# Belle II – RM3: preventivi 2026

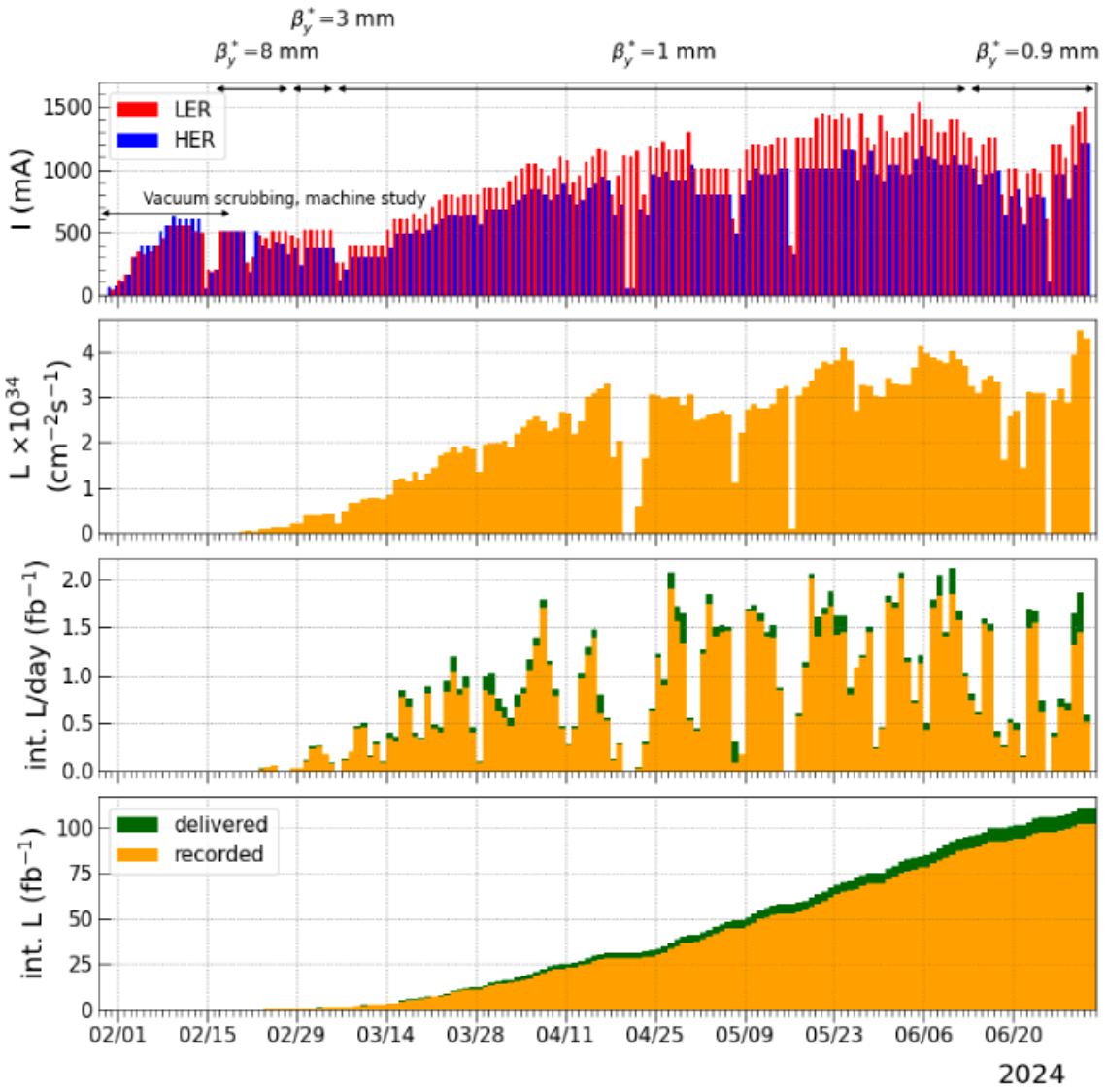
*CdS Roma Tre 04/07/2025*

A. Passeri

Outline:

- Quadro generale Belle II
- Gruppo RM3
- Attività RM3
- Richieste 2026

# **Run 2024ab** 29 jan-1 jul 2024 (155 days)




2022 performances reproduced:

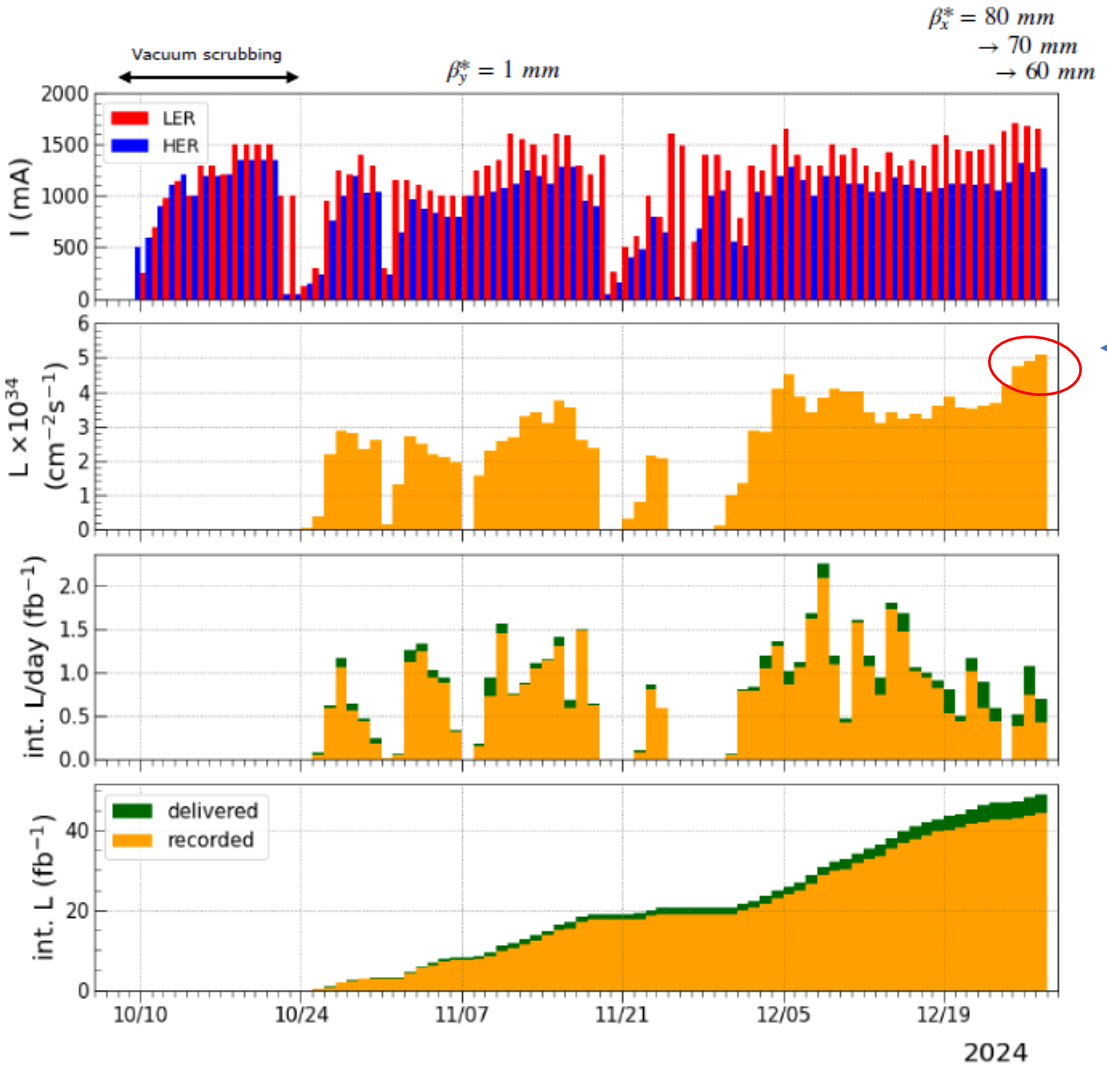
| | |
|---|---|
| $e^+$ and $e^-$ currents | 1.5 A and 1.21 A |
| $\beta_y^*$ | 0.9 mm |
| peak luminosity | 4.47 x 10$^{34}$ cm$^{-2}$s$^{-1}$ |

However:

- Frequent beam losses limited machine operation
- Sudden Beam Losses (SBL) happen with no precursor in less than 1 turn → dangerous for IR detectors (PXD kept off since april)
- Low injection efficiency

Priority given to machine studies: only 103 fb$^{-1}$ integrated for physics

# **Run 2024c** 9 Oct-27 Dec 2024 (80 days)




| | |
|---|---|
| $e^+$ and $e^-$ currents | 1.7 A and 1.3 A |
| $\beta_y^*$ | 1 mm |
| peak luminosity | **5.1 x $10^{34}$ cm$^{-1}$ s$^{-1}$** |

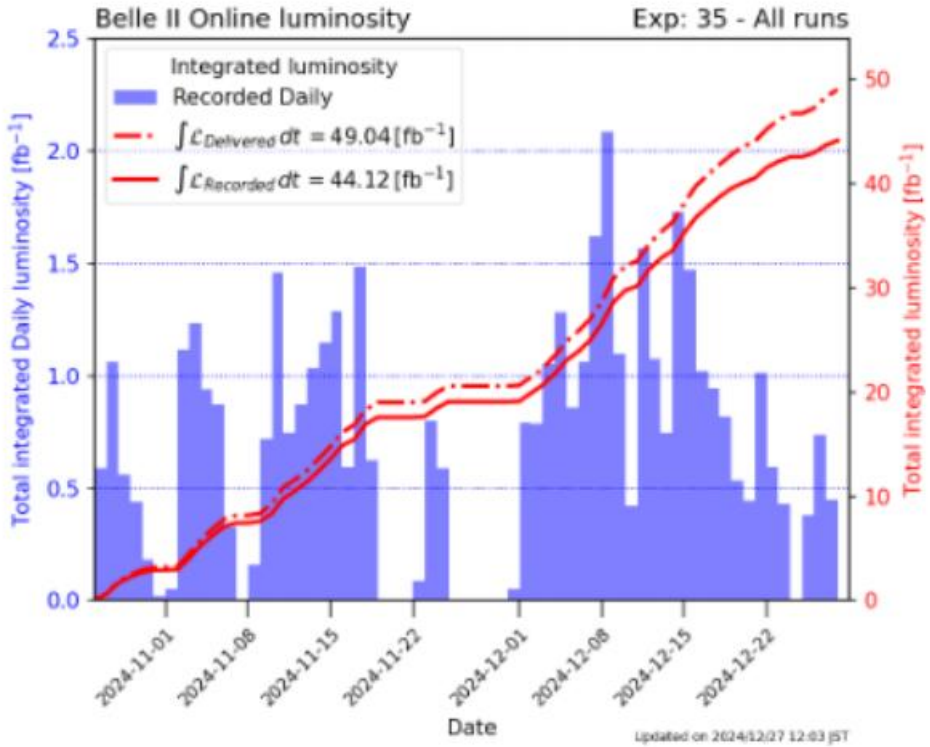
- Sudden Beam Losses not solved, but new clue detected
- PXD kept off for safety
- Discharging RF-gun to be replaced
- HER emittance increased significantly
- High radiation levels but improved background collimators and threshold tuning.

# Peak luminosity record on the last day of the run


| | Old record | New record |
|---|---|---|
| Date and time | 2022/06/22 | 2024/12/27 |
| Luminosity | $4.71 \times 10^{34}$ cm$^{-2}$s$^{-1}$ | $5.105 \times 10^{34}$ cm$^{-2}$s$^{-1}$ |
| Specific luminosity | $6.95 \times 10^{31}$ cm$^{-2}$s$^{-1}$mA$^{-2}$ | $5.83 \times 10^{31}$ cm$^{-2}$s$^{-1}$mA$^{-2}$ |
| LER current | 1460 mA | 1632 mA |
| HER current | 1145 mA | 1259 mA |

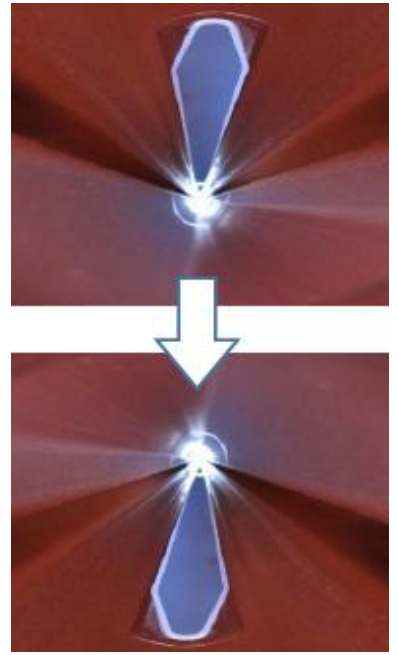
Priority always given to machine studies

Integrated luminosity 44.1 fb$^{-1}$



# Fighting *Sudden Beam Losses* (SBL)

i.e. losses which happen in 1 turn (10 μs) or less



- Dust from keramic electrodes in wiggler sections spotted as possible SBL source in 2024ab

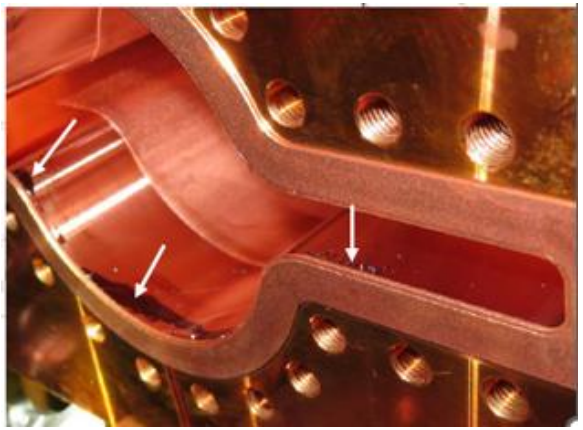
  15/50 beam pipes turned upside down during summer shutdown

  In 2024c frequency of SBL with *pressure burst* in the «flipped» area increased with beam currents….. Definitely was not the right solution.

- Black deposits and small dust particles found in the bellows of a region where many *pressure bursts* occurred.

  After careful cleaning and re-installation the frequency of SBLs from that location has decreaed dramatically.

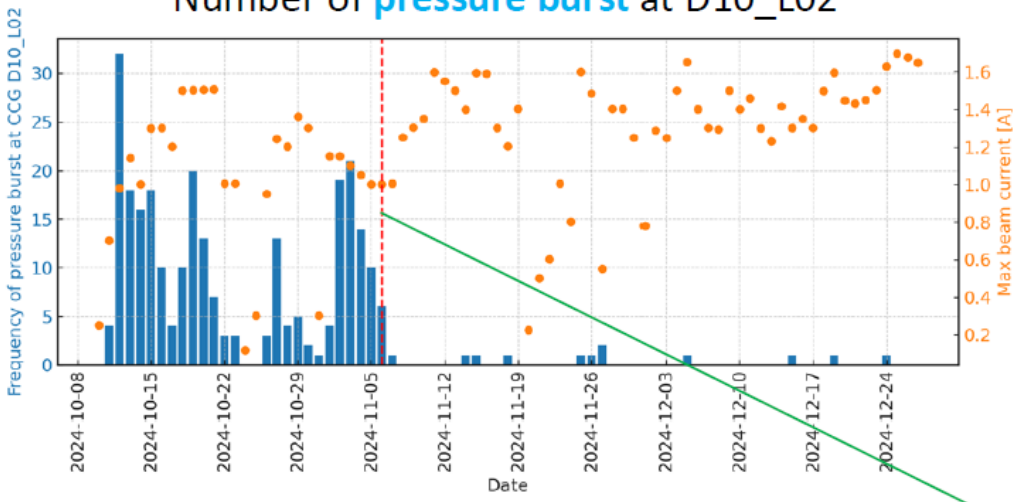
  Extensive internal inspection and cleaning is planned for the next stop.

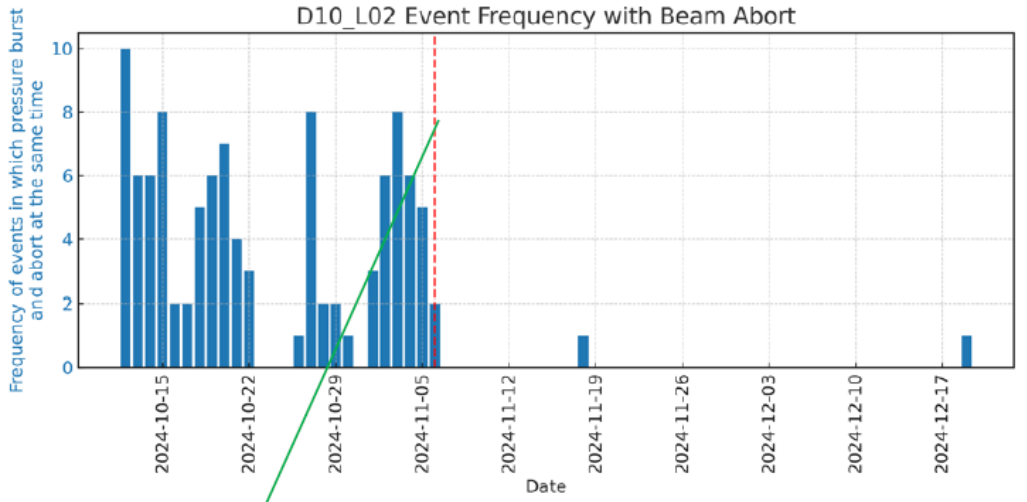
# Disappearance of beam abort events after VACSEAL removal during 2024c run

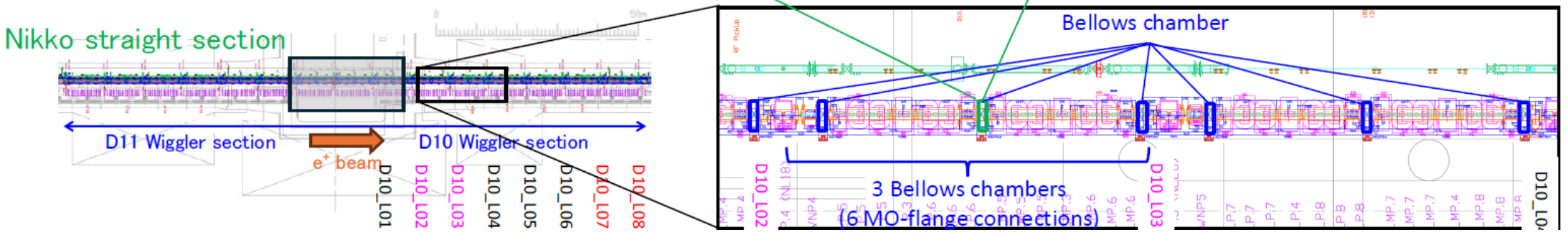
- A bellows chamber near CCG D10_L02 was replaced, and VACSEAL was removed from the adjacent beam pipes on Nov. 6 during the 2024c run, using the same cleaning method.
- After this work, the number of pressure bursts in the area has been significantly reduced.

