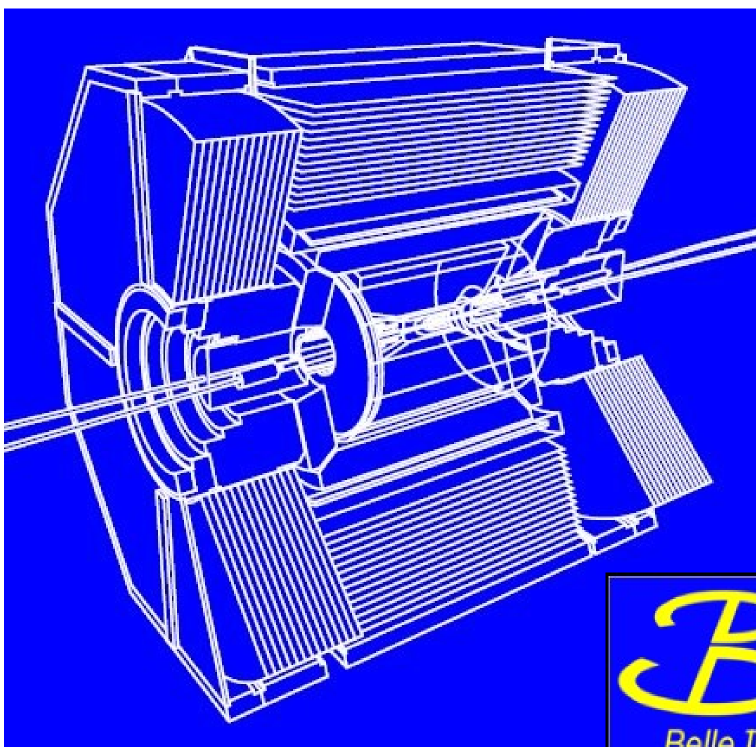
Status of Belle II



Karim Trabelsi
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2021/10/29

Belle II, a flavour-factory,

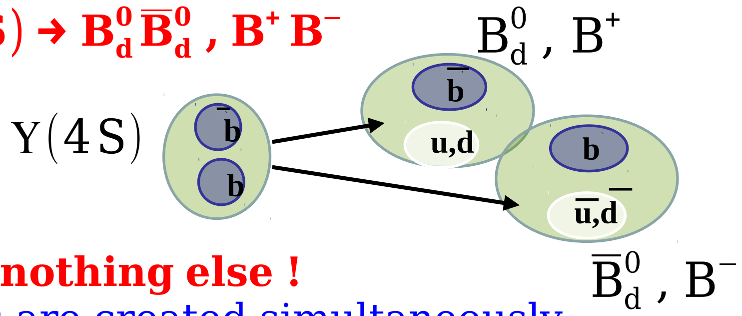
(Belle ~ 1 ab^{-1}) **a rich physics program…**

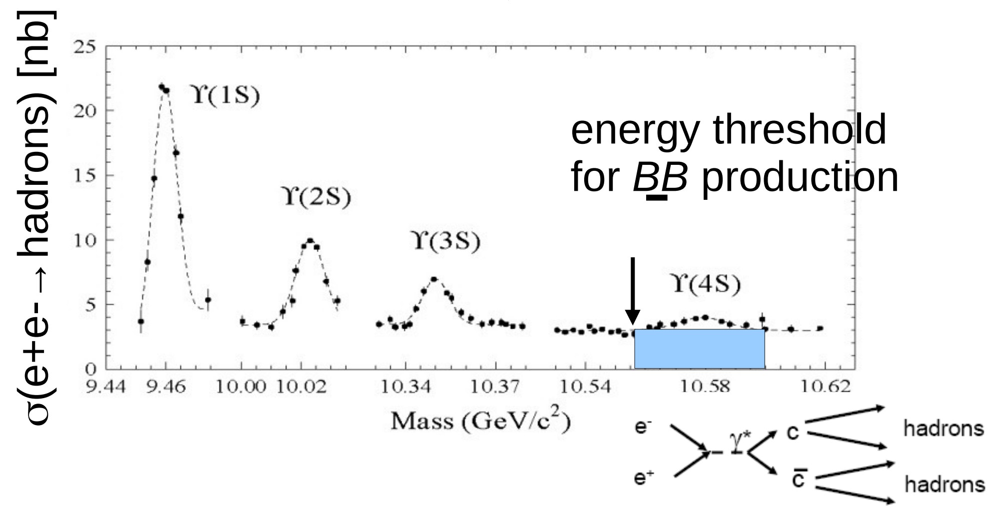
- We plan to collect (**at least**) 50 ab^{-1} of e^+e^- collisions at (or close to) the $\Upsilon(4S)$ resonance, so that we have:

– a (Super) B-factory ($\sim 1.1 \times 10^9$ $B\bar{B}$ pairs per ab^{-1})

"on resonance" production

$e^+e^- \to \Upsilon(4S) \to B_d^0 \bar{B}_d^0$, B^+B^-





- **2 B's and nothing else !**
- 2 B mesons are created simultaneously in a L=1 coherent state

– a (Super) charm factory ($\sim 1.3 \times 10^9$ $c\bar{c}$ pairs per ab^{-1})

(but also charmonium, X, Y, Z, pentaquarks, tetraquarks, bottomonium…)

– a (Super) τ factory ($\sim 0.9 \times 10^9$ $\tau^+\tau^-$ pairs per ab^{-1})

– exploit the clean e^+e^- environment to probe the existence of exotic hadrons, dark photons/Higgs, light Dark Matter particles, ALPs, LLPs …

⇒ to reach 6×10^{35} $cm^{-2}s^{-1}$

⇒ cumulate 50 ab^{-1} by ~2031

Belle(II), LHCb side by side

Belle (II)

$e^+e^- \to \Upsilon(4S) \to b\bar{b}$

at $\Upsilon(4S)$: 2 B's (B^0 or B^+) and nothing else ⇒ clean events

(flavour tagging, B tagging, missing energy)

$\sigma_{b\bar{b}} \sim 1\,\mathrm{nb} \Rightarrow 1\ \mathrm{fb}^{-1}$ produces $10^6\ B\bar{B}$

$\sigma_{b\bar{b}}/\sigma_{\mathrm{total}} \sim 1/4$

LHCb

$pp \to b\bar{b}X$

production of B^+, B^0, B_s, B_c, Λ_b...

but also a lot of other particles in the event

⇒ lower reconstruction efficiencies

$\sigma_{b\bar{b}}$ much higher than at the $\Upsilon(4S)$

	$\sqrt{s}$ [GeV]	$\sigma_{b\bar{b}}$ [nb]	$\sigma_{b\bar{b}}/\sigma_{tot}$
HERA pA	42 GeV	~30	~10^{-6}
Tevatron	2 TeV	5000	~10^{-3}
LHC	8 TeV	~3×10^5	~ 5×10^{-3}
	14 TeV	~6×10^5	~10^{-2}

$b\bar{b}$ production cross-section at LHCb ~ 500,000 × BaBar/Belle !!

$\sigma_{b\bar{b}}/\sigma_{\mathrm{total}}$ much lower than at the $\Upsilon(4S)$

⇒ lower trigger efficiencies

B mesons live relativey long

mean decay length $\beta\gamma c\tau \sim 200\ \mu m$

mean decay length $\beta\gamma c\tau \sim 7$ mm

(displaced vertices)

data taking period(s)

[1999-2010] = 1 ab^{-1}

[2019-...] = ...

[run I: 2010-2012] = 3 fb^{-1},

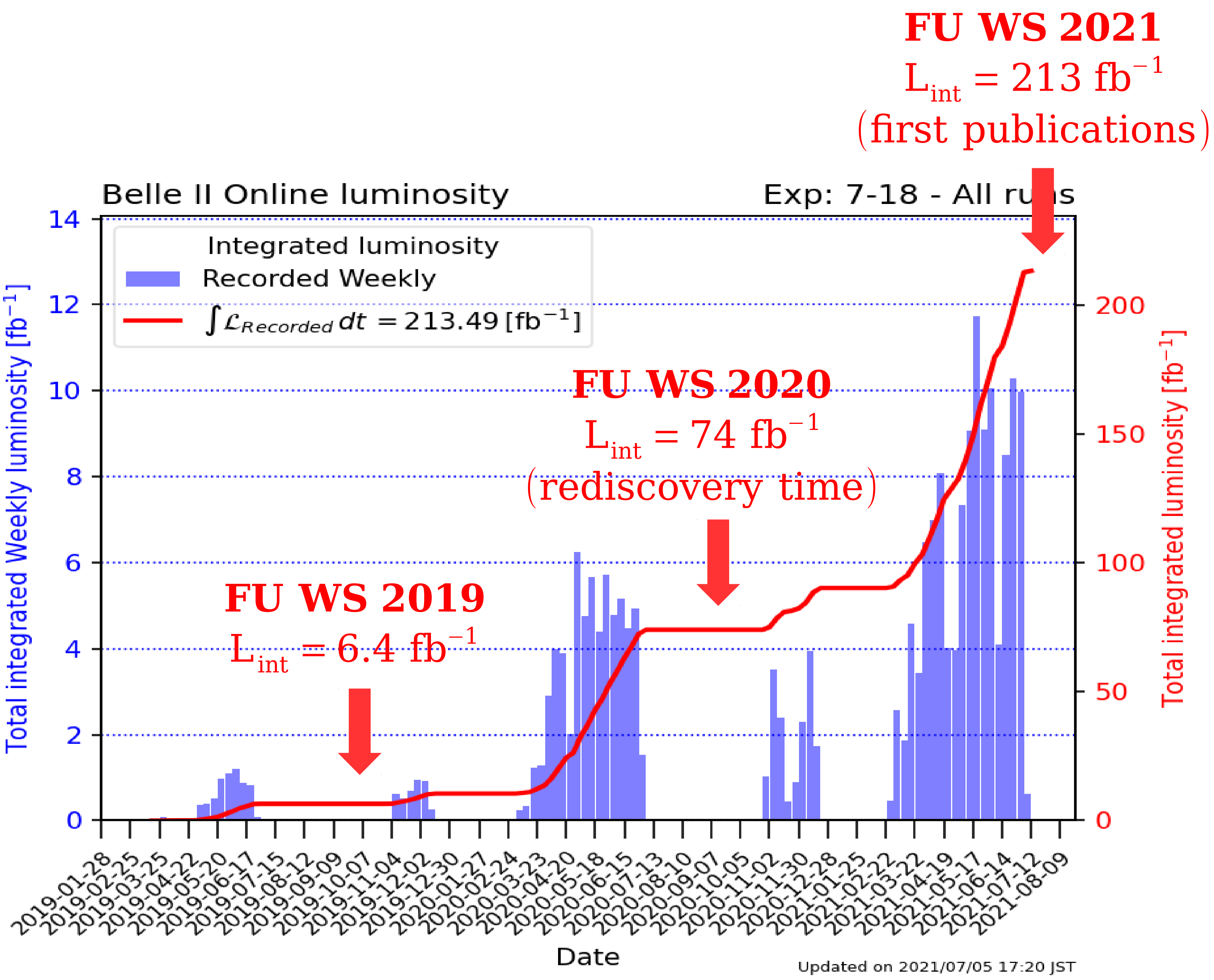
[run II: 2015-2018] = 6 fb^{-1}

(near) future

[Belle II from 2019] → 50 ab^{-1}

[LHCb upgrade from 2021]

News from Belle II



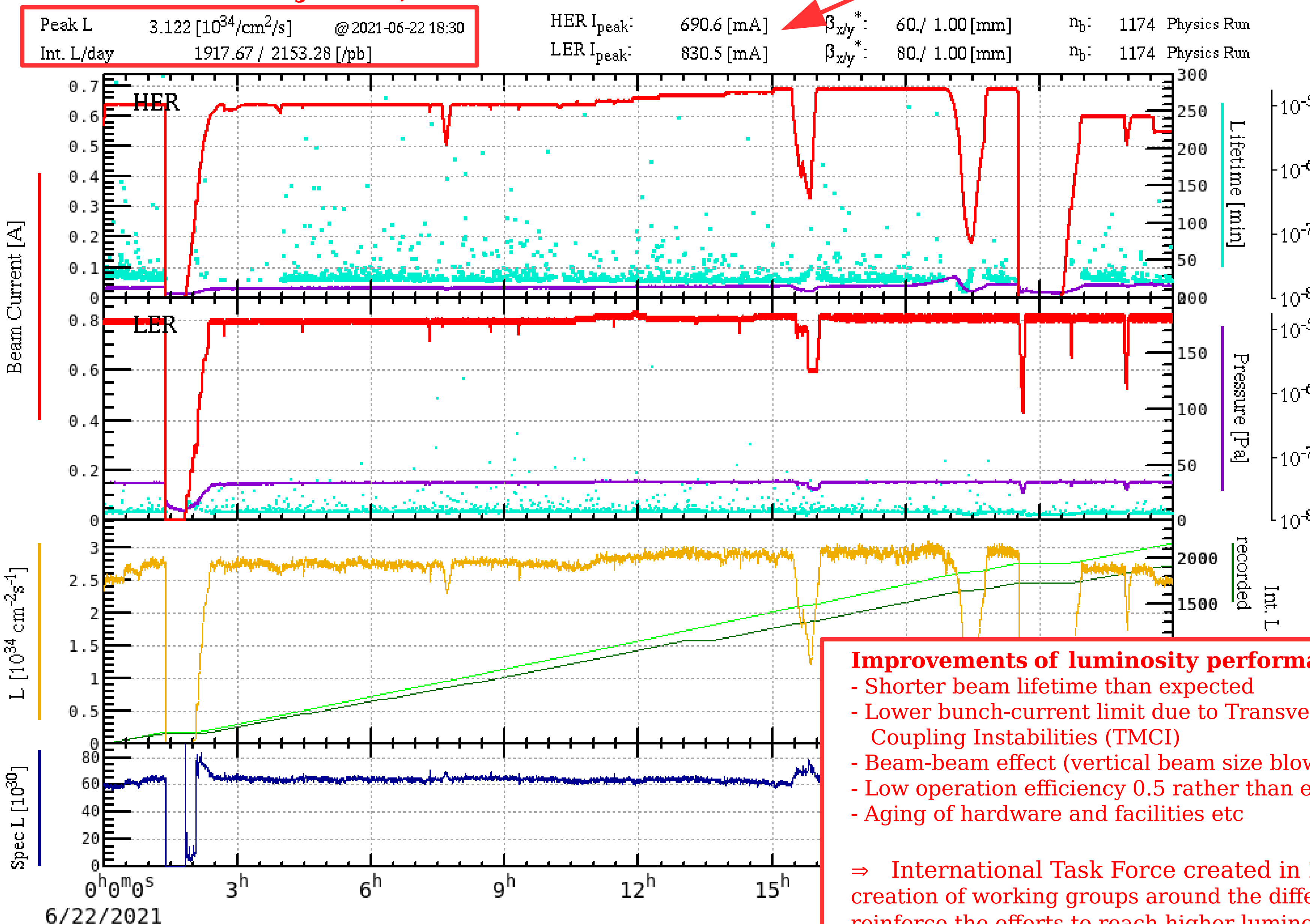
News about SuperKEKB

- despite difficult conditions, continued to take data since March 2020 ! yes, no excuse... will be of little value around here...

