Belle II Commissioning, First Results, and Future Prospects

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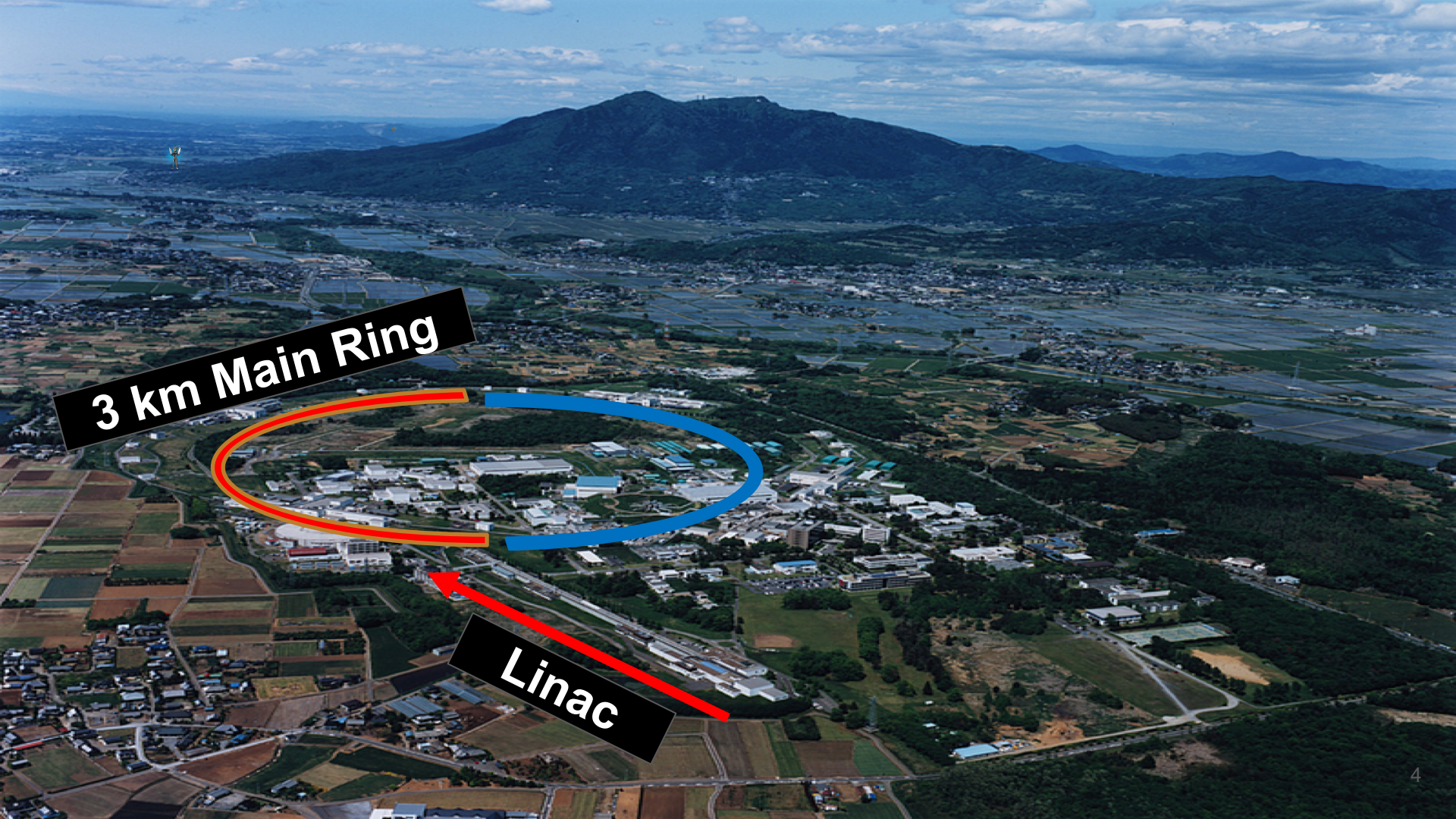
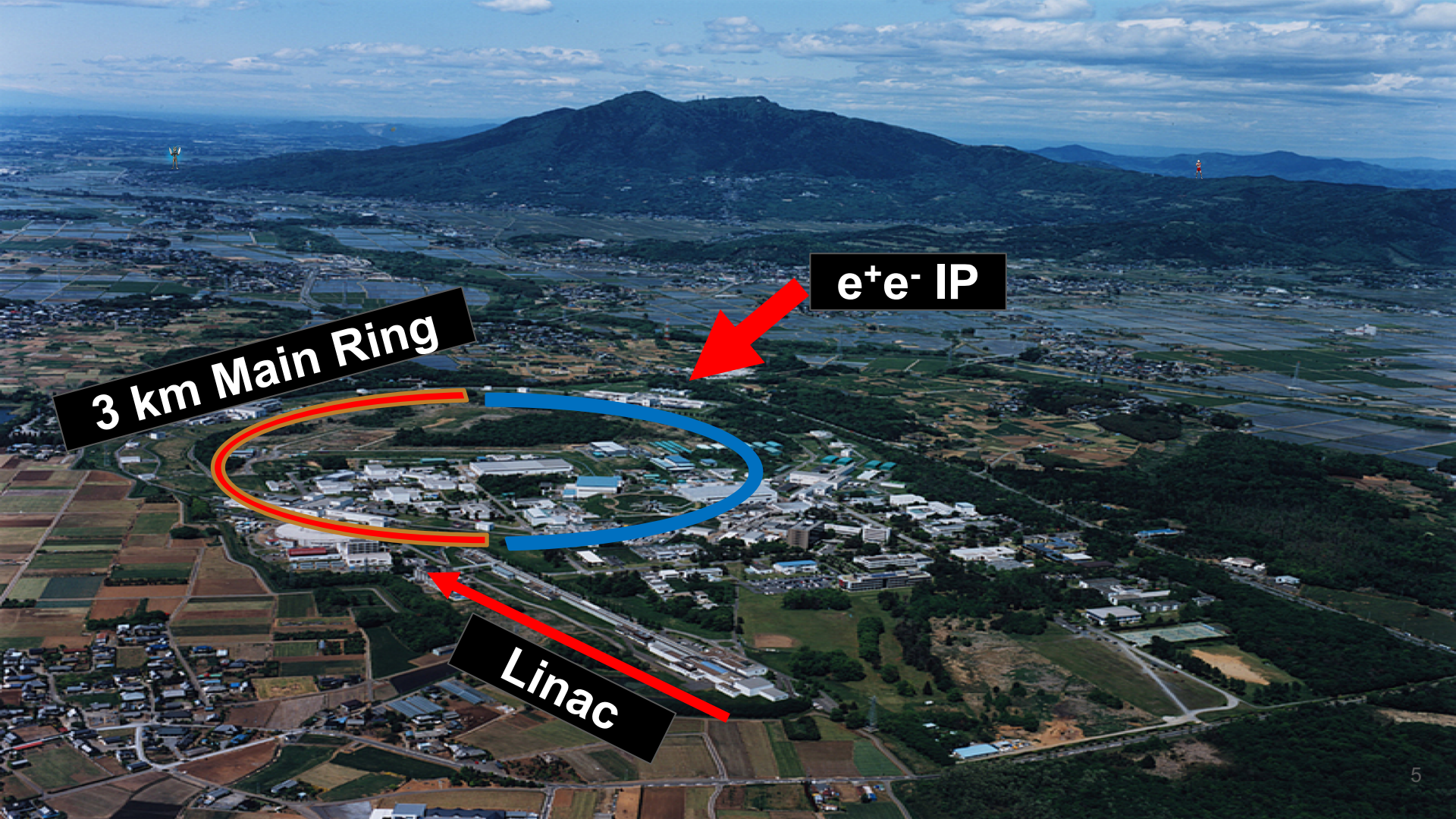
DPF 2019 Boston
On behalf of the BELLE II Collaboration


Linac


3 km Main Ring
Linac

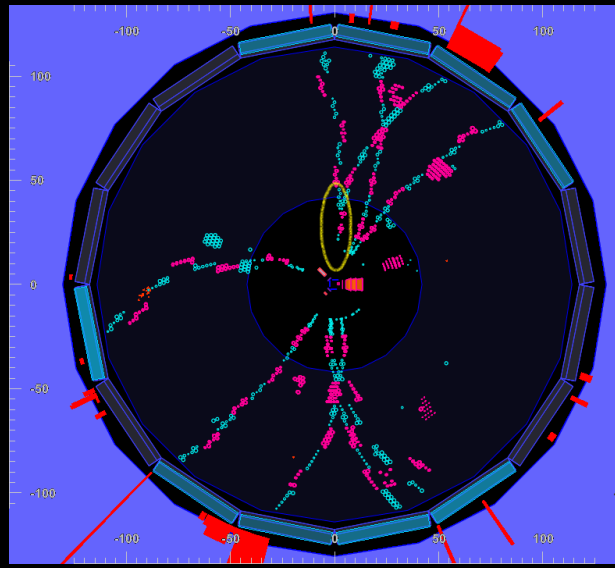

3 km Main Ring
e+e- IP
Linac

The Belle II Collaboration

- International collaboration hosted at KEK in Tsukuba, Japan
- ~980 collaborators from 112 institutions in 26 countries

