2023 TYL-FJPPL Young Investigator Award

Tristan Fillinger

09/05/23

Outline

FLAV-05 TYL

- Time-dependent CP violation (TDCPV) analysis on b ⟶ s γ process
  - **With Belle**: on $B^0 \longrightarrow K_s^0 \pi\pi\gamma$ using a new method to constrain the Standard model
  - **With Belle II**: Rediscovery of $K_s^0 \pi\pi\gamma$ and $K_s^0 \pi^0 \gamma$ channels on data

D-RD-24 TYL

- Upgrade of the vertex detector of Belle II
  - Development of new fully pixelated geometries

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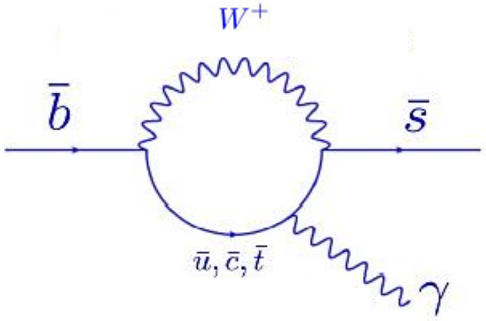
Why b ⟶ sγ decays are interesting?

- **Goal : Discover New Physics beyond Standard Model**



- With b ⟶ s γ transitions:
  - Flavor changing neutral current (FCNC) transitions occurring at loop level only > Highly suppressed
  - In SM, photon almost fully polarized:

$$b \rightarrow s\, \gamma_L \qquad \text{or} \qquad \bar{b} \rightarrow \bar{s}\, \gamma_R$$

  - Loop described by Wilson coefficients:

$$\mathcal{H}_{\text{eff}} \cong -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} [\boldsymbol{C_7} \langle \mathcal{O}_7 \rangle + \boldsymbol{C_7'} \langle \mathcal{O}_7' \rangle]$$

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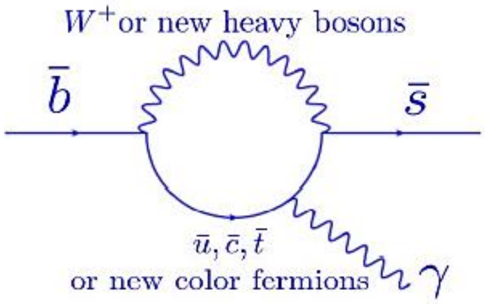

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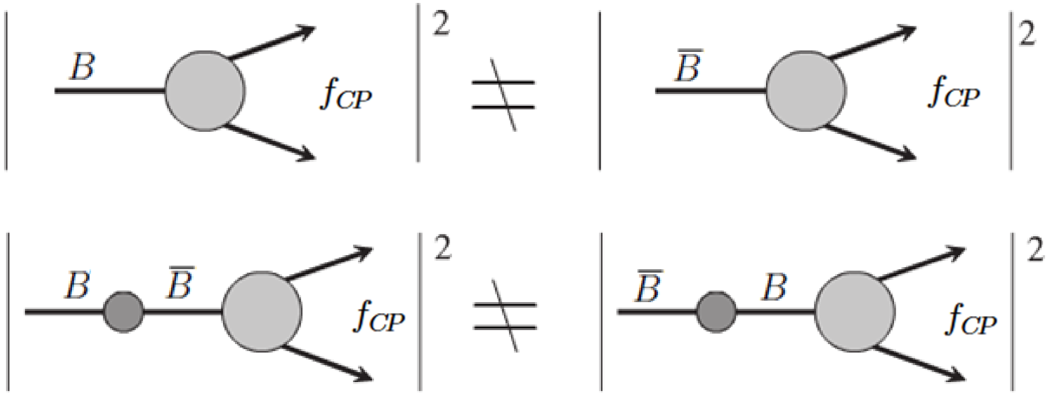
$$\mathcal{H}_{\text{eff}} \cong -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^{*}\left[\left(\boldsymbol{C_7^{\mathrm{SM}}} + \boldsymbol{C_7^{\mathrm{NP}}}\right)\langle\mathcal{O}_7\rangle + \left(\boldsymbol{C_7'^{\mathrm{NP}}}\right)\langle\mathcal{O}_7'\rangle\right]$$

  - New physics: Different couplings which enhance right-handed photon contributions (MSSM, LRSM, SUSY SU(5) GUT…)
    - Atwood *et al.*, 1997; E. Kou *et al.*, 2013; N. Haba *et al.*, 2015
  - Several analysis sensitive to photon polarization:

    > Time-dependent CP observable measurement

Time dependent CP violation (TDCPV)

- **Source of the CP violation:**



CP violation in the decay

+ Interference between the 2

CP violation in mixing

$$\frac{\Gamma\left(B^0(\Delta t) \to f_{CP}\right) - \Gamma\left(\bar{B}^0(\Delta t) \to f_{CP}\right)}{\Gamma\left(B^0(\Delta t) \to f_{CP}\right) + \Gamma\left(\bar{B}^0(\Delta t) \to f_{CP}\right)} \cong \underbrace{S}_{} \sin(\Delta m \Delta t) + \underbrace{A}_{} \cos(\Delta m \Delta t)$$

CP violation coefficient

- Photon polarization impacts the value of S (thus C_7 and C'_7)

$\longrightarrow$ In the Standard Model: $S \simeq 0$ in b $\longrightarrow$ s γ

$\longrightarrow$ If new physics : $S \neq 0$

Time dependent CP violation (TDCPV)

- Already measured:

Statistically limited

BR ~ 10^{-5}

[BaBar PRD78 (2008)]: $S_{\pi^0 K_S^0 \gamma}$ = -0.78 ± 0.59 ± 0.09 (467e6 $B\bar{B}$)

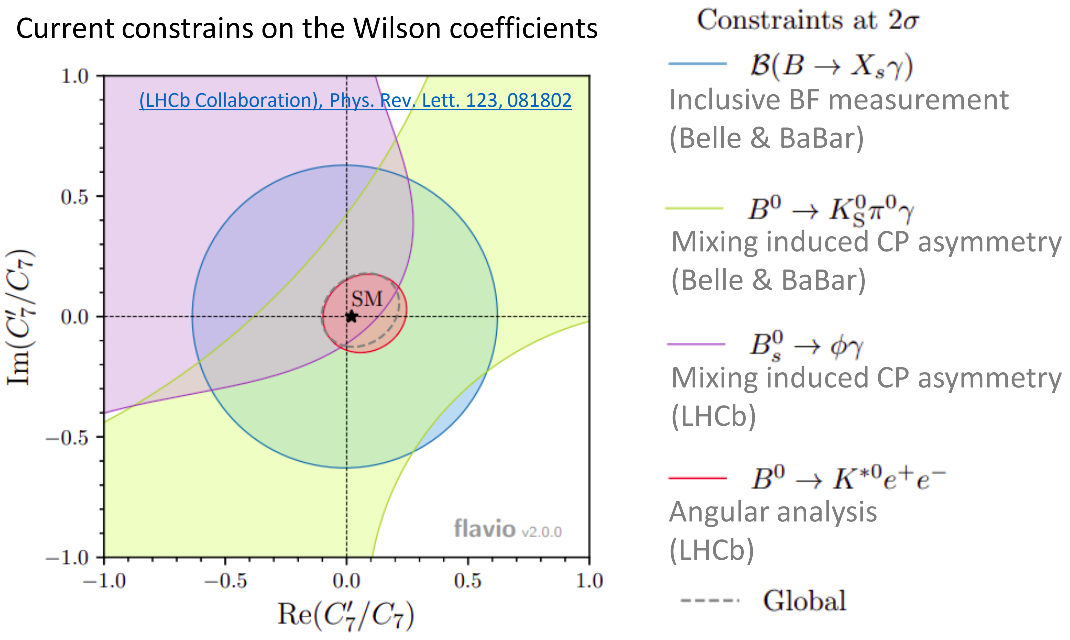
[Belle PRD74 (2006)]: $S_{\pi^0 K_S^0 \gamma}$ = -0.10 ± 0.31 ± 0.07 (535e6 $B\bar{B}$)

[BaBar PRD93 (2015)]: $S_{\pi^+\pi^- K_S^0 \gamma}$ = 0.14 ± 0.25 ± 0.03 (471e6 $B\bar{B}$)

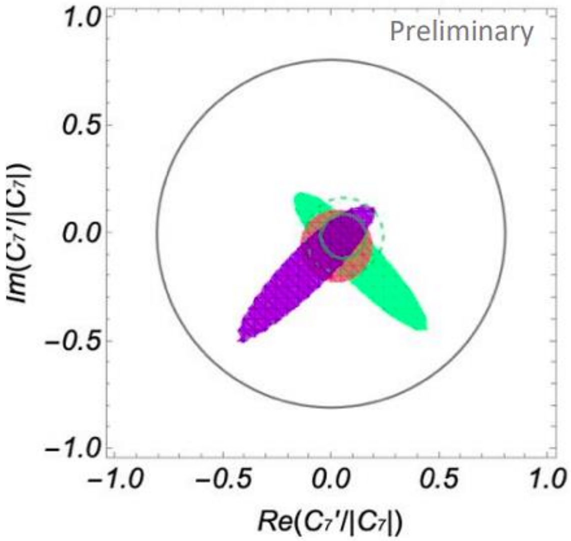
[Belle PRL101 (2008)]: $S_{\pi^+\pi^- K_S^0 \gamma}$ = 0.11 ± 0.33 ± 0.07 (657e6 $B\bar{B}$)

- **Get more data to reduce the uncertainty (Belle II analysis)**
- **Use the new method to better constrain the SM (started with Belle)**

Current constrains on the Wilson coefficients



JHEP 09 (2019) 034



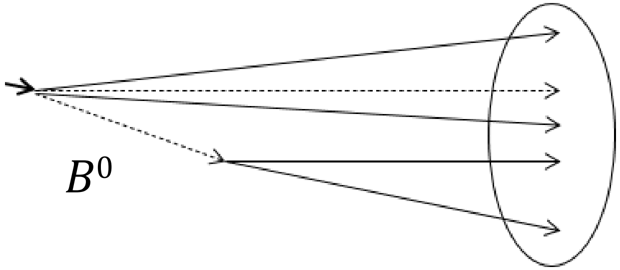
New constrains with 10 ab^{-1} of Belle II data

Outline

- Time-dependent CP violation (TDCPV) analysis on b ⟶ s γ process
  - **With Belle**: on $B^0 \to K_s^0 \pi\pi\gamma$ using a new method to constrain the Standard model
    - Re-implementation of the full analysis up to the final fit to get the parameters
    - Analysis done on MC
  - With Belle II: on $K_s^0\pi\pi\gamma$ and $K_s^0\pi^0\gamma$ channels
- Upgrade of the vertex detector of Belle II
  - Development of new fully pixelated geometries

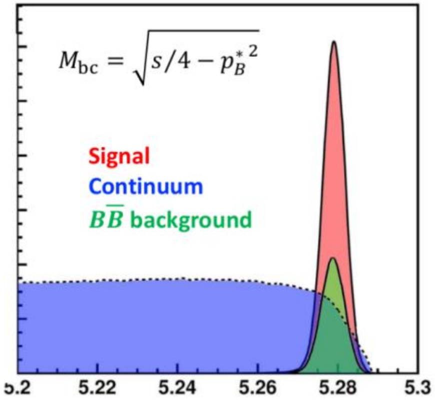
Analysis strategy

- Reconstruction and preselection
  - Reconstruct final state particles and K_s^0
  - Reconstruct B meson + perform vertex fit



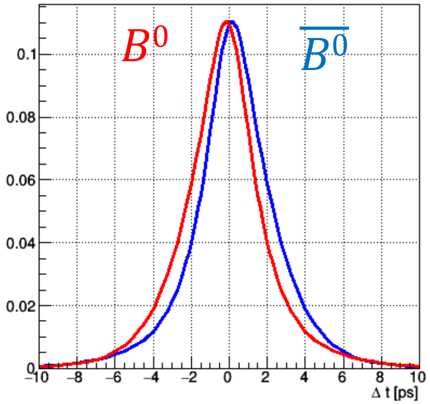
- Apply Flavor tagger to get the B flavor

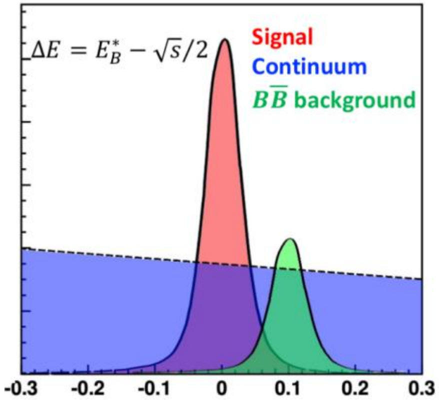
- Apply selection cuts on powerful variables
  - Continuum Suppression: to reduce the $e^+e^- \rightarrow q\bar{q}$ $(c\bar{c}, s\bar{s}, u\bar{u}, d\bar{d})$ with a multivariate classifier
  - pion PID, m_{Kres}., $m_{\pi\pi}$…



- Best candidate selection based on signal vertex confidence
  - Impact ~6% of events

- 3D fits : Simultaneous fit of m_{bc}, ΔE and Δt
  - Fit PDFs shapes for each contribution from MC
  - Fit complete distribution to extract A and S





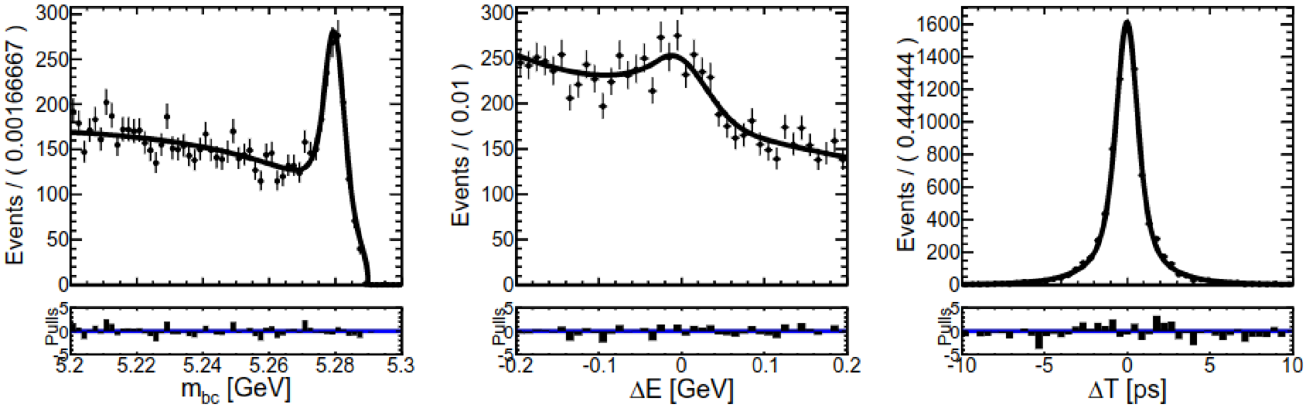
$K_s^0\pi\pi\gamma$ analysis in Belle: Final 3D fit

