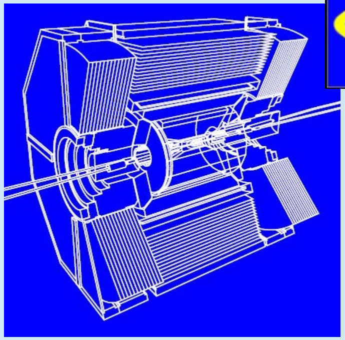
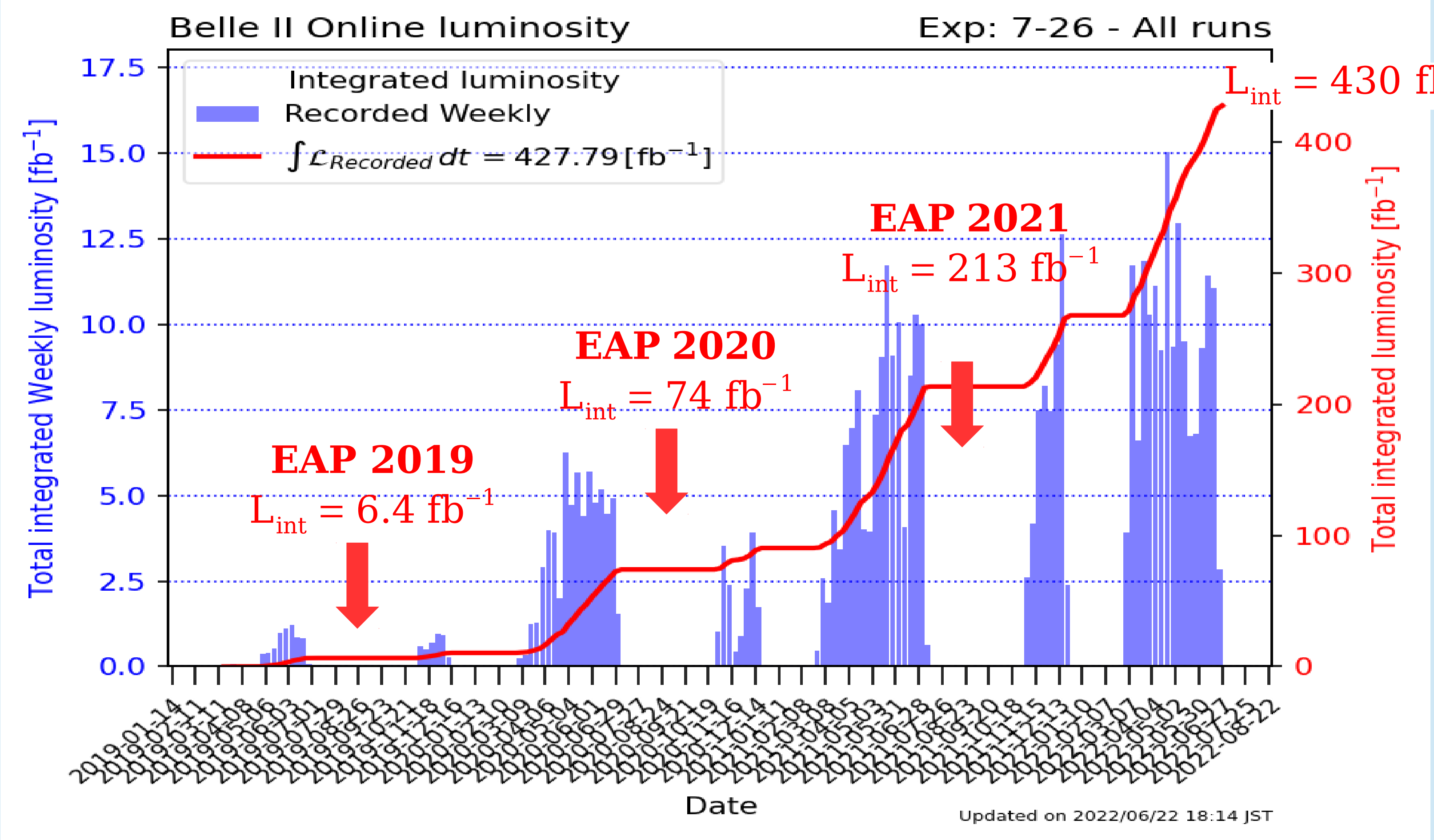
Projet de participation a une jouvence de l'experience Belle II

Situation du projet, programme scientifique et engagement des equipes IN2P3

K.Trabelsi (IJCLab)





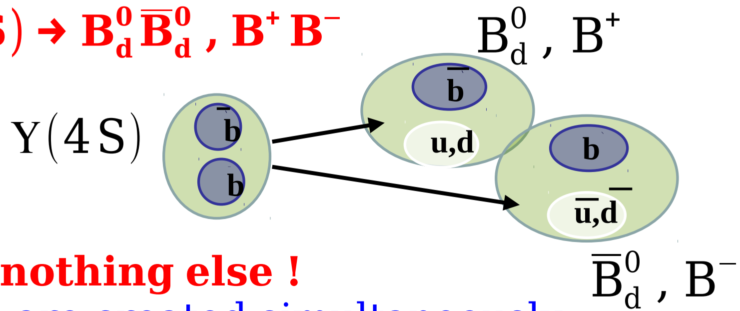
Belle II, a flavour-factory,

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

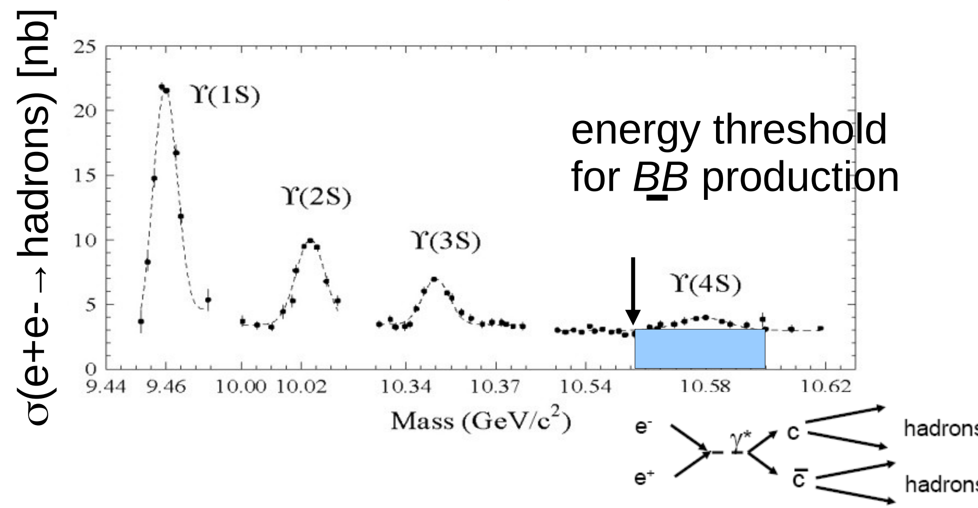
- We plan to collect (**at least**) 50 ab^{-1} of e^+e^- collisions at (or close to) the $\Upsilon(4S)$ resonance, so that we have:

– 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 ~2035

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 $10^6\ B\bar{B}$

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

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 !!

higher luminosity

$\sigma_{b\bar{b}}/\sigma_{total}$ 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 2022]

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

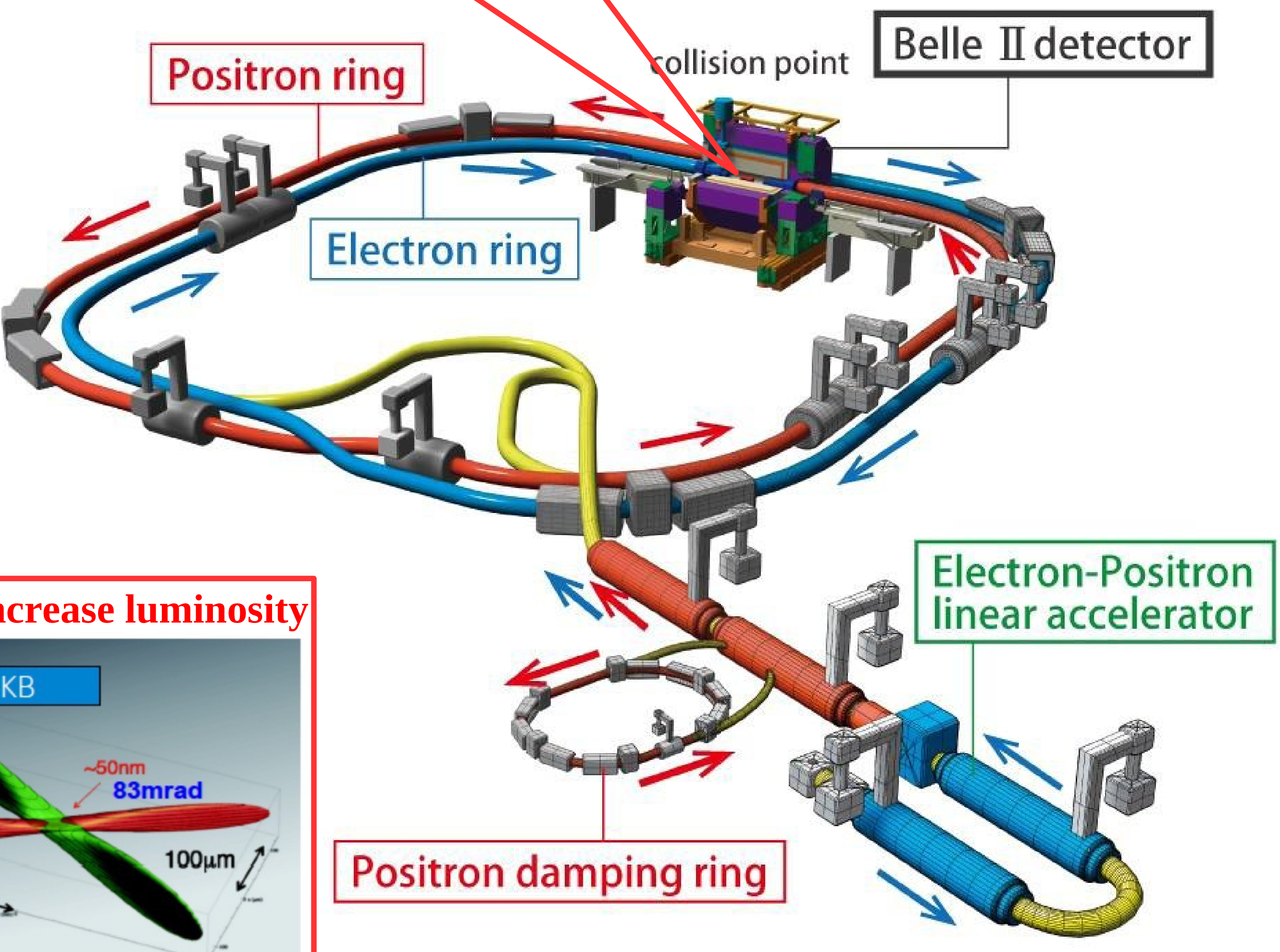
First Collisions $(0.5\ fb^{-1})$

April 27 - July 17, **2018**

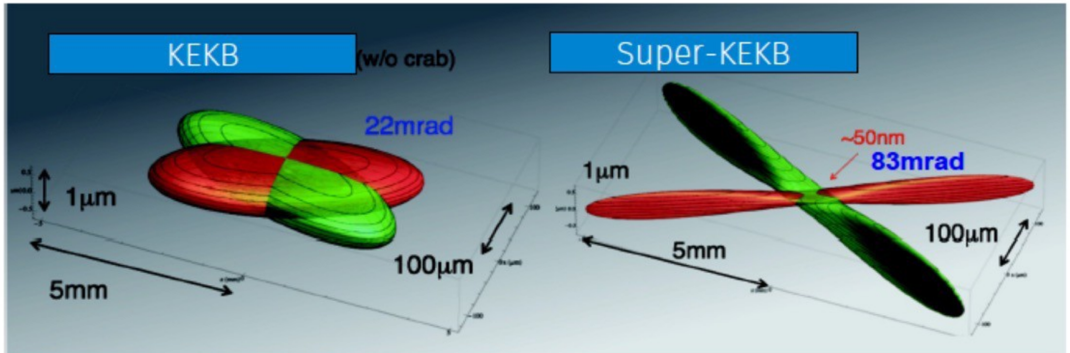
Phase 3: Physics run

Since April , **2019**

Squeeze strongly at IP



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	

⇒ to reach $\sim 6 \times 10^{35}\ cm^{-2} s^{-1}$

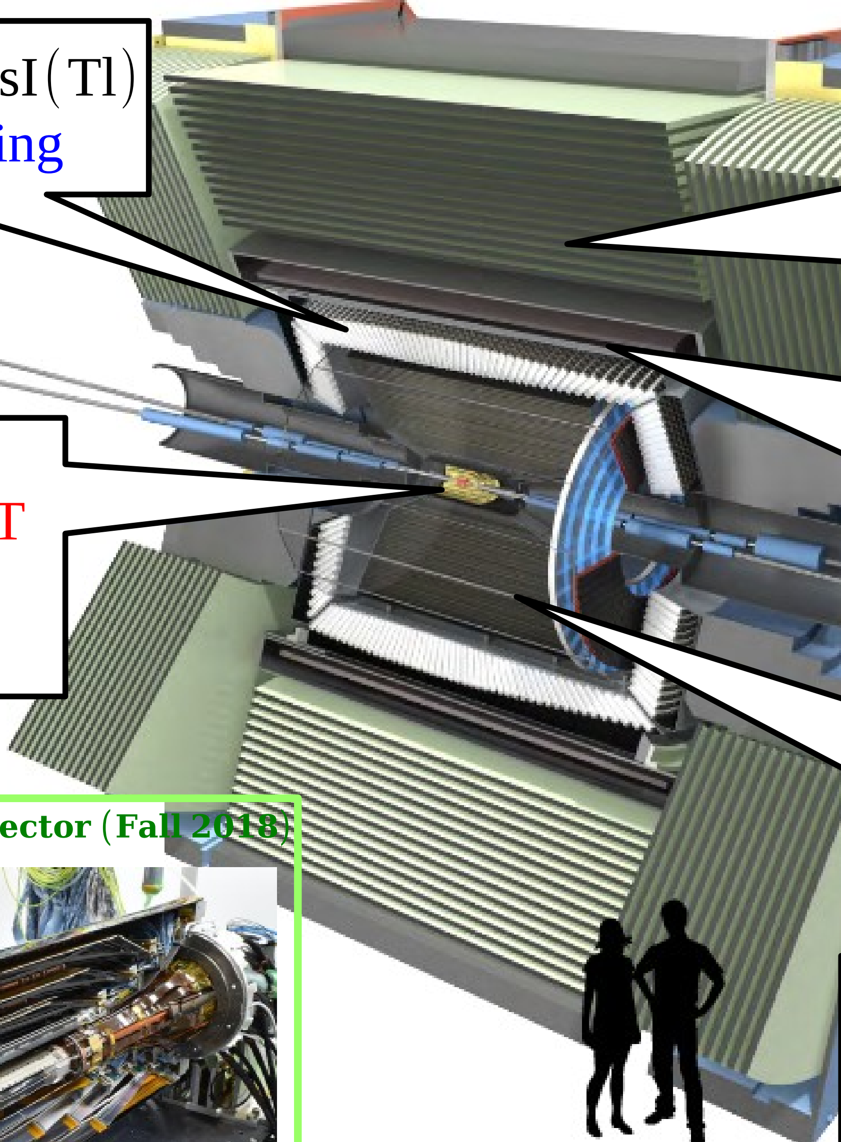
⇒ cumulate 50 ab^{-1} by ~2035

Belle II detector

Main challenge: Preserve detector performances while luminosity (so beam background) increases

EM Calorimeter: CsI(Tl)
waveform sampling

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

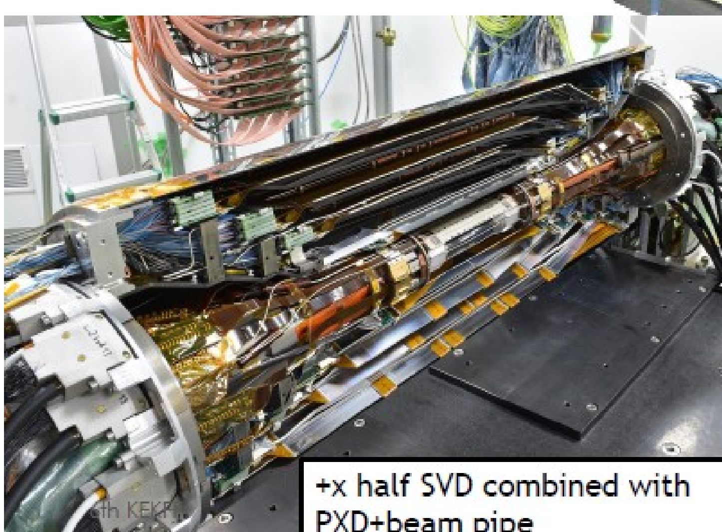


Particle Identification
Time-Of-Propagation
counter (barrel)
Prox. focusing Aerogel RICH

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

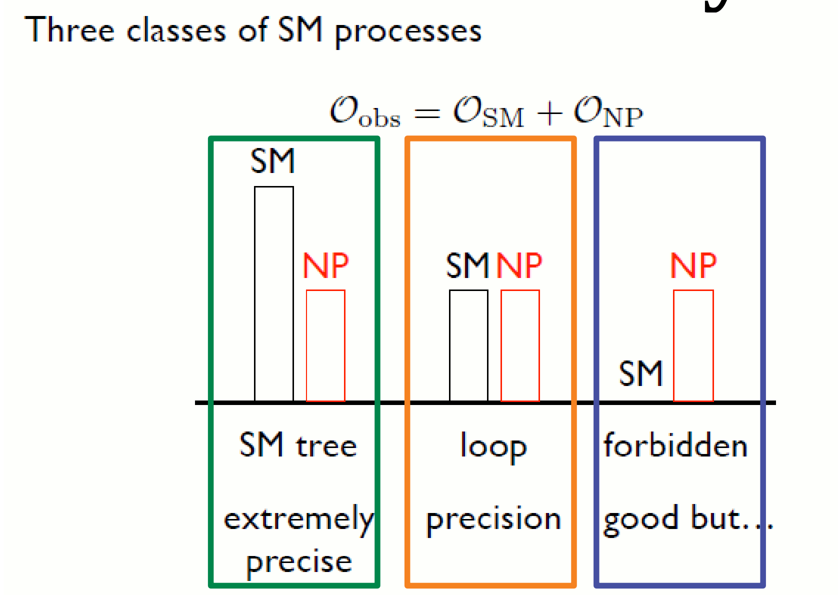
Installation of Vertex Detector (Fall 2018)



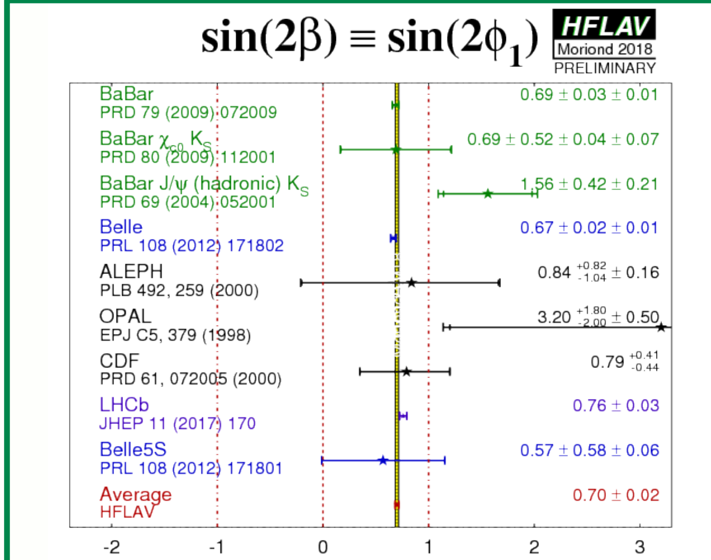
on-going DAQ upgrade
(installed in 2021-2023)
PCIe40 board, capable of reading via high speed optical links and to write to computer at rate of 100 Gb/s:
limited number of boards (20) enough
to read entire Belle II detector

considering now VTX upgrade (2027 or later)

