V1.5 2019-07-11

Belle II and flavor physics in e^+e^-

EPS-HEP, Ghent, July 16, 2019

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INFN and University, Pisa

Outline

- Flavor opens a window on new physics
- e^+e^- colliders provide good lenses to look through the window
- Recent results from:
  - BES III
  - Babar
  - Belle
- The promise of the future: Belle II
  - Initial running and performance
  - Perspectives

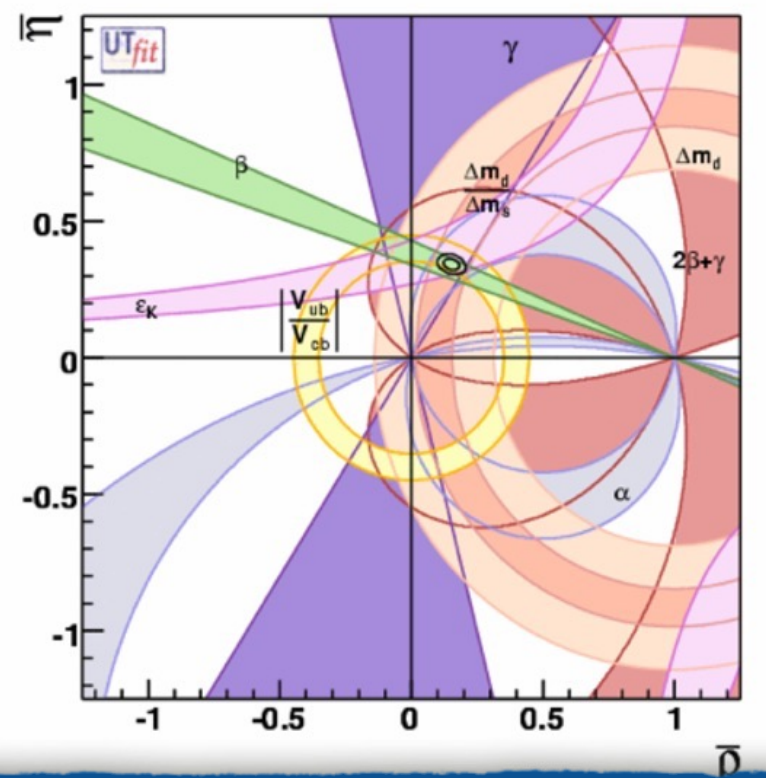
Note: most links are active, just click on the ad.

Past successes of flavor

Indirect discoveries of flavor experiments

- suppression of $K_L^0 \to \mu^+\mu^-$ decays
  $\Rightarrow$ existence of charm quark by GIM mechanism
- $K^0\bar{K}^0$ oscillations, $B^0\bar{B}^0$ oscillations
  $\Rightarrow$ charm and top quark masses
- CPV in K^0 systems
  $\Rightarrow$ 3rd generation of quarks & KM mechanism

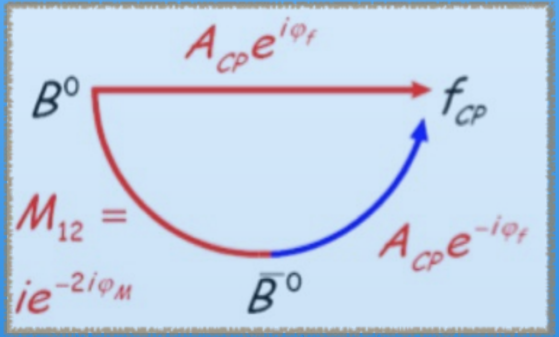
Precision measurement of CKM elements

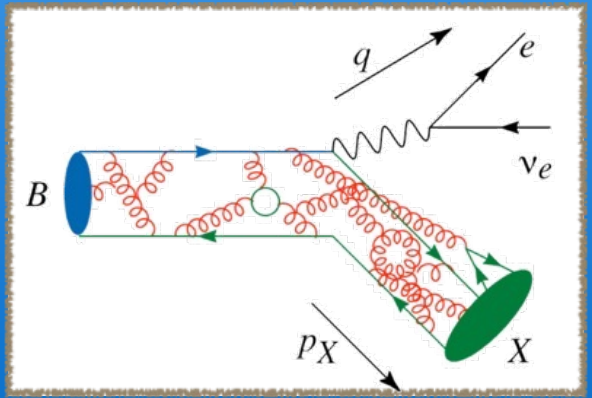


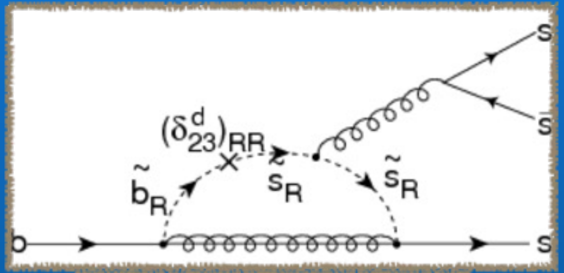
The power of flavor

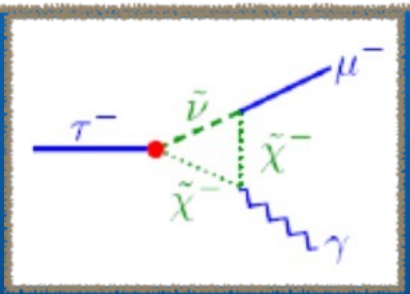
Statistics

- **Explore the origin of CP violation**
  - Key element for understanding the matter content of our present universe
  - Established in the B meson in 2001
  - Direct CPV established in B mesons in 2004
- **Precisely measure parameters of the standard model**
  - For example the elements of the CKM quark mixing matrix
  - Disentangle the complicated interplay between weak processes and strong interaction effects
- **Search for the effects of physics beyond the standard model in precision measurements**
  - Potentially large effects on rates of rare decays, time dependent asymmetries, lepton flavor violation
  - Sensitive to large New Physics scale, as well as to phases and size of NP coupling constants
  - → **Lepton Flavour Universality / Violation tests**









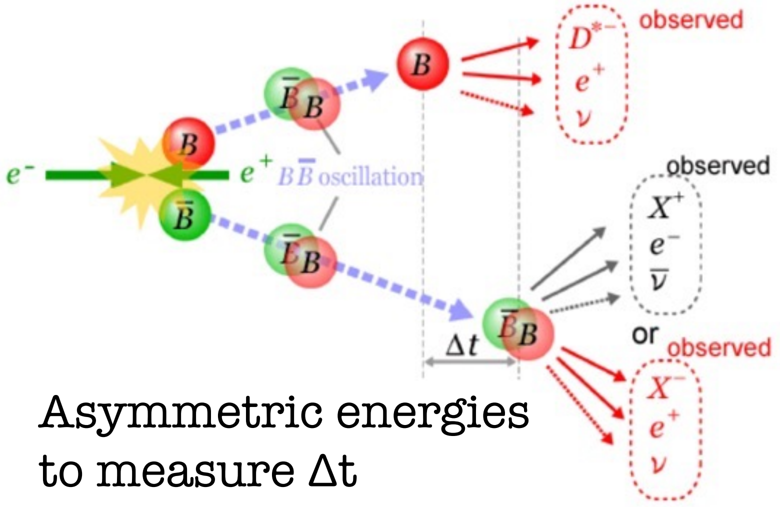
Flavor Physics → BSM

- EW Hierarchy… driven by the top in SM
- Strong CP problem
- Origin of weak CP and matter-antimatter asymmetry
- Flavour puzzle (quarks, charged leptons, neutrinos)

Flavour is the usual graveyard of BSM electroweak theories

Advantages of e^+e^- flavor production
(compared to hadron machines)

- Coherent and well defined initial state and no additional interactions
- Low (physics) backgrounds, high trigger efficiency, little bias
- Excellent neutral reconstruction (γ, π^0, K_L)
- Good kinematic and vertex resolution
- High flavor-tagging efficiency with low dilution
- Many channels are unique to e^+e^- flavor factories
- Absolute branching fractions can be measured.
- Can look at
    - Forbidden decays, invisible decays
    - Asymmetries (CP, isospin)
    - Angular distribution
- Systematics quite different from hadronic machines. If NP is seen by one of the experiments, confirmation by the other would be important.



Asymmetric energies to measure Δt

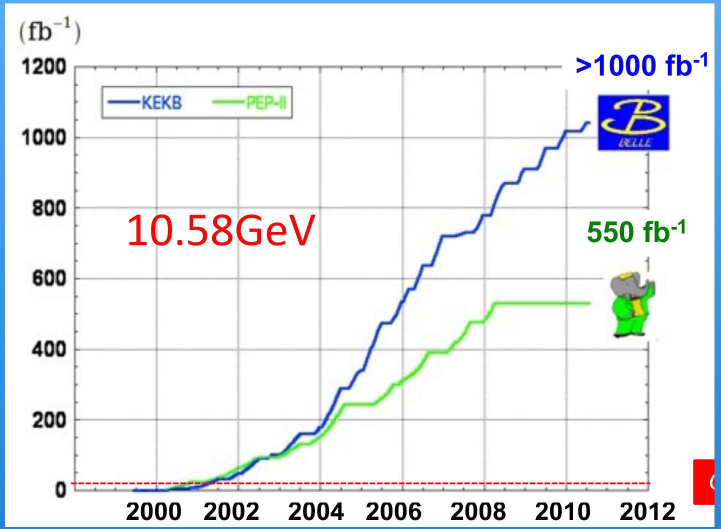
Price to pay: much smaller cross section

Experiments and data sets

Current $D/D_s/\Lambda_c$ analyses are based 2.9/3.2/0.567 fb^{-1} data at 3.773/4.178/4.6 GeV

Beam energy:	**1.0-2.3 GeV**
Optimum energy:	**1.89 GeV**
Designed luminosity:	**1.00×10^{33} $cm^{-2}s^{-1}$**
Data taken from:	**2009**
Achieved luminosity:	**1.00×10^{33} $cm^{-2}s^{-1}$**

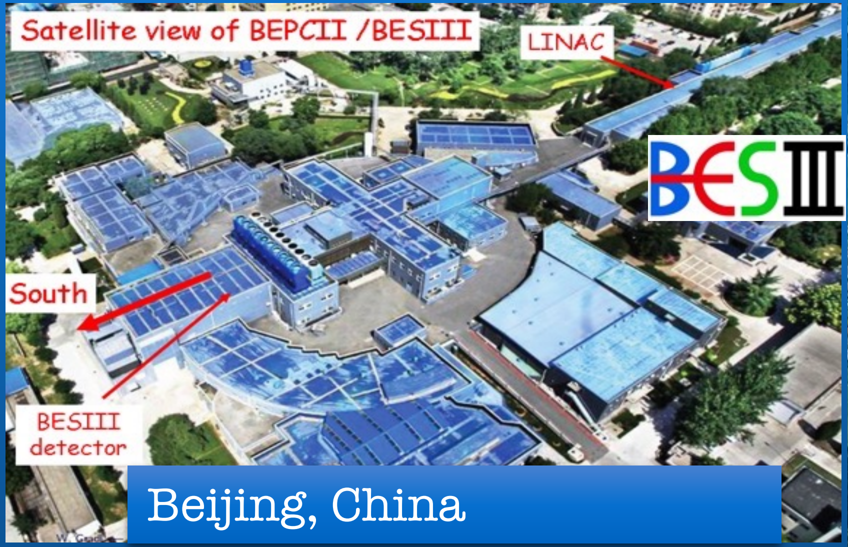
Channel	Belle	BaBar	Belle II (per year)
$B\bar{B}$	7.7×10^{8}	4.8×10^{8}	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^{6}	–	6.0×10^{8}
$\Upsilon(1S)$	1.0×10^{8}		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^{8}	0.9×10^{7}	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^{7}	1.0×10^{8}	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^{7}	–	3.0×10^{9}
$\tau\tau$	1.0×10^{9}	0.6×10^{9}	1.0×10^{10}

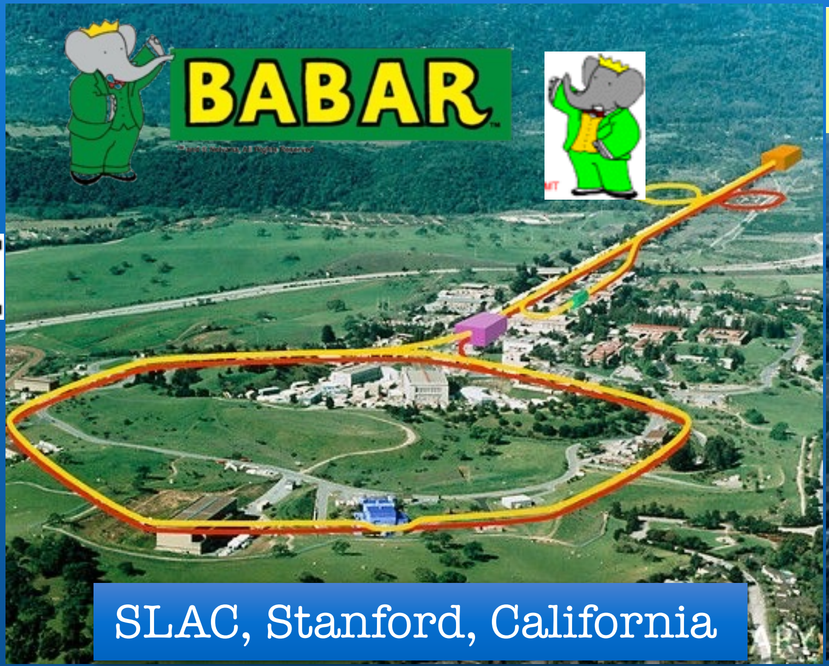


BABAR @ PEP-II: 1999-2008

BELLE @ KEKB: 1999-2010

BESS III @ BEPCII: 2009--





Recent results

- BES III
  - Charm Decays
  - Lepton Flavor Universality tests
- BABAR
  - 4D analysis of B→D*lv decay
  - Rare D decays
  - Lepton Flavor and Lepton Number Violations in D^0 decays
- BELLE
  - Update on R(K*) and R(K)
  - Update on R(D*)

SM

↓

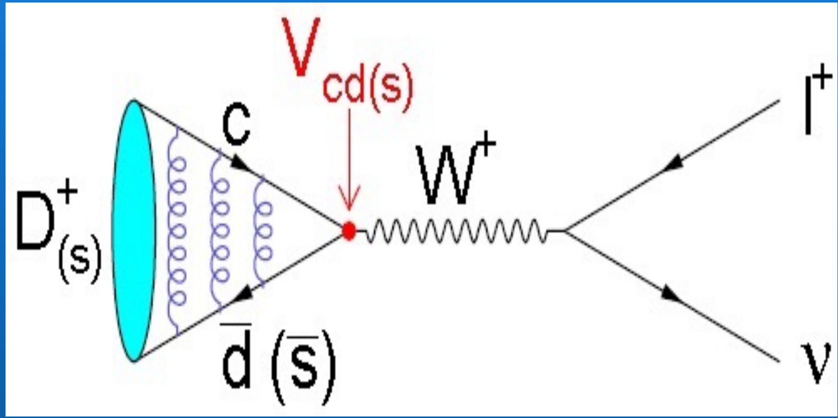
BSM

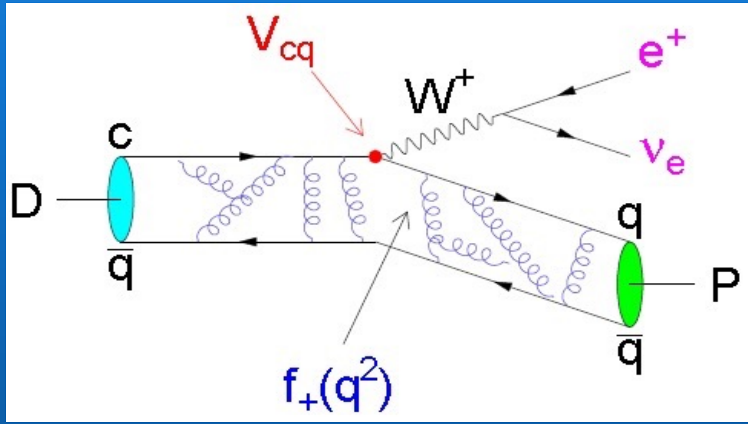
BES III – Charm decays

- Leptonic and hadronic decays of charmed hadrons (D^0, D^+, D_s^+, Λ_c^+) provide ideal test-beds to explore weak and strong effects

1. $|V_{cs(d)}|$: better test on CKM matrix unitarity
2. [Semi-]leptonic $D_{(s)}$ decays allow for LFU tests
3. $f_{D(s)+}$, $f_+^{K(\pi)}(0)$: better calibrate LQCD

$$U = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ \boxed{V_{cd} \quad V_{cs}} & & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$





$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi}|V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}}\left(1-\frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|V_{cd(s)}|^2}{24\pi^3}p^3|f_+(q^2)|^2$$

BES III LFU Tests

SM prediction: (xxx)

- Leptonic $D_{(s)}$ decays

$$\frac{B[D^+ \to \tau^+ \nu]}{B[D^+ \to \mu^+ \nu]} = 3.21 \pm 0.64_{\text{stat}} \quad (2.66)$$

$$\frac{B[D_s^+ \to \tau^+ \nu]}{B[D_s^+ \to \mu^+ \nu]} = 9.98 \pm 0.52 \quad (9.74)$$

- Semileptonic D decays to π & K

$$\frac{\Gamma[D^0 \to \pi^- \mu^+ \nu]}{\Gamma[D^0 \to \pi^- e^+ \nu]} = 0.922 \pm 0.030 \pm 0.022 \quad (0.985)$$

$$\frac{\Gamma[D^+ \to \pi^0 \mu^+ \nu]}{\Gamma[D^+ \to \pi^0 e^+ \nu]} = 0.964 \pm 0.037 \pm 0.026 \quad (0.985)$$

$$\frac{\Gamma[D^0 \to K^- \mu^+ \nu]}{\Gamma[D^0 \to K^- e^+ \nu]} = 0.978 \pm 0.007 \pm 0.012 \quad (0.97)$$

$$\frac{\Gamma[D^+ \to \overline{K}^0 \mu^+ \nu]}{\Gamma[D^+ \to \overline{K}^0 e^+ \nu]} = 1.00 \pm 0.03 \quad (0.97)$$

- Semileptonic D_s decays to φ/η

$$\frac{\Gamma[D_s^+ \to \phi \mu^+ \nu]}{\Gamma[D_s^+ \to \phi e^+ \nu]} = 0.86 \pm 0.29$$

$$\frac{\Gamma[D_s^+ \to \eta \mu^+ \nu]}{\Gamma[D_s^+ \to \eta e^+ \nu]} = 1.05 \pm 0.24$$

$$\frac{\Gamma[D_s^+ \to \eta' \mu^+ \nu]}{\Gamma[D_s^+ \to \eta' e^+ \nu]} = 1.14 \pm 0.68$$

- Semileptonic Λ_c decays

$$\frac{\Gamma[\Lambda_c^+ \to \Lambda \mu^+ \nu]}{\Gamma[\Lambda_c^+ \to \Lambda e^+ \nu]} = 0.96 \pm 0.16 \pm 0.04$$

No significant deviation seen
More statistic is coming

See additional material slides for references

Summary and prospect at BESIII

- Important constants

Constant	Systematic error	Statistical error	
		Now	Exp.
$\Delta f_{D+}/f_{D+}$	~0.9%	2.6%	1.3%
$\Delta f_{Ds+}/f_{Ds+}$	~1%	1.2%	0.6%
$\Delta f_{D\to K}/f_{D\to K}$	~0.5%	0.35%	0.18%
$\Delta f_{D\to\pi}/f_{D\to\pi}$	~0.7%	1.26%	0.63%
$\lvert V_{cs}\rvert^{Ds+\to l+v}$	~1%	1.2%	0.6%
$\lvert V_{cs}\rvert^{D0\to K-e+v}$	2.5% (2.4%^{LQCD})	0.35%	0.18%
$\lvert V_{cd}\rvert^{D+\to\mu+v}$	~0.9%	2.6%	1.3%
$\lvert V_{cd}\rvert^{D0\to\pi-e+v}$	4.5% (4.4%^{LQCD})	1.26%	0.63%

- LFU tests

Decay	Syst. Error	Statistical error	
		Now	Exp.
$D^+\to l^+v$ [μ/τ]	~10%	20%	10%
$D_s^+\to l^+v$ [μ/τ]	~3%	4%	2%
$D^0\to K^-l^+v$ [e/μ]	~1%	0.7%	0.35%
$D^0\to \pi^-l^+v$ [e/μ]	~2%	3.3%	1.7%
$D_s^+\to \phi l^+v$ [e/μ]	~4%	6%	3%
$D_s^+\to \eta l^+v$ [e/μ]	~3%	4%	2%
$\Lambda_s^+\to \Lambda l^+v$ [e/μ]	~4%	17%	5%

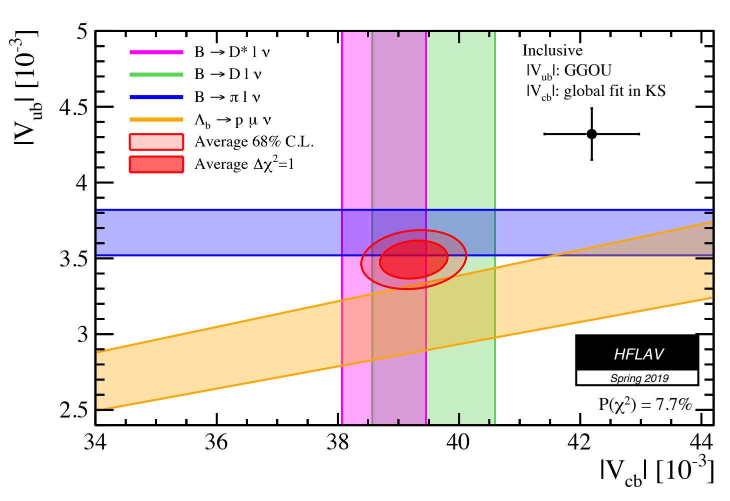
Now: Current $D/D_s/\Lambda_c$ analyses are based 2.9/3.2/0.567 fb^{-1} data at 3.773/4.178/4.6 GeV

