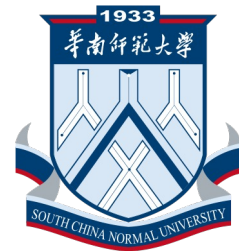




CLHCP2025 新乡

第十一届中国LHC物理会议

The 11th China LHC Physics Conference



LHCb Upgrades

Hengne Li (李衡讷)

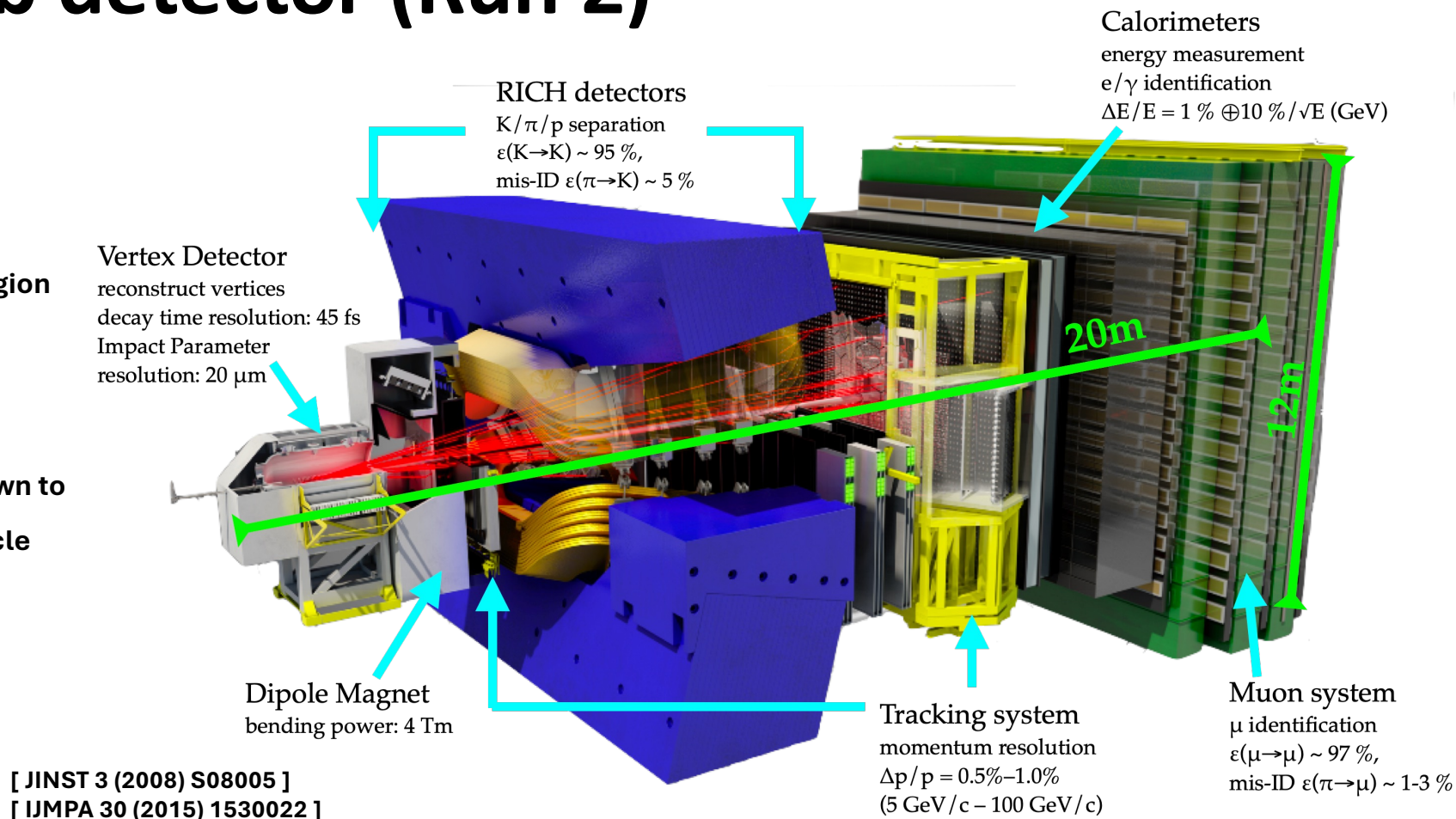
South China Normal University (华南师范大学)

On behalf of the LHCb collaboration

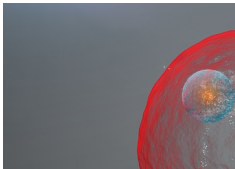
2 Nov. 2025, Xinxiang

The LHCb detector (Run 2)

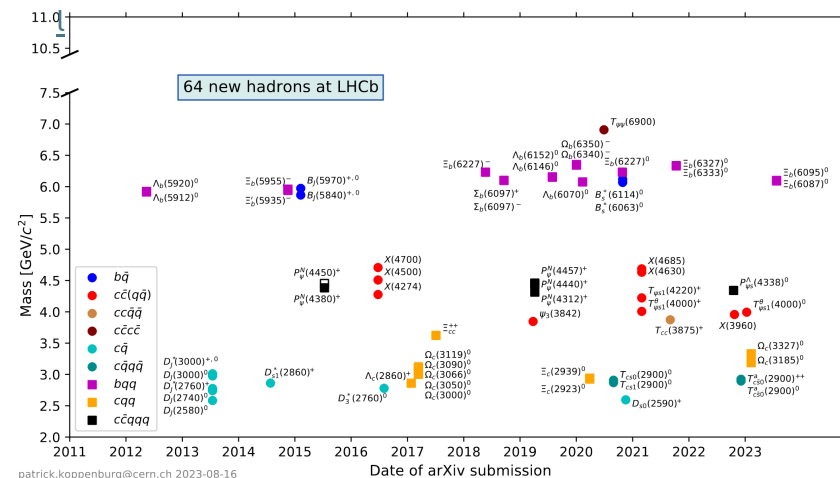
- LHCb is the only dedicated detector (at LHC) fully instrumented in forward region
- Unique kinematic coverage
 $2 < \eta < 5$
- A high precision device, down to very low- p_T , excellent particle ID, precise vertex and track reconstruction.



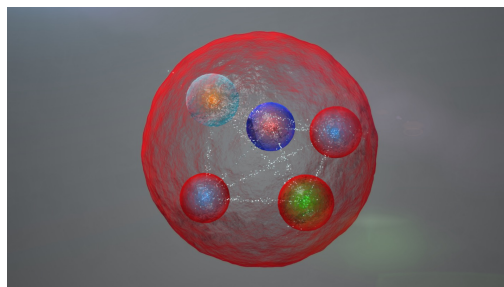
LHCb: a history of success

- 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
- 

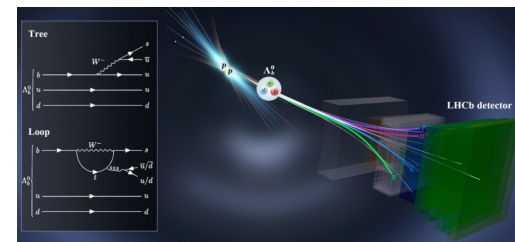
<https://www.nikhef.nl/~pkoppenb/particles.htm>



Observation of a new pentaquark

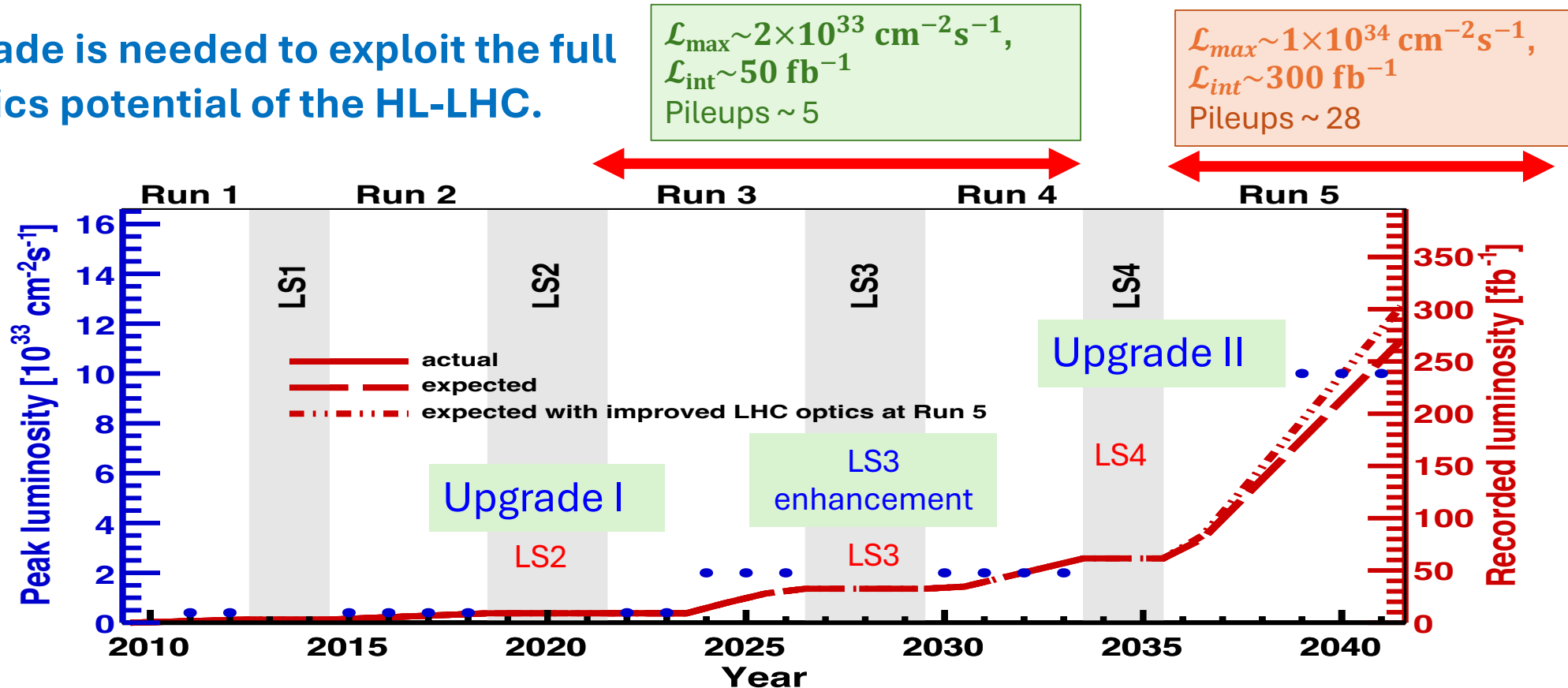


First observation of CP violation in baryon decays



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 Upstream Tracker (UT)
Silicon strips**

**New
dedicated
luminometer
(PLUME)**

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

SciFi
Tracker

RICH2

M2

M3

M4

M5

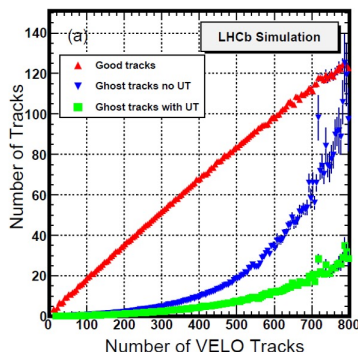
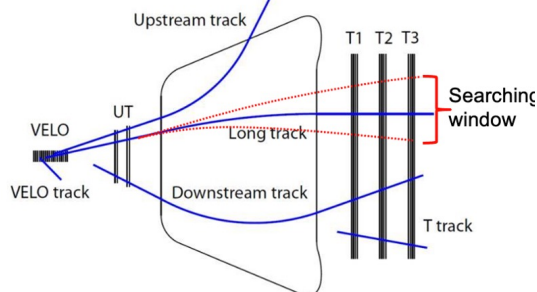
**Calorimeters:
removed PreShower (PS) and
Scintillating Pad Detector (SPD),
new readout**

**Muon: Removed M1 and new
readout**

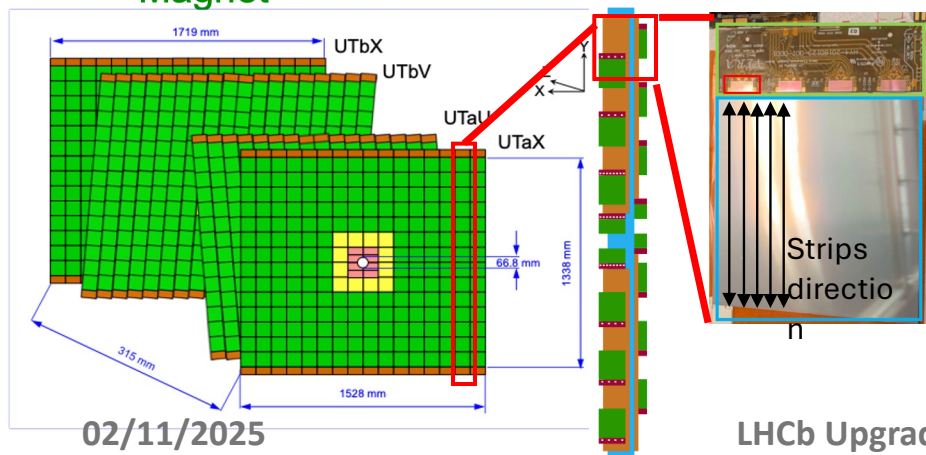
$$L_{inst} = 2 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1} \text{ (x5 w.r.t. Run 1)}$$

