The Belle II experiment.

First results, status, and prospects

Sam Cunliffe
Epiphany XXVII, Krakow (→ virtual), 07.01.2021

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Belle II

DESY.

Dziękuję za zaproszenie

What I will talk about...

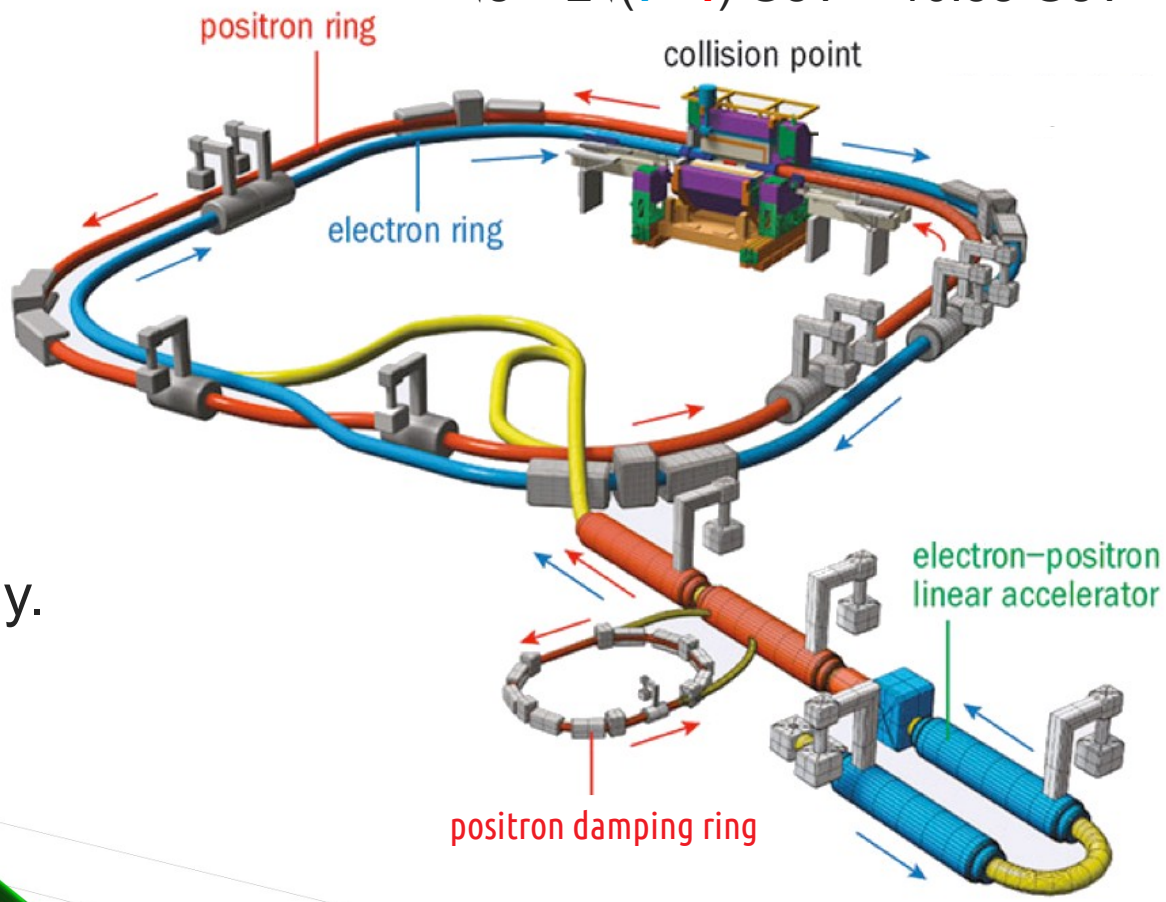
- The experimental apparatus.
- Where we are in data-taking.
- First (world-leading) physics!
- Physics status and prospects.

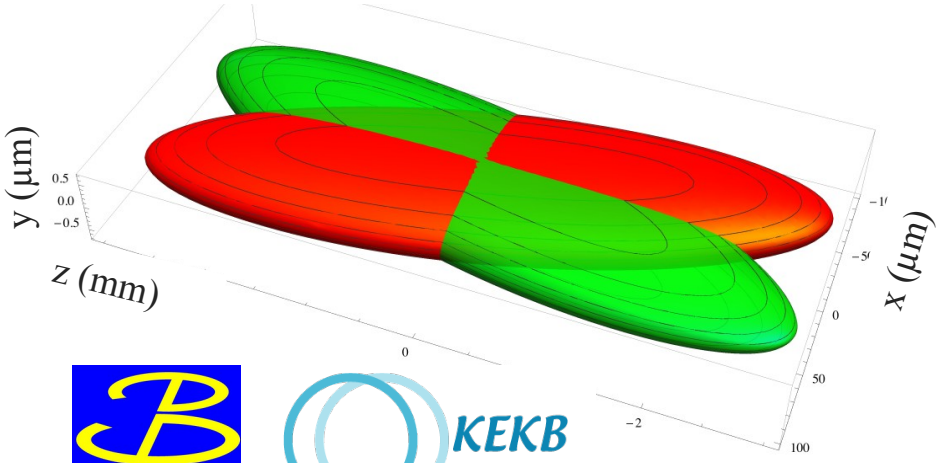
Apparatus

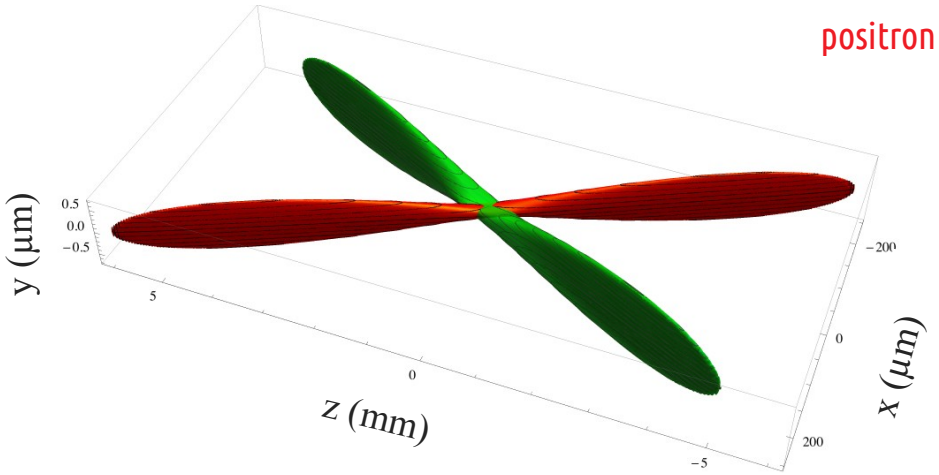
SuperKEKB

$\sqrt{s} = 2\sqrt{(7\times4)}$ GeV = 10.58 GeV

- Reason for the second iteration of the project: **upgraded accelerator**.
- Factor **30** increase in instantaneous luminosity
  - ×1.5 from upgraded ring (higher current).
  - ×20 β* from final focus magnets.
- Asymmetric collision. Nominally at Υ(4S) energy.
  - $\mathcal{B}$ [Υ(4S) → B$\bar{\text{B}}$] ≈ 100%

