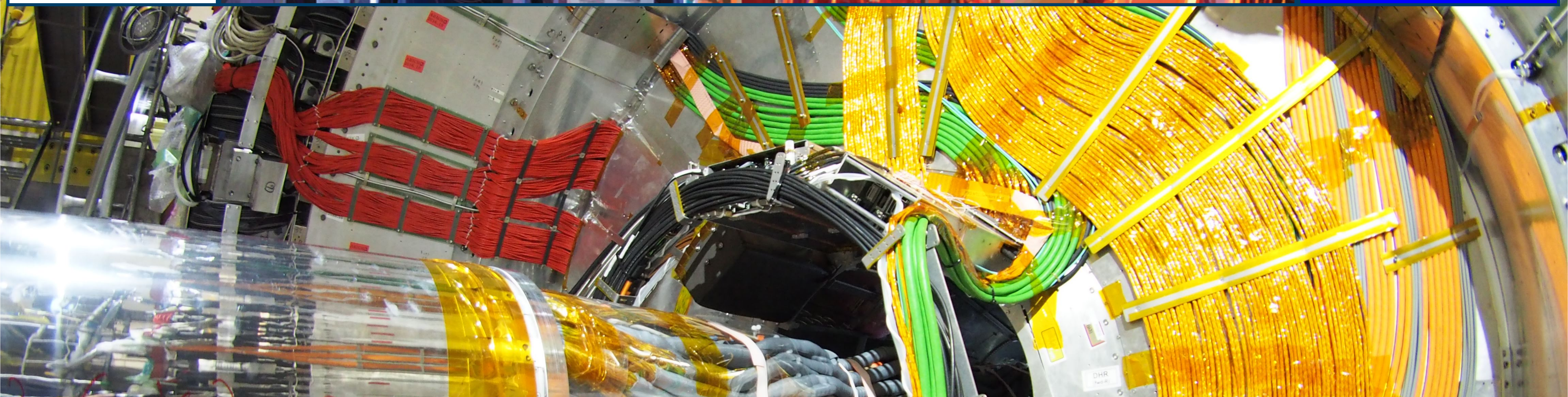
ICHEP 2020 | PRAGUE



Leptonic and semileptonic decays with taus at the Belle II experiment

Marco Milesi, on behalf of the Belle II collaboration
School of Physics - The University of Melbourne

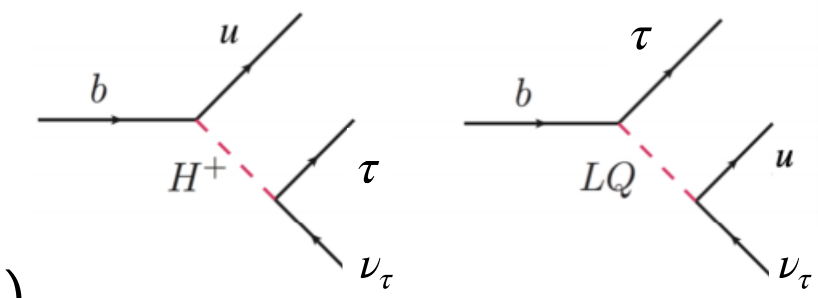
ICHEP 2020, Prague, July, 31st 2020

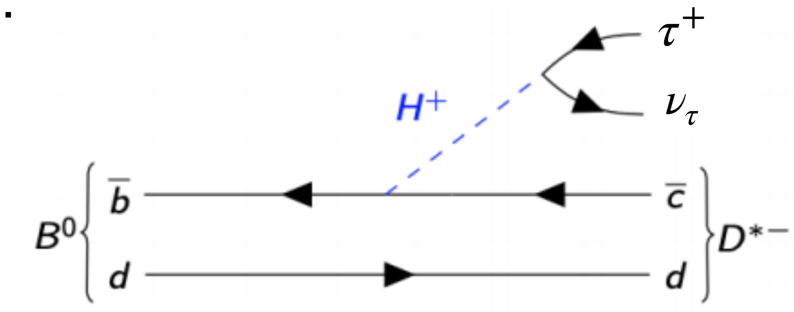
Motivation for $B \to \tau\nu, B \to (X)\tau\nu$

1. Powerful test for lepton flavour universality violation $\rightarrow$ portal to new physics:

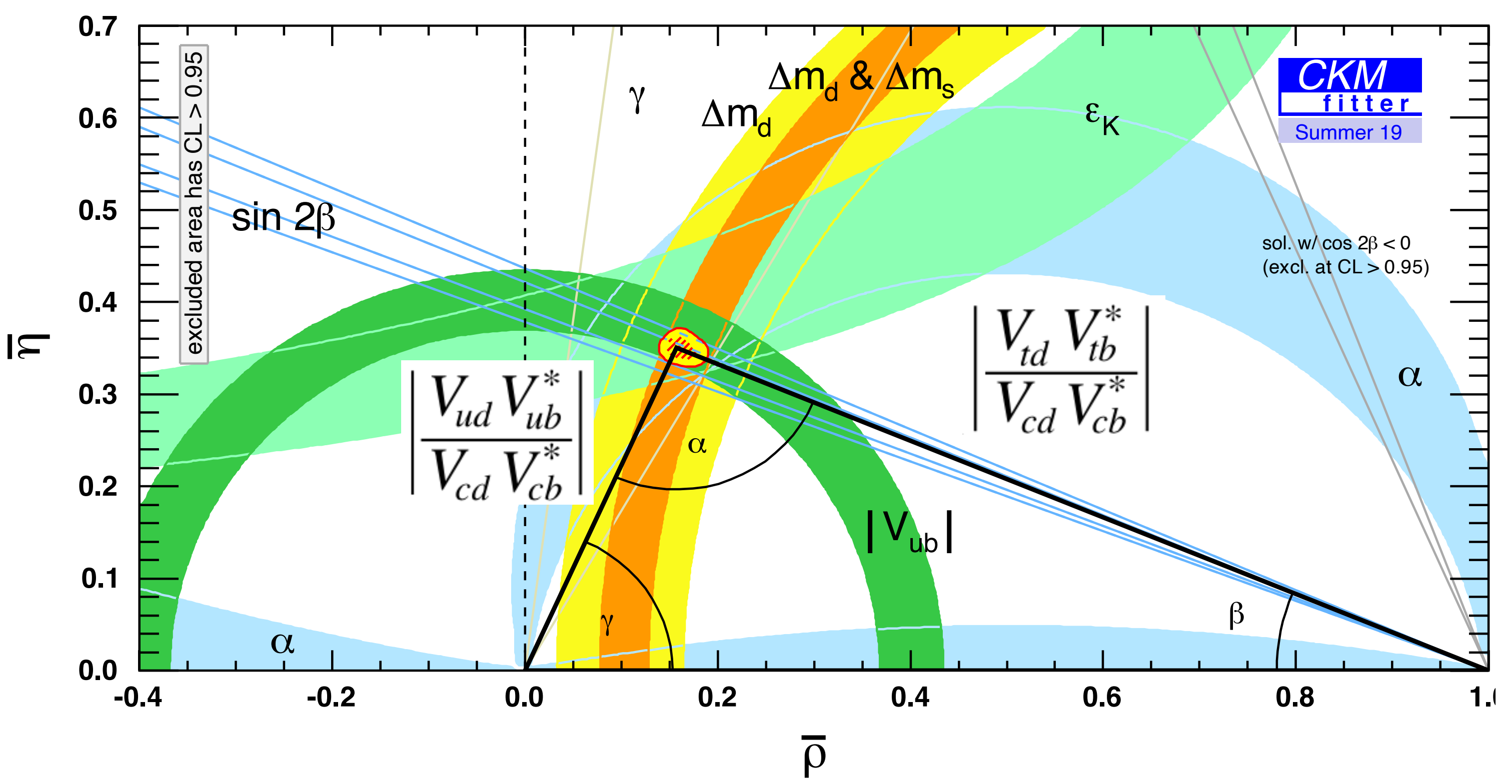
   - Two-Higgs doublet models (stronger coupling to τ leptons).
   - Leptoquarks.

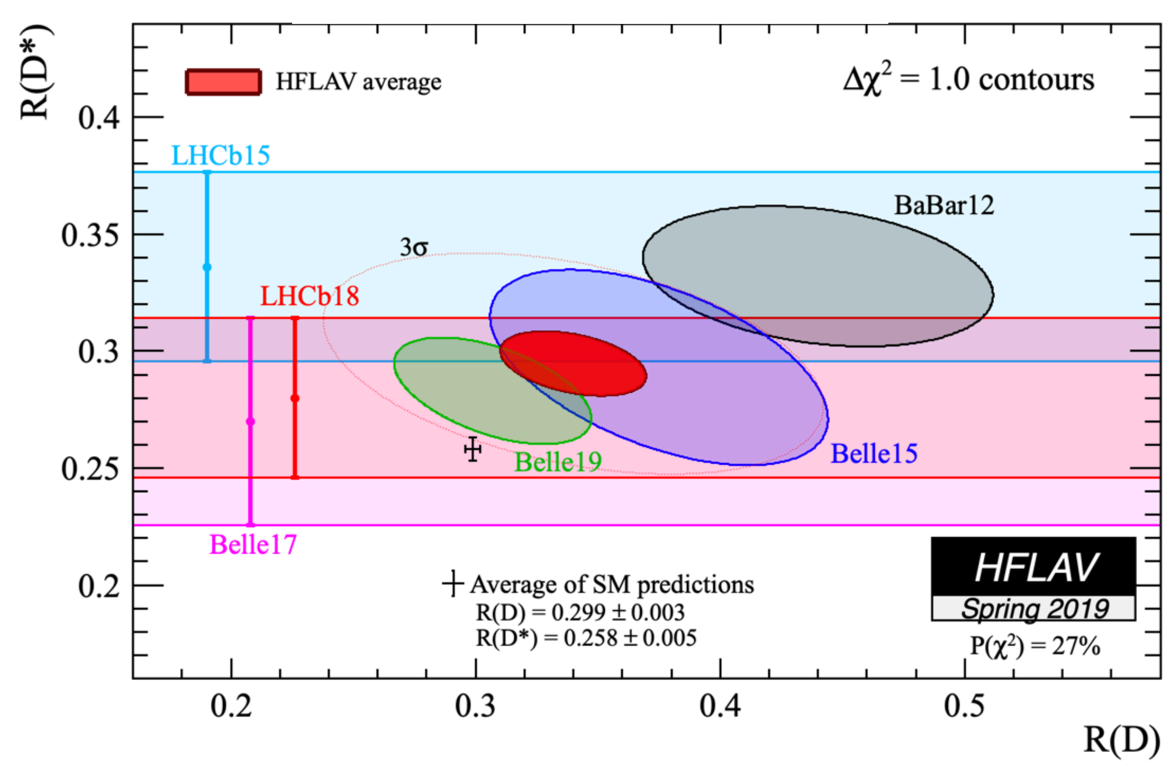
2. Complementary measurements of V_{ub}, V_{cb} to light lepton (e, μ) channels $\rightarrow$ input to CKM global fits.



