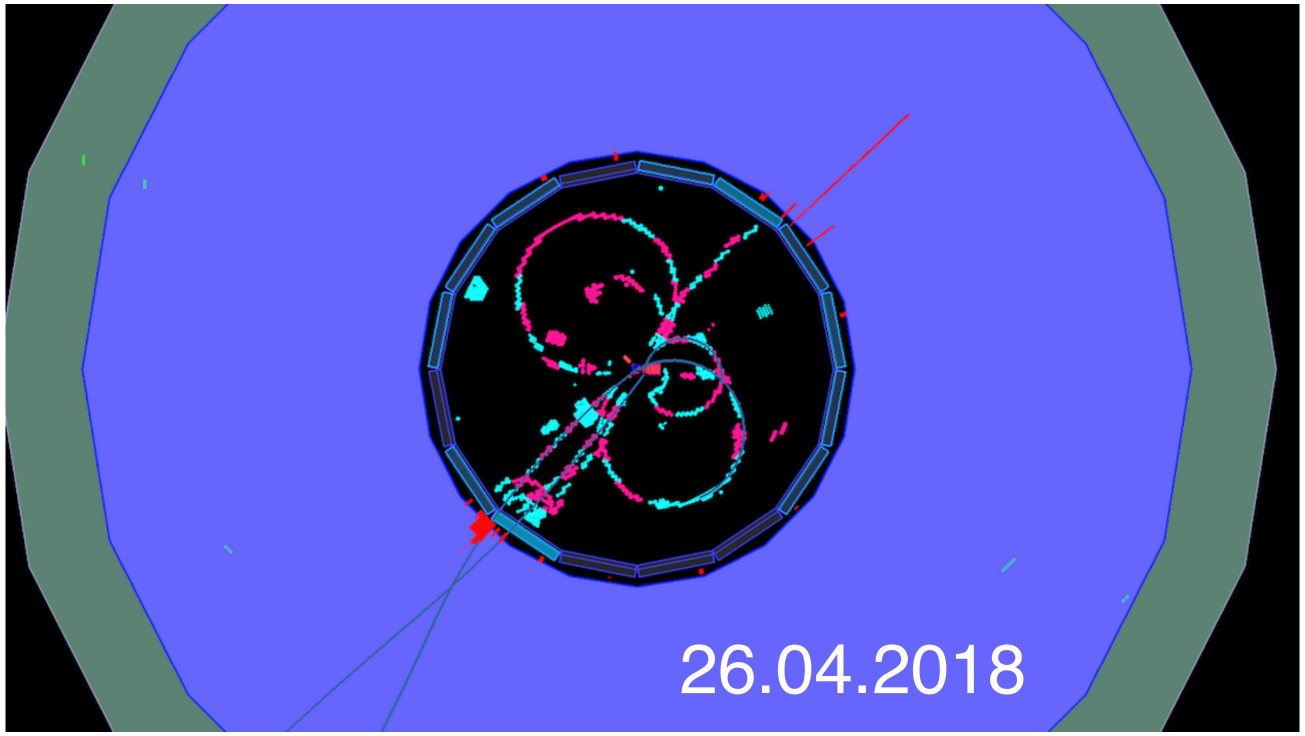
Semileptonic B decays at Belle II

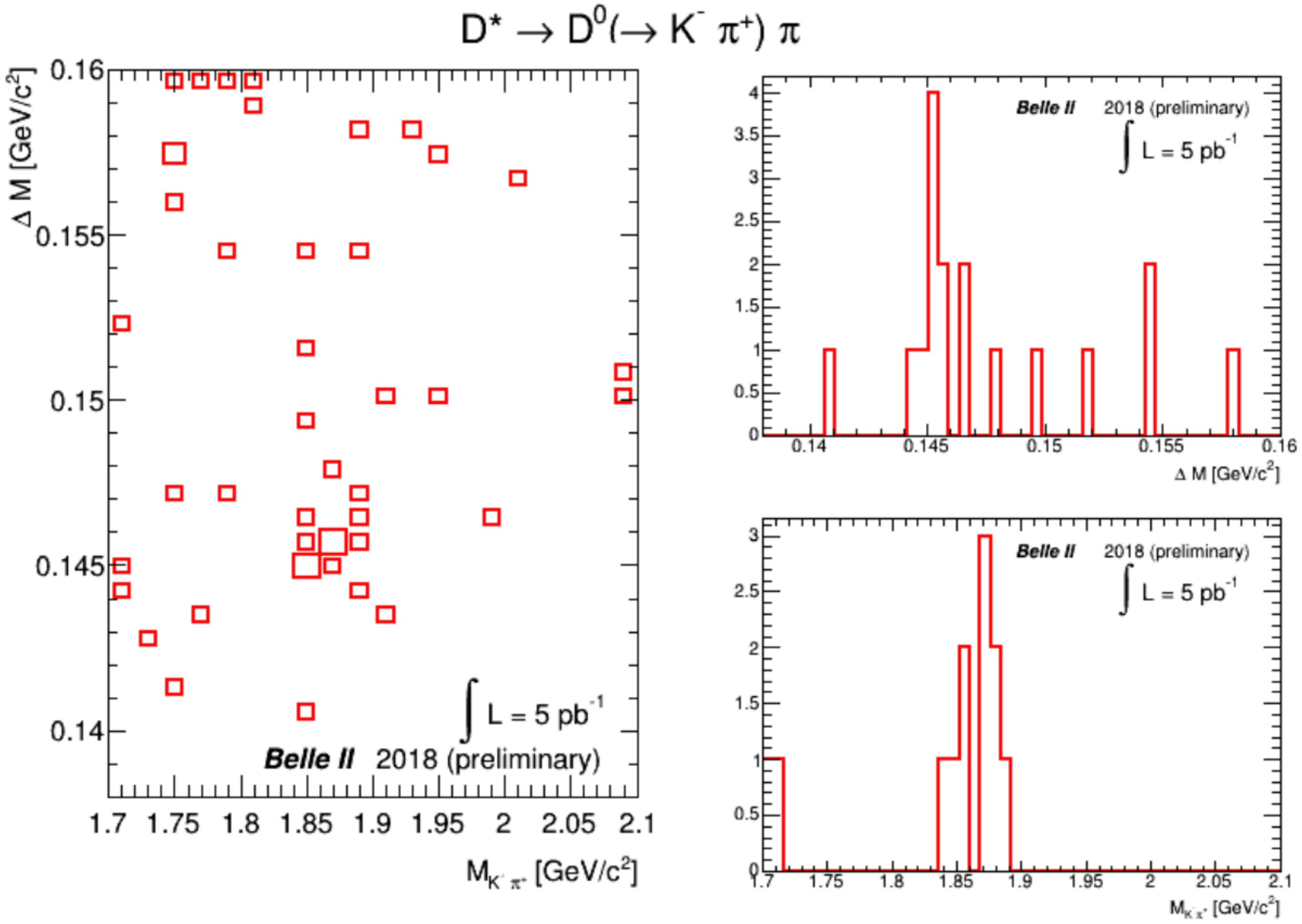
Jo-Frederik Krohn
Yamagata "Heavy Quarks and Leptons"
May 2018
On behalf of the Belle II Collaboration

Status Belle II

- First collision on 26th of April
- Accelerator is running in collision mode
- > 60 pb^{-1} of data collected (as of 28th of May 2018)
- First D* meson candidates found !

First collision





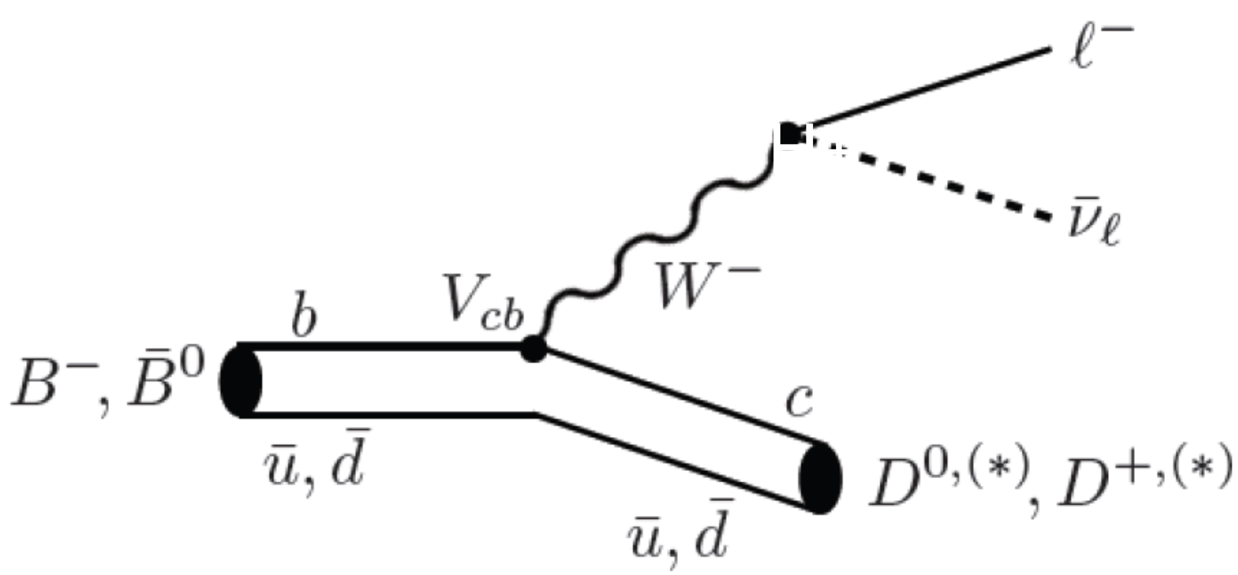
Semileptonic decays

BGL Phys.Rev.Lett 74, 4603

CLN arXiv: 1010.5620

arXiv: 1703.06124

- Will talk about V_{cb}, V_{ub} (from l = e, μ)
  - B → D(*) l ν and B → π l ν , l = e, μ
  - B → D(*) τ ν (R_τ)

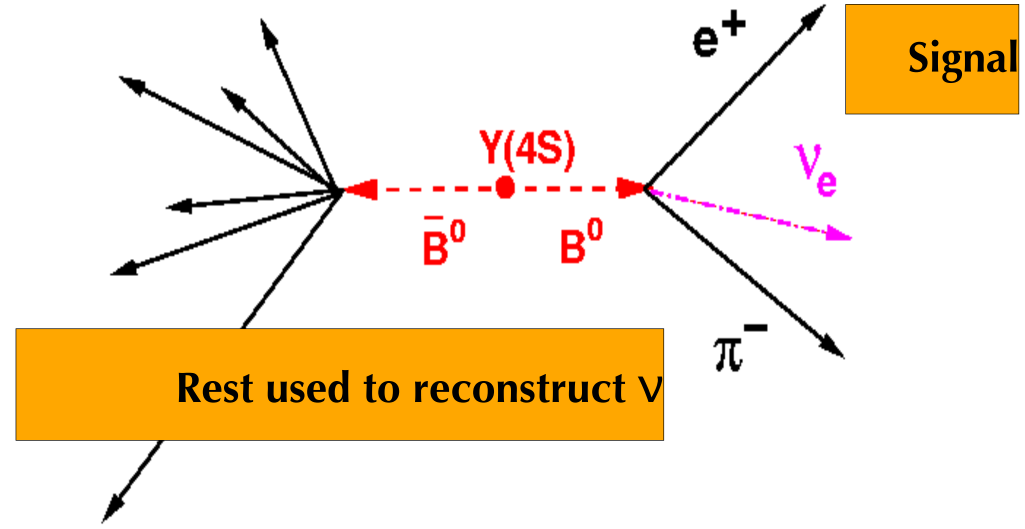
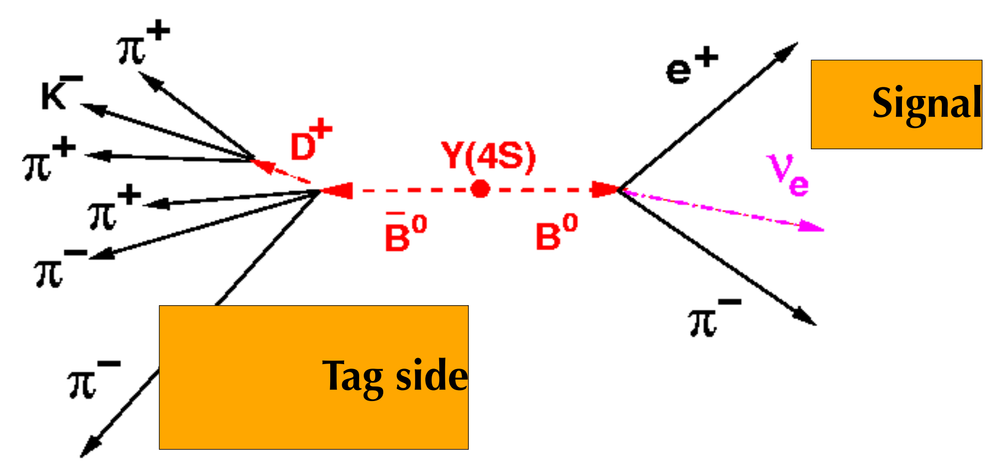


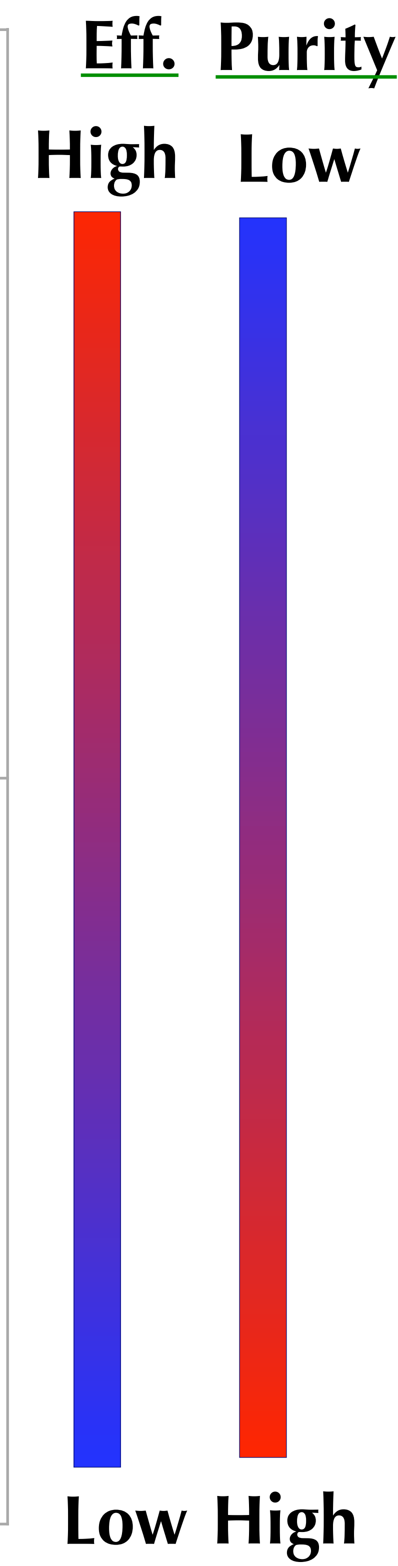
$$\frac{d\Gamma^{SM}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)}{dq^2} = \underbrace{\frac{G_F^2 |V_{cb}|^2 |p^*_{D^{(*)}}| \, q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_\ell^2}{q^2}\right)^2}_{\text{universal and phase space factors}}$$

$$\times \underbrace{\left[(|H_+|^2 + |H_-|^2 + |H_0|^2) \left(1 + \frac{m_\ell^2}{2q^2}\right) + \frac{3m_\ell^2}{2q^2} |H_s|^2 \right]}_{\text{hadronic effects}} .$$

- In the SM, the decay B→D* l ν proceed through a <u>tree level</u> decay

Approaches to Measuring B → X l ν

Untagged initial 4-momentum known missing 4-momentum = ν Reconstruct $B \to X_q\, l\, \nu$ Use other side to constrain B flight direction.	
Fully Reconstructed Tag One B reconstructed completely in a known b → c mode without ν. **“B-meson Beam”** $\left(p_{e^+e^-} - p^B_{\text{tag}} - p^{D^*} - p_\ell\right)^2 = (p_\nu)^2 = m^2_{\text{miss}} \backsim 0$	