Exp.: Expected precision is based on 12/12/5 fb^{-1} data at 3.773/4.178/4.65 GeV

- More results will be coming in the near future

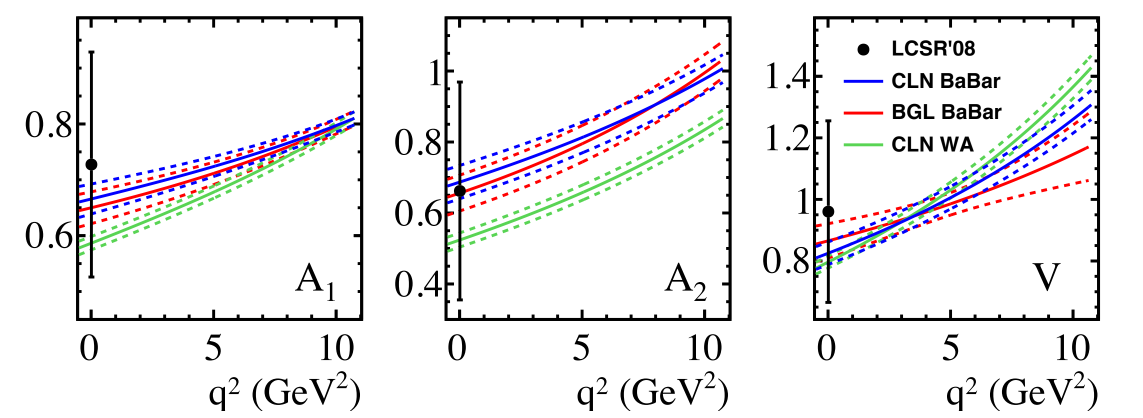
Babar: B→D*lν tagged full 4d angular analysis

- Persisting tension between inclusive/exclusive V_{cb} and V_{ub}.
- Form Factors also important for R(D*)
- First full 4d angular analysis to extract the FF's.
- Two parametrizations: BGL, CLN. Test of HQET



- Effect of increasing the error on the R(D*) prediction
- Also polarizations are very sensitive to FF (and NP)

- P_τ: -0.483 ± 0.027 (BABAR-BGL), $-0.38 \pm 0.51^{+0.21}_{-0.16}$ (Belle'17)
- $F_L^{D^*}$: $\underbrace{+0.454 \pm 0.011}_{\text{predictions}}$ (BABAR-BGL), $\underbrace{+0.60 \pm 0.08 \pm 0.035}_{\text{measurements}}$ (Belle'19)



- BABAR FF's significantly different from CLN-WA. CLN p-value: 0.0017
- BABAR $|V_{cb}|$ is consistent with WA $|V_{cb}|_{\text{excl.}}$ and remains in tension with WA $|V_{cb}|_{\text{incl.}}$

485. Study of $B\to D^{(*)} l \nu$ decays with a full angular analysis at $BABAR$, Biplab Dey

Babar rare D decays

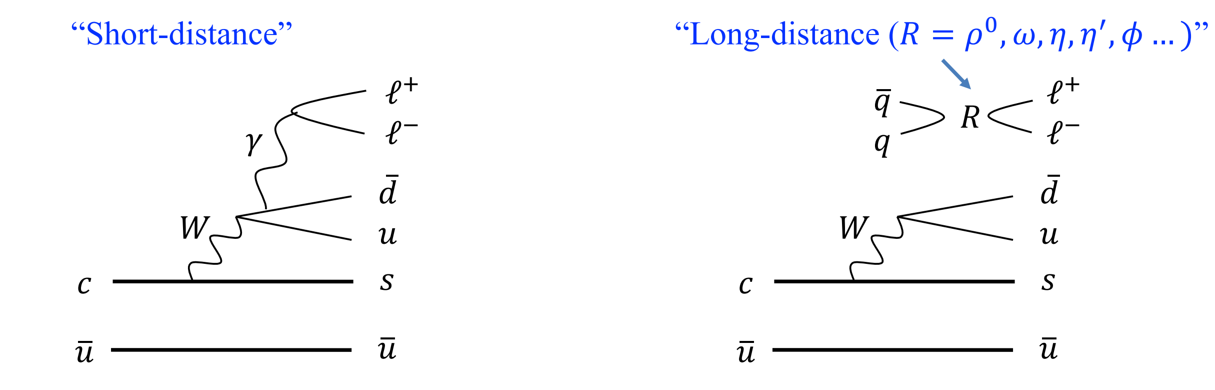
[488. Observation of the rare decay $D^0\to K^-\pi^+e^+e^-$, Fergus Wilson](#)

PRL 122, 081802 (2019)

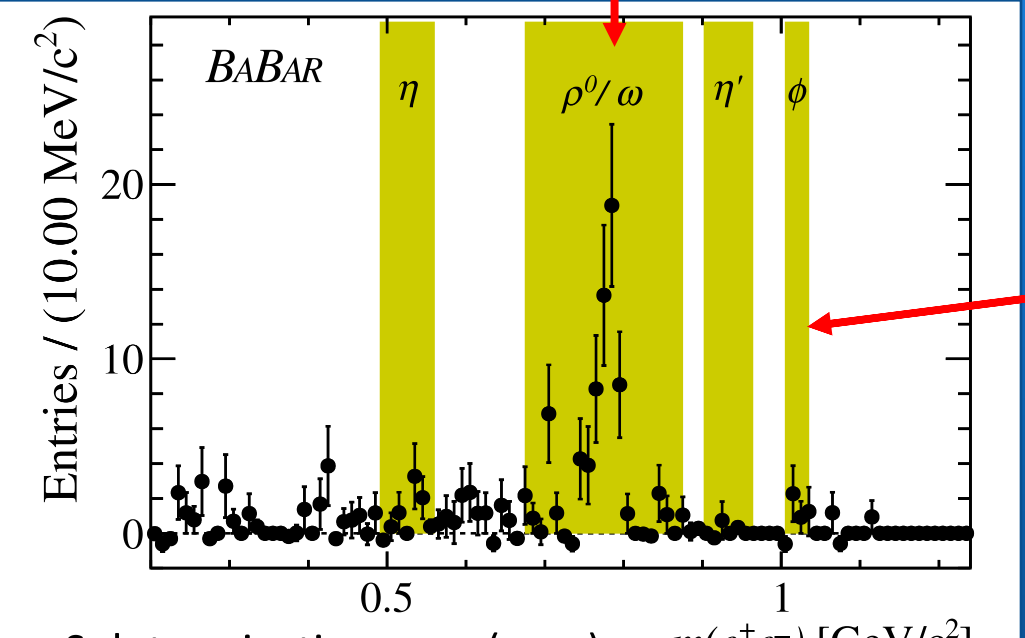
Rare or forbidden processes in the SM that provide windows on new physics

$D^{*+} \to D^0\pi^+$
$\quad \hookrightarrow K^-\pi^+e^+e^-$

Observation. First study in non resonant region



For $m(ee) \in [675, 875]$ MeV:
$Br = (4.0 \pm 0.5 \pm 0.2 \pm 0.1)\times10^{-6}$



Splot projection on m(e+e-)

For $m(ee) \in [1005, 1035]$ MeV:
$Br = \left(0.11\,^{+0.15}_{-0.11} \pm 0.06\right)\times10^{-6}$

For $m(ee)$ in the non-resonant range (unshaded):

- $Br = (1.6 \pm 0.6 \pm 0.7)\times10^{-6}$, Significance = 2.6σ
- 90% CL UL: Br $< 3.1\times10^{-6}$

Probing short distance and potential NP

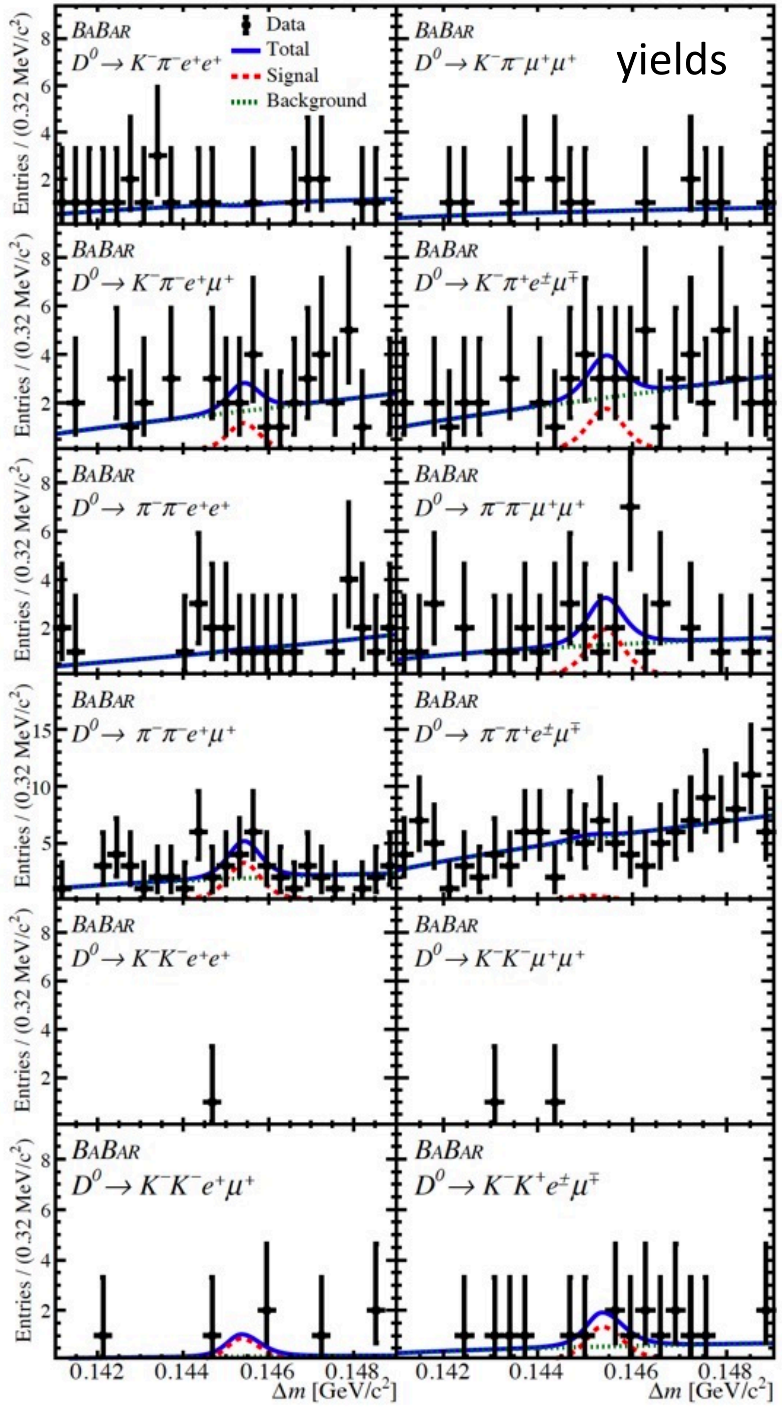
[arXiv:1905.00608v1](https://arxiv.org/abs/1905.00608v1)

Violations in D0→ hh'll'

- No signal, but large improvements w.r.t. previous limits

- Lepton-flavor violating (LFV):
  - $\pi^-\pi^+e^\pm\mu^\mp$, $K^-\pi^+e^\pm\mu^\mp$, $K^-K^+e^\pm\mu^\mp$
- Lepton-number violating (LNV):
  - $\pi^-\pi^-e^+e^+$, $\pi^-\pi^-\mu^+\mu^+$, $\pi^-\pi^-e^+\mu^+$
  - $K^-\pi^-e^+e^+$, $K^-\pi^-\mu^+\mu^+$, $K^-\pi^-e^+\mu^+$
  - $K^-K^-e^+e^+$, $K^-K^-\mu^+\mu^+$, $K^-Ke^+\mu^+$

Decay mode $D^0 \to$	N_{sig} (candidates)	ϵ_{sig} (%)	$\mathcal{B}$ $(\times 10^{-7})$	$\mathcal{B}$ 90% U.L. $(\times 10^{-7})$	Previous best limit $(\times 10^{-7})$
$\pi^-\pi^-e^+e^+$	$0.22 \pm 3.15 \pm 0.54$	4.38	$0.27 \pm 3.90 \pm 0.67$	9.1	1120
$\pi^-\pi^-\mu^+\mu^+$	$6.69 \pm 4.88 \pm 0.80$	4.91	$7.40 \pm 5.40 \pm 0.91$	15.2	290
$\pi^-\pi^-e^+\mu^+$	$12.42 \pm 5.30 \pm 1.45$	4.38	$15.4 \pm 6.59 \pm 1.85$	30.6	790
$\pi^-\pi^+e^\pm\mu^\mp$	$1.37 \pm 6.15 \pm 1.28$	4.79	$1.55 \pm 6.97 \pm 1.45$	17.1	150
$K^-\pi^-e^+e^+$	$-0.23 \pm 0.97 \pm 1.28$	3.19	$-0.38 \pm 1.60 \pm 2.11$	5.0	2060
$K^-\pi^-\mu^+\mu^+$	$-0.03 \pm 2.10 \pm 0.40$	3.30	$-0.05 \pm 3.34 \pm 0.64$	5.3	3900
$K^-\pi^-e^+\mu^+$	$3.87 \pm 3.96 \pm 2.36$	3.48	$5.84 \pm 5.97 \pm 3.56$	21.0	2180
$K^-\pi^+e^\pm\mu^\mp$	$2.52 \pm 4.60 \pm 1.35$	3.65	$3.62 \pm 6.61 \pm 1.95$	19.0	5530
$K^-K^-e^+e^+$	$0.30 \pm 1.08 \pm 0.41$	3.25	$0.43 \pm 1.54 \pm 0.58$	3.4	1520
$K^-K^-\mu^+\mu^+$	$-1.09 \pm 1.29 \pm 0.42$	6.21	$-0.81 \pm 0.96 \pm 0.32$	1.0	950
$K^-K^-e^+\mu^+$	$1.93 \pm 1.92 \pm 0.83$	4.63	$1.93 \pm 1.93 \pm 0.84$	5.8	570
$K^-K^+e^\pm\mu^\mp$	$4.09 \pm 3.00 \pm 1.59$	4.83	$3.93 \pm 2.89 \pm 1.45$	10.0	1800



Belle R_{K^*}

$$R_{K^*} = \frac{BR(B \to K^* \mu^+ \mu^-)}{BR(B \to K^* e^+ e^-)}$$

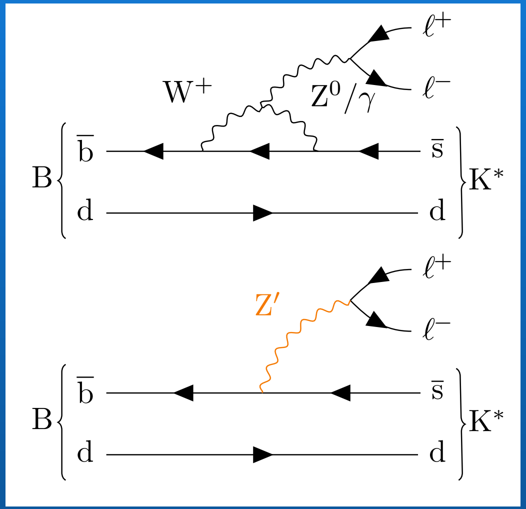
$B^0 \to K^{*0}\ell^+\ell^-$
$B^+ \to K^{*+}\ell^+\ell^-$

$K^{*0} \to K^+\pi^-$
$K^{*+} \to K^+\pi^0$
$K^{*+} \to K^0_S\pi^+$

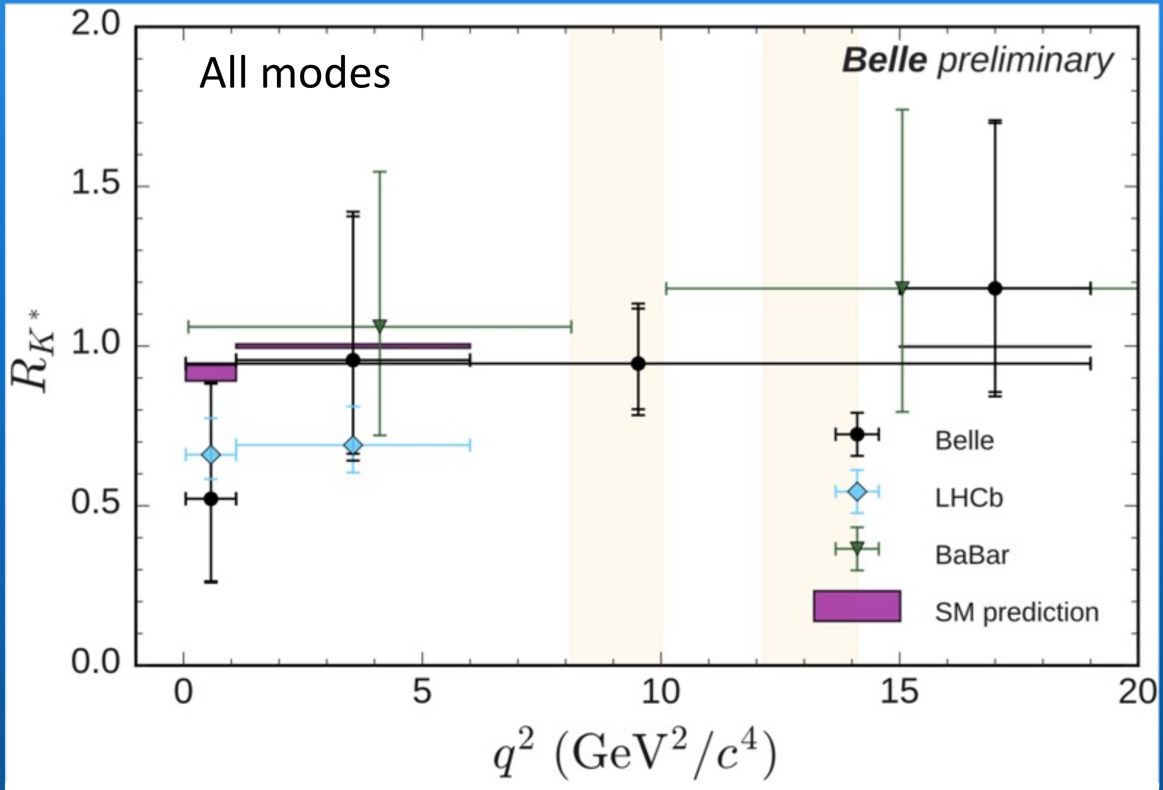
arXiv:1904.02440

First measurement of $R(K^{*+})$.

- Test of lepton flavor universality
- Theoretically clean
- Sensitive to new physics



- All measured values are in accordance with the SM and other recent measurements.



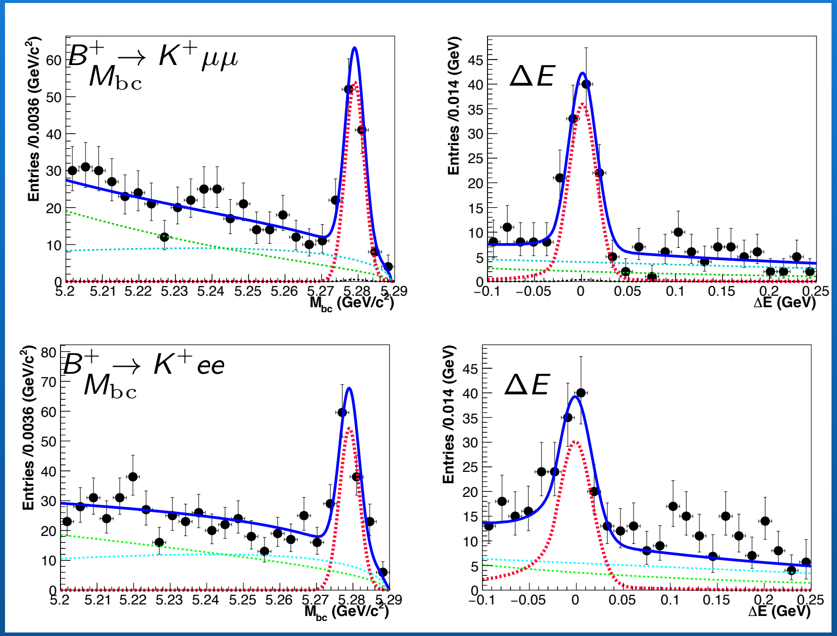
- $103.0^{+13.4}_{-12.7}$ ($139.0^{+16.0}_{-15.4}$) events in the electron (muon) modes.

