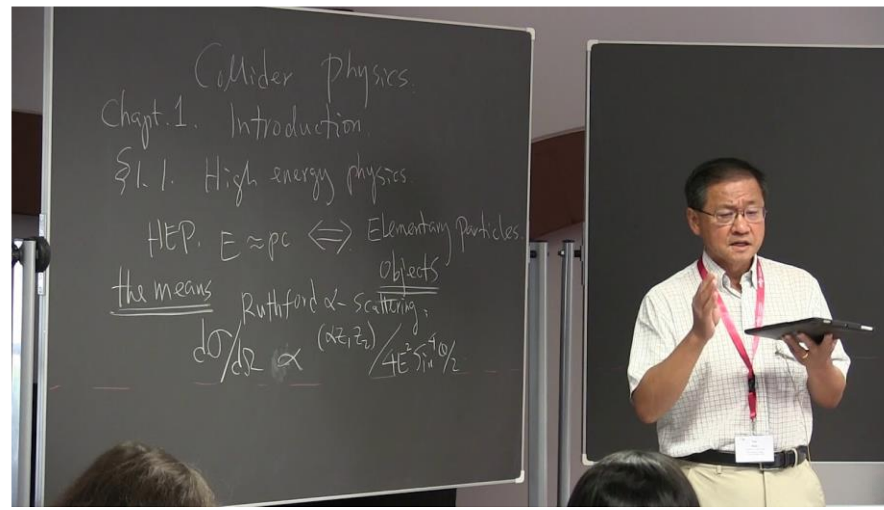
Greetings to Pitt Colleagues !

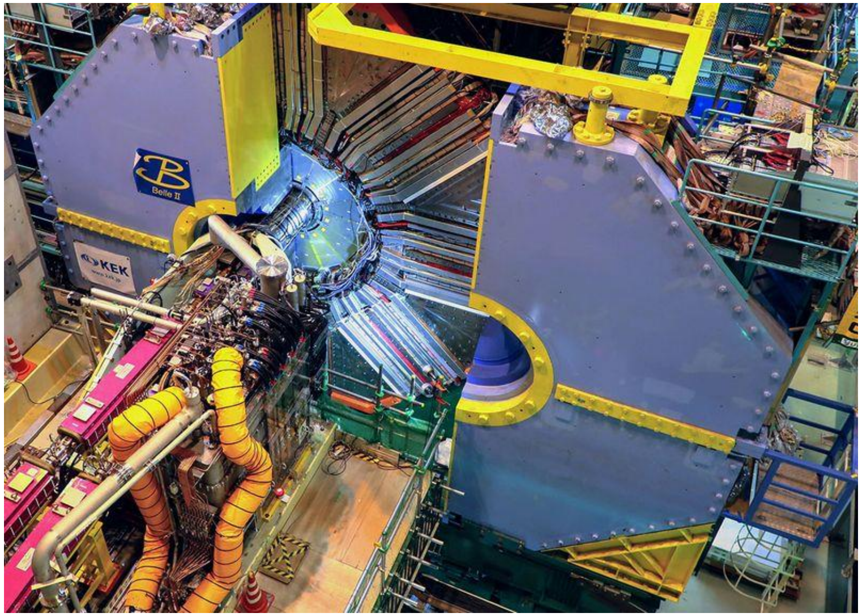
Vladimir Savinov, my
Belle II colleague.



Please feel free *to interrupt right away* with questions and comments. This will make the seminar *more interesting and exciting*.

First Physics Results from Belle II@SuperKEKB

Tom Browder, University of Hawai'i at Manoa



The complex superconducting final focus is partially visible here (before closing the endcap).

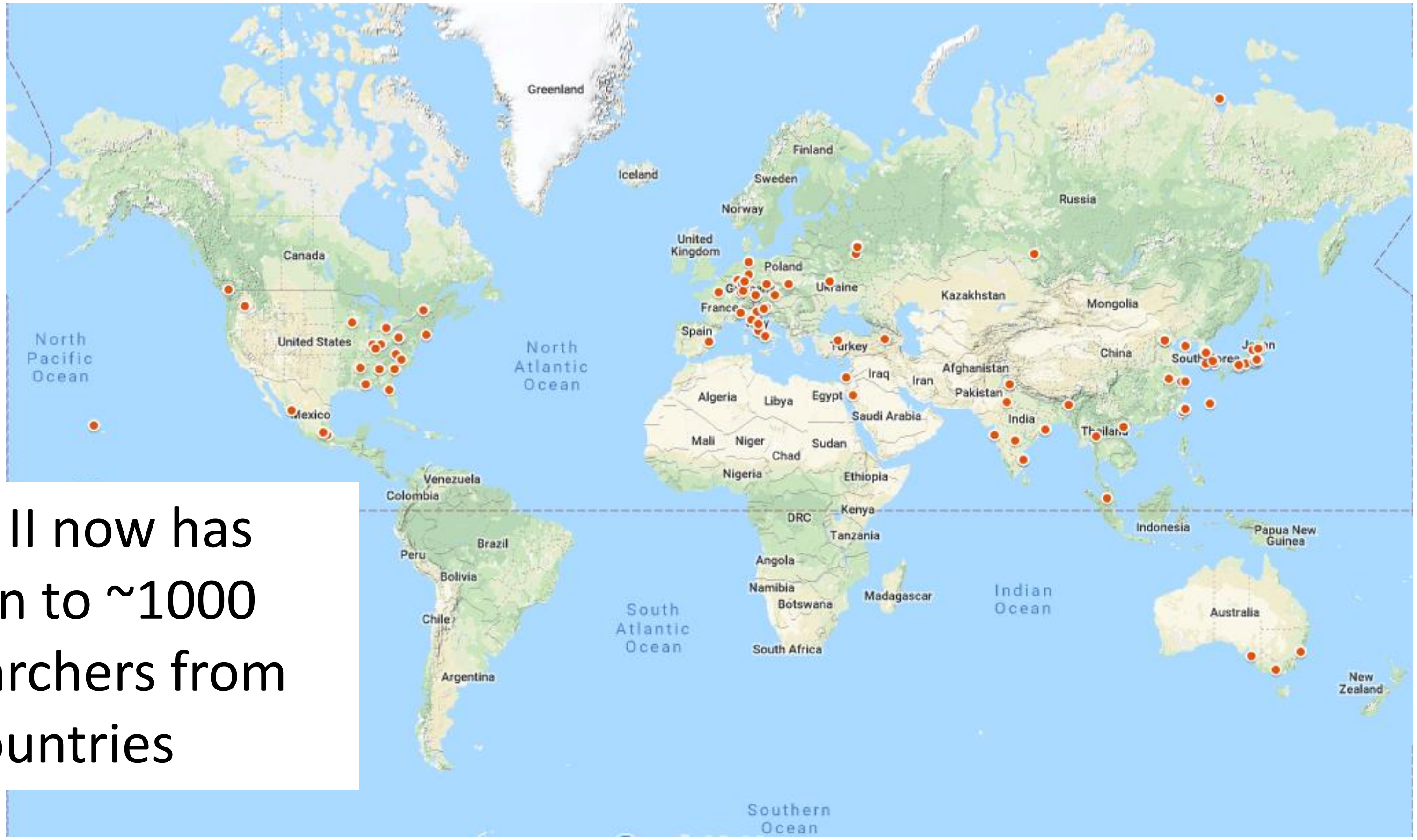
Vertex detector before installation

Highlights from the last Belle II Physics Run (spring 2020 *during the global pandemic*), which concluded on July 1st. (L_{peak}=2.4 x 10^{34}/cm^2/sec), +*fall 2020 update.*

First Physics Results from Belle II: Dark Sector , B physics, charm physics and tau physics.

The Road Ahead to high luminosity and cutting edge physics (and the upgrades to SuperKEKB and Belle II that are needed).

The Geography of the International Belle II collaboration



Belle II now has grown to ~1000 researchers from 26 countries

This is <u>rather unique</u> in Japan. The only comparable example is the T2K experiment at JPARC, which is also an <u>international collaboration</u>

Youth and potential: There are ~330 graduate students in the collaboration

US Belle II, 18 institutes, 120 members

Brookhaven National Laboratory (BNL)
Carnegie Mellon University
Duke University
Iowa State University
Indiana University
Kennesaw State University
Luther College
Pacific Northwest National Laboratory (PNNL)
Virginia Tech

University of Cincinnati
University of Florida
University of Hawai'i
University of Louisville
University of Mississippi
University of Pittsburgh
University of South Alabama
University of South Carolina
Wayne State University

The B Factories focused on establishing large CP violation in the B Meson System in the SM and constraints on the CKM matrix. PEP II/BaBar stopped in 2008 while KEKB/Belle completed operations in 2010.

Parameters			PEP-II	KEKB
Beam energy		(GeV)	9.0 (e^-), 3.1 (e^+)	8.0 (e^-), 3.5 (e^+)
Beam current		(A)	1.8 (e^-), 2.7 (e^+)	1.2 (e^-), 1.6 (e^+)
Beam size at IP	x	(μm)	140	80
	y	(μm)	3	1
	z	(mm)	8.5	5
Luminosity		($\text{cm}^{-2}\,\text{s}^{-1}$)	1.2×10^{34}	2.1×10^{34}
Number of beam bunches			1732	1584
Bunch spacing		(m)	1.25	1.84
Beam crossing angle		(mrad)	0 (head-on)	±11 (crab-crossing)

$$V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \qquad V_{\text{CKM}} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

A single irreducible complex phase explains all CPV

Revisionist History and Paradigm Shift

The B factory experiments, Belle and BaBar, discovered large CP violation in the B system in 2001, compatible with the SM and provided a large range of CKM measurements. These provided the experimental foundation for the 2008 Nobel Prize to Kobayashi and Maskawa.

In the meantime, the LHC was constructed in 2008, ATLAS and CMS completely changed the nature of high energy physics. Of particular importance was the landmark discovery in 2012 of the Higgs boson.

This discovery was recognized by the 2013 Physics Nobel Prize to Englert and Higgs.

In addition, the high pT experiments, established tight constraints on direct production of high mass particles (e.g. M(Z'), M(W')>3 TeV, vector-like fermions > 800 GeV) and limits on SUSY. This noble search continues with the high luminosity LHC.

Paradigm shift: inspired by intriguing results from LHCb and the potential of Belle II, the possibility of finding new physics in flavor has emerged as a *complementary* route to the LHC.

Younger theorists: Dark Sector may be another path.

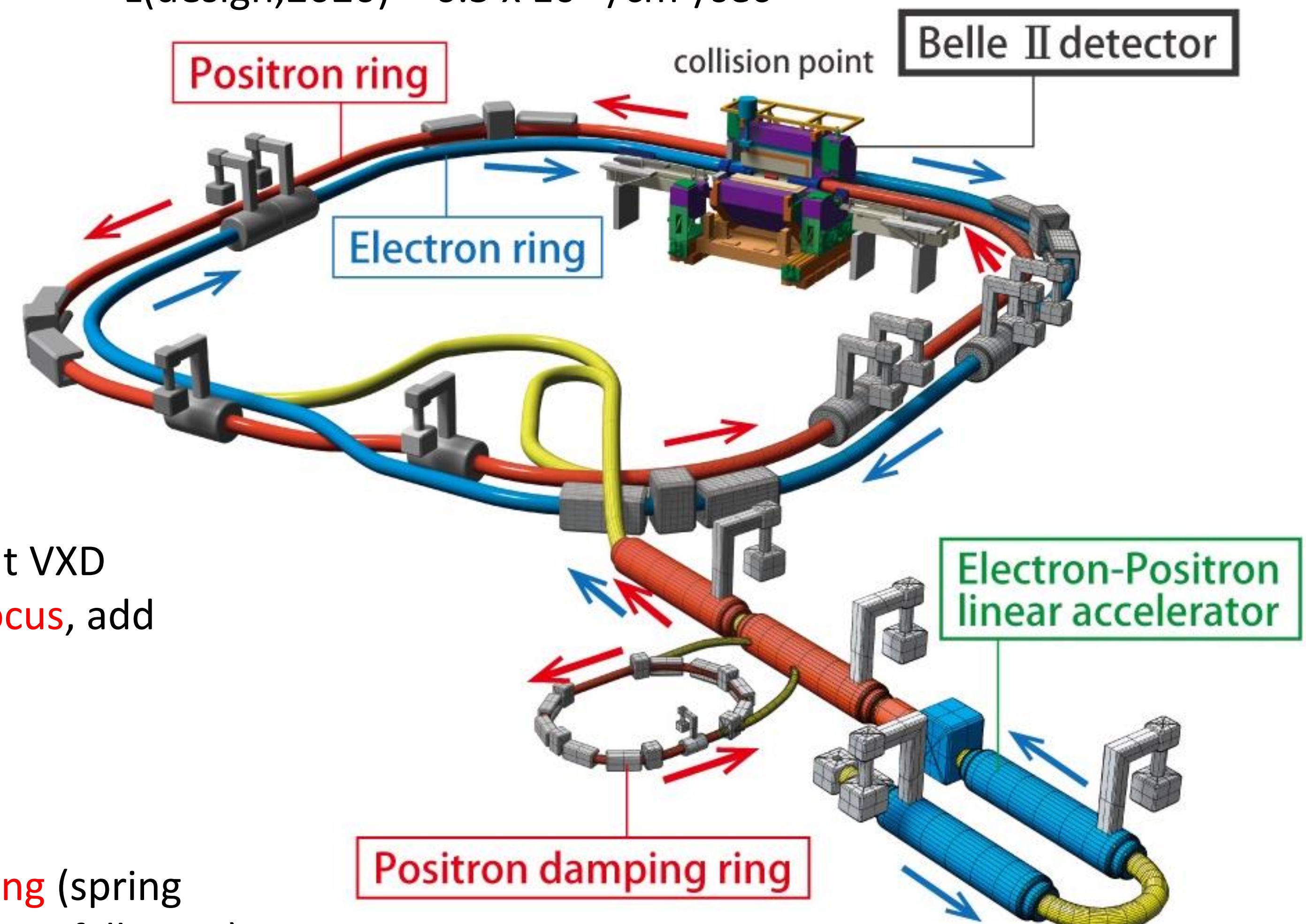
ESG report

The quest for dark matter and the exploration of flavour and fundamental symmetries are crucial components of the search for new physics. This search can be done in many ways, for example through precision measurements of flavour physics and electric or magnetic dipole moments, and searches for axions, dark sector candidates and feebly interacting particles. There are many options to address such physics topics including energy-frontier colliders, accelerator and non-accelerator experiments. A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy. ***Experiments in such diverse areas that offer potential high-impact particle physics programmes at laboratories in Europe should be supported, as well as participation in such experiments in other regions of the world.***

The observed pattern of masses and mixings of the fundamental constituents of matter, quarks and leptons, remains a puzzle in spite of the plethora of new experimental results obtained since the last Strategy update. Studying the flavour puzzle may indicate the way to new physics with sensitivity far beyond what is reachable in direct searches, e.g. the evidence for the existence of the top quark that followed from the study of B-meson mixing. In addition, flavour physics and CP violation, which play a vital role in determining the parameters of the Standard Model, are explored by a wide spectrum of experiments all over the world. These include measurements of electric or magnetic dipole moments of charged and neutral particles, atoms and molecules, rare muon decays with high intensity muon beams at PSI, FNAL and KEK, rare kaon decays at CERN and KEK, and a variety of charm and/or beauty particle decays at the LHC, in particular with the LHCb experiment. New results are expected in the near future from the Belle II experiment at KEK in Japan and from LHCb (currently undergoing an upgrade) at CERN.

SuperKEKB, the first new collider in particle physics since the LHC in 2008 (electron-positron (e^+e^-) rather than proton-proton (pp)). Operates on the Upsilon(4S) resonance with 7 GeV(e-) on 4 GeV(e+) beams.

L(design,2020) = 6.5 x 10^{35}/cm^2/sec



Phase 1:
Background, Optics Commissioning Feb-June 2016.
Brand new 3 km positron ring.

Phase 2: Pilot run without VXD Superconducting Final Focus, add positron damping ring, First Collisions (0.5 fb^{-1}). April 27-July 17, 2018

Phase 3: → Physics running (spring 2019, fall 2019, spring 2020, fall 2020). Have integrated 90 fb^{-1} so far.

Accelerator innovations: nano-beams and crab waist optics (*rather than large beam currents*)

SuperKEKB/Belle II Luminosity Profile

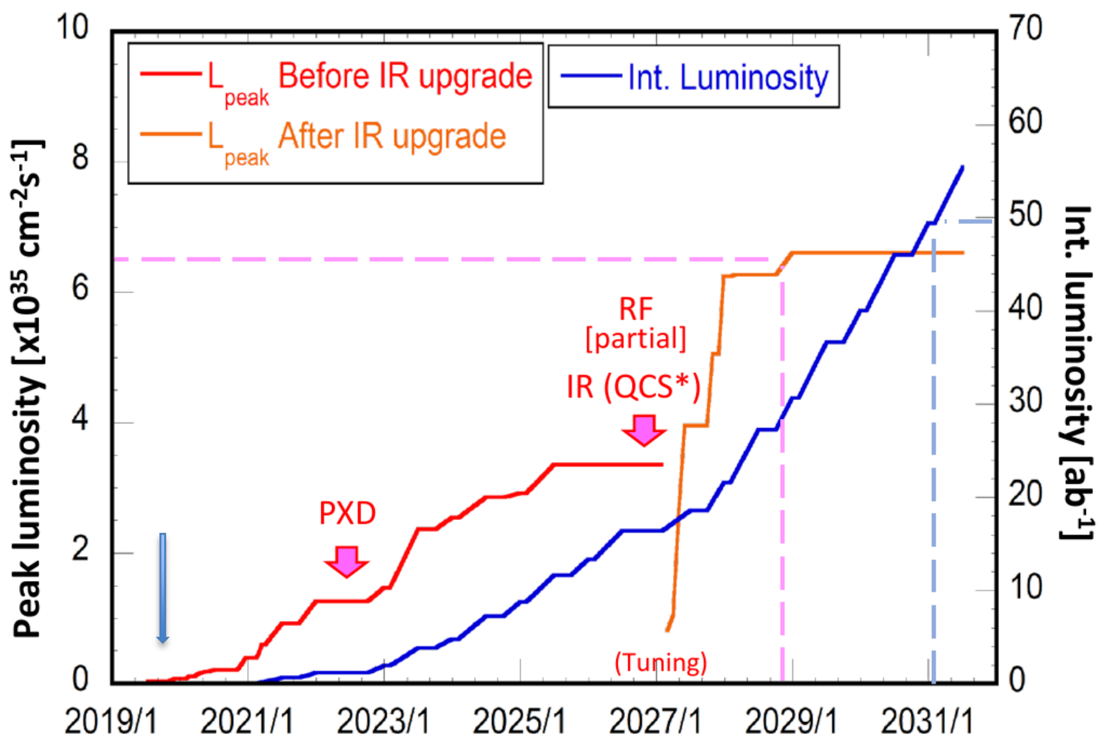
Recently updated.

Belle/KEKB recorded ~1000 fb^{-1} . Now have to change units on the y-axis to ab^{-1}

Beam currents *only* a factor of two higher than KEKB (~ PEPII)

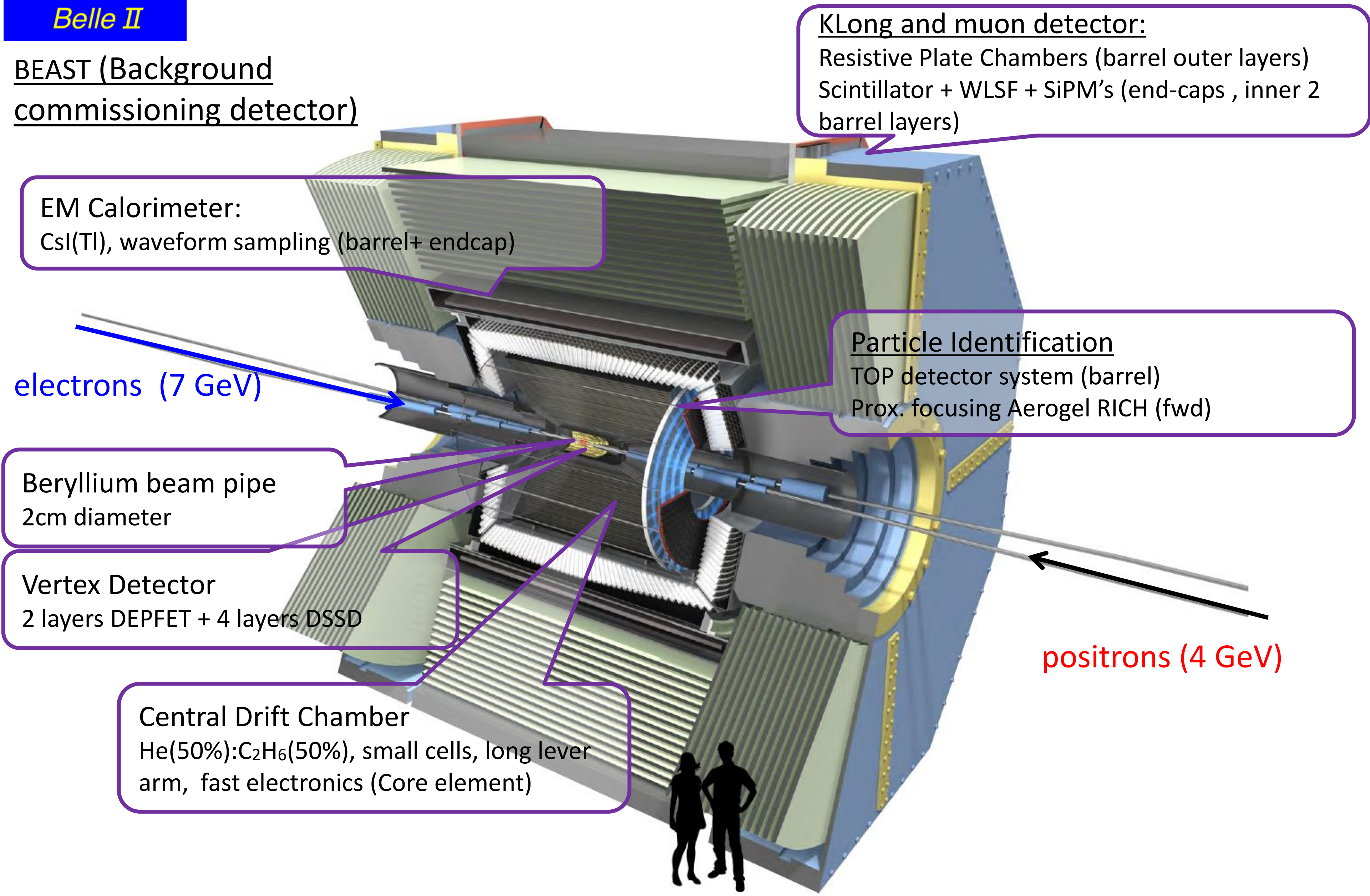
"nano-beams" are the key; vertical beam size is 50nm at the IP

Superconducting Final Focus and IR (Interaction Region) need to be upgraded in ~2026



N.B. To realize this steep turn-on will require lots of ***running time***, close cooperation between Belle II and SuperKEKB [and ***international collaboration*** on the accelerator, including the US and Europe]: BNL built the corrector coils for the SuperKEKB superconducting final focus, LAL Orsay does *fast* luminosity monitoring, DESY built the RVC (Remote Vacuum Connection)]. CERN accel. collaboration in the future ?

Belle II Detector

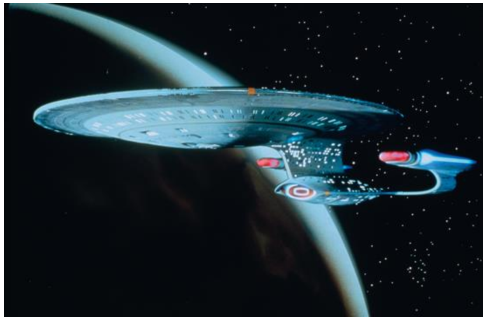


Advanced & Innovative Technologies used in Belle II

Pixelated photo-sensors play a central role

MCP-PMTs in the iTOP
HAPDs in the ARICH
SiPMs in the KLM

Collaboration with Industry



DEPFET pixel sensors

Waveform sampling with precise timing is "saving our butts".

Front-end custom ASICs for most subsystems
→ DAQ with high performance network switches, large HLT software trigger farm

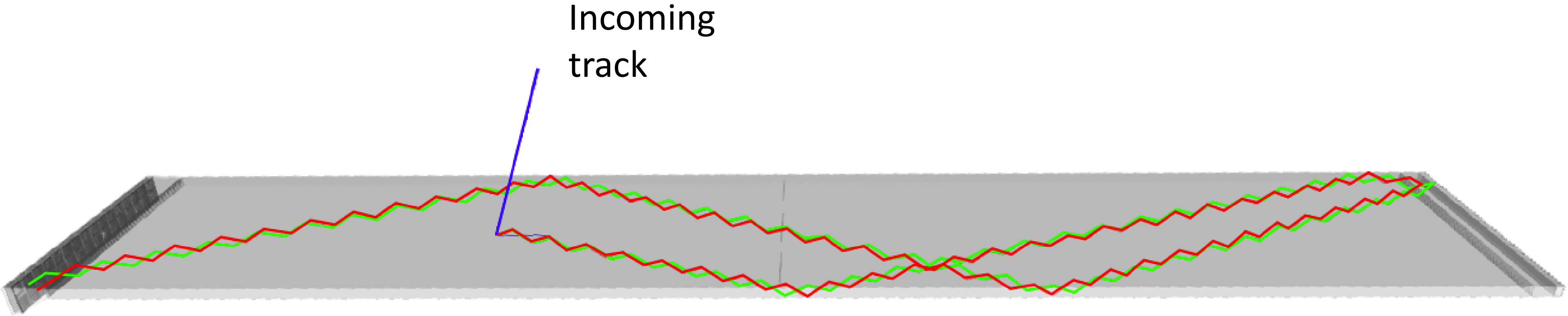
→ a 21st century HEP experiment.

KLM *(TARGETX* ASIC)
ECL (New waveform sampling backend with good timing)
TOP *(IRSX* ASIC)
ARICH (KEK custom ASIC)
CDC (KEK custom ASIC)
SVD (APV2.5 readout chip adapted from CMS)
PXD (3 Readout ASICs)

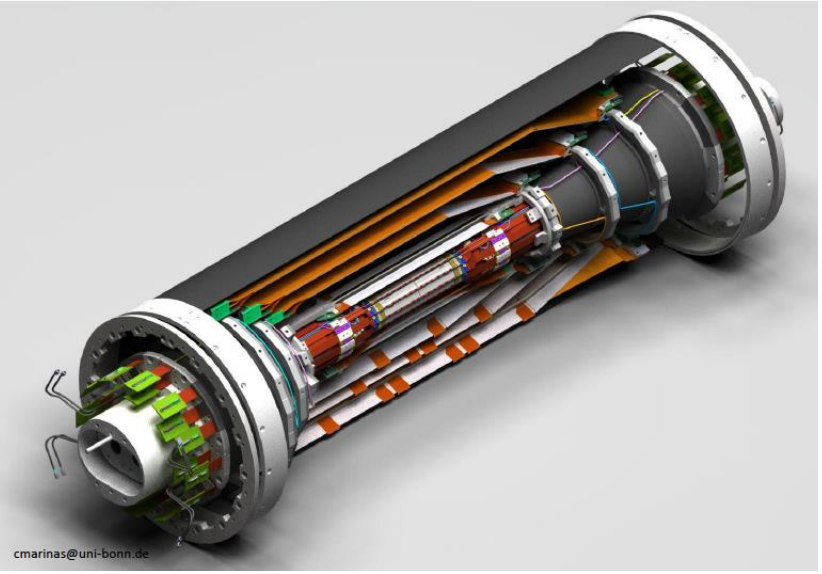
New methods of neutron detection with TPC's for the background. Directionality !

Barrel Particle Identification (uses Cherenkov radiation)

The paths of Cherenkov photons from a 2 GeV pion and kaon interacting in a TOP quartz bar. (Japan, US, Slovenia, Italy)



Vertexing/Inner Tracking



Beampipe r= 10 mm

DEPFET pixels (Germany, Czech Republic…)

Layer 1 r=14 mm

Layer 2 r= 22 mm

DSSD (double sided silicon detectors)

Layer 3 r=38 mm (Australia)

Layer 4 r=80 mm (India)

Layer 5 r=115 mm (Austria)

Layer 6 r=140 mm (Japan)

FWD/BWD Italy

+Poland, Korea

FAQ: How do Belle II and LHCb capabilities compare ?

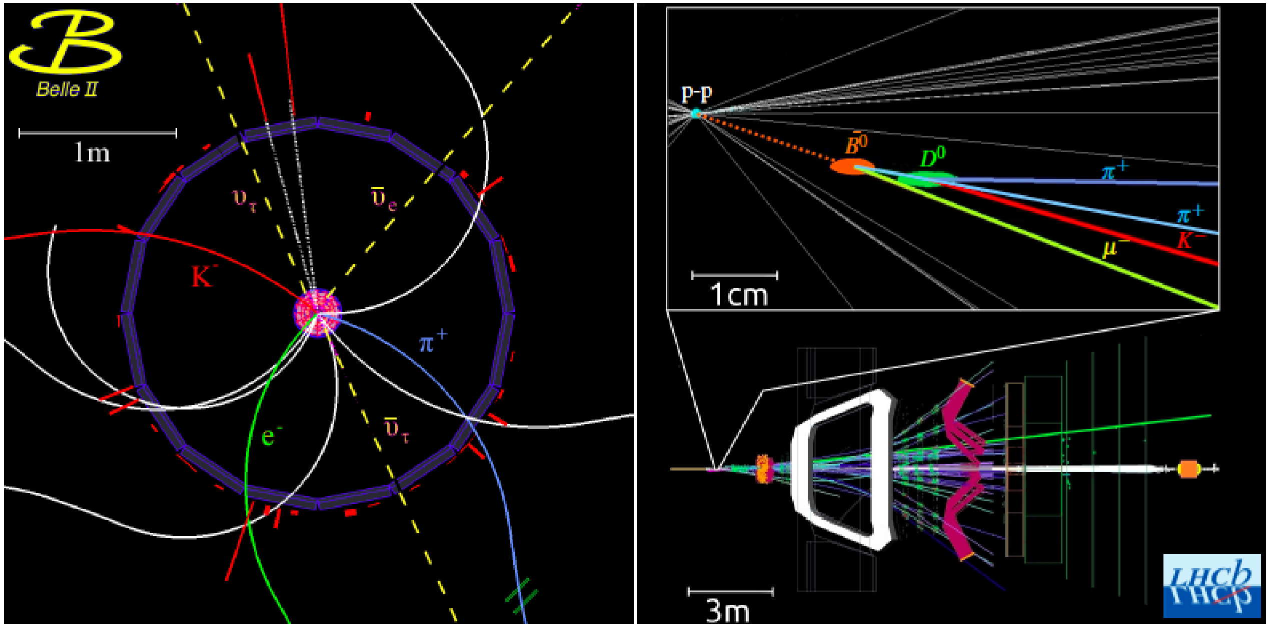


Figure credit:
G. Ciezarak et al, Nature 546, 227 (2017)

+Belle II can do the dark sector

1. LHCB has a large b bbar cross-section (hundreds of microbarns versus nanobarns) and good sensitivity, signal to background, for modes with dimuons, and all charged final states using vertexing. Triggering and flavor tagging effs. are much lower than in e+e-.

Rule of thumb for statistics in this case: 1 fb^{-1} at LHCb is 1 ab^{-1} at Belle II.
(➔Need good SuperKEKB performance)

2. Belle II has a simple event environment with B-anti B pairs produced in a coherent QM state with no additional particles.

3. Belle II can measure inclusive processes

4. Belle II can measure electrons as well as muons. (important for lepton universality checks).

5. Belle II can measure final states with gamma’s, Kshorts and missing neutrinos well.

FAQ: How can an international experiment and accelerator operate during a global pandemic ?

SuperKEKB/Belle II was and is operating during the COVID-19 pandemic with protocols in place to maximize safety and minimize the risk of infection. Difficult with travel restrictions and a very heavy load on a skeleton crew at KEK (~40 people). This included ~10 people onsite from the US in the spring 2020 run.

Developed a "social distancing" scheme for on-site shifts in the Belle II and SuperKEKB control rooms. Mobilized remote shifters around the world – depended heavily on internet chat utilities for communication and monitoring.

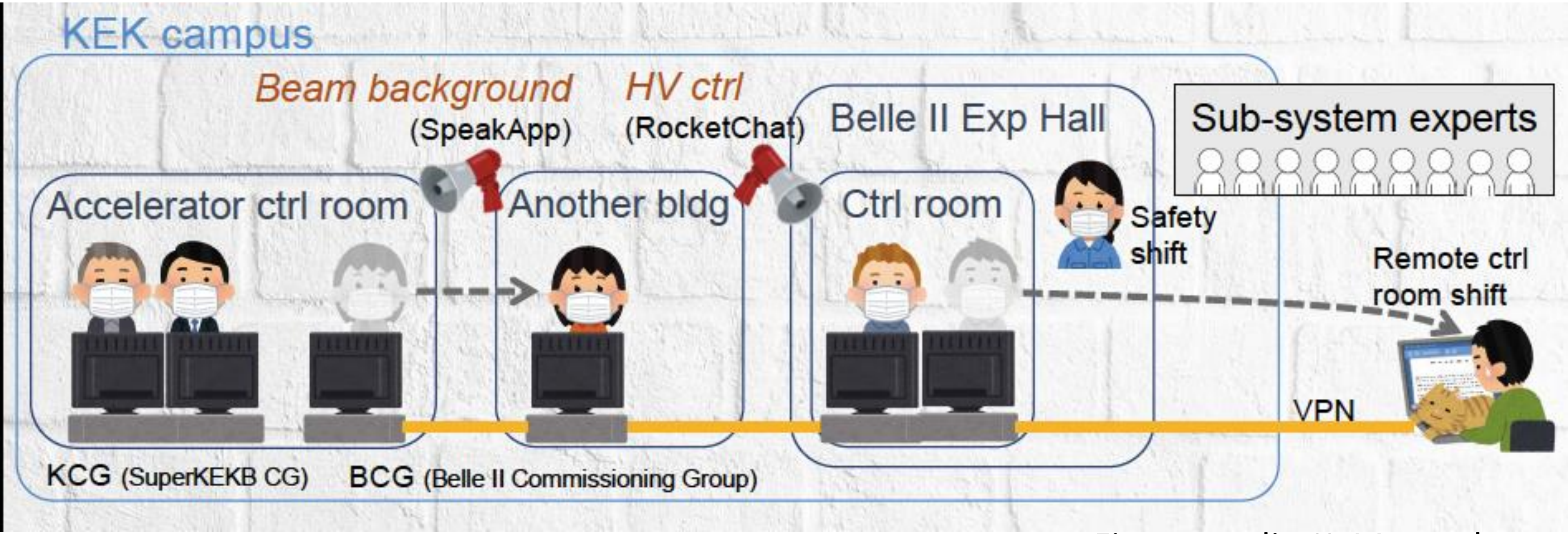
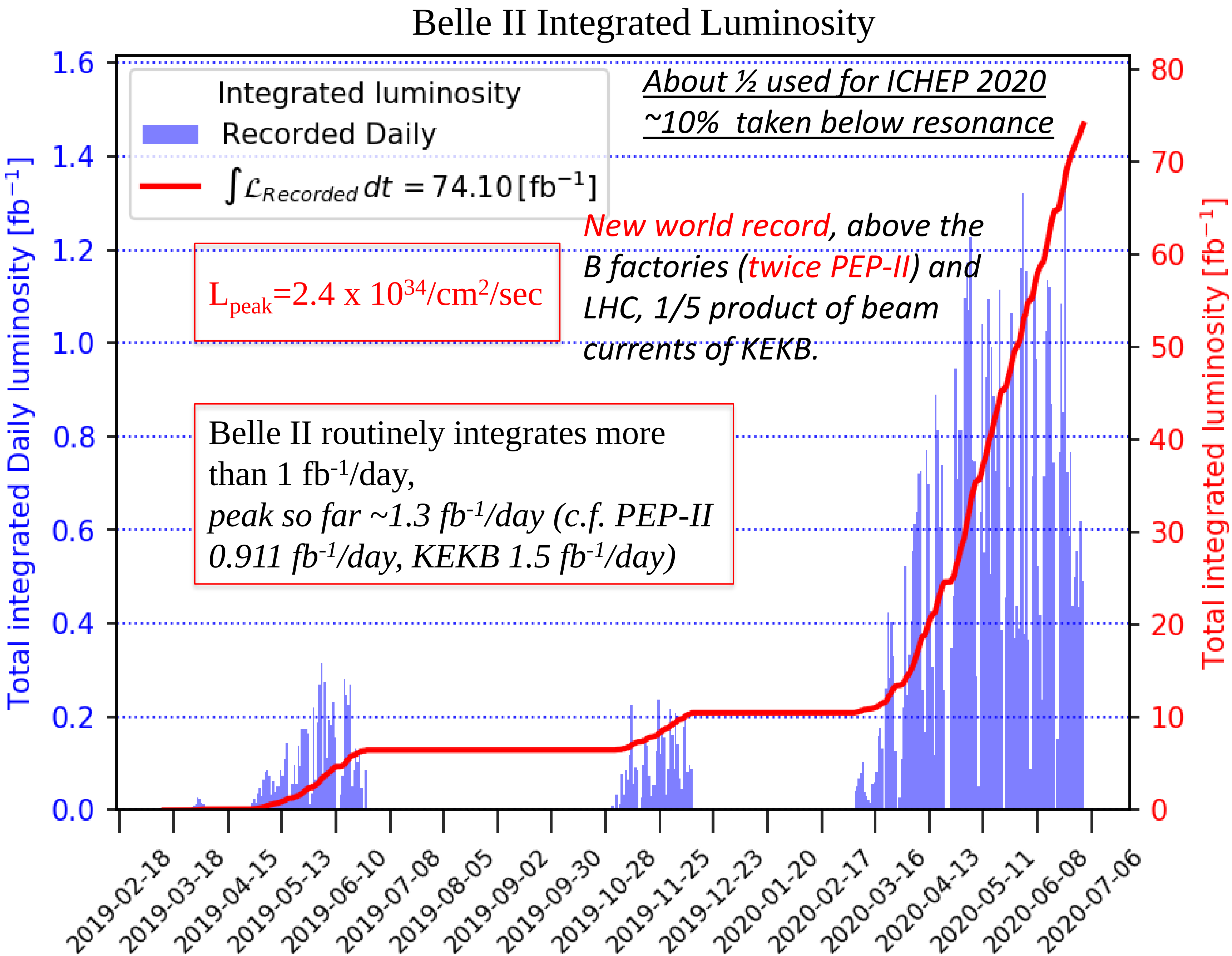
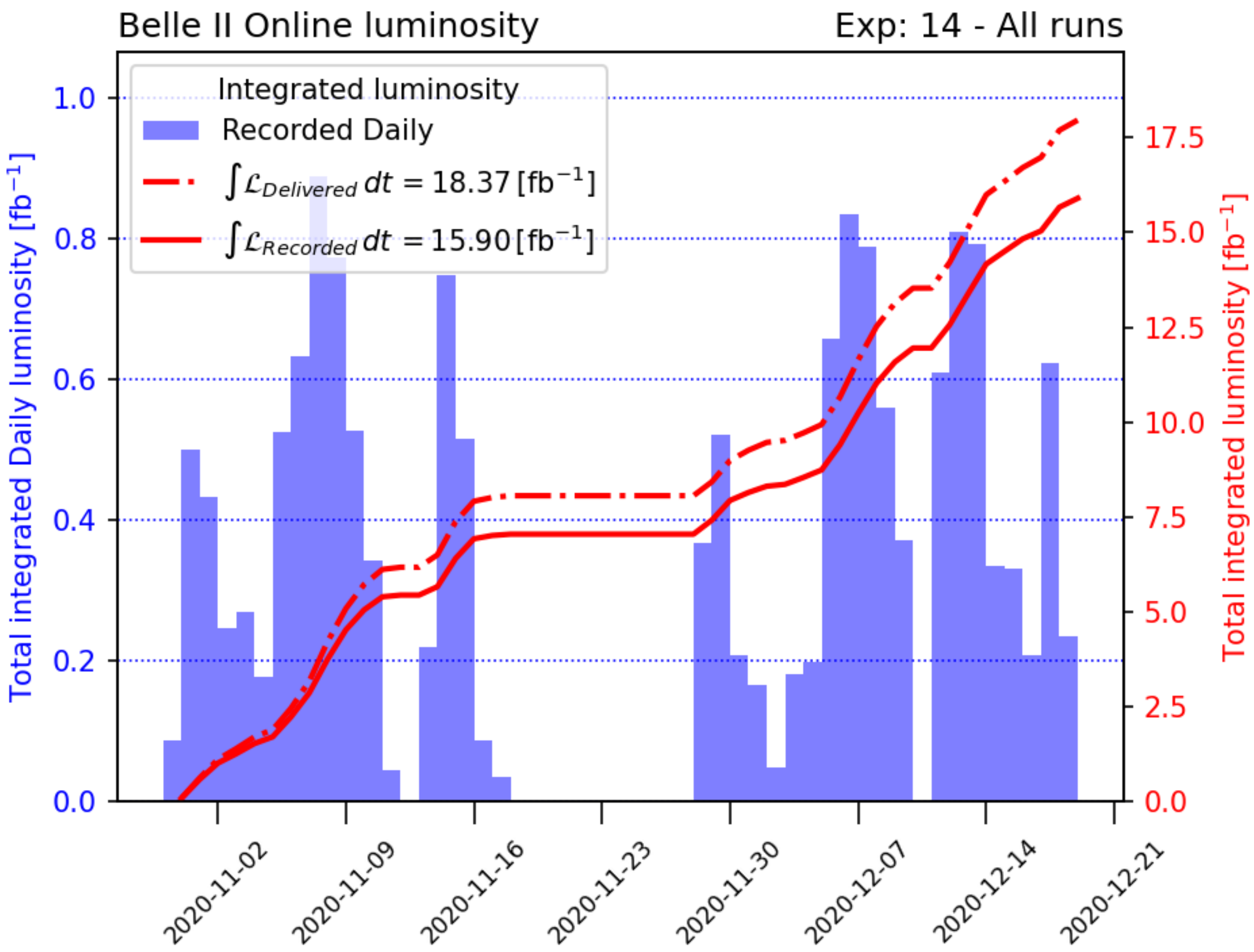


Figure credit: K. Matsuoka



https://cerncourier.com/a/kek-reclaims-luminosity-record/ for impact on future e+e-machines.

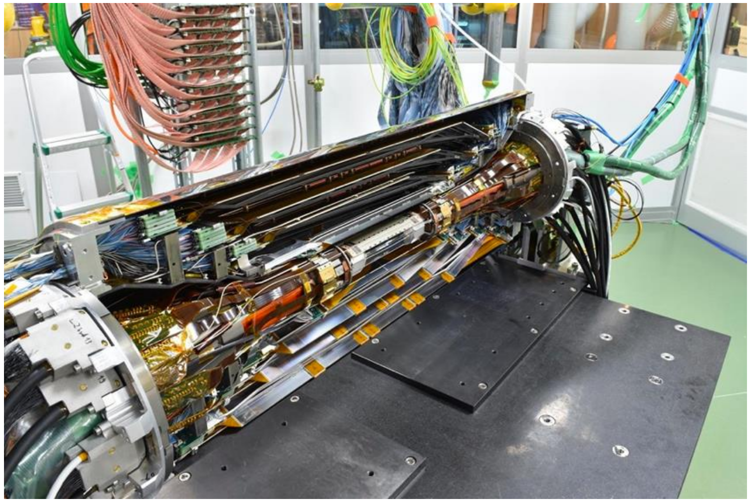


Fall 2020 (2 months of running) and *many lessons learned*.

Installed a pure carbon collimator following the LHC model. This excited instabilities in the beam (not able to store high currents and make world record-luminosity) also lost 2 weeks from a bad “dust event”, which damaged a collimator. Will start again in mid-Feb 2021 without this collimator and other improvements.

Belle II/SuperKEKB Phase 3 (Physics Run) Goals

Early aims: Demonstrate SuperKEKB Physics running with acceptable backgrounds, and all the detector, readout , DAQ and trigger capabilities of Belle II including tracking, electron/muon id, high momentum PID, and especially the *ability to do time-dependent measurements needed for CP violation.*

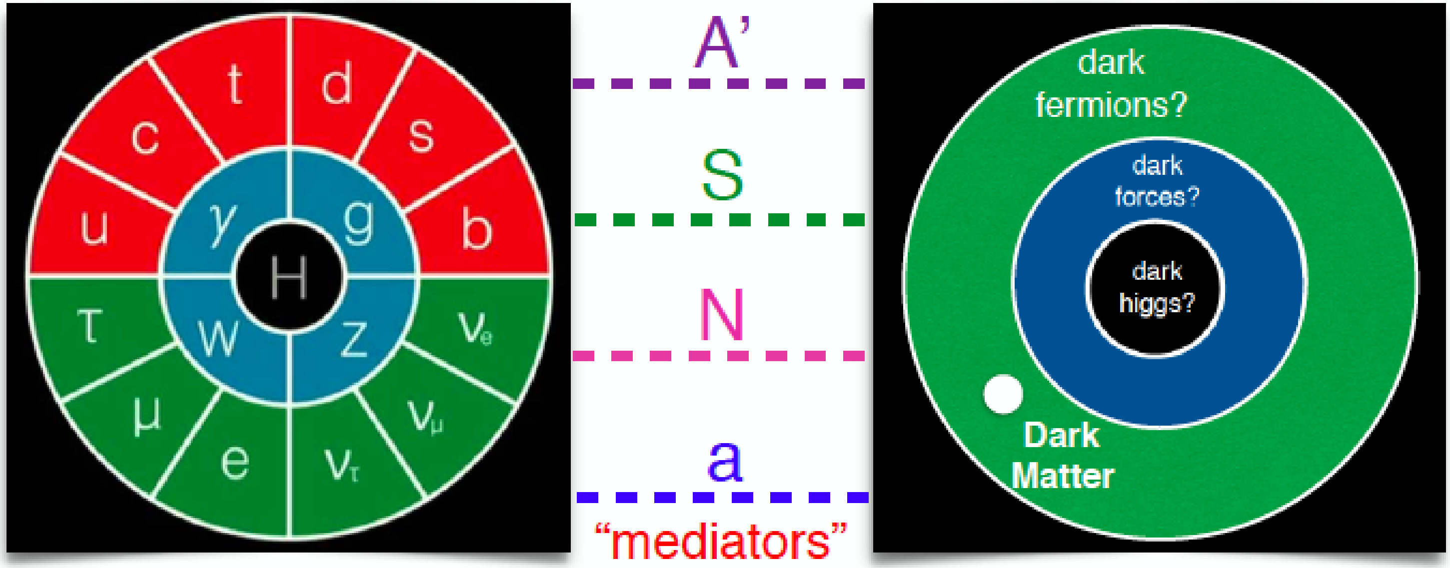


Carry out innovative and world leading dark sector searches/measurements. Publish first papers.