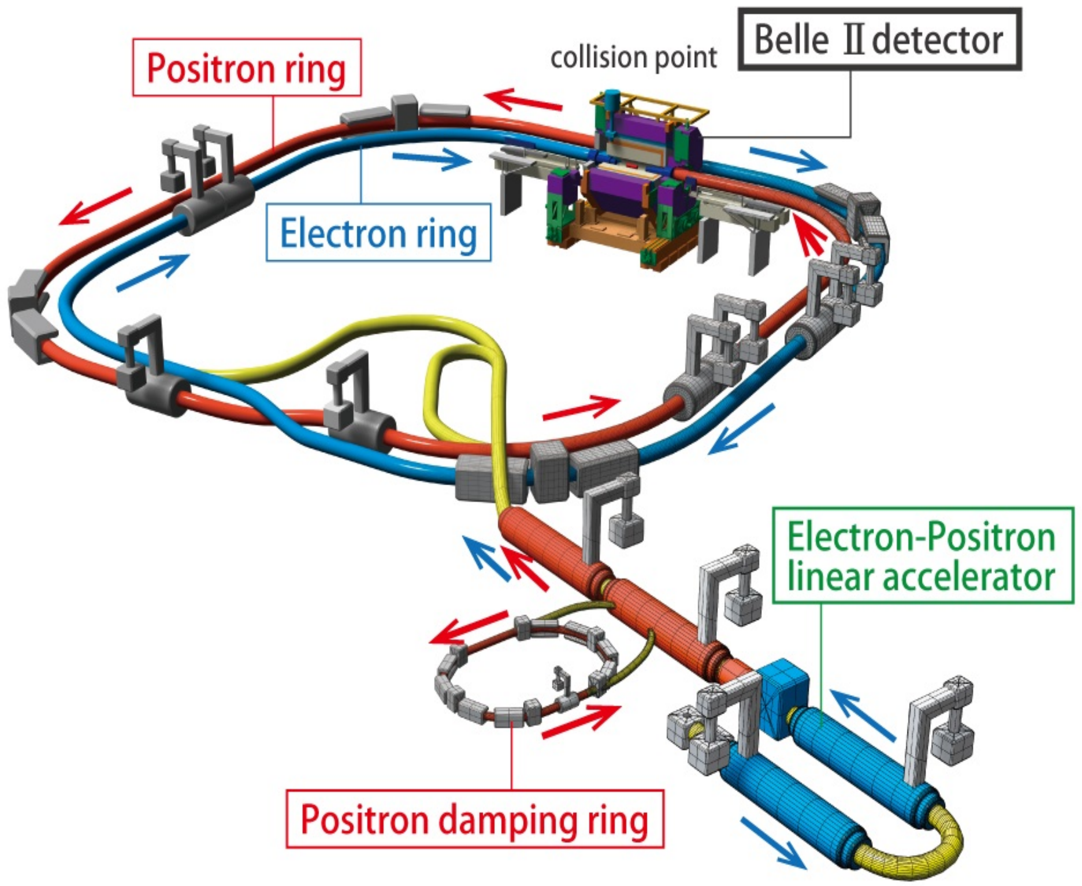


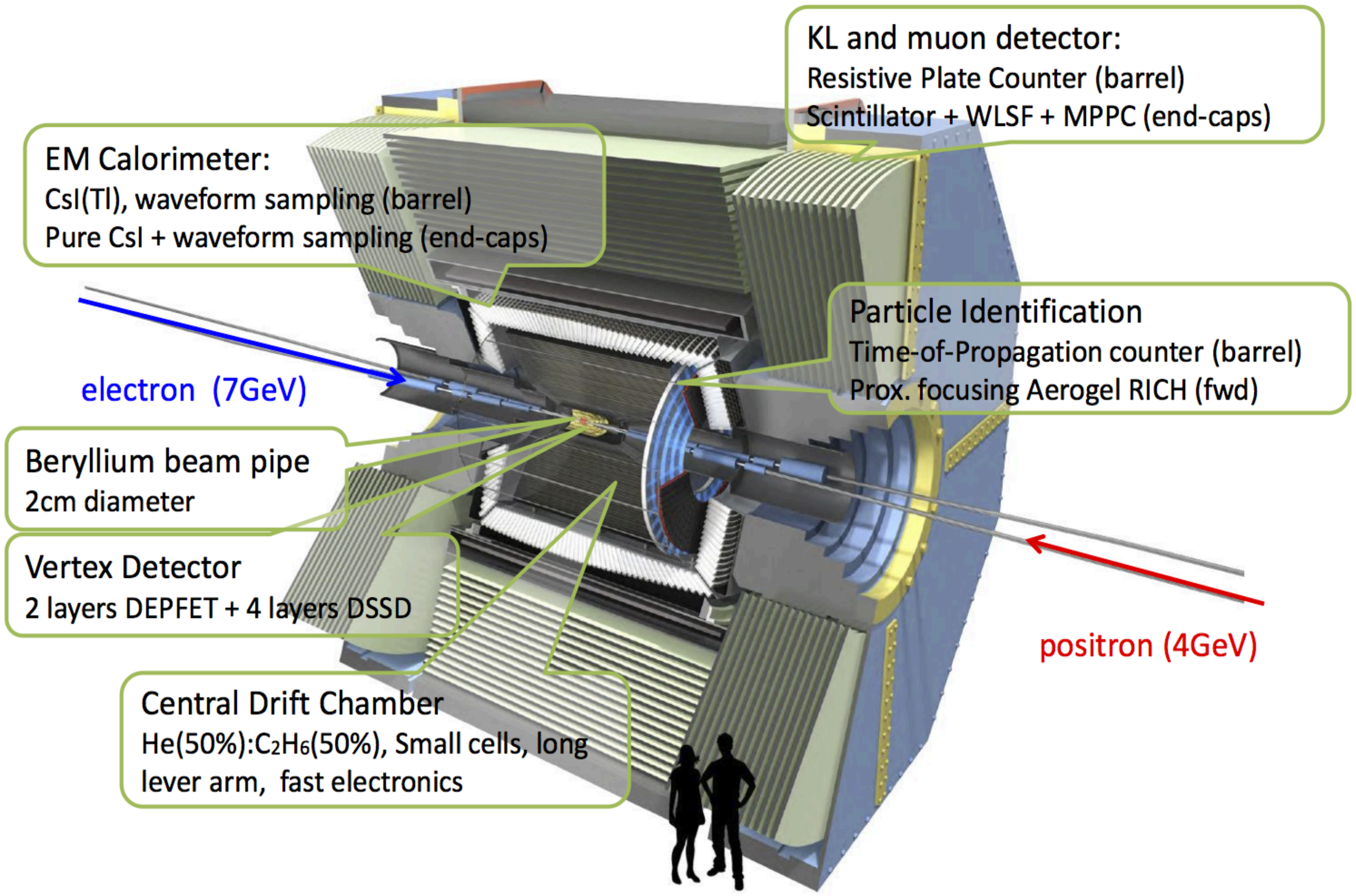
$$R(D^{(*)}) = \frac{\mathcal{B}\left(B \to D^{(*)}\tau\nu\right)}{\mathcal{B}\left(B \to D^{(*)}\ell\nu\right)}$$