Upstream Tracker (UT)

LHCb tracking system



Magnet



02/11/2025

LHCb Upgrade, CLHCP 2025, Hengne Li

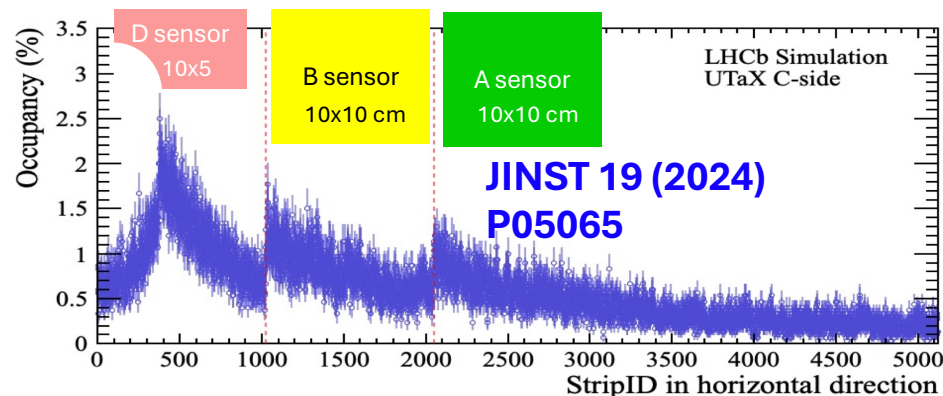
UT: Si Strip detector

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 $\sim 1\%$

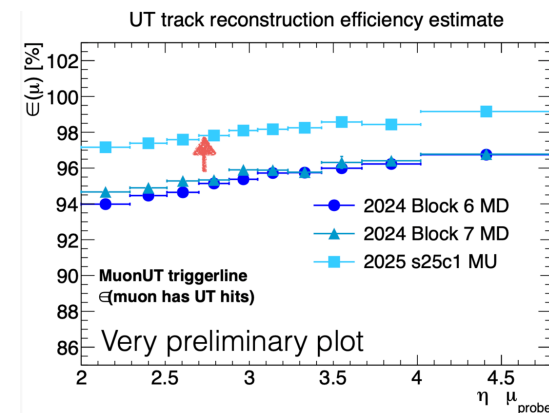


China group contribution to UT

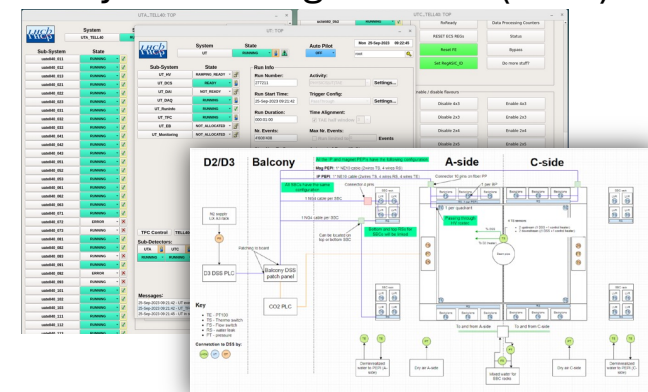
Chinese groups contributed to **UT installation**, ensuring LHCb Upgrade I completion in time (IHEP/HNU/CCNU/TUHU/SCNU/LZU)



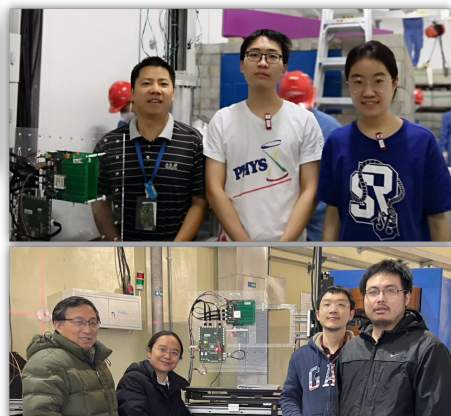
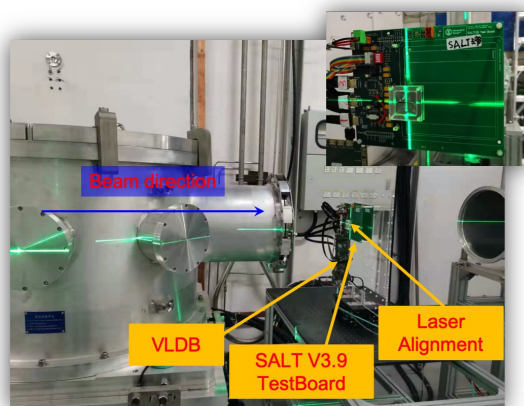
Large improvement with UT



Lead development in control and safety monitoring software (IHEP)



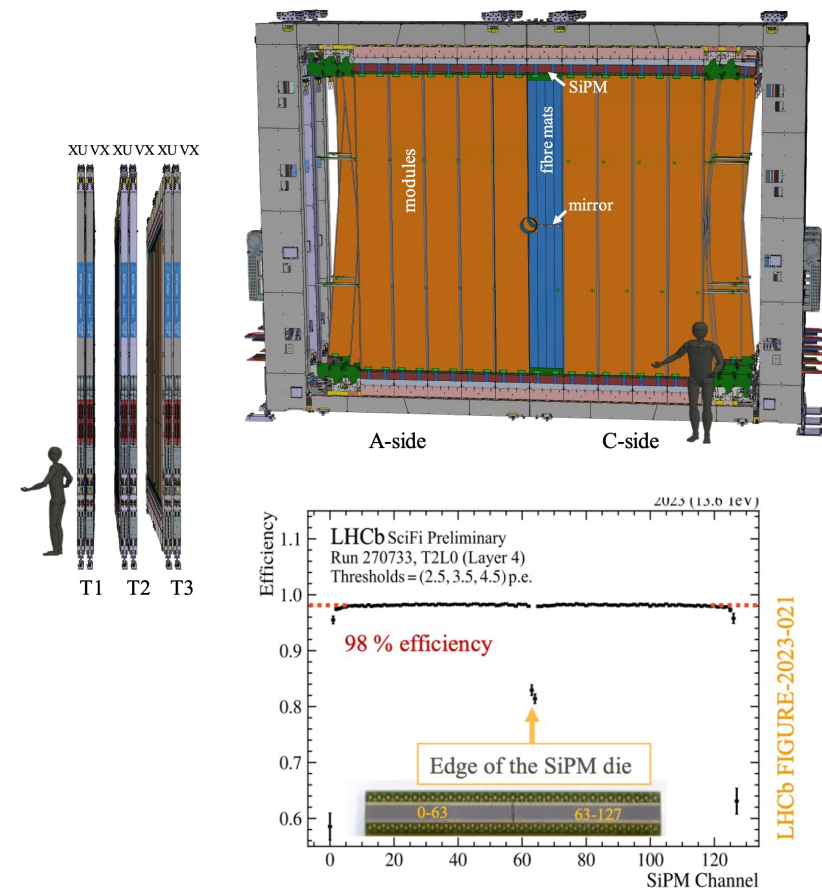
Performed **key radiation tests** for **SALT chip** using **Chinese facilities** during pandemic (IHEP/HNU)



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

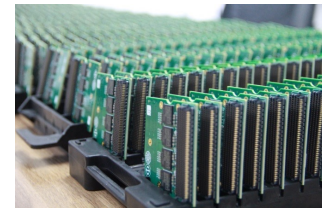
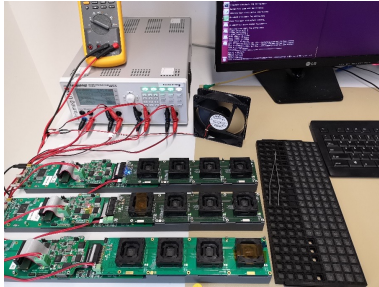
Good performance in 2023 + 2024

China group contribution to SciFi

QA System for readout ASICs & the Front-End Board

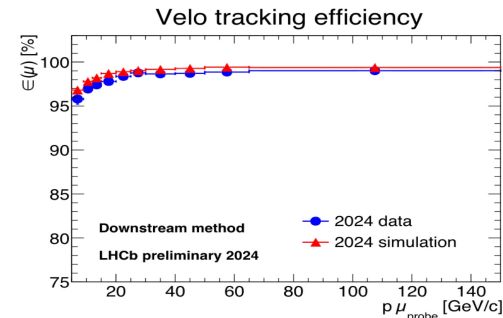
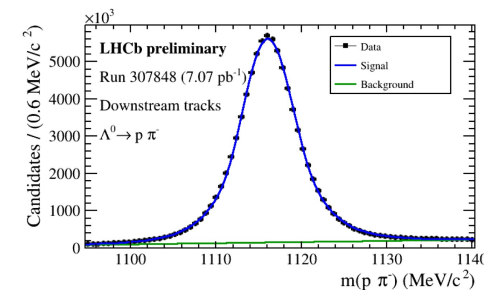
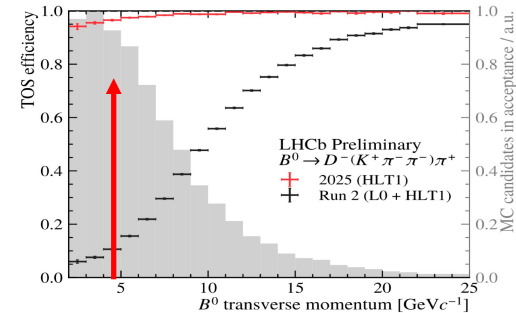
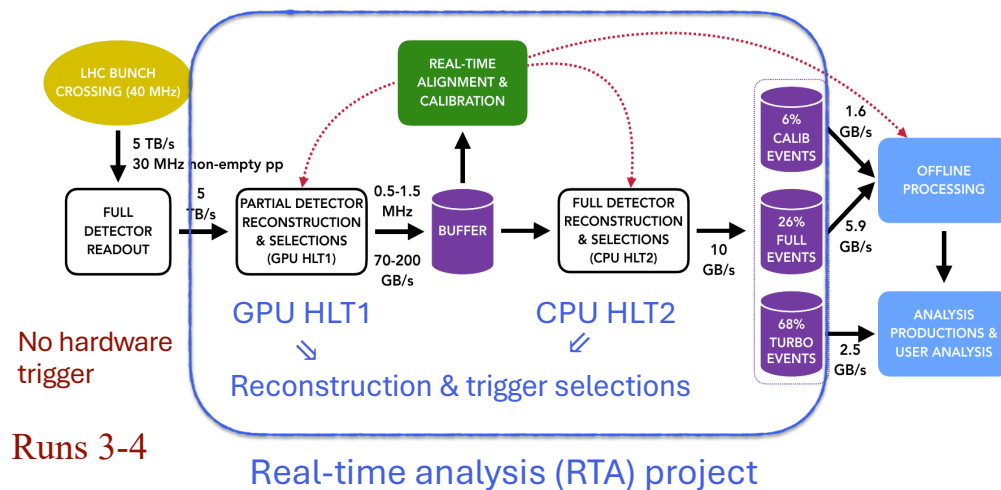
SciFi: 524,000 SiPM channels

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

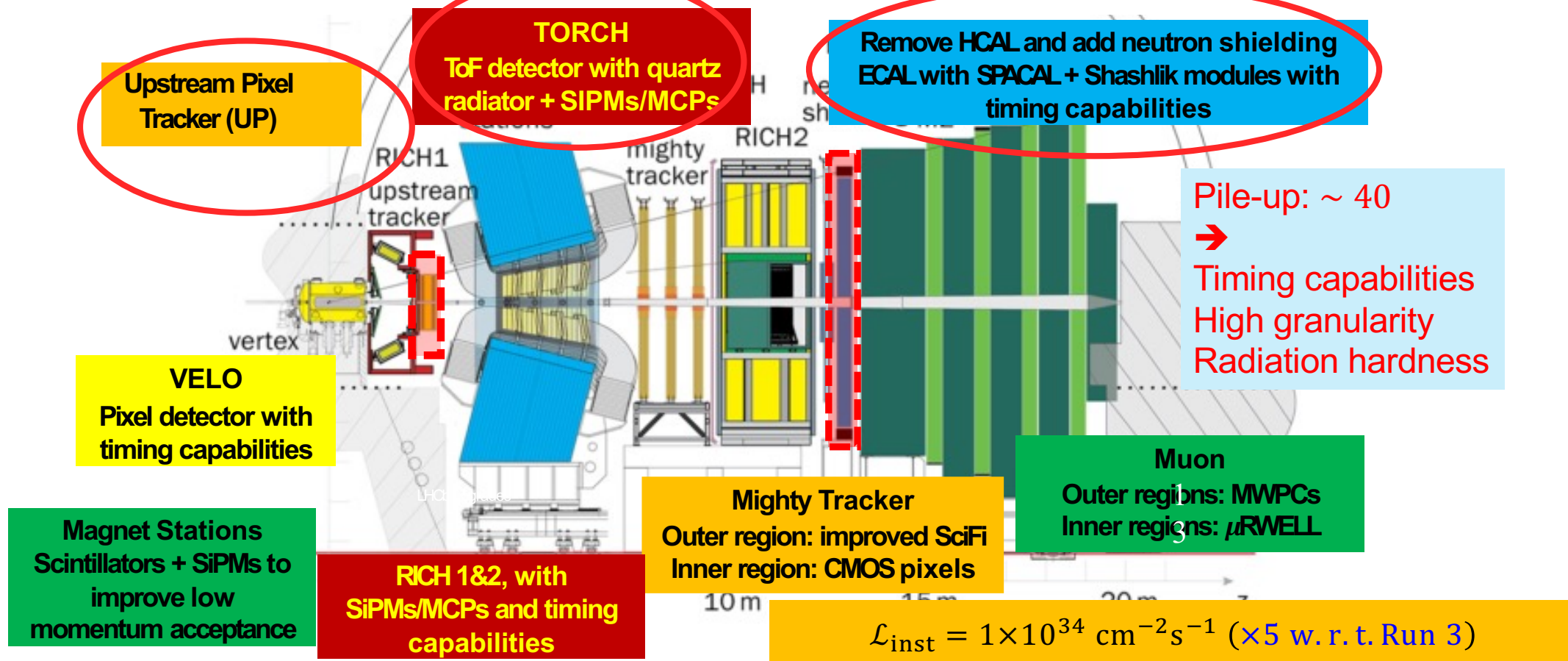
Run 3 Trigger & Performance (Real-time analysis)