Number of **pressure burst** at D10_L02




Number of **beam abort accompanied by pressure burst** at D10_L02



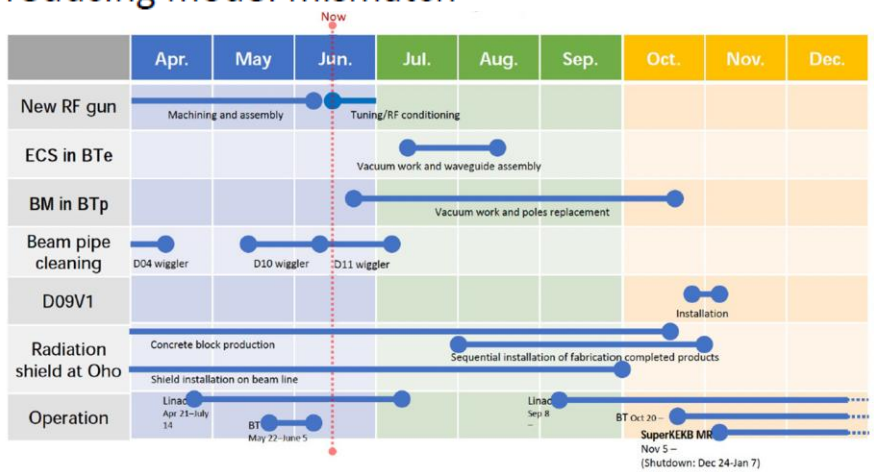

**Almost full VACSEAL removal during shutdown will definitely reduce beam aborts**

# Operational Plan for 2025c-2026b – Challenges and Countermeasures

Black: both
Blue: HER
Red: LER

- Increasing Beam Current
  - Installation of the updated RF gun
    - Enables stable two-bunch injection

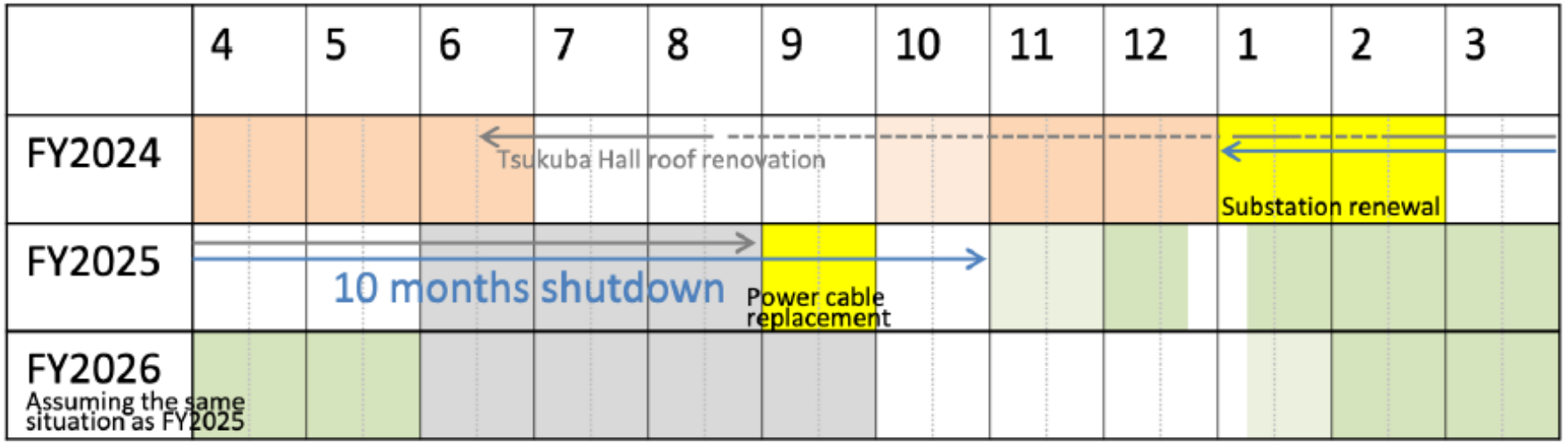
    (HER two-bunch injection had not been possible since a discharge in late Nov. 2024)
  - Installation of BT $e^-$ ECS
    - Reduces energy spread → improves injection efficiency
  - Radiation shielding at Oho
    - Open the D06V1 aperture and make more effective use of D05V1 → reduce the detector background and vertical impedance
  - Replacement of BT $e^+$ bending magnet poles
    - Suppress vertical emittance growth → improves injection efficiency
  - Investigation and realignment of the LER injection point beam pipes
    - Better alignment near the injection point may improve injection efficiency by reducing model mismatch
- Improving Accelerator Efficiency
  - Cleaning of beam pipes (VACSEAL removal)
  - Installation of the updated RF gun
    - Discharges in the cavity intermittently interrupted HER injection.
  - Relocation of the D06V2 to the D03V4 collimator
    - Protect D02V1 and detectors from SBLs.
- Enhancing Specific Luminosity
  - Suppression of horizontal beam size blow-up in LER
    - Lowering $\beta_x^*$ from 80 mm to 60 mm suppresses beam size growth at high-current
  - Measures against manufacturing error in leak-field cancellation coils (HER QCS)
    - May be degrading luminosity; countermeasures are under consideration
  - Unsolved large emittance in HER (cause under investigation)
  - Upgrading beam-beam simulations



# Updated SuperKEKB shedule

[ Baseline ]

Faint colors for the machine start-up time




- 7 months running starting nov. 2025 until may 2026, with only 2 weeks break for new year holydays
- 2 months running being considered for end 2026, subject to budget availability due to electricity cost.

# Run Plan for nov 2025- may 2026

## Scenario A:

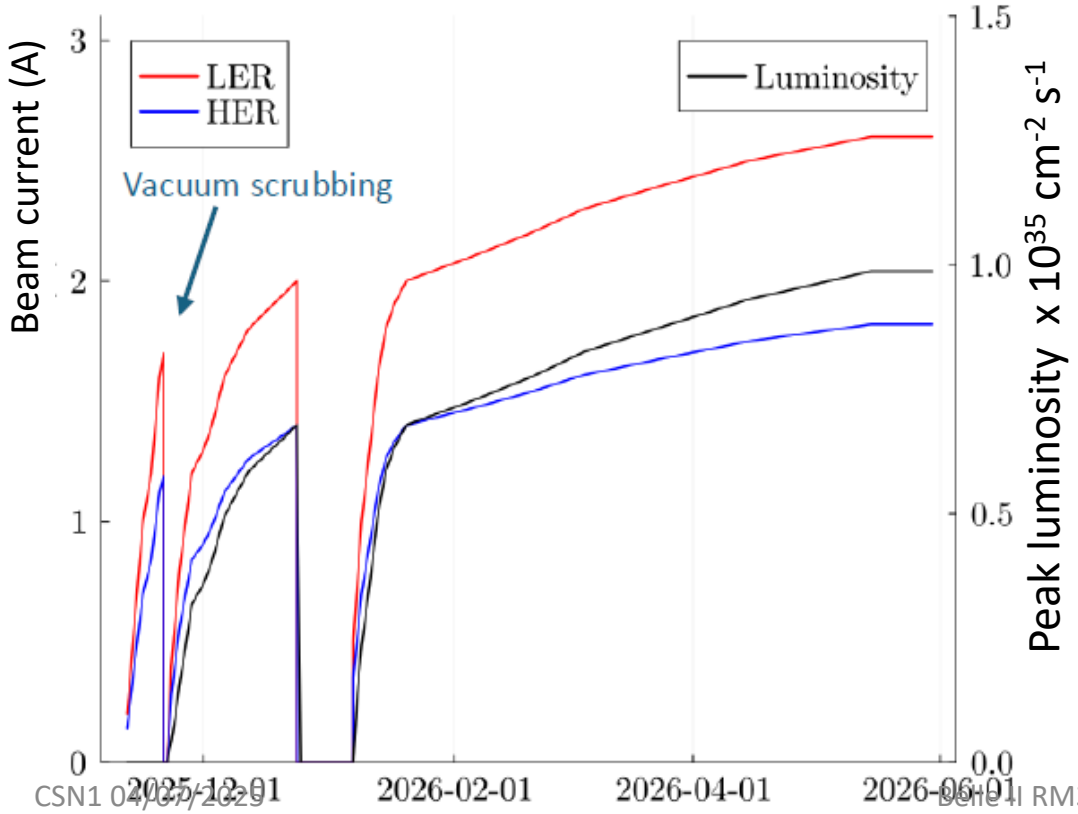
Beam currents can be increased above 2 (1.5) A for HER (LER), with $\beta_y^* = 1\ mm$

→ Peak luminosity can reach 1 x $10^{35}$ $cm^{-2}$ $s^{-1}$

Take physics run for 80% of the active run time

Assuming accelerator efficiency 60% (was 67% in 2024)

→ Collect ~550 $fb^{-1}$



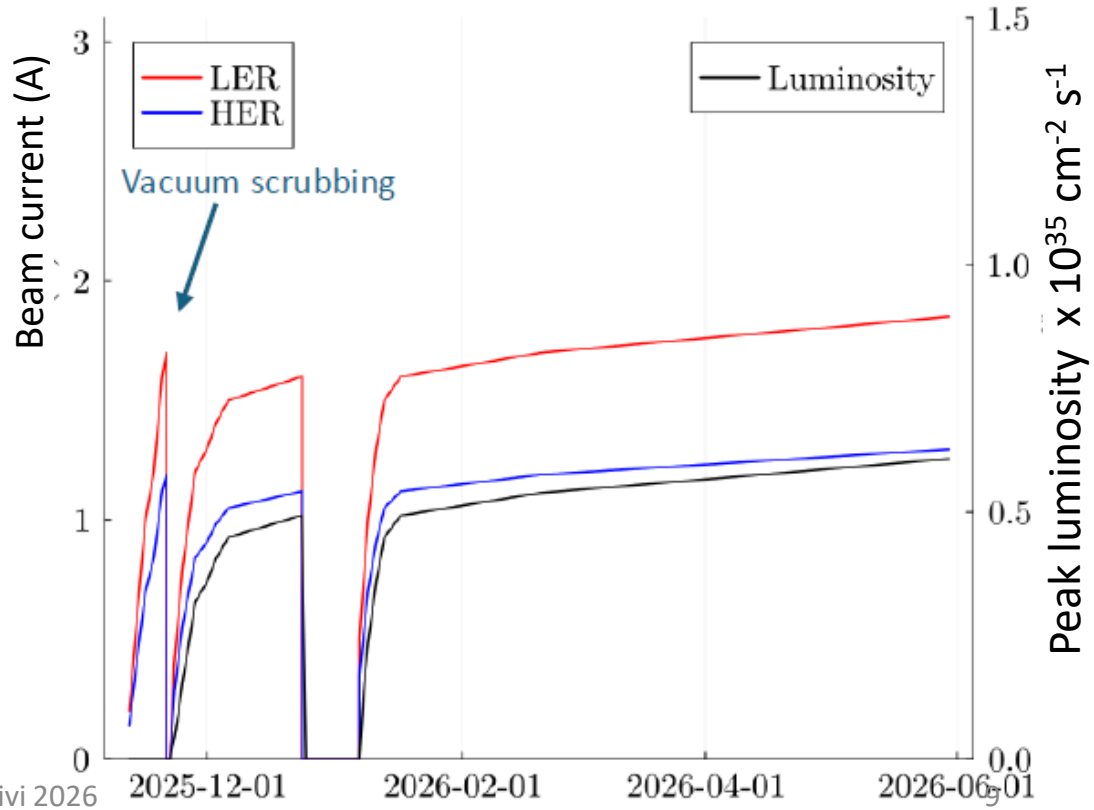

## Scenario B:

Beam currents cannot be increased much

→ Peak luminosity stays around 0.6 x $10^{35}$ $cm^{-2}$ $s^{-1}$

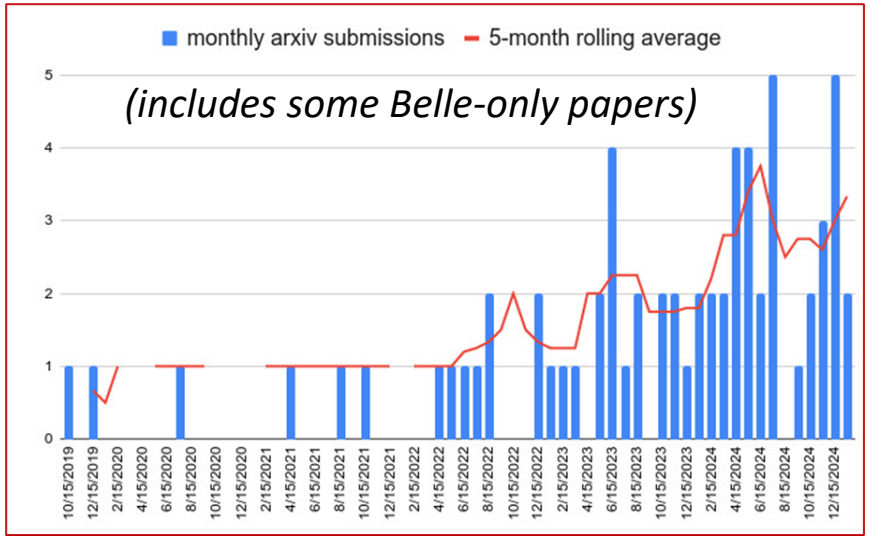
Take physics run for 80% of the active run time

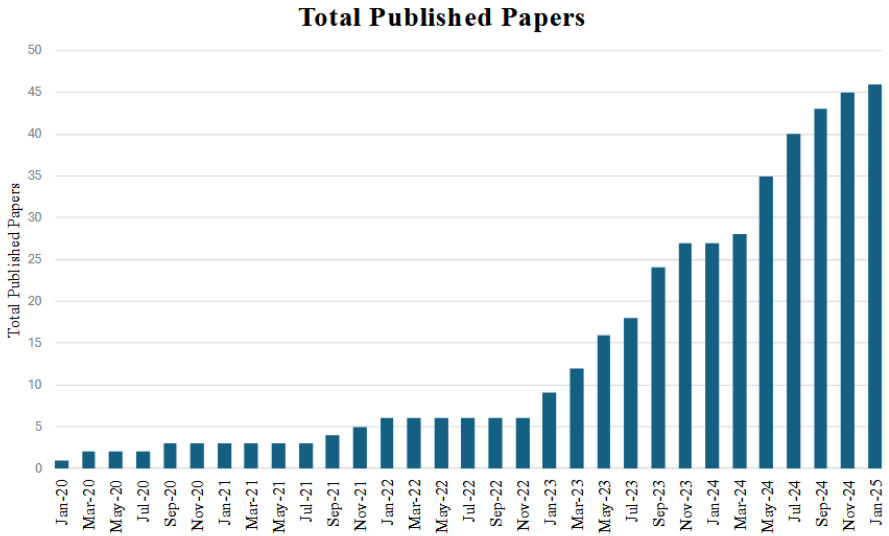
Assuming accelerator efficiency 85% (best reached in 2022) → Collect ~530 $fb^{-1}$



# Belle II Physics Analysis keeps competitive

- Journal papers statistics:
  - → **52 published papers + 3 accepted for publication**;
  - → + 9 more submitted;
  - → + ~20 more in the pipeline
- First results using 2024 data in Summer 2025.




Few highlights in the following slides, with an eye to results more «Belle2-specific» and/or with important italian contriution (avoiding to repeat those already shown to CSN1).

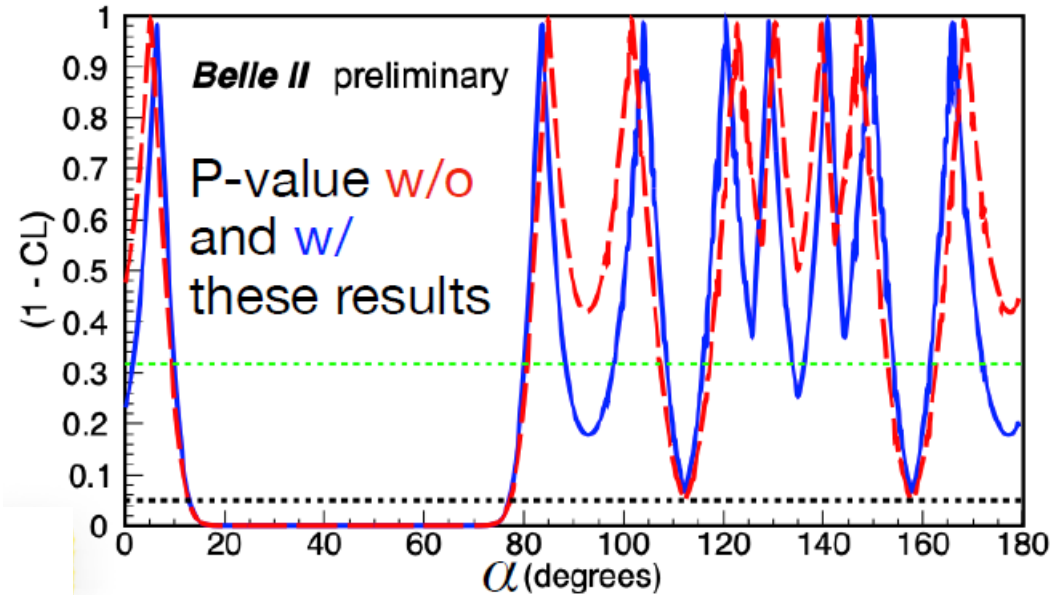
*Note: Belle2 is producing results in all the branches of its physics program, but not all of them are represented here (some more in the backup slides).*

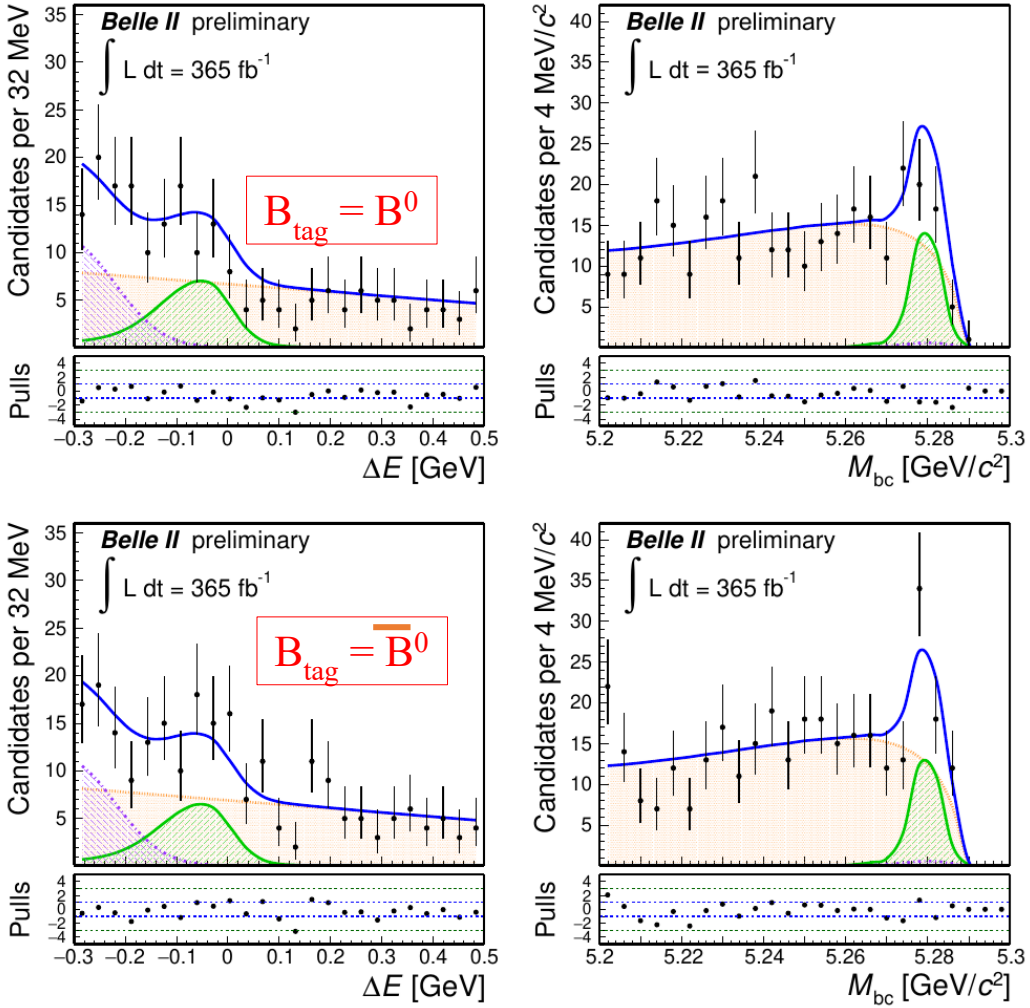
# $B^0 \to \pi^0\pi^0$

Arxiv:2412.14260 accepted by PRD

- Four-photon final state, no vertex: only at Belle II!
- Branching ratio and direct ACP are fundamental inputs for $\alpha/\phi_2$;
- Continuum suppressed with dedicated BDT. Tag the flavour to measure the CP asymmetry. Extract signal from a 4D fit

$$\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.26 \pm 0.20 \pm 0.11) \times 10^{-6}$$
$$\mathcal{A}_{CP}(B^0 \to \pi^0\pi^0) = 0.03 \pm 0.30 \pm 0.05$$




Best precision on BR and same accuracy as WA on the CP asymmetry!