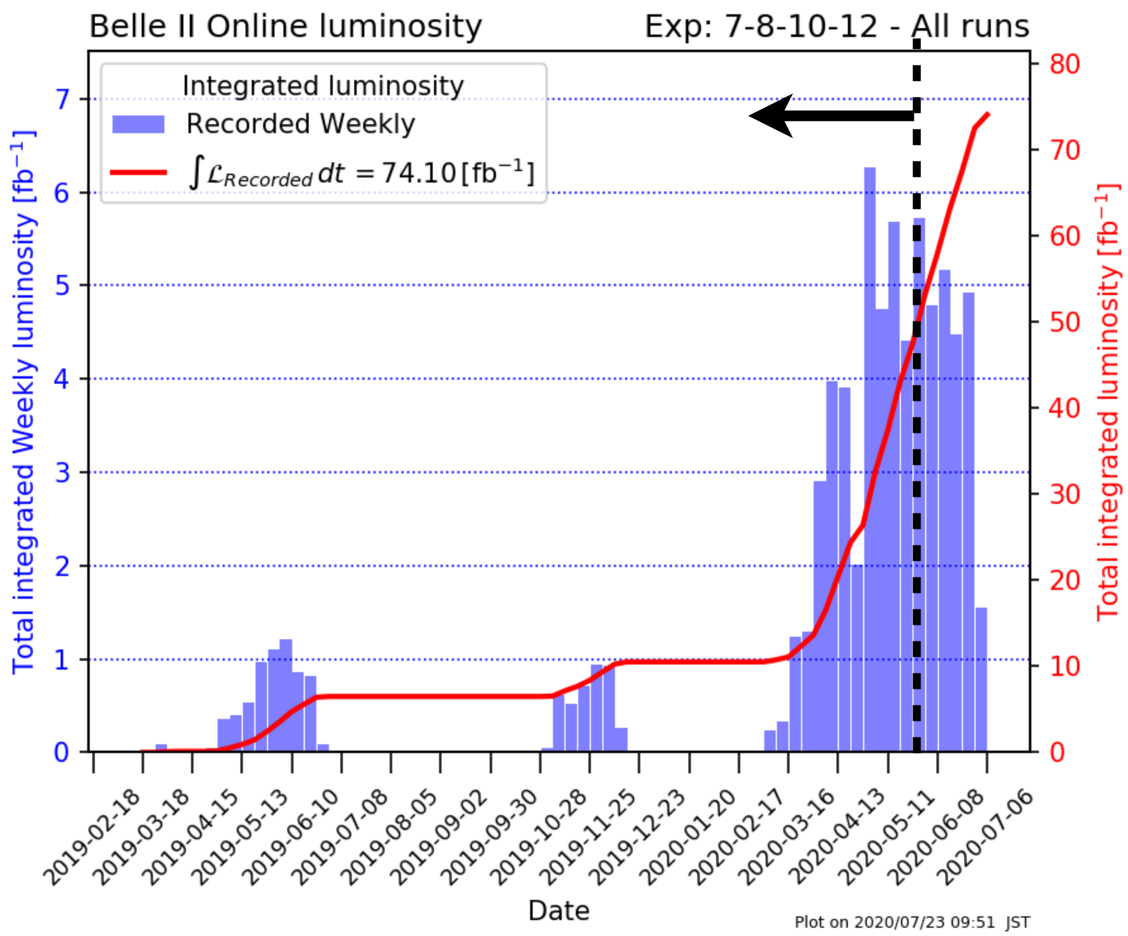
SuperKEKB and the Belle II detector

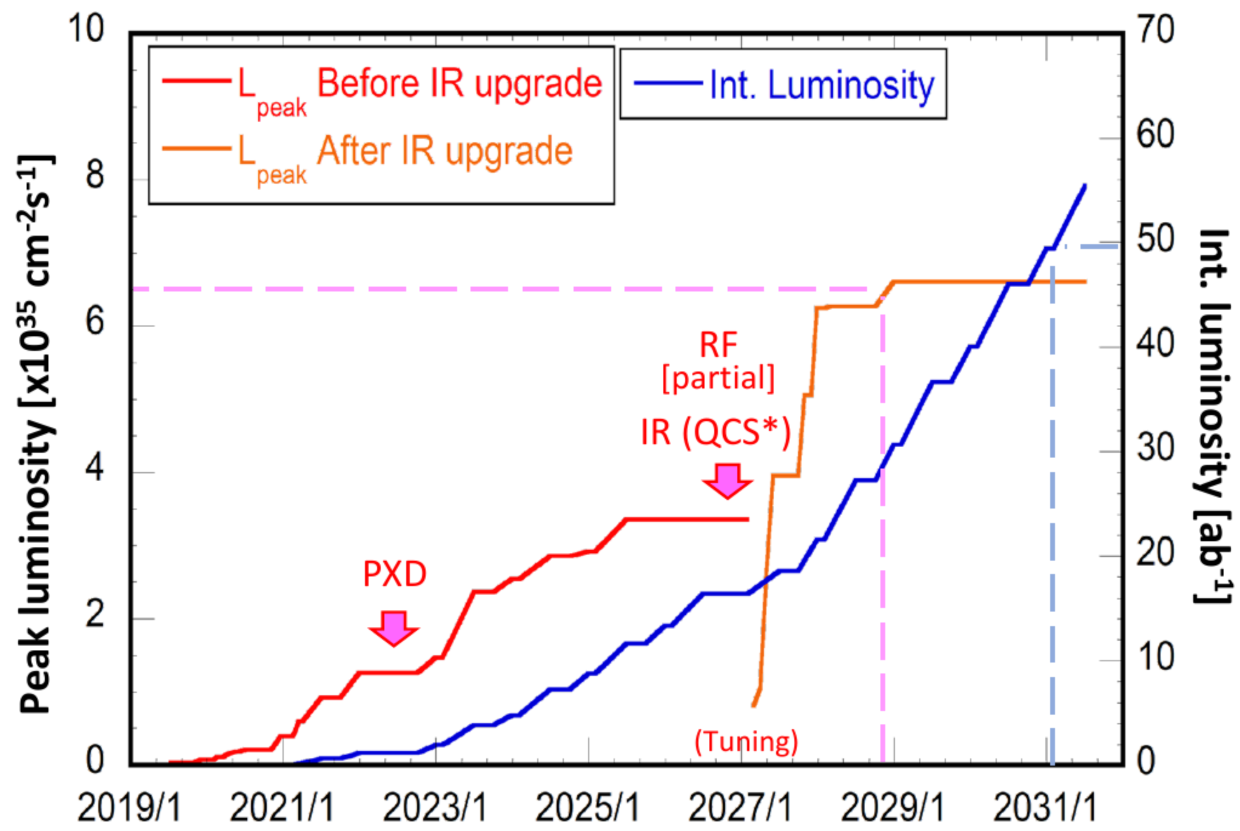




- *SuperKEKB*: 40x higher instantaneous luminosity than KEKB $\to \mathscr{L} = 6 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- *Belle II*: major upgrade of Belle detector to cope with harsher beam background conditions.
- Improvements in reconstruction algorithm, esp. on vertexing and particle identification.

Current Belle II dataset and projected luminosity





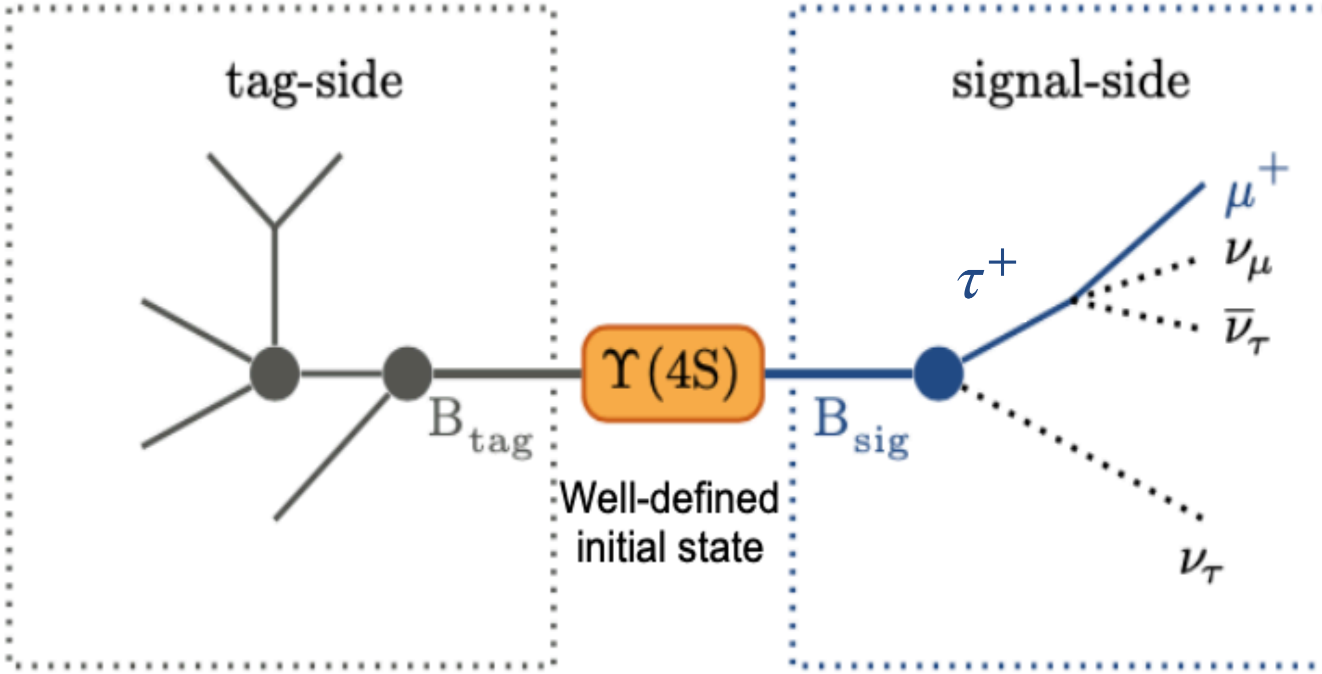
ICHEP 2020 dataset: $\int \mathscr{L} dt = 34.6\ \mathrm{fb}^{-1}$

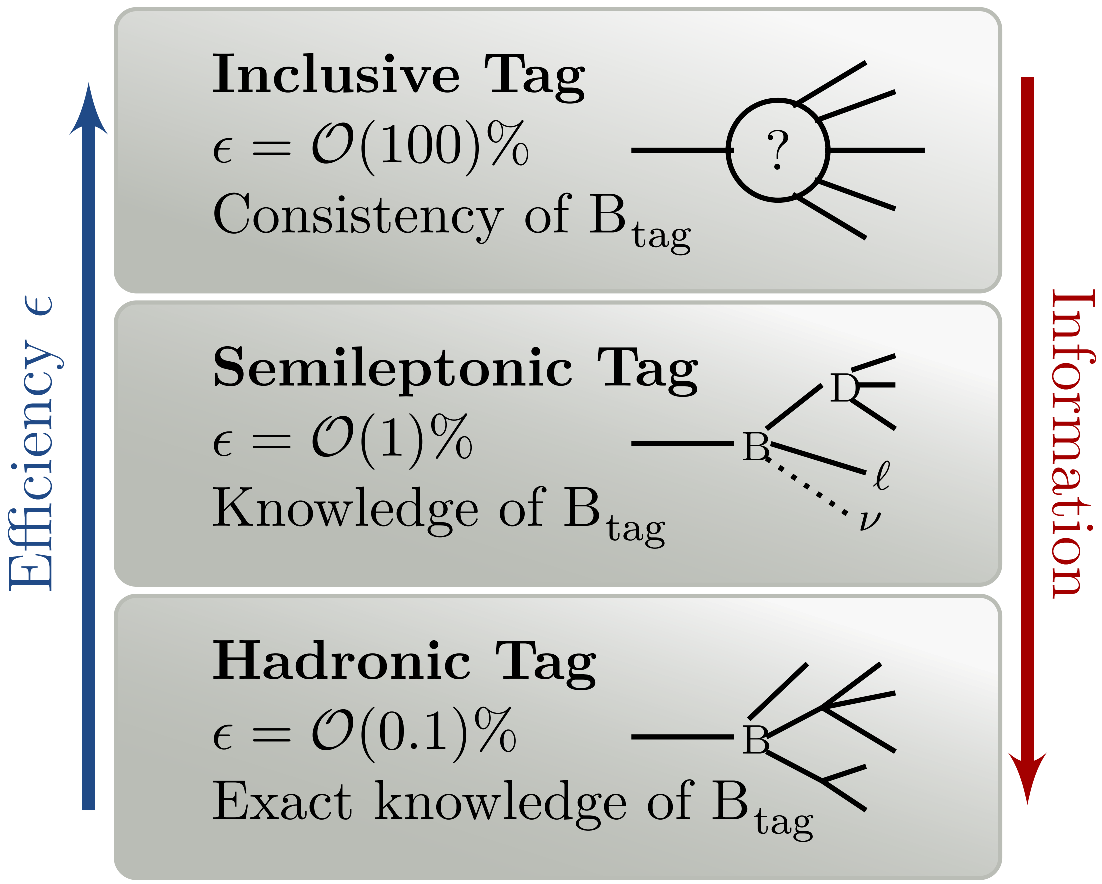
- Present data sample too limited for performing actual physics measurements.

  $\rightarrow$ Studied data/MC comparisons to demonstrate understanding of detector performance.

- Expecting first semileptonic B measurements with τ's with $\mathcal{O}(200\ \mathrm{fb}^{-1})$ in 2021.

Event reconstruction strategy





- Exploit flavour and kinematic constraints on "signal" B system by *tagging* the other.

