First results from Belle II.

Torben Ferber (torben.ferber@desy.de)
on behalf of the Belle II collaboration

January 20 2020, 58. International Winter Meeting on Nuclear Physics

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

Belle II

DESY.

Overview

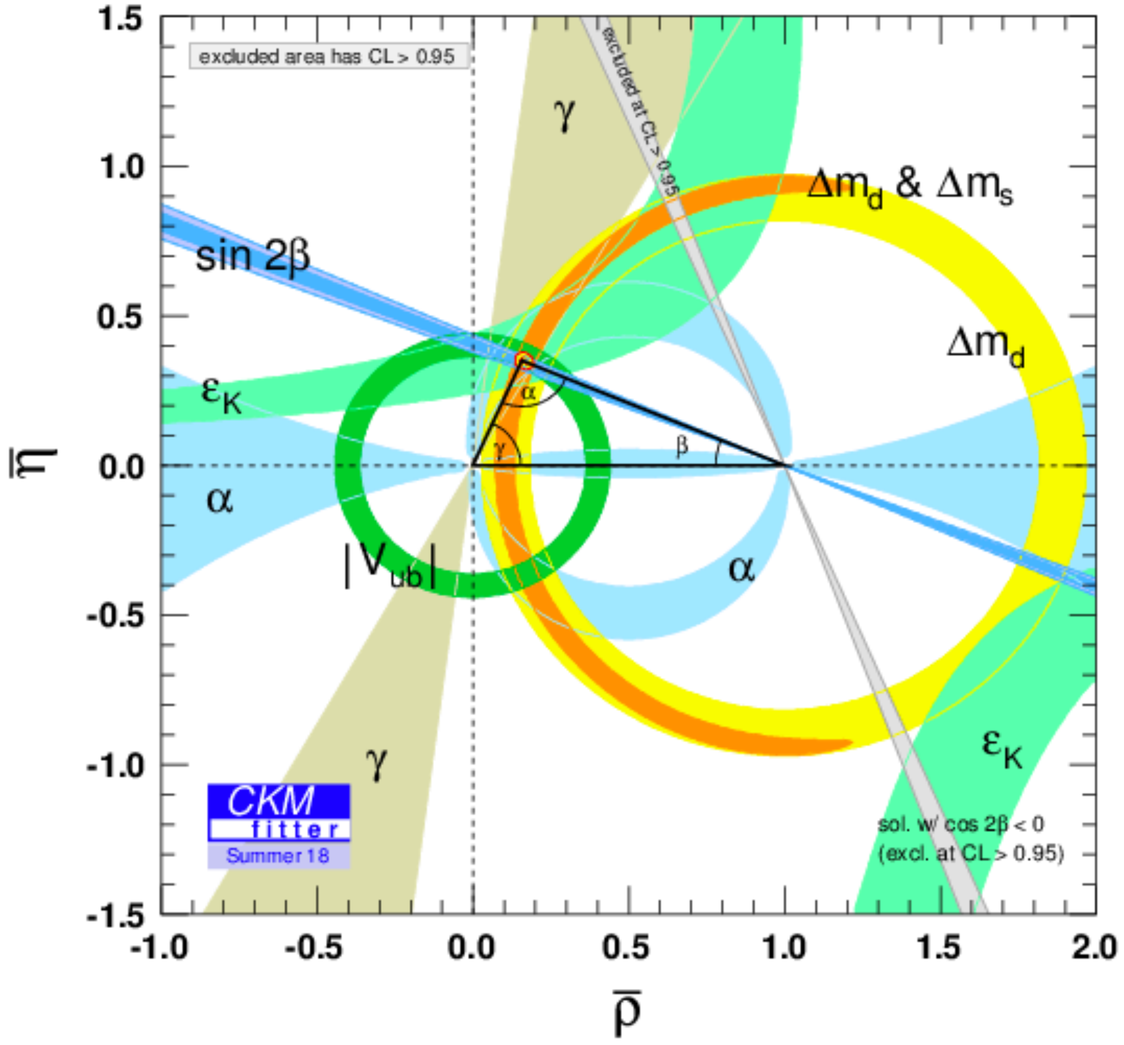
- B-factories
- SuperKEKB
- Belle II
- First results: 2018, 2019
- Outlook 2020

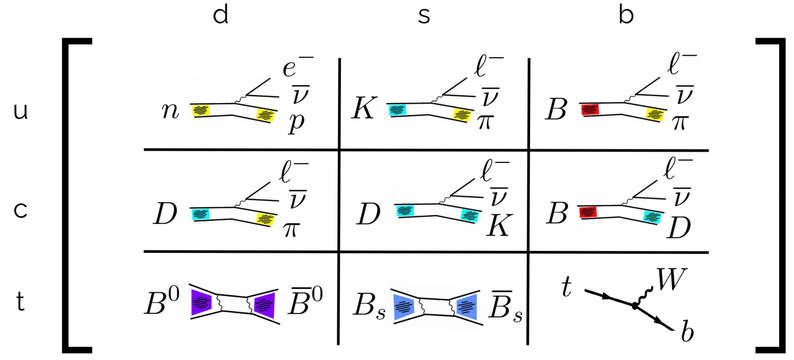
First Results and Prospects for τ lepton physics at Belle II
Thomas Kraetzschmar
Wednesday 18:40

Lepton Flavour Universality Violation (LFV) search τ→μμμ at Belle II
Alberto Martini
Friday 17:40

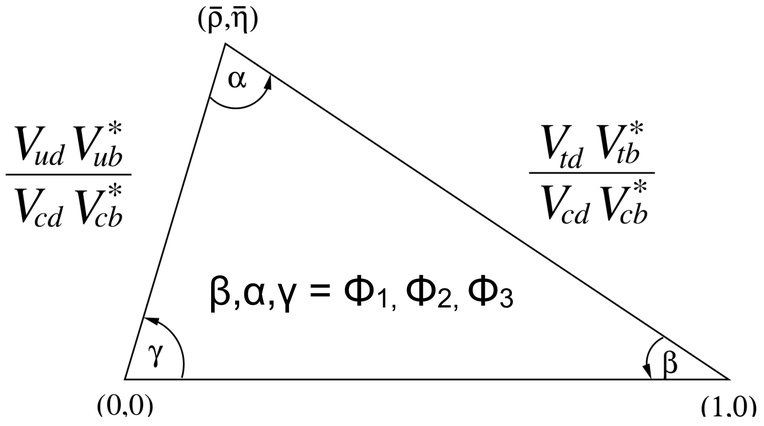
B-Factories.

CKM Metrology

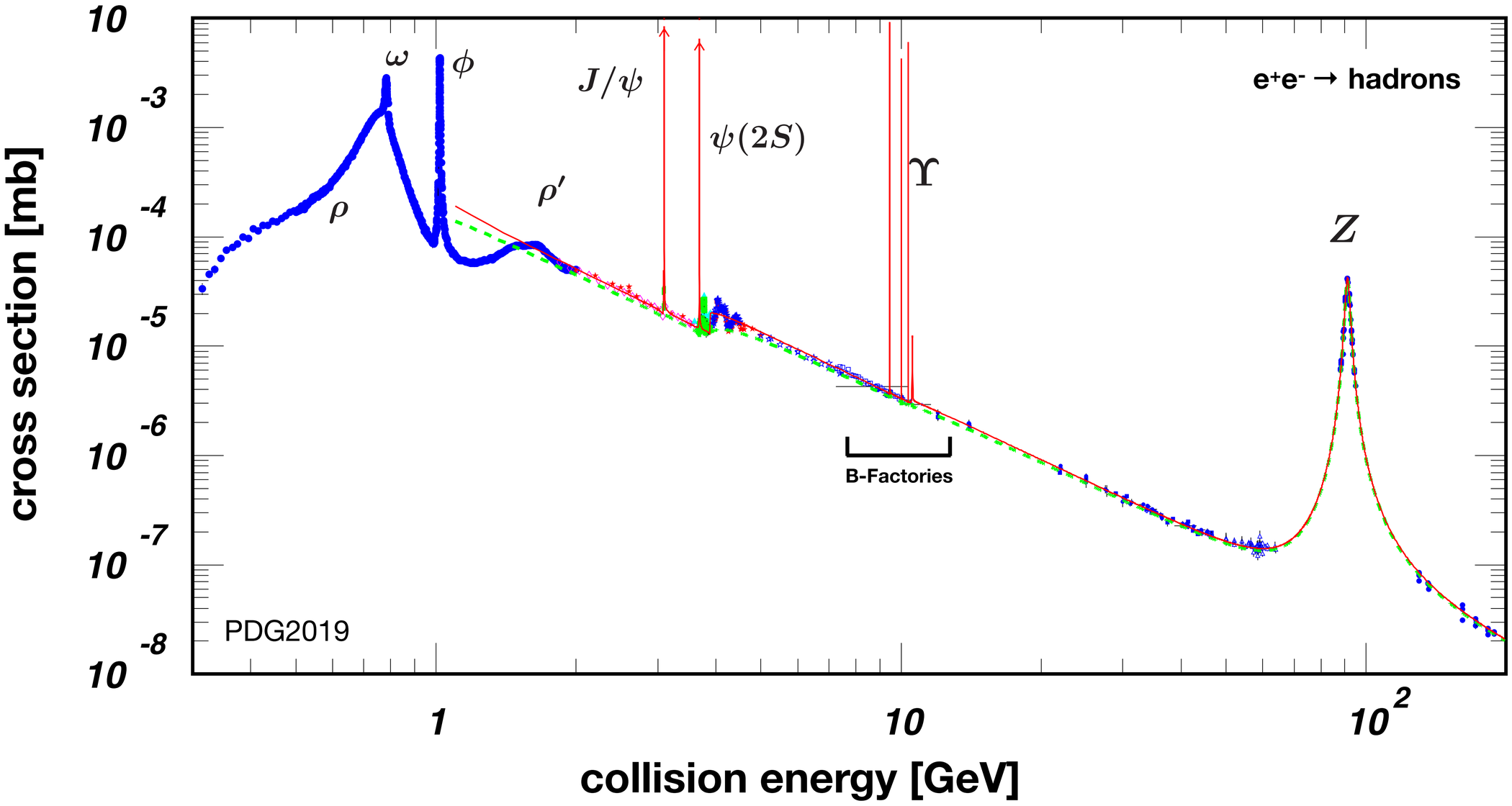




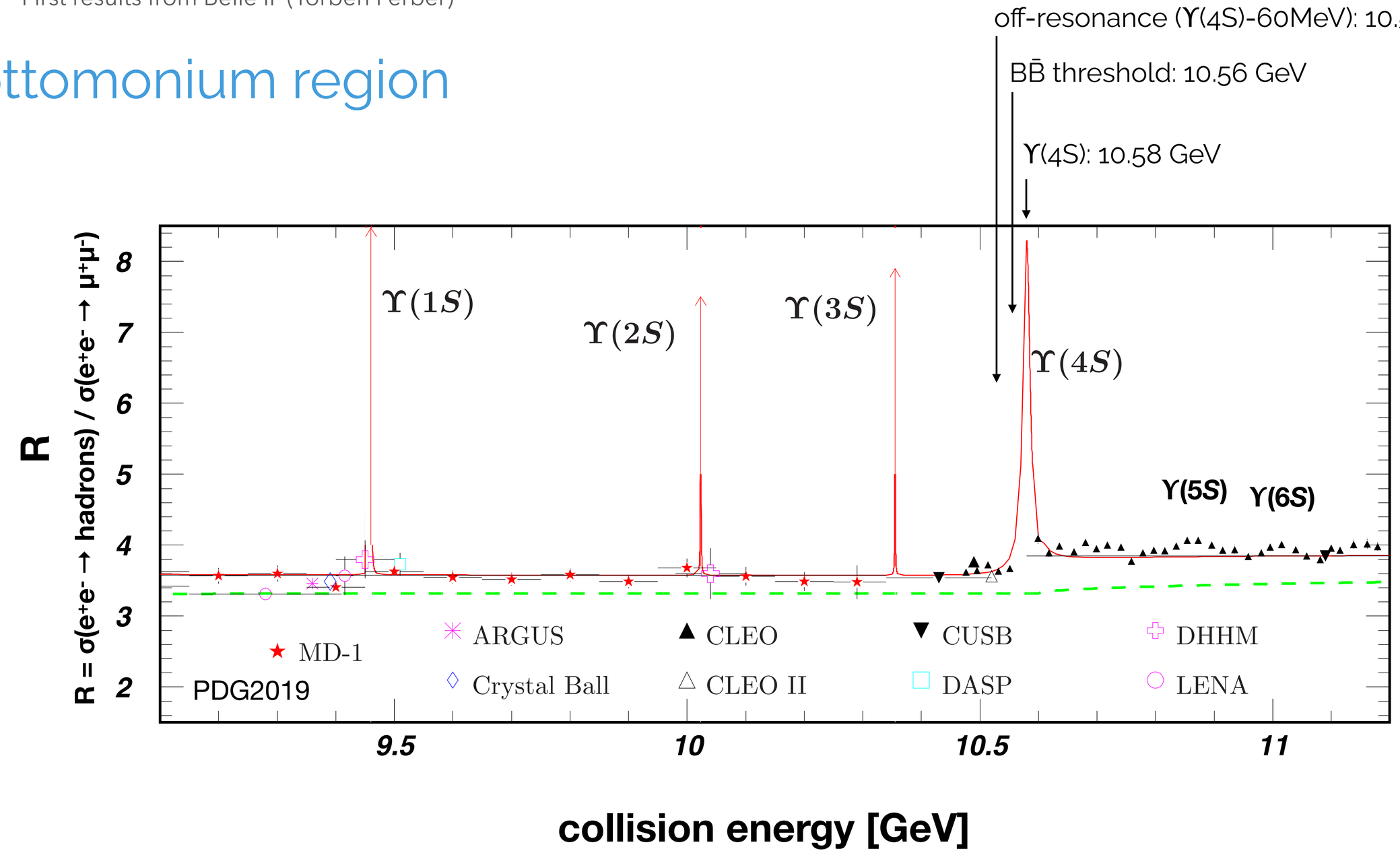
from Sebastian Descotes-Denon



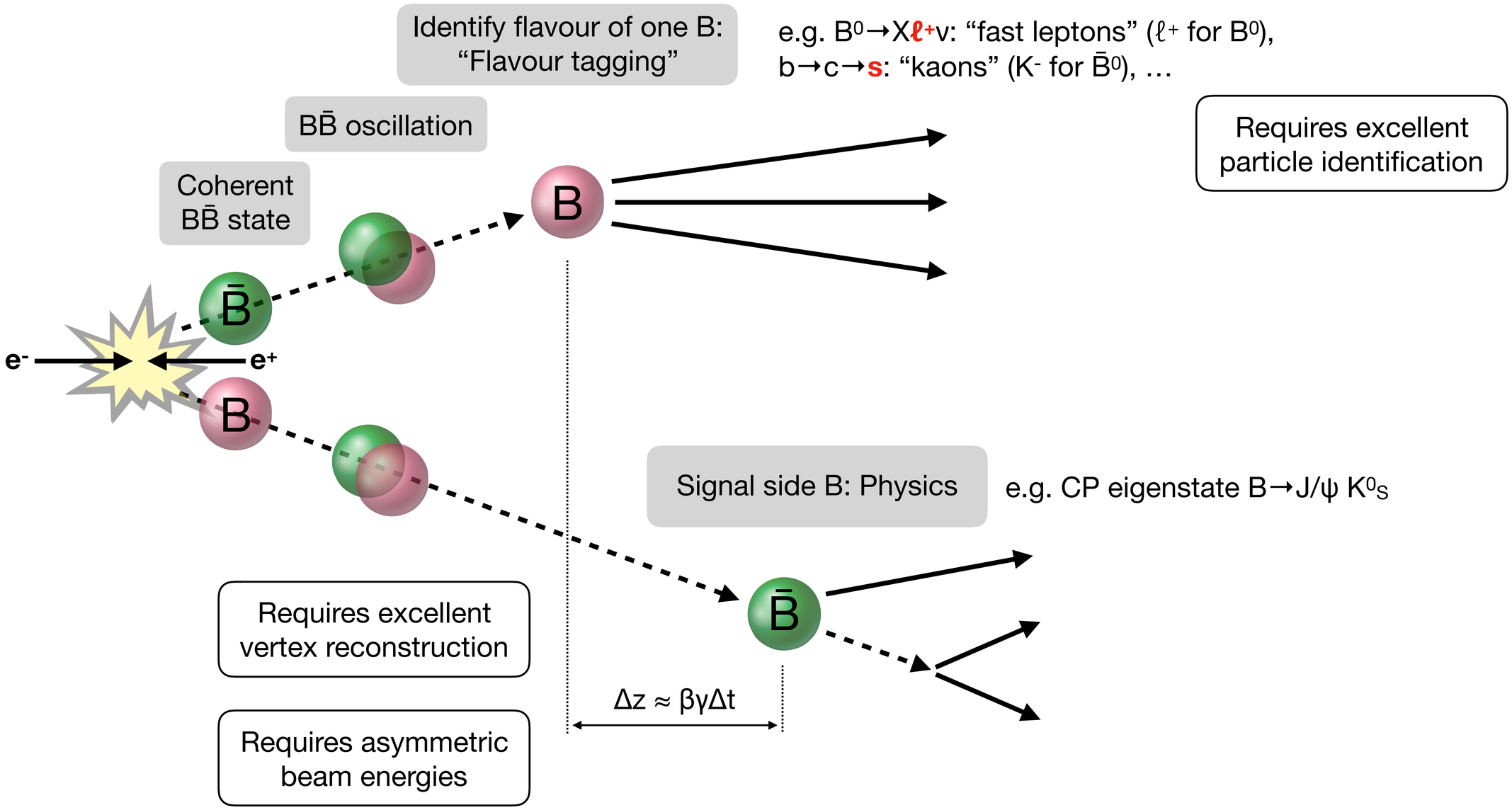
Hadronic cross section in e^+e^- collisions