- 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

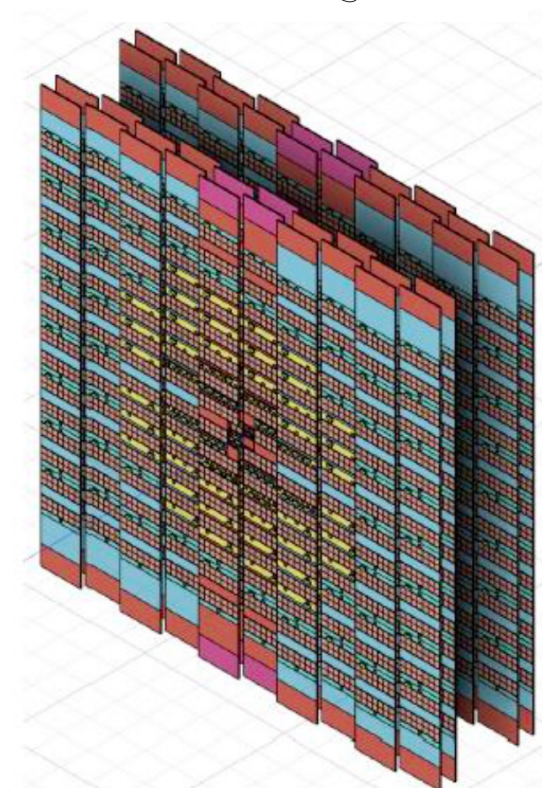
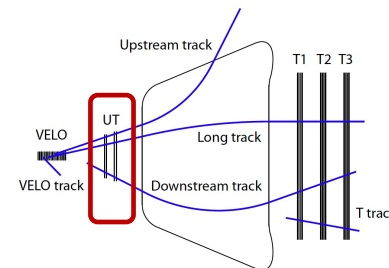
- Upgrade I (2019 – 2023)
- L3 Enhancement (Q3.2026-2029)
- Upgrade II (2034 - 3035)

LHCb Upgrade II (including LS3 enhancement)



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

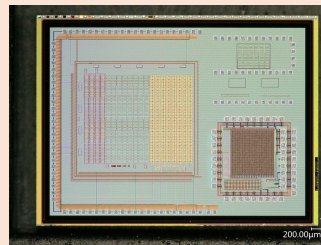
UP sensor development

- 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



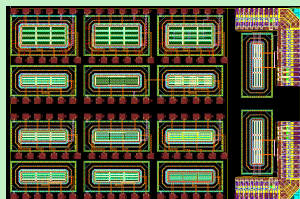
CMOS SENSOR IN
FIFTY-FIVE NM PROCESS

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	$\leq 200 \text{ mW/cm}^2$



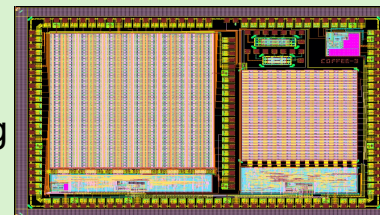
COFFEE1

- 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



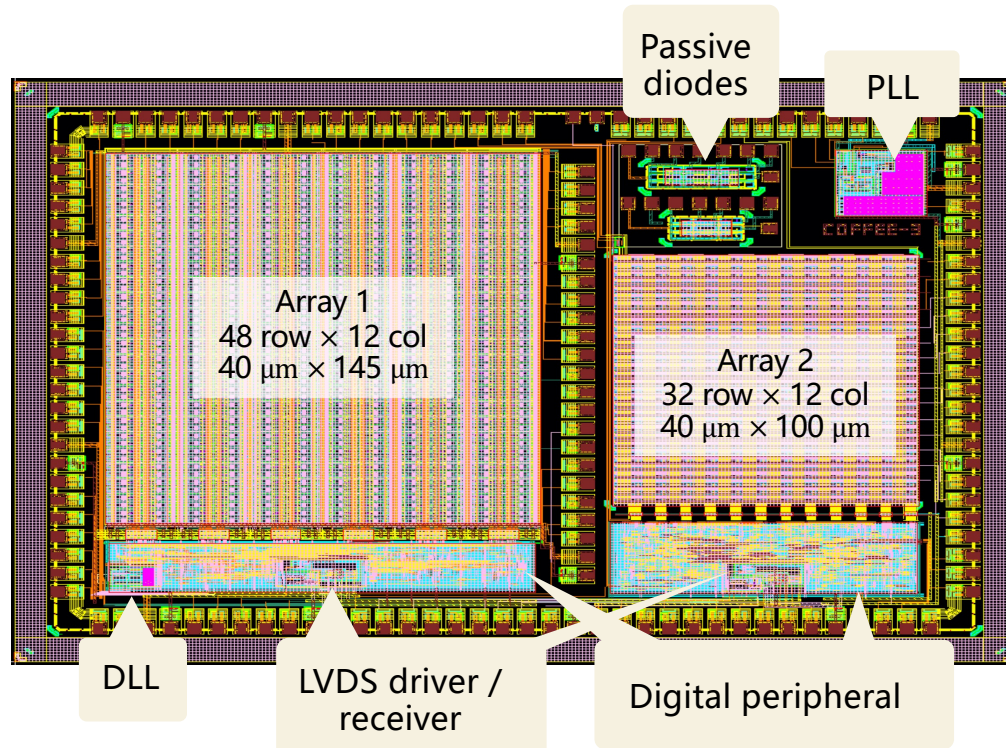
Large prototype planned around 2027

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

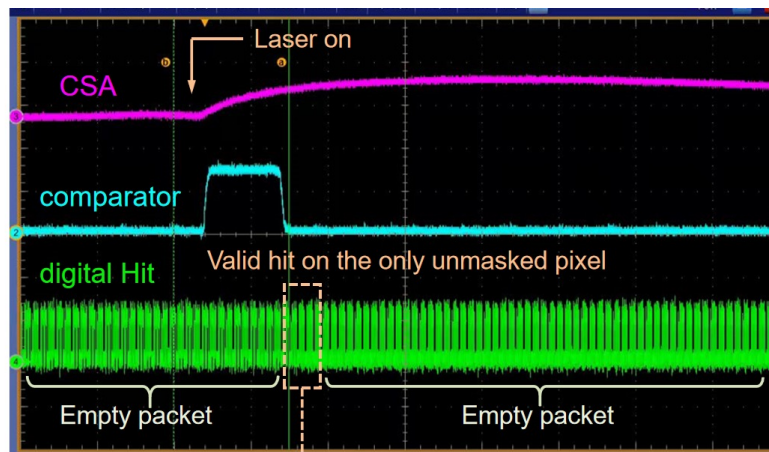


Architecture 2:

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

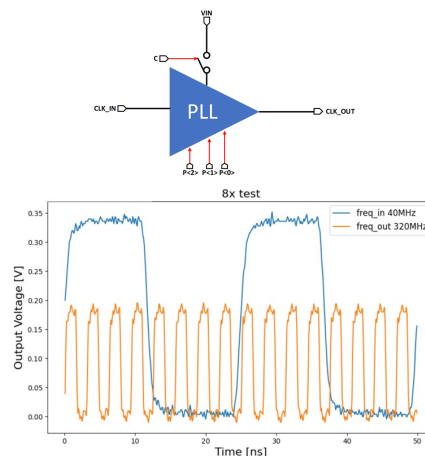


4 bit	4 bit	8 bit	8 bit	6 bit	2 bit	7 bit	3 bit
header	CHIP_TS	LE_coarse	TE_coarse	LE_fine	TE_fine	Addr_Row	Add_Col
0 1 1 0	0 1 0 1	0 0 0 1 0 1 1 0	0 1 1 0 1 0 1 1	1 1 0 0 0 0 0	0 0 0	0 0 0 0 0 0 1	0 0 0

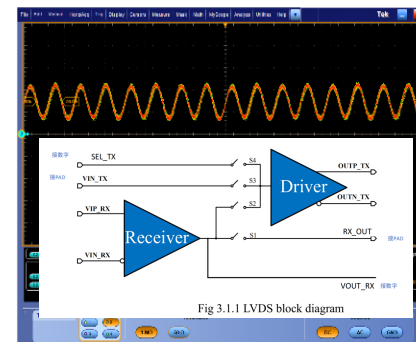
A valid transmission packet corresponding to a hit

Correct row & column address

Laser signal on a single pixel corrected read



Phase Lock Loop works up to 640MHz



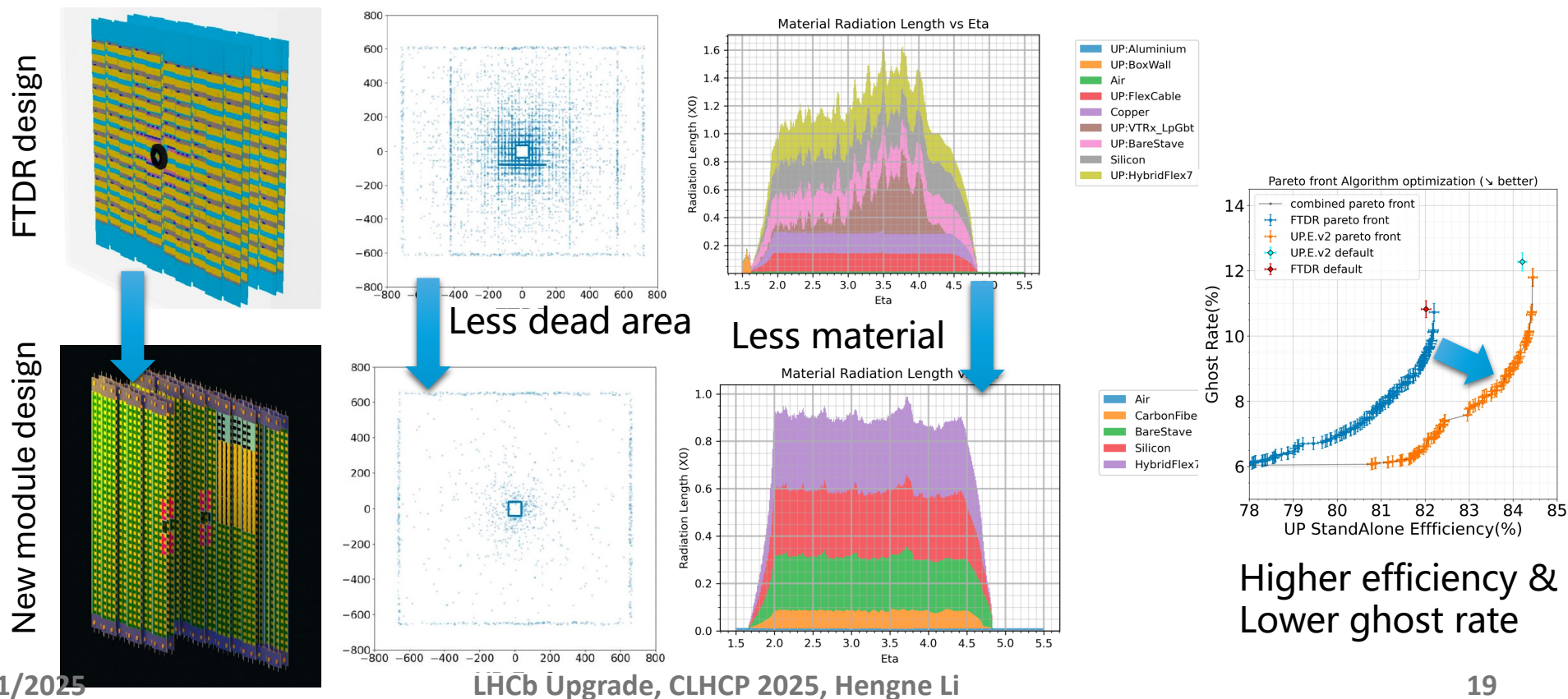
LVDS
tranceiver
works at
640MHz



DLL delays
main clock
to achieve
finer timing

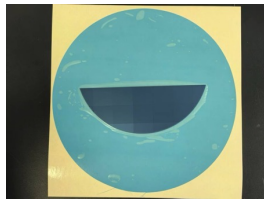
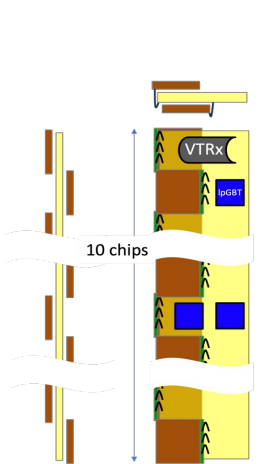
Simulation and performance study

