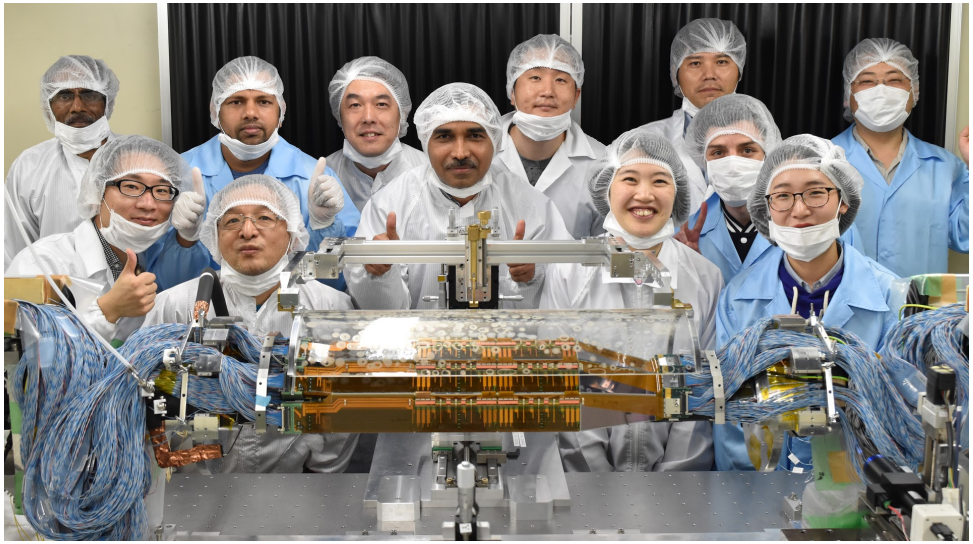
# First light from Belle II

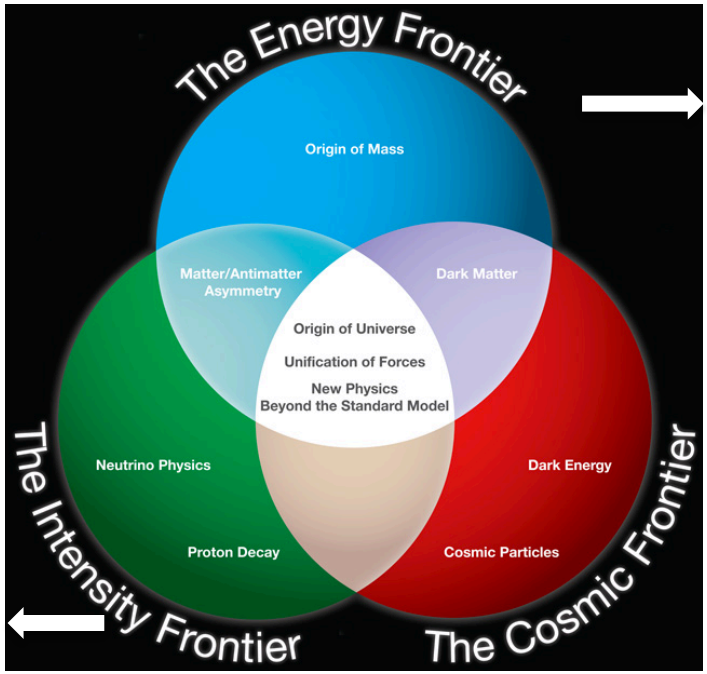


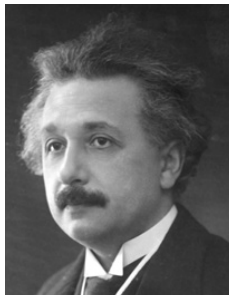

March 17-23, 2019

Gagan Mohanty

tifr

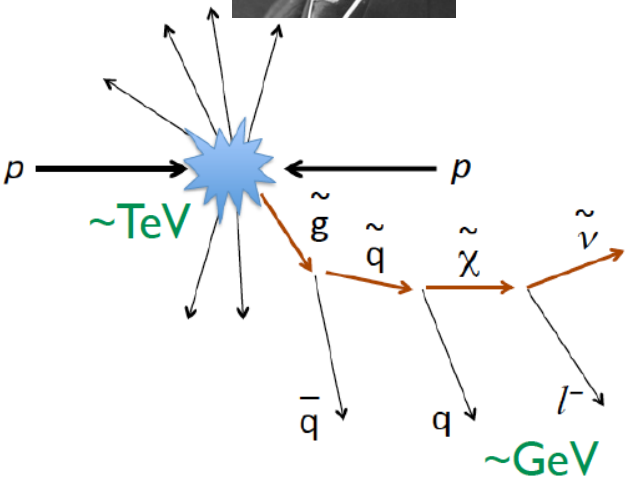
# Flavor physics: why?

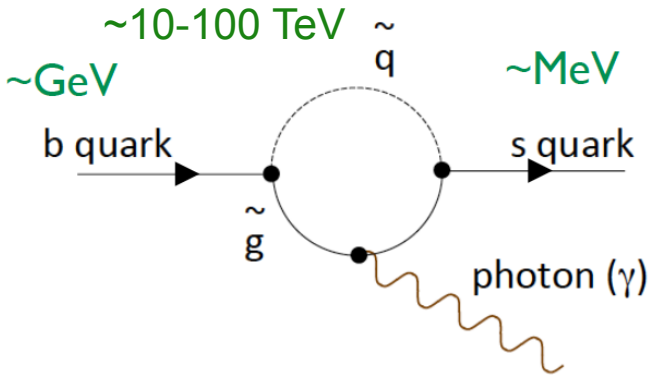


**E ~ m**

**Δm.Δt ~ 1**




- Provides us a unique probe to unravel deeper mysteries of the universe with intense sources and highly sensitive detectors

- Main players at energy and intensity frontiers:

ATLAS EXPERIMENT

CMS

LHCb

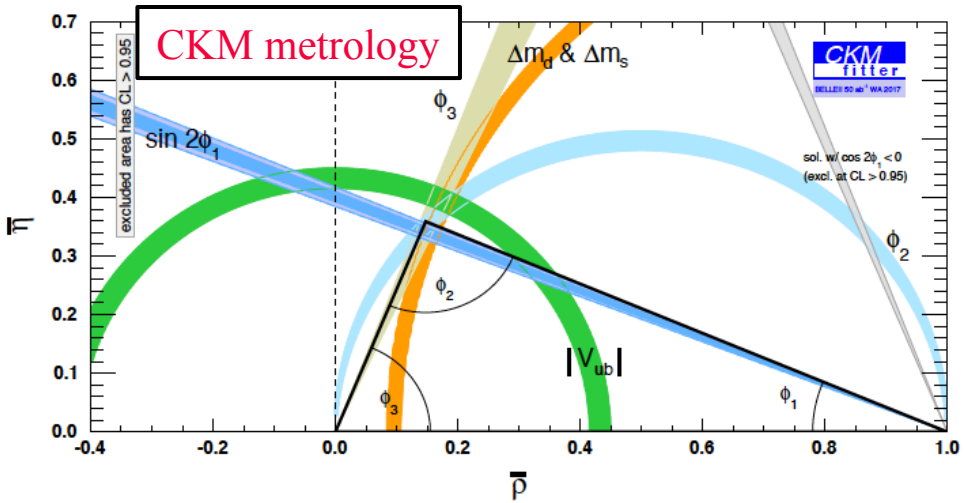
# Some of the grand questions for FP

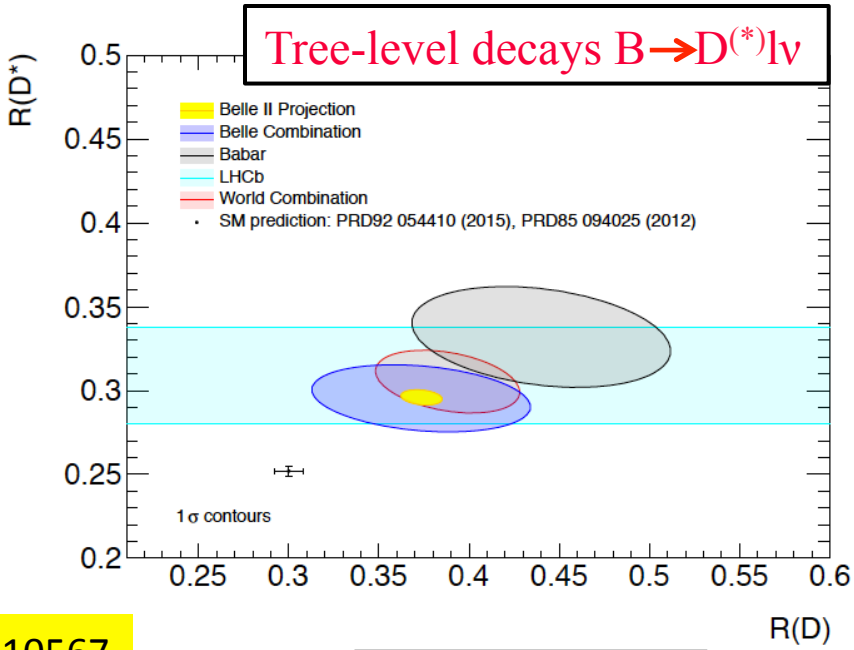
- Are there any new CP violating phases?
  - ➔CP violation (CPV) in B and D decays
- Any right-handed current from new physics?
  - ➔Photon polarization in radiative decays
- Are there any imprints of new physics beyond the SM in flavor changing neutral current transitions?
  - ➔Electroweak penguin decays e.g. $b \to sll$
- Are there any signature of charged Higgs boson? Or, leptoquark?
  - ➔Tree-level B decays to $\tau\nu$ or $D^{(*)}\tau\nu$ final state
- Neutrino oscillation being firmly established, what are the implications for lepton flavor violation in the charged lepton sector?
  - ➔Lepton flavor violating (LFV) tau decays
- Understanding exotic QCD states? Tetraquark, pentaquark, hybrid?
- Can we chase down dark matter from bottom? Hidden dark sector?