Bottomonium region



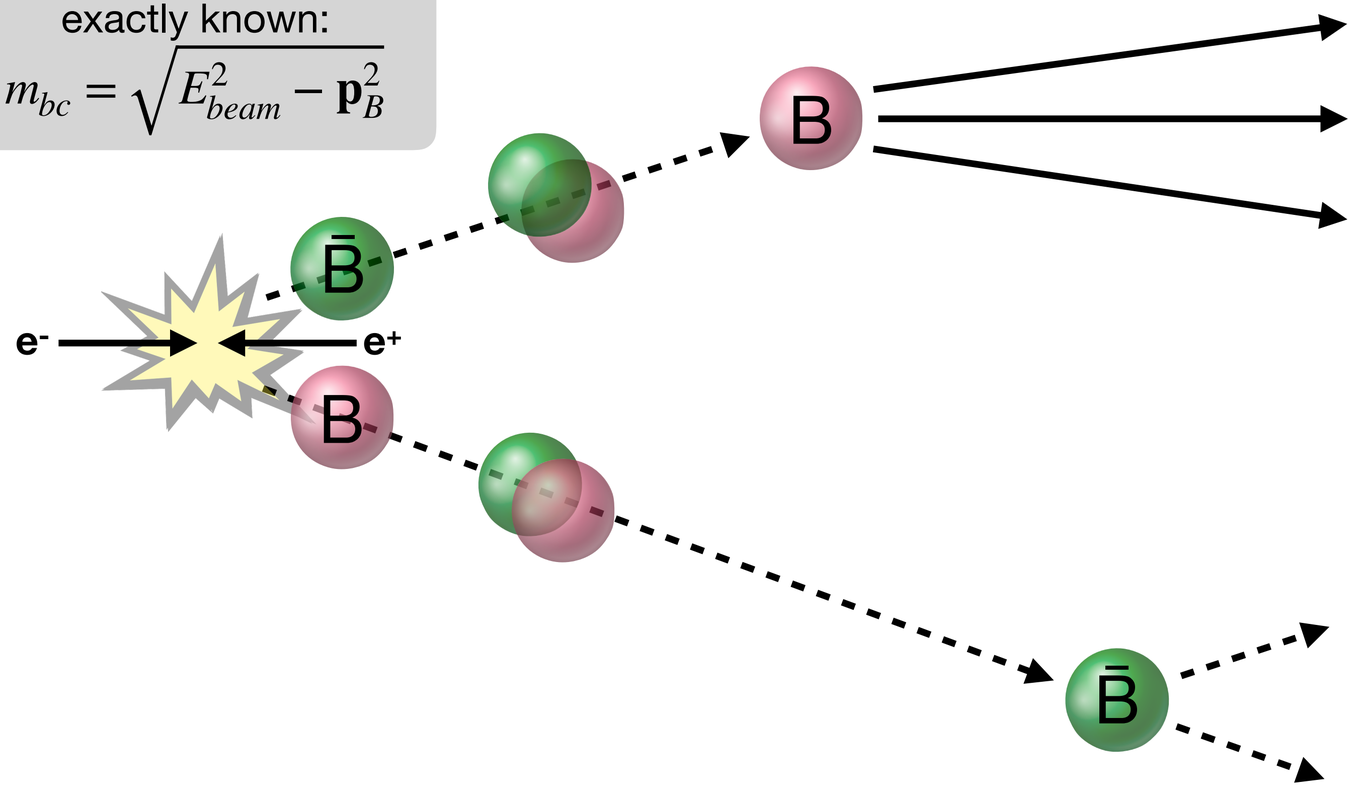
Time-dependent CP violation



Full event interpretation (FEI) and beam-constraint mass m_{bc}

Initial four-momentum exactly known:

$$m_{bc} = \sqrt{E_{beam}^2 - \mathbf{p}_B^2}$$



Fully reconstruct one of the B mesons: **FEI**

Overconstrain second B meson: Neutrino(s) in the final state, …

Cross section in e^+e^- collisions at 10.58 GeV

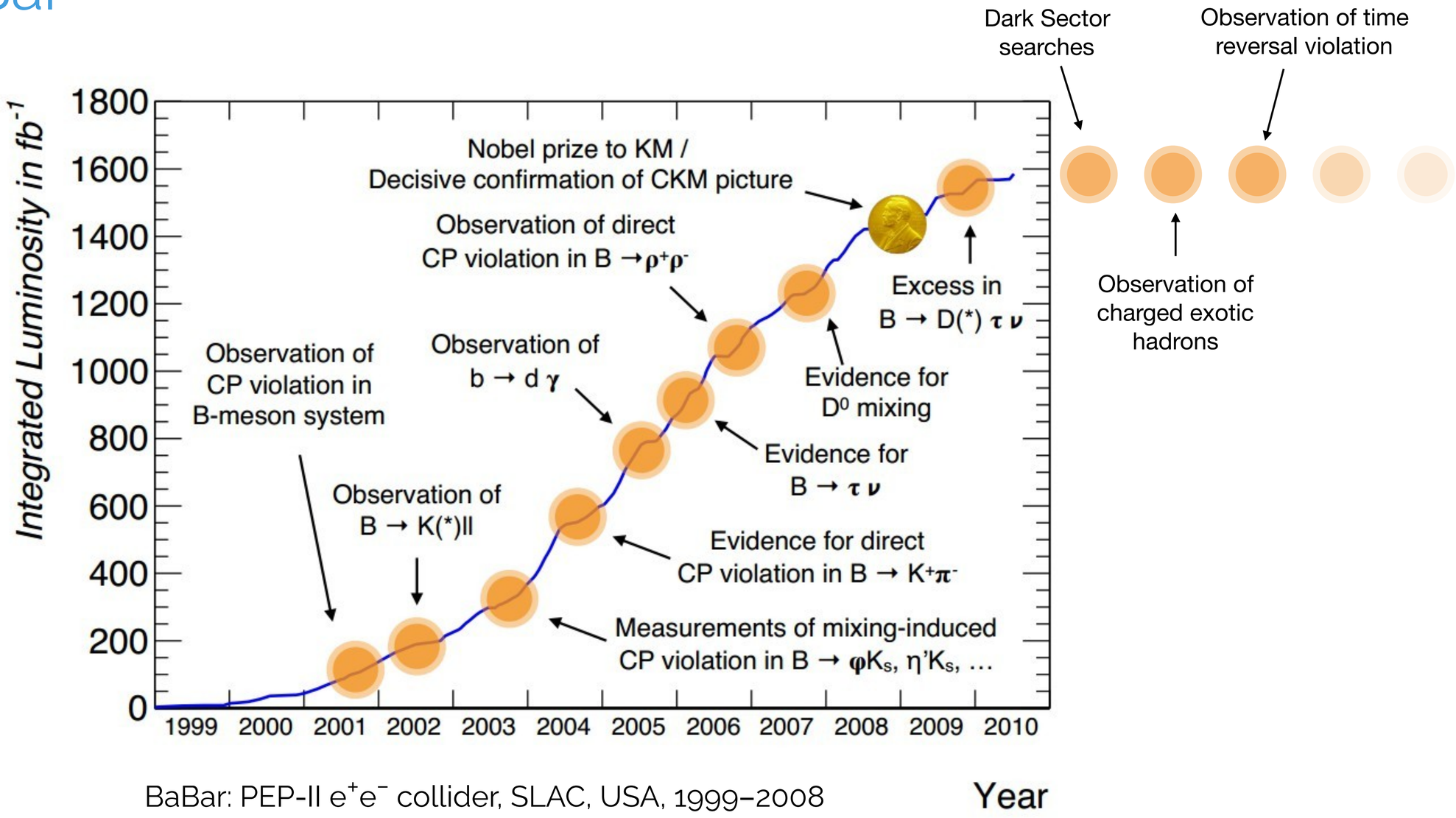
1 nb cross section → 10^6 events per 1 fb^{-1} integrated luminosity

Physics process	Cross section [nb]	Cuts
$\Upsilon(4S)$	1.05 ± 0.10	-
$u\bar{u}(\gamma)$	1.61	-
$d\bar{d}(\gamma)$	0.40	-
$s\bar{s}(\gamma)$	0.38	-
$c\bar{c}(\gamma)$	1.30	-
$e^+e^-(\gamma)$	300 ± 3 (MC stat.)	$10^\circ < \theta^*_{e's} < 170^\circ$, $E^*_{e's} > 0.15$ GeV
$e^+e^-(\gamma)$	74.4	e's (p >0.5GeV) in ECL
$\gamma\gamma(\gamma)$	4.99 ± 0.05 (MC stat.)	$10^\circ < \theta^*_{\gamma's} < 170^\circ$, $E^*_{\gamma's} > 0.15$ GeV
$\gamma\gamma(\gamma)$	3.30	γ's (p >0.5GeV) in ECL
$\mu^+\mu^-(\gamma)$	1.148	-
$\mu^+\mu^-(\gamma)$	0.831	μ's (p >0.5GeV) in CDC
$\mu^+\mu^-\gamma(\gamma)$	0.242	μ's (p >0.5GeV) in CDC, ≥ 1 γ (E_γ >0.5GeV) in ECL
$\tau^+\tau^-(\gamma)$	0.919	-
$\nu\bar{\nu}(\gamma)$	0.25×10^{-3}	-

QED backgrounds are huge

B-factories are also τ-factories

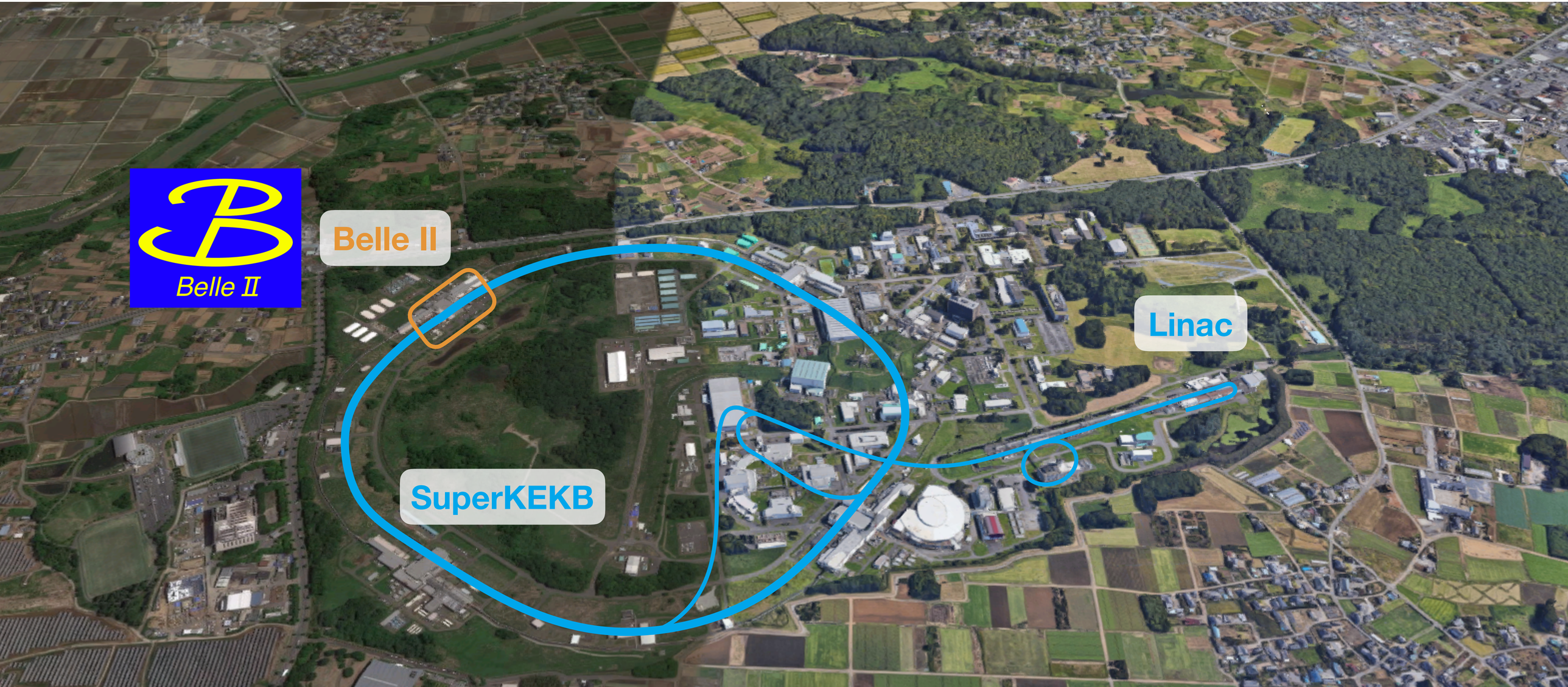
Belle and BaBar



BaBar: PEP-II e^+e^- collider, SLAC, USA, 1999–2008
Belle: KEKB e+e− collider, KEK, Tsukuba, Japan, 1999–2010

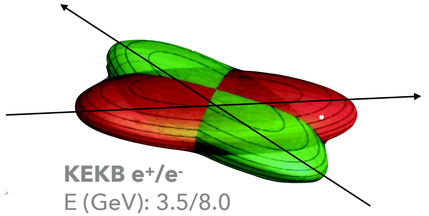
SuperKEKB.

KEK in Tsukuba (Japan)

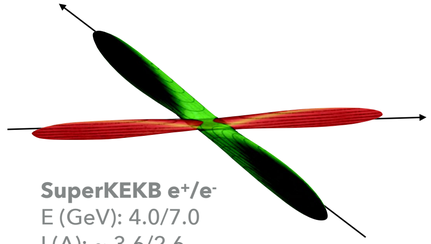


SuperKEKB

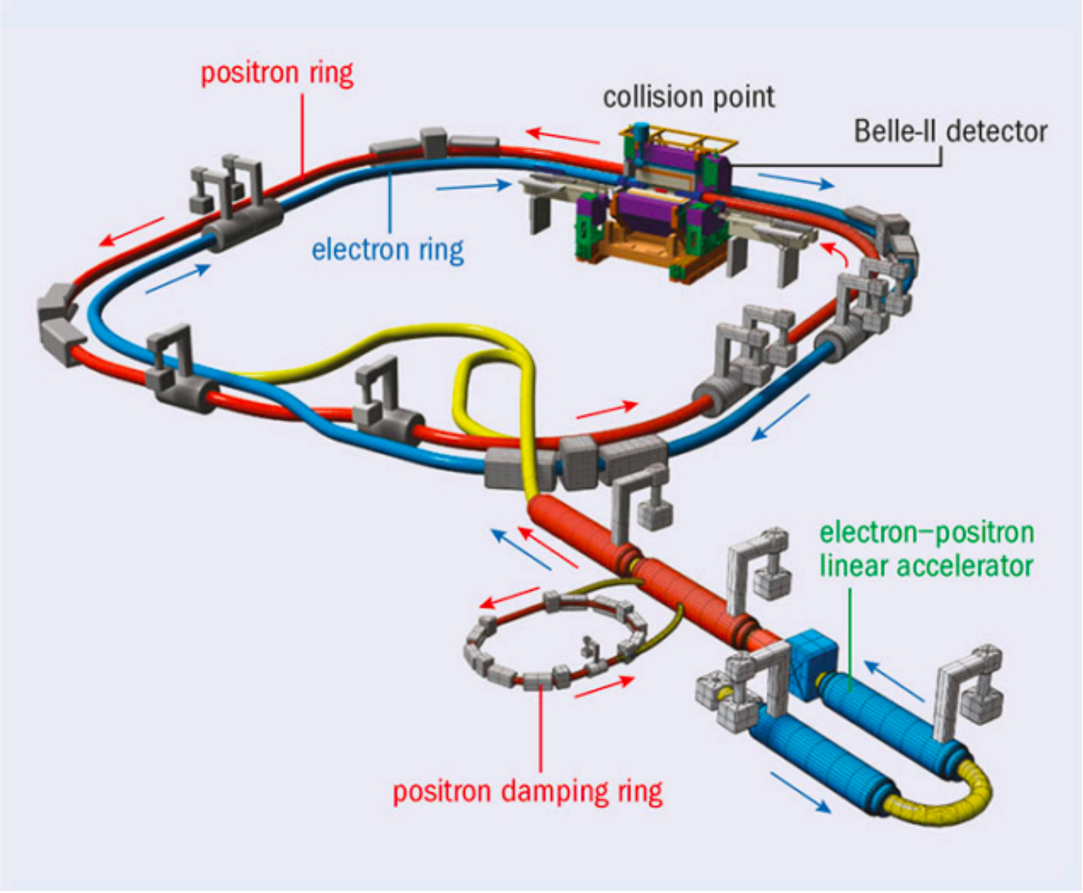
- Asymmetric (4.0 GeV/7.0 GeV) e^+e^- collider, sqrt(s) = 10.58 GeV
- Large crossing angle of 83mrad
- Major upgrade to the accelerator with 40× the KEKB design luminosity ($8x10^{35}$ $cm^{-2}s^{-1}$)
  - 2× higher beam currents
  - 20× smaller beam spot (σ_y=50 nm): "Nano-beam scheme"
- Ultimate goal: $50ab^{-1}$ (50× Belle)



