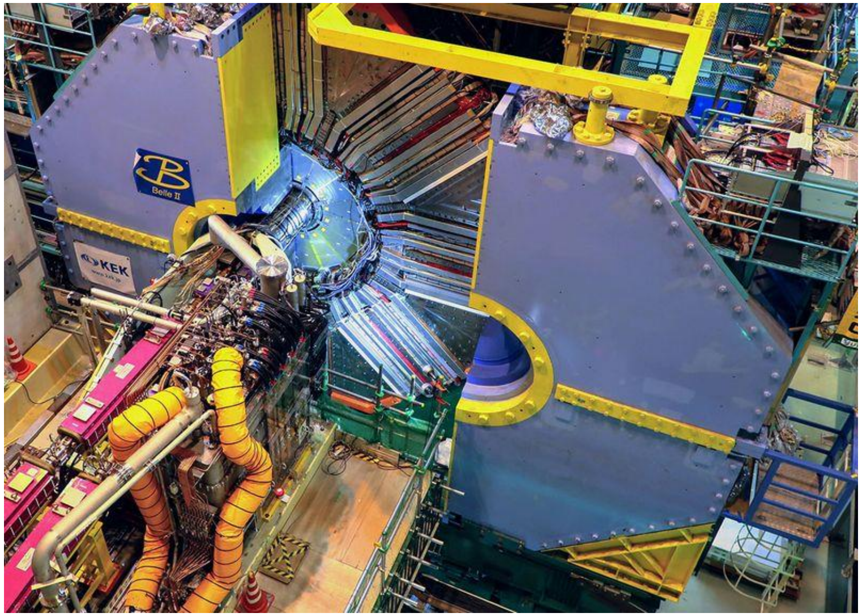
News from Belle II @SuperKEKB

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 First Belle II Physics Run (spring 2019), which just concluded a month ago.

Demonstration of Belle II performance including B signals and rediscoveries of known B phenomena.

First Physics Result from Belle II.

Comment on The Road Ahead to high luminosity and cutting edge physics.

The Geography of the International Belle II collaboration

Montreal,
UBC,
McGill,
Victoria,
Xavier

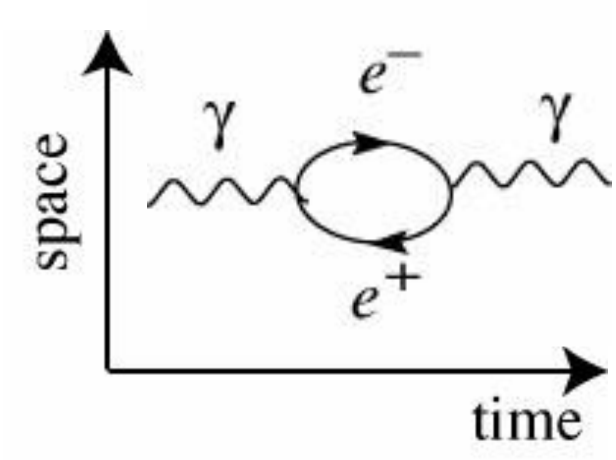
Belle II now has grown to ~947 researchers from 26 countries

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>

Canada: 27 Belle II members

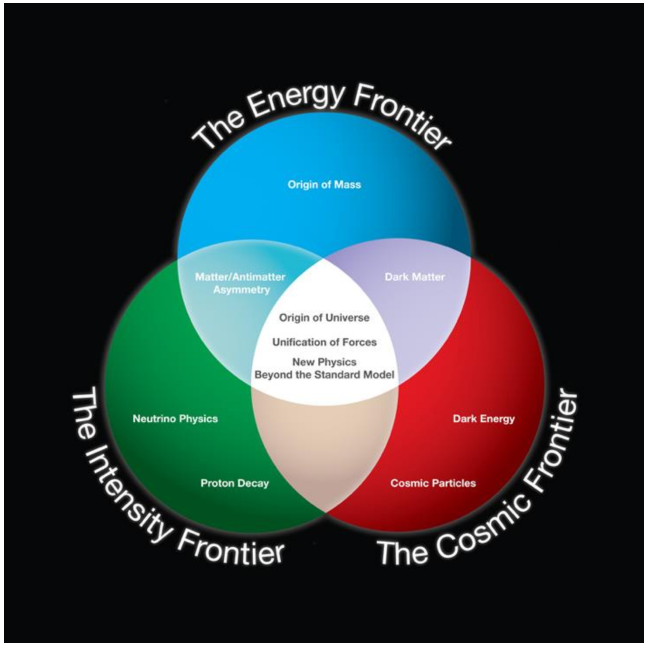
Youth and potential: There are 330 graduate students in the collaboration

NP: Quantum Mechanical (QM) Finesse versus Brute Force



Energy conservation ?

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



Banking Analogy (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

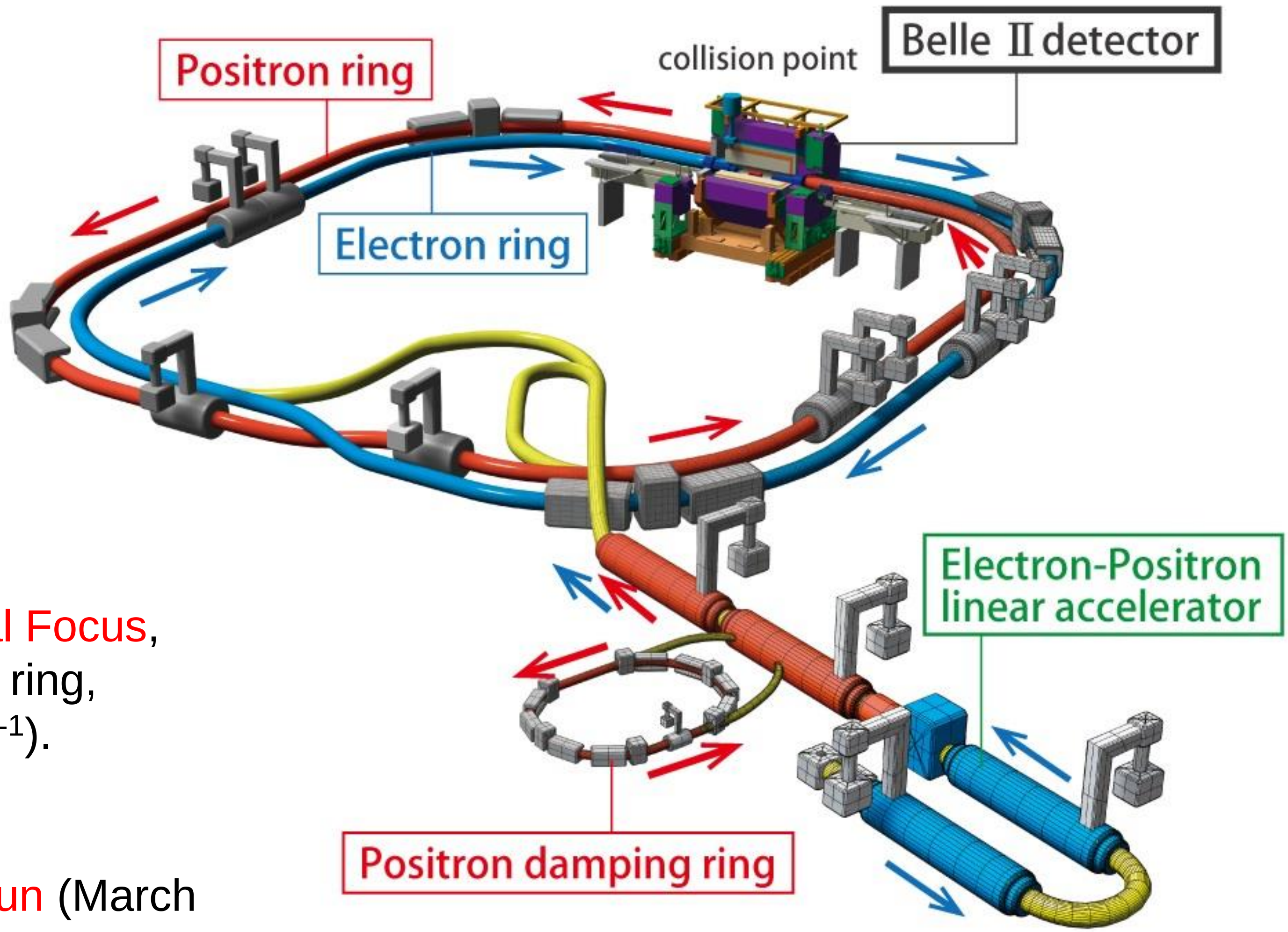
SuperKEKB, the first new collider in particle physics since the LHC in 2008 (electron-positron (e^+e^-) rather than proton-proton (pp))

Super KEKB

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

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

Phase 3: → Physics run (March 27-June 30th, 2019)

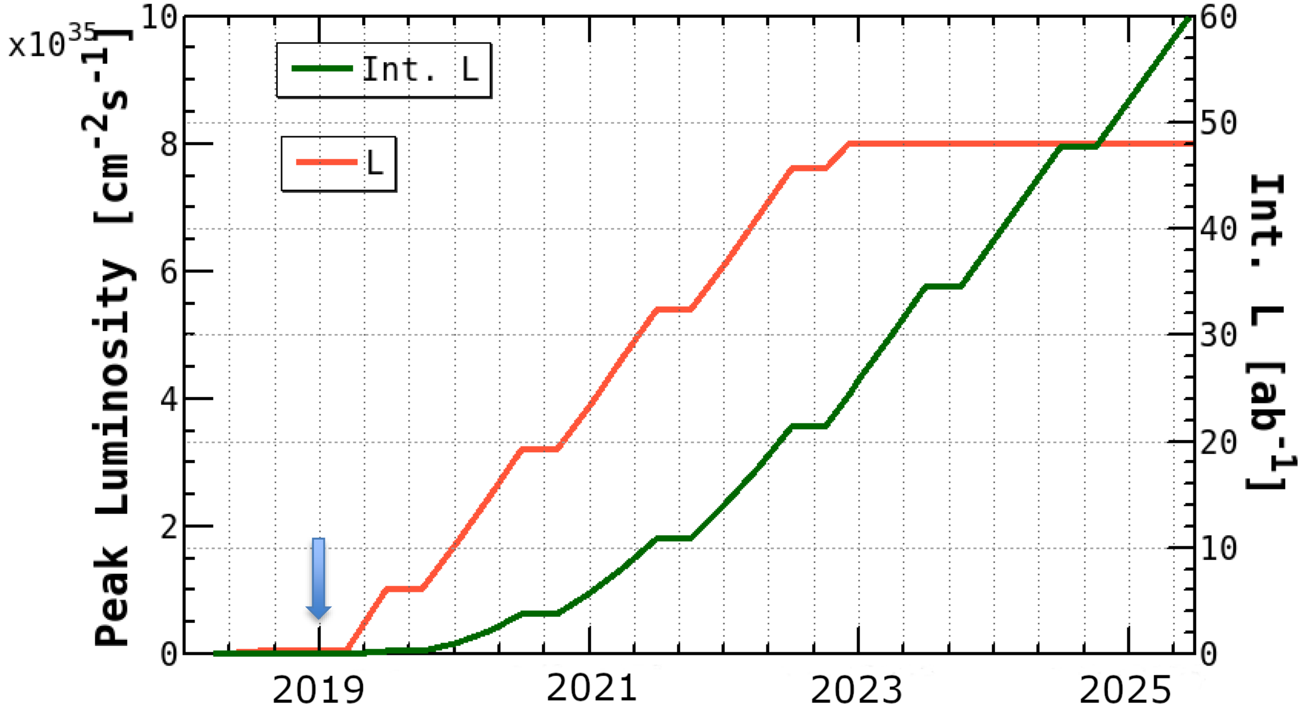


SuperKEKB/Belle II Luminosity Profile

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



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 jargon (Phase 1, Phase 2, Phase 3)

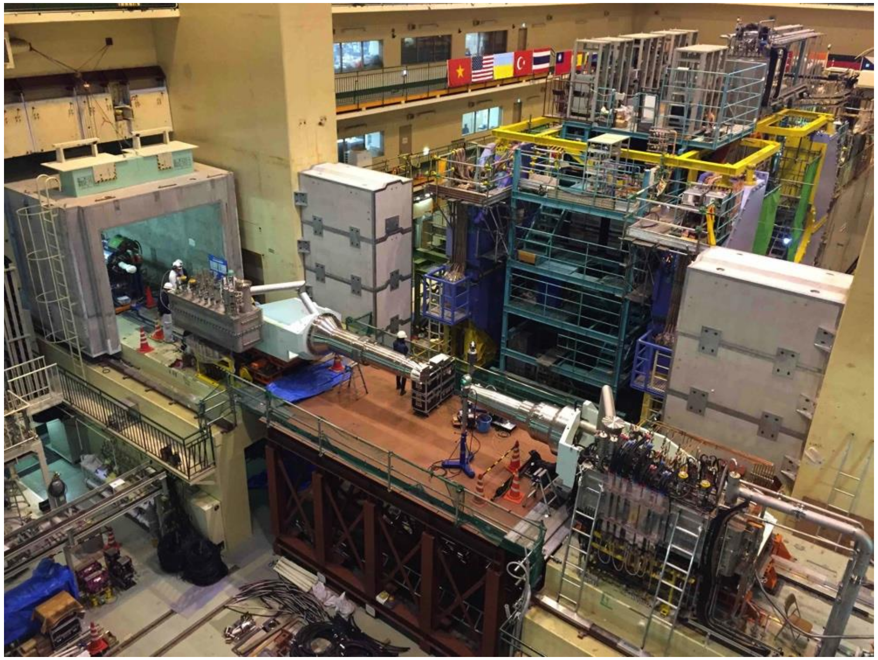
Phase 1: Simple background commissioning detector (diodes, diamonds TPCs, crystals…) BEAST II. No final focus. Only *single* beam background studies possible [started in Feb 2016 and completed in June 2016].

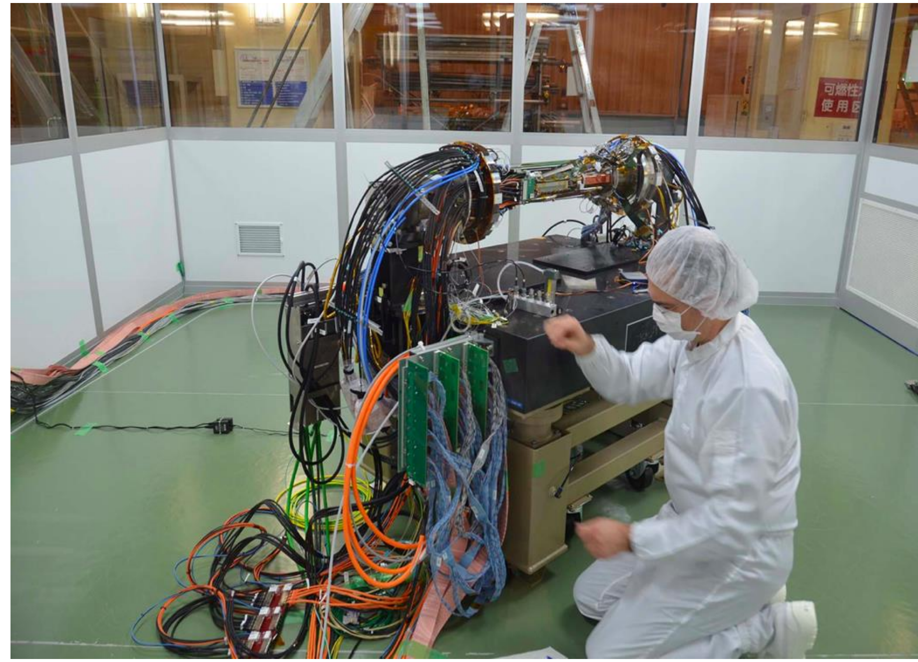
Large crossing angle, 83mrad, is visible

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)



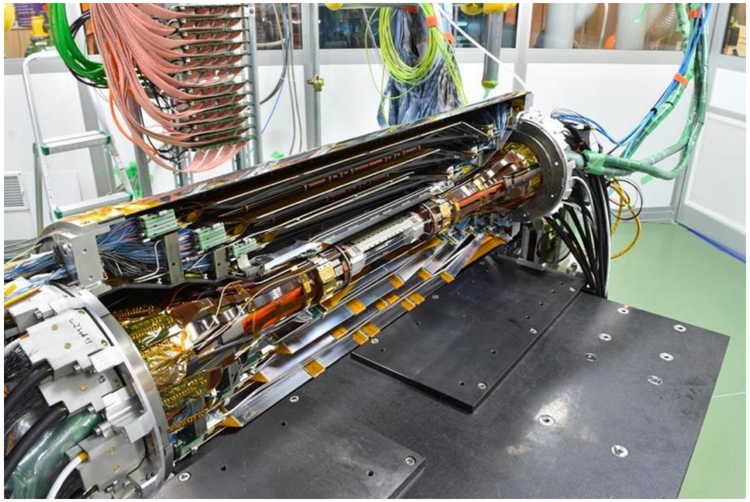


Phase 2: A pilot run with a more elaborate inner background commissioning detector (VXD samples). Full Belle II *outer* detector. Full superconducting final focus. *No vertex detectors. Collisions !* *[Phase 2 collisions: April 26-July 17, 2018]*

Phase 3: Installed the VXD in Belle II. First Physics Run with the full Belle II detector [March 26-June 30, 2019]

Belle II/SuperKEKB Phase 3 Goals

Early aims: Resolve the problems uncovered in the Phase 2 pilot run. 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 dark sector searches/measurements as well.

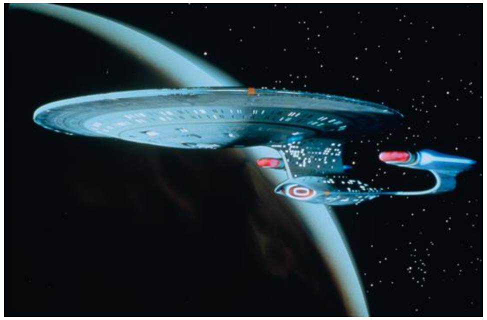
Long term: *Integrate the world's largest e^+e^- data samples and observe or constrain New Physics.*

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



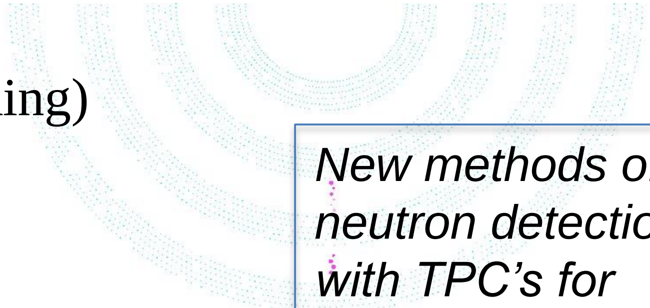
DEPFET pixel sensors

Waveform sampling with precise timing is “saving us”.

Front-end custom ASICs (Application Specific Integrated Circuits) for most subsystems
→ DAQ with high performance network switches, large HLT software trigger farm

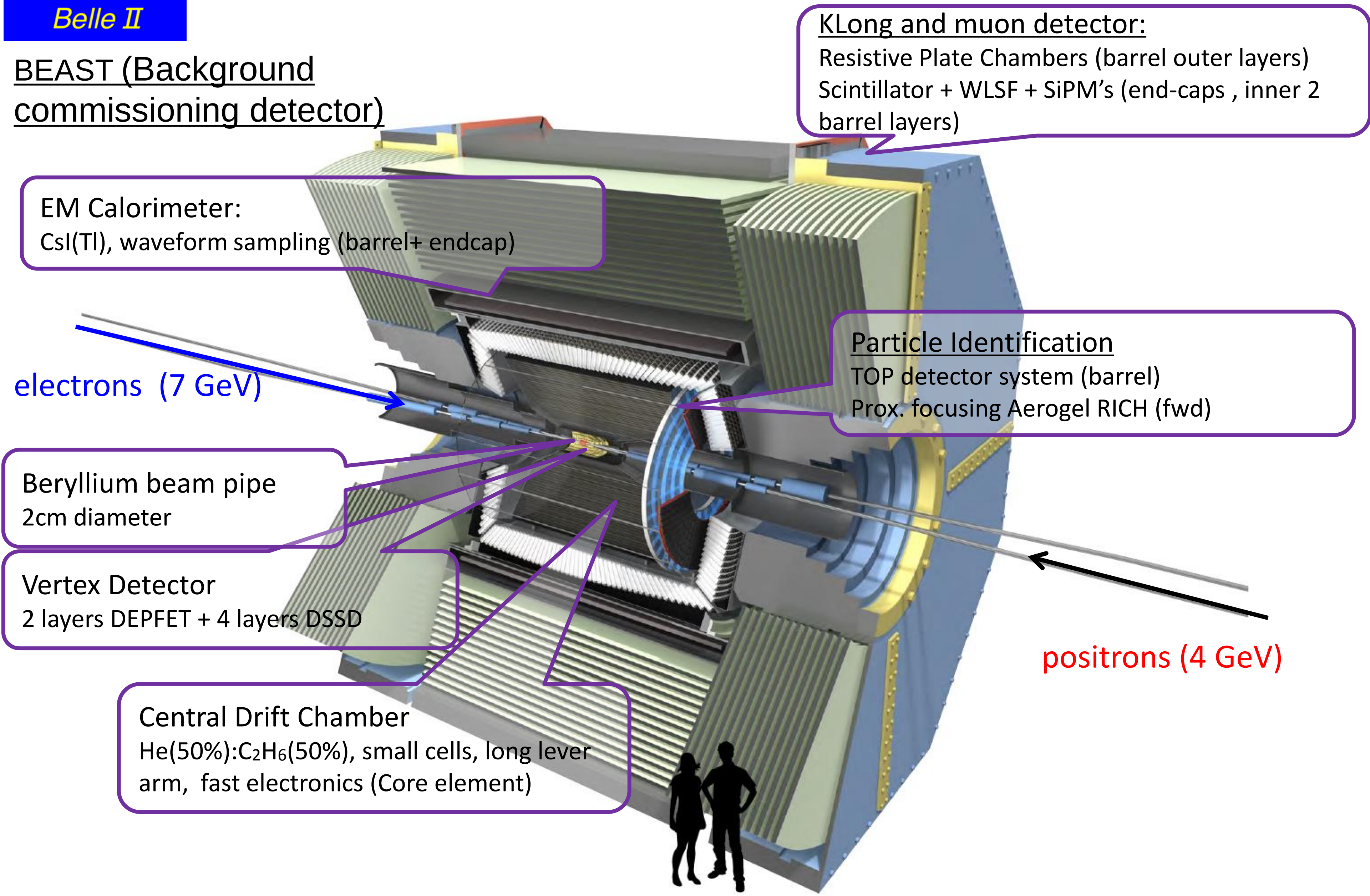
→ a 21^{st} century HEP experiment.

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)



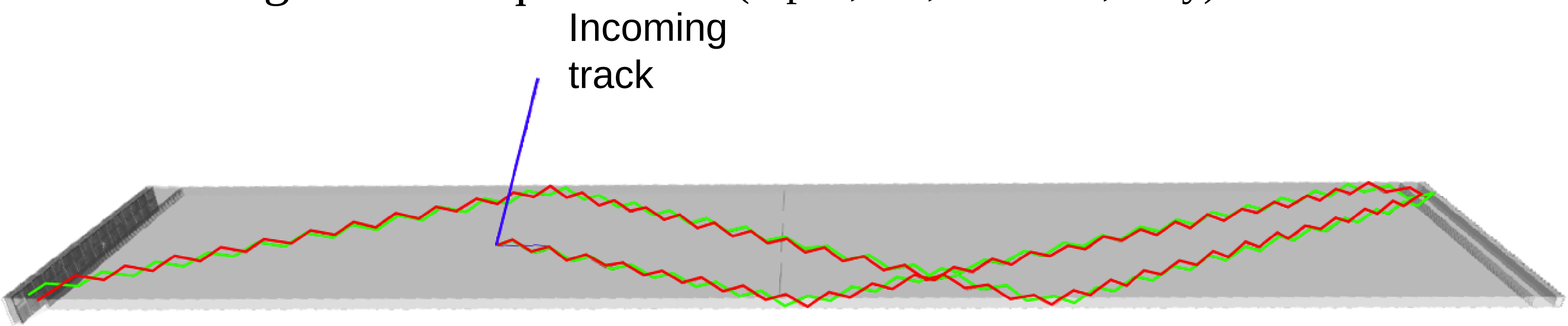
New methods of neutron detection with TPC’s for the background. Directions !

