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Prospects for rare B decays at Belle II

Sam Cunliffe

on behalf of the Belle II radiative and electroweak penguin physics group

APS DPF meeting, FNAL, 31 July - 4 August 2017

U.S. DEPARTMENT OF ENERGY

PNNL-SA-127810

This talk

- **Why rare B decays?**
- **The next generation B-factory**
  - SuperKEKB
  - Belle II
- **Prospects at Belle II**
  - Inclusive analyses in general, and $B \to X_{s,d}\gamma$
  - Lepton (non) universality
  - $B \to K^{(*)}\nu\nu$
  - $B_{(s)} \to \tau\tau$; $B \to K^{(*)}\tau\tau$
- **Conclusions**

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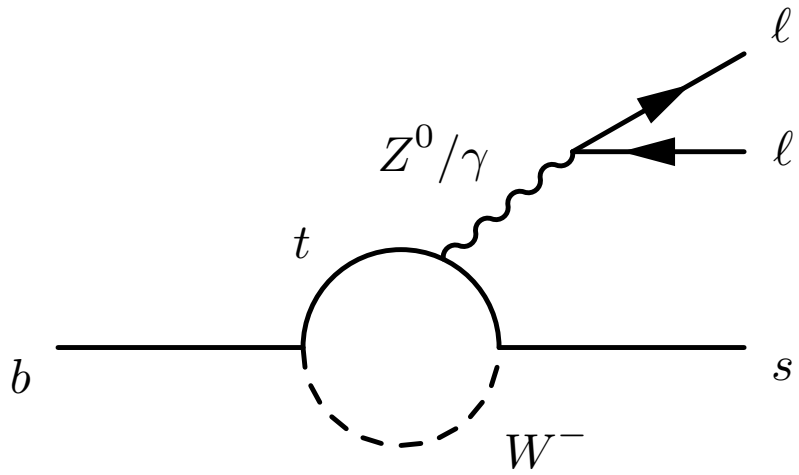
Why rare B decays?



b→sℓℓ ℓ=eμτν
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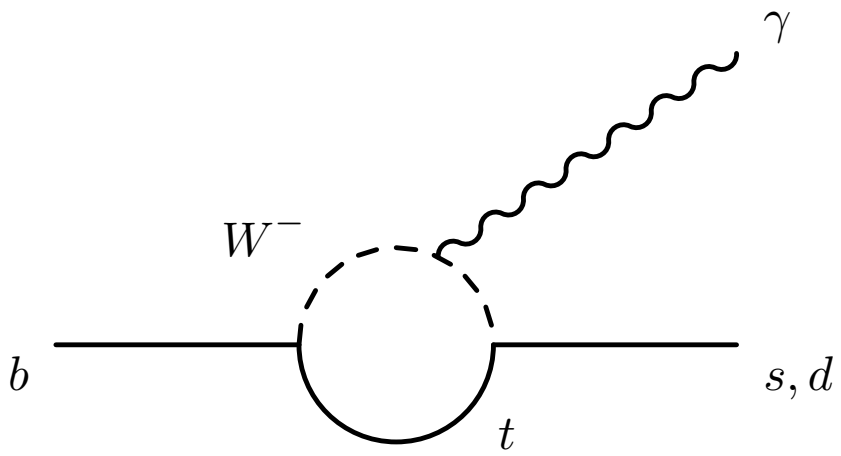
SM



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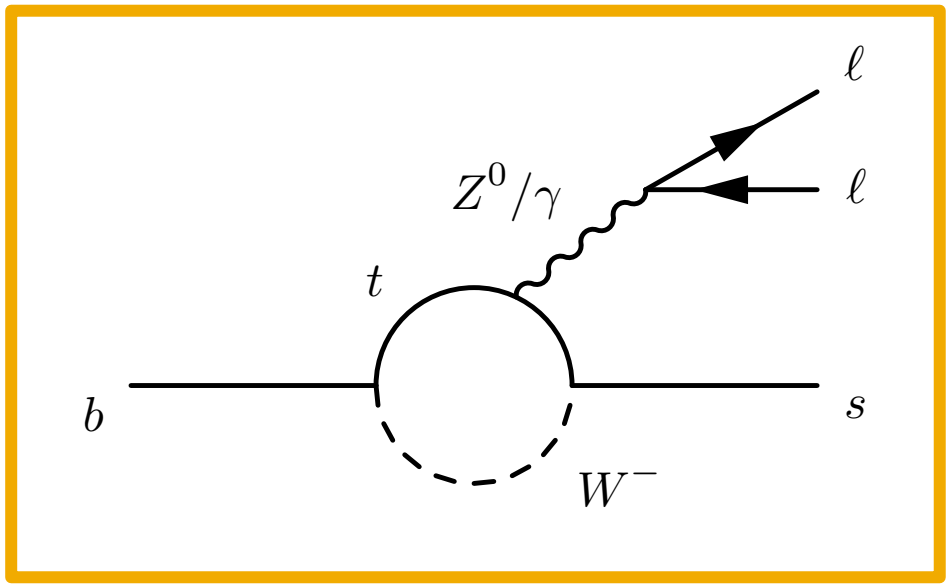

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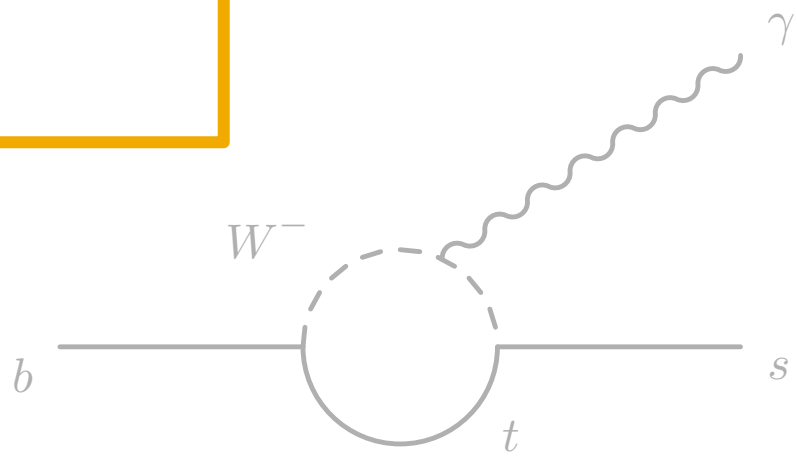

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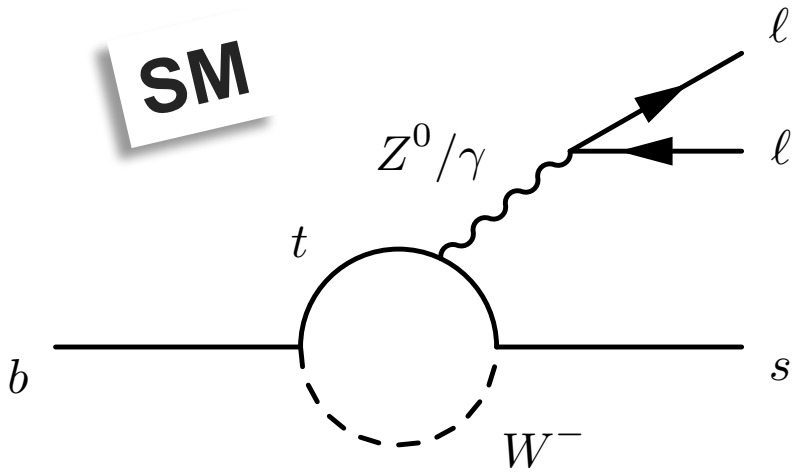

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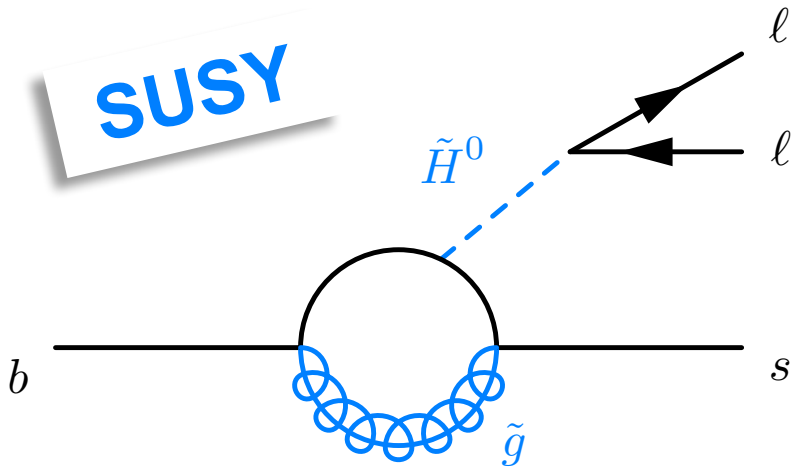

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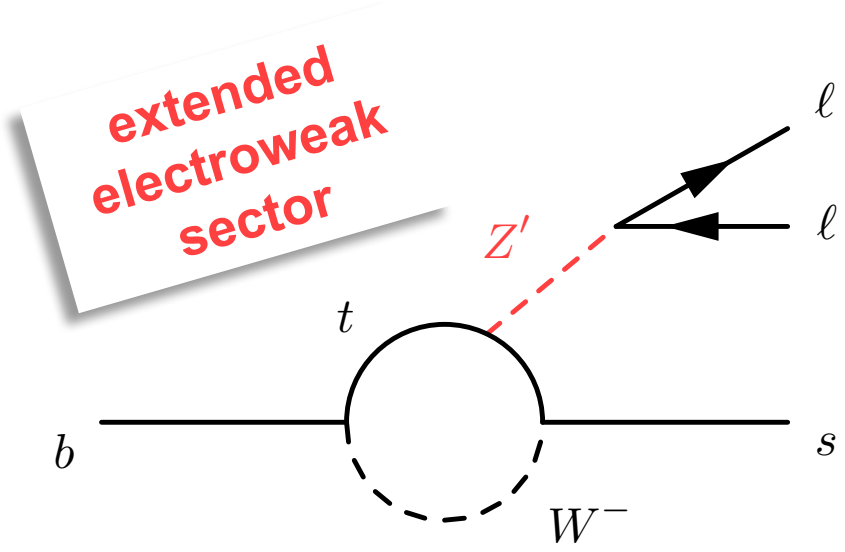

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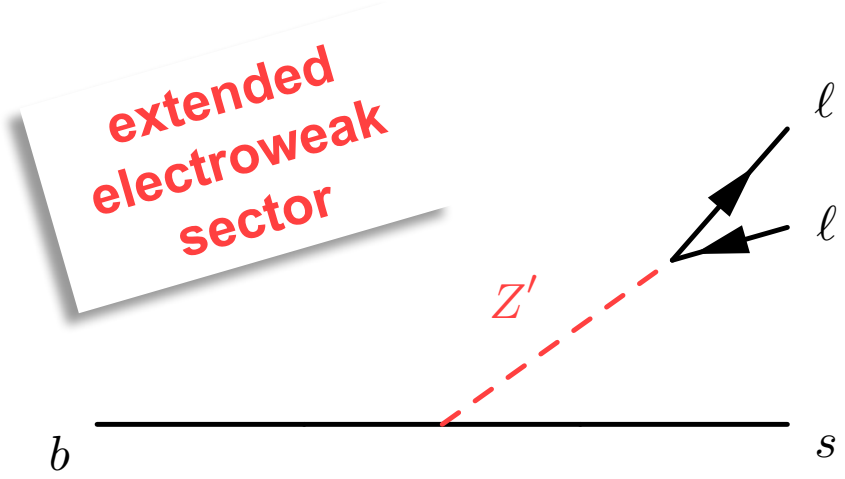

