
- L3 Enhancement (Q3.2026-2029)
- Upgrade II (2034 - 3035)

Upgrade I: a brand new detector

CERN-LHC-2012-007
[arXiv:2305.10515](https://arxiv.org/abs/2305.10515)

New dedicated luminometer (PLUME)

New Upstream Tracker (UT)
Silicon strips

Vertex Locator

New VELO
Pixel detector

New SMOG2
system

New RICH 1 optics
New photodetectors and
readout for RICH 1 and 2

New SciFi Tracker (SciFi)
Scintillating fibres

ECAL HCAL

RICH2

M2 M3 M4 M5

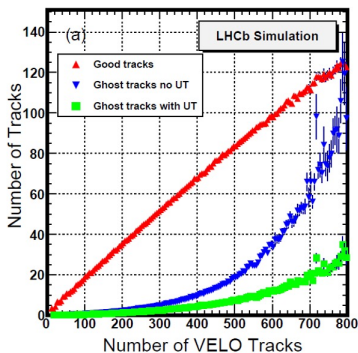
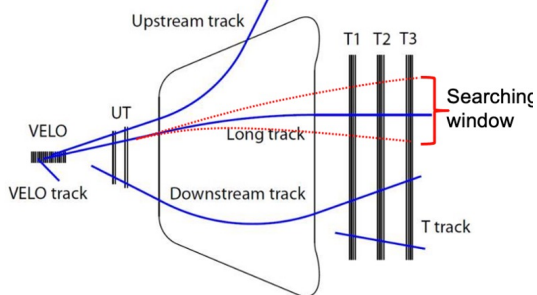
Calorimeters:
removed PreShower (PS) and
Scintillating Pad Detector (SPD),
new readout

Muon: Removed M1 and new
readout

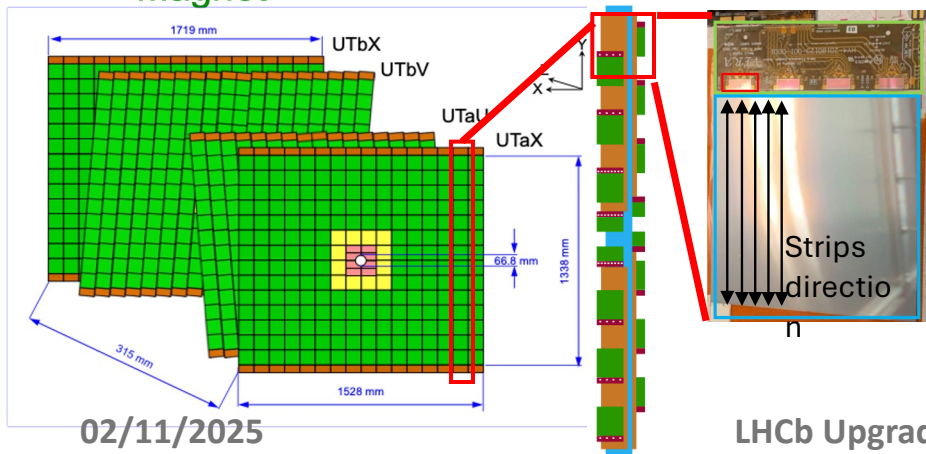
$$L_{inst} = 2 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1} \text{ (x5 w.r.t. Run 1)}$$

Upstream Tracker (UT)

LHCb tracking system



Magnet



02/11/2025

LHCb Upgrade, CLHCP 2025, Hengne Li

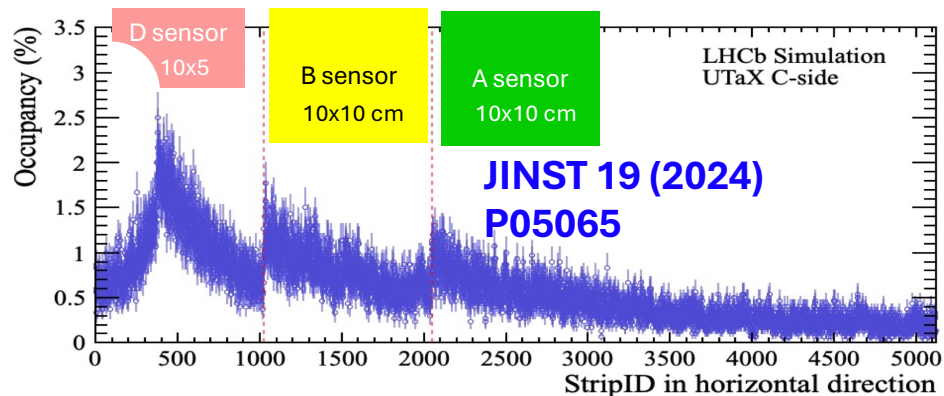
UT: Si Strip detector

CERN-LHCC-2014-001

- Speed up tracks reconstruction & reduce P_{GhostTrk}
- High coverage, segmentation, resolution

Different sensors for different regions

- A type: p-in-n; 98x98 mm; strip pitch 190 μm
- B type: n-in-p; 98x98 mm; strip pitch 95 μm
- C/D type: n-in-p; 98x49 mm; strip pitch 95 μm
- Maximum occupancy $\sim 1\%$



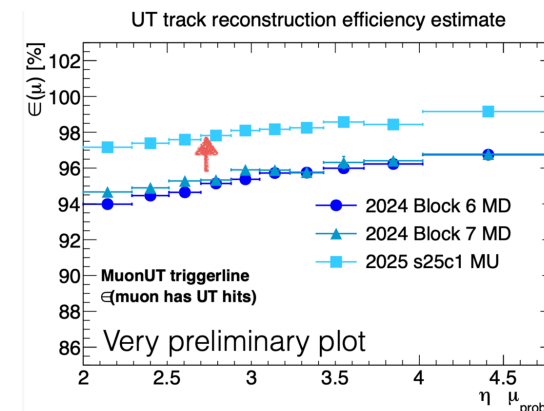
JINST 19 (2024)
P05065

China group contribution to UT

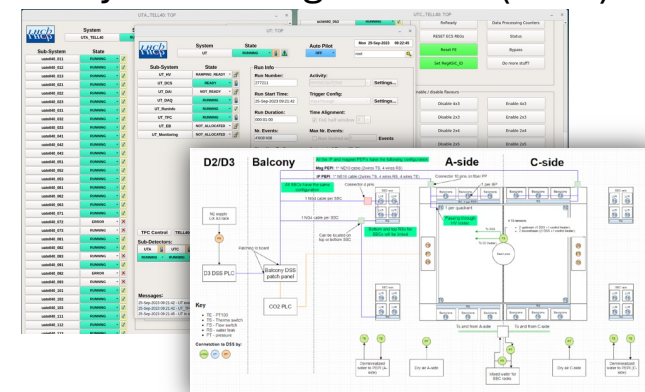
Chinese groups contributed to **UT installation**, ensuring LHCb Upgrade I completion in time (IHEP/HNU/CCNU/TUHU/SCNU/LZU)



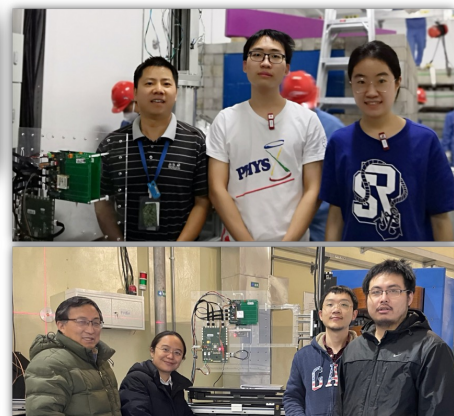
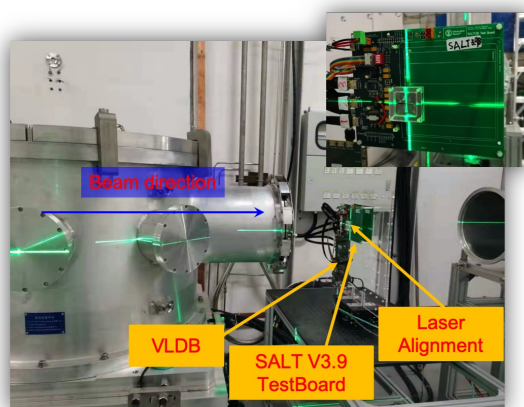
Large improvement with UT



Lead development in control and safety monitoring software (IHEP)



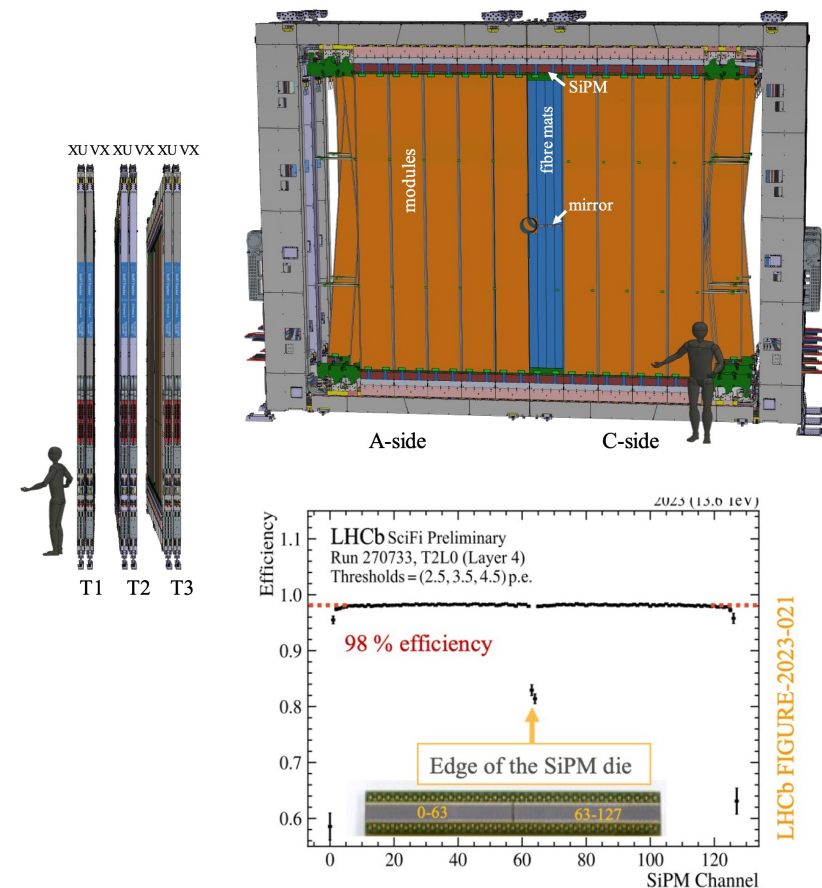
Performed **key radiation tests** for **SALT chip** using **Chinese facilities** during pandemic (IHEP/HNU)



02/11/2025

LHCb Upgrade, CLHCP 2025, Hengne Li

Scintillating Fibers tracker (SciFi)



Brand new detector with scintillating fibers

- 3 station x 4 detection layers
- Fibers diameter and length: $250 \mu\text{m}$ / 2.4 m
- Decay-time constant: 2.8 ns
- ~ 12 km fibers, covering 340m^2 area

Light detected by SiPMs installed at one end of the fibers

- -40°C to reduce dark counts

New ASIC (PACIFIC), 64 channels 130 nm CMOS

- Clusterization of hits implemented in FPGA after signal digitization

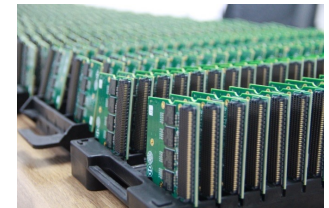
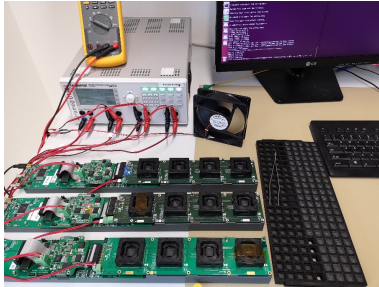
Good performance in 2023 + 2024

China group contribution to SciFi

QA System for readout ASICs & the Front-End Board

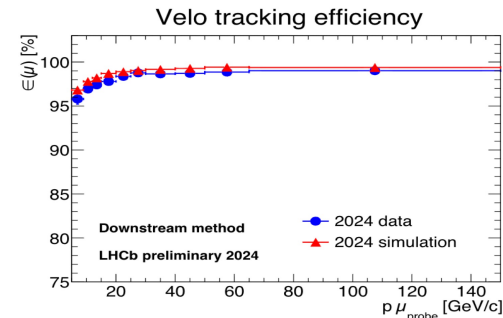
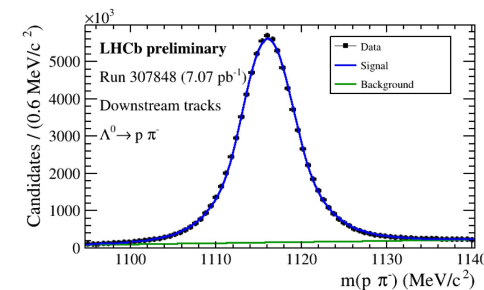
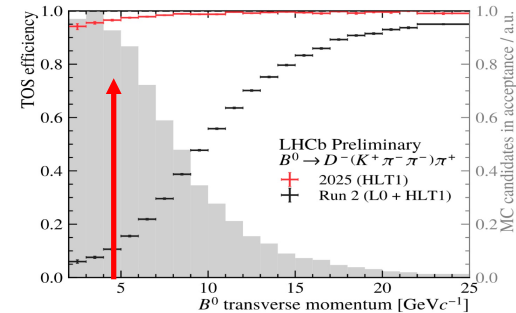
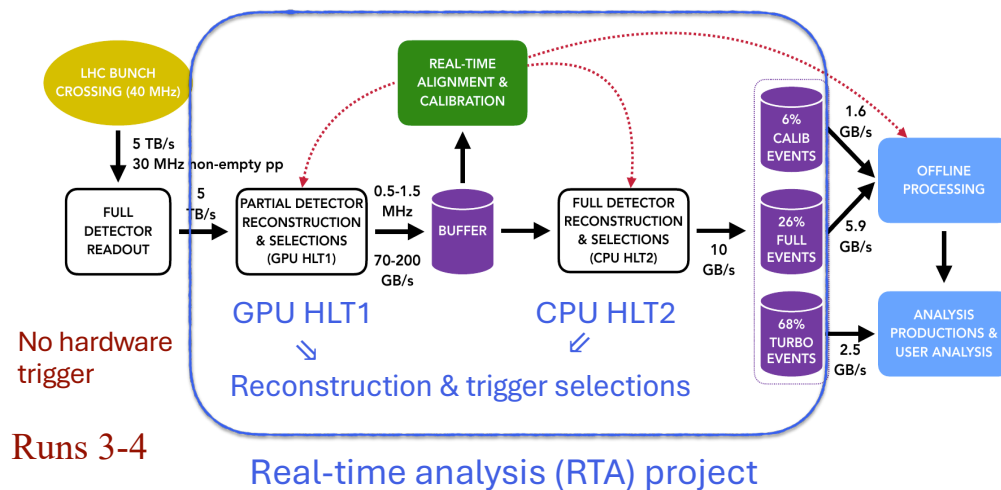
SciFi: 524,000 SiPM channels