B-tagging

Hadronic tag channels

B^+ modes	B^0 modes
$B^+ \to \bar{D}^0\pi^+$	$B^0 \to D^-\pi^+$
$B^+ \to \bar{D}^0\pi^+\pi^0$	$B^0 \to D^-\pi^+\pi^0$
$B^+ \to \bar{D}^0\pi^+\pi^0\pi^0$	$B^0 \to D^-\pi^+\pi^+\pi^-$
$B^+ \to \bar{D}^0\pi^+\pi^+\pi^-$	$B^0 \to D_s^+D^-$
$B^+ \to D_s^+\bar{D}^0$	$B^0 \to D^{*-}\pi^+$
$B^+ \to \bar{D}^{*0}\pi^+$	$B^0 \to D^{*-}\pi^+\pi^0$
$B^+ \to \bar{D}^{*0}\pi^+\pi^0$	$B^0 \to D^{*-}\pi^+\pi^+\pi^-$
$B^+ \to \bar{D}^{*0}\pi^+\pi^+\pi^-$	$B^0 \to D^{*-}\pi^+\pi^+\pi^-\pi^0$
$B^+ \to \bar{D}^{*0}\pi^+\pi^+\pi^-\pi^0$	$B^0 \to D_s^{*+}D^-$
$B^+ \to D_s^{*+}\bar{D}^0$	$B^0 \to D_s^+D^{*-}$
$B^+ \to D_s^+\bar{D}^{*0}$	$B^0 \to D_s^{*+}D^{*-}$
$B^+ \to \bar{D}^0K^+$	$B^0 \to J/\psi K_s^0$
$B^+ \to D^-\pi^+\pi^+$	$B^0 \to J/\psi K^+\pi^+$
$B^+ \to J/\psi K^+$	$B^0 \to J/\psi K_s^0\pi^+\pi^-$
$B^+ \to J/\psi K^+\pi^+\pi^-$	
$B^+ \to J/\psi K^+\pi^0$	
$B^+ \to J/\psi K_s^0\pi^+$	
$B^+ \to D^-\pi^+\pi^+\pi^0$	$B^0 \to D^-\pi^+\pi^0\pi^0$
$B^+ \to \bar{D}^0\pi^+\pi^+\pi^-\pi^0$	$B^0 \to D^-\pi^+\pi^+\pi^-\pi^0$
$B^+ \to \bar{D}^0D^+$	$B^0 \to \bar{D}^0\pi^+\pi^-$
$B^+ \to \bar{D}^0D^+K_s^0$	$B^0 \to D^-D^0K^+$
$B^+ \to \bar{D}^{*0}D^+K_s^0$	$B^0 \to D^-D^{*0}K^+$
$B^+ \to \bar{D}^0D^{*+}K_s^0$	$B^0 \to D^{*-}D^0K^+$
$B^+ \to \bar{D}^{*0}D^{*+}K_s^0$	$B^0 \to D^{*-}D^{*0}K^+$
$B^+ \to \bar{D}^0D^0K^+$	$B^0 \to D^-D^+K_s^0$
$B^+ \to \bar{D}^{*0}D^0K^+$	$B^0 \to D^{*-}D^+K_s^0$
$B^+ \to \bar{D}^0D^{*0}K^+$	$B^0 \to D^-D^{*+}K_s^0$
$B^+ \to \bar{D}^{*0}D^{*0}K^+$	$B^0 \to D^{*-}D^{*+}K_s^0$
$B^+ \to \bar{D}^{*0}\pi^+\pi^0\pi^0$	$B^0 \to D^{*-}\pi^+\pi^0\pi^0$

D^+,D^{*+},D_s^+ modes	D^0,D^{*0} modes
$D^+ \to K^-\pi^+\pi^+$	$D^0 \to K^-\pi^+$
$D^+ \to K^-\pi^+\pi^+\pi^0$	$D^0 \to K^-\pi^+\pi^0$
$D^+ \to K^-K^+\pi^+$	$D^0 \to K^-\pi^+\pi^+\pi^-$
$D^+ \to K^-K^+\pi^+\pi^0$	$D^0 \to \pi^-\pi^+$
$D^+ \to K_s^0\pi^+$	$D^0 \to \pi^-\pi^+\pi^0$
$D^+ \to K_s^0\pi^+\pi^0$	$D^0 \to K_s^0\pi^0$
$D^+ \to K_s^0\pi^+\pi^+\pi^-$	$D^0 \to K_s^0\pi^+\pi^-$
$D^{*+} \to D^0\pi^+$	$D^0 \to K_s^0\pi^+\pi^-\pi^0$
$D^{*+} \to D^+\pi^0$	$D^0 \to K^-K^+$
$D_s^+ \to K^+K_s^0$	$D^0 \to K^-K^+K_s^0$
$D_s^+ \to K^+\pi^+\pi^-$	$D^{*0} \to D^0\pi^0$
$D_s^+ \to K^+K^-\pi^+$	$D^{*0} \to D^0\gamma$
$D_s^+ \to K^+K^-\pi^+\pi^0$	
$D_s^+ \to K^+K_s^0\pi^+\pi^-$	
$D_s^+ \to K^-K_s^0\pi^+\pi^+$	
$D_s^+ \to K^+K^-\pi^+\pi^+\pi^-$	
$D_s^+ \to \pi^+\pi^+\pi^-$	
$D_s^{*+} \to D_s^+\pi^0$	
$D^+ \to \pi^+\pi^0$	$D^0 \to K^-\pi^+\pi^0\pi^0$
$D^+ \to \pi^+\pi^+\pi^-$	$D^0 \to K^-\pi^+\pi^+\pi^-\pi^0$
$D^+ \to \pi^+\pi^+\pi^-\pi^0$	$D^0 \to \pi^-\pi^+\pi^+\pi^-$
$D^+ \to K^+K_s^0K_s^0$	$D^0 \to \pi^-\pi^+\pi^0\pi^0$
$D^{*+} \to D^+\gamma$	$D^0 \to K^-K^+\pi^0$
$D_s^+ \to K_s^0\pi^+$	
$D_s^+ \to K_s^0\pi^+\pi^0$	
$D_s^{*+} \to D_s^+\pi^0$	

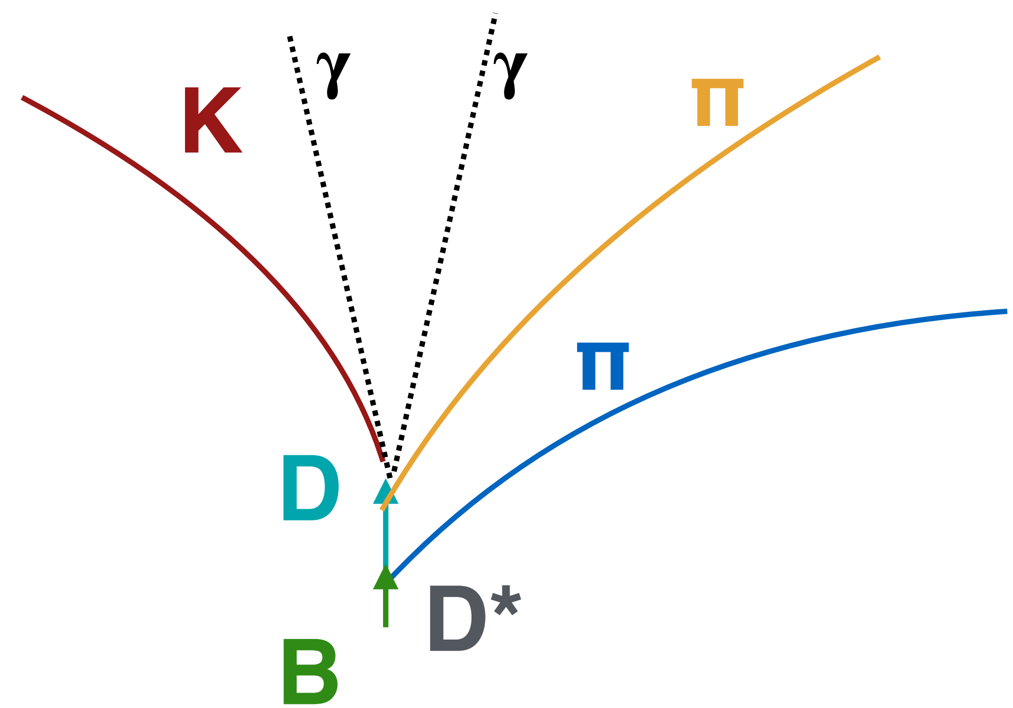
New channels

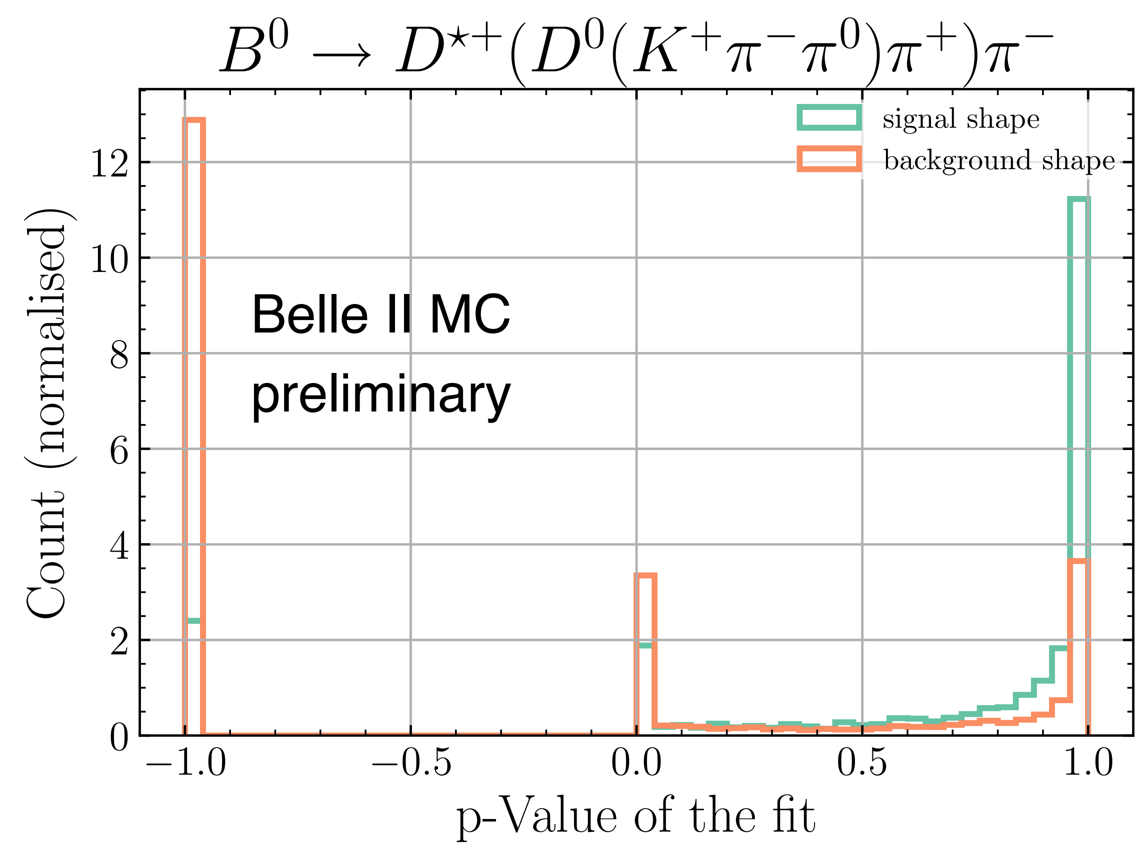
Tag algorithm	MVA	Efficiency	Purity
Belle v1 (2004)	Cut-based	-	-
Belle v3 (2007)	Cut-based	0.1%	0.25%
Belle NB	**Neurobayes**	**0.2%**	**0.25%**
Belle II FEI (2017)	BDT	0.5%	0.25%

- New, more efficient tag algorithm
  - Includes more channels
  - ~5000 channels !
- Semileptonic tag Fast BDT tag, based on B → D(*) l ν and B → D(*)π l ν…
  - > 200 channels

Improving hadronic tag

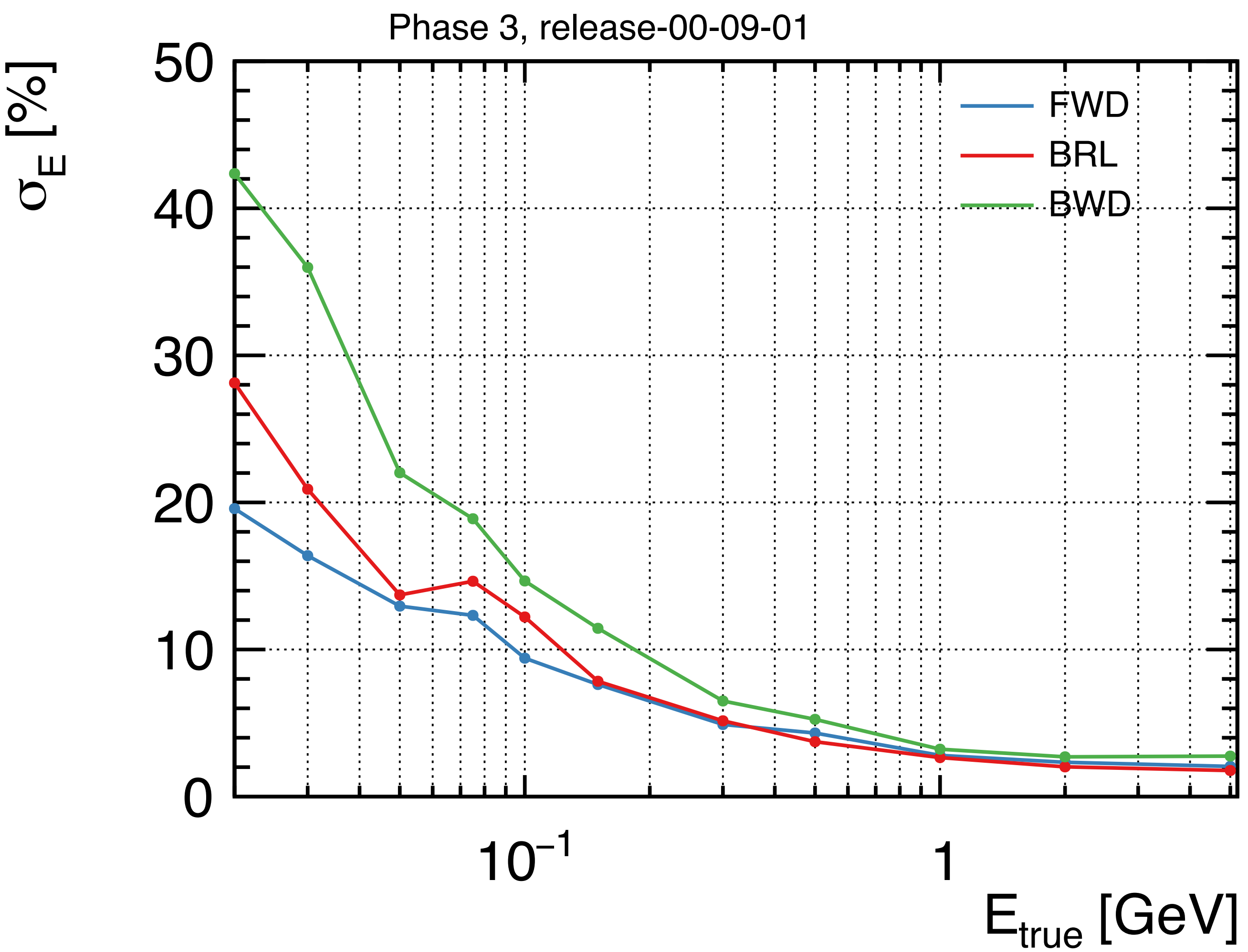
- Instead of fitting cascades of fits (Belle)
  - **$D \to K\pi\pi^0$, $D^* \to D\pi$, $B \to D^*\pi$** in three fits
- Fit the decay tree in one global fit **$[D^*[\to D[\to K\pi\pi^0]\pi]$**
- **New technique**
  - Aimed at channels with neutrals **$D^* \to D\pi^0$, $D^* \to D\gamma$, $D \to K\pi\pi^0$, …**
  - Allows to reject background
    - Better tag purity

