STUDIES OF MISSING ENERGY DECAYS OF B-MESONS AT BELLE II

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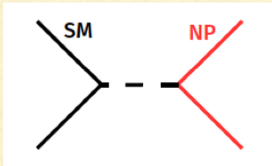
on behalf of the Belle II collaboration

supported by **JENNIFER** – Japan and Europe Network for Neutrino and Intensity Frontier Experimental Research – EC grant n.644294

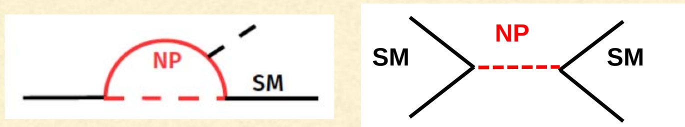
Belle II and New physics searches

Search for new physics (NP)

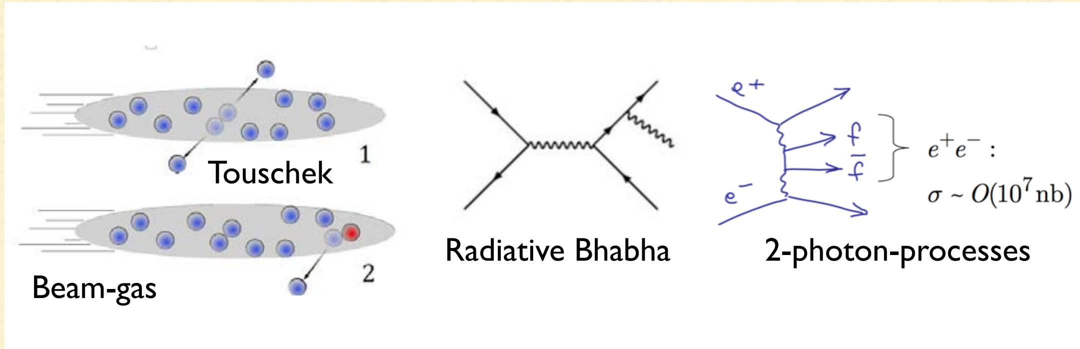
- Energy frontier: direct production of new particles - limited by beam energy (LHC - ATLAS, CMS)



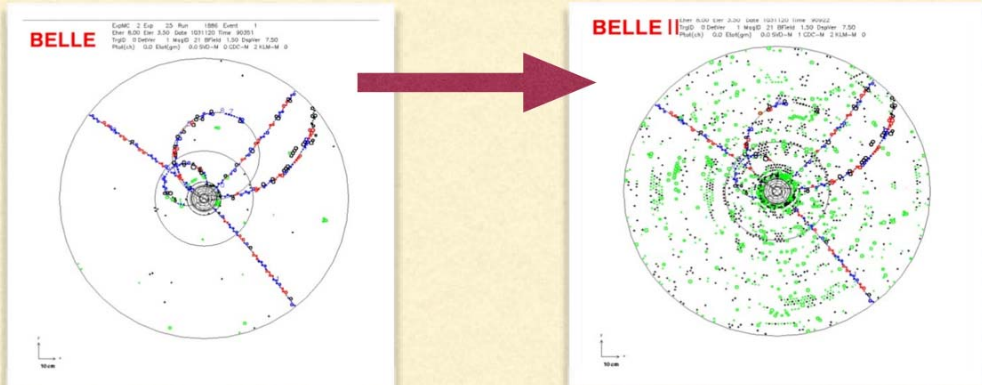
- Intensity frontier: new virtual particles in loops/trees transitions, deviation from SM expectations (B factories, LHCb)



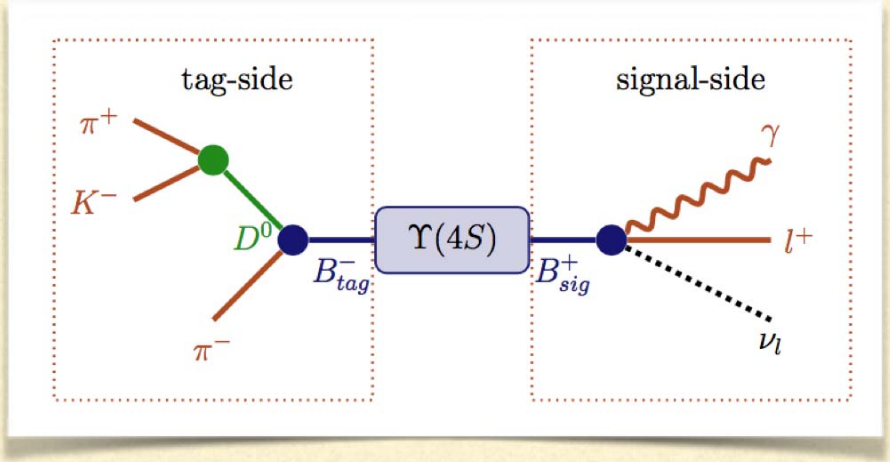
- From Belle to Belle II: Factor x40 luminosity → higher data samples + higher rate and radiation damage to detectors from "machine background processes"