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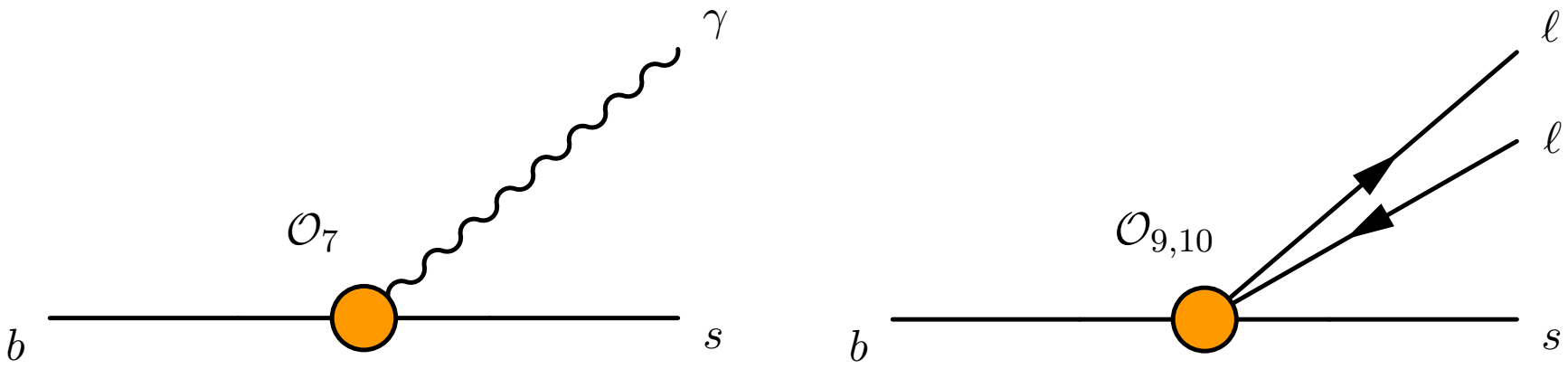

- **<u>Wilson Coefficient</u>**, C_i
  model-independent coupling in the effective field theory of b quark transitions. Paired with an operator, $\mathcal{O}_i$.
  - Consists of a SM bit and a new physics bit: $\mathbf{C_i = C_i^{SM} + C_i^{NP}}$.
  - $\mathbf{C_9}$, $\mathbf{C_{10}}$: vector and axial vector Wilson Coefficients.
  - $\mathbf{C_7}$: radiative photon Wilson Coefficient.

Why rare B decays?

arxiv:1705.05802; LHCb-PAPER-2017-017

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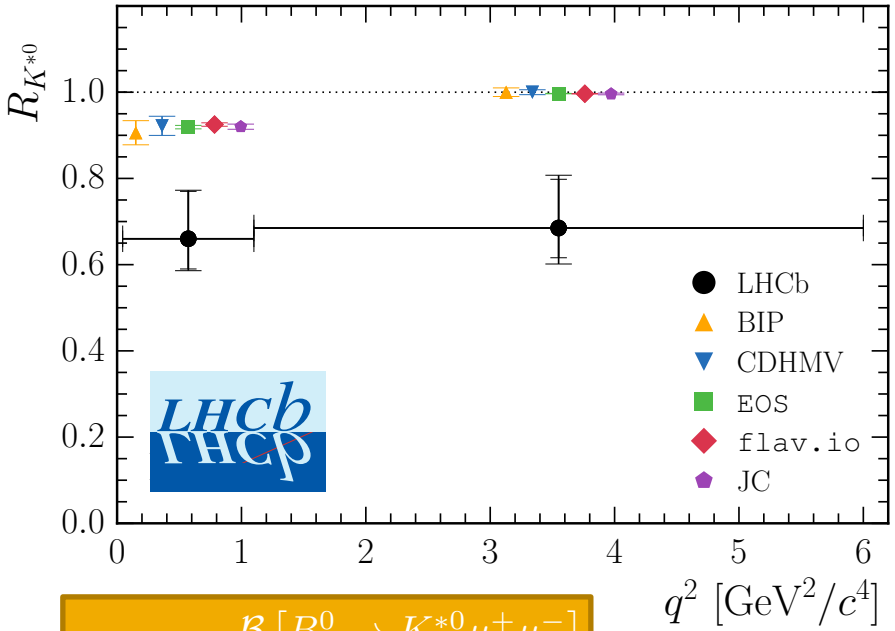
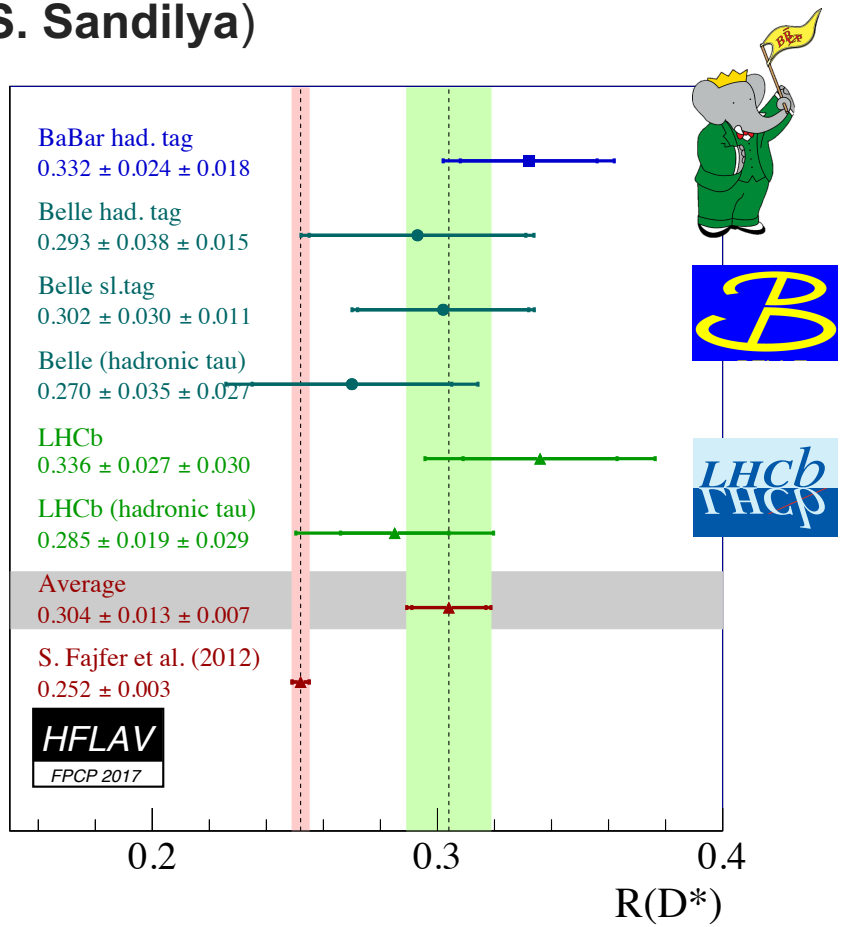
- We've heard from LHCb. Hopefully this slide does not steal their thunder.
- Stay tuned after lunch to hear from Belle (**S. Sandilya**)



$$R_{K^{*0}} \equiv \frac{\mathcal{B}\left[B^0 \to K^{*0}\mu^+\mu^-\right]}{\mathcal{B}\left[B^0 \to K^{*0}e^+e^-\right]}$$

$$R(D^{*0}) \equiv \frac{\mathcal{B}\left[B \to D^*\tau^+\nu_\tau\right]}{\mathcal{B}\left[B \to D^*\mu^+\nu_\mu\right]}$$



The next generation B factory

Photo: Markus Freidl

SuperKEKB

Second generation B factory

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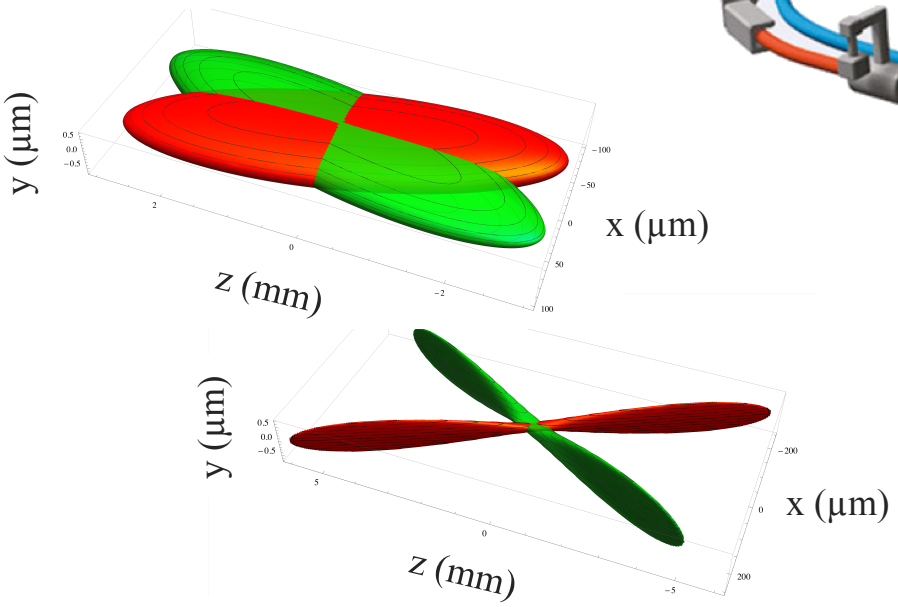
- **×40** higher luminosity than KEKB
  - Smaller β* (×20)
  - Higher current (×2)