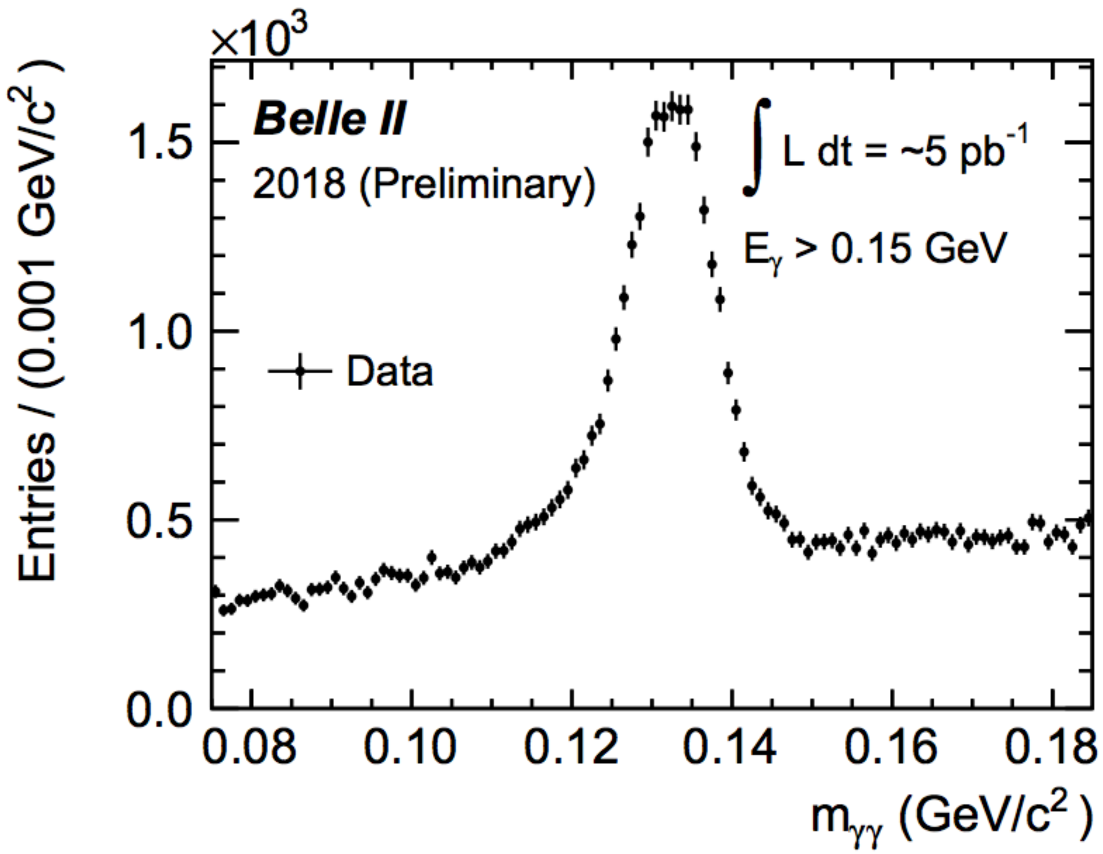




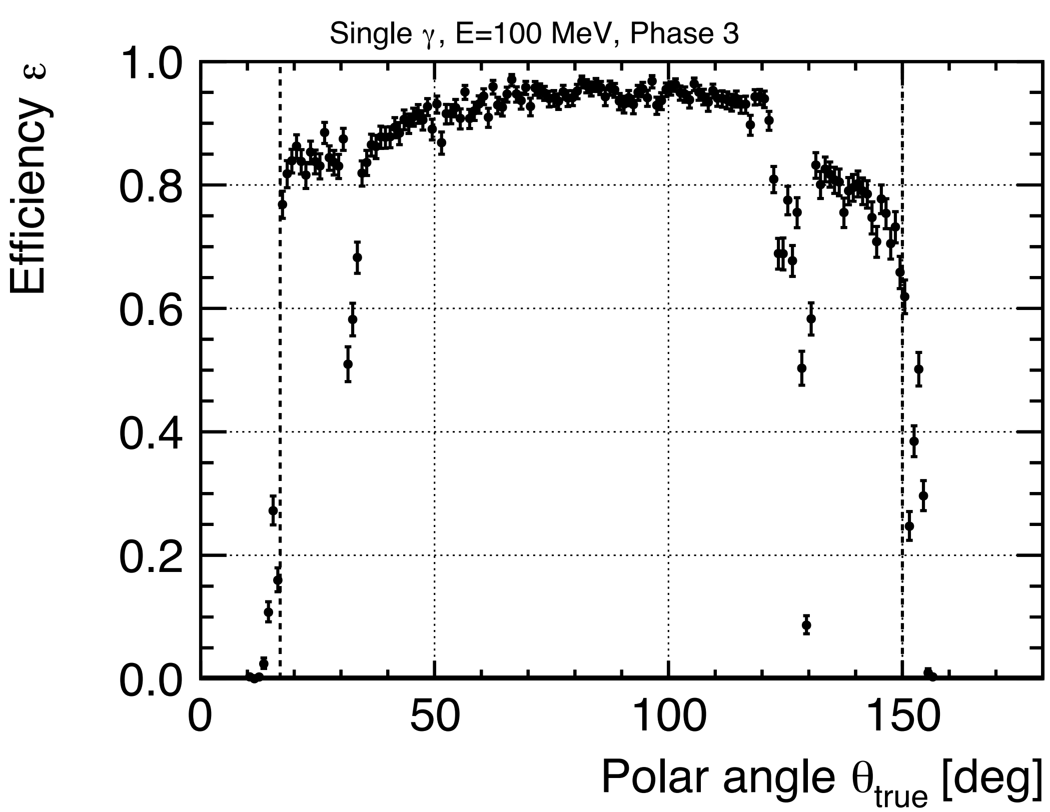
(Paper in review)

π^0 reconstruction



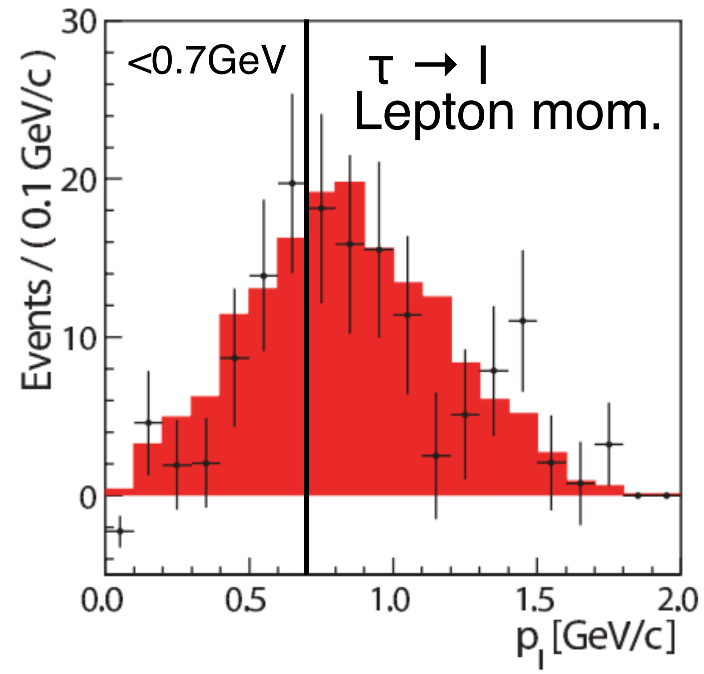


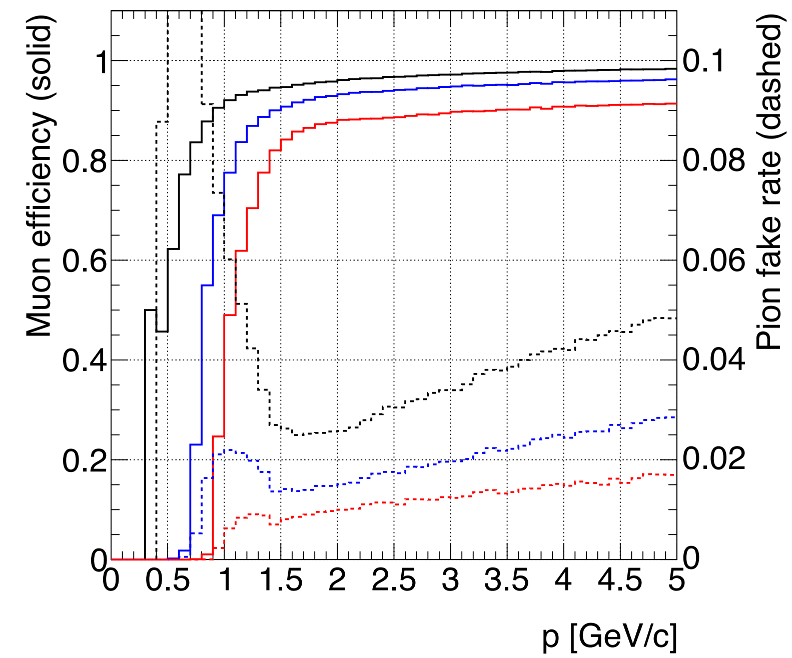
- Important for tagging and τ reconstruction
- π^0 invariant mass in early Belle II data
- **Expected resolution on photon energy of ~3-5%**



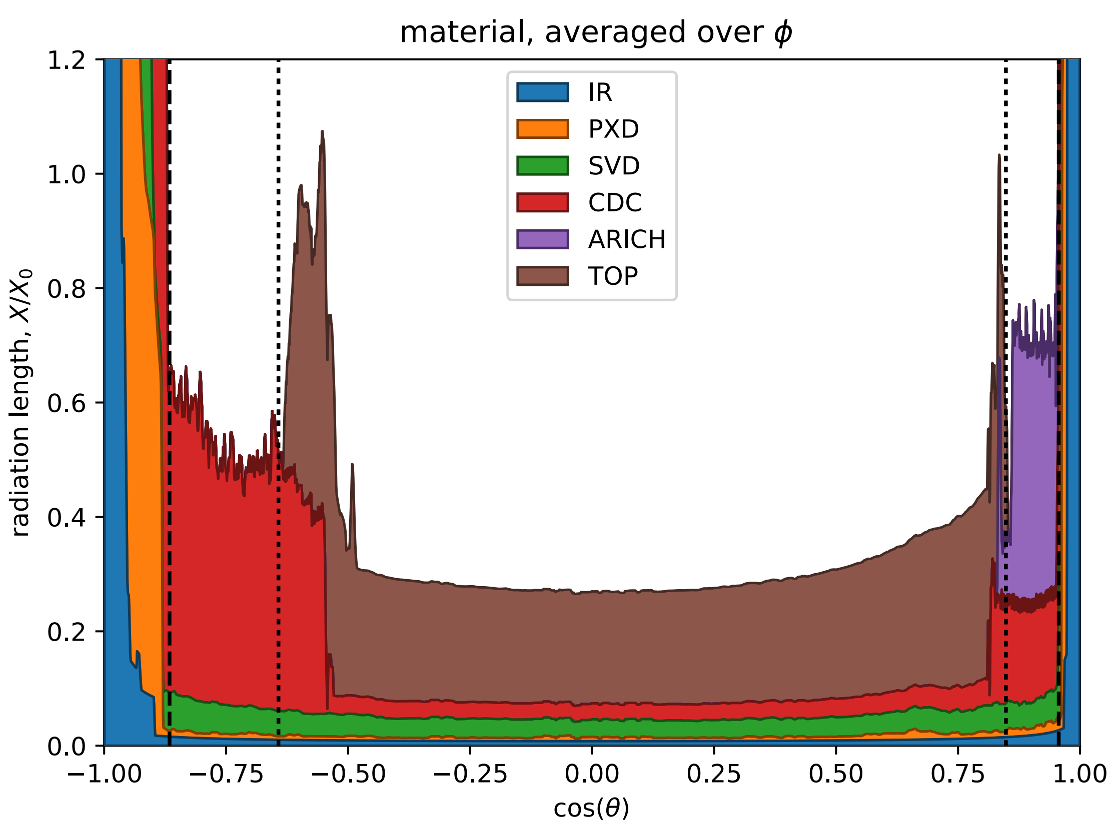
Muon identification and Electron identification

Belle, Phys. Rev. D 94,





- Electrons are light: **Final state radiation**
  - **Bremsstrahlung recovery** partially fixes this
- Belle II:
  → **MVA for low momentum in progress.**
- **Material budget in tracking value allows good electron identification**



- Muons are the easier to identify
  - Little to **no radiation** (heavy)
  - In B-factories, need p > 700 MeV/c to reach muon detectors
- ECL not used for μID at Belle → to be used in Belle II.

B → D(*) l ν

arXiv:1611.07387
arXiv:1801.01112
B2TIP

Exclusive **CLN parametrised!**

$$|V_{cb}|_{D^*\ell\nu} = (39.05 \pm 0.47_{\rm exp} \pm 0.58_{\rm th}) \times 10^{-3} \,,$$

$$|V_{cb}|_{D\ell\nu} = (39.18 \pm 0.94_{\rm exp} \pm 0.36_{\rm th}) \times 10^{-3} \,.$$

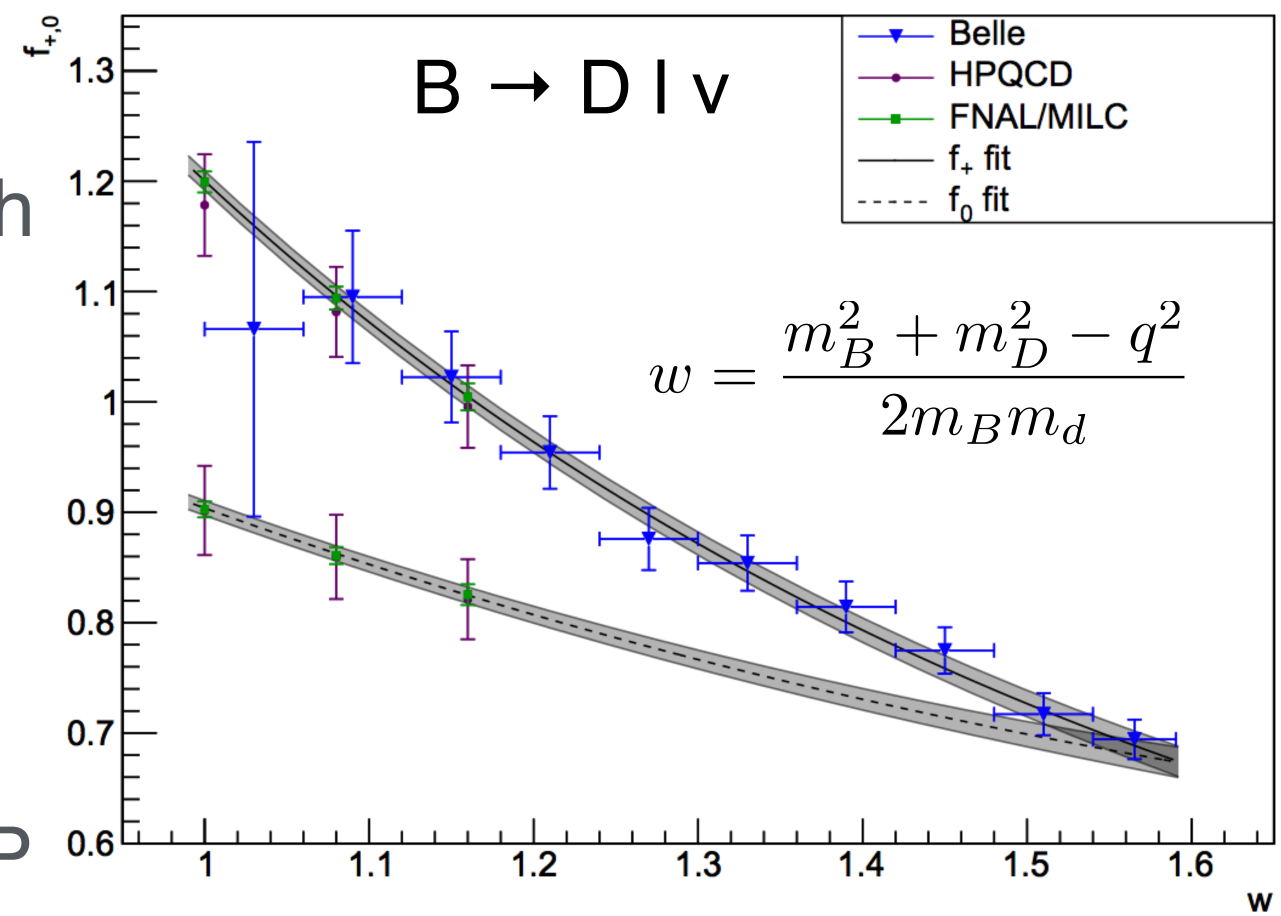
Inclusive **(~2.5 σ)**

$$|V_{cb}| = (42.11 \pm 0.74) \times 10^{-3}$$

ℓ	$\nu^{\rm sig}$	$\nu^{\rm sig}_{\rm MC}$	$\epsilon_{\rm reco}\epsilon_{\rm tag}$
$e+\mu$	2374 ± 53	2310.1	3.19×10^{-5}
e	1306 ± 40	1248.8	3.45×10^{-5}
μ	1066 ± 34	1061.3	2.93×10^{-5}

Belle arXiv:1702.01521

- → measure V_{cb}
- Example B → D l ν:
  - Hadronically tagged, calibrated with B→X l ν
  - Signal from un-binned maximum likelihood fit to M^2_{miss}
  - Yields extracted in 10 bins (4x10 for D*)
- W spectrum important to constrain NP form factors



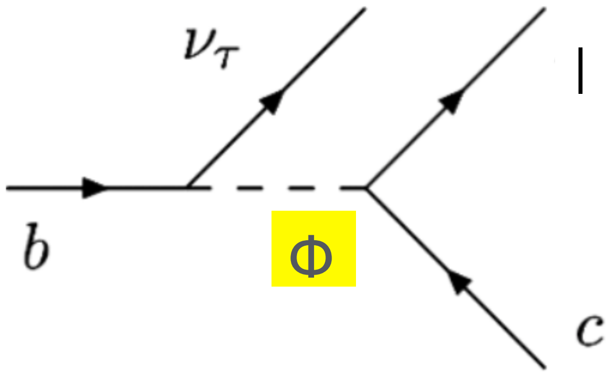
$$w = \frac{m_B^2 + m_D^2 - q^2}{2 m_B m_d}$$