Belle II Detector

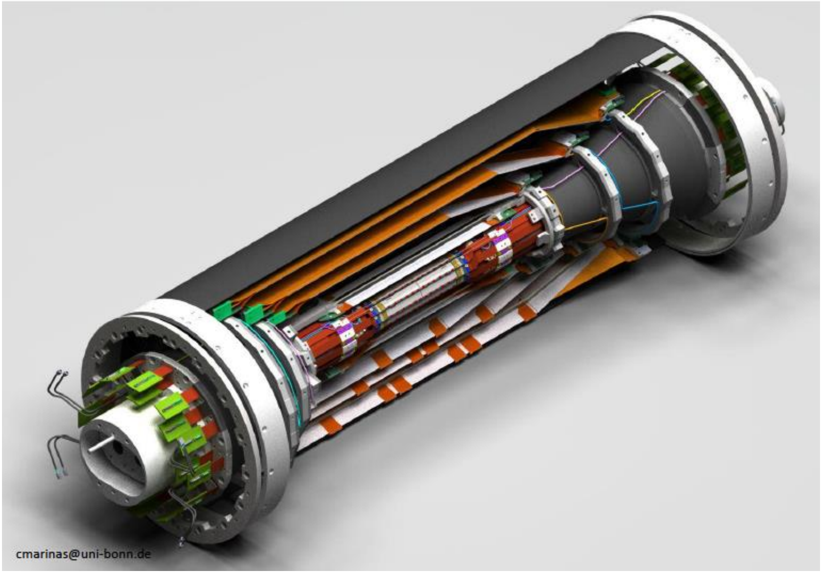


Barrel Particle Identification (uses Cherenkov radiation)

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

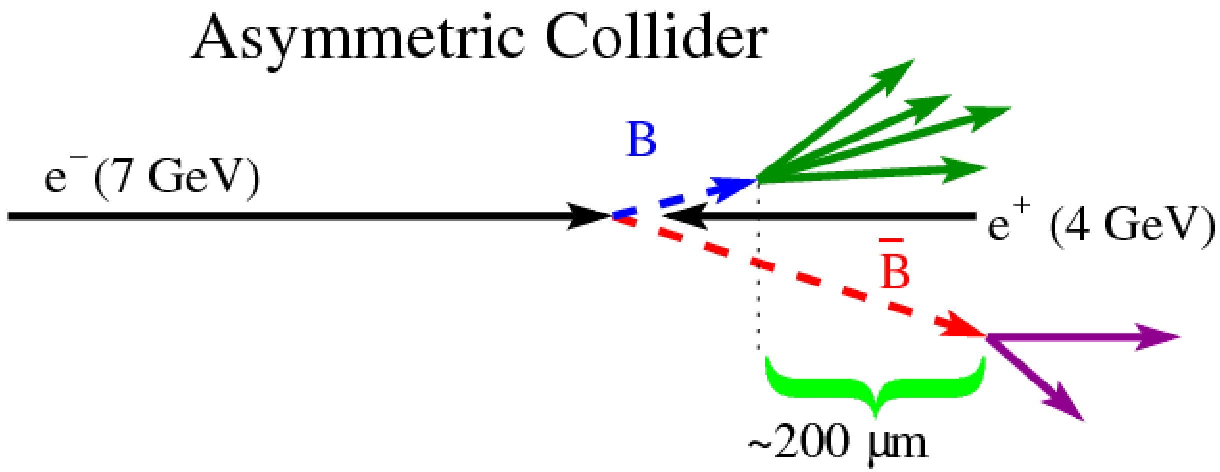
The B-anti B meson pairs at the Upsilon(4S) are produced in a <u>coherent</u>, *entangled* **quantum mechanical state**.

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

(Note the minus sign)

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)



Not to scale

<u>The beam energies are asymmetric (7 on 4 GeV)</u>

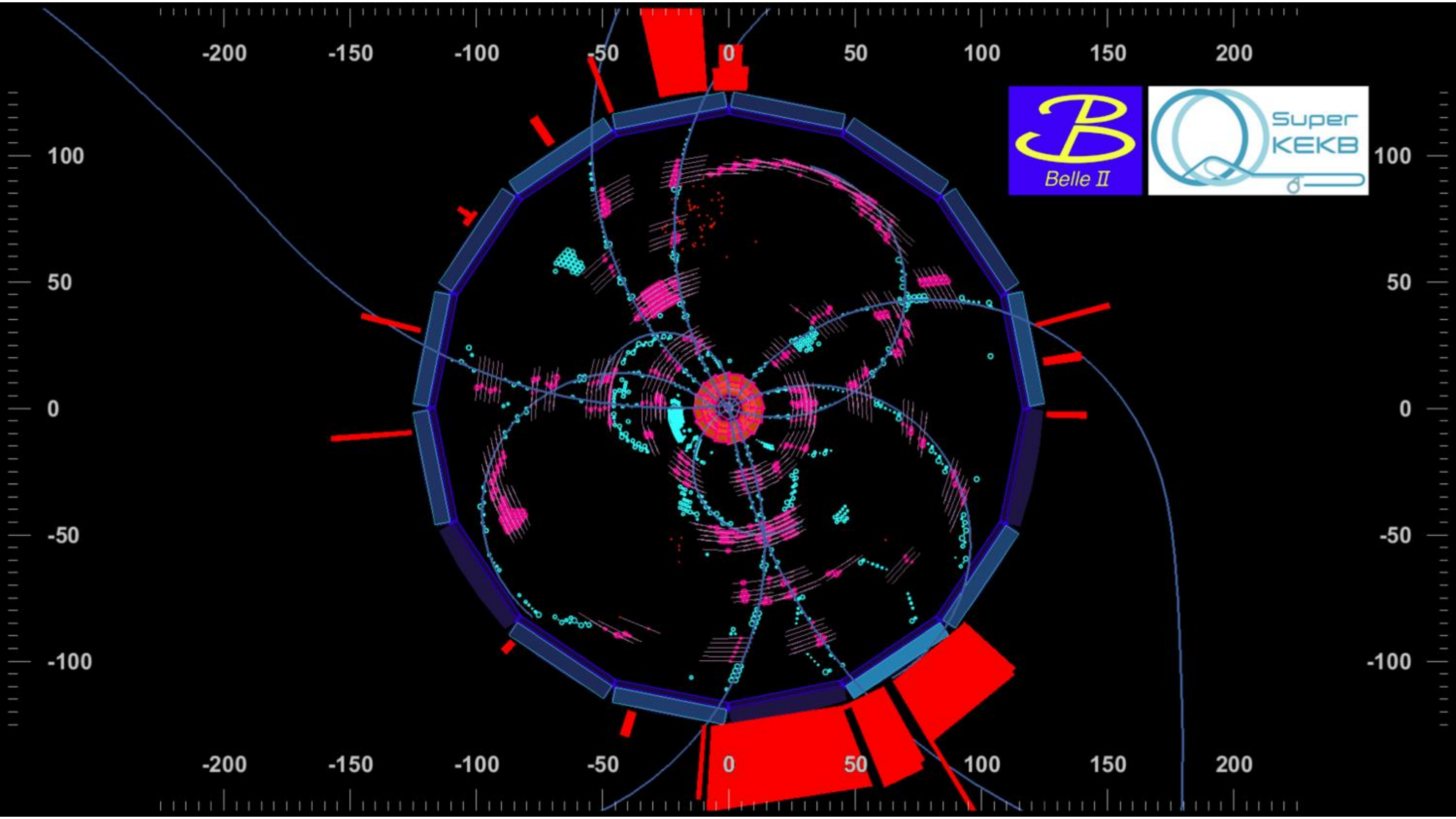
<u>The decay distance is increased by around a factor ~7</u>

2018: Phase 2 (Belle II outer detector only): First collisions.
The scene at the experimental control room in Tsukuba Hall B3

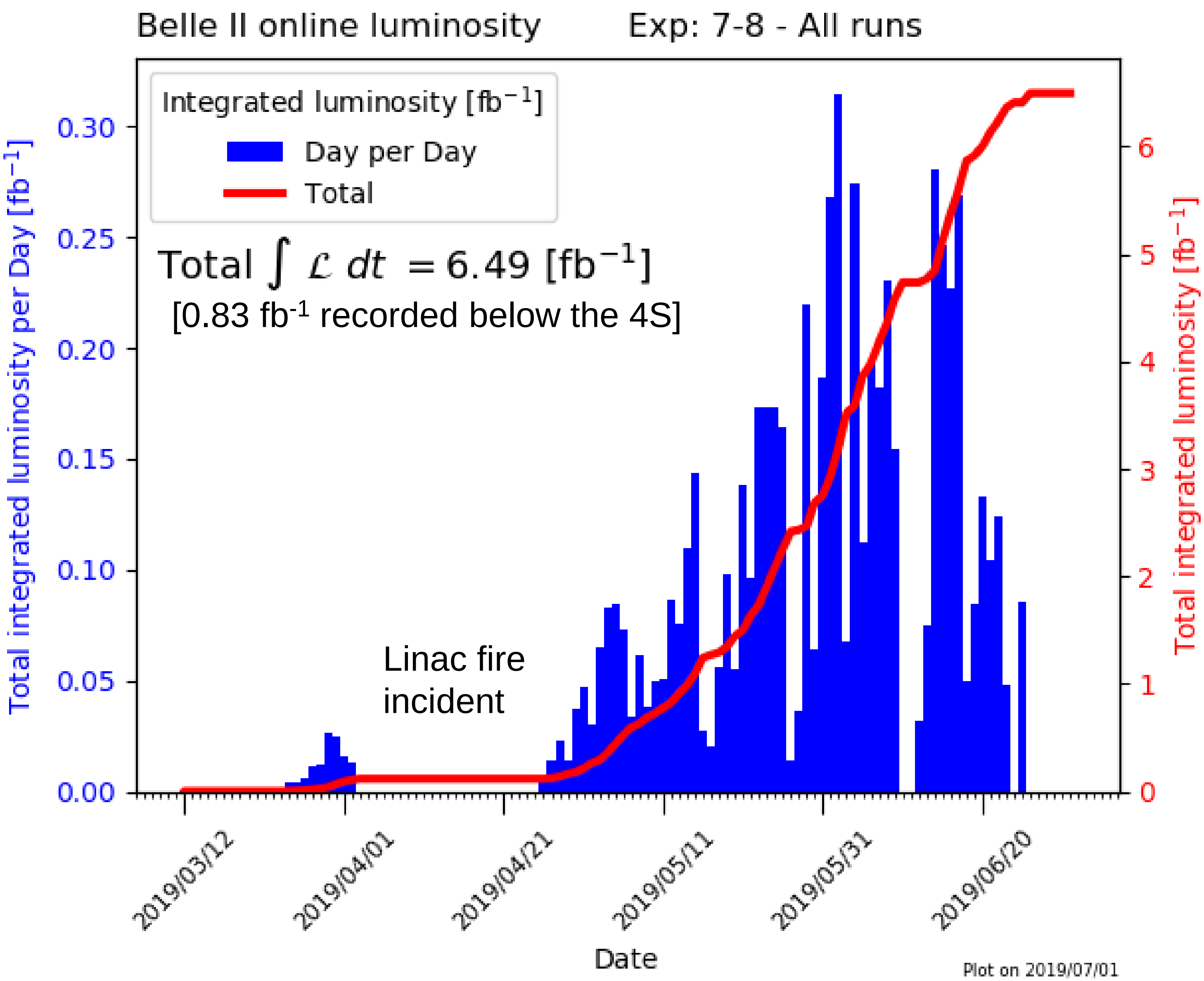
This is scientific history in the making: SuperKEKB/Belle II joins DORIS/ARGUS, CESR/CLEO, and PEP-II/BaBar and KEKB/Belle

2019: First Collisions in the Phase 3 Physics Run (the VXD is installed in Belle II).

2019: First Collisions in Phase 3, the Physics Run



Spring 2019, First Phase 3 Physics Run: “*It was a wild ride*”



Only 2 months of collisions.

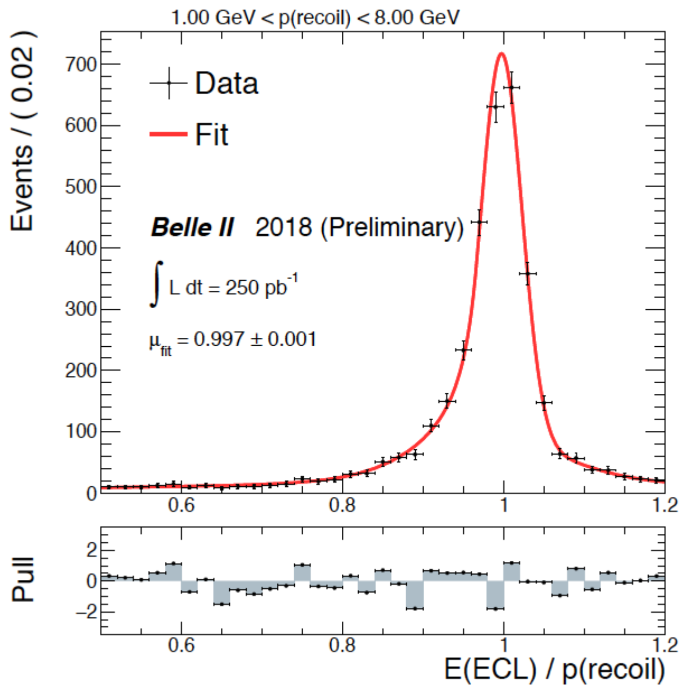
L(peak) ~5.5 x 10^{33}/cm^2/sec (β_y^*=3mm)

L(SuperKEKB peak, last week) ~1.2 x 10^{34}/cm^2/sec (→β_y^*=2mm)

Comparable to PEP-II best but bkgs X 3 too large to turn on Belle II

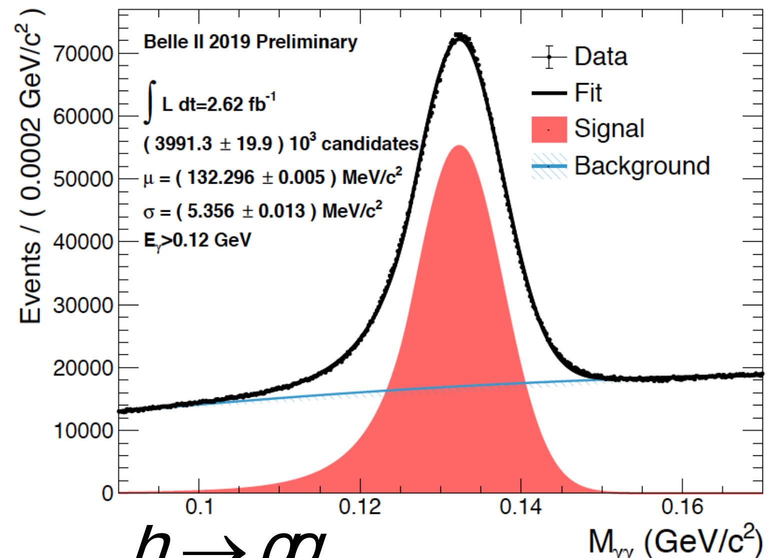
Most of the Belle II detector subsystems are working well. Some nice examples of *signals* involving photons.

$e^+e^- \to m^+m^-g$

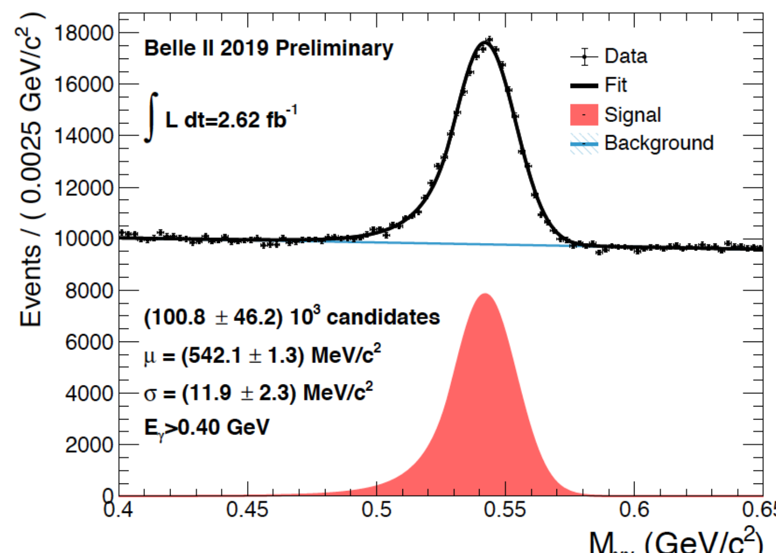


Single Photon Lines

$p^0 \to gg$



$h \to gg$

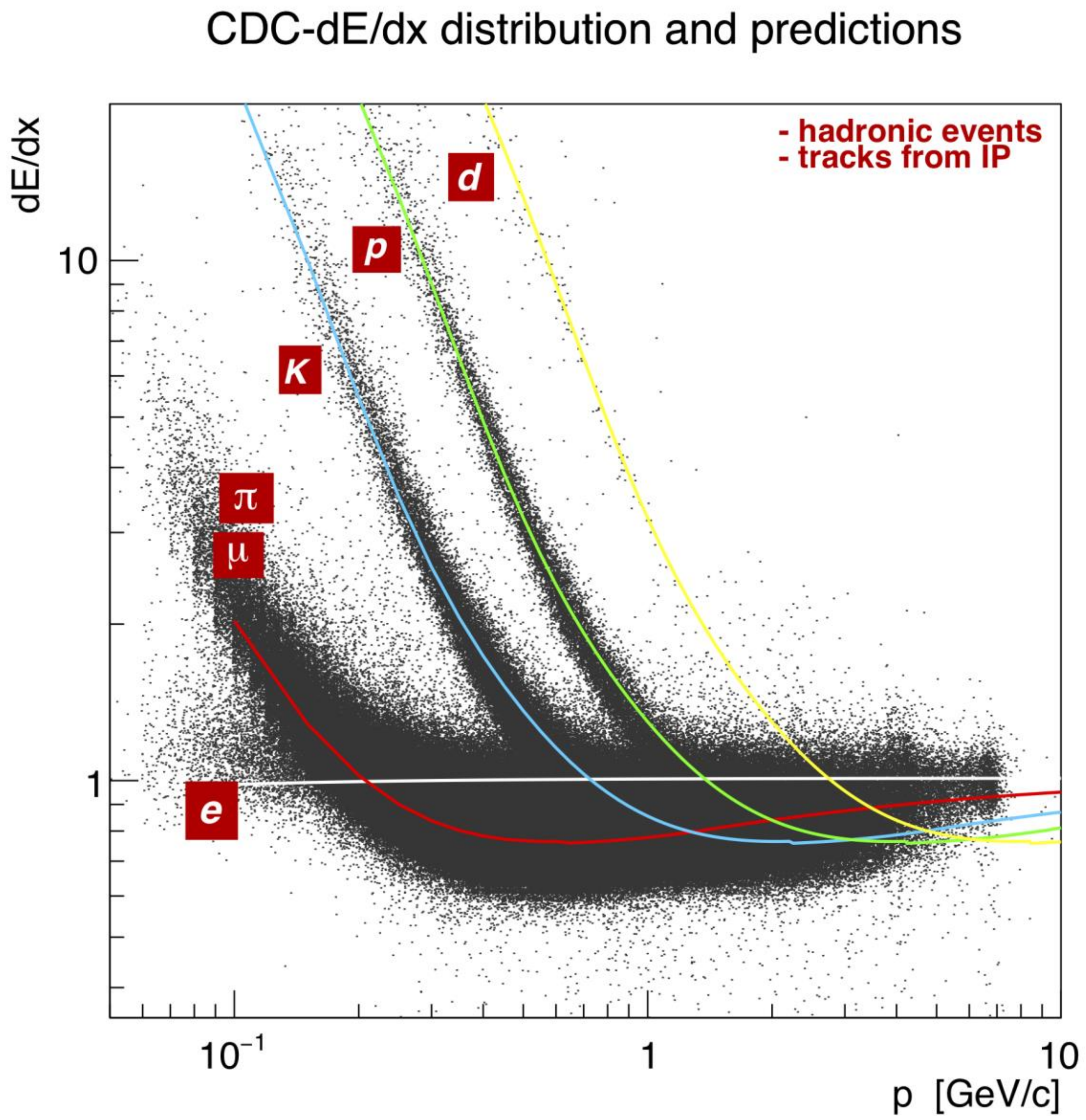


Ready for the dark sector !

$$e^+e^- \to gX$$

$$e^+e^- \to gALP \to g(gg)$$

All the Belle II detector subsystems are working well.
Some examples of *signals* involving charged tracks.

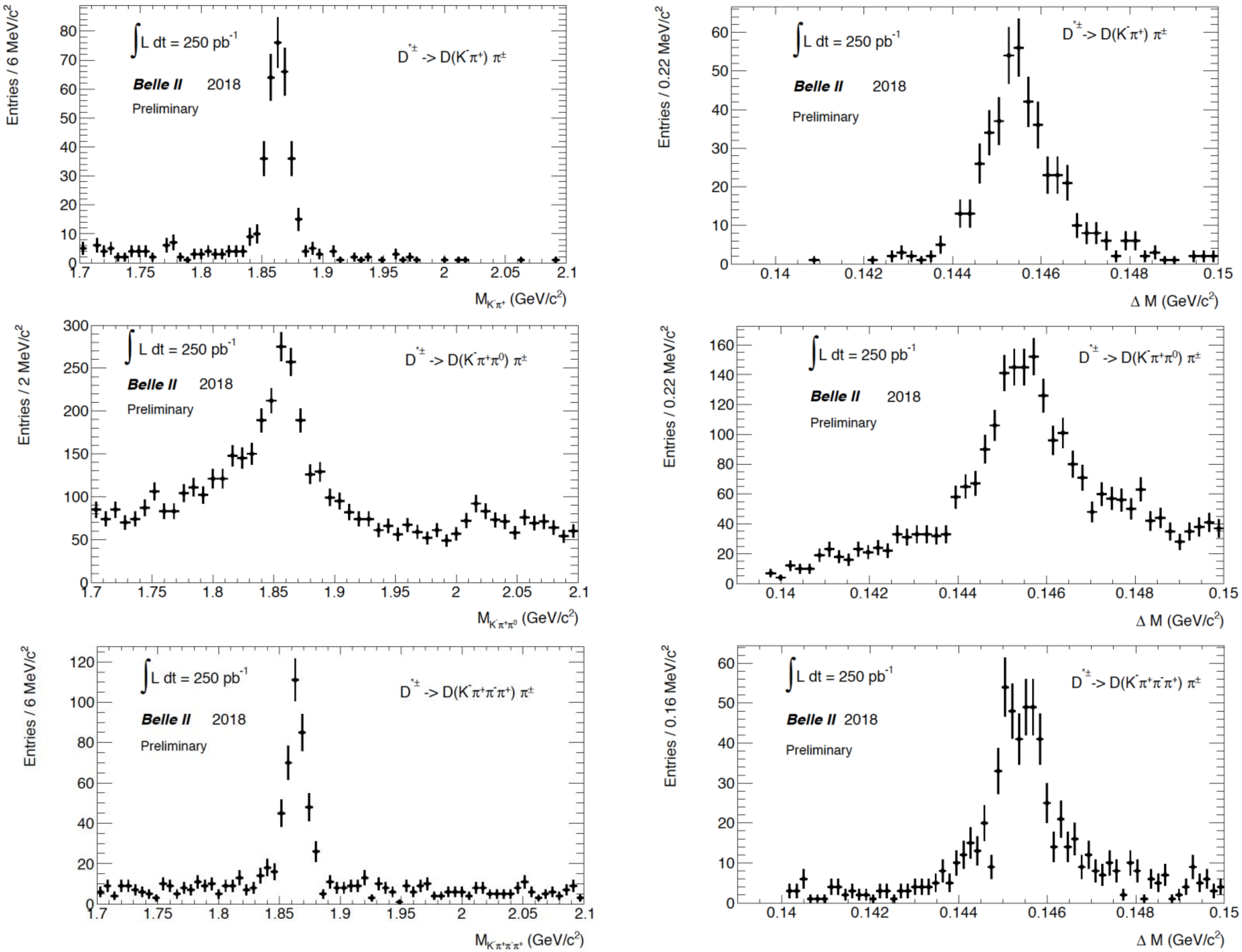


$$e^{+}e^{-} \rightarrow c\bar{c}$$

$$D^{*+} \rightarrow D^{0} p^{+},$$

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

The signal peaks are charmed particles



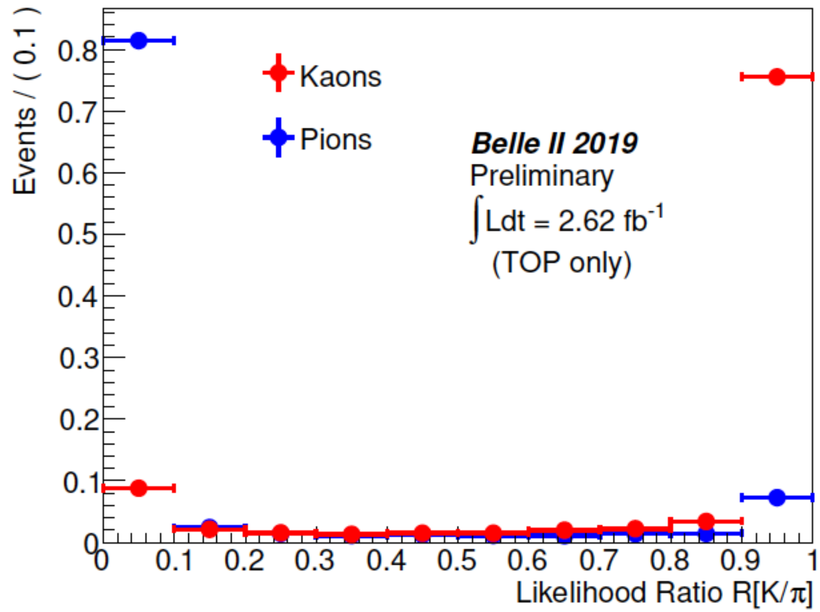
Clearly illustrates the capabilities of Belle II and the potential for charm physics and the <u>building blocks of B mesons.</u>

