LHCb Status Report

Martino Borsato

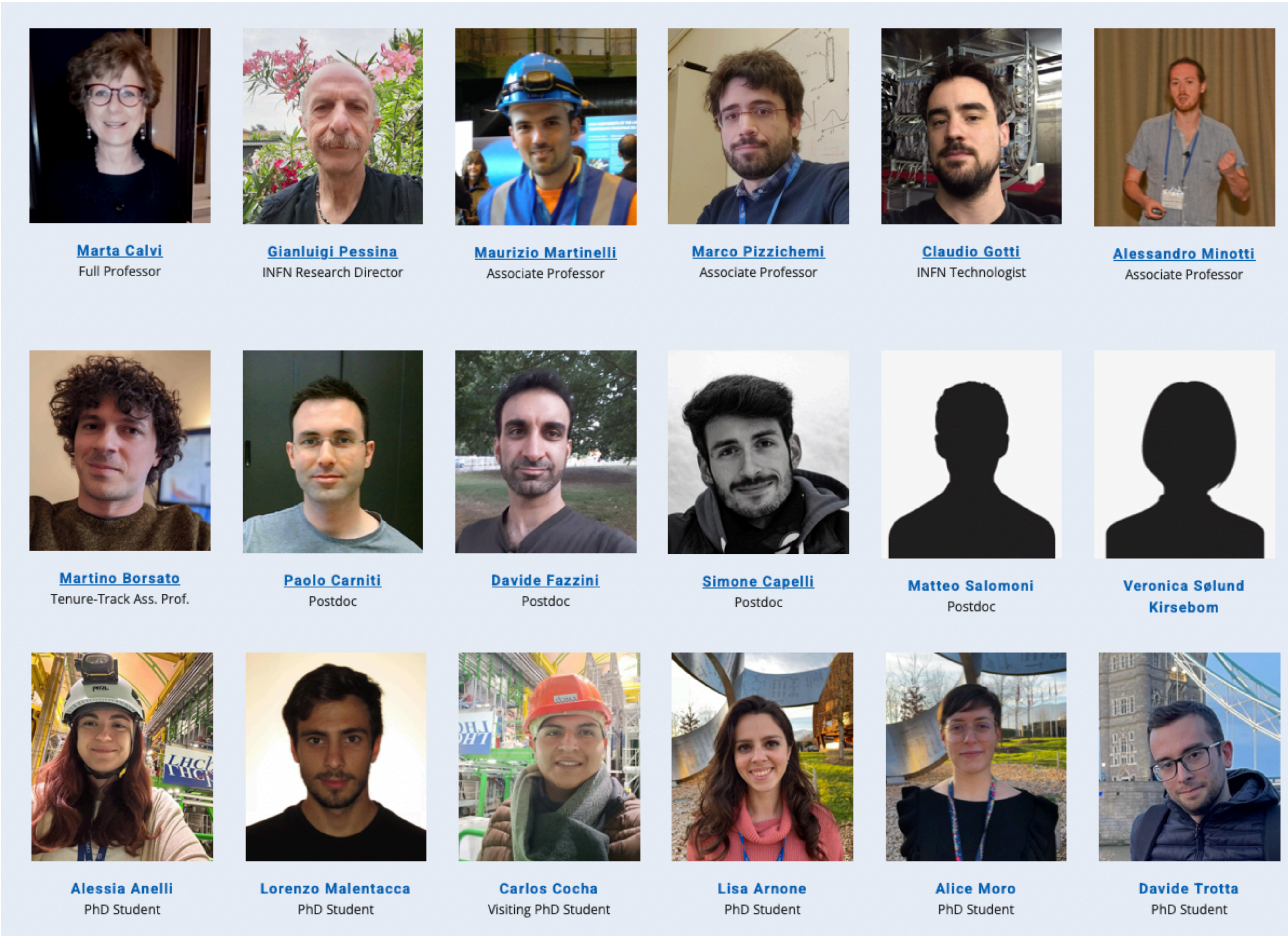
July 10, 2025
Consiglio di Sezione
INFN Milano-Bicocca

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

INFN Istituto Nazionale di Fisica Nucleare

LHCb@Bicocca

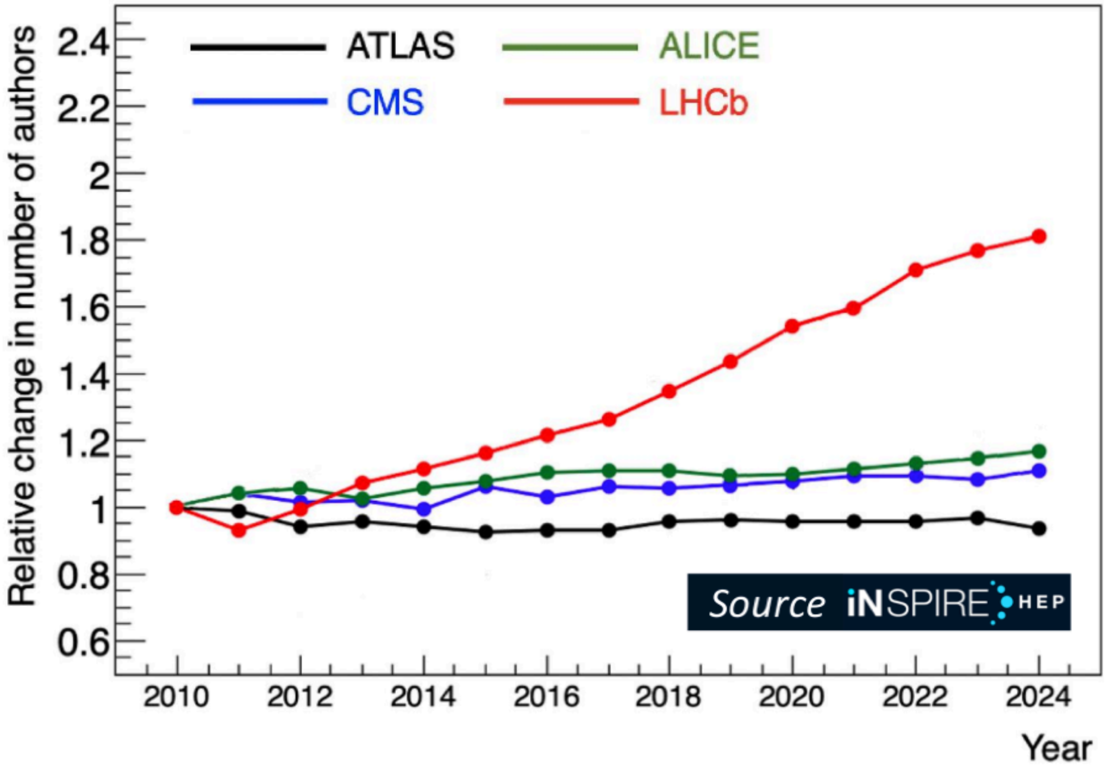
LHCb@Bicocca

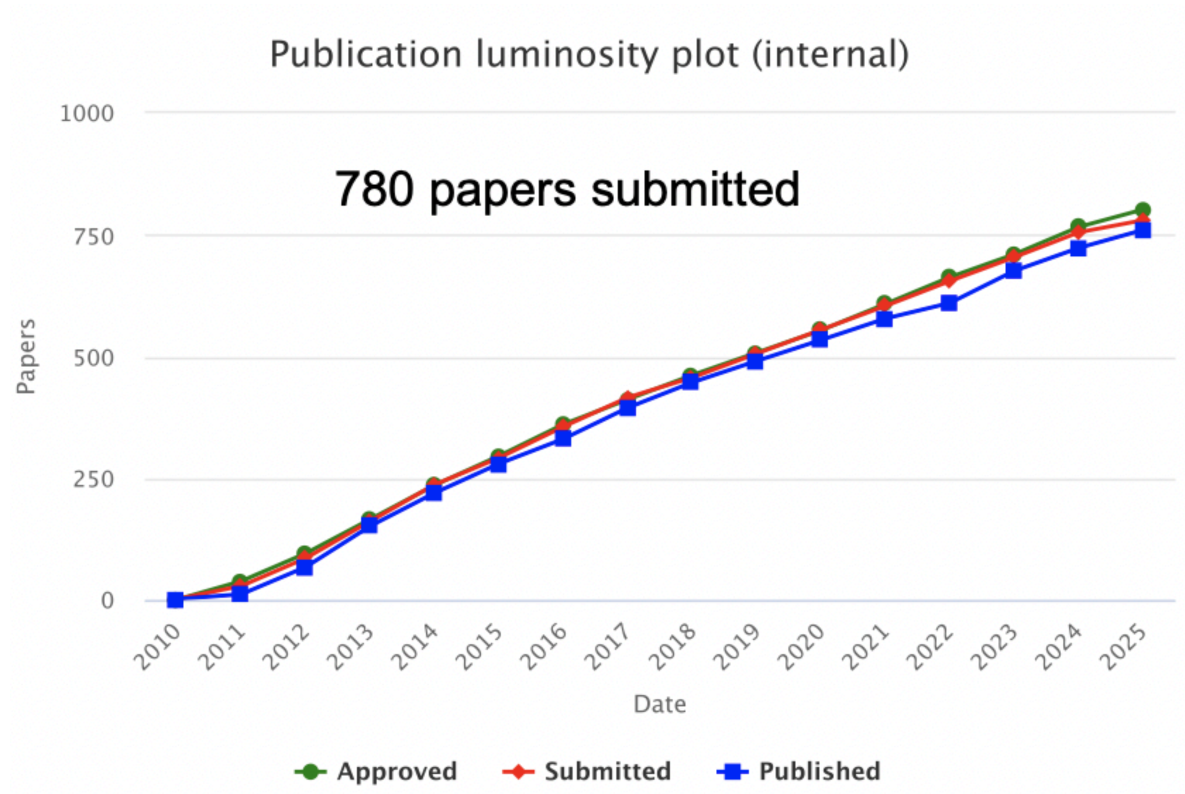


Totale FTE: 11.9

Status of LHCb in July 2025

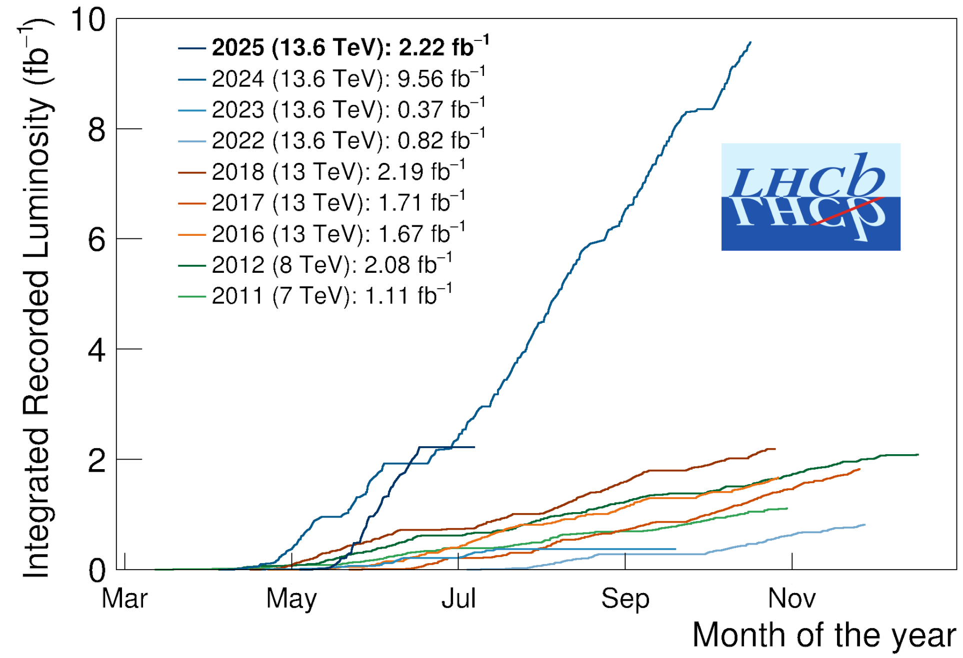
- 1848 members from 103 institutes (and growing)
- Almost 800 papers submitted