S. Choudhury, Measurement of Lepton Flavor Universality in B decays at Belle, Flavor and CP Violation, Friday 14:50

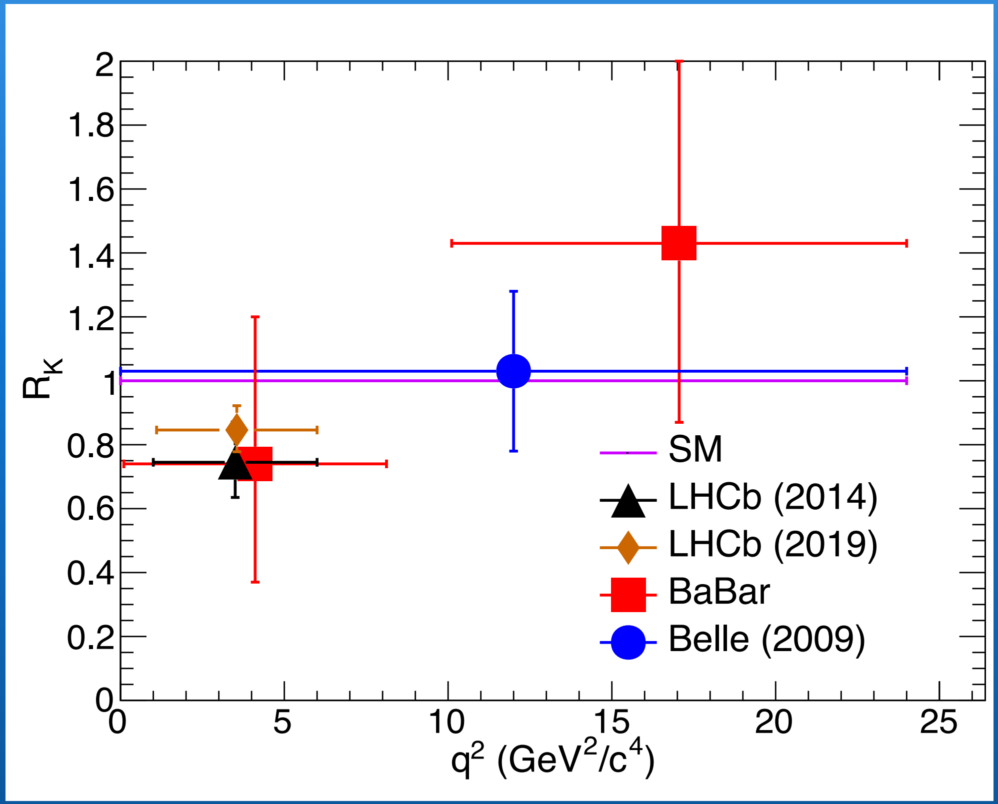
$$R_K = \frac{BR(B^+ \to K^+\mu^+\mu^-)}{BR(B^+ \to K^+e^+e^-)}$$

Belle R(K)

- New measurement with 711 fb^{-1} (was 605 fb^{-1})
- Both charged and neutral mode
- Multidimensional M_{bc} ΔE fit to extract the yield



Previous results



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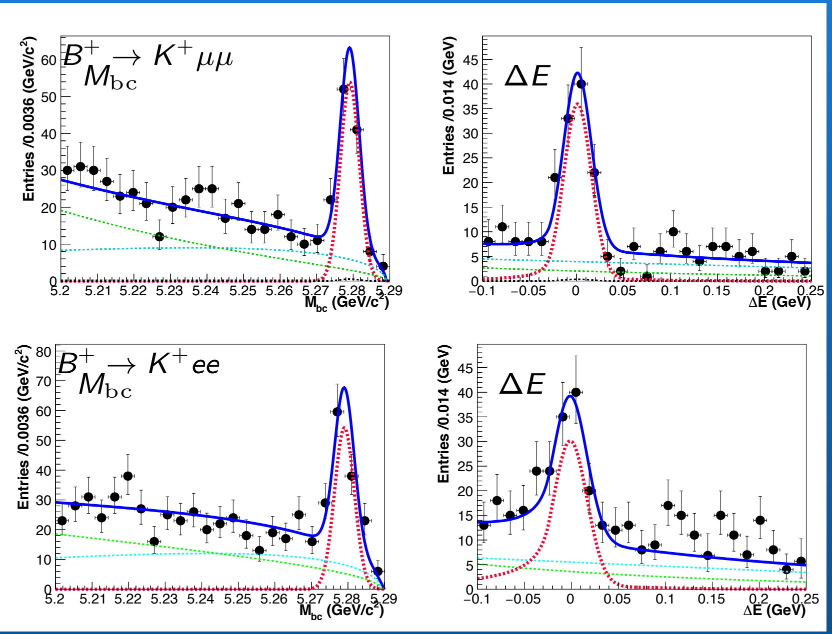
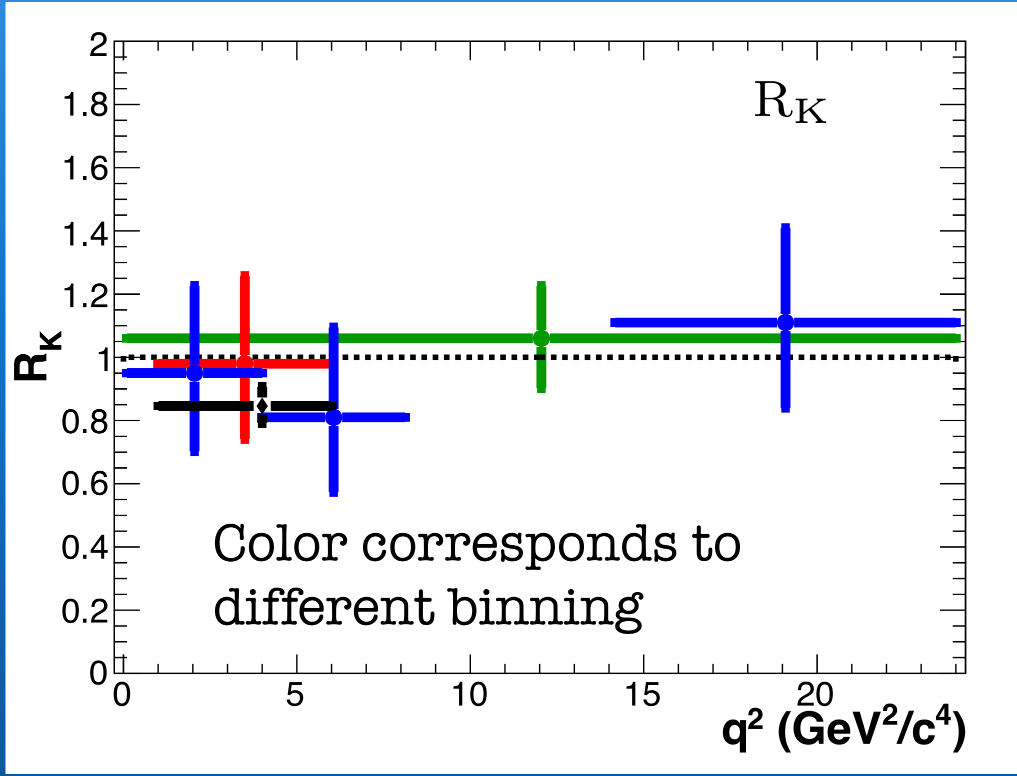


New result: no discrepancy



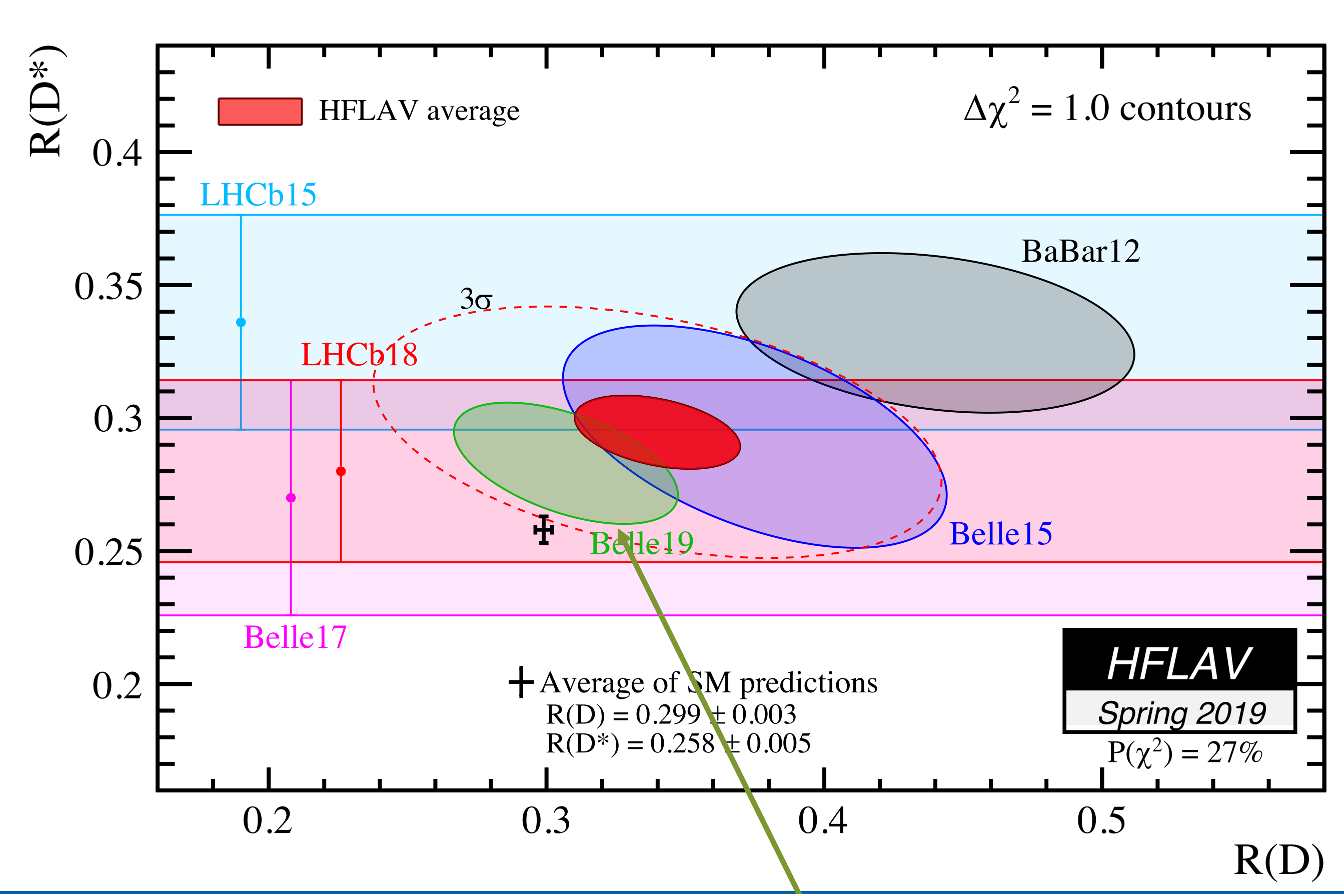
442. Measurement of Lepton Flavor Universality in B decays at Belle, Seema Choudhury

$$R(D^*) \equiv \frac{\mathcal{B}(\bar{B} \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{*+}\ell^-\bar{\nu}_\ell)}$$

Belle R(D$^{(*)}$)

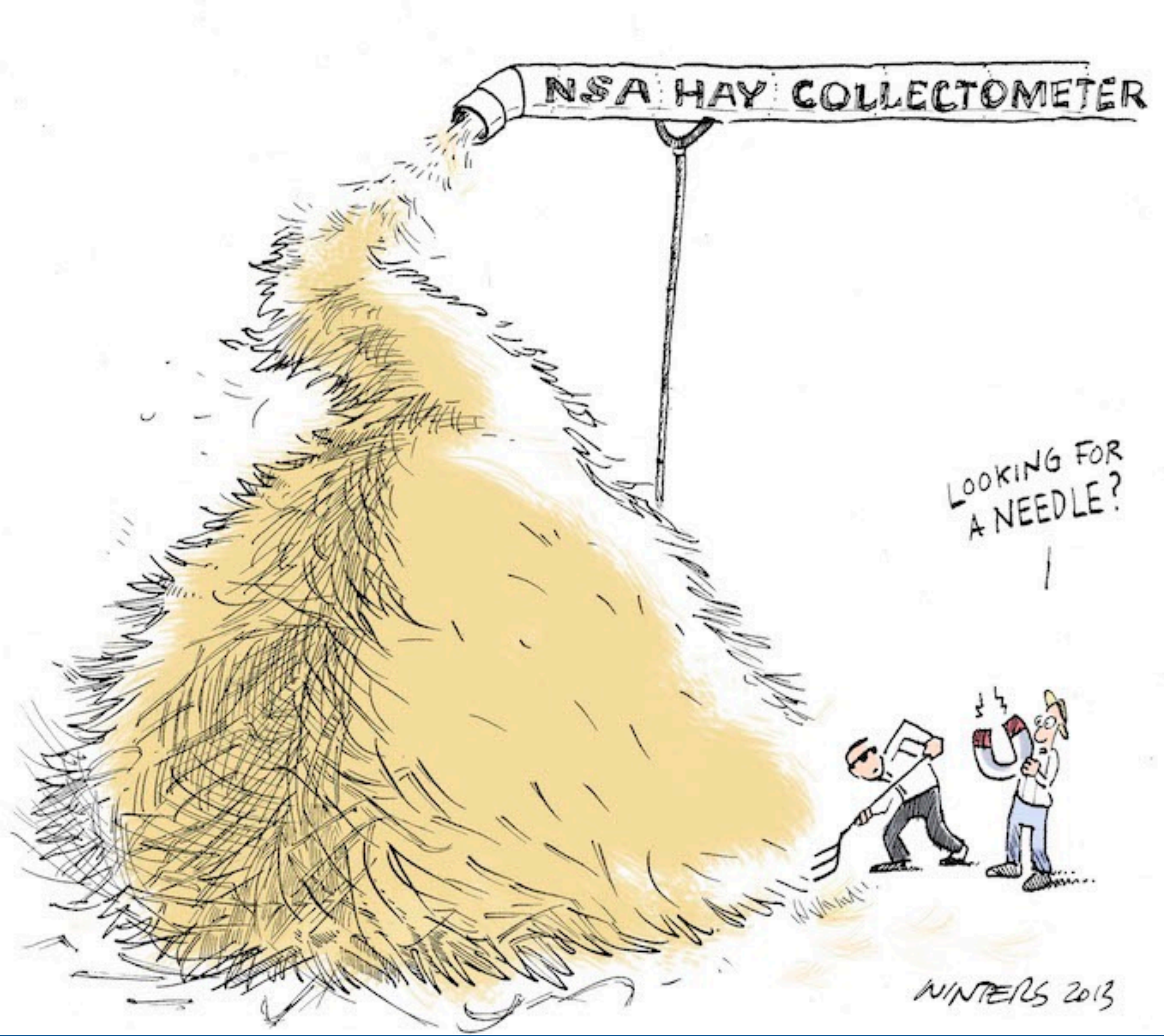
arXiv:1904.08794v2

- Long standing tension with SM prediction (was 3.8σ)
- New measurement using semileptonic tag (first measurement for R(D))
- Single most precise result: compatible with SM @ 1.2σ
  - Still statistically limited
- R(D)-R(D*) exp. world average tension with SM decreases to 3.1σ



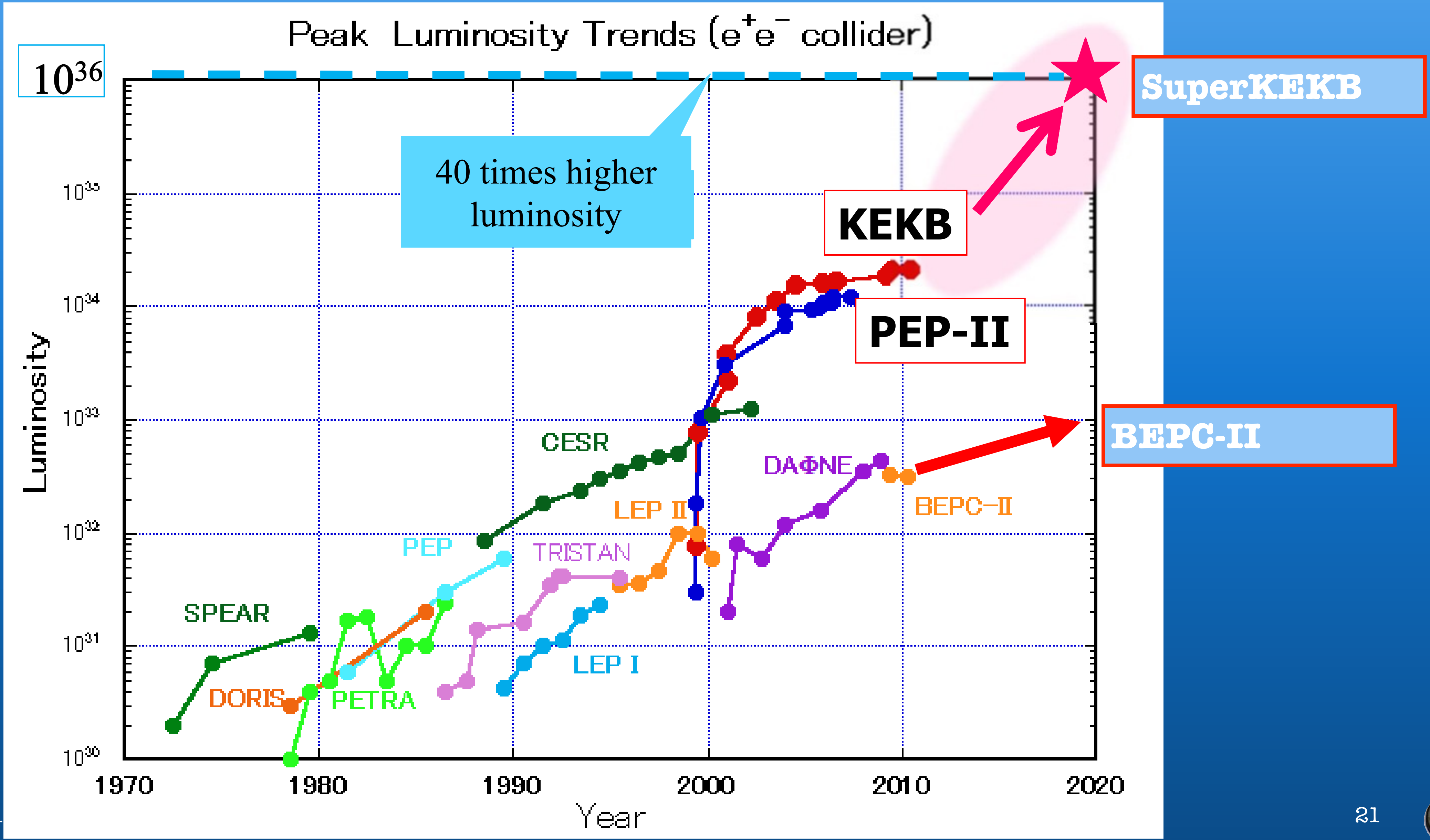
Belle 2019:

$$\begin{aligned} \mathcal{R}(D) &= 0.307 \pm 0.037 \pm 0.016 \\ \mathcal{R}(D^*) &= 0.283 \pm 0.018 \pm 0.014 \end{aligned}$$

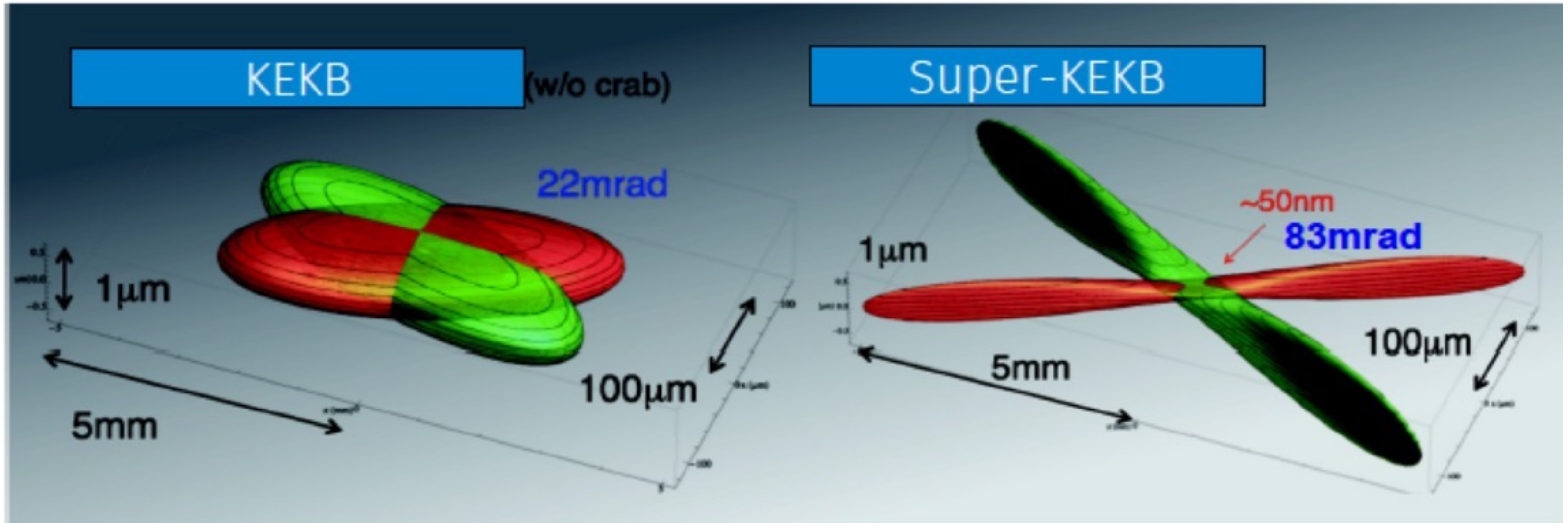

NSA HAY COLLECTOMETER
LOOKING FOR A NEEDLE?
WINTERS 2013

The promise for the future
Belle II @ SuperKEKB

The intensity frontier



The path to higher luminosity



	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}

factor 20 factor 2-3

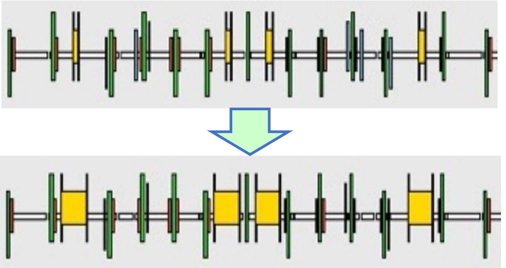
- **Reduce Beam size**
  KEKB: 100μm x 2μm
  SuperKEKB: 10μm x 0.06μm

- **Change beam energies** to solve the problem of short lifetime for the LER
- Consequence βγ: decrease 0.42 → 0.28

- **Nano-beams and more beam current** to increase luminosity
- **Large crossing angle**