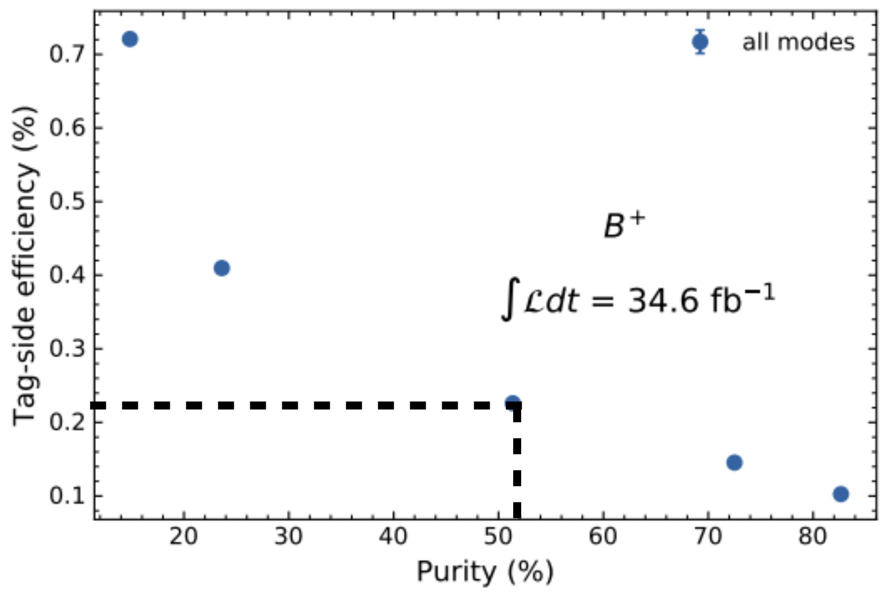
$$M_{bc} = \sqrt{E_{beam}^2/4 - p_{B_{tag}}^{*2}}$$

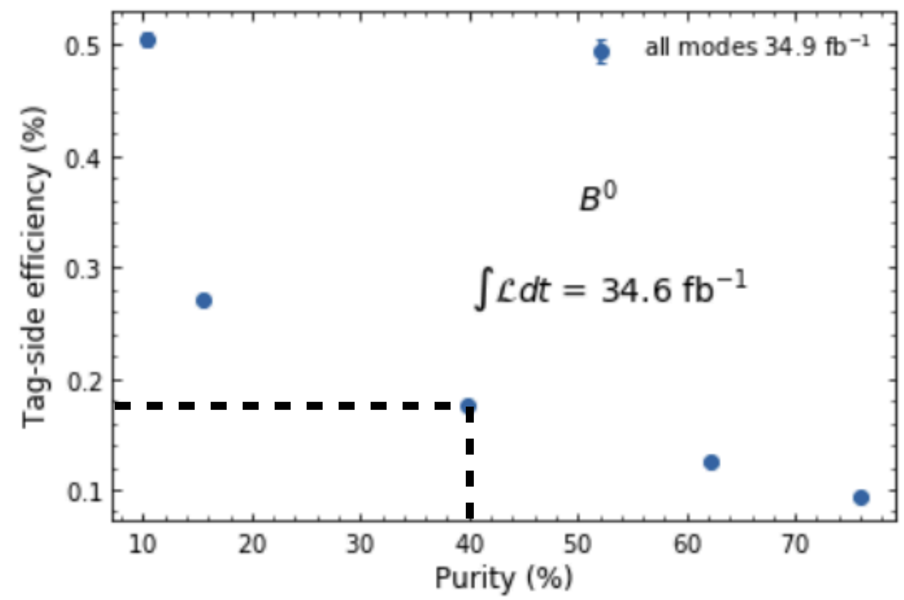
- Signal B reconstructed through leptonic decays of the τ (BR ~34 %) to further minimise background.

Full Event Interpretation algorithm for tag reconstruction

- New Full Event Interpretation (FEI) algorithm developed in Belle II software

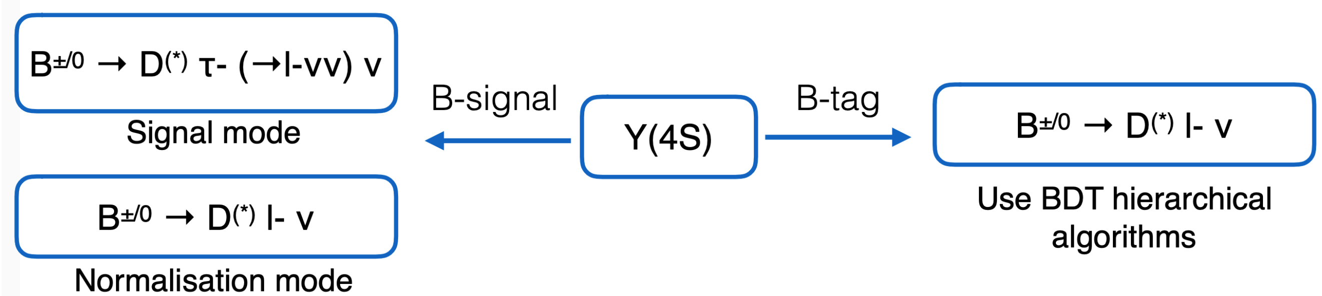
$\rightarrow$ BDT classifier trained on $\mathcal{O}(200)$ B decay channels to identifiy the B_{tag}





W. Sutcliffe's talk

- FEI successfully exploited in $R(D^{(*)})$ "semileptonic tag" analysis on Belle data analysed with the Belle II software.

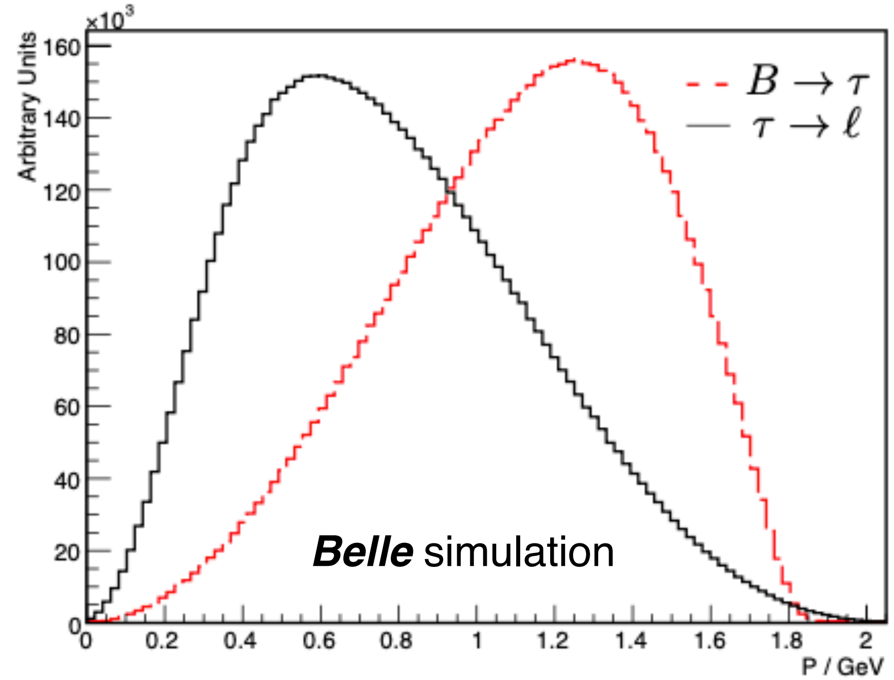


G. Caria *et al.* (Belle Collaboration), Phys. Rev. Lett. **124**, 161803

Experiment	Tag method	τ mode	R(D)	R(D*)	
Babar '12	Hadronic	ℓ ν ν	0.440 ± 0.058 ± 0.042	0.332 ± 0.024 ± 0.018	
Belle '15	Hadronic	ℓ ν ν	0.375 ± 0.064 ± 0.026	0.293 ± 0.038 ± 0.015	
LHCb '15	-	ℓ ν ν	-	0.336 ± 0.027 ± 0.030	
Belle '16	Semileptonic	ℓ ν ν	-	0.302 ± 0.030 ± 0.011	B^0
Belle '17	Hadronic	π ν, ρ ν	-	0.270 ± 0.035 ± 0.027	
LHCb '18	-	π π π ν	-	0.291 ± 0.019 ± 0.029	
Belle '19 *preliminary*	**Semileptonic**	**ℓ ν ν**	**0.307 ± 0.037 ± 0.016**	**0.283 ± 0.018 ± 0.014**	B^0, B^+
Average (2018)	-	-	*0.407 ± 0.039 ± 0.024*	*0.306 ± 0.013 ± 0.007*	
Average (2019)	-	-	**0.340 ± 0.027 ± 0.013**	**0.295 ± 0.011 ± 0.008**	
SM			0.299 ± 0.003	0.258 ± 0.005	

Signal region observables for B decays with τ

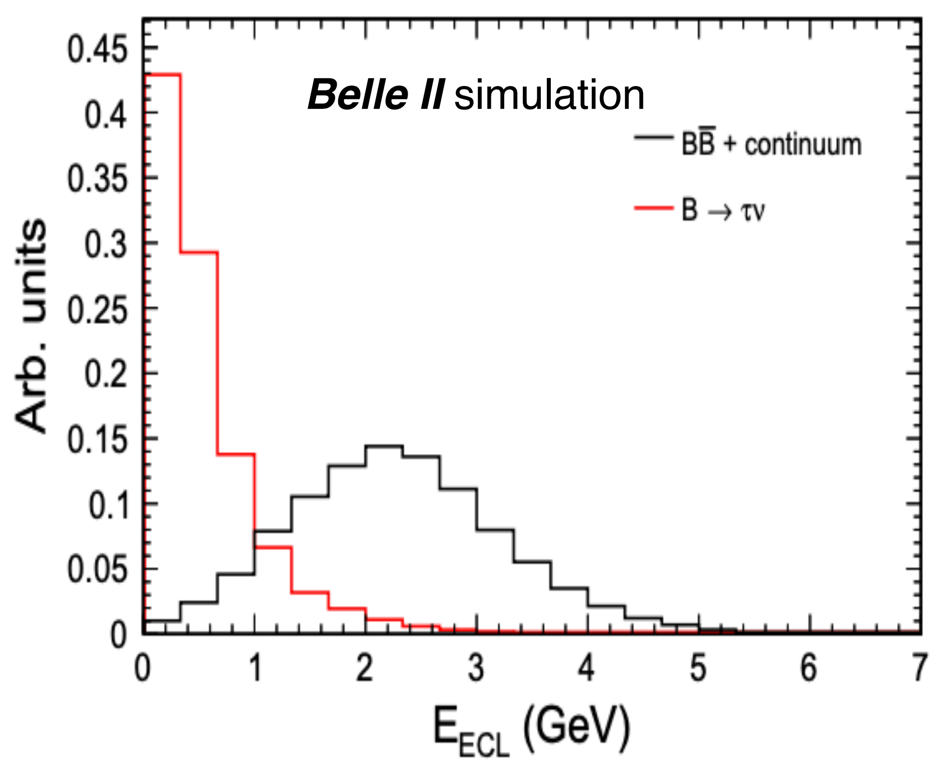
- p^*_ℓ → crucially dependent on good lepton identification performance.
    - Challenging due to low momentum of lepton daughters.



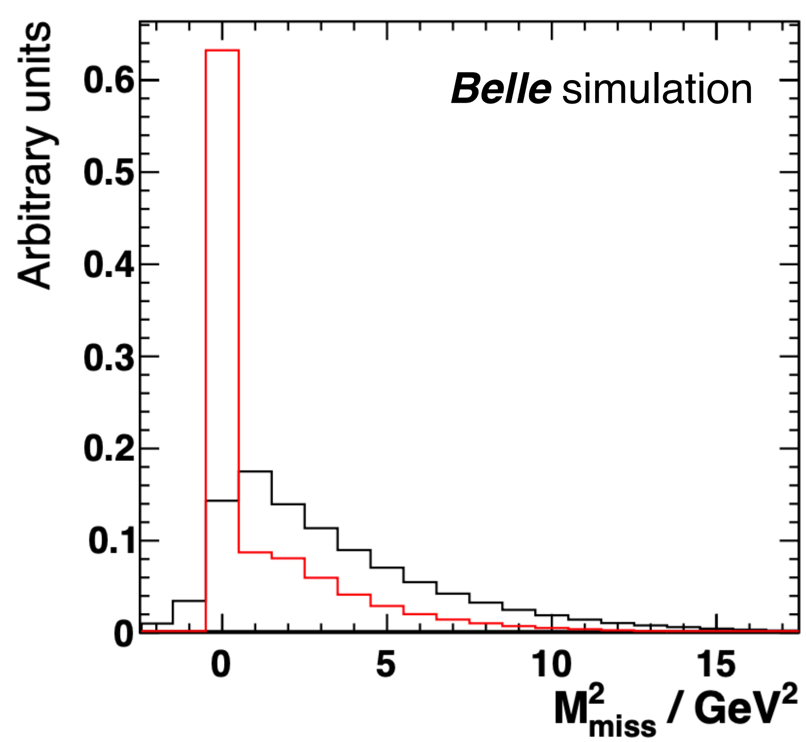
- m^2_{miss} → separates signal from $B \to X\ell\nu$, pure hadronic final states.