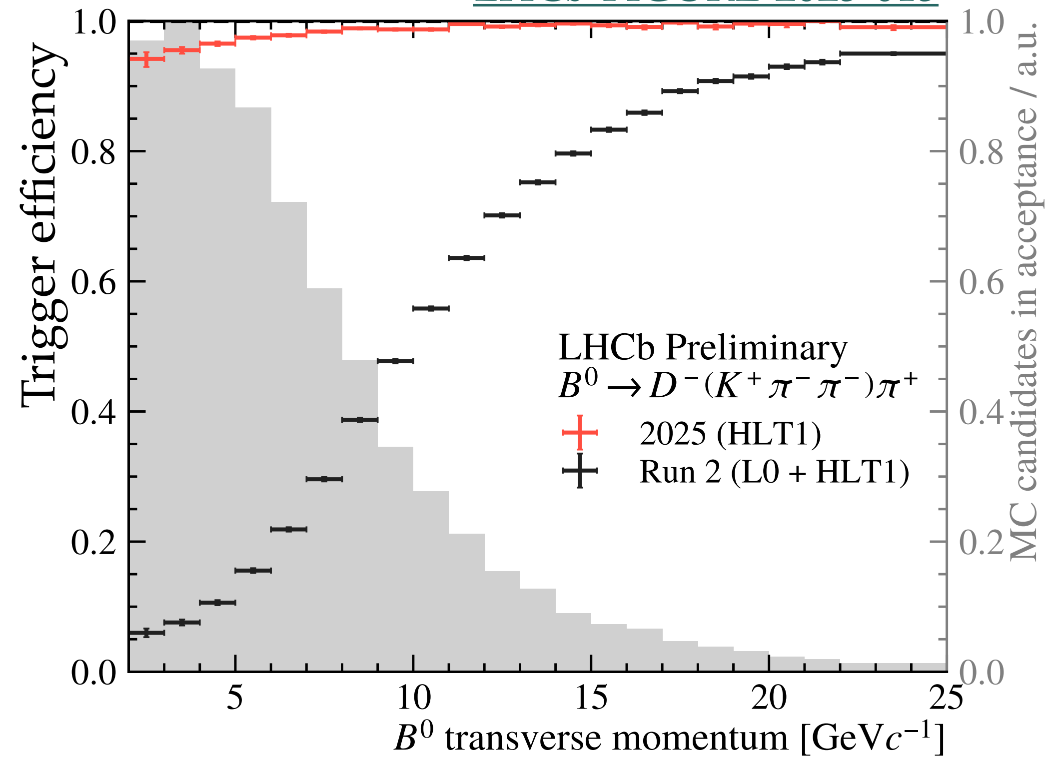


Status of LHCb in July 2025

- Experiment was upgraded for Run-3
  - Able to operate at 5x higher luminosity with no performance loss
  - Readout at 30 MHz to GPU-based trigger
  - Huge efficiency gains in several channels
- **Integrated more lumi in 2024 than in Run 1+2 $\rightarrow$ about 10^{12} $b\bar{b}$ in the LHCb acceptance**
- **Positive feedback from LHCC in May 2025:**
  - Successful work during YETS
  - Smooth start to 2025 data-taking
  - All subdetectors performing better than in 2024
    - Stable DAQ of the UT and the
    - VELO performance fully recovered



LHCb-FIGURE-2025-015



LHCb physics in Bicocca

Charged-current
b decays

Rare decays of
b and τ

Charm decays

Charged-current b decays

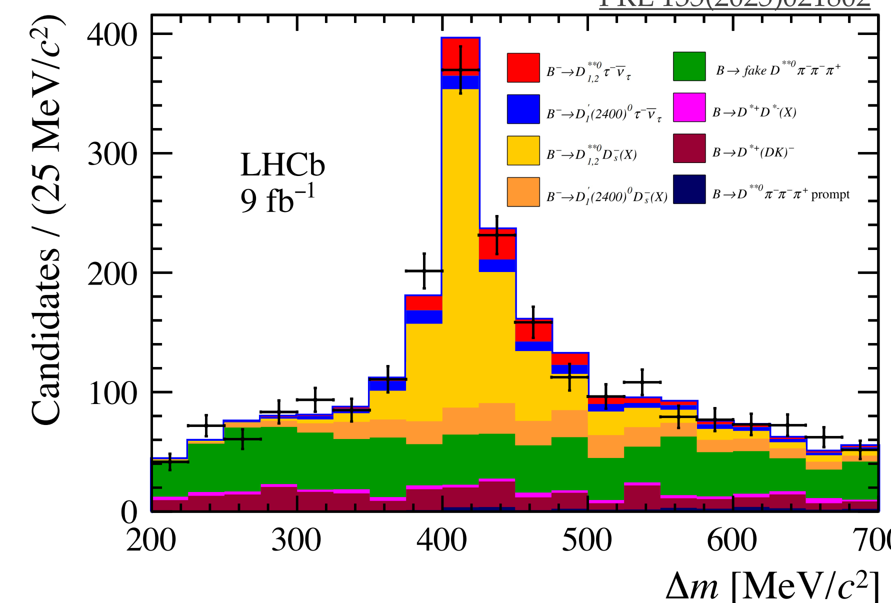
(1) Evidence for $B^- \to D^{**}\tau\nu$ decay
PRL 135(2025)021802

(2) Precision measurement of $|V_{ub}|$ with $B_s \to K\mu\nu$

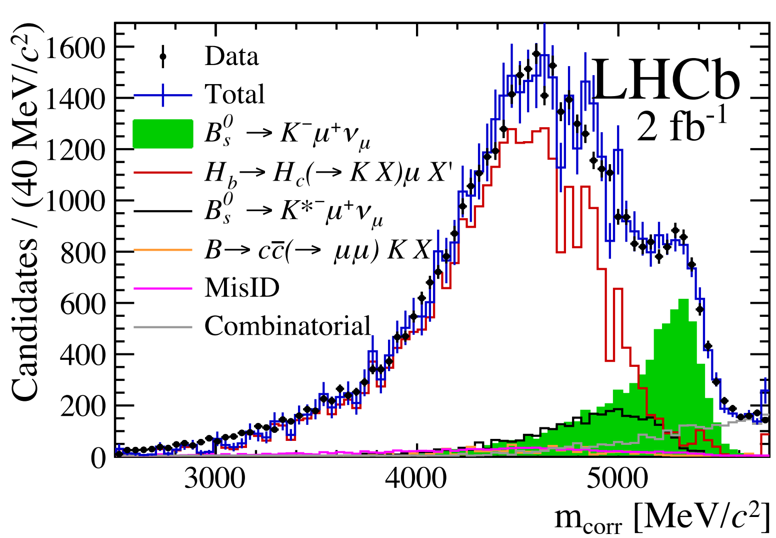
(3) Precision measurement of $|V_{ub}|$ with $B^+ \to \rho\mu\nu$

(4) Search for $B^+ \to \ell\nu\gamma$ to test B meson sub-structure

PRL 135(2025)021802

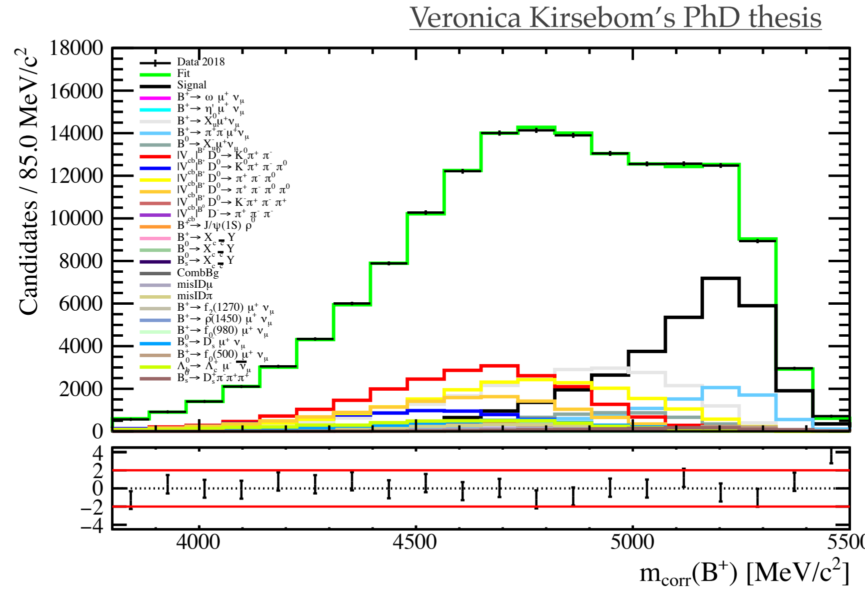


(1)

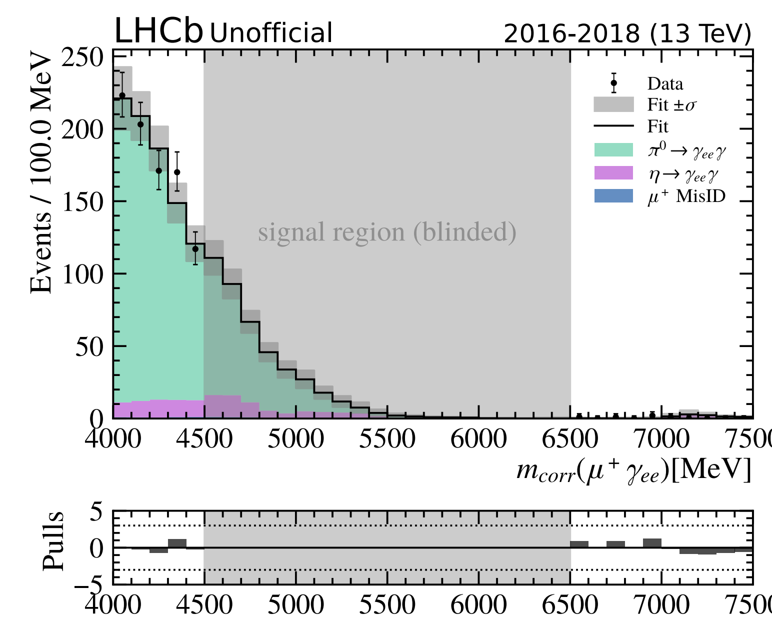


(2)

Veronica Kirsebom's PhD thesis



(3)



(4)

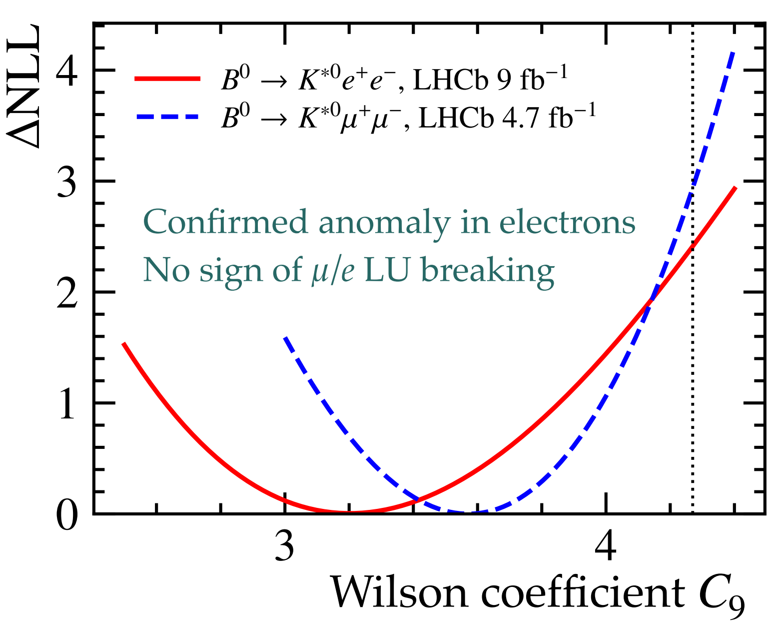
Rare decays of b and τ

(1) Angular analysis of $B \to K^*ee$ (P_5')
<u>*JHEP 2506 (2025) 140*</u>

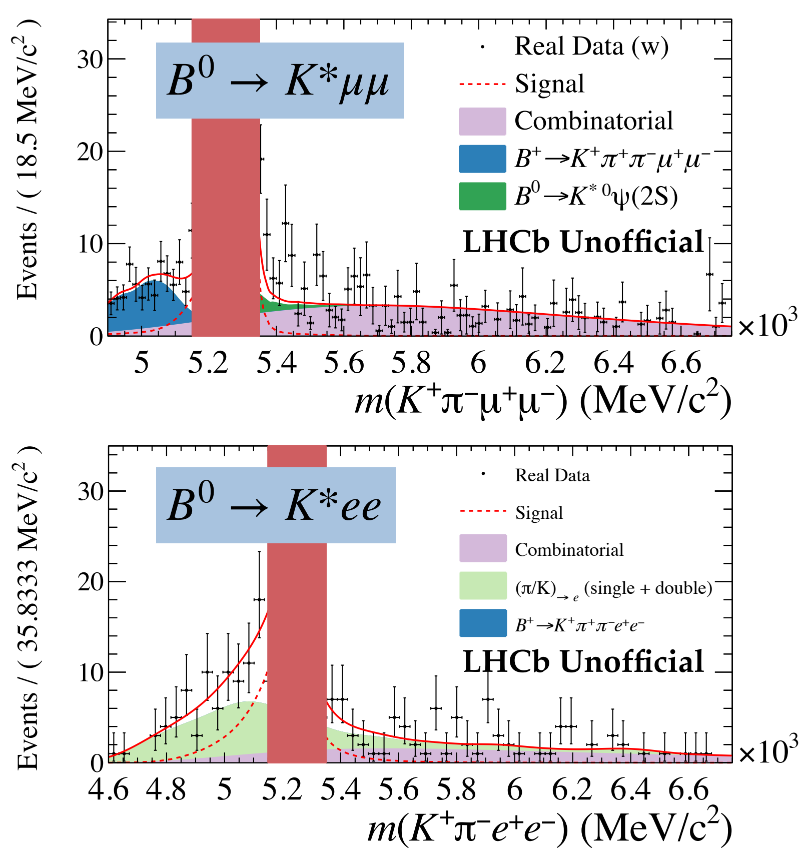
(2) Test of lepton universality in $B^0 \to K^*\ell\ell$ at high q^2