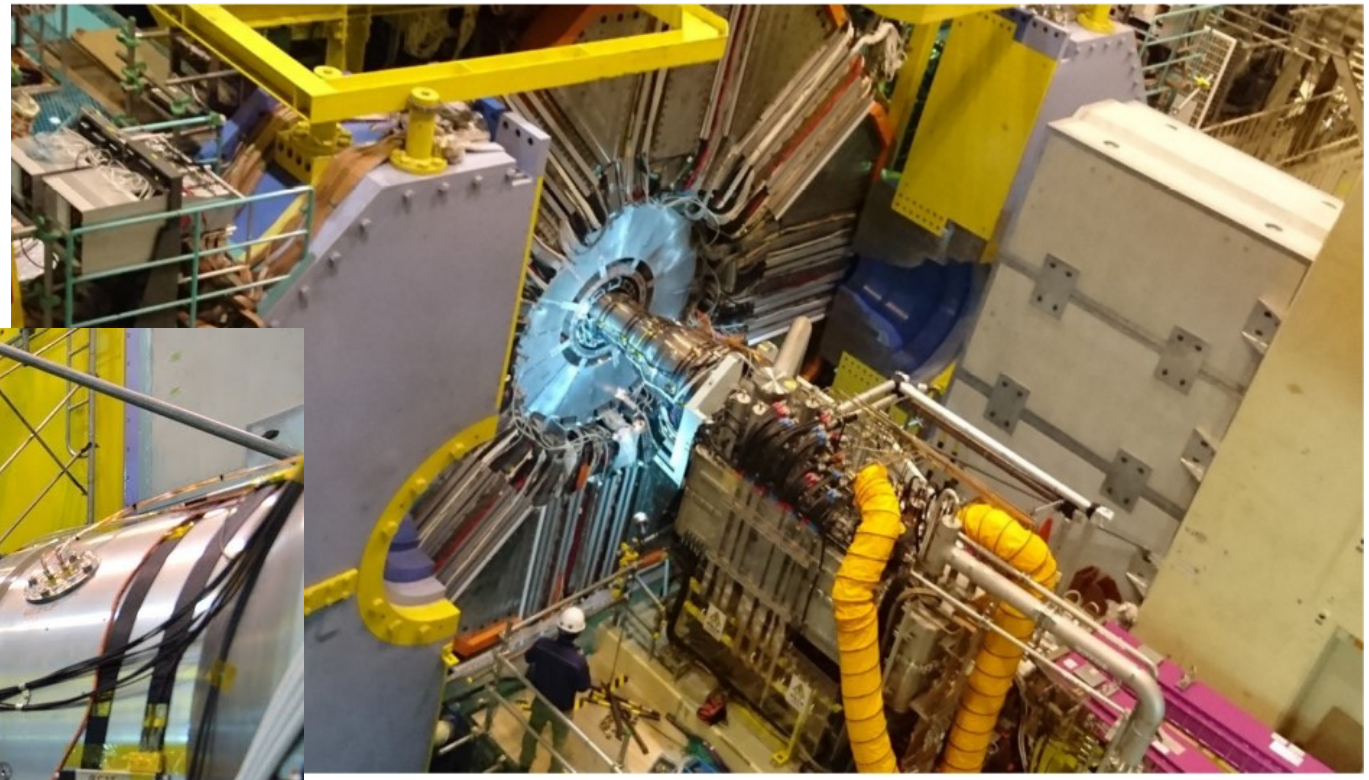


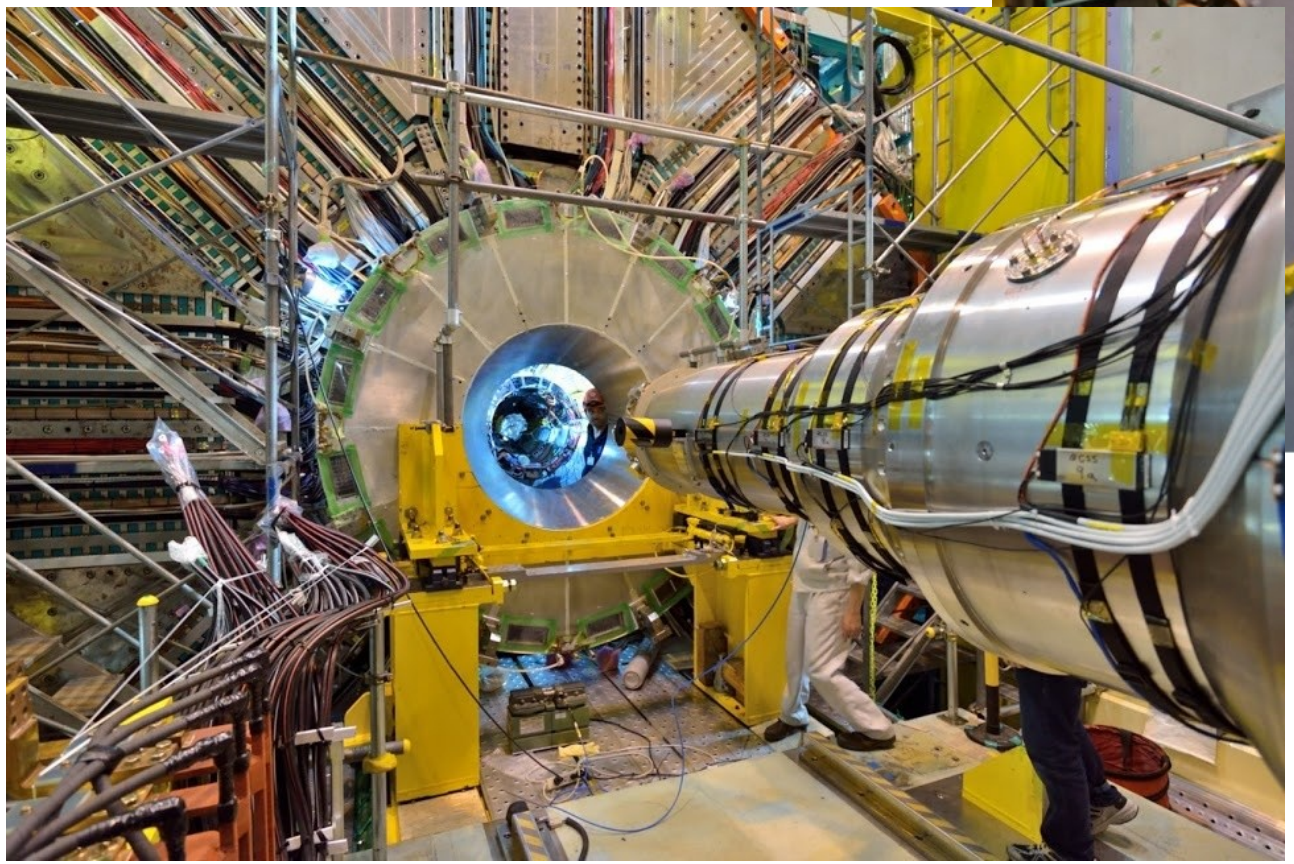




Final focus magnets

February 2018

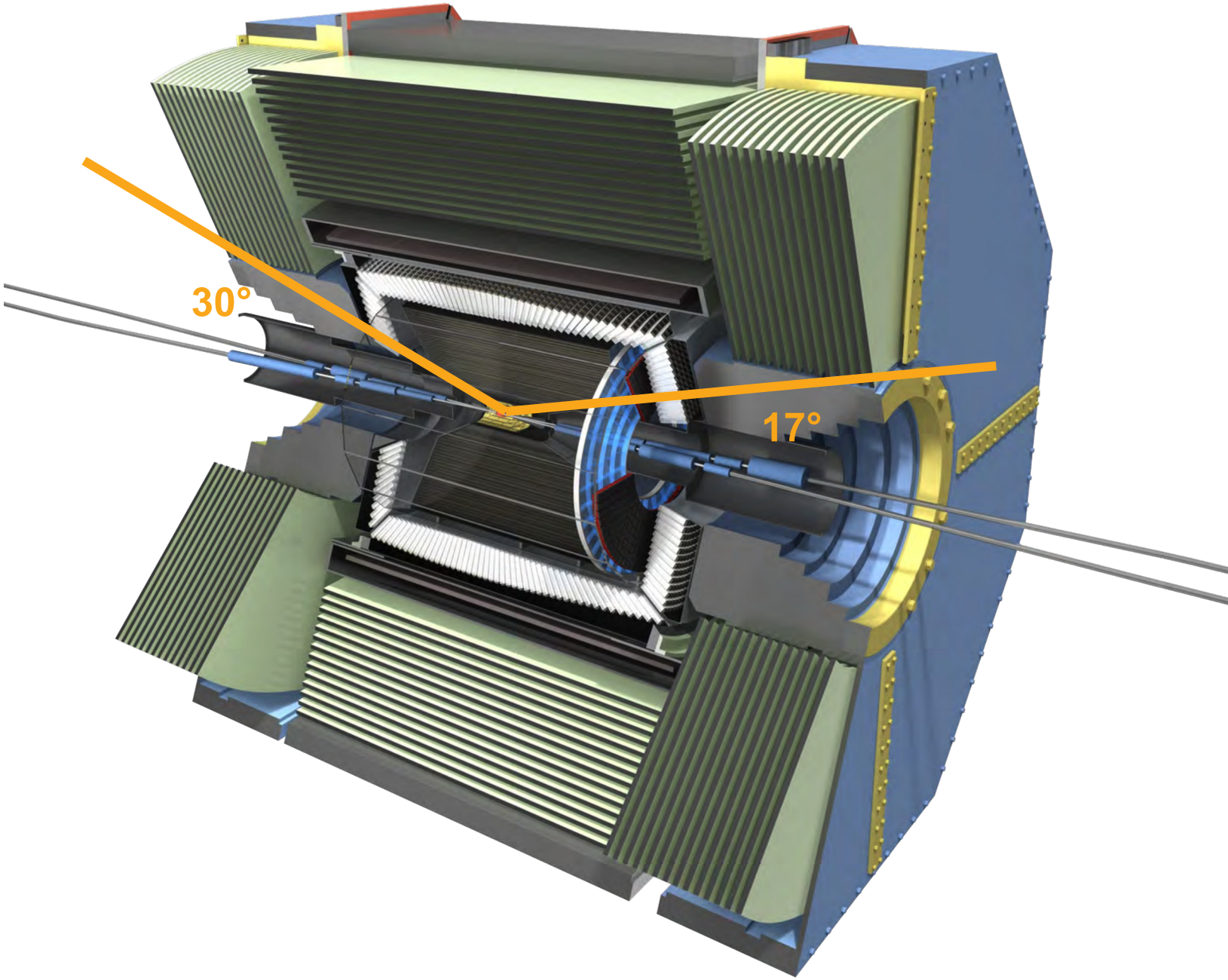




Belle II

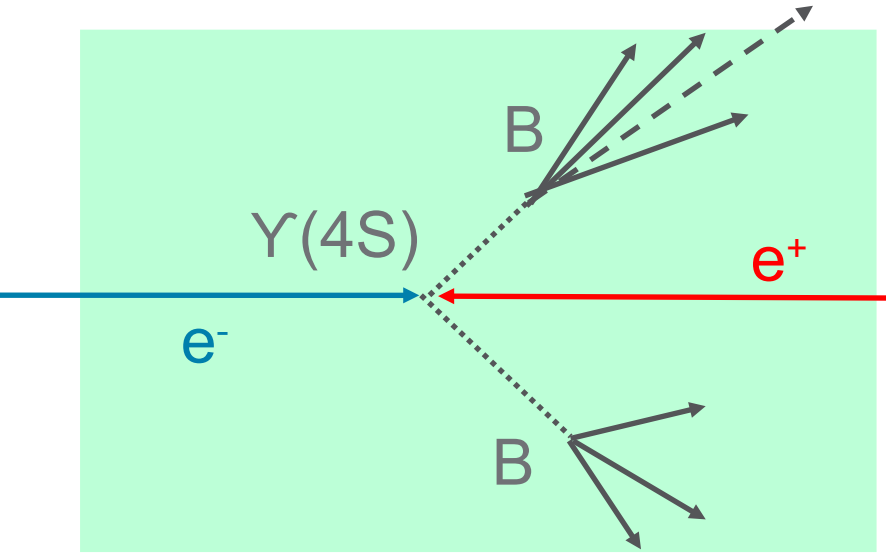
The detector

Direction of boost
Direction of electron beam
“Forward”

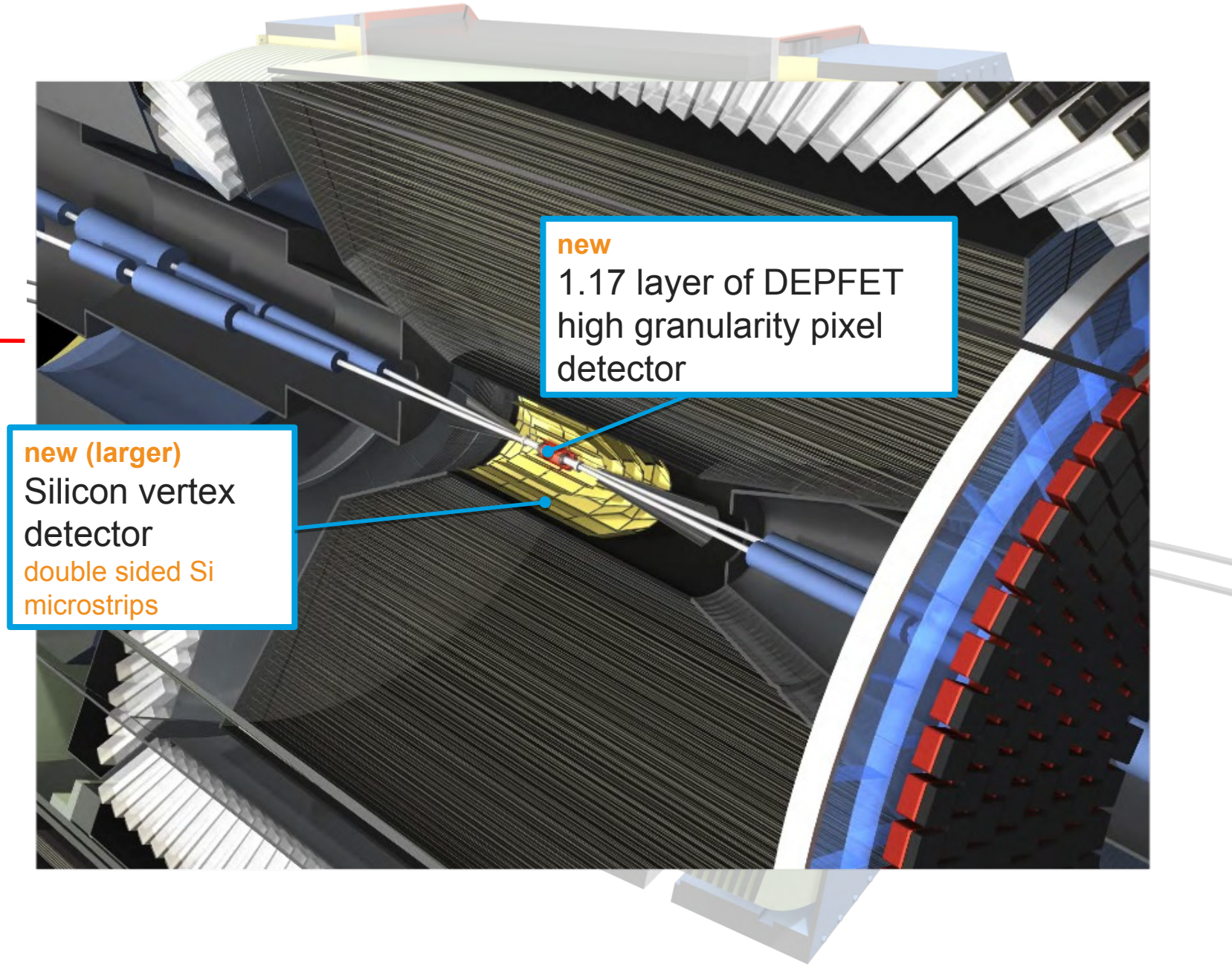


Belle II

The detector

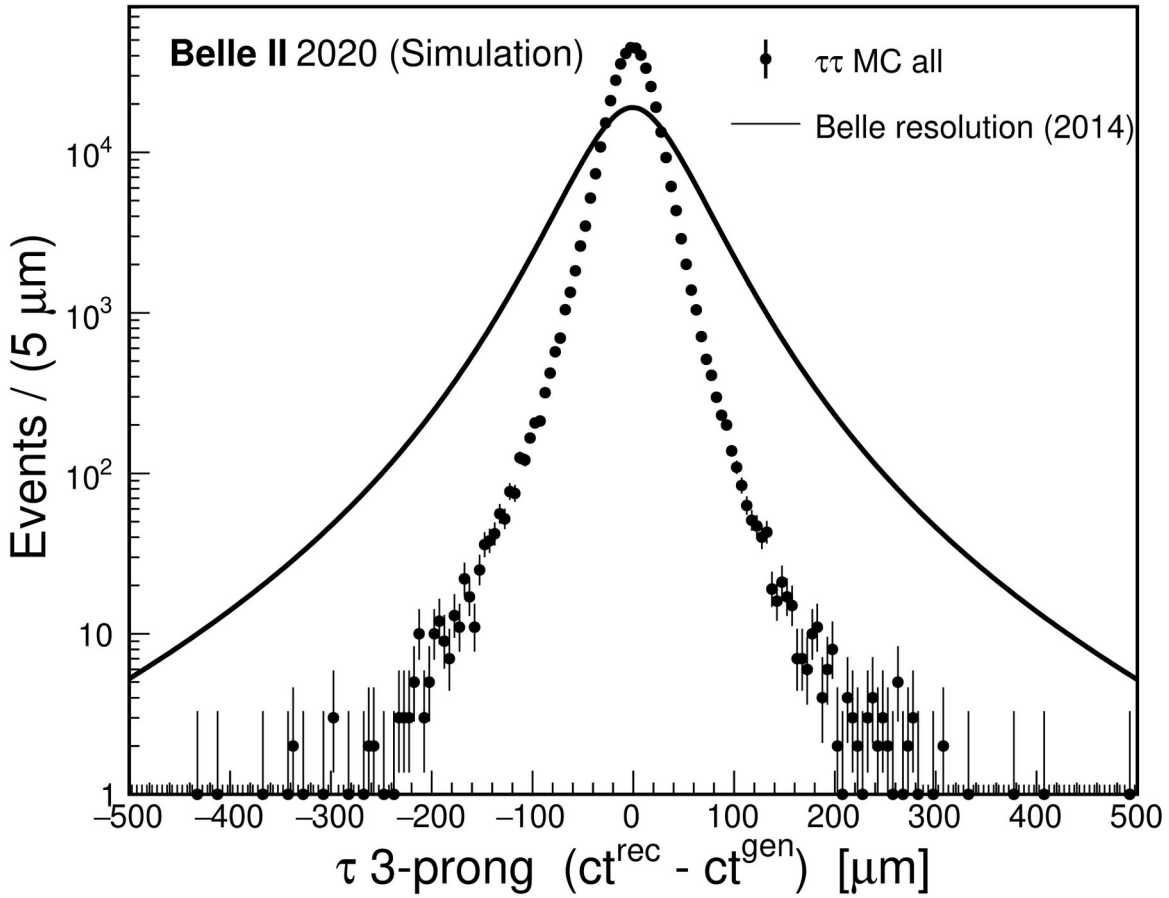


- B mesons fly ~130 μm in Belle II ($\beta\gamma \approx 0.284$).
  - *c.f.* O(mm) in LHCb.
- ∴ Vertex detectors for tagging, and measuring lifetimes.



Vertex detectors

Talks by Stefano and Tristan on Sunday



Tau decay proper time resolution (stolen from Stefano's talk).

~ ×2 narrower than Belle.

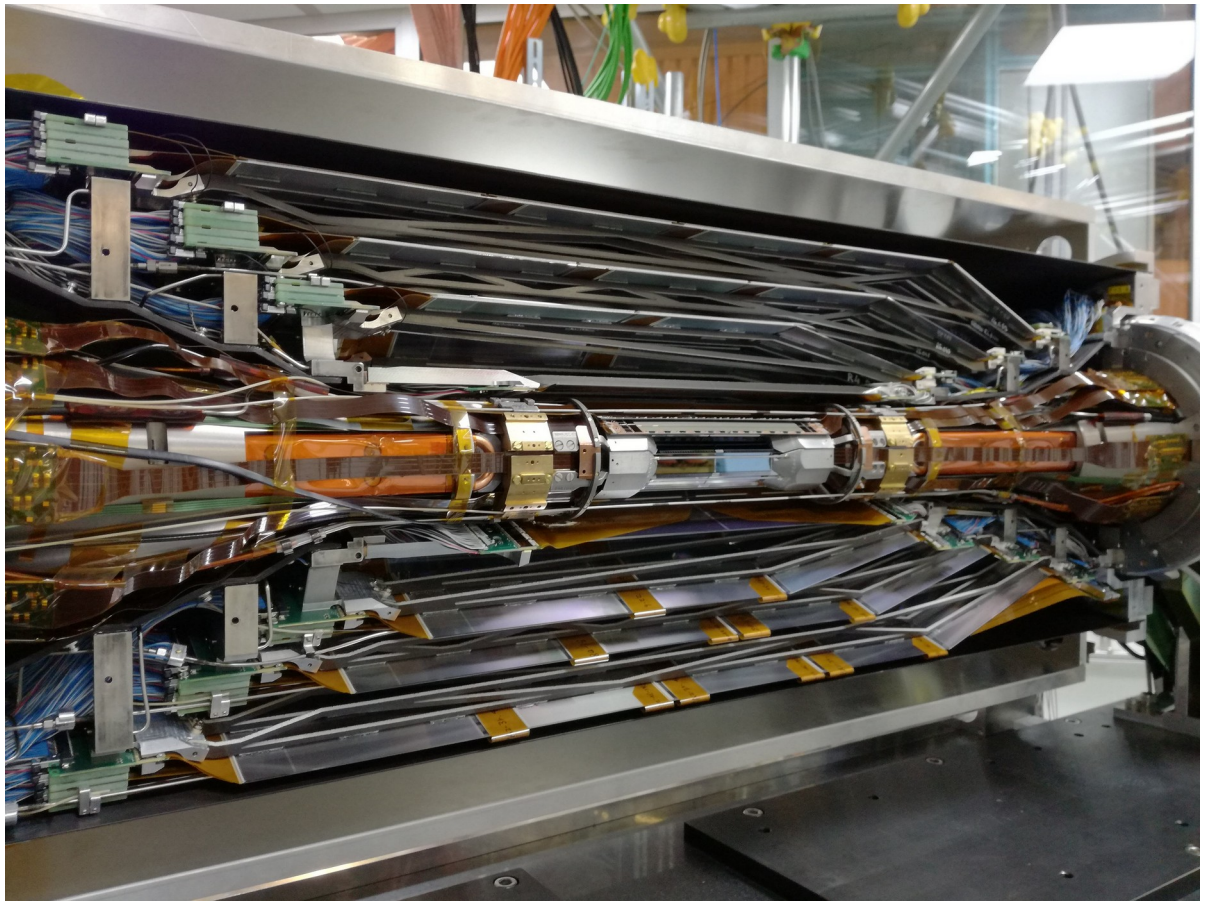
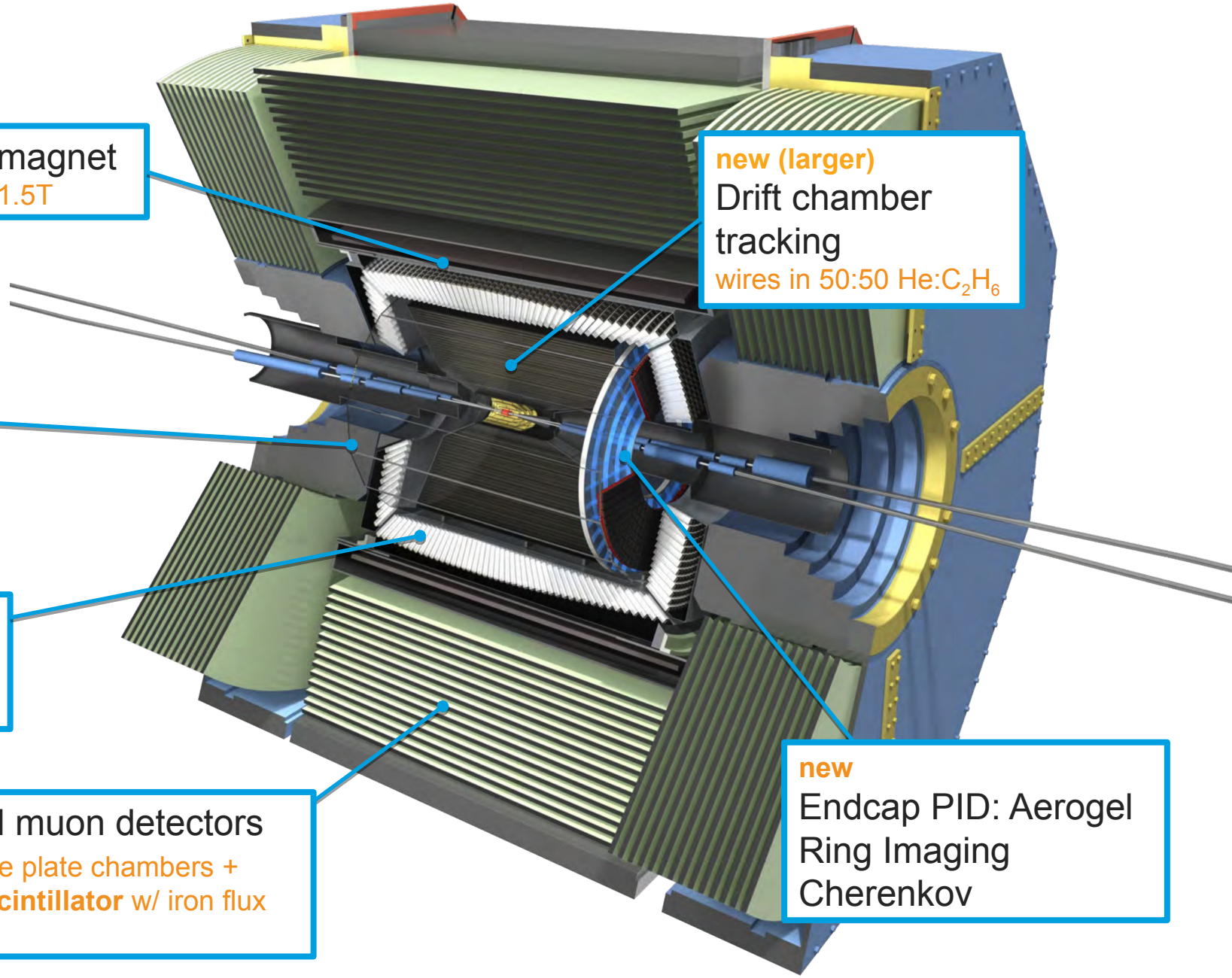