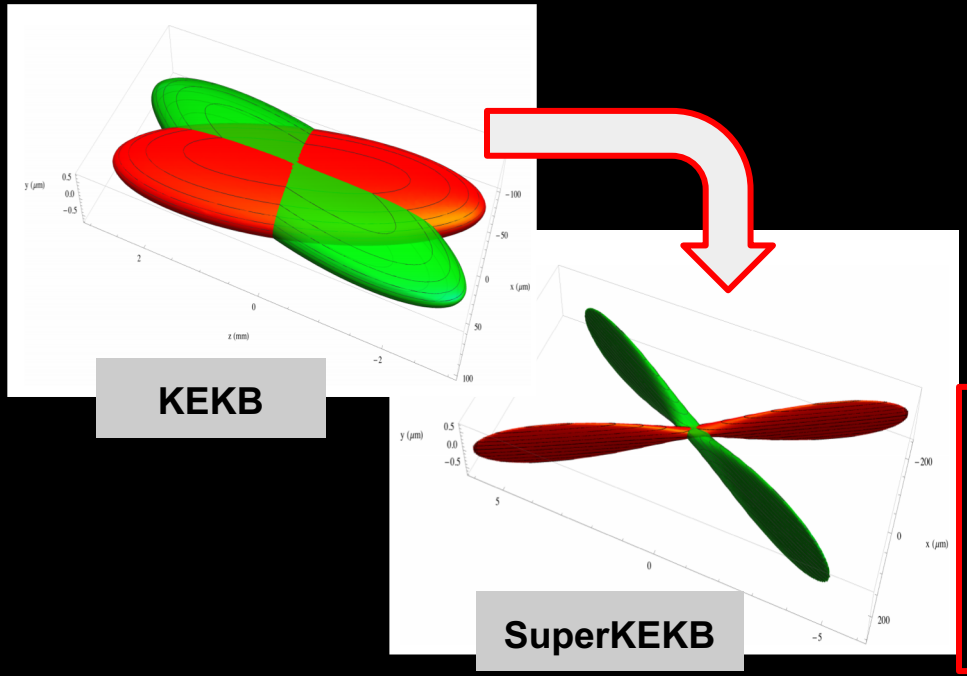
e^+e^- B Factories: B meson pairs in a clean environment

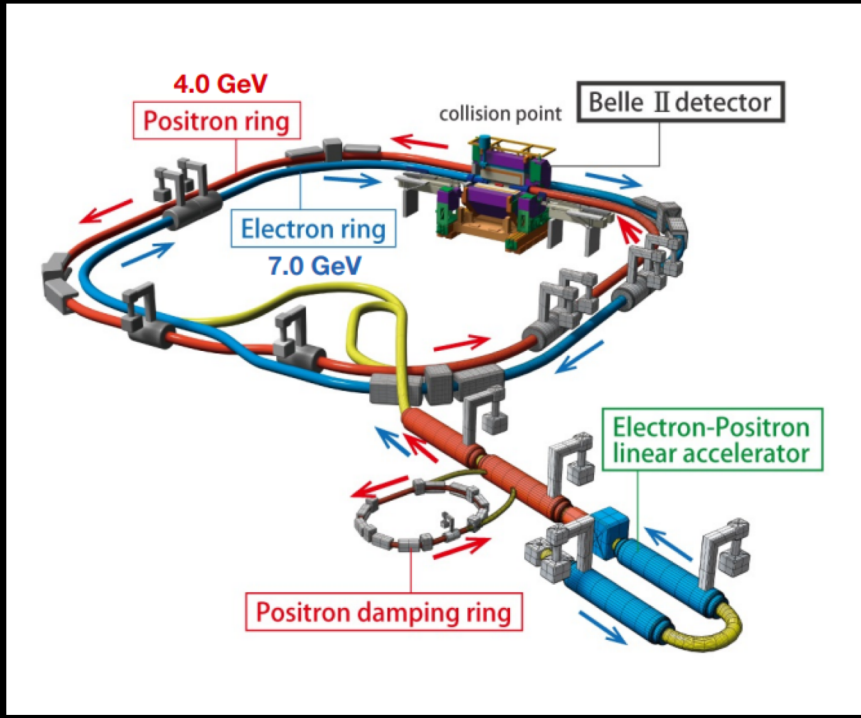
- Aim to provide insights into new physics via precision measurements and rare decays
- e^+e^- collisions provided with asymmetric energy (7 GeV / 4 GeV)
  - Meson pairs boosted → measureable lifetimes
  - Individual quantum-correlated $B\bar{B}$ pairs
  - Clean event topology
    - Efficient detection of neutrals
  - Large sample of clear τ decays
- Complementary to LHCb hadron collisions
  - Different strengths and systematics
  - → Can work in tandem to achieve better results!
- Previous-gen B-Factories (Belle, BaBar) provided 1.5 ab^{-1}… Belle II will go much further!



From KEKB to SuperKEKB

- SuperKEKB: The B-factory at KEK
- Asymmetric energy e^- - e^+ collider
- 10.58 GeV $\sqrt{s}$ energy



