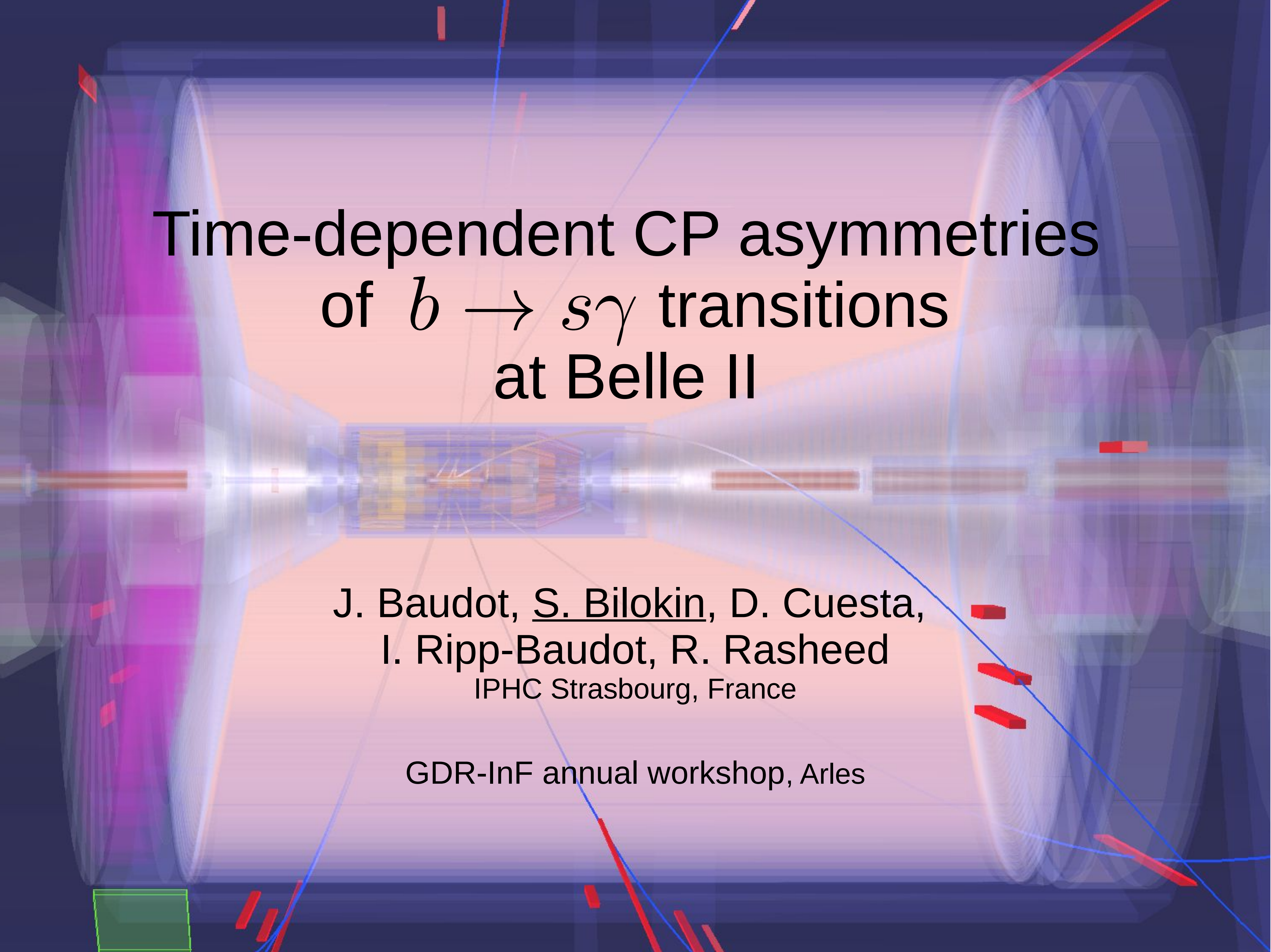

Time-dependent CP asymmetries of $b \to s\gamma$ transitions at Belle II

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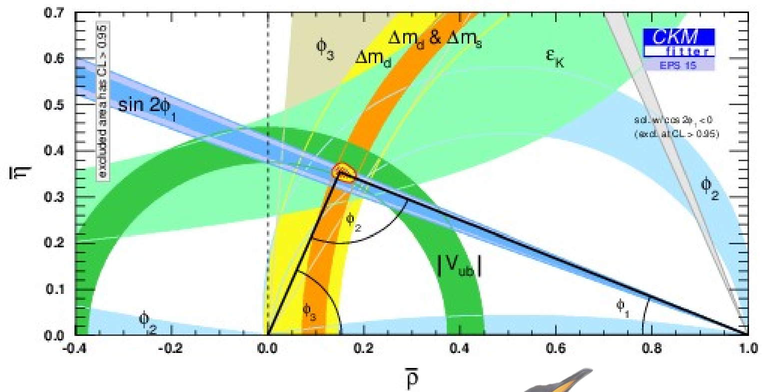
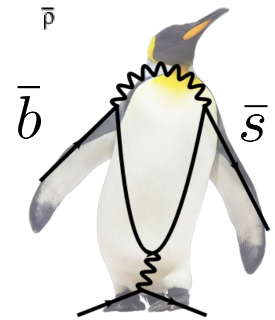
IPHC Strasbourg, France

GDR-InF annual workshop, Arles

Scientific motivation

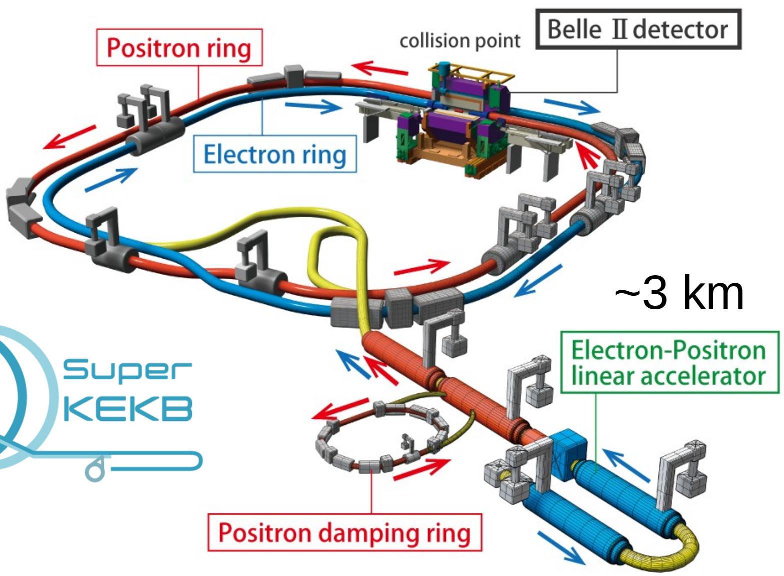
- Belle II @ SuperKEKB is the new e^+e^- facility at intensity frontier, which studies properties of rare B meson decays – **b-factory**
  - High-Lumi successor of **Belle @ KEKB** and **BaBar @ PEP II**
  - Rich physics program
    - Direct searches of BSM
      - Dark matter, axions, exotics ...
    - Indirect searches
      - **B physics (CKM, EW penguins, <u>radiative decays</u>)**
      - Charm physics
      - Tau physics
    - Quarkonium and QCD studies