Long term: *Integrate the world's largest e^+e^- data samples and observe or constrain New Physics in B decays, charm and tau decays.*

From a pre-Snowmass meeting

How to gain access to the dark sector?



Only a few interactions exist that are allowed by Standard Model symmetries:

"mediators"	"portal interactions"
Dark photon	$\epsilon B^{\mu\nu} A'_{\mu\nu}$
Higgs	$\kappa \lvert H \rvert^2 \lvert S \rvert^2$
Neutrino	$y H L N$
Axion	$g_{a\gamma} a \tilde{F}_{\mu\nu} F^{\mu\nu}$

We will look at several examples of these mediators in early Belle II data including a special Z' and an axion. Prospects for a dark photon will be mentioned.

S.Gori

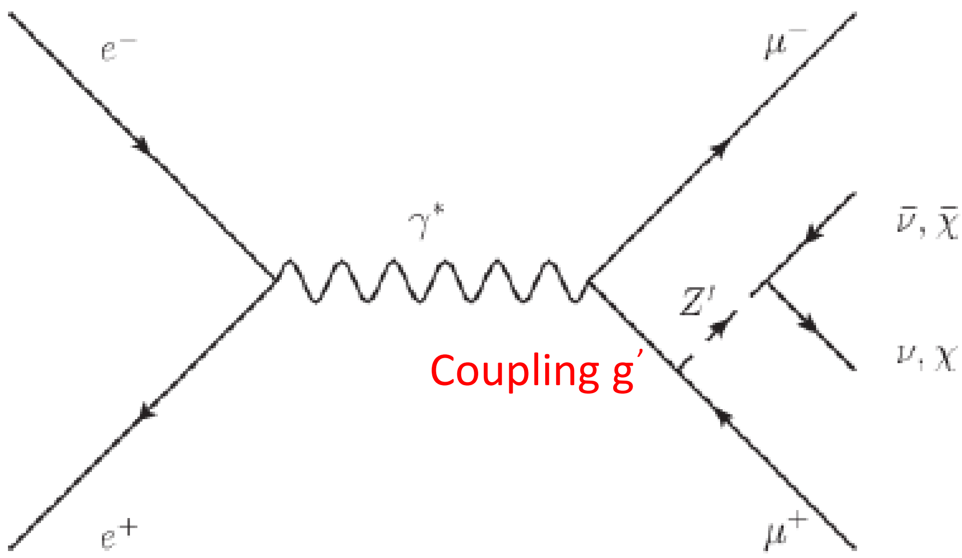
Dark Sector:

Previously limited by Triggering, QED backgrounds and theoretical imagination. *Now new possibilities of triggering, more bandwidth*.

There are a variety of possible dark sector portal particles: Vector, Scalar, Pseudo-scalars.

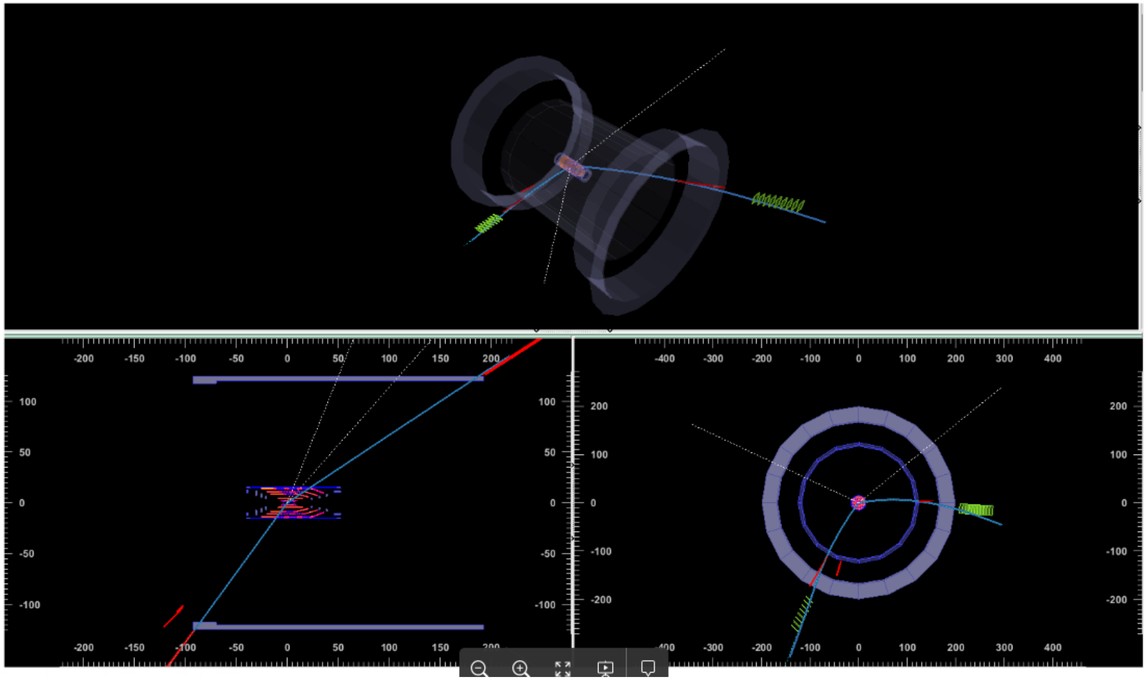
They may decay to lepton pairs, photon pairs, or Invisible particles

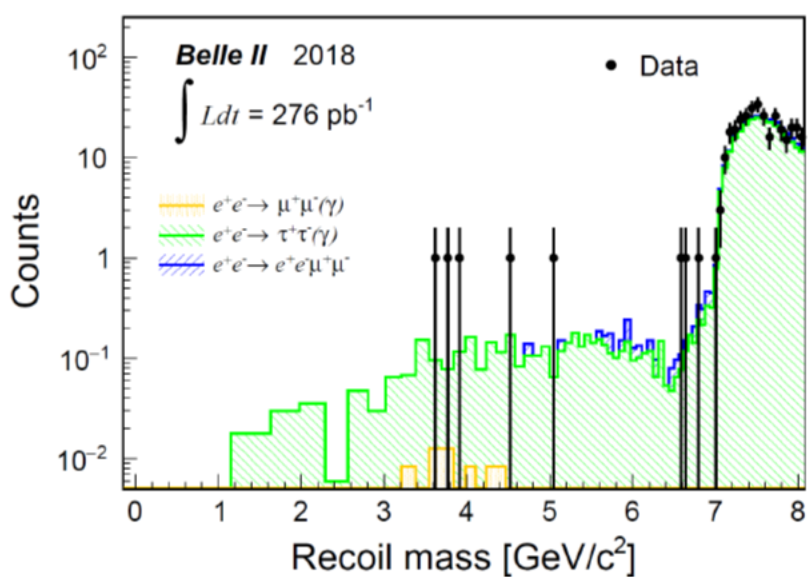
Belle II First Physics. A novel result on the dark sector (Z' →nothing) recoiling against di-muons *or* an electron-muon pair. *Both possibilities are poorly constrained at low Z' mass and in the first case, could explain the muon g-2 anomaly.*



Also examine a *lepton flavor violating* NP signature in the dark sector

Monte Carlo simulation of a Z' →invisible event

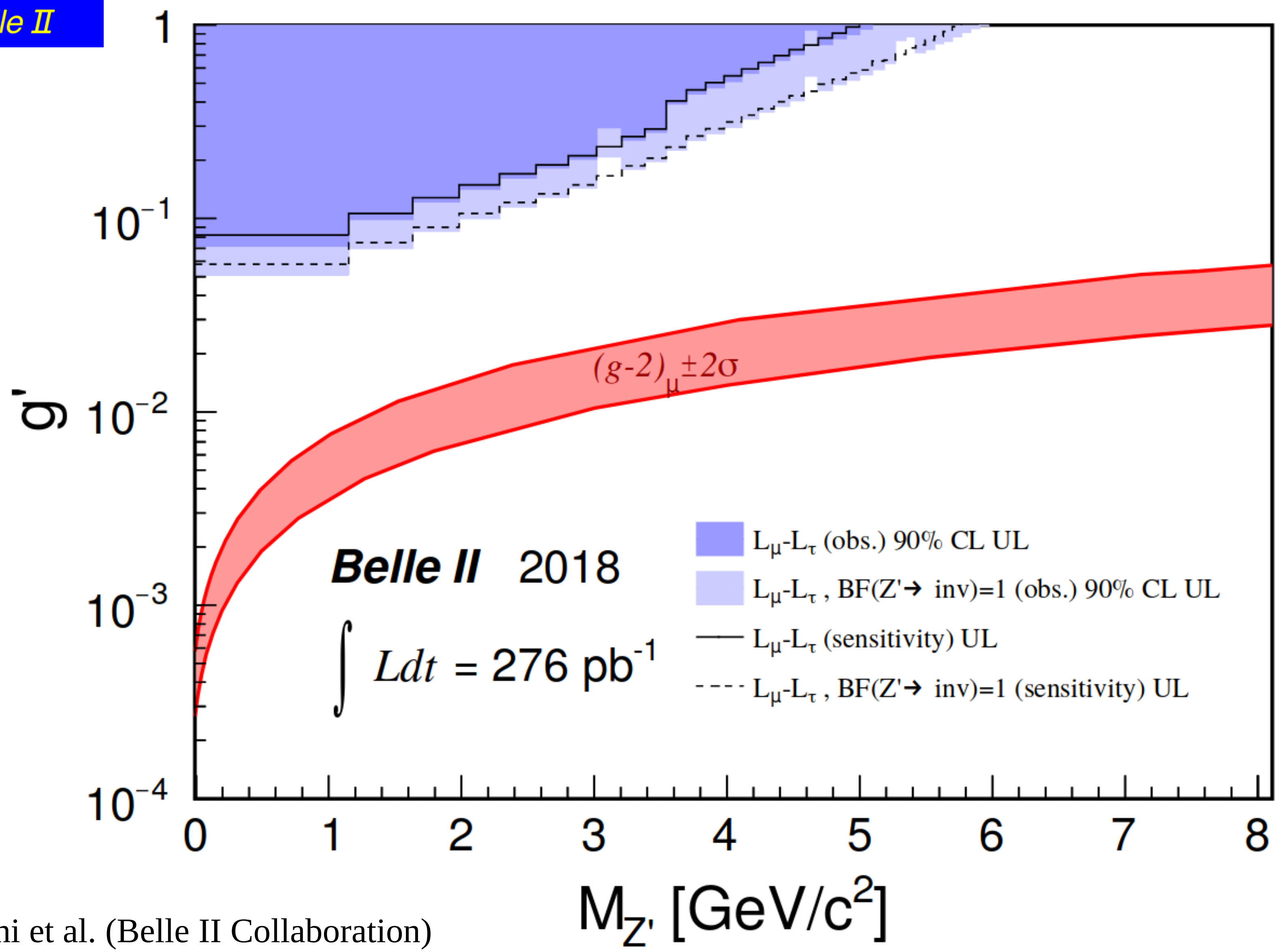




However, in data we do not find any excess in recoil mass.

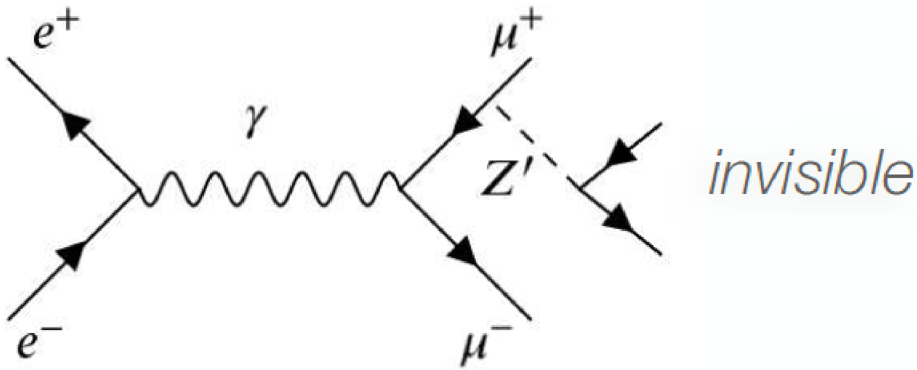
Bkg dominated by $e^+e^- \rightarrow \tau^+ \tau^- \gamma$

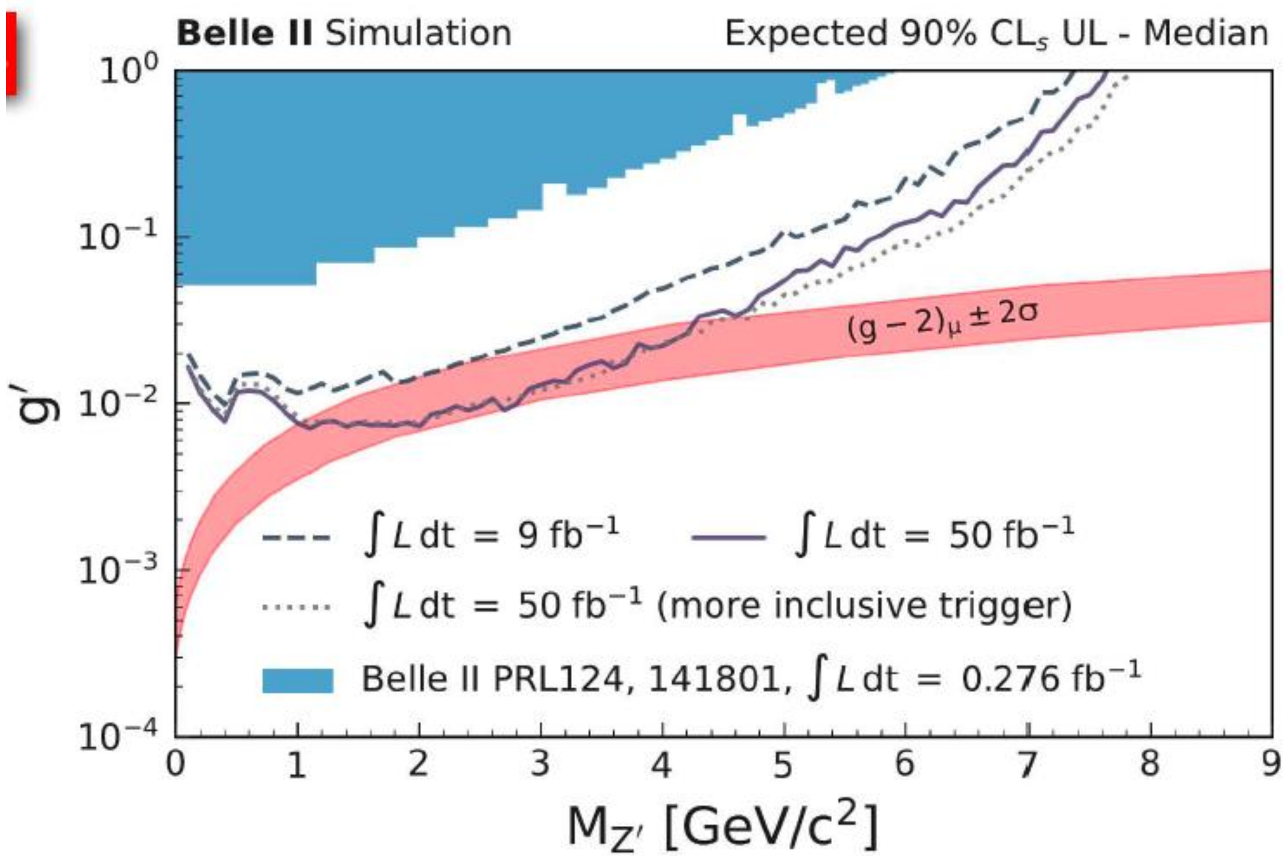
With 278 pb^{-1} from the Phase 2 “pilot run”



I. Adachi et al. (Belle II Collaboration)
Phys. Rev. Lett. 124, 141801 – PRL Editor’s Choice

Near term prospects for Z' →invisible

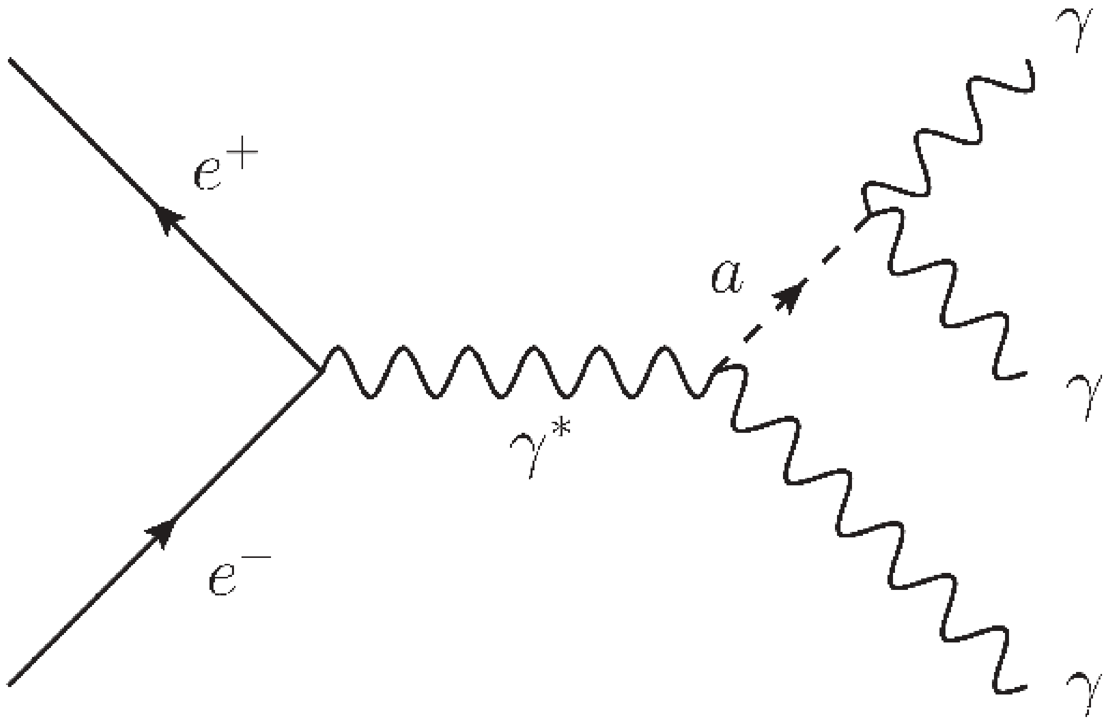




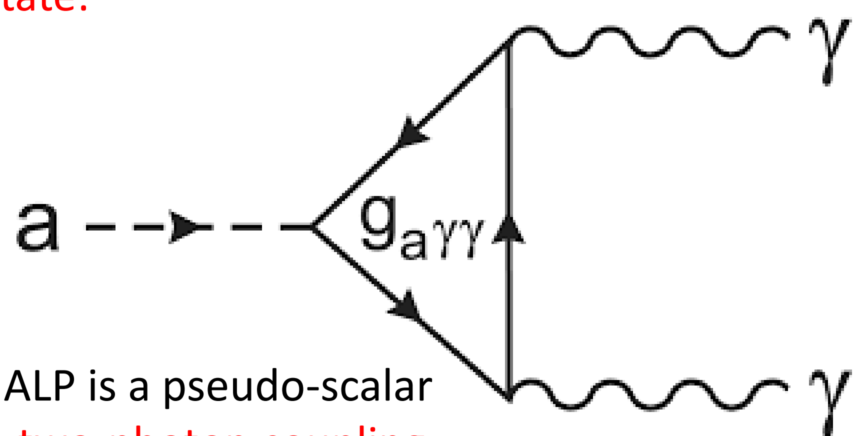
Uses Phase 3 data on tape. Adding in KLM triggers may allow us to "break through" the g-2 band.

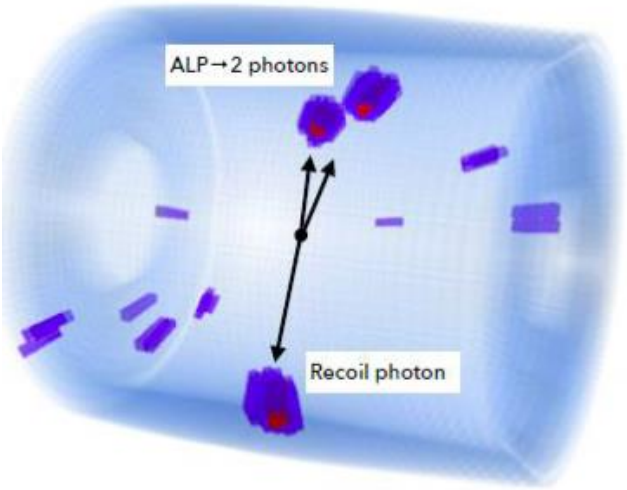
Search for ALPs (Axion Like Particles) at Belle II

An extra term was introduced in the QCD Lagrangian by Peccei, Quinn to solve the strong CP problem in 1977. Wilczek introduced a particle interpretation called the Axion. Expected to be very light (microeV or millieV).



Examine the three photon final state:





The ALP is a pseudo-scalar with two-photon coupling

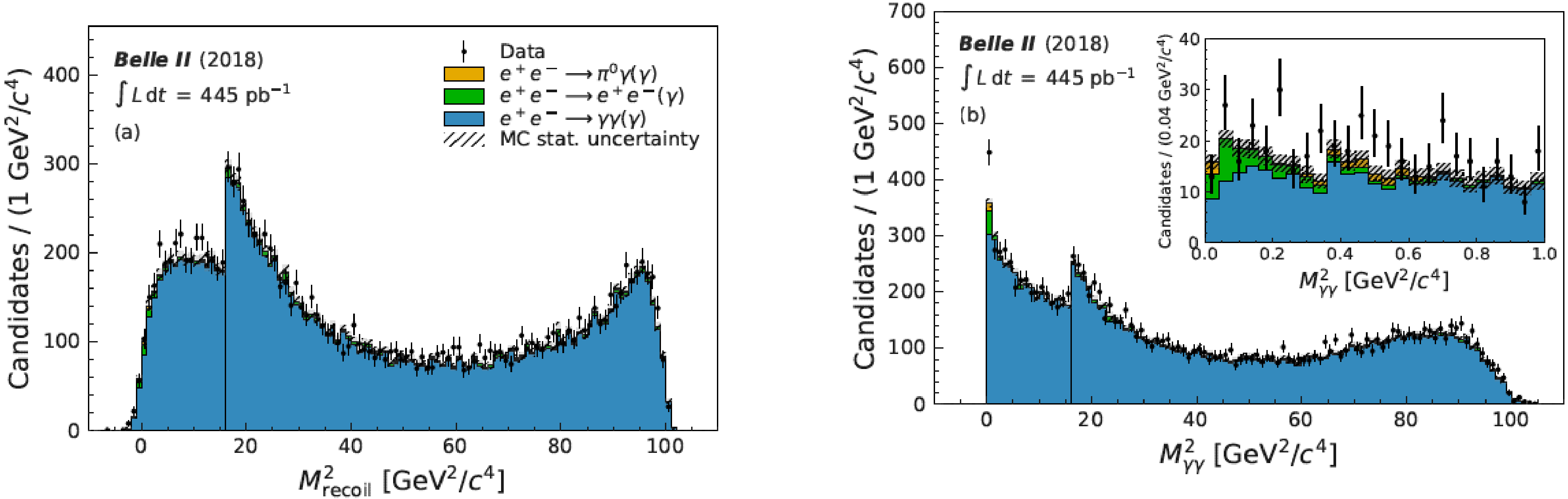


FIG. 1. $M^2_{\rm recoil}$ distribution (a) and $M^2_{\gamma\gamma}$ distribution (b) together with the stacked contributions from the different simulated SM background samples. For $M^2 \leq 16\ \mathrm{GeV}^2/c^4$, the selection is $E_\gamma > 1.0$ GeV; for $M^2 > 16\ \mathrm{GeV}^2/c^4$, it is $E_\gamma > 0.65$ GeV. Simulation is normalized to luminosity. The inset in (b) shows a zoom of the low-mass region $M^2_{\gamma\gamma} < 1\,\mathrm{GeV}^2/c^4$.

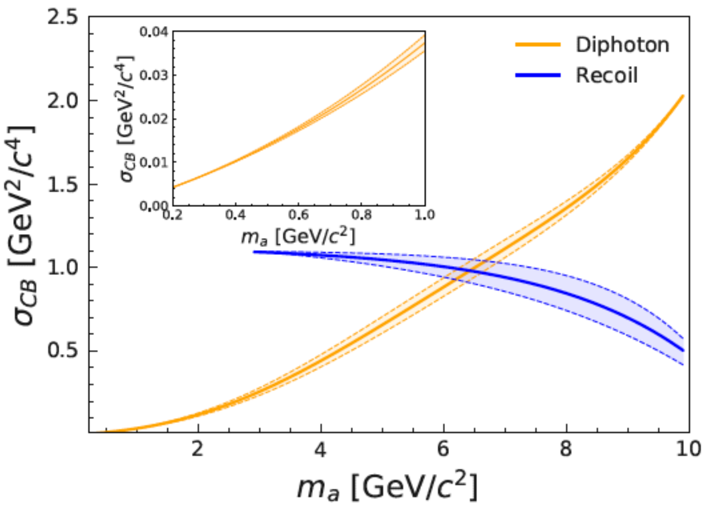
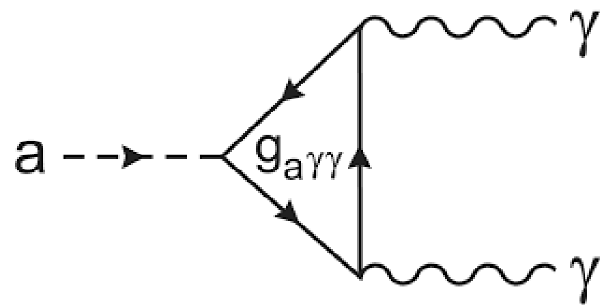


FIG. 2. $M^2_{\gamma\gamma}$ and $M^2_{\rm recoil}$ resolutions with uncertainty as a function of ALP mass m_a. The inset shows a zoom of the low-mass region $m_a < 1\,\mathrm{GeV}/c^2$.

$$e^+e^- \to \gamma a \to \gamma(\gamma\gamma)$$

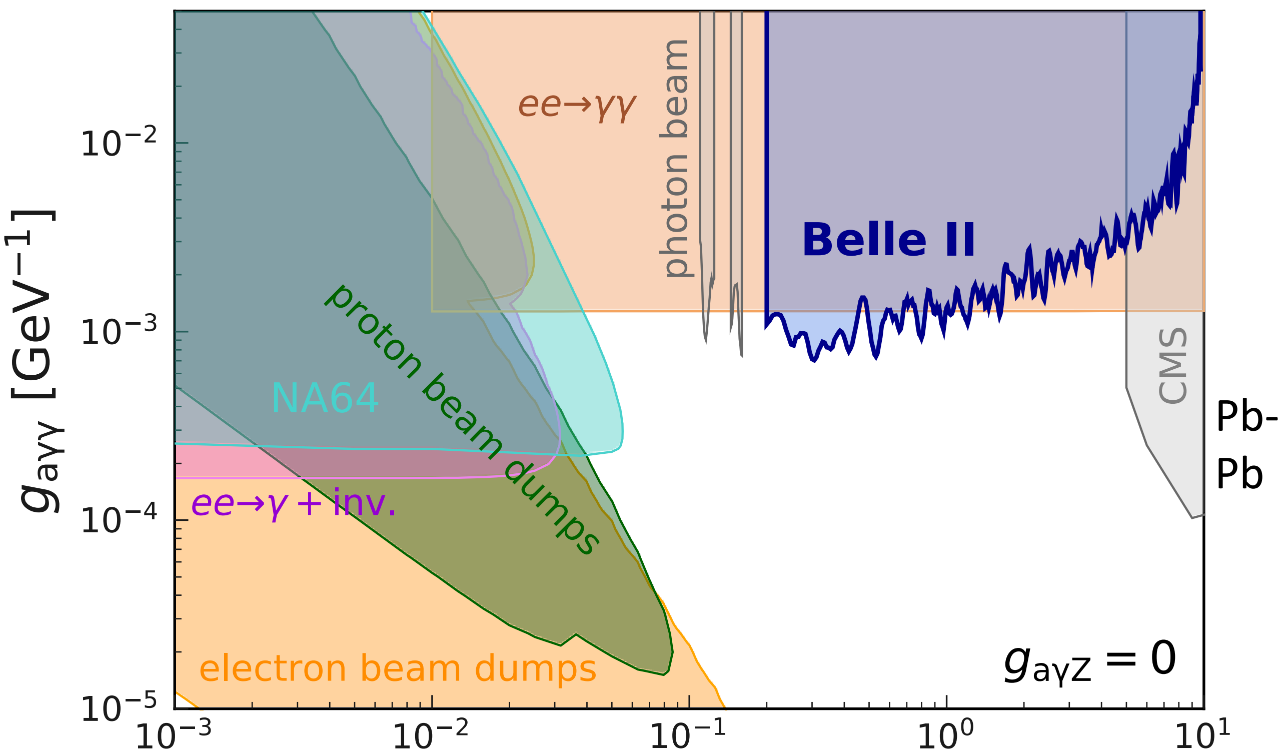
We fit M(γγ)^2 in bins at low mass and M(recoil)^2 at high mass. No significant excess is found.

The Belle II mass range is <u>*200 MeV to 9.7 GeV*</u>, *far above* the keV mass range suggested by the Xenon1T excess. https://arxiv.org/abs/2006.09721



F. Abudinén *et al.* (Belle II Collaboration)
Phys. Rev. Lett. 125, 161806 (2020)

Final ALPS results with 445 pb^{-1} of pilot run (Phase 2) data

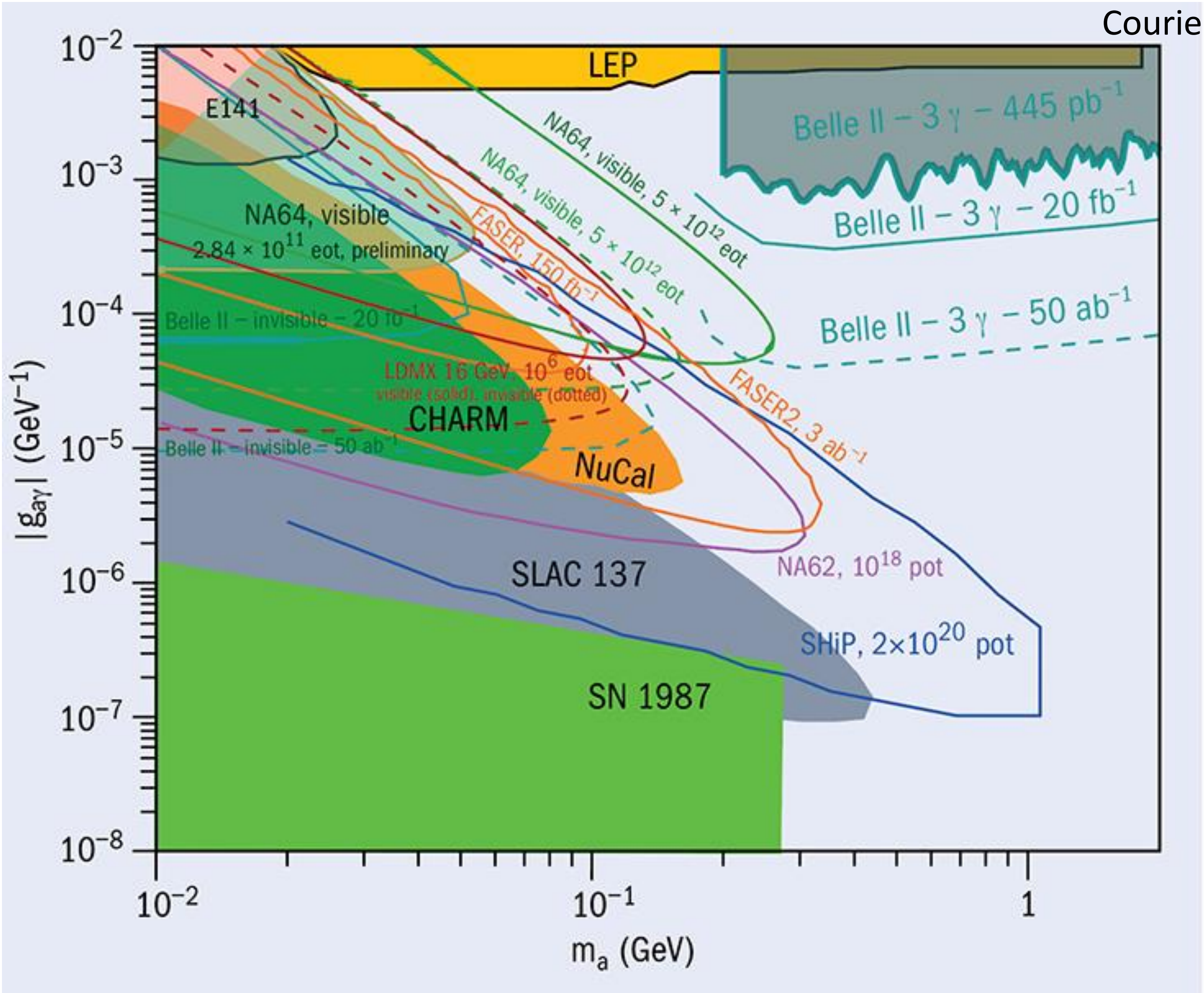


Plan to update with two orders of magnitude more data→one order of magnitude improvement in g

Revised plot includes LEPII recast, NA64 m_a [GeV/c^2]

Future Prospects for ALPS

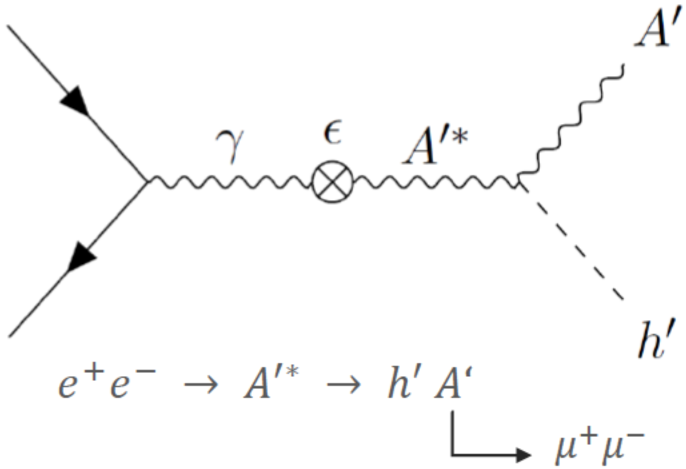
Figure credit: CERN Courier



Dark Higgsstrahlung Sensitivity

There are a variety of possible dark sector portal particles: Vector, Scalar, Pseudo-scalars.

They may decay to lepton pairs, photon pairs, or Invisible particles



Here Ex is the asymmetry of the muon energies; the background from radiative tau pairs peaks near one and the signal is flat.

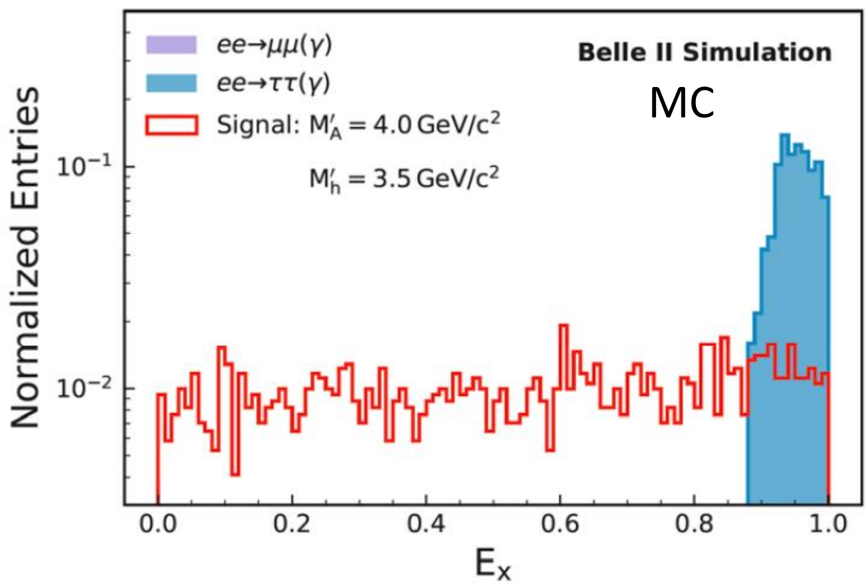
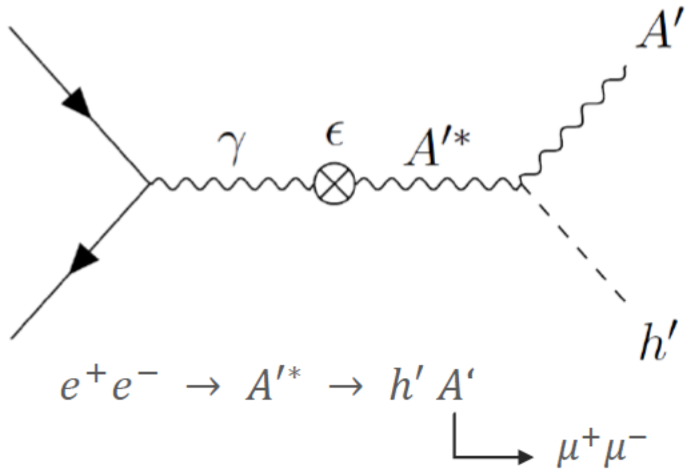


FIG. 3: Distribution of the final background suppression variable E_x. E_x is the absolute value of the asymmetry computed along the line described by the distribution $E^{CMS}_{\mu 1}$ vs $E^{CMS}_{\mu 0}$ in a mass window. Here $M_{A'} = 3.5\,GeV/c^2$, $M_{h'} = 4.0\,GeV/c^2$. The background here is dominated by the $\tau\tau(\gamma)$ contribution.

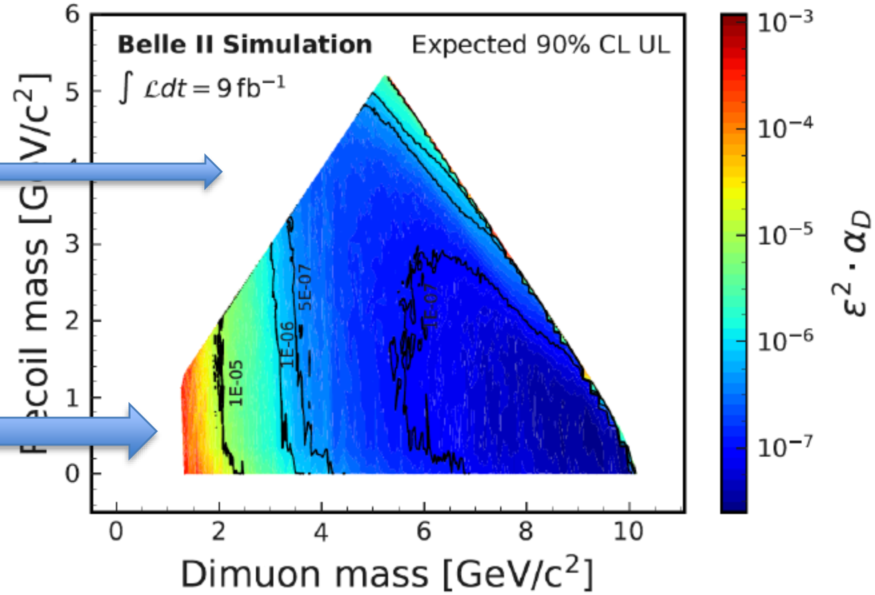
Dark Higgsstrahlung Sensitivity



Final state similar to Z' →invisible but with a much different matrix element and kinematics.

Recast of Belle and BaBar multi-lepton dark searches

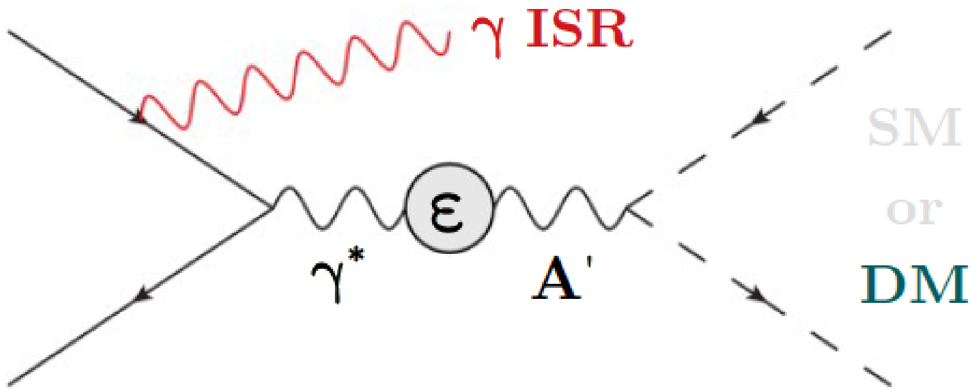
Low Belle II trigger efficiency but covered by KLOE.



Expected sensitivities in $\epsilon^2 \cdot \alpha_D$ the final background suppression (E_x selection) estimated with a Bayesian counting technique. Preliminary conservative systematics considered. Smoothed version.

Upper left side:
PRL 108, 211801 (2012) BaBar; PRL 114, 211801 (2015) Belle

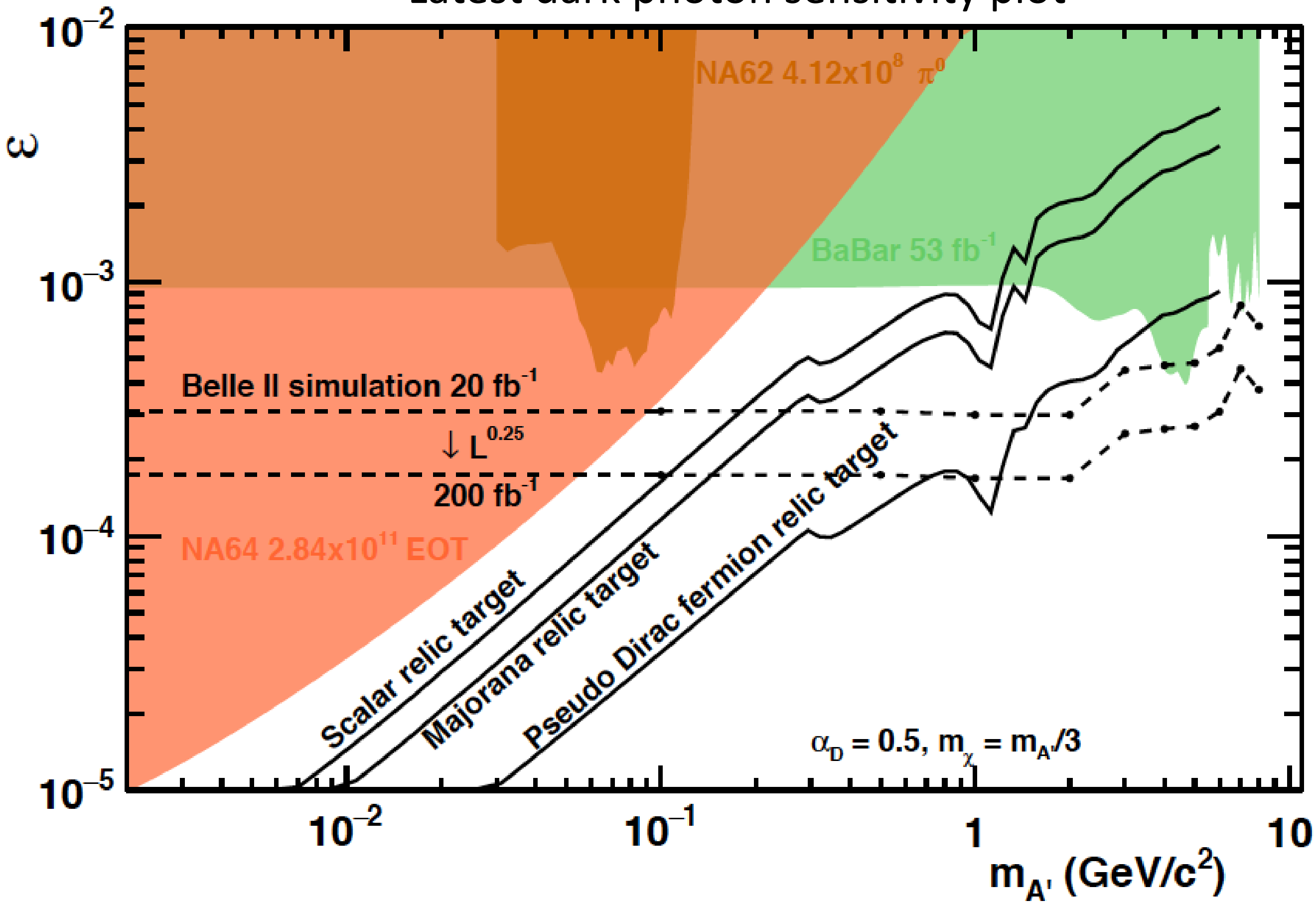
Expect a result in 2021.