- E_{extra} (aka E_{ECL}) → energy in the calorimeter not associated to reconstructed particles.

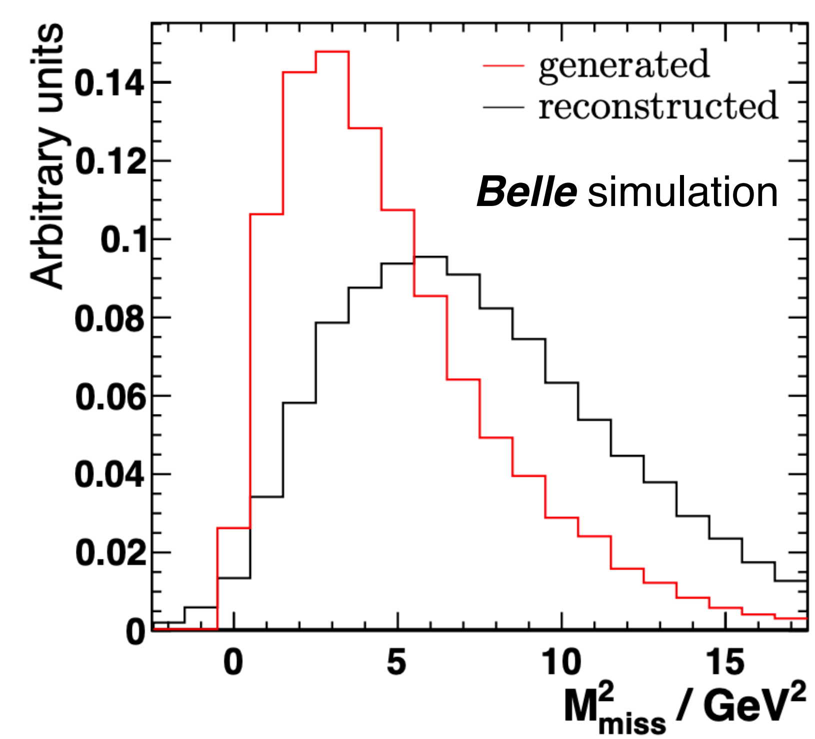
$B \to \tau\nu$ *(MC reco only)*



$B \to X\ell\nu$

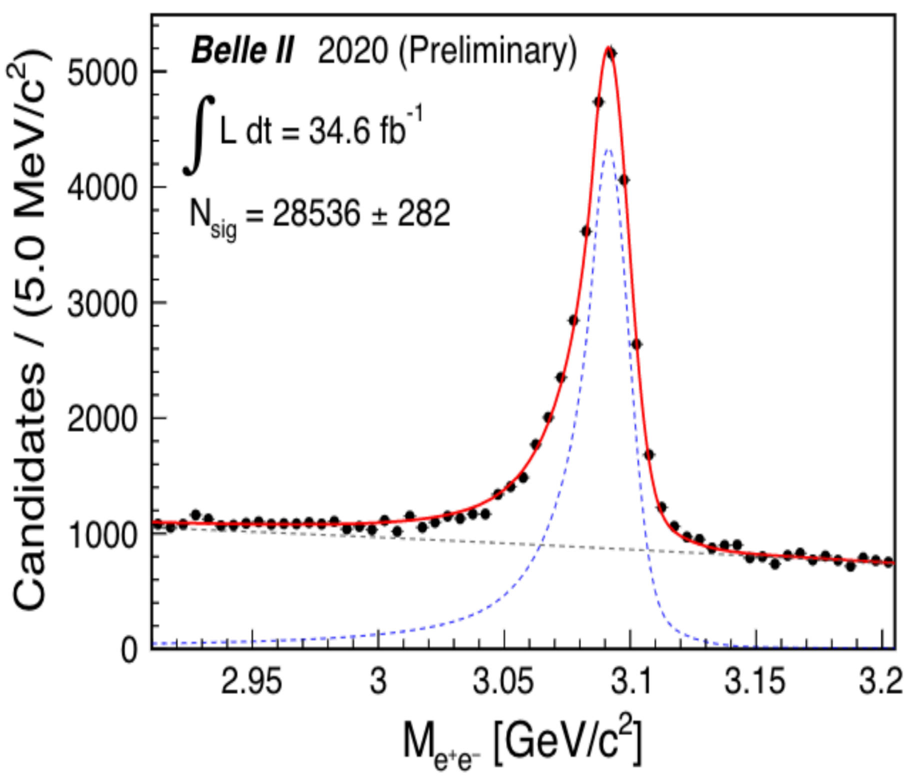


$B \to X\tau\nu$



Lepton identification performance in 2020 data

$J/\psi \to e^+e^-$



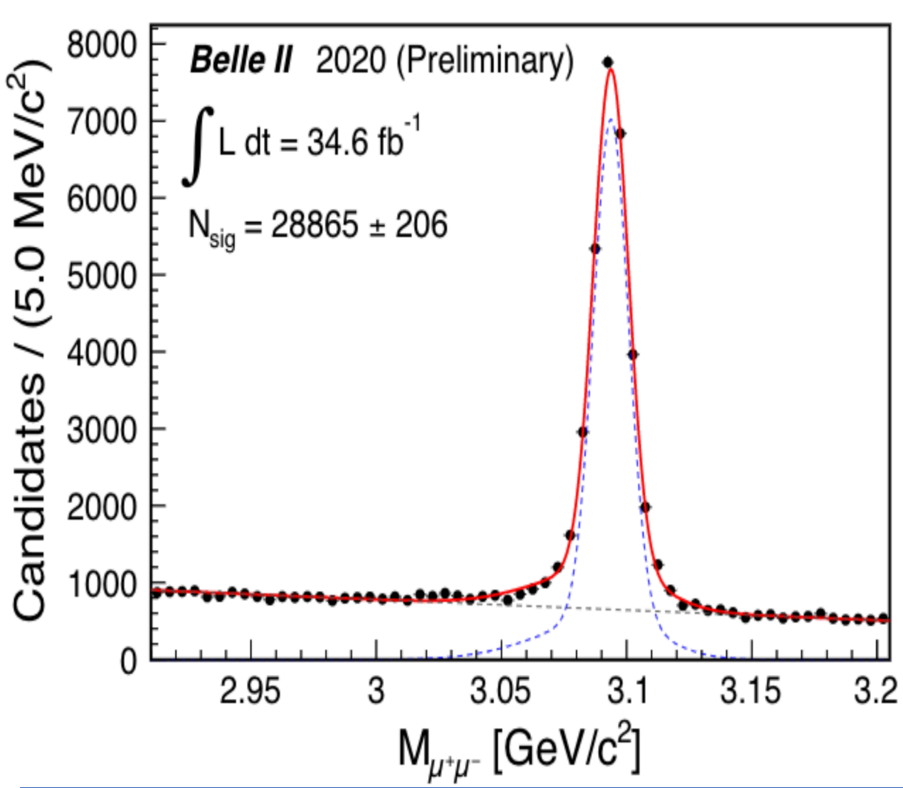
- Lepton identification & hadron mis-id performance in simulation calibrated to data using several "standard candles" → tag and probe.

likelihood ratio (w/ inputs from all sub-detectors)

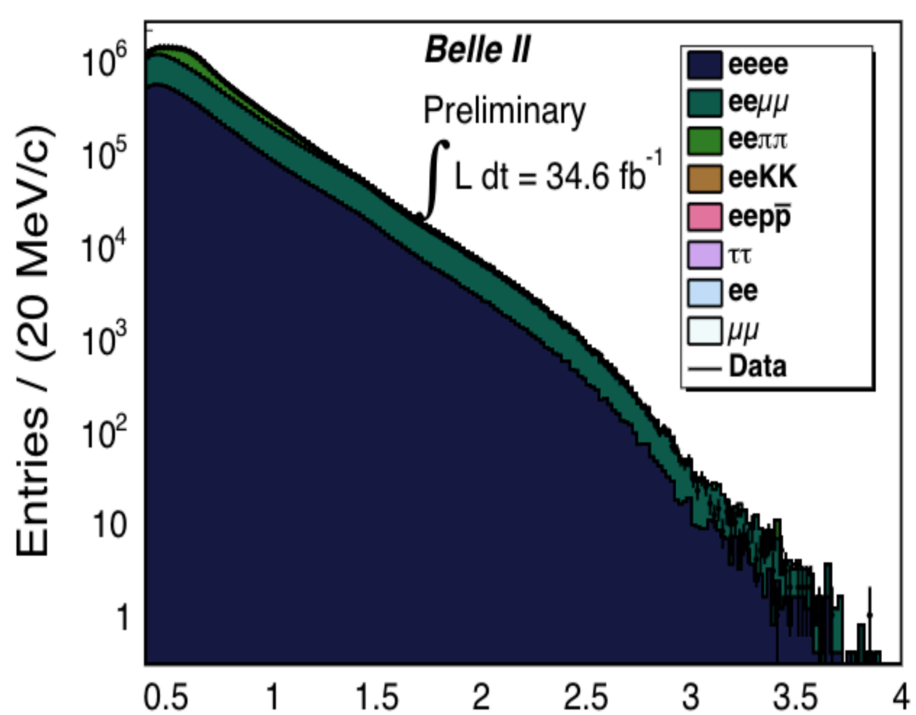
$$\ell\mathrm{ID} = \frac{\mathcal{L}_\ell}{\mathcal{L}_e + \mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K + \mathcal{L}_p}.$$