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

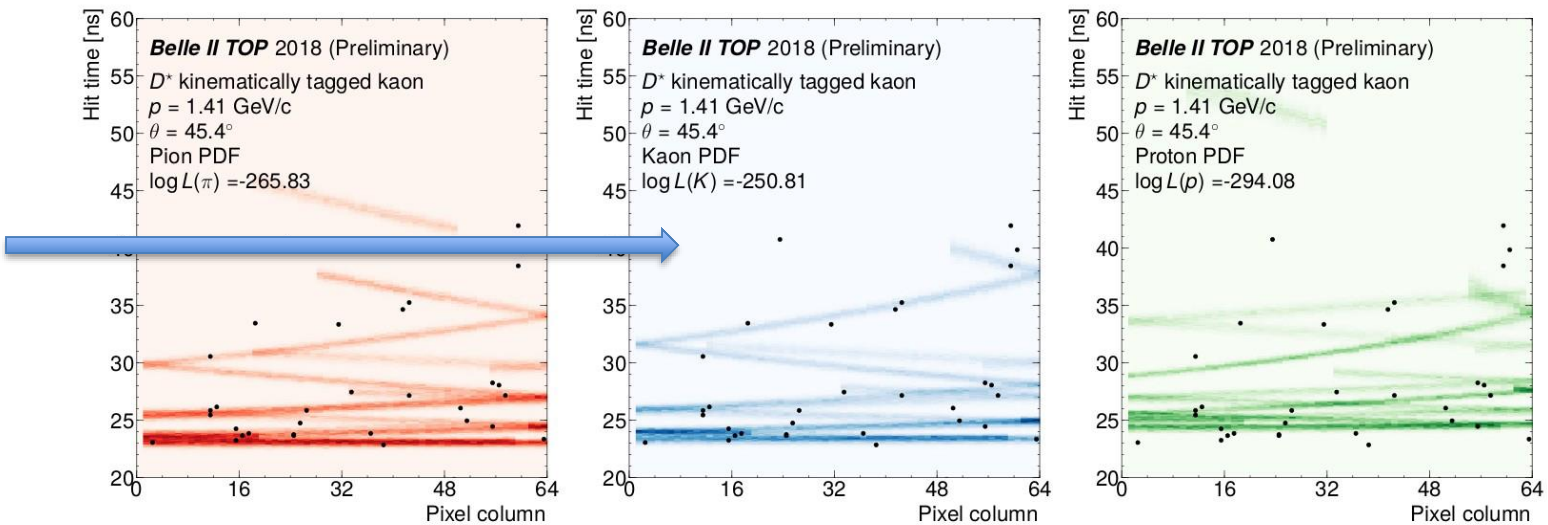
Use kinematically identified kaons and pions from D's*

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

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

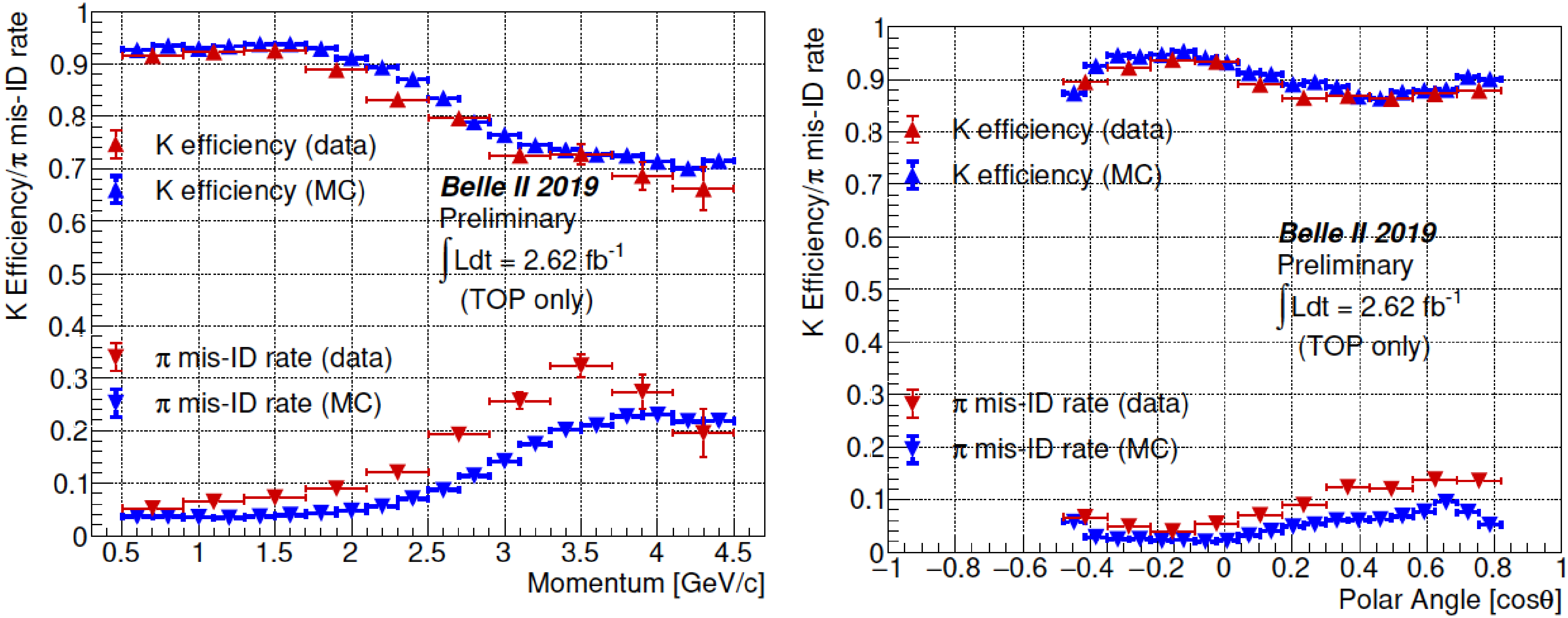


Kaon in the TOP; Cherenkov x vs t pattern



TOP Performance in Phase 3 measured with kinematically identified D*'s

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

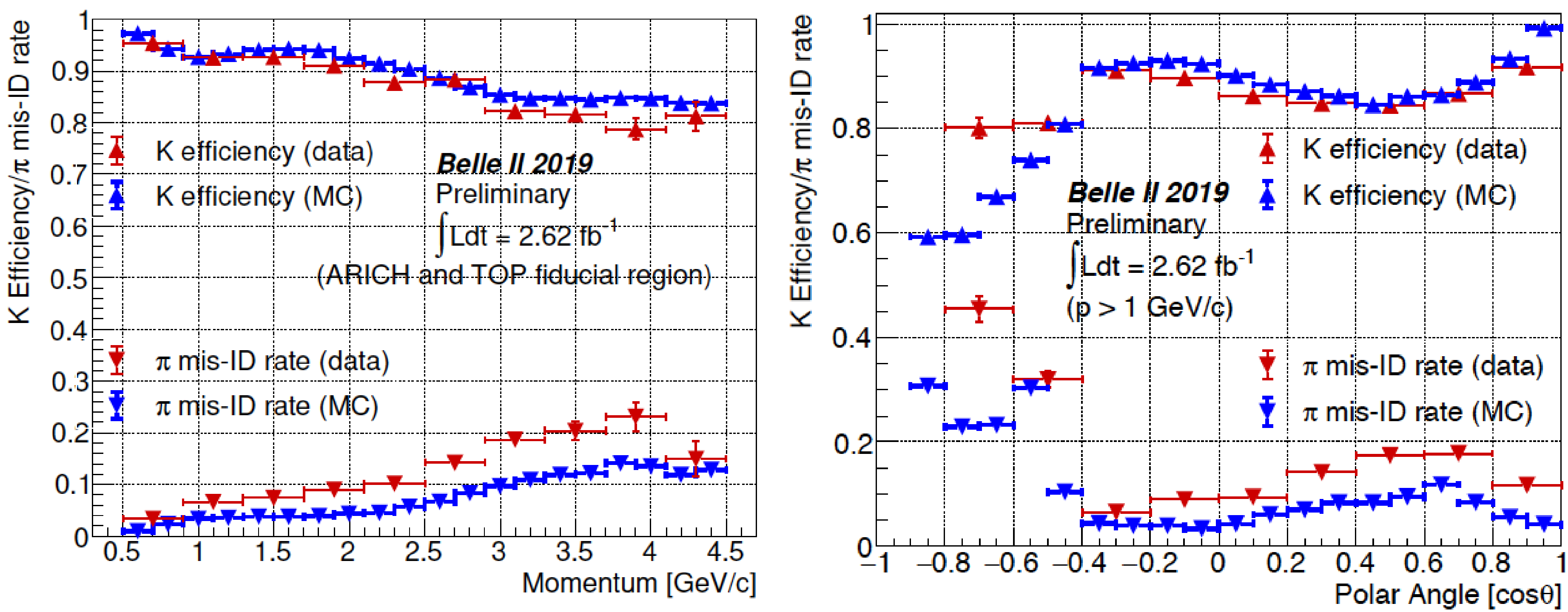


TOP performance is approaching MC expectations. The current MC simulation (MC12, July 2019) does not include embedded random triggers to correctly represent the effect of beam background and electronic noise.

Now let's examine "high momentum PID" by combining CDC dE/dx, the TOP (barrel) and ARICH (forward endcap) detectors.

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

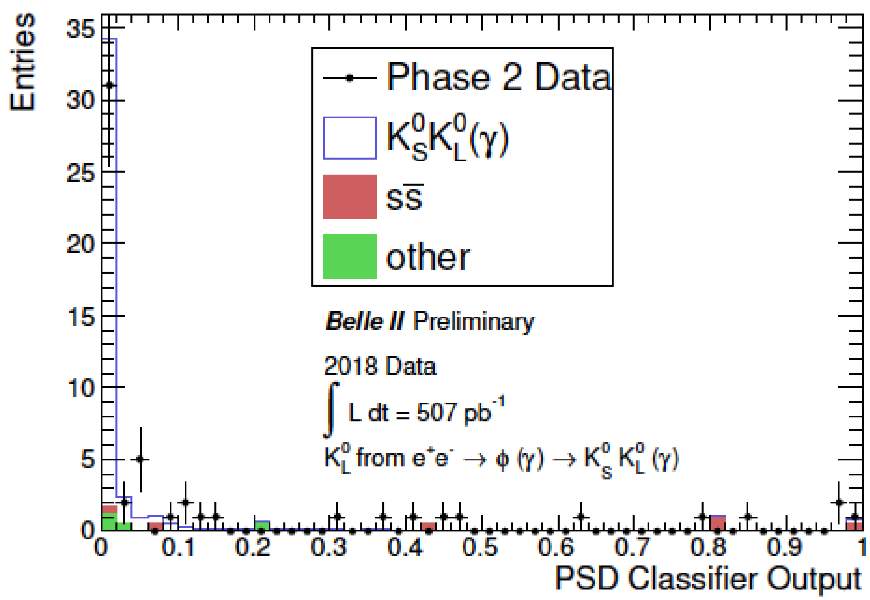
High momentum PID performance



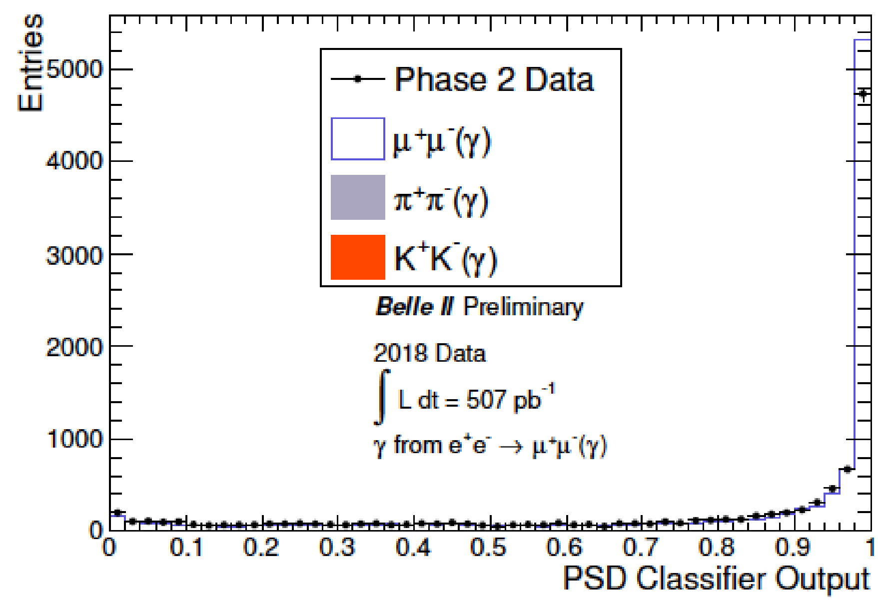
The current MC simulation (MC12, July 2019) does not include embedded random triggers to correctly represent the effect of beam background and electronic noise on the CDC, ARICH and TOP.

New PID methodology: Identification of K_L's using ECL (Crystal Calorimeter) waveforms

K_L sample



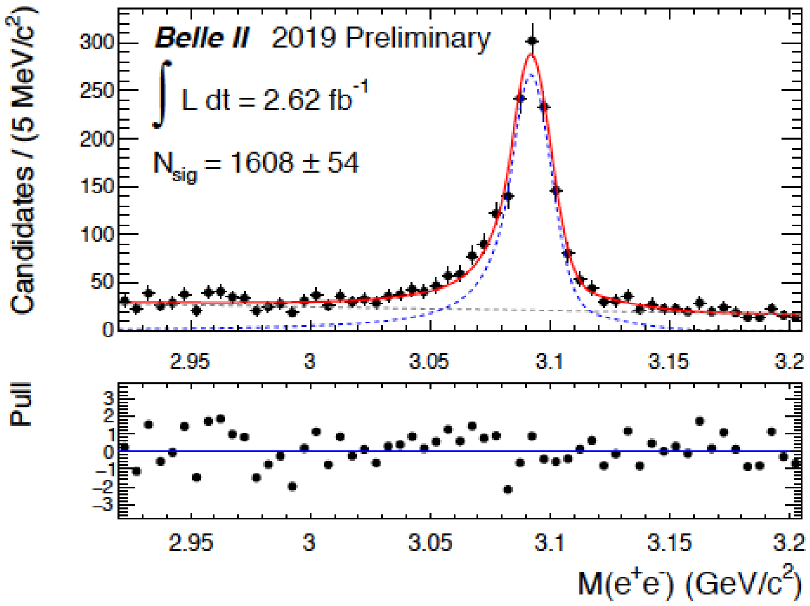
Sample of γ's

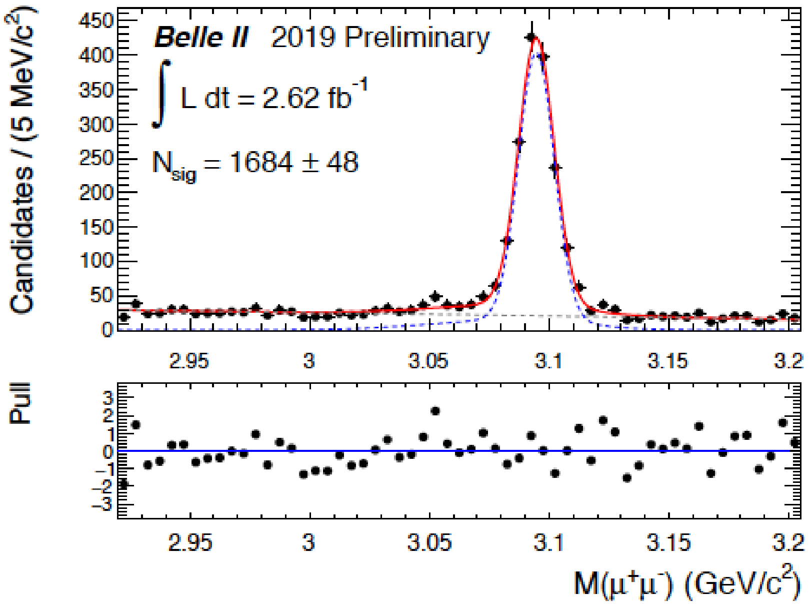


How does one obtain a pure sample of K_L mesons ?

$$\text{Ans:}\ e^+e^- \to \phi\gamma \to K_S K_L(\gamma)$$

Signals for B→J/ψ X in Phase 3 data

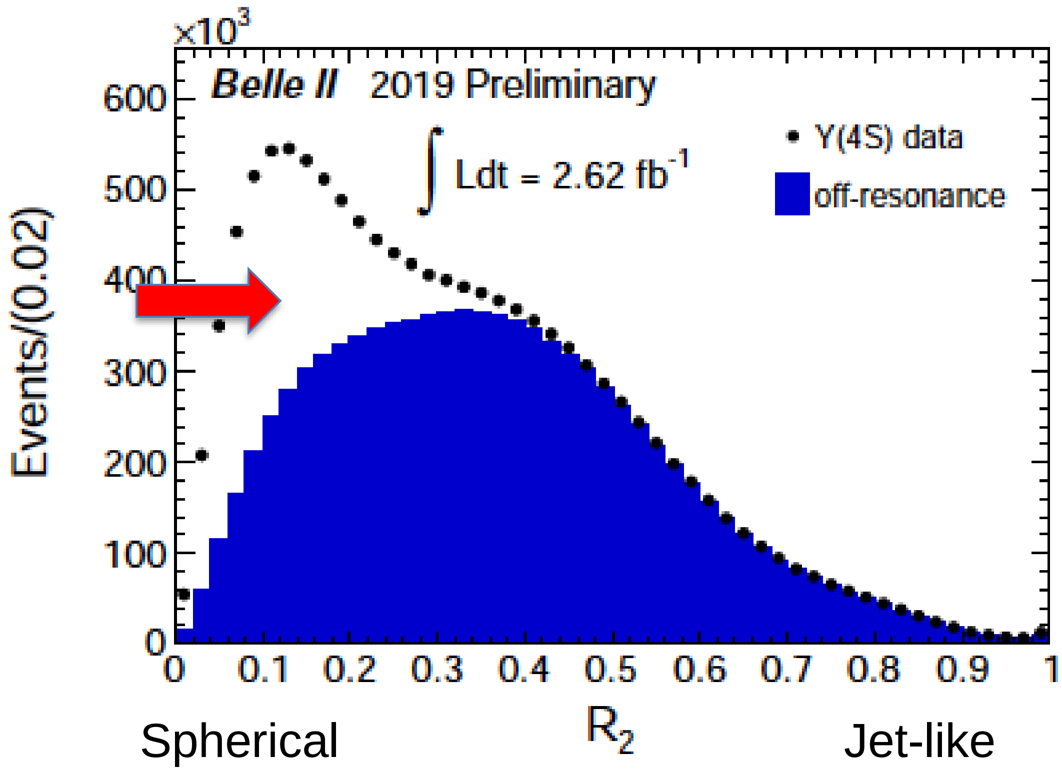


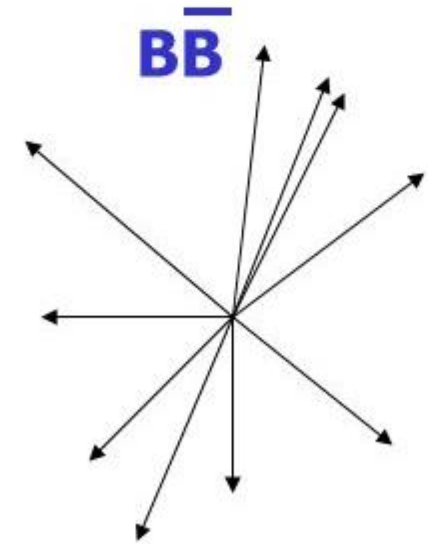


Clear signals for B→J/ψ X in ~1/2 of Phase 3 data. Note the small radiative tail on the di-electrons (does include bremsstrahlung recovery).

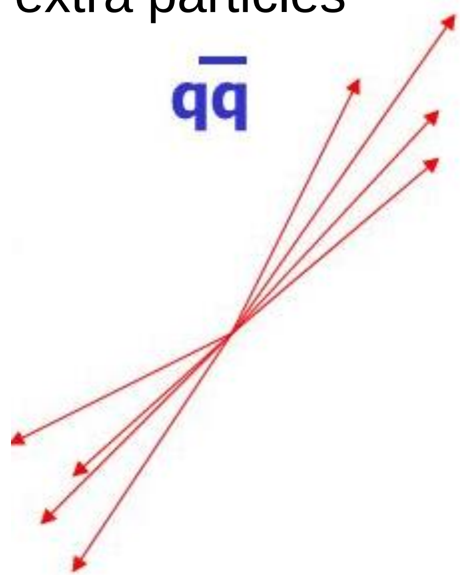
→*Belle II has equally strong capabilities for electrons and muons.*

Event Topology tells us we are seeing *B's*





B pairs produced at rest in the CM with no extra particles



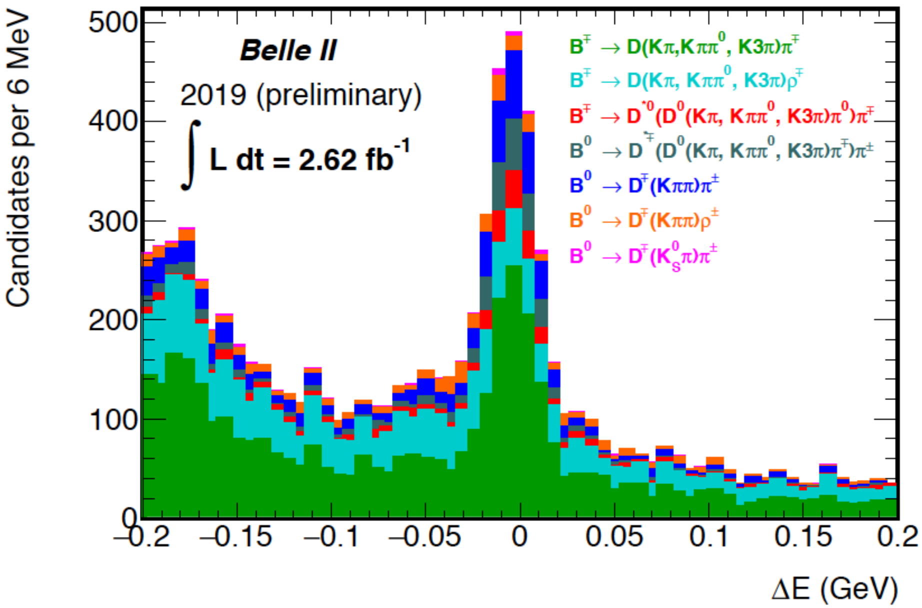
We are on the Y(4S) resonance and recording B-anti B pairs with ~99% efficiency.

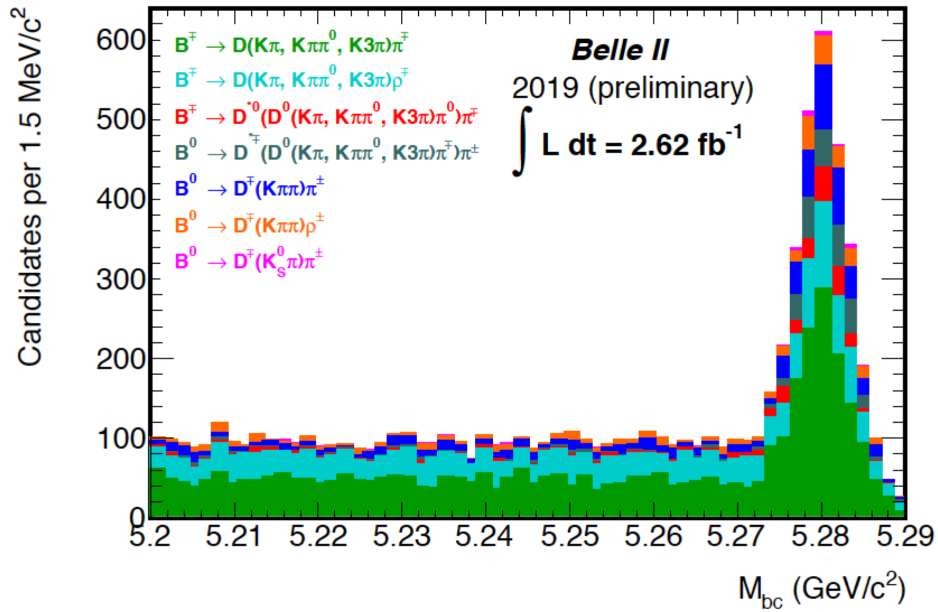
$$N_{B\bar{B}} \approx 2.8 \times 10^{6}$$

For many plots shown today

We have *rediscovered* the B meson (~1/2 of Phase 3 data)

$$DE = E_{cm} / 2 - E_{recon} \qquad M_{bc} = \sqrt{(E_{cm} / 2)^2 - p^2_{recon}}$$





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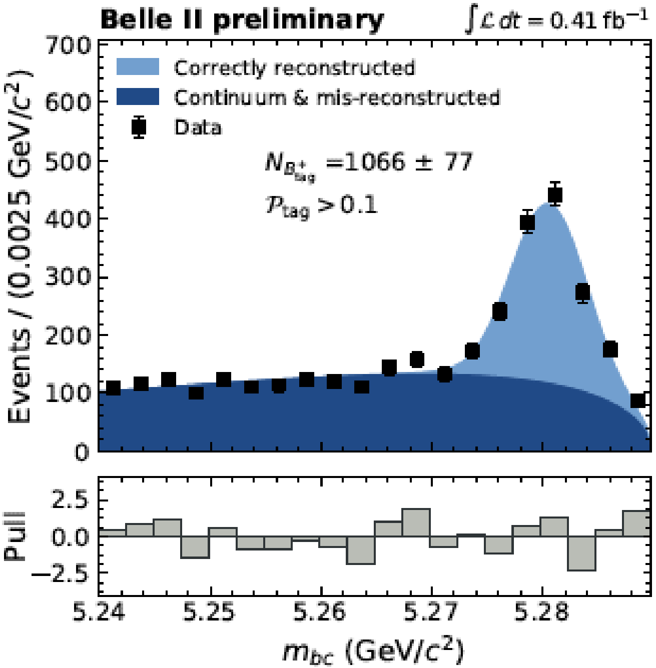
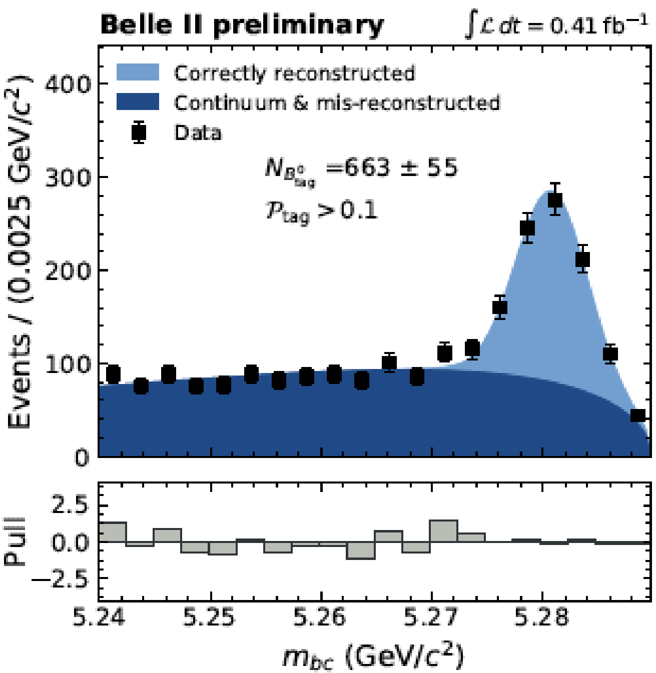
2200 Fully reconstructed hadronic B decays

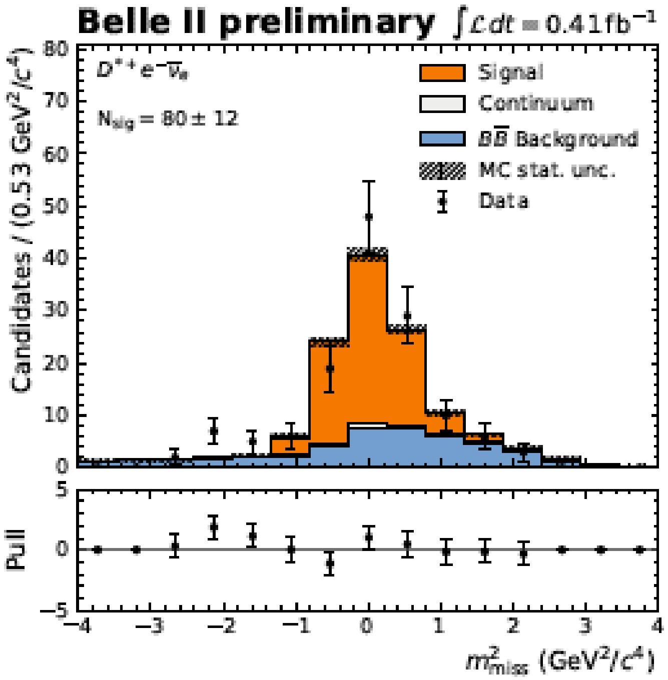
Demonstration of Belle II's B Physics Capabilities: Modes with neutrals, and K_S mesons are efficiently reconstructed along with all-charged final states containing kaons and pions.