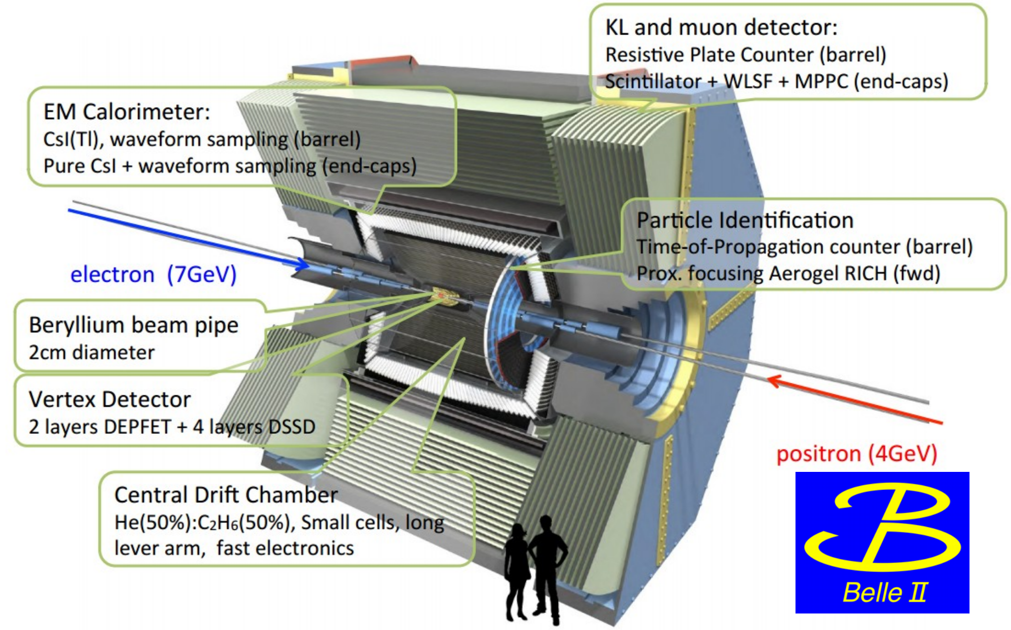




- No New Physics (NP) particles have been discovered at the LHC yet
  - Importance of the indirect searches is rising
  - Belle II can reach beyond the energy frontier sensitivity
- Constructive complementarity & competition with LHC

Belle II at SuperKEKB





- Most of the data will be taken at the Y(4S) resonance
  - $E(e^-) = 7\,GeV,\ E(e^+) = 4\,GeV$
- Nano-beam scheme and doubling the beam current
  - Vertical beam size is 50nm
  - Higher beam background
- $\mathcal{L} = 8 \cdot 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}(\mathrm{KEKB\ x\ 40})$

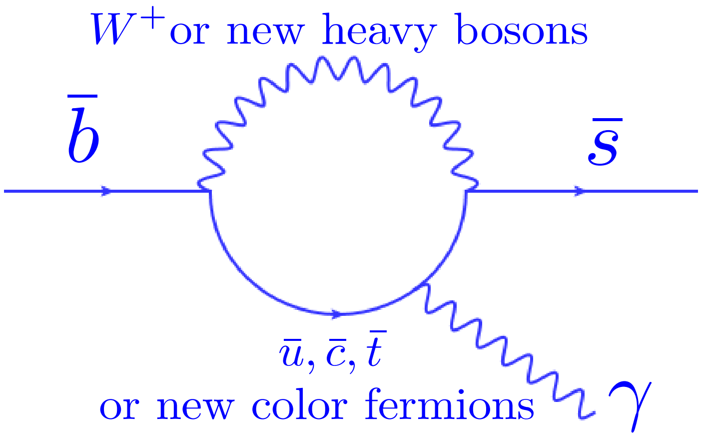
Belle II TDR - arXiv:1011.0352

- Improved vertex resolution, PID, tracking, etc...
- High detection efficiency $\gamma, \pi^0, K^0_{S,L}$
- **Detector commissioning has been started**
  - **0.5 fb^{-1} collected**
    $\mathcal{L} = 5.5 \cdot 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- **Almost full Belle II next year**

Plan to collect 50 ab^{-1} by 2025

Introduction

- We are interested in time-dependent CP analysis of $b \to s\gamma$ transitions
  - In Standard Model
    no time-dependent CP violation (TDCPV)
    is expected due to its V-A structure
    and photon polarization
  - Sensitive to New Physics effects



- We are studying two channels:
  - $B^0 \to K_S^0 \pi^0 \gamma$ $\quad$ $B^0 \to K_S^0 \pi^+ \pi^- \gamma$
  - BR: 9.5×10^{-6} $\quad$ 7×10^{-6} where $K_S^0 \to \pi^+ \pi^-$

- These processes go through several resonances K^{*0} and higher K_1^0, K_2^0, … etc, often called $\mathbf{X_{sd}}$
  - $B^0 \to K_S^0 \pi^0 \gamma$ goes through K^{*0} and X_{sd}
  - $B^0 \to K_S^0 \pi^+ \pi^- \gamma$ goes through X_{sd}, includes non-CP eigenstates

TDCPV measurement

- We are interested in time-dependent asymmetry:

$$A_f(t) = \frac{\Gamma(B^0(t) \to f) - \Gamma(\bar{B}^0(t) \to \bar{f})}{\Gamma(B^0(t) \to f) + \Gamma(\bar{B}^0(t) \to \bar{f})}$$

- This asymmetry can be parametrized as following:

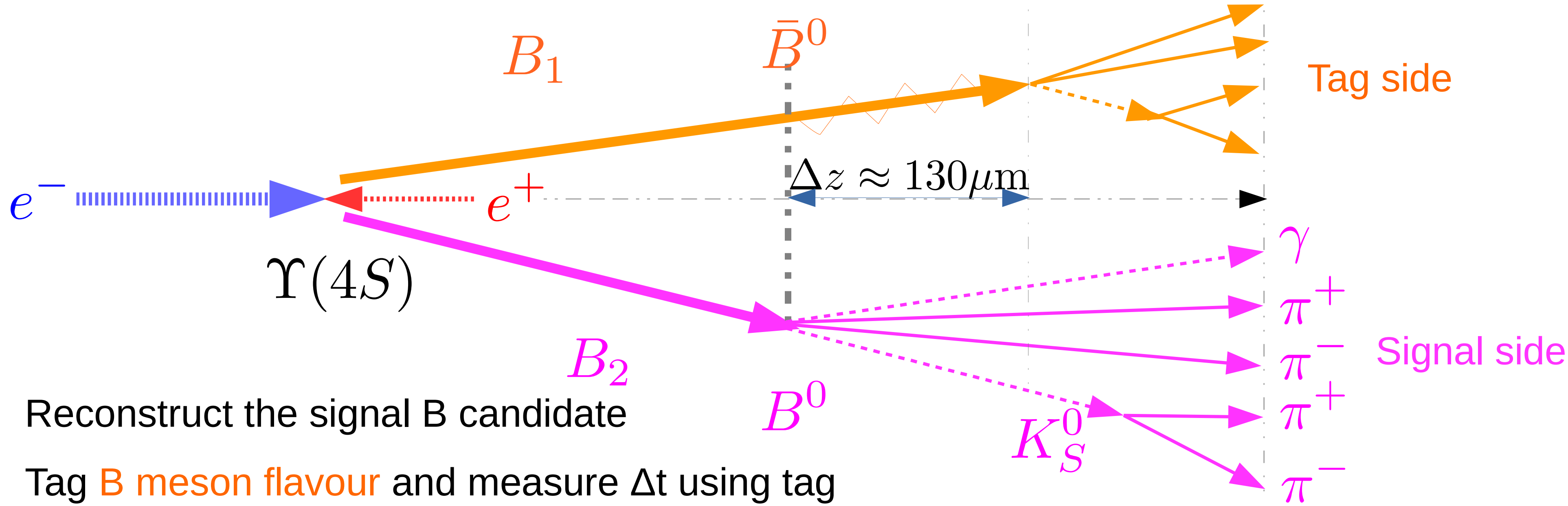
$$A_f(t) = A \cos(\Delta m \cdot t) + S \sin(\Delta m \cdot t)$$

- At B factories we can measure only proper decay time difference Δt:

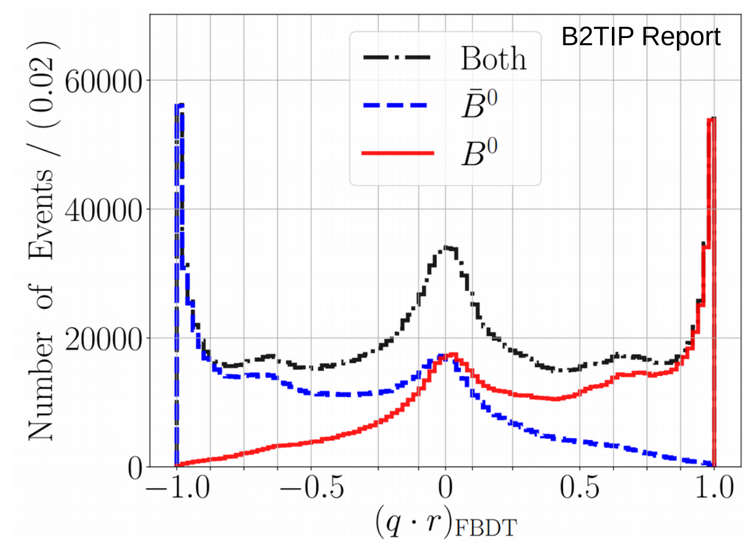
$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau}[1 + q(S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t))]$$

- This measurement requires a precise vertexing and flavor tagging ***q***, see next slide

TDCPV measurement at B Factories



- Reconstruct the signal B candidate
- Tag B meson flavour and measure Δt using tag side and signal side B candidate vertices
  - Effective flavour tagging efficiency is 33.6%
    - Detector improvement: +3%
    - Algorithm improvement: +3%
- Compute discriminating observables
- Build signal and background probability density functions (PDFs) models and extract S and A TDCPV parameters



Results by the previous experiments

arXiv:hep-ex/0608017
arXiv:0806.1980v1

arXiv:0807.3103
arXiv:1512.03579

$$B^0 \to K_S^0 \pi^0 \gamma$$

~ 0.48 ab^{-1}

$$\begin{aligned}
\mathcal{S}_{K^{*0}\gamma} &= -0.32^{+0.36}_{-0.33}(\text{stat}) \pm 0.05 \\
\mathcal{A}_{K^{*0}\gamma} &= -0.20 \pm 0.24(\text{stat}) \pm 0.05 \\
\mathcal{S}_{K_S^0\pi^0\gamma} &= -0.10 \pm 0.31(\text{stat}) \pm 0.07 \\
\mathcal{A}_{K_S^0\pi^0\gamma} &= -0.20 \pm 0.20(\text{stat}) \pm 0.06
\end{aligned}$$

~ 0.42 ab^{-1}

$$\begin{aligned}
S_{K^*\gamma} &= -0.03 \pm 0.29\ (\text{stat}) \pm 0.03 \\
C_{K^*\gamma} &= -0.14 \pm 0.16\ (\text{stat}) \pm 0.03 \\
S_{K_S^0\pi^0\gamma} &= -0.78 \pm 0.59\ (\text{stat}) \pm 0.09 \\
C_{K_S^0\pi^0\gamma} &= -0.36 \pm 0.33\ (\text{stat}) \pm 0.04
\end{aligned}$$

$$B^0 \to K_S^0 \pi^+ \pi^- \gamma$$

~ 0.6 ab^{-1}

$$\begin{aligned}
\mathcal{S}_{K_S^0\pi^+\pi^-\gamma} &= 0.09 \pm 0.27^{+0.04}_{-0.07} \\
\mathcal{A}_{K_S^0\pi^+\pi^-\gamma} &= 0.05 \pm 0.18 \pm 0.06
\end{aligned}$$

~ 0.43 ab^{-1}

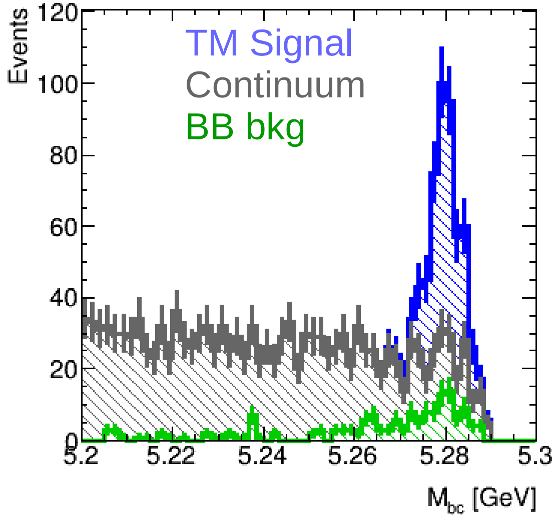
$$\begin{aligned}
\mathcal{S}_{K_S^0\pi^+\pi^-\gamma} &= 0.14 \pm 0.25 \pm 0.03, \\
\mathcal{C}_{K_S^0\pi^+\pi^-\gamma} &= -0.39 \pm 0.20^{+0.03}_{-0.02}.
\end{aligned}$$

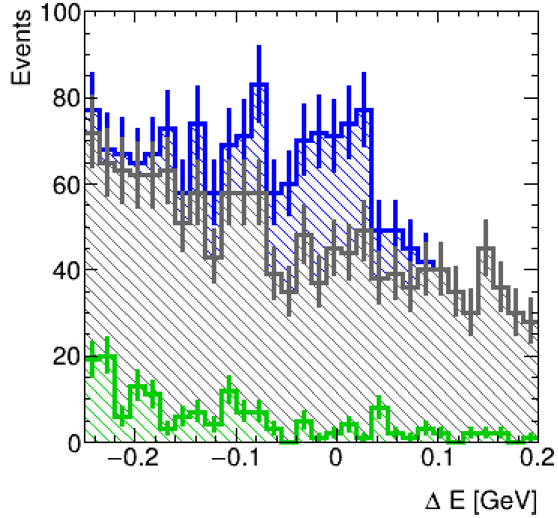
- **The results of the previous b-factories, Belle and BaBar are statistically limited → increase sensitivity ~x10 with Belle II**

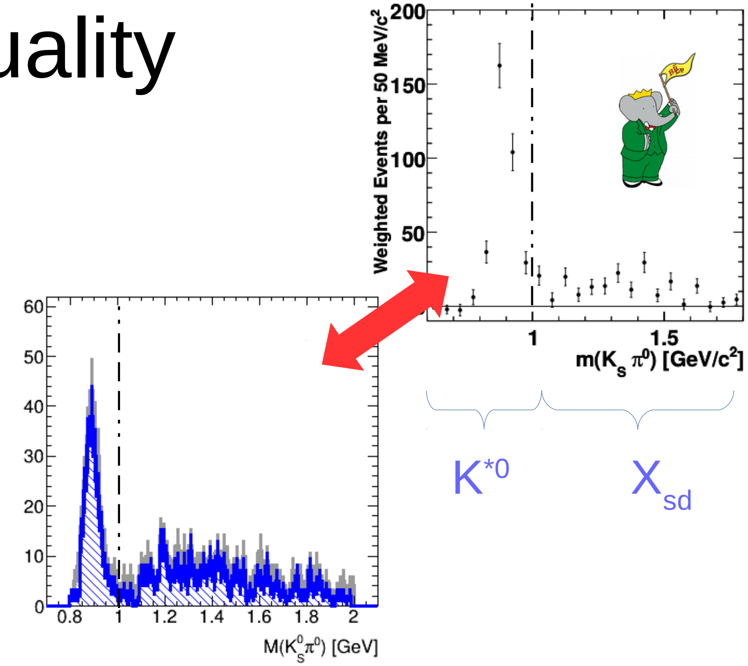
Reconstruction quality

- Using full Belle II simulation sample 1 ab^{-1}:

$$B^0 \to K_S^0 \pi^0 \gamma$$





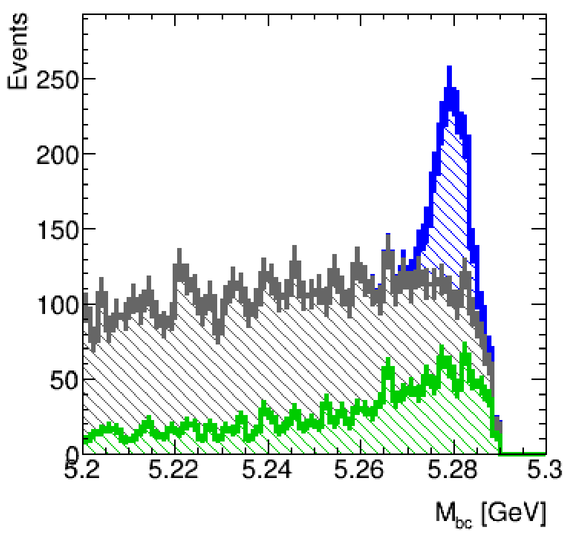


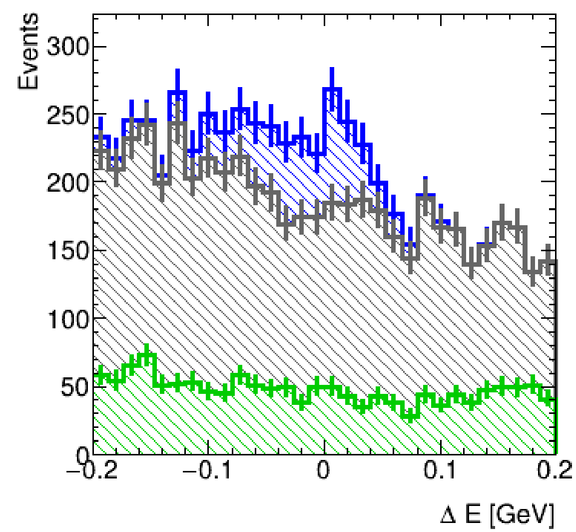
Eff$_{reco}$(signal) = 3.7%

$$m_{bc} = \sqrt{(E_{beam}^{c.m.s.})^2 - (p_B^{c.m.s.})^2}$$

$$\Delta E = E_B^{c.m.s.} - E_{beam}^{c.m.s.}$$

$$B^0 \to K_S^0 \pi^+ \pi^- \gamma$$

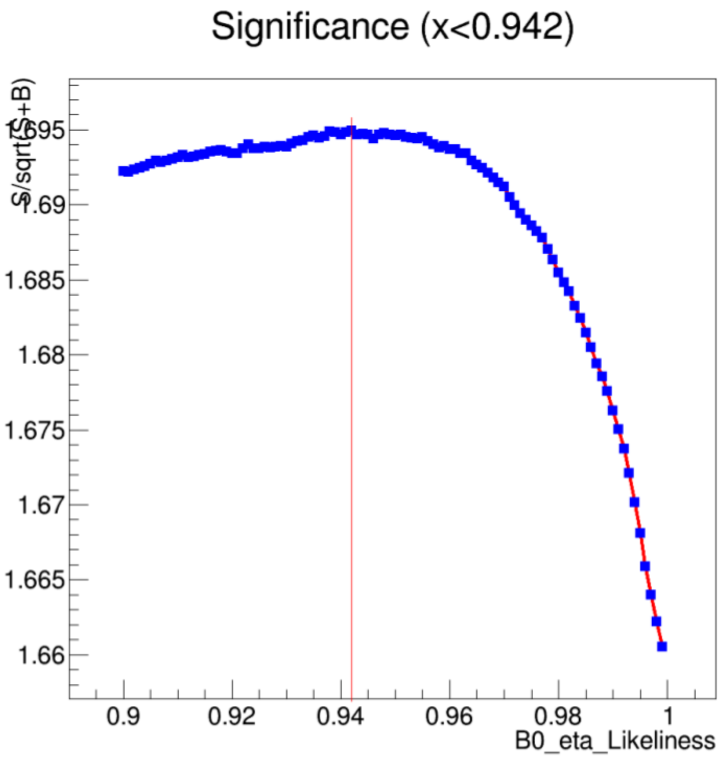


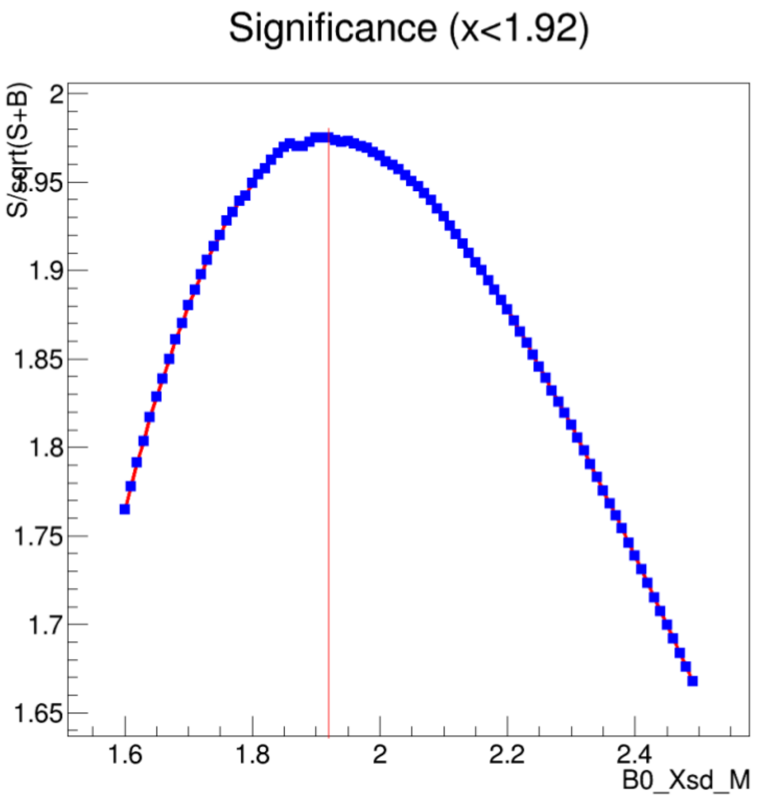


Eff$_{reco}$(signal) = 4.2%

Cut optimization

- Cut optimization is on-going:



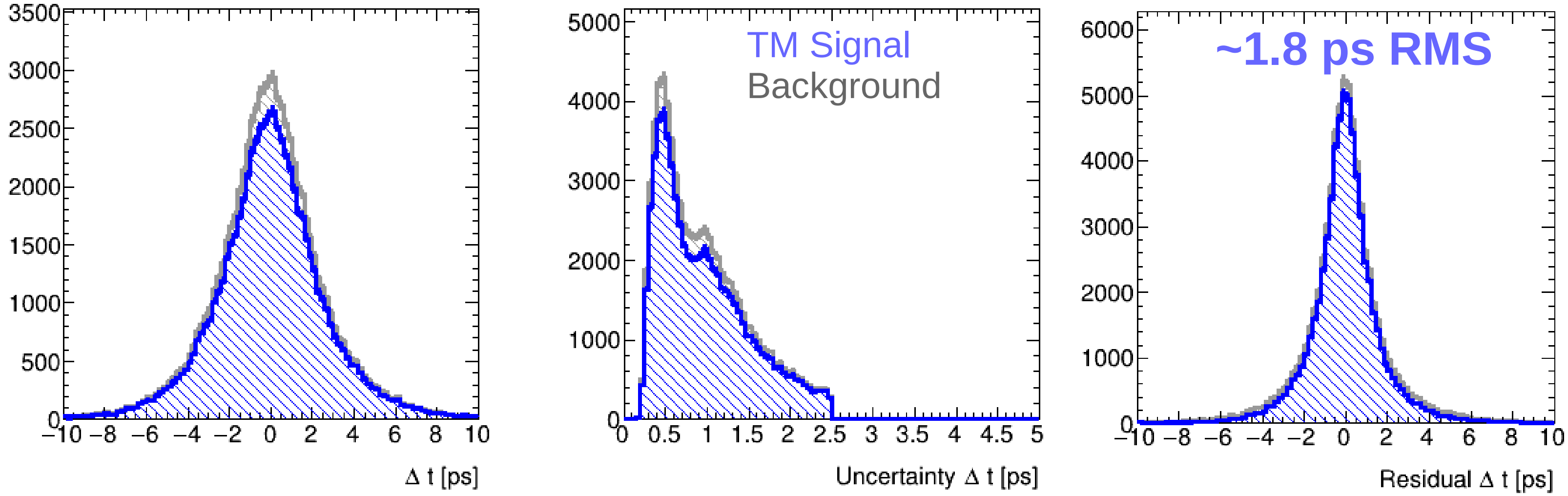


- By optimization of cuts using Figure-Of-Merit in several steps we get 10% improvement on the final uncertainties