(3) Search for lepton-flavour violation with $\tau \to \mu\mu\mu$

(1)



(2)



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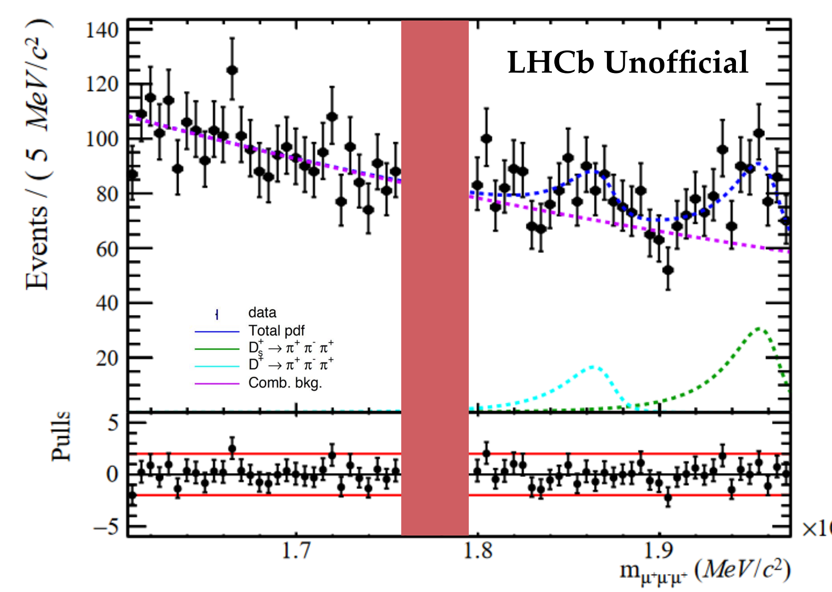


$\tau \to \mu\mu\mu$

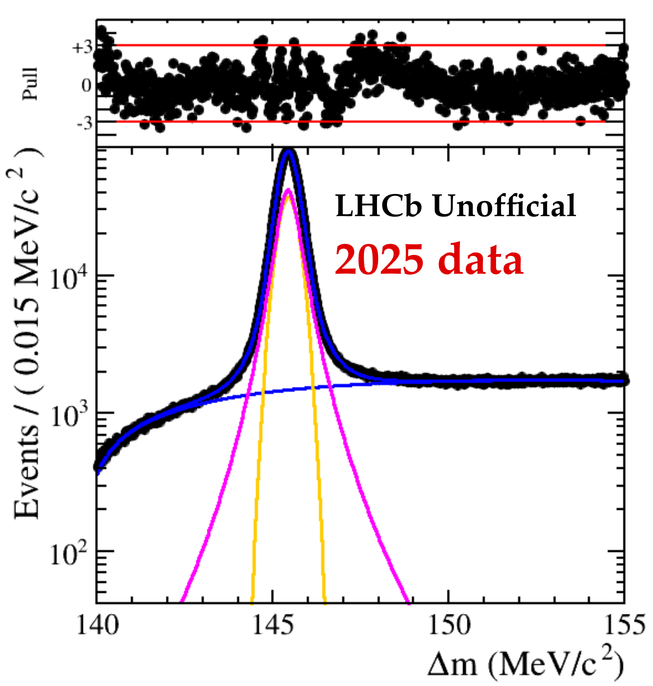
Charm decays

(1) CP violation in $D^0 \to K_S KK$ and $D^0 \to K_S \pi\pi$

(2) CP violation in rare $D^0 \to V\gamma$ decays

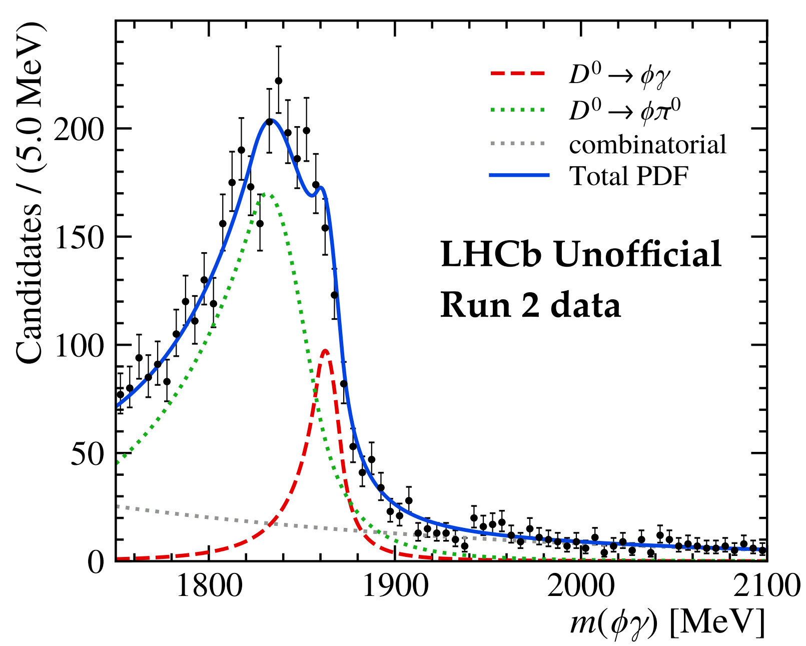
(3) Search for dark photons in charm decays

(1)



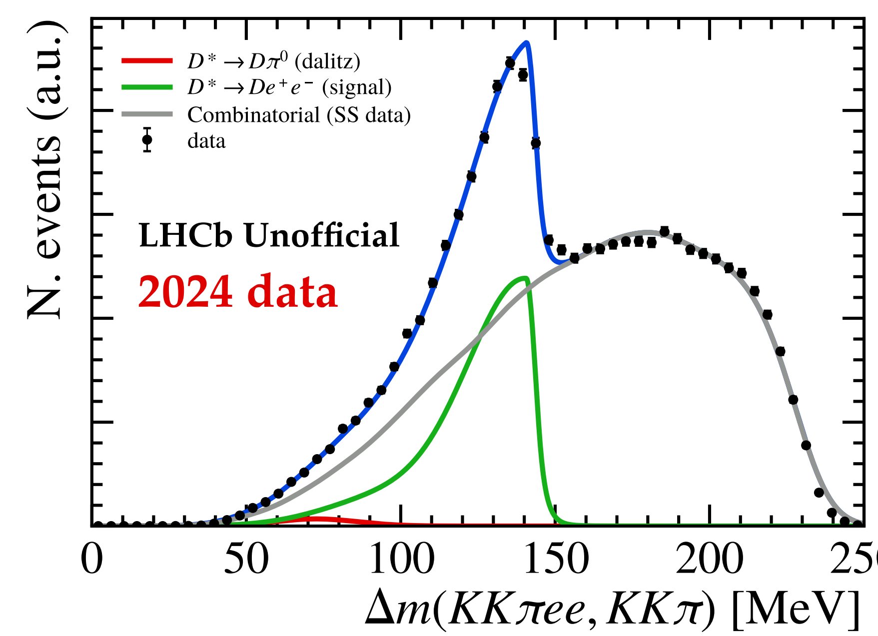
$D^0 \to K_S \pi\pi$

(2)



$D^0 \to \phi\gamma$

(3)



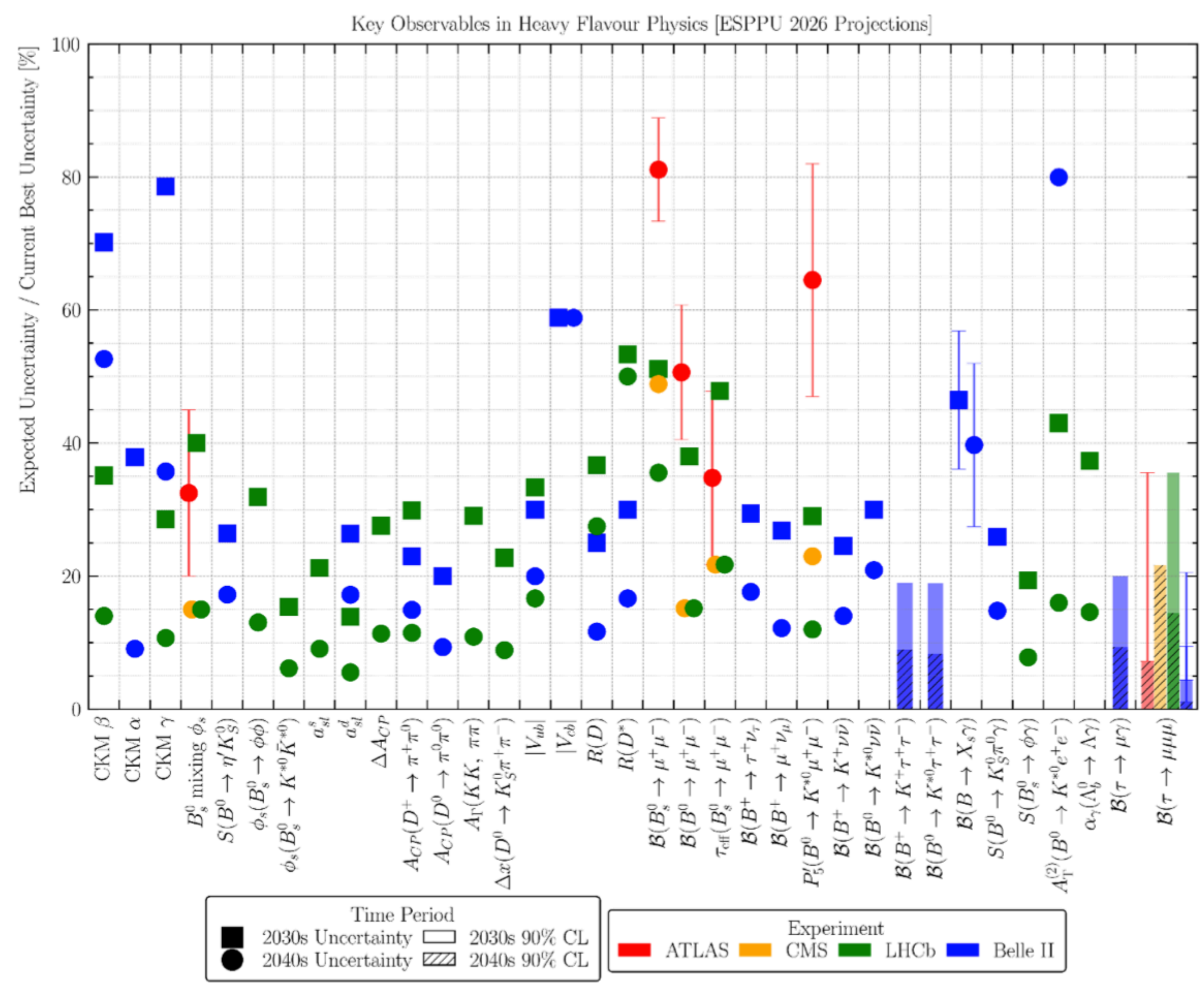
$D_s^* \to D^0 e^+ e^-$

Dark photons searched in $m(e^+e^-)$

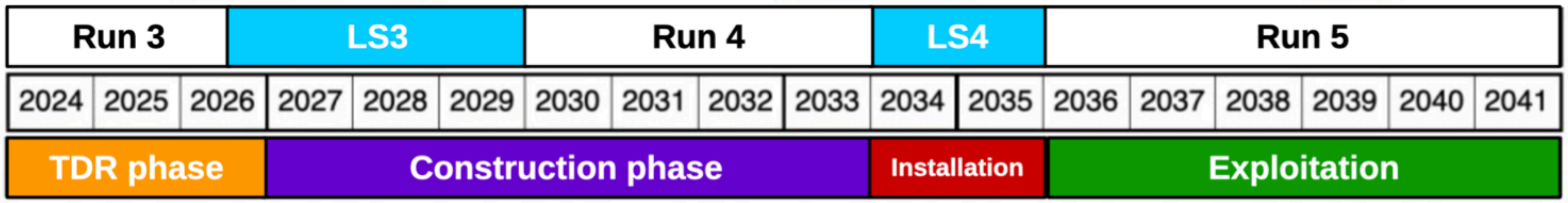
LHCb Upgrade II

LHCb Upgrade II motivation

- LHCb Upgrade II to collect 300/fb
- Projected to achieve **best precision** in the widest spectrum of key flavour observables
- Flavour-physics legacy unparalleled for several decades after the end of the LHC
- European Strategy documents submitted:
  - Discovery potential of LHCb Upgrade II
  - Technology developments for LHCb Upgrade II
  - Heavy ion physics at LHCb Upgrade II
  - Computing and software for LHCb Upgrade II
  - Projections for Key Measurements in Heavy Flavour Physics [with ATLAS, CMS, Belle II]