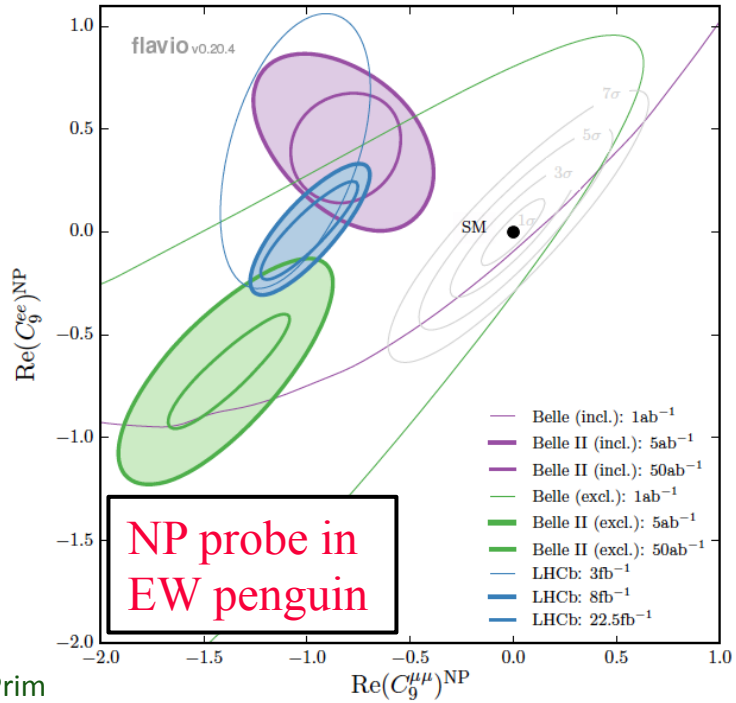
# A new player on the field

G. Caria

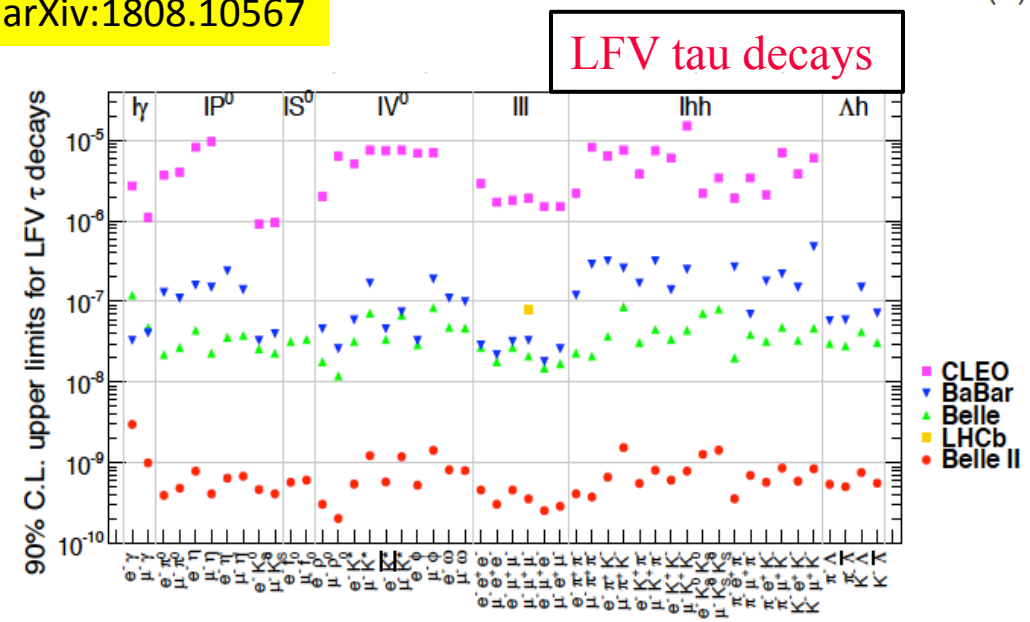
- Will address a broad range of topics:



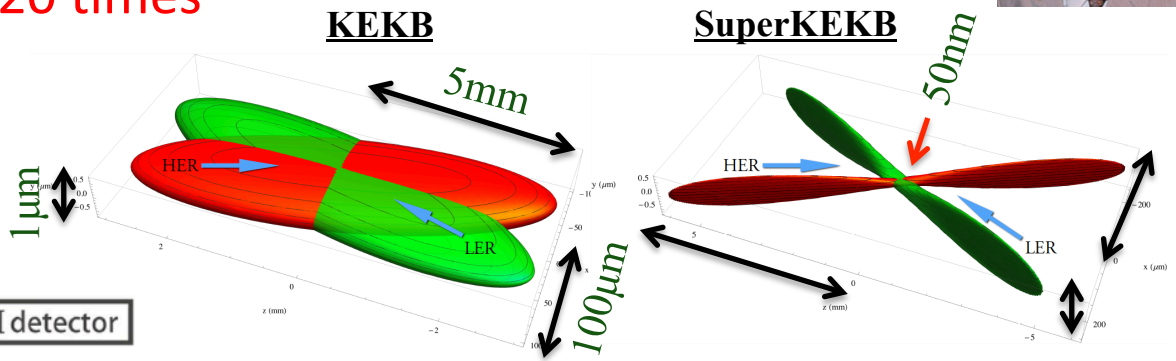



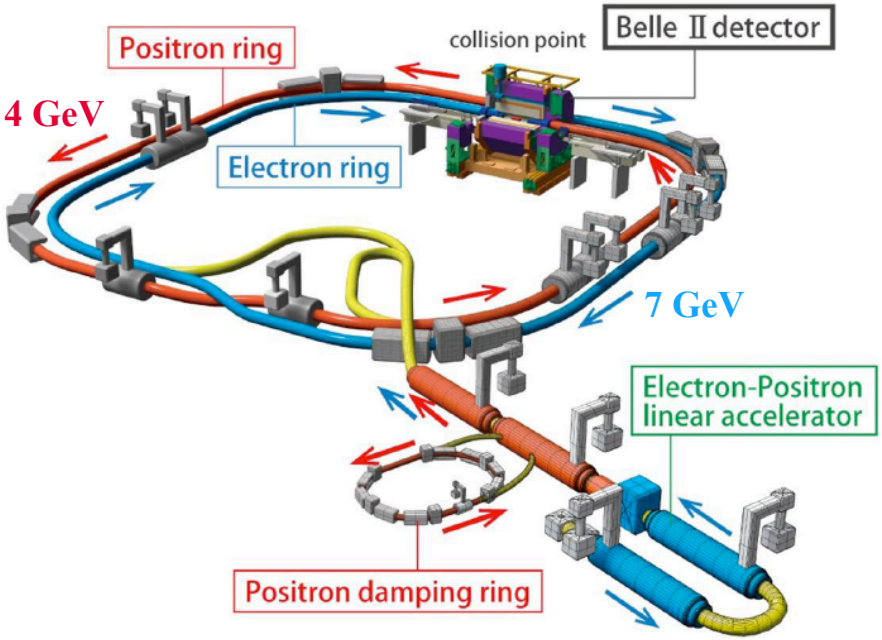

arXiv:1808.10567

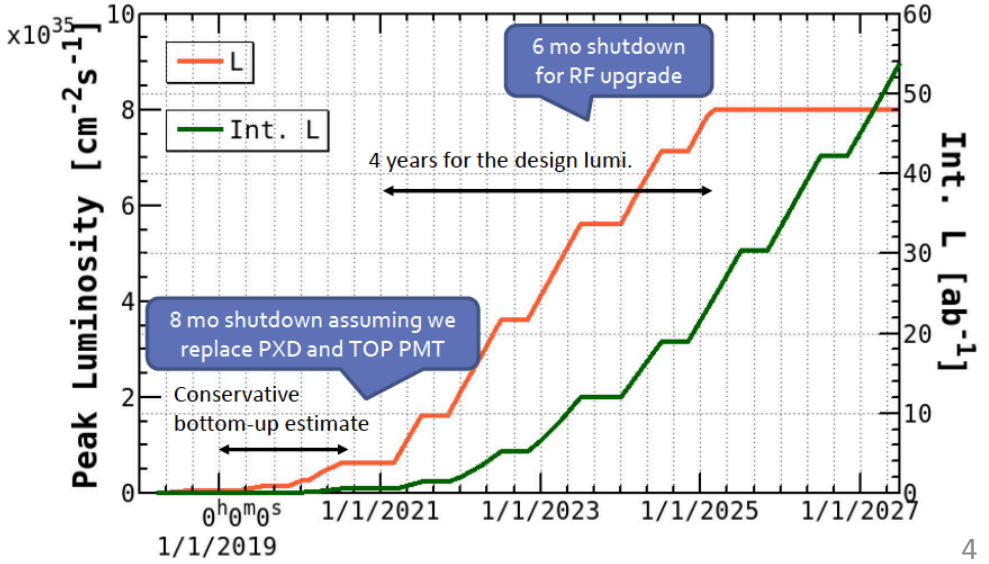


# SuperKEKB: New intensity frontier machine

- Targets to deliver $e^+e^-$ collisions at a peak luminosity of $8\times10^{35}\ cm^{-2}s^{-1}$
  - ➔ 40 times that of KEKB:
    - ✧ Increase beam currents twice
    - ✧ Reduce beam size by 20 times