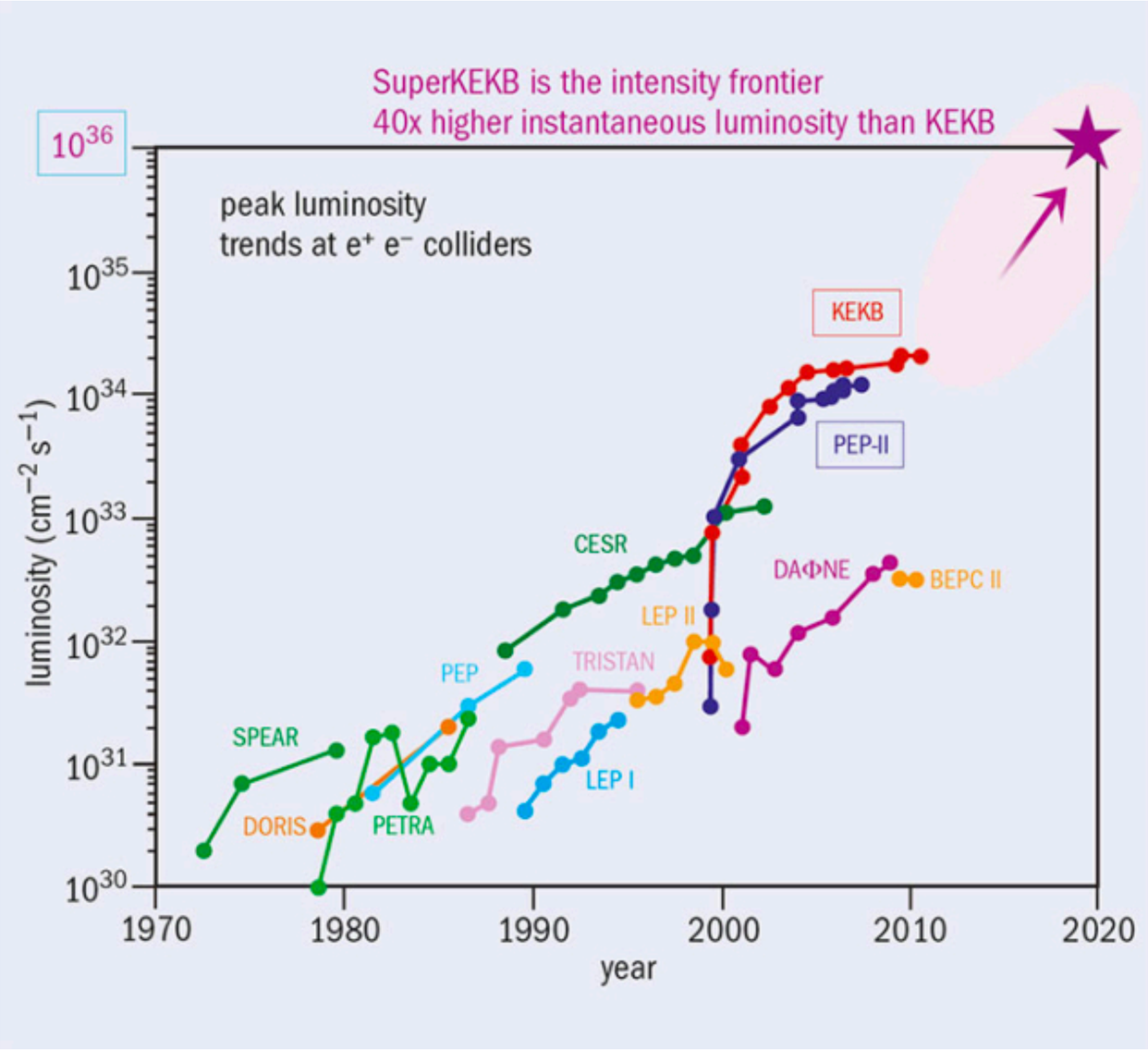
KEKB e^+/e^-
E (GeV): 3.5/8.0
I (A): ~ 1.6/1.2
β^*_y (mm): ~5.9/5.9
Crossing angle (mrad): 22



SuperKEKB e^+/e^-
E (GeV): 4.0/7.0
I (A): ~ 3.6/2.6
β^*_y (mm): ~0.27/0.3
Crossing angle (mrad): 83

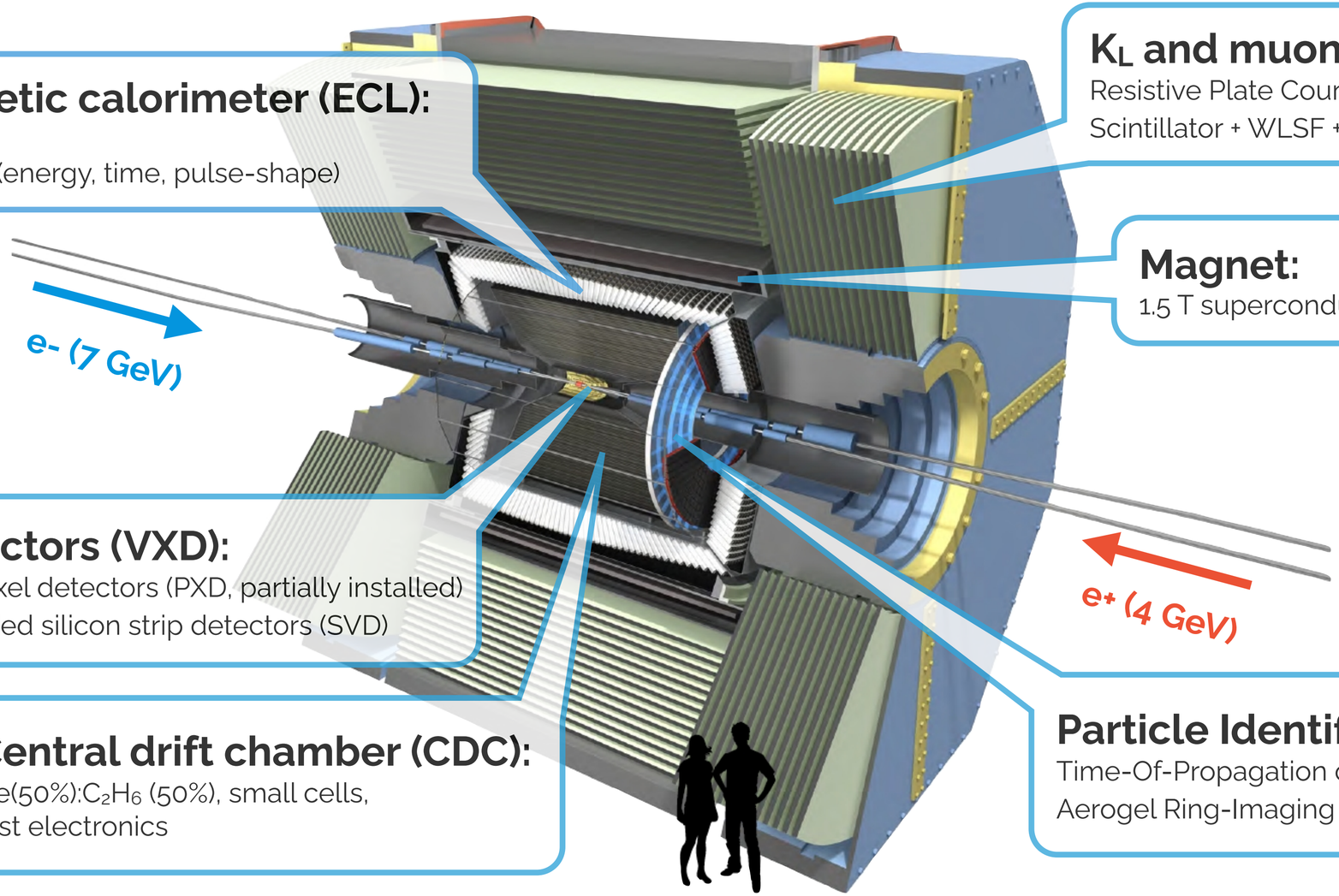


SuperKEKB


SuperKEKB is the intensity frontier
40x higher instantaneous luminosity than KEKB
peak luminosity
trends at e+ e− colliders
luminosity (cm−2 s−1)
year
KEKB
PEP-II
CESR
DAΦNE
BEPC II
LEP II
TRISTAN
PEP
SPEAR
LEP I
DORIS
PETRA

Belle II.

Belle II



Electromagnetic calorimeter (ECL):
CsI(Tl) crystals
waveform sampling (energy, time, pulse-shape)

K_L and muon detector (KLM):
Resistive Plate Counters (RPC) (outer barrel)
Scintillator + WLSF + MPPC (endcaps, inner barrel)

Magnet:
1.5 T superconducting

Trigger:
Hardware: < 30 kHz
Software: < 10 kHz

Vertex detectors (VXD):
2 layer DEPFET pixel detectors (PXD, partially installed)
4 layer double-sided silicon strip detectors (SVD)

Central drift chamber (CDC):
He(50%):C_2H_6 (50%), small cells,
fast electronics

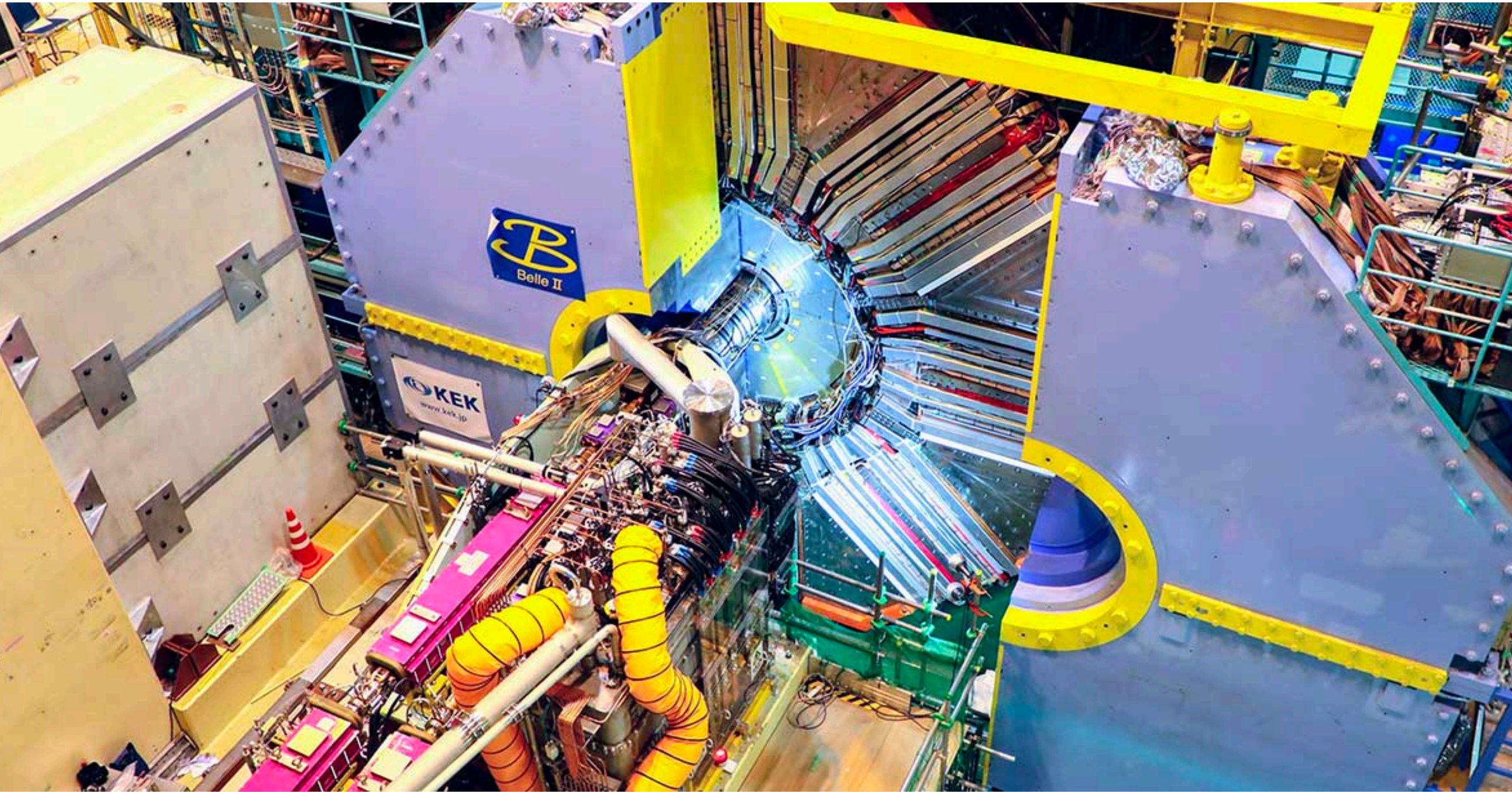
Particle Identification (PID):
Time-Of-Propagation counter (TOP) (barrel)
Aerogel Ring-Imaging Cherenkov Counter (ARICH) (FWD)

DEPFET: depleted p-channel field-effect transistor
WLSF: wavelength-shifting fiber
MPPC: multi-pixel photon counter

Belle II: Challenges

- **Reduced boost** $\beta\gamma$=0.42@KEKB → $\beta\gamma$=0.28@SuperKEKB requires better vertex resolution for the same B mixing performance
- Much **higher backgrounds** require faster electronics and radiation hardness
- Much **higher event rates** require new DAQ and multi-level trigger system
- Much **higher data rates** require new software and computing design

→ **Belle II is a new experiment** with many Belle and BaBar members


Belle II
KEK

First results.

2018

Beam commissioning

No vertex detectors

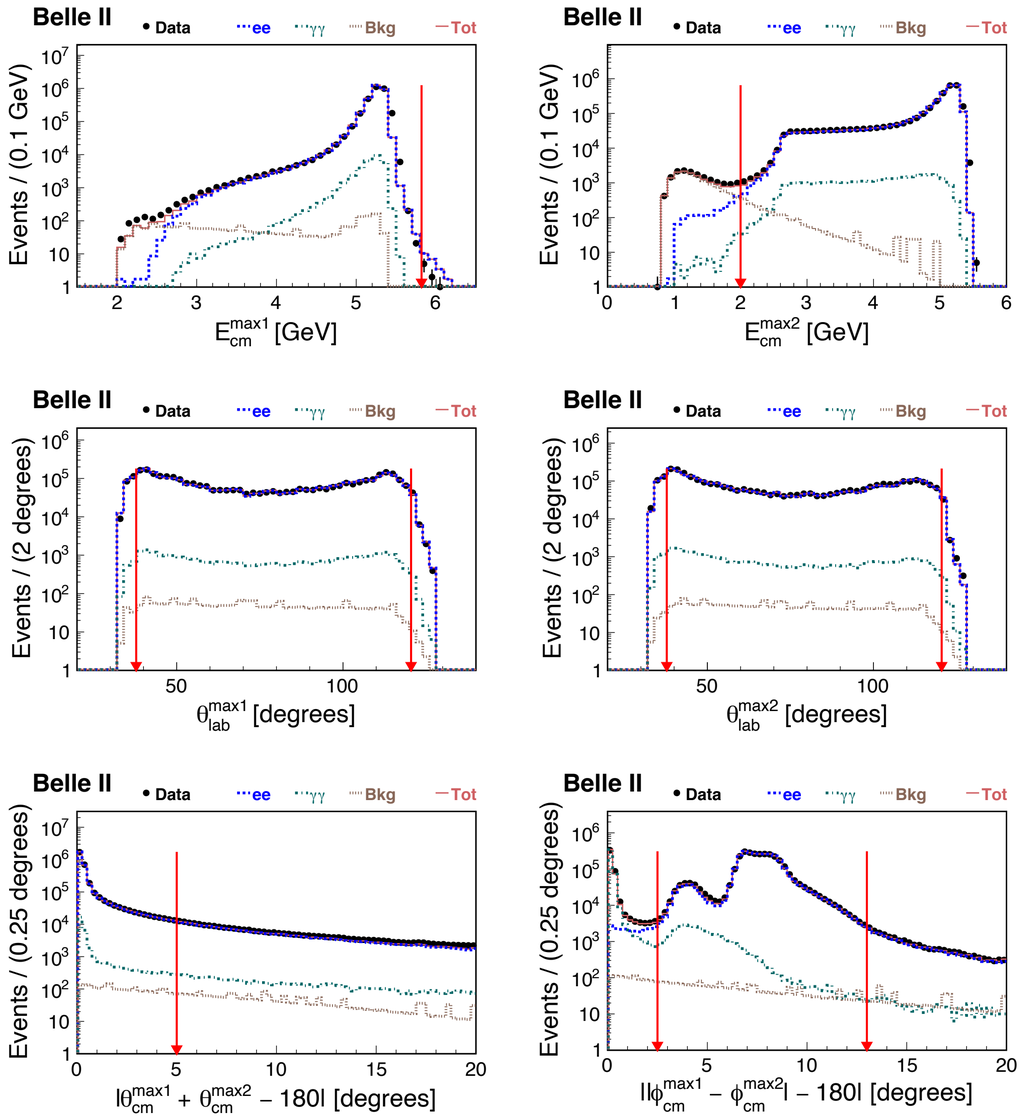
No muon system

Very loose triggers

$$L = (496.3 \pm 0.3 \pm 3.0)\ pb^{-1}$$

(0.001% of final dataset)

