Prospects for measurement of $R(D)$ and $R(D^*)$ in Belle II.

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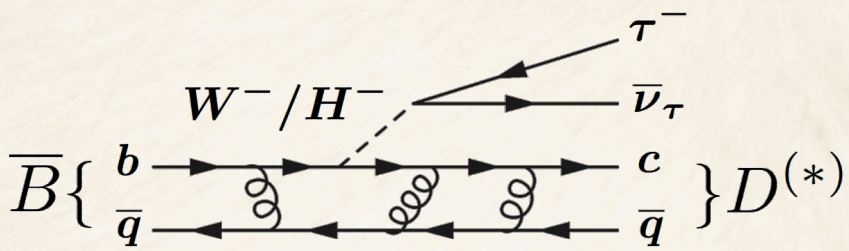
Introduction

Introduction

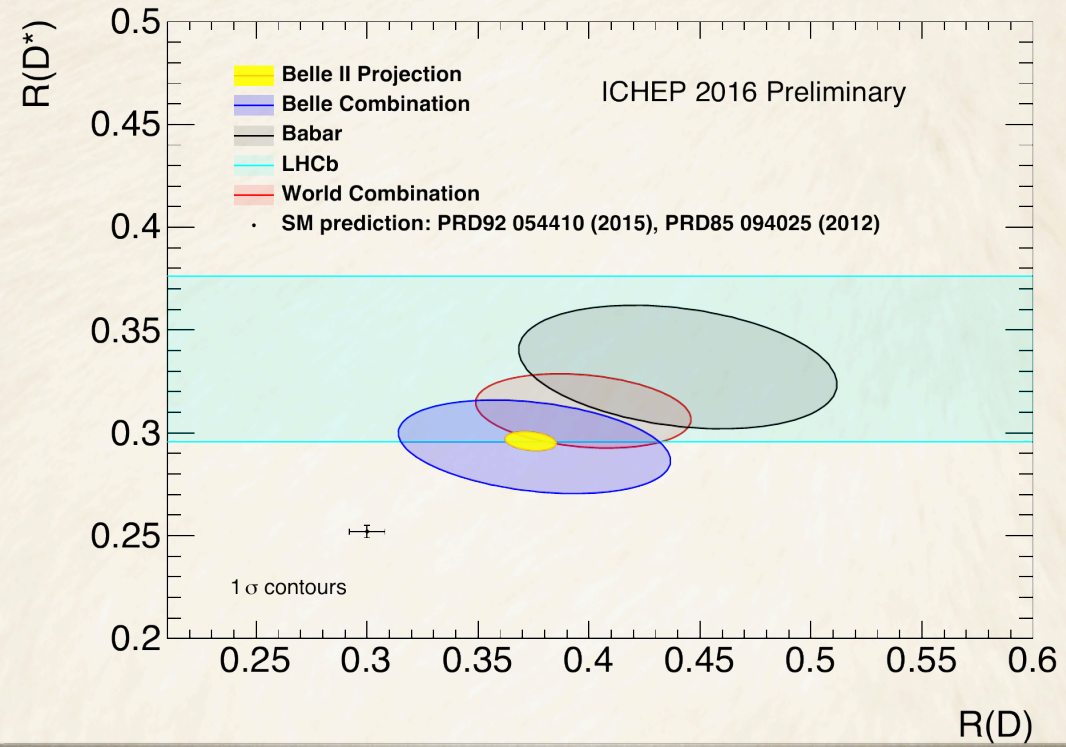
- In the Standard Model, the only difference between $B \to D\tau\nu_\tau$ and $B \to D\mu\nu_\mu$ is the mass of the lepton.
- The ratios $R(D)$ and $R(D^*)$ are sensitive to charged Higgs and leptoquark.
- Current World average is in $\sim 4\sigma$ tension with SM.



$$R(D) = \frac{\mathscr{B}(B \to D\tau\nu_\tau)}{\mathscr{B}(B \to D\mu\nu_\mu)} \quad (1) \qquad R(D^*) = \frac{\mathscr{B}(B \to D^*\tau\nu_\tau)}{\mathscr{B}(B \to D^*\mu\nu_\mu)} \quad (2)$$

