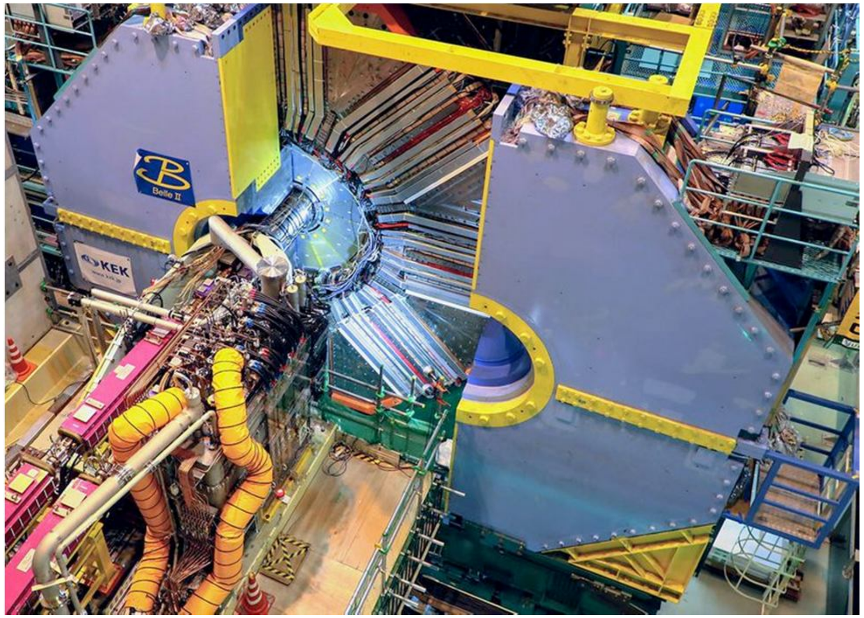
Belle II/SuperKEKB: New Physics and the Next Generation

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

Introduction, History and Motivation:
What's happening in high energy physics ?

Some Highlights from First Collisions and the Phase 2 Belle II Pilot Run.

Physics and the Road Ahead to Phase 3, the first Physics run

Conclusion; opportunities for Vietnam

The Geography of the International Belle II collaboration

Belle II now has grown to ~800 researchers from 26 countries

This is rather unique in Japan and Asia. The only comparable example is the T2K experiment at JPARC, which is also an international collaboration

Including one very good one from Vietnam, Dong Van Thanh

Youth and potential: There are ~267 graduate students in the collaboration

What is happening these days in high energy physics ?

(Personal perspective, based on trips to international conferences and summer schools.)

Typical scenes in Hanoi, Vietnam

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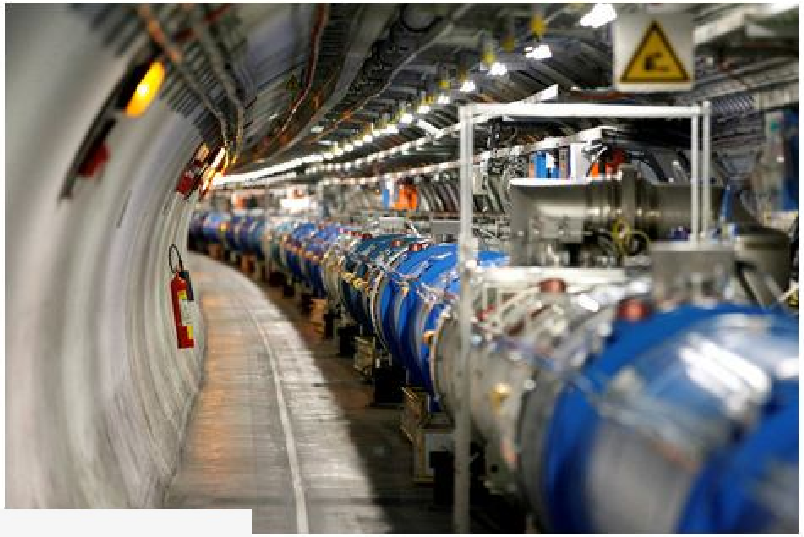
The Particle That Wasn't

NY Times on Aug 5, 2016

By DENNIS OVERBYE AUG. 5, 2016

2016: US Belle II summer school, @PNNL in Richland, Washington



N in 2014. Pierre Albouy/Reuters

ave been" for the universe, or at least for the
' it, disappeared Friday.

wo teams of physicists working at CERN's Large
reported that they might have seen traces of what
ndamental constituent of nature, an elementary
t part of the Standard Model that has ruled
or the last half-century.

ICHEP2016CHICAGO

Some other media headlines on ICHEP:

"Physicists look to the future as new particle dream dies"

"Particle Physics in Mourning"

"The End of the Beginning"

RELATED COVERAGE

Friday August 5, 2016 at ICHEP in Chicago, the ATLAS and CMS collaborations announced that the 750 GeV di-photon excess had *disappeared* in the large Run II 13 TeV dataset.

2017 US Belle II School@Ole Miss

New York Times, June 19, 2017

CERN hosts thousands of scientists, representing 22 member countries, all working to understand how the universe was created. CMS is one of seven detectors on site. Leslye Davis/The New York Times

Yearning for New Physics at CERN, in a Post-Higgs Way

Physicists monitoring the Large Hadron Collider are seeking clues to a theory that will answer deeper questions about the cosmos. But the silence from the frontier has been ominous.

By DENNIS OVERBYE JUNE 19, 2017

But since then, the silence from the energy frontier has been ominous. "The feeling in the field is at best one of confusion and at worst depression," Adam Falkowski, a particle physicist at the Laboratoire de Physique Théorique d'Orsay in France, wrote recently in an article for the science journal Inference. "*These are difficult times for the theorists*," Gian Giudice, the head of CERN's theory department, said. "Our hopes seem to have been shattered. We have not found what we wanted."

Summer 2018

1200 international participants.

LHC High pt: Expected Standard Model (SM) t-tbar-Higgs coupling observed by CMS and ATLAS, SM *Higgs→b bbar* evidence found, *no SUSY (SUperSYmmetric) or extra particles.*

Dark Matter: No dark matter (DM) signals in Xenon 1T or other leading DM experiments (i.e. DEAP(Canada), LUX (US), PandaX (China))

Neutrinos: Sterile neutrinos at reactors disfavored by Daya Bay results. Planck only needs 3 neutrinos for the CMB (Cosmic Microwave Background). Hints of a normal hierarchy for neutrino masses at NoVa at Fermilab.

This is not what the theorists told us to expect !

US Belle II
summer school
July 2018,
Cincinnati, Ohio

Forbes Billionaires Innovation Leadership Money Consumer Industry

Five Years After The Higgs, What Else Has The LHC Found?

Ethan Siegel Contributor
Starts With A Bang
Apr 11, 2018, 10:00am • #WhoaScience

"Not found: Any evidence for additional particles. There's no sugar-coating this one: this was perhaps the greatest hope of most physicists. New particles at scales between 100 GeV and ~2 TeV were sorely hoped for, and at various times, some statistically suggestive evidence emerged for a few candidates. Unfortunately, with more and better data, this tentative evidence evaporated, and now, with Run I and Run II complete, *there are not even any good suggestions of where such a new particle might be.*

NEWS IN BRIEF PARTICLE PHYSICS

Dark matter particles elude scientists in the biggest search of its kind

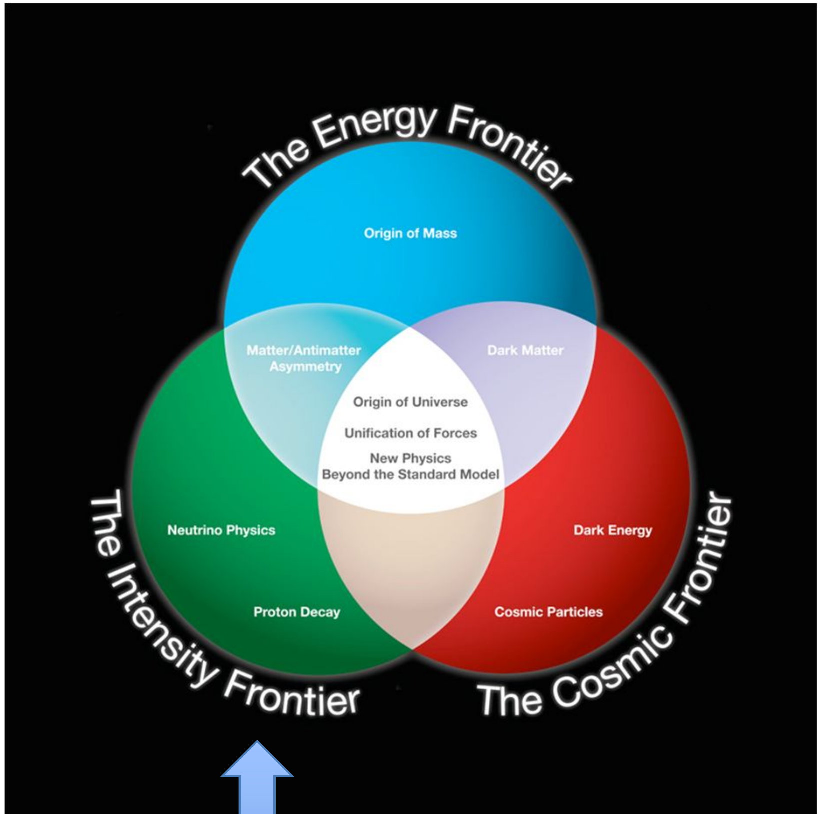
But XENON1T's results narrow where to search
BY EMILY CONOVER 5:00AM, MAY 28, 2018

That means it's important to try new things, including general searches, says Gian Giudice, who heads CERN's theory department and is not involved in any of the experiments. "This is the right approach, at this point." (Scientific American, Aug 2018)

Remain Calm, Do not Panic !

Stay calm. Don't panic !!

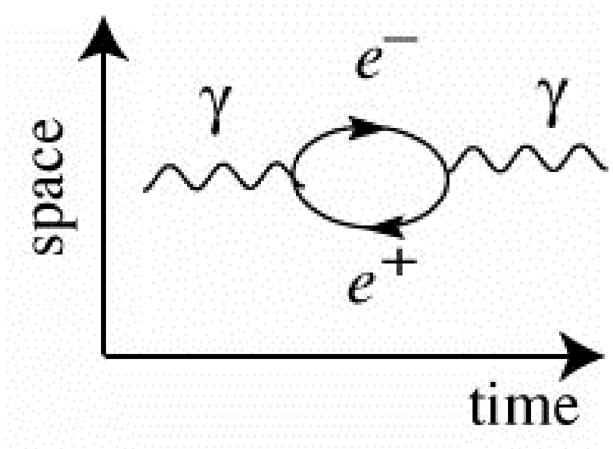
The intensity frontier will save you (again) as it has done many times in the past. ($K_L \rightarrow \mu\mu$, B mixing, $A_{FB}(e^+e^- \rightarrow \mu^+ \mu^-)$, Electroweak corrections etc…)



Beauty and the Beast

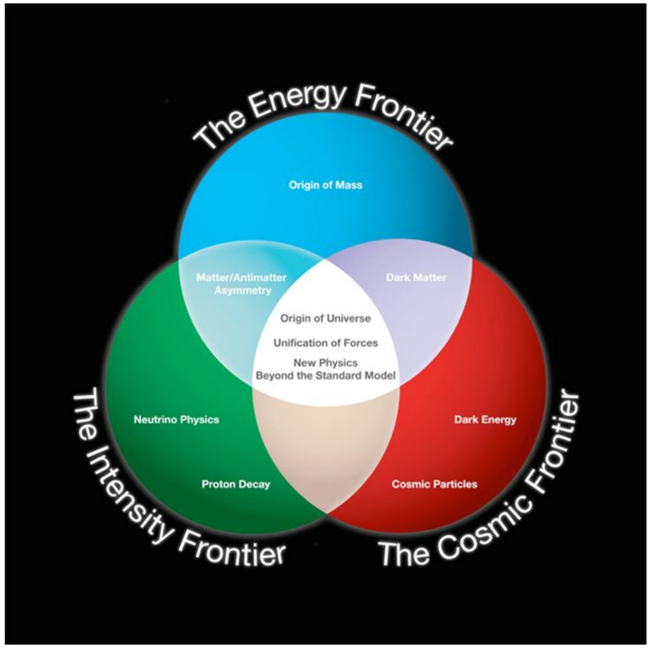
The legend is reborn

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.*

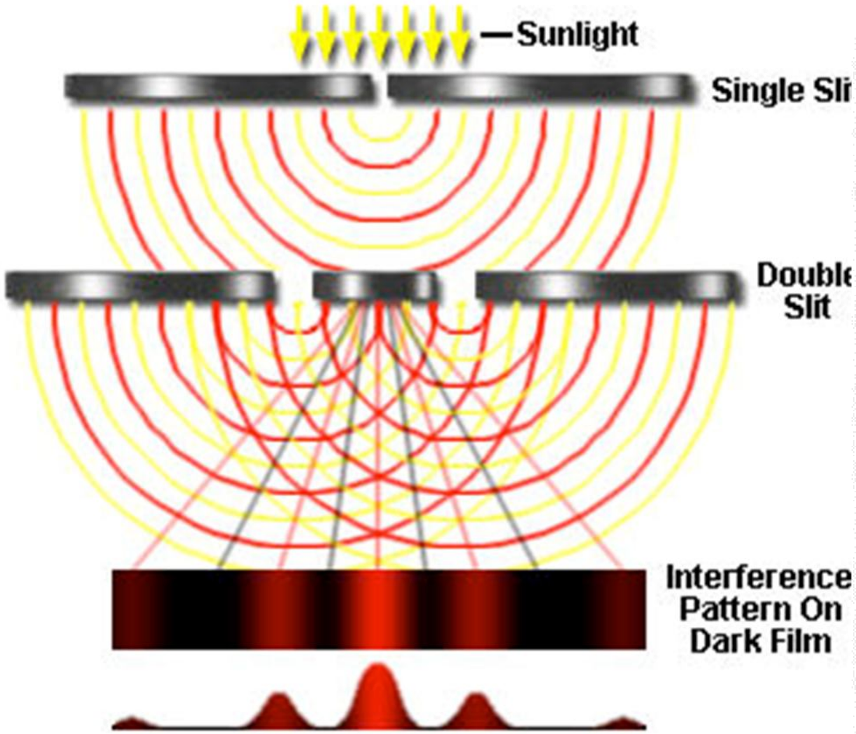
N.B. Sometimes it is much better to have a large collateral and pay back the loan *directly* after a longer time.

Werner Heisenberg,
Physicist and QM banker

Time-dependent *CP* violation is

"*A Double-Slit experiment*" with particles and antiparticles

QM interference between two diagrams



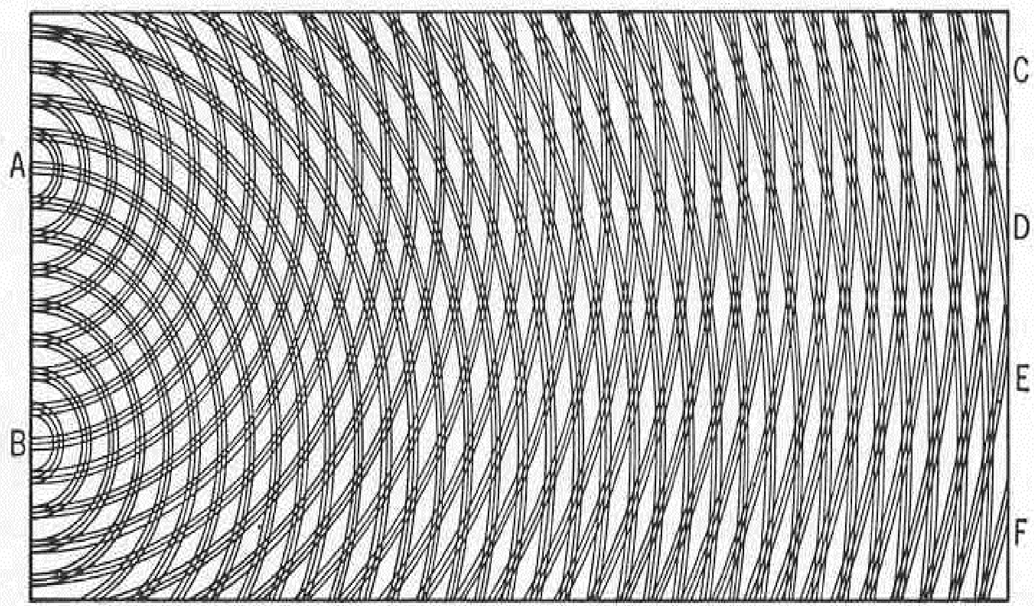
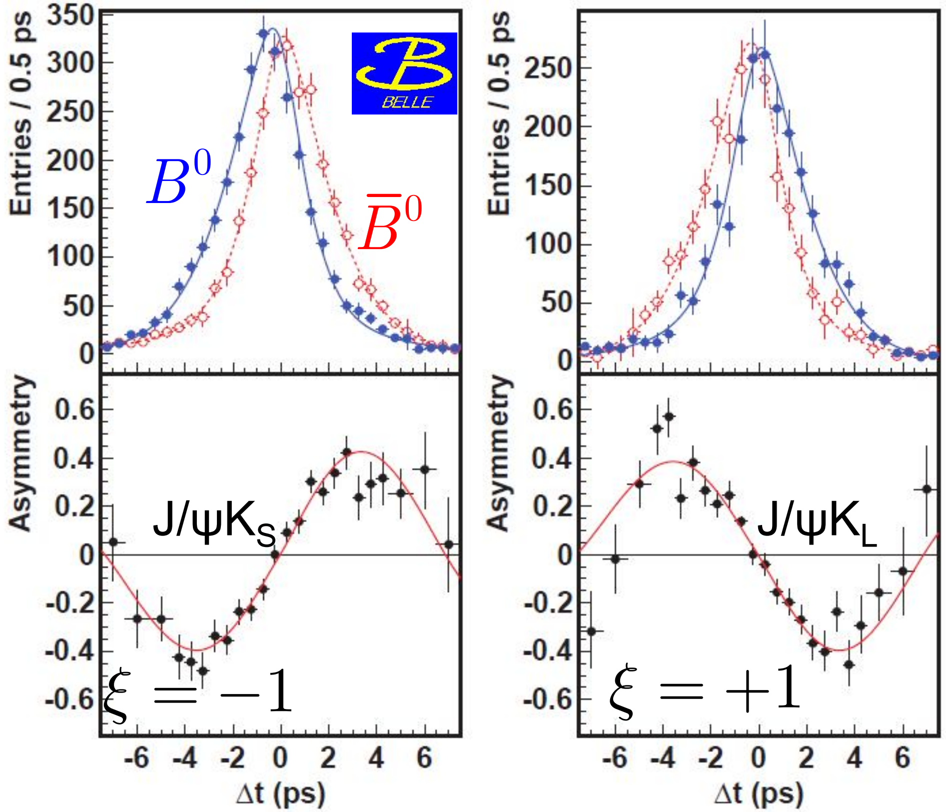
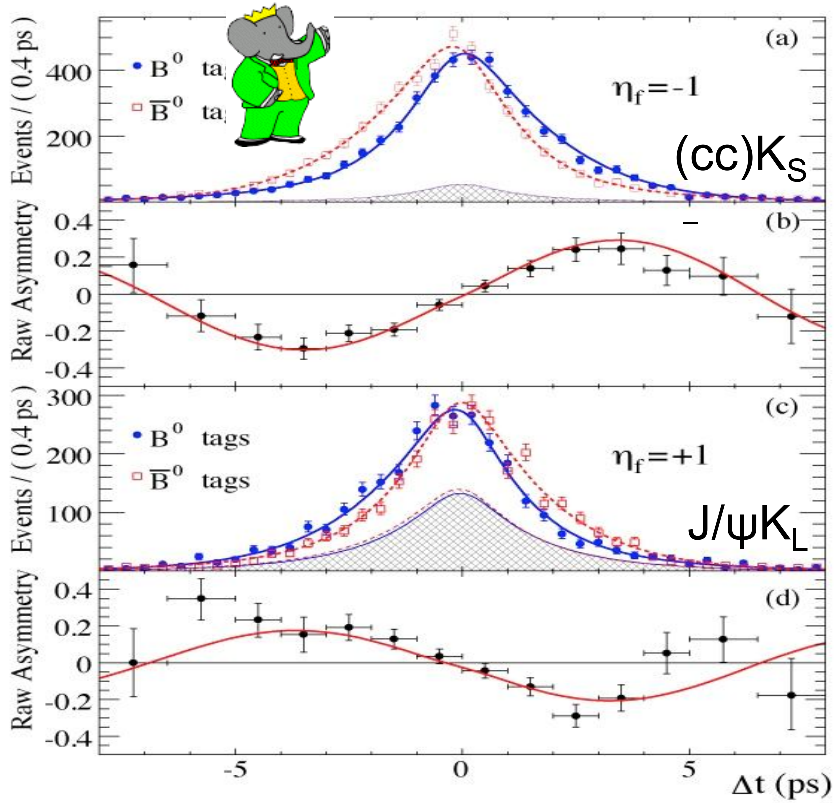


FIG. 1

Measures the phase of the V_{td} weak interaction coupling constant or equivalently the phase of B_d–anti B_d mixing.

Measurement of sin(2φ_1)/sin(2β) in B→Charmonium K^0 modes





sin2φ_1=0.667±0.023±0.012
A_f=0.006±0.016±0.012
PRL108,171802 (2012)

sin2φ_1=0.687±0.028±0.012
A_f=-0.024±0.020±0.016
PRD79,072009 (2009)

Overpowering evidence for CP violation (matter-antimatter asymmetries). >>>> The phase of V_{td} is in good agreement with Standard Model expectations. *This is the phase of B_d mixing.*

2008:

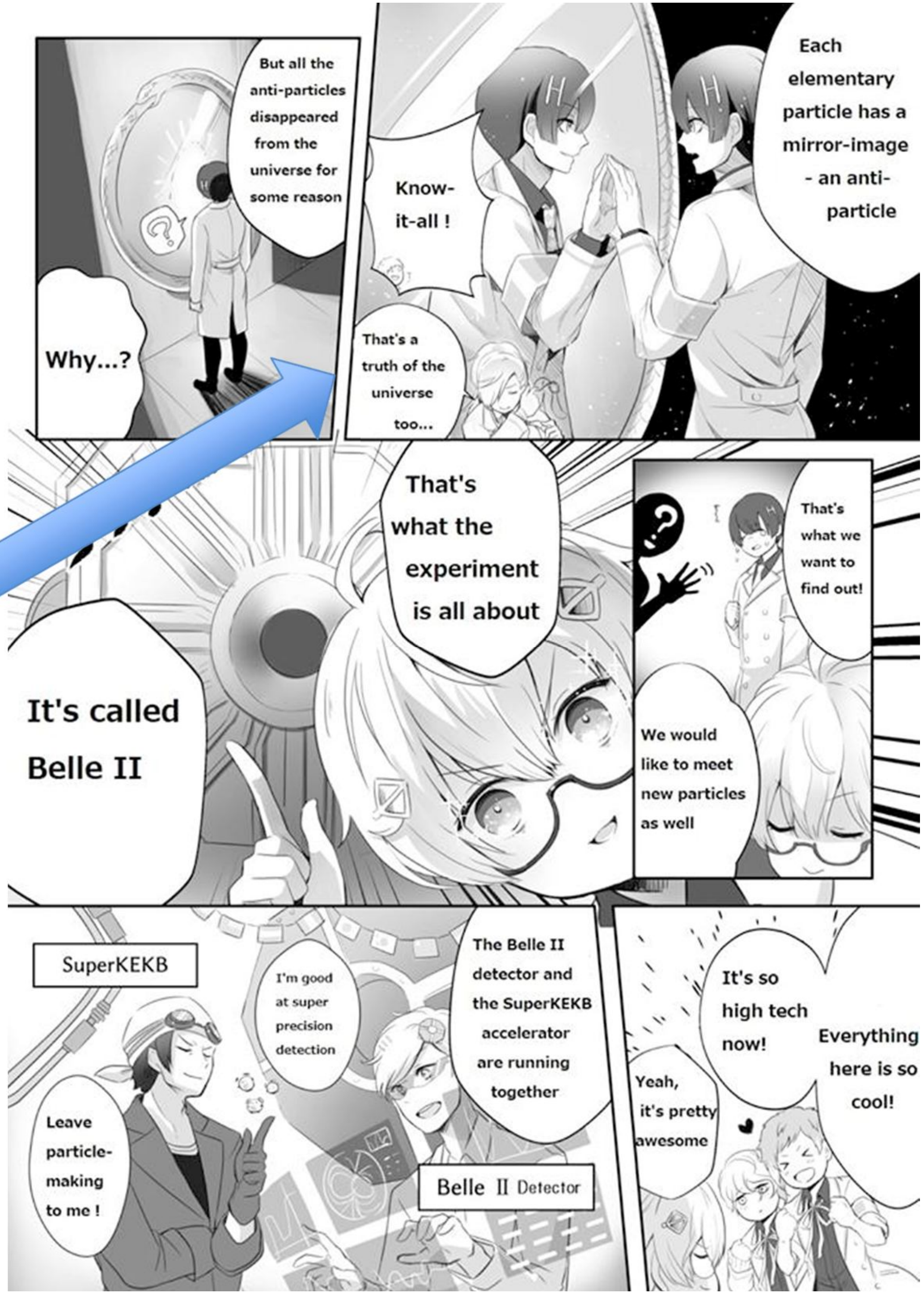
Critical Role of the B factories in Japan and the US in the verification of the Kobayashi-Maskawa hypothesis was recognized and cited by the Nobel Foundation

A single irreducible phase accounts for all the matter-antimatter asymmetries in particle physics.

CP violating effects in the B sector are O(1) rather than O(10^{-3}) as in the kaon system.

CP Violation is now included in most of the undergraduate particle physics textbooks.

I will skip the comic book or manga explanation of CP violation.

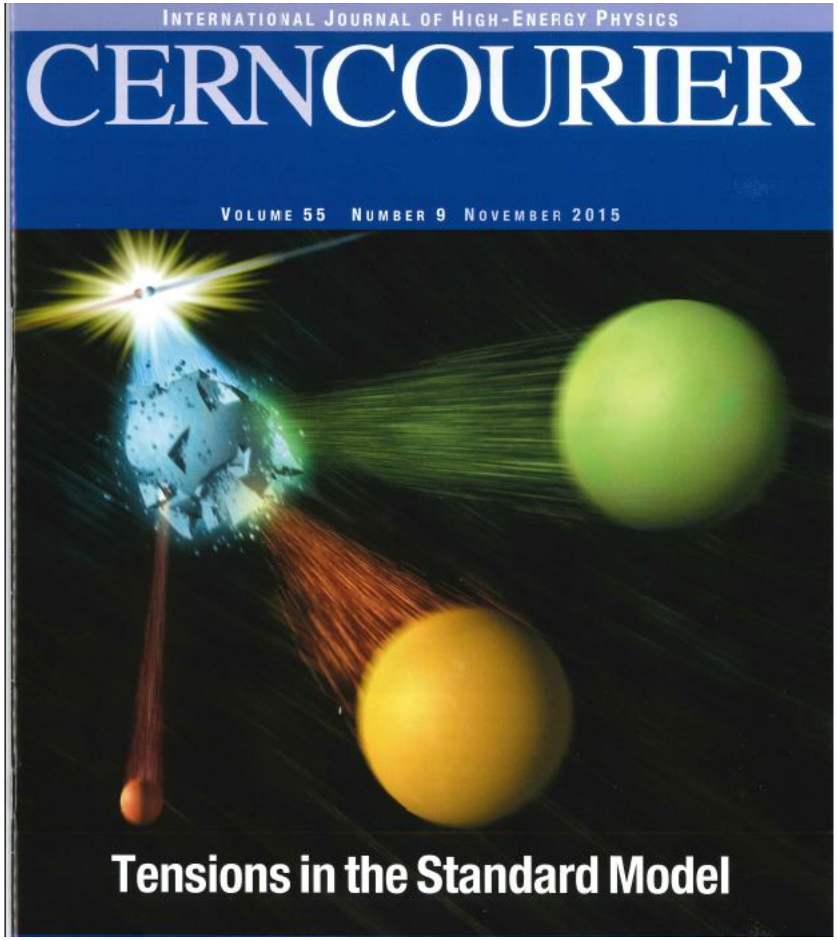


I will also not cover the famous competition/race between Belle and BaBar to discover CP violation in the b-sector in 2001.

And I will gloss over the critical role of the original Belle experiment in the 2008 Nobel Prize for Kobayashi and Maskawa.

Sorry this manga is all males.

2015: "Missing Energy Decays" of the B meson



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2 Accelerators Find Particles That May Break Known Laws of Physics

The LHC and the Belle experiment have found particle decay patterns that violate the Standard Model of particle physics, confirming earlier observations at the BaBar facility

By Clara Moskowitz | September 9, 2015 | Véalo en español

physicstoday

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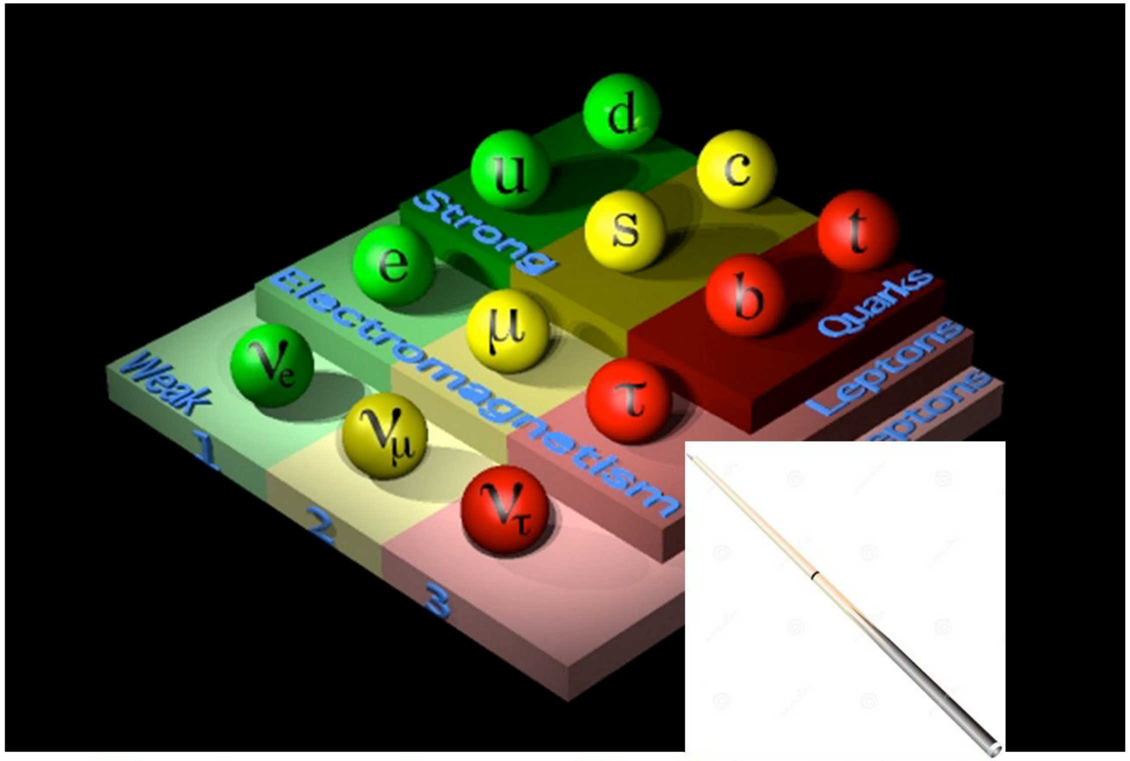
Democracy suffers a blow—in particle physics

Three independent B-meson experiments suggest that the charged leptons may not be so equal after all.