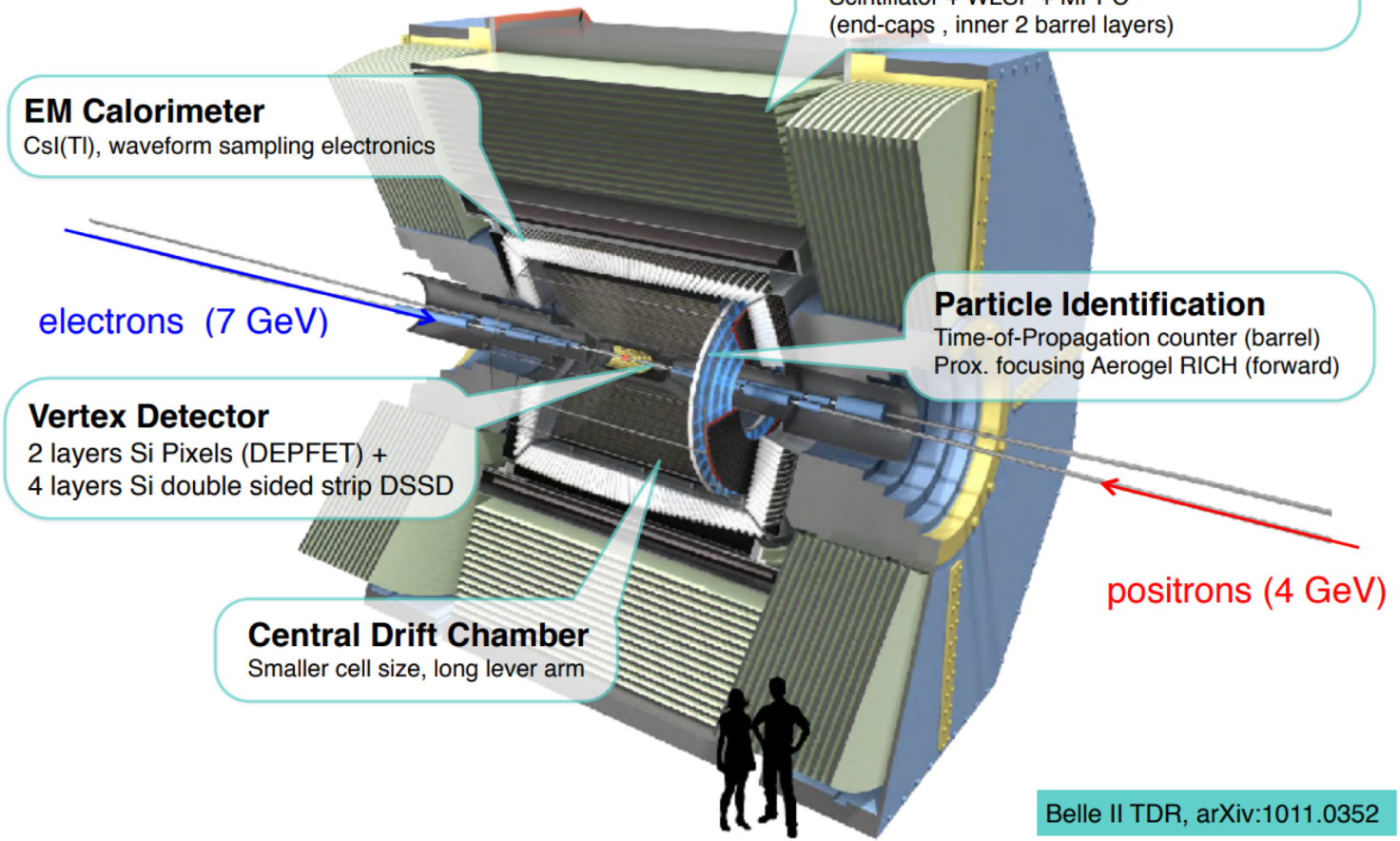


Doubled beam currents and change to 'nanobeam' – 1/20th size at IP

→ **40x** KEKB instantaneous luminosity

→ **50x** KEKB integrated luminosity

Belle II Detector



Belle II TDR, arXiv:1011.0352

Challenges in a High-Luminosity Environment

- Increased beam backgrounds
  - 10 - 20 fold increase expected
  - Problematic for data analysis
  - Radiation damage to detector components
    - → Possibly reduced lifetime
- Increased occupancy
- Very high event rates (~30 kHz at L1 trigger)

In the Beginning: Commissioning Phases

Two dedicated runs to prepare for upcoming challenges and ensure running conditions would be safe for Belle as luminosity increases:

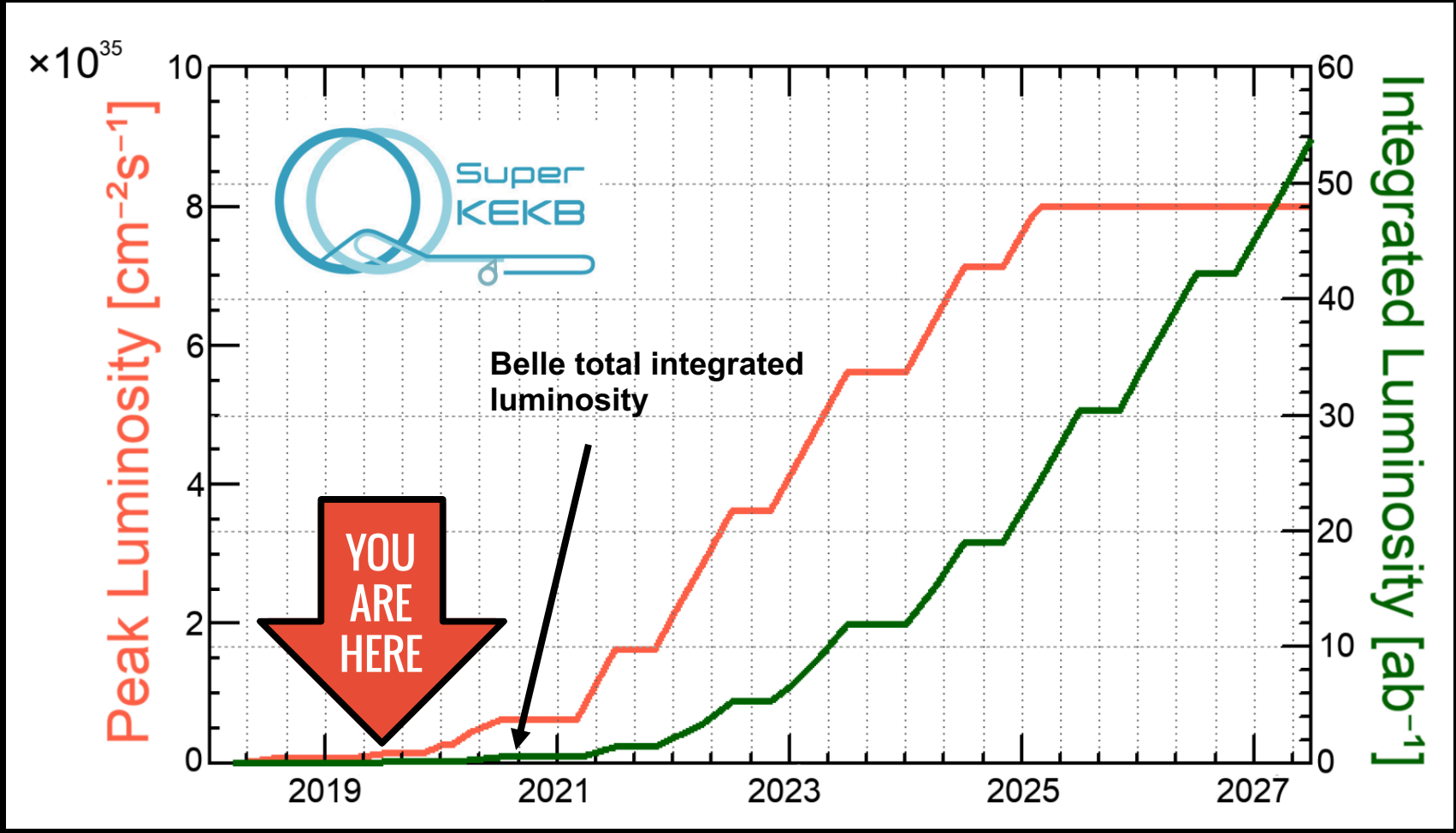
Phase I

- February – July 2016
- -Accelerator commissioning focus
- -No beam-beam collisions
- -Dedicated background detection system (BEAST II) placed at IP
- -Results of background studies published last year: arXiv:1802.01366

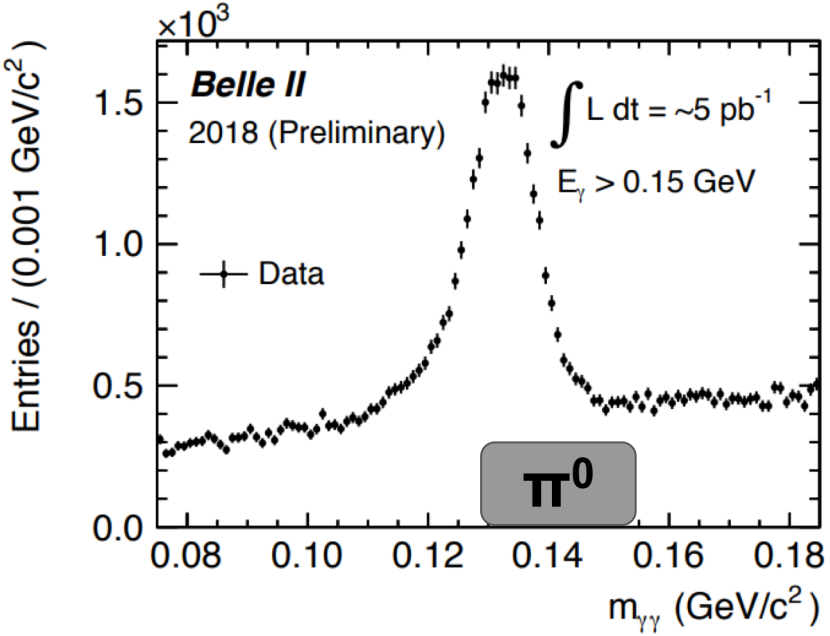
Phase II

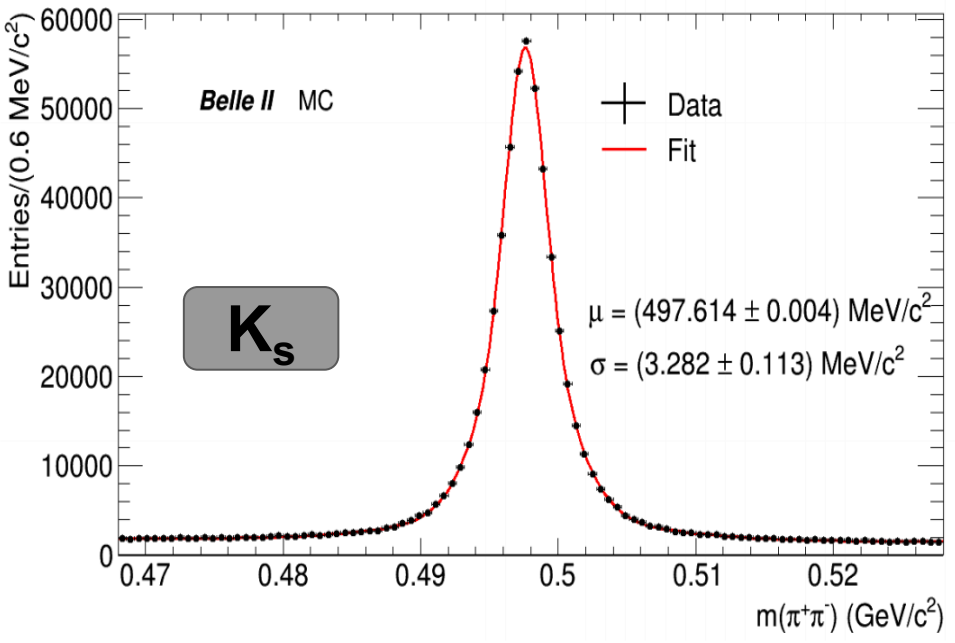
- -March – July 2018
- -First collisions: April 26th
- -More dedicated background studies carried out along with accelerator beam tuning
- -Ultimately predicted Phase III could safely begin
- -Results forthcoming! (Several papers in the works)