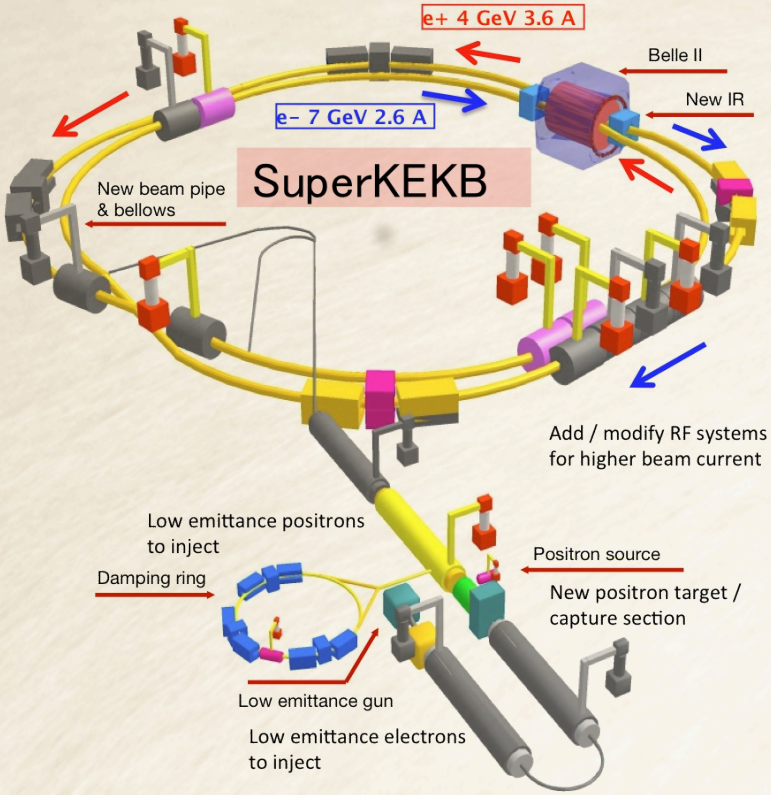
Experimental status

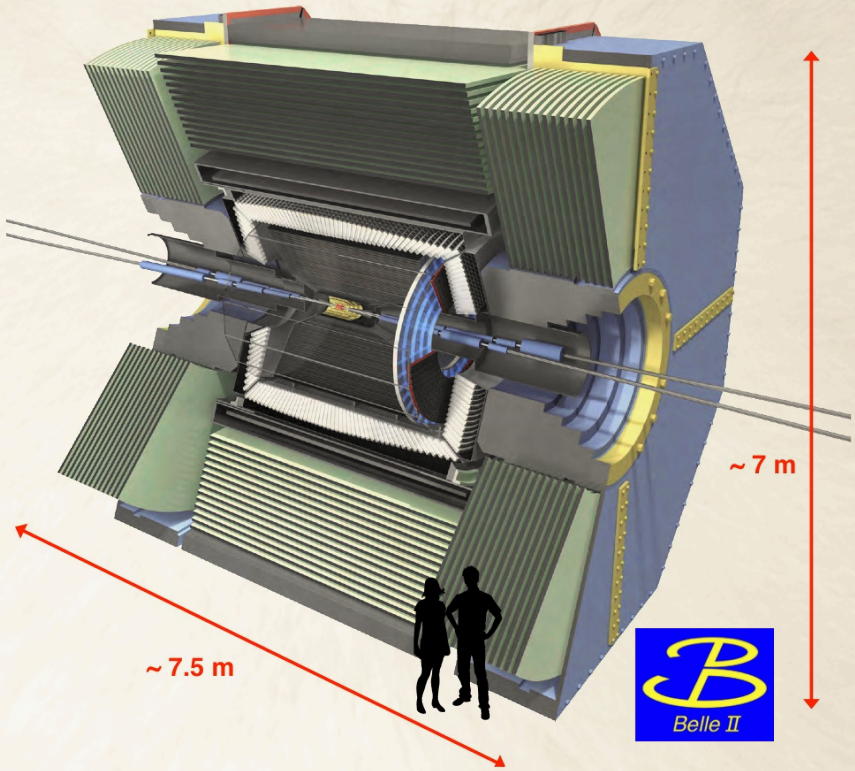
Experiment	Tag method	τ mode	$R(D)$	$R(D^*)$	ρ
Belle 07	inclusive	$e\nu\nu$, $\pi\nu$	0.38 ± 0.11	0.34 ± 0.08	–
Belle 10	inclusive	$\ell\nu\nu$, $\pi\nu$			
BaBar 12	hadronic	$\ell\nu\nu$	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.018$	-0.27
Belle 15	hadronic	$\ell\nu\nu$	$0.375 \pm 0.064 \pm 0.026$	$0.293 \pm 0.038 \pm 0.015$	-0.32
Belle 16	semileptonic	$\ell\nu\nu$	–	$0.302 \pm 0.030 \pm 0.011$	–
Belle 17	hadronic	$\pi\nu$, $\rho\nu$	–	$0.270 \pm 0.035 \pm 0.027$	–
LHCb 16	–	$\ell\nu\nu$	–	$0.336 \pm 0.027 \pm 0.030$	–
HFAG	–	–	$0.403 \pm 0.040 \pm 0.024$	$0.310 \pm 0.015 \pm 0.008$	-0.23
SM	–	–	0.300 ± 0.008	0.252 ± 0.003	–



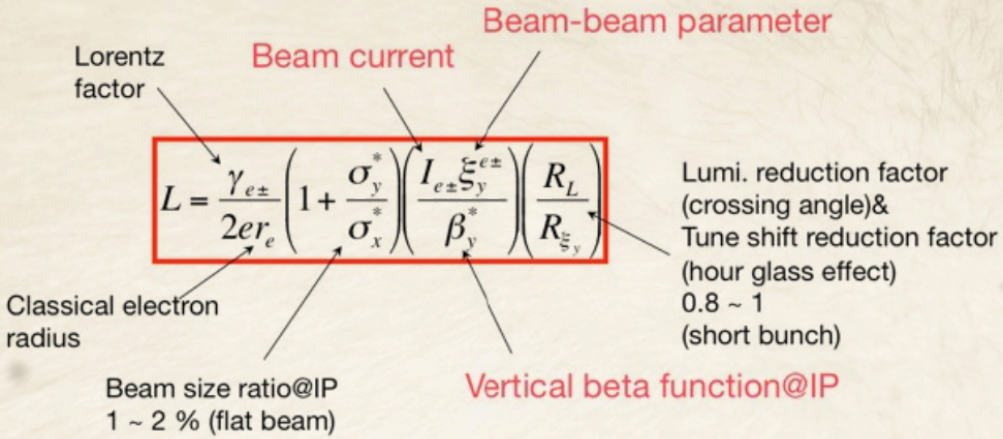
Belle II experiment

SuperKEKB

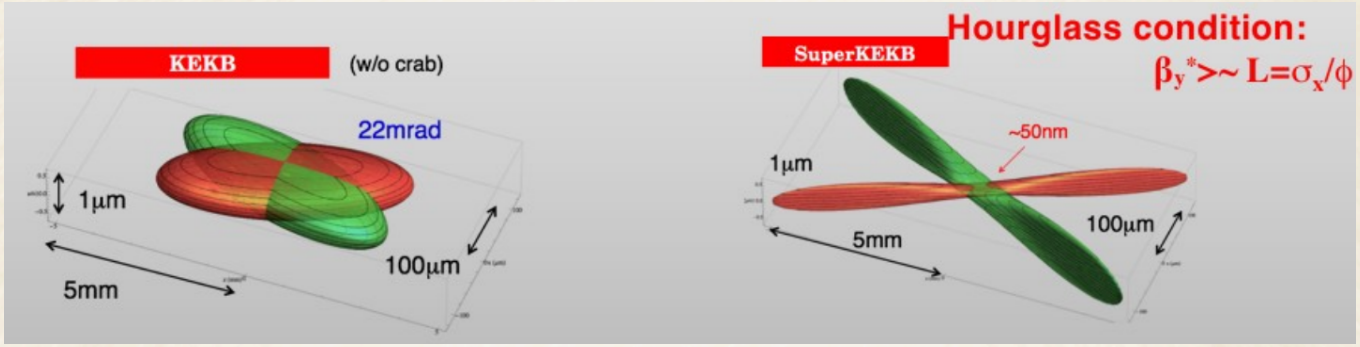

e+ 4 GeV 3.6 A
Belle II
New IR
e- 7 GeV 2.6 A
SuperKEKB
New beam pipe
& bellows
Add / modify RF systems
for higher beam current
Low emittance positrons
to inject
Positron source
Damping ring
New positron target /
capture section
Low emittance gun
Low emittance electrons
to inject