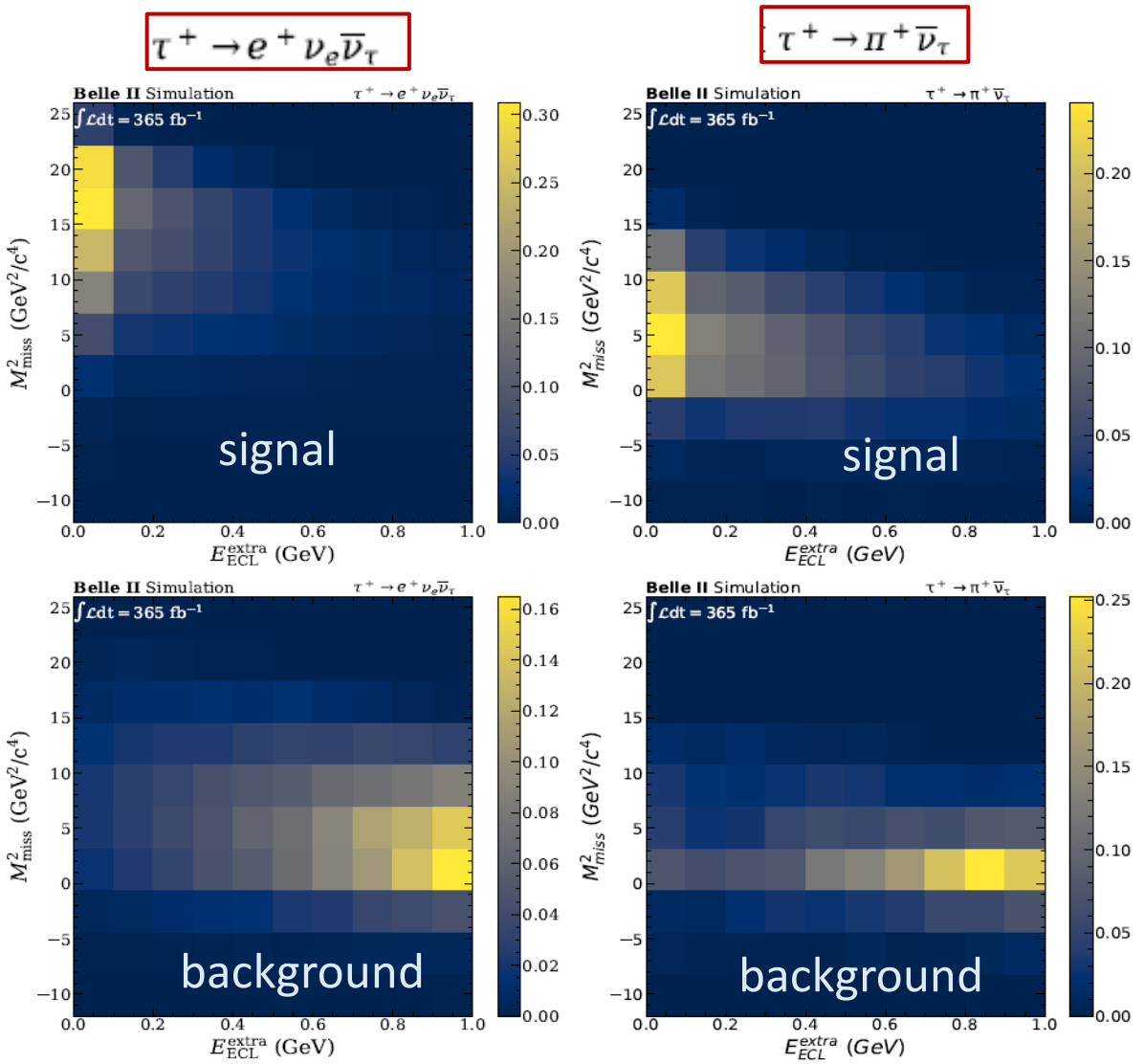
# Evidence of B → τ ν

Arxiv: 2502.04885

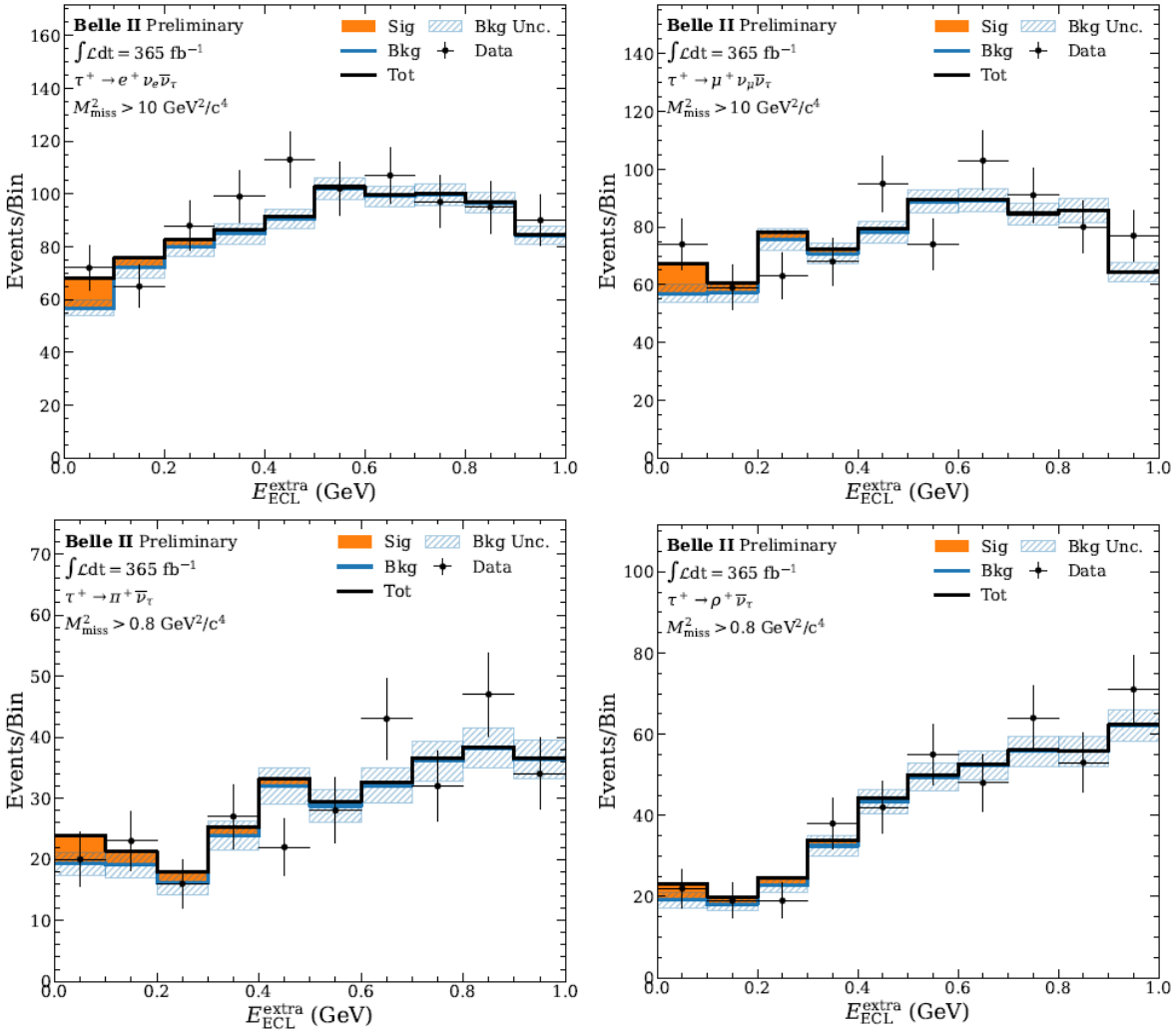
Ideal process to measure $V_{ub}$, but helicity suppressed.
Sensitive to BSM contributions.

- Hadronic tagging
- τ decay reconstruction in leptons, π, ρ
- Large missing energy
- Nothing else: no residual energy in calorimeter

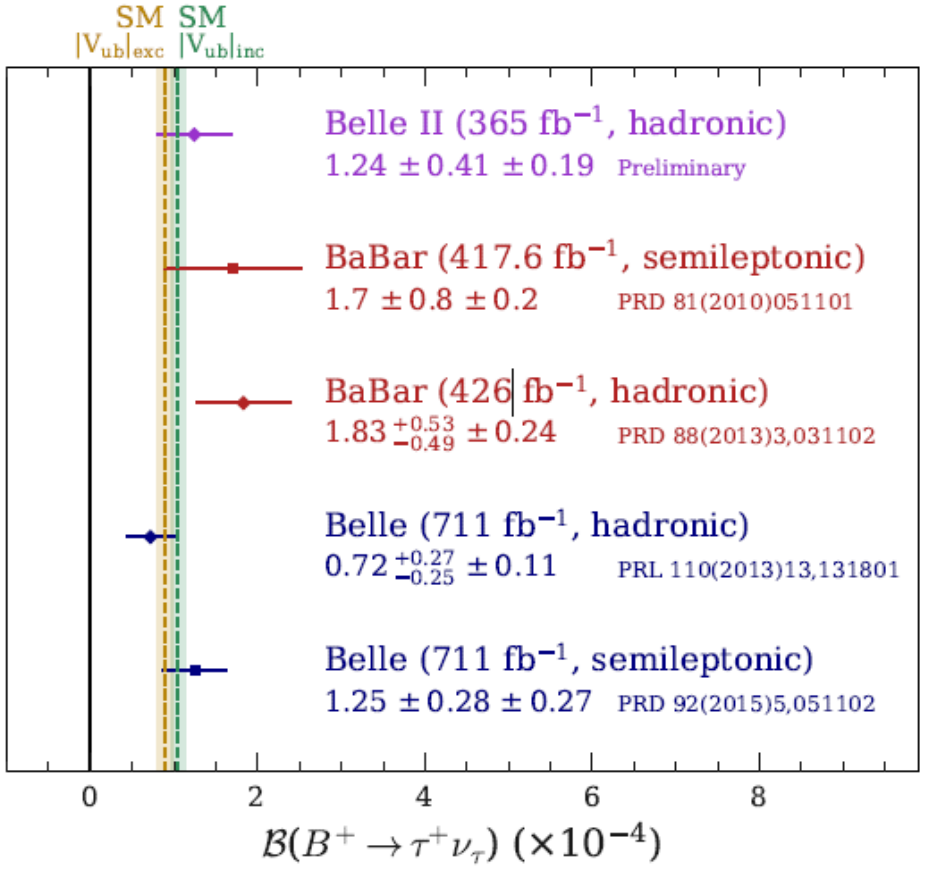
Signal extracted by a fit to the 2-dim distribution of $E_{extra}$ and $M^2_{miss}$



# Evidence of B → τ ν

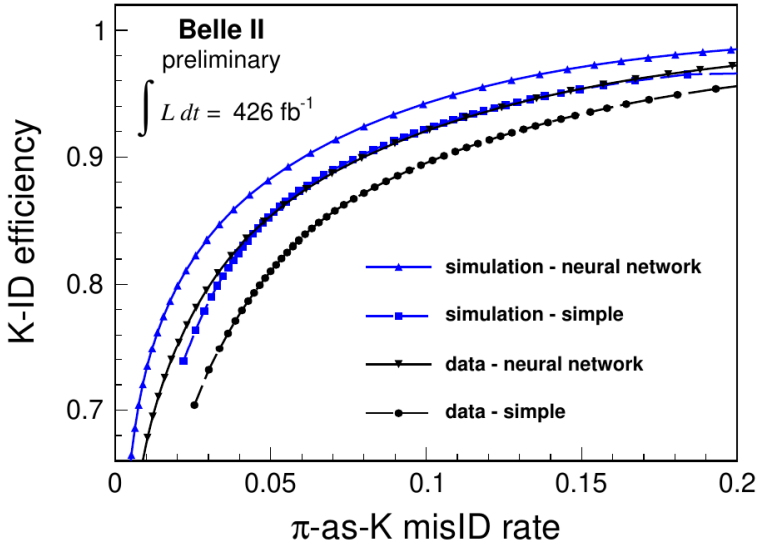


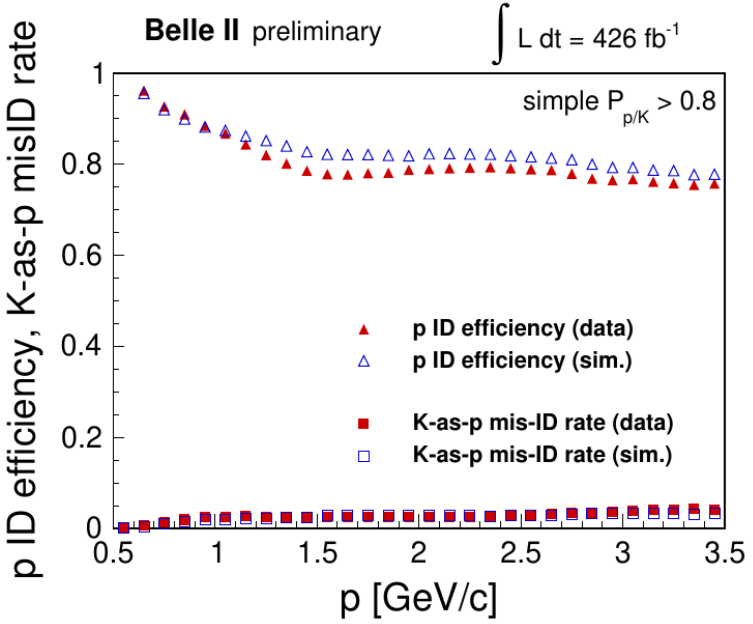

Fit 94 ± 31 events: result in agreement with SM and previous measurements



# Hadron ID (π, K, p) performance paper (CNS1 milestone 2025)

- Motivations: describe hadron ID at Belle II, with particular reference to what we achieved during Run1 data taking (2019-2022);
- We describe:
  - → the sources of PID information and how they are combined into variables made available to analysts;
  - → the software tools and data samples used to measure efficiencies and misID rates;
  - → how corrections and (systematic) uncertainties are derived;
- We show the performance in terms of K vs π and K vs p separation;
- We critically discuss problems encountered, mitigation strategies, and future developments;
- Submitted to EPJC;
- https://arxiv.org/abs/2506.04355



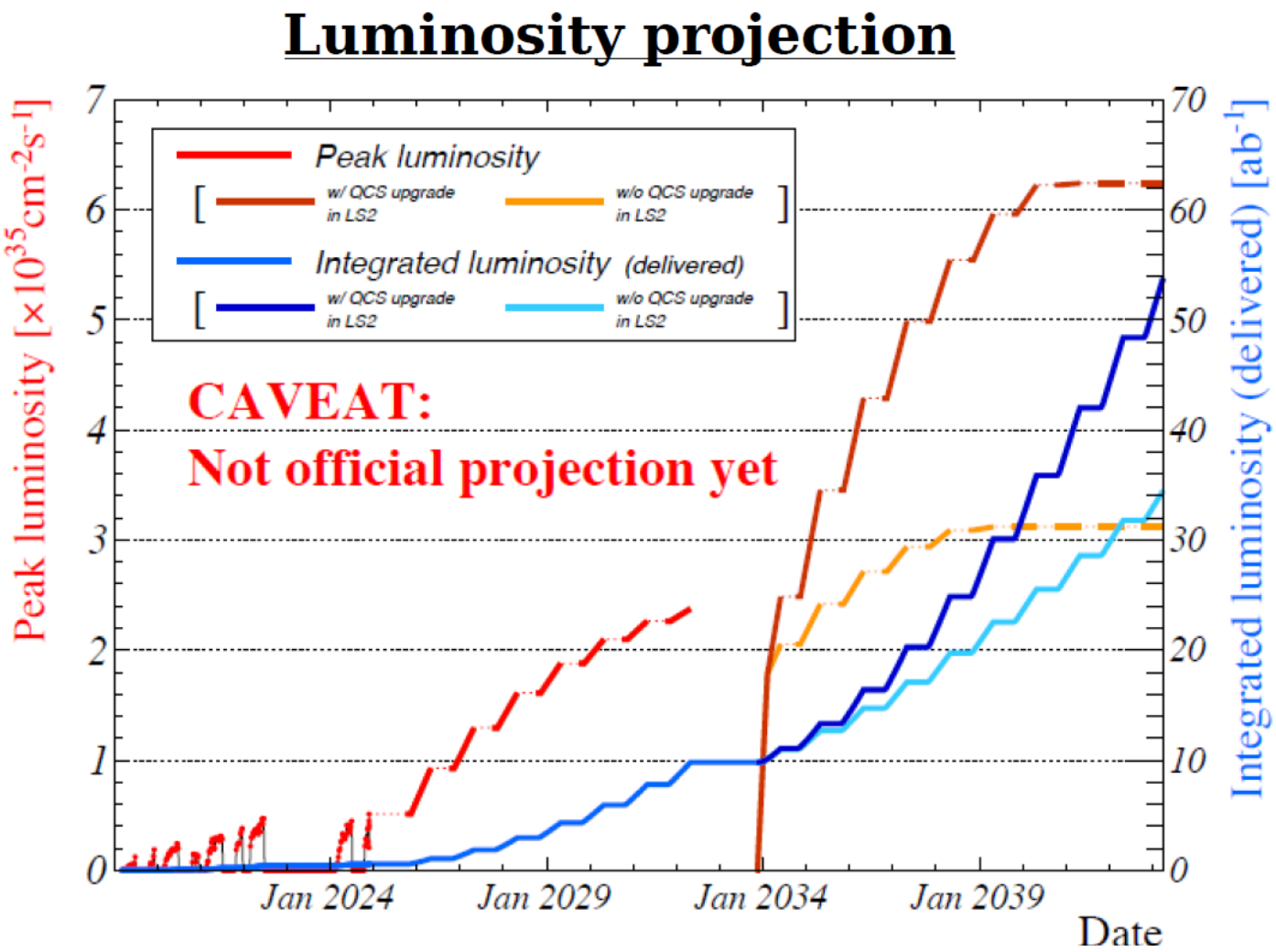



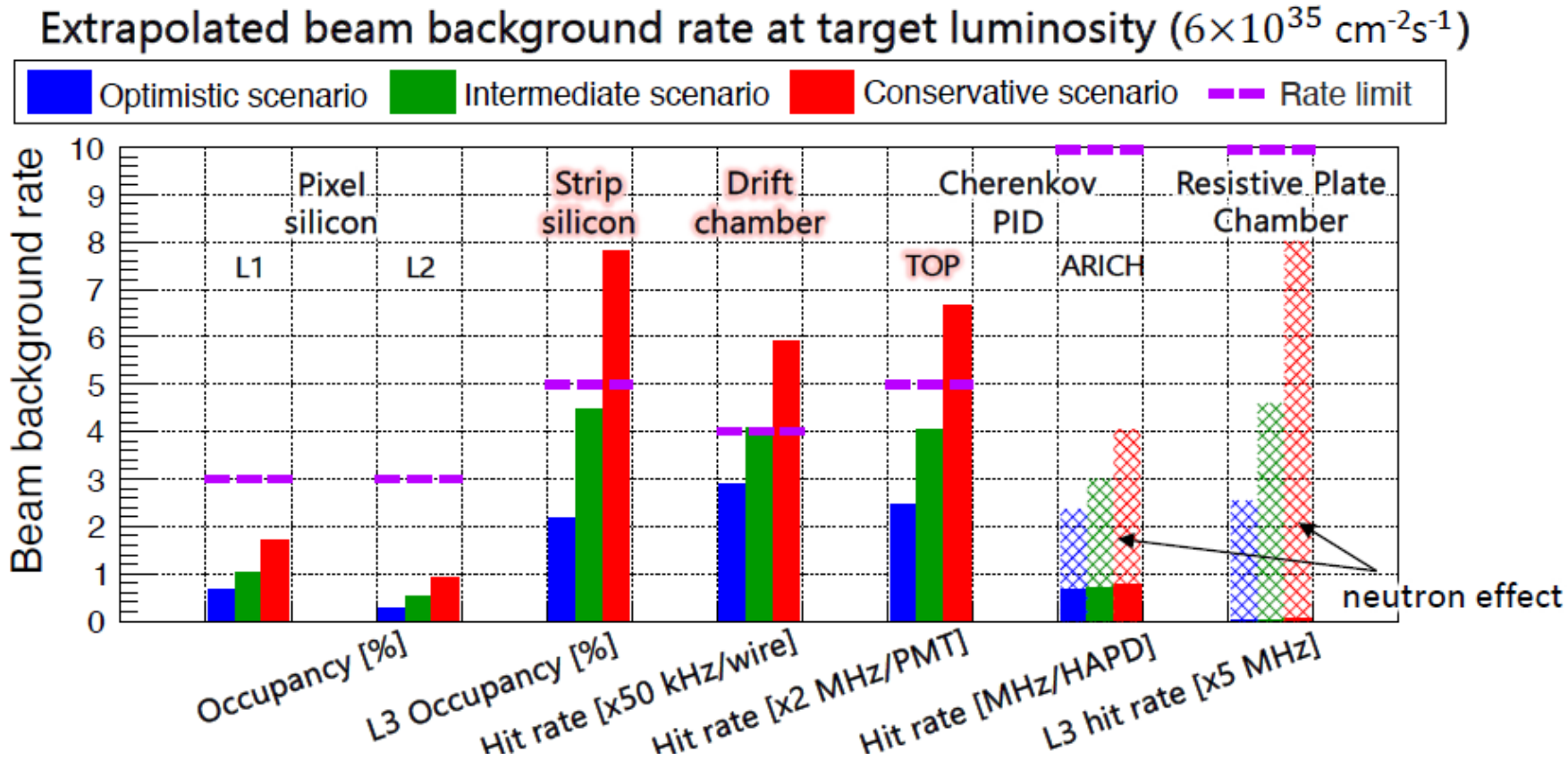
# Longer term plans

- Reach asap $L_{peak} = 10^{35}$ cm$^{-2}$ s$^{-1}$ and go up to $2x10^{35}$ running until ~ 2032 to integrate *o*(10 ab$^{-1}$)