Belle II Data Taking Plan



Phase II Data: Early Particle Re-discoveries

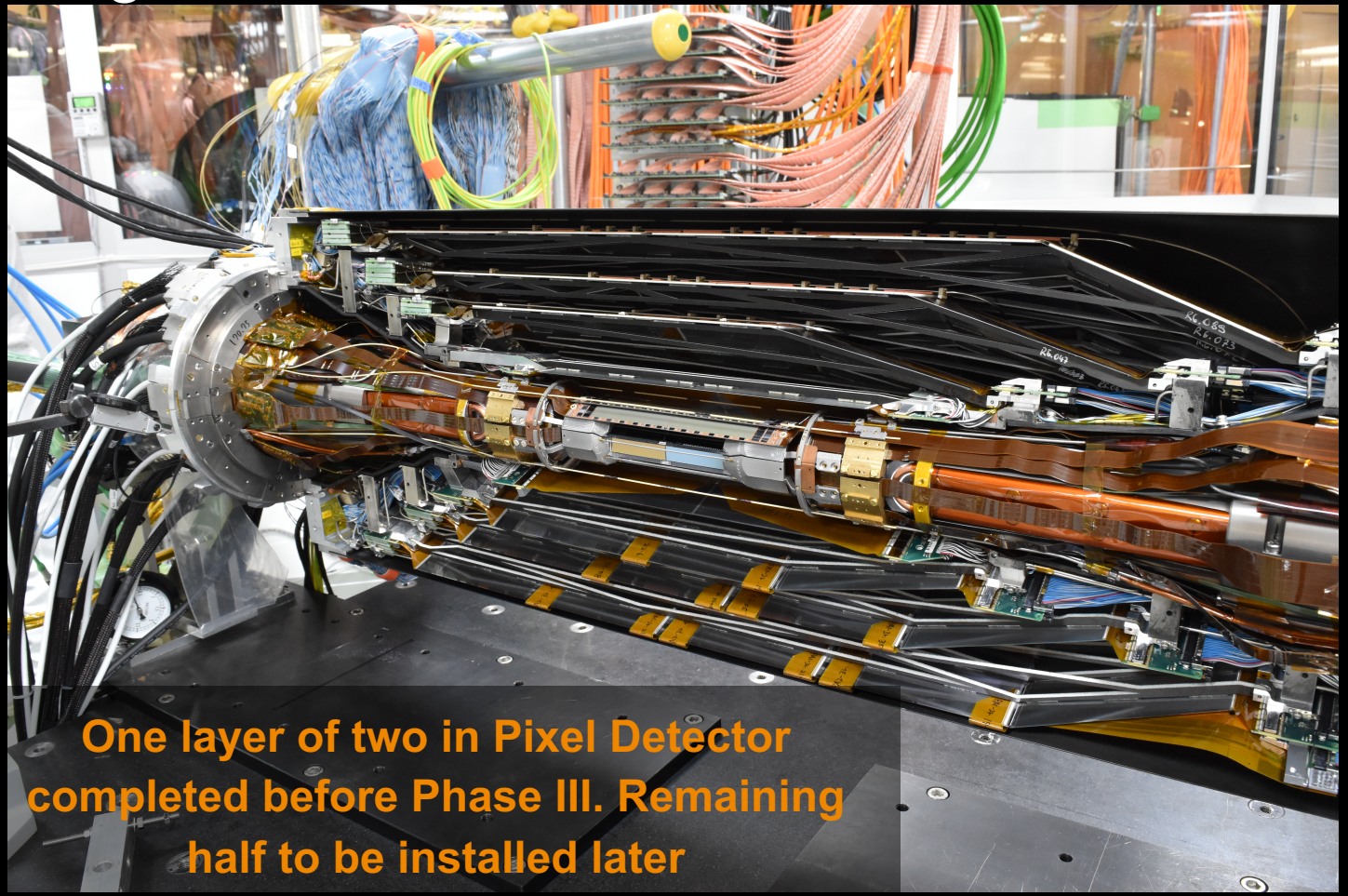




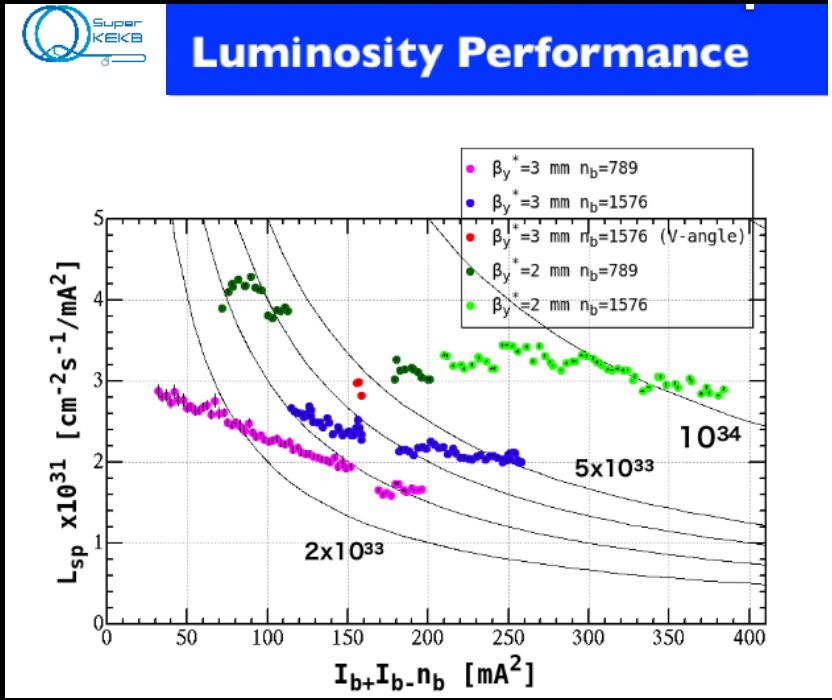
First Collisions - SuperKEKB Control Room

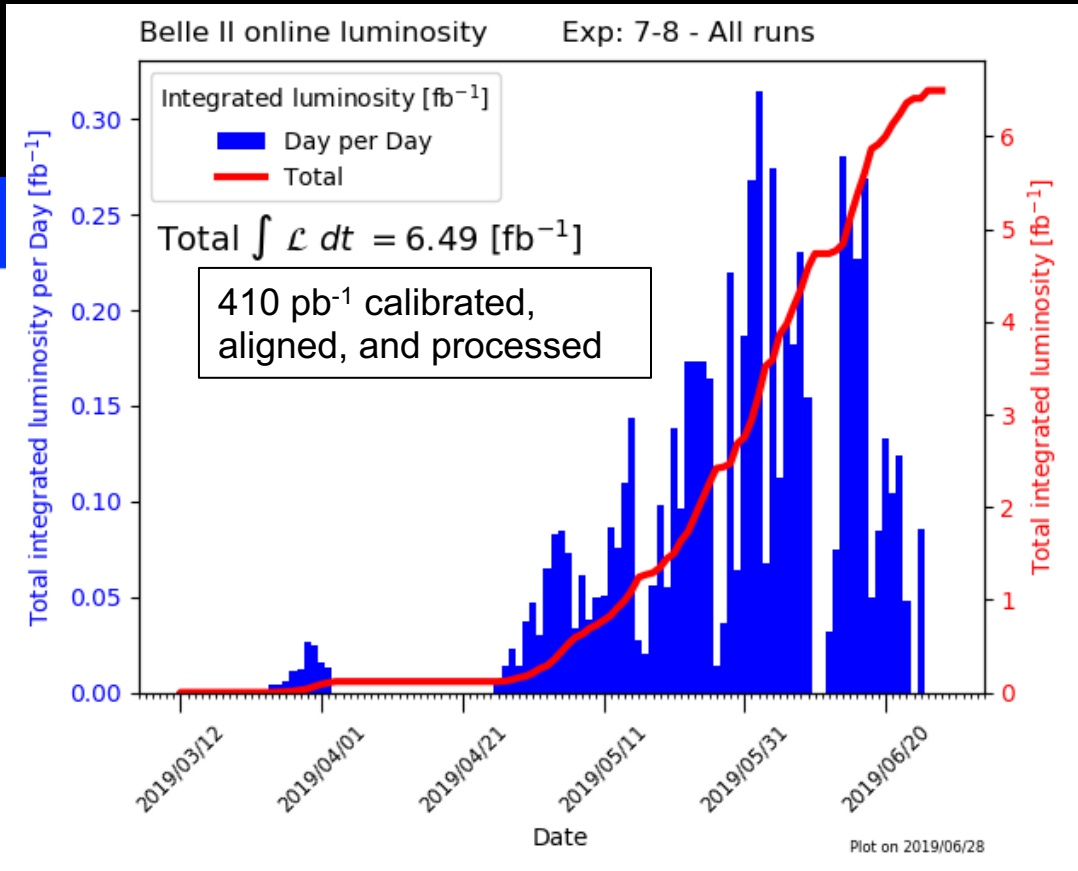
First Collisions - Belle II Control Room