- Upgrade of Belle detector and reconstruction algorithm in order to keep same or better performances wrt Belle in higher radiation environment



B meson decays with missing energy: how to



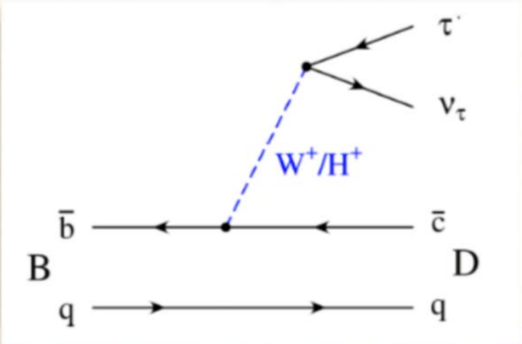
- Clean event environment and well defined initial state.
- Good and efficient reconstruction of decays with neutrals
- Full solid angle detector, lower boost wrt Belle/BaBar ↔ higher detector hermeticity

→ Ideal environment to search for decays with missing energy in the final state

- Full Event interpretation reconstruction algorithm:
  - Multivariate technique to reconstruct the B-tag side through both semileptonic (SL) and hadronic (HAD)
  - Signal specific training technique.

→ x2 in both HAD and SL reconstruction efficiency wrt Belle

$B \to D^{(*)}\tau\nu$: theoretical and experimental status

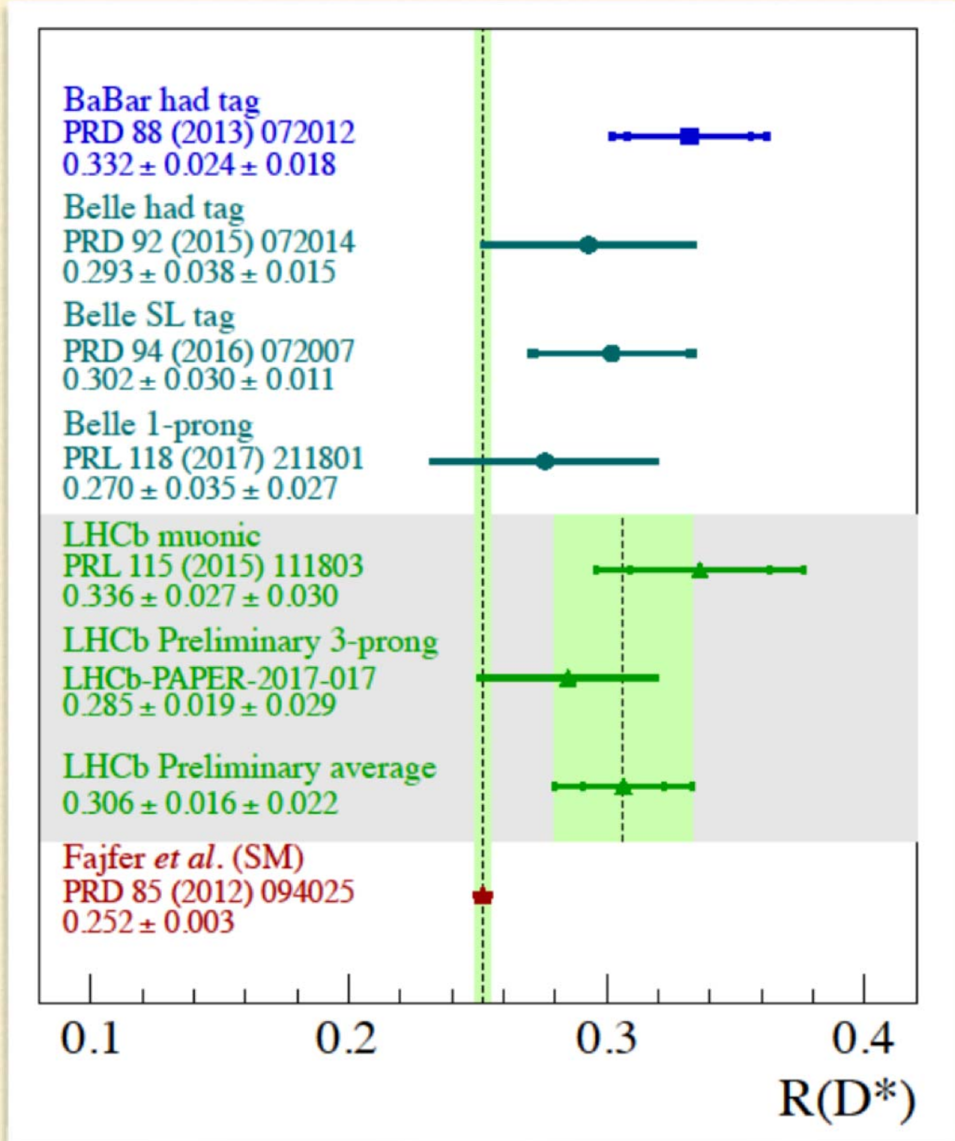


- Observable:

$$R(D^{(*)}) \equiv \frac{\Gamma(B \to \bar{D}^{(*)}\tau^+\nu_\tau)}{\Gamma(B \to \bar{D}^{(*)}\ell^+\nu_\ell)} \qquad \ell = e, \mu$$