- Fit the signal with the dedicated Belle resolution function

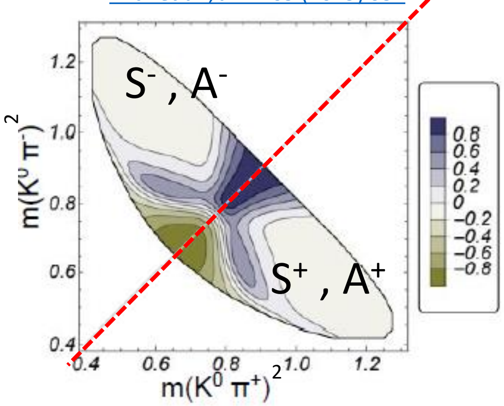
$$F_{\rm sig}(\Delta t) = P_{\rm phys} \otimes R_{\rm sig}(\Delta t) \otimes R_{\rm tag}(\Delta t) \otimes R_{\rm np}(\Delta t) \otimes R_{\rm kin}(\Delta t)$$

- Fit the 4 other types of background separately with various PDFs
  - Crossfeed, BB, continuum, rare decays

- **Final** three dimensional extended unbinned maximum likelihood fit:



Akar *et al.*, JHEP 09 (2019) 034



- **CP violating parameters sensitivity estimated on 1 ab^{-1} MC:**

$$\mathcal{A} = 0.07 \pm \boxed{0.10}$$
$$\mathcal{S} = -0.09 \pm \boxed{0.12}$$

From the last Belle measurement

$$\mathcal{A}_{\rm eff} = 0.05 \pm 0.18 \pm 0.06$$
$$\mathcal{S}_{\rm eff} = 0.09 \pm 0.27^{+0.04}_{-0.07}$$

Competitive result

- **Fit with Dalitz separation**

$$\mathcal{S}^+ = -0.17 \pm 0.24$$
$$\mathcal{S}^- = 0.03 \pm 0.24.$$

First time estimation of the new parameters

- Data measurement planned for end of 2022

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  - **With Belle II**: on $K_s^0\pi\pi\gamma$ and $K_s^0\pi^0\gamma$ channels
    - With current Belle II data (190 fb^{-1}): rediscovery + BR measurement
    - Develop both analysis from scratch
- Upgrade of the vertex detector of Belle II
  - Development of new fully pixelated geometries

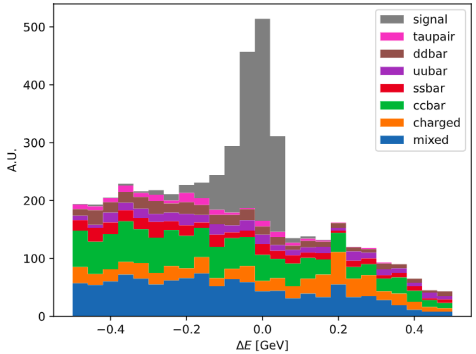
$K_s^0\pi\pi\gamma$ and $K_s^0\pi^0\gamma$ analysis in Belle II

- Reconstruction and preselection
  - Reconstruct final states particles and K^0_S the B meson with a vertex fit
- **Main challenge:** Selection
  - Optimize the selection with $\frac{S}{\sqrt{S+B}}$ FOM with a few variables:
    - **Multivariate classifier**: remove dominant background $e^+e^- \to q\bar{q}$ $(c\bar{c}, s\bar{s}, u\bar{u}, dd)$, trained on fastBDT
    - $m_{K_S{}^0\pi^0}$: reduce other K_{res} (& soft cut for $m_{K\pi\pi}$)
    - K_S^0 **decay length significance**: good K^0_S selection
    - **M_{bc}** : reduce continuum and $B\bar{B}$ background

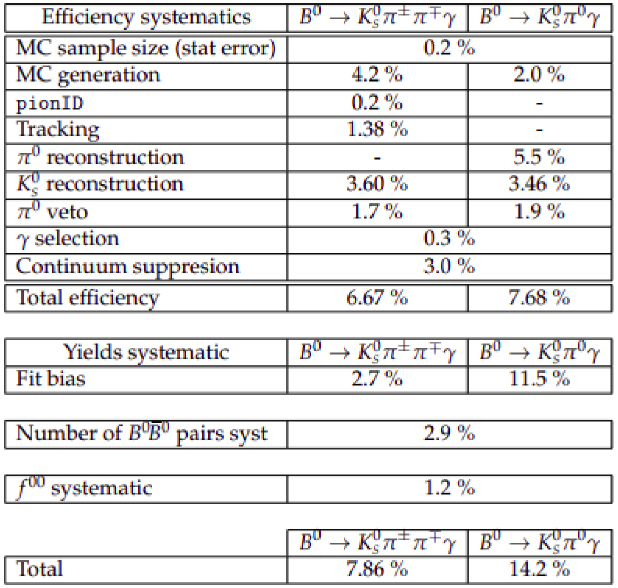
> ~8% efficiency for $K_S\pi^+\pi^-\gamma$ and $K_S\pi^0\gamma$

- ΔE fit to estimate the signal yield
- Systematic uncertainties study
- Data/MC comparison first without then with the signal region
  - **If everything is under control: Final ΔE fit on data and BR measurement!**

Background contribution for $K_s^0\pi\pi\gamma$ after the selection



Systematics uncertainties table



Efficiency systematics	$B^0 \to K_S^0\pi^\pm\pi^\mp\gamma$	$B^0 \to K_S^0\pi^0\gamma$
MC sample size (stat error)	0.2 %	
MC generation	4.2 %	2.0 %
`pionID`	0.2 %	-
Tracking	1.38 %	-
π^0 reconstruction	-	5.5 %
K_S^0 reconstruction	3.60 %	3.46 %
π^0 veto	1.7 %	1.9 %
γ selection	0.3 %	
Continuum suppresion	3.0 %	
Total efficiency	6.67 %	7.68 %

Yields systematic	$B^0 \to K_S^0\pi^\pm\pi^\mp\gamma$	$B^0 \to K_S^0\pi^0\gamma$
Fit bias	2.7 %	11.5 %

Number of $B^0\bar{B}^0$ pairs syst	2.9 %

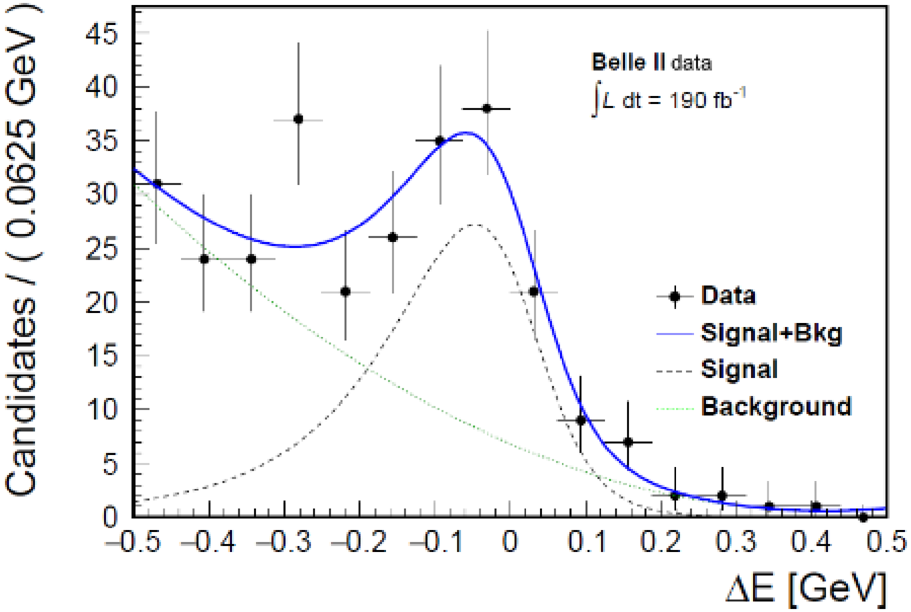
f^{00} systematic	1.2 %

	$B^0 \to K_S^0\pi^\pm\pi^\mp\gamma$	$B^0 \to K_S^0\pi^0\gamma$
Total	7.86 %	14.2 %

$K_s^0\pi\pi\gamma$ and $K_s^0\pi^0\gamma$ analysis in Belle II: unblinding

- **$K_s^0\pi\pi\gamma$**: Continued by next student

- **$K_s^0\pi^0\gamma$**: Unblinding and BR measurement!



- Result presented at Moriond 2022

- arXiv published in June 2022
  [arXiv:2206.08280]

- First step toward the TDCPV measurement in Belle II

$$\mathcal{B}\left(B^0 \to K_S^0\pi^0\gamma\right) = (7.28 \pm 1.75(\mathrm{stat}) \pm 1.03(\mathrm{syst})) \times 10^{-6}$$

Compatible with known value

Conclusion

- Time-dependent CP violation (TDCPV) analysis on b ⟶ s γ process
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  - **With Belle II**: Rediscovery of $K_s^0\pi\pi\gamma$ and $K_s^0\pi^0\gamma$ channels on data
- Upgrade of the vertex detector of Belle II
  - Development of new fully pixelated geometries
- **Now postdoc at KEK**
  - Precise measurement of $\boldsymbol{B} \rightarrow \boldsymbol{\tau\nu}$ with SL FEI
  - Upgrade of the vertex detector with SOI/DuTiP technology

Thank you for your attention

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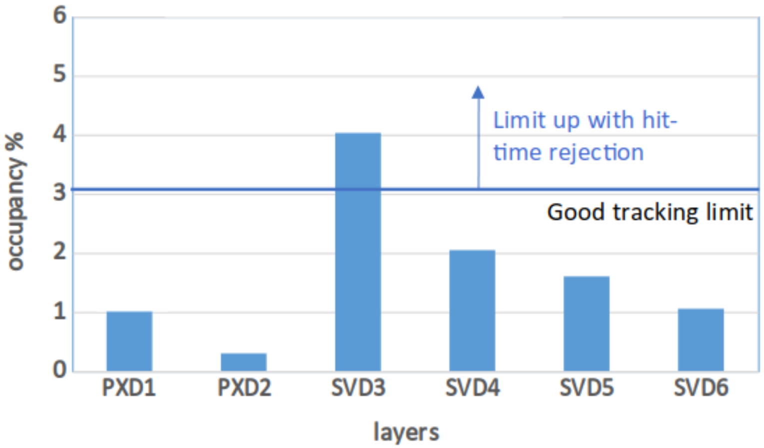
- Upgrade of the vertex detector of Belle II
  - Development of new fully pixelated geometries
  - **Implementation in the Belle II software**
  - Performance comparisons

Implementation of the upgrade

- Why upgrade?

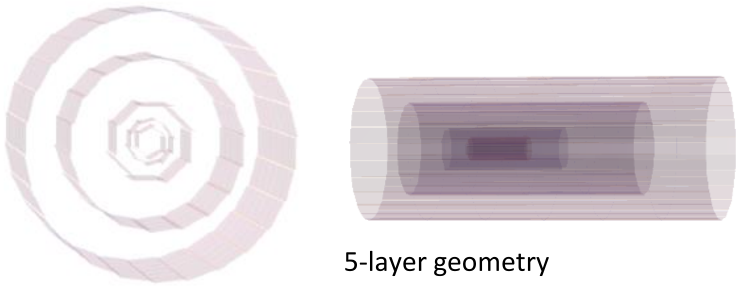
  Current occupancy extrapolation at peak luminosity close to a limit



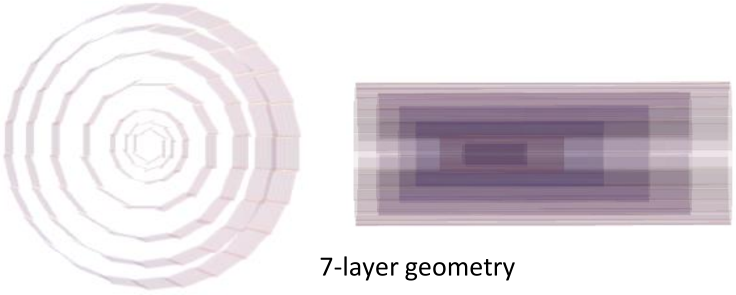
- Opportunity to upgrade the vertex detector in 2026:
  - Better physics performances
  - Better background handling

    > Fully pixelated and fast detector (CMOS technology)

- Can Belle II benefit from a fully pixelated vertex detector?
  - Implement simulation of CMOS sensor
  - Implement new geometries



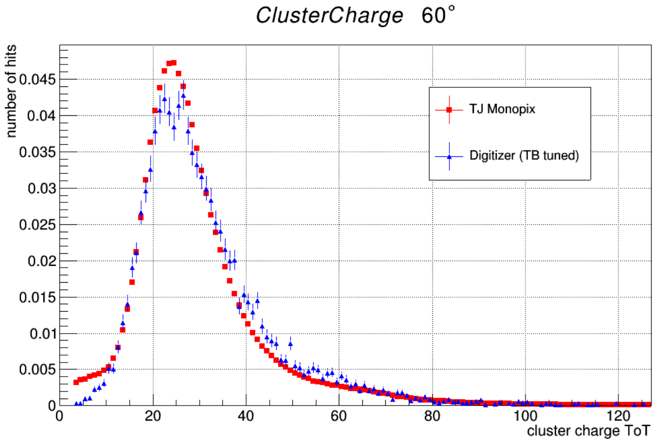
5-layer geometry



7-layer geometry

Implementation of the upgrade

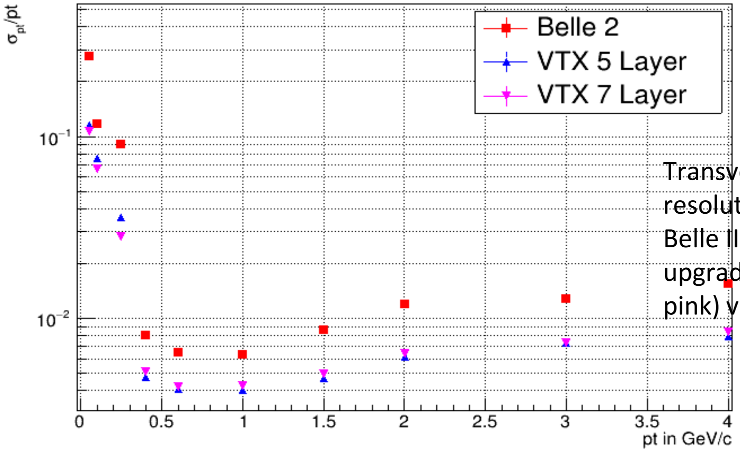
- Tuning of the digitizer to reproduce the performances of the technology candidate