Luminosity measurement



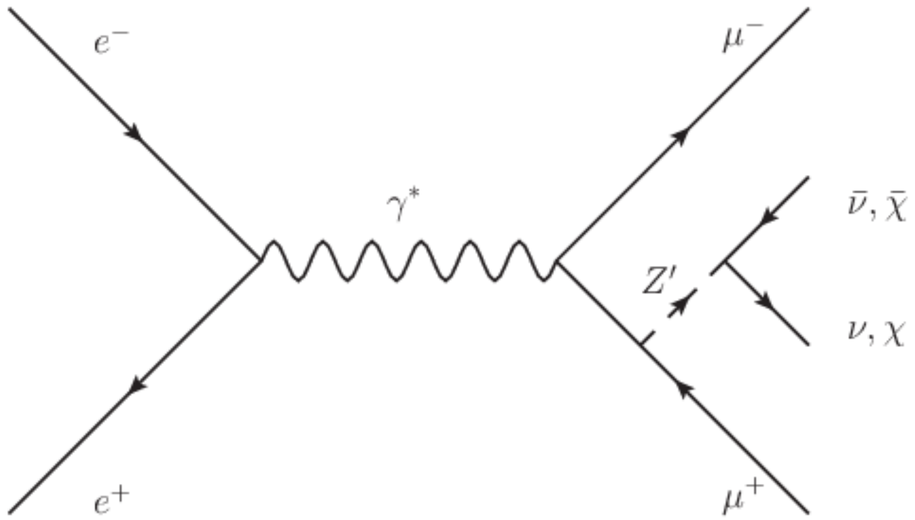
- Calorimeter-only selection of large angle Bhabha events

Source	ee (%)	$\gamma\gamma$ (%)	ee + $\gamma\gamma$ (%)
Cross section	±0.1	±0.1	±0.1
CM energy	±0.2	±0.2	±0.2
$\theta_{\rm cm}$ range	±0.0	±0.4	±0.1
IP position	±0.2	±0.1	±0.1
ECL location	±0.2	±0.2	±0.2
MC statistics	±0.1	±0.1	±0.1
Beam backgrounds	±0.1	±0.1	±0.1
Cluster reconstruction	±0.2	±0.2	±0.2
$E_{\rm cm}$ distributions	±0.1	±0.1	±0.1
$\theta_{\rm lab}$ distributions	±0.1	±0.2	±0.1
$\theta_{\rm cm}$ distributions	±0.3	±0.3	±0.3
$\phi_{\rm cm}$ distributions	±0.1	±0.3	–
Material effects	-0.1	$+0.7$	$+0.1$
Overlapping clusters	±0.1	±0.1	±0.1
Colliding backgrounds	±0.1	±0.3	±0.1
Quadrature sum	±0.6	$^{+1.1}_{-0.8}$	±0.6

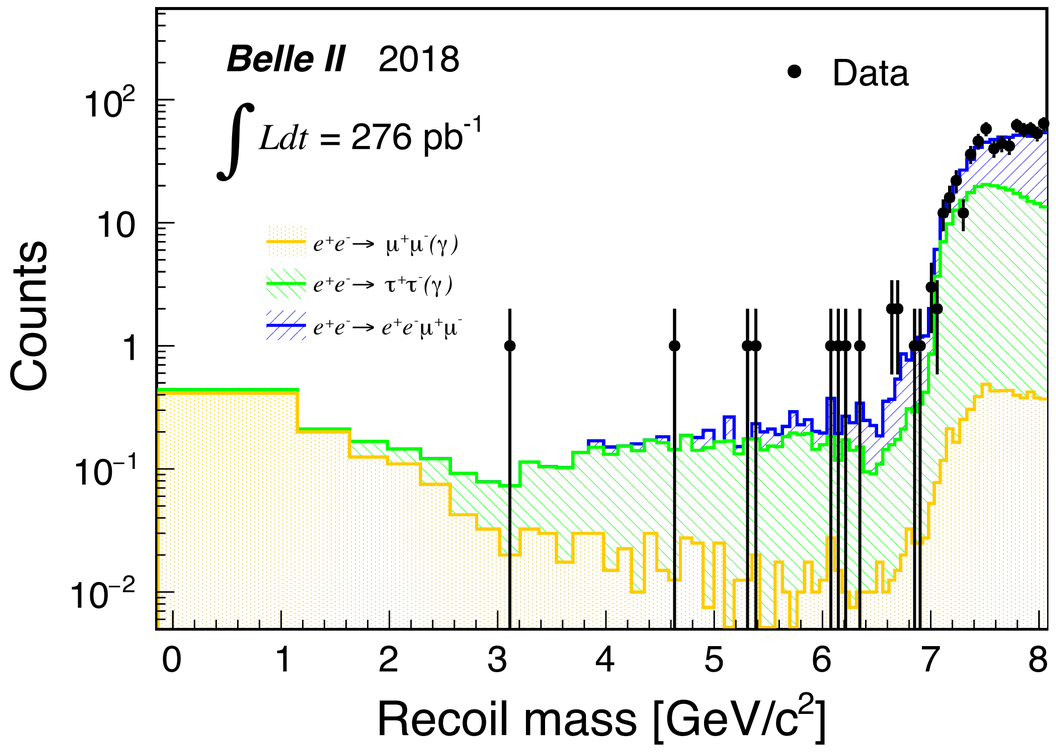
to appear in Chinese Physics C (arXiv:1910.05365)

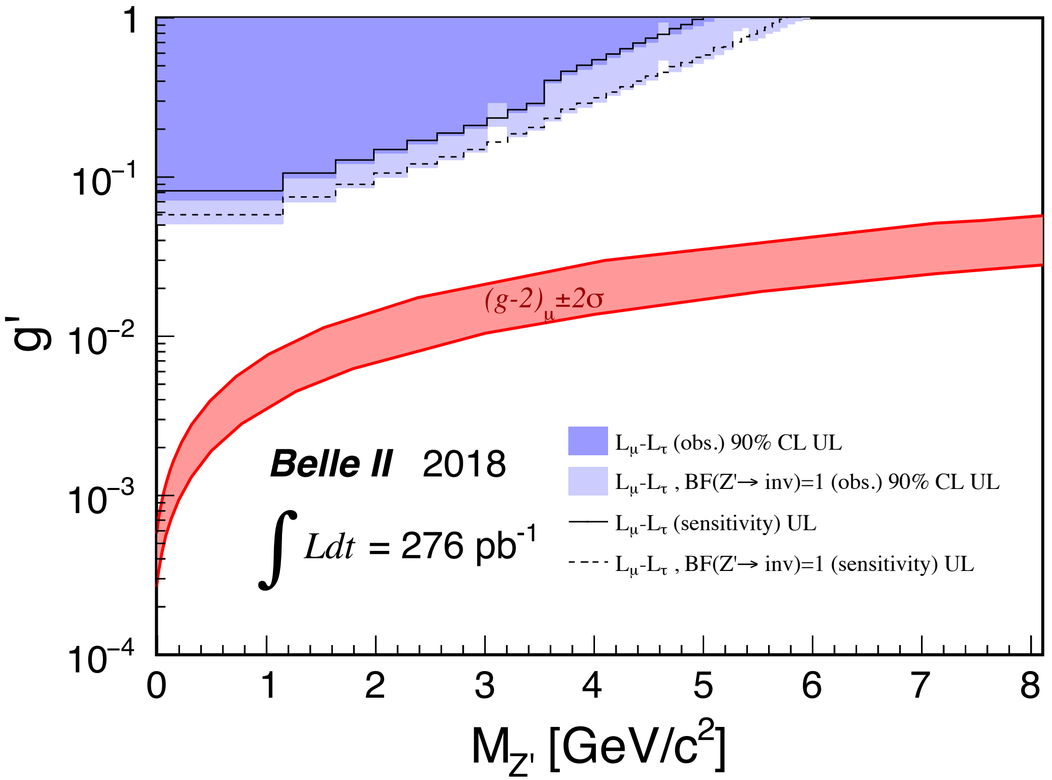
Search for an invisibly decaying Z' boson

- Search for vector boson Z' that couples to 2nd and 3rd generation only
  - No coupling to electrons avoids strong existing Dark Photon bounds
- Visible decays lead to four muon final state ("Muonic force") search (BaBar)
- Invisible decays to Dark Matter or neutrinos
- Possible explanation for g-2 anomaly
- First physics paper targeting publication



Search for an invisibly decaying Z' boson





submitted to PRL, arXiv:1912.11276v1

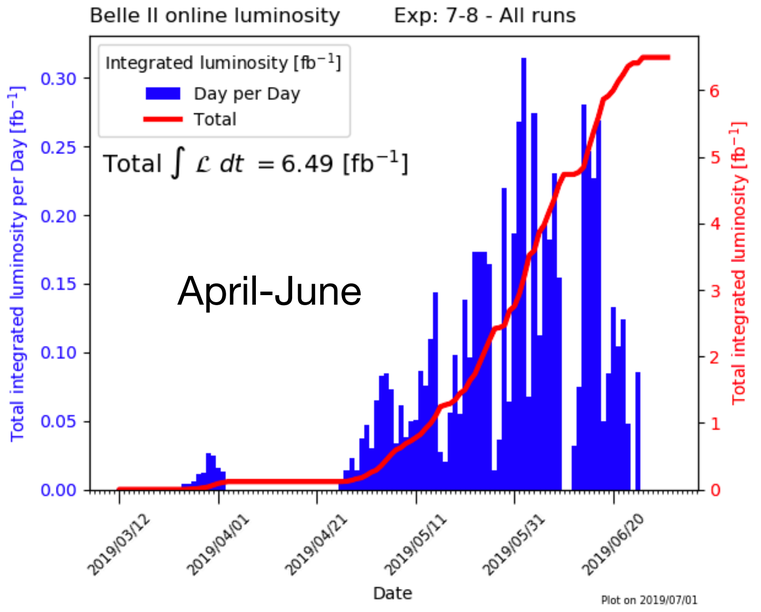
2019

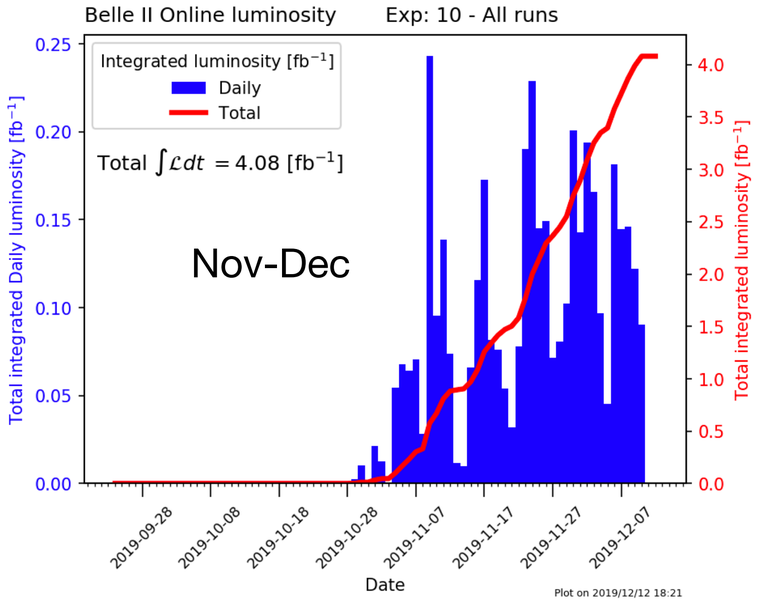
Physics runs

Vertex detector

Muon system

Loose trigger



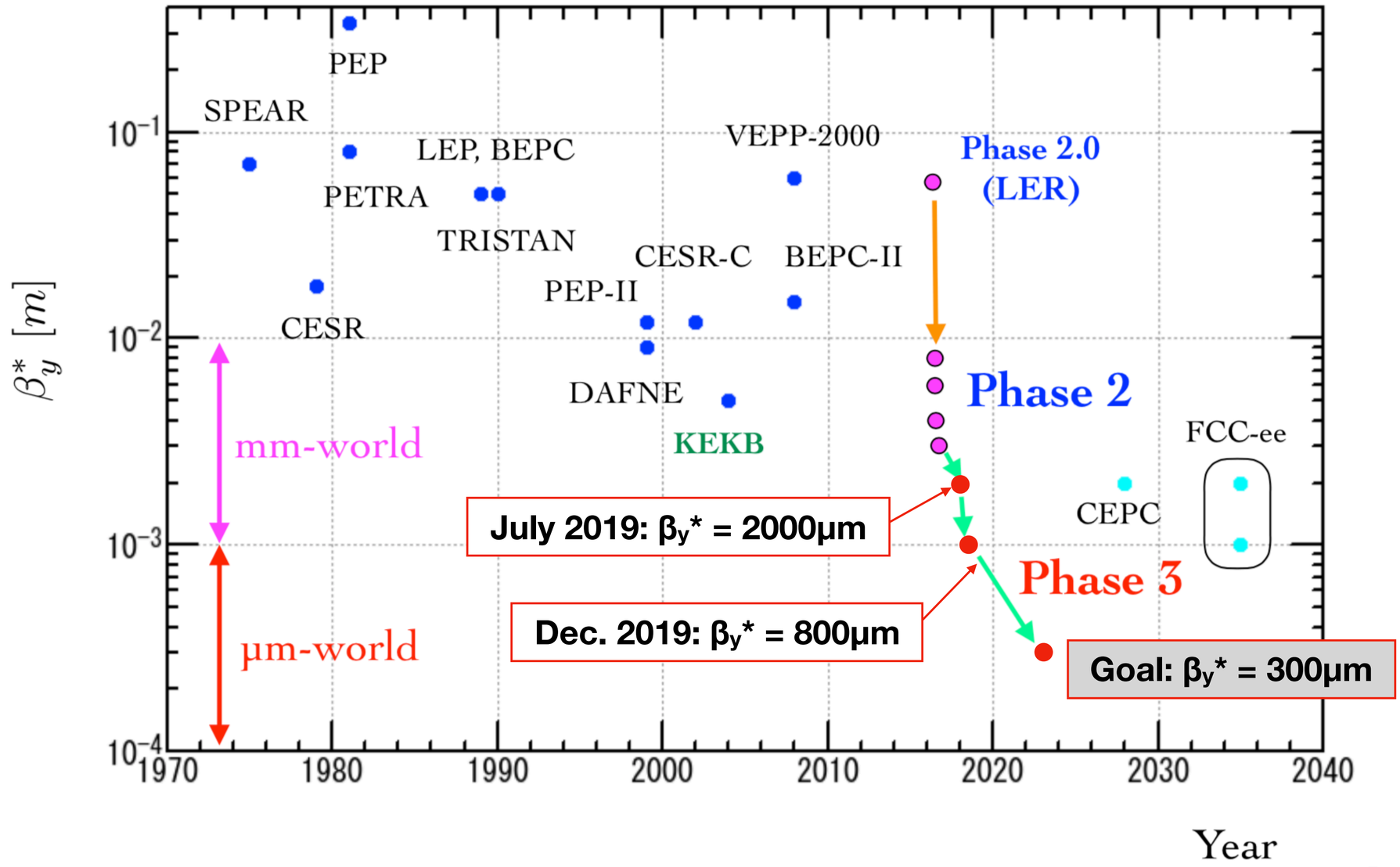


L = 10.57 fb^{-1}

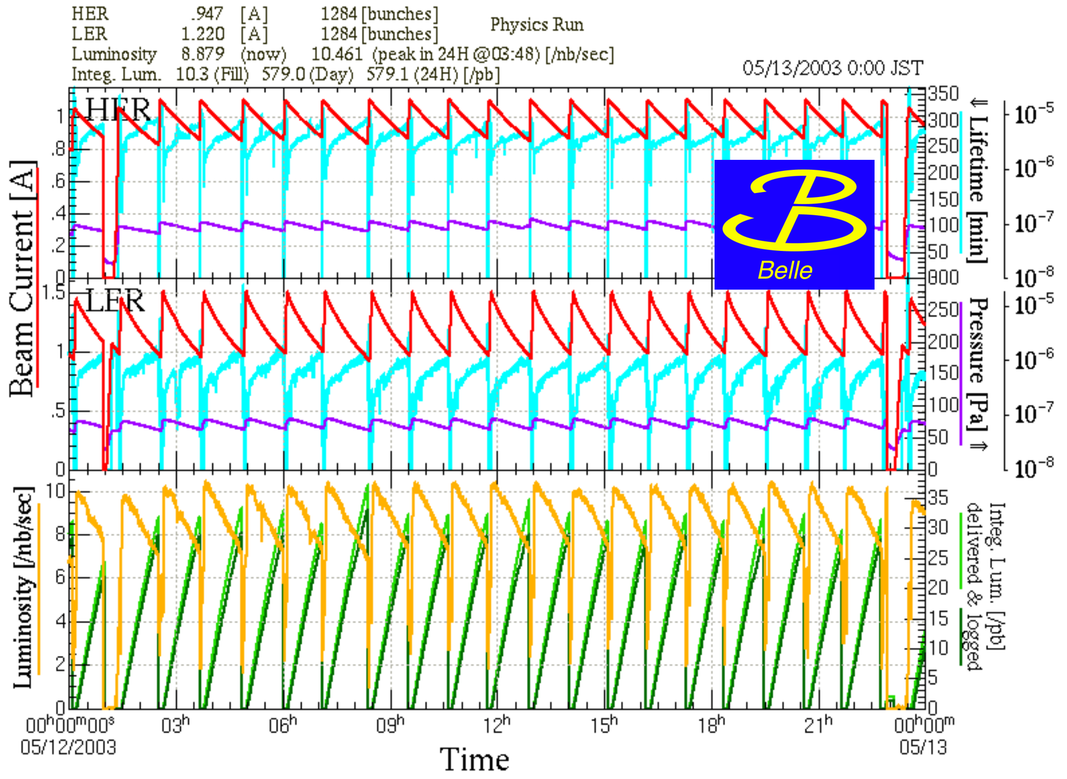
(0.021% of final dataset)