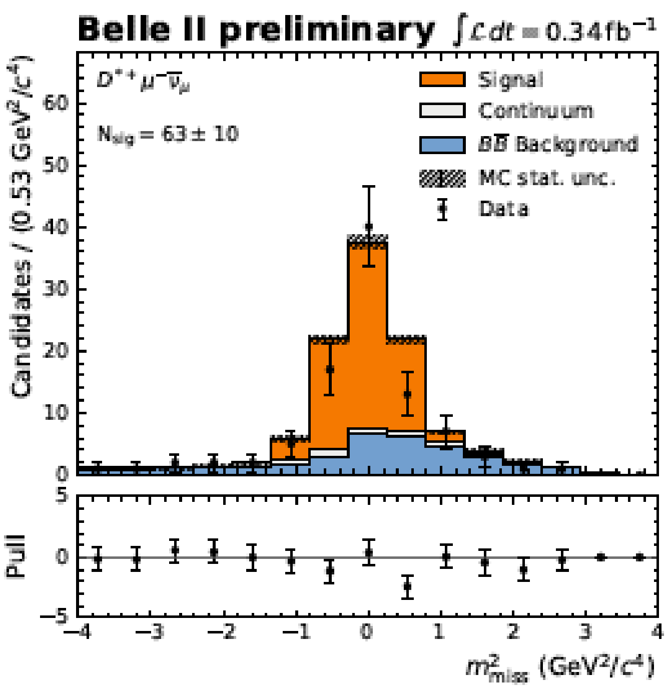




FEI = Full Event Interpretation using a machine learning technique (BDT (boosted decision trees) and a large number of B decay modes. Increase yields by O(X 8).

Only ~1/10 of the Phase 3 data is shown here. (fairly large yields.)





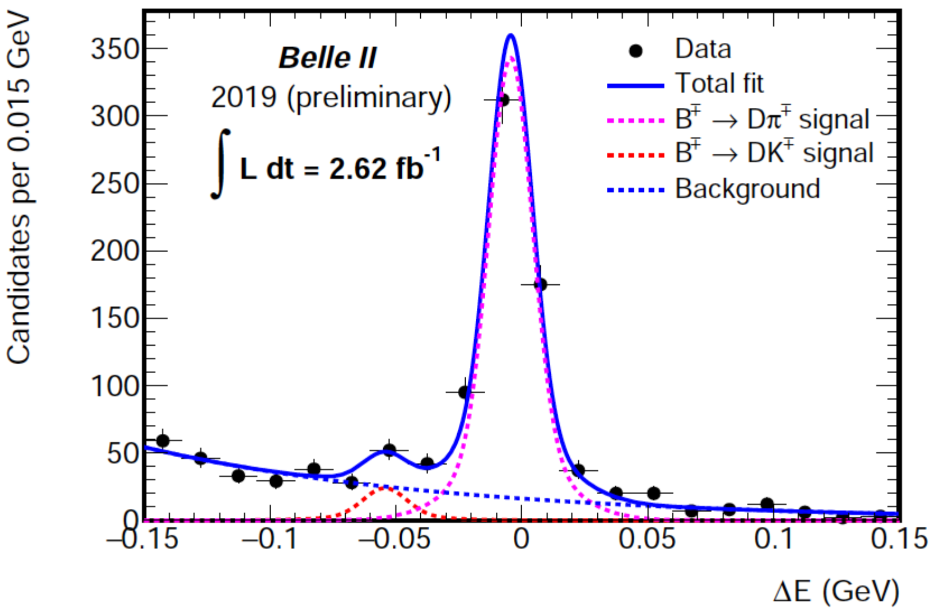
Signals for $B \rightarrow D^{*+} l^- \nu$, $D^{*+} \rightarrow D^0 \pi^+$ using the recoil-mass technique or M_{miss}^2 variable.

Clear signals are found in both the electron and muon modes.

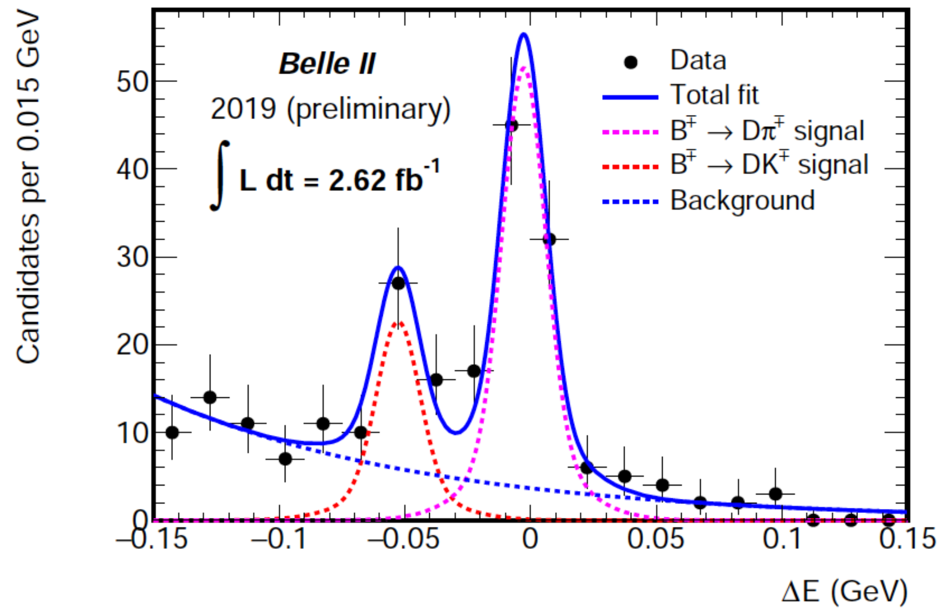
Here only ~1/10 of the Phase 3 data is shown.

Observation of $B^- \rightarrow D^0 K^-$

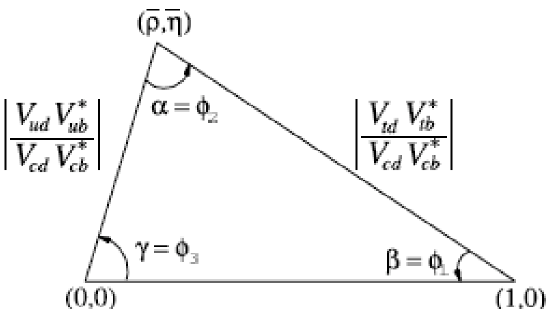
No PID



With high momentum PID



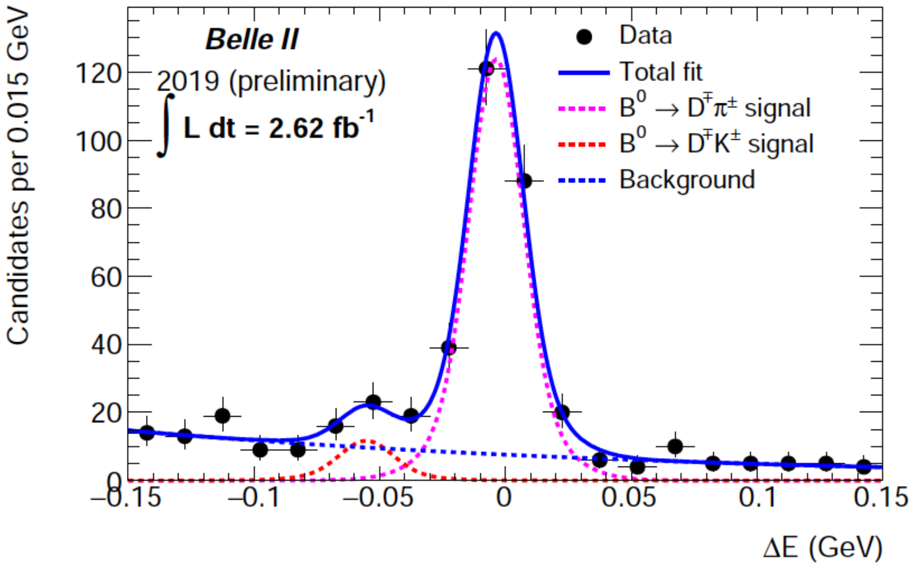
N(D K) = 38±8, fit gives 6σ



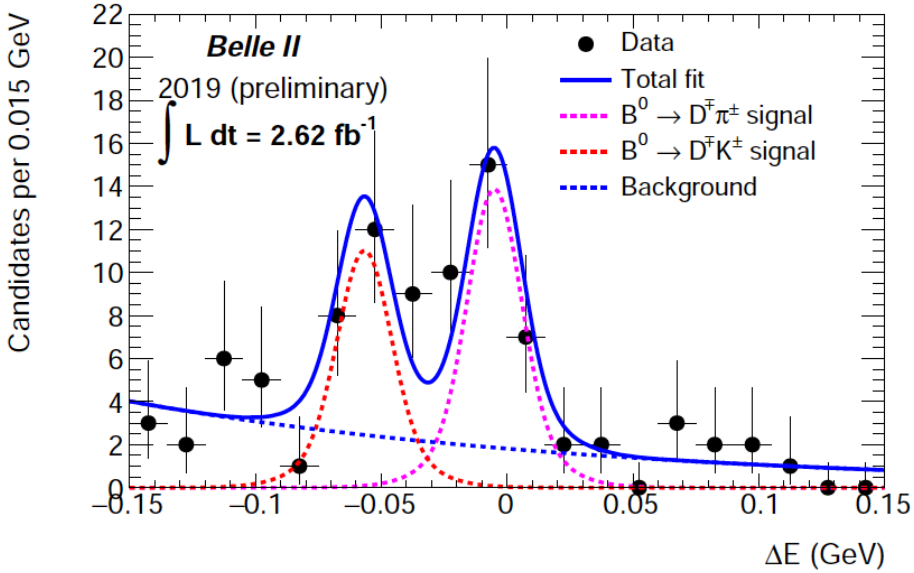
Demonstration of Belle II high momentum PID on a decay mode to be used for future determinations of the unitarity angle γ (a.k.a ϕ_3)

Evidence of $B^0 \rightarrow D^- K^+$

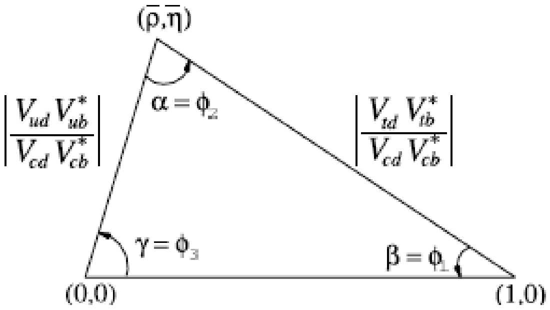
No PID



With high momentum PID

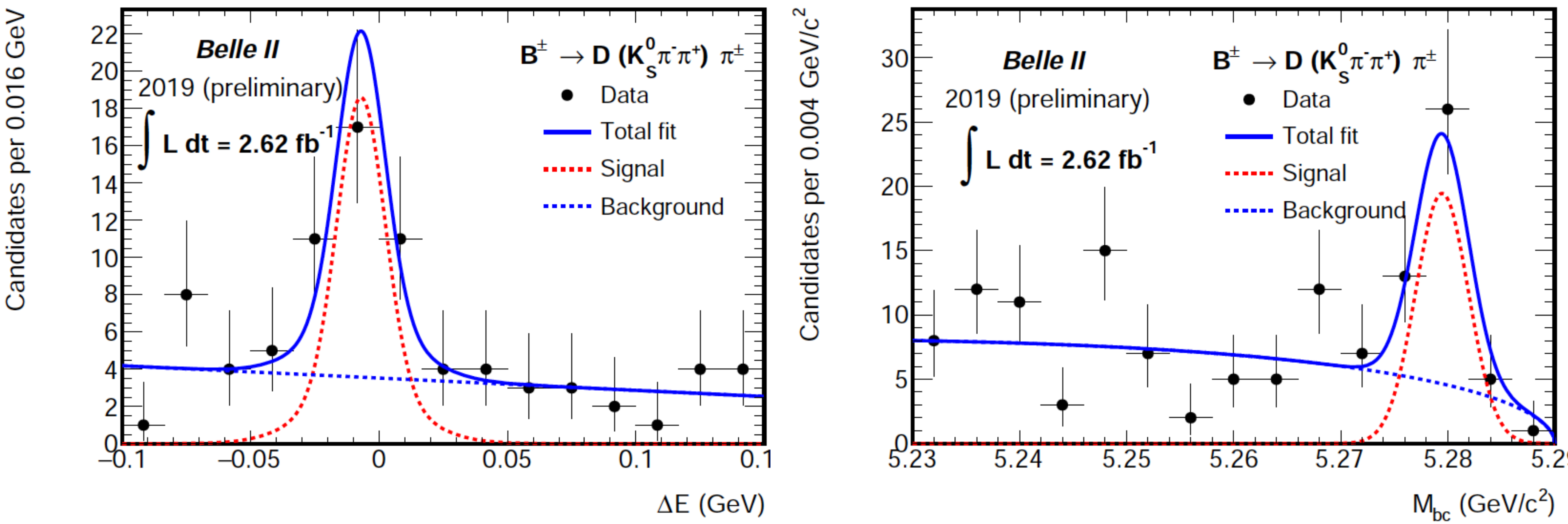


N(D K) = 23±6, fit gives 3.3σ



Demonstration of Belle II high momentum PID on a decay mode to be used for future determinations of the unitarity angle γ (a.k.a ϕ_3)

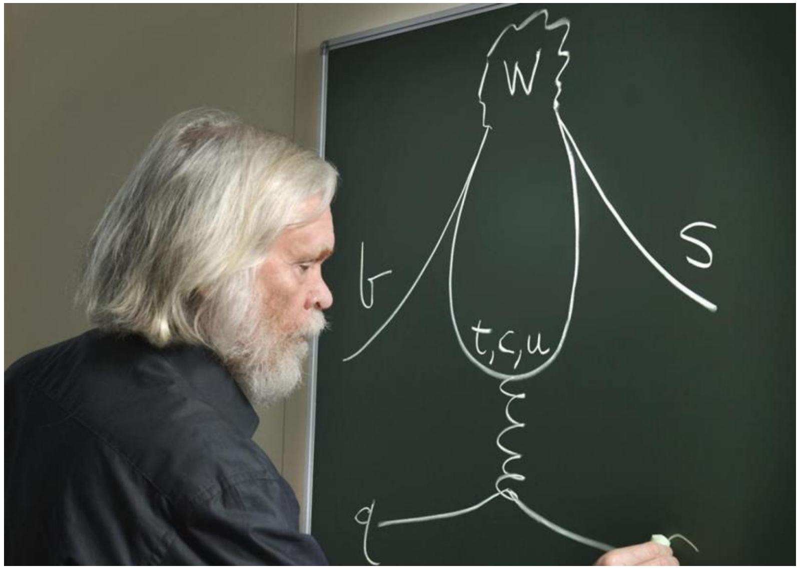
$$B^- \rightarrow D^0(K_S p^+ p^-)p^-$$



Another important channel used in the Dalitz determination of the unitarity angle γ (a.k.a. ϕ_3)

Re-discovery of Radiative Penguins at Belle II

1975: Vainshtein, Zakharov and Shifman



Examine the following b→s γ decay modes in the Belle II Phase 3 dataset (using ~1/2 of total recorded this spring).

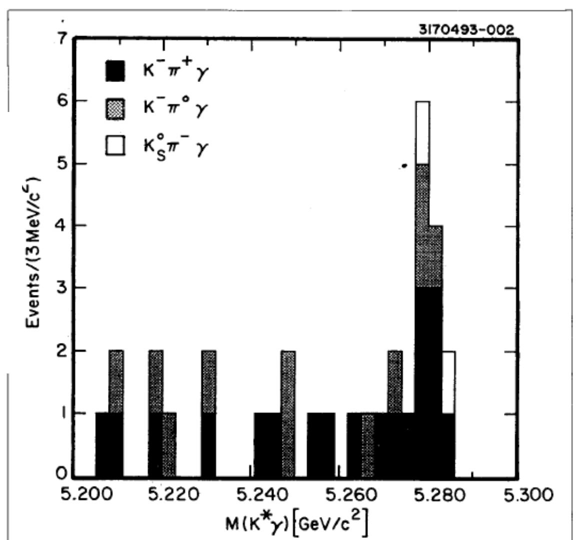
$$B^0 \to K^{*0} g \to K^+ p^- g$$

$$B^0 \to K^{*+} g \to K^+ p^0 g$$

$$B^0 \to K^{*+} g \to K_S^0 p^+ g$$

1993 CERN Courier:

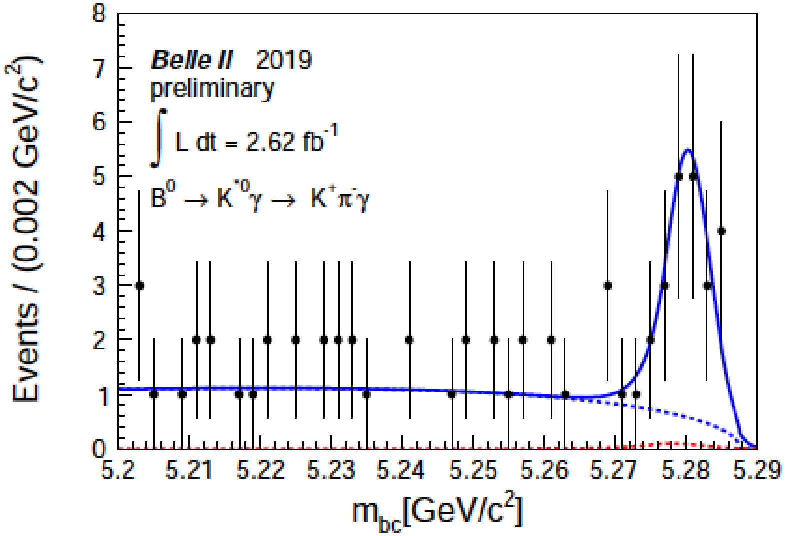
CORNELL
CLEO discovers
B meson penguins

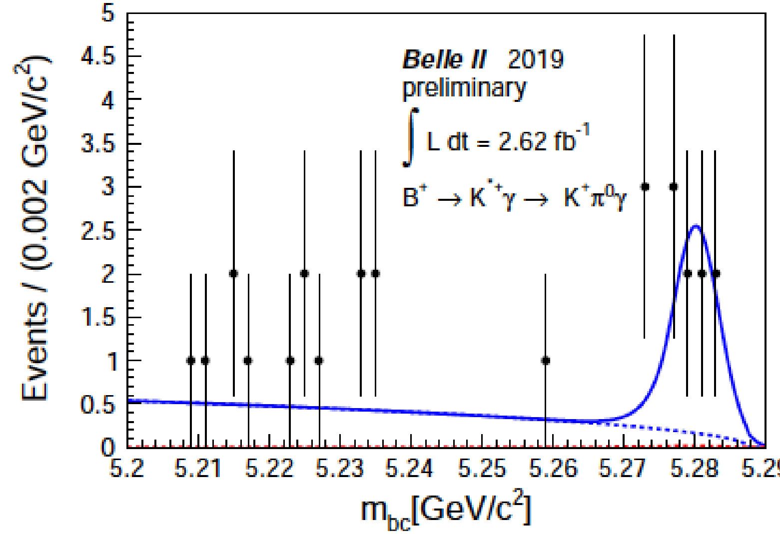


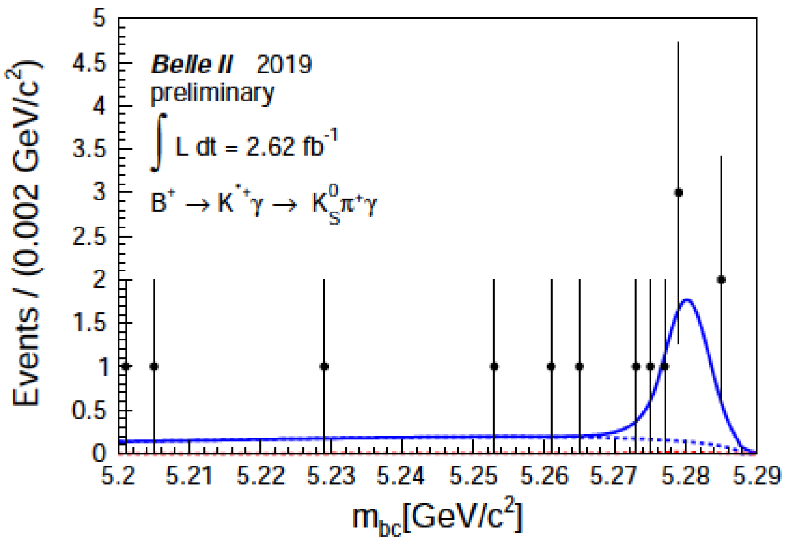
Using 1.5 x 10^6
B meson pairs

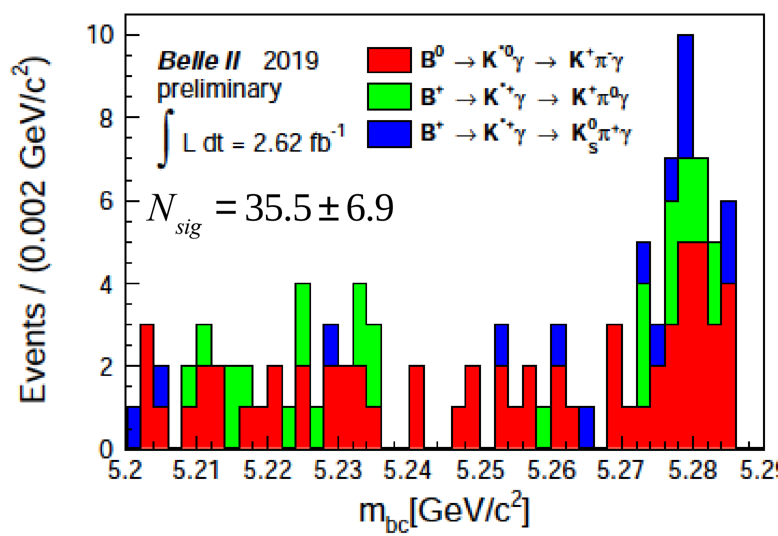
Belle II's 1st penguin: Observation of B→K* γ