Cluster charge in basf2 (blue) and the testbeam result (red)

- Connect the geometry to the tracking algorithm

- Benchmarking the new configurations:
  - According to MC:
    - Better tracking performances
    - More robust to background
    - Lower occupancy



Transverse momentum resolution for current Belle II (red) and the upgraded (blue and pink) vertex detectors

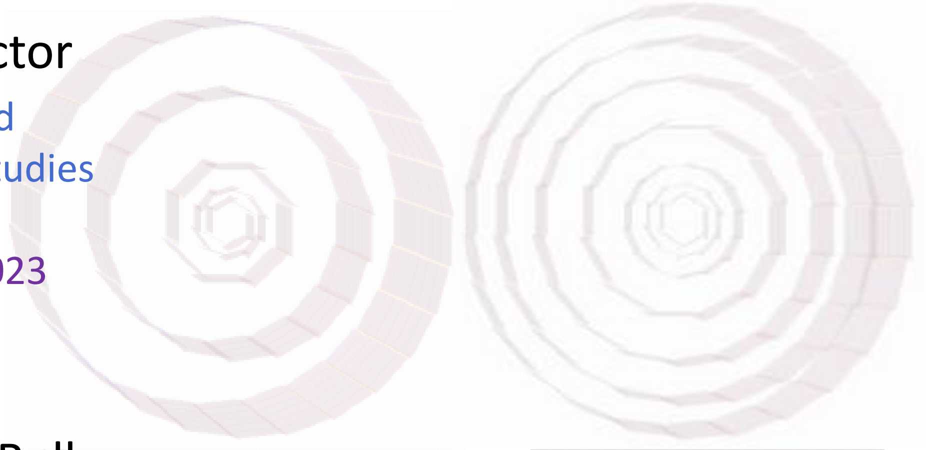
- **I presented the results in the XXVII Cracov EPIPHANY Conference and it led to a proceeding**
- **Foundation of the vertex detector upgrade program of Belle II**

Conclusion and perspective

I. Work on the upgrade of the vertex detector

- Implementation in Belle II simulation finished
- Allowed tracking and physic performances studies

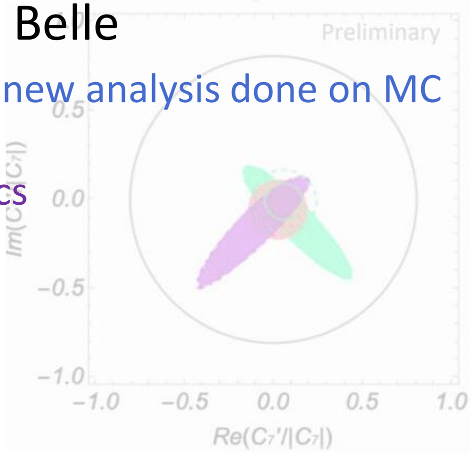
- Input for the conceptual design report for 2023

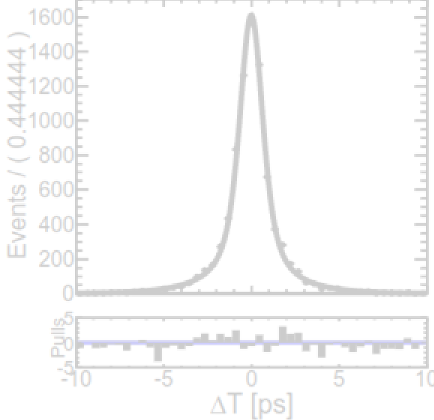


II. TDCP analysis with Dalitz separation in Belle

- First A and S sensitivity estimation with the new analysis done on MC

- Study ongoing to estimate all the systematics
- Last step before measurement on data

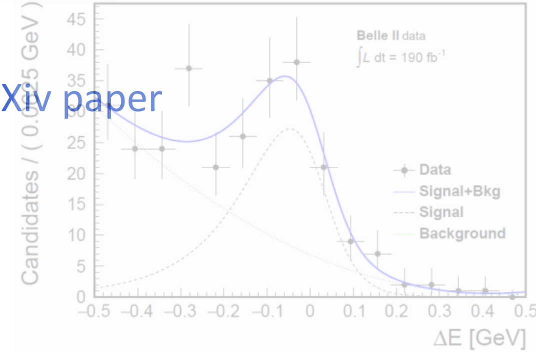




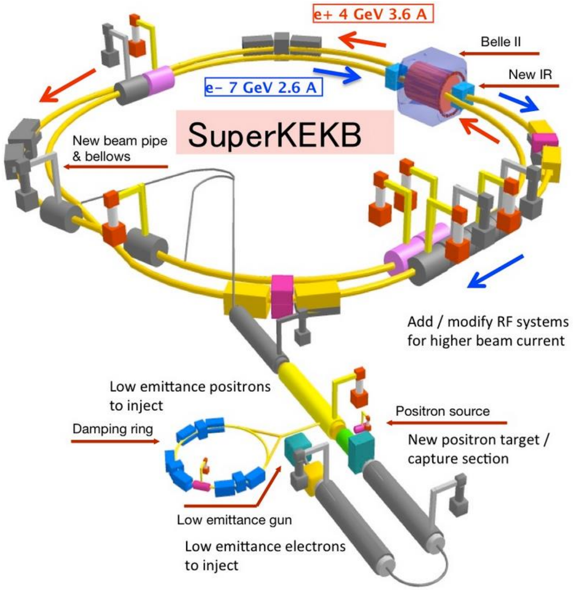
III. BR measurement in Belle II

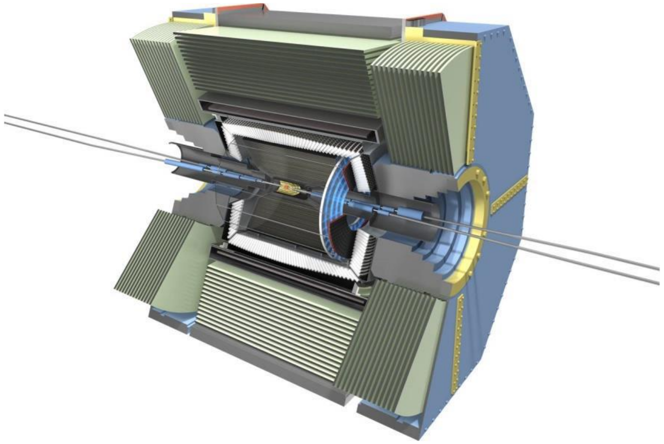
- First step toward the TDCPV measurement with Belle II
- BR measurement for $K_S\pi^0\gamma$ shown at conferences and arXiv paper

- TDCPV study planned for 2023



SuperKEKB collider and Belle II





- Started in 2019
- Electron (7 GeV) - Positron (4 GeV) collider
- B, charm and τ factory

Today

- Peak luminosity: $2.8 \cdot 10^{34}$ cm^{-2} s^{-1}
- Int. luminosity: ~ 166 fb^{-1} of data collected

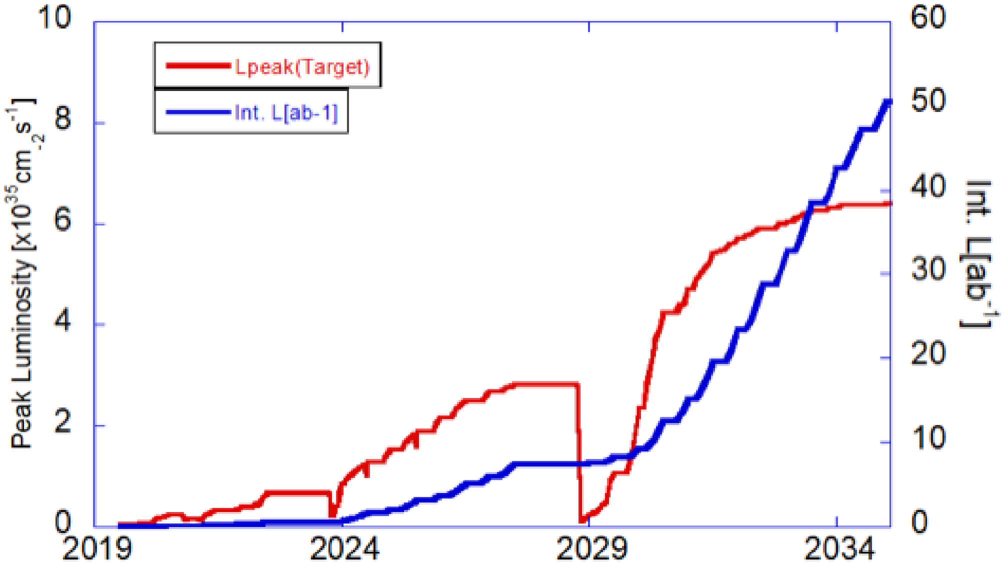
Goal

- Peak luminosity: $6 \cdot 10^{35}$ cm^{-2} s^{-1}
- Int. luminosity: 50 ab^{-1}
- Belle Int. luminosity: 1 ab^{-1}

Long shutdown in 2026:

> Opportunity for upgrade of detector

Current projection

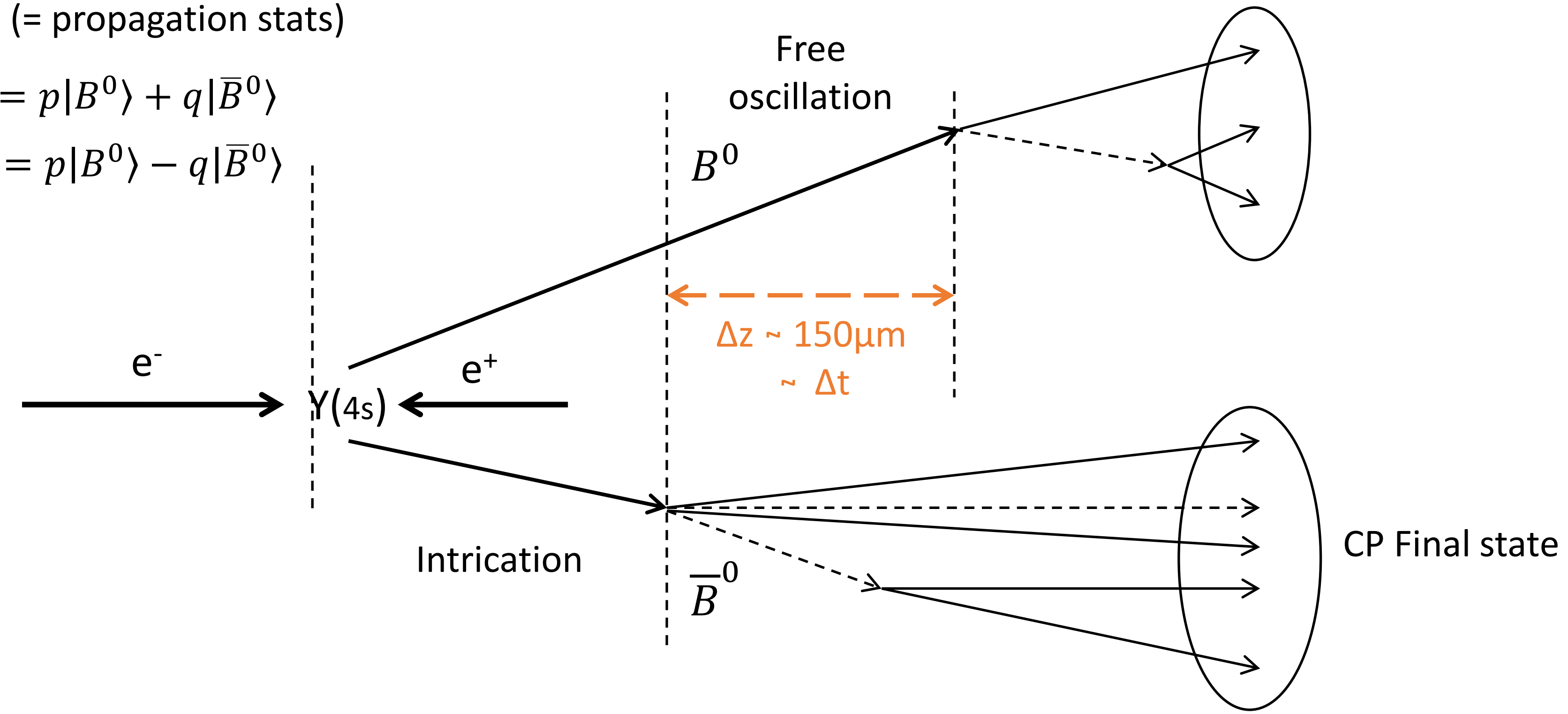


Time dependant CP violation (TDCPV)

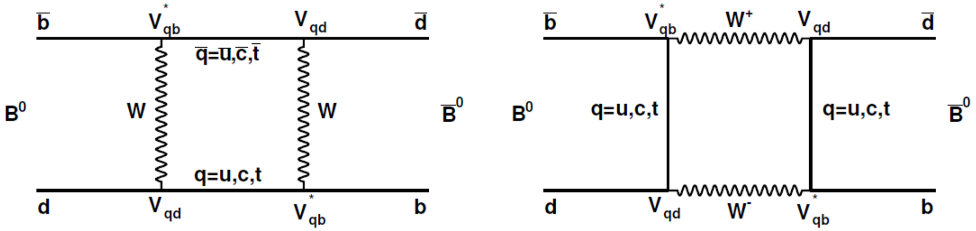
Mass stats (= propagation stats)

$$|B_L\rangle = p|B^0\rangle + q|\overline{B}^0\rangle$$

$$|B_H\rangle = p|B^0\rangle - q|\overline{B}^0\rangle$$



Feynman Diagram describing the oscillations



Asymmetry

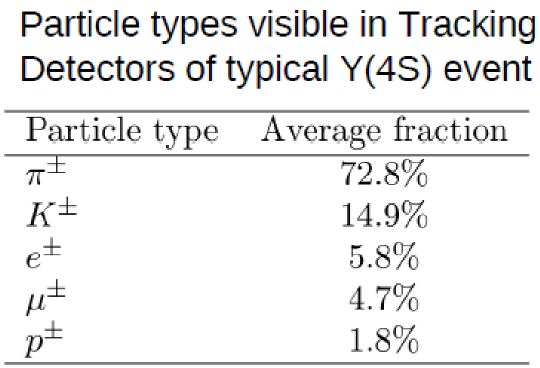
$$\mathcal{A}_{CP}(\Delta t) = \frac{\Gamma\left(B_{\text{tag}=B^0}(\Delta t) \to f_{CP}\right) - \Gamma\left(B_{\text{tag}=\bar{B}^0}(\Delta t) \to f_{CP}\right)}{\Gamma\left(B_{\text{tag}=B^0}(\Delta t) \to f_{CP}\right) + \Gamma\left(B_{\text{tag}=\bar{B}^0}(\Delta t) \to f_{CP}\right)}$$

Challenge of tracking at Belle II

- Average track multiplicity:
    - **11 physics tracks**.