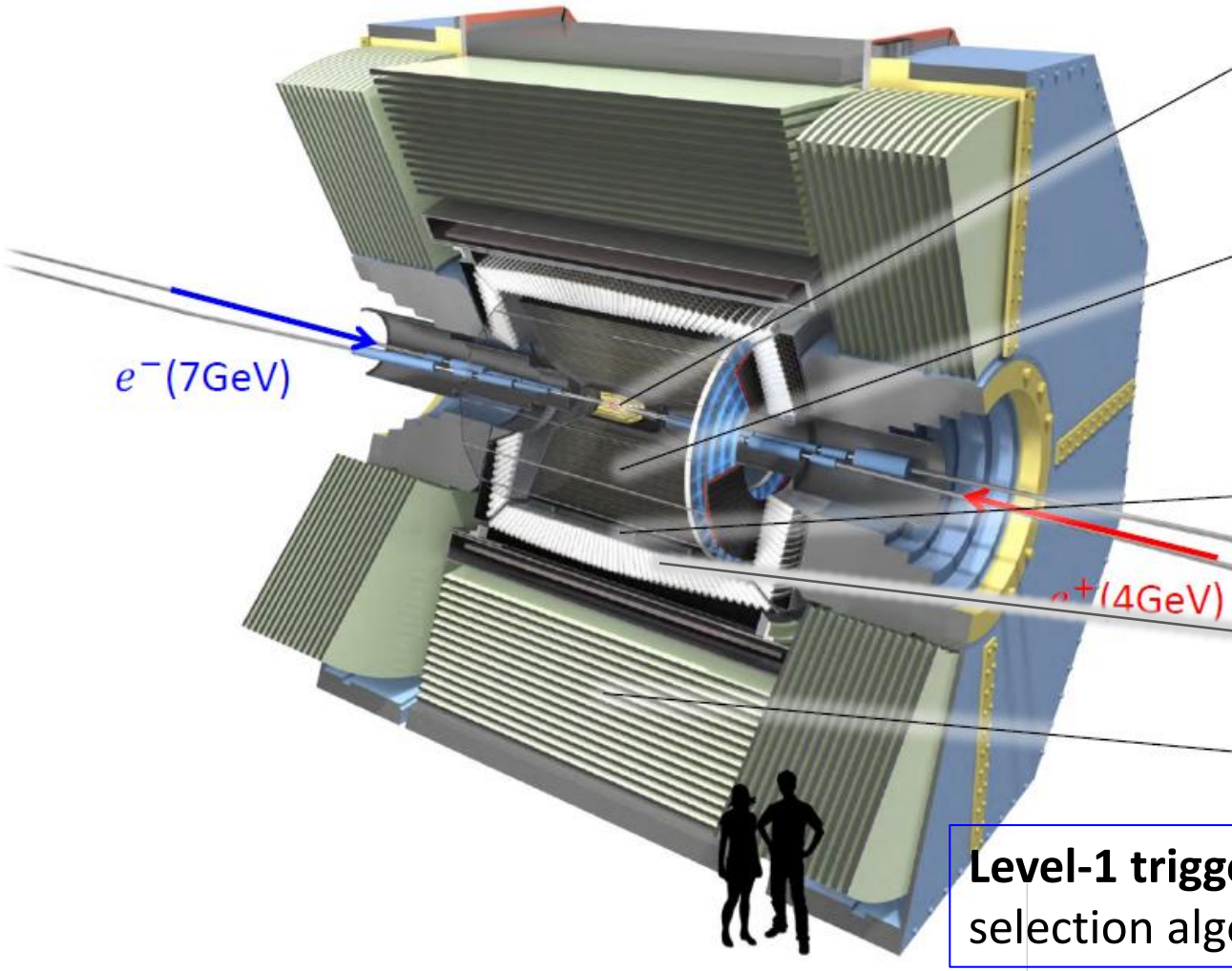
- during a second long shutdown (LS2) upgrade detector and accelerator. IR upgrade being considered with superconductive final focus, which would allow to reach even higher liuminosities.

- Restart in ~ 2034 and run 10 years at top luminosity to integrate about 30 (50 if IR upgrade) ab$^{-1}$




Extrapolated beam background rate at target luminosity ($6\times10^{35}$ cm$^{-2}$s$^{-1}$)
Optimistic scenario
Intermediate scenario
Conservative scenario
Rate limit
Beam background rate
0
1
2
3
4
5
6
7
8
9
10
Pixel silicon
L1
L2
Strip silicon
Drift chamber
Cherenkov PID
TOP
ARICH
Resistive Plate Chamber
neutron effect
Occupancy [%]
L3 Occupancy [%]
Hit rate [x50 kHz/wire]
Hit rate [x2 MHz/PMT]
Hit rate [MHz/HAPD]
L3 hit rate [x5 MHz]

# LS2 upgrades under consideration




**Vertex detector**: fully pixelated CMOS-DMAPS detector

**Drift chamber (CDC):** new FE electronics (radhard, less power, less Xtalk)
Possibly new chamber (pixel + gas)

**Barrel PID:** Replace PMTs with life extended ones
New FE electronics (less power)
Possibly use SiPMs

**Electromagnetic calorimeter (ECL)**
New FE electronics. Possibly use SiPMs

**KL and μ detector (RPCs + scintillators)**
Operate RPCs in avalanche mode (new gas and FE)

**Level-1 trigger:** New electronics to allow ML selection algorithms and increase bandwidth

# Gruppo Belle2-RM3 2026 (da verificare)

| cognome | nome | note | contratto | profilo | perc |
|---|---|---|---|---|---|
| Branchini | Paolo | | Dipendente | Dirigente di Ricerca | 100% |
| Budano | Antonio | FTE 0.25 PNRR ROMETECH sinergica. CC3M Belle II VR/Masterclass Belle II/Eventi locali | Dipendente | Primo Tecnologo | 25% |
| Bussino | Severino | | Associato | Incarico di Ricerca scientifica | 50% |
| Carcione | Rocco | | Associato | Dipendente ENEA | 25% |
| Cemmi | Alessia | | Associato | Dipendente ENEA | 25% |
| Ciuchini | Marco | | Dipendente | Dirigente di Ricerca | 20% |
| De Angelis | Ilaria | CC3M Belle II VR/Masterclass/Eventi locali | Associato | Incarico di Ricerca tecnologica | 20% |
| Di Sarcina | Ilaria | | Associato | Dipendente ENEA | 25% |
| Graziani | Enrico | CC3M Masterclass Belle II | Dipendente | Primo Ricercatore | 100% |
| Iorio | Giulia | | Dipendente | Assegno di Ricerca | 100% |
| Passeri | Antonio | CC33M Masterclass Belle II + FTE 0.20 JENNIFER3 sinergica | Dipendente | Primo Ricercatore | 50% |
| Salutari | Laura | Dottoranda XXXVIII ciclo | Associato | Scientifica Dottorandi | 100% |
| Scifo | Jessica | | Associato | Dipendente ENEA | 25% |
| Tagnani | Diego | | Dipendente | Tecnologo | 40% |
| Thaller | Arthur | | Dipendente | Assegno di Ricerca | 100% |
| Tortora | Luca | | Associato | Incarico di Ricerca tecnologica | 30% |
| Verna | Adriano | | Associato | Dipendente ENEA | 25% |
| Vincenzi | Dario | | Associato | Scientifica Dottorandi | 100% |
| Zani | Laura | | Dipendente | Ricercatore | 100% |
| | | | | **TOT FTE** | **10,6** |

# Attività Belle2-RM3 2026

Detector:

- Responsabilità generale SVD (L.Zani system coordinator). Operation, monitor, maintenance (A.Thaller, L.Zani)
- Manutenzione front end RPC del KLM (Branchini, Tagnani). R&D upgrade RPC in regime porporzionale (Breanchini, Passeri, Tagnani). A.Passeri KLM upgrade coordinator.

Performance:

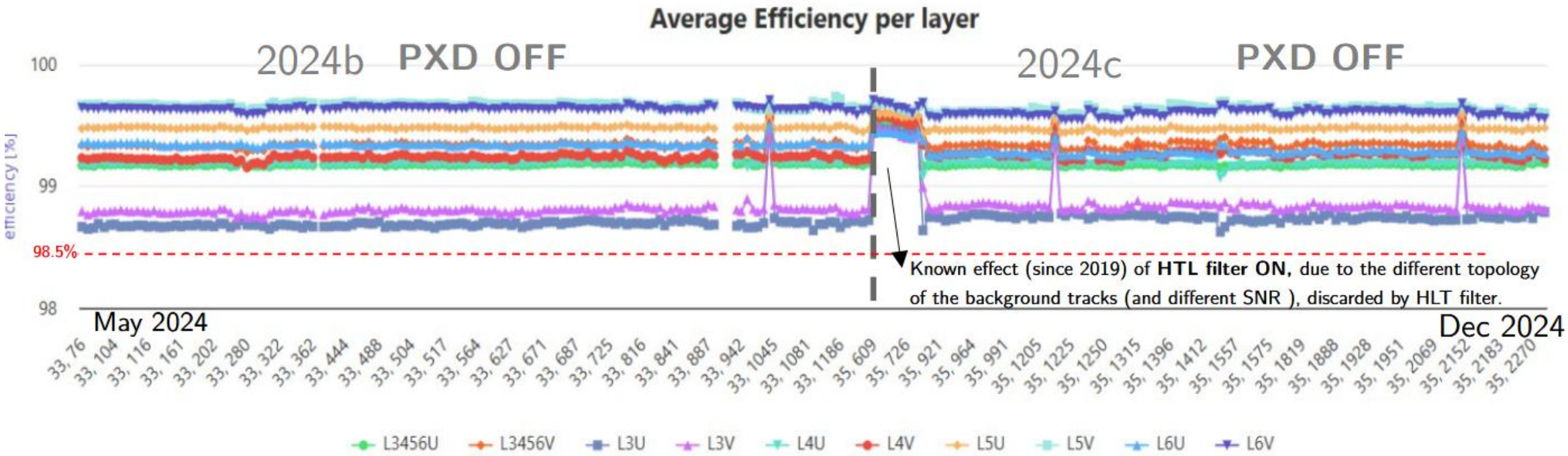
- Contributo SVD al tracking (Thaller, Zani)
- Ricostruzione mesoni $K_L$ (Passeri, col gruppo di LNF)

Analisi:

- L.Zani convenor gruppo analisi fisica del $\tau$. Partenza nuova analisi con A.Thaller misura $V_{us}$ nel decadimento $\tau \rightarrow K \nu$
- Ricerca dark photon prodotto insieme a dark higgs (dark higgsstrahlung): tesi di L.Salutari, supervisor E.Graziani
- Misura violazione CD dipendente dal tempo in $B \rightarrow \eta' K_L$ (tesi S.Cuccuini, associato a LNF, cosupervisor Passeri)

# SVD operation in 2024c

- SVD was stable during 2024c, also in high background conditions: **overall occupancy under control and excellent hit efficiency**
- Some DAQ and HV issues experienced (contribute to 7.2% run stops)
  - more frequent APV25 readout chip misconfiguration related to **Single Event Upset (SEU)**



# Improve SVD DAQ efficiency in 2025

- APV25 misconfiguration from radiation effect happened in the past in coincidence with high dose beam abort
- **111 occurrences in 2024c, ~ 3x 2024ab,** due to worse injection background conditions (also related to the largely relaxed diamond threshold during the injection)
- Recovery: by stopping the run and restarting (reconfiguration of chips) directly by CR shifter

**Automatic recovery of APV25 after SEU**

- Implement the recovery of the APV25 chip by **reconfiguring without fully stopping the run**
  - Requires firmware, online and offline software modifications → standalone tests with spare completed in April, more details here
- VXD campaign for SVD functional **tests with PXD + IBBelle cooling on completed (June 2-11)**
  - Report in the eLog, preliminary results are **promising and the auto-recovery feature has confirmed to work reliably!**
  - **Reduction of recovery time from ~few second to 20 ms**
  - **Offline analysis planned** to test the full DQM diagnostic tools before deploying for data taking with release/09

**Many thanks to all SVD experts, sub-detectors experts, the cryogenic group and all the people involved in operation!**

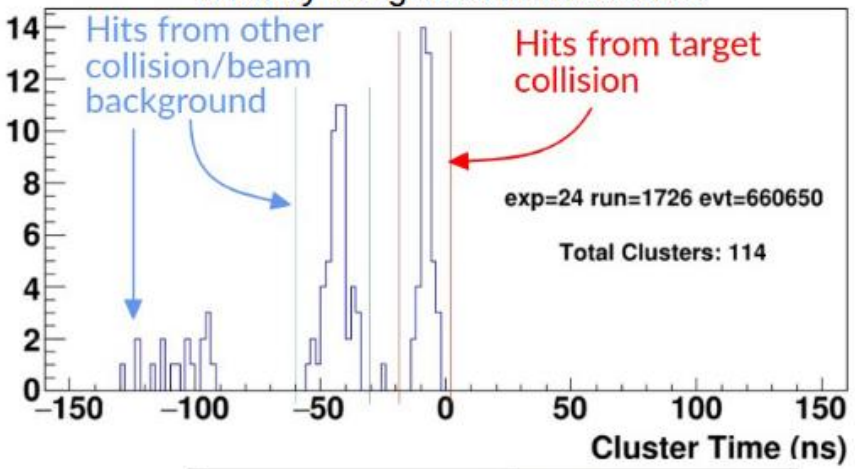
→ next (final) commissioning campaign foreseen for October 2025

# SVD background rejection

Test in 2025 data

- Crucial to reduce occupancy in higher background scenario for good tracking performance: exploit excellent **SVD time resolution (< 3 ns)** in several type of selections
- More refined selections based on **cluster grouping** (= event-by-event time-based cluster classification) and **track time** (=average clusters-on-track time ) may allow the **SVD limit to be ~6% at L ~ 6 x $10^{35}$ /cm²s**

Introduced in release/08 by S. Mondal
already integrated in release/09



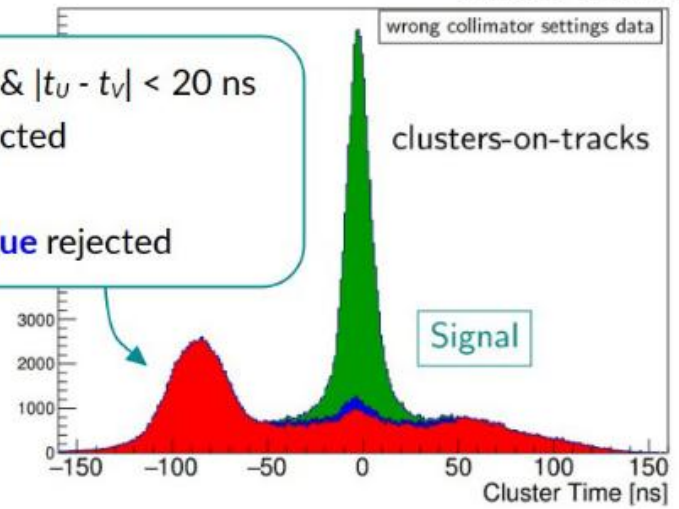

**Track time**

$$t_{\text{track}} = \frac{1}{N_{\text{cls}}} \sum_{i=1}^{N_{\text{cls}}} t_i^{\text{cls}} - t_0^{\text{SVD}}$$

**SVD EventT0**

$$t_0^{\text{SVD}} = \frac{1}{N_{\text{cls}}} \sum_{i=1}^{N_{\text{cls}}} t_i^{\text{cls}}$$

- $|t| < 50$ ns & $|t_U - t_V| < 20$ ns
  → **red** rejected
- Grouping
  → **red** + **blue** rejected

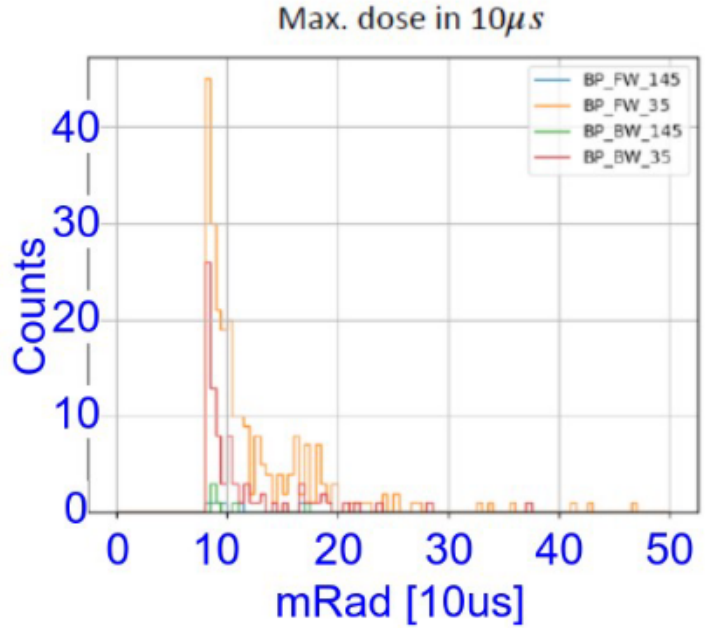


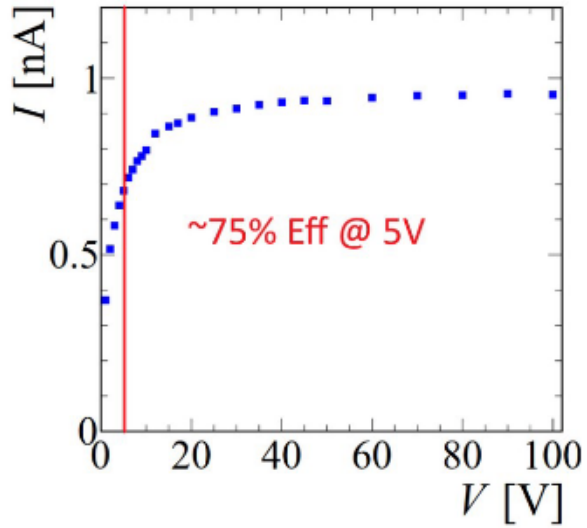

- Background extrapolation **at L ~ 6 x $10^{35}$ /cm²s** gives L3 occupancy between **4.7% -9%** (intermediate - conservative scenarios)
- Still room for improvement in optimal use of SVD timing information