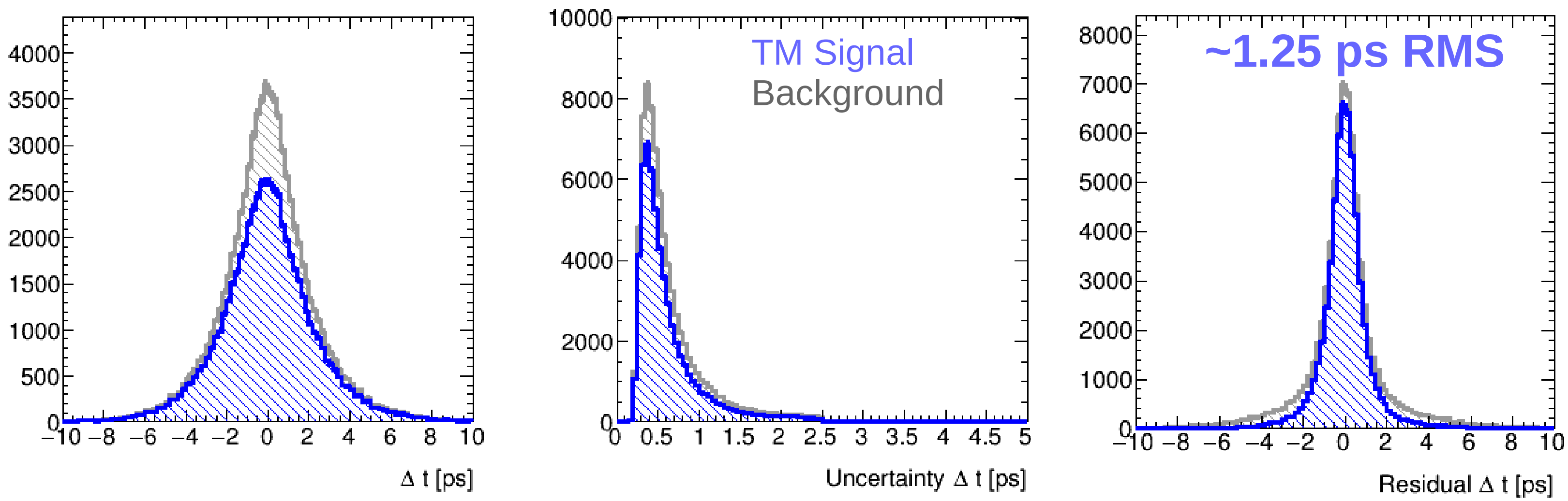
Reconstruction quality

- Using full Belle II simulation signal samples:

$$B^0 \to K_S^0 \pi^0 \gamma$$

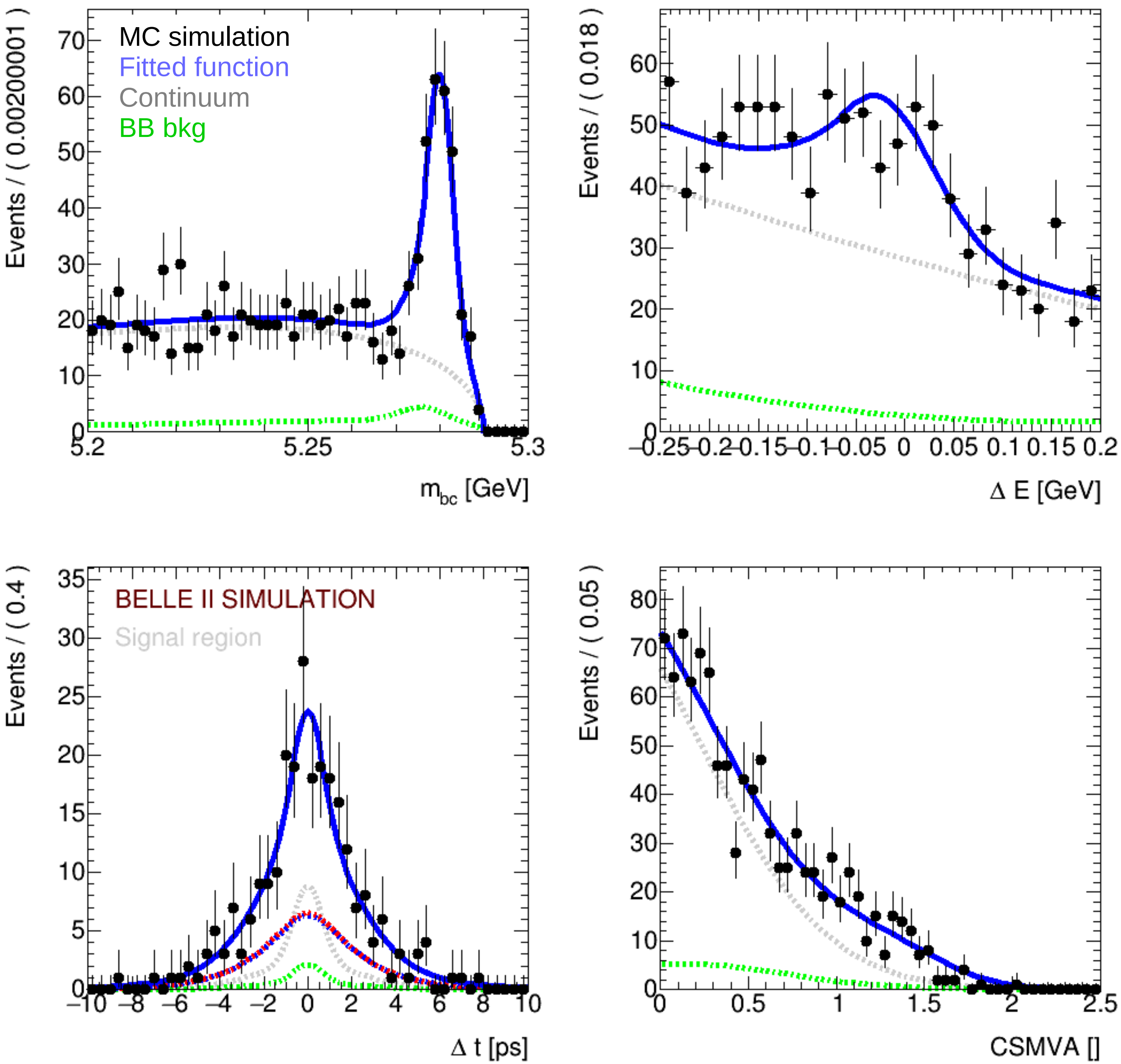


$$B^0 \to K_S^0 \pi^+ \pi^- \gamma$$



Fit of $B^0 \to K_S^0 \pi^0 \gamma$

- Using MC sample of L = 1 ab^{-1}, **K* mass region**:



- 4D unbinned likelihood fit gives the precision on TDCPV parameters *A* & *S*
- 2 background models and 1 signal model
- Continuum bkg shape, signal fraction, A and S are determined from the fit

MC numbers:

- N(total) = 1029
- N(signal) = 203

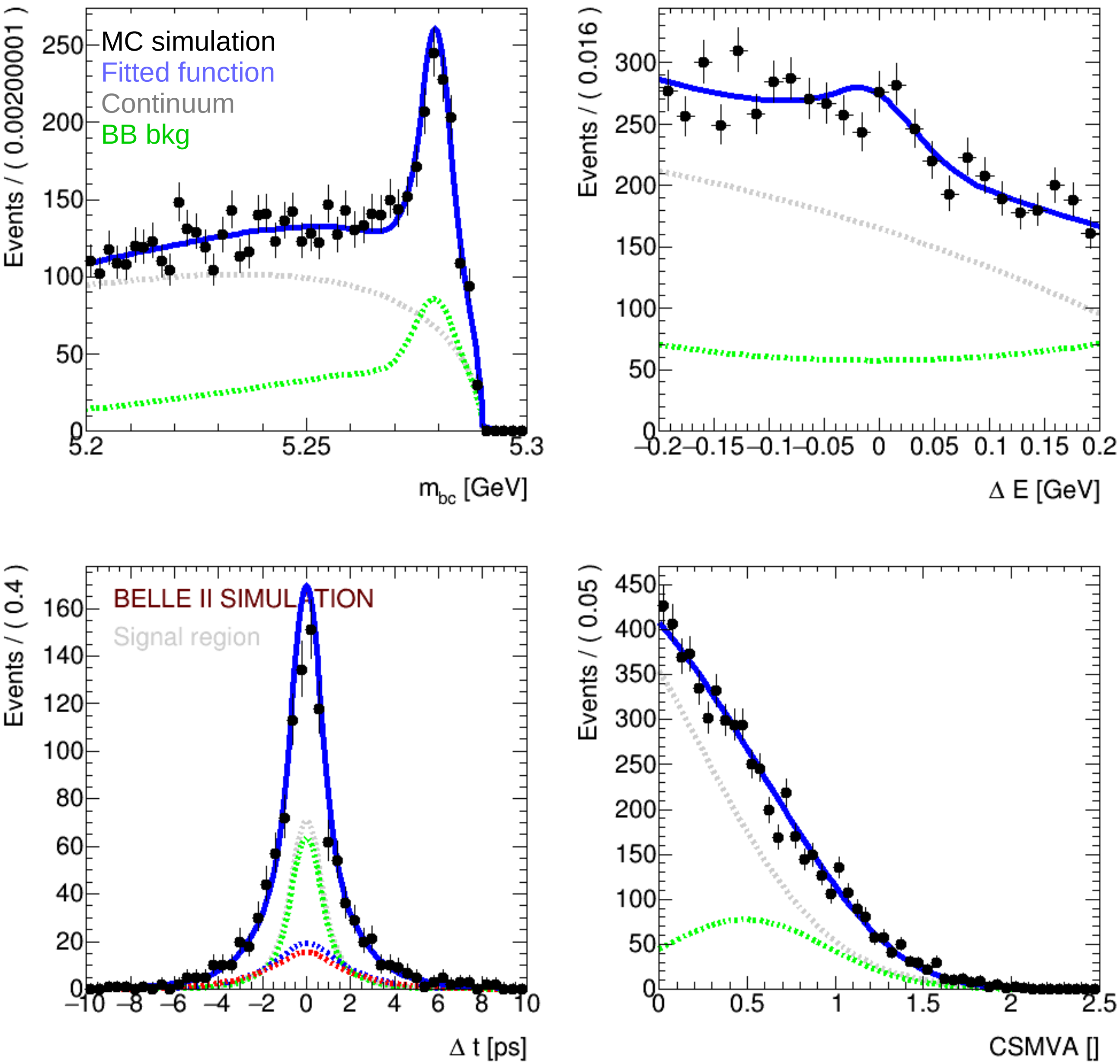
Fit results:

N(signal) =220±18

$$A = +0.03 \pm 0.19$$
$$S = +0.02 \pm 0.30$$

Fit of $B^0 \to K_S^0 \pi^+ \pi^- \gamma$

- Using MC sample of L = 1 ab^{-1}:



- 4D unbinned likelihood fit gives the precision on TDCPV parameters *A* & *S*
- 2 background models and 1 signal model
- Continuum bkg shape, signal fraction, A and S are determined from the fit

MC numbers:

- N(total) = 6002
- N(signal) = 436

Fit results:

N(signal) = 428±29

$$A = -0.21 \pm 0.17$$
$$S = -0.09 \pm 0.20$$

Preliminary systematic uncertainties

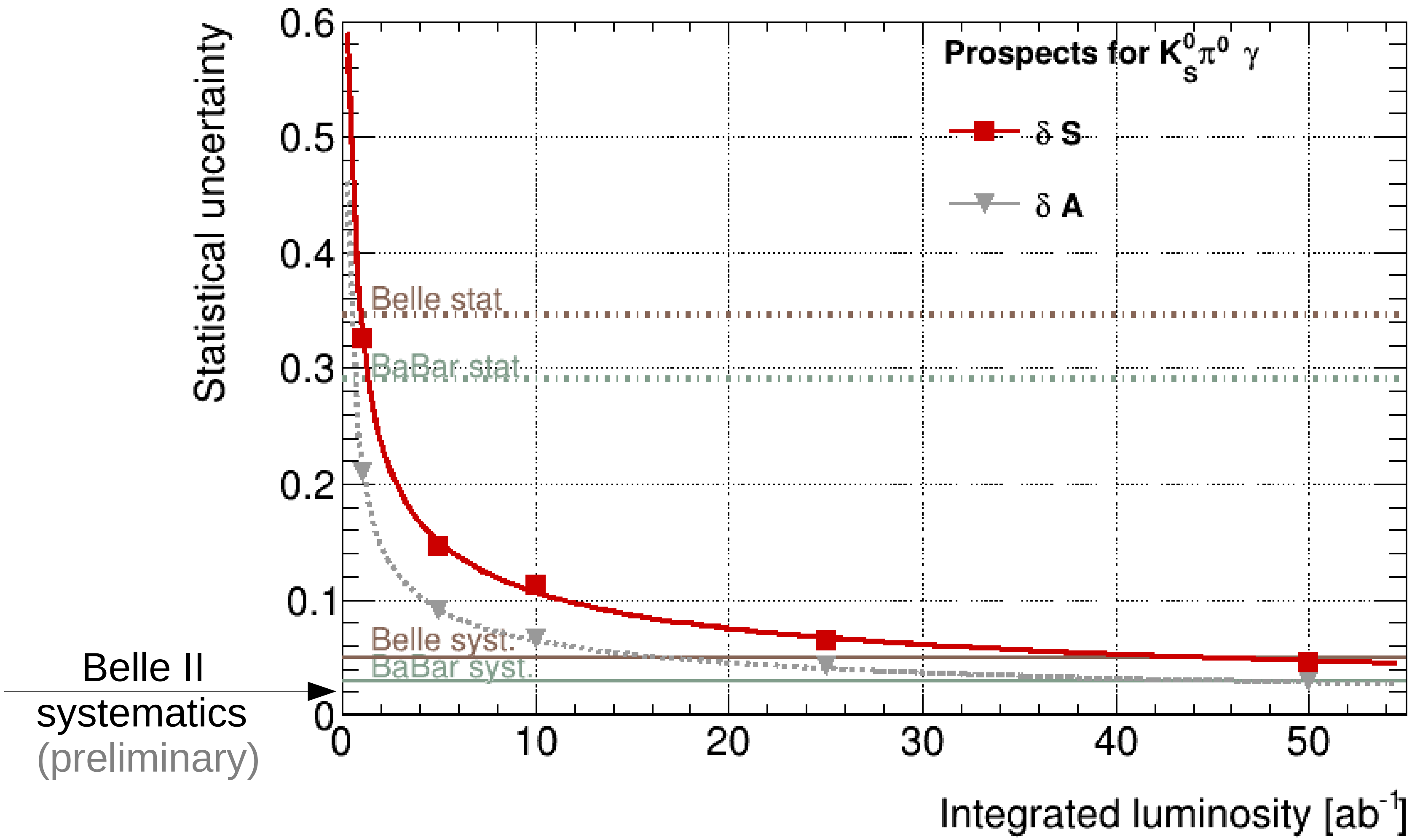
- We expect the following sources of systematics for $B^0 \to K_S^0 \pi^0 \gamma$:

		ΔS	ΔA
	Physics parameters	0.0066	0.008
	Flavor tagging	0.005	0.002
Winner	Fitting procedure	0.015	0.016
	Signal and Bkg fraction	0.00506	0.00680
	Resolution function	0.0016	0.0015
	SVT alignment	0.006	0.004
	CP from BB bkg	0.008	0.002
	Tag Side Interference	0.001	0.015
	Total	0.02	0.024