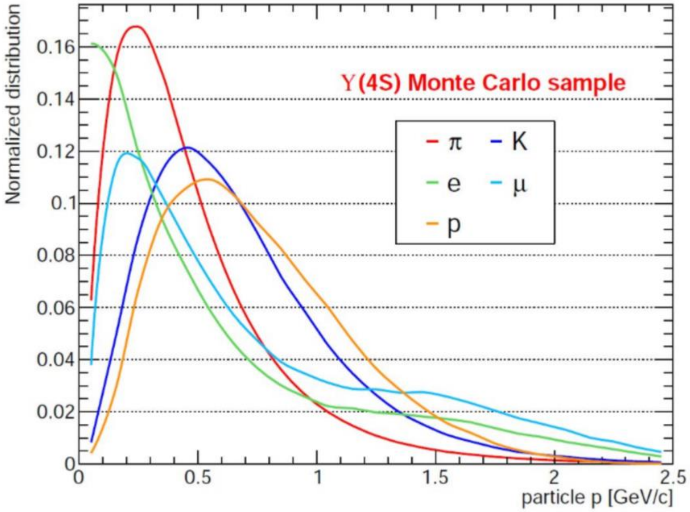
- **Similar momentum ranges and distributions**.

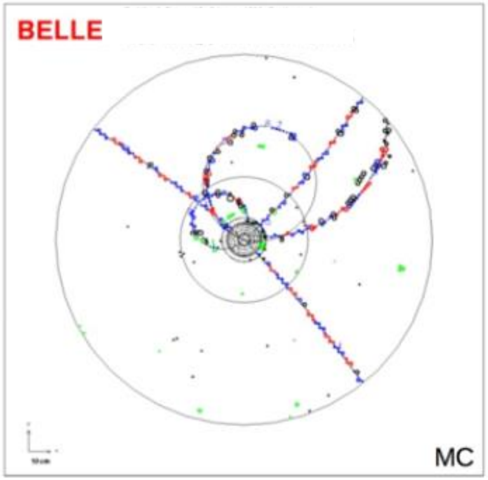
- **Low momentum tracks**
  > multiple scattering, curling tracks.

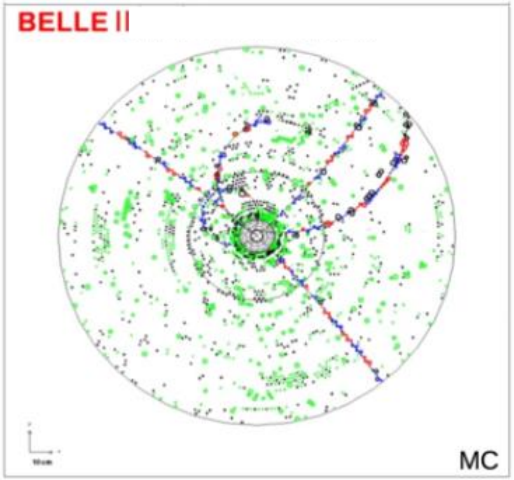


Particle types visible in Tracking Detectors of typical Υ(4S) event

Particle type	Average fraction
$\pi^{\pm}$	72.8%
$K^{\pm}$	14.9%
$e^{\pm}$	5.8%
$\mu^{\pm}$	4.7%
$p^{\pm}$	1.8%



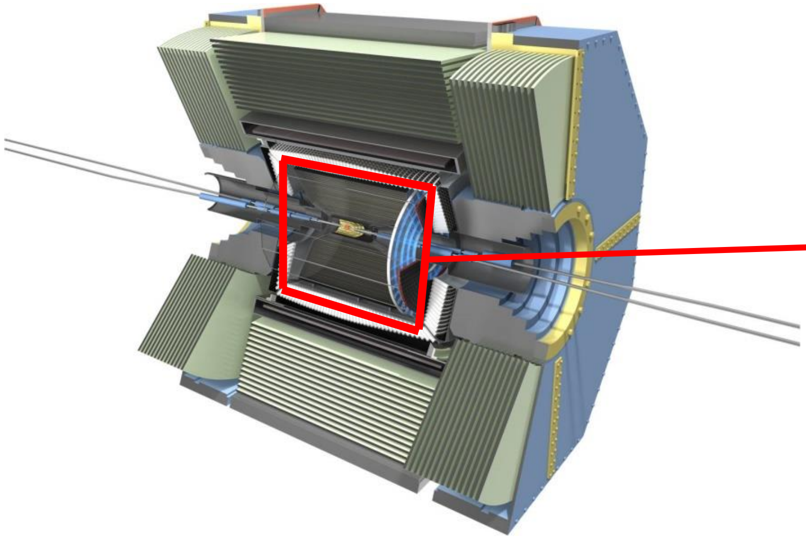


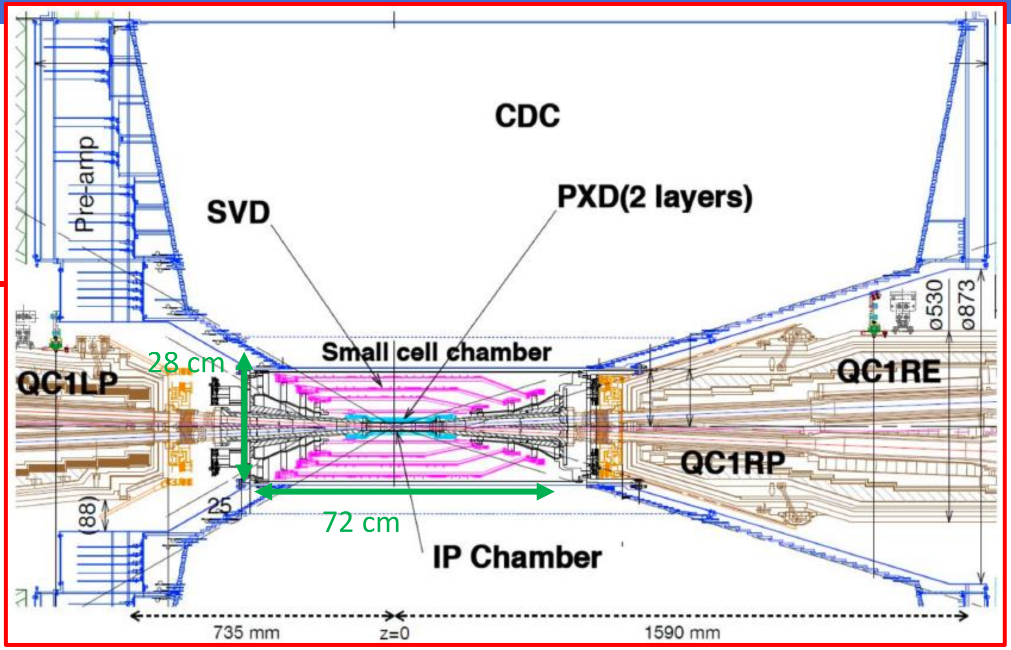


- Sizeable **beam-induced background**.

- Occupancy **dominated** by background

Belle II detector





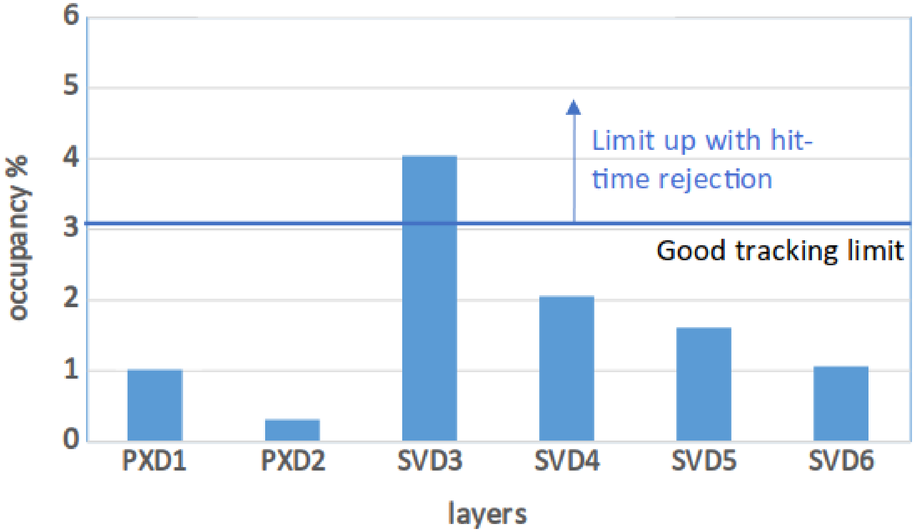
Challenges addressed by dedicated detectors:

- Central drift chamber CDC
- Vertex detector VXD:
  - Four double-sided silicon strip detectors SVD
  - Two pixelated vertex detectors PXD

Track finding

Precise vertices measurement

Vertex detector upgrade?



Current occupancy extrapolation at peak luminosity (background hard to extrapolate) close to a limit (above 3-5% occupancy, serious performance degradation) + large uncertainty on background from continuous injection.

- Opportunity to upgrade the vertex detector in 2026:
  - Better performances
  - Better background handling
  - Fully pixelated and fast detector (CMOS technology)

- $occupancy \propto \frac{t_{integration}}{granularity}$

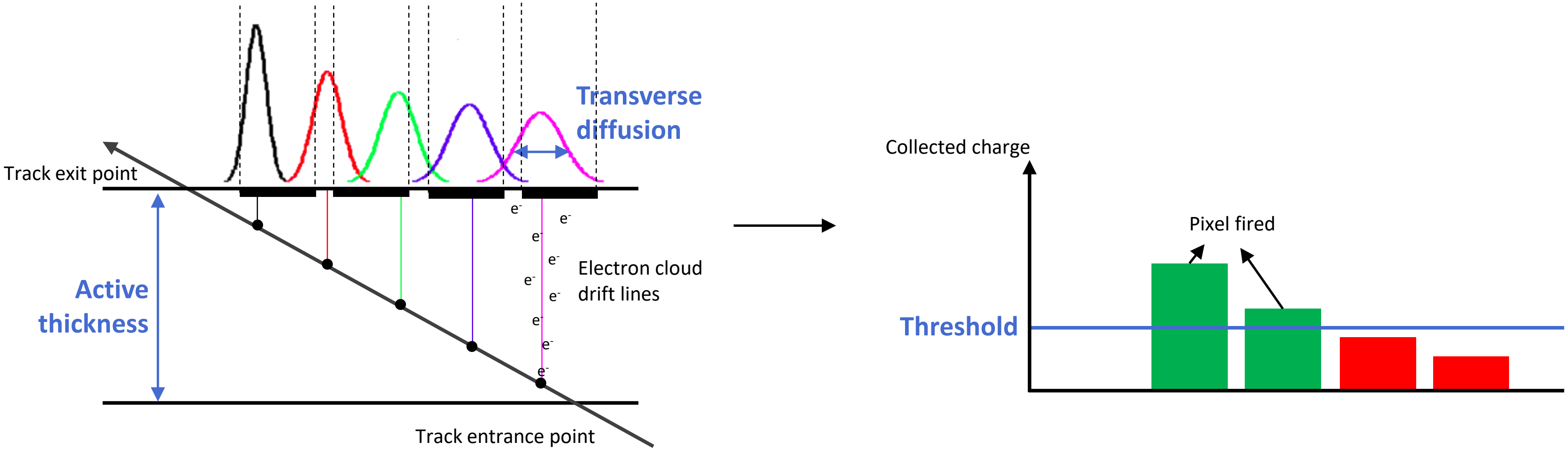
fast ↑ (over $t_{integration}$)

pixel ↓ (under $granularity$)

- Goals:
  - Use current Belle II software (basf2)
  - Implement new technologies and geometries
  - Develop a full simulation
  - Show that Belle II can benefit from a fully pixelated vertex detector

Tuning of the digitizer

- When a particle goes through the silicon layer, it creates charge diffusion inside the depleted width. Those charges are then converted to digits to process them.



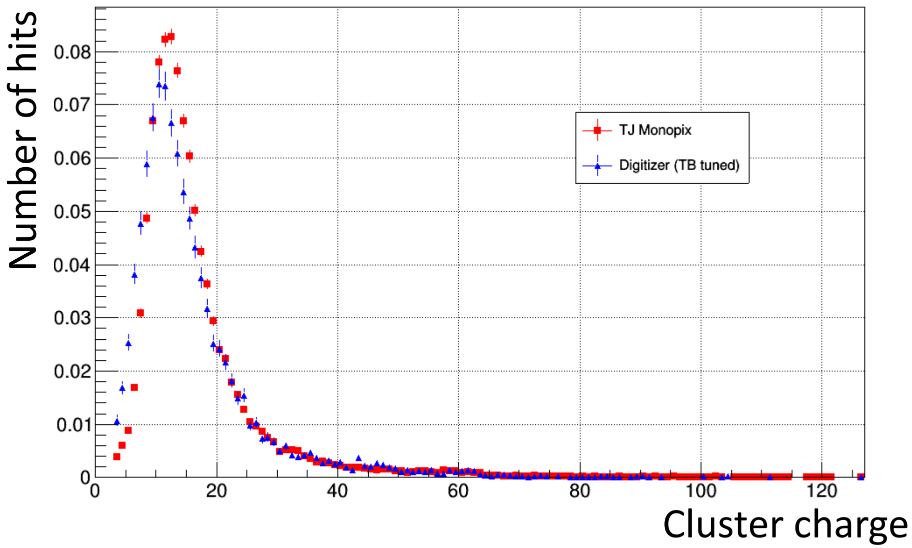
- Few parameters should be adjusted: the integration time window, the active thickness, the transverse diffusion or the hit threshold.

- Those parameters have been tuned to match a test-beam experiment made at DESY with TJ MonoPix-1 **[1]** chips, predecessor of TJ MonoPix-2 which is a good candidate for the upgrade.