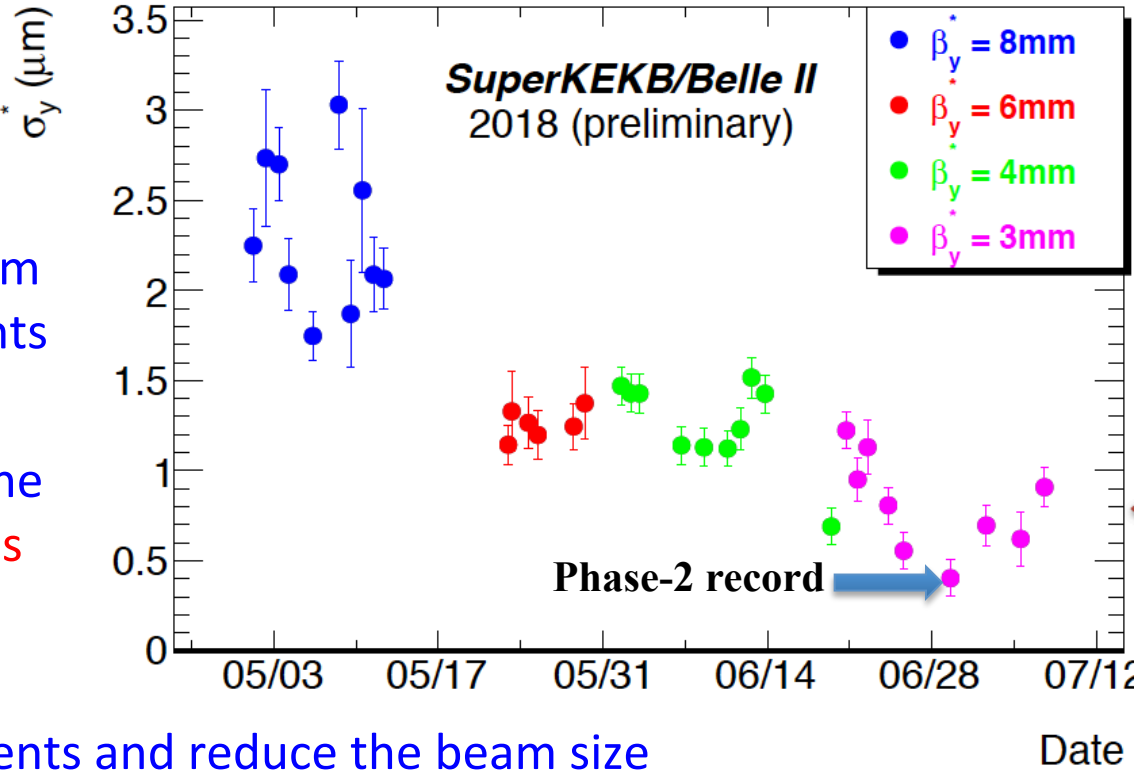




- ➤ First new particle collider after LHC!

# How far have we gone?

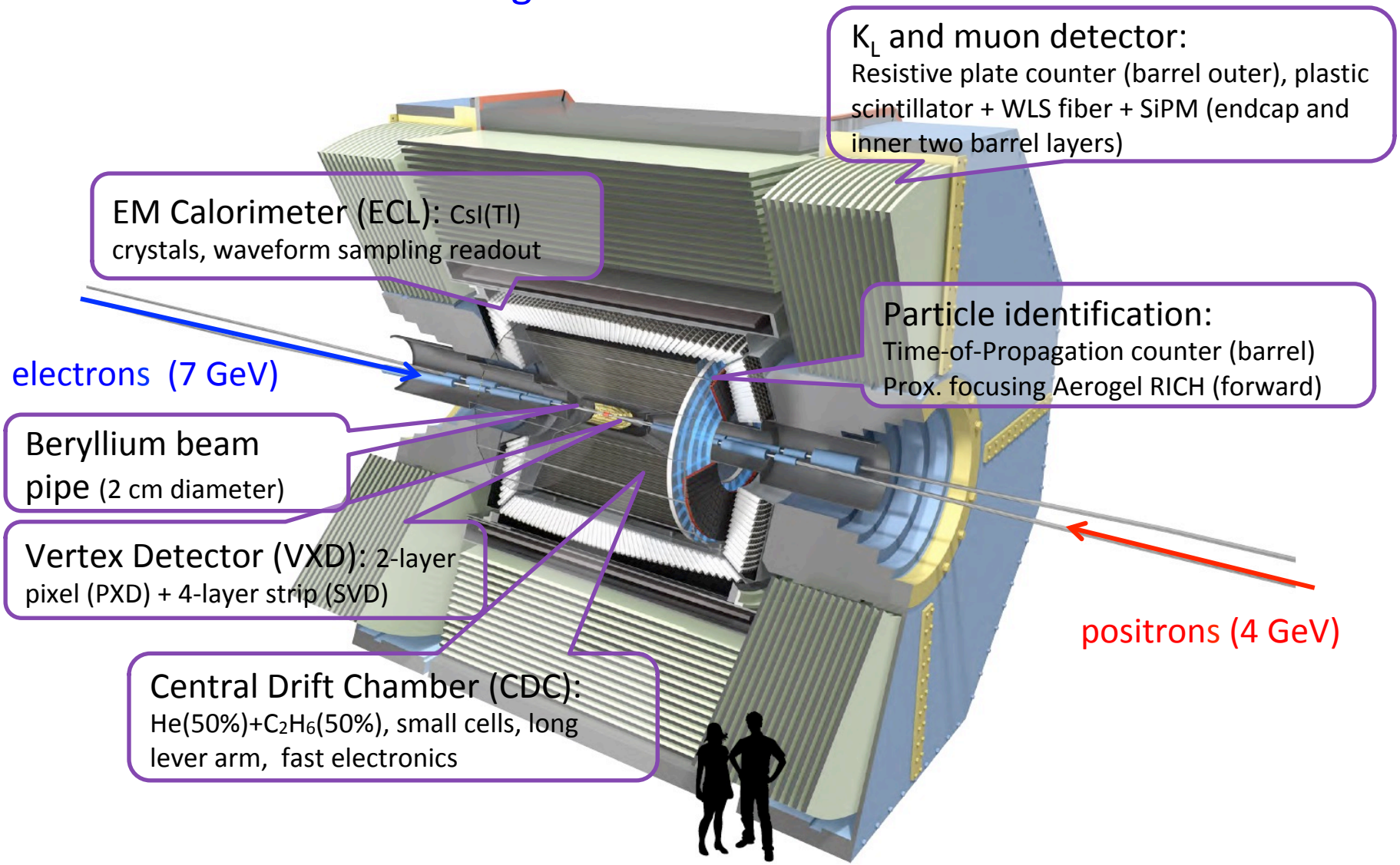
- Phase 2 (2018): beam commissioning (establish nano-beam scheme, reach the KEKB luminosity, and measure beam backgrounds) as well as do some physics with partial vertex detector ➔ ~500 $pb^{-1}$
- Phase 3 (2019 onward): physics run with the vertex detector




- Phase-2 record was $\sigma_y^*$ = 400nm with only ~15mA beam currents
- Continue with $\beta_y^*$ = 3mm for the early phase 3 (expect collisions by end of this week)
- Gradually increase beam currents and reduce the beam size

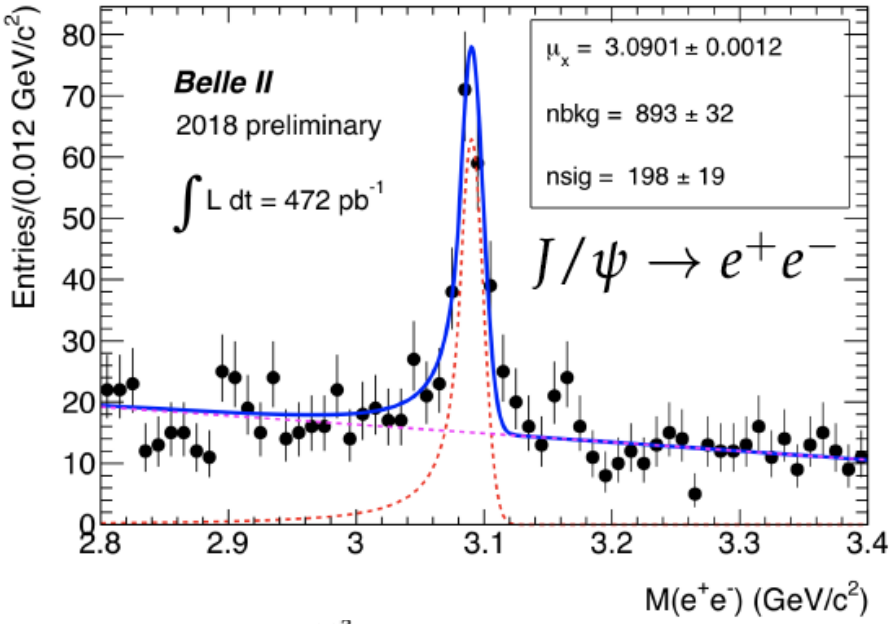
# Belle II: A 21st century HEP experiment