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



UP module and mechanics

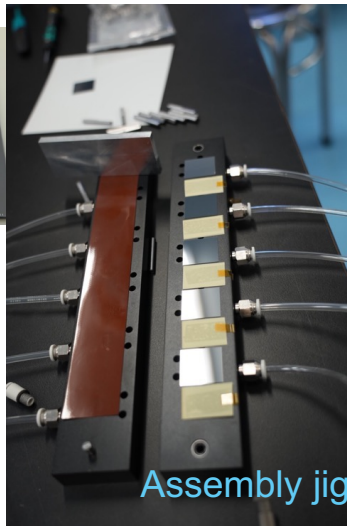
- Module design updated to reduce dead area
- Prototyping starting with dummy components
 - Dummy silicon sensors produced with similar thermal mechanical properties
 - Tools designed for assembly procedure
 - Thermal simulation + market survey for realistic mechanical design



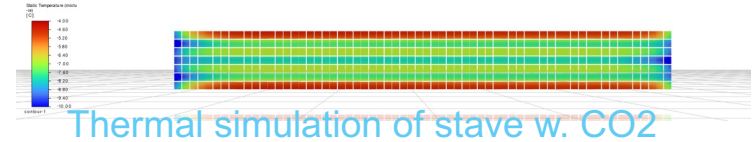
1st dummy sensor



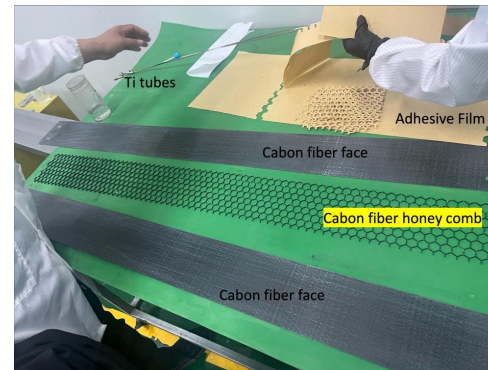
1st dummy hybrid



Assembly jig



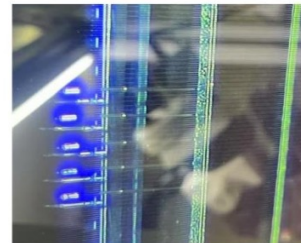
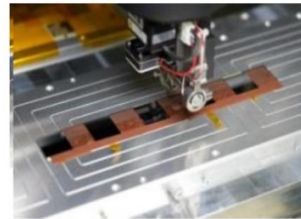
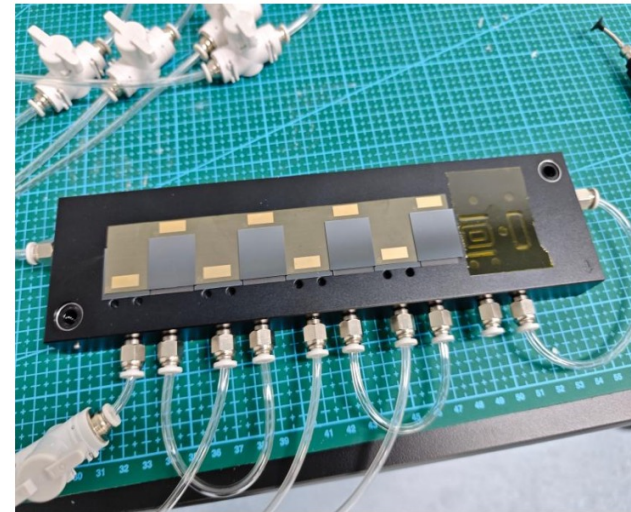
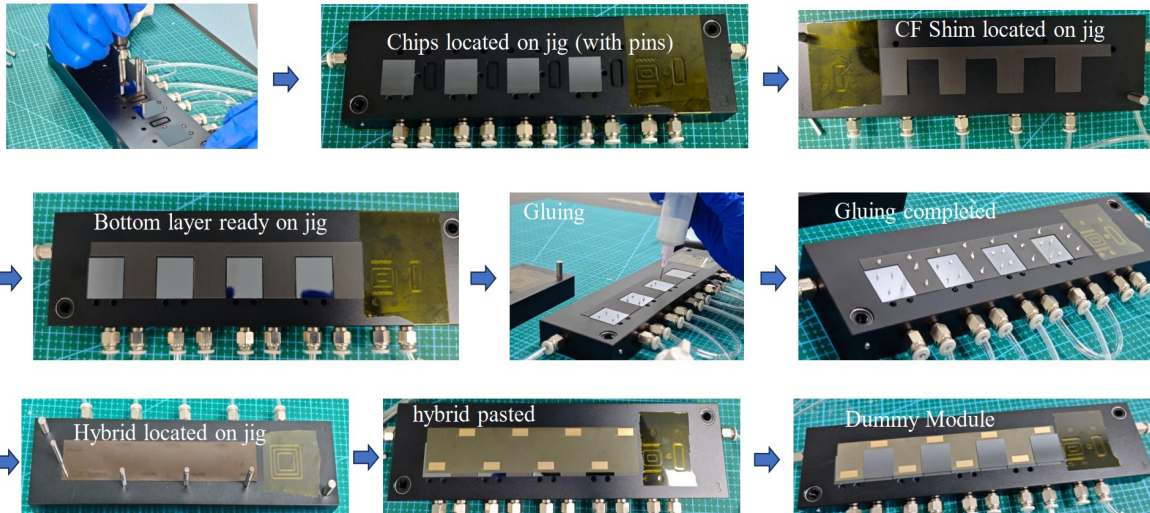
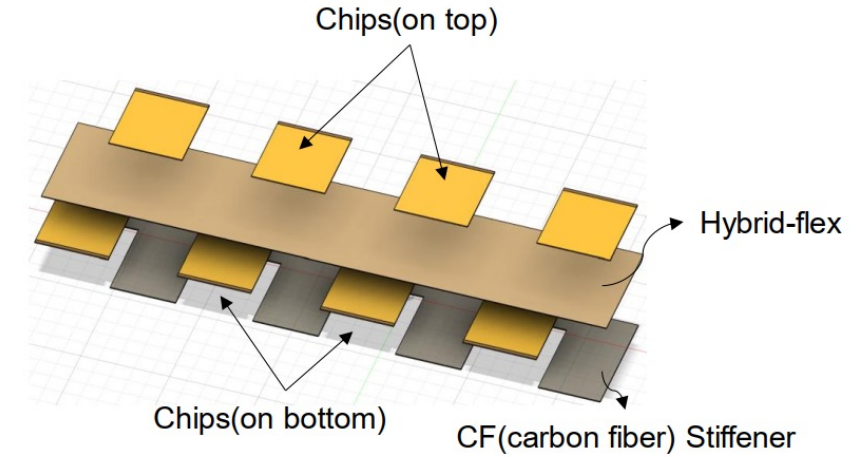
Thermal simulation of stave w. CO2



Tiange Li@HNU

Module prototyping

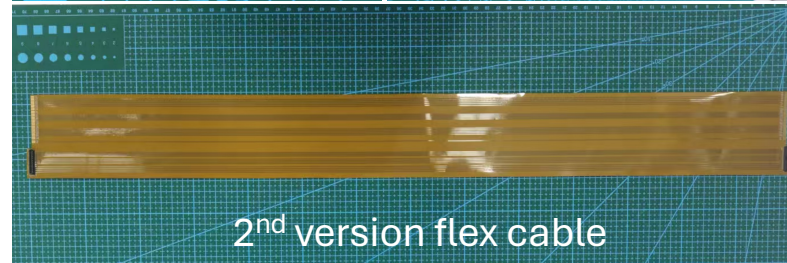
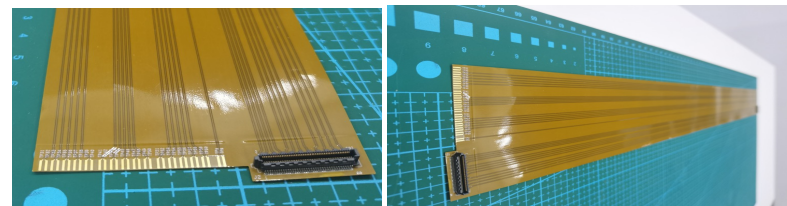
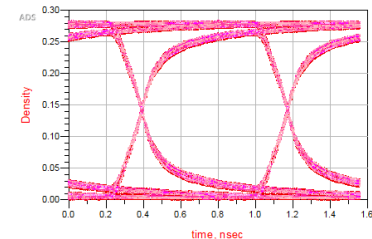
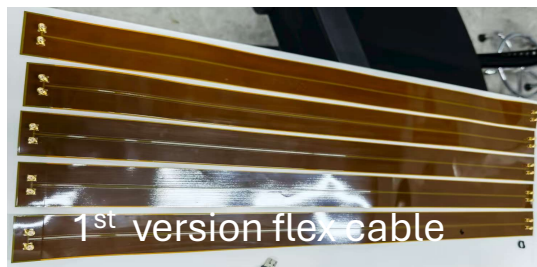
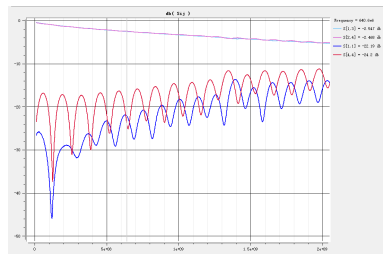
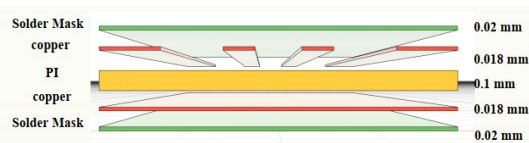
- First modules developed with dummy silicon sensors and dedicated tools



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.

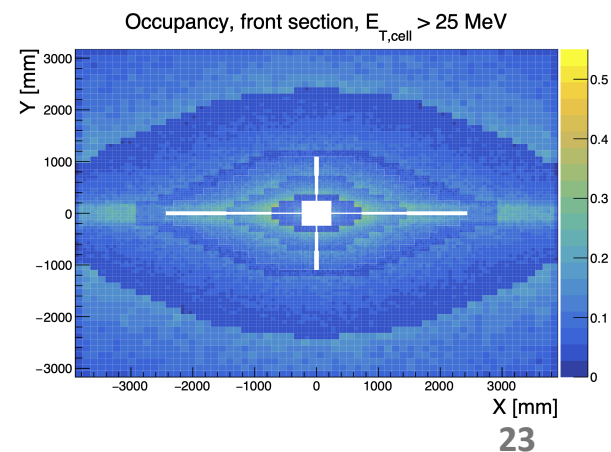
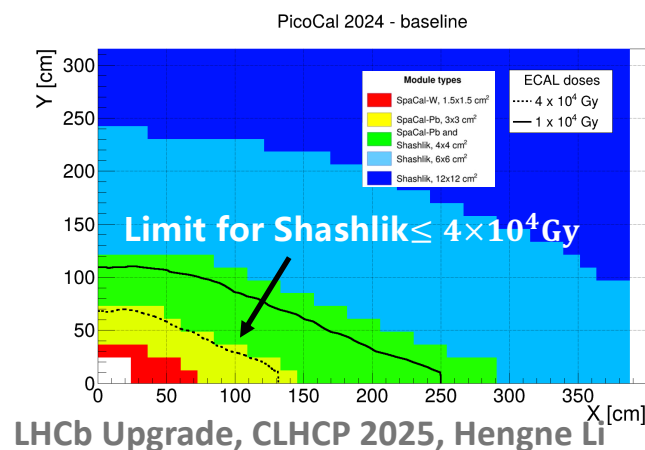
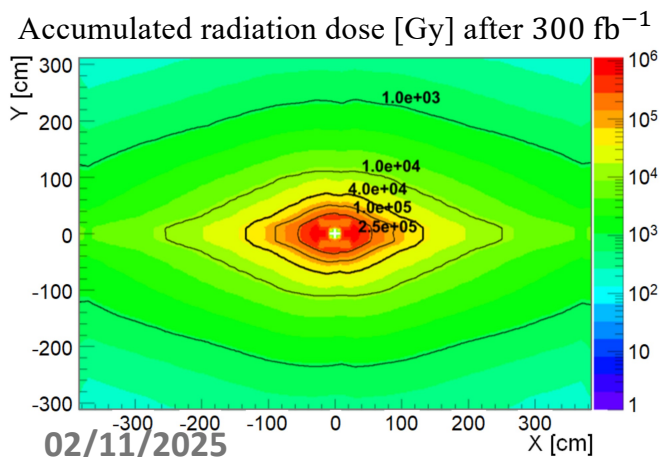
Normal	b'00	Chip	BXID	Col	Row
Normal Compact	b'01	Chip	BXID	NumHits	
	Col 1		Row 1	Col 2	Row 2
	...			...	
	Col N		Row N	(0x5555, for odd NHits)	
Calibration	b'10	Chip	BXID	Col	Row
	0x0C	ToT	ToA	0x0C	ToT ToA
Status	b'11	Chip	BXID	Type	0xAAA



