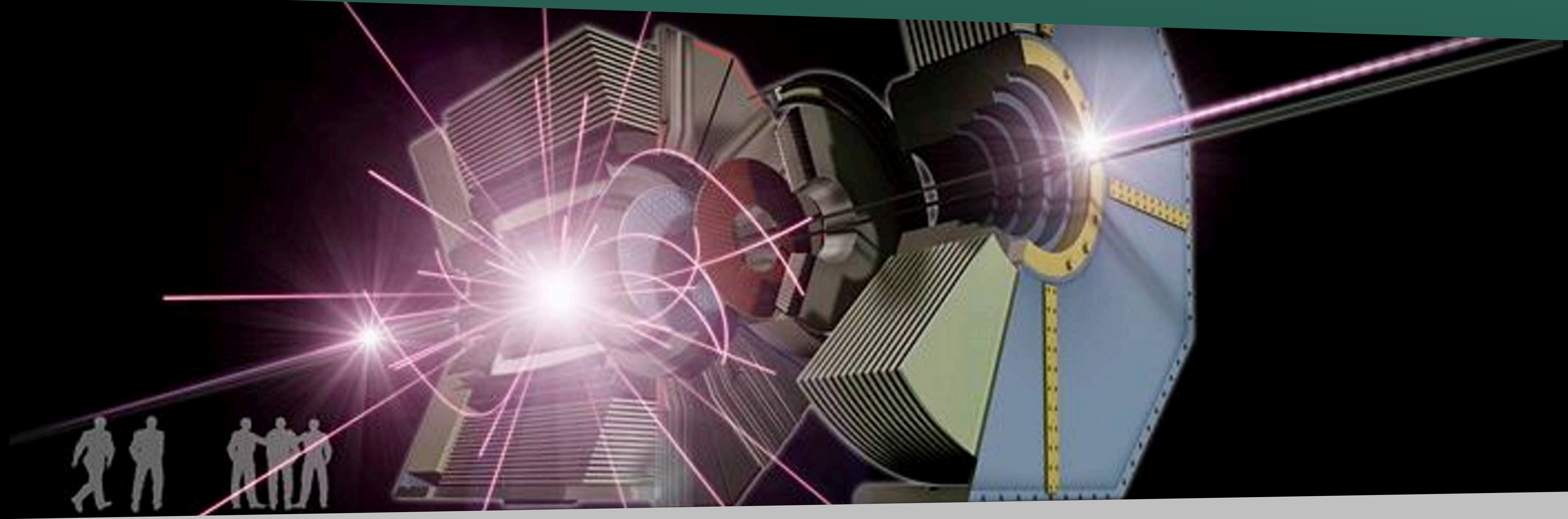
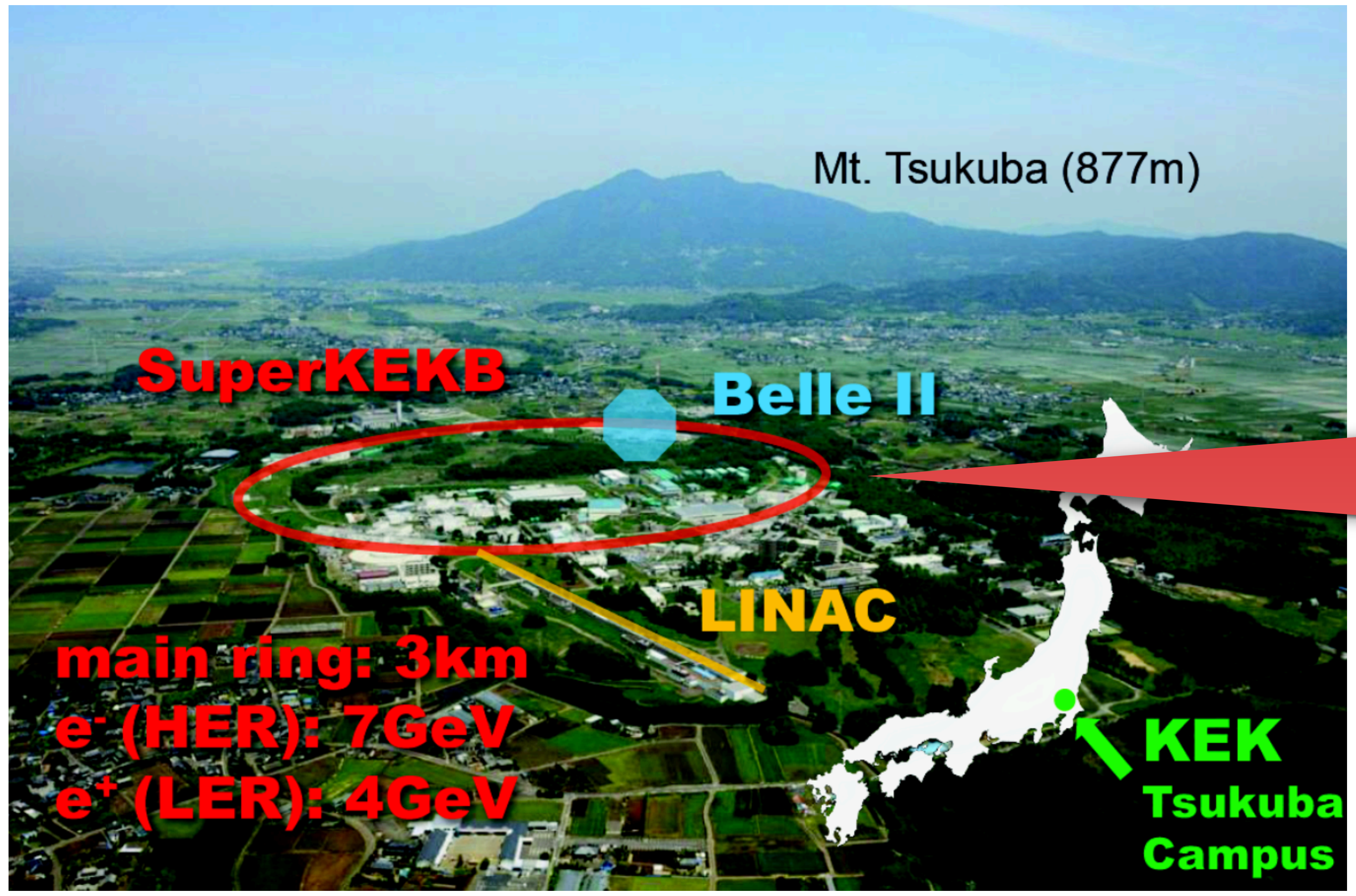
Semileptonic Results from 2018 Belle II Commissioning Data