Upgrade II status



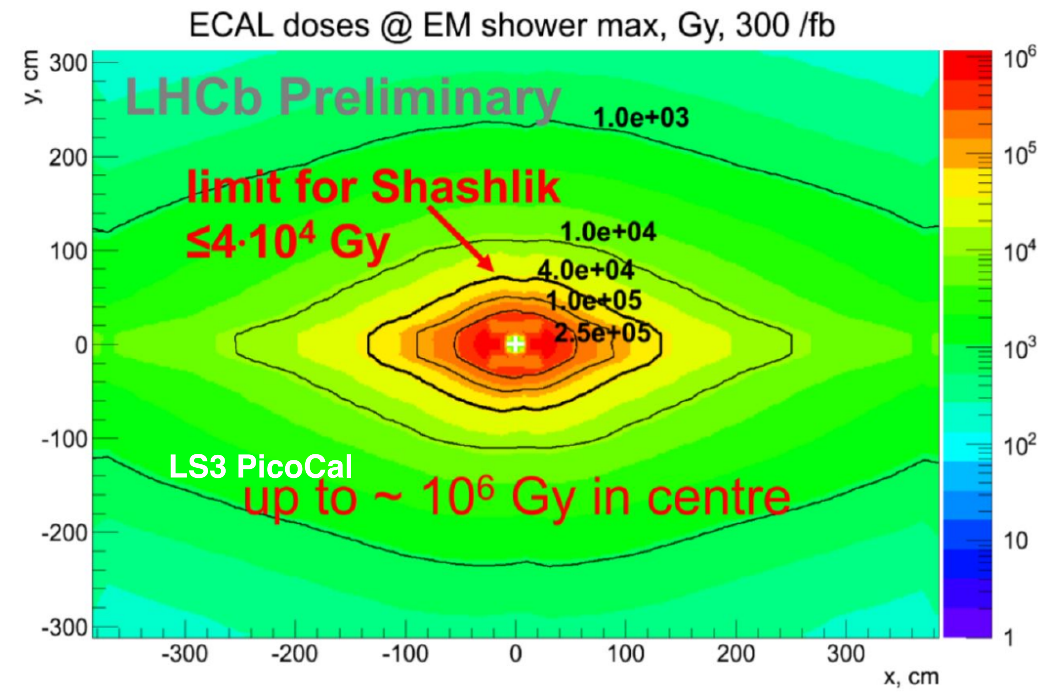
EoI (2017), Physics Case (2018), fTDR (2021), Scoping (2024) - LS3-TDRs: RICH/CALO (2024), DAQ (2024)

- LHCb Upgrade II preparations advancing quickly
- Scoping Document with three design-cost scenarios
  - CERN RB approved and recommended “middle scenario”
- TDRs to be completed by 2026
- LS4 too short for all installations: anticipated by LS3 enhancements (RICH, CALO and DAQ)

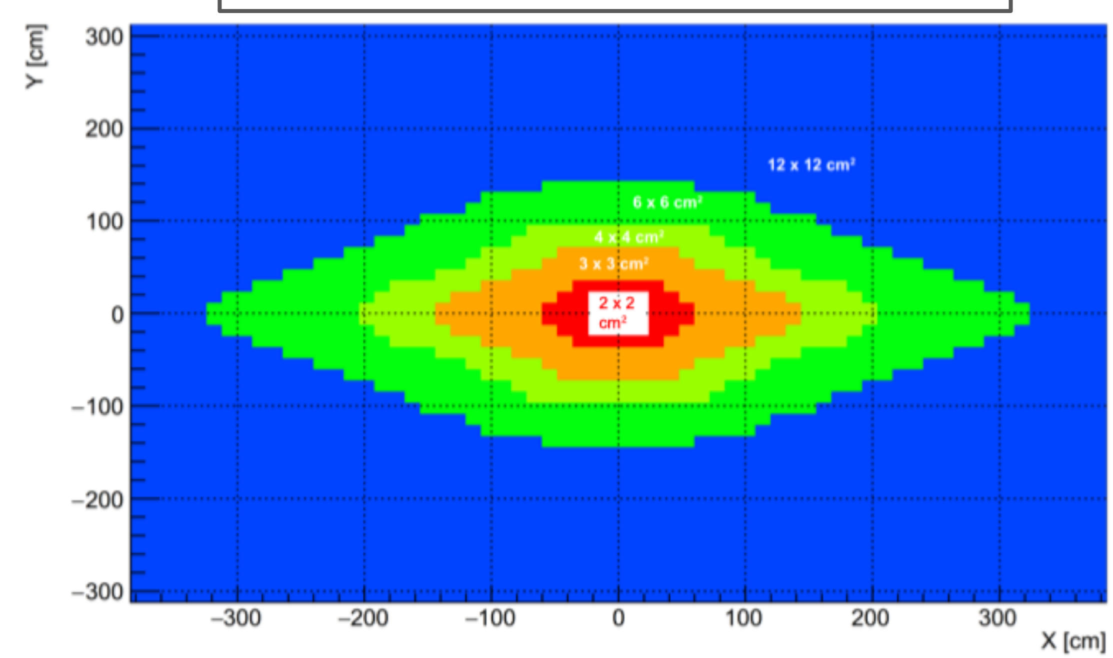
PicoCal for LHCb Upgrade-II

LHCb ECAL Upgrade → PicoCal

- Keep current performance while coping with **harsher operating conditions**
  - Sustain higher radiation dose (up to 1 MGy)
  - Mitigate higher pile-up
- Current focus on **LS3 enhancement**
  - Introduce single-section radiation-tolerant SpaCal (spaghetti calorimeter) modules
  - 32x SpaCal-W with plastic scintillator
  - 144x Spacal-Pb modules with plastic scintillator fibres
- **Contribution of the Milano-Bicocca group**
  - Search for suitable scintillating fibers
  - Development of SpaCal modules focusing on light coupling between scintillators and PMTs
  - Search for suitable PMTs
  - Development of simulation and reconstruction code



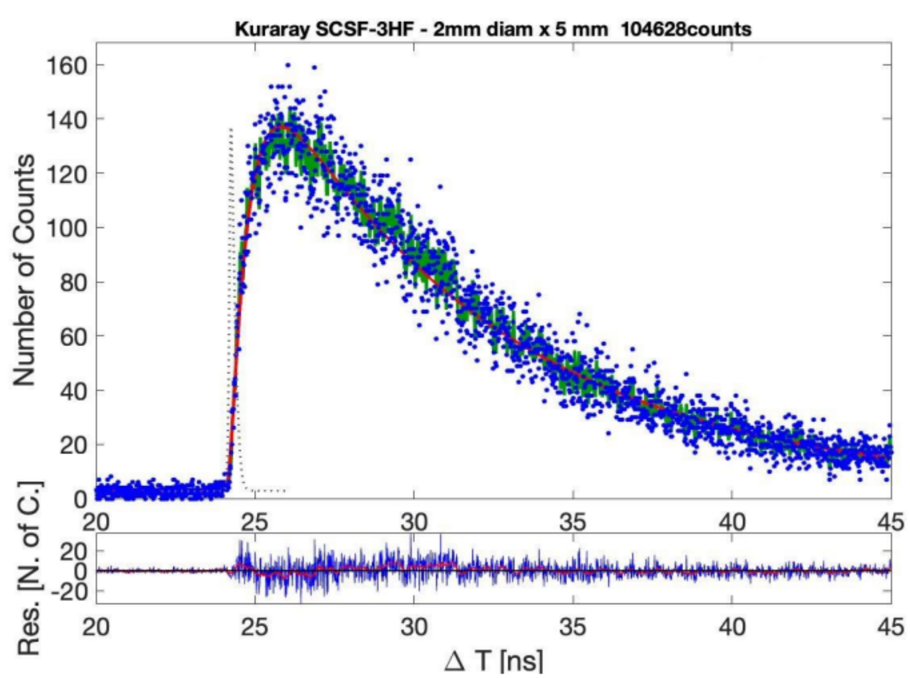
Cell size:	Modules:
2x2 cm²	32 new SpaCal-W modules with plastic fibers
3x3 cm²	144 new SpaCal-Pb modules with plastic fibers
4x4 cm²	176 existing Shashlik modules
6x6 cm²	448 existing Shashlik modules
12x12 cm²	2512 existing Shashlik modules



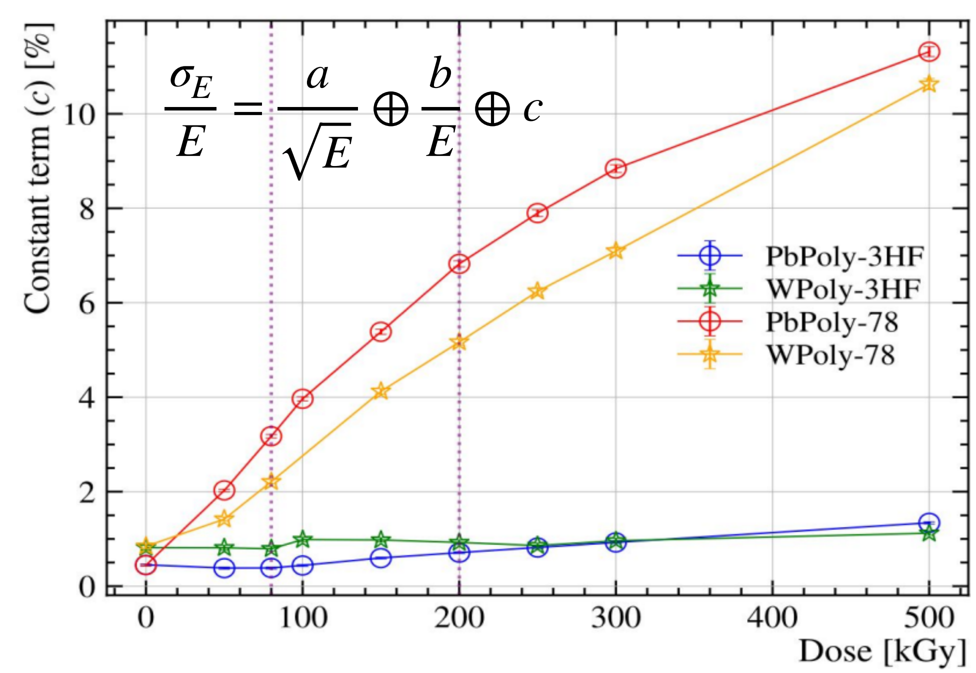
Scintillating fibers selection

Kuraray SCSF-3HF selected as optimal candidate, after investigation campaign combining laboratory measurements, test beam data, irradiation tests and detailed simulations