Phys. Rev. D 94, 072007

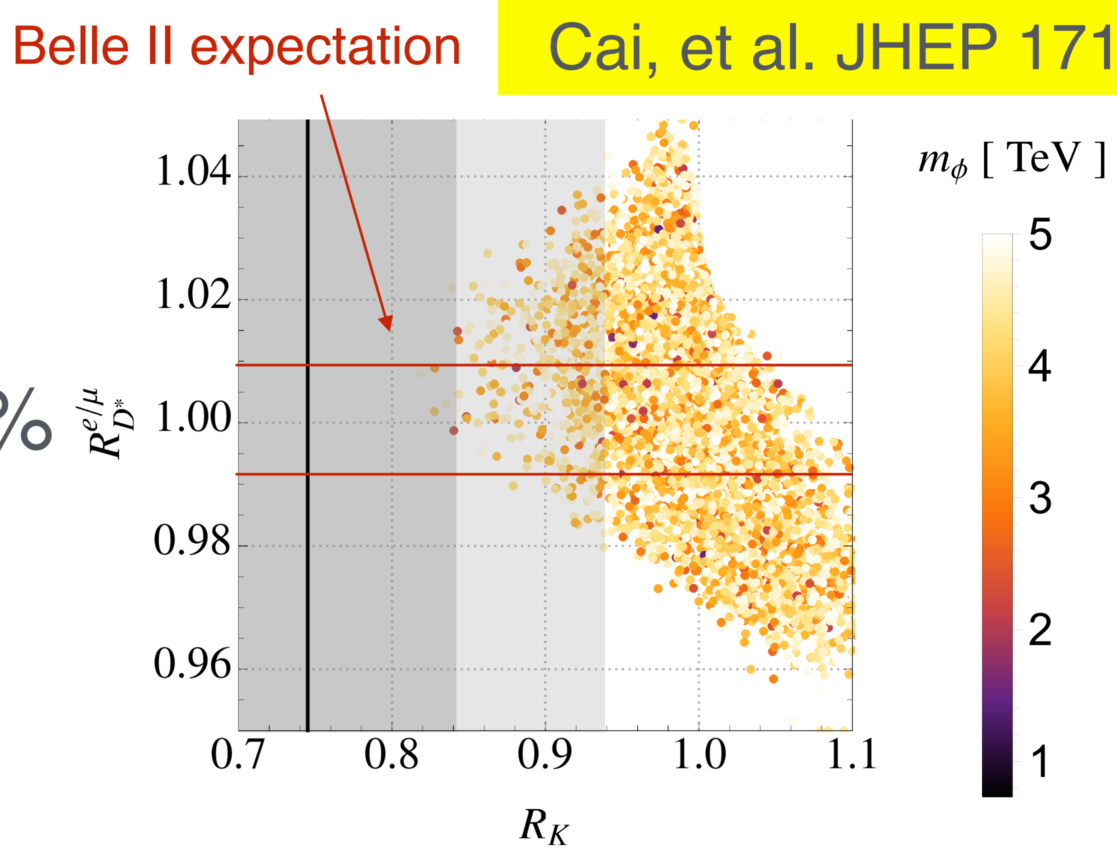
Belle II projections for B→ D(*) l ν

- Most errors cancel in LFUV measurement, except for eID, μID [data driven errors]
- B→ D* l ν ,
  - $|V_{cb}|$ Experiment Error : 3% → 1%
  - **$R_{e/\mu}$: 5% approx. → ~1%**
  - lepton ID, slow π
- B→ D l ν ,
  - $|V_{cb}|$ Experiment Error 3% → 1%
  - **$R_{e/\mu}$: (6% approx.) → ~1%**
  - hadronic tag purity

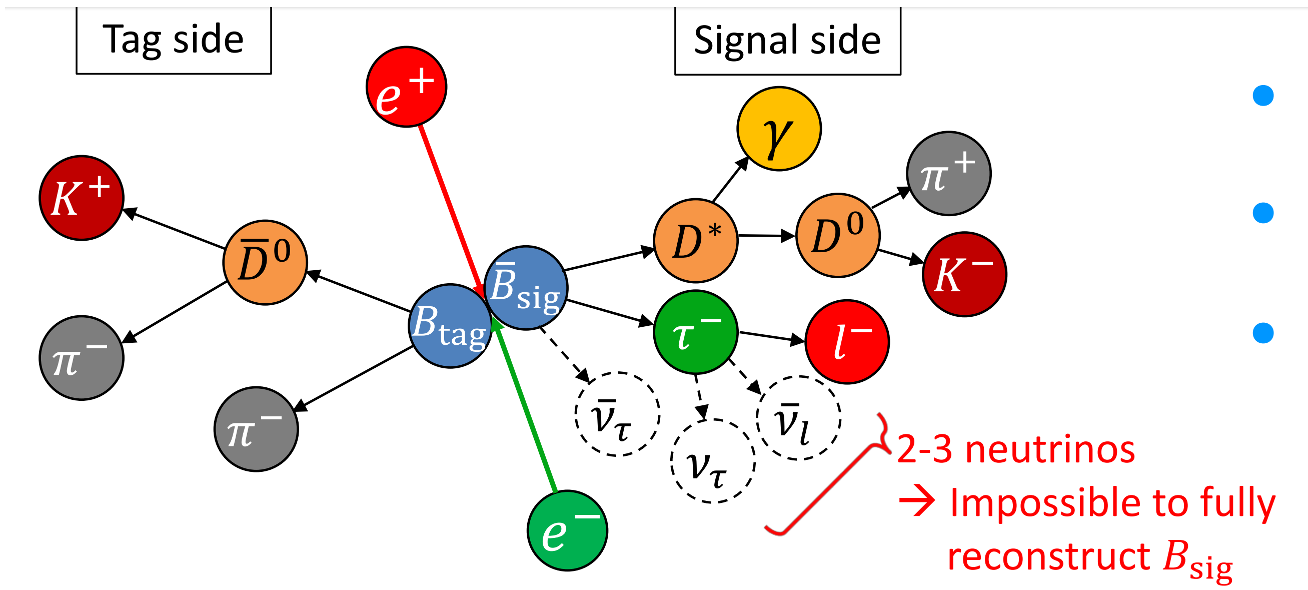
$$\mathcal{R}_{e/u} = \frac{\mathcal{B}(B^0 \to D^{*+} e^- \nu_e)}{\mathcal{B}(B^0 \to D^{*+} \mu^- \nu_\mu)}$$



Cai, et al. JHEP 1710



B→ D(*) τ ν signal



- Identification / reconstruction of τ leptons is very challenging
  - **Short lifetime** of 10^{-12} s
  - Hadronic decay with **π's and 1 ν**
  - Leptonic decay with **e/μ and 2 ν**
  - Lack of full reconstruction implies **background mimics the the signal where some daughters are lost e.g. K_L, π^0**. Often difficult to constrain with "sideband" data.
  - New MVA based **K_L** identification

	R_D	R_{D^*}
BaBar (Had, ℓ^-)	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.018$
Belle (Had, ℓ^-)	$0.375 \pm 0.064 \pm 0.026$	$0.293 \pm 0.038 \pm 0.015$
Belle (SL, ℓ^-)	NA	$0.302 \pm 0.030 \pm 0.011$
LHCb	NA	$0.336 \pm 0.027 \pm 0.030$
Belle (Had, h^-)	NA	$0.270 \pm 0.035^{+0.028}_{-0.025}$
Average	$0.397 \pm 0.040 \pm 0.028$	$0.310 \pm 0.015 \pm 0.008$

$$\mathcal{R}(D^*) = \frac{\mathcal{B}(\bar{B} \to D^*\tau^-\bar{\nu}_\tau^-)}{\mathcal{B}(\bar{B} \to D^*l^-\bar{\nu}_l^-)}$$

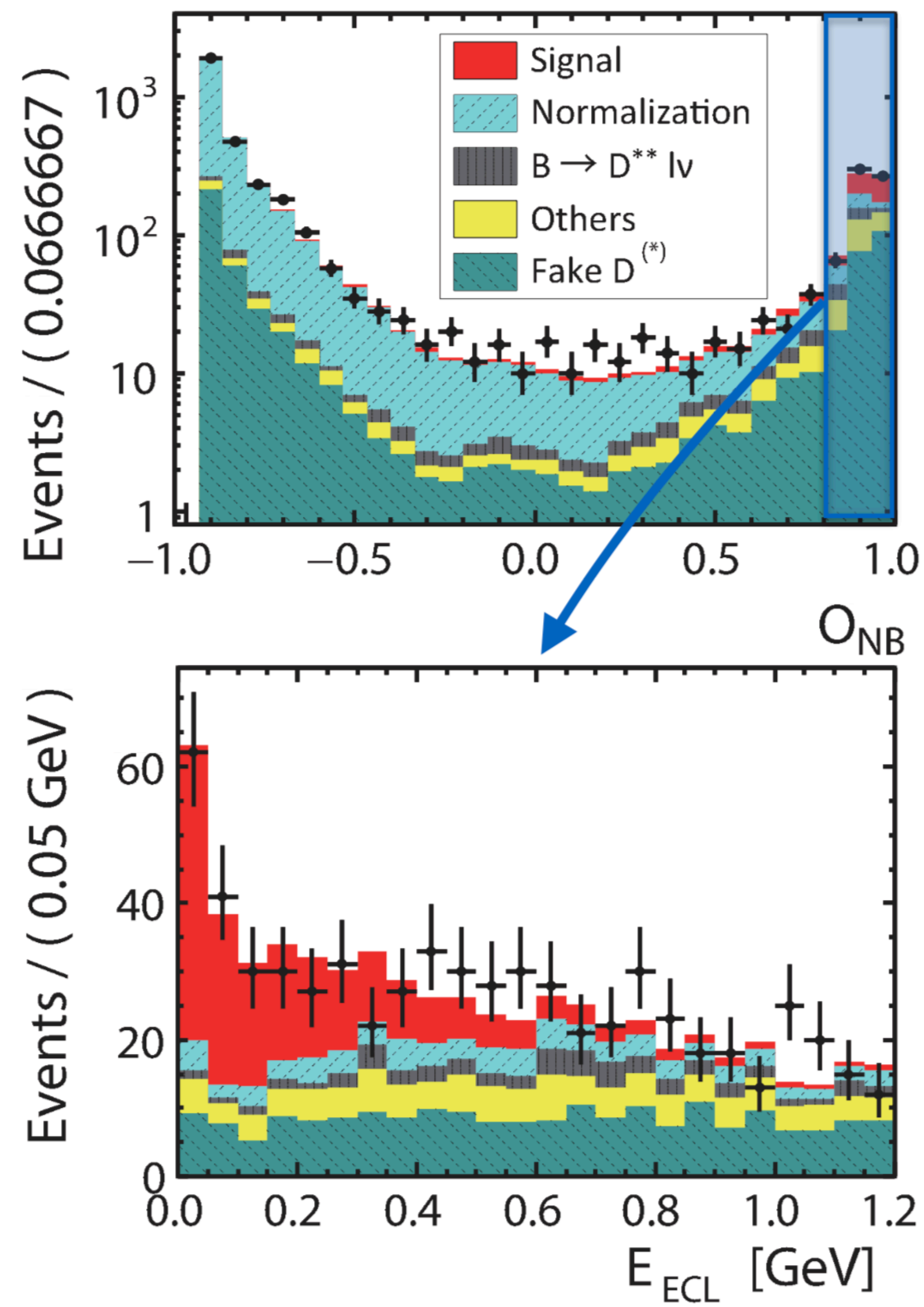
Phys.Rev.Lett. 109.101802
Phys.Rev.D 88. 072012
Phys.Rev.D 92. 072014
Phys.Rev. D94.072007

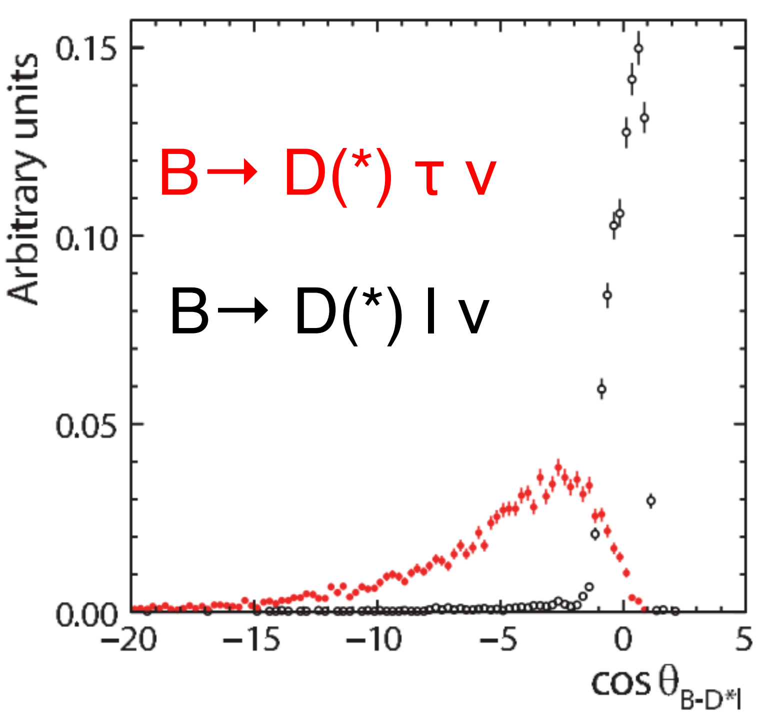
B→ D(*) τ ν (R(*)$_\tau$)

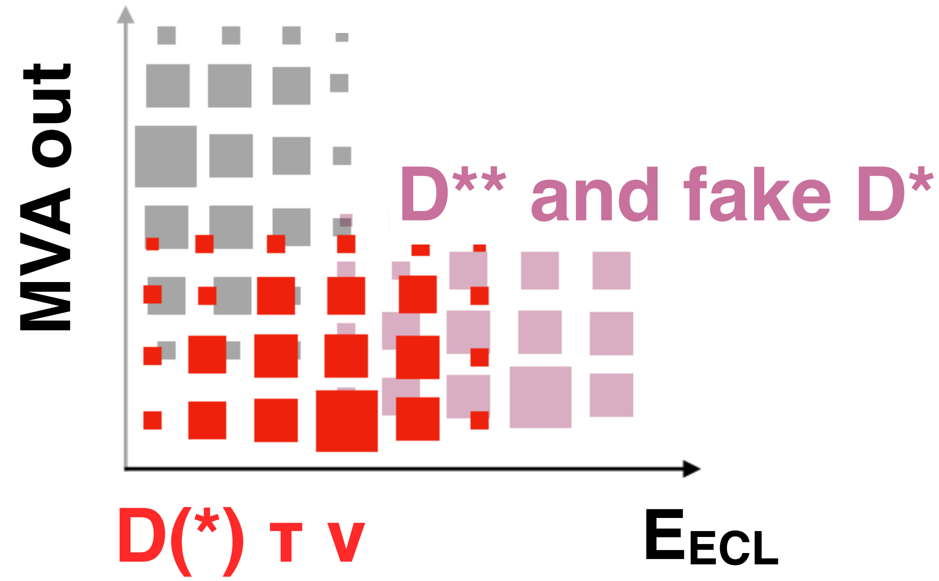
Belle, Phys. Rev. D 94, 072007 (2016)

- Semileptonic tag
- Discriminate B→ D(*) τ ν and B→ D(*) l ν using MVA, based on M^2_{miss} cosθ_B, $E_{Btag}+E_{Bsig}$
- Yield extracted using a 2d fit of the classifier output and E_{ECL}

$$\mathcal{R}(D^*) = \frac{\mathcal{B}(\bar{B} \to D^* \tau^- \bar{\nu}_\tau^-)}{\mathcal{B}(\bar{B} \to D^* l^- \bar{\nu}_l^-)}$$