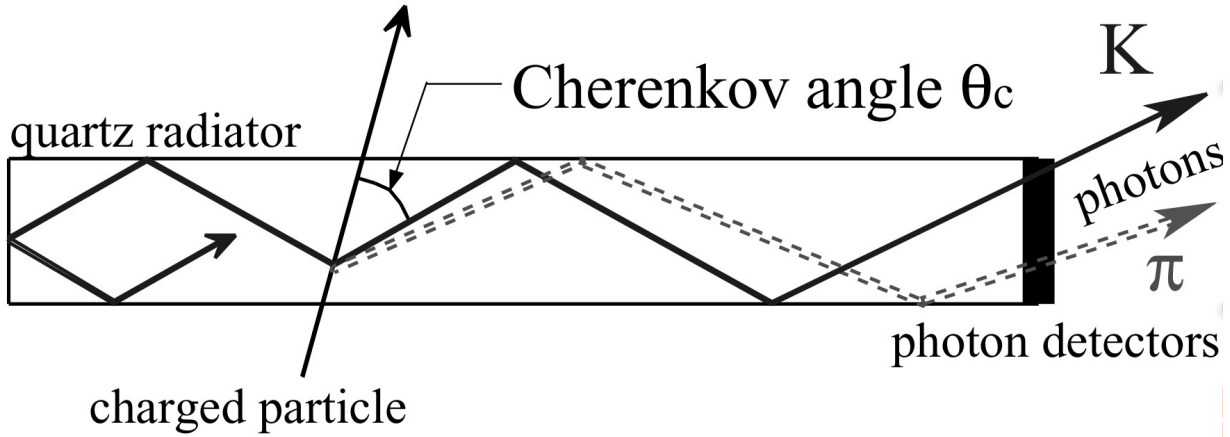
Photo: Laura Zani

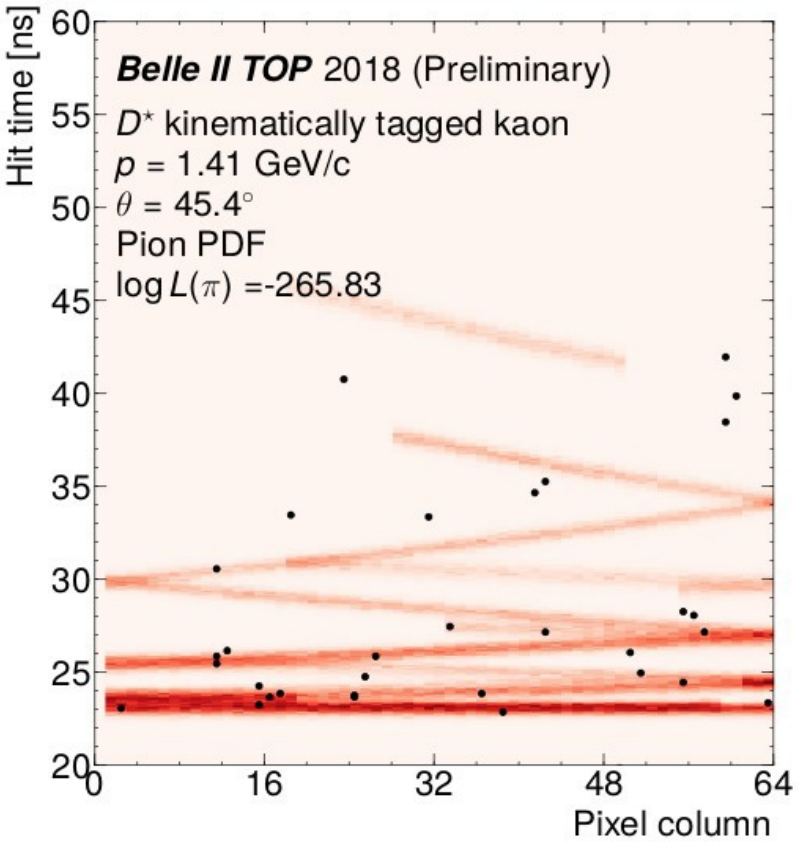
Belle II

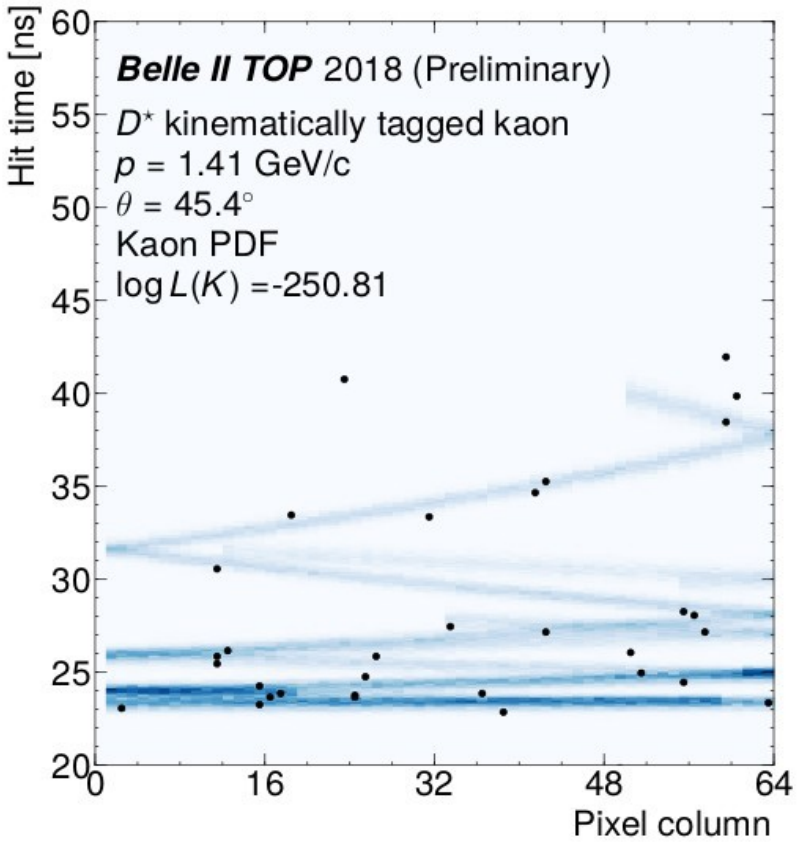
The detector

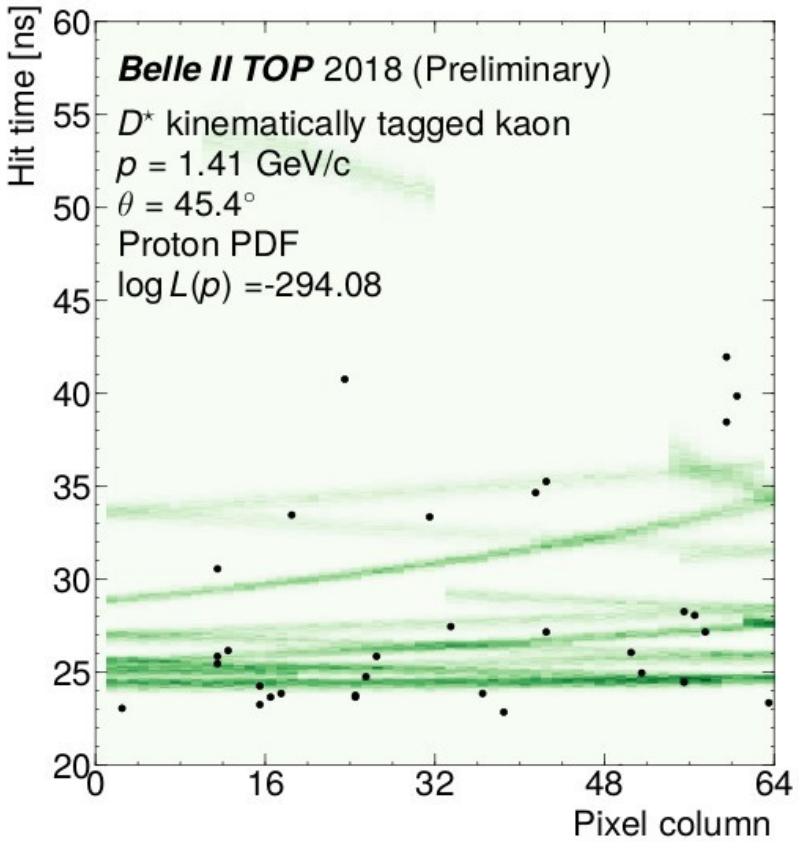


Barrel particle identification





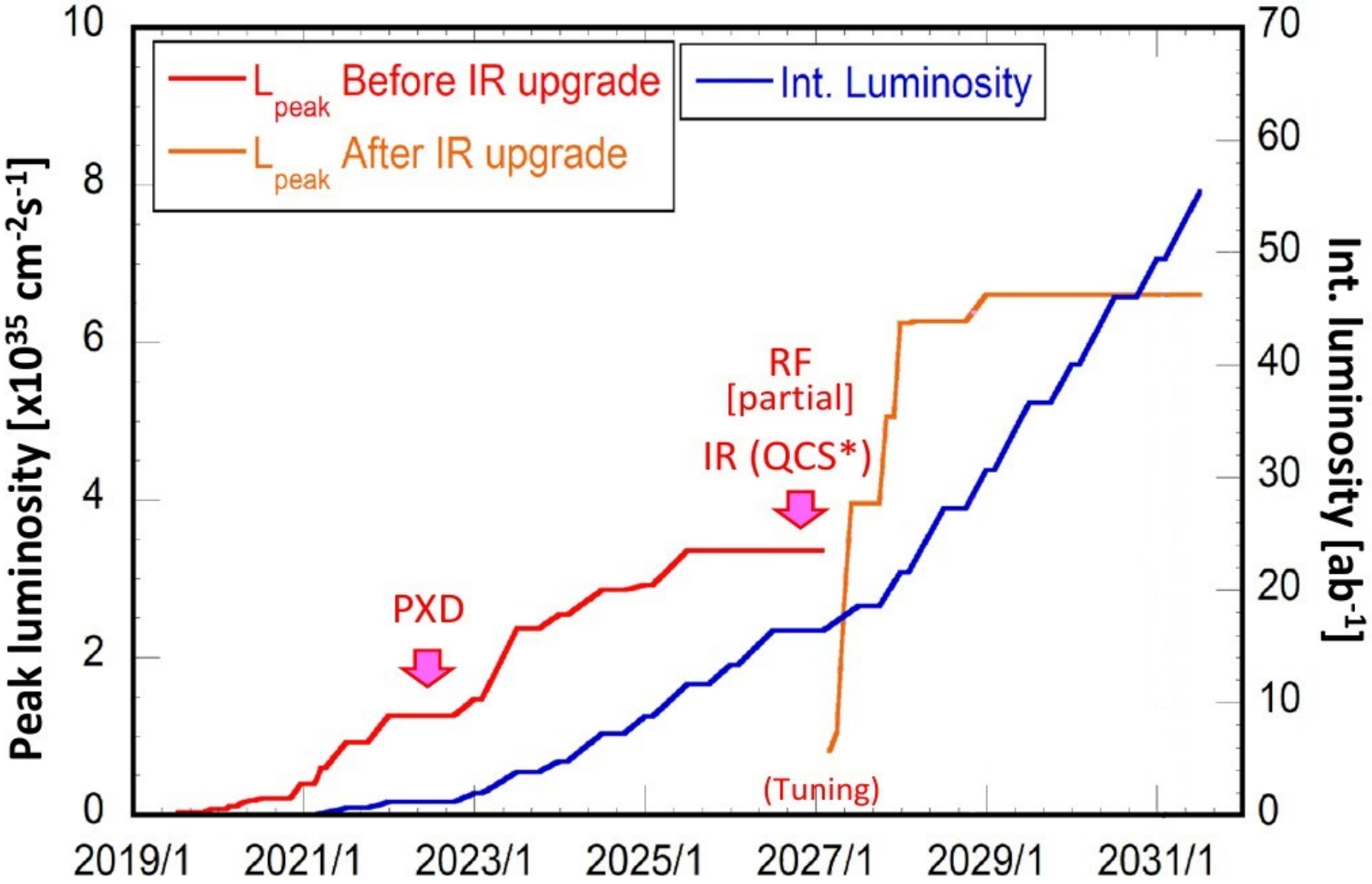




Data

Lifetime data plans

Plot dated 2020.05



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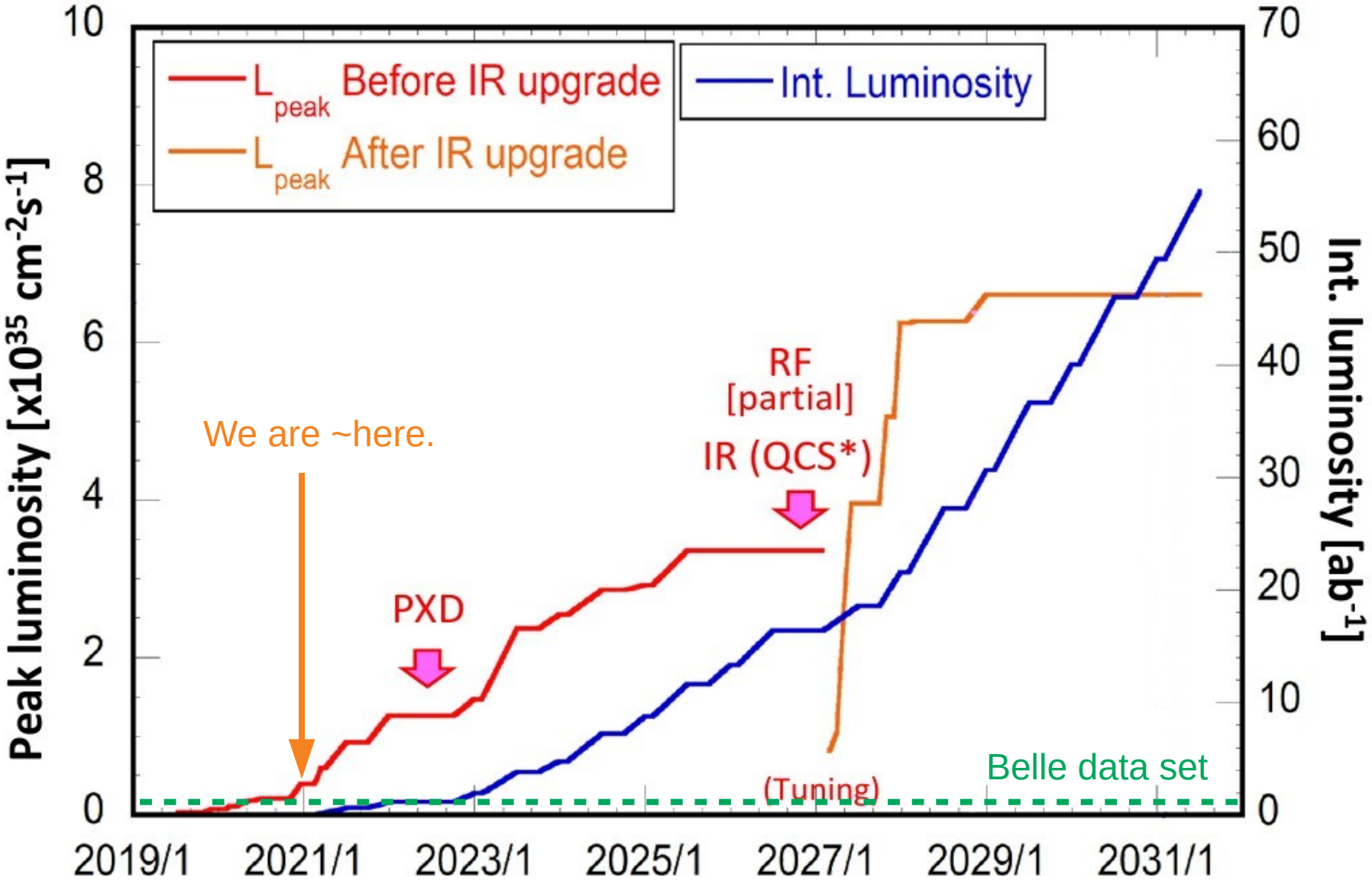
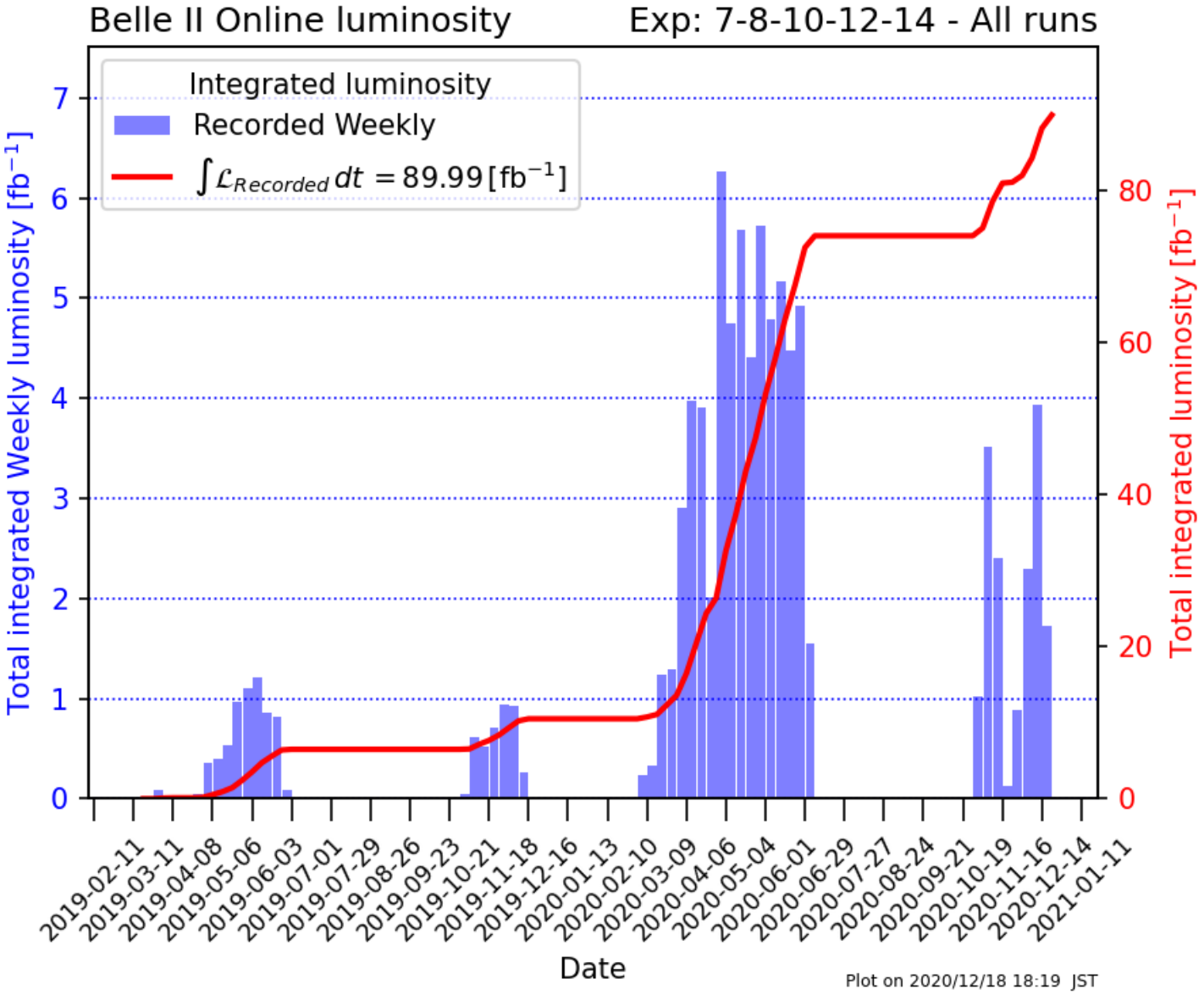


Data taking

Public luminosity status

- Last run period was relatively unaffected by pandemic.
  - Social distancing in the control room + increased remote shifts.
  - ***Heroic*** effort by local collaborators.
  - Probably not sustainable.
- Luminosity world record towards the end of June.



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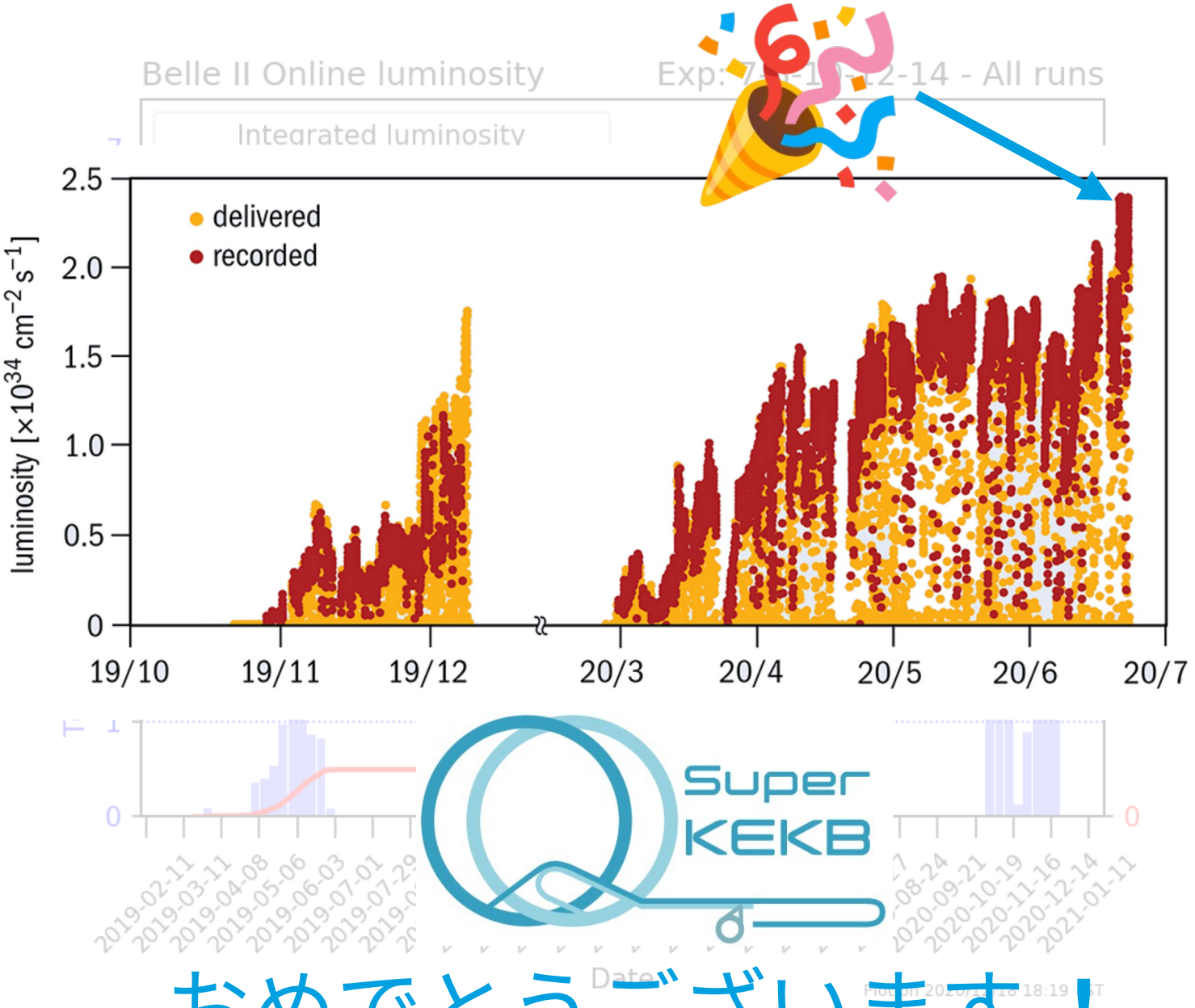


おめでとうございます！

Physics

Physics results