Yields consistent with WA branching fraction



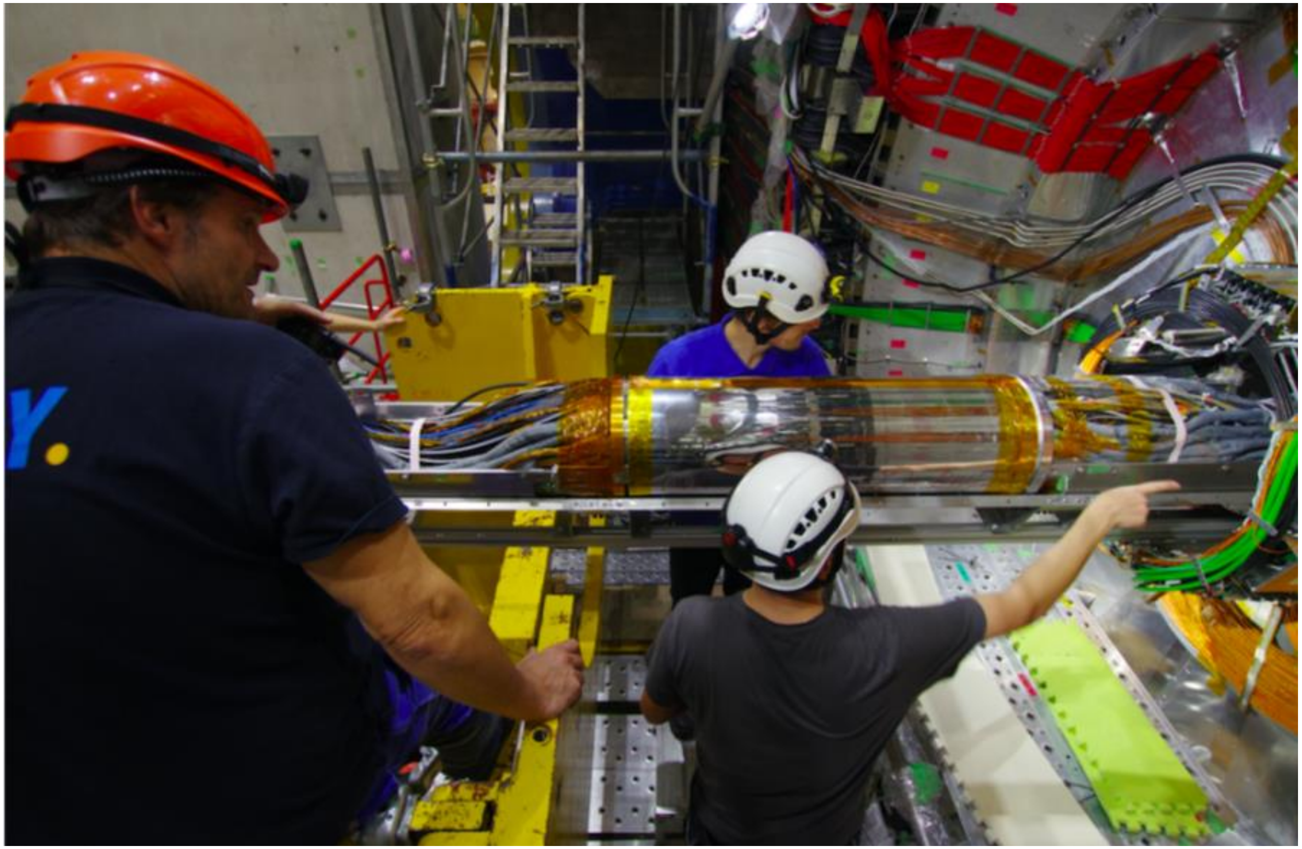






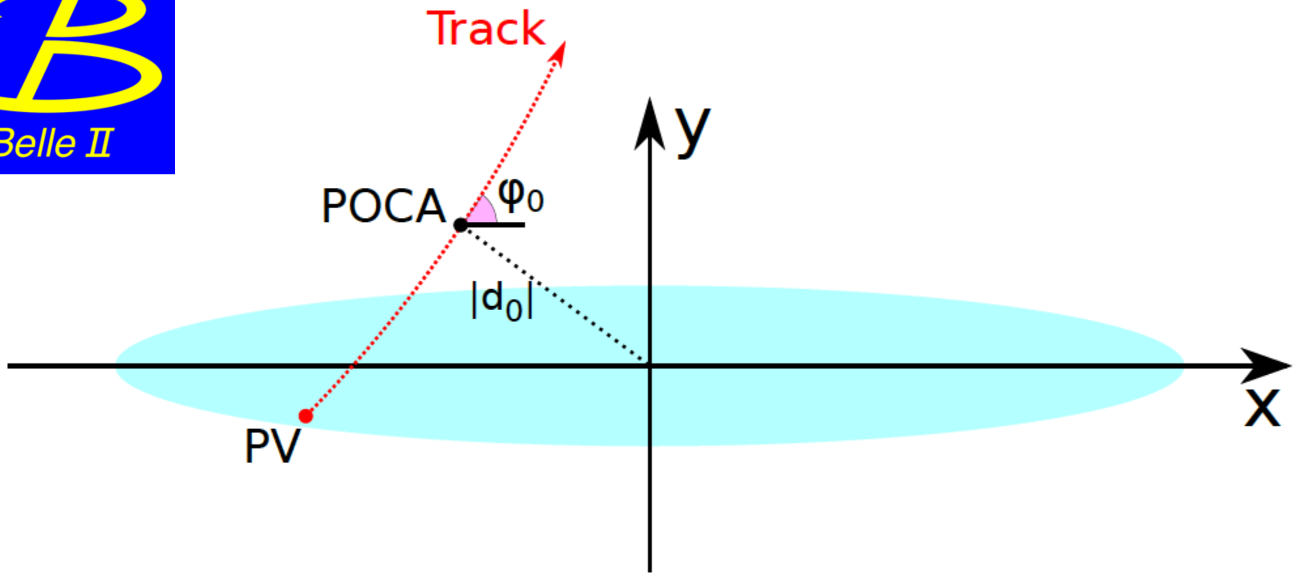
~1/2 of the initial Phase 3 dataset

Time Dependent Measurements at Belle II

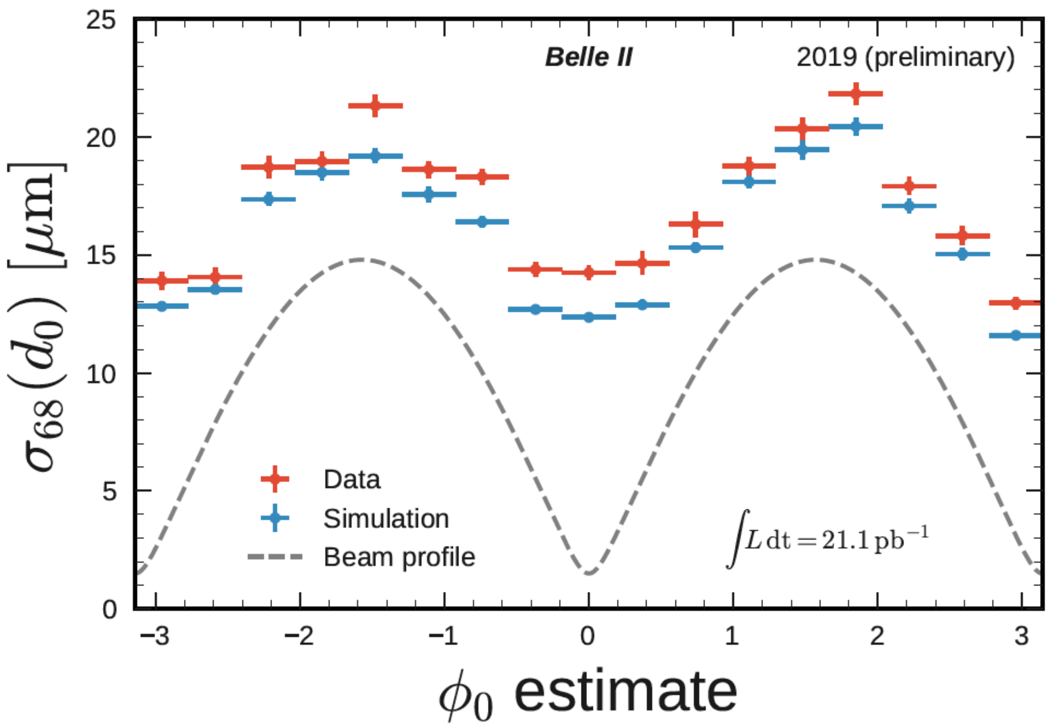


Belle II VXD installed on Nov 21, 2018. (PXD L1 and two ladders of L2. and the SVD (4 layers))

Impact parameter distributions in two-track events. *Alignment and calibration are working well.*



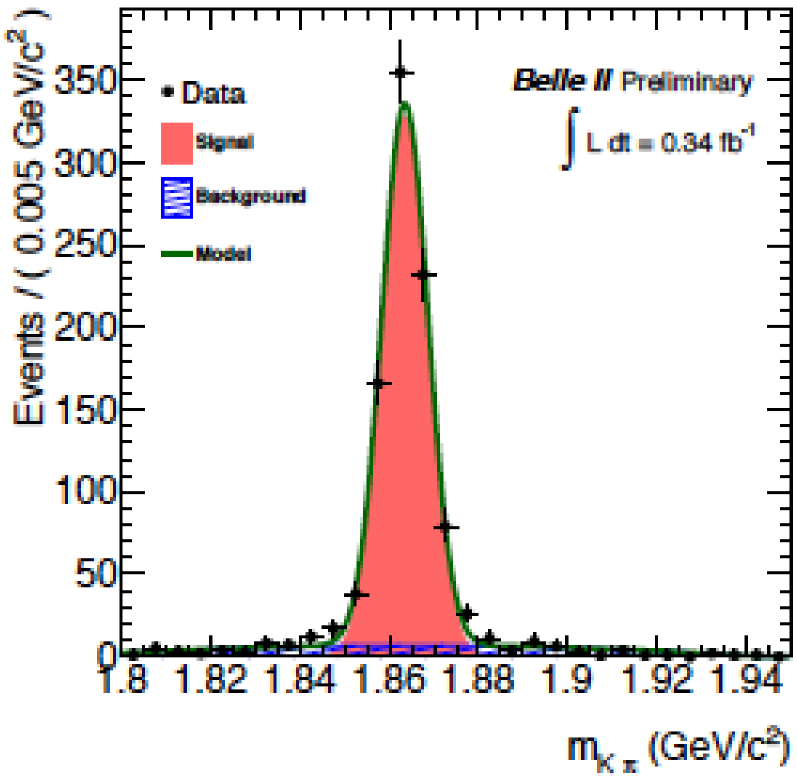
Width of impact parameter resolution distribution



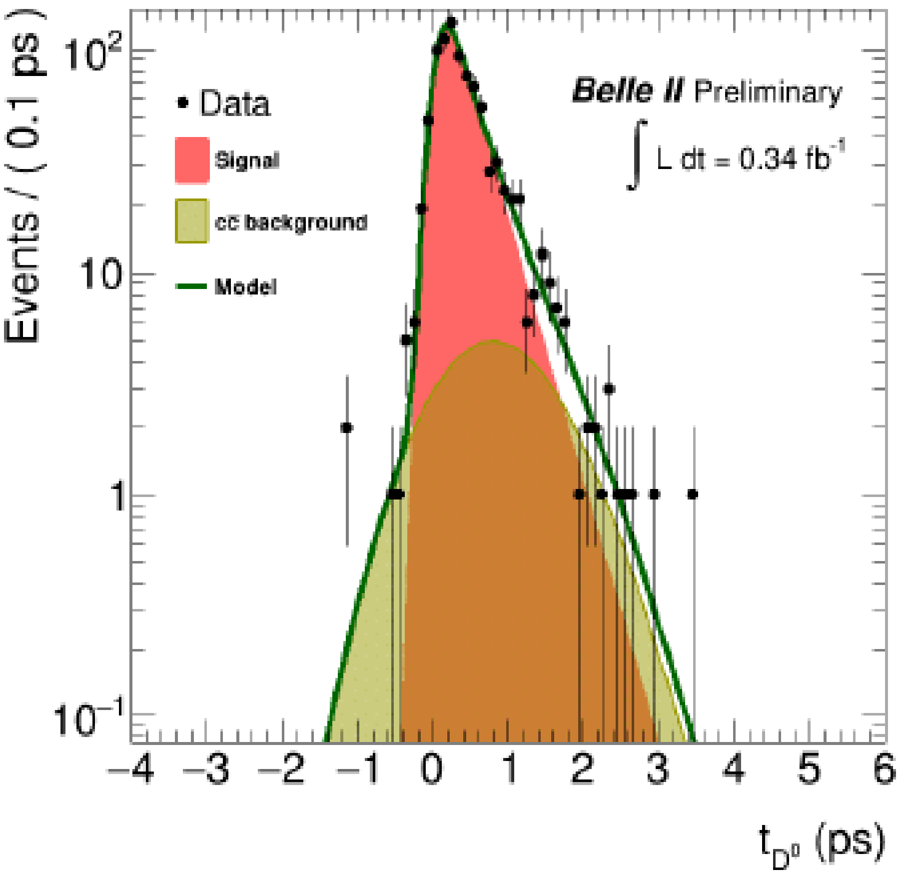
VXD resolution in impact parameter ~14 microns

D^0 Lifetime in Belle II Phase 3 data

$$N_{sig} = 860 \pm 30$$



$$t_{D^0} = 370 \pm 40(stat)\ \text{fs}$$



Uses ~1/15 of the Phase 3 dataset

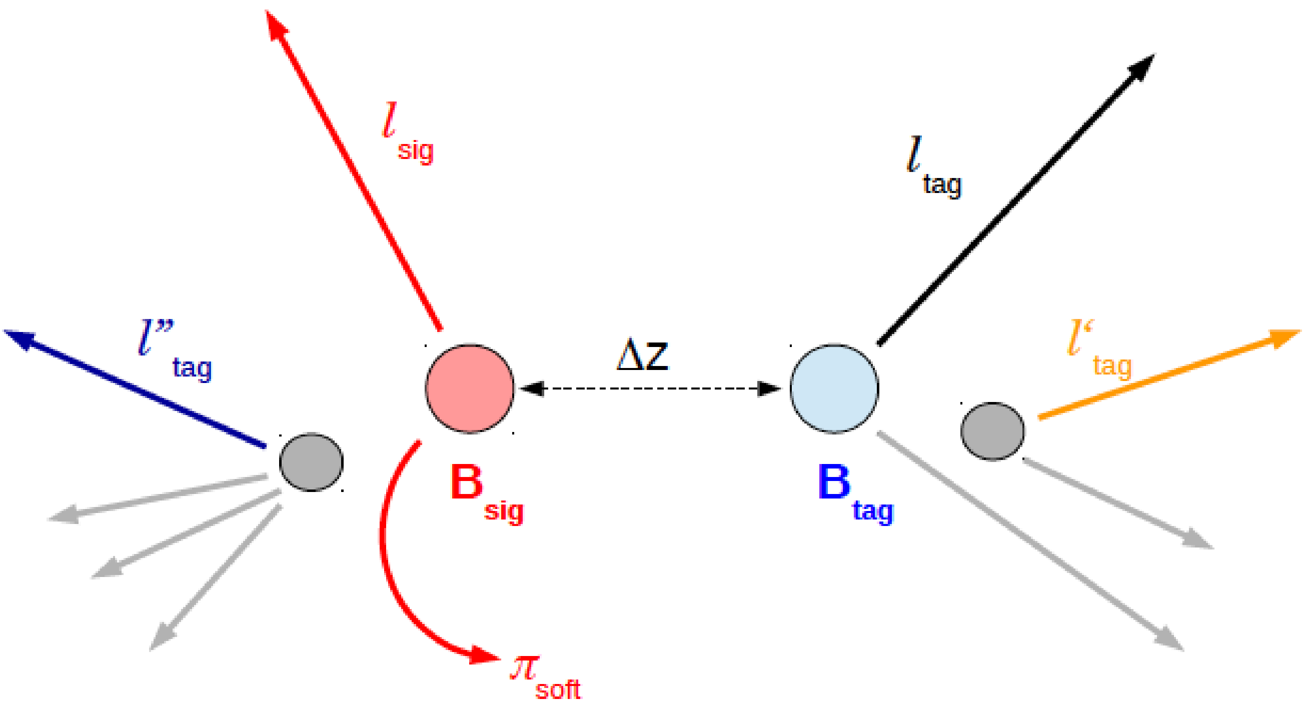
Clearly demonstrates the combined performance of the PXD and SVD (VXD system). Accepted value 410 fs.

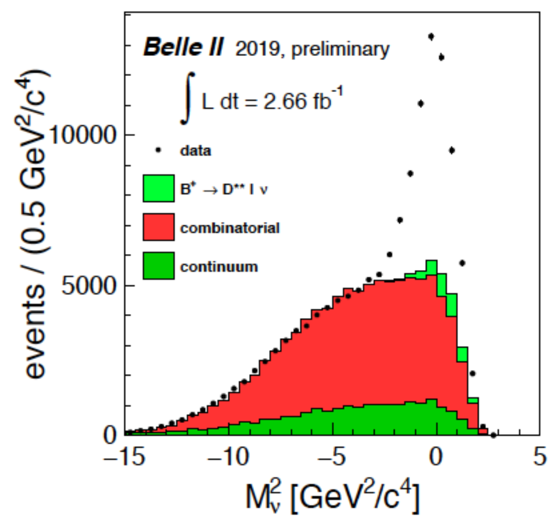
Particle Anti-Particle Mixing
(a remarkable and useful phenomenon).

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 v signal from partial reconstruction: 35492±2209

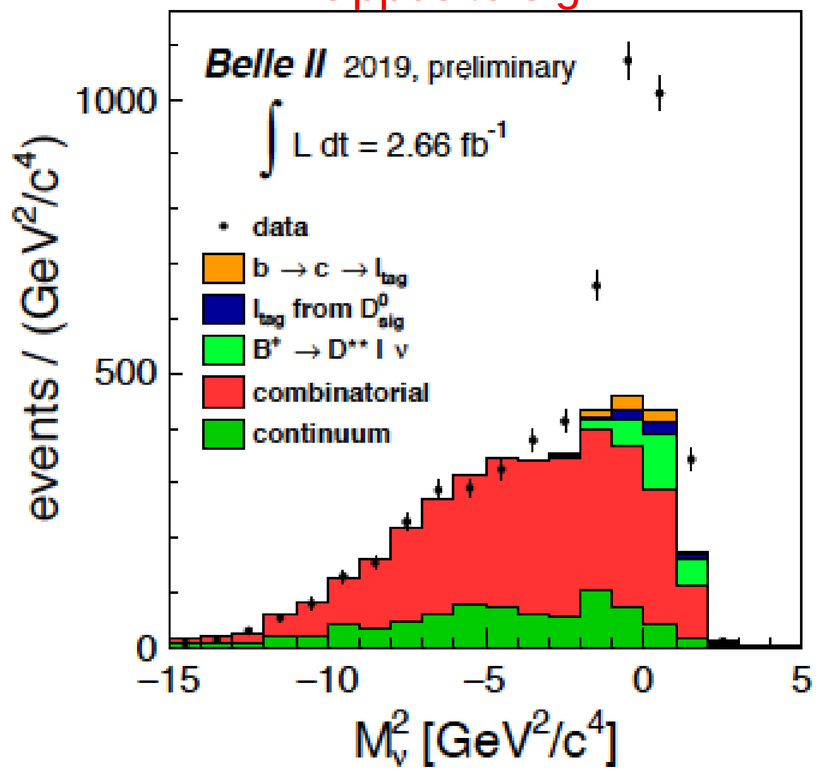




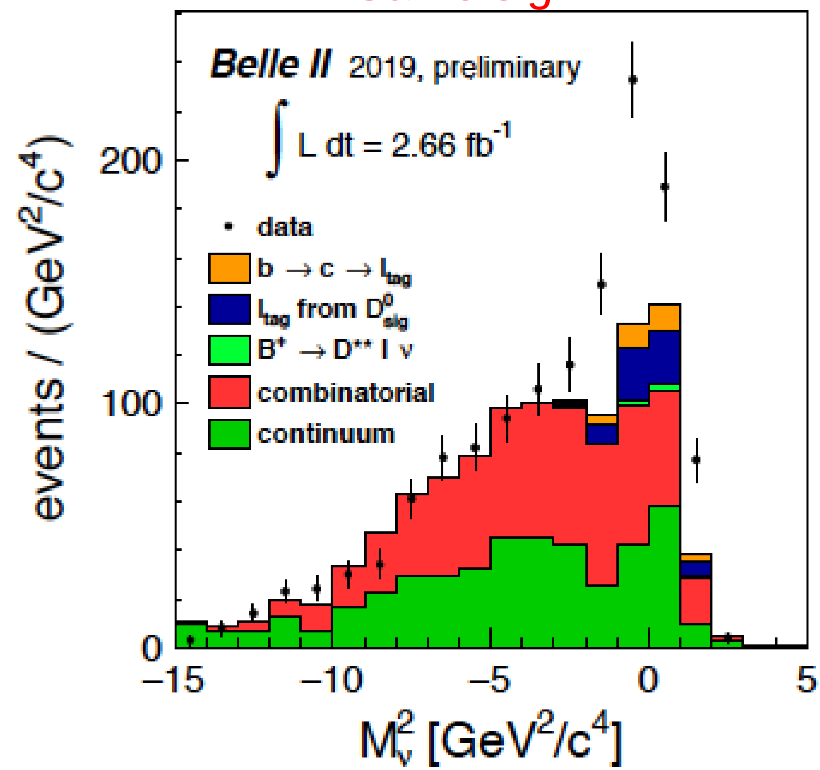
The leptons may come from the B weak decay or (primed case) from a cascade decay B→D→l decay.

Time Integrated Mixing Analysis

Opposite sign



Same sign



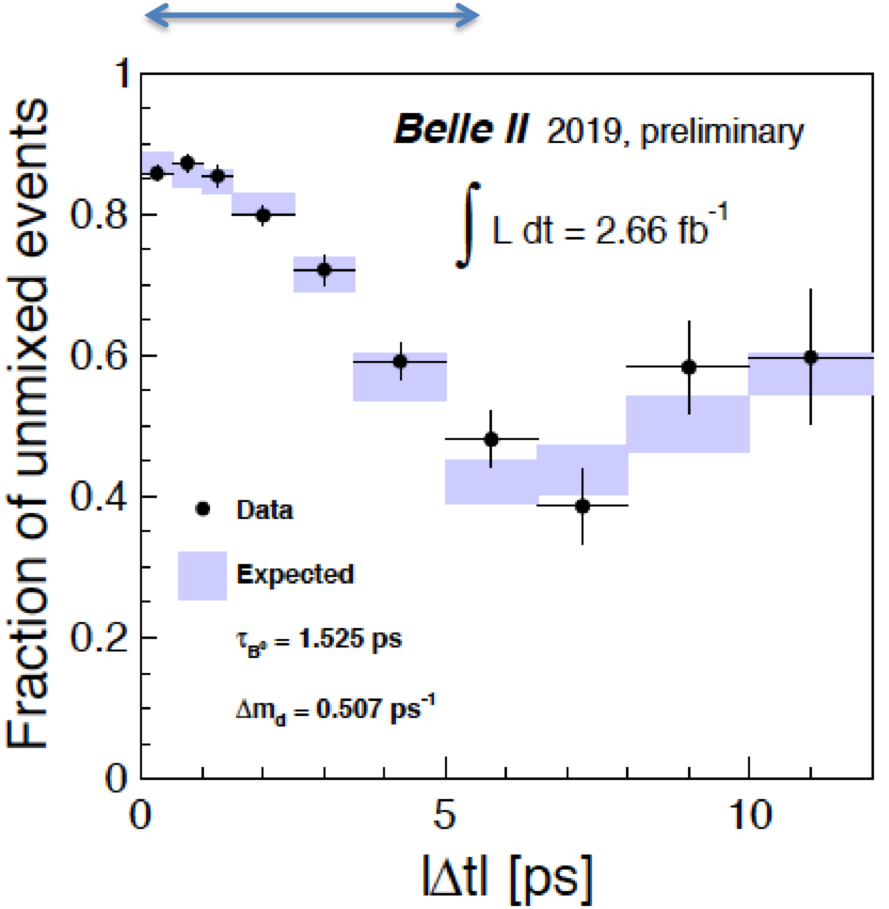
Channel	Data
Untagged e only	18514 ± 1128
Untagged μ only	16625 ± 1111
Untagged (e or μ)	35492 ± 2209
Tagged unmixed (N_U)	1642 ± 133
Tagged mixed (N_M)	253 ± 45
($\varepsilon_U/\varepsilon_M$) correction factor	1.35 ± 0.10
χ_d (fraction of mixed events)	$(17.2 \pm 3.6)\%$

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

First oscillation



$$\overline{B}^0 \rightarrow D^{*+}\ell^- n \rightarrow (D^0)p_s^+\ell^- n$$

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:

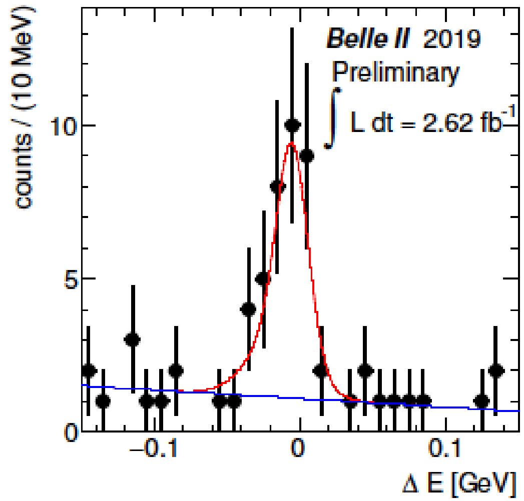
$f_{unmix}(t) = K\,[1 + \cos(\Delta m_d\,\Delta t)]$

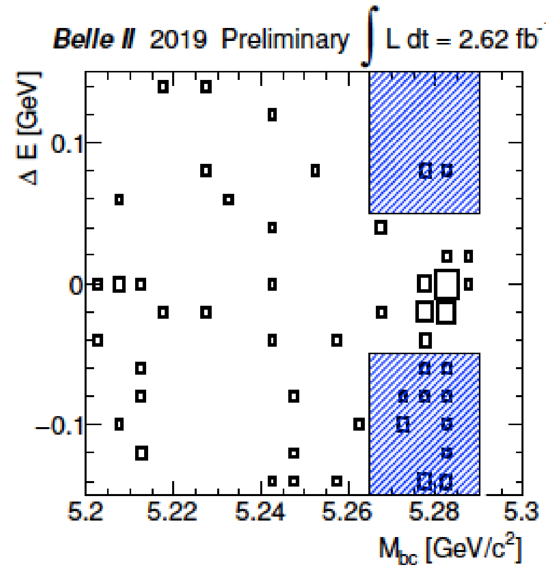
Use flavor specific final states but requires tagging. Verifies Belle II VXD capabilities for CP violation.