Steven K. Blau 17 September 2015

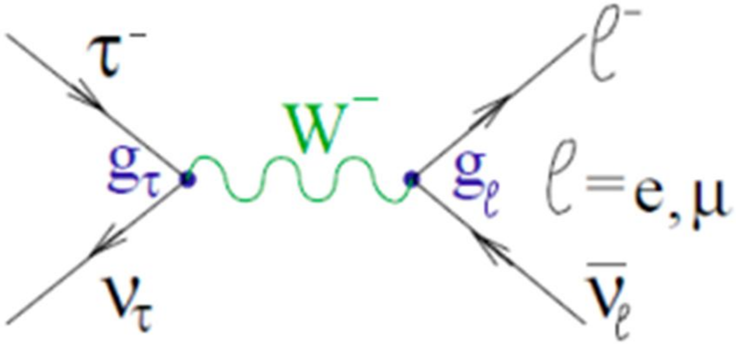
New Frontier: Start of a NP program that will last a decade or more.

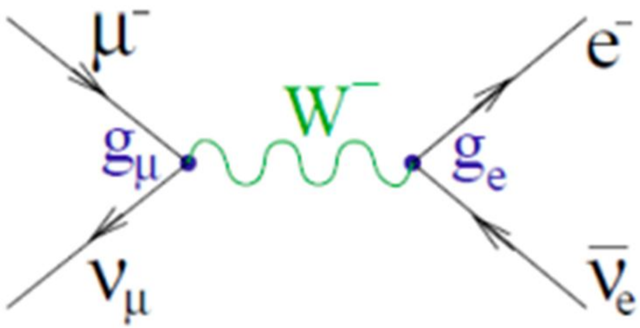
Quantum Mechanical Lepton Billiards



Standard Model 3-D Billiard Table.

tests of lepton universality in the SM: $g_e = g_\mu = g_\tau$



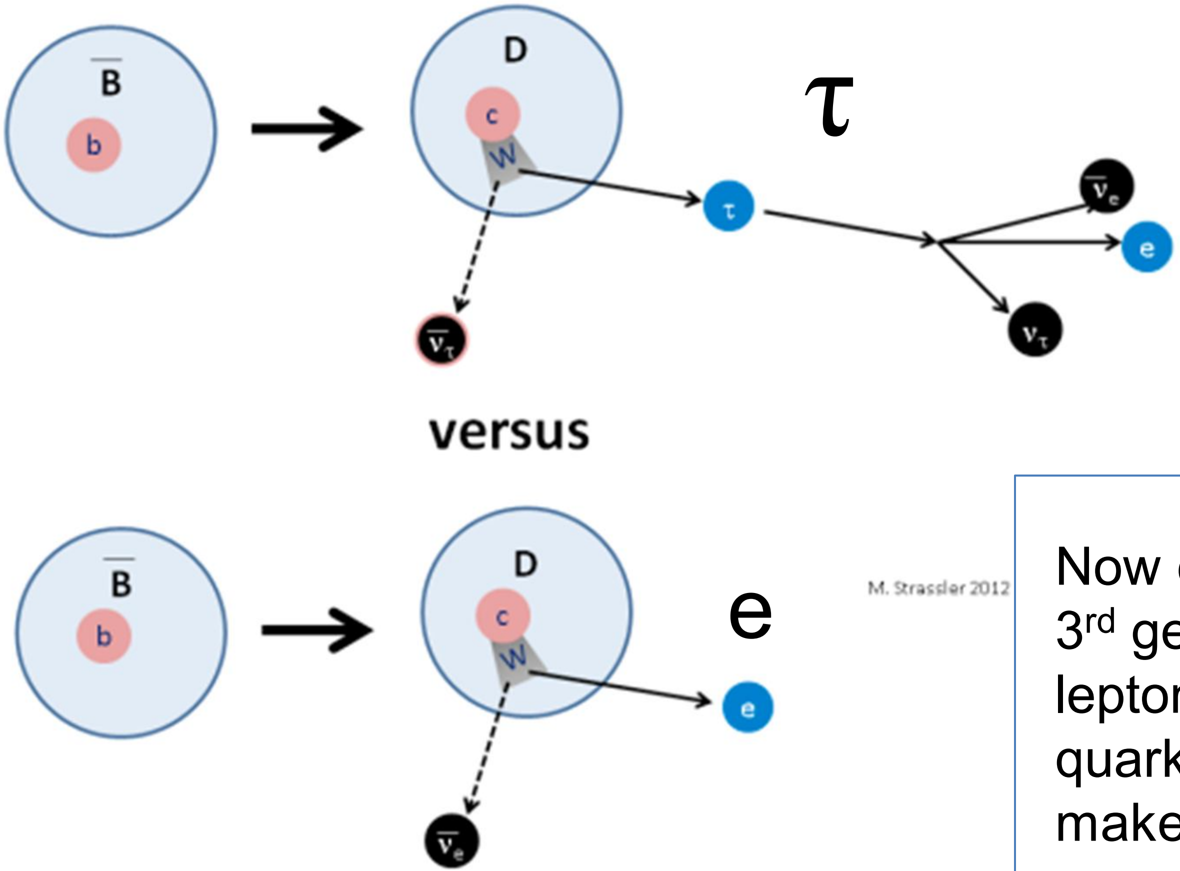


Experimentally good for leptonic decays to an accuracy much better than 1%.

$$\frac{g_\tau}{g_\mu} = 1.0000 \pm 0.0014$$

To the 1% level, $\dfrac{\Gamma(K^- \to \mu^- \nu)}{\Gamma(K^- \to e^- \nu)} \cong 1$

But what about semi-leptonic decays of beauty ?



Now can access the 3^{rd} generation of leptons and couple to quarks ! Does that make a difference ?

Belle

Unexpected competition from LHCb@CERN

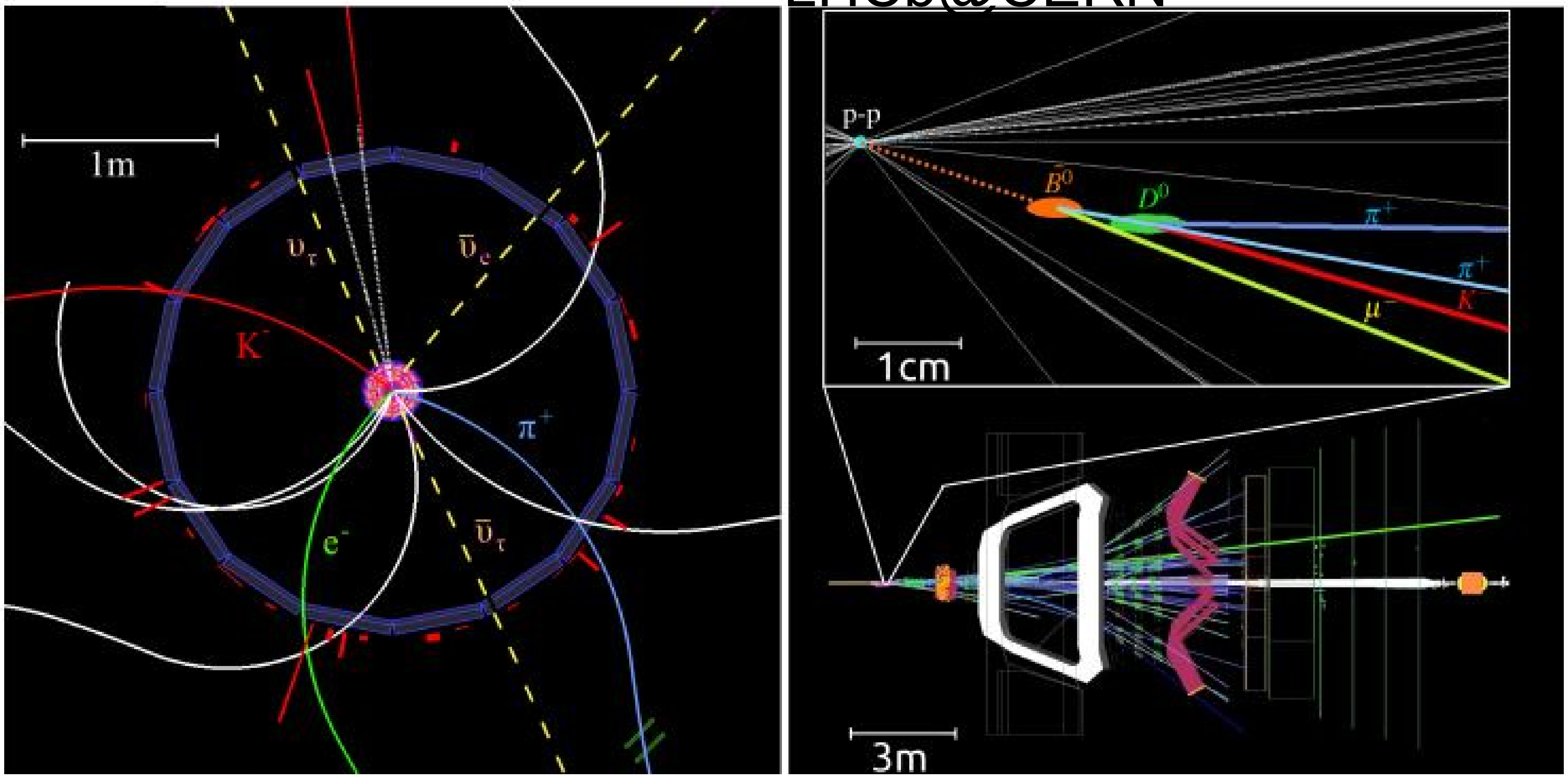
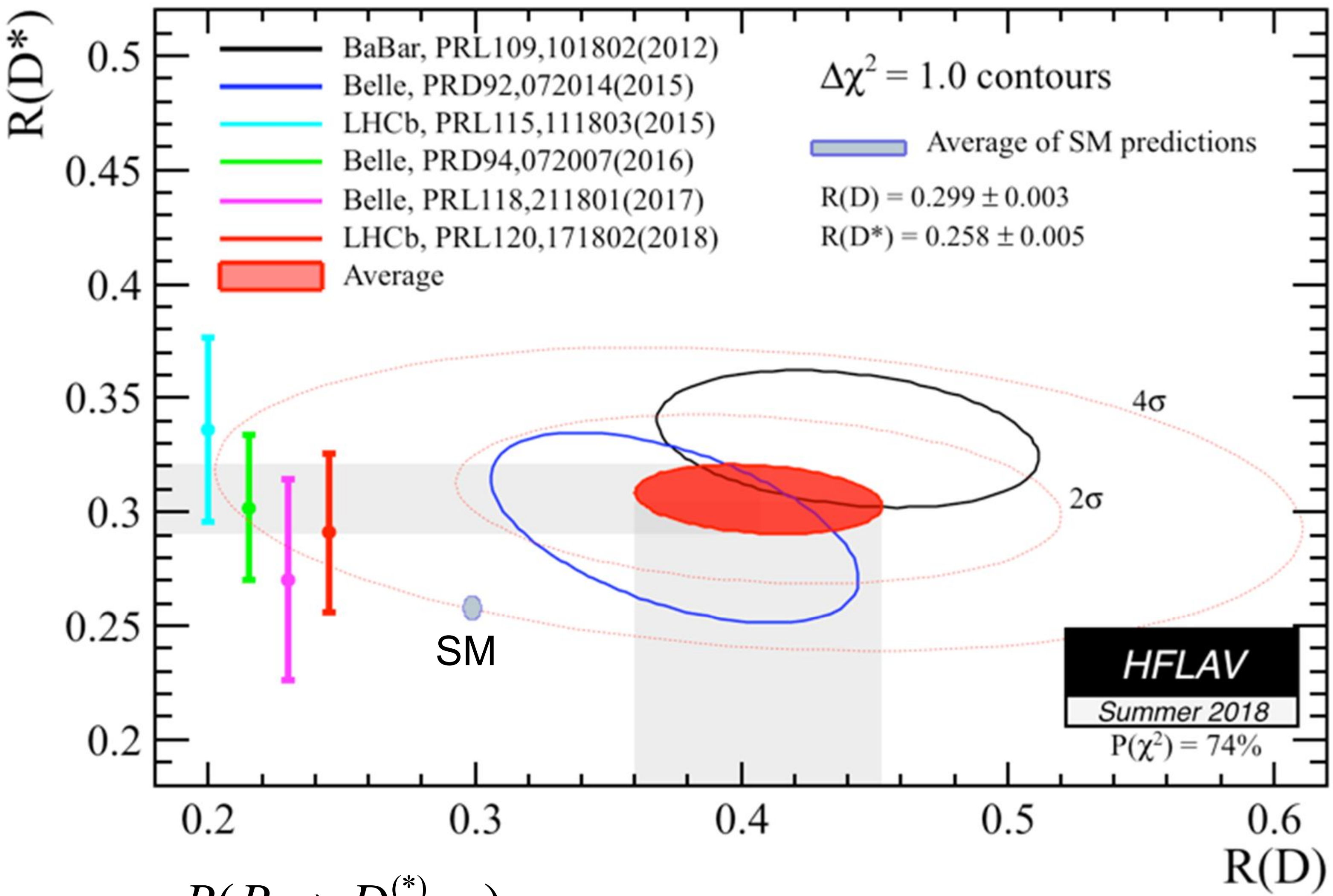


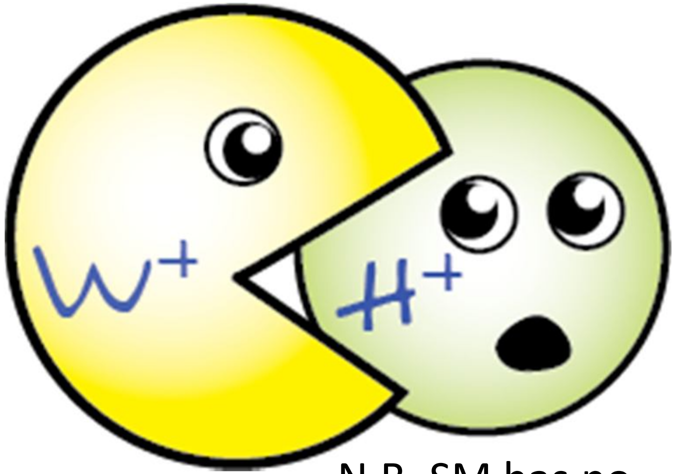
Figure 2. Belle (a) and LHCb (b) single event displays illustrating the reconstruction of semileptonic B meson decays: Trajectories of charged particles are shown as colored solid lines, energy deposits in the calorimeters are depicted by red bars. The Belle display is an end view perpendicular to the beam axis with the silicon detector in the center (small orange circle) and the device measuring the particle velocity (dark purple polygon). This is a $\Upsilon(4S) \to B^+B^-$ event, with $B^- \to D^0\tau^-\bar{\nu}_\tau$, $D^0 \to K^-\pi^+$ and $\tau^- \to e^-\nu_\tau\bar{\nu}_e$, and the B^+ decaying to five charged particles (white solid lines) and two photons. The trajectories of undetected neutrinos are marked as dashed yellow lines. The LHCb display is a side view with the proton beams indicated as a white horizontal line with the interaction point far to the left, followed by the dipole magnet (white trapezoid) and the Cherenkov detector (red lines). The area close to the interaction point is enlarged above, showing the tracks of the charged particles produced in the pp interaction, the B^0 path (dotted orange line), and its decay $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$ with $D^{*+} \to D^0\pi^+$ and $D^0 \to K^-\pi^+$, plus the μ^- from the decay of a very short-lived τ^-.

Summer 2018 ICHEP:
World Average is still ~4σ from the Standard Model



$$R(D^{(*)}) = \frac{B(B \to D^{(*)}\tau\nu)}{B(B \to D^{(*)}l\nu)}$$

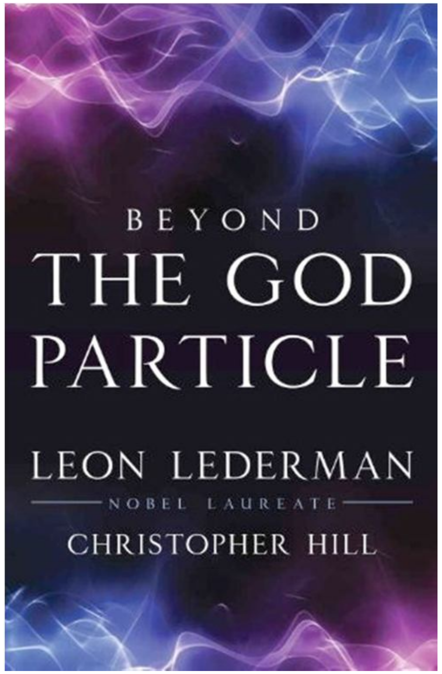
The neutral BEH boson is now firmly established by experimental results from ATLAS and CMS. *Now planning for future Higgs flavor factory facilities (e.g ILC, HL-LHC, CEPC, FCC).*



N.B. SM has no charged Higgs

PGU Question: What do these acronyms stand for ?

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



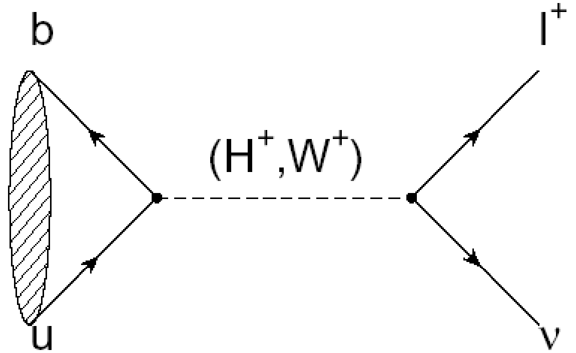
Y. Nambu, 1921-2015

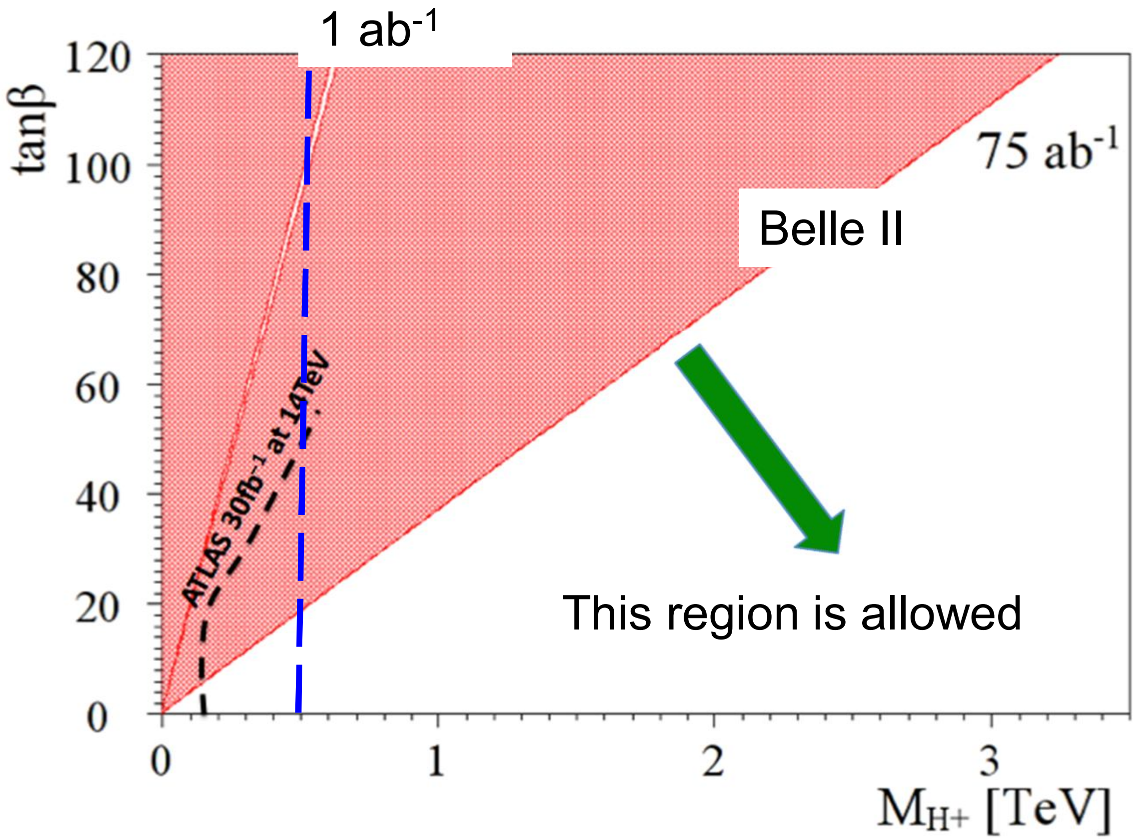
PGU Question: How would the LHC observe a charged Higgs ?

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

Complementarity of e+ e- and LHC

The current combined B→τυ limit places a stronger constraint than direct searches from LHC exps. for the next few years.





$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

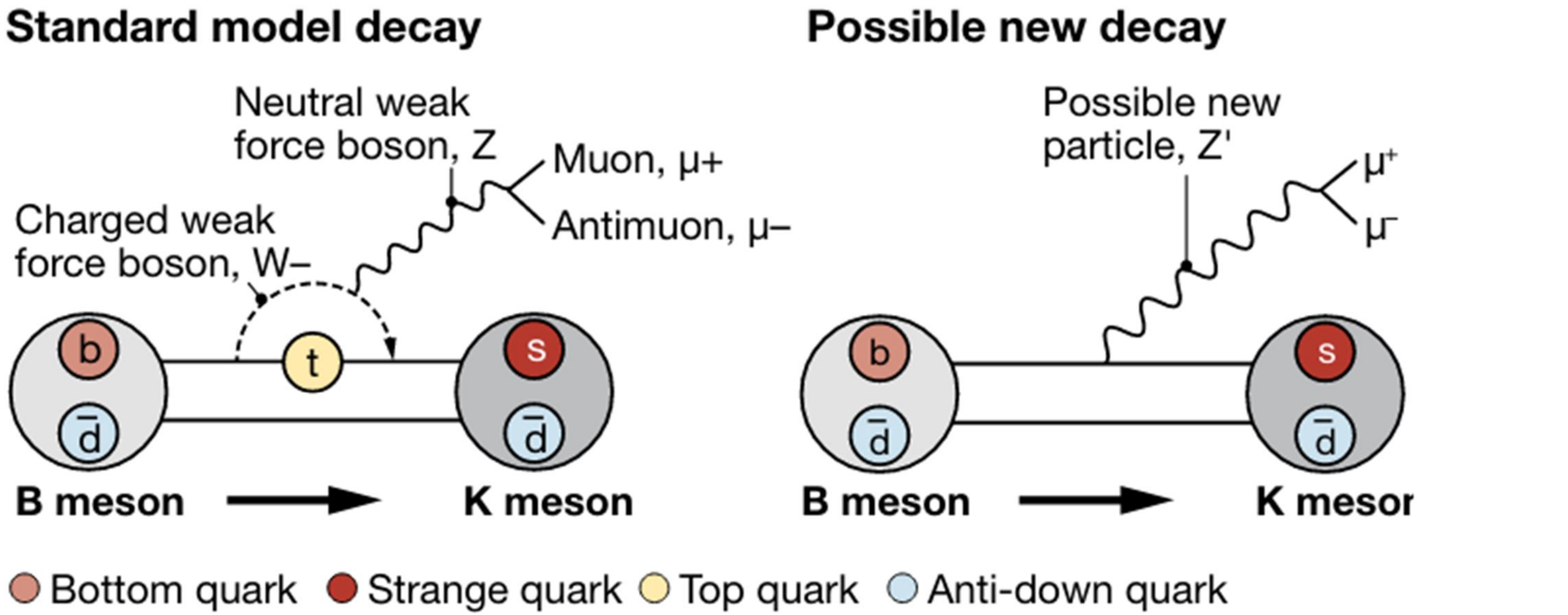
Currently inclusive b→sγ rules out m_{H+} below ~480 GeV/c^2 range at 95% CL (independent of tanβ), M. Misiak et al. (assuming no other NP)

http://arxiv.org/abs/1503.01789

Science Magazine

Strangely familiar

A new process appears to be modifying one of the standard ways a B meson decays to a K meson. It may involve a new force-carrying particle called a Z' that avoids creating a short-lived top quark.



V. ALTOUNIAN/*SCIENCE*

In familiar decays, a whiff of new physics

Deviations in B meson decays provide hints of new particles at the Large Hadron Collider

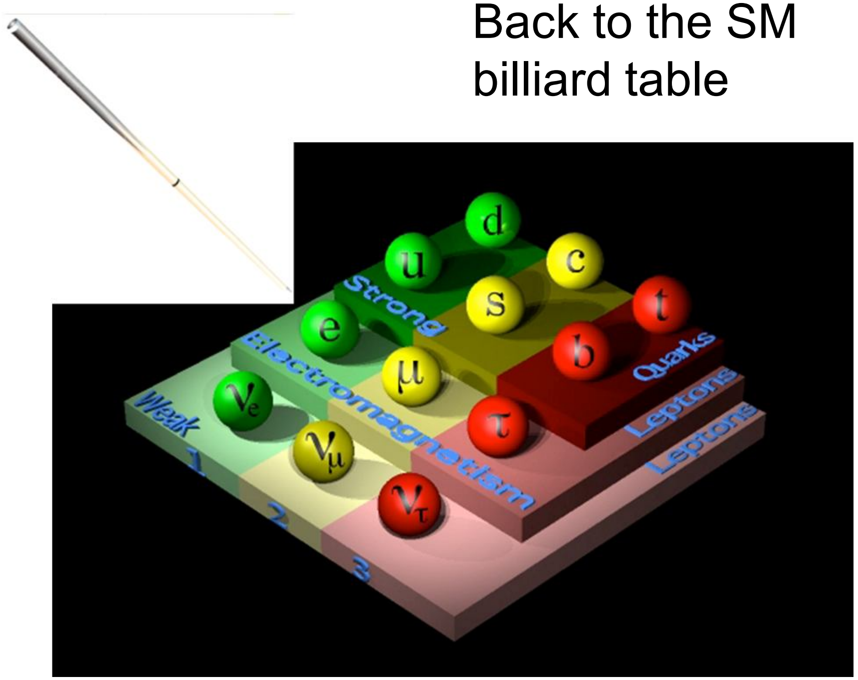
More QM Leptonic Flavor Billiards

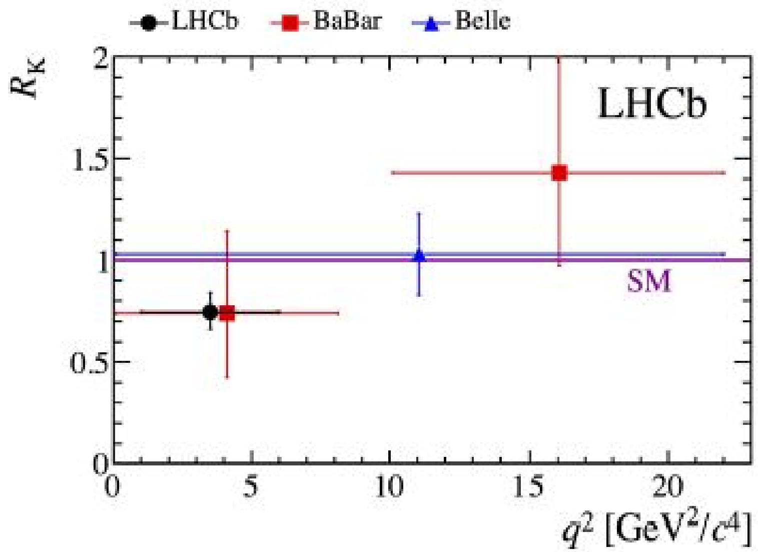
$$R_{K(*)}(q^2) = \frac{BF(B \to K^{(*)}\mu^+\mu^-)}{BF(B \to K^{(*)}e^+e^-)}$$

For experts:
$q^2 = M^2(l^+l^-)$

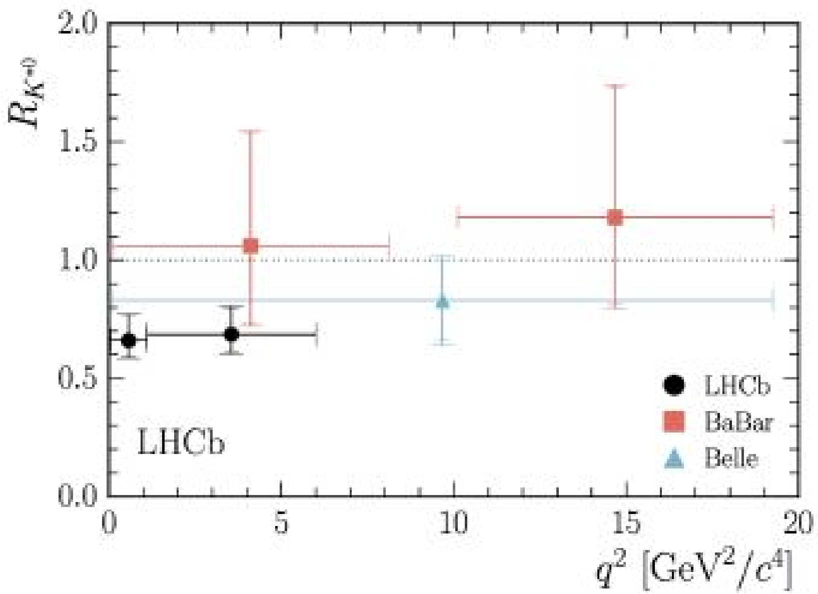
Experts: Angular correlations in $B \to K^* l\, l$ also show deviations from the SM, 4-5σ