3.1×10^{34}/cm^2/s ! ~2 fb^{-1} per day

record of KEKB/Belle
2.1×10^{34}/cm^2/s currents > 1 A
record of PEPII/BaBar
1.2×10^{34}/cm^2/s currents > 2 A

June 21, 2021 **currents ~ 0.7 − 0.8 A**



Improvements of luminosity performance needed
- Shorter beam lifetime than expected
- Lower bunch-current limit due to Transverse Mode Coupling Instabilities (TMCI)
- Beam-beam effect (vertical beam size blow-up)
- Low operation efficiency 0.5 rather than expected 0.65
- Aging of hardware and facilities etc

⇒ International Task Force created in 2021
creation of working groups around the different SKEKB issues
reinforce the efforts to reach higher luminosity by 2022

$R_{K^{(*)}}$ at Belle and Belle II

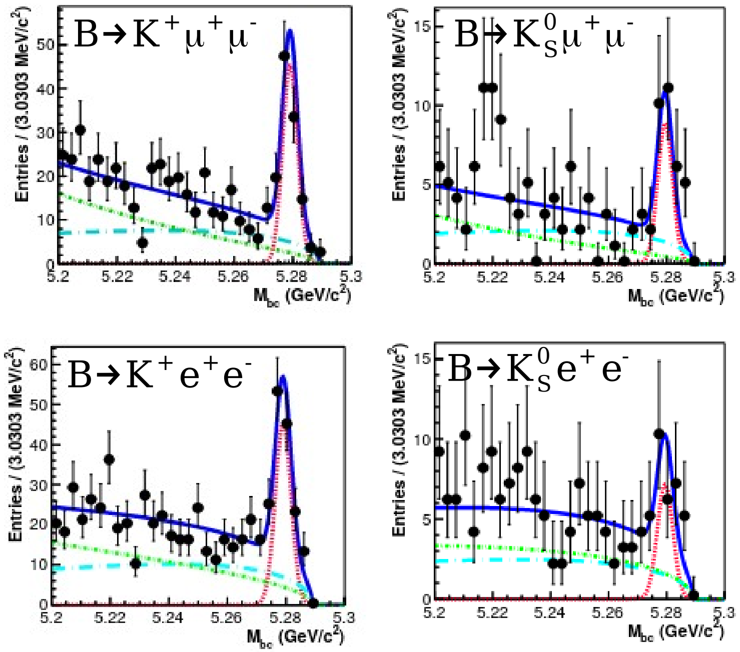
The "clean" Lepton Flavor Universality ratio

$$R_{K^{(*)}} = \frac{Br(B \to K^{(*)}\mu\mu)}{Br(B \to K^{(*)}ee)}$$

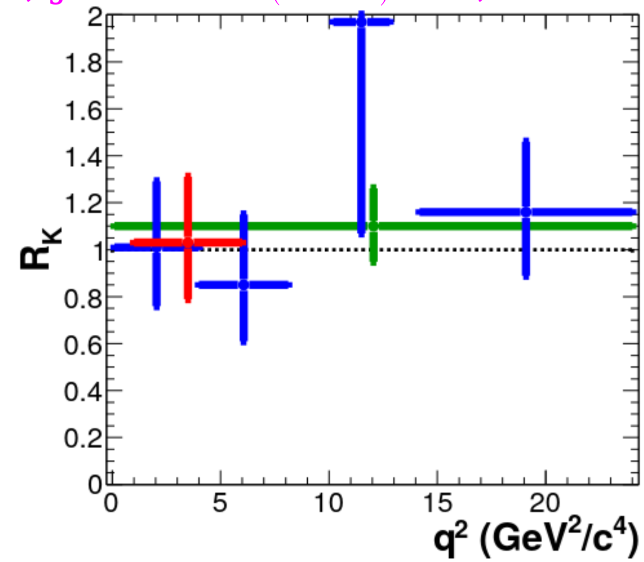
SM prediction very robust: $R_K(SM) = 1$

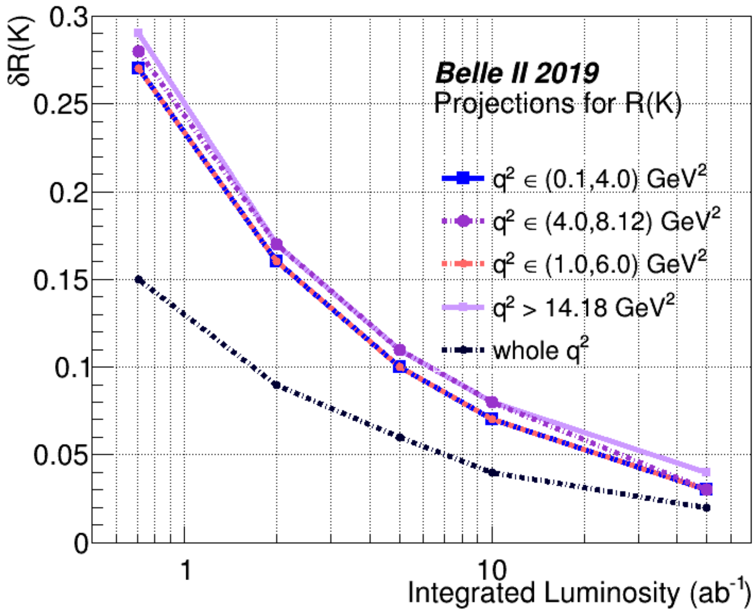
[up tiny QED and lepton mass effects]

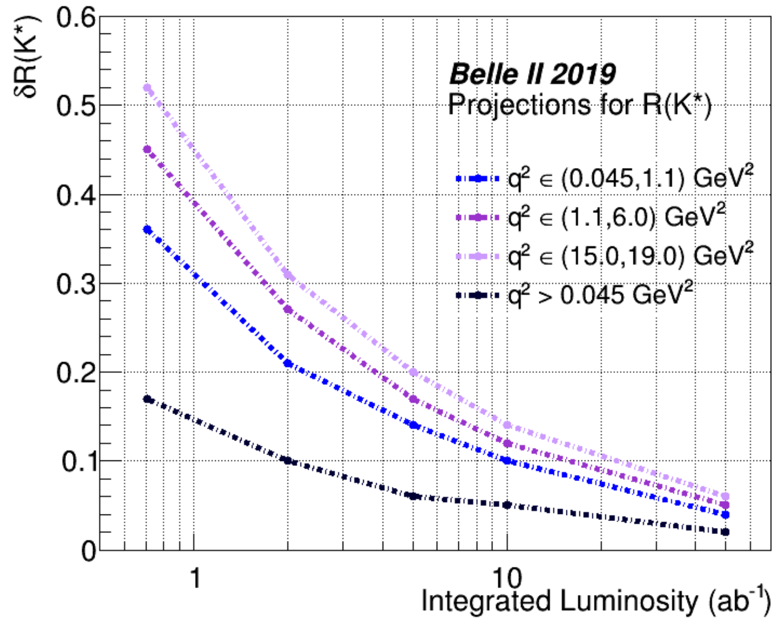
signs of NP seen by LHCb ?



[Belle, JHEP 2013 (2021) 105, arXiv:1908.01848]







Lepton (non) universality using $B \to K^{(*)} l^+ l^-$ decays

Model candidates

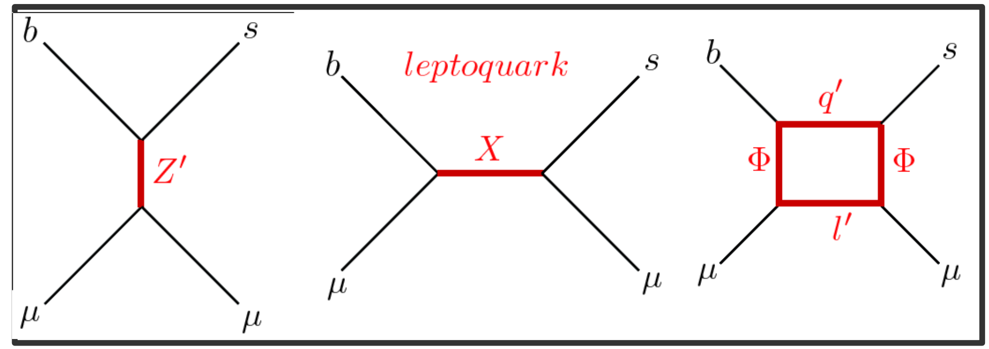
- ✓ Effective operator from Z' exchange
- ✓ Extra U(1) symmetry with flavor dependent charge

✧ **Models with leptoquarks**

- ✓ Effective operator from LQ exchange
- ✓ Yukawa interaction with LQs provide flavor violation

✧ **Models with loop induced effective operator**

- ✓ With extended Higgs sector and/or vector like quarks/leptons
- ✓ Flavor violation from new Yukawa interactions



Leptoquarks are color-triplet bosons that carry both lepton and baryon numbers

Lot of those models predict also LFV $b \to s e \mu$, $b \to s e \tau$, ...

(see Damir, Sebastien, Olcyr's work)

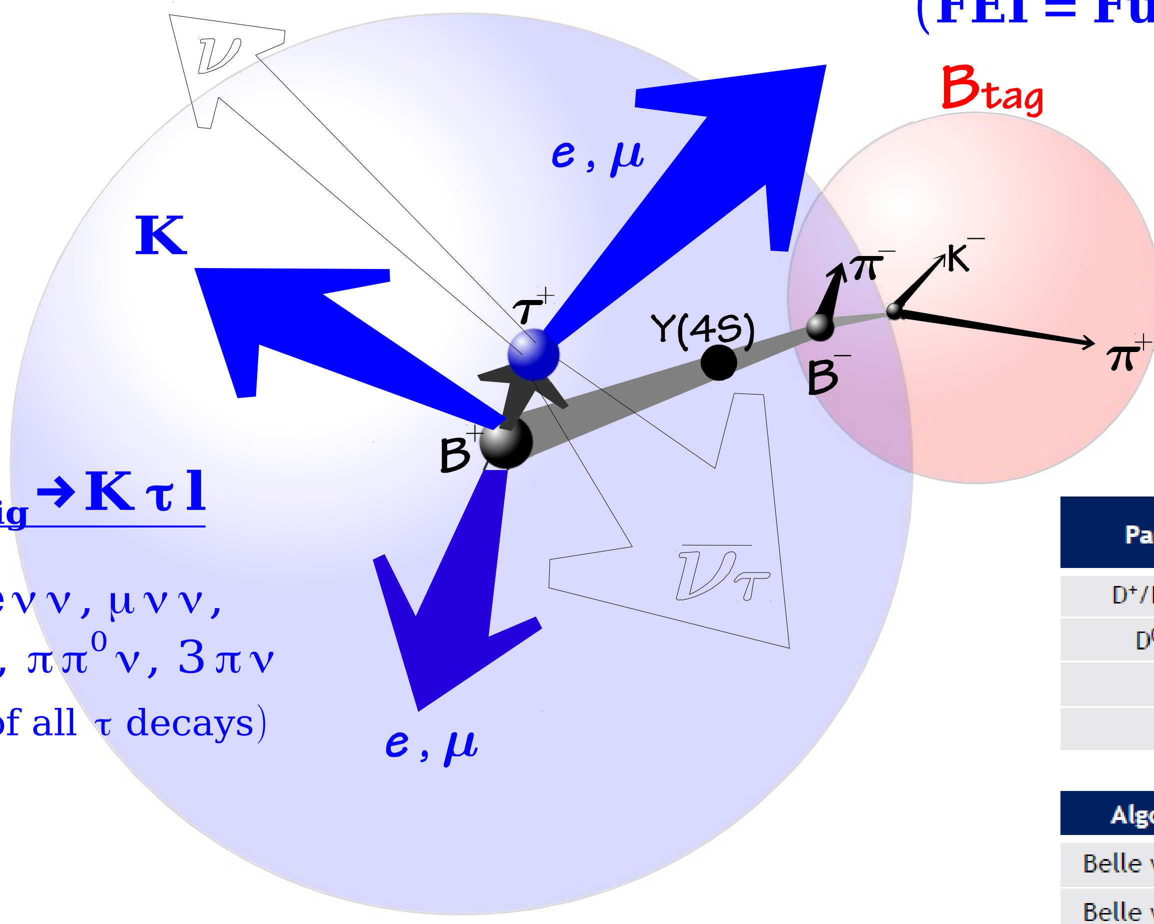
G.Isidori, FPCP 2020: correlations among $b \to s(d) l l'$ within the U(2)-based EFT

	$\mu\mu$ (ee)	$\tau\tau$	$\nu\nu$	$\tau\mu$	μe
$b \to s$	R_K, R_{K^*} O(20%)	$B \to K^{(*)} \tau\tau$ $\to 100\times$SM	$B \to K^{(*)} \nu\nu$ O(1)	$B \to K \tau\mu$ $\to 10^{-6}$	$B \to K \mu e$???
$b \to d$	$B_d \to \mu\mu$, $B \to \pi \mu\mu$, $B_s \to K^{(*)} \mu\mu$ O(20%) [R_K=R_π]	$B \to \pi \tau\tau$ $\to 100\times$SM	$B \to \pi \nu\nu$ O(1)	$B \to \pi \tau\mu$ $\to 10^{-7}$	$B \to \pi \mu e$???

(but the τ is much more challenging...)

Event reconstruction in B→Kτl at B factories

(FEI = Full Event Interpretation)



B_{sig}→Kτl

$\tau \to e\nu\nu, \mu\nu\nu,$
$\tau \to \pi\nu, \pi\pi^0\nu, 3\pi\nu$
(70 % of all τ decays)

B_{tag}

hadronic tag

$B \to D^{(*)}\pi, D^{(*)}\rho\ldots$
$\epsilon \sim 0.5\%$

semileptonic tag

$B \to D^{(*)} l \nu X$
$\epsilon \sim 2\%$

Particle	# channels (Belle)	# channels (Belle II)
$D^+/D^{*+}/D_s^+$	18	26
D^0/D^{*0}	12	17
B^+	17	29
B^0	14	26

Algorithm	MVA	Efficiency	Purity
Belle v1 (2004)	Cut based (Vcb)		
Belle v3 (2007)	Cut based	0.1	0.25
Belle NB (2011)	Neurobayes	0.2	0.25
Belle II FEI (2017)	Fast BDT	0.5	0.25

Improvement to tagging efficiency in Belle II

(think about flavour tagging at LHCb...)

physics program related to this activity
$B \to K^{(*)}\tau\tau, K^{(*)}\nu\nu, D^{(*)}\tau\nu, \tau\nu, \mu\nu$ etc...

$B^+ \to K^+ \tau \ell$ SEARCH WITH FEI

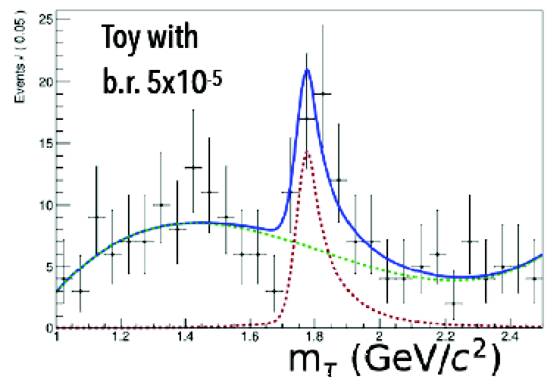
HADRONIC FEI + Belle

Belle Note N.1576

Under refereeing

- $\tau \to \pi/\rho/e/\mu$ decays
- $\ell = \{e, \mu\}$
- MVA is adopted for background suppression
- Fit to m_τ distributions
- Control samples
  $B^+ \to D^-(\to K^+\pi^-\pi^-)\pi^+\pi^+$,
  $B^+ \to J/\psi(\to \ell\ell)K^+$
- Sensitivity $\mathcal{O}(10^{-5})$
  First Belle result!