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)

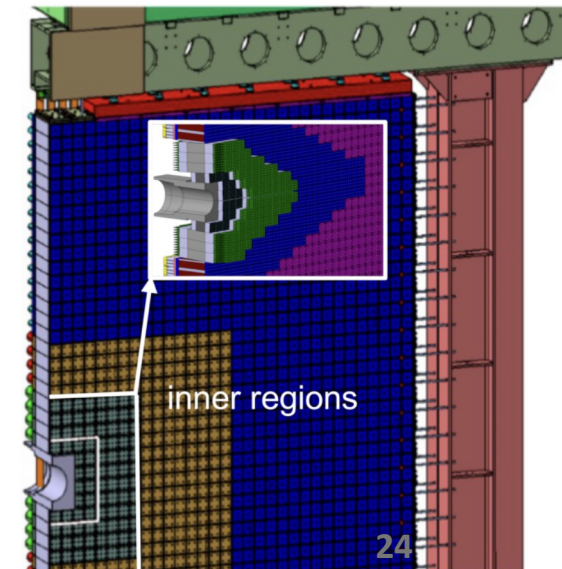
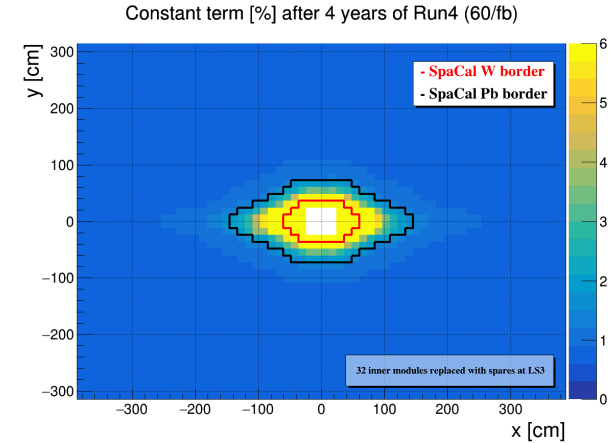
LS3 consolidation in Q3/2026-2029:

- 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):

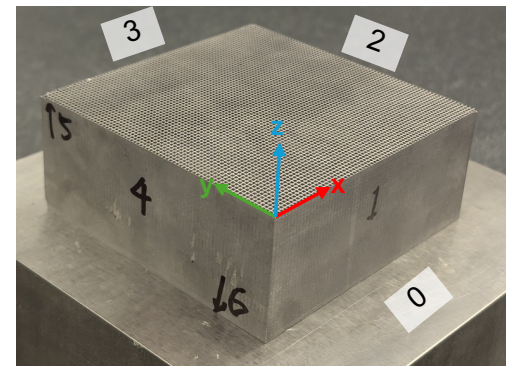
- Introduce **double-section rad. hard SPACAL** (1.5×1.5 , 3×3 & $4 \times 4 \text{ cm}^2$ cells) and improve timing of Shashlik modules for a luminosity of up to $L = 1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
 - Innermost SPACAL-W modules equipped with **crystal fibres**
 - Include **timing**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

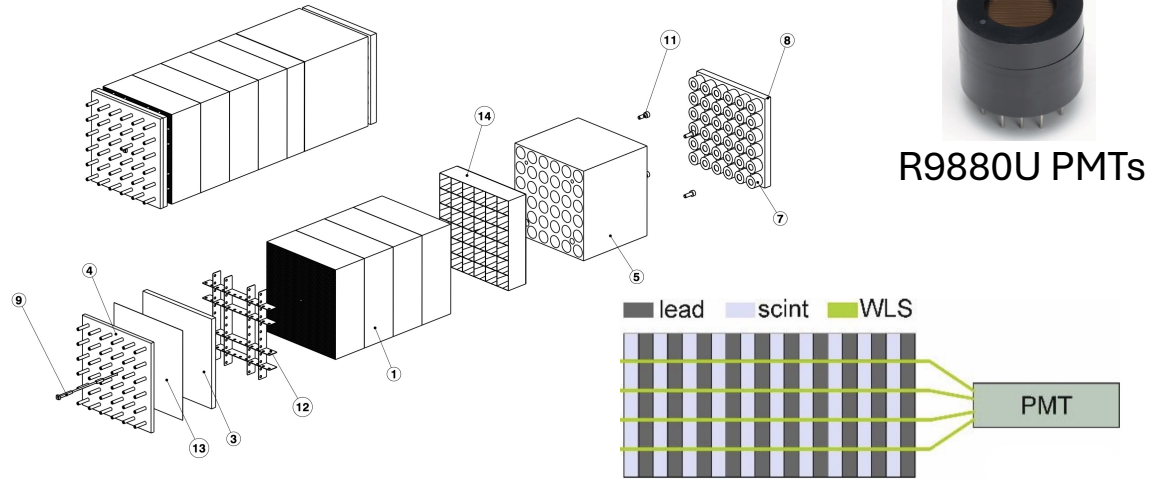
Loris M. & Daniele M.

* China: Peking, Tsinghua, Wuhan, SCNU



Ongoing R&D: Assembly for LS3

Both use W absorbers from
China group



Module assembled in
Beijing in May 2025

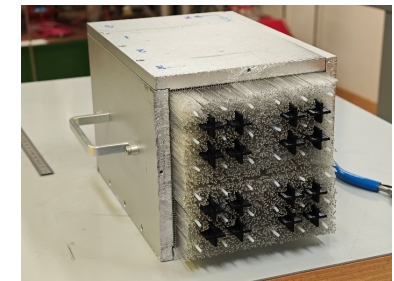
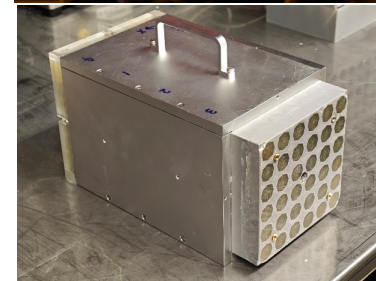
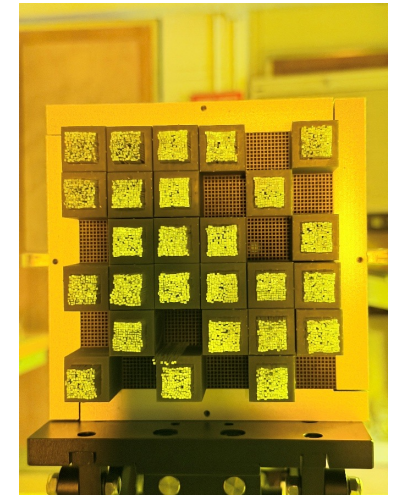
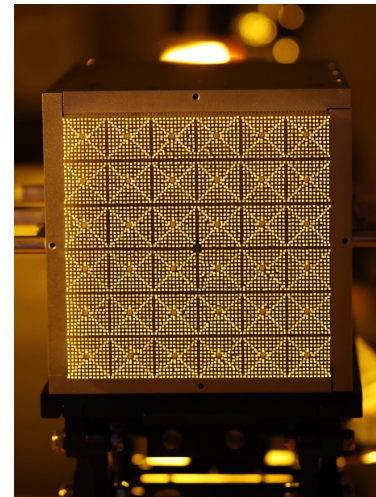
Module assembled at
CERN in Oct. 2025

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:

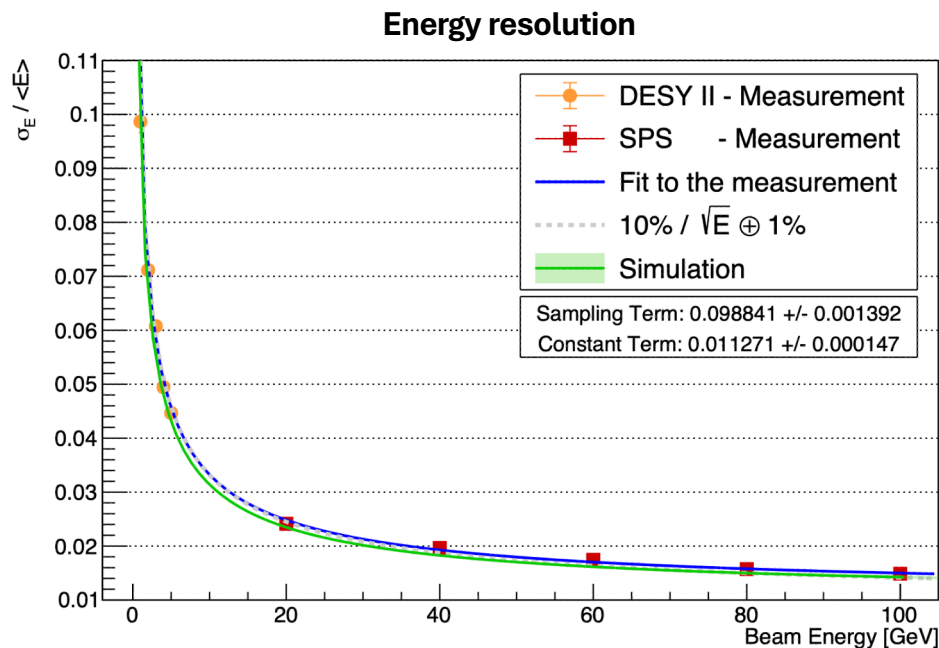
- W absorbers from China group.
- 3HF green plastic fibres (square fibres $1 \times 1 \text{ mm}^2$)
- Optics assembly with bundlers and long “hollow” light guides
- Cable clipping circuits, 10 m signal cables, read-out with Run 3&4 FE electronics

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



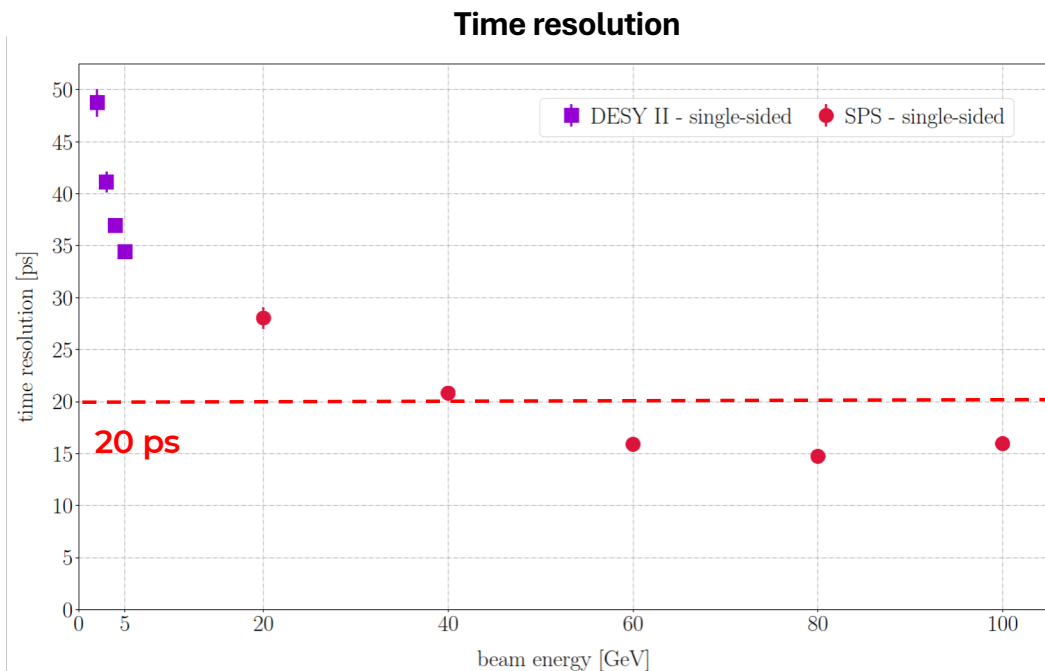
SpaCal - W Absorber - Polystyrene Fibres

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

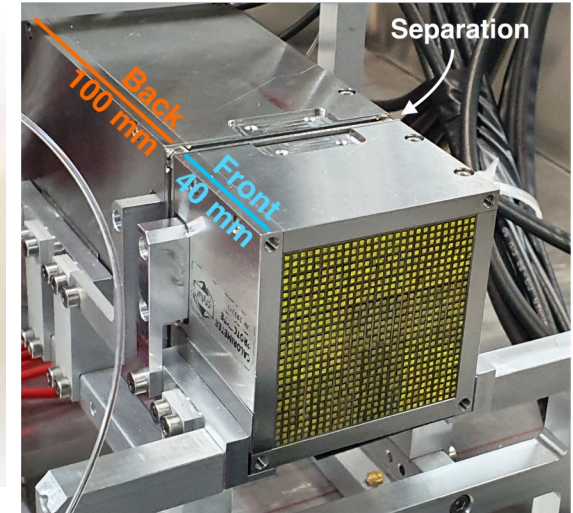
NIM A 1000, 165231 (2021)