Physics at Belle II

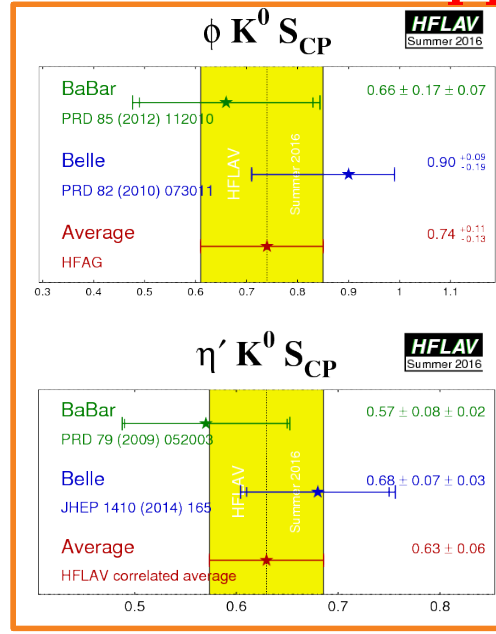


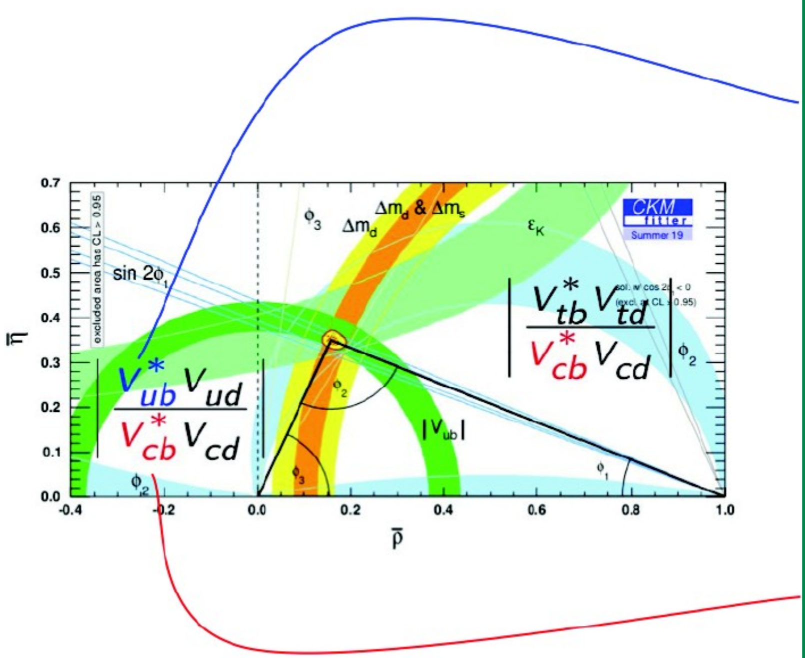
$B \to J/\psi K^0$

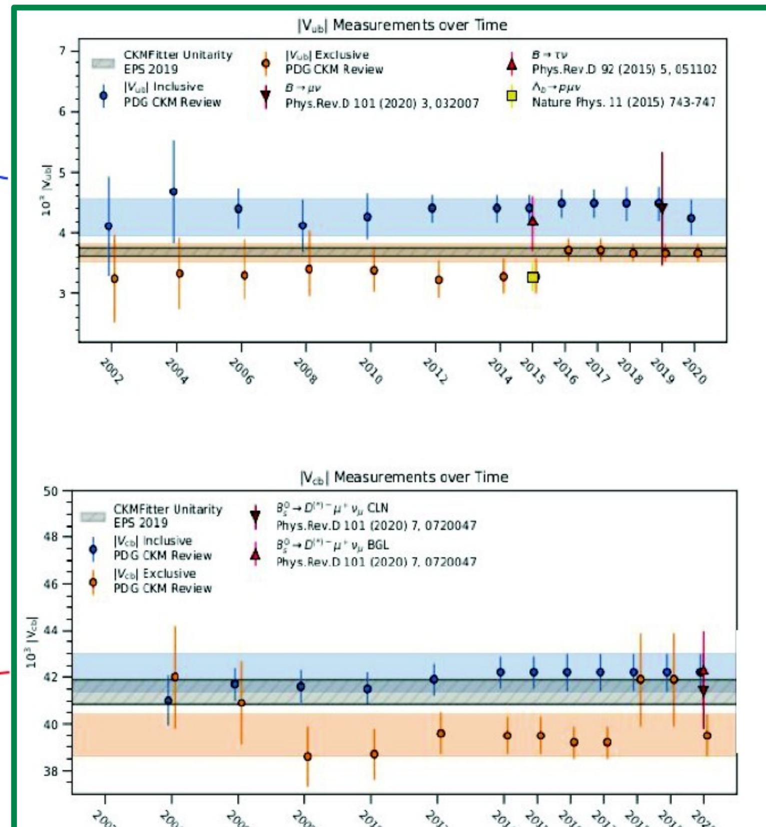


$\sin 2\beta = 0.72 \pm 0.06 \pm 0.02$ w/190 fb^{-1} only !

$b \to s q \bar{q}$







V_{ub}

V_{cb}

Test of lepton universality using $B^+ \to K^{(*)} l^+ l^-$ decays

Model candidates

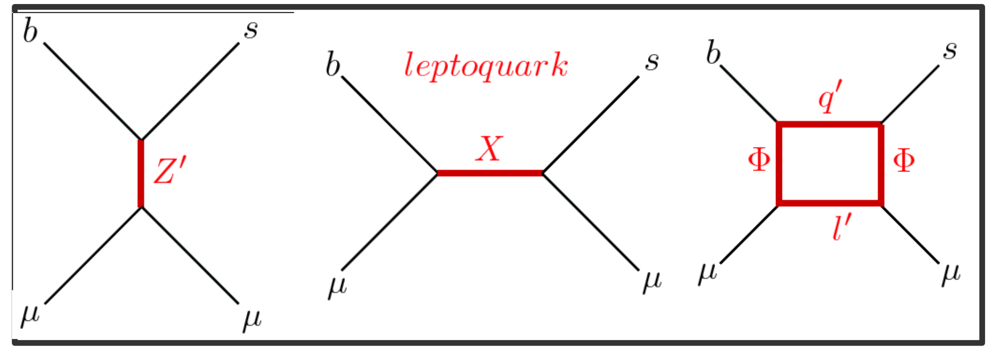
- ✓ Effective operator from Z' exchange
- ✓ Extra U(1) symmetry with flavor dependent charge

✧ **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



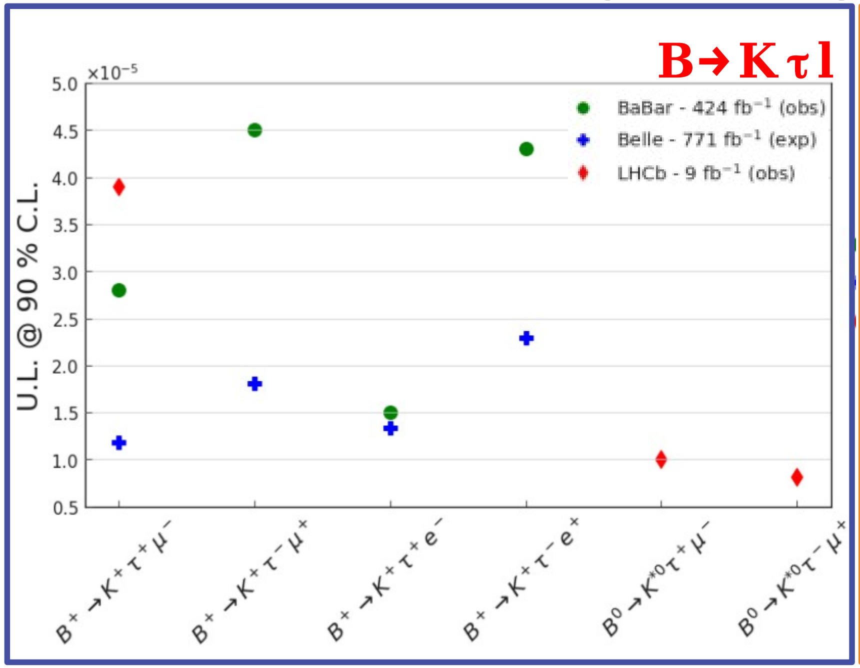
Leptoquarks are color-triplet bosons that carry both lepton and baryon numbers

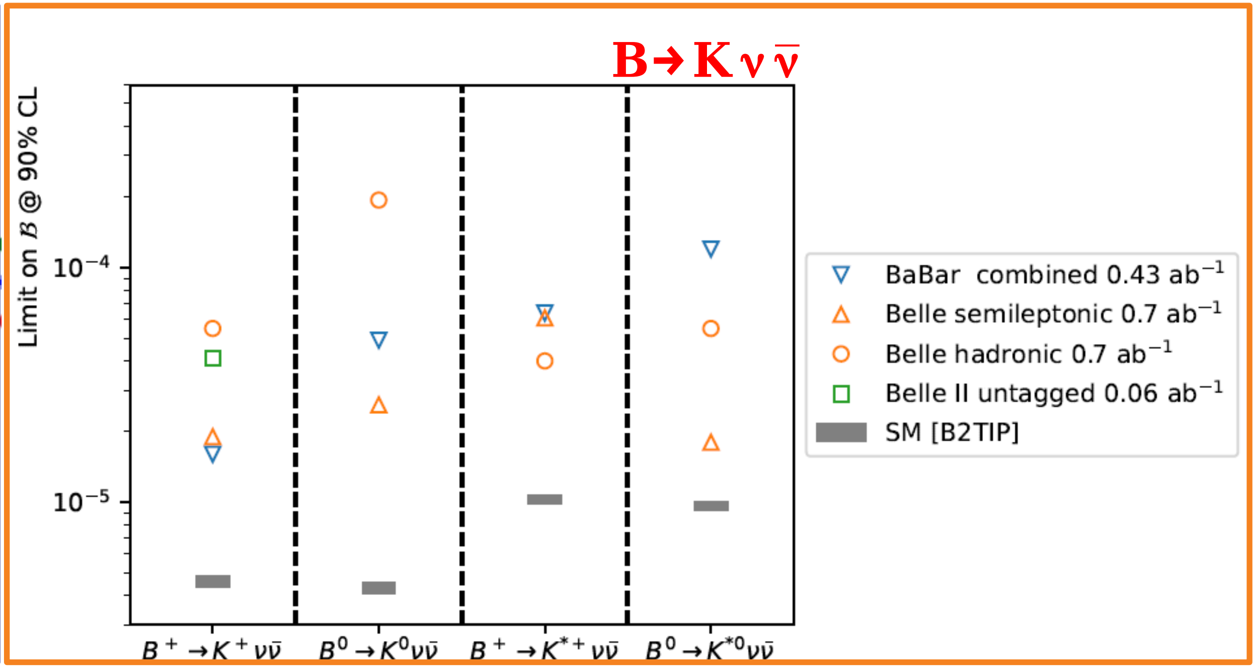
Lot of those models predict also LFV $b \to se\mu$, $b \to se\tau$, ...

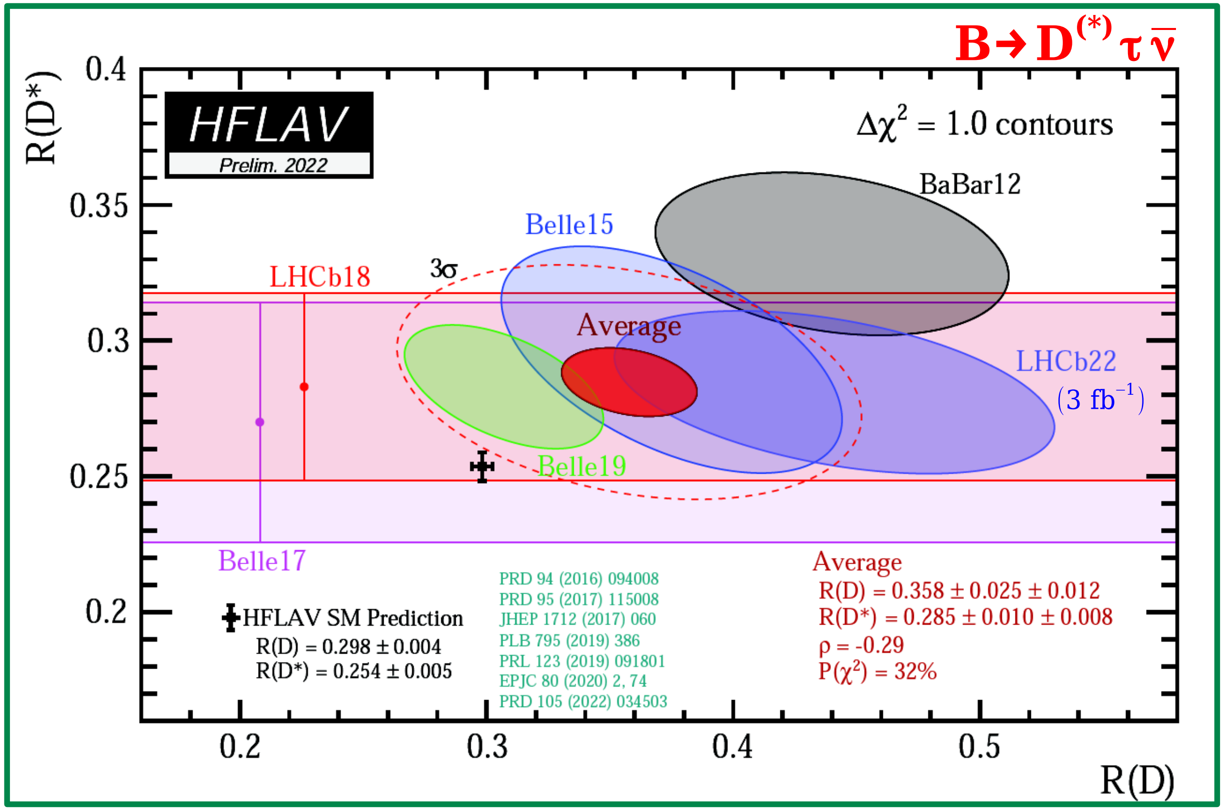
G.Isidori, FPCP 2020: correlations among $b \to s(d)ll'$ within the U(2)-based EFT

	μμ (ee)	ττ	νν	τμ	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%) $[R_K=R_\pi]$	$B \to \pi \tau\tau$ $\to 100\times SM$	$B \to \pi \nu\nu$ O(1)	$B \to \pi \tau\mu$ $\to 10^{-7}$	$B \to \pi \mu e$???

Missing energy analyses (so efficient ....)







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

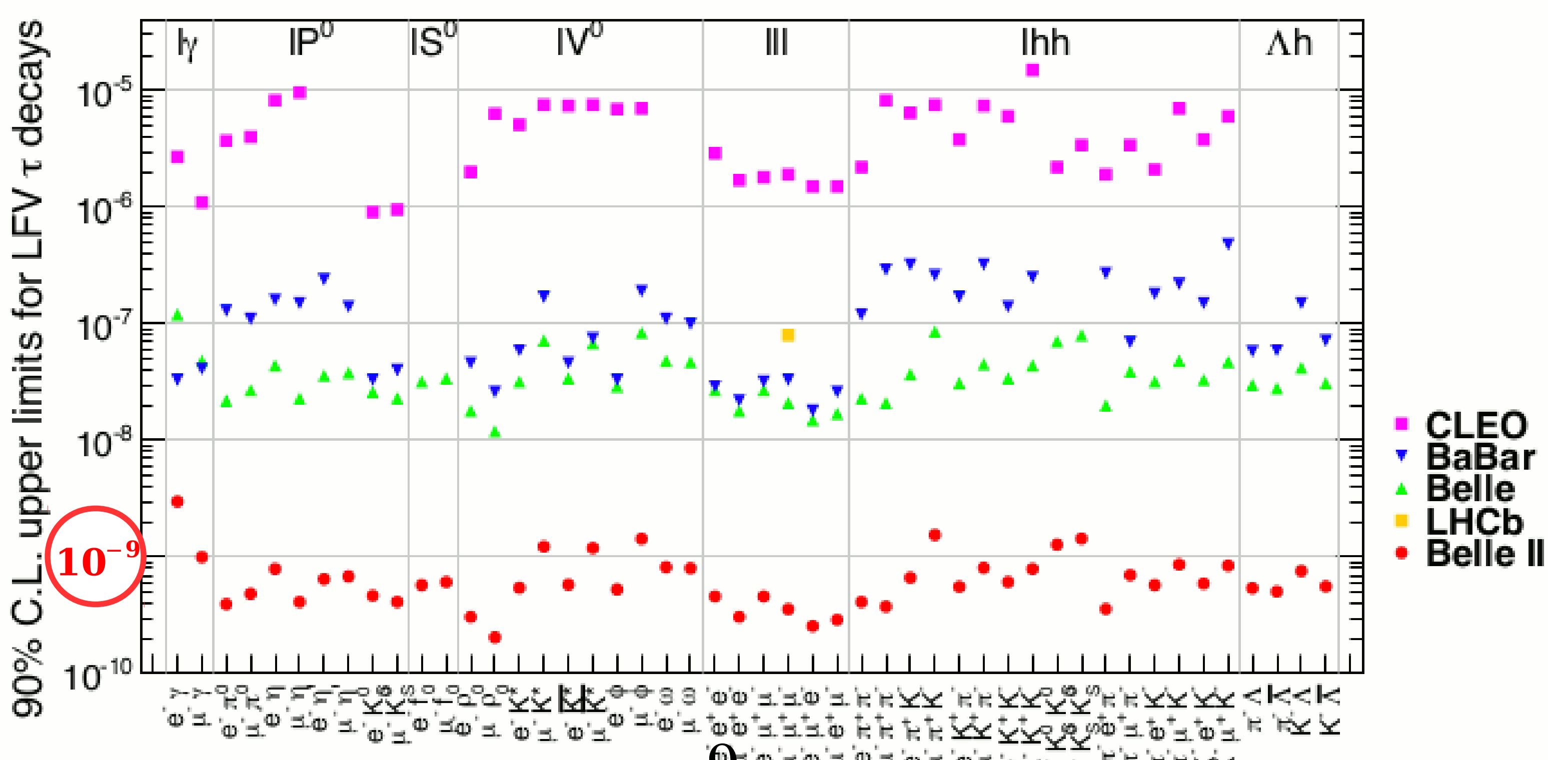
$$\mathcal{B}_{\nu SM}(\tau \to \mu\gamma) = \frac{3\alpha}{32\pi}\left|U^*_{\tau i}U_{\mu i}\frac{\Delta m^2_{3i}}{m^2_W}\right|^2 < 10^{-40}$$

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

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}

Type	Operator	$\tau\to 3\mu$	$\tau\to\mu\gamma$	$\tau\to\mu\pi^+\pi^-$	$\tau\to\mu K\bar{K}$	$\tau\to\mu\pi$	$\tau\to\mu\eta^{(\prime)}$
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)