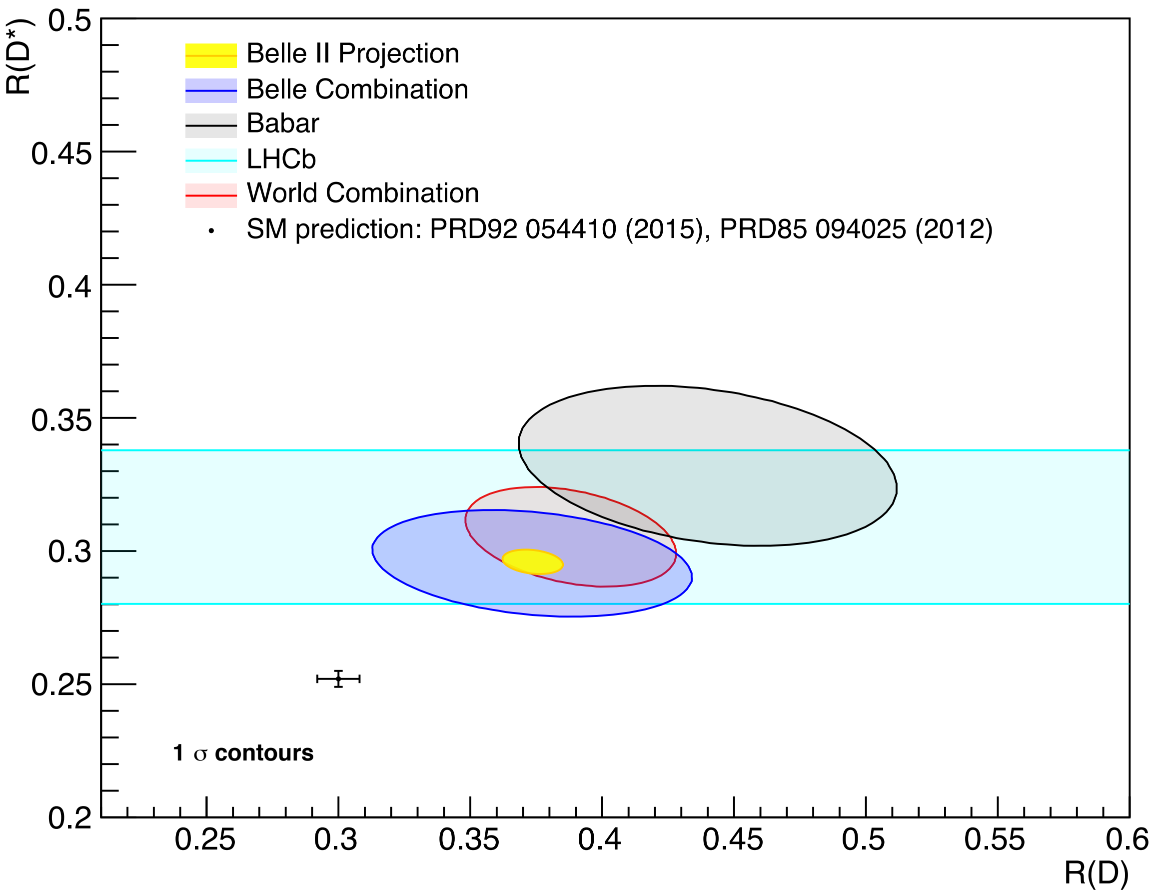






Belle II projections B→ D(*) τ ν

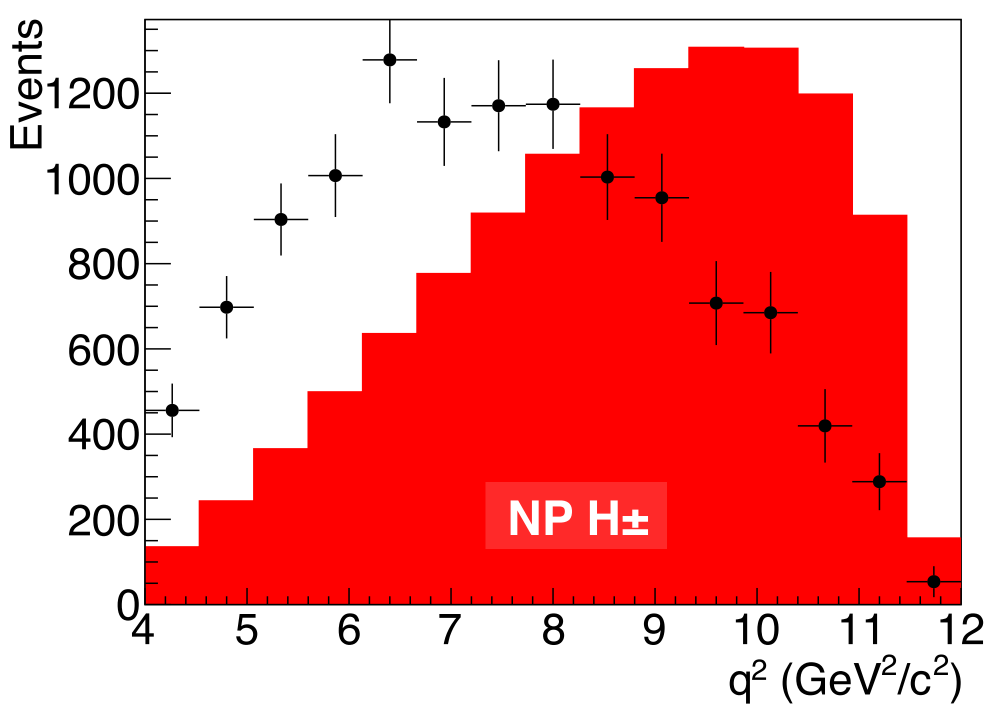
LHCb arXiv:1711.02505
LHCb arXiv:1711.05623
Belle PRD 94, 072007 (2016)
Belle PRL 118, 211801 (2017)



Stat error improvement from tagging

	ΔR(D) [%]			ΔR(D*) [%]		
	Stat	Sys	Total	Stat	Sys	Total
Belle 0.7	14	6	16	6	3	7
Belle II 5	5	3	6	2	2	3
Belle II 50 ab^{-1}	2	3	3	1	2	2

D**



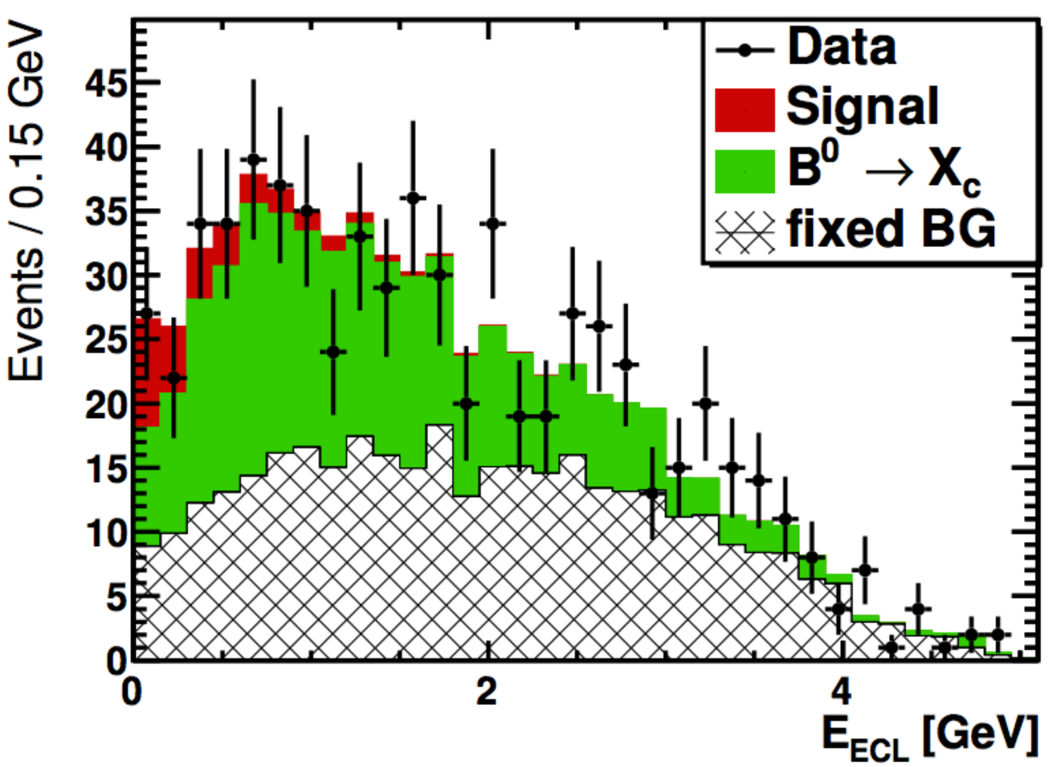
50 ab-1 projection of the subtracted q^2 spectrum in B → D* τ ν

- Full sim sensitivity studies in progress.
- Projections based on Belle + assumed $R(D)_{SL}$ precision
- Background modelling (D**) will dominate error @ 50 ab^{-1}.
- Precise analysis of kinematics

$B \to \pi \tau \nu$ and $B \to \pi l \nu$

Belle Phys.Rev. D88, 032005
Belle Phys. Rev. D 93, 032007
B2Tip

- $B \to \pi \tau \nu$ at Belle (no R_π @Belle)
- $\tau \to l \nu \nu$, $\tau \to \pi \nu$, $\tau \to \pi \nu$
- Measured using M^2_{miss} and signal BDT (reject $B \to \pi l \nu$)
- Yield extracted in E_{ECL} ($\to$upper limit)



$$\mathcal{B}\left(B^0 \to \pi^- \tau^+ \nu_\tau\right) < 2.5 \times 10^{-4}$$

- **Belle II:**
  - $|V_{ub}|$ should be measured to ~1-2% accuracy with $B \to \pi l \nu$ (based on Belle II full sim.)
  - Can do LFUV tests, $e/\mu/\tau$

Belle II projection

$$R_\pi^{5\,\mathrm{ab}^{-1}} = 0.64 \pm 0.23\,,$$
$$R_\pi^{50\,\mathrm{ab}^{-1}} = 0.64 \pm 0.09\,.$$

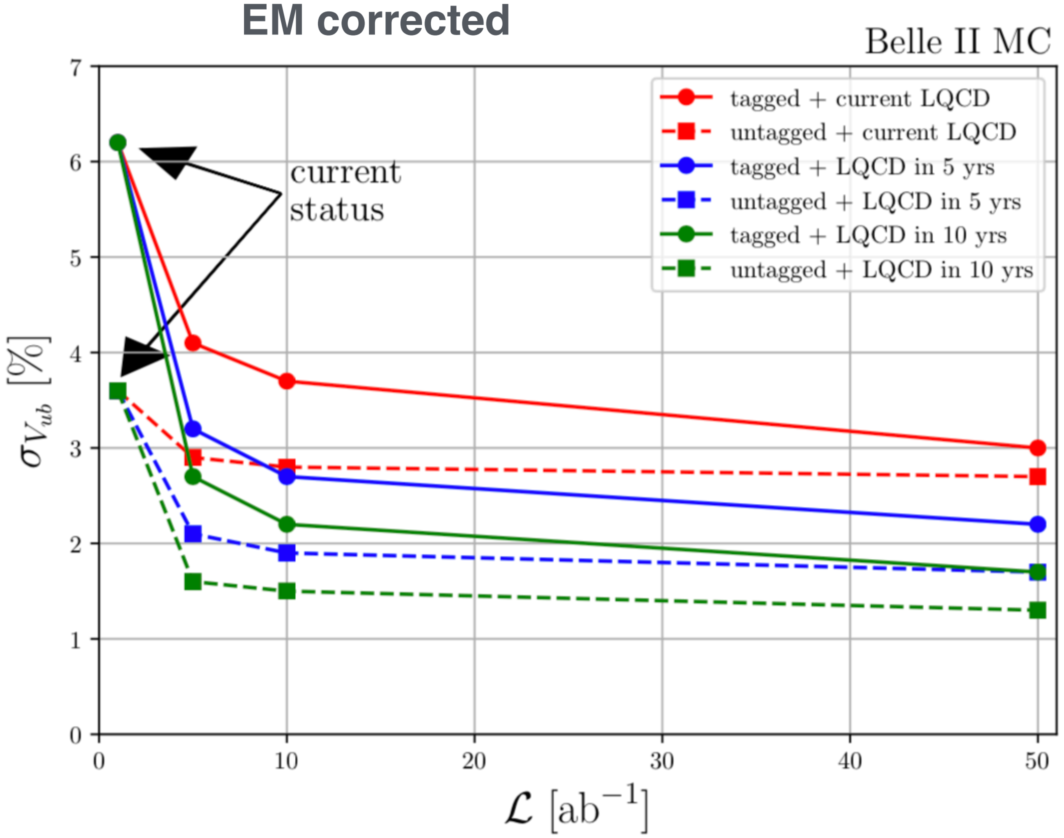
L [ab^{-1}]	$\pi l \nu$	σV_{ub} [%]
1	tagged	6.2
	untagged	3.6
5	**tagged**	**3.2**
	untagged	**2.1**
	leptonic	**5**
50	tagged	1.7
	untagged	1.3
	leptonic	1.5 - 2