S. Watanuki (Yonsei U.)
G. de Marino (IJCLab)
K. Trabelsi (IJCLab)

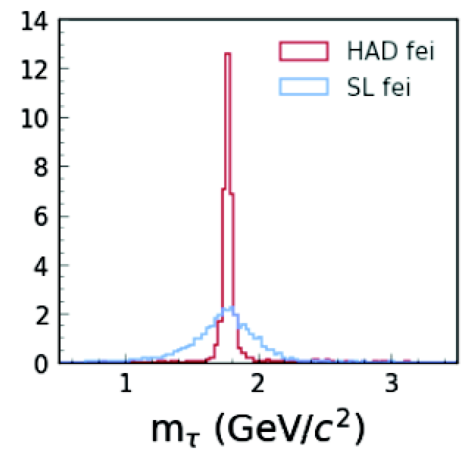


SL FEI

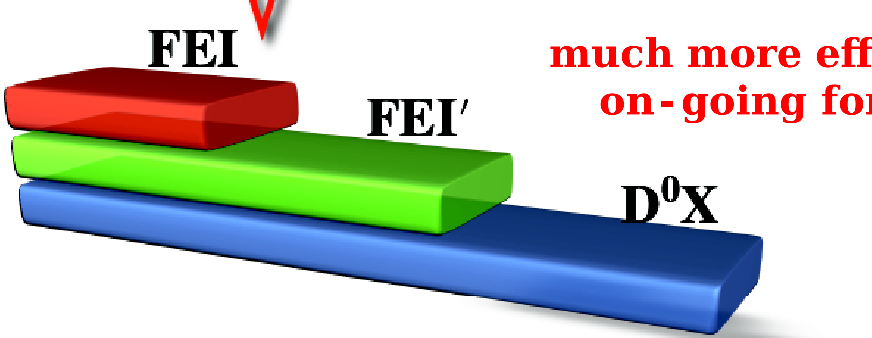
- SL tags: orthogonal sample that can be exploited
- Recoil mass still peaks at m_τ but the resolution is a factor ~2-3 worse

$$m_\tau = [m_B^2 + m_{K\mu}^2 - 2(\underbrace{E_B^*}_{E^*_{beam}} E_{K\mu}^* + \underbrace{|\vec{p}_B^*|}_{\sqrt{(E^*_{beam})^2 - m_B^2}}|\vec{p}_{K\mu}^*|\cos\theta)]^{\frac{1}{2}}$$

θ: angle between $\vec{p}^*_{B_{tag}}$ and $\vec{p}^*_{K\mu}$



- High efficiency but worse resolution
- → Sensitivity? (higher background level)



much more efforts at IJCLab on-going for B-tagging

Mode	U.L. (90% CL)	Exp.
$B^+ \to K^+\tau\mu$	4.8×10^{-5}	BABAR
$B^+ \to K^+\tau e$	3.0×10^{-5}	BABAR
$B^+ \to K^+\tau^+\mu^-$	3.9×10^{-5}	LHCb

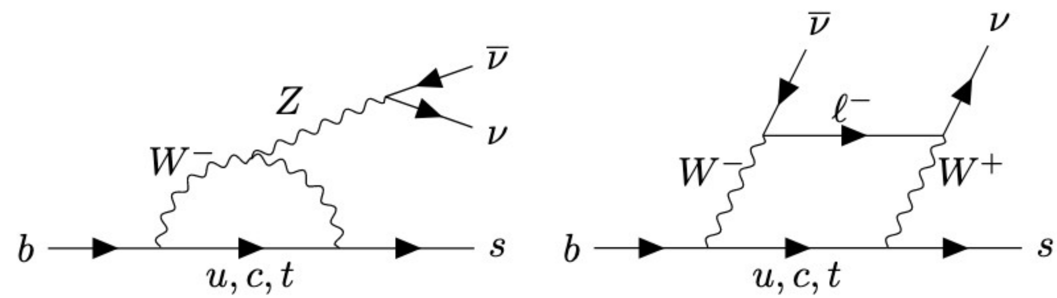
[BaBar, PRD86, 012004 - LHCb, JHEP 06 (2020) 129]

$B^+ \to K^+ \nu \bar{\nu}$

- SM predictions:

T. Blake et al, Prog. Part.Nucl. Phys.92, 50 (2017)

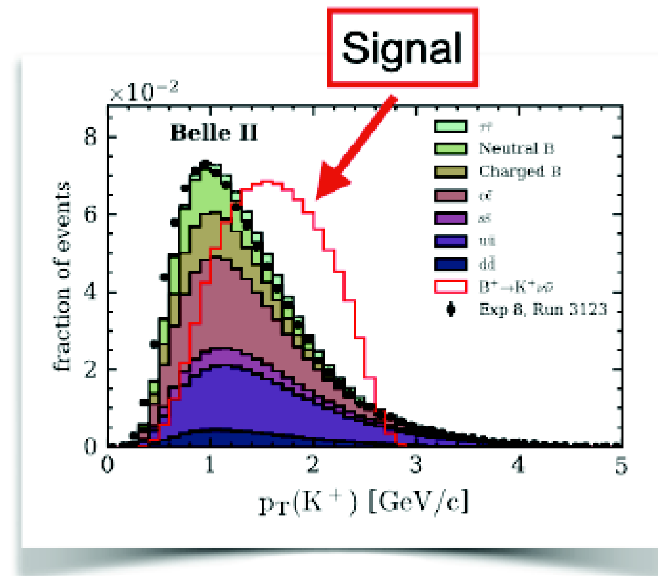
$$\mathrm{BR}(B^+ \to K^+ \nu\bar{\nu})_{\mathrm{SM}} = (4.6 \pm 0.5) \times 10^{-6}\,,$$
$$\mathrm{BR}(B^+ \to K^{*+} \nu\bar{\nu})_{\mathrm{SM}} = (8.4 \pm 1.5) \times 10^{-6}\,,$$



(a) Penguin diagram (b) Box diagram

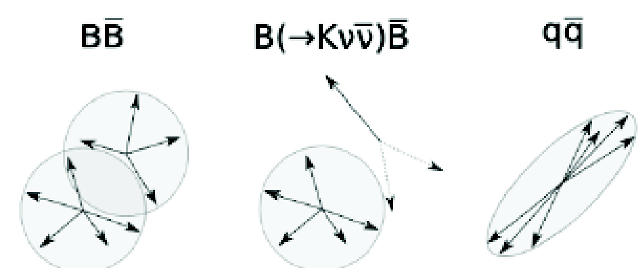
NOVEL INCLUSIVE APPROACH on 63 fb^{-1} of Belle II data:

- Signal kaon = highest p_T track



- Associate all other tracks and clusters to other B in the event

- Use multivariate approach (2 BDTs in cascade) based on kinematics, event shape and vertexing variables to suppress background

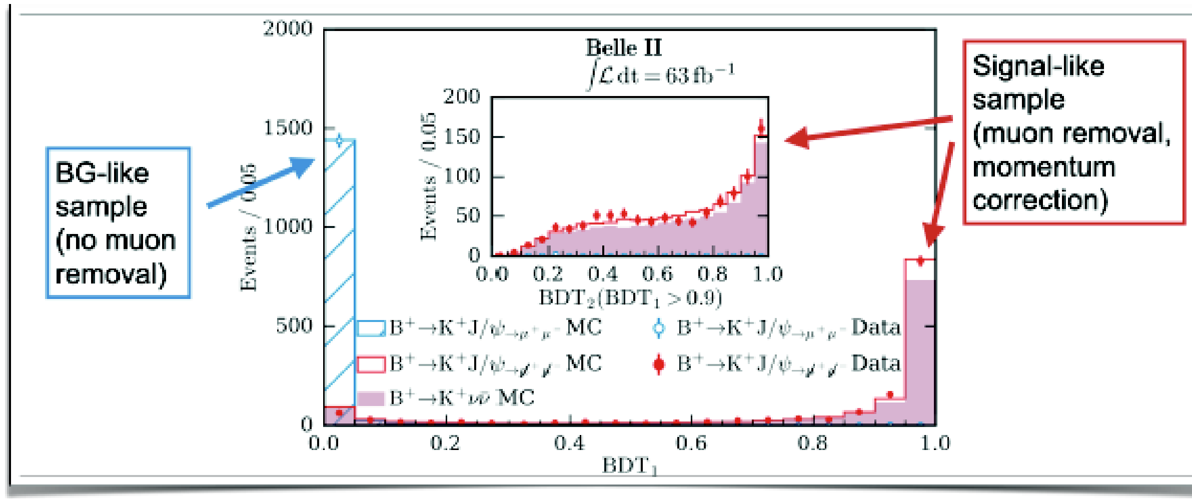


- **Signal efficiency ~ 4.3 %** (SM signal)

$B^+ \to K^+ \nu \bar{\nu}$ measurement at Belle II

[arXiv:2104.12624]
accepted by PRL

- Check data-simulation agreement in BDTs output using $B^+ \to J/\psi(\mu^+\mu^-)K^+$ control sample
- **Data/MC ratio in fit region**: 1.06 ± 0.10

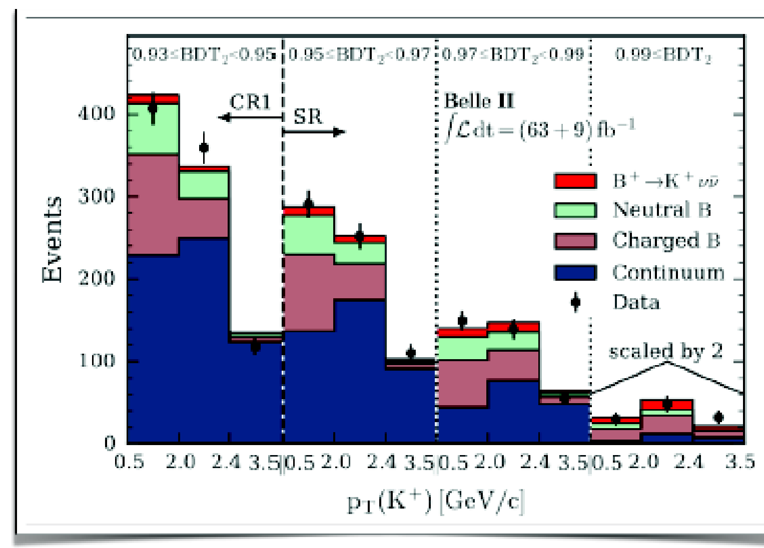


- Extract signal from simultaneous maximum likelihood fit to on-resonance + off- resonance data (taken 60MeV below $\Upsilon(4S)$ resonance) in bins of $p_T(K^+)$ and second BDT (BDT$_2$):

Signal strength:

$$\mu = 4.2^{+2.9}_{-2.8}(\mathrm{stat})^{+1.8}_{-1.6}(\mathrm{syst})$$

- consistent with SM exp (μ=1) at 1 σ
- consistent with background-only hypothesis at 1.3 σ



- Leading systematics: **background normalisation** uncertainty can be also reduced with increasing statistics

$B^+ \to K^+ \nu \bar{\nu}$ measurement at Belle II

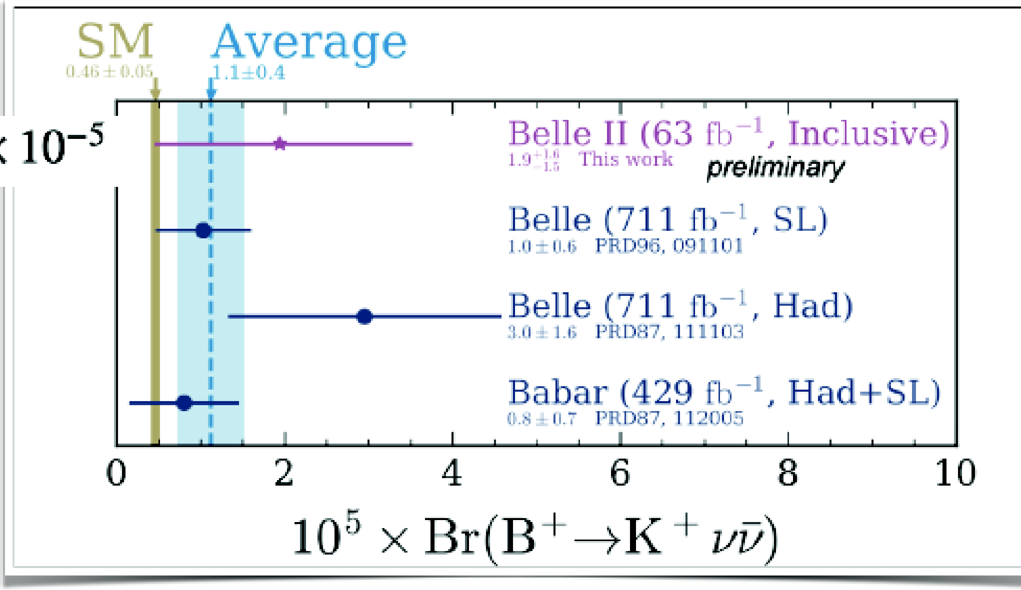
[arXiv:2104.12624]
accepted by PRL

- No evidence for signal, upper limit on BR using CLs method (assuming SM signal)

$$\mathscr{B}(B^\pm \to K^\pm \nu\bar{\nu}) < (4.1 \pm 0.5) \times 10^{-5} \,@\, 90\,\%\,\mathrm{CL}$$

- Comparing theory and experiments:

$$\mathscr{B}(B^+ \to K^+ \nu\bar{\nu}) = 1.9^{+1.6}_{-1.5} \times 10^{-5}$$



  - When converted to the same luminosity, **our measurement is better*) than semi-leptonic tagging by 10-20%**
  - … **and than hadronic tagging by a factor 3.5!**

*) assuming the total uncertainty on the branching-fraction scales with $1/\sqrt{L}$

- Room for **improvement** in K^+ channel, application of inclusive method to **other channels** in progress

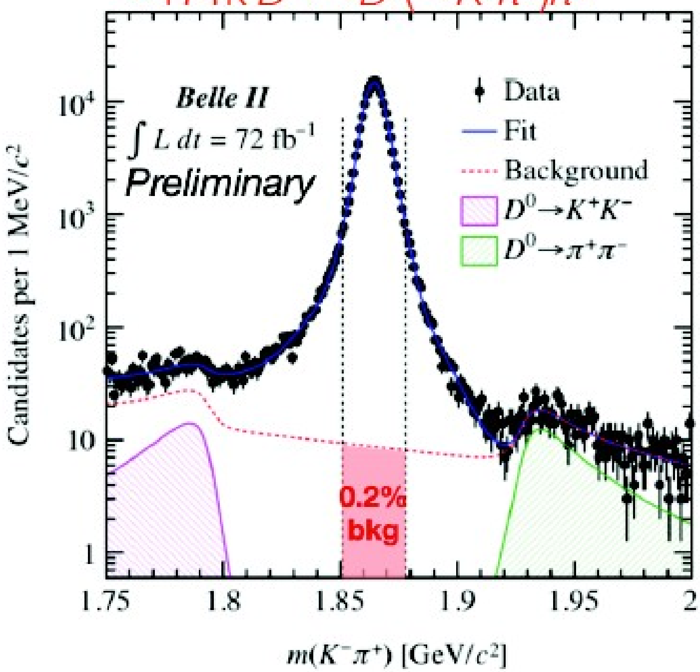
Signal Decays

use 72 fb^{-1} (~1/3 of the data now on disk)