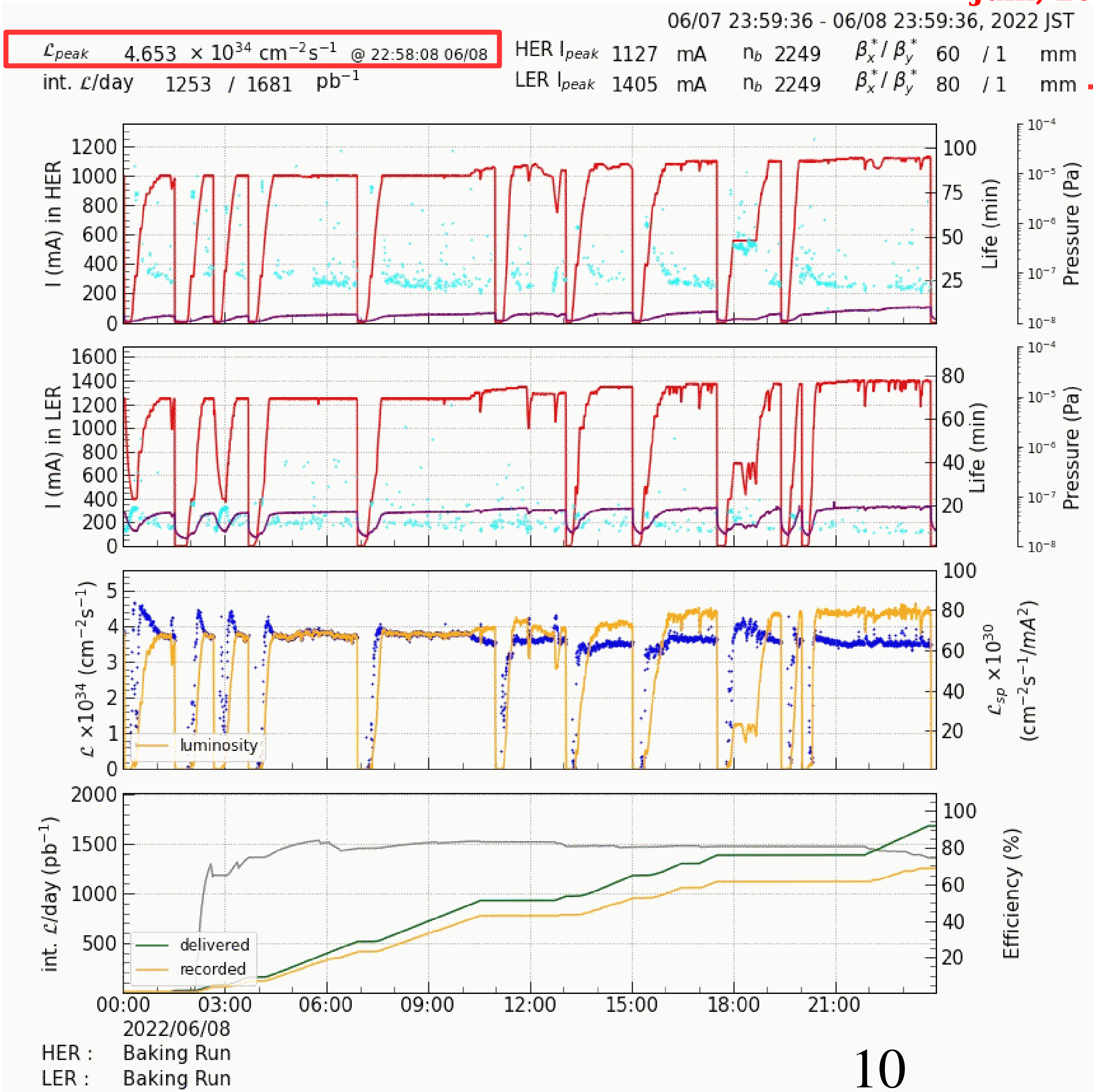
Belle II run I (2019 - 2022)

prise de donnees de mars 2019 a juin 2022

→ malgre des conditions difficiles depuis mars 2020 (Covid, guerre en Ukraine, cout de l'energie...)

luminosity : $4.7\times10^{34}/cm^2/s$! > 2 fb^{-1} per day !

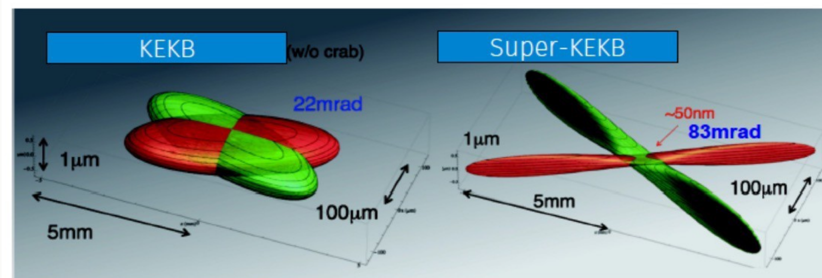
Juin, 2022



→ **$\beta_y^* = 1\,mm$, $I_{LER/HER} = 1.4/1.2$ A**

record de KEKB/Belle
$2\times10^{34}/cm^2/s$ currents > 1 A

record de PEPII/BaBar
$1\times10^{34}/cm^2/s$ currents > 2 A

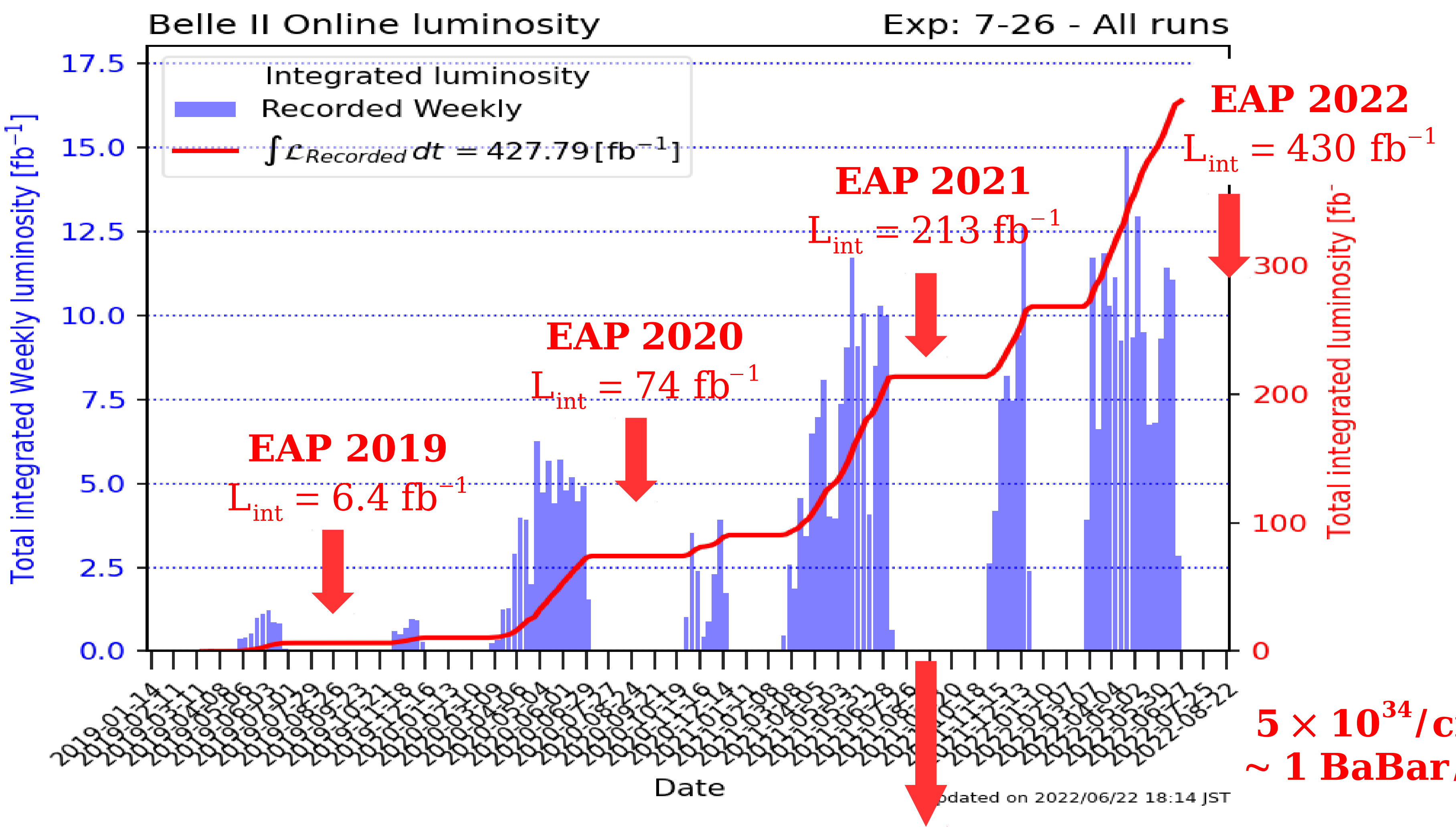


	E (GeV) LER/HER	β*y (mm) LER/HER	β*x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L (cm⁻²s⁻¹)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10³⁴
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10³⁴

factor 20 factor 2-3

squeezing further β_y^* (→ 0.6 mm)
doubling (or more) the currents
⇒ L > $10^{35}/cm^2/s$ after LS1

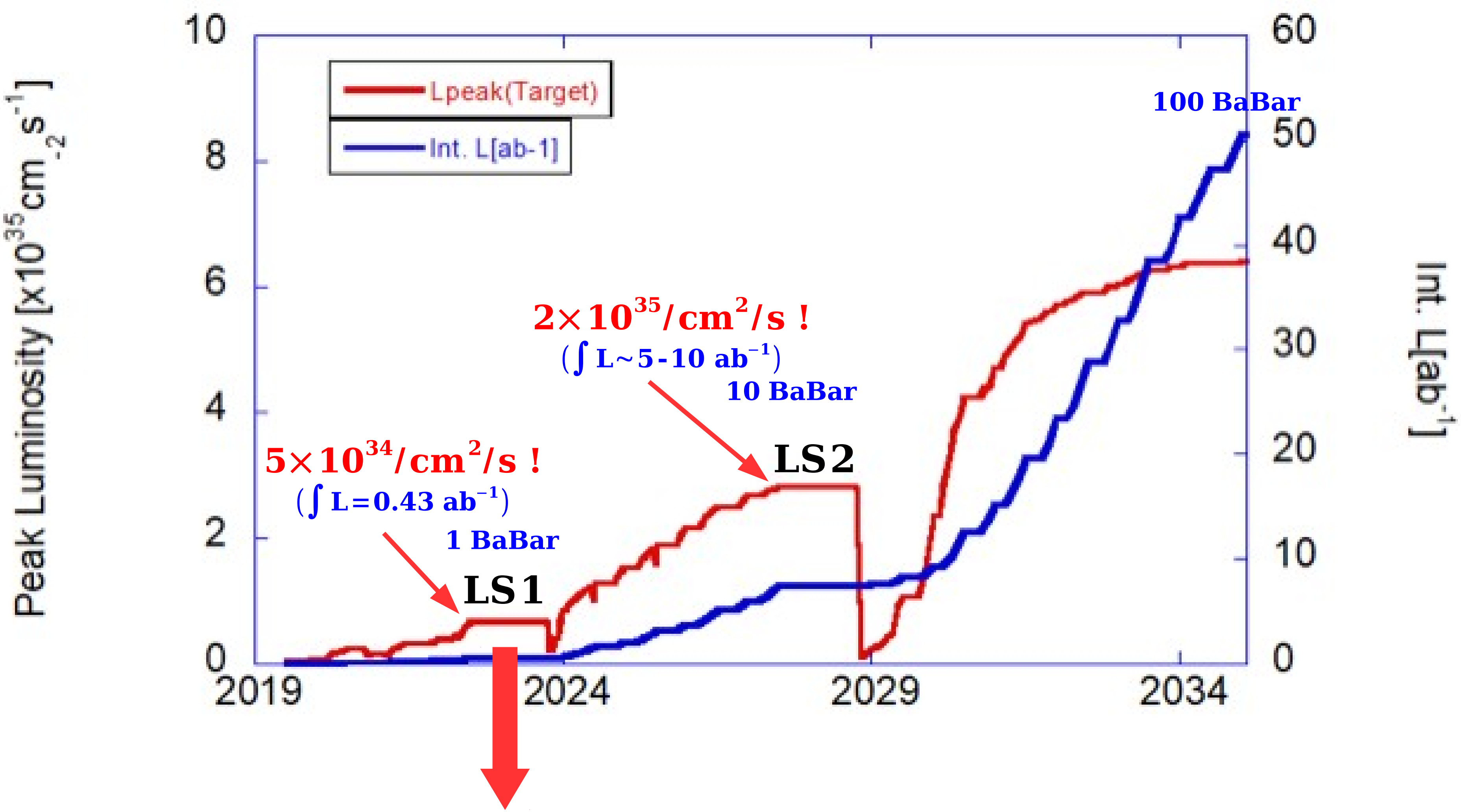
Belle II run I (2019 - 2022)



$5 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$
$\sim$ 1 BaBar/year

ICHEP 2022 results

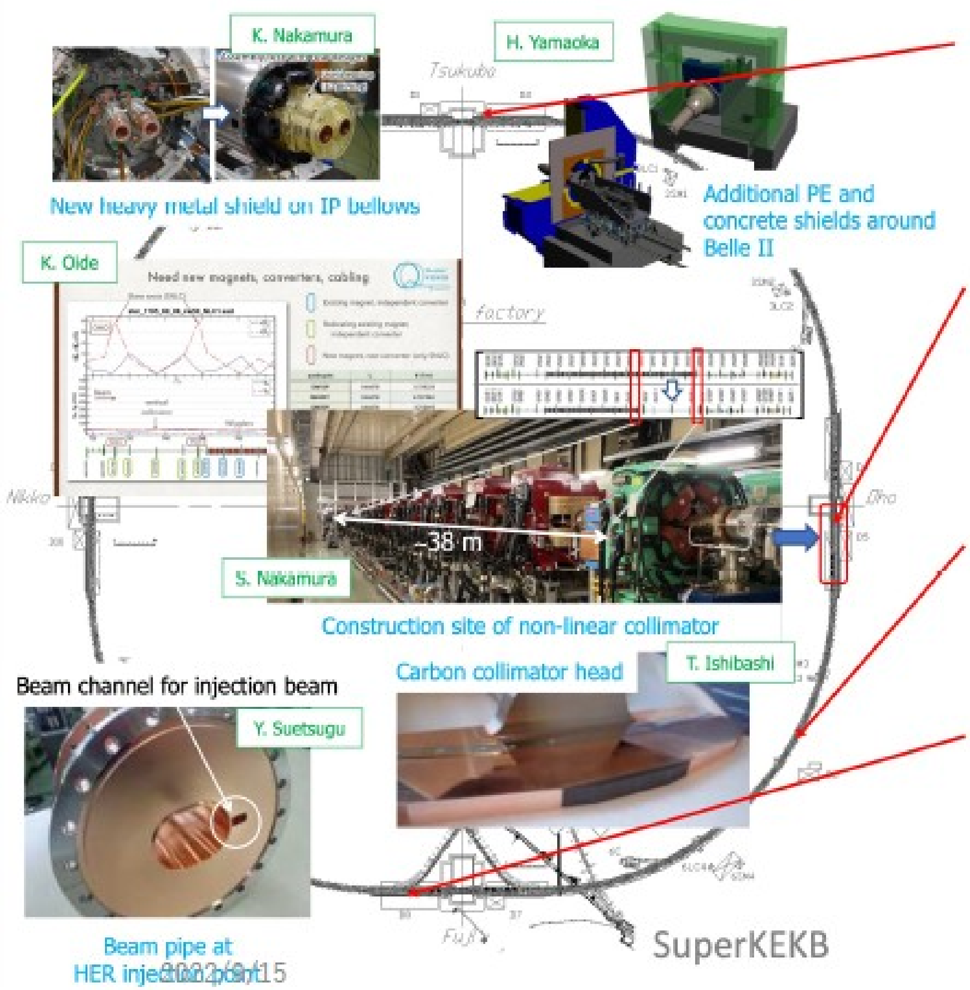
LS1 work for SuperKEKB



first long shutdown :

- accelerator : Linac upgrade + main ring improvements
- Belle II detector : PXD2 and few PMTs/boards replacements (TOP/CDC) + beam background shielding

Upgrade Items during Long Shutdown (LS1)



- IR radiation shield modification
  - For BG reduction
    - New heavy metal shields around IP bellows
    - Additional concrete & polyethylene shields around Belle II
    - Material change from W to SUS of QCS cryostat front plate
- Nonlinear collimator (LER)
  - For impedance and BG reduction
    - New collimation scheme less likely to cause TMCI
    - Removal of 50 wiggler magnets
    - Installation of 2 skew sextupole and 5 quadrupole magnets
    - Installation of new vertical collimator with wider aperture
- Robust collimator head (LER)
  - As countermeasure against kicker-pulser misfiring and resulting destruction of collimator
    - Replacement with carbon head of horizontal collimator D06H3
- New beam pipes with wider aperture at HER injection point
  - For improvement of injection efficiency
    - New beam pipes with wider aperture
    - New BPM for precise measurement of injected beam.