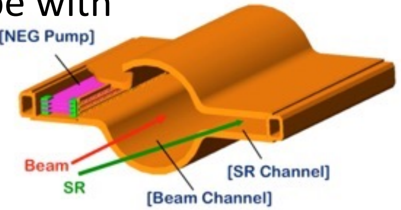
KEKB → SuperKEKB

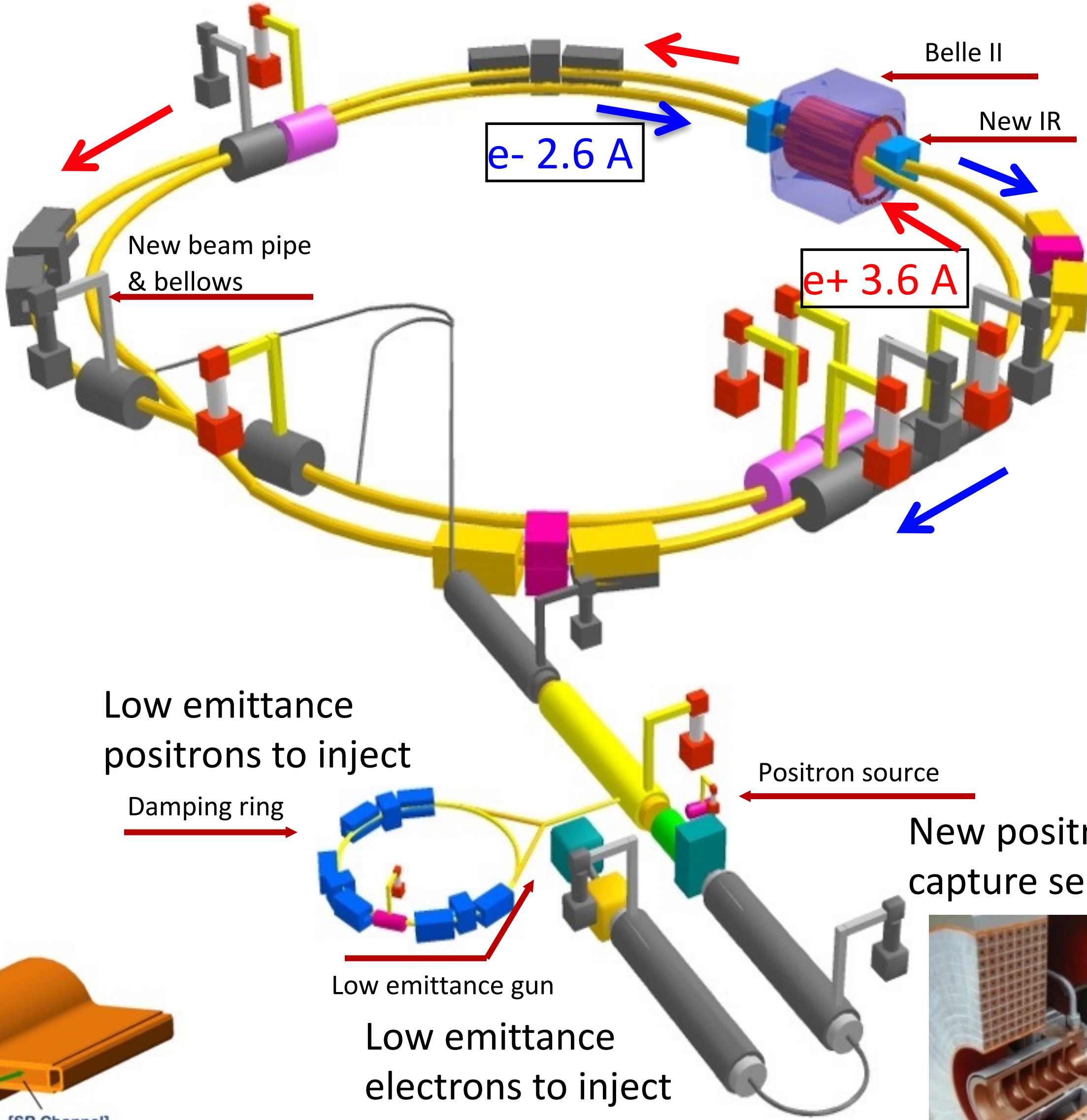
Replace short dipoles
with longer ones (LER)



Redesign the lattices of HER &
LER to squeeze the emittance

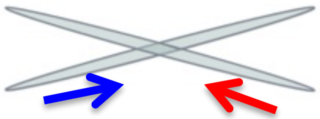
TiN-coated beam pipe with
antechambers



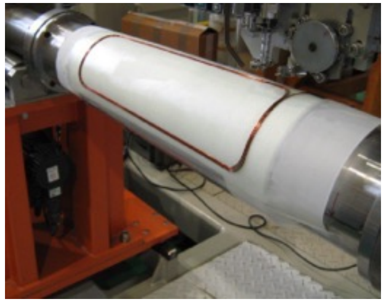


Low emittance
positrons to inject

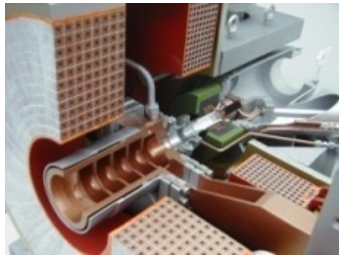
Low emittance
electrons to inject



New superconducting /permanent
final focusing quads near the IP

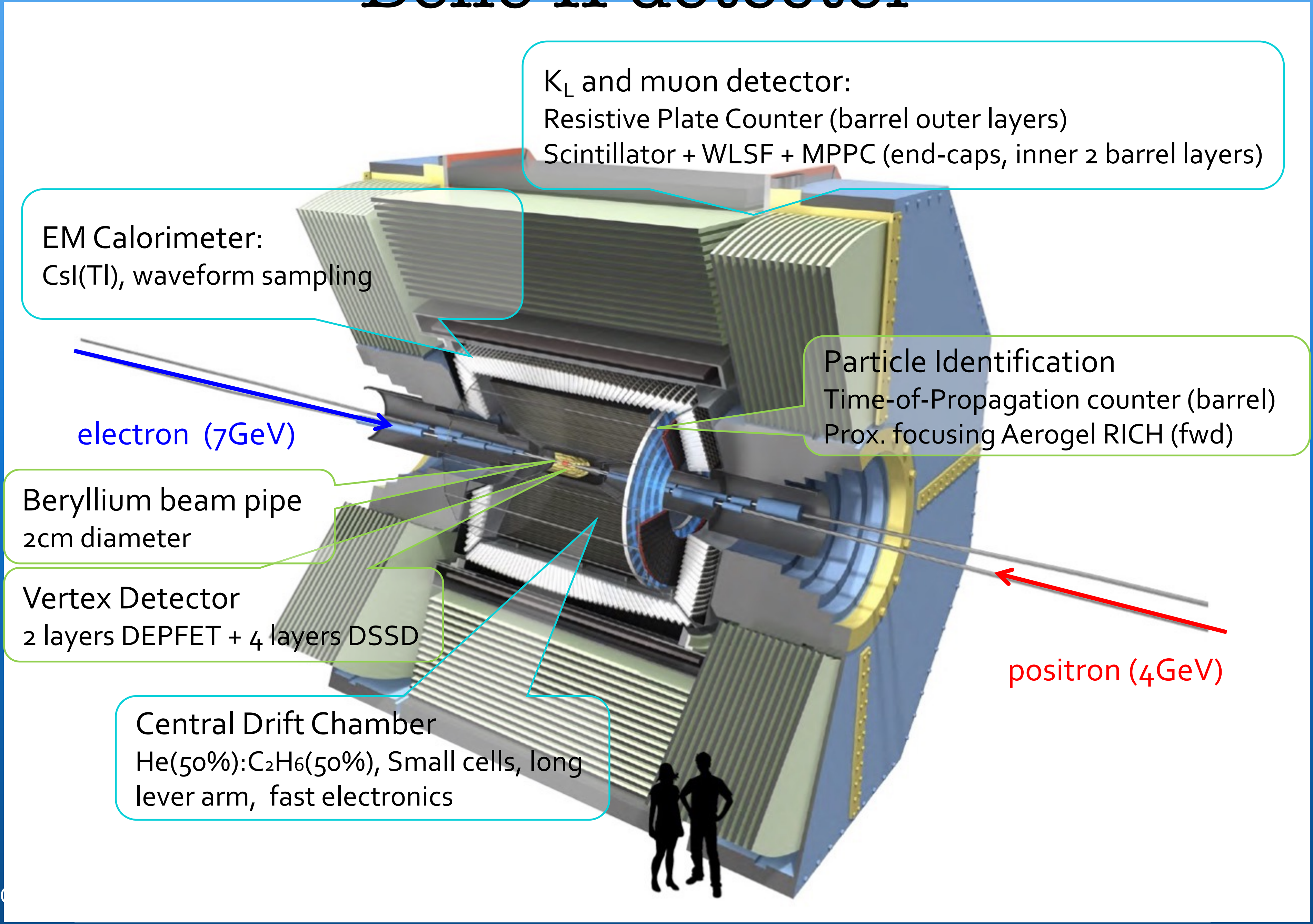


New positron target /
capture section



Add / modify RF systems
for higher beam current

Belle II detector



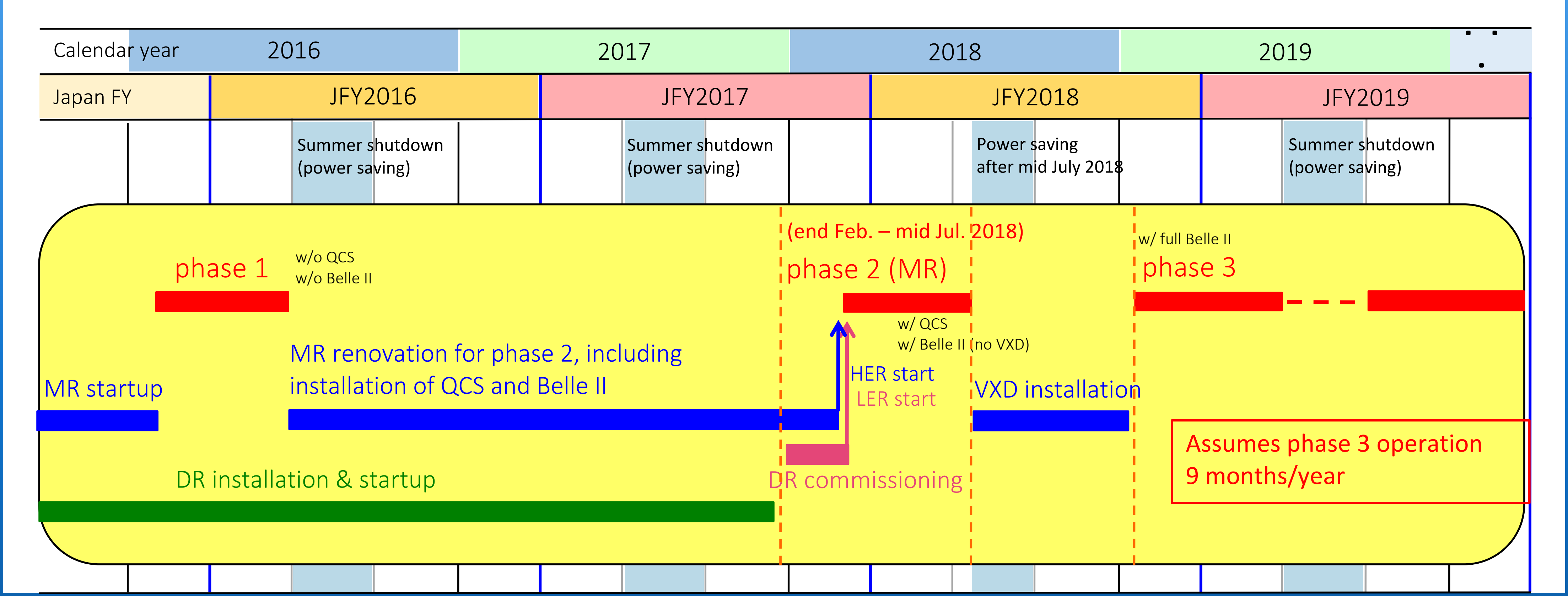
VXD Installed in Dec 2018

Partial PXD layer 2, will be completed in 2021

774. Commissioning of the Belle II Pixel Vertex Detector, Dr Hua Ye

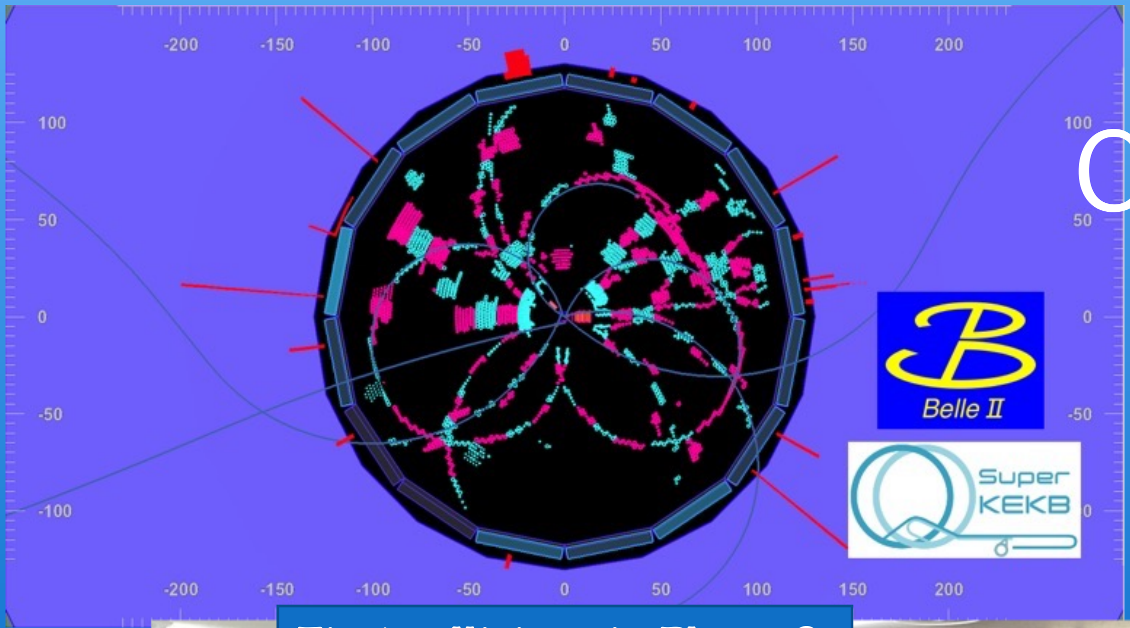
722. Performance of the Belle II Silicon Vertex Detector, Antonio Paladino

SuperKEKB/Belle II schedule



Phase 1 (2016): SuperKEKB commissioning and background estimation – no collisions
Phase 2 (2018): Collision runs with final focus, but without VXD → first physics data
Phase3 (2019-->): Physics run started in March 2019. Will continue with 7-9 months/year

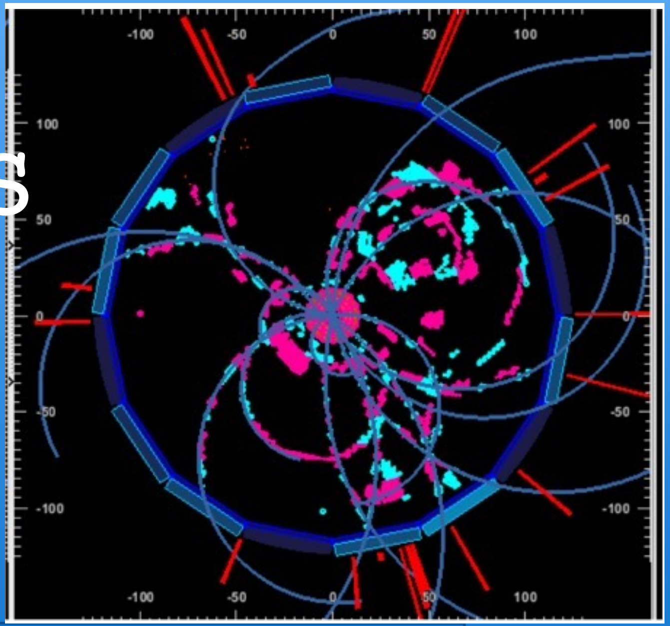
Collisions



First collisions in Phase 2

Apr 26, 2018

$$e^+e^- \to B\overline{B}$$

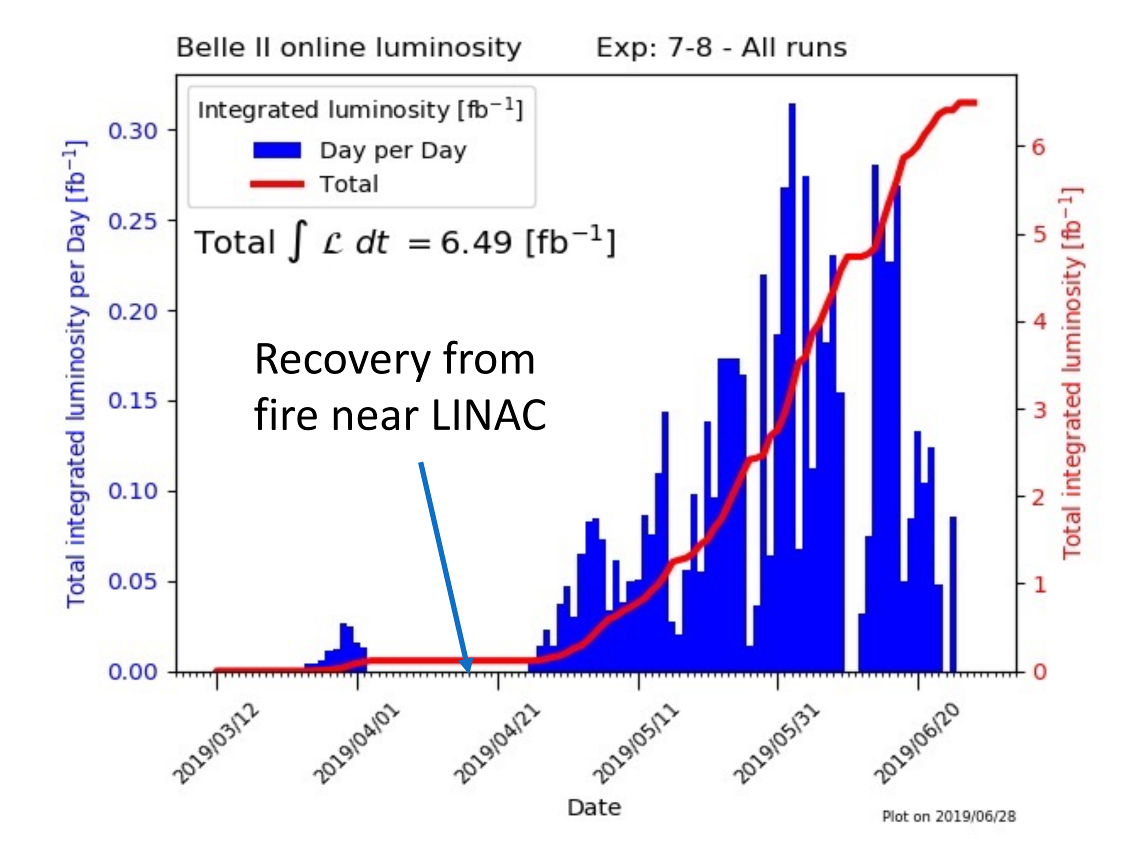


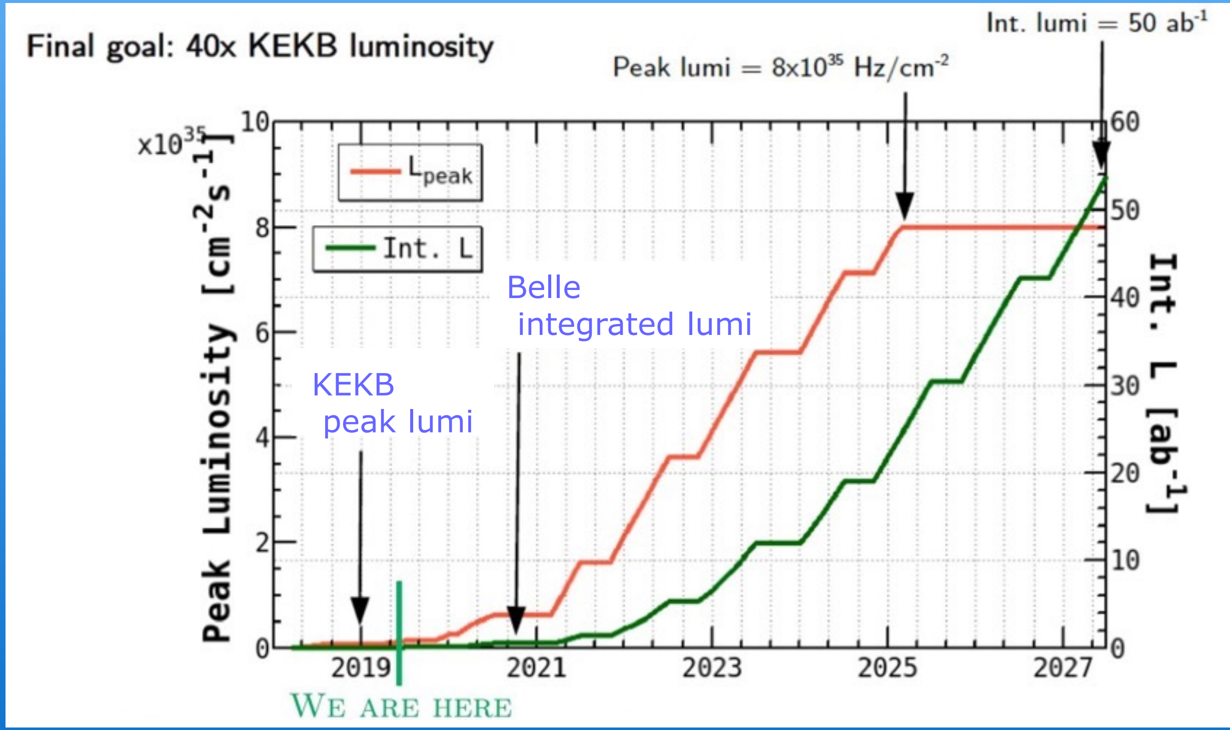
First collisions in Phase 3

March 26, 2019

Luminosity

- Backgrounds are still high
- Luminosity limited by beam blow-up
- New machine: lot of tuning required