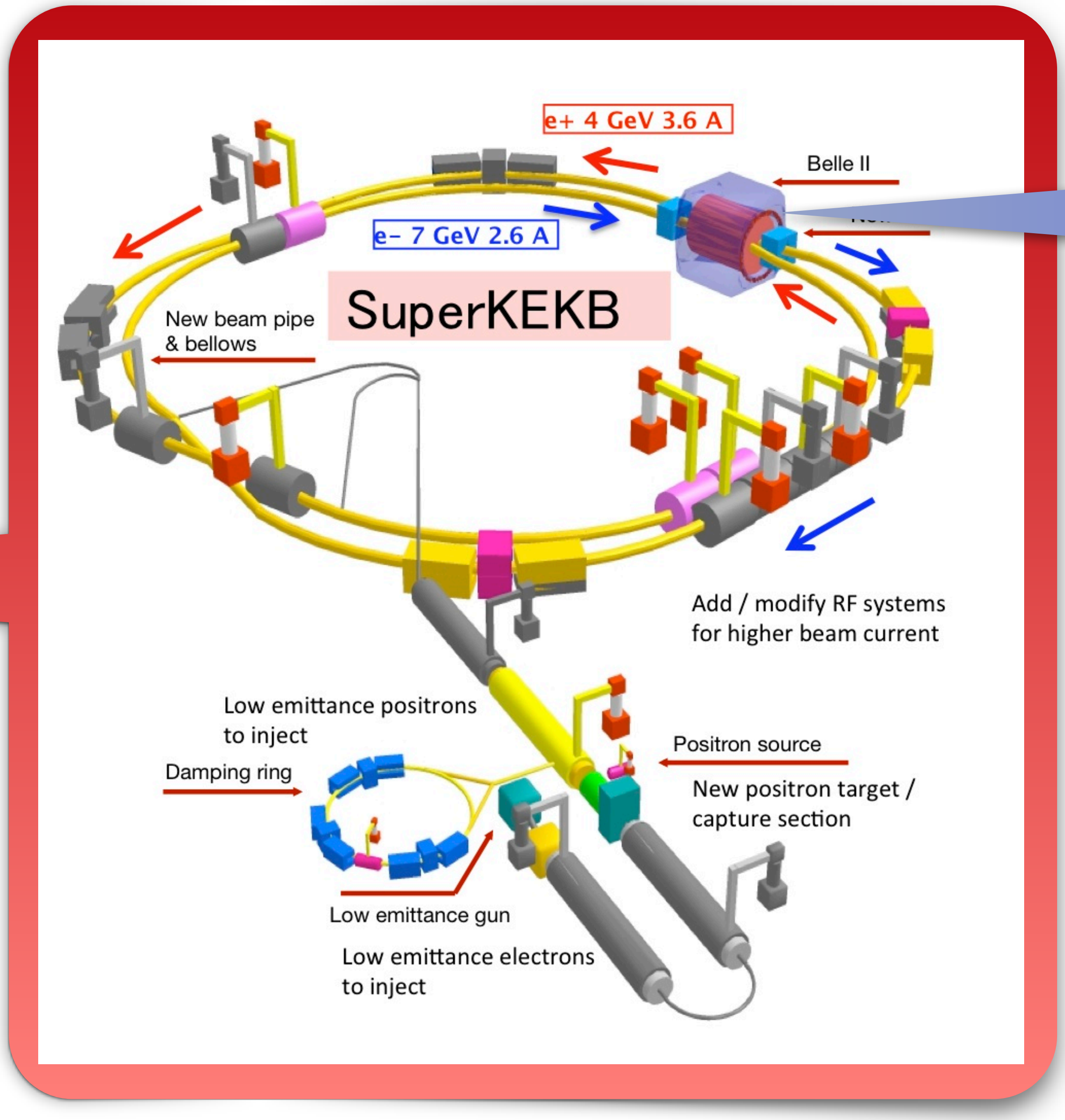


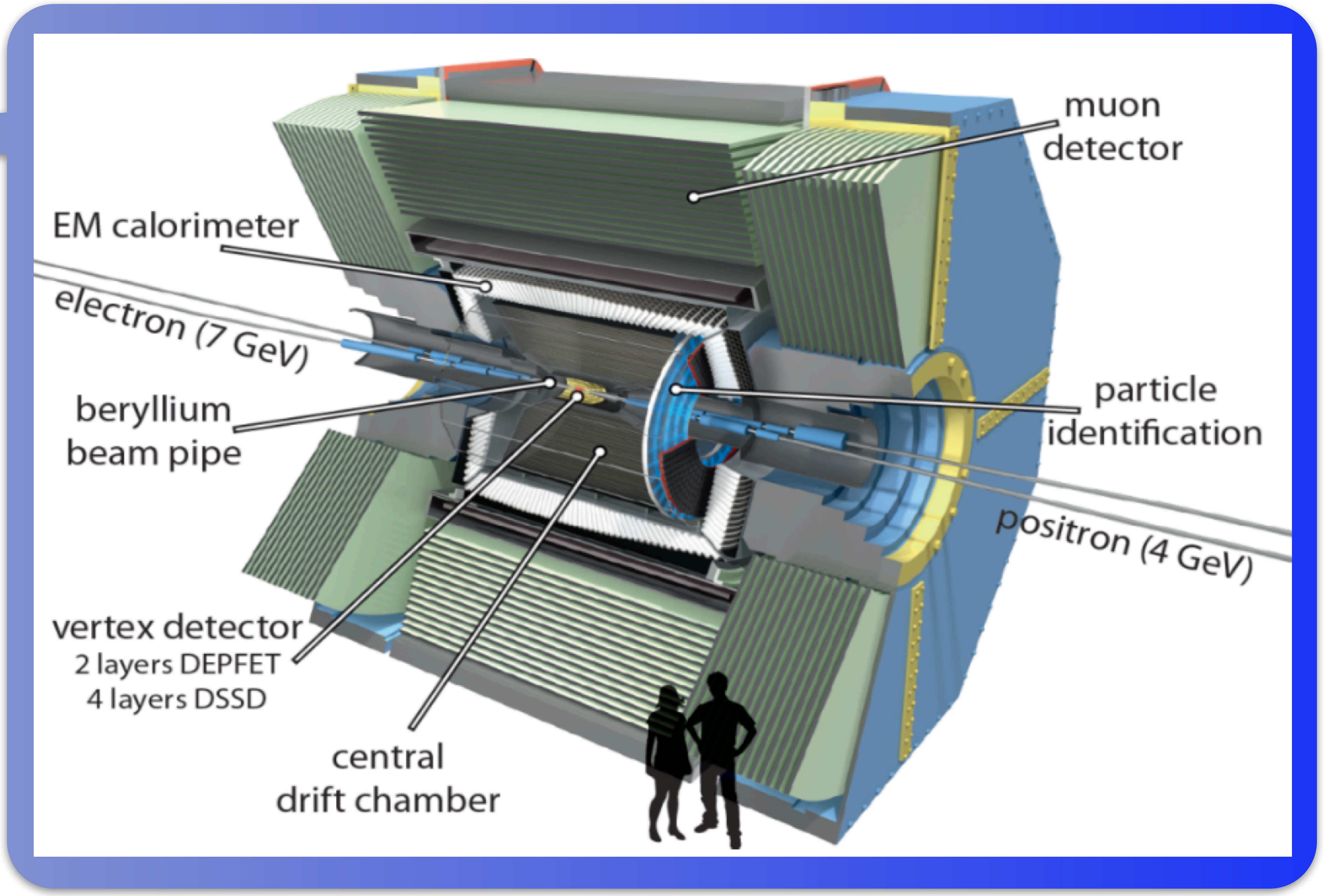
Lu Cao
for the Belle II Collaboration

21 May 2019 @ MIAPP, Munich

Belle II Experiment







- 40 times higher instantaneous luminosity from KEKB to SuperKEKB: $8 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Detector upgraded for higher particle multiplicity and tracking capacity
- Physics data taking with full detector started in March

SuperKEKB/Belle II Schedule

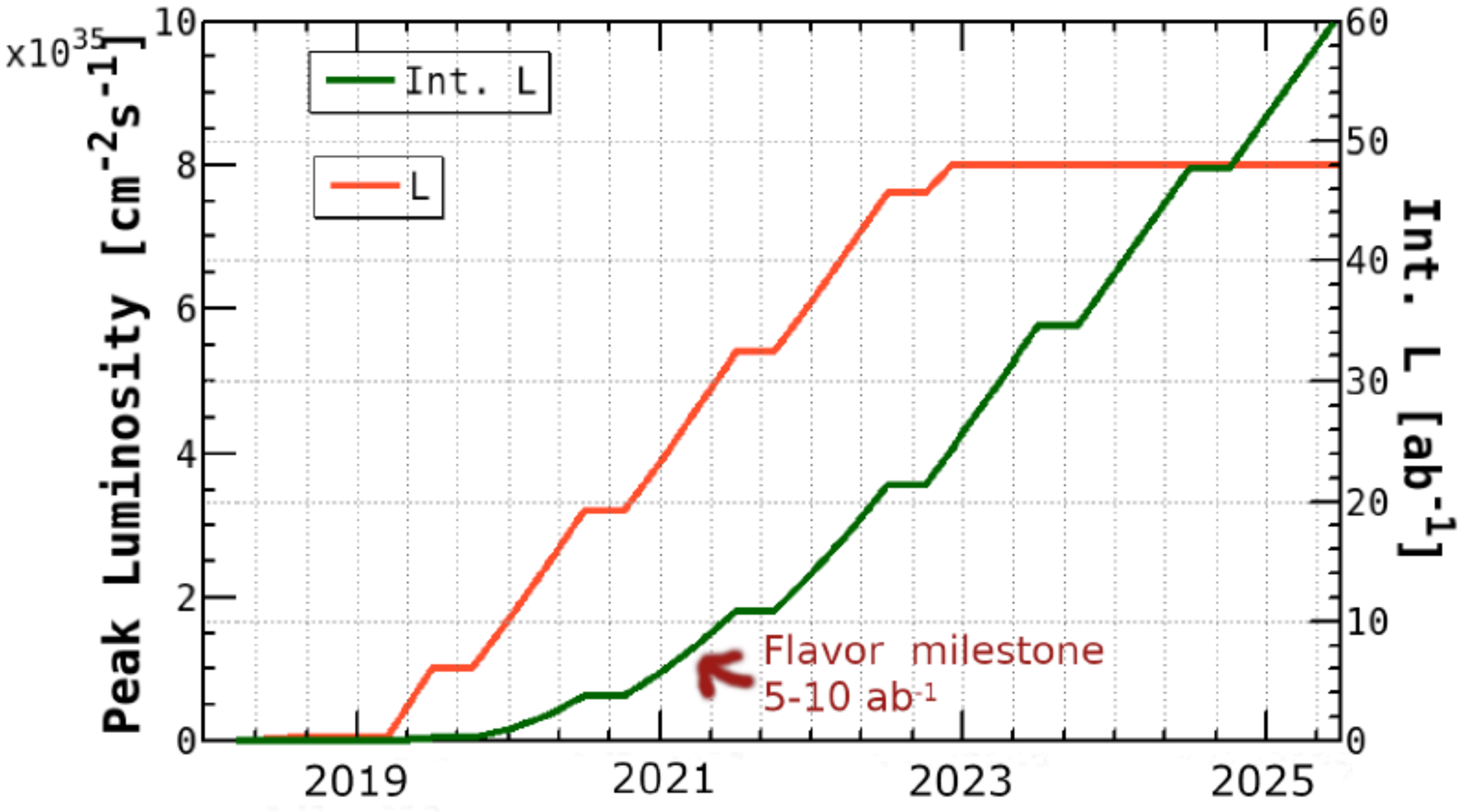
Phase 1: Beam operation run (2016) ✔

Phase 2: Commissioning run (2018) ✔

- With partial vertex detector
- Collected int. L = **0.5 fb^{-1}**

Phase 3: Physics run ⇚

- On-going data taking
- 9 months/year operation
- Will reach "**flavour milestone**" in two year