2022/9/15 4

Fast beam loss abort is a serious problem (BCS quench and collimator damages)

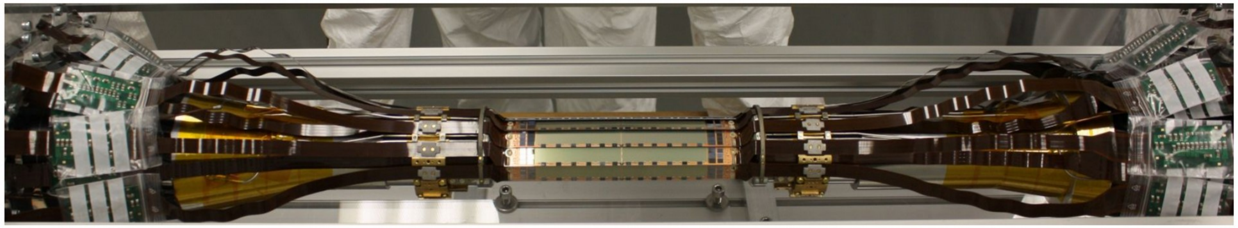
cause not fully understood (improve simulation and prepare additional monitors)

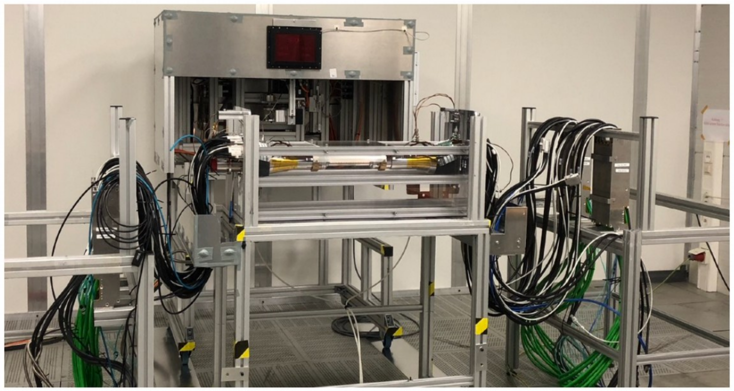
Linac + BT upgrade items during LS 1 :

- electron two-bunch injection suffered from vertical orbit shift and emittance growth of the 2^{nd} bunch
  ➜ Linac fast kicker to solve the orbit shift
- Installation of 8 pulsed quads at J-arc matching section
- Installation of 4 pulsed quads at e+/e- compatible optics region

LS1 work for Belle II

Status of Half Shell Testing





- Cooling
  - CO_2 lines connected
  - pressure test pending
- Services
  - patch panels connected
  - two HS links need to be investigated (badly plugged, dirty or broken fibres?)
- HS1 Tests
  - warm module tests have started
  - cold tests will start next week

PXD2
(+new beampipe)

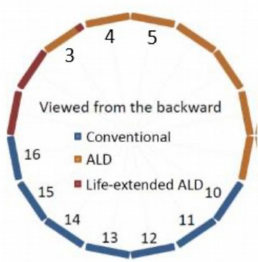
⇒ news about PXD2

all ladders for L1 and L2 ready
half–shelves mounted
need to understand glue issues with 2 ladders
→ expect no significant impact on schedule

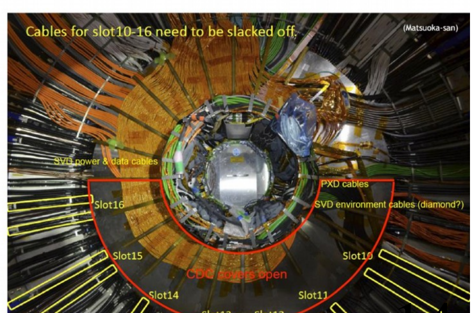
MCP-PMT access during LS1

5

- Want to take out PMTs and confirm QE by measurement system at Nagoya
  - Modify the system to attach PMT module directly
- Take out some conventional PMTs at around Sep.-Oct.
  - Current candidate is slot16.
    - Also get PMTs with low output charge.
- Take out some ALD PMTs
  - Need VXD cable works. Then take out some PMTs in slot3,4 or 5.
    - Then check at Nagoya
- Want to replace bad electronics in slot4*, 6*, 8*, 16, 13, 5*, 10, (7*, 14)
  - *; Accessible only during VXD work



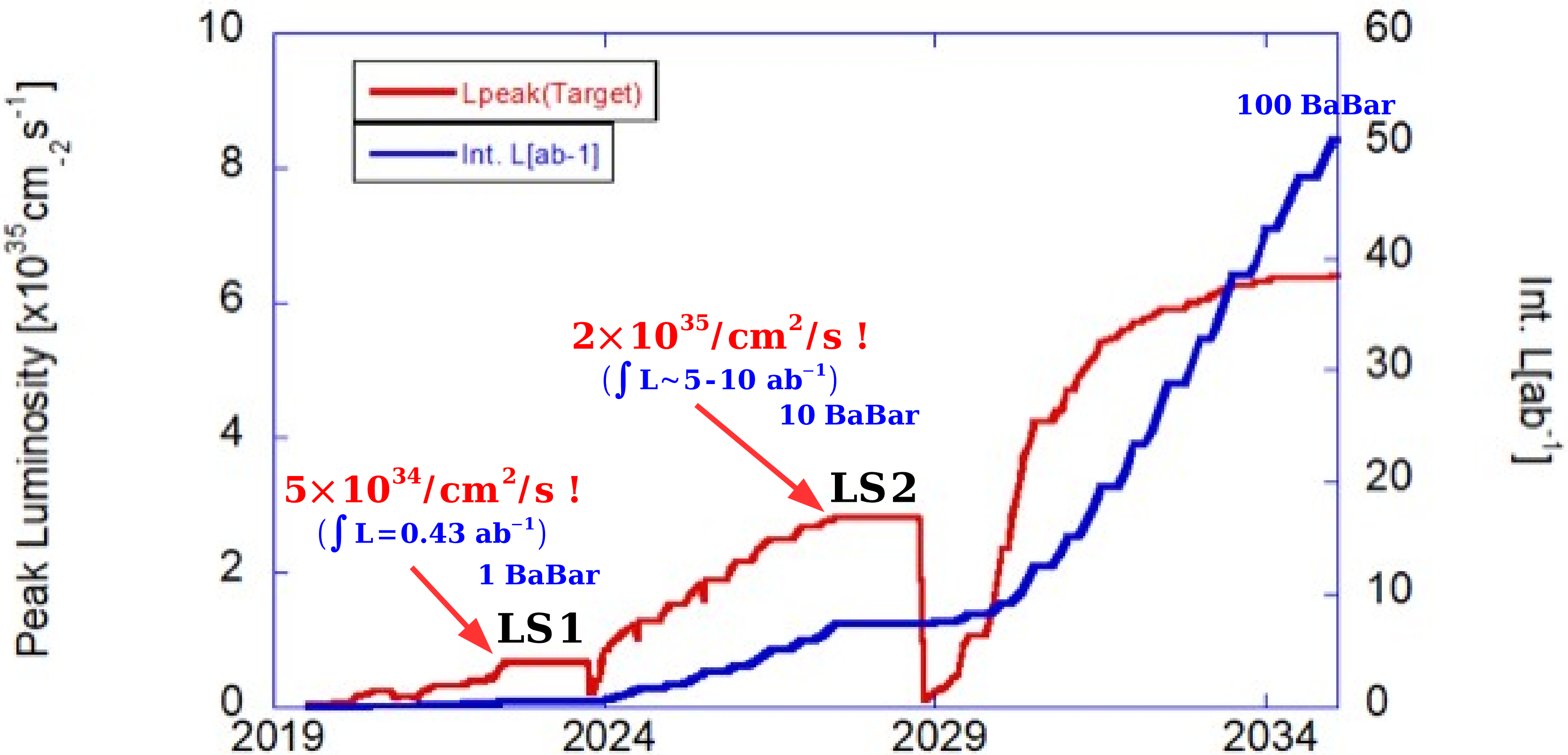
TOP



and also CDC: HV resistor replacement, FE repair..

⇒ reprise prevue pour fin 2023

Calendrier de Belle II



run 1 (➔ juin 2022): luminosite integre $\sim 0.43\ ab^{-1}$, $4-5\times10^{34}/cm^2/s$

PXD complet (2 couches) a installe durant LS1 (2022-2023)

(+ beampipe + TOP PMTs)

run 2 (➔ 2027): luminosite integre 5-10 ab^{-1}, $2\times10^{35}/cm^2/s$

2027 : collider upgrade (QCS+RF) ➔ installation upgraded detector

run 3 (➔ > 2030): 50 ab^{-1}

➔ SuperKEKB with polarized beams, White Paper (arXiv:2205.12847)

(A. Martens for polarimety part)

<u>Belle II France</u> (23 - 24 septembre 2021 @ IJCLab)

⇒ prochain meeting Belle II France printemps 2023 @ IPHC

Composition des equipes Belle II (2022)

- **Permanents et post−docs** [arrivee recente/prochaine, depart prochain/activite reduite]
  (concernes par les M&O payes par l'IN2P3)

+ ~4 PhD students/group

@ CPPM	Justine Serrano	CNRS, CR/HDR
	Giampiero Mancinelli	CNRS, DR1 (depuis 01/2022)
	Laura Zani	postdoc ERC (03/2020−02/2023)
	Klemens Lautenbach	postdoc ERC (03/2021−02/2024)
	Valerio Bertacchi (*)	postdoc ERC (09/2021−08/2024)

(*) visiteur a l'IJCLab depuis 1 an

@ IJCLab	Philip Bambade	CNRS, DR1
	Emi Kou	CNRS, DR2
	Francois Le Diberder	Universite, Prof
	Aurelien Martens	CNRS, CR (30%)
	Karim Trabelsi	CNRS, DR2
	Tak Shun Lau	postdoc IN2P3 (11/2021 - 10/2023)

@ IPHC	Jerome Baudot	Universite, Prof
	Giulio Dujany	CNRS, CR
	Christian Finck	CNRS, CR/HDR (50%)
	Isabelle Ripp-Baudot	CNRS, DR1
	Varghese Babu	postdoc IN2P3 (11/2021 - 10/2023)
	Jacopo Cerasoli	postdoc ANR (03/2022 - 02/2024)

+ post-doc AIDAinnova 50% on Belle II from 01/2023 to 07/2024

Production scientifique

Justine Serrano: membre du publication committee
Emi Kou: membre du physics week committee
Isabelle Ripp: membre du speaker committee
Jerome Baudot: membre du Physics Statistics Advisory Committee

- Analyses :

Desintegrations rares/interdites du B ($b \rightarrow s$: $B \rightarrow K\tau\tau$, $K\tau l$, $K^{(*)}\nu\bar{\nu}$, $K\pi(\pi)\gamma$)
"tau center": Desintegrations rares/interdites du tau ($\tau \rightarrow l\phi$, lK^0_S, lll...), CPV, $(g-2)_\tau$
Mesures de precision : determination de l'angle γ (analyses Belle+Belle II)

- Construction/instrumentation :

DAQ upgrade (cartes PCIe40 installees en 2021−2022) [IJCLab, CPPM]
SVD (calibration, slow-control, shifts) [IPHC, CPPM]
Beam pipe cooling [IJCLab]
Luminometre rapide de Belle II [IJCLab]

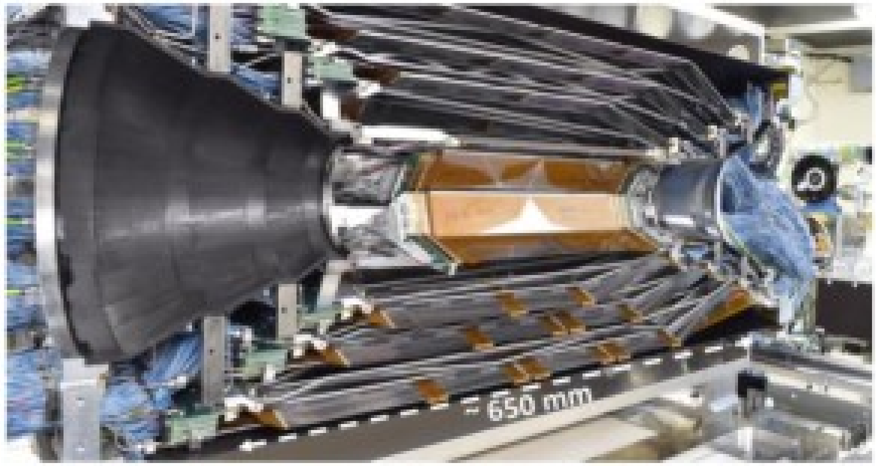
- Data/Software :

Quality Assurance Monitoring, HLT [IJCLab], Calibration [CPPM, IPHC]
Tracking/trigger performances [CPPM]
Code optimisation pour minimiser usage du CPU du HLT [IJCLab/CPPM]
Raw data center au CCIN2P3 (A. Vedaee)
activites GRID

Responsabilites/Implications dans Belle II Run 1

Nombreuses contributions pendant cette periode de prise de donnees:
shifts, operation SVD et HLT, calibration, monitoring/performance

@CPPM, IPHC, activites SVD:



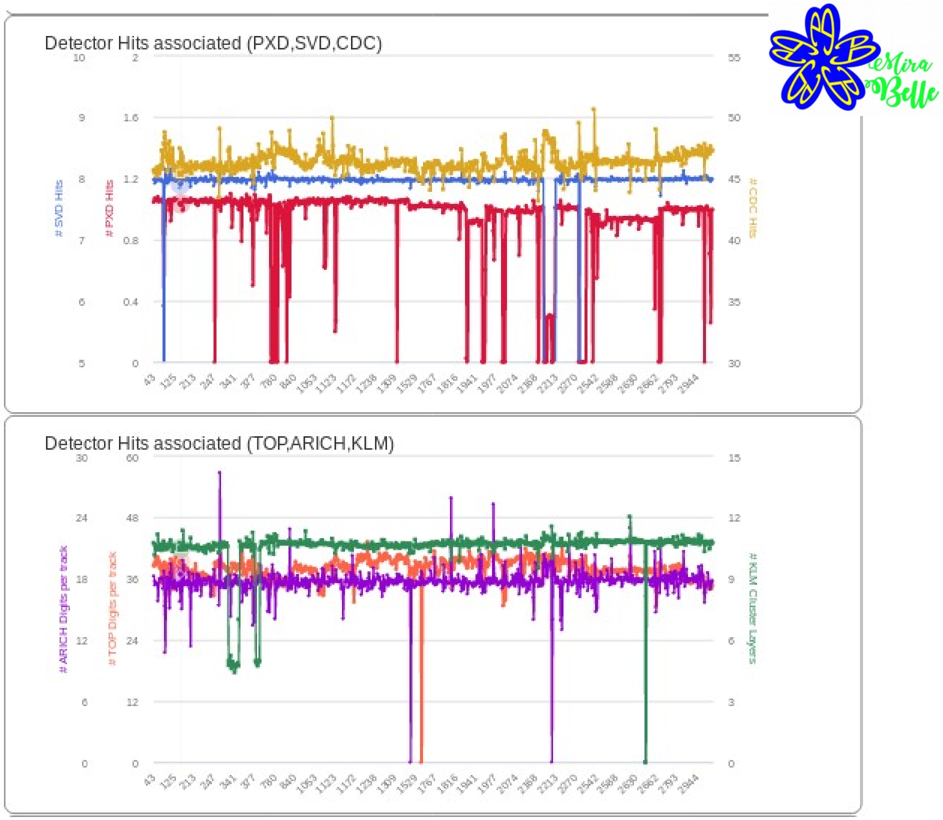
– SVD operation
remote monitoring and operator shifters
coordinator: Klemens Lautenbach (09-12/2021)

– Study of the SVD cluster position resolution and optimization of the cluster position reconstruction

– Calibration manager : Laura Zani (11/2020 - 10/2022)
➔ tracking performance convener a partir d'octobre

– Giulio Dujany: software de la calibration de Belle II

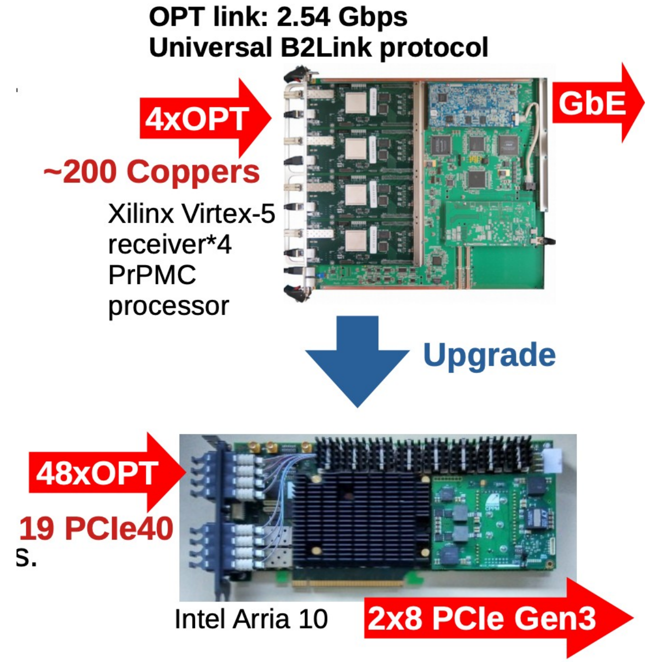
@IJCLab, activites QAM (MiraBelle)/HLT:

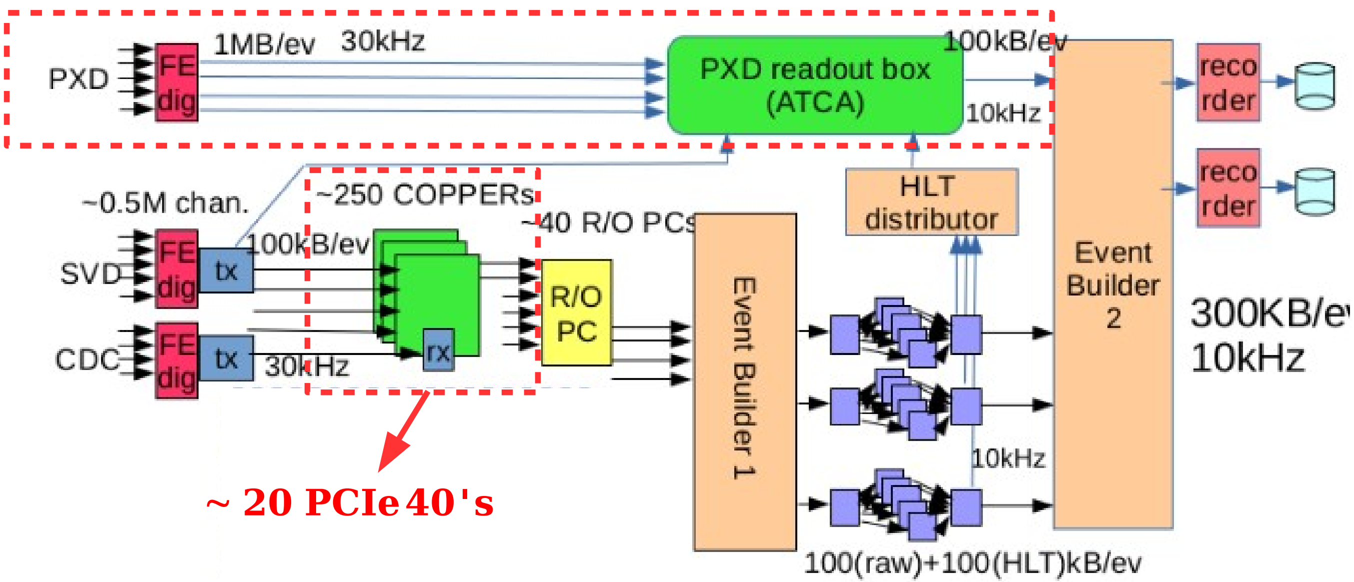


⇒ inclus recemment dans online... au niveau HLT...
HLT skims (calibration/physique) manager
Gaetano de Marino (2020–2022)
HLT monitoring/optimization : Vidya Vobbilisetti (2021–2022)

Belle II DAQ upgrade [IJCLab , CPPM]

Belle II collaboration wanted to remplace part of DAQ (between Front End electronics and Software Trigger farm) to face the high luminosity expected at SuperKEKB
⇒ In 2018, IJCLab group proposed to use cards (PCIe40) developped by CPPM for LHCb upgrade





solution proposed by IJCLab (PCIe40 card) lent and tested
→ final decision of Belle II at the end October 2019
→ cards paid by IN2P3, produced, tested at CERN
→ **development of the firmware/software in 2020-2021**
→ **cards delivered at KEK end August 2020**
→ **installation for TOP/KLM (summer 2021), ARICH (winter 2022), during LS1 for the rest**

France (CCIN2P3) un des raw data centers de Belle II depuis 2021

MoU (2019)

Year	2019	2020	2021	2022	2023	2024	2025	2026	2027
BNL	100	100	30	30	30	30	30	30	30
Canada	0	0	15	15	15	15	15	15	15
France	0	0	15	15	15	15	15	15	15
Germany	0	0	20	20	20	20	20	20	20
Italy	0	0	20	20	20	20	20	20	20

TABLE V: Sharing of the copy of raw data (%).