NIM A 816 (2016) 176

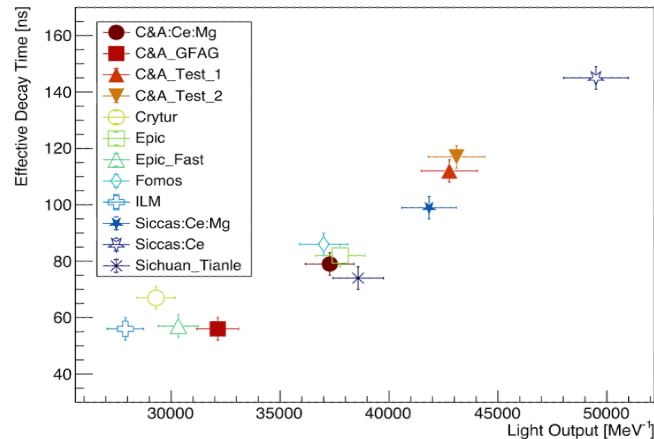
SPACAL prototype with **W absorber** and **garnet crystals**

➤ Module details:

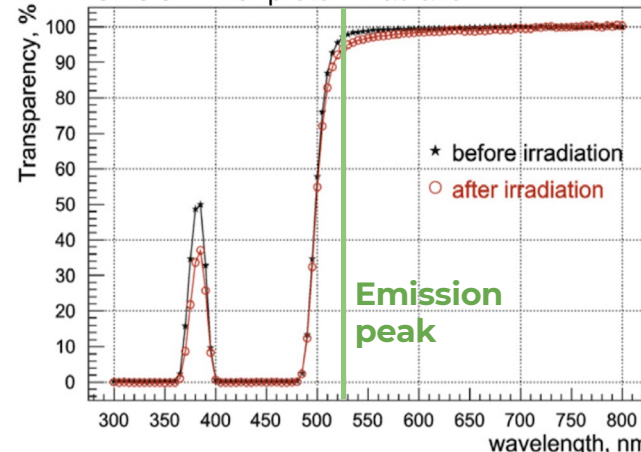
- Absorber in pure tungsten 19 g/cm³
- 9 cells of 1.5×1.5 cm² ($R_M \sim 1.5$ cm)
- 4 + 10 cm long (7 + 18 X₀)
- Reflective mirror between sections
- Squared garnet crystal fibres (1×1 mm² cross section)



Effective Decay Time vs Light Output



GAGG - After proton-irradiation



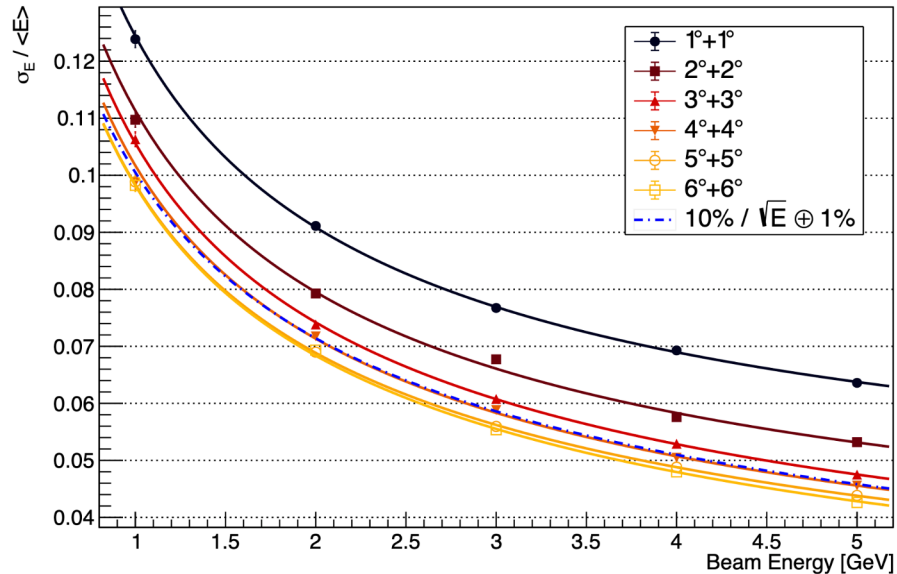
GAGG as scintillating material

- 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



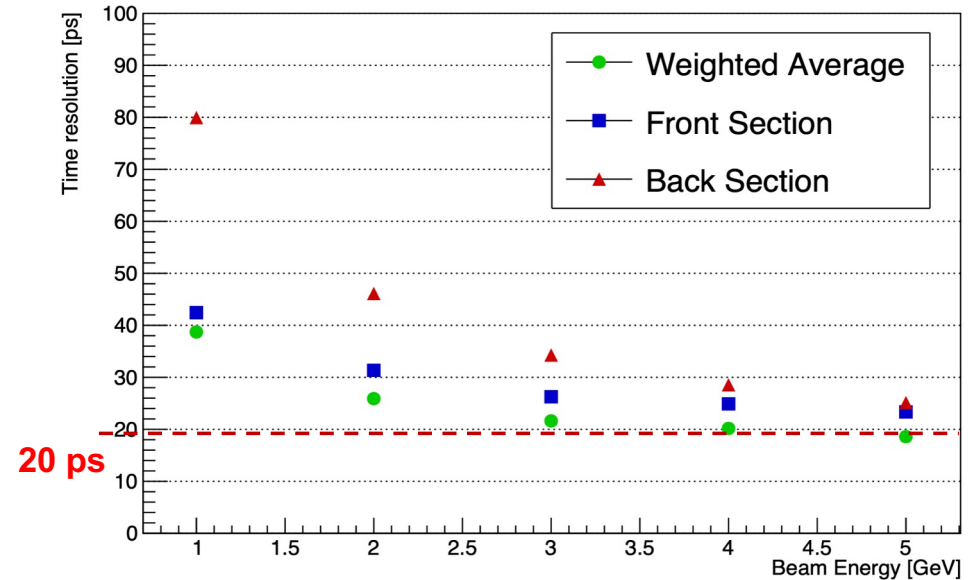
- Resolution improves increasing the incidence angle

➤ 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

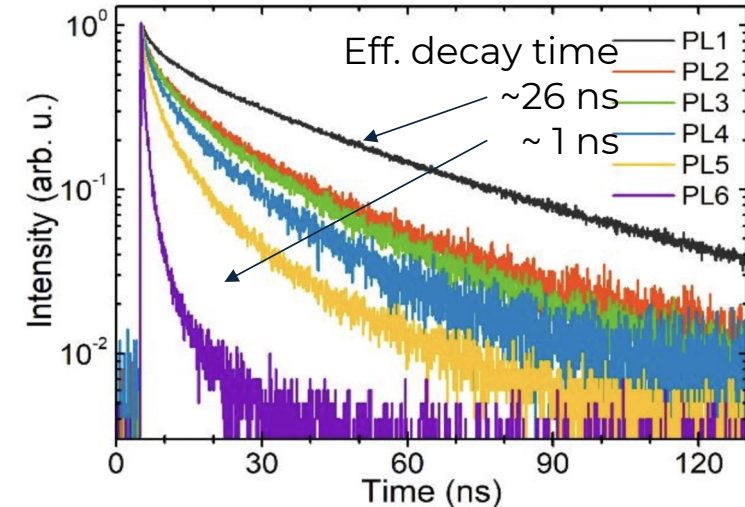


- Time stamps obtained using CFD algorithm

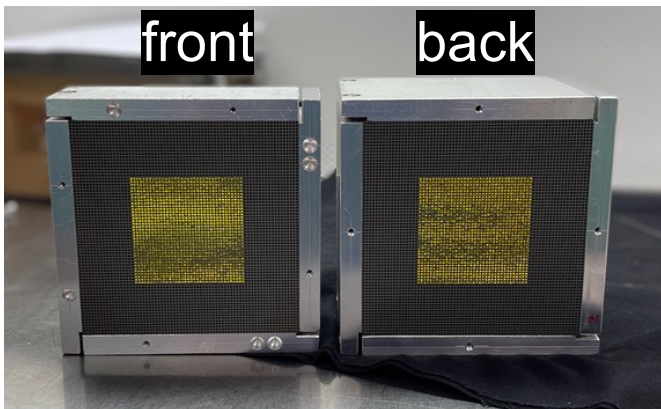
➤ Time resolution C&A GAGG at $3^\circ+3^\circ$:

- 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

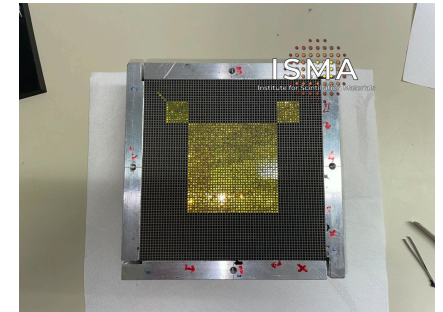


Material Advances, 2022, 3, 6842



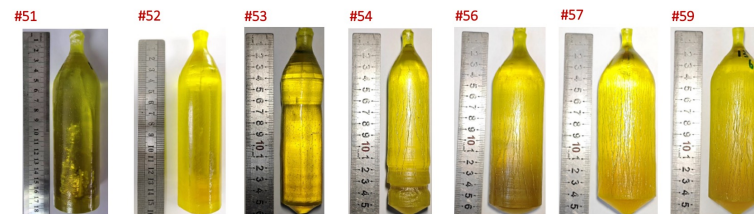
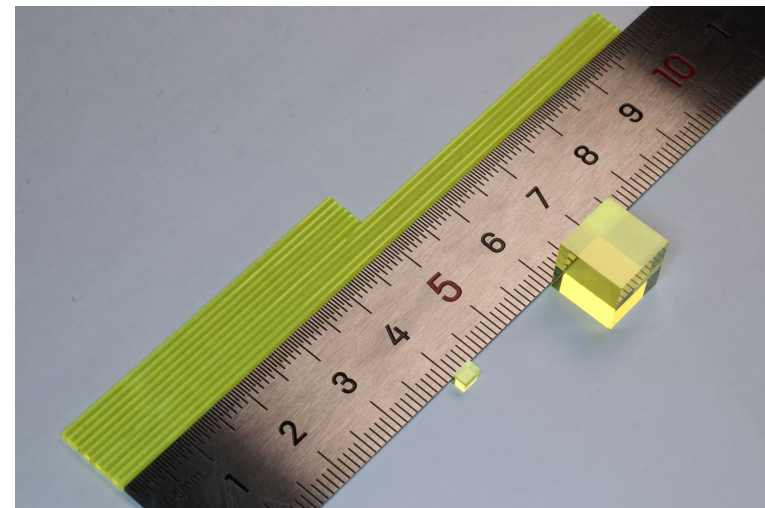
02/11/2025

- **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

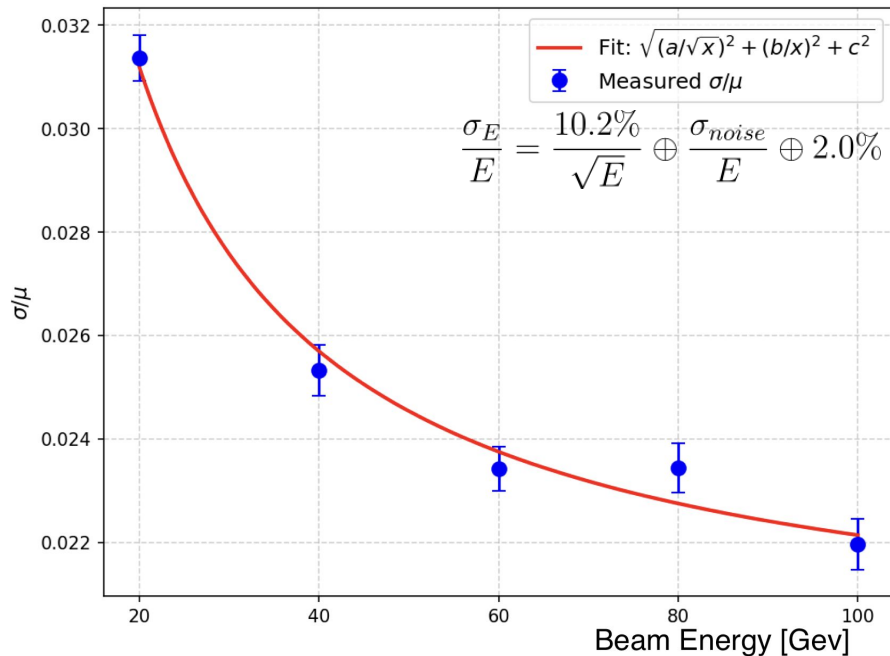
- **Chinese group started R&D of fast GAGG in the end of 2021**
 - Collaboration with SIPAT (a company in Chongqing, China) for GAGG production
 - A new laboratory was built at Peking University (PKU) for scintillator characterization
 - Students from Tsinghua University (THU) and PKU involved in the 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