Public wiki pages here

- 2 published PRL dark-sector searches:
  - Search for an invisibly decaying Z' boson. [PRL 124(2020)141801]
  - Search for an axion-like particles. [PRL 125(2020)161806]

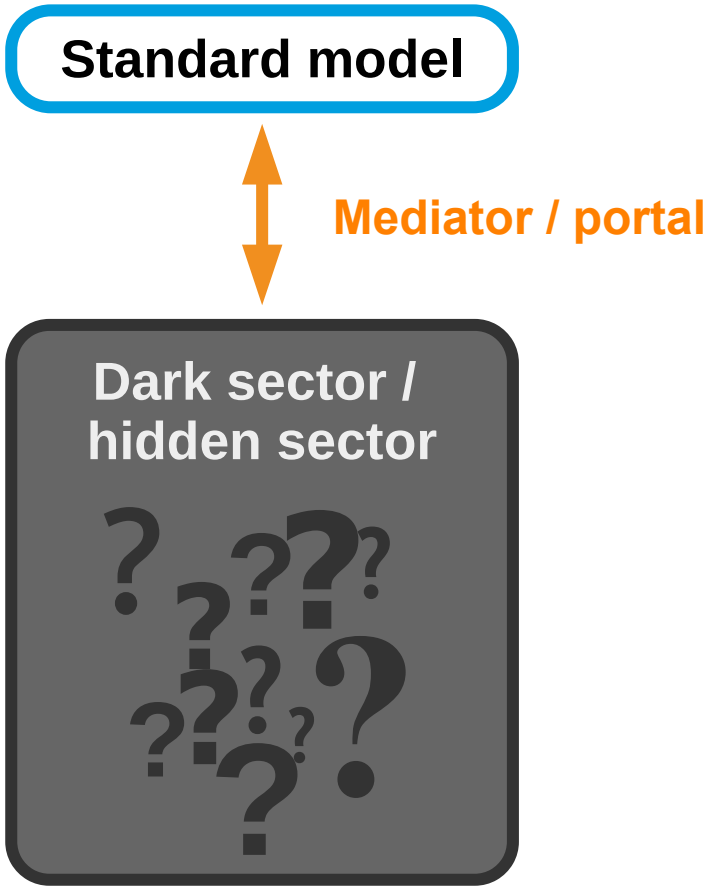
Talk by Michael on Sunday

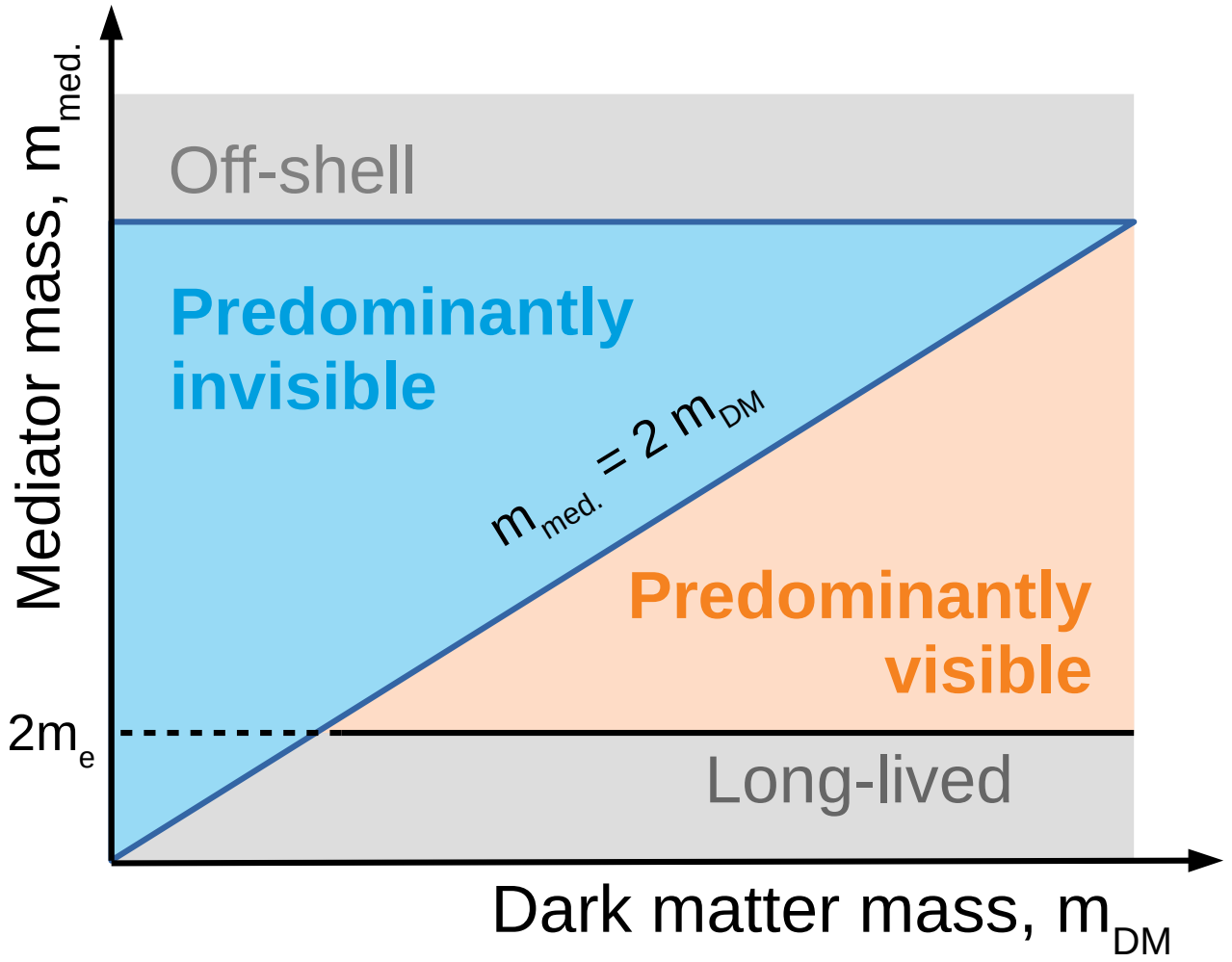
- 12 conference papers posted to arXiv:
  - Calibration of the hadronic full-event interpretation.
  - $B^0 \to D^{*+}\ell\nu$ (×3: first result, untagged, using FEI).
  - Hadronic mass moments of $B \to X_c\ell\nu$ decays.
  - Rediscovery of $B \to \pi\ell\nu$.
  - B lifetime in hadronic decays.
  - Calibration of the flavour tagger,
    then used to make demonstration "rediscovery" of CPV in $B \to J/\psi\, K_S$.
  - Rediscovery of $B \to \varphi K^*$.
  - B → charmless (×2 first result, CP asymmetries).
  - Tau lepton mass measurement.

Talk by Janice on Sunday

What is the dark sector?