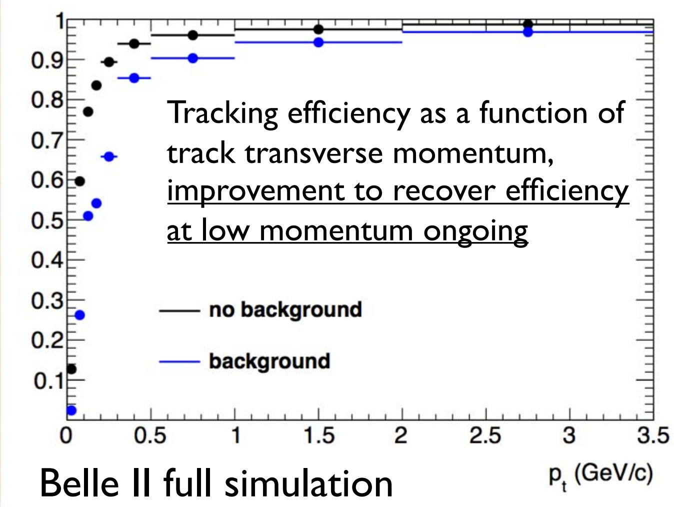
- Very precise theoretical calculation in the SM framework: 3-4% level for R(D)[rd1], 1% level for R(D*) [rd2]
- Experimental world average 4.08 σ away from SM expectations
- τ polarisation measured by Belle[rd3] :

$$P(\tau) = -0.38 \pm 0.51^{+0.21}_{-0.16}$$



$B \to D^{(*)}\tau\nu$: perspectives @ Belle II

- Current measurements are statistically limited, dominant systematic uncertainties from
  - limited signal MC samples → larger at Belle II
  - limited knowledge of dominant bkg (involving soft pions) → dedicated measurement with large data samples feasible at Belle II

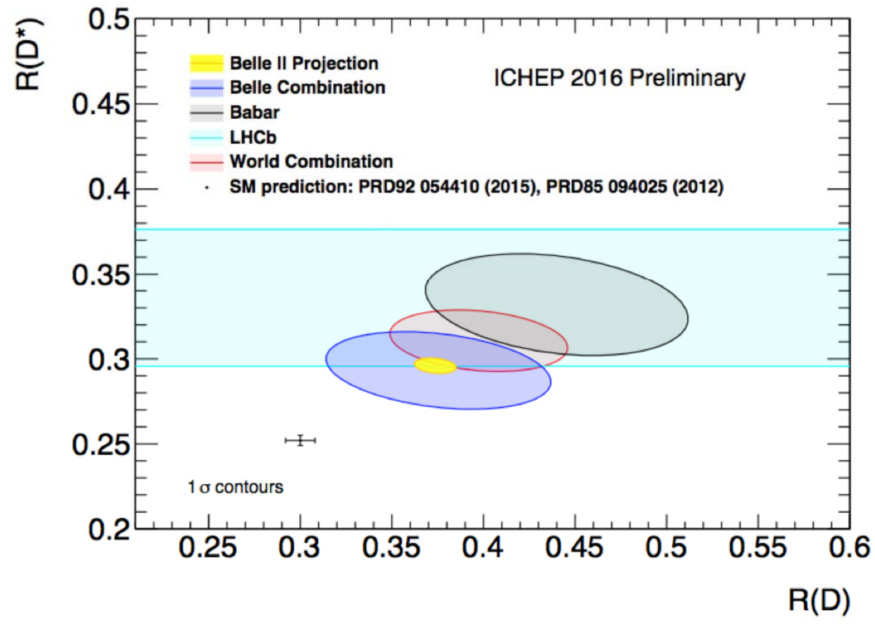


- With higher statistics, also study of q^2 distributions, essential to distinguish NP models, feasible
- Extrapolation from existing BaBar and Belle results:

$$\left.\frac{\sigma_{R_D}}{R_D}\right|_{50\text{ab}^{-1}} = 2.0\%(\text{stat.}) \pm 2.5\%(\text{syst.}),$$

$$\left.\frac{\sigma_{R_{D^*}}}{R_{D^*}}\right|_{50\text{ab}^{-1}} = 1.0\%(\text{stat.}) \pm 2.0\%(\text{syst.}),$$