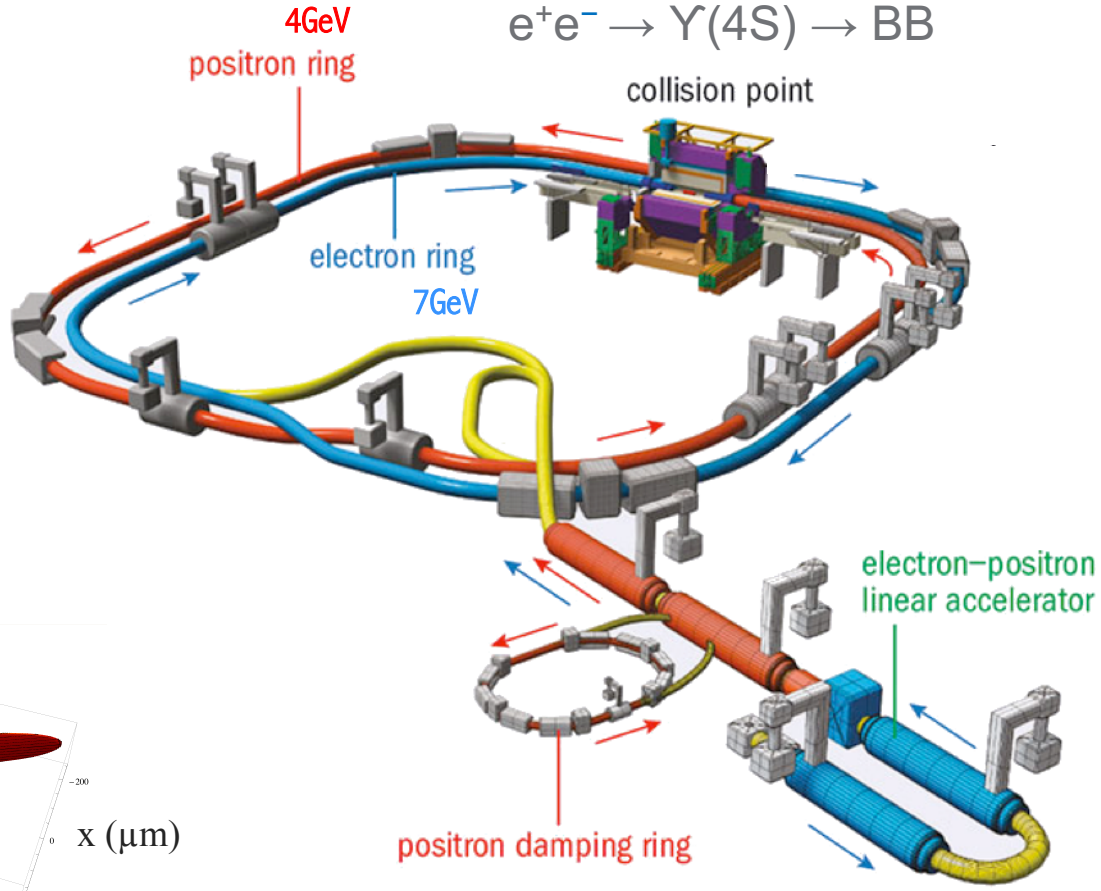


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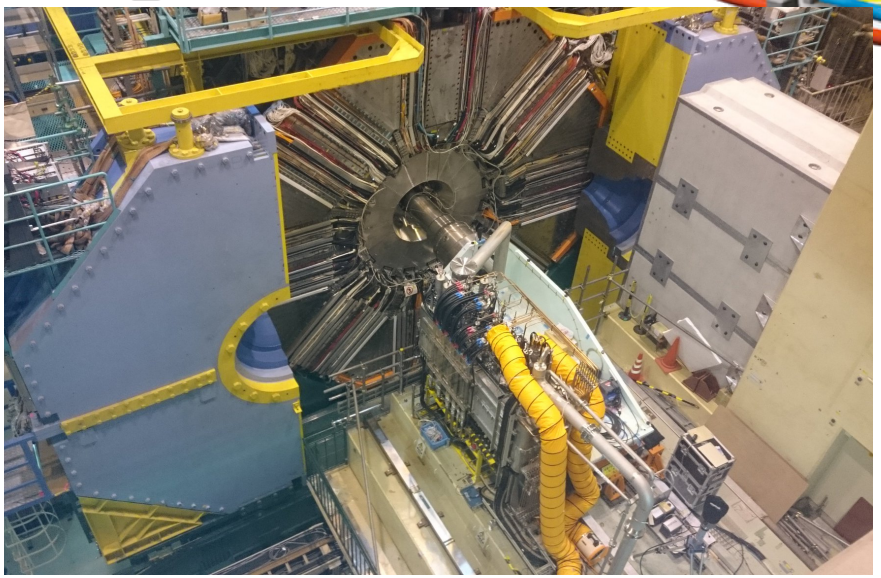
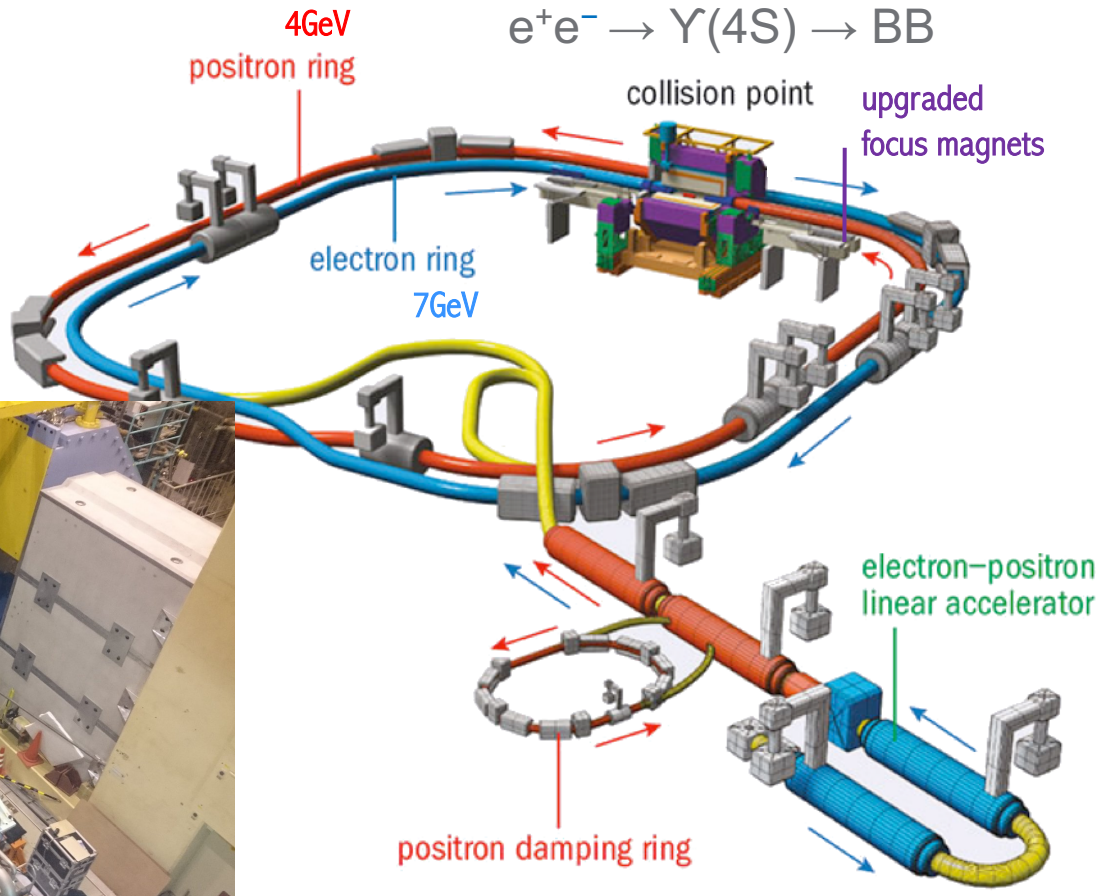
Photo: @belle2collab





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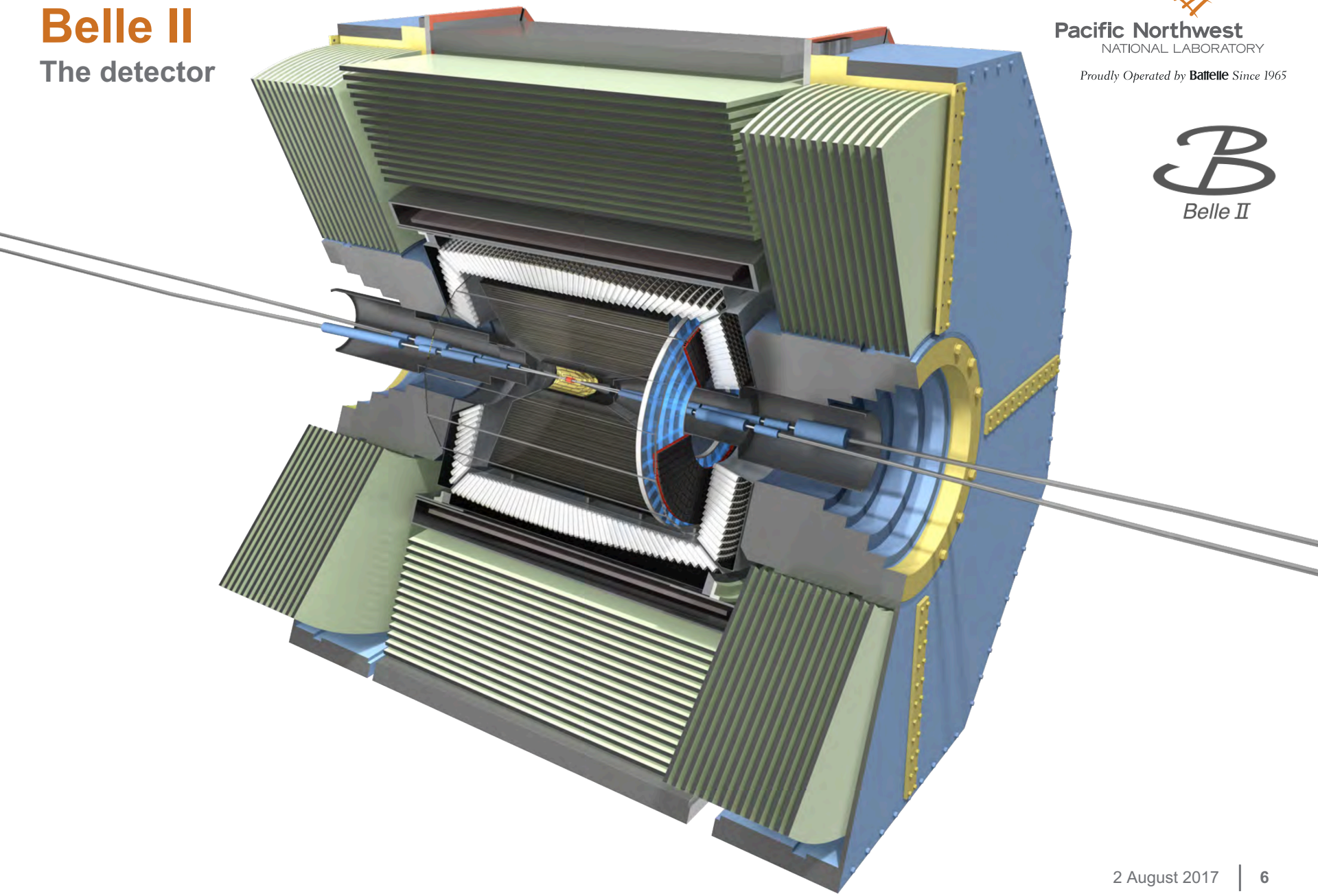
The detector