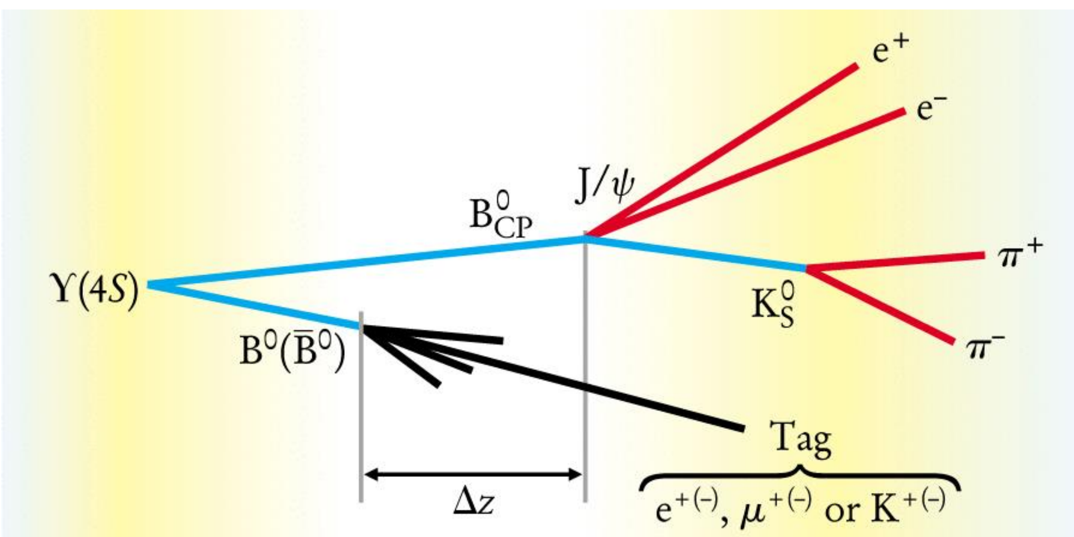
Observation of B→J/ψ K_S

A Golden CP Eigenstate

About ½ of the initial Phase 3 data sample.







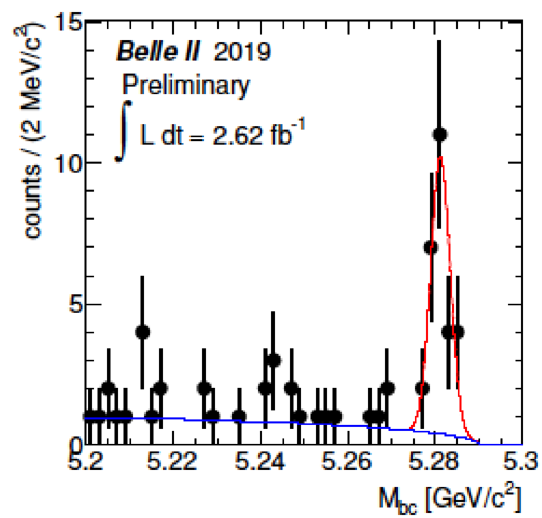
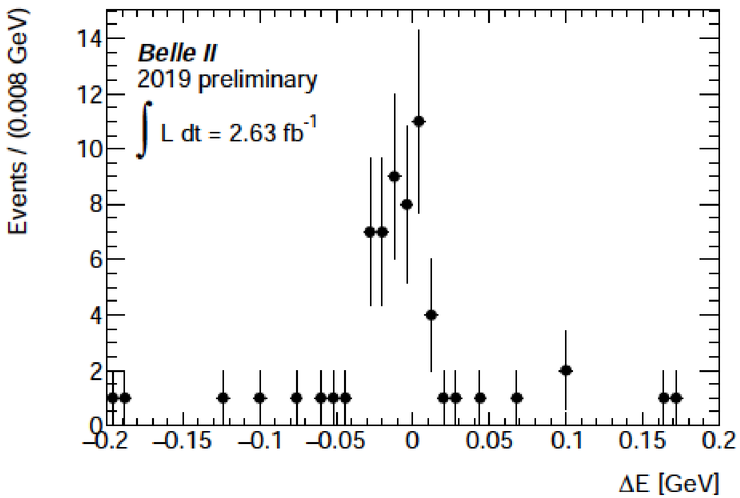
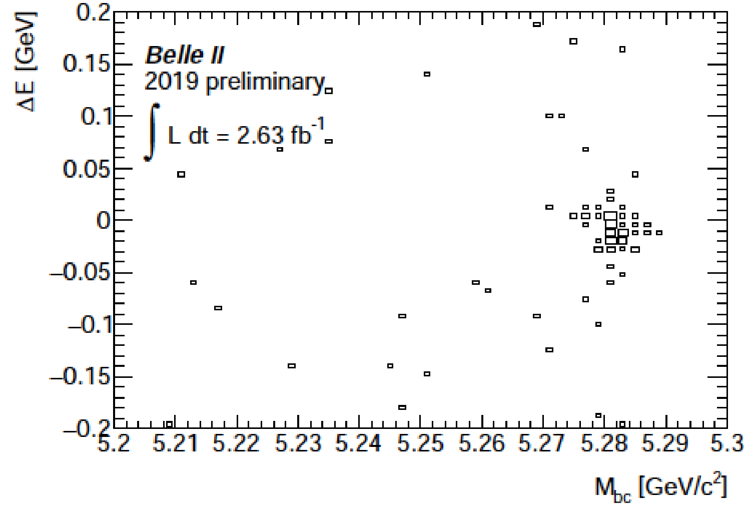


Figure credit: Physics Today

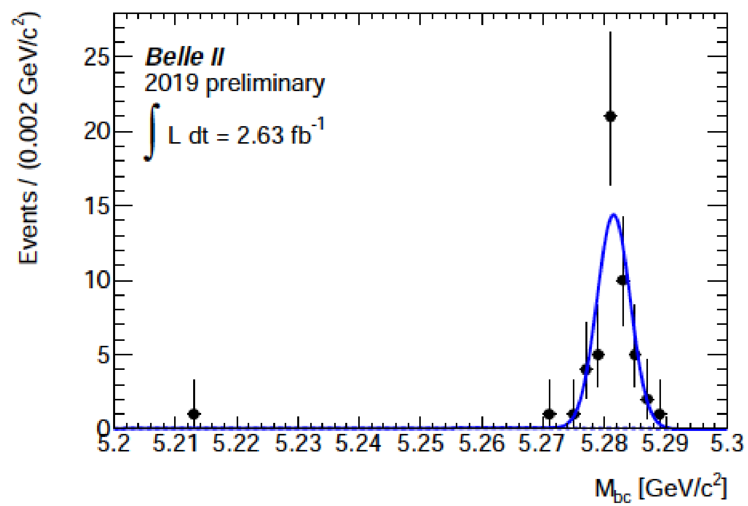
$$N(B \to J/\psi\, K_S) = 26.9 \pm 5.2$$

Observation of B→J/ψ K*0





About ½ of the initial Phase 3 data sample



Note:

$$B \to J/\psi\, K^{*0} \to J/\psi\ \ K^{-}\pi^{+}$$

is not a CP eigenstate. Need

$$B \to J/\psi\, K^{*0} \to J/\psi\ \ K_S^0\pi^0$$

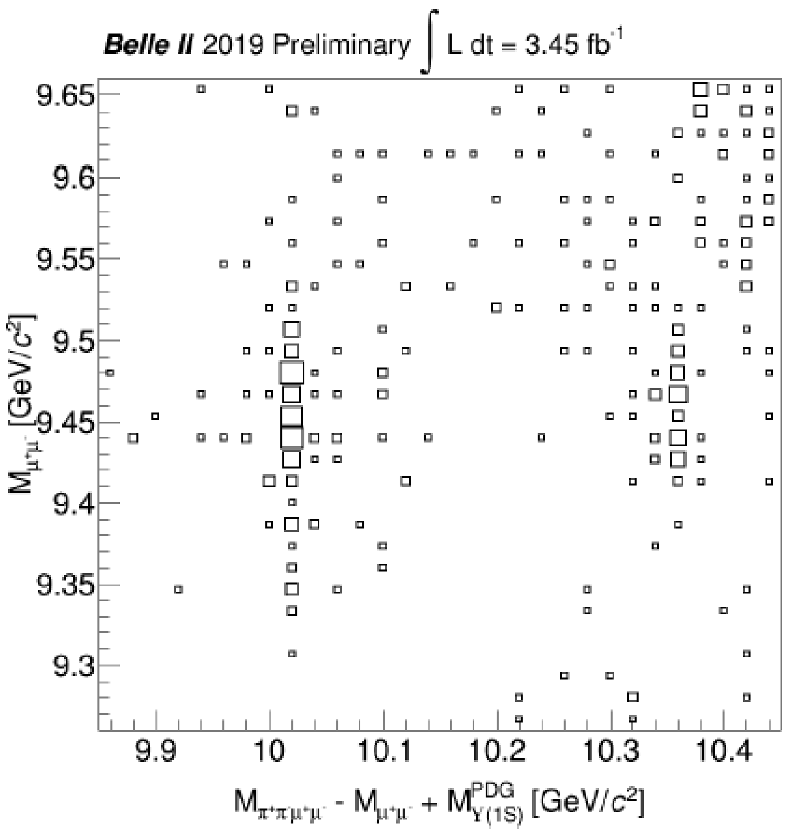
$$N(B \to J/\psi\, K^{*0} \to J/\psi\ \ K^{-}\pi^{+}) = 48.6 \pm 7.0$$

ISR

$$e^+e^- \to g\,\Upsilon(3S,2S)$$

$$\Upsilon(3S,2S) \to p^+p^-\,\Upsilon(1S) \to m^+m^-$$

Upsilon(2S), Upsilon(3S) via Initial State Radiation (ISR)



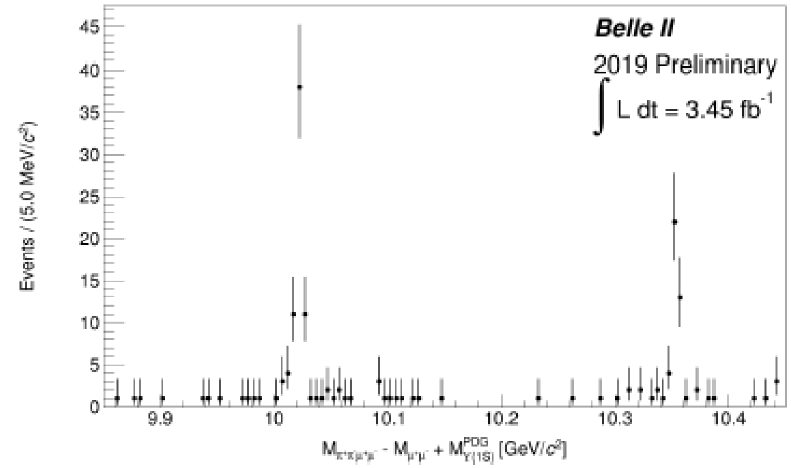
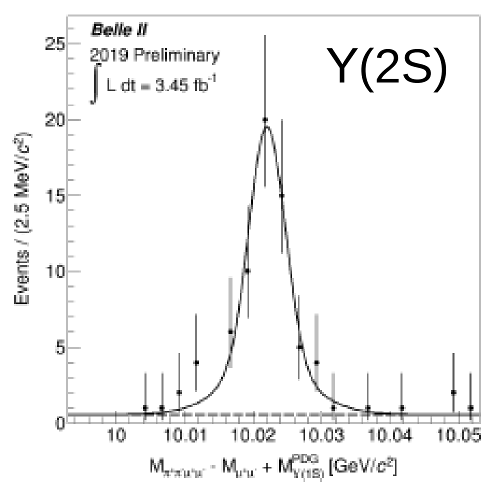
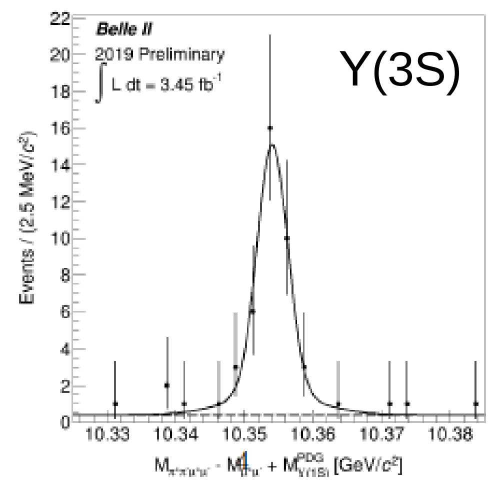


FIG. 2: Plot of $M_{\pi^+\pi^-\mu^+\mu^-} - M_{\mu^+\mu^-} + M^{PDG}_{\Upsilon(1S)}$ with a requirement of $|M_{\mu\mu} - M^{PDG}_{\Upsilon(1S)}| < 50$ MeV. The peaks indicate $\Upsilon(2S)$ and $\Upsilon(3S)$ dipion decay signals.



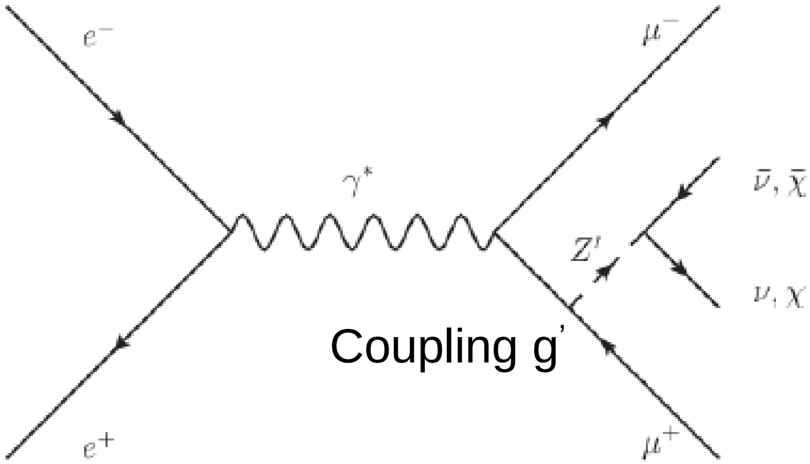


In Belle and BaBar, ISR was an important tool for finding new particles.

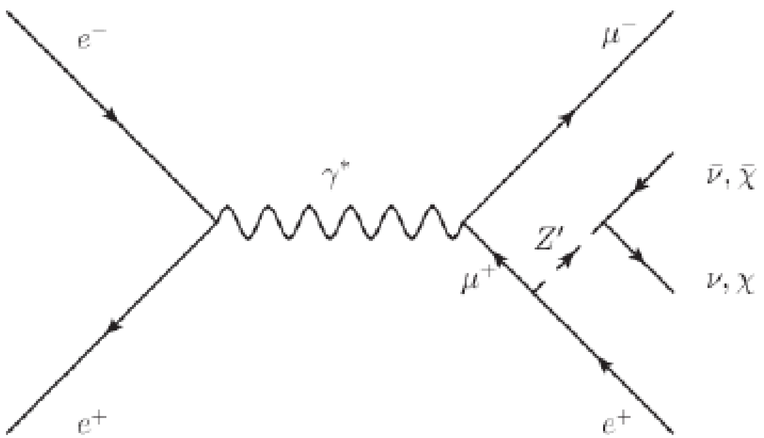
Dark Sector:

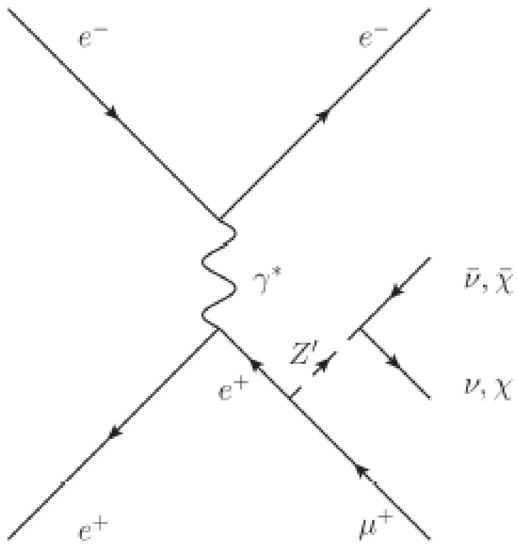
Previously limited by Triggering, QED backgrounds and theoretical imagination. *Now new possibilities of triggering, more bandwidth.*

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.*



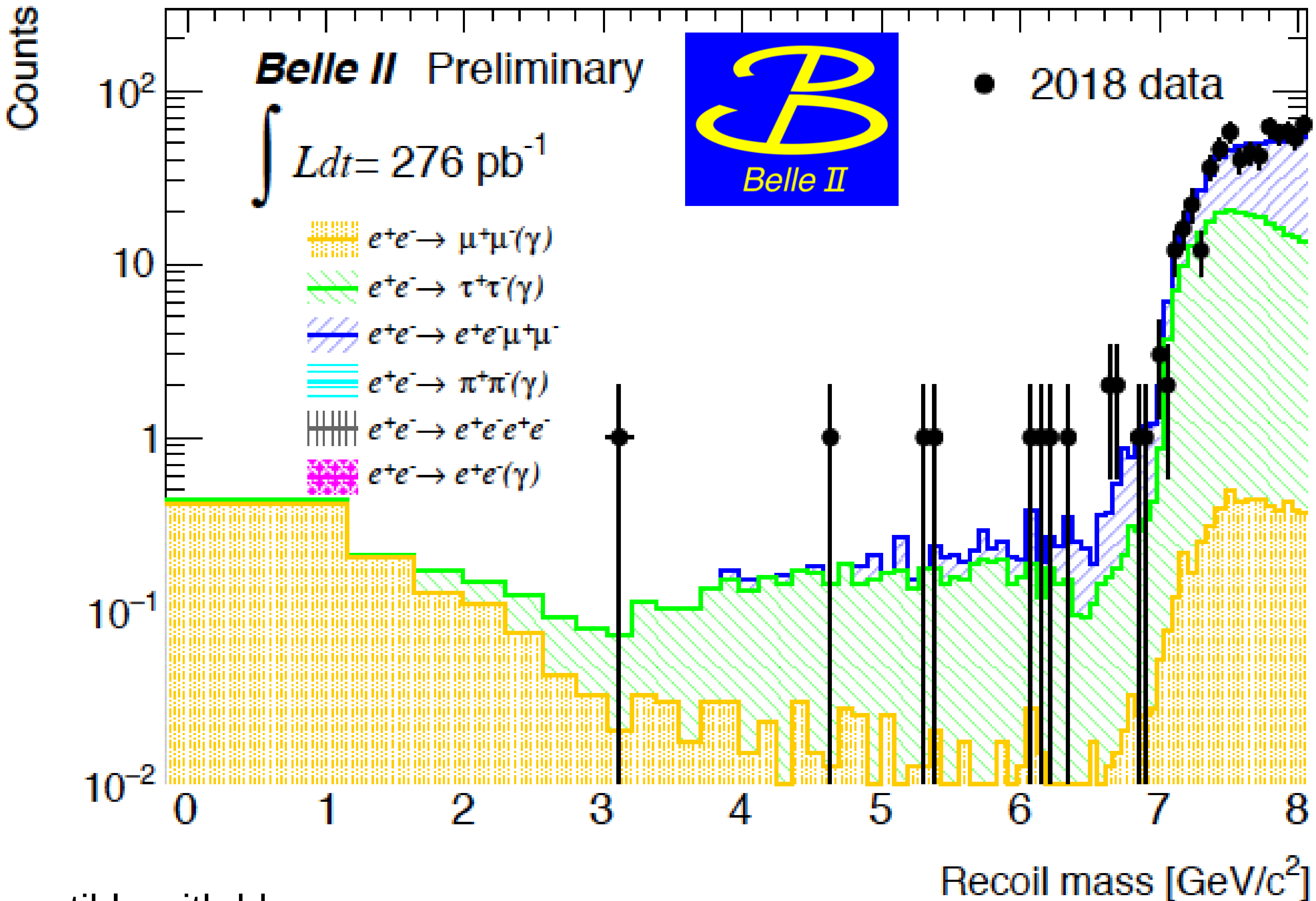
Also examine a lepton flavor violating NP signature in the dark sector





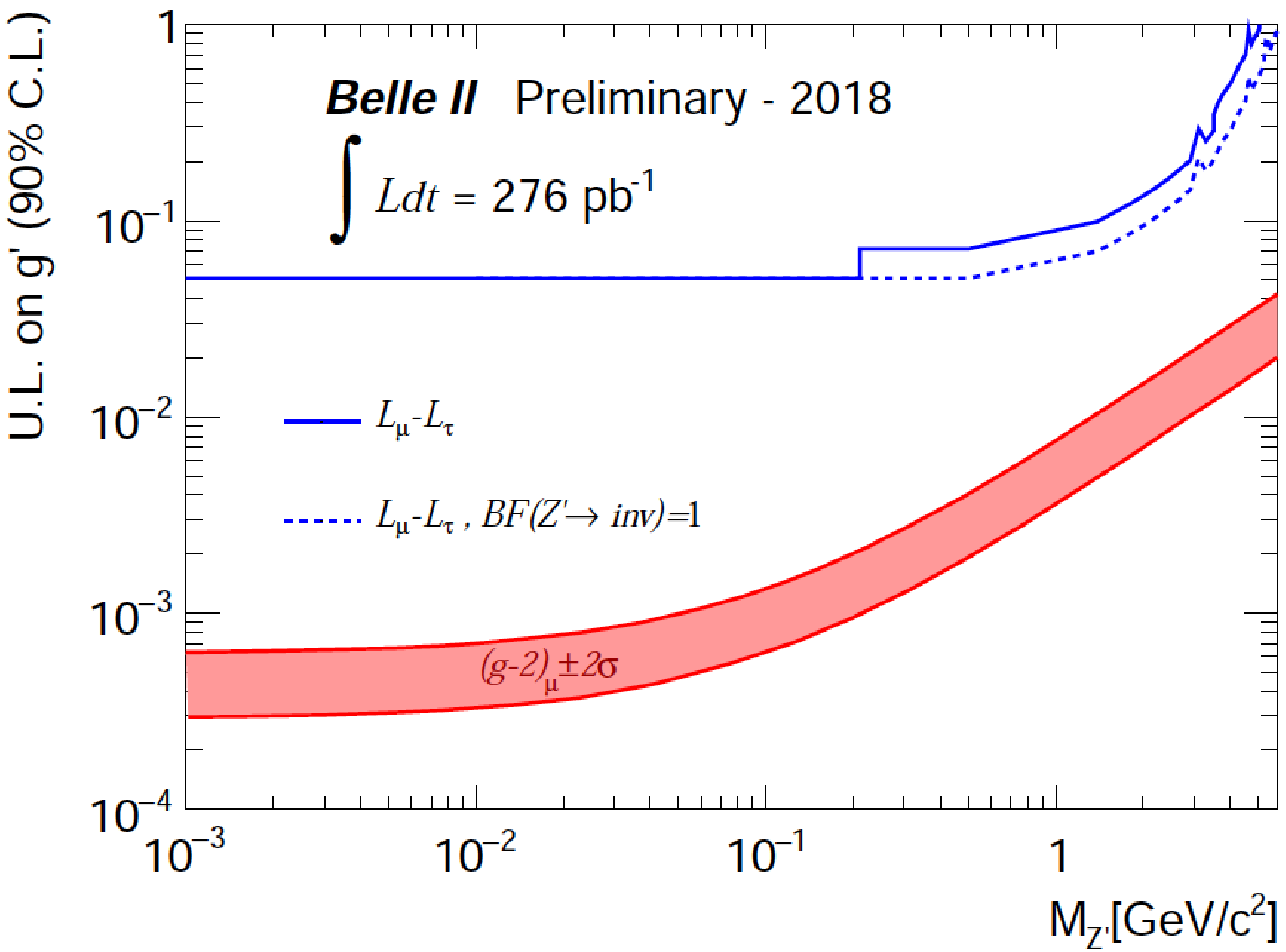
After tau suppression cuts
and unblinding.