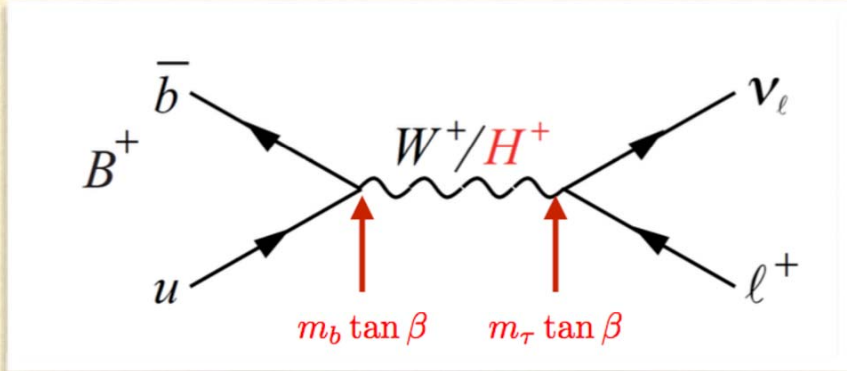
$$\sigma_{P_\tau(D^*)}\big|_{50\text{ab}^{-1}} = 0.06(\text{stat.}) \pm 0.04(\text{syst.}).$$



B→τν : theoretical and experimental status

- SM branching fraction:

$$\mathcal{B}(B^+ \to \tau^+\nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left[1 - \frac{m_\tau^2}{m_B^2}\right]^2 f_B^2 |V_{ub}|^2 \tau_{B^+}$$



- Using $|V_{ub}|_{excl} = (3.55 \pm 0.12) \times 10^{-3}$, $f_B = (186 \pm 4)$ MeV [tn1]:

$$\mathcal{B}(B \to \tau\nu) = (0.77 \pm 0.06) \times 10^{-4}$$

World average of BaBar and Belle measurements using both semileptonic and hadronic tag [tn2]:

$$\mathcal{B}(B \to) = (1.06 \pm 0.19) \times 10^{-4}$$

  - 5σ significance exceeded combining the two experiments
  - consistent with SM expectation at 2 level

- Statistically limited , dominant systematic effects
  - data/MC disagreement and efficiency estimations
  - signal and bkg parameterisation in final fit

(partly) statistical in origin

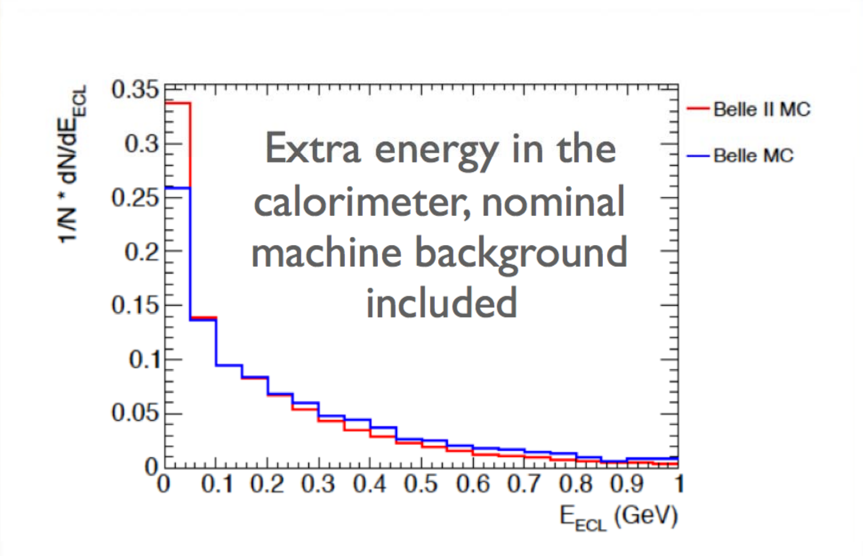
B→τν : perspectives @ Belle II

- Analysis on Belle II Full simulation using hadronic B reconstruction
  - signal and background yield extracted from ML fit to extra neutral energy

- Comparison with hadronic Belle analysis:

E_{ECL}		< 0.25 GeV
Belle II	# background events	1348
	# signal events	136
	signal efficiency (‰)	1.6
Belle	# background events	365
	# signal events	60
	signal efficiency (‰)	0.7