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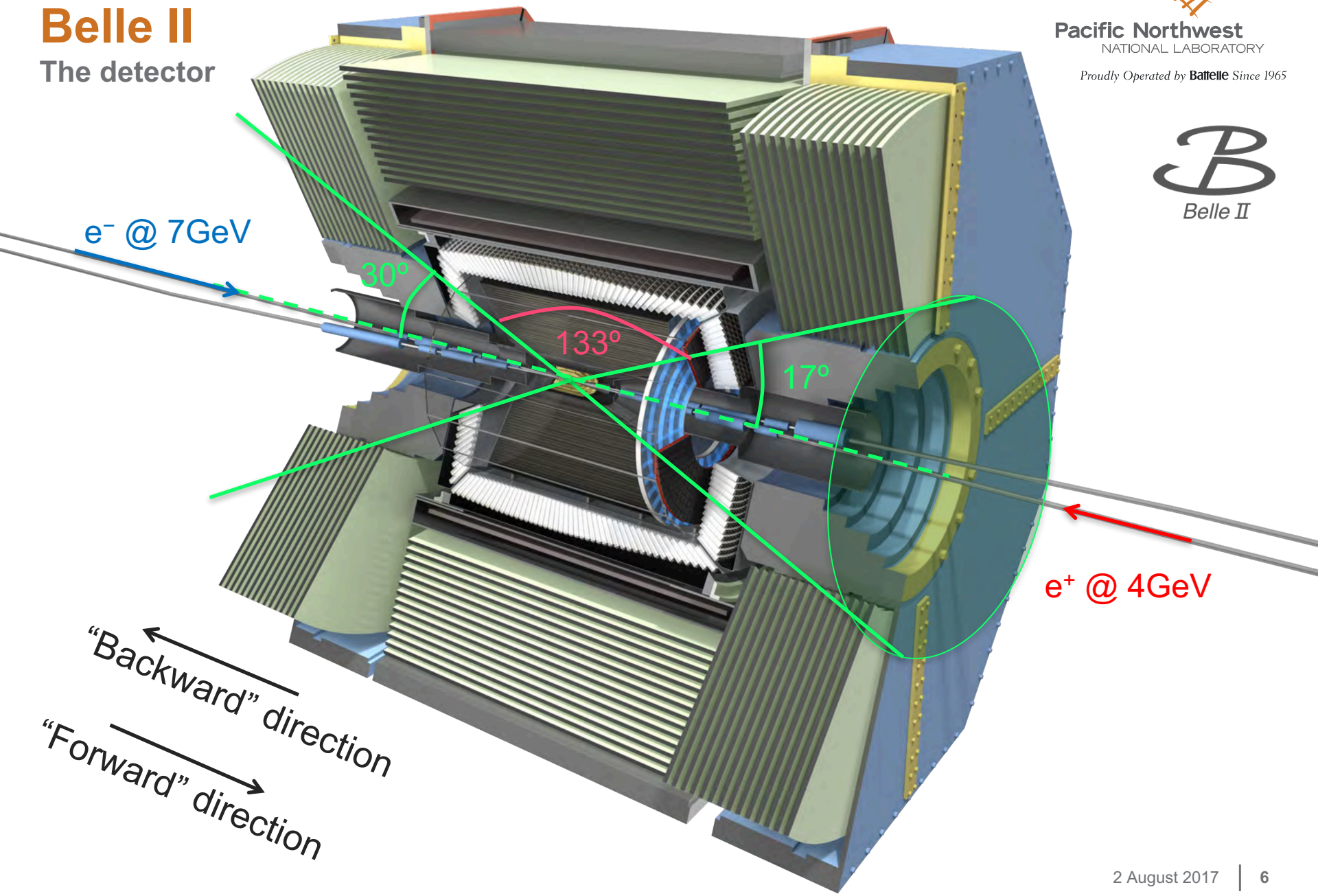

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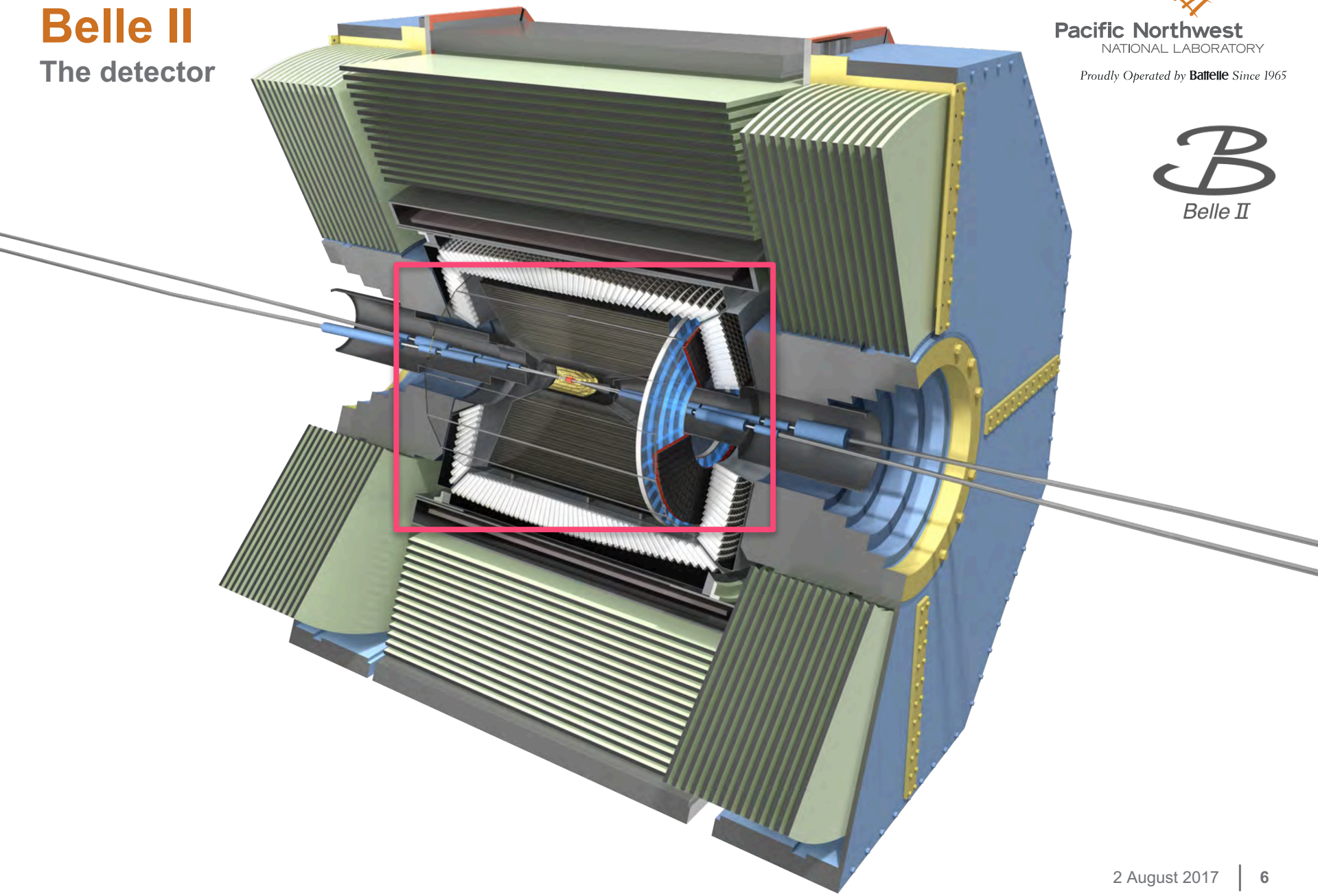

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Interaction point region

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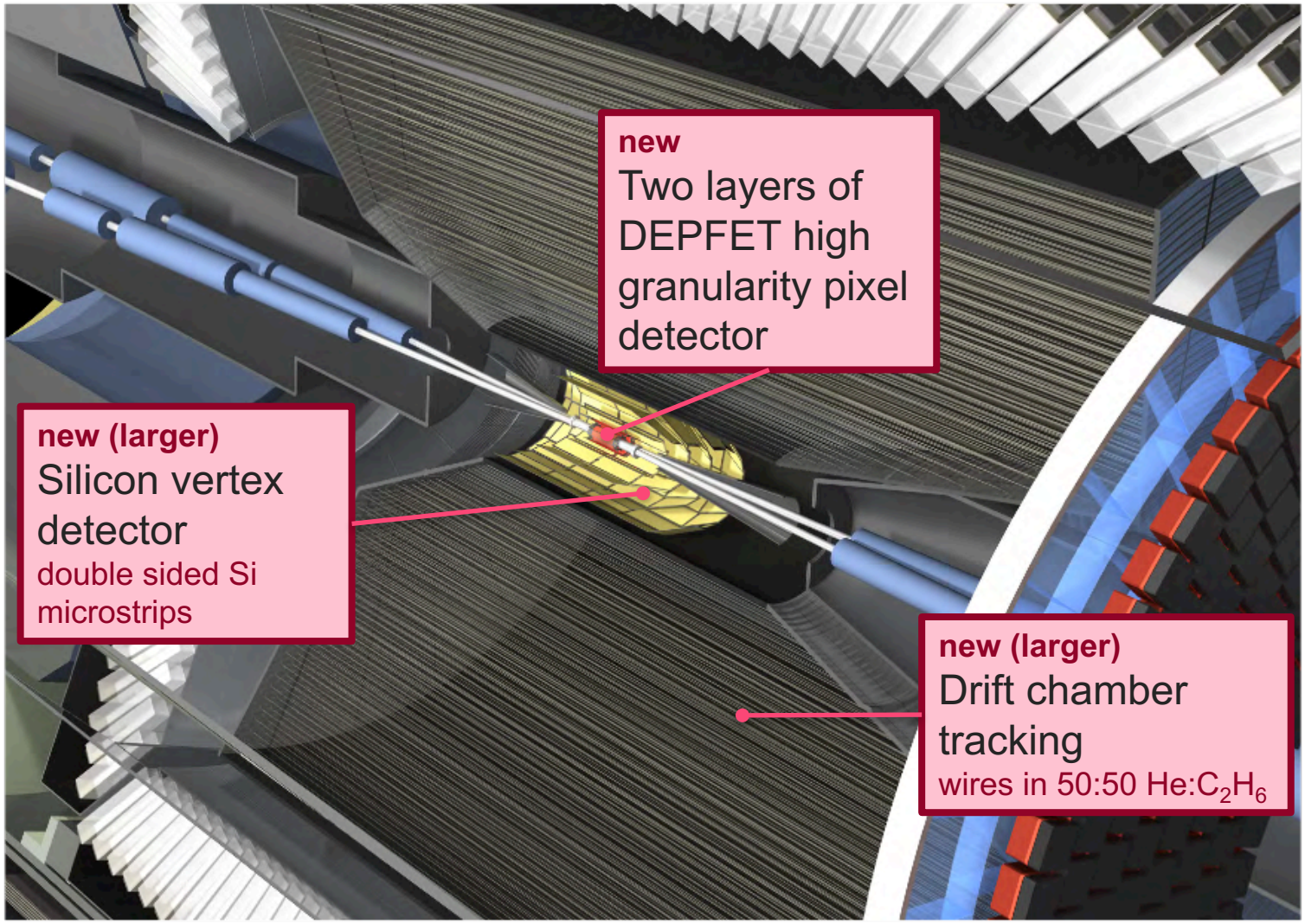

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The detector

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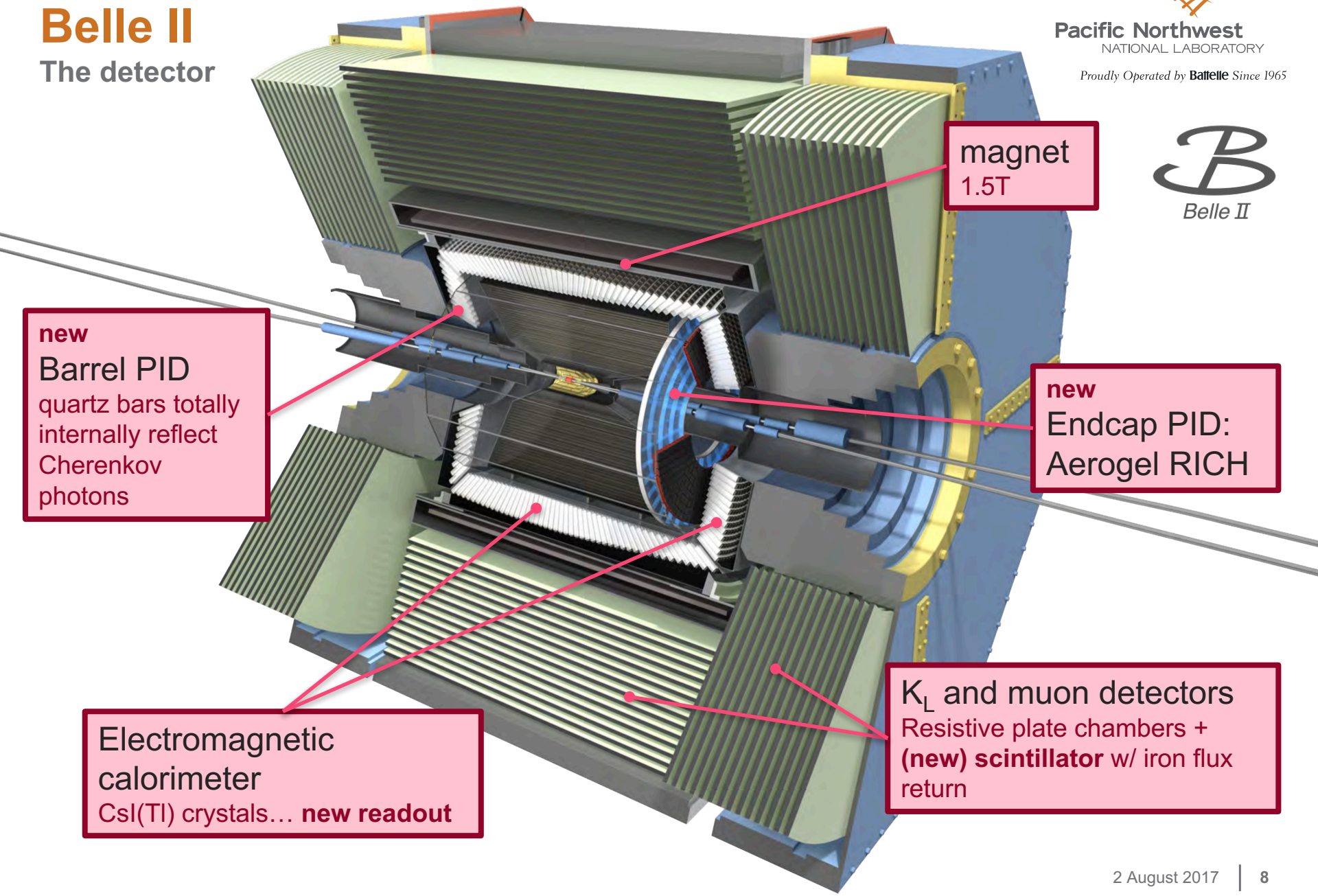