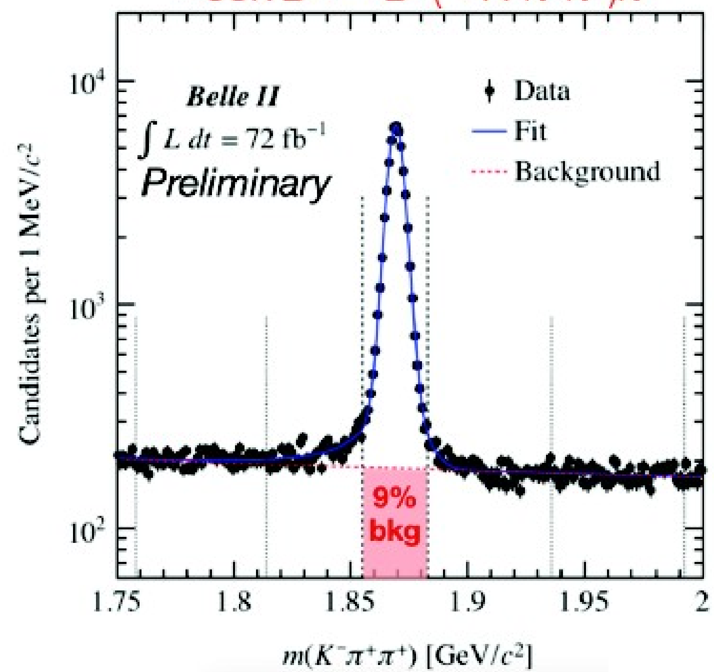
➡ Selected high-purity samples to limit the background-related systematic uncertainty

- removed candidates from B decays to avoid bias on the D production vertex

~171k $D^{*+} \to D^0(\to K^- \pi^+)\pi^+$



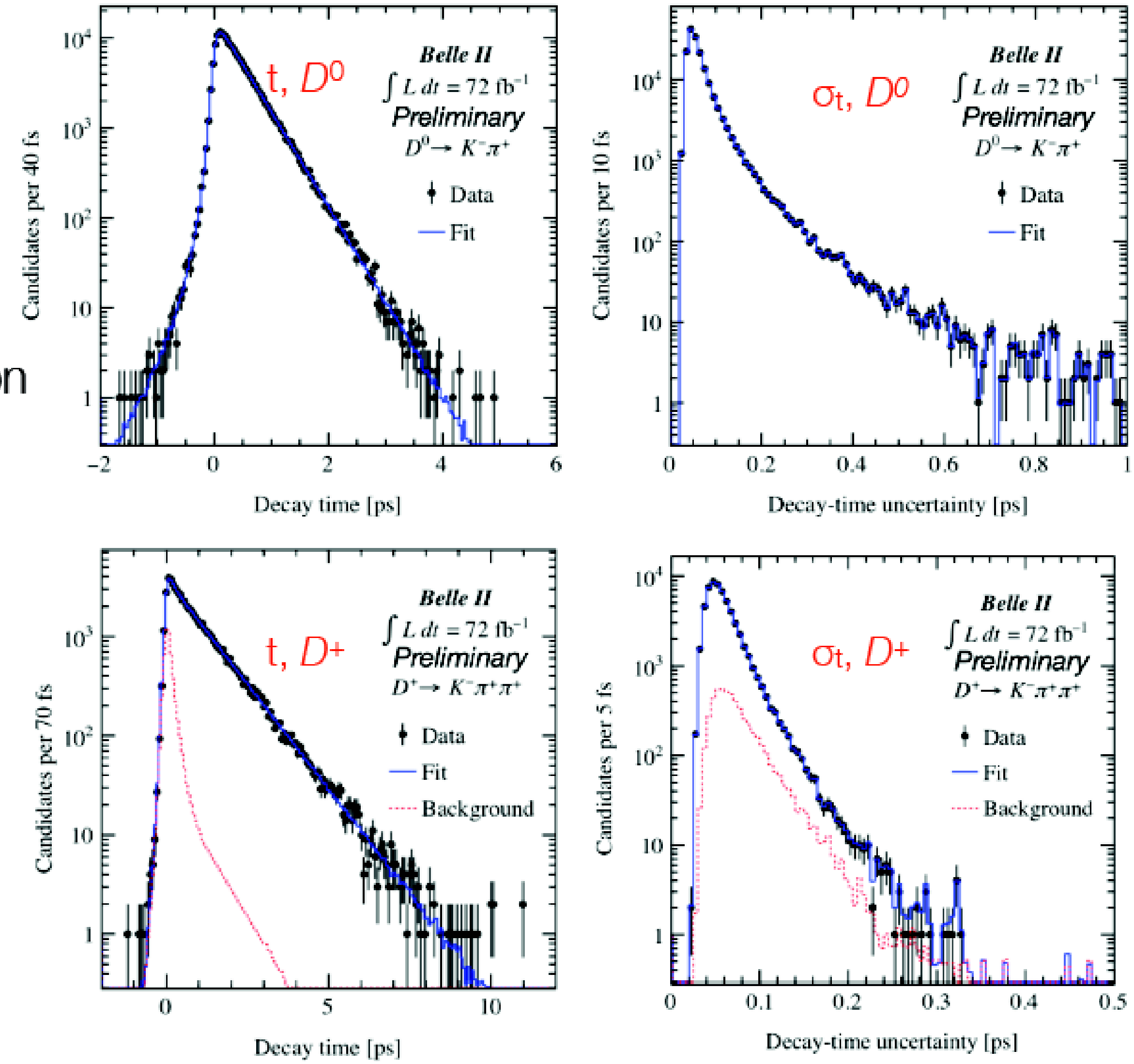
~59k $D^{*+} \to D^+(\to K^- \pi^+ \pi^+)\pi^0$



Lifetime Fit

unbinned ML fit to (t,σ_t)

- Resolution and background models extracted on data, no input from simulation
  - resolution ~ 60-70 fs
  - MC just used for validation and to assess a few systematic uncertainties
- Blind analysis:
  - selection, validation, crosschecks and assessment of the systematic uncertainty performed before looking at the lifetime
  - except for 2019 data (~13% of the sample) unblinded since ICHEP 2020 (compatible with WA).



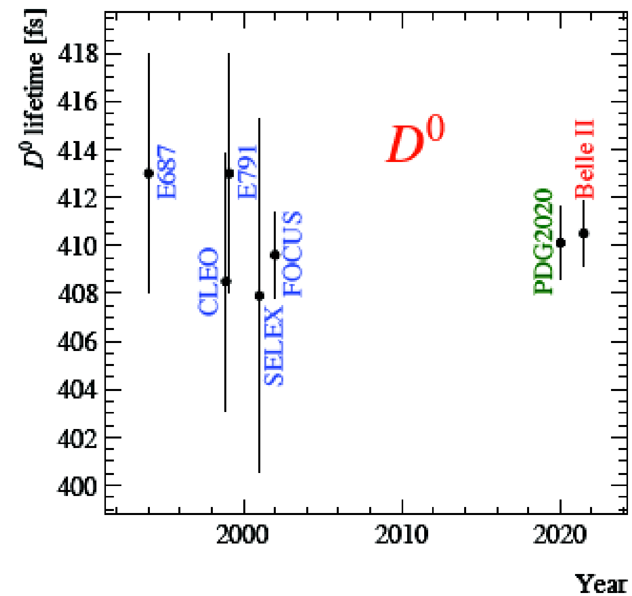
Results

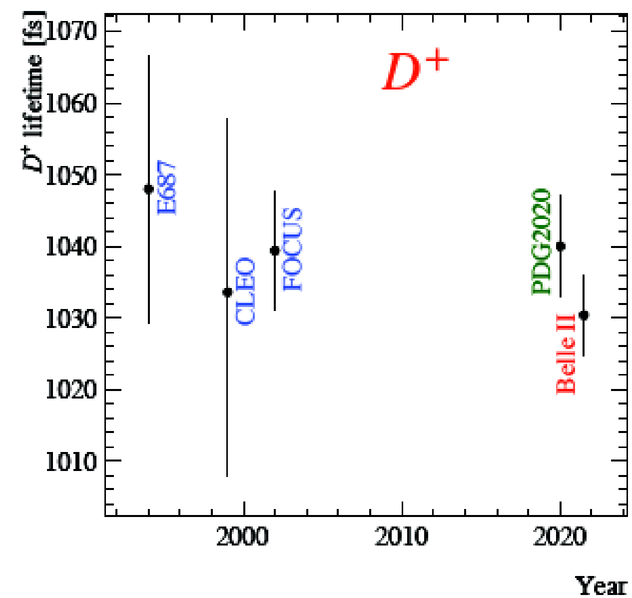
$$\tau(D^0) = \ \ 410.5 \pm 1.1 \pm 0.8\,\text{fs}$$
$$\tau(D^+) = 1030.4 \pm 4.7 \pm 3.1\,\text{fs}$$

$$\tau(D^+)/\tau(D^0) = 2.510 \pm 0.015$$

determined considering correlations between (systematic) uncertainties

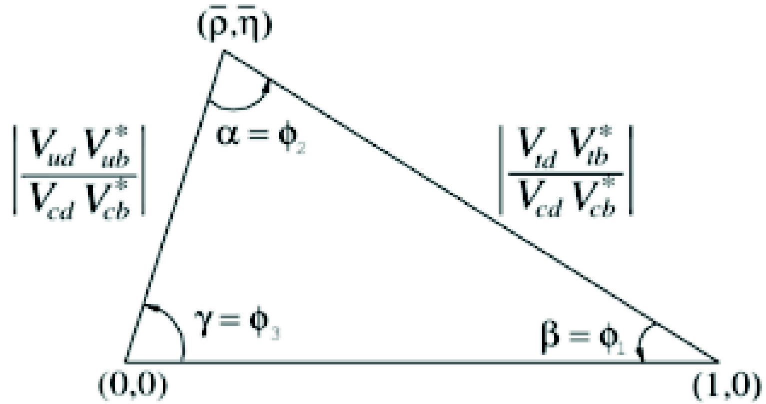
- ➡ Consistent with current world averages 410.1±1.5 fs (D^0) and 1040±7 fs (D^+).
- ➡ World's most precise measurements of the D^0 and D^+ lifetimes
- ➡ Few ‰ accuracy (3.5‰ for the D^0 and 5.4‰ for the D^+) establishes excellent performance of our detector!
- ➡ submitted to PRL, https://arxiv.org/abs/2108.03216



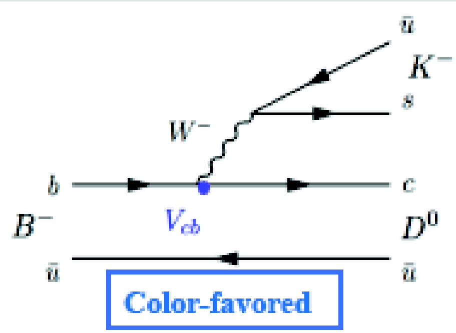


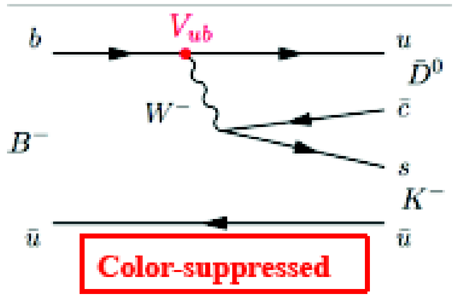
The CKM angle ϕ_3

$$\phi_3/\gamma \equiv arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$



- Very precise theoretical prediction $\frac{\delta\phi_3}{\phi_3} \sim 10^{-7}$ arxiv:1308.5663
- Test physics beyond SM





- The interference between color-favored and color-suppressed processes can be related :

$$\boxed{\frac{A^{suppr.}[B^-\to\overline{D^0}K^-]}{A^{favor.}[B^-\to D^0K^-]} = r_B e^{i(\delta_B-\phi_3)}}$$

r_B -the magnitude of the ratio of amplitudes ~0.1 ; δ_B -strong-phase difference

- 3 main methods to extract ϕ_3:
  - GLW method: CP eigenstates: K^-K^+, $\pi^-\pi^+$, $K_S^0\pi^0$
  - ADS method: DCS modes: $K^+\pi^-$, $K^+\pi^-\pi^0$
  - BPGGSZ method: self-conjugate multibody final states: $K_S^0\pi^+\pi^-$, $K_S^0K^+K^-$, $K_S^0\pi^+\pi^-\pi^0$

- Foreseen precision of ϕ_3 is expected to be $\mathcal{O}(1°)$ (current world-average $\delta\phi\sim4°$) with the full Belle II dataset of 50 ab^{-1}

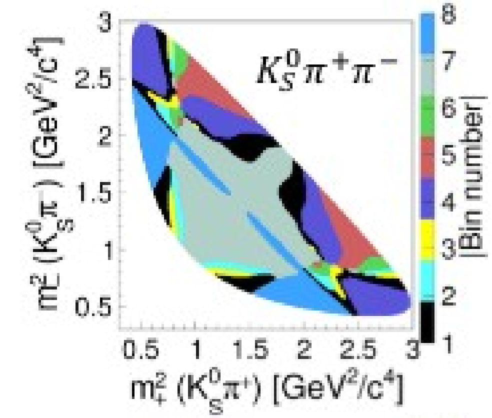
BPGGSZ Method Study of $B^- \to D(\to K_S^0 h^+ h^-)h^-$

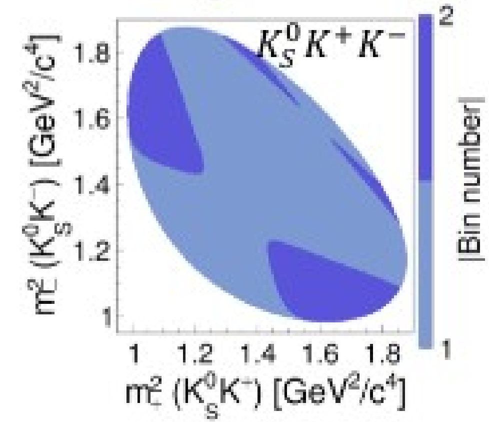
https://arxiv.org/abs/2110.12125

$h = \pi, K$

First Belle + Belle II analysis

- $B^- \to D(\to K_S^0\pi^+\pi^-)K$ is golden mode at Belle II
- Sensitivity to ϕ_3 by comparing D Dalitz (fit with full amplitude model)distribution of B^- and B^+ :
$$A_B = \overline{A}(m_-^2, m_+^2) + r_B e^{i(\delta_B+\phi_3)} A(m_+^2, m_-^2)$$
- Model-dependent analysis have model uncertainty up to 3° -9°
- Using binned model-independent approach





> - Optimal binning of the D Dalitz plot which gives the maximum sensitivity to ϕ_3
> - Observed yields in each bin can be related to physics parameters of interest and D^0 decay information

$$N_i^{\pm} = h_{B^\pm}\left[F_i + r_B^2\overline{F}_i + 2\sqrt{F_i\overline{F}_i}(c_i x_\pm + s_i y_\pm)\right].$$

> - $h_{B^\pm}$:Normalization constant
> - Physics parameters of interest: $(x_\pm,\ y_\pm) = r_B(\cos(\phi_3 + \delta_B),\ \sin(\phi_3 \pm \delta_B))$
> - Amplitude-averaged strong phase difference between $\overline{D^0}$ and D^0 over i^{th} bin and are obtained from external charm factories like CLEO and BESIII
> - Fraction of pure D^0 decay to bin i taking into account the reconstruction and selection efficiency

BPGGSZ Method Study of $B^- \to D(\to K_S^0 h^+ h^-)h^-$

https://arxiv.org/abs/2110.12125

$h = \pi, K$

First Belle + Belle II analysis !