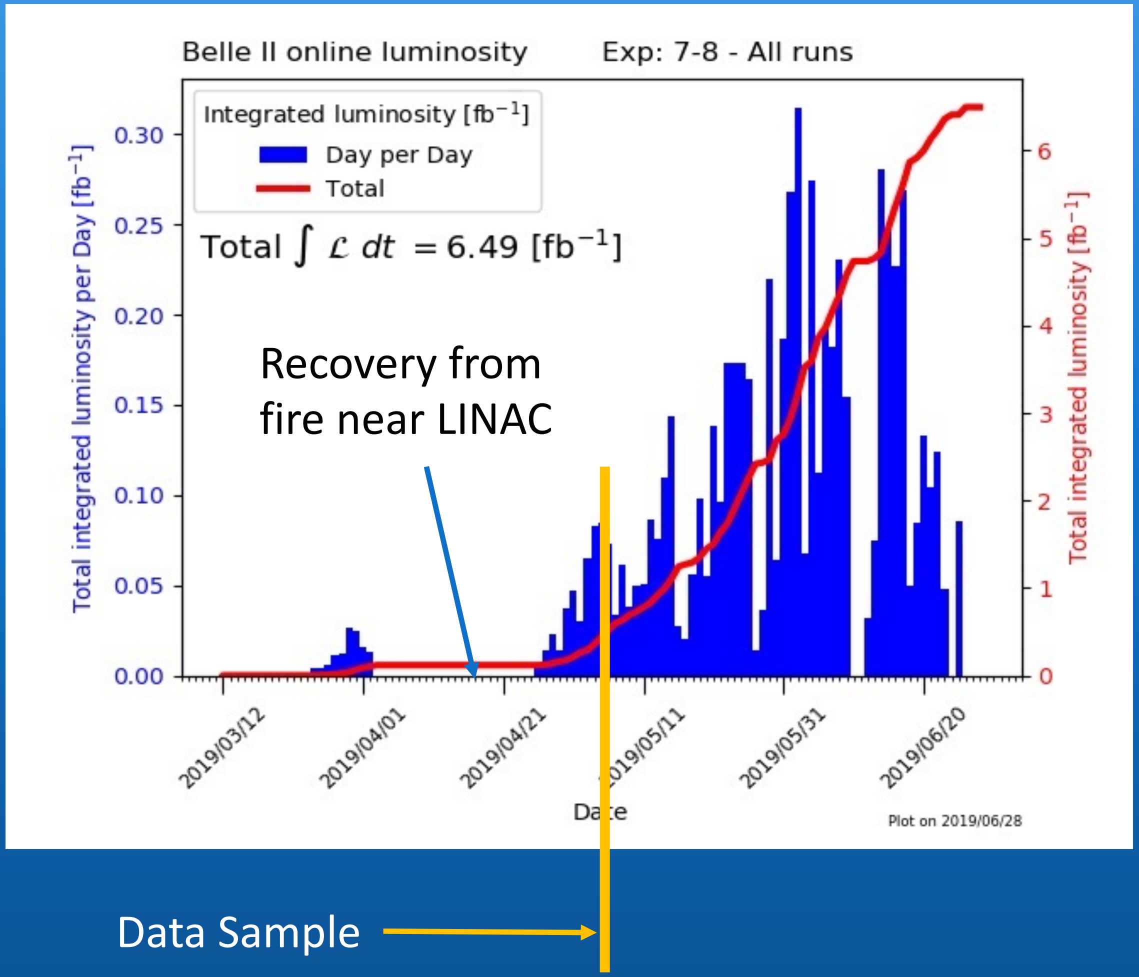




Parameter	Achieved	Target
I_{LER}(max)(A)	0.880	2.6
I_{HER}(max)(A)	0.940	3.6
β_y* (mm)	2	0.3
# bunches	1576	2364
L_{peak}(cm^{-2} s^{-1})	6.1 x 10^{33}	8 x 10^{35}
L(det OFF)	12 x 10^{33}	

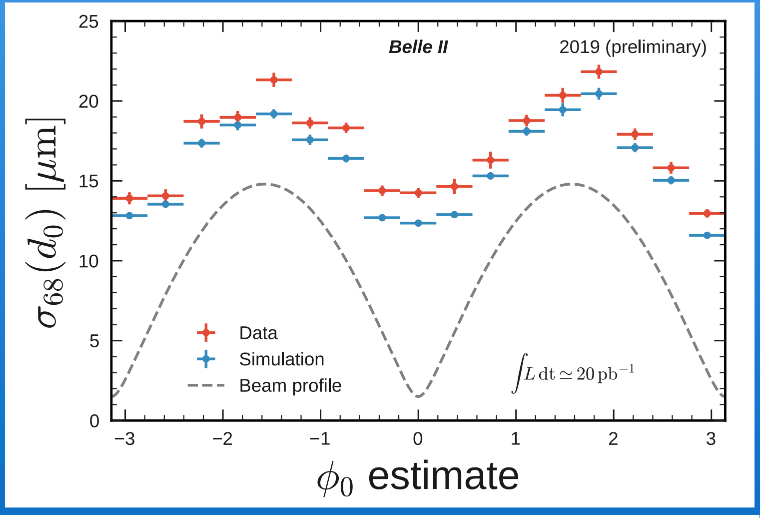
Results

- The run has just finished (July 1st)
- In this talk present performance studies and initial cross checks and results
- Data sample: 410 pb^{-1} calibrated, aligned and reprocessed data.
- Less than 1/10 of the total data 6.49 fb^{-1}



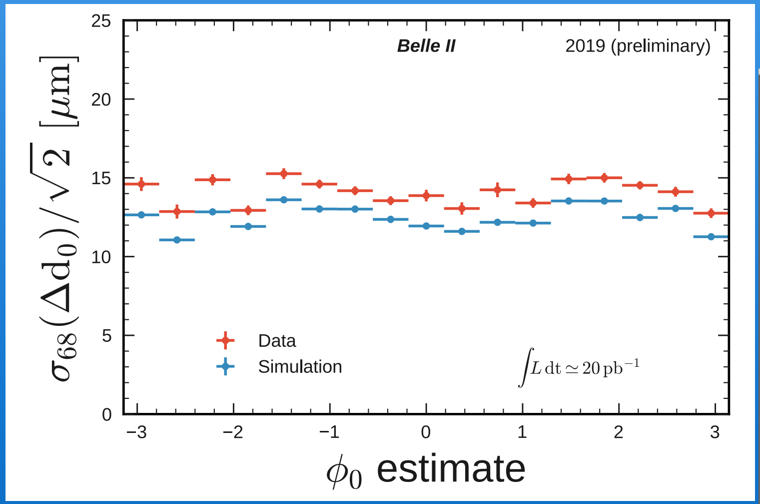
Tracking performance

- Impact parameter resolution 2-track events



Beam profile computed with $\sigma_x = 14.8\,\mu\mathrm{m}$ and $\sigma_y = 1.5\,\mu\mathrm{m}$.

-



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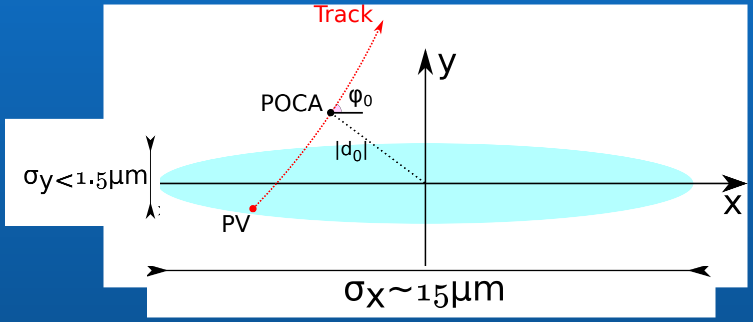
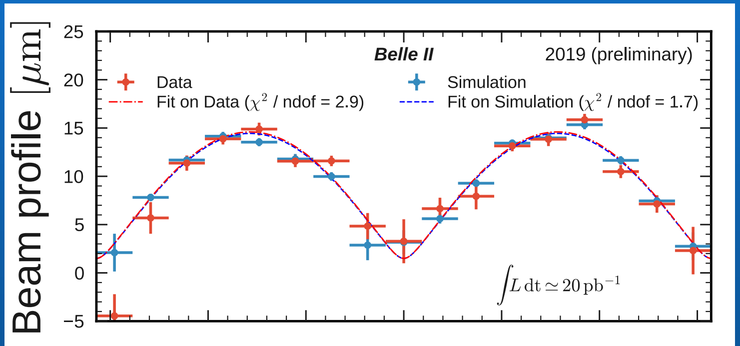
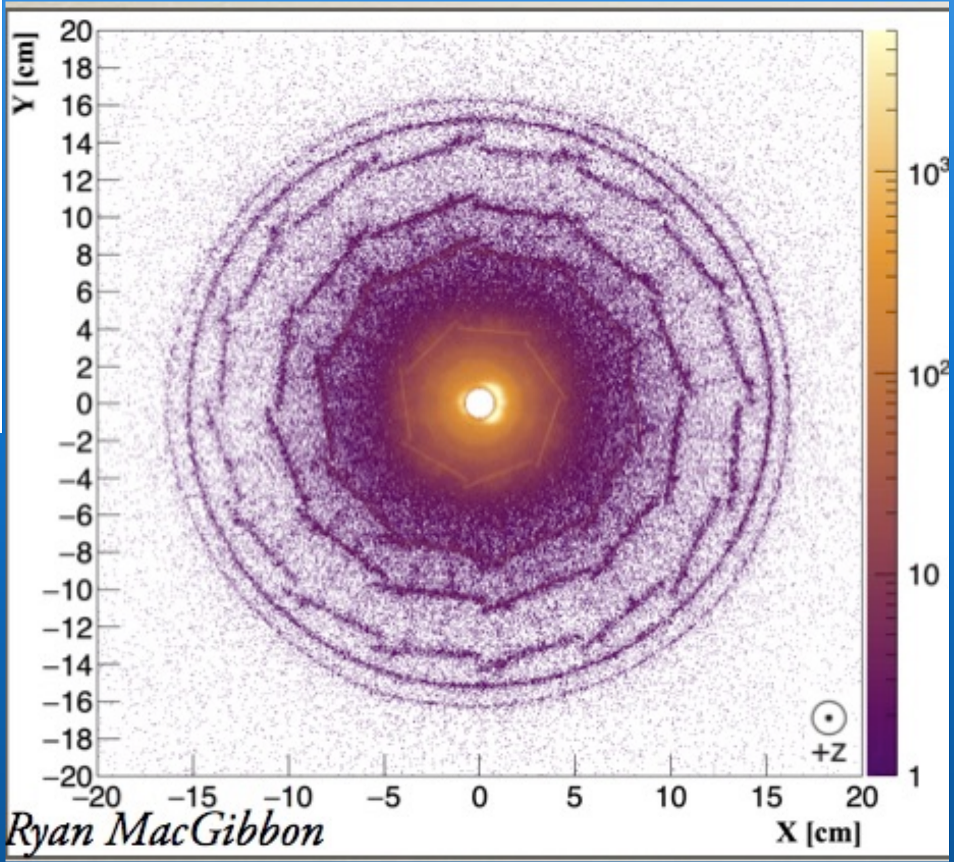




Confirmation of Beam Profile

- V0s from pp

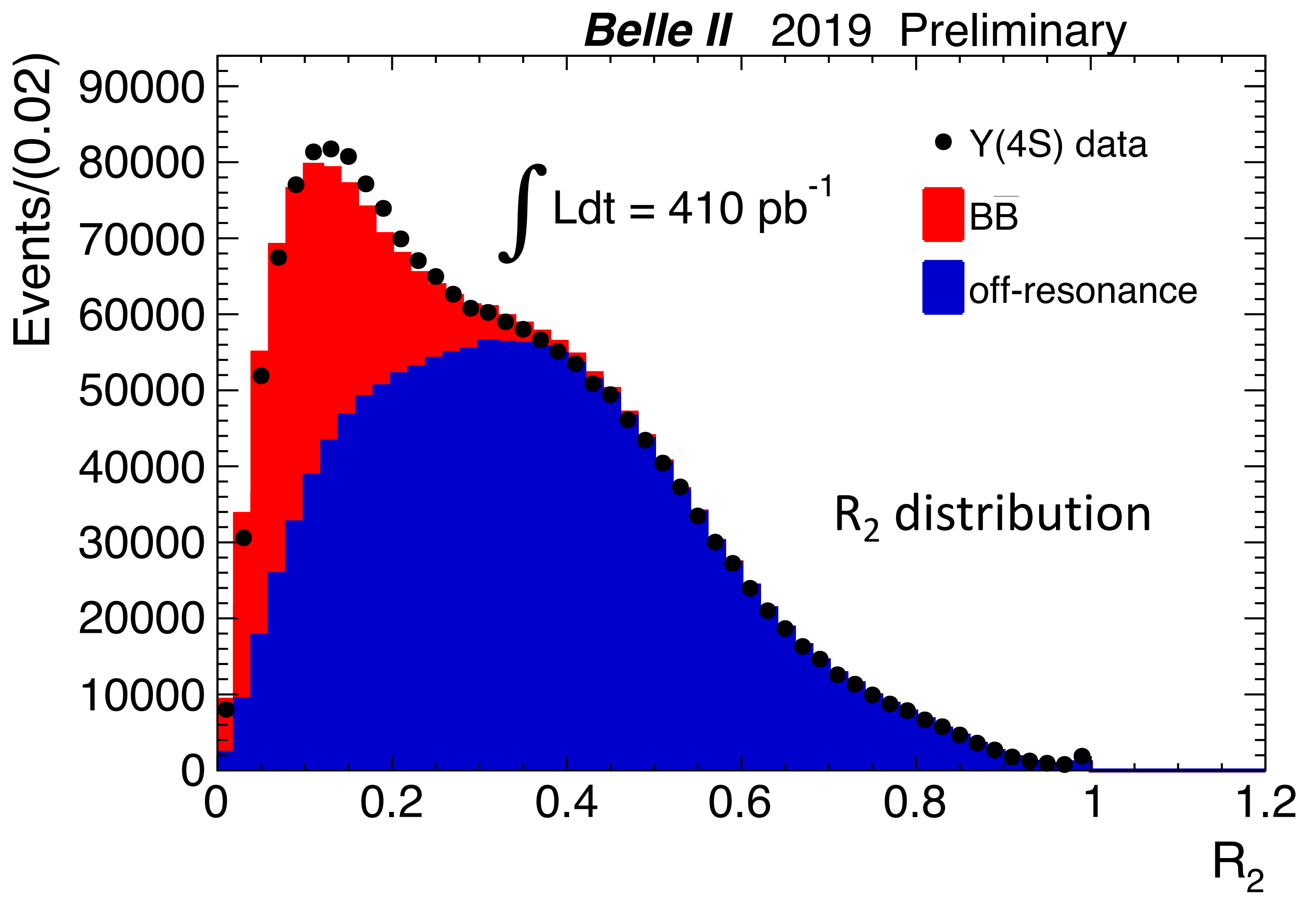


Event shape and B counting

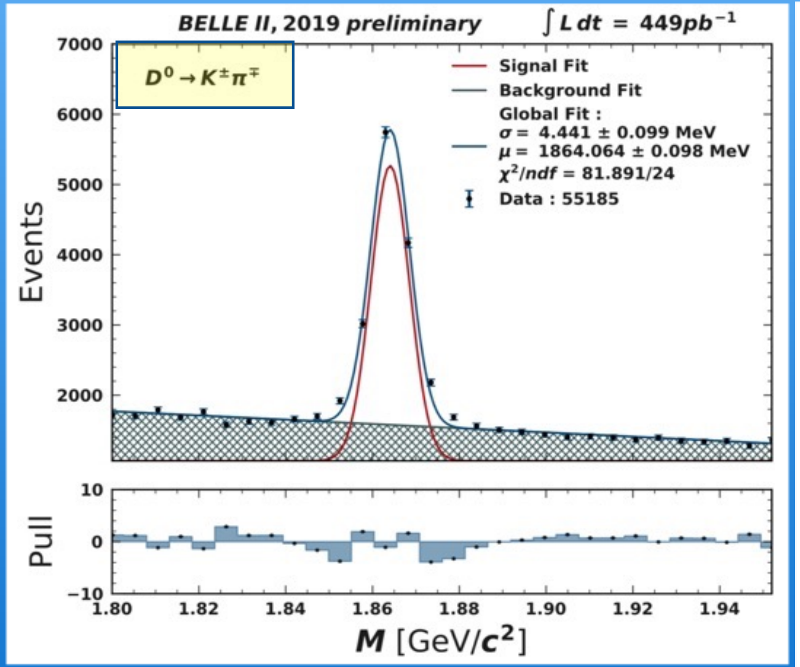
$$H_l = \Sigma_{ij} |p_i||p_j| P_l(\cos\theta_{ij})$$

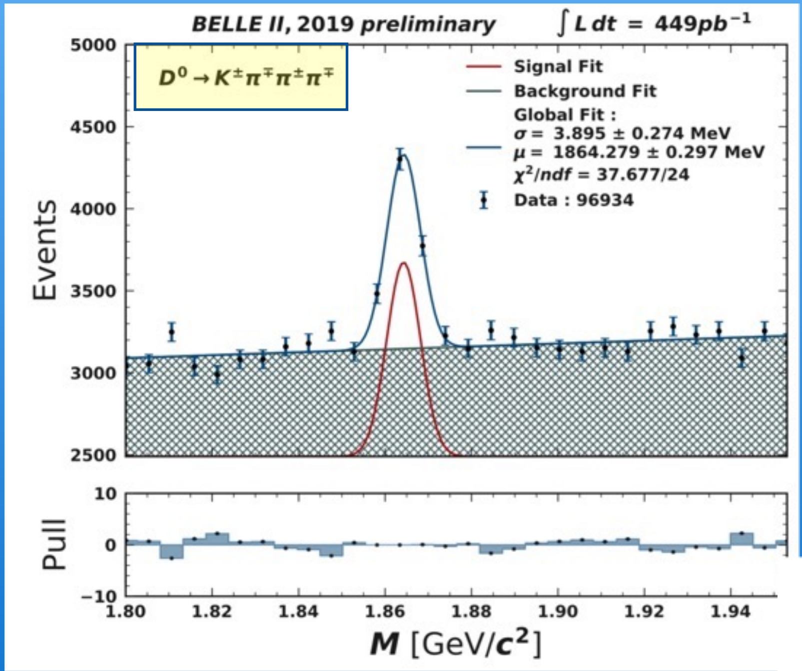
$$R_2 = H_2/H_0$$

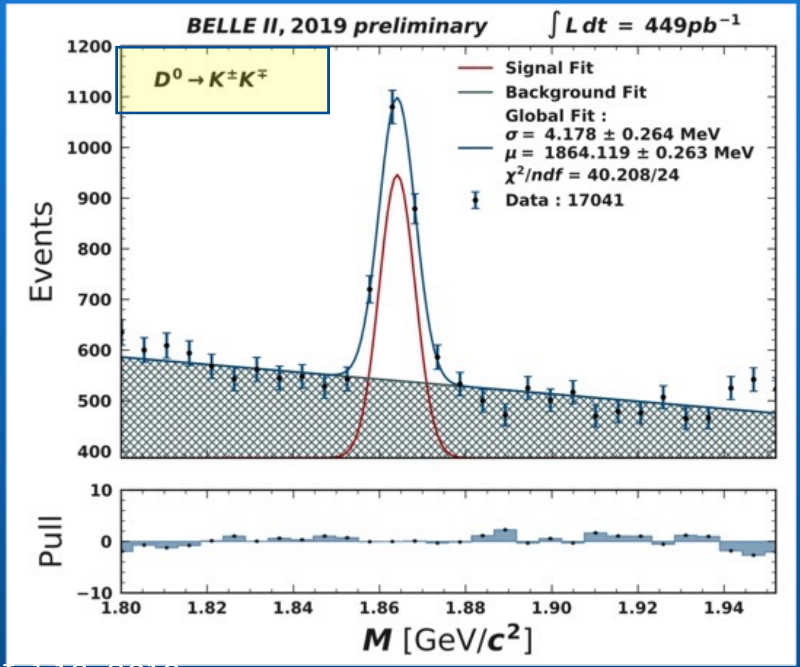
- Using continuum MC find excess events in data.
- Most likely due to an imperfect machine background modelling
- Use off-resonance data for continuum modelling