Back to the SM billiard table





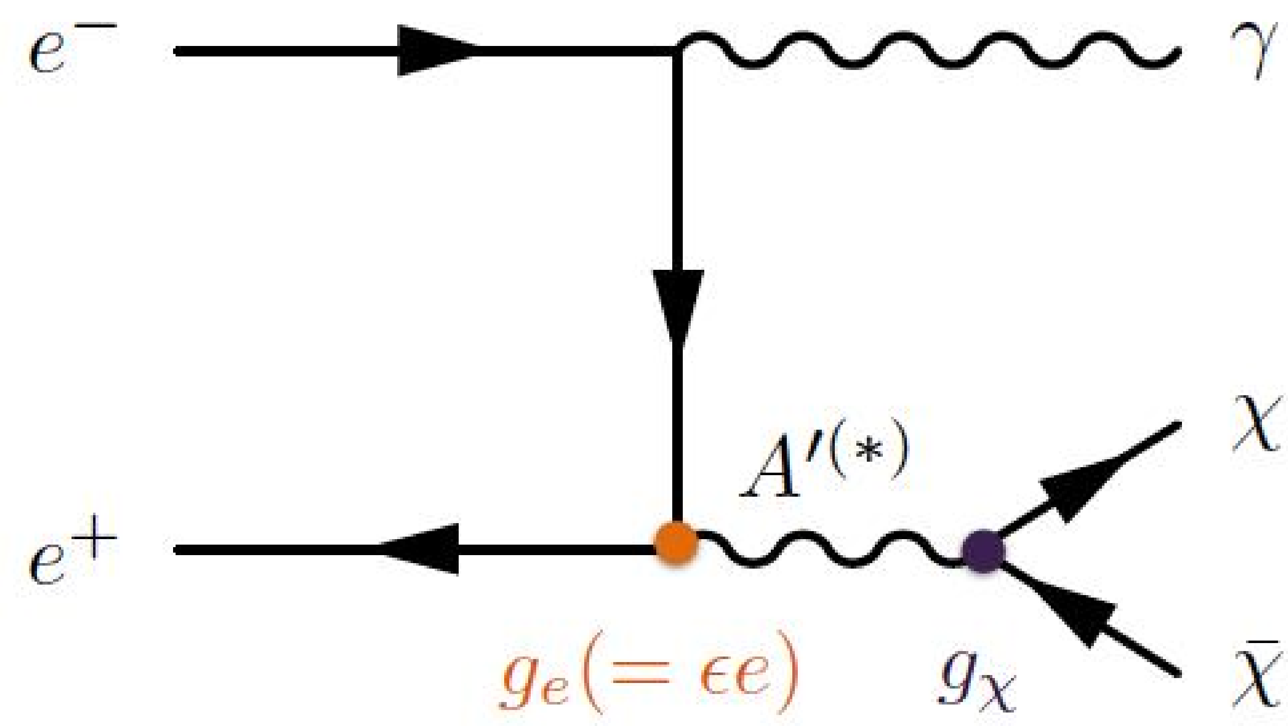
R_K is ~2.6σ from the SM



R_{K^*} ~2.1σ (low bin), 2.5σ (central bin)

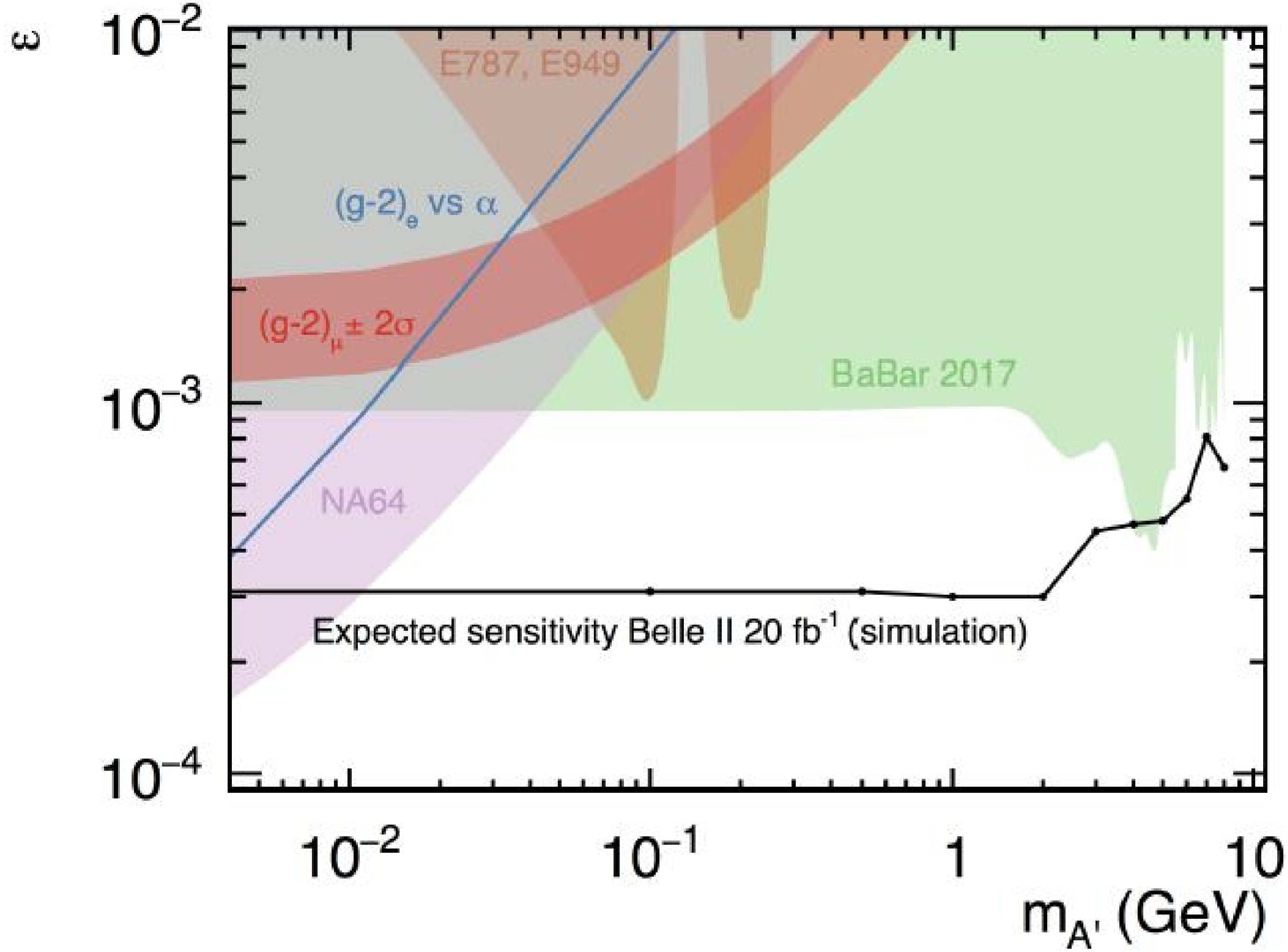
“Light DM” sensitivity in $e^+e^- \rightarrow \gamma$+nothing

Signal: mono-photon event



This is hard. Requires a special new trigger that is being developed for Belle II. Should be tested during Phase III in 2019.

“Light DM” sensitivity in γ+nothing



nature

The world is waiting for our results.

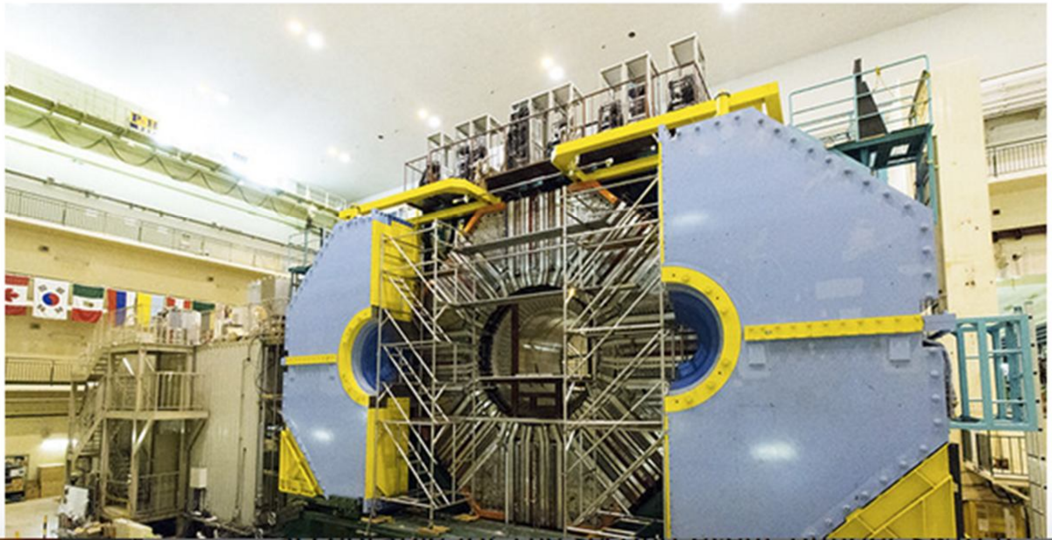
January 2018

NEWS · 12 JANUARY 2018

Revamped collider hunts for cracks in the fundamental theory of physics

Experiment smashes electrons into positrons to search for unseen particles and problems with overarching physics framework.

Elizabeth Gibney



PDF version

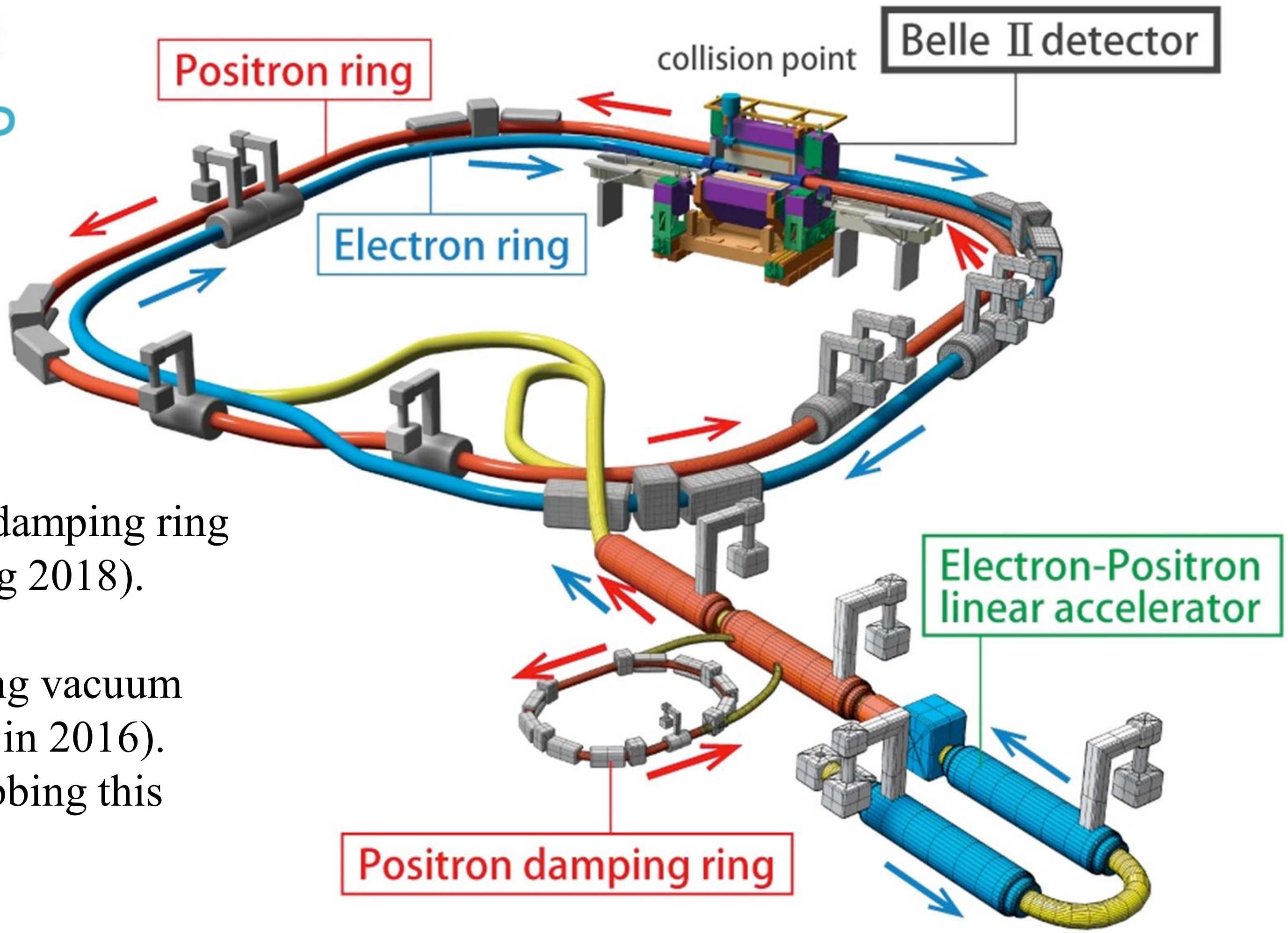
RELATED ARTICLES

Rare particle decays offer hope of new physics

Physicists excited by latest LHC anomaly

https://www.nature.com/articles/d41586-018-00162-x

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



Some items to note:

1) Brand-new positron damping ring (commissioned spring 2018).

2) New 3 km positron ring vacuum chamber (commissioned in 2016). Optics and vacuum scrubbing this spring.

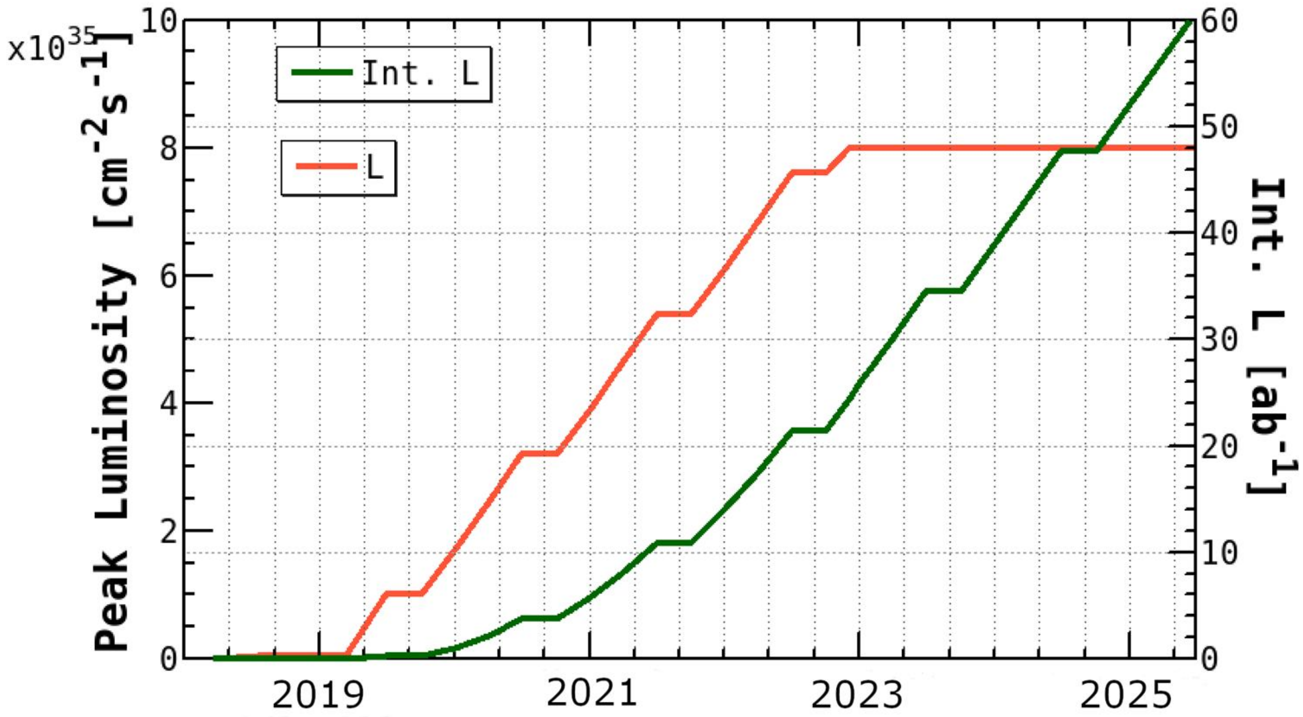
3) New complex superconducting final focus (commissioned this spring 2018).

SuperKEKB/Belle II Luminosity Profile

Belle/KEKB recorded ~1000 fb^{-1} . Now have to change units on 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, requires close cooperation between Belle II and SuperKEKB [and some *international collaboration* on the accelerator, including the US and Europe].

Vietnam: The old 1 ab^{-1} Belle dataset can be analyzed by Belle II collaborators.

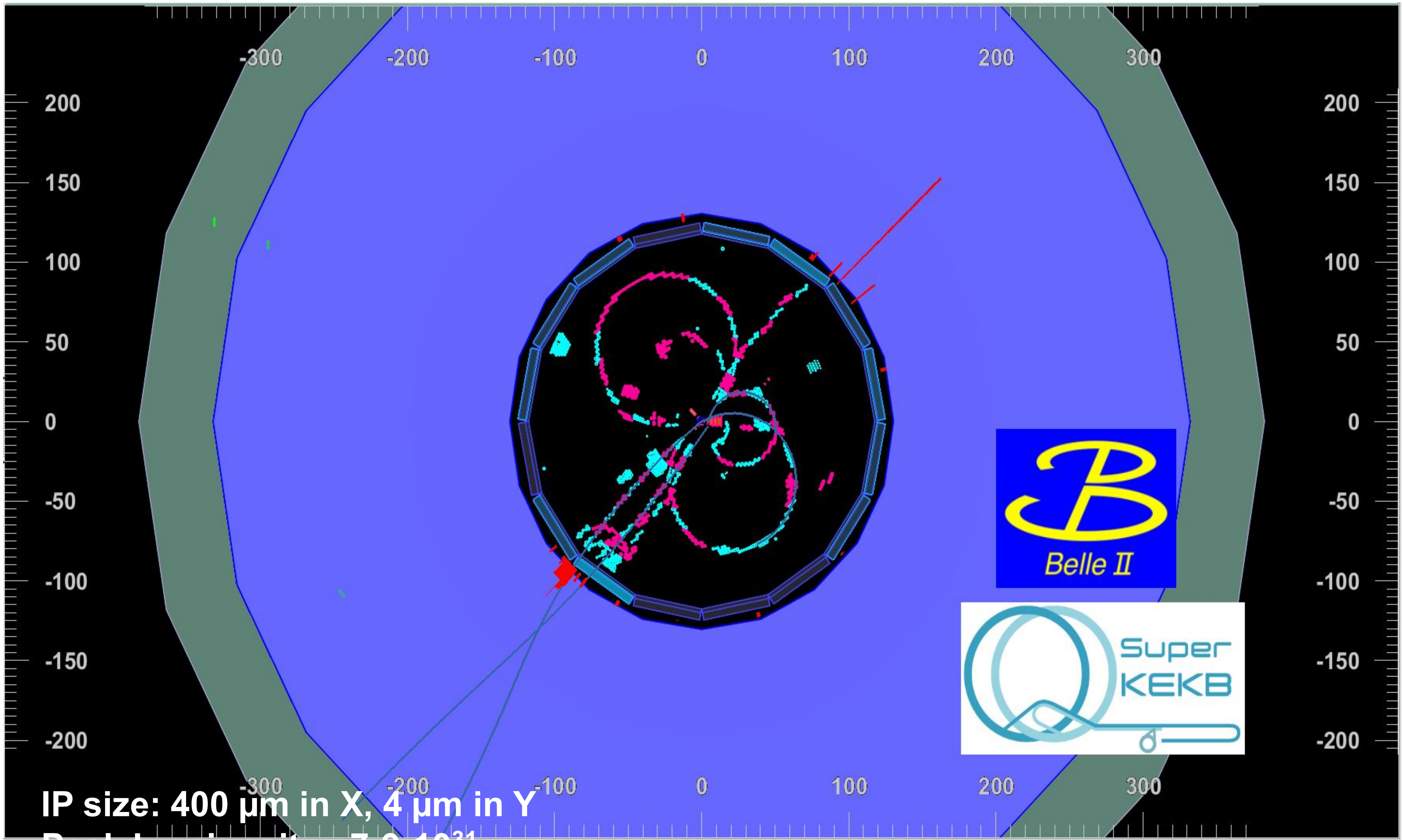
Some Belle II jargon

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

Phase 2: More elaborate inner background commissioning detector (VXD samples). Full Belle II outer detector. Full superconducting final focus. *No vertex detectors. Collisions !*

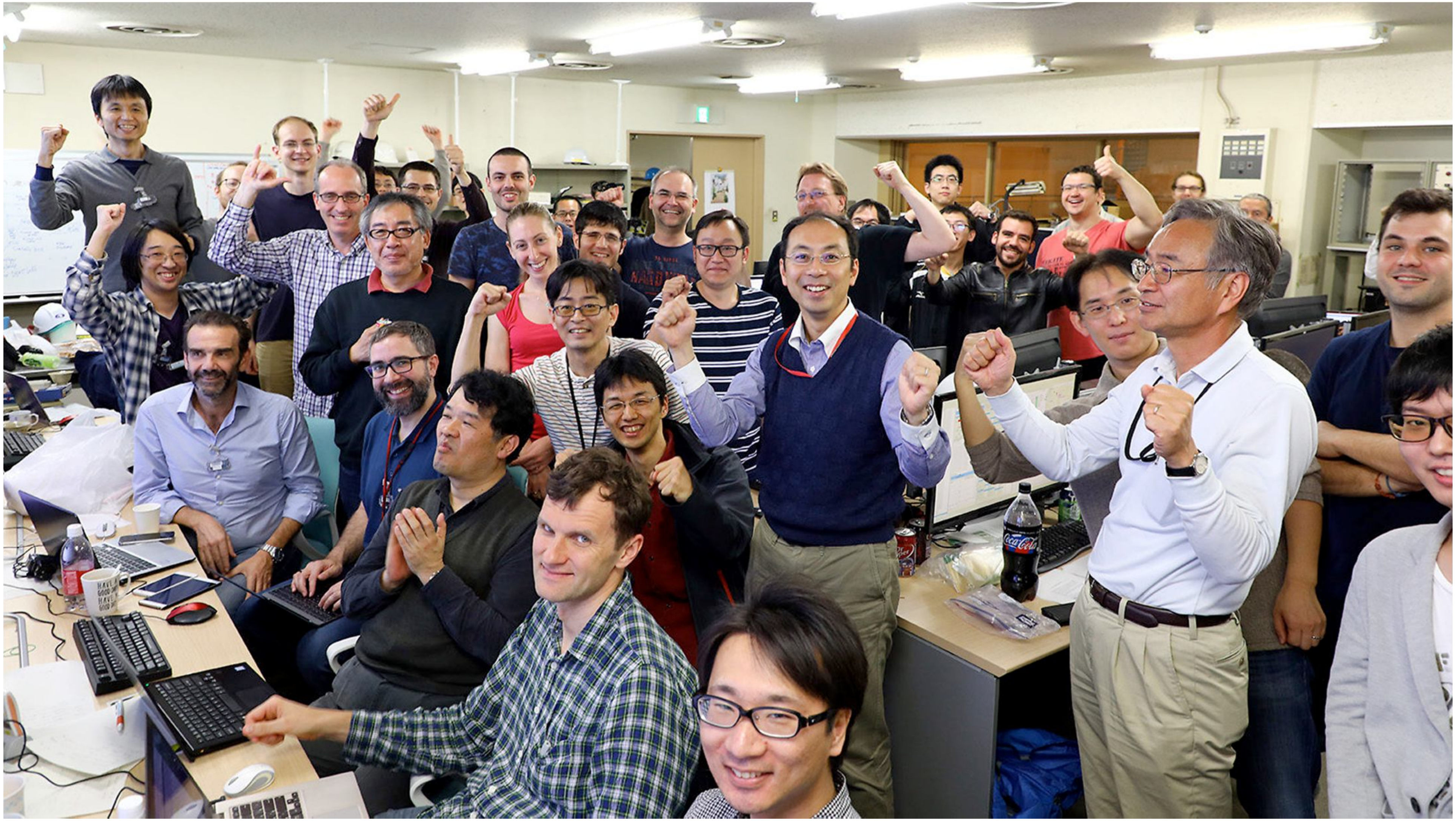
[Phase 2 collisions: April 26-July 17, 2018]

Antimatter-matter annihilation in Tsukuba, Japan



Probably $e^{+}e^{-} \rightarrow \gamma^{*} \rightarrow q\bar{q}$

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

Welcome to the world of large crossing angle nano-beams !

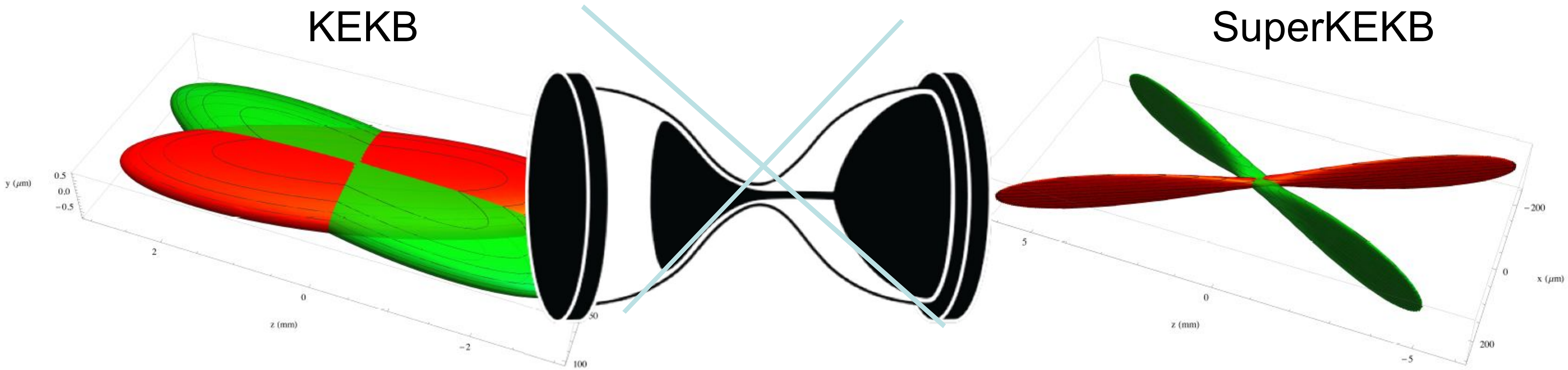
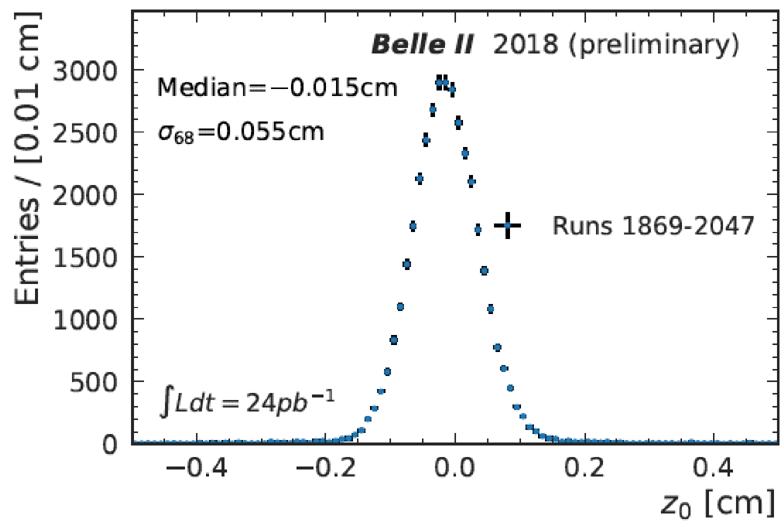


FIG. 1: Schematic view of Belle-I beam crossing at the interaction region. The spread of the z vertex distribution can be estimated as $\sigma_z = \frac{\sqrt{\epsilon_x \beta_x^*}}{\sqrt{2}\phi_x}$ where for Belle-I optics the horizontal emittance $\epsilon_x = 20 \times 10^{-6}$ mm, $\beta_x^* = 1200$ mm, and the crossing angle $\phi_x = 11$ mrad leading to expected $\sigma_z = 1$ cm.

FIG. 2: Schematic view of Belle-II beam crossing at the interaction region. The spread of the z vertex distribution can be estimated as $\sigma_z = \frac{\sqrt{\epsilon_x \beta_x^*}}{\sqrt{2}\phi_x}$ where for Belle-II optics in phase 2 the horizontal emittance $\epsilon_x = 4 \times 10^{-6}$ mm, $\beta_x^* = 200$ mm, and the crossing angle $\phi_x = 41$ mrad leading to expected $\sigma_z = 0.049$ cm.

As expected, the effective bunch length is *reduced* from ~10 mm (KEKB) to 0.5 mm (SuperKEKB)

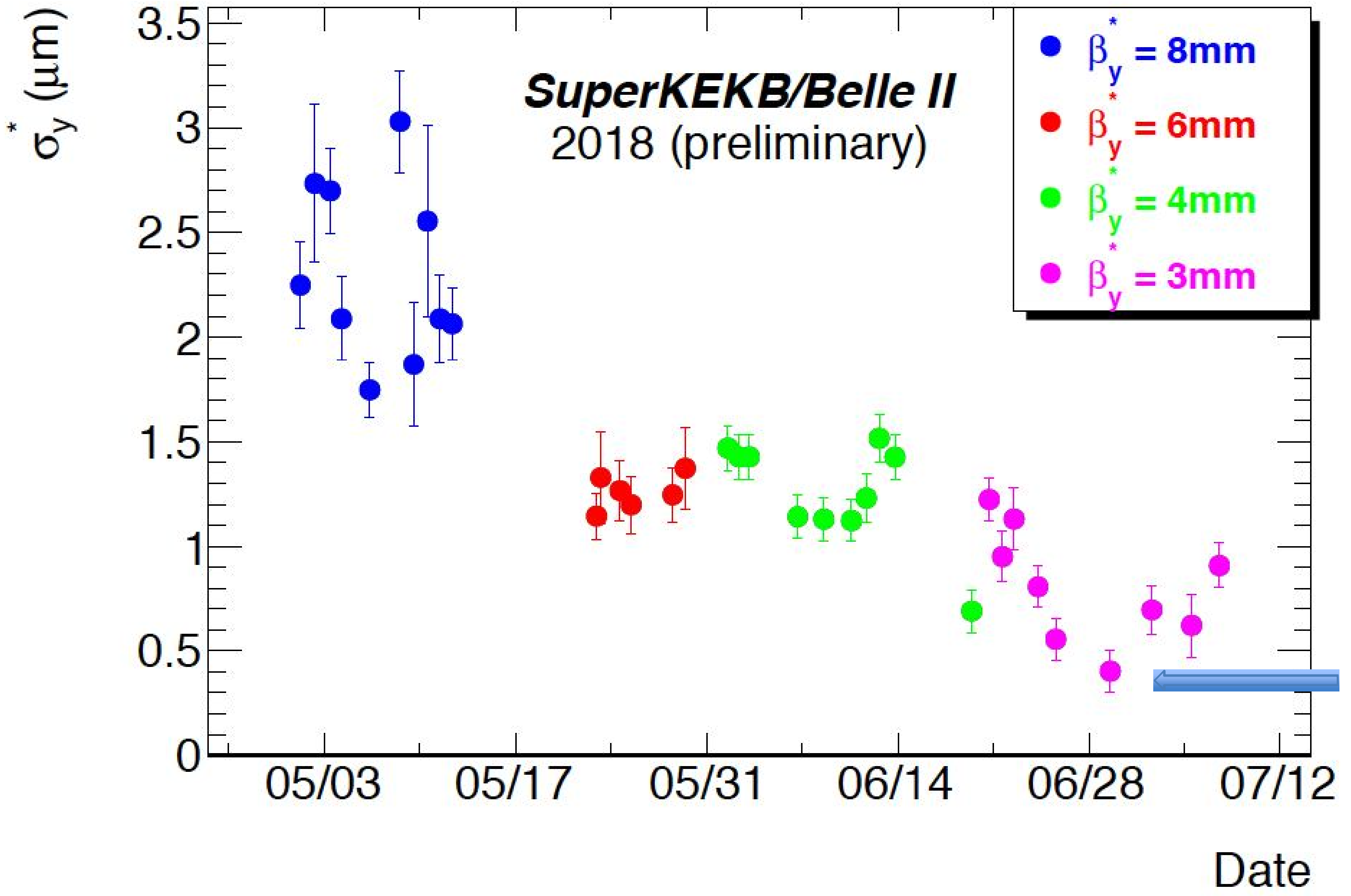
We measure this in two track events in Belle II data.