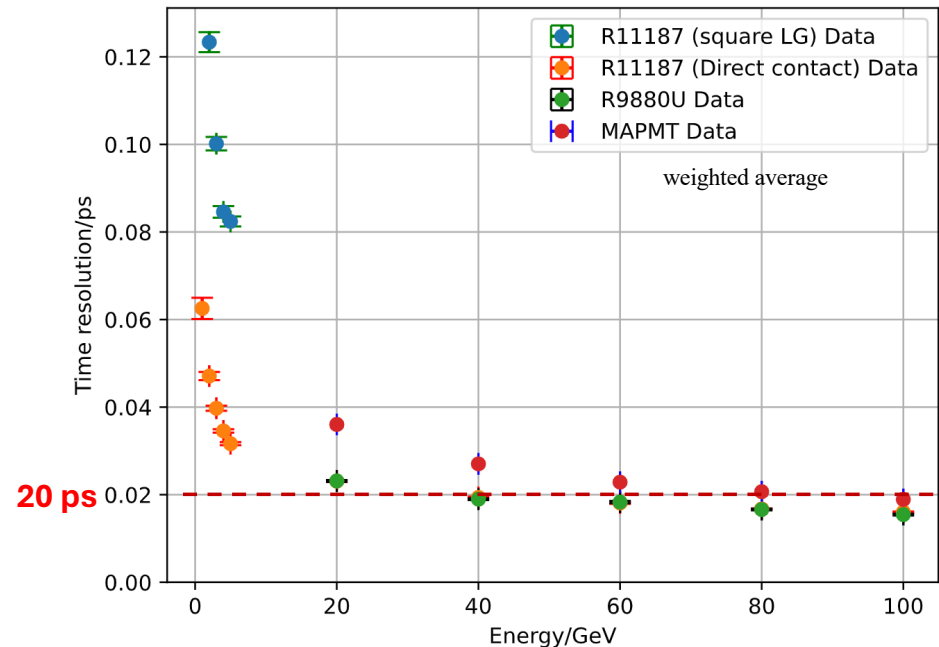


➤ **Energy resolution at 3°+3°:**

- 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

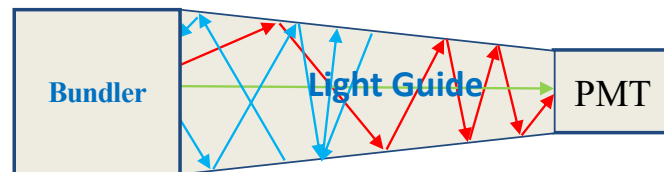
Hollow ESR Light Guides

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

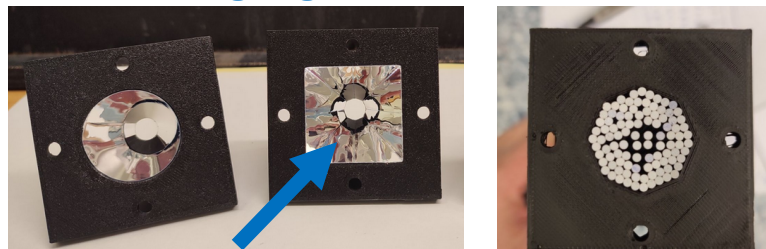
New Fiber Bundling Process

- **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



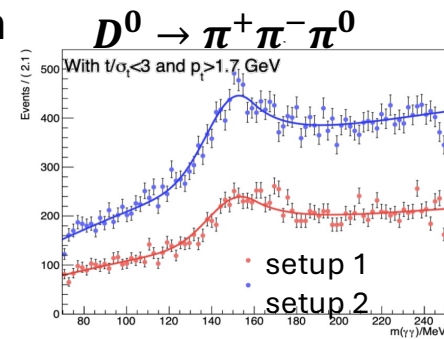
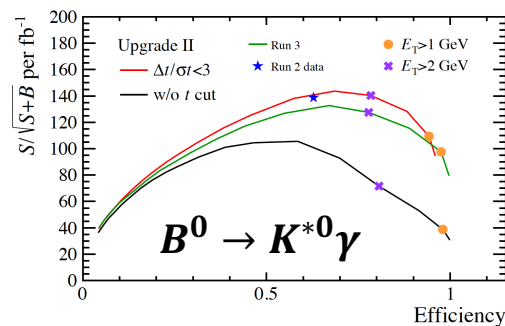
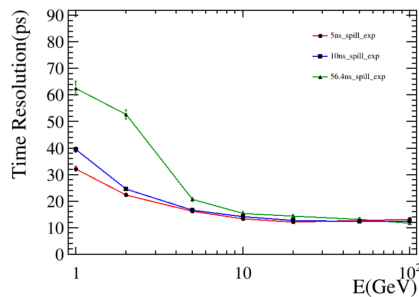
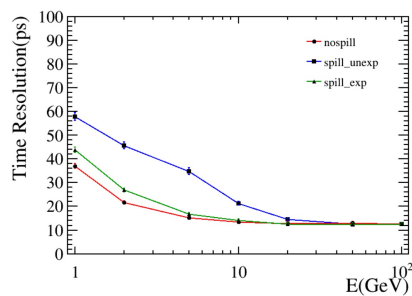
Steel 3D print



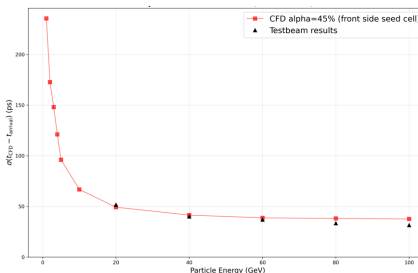
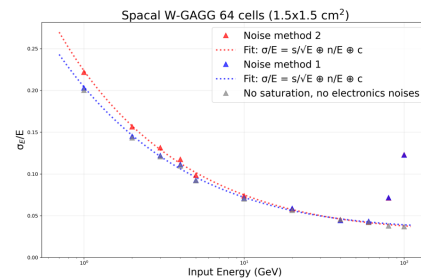
CNC machining

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

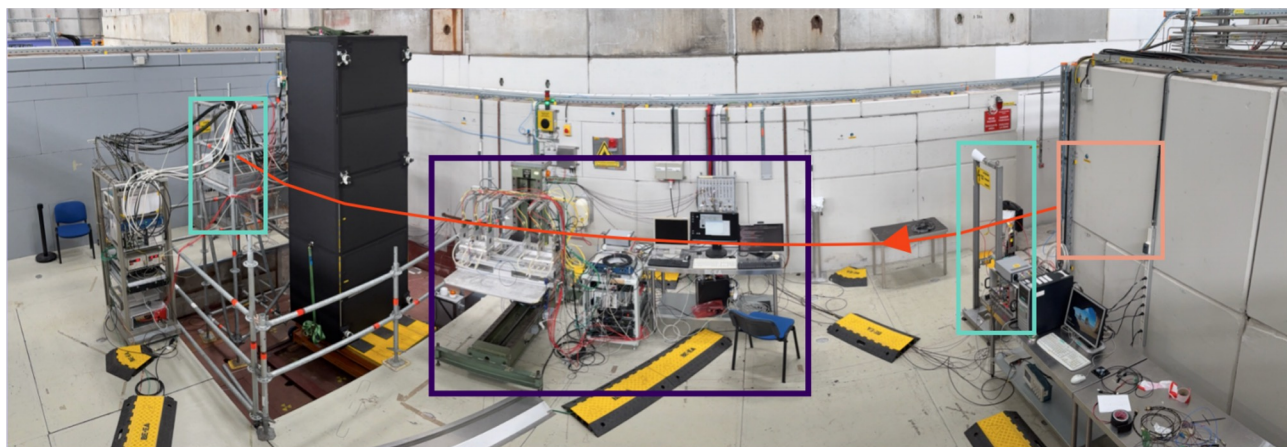


- Software development
 - ✓ Construction of simulation in LHCb official framework
 - templated pulse method for digitization
 - ✓ Integration of reconstruction algorithm to the LHCb official framework



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

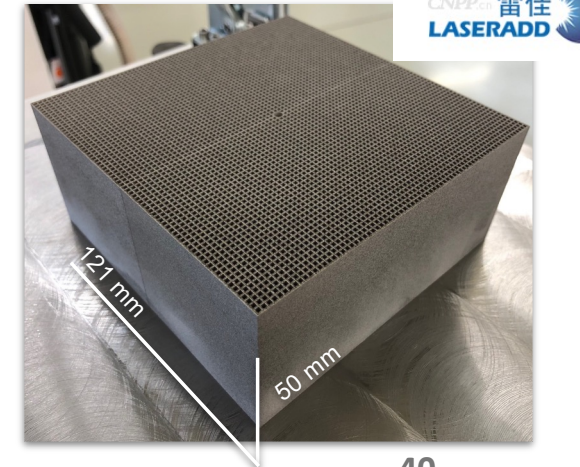
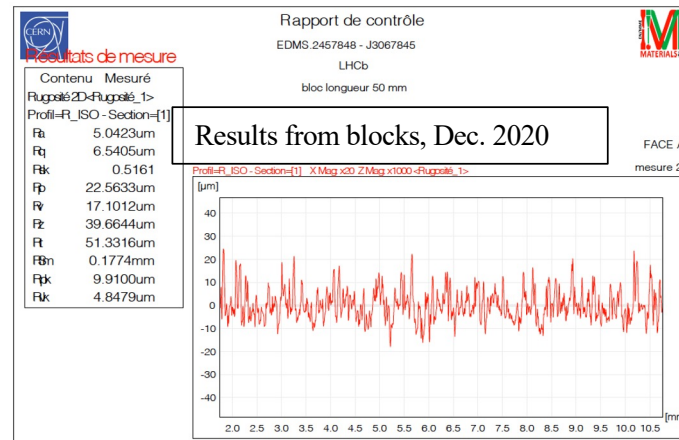
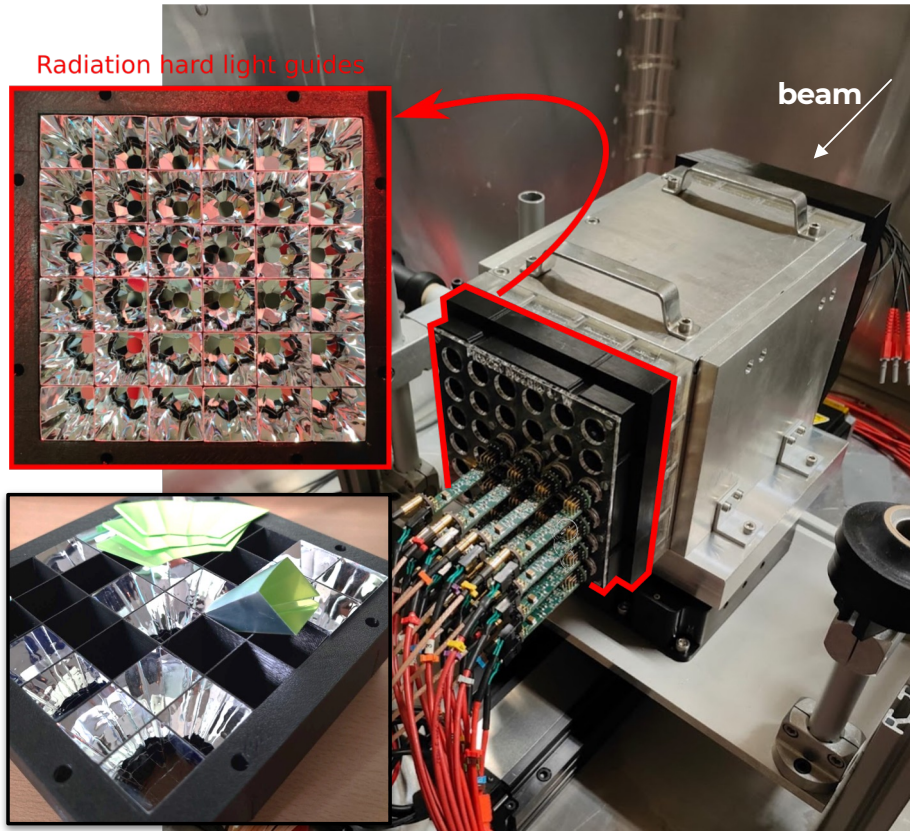
- Full size $121 \times 121 \text{ mm}^2$ **Module 0** assembled at CERN in 2023:
- Passive materials:

- 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](#)

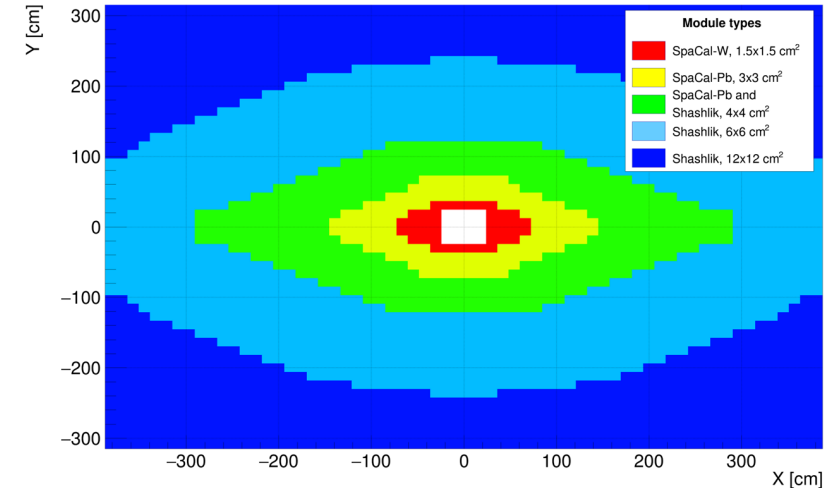
SPACAL technology for inner region.