Light dark matter theories, mass scale MeV → GeV

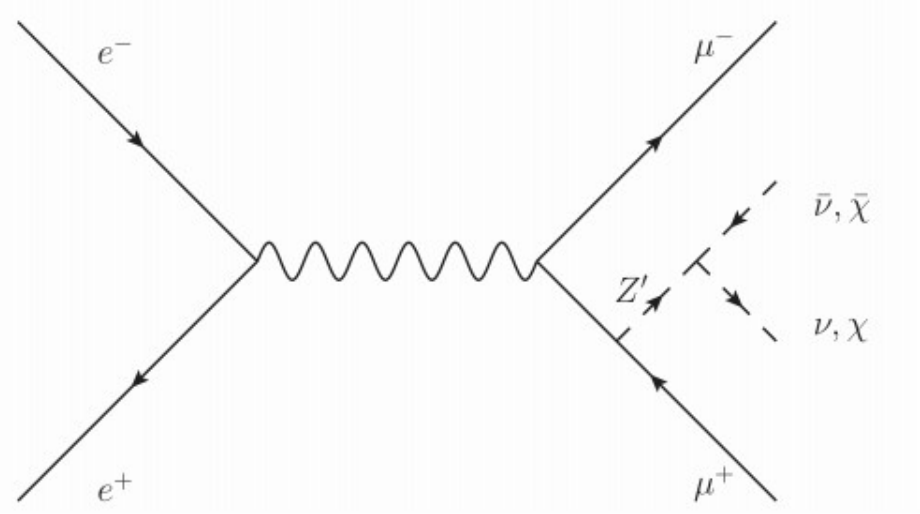


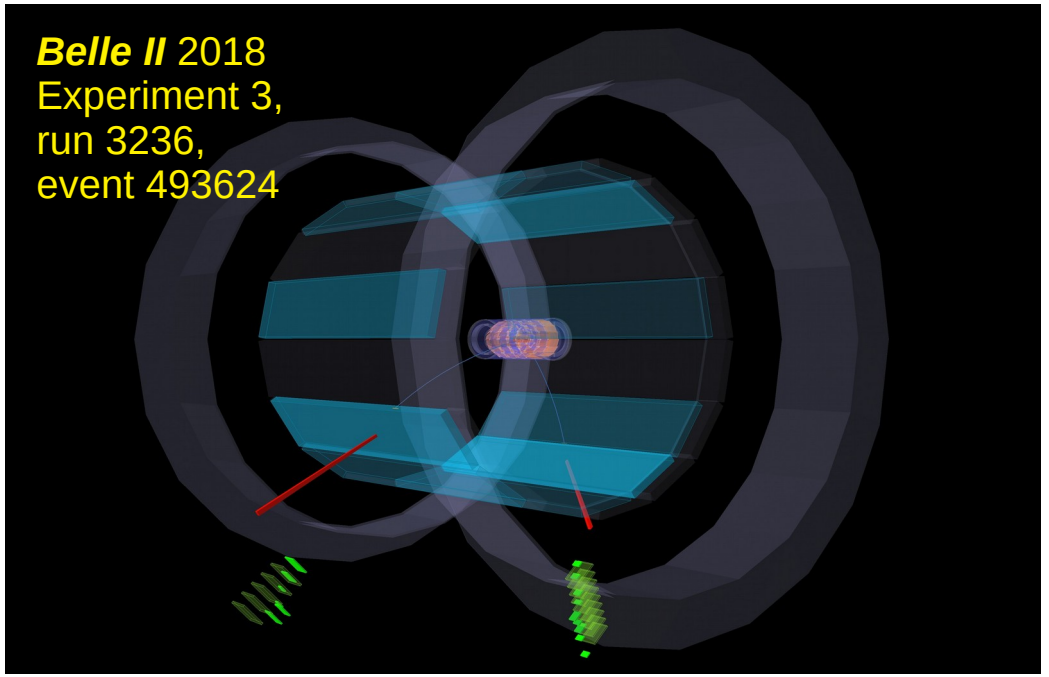


Search for an invisibly decaying Z’

PhysRevLett.124.141801

- Z’ would connect to dark-sector.
  - Heavier than the sterile light DM
    ∴ decays invisibly!
  - Also look for LFV ee → μeZ’.
- Analysis:
  - Search for 2 tracks with e/μ -like calorimeter clusters + missing energy.
  - Nothing else in event (above beam background).
  - Bump hunt in recoil mass.

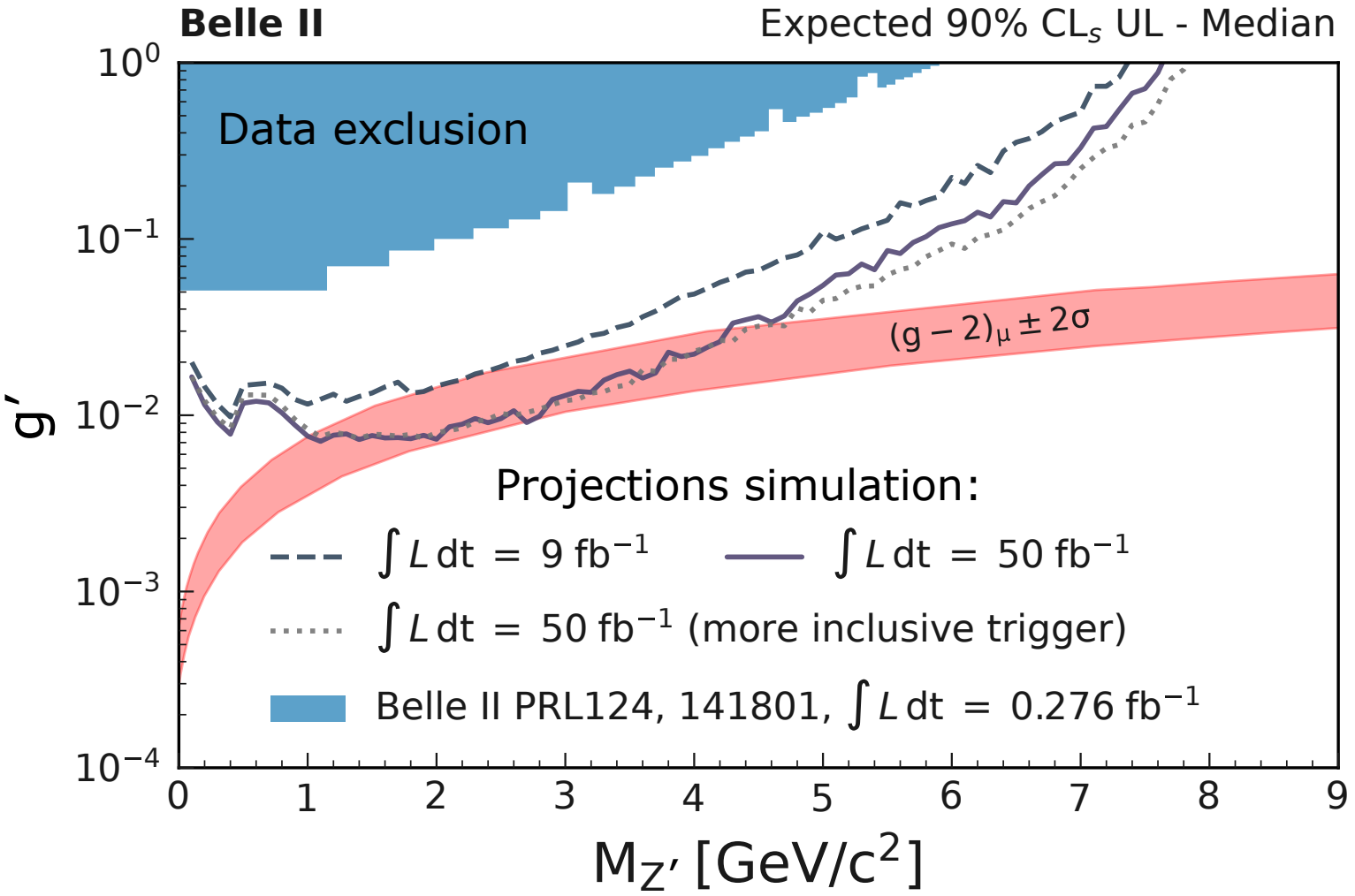




Z' results

PhysRevLett.124.141801, BELLE2-NOTE-PL-2020-012

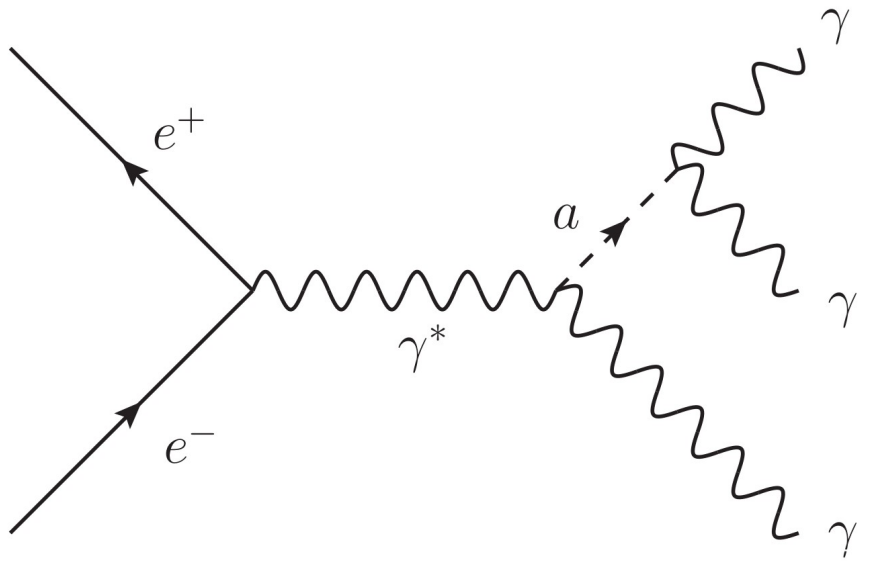
- Set limits in Z' coupling vs. Z' mass.
- For LFV mode: simply set limits on product of efficiency and cross section: ϵ×σ (no theory model at time of publication).
- Not bad for our very first physics!

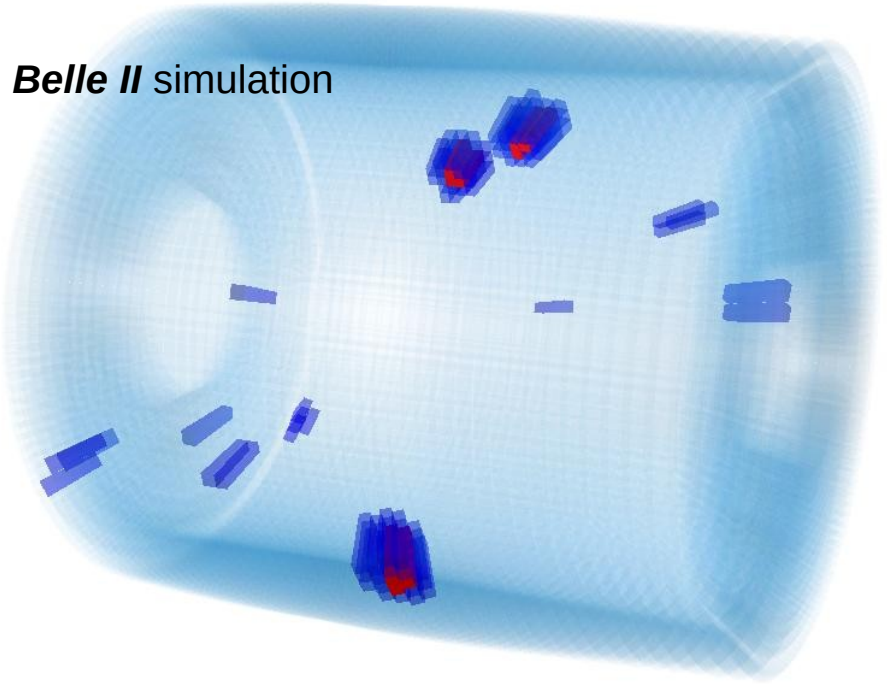


Axion-like particle

PhysRevLett.125.161806

- World-leading direct search for an ALP, $a \rightarrow \gamma\gamma$.
- Analysis:
  - Search for ALPstrahlung production process ($ee \rightarrow \gamma a \rightarrow 3\gamma$ final state).
  - 3γ with invariant mass close to $\sqrt{s}$.
  - Nothing else in event (above beam background).
  - Bump-hunt in $\gamma\gamma$/recoil mass.