- Analysis with $711 fb^{-1}$ Belle data and $128 fb^{-1}$ Belle II data

- Unbinned 2D simultaneous fit of ΔE versus C' (right plot) for $B^- \to D^0(K_S^0\pi^+\pi^-)K^-$.

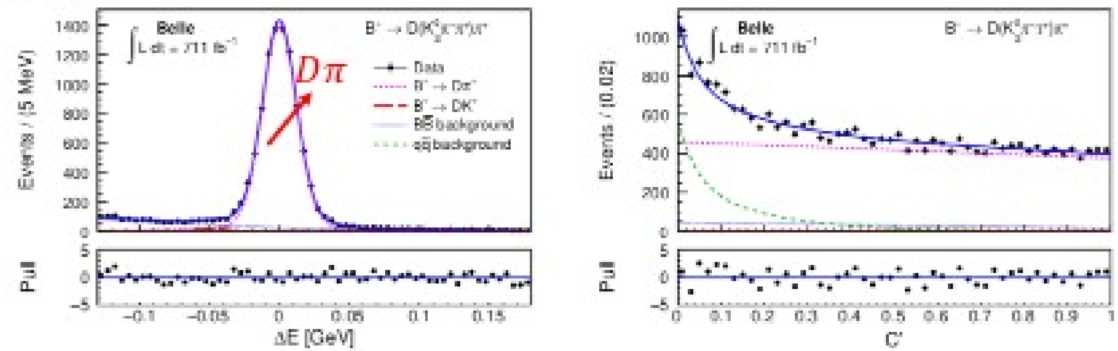
Component	PDF (ΔE)	PDF (FBDT$_{\mathrm{trans}}$)
Signal	DG + Bifur-Gaus	poly (1st)
$B\bar{B}$ bkg	expo +(poly)	Chebychev poly-1st(2nd)
$q\bar{q}$ bkg	Chebychev poly (1st)	2 expo
DK ($D\pi$) component	DG + Bifur-Gaus	Chebychev poly (1st)

- Performed simultaneous fit in 160 categories; 80(16×4 + 4×4) of Belle and 80 of Belle II

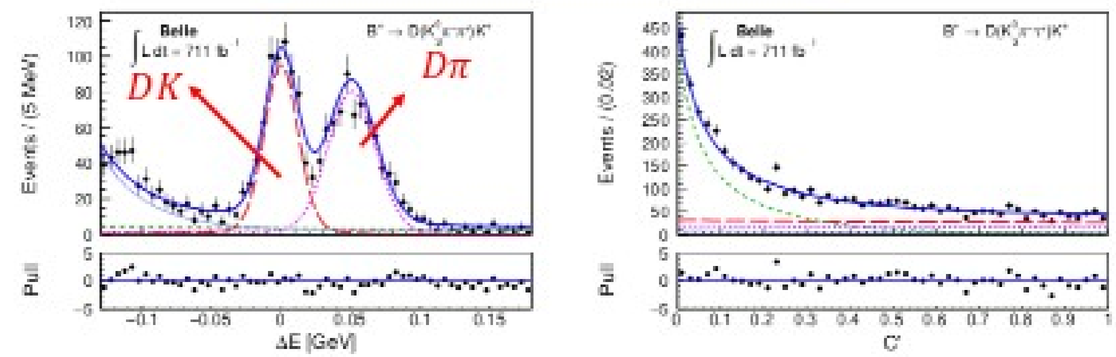
- Signal region :
  - $|\Delta E| < 0.05\ GeV$
  - $0.65 < C' < 1.0$

$(x_\pm, y_\pm) = r_B(\cos(\phi_3 + \delta_B), \sin(\phi_3 \pm \delta_B))$ are common to all the bins and are extracted from the fit

pion enhanced $\mathcal{L}(K/\pi)$<0.6



kaon enhanced $\mathcal{L}(K/\pi)$>0.6



BPGGSZ Method Study of $B^- \to D(\to K_S^0 h^+ h^-)h^-$

https://arxiv.org/abs/2110.12125

$h = \pi, K$

First Belle + Belle II analysis

- Analysis with $711 fb^{-1}$ Belle data and $128 fb^{-1}$ Belle II data

- Unbinned 2D simultaneous fit of ΔE versus C' (right plot) for $B^- \to D^0(K_S^0\pi^+\pi^-)K^-$.

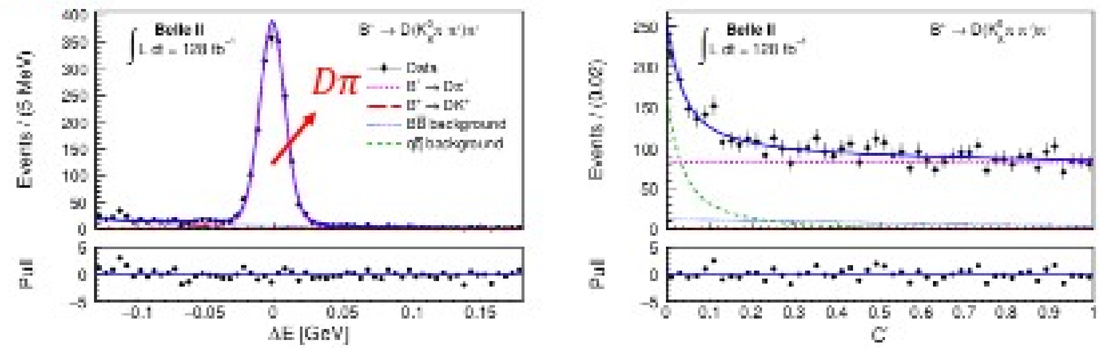
Component	PDF (ΔE)	PDF ($\mathrm{FBDT_{trans}}$)
Signal	DG + Bifur-Gaus	poly (1st)
$B\overline{B}$ bkg	expo +(poly)	Chebychev poly-1st(2nd)
$q\overline{q}$ bkg	Chebychev poly (1st)	2 expo
DK ($D\pi$) component	DG + Bifur-Gaus	Chebychev poly (1st)

- Performed simultaneous fit in 160 categories; 80(16×4 + 4×4) of Belle and 80 of Belle II

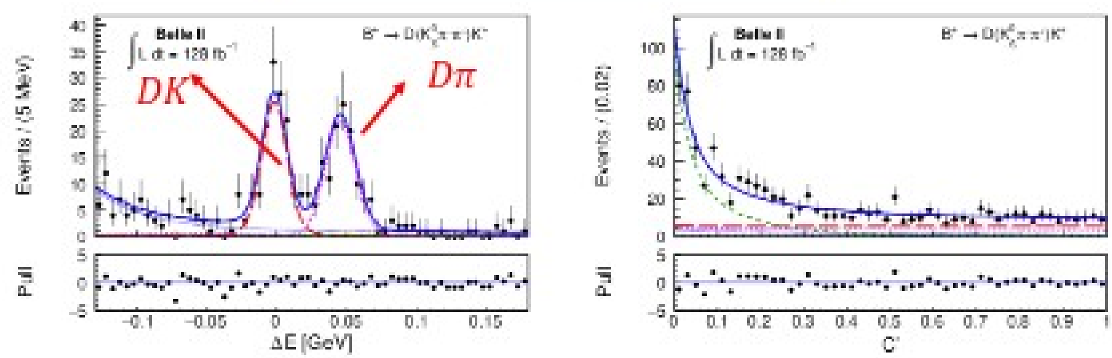
- Signal region :
  - $|\Delta E| < 0.05\ GeV$
  - $0.65 < C' < 1.0$

$(x_\pm, y_\pm) = r_B(\cos(\phi_3 + \delta_B), \sin(\phi_3 \pm \delta_B))$ are common to all the bins and are extracted from the fit

pion enhanced $\mathcal{L}(K/\pi)$<0.6



kaon enhanced $\mathcal{L}(K/\pi)$>0.6



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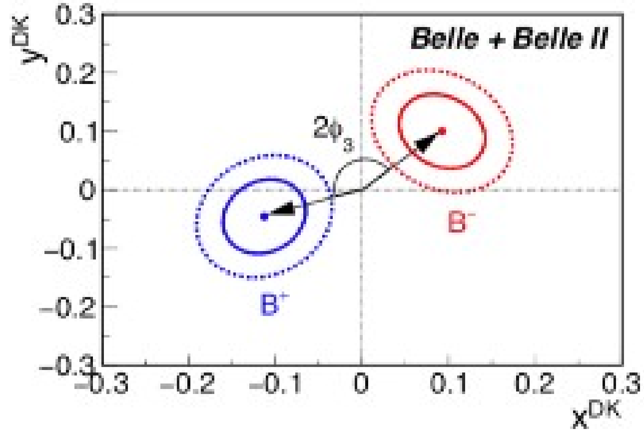
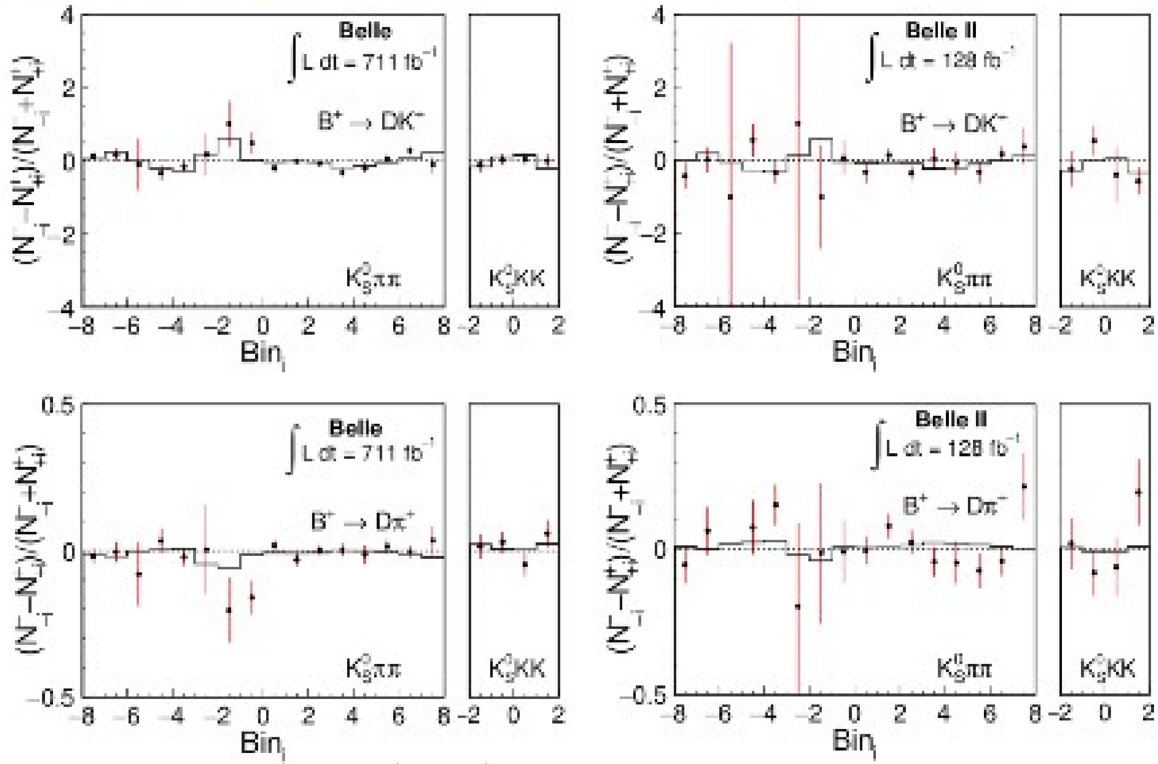


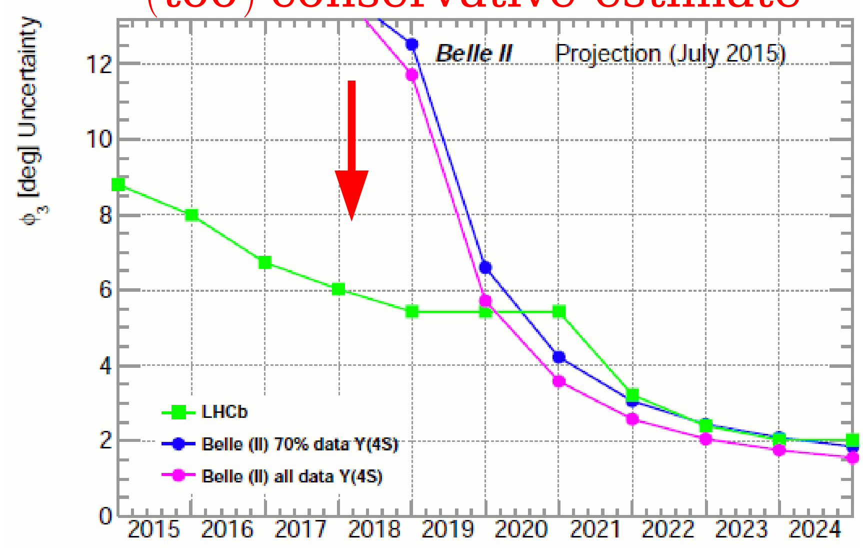


Uncertainty ~14° in earlier Belle measurement
PhysRevD.85.112014

- Preliminary result :

$\delta_B(°)$ = 124.8 ± 12.9 (stat.) ± 0.5 (syst.) ± 1.7 (ext. input)
r_B^{DK} = 0.129 ± 0.024 (stat.) ± 0.001 (syst.) ± 0.002 (ext. input)
$\phi_3(°)$= 78.4 ± 11.4 (stat.) ± 0.5 (syst.) ± 1.0 (ext. input)

(too) conservative estimate

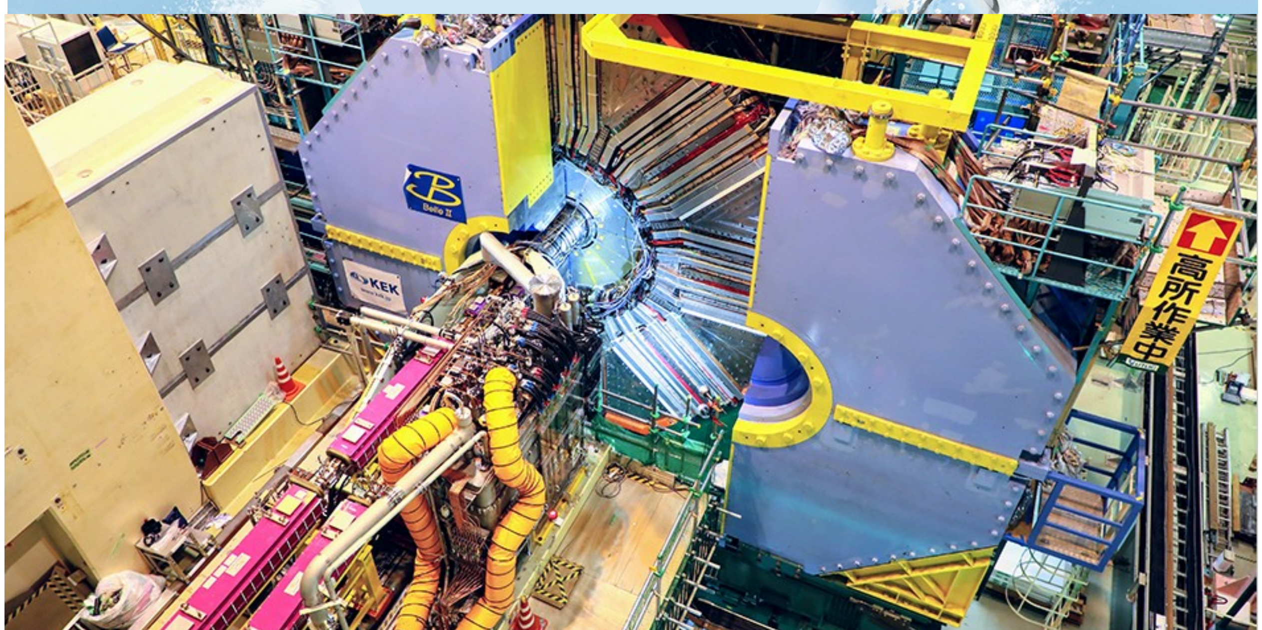


long way to go … (→σ_γ = 1° or less ?)