New Raw Data Centers

- Until 2020, Belle II raw data were stored at KEK and replicated at BNL
- Since the beginning of JFY 2021, the replica of raw data is distributed to BNL, CNAF, DESY, GridKa, IN2P3 and raw data processing is done in all those sites.
  - Raw data distribution is going smoothly and RDC are receiving the expected amount of raw data.
  - UVic will start receiving raw data soon
- Prompt Calibration is done at BNL and recalibration at DESY
  - hRaw are a subset of raw data (defined by HLT decision) produced offline and used for calibrations and other special tasks
  - Data for Calibration were not included in the resource estimate for JFY 2021

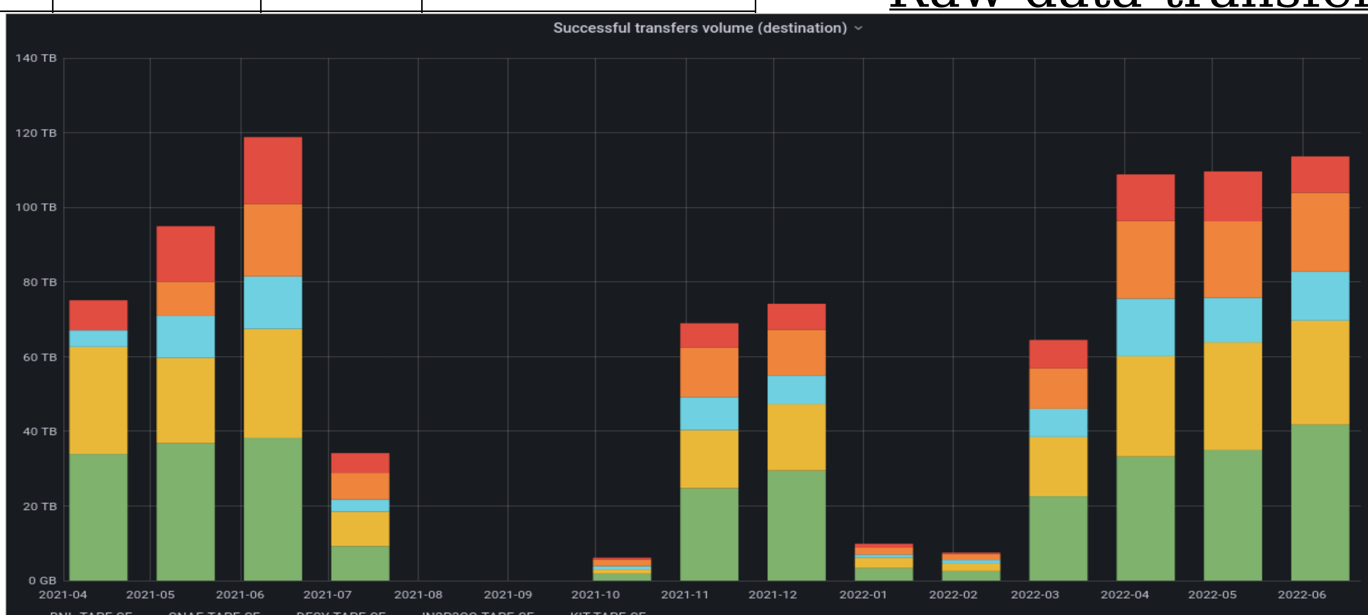
	Raw Data (TB)	hRaw (TB)	Data for Calibration (TB)
KEK	2807	703	
BNL	2070	435	200(Disk)
CNAF	135	27	
DESY	60	9	573
GridKa	71	11	
IN2P3	65	14	

2022/04/26

2022/04/26

Visite de Sabine Crepe-Renaudin
fin juin 2022 @ IJCLab

Raw data transfert



Summary

Belle II

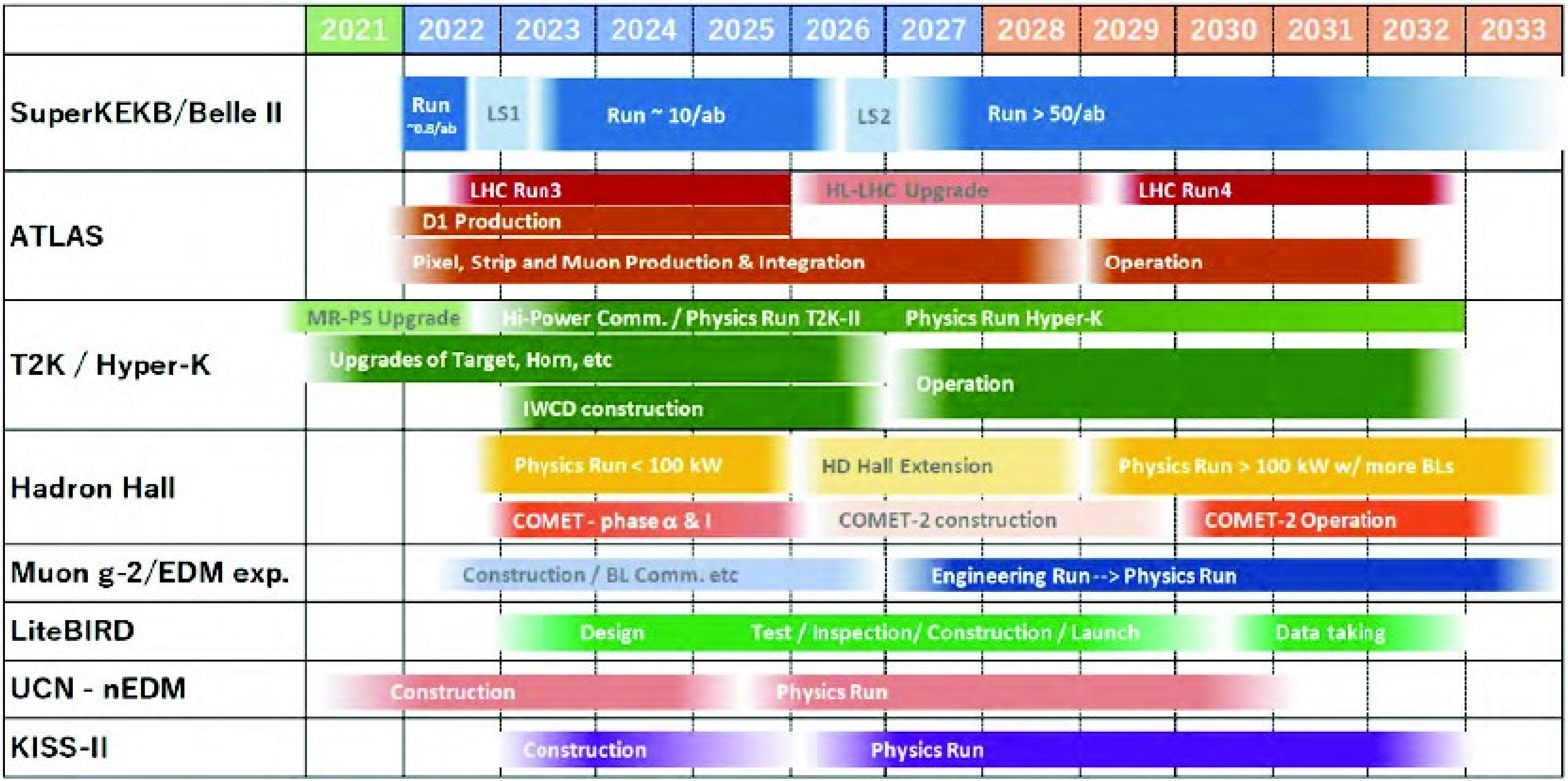
- the stat of a B-factory by summer of 2022... (Run 1, > 400 fb^{-1})
- PXD2 installation during LS1
- Run 2: until ~ 7 ab^{-1}
- ~ 2027: upgrade QCS/VXD (LS2)
- Run 3: until 50 ab^{-1} by 2035

- Responsibilities in DAQ/HLT/SVD/Calibration
- Strong involvement in physics analyses in unique sectors ($b \to s$, τ)
- Interesting perspectives in a coming vertex upgrade

Backup

The Timeline (ver 2022.01.26)

- Intended schedule by IPNS, so far
- ILC will be mentioned after the conclusion by an external panel under MEXT, then follow-up discussion by community



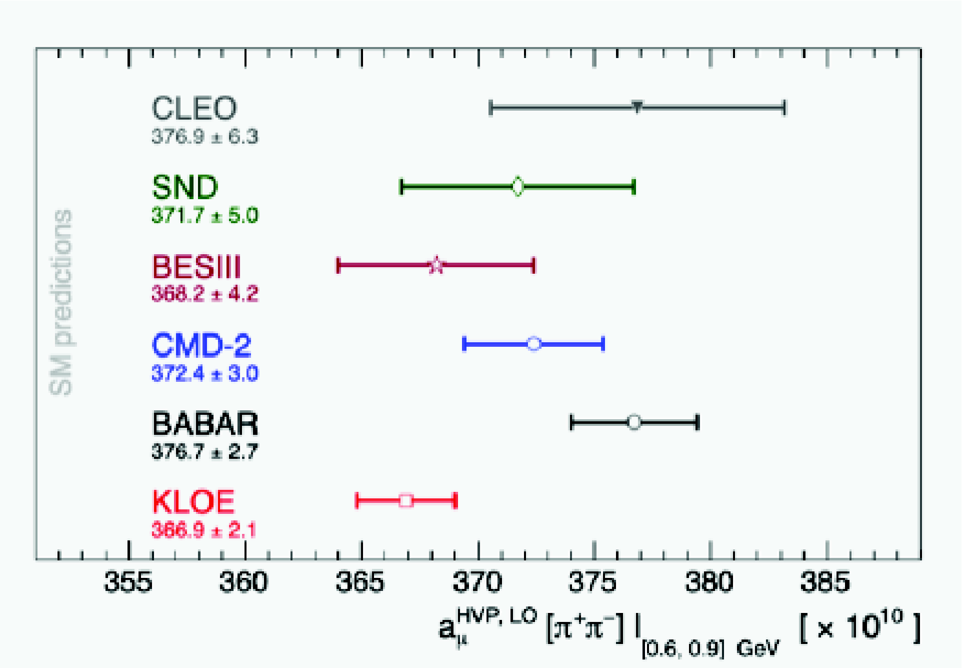
Dominated by Belle I
competitive with current dat

Cross-section for $e^+e^- \to \pi^+\pi^-(\gamma)$

Uncertainty in $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))$ at ω–ρ interference dominates leading-order hadronic contribution to predictions of $(g-2)_\mu$ based on dispersion relations

Boils down to a permille measurement of $\sigma(e^+e^- \to \pi^+\pi^-(\gamma))/\ \sigma(e^+e^- \to \mu^+\mu^-(\gamma))$ *vs* two-body mass.

Dominated by PID systematic uncert.



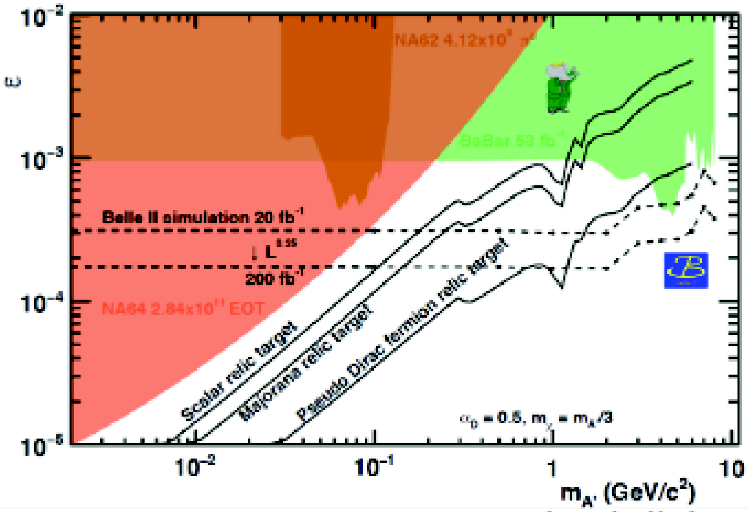
Projections are hard: no Belle measurement, no preliminary Belle II result.

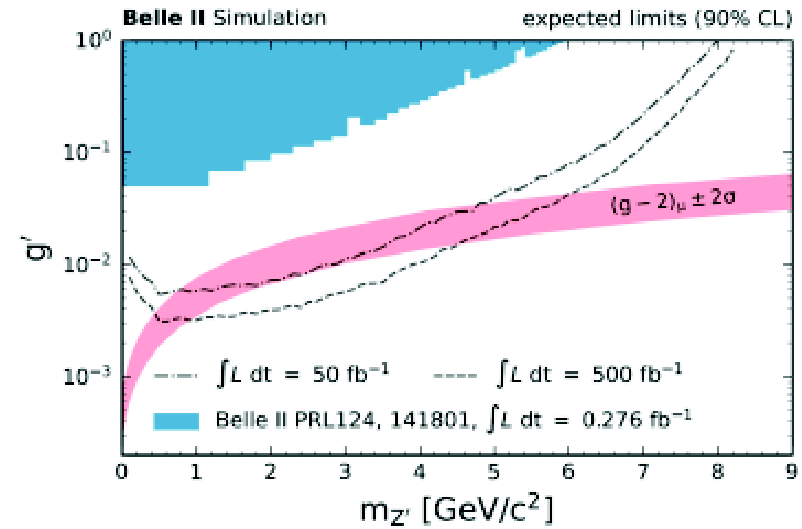
Safe to assume a measurement at least as precise as Babar's.

Unique to Belle I
competitive with current dat

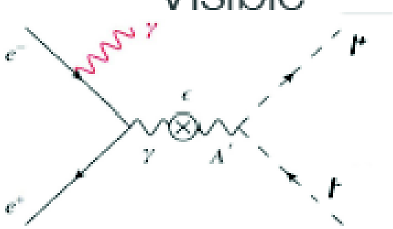
Low-mass dark sector

- Triggering on low-multiplicity without clogging DAQ with ee → ℓℓ, ℓℓℓℓ, γγ
- Understand collision backrgounds (SM simulations, beam bckg), cosmics and detector hermeticity to achieve > ppm rejections

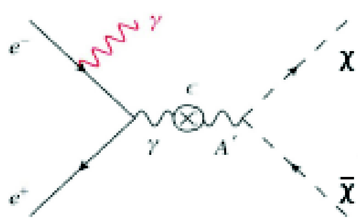


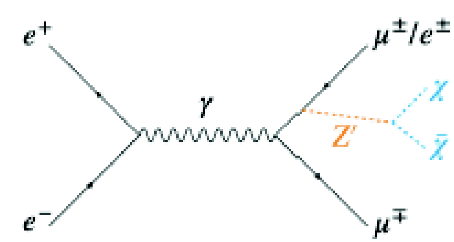


Visible



Invisible





"Easier," but less generic
Challenge: can extend to electrons?

Harder, truly generic
Challenge: understanding of material/hermeticity: KLM vetoes crucial. Trigger.

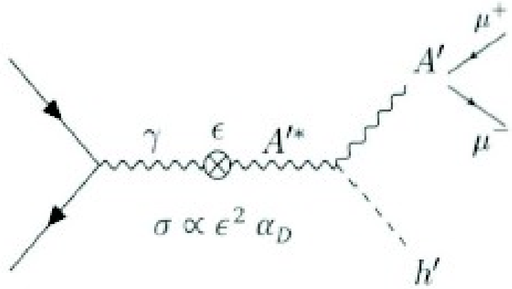
Probes plausible explanation for muon g-2

Also ALP → γγ (PRL 125 (2020) 161806)

Recent example - Darkhiggstrahlung

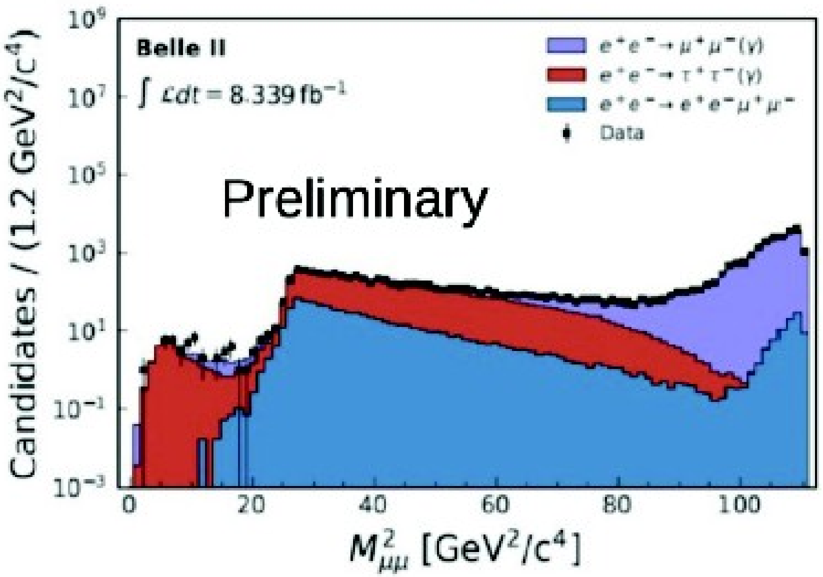
Unique to Belle II

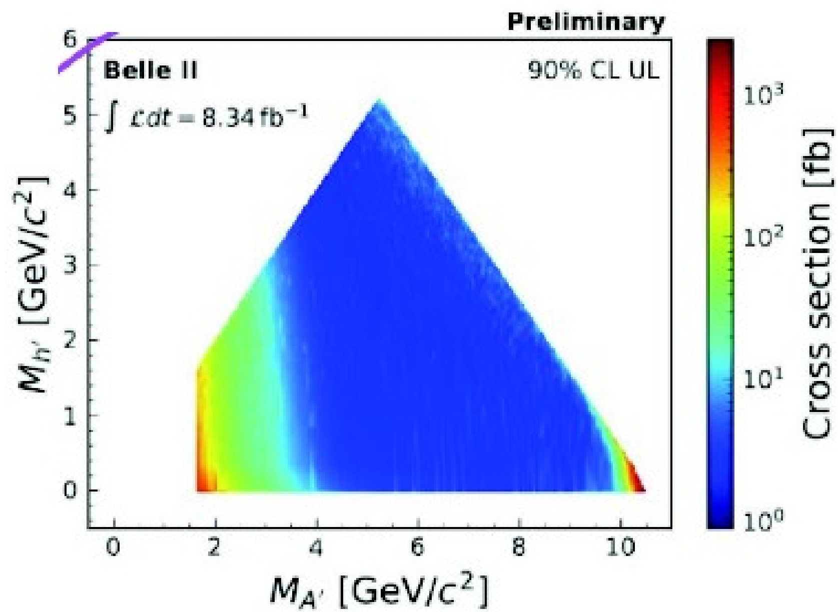
If dark photon A' exists, its mass can be generated by Higgs-like mechanism mediated by a dark higgs (h') field.