SciFi readout ASIC (PACIFIC): a 64-channel SiPM readout



- LHCb SciFi China Group (Tsinghua U):
 - **Co-design** the ASIC Frontend Board (with Heidelberg)
 - **Manufacture all 2,528 ASIC Boards** (64,168 channels in total)
 - **Test 1/2 of ASIC Boards and all the chips**
 - 11 setups of Quality Assurance System for ASICs & boards

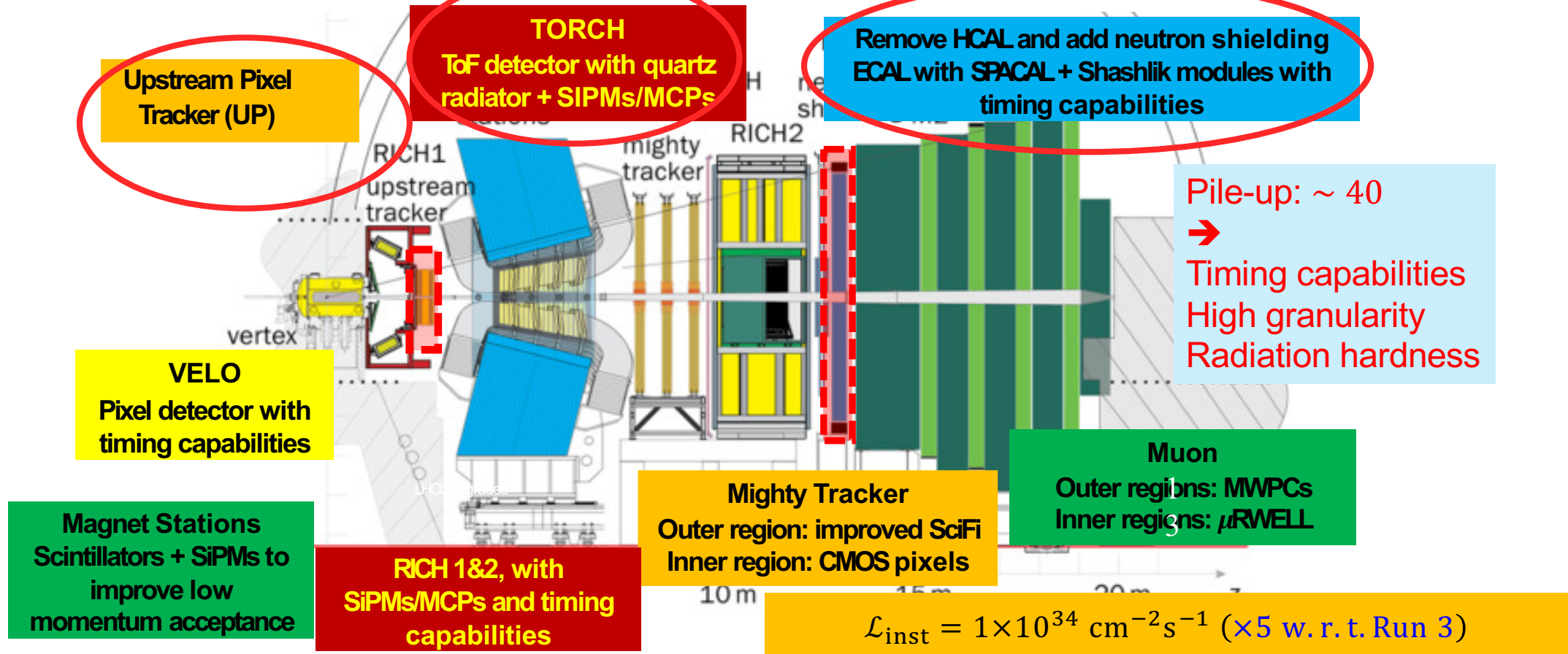
Run 3 Trigger & Performance (Real-time analysis)



- 2~4x times increase in the trigger efficiencies for hadronic decay modes
- Downstream tracking in HLT1 extends physics potential for long-lived particles
- Significant contribution of Chinese group to the RTA system
 - Long-term maintainer of the whole software
 - Responsible for Muon alignment & Tracking efficiency calibration
- Actively participating in the reconstruction R&D for Upgrade II

- Upgrade I (2019 – 2023)
- L3 Enhancement (Q3.2026-2029)
- Upgrade II (2034 - 3035)

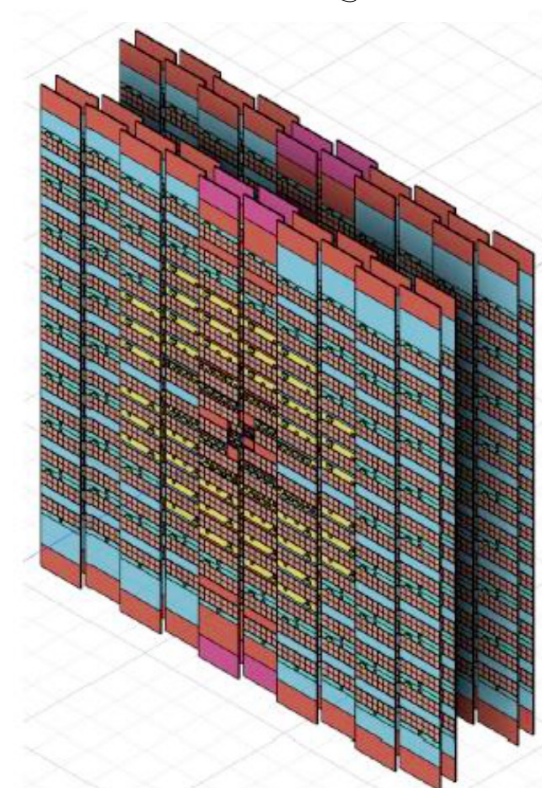
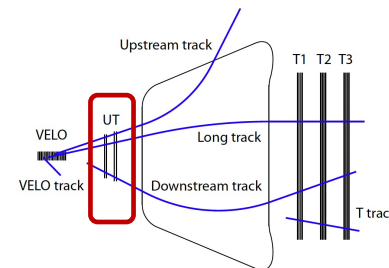
LHCb Upgrade II (including LS3 enhancement)



$$\mathcal{L}_{\text{inst}} = 1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} (\times 5 \text{ w. r. t. Run 3})$$

Upstream Pixel Tracker (UP)

- Upstream tracker is a key component in LHCb tracking system:
 - Speed up tracking to allow software-only trigger
 - Ensure efficient tracking for long-lived particles
 - Improve momentum resolution
- Current silicon strip based UT cannot handle the high data rate and radiation in Upgrade II
 - New UT with silicon pixel detector
 - Hit density up to 4 hit/cm²/BX
 - Expected radiation level of $3 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$



Upstream Pixel Tracker (UP)

- R&D collaboration formed mainly by Chinese and French institutes
- Leading development in all aspects
 - Simulation & performance
 - CMOS sensor R&D
 - Module and mechanics prototyping



PL: 王建春(IHEP, UT/UP)

DPL: Tomasz Skwarnicki (Syracuse, UT), Benjamin Audurier (IRFU, UP)

Steve Blusk / Syracuse
袁煦昊 / IHEP

Simulation, reconstruction & performance

李一鸣 / IHEP

Fabrice Guilloux / IRFU

Pixel sensor chip development

陈凯 / CCNU

徐子骏 / IHEP

Data acquisition system

Ray Mountain/Syracuse
俞洁晟/HNU

Manuel Guittiere/Subatech

Module and stave

Theo Bigourdan / Subatech

Overall mechanics, integration & services

刘凯 / LZU

Christophe Renard / Subatech

Electronics

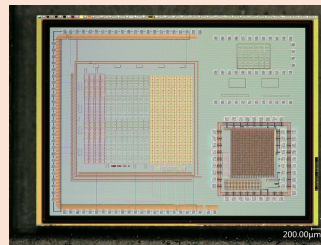
UP sensor development

- High Voltage CMOS is a promising technology candidate
- A series of small prototypes developed using advanced process

COFFEE 2

First HVCMOS 55nm prototype chip

- Breakdown at -70V
- Responsive to laser, X-ray and beta-ray sources



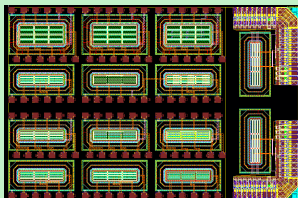
CMOS SENSOR IN
FIFTY-FIVE NM PROCESS

Parameter	UP Specification
Pixel size, square rectangular	$\leq 85 \times 85 \mu\text{m}^2$ $\leq 50 \times 200 \mu\text{m}^2$
Substrate thickness	$< 200 \mu\text{m}$
Pixel orientation	x
Max. Particle Rate (R_{part})	74(34) MHz/cm ²
Max. Hit Rate	150 Mhit s ⁻¹ cm ⁻²
Max. length of data word	32
Overall efficiency	>96%
In-time efficiency	>99% within 25 ns
Noise rate (End of life)	$\leq 400\text{kHz/cm}^2$
Transmission rate	$N \times 1.28 \text{ Gbit/s}$
NIEL	$3 \times 10^{15} n_{eq}/\text{cm}^2$
TID	240 MRad
Power Consumption	$\leq 200 \text{ mW/cm}^2$



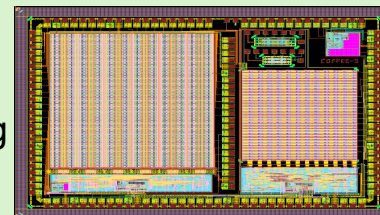
COFFEE1

- Prototype in LL process
- Validation of deep N-well structure



COFFEE3

- Two pixel arrays with data-driven readout
- Designed for good timing resolution and moderate power consumption



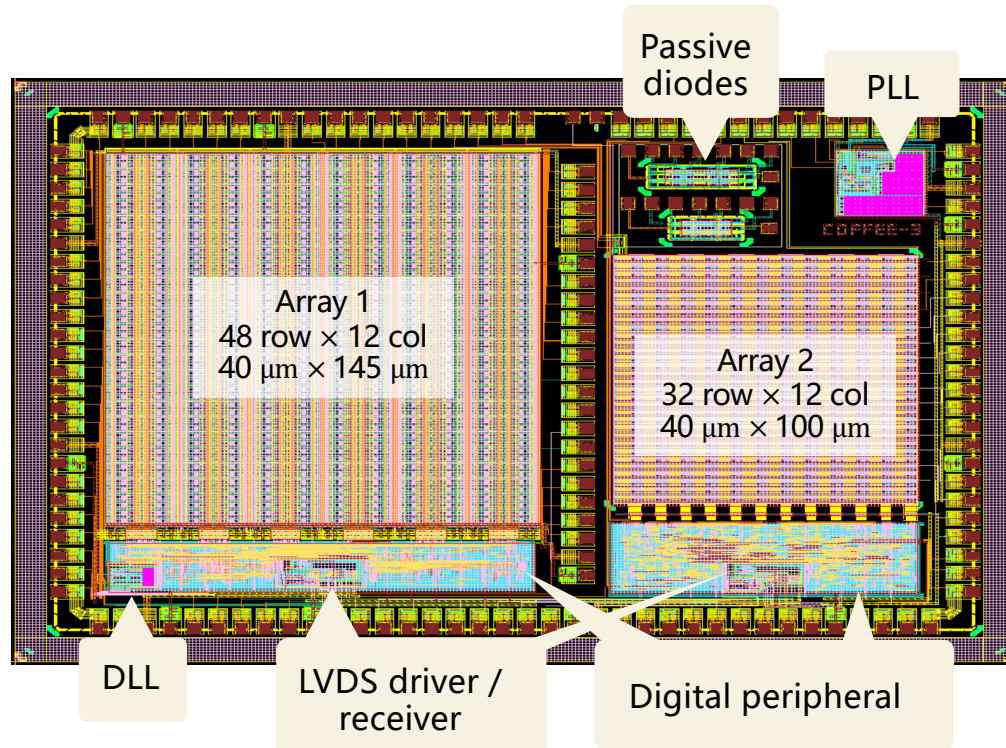
Large prototype planned around 2027

COFFEE3 sensor

- A prototype with key designs implemented to tackle high data rate at Upgrade II
 - 4mm x 3mm, submitted in Jan 2025, received in May 2025
 - Two novel readout architectures in two pixel arrays
 - Standalone function modules to integrate into full-size chip

Architecture 1:

CMOS in-pixel digital design fully exploiting 55nm advantage

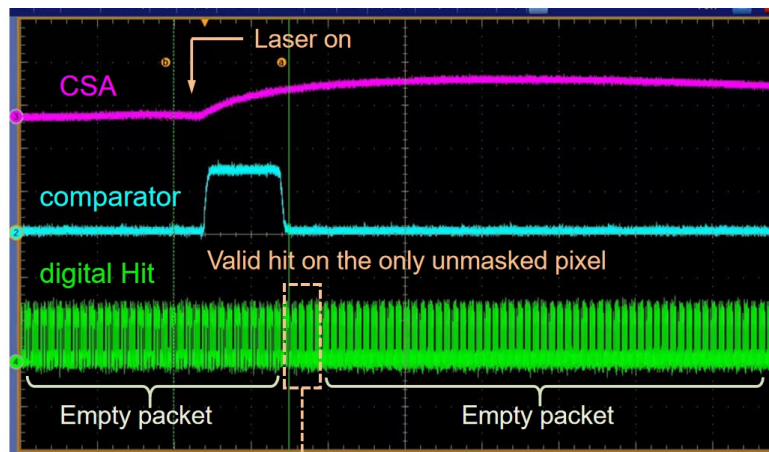


Architecture 2:

NMOS-only in-pixel digital design: lower power consumption in pixel; no process modification needed

First COFFEE3 results

- Preliminary tests show that both readout array function well
- Standalone modules meet design goal: PLL, LVDS, DLL

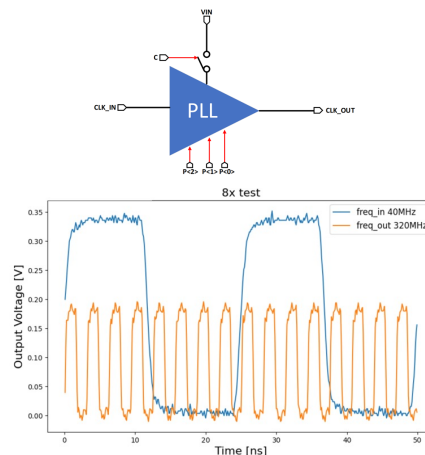


4 bit	4 bit	8 bit	8 bit	6 bit	2 bit	7 bit	3 bit
header	CHIP_TS	LE_coarse	TE_coarse	LE_fine	TE_fine	Addr_Row	Add_Col
0 1 1 0	0 1 0 1	0 0 0 1 0 1 1 0	0 1 1 0 1 0 1 1	1 1 0 0 0 0	0 0 0	0 0 0 0 0 0 1	0 0 0

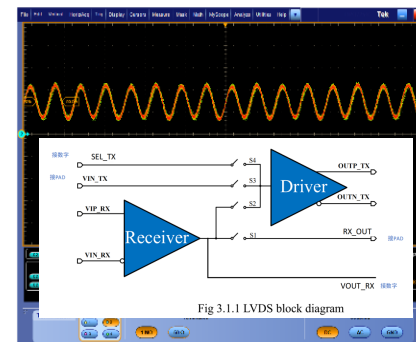
A valid transmission packet corresponding to a hit

Correct row & column address

Laser signal on a single pixel corrected read



Phase Lock Loop works up to 640MHz



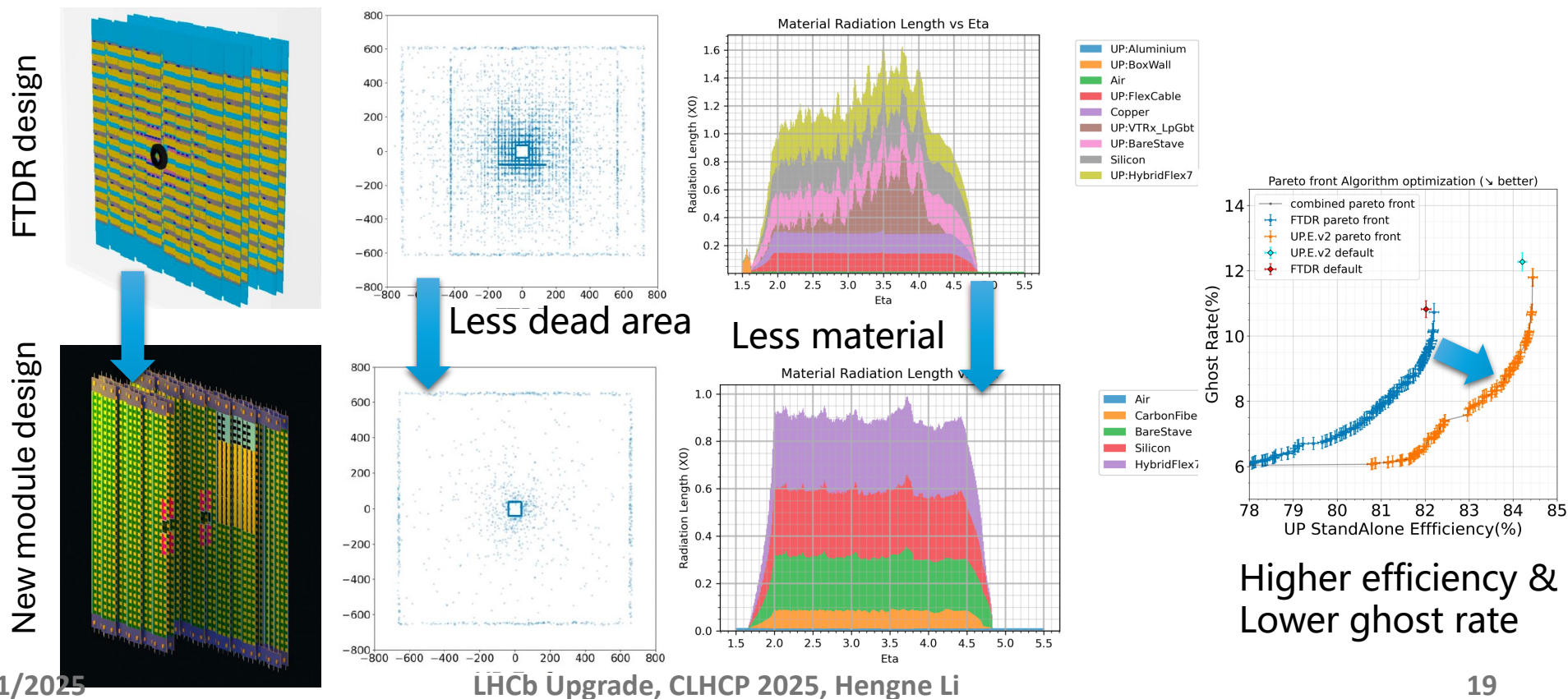
LVDS trceiver works at 640MHz



DLL delays main clock to achieve finer timing

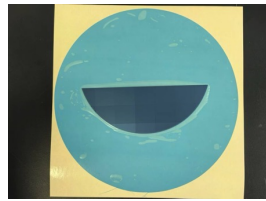
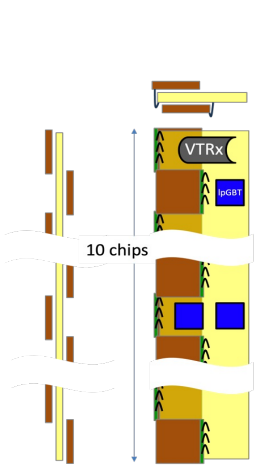
Simulation and performance study

- New UP design implemented in LHCb official framework followed by tremendous work on tracking algorithm and detector optimisation



UP module and mechanics

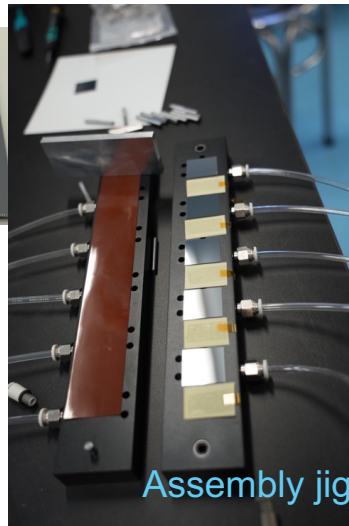
- Module design updated to reduce dead area
- Prototyping starting with dummy components
 - Dummy silicon sensors produced with similar thermal mechanical properties
 - Tools designed for assembly procedure
 - Thermal simulation + market survey for realistic mechanical design



1st dummy sensor



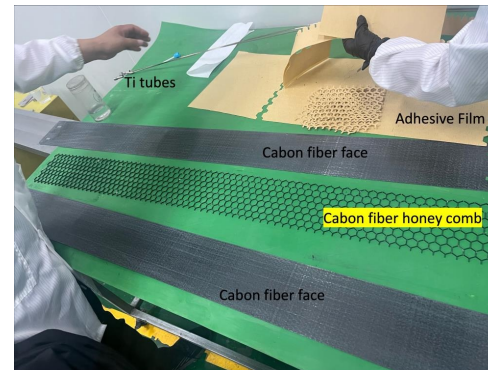
1st dummy hybrid



Assembly jig



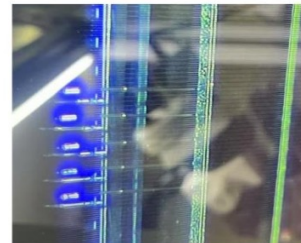
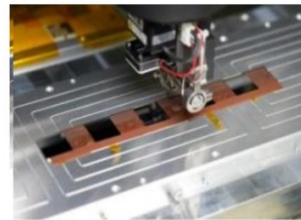
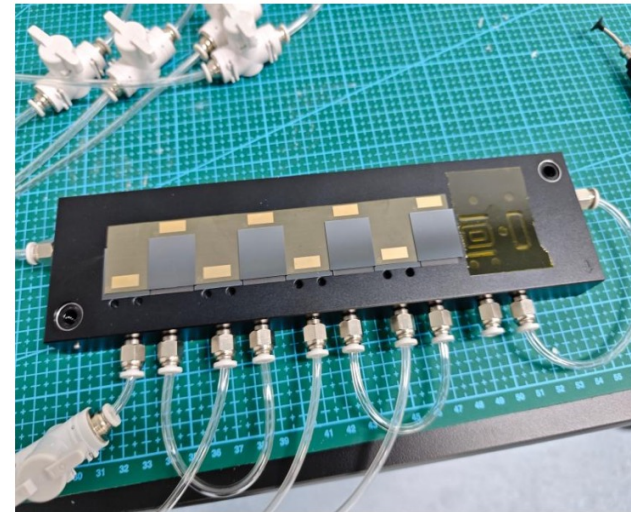
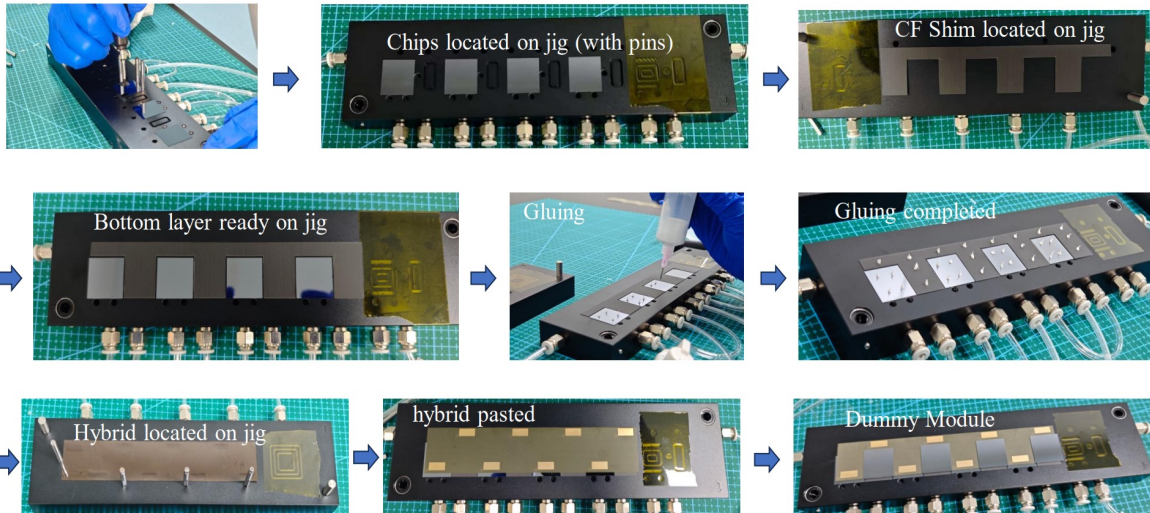
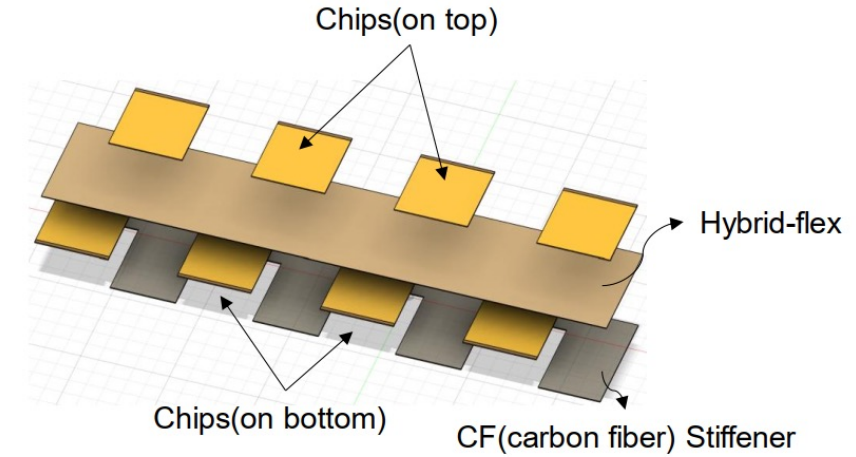
Thermal simulation of stave w. CO2