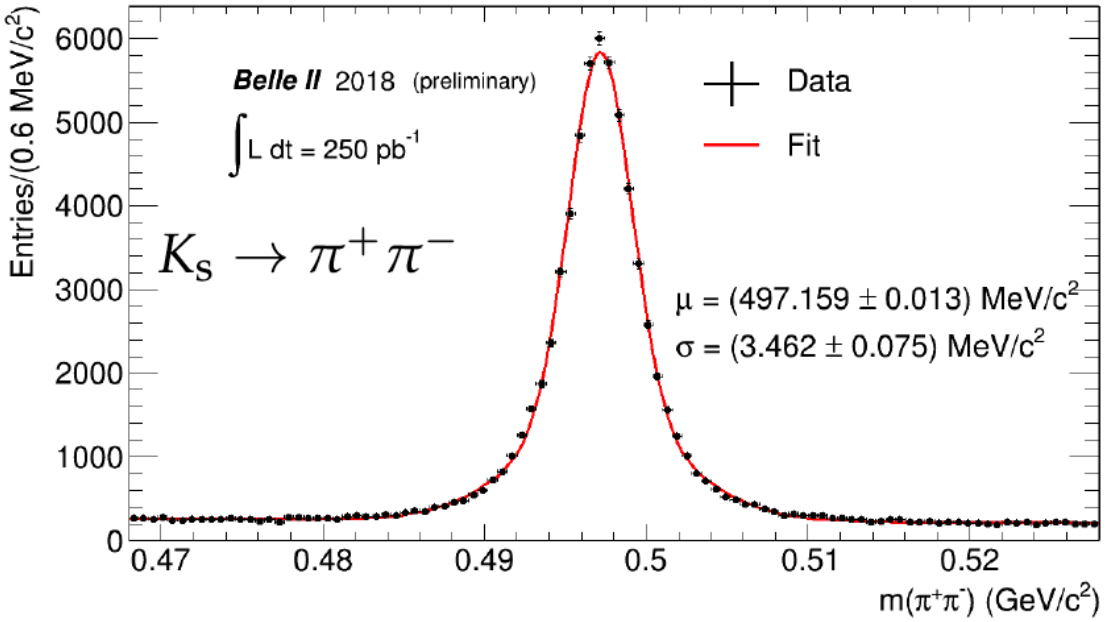
- Designed to operate with a performance similar to or better than Belle, but in a harsh beam background condition

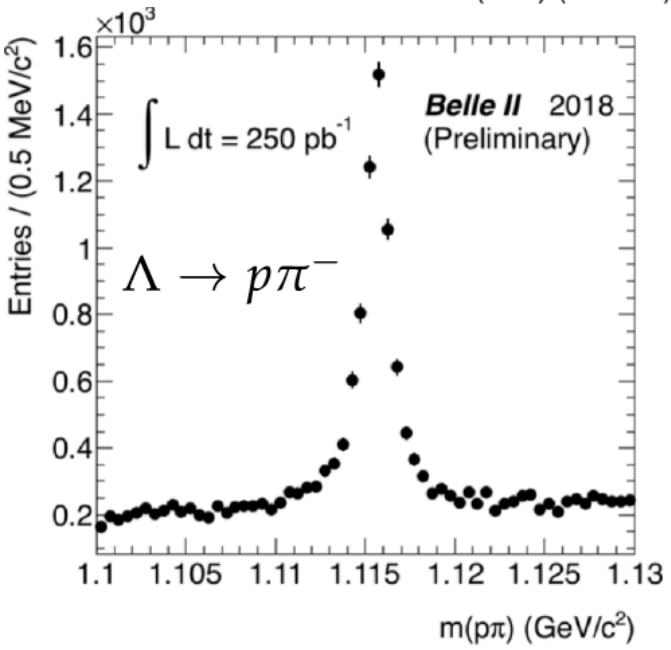


# Tracking system is working fine!

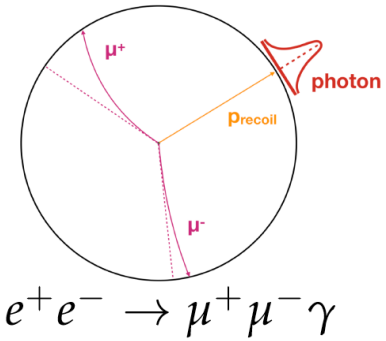
- Charged tracks reconstructed using info mostly from the CDC are available since the beginning of collisions
- Mass resolutions of known particles in data in agreement with simulations (B field measured well and sub-detectors also aligned)



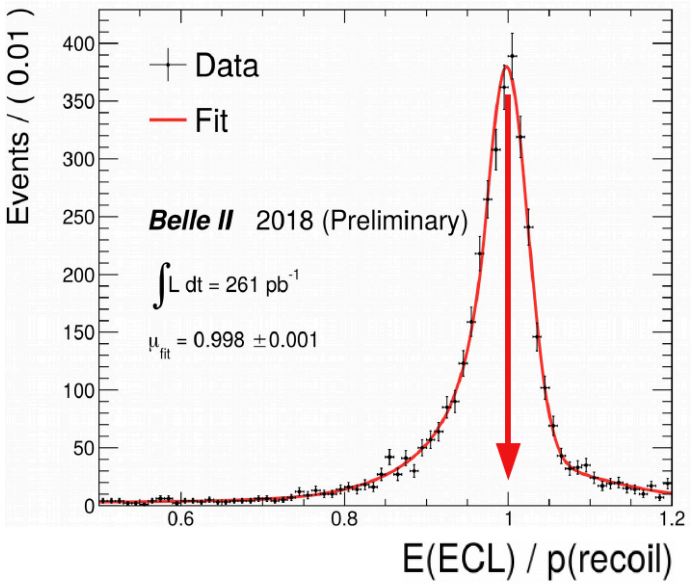



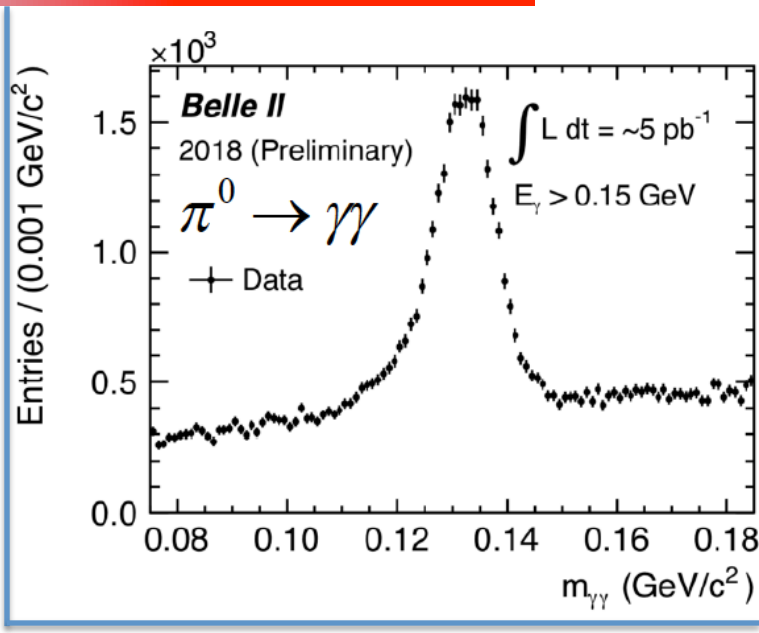



# Neutral construction: Belle II strength




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

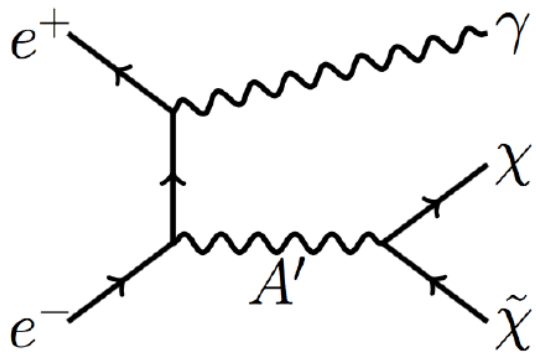


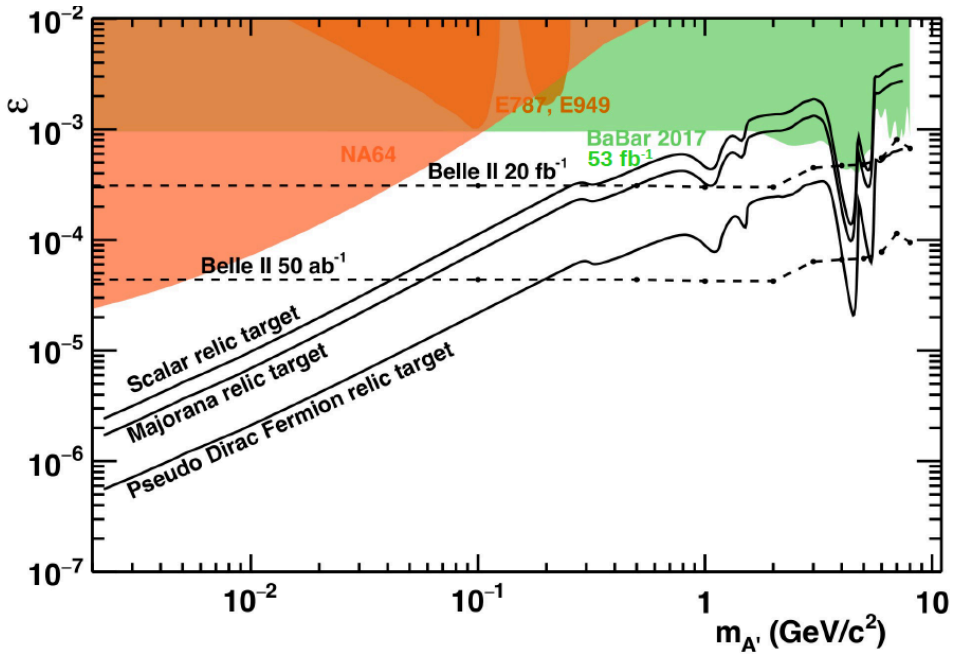




- All set to probe the dark sector:

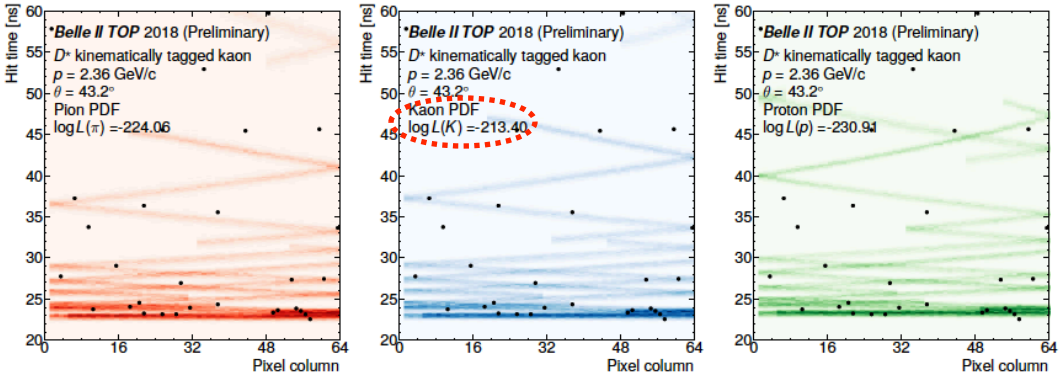
$e^+e^- \to \gamma X$

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



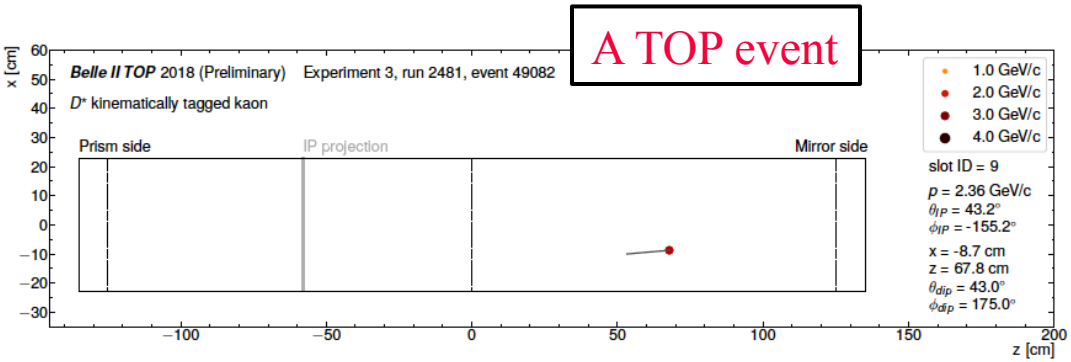



# Particle identification: A key element

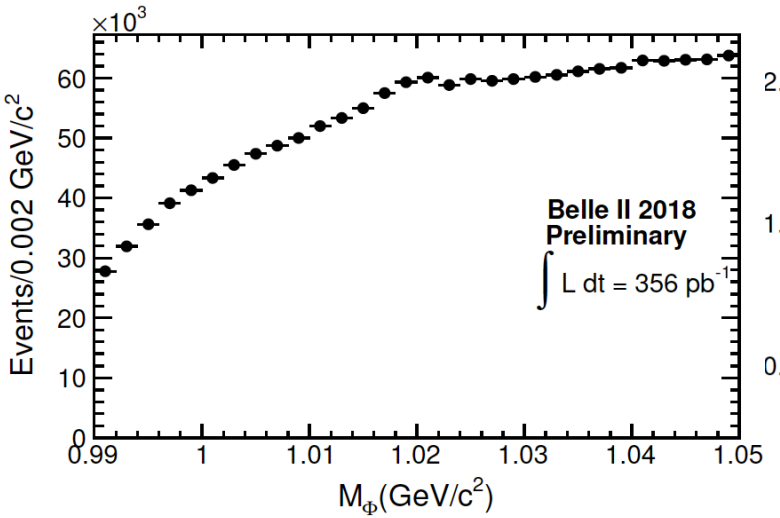


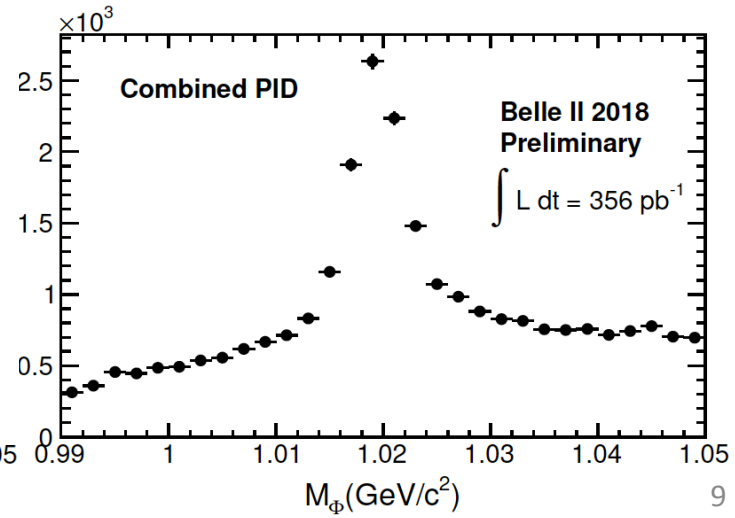

$$D^{*+} \to D^0 \pi_s^+ ; D^0 \to K^- \pi^+$$

- Kaon track is kinematically tagged by the charge of $\pi_s$ arising from the D* decays
- Check consistency of hit pattern ($x$ vs. $t$) of Cherenkov photons