- Methods cover broad p range: $p \in [0.4 - 6.0]$ GeV/c

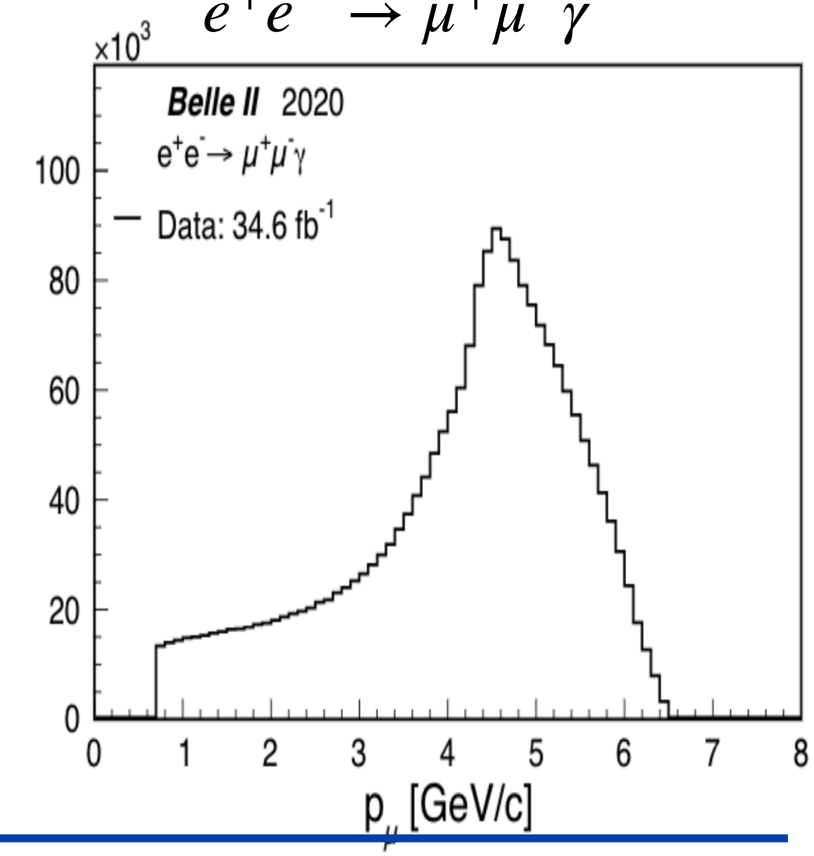
$J/\psi \to \mu^+\mu^-$



$e^+e^- \to (e^+e^-)\ell^+\ell^-$

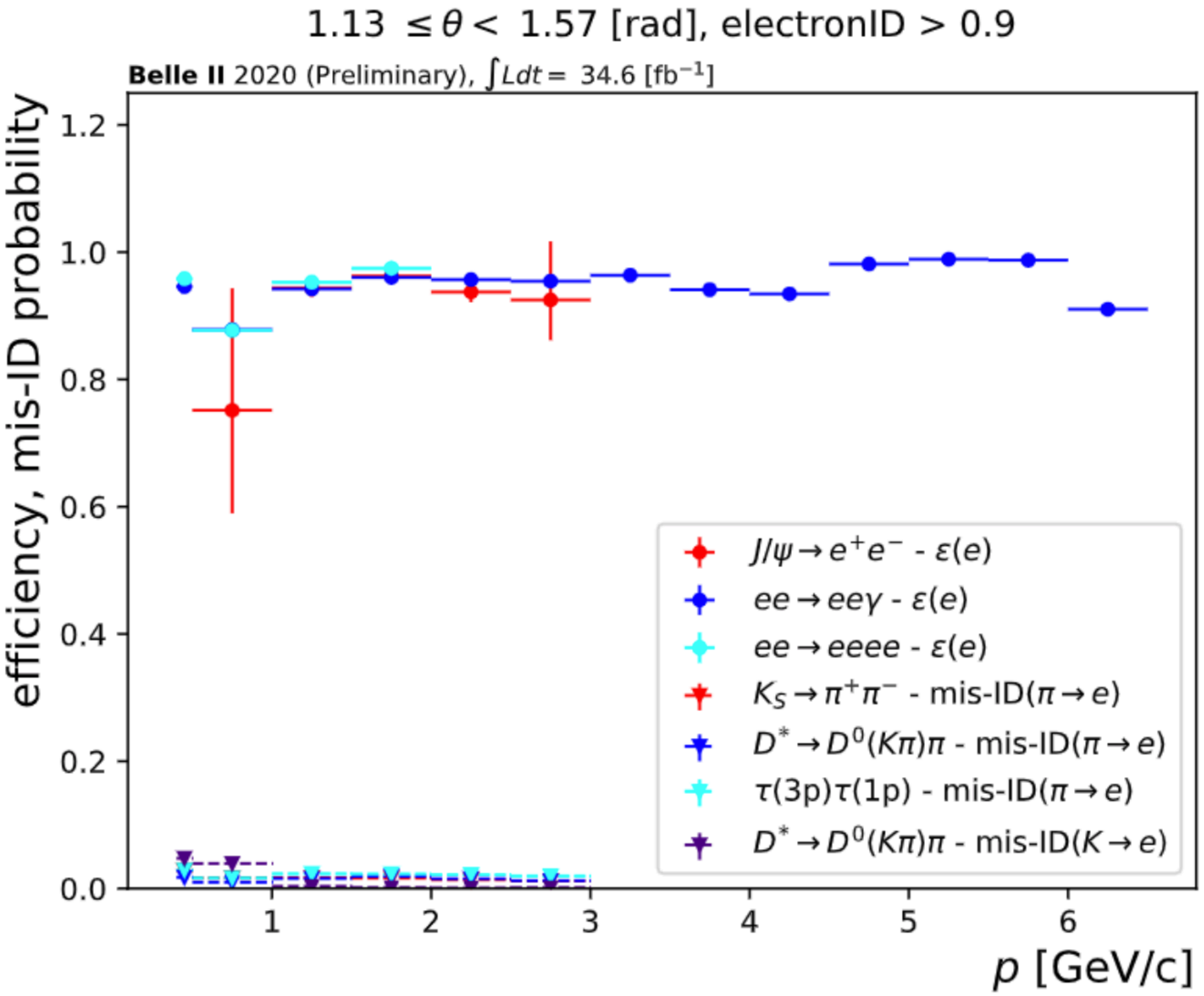


$e^+e^- \to \mu^+\mu^-\gamma$

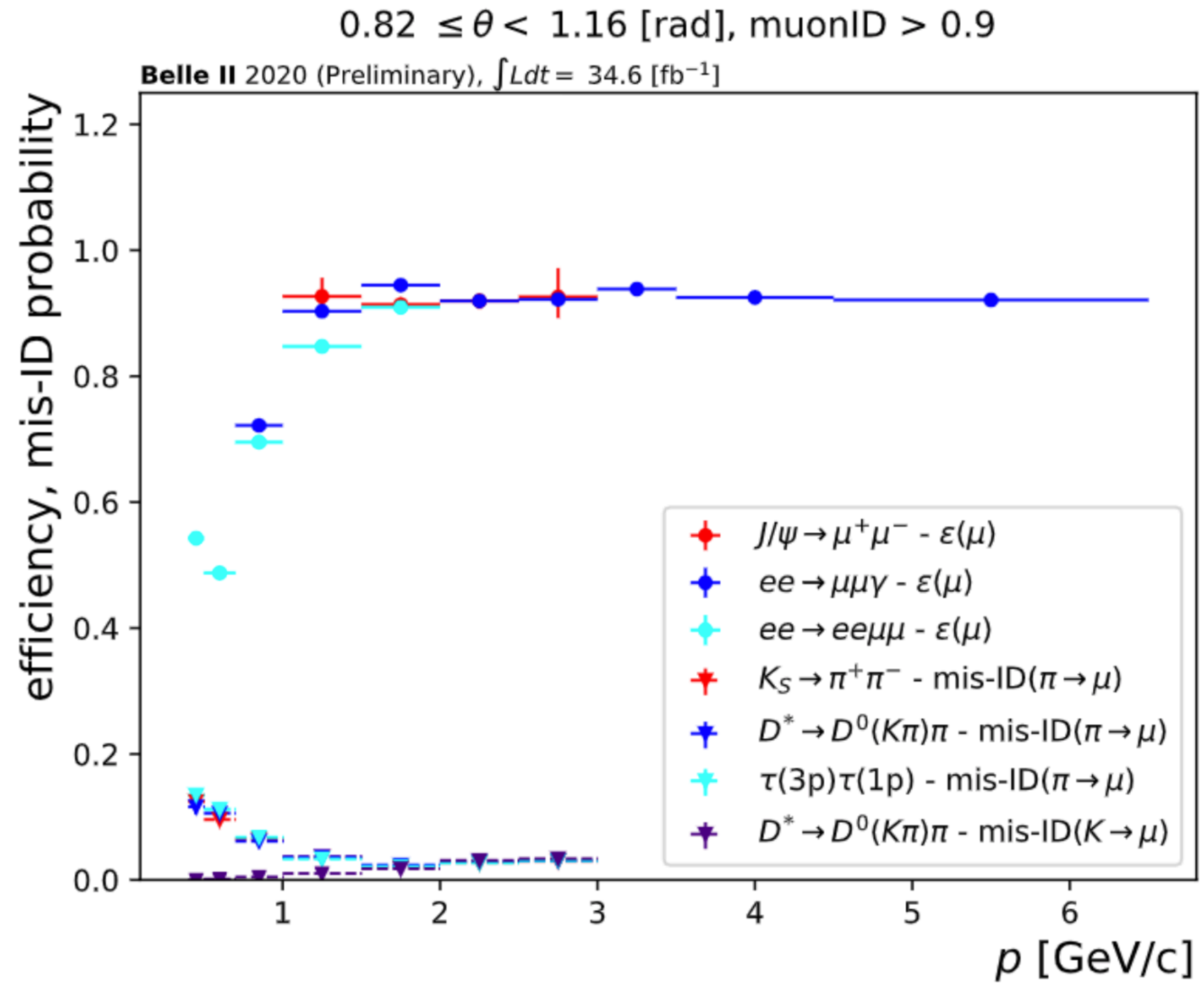


Lepton identification performance in 2020 data

Electrons



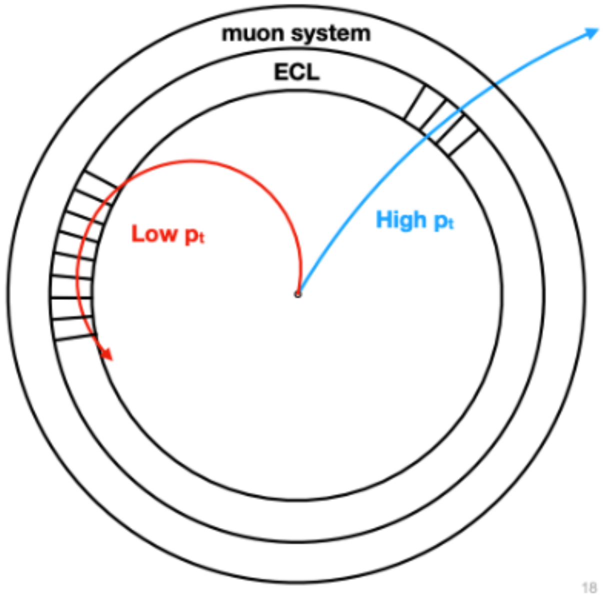
Muons



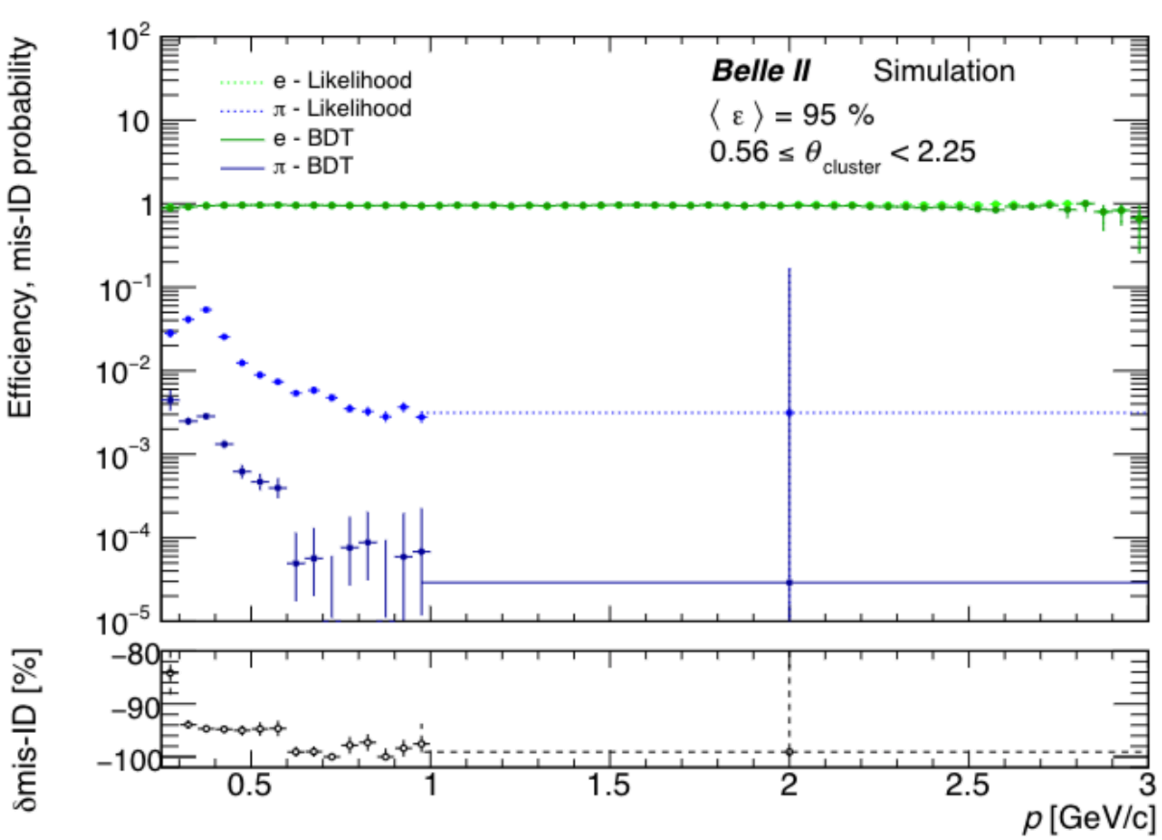
- e, $\mathscr{L}_{ratio} > 0.9 \rightarrow$ average ID efficiency of 94%, with 2% pion misidentification probability.
- μ, $\mathscr{L}_{ratio} > 0.9 \rightarrow$ average ID efficiency of 90%, with 4% pion misidentification probability.