magnet
1.5T

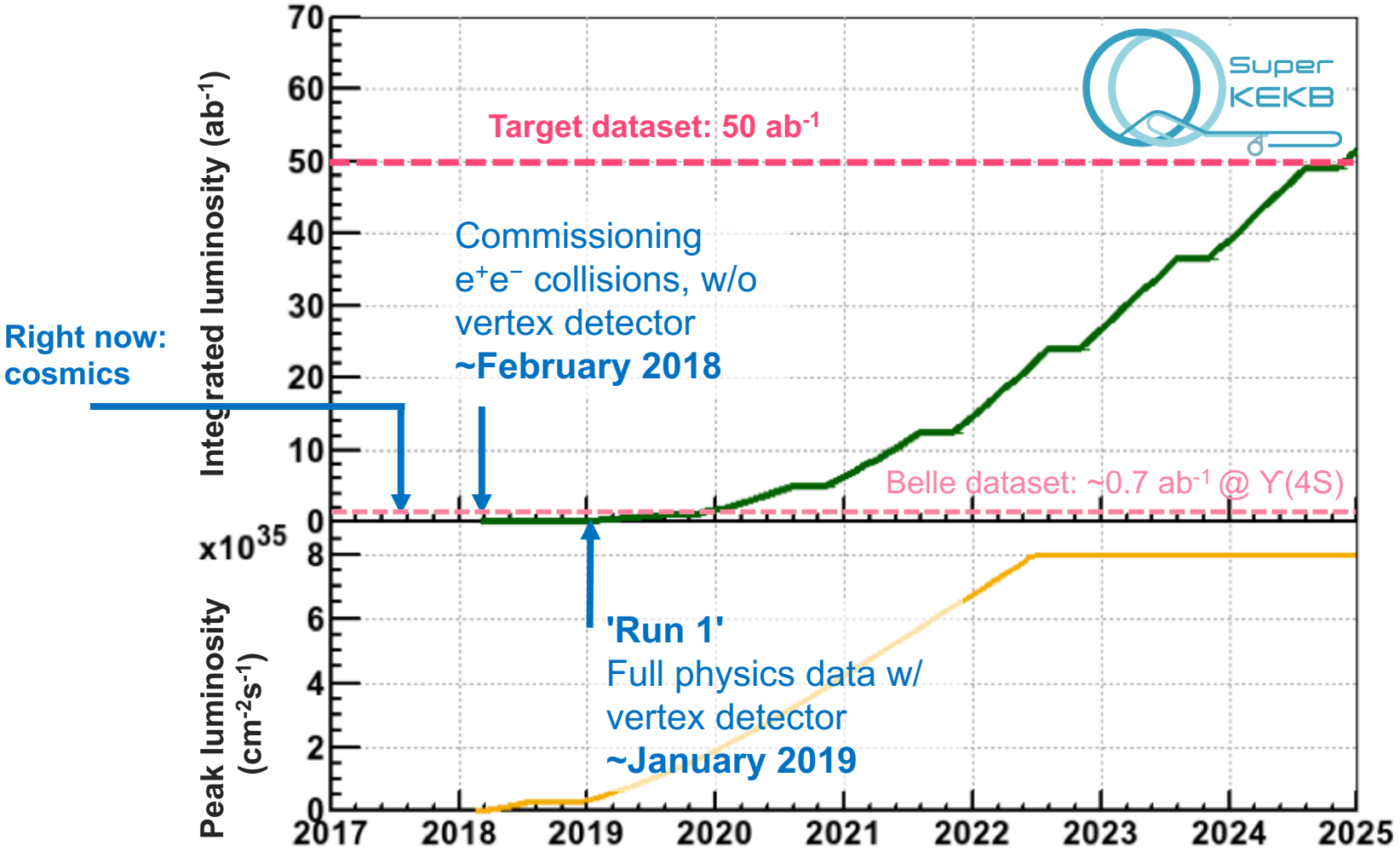
new
Barrel PID
quartz bars totally internally reflect Cherenkov photons

new
Endcap PID:
Aerogel RICH

Electromagnetic calorimeter
CsI(Tl) crystals… **new readout**

K_L and muon detectors
Resistive plate chambers + **(new) scintillator** w/ iron flux return

So when do you start taking data?



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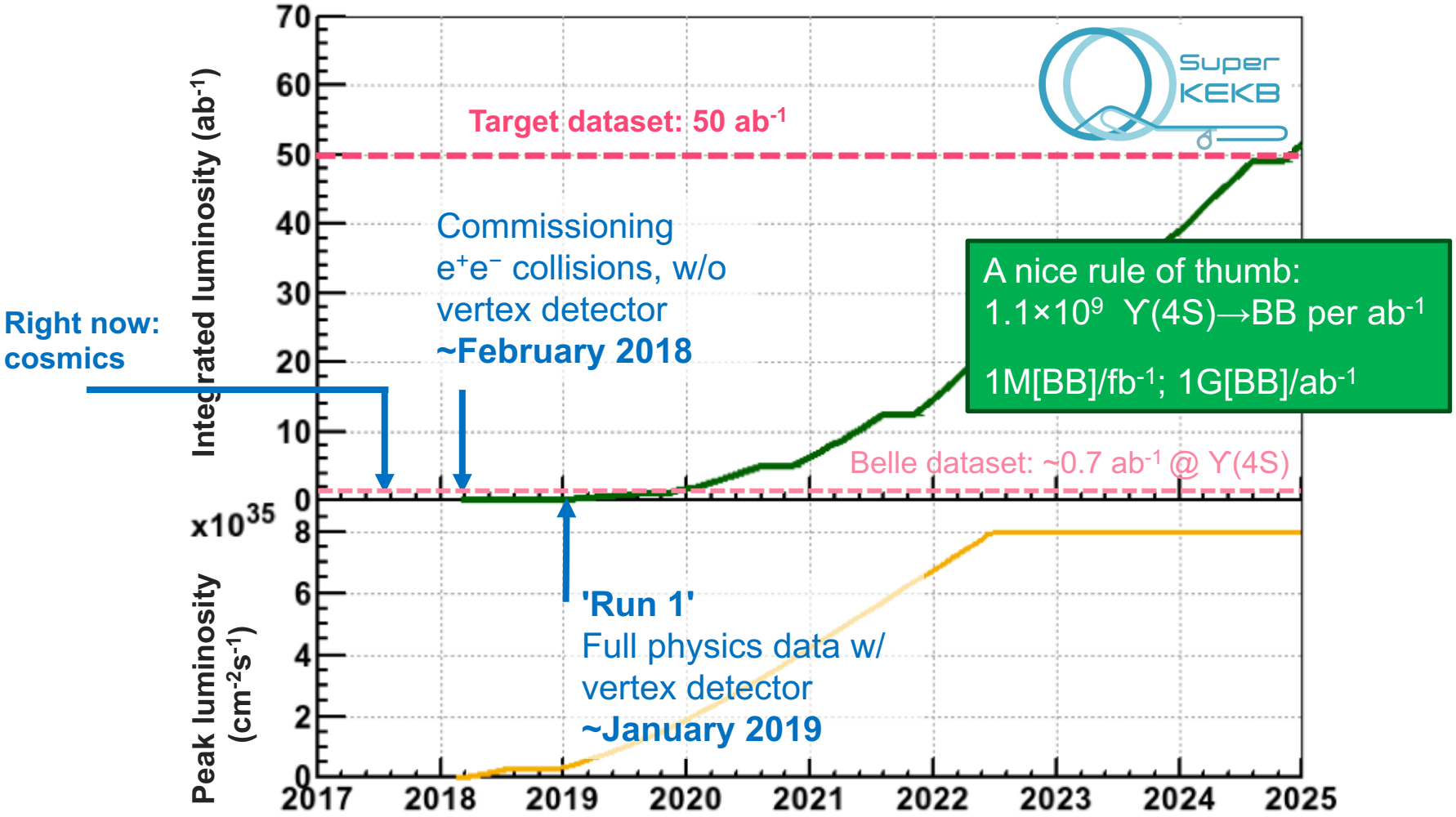

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  - $B_{(s)} \to \tau\tau$; $B \to K^{(*)}\tau\tau$
- Conclusions

Inclusive analysis strategies

$B \to X_{s,d}(\gamma,\ell\ell)$

Belle II

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1. Fully inclusive

- Exploit clean decay environment at Belle II *c.f.* LHCb.
- Can be **fully hadronic tag** (have full event information)
- …or **semi-leptonic tag** (don't have full event)

2. Sum-of-exclusives

- Reconstruct, the 'X' from many exclusive decays: $X_s \to K n\pi$, $3K m\pi$, $K\eta m\pi$ ($n>1$, $m\geq 1$).
- Specify flavour if X (X_s or X_d).
- Know flavour of B.
- Know isospin.