- **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

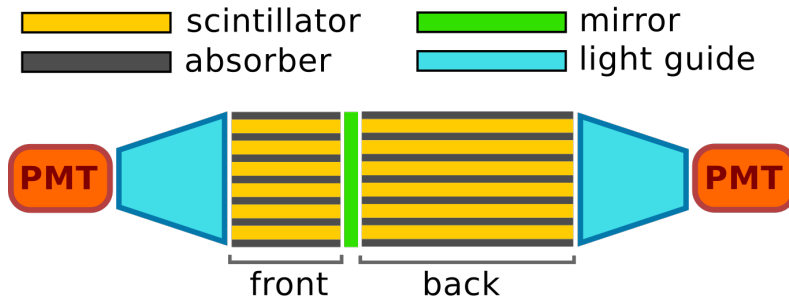
Shashlik technology for outer region

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

PicoCal 2024 - baseline

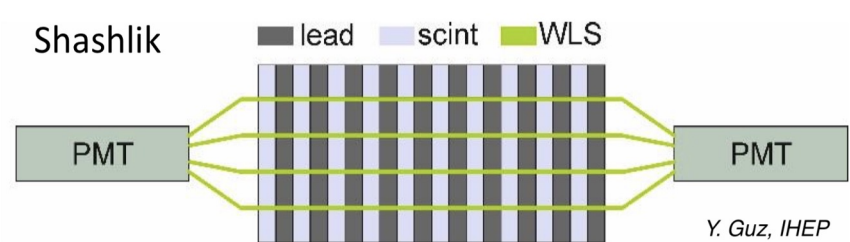


Side view



→ Beam direction

02/11/2025



→ Beam direction

LHCb Upgrade, CLHCP 2025, Hengne Li

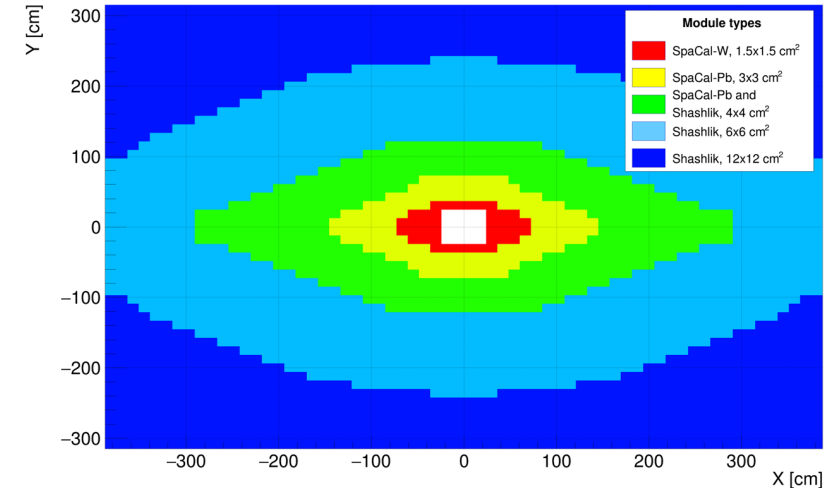
Y. Guz, IHEP

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)**

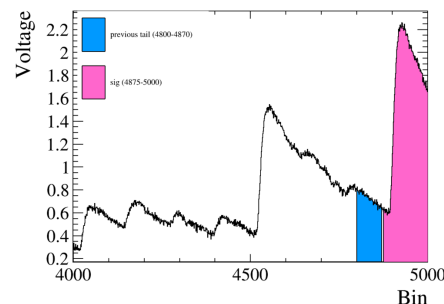
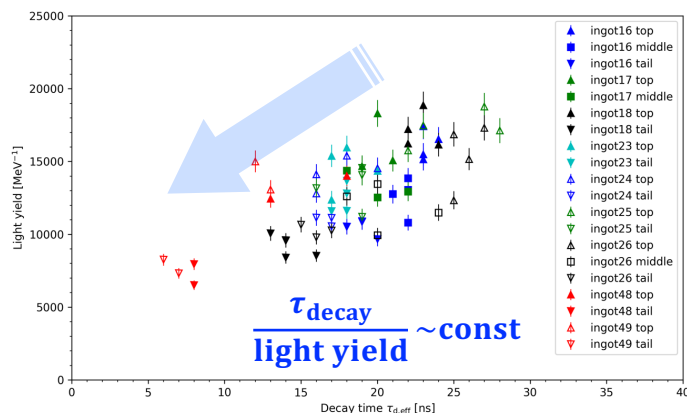
PicoCal 2024 - baseline



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

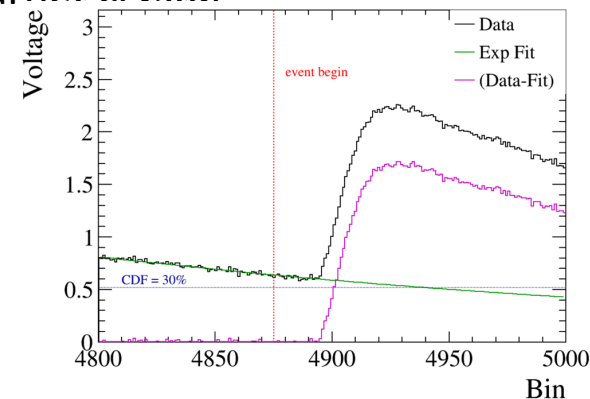
Simulation, reconstruction and performance studies

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

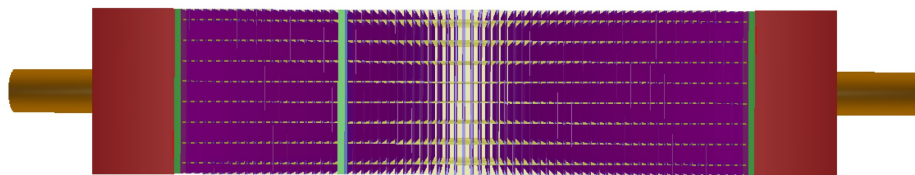


event train with bunch crossing of 25 ns

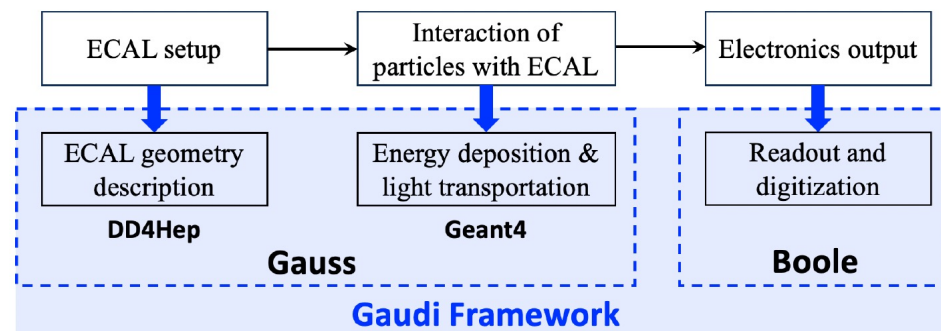
- ✓ spill-over effect on energy & time resolution being studied by subtracting contribution from previous events with exponential fit



- Construction of simulation in LHCb official framework

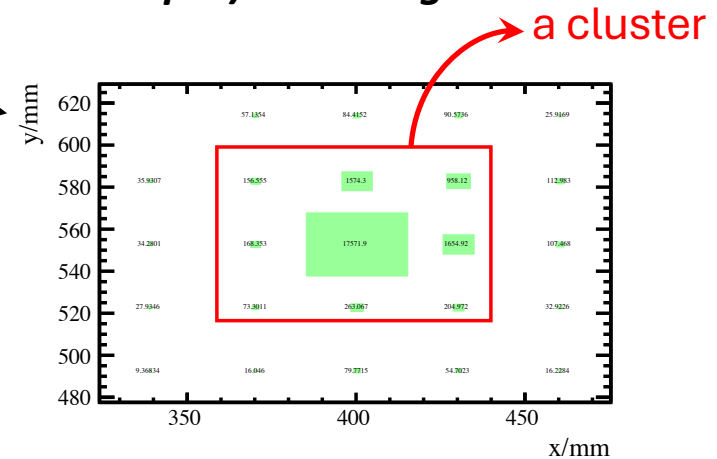
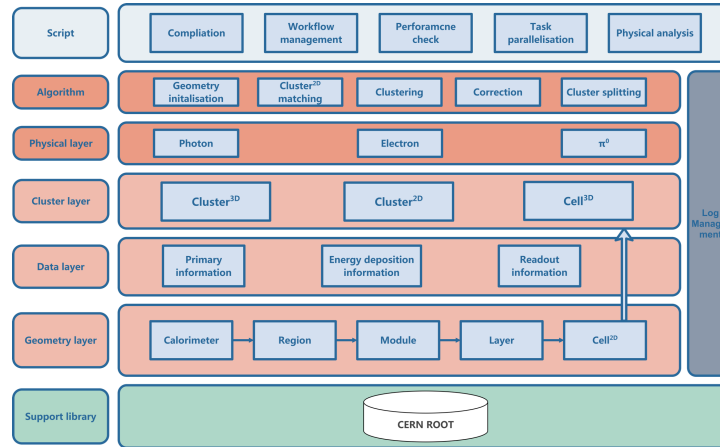


Shashlik module in DD4Hep

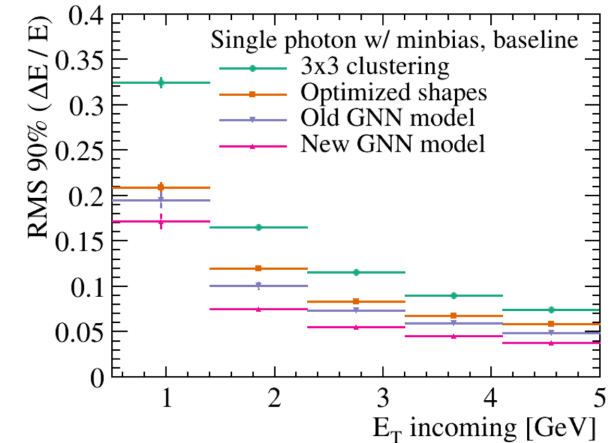
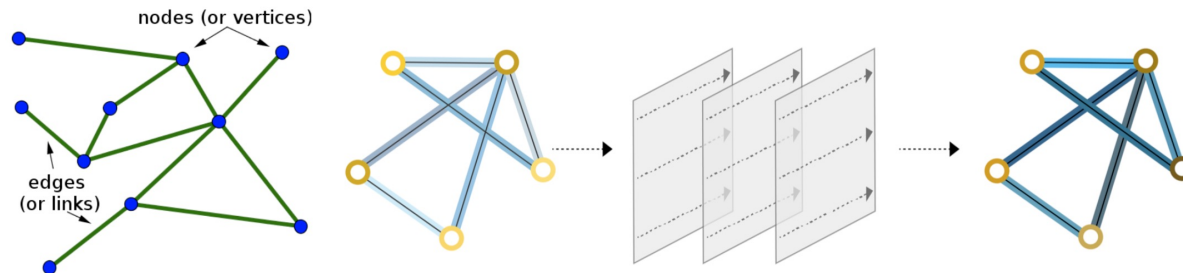


PicoCAL - reconstruction

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



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



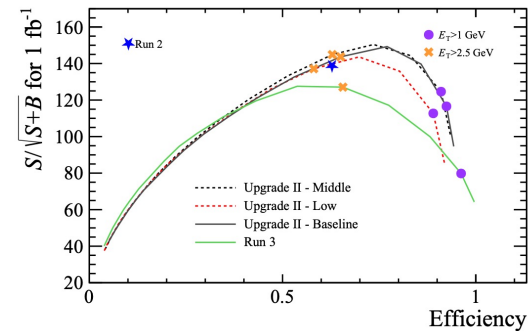
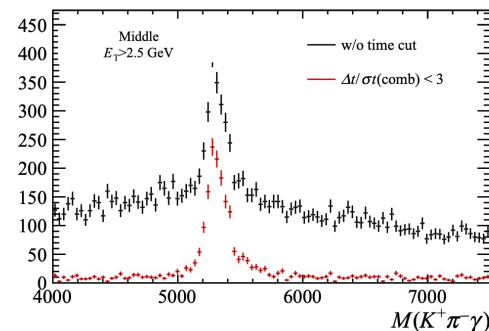
PicoCAL - performance

- Performance compared between different scenarios for benchmarking physics modes

Baseline	Middle	Low
$1.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	$1.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	$1.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
<u>PicoCal</u>		
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]

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



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