Summary

- first Belle II published results with o($100\ \mathrm{fb}^{-1}$)
  detector is fully operational, ready for physics
- continue data taking until 2023
  with target: $\sim 1\ \mathrm{ab}^{-1}$, $10^{35}/\mathrm{cm}^2/\mathrm{s}$
- followed by a LS1 to install PXD 2 layers
  → 50/ab by 2031…


LE MYSTÈRE DES PINGOUINS
ペンギン・ハイウェイ
penguin highway

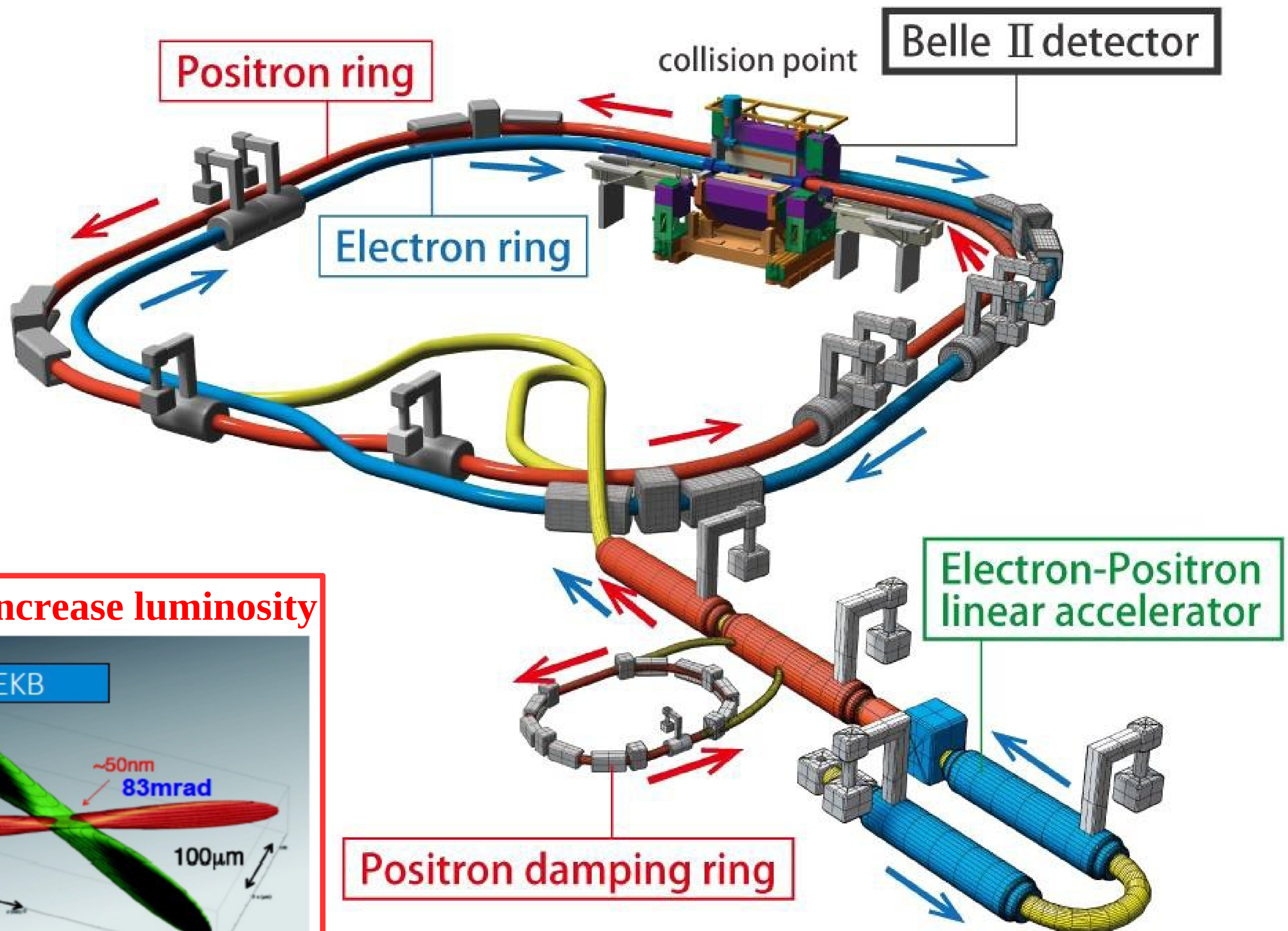

KEK
高所作業中

SuperKEKB, the first new collider in particle physics since the LHC in 2008 (electron-positron $(e^+ e^-)$ rather than proton-proton (p-p))

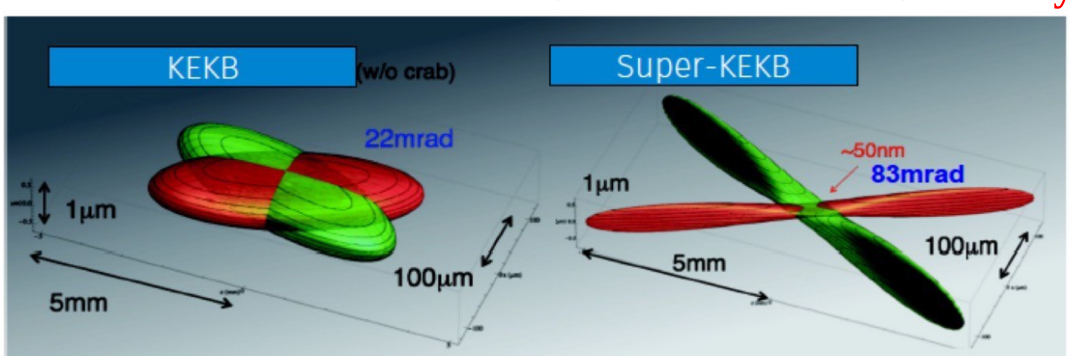
Phase 1
Background , Optics commissioning
Feb - June **2016**
Brand new 3 km positron ring

Phase 2: Pilot run
Superconducting Final Focus
add positron damping ring
First Collisions $(0.5\ \mathrm{fb}^{-1})$
April 27 - July 17, **2018**

Phase 3: Physics run
Since April , **2019**



Nano-beams and more beam current to increase 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 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

factor 20 factor 2-3

$\Rightarrow$ **to reach $6\times10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$**

$\Rightarrow$ **cumulate 50 ab^{-1} by ~2031**

Belle II detector

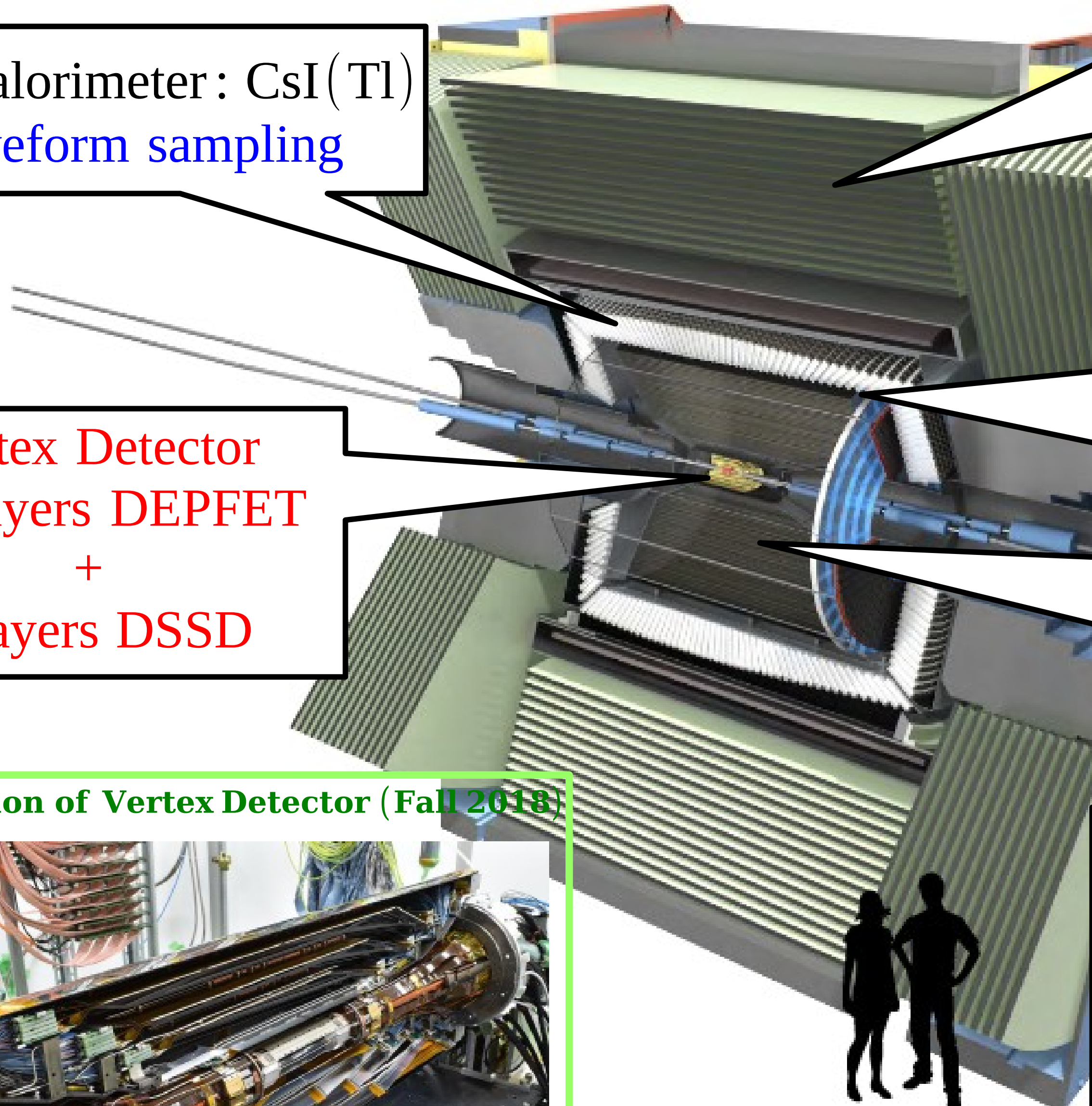
EM Calorimeter: CsI(Tl)
waveform sampling

K_L and muon detector
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC
(endcaps)

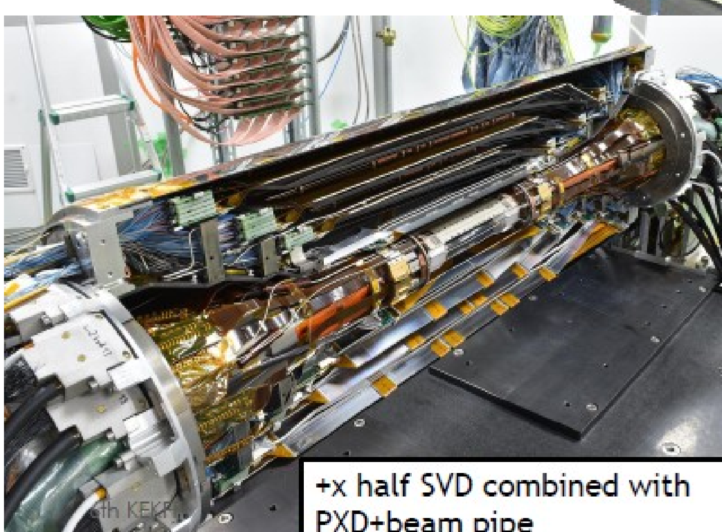
Particle Identification
Time-Of-Propagation
counter (barrel)
Prox. focusing Aerogel RICH

Vertex Detector
1/2 layers DEPFET
+
4 layers DSSD

Central Drift Chamber
He (50%):C_2H_6 (50%)
small cells, long level arm,
fast electronics



Installation of Vertex Detector (Fall 2018)



on-going DAQ upgrade
(to be installed in 2021-2022)
PCIe40 board, capable of reading via high speed optical links and to write to computer at rate of 100 Gb/s:
limited number of boards (20) enough
to read entire Belle II detector
(P.Robbe, D.Charlet et al)

considering now VTX upgrade (2025 or later)
(also luminometer LumiBelle2, P.Bambade et al)

Background Description

only for the D^+ channel

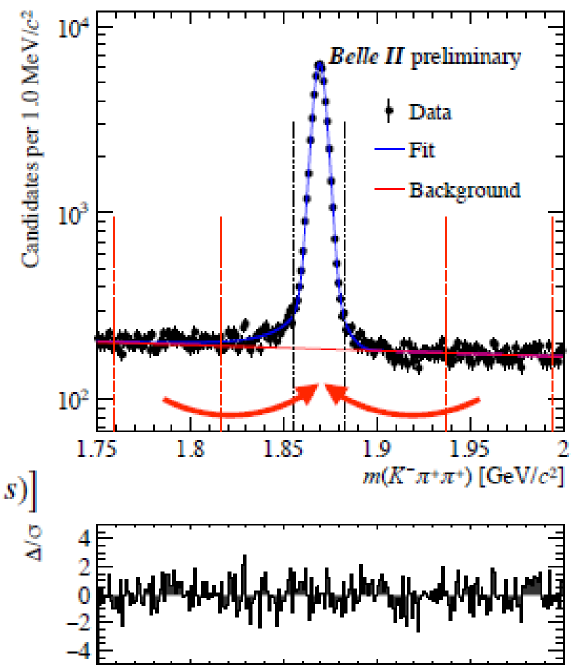
- The ~9% background contamination in the signal region can't be ignored → include it in the fit
- Use an empiric model derived from the data sidebands
  - simulation shows that the sidebands represent a good proxy of the background in the signal region
  - background PDF: $\mathrm{pdf}_{\mathrm{bkg}}(t, \sigma_t) = \mathrm{pdf}_{\mathrm{bkg}}(t \,|\, \sigma_t)\ \mathrm{pdf}_{\mathrm{bkg}}(\sigma_t)$

zero-lifetime component *lifetime#1 component* *lifetime#2 component*

$$\mathrm{pdf}_{\mathrm{bkg}}(t \,|\, \sigma_t) = (1 - f_{bl}) R(t \,|\, b + \boxed{b_{\mathrm{bkg}}}, s\sigma_t) + f_{bl}\left[f_{bl1}\mathrm{pdf}_{bl1}(t \,|\, \sigma_t, \boxed{\tau_{b1}}, b + b_{\mathrm{bkg}}, s) + (1 - f_{bl1})\mathrm{pdf}_{bl2}(t \,|\, \sigma_t, \boxed{\tau_{b2}}, b + b_{\mathrm{bkg}}, s)\right]$$

- Signal and sideband regions are **fit simultaneously** with all shape parameters free
  - the background fraction is constrained to the result of the mass fit

$D^{*+} \to D^+(\to K^-\pi^+\pi^+)\pi^0$



Systematics Breakdown

total uncertainties are 1.4 fs (D^0) and 5.6 fs (D^+)