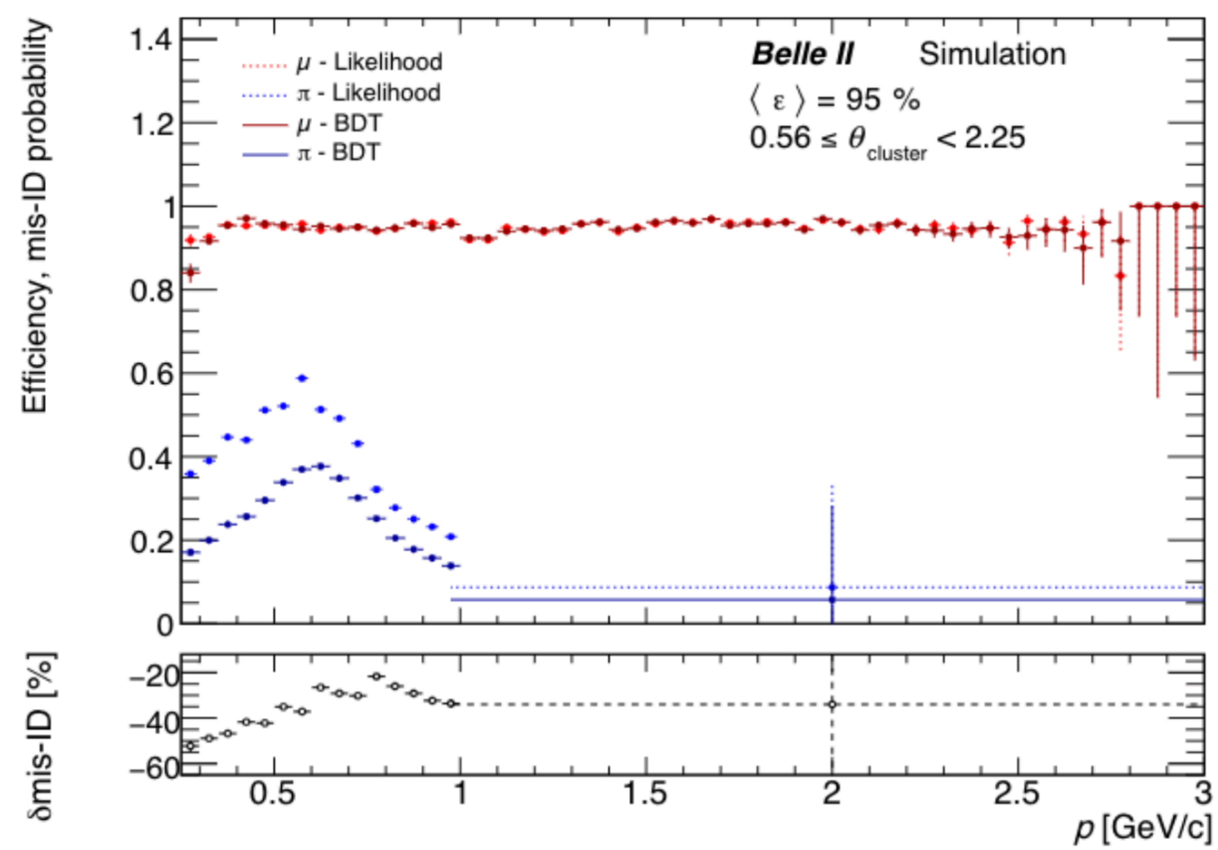
Upgrades to lepton identification

•.At low momentum, limit in KLM acceptance and large energy losses for electrons before the ECL make lepton identification a challenge.



→ Combine several calorimetric observables (lateral shower shapes, extrapolated track depth in the ECL...) in a BDT to improve lepton-hadron separation.

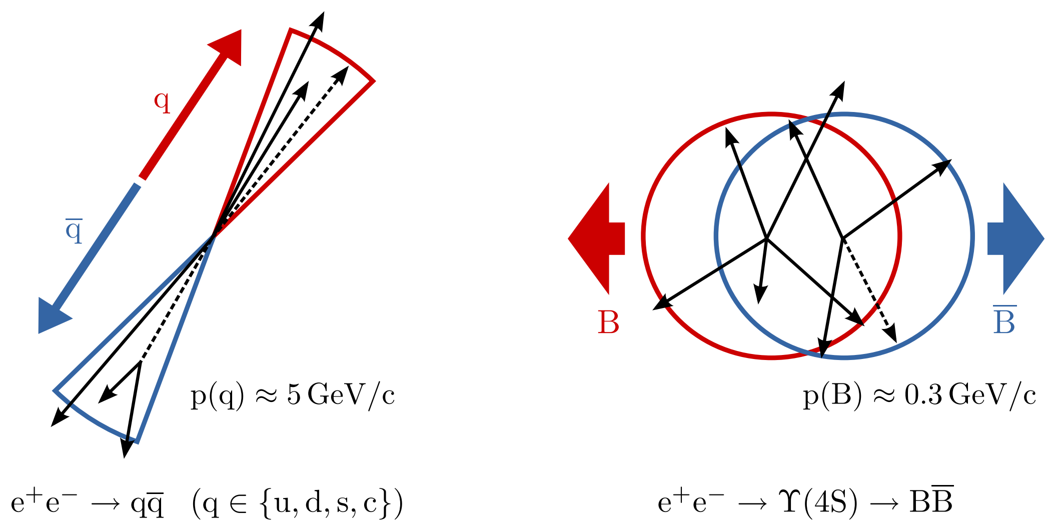




• Factor 10 reduction in $\pi - e$ fake rate, and a factor 2 in $\pi - \mu$ fake rate for $p < 1$ GeV/c (MC)

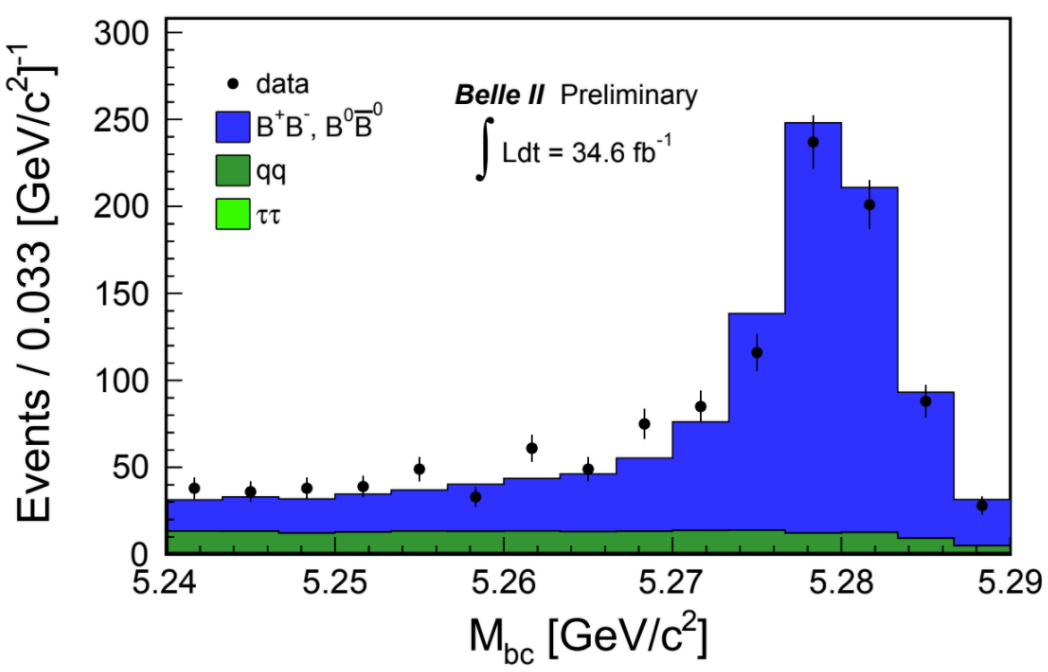
Full leptonic $B \to \tau\nu_\tau$ - Preliminary results