~ 7 m
~ 7.5 m
Belle II

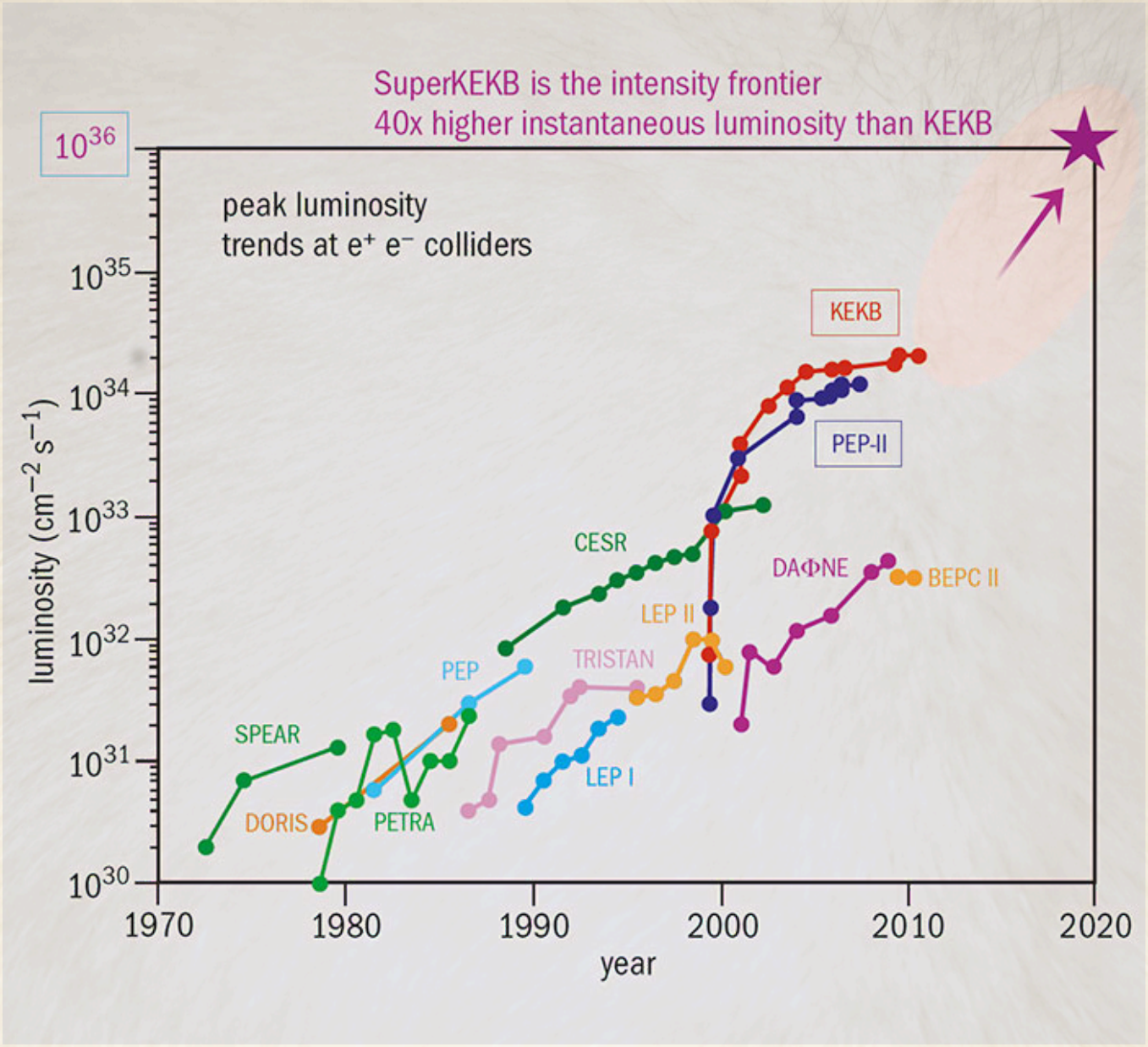
SuperKEKB



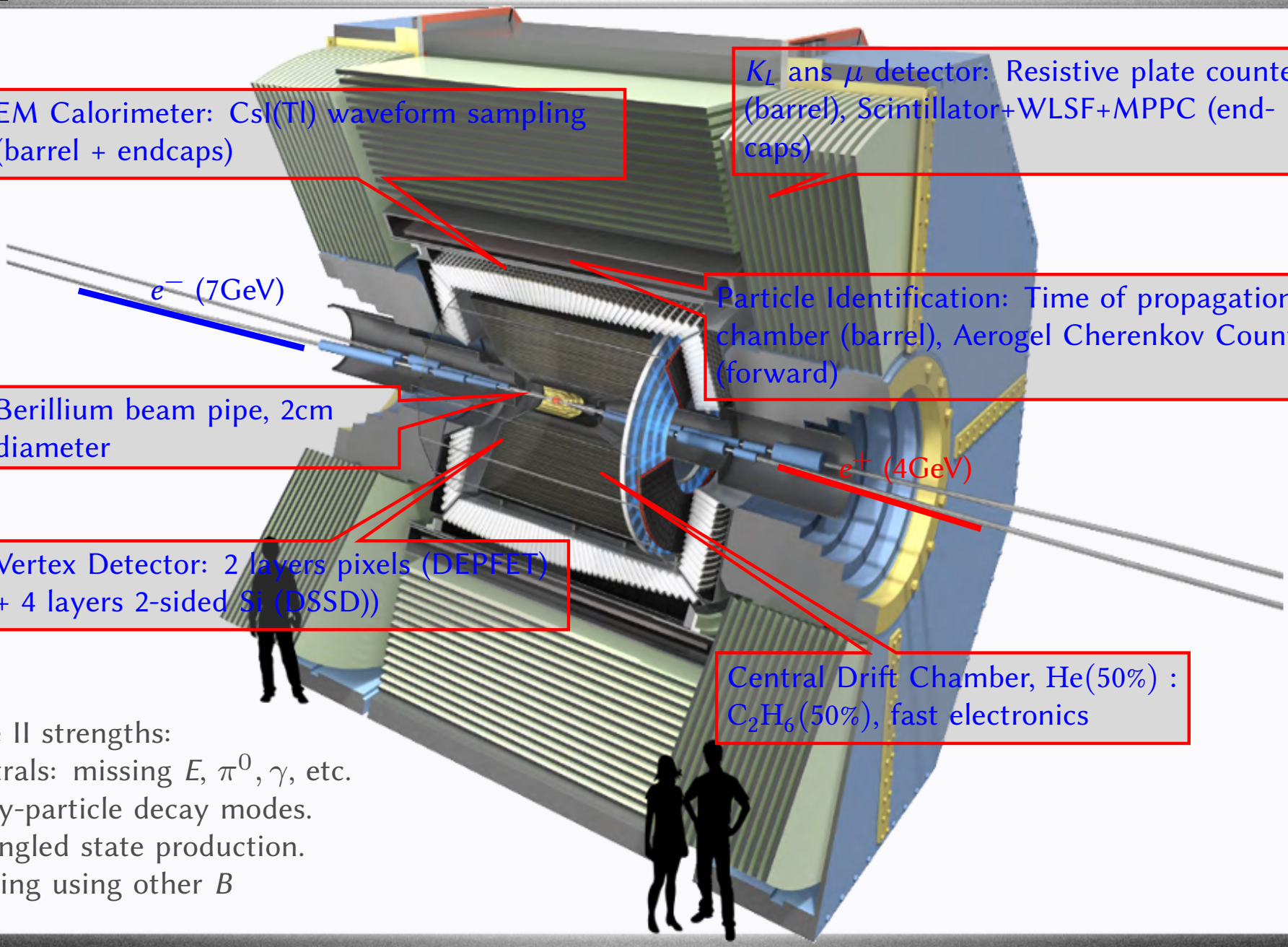
	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}



SuperKEKB

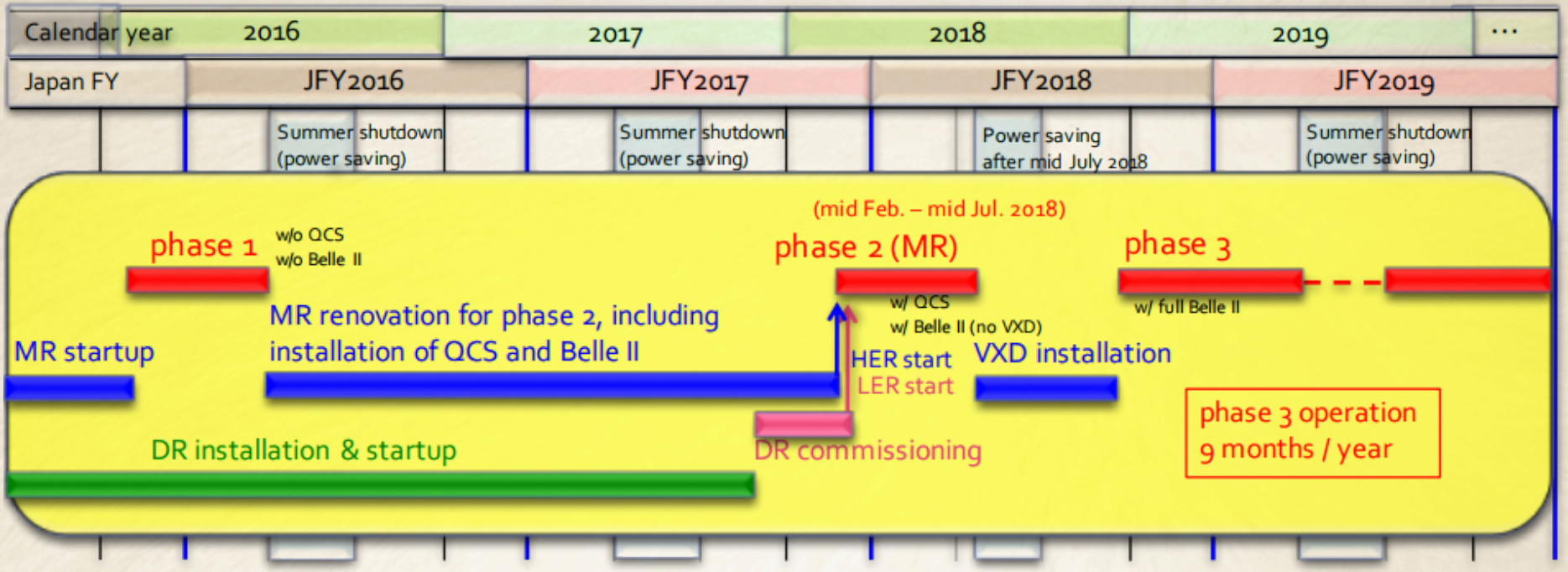

SuperKEKB is the intensity frontier
40x higher instantaneous luminosity than KEKB
peak luminosity
trends at e+ e− colliders
10^36
10^35
10^34
10^33
10^32
10^31
10^30
luminosity (cm^−2 s^−1)
1970
1980
1990
2000
2010
2020
year
KEKB
PEP-II
CESR
DAΦNE
BEPC II
LEP II
TRISTAN
PEP
SPEAR
LEP I
DORIS
PETRA