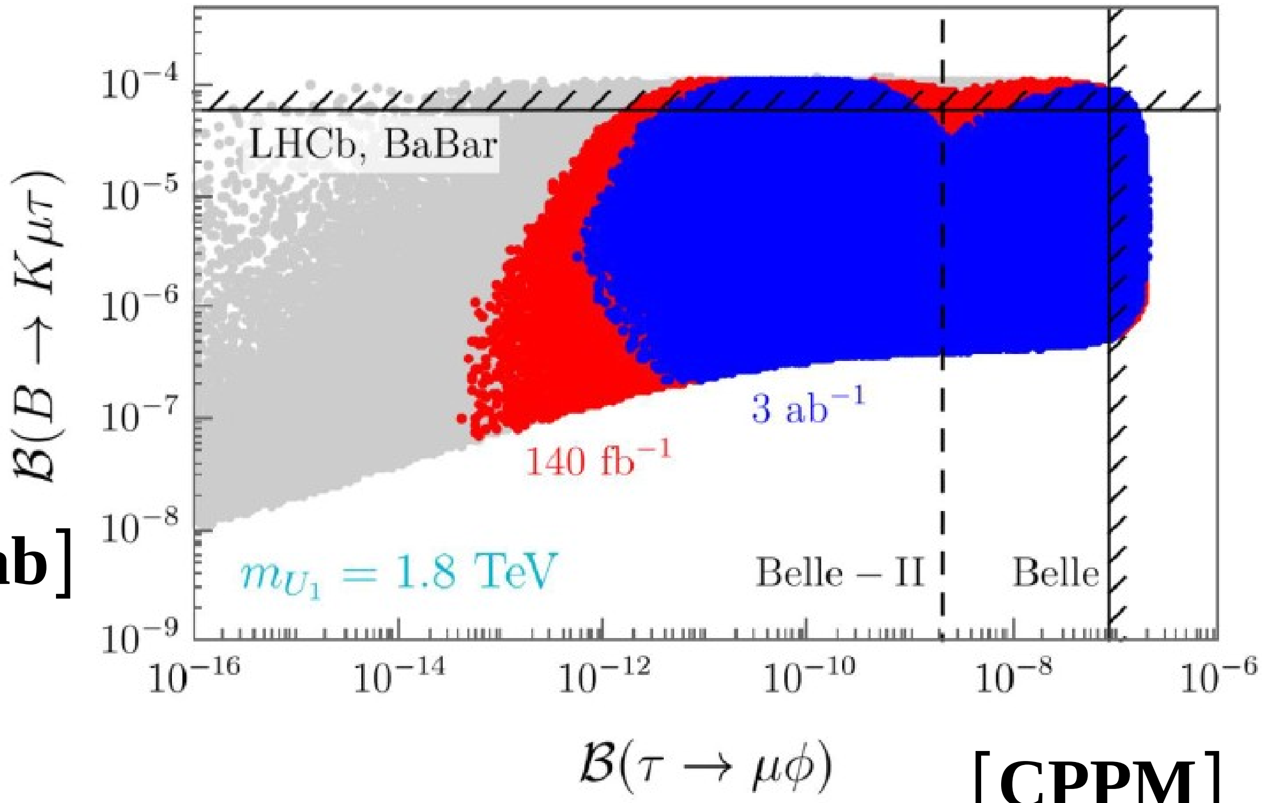
- Most critical contribution to the systematic uncertainty comes from the **alignment**
  - affecting the length scale
  - estimated using several different versions of reconstructed misaligned signal MC samples (next slide), from the same generated sample
- Dominant systematics for the D^+ is related to the **backgrounds**
  - to account for imperfect data-MC agreement of the decay-time distribution in the low-mass sideband

Source	Uncertainty (fs)	
	$D^0 \to K^-\pi^+$	$D^+ \to K^-\pi^+\pi^+$
Statistical	1.1	4.7
Resolution model	0.16	0.39
Backgrounds	0.24	2.52
Detector alignment	0.72	1.70
Momentum scale	0.19	0.48
Input charm masses	0.01	0.03
Total systematic	0.8	3.1

- Both the dominant contributions can be improved:
  - reduce bkg contamination in the D^+ signal region
  - improved alignment algorithm already in place

Nice complementarity

[IJCLab]



[CPPM]

A. Angelescu et al., arXiv:2103.12504v2 (21 Apr 2021)

cLFV : beyond the Standard Model

long-standing, and well motivated (particularly since the discovery of neutrino oscillations) programme of searches for charged Lepton Flavour Violation

less stringent limits in 3rd generation, but here BSM effects may be higher

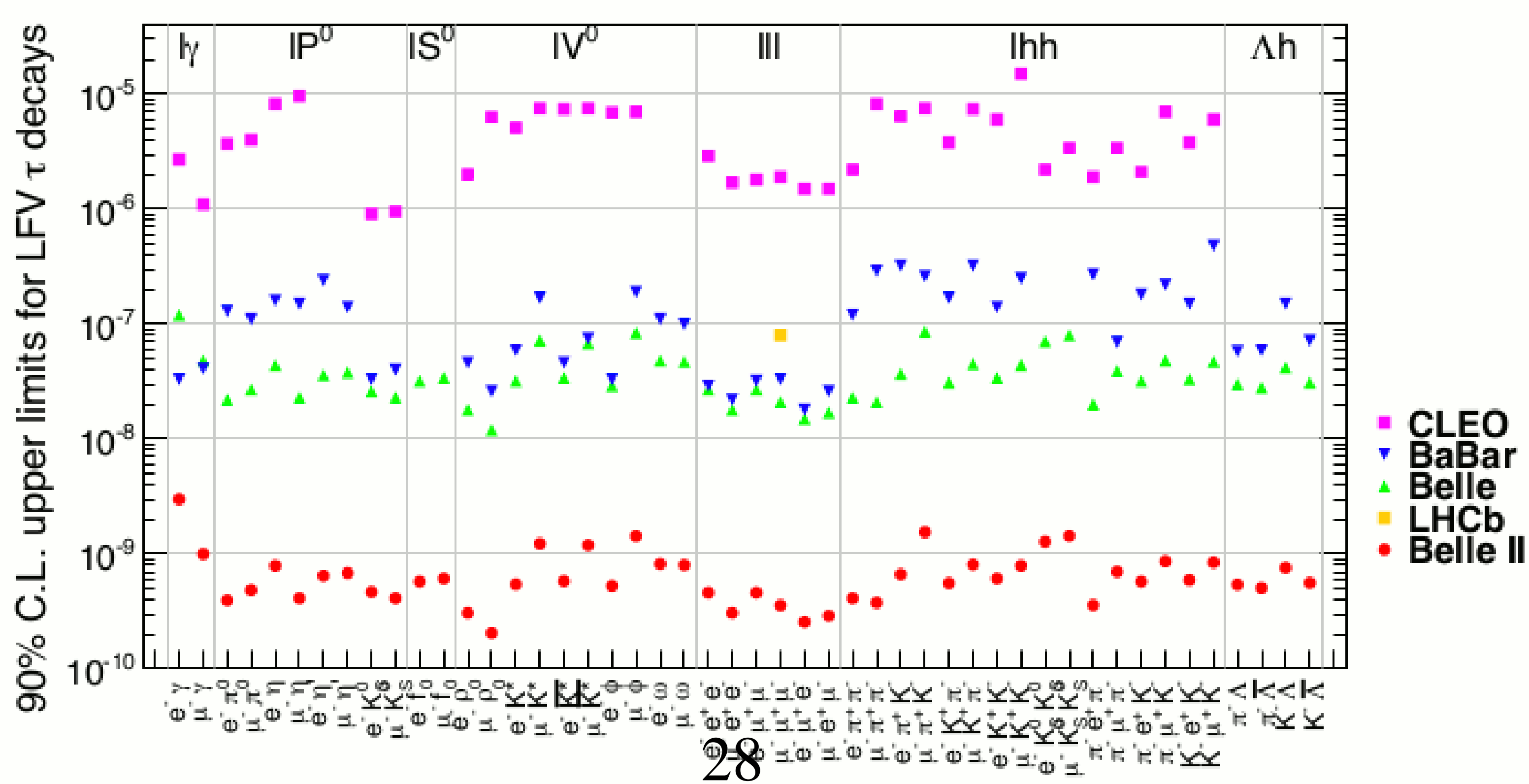
$$\mathcal{B}_{\nu SM}(\tau \to \mu\gamma) = \frac{3\alpha}{32\pi}\left|U^*_{\tau i}U_{\mu i}\frac{\Delta m^2_{3i}}{m^2_W}\right|^2 < 10^{-40}$$

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{C^{(5)}}{\Lambda}O^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2}O_i^{(6)} + \ldots$$

Model	Reference	τ→μγ	τ→μμμ
SM+ ν oscillations	EPJ C8 (1999) 513	10^{-40}	10^{40}
SM+ heavy Maj ν_R	PRD 66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66 (2002) 115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566 (2003) 217	10^{-10}	10^{-7}

		$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K\bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$
4-lepton	$O^{4\ell}_{S,V}$	✓	–	–	–	–	–
dipole	O_D	✓	✓	✓	✓	–	–
lepton-quark	O^q_V	–	–	✓ (I=1)	✓(I=0,1)	–	–
lepton-quark	O^q_S	–	–	✓ (I=0)	✓(I=0,1)	–	–
lepton-gluon	O_{GG}	–	–	✓	✓	–	–
lepton-quark	O^q_A	–	–	–	–	✓ (I=1)	✓ (I=0)
lepton-quark	O^q_P	–	–	–	–	✓ (I=1)	✓ (I=0)
lepton-gluon	$O_{G\tilde{G}}$	–	–	–	–	–	✓

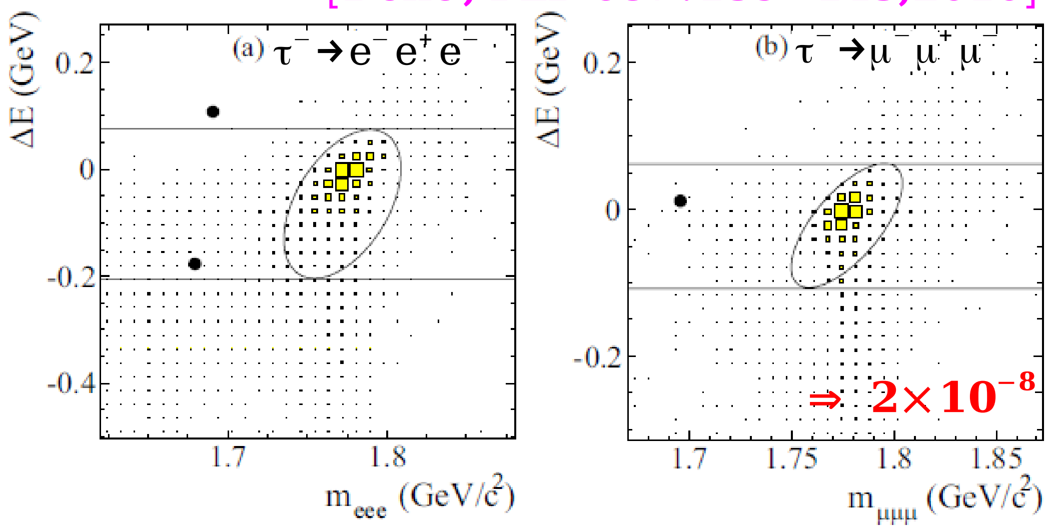
Celis, Cirigliano, Passemar (2014)



cLFV : beyond the Standard Model

τ LFV searches at Belle II will be extremely clean with very little background (if any), thanks to pair production and double-tag analysis technique.

[Belle, PLB 687:139–143,2010]



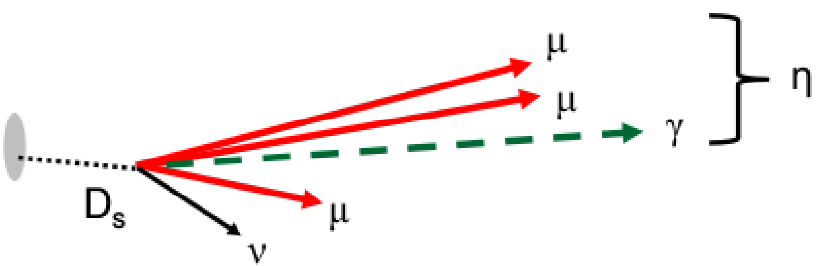
$\Rightarrow$ 2×10^{-8} at 90%CL

how to improve further ?

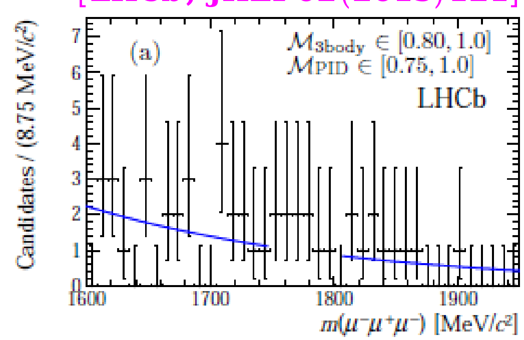
...considering $\tau \to \mu/e\, h^+ h^-$ in function of one prong tag categories

...for $\tau \to 3$ muons, improve μ-ID at low mom (ECL info)

In contrast, hadron collider experiments must contend with larger combinatorial and specific backgrounds



[LHCb, JHEP02(2015)121]



$\Rightarrow$ 5×10^{-8} at 90%CL

Background modes normalised to $D_s \to \eta(\mu\mu\gamma)\mu\nu$ (BR ~ 10^{-5})

Decay channel	Relative abundance
$D_s \to \eta(\mu\mu\gamma)\mu\nu$	1
$D_s \to \phi(\mu\mu)\mu\nu$	0.87
$D_s \to \eta'(\mu\mu\gamma)\mu\nu$	0.13
$D \to \eta(\mu\mu\gamma)\mu\nu$	0.13
$D \to \omega(\mu\mu)\mu\nu$	0.06
$D \to \rho(\mu\mu)\mu\nu$	0.05

Most improvement in coming decade is expected from Belle II, which can reach 1×10^{-9} [arXiv:1011.0352] and will do even better if can achieve ~ zero bckgd

Many more interesting τ topics

CP asymmetry (CPV not yet observed in the lepton sector)

$$A_\tau \equiv \frac{\Gamma(\tau^+ \to \pi^+ K^0_S \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K^0_S \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K^0_S \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K^0_S \nu_\tau)}$$

$$A_\tau = (-3.6 \pm 2.3 \pm 1.1)\, 10^{-3}$$

$(\geq 0\,\pi^0)$ [Babar, PRD85, 031102 (2012)]

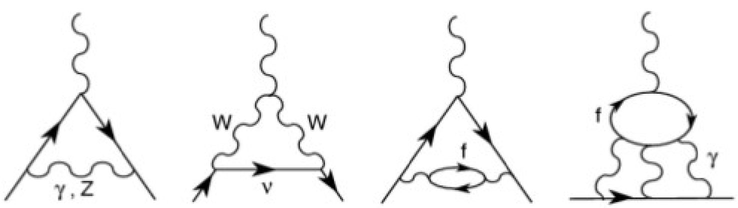
$$A_\tau^{SM} = (+3.6 \pm 0.1)\, 10^{-3}$$

(CPV in K^0 system)

[Bigi-Sanda, Grossman-Nir]

- Belle shows no indication of CP aymmetry in angular distribution of $\tau^- \to K_S \pi^- \nu_\tau$
- a variety of CPV observables to be studied: $\tau \to K\pi\pi\nu_\tau$, $\tau \to \pi\pi\pi\nu_\tau$ rate, angular asymmetries, triple products...