How do we measure the vertical height of nanobeams ?

Ans: Width of Luminosity scans with diamond detectors

B2NOTE-PH-2018-007



1. For early Phase 3, we will continue with β_y^*=3mm

2. The record is 400 nm and beam currents of only ~15mA

Heading downwards but still struggling with beam-beam blow-up (a major issue for Phase 3 too.)

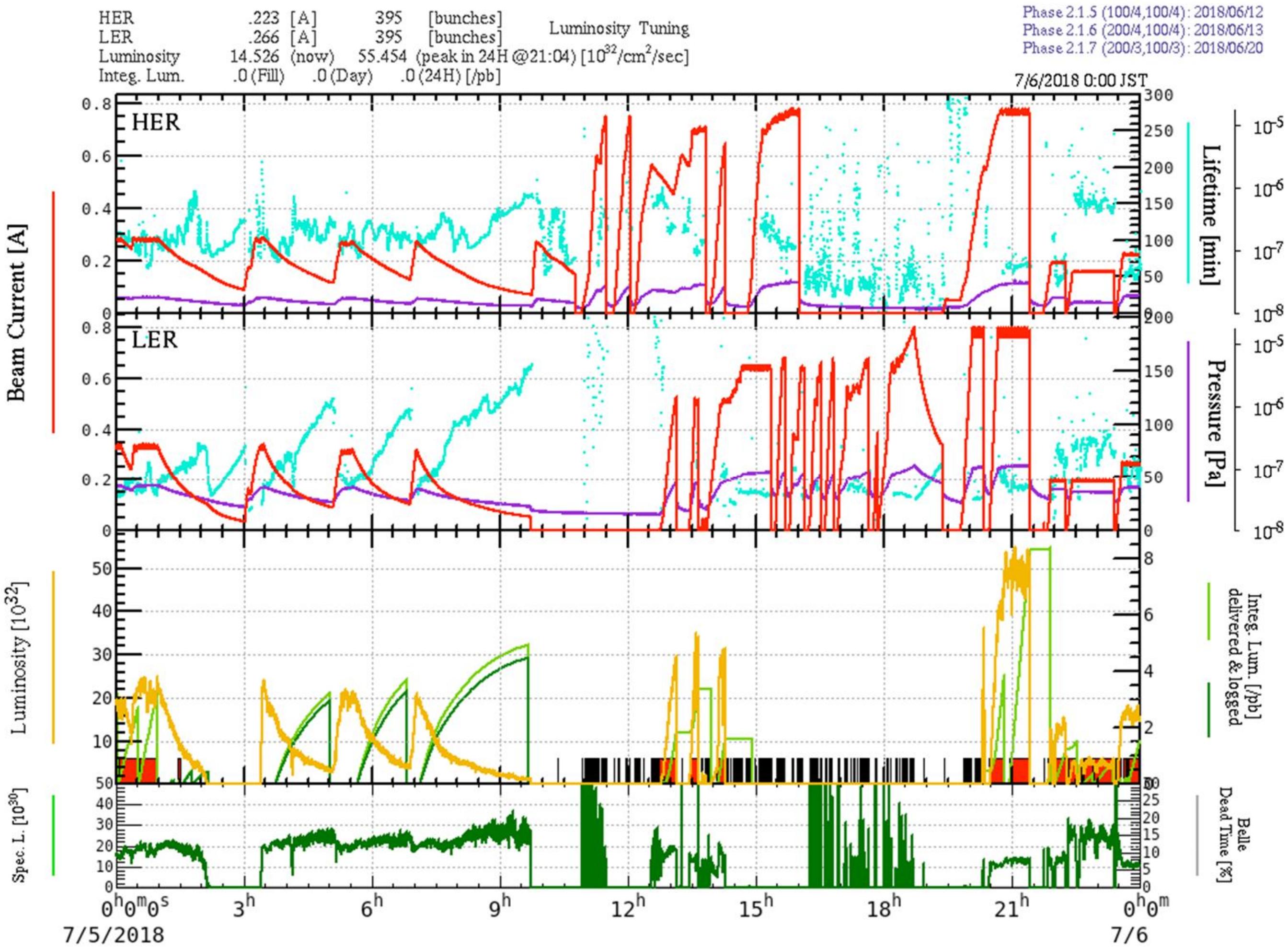
S. Di Carlo et al. (LAL Orsay)

Keep on squeezing the two beams with the superconducting final focus β_y^*=3mm, making sure that the two "thin pancakes" are well aligned. One then adds beam current…..

PEP-II design luminosity 3 x 10^{33}

$$L_{peak} = 5.5 \times 10^{33} / cm^2 / \sec$$

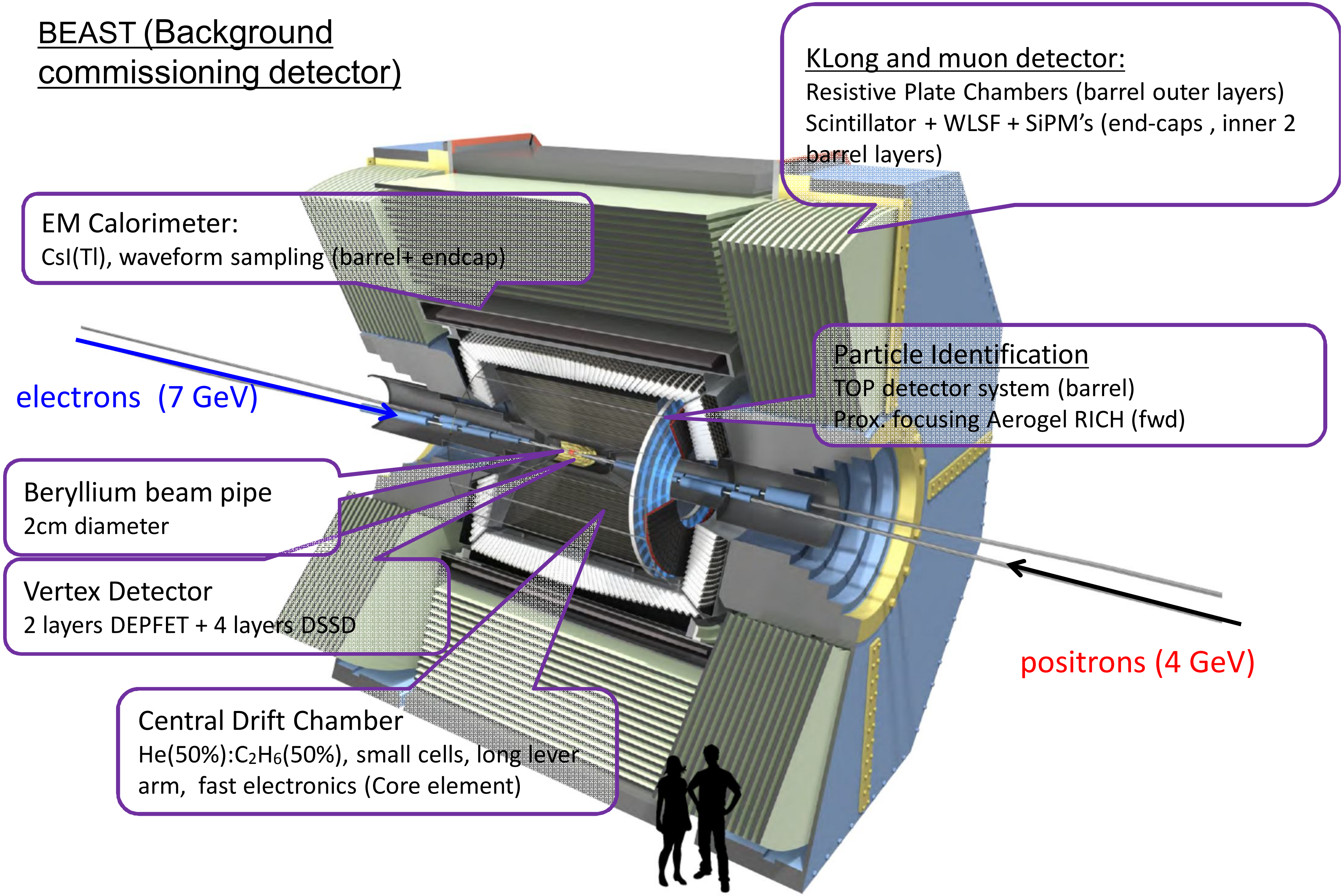
Phase 2, July 2018



N.B. Still a long way to go with the superconducting final focus (one order of magnitude in β_y^*)

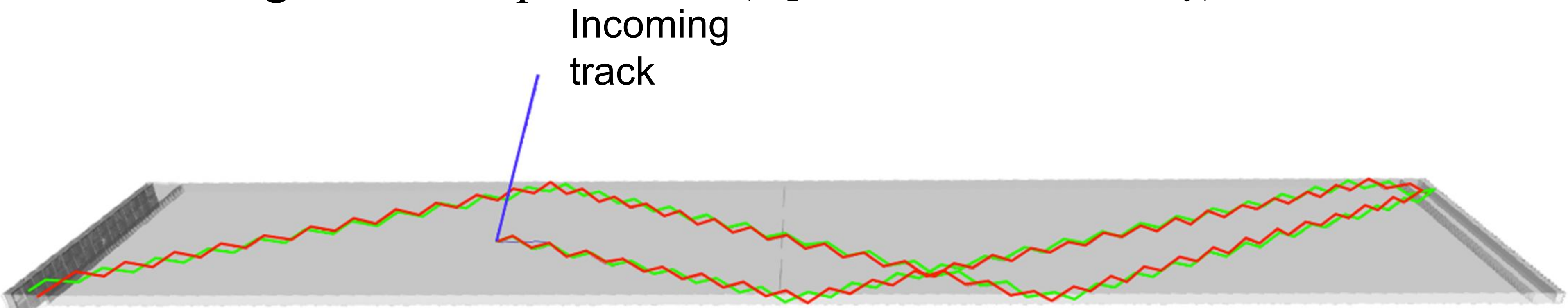
Luminosity tuning has priority. When accelerator physicists become tired, Belle II does commissioning or takes data (usually owl shift only). Only able to record ~0.5 fb^{-1} during Phase 2 pilot run.

Belle II Detector ("A Universal Spectrometer")

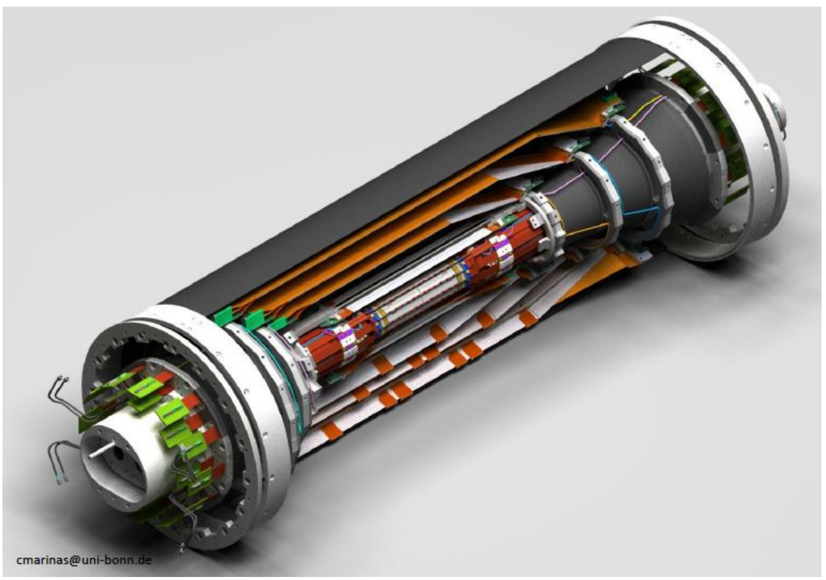


Barrel Particle Identification (uses Cherenkov radiation)

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

Advanced & Innovative Technologies used in Belle II

<ins>Pixelated photo-sensors play a central role</ins>

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

Collaboration with Industry

DEPFET pixel sensors

<ins>Waveform sampling with precise timing is “saving our butts”.</ins>

Front-end custom ASICs (Application Specific Integrated Circuits) for all subsystems
→ DAQ with high performance network switches, large HLT software trigger farm
→ <ins>a 21st century HEP experiment.</ins>

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 !

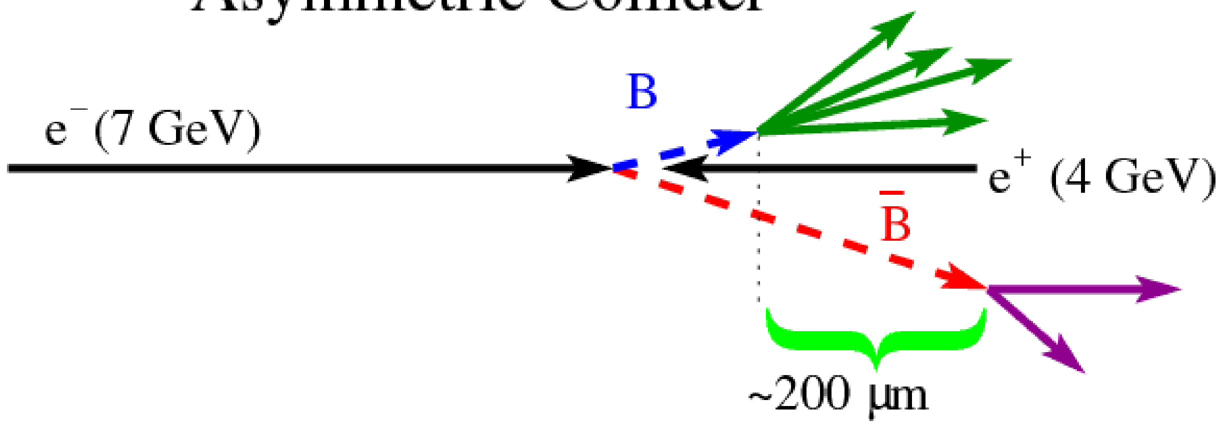
The B-anti B meson pairs at the Upsilon(4S) are produced in a <u>coherent</u>, *entangled* **quantum mechanical state**.

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

Need to measure decay times to observe CP violation (particle-antiparticle asymmetry). (PGU: Why is there a minus sign above ?)

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

Asymmetric Collider



Not to scale

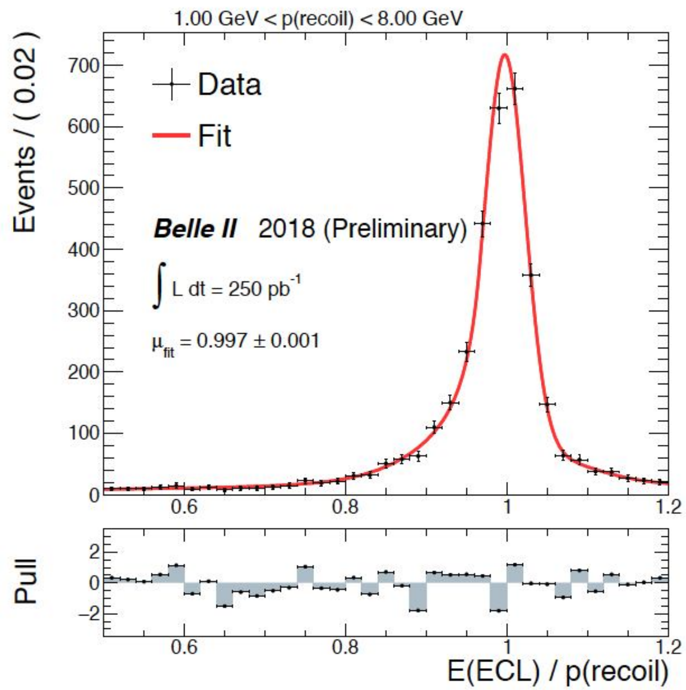
<u>The beam energies are asymmetric (7 on 4 GeV)</u>

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

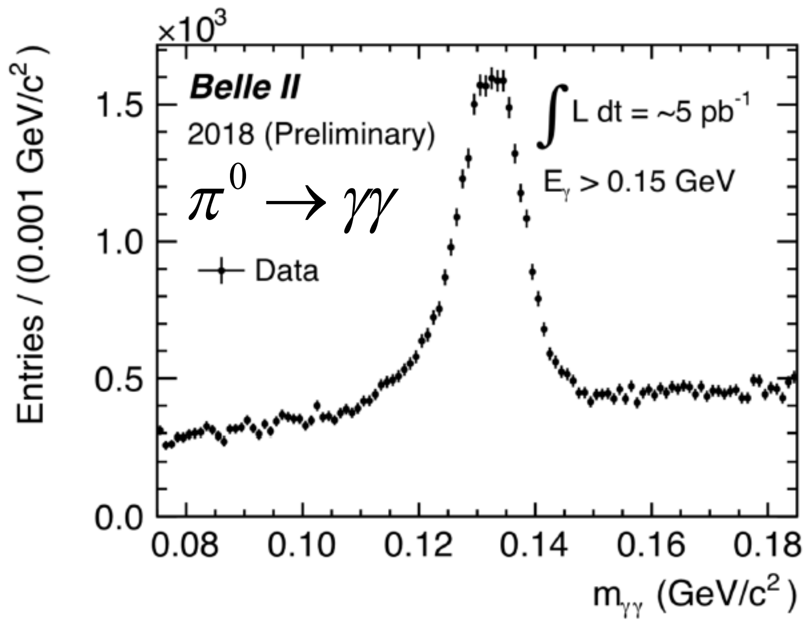
Most of the Belle II detector subsystems are working well.

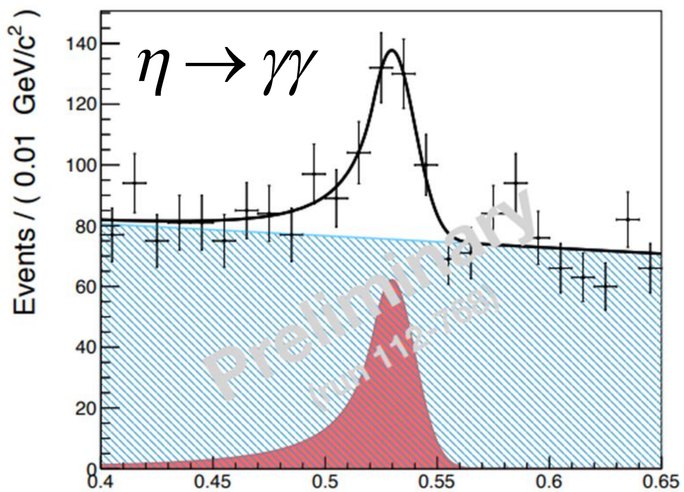
Some nice examples of *signals* involving photons.

$e^+e^- \to \mu^+\mu^-\gamma$



Single Photon Lines



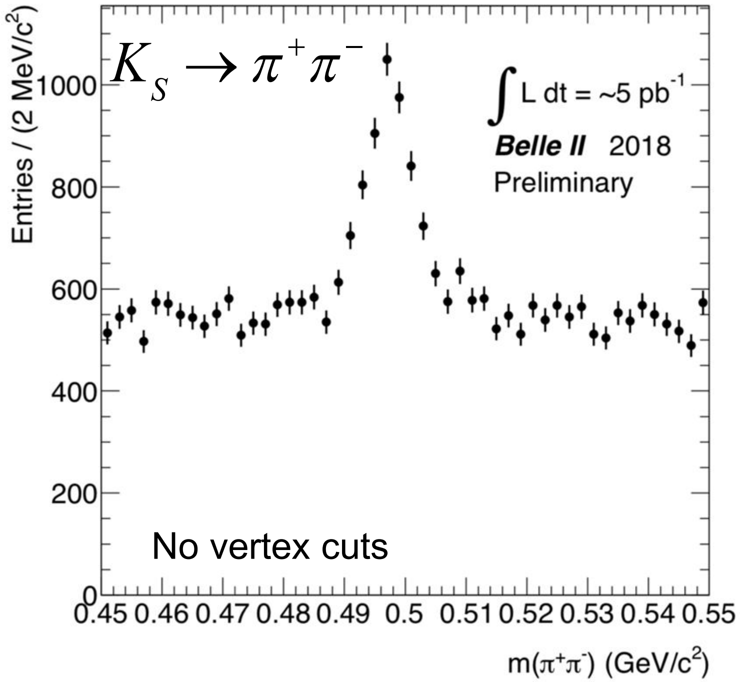


Ready for the dark sector !

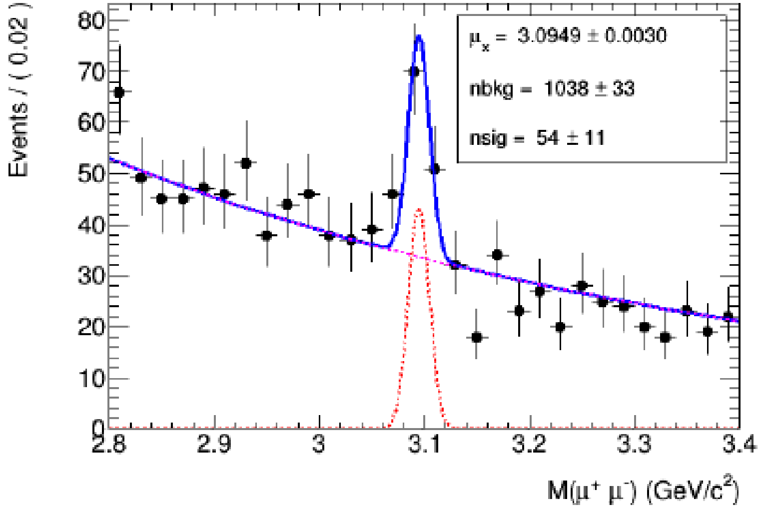
$$e^+e^- \to \gamma\, X$$

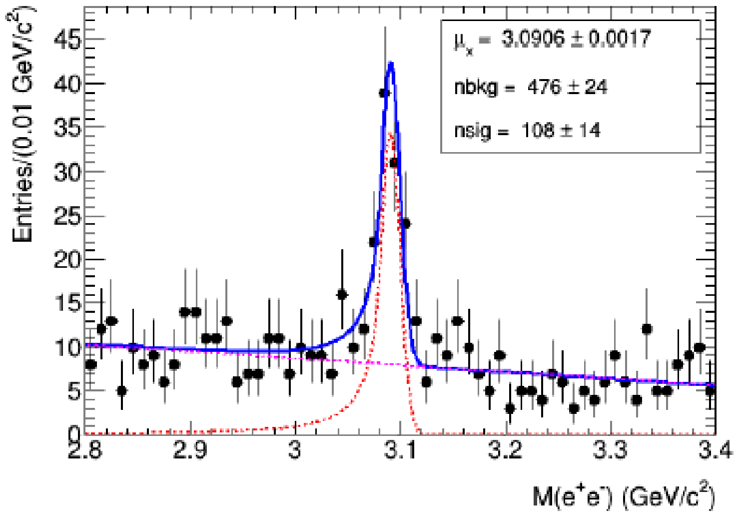
$$e^+e^- \to \gamma\, ALP \to \gamma\,(\gamma\gamma)$$

Most of the Belle II detector subsystems are working well.
Here are some *signals* involving charged tracks.



$J/\psi \to \mu^+\mu^-$, $J/\psi \to e^+e^-$



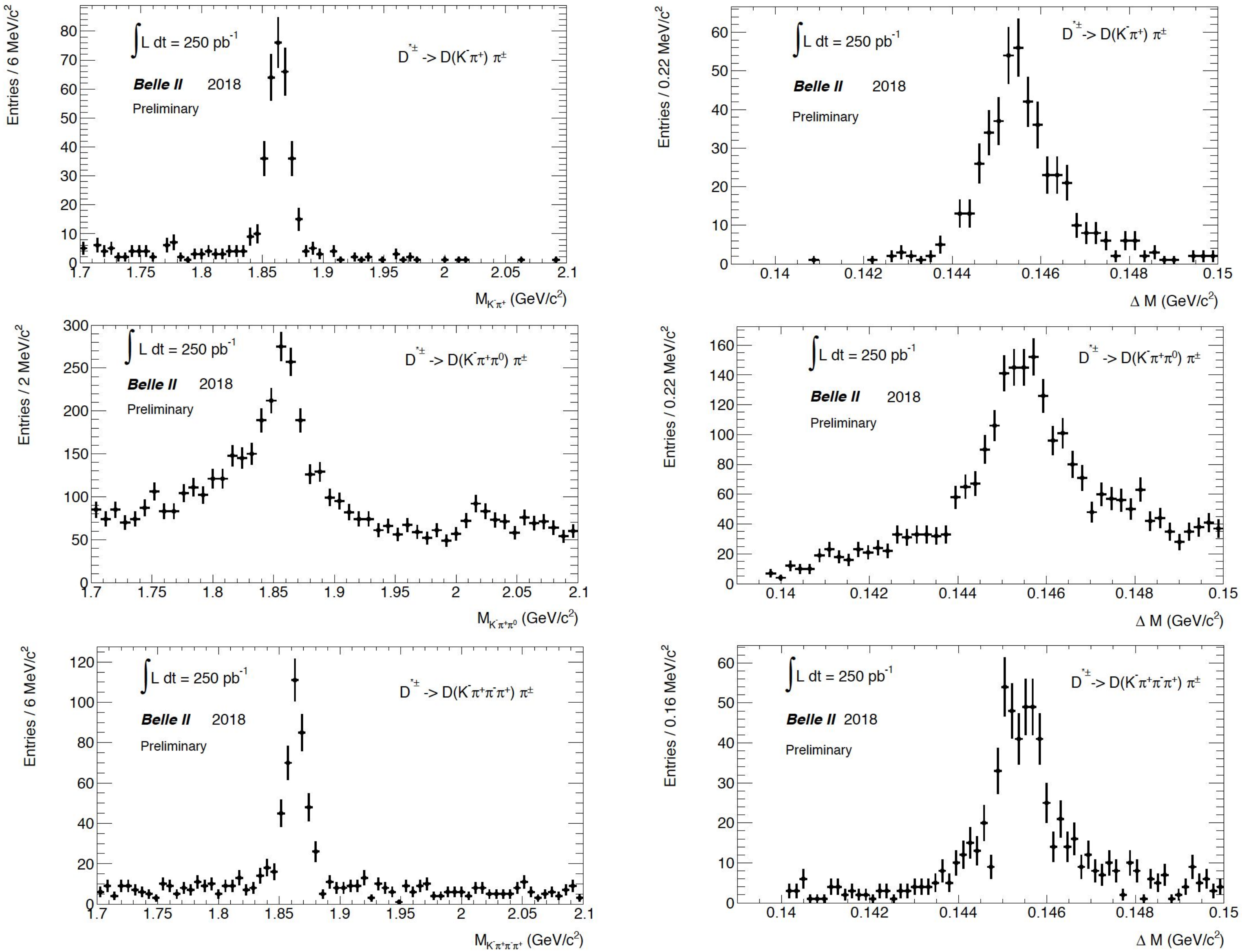


$$e^+e^- \to c\bar{c}$$

$$D^{*+} \to D^0\pi^+,$$

$$D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+$$

The signal peaks are charm in continuum not B's



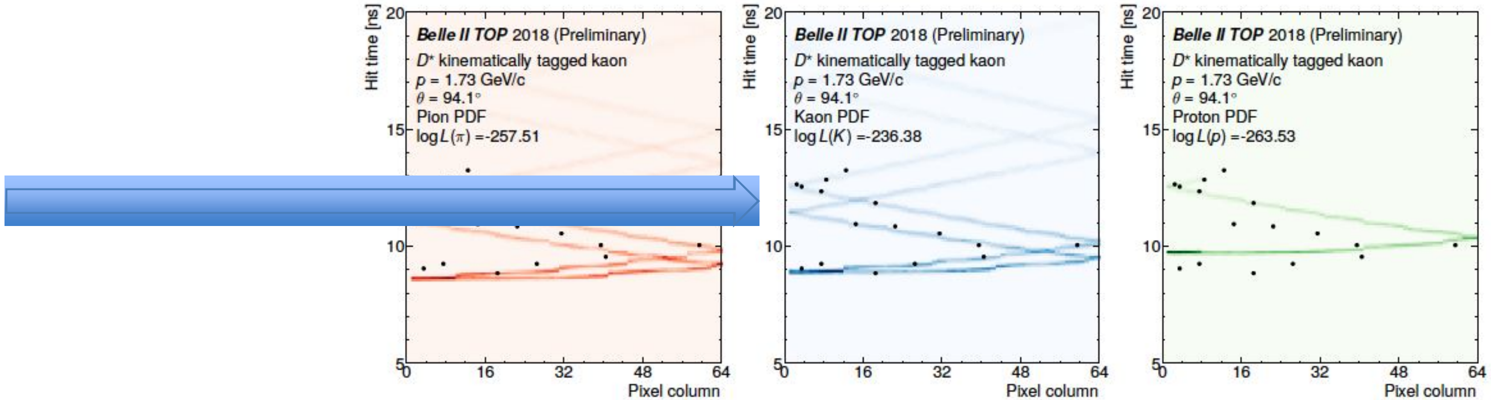
Clearly illustrates the capabilities of Belle II and the potential for charm physics and the <u>building blocks of B mesons.</u>

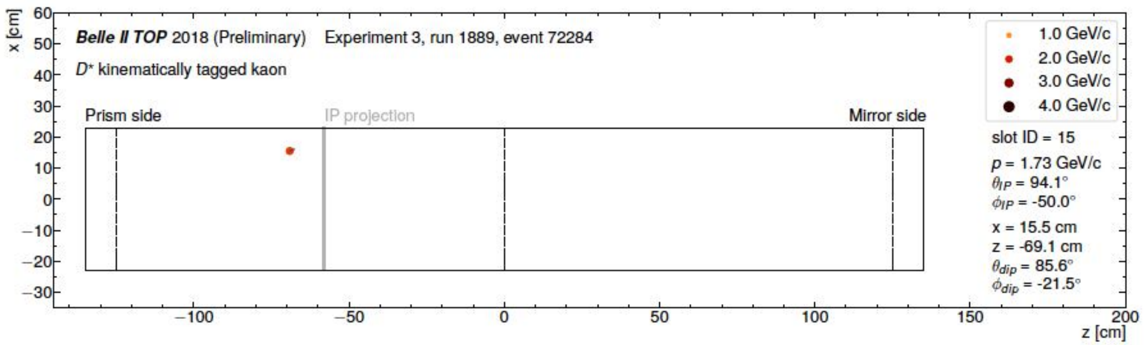
TOP Particle Identification

$$D^{*+} \rightarrow D^0 \pi_s^{\ +}; D^0 \rightarrow K^- \pi^+$$

N.B. The charge correlation with the slow pion determines which track is the kaon (or pion)

Kinematically identified kaon from a D^{*+} in the TOP;
Cherenkov x vs t pattern (mapping of the Cherenkov radiation ring)





$\phi \rightarrow K^- K^+$ inclusive

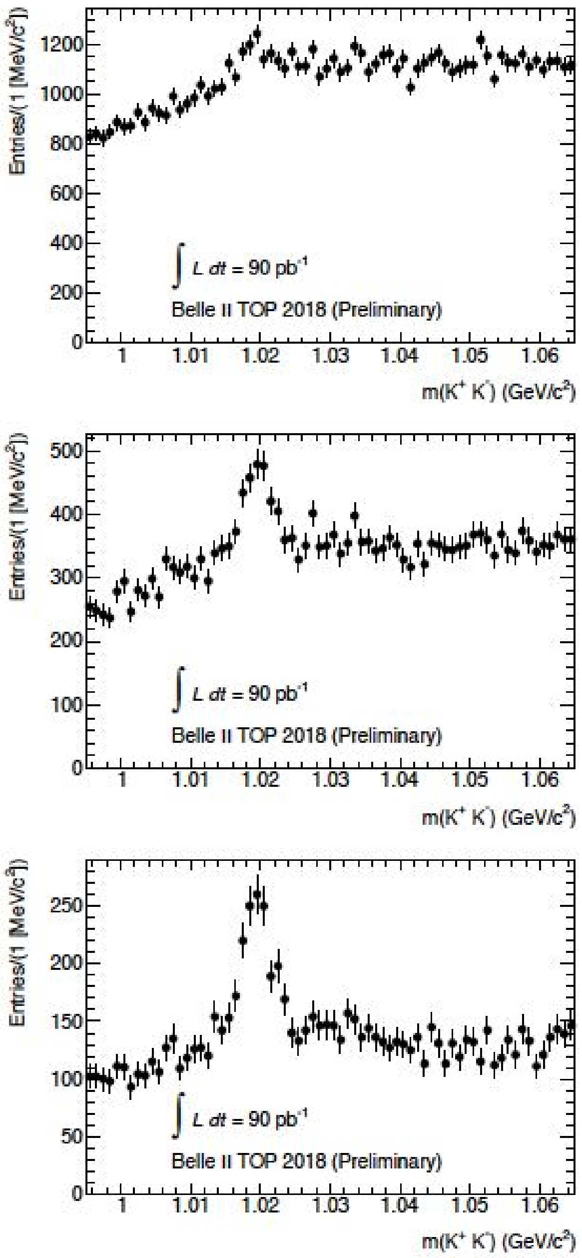


FIG. 7: $m(K^+K^-)$ distributions for runs with TOP calibration (run number up to 2531). Tracks are required to be in the TOP acceptance. Top: No PID requirement. Middle: $LL(K)^{TOP} > LL(\pi)^{TOP}$ for one of the tracks. Bottom: $LL(K)^{TOP} > LL(\pi)^{TOP}$ for both tracks.