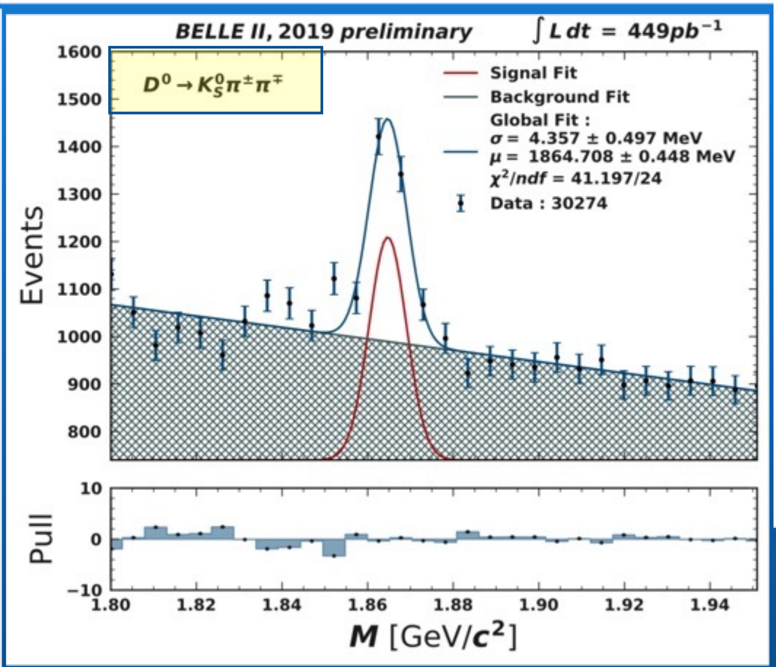


Mass peaks

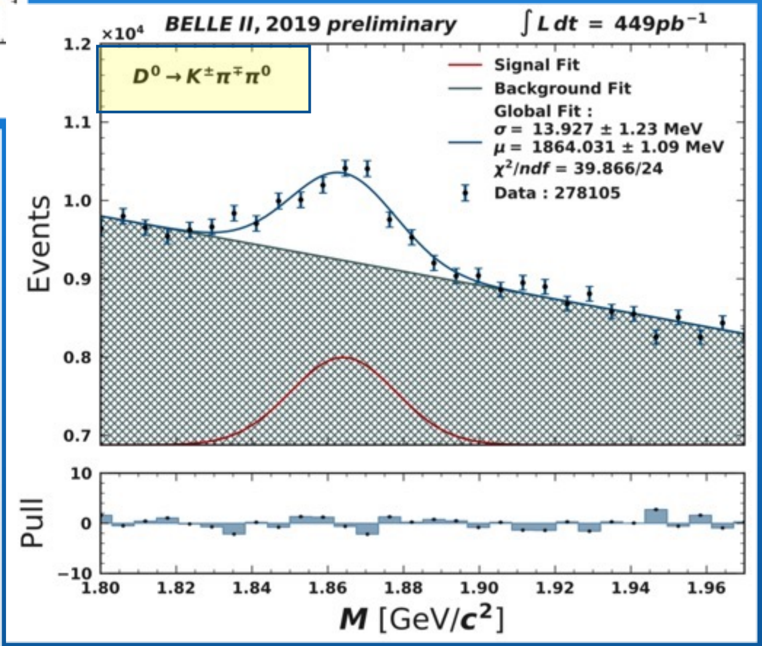






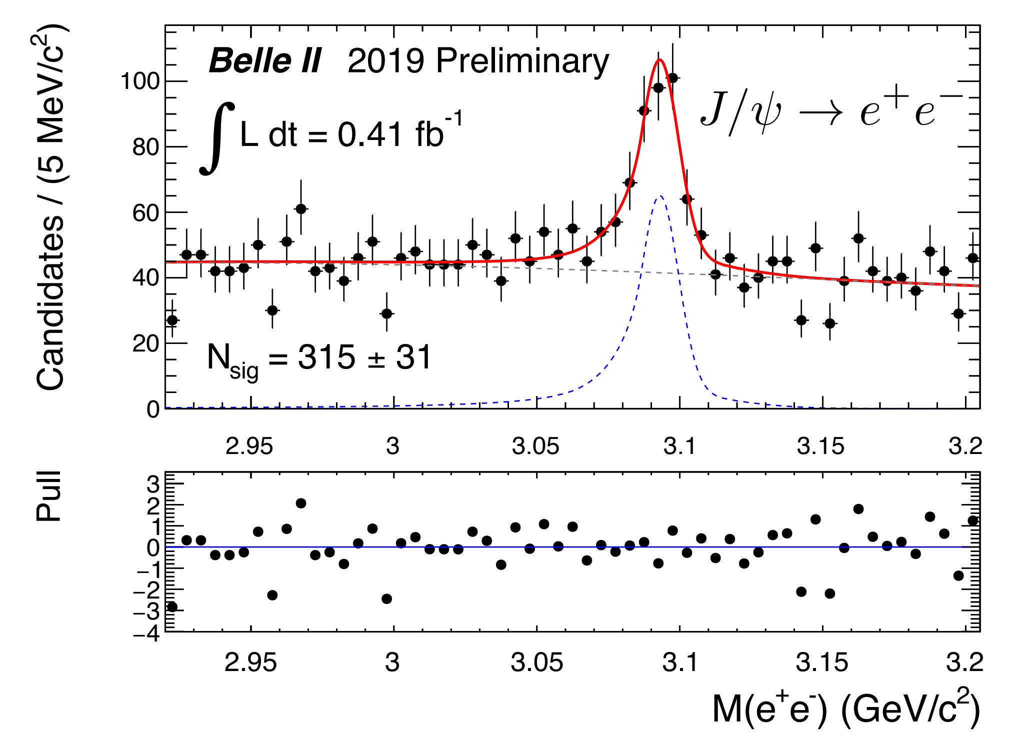


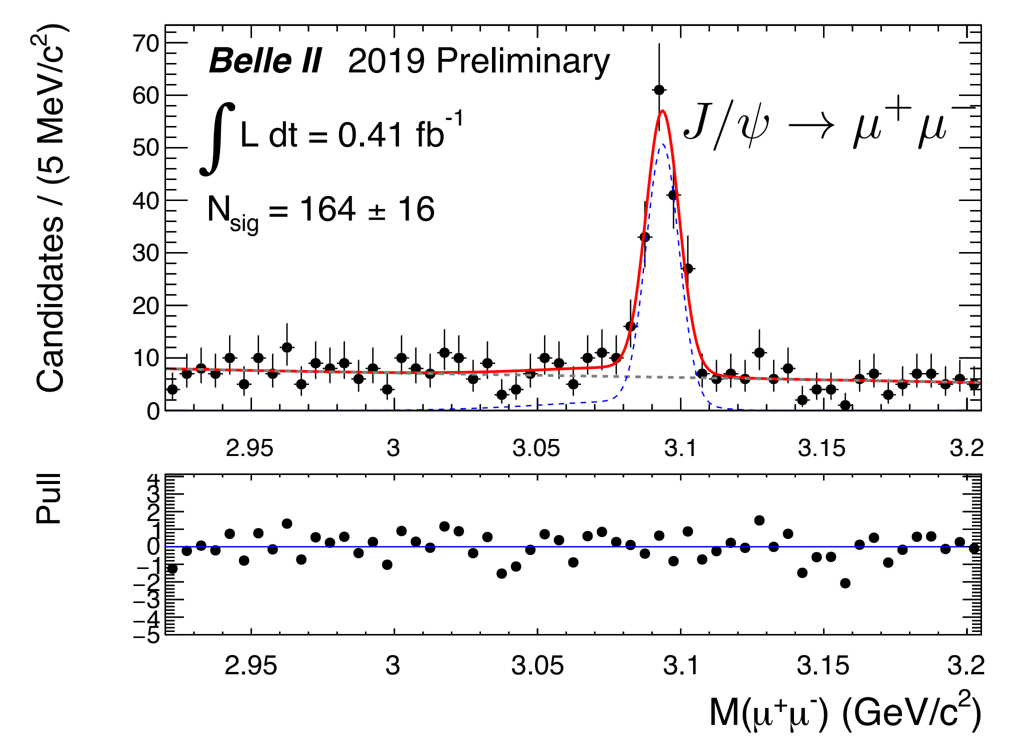
- Identify Kaons, pions, ….



Mass peaks

- …electrons, muons
- Reconstruct vertices.

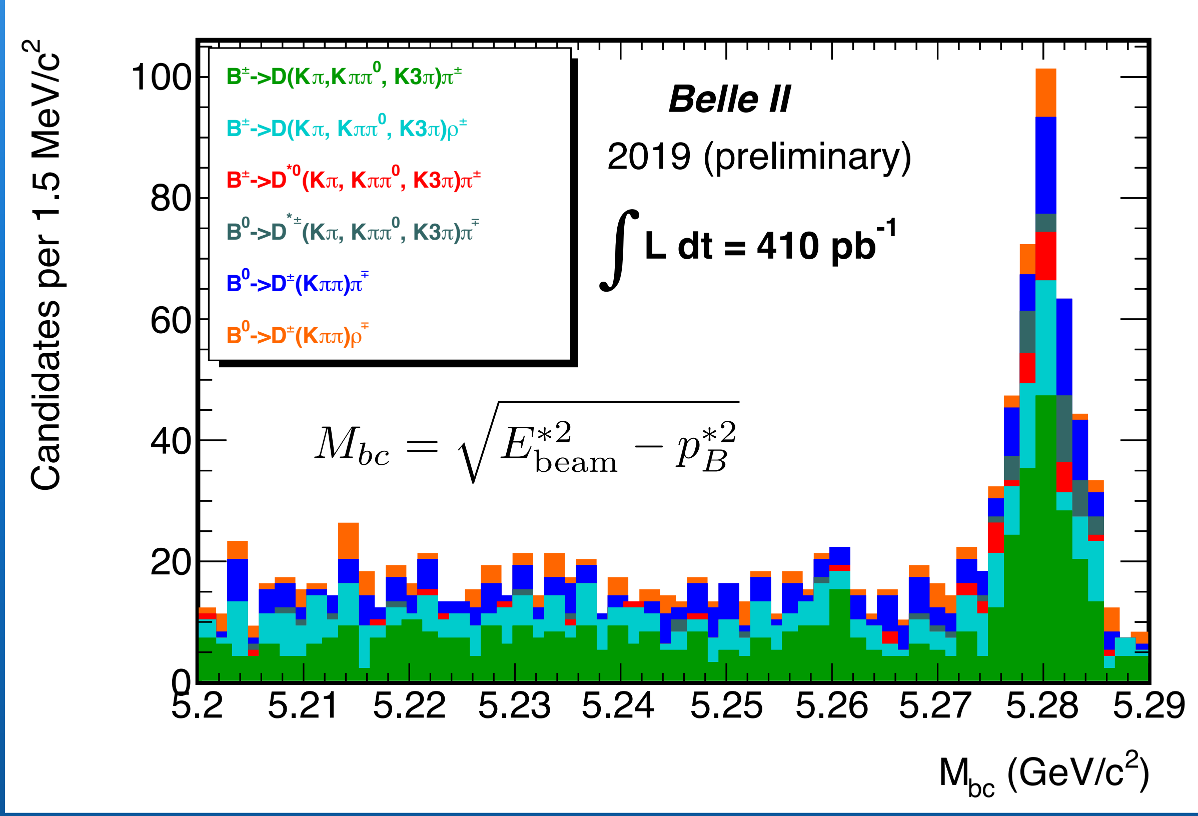


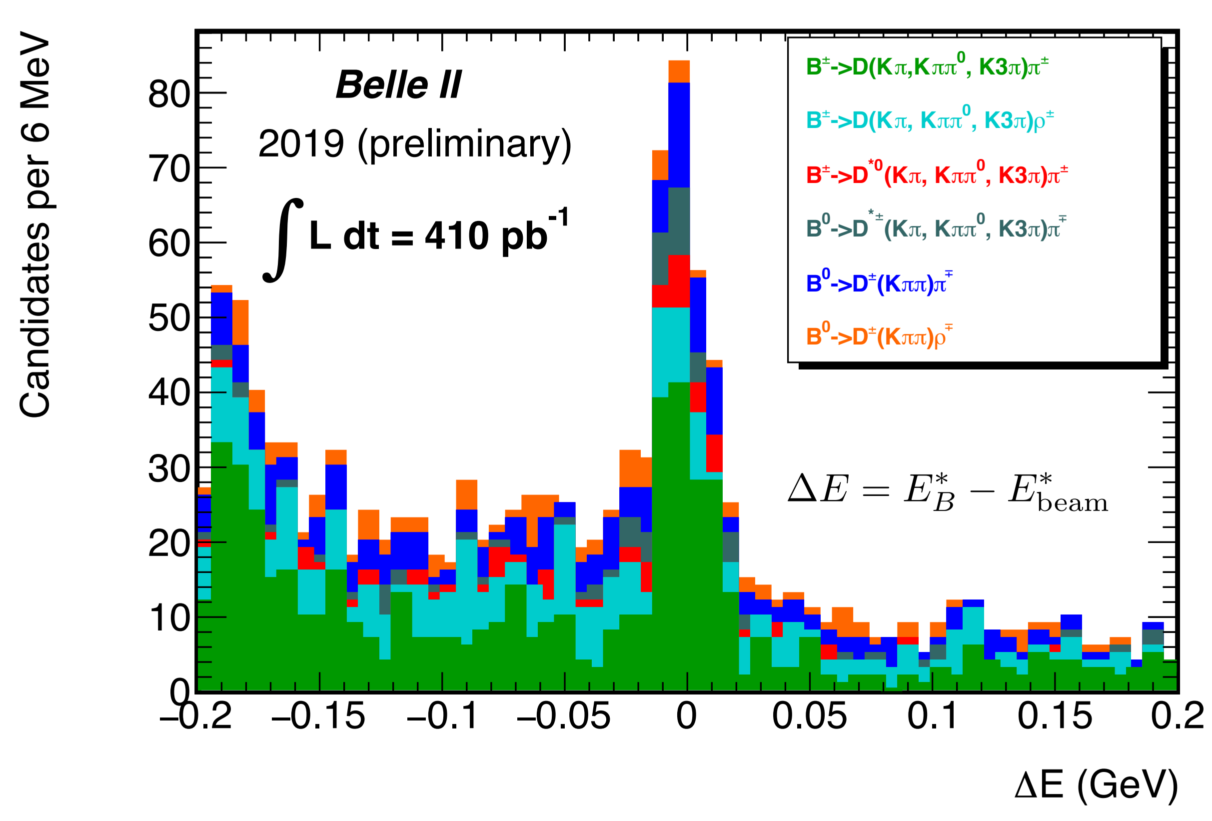


B→Dh exclusive reconstruction

$$B \to D\pi$$
$$B \to D\rho$$
$$B \to D^{*0}\pi$$
$$B^0 \to D^{*\pm}\pi$$
$$B^0 \to D^-\pi^+$$
$$B^0 \to D^-\rho^+$$

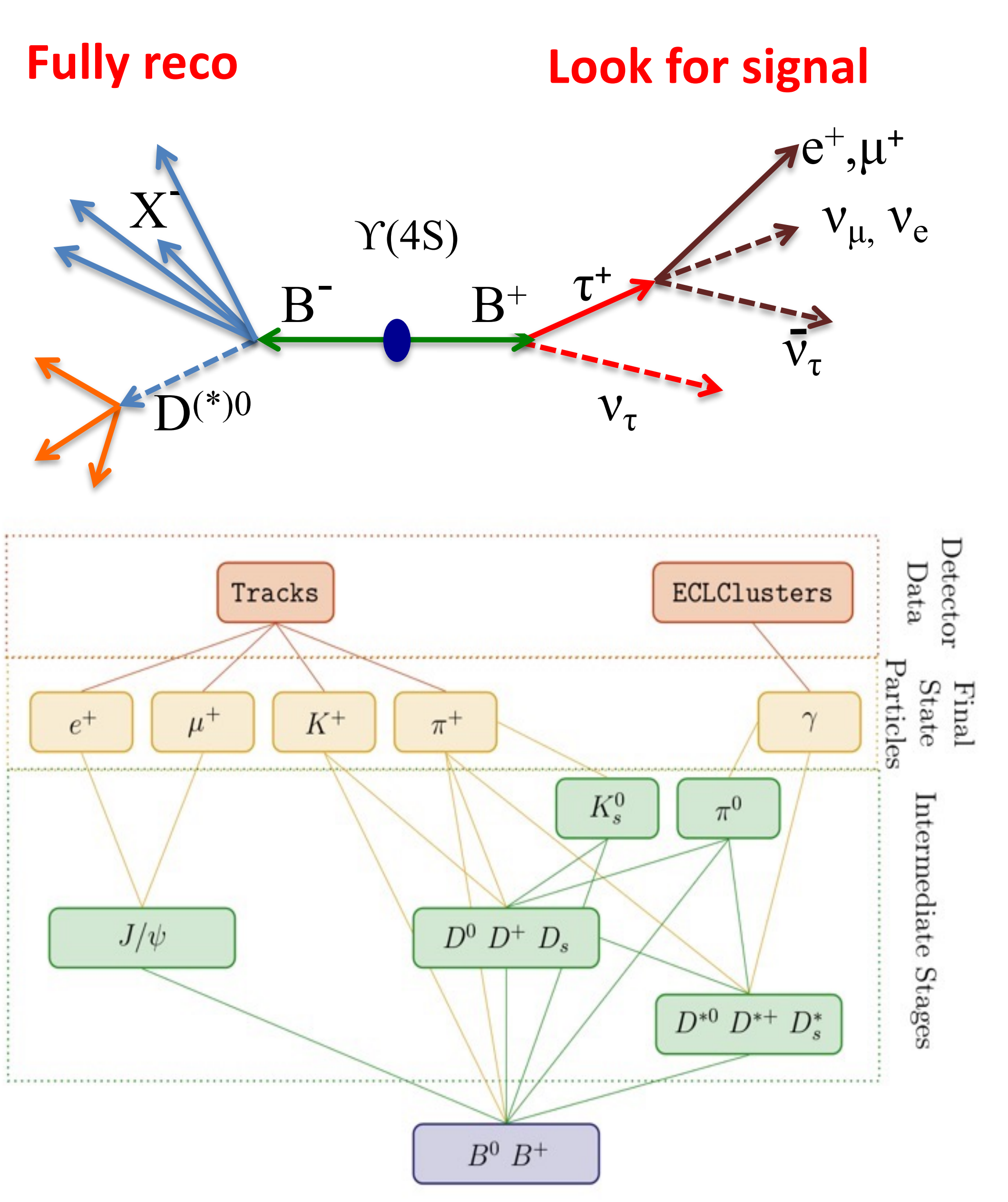
Approximately 300 selected events in 410pb^{-1}





Full Event Interpretation

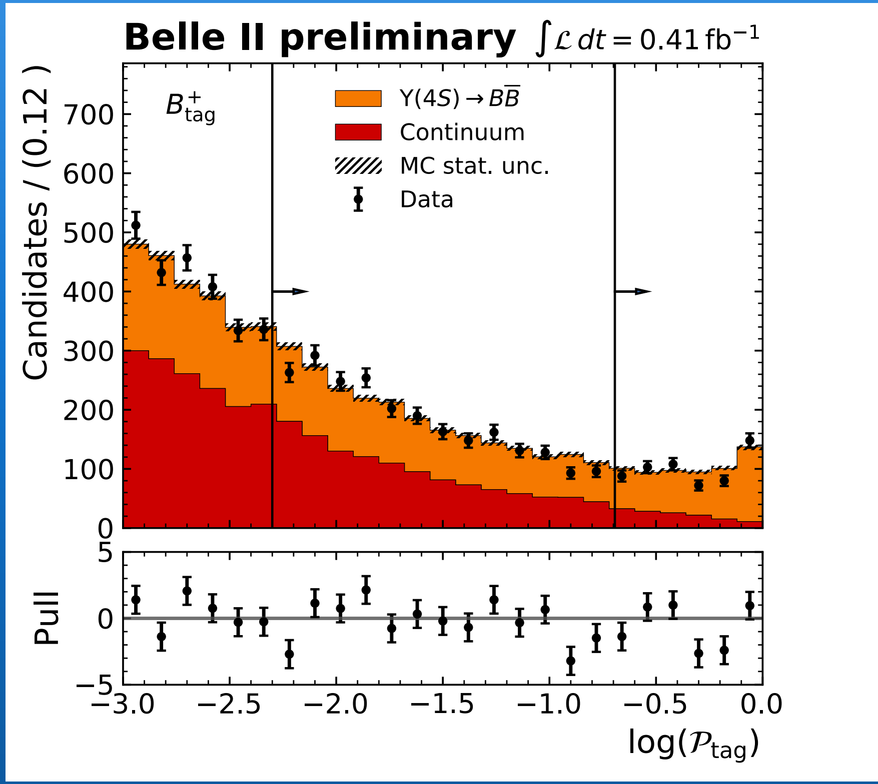
- Fully reconstruct B decays in many many modes to reduce backgrounds and provide tagging
- Useful for channels with weak exp. signature
  - Missing momentum (many neutrinos in the final state)
  - Inclusive analyses
- Tag with semileptonic decays
  - PRO: Higher efficiency εtag ~ 1.5%
  - CON: more background, B momentum unmeasured
- Tag with hadronic decays
  - PRO: cleaner events, B momentum reconstructed
  - CON: smaller efficiency εtag ~ 0.3%



T.Keck, et al. Comput Softw Big Sci (2019) 3: 6.