The Belle II Detector



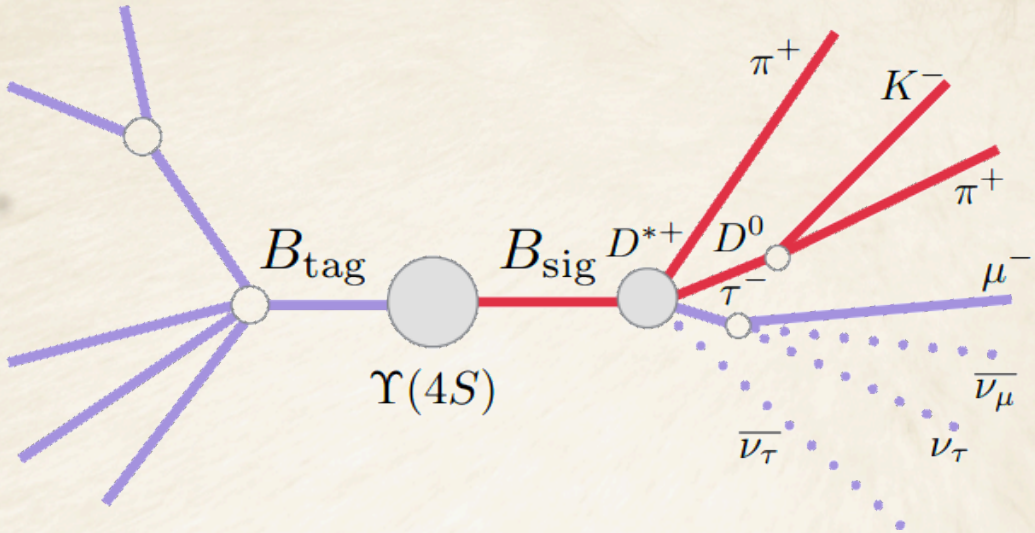
Belle II strengths:
Neutrals: missing E, π^0, γ, etc.
Many-particle decay modes.
Entangled state production.
Tagging using other B

Belle II timeline



Analysis method

Analysis method



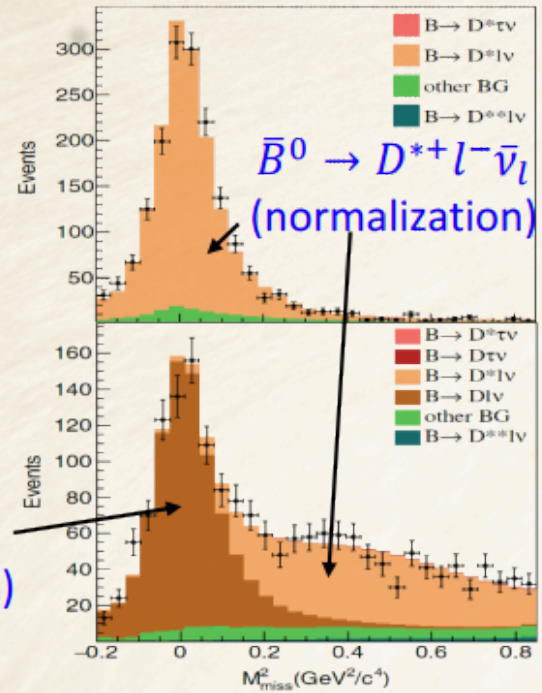
- Fully reconstruct the B_{tag} side with hadronic decays, or partially with semileptonic decays.

Hadronic tagging

$$M^2_{miss} = (p_{e^+e^-} - p_{B_{tag}} - p_{D^{(*)}} - p_\ell)^2$$

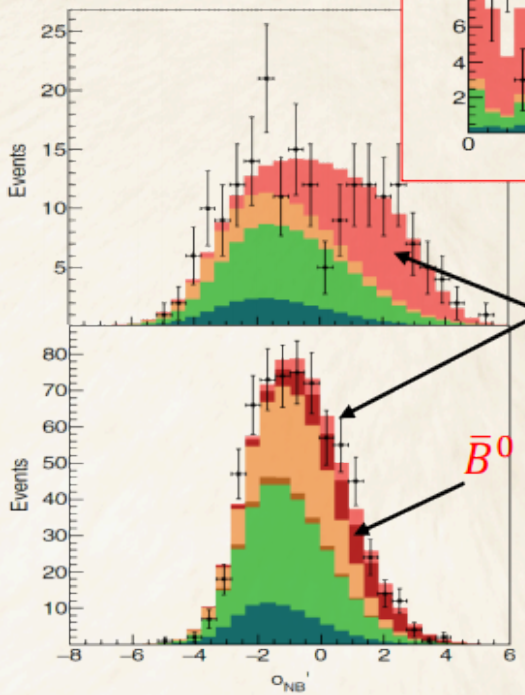
$\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$ sample

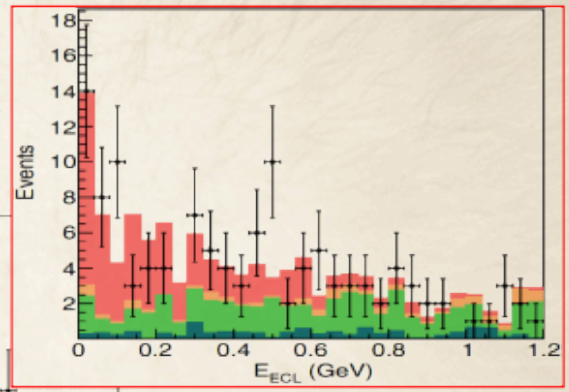
$\bar{B}^0 \to D^{+}\tau^-\bar{\nu}_\tau$ sample



$\bar{B}^0 \to D^{*+}l^-\bar{\nu}_l$ (normalization)

$\bar{B}^0 \to D^{+}l^-\bar{\nu}_l$ (normalization)