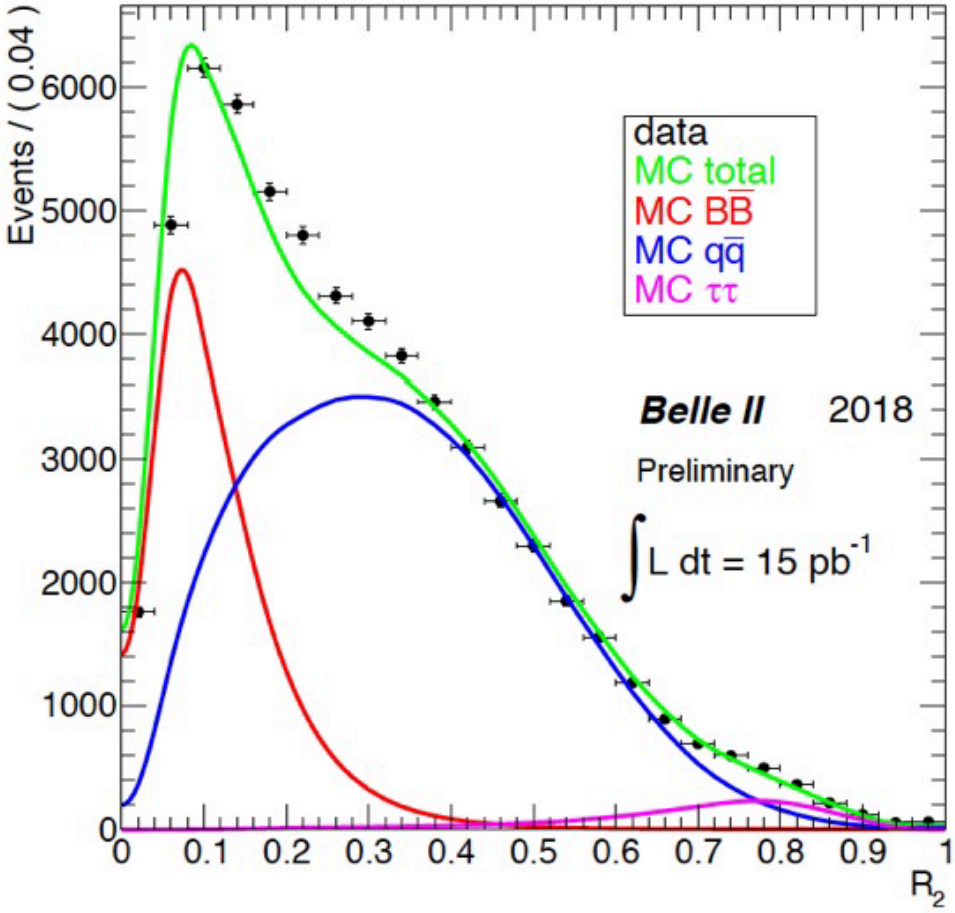


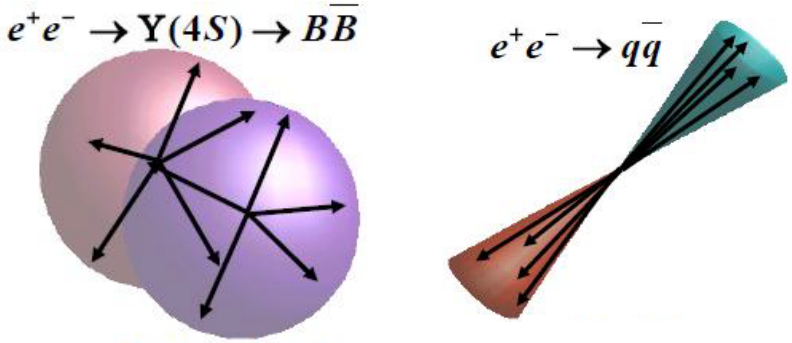

- PID capability with early calibration & alignment



# Rediscovery of B mesons

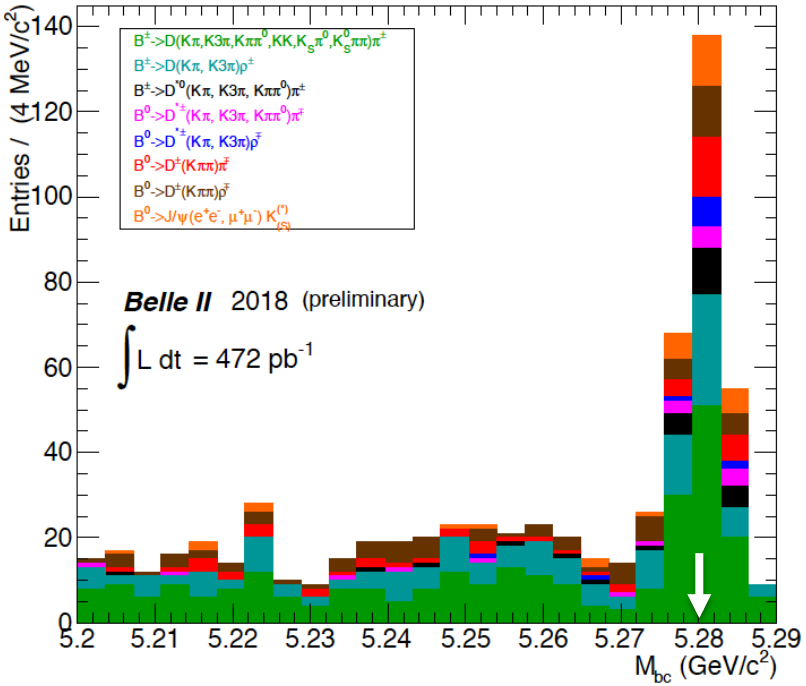


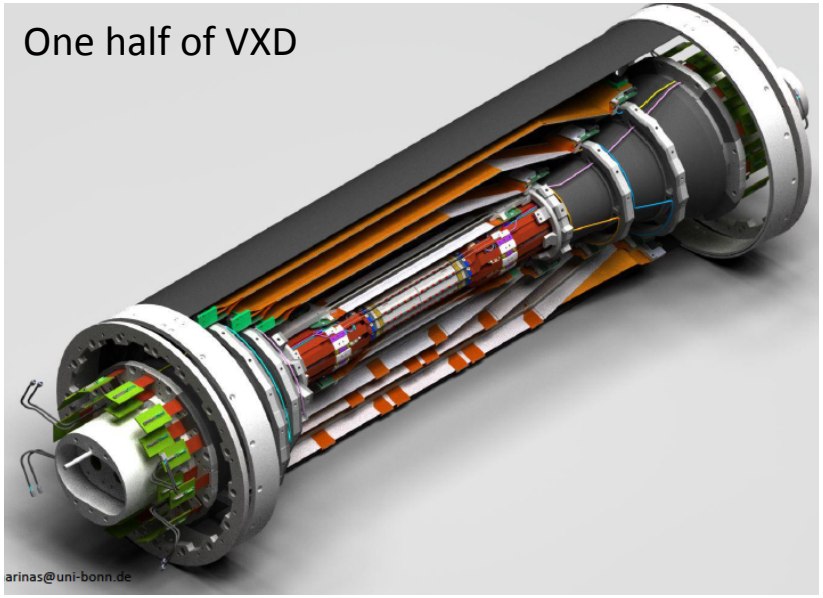

**Spherical** ($R_2 \sim 0$) **Jetlike** ($R_2 \sim 1$)

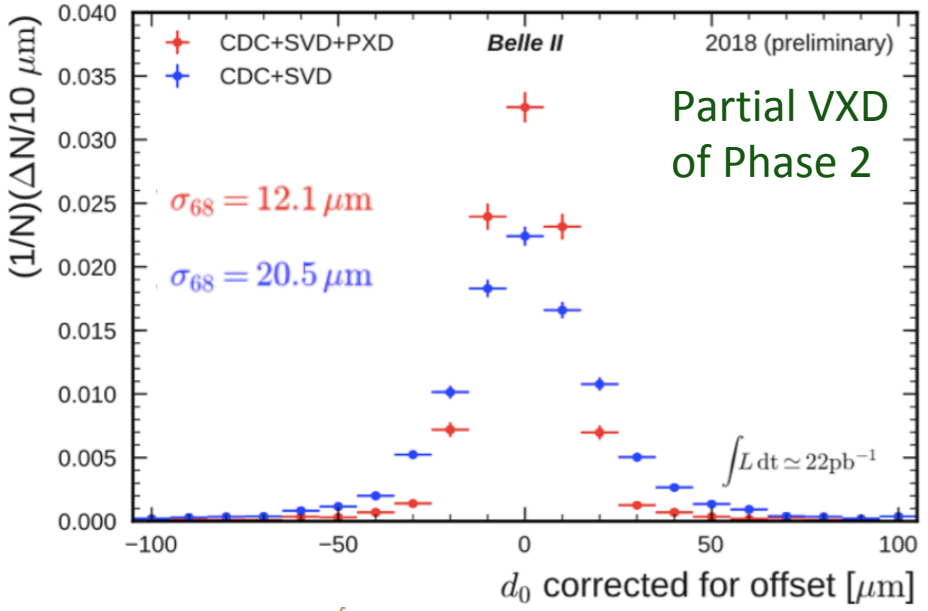
- Event topology tells us that we are seeing spherical $B\bar{B}$ events

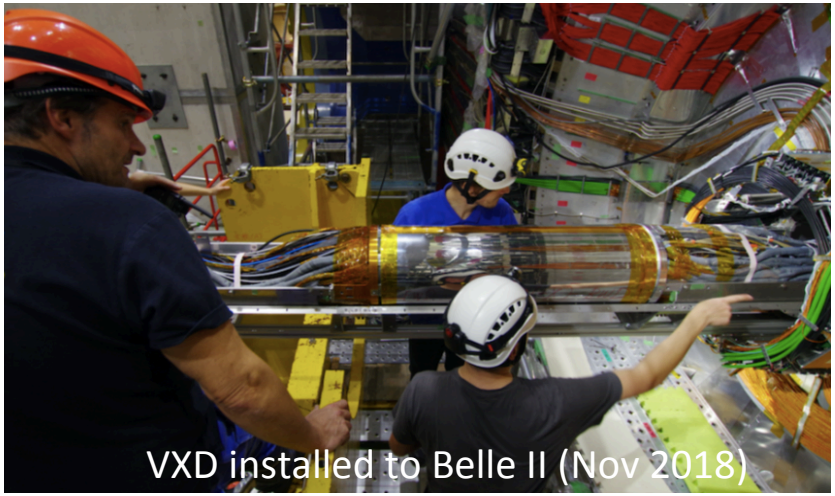
- Further proof came from the plot of the beam-energy constrained mass

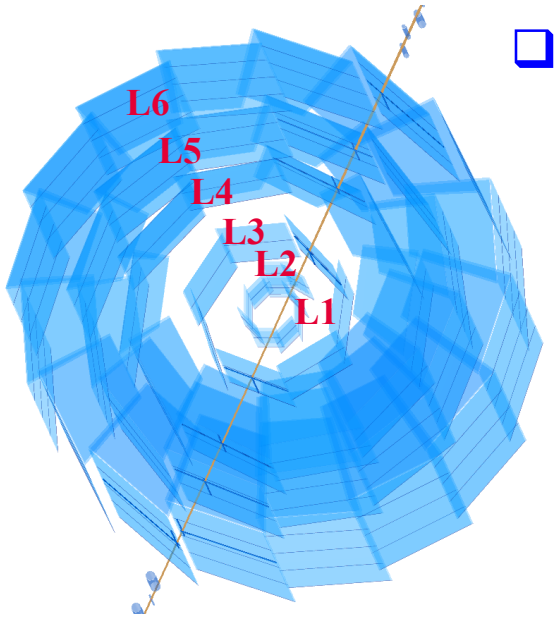


# VXD: Another key element is now ready




- Large improvement in vertex resolution
- PXD: L1+1/6 of L2 (rest will be added in 2020)