Fiber characteristics	Impacts on	Run 4 Requirement	Kuraray SCSF-3HF	
Scintillation Light yield	Energy Resolution	6000 Ph/MeV	6000 +/- 300 Ph/MeV	✓
Scintillation Rise Time	Spillover	< 1 ns	500 +/- 50 ps	✓
Scintillation Decay Time	Spillover	< 8 ns	7.5 +/- 0.5 ns	✓
Light Attenuation Length	Energy Resolution	> 4 m	> 5 m	✓
Radiation Tolerance	Energy Resolution	Up to 200 kGy	Up to 500 kGy	✓

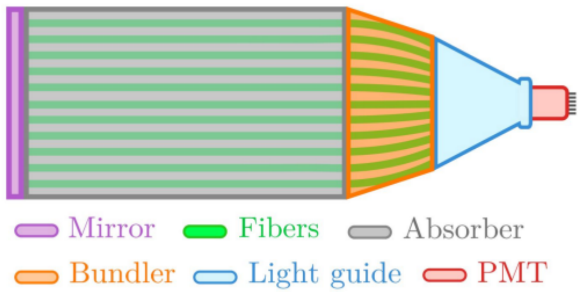


Time Correlated Single Photon Counting (TCSPC) measurement of SCSF-3HF scintillation profile



Predicted degradation of constant term of energy resolution with dose (combination of irradiation measurements and simulations)

Optical coupling

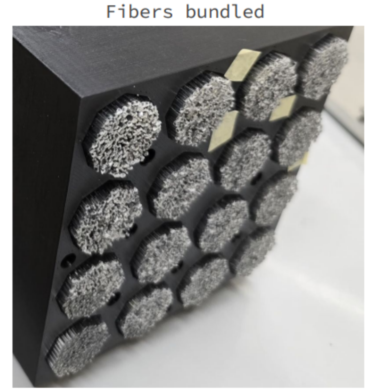


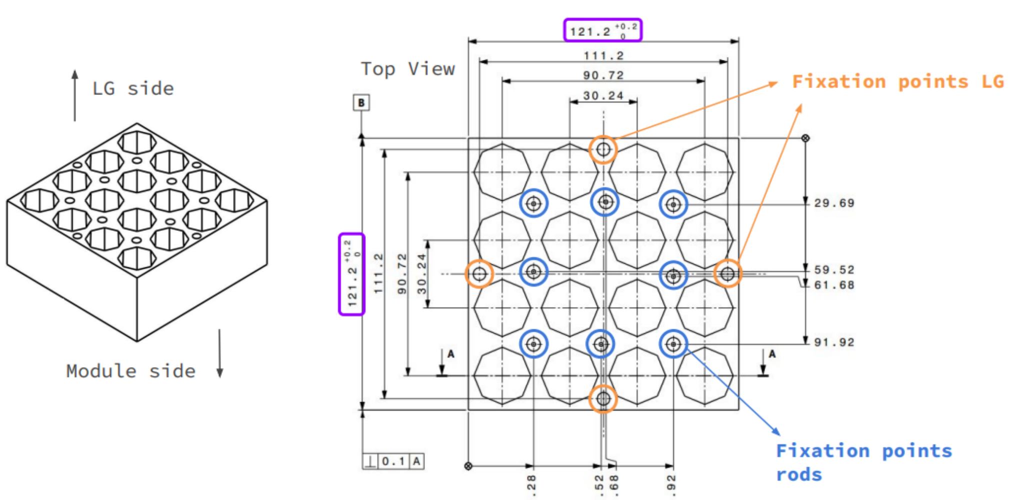
Developed an efficient and rad-hard optical coupling scheme for SpaCal modules: combination of **bundling** and **hollow light guide**

SpaCal-Pb bundling

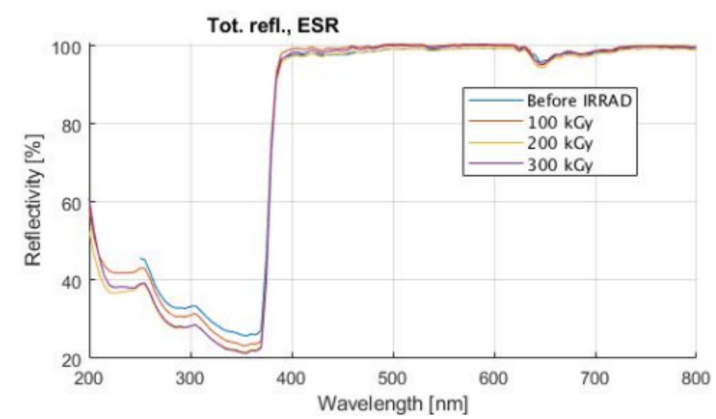
Fibers prepared to be bundled

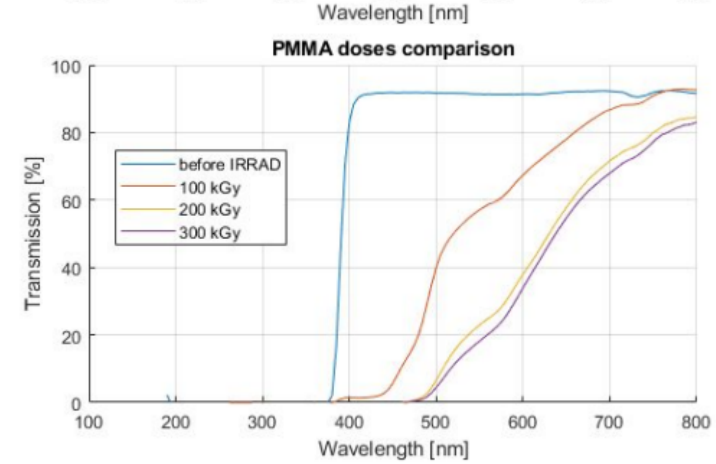
Fibers bundled





Radiation tolerance of hollow light guide (ESR) and standard light guide (PMMA)





Optimal PMT choice

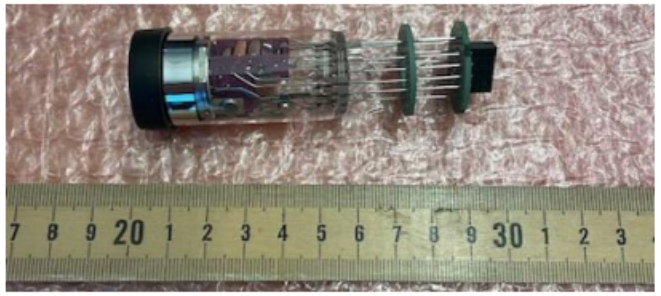
Requirements for the PMTs

•SpaCAL-W – 1400 pcs
Sustain Integrated charge of at least 10000 C
Gain from 1000 to 100000
Linearity: better than 2% at 10 mA for the gain range 2
Good time resolution: TTS < 400 ps
Pulse width < 1 ns rise time and 2 ns FWHM
Radiation tolerant to hadron irradiation up to 300 kGy -> UV window
Rate effect: 2% for 1 uA
Up to 15 mT magnetic field expected
Smaller than 1.5 × 1.5 square cm transverse to the PMT axis

•SpaCAL-Pb – 2600 pcs
Sustain Integrated charge of at least 10000 C
Gain from 10000 to 100000
Linearity: better than 2% at 10 mA for the gain range 2
Good time resolution: TTS < 400 ps
Pulse width < 1 ns rise time and 2 ns FWHM
Radiation tolerant to hadron irradiation up to 100 kGy -> UV window
Rate effect: 2% for 1 uA
Up to 10 mT magnetic field expected
Smaller than 3 × 3 square cm transverse to the PMT axis

Optimal PMT still to be selected

- Best candidates so far:
  - **Hamamatsu R9880-U MCD** technology for SpaCal-W modules
  - **Hamamatsu R9800-U** or **Nightvision N2014** for SpaCal-Pb modules

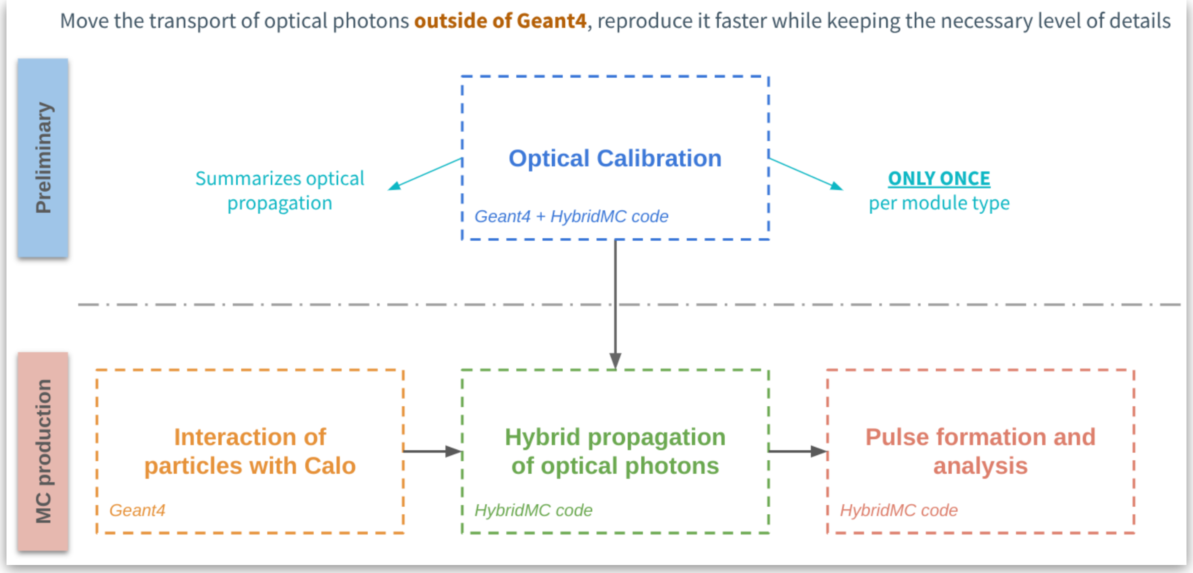


- Under development in Milano-Bicocca:
  - Test bench to optimize the PMT voltage dividers
  - **PMT characterization bench**, which will naturally evolve into a Quality Assurance setup to test part of the 4000 PMTs needed for LS3

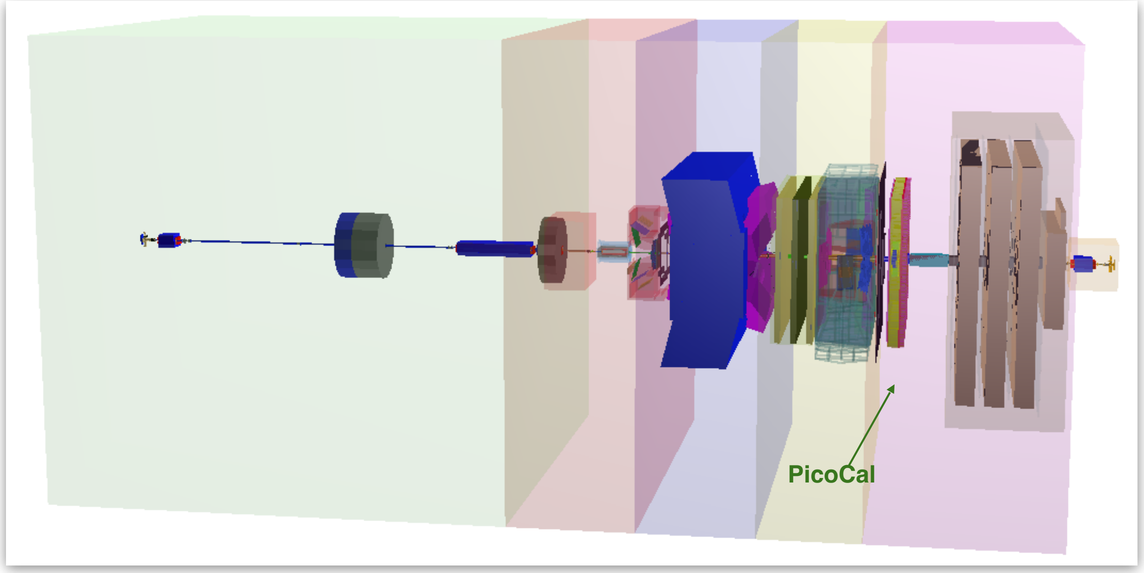
Sim and Reco software

Milano-Bicocca holds the coordination role of the software work package in PicoCal