Hadronic FEI

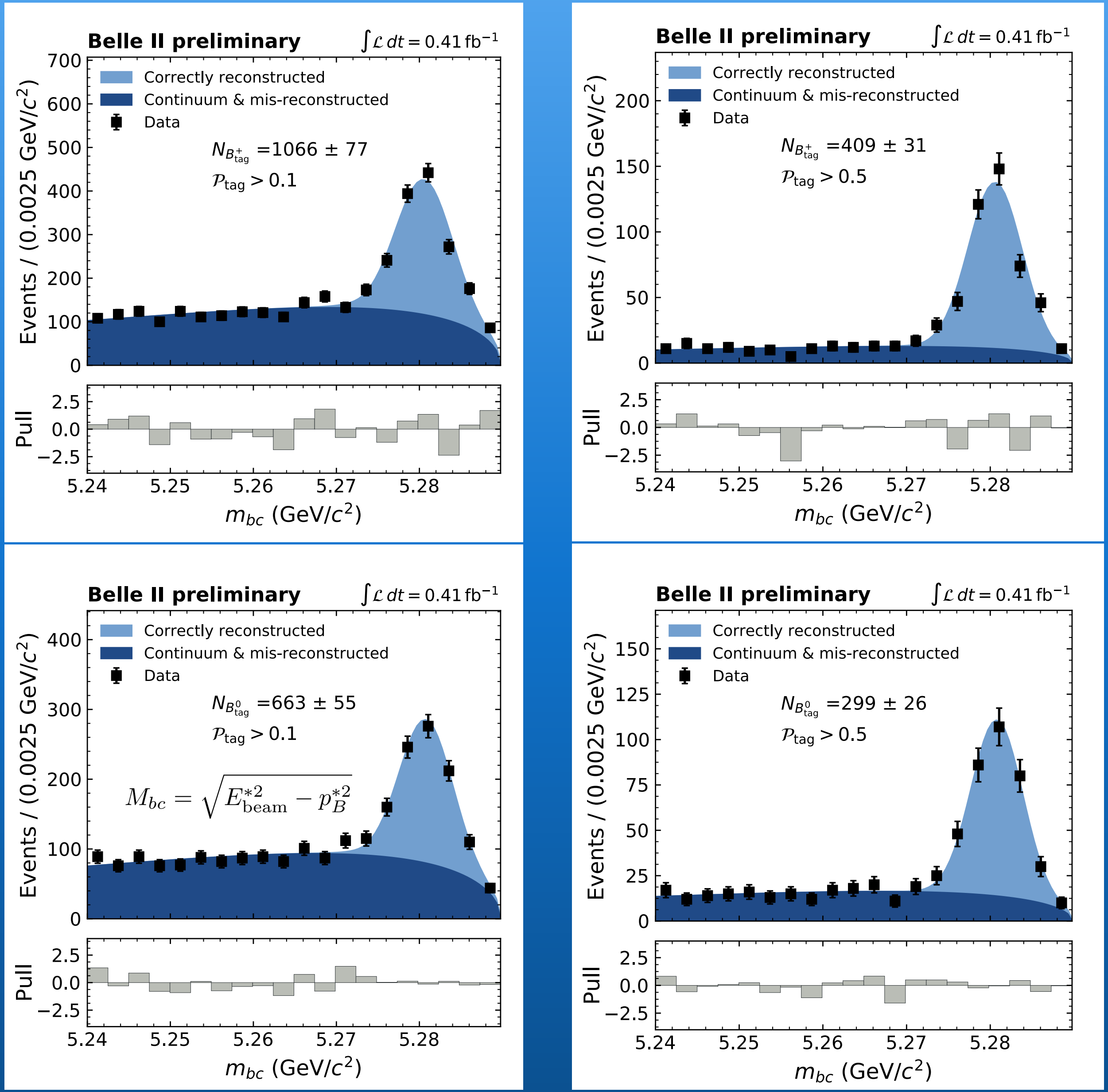
Classifier output to discriminates tag side from background



[61. Missing energy and electroweak penguin modes in early Belle II data](), William Sutcliffe

Loose

Tight



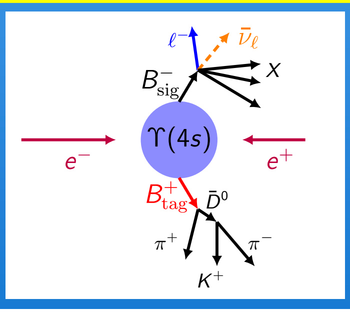
B^+

B^0

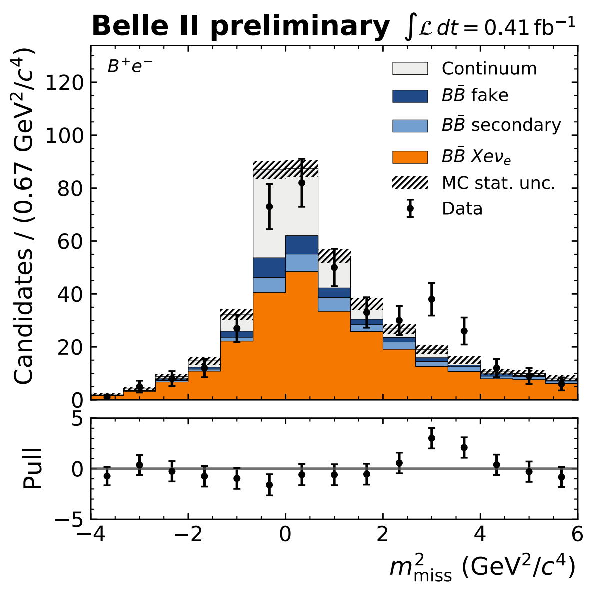
Semileptonic decays

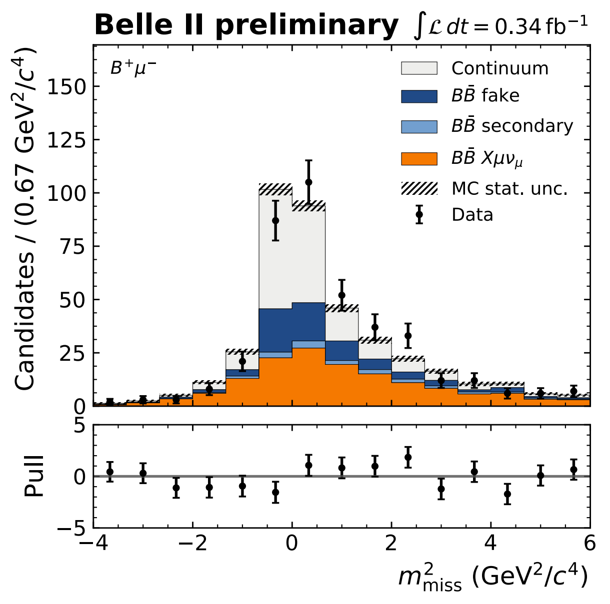
- Look e.g. at missing mass distribution

$$m^2_{\mathrm{miss}} = (p^*_{e^+e^-} - p^*_{B_{\mathrm{tag}}} - p^*_{\ell} - p^*_X)^2$$

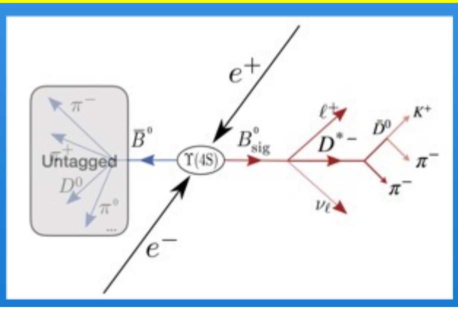


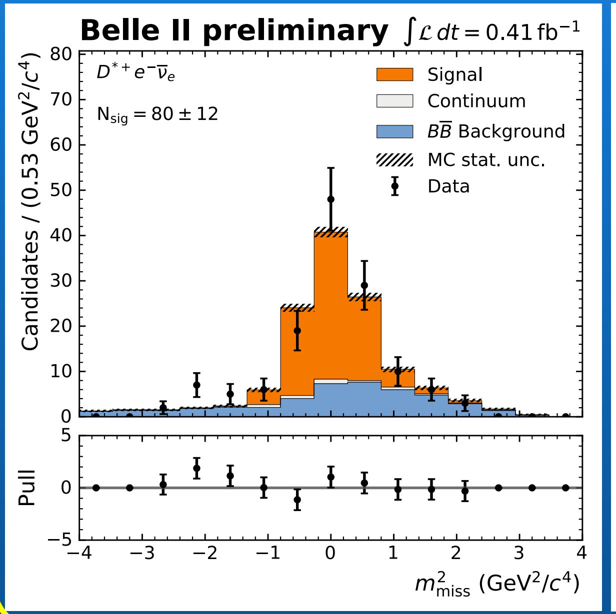
B→Xlν with hadronic tag

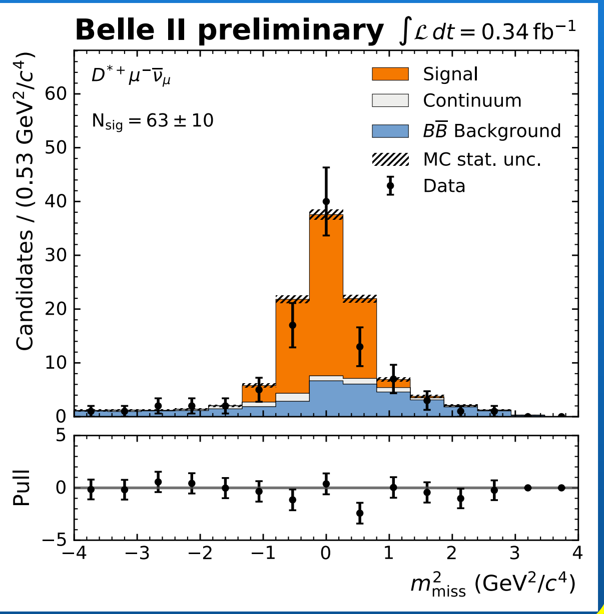




Untagged B→D*lν

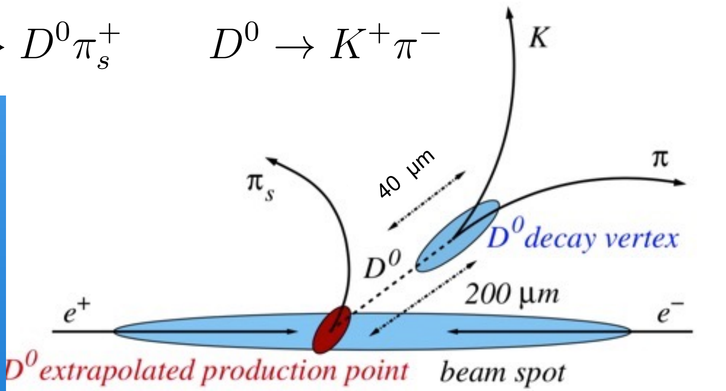


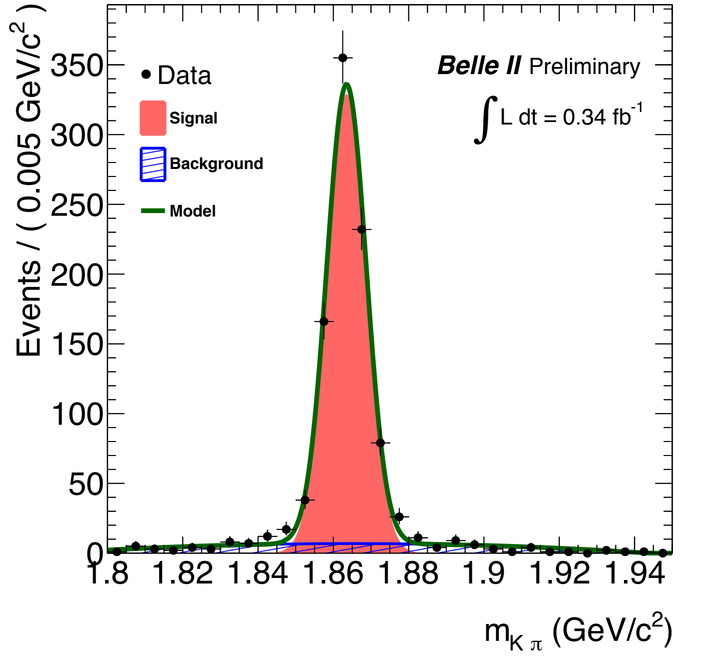




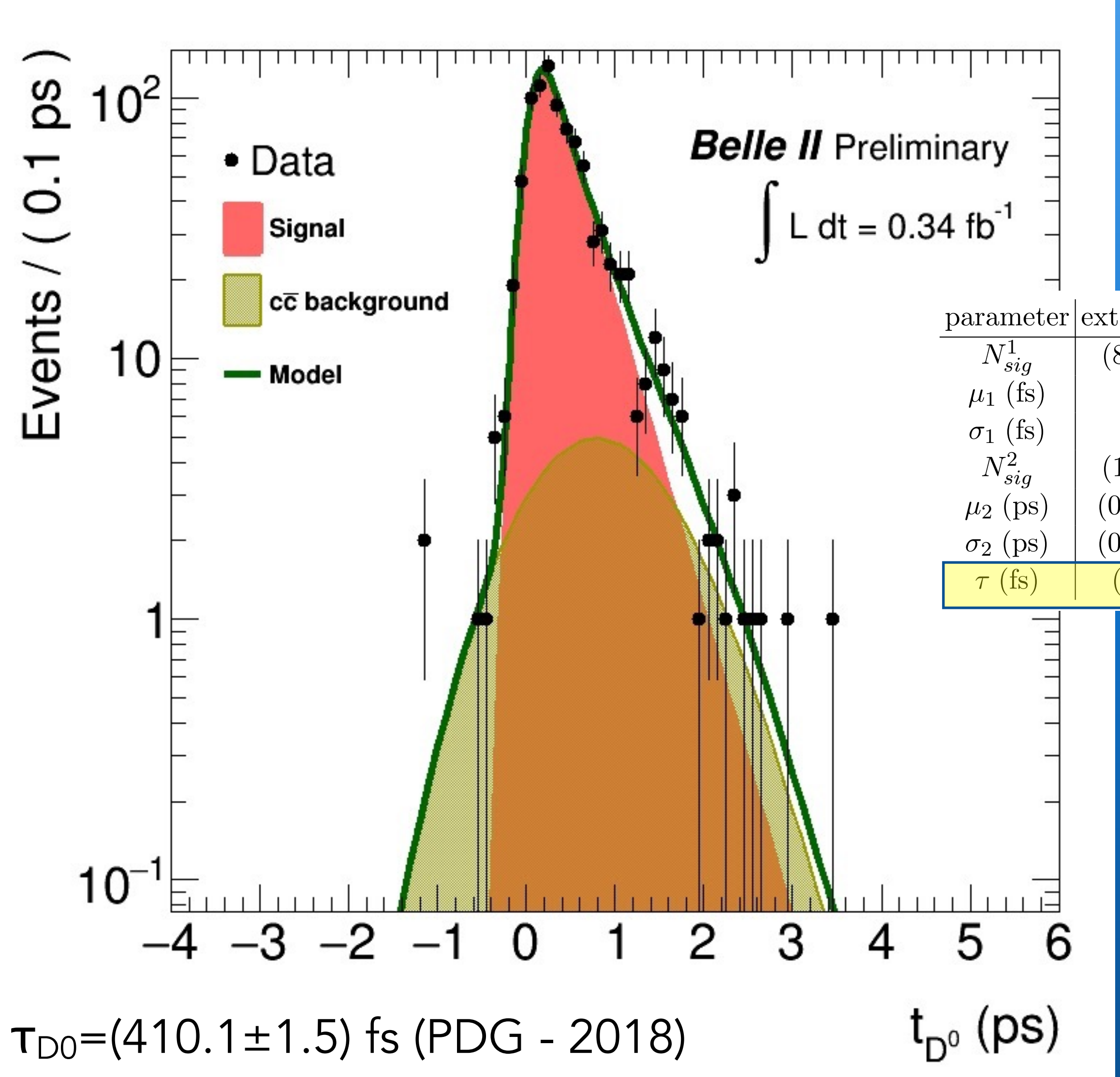
D0 lifetime

$D^* \to D^0 \pi_s^+ \qquad D^0 \to K^+ \pi^-$





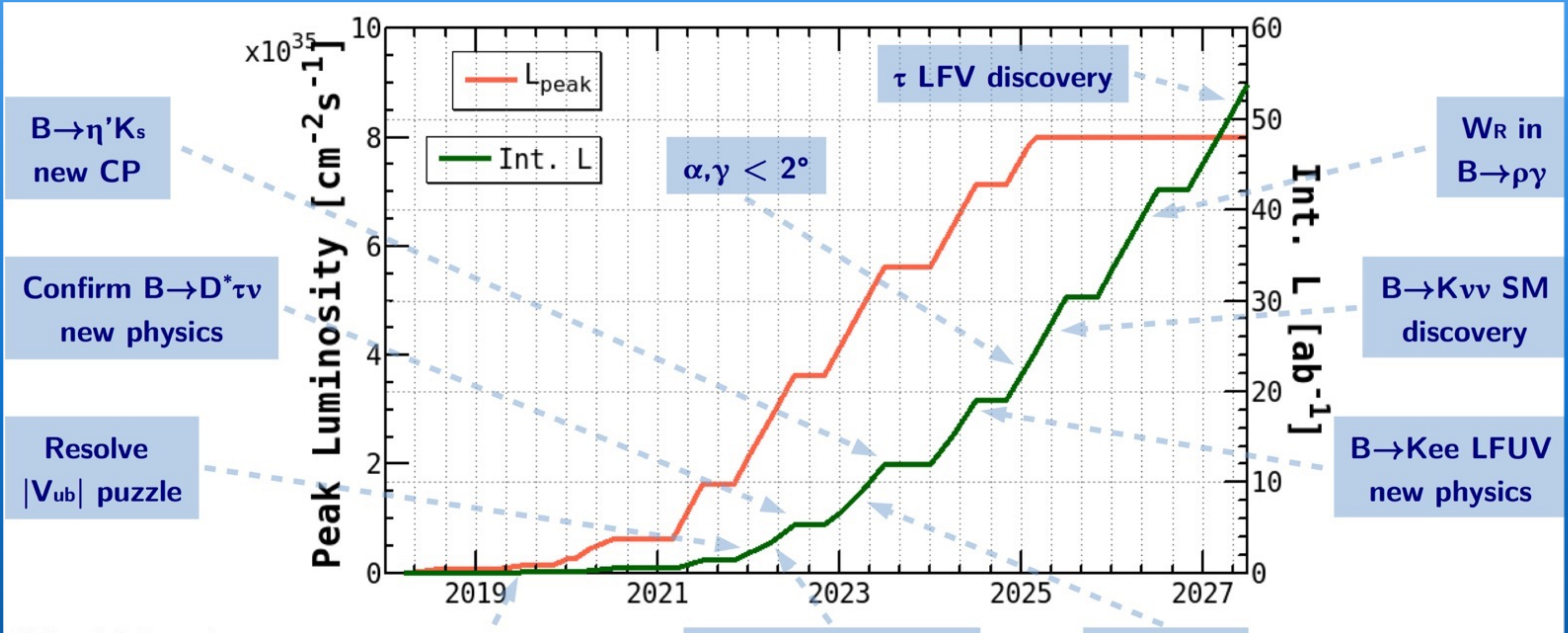
m_{D0}=(1864.83±0.05) MeV/c^2 (PDG - 2018)



parameter	extracted value
N^1_{sig}	$(81 \pm 6) \cdot 10$
μ_1 (fs)	31 ± 16
σ_1 (fs)	127 ± 15
N^2_{sig}	$(10 \pm 5) \cdot 10$
μ_2 (ps)	(0.48 ± 0.17)
σ_2 (ps)	(0.73 ± 0.13)
τ (fs)	(370 ± 40)

τ_{D0}=(410.1±1.5) fs (PDG - 2018)

Physics potential and timeline



All the details are in
"The Belle II Physics Book"
E. Kou, P. Urquijo et al.,

https://arxiv.org/abs/1808.10567
https://inspirehep.net/record/1692393/

421. First look at CKM parameters from early Belle II data, Isabelle Ripp-Baudot

Belle II Improvement program

- Short term
  - Replacement of TOP PMTs with ALD PMTs
  - Replacement of the PXD with complete detector
  - DAQ upgrade
- Medium term
  - Looking at options to make the detector more robust against background and radiation bursts
- Longer term
  - Started looking at luminosity upgrade possibilities

Conclusion and perspectives

- Flavor physics provide an extremely rich landscape of measurements opening windows on New Physics
- High luminosity e^+e^- colliders offer a pristine and well defined environment
- Existing data sets (Babar, Belle) are still providing new results more than 10 years after the end of data taking
- BES III is providing more and more measurement at the tau/charm energy
- Belle II just started data taking with good performance and looking forward to more luminosity


KEEP
CALM
AND
COLLECT
MORE DATA

Belle II Presentations @ EPS-HEP

- First Physics:
  - I.Ripp-Baudot:"*First look at CKM parametersf rom early Belle II data*", Flavour Physics and CP Violation: Thursday 09:00
  - O.Hartbrich: "*Start of the Belle II Experiment at SuperKEKB*" , Flavour Physics and CP Violation: Thursday 14:50
  - K.Lautenbach: "*Exotic and Conventional Quarkonium Physics Prospects at Belle II*" QCD and Hadronic Physics: Thursday 14:45
  - S. Cunliffe: "*Dark Sector Physics with Belle II*" Dark Matter: Thursday 15:10
  - W.Sutcliffe: "*Missing energy and electroweak penguin modes in early Belle II data*" Flavour Physics and CP Violation: Friday 09:45
  - F.Forti: "*BELLE II and flavor physics in e+e-*" Plenary: Tuesday 10:00
- Detectors:
  - H.Ye: "*Commissioning of the Belle II Pixel Vertex Detector*" Detector R&D and Data Handling: Thursday 10:15
  - O.Hartbrich: "*First Experiences with the Novel Time of Propagation (TOP) Barrel PID Detector in the BelleII Experiment*", Detector R&D and Data Handling: Thursday 11:30
  - S.Longo: "*A Novel Approach to Calorimeter-based Particle Identification at the Belle II Experiment using Scintillator Pulse Shape Discrimination*", Detector R&D and Data Handling: Friday 09:30
  - A.Paladino: "*Performance of the Belle II Silicon Vertex Detector*", Poster: Monday 18:30
  - L.Santelj: "*The Aerogel RICH detector of the Belle II experiment*", Poster: Monday 18:30

Additional material

BESIII Detector

BESIII detector: all new !