# Diamond system: new abort thresholds

- **New DCU (Diamond Control Unit) firmware deployed in 2024c** with a relaxed ("**high**") beam abort thresholds during injection and stricter ("**low**") thresholds outside injection. Values derived from a quantitative analysis of diamond post-abort data recorded at end of 2024b run
  - "high thresholds": 50/40/12/12 [mrad integrated in 10 μs] for the aborting diamonds on the beam pipe BP_FW_35/BP_BW_35/BP_FW_145/BP_BW_145; "low thresholds" outside injection 8/8/8/8 [mrad integrated in 10 μs]
- 400 $\mu$**s** window when most abort systems are disabled; PXD OFF for 2024c; SVD proved to be robust at this background level → **safe and optimal for data taking**

  → Significant reduction > 57 % in injection-related diamond aborts despite worse injection conditions. Keep **same thresholds also for 2025c**




- As mitigation of DCU preamplifiers damage (experienced in 2024b), diamond HV was reduced from 100V to 5V for QCS and BP monitoring diamonds → **No damage to preamplifiers in 2024c**

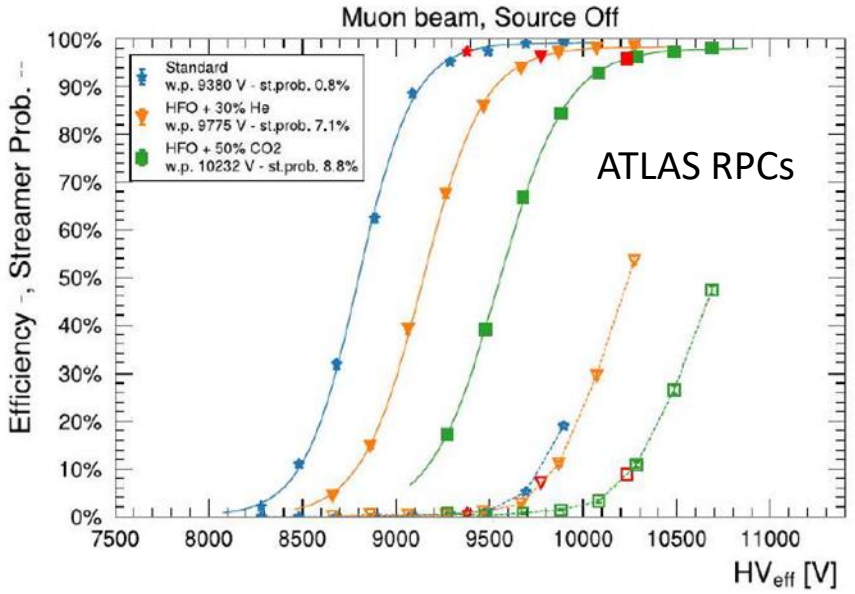
  → additionally, purchase of a second spare DCU is planned for 2025c
- Purchase and installation of **picoscope as online background monitor**: possibility to check the injection background on both aborting and monitoring diamonds (also timing and width)

Roma Tre, Frascati, KEK, Iowa

# R&D on RPC operation in avalanche mode

Need to study:

- Gas mixture: need eco-friendly quencher
- FEE: lower gain requires amplification




Test stands being setup at:

KEK

- Use single gap prototype RPCs.
- Record waveforms contiously. Monitors gas flow and $H_2O$ levels.
- Compares diferent prototypes, and gas mixtures.

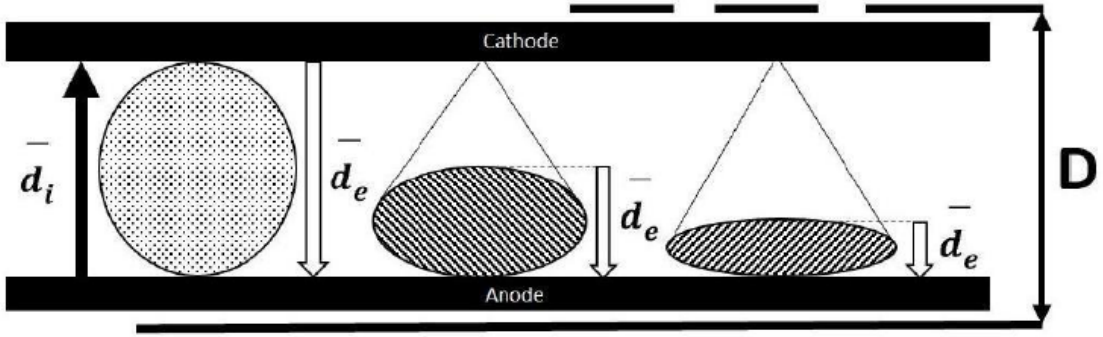
INFN Frascati - Roma Tre

- Use single gap prototype from KEK.
- Record waveforms and will study different mixtures, HV
- Will test a signal amplifier prototype
- **Have built full double gap RPC prototype.**

Iowa S.U.

- Setup in progress
- Plan also to build test RPC prototypes

# Streamer vs Avalanche

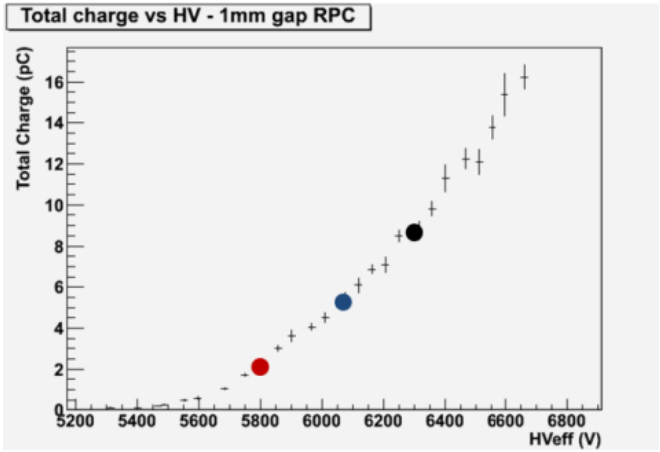



Streamer

Highly saturated avalanche

Low saturated avalanche

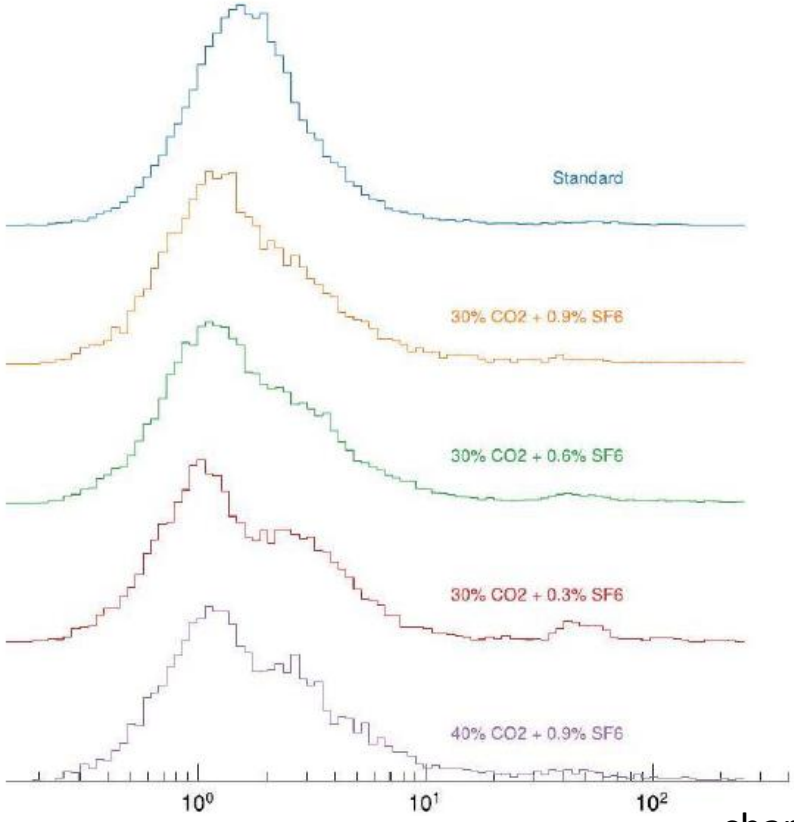
*Credits to R.Cardarelli, 2018*




- **Streamer working mode**: characterized by a high electric field causing ion-electron pairs to recombine and emit photons, generating avalanches with significant charge (0.1 - 1 nC) across the gas gap, resulting in a gas gain between 6 × 10^7 and 6 × 10^8 .
- Improved electronics revealed the **avalanche discharge process** and adding electronegative SF6 separated it from the streamer process, reducing the gas electric field. In avalanche mode, the discharge grows exponentially until the space charge effect, stabilizing the total charge and suppressing photon production, with discharge in the electron drift direction.
- This regime has two intervals based on electric field: high **saturated avalanche** (total charge 20 - 40 pC) and **low saturated avalanche** (total charge 1 - 5 pC).
- Compared to the streamer mode, the gas gain drops by over two orders of magnitude, necessitating recovery in the electronics front end.

# Gas Mixtures

- KLM gas mixture of 30 % argon, 62 % C2 H2 F4, and 8 % butane-silver (iso-/n- ~25 / 75)
- ALICE RPCs gas mixture of 89.7 % C2 H2 F4,  10 % i-C4 H10 and 0.3 % SF6.
- CMS/ATLAS standard gas mixture (STD) (95.2 % C2 H2  F4, 4.5 % i-C4 H10. and .0.3 % SF6)



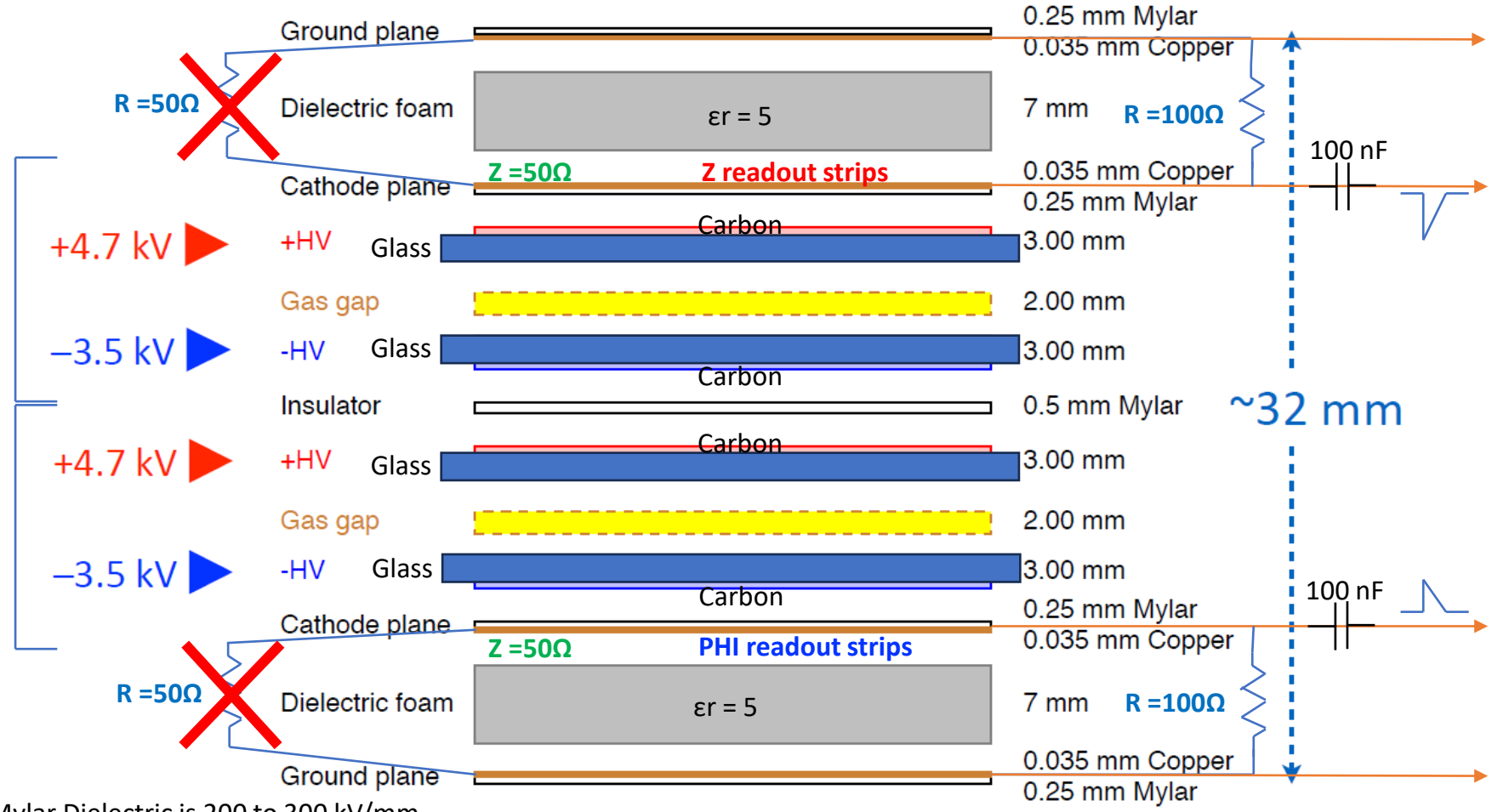

R&D is needed to dermine the best compromise between quenching and signal charge.

Use of eco-gas: SF6 has 23500 GWP (global warming potential) while C2H2F4 has 1300 GWP. Replacing 62% of C2H2F4 with 2% SF6 still advantageos.

Gas recirculation system should be also be implemented

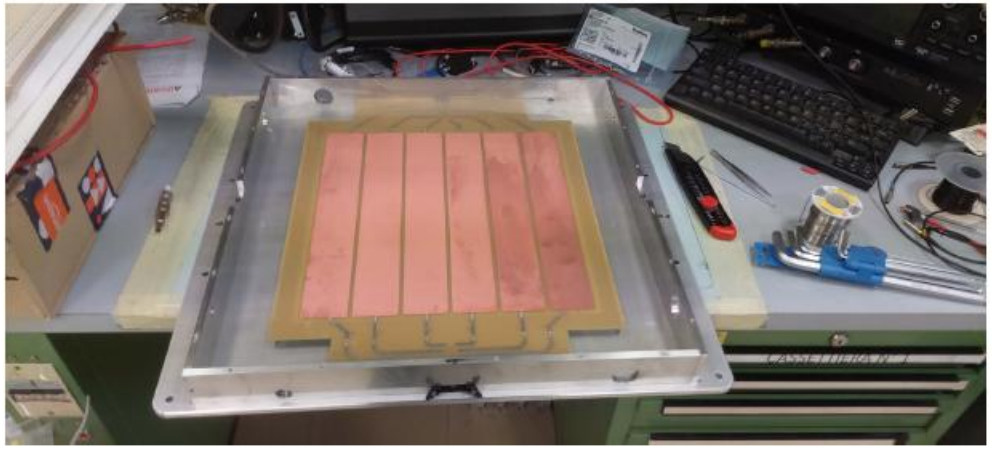
# Full RPC structure

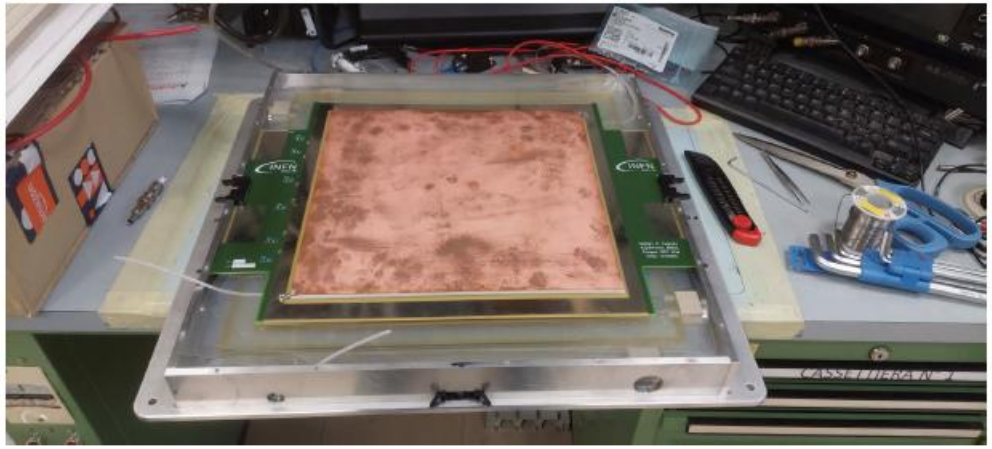
A double gap prototype, Width = 42,5 mm; $\varepsilon_r = 5$; Pitch = 46,5 mm is being built at Roma Tre