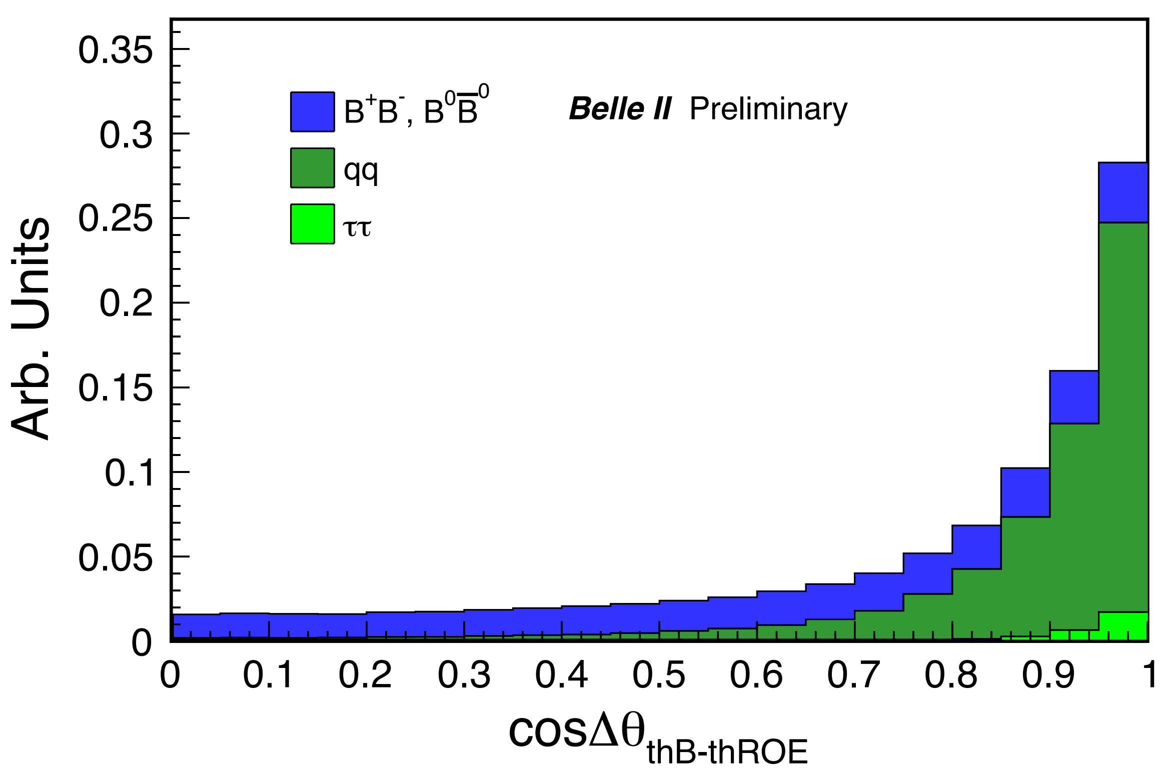
- .Describe selection, data and MC
- .Only electrons
- .Wait for Mario's final approved plots...



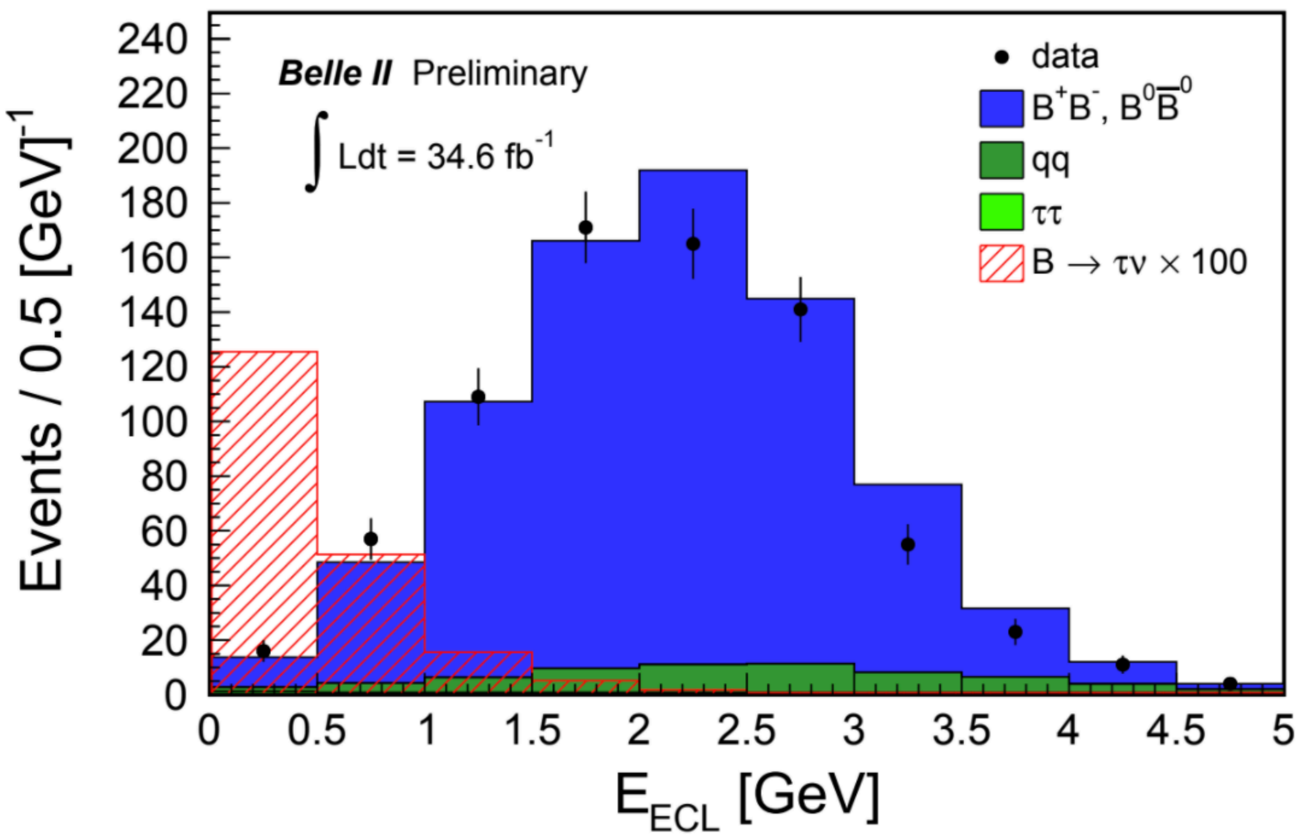
(I like this plot of costheta_thrust to describe continuum suppression)

Btag Mbc shows good performance of the FEI aalgorithm





Full leptonic $B \to \tau\nu_\tau$ - Preliminary



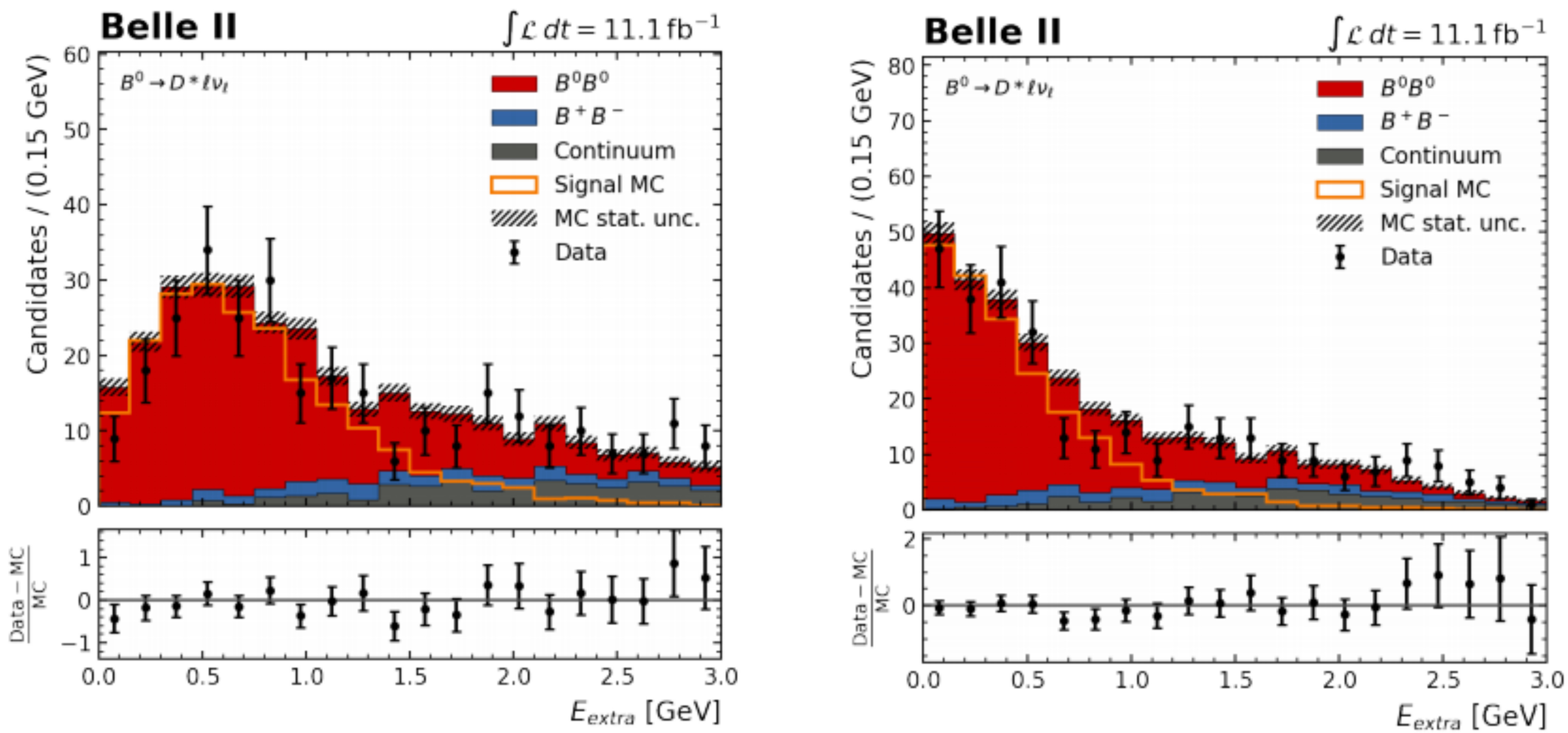
•.Good modelling of background in the low E_{ECL} region $\to$ potential for observation of $B \to \tau\nu$ with larger statistics.

Beam background suppression for E_{extra}

- Beam background broadens distribution in the "rest of event" (ROE $\rightarrow$ what is not associated to any reconstructed final state particles on both signal and tag sides)

  $\rightarrow$ detrimental for semileptonic tau analyses relying on E_{extra}

- BDT developed to reduce beam background contamination on ROE E_{extra} in the $\bar{B}^0 \rightarrow D^{*+}\ell^-\nu$ analysis, based on ECL shower shape variables and cluster angular positions.



Prospects for semileptonic B decays with τ leptons

- .WIP....suggestions welcome (other than BII 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%

$R(D), R(D^*)$ projections

- .WIP....suggestions welcome (other than BII Physics Book)

Conclusions