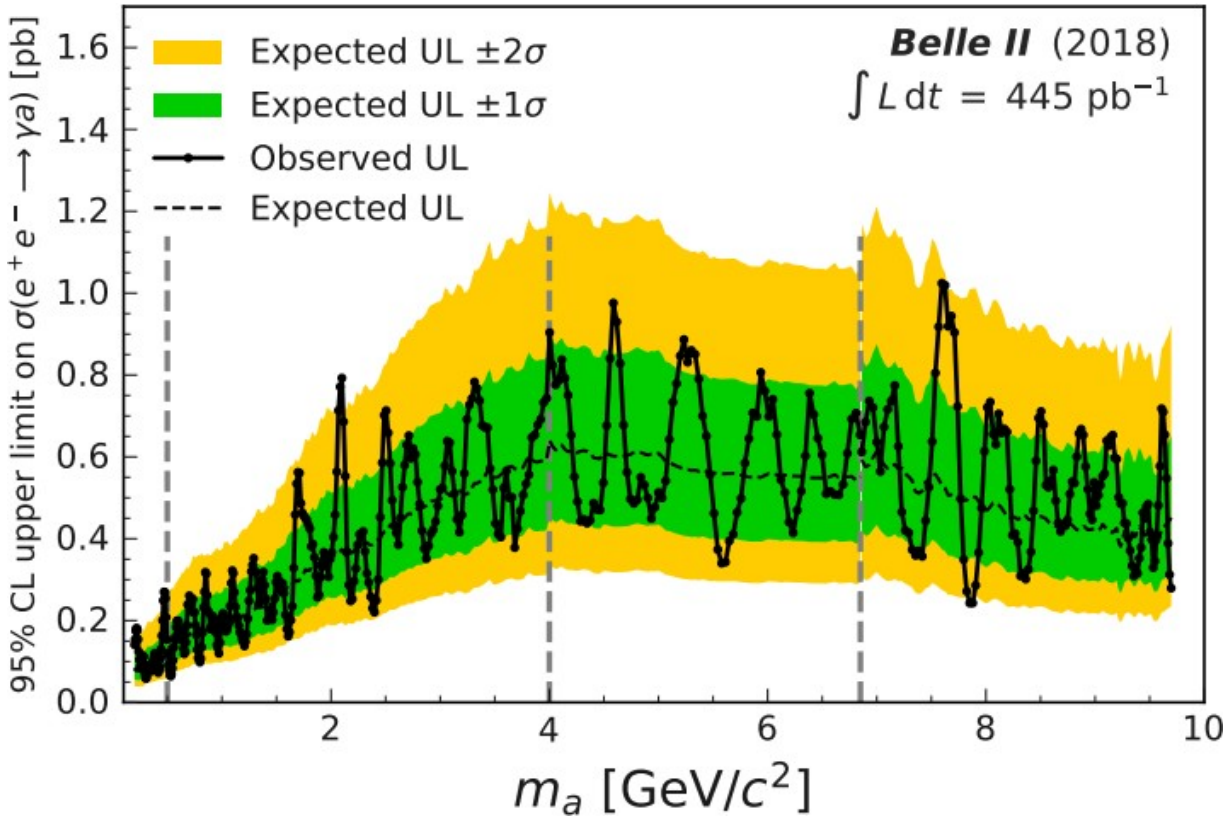


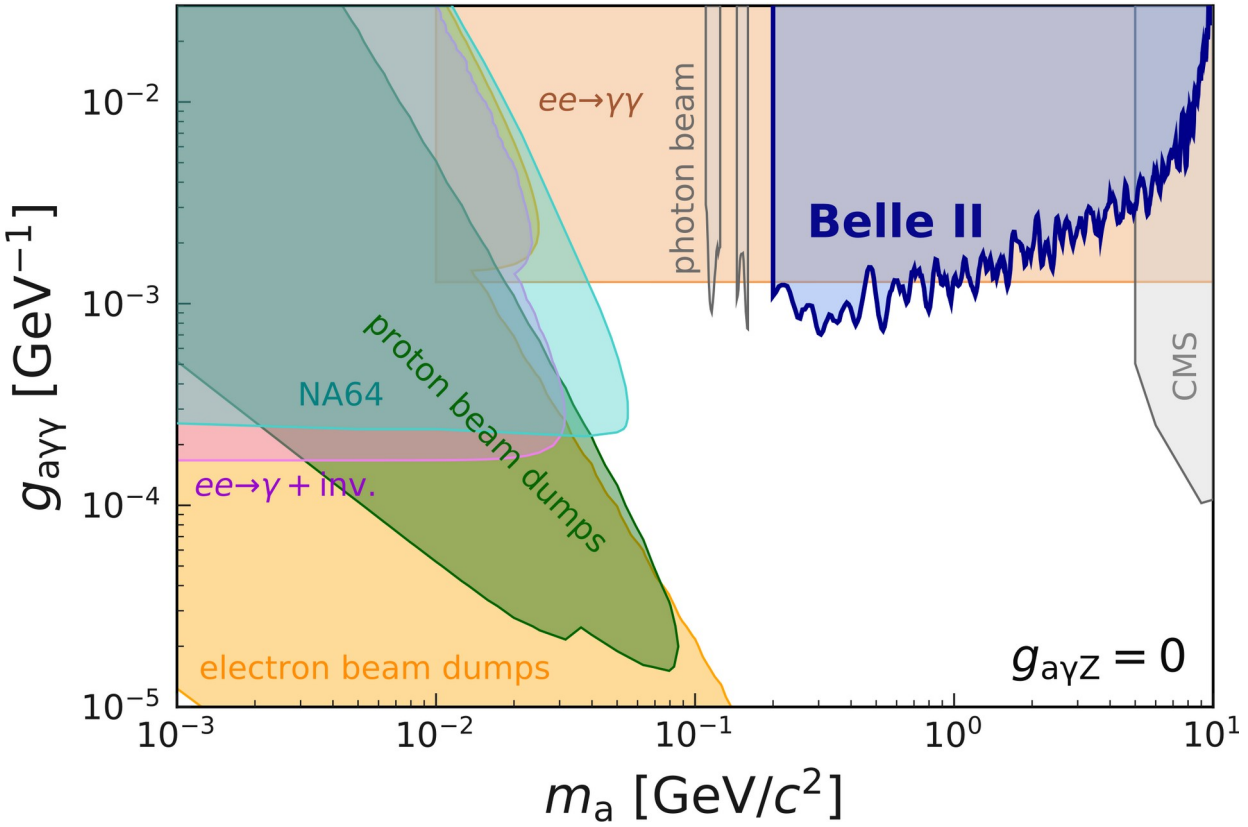


Axion-like particle

PhysRevLett.125.161806

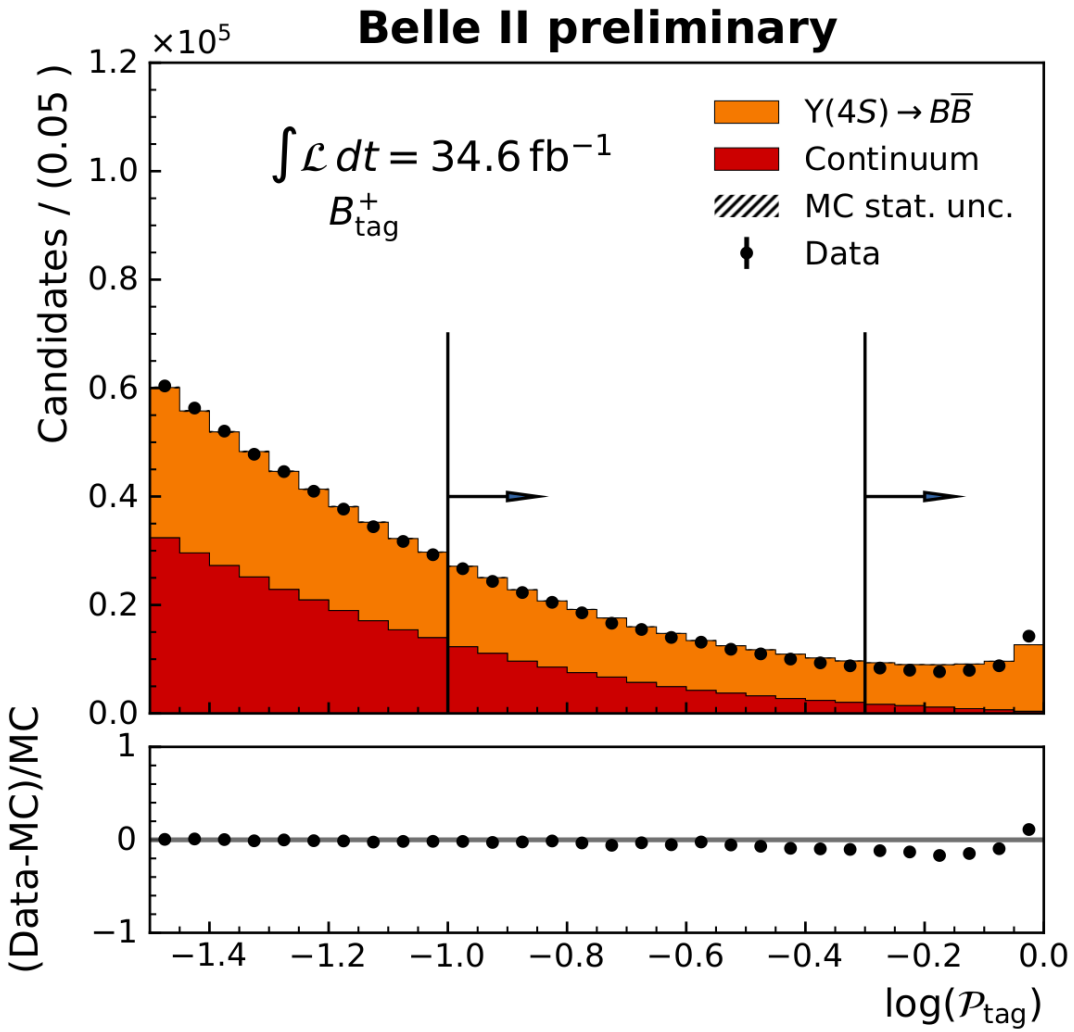
For all the details: see talk by Michael on Sunday



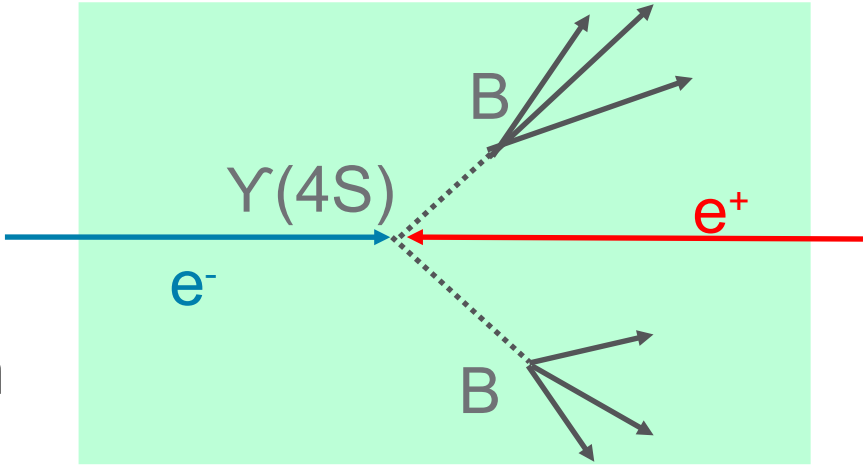


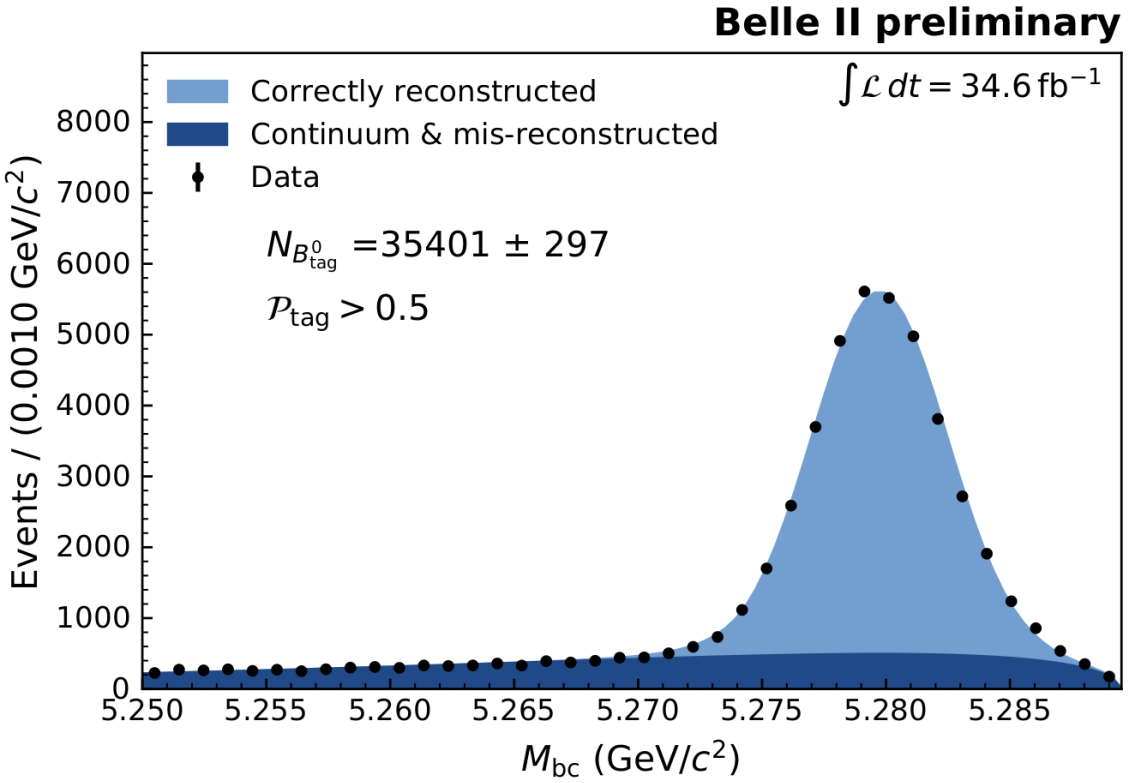
Generic B's

arXiv:2008.06096, Comput Softw Big Sci 3, 6 (2019)



Full event interpretation (**FEI**)

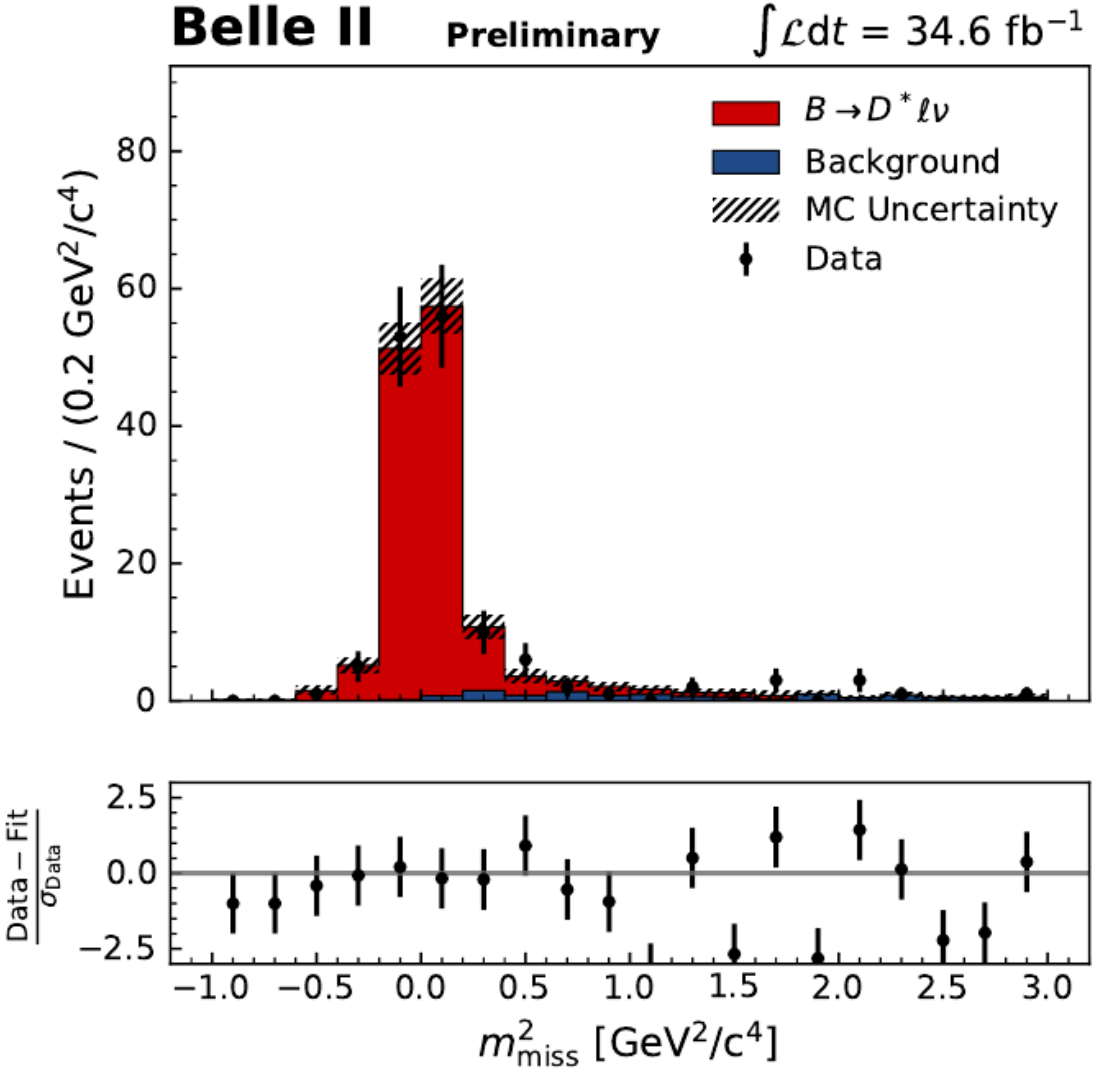




$B^0 \to D^{*+}\ell\nu$

arXiv:2008.08819

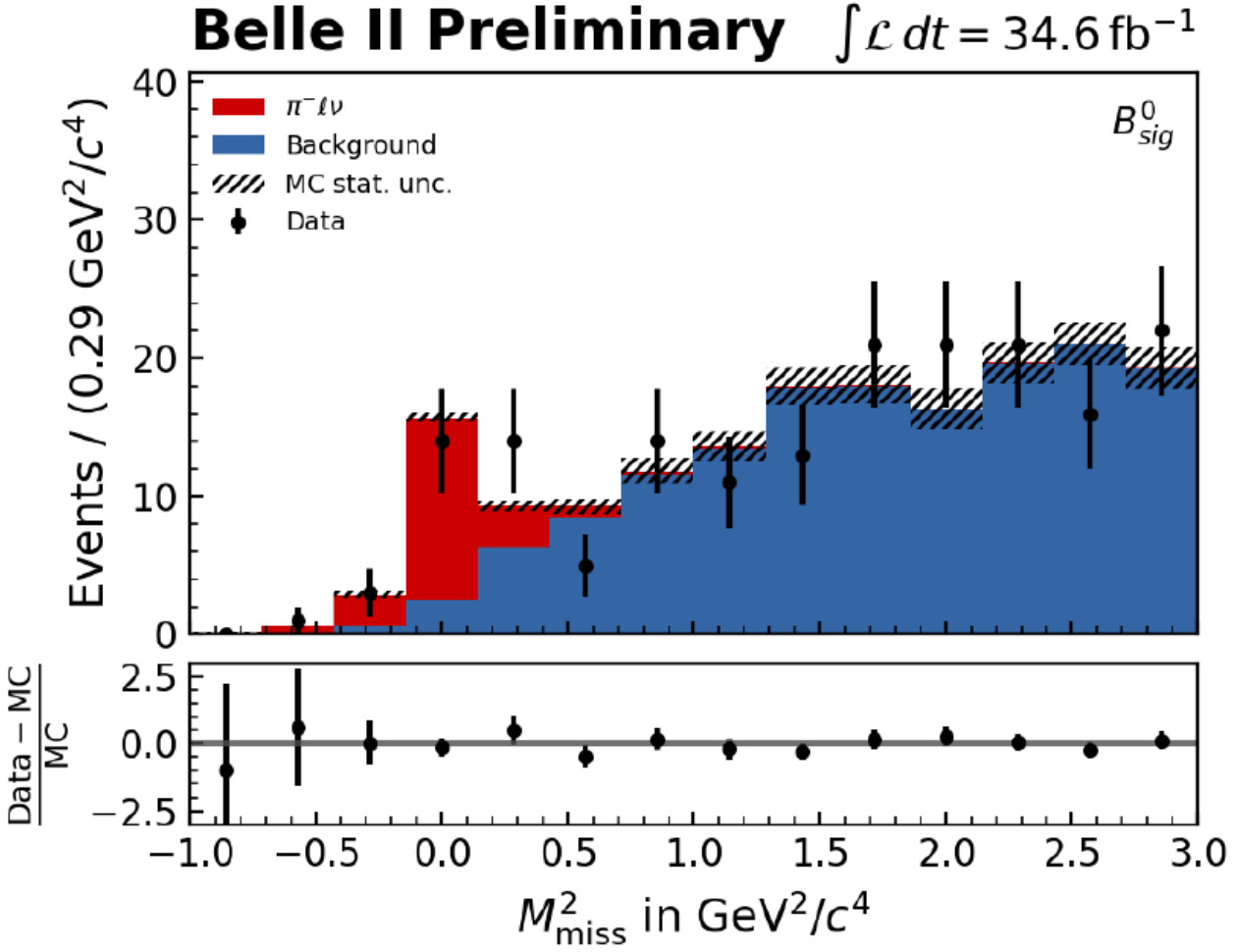
- One of our golden (platinum?) channels.
- Important use of FEI
  (although we also see it untagged).
- ~Everyone in HEP: "*When will you resolve the R_{D^*} tension?*"
  - Not for a few 100 fb^{-1} yet.
- We can see a nice peak and measure:
  $\mathcal{B}$ [$B^0 \to D^*\ell\nu$]
  = 4.51 ± 0.41(stat) ± 0.27(syst) ± 0.45(π_s) %
- PDG: 5.05 ± 0.14 %