Moving to Phase III - Vertex Detector Installation

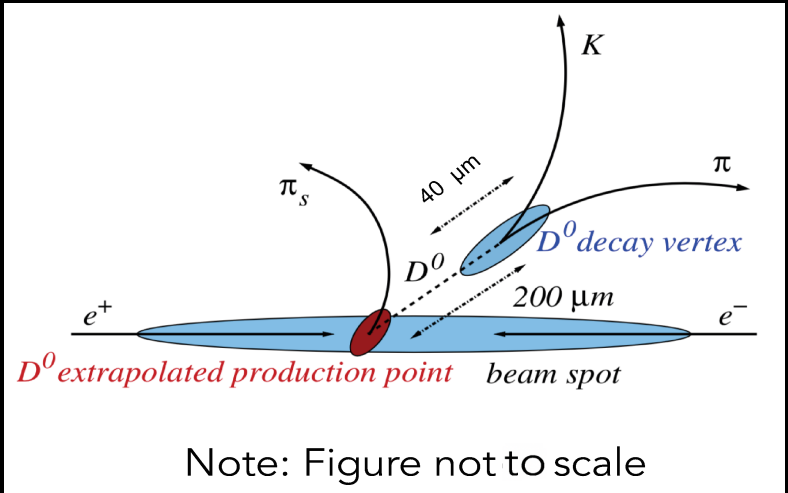


Phase III… so far

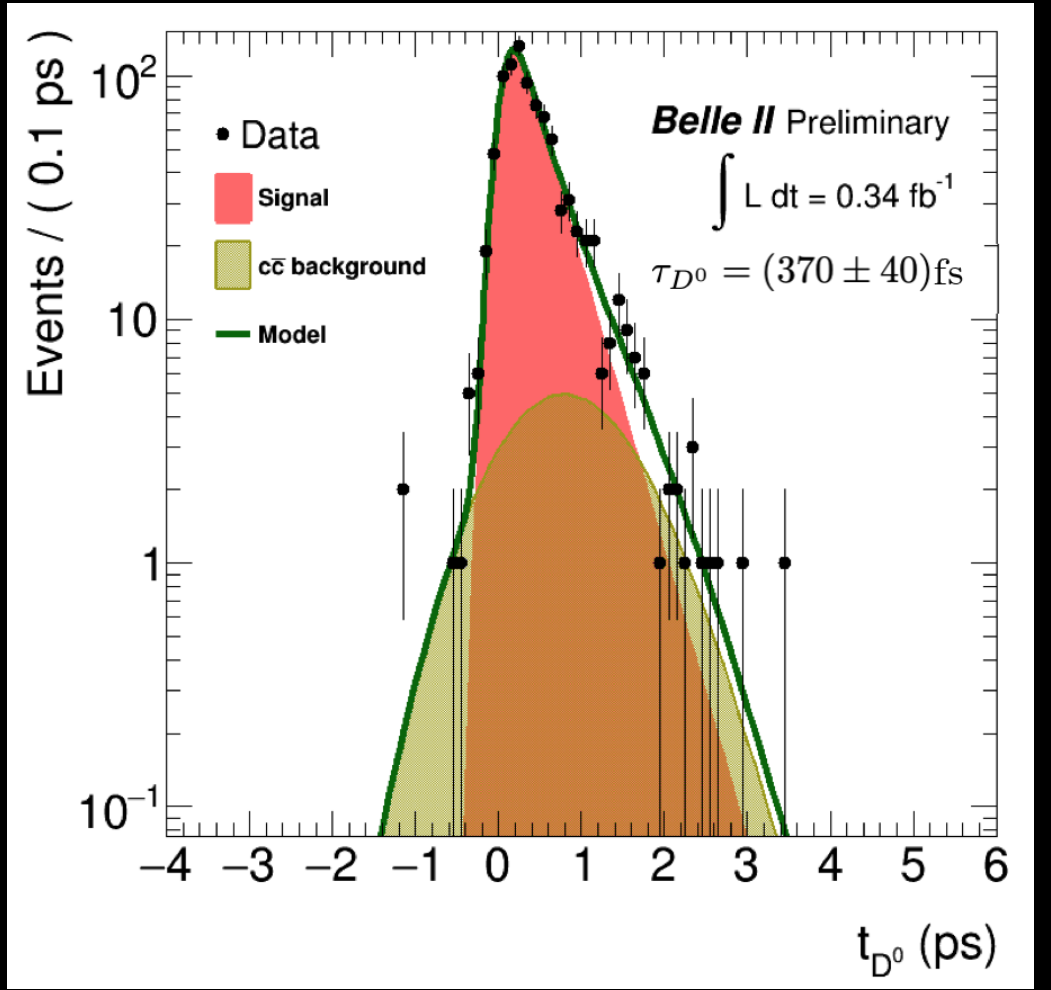




D^0 Meson Lifetime



- Measured lifetime of D^0
- Small subset of collected data used
- Tiny flight distances → great test of vertex detector performance
- Measurements in agreement with PDG (410.1 ± 1.5 fs)

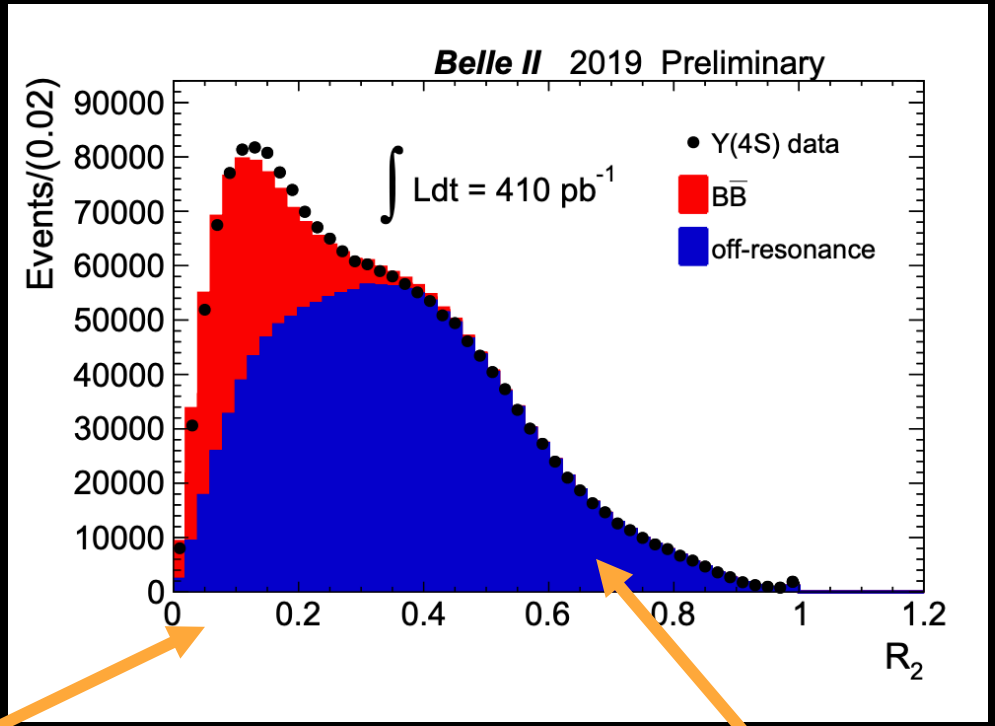


R_2 Fit and B Prediction

$$H_l = \sum_{i,j} \frac{|P_i||P_j|}{E_j^{vis}} P_l(cos\theta_{ij})$$

$$R_2 \equiv {}^{H_2}/_{H_0}$$

- R_2 provides discrimination between continuum and $B\bar{B}$
- Excess of data found at low values in on-resonance data
  → likely underestimated beam-gas BG
- Use off-resonance data for continuum modeling