(20× more than 2018)

Towards nano-beams

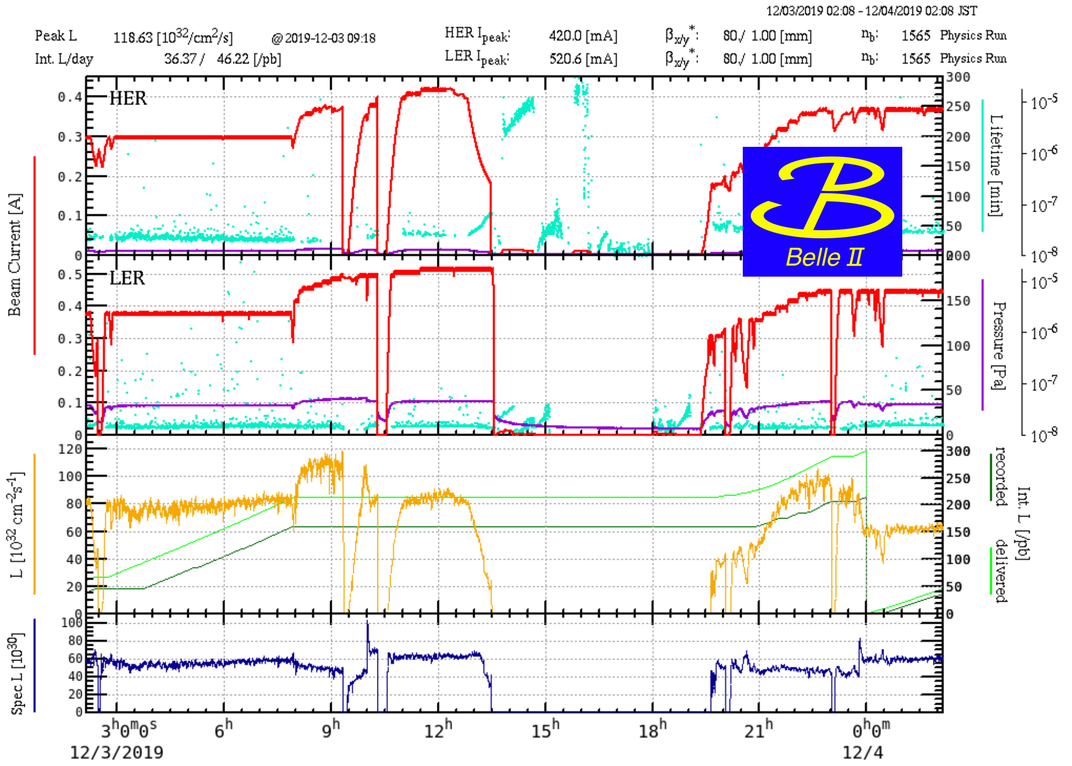


Nano-beams at SuperKEKB: L > 1×10^{34} cm^{-2}s^{-1}



13.05.2003: β_y^* = 5.0 mm

I_{LER} = 1.2A, I_{HER}=0.95A



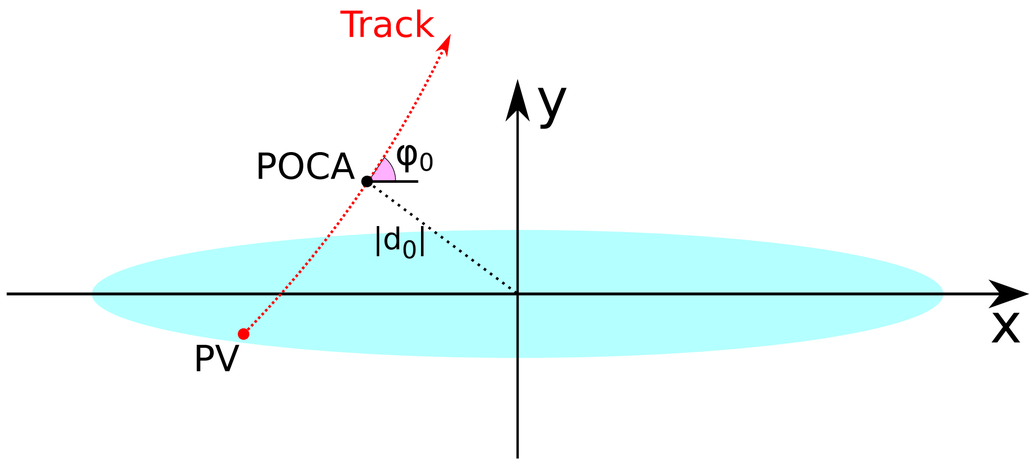
03.12.2019: β_y^* = 0.8 mm

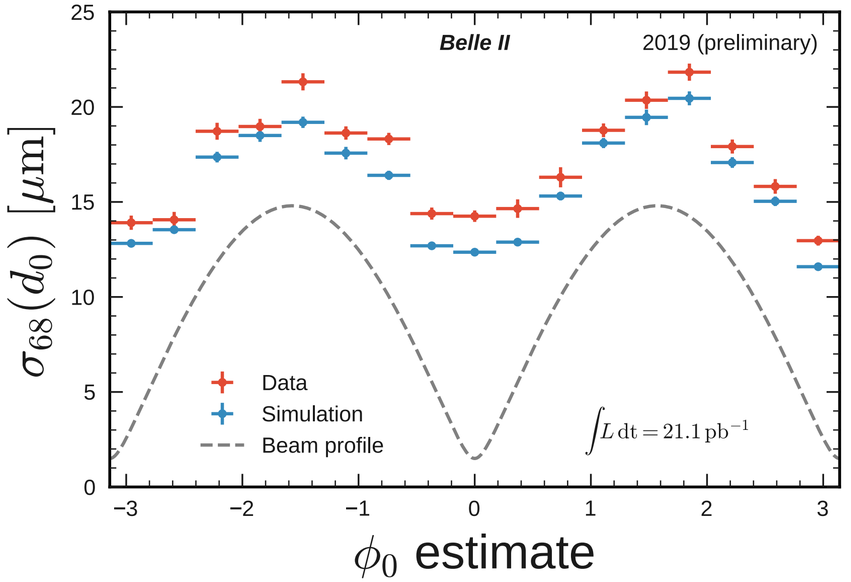
I_{LER} = 0.52A, I_{HER}=0.42A

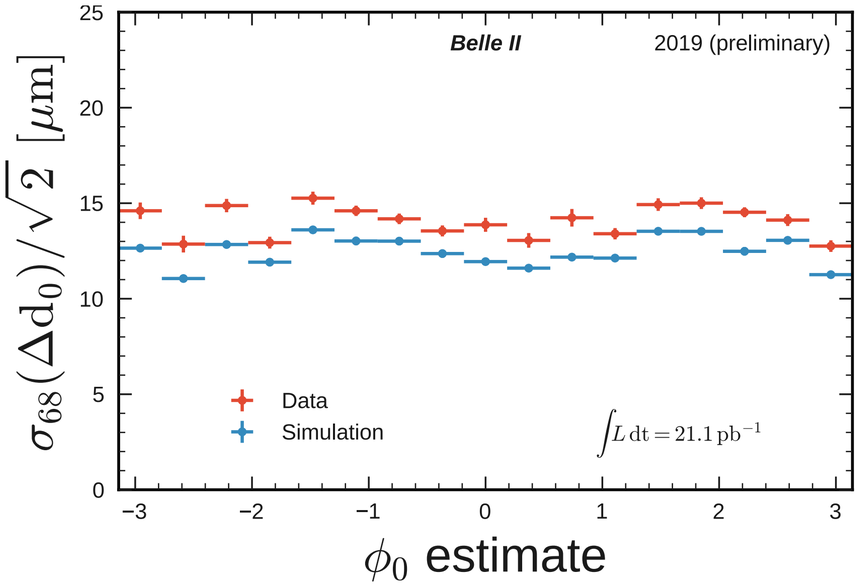
Vertex resolution

- Vertex fit of 2-track events (~Bhabha) selecting "good" tracks with PXD, SVD and CDC hits

- **14.1±0.1 (stat) µm** resolution (×2 better than Belle)

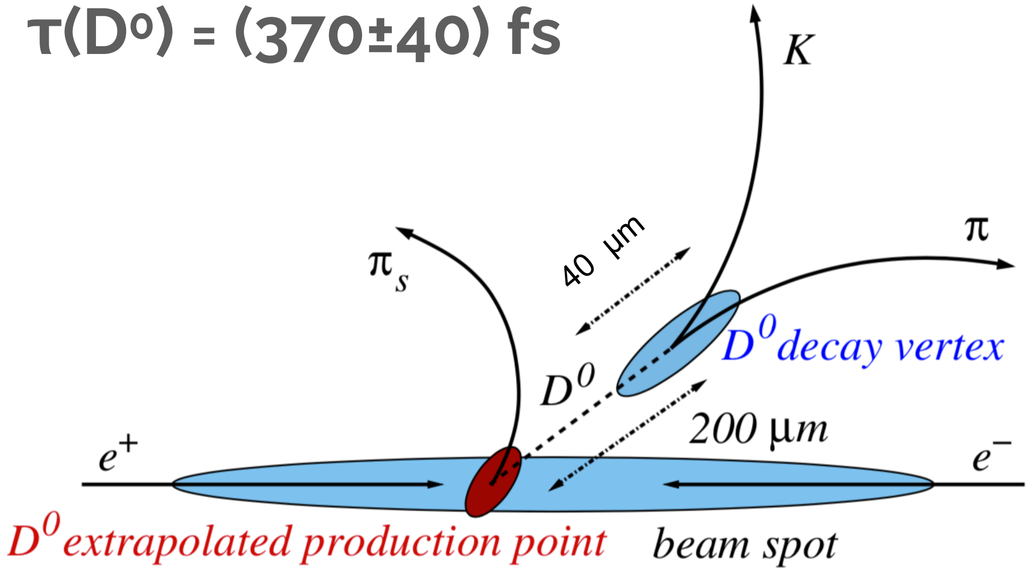


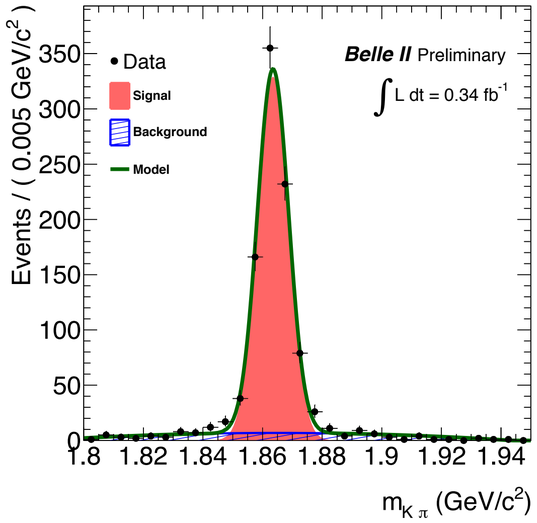


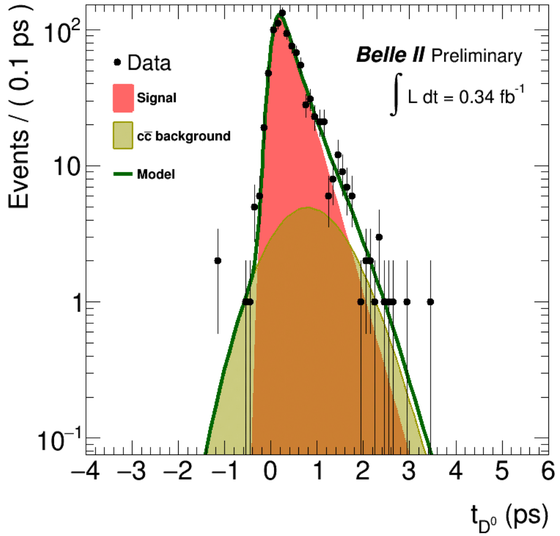


D⁰ lifetime

- Powerful test of Belle II vertex fitting performance
- TreeFitter algorithm for full decay chain fitting (arXiv:1901.11198)
- D*(shortlived) constrained to beam spot region
- **τ(D⁰) = (370±40) fs**