1 ab^{-1} equivalent statistics

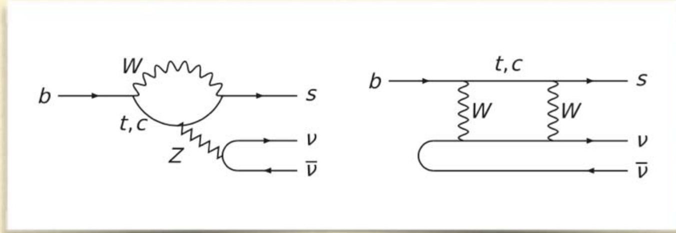


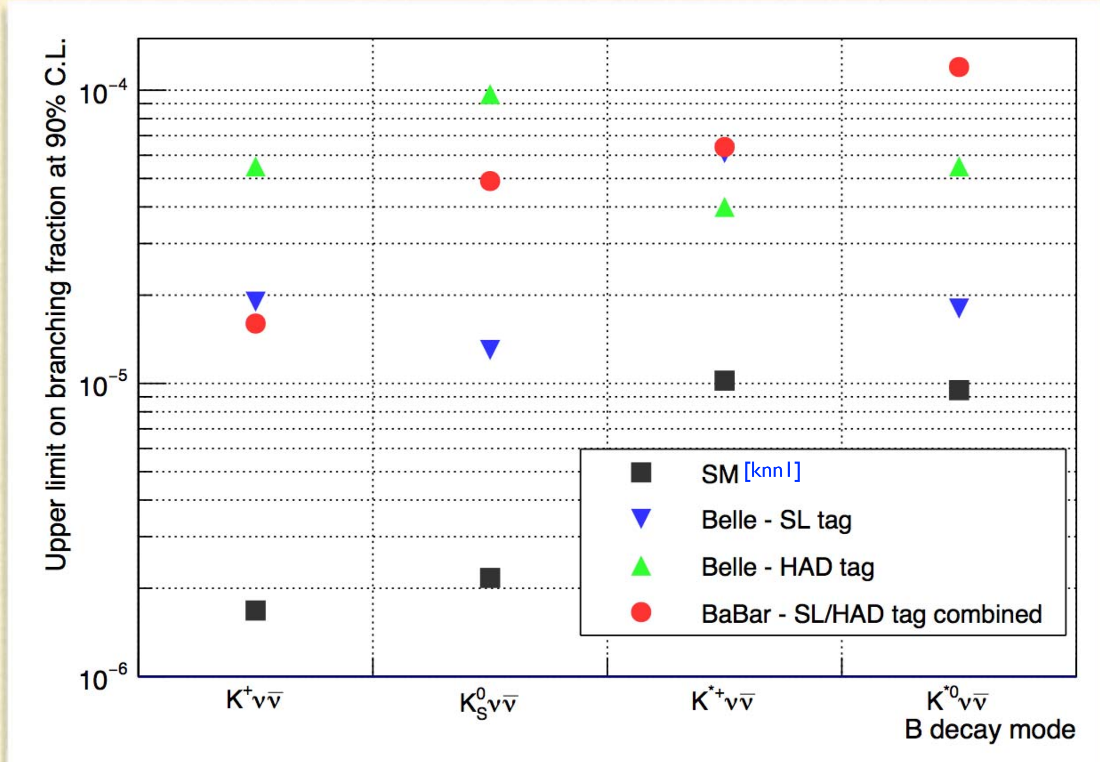
- Combination with Belle SL tag analysis [tn1], and extrapolation at full Belle II statistics:

	Integrated Luminosity (ab^{-1})	50
hadronic tag	statistical uncertainty (%)	4.1
	systematic uncertainty (%)	4.6
	total uncertainty (%)	6.2
semileptonic tag	statistical uncertainty (%)	2.7
	systematic uncertainty (%)	4.5
	total uncertainty (%)	5.3

$B \to K^{(*)} \nu\nu$: theoretical and experimental status

- Flavour changing neutral current, prohibited at tree level in the SM
  - NP contribution (from new mediators or sources of missing energy) may be comparable to SM ones
  - free of uncertain long-distant hadronic effects, theoretically clean
  - Experimental searches from BaBar and Belle on both HAD and SL recoil[knn2]
    - no signal evidence, UL less than 1 order of magnitude away from SM predictions for K^* channels





$B \to K^{(*)}\nu\nu$: robustness against machine background

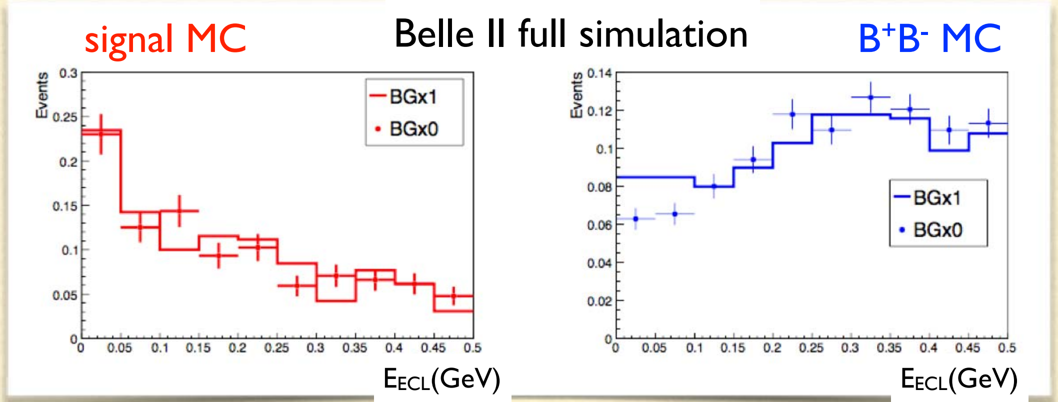
- Analysis on Belle II Full simulation using hadronic B reconstruction using $K^{*+} \to K\pi^0$ to establish machine background impact