- **Fast detailed Monte Carlo framework** (Hybrid-MC) developed for PicoCal R&D
- Current effort to **integrate it into the LHCb Framework**
- **Development of reconstruction software**
  - Traditional clustering algorithms, with inclusion of longitudinal segmentation and timing information
  - Reconstruction with Graph Neural Networks



Schematic representation of the Hybrid-MC framework developed for fast detailed simulation of PicoCal modules and full detector



Implementation of PicoCal into the LHCb Simulation Framework. Geometry described using the DD4Hep package

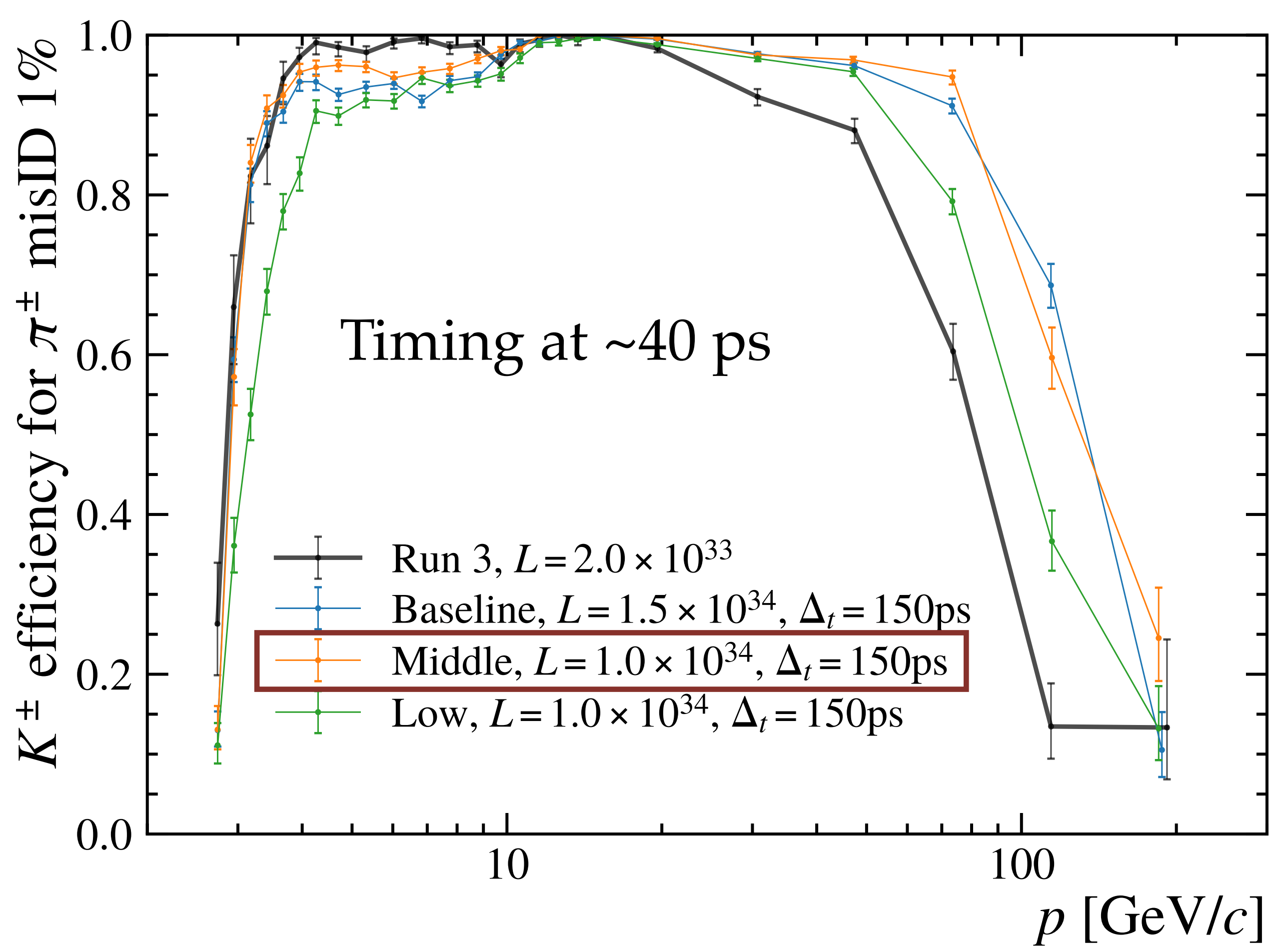
RICH for LHCb Upgrade II

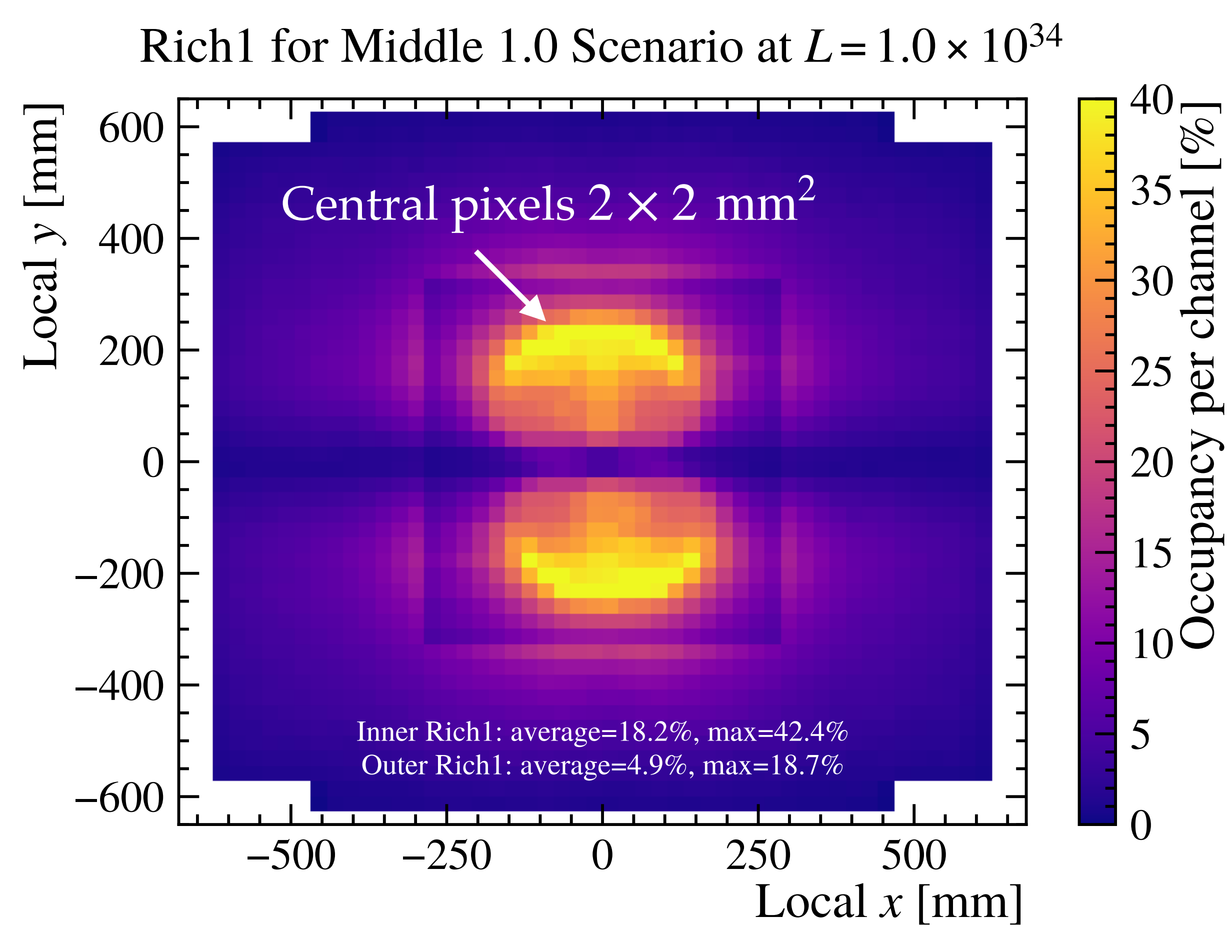
U2 RICH Performance studies

- Contributed MC-based emulation of performance of various RICH design options for U2
- Studied pixel size, timing performance, dark counts
- Studies went into Scoping document

<u>Requirements</u>:

- **Small pixels:** down to 1.4 x 1.4 mm^2
- **Time resolution:** O(100 ps) RMS
- **Radiation tolerance**: low DCR up to a few 10^{13} n_{eq}/cm^2





RICH Upgrade-II R&D

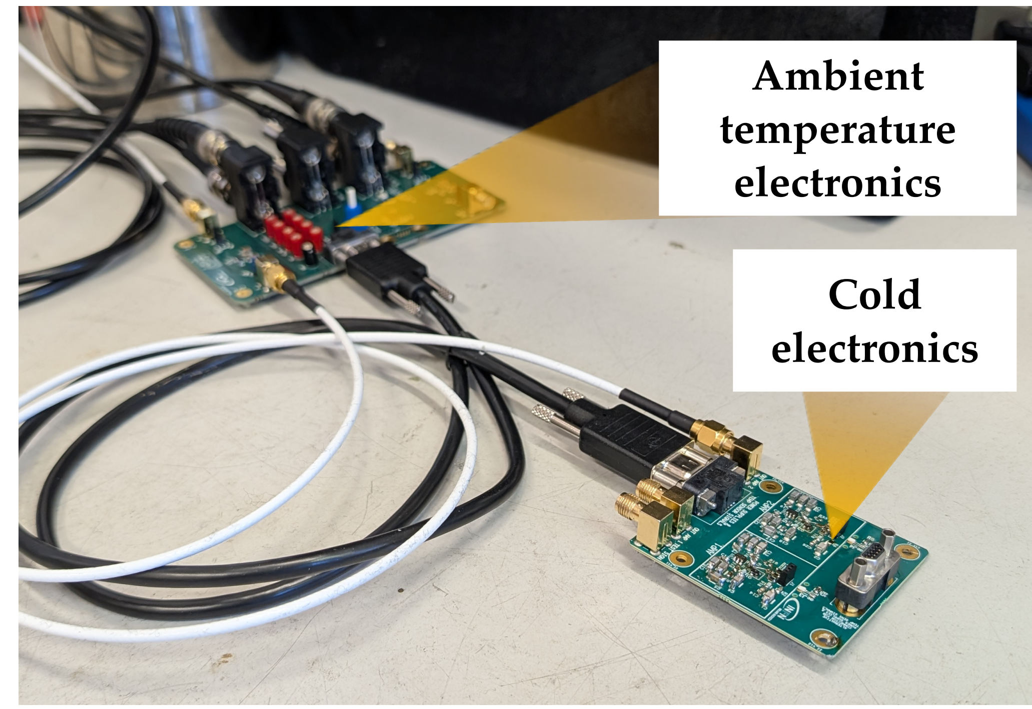
Leading candidate: **SiPMs cooled to cryogenic temperature**

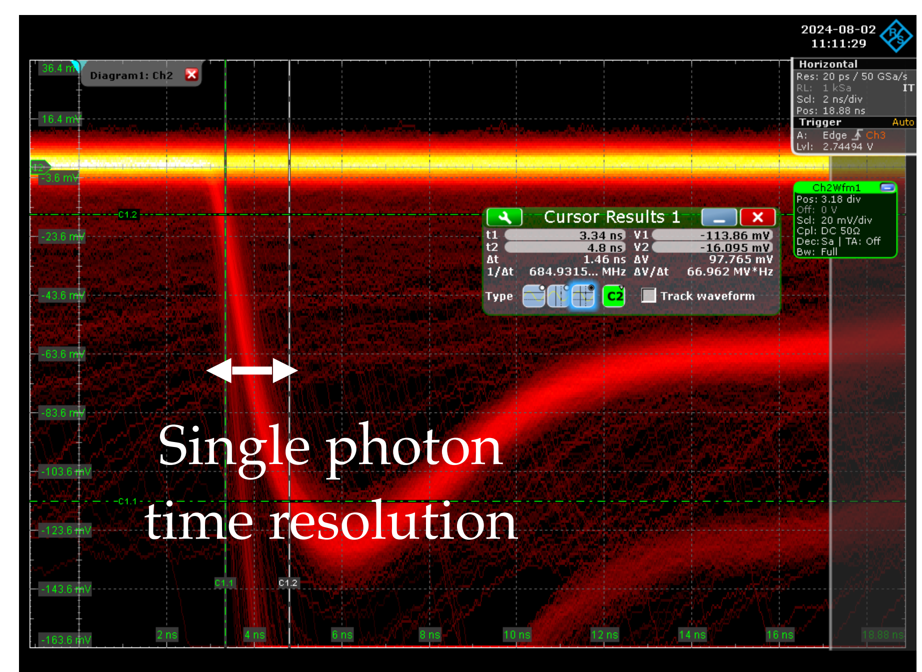
- R&D is required to choose the best device
- Led by italian institutes: Ferrara, Genova, Milano-Bicocca, Padova, Perugia
- Collaboration with Hamamatsu
  - Phase 1 (in progress): study of existing technologies
  - Phase 2 (near future): runs for new/modified technology
- Short timeline (3-year R&D; SiPM production in 2029)