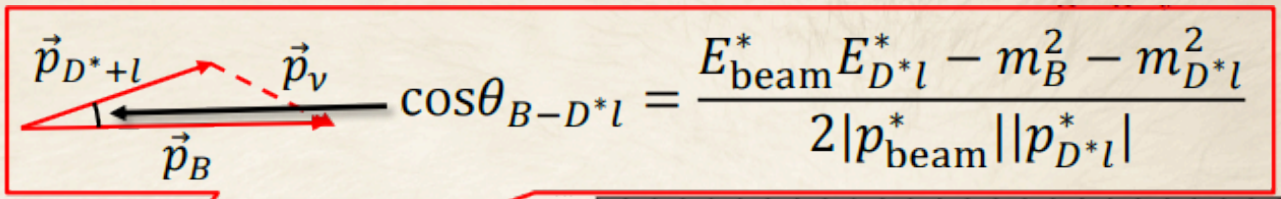




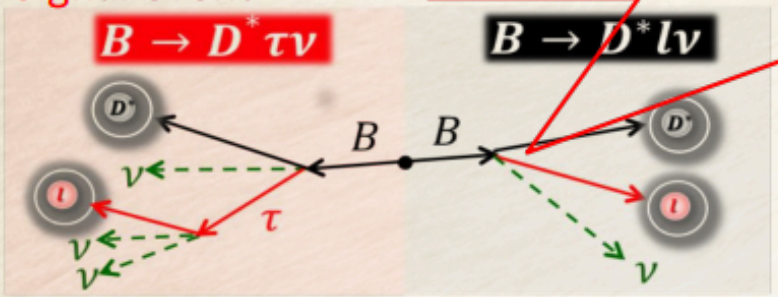
$\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$ (signal)

$\bar{B}^0 \to D^{+}\tau^-\bar{\nu}_\tau$ (signal)

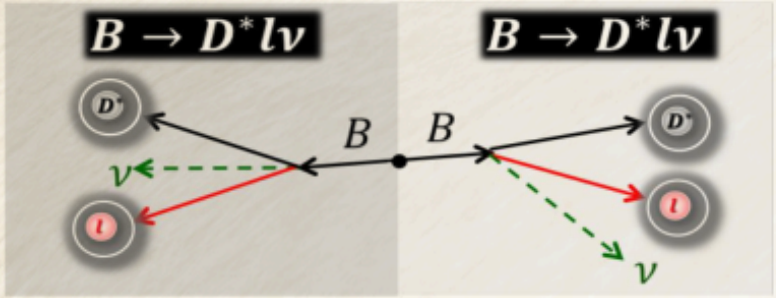
Semileptonic tagging

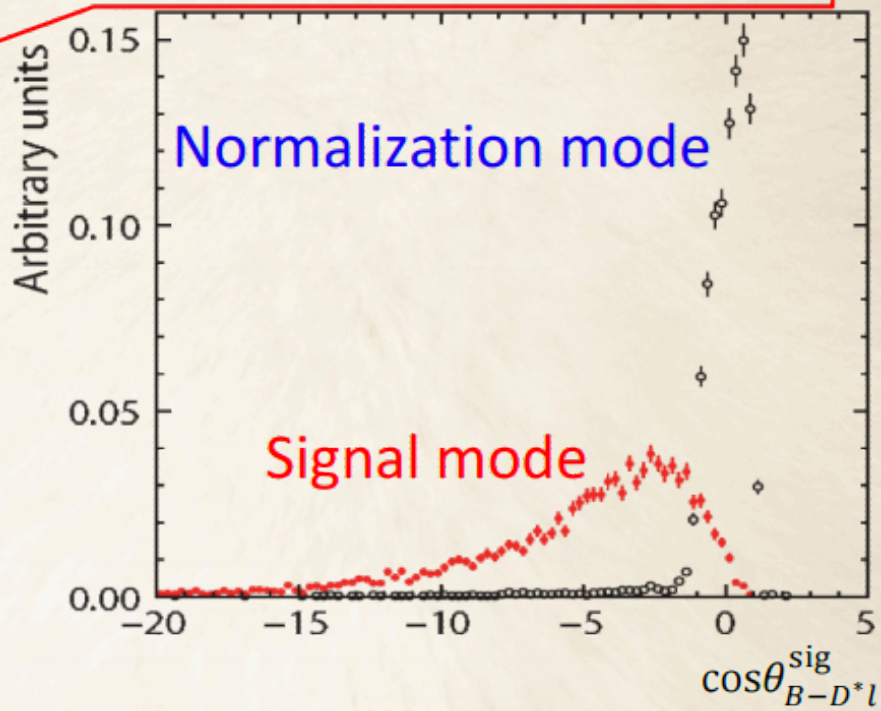


Signal event



Normalization event





Systematic Uncertainities

List of main Belle Uncertainities

	Experiment	Error profile*	SL tag R_{D^*}	Had tag R_{D^*}, $\tau \to h\,\nu$	Had tag R_{D^*}, $\tau \to l\,\nu\,\nu$	Had tag R_D, $\tau \to l\,\nu\,\nu$
1	MC statistics	Gauss	2.2	3.5		
2	**B → D** l ν modelling**	**Uniform**	**+1, -1.7**	**0.7**	**1.5**	**4.2**
3	B → D* l ν	Gauss	+1.3, -0.2	0.8		
4	**D** decay modes**	**Uniform**	**(in 2)**	**(in 2)**	**1.3**	**3.0**
5	**Hadronic B decays**	**Uniform**	**1.1**	**4.4**		
6	**B → D** τ ν**	**Uniform**	**(in 2)**	**2.7**		
7	Fake $D^{(*)}$	Gauss	1.4	0.2	0.3	0.5
8	Fake lepton	Gauss		-	0.6	0.5
9	Lepton ID	Gauss	1.2	1.8	0.5	0.5
10	τ Br	Gauss	0.2			
	Total		3.5	7.1	5.2	7.1