No kaons identified

One kaon identified in the TOP.

Both kaons identified in the TOP.

Another example of TOP particle identification with early calibration and alignment.

Example of unique capabilities in the Phase 2 pilot run

$$CP \text{ Eigenstate: } D^0 \rightarrow K_S \pi^0$$

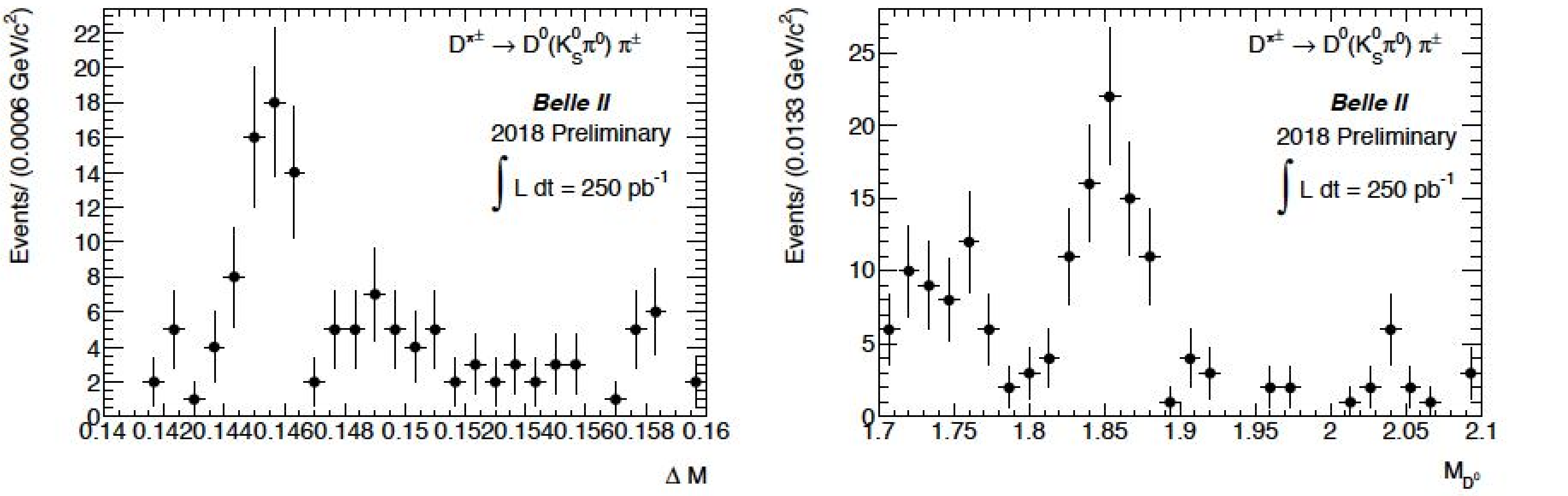


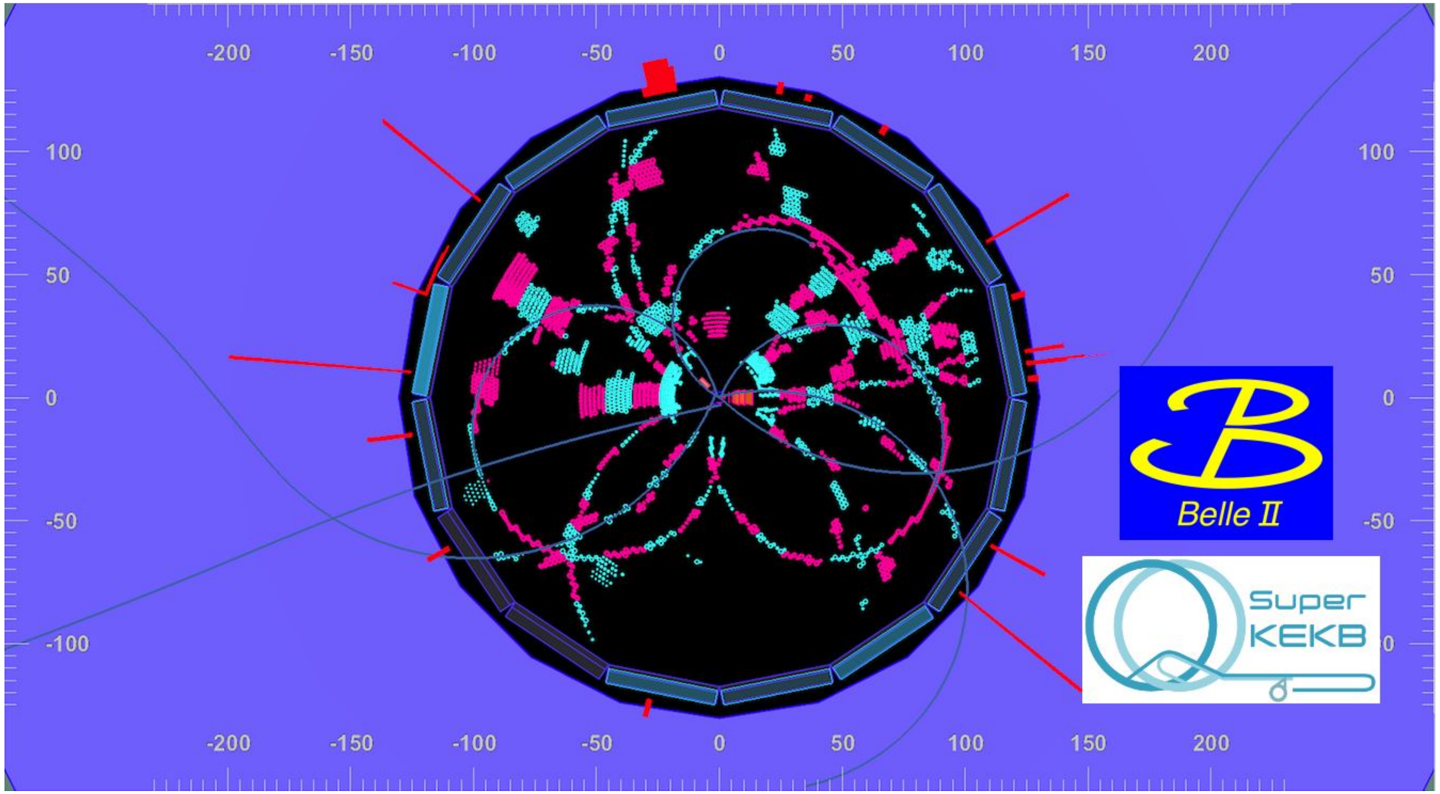
FIG. 36: ΔM (left) and M_D (right) signal-enhanced projections in 250 pb^{-1} prod4 data sample for $D \rightarrow K_S^0\pi^0$ final state.

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

Comment from LHCb colleagues: "*This* would be impossible at LHCb."

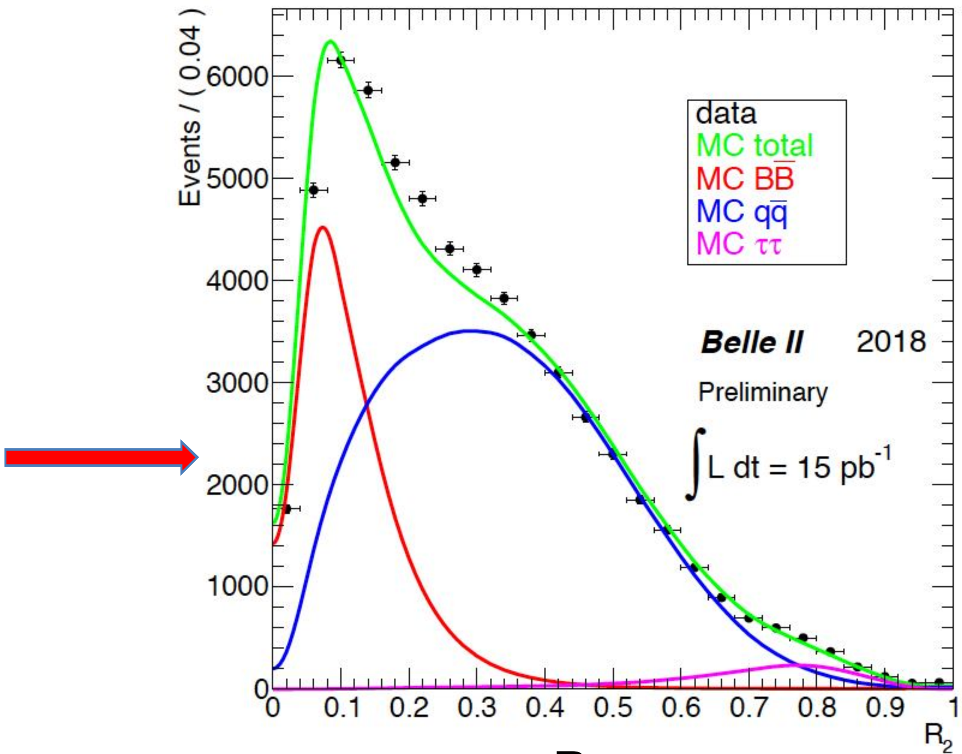
More matter-antimatter annihilation in Tsukuba: Another event from Belle II's first evening

$$e^+e^- \to \gamma^* \to B\bar{B}$$

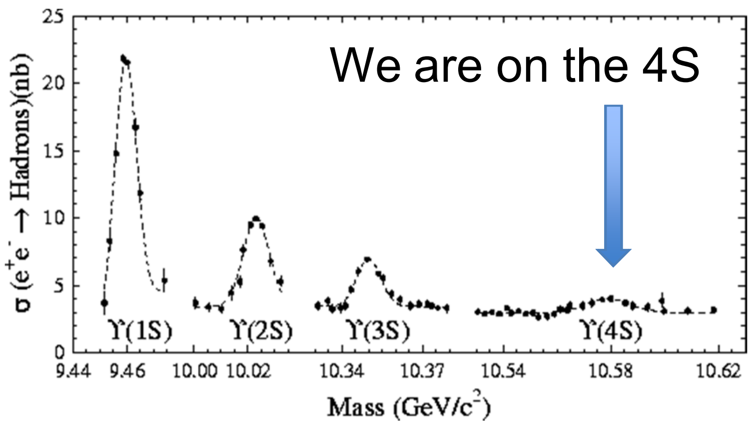


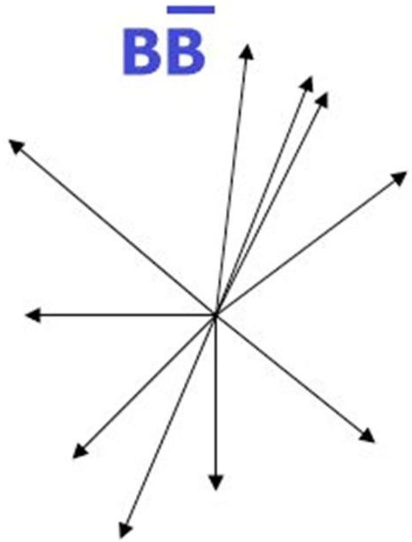
A potential e+ e- →B anti-B candidate

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

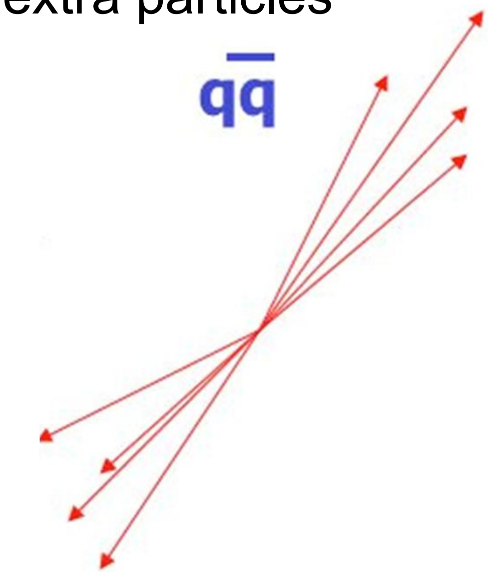


Spherical R_2 Jet-like





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

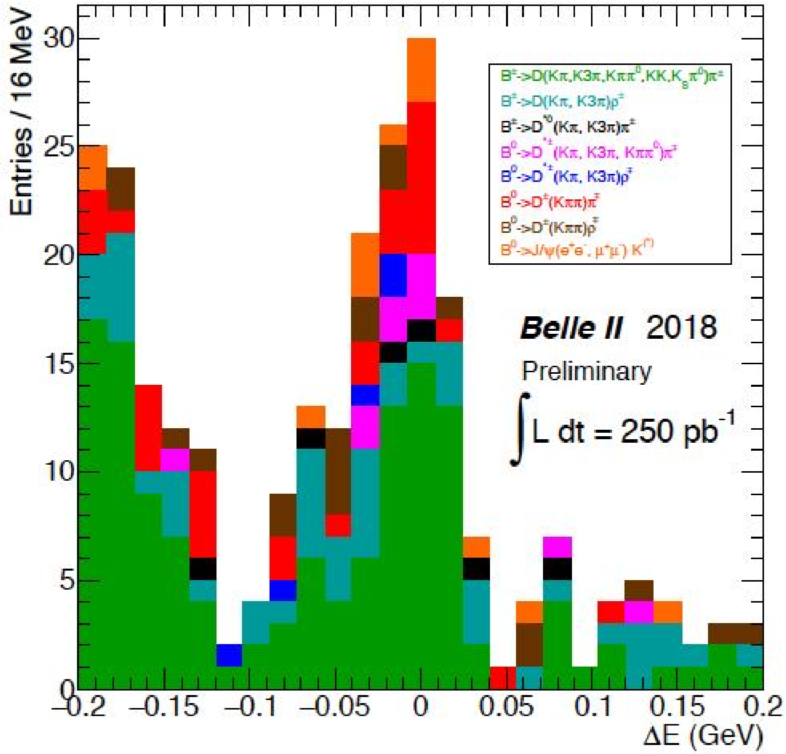


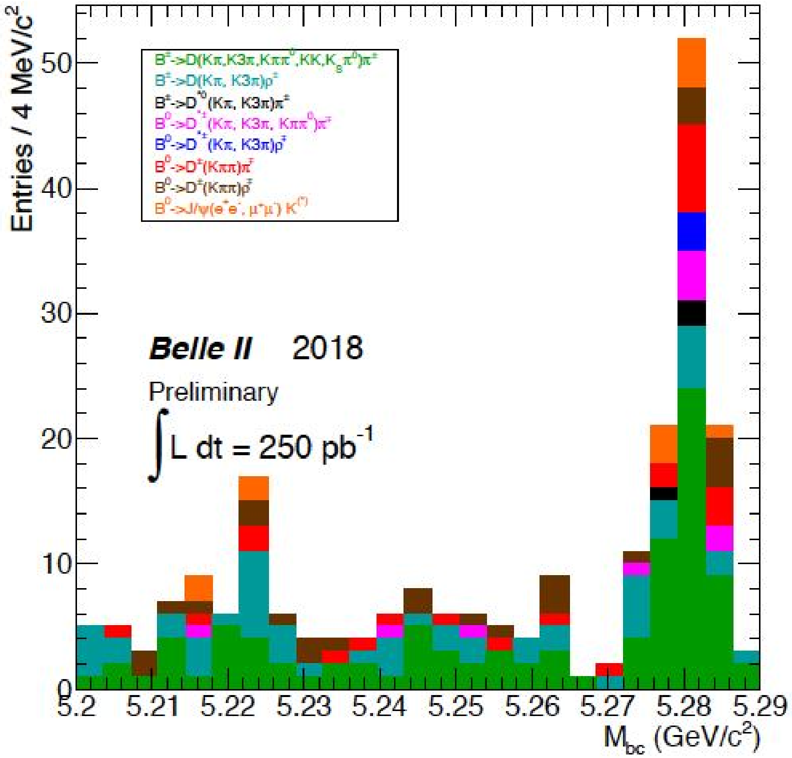
We have *rediscovered* the B meson !

Belle II

$$\Delta E = E_{cm} / 2 - E_{recon}$$

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





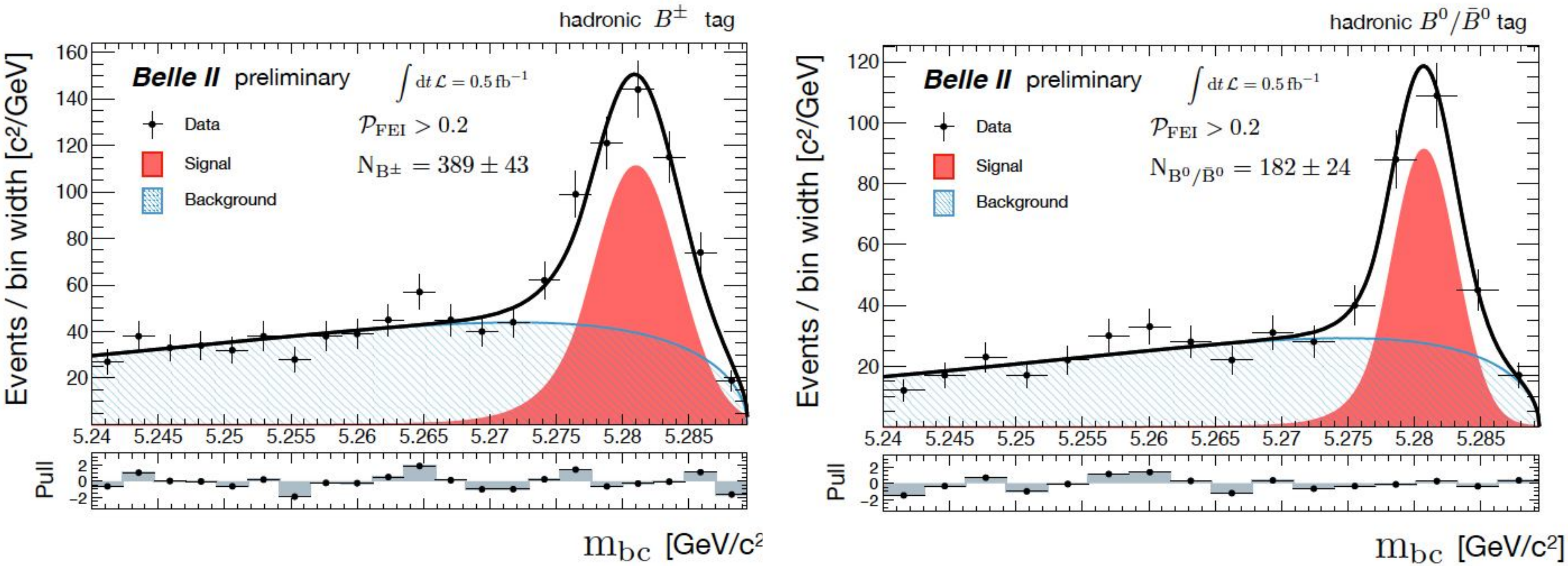
History 1983:

VOLUME 50, NUMBER 12 PHYSICAL REVIEW LETTERS 21 MARCH 1983

Observation of Exclusive Decay Modes of *b*-Flavored Mesons **40.7 pb^{-1}**

B-meson decays to final states consisting of a D^0 or $D^{*\pm}$ and one or two charged pions have been observed. The charged-B mass is $5270.8 \pm 2.3 \pm 2.0$ MeV and the neutral-B mass is $5274.2 \pm 1.9 \pm 2.0$ MeV.

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)

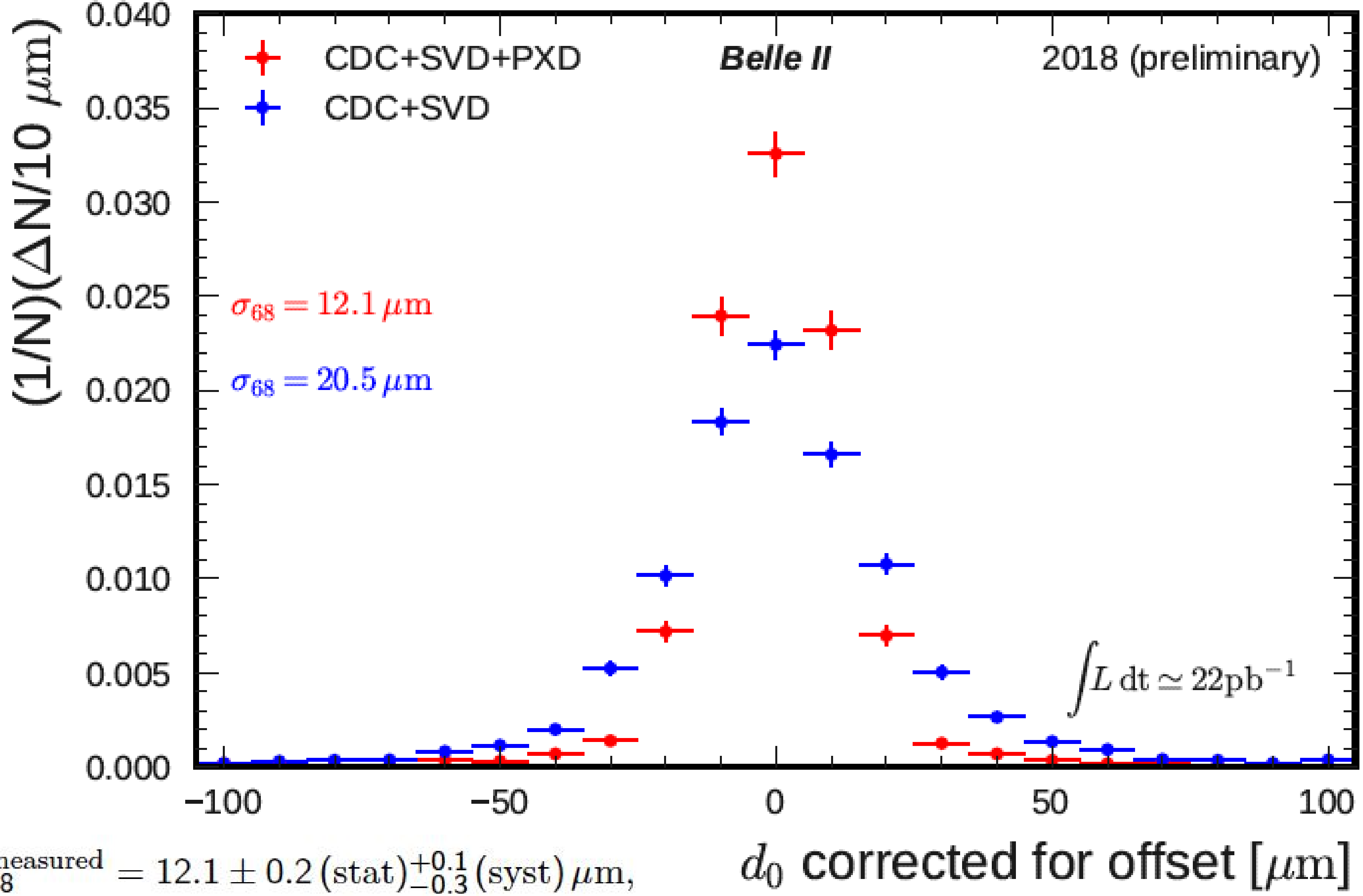


We now observe ~571 fully reconstructed B mesons (389+182) or an improvement of a factor of ~O(3.6) in overall efficiency by using this advanced analysis method that covers many more decay channels.

B2NOTE-2018-031-1,
W. Sutcliffe, F. Bernlochner

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

Impact parameter resolution in the Phase 2 pilot run with the BEAST2 VXD

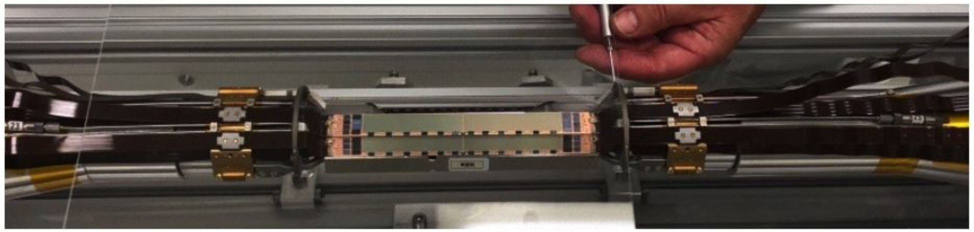


$$\sigma_{68}^{\mathrm{measured}} = 12.1 \pm 0.2\,(\mathrm{stat})^{+0.1}_{-0.3}\,(\mathrm{syst})\,\mu\mathrm{m},$$
$$\sigma^{\mathrm{expected}} = 9.9 \pm 0.2\,(\mathrm{stat})\,\mu\mathrm{m}.$$

Onwards to Phase 3 and the Physics Run

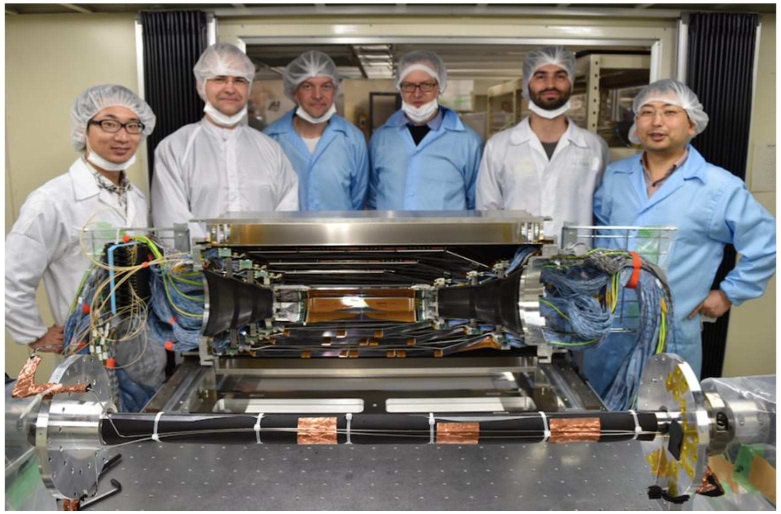
The VXD has now been installed.
Restart Belle II data taking in mid-March 2019.