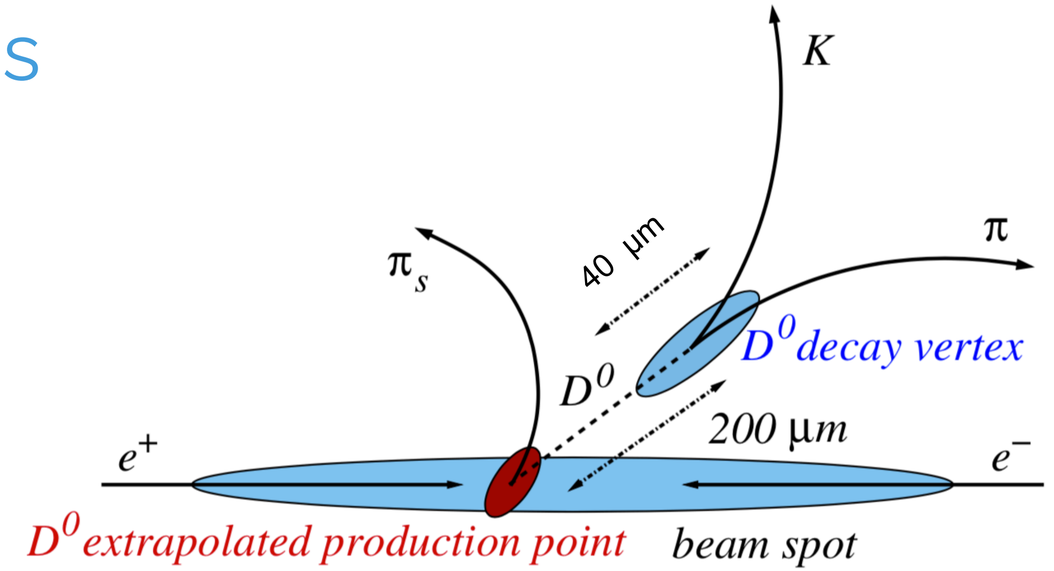


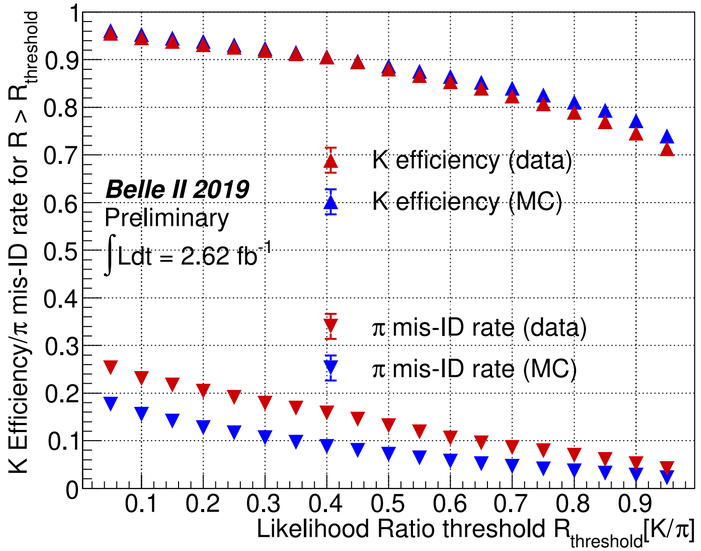




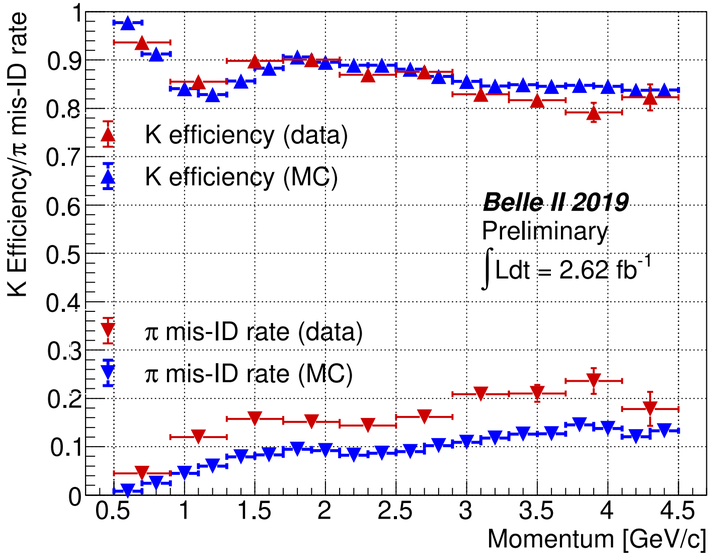
Hadron Identification: Kaons and pions

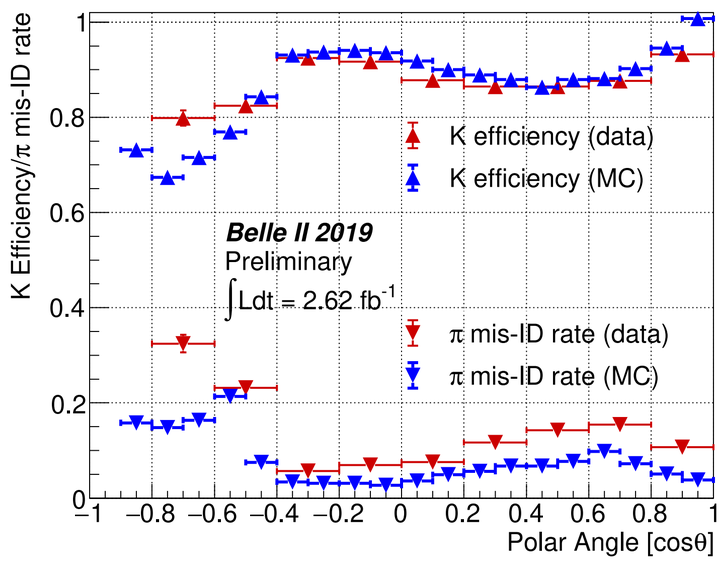
- CDC, TOP (barrel) and ARICH (endcap)
- Select $D^* \rightarrow D^0(K\pi)\,\pi_s$
- Tag ($K\pi$) charge via slow pion charge





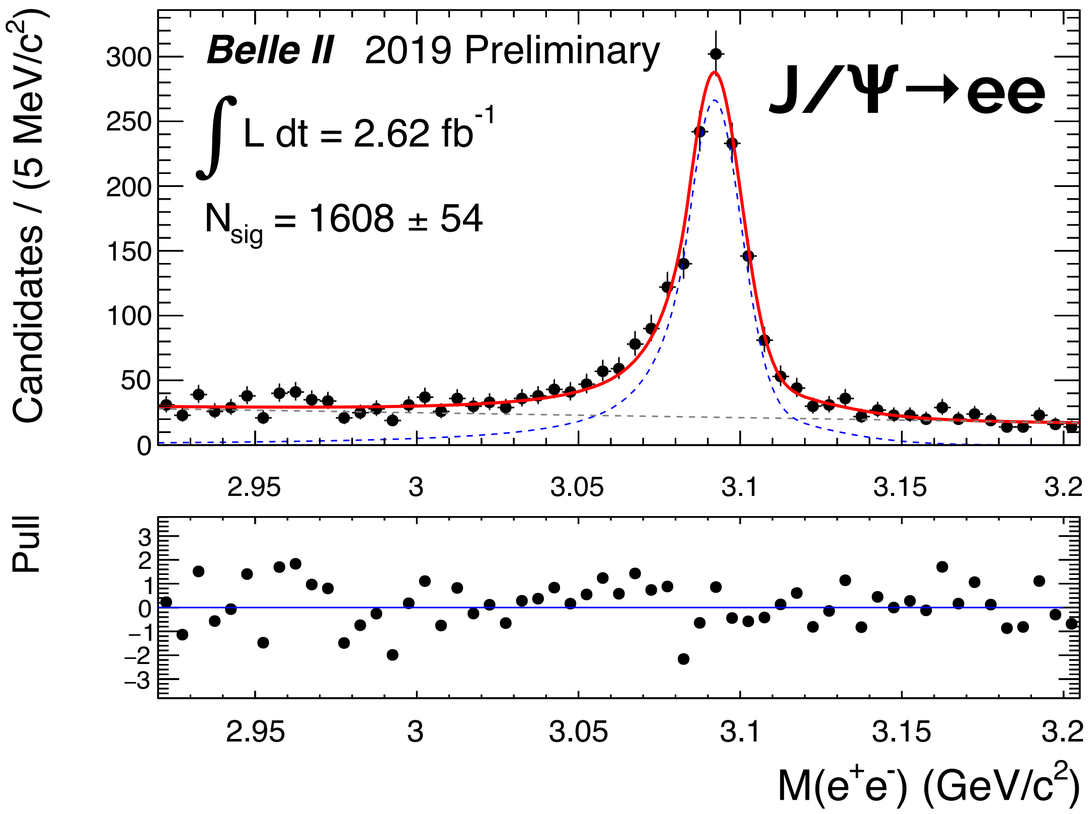
R > 0.5

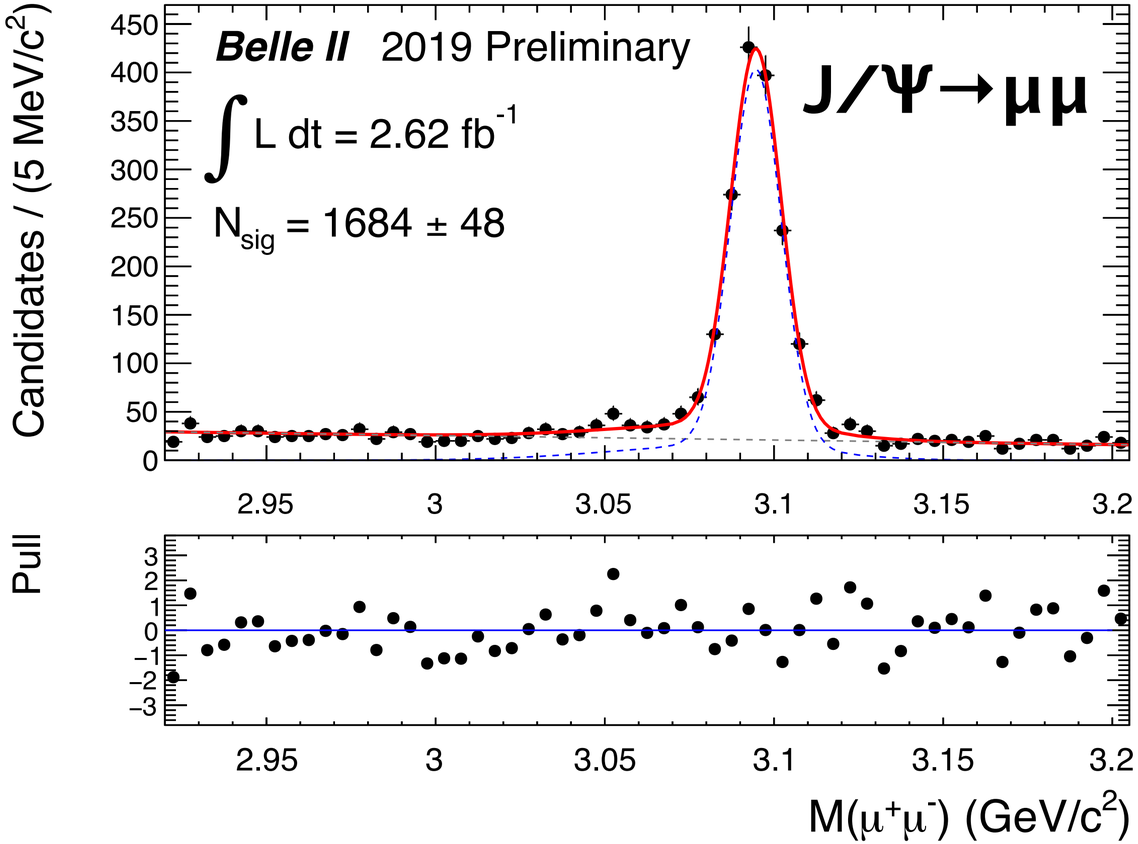




Lepton Identification: Muons and electrons

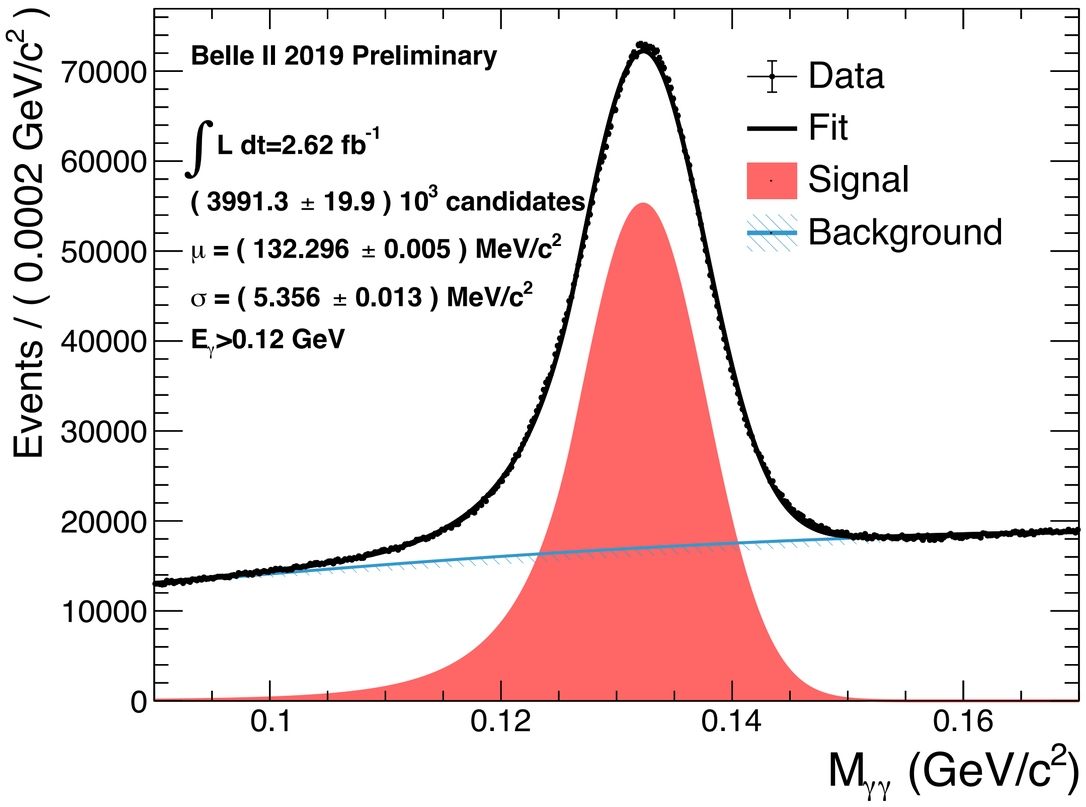
- Mostly ECL (calorimeter) and KLM (muon system