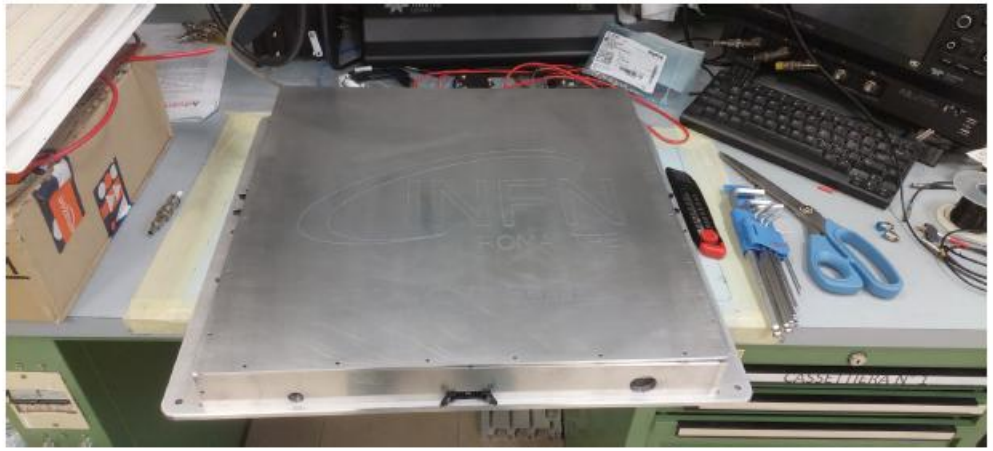


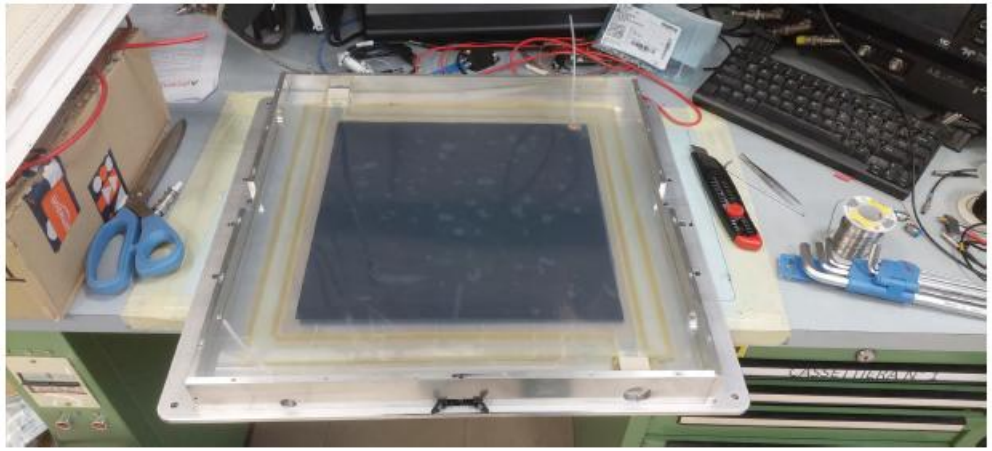

Mylar Dielectric is 200 to 300 kV/mm

# RPC prototype construction @Roma Tre

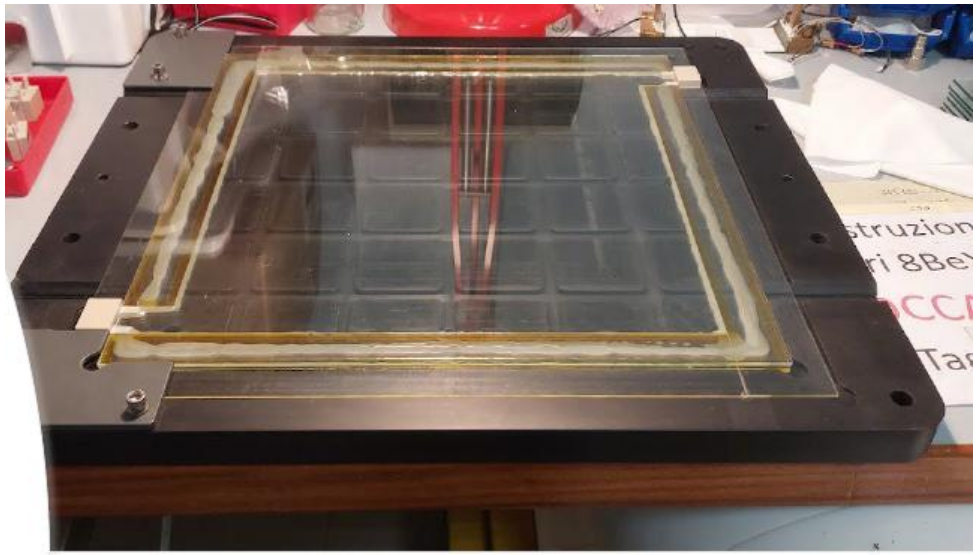


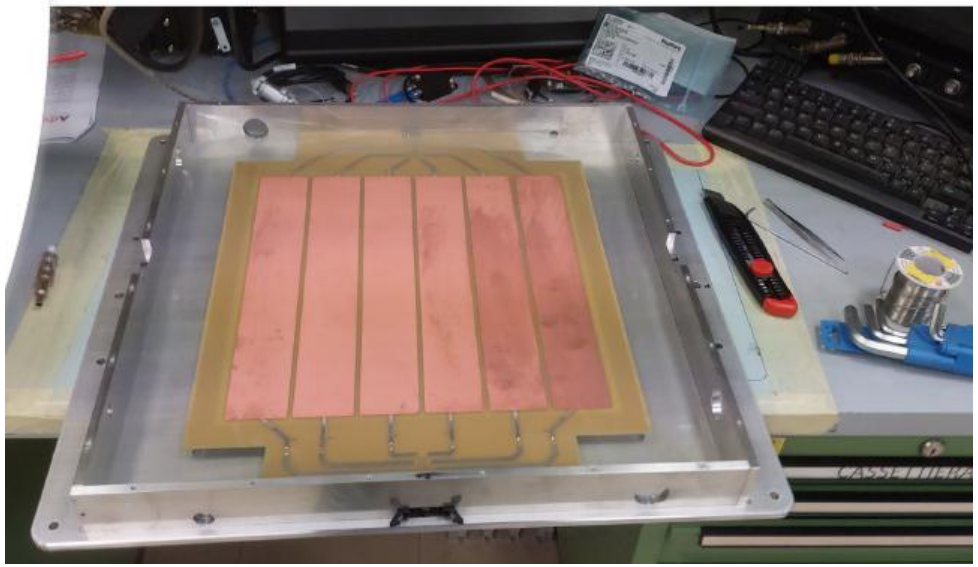






# RPC prototype completed and installed in test stand @Frascati

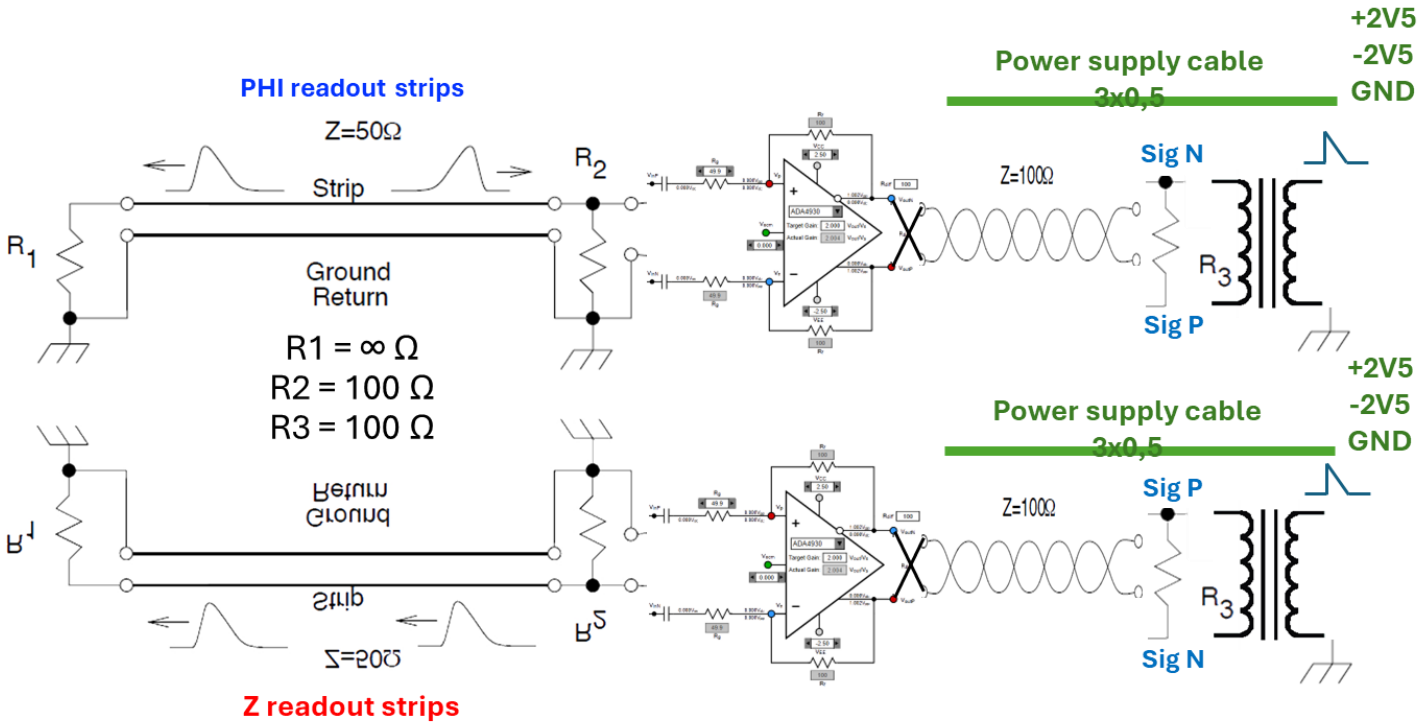


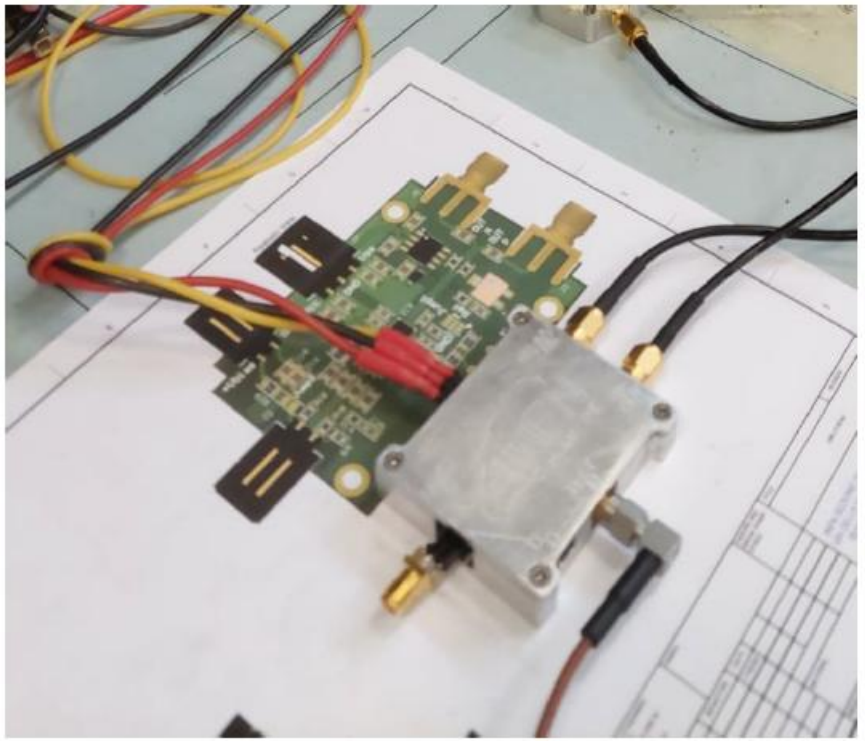


Tested for gas tightness

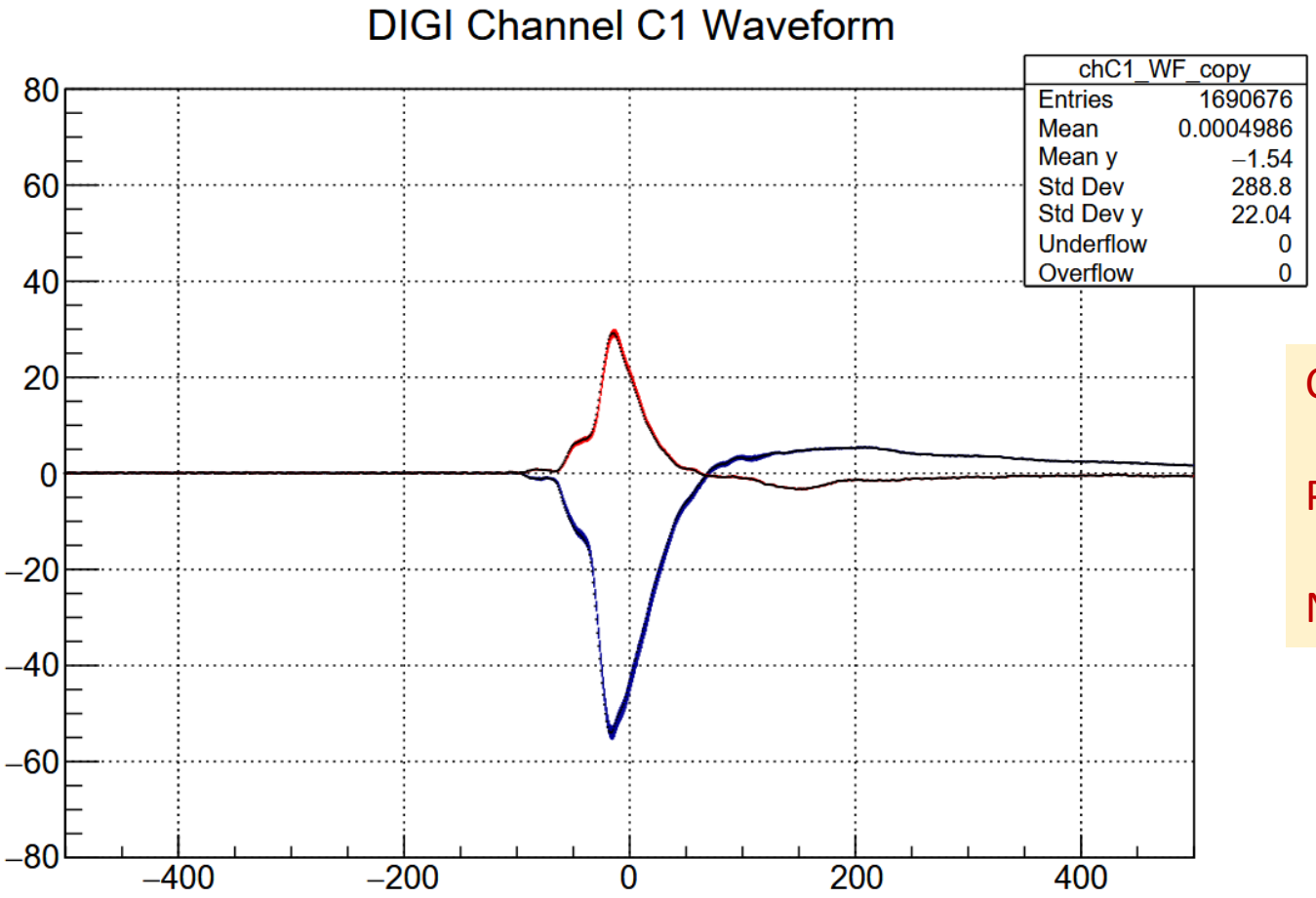
First signals observed with both polarities
Amplitude ~ 40 mV

# Amplifier prototype designed and produced @Roma Tre



# Amplifier prototype successfully installed on Frascati test stand and operated at low gain




The gain has been intentionally kept low (by a factor of 2) because we are using the standard gas mixture

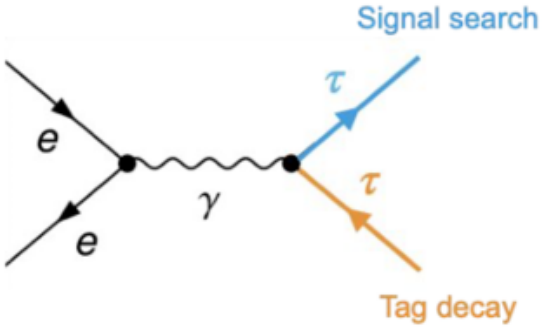
Cosmic events

Positive signal: simple RPC output

Negative signal: output amplified x2

# $\tau$ lepton physics at Belle II

- $\tau$ pairs produced in the $e^+e^-$ collisions of Belle II provide a unique laboratory to test the SM:
  - The $\tau$ is the heaviest lepton and the only one massive enough to decay into hadrons (>200 hadronic channels).
  - Decay channels of $\tau$ allow a clean theoretical analysis of the hadronization, determination of SM parameters, and searches for new physics.




## Active Analyses

### SM properties

- $\tau$ lifetime
- $\tau \to K_S\pi\nu$ CPV
- $\tau \to K_S\pi\nu$ angular CPV
- $V_{us}$ incl. & excl.
- $\tau \to \pi\pi^0\nu$ BF & SF
- $\tau \to 3\pi\nu$ PWA
- $\tau \to K2\pi\nu$ PWA
- $\tau \to K2\pi\nu, 3\pi\nu$ CPV
- LFU 3x1
- $\tau$ mass update
- $\tau \to \ell\nu\bar{\nu}$ BFs
- $\tau \to K2\pi\nu$ SF
- $\tau \to K\pi^0\nu$ BF & SF
- $\tau \to K_S\pi\nu$ SF
- HVP (non-strange SF)
- $\tau \to K\eta\nu$

### Direct LFV searches

- $\tau \to e2\ell$
- $\tau \to \mu\gamma$
- $\tau \to \ell\alpha$ (invisible)
- $\tau \to \ell\pi^0$
- $\tau \to \ell\eta$
- $\tau \to \ell\eta'$
- $\tau \to 3\mu$ (displ. vtx)
- $\tau \to e\gamma$

# Tau Physics Program

## Precision SM measurements.

Indirect hints of New Physics in SM deviations.

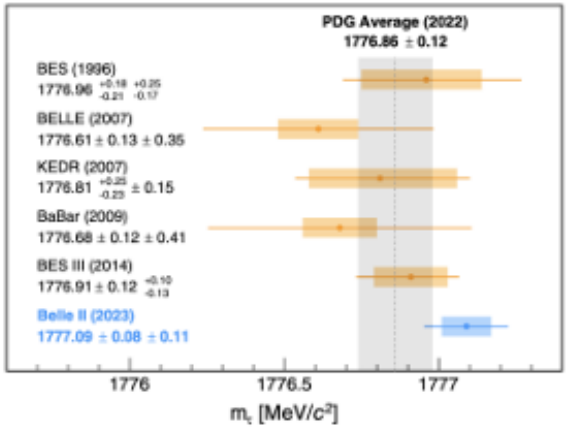
- ✦ $\tau$ properties (mass, lifetime), couplings (e-μ universality, $V_{us}$), CP violation, etc
- ✦ Often sub-% measurements: systematics are usually the dominant error source.

## Search for rare or forbidden processes.

Direct observation would be unambiguous sign of NP.

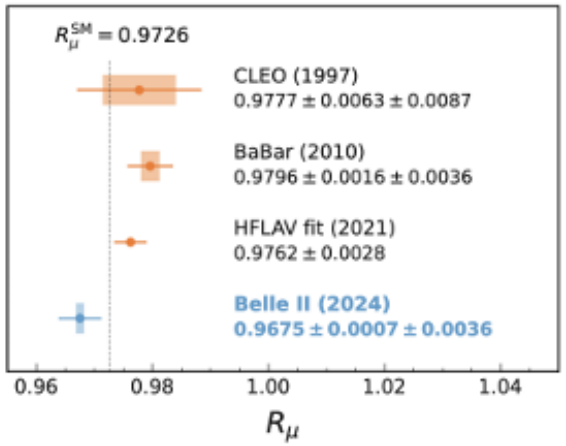
- ✦ Mostly Lepton Flavor Violating (LFV) $\tau$ decays. Often very little to no background.
- ✦ Need to be smart to beat limits from Belle with ½ data.
  - ▸ Requires high reconstruction efficiencies
  - ▸ Machine learning techniques, inclusive tagging

$\tau$ mass




PRD 108, 032006 (2023)

e-μ universality




JHEP 2024, 205 (2024)

$\tau \to 3\mu$

JHEP 2024, 062 (2024)

$\tau \to \Lambda\pi$

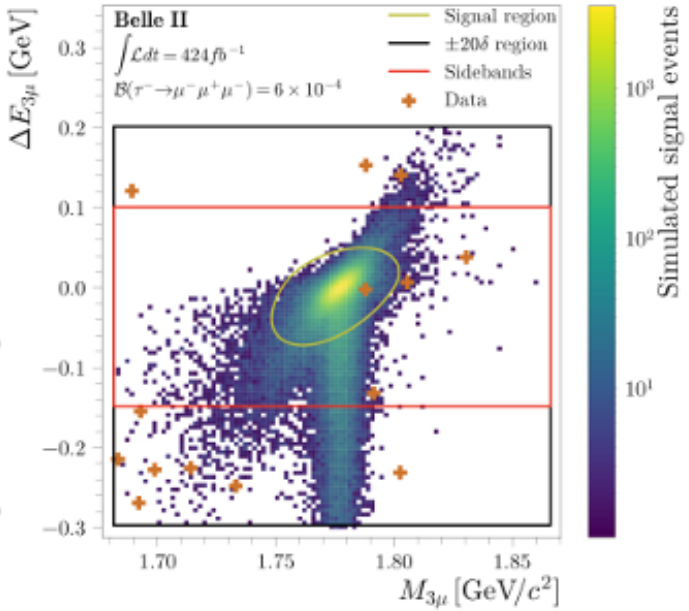
PRD 110, 112003 (2024)

$\tau \to \ell\alpha$

arXiv:2503.22195 (2025)
PRL 130, 181803 (2023)

$\tau \to \ell K_S^0$

arXiv:2504.15745 (2025)