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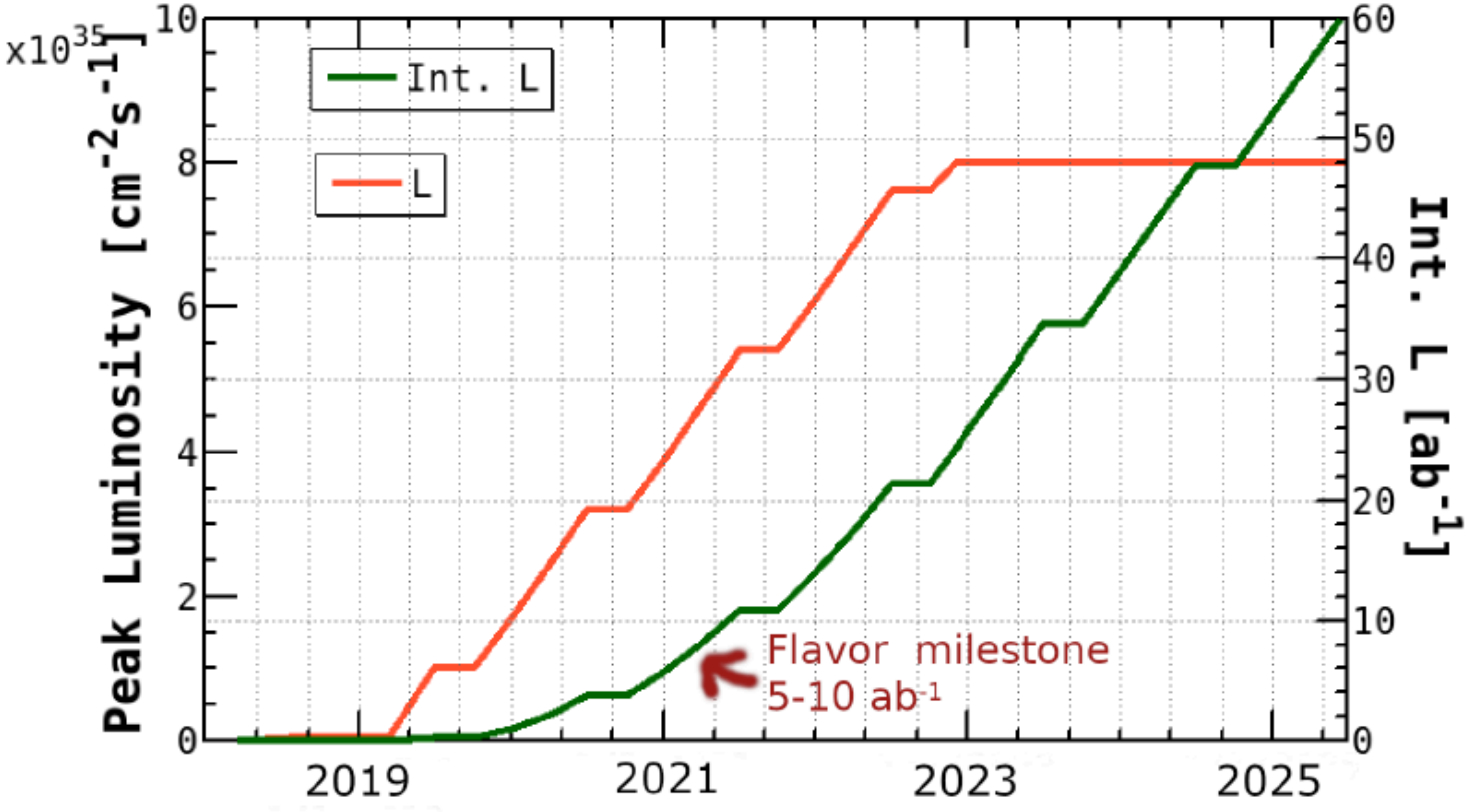
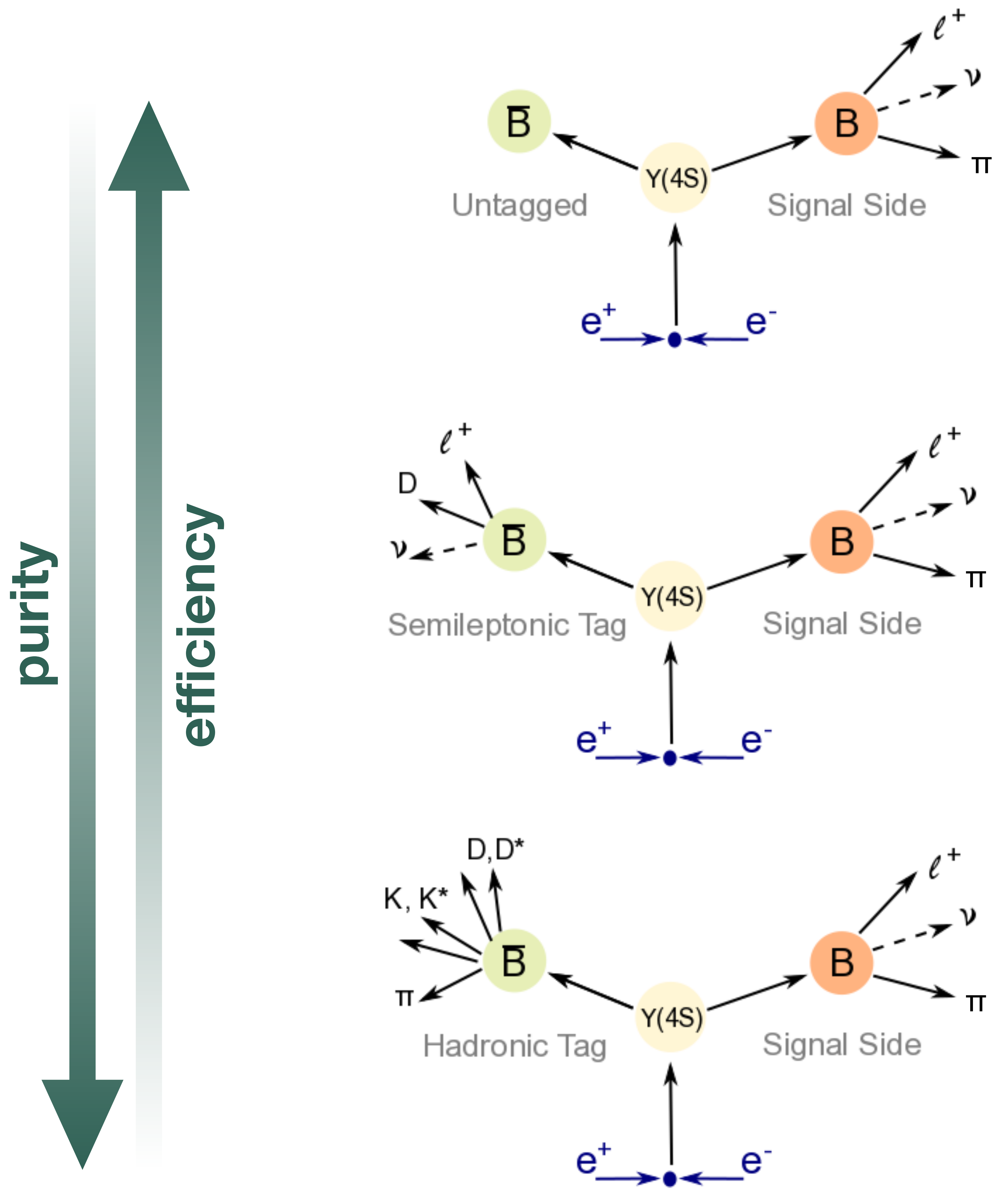


Event Reconstruction with Tagging Techniques

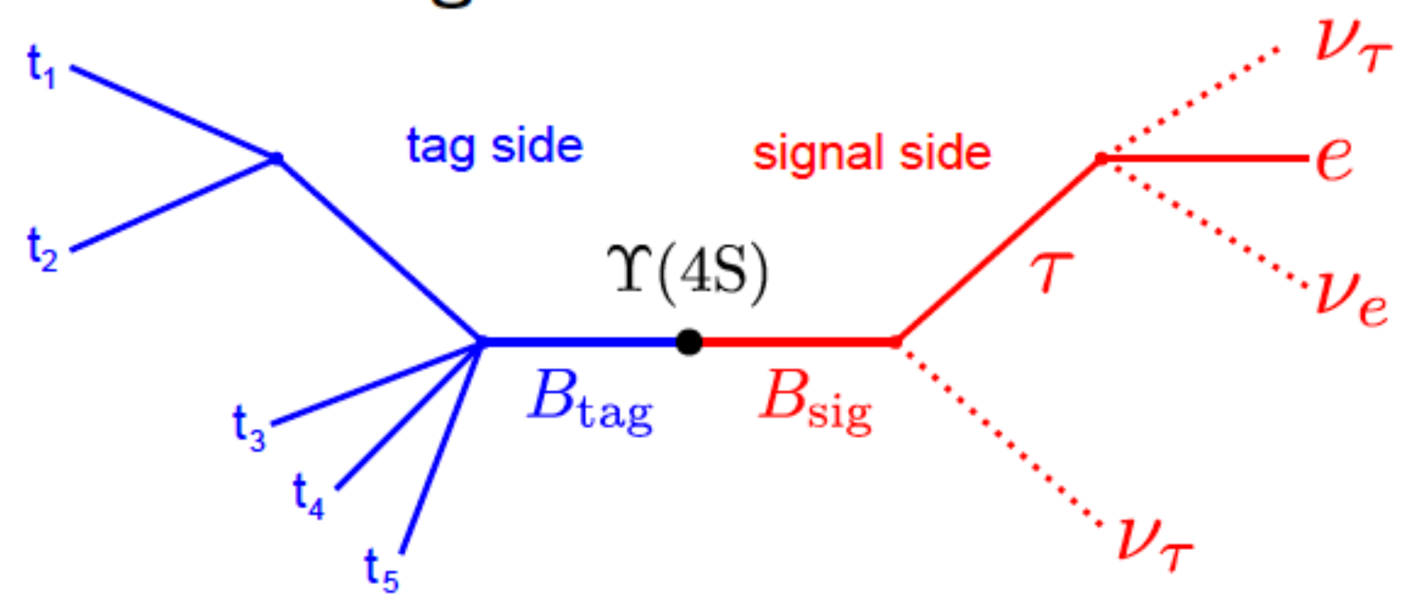


- Untagged
  - Loose constraints on signal
  - Very large statistics, but also very large background
  - Efficiency $\epsilon \approx \mathcal{O}(100\%)$
- Semileptonic tag
  - Mid-range reconstruction efficiency $\epsilon \approx \mathcal{O}(1\%)$
  - Due to multiple neutrinos, less information about B_{tag}
- Hadronic tag
  - Cleaner sample
  - Knowledge of $p(B_{sig})$
  - Low tag-side efficiency $\epsilon \approx \mathcal{O}(0.1\%)$