Sensitivity for the "dark photon" with the signature: e+e- →γ + nothing

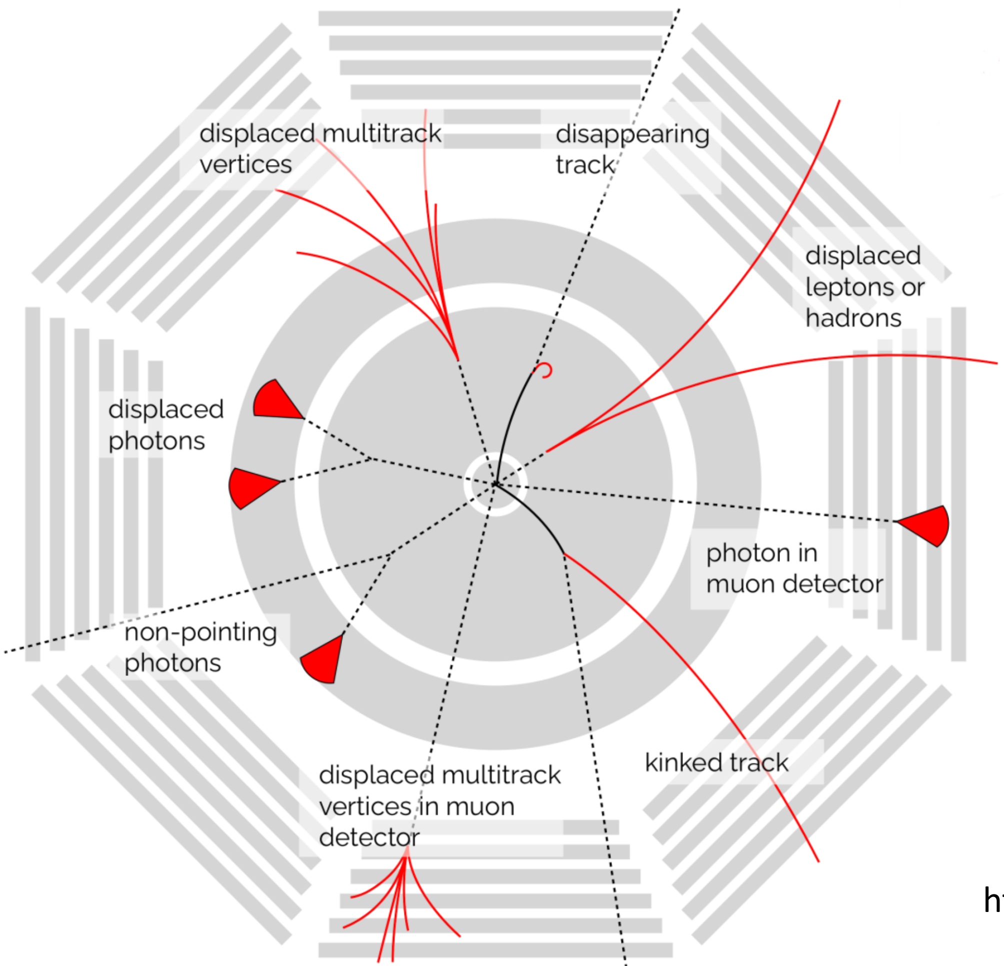
- a bump in the recoil mass: $E_\gamma = \frac{s - m_{A'}^2}{2\sqrt{s}}$

Latest dark photon sensitivity plot

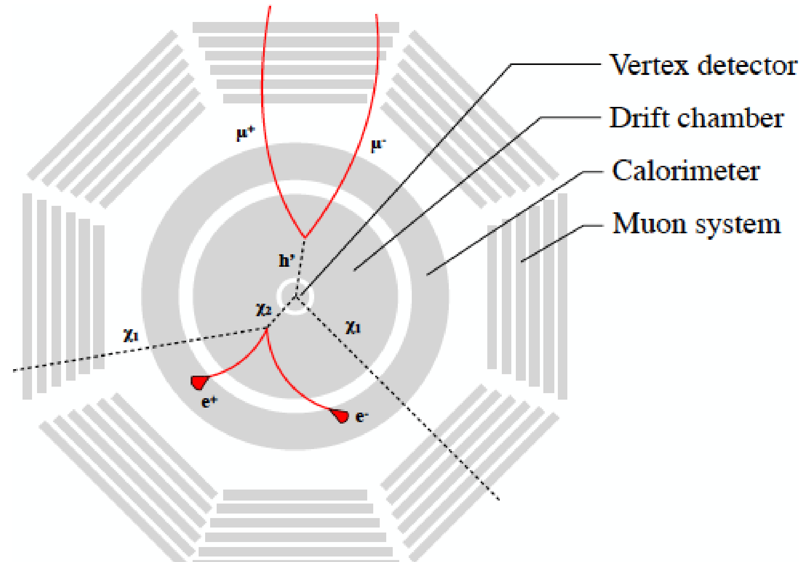


This is probably the most difficult dark sector signature.

LLP (Long-Lived Particle) signatures in Belle II



The feasibility of this possibility has been studied with theorists.



Workshop in 2020

https://indico.belle2.org/event/2920/?view=nicecompact

Experimental prospects: seem to need a displaced vertex *trigger* to obtain sensitivity to LLPs (this is being proposed by some German groups in Belle II).

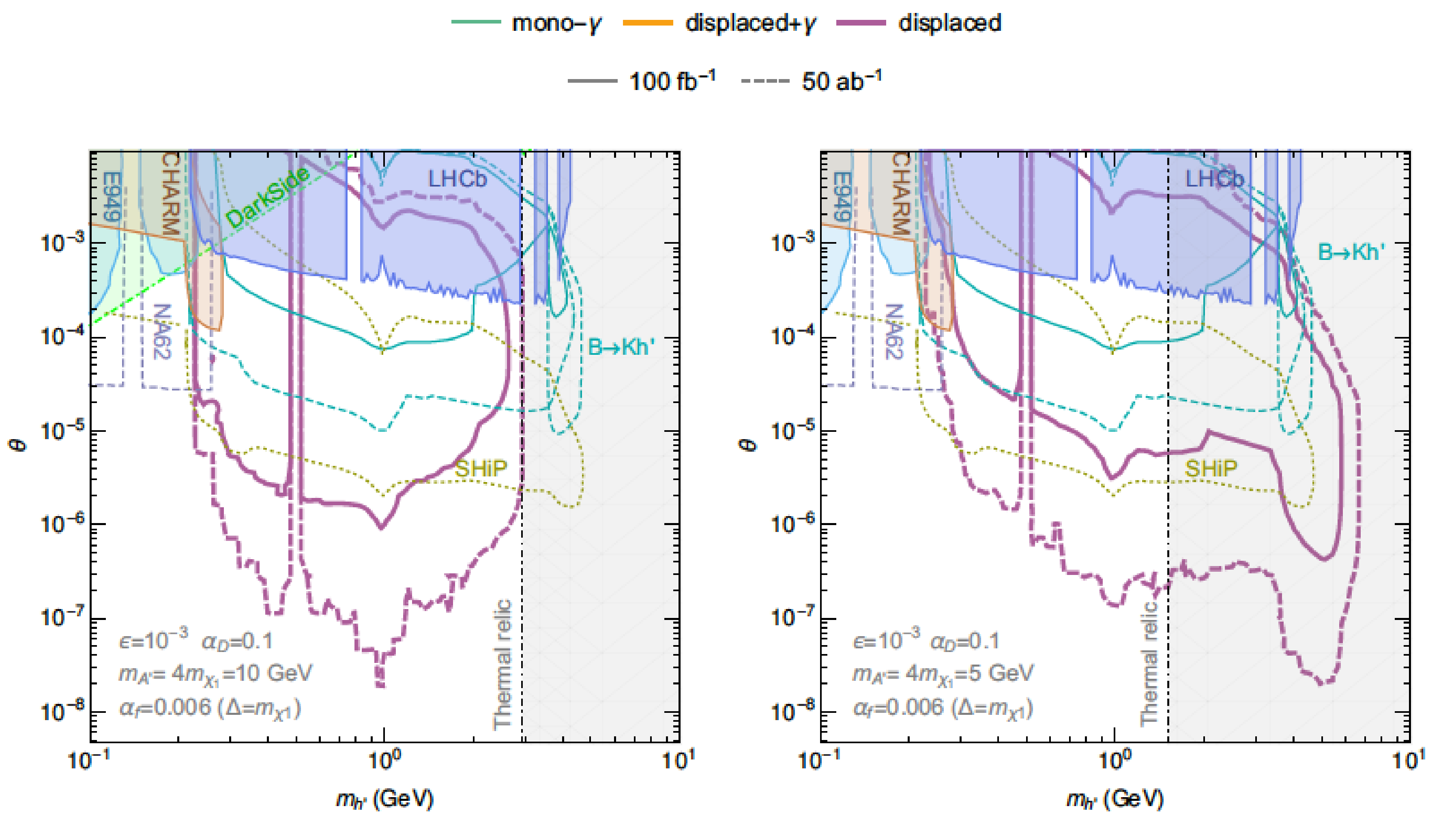
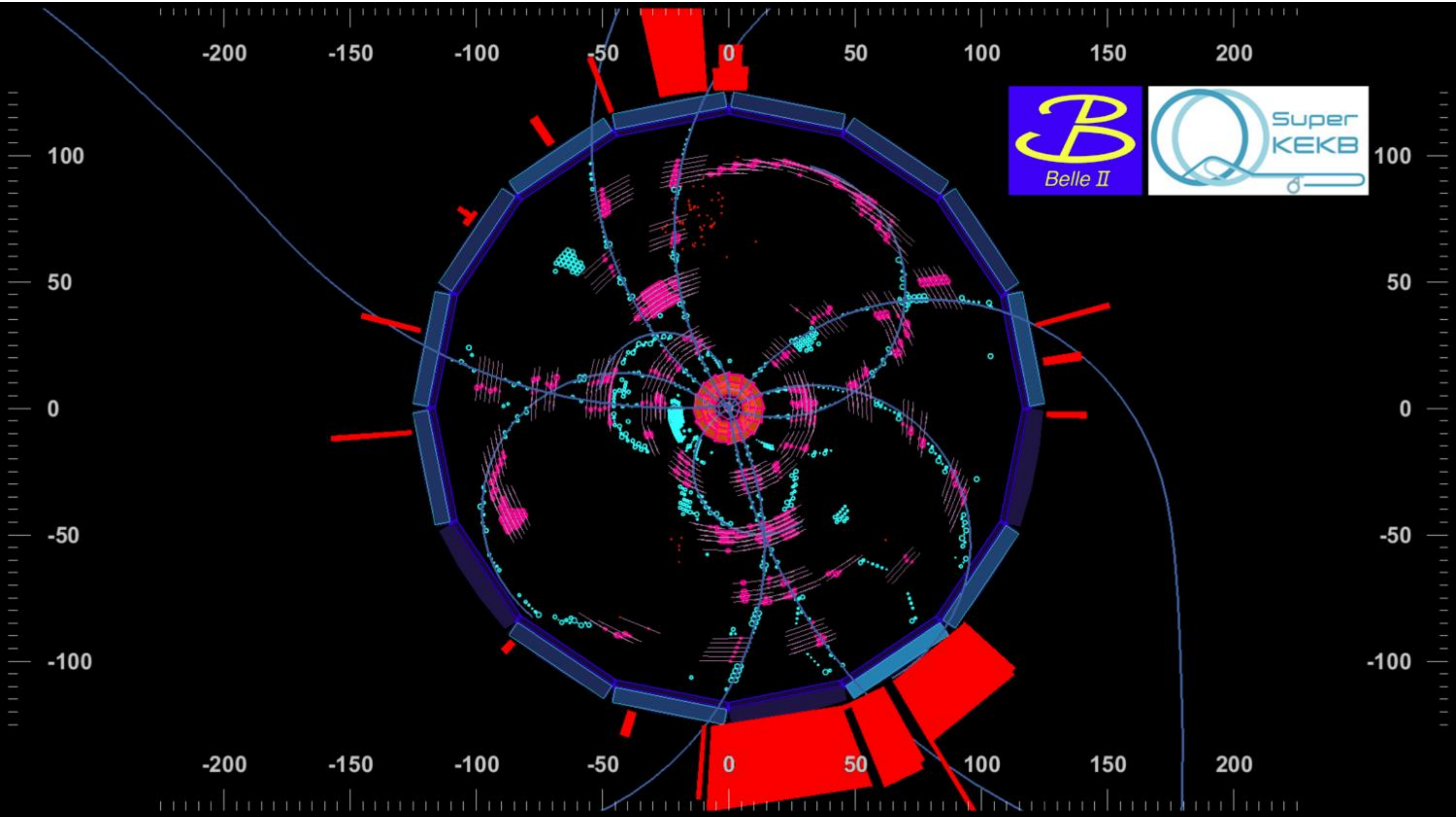


Figure 4: Expected sensitivities of the different searches at Belle II in the $\theta - m_{h'}$ parameter plane for integrated luminosities of 100 fb^{-1} (solid lines) and 50 ab^{-1} (dashed lines). We also show current limits from DarkSide [60], LHCb, CHARM and E949.

https://arxiv.org/pdf/2012.08595.pdf

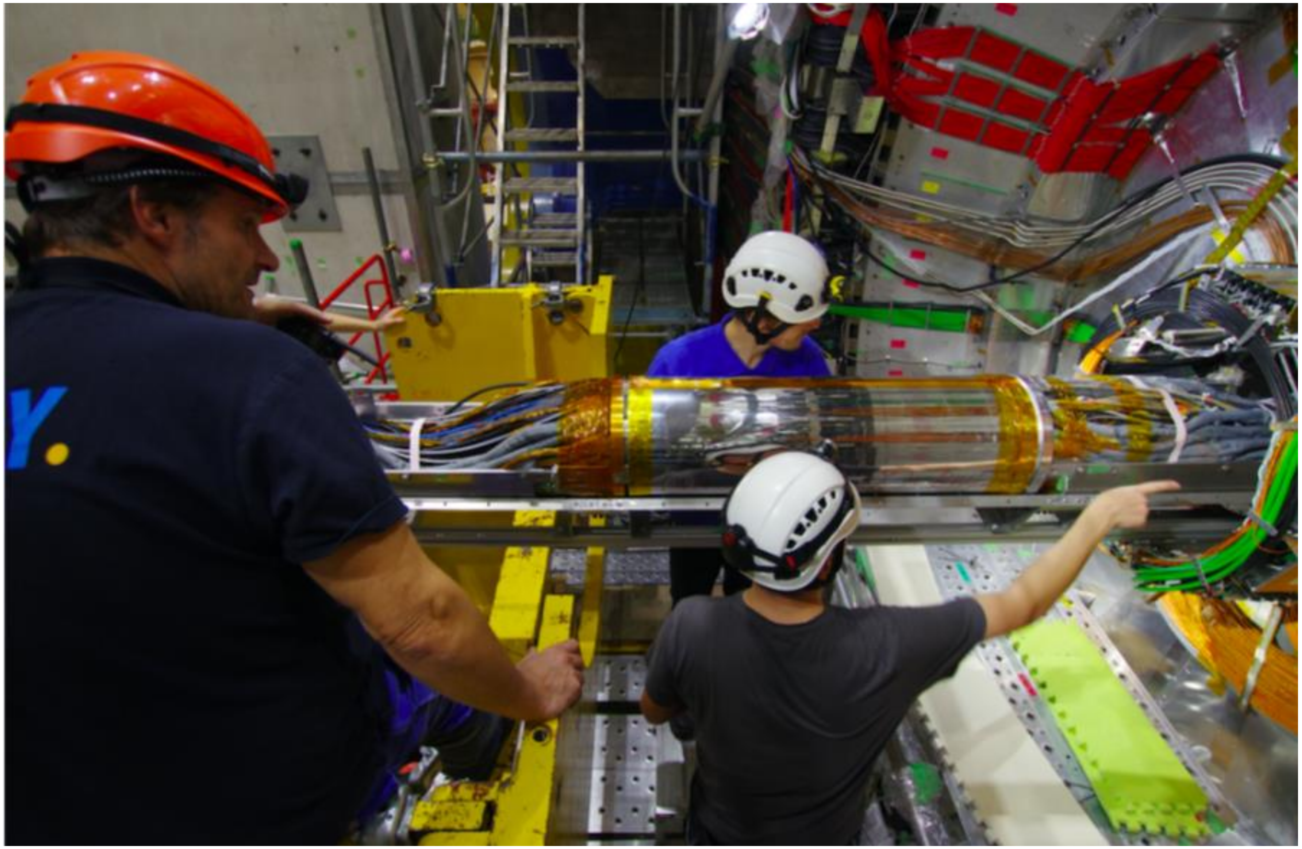
Work is underway to determine the feasibility of the LLP dark sector signatures.

Flavor Results from the Physics Run (“Phase 3”)



Belle II is not just a “dark sector” experiment…..

Time Dependent Measurements at Belle II



Belle II VXD installed on Nov 21, 2018. (PXD L1 and two ladders of L2. and the SVD (4 layers))

The B-anti B meson pairs at the Upsilon(4S) are produced in a coherent, *entangled* **quantum mechanical state**.

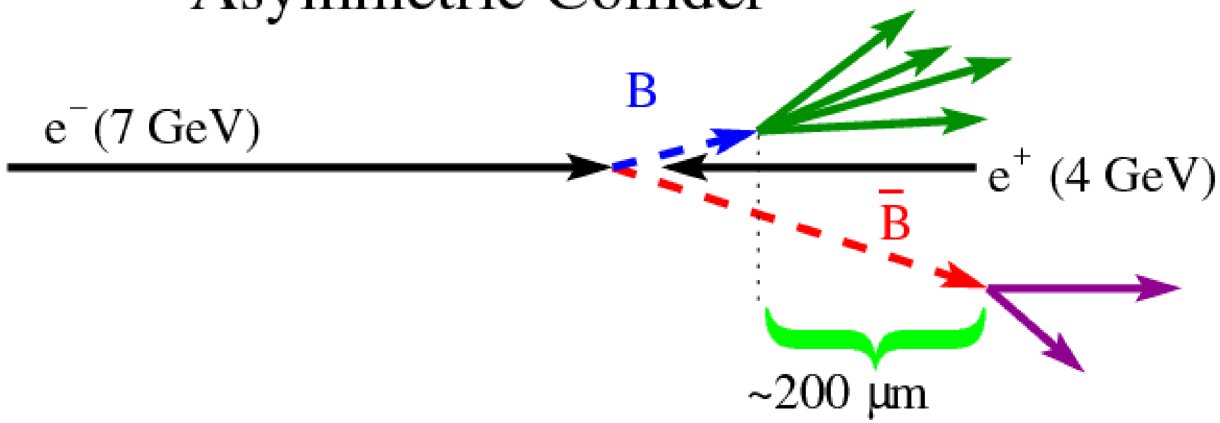
(Note the minus sign)

$$|\Upsilon\rangle = |B^0(t_1,f_1)\overline{B^0}(t_2,f_2)\rangle - |B^0(t_2,f_2)\overline{B^0}(t_1,f_1)\rangle$$

Need to measure decay times to observe CP violation (particle-antiparticle asymmetry).

One B decays → collapses the flavor wavefunction of the other anti-B. (N.B. One B must decay before the other can mix)

Asymmetric Collider



Not to scale

The beam energies are asymmetric (7 on 4 GeV)

The decay distance is increased by around a factor ~7

Check time-dependent capabilities: Example of D^0 lifetime results.

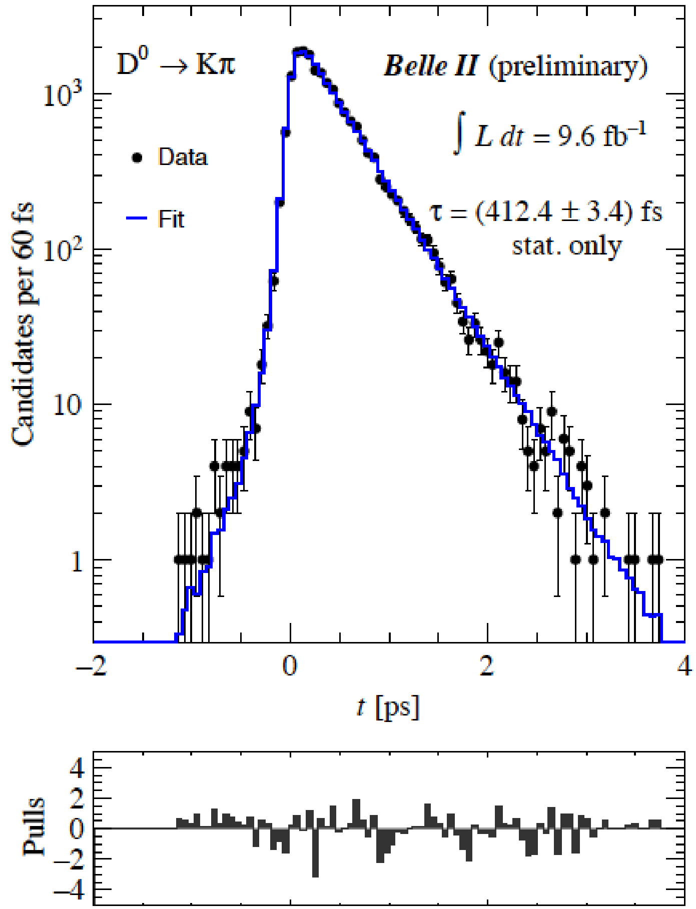


Figure 2: Fit to the proper-time distributions of D^*-tagged $D^0 \to K^-\pi^+$ candidates reconstructed with 2019 Belle II data. The extracted lifetime in this channel is (412.4 ± 3.4) fs, the estimated average proper time resolution is (97 ± 8) fs.

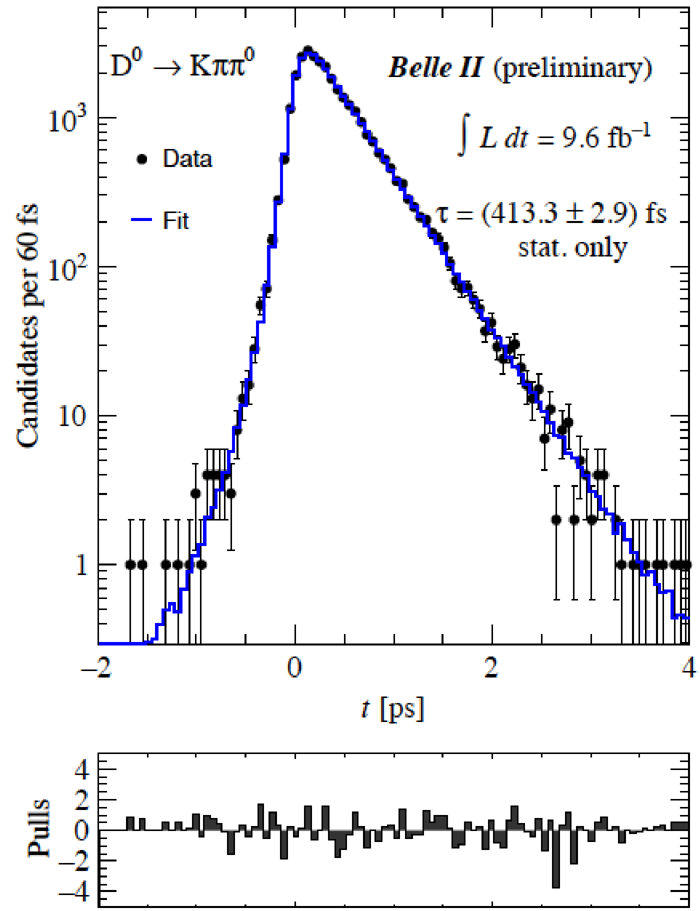
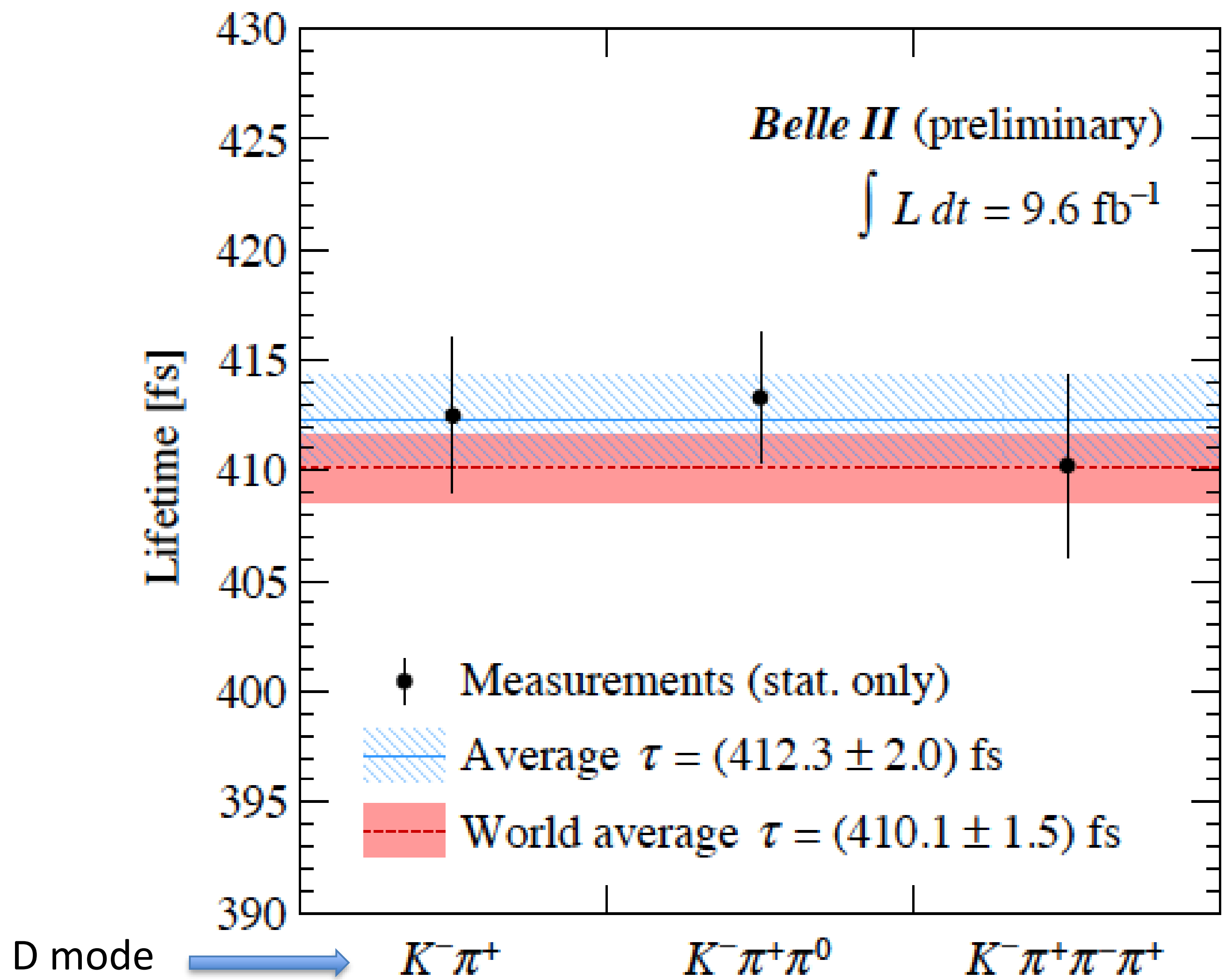


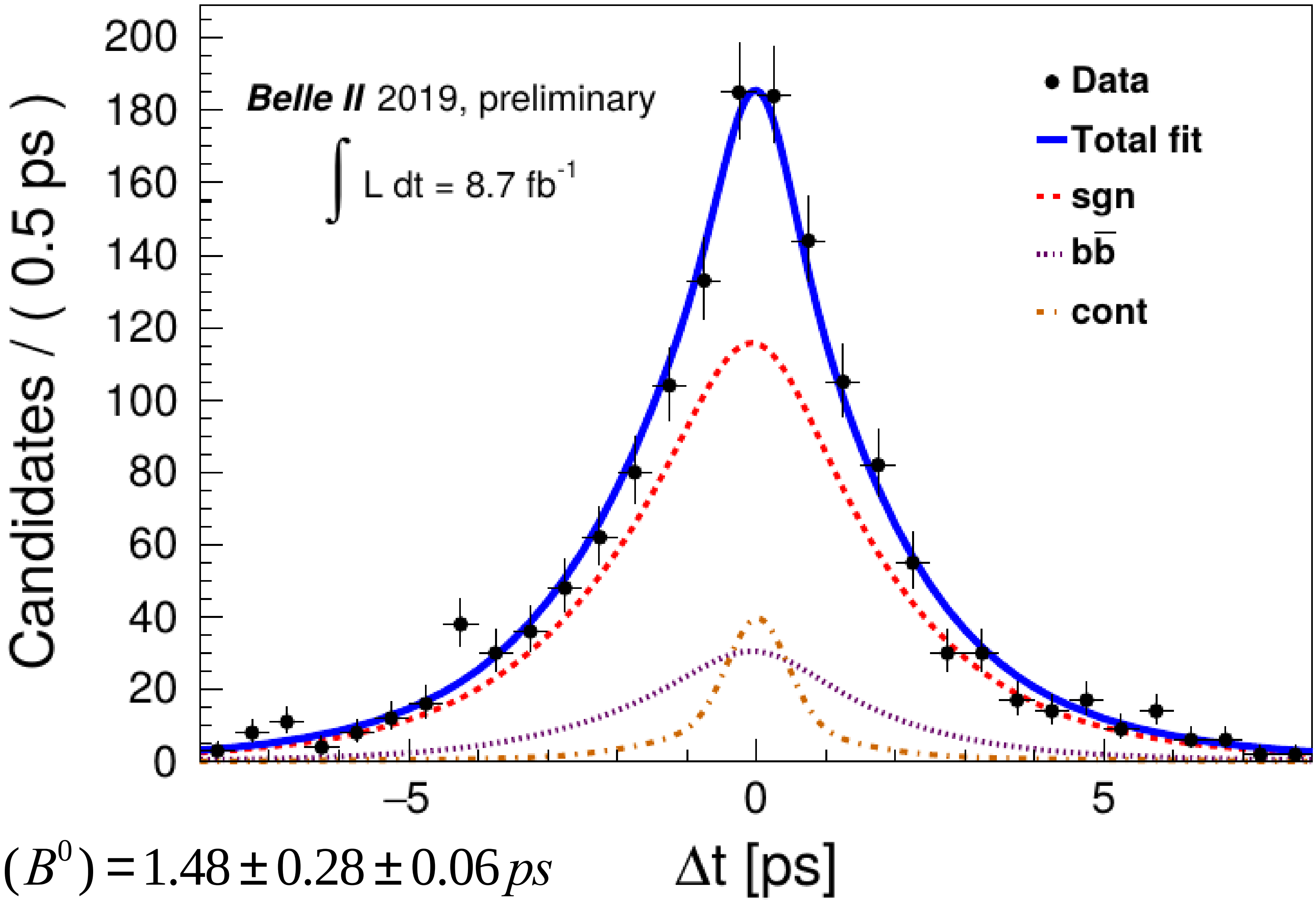
Figure 3: Fit to the proper-time distributions of D^*-tagged $D^0 \to K^-\pi^+\pi^0$ candidates reconstructed with 2019 Belle II data. The extracted lifetime in this channel is (413.3 ± 2.9) fs, the estimated average proper time resolution is (128 ± 9) fs.

Time resolution parameterization can be determined from data.



The addition of a pixel vertex detector (with a 1cm radius beampipe) gives a *factor of two improvement* in proper time resolution for charm lifetime measurements compared to Belle. Alignment systematics are much improved. Should have world-competitive *charm lifetime* results in the near future.

Next: B^0 Lifetime measurement ($B \rightarrow D^{(*)} h$)

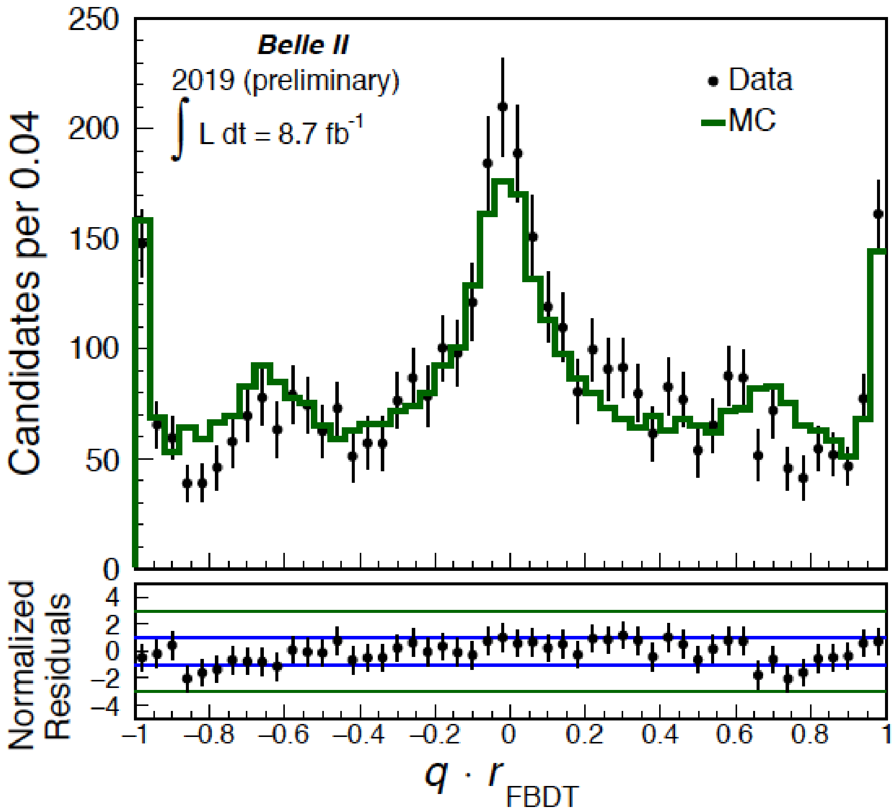


$$t(B^0) = 1.48 \pm 0.28 \pm 0.06\, ps$$

$$WA = 1.519 \pm 0.004\, ps$$

https://arxiv.org/pdf/2005.07507

Flavor Tagging (b quark or anti-b quark ?)



Categories	Targets for $\overline{B}^0$
Electron	e^-
Intermediate Electron	e^+
Muon	μ^-
Intermediate Muon	μ^+
Kinetic Lepton	l^-
Intermediate Kinetic Lepton	l^+
Kaon	K^-
Kaon-Pion	K^-, π^+
Slow Pion	π^+
Maximum P*	l^-, π^-
Fast-Slow-Correlated (FSC)	l^-, π^+
Fast Hadron	π^-, K^-
Lambda	Λ

Underlying decay modes

$\overline{B}^0 \to D^{*+}\ \overline{\nu}_\ell\ \ell^-$
$\hookrightarrow D^0\ \pi^+$
$\hookrightarrow X\ K^-$

$\overline{B}^0 \to D^+\ \pi^-\ (K^-)$
$\hookrightarrow K^0\ \nu_\ell\ \ell^+$

$\overline{B}^0 \to \Lambda_c^+\ X^-$
$\hookrightarrow \Lambda\ \pi^+$
$\hookrightarrow p\ \pi^-$

$B^0 \to D^{(*)-}h^+$	$\varepsilon_i \pm \delta\varepsilon_i$		$w_i \pm \delta w_i$		$\varepsilon_{\mathrm{eff},i} \pm \delta\varepsilon_{\mathrm{eff},i}$	
r- Interval	Belle II	Belle	Belle II	Belle	Belle II	Belle
0.000 – 0.100	20.3 ± 1.8	22.2 ± 0.4	47.4 ± 4.2	50.0	0.1 ± 0.2	0.0
0.100 – 0.250	17.4 ± 0.9	14.5 ± 0.3	42.8 ± 4.4	41.9 ± 0.4	0.4 ± 0.4	0.4 ± 0.1
0.250 – 0.500	21.2 ± 1.0	17.7 ± 0.4	26.9 ± 3.7	31.9 ± 0.3	4.5 ± 1.5	2.3 ± 0.1
0.500 – 0.625	11.1 ± 0.7	11.5 ± 0.3	16.7 ± 5.5	22.3 ± 0.4	4.9 ± 1.7	3.5 ± 0.1
0.625 – 0.750	9.6 ± 0.9	10.2 ± 0.3	9.2 ± 6.5	16.3 ± 0.4	6.4 ± 2.1	4.6 ± 0.2
0.750 – 0.875	7.0 ± 0.6	8.7 ± 0.3	1.2 ± 5.7	10.4 ± 0.4	4.0 ± 1.2	5.5 ± 0.1
0.875 – 1.000	13.4 ± 0.8	15.3 ± 0.3	0.0 ± 3.3	2.5 ± 0.3	13.4 ± 1.9	13.8 ± 0.3
Total	$\varepsilon_{\mathrm{eff}} = \sum_i \varepsilon_i \cdot (1-2w_i)^2 =$				33.8 ± 3.9	30.1 ± 0.4

We obtain $\varepsilon_{\mathrm{eff}} = \varepsilon(1\text{-}2\ w)^2$ = 33.8+-3.9 %, which is a slight improvement over the Belle result of 30.1+-0.4%

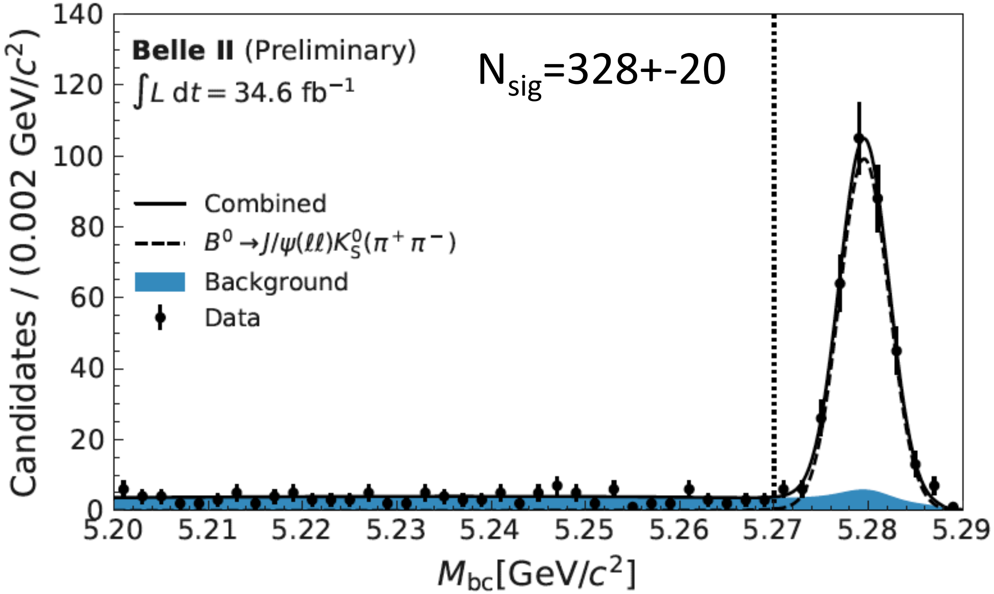
BELLE2-CONF-2020-018

https://arxiv.org/abs/2008.02707

Observation of B→J/ψ K_S and the road to CPV

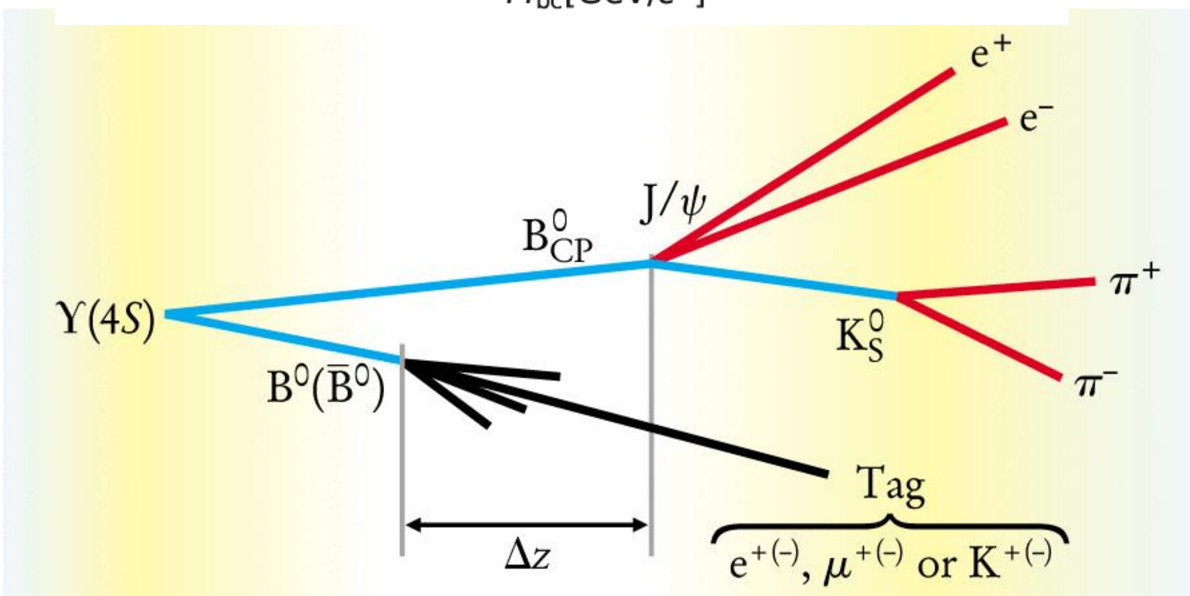
A “Golden” CP Eigenstate

About ½ of the *first* Phase 3 data sample.



Now apply a *simplified analysis:*

1) Only one CP eigenstate
2) No beam spot constraint
3) Flavor tagging does not separate r-



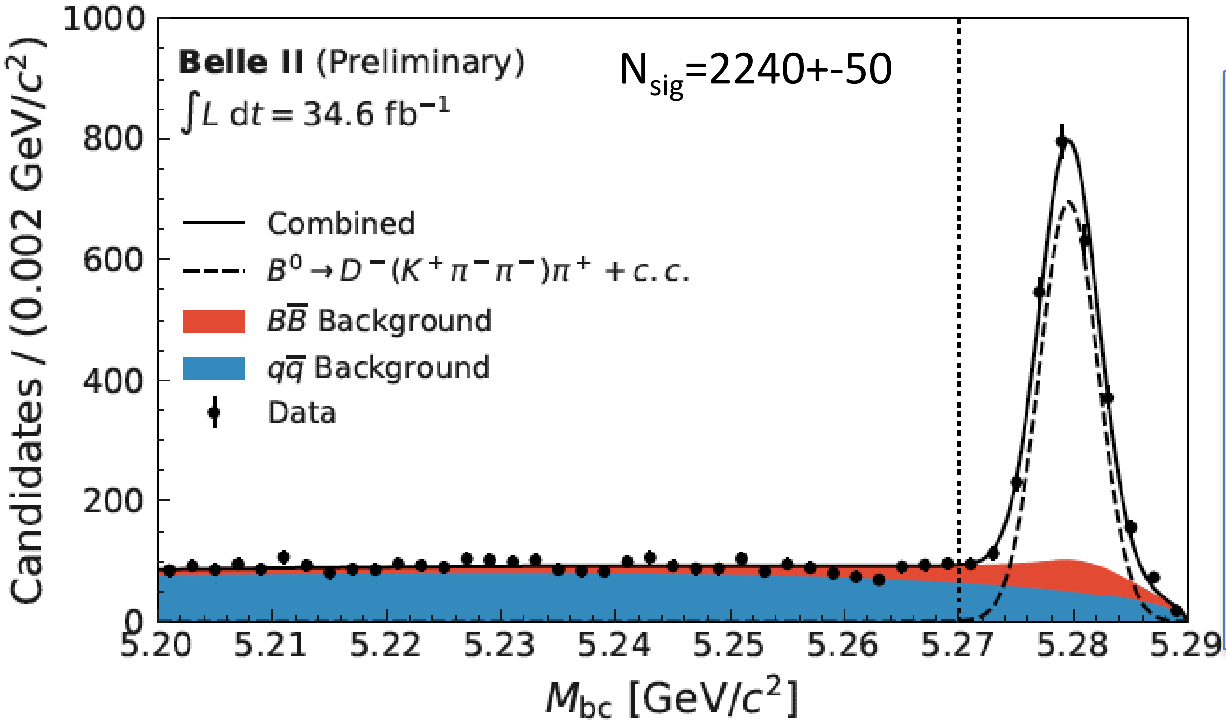
$$Dt \approx \frac{Dz}{bg}$$

Figure credit: Physics Today

$$B^0 \to f\ ;\ B^0 \to \overline{B^0} \to f$$

This is a flavor-specific B decay mode with a charged track topology similar to the $B \rightarrow J/\psi\, K_S$ signal.

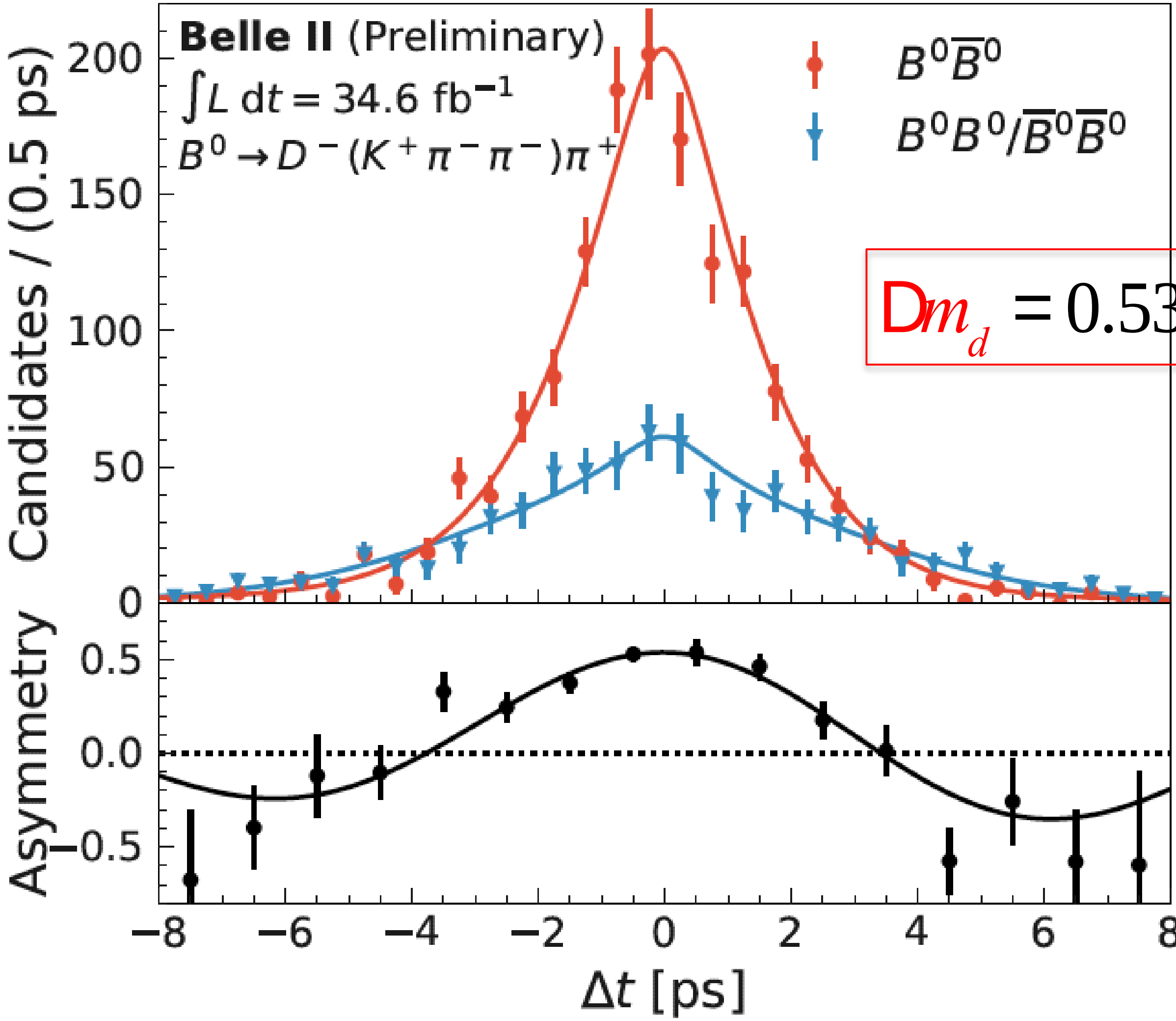
$B^0 \rightarrow D^- \pi^+$ is not self-conjugate and is not a CP eigenstate (but can be used to check time-dependence of B-Bbar mixing).



Start with a B^0 (wait a while, ~a few x 10^{-12} sec).