PXD layer 1 ladders, Feb 2018



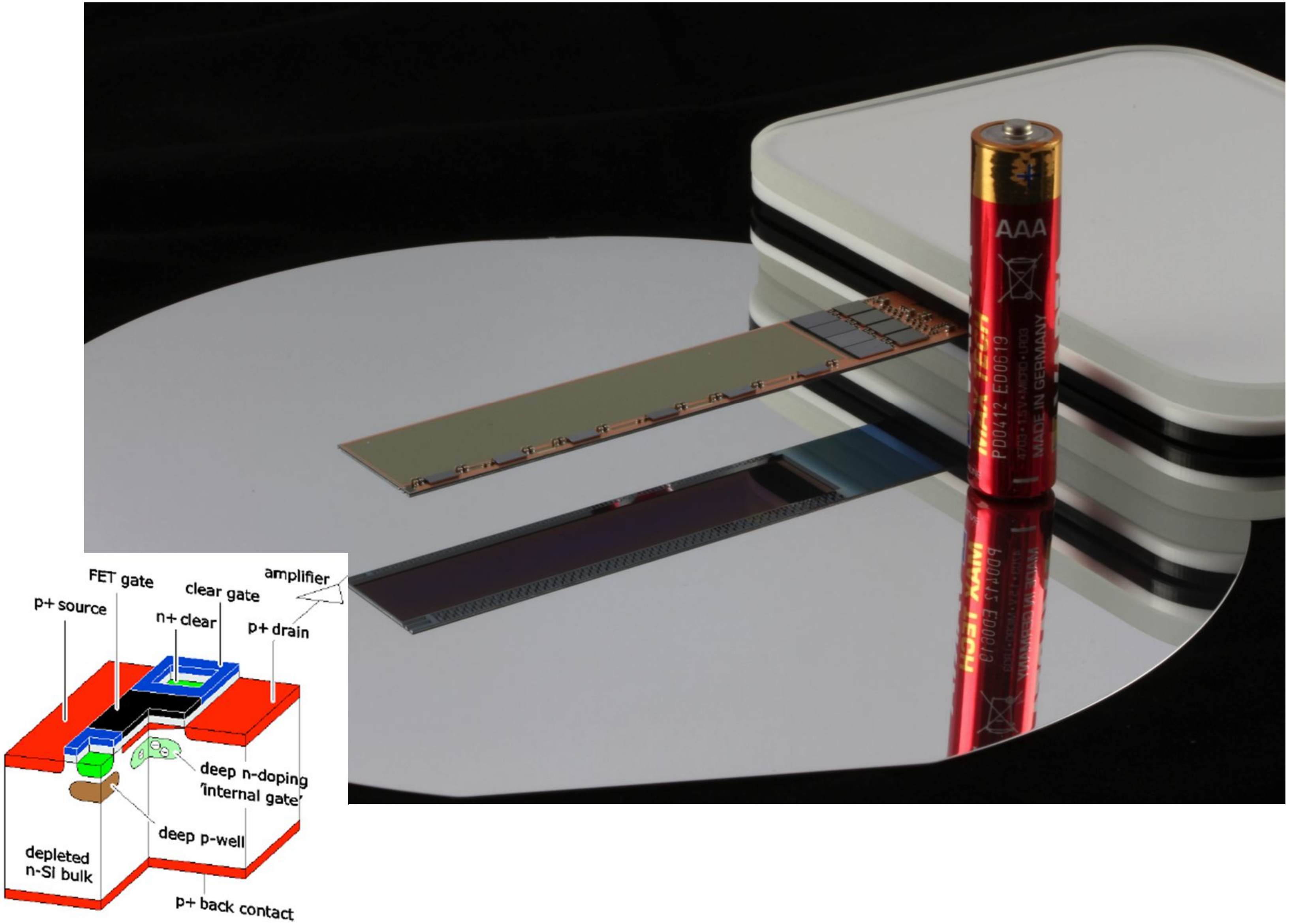
First PXD half-shell being tested at DESY, July 2018

SVD +x half-shell, Jan 2018 KEK



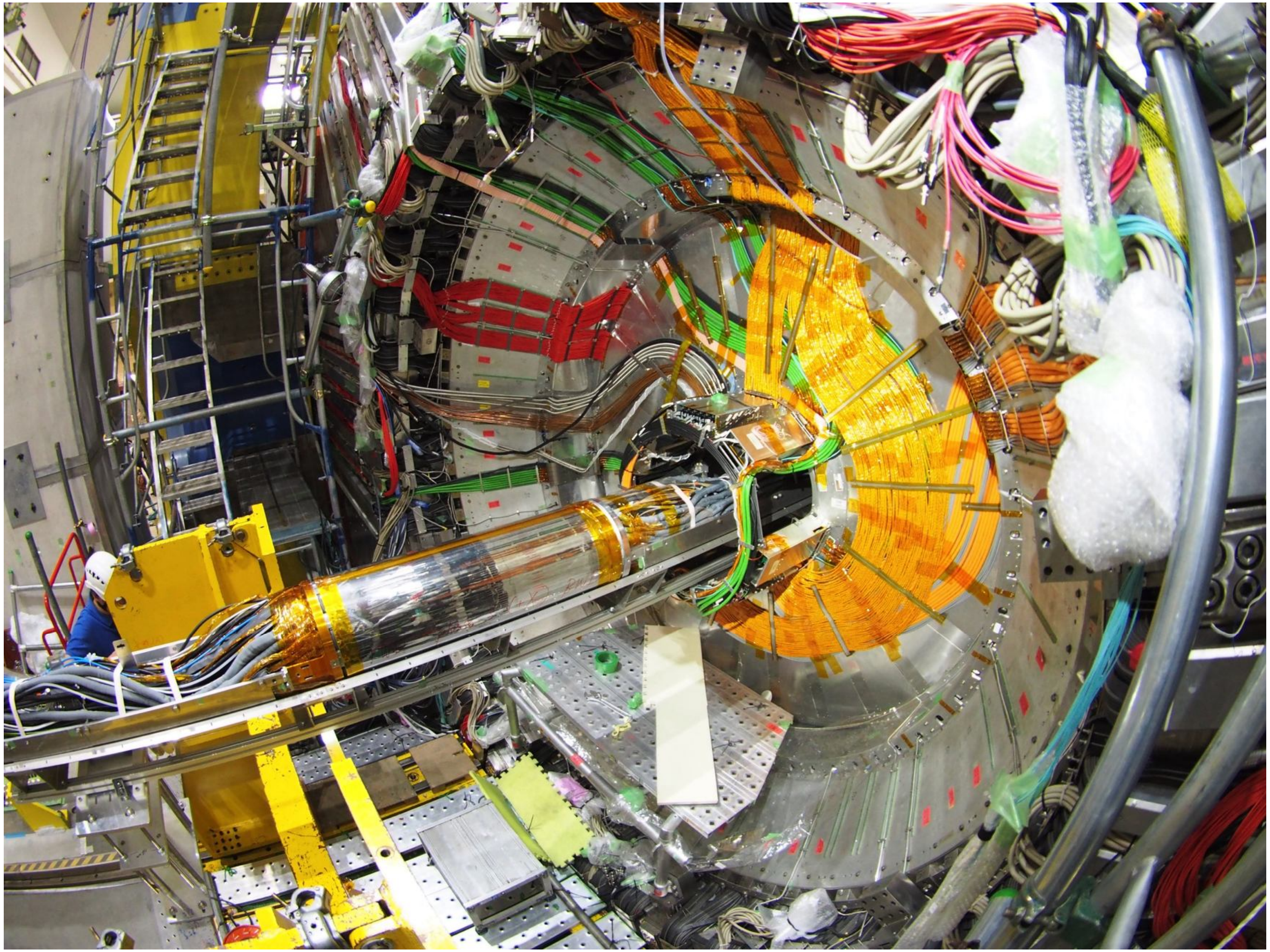
SVD -x half-shell, July 2018, KEK

“Full sized” pixel detector module 0



75 µm
thick

Installation of VXD into Belle II (Nov 21, 2018)



Early Phase 3 Physics (March-June, 2019) Plan

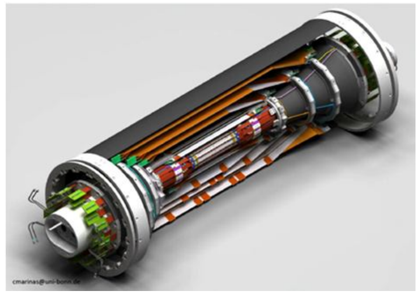
We assume a *plausible* scenario with three months in which we integrate luminosity: (2 fb^{-1}, 4 fb^{-1}, 4 fb^{-1}) + 1 fb^{-1} continuum or ~11 fb^{-1} for Lepton-Photon 2019 in Toronto, Canada. <u>All detector subsystems, DAQ and trigger will be operating well</u>. Software, calibrations and computing will be ready.

<u>Semileptonic</u>

- B→ π l ν and ρ l ν untagged (CLEO saw a signal with 2.66 fb^{-1})

<u>Time Dependent CP Violation/Charm</u>

- D lifetimes (2 fb^{-1})
- Doubly Cabibbo suppressed $D^0 \to K^+ \pi^-$, $D^0 \to K^+ \pi^- \pi^0$ (10 fb^{-1})
- B lifetimes (2-10 fb^{-1})
- Time dependent B-anti B mixing (10 fb^{-1})



Demonstrate VXD physics performance

<u>Radiative/Electroweak Penguins</u>

- B→K* γ (b→s) (2 fb^{-1}) rediscover penguins
- B→Xs γ (b→s) (~10 fb^{-1} depending on off-resonance data taking)

<u>Hadronic B decays (not time dependent)</u>

- B→K π (b→u) (10 fb^{-1})
- B→ Φ K (b→s) (10 fb^{-1})
- B→J/ψ K (with more significance 2-10 fb^{-1})

++ Dark Sector Physics Publications

P. Urquijo et al.

Particle Boys
Manga
素粒子男子
漫画

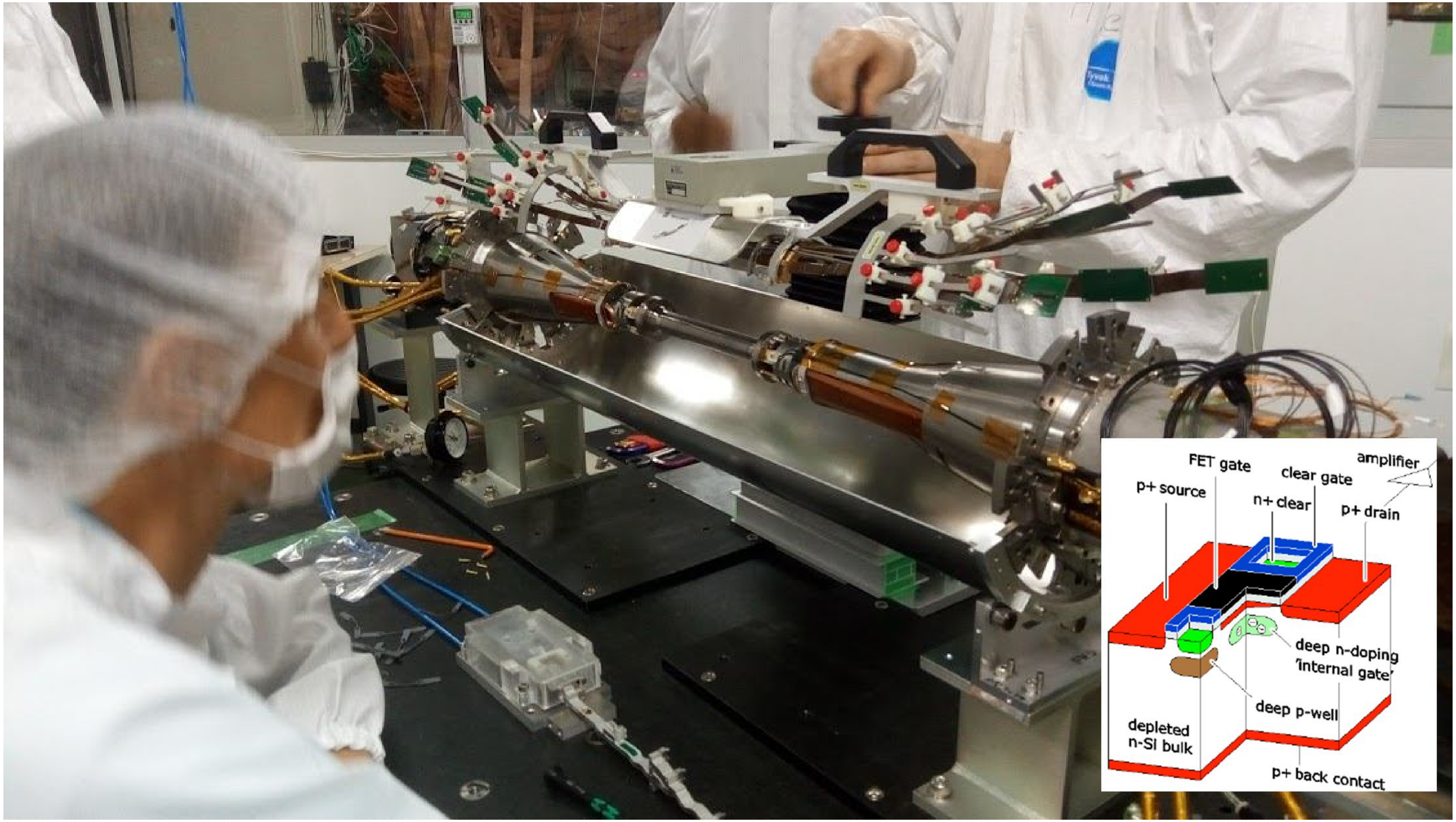
- Belle II will explore New Physics on the Luminosity or Intensity Frontier. This is different and complementary to the LHC high p_T experiments, which operate on the Energy Frontier. *Time for a paradigm shift ?*

- There is competition and complementarity with LHCb (@CERN)

- We are ready to start a long physics run in the Super Factory mode (Phase 3) in March 2019. This requires *high-efficiency* data-taking by Belle II and *extensive running* by Super KEK-B, soon to be the world's highest luminosity accelerator.

- The world is waiting for our results. (First ones expected at LP2019)
- There are excellent opportunities for collaborators from Vietnam

“Breaking news”



Lufthansa

First PXD was flown to Japan (business class).
This PXD half-shell being installed at KEK, last week.

Particle Boys Manga
素粒子男子
漫画

- Belle II will explore New Physics on the Luminosity or Intensity Frontier. This is different and complementary to the LHC high p_T experiments, which operate on the Energy Frontier. *Time for a paradigm shift ?*

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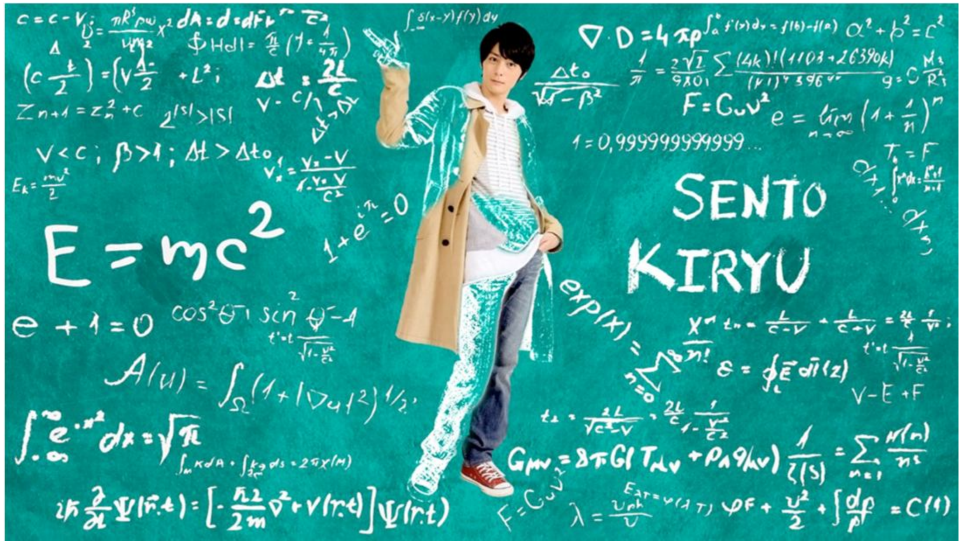
- The world is waiting for our results. (First ones expected at LP2019)

Backup Slides


ボトムクォークを大量(一千億個!)に生み出しその反応を測定する!!
どうなるかな？
パワーアップした二つの力で新たな物理法則が見つかるかもしれないのだ!!
ちなみにKEKBの性能は世界一を記録したんだよ
わ〜るど れこ〜〜ど
SuperKEKBはさらにその上をいく性能になる予定!
自分の記録を自分で抜いてしまうのだな
その力でぼくたちは宇宙への新たな一歩を踏み出した
それが今回の初衝突（ファースト・コリジョン）なんだよ
スー…
あれって…
素粒子のフレンズ…
新種か!?
待てっ…
ってあいつは…!?
★ファースト・ミーティン…!?

https://en.wikipedia.org/wiki/Kamen_Rider



“Now then, shall we start the experiment ?”

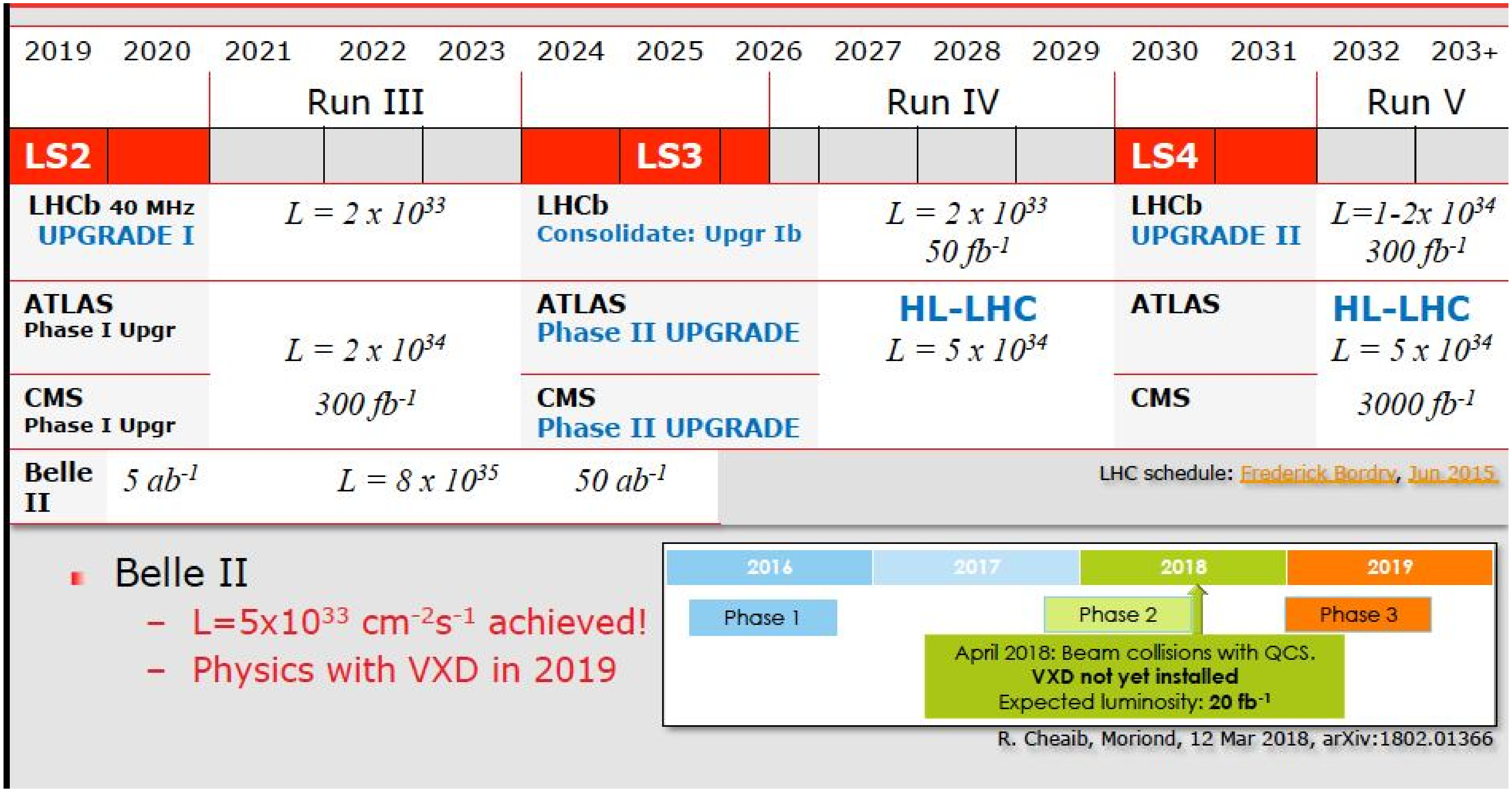
“さぁ、実験を始めようか。*Sa, jikken o hajimeyou ka.*”

Sento Kiryu (桐生 戦兎 Kiryū Sento), theoretical scientist and character in the “Kamen Rider Build” TV show

東都先端物質学研究所 *Touto Sendan Busshitsukakui Kenkyūsho (an imaginary research institute in the TV show)*

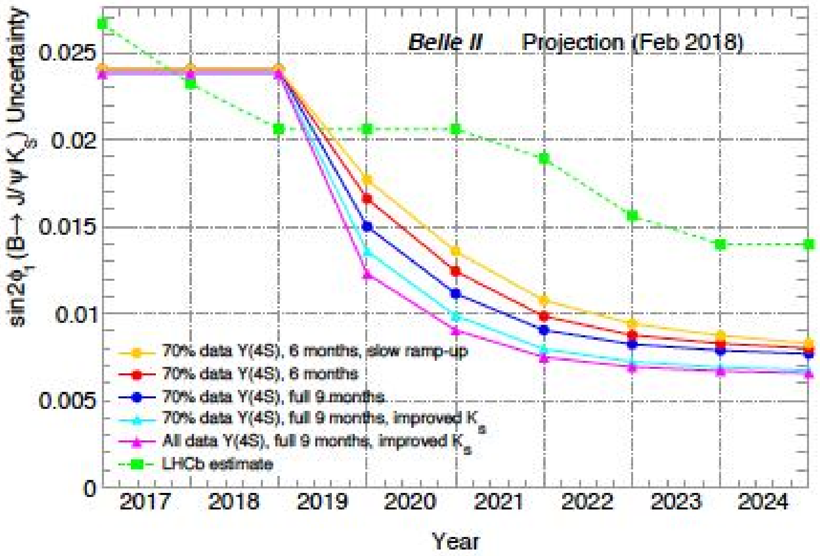
Thanks to Hiro Nakayama

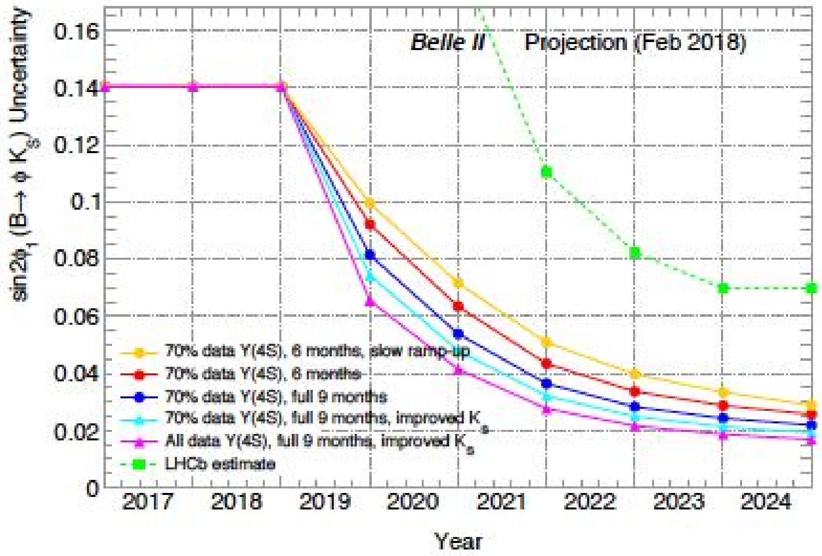
Physics Competition and Complementarity

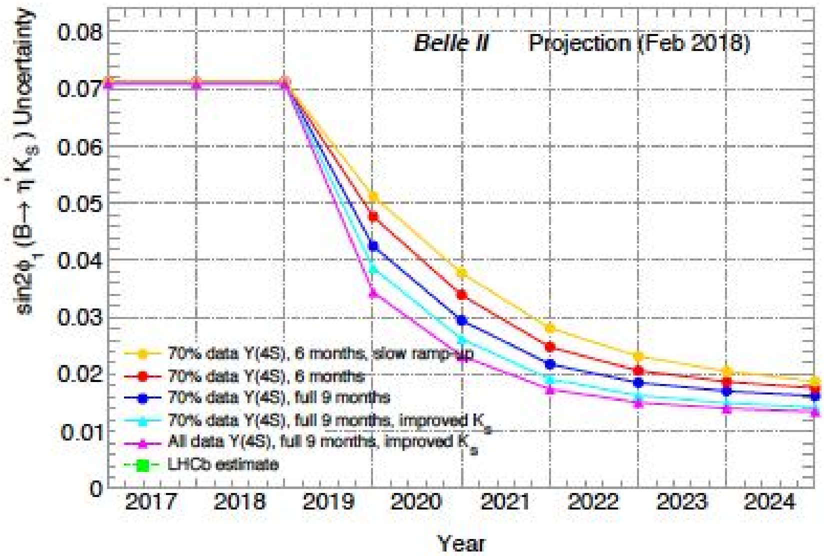


Outside perspective: Belle II inserted into the CERN global schedule. [slide from a plenary talk by Niels Tuning, ICHEP 2018 in Seoul, Korea]

Examples of Physics Competition and Complementarity



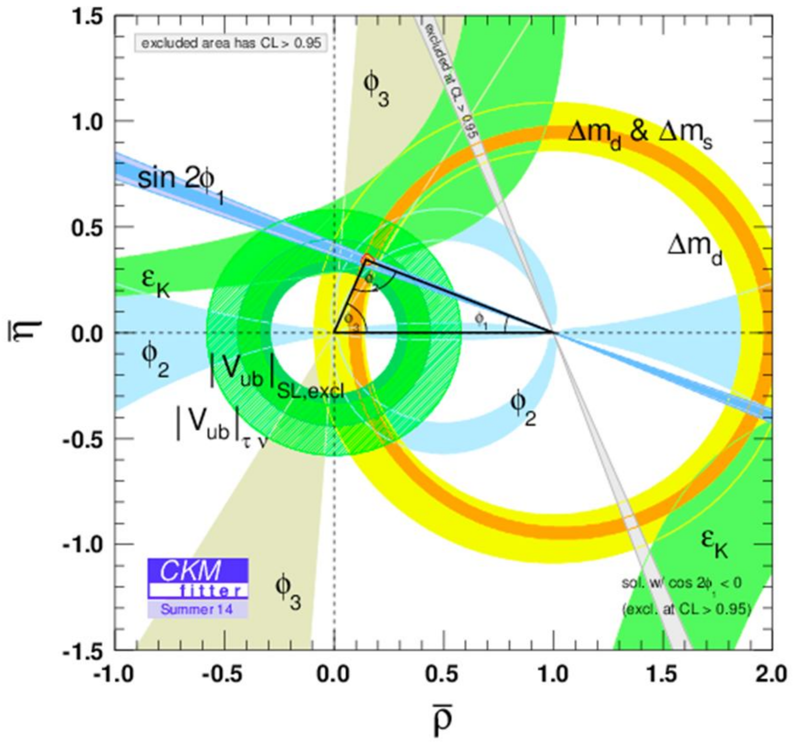




Use publicly available LHCb projections.

Results from Global Fits to Data (CKMFitter Group)

Great progress on φ_3 or γ (first from B factories and now in the last four years from LHCb). *These measure the phase of V_{ub}*

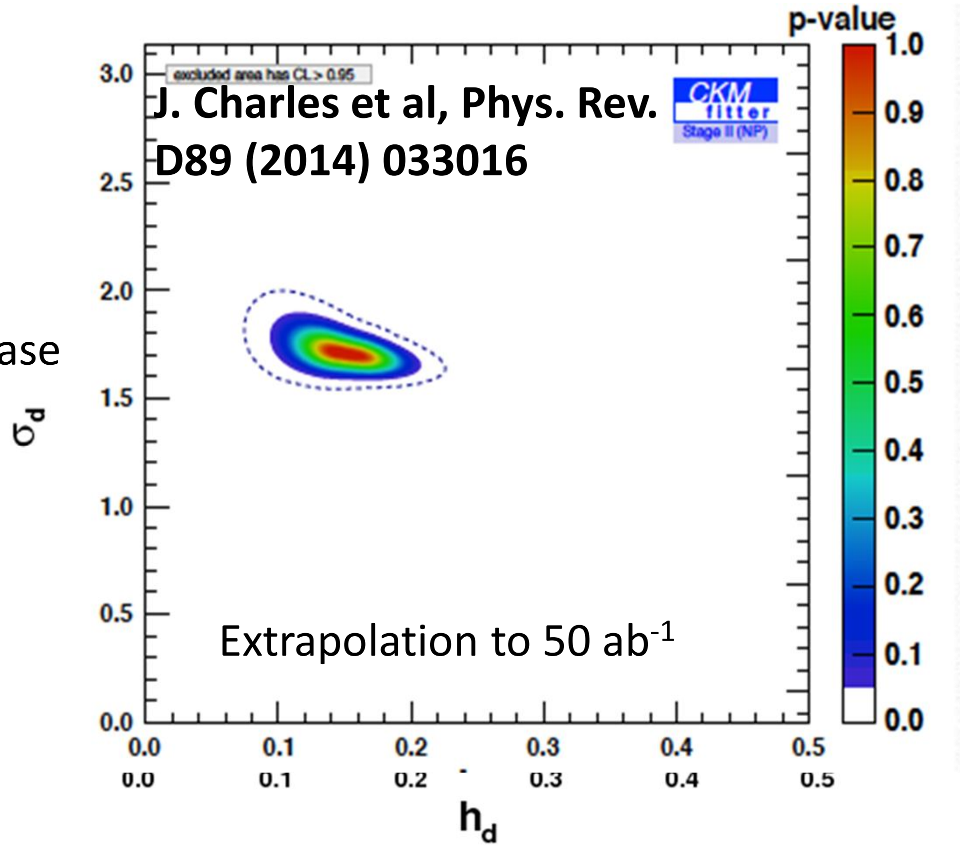


Looks good

(except for an issue with $|V_{ub}|$)

Similar results from UTFIT

NP Phase



NP/SM amplitude ratio

But a 10-20% NP amplitude in B_d mixing is perfectly compatible with all current data.

How can we establish NP in $B \rightarrow K^* l^- l^+$?

Ans: Observe and measure the rate for $B \rightarrow s\nu\bar{\nu}$ and thus isolate the Z penguin (C_9) at *Belle II*

Answer from Buras et al.

B2SS exercise: Draw the Feynman diagram for this process.
Draw this for two cases: kaon and K^* in the final state.

TABLE I: Projections for the statistical uncertainties on the $B \to K^{(*)}\nu\bar{\nu}$ branching fractions.

Mode	$\mathcal{B}$ $[10^{-6}]$	Efficiency Belle $[10^{-4}]$	$N_{\text{Backg.}}$ 711 fb^{-1} Belle	$N_{\text{Sig-exp.}}$ 711 fb^{-1} Belle	$N_{\text{Backg.}}$ 50 ab^{-1} Belle II	$N_{\text{Sig-exp.}}$ 50 ab^{-1} Belle II	Statistical error 50 ab^{-1}	Total Error
$B^+ \to K^+\nu\bar{\nu}$	3.98	5.68	21	3.5	2960	245	23%	24%
$B^0 \to K^0_S\nu\bar{\nu}$	1.85	0.84	4	0.24	560	22	110%	110%
$B^+ \to K^{*+}\nu\bar{\nu}$	9.91	1.47	7	2.2	985	158	21%	22%
$B^0 \to K^{*0}\nu\bar{\nu}$	9.19	1.44	5	2.0	704	143	20%	22%
$B \to K^*\nu\bar{\nu}$ combined							15%	17%

What's Ahead ?