Improved Tagging Algorithms

1807.08680

New Full Event Interpretation (FEI) algorithm for tag-side reconstruction

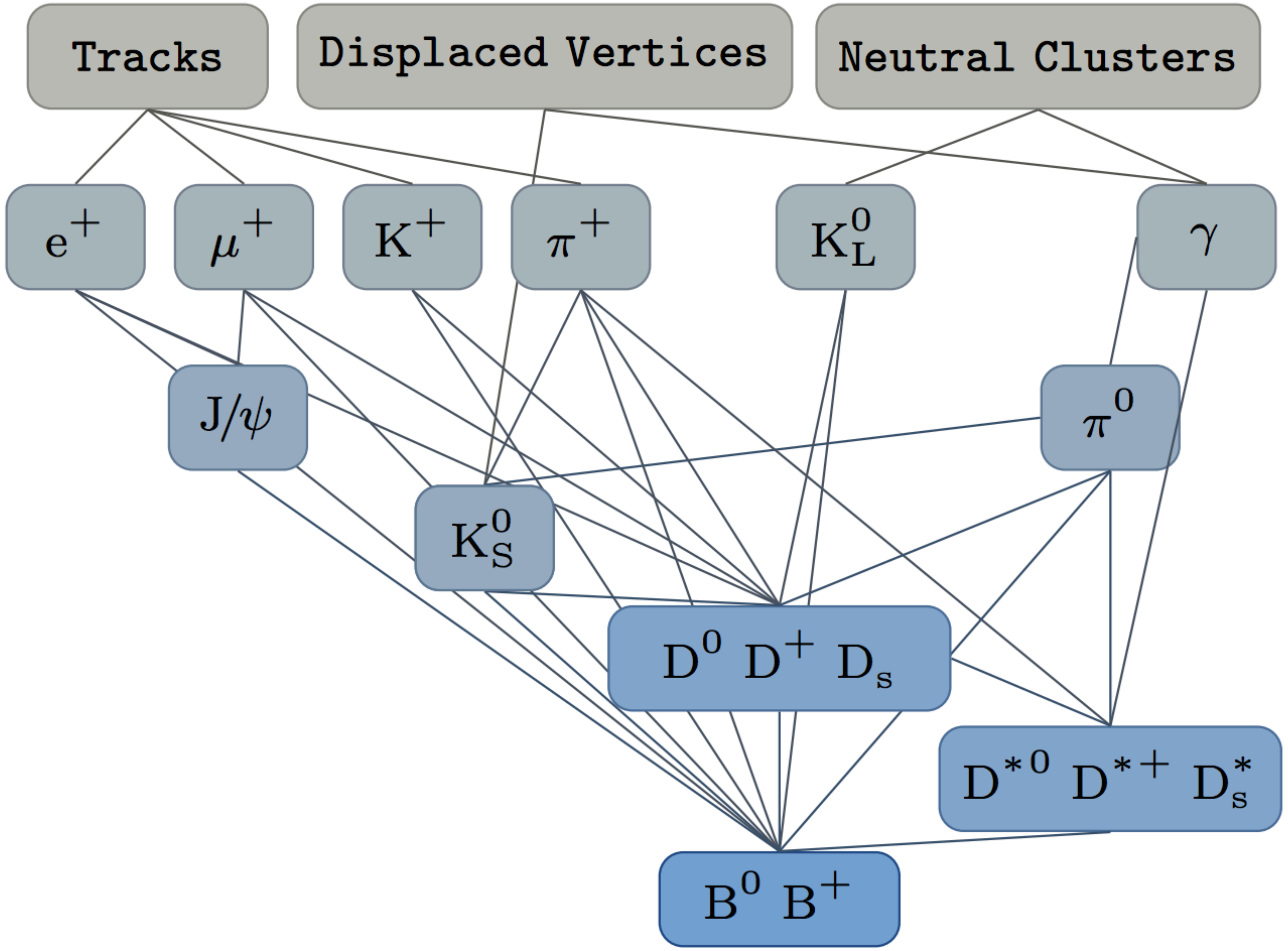


- > 5000 B decays modes reconstructed
- O(200) particle decay channels for training
- Output is candidate-wise **signal probability**

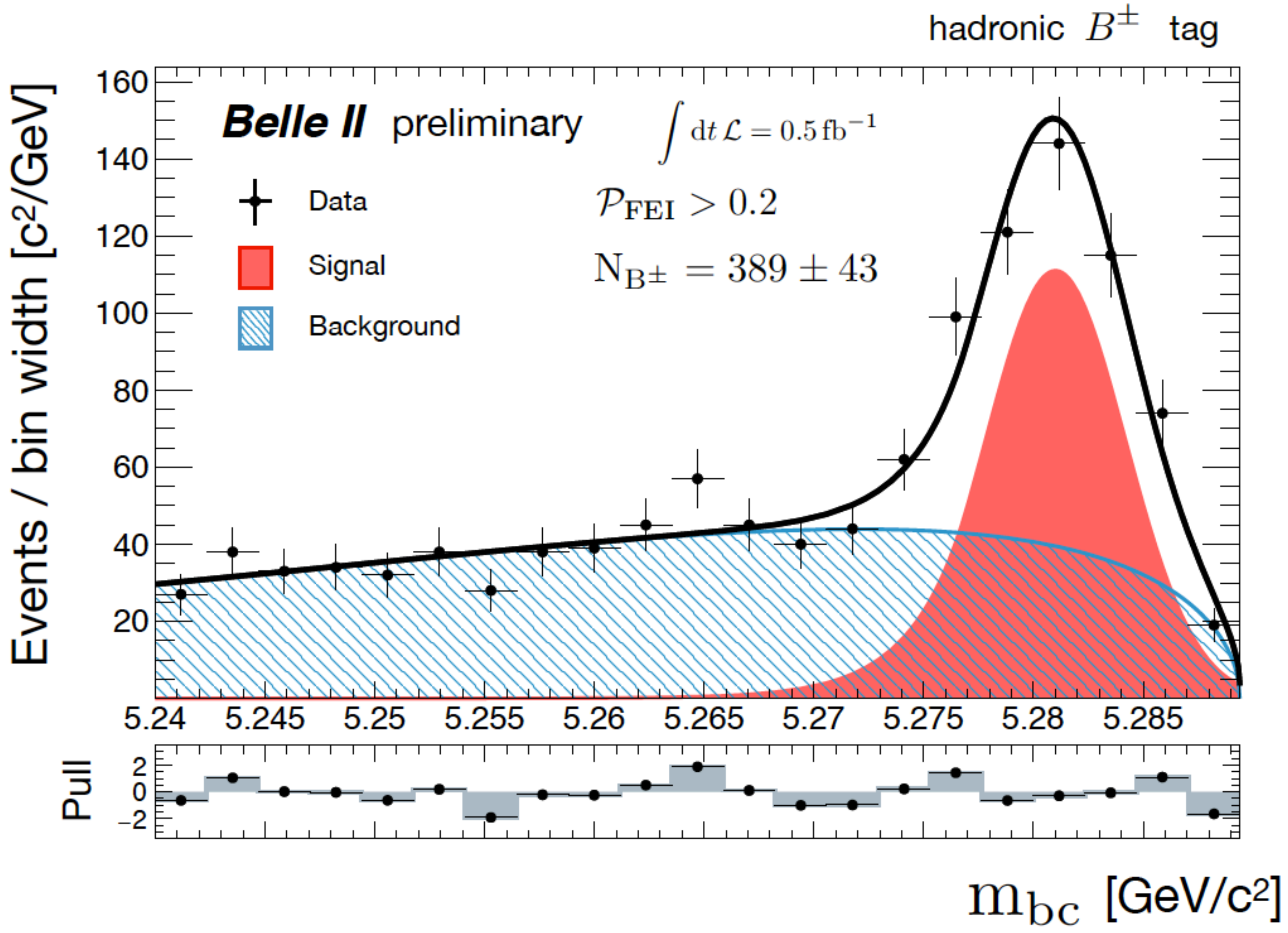
Tagging ε on MC

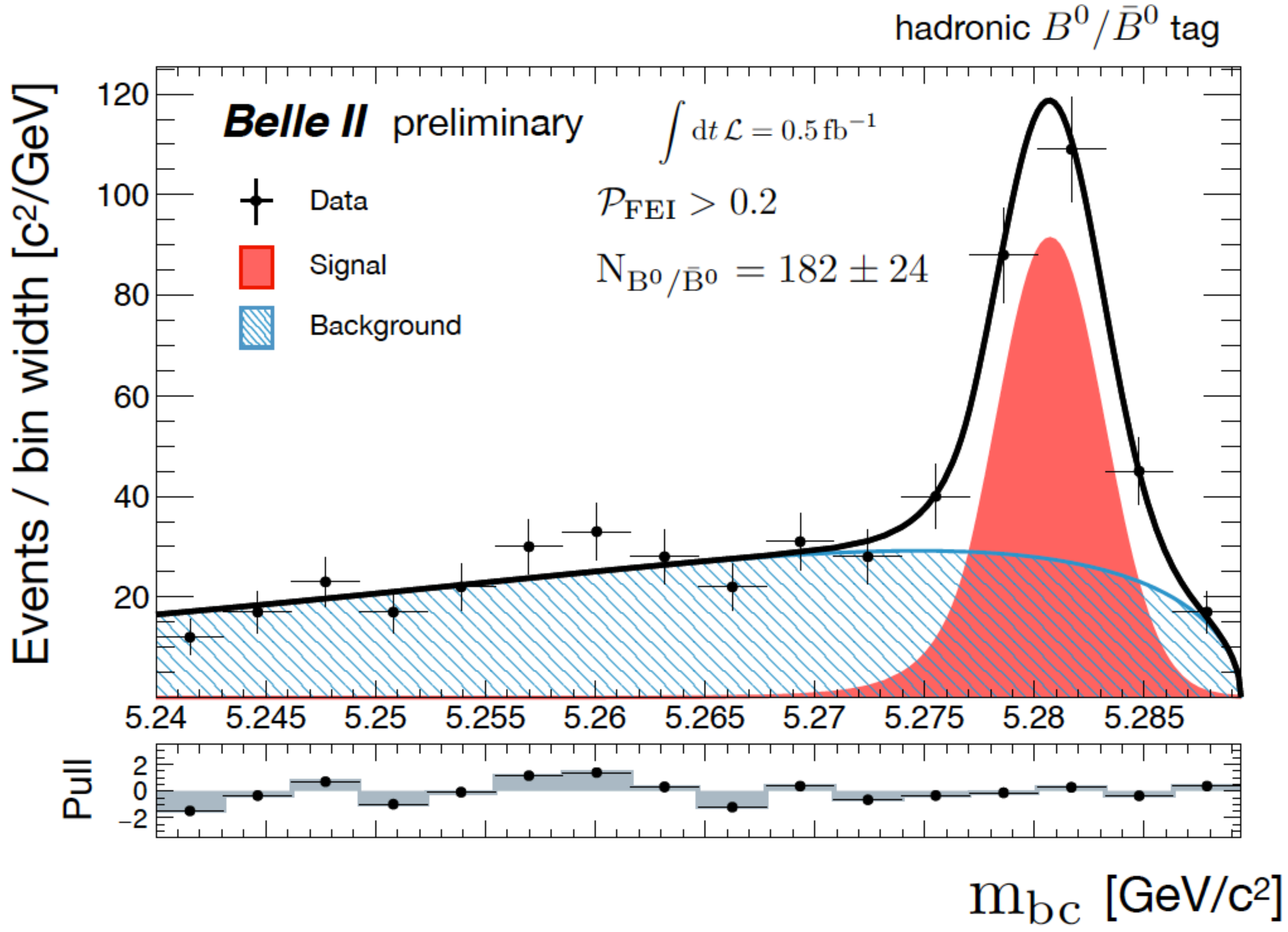
Tag	FR[1]	FEI Belle	FEI Belle II
Hadronic B^+	0.28%	0.76%	0.66%
SL B^+	0.67%	1.80%	1.45%
Hadronic B^0	0.18%	0.46%	0.38%
SL B^0	0.63%	2.04%	1.94%

[1] Belle Full Reconstruction algorithm.