Search for $e^+e^- \to m^+ m^- Z', Z' \to nothing$

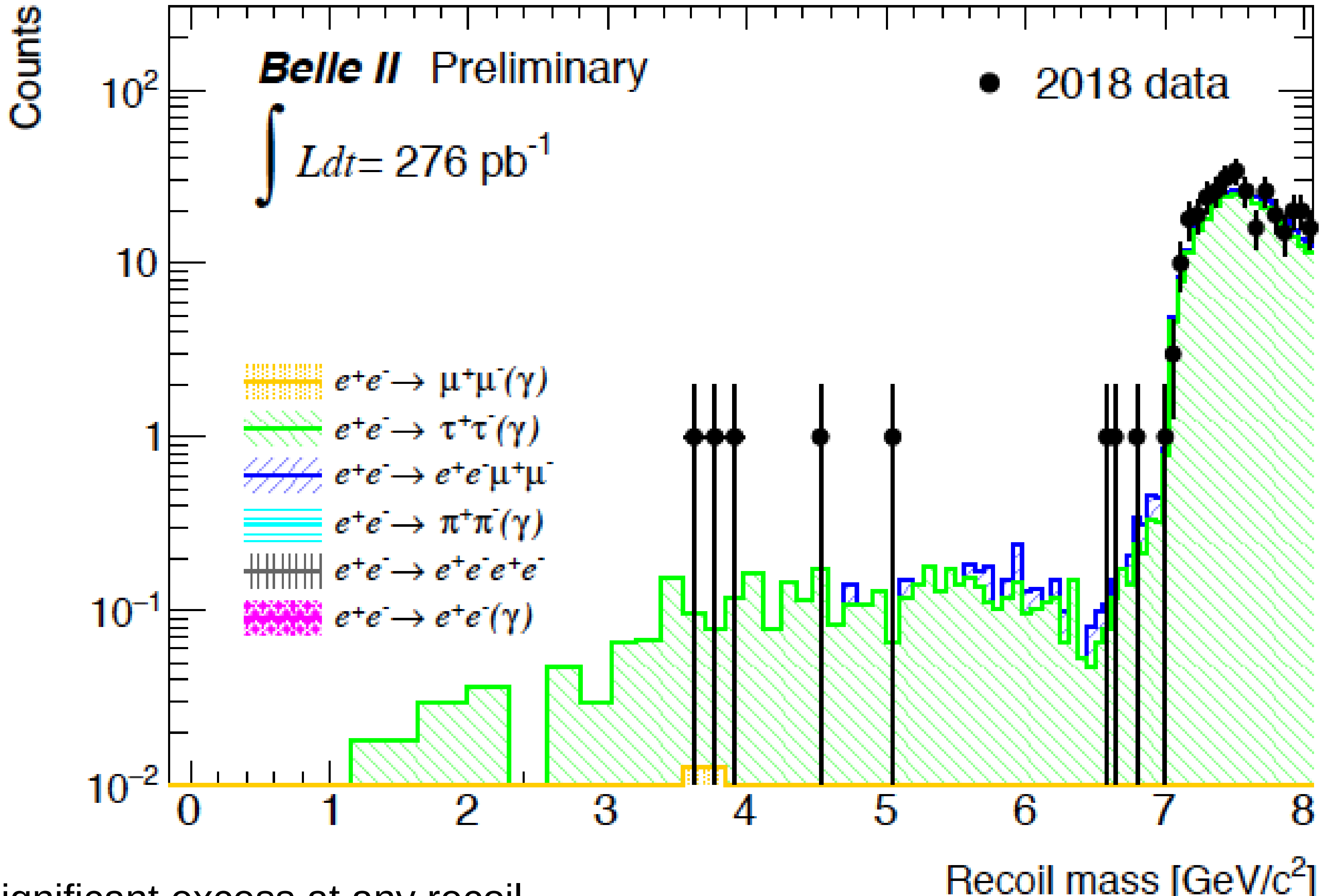


Compatible with bkgs,
No excess above 3σ

Search for $e^+e^- \to \mu^+\mu^- Z', Z' \to nothing$

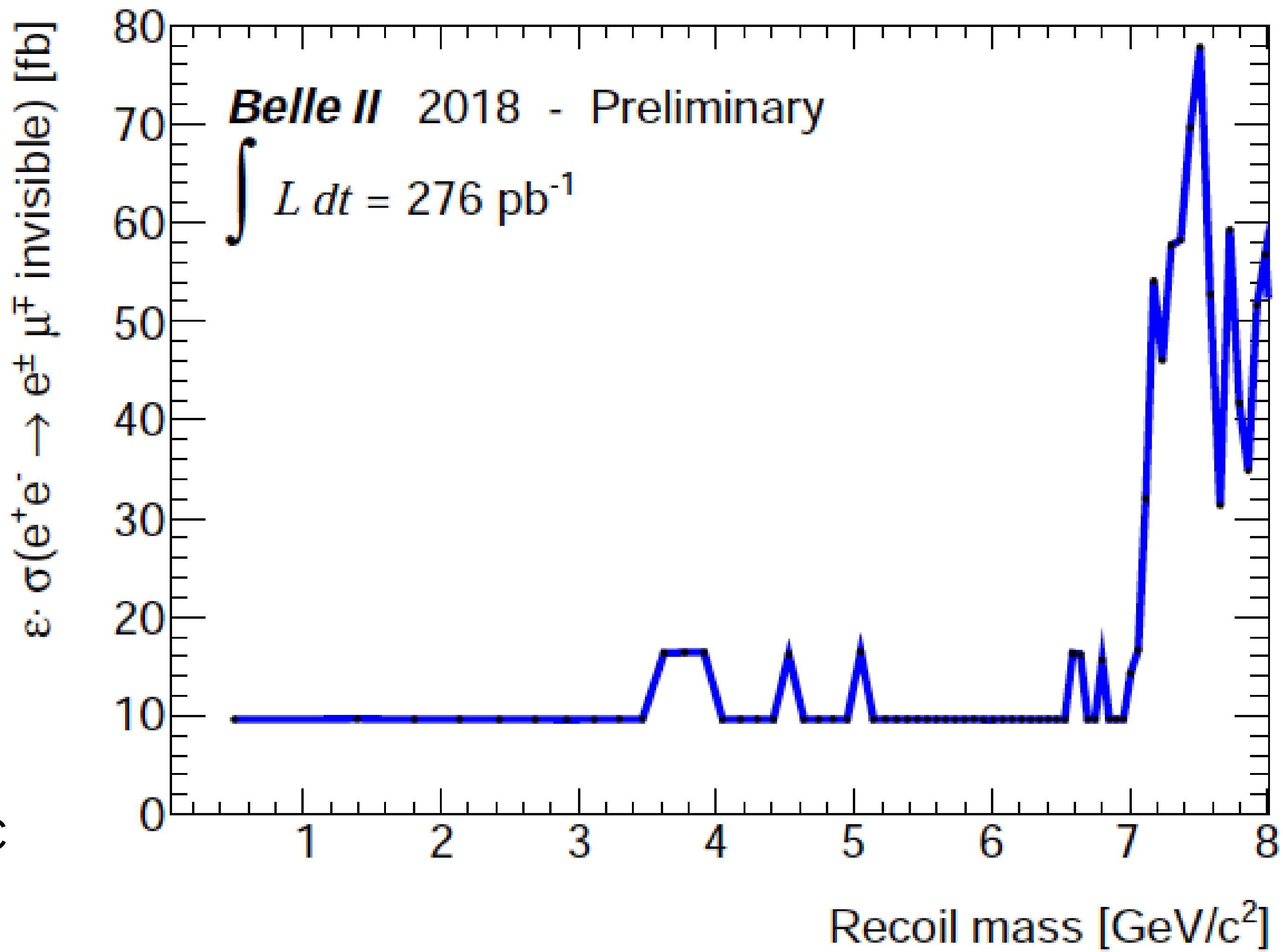


Search for $e^+e^- \rightarrow \mu^{\pm} e^{\mp} Z'_{LFV}$, $Z'_{LFV} \rightarrow nothing$



No significant excess at any recoil mass

Search for $e^+e^- \to \mu^{\mp} e^{\pm} Z'_{LFV}, Z'_{LFV} \to nothing$



Some theory work on the MC needed to extract cross-section result

FIG. 75: 90% CL upper limits to $\epsilon \times \sigma[e^+e^- \to e^{\pm}\mu^{\mp}\text{invisible}]$.

https://arxiv.org/abs/1808.10567

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

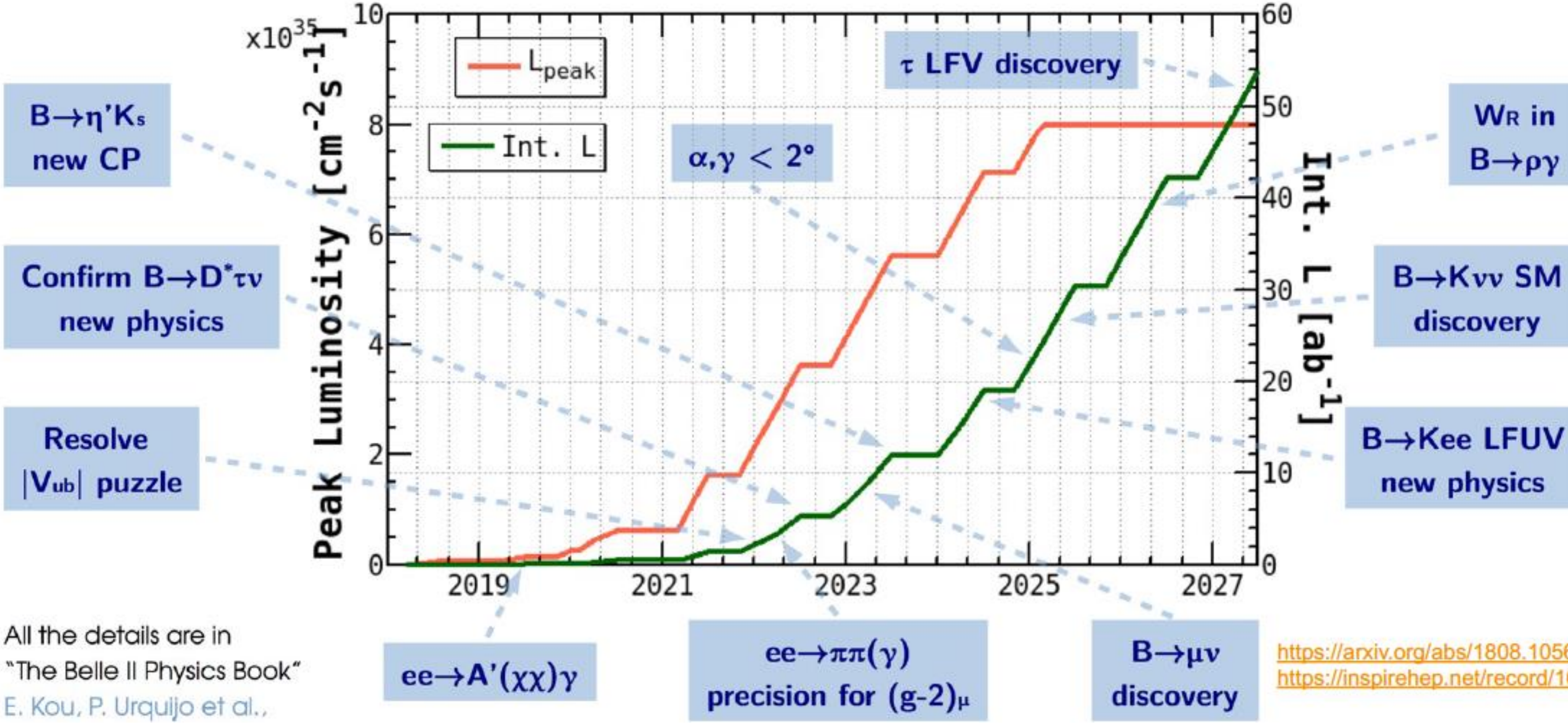
Strong participation from theory community,
lattice QCD community and Belle II experimenters.
689 pages, published by Oxford University Press

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,¶],

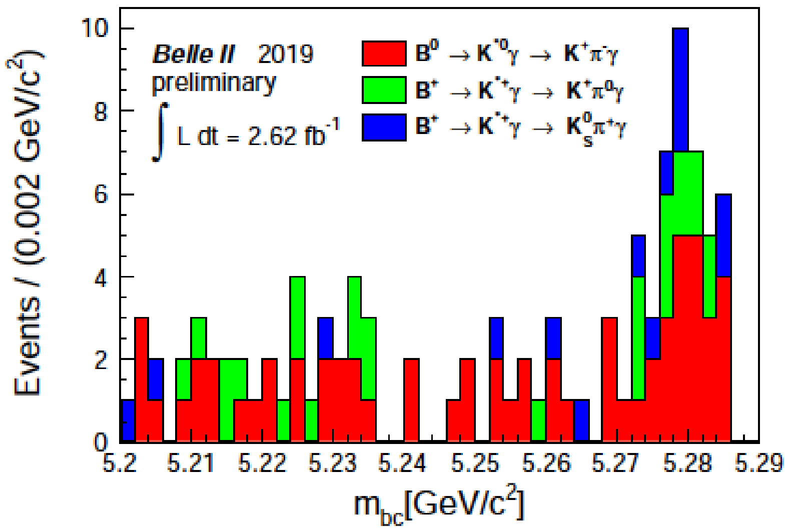
Long term prospects of Belle II (Belle II physics book).

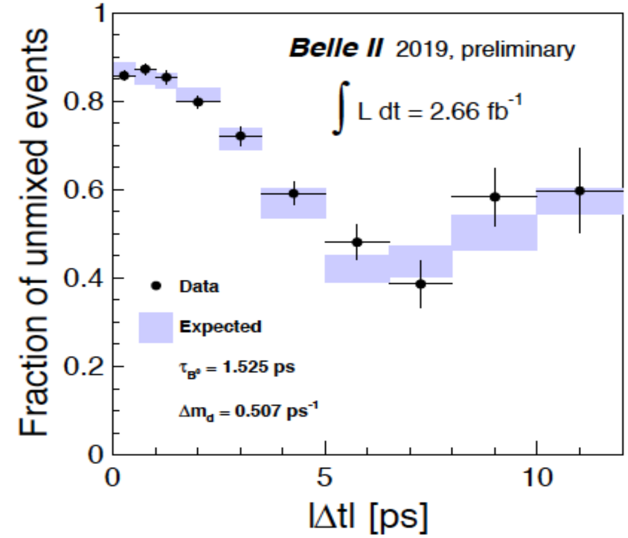


All the details are in "The Belle II Physics Book"
E. Kou, P. Urquijo et al.,

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

Visualization
by F. Forti





We have just completed the first physics run in the Super B Factory mode (Phase 3) in spring 2019. Integrated ~6.5 fb^{-1} . Good results so far but further progress requires *high-efficiency* data-taking by Belle II and much more *operation time* for SuperKEKB, soon to be the world's highest luminosity accelerator.

Rediscoveries of known phenomena and demonstration of time-dependent capabilities with early Phase 3 data (6.5 fb^{-1}). *First physics result on the dark sector.*

Start again in mid-October and continue until end of June 2020.

Belle II LP2019 Parallel Session Talks

Dark Sector Physics with Belle II, Marcello Campajola

Precision Electroweak Physics with Polarized Beams
at SuperKEKB, Michael Roney

B lifetime and B-Bbar mixing results from
early Belle II data, Reem Rashad

First Look at Time Dependent CP violation
using early Belle II data, Daniel Cerenkov

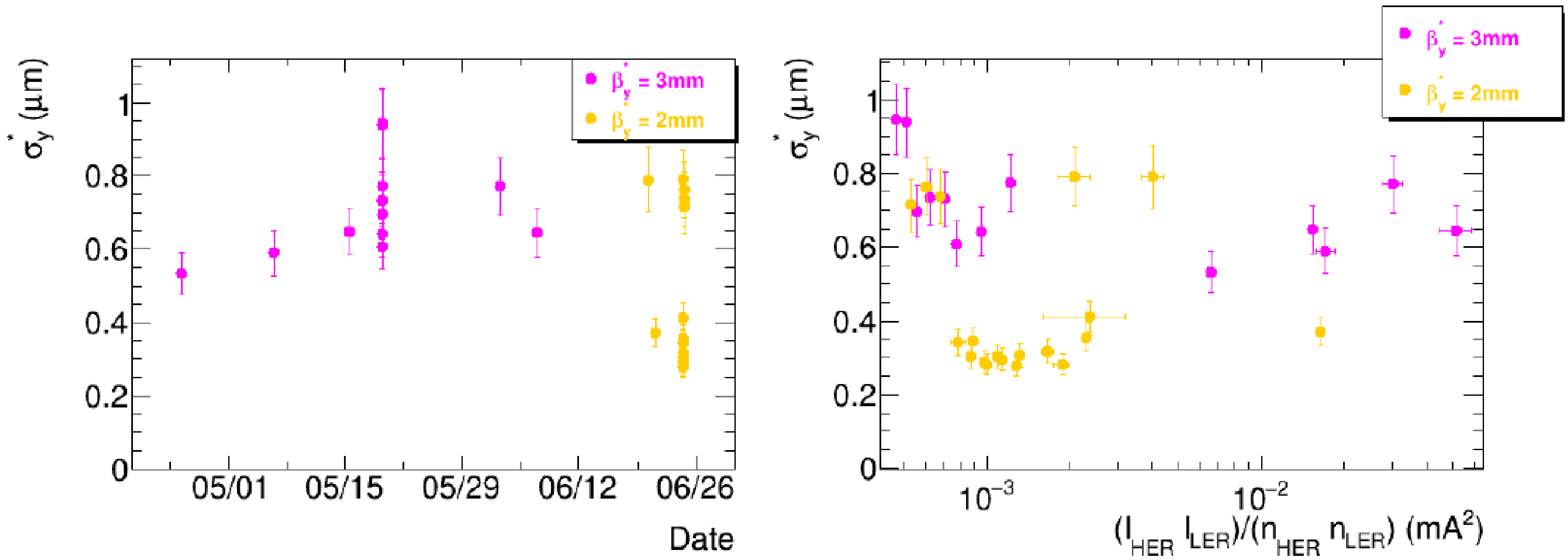
Exotic and Conventional Quarkonium Physics Prospects
at Belle II, Bryan Fulsom

Belle2VR, An Interactive Virtual Reality Visualization
of GEANT4 Event Histories, Leo Piilonen

Backup Slides

Phase 3 Results from LumiBelle2

Vertical beam size determination



- OPTICS1: $\beta^*_{x,HER} = 100mm,\ \beta^*_{x,LER} = 200mm, \beta^*_{y,HER} = 3mm,\ \beta^*_{y,HER} = 3mm$
- OPTICS 2: $\beta^*_{x,HER} = 80mm,\ \beta^*_{x,LER} = 80mm, \beta^*_{y,HER} = 2mm,\ \beta^*_{y,HER} = 2mm$

LAL Orsay,
SuperKEKB

Reached vertical beam spot below 300 nm at low currents with β_y^*=2mm optics.

Observation of B→ψ(2S) in the di-muon channel

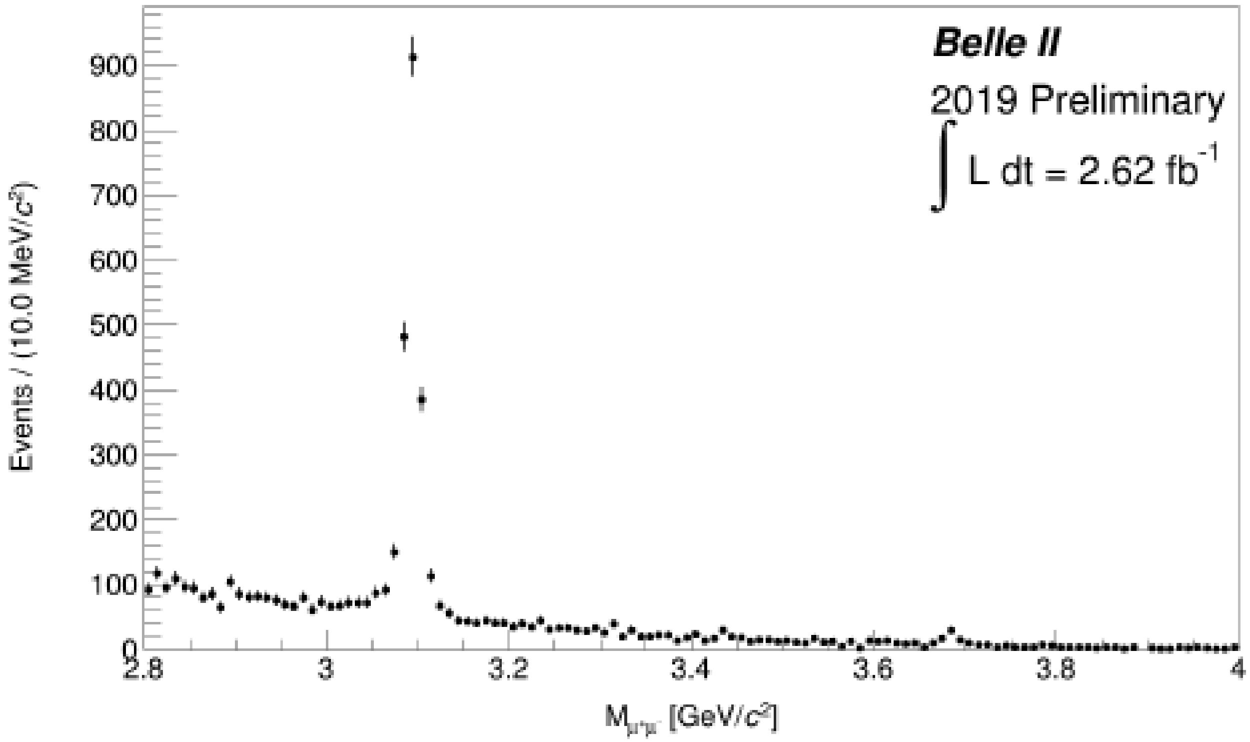
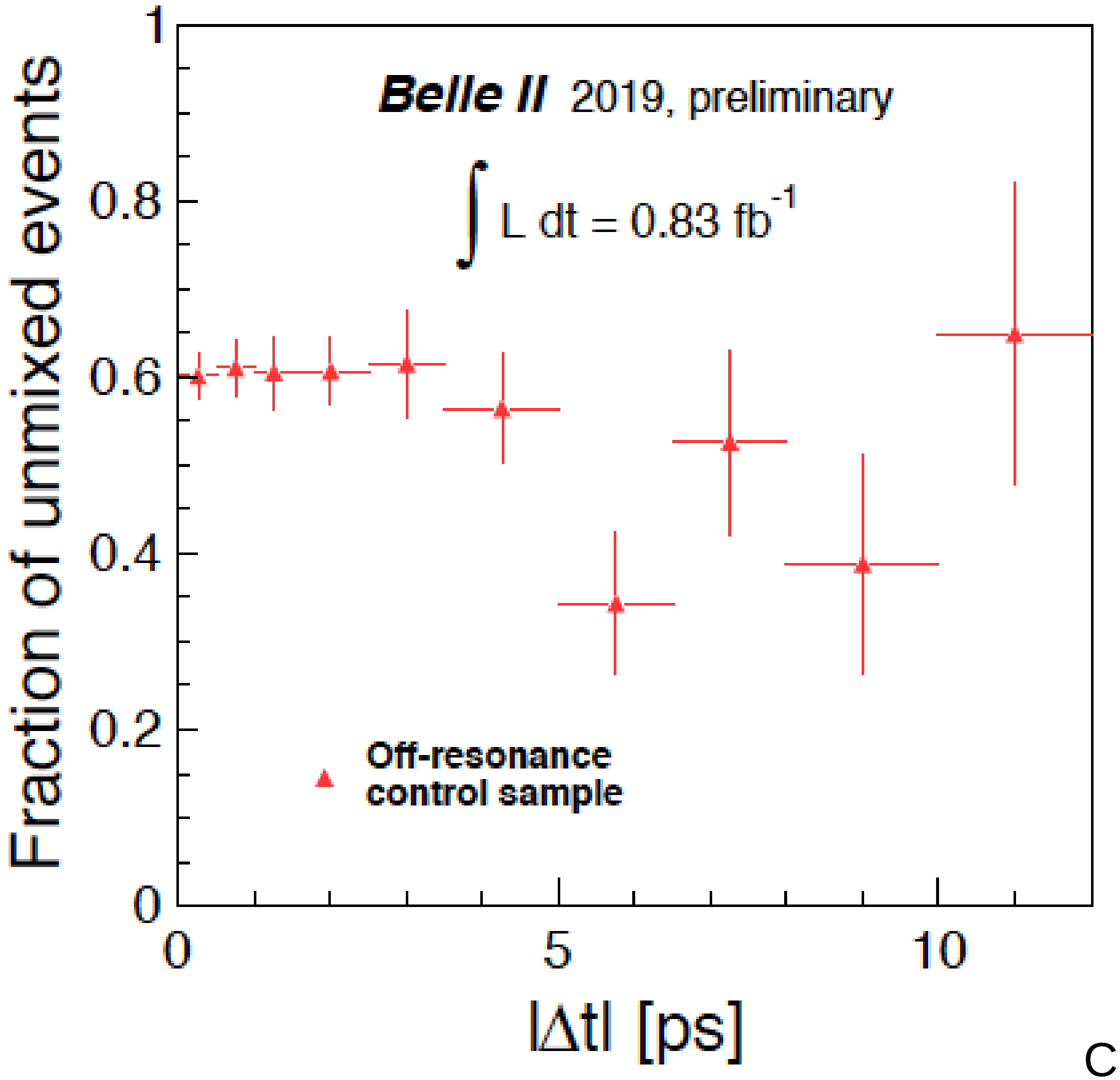


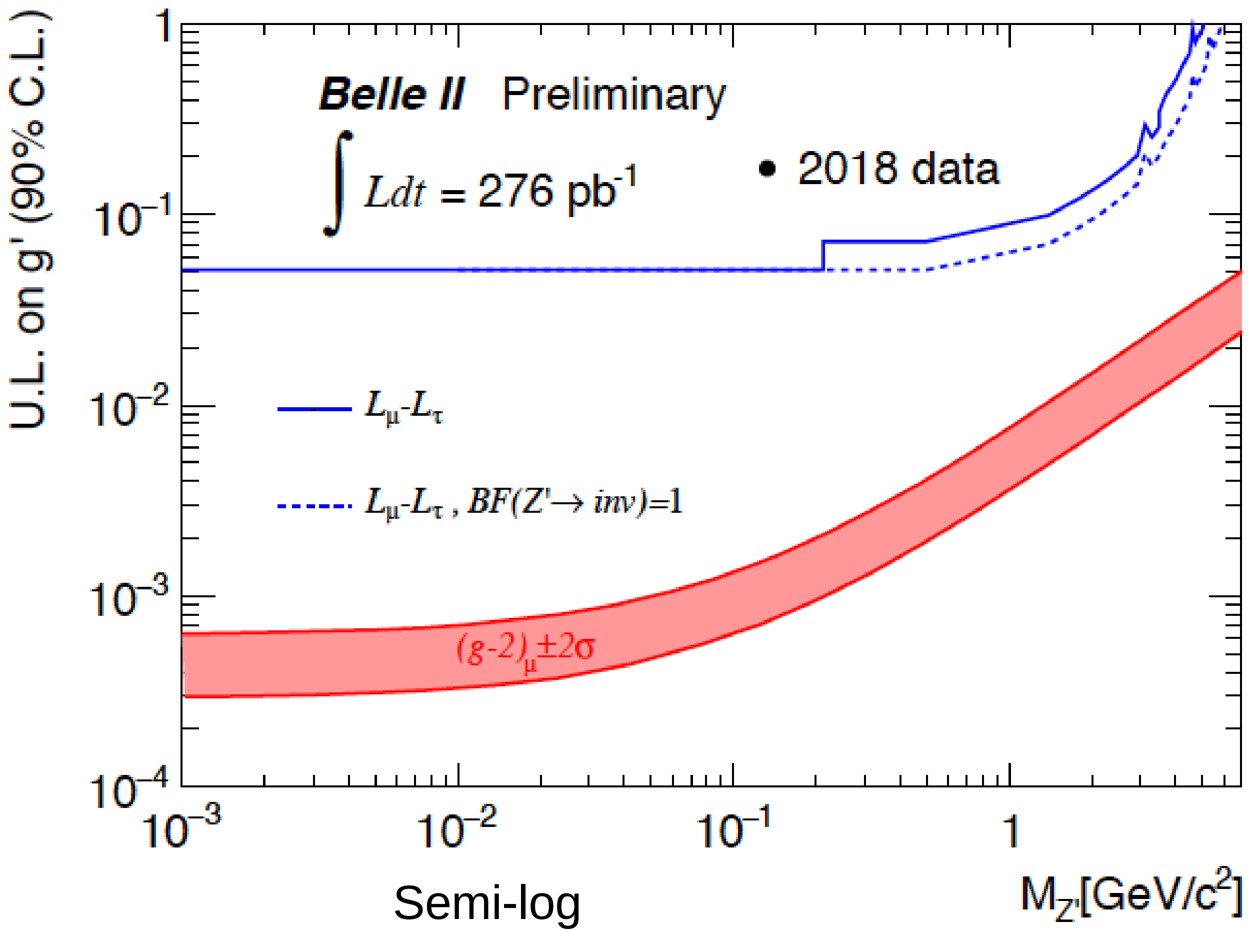
FIG. 5: Plot of inclusive charmonium decays to $\mu\mu$. Decays from B mesons are enhanced in this sample by requiring $R_2 < 0.3$, $p^*_{\mu^+\mu^-} < 4.25$ GeV/c, and greater than 4 tracks in the event. $muonID > 0.8$ is applied to both reconstructed muons. Peaks are seen for J/ψ and $\psi(2S)$ decays. The points with error bars represent data.