Bump hunt for a peak in the two-dimensional plane of mumu and recoil masses with very early data

Belle II has unique capability to probe the ***invisible h' decay ($m_{h'} < m_{A'}$)*** with A' decaying to a muon pair





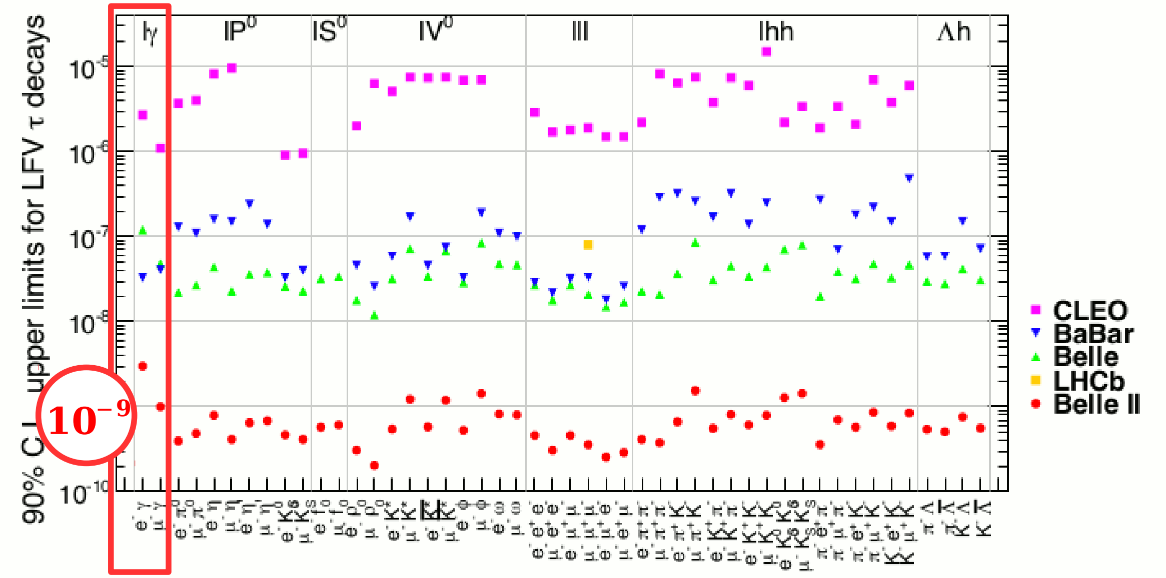
World best results in 2-10 GeV range

"τ center"

- **B-factory is also a τ-factory!**
- **lepton flavour violating decays of the τ as NP probe**

⇒ LFV accidental symmetry of SM, many NP models can naturally break this symmetry

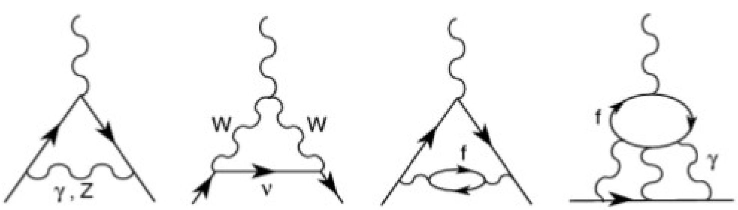
Model	Reference	τ→μγ	τ→μμμ
SM+ ν oscillations	EPJ C8 (1999) 513	10^{-40}	10^{-40}
SM+ heavy Maj ν_R	PRD 66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66 (2002) 115013	10^{-7}	10^{-9}
SUSY Higgs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



- Search of $\tau \to p\mu\mu$ ($\tau \to p l^+ l'^-$) decays with Belle [with D.Sahoo (TIFR)]

⇒ results summarized in PRD 102 (2020) 111101

τ Anomalous Magnetic Moment (A.Martens, F.Zomer)



$$a_\mu^{exp} - a_\mu^{th} \sim 4\sigma$$

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

Physique en une page

⇒ detecteur entierement fonctionnel

programme de physique avec 0.5 ab^{-1} deja pertinent (Belle peut encore publier 30 articles/an et rester competitif face a LHCb dans de nombreux secteurs (TCPV, τ et energie manquante))

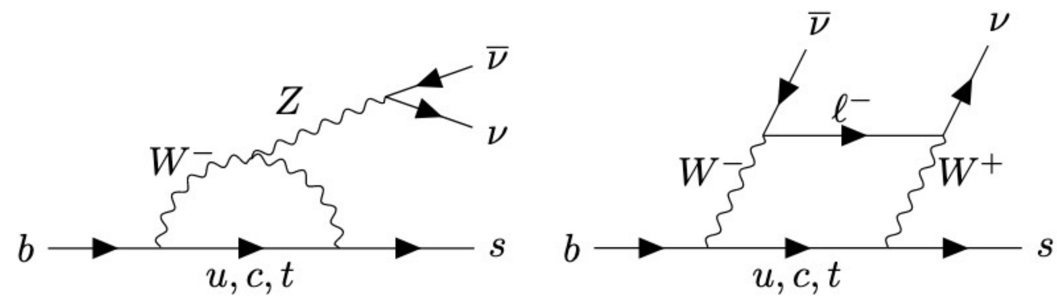
et l'ensemble des donnees pretes (et le MC !) pour l'analyse des 430 fb^{-1} pour 2023

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

- SM predictions:

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

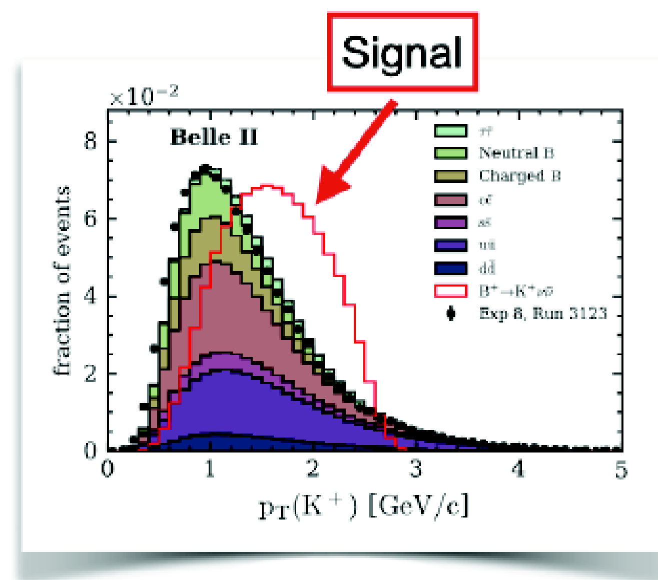
$$\mathrm{BR}(B^+ \to K^+\nu\bar{\nu})_{\mathrm{SM}} = (4.6 \pm 0.5) \times 10^{-6}\,,$$
$$\mathrm{BR}(B^+ \to K^{*+}\nu\bar{\nu})_{\mathrm{SM}} = (8.4 \pm 1.5) \times 10^{-6}\,,$$

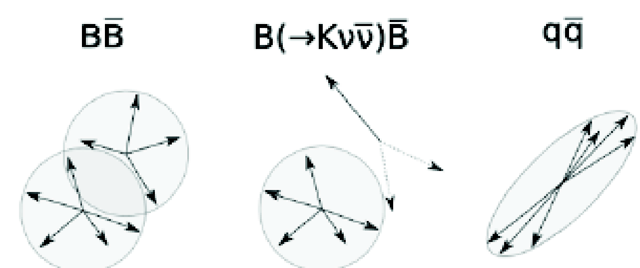


(a) Penguin diagram (b) Box diagram

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)

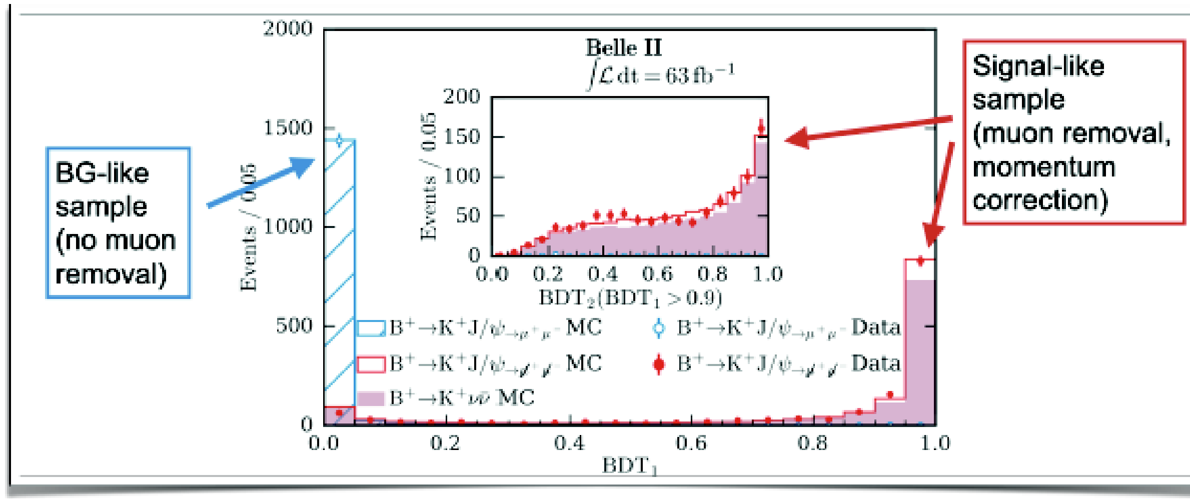




$B^+ \to K^+ \nu \bar{\nu}$ measurement at Belle II

[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

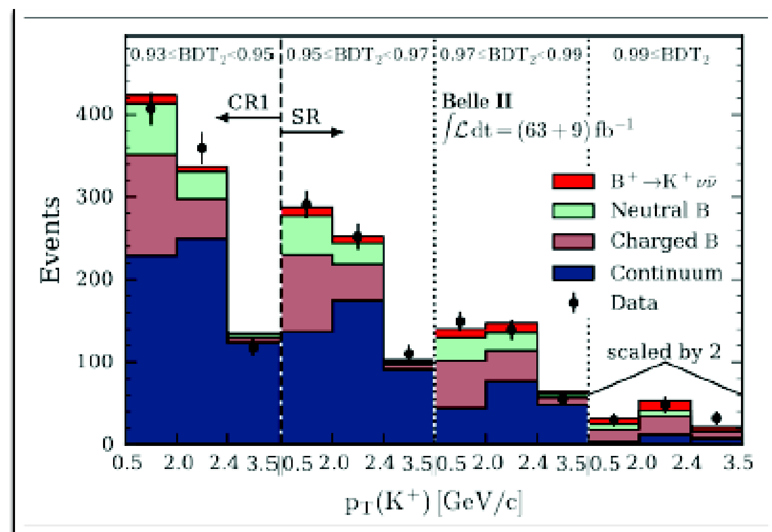


- Extract signal from simultaneous maximum likelihood fit to on-resonance + off- resonance data (taken 60MeV below $\Upsilon(4S)$ resonance) in bins of $p_T(K^+)$ and second BDT (BDT_2):

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

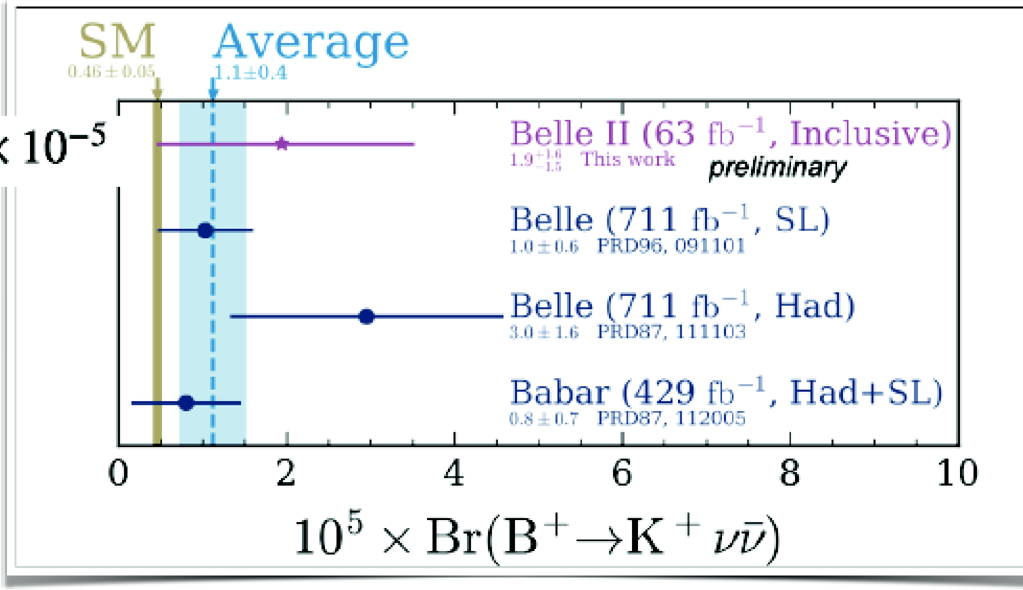
[arXiv:2104.12624]
accepted by PRL

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

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

- Comparing theory and experiments:

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



- 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!**

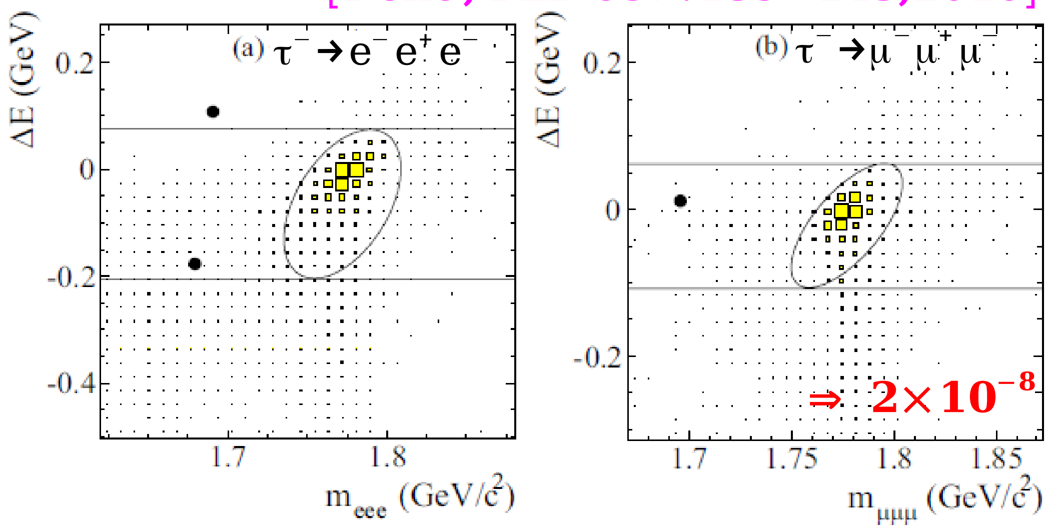
*) assuming the total uncertainty on the branching-fraction scales with $1/\sqrt{L}$

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

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]

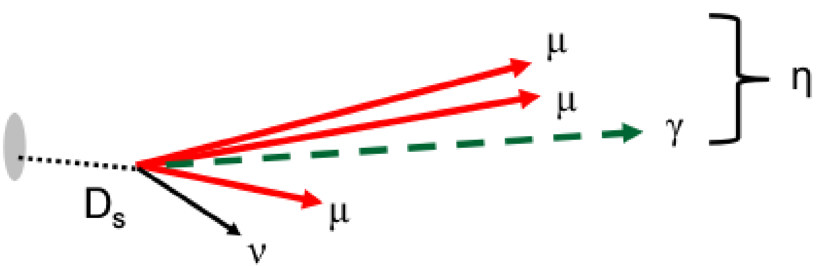


$\Rightarrow$ 2×10^{-8} at 90%CL

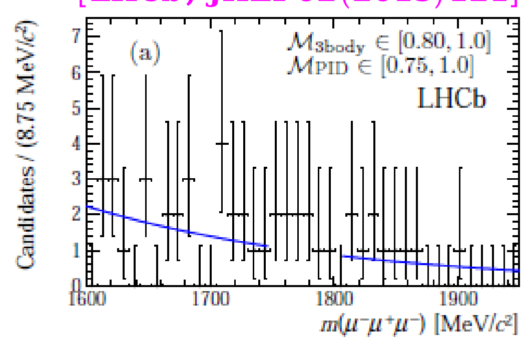
how to improve further ?

...considering $\tau\to\mu/e\,h^+h^-$
in function of one prong tag categories
...for $\tau\to3$ 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

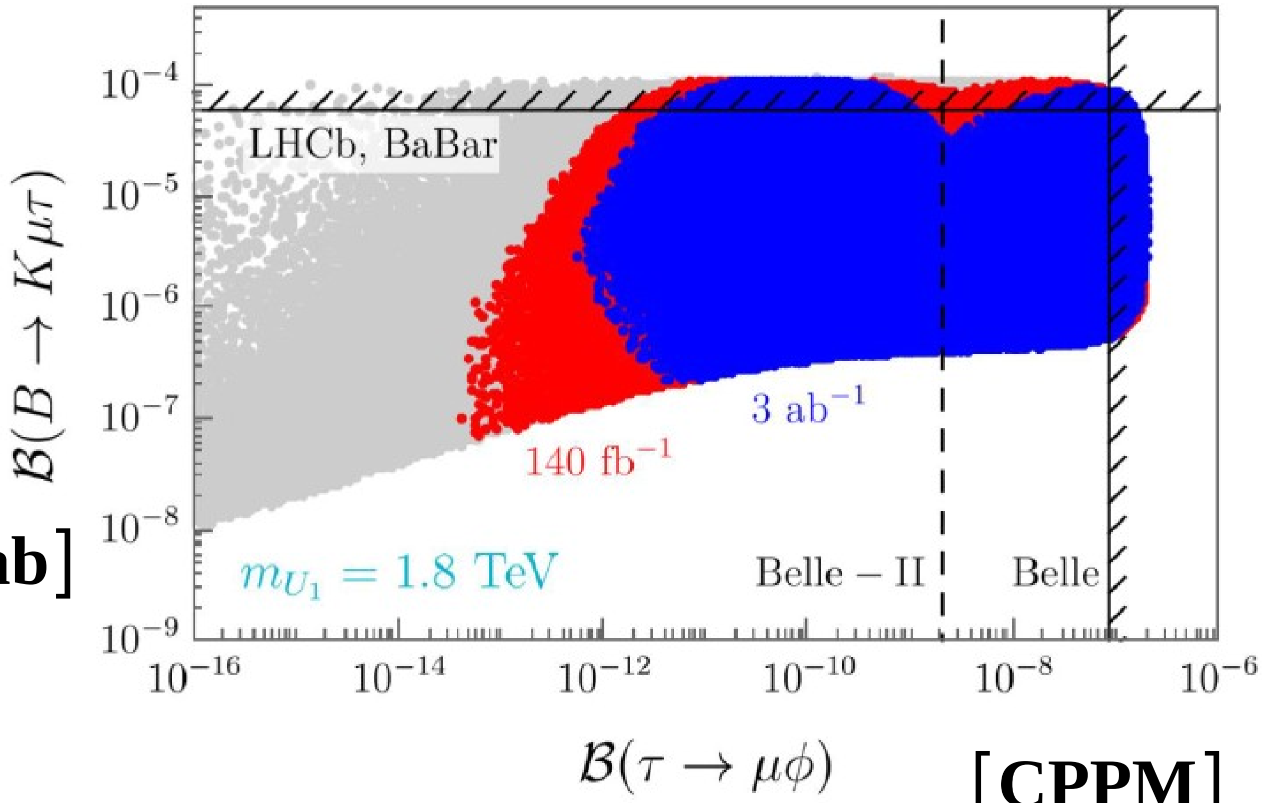
Background modes normalised to $D_s\to\eta(\mu\mu\gamma)\mu\nu$ (BR ~ 10^{-5})

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

Nice complementarity

[IJCLab]



[CPPM]

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

Impact of VTX upgrade

➜ **Impact on vertexing:**
- preserve good resolution, important with smaller boost of Belle II
- essential for TCPV analyses

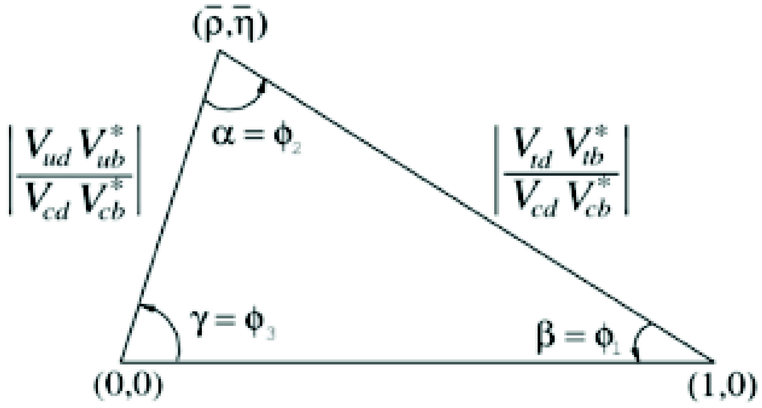
➜ **Missing energy analyses:**
- lower number of fake tracks
- crucial for no extra energy analyses
- vertexing in the analyses (Kl versus τ daughter)

➜ **improve the pattern recognition**
- 4 SVD layers ➜ 5 layers

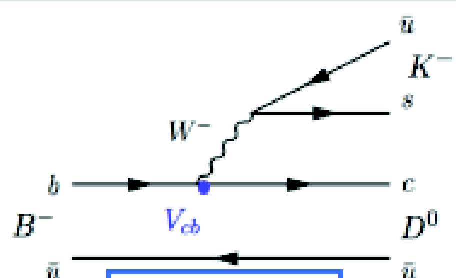
➜ **simplify/faster HLT (currently 2 steps)**
- reprocessed data at the online level
- faster, transparent

The CKM angle ϕ_3

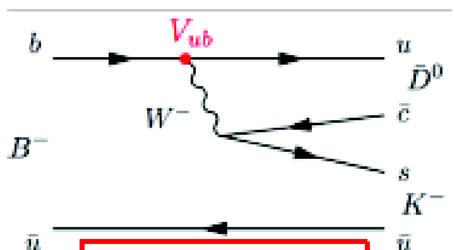
$$\phi_3/\gamma \equiv arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$



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



Color-favored



Color-suppressed

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

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

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 $\delta\phi\sim 4°$) 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

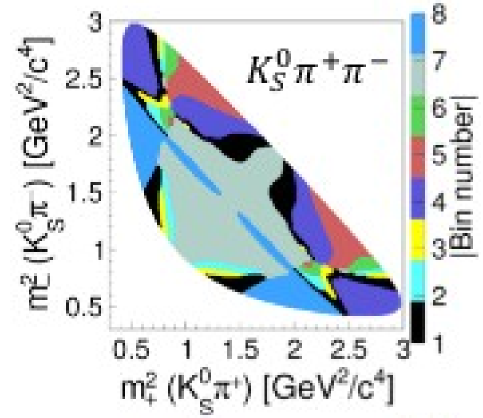
$h = \pi, K$

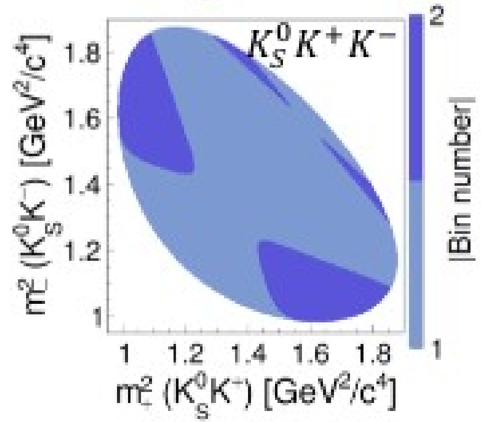
First Belle + Belle II analysis

- $B^- \to D(\to K_S^0 \pi^+ \pi^-)K$ 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 $B^- \to D^0(K_S^0\pi^+\pi^-)K^-$.