Tiange Li@HNU

Module prototyping

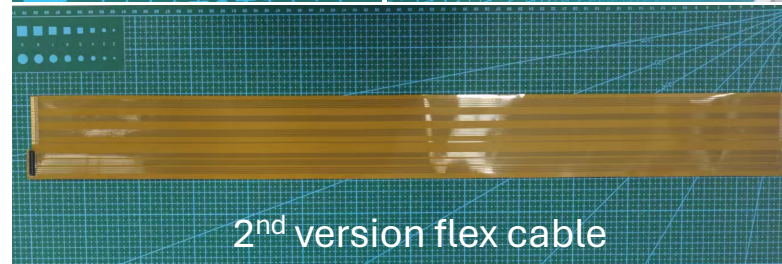
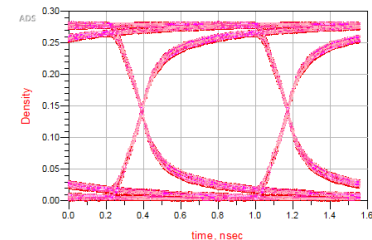
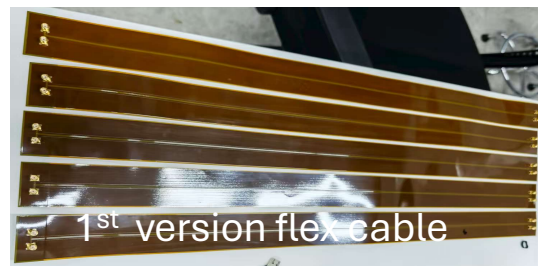
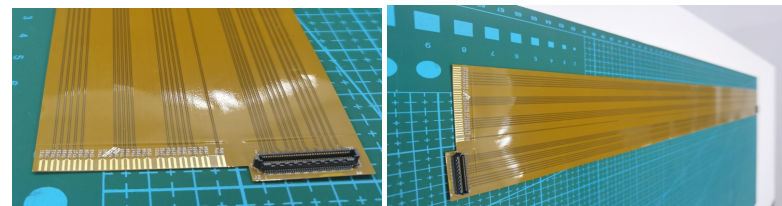
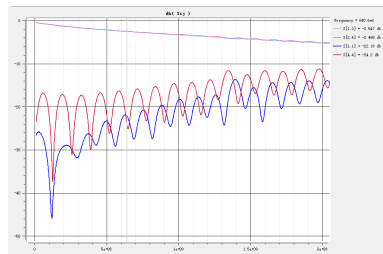
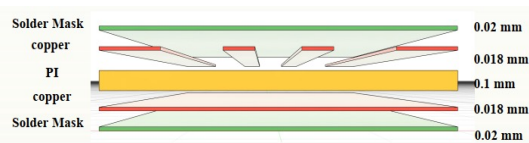
- First modules developed with dummy silicon sensors and dedicated tools



Electronics and readout

- Studied the signal integrity with flex cable prototype : ~70 cm long and 1.28 Gbps
- Studies on cross talk with 2nd version flex cable is ongoing.
- Data format proposed.

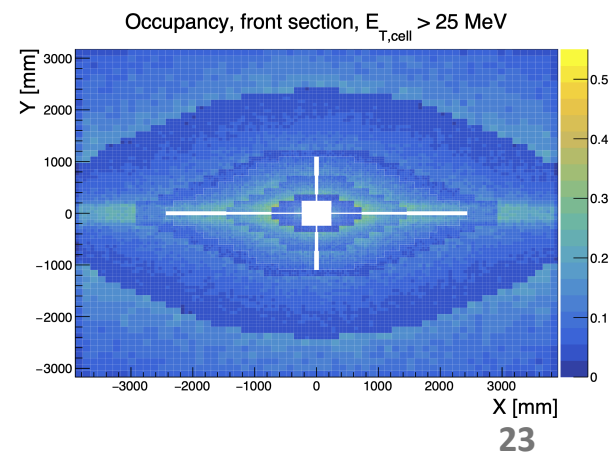
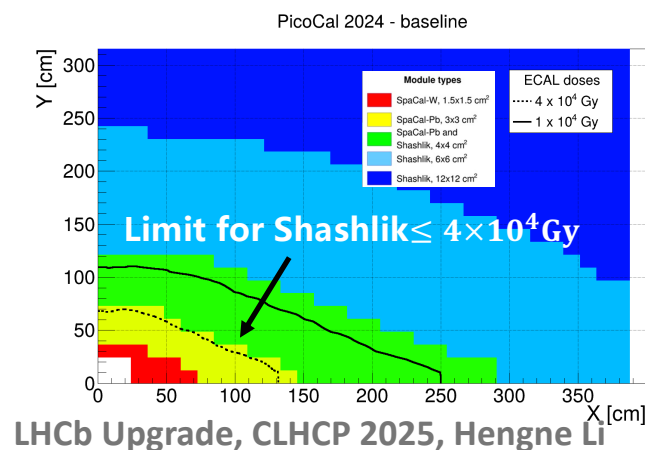
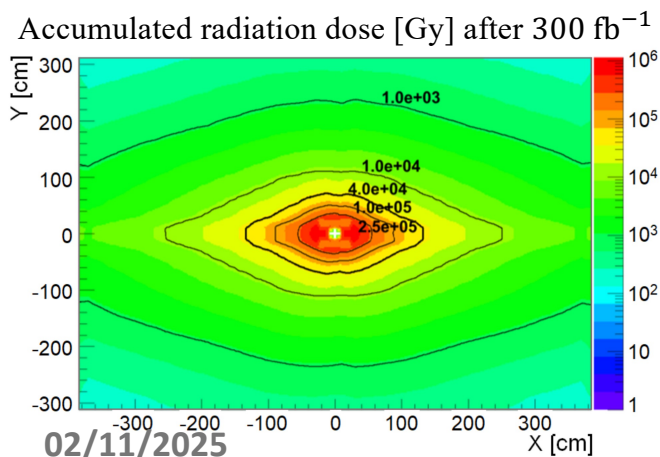
Normal	b'00	Chip	BXID	Col	Row
Normal Compact	b'01	Chip	BXID	NumHits	
	Col 1		Row 1	Col 2	Row 2
	...			...	
	Col N		Row N	(0x5555, for odd NHits)	
Calibration	b'10	Chip	BXID	Col	Row
	0x0C	ToT	ToA	0x0C	ToT ToA
Status	b'11	Chip	BXID	Type	0xAAA



ECAL Upgrade II

Requirements for the Upgrade II:

- Radiation doses up to **1 MGy** and $\leq 6 \times 10^{15}$ 1 MeV neq/cm² in the centre for 300 fb⁻¹
 - New technologies required for the center
- Pile-up mitigation crucial
 - Timing $\mathcal{O}(10 \text{ ps})$ precision
 - Increased granularity
 - longitudinal segmentation
- Keep current energy resolution of $\sigma(E)/E \approx 10\%/\sqrt{E} \oplus 1\%$



The Upgrade Strategy

Run 3		LS3					Run 4					LS4		Run 5					
2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041		

Run 3 in 2022-Q2/2026:

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

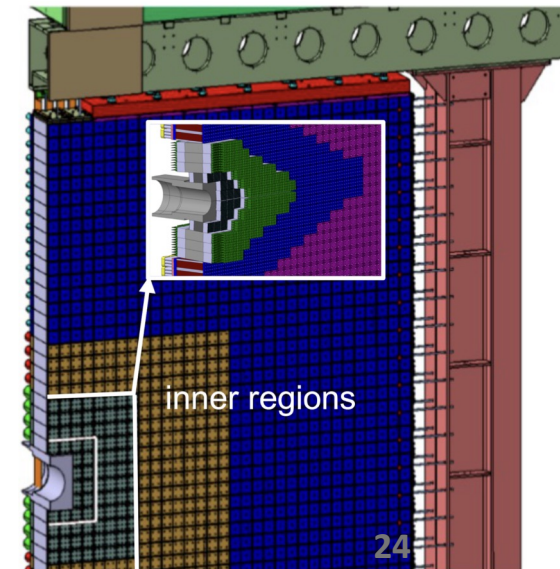
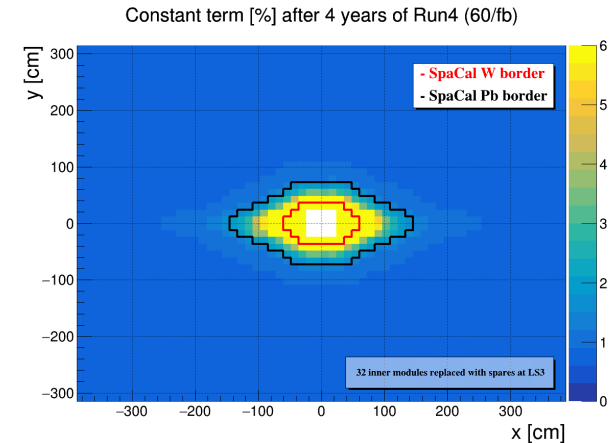
LS3 consolidation in Q3/2026-2029:

- Introduce **single-section rad. tolerant SPACAL** (2×2 and $3 \times 3 \text{ cm}^2$ cells) in inner regions and **rebuild ECAL in rhombic shape** to improve performance at $L = 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
 - 32 SPACAL-W & 144 SPACAL - Pb modules with plastic fibres **compliant with Upgrade II** conditions

LS4 Upgrade II in 2034-2035 (PicoCal):

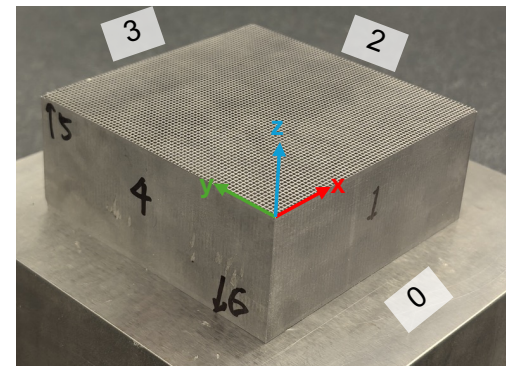
- Introduce **double-section rad. hard SPACAL** (1.5×1.5 , 3×3 & $4 \times 4 \text{ cm}^2$ cells) and improve timing of Shashlik modules for a luminosity of up to $L = 1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
 - Innermost SPACAL-W modules equipped with **crystal fibres**
 - Include **timing** information and double-sided readout for pile-up mitigation

LHCb-TDR-023, LHCb-TDR-024, LHCb-TDR-026



China contributions to ECAL upgrade

- Simulation, reconstruction and performance studies
- Fast GAGG crystal fibre development, collaborating with SiPAT (电科芯片)+CERN, decay time τ_{eff} : 50 ns (2022) $\rightarrow$ 20 ns (2024) $\rightarrow$ 8 ns (2025)
- **3D printed tungsten (W) absorbers, collaborating with LaserAdd (雷佳)**
- Light-guide system development
- Module assembly for beam tests:
 - SpaCal-W-GAGG prototype assembly in 2024
 - SpaCal-W-Polystyrene prototype assembly in 2025
- PMT R&D: (just started) collaborating with NNVT(北方夜视)



ECAL/PicoCal management structure

ECAL organisation towards LS3 enhancement

ECAL Upgrade Project Leader: Philipp R.
(since July 2024)

WP1: Absorbers

CERN & China*

Hubert G.
Sergey K. & J. Wang

WP2: Optics assembly (fibers & lightguides)

Maryland & Milano & China*

Matteo S. & Z. Yuan

WP3: Organic & crystal fibers R&D

CERN & China*

Etiennette A. & Ming Z.

WP4: PMT & HV & LED system

CERN, ICCUB, CSIC, Maryland, Cincinnati, Bologna, Milano

Phoebe H. & Yuri G. & Conor H.

WP5: Electronics

IJCLab, LPC, LAPP, ICCUB, CSIC, Syracuse

Patrick R. & Christophe B.

WP6: Infrastructure (incl. cabling)

CERN, LAPP, Imperial

Rolf L. & Andrei G.

WP7: Detector Software

CERN, China*, La Salle, Milano-Bicocca, Padova, MIT, Syracuse

Marco P. & Liupan A.

WP8: Testbeam coordination & analysis

CERN & All

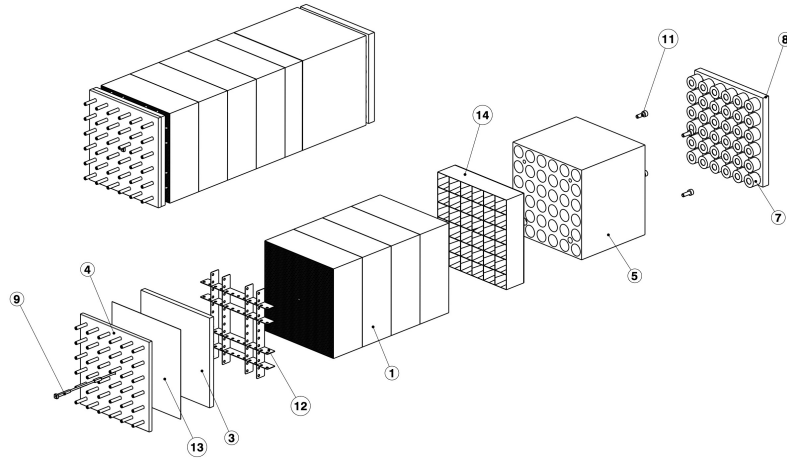
Loris M. & Daniele M.