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 %

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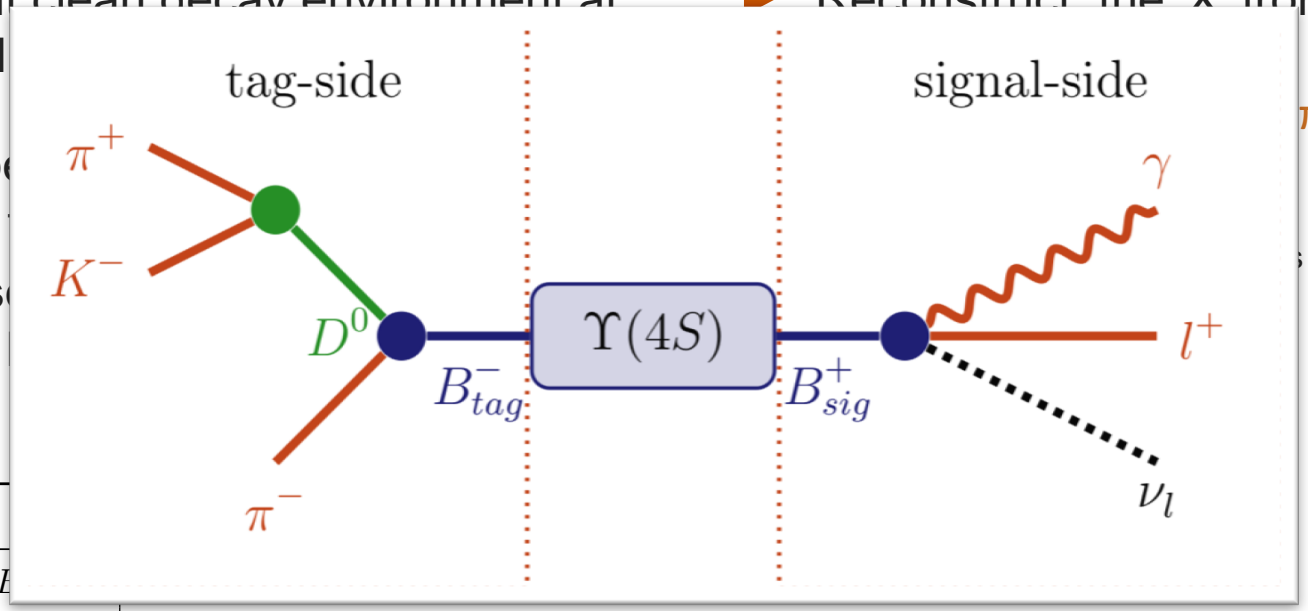
- Reconstruct the 'X' from many

π

, or X_d).



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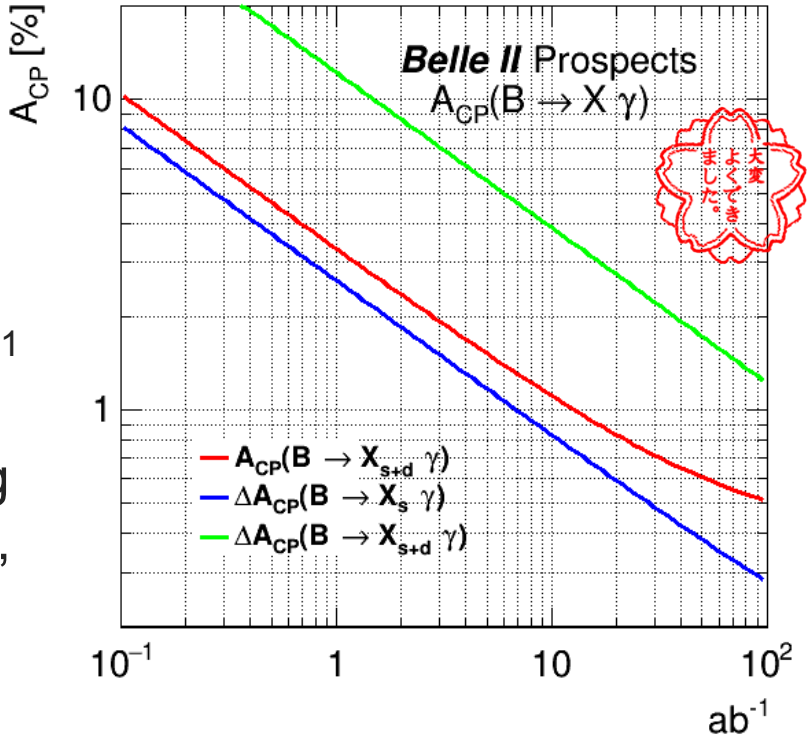
$B \to X_{s,d}\gamma$

- Belle II 'golden channel'.
  - High yield. Usually good S/B ratio.
- Sub-percent level uncertainties for A_{CP}, ΔA_{CP}, Isospin asymmetry (Δ_{0+}) w/ 50ab^{-1}
- Percent level uncertainties for branching fraction, and time-dependent CPV (S_{CP}), and $|V_{td}/V_{ts}|$



reco. method	tagging	effi.	S/B	q	p_B	A_{CP}	Δ_{0+}	ΔA_{CP}
sum-of-exclusive	none	high	moderate	s or d	yes	yes	yes	yes
fully-inclusive	had. B	very low	very good	s and d	yes	yes	yes	yes
	SL B	very low	very good	s and d	no	yes	yes	yes
	L	moderate	good	s and d	no	yes	no	no
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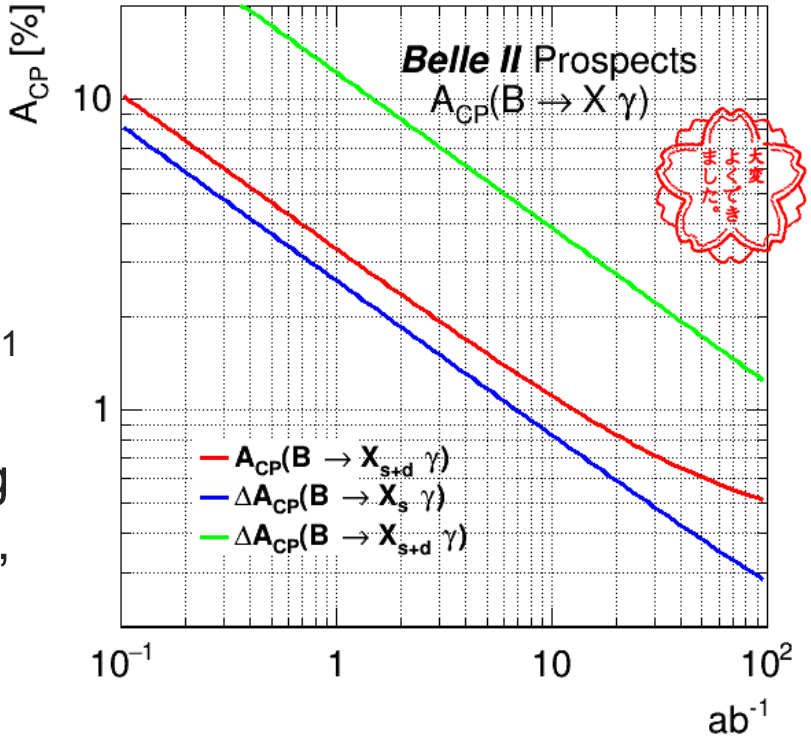

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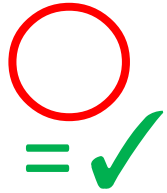

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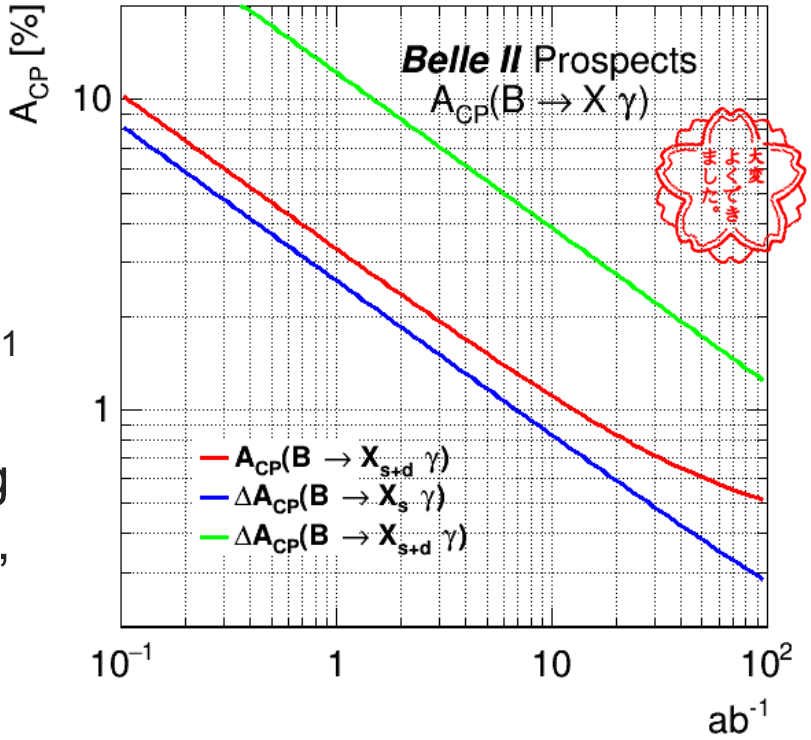

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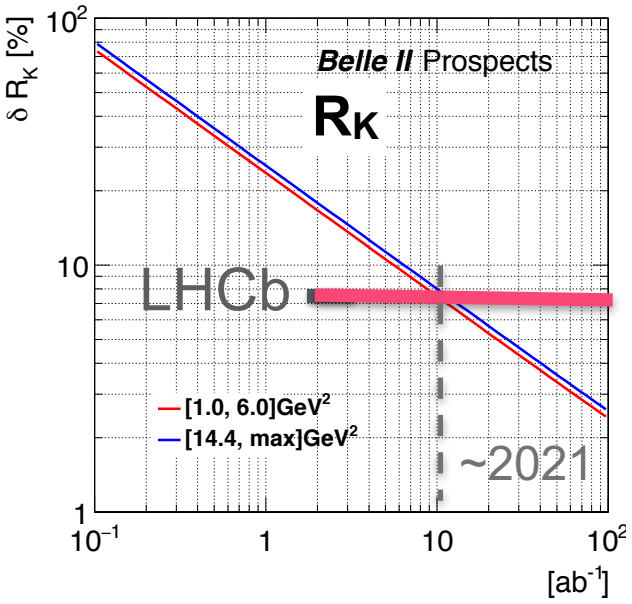
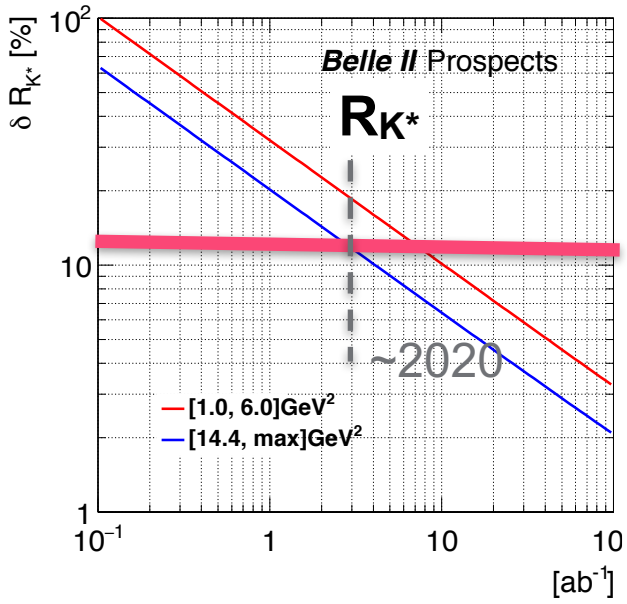
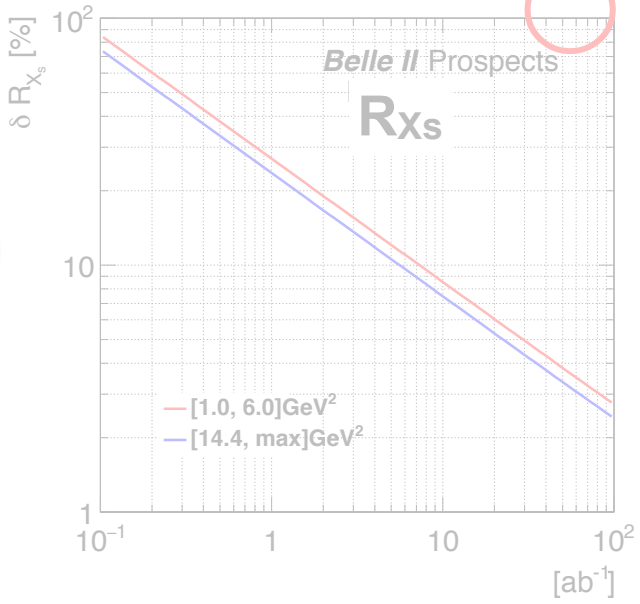
Lepton (non) universality; b→sℓℓ

- Not a Belle II golden channel (silver, bronze?).
- Independent verification strongly desired, since this is a hot topic.
- Ratio built from inclusive decays " R_{X_s}" only[?] possible at Belle II.
- Better electron recovery at Belle II than LHCb.