There is a large probability that the B^0 will turn into its anti-particle, an anti-B^0 (*20th century physics*, discovered by ARGUS at DESY in 1987)

Time Dependent Mixing asymmetry (not CPV)



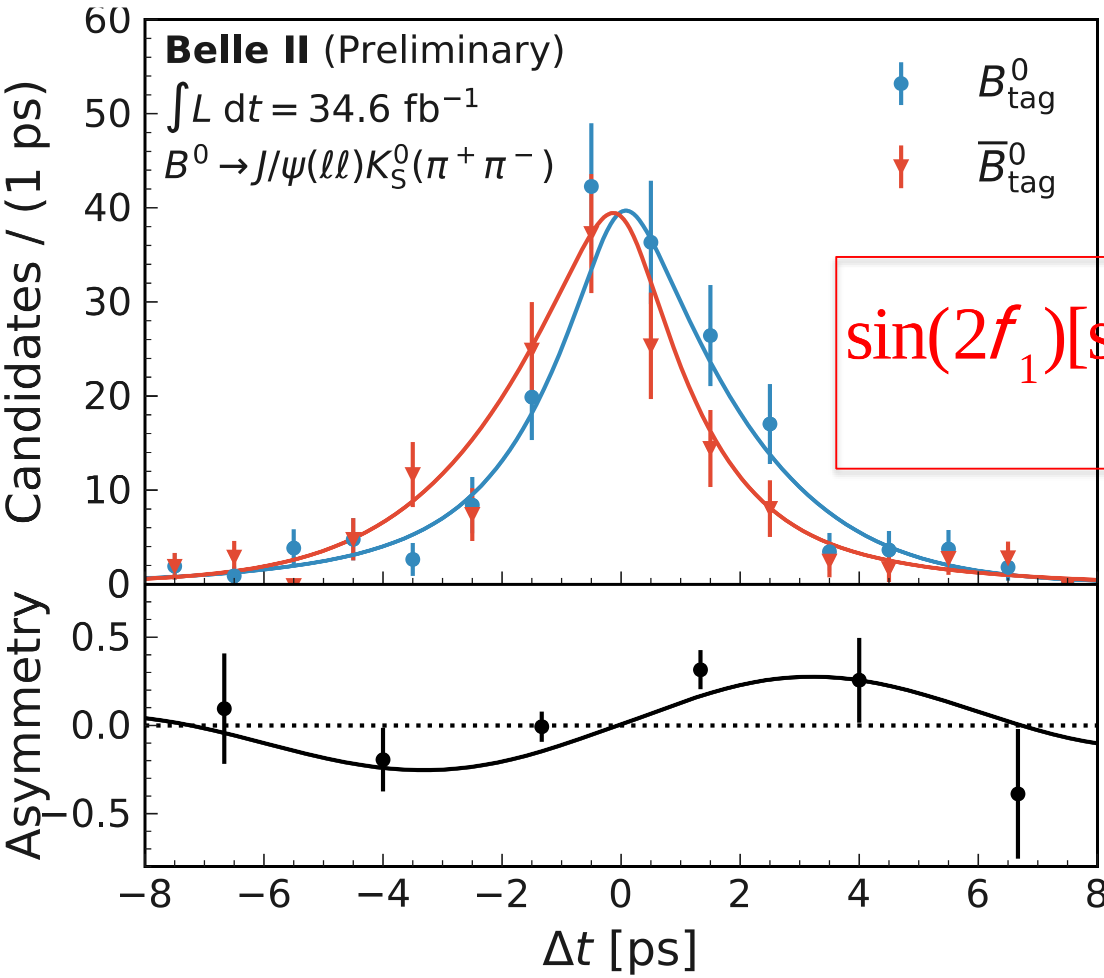
$$\Delta m_d = 0.531 \pm 0.046 \pm 0.013\, ps^{-1}$$

(WA=0.5065 ±0.019 ps^{-1})

$$Asym(mixing) = \frac{OF - SF}{OF + SF}$$

$$N_{SF/OF} \propto \frac{\exp(-|\Delta t|/\tau)}{4\tau}[1 \pm (1-2w)\cos(\Delta m_d \Delta t)] \otimes R(\Delta t)$$

Hint of time-dependent CPV from Belle II (2.7σ significance)



$\sin(2\phi_1)[\sin(2\beta)] = 0.55 \pm 0.21 \pm 0.04$

(WA=0.685±0.019)

Based on the interference of

$$B^0 \to f_{CP}\ ;\ B^0 \to \overline{B^0} \to f_{CP}$$

$$N_{+/-} \propto \frac{\exp(-|\Delta t|/\tau)}{4\tau}\left\{1 \pm (1-2w)\sin(2\phi_1)\sin(\Delta m_d \Delta t)\right\} \otimes R(\Delta t)$$

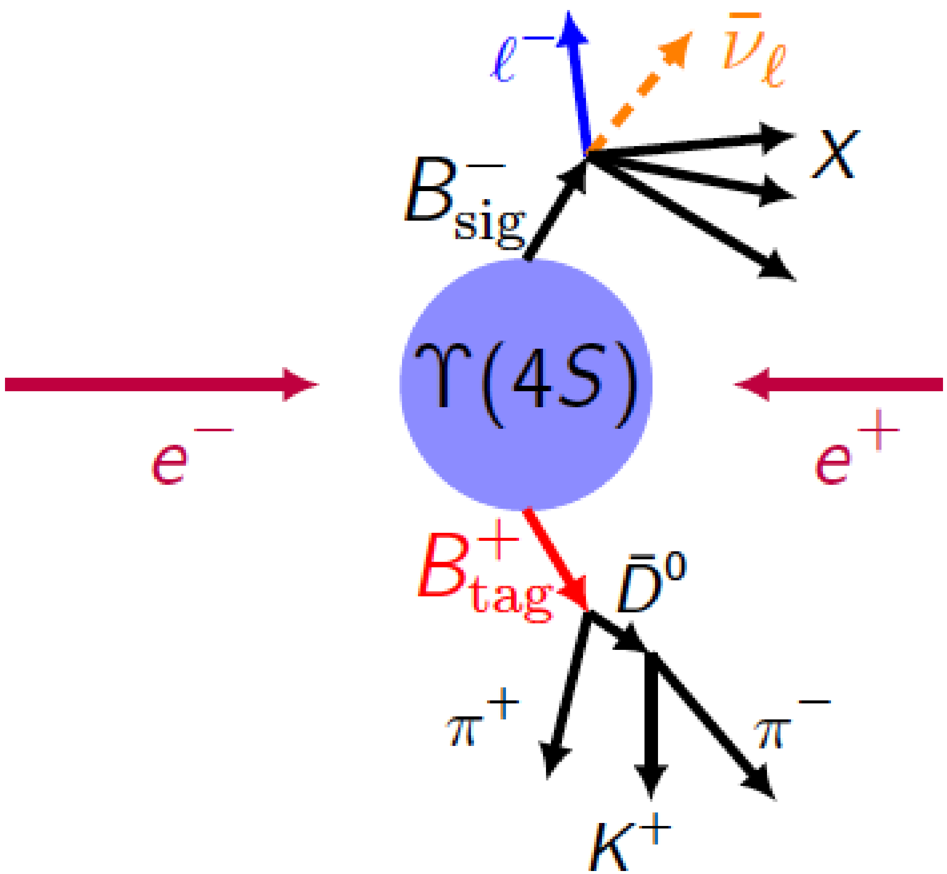
Some critical Belle II capabilities for flavor (B, D, tau) physics

Full and equally strong capabilities for electrons and muons

Photons, K_S's with excellent resolution and efficiency

Neutrinos via "missing energy" and missing momentum. Hermeticity.

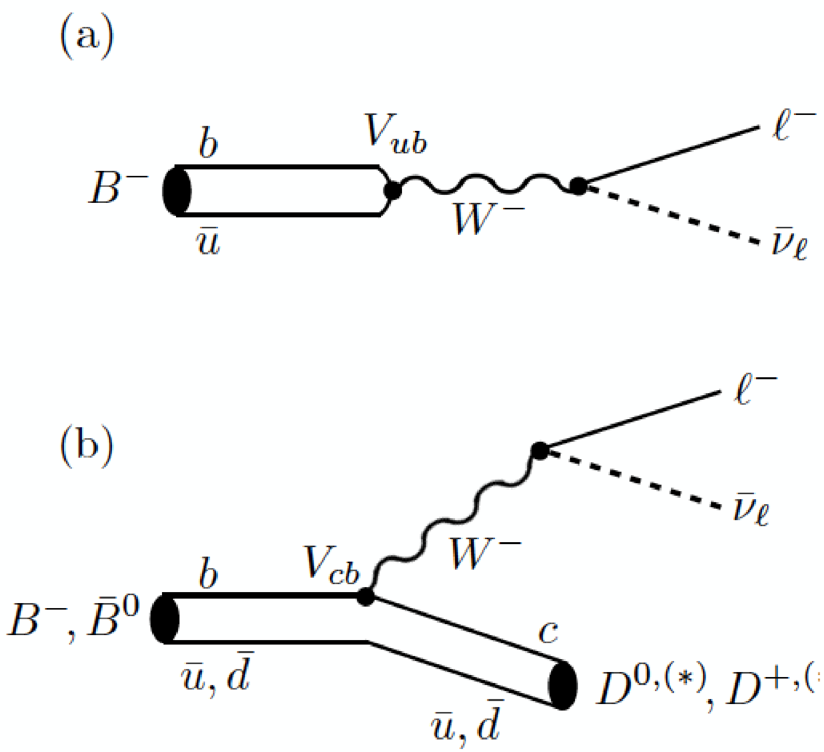
https://arxiv.org/abs/2008.06096

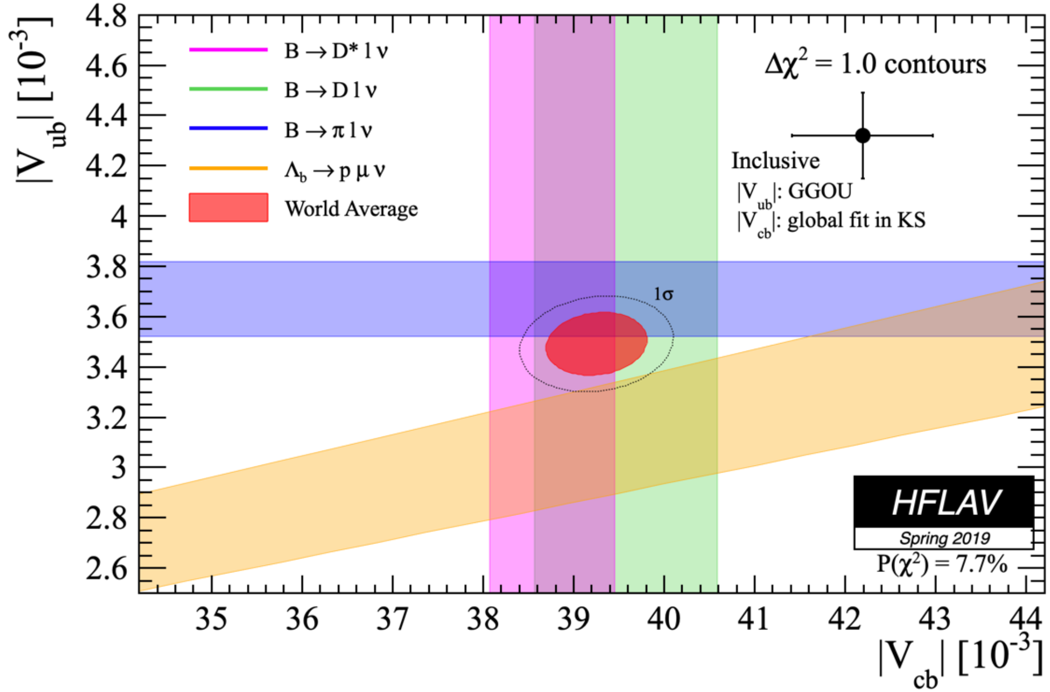


This is now called FEI "Full Event Interpretation" and uses large numbers of tag modes via a BDT (Boosted Decision Tree). About a factor of two improvement compared to Belle is expected.

T. Keck et al., Comput. Softw. Big Sci. 3, 6 (2019), arXiv:1807.08680 [hep-ex].

Motivation for semileptonic decays: V_{cb} , V_{ub}





a) Purely leptonic decays e.g. $B^+ \to \tau^+ \nu$

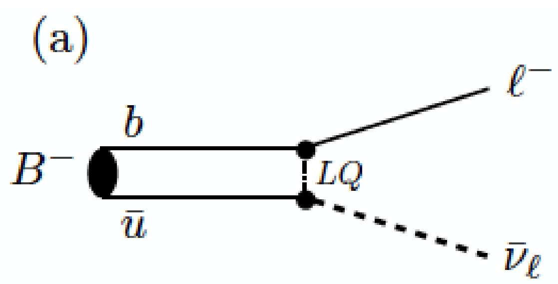
b) Semileptonic decays e.g.
$B \to D^{(*)} \tau\nu$ or $B \to D^{(*)} l \nu$

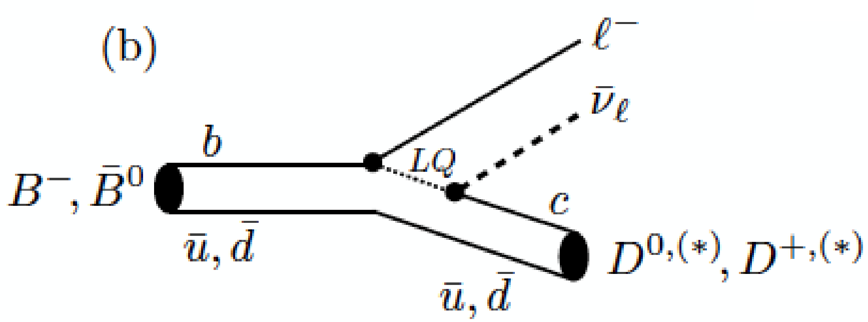
Tensions persist between exclusive and inclusive (e+e-) measurements of fundamental CKM elements $|V_{cb}|$, $|V_{ub}|$

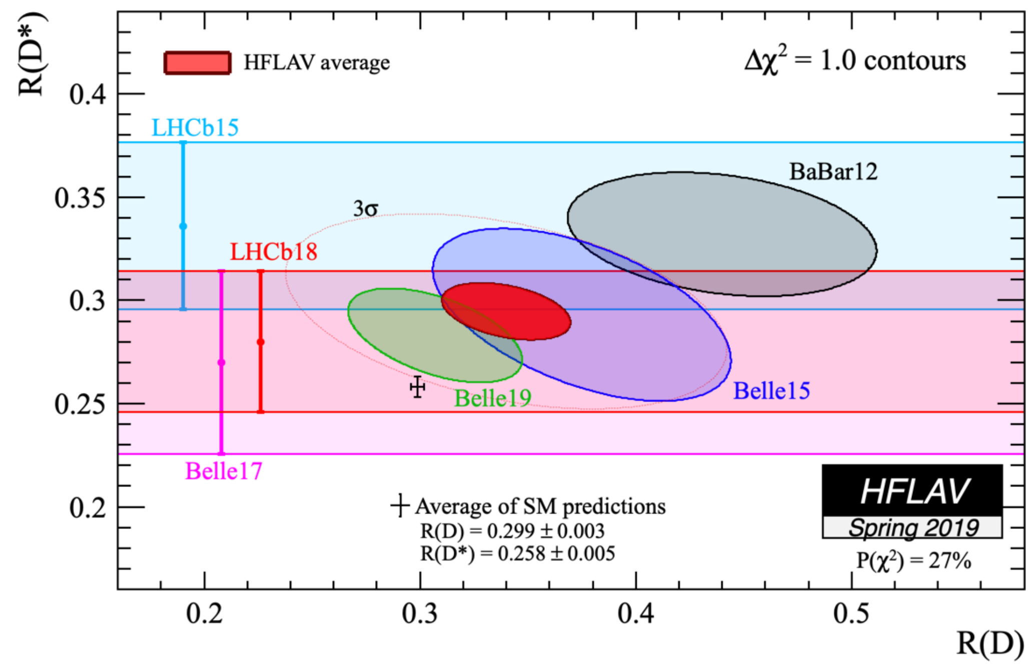
Figure credit:
https://www.nature.com/articles/nature22346

B→D$^{(*)}$ τ υ, lepton universality and NP

Some new physics possibilities (leptoquarks (LQ), charged Higgs type 3 etc..):



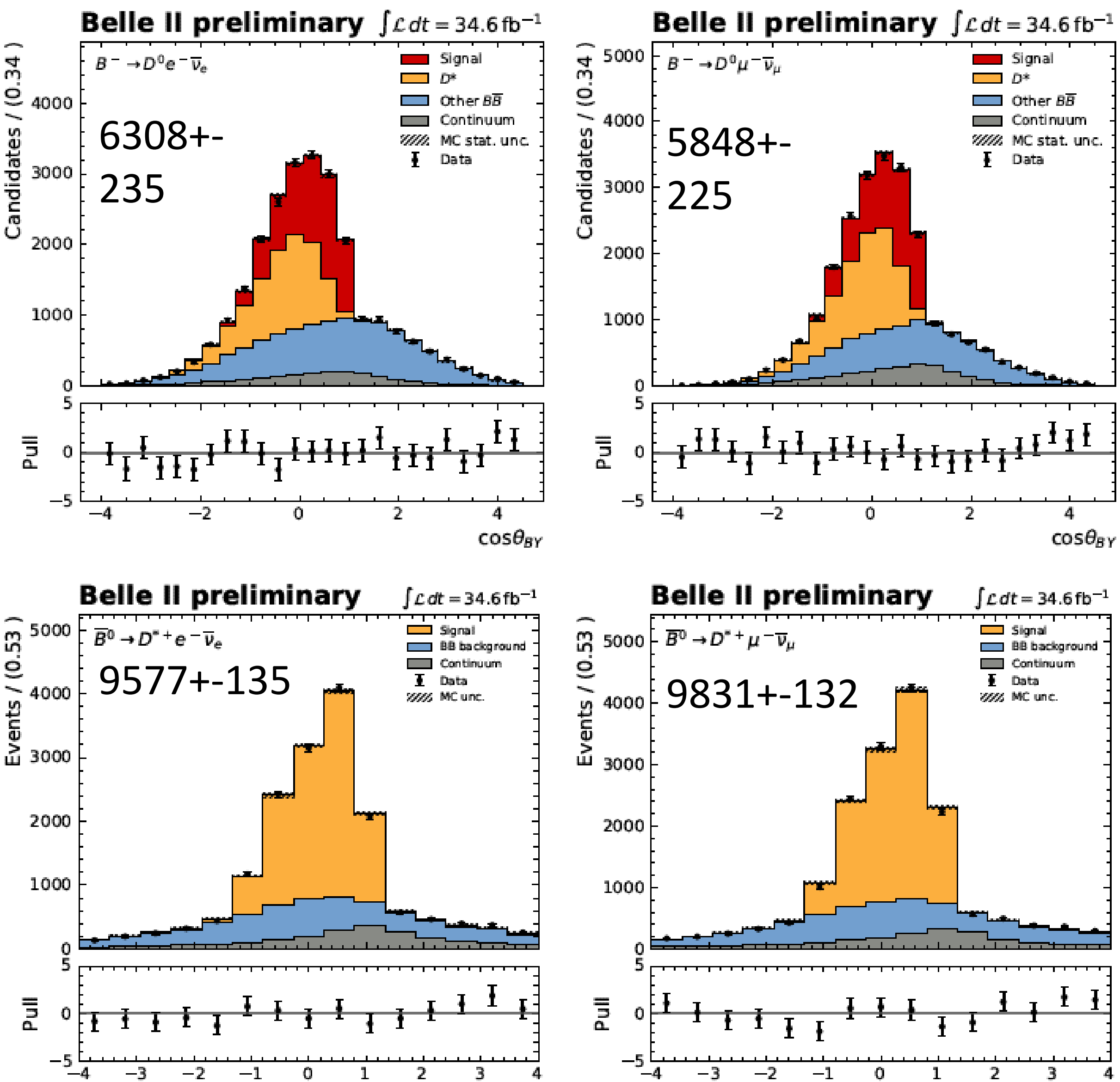




With current data from Belle, LHCb and BaBar:

Evidence of lepton universality breakdown in semileptonic B decays with τ leptons. Latest Belle measurement with semileptonic tags brings down to the WA discrepancy to 4→3σ

B→D*$^+$ l$^-$ ν and D^{0}l$^-$ ν (untagged)



$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_l) = (4.59 \pm 0.05_{\rm stat} \pm 0.18_{\rm syst} \pm 0.45_{\pi_s})\,\%$$

Can already measure B meson branching fractions.

Have to work more on the systematic uncertainty from slow pion detection.

Rather than missing-mass squared, we fit cos θ_{BY}, peaks at zero in [-1,1] for correctly reconstructed signal

$$R_{e/m} = \frac{BF(B \to D^{*-} e^+ n_e)}{BF(B \to D^{*-} m^+ n_m)} = 0.99 \pm 0.03$$

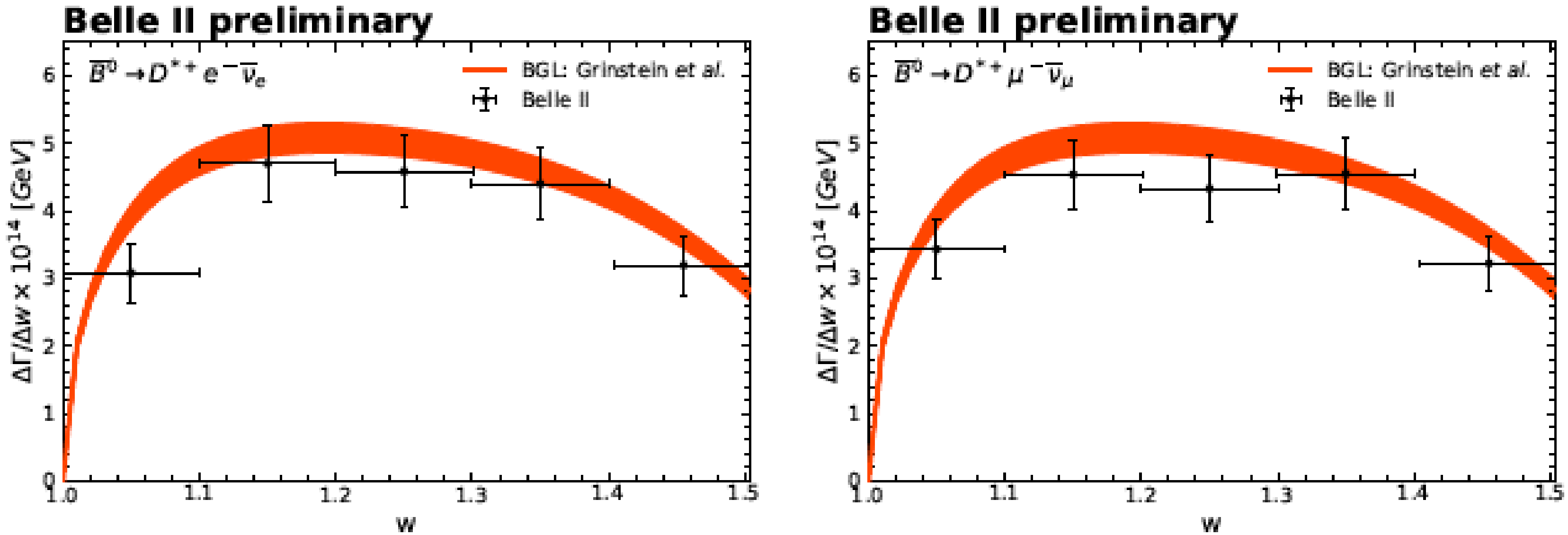
Ready for lepton universality checks.

https://arxiv.org/abs/2008.07198

BELLE2-CONF-2020-022

B→D*+ l- nu (untagged)

Warning: Not a fit! ; this merely shows that a $|V_{cb}|$ extraction will be possible in the near future.



Zero recoil point

Zero recoil point

FIG. 5. The measured partial decay rates for electrons and muons are compared to the BGL form factor parameters of Ref. [17, 18].

$$w = \frac{m_B^2 - m_{D^{*+}}^2 - q^2}{2 m_B m_{D^{*+}}} = v_B \cdot v_{D^{*+}}$$

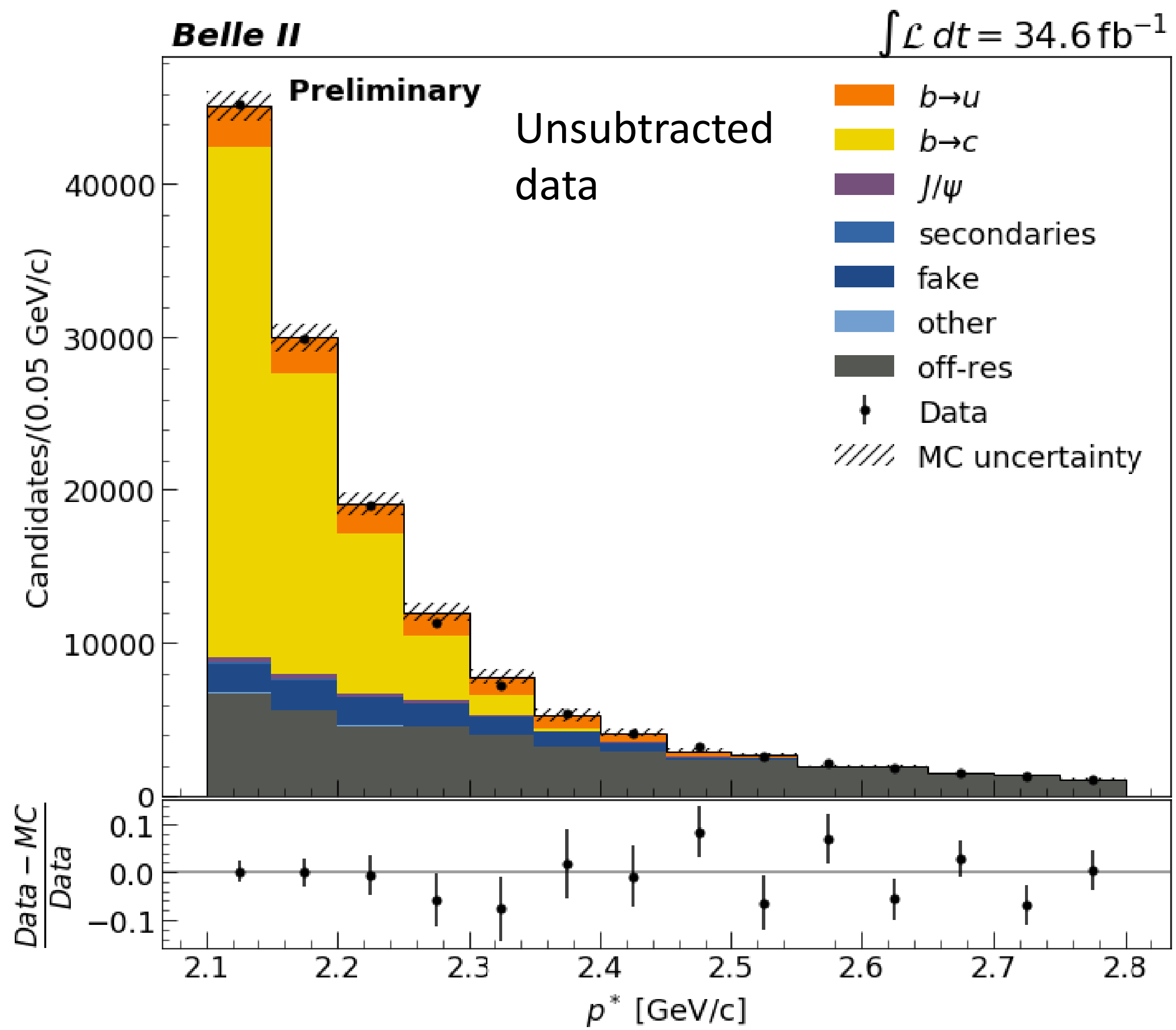
At w=1 (zero recoil), a nearly model independent determination of $|V_{cb}|$ is possible.

$$\mathcal{B}(\overline{B}^0 \to D^{*+} \ell^- \overline{\nu}_l) = (4.59 \pm 0.05_{\text{stat}} \pm 0.18_{\text{syst}} \pm 0.45_{\pi_s})\,\%$$

https://arxiv.org/abs/2008.07198
BELLE2-CONF-2020-022

V_{ub}: Inclusive signal of b→u transitions in the lepton momentum endpoint region is *identified* by an excess beyond the b→c contribution.

At the Upsilon(4S) resonance, it is possible to isolate inclusive B signals with event shape cuts and *after subtracting* continuum data taken below the 4S resonance.

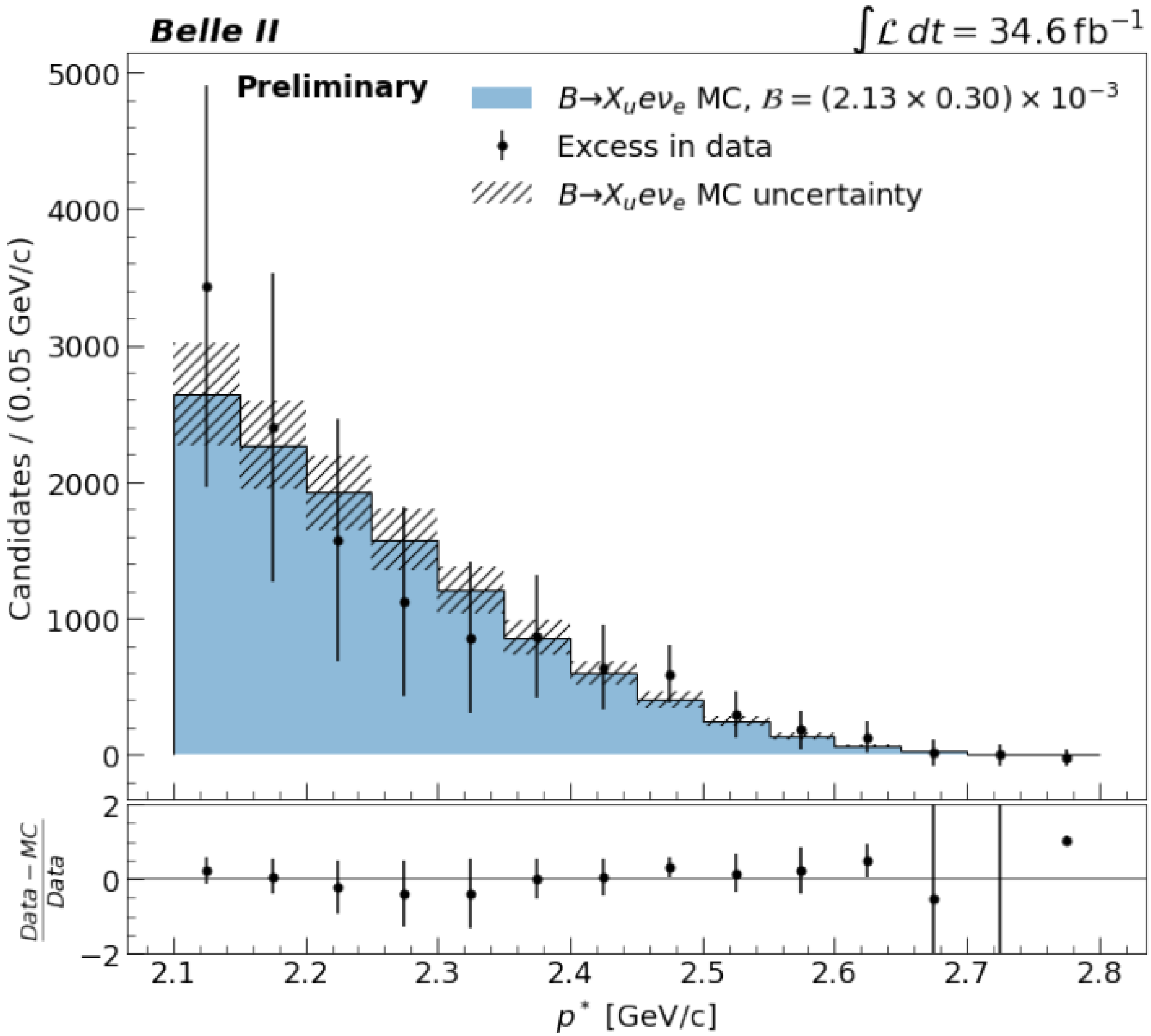


Center-of-mass frame electron momentum

N.B. FEI is *not* used here

V_{ub}: Inclusive signal of $b \to u$ transitions in the lepton momentum endpoint region.

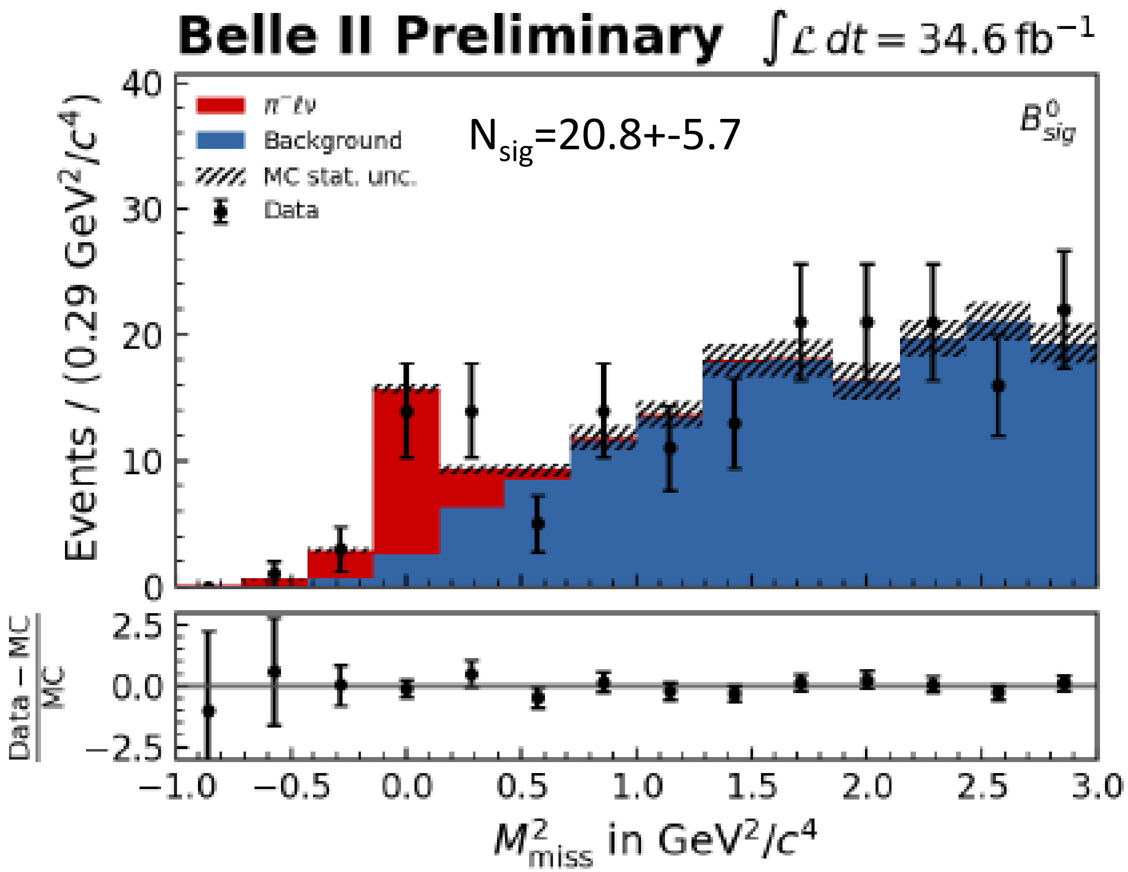
Obtain N_{sig} ($b \to u$) = 12098 ±2303 events in the [2.1, 2.6] GeV momentum window



Center-of-mass frame electron momentum

V_{ub}: Exclusive $B \rightarrow \pi^- l^+ \nu$ with FEI

Measurements of the BF at q^2(max) combined with lattice QCD gives $|V_{ub}|$



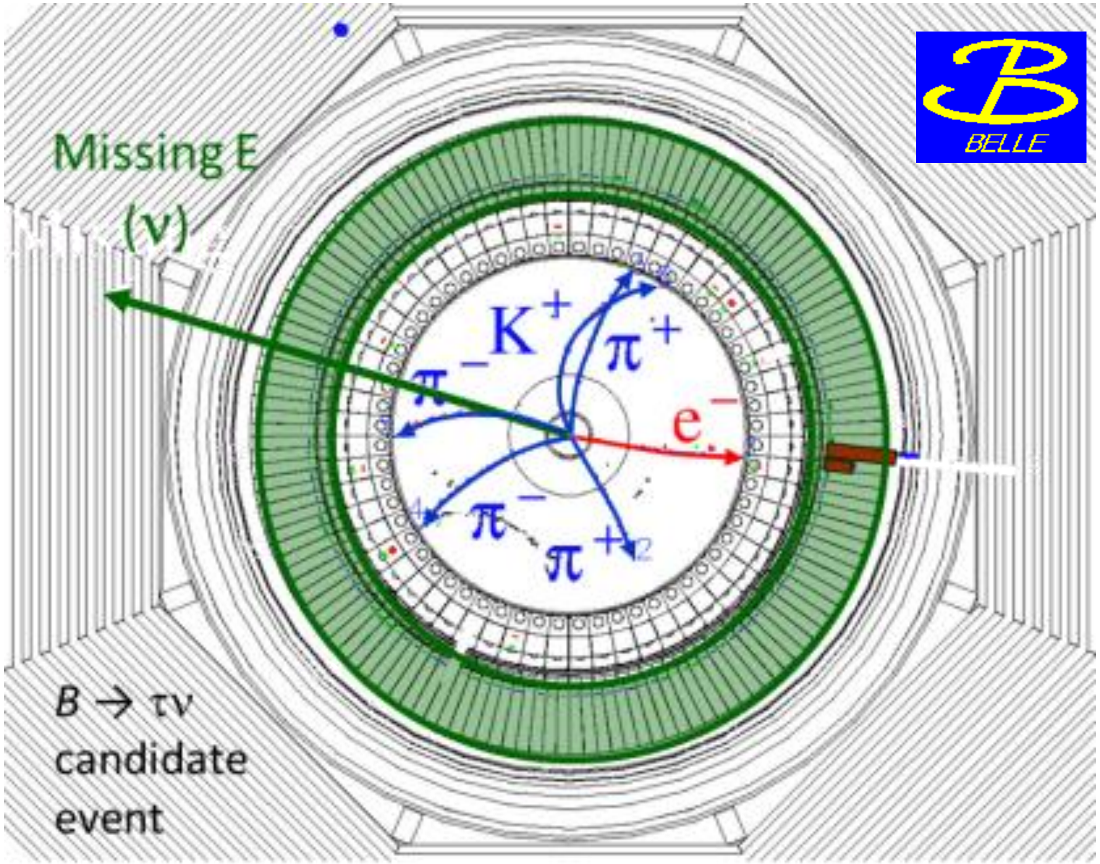
$$BF(B^0 \rightarrow p^- l^+ n) = [1.58 \pm 0.43(stat) \pm 0.07(sys)] \times 10^{-4}$$

https://arxiv.org/abs/2008.08819

Example of a *Missing Energy Decay* (B→τν) *in old Belle* *Data*

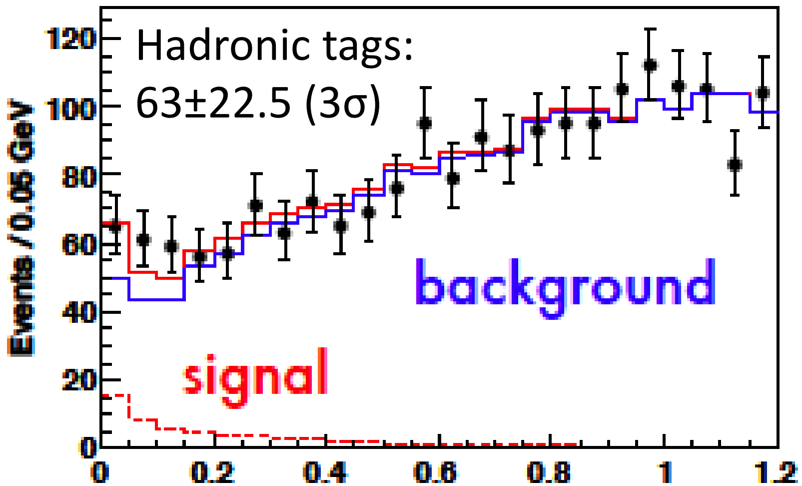
(recorded before 2010)

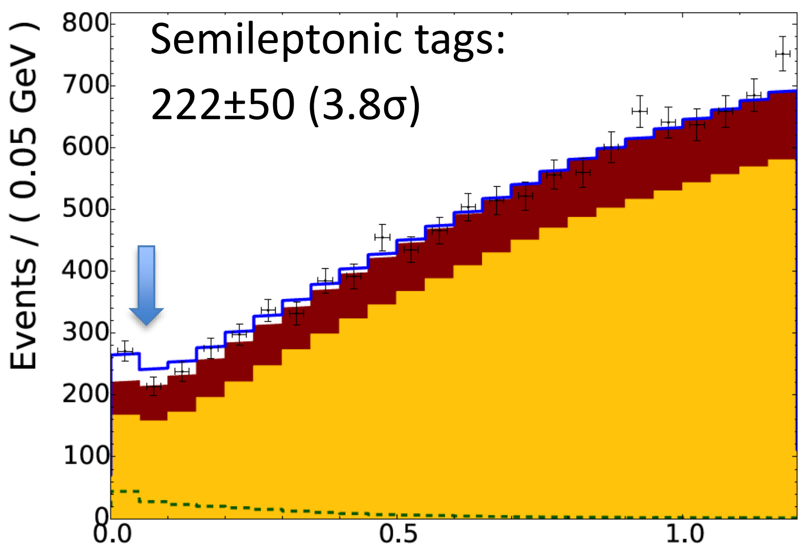
$$B^+ \to D^0 \pi^+$$
$$(\to K\pi^-\pi^+\pi^-)$$
$$B^- \to \tau(\to e\nu\bar{\nu})\nu$$

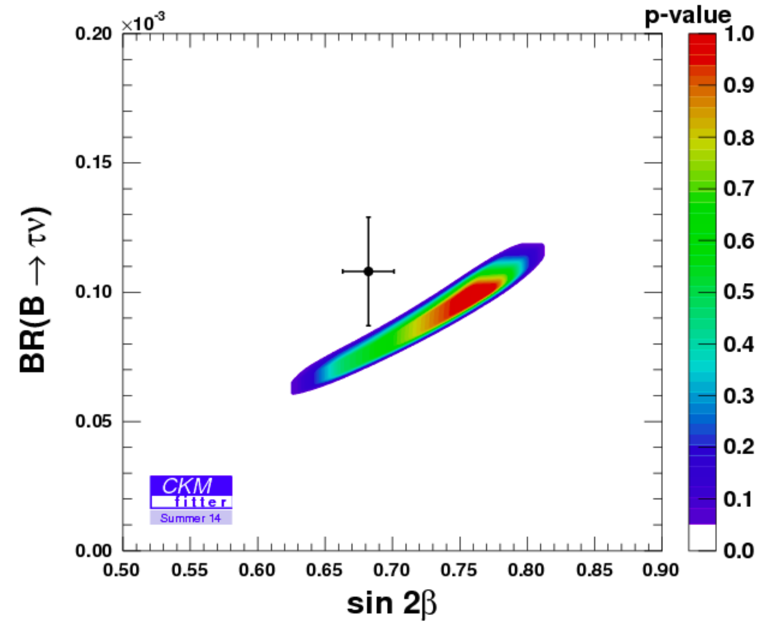


The clean e^+e^- environment (and the CsI(Tl) crystal calorimeter) makes this possible.

Example: old Belle $B \rightarrow \tau\nu$ results with full *reprocessed* data sample: either hadronic or semileptonic tags (PRD 92, 051102 (2015))



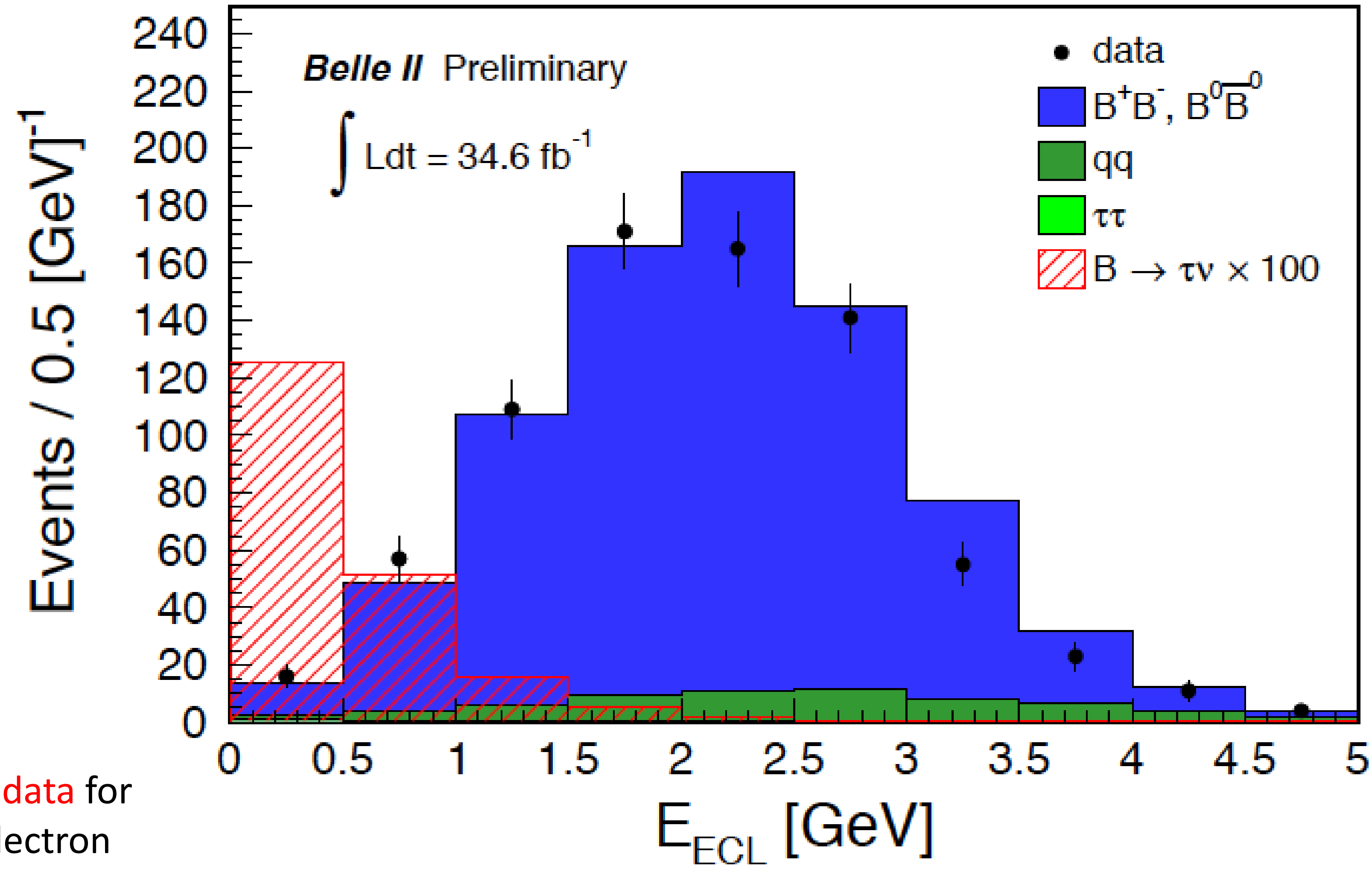




With the full B factory statistics only “evidence”. No single observation from either Belle or BaBar.