* China: Peking, Tsinghua, Wuhan, SCNU



Ongoing R&D: Assembly for LS3

Both use W absorbers from
China group

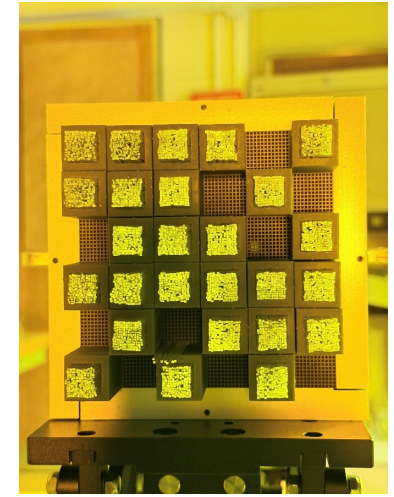
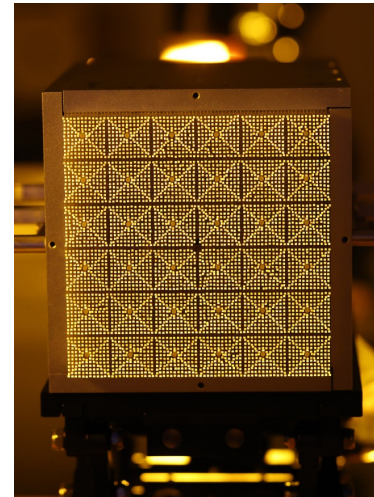


R9880U PMTs



Module assembled in
Beijing in May 2025

Module assembled at
CERN in Oct. 2025

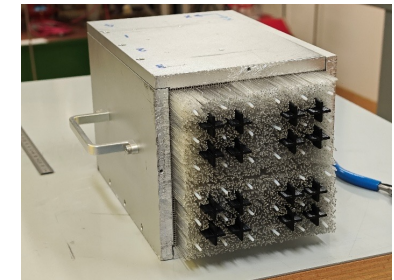
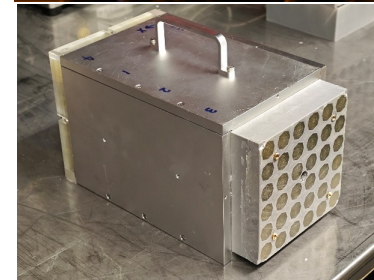


Beam tests in May, Sept., and Nov. 2025 CERN SPS beam tests:

➤ First test of full Run 4 chain with 2 new prototypes assembled in Beijing and CERN:

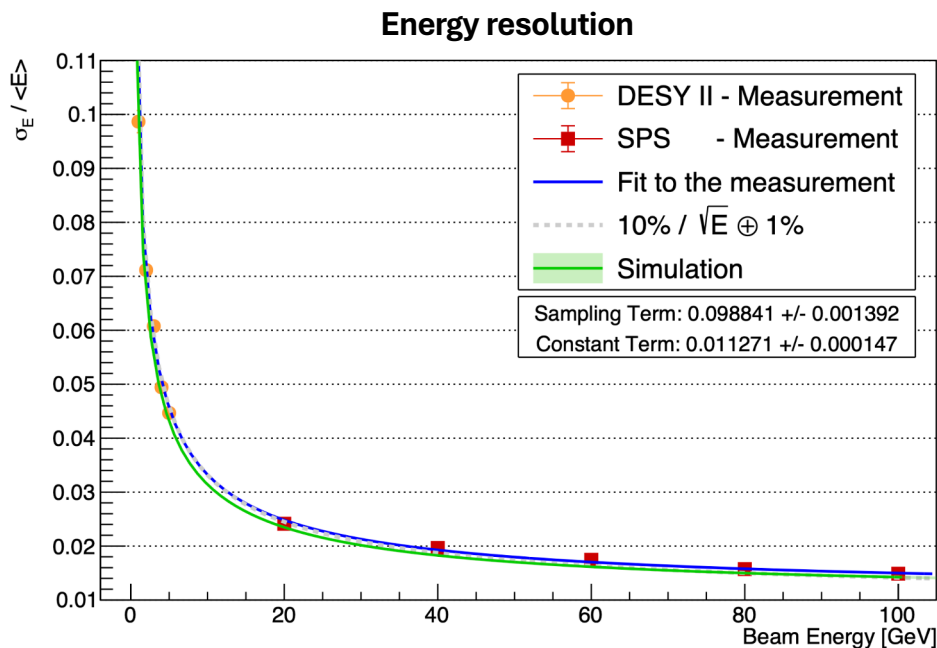
- W absorbers from China group.
- 3HF green plastic fibres (square fibres $1 \times 1 \text{ mm}^2$)
- Optics assembly with bundlers and long “hollow” light guides
- Cable clipping circuits, 10 m signal cables, read-out with Run 3&4 FE electronics

Test plan with new prototype in Nov. 2025 at DESY and CERN with final assembly strategy



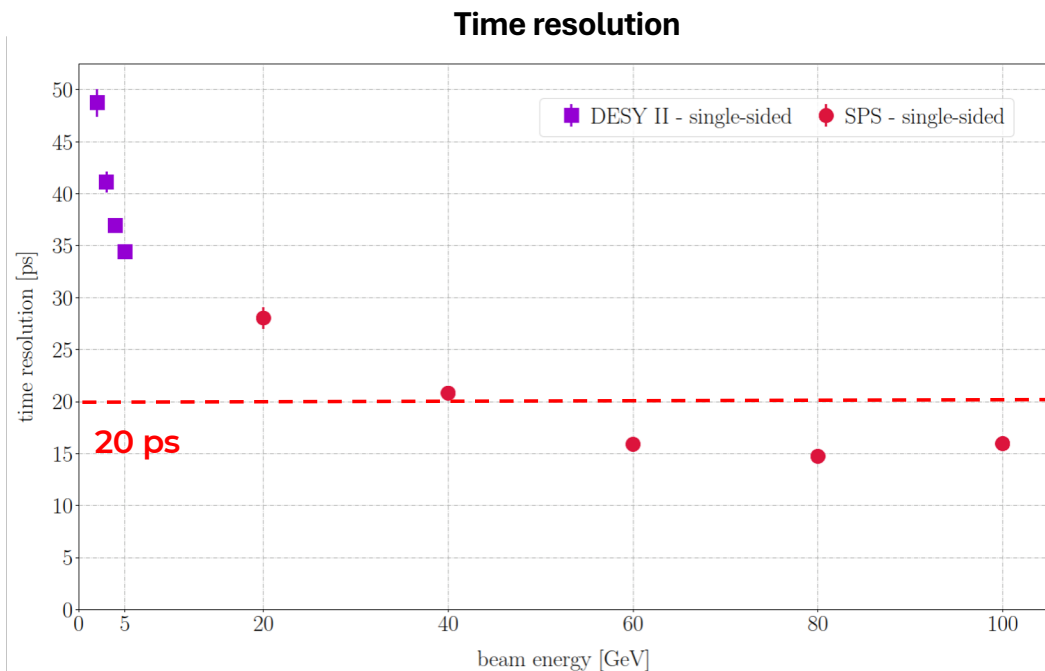
SpaCal - W Absorber - Polystyrene Fibres

LHCB-TDR-024 NIM A 1079, 170608 (2025)



➤ Energy resolution at $3^\circ+3^\circ$:

- Noise contribution subtracted
- R14755U-100 PMT
- Symmetric LGs: square to octagon
- Sampling term: $9.9 \pm 0.1 \%$
- Constant term: $1.13 \pm 0.01 \%$
- Very good agreement with simulation



➤ Time resolution at $3^\circ+3^\circ$:

- Multi-Anode(R7600U-M4) PMT with 4 channels
- Asymmetric LGs: square to square
- Single-sided readout
- Time resolution above 40 GeV: better than 20 ps

Performance in line with targets

SpaCal - W Absorber - Crystal Fibres

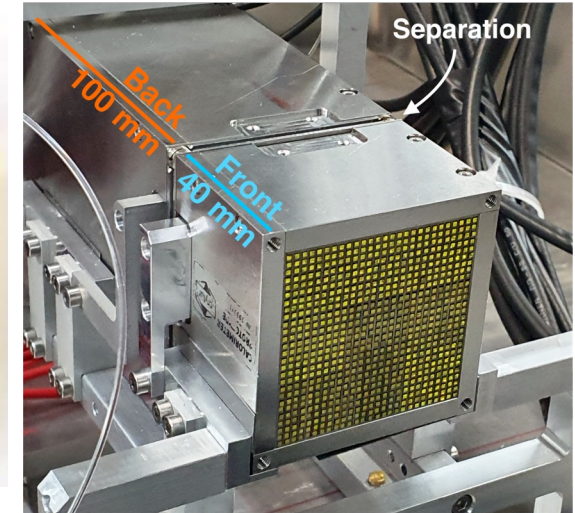
NIM A 1000, 165231 (2021)

NIM A 816 (2016) 176

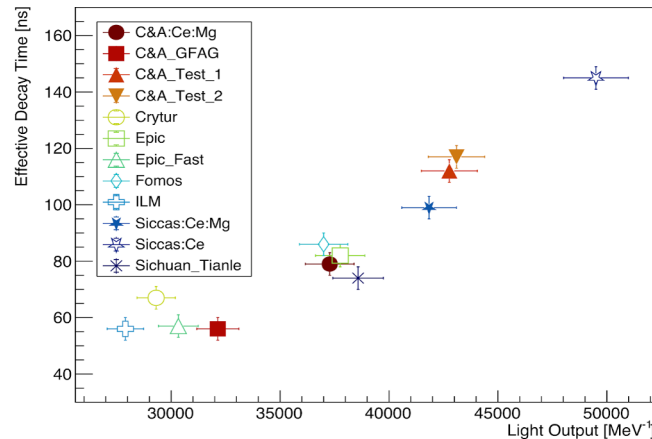
SPACAL prototype with **W absorber** and **garnet crystals**

➤ Module details:

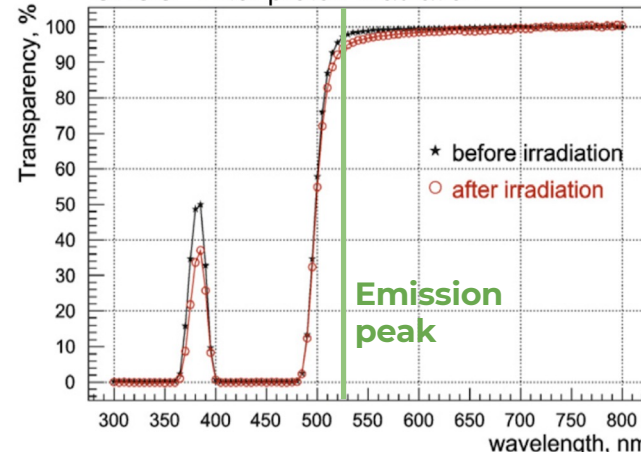
- Absorber in pure tungsten 19 g/cm³
- 9 cells of 1.5×1.5 cm² ($R_M \sim 1.5$ cm)
- 4 + 10 cm long (7 + 18 X₀)
- Reflective mirror between sections
- Squared garnet crystal fibres (1×1 mm² cross section)



Effective Decay Time vs Light Output



GAGG - After proton-irradiation



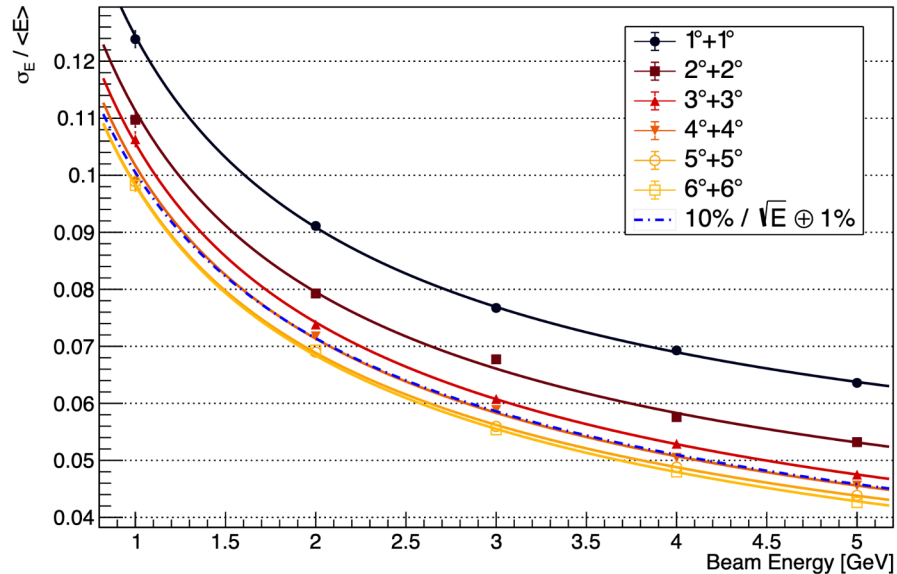
GAGG as scintillating material

- High light output and relatively fast decay time (~50 ns)
 - Tunable scintillation properties
- Radiation hardness tested up to 1 MGy

SpaCal - W Absorber - Crystal Fibres

NIM A 1045, 167629 (2022)

Energy Resolution



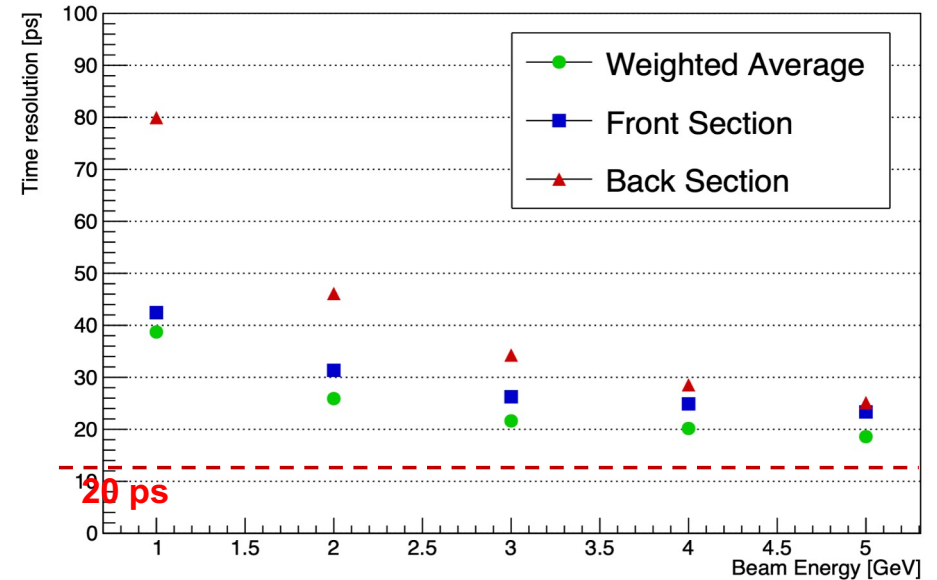
- Resolution improves increasing the incidence angle