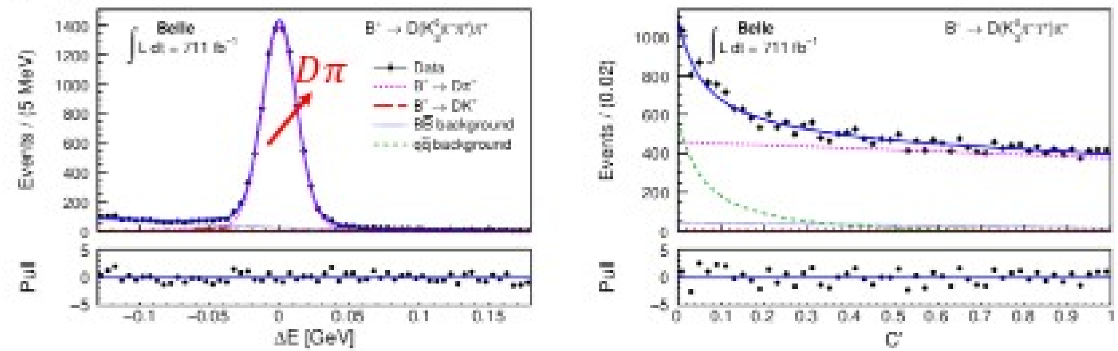
Component	PDF (ΔE)	PDF ($\mathrm{FBDT_{trans}}$)
Signal	DG + Bifur-Gaus	poly (1st)
$B\bar{B}$ bkg	expo +(poly)	Chebychev poly-1st(2nd)
$q\bar{q}$ bkg	Chebychev poly (1st)	2 expo
DK ($D\pi$) component	DG + Bifur-Gaus	Chebychev poly (1st)

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

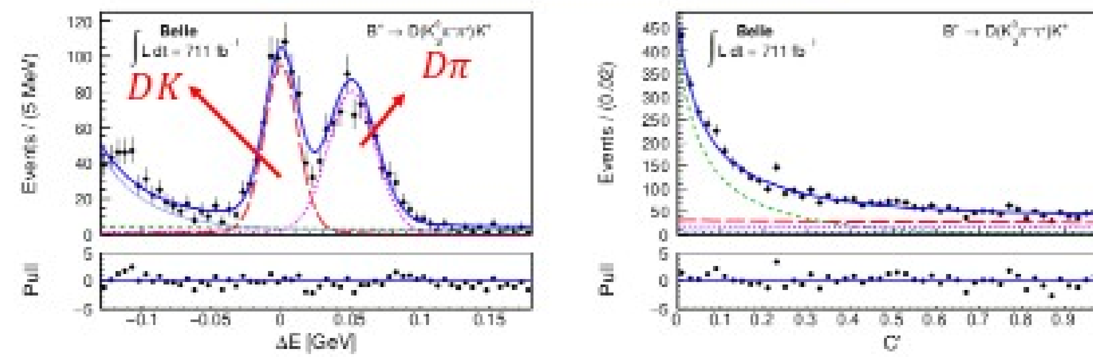
- Signal region :
  - $|\Delta E| < 0.05\ GeV$
  - $0.65 < C' < 1.0$

$(x_\pm, y_\pm) = r_B(\cos(\phi_3 + \delta_B), \sin(\phi_3 \pm \delta_B))$ 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 $B^- \to D^0(K_S^0\pi^+\pi^-)K^-$.

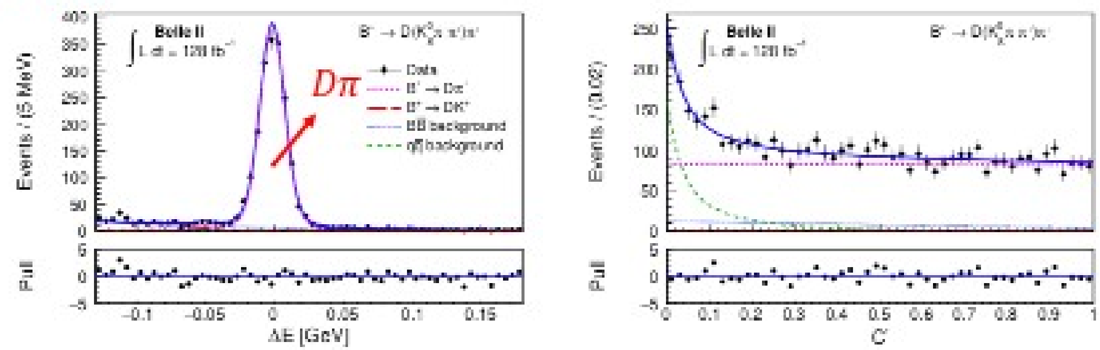
Component	PDF (ΔE)	PDF ($\text{FBDT}_{\text{trans}}$)
Signal	DG + Bifur-Gaus	poly (1st)
$B\overline{B}$ bkg	expo +(poly)	Chebychev poly-1st(2nd)
$q\overline{q}$ bkg	Chebychev poly (1st)	2 expo
DK ($D\pi$) component	DG + Bifur-Gaus	Chebychev poly (1st)

- 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



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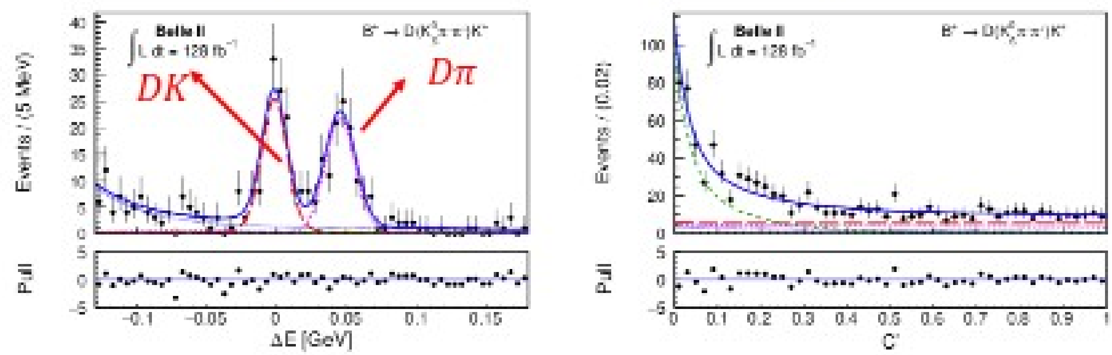

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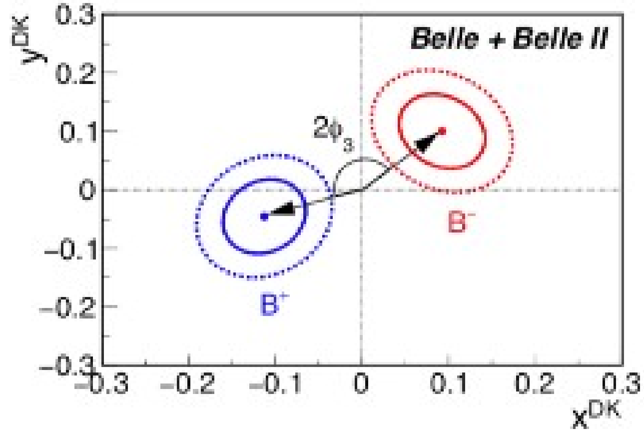
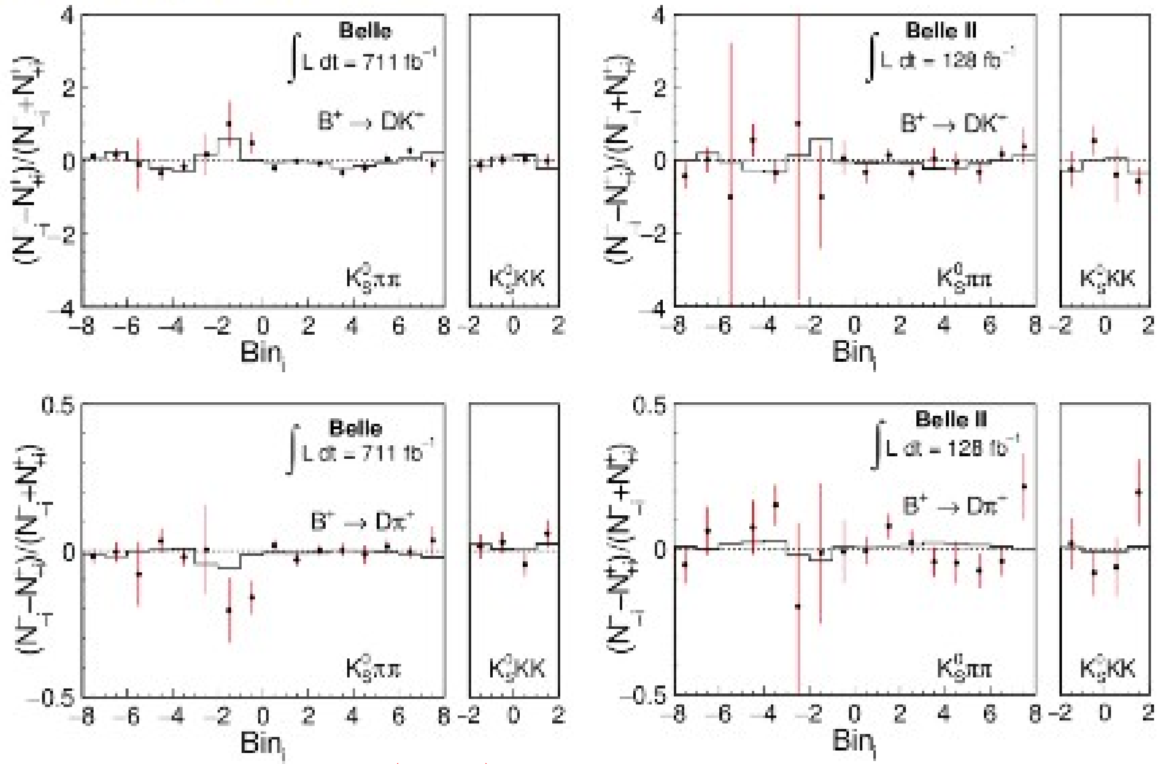




Uncertainty ~14° in earlier Belle measurement

PhysRevD.85.112014

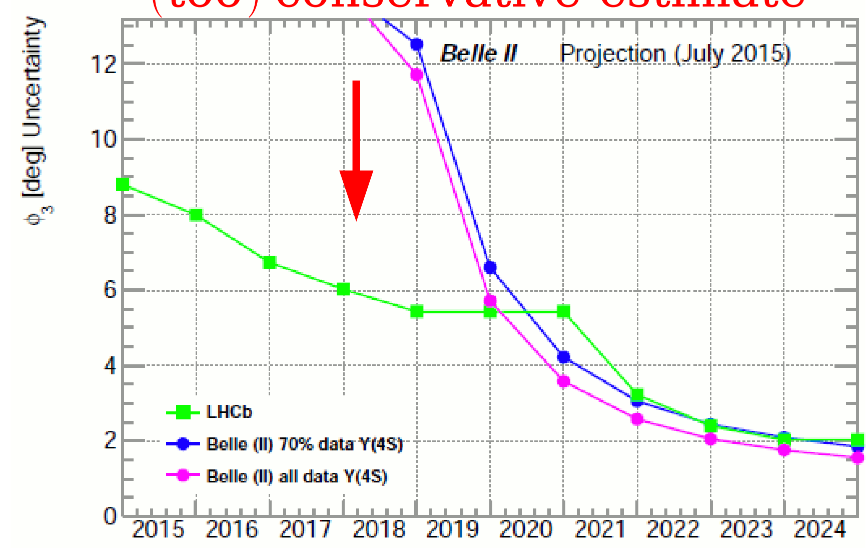
- Preliminary result :

$\delta_B(°)$ = 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

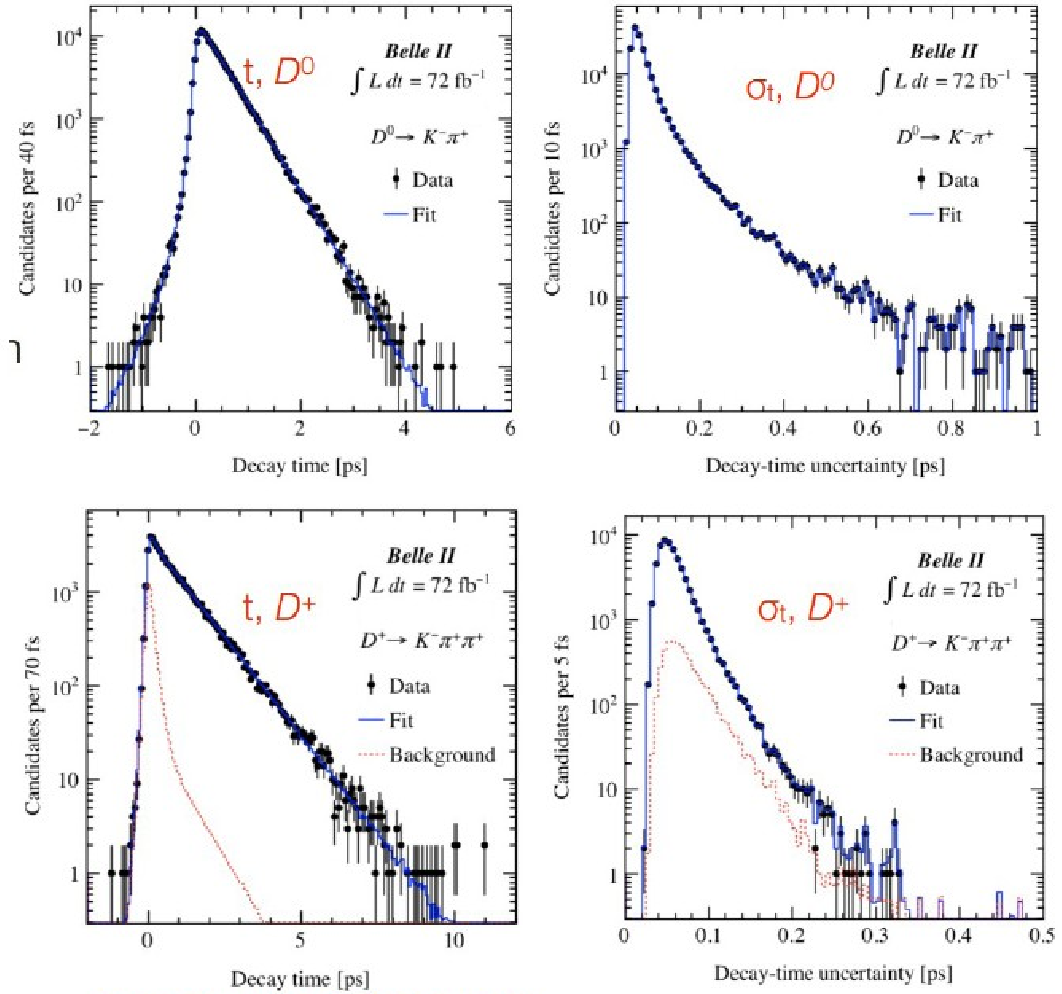


long way to go … (→ σ_γ = 1° or less ?)