EDM (CPV in tau pair production), τ Anomalous Magnetic Moment



$$a_\mu^{exp} - a_\mu^{th} \sim 3.5\,\sigma$$

Enhanced sensitivity to new physics: $(m_\tau/m_\mu)^2 = 283$

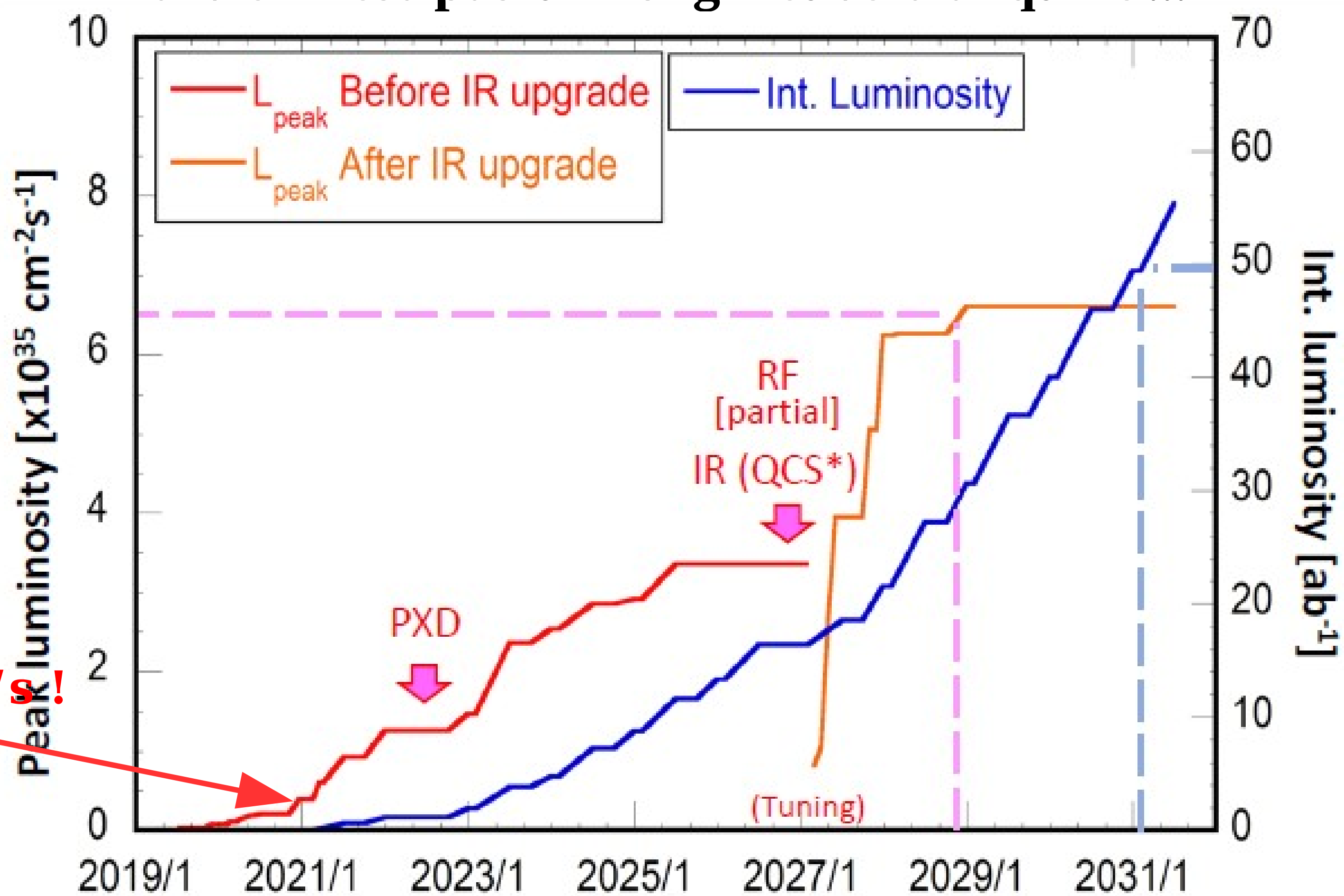
S.Eidelman, M.Passera

$10^8 \cdot\ a_\tau^{th} =$	117 324	± 2	QED
	+ 47.4	± 0.5	EW
	+ 337.5	± 3.7	hvp
	+ 7.6	± 0.2	hvp NLO
	+ 5	± 3	light-by-light
	= 117 721	**± 5**	

- difficult to measure, $a_\tau^{exp} = (-0.018 \pm 0.017)$, DELPHI, EPJC 35 (2004) 159

Calendrier de Belle II

la vie n'est pas un long fleuve tranquille ...



3×10^{34}/cm^2/s!

By summer 2022: ~1 ab^{-1}

complete PXD (2 layers) installed in end of 2022 (or a bit later)

(replace some TOP PMT)

➔ ... et d'opportunites

2026: collider upgrade (QCS+RF) ➔ installation upgraded detector

2031: 50 ab^{-1}

➔ SuperKEKB with polarized beams

writing White Paper (A.Martens for polarimety part)

Main priorities (focusing on charged B modes)

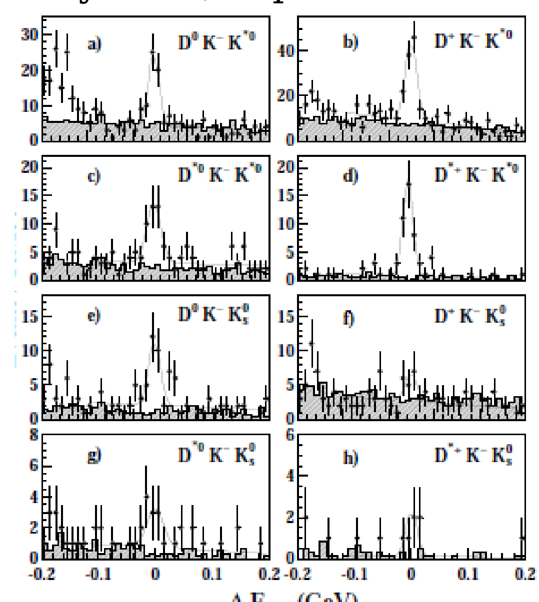
- $B^- \rightarrow D^0 \pi^+ \pi^- \pi^+$: measure $D^0 a_1^+$, $D^0 \rho^0 \pi^-$, $D^0 \pi^+ \pi^- \pi^+$ NR
- Modes with one π^0:
  - $D^0 \rho^+$, OLD $\left(\text{CLEO } 0.9\, \text{fb}^{-1}\right)$
  - $D^{*-} \pi^+ \pi^+ \pi^0$, OLD $\left(\text{ARGUS } 0.25\, \text{fb}^{-1}\right)$
  - $D^- \pi^+ \pi^+ \pi^0$, never measured (guessed in DECAY.DEC file)
  - $D^{(*)0} \pi^+ \pi^+ \pi^- \pi^0$, OLD $\left(\text{CLEO } 9\, \text{fb}^{-1}\right)$
- Modes with η (PYTHIA), $D^{(*)0} \eta \pi^+$ (link to SL gap filled with $D^{(*)0} \eta l^{+\%} \nu$)
- ... also DKK^* ...

...and also add B^0 modes

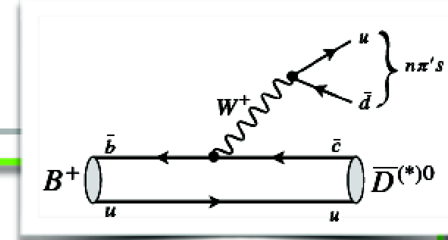
crucial for FEI hadronic modes:
- better modeling = optimal result
- new modes = higher efficiency

but also important for inclusive tagging
.... trained on MC

Observation of $B \rightarrow D^{(*)} K^{-\%} K^{0(*)}$ decays
A.Drutskoy et al, hep-ex/0207041 $[29\ \text{fb}^{-1}]$



BEYOND FEI - DIRECTIONS (I)



- $B \rightarrow K\tau\ell$ **is the ideal mode to exploit B-tagging improvements - unique case with m_τ as variable of signal extraction**

- Multi-pion modes
  - **Improve MC modelling**
    - PHSP model often not accurate (intermediate resonances)
    - Wrong interpretation of PDG b.r.'s (double counting) - Resonant vs. NR e.g. $\overline{D}^0\pi^+\pi^+\pi^-$
    - Large uncertainty on high-b.r. decay modes

$\Leftarrow$

Request measurements from BtoCharm @ Belle II!

$D^{*-}\pi^+\pi^+\pi^0$ (ARGUS 0.2 fb-1)

$\overline{D}^{*0}\pi^+\pi^+\pi^-\pi^0, \overline{D}^{*0}\rho^+, \overline{D}^{(*)0}\pi^+\omega$ (CLEO 9.1 fb-1)

$\overline{D}^0\rho^+$(CLEO 0.9 fb-1)

$D^-\pi^+\pi^+\pi^0$ (guessed in DECFILE)

$\overline{D}^{(*)0}\pi^+\eta$ (Appear as PYTHIA decays but also SL `gap')

$\Downarrow$

  - **FEI' = Re-trained FEI**

+ new modes

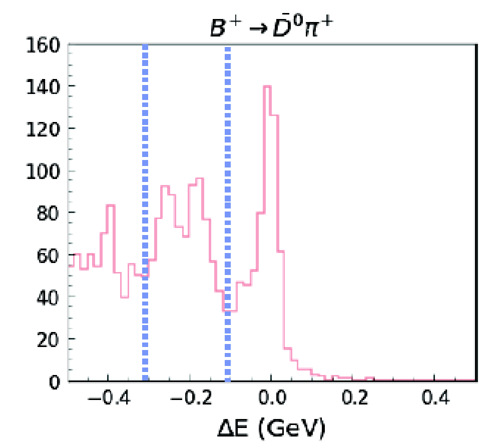
$D^{*0}D_s^{*+}$ (1.7)

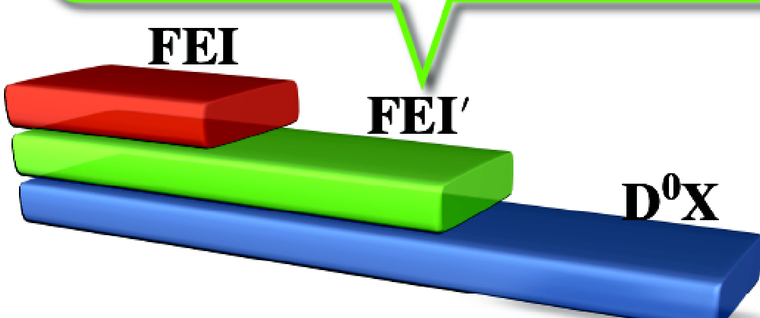
$D^{*-}\pi^+\pi^+\pi^0$ (1.8)

$\overline{D}^{(*)0}K^{(*)+}K^{(*)0}$ (~0.5)

+ 'Recycling'

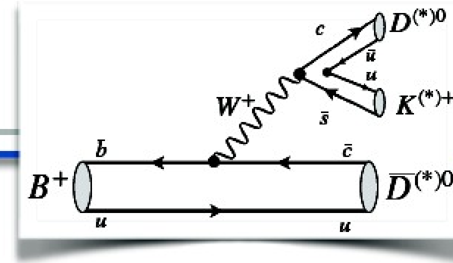
- Decays with D* are lost as soon as one γ or π^0 is missing
- Select the ΔE~-0.2 GeV region with known shift (missing γ or π^0) → recoil mass is still fine!

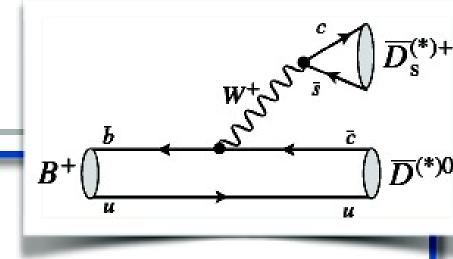


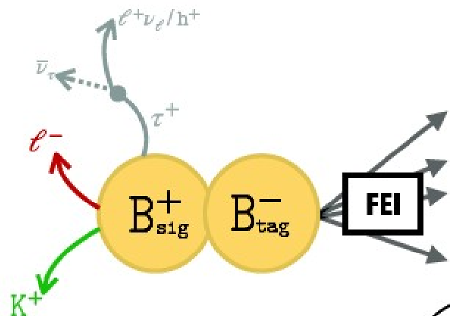


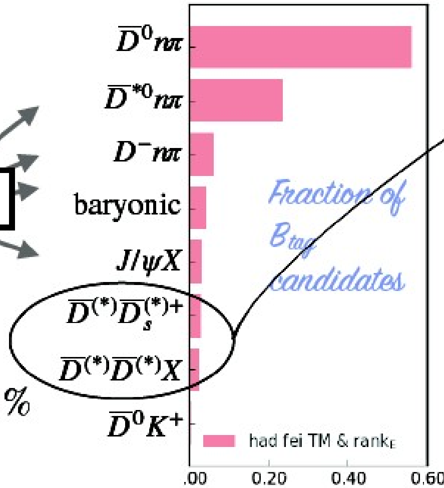
A better MC modelling is anyway beneficial for the training of FEI and any tagging algorithms (even inclusive ones!)

BEYOND FEI -DIRECTIONS (II)









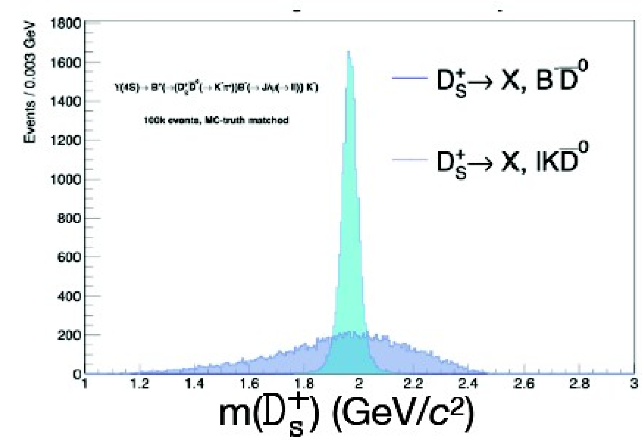
$\varepsilon_{\rm FEI} \sim 0.03\,\%$

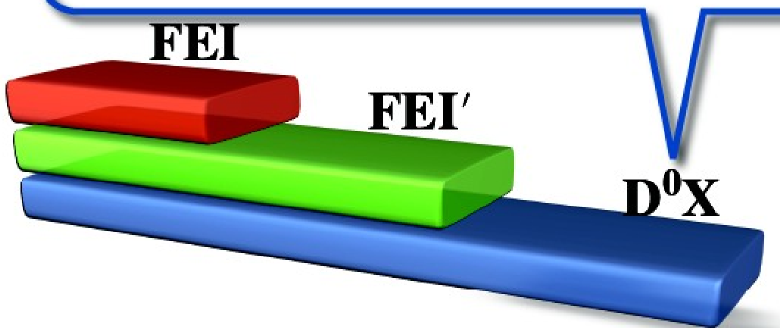
Double charm modes give small \`FEI' contribution, despite the high branching ratios ($DD_sX \sim 8\,\%$, $DDKX \sim 5\,\%$) because of the full reconstruction of 2 D mesons

$\varepsilon_{\rm FEI}(D^0) \times \varepsilon_{\rm FEI}(D_s^+)$

$\sim 10\%$ $\sim 3\%$

Avoid reconstructing both D's. Instead D^0X tagging where X has specific properties (i.e. # kaons, invariant mass etc.)





- **Semi-inclusive approach for higher tagging efficiency**