- Simple cut-and-count analysis, signal efficiency and bkg yield estimanted in extra neutral energy signal region
- nominal machine bkg (BGx1) and machine bkg-free (BGx0) simulated samples analysed

- Negligible impact of machine background both in terms of variables shape and signal significance

1 ab^{-1} equivalent statistics

	"BGx0"	"BGx1"
N_{bkg}	6415 ± 80	3678 ± 61
ε (10^{-4})	10.3 ± 0.3	5.38 ± 0.23
$N_{sig}/\sqrt{N_{bkg}}$	0.16	0.15
UL (10^{-4})	2.6	3.8



- Detector performances and reconstruction proves to be robust against machine background

$B \to K^{(*)}\nu\nu$: perspectives @ Belle II

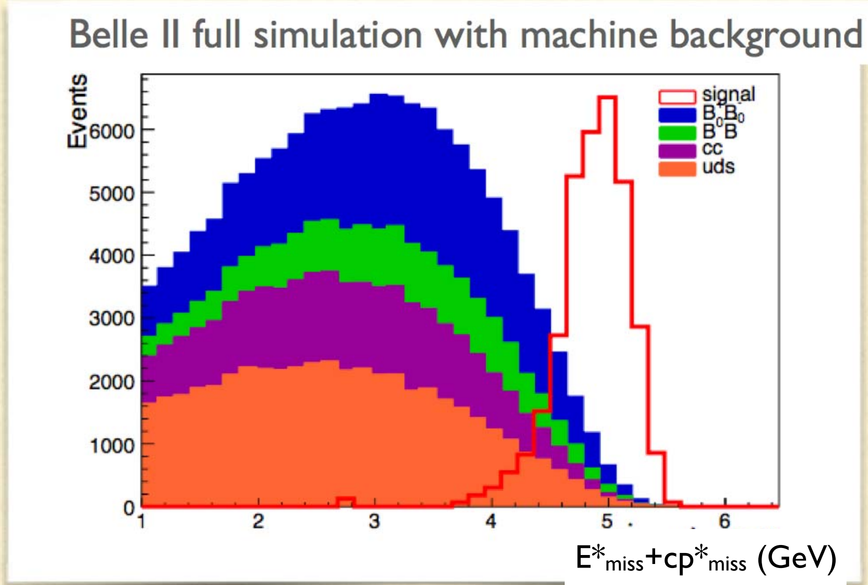
- Extrapolation on full Belle II statistics on Belle HAD and SL analyses, assuming two times better B_{tag} reconstruction efficiency:
  - observation with about 18 ab^{-1}
  - precision on the branching fraction at 50 ab^{-1}:

	stat only	total
$B^+ \to K^+\nu\nu$	9,5%	10,7%
$B^+ \to K^{*+}\nu\nu$	7,9%	9,3%
$B^+ \to K^{*0}\nu\nu$	8,2%	9,6%

- Fraction of longitudinally polarized K* may
- be measured, ~20% precision with full statistics

- Robustness against machine background proved,

predicted precision can be exceeded by improving analysis strategy



Summary

- Belle II unique or very competitive environment to study B decays with missing energy, sensitive to indirect NP effects
- x40 luminosity (and much higher machine background) wrt first generation B-factories
- Belle II full simulation studies proved the detector performances and the reconstruction algorithms to be robust against simulated machine background
  - measurements on machine background rates and spectra during phase I (2016) and phase II (starting Nov. 2018) operation phases
- Improvements in analysis strategy and larger data sample will allow to approach SM prediction ($B \to K^{(*)}\upsilon\upsilon$) or further investigate deviation from/consistency with the SM predictions ($B \to \tau\upsilon$ and $B \to D^{(*)}\tau\upsilon$)
- B2TIP report: Belle II detector, simulation, software, analysis tools, physics program (https://confluence.desy.de/display/BI/B2TiP+ReportStatus), to be published in 2017
- Phase III operation (Full detector) starting end 2018