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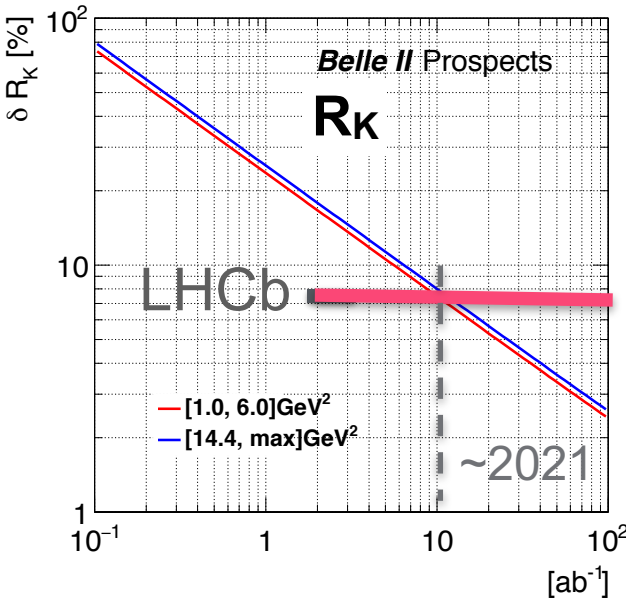
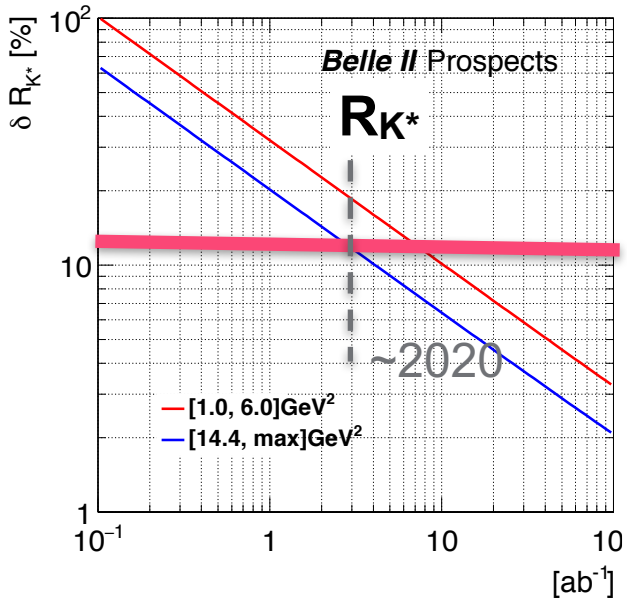
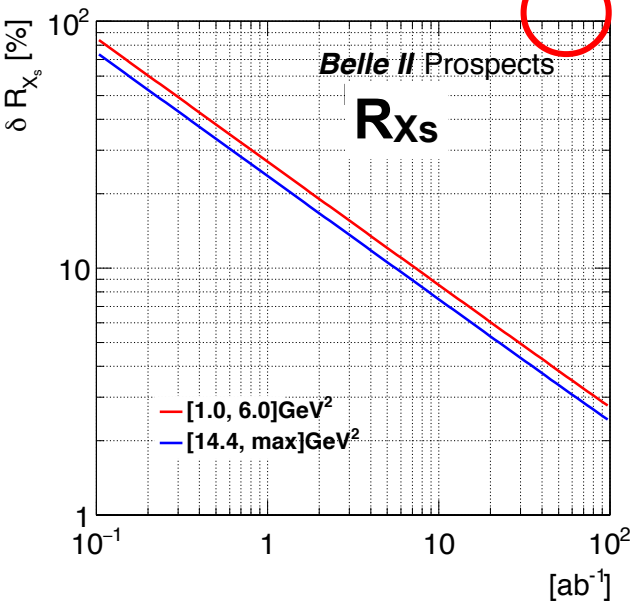
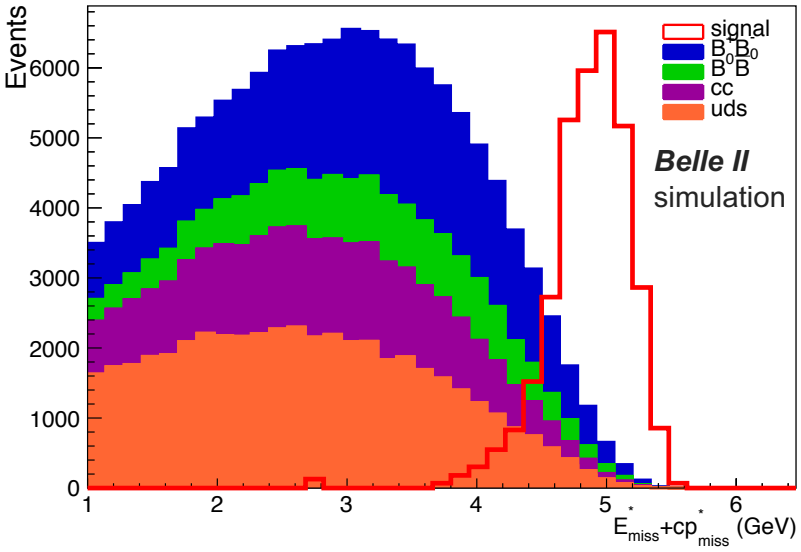






$B \to K^{(*)} \nu\nu$

- Another Belle II 'golden channel'
- Observable at Belle II (if SM)
  - 10-12% uncertainty w/ 50ab^{-1}
- Use full event reconstruction
  - Exploit the missing energy + sum of missing 3 momentum in CoM frame ($E^*_{miss}+cp^*_{miss}$)



Mode	$\mathcal{B}$ $[10^{-6}]$	Efficiency Belle $[10^{-4}]$	$N_{\mathrm{Backg.}}$ 711 fb^{-1} Belle	$N_{\mathrm{Sig-exp.}}$ 711 fb^{-1} Belle	$N_{\mathrm{Backg.}}$ 50 ab^{-1} Belle II	$N_{\mathrm{Sig-exp.}}$ 50 ab^{-1} Belle II	Statistical error 50 ab^{-1}	Total Error
$B^+ \to K^+ \nu\bar{\nu}$	4.68	5.68	21	3.5	2960	245	20%	22%
$B^0 \to K^0_S \nu\bar{\nu}$	2.17	0.84	4	0.24	560	22	94%	94%
$B^+ \to K^{*+} \nu\bar{\nu}$	10.22	1.47	7	2.2	985	158	21%	22%
$B^0 \to K^{*0} \nu\bar{\nu}$	9.48	1.44	5	2.0	704	143	20%	22%
$B \to K^* \nu\bar{\nu}$ combined							15%	17%

Predictions: D. Straub + Belle II

$B_{(s)} \to \tau\tau$; $B \to K^{(*)}\tau\tau$

Belle II

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- Very challenging to measure at LHCb.
- *Rare* + *missing energy*: not observable in Belle II assuming SM.
- Limit on branching fraction of $B \to K^{(*)}\tau\tau$ @ 10^{-6} with $50ab^{-1}$.
  - c.f. SM 10^{-7}.
- Limit on branching fraction of $B \to \tau\tau$ @ 10^{-5} with $50ab^{-1}$.
  - c.f. SM 10^{-7}. Enhanced by LH currents to 10^{-6}.
  - B_s mode dependent on SuperKEKB running schedule: $\Upsilon(5S) \to B_s B_s$
- Interesting case for R&D, tagging improvements, reconstruction improvements. Recall tagging efficiencies <2%.
- Other interesting possible LFV, LNU searches only possible at Belle II with full event reconstruction: $B \to (K^{(*)})e\tau$, $B \to (K^{(*)})\mu\tau$.

Conclusions

- Commissioning collisions **2018**.
- **Full detector physics** data expected to start in **2019**.
  - Quickly overtake Belle dataset.
- Target data sample **$50ab^{-1}$**
  - Roughly 1G[BB pairs] per ab^{-1} @ $\Upsilon(4S)$

		Belle II	LHCb
$B \to X_{s,d}\gamma$	improve precision		?
$B \to K^{(*)}\nu\nu$	will observe if SM		×
$B_{(s)} \to \tau\tau$; $B \to K^{(*)}\tau\tau$	limit if SM, possible in some NP scenarios	○	×
$B \to X\ell\ell$; R_{X_s}	independent check of LHCb, strong C_9^{NP} constraints	○	?
$B \to K^{(*)}\ell\ell$; R_{K,K^*}	check of LHCb's indications of LNU	--	

Conclusions

- Commissioning collisions **2018**.
- **Full detector physics** data expected to start in **2019**.
  - Quickly overtake Belle dataset.
- Target data sample **$50ab^{-1}$**
  - Roughly 1G[BB pairs] per ab^{-1} @ $\Upsilon(4S)$

		Belle II	LHCb
$B \to X_{s,d}\gamma$	improve precision	✓✓	?
$B \to K^{(*)}\nu\nu$	will observe if SM	✓✓	×
$B_{(s)} \to \tau\tau$; $B \to K^{(*)}\tau\tau$	limit if SM, possible in some NP scenarios	✓	×
$B \to X\ell\ell$; R_{X_s}	independent check of LHCb, strong C_9^{NP} constraints	✓	?
$B \to K^{(*)}\ell\ell$; R_{K,K^*}	check of LHCb's indications of LNU	--	✓✓

http://www.pnnl.gov/particle_physics

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http://belle2.jp
http://belle2.org