Dedicated single-channel amplifier needed:

- Wide bandwidth (< 1 ns rise time)
- Low noise and excellent timing (≈10 ps jitter)
- Able to operate in the entire temperature range 77-300 K

  → Developed at Milano-Bicocca (Davide Trotta)

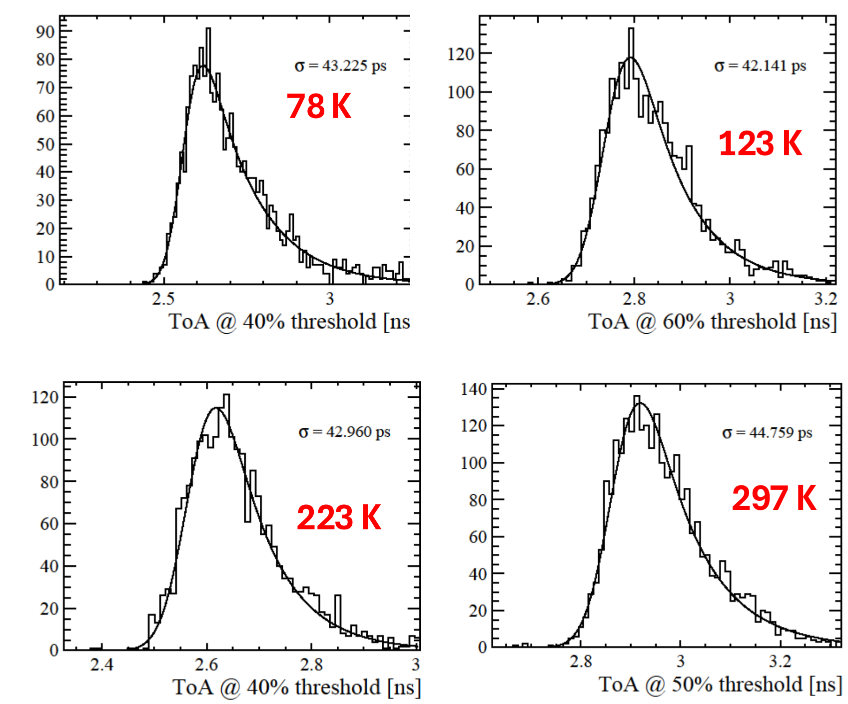


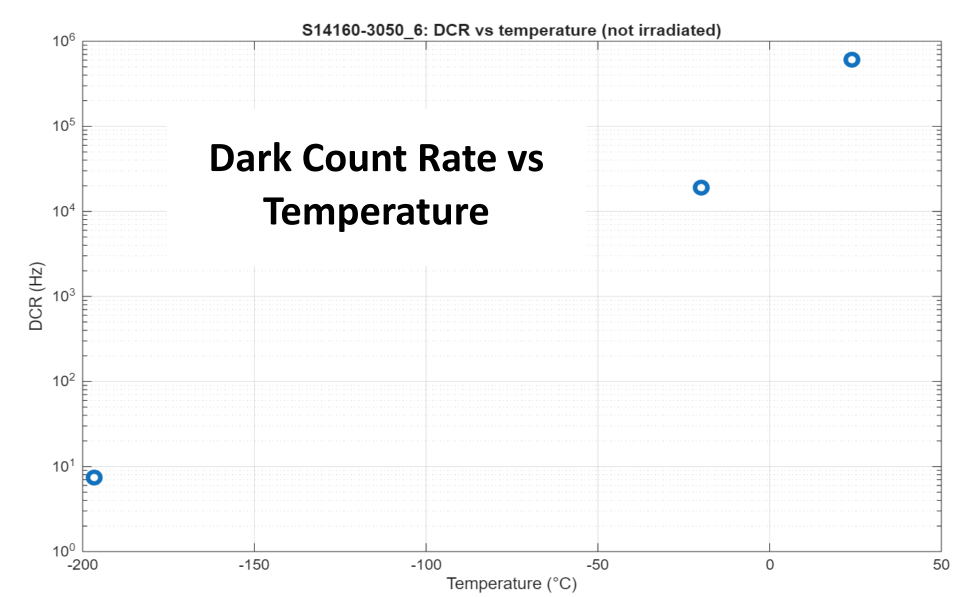


SiPM characterisation

- SiPM characterization at different temperaures, before irradiation: almost complete on all Hamamatsu devices available off-the-shelf
- One device (s14160, five samples) irradiated in Ljubljana in May; now under test @MiB
- Irradiation and characterization of the other devices to happen in the next months
- Request to INFN (by Ferrara, for all the groups involved) for funds for a «s13360-mod» dedicated run, to be tested in 2026

Measurements done in Ferrara with the MiB amplifier

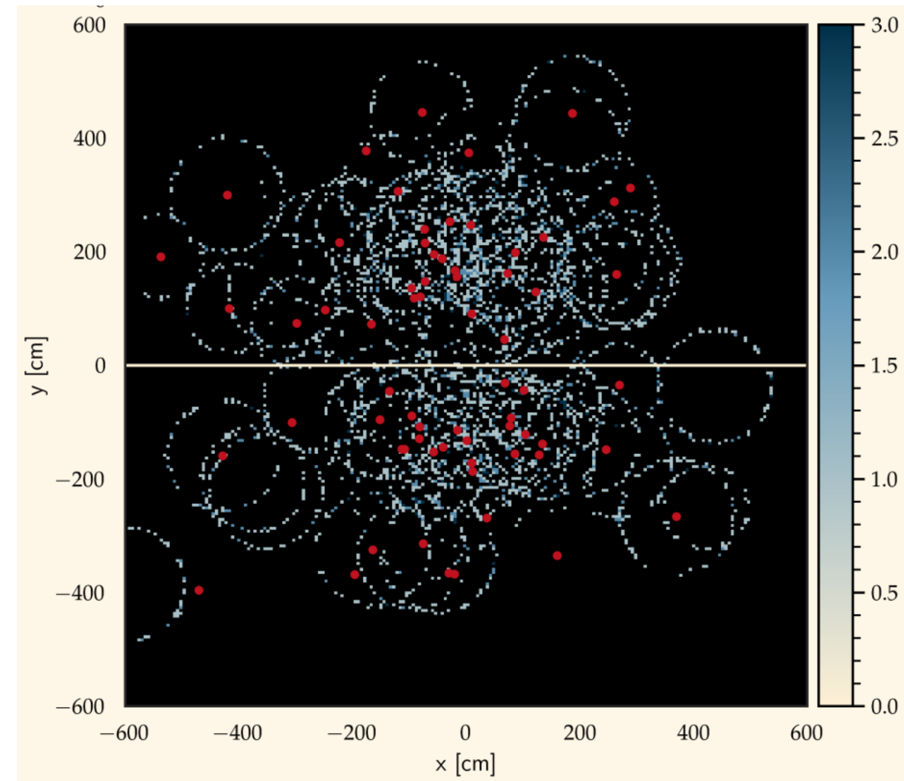




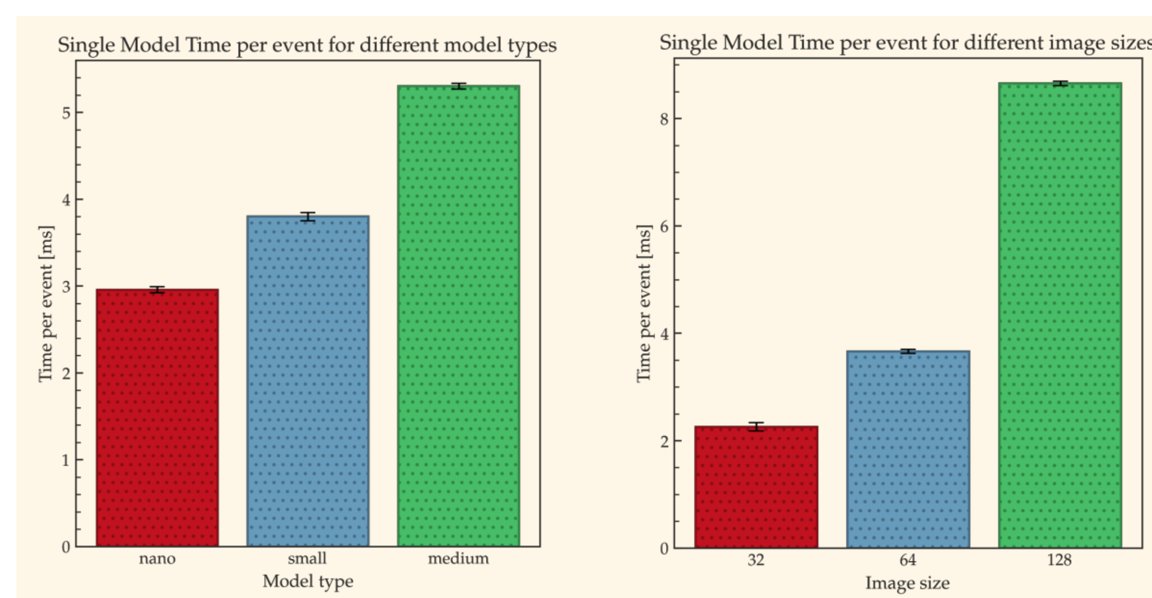
Real-time reconstruction

Fast ML for RICH reco

- Cherenkov ring reconstruction takes time (still missing from Hlt1 reco in LHCb)
- Testing technique based on modern computer vision for real-time object identification (YOLO)
- Task: Given track and Cherenkov hits, classify PID
- Reaching good PID performance with 20ms inference (full event) on NVIDIA A6000
- **Results presented at EuCAIFCon 2025**