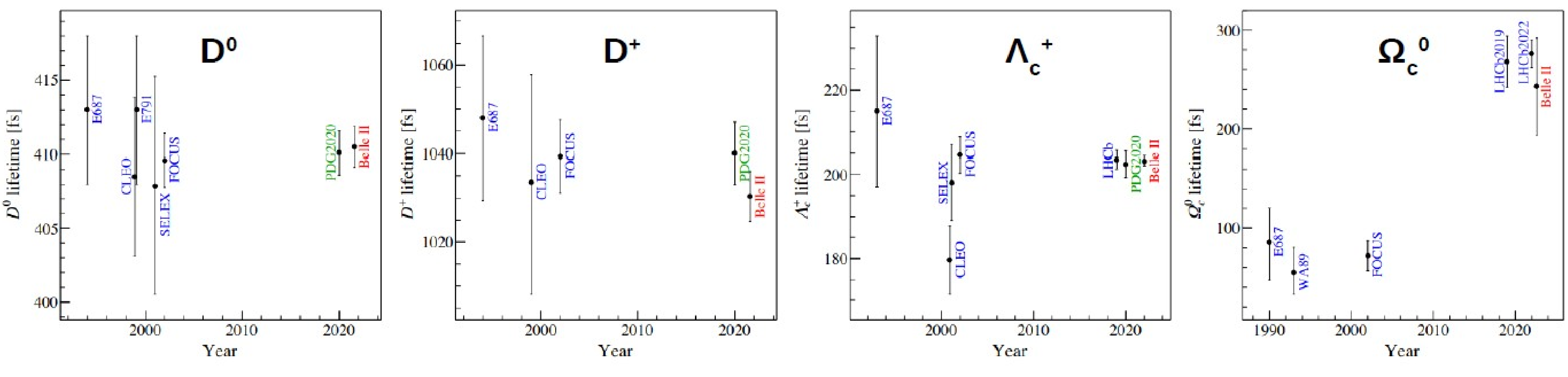
$$\tau(D^0) = \;\; 410.5 \pm 1.1 \pm 0.8\,\text{fs}$$
$$\tau(D^+) = 1030.4 \pm 4.7 \pm 3.1\,\text{fs}$$
$$\tau(D^+)/\tau(D^0) = 2.510 \pm 0.015$$

- Most precise to date and consistent with WA, improving LHCb reference
- Only preliminary alignment used
- Demonstrates excellent vertexing

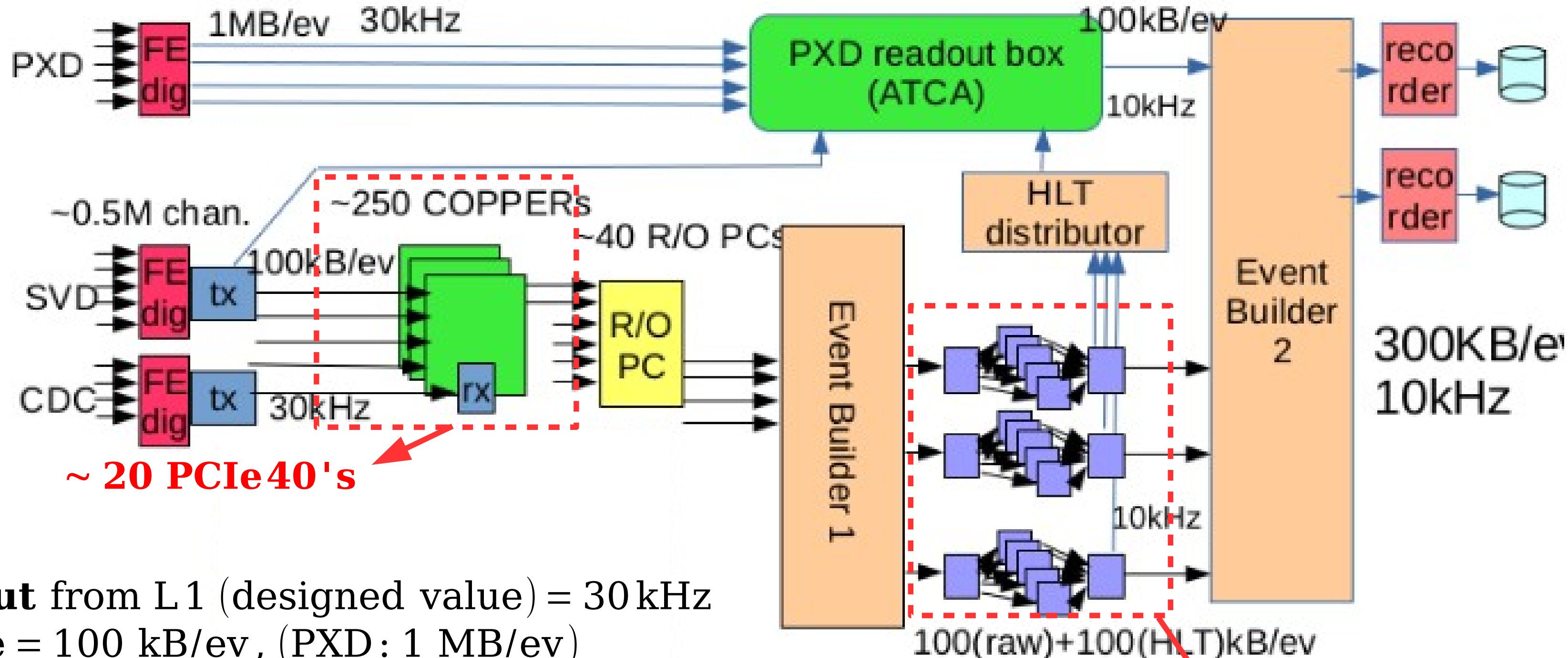
Source	Uncertainty (fs)	
	$D^0 \to K^-\pi^+$	$D^+ \to K^-\pi^+\pi^+$
Statistical	1.1	4.7
Resolution model	0.16	0.39
Backgrounds	0.24	2.52
Detector alignment	0.72	1.70
Momentum scale	0.19	0.48
Input charm masses	0.01	0.03
Total systematic	0.8	3.1



Phys. Rev. Lett. 127, 211801 (2021)



Belle 2 High Level Trigger [IJCLab]



- max. **input** from L1 (designed value) = 30 kHz
- event size = 100 kB/ev, (PXD: 1 MB/ev)
- max. **output** = 10 kHz
- event size = (100 + 100 (PXD)) kB/ev

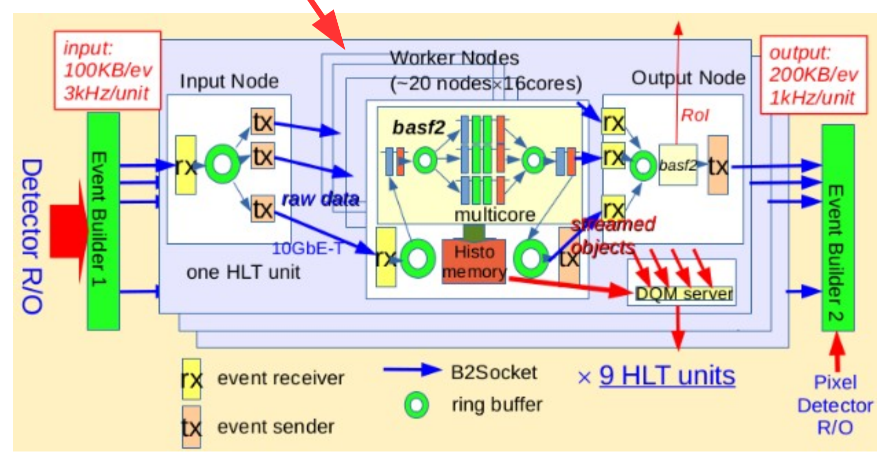
IJCLab group organized the switch on in Spring 2021

⇒ main functions of HLT

- trigger rate: reduction by a factor 5(*)

(*) or more depending also on how loose is the L1 trigger

- reconstruction without PXD → RoI feedback to Pixel Detector Readout
- tag events for calibration and physics skims
- monitoring (DQM on HLT/ExpressReco)



1 HLT unit, ~ 400 CPU cores/unit
each unit is completely independent
keep up with luminosity increase

⇒ HLT activities
- performances + optimization
  → Vidya, Gaetano, H.Grasland

Belle 2 High Level Trigger [IJCLab]

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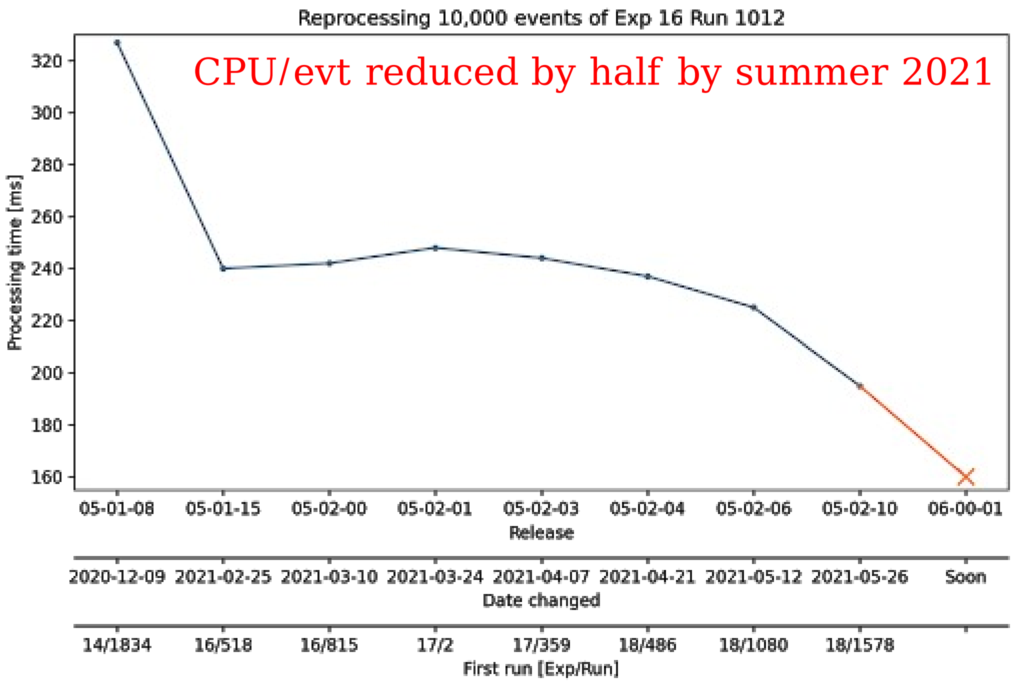
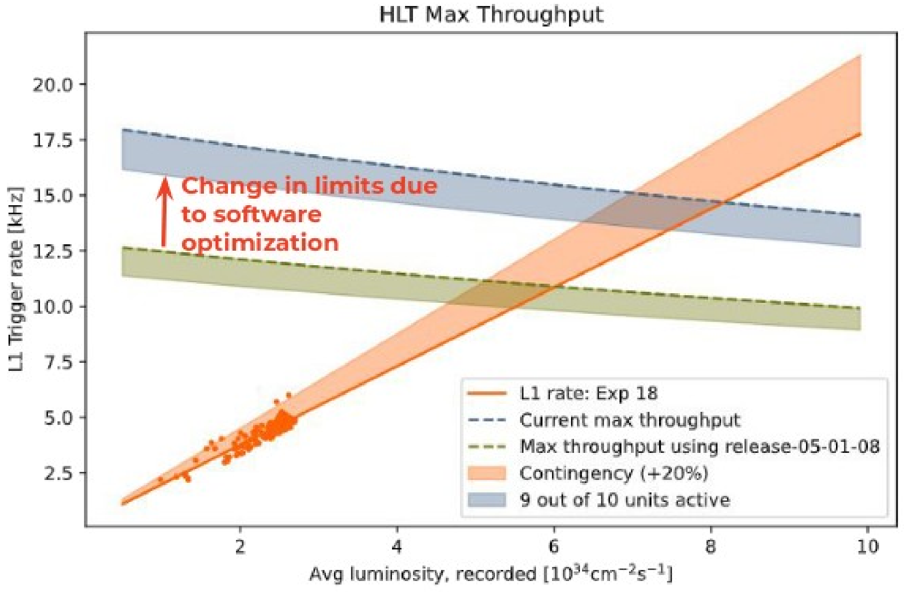




~9 kHz → ~13 kHz max.

allow to run at higher luminosity (→ LS 1)

⇒ HLT activities

– performances + optimization

→ Vidya, Gaetano, KT + H. Grasland

further optimization now under going optimizing Kalman filter part (with V. Bertacchi, CPPM)

→ improve performance further beyond LS 1

LS 2

Revisit QC1P modification

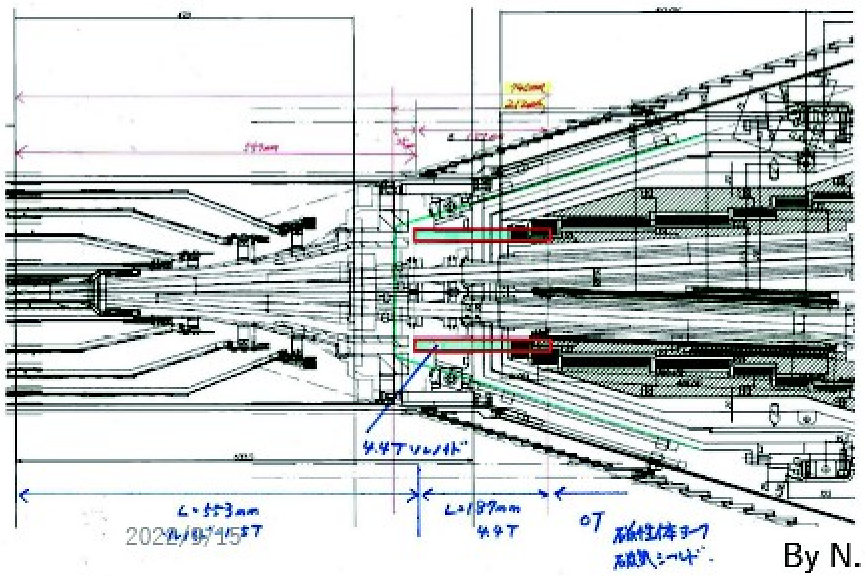
QC1Pとビームパイプ

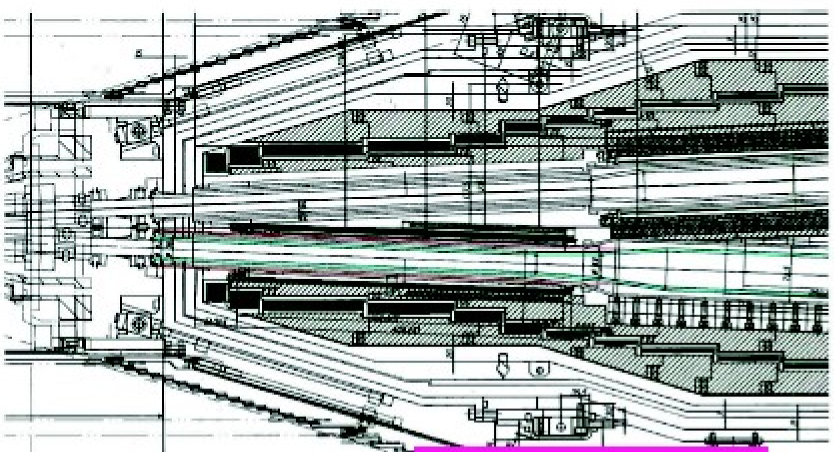
- Increase QC1P aperture (vertical) from 13mm to (18mm) 20.7 mm
  - Larger physical aperture
- Fabricate new anti-solenoid coil and move it closer to the IP
  - less x-y coupling is expected
- Cover QC1P by magnetic material
  - magnetic coupling reduction is expected

Working with the Optics G

QCSシステム改善：#3について

1. 4極電磁石は、そのまま流用。
   - 補正電磁石は、QC1Pの外周部へ移動。
   - QC1Pは、磁性体ヨークを被る。対抗ビームラインも磁気シールドあり。
2. 補正ソレノイドをQC1Pの前に出す。
3. QC1Pのビームパイプ内径を大きくする。
   - これまでの提案：R13.5mm→R18mm→R20.7mm





By N. Ohuchi on Sep.14, 2022

Cost-effectiveness ?

Using this LS1 period :

We will focus on putting efforts into seeking an upgrade path to 6×10^{35}

- Carrying out more beam-beam simulations, including crab waist, impedance, lattice errors, etc., to guide the upgrade path.
- Considering increasing the number of focused task-force groups to other key areas such as IR/QCS.

Approaches from

New ideas, innovative ideas, etc.

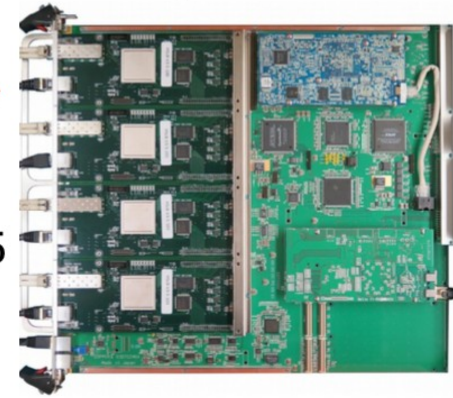
Feasibility study (hardware)

Belle II DAQ upgrade

[IJCLab]

(P.Robbe, D.Charlet, E.Plaige, M.Taurigna...)
(collaboration with KEK, IPMU, UH)

- difficulty in future maintenance of COPPER boards: increasing malfunctioning pieces, parts out of production...
- Switch to PCIe40 board, developed for LHCb and ALICE upgrades (more compact system with large input and output capacities)



- Performances and stability fullfill requirements (30 kHz trigger rate)
  - Many improvements added to the DAQ in general together with this upgrade

⇒ **Tak Shun Lau (IN2P3 post-doc), new firmware/software development**

- Integration into Belle II global DAQ
  PCIe40 has been used for few Belle II sub-detectors during LS1 (first time the board is used in a particle physics experiment) !!
  - First in parallel with old COPPER system, for only 2 detectors (TOP and KLM), then ARICH
  - quickly extended to other detectors (migration completed during LS1)

⇒ **PCIe400 for VTX upgrade (LS2 in 2027) ?**

Electron beam polarisation

- Goal is ~70% polarization with 80% polarized source (SLC had 75% polarization at the experiment)
- Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode (similar to SLC source)
- Inject vertically polarized electrons into the High Energy Ring (HER) - needs low enough emittance source to be able to inject.
- Rotate spin to longitudinal before IP, and then back to vertical after IP using solenoidal and dipole fields
- Use Compton polarimeter to monitor longitudinal polarization with <1% absolute precision, higher for relative measurements (arXiv:1009.6178) - needed for real time polarimetry
- Use tau decays to get absolute average polarization at IP

Interesting prospects for polarizing electrons in SuperKEKB:

- Extends physics case of Belle II (à la SuperB)
- Challenge: preserve high lumi and high polarization at IP

Design is progressing towards White Report:

- In-line with Snowmass and its delays…

IJCLab contributes to Compton polarimetry:

- Laser polarisation control
- Fast photon detection

Composition des equipes Belle II (2022)

- **Doctorants** [arrivee recente/prochaine, depart prochain]

@ CPPM

- Leonard Polat, ERC (10/2019–12/2022)
- Robin Leboucher, ERC (10/2020–09/2023)
- Arthur Thaller, ERC (10/2021–09/2024)
- Clothilde Lemettais, ERC (10/2022–09/2025)

@ IJCLab

- Gaetano de Marino, IN2P3/Paris-Saclay (11/2019-12/2022)
- Vidya Vobbilisetti, Paris-Saclay (10/2020-9/2023)
- Meihong Liu, visiteuse CAS Fudan University (11/2021-11/2023)
- Pavel Oskin, PAUSE (09/2022-09/2023)
- Farah Mawas, Paris-Saclay (10/2022-09/2025)

@ IPHC

- Tristan Fillinger, CNRS (10/2019–09/2022)
- Lucas Martel, Unistra (10/2020–09/2023)
- Petros Stravroulakis, Unistra (10/2022–09/2025)

Composition des equipes Belle II (2022)

- **IT contribuant aux activites, associes techniques**

@ CPPM

Marlon Barbero, Patrick Pangaud – upgrade VXD
Pierre Barrillon, Patrick Breugnon, Eric Vigeolas
+ Danwei XU (post-doc)

@ IJCLab

D.Charlet, E.Plaige, E.Jules, P.Robbe, M.Taurigna, C.Beigbeder – DAQ
Hadrien Grasland – activites software (optimization)
Michel Jouvin, Guillaume Philippon – activites GRID
Sandry Wallon – LumiBelle2
Fabian Zomer – Polarization faisceaux
Julien Bonis, Didier Auguste, Yann Peinaud, Marc Winter – cooling beampipe (PXD2)
[Aresh Vedaee – Computing/CCIN2P3]

@ IPHC

Jean Sebastien Pelle – slow-control SVD
Andrei Dorokhov, Luca Federici, Christine Hu-Guo, Hung Pham, Isabelle Valin – Micro-elec, upgrade VXD
Yannick Patois, Jerome Pansanel – Computing et DIRAC Belle II