Hadronic FEI Performance





Beam-constrained mass: $M_{\mathrm{bc}} = \sqrt{(\sqrt{s}/2)^2 - \vec{p}^{\,2}_{B_{\mathrm{tag}}}}$

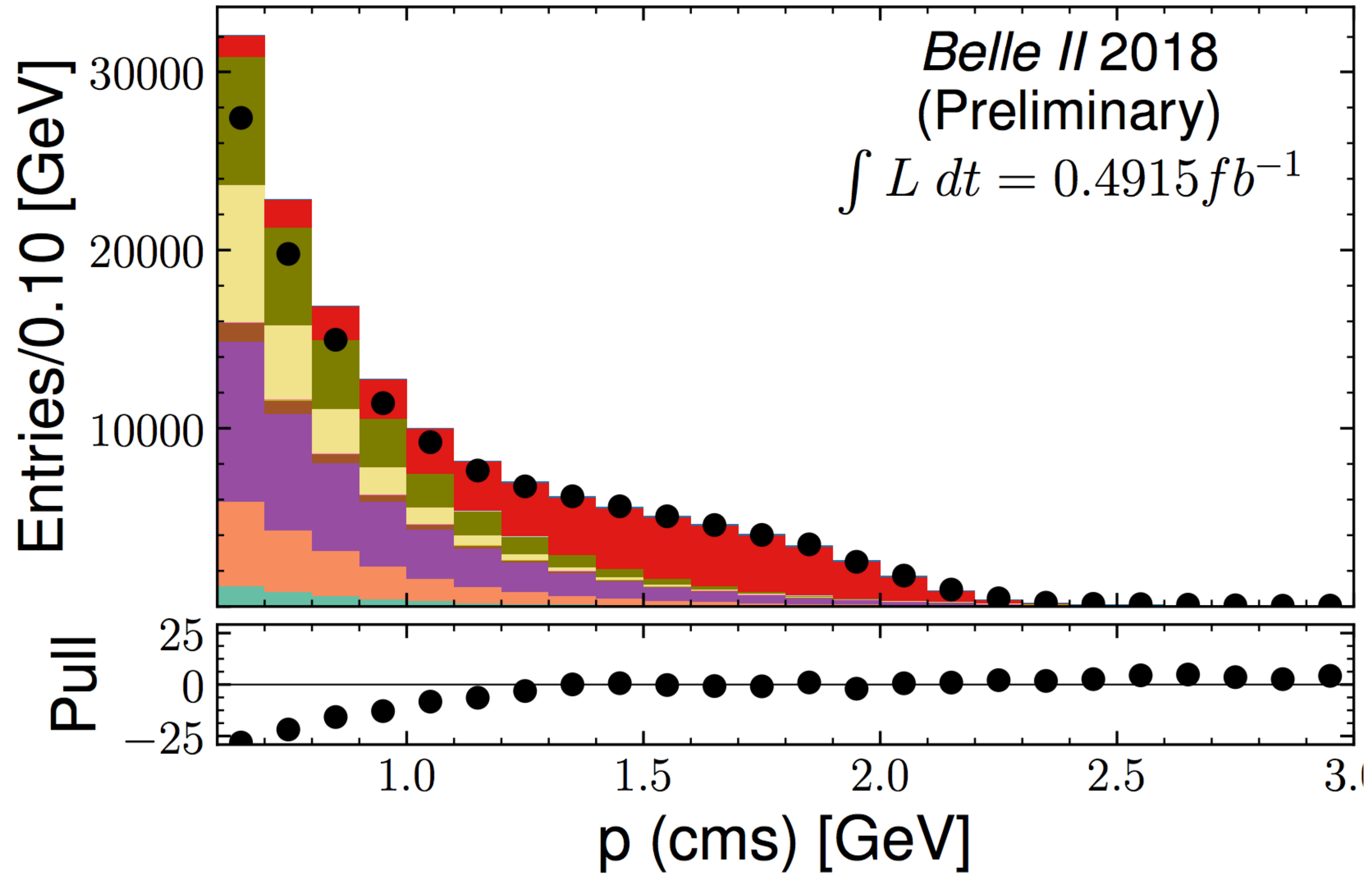
Hadronic FEI Performance

	Candidates	Efficiency	Purity
	FEI Signal Probability $\mathcal{P} > 0.01$		
Charged Candidates	937±126	0.17%	24%
Neutral Candidates	394± 59	0.09%	25%
	FEI Signal Probability $\mathcal{P} > 0.2$		
Charged Candidates	389± 43	0.07%	63%
Neutral Candidates	182± 24	0.03%	73%

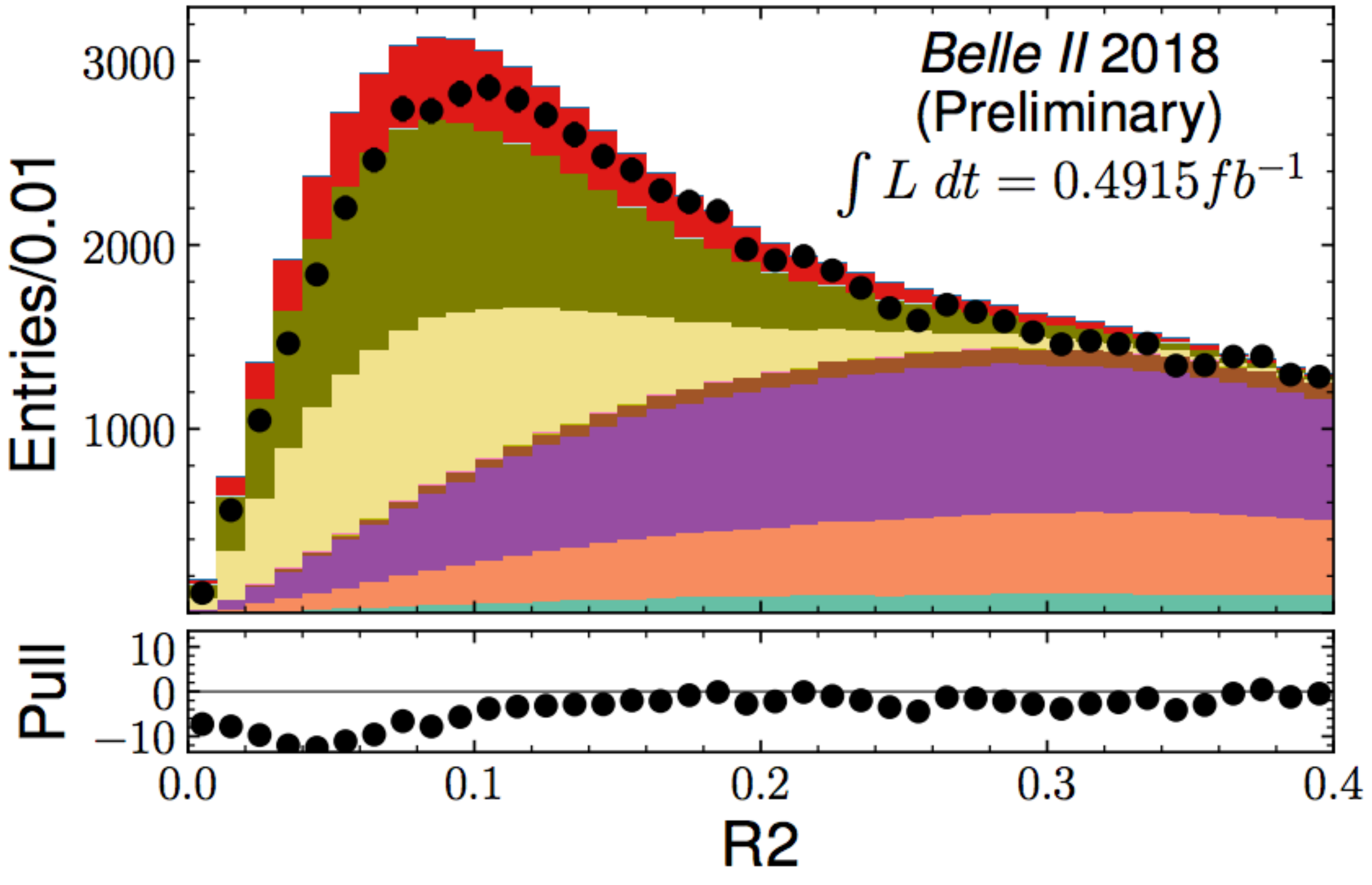
Efficiency = $\frac{N_{\mathrm{B}}^{correct}}{N_{\Upsilon(4S)}^{total}}$ Purity = $\frac{N_{\mathrm{B}}^{correct}}{N_{\mathrm{B}}^{all}}$

Analysis of Inclusive $B \to Xe\nu$

- Commissioning run data 0.4915 fb^{-1}
- Fox-Wolfram moment R2 < 0.4 to suppress continuum background
- Veto leptons from J/ψ decay