➤ Energy resolution at $3^\circ+3^\circ$:

- Sampling term: $10.2 \pm 0.1 \%$
- Constant term: $1 - 2 \%$

Performance in line with targets

Time Resolution C&A GFAG

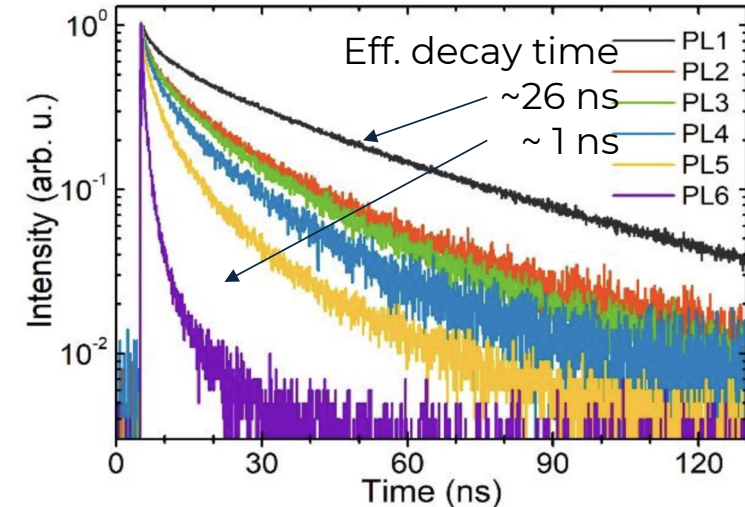


- Time stamps obtained using CFD algorithm

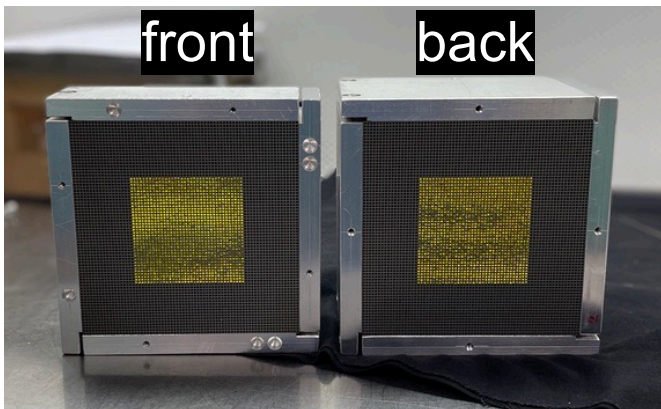
➤ Time resolution C&A GAGG at $3^\circ+3^\circ$:

- Measurement in direct contact with MCD(R7600U-20) PMTs for ultimate performance
- Double-sided readout
- $18.5 \pm 0.2 \text{ ps @ } 5 \text{ GeV}$

Ongoing R&D: Accelerating Scintillation

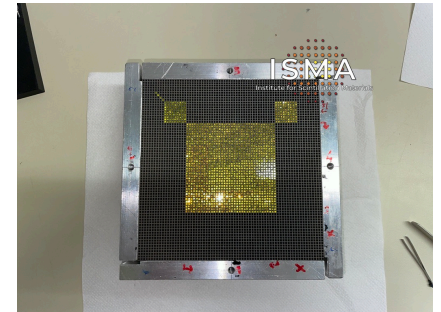


Material Advances, 2022, 3, 6842



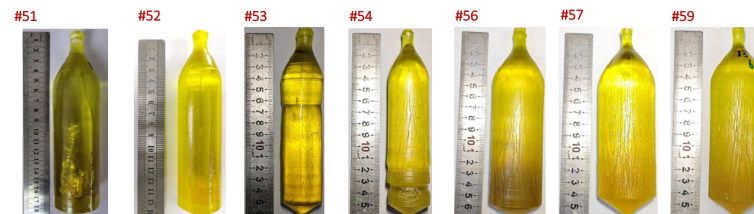
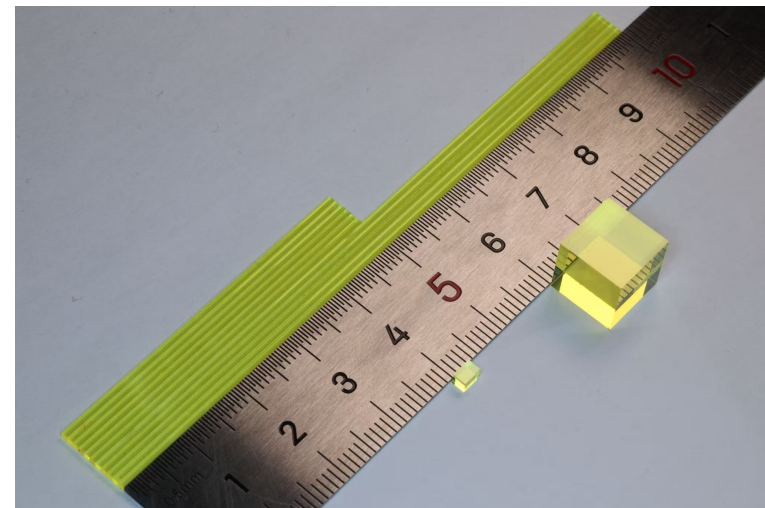
02/11/2025

- **The issue:** current commercial GAGG has scintillation decay time > 40 ns
 - Mitigate spill-over effect on time resolution
- **Novel GAGG compositions developed to quench scintillation**
 - Light yield reduced
 - Decay time accelerated
 - Time resolution kept competitive
- **R&D to produce large-size and homogeneous Czochralski ingots**
- **Collaboration with:**
 - SiPAT, China
 - FZU and Crytur, Czech Republic
 - European project TWISMA including CERN, ILM & UCB, and ISMA
- **The Second prototype in June 2024**
 - SiPAT GAGG with decay time ~ 20 ns
 - 3D-printed absorber with LaserAdd, China
 - **Two more cells filled in 2025 with new GAGG fibers with decay time ~10 ns**
 - **FZU/Crytur & SiPAT**



Ongoing R&D: Accelerating Scintillation

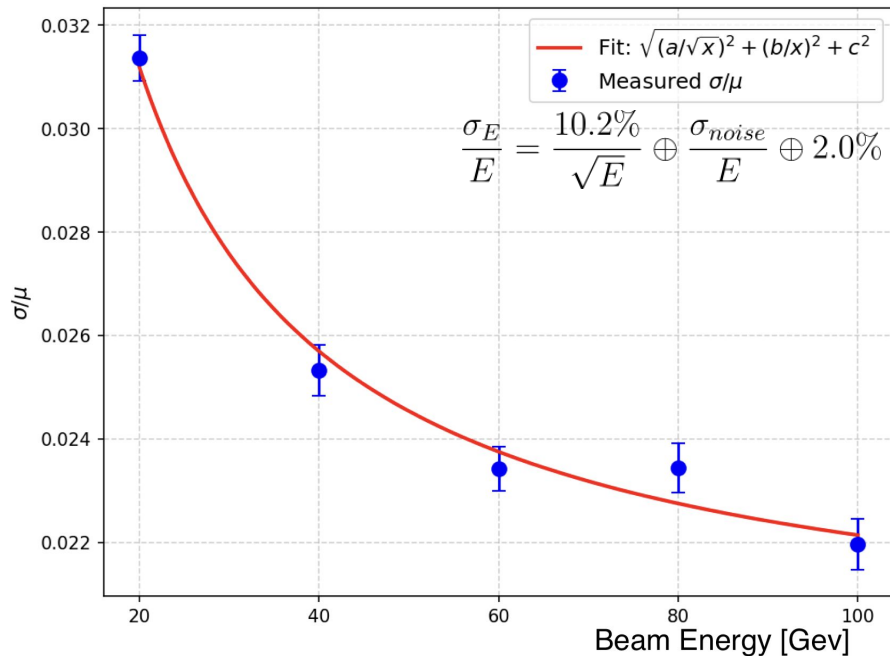
- **Chinese group started R&D of fast GAGG in the end of 2021**
 - Collaboration with SIPAT (a company in Chongqing, China) for GAGG production
 - A new laboratory was built at Peking University (PKU) for scintillator characterization
 - Students from Tsinghua University (THU) and PKU involved in the R&D
- **Novel GAGG compositions are developed at SIPAT to decrease the decay time**
 - First batch of SIPAT GAGG samples delivered to PKU in Jan. 2023
 - **About 60 ingots** with optimization have been produced so far
 - Tests on the samples show **significant improvement in decay time**
- **Close collaboration with CERN colleagues in GAGG testing**
 - Besides testing at PKU, half of the samples are also **delivered to and tested at CERN**



**Increase doping , LY decrease,
time resolution increase**

SpaCal - W Absorber - Crystal Fibres

Energy resolution

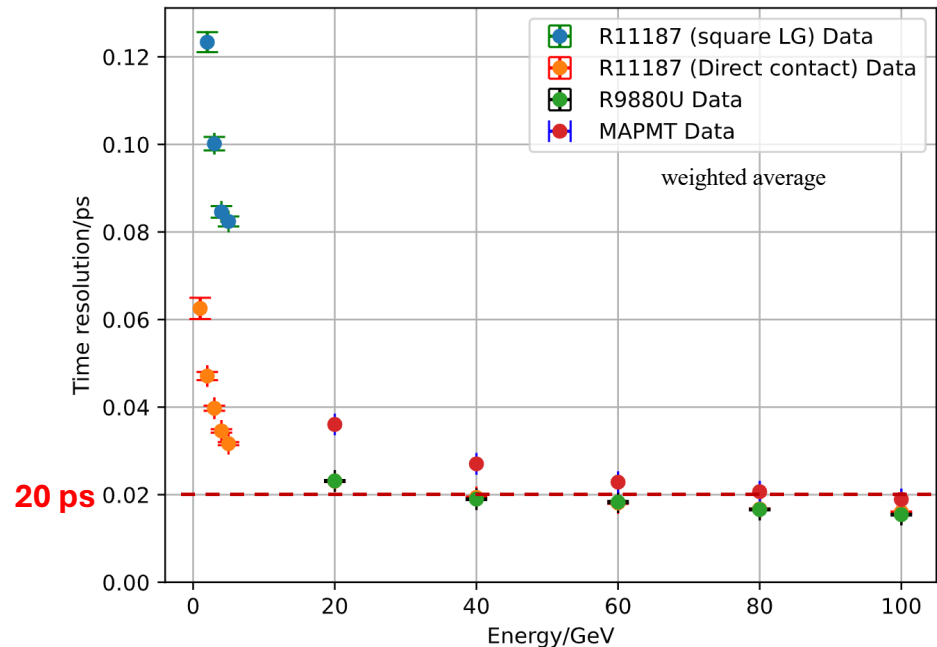


➤ **Energy resolution at 3°+3°:**

- Sampling term: $10.6 \pm 0.2 \%$
- Constant term: $\sim 2 \%$

**First measurements performed with non-optimal configuration
degradation of energy and time resolution expected**

Time resolution



➤ **Time resolution SIPAT GAGG at 3°+3°:**

- R11187 (Direct contact) and R9880U have similar performance (< 20 ps when > 20 GeV)
- MAPMT and R11187 (square LG and only front part) much worse in time resolution

Light Guide System for SpaCal

- Conventional plastic Light Guide is not rad-hard
- Radiation-hard Hollow Light Guide

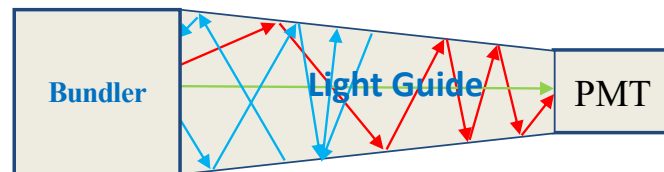
Hollow ESR Light Guides

- **ESR foil radiation-hard** (>90% reflectivity at 300 kGy)
- **Fast timing** (~60 ps jitter)

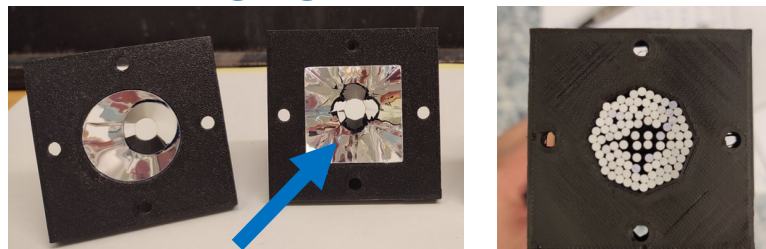
New Fiber Bundling Process

- **Higher light yield** (>30% increase)
- **Uniform response** (<10% non-uniformity)

- Design & validation for LS3 enhancement are done
- Preparing for production



Test light guide and bundler



ESR reflection film

Test different production method



Resin 3D print



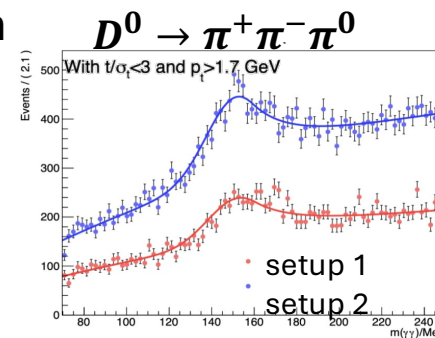
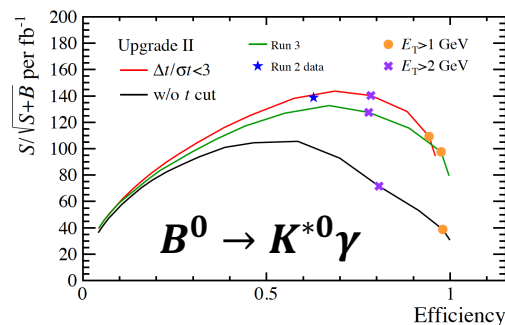
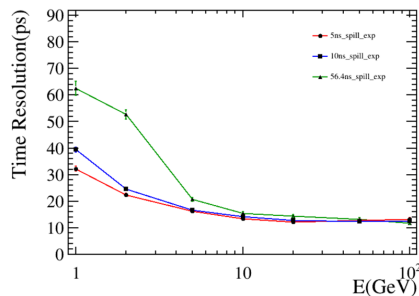
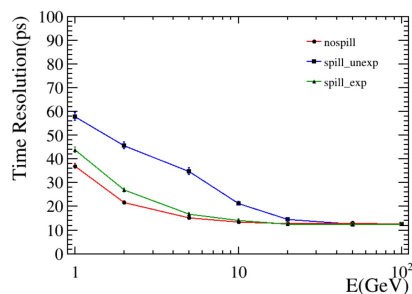
Steel 3D print