- In the fitting algorithm we fix many parameters, which automatically converts to the systematic uncertainty
- The signal Δt resolution function parameters have the largest contribution → need to reparametrize it

Preliminary prospects for $B^0 \to K_S^0 \pi^0 \gamma$

- 200 Toy MC experiments, **K*0 mass region**:

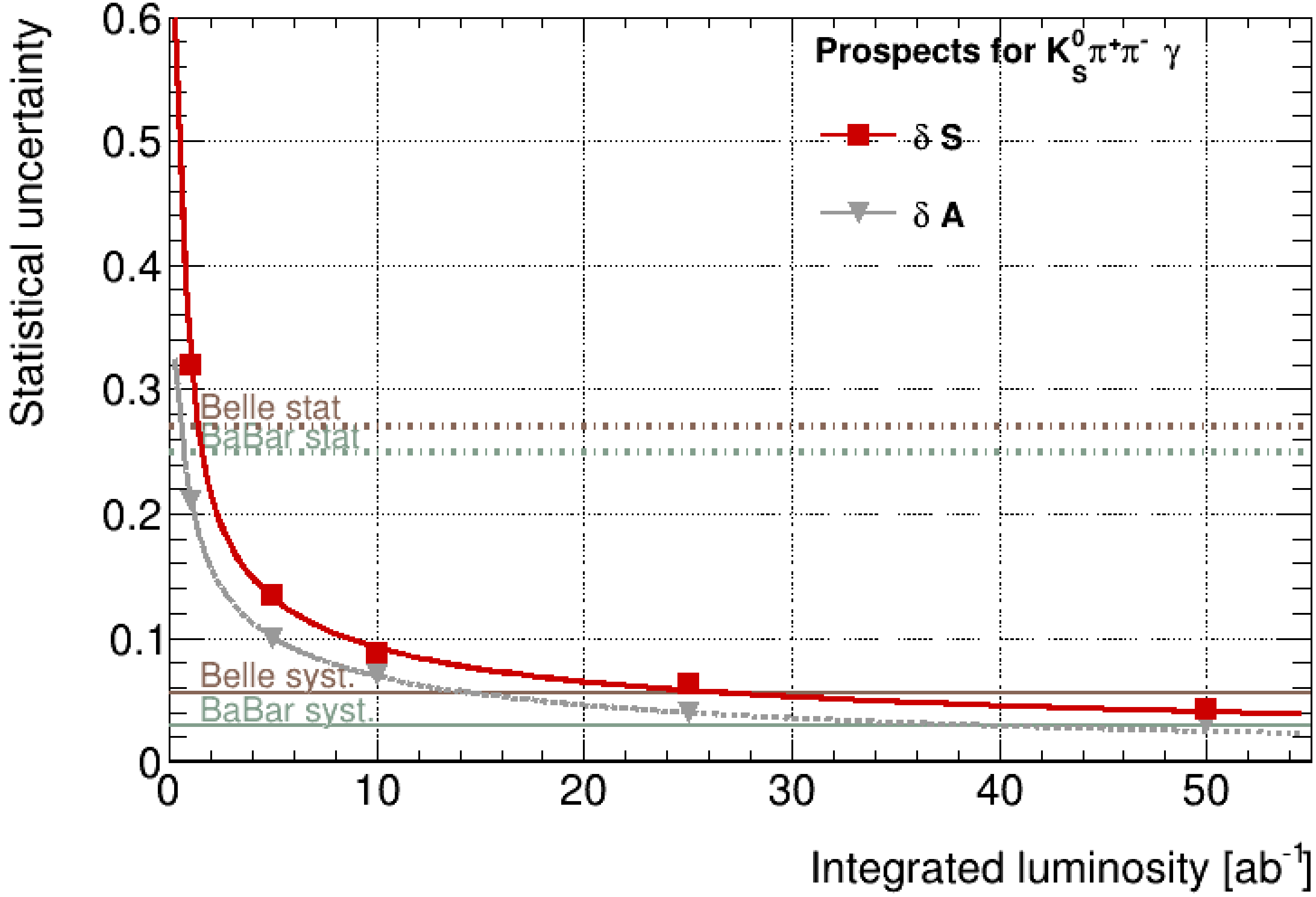


- The statistical error of full Belle II dataset is on the level of systematics

*Belle and BaBar errors are for S parameter

Preliminary prospects for $B^0 \to K_S^0 \pi^+ \pi^- \gamma$

- 200 Toy MC experiments:



- Non CP eigenstates can dilute the precision on S by ~20%

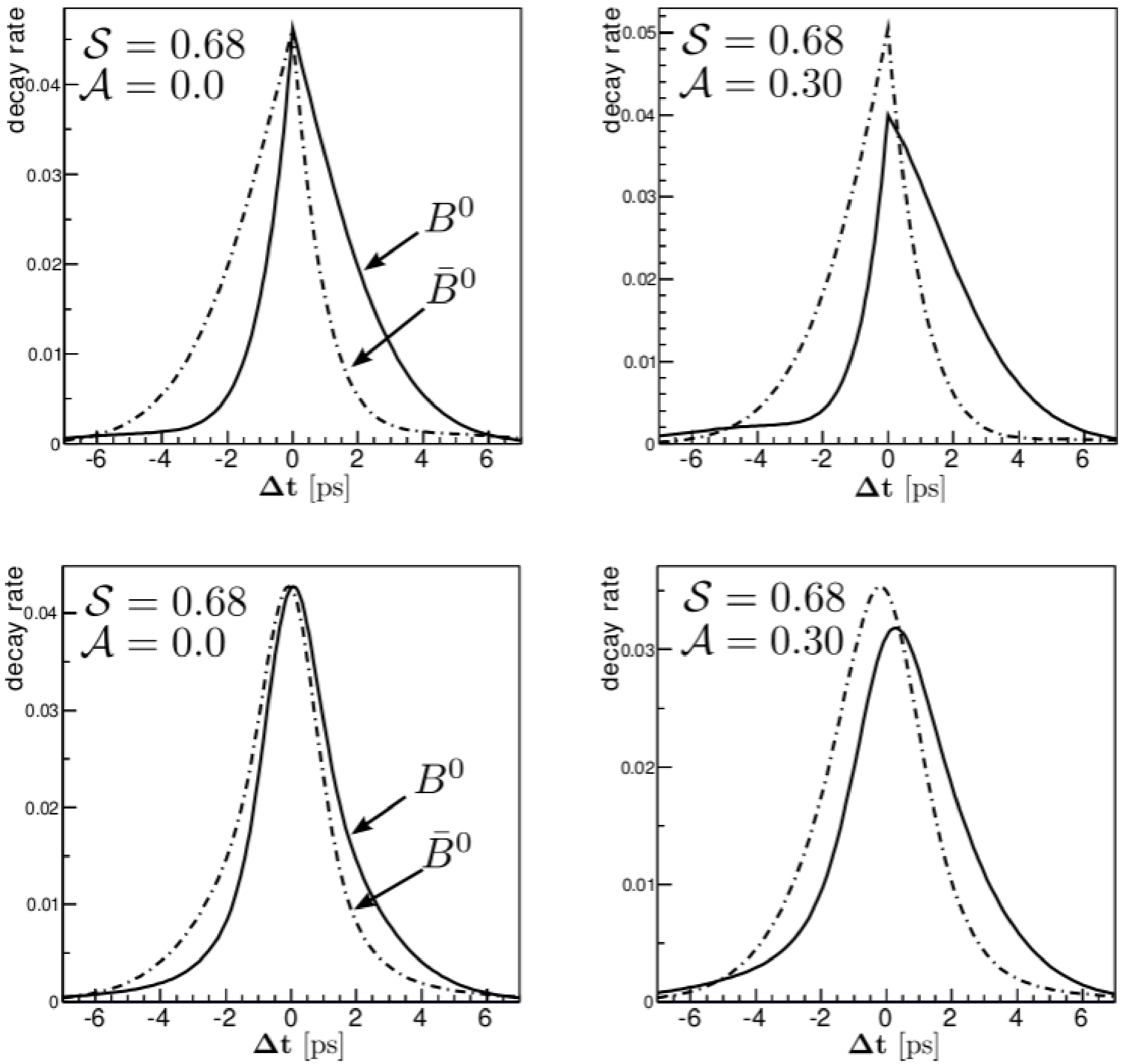
*Belle and BaBar errors are for S parameter