$p_e^{\text{cms}} < 1\text{GeV}$



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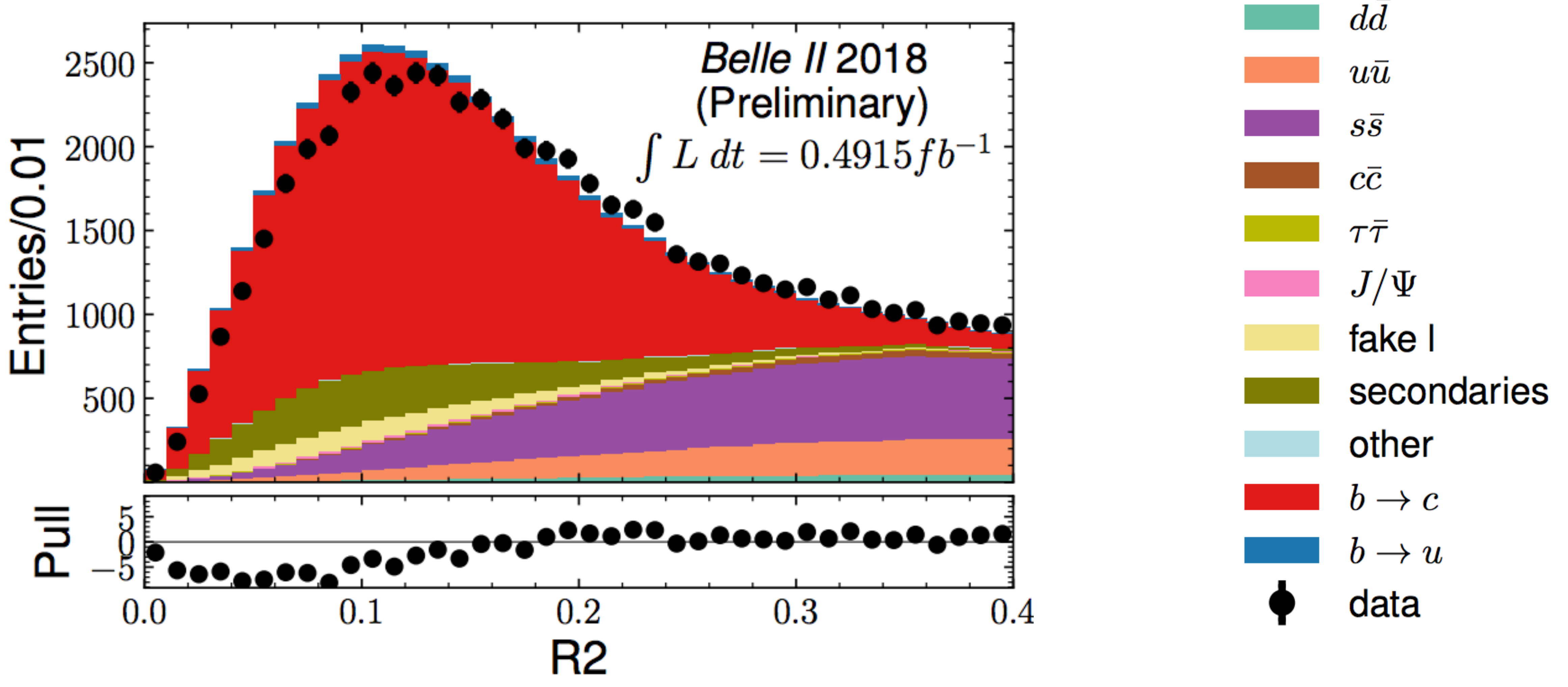
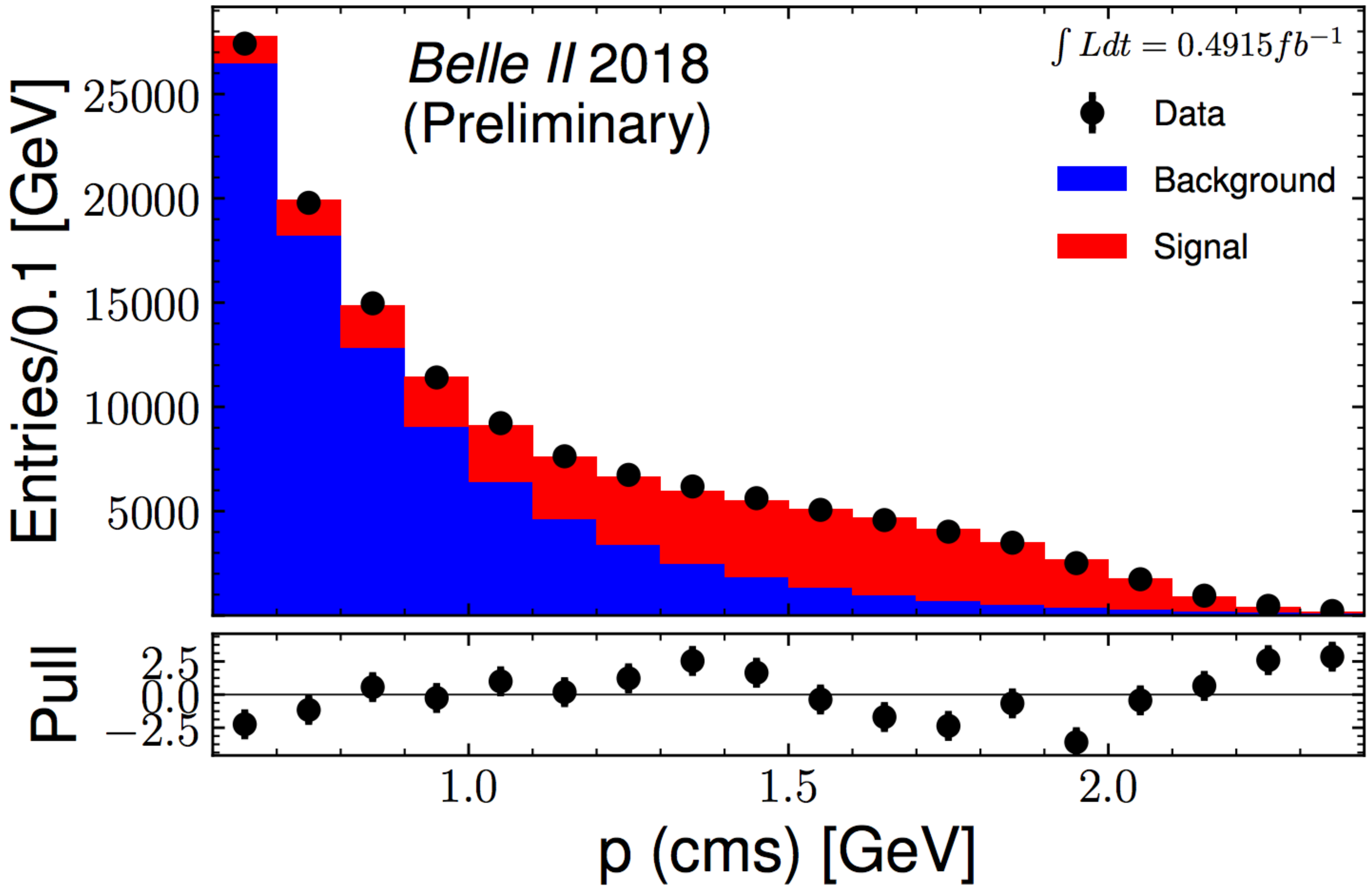


Analysis of Inclusive $B \to Xe\nu$

- Observed 42191± 304 (expected 40209 ± 200) signal events in 0.6 < p(cms) < 2.4 GeV
- Agreement of data and MC for momenta above 1 GeV
- No statements on $|V_{ub}|$, $|V_{cb}|$ or branching fractions (due to the lack of off-resonance data and unknown tracking efficiencies etc.)

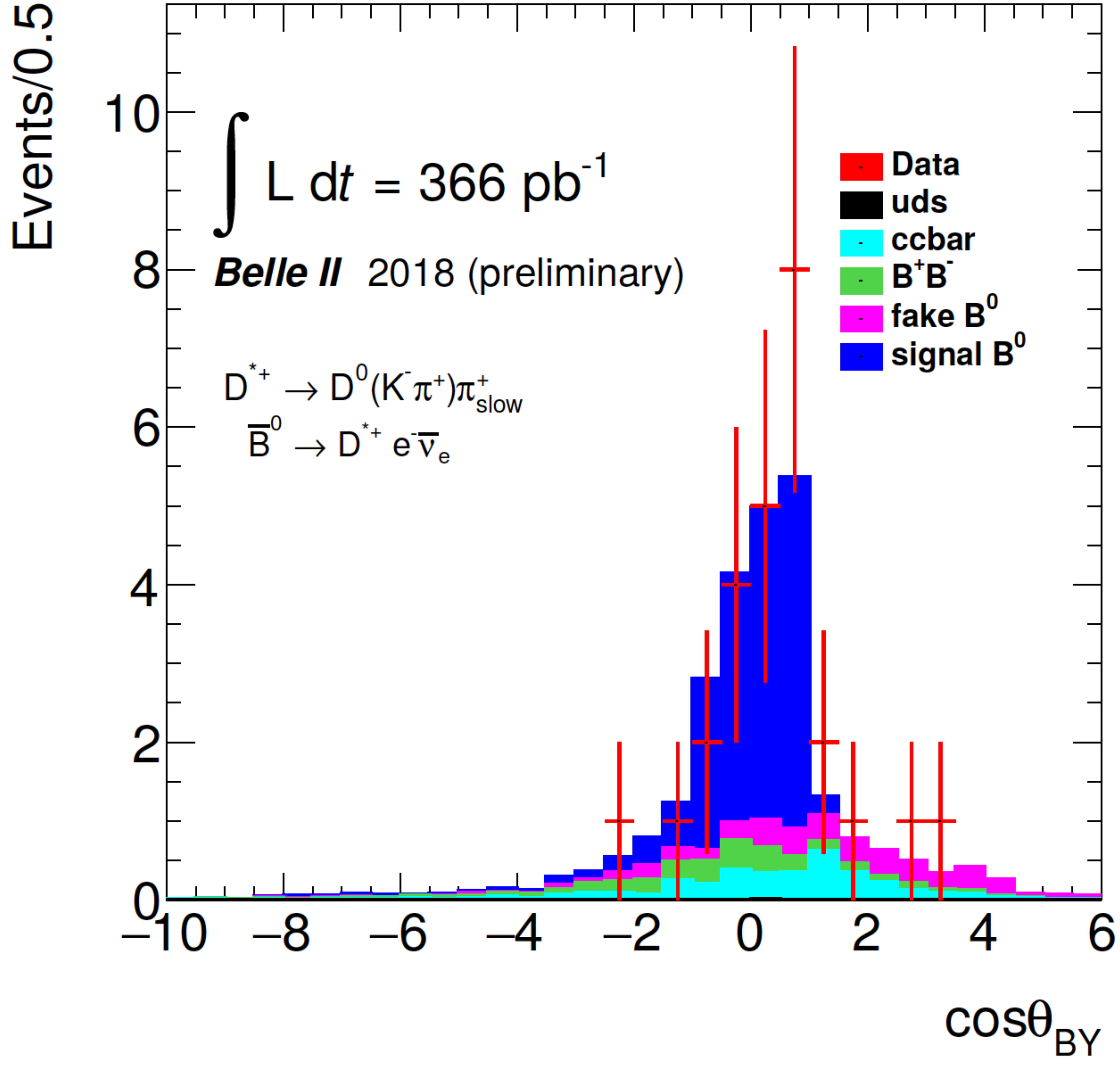


Analysis of $\bar{B}^0 \to D^{*+} e^- \bar{\nu}_e$

- Commissioning run data 366 pb^{-1}
- Analysed decay chain: $B \to D^* e\nu, D^* \to D^0(\to K\pi)\pi_{\text{slow}}$
- Slow pions p(cms) < 0.4 GeV/c
- Reconstructed mass of D in (1.85, 1.88) GeV/c^2
- Mass difference between D* and D in (0.144, 0.148) GeV/c^2
- Continuum suppressed by R2 < 0.25
- Eventually measure $\cos\theta_{BY} = \dfrac{2E_B^* E_Y^* - M_B^2 - m_Y^2}{2p_B^* p_Y^*}$, Y - visible final system (D^*, e)