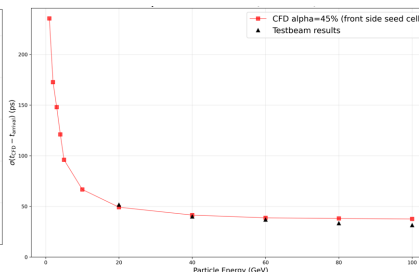
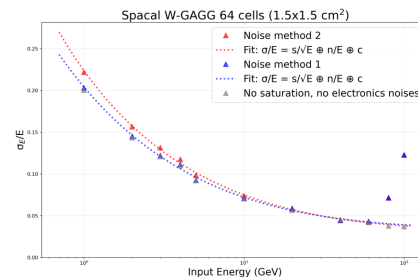
CNC machining

PicoCal: Simulation study and software development

- Simulation study
 - ✓ Material R&D: study of spill-over effect to identify target decay time of garnet crystal
 - ✓ Performance compared between different scenarios for benchmarking physics modes
 - Timing information plays a critical role in background reduction

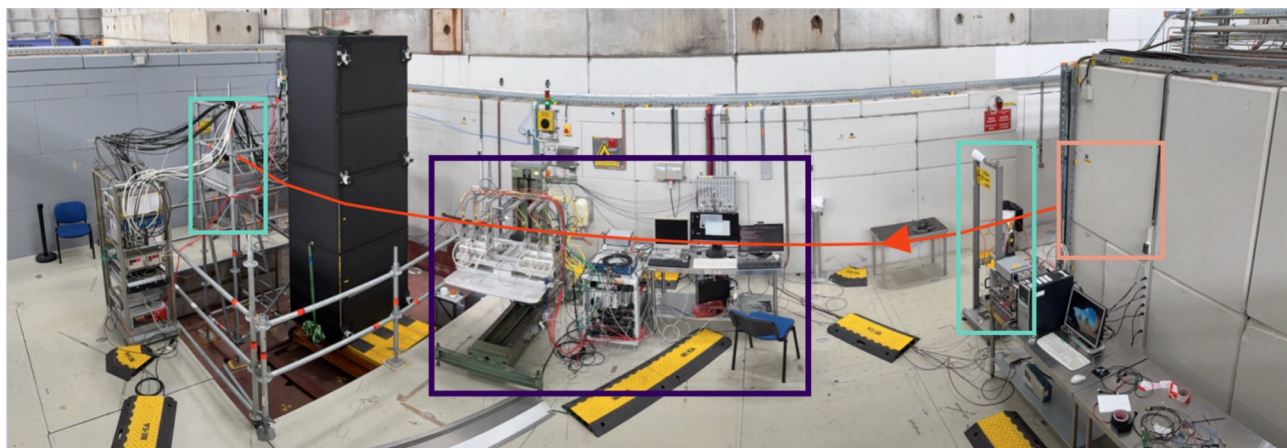


- Software development
 - ✓ Construction of simulation in LHCb official framework
 - templated pulse method for digitization
 - ✓ Integration of reconstruction algorithm to the LHCb official framework



New efforts: TORCH detector

- **TORCH for Upgrade II:** Dedicated PID for low-momentum tracks (<10 GeV/c) to boost LHCb's flavor physics.
- **LHCb China Teams:** UCAS, USTC, and AUST are engaged in simulation, SiPMs, mechanics, and test beams.
- **Leadership & Milestone:** Convening simulation (Peilian Li); 2025 test beam for full-size module validation.



Upgrade Talks at CLHCP 2025

Talk/Poster	Title	Speaker	Upgrade/Computing Session, Date and Time
Talks	R&D on the fast GAGG for LHCb upgrade II	Zhiyang Yuan (Peking University)	Oct 31, 2025, 2:00 PM
	Development and test-beam measurements of LHCb PicoCal modules	Xiaofan Pan (Tsinghua University)	Oct 31, 2025, 3:00 PM
	Software development for LHCb ECAL upgrade	Zifan Li (Peking University)	Oct 31, 2025, 3:20 PM
	Simulation studies for LHCb ECAL upgrade	Chenjia Zhang (Peking University)	Oct 31, 2025, 3:40 PM
	The simulation and reconstruction studies on LHCb UP detector for Upgrade II	Mingjie Feng (IHEP)	Oct 31, 2025, 5:00 PM
	Development of 3D-Printed Tungsten Absorbers for the LHCb ECAL Upgrades	Jike Wang (Wuhan University)	Oct 31, 2025, 6:00 PM
	Sensor development for LHCb Upstream Pixel Tracker	Zeng Cheng (IHEP, CAS)	Nov 1, 2025, 2:00 PM
	LHCb UP Module and Stave Assembly Development	Zhijie Wang (Lanzhou University)	Nov 1, 2025, 3:20 PM
	Operation and performance of LHCb Upstream Tracker	Yuan YUAN (IHEP)	Nov 1, 2025, 4:40 PM
	Real-time analysis at LHCb for Run 3 and beyond	Peilian Li (UCAS)	Nov 1, 2025, 3:30 PM
Poster	Status of LZU Tier 2 and 3 cluster	Kunpeng Yu (Lanzhou University)	Nov 1, 2025, 2:20 PM
	UP bare stave design and thermal study	Tiange Li (Hunan University)	Oct 30, 2025
	Test of signal integrity in flex cable	Hanbing Liu (Lanzhou University)	Oct 30, 2025

Summary

- LHCb upgrade is needed to continue deliver excellent physics results
- China group is contributing more than before in the upgrade projects.
- Upgrade I, made critical contributions, including Run3 trigger & performance.
 - UT (installation and radiation test)
 - SciFi (QA system and Front-End Board)
- LS3 enhancement and Upgrade II, now playing a leading role in UP and ECAL
 - UP: Taking leading roles in 5 of the 6 WPs, esp. in CMOS chips as the key technology.
 - ECAL: Taking leading roles in W Absorber and GAGG Fiber, and critical contribution in simulation and software, optical assembly, prototyping, also starting in PMT.
 - TORCH: New efforts started!

backups

SpaCal - W Absorber - Polystyrene Fibres

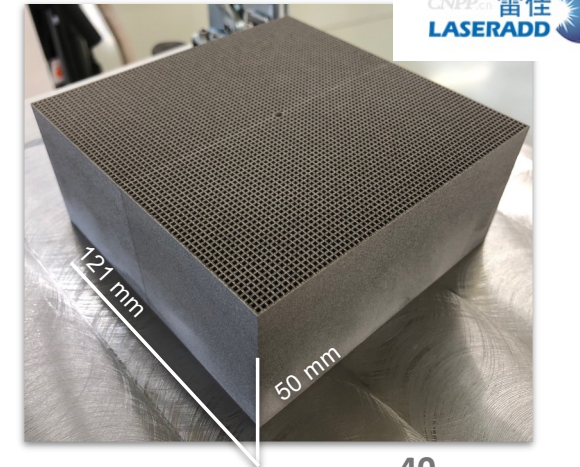
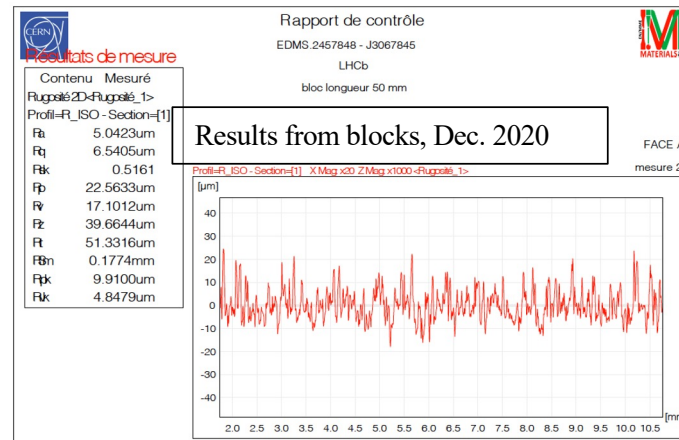
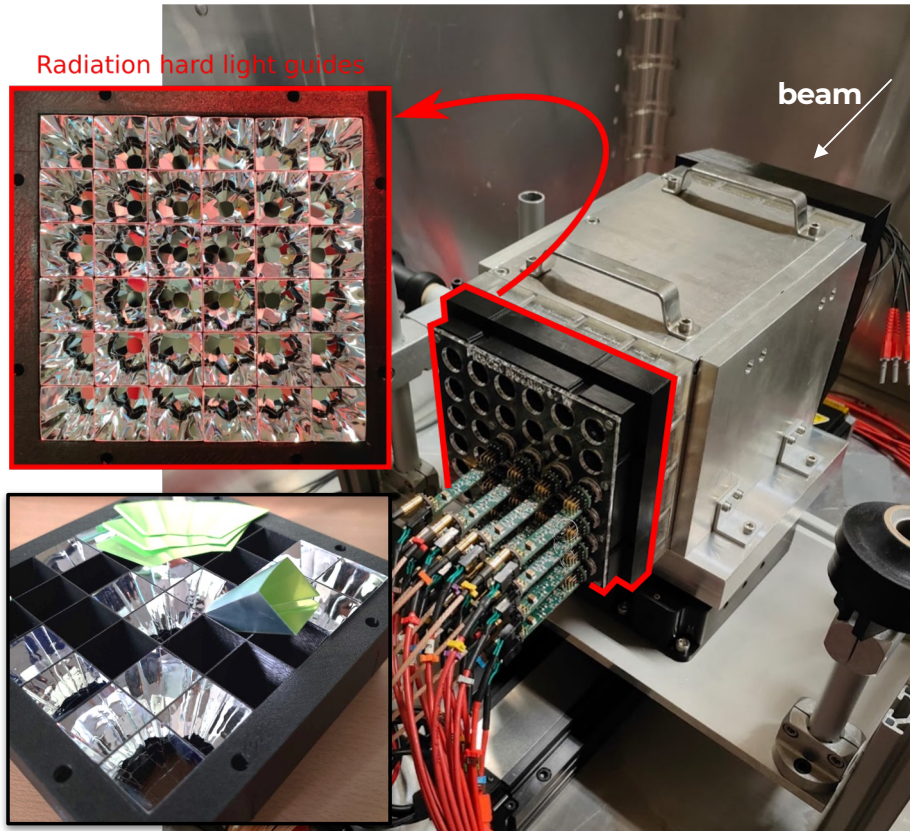
- Full size $121 \times 121 \text{ mm}^2$ **Module 0** assembled at CERN in 2023:
- Passive materials:

- 3D-printed W absorber
 - $3 \times 50 \text{ mm} + 1 \times 40 \text{ mm}$ long blocks
 - R&D performed with EOS, Germany
- Very good mean roughness $R_a = 5 \mu\text{m}$ achieved
 - Smooth surface mandatory not to damage fibres
- Radiation-hard “hollow light guides” made of 3M ESR

➤ Active materials:

- Single-cladded Kuraray SCSF-78 square fibres $1 \times 1 \text{ mm}^2$

LS3 Enhancement



Technologies for ECAL Upgrade II

[LHCb-TDR-023](#), [LHCb-TDR-024](#), [LHCb-TDR-026](#)

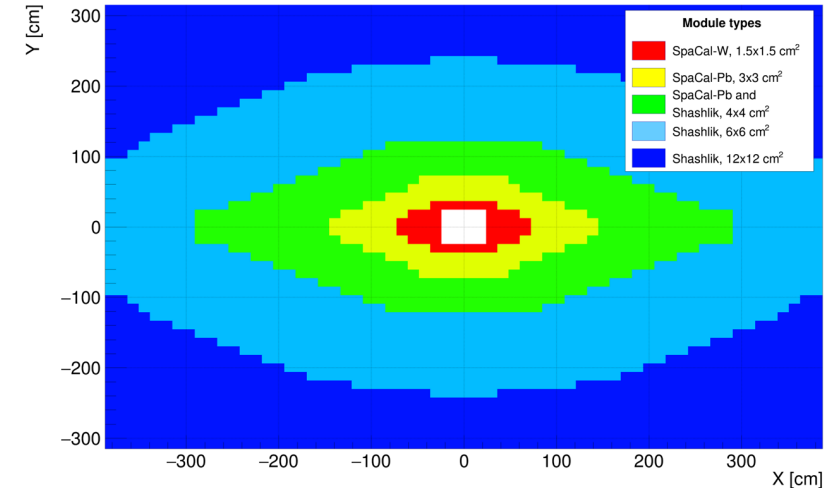
SPACAL technology for inner region.