➔ The horizontal axis is the “Extra Calorimeter Energy” or E_{ECL}

E_{ECL} (extra energy in the calorimeter) is one of the critical variables for $B \to \tau\nu$. FAQ: Does this work for Belle II ?

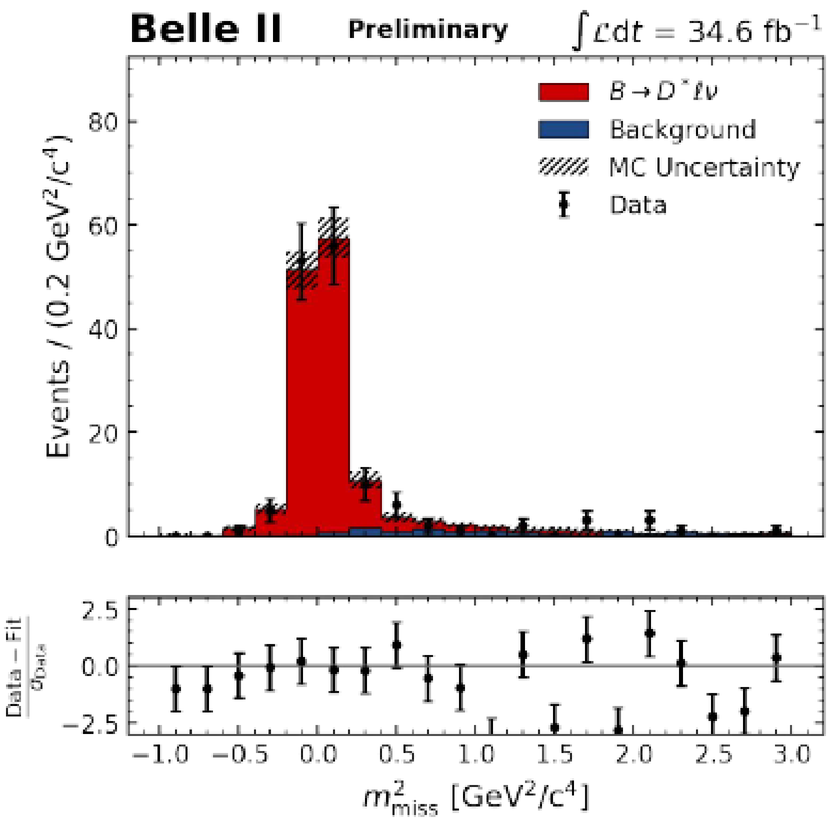


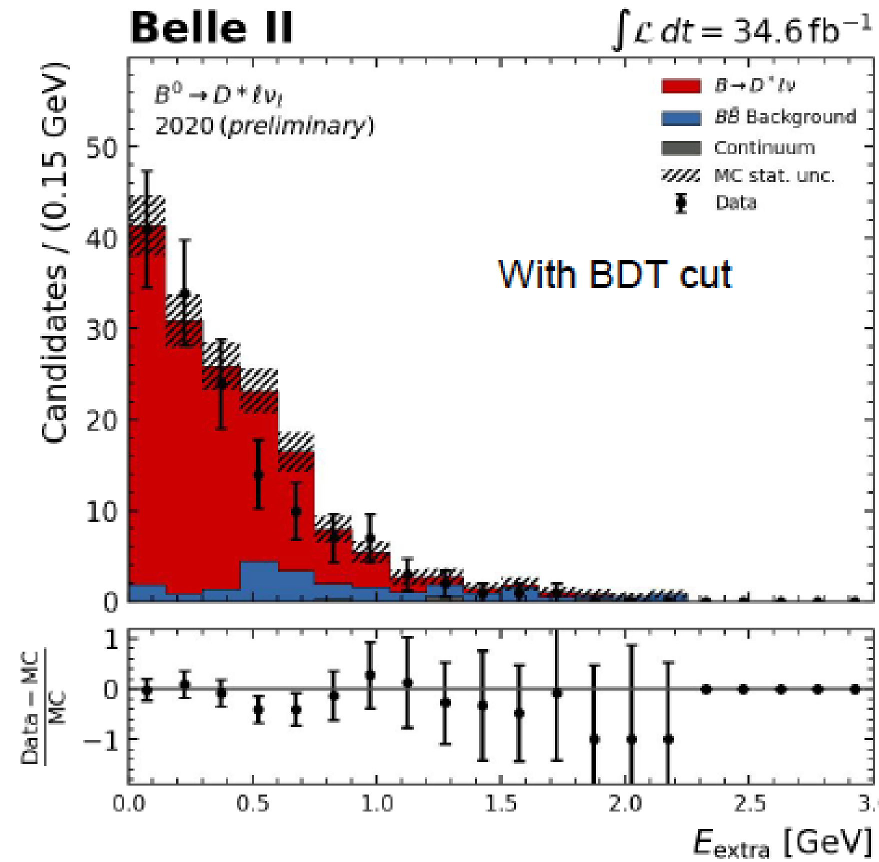
Check in data for the $\tau \to$ electron channel and with FEI.

BELLE2-CONF-2020-027

FAQ: E_{ECL}, Does this work for Belle II ?
Verification of E_{ECL} in data using $B^0 \rightarrow D^{*-} l^+ \nu_l$ with FEI

Low background with FEI





$$\mathcal{B}(\overline{B}^0 \to D^{*+}\ell^-\overline{\nu}_l) = \left(4.45 \pm 0.40_{\text{stat}} \pm 0.53_{\text{syst}}\right)\%$$

BELLE2-CONF-2020-023

https://arxiv.org/abs/2008.10299

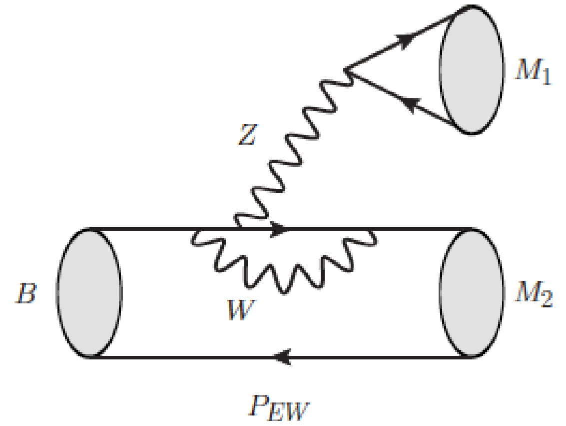
The isospin sum rule

https://arxiv.org/abs/hep-ph/0508047

$$A_{\rm CP}(K^+\pi^-) \;+\; A_{\rm CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} \;=\; A_{\rm CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{\rm CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

A_{CP}			
Mode	BaBar	Belle	LHCb
$K^+\pi^-$	$-0.107 \pm 0.016^{+0.006}_{-0.004}$	$-0.069 \pm 0.014 \pm 0.007$	$-0.080 \pm 0.007 \pm 0.003$
$K^+\pi^0$	$0.030 \pm 0.039 \pm 0.010$	$0.043 \pm 0.024 \pm 0.002$	
$K^0\pi^+$	$-0.029 \pm 0.039 \pm 0.010$	$-0.011 \pm 0.021 \pm 0.006$	$-0.022 \pm 0.025 \pm 0.010$
$K^0\pi^0$	$-0.13 \pm 0.13 \pm 0.03$	$0.14 \pm 0.13 \pm 0.06$	

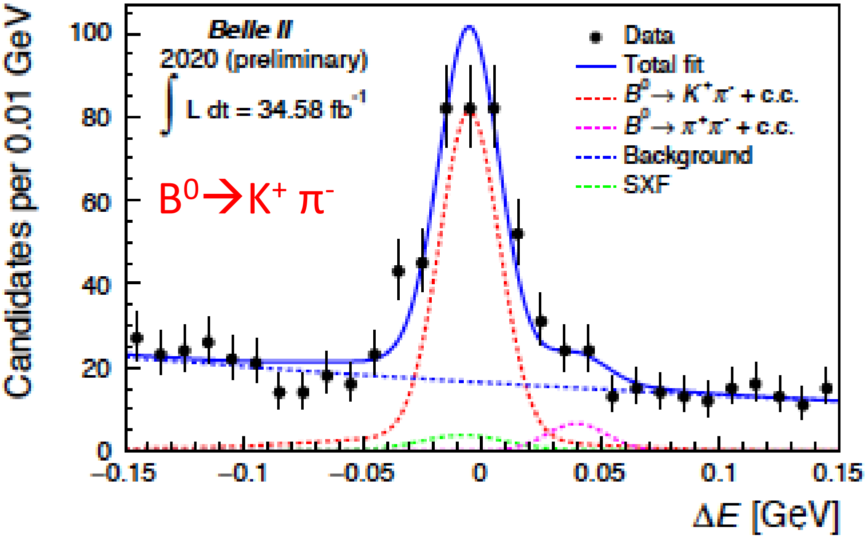
To check for new physics from electroweak penguins in the B→Kπ system in a model-independent manner using the isospin sum rule, need to measure all *four final states* and their CP asymmetries. Need to measure modes with π^0's and Kshort's.

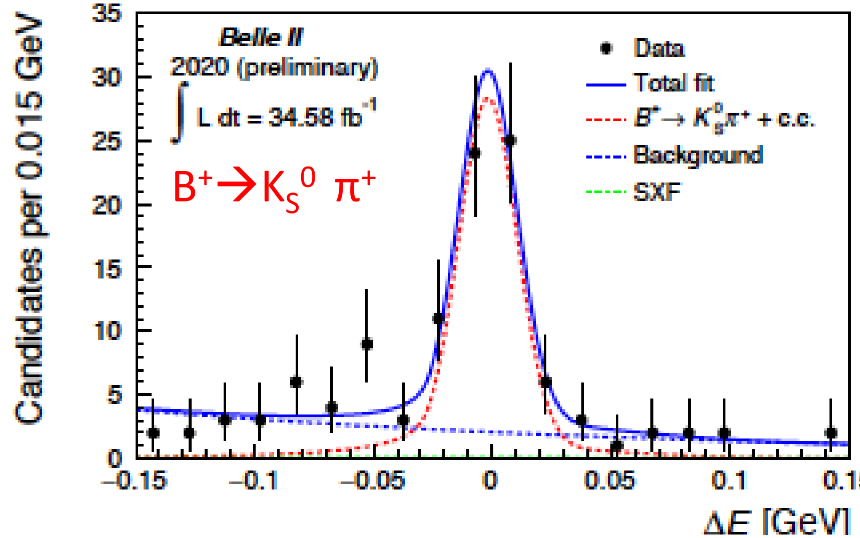


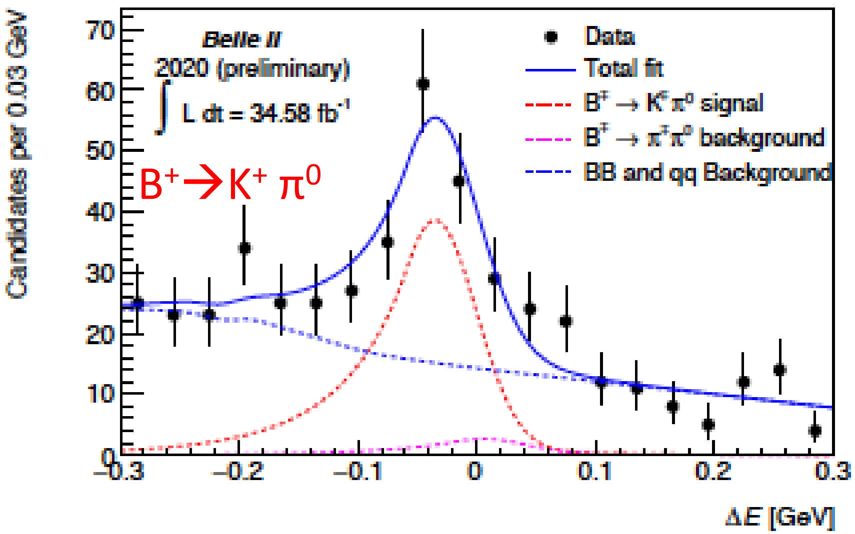
Breaking news: LHCb has reported results on A_{CP} ($B \to K^+ \pi^0$)

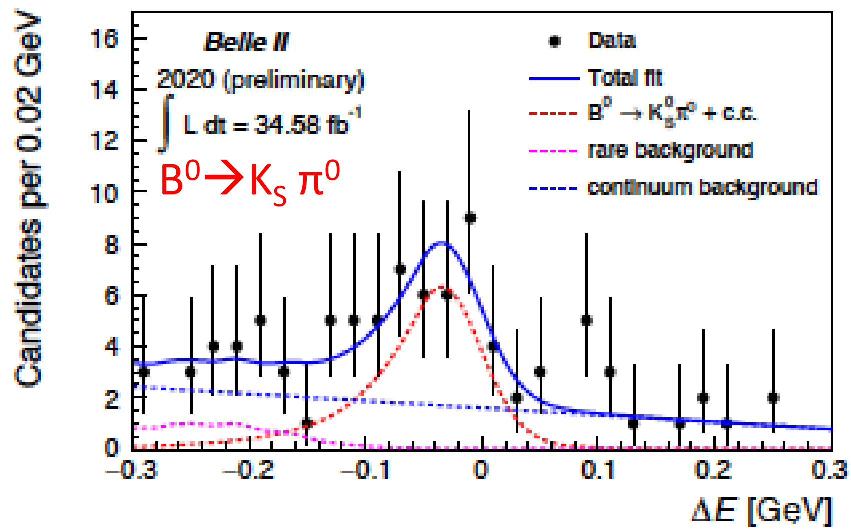
https://arxiv.org/pdf/2012.12789.pdf

Have now observed the four B→K π modes, needed for the isospin sum rule test of NP. This includes the difficult mode B→K_S π^0. Have also reported A_{CP} for 3 out of 4 modes.

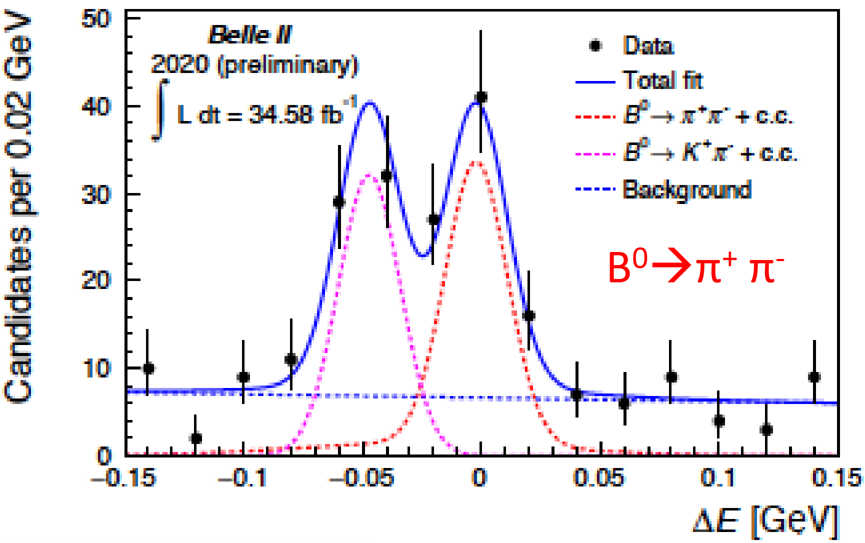


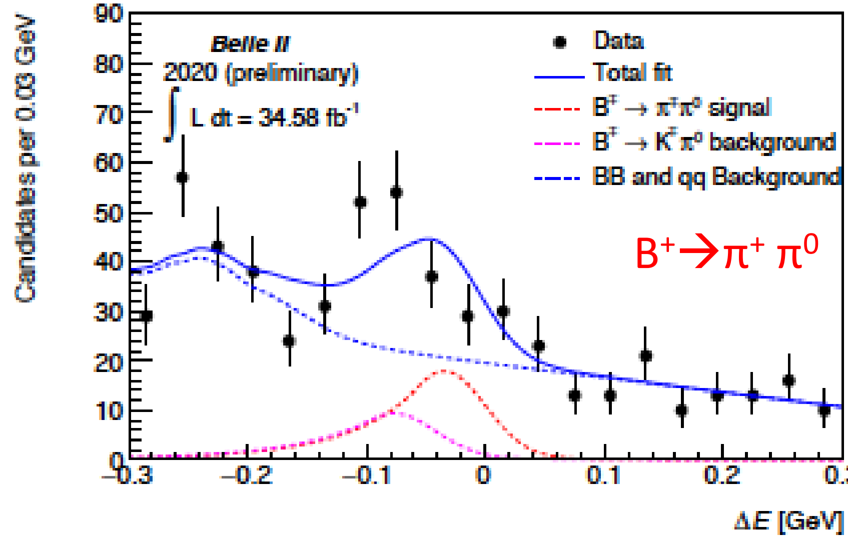




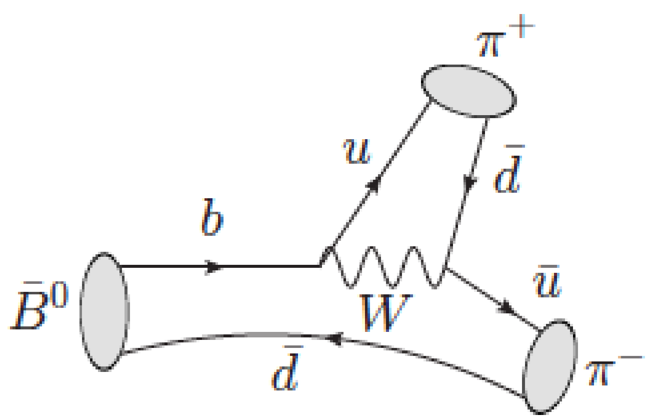


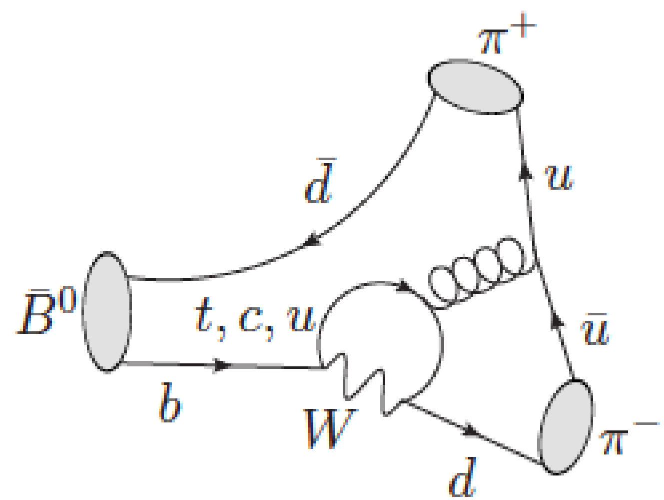
Have now established 2/3 B→ππ modes needed for the isospin triangle and the α/ϕ_2 CKM angle determination. Work on $B \to \pi^0 \pi^0$ is in progress.





Need to separate the b→u tree and b→d penguin contributions to extract fundamental parameters.





Charmless two-body and three-body hadronic decays.

$$\mathcal{B}(B^0 \to K^+\pi^-) = [19.0 \pm 1.4(\text{stat}) \pm 0.8(\text{syst})] \times 10^{-6},$$

$$\mathcal{B}(B^+ \to K^+\pi^0) = [12.7^{+2.2}_{-2.1}(\text{stat}) \pm 1.1(\text{syst})] \times 10^{-6},$$

$$\mathcal{B}(B^+ \to K^0_S\pi^+) = [7.5 \pm 1.0(\text{stat}) \pm 1.0(\text{syst})] \times 10^{-6},$$

$$\mathcal{B}(B^0 \to K^0_S\pi^0) = [10.9^{+2.9}_{-2.6}(\text{stat}) \pm 1.6(\text{syst})] \times 10^{-6},$$

$$\mathcal{B}(B^0 \to \pi^+\pi^-) = [5.8 \pm 0.9(\text{stat}) \pm 0.2(\text{syst})] \times 10^{-6},$$

$$\mathcal{B}(B^+ \to \pi^+\pi^0) = [5.7 \pm 2.3(\text{stat}) \pm 0.5(\text{syst})] \times 10^{-6},$$

$$\mathcal{B}(B^+ \to K^+K^-K^+) = [31.6 \pm 2.2(\text{stat}) \pm 1.7(\text{syst})] \times 10^{-6},$$

$$\mathcal{B}(B^+ \to K^+\pi^-\pi^+) = [45.9 \pm 3.8(\text{stat}) \pm 3.3(\text{syst})] \times 10^{-6},$$

$$\mathcal{A}(B^0 \to K^+\pi^-) = 0.029 \pm 0.065(\text{stat}) \pm 0.007(\text{syst}),$$

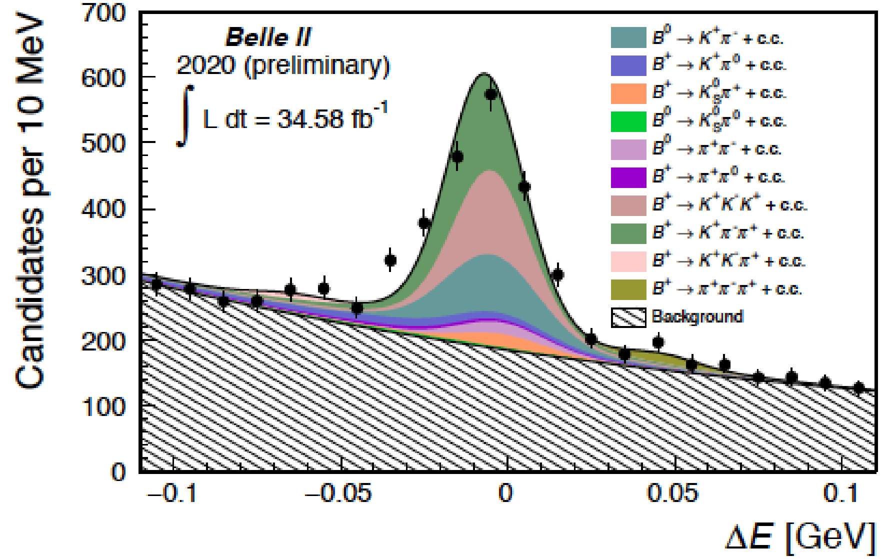
$$\mathcal{A}(B^+ \to K^+\pi^0) = 0.052^{+0.121}_{-0.119}(\text{stat}) \pm 0.022(\text{syst}),$$

$$\mathcal{A}(B^+ \to K^0_S\pi^+) = -0.072^{+0.109}_{-0.114}(\text{stat}) \pm 0.024(\text{syst}),$$

$$\mathcal{A}(B^+ \to \pi^+\pi^0) = -0.268^{+0.249}_{-0.322}(\text{stat}) \pm 0.123(\text{syst}),$$

$$\mathcal{A}(B^+ \to K^+K^-K^+) = -0.049 \pm 0.063(\text{stat}) \pm 0.022(\text{syst}), \text{ and}$$

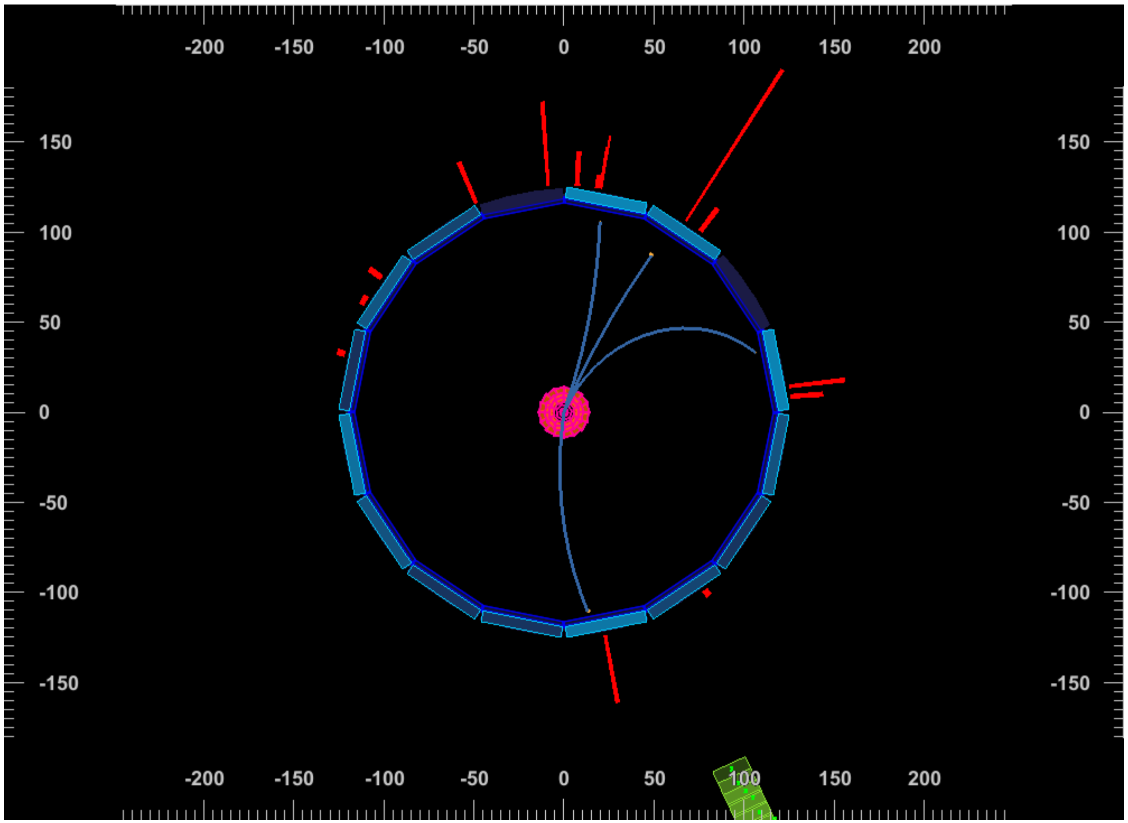
$$\mathcal{A}(B^+ \to K^+\pi^-\pi^+) = -0.063 \pm 0.081(\text{stat}) \pm 0.023(\text{syst}).$$



Note initial results on direct CPV asymmetries and three-body rare decays.

Details in BELLE2-CONF-2020-026

Tau (τ) and charm physics highlight(s)

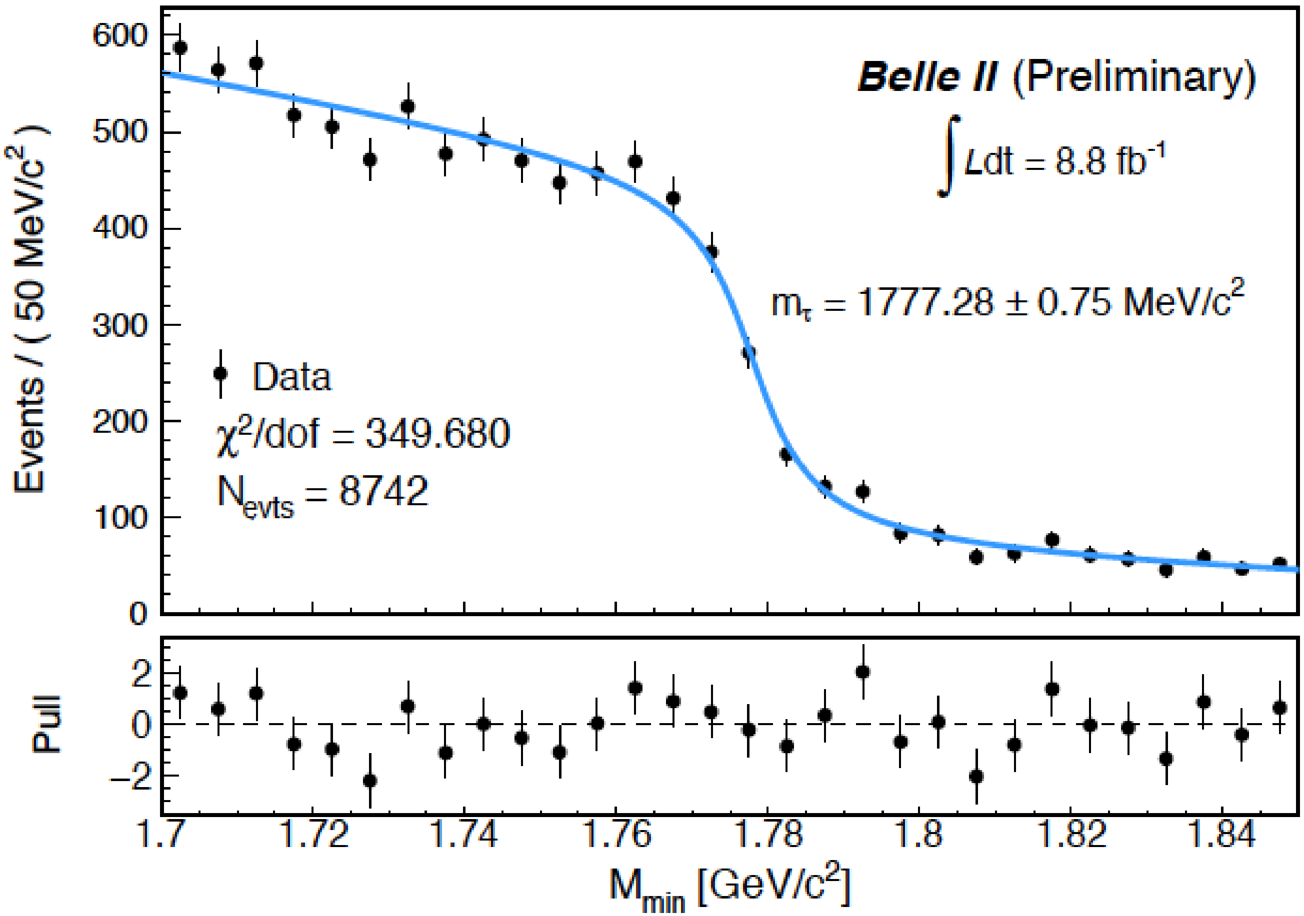


An example of a 1-prong vs 3 prong e+e- → $\tau^+ \tau^-$ at Belle II

At least two neutrinos are missing.

Tau Mass Measurement

Use 1 prong vs 3-prong tau pair events from e+e- → $\tau^+ \tau^-$



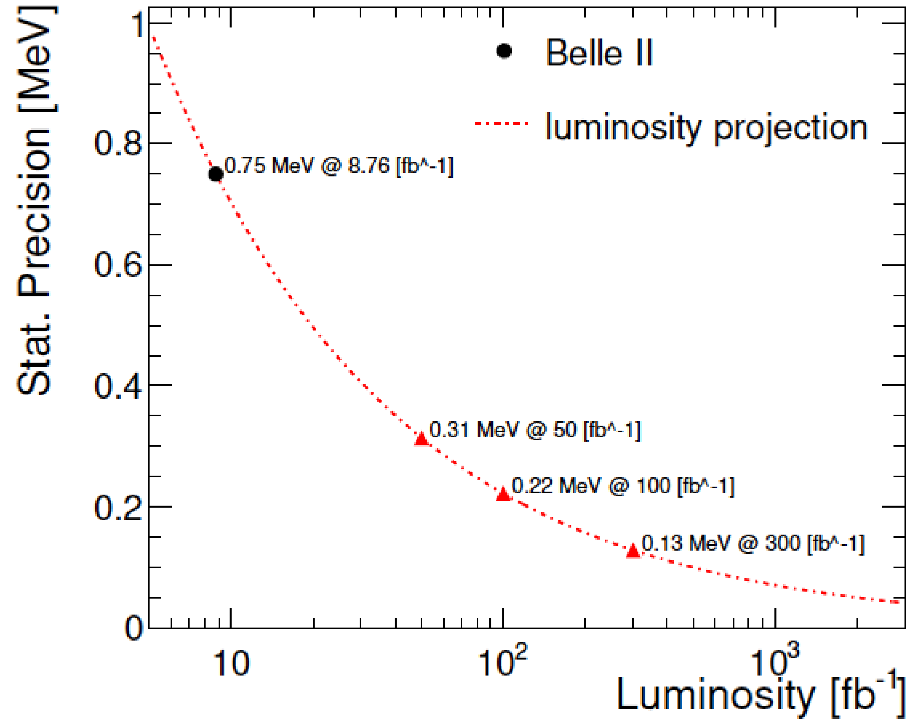
$$M_{\mathrm{min}} = \sqrt{M_{3\pi}^2 + 2(E_{\mathrm{beam}} - E_{3\pi})(E_{3\pi} - P_{3\pi})} \leq m_\tau$$

$$m(t) = 1777.28 \pm 0.75(stat) \pm 0.33(sys)\mathrm{MeV/c^2}$$

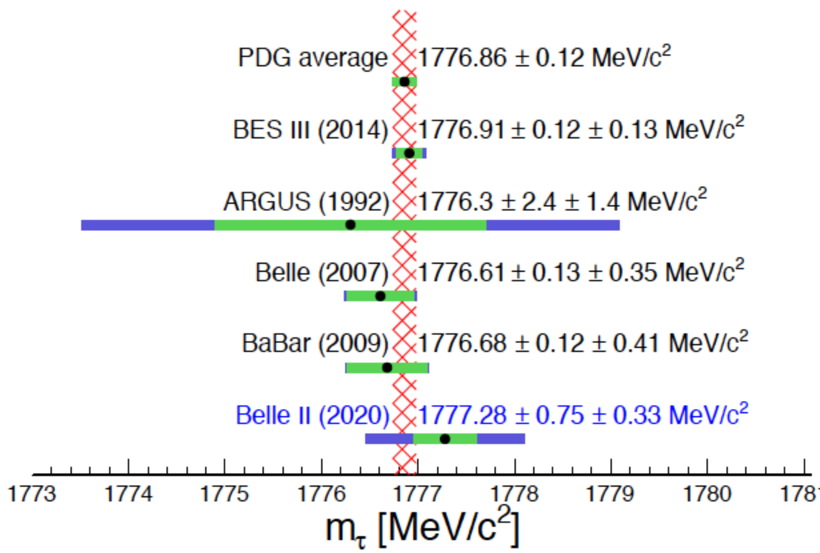
BELLE2-CONF-2020-024

https://arxiv.org/abs/2008.04665

Systematic uncertainty	MeV/c^2
Momentum shift due to the B-field map	0.29
Estimator bias	0.12
Choice of p.d.f.	0.08
Fit window	0.04
Beam energy shifts	0.03
Mass dependence of bias	0.02
Trigger efficiency	≤ 0.01
Initial parameters	≤ 0.01
Background processes	≤ 0.01
Tracking efficiency	≤ 0.01
Decay model	-



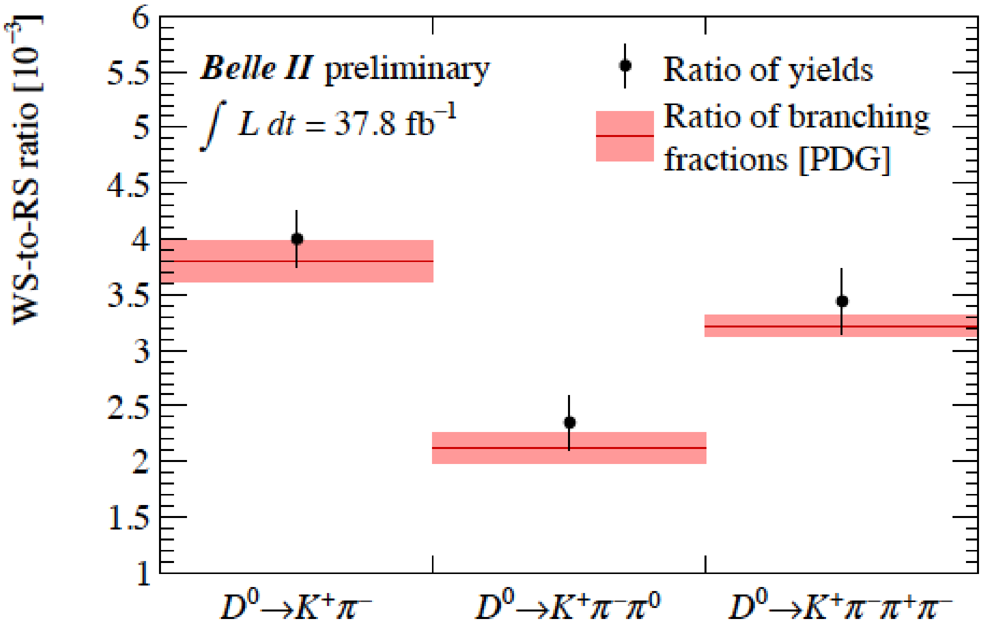
Currently BESIII dominates the world average.

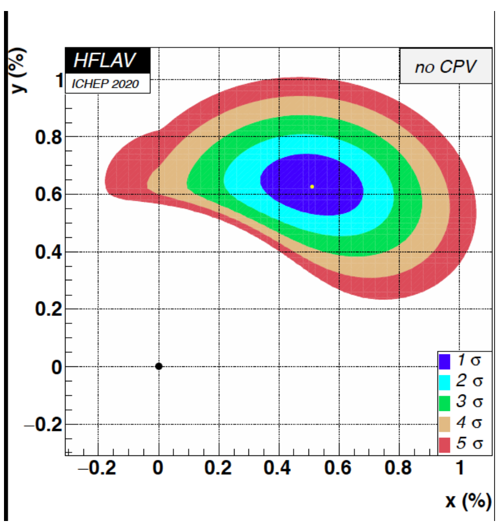


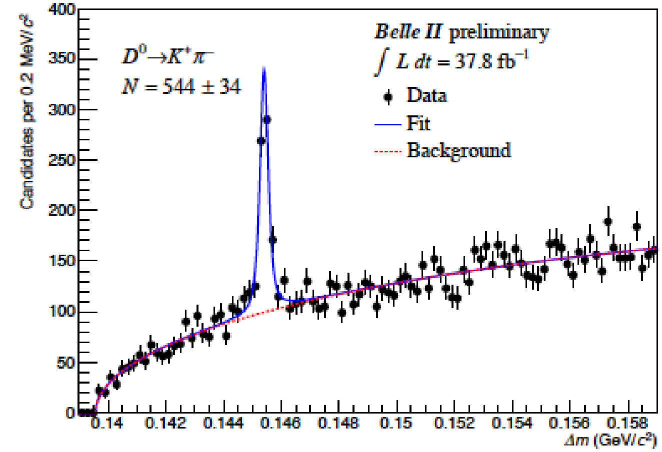
BELLE2-CONF-2020-024

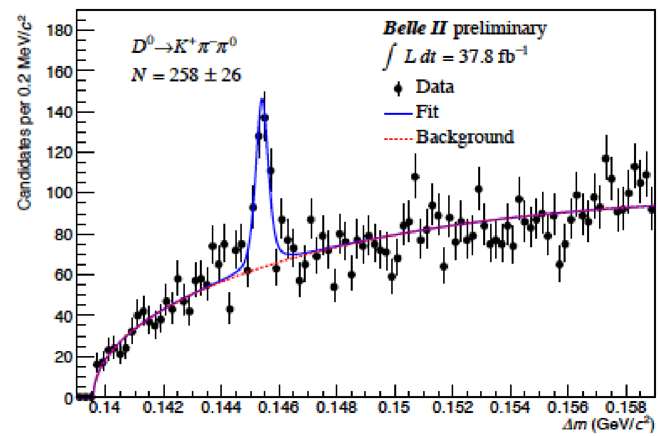
https://arxiv.org/abs/2008.04665

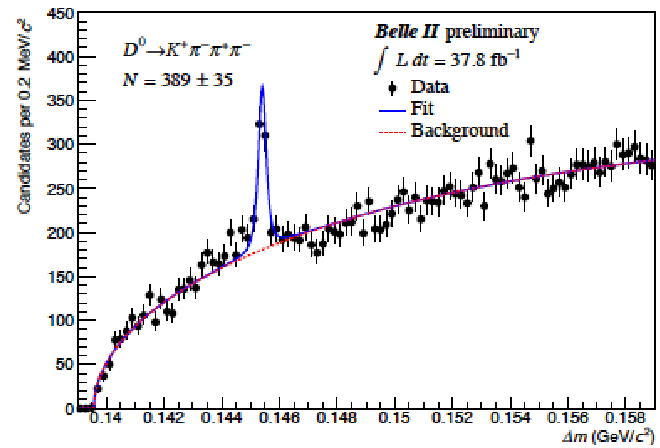
Three wrong-sign D decay modes clearly observed. These can be used for D-Dbar mixing measurements in the future.











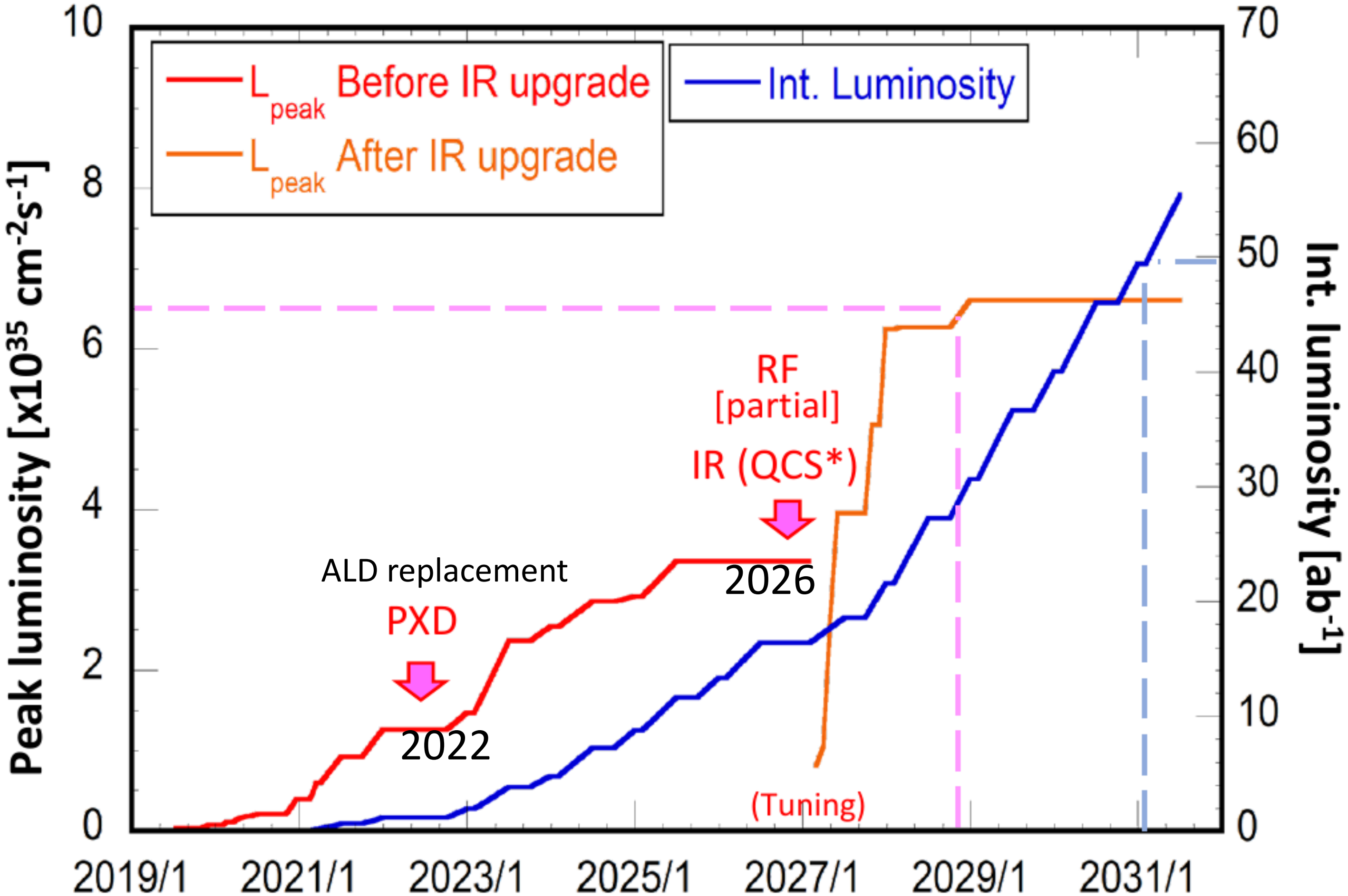
Preparing for Snowmass *2022* (International Physics Rodeo)

Scenes from the actual Snowmass Rodeo in Colorado

N.B. Snowmass 2021 to be held in Seattle, Washington in summer of 2022 and the last one was held in Minneapolis, Minnesota in 2013. It is unlikely that there will ever be another month-long planning meeting in Snowmass, CO.

Historical note: <u>Young(ish) Scientist Pier Oddone</u> (originally from Peru/Italy) introduced the concept and first proposal for an asymmetric energy B-factory to the broad HEP community at a Snowmass in 1988.

Updated plan for SuperKEKB (Roadmap 2020)



Two steps: *Intermediate luminosity* (1-2 x 10^{35} /cm^2/sec, 5-10 ab^{-1});

High Luminosity (6.5 x 10^{35}/cm^2/sec, 50 ab^{-1}) with a detector upgrade

Future steps: Polarization Upgrade, Advanced R&D

Ultra high luminosity (4 x 10^{36}/cm^2/sec, 250 ab^{-1}), R&D Project

https://arxiv.org/abs/1808.10567

Outcome of the B2TIP (Belle II Theory Interface) Workshops (2014-2018)
Emphasis is on New Physics (NP) reach.