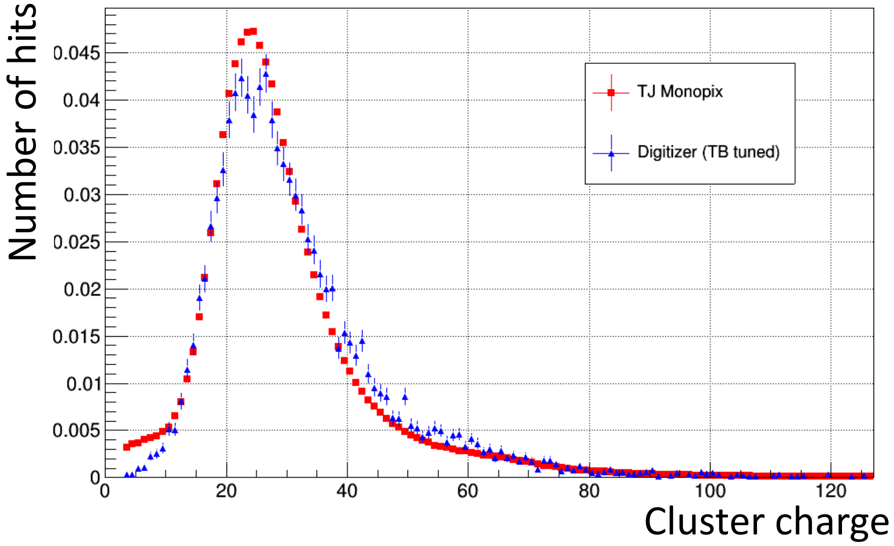
[1] https://indico.cern.ch/event/884089/

MonoPix-1 simulation results: clusters

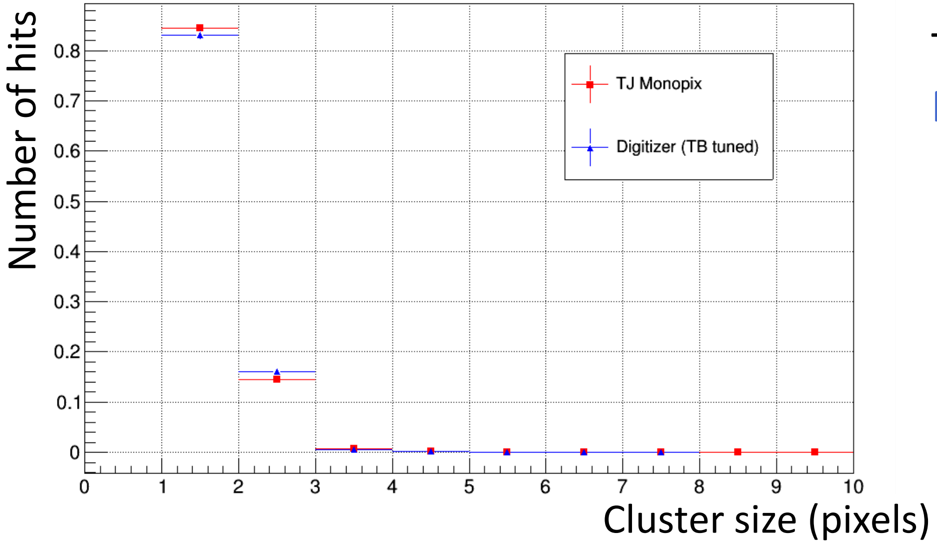
ClusterCharge at 0° (polar angle)



ClusterCharge at 60°



ClusterSize at 60°



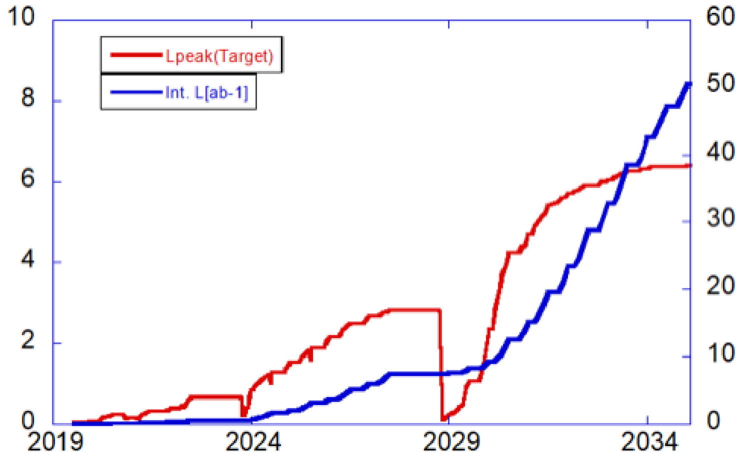
The tuned digitizer reproduces fairly well the MonoPix-1 test-beam data:

- Good agreement with cluster charge and cluster size
- resolution reproduced within 20%

> Digitizer validated for the full simulation

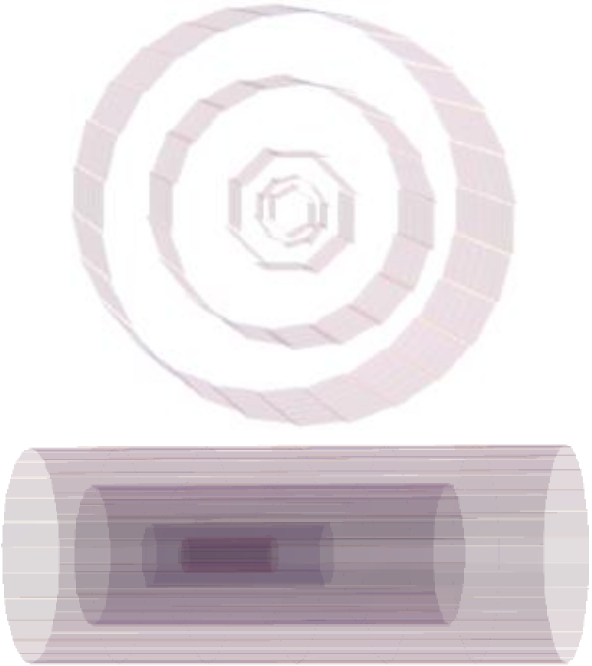
New Geometries

- **2026:** Replacement of the current VXD for:
    - Better background handling
    - Better performances
    - All layers contributing to tracking
- Fully pixelated detector (CMOS technology)

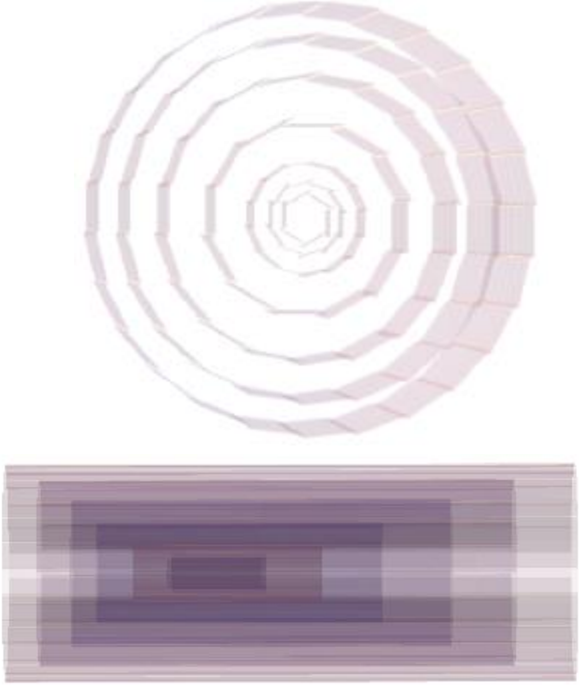


- 3 new “**VTX**” (*Vertex*) geometries implemented and connected to existing tracking:

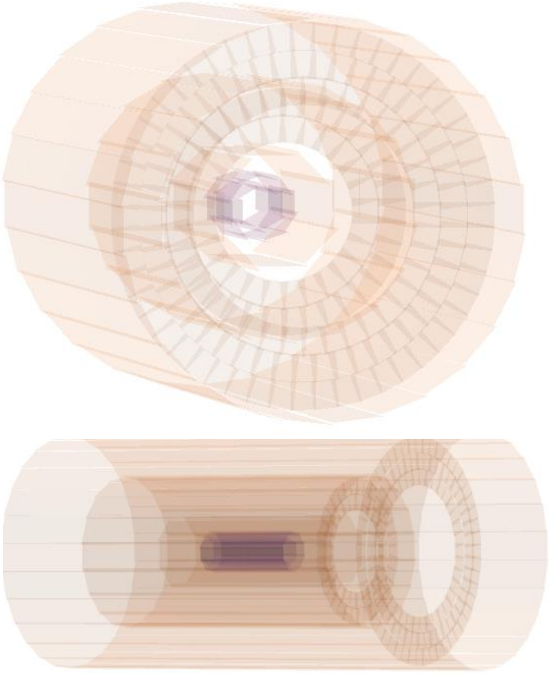
CMOS 5 layer



CMOS 7 layer

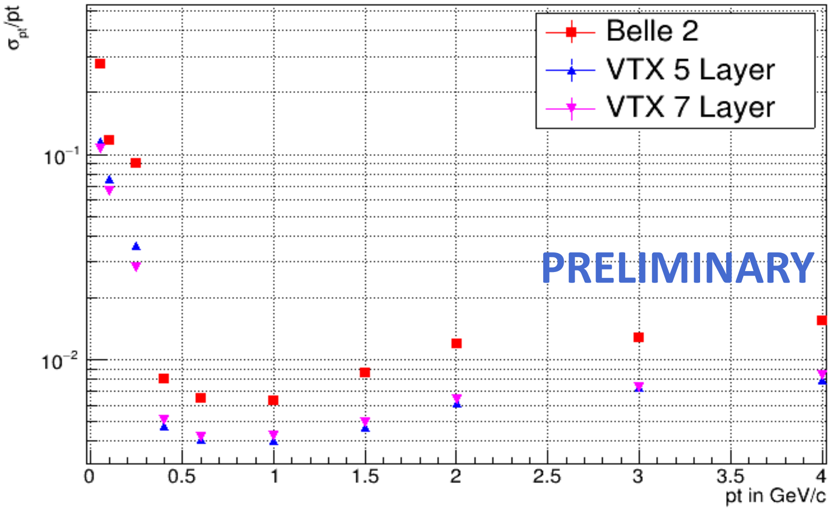


CMOS 5 layer + forward discs



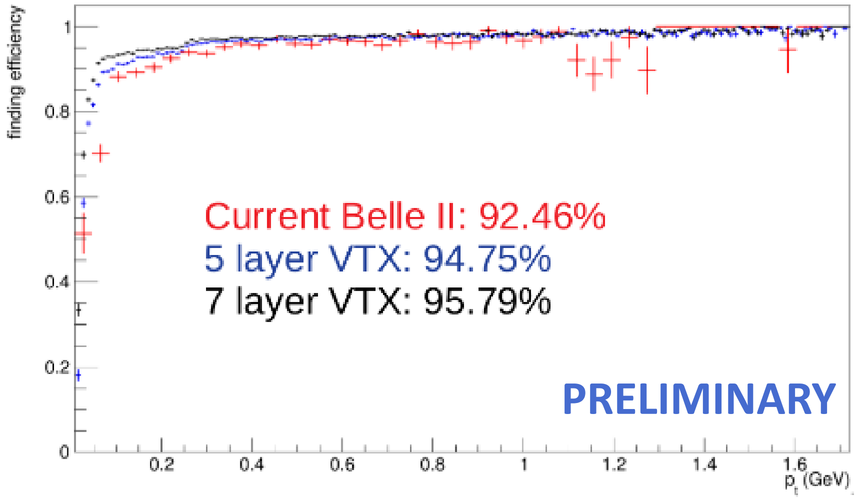
Performance

- **Transverse momentum resolution vs p_t**



- **Finding efficiency vs p_t**

Full-tracking (CDC + VTX) performance



- **Occupancy**
  - Average VTX layer 1 occupancy: 0.0016%
    > 3 order of magnitude lower than VXD

- **Tracking efficiency**

	Background x 1	**Background x 5**
Current SVD	0.961	0.907
5 layer	0.984	0.979
7 layer	0.987	0.978

- Better tracking performances at low momentum range
- Very low occupancy in innermost VTX layers
- Robust to the increase of the background

TDCPV with Dalitz separation

- **Channels chosen for the TDCPV analysis:** $B^0 \longrightarrow K_s{}^0\pi^0\gamma$ (Belle II) and $B^0 \longrightarrow K_s{}^0\pi^+\pi^-\gamma$ (Belle + Belle II)

$$B^0 \to (K^*(892)^0 \to \pi^0 K_S^0)\gamma$$ CP final state → Measure ***S*** **and** ***A*** directly

---

$$B^0 \to \boxed{K_{\text{res}}}\gamma \to \pi^+\pi^- K_S^0\gamma$$

$K_1(1270)$, $K_1(1400)$

$K^*(1410)$, $K^*(1680)$

$K_2^*(1430)$

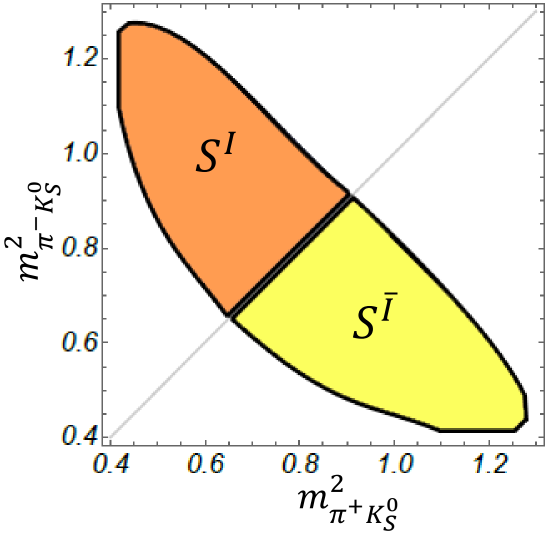
&

$$B^0 \to K_{\text{res}}\gamma \to (\rho^0 K_S^0)\gamma \to K_S^0(\pi^+\pi^-)\gamma,$$ CP final stat

$$\left.\begin{array}{l} B^0 \to K_{\text{res}}\gamma \to (K^{*+}\pi^-)\gamma \to (K_S^0\pi^+)\pi^-\gamma, \\ B^0 \to K_{\text{res}}\gamma \to ((K\pi)_0^+\pi^-)\gamma \to (K_S^0\pi^+)\pi^-\gamma, \end{array}\right\}$$ Non-CP final stat

Dilution factor: $\mathcal{D} = \frac{S_{\pi^+\pi^-K_S^0\gamma}}{S_{\rho^0K_S^0\gamma}}$

Obtained with $B^+ \longrightarrow K^+\pi^+\pi^-\gamma$ analysis



→ Measure ***S*** **and** ***A*** directly considering the dilution factor

→ Use new method from Simon AKAR *et al.* which separate the Dalitz plane to gain more information on C_7 and C'_7

Akar *et al.*, JHEP 09 (2019) 034

New observables: $S^+_{\pi^+\pi^-K_S^0\gamma} = S^I + S^{\bar{I}}$ $S^-_{\pi^+\pi^-K_S^0\gamma} = S^I - S^{\bar{I}}$