- **1.5×1.5 cm² cell - W absorber and crystal fibres**
 - Development of radiation-hard crystal fibres
 - Polystyrene fibres for Run 4, then replaced by crystals
- **3×3, 4×4 cm² cell - Pb absorber and plastic fibres:**
 - Need radiation-tolerant plastic fibres

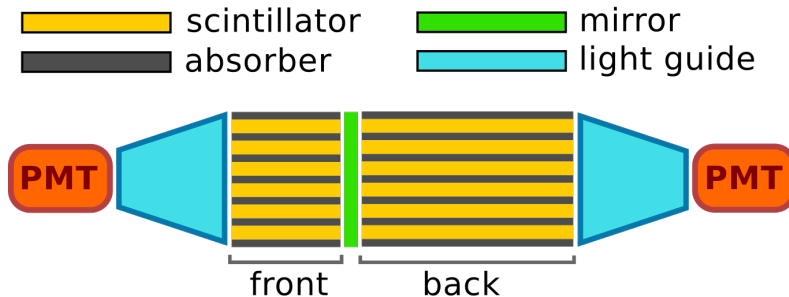
Shashlik technology for outer region

- **4×4, 6×6, 12×12 cm² cell**
 - Timing improved with faster WLS fibres and double-sided readout

PicoCal 2024 - baseline

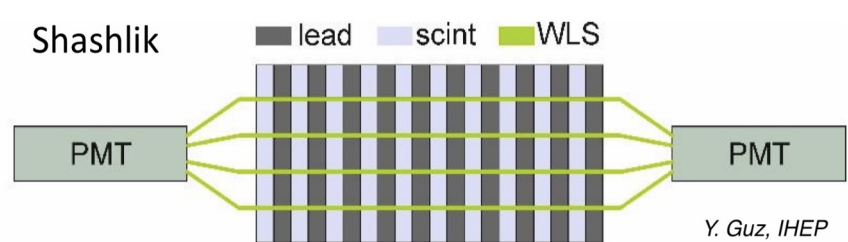


Side view



→ Beam direction

02/11/2025



→ Beam direction

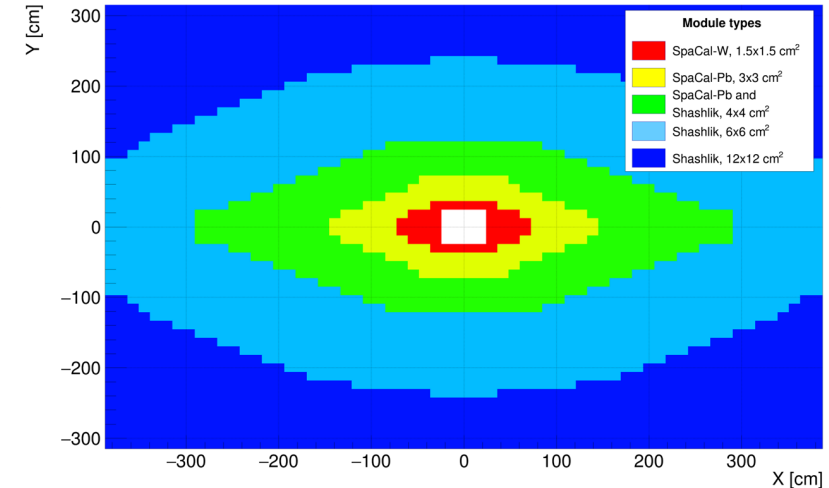
LHCb Upgrade, CLHCP 2025, Hengne Li

ECAL configuration to be installed during LS3

[LHCB-TDR-023](#), [LHCB-TDR-024](#), [LHCB-TDR-026](#)

- **176 new SpaCal modules in the inner region**
→ This region covers about 35% of photons and neutral pions from B-hadron decays over the ECAL acceptance
- **The existing modules will be rearranged in rhombic areas (32 Shashlik modules with 4×4 cm² cell size will be replaced)**

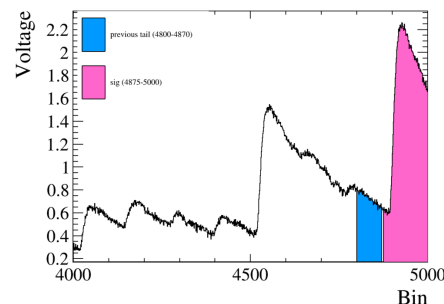
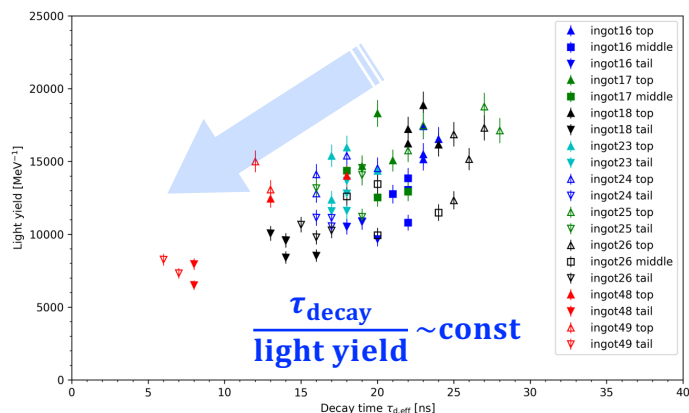
PicoCal 2024 - baseline



Cell size:	Modules:	Number of cells:
2×2 cm ²	16 new SpaCal-W modules with plastic fibres	576
2×2 cm ²	16 new SpaCal-W modules with plastic fibres - special shape	480
3×3 cm ²	104 new SpaCal-Pb modules with plastic fibres	1664
3×3 cm ²	40 new SpaCal-Pb modules with plastic fibres - special shape	480
4×4 cm ²	176 existing Shashlik modules	1584
6×6 cm ²	448 existing Shashlik modules	1792
12×12 cm ²	2'512 existing Shashlik modules	2512

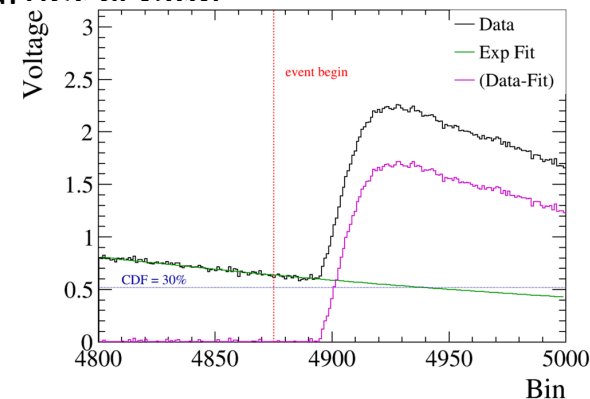
Simulation, reconstruction and performance studies

- Material R&D: study of spill-over effect to identify target decay time of garnet crystal

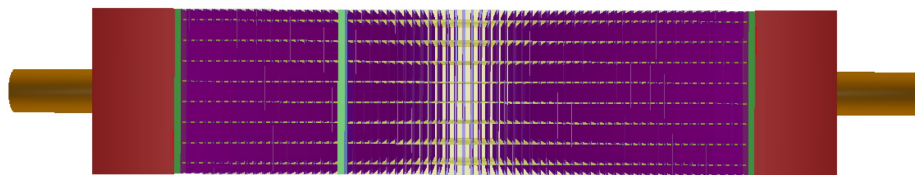


event train with bunch crossing of 25 ns

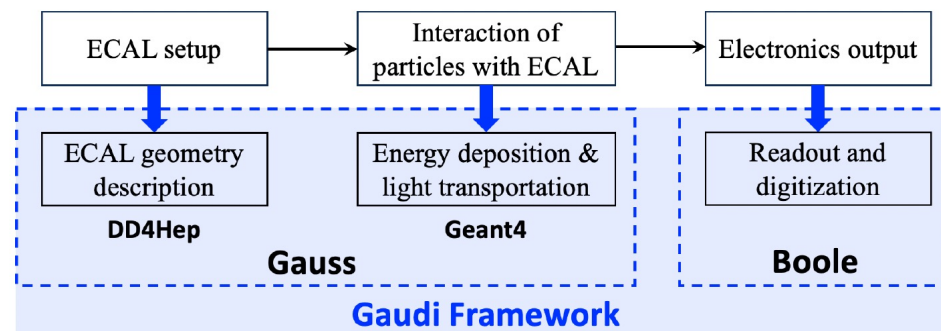
- ✓ spill-over effect on energy & time resolution being studied by subtracting contribution from previous events with exponential fit



- Construction of simulation in LHCb official framework

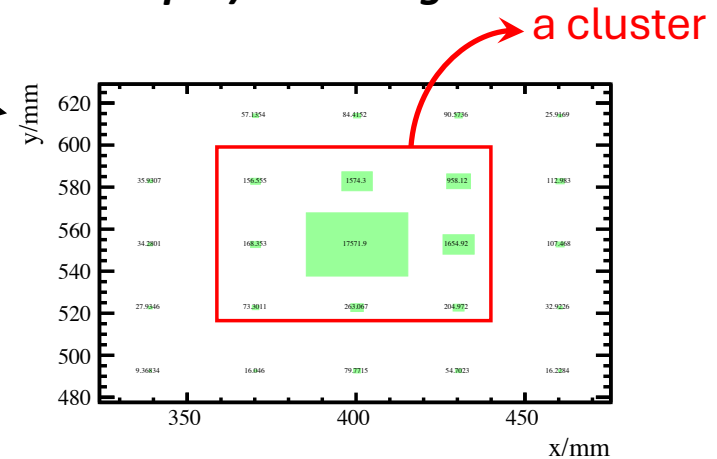
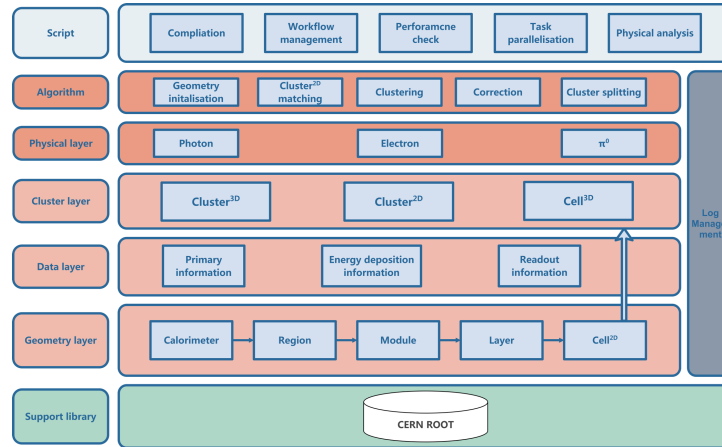


Shashlik module in DD4Hep

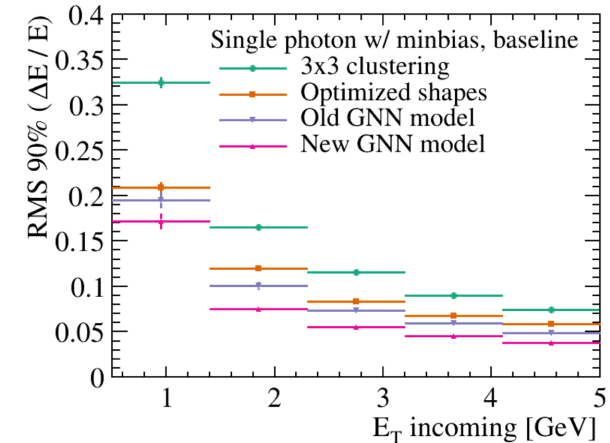
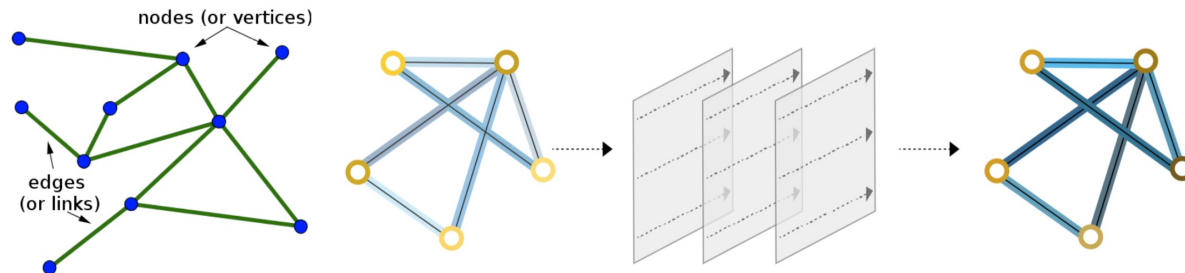


PicoCAL - reconstruction

- Build-up of a working package based on *layered 3x3 (& optimized shapes) clustering*



- Development of *machine learning approaches* for clustering – *GNN* method



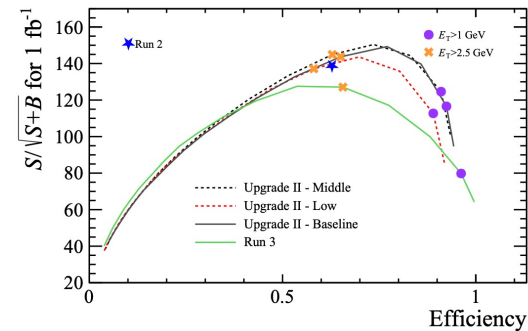
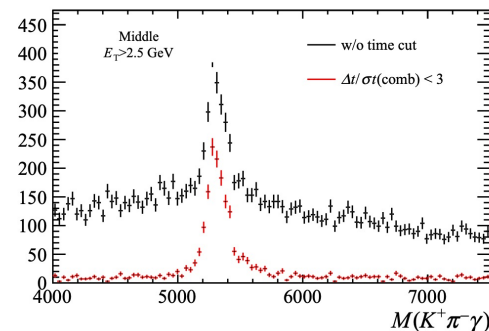
PicoCAL - performance

- Performance compared between different scenarios for benchmarking physics modes

Baseline	Middle	Low
$1.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	$1.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	$1.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
PicoCal		
40 SpaCal-W	40 SpaCal-W	40 SpaCal-W
408 SpaCal-Pb	408 SpaCal-Pb	408 SpaCal-Pb
2864 Shashlik	2864 Shashlik	2864 Shashlik
double R/O	double R/O	single R/O except 176 inner
30,976 channels	30,976 channels	20,224 channels

- Studies based on *3x3 clustering approach*
- Timing information** plays a critical role in background reduction
- Results included in **LHCb Upgrade II Scoping Document** [CERN-LHCC-2024-010, LHCb-TDR-026]

$$B^0 \rightarrow K^{*0} \gamma$$



$$D^0 \rightarrow \pi^+ \pi^- \pi^0$$