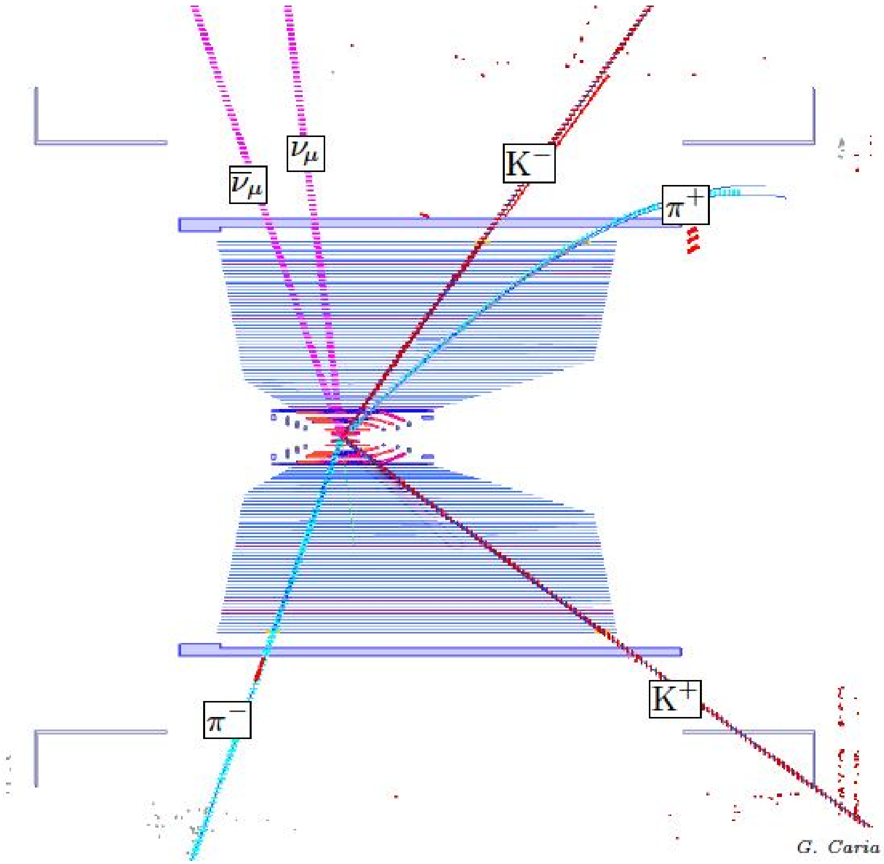
"Missing Energy Decay" in a Belle II GEANT4 MC simulation

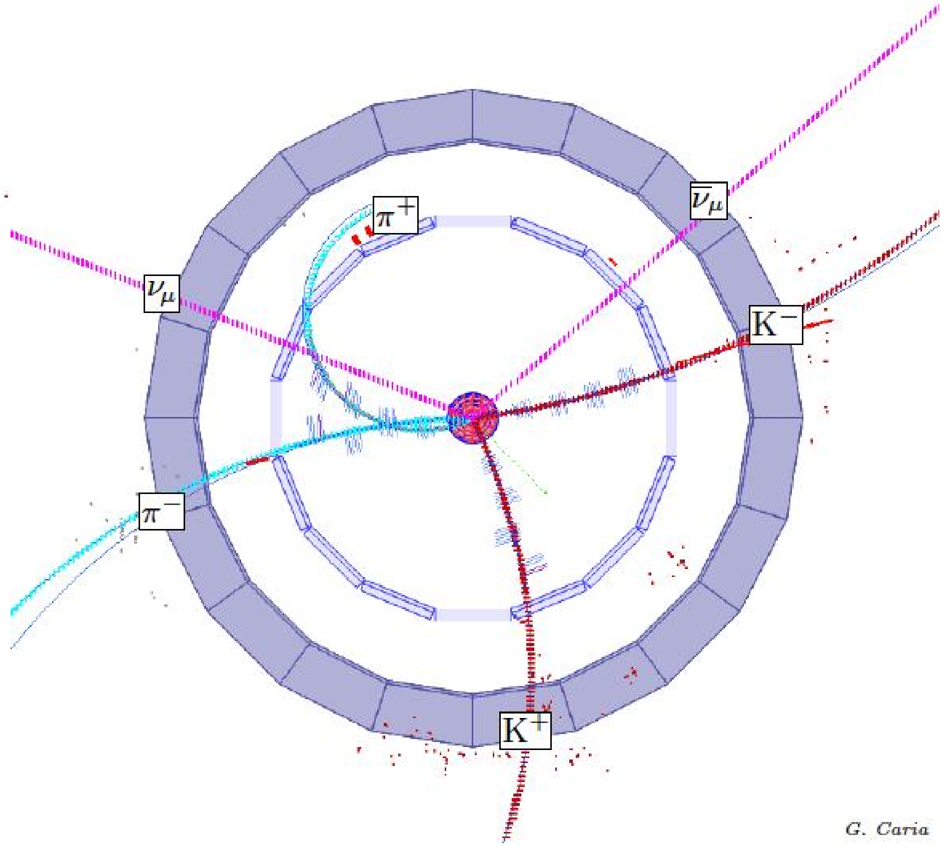
Signal: B→K ν ν

tag mode: B→Dπ; D→Kπ

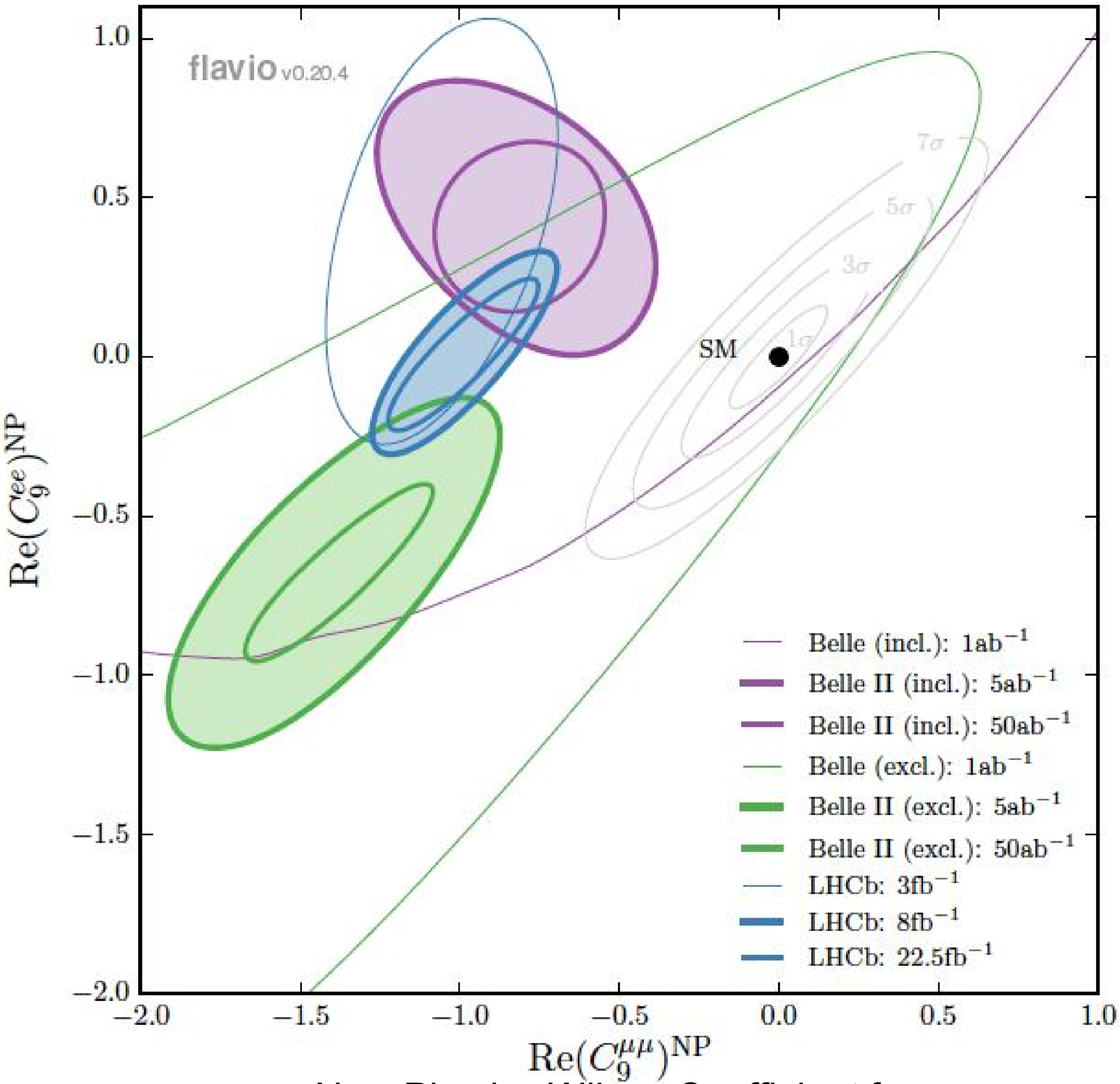
View in r-z

Zoomed view of the vertex region in r--phi





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

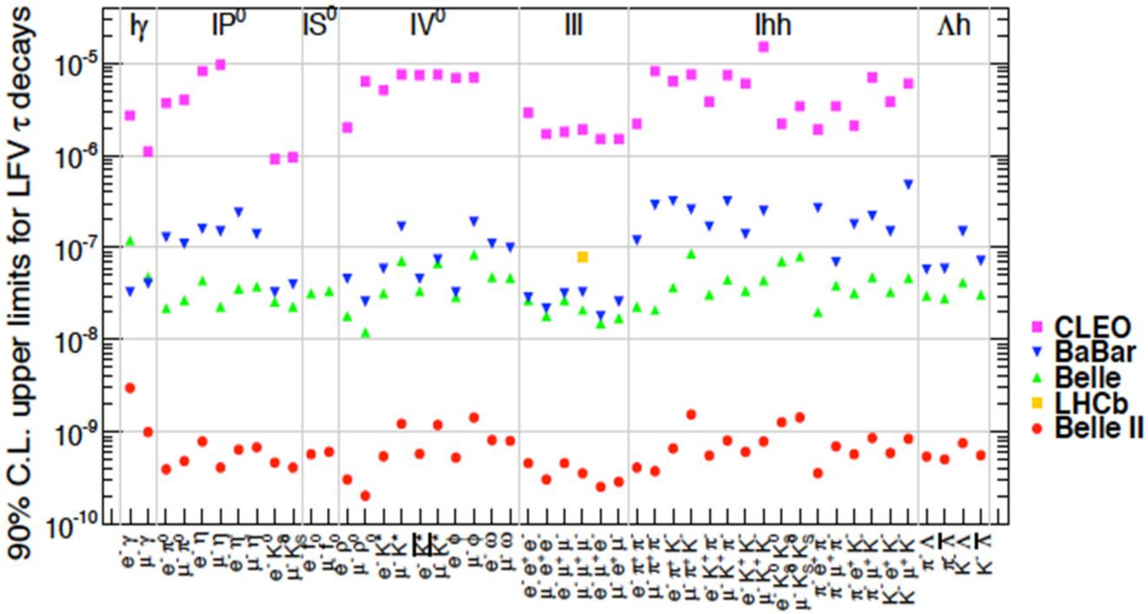


New Physics Wilson Coefficient for muons

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

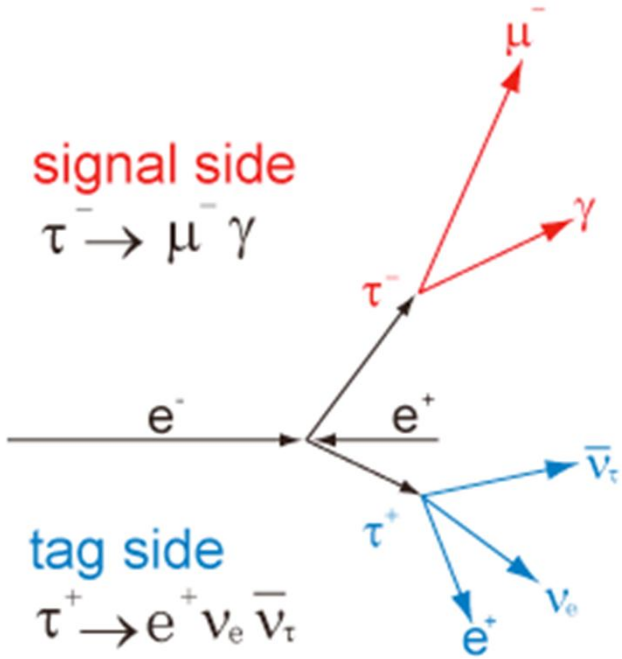
Belle II can do both <u>inclusive</u> and exclusive. Equally strong capabilities for electrons and muons.

What's ahead: τ Lepton Flavor Violation



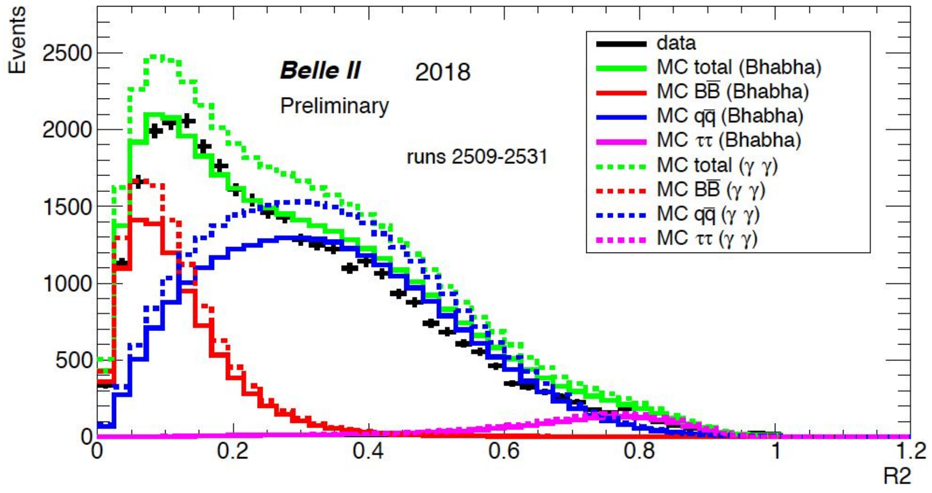
Note vertical log-scale (50 ab^{-1} assumed for Belle II; 3 fb^{-1} result for LHCb

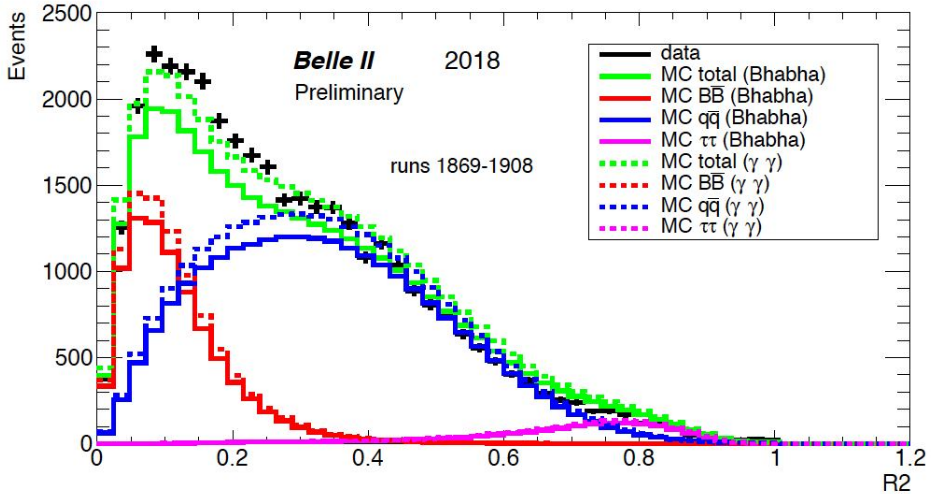
Example of the decay topology

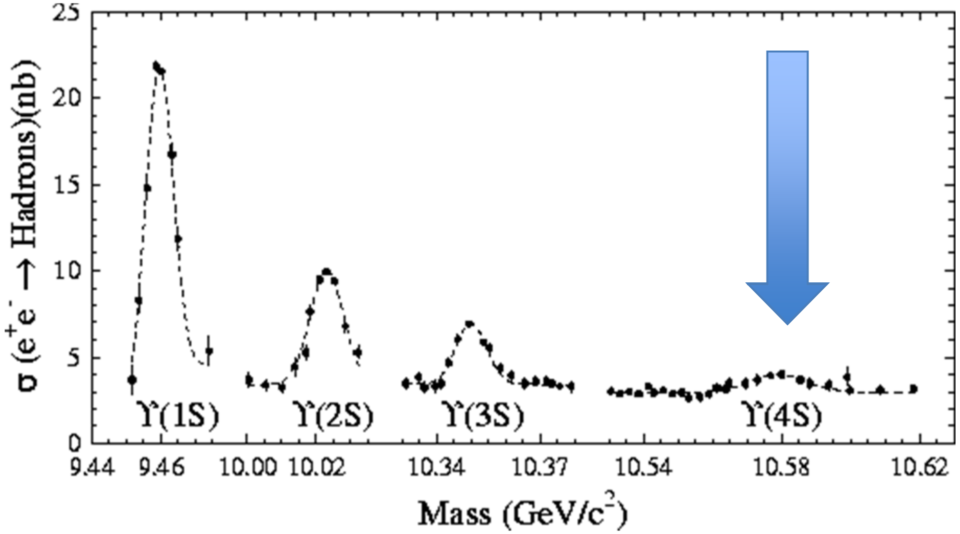


<u>Belle II will push many limits below 10^{-9}</u>;
LHCb, CMS and ATLAS have very *limited* capabilities.

LHC high pt: The modes τ→μγ and τ →μ h+ h- provide important constraints on H→μτ







PGU exercise:
Why is the 4S broad while the other three are narrow ?

Event Topology (fits to R_2) tells us we are seeing B's

Not so obvious: When we change accelerator optics, we remain on the Upsilon(4S) resonance.

Technical note: $R_2 = H_2/H_0$

$$H_l = \sum_{i,j} \frac{|\mathbf{p}_i||\mathbf{p}_j|}{E_{\text{vis}}^2} P_l(\cos\theta_{ij}) \, ,$$

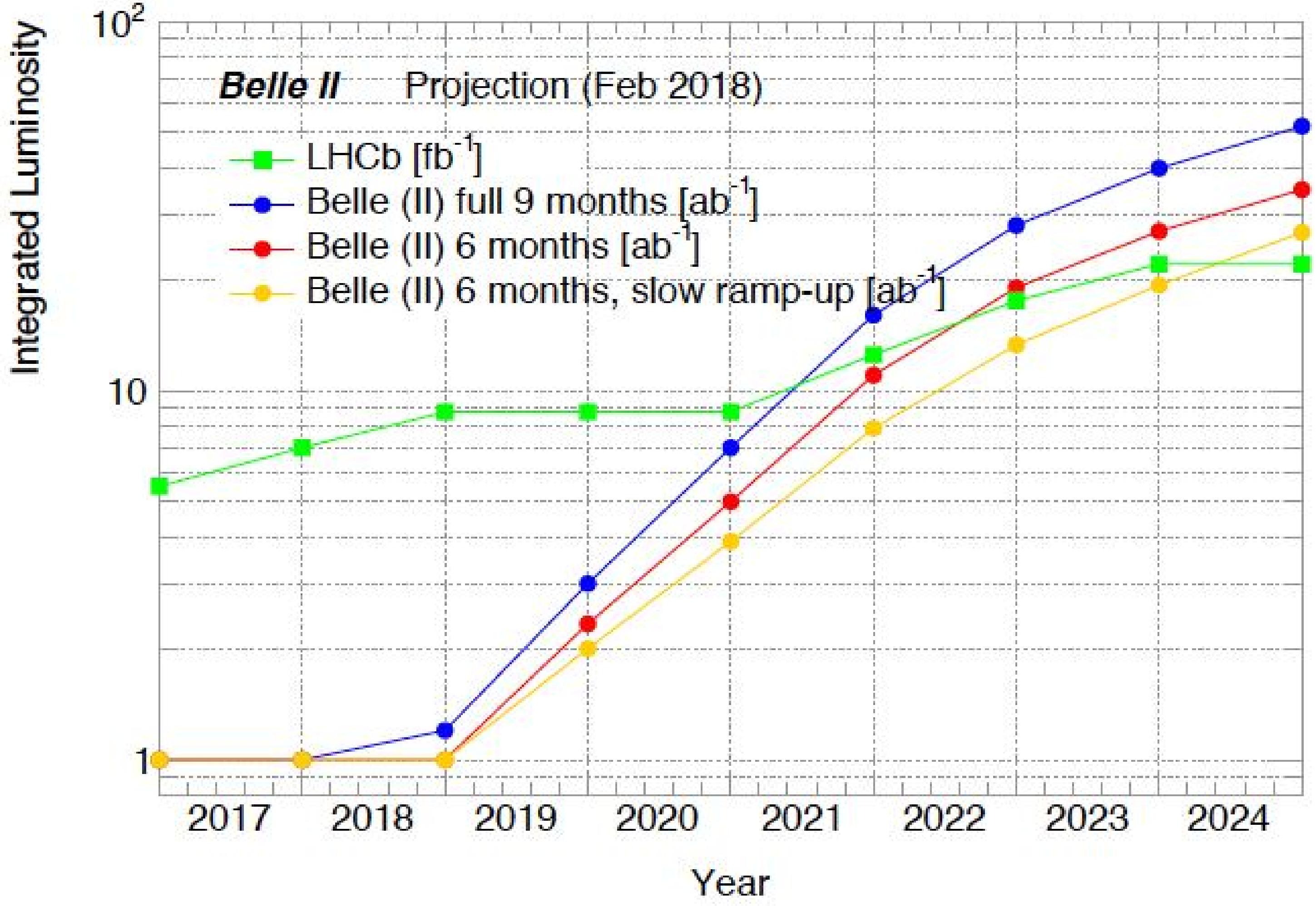


FIG. 2: SuperKEKB and LHCb integrated luminosity projections in fb^{-1} and ab^{-1} respectively.

More examples of Physics Competition and Complementarity

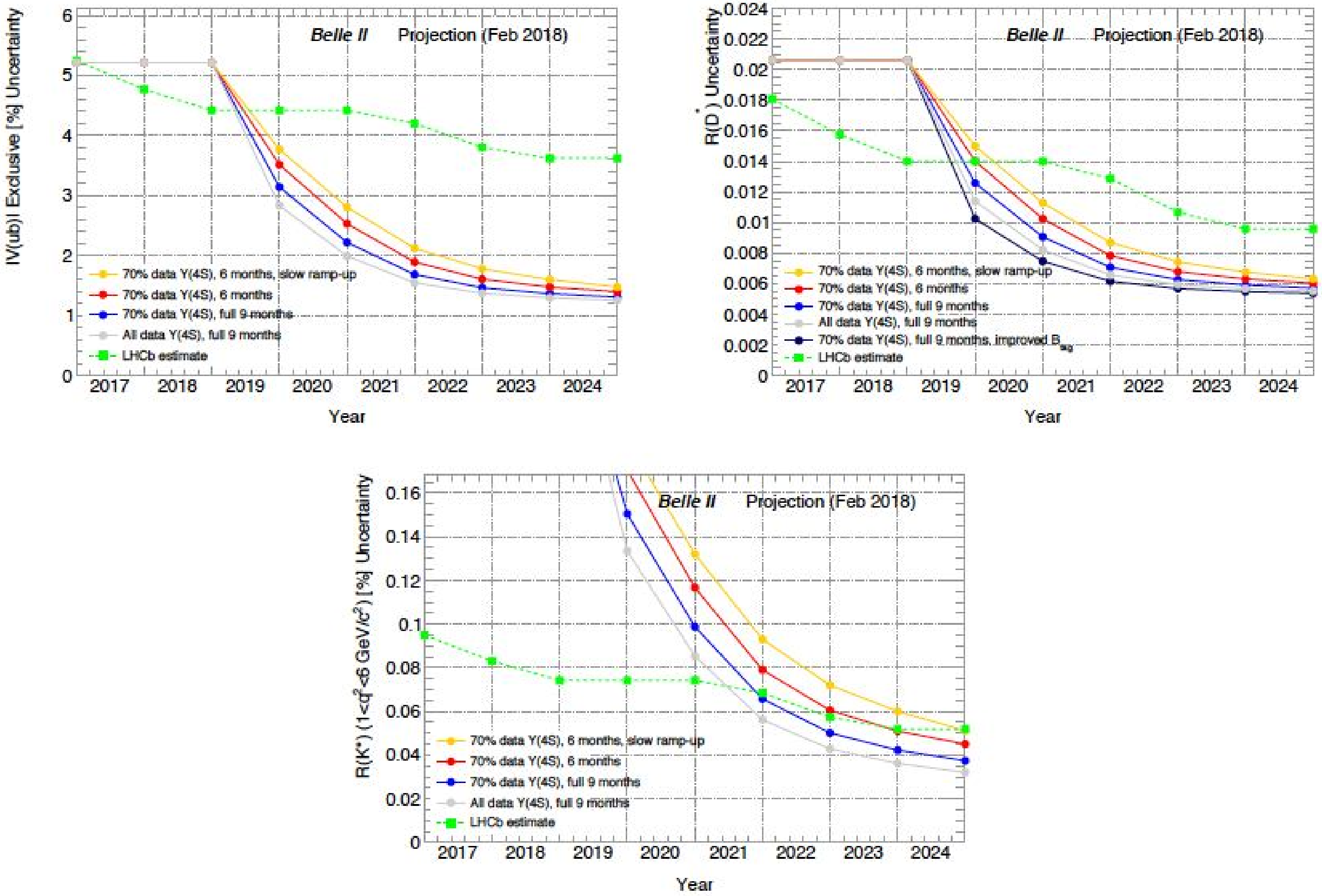
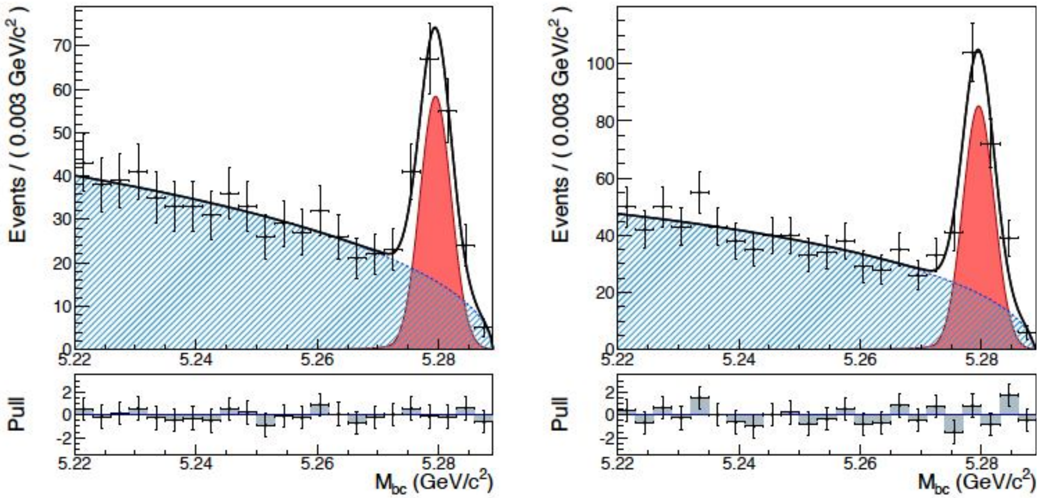


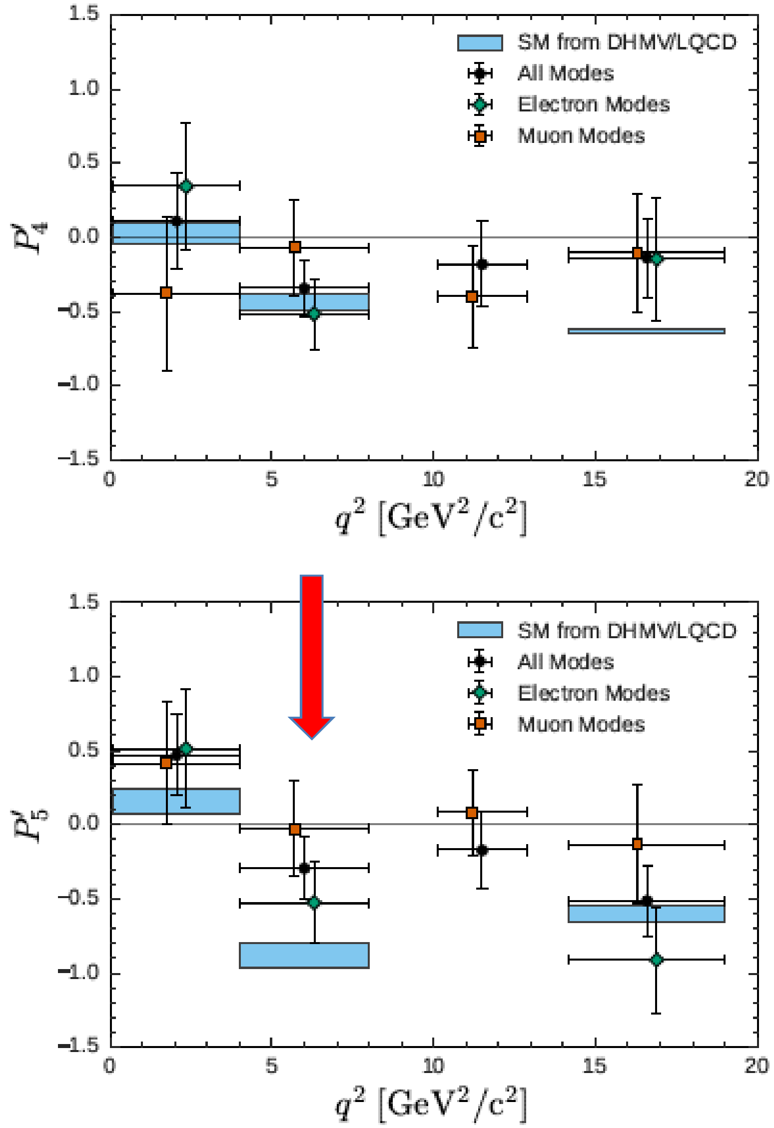
FIG. 6: Projected precision for various measurements of semileptonic B decays.

Use publicly available LHCb projections.

“We need more data !!”

Signal of
~312 events





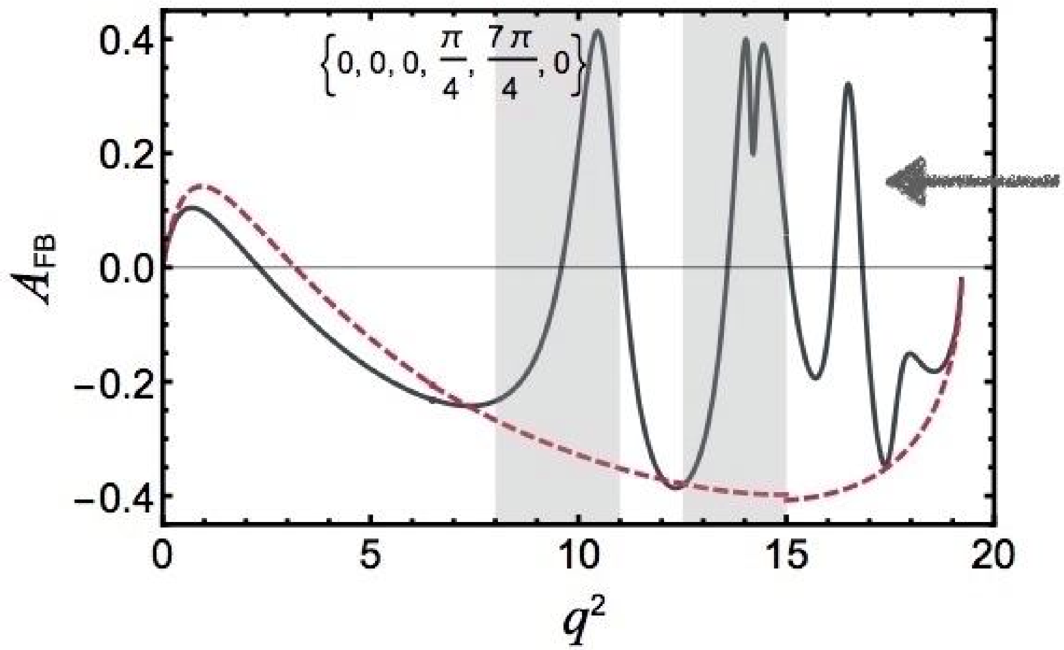
Belle I data. S. Wehle et al. (Belle collab)
arXiv: 1612.05014, published in PRL

Slide from R. Mandal

Systematics from charmonium resonances in ArXiv:1603.04355

$c\bar{c}$ bound states added: J/ψ, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, $\psi(4415)$.