In global cosmic since Jan 2019

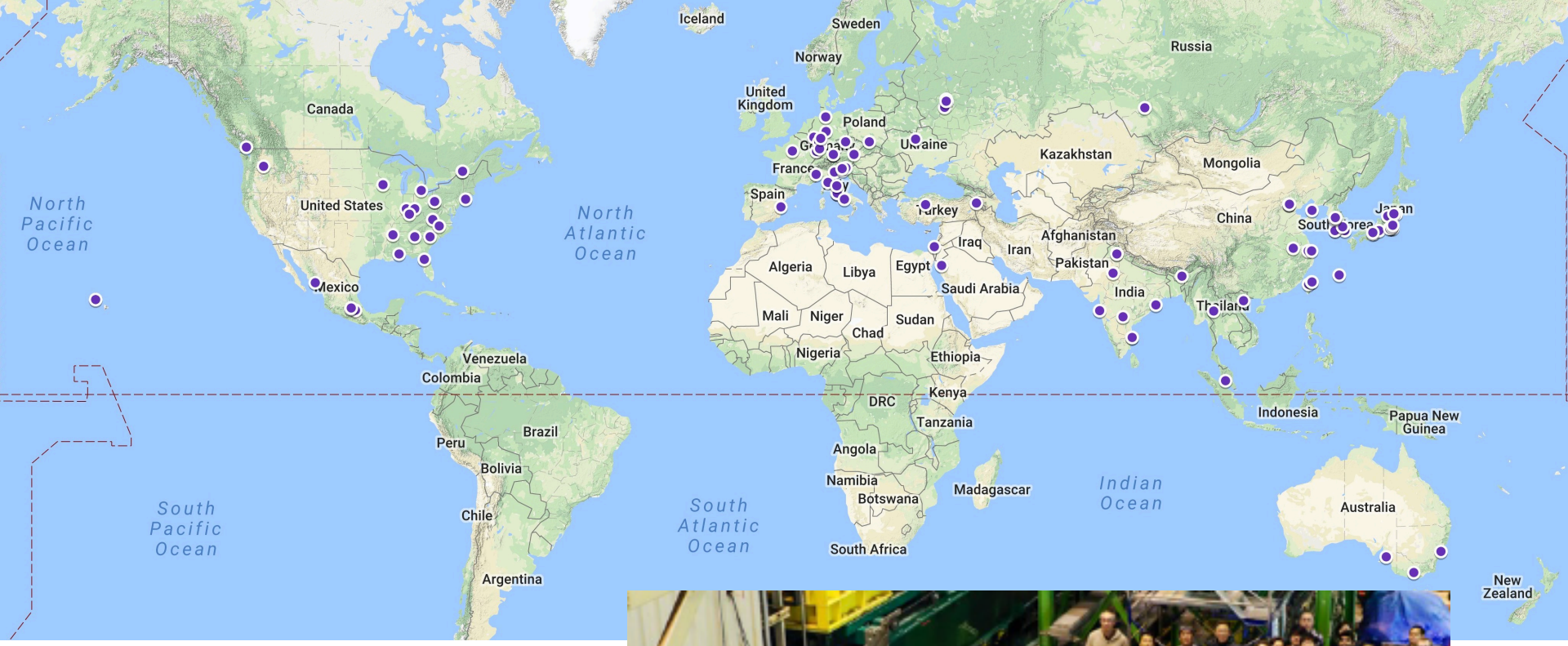
# Early physics harvesting from Phase 3

- Integrated luminosity will depend on machine and detector performance
- Nevertheless, we expect around 10 $fb^{-1}$ by Summer 2019 that would be used to study an array of topics

- Low multiplicity:
  - Dark photon, ALP (1-2 $fb^{-1}$)
  - Magnetic monopole (0.5 $fb^{-1}$)
- Tau:
  - $\tau \to l\alpha$, $\omega h\nu$, $\omega h\pi^0\nu$ (1 $fb^{-1}$)
  - Lifetime (2 $fb^{-1}$)
- Charm:
  - D lifetime (2 $fb^{-1}$)
  - Doubly Cabibbo suppressed $D^0 \to K^+\pi^-$, $K^+\pi^-\pi^0$ (10 $fb^{-1}$)
- Semileptonic B:
  - $B \to D^{(*)}l\nu$ untagged (0.5-10 $fb^{-1}$)
  - $B \to \pi/\rho l\nu$ untagged (2-10 $fb^{-1}$)
- Charmless B (no time dependent):
  - $B \to K\pi$ (10 $fb^{-1}$)
  - $B \to \phi K$ (10 $fb^{-1}$)
- Charmed B:
  - $B \to D^{(*)}h$ CF decays (1 $fb^{-1}$)
  - $B \to D^{(*)}K$, $D^{(*)}\pi^0$ (10-20 $fb^{-1}$)
- EW penguins:
  - $B \to K^* \gamma$ (2 $fb^{-1}$)
  - $B \to X_s \gamma$ (2-10 $fb^{-1}$)
- Time-dependent CPV:
  - B lifetime (2-10 $fb^{-1}$)
  - Mixing in $B \to Dh$, $Dl\nu$ (2-10 $fb^{-1}$)
  - sin $2\phi_1$ in $B \to J/\psi K_S$ and related modes (10+ $fb^{-1}$)

# Closing words

- Belle II will probe new physics at the intensity frontier ➔complementary to high $p_T$ programs of ATLAS and CMS experiments at the LHC
- As for LHCb, there is healthy competition and complementarity
- Marathon (physics run) has just begun in the super factory mode ➔ need high-efficiency data taking as well as extensive running of SuperKEKB
- First results expected by LP2019

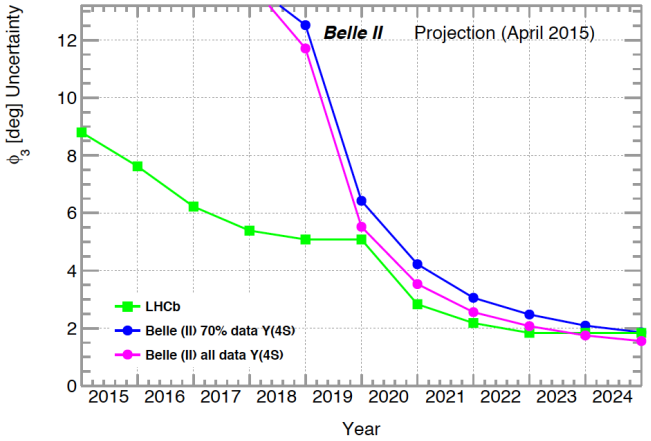


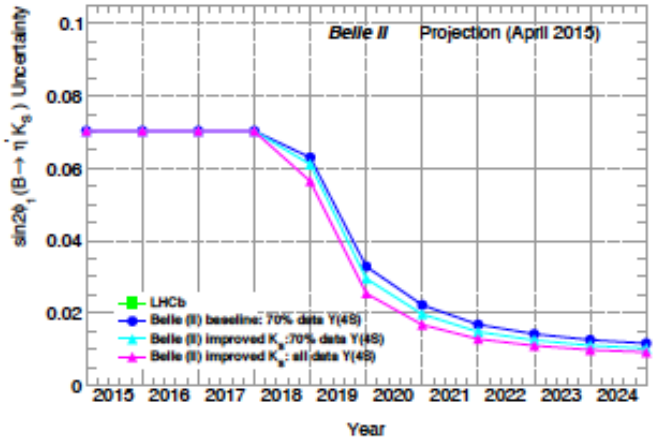

- ❑ >800 members
- ❑ 104 institutions
- ❑ 26 countries
- ❑ 4 continents!

# Belle II vs. LHCb

| Observable | Expected th. accuracy | Expected exp. uncertainty | Facility |
|---|---|---|---|
| CKM matrix | | | |
| $\|V_{us}\|$ $[K \to \pi\ell\nu]$ | ** | 0.1% | $K$-factory |
| $\|V_{cb}\|$ $[B \to X_c\ell\nu]$ | ** | 1% | Belle II |
| $\|V_{ub}\|$ $[B_d \to \pi\ell\nu]$ | * | 4% | Belle II |
| $\sin(2\phi_1)$ $[c\bar{c}K^0_S$ | *** | $8 \cdot 10^{-3}$ | Belle II/LHCb |
| $\phi_2$ | | 1.5° | Belle II |
| $\phi_3$ | *** | 3° | LHCb |
| CPV | | | |
| $S(B_s \to \psi\phi)$ | ** | 0.01 | LHCb |
| $S(B_s \to \phi\phi)$ | ** | 0.05 | LHCb |
| $S(B_d \to \phi K)$ | *** | 0.05 | Belle II/LHCb |
| $S(B_d \to \eta' K)$ | *** | 0.02 | Belle II |
| $S(B_d \to K^*(\to K^0_S\pi^0)\gamma))$ | *** | 0.03 | Belle II |
| $S(B_s \to \phi\gamma))$ | *** | 0.05 | LHCb |
| $S(B_d \to \rho\gamma))$ | | 0.15 | Belle II |
| $A^d_{SL}$ | *** | 0.001 | LHCb |
| $A^s_{SL}$ | *** | 0.001 | LHCb |
| $A_{CP}(B_d \to s\gamma)$ | * | 0.005 | Belle II |
| rare decays | | | |
| $\mathcal{B}(B \to \tau\nu)$ | ** | 3% | Belle II |
| $\mathcal{B}(B \to D\tau\nu)$ | | 3% | Belle II |
| $\mathcal{B}(B_d \to \mu\nu)$ | ** | 6% | Belle II |
| $\mathcal{B}(B_s \to \mu\mu)$ | *** | 10% | LHCb |
| zero of $A_{FB}(B \to K^*\mu\mu)$ | ** | 0.05 | LHCb |
| $\mathcal{B}(B \to K^{(*)}\nu\nu)$ | *** | 30% | Belle II |
| $\mathcal{B}(B \to s\gamma)$ | | 4% | Belle II |
| $\mathcal{B}(B_s \to \gamma\gamma)$ | | $0.25 \cdot 10^{-6}$ | Belle II (with 5 ab$^{-1}$) |
| $\mathcal{B}(K \to \pi\nu\nu)$ | ** | 10% | $K$-factory |
| $\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$ | *** | 0.1% | $K$-factory |
| charm and $\tau$ | | | |
| $\mathcal{B}(\tau \to \mu\gamma)$ | *** | $3 \cdot 10^{-9}$ | Belle II |
| $\|q/p\|_D$ | *** | 0.03 | Belle II |
| $arg(q/p)_D$ | *** | 1.5° | Belle II |