TDCP asymmetry, experimental function

- Various contribution:
    - Wrong flavor
    - Continuum events
    - Other (non signal) B
    - Signal B but miss-reconstructed

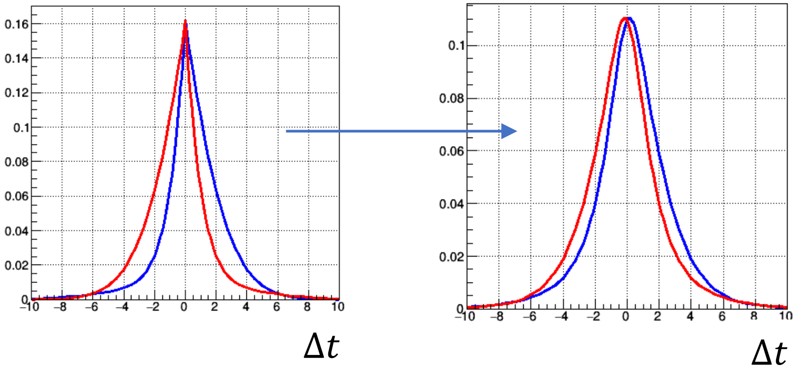
- Signal Δt experimental function

$$\boxed{P(\Delta t, q) = f_{sig}\,\frac{e^{-|\Delta t|/\tau}}{4\tau} * [1 - q\Delta w + q(1-2w)(A\cos\Delta m_d \Delta t + S\sin\Delta m_d \Delta t)] \otimes R_{res}}$$

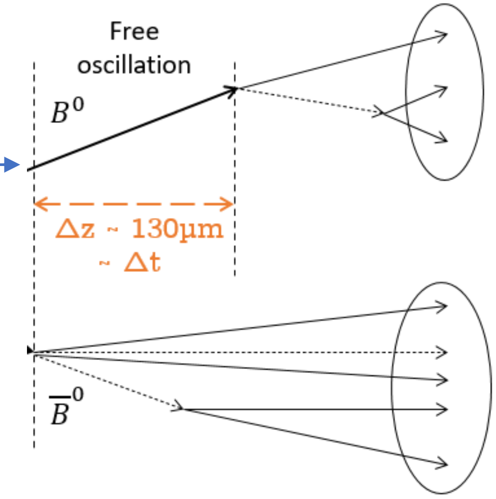
$$\boxed{+\left(1 - f_{sig}\right) P_{bkg}}$$

- **Measured**:
  - f_{sig} : Signal fraction
  - q_{tag}: flavor of the B (0 or 1)
  - Δt : Time difference between the decay of the *B*

- Resolution function R_{res}:
  Convolution of various resolutions



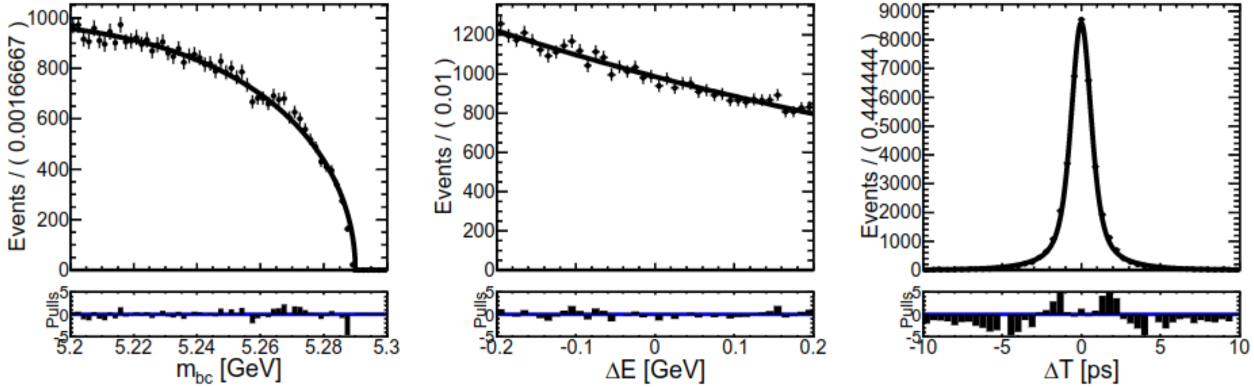
- **Constant**:
  - τ : B^0 lifetime
  - $\Delta\, m_d \;= M_H - M_L$
  - w: mistag fraction
  - Δw: tagging efficiency difference for B or $\overline{B}$



3D fit – Determination of PDFs with MC

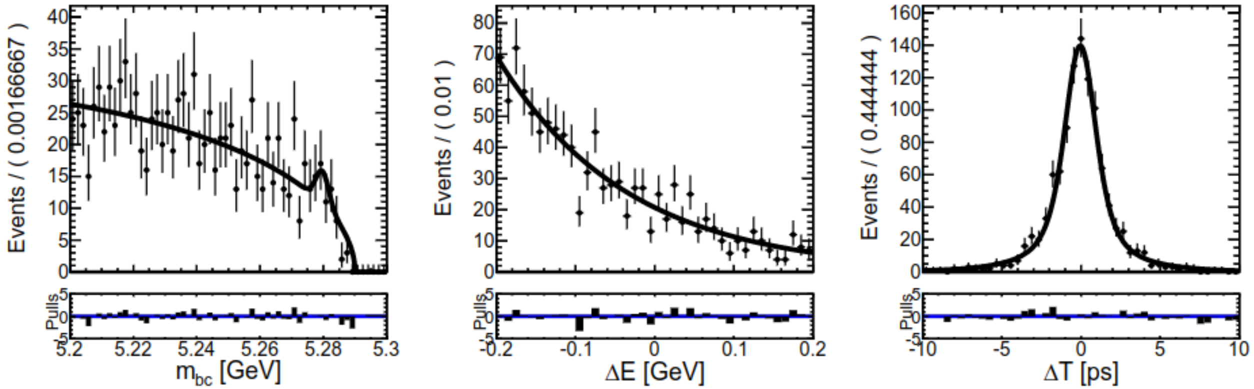
Continuum

- $u\bar{u}$ $d\bar{d}$ $s\bar{s}$
- $c\bar{c}$



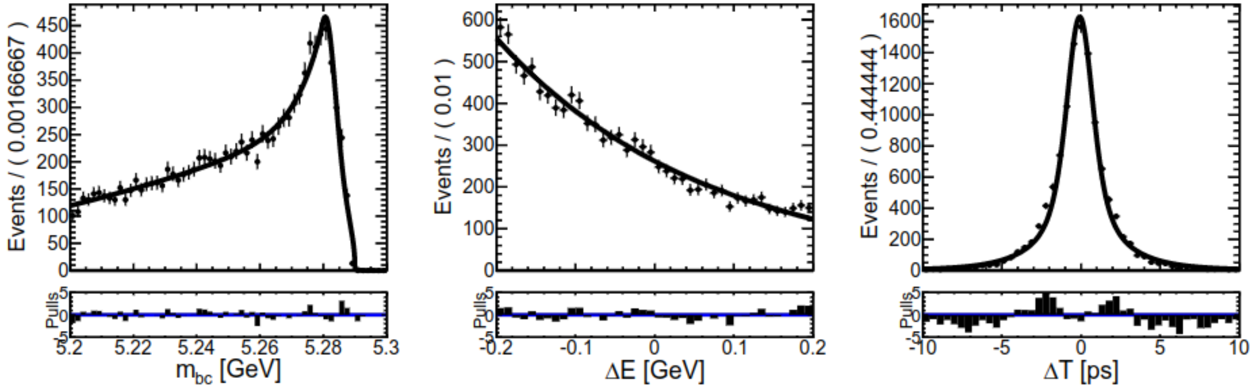
BB bkg

- $B^0\bar{B}^0 + B^+B^-$
- Without our signal



Rare bkg

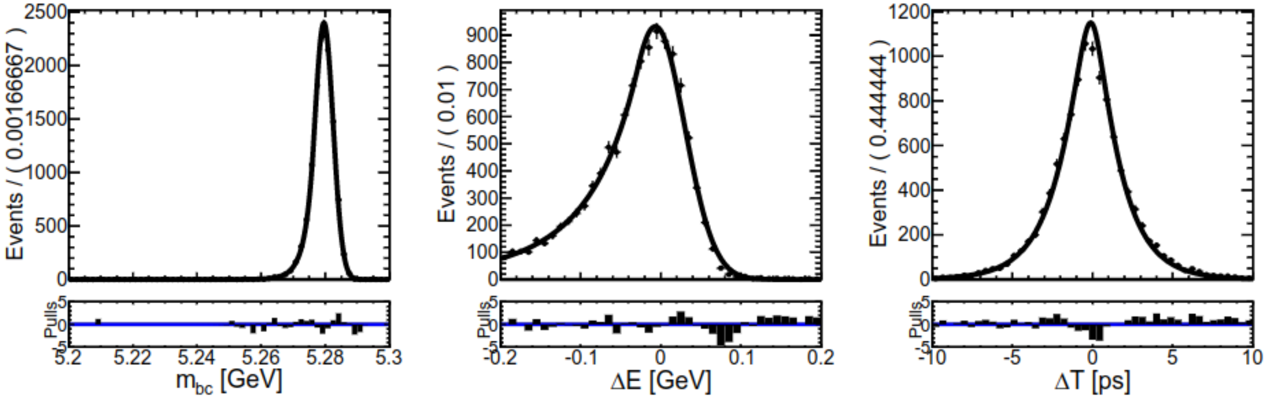
- Enhanced rare b decays
- Without our signal



3D fit – Determination of PDFs with MC

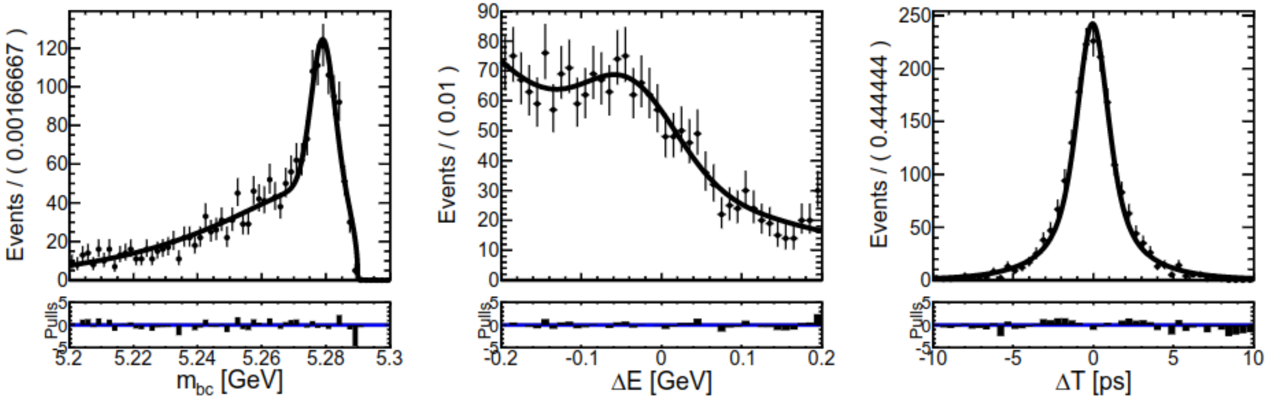
Signal

- Private Signal MC
- Truth matched
- 2.28 ± 0.02 % efficiency



Self-Crossfeed

- Not all tracks are from the signal side
- Private Signal MC
- Without our signal



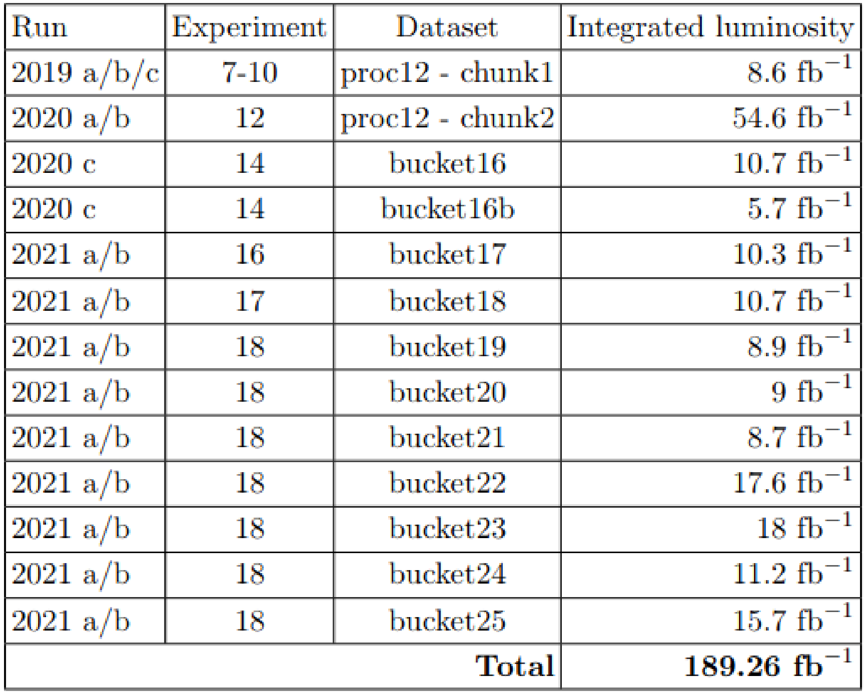
Dataset used

- **MC: 700 fb^{-1} MC14ri_d and 200 fb^{-1} MC14ri_a sample**
  - $B^0\bar{B}^0, B^+B^-, c\bar{c}, s\bar{s}, u\bar{u}, d\bar{d}, \tau\tau$
  - 200 fb^{-1}: Same size as the final Data dataset, used to estimate expected yields
  - 700fb^{-1}: Used to optimize the selection, determine the fit functions and background rejection

- **MC Signal only samples:**
  - 2M events
    - $B \rightarrow K^{*0}\gamma \rightarrow K_s^0\pi^0 \rightarrow \pi^+\pi^-$
  - Used to calculate the signal efficiency

- **Data: 190 fb^{-1}**

  proc12 to bucket25 →



Run	Experiment	Dataset	Integrated luminosity
2019 a/b/c	7-10	proc12 - chunk1	8.6 fb^{-1}
2020 a/b	12	proc12 - chunk2	54.6 fb^{-1}
2020 c	14	bucket16	10.7 fb^{-1}
2020 c	14	bucket16b	5.7 fb^{-1}
2021 a/b	16	bucket17	10.3 fb^{-1}
2021 a/b	17	bucket18	10.7 fb^{-1}
2021 a/b	18	bucket19	8.9 fb^{-1}
2021 a/b	18	bucket20	9 fb^{-1}
2021 a/b	18	bucket21	8.7 fb^{-1}
2021 a/b	18	bucket22	17.6 fb^{-1}
2021 a/b	18	bucket23	18 fb^{-1}
2021 a/b	18	bucket24	11.2 fb^{-1}
2021 a/b	18	bucket25	15.7 fb^{-1}
		Total	**189.26 fb^{-1}**

TABLE II: List of the various datasets used in this analysis.