Projections for CKM

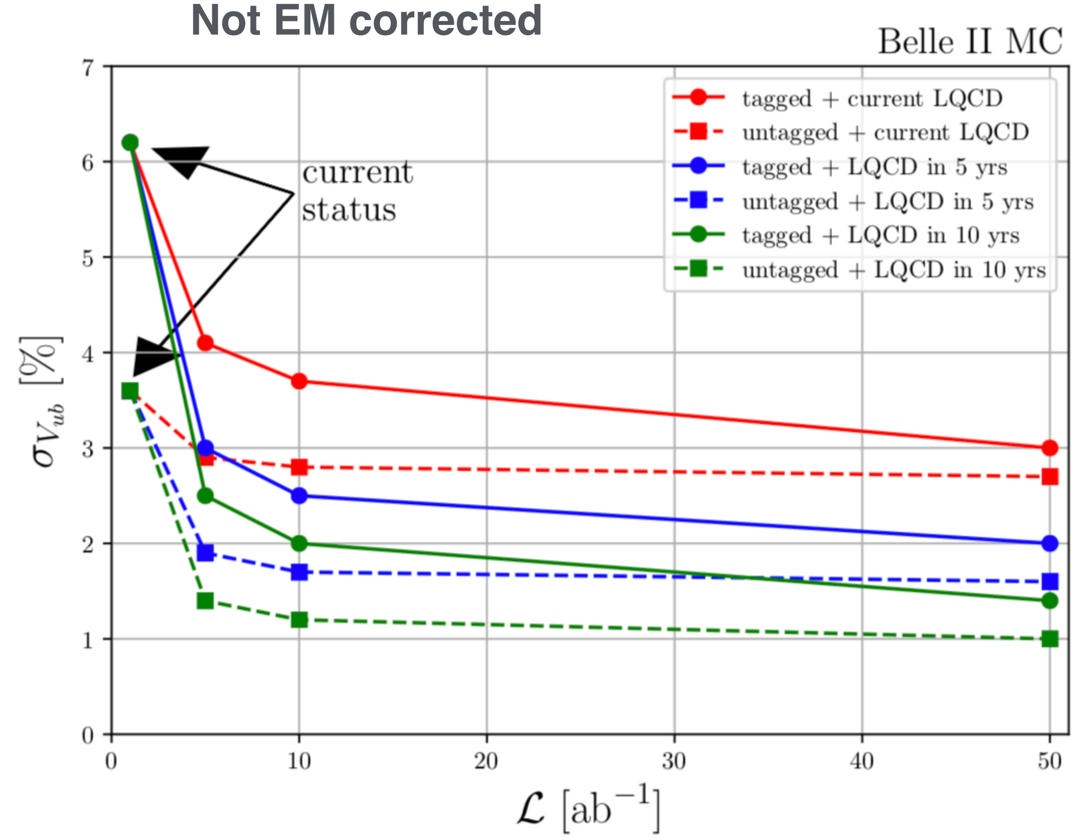
B2Tip

V_{ub} from $B \to \pi l \nu$

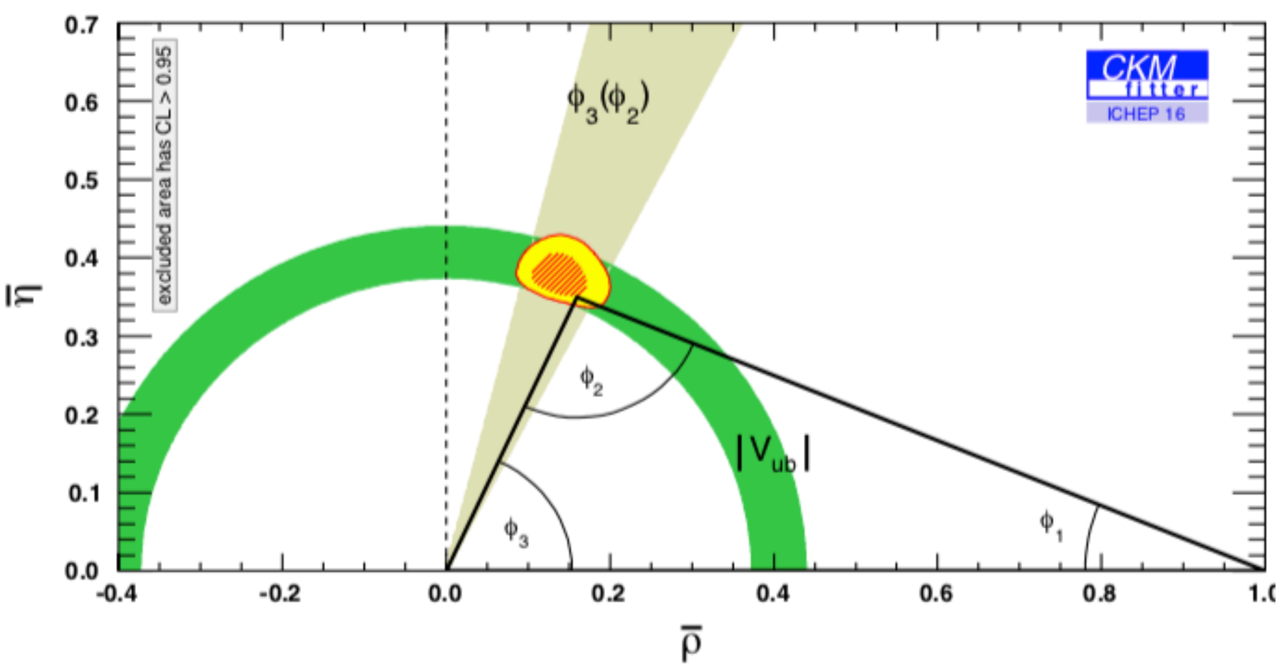
EM corrected



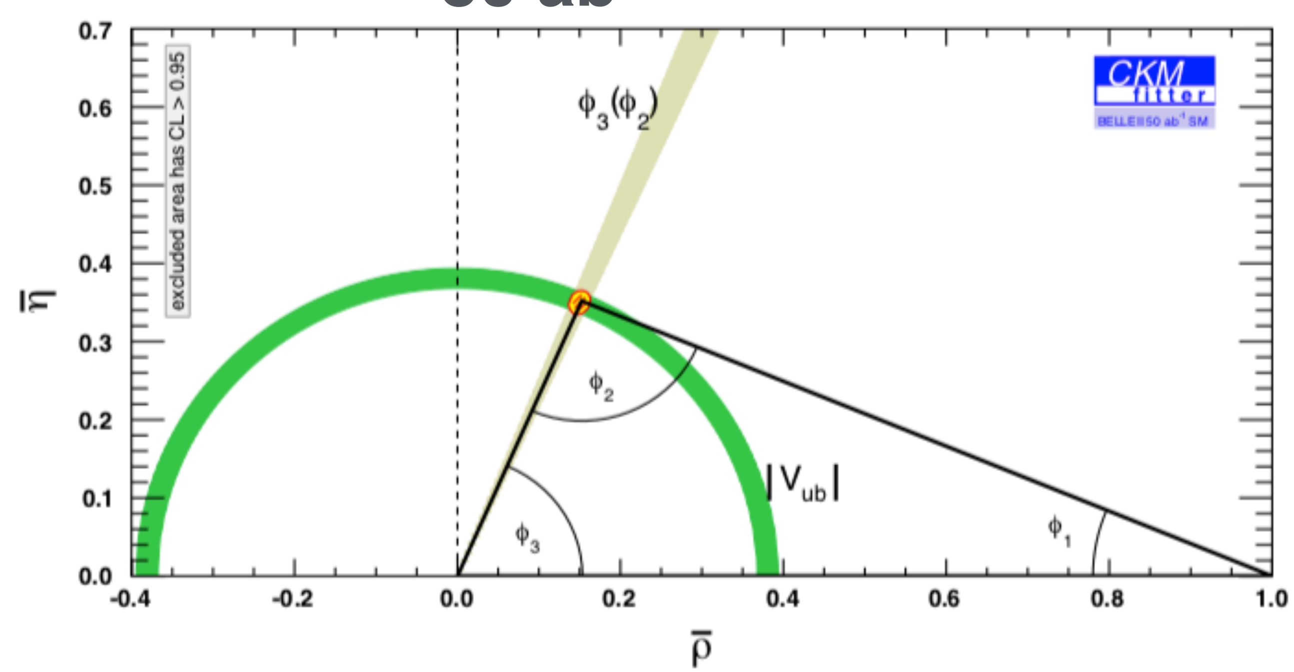
Not EM corrected



Current situation

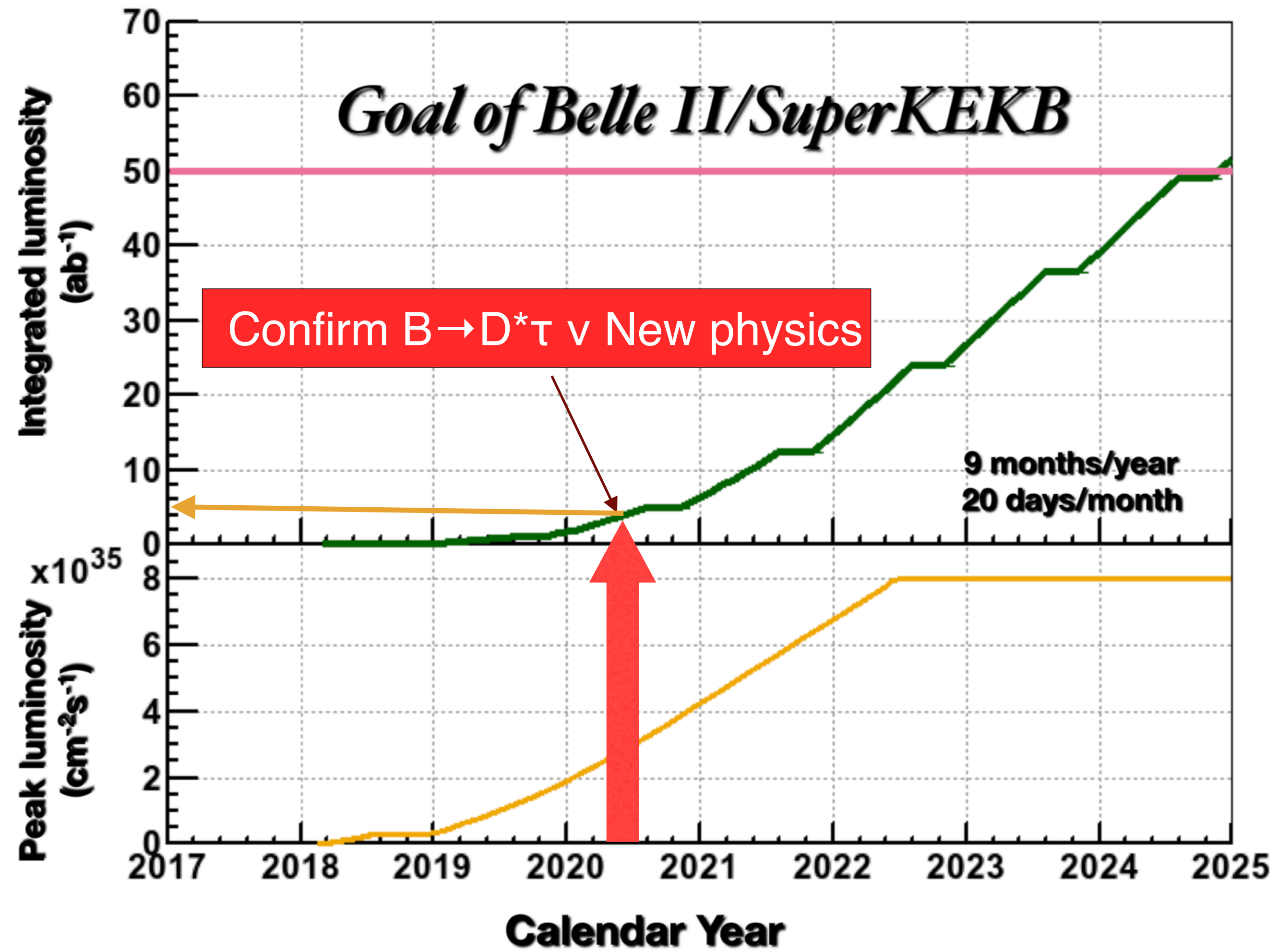


50 ab^{-1}



Summary

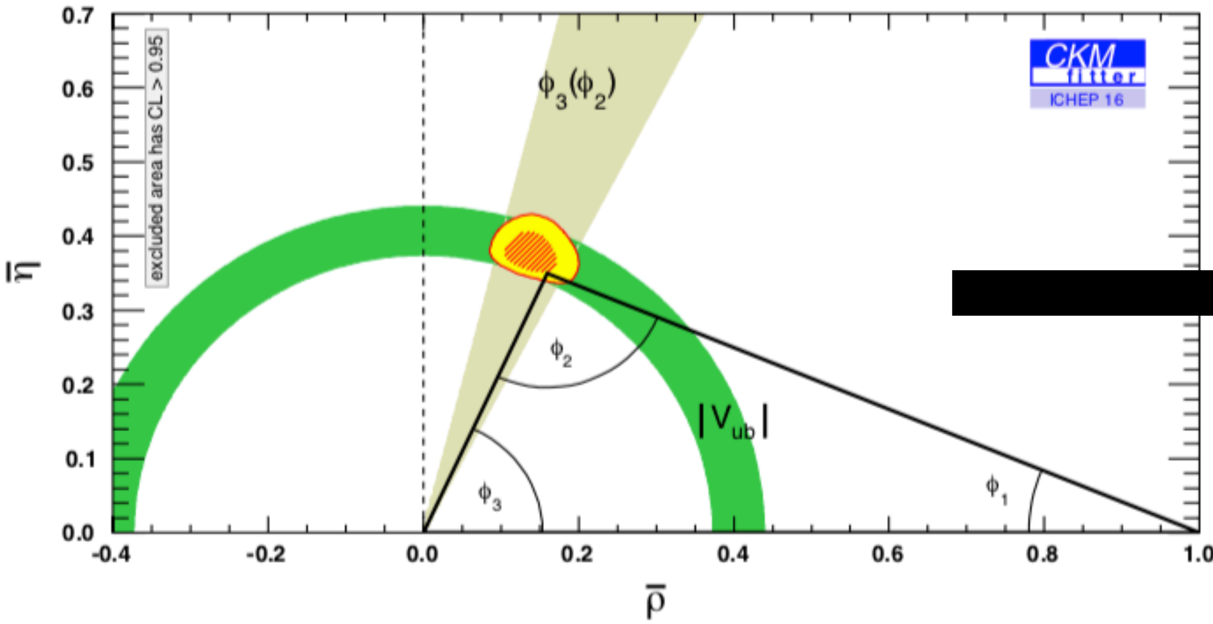
- Belle II will collect 5(50) ab^{-1} data by 2020(2025)
- With about 5 ab^{-1} (mid 2020) we will be able to confirm new physics in $B \rightarrow D^{(*)} \tau \nu$ and other characteristics (τ-polarisation)
- Precise, model independent measurements of CKM matrix elements V_{cb} and V_{ub} in **4d** bins
- Probe LFUV

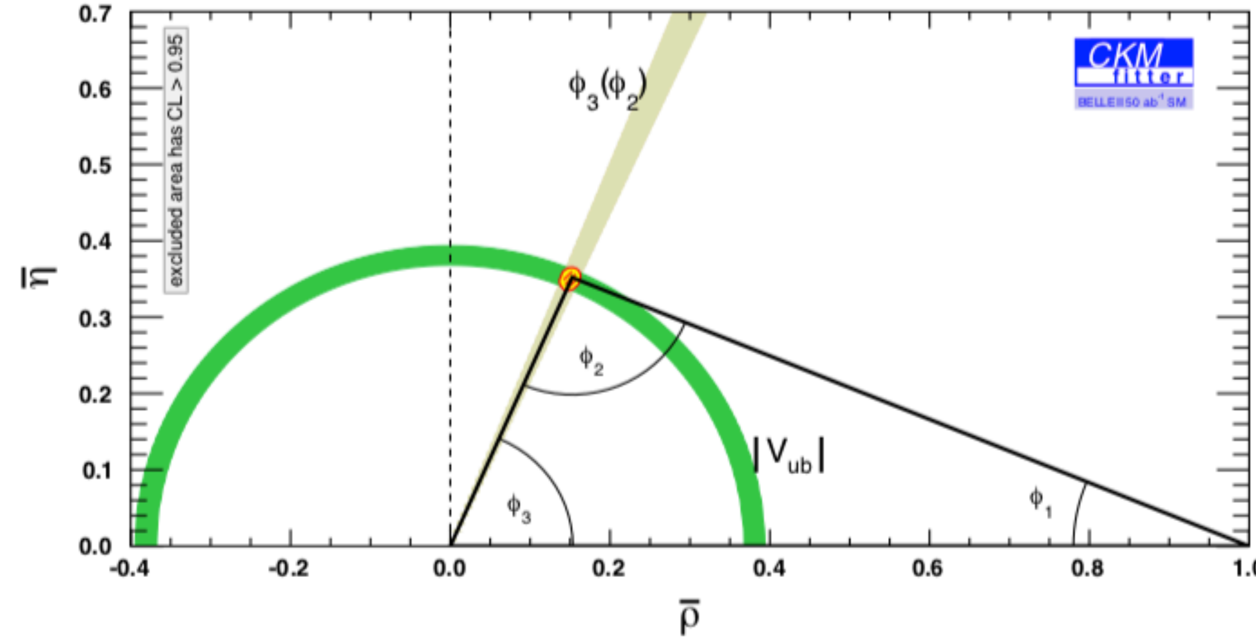


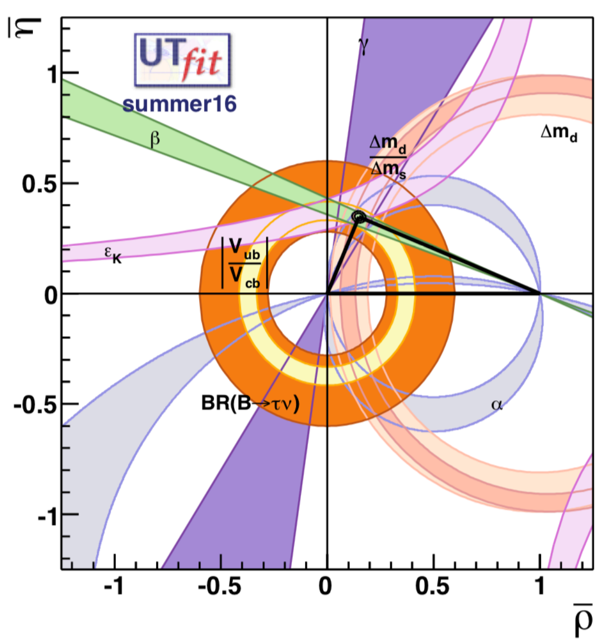
END

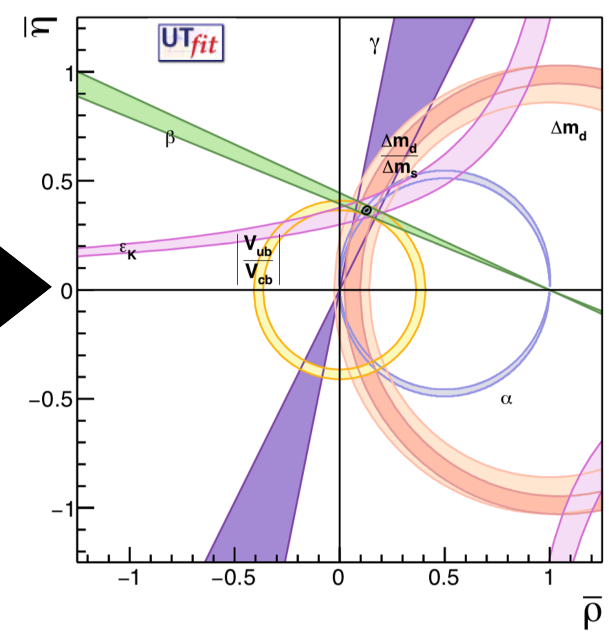
Thank you

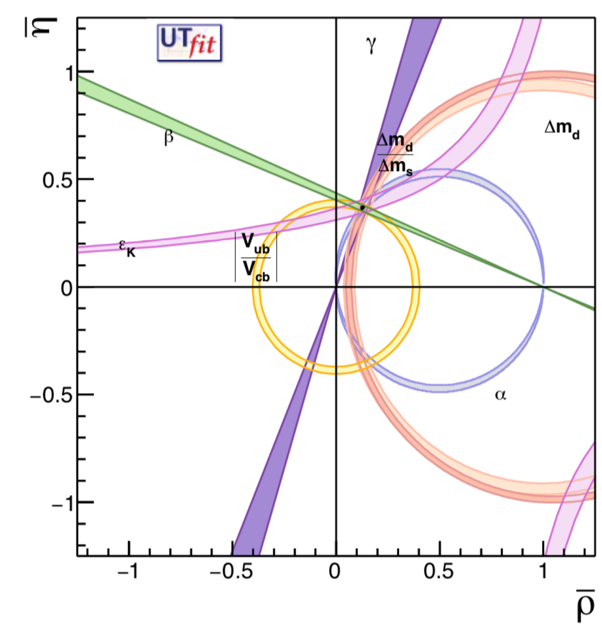
Projections for CKM











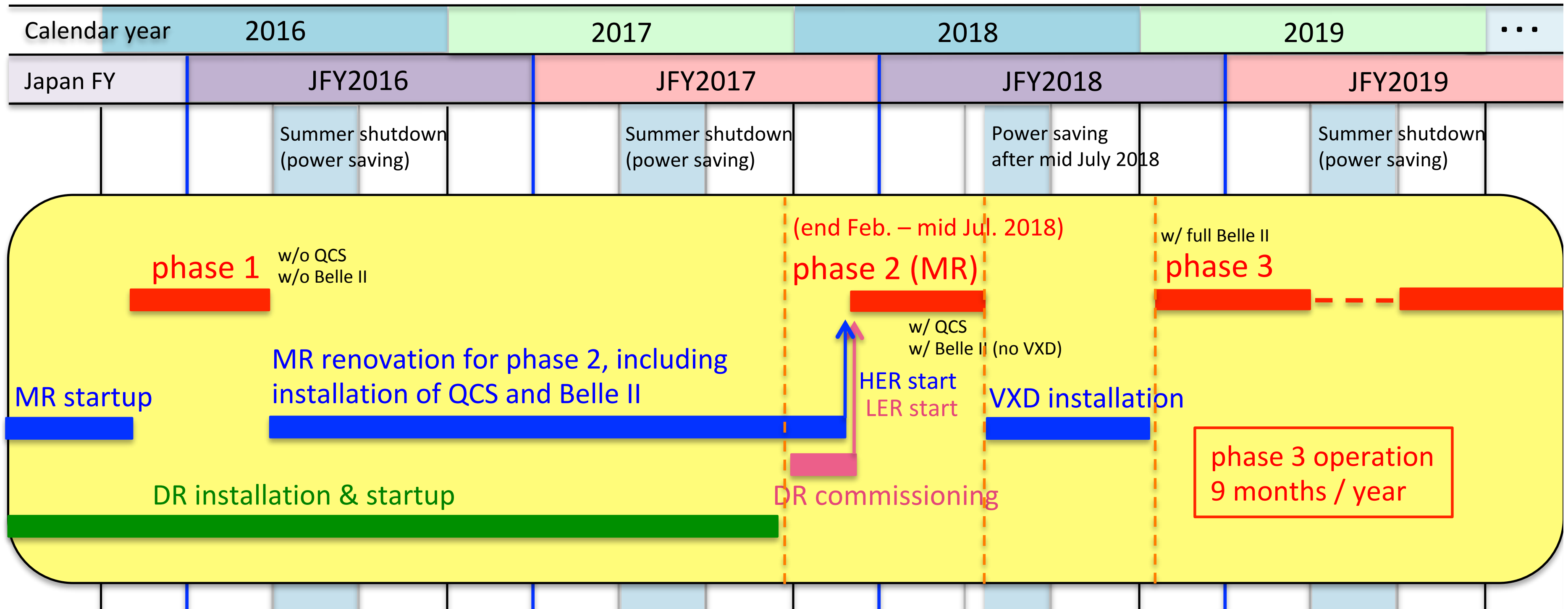
Overview Belle

- $B \to D(*)\ l\ \nu$
  - $|V_{cb}|$
  - **$R(*)_{e/\mu}$**

Not precisely studied at Belle

- $B \to D(*)\ \tau\ \nu$
  - $R(*)_{\tau/l}$,anomaly Δ~30%(~4σ)
  - q^2, **kinematics**
- $B \to X_c\ l\ \nu$
  - V_{cb} anomaly, inclusive vs exclusive Δ~5-6% (~2.5 σ)
- $B \to \pi\ l\ \nu$

Belle II General Status and Timeline



- Phase 2 (w/final focusing Q, w/Belle II, w/ partial Si configuration & background monitors)
- Verification of nano-beam scheme
  - Target L > 10^{34} cm-2s-1
- Understand beam background and its luminosity scaling - particularly in VXD volume.