Observable $=$ Form-factors $+$ Kruger & Sehgal parametrization



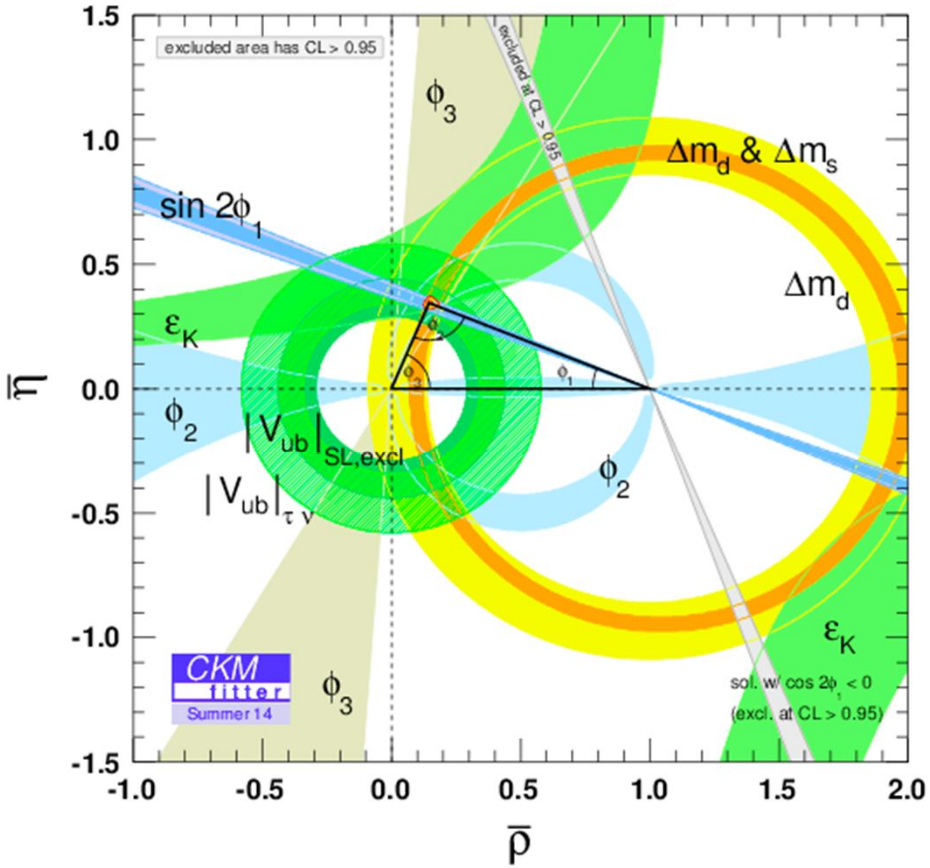
Asymmetries decrease in high q^2 region

makes observable ω_1 unphysical

Random variation of each strong phases

Conclusions about the presence of NP unchanged

Results from Global Fits to Data (CKMFitter Group)



PGU Question:
What are the x and y axes ?

PGU Question: What is ε_K ? Why is the band so broad ?

PGU Question: What is Δm_d , Δm_s ? What is their ratio in terms of CKM parameters ?

PGU Question: Why is the region for V_{ub} a circular disk ?

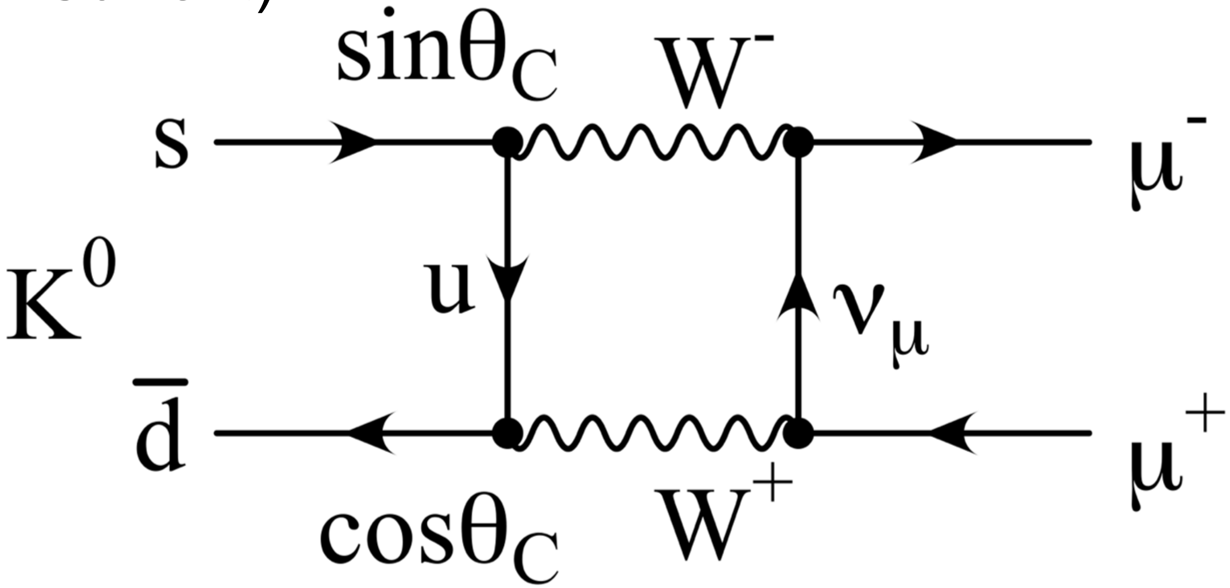
PGU Question: Where are the measurements of $B \rightarrow J/\psi$ K ? Why are there two associated regions ?

High Energy Physics
Spot Check

- What do the acronyms LER and HER stand for ?
- Why aren’t the electron and positron beam energies equal ?
- Why is a larger current stored in the positron beam ?
- BTW, the LHC uses p p collisions rather than proton-anti proton collisions as at the Fermilab Tevatron and earlier hadron colliders. Why ?

PGU: What is the GIM (Glashow Illiopoulus-Maiani) Mechanism ?
Or GIM suppression ? What is an FCNC (Flavor Changing Neutral Current) ?

Hint:



"Tsukuba, we have a Problem"

(apologies to Tom Hanks, Apollo 13)

WMAP data

$$\eta \equiv \frac{n_b - n_{\bar{b}}}{n_\gamma} = (6.21 \pm 0.16) \times 10^{-10}$$

KM Theoretical prediction

$$\left(\frac{n_b}{n_\gamma}\right)^{\text{SM}} \propto \frac{J_{CP}}{T_c^{12}} \sim 10^{-20}$$

The CP Violation predicted by Kobayashi and Maskawa is too small by *~10 orders of magnitude* in the Standard Model.

→ What does this mean ?

"Tsukuba: we need some New Physics"

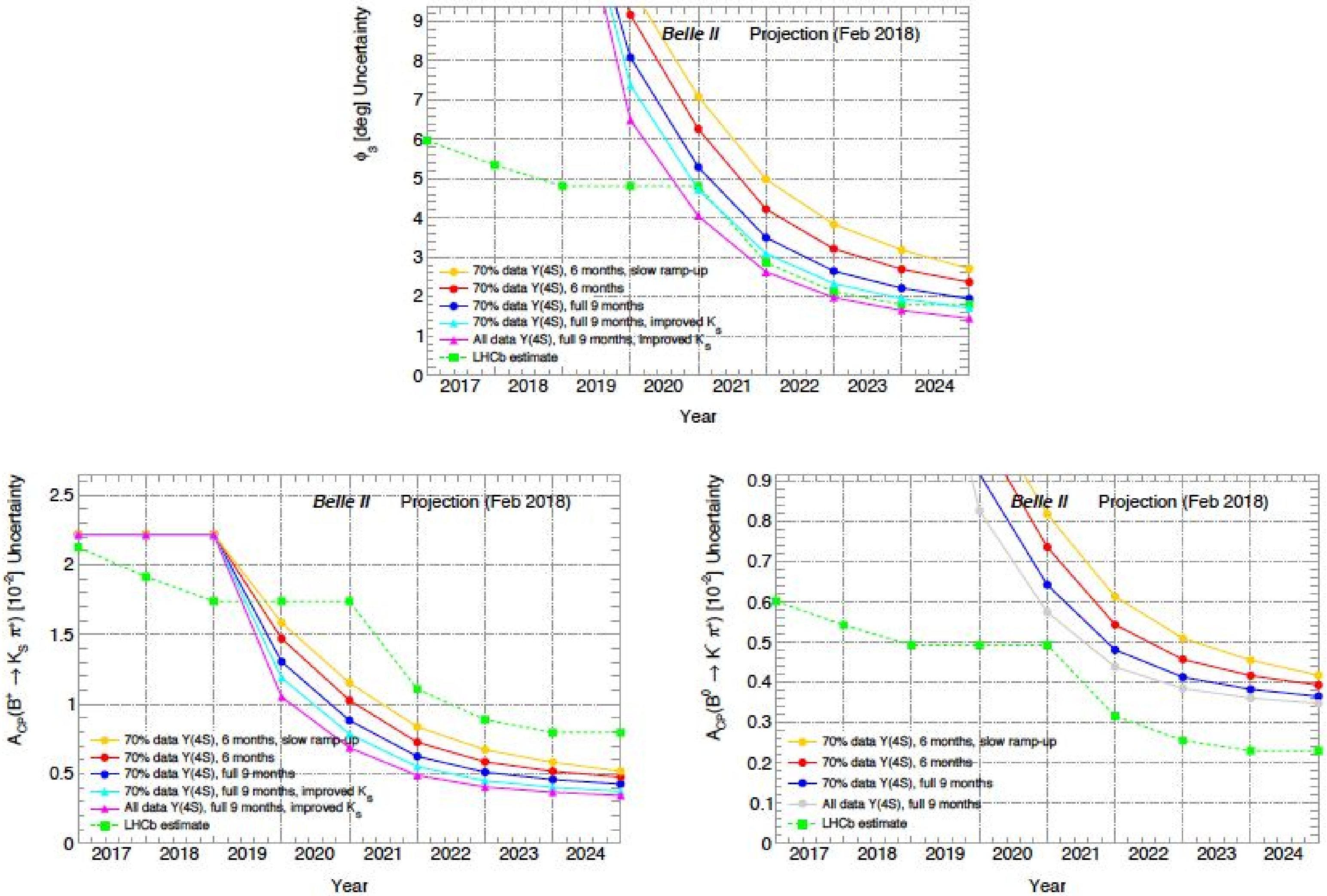
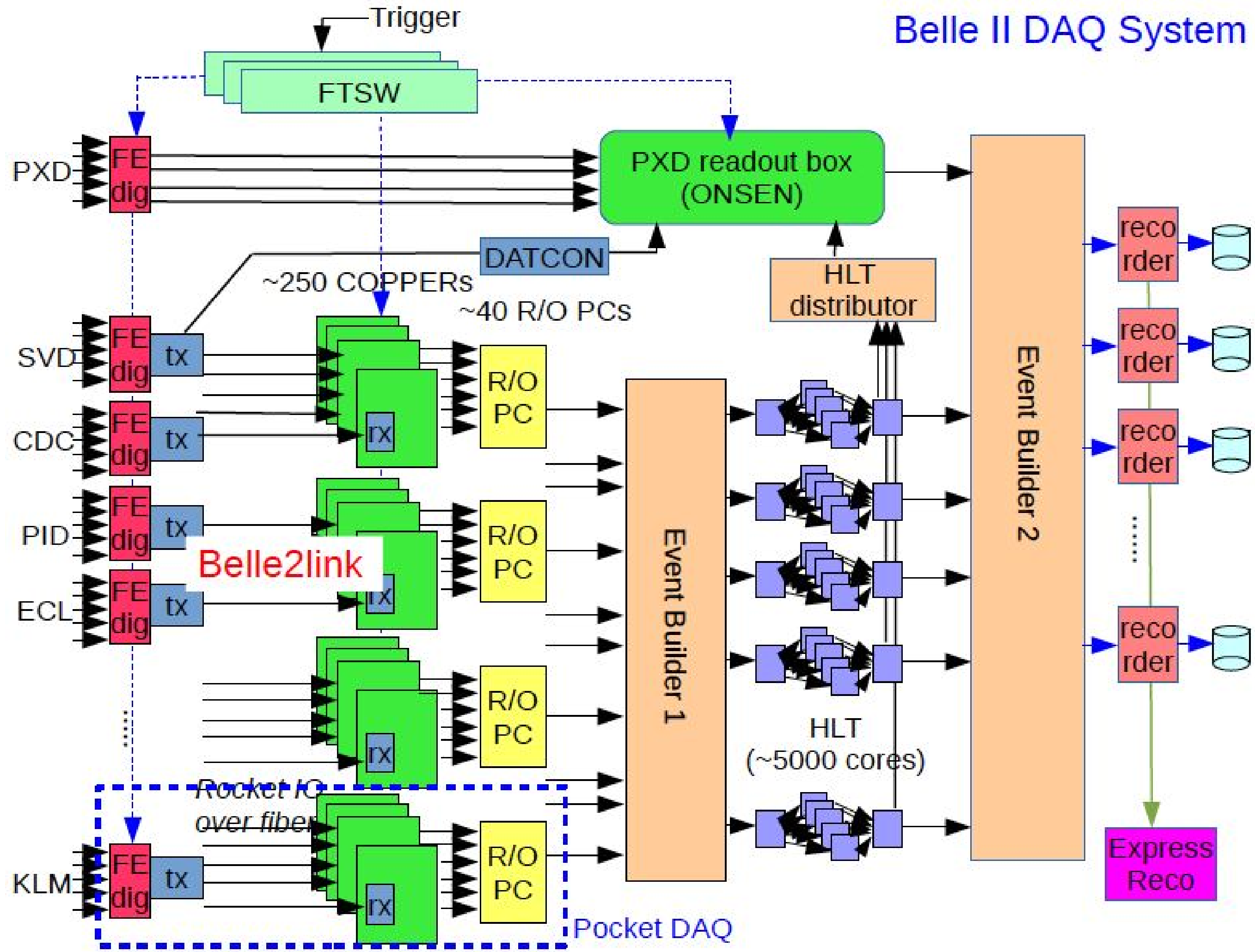


FIG. 5: Projected precision for various measurements of direct CP violation.

Machine Parameters

2017/September/1	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28		includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	3.20×10^{-4}	4.55×10^{-4}		
σ_δ	$7.92(7.53)\times10^{-4}$	$6.37(6.30)\times10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6(4.7)	5(4.9)	mm	():zero current
ν_s	-0.0245	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.76	2.43	MeV	
$\tau_{x,y}/\tau_s$	45.7/22.8	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$	

Belle II has a modern DAQ and readout system

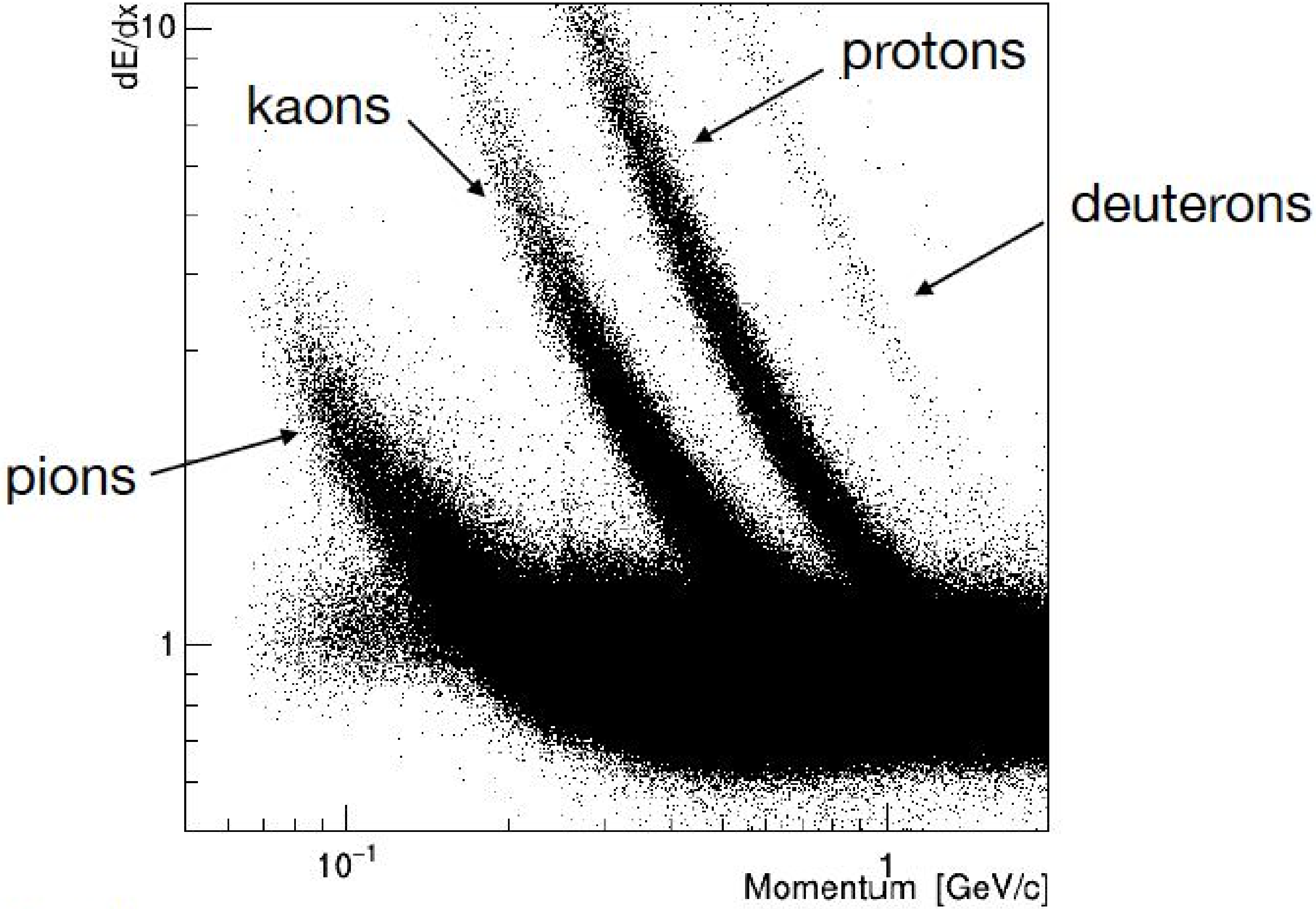


Item to note: Front-end readout electronics and Gb fiber optic link(Belle2link) to the back-end.

More on G. Varner's B2SS talk.

Item to note: Note ROI(Region of Interest) for PXD data volume.

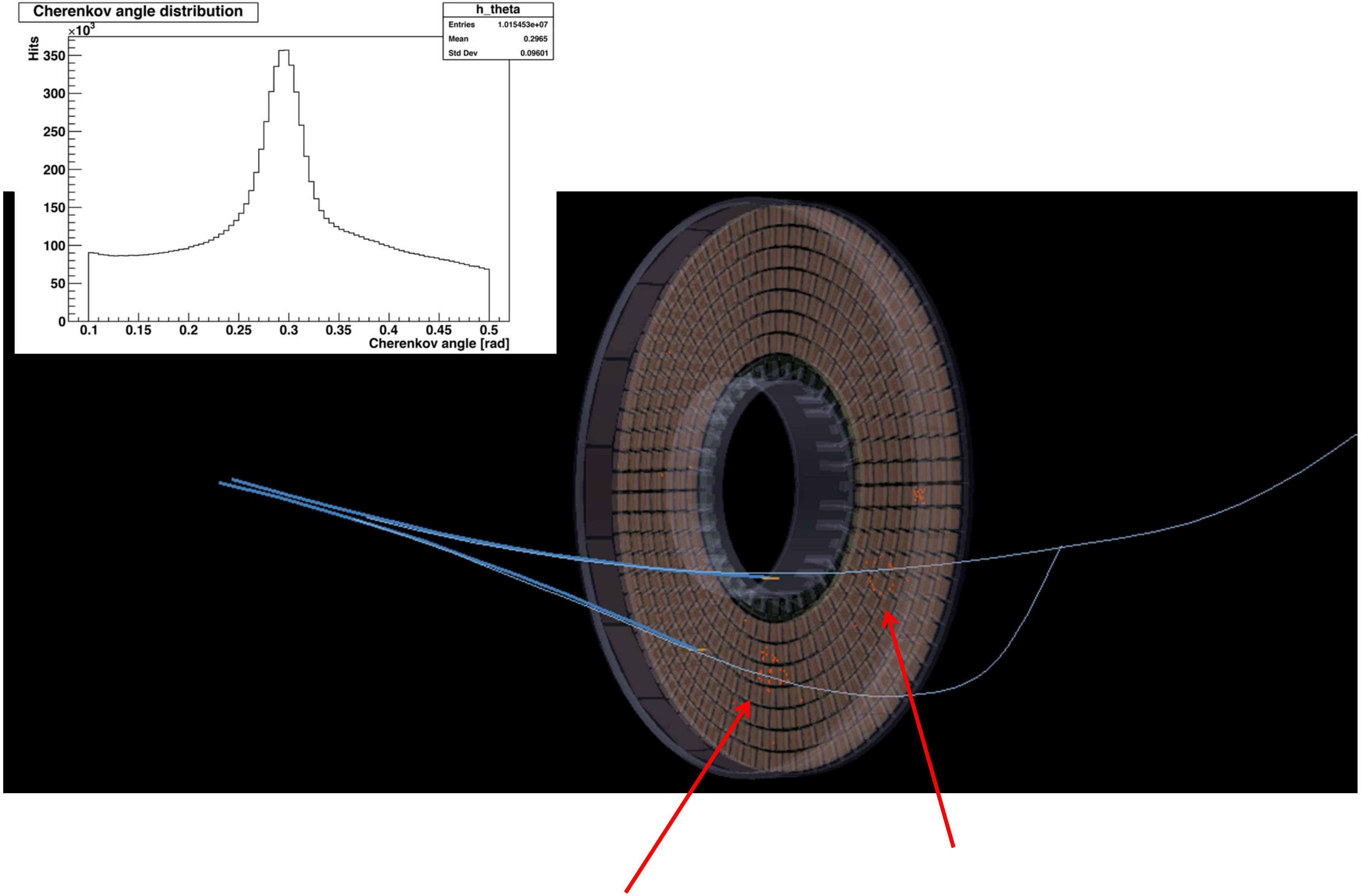
Performance of CDC dE/dx particle identification with early calibrations in the hadronic event sample.



Extra cuts:
- |d0| < 1
- |dz| < 3
- # layers hit > 20

Jake Bennett, Roy Briere et al.

Endcap particle identification via Aerogel RICH (ARICH)

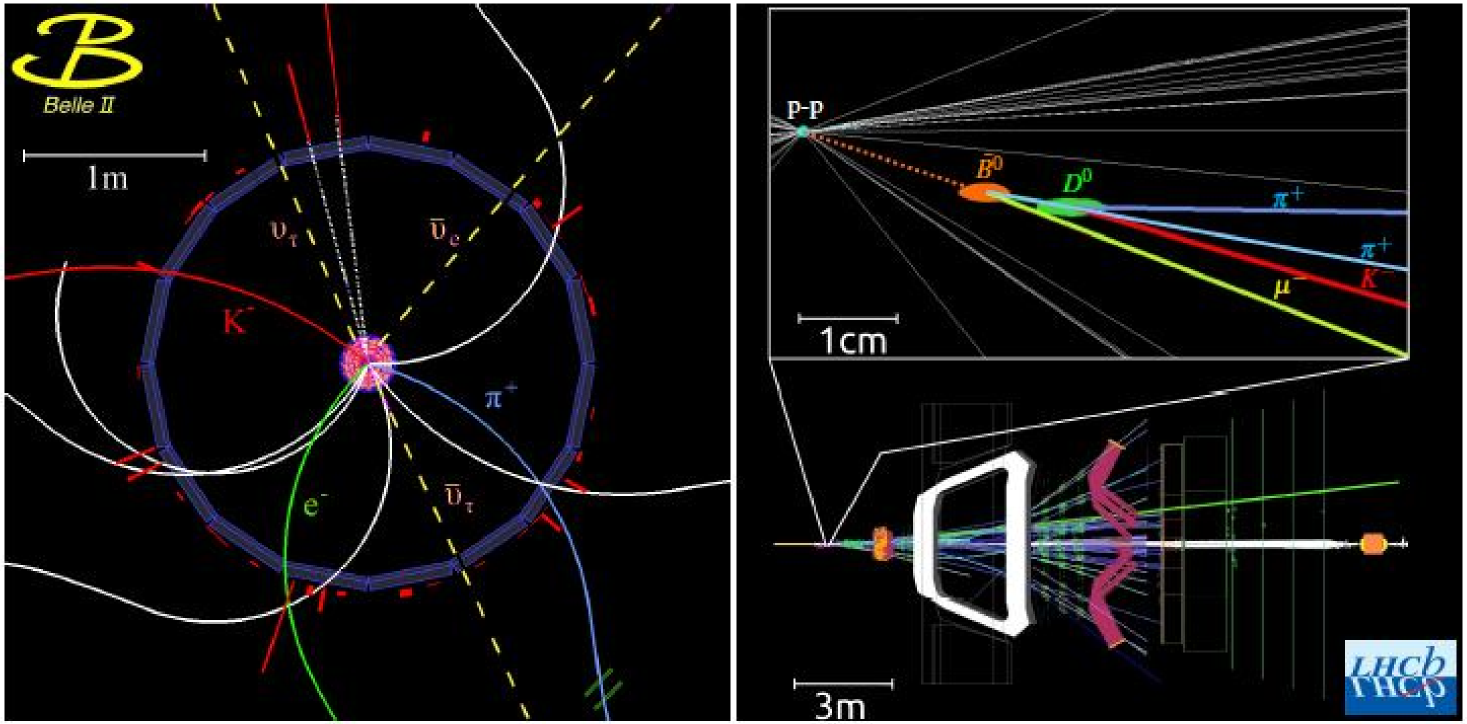


ArXiv: 1703.01766, published in Nature 546, 227–233 (08 June 2017)

A Challenge to Lepton Universality in B Meson Decays

Gregory Ciezarek[1], Manuel Franco Sevilla[2], Brian Hamilton[3], Robert Kowalewski[4], Thomas Kuhr[5], Vera Lüth[6], Yutaro Sato[7]

One of the key assumptions of the Standard Model of fundamental particles is that the interactions of the charged leptons, namely electrons, muons, and taus, differ *only* because of their different masses. While precision tests comparing processes involving electrons and muons have not revealed any significant violation of this assumption, recent studies involving the higher-mass tau lepton have resulted in observations that challenge lepton universality at the level of four standard deviations. A confirmation of these results would point to new particles or interactions, and could have profound implications for our understanding of particle physics.



Outer Detector Highlights

Belle II Jargon/Acronym Check

KLM = [KLong- Muon] detector (Endcap and Barrel) [RPC = Resistive Plate Chamber];

EKLM = Endcap KLM; BKLM= Barrel KLM

CsI(Tl) crystals (measures energies of photons et al.)

(ECL = Electromagnetic CaLorimeter)

Barrel PID Distinguishes kaons from pions/Cherenkov radiation

(iTOP = imaging Time Of Propagation)

Endcap PID Distinguishes kaons from pions/Cherenkov radiation

(ARICH = Aerogel Ring Imaging Cherenkov)

CDC = Central Drift Chamber (provides momenta). Via tracking in a 1.5 T B field.

History/Background:

The Flagship Measurement for the “old” B Factories

At the Upsilon(4S), we produce pairs of QM entangled B anti-B pairs in a C=-1 state.

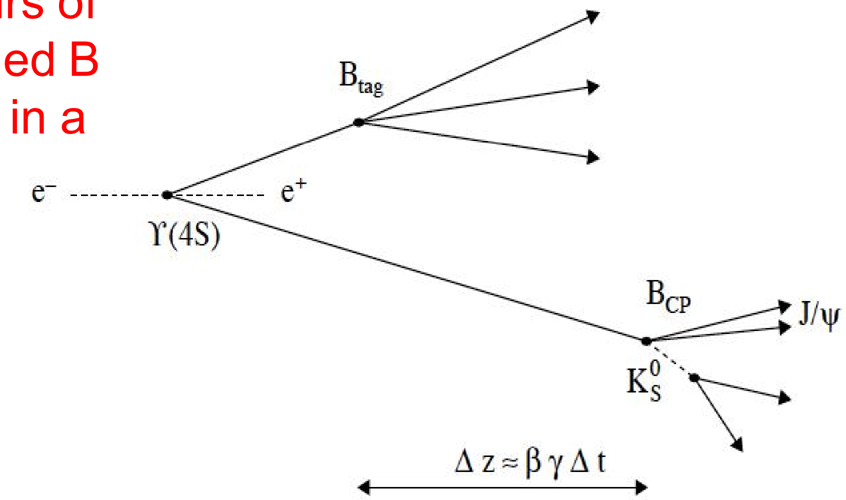


Figure 10.2.1. An illustration (not to scale) of a B meson pair decaying in the laboratory frame of reference. On the left hand side of the figure, the initial e^+e^- pair collides producing an $\Upsilon(4S)$. This subsequently decays into two B mesons described by the wave function given in Eq. (10.2.1), one decaying into a $B_{\rm tag}$ final state and the other into a B_{CP} final state. Once the first B meson decays, the remaining one oscillates with the characteristic frequency Δm_d before finally decaying. The spatial distance Δz between the decay vertices of the $B_{\rm tag}$ and B_{CP} as measured in the laboratory frame of reference is related to the proper time difference Δt between the decays of these particles in the center-of-mass frame of reference (see Section 6.5). In this example the B_{CP} final state is $J/\psi K_S^0$.

Boost factors and asymmetric energies:

PEPII/BaBar βγ-0.56;
(9 x 3.1 GeV)

KEKB/Belle βγ-0.43;
(8.0 x 3.5 GeV)

SuperKEKB/Belle II βγ=0.284 (7.0 x 4.0 GeV); smaller boost but improved LER lifetime and backgrounds; better acceptance for “missing energy” decays

Exercises:

1) Why do time-integrated asymmetries vanish at the 4S ?
2) Verify the βγ factors