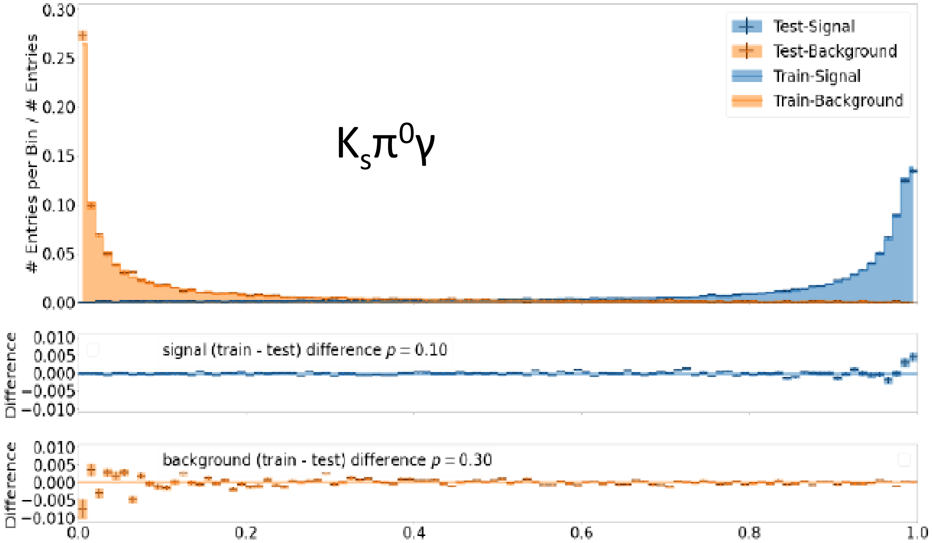
Analysis workflow

Continuum Suppression (CSMVA)

- Trained with BASF2 fastBDT with standard settings
  - 30 continuum variables: R2,cosTBTO, cosTBz, thrustOm, thrustBm, Kakuno-Super-Fox-Wolfram moments, CLEO cones

- Training sample:
  - 60k evts from the 2M with signal truth matching + 60k continuum evts from 700fb^{-1}
- Test sample:
  - 30k evts 2M + 30k 700fb^{-1}

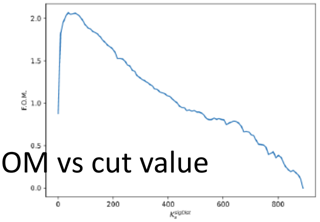
- **Good discrimination between signal and continuum**

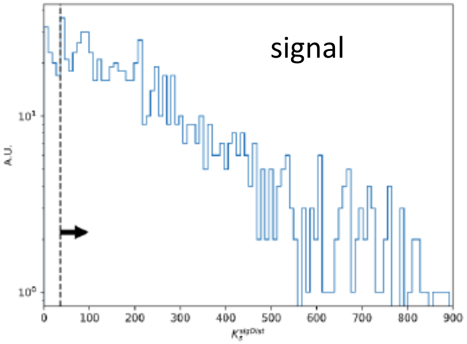


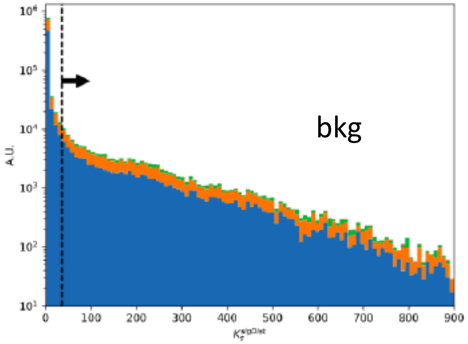
Selection strategy

- Selected variables:
    - **CSMVA output**: reduce continuum
    - $m_{K_S{}^0\pi^0}$: reduce other K_{res}
    - K_S^0 **decay length significance**: good K_s selection, further reduce continuum
    - $\mathbf{m_{bc}}$ **:** reduce continuum and $B\bar{B}$ background
- Figure of merit (FOM): $\frac{S}{\sqrt{S+B}}$
- In the signal range: $5.26 < m_{bc} < 5.3$ GeV/c; $-0.2 < \Delta E < 0.1$ GeV

- **Selection procedure**:
    1. For each variable, the FOM is measured as a function of the variable cut values and the one with the highest FOM is chosen.
    2. All found cuts are applied, then a new variable is optimized the same way
    3. Repeat until no variable left
- The order of the variables is also optimized

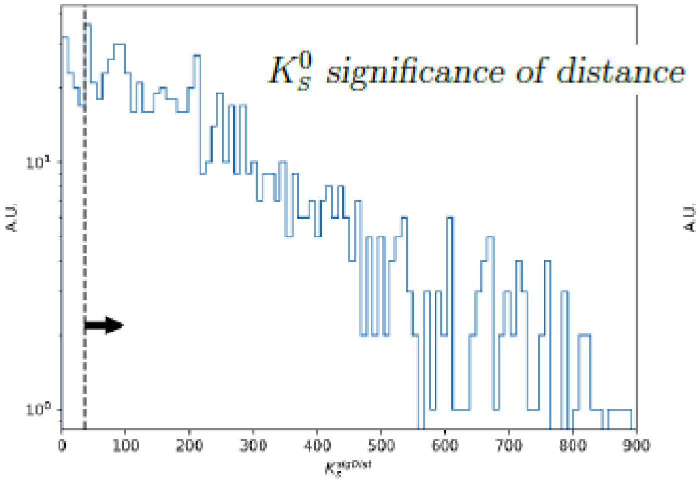


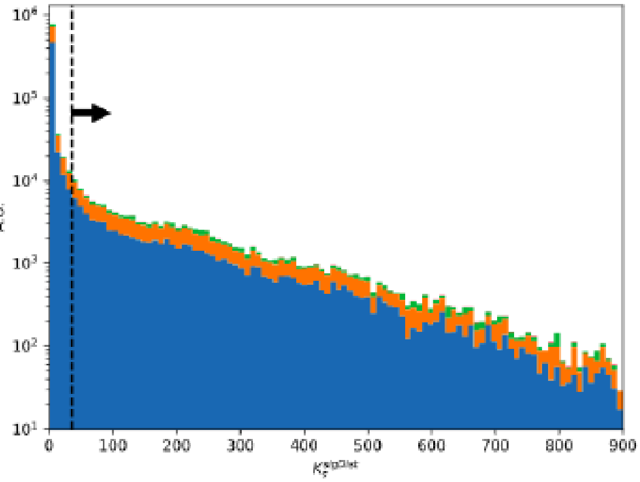


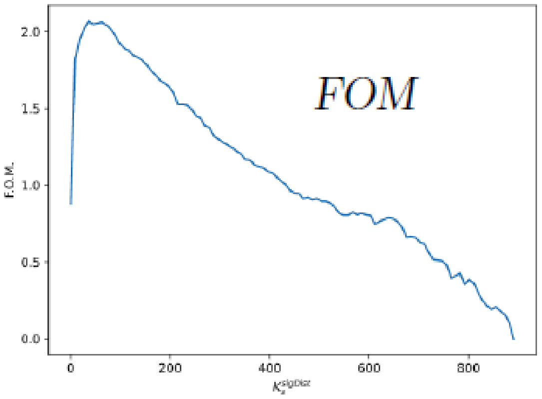


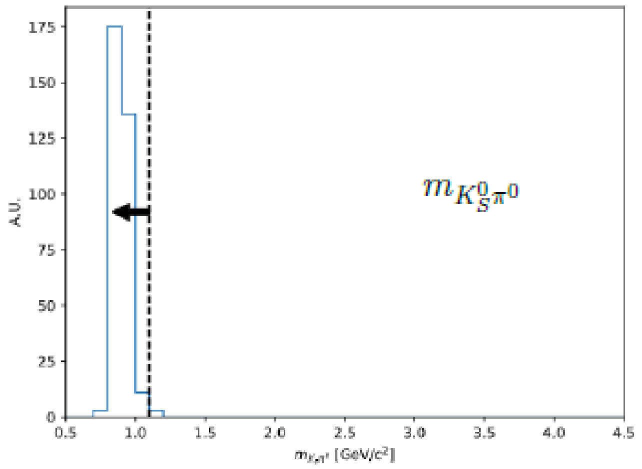
Selection strategy – $K_s\pi^0\gamma$ - example

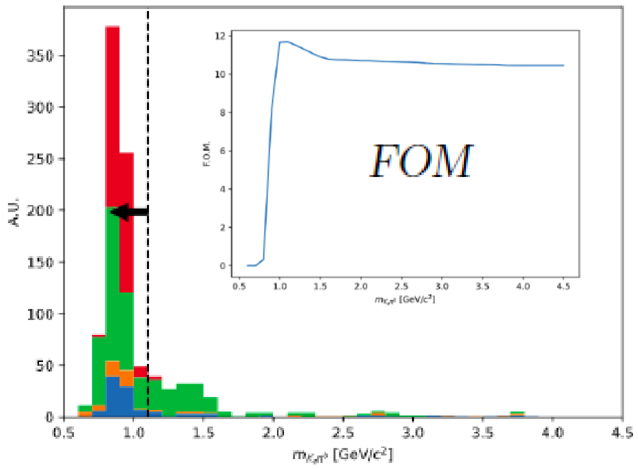
Blue is qq, orange cc and green BB



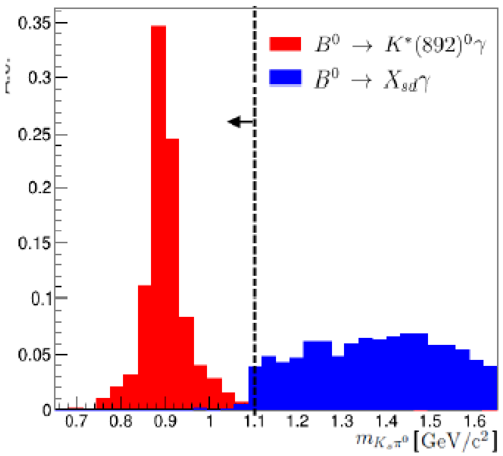






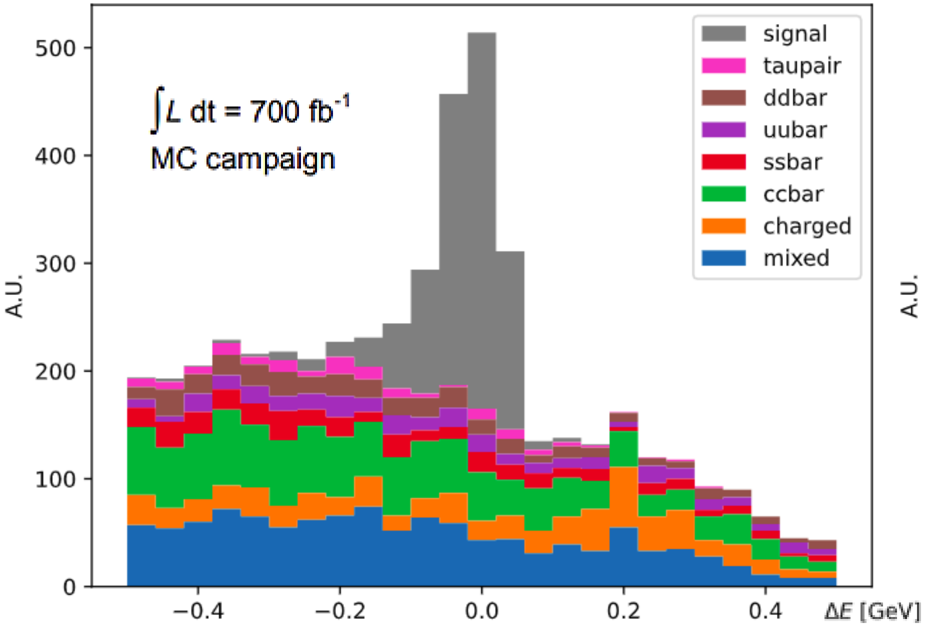


m_{KSpi0} cut removes the X_{sd} resonnance



Contributions after the selection

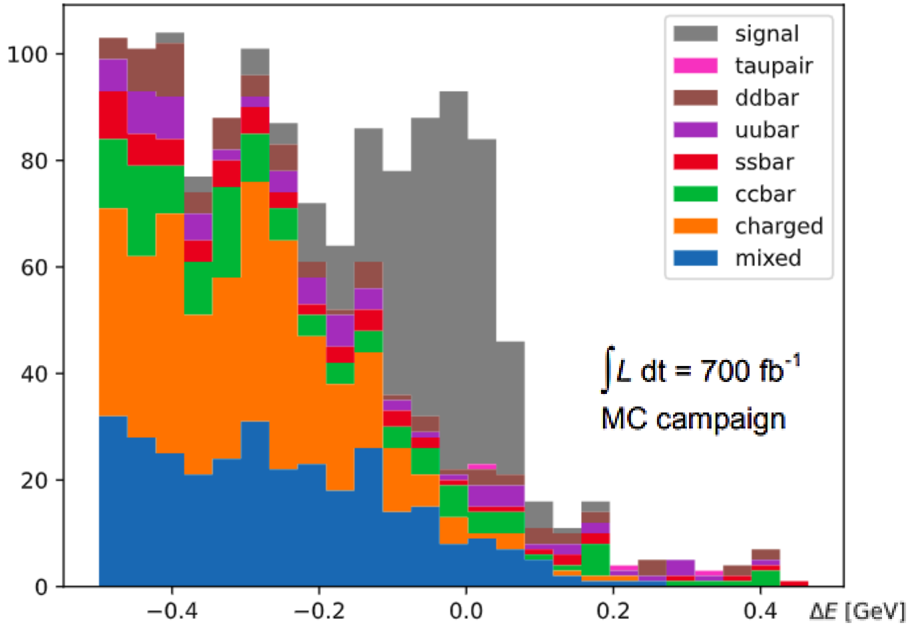
$K_s^0\pi\pi\gamma$



cut value
$m_{K_s\pi\pi} < 1.8$ GeV/c^2
$m_{\text{bc}} > 5.275$ GeV/c^2
$K_s^{sigDist} > 63$
CSMVA > 0.88

- **Signal efficiency:** (8.29 ± 0.02)%
- **Significance** from 4 to (22 ± 0.5)

$K_s^0\pi^0\gamma$



cut value
$K_s^{sigDist} > 36$
$m_{\text{bc}} > 5.275$ GeV/c^2
CSMVA > 0.96
$m_{K_s\pi^0} < 1.1$ GeV/c^2