# Dark Photon and Dark Higgs search

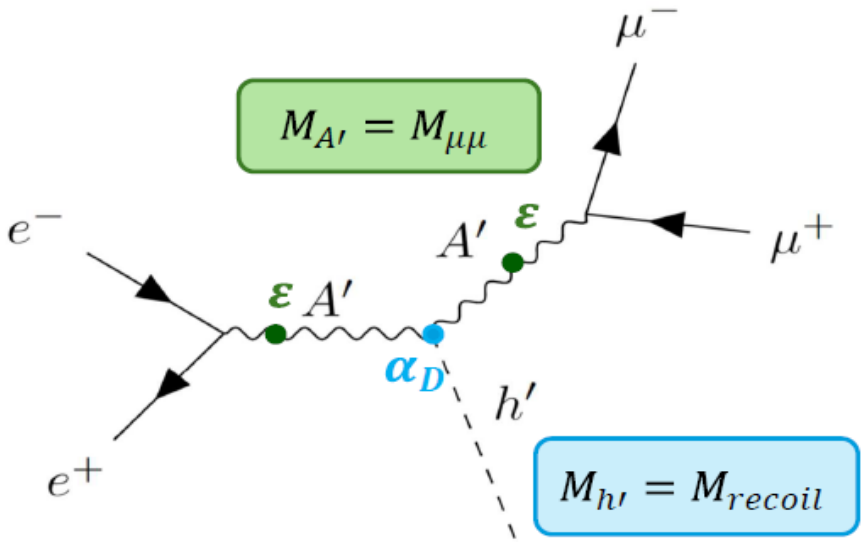
L. Salutari, E.Graziani

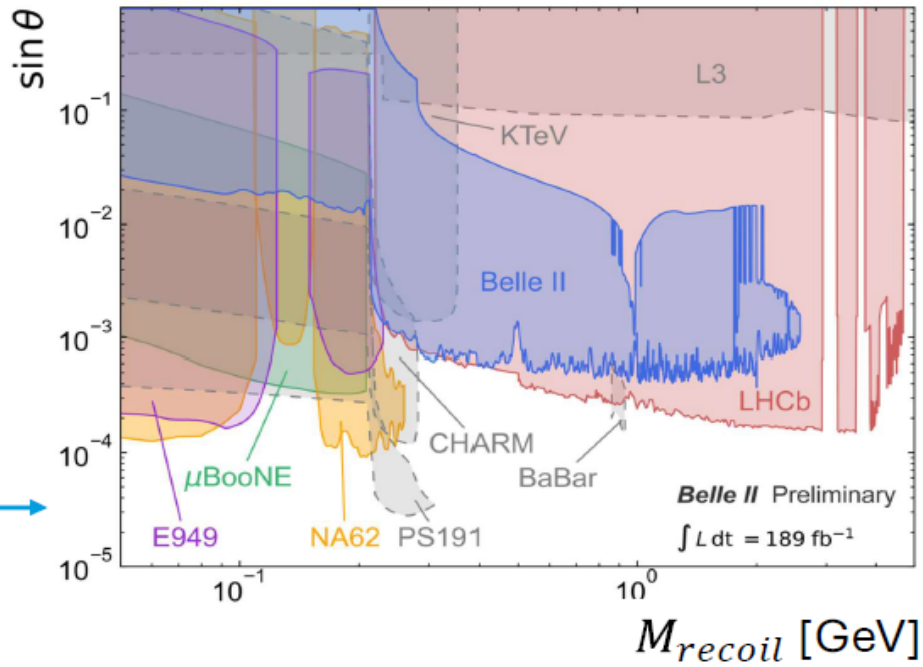
Simultaneous search of two dark sector particles

- Model (arXiv:2012.08595) with 5 parameters:
  - $M_{A'}$ and $M_{h'}$
  - **$\varepsilon$ as A'-$\gamma$ mixing**
  - **$\theta$ as h'-$h_{SM}$ mixing**
  - $\alpha_D$ as A' – h' coupling
  - Hipothesys: other possible DM particles are kinematically excluded
- Assumptions on h'
  - $M_{h'} < M_{A'}$
  - Small mixing $\theta$ → h' is long-lived and escapes Belle II detector

**Final state given from two muons from A' decay and missing energy from h'**

Targeting both $\varepsilon^2 \times \alpha_D$ couplings and $\theta$ parameter

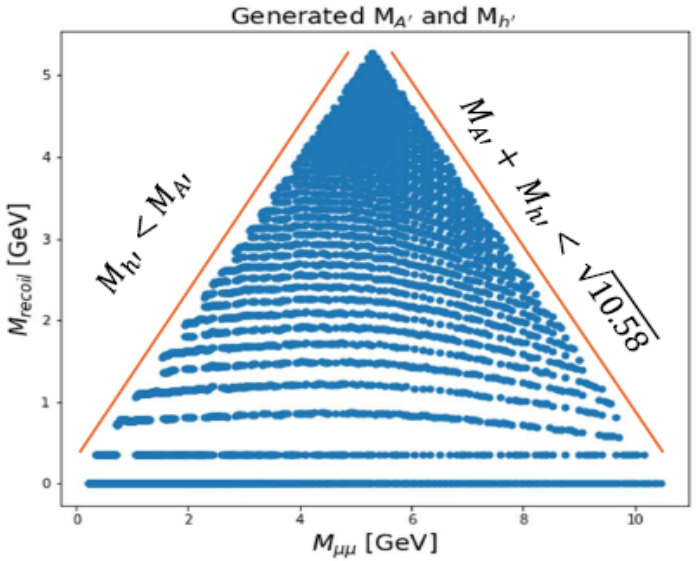


# Dark Photon and Dark Higgs search

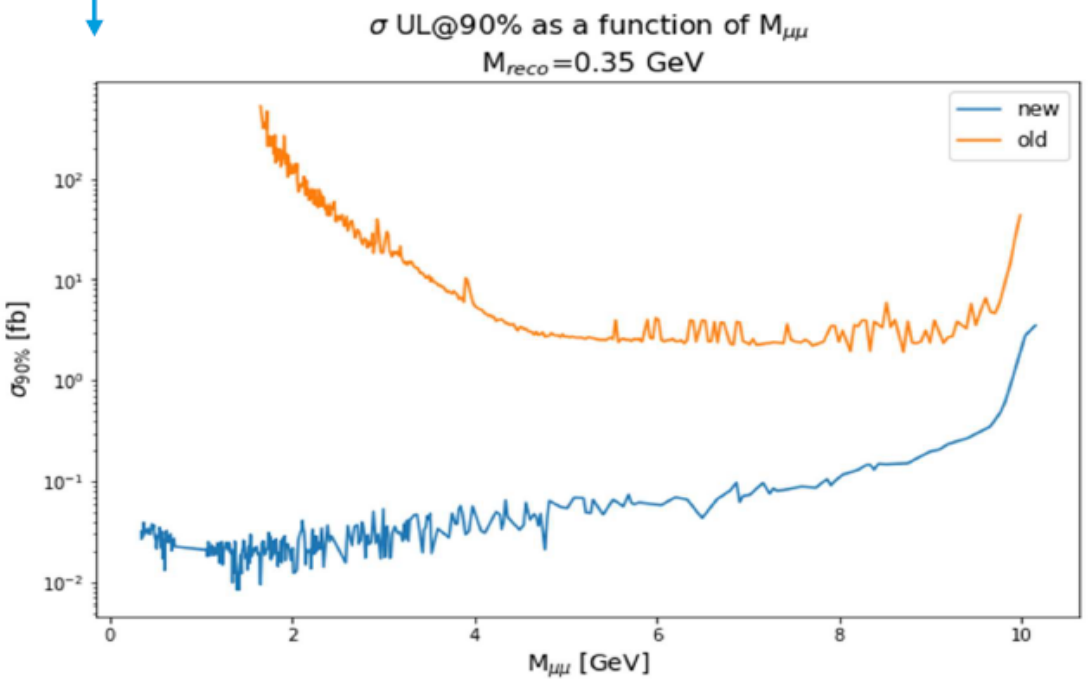
Project timeline:

- Production of signal MC
- Choice of preselections and signal region where to study signal & background
- Cut optimization for signal/bkg ratio
- Estimate of 90%CL upper limits on cross section
- Validation on control samples
- Evaluation of systematic uncertainites
- Signal extraction procedure
- Data unblinding




Preliminary sensitivity on the production cross section as a functions of $M_{\mu\mu}$ for fixed $M_{recoil}$

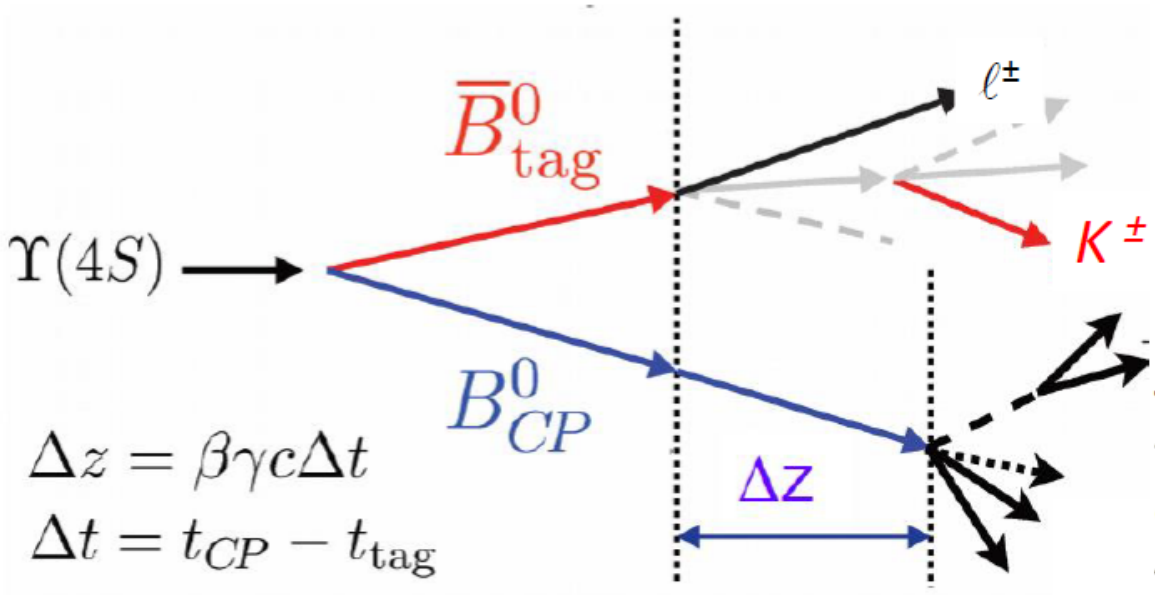
Roughly comparing with previous analysis (PRL 130 (2023) 071804) limits → 1-3 order of magnitude expected improvement!



# Determination of $\alpha, \beta$ ($\phi_2$ , $\phi_1$)

**Time dependent CP asymmetries:**

$$a_{CPV}(\Delta t) = \frac{\Gamma_{\overline{B}\to\bar{f}}(\Delta t) - \Gamma_{B\to f}(\Delta t)}{\Gamma_{\overline{B}\to\bar{f}}(\Delta t) + \Gamma_{B\to f}(\Delta t)} = S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)$$



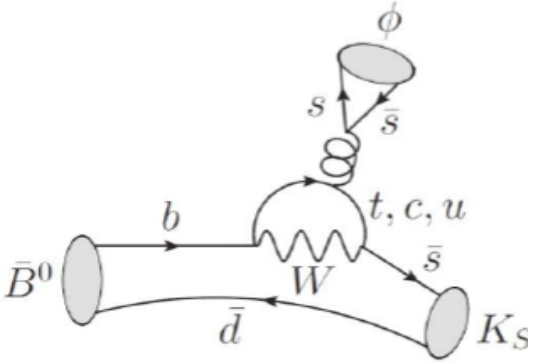

J/ψ $K_S$
π π
φ K
η' $K_S$
.....

S → indirect CP (tree level)
C = -A → direct CP (penguins)

at Belle II:
Δz ~ 130 μm
βγ ~ 0.28
(was 0.45 in Belle)

**Need efficient flavour tagging with charged tracks.**
**Position of both B decay vertexes is required. Δt resolution dominated by the error on the position of the B-tag vertex.**

# sin2β (sin2$\phi_1$) from b → q $\bar{q}$ s

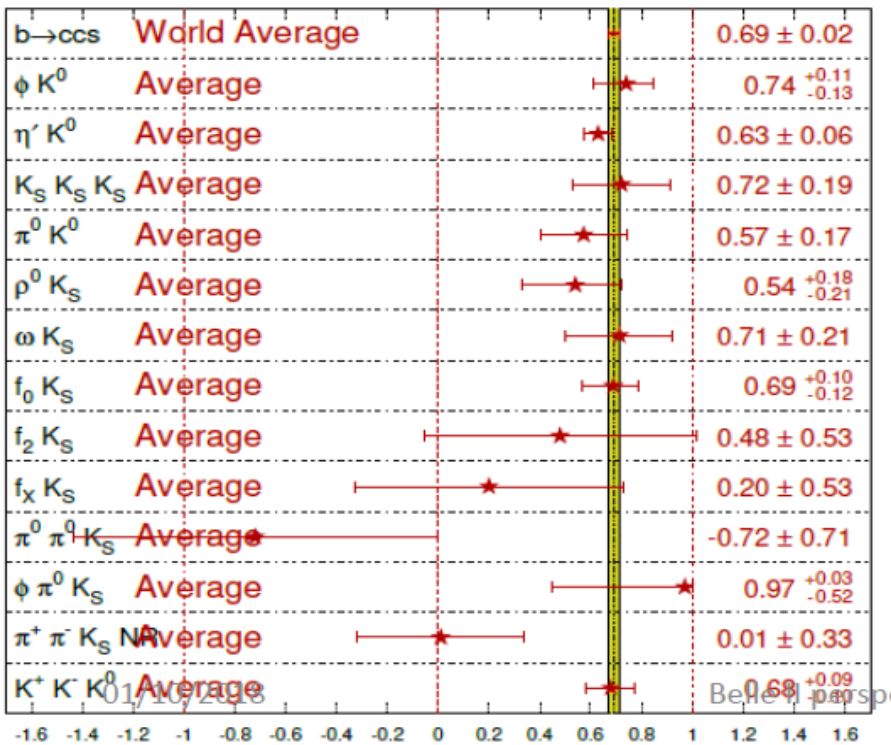



**Penguin dominated modes: depend on β via different vertexes. Tree pollution under control. More sensitive to NP !**

$B \rightarrow \phi K_s$, $B \rightarrow \eta' K_s$, $B \rightarrow \omega K_s$, $B \rightarrow \pi^0 K_s$
With many different final states.
At present all statistically dominated.

$$S_f \sim \sin(2\phi_1) + \Delta S_f(\text{tree} + \text{NP})$$

$$\sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}})$$ HFLAV Summer 2016




Main background is combinatorial from continuum. Small contamination from b → c decays.

Special care required by signal cross feed from other charmless CP violating B decays . Δt resolution *~0.75 (1.5) ps* for φ $K_s$ (η′ $K_s$ ).

S and A extracted from a multidimensional fit to Δt + various backgr discriminating variables.

# Datasets of the analysis method with MC

To tune the analysis we have used about 2 million events of MC16rd signal samples.

For signal we have reconstructed three separate decay chains:

- $B \rightarrow \eta' K_L$ with $\eta' \rightarrow \eta\, \pi^+\pi^-$ and $\eta \rightarrow \gamma\gamma$ $(BR = 5.6 * 10^{-6})$. ;
- $B \rightarrow \eta' K_L$ with $\eta' \rightarrow \eta\, \pi^+\pi^-$ and $\eta \rightarrow \pi^+\pi^-\pi^0$ $(BR = 3.2 * 10^{-6})$;
- $B \rightarrow \eta' K_L$ with $\eta' \rightarrow \rho^0\gamma$ $(BR = 9.7 * 10^{-6})$.

Analysis is then performed on generic $b\bar{b}$ and continuum $udsc\tau$ in run1 MC simulation, with a full on peak luminosity of $365{,}29\ x\ 4\ fb^{-1}$.

# $K_L$ selection

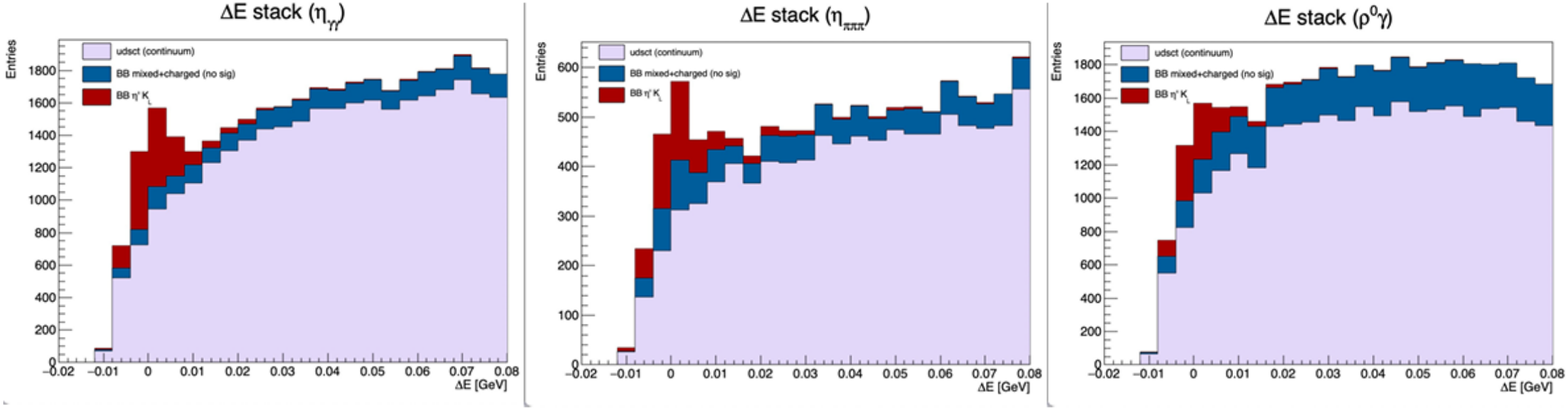
Neutral clusters in each event are associated to an $\eta'$ candidate to create a B meson if it survives these selctions:

- one cluster in ECL with **E > 0.15 GeV (E > 0.25 GeV and PulseShapeDiscriminationMVA <= 0.15 for $\eta_{\pi\pi\pi}$,** applied at skim level**);**

- one KLM cluster with **1 ≤ Nlayers ≤ 10 and 1 <= InnermostLayer ≤ 10 (KLID >= 0.1 for $\eta_{\pi\pi\pi}$,** applied at skim level**);**

- In some events, there are $K_L$ candidates that leave clusters in **BOTH** calorimeters, we create this new category of candidates if clusters are separated by less than 0.35 rad.

# $\Delta E$ distributions after all selections in $b\bar{b} + udsc\tau$




B0ch7 and B0ch8 show a better peak resolution in the peak around zero.

Lower purity in $\rho^0\gamma$ channel is expected. It is possible to further tune selections to make the fit optimization on Signal and Background pdfs more precise.