Off-resonance, loose cut check of time-dependent mixing.



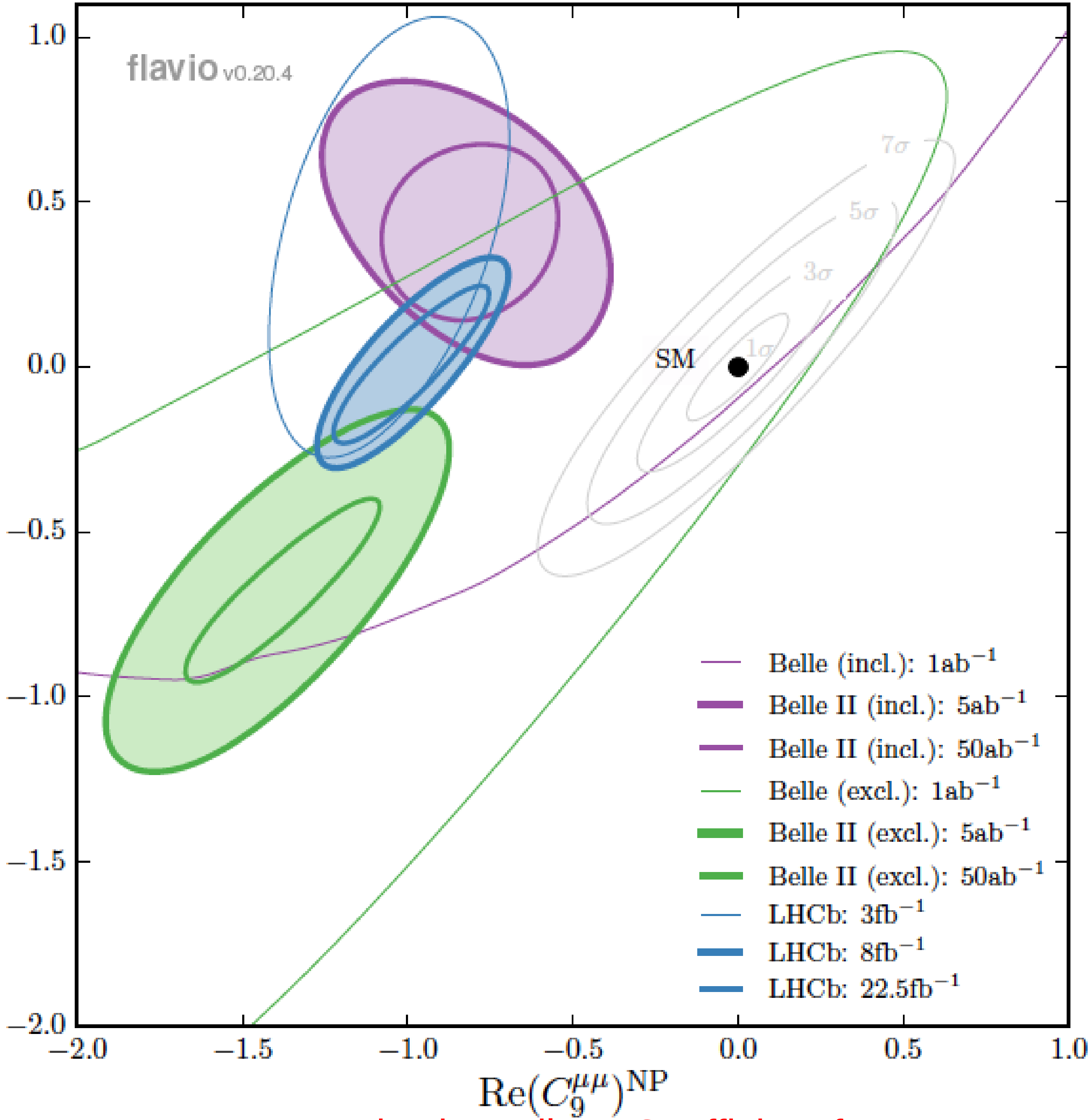
Consistent with flat, P(chi^2) ~12%

Search for $e^+e^- \to \mu^+\mu^- Z', Z' \to nothing$



Semi-log
mass scale

FIG. 67: 90% CL upper limits to g'. The solid line assumes the $L_\mu - L_\tau$ predicted branching fraction for $Z' \to$ invisible while the dashed line assumes $BF[Z' \to \text{invisible}]=1$. The red band shows the region that could explain the anomalous muon magnetic moment $(g_\mu - 2) \pm 2\sigma$.



NP Wilson Coefficient for electrons

New Physics Wilson Coefficient for muons

NP in $b \rightarrow s\, l^+ l^-$

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.

Example of Belle II's unique capabilities in the Phase 2 pilot run

CP Eigenstate: $D^0 \to K_S \rho^0$

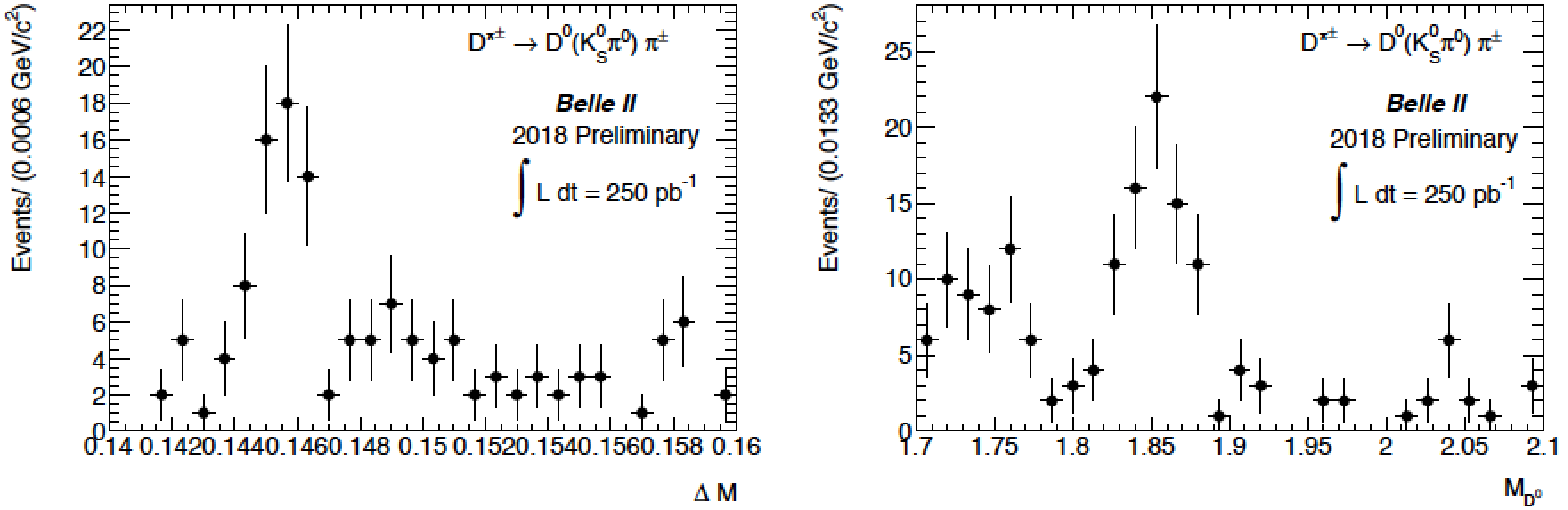


FIG. 36: ΔM (left) and M_D (right) signal-enhanced projections in 250 pb^{-1} prod4 data sample for $D \to K^0_S \pi^0$ final state.

Need a pair of pions with a displaced vertex and two photons measured with good resolution and low background

Difficult mode at LHCb

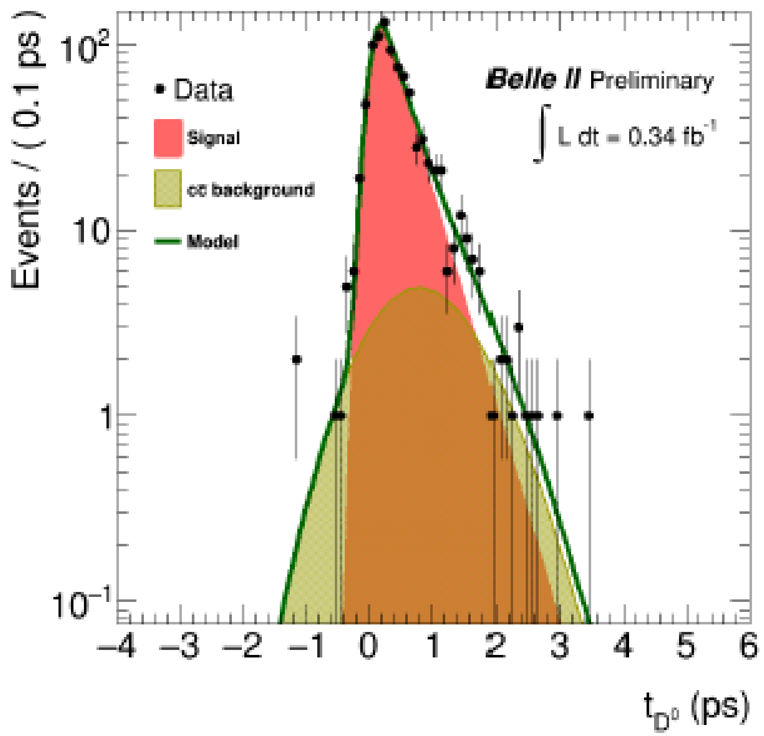
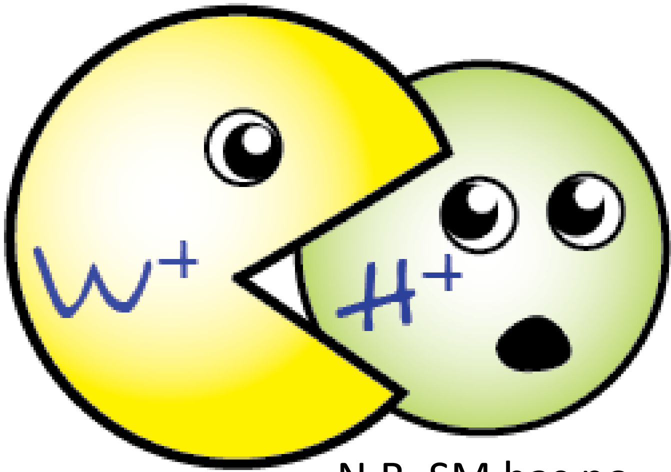


FIG. 6: Fit to the reconstructed proper time for candidates belonging to the signal region, as defined in 4 and 5. The model is defined accordingly to background studies on MC.

parameter	extracted value
N^1_{sig}	$(80 \pm 6) \cdot 10$
μ_1 (fs)	30 ± 16
σ_1 (fs)	126 ± 15
N^2_{sig}	$(10 \pm 5) \cdot 10$
μ_2 (ps)	(0.48 ± 0.17)
σ_2 (ps)	(0.73 ± 0.13)
τ (fs)	(370 ± 40)

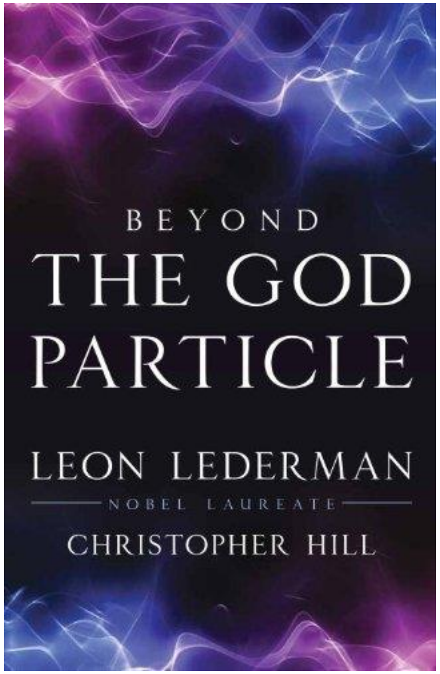
TABLE IV: Parameters extracted from the unbinned fit of the reconstructed Proper Time distribution.

The neutral BEH boson is now firmly established by experimental results from ATLAS and CMS. *Now planning for future Higgs flavor factory facilities (e.g ILC, HL-LHC, CEPC, FCC).*



N.B. SM has no charged Higgs

Does the GP (Brout-Englert-Higgs particle) have a “brother” i.e. the charged Higgs ?

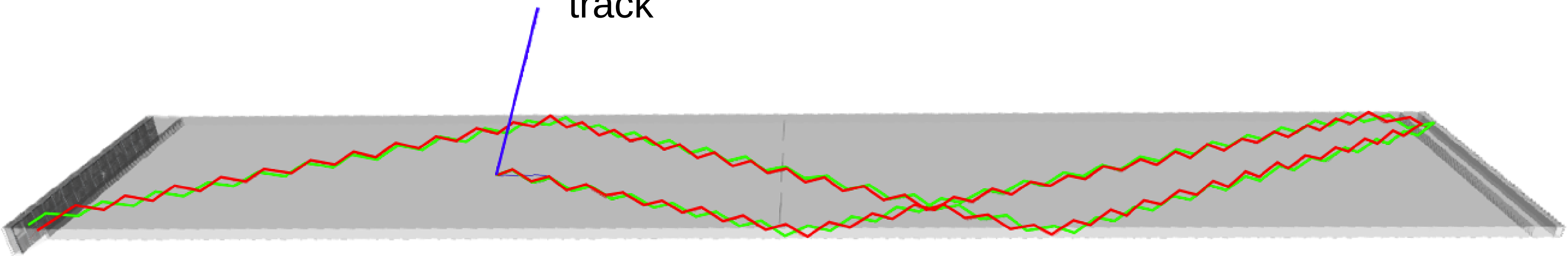


Y. Nambu, 1921-2015

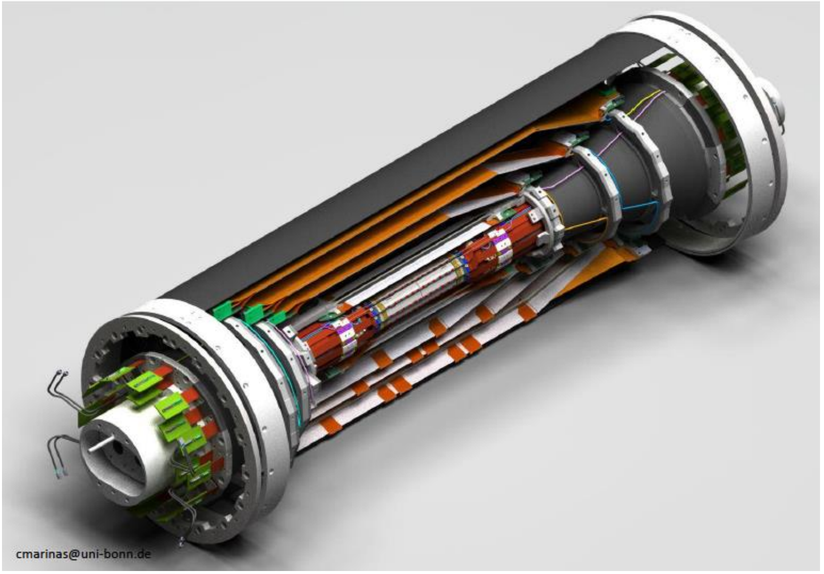
Measurements at Belle II and direct searches at hadron colliders take *complementary* approaches. *N.B. Leptoquarks are also possible.*

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

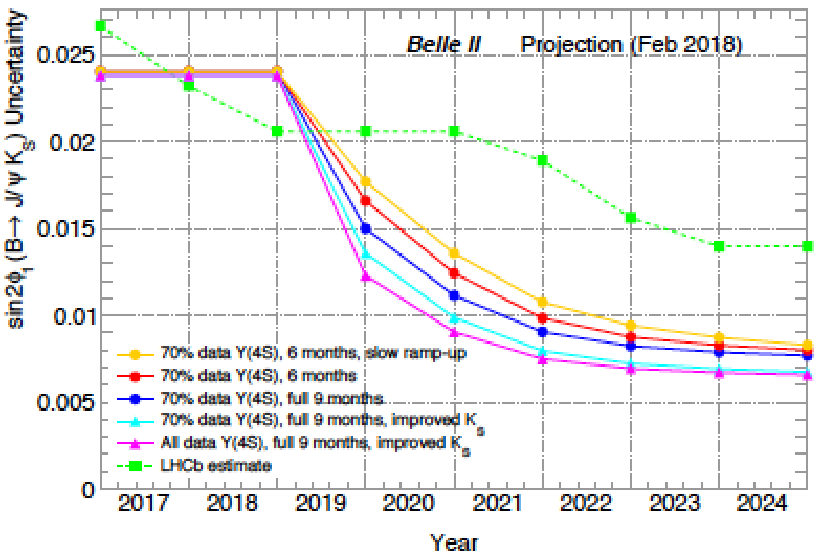
DSSD (double sided silicon detectors)

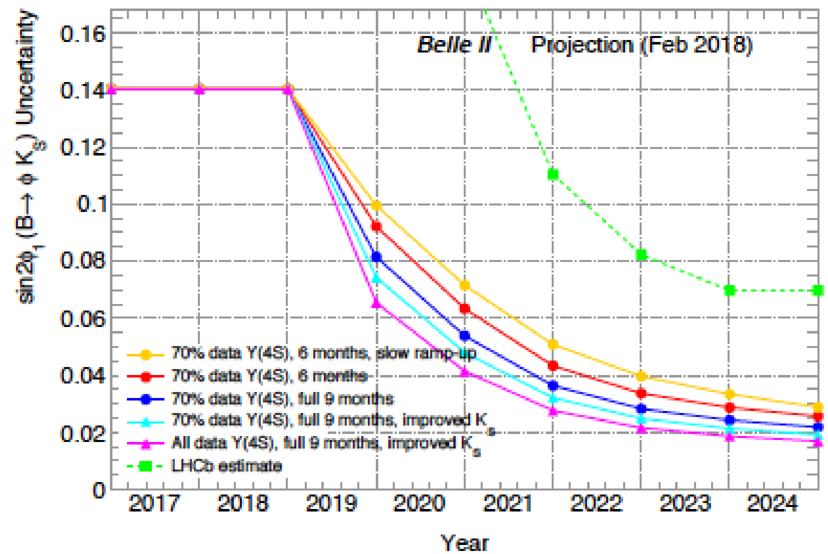
- Layer 3 r=38 mm (Australia)
- Layer 4 r=80 mm (India)
- Layer 5 r=115 mm (Austria)
- Layer 6 r=140 mm (Japan)

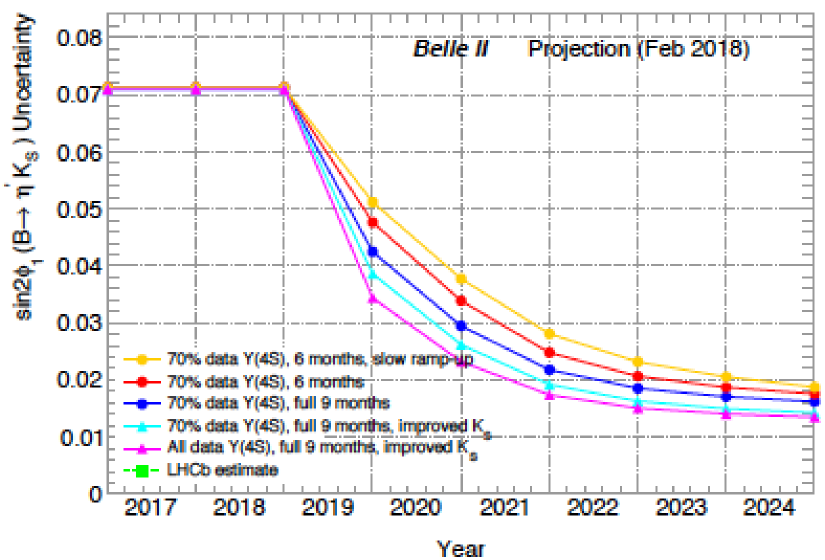
FWD/BWD Italy

+Poland, Korea

Examples of Physics Competition and Complementarity

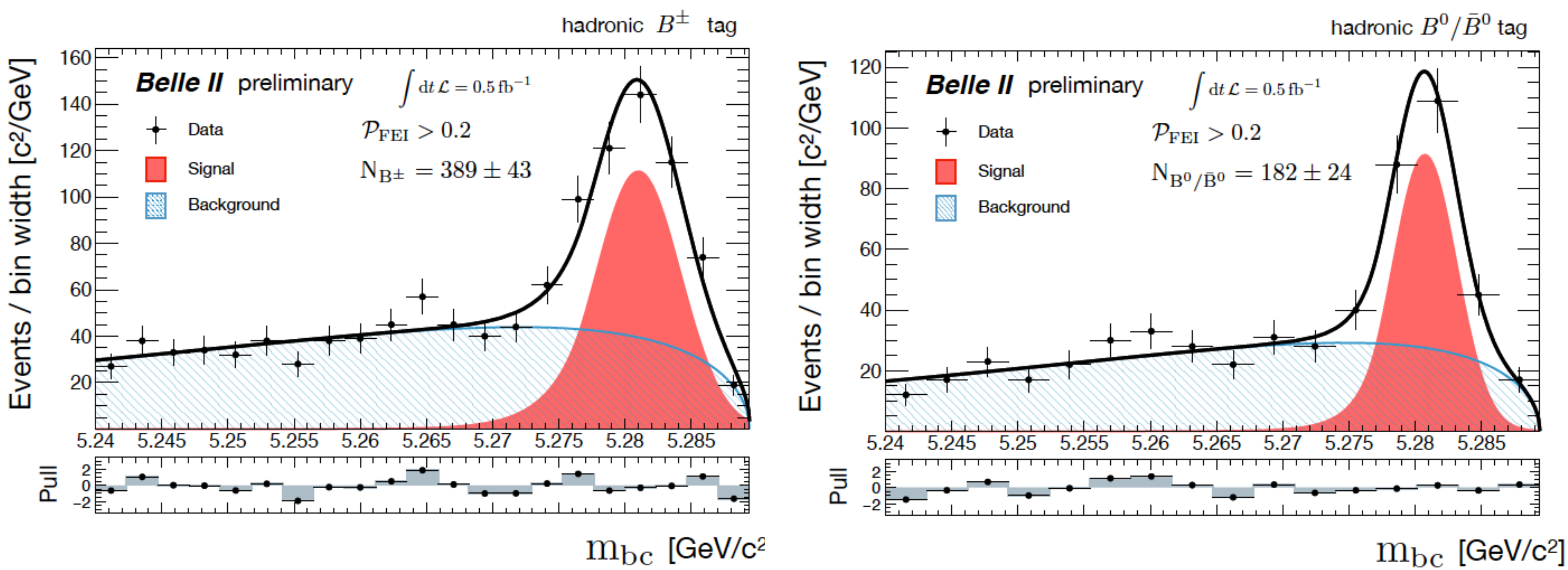






Use publicly available LHCb projections.

Now use the full Phase 2 pilot run dataset and apply the FEI (Full Event Interpretation) technique based on boosted decision trees (BDTs, a machine learning technique)



We now observe ~571 fully reconstructed B mesons (389+182) or an improvement of a factor of ~O(3.6) in overall efficiency by using this advanced analysis method that covers many more decay channels.

Further improvement (X 2) is definitely possible (PID, low p tracking will play a major role).

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