Analysis of $\bar{B}^0 \to D^{*+} e^- \bar{\nu}_e$

- Observed 22 signal events in total after all selection
- 15 events found in $-1 < \cos\theta_{BY} < 1$
- Expected 13 events



Early Physics Run Results …coming soon

Looking for forward to early Physics run results (later summer):

- Hadronic and semileptonic FEI performances study and calibration
- Untagged inclusive $B \to X\ell\nu$ endpoint measurement
- Hadronic and/or semileptonic tagged inclusive $B \to X\ell\nu$
- Untagged $B \to \pi\ell\nu$ and $B \to \rho\ell\nu$
- Hadronic tagged and untagged $B \to D^*\ell\nu$

and more…

Prospects of Belle II

Belle II Physics Book

Observables	Belle (2017)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\lvert V_{cb}\rvert$ incl.	$42.2 \cdot 10^{-3} \cdot (1 \pm 1.8\%)$	1.2%	–
$\lvert V_{cb}\rvert$ excl.	$39.0 \cdot 10^{-3} \cdot (1 \pm 3.0\%_{\mathrm{ex.}} \pm 1.4\%_{\mathrm{th.}})$	1.8%	1.4%
$\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3} \cdot (1 \pm 6.0\%_{\mathrm{ex.}} \pm 2.5\%_{\mathrm{th.}})$	3.4%	3.0%
$\lvert V_{ub}\rvert$ excl. (WA)	$3.65 \cdot 10^{-3} \cdot (1 \pm 2.5\%_{\mathrm{ex.}} \pm 3.0\%_{\mathrm{th.}})$	2.4%	1.2%
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$91 \cdot (1 \pm 24\%)$	9%	4%
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%
$R(B \to D\tau\nu)$ (Had. tag)	$0.374 \cdot (1 \pm 16.5\%)$	6%	3%
$R(B \to D^*\tau\nu)$ (Had. tag)	$0.296 \cdot (1 \pm 7.4\%)$	3%	2%

Summary of $|V_{ub}|$ Projections

Belle II Physics Book

	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{ub}\rvert$ exclusive (had. tagged)					
711 fb^{-1}	3.0	(2.3, 1.0)	3.8	7.0	8.0
5 ab^{-1}	1.1	(0.9, 1.0)	1.8	1.7	3.2
50 ab^{-1}	0.4	(0.3, 1.0)	1.2	0.9	1.7
$\lvert V_{ub}\rvert$ exclusive (untagged)					
605 fb^{-1}	1.4	(2.1, 0.8)	2.7	7.0	7.5
5 ab^{-1}	1.0	(0.8, 0.8)	1.2	1.7	2.1
50 ab^{-1}	0.3	(0.3, 0.8)	0.9	0.9	1.3
$\lvert V_{ub}\rvert$ inclusive					
605 fb^{-1} (old B tag)	4.5	(3.7, 1.6)	6.0	2.5–4.5	6.5–7.5
5 ab^{-1}	1.1	(1.3, 1.6)	2.3	2.5–4.5	3.4–5.1
50 ab^{-1}	0.4	(0.4, 1.6)	1.7	2.5–4.5	3.0–4.8
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (had. tagged)					
711 fb^{-1}	18.0	(7.1, 2.2)	19.5	2.5	19.6
5 ab^{-1}	6.5	(2.7, 2.2)	7.3	1.5	7.5
50 ab^{-1}	2.1	(0.8, 2.2)	3.1	1.0	3.2
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (SL tagged)					
711 fb^{-1}	11.3	(10.4, 1.9)	15.4	2.5	15.6
5 ab^{-1}	4.2	(4.4, 1.9)	6.1	1.5	6.3
50 ab^{-1}	1.3	(2.3, 1.9)	2.6	1.0	2.8

$|V_{ub}|$ uncertainty @ Belle II

exclusive ~1.5%

inclusive ~ 4%

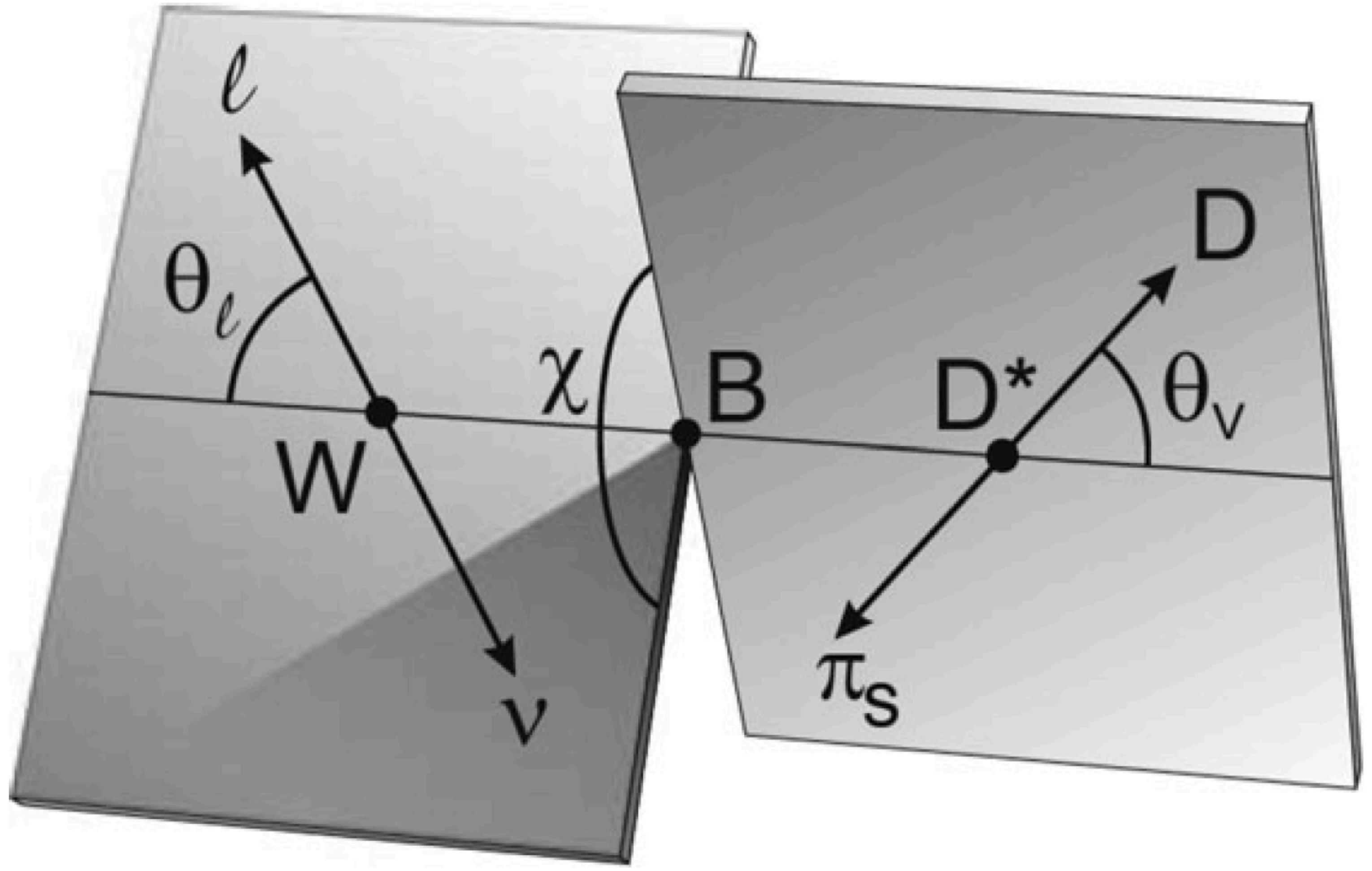
leptonic ~ 3%

$B \to D^{(*)}\ell\nu \ (\ell = \tau, e, \mu)$ @ Belle II MC

- R(D) and R(D*) provides a good test for LFV and NP (uncertainties on FF, $|V_{cb}|$ cancelled out)

- Polarisations of τ and D* also sensitive to NP

- Other useful observables: precise differential measurements in q^2 and helicity angles



$$R_{D^{(*)}} = \frac{\mathrm{Br}\left(B \to D^{(*)}\tau\nu_\tau\right)}{\mathrm{Br}\left(B \to D^{(*)}\ell\nu_\ell\right)} \ (\ell = e, \mu)$$