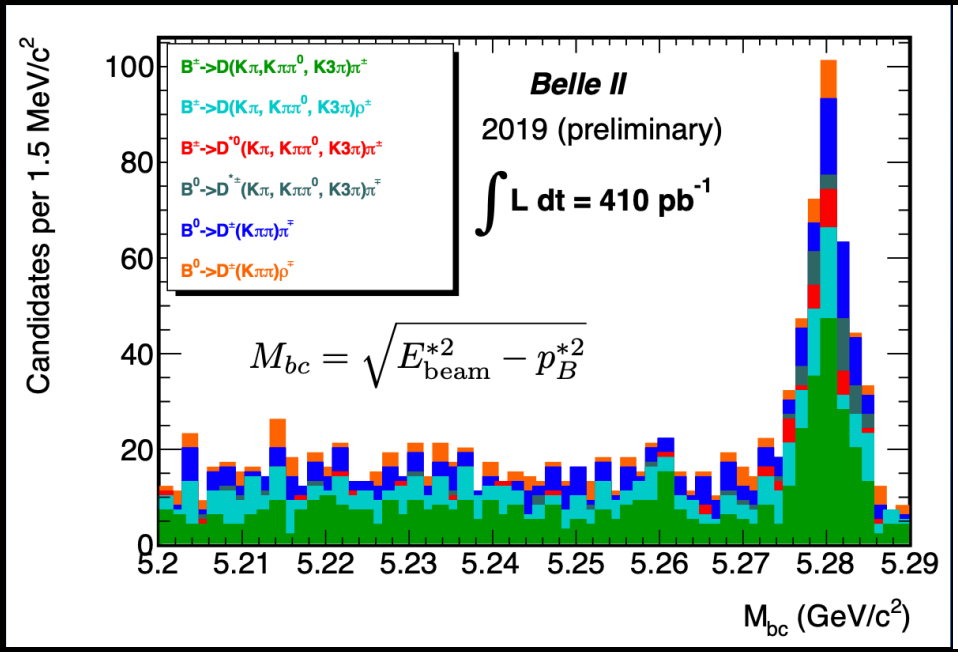


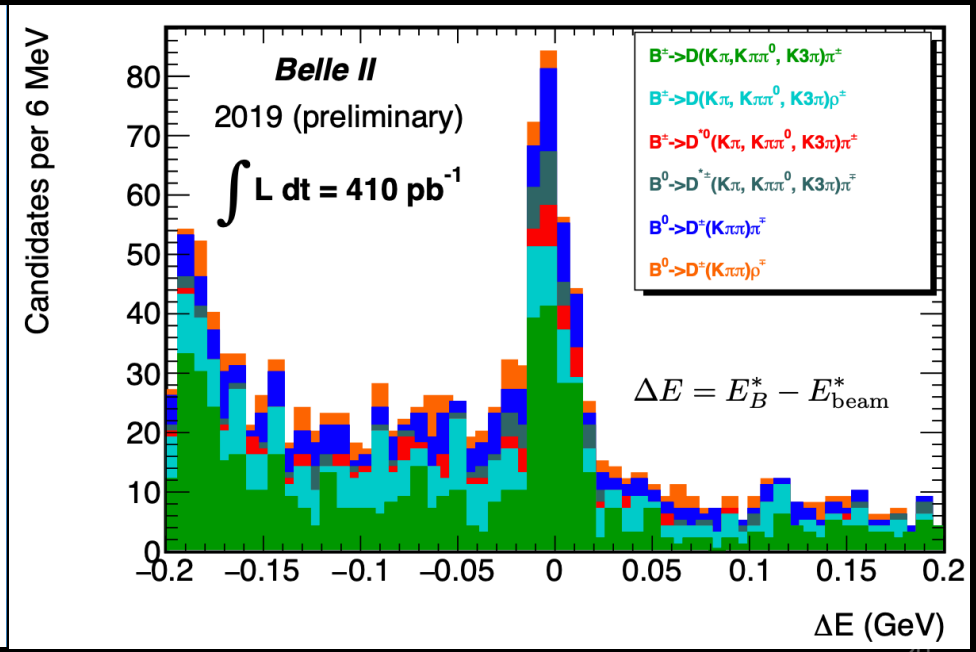
Spherical BB-like events

Comtinuum-like events

B → Dh Reconstruction

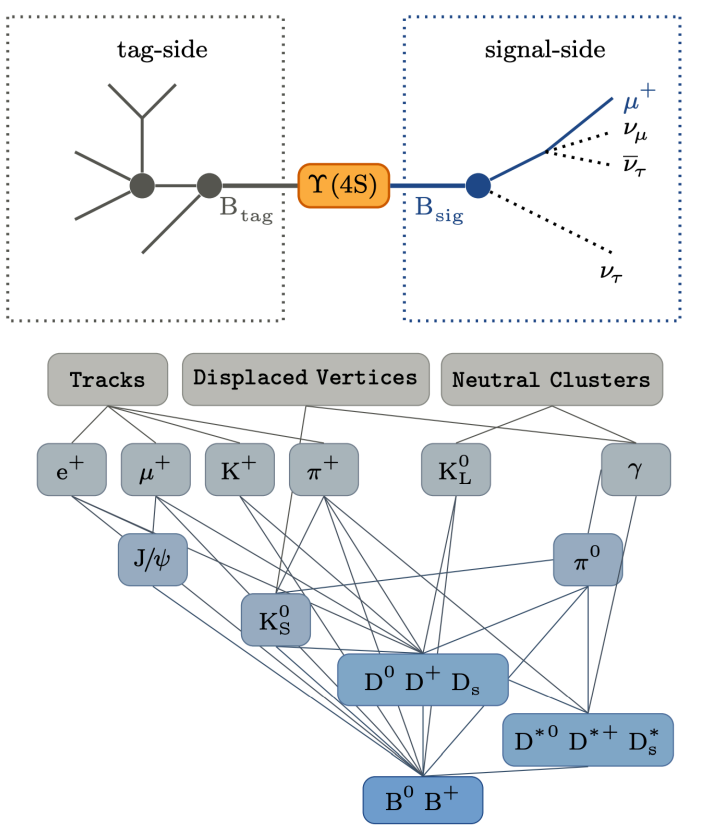
- B meson signals reconstructed from early data set
- ~300 candidate events reconstructed from a 410 pb^{-1} sample

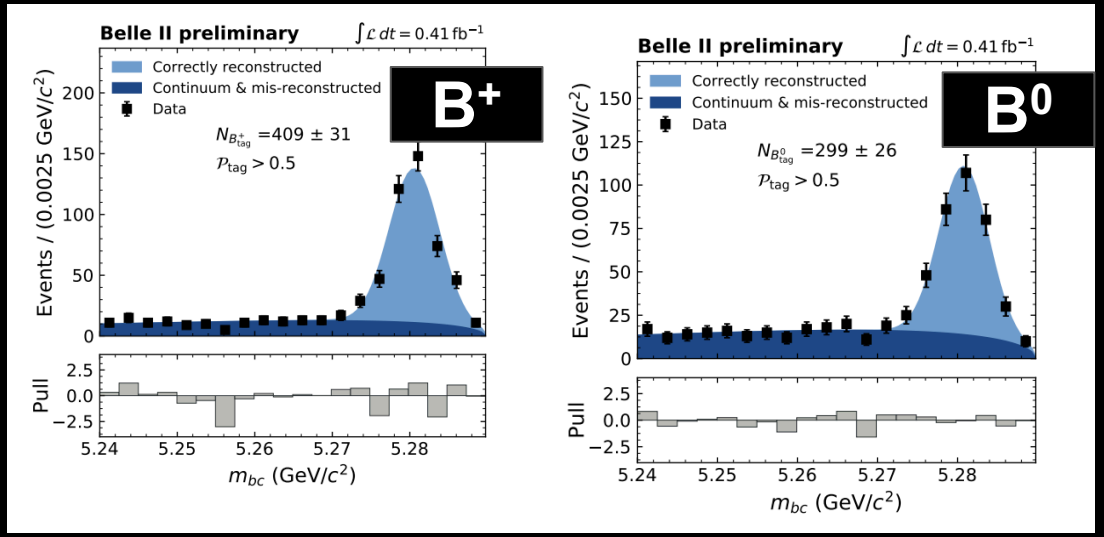




Full Event Interpretation

- Fast BDT-based algorithm fully reconstructs B decays with > 1000 B decay modes
- Useful for channels with weak signature, e.g., missing momentum (vs in final state)
- Performance on early data shows improvement compared to predecessor algorithm