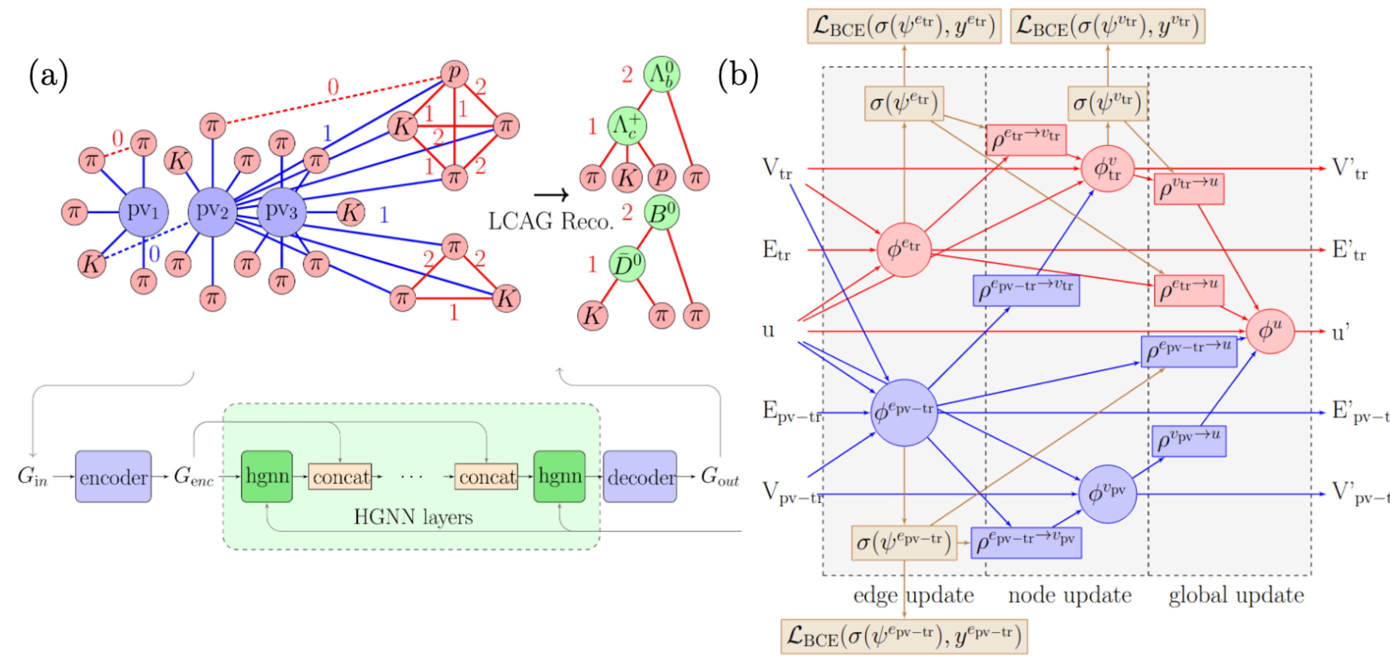


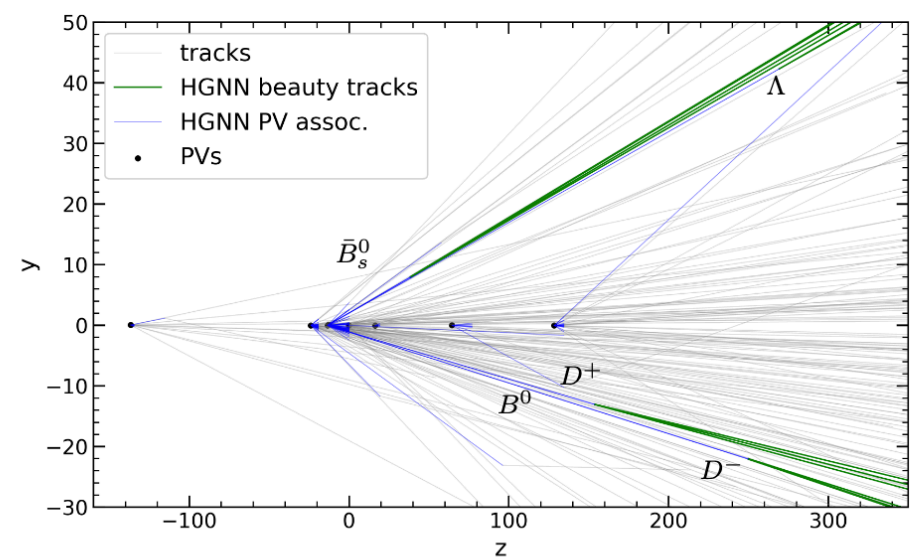
EUROPEAN AI FOR FUNDAMENTAL PHYSICS CONFERENCE
EuCAIFCon 2025



DFEI project

DFEI = Deep-learning based Full Event Interpretation





ArXiv:2504.21844v2

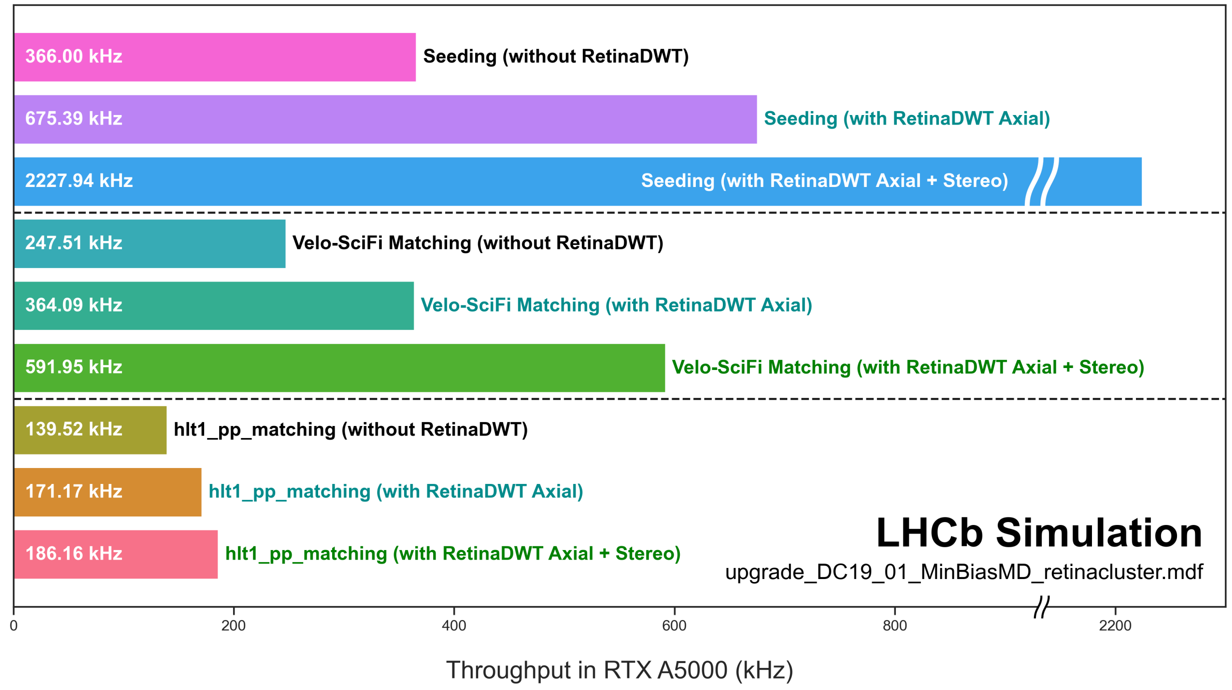
Scalable Multi-Task Learning for Particle Collision Event Reconstruction with Heterogeneous Graph Neural Networks (HGNN)

- Based on DFEI GNN algorithm (Comput Softw Big Sci 7, 12 (2023))
- Included PV association, which is critical at high-lumi
- Integrated graph pruning layers.
- Developed on custom Pythia simulation.
- Training on RUN3 full-simulation ongoing

Use of FPGAs

New FPGA cluster at MiB

- New FPGA cluster installed in MiB
  - In collab with F.Brivio, P.Dini and S.Gennai
  - +Help from LHCb-Pisa colleagues
  - Issue with analog-to-optical transducer → might need replacement
- Plan to test DWT device to reconstruct LHCb downstream tracks to be installed in LS3 LHCB-TDR-025, LHCb-PUB-2024-001



BACKUP

(anagrafica, dettagli richieste, …)

Anagrafica LHCb Bicocca

nome	cognome	ruolo	%	responsabilità
Anelli	Alessia	PhD	100	Charm WG liason
Arnone	Lisa	PhD	100	
Borsato	Martino	RTDB	100	Rare Decay WG Convener, SB member
Calvi	Marta	PO	100	
Capelli	Simone	AR	100	
Carniti	Paolo	RTDA	50	
Fazzini	Davide	RTDA	100	Semileptonic Sub-WG Convener
Kirsebom	Veronica	AR	100	Semileptonic WG liason
Gotti	Claudio	Tecn INFN	40	RICH deputy PL
Martinelli	Maurizio	PA	95+5	
Minotti	Alessandro	PA	70	
Moro	Alice	PhD	100	
Pessina	Gianluigi	Dir.Tecn INFN	10	
Pizzichemi	Marco	PA	100	UP2 WG convener
Salomoni	Matteo	RTDA	0	UP2 WG convener (associazione INFN PV)
Trotta	Davide	PhD	20	
TOTALE FTE			11,90	

Richieste PicoCal 2026

CORE

350 kCHF

*Contributo ad acquisto fibre di **scintillatori plastici** per moduli SpaCal da installare durante LS3*

Circa ⅓ della spesa totale di PicoCal sugli scintillatori in LS3

Milano-Bicocca
150 kCHF

Bologna
100 kCHF

Padova
100 kCHF

- Distribuzione tra le sezioni pesata sugli FTE PicoCal in LS3
- Fondi da trasferire su **budget code** CERN → acquisto centralizzato permette notevole risparmio sui costi

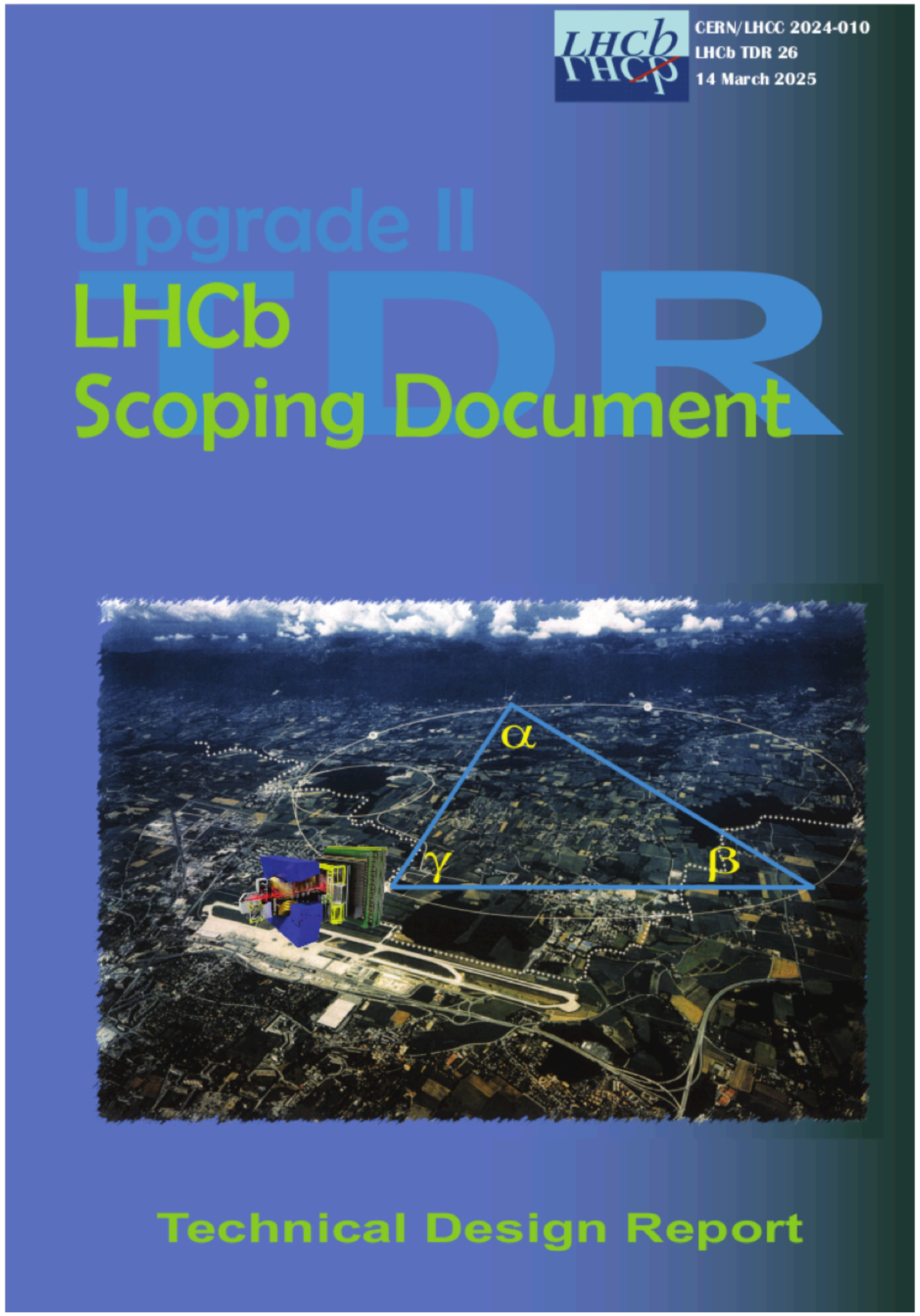
INFRASTR.

30 kEuro

*Sviluppo di una **bench per QA dei PMT** da installare in PicoCal durante LS3*

(Pulser + LED + diodi + HV power supply + digitizers)

Milano-Bicocca
30 kEuro



Scoping process

- Tre scenari di scope: 'Baseline', 'Middle', 'Low'
- 2 Sep 2024: LHCb-TDR-26 submitted to LHCC
- 17 Feb 2025: Re-submitted after LHCC comments
- 17 March 2025: LHCC review concluded, final version public on CDS:
  https://cds.cern.ch/record/2903094
- 19 March 2025: Research Board meeting
- 29 Apr 2025: RRB meeting
  - **Recommendation that LHCb concentrates on the Middle scoping scenario**
  - Endorses two expert reviews (both LHCb and ALICE):
    - ASICs design (caused delays to ATLAS/CMS)
    - Installation schedules (short LS4 duration)
  - Approval of the chosen scope for each experiment to be made later this year following the October RRB (Money Matrix expected from Funding Agencies)