Beam background (MC

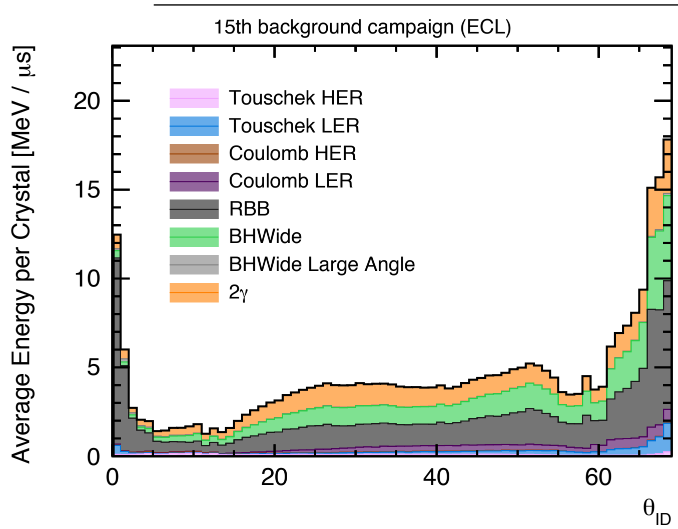
- Increases occupancy in inner Si layers - can degrade tracking.

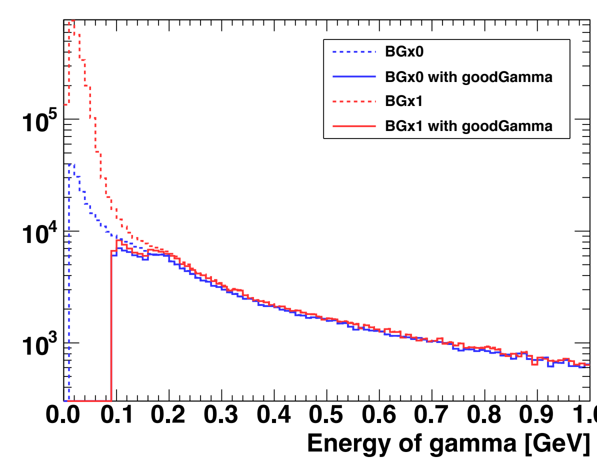
Processes

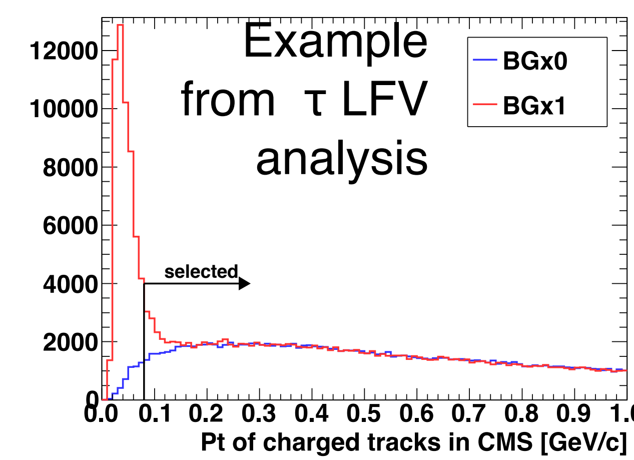
type	source	rate [MHz]
radiative Bhabha	HER	1320
radiative Bhabha	LER	1294
radiative Bhabha (wide angle)	HER	40
radiative Bhabha (wide angle)	LER	85
Touschek scattering	HER	31
Touschek scattering	LER	83
beam-gas interactions	HER	1
beam-gas interactions	LER	156
two-photon QED	-	206

Occupancy

component	background	generic $B\overline{B}$
PXD	10000 (580)	23
SVD	284 (134)	108
CDC	654	810
TOP	150	205
ARICH	191	188
ECL	3470	510
BKLM	484	33
EKLM	142	34

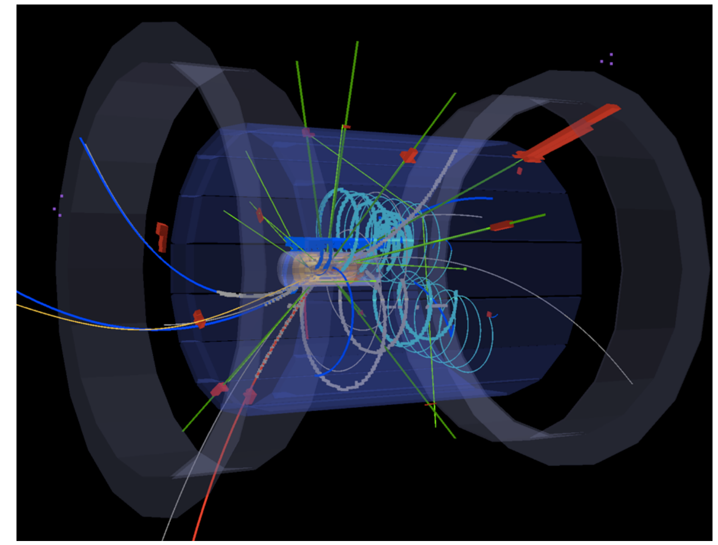


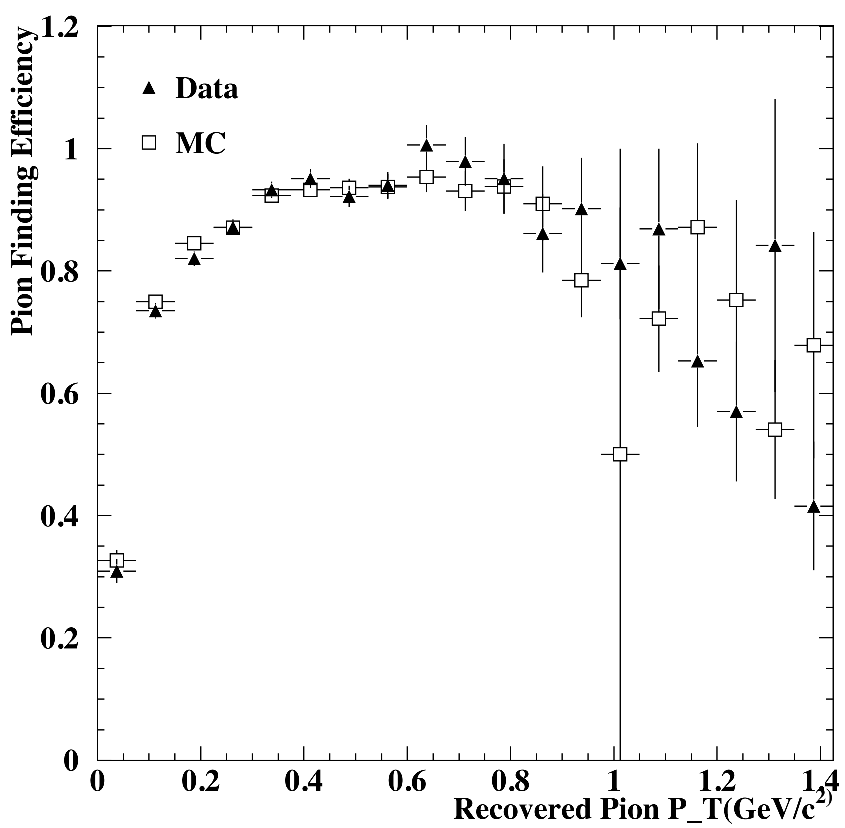


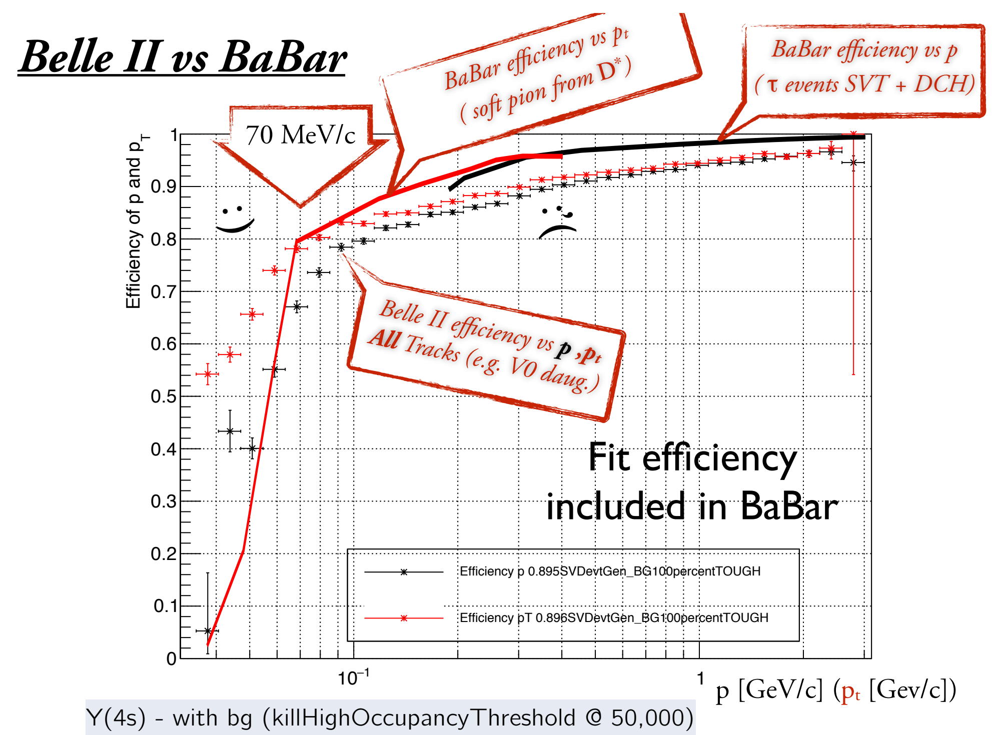


Track efficiencies

- VXD (Pixel + Strip) & CDC
- VXD-dedicated tracking







- 2017, Hadron tag, τ → h ν

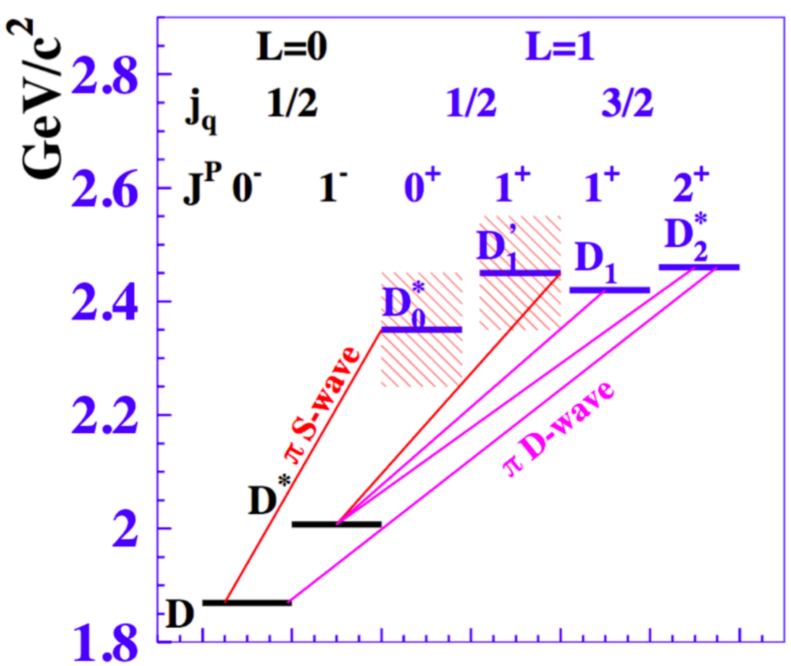
Source	Combined $R(D^*)$	Combined P_τ
$D^{**}l^-\bar{\nu}_l$ + had. B composition	5.2%	0.17
MC stat. for PDF construction	3.5%	0.16
Fake D^* yield	2.0%	0.048
Semileptonic decay model	1.9%	0.015
Efficiency corr. for $l^-/\pi^-/\rho^-$	1.8%	0.013
P_τ correction function	0.33%	0.012
Efficiency uncertainty (MC stat.)	0.78%	0.008
$\bar{B} \to D^*l^-\bar{\nu}_l$ yield	0.65%	0.027
M^2_{miss} shape for $\bar{B} \to D^*l^-\bar{\nu}_l$	0.41%	0.001
Fake D^* PDF shape	0.22%	0.001
Total	7.1%	0.24
Expected stat. error	$\sim$ 14%	$\sim$ 0.56

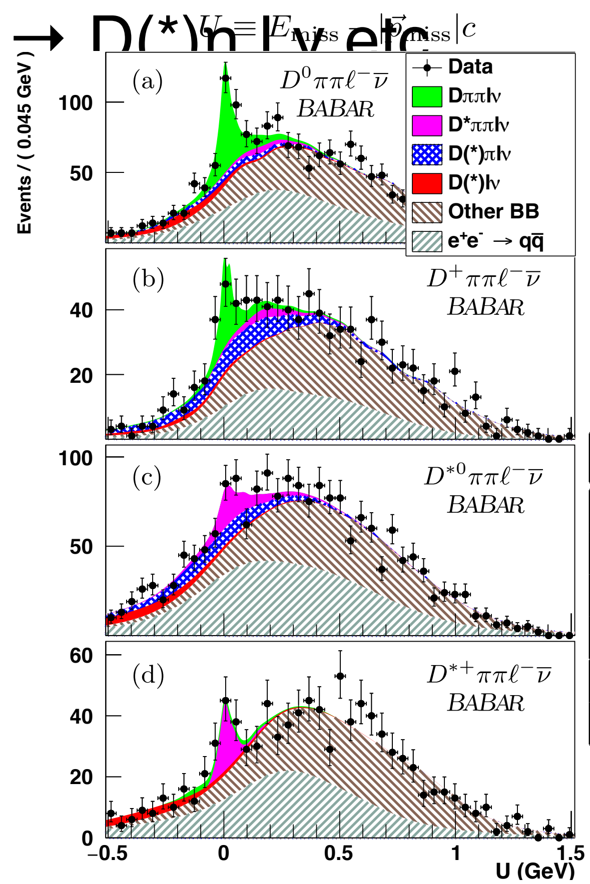
Source	Combined $R(D^*)$	Combined P_τ
$B \to D^{**}l^-\bar{\nu}_l$	0.17%	0.011
$\bar{B} \to D^{**}l^-\bar{\nu}_l$ (100% error)	0.84%	0.054
$\bar{B} \to D^{**}\tau^-\bar{\nu}_l$ (100% error)	2.7%	0.016
Two D	0.77%	0.020
$\bar{B} \to D^*K^-/\pi^-K^0_L$	0.25%	0.014
Other K^0_L mode (100% error)	0.28%	0.021
Other B decays	1.4%	0.058
Other B decays (100% error)	4.1%	0.14
Total	5.2%	0.17

B → D** l ν

Babar PRL 116, 041801 (2016)

- 3 problems to cover in Belle II
  - Modelling of B →D** l ν kinematics
  - Normalisation
    - Unmeasured D** → modes, for saturation of B → X l ν
    - B → D(*)nπ l ν + B → D(*)η l ν etc.