# Richieste 2026 RM3

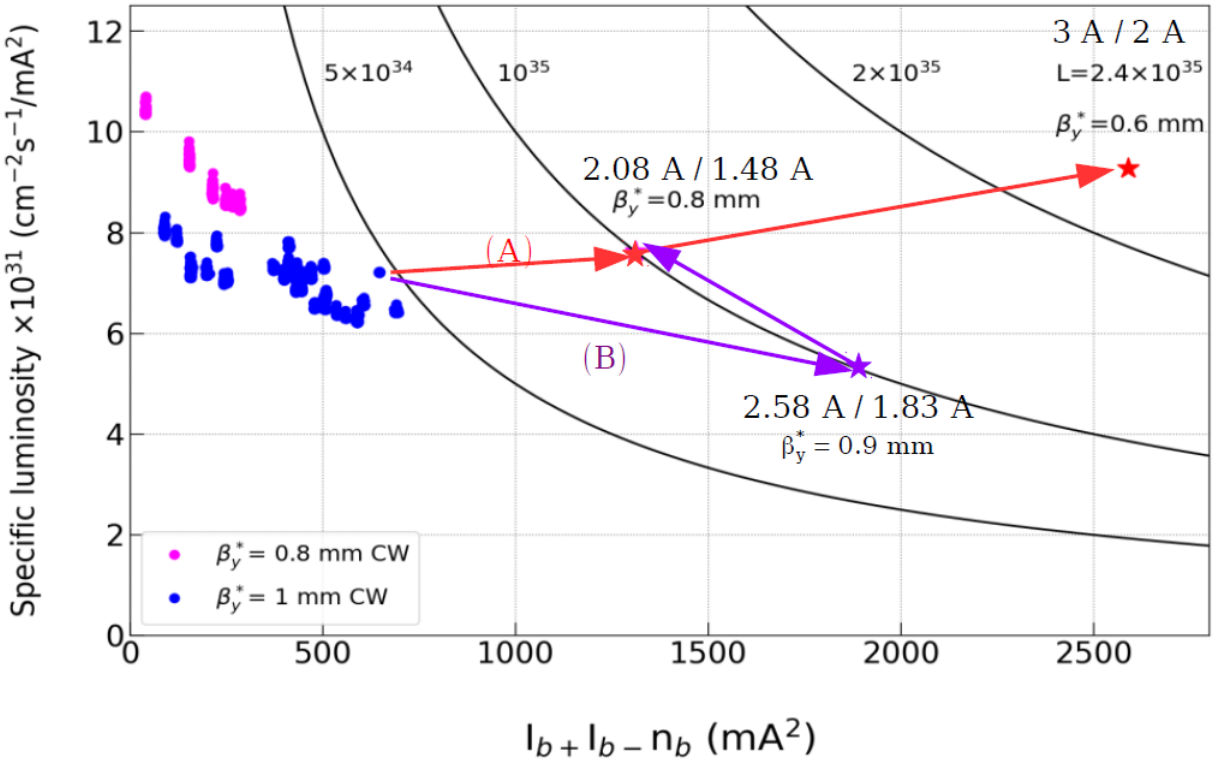
| capitolo | | richiesta | richiesta s.j. |
|---|---|---|---|
| missioni | metabolismo (1mp+1k€)*FTE | 79,5 | |
| missioni | turni centrali (5 mesi run, quota rm3) | 6,5 | |
| missioni | turni centrali 2 mesei sj quota indivisa | | 14 |
| missioni | gettone RN | 5 | |
| missioni | gettone Zani (SVD+tau) | 5 | |
| missioni | 3 turni SVD local operation | 9,8 | |
| missioni | 2 turni SVD local operation run sj | | 6,5 |
| missioni | turni KLM run 5 mesi + 2 sj | 5 | 3 |
| missioni | manutenzione FEE RPC | | 12 |
| | | | |
| consumo | prototipi 12 canali FEE RPC in proporzionale | 5 | |
| consumo | metabolismo 1.5k€*FTE | 15,9 | |
| | | | |
| spservizi | quota MOF Italia 2026 | | 200 |
| | **TOTALI** | **131,7** | **235,5** |

# Richieste 2026
# Servizi di sezione RM3

| servizio | Per cosa | quanto |
|---|---|---|
| Meccanico | Prototipi RPC per test proporzionale | 6 mesi persona |
| elettronico | Front end RPC proporzionale | 3 mesi persona |
| eletronico | Manutenzione FEE on detector KLM (s.j. necessità) | 2 mesi persona |

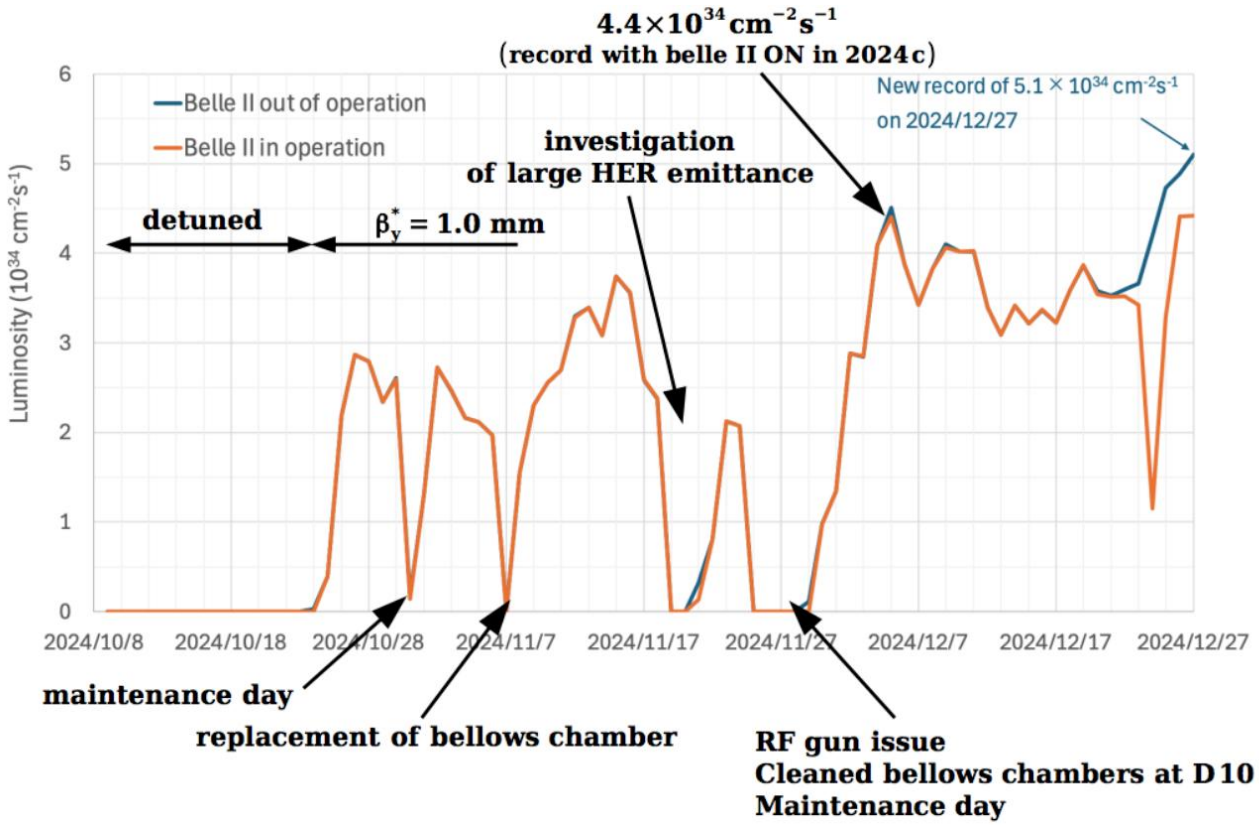
# SPARES

# The strategy….

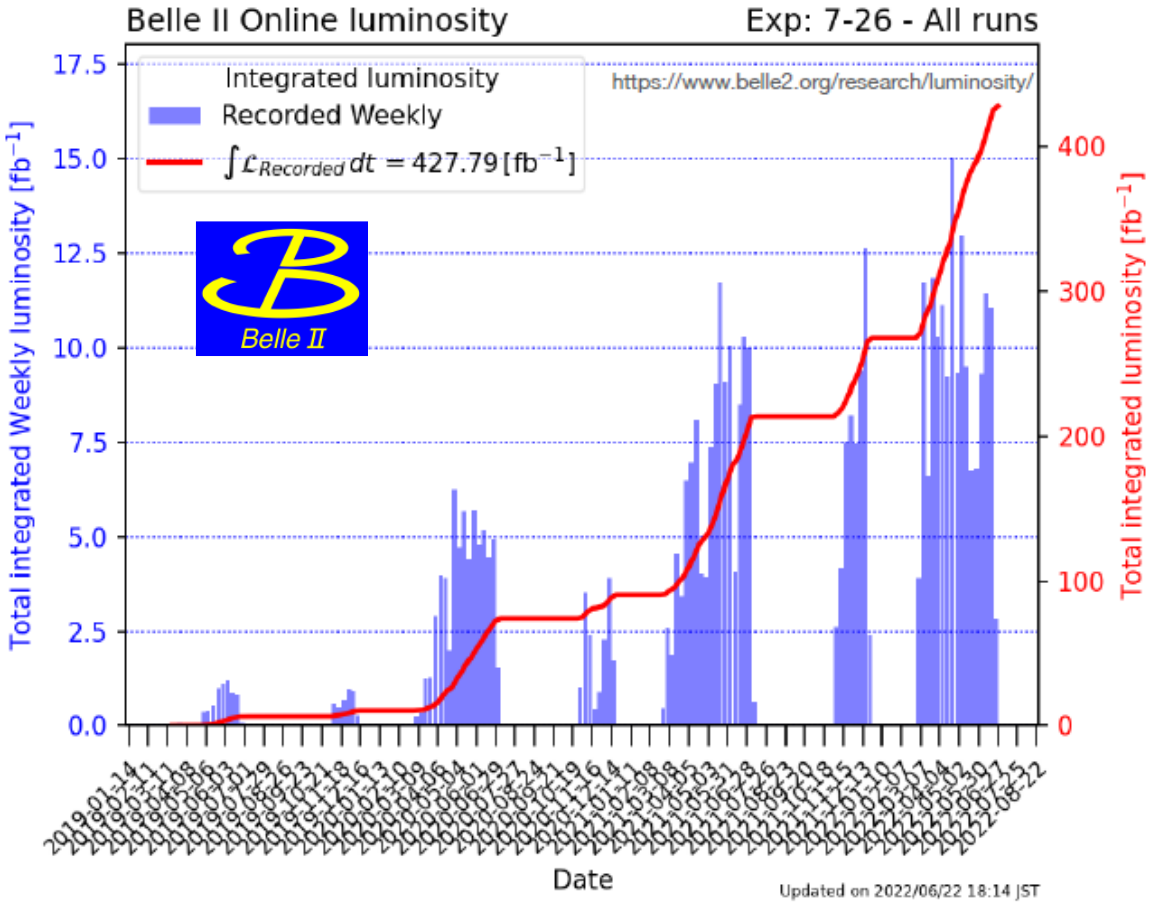



more runs are needed to implement the strategy

## ….the reality in 2024c



# Run 1 data sample (2019-2022)

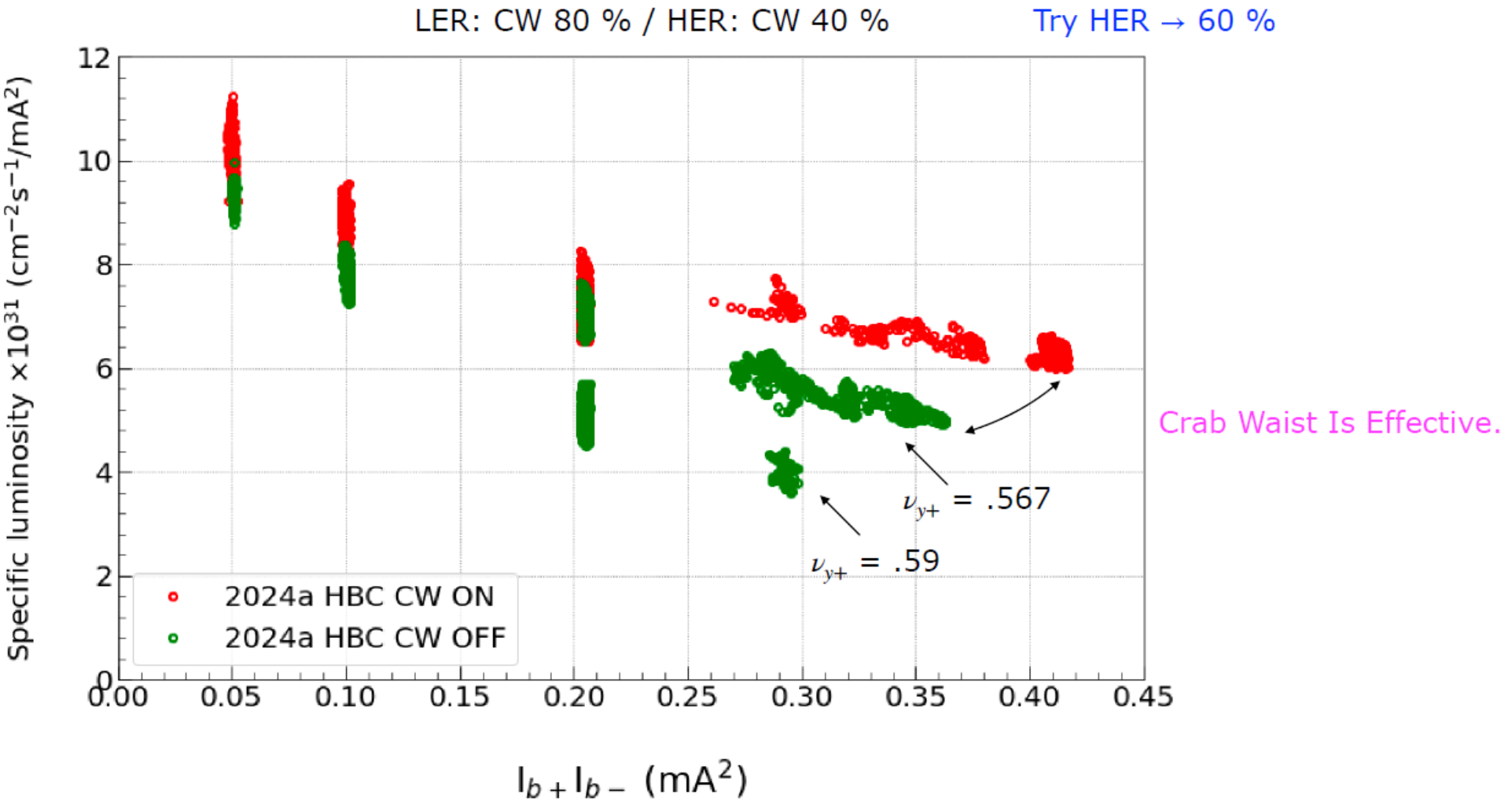



Belle II collected about the BABAR statistics, but improved analysis techniques allow to obtain higher sensitivity for most analyses.
Moreover many analyses can be jointly performed with the Belle data sample.

Belle II already published about 50 papers + 10 submitted and are being reviewed.
Many more analyses are underway both in B physics, tau physics, dark sector, spectroscopy…

Some results will be shown later in this presentation

# Crab waist OK




A marzo riprodotto working point equivalente al 2022.

A maggio in condizioni simili, ottenuta luminosita' specifica minore con la stessa corrente dei bunch--> condizioni della macchina ancora non stabili, anche legati ai problemi di iniezione, in corso di studio.

# Sudden Beam losses

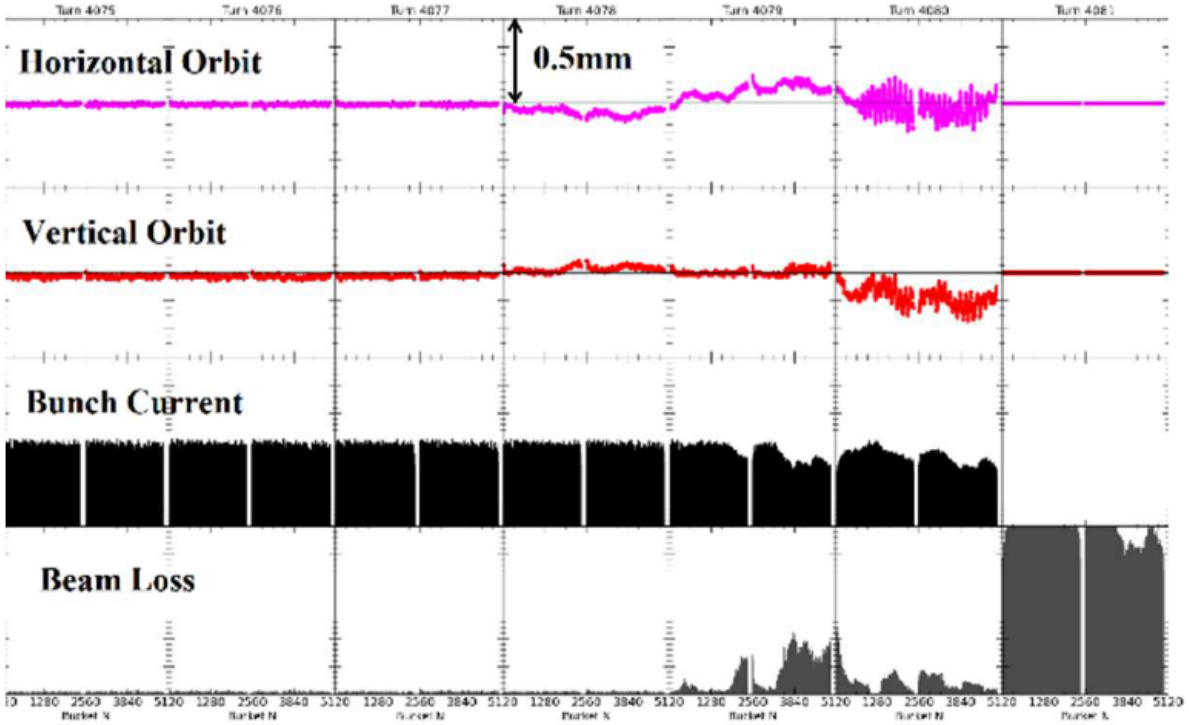
**Beam loss that occurs suddenly within 1 turn (10μs) without precursory phenomena. ＝ Sudden Beam Loss（SBL）**

- The cause of SBL has been unknown.
- A significant percentage of the beam is before the abort trigger is issued and stored beam is dumped

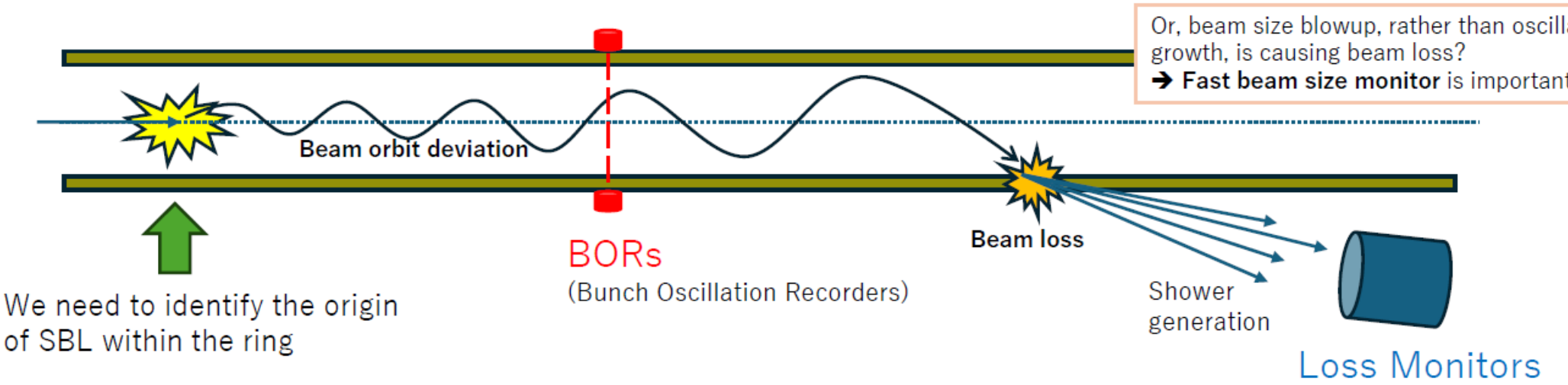
→ Harmful effects of SBL;

- Damage to collimators and other accelerator components,
- Quench of the final focusing superconducting magnets (QCS),
- Large backgrounds to the Belle-II detector,
- Inability to store high current due to beam abort.

Beam signal measured by
Bunch Oscillation Recorder(BOR) & Bunch Current Monitor(BCM)



# Sensors to find the origin of SBL events




- **Loss Monitors**
  - Equipped with fast readout and provide chronological order of beam loss along the ring
  - Many LMs have been installed before LS1
- **BORs**
  - Can observe earlier stage of beam orbit deviation, prior to the beam loss
  - Multiple LER BORs are installed from 2024, making timing/phase analysis possible
  - This provides new and unique insights into understanding the origin of SBL
- Fast beam size monitors are also important to detect possible beam size blowup just before the abort

# 2024ab integrated luminosity

Priority given to machine studies