$$P_\tau\left(D^{(*)}\right) = \frac{\Gamma^+ - \Gamma^-}{\Gamma^+ + \Gamma^-}$$

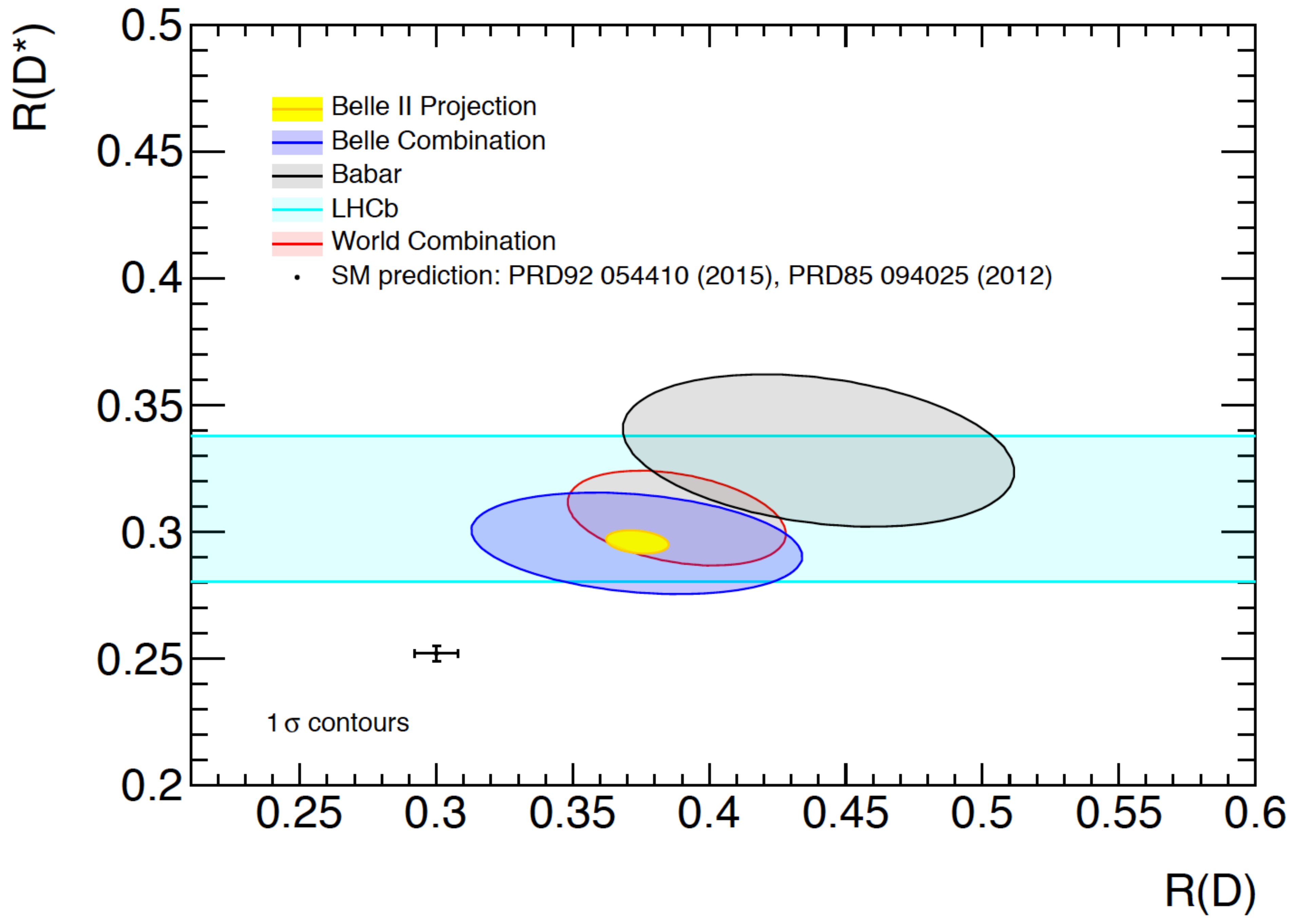
$$P_{D^*} = \frac{\Gamma_L}{\Gamma_L + \Gamma_T}$$

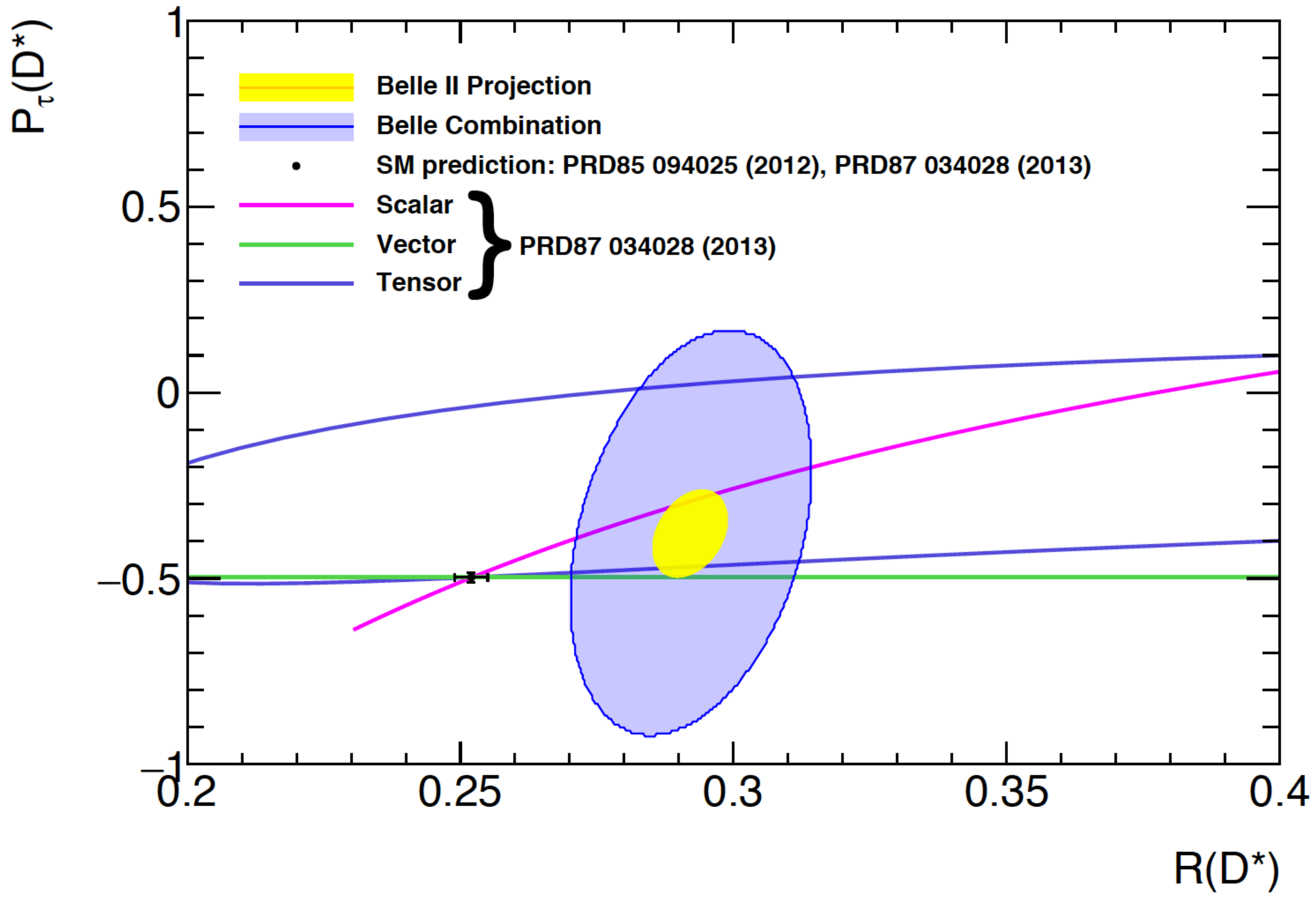
$B \to D^{(*)}\ell\nu \;\; (\ell = \tau, e, \mu)$ @ Belle II MC

Belle II Physics Book

- Had/SL/untagged analyses
- Leptonic τ decay chosen for cleaner background
- Dominant background is $B \to D^{**}\ell\nu$

	5 ab^{-1}	50 ab^{-1}
R_D	$(\pm 6.0 \pm 3.9)\%$	$(\pm 2.0 \pm 2.5)\%$
R_{D^*}	$(\pm 3.0 \pm 2.5)\%$	$(\pm 1.0 \pm 2.0)\%$
$P_\tau(D^*)$	$\pm 0.18 \pm 0.08$	$\pm 0.06 \pm 0.04$





Golden Channels @ Belle II

Flavour Milestone (5-10 ab^{-1})

Belle II Physics Book

Process	Observable	Theory	Sys. limit (Discovery) [ab^{-1}]	vs LHCb	vs Belle	Anomaly	New Physics
$B \to \pi l \nu$	$\lvert V_{ub}\rvert$	★★★	10-20	★★★	★★★	★★	★
$B \to X_u l \nu$	$\lvert V_{ub}\rvert$	★★	2-10	★★★	★★	★★★	★
$B \to \tau \nu$	$\mathcal{B}$	★★★	>50 (2)	★★★	★★★	★	★★★
$B \to \mu \nu$	$\mathcal{B}$	★★★	>50 (5)	★★★	★★★	★	★★★
$B \to D^{(*)} l \nu$	$\lvert V_{cb}\rvert$	★★★	1-10	★★★	★★	★★	★
$B \to X_c l \nu$	$\lvert V_{cb}\rvert$	★★★	1-5	★★★	★★	★★	★★
$B \to D^{(*)} \tau \nu$	$R(D^{(*)})$	★★★	5-10	★★	★★★	★★★	★★★
$B \to D^{(*)} \tau \nu$	P_τ	★★★	15-20	★★★	★★★	★★	★★★
$B \to D^{**} l \nu$	$\mathcal{B}$	★	-	★★	★★★	★★	-
$B \to l \nu \gamma$	λ_B	★★	-	★★★	★★★	★	★★
$B \to K^{(*)} \nu \nu$	$\mathcal{B},\ F_L$	★★★	>50	★★★	★★★	★	★★

see also:
Flavor Physics at Belle II by Francesco Tenchini

Summary

- Belle II has successfully finished commissioning run and started physics run
- Improved tagging algorithm FEI successfully applied on data
- Successful observation on $B \to Xe\nu$ and rediscovery of $B \to D^{*}\mathrm{e}\nu$

- Long-term prospects are promising
- Early physics run results can be expected in later summer

  and much more on the way…

Back up

$\bar{B}^0 \to \pi^+ l^- \nu$ @ Belle

Source	Error (Limit) [%] Tagged [%]	Untagged
Tracking efficiency	0.4	2.0
Pion identification	–	1.3
Lepton identification	1.0	2.4
Kaon veto	0.9	–
Continuum description	1.0	1.8
Tag calibration and $N_{B\bar{B}}$	4.5 (2.0)	2.0 (1.0)
$X_u \ell \nu$ cross-feed	0.9	0.5 (0.5)
$X_c \ell \nu$ background	–	0.2 (0.2)
Form factor shapes	1.1	1.0 (1.0)
Form factor background	–	0.4 (0.4)
Total (reducible, irreducible)	5.0 (4.6, 2.0)	4.5 (4.2, 1.6)

$B \to X_u l \nu$ @ Belle

Source	Error on $\mathcal{B}$ (irreducible limit)
$\mathcal{B}(D^{(*)}\ell\nu)$	1.2 (0.6)
Form factors $(D^{(*)}\ell\nu)$	1.2 (0.6)
Form factors & $\mathcal{B}(D^{(**)}\ell\nu)$	0.2
$B \to X_u \ell\nu(\mathrm{SF})$	3.6 (1.8)
$B \to X_u \ell\nu(g \to s\bar{s})$	1.5
$\mathcal{B}(B \to \pi/\rho/\omega\ell\nu)$	2.3
$\mathcal{B}(B \to \eta^{(\prime)}\ell\nu)$	3.2
$\mathcal{B}(B \to X_u\ell\nu)$ unmeasured/fragmentation	2.9 (1.5)
Continuum & Combinatorial	1.8
Secondaries, Fakes & Fit	1.0
PID& Reconstruction	3.1
BDT/Normalisation	3.1 (2.0)
Total	8.1
(Total reducible)	7.4
(Total irreducible)	3.2