Summary

- Radiative processes, like $b \to s\gamma$, are sensitive probes for New Physics
  - The e+e- collisions at Belle II is an excellent environment to study radiative processes
- For $B^0 \to K_S^0 \pi^+ \pi^- \gamma$ statistical uncertainty on δS ~ 0.043 is reachable
- Another channel $B^0 \to K_S^0 \pi^0 \gamma$ gives δS ~ 0.045, it is easier to interpret
- **Belle II will provide enough data to have statistical uncertainties comparable to the systematic ones for the radiative TDCPV studies**
- Future work:
  - Early phase III measurements: rediscovery of the processes, flavor tag systematics, Δt resolution measurements
  - Intrerpretation of the results
- PhD thesis for Oct 2019 to work on Lepton Flavor Universality

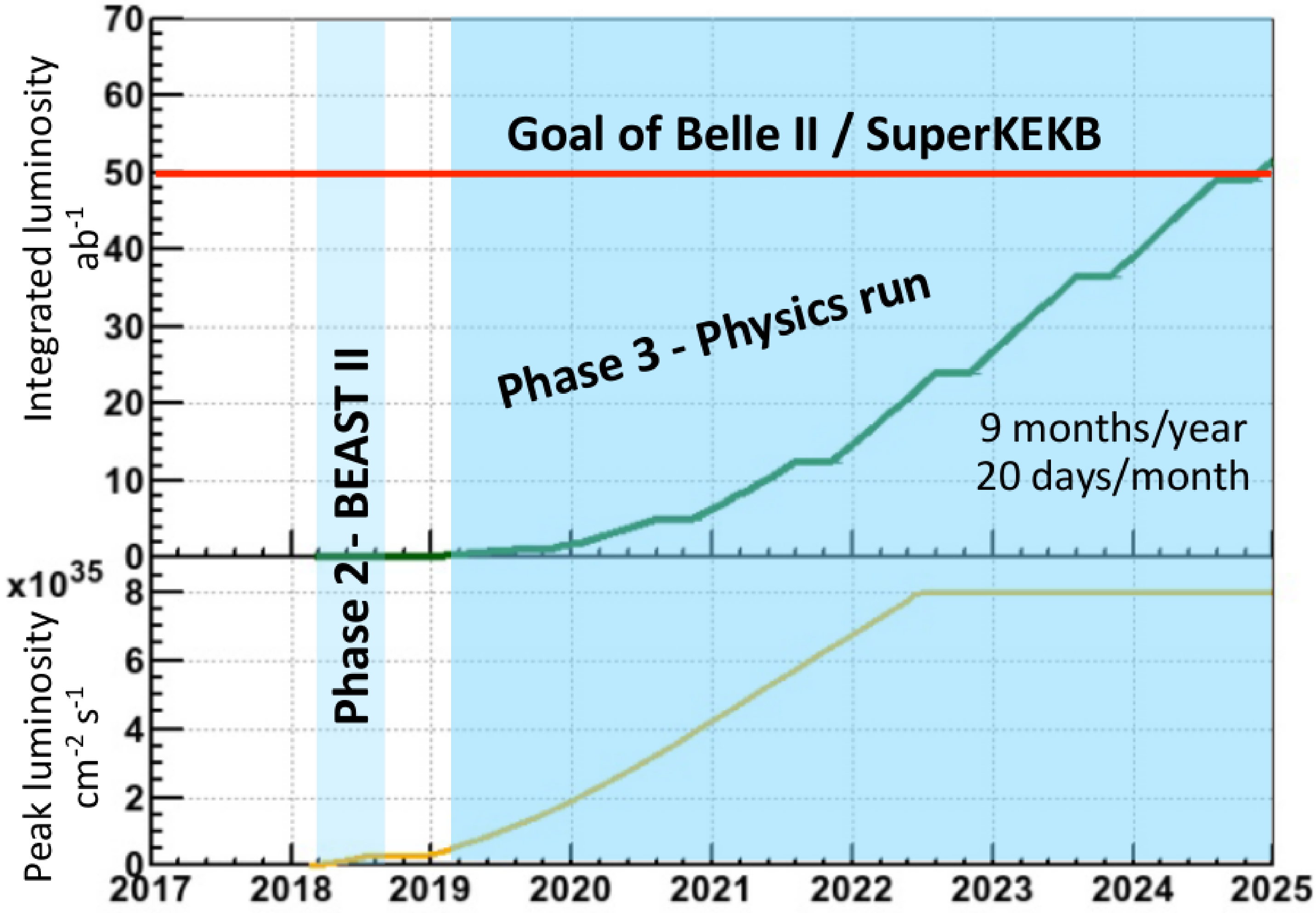
Thank you!

Delta T



- Change of S and A parameters and influence of experimental resolution

Initial SuperKEKB planning



Belle II parameters

Component	Type	Configuration	Readout	Performance
Beam pipe	Beryllium double-wall	Cylindrical, inner radius 10 mm, 10 μm Au, 0.6 mm Be, 1 mm coolant (paraffin), 0.4 mm Be		impact parameter resolution $\sigma_{z_0} \sim 20\ \mu$m (PXD and SVD)
PXD	Silicon pixel (DEPFET)	Sensor size: 15×100 (120) mm^2 pixel size: 50×50 (75) μm^2 2 layers: 8 (12) sensors	10 M	
SVD	Double sided Silicon strip	Sensors: rectangular and trapezoidal Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm 4 layers: 16/30/56/85 sensors	245 k	
CDC	Small cell drift chamber	56 layers, 32 axial, 24 stereo r = 16 - 112 cm - 83 $\leq z \leq$ 159 cm	14 k	$\sigma_{r\phi} = 100\ \mu$m, $\sigma_z = 2$ mm $\sigma_{p_t}/p_t = \sqrt{(0.2\% p_t)^2 + (0.3\%/\beta)^2}$ $\sigma_{p_t}/p_t = \sqrt{(0.1\% p_t)^2 + (0.3\%/\beta)^2}$ (with SVD) $\sigma_{dE/dx} = 5\%$
TOP	RICH with quartz radiator	16 segments in ϕ at $r \sim 120$ cm 275 cm long, 2 cm thick quartz bars with 4x4 channel MCP PMTs	8 k	$N_{p.e.} \sim 20$, $\sigma_t = 40$ ps K/π separation : efficiency > 99% at < 0.5% pion fake prob. for $B \to \rho\gamma$ decays
ARICH	RICH with aerogel radiator	4 cm thick focusing radiator and HAPD photodetectors for the forward end-cap	78 k	$N_{p.e.} \sim 13$ K/π separation at 4 GeV/c: efficiency 96% at 1% pion fake prob.
ECL	CsI(Tl) (Towered structure)	Barrel: $r = 125$ - 162 cm End-cap: $z =$ -102 cm and +196 cm	6624 1152 (F) 960 (B)	$\frac{\sigma E}{E} = \frac{0.2\%}{E} \oplus \frac{1.6\%}{\sqrt[4]{E}} \oplus 1.2\%$ $\sigma_{pos} = 0.5\ \mathrm{cm}/\sqrt{E}$ (E in GeV)
KLM	barrel: RPCs	14 layers (5 cm Fe + 4 cm gap) 2 RPCs in each gap	θ: 16 k, ϕ: 16 k	$\Delta\phi = \Delta\theta = 20$ mradian for K_L ~ 1 % hadron fake for muons
	end-caps: scintillator strips	14 layers of $(7 - 10) \times 40$ mm^2 strips read out with WLS and G-APDs	17 k	$\Delta\phi = \Delta\theta = 10$ mradian for K_L $\sigma_p/p = 18\%$ for 1 GeV/c K_L

Belle II vertex detector