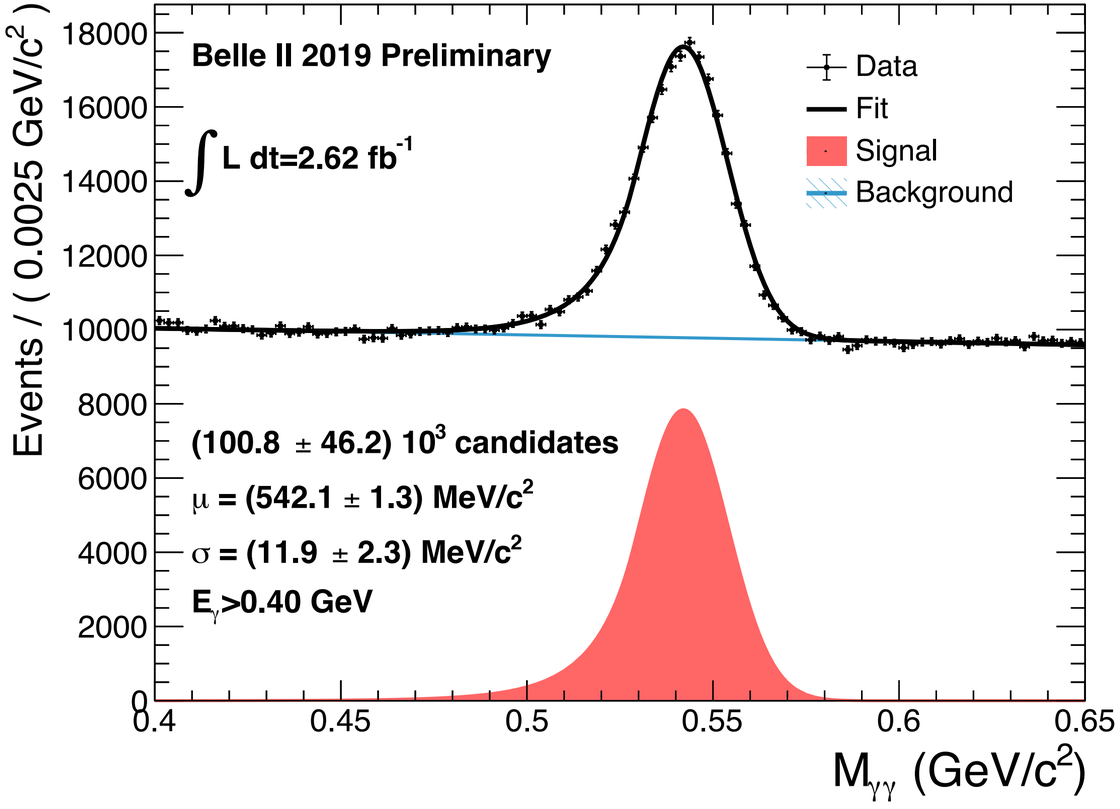


Neutral reconstruction

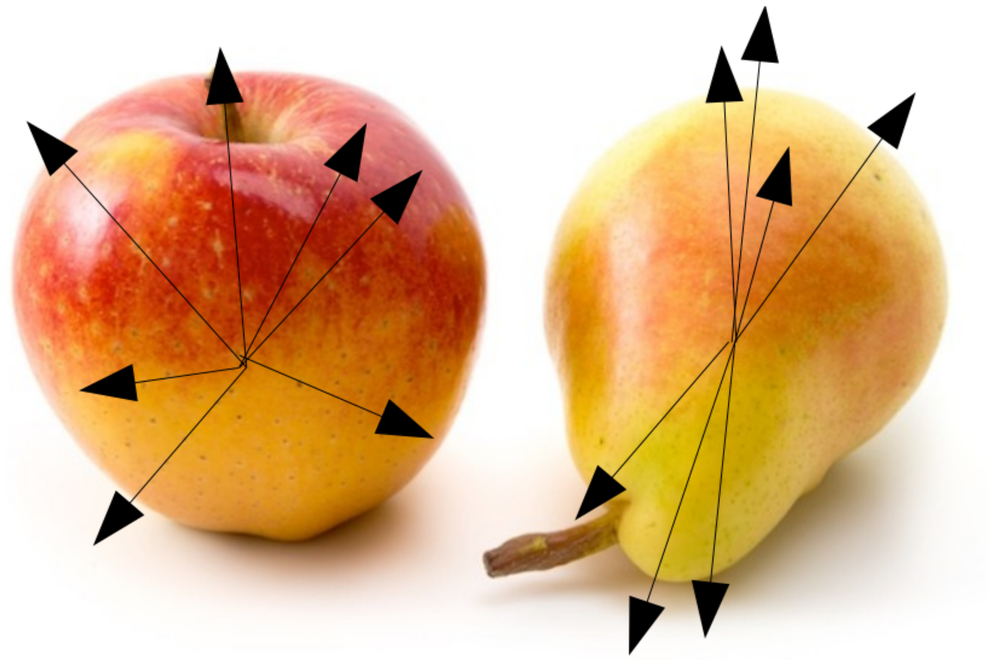
$\pi^0 \to \gamma\gamma$



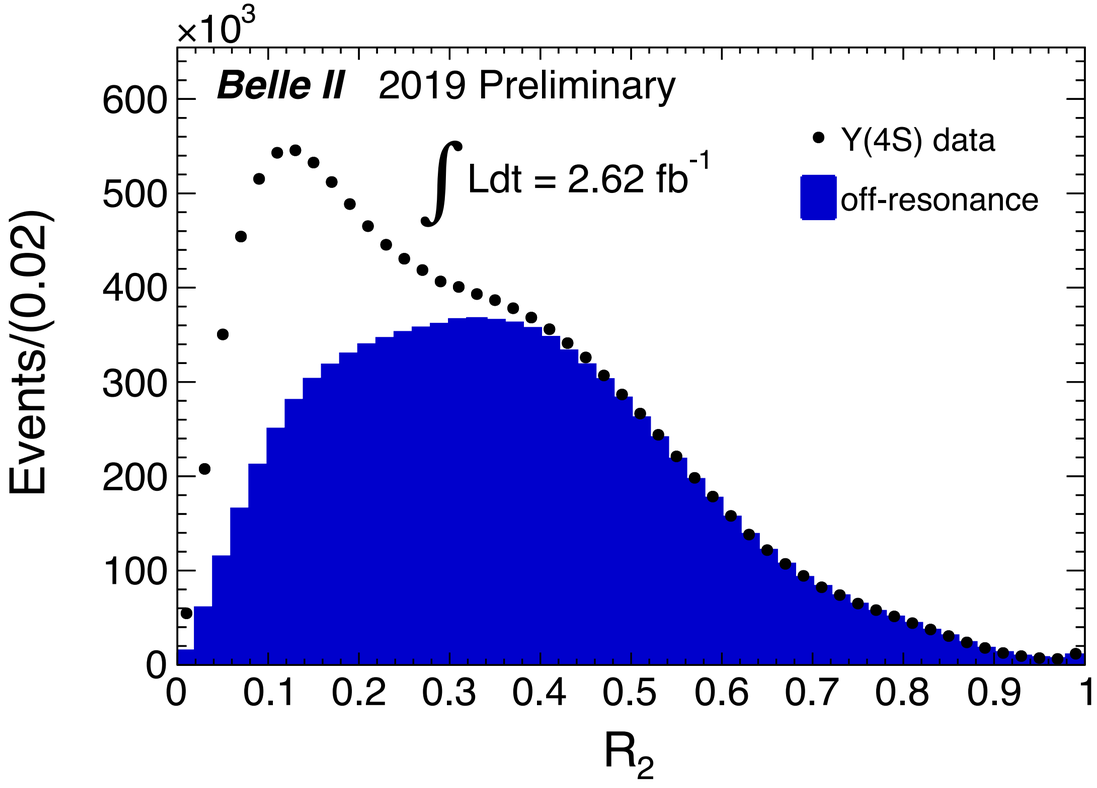
$\eta \to \gamma\gamma$



B-counting

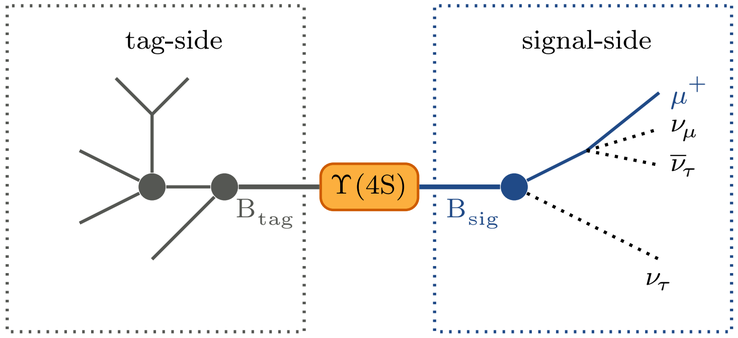


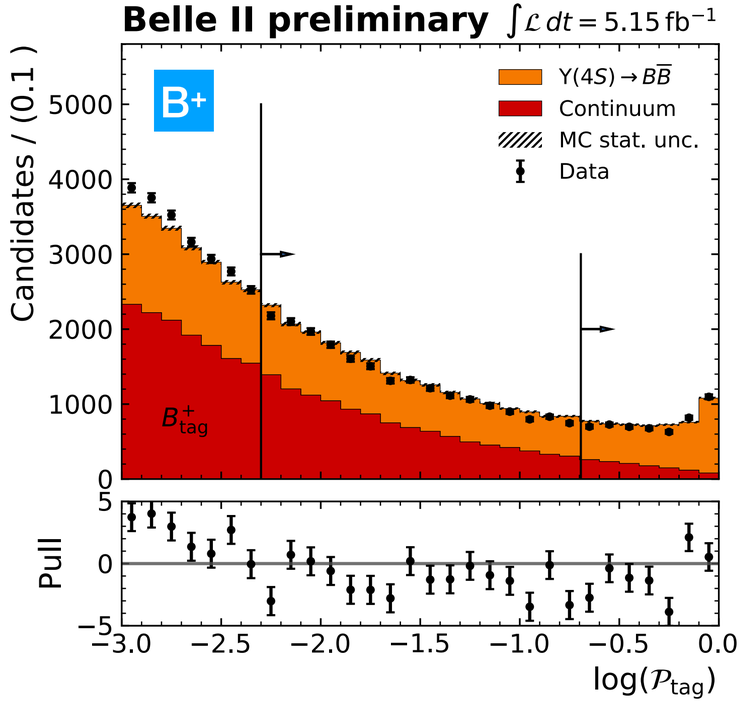
BB̄: R2 → 0 **light quarks: R2 → 1**

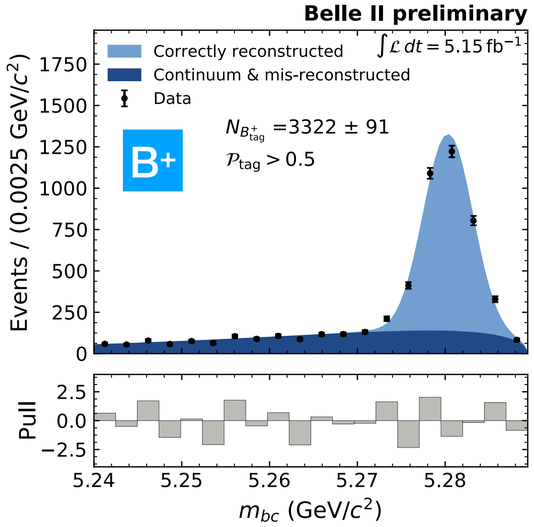


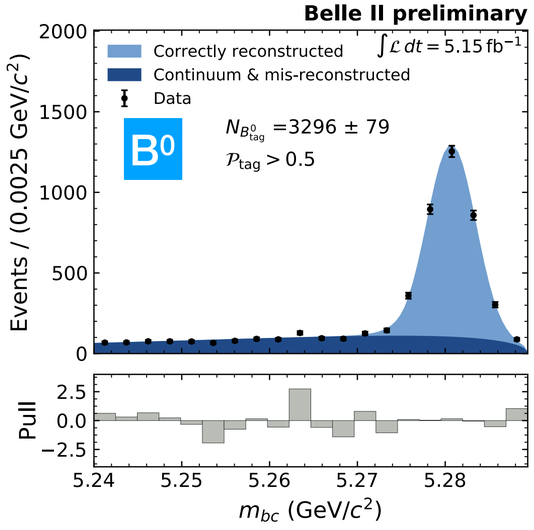
BELLE2-NOTE-PL-2019-017

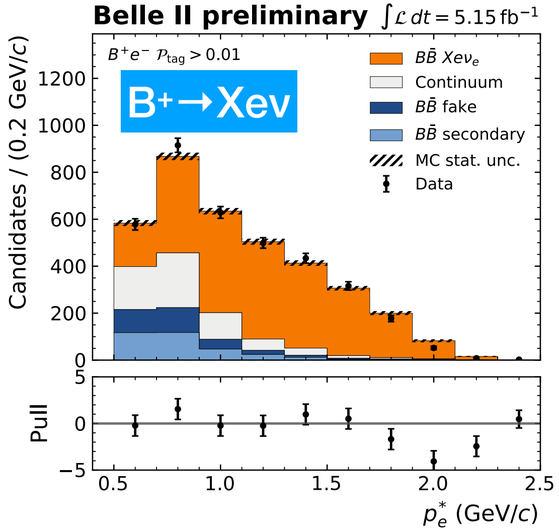
Full event interpretation (FEI)

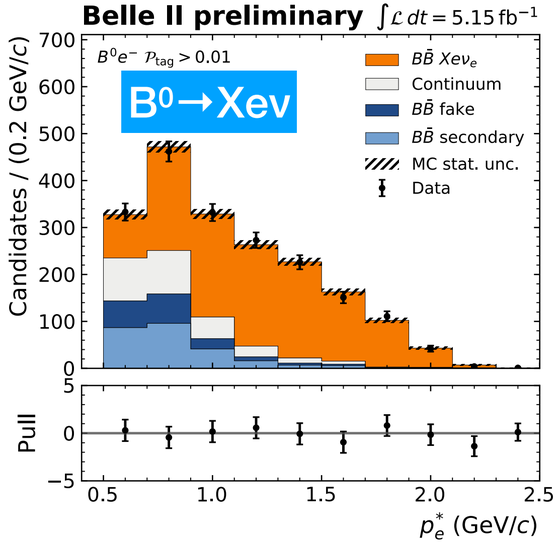












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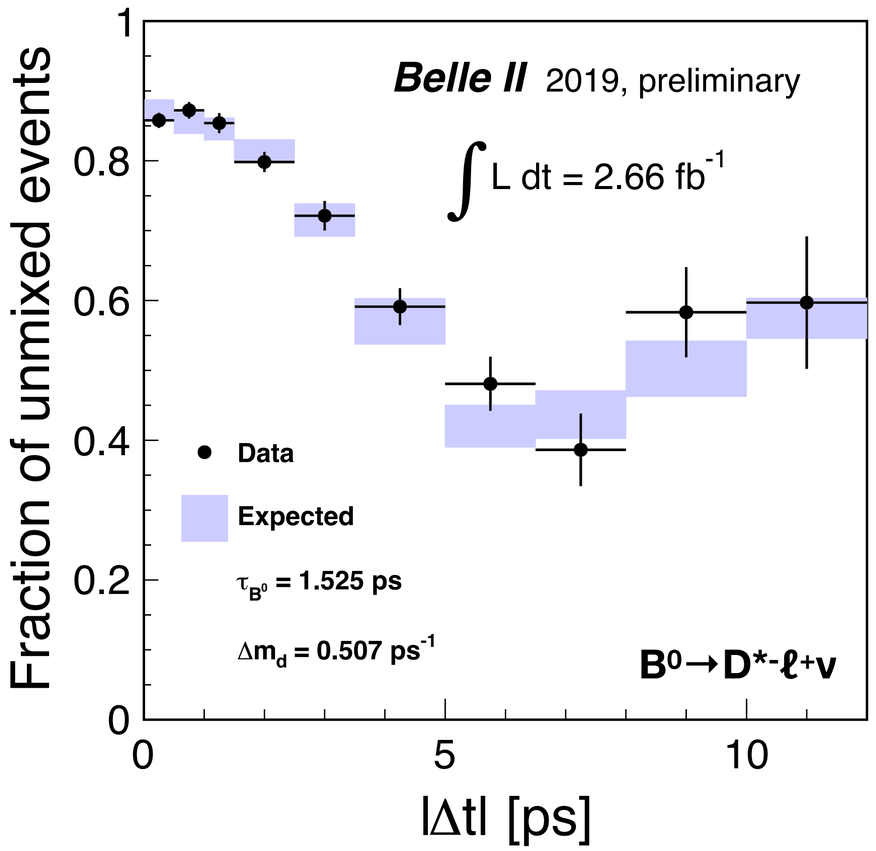
Physics with O(10fb^{-1})

- **B→ Xℓν, B→D*ℓν**, semi-leptonic FEI
- Rediscovery of B→η'K_S, ΦK_S, J/ΨK_L
- Rediscovery of **time-dependent CP asymmetry** in B→ J/ΨK_S
- Rediscovery of **Φ_3** "golden modes": B→D_s^*D and B→ $D_s^*\pi^0$
- Rediscovery of **B→ hh'** and charm-less three body decays
- Rediscovery of **X(3872)**
- Branching fractions in **τ decays** and measurement of the τ mass
- **Z'→Invisible** with more data (and smaller systematics)



Outlook.

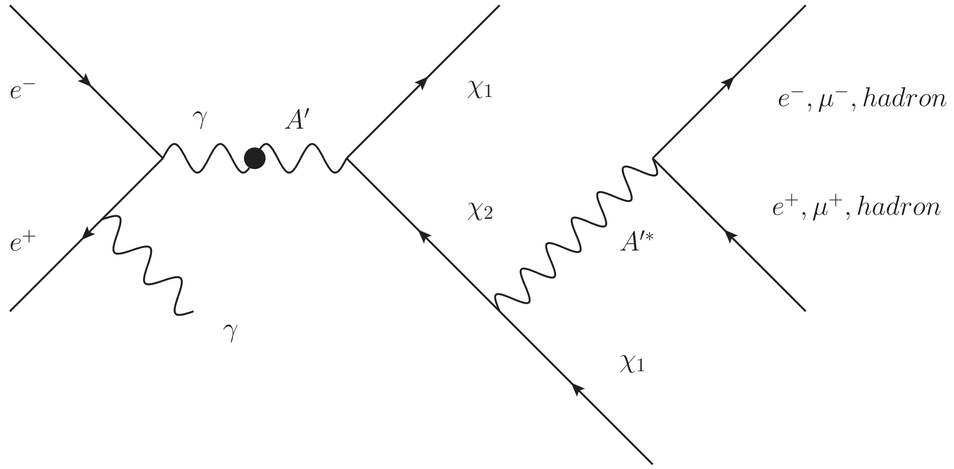
Physics with O(200fb^{-1})

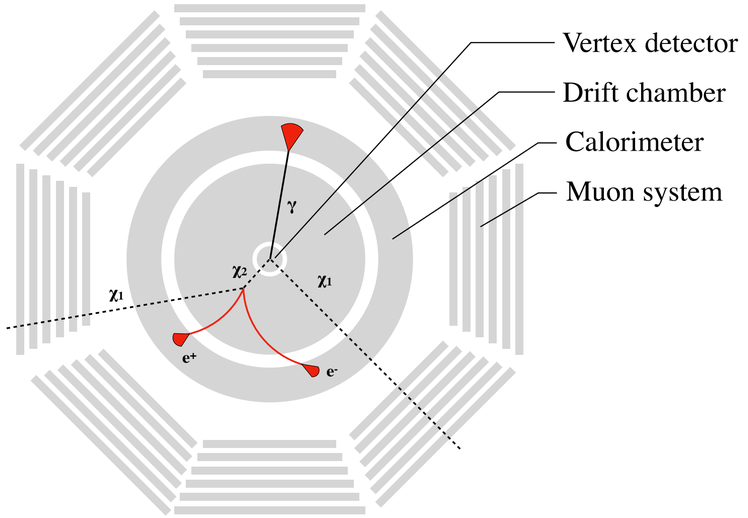
- **Exclusive V_{ub}** via $B \to \pi \ell \nu$, **V_{cb}** via $B \to D^* \ell \nu$
- Rediscovery **$b \to s \ell \ell$** and inclusive **$b \to s \gamma$**
- **Time-dependent CP Asymmetry** in $B \to J/\Psi K$
- Rediscovery **$B \to \pi^0 \pi^0$**
- Charged **Z**-States, **Υ(nS)** via ISR
- **$\tau \to h \omega \nu$** and search for BSM, e.g **$\tau \to \ell \alpha$**
- Search for **Long-lived particles (LLPs)**
- Search for **invisible Dark Photons and invisible ALPs**

Search for inelastic Dark Matter (iDM)

arXiv:1911.03176, to appear in JHEP
M. Duerr, **TF**, C. Hearty, F. Kahlhoefer, K. Schmidt-Hoberg, P. Tunney

- Search for heavy DM χ_2 decaying into light DM χ_1 via Dark Photon mediator (5 free parameters)
  - **Single photon** state if χ_2 long lived or fermion pair is low mass
  - **Displaced** e^+e^- vertex otherwise
- Kinematically forbidden in direct-detection searches
- Background from photon conversions
- Displaced vertex trigger needed for highest masses





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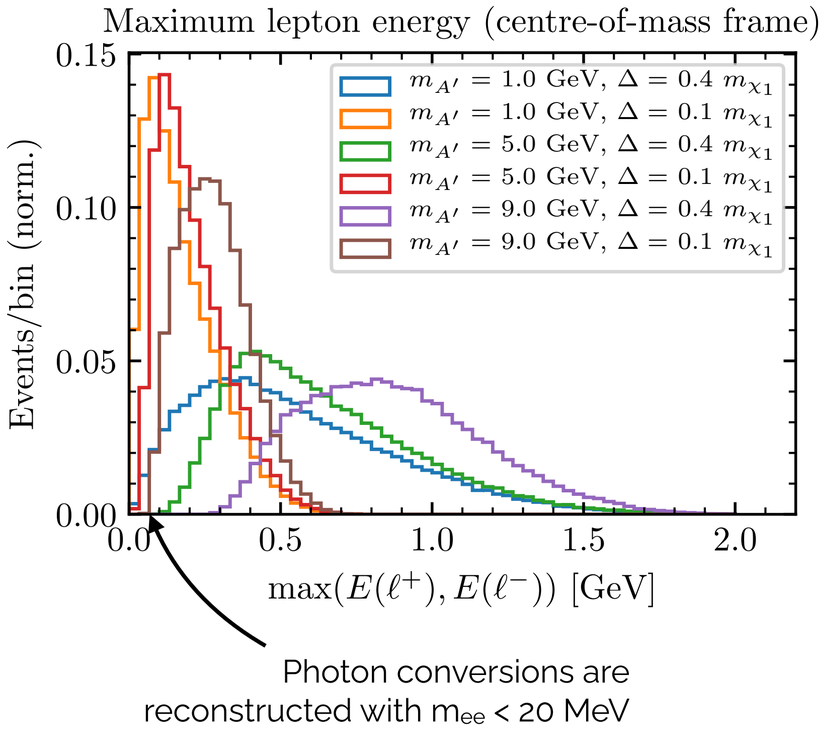