T. Keck et al.,
Comput. Softw. Big Sci (2019) 3: 6.

Belle II Physics Plan

- Wide-ranging plan for physics studies, including:
  - Precision CKM
  - EW Penguin decays
  - Tauonic decays
  - Charm decays
  - Dark Sector searches
  - Hadron spectroscopy

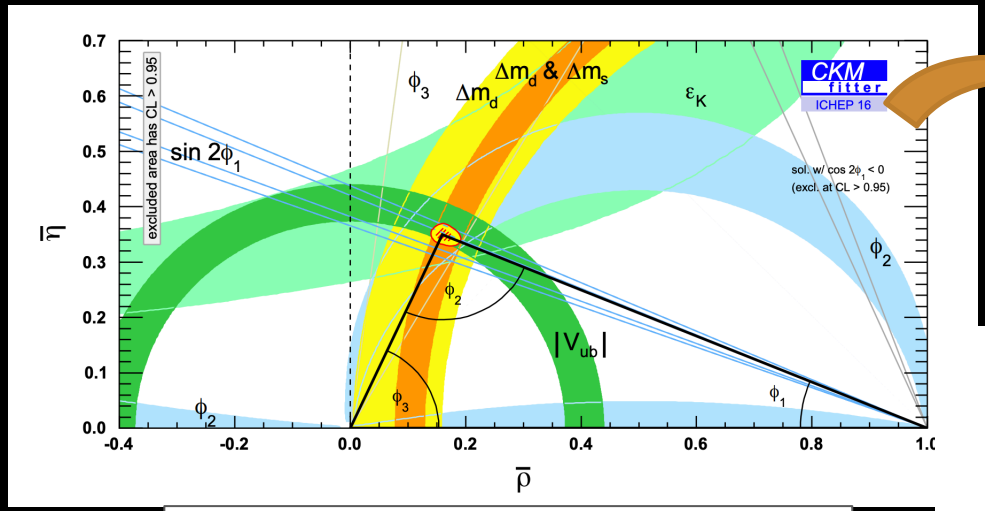
Process	Observable	Theory	Sys. limit (Discovery) [ab^{-1}]	vs LHCb	vs Belle	Anomaly	NP
$B \to K^{(*)}\nu\nu$	$Br., F_L$	⋆⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆
$B \to X_{s+d}\gamma$	A_{CP}	⋆⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆	⋆⋆
$B \to X_d\gamma$	A_{CP}	⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	-	⋆⋆
$B \to K^0_S\pi^0\gamma$	$S_{K^0_S\pi^0\gamma}$	⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆	⋆⋆⋆
$B \to \rho\gamma$	$S_{\rho\gamma}$	⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	-	⋆⋆⋆
$B \to X_s l^+ l^-$	$Br.$	⋆⋆⋆	>50	⋆⋆⋆	⋆⋆	⋆⋆	⋆⋆⋆
$B \to X_s l^+ l^-$	R_{X_s}	⋆⋆⋆	>50	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆⋆
$B \to K^{(*)}e^+e^-$	$R(K^{(*)})$	⋆⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆⋆⋆	⋆⋆⋆
$B \to X_s\gamma$	$Br.$	⋆⋆	1-5	⋆⋆⋆	⋆	⋆	⋆⋆
$B_{d,(s)} \to \gamma\gamma$	$Br., A_{CP}$	⋆⋆	> 50(5)	⋆⋆	⋆⋆	-	⋆⋆
$B \to K^*e^+e^-$	P'_5	⋆⋆	>50	⋆⋆⋆	⋆⋆	⋆⋆⋆	⋆⋆⋆
$B \to K\tau l$	$Br.$	⋆⋆⋆	>50	⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆⋆

Observables	Expected the. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***		Belle II
ϕ_2 [°]	**		Belle II
ϕ_3 [°]	***		Belle II
$\|V_{cb}\|$ incl.	***	1%	
$\|V_{cb}\|$ excl.	***	1.5%	
$\|V_{ub}\|$ incl.	**	3%	Belle II
$\|V_{ub}\|$ excl.	**	2%	Belle II/LHCb
CP Violation			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II
(Semi-)leptonic			
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II
$R(B \to D\tau\nu)$	***	3%	Belle II
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb
Radiative & EW Penguins			
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II
$S(B \to K^0_S\pi^0\gamma)$	***	0.03	Belle II
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\bar{\nu})$ $[10^{-6}]$	***	15%	Belle II
$\mathcal{B}(B \to K\nu\bar{\nu})$ $[10^{-6}]$	***	20%	Belle II
$R(B \to K^*\ell\ell)$	***	0.03	Belle II/LHCb
Charm			
$\mathcal{B}(D_s \to \mu\nu)$	***	0.9%	Belle II
$\mathcal{B}(D_s \to \tau\nu)$	***	2%	Belle II
$A_{CP}(D^0 \to K^0_S\pi^0)$ $[10^{-2}]$	**	0.03	Belle II
$\|q/p\|(D^0 \to K^0_S\pi^+\pi^-)$	***	0.03	Belle II
$\phi(D^0 \to K^0_S\pi^+\pi^-)$ [°]	***	4	Belle II
Tau			
$\tau \to \mu\gamma$ $[10^{-10}]$	***	< 50	Belle II

1808.10567

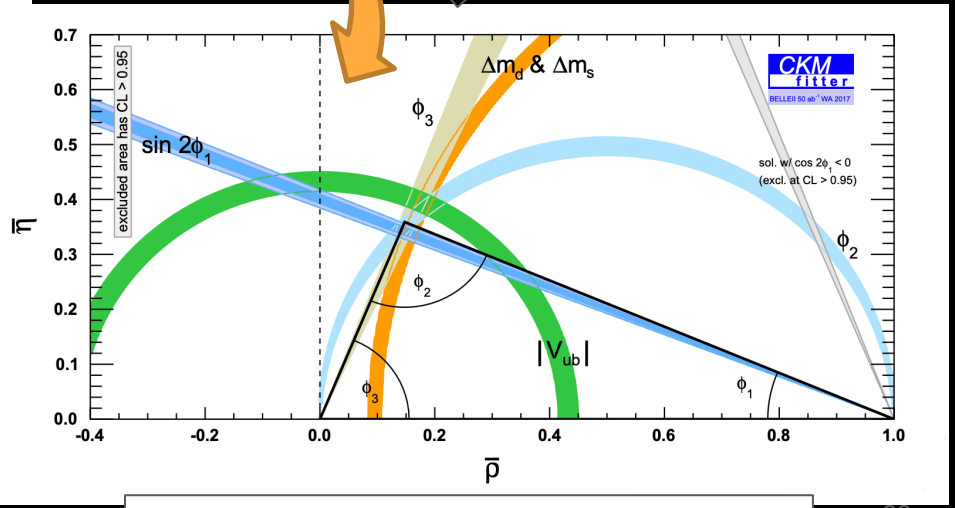
Also see talk by S. Sandilya for more on rare decays and lepton universality