- Great for neutral and missing energy modes
- Inclusive measurement: OK
- Excellent flavor tagging and $K_S$ reconstruction

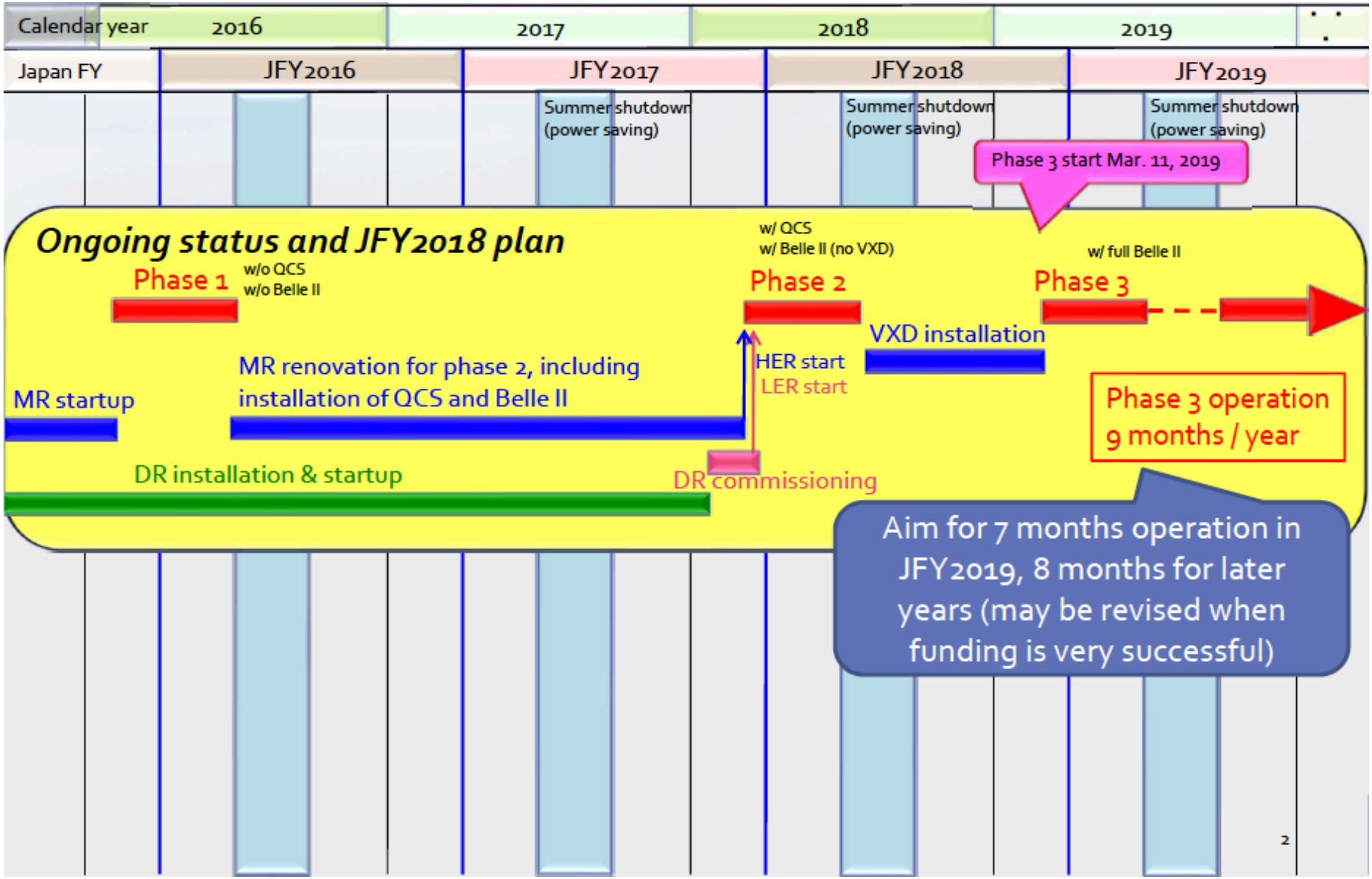


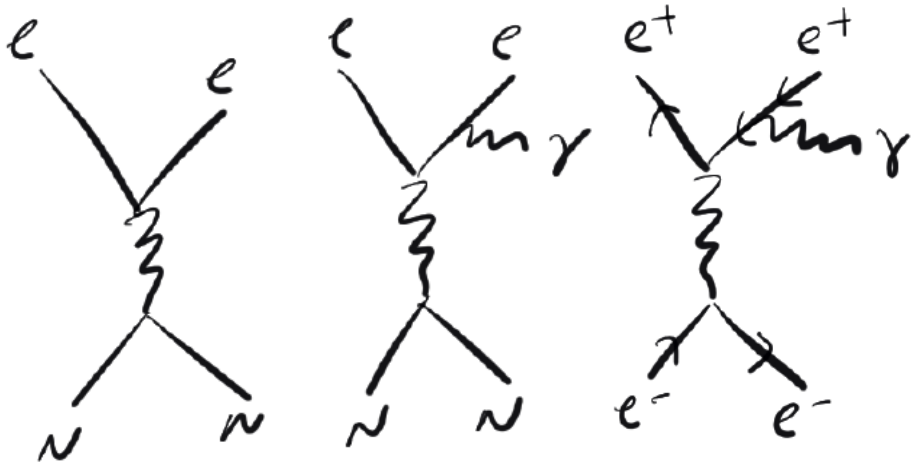
# Comparison: KEKB vs. SuperKEKB

| parameters | | KEKB | | SuperKEKB | | units |
|---|---|---|---|---|---|---|
| | | LER | HER | LER | HER | |
| Beam energy | $E_b$ | 3.5 | 8 | 4 | 7 | GeV |
| Half crossing angle | $\phi$ | 11 | | 41.5 | | mrad |
| Horizontal emittance | $\epsilon_x$ | 18 | 24 | 3.2 | 4.6 | nm |
| Emittance ratio | $\kappa$ | 0.88 | 0.66 | 0.37 | 0.40 | % |
| Beta functions at IP | $\beta_x^*/\beta_y^*$ | 1200/5.9 | | 32/0.27 | 25/0.30 | mm |
| Beam currents | $I_b$ | 1.64 | 1.19 | 3.60 | 2.60 | A |
| beam-beam parameter | $\xi_y$ | 0.129 | 0.090 | 0.0881 | 0.0807 | |
| Luminosity | L | $2.1 \times 10^{34}$ | | $8 \times 10^{35}$ | | $cm^{-2}s^{-1}$ |

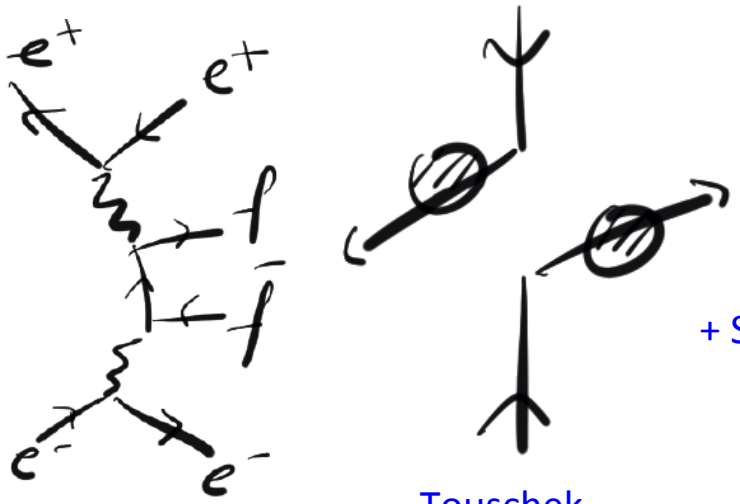
# Global Belle II schedule



# Beam background commissioning



Coulomb scattering | Bremsstrahlung | Bhabha scattering



Two-photon | Touschek (intra-bunch scattering)

+ Synchrotron radiation

arXiv:1802.01366