* Gauss = data driven, Uniform = nominal central value is arbitrary

Task force

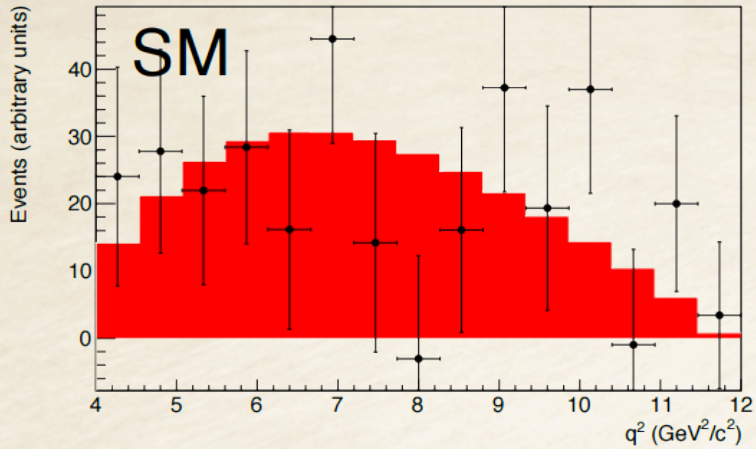
Name	Institution	Task/Expertise
Anze Zupanc	Faculty at the University of Ljubljana	Interested in developing skimming scripts and analysis variables/tuples
Andrzej Bozek	Associate Professor at the Institute of Nuclear Physics, Kraków	Experience and interest in analyses with inclusive B_{tag}.
Chanseok Park	PhD student	Experience in hadronic tagging Interested in FEI or hadronic tagging
@Jorge Martinez-Ortega	Postdoc	Interested in analysis framework development
Koji Hara	Assistant Professor at KEK	Experience in B→ tau nu and B→ D* tau nu analysis. Author of BSTD
Romulus Godang	Professor at the University of South Alabama	Experience and interest in analyses with partially reconstructed D* can
Mario Merola		MC production liaison
Shigeki Hirose	PhD student at Nagoya University	Experience in polarization measurements. Working on debugging the BSTD generator.
@Sophie Hollitt	PhD Student at the University of Adelaide	Experience and interest in FEI, tagging and possibly the analysis frame
Valerio Bertacchi	Masters Student	Interest in tagging and possibly other tasks.
Yubo Li	PhD student	Experience in Belle analysis. Interested in B-tagging (summer 2017).
@Stephan Duell	PhD student at the University of Bonn	Experience in Hammer framework and can help with the truth-matching
Toru Ijima	Professor at Nagoya University	Experience in R(D) and R(D*) as well as B→tau nu analysis. Interested in BSDT generator, PID systematics, and the analysis frame
Kodai Matsuoka	Associate Professor at Nagoya University	Experience in R(D) and R(D*) as well as B→tau nu analysis. Interested in understanding detector performance and background.
Karol Adamczyk	Researcher at the Institute of Nuclear Physics, Kraków	Measuring polarization of the D* and tau with inclusive Btag reconstruc
Thomas Kuhr	Professor at LMU Munich	Experience in R(D) and R(D*) as well as B→tau nu analysis. Interested in tagging and analysis framework
Giacomo Caira		B→D** l nu studies and analysis framework.
Abi Soffer	Professor at Tel Aviv University	Interested in improving B→D(*)taunu using vertexing, CP violation
Katsuro Nakamura	Assistant Professor at KEK	Interested in B→D(*)taunu S/BG improvement with vertex information

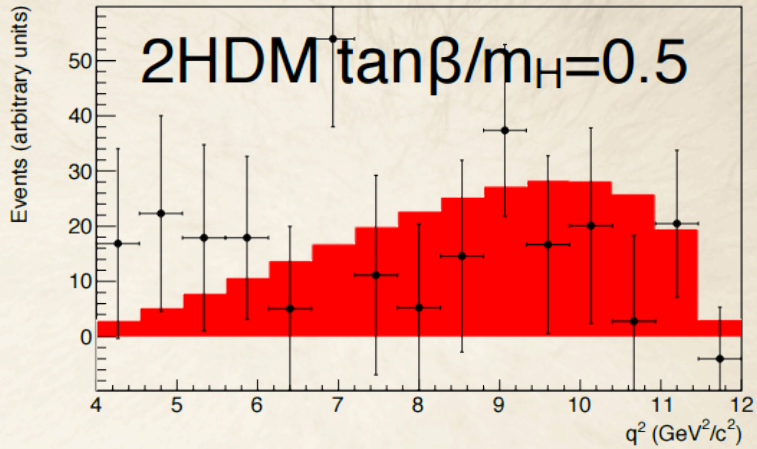
Status

- Algorithms for full event reconstructions are ready to use.
- Progress on MC generation and skimming.
- **Reconstruction algorithms are being developed.**

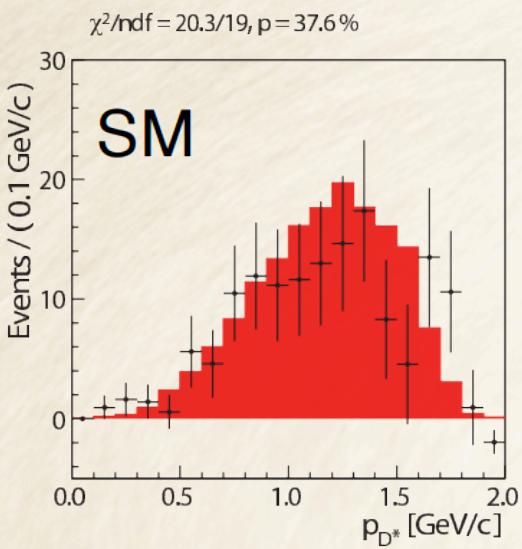
NP Scenarios

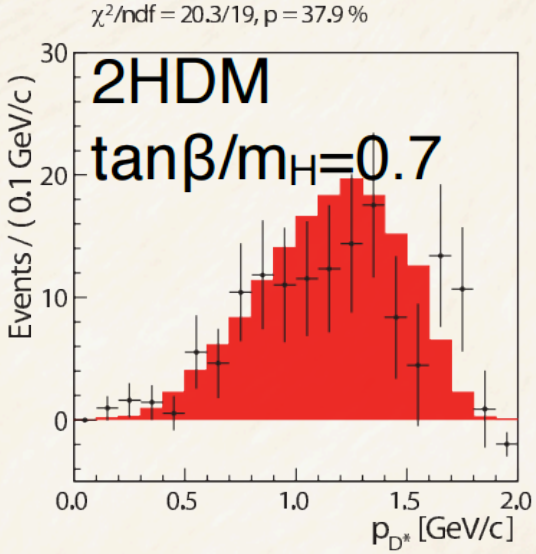
Belle had tag B→ D τ ν, Stat errors only! (same case for Babar)