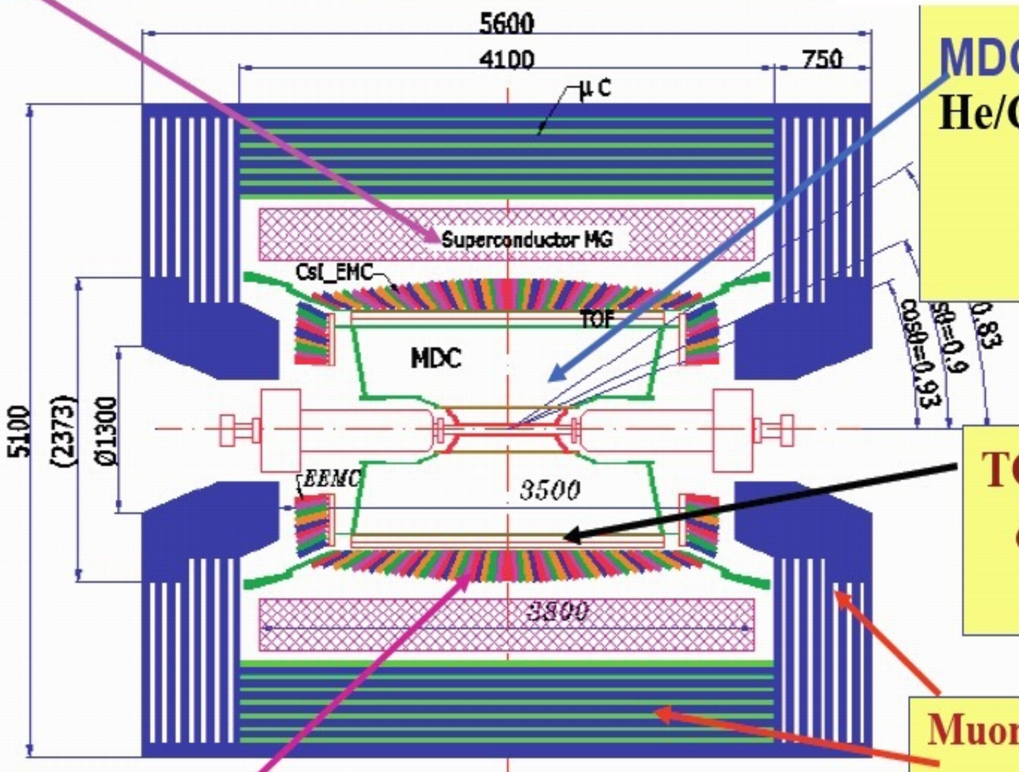
CsI calorimeter

Precision tracking

Time-of-flight + dE/dx PID

Nucl. Instr. Meth. A614, 345 (2010)

Magnet: 1 T Super conducting



MDC: small cell & Gas:
He/C_3H_8 (60/40), 43 layers
σ_{xy}=130 μm
σ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

Muon ID: 9 layers RPC
8 layers for endcap

60 ps for ETOF after upgraded in 2015

EMC: CsI crystal, 28 cm
$\Delta E/E$ = 2.5% @1 GeV
$\sigma z = 0.6\ \mathrm{cm}/\sqrt{E}$

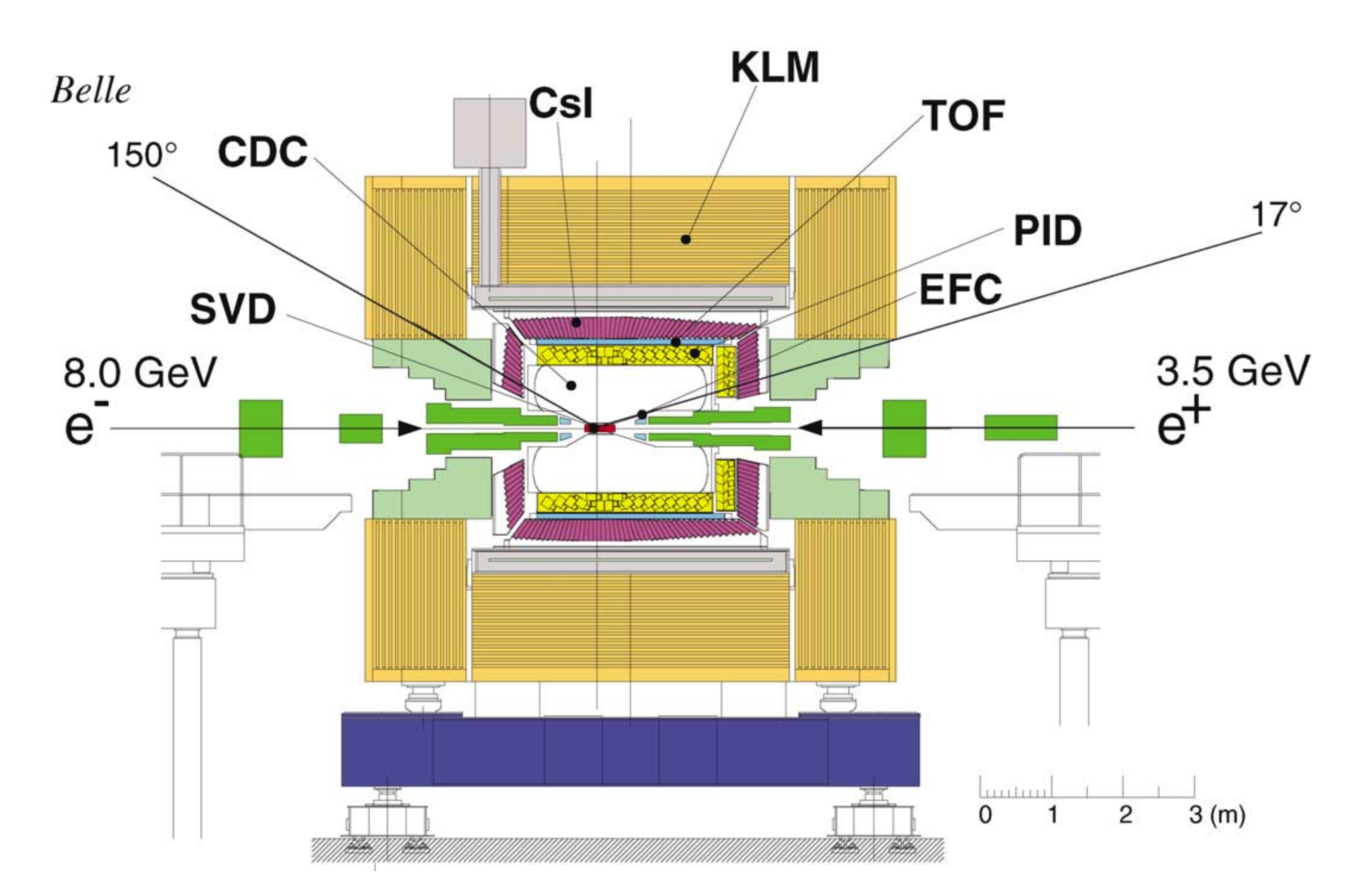
Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

BES III References

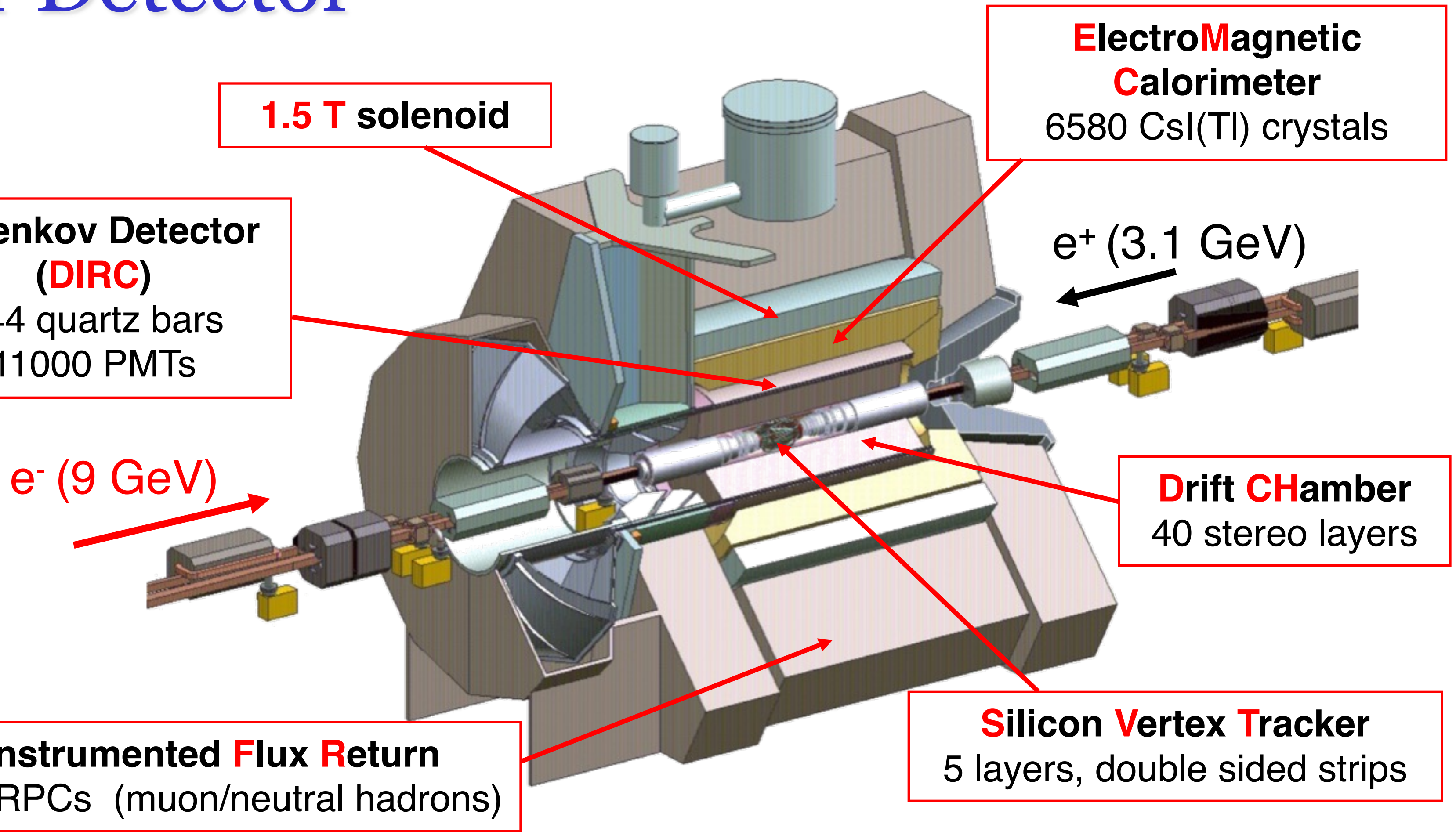
Λ_c weak decay asymmetry	[submitted to PRL]	1905.04707
Amplitude analysis of $D^+_s \to \eta\pi^+\pi^0$	[submitted to PRL]	1903.04164
Amplitude analysis of $D^+ \to K^0_S\pi^+\pi^+\pi^-$	[Submited to Phys.Rev.D]	1901.05936
Measurement of $\Lambda_c \to \Sigma\eta(\eta')$	[Accepted CPC]	1811.08028
Measurement of $D^+_s \to K^0_{S/L} K^+$	[Accepted by PRD]	1903.04118
Amplitude analysis of $D^0 \to K^-\pi^+ \pi^0\pi^0$	Phys.Rev.D99(2019)092008	1903.06316
Search for the radiative decay $D^+_s \to \gamma e^+\nu$	Phys.Rev.D99(2019)032010	1902.03351
Measurements of $D^+_s \to \omega\pi^+$ and ωK^+	Phys.Rev.D99(2019)091101	1811.00392
Study of the dynamics of $D^+_s \to \eta^{(\prime)} e^+\nu$	Phys.Rev.Lett.122(2019)121801	1901.02133
Measurement of $\Lambda_c \to \Lambda \pi \eta$	Phys.Rev.D99(2019)032010	1812.10731
Study of $D^+_s \to \mu^+ \nu$	Phys.Rev.Lett.122(2019)071802	1811.10890
Study of $D^+_s \to$ p n-bar	Phys.Rev.D99(2019)031101	1811.00752
Study of $D^+ \to K^0_{S/L} K^+ (\pi^0)$	Phys.Rev.D99(2019)032002	1812.05400
Study of $D^+_s \to K^{0(*)} e^+\nu$	Phys.Rev.Lett.122(2019)061801	1811.02911
Study of $D^{0(+)} \to \pi \pi e^+\nu$	Phys.Rev.Lett.122(2019)062001	1809.06496
Study of $D^0 \to K^0\text{bar}\, \pi^- e^+\nu$	Phys.Rev.D99(2019)011103	1811.11349
Study of $D^0 \to K^- \mu^+\nu$	Phys.Rev.Lett.122(2019)011804	1810.03127
Measurement of $\Lambda_c \to e X$	Phys.Rev.Lett.121(2018)251801	1805.09060
Analysis of $D \to K \pi \eta'$	Phys.Rev.D.98, 092009(2018)	1809.03750

Branching Fractions of $D \to \pi \mu \nu$	Phys. Rev. Lett. 121, 171803(2018)	1802.05492
Measurement of $\Lambda_c \to \Lambda X$	Phys. Rev. Lett. 121, 062003(2018)	1803.05706
Observation of $D \to a_0 e \nu$	Phys. Rev. Lett. 121, 081802(2018)	1803.02166
Branching Fractions of $\Lambda_c \to \Xi^* K^+$	Phys. Lett. B 783, 200(2018)	1803.04299
Analysis of $D \to (\eta,\eta') e \nu$	Phys. Rev. D 97, 092009(2018)	1803.05570
Study of SCS decays $D^0 \to 3\pi^0$ and $D^0 \to 2\pi^0\eta$	Phys. Lett. B 781, 268(2018)	1803.05769
Measurements of absolute branching fractions for D mesons decays into two pseudoscalar mesons	Phys. Rev. D 97, 072004(2018)	1802.03119
Measurements of the branching fractions of the singly Cabibbo-suppressed decays $D^0 \to \omega\eta, \eta^{(\prime)}\pi^0$, and $\eta^{(\prime)}\eta$	Phys. Rev. D 97, 052005(2018)	1801.05988
Measurements of the branching fractions for the singly semileptonic decays $D^+_s \to \phi e \nu_e, D^+_s \to (\phi,\eta,\eta')\mu\nu_\mu$	Phys. Rev. D 97, 012006(2018)	1709.03680

The Belle Detector



Babar Detector



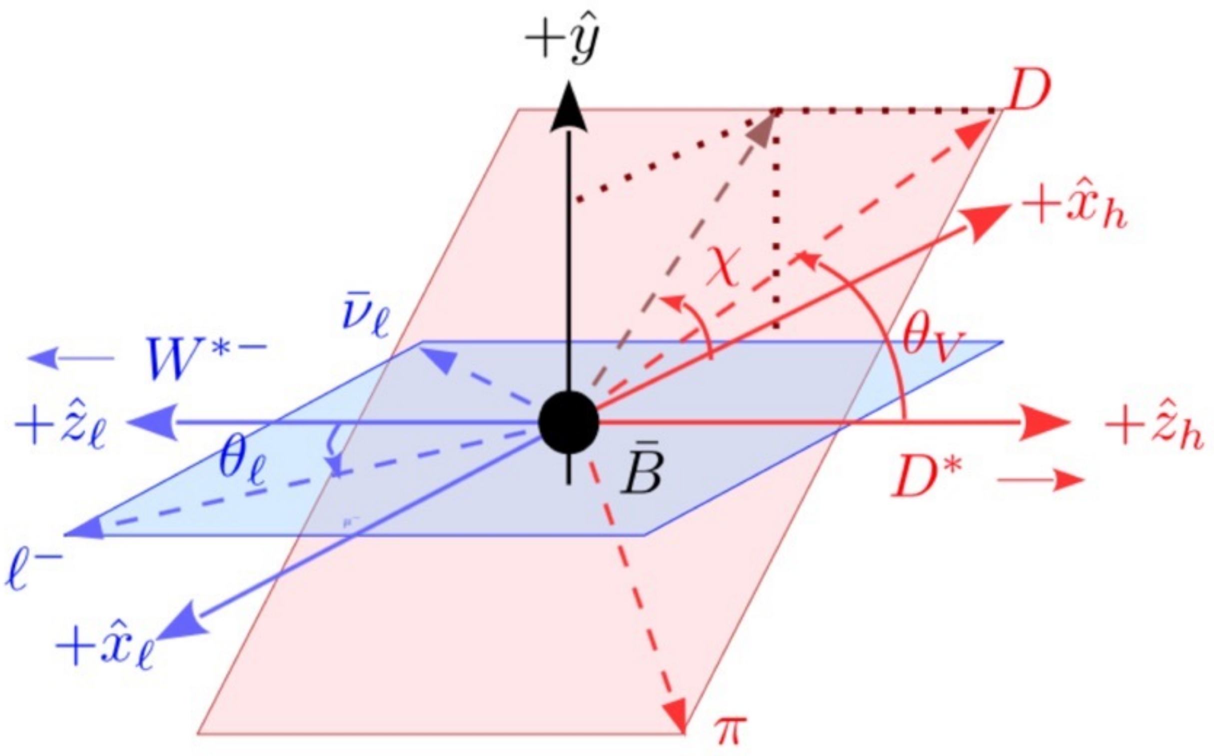
SVT: 97% efficiency, 15 μm z hit resolution (inner layers, $\perp$ tracks)

SVT+DCH: $\sigma(p_T)/p_T = 0.13\ \% \times p_T + 0.45\ \%$

DIRC: K-π separation 4.2σ @ 3.0 GeV/c $\rightarrow$ >3.0σ @ 4.0 GeV/c

EMC: $\sigma_E/E = 2.3\ \% \times E^{-1/4} \oplus 1.9\ \%$

The 4D variables



- 4-body decay topology
- $\sqrt{q^2}$: di-lepton mass.
- 3 angles: $\Omega \in \{\theta_l, \theta_V, \chi\}$
- Spin-1 D^* retains full spin info of the recoiling W^* in $b \to cW^{*-}$, unlike spin-0 D, where this info is reduced $\Rightarrow$ richer pheno!

How to increase the luminosity?

Beam-beam parameter

Lorentz factor

Beam current

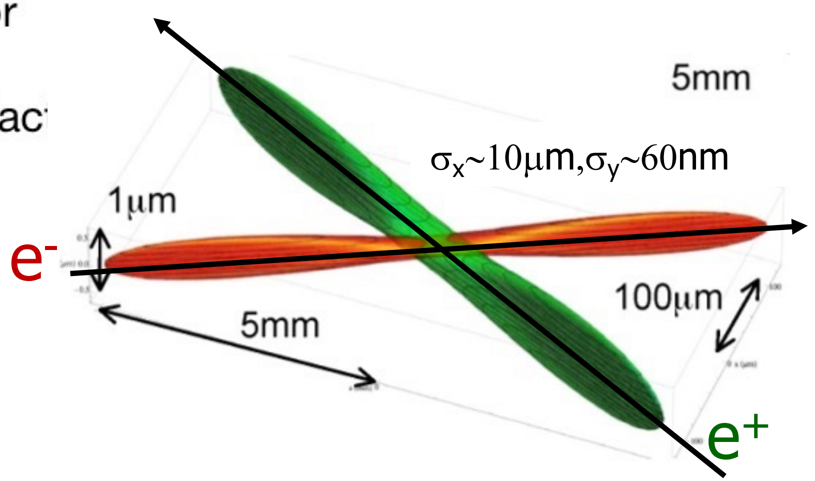
$$\boxed{L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)}$$

Lumi. reduction factor (crossing angle)&
Tune shift reduction fac
(hour glass effect)
0.8 - 1
(short bunch)

Classical electron radius

Beam size ratio@IP
1 - 2 % (flat beam)

Vertical beta function@IP



(1) Smaller β_y^*
(2) Increase beam currents
(3) Increase ξ_y

"Nano-Beam" scheme

$$\sigma(s) = \sqrt{\epsilon \cdot \beta(s)}$$

Collision with very small spot-size beams

Invented by Pantaleo Raimondi for SuperB

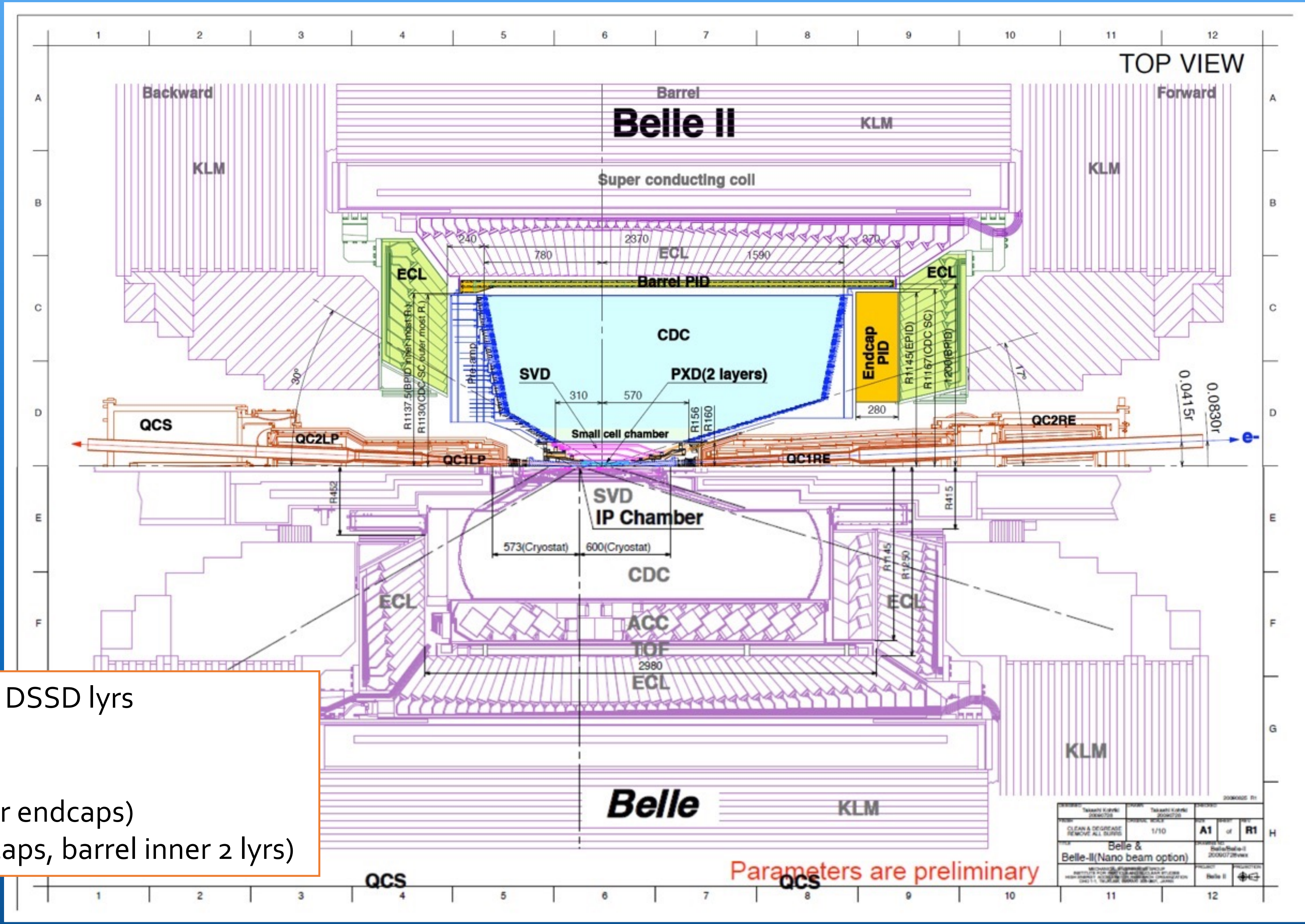
SuperKEKB design parameters

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	ϕ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.37	0.40	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.60	2.60	A
beam-beam parameter	ξ_y	0.129	0.090	0.0881	0.0807	
Luminosity	L	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

- **Nano-beams and a factor of two more beam current** to increase luminosity
- **Large crossing angle**

- **Change beam energies** to solve the problem of short lifetime for the LER
- Consequence $\beta\gamma$: decrease 0.42 → 0.28

Belle → Belle II



SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)