Photon conversions are reconstructed with $m_{ee} < 20$ MeV

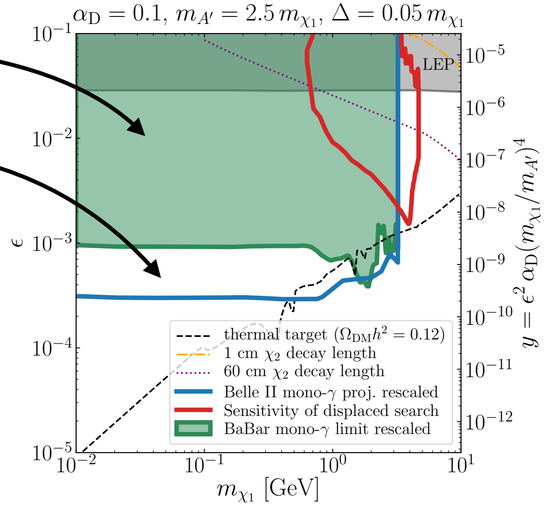
BaBar single photon search

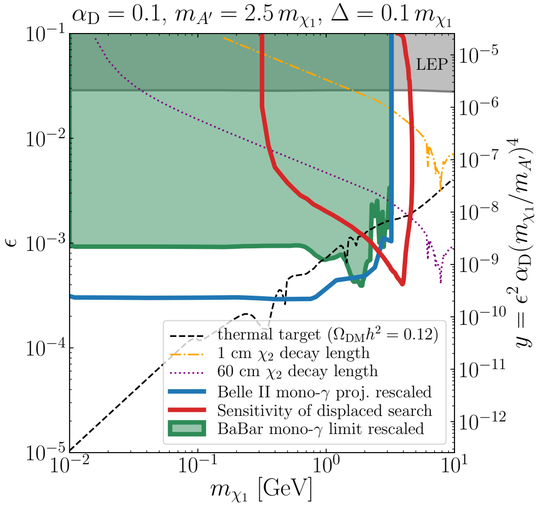
Belle II single photon reach (20fb-1)

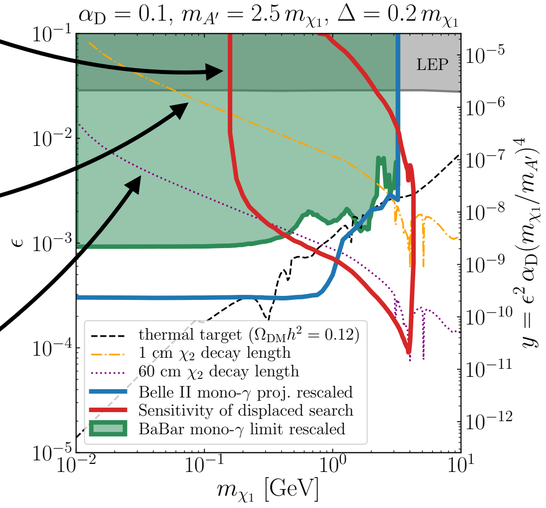
Belle II displaced reach (20fb-1)

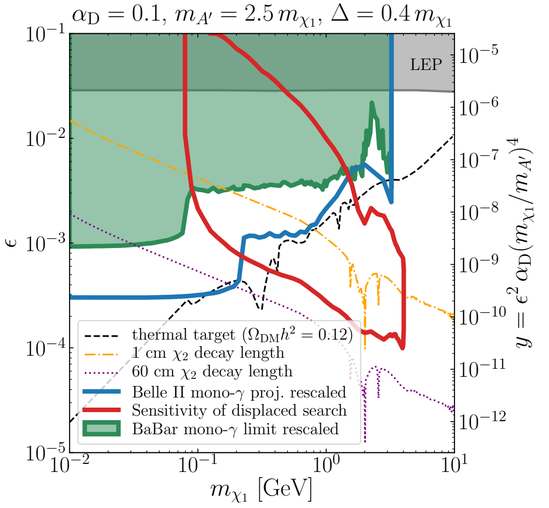
χ_2 decay length 1cm

χ_2 decay length 60cm

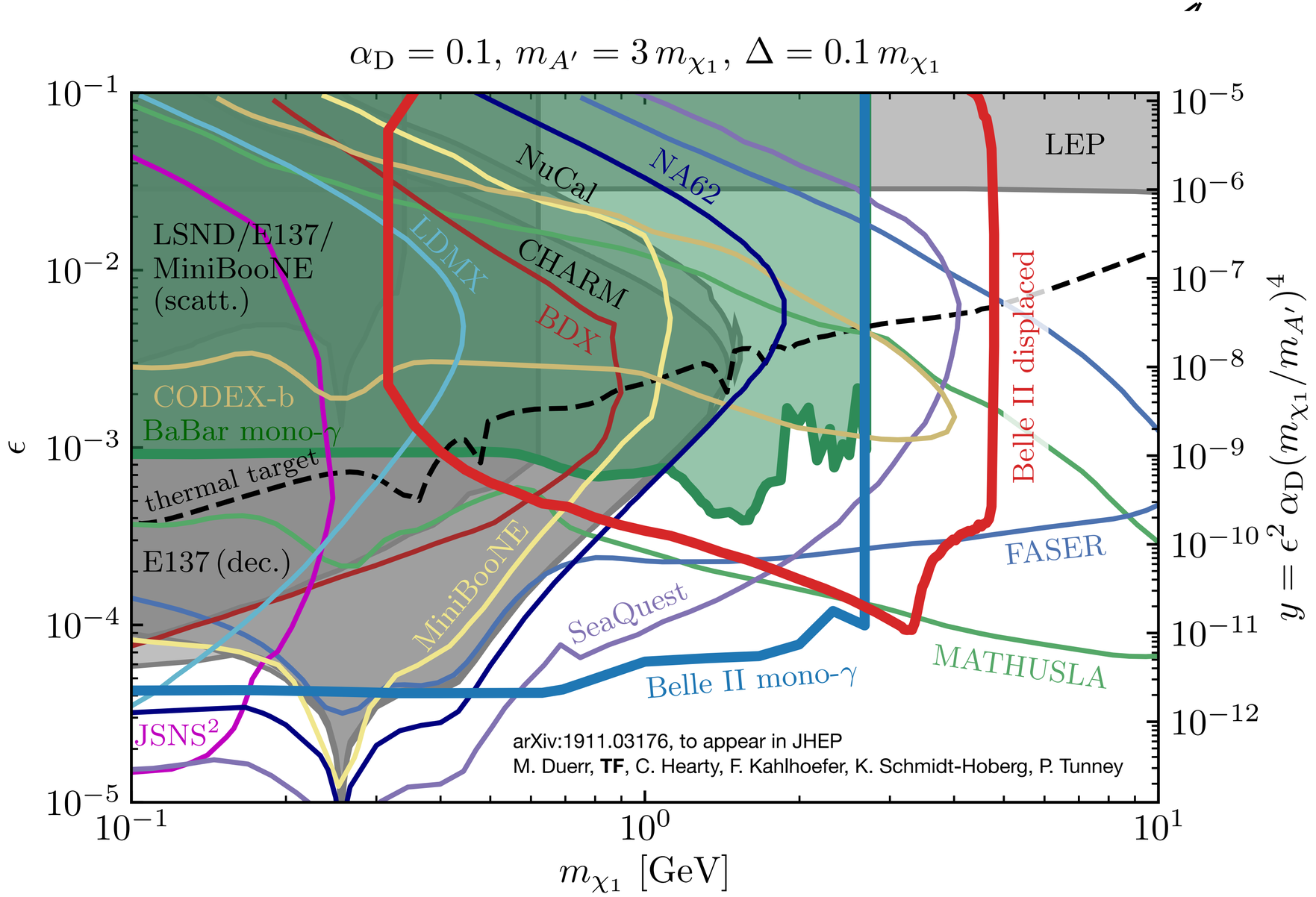








Search for inelastic Dark Matter (iDM)



Summary

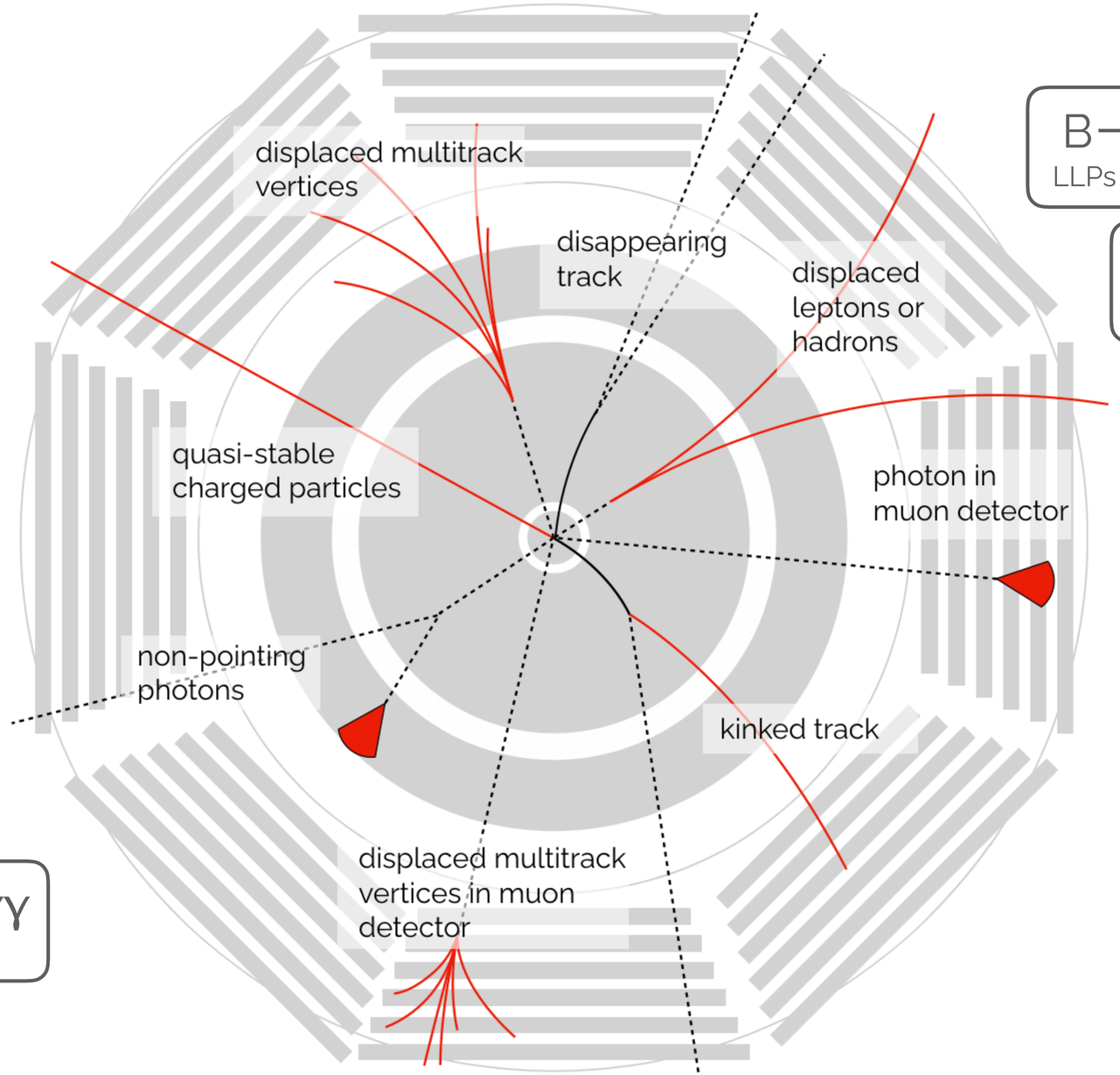
- Belle II established nano-beam scheme in 2019 and takes physics runs with $L > 10^{34}\,cm^{-2}s^{-1}$
- Detector performance generally as expected, but beam background levels are higher than expected
- Long shutdown 2021 to install full PXD and replace TOP PMTs
- Searches for the direct production of low-mass new particles are a priority for the early running period of Belle II
- 10 fb^{-1} done. 49990 fb^{-1} to go.

Backup.

Magnetic Monopoles

$B \to K\Phi$, $\Phi \to \ell\ell$
LLPs in meson decays

Inelastic DM
LLPs in direct production

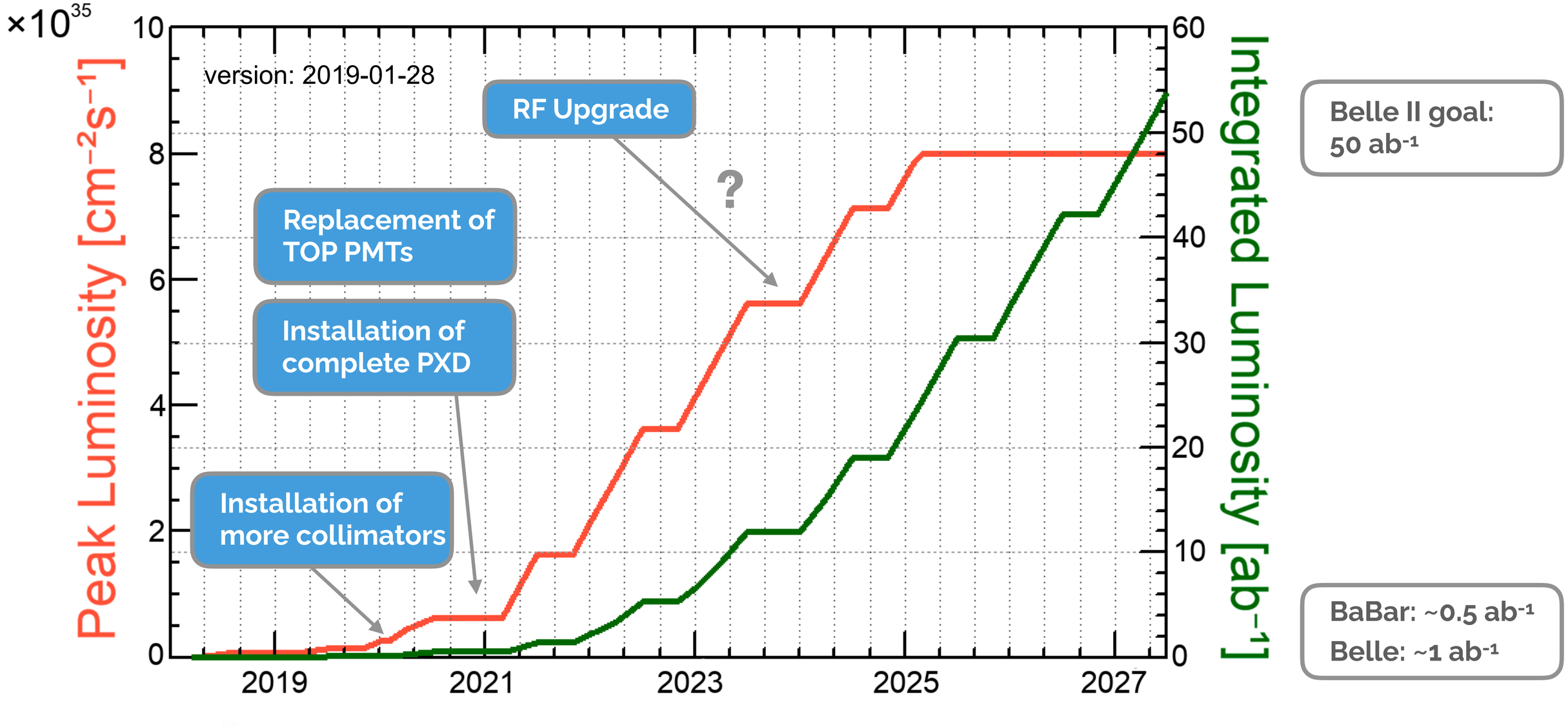


LLP ALPs

$B \to K\Phi$, $\Phi \to \gamma\gamma$
LLPs in meson decays

$ee \to \gamma a_1 \to \gamma a_2 a_2 \to \gamma\gamma\gamma\gamma$
LLPs in ext. ALP sectors

Timeline



Belle II goal: 50 ab^{-1}

BaBar: ~0.5 ab^{-1}
Belle: ~1 ab^{-1}

Contact

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