Summary

- Belle II uniq… missing energy, sens…
- x40 l… B-factories
- Belle I… construction algorit…
    - mea… 2016) and phase II (sta…
- Improvem… SM prediction… e SM predictions
- B2TIP report… (https:// confluence.c… 2017
- Phase III …ull


INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

VOLUME 57 NUMBER 5 JUNE 2017

FACILITIES

Belle II rolls in

On 11 April, the Belle II detector at the KEK laboratory in Japan was successfully "rolled-in" to the collision point of the upgraded SuperKEKB accelerator, marking an important milestone for the international B-physics community. The Belle II experiment is an international collaboration hosted by KEK in Tsukuba, Japan, with related physics goals to those of the LHCb experiment at CERN but in the pristine environment of electron–positron collisions. It will analyse copious quantities of B mesons to study CP violation and signs of physics beyond the Standard Model (*CERN Courier* September 2016 p32).

"Roll-in" involves moving the entire 8 m-tall, 1400 tonne Belle II detector system from its assembly area to the beam-collision point 13 m away. The detector is now integrated with SuperKEKB and all its seven subdetectors, except for the innermost vertex detector, are in place. The next step is to install the complex focusing magnets around the Belle II interaction point. SuperKEKB achieved its first turns in February 2016, with operation of the main rings scheduled for early spring and phase-III "physics" operation by the end of 2018.

Compared to the previous Belle …

… collected with much improved precision. "After six years of gruelling work with many unexpected twists and turns, it was a moving and gratifying experience for everyone on the team to watch the Belle II detector move to the interaction point," says Belle II spokesperson Tom Browder. "Flavour physics is now the focus of much attention and interest in the community and Belle II will play a critical role in the years to come."

KEK

The Belle II detector is now in place at the SuperKEKB facility in Japan.

READY TO GO!

References

[rd1] HPQCD 2015, FNAL/MILC 2015

[rd2] S. Fajfer et al. 2012

[rd3] Belle collaboration, Phys.Rev.Lett. 118 (2017) no.21, 211801

[tn1] C. Patrignani et al. (Particle Data Group), Chin. Phys. C, 40, 100001 (2016)

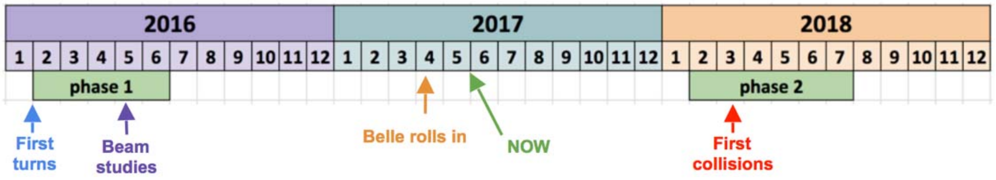
[tn2] Belle collaboration, Phys.Rev. D92 (2015) no.5, 051102; Belle collaboration, Phys.Rev.Lett. 110 (2013) no.13, 13180; BaBar collaboration, Phys.Rev. D88 (2013) no.3, 031102; BaBar collaboration, Phys. Rev.D 77, 011107(R) (2008)

[knn1] BELLE2-MEMO-2016-007, Buras et al. JHEP 1502 (2015) 184

[knn2] Belle collaboration, arXiv:1702.03224; Belle collaboration, Phys.Rev. D87 (2013) no.11, 111103; BaBar collaboration, Phys.Rev. D87 (2013) no.11, 112005

BACK-UP SLIDES

SuperKEKB Commissioning



Phase I (2016)

- No Belle II
- Circulate both beams; no collisions
- Tune accelerator optics, etc.
- Vacuum scrub
- **Beam studies**

Phase II (2018)

- First collisions
- Develop beam abort
- Tune accelerator optics, etc. (nano-beam)
- **Beam studies**

Phase 1 (no collisions)

***Touschek* scattering:**
- intra-bunch scattering process
- dominant with highly compressed beams
- 20 times higher

Beam-gas scattering:
- Bremsstrahlung (negligible) & Coulomb interactions (up to 100 times higher) with residual gas atoms & molecules

Synchrotron radiation:
- emission of photons by charged particles (e^+e^-) when deflected in *B*-field