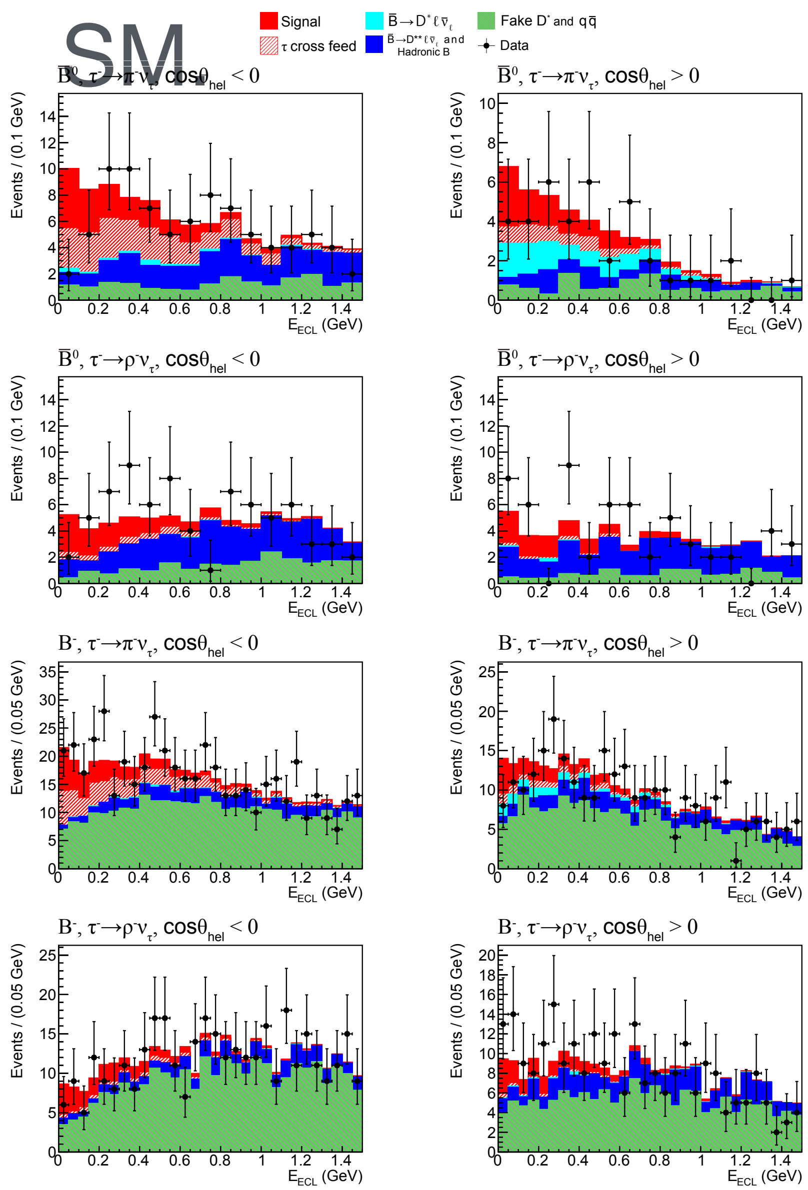


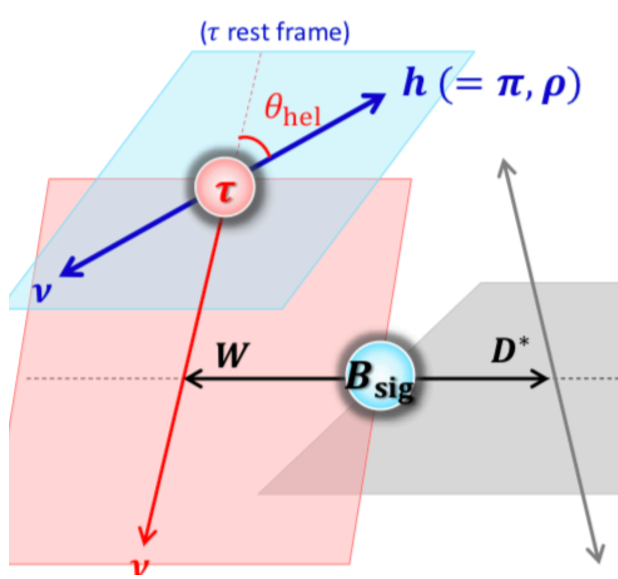
Channel	$R^{(*)}_{\pi^+\pi^-} \times 10^3$	$\mathcal{B} \times 10^5$
$D^0\pi^+\pi^-\ell^-\overline{\nu}$	$71 \pm 13 \pm 8$	$161 \pm 30 \pm 18 \pm 8$
$D^+\pi^+\pi^-\ell^-\overline{\nu}$	$58 \pm 18 \pm 12$	$127 \pm 39 \pm 26 \pm 7$
$D^{*0}\pi^+\pi^-\ell^-\overline{\nu}$	$14 \pm 7 \pm 4$	$80 \pm 40 \pm 23 \pm 3$
$D^{*+}\pi^+\pi^-\ell^-\overline{\nu}$	$28 \pm 8 \pm 6$	$138 \pm 39 \pm 30 \pm 3$
$D\pi^+\pi^-\ell^-\overline{\nu}$	$67 \pm 10 \pm 8$	$152 \pm 23 \pm 18 \pm 7$
$D^*\pi^+\pi^-\ell^-\overline{\nu}$	$19 \pm 5 \pm 4$	$108 \pm 28 \pm 23 \pm 4$

B-> D* τ ν: τ Polarisation with τ → π ν, had

Belle PRL 118,

- First measurement, consistent with SM





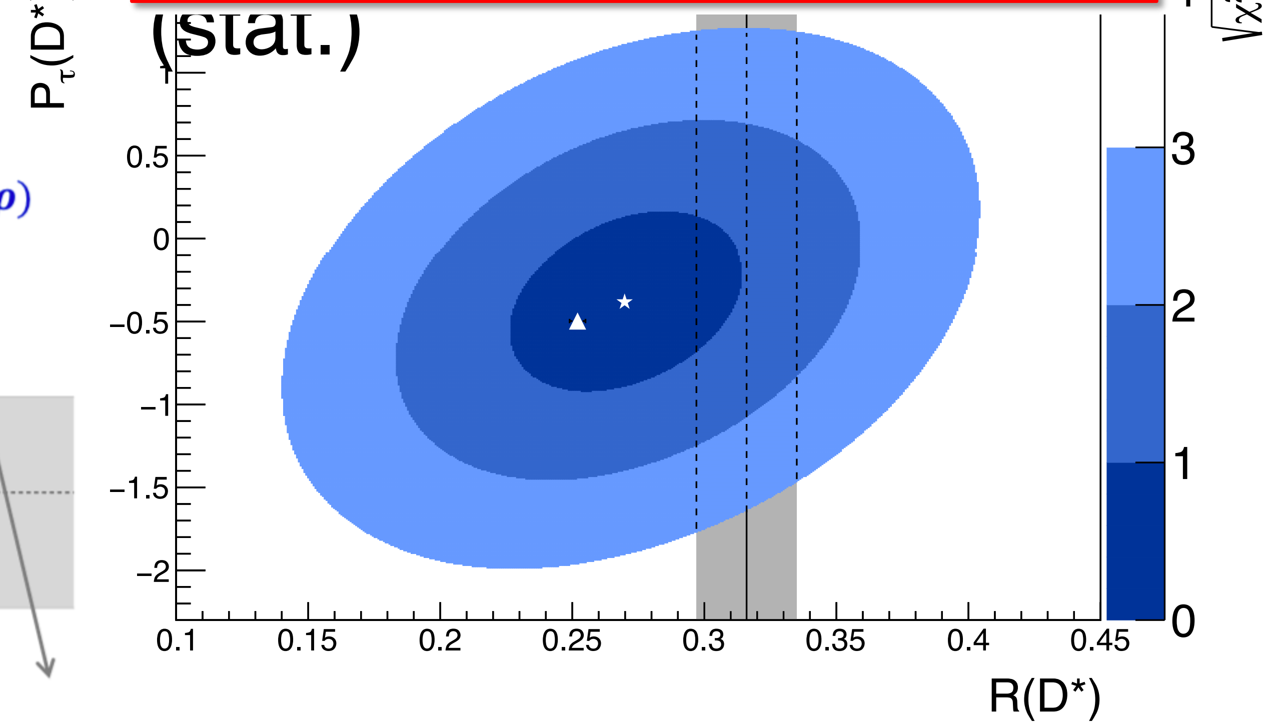
- B± → D* τ+ ν : 210±27(stat)

  B± → D* l+ ν: 4711 ±57(stat.)

- B0 → D* τ+ ν : 88±11(stat) events

  (stat.)

$$R(D^*) = 0.270 \pm 0.035(\text{stat.})\ ^{+0.028}_{-0.025}(\text{syst.})$$
$$P_\tau(D^*) = -0.38 \pm 0.51(\text{stat.})\ ^{+0.21}_{-0.16}(\text{syst.})$$



LFUV in e/μ, and Model Independent SL Form

$$\frac{d\Gamma}{dw}(B \to D\ell\nu) \sim (\text{Phase Space})|V_{cb}|^2 G(w)^2$$

$$\frac{d\Gamma}{dw}(B \to D^*\ell\nu) \sim (\text{Phase Space})|V_{cb}|^2 F(w)^2 \sum_{i=+,0,-} |H_i(w)|^2$$

$$w = \frac{m_B^2 + m_D^2 - q^2}{2 m_B m_d}$$

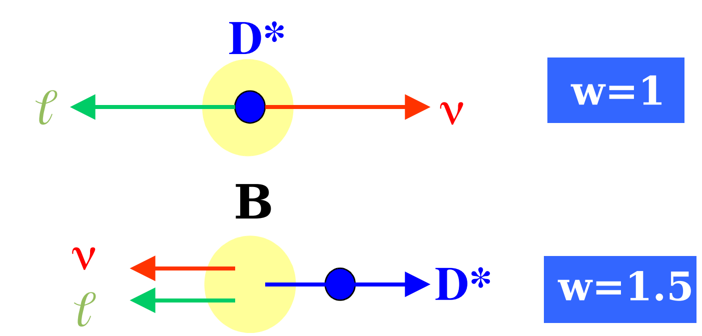
BGL, Boyd, Grinstein, Lebed Phys.Rev.Lett 74, 4603 (1995)

$$F_i(w) = \frac{p_i(w)}{B_i(z)\phi_i(z)} \sum_{n=0}^{N} a_n^{(i)} z^n$$

$$z = (\sqrt{w+1} - \sqrt{2})/(\sqrt{w+1} + \sqrt{2})$$

Normalisation: $\xi(w=1)=1$

(heavy quark limit)



CLN, Caprini, Lellouch, Neubert Nucl.Phys.B530, 153 (1998)

$$G(w) = G(1)[1 - 8\rho^2 z + (51\rho^2 - 10)z^2 - (252\rho^2 - 84)z^3]$$

HFLAV (CLN)

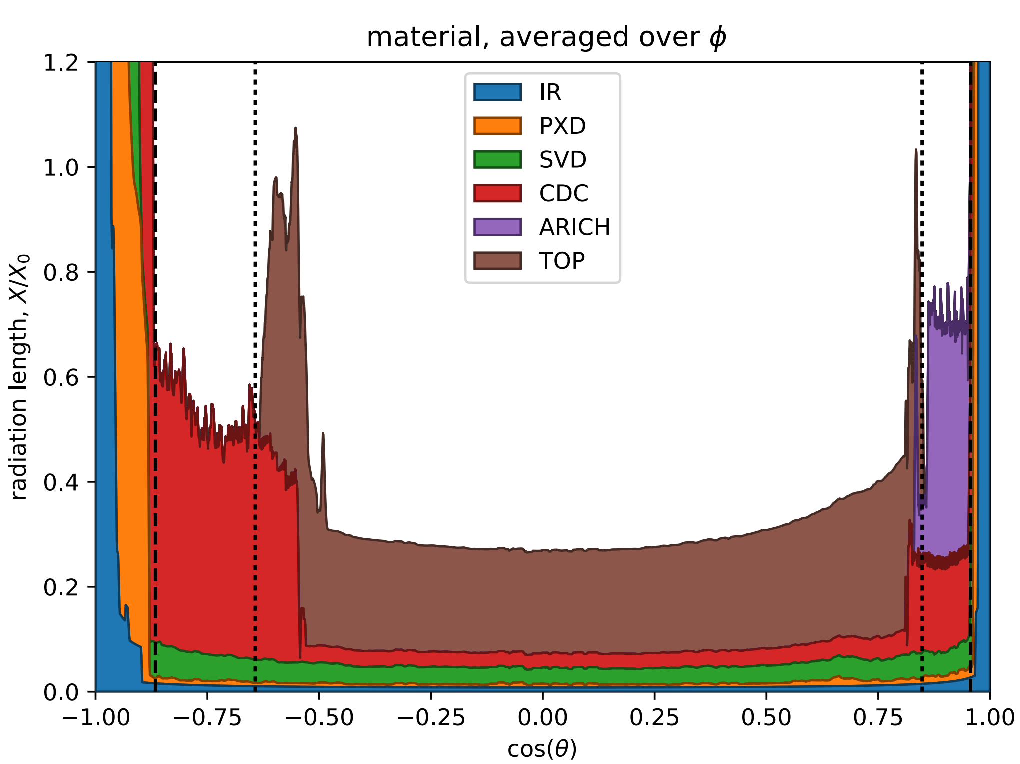
$|V_{cb}| = (42.19 \pm 0.78) \cdot 10^{-3}$ from $B \to X_c l\nu$

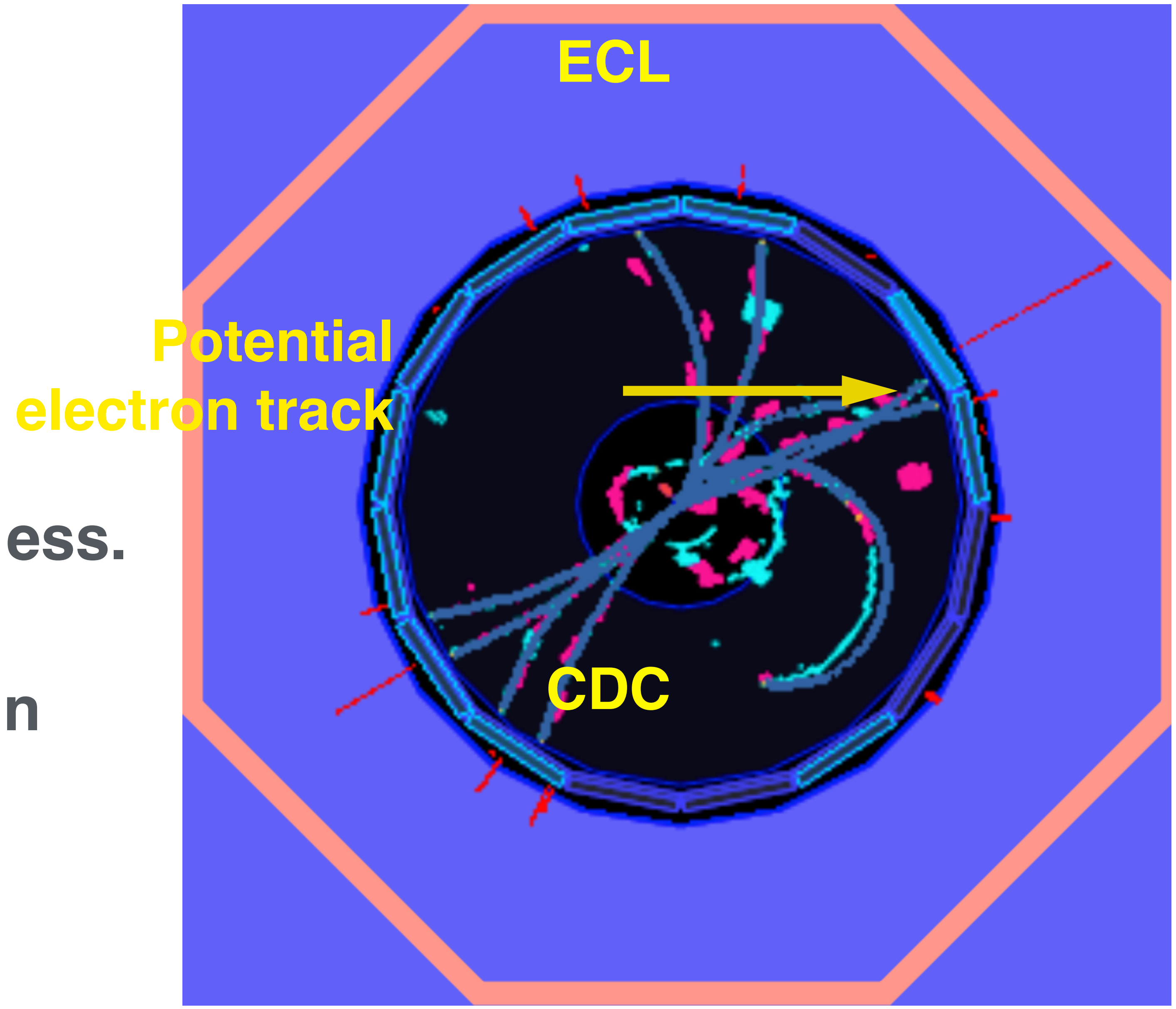
$|V_{cb}| = (39.05 \pm 0.47_{\text{exp}} \pm 0.58_{\text{th}}) \cdot 10^{-3}$ from $B \to D^* l\nu$

$|V_{cb}| = (39.18 \pm 0.94_{\text{exp}} \pm 0.36_{\text{th}}) \cdot 10^{-3}$ from $B \to D l\nu$

Electron identification

- Electrons are light: **Final state radiation**
  - **Bremsstrahlung recovery** partial fixes this
- Be... II: TOP ARICH dE/dx ECL sh... → ... ess.
- **M... ca... n id...**





Muon identification

- Muons are the easiest to identify
  - Little to **no radiation** (heavy)
  - **Stable** within particle detectors
  - No strong interactions in absorber material
  - In B-f 700 MeV/ detec