Strong participation from theory community,
lattice QCD community and Belle II experimenters.
689 pages, published by Oxford University Press

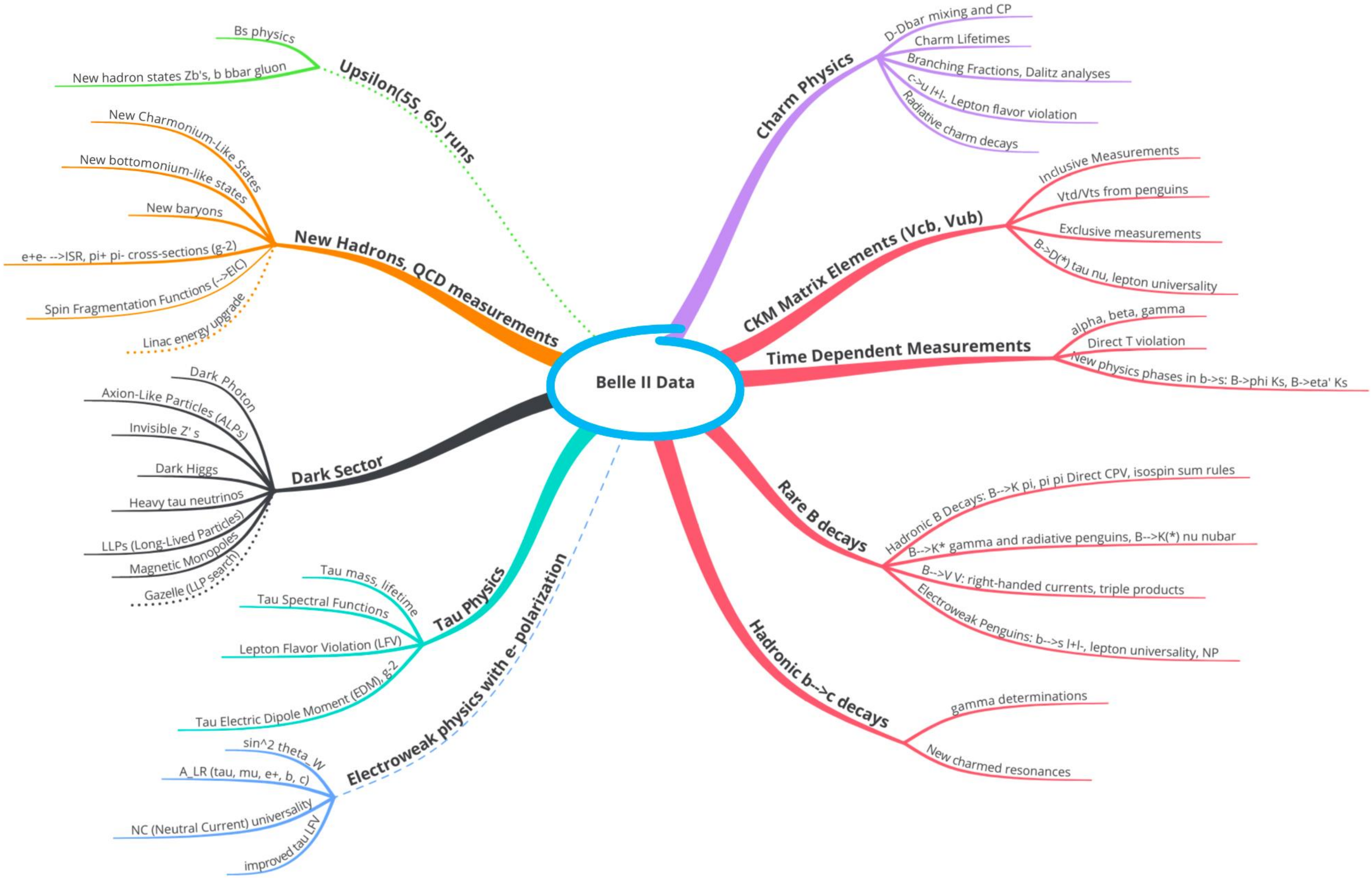
First steps toward realizing this program at ICHEP2020 in Prague, Czech Republic

The Belle II Physics Book

E. Kou[74,¶,†], P. Urquijo[143,§,†], W. Altmannshofer[133,¶], F. Beaujean[78,¶], G. Bell[120,¶], M. Beneke[112,¶], I. I. Bigi[146,¶], F. Bishara[148,16,¶], M. Blanke[49,50,¶], C. Bobeth[111,112,¶], M. Bona[150,¶], N. Brambilla[112,¶], V. M. Braun[43,¶], J. Brod[110,133,¶], A. J. Buras[113,¶], H. Y. Cheng[44,¶], C. W. Chiang[91,¶], M. Ciuchini[58,¶], G. Colangelo[126,¶], H. Czyz[154,29,¶], A. Datta[144,¶], F. De Fazio[52,¶], T. Deppisch[50,¶], M. J. Dolan[143,¶], J. Evans[133,¶], S. Fajfer[107,139,¶], T. Feldmann[120,¶], S. Godfrey[7,¶], M. Gronau[61,¶], Y. Grossman[15,¶], F. K. Guo[41,132,¶], U. Haisch[148,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[88,¶], J. Hisano[88,89,¶], L. Hofer[125,¶], M. Hoferichter[166,¶], W. S. Hou[91,¶], T. Huber[120,¶], S. Jaeger[157,¶], S. Jahn[82,¶], M. Jamin[124,¶], J. Jones[102,¶], M. Jung[111,¶], A. L. Kagan[133,¶], F. Kahlhoefer[1,¶], J. F. Kamenik[107,139,¶], T. Kaneko[30,26,¶], Y. Kiyo[63,¶], A. Kokulu[112,138,¶], N. Kosnik[107,139,¶], A. S. Kronfeld[20,¶], Z. Ligeti[19,¶], H. Logan[7,¶], C. D. Lu[41,¶], V. Lubicz[151,¶], F. Mahmoudi[140,¶], K. Maltman[171,¶], S. Mishima[30,¶], M. Misiak[164,¶],

Belle II Physics "Mind Map" for Snowmass 2022

Wealth of new physics possibilities in different domains of HEP (weak, strong, electroweak interactions). Many opportunities for *initiatives* by young scientists.



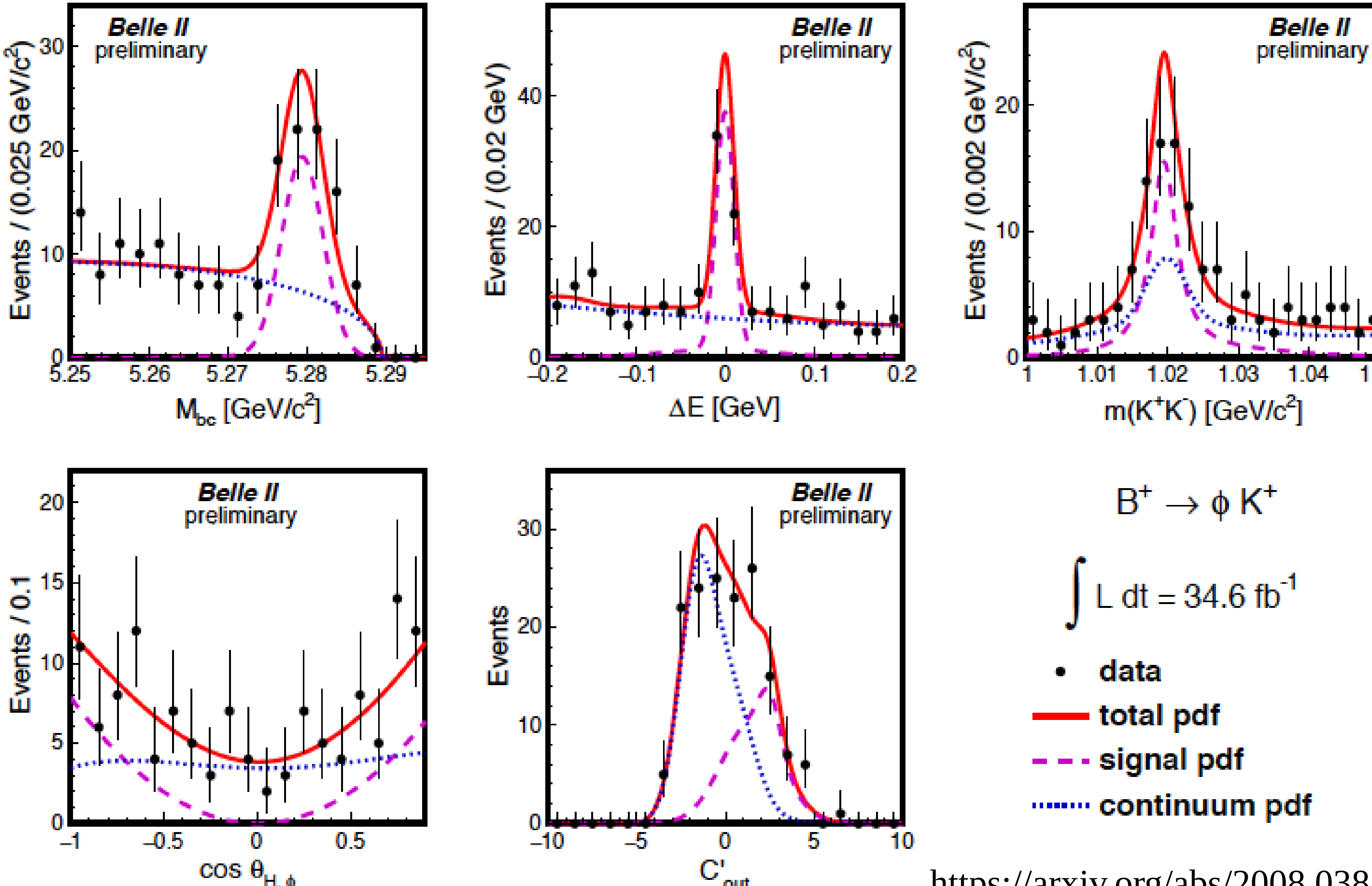
Dashed lines indicate extensions to SuperKEKB/Belle II that can enhance the physics reach of the facility. LOIs: https://confluence.desy.de/display/BI/Snowmass+2021

Conclusions

- Belle II is working well and is now producing physics. SuperKEKB has broken the instantaneous world-luminosity record and is now a "Super B Factory".
- *World-leading results already on the dark sector* (Search for Z' → invisible and ALPs PRL's)
- Rediscovering many of the signals seen at the B factories: semileptonic decays, improving FEI, establishing "missing energy" and time-dependent capabilities, and beginning to see hints of time-dependent CP violation. *Need more data (2021) to make further progress.*
- *A decade-long program of discoveries ahead*. Belle II is fully engaged in the rare and precision and dark sector frontiers, and instrumentation, computing and accelerator frontiers. *Great opportunities for young US scientists*.

Backup slides

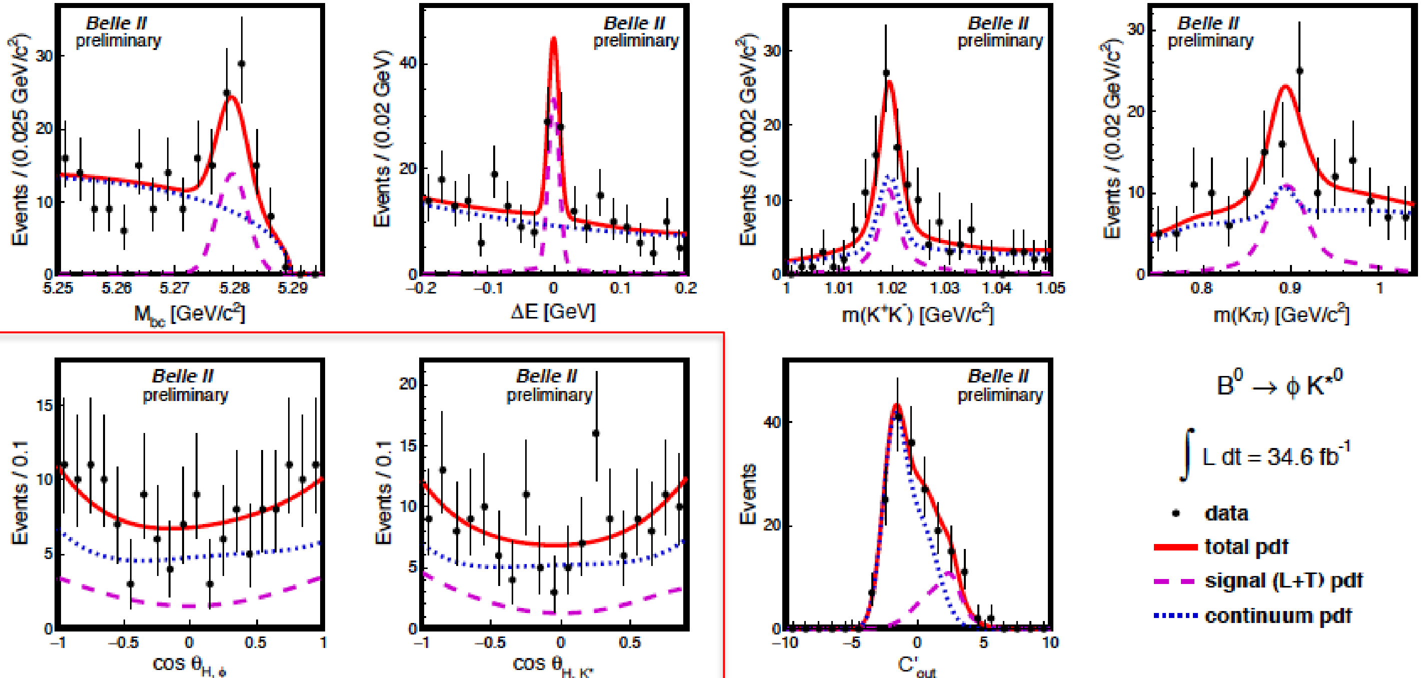
Rediscovery of $B \rightarrow \phi K^+$ mode



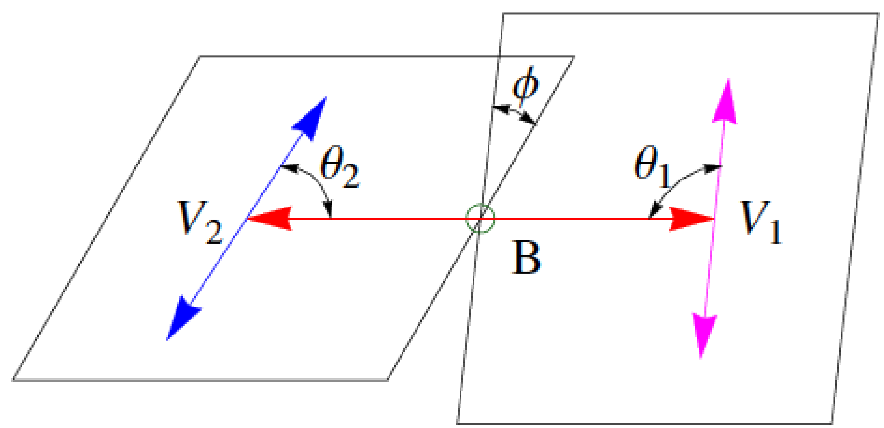
https://arxiv.org/abs/2008.03873

Polarization in B→V V penguin mode: B→φ K^{*0}

https://arxiv.org/abs/2008.03873



Rediscovery: The fraction of longitudinal polarization (f_L~0.5) rather than fully polarized (naïve QCD expectation, f_L~1).



Summary of B→φ K$^{(*)}$ Results

Table 5: Summary of the results obtained in this analysis.

	This analysis	World Average [2]
$\mathcal{B}(\times 10^{-6})$		
ϕK^+	$6.7 \pm 1.1 \pm 0.5$	8.8 ± 0.7
ϕK^0	$5.9 \pm 1.8 \pm 0.7$	7.3 ± 0.7
$I_{\phi K}$	$1.1 \pm 0.4 \pm 0.2$	1.21 ± 0.15
ϕK^{*+}	$21.7 \pm 4.6 \pm 1.9$	10.0 ± 2.0
ϕK^{*0}	$11.0 \pm 2.1 \pm 1.1$	10.0 ± 0.5
$I_{\phi K^*}$	$2.0 \pm 0.6 \pm 0.3$	1.00 ± 0.21
f_L		
ϕK^{*+}	$0.58 \pm 0.23 \pm 0.02$	0.50 ± 0.05
ϕK^{*0}	$0.57 \pm 0.20 \pm 0.04$	0.497 ± 0.017

CPV studies, more advanced B->VV angular analyses for T violation and right-handed currents are possible with more data.

BELLE2-CONF-2020-20

https://arxiv.org/abs/2008.03873

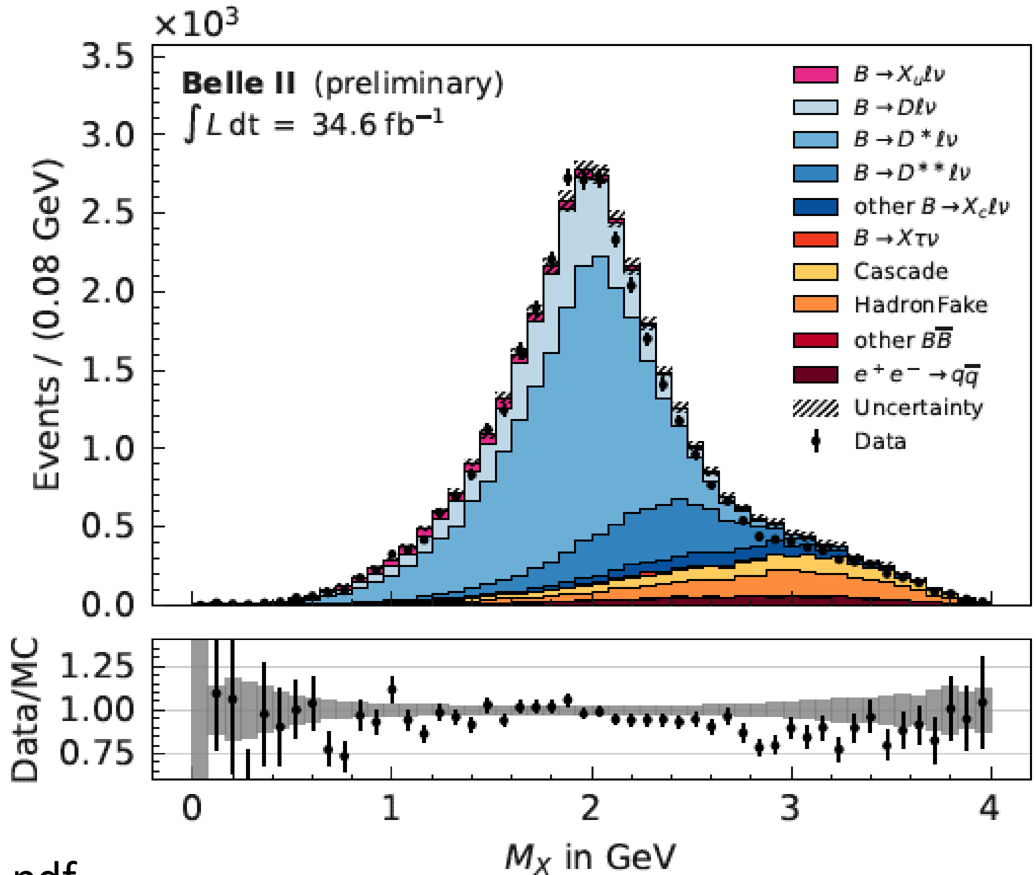
M_X moments of $B \rightarrow X_c l\, \nu$ (application of FEI)

Skip if time
is short.

For example, see https://arxiv.org/abs/1307.4551

These moments can determine non-perturbative parameters, needed to extract V_{cb} from inclusive semileptonic decays

e.g <M(X)>, <M²(X)>….



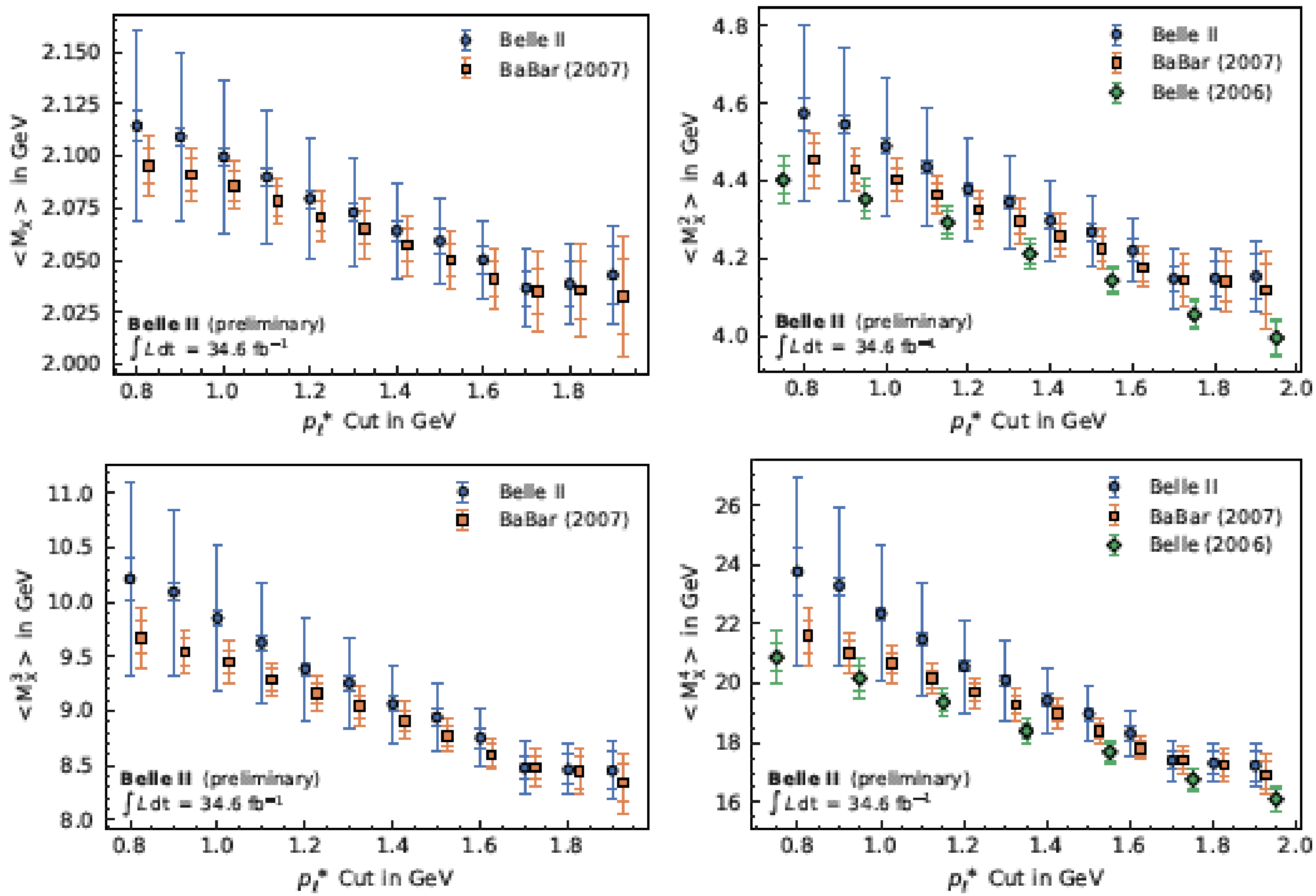
https://arxiv.org/pdf/2009.04493.pdf

FIG. 1: Reconstructed M_X distribution with event selection criteria and BCS applied. The uncertainty band covers the MC statistics, signal lepton PID efficiency and pion fake rate correction and the FEI efficiency correction for $B\overline{B}$ and continuum events. In the bottom part the per bin ratio of data and MC is shown. The grey boxes visualize the ratio between the MC expectation plus its uncertainty and the nominal value.

BELLE2-CONF-20200-025

M_X moments of $B \rightarrow X_c l \nu$ (application of FEI)

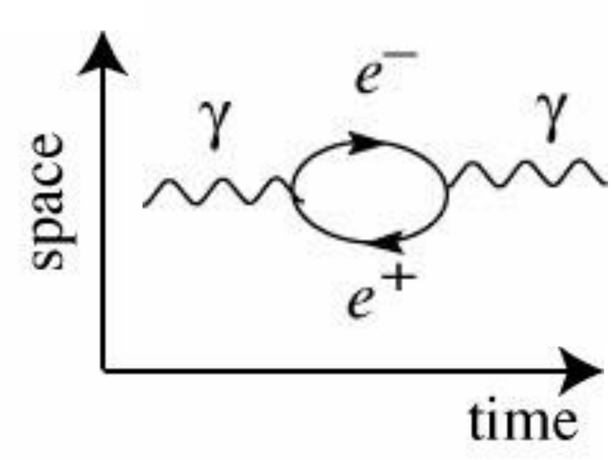
These moments can determine non-perturbative parameters, needed to extract $|V_{cb}|$ from inclusive semileptonic decays

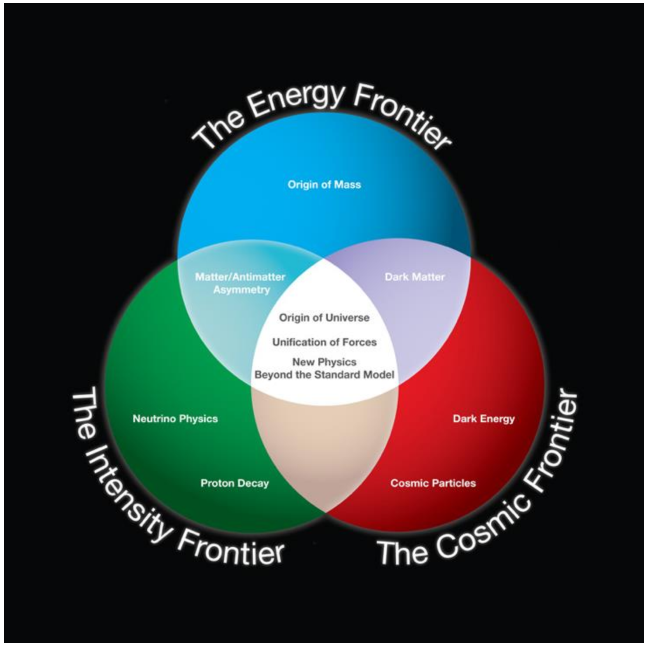


Still a large systematic from B→D** l nu MC modeling at low p_l

https://arxiv.org/pdf/2009.04493.pdf

NP: Quantum Mechanical (QM) Finesse versus Brute Force





Energy conservation ?

$$\Delta E \Delta t \geq \hbar / 2$$

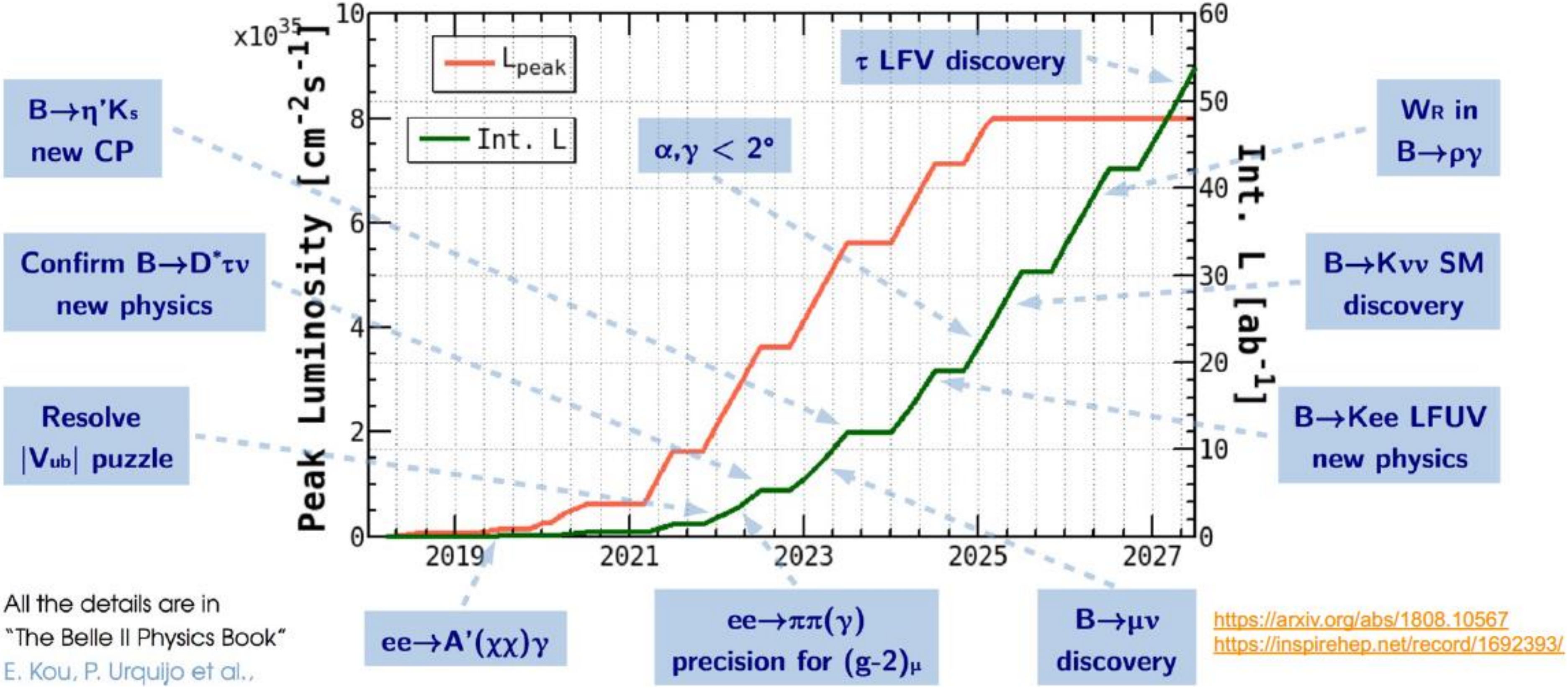
<u>Banking Analogy</u> (may be easier to understand):
At the Heisenberg Quantum Mechanical bank, customers with no collateral may take out billion Euro loans if they return the full loan within a billionth of a second.

If a *beautiful but rare* customer takes out such huge loans very frequently, the bank will take notice. *Looks odd (or asymmetric) in the bank's special full length mirror.*

N.B. Sometimes it is much better to have a large collateral and pay back the loan *directly* after a longer time.

Werner Heisenberg, Physicist and QM banker

Long term prospects of Belle II (based on the Belle II physics book).

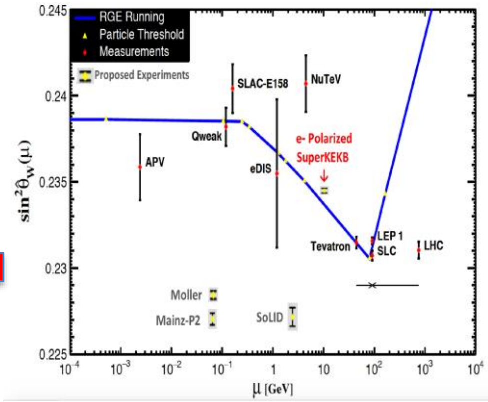


All the details are in
"The Belle II Physics Book"
E. Kou, P. Urquijo et al.,

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

Visualization by
F. Forti

Upgrading SuperKEKB with Polarized e- Beams



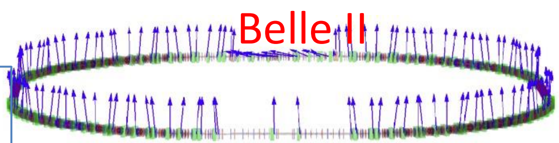
Physics case: precision $\sin^2\theta_W$ measurements from b, c, e, μ & τ, probing its running and universality (*White Paper in Preparation by M. Roney*).

Planning 70% polarization with 80% polarized source.

NEW HARDWARE FOR POLARIZATION UPGRADE:

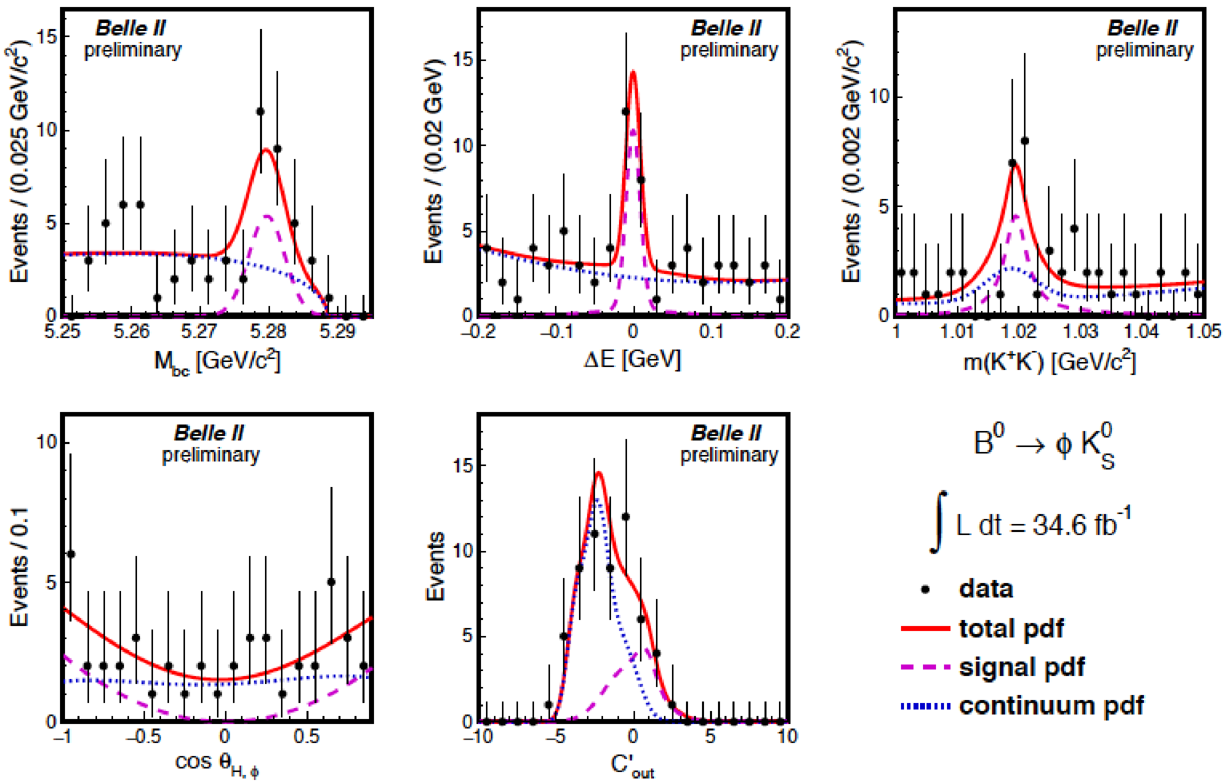
- **Low emittance polarized Source:** electron helicity can be flipped bunch-to-bunch by controlling circular polarization of source laser illuminating a GaAs photocathode (à la SLC). Inject vertically polarized electrons into the 7 GeV e- Ring, needs low enough emittance source to be able to inject.
- **Spin rotators:** Rotate spin to longitudinal before Interaction Point (IP) in Belle II, and then back to vertical after IP using solenoidal and dipole fields
- **Compton polarimeter:** monitors longitudinal polarization with <1% absolute precision, higher for relative measurements (arXiv:1009.6178) - provides real time polarimetry. → Use tau decays from $e^+e^- \to \tau^+\tau^-$ measured in Belle II to provide high precision absolute average polarization at IP.

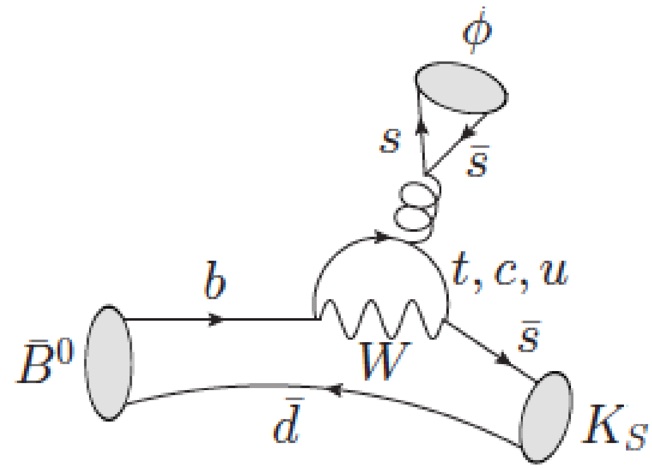
Planning for implementation ~2026 in mid-decade upgrade window for new final focus; This upgrade proposal to be included in KEK Roadmap for MEXT to be submitted 2021



e- spin vector around ring

Rediscovery of B→ϕ K_S (a b→s CP eigenstate)





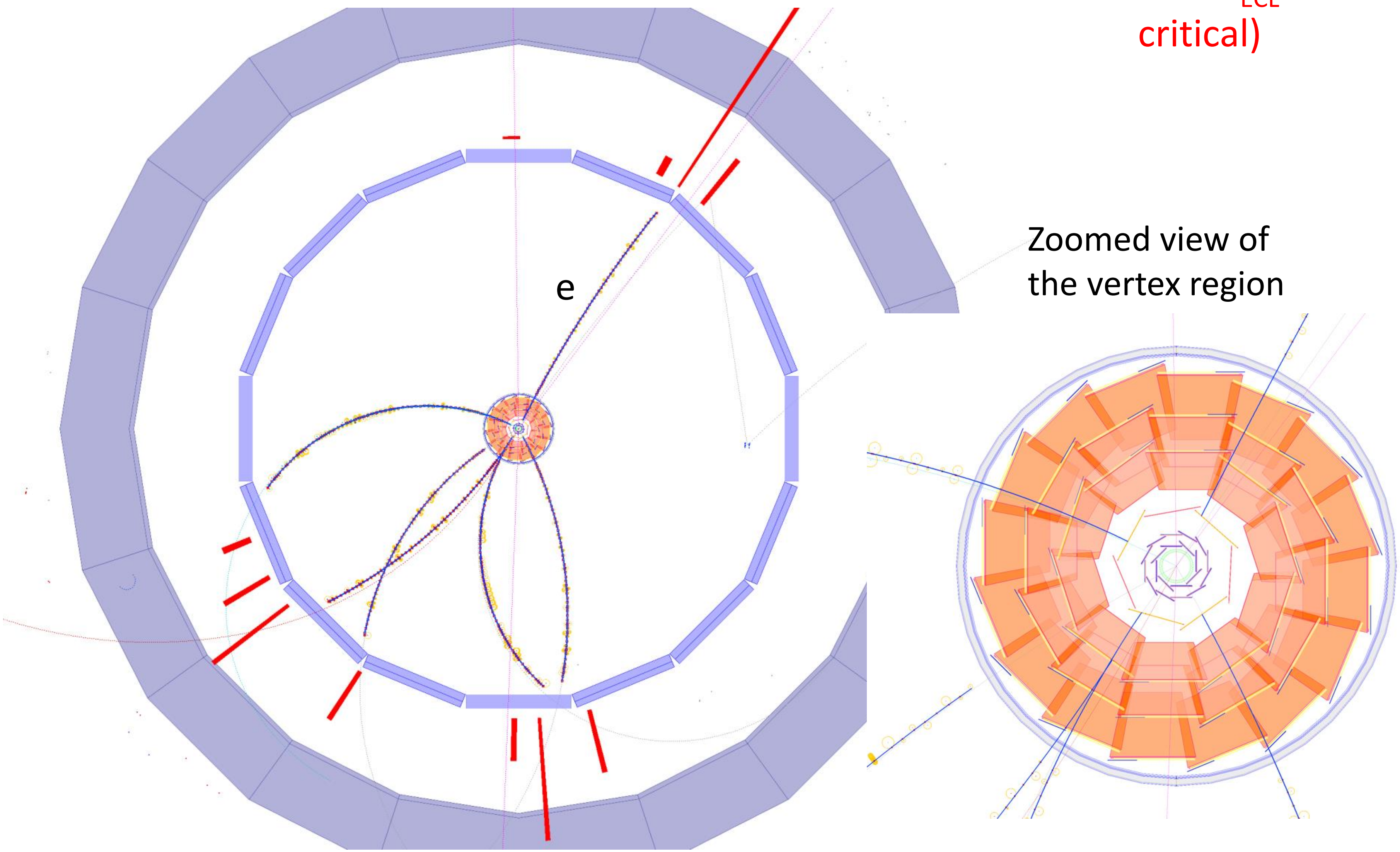
Here is the dominant b→s gluon transition.

https://arxiv.org/abs/2008.03873

“Missing Energy Decay” in a Belle II GEANT4 MC simulation

$B \rightarrow \tau\nu$, $\tau \rightarrow e\nu\nu$ $\quad$ $B \rightarrow D\pi$, $D \rightarrow K\pi\pi\pi$

(Hermiticity and E_{ECL} critical)



https://arxiv.org/abs/1808.10567

Outcome of the B2TIP (Belle II Theory Interface) Workshops
Emphasis is on New Physics (NP) reach.

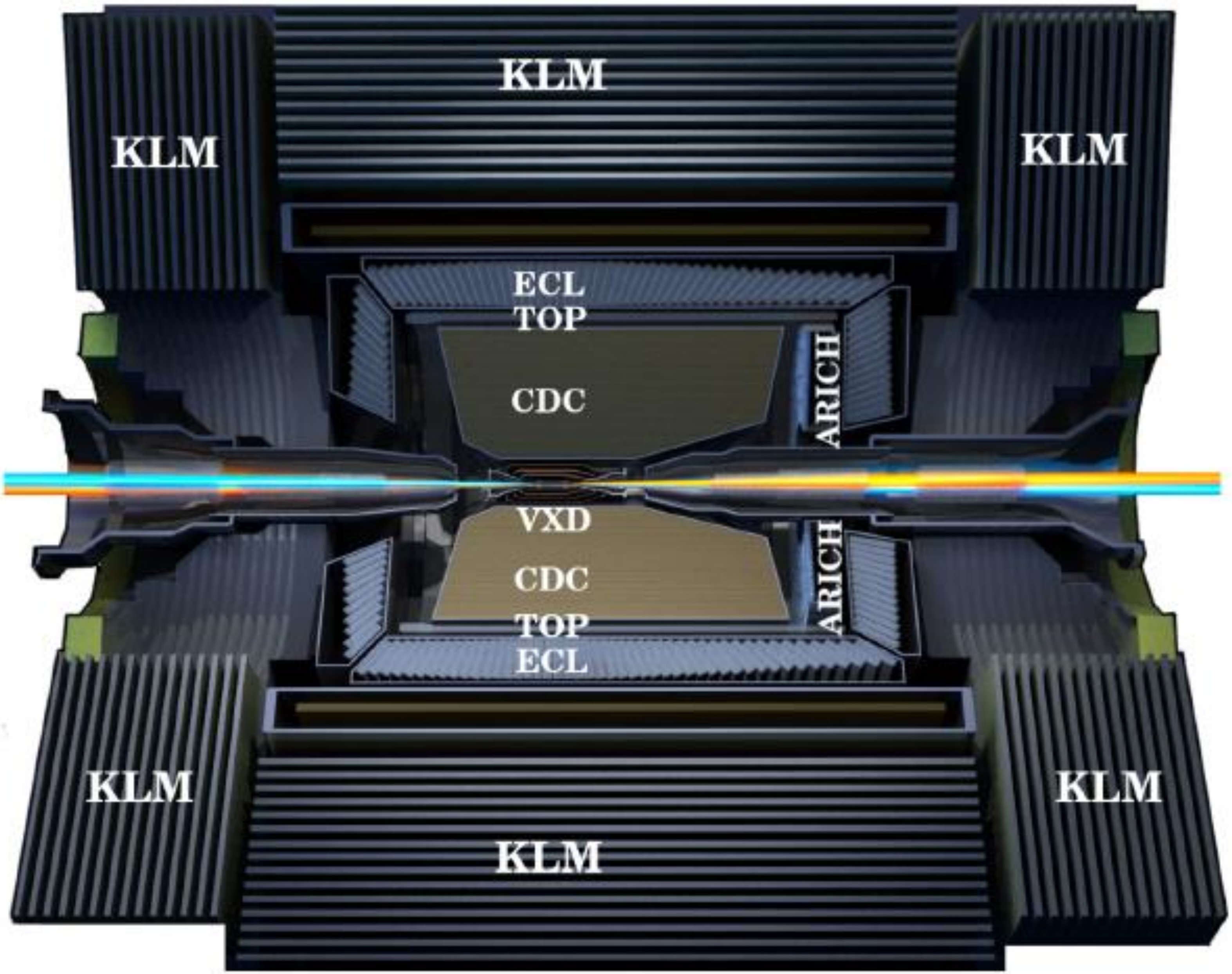
Strong participation from theory community,
lattice QCD community and Belle II experimenters.
689 pages, published by Oxford University Press

KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

The Belle II Physics Book

E. Kou[74,¶,†], P. Urquijo[143,§,†], W. Altmannshofer[133,¶], F. Beaujean[78,¶], G. Bell[120,¶], M. Beneke[112,¶], I. I. Bigi[146,¶], F. Bishara[148,16,¶], M. Blanke[49,50,¶], C. Bobeth[111,112,¶], M. Bona[150,¶], N. Brambilla[112,¶], V. M. Braun[43,¶], J. Brod[110,133,¶], A. J. Buras[113,¶], H. Y. Cheng[44,¶], C. W. Chiang[91,¶], M. Ciuchini[58,¶], G. Colangelo[126,¶], H. Czyz[154,29,¶], A. Datta[144,¶], F. De Fazio[52,¶], T. Deppisch[50,¶], M. J. Dolan[143,¶], J. Evans[133,¶], S. Fajfer[107,139,¶], T. Feldmann[120,¶], S. Godfrey[7,¶], M. Gronau[61,¶], Y. Grossman[15,¶], F. K. Guo[41,132,¶], U. Haisch[148,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[88,¶], J. Hisano[88,89,¶], L. Hofer[125,¶], M. Hoferichter[166,¶], W. S. Hou[91,¶], T. Huber[120,¶], S. Jaeger[157,¶], S. Jahn[82,¶], M. Jamin[124,¶], J. Jones[102,¶], M. Jung[111,¶], A. L. Kagan[133,¶], F. Kahlhoefer[1,¶], J. F. Kamenik[107,139,¶], T. Kaneko[30,26,¶], Y. Kiyo[63,¶], A. Kokulu[112,138,¶], N. Kosnik[107,139,¶], A. S. Kronfeld[20,¶], Z. Ligeti[19,¶], H. Logan[7,¶], C. D. Lu[41,¶], V. Lubicz[151,¶], F. Mahmoudi[140,¶], K. Maltman[171,¶], S. Mishima[30,¶], M. Misiak[164,¶],

Slide from J. Hewett/HE PAP DOE


KLM
KLM
KLM
ECL
TOP
CDC
ARICH
VXD
ARICH
CDC
TOP
ECL
KLM
KLM
KLM

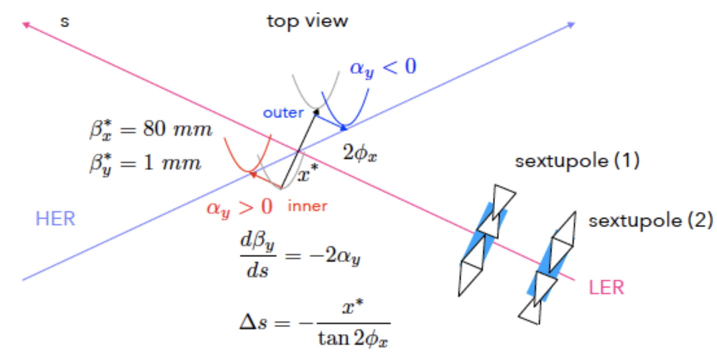
SuperKEKB Luminosity in 2020a,b

- Max current = 770mA(LER) / 660mA(HER)
- L_{peak} = 2.4 x 10^{34} $cm^{-2}s^{-1}$ (world highest)
- Int. luminosity/day = 1.346 fb^{-1}/1.498 fb^{-1}
  recorded delivered

KEKB record
- L_{peak} = 2.11 x 10^{34} $cm^{-2}s^{-1}$
- $L_{day}^{rec.}$ = 1.48 fb^{-1} (2009.6.14)

- LER: β_x^*/β_y^* = 80mm/1mm → 60mm/0.8mm
- HER: β_x^*/β_y^* = 60mm/1mm → 60mm/0.8mm

"Crab Waist" scheme



Operation history in 2020a,b

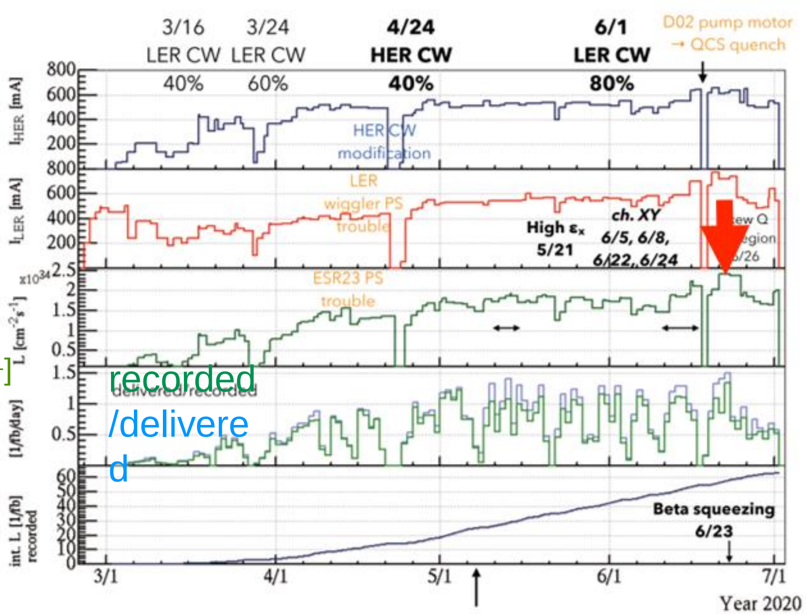
I_{HER}[mA]

I_{LER}[mA]

L_{peak} [x10^{34} $cm^{-2}s^{-1}$]

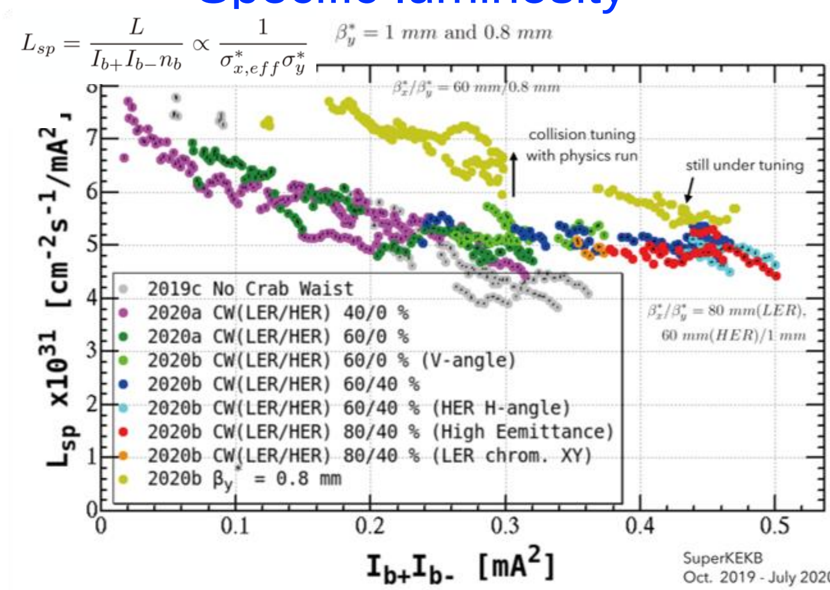
L_{day}[fb^{-1}]

L_{int}[fb^{-1}]



Remarks : Online luminosity does not include trigger-veto dead-time before May 7.