@belle2collab

Extra material

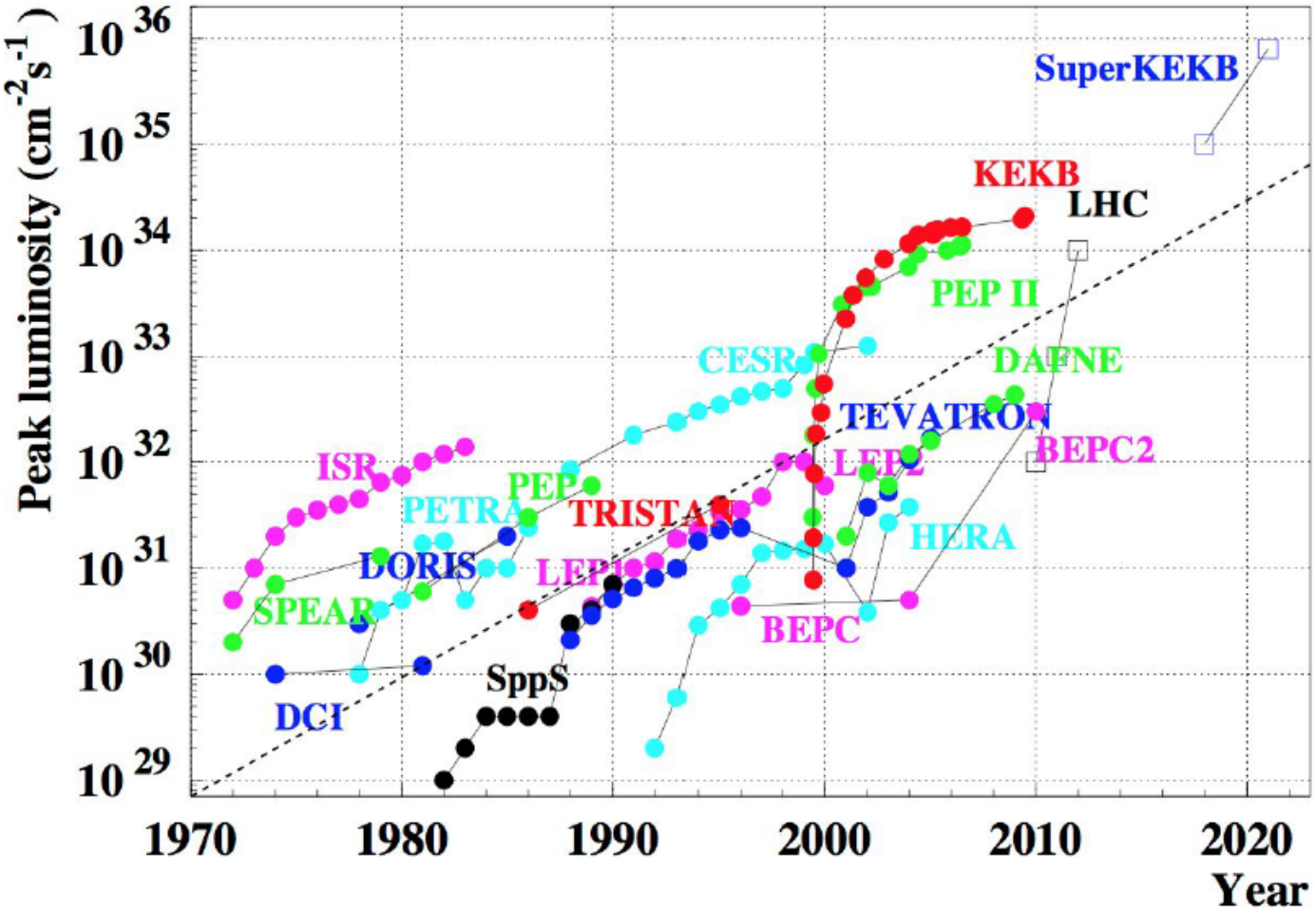
SuperKEKB

Second generation B factory

Belle II

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

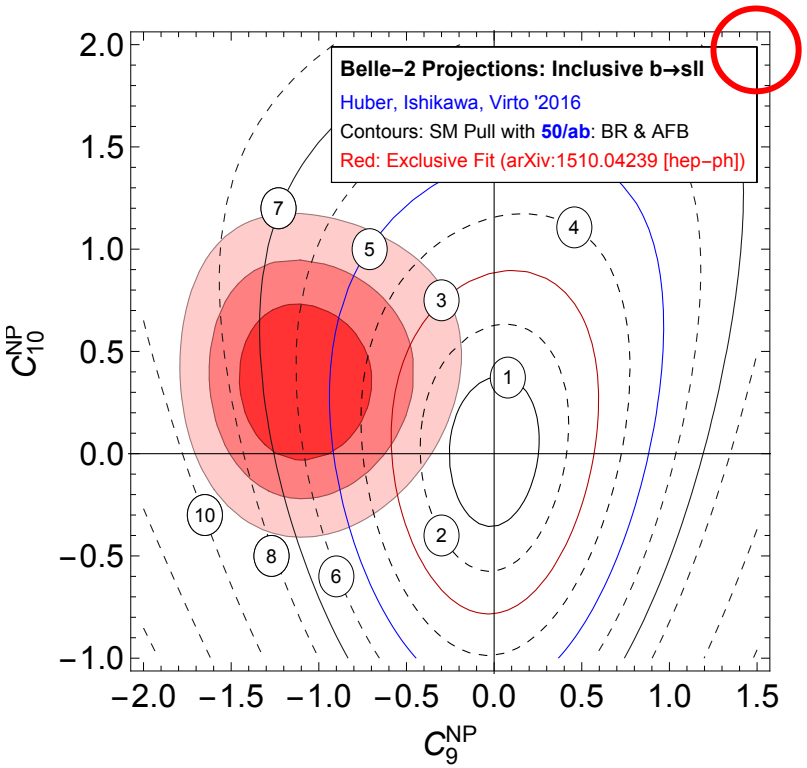


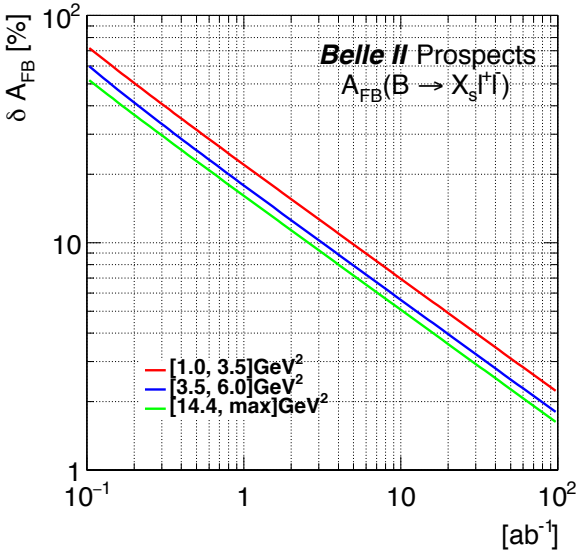
Inclusive b→sℓℓ

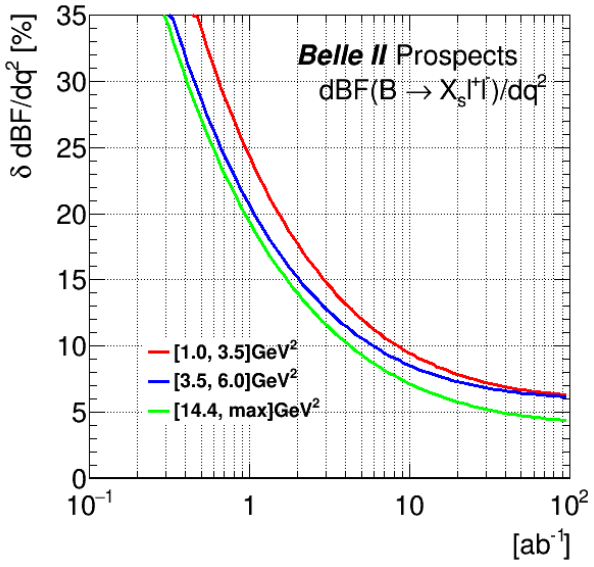
- (Obviously) detailed angular analysis not possible in inclusive scheme (hadron fragments).
- Percent level uncertainty for **dB/dq²**, forward-backward asymmetry of leptons, **A_{FB}**.

Assume **C_9^{NP}**, add Belle II inclusive measurements into exclusion plot.

Will push the 'discrepancy' way into 'observation' land (i.e. <6σ)

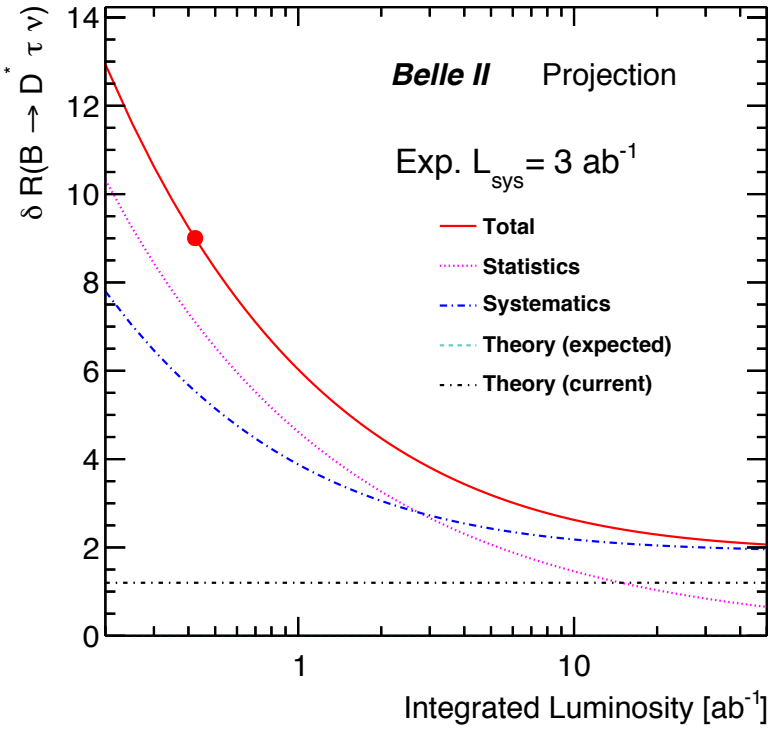


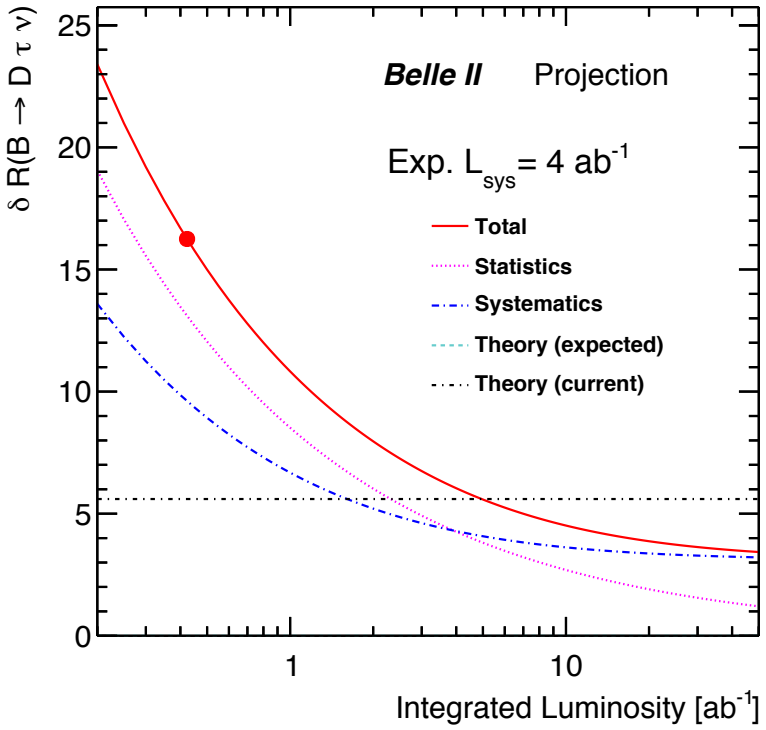




$B \to D^{(*)}\tau\nu$

- Percent level uncertainties on (individual) ratio of branching fractions $B \to D^{(*)}\tau\nu$ to $B \to D^{(*)}\ell\nu$, **$R(D^{(*)})$**, and polarisations of D* and τ.
- Becomes **systematics limited** before $5ab^{-1}$.





Current R&D: machine learning

Benchmarking with B→K*γ

- Improvements seen with **TensorFlow** neural networks *c.f.* TMVA [https://www.tensorflow.org]
- Becoming industry standard, actively maintained / improved.
- Benchmarking in 'easy' mode: precursor to trying out with more complex analysis (e.g. $B \to K^{(*)}\tau\tau$).