$B^0 \to \pi \ell \nu$

arXiv:2008.08819

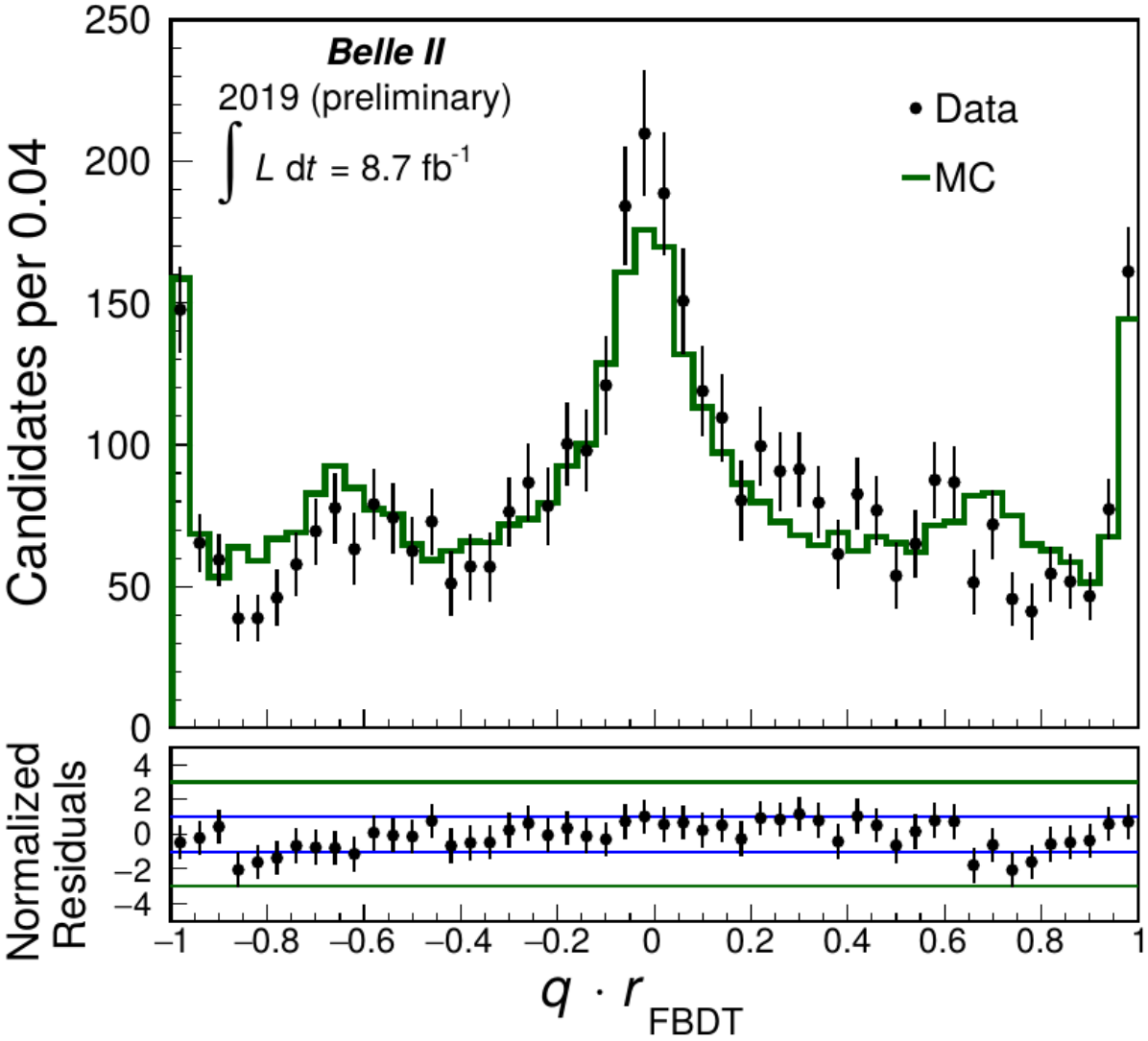
- Cabibbo-suppressed semileptonic decays.
- 5σ "rediscovery" with the FEI.
- Measure:
  $\mathcal{B}[B^0 \to \pi^- \ell^+ \nu]$
  $= (1.58 \pm 0.43(\text{stat}) \pm 0.07(\text{syst})) \times 10^{-4}$
- PDG: $(1.50 \pm 0.06) \times 10^{-4}$
- With more data, can measure V_{ub}.



Flavour tagger

arXiv:2008.02707

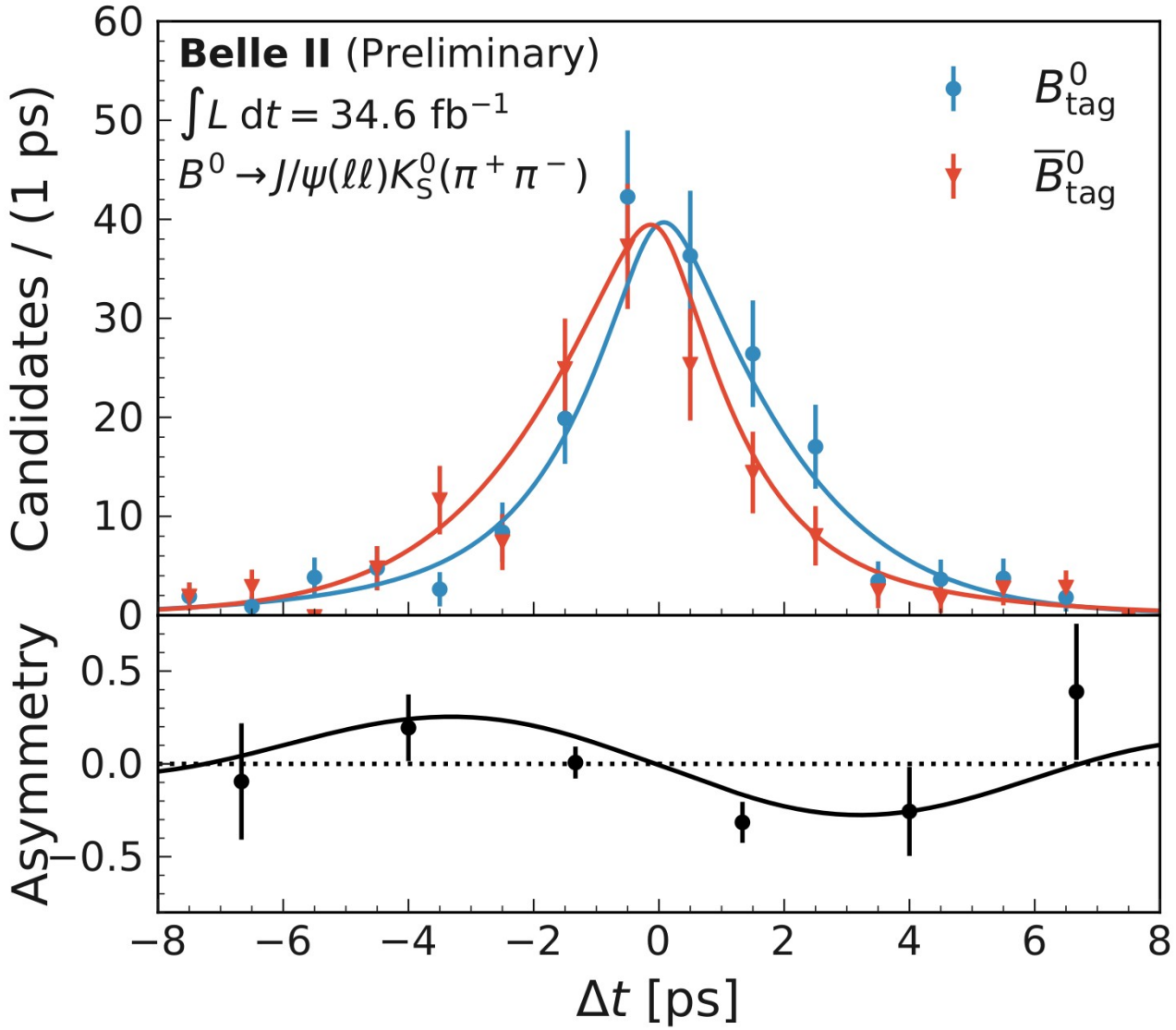
- "Similar but different" to FEI.
- "Only" want the *flavour* of the tag and its vertex. Don't need the full kinematic object.
  - MVA algorithm returns flavour (q) and dilution factor (r).
- Measure effective flavour tagging efficiency:
  ε_{eff} = 33.8 ± 3.6(stat) ± 1.6(syst) %
- Belle: 30.1 ± 0.4 %; BaBar: 33.1 ± 0.3 %
- Expect ε_{eff} ≈ 37 % based on MC.



$B^0 \to J/\psi\, K_S$

BELLE2-NOTE-PL-2020-011

- "Golden" mode for time dependent CPV and demonstration of the flavour tagger.
- Rather subtle analysis with several ingredients: mixing frequency, resolution function…
- Measure $S_f \approx \sin 2\varphi_1 = \sin 2\beta$.
  $S_f = 0.55 \pm 0.21(\text{stat}) \pm 0.04(\text{syst})$
  - **2.7σ from zero** (no CPV).
- PDG: 0.691 ± 0.017.

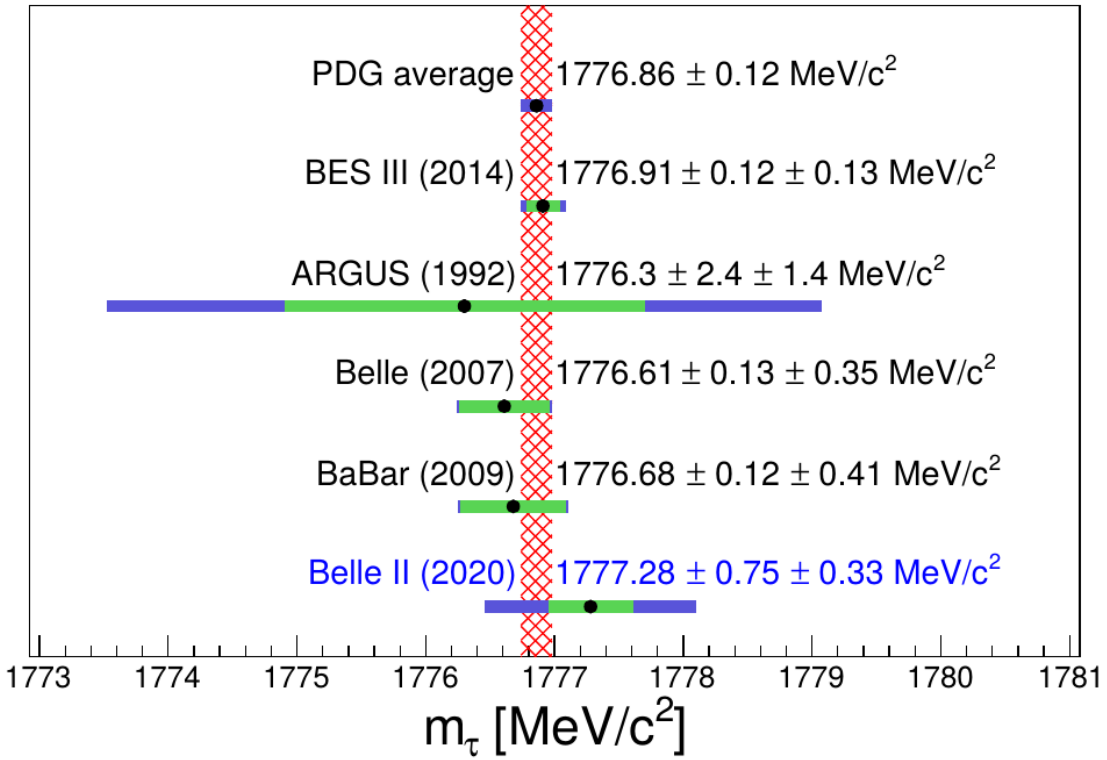


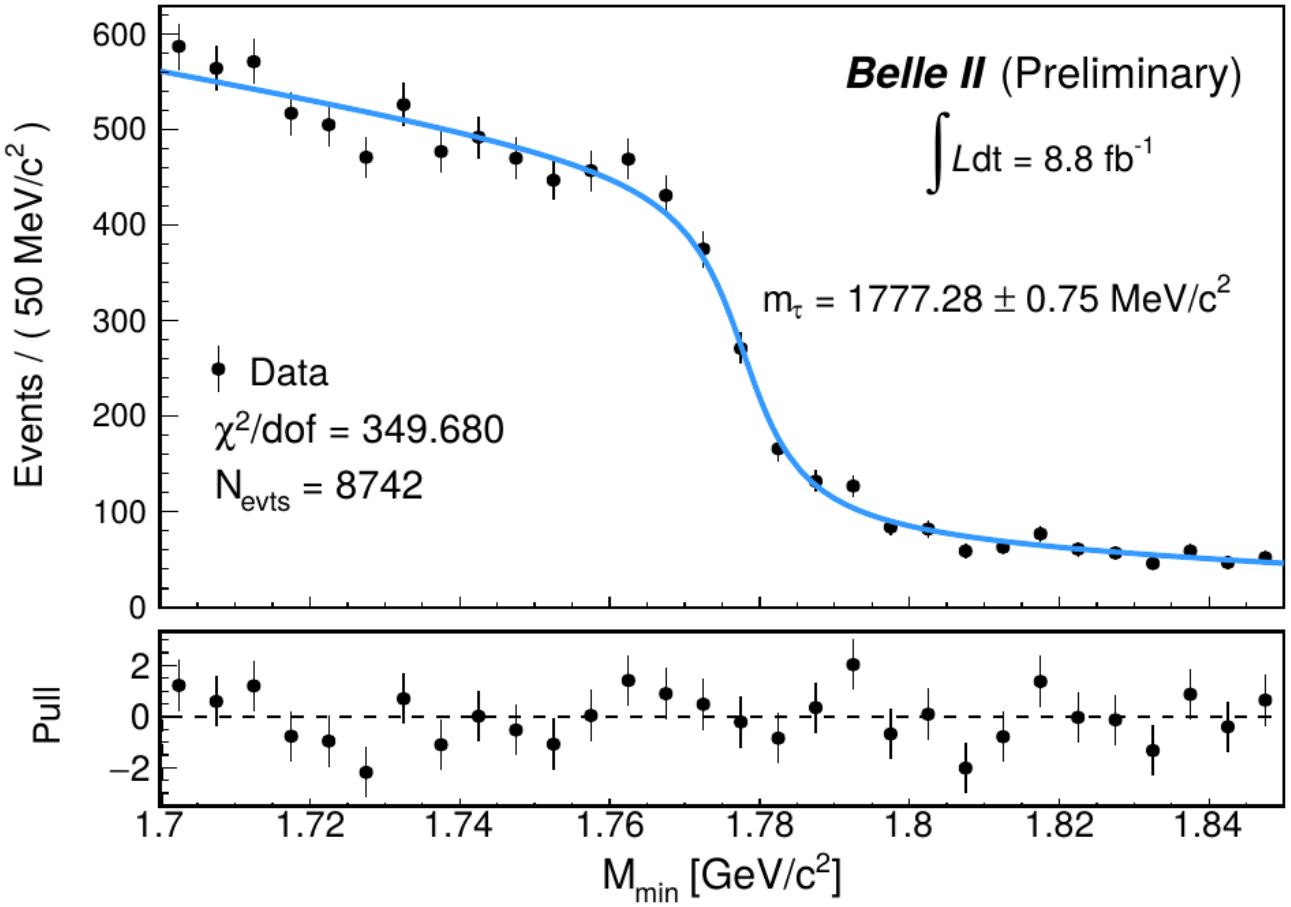
Tau mass measurement

arXiv:2008.04665

More with taus: see talk by Stefano on Sunday

- Mass of τ lepton measured from the threshold in “pseudo-mass” variable.