Specific luminosity



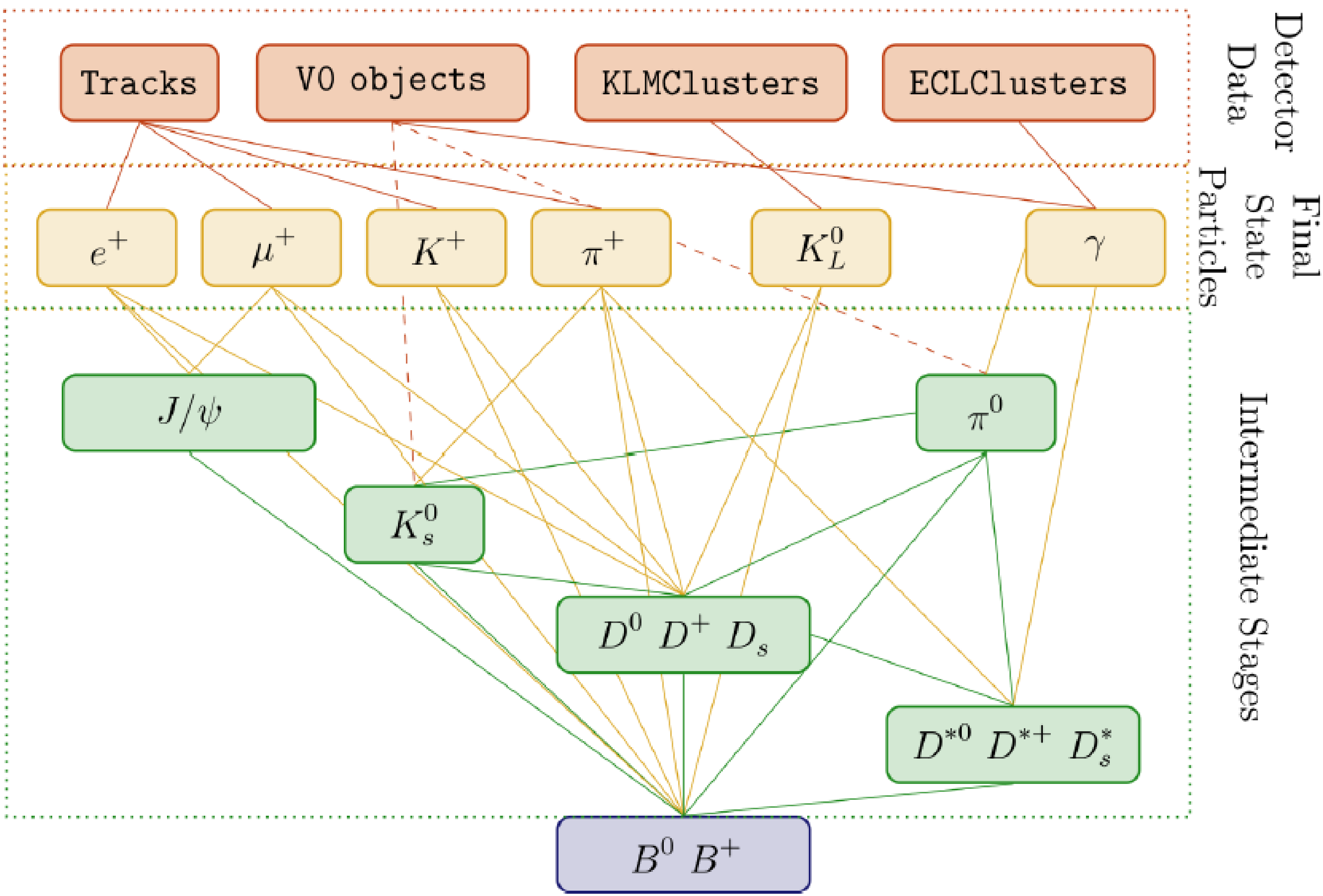


Fig. 50: Hierarchy of the Full Event Interpretation algorithm.

Table 28: Tag-side efficiency defined as the number of correctly reconstructed tag-side B mesons divided by the total number of $\Upsilon(4S)$ events. The presented efficiencies depend on the used BASF2 release (7.2), MC campaign (MC 7) and FEI training configuration.

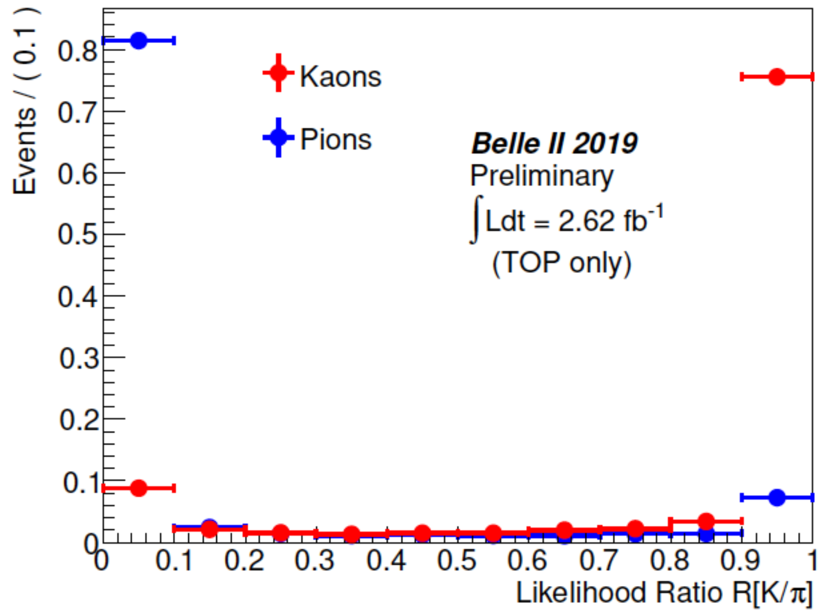
Tag	FR[10] @ Belle	FEI @ Belle MC	FEI @ Belle II MC
Hadronic B^+	0.28 %	0.49 %	0.61 %
Semileptonic B^+	0.67 %	1.42 %	1.45 %
Hadronic B^0	0.18 %	0.33%	0.34 %
Semileptonic B^0	0.63 %	1.33%	1.25 %

Here are some *results* involving charged tracks and TOP particle id in Phase 3

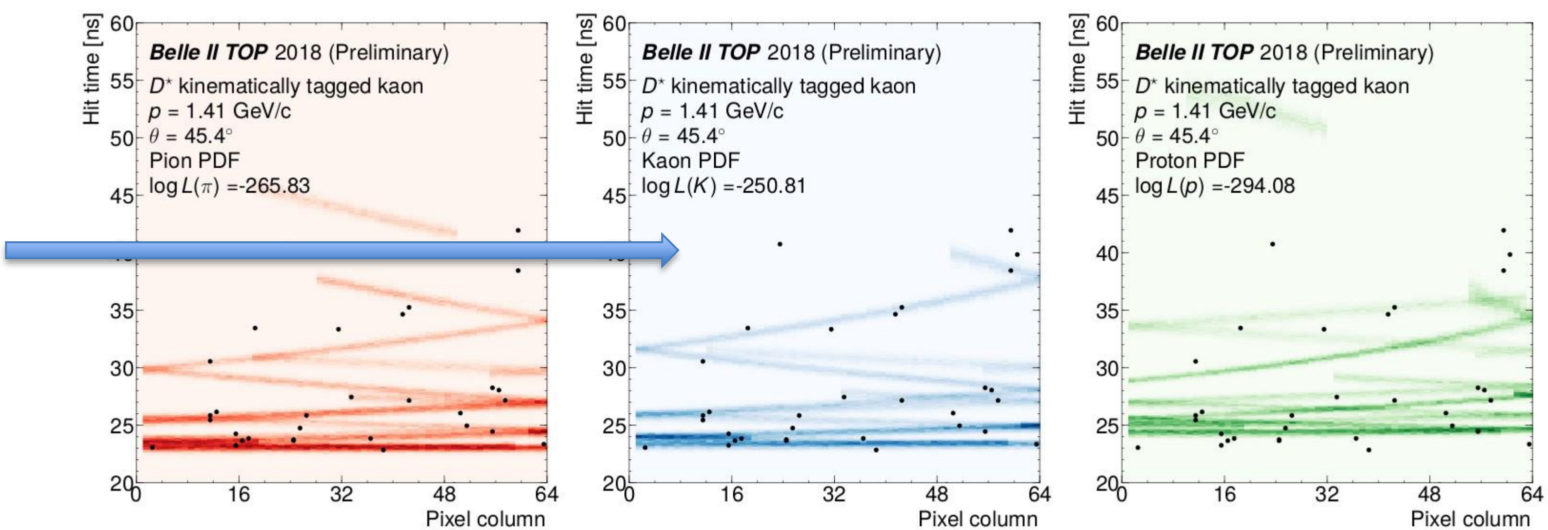
Use kinematically identified kaons and pions from D's*

$$D^{*+} \rightarrow D^0 p_s^{\,+} ; D^0 \rightarrow K^- p^+$$

Note the charge correlation between the kaon and pion and the "slow pion"



Kaon in the TOP; Cherenkov x vs t pattern



June 2020: Current High Momentum PID Performance in Belle II

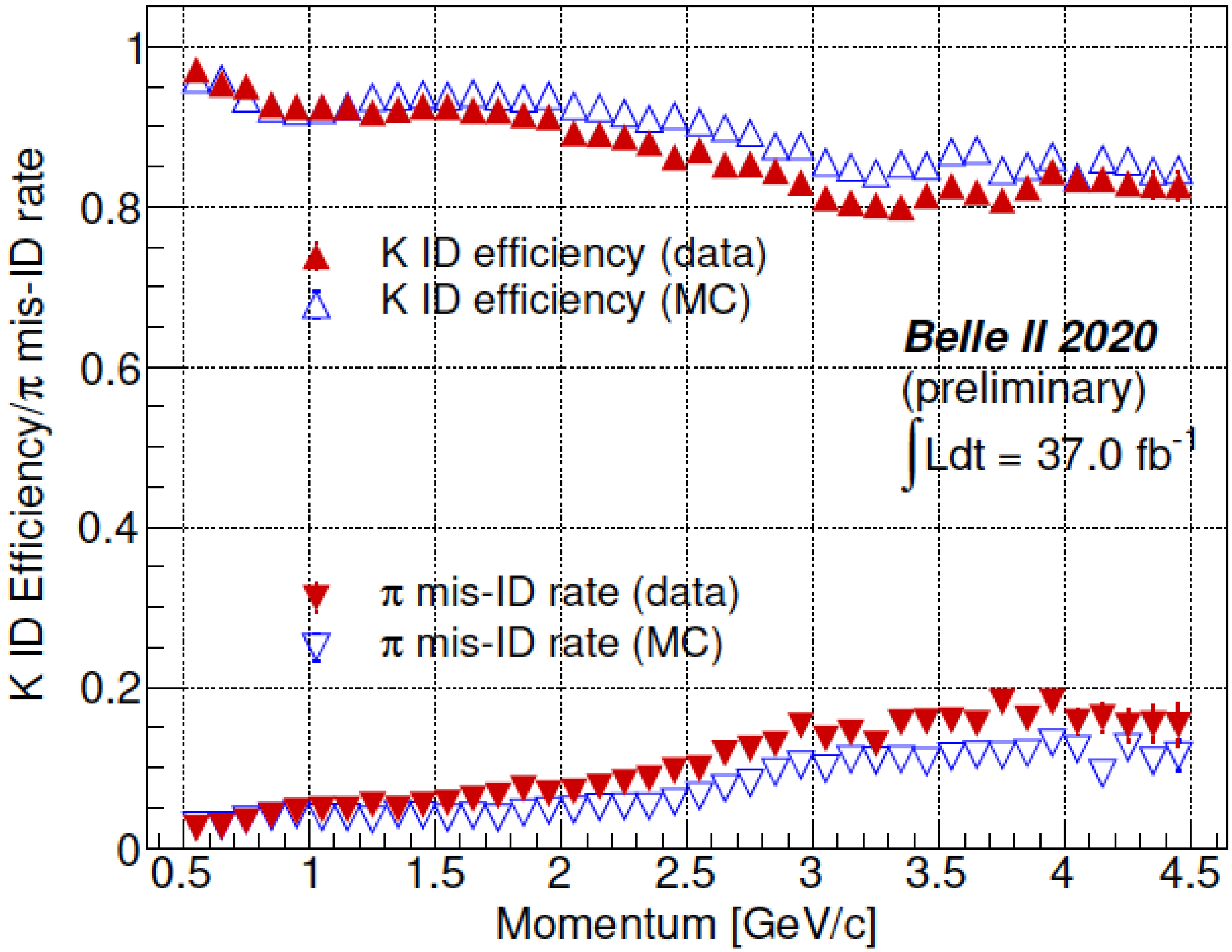


FIG. 6: Kaon efficiency and pion mis-ID rate for the PID criterion $\mathcal{R}_{K/\pi} > 0.5$ using the decay $D^{*+} \to D^0[K^-\pi^+]\pi^+$ in the bins of laboratory frame momentum of the tracks which produces atleast produce hit in ARICH or TOP detector.

June 2020: Current PID Performance in Belle II

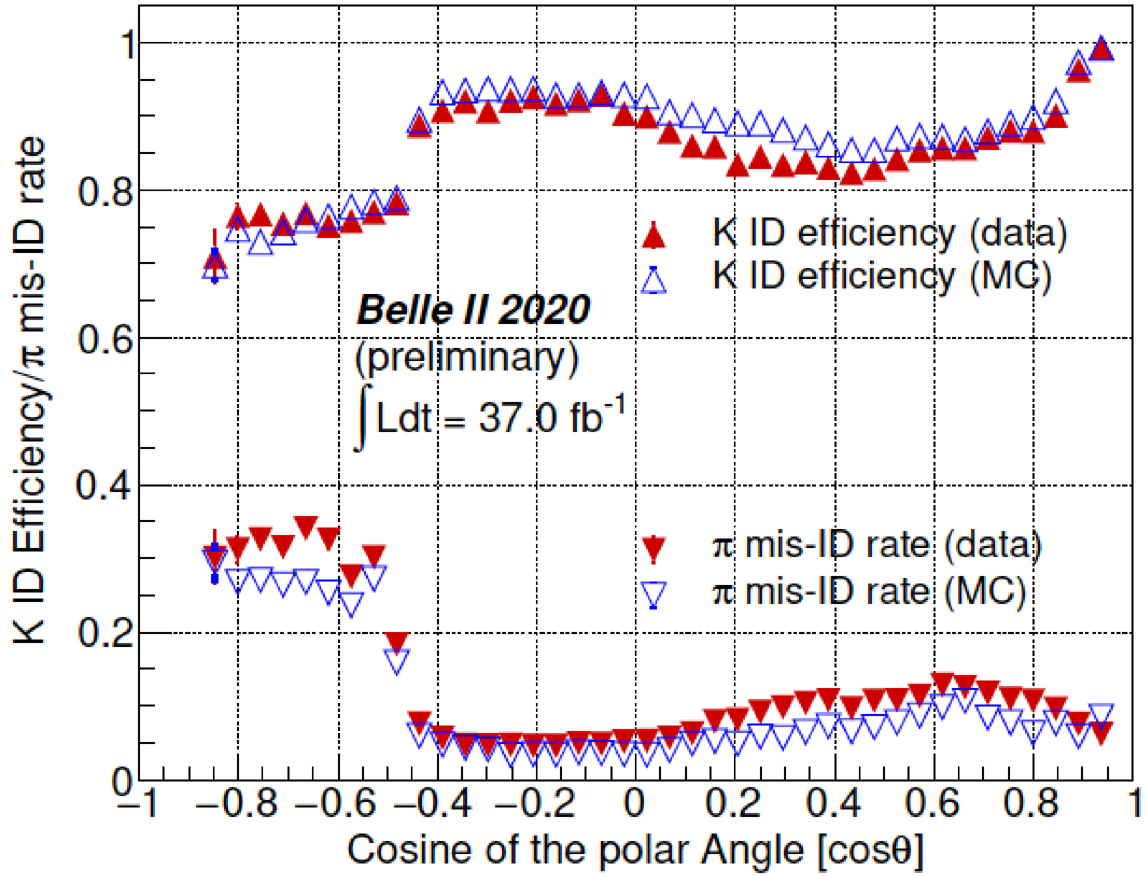
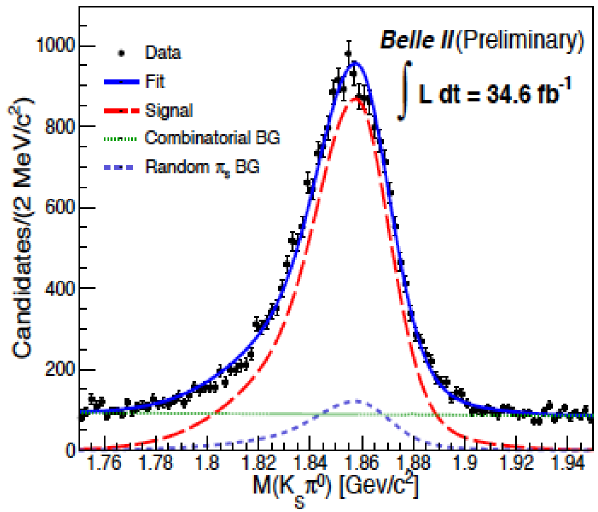
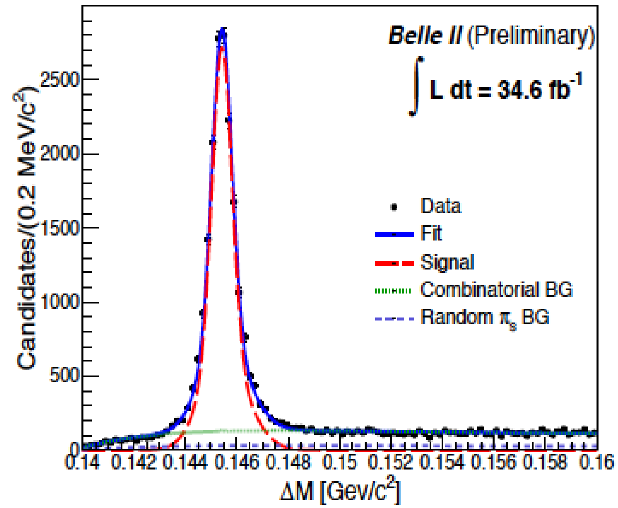


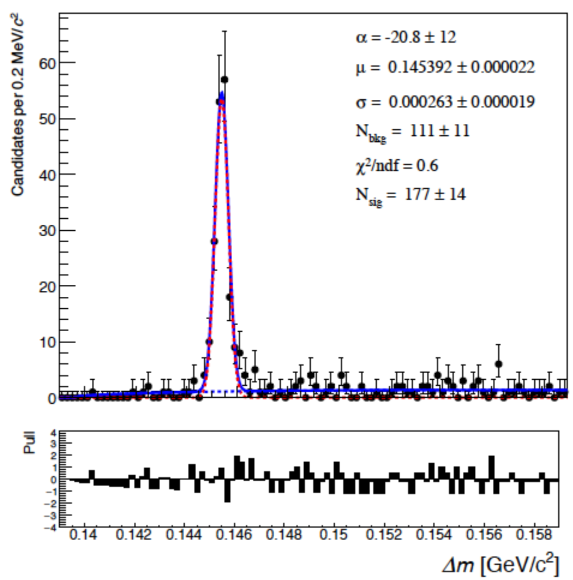
FIG. 5: Kaon efficiency and pion mis-ID rate for the PID criterion $\mathcal{R}_{K/\pi} > 0.5$ using the decay $D^{*+} \to D^0[K^-\pi^+]\pi^+$ in the bins of polar angle (laboratory frame) of the tracks. Note that the acceptance regions of CDC, TOP and ARICH in polar angle ($\cos\theta$) are $[-0.87, 0.96]$, $[-0.48, 0.82]$, and $[0.87, 0.97]$, respectively.

D→Ks pi0, D→Ks Ks
CP eigenstates of the D



(a)





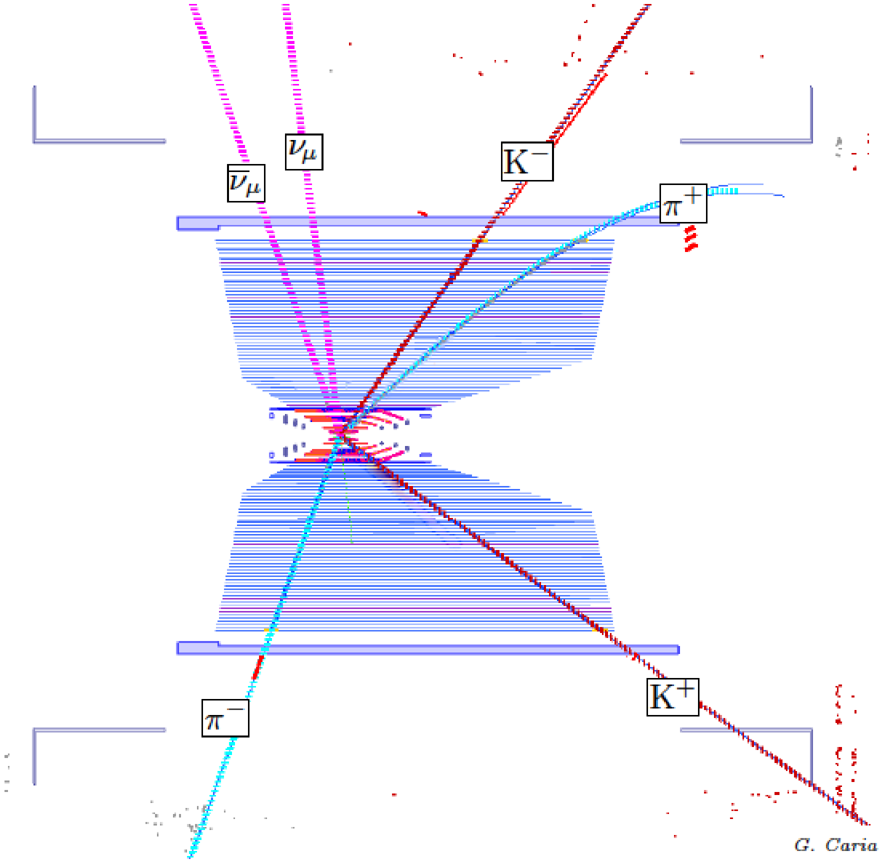
Prospects for the angle gamma/phi_3

Example of Belle II Physics studies (Need E_{ECL} here too)

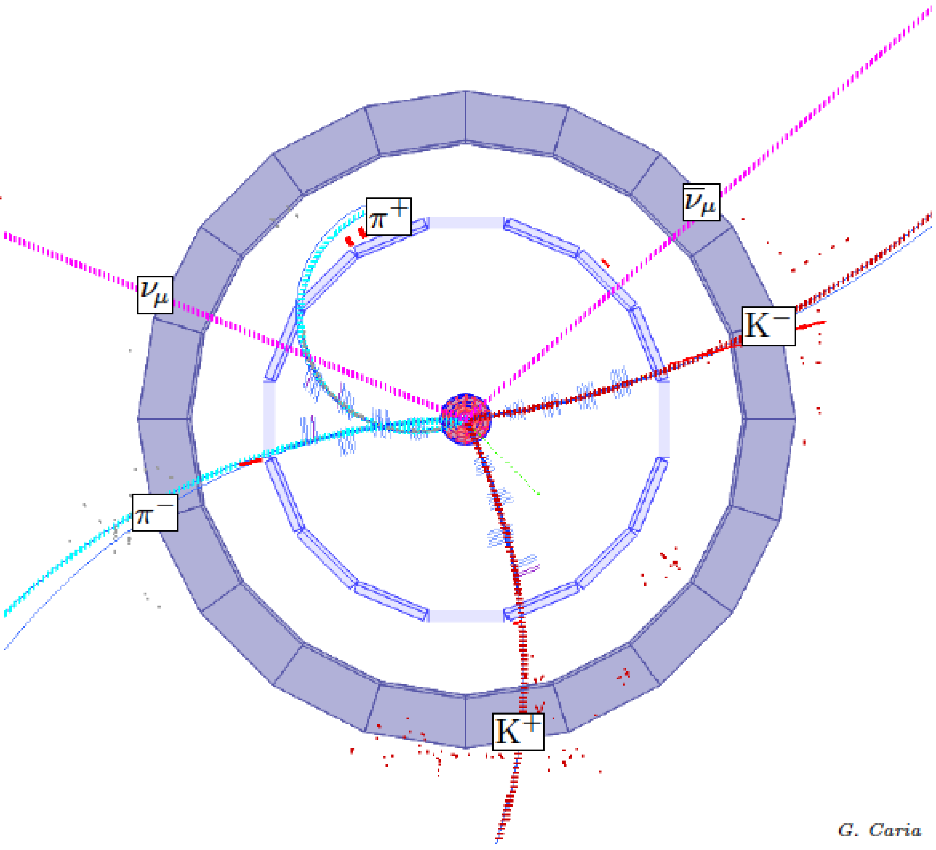
"Missing Energy Decay" in a Belle II GEANT4 MC simulation

Signal $B \rightarrow K \nu \nu$ tag mode: $B \rightarrow D\pi$; $D \rightarrow K\pi$

View in r-z



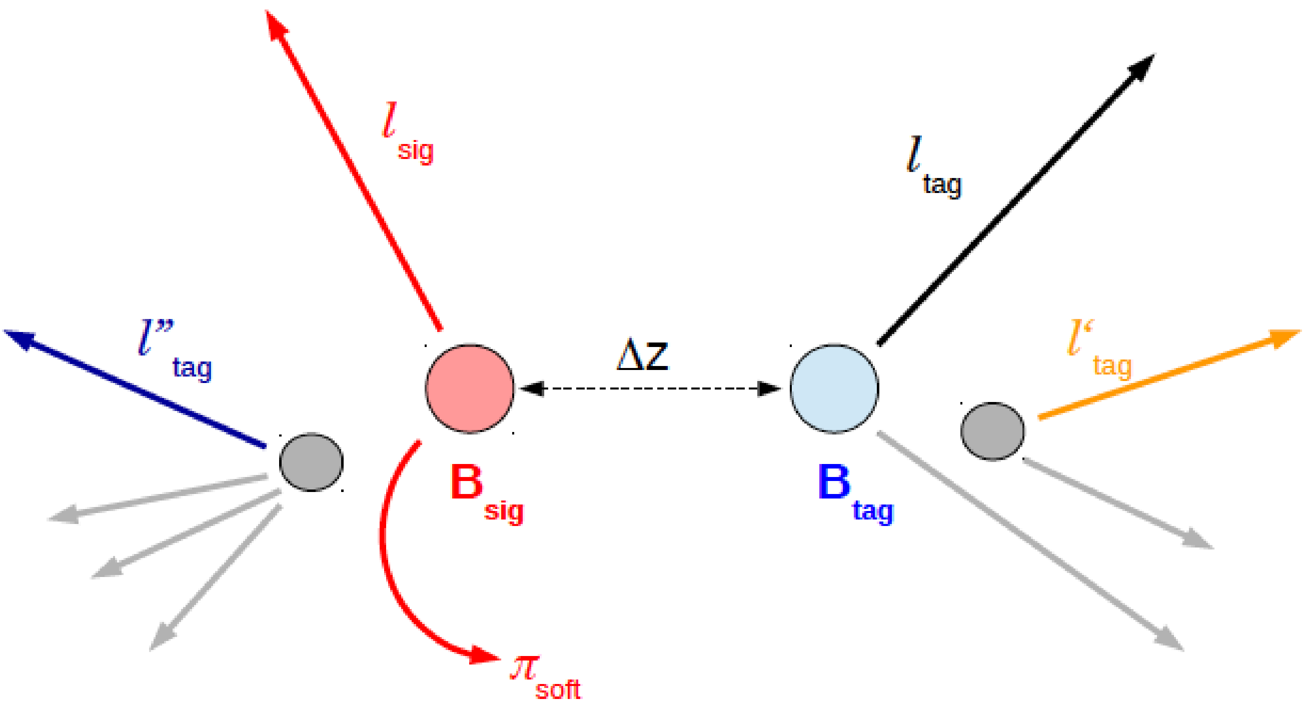
Zoomed view of the vertex region in r--phi



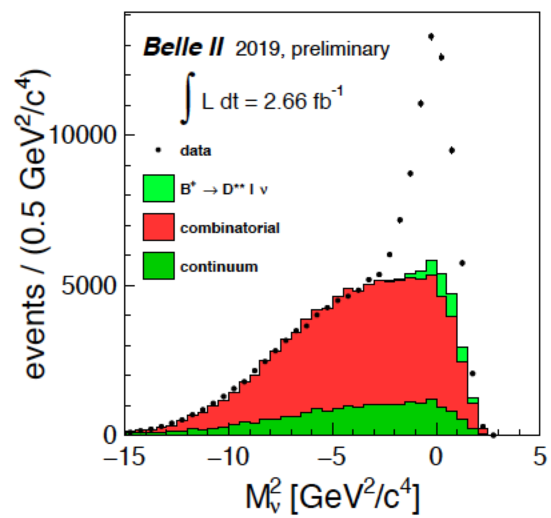
Particle Anti-Particle Mixing
(a remarkable and useful phenomenon).

Start with a B^0 (wait a while, ~a few x 10^{-12} sec).

There is a large probability that the B^0 will turn into its anti-particle, an anti-B^0 (discovered by ARGUS at DESY in 1987)



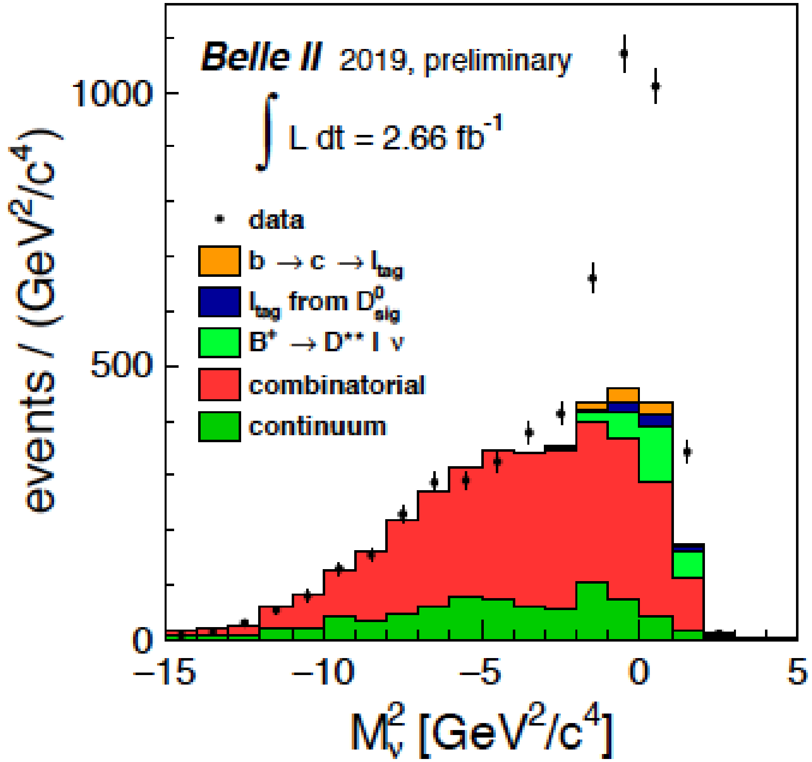
Large B--.D l ν signal from partial reconstruction: 35492±2209



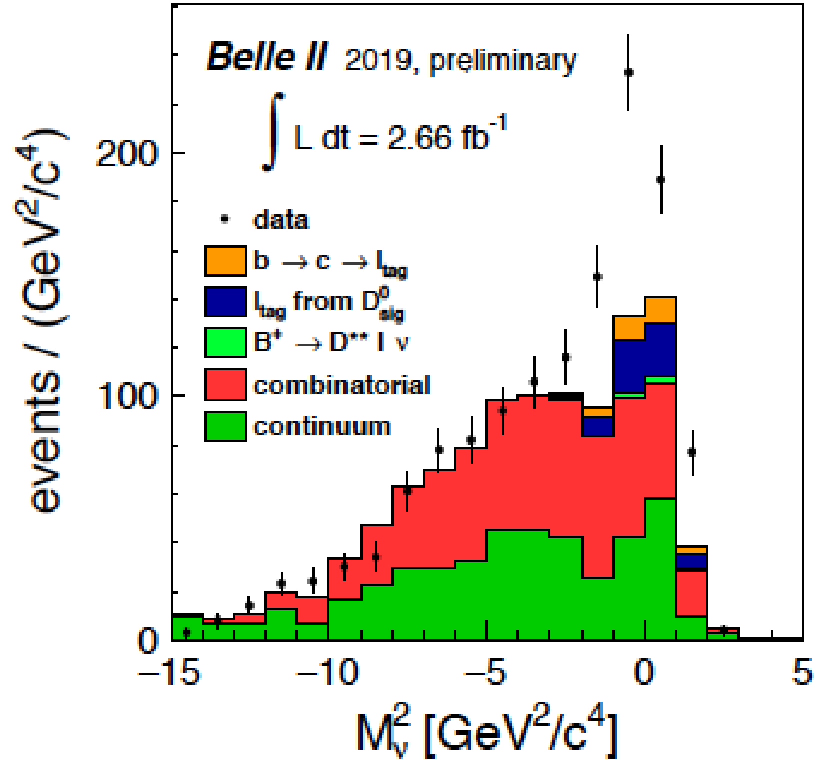
The leptons may come from the B weak decay or (primed case) from a cascade decay B→D→l decay.

Time Integrated Mixing Analysis

Opposite sign



Same sign

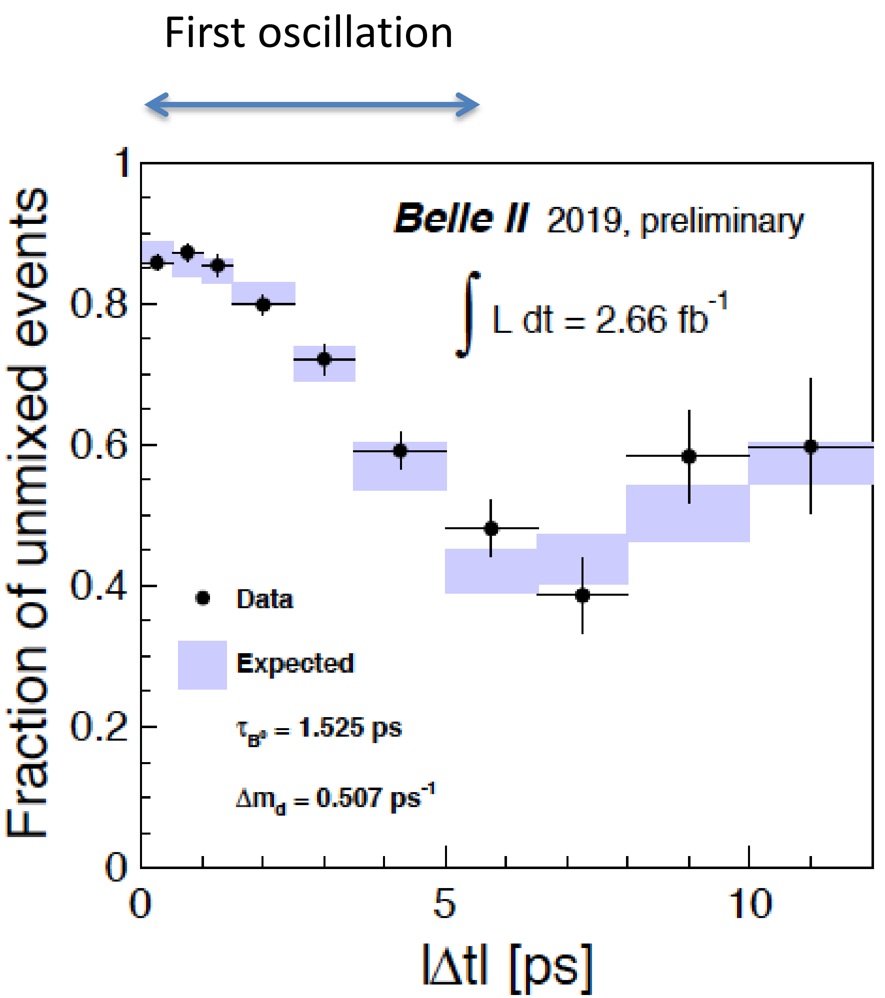


Channel	Data
Untagged e only	18514 ± 1128
Untagged μ only	16625 ± 1111
Untagged (e or μ)	35492 ± 2209
Tagged unmixed (N_U)	1642 ± 133
Tagged mixed (N_M)	253 ± 45
($\varepsilon_U / \varepsilon_M$) correction factor	1.35 ± 0.10
χ_d (fraction of mixed events)	$(17.2 \pm 3.6)\%$

Component	Untagged	ℓ tagged	
		Unmixed	Mixed
$B^{\pm} \to D^{*}\pi\ell\nu$	8.4%	11.1%	2.1%
$b \to c \to \ell_{tag}$	-	3.8%	8.3%
ℓ_{tag} from D^0_{sig}	-	2.7%	17.0%

WA=
18.6%

Time-dependent B-Bbar mixing signature



$$\overline{B}^0 \to D^{*+} \ell^- \nu \to (D^0) \pi_s^+ \ell^- \nu$$

Partial reconstruction and time determination uses only Lepton tagging. (Belle II data)

Check Mv^2 sideband (consistent with MC) and continuum with loose cuts (no oscillation)

Not CP violating:

$f_{unmix}(t)= K\ [1+ \cos(\Delta m_d\ \Delta t)]$

Use flavor specific final states but requires tagging. Verifies Belle II VXD capabilities for CP violation.

Belle II jargon (Phase 1, Phase 2, Phase 3)

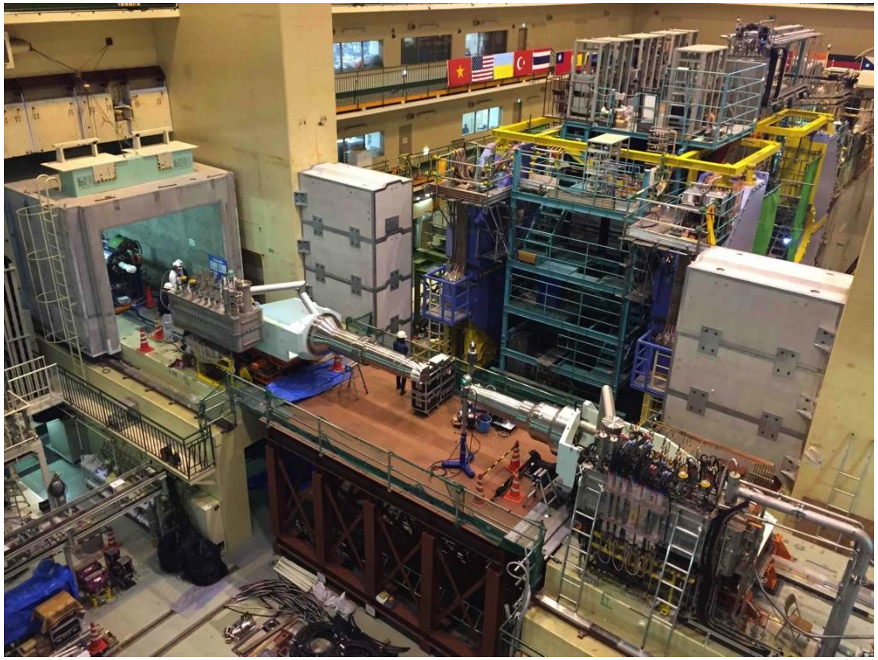
<u>Phase 1</u>: Simple background commissioning detector (diodes, diamonds TPCs, crystals…) BEAST II. <u>No</u> final focus. Only *single* beam background studies possible [started in Feb 2016 and completed in June 2016].

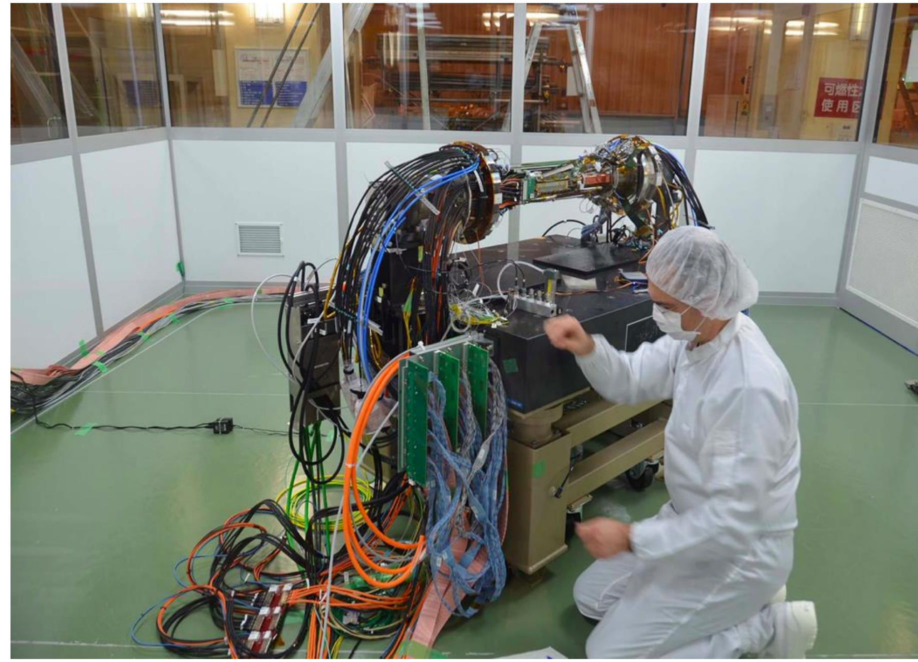
Large crossing angle, 83mrad, is visible

Comprehensive study of beam bkgs published in Jan 2019 issue of NIMA, vol 914, 69 (2019)

Belle II was "rolled-in" in 2017 after delivery of the superconducting final focus.
This was followed by the Phase 2 run in 2018.