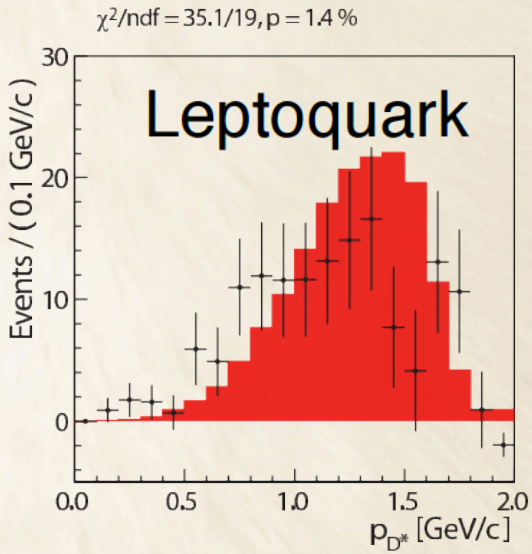




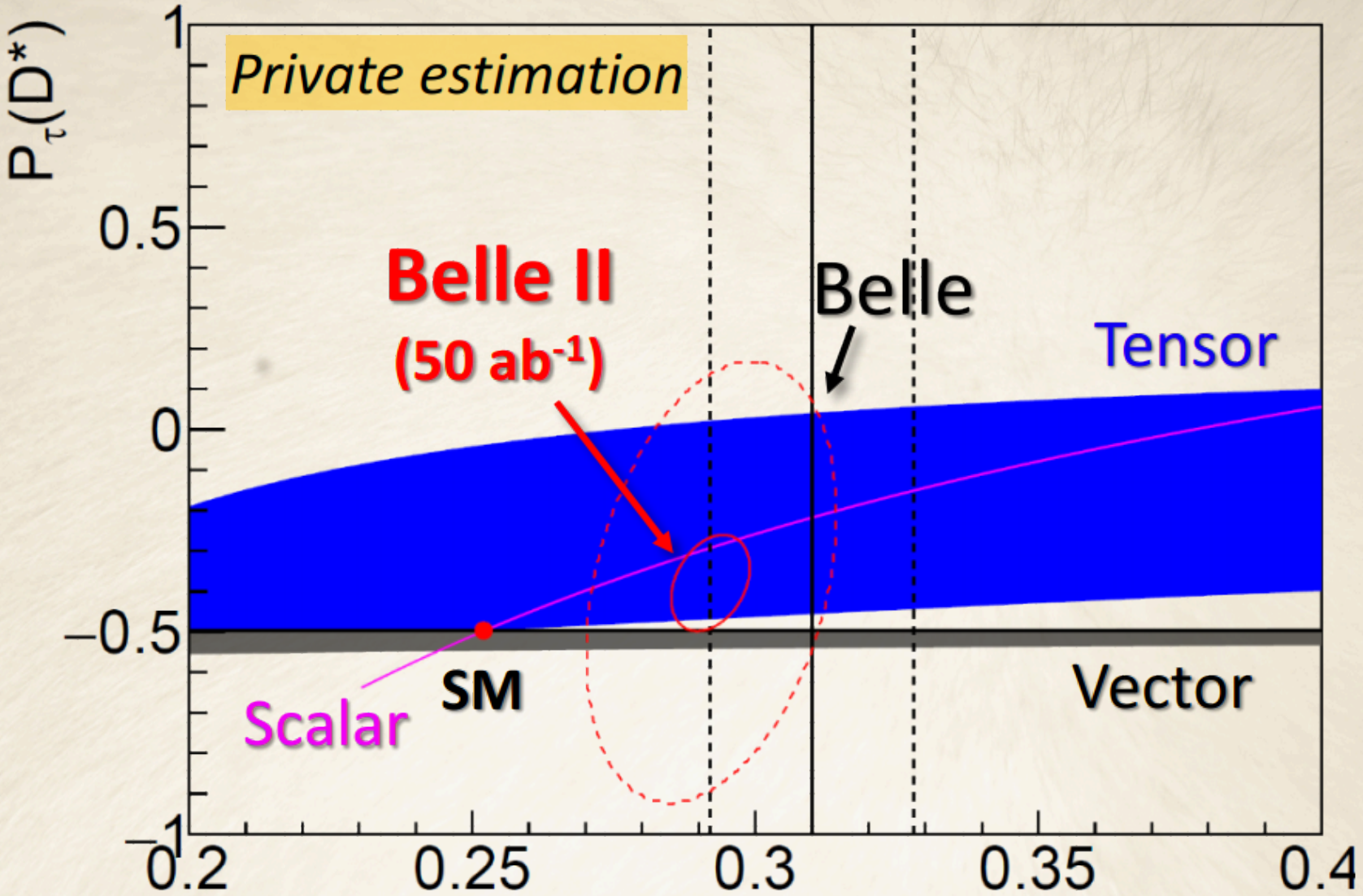
Belle SL tag B → D* τ ν, Stat errors only.







τ polarization



Theoretical calculation based on M. Tanaka and R. Watanabe, Phys. Rev. D 87, 034028 (2013)

Conclusions

- Lepton universality tests are a good places to look for physics BSM.
- Current measurements show a $\sim 4\sigma$ tension with SM.
- Semileptonic decays could also been able to dicern between NP models or operators.
- We expect to reduce systematic error by better modeling of $D^{**}\ell\nu$ background.
- A task force was recently formed in Belle II, in order to be ready when data is available.

Thank you.