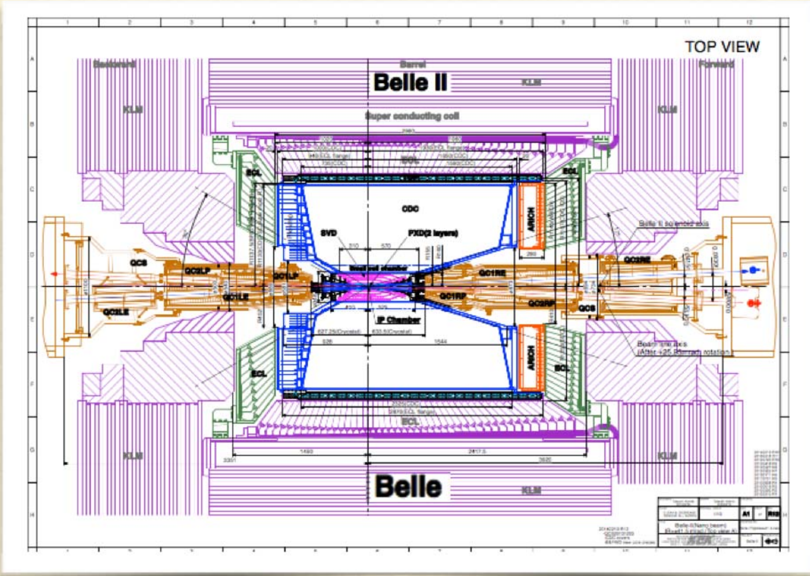
Phase 2 (collisions)

***Radiative Bhabha* process:**
photon emission prior or after *Bhabha* scattering
interaction with iron in the magnets leads to neutron background

***Two photon* process:**
- very low momentum e^+e^- pairs via $e^+e^- \longrightarrow e^+e^-e^+e^-$
- increased hit occupancy in inner detectors

Injection Background:
- covered later in the talk

Belle II detector (I)



- Detector an reconstruction algorithm improvements results in
  - Fast signal shaping and waveform fit of e.m. calorimeter signals to preserve excellent energy resolution in high-pileup environment
  - Increase Ks efficiency (by ~30%)
  - Improve IP and secondary vertex resolution (~factor 2)
  - Better K/π separation (π fake rate decreases by ~2.5)
  - Improve π^0 reconstruction

FEI performances

Table 5: Tag-side efficiency: Number of correctly reconstructed tag-side B mesons divided by the total number of $\Upsilon(4S)$ events. The presented efficiencies depend on the used BASF2 release (7.2), MC campaign (MC 7) and FEI training configuration.

Tag	FR^2 @ Belle	FEI @ Belle MC	FEI @ Belle II MC
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^+0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %

$B \to D(*)\ \tau\nu$: theoretical and experimental status

Exp.	Tag method	τ^- decays	Observables	Fit variables
Belle [37]	Untagged	$e^-\nu_\tau\bar{\nu}_e, \pi\bar{\nu}_\tau$	$\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)$	$M_{\rm bc}^{\rm comp}$
Belle [38]	Untagged	$\ell^-\nu_\tau\bar{\nu}_\ell, \pi\bar{\nu}_\tau$	$\mathcal{B}(B^- \to D^{(*)0}\tau^-\bar{\nu}_\tau)$	$M_{\rm bc}^{\rm comp}$ and p_{D^0}
Belle [26]	Hadronic	$\ell^-\nu_\tau\bar{\nu}_\ell$	R_D, R_{D^*}, q^2, $\lvert p_\ell^*\rvert$	$M_{\rm miss}^2$ and $\mathcal{O}_{NB}$†
Belle [39]	Semileptonic	$\ell^-\nu_\tau\bar{\nu}_\ell$	R_{D^*}, $\lvert p_\ell^*\rvert$ $\lvert p_{D^*}^*\rvert$	$E_{\rm ECL}$ and $\mathcal{O}'_{NB}$‡
Belle [40]	Hadronic	$h^-\nu_\tau$	R_{D^*}, $P_\tau(D^*)$	$E_{\rm ECL}$ and $\cos\theta_{\rm hel}$
BaBar [25, 41]	Hadronic	$\ell^-\nu_\tau\bar{\nu}_\ell$	R_D, R_{D^*}, q^2	$M_{\rm miss}^2$ and p_ℓ

Table 7: Summary of experimental measurements of semitauonic B decays. † Mainly based on $E_{\rm ECL}$. ‡ Mainly based on $\cos\theta_{B\text{-}D^*\ell}$: further description in the text.

	R_D	R_{D^*}	Correlation
BaBar	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.018$	-0.45/-0.07/-0.27
Belle (had. tag, $\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau$)	$0.375 \pm 0.064 \pm 0.026$	$0.293 \pm 0.038 \pm 0.015$	-0.56/-0.11/-0.49
Belle (sl tag)	NA	$0.302 \pm 0.030 \pm 0.011$	NA
LHCb	NA	$0.336 \pm 0.027 \pm 0.030$	NA
Belle (had. tag, $\tau^- \to h^-\nu_\tau$)	NA	$0.270 \pm 0.035^{+0.028}_{-0.025}$	NA
Average	$0.397 \pm 0.040 \pm 0.028$	$0.310 \pm 0.015 \pm 0.008$	-0.23

Table 8: Measurements of $R_{D^{(*)}}$ by Babar, Belle and LHCb. The averages presented are performed by HFlav [8]. The correlation column list the statistical, systematic and total correlations respectively..