Belle II jargon (Phase 2, Phase 3)





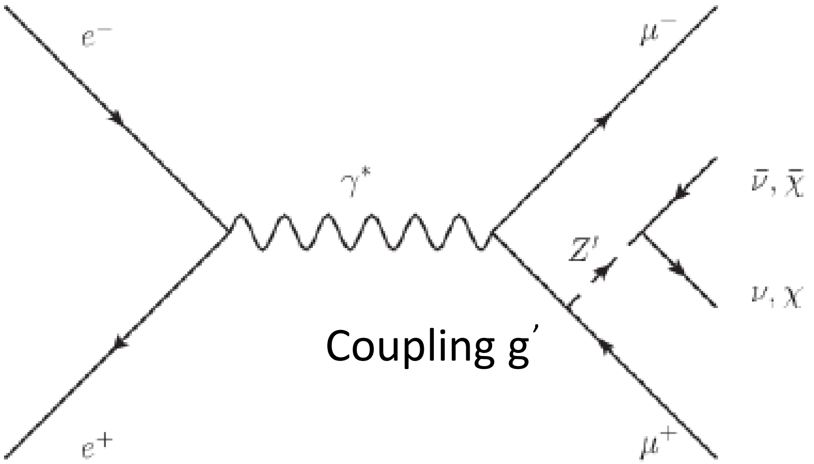
__Phase 2__: A pilot run with a more elaborate inner background commissioning detector (VXD samples). Full Belle II *outer* detector. Full superconducting final focus. *No vertex detectors. Collisions !* *[Phase 2 collisions: April 26-July 17, 2018]*

Phase 3: Installed the VXD in Belle II. First Physics Run with the full Belle II detector [March 26-July 1, 2019]

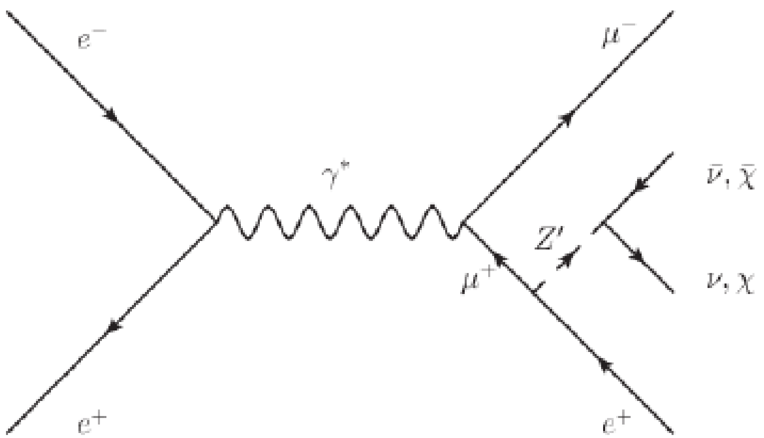
Dark Sector:

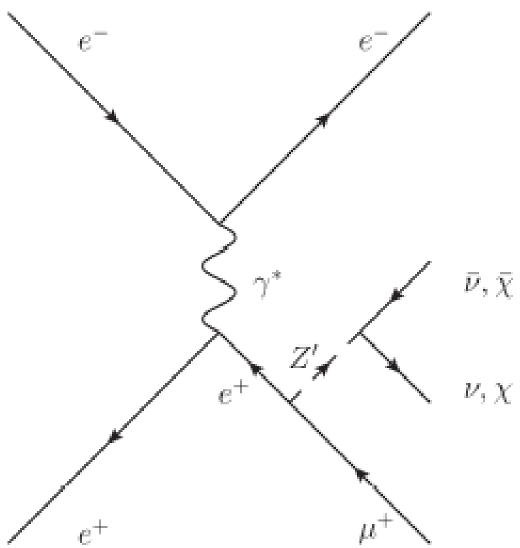
Previously limited by Triggering, QED backgrounds and theoretical imagination. *Now new possibilities of triggering, more bandwidth.*

Belle II First Physics. A novel result on the dark sector (Z' →nothing) recoiling against di-muons *or* an electron-muon pair. *Both possibilities are poorly constrained at low Z' mass and in the first case, could explain the muon g-2 anomaly.*

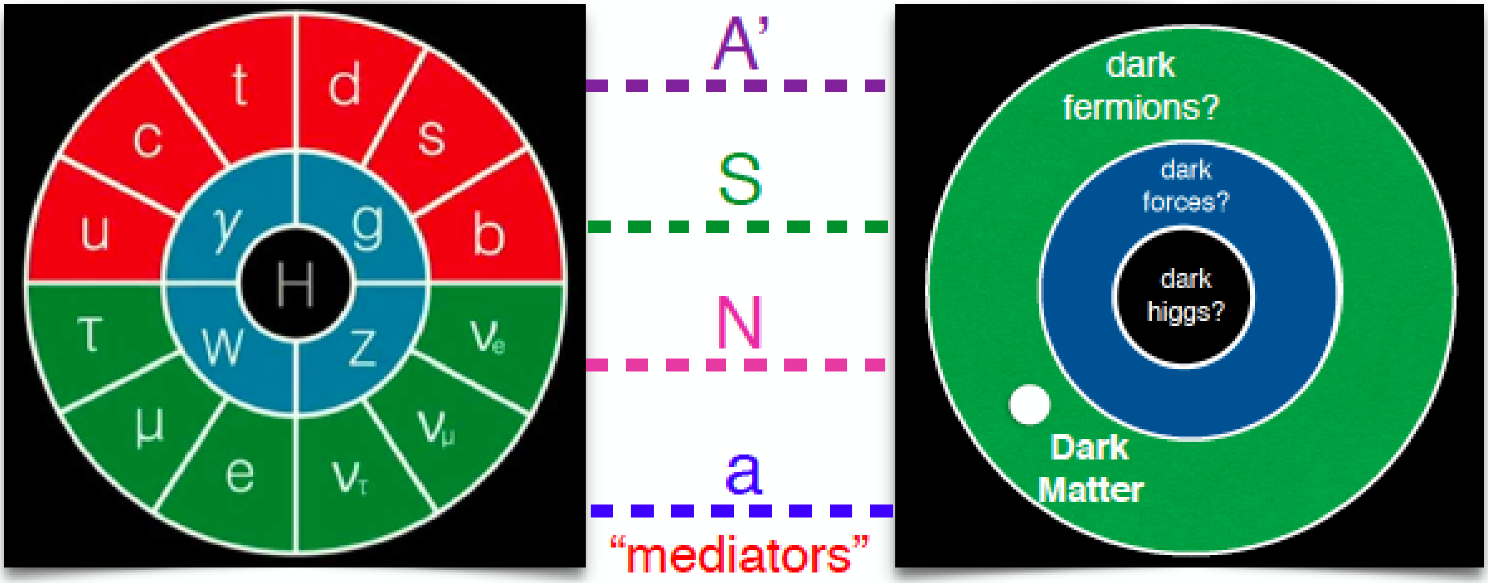


Also examine a lepton flavor violating NP signature in the dark sector





How to gain access to the dark sector?



Only a few interactions exist that are allowed by Standard Model symmetries:

+ possible new dark gauge bosons obtained gauging e.g. B-L, L_μ-L_τ, …

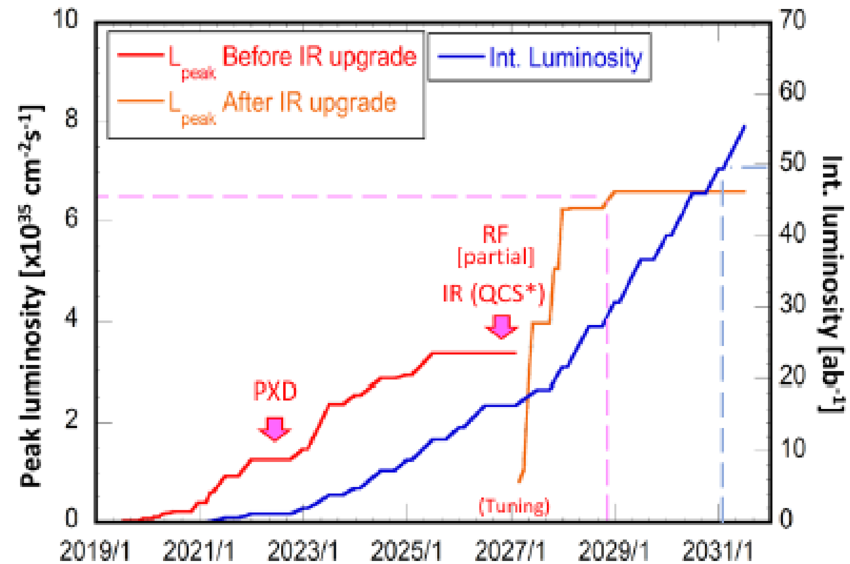
"mediators"	"portal interactions"
Dark photon	$\epsilon B^{\mu\nu} A'_{\mu\nu}$
Higgs	$\kappa\vert H\vert^2\vert S\vert^2$
Neutrino	$y H L N$
Axion	$g_{a\gamma} a \tilde{F}_{\mu\nu} F^{\mu\nu}$

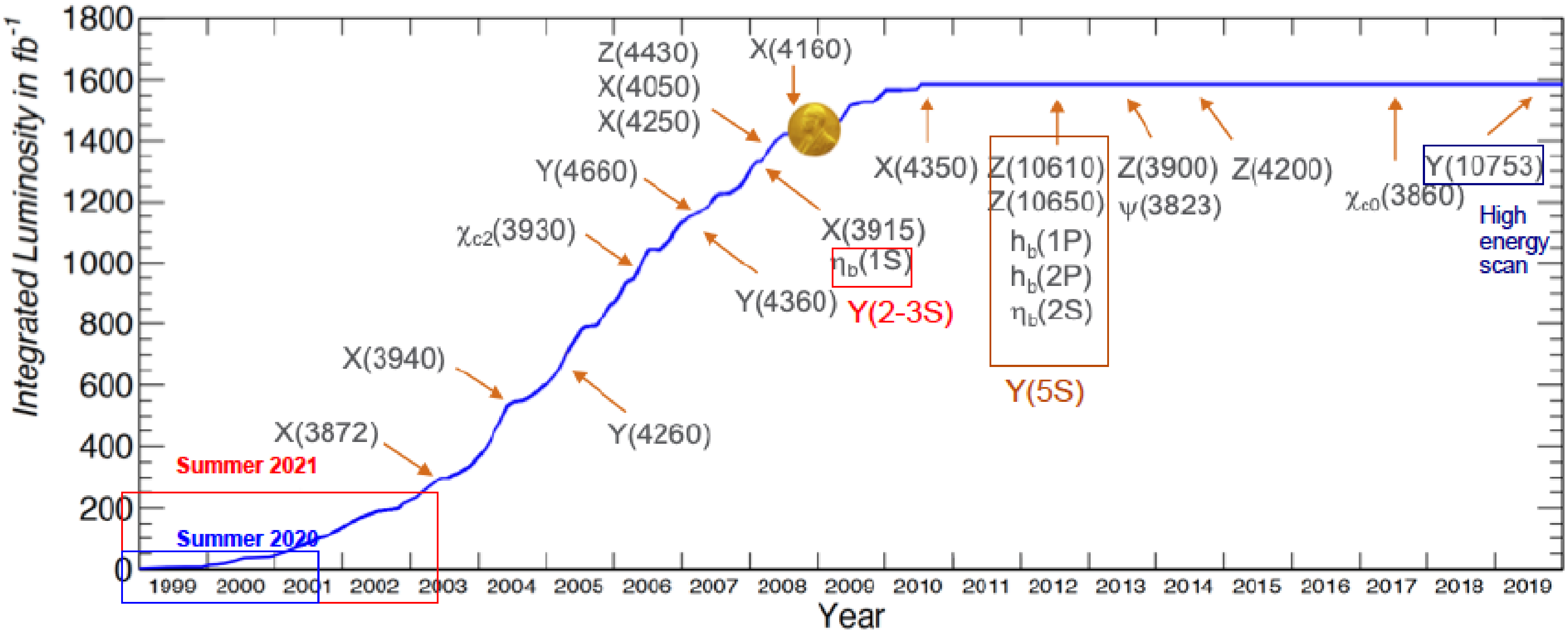
S.Gori

Just warming up the engines

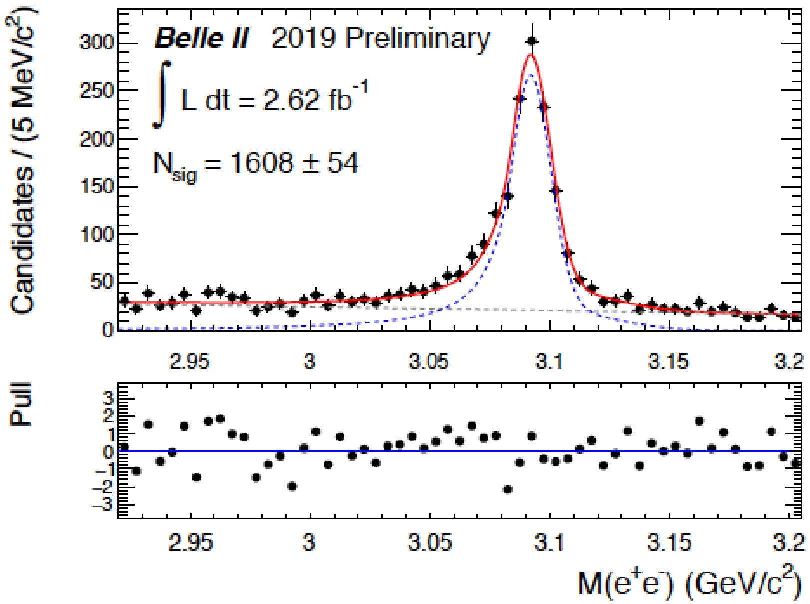
Rediscovery of most surprises from B factories expected after 250 fb^{-1}

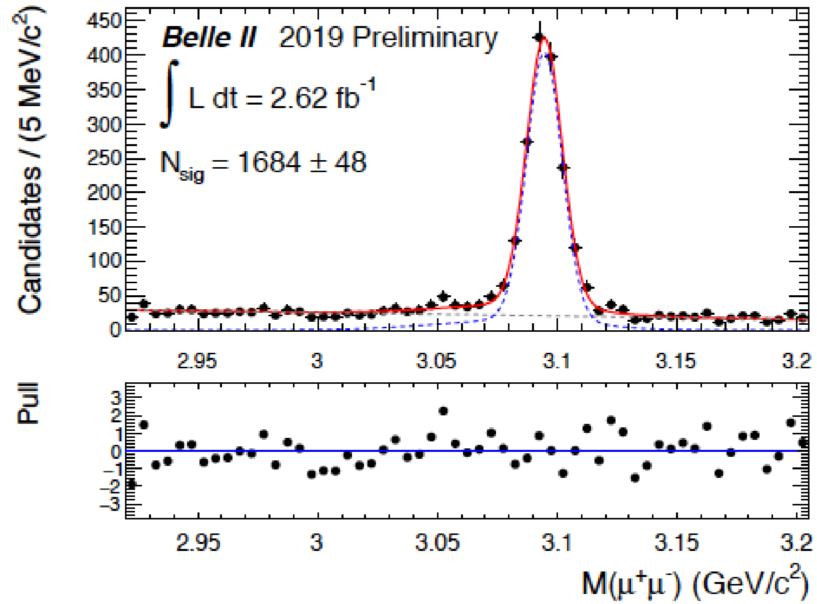
- Stay tuned for Summer 2021 conferences
- First ab^{-1} before 2022 shutdown
- Data taking at 10.75 under discussion





Signals for B→J/ψ X in Phase 3 data

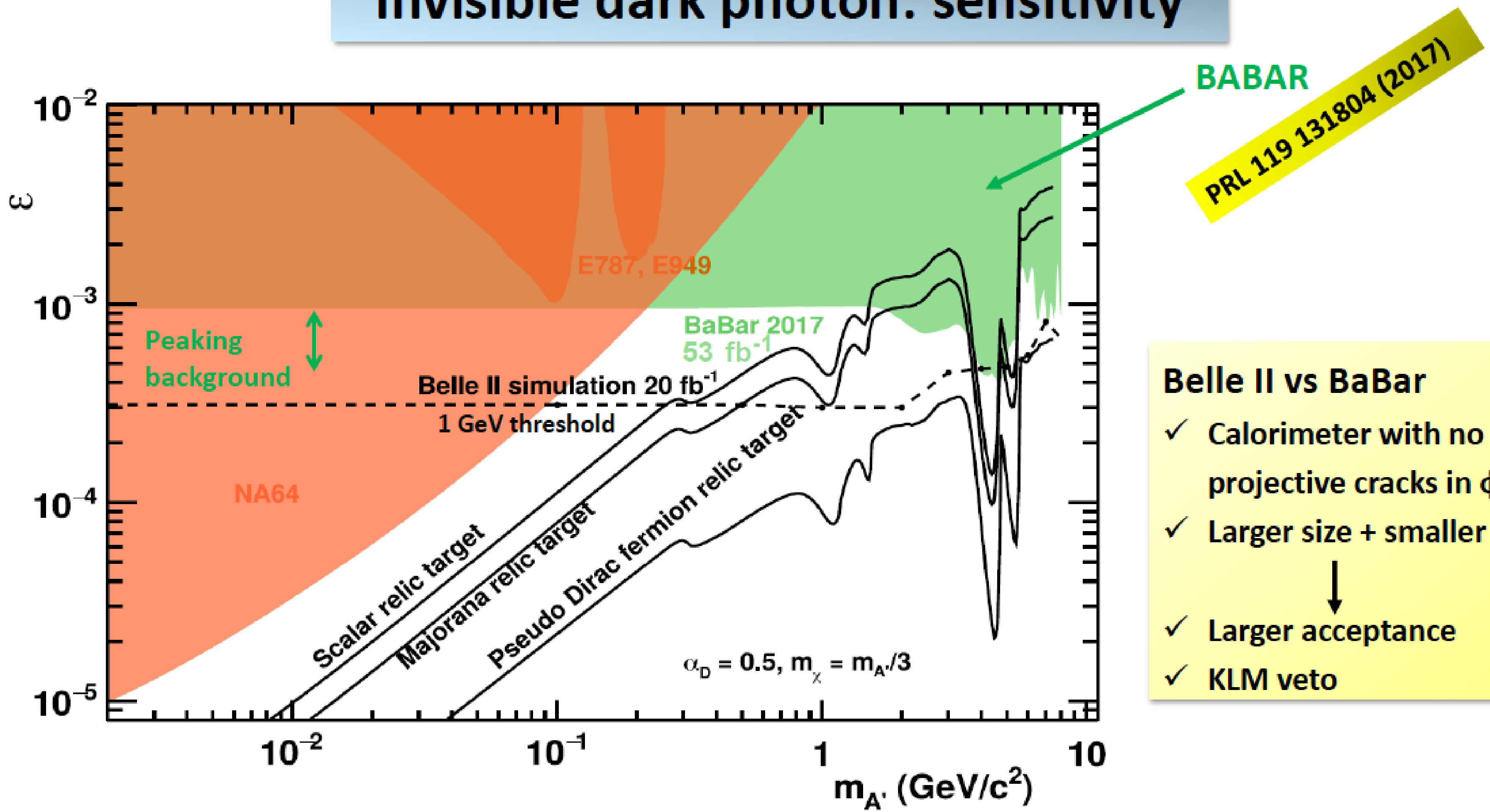




Clear signals for B→J/ψ X in ~1/2 of Phase 3 data. Note the small radiative tail on the di-electrons (does include bremsstrahlung recovery).

→*Belle II has equally strong capabilities for electrons and muons.*

Invisible dark photon: sensitivity



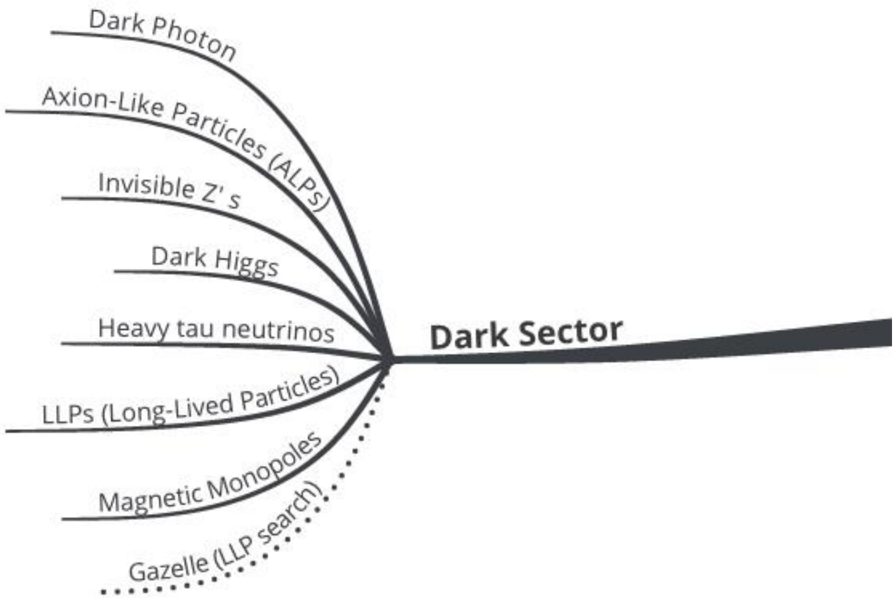
Belle II vs BaBar

- ✓ Calorimeter with no projective cracks in ϕ
- ✓ Larger size + smaller boost

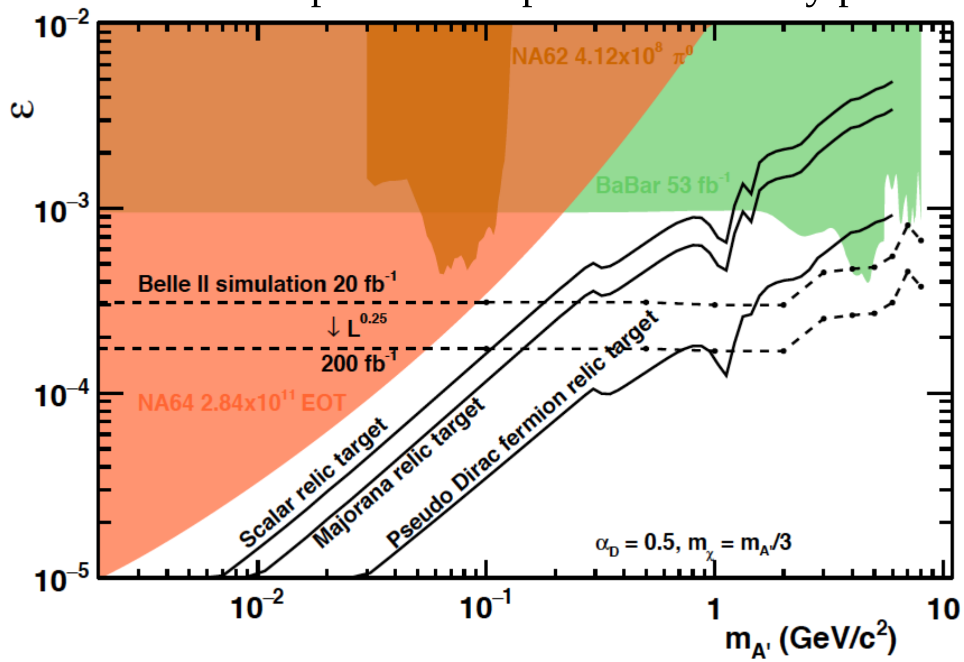
↓

- ✓ Larger acceptance
- ✓ KLM veto

Zoom in on the Dark Sector



Updated dark photon sensitivity plot



LLP White Paper (including the Gazelle proposal): Torben Ferber, Suzanne Westhof et al

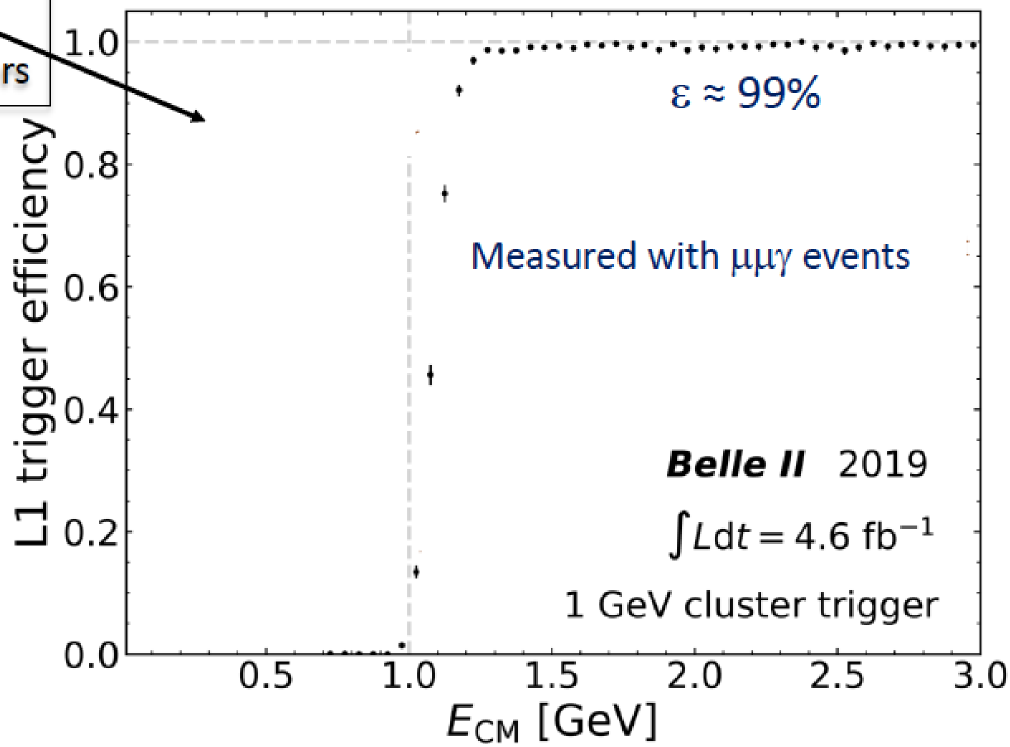
Dark Sector Capabilities of Belle II White Paper, Chris Hearty, Kevin Flood et al.

Invisible dark photon: single photon trigger

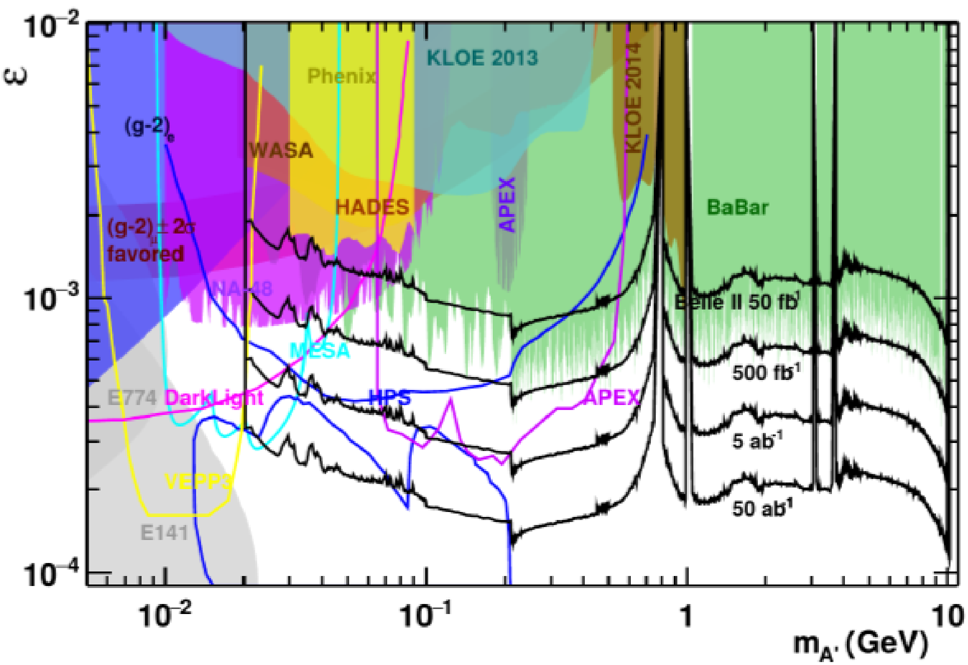
- **E_{CM} > 2 GeV**
- **E_{CM} > 1 GeV** in barrel + no other clusters
- **E_{CM} > 0.5 GeV** in central barrel + no other clusters

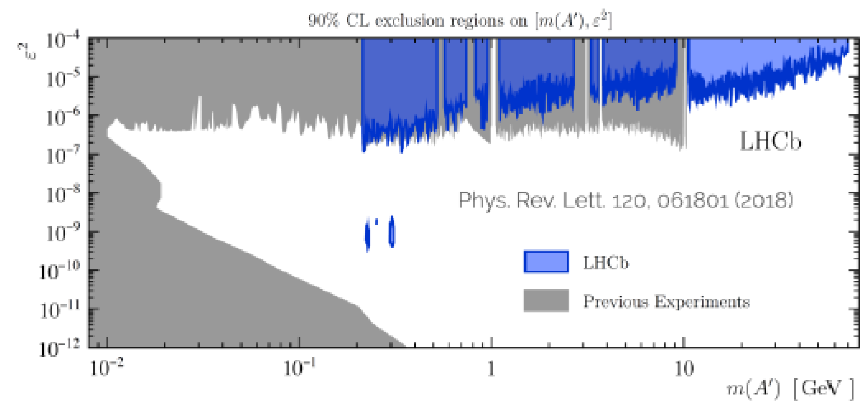
Would extend the search range up to $M_{A'}$<≈10 GeV (psycological threshold)

Much more aggressive than originally expected. Good conditions to perform the measurement as soon as possible.



Visible dark photon: sensitivity





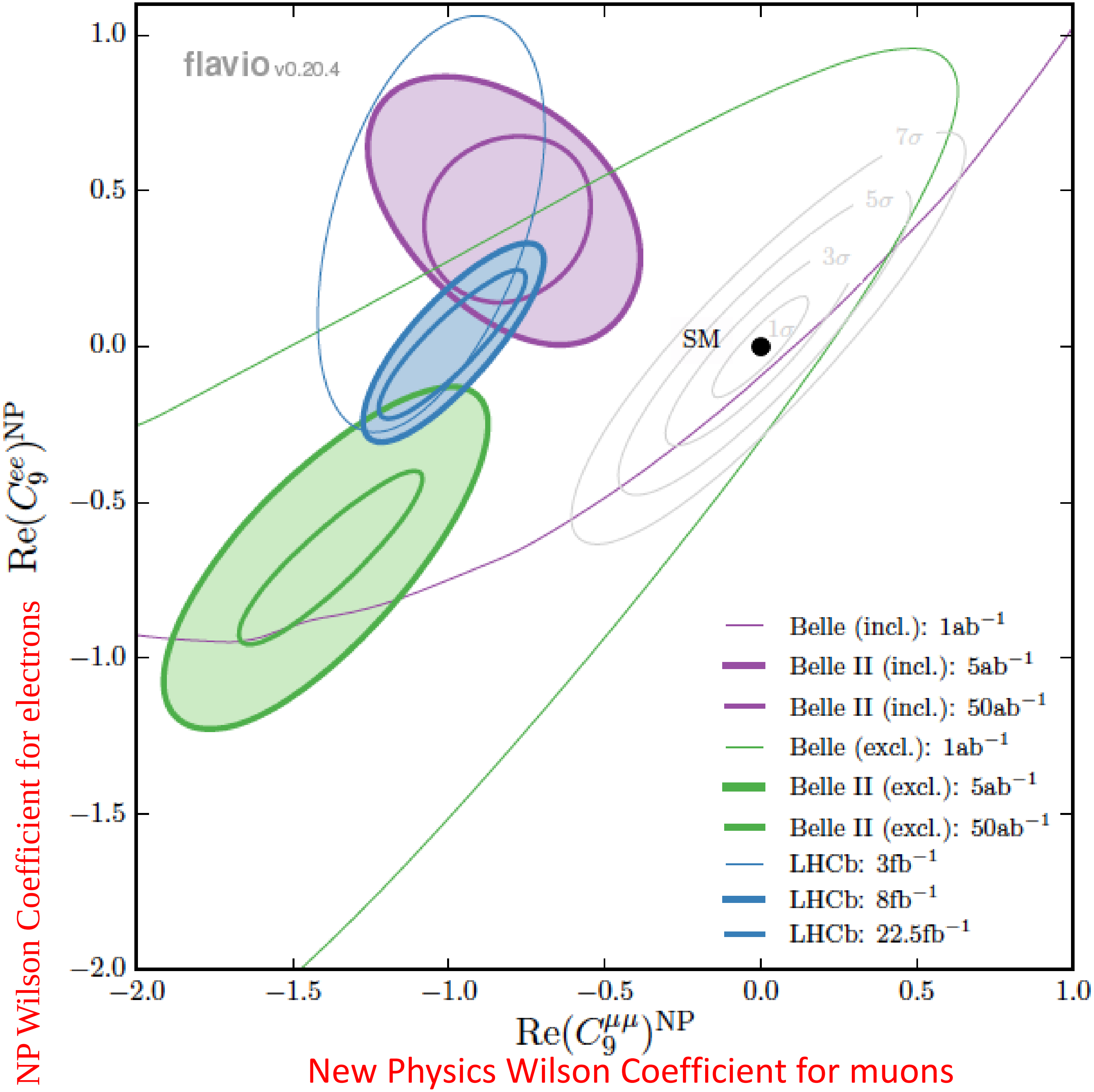
Competition with LHCb:

Drell-Yan processes
Displaced vertices
$D^* \rightarrow D A', A' \rightarrow ee$

PRL 113, 201801 (2014)

Best limits in the GeV region from **BaBar**
Belle had no suitable low mutiplicity triggers for this search
Hadronic and ττ final states much harder

Belle II needs some years of data for leading sensitivity: search currently in preparation



NP in b→s l^+l^-

Prepared by D. Straub et al. for the Belle II Physics Book (edited by P. Urquijo and E. Kou)

Belle II can do both inclusive and exclusive. Equally strong capabilities for electrons and muons.

Snowmass 2021 Letter of Interest: B Physics at Belle II

on behalf of the U.S. Belle II Collaboration

D. M. Asner[1], Sw. Banerjee[2], J. V. Bennett[3], G. Bonvicini[4], R. A. Briere[5], T. E. Browder[6], D. N. Brown[2], C. Chen[7], D. Cinabro[4], J. Cochran[7], L. M. Cremaldi[3], A. Di Canto[1], K. Flood[6], B. G. Fulsom[8], R. Godang[9], W. W. Jacobs[10], D. E. Jaffe[1], K. Kinoshita[11], R. Kroeger[3], R. Kulasiri[12], P. J. Laycock[1], K. A. Nishimura[6], T. K. Pedlar[13], L. E. Piilonen[14], S. Prell[7], C. Rosenfeld[15], D. A. Sanders[3], V. Savinov[16], A. J. Schwartz[11], J. Strube[8], D. J. Summers[3], S. E. Vahsen[6], G. S. Varner[6], A. Vossen[17], L. Wood[8], and J. Yelton[18]

[1]*Brookhaven National Laboratory, Upton, New York 11973*
[2]*University of Louisville, Louisville, Kentucky 40292*
[3]*University of Mississippi, University, Mississippi 38677*
[4]*Wayne State University, Detroit, Michigan 48202*
[5]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*
[6]*University of Hawaii, Honolulu, Hawaii 96822*
[7]*Iowa State University, Ames, Iowa 50011*
[8]*Pacific Northwest National Laboratory, Richland, Washington 99352*
[9]*University of South Alabama, Mobile, Alabama 36688*
[10]*Indiana University, Bloomington, Indiana 47408*
[11]*University of Cincinnati, Cincinnati, Ohio 45221*
[12]*Kennesaw State University, Kennesaw, Georgia 30144*
[13]*Luther College, Decorah, Iowa 52101*
[14]*Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061*
[15]*University of South Carolina, Columbia, South Carolina 29208*
[16]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*
[17]*Duke University, Durham, North Carolina 27708*
[18]*University of Florida, Gainesville, Florida 32611*

Corresponding Author:
Soeren Prell (Iowa State University), prell@iastate.edu

Thematic Area(s):

■ (RF01) Weak Decays of b and c Quarks

Snowmass 2021 Letter of Interest: Dark sector studies at Belle II

on behalf of the U.S. Belle II Collaboration

D. M. Asner[1], Sw. Banerjee[2], J. V. Bennett[3], G. Bonvicini[4], R. A. Briere[5], T. E. Browder[6], D. N. Brown[2], C. Chen[7], D. Cinabro[4], J. Cochran[7], L. M. Cremaldi[3], A. Di Canto[1], K. Flood[6], B. G. Fulsom[8], R. Godang[9], W. W. Jacobs[10], D. E. Jaffe[1], K. Kinoshita[11], R. Kroeger[3], R. Kulasiri[12], P. J. Laycock[1], K. A. Nishimura[6], T. K. Pedlar[13], L. E. Piilonen[14], S. Prell[7], C. Rosenfeld[15], D. A. Sanders[3], V. Savinov[16], A. J. Schwartz[11], J. Strube[8], D. J. Summers[3], S. E. Vahsen[6], G. S. Varner[6], A. Vossen[17], L. Wood[8], and J. Yelton[18]

[1]*Brookhaven National Laboratory, Upton, New York 11973*
[2]*University of Louisville, Louisville, Kentucky 40292*
[3]*University of Mississippi, University, Mississippi 38677*
[4]*Wayne State University, Detroit, Michigan 48202*
[5]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*
[6]*University of Hawaii, Honolulu, Hawaii 96822*
[7]*Iowa State University, Ames, Iowa 50011*
[8]*Pacific Northwest National Laboratory, Richland, Washington 99352*
[9]*University of South Alabama, Mobile, Alabama 36688*
[10]*Indiana University, Bloomington, Indiana 47408*
[11]*University of Cincinnati, Cincinnati, Ohio 45221*
[12]*Kennesaw State University, Kennesaw, Georgia 30144*
[13]*Luther College, Decorah, Iowa 52101*
[14]*Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061*
[15]*University of South Carolina, Columbia, South Carolina 29208*
[16]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*
[17]*Duke University, Durham, North Carolina 27708*
[18]*University of Florida, Gainesville, Florida 32611*

Corresponding Authors:
Christopher Hearty (University of British Columbia / IPP), hearty@physics.ubc.ca
Kevin Flood (University of Hawaii), kflood@hawaii.edu

Thematic Area(s):

■ (RF06) Dark Sector at Low Energies

Snowmass 2021 Letter of Interest: Belle II Detector Upgrades

on behalf of the U.S. Belle II Collaboration

D. M. Asner[1], Sw. Banerjee[2], J. V. Bennett[3], G. Bonvicini[4], R. A. Briere[5], T. E. Browder[6], D. N. Brown[2], C. Chen[7], D. Cinabro[4], J. Cochran[7], L. M. Cremaldi[3], A. Di Canto[1], K. Flood[6], B. G. Fulsom[8], R. Godang[9], W. W. Jacobs[10], D. E. Jaffe[1], K. Kinoshita[11], R. Kroeger[3], R. Kulasiri[12], P. J. Laycock[1], K. A. Nishimura[6], T. K. Pedlar[13], L. E. Piilonen[14], S. Prell[7], C. Rosenfeld[15], D. A. Sanders[3], V. Savinov[16], A. J. Schwartz[11], J. Strube[8], D. J. Summers[3], S. E. Vahsen[6], G. S. Varner[6], A. Vossen[17], L. Wood[8], and J. Yelton[18]

[1]*Brookhaven National Laboratory, Upton, New York 11973*
[2]*University of Louisville, Louisville, Kentucky 40292*
[3]*University of Mississippi, University, Mississippi 38677*
[4]*Wayne State University, Detroit, Michigan 48202*
[5]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*
[6]*University of Hawaii, Honolulu, Hawaii 96822*
[7]*Iowa State University, Ames, Iowa 50011*
[8]*Pacific Northwest National Laboratory, Richland, Washington 99352*
[9]*University of South Alabama, Mobile, Alabama 36688*
[10]*Indiana University, Bloomington, Indiana 47408*
[11]*University of Cincinnati, Cincinnati, Ohio 45221*
[12]*Kennesaw State University, Kennesaw, Georgia 30144*
[13]*Luther College, Decorah, Iowa 52101*
[14]*Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061*
[15]*University of South Carolina, Columbia, South Carolina 29208*
[16]*University of Pittsburgh, Pittsburgh, Pennsylvania 15260*
[17]*Duke University, Durham, North Carolina 27708*
[18]*University of Florida, Gainesville, Florida 32611*

Corresponding Authors:
Sven Vahsen (University of Hawaii), sevahsen@hawaii.edu
Gary Varner (University of Hawaii)
Francesco Forti (INFN and University of Pisa)

Snowmass 2021 Letter of Interest: Computing, Software, and Data Analysis at Belle II

on behalf of the U.S. Belle II Collaboration

D. M. Asner[1], Sw. Banerjee[2], J. V. Bennett[3], G. Bonvicini[4], R. A. Briere[5], T. E. Browder[6], D. N. Brown[2], C. Chen[7], D. Cinabro[4], J. Cochran[7], L. M. Cremaldi[3], A. Di Canto[1], K. Flood[6], B. G. Fulsom[8], R. Godang[9], M. Hernández Villanueva[3], W. W. Jacobs[10], D. E. Jaffe[1], K. Kinoshita[11], R. Kroeger[3], R. Kulasiri[12], P. J. Laycock[1], F. Meier[13], K. A. Nishimura[6], T. K. Pedlar[14], L. E. Piilonen[15], S. Prell[7], C. Rosenfeld[16], D. A. Sanders[3], V. Savinov[17], A. J. Schwartz[11], J. Strube[8], D. J. Summers[3], S. E. Vahsen[6], G. S. Varner[6], A. Vossen[13], L. Wood[8], and J. Yelton[18]

[1]Brookhaven National Laboratory, Upton, New York 11973
[2]University of Louisville, Louisville, Kentucky 40292
[3]University of Mississippi, University, Mississippi 38677
[4]Wayne State University, Detroit, Michigan 48202
[5]Carnegie Mellon University, Pittsburgh, Pennsylvania 15213
[6]University of Hawaii, Honolulu, Hawaii 96822
[7]Iowa State University, Ames, Iowa 50011
[8]Pacific Northwest National Laboratory, Richland, Washington 99352
[9]University of South Alabama, Mobile, Alabama 36688
[10]Indiana University, Bloomington, Indiana 47408
[11]University of Cincinnati, Cincinnati, Ohio 45221
[12]Kennesaw State University, Kennesaw, Georgia 30144
[13]Duke University, Durham, North Carolina 27708
[14]Luther College, Decorah, Iowa 52101
[15]Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061
[16]University of South Carolina, Columbia, South Carolina 29208
[17]University of Pittsburgh, Pittsburgh, Pennsylvania 15260
[18]University of Florida, Gainesville, Florida 32611

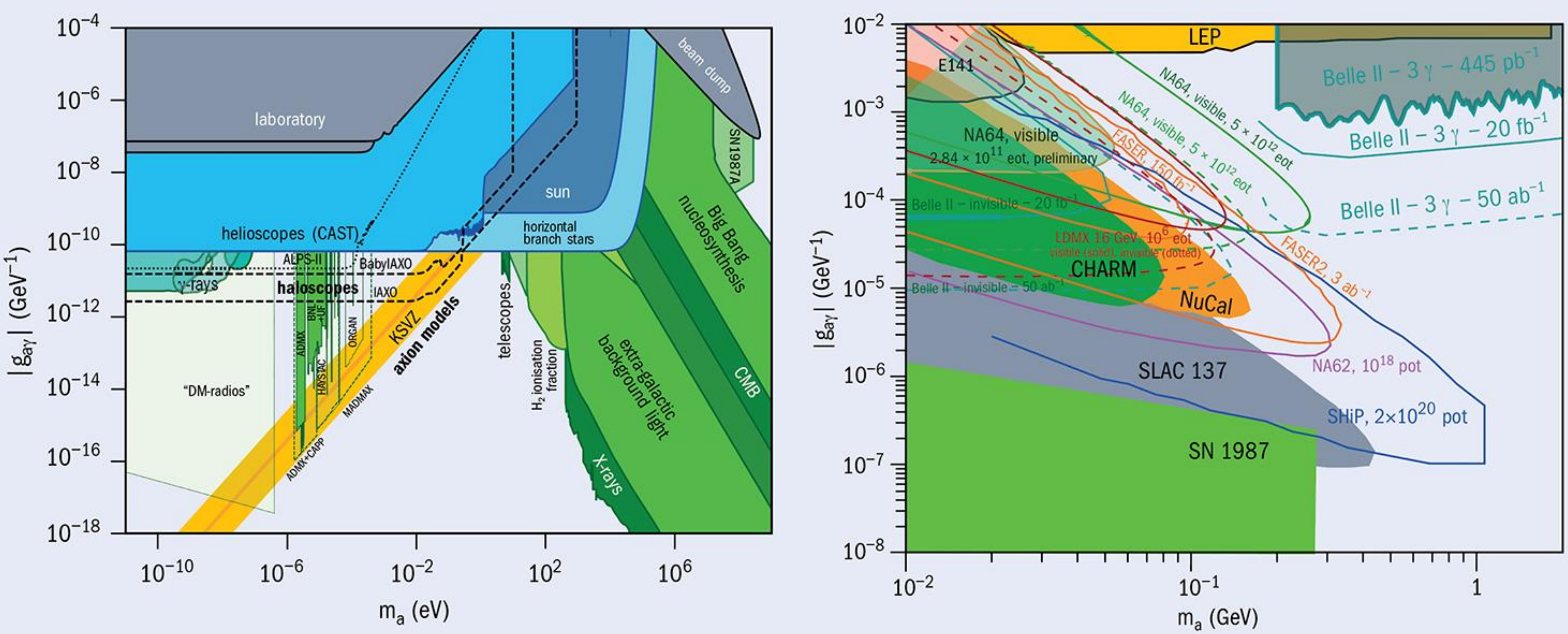
Corresponding Author:
J. V. Bennett (University of Mississippi), jvbennet@olemiss.edu

ODDONE: And then there are several interesting things about the
Japan decided to do one also, and they had a remarkably similar situa
extraordinary is that KEKB, the Japanese machine, and the Asymmet
neck and neck the whole way through to the discovery of CP violatio

Former Fermilab director Pier Oddone at his vineyard in California. CREDIT: Barbara Oddone

ODDONE: These are complicated machines. There were lots of things to do that could go wrong. It's so easy to fall out of sequence with some component so that you would be six months behind. But it didn't happen. It was neck and neck the whole five years of building the machine, the detectors, all the way to the discovery paper. So, at the end, they have been very, very productive machines. The Asymmetric B Factory got killed probably prematurely with the budget crisis in 2008. The Japanese went ahead and have built SuperKEKB, the successor to KEKB, which is starting to work now to get even 40 times more luminosity than the Asymmetric B Factory. We'll see how far they get. It's not clear. And, of course, there was very productive B physics with CDF at the Tevatron and now with LHCb at CERN.

Interview May 2020



laboratory
beam dump
helioscopes (CAST)
sun
horizontal branch stars
SN1987A
Big Bang nucleosynthesis
ALPS-II
BabyIAXO
IAXO
haloscopes
γ-rays
"DM-radios"
ADMX
BNL +UF
HAYSTAC
ORGAN
ADMX+CAPP
MADMAX
KSVZ
axion models
telescopes
H_2 ionisation fraction
extra-galactic background light
X-rays
CMB
$|g_{a\gamma}|$ (GeV^{-1})
m_a (eV)
LEP
E141
Belle II – 3 γ – 445 pb^{-1}
Belle II – 3 γ – 20 fb^{-1}
Belle II – 3 γ – 50 ab^{-1}
NA64, visible, 5 × 10^{12} eot
NA64, visible
2.84 × 10^{11} eot, preliminary
FASER, 150 fb^{-1}
FASER2, 3 ab^{-1}
Belle II – invisible – 20 fb^{-1}
Belle II – invisible – 50 ab^{-1}
LDMX 16 GeV 10^{6} eot
visible (solid), invisible (dotted)
CHARM
NuCal
SLAC 137
NA62, 10^{18} pot
SHiP, 2×10^{20} pot
SN 1987
$|g_{a\gamma}|$ (GeV^{-1})
m_a (GeV)