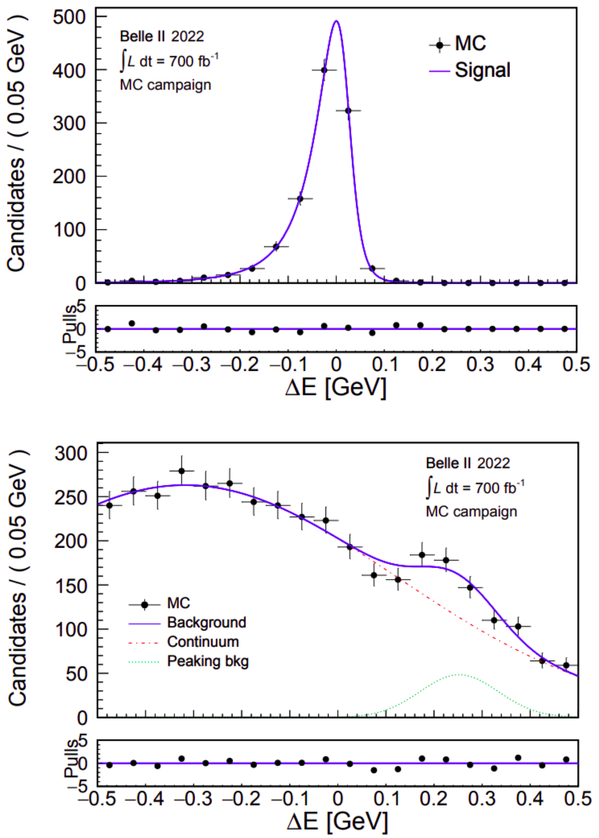
- **Signal efficiency:** (8.69 ± 0.02)%
- **Significance** from 2 to (12 ± 0.5)

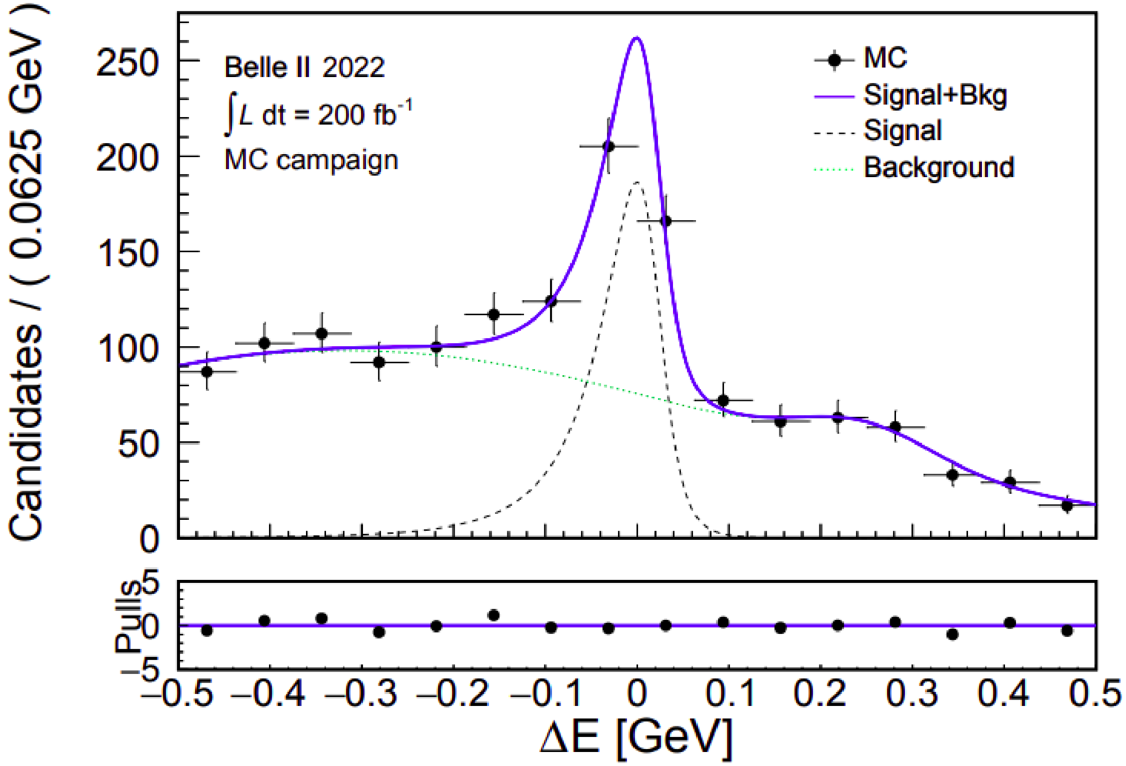
ΔE fit – $K_s^0\pi\pi\gamma$

- Shape parameters fixed from 700 fb^{-1} sample
- Yields left free
- $f_{peakingBkg}$, μ_{sig} and σ_{sig} free

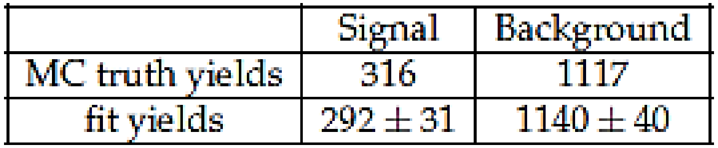
- ΔE distribution of signal+bkg
- **200 fb^{-1}** (~ final data sample size)

Templates





Results



	Signal	Background
MC truth yields	316	1117
fit yields	292 ± 31	1140 ± 40

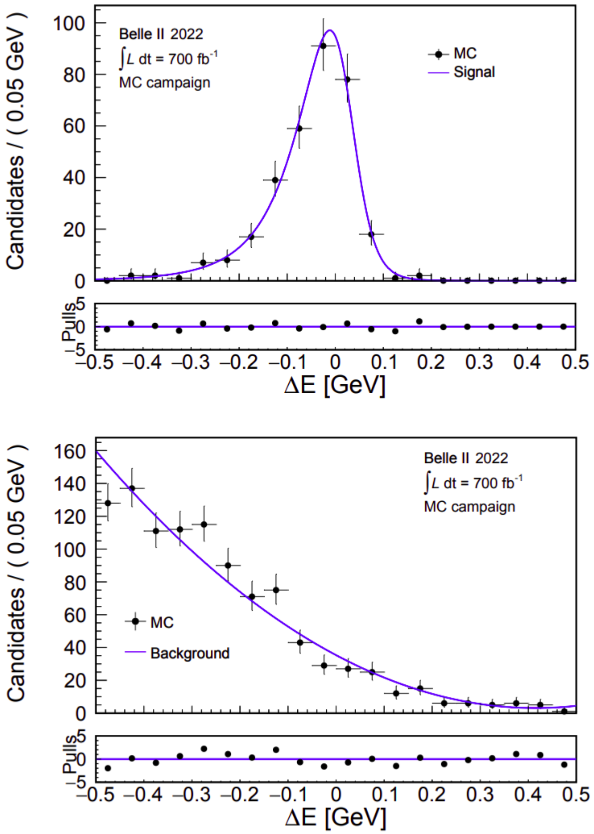
Compatible yields, μ_{sig} and σ_{sig}

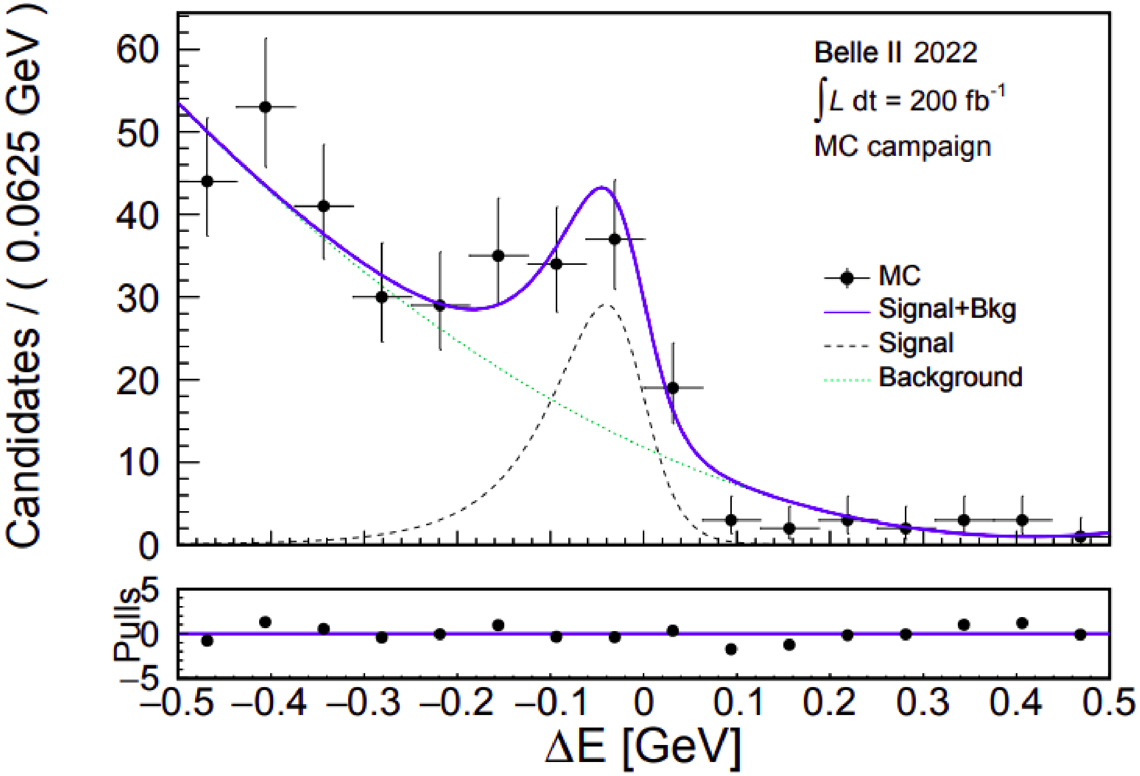
ΔE fit – $K_s^0 \pi^0 \gamma$

- Bkg shape parameters fixed from 700fb^{-1} sample
- Yields left free
- μ_{sig} and σ_{sig} free

- ΔE distribution of signal+bkg
- **200 fb^{-1}** (~ final data sample size)

Templates





Results

	Signal	Background
MC truth yields	75	264
fit yields	67 ± 15	272 ± 21

Compatible yields, μ_{sig} and σ_{sig}

Systematic uncertainties study and BR calculation

$$\mathcal{B} = \frac{N}{2\varepsilon f^{00} N_{B\overline{B}}}$$

- N: yield extracted from the ΔE fit
- ε : efficiency of the selection

$$\epsilon(B^0 \to K_S^0\pi^+\pi^-\gamma) = (8.566 \pm 0.571)\%$$
$$\epsilon(B^0 \to K_S^0\pi^0\gamma) = (8.669 \pm 0.666)\%$$

- f^{00} : BR of Υ(4S) going to $B^0\overline{B^0}$ (from PDG)
- $N_{B\overline{B}}$:estimated number of $B\overline{B}$ pairs produced in the data sample

Efficiency systematics	$B^0 \to K_S^0\pi^+\pi^-\gamma$	$B^0 \to K_S^0\pi^0\gamma$
MC sample size (stat error)	0.2 %	
MC generation	4.2 %	2.0 %
pion PID	0.2 %	-
Tracking	1.38 %	-
π^0 reconstruction	-	5.5 %
K_S^0 reconstruction	3.60 %	3.46 %
π^0 veto	1.7 %	1.9 %
γ selection	0.3 %	
Continuum suppresion	3.0 %	
Total efficiency	6.67 %	7.68 %

Yields systematic	$B^0 \to K_S^0\pi^+\pi^-\gamma$	$B^0 \to K_S^0\pi^0\gamma$
Fit bias	2.7 %	11.5 %

Number of $B^0\bar{B}^0$ pairs syst	2.9 %

f^{00} systematic	1.2 %

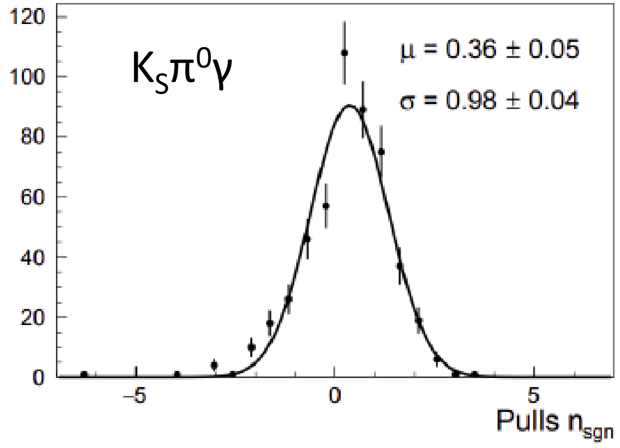
	$B^0 \to K_S^0\pi^+\pi^-\gamma$	$B^0 \to K_S^0\pi^0\gamma$
Total	7.86 %	14.2 %

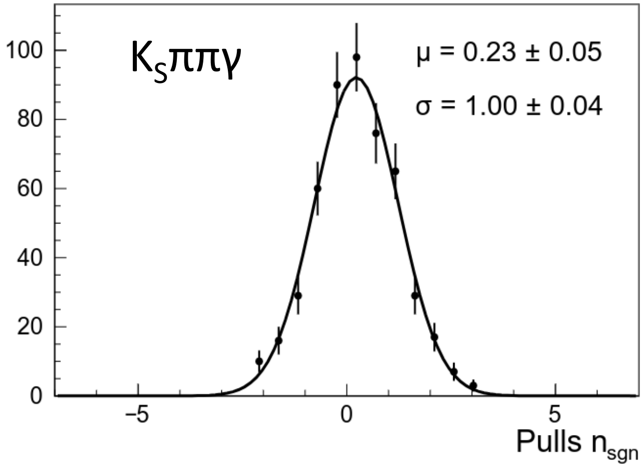
Fit stability

- 500 x 200 fb^{-1} MC datasets created by **bootstrapping** the initial 700 fb^{-1}
- Fit all the 500 datasets
- Plot pulls:

$$n_{\text{sgn } diffs} = n_{\text{sgn } fit} - n_{\text{sgn } true}$$

$$n_{\text{sgn } pulls} = \frac{n_{\text{sgn } diffs}}{n_{\text{sgn } fit-error}}$$





- Over estimation of the signal, taken into account as a systematic of 11.5% for $K_S^0\pi^0\gamma$ and 2.7% for $K_S^0\pi\pi\gamma$
- Leading systematic for $K_S^0\pi^0\gamma$
  > We tried a lot of different fit functions and to fit the peaking B^+B^- background but no improvements were observed