$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(E_{\text{beam}} - E_{3\pi})(E_{3\pi} - P_{3\pi})}$$

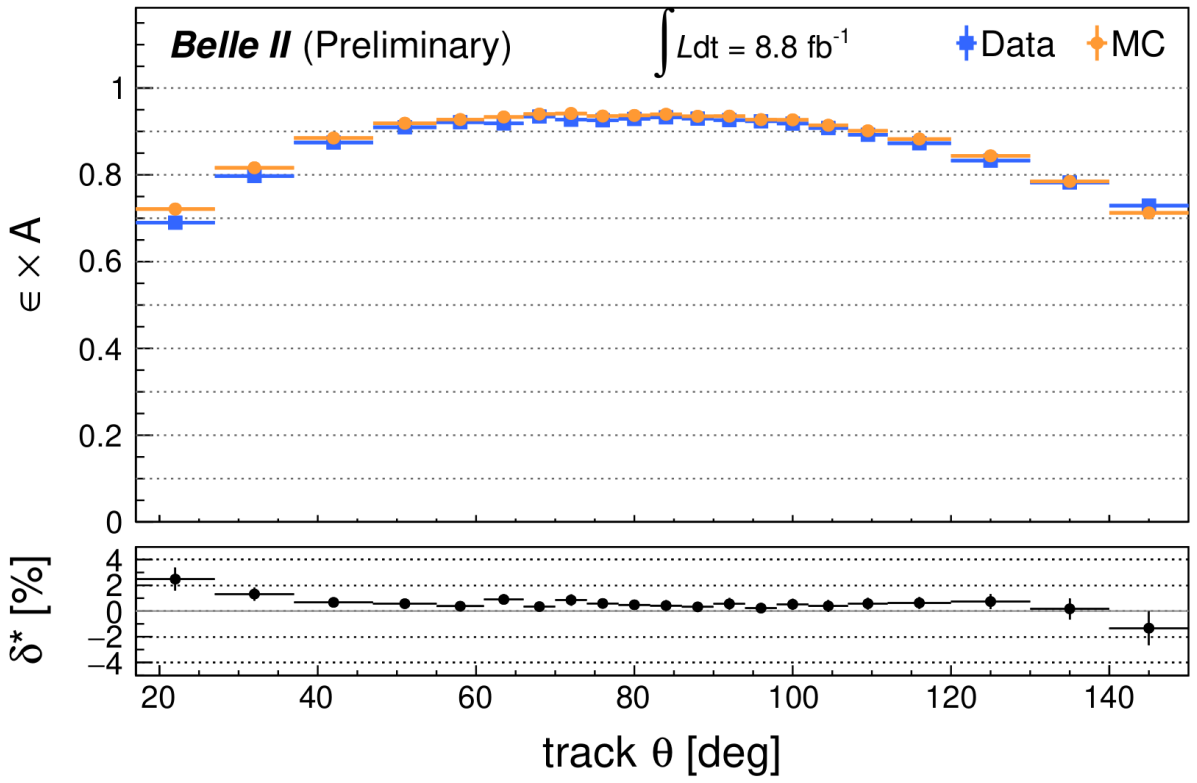
To conclude...

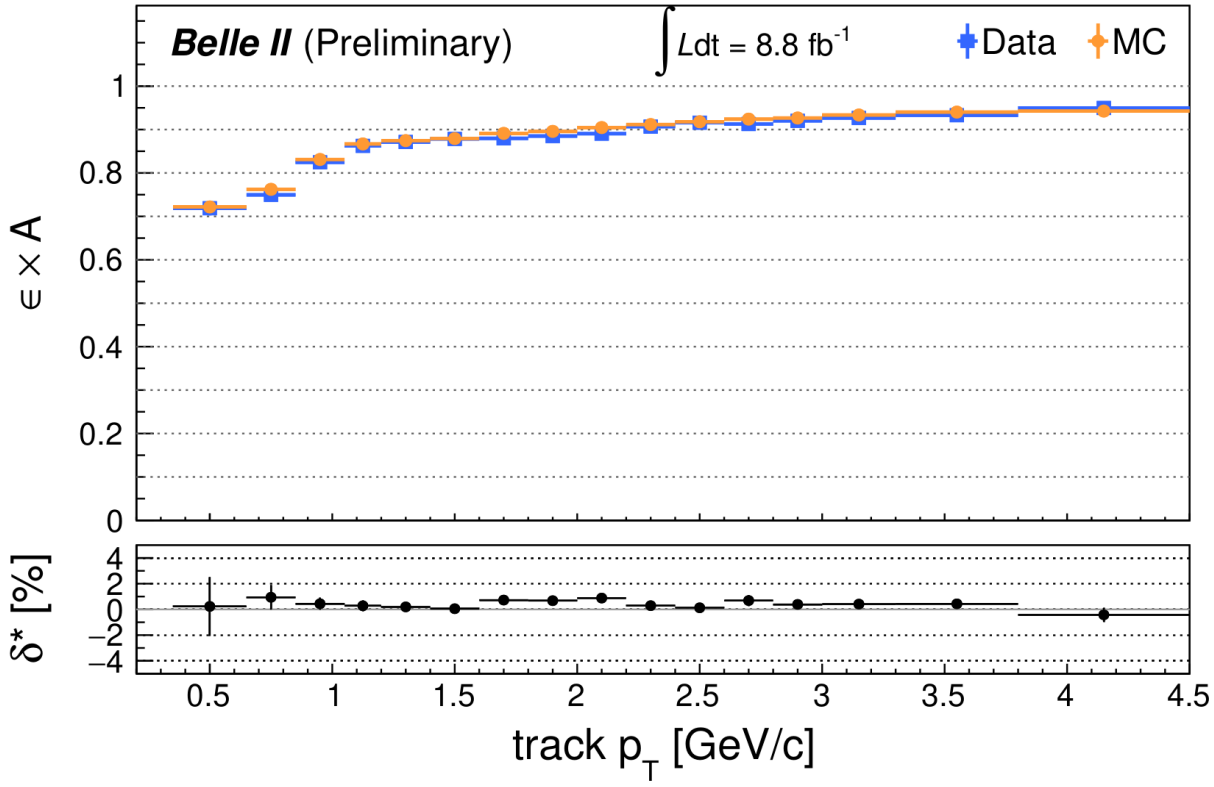
- Belle II is working quite well. Stable running in 2019–2020.
- COVID19: relatively modest effect. Social distancing but operational.
  - We start again end of February.
- Extended schedule for data taking to get 50 ab^{-1}.
- First “rediscoveries” and “proof of concept” analyses in B physics.
  - Full-event interpretation and flavour tagging are nicely demonstrated.
  - We almost see time-dependent CP violation.
  - We see semileptonics, B → charmless, radiative penguins, B lifetime, …
- World-leading results from a different area: light dark matter.
  - Expect more here: we will be leading things in the mid-term.

Extra slides

Tracking efficiency measured in tau decays

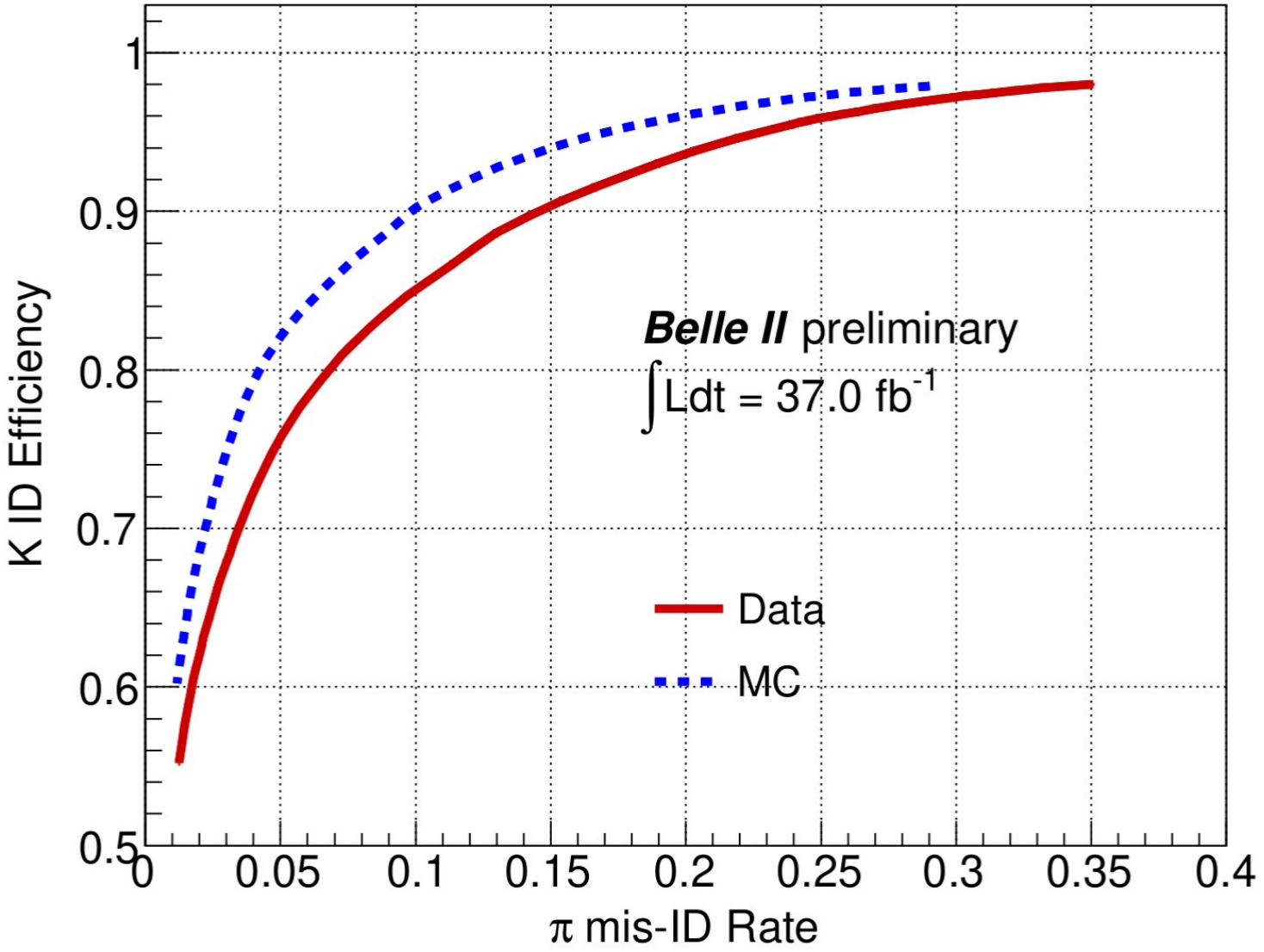
BELLE2-NOTE-PL-2020-014

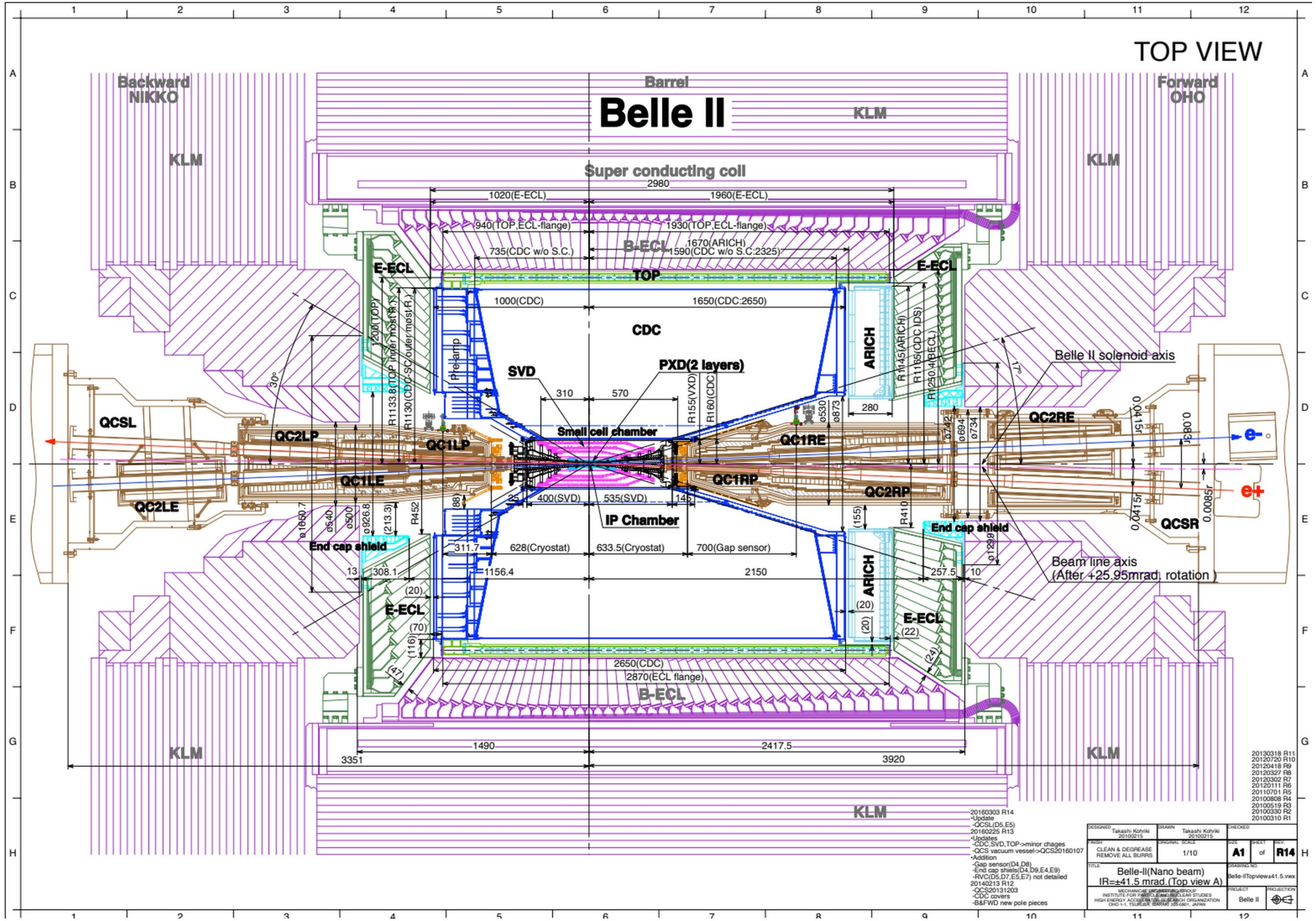




Particle identification performance

BELLE2-NOTE-PL-2020-024




TOP VIEW
Backward
NIKKO
Barrel
Belle II
Forward
OHO
KLM
Super conducting coil
2980
1020(E-ECL)
1960(E-ECL)
940(TOP,ECL-flange)
1930(TOP,ECL-flange)
735(CDC w/o S.C.)
B-ECL
1670(ARICH)
1590(CDC w/o S.C:2325)
E-ECL
TOP
1000(CDC)
1650(CDC:2650)
CDC
ARICH
SVD
PXD(2 layers)
310
570
Small cell chamber
IP Chamber
400(SVD)
535(SVD)
140
25
280
Belle II solenoid axis
QCSL
QC2LP
QC1LP
QC1LE
QC2LE
QC1RE
QC1RP
QC2RP
QC2RE
QCSR
e-
e+
End cap shield
311.7
628(Cryostat)
633.5(Cryostat)
700(Gap sensor)
1156.4
2150
257.5
10
13
308.1
2650(CDC)
2870(ECL flange)
1490
2417.5
3351
3920
Beam line axis
(After +25.95mrad. rotation)
20160303 R14
•Update
-QCSL(D5,E5)
20160225 R13
•Updates
-CDC,SVD,TOP->minor chages
-QCS vacuum vessel->QCS20160107
•Addition
-Gap sensor(D4,D8)
-End cap shiels(D4,D9,E4,E9)
-RVC(D5,D7,E5,E7) not detailed
20140213 R12
-QCS20131203
-CDC covers
-B&FWD new pole pieces
20130318 R11
20120720 R10
20120418 R9
20120327 R8
20120302 R7
20120111 R6
20110701 R5
20100808 R4
20100519 R3
20100330 R2
20100310 R1
DESIGNED Takashi Kohriki 20100215
DRAWN Takashi Kohriki 20100215
CHECKED
FINISH CLEAN & DEGREASE REMOVE ALL BURRS
ORIGINAL SCALE 1/10
SIZE A1
SHEET of
REV. R14
TITLE Belle-II(Nano beam) IR=±41.5 mrad.(Top view A)
DRAWING NO. Belle-IITopview±41.5.vwx
PROJECT Belle II
PROJECTION

Contact

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