CKM Improvement Projections



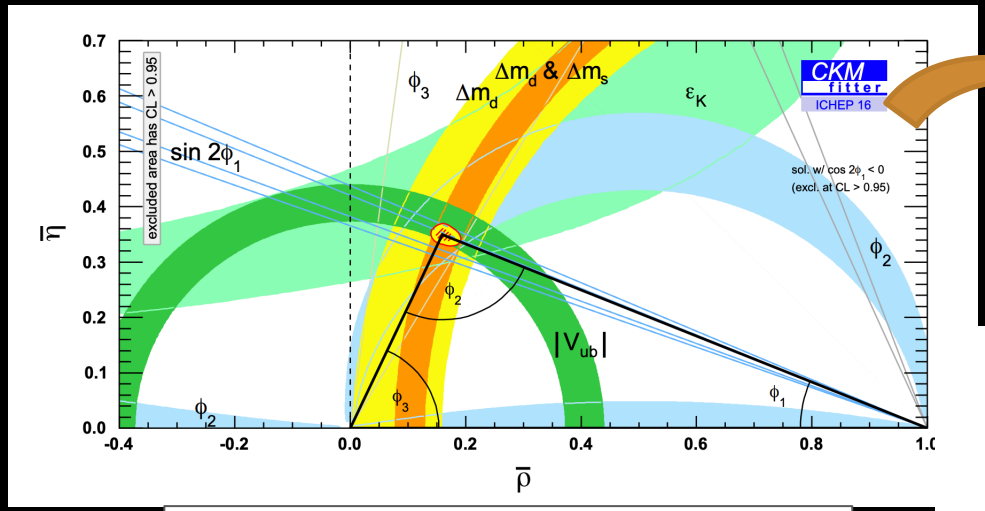
Current fitted parameters

50 ab-1



Belle II + LHCb Projection

CKM Improvement Projections



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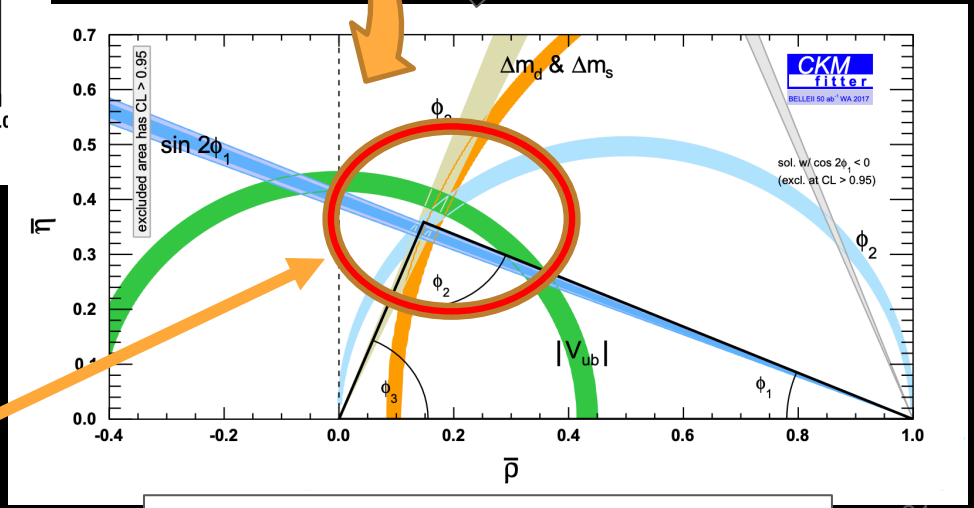


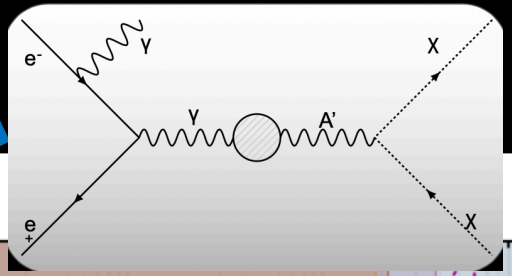
Belle II + LHCb Projection

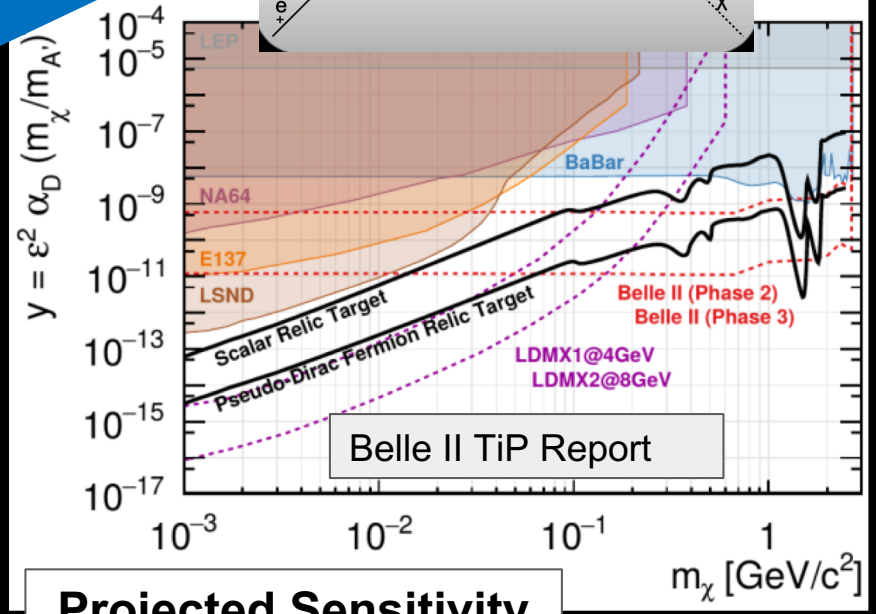
Projected to be able to resolve NP in CKM triangle

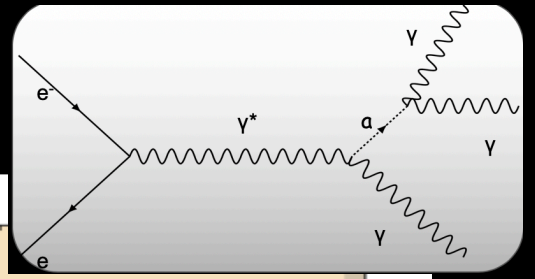
Dark Sector Searches: Dark Photons and ALPs

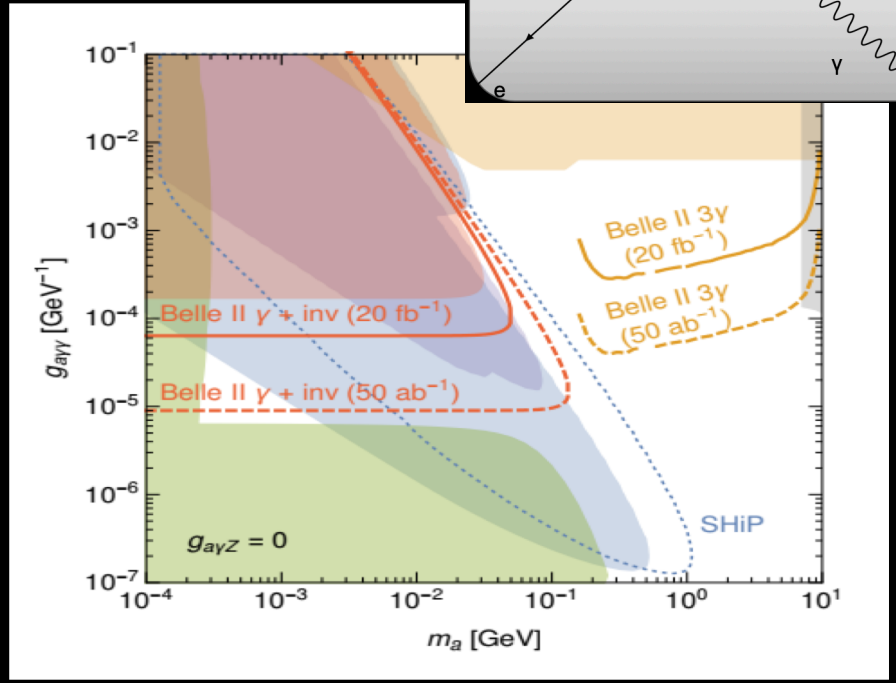
Improved luminosity and calorimeter hermiticity can allow great improvement!

Light DM: GeV scale









Projected Sensitivity

Summary

- The Belle II experiment at SuperKEKB is running with a full detector
- Physics run began Spring 2019 following 2 dedicated commissioning phases
  - Vertex detector installed around IP before physics runs for precision measurements
- 6.49 fb^{-1} collected so far, of a planned 50 ab^{-1}
- Wide ranging physics plan, including precision measurements, dark sector searches, and much more
- Still ramping up to full luminosity
  - → Many exciting results to come!

Full physics plan at 1808.10567

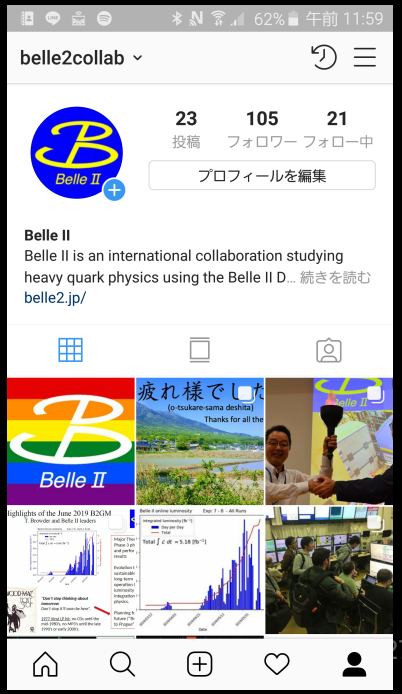
Stay tuned for more!

Follow us on social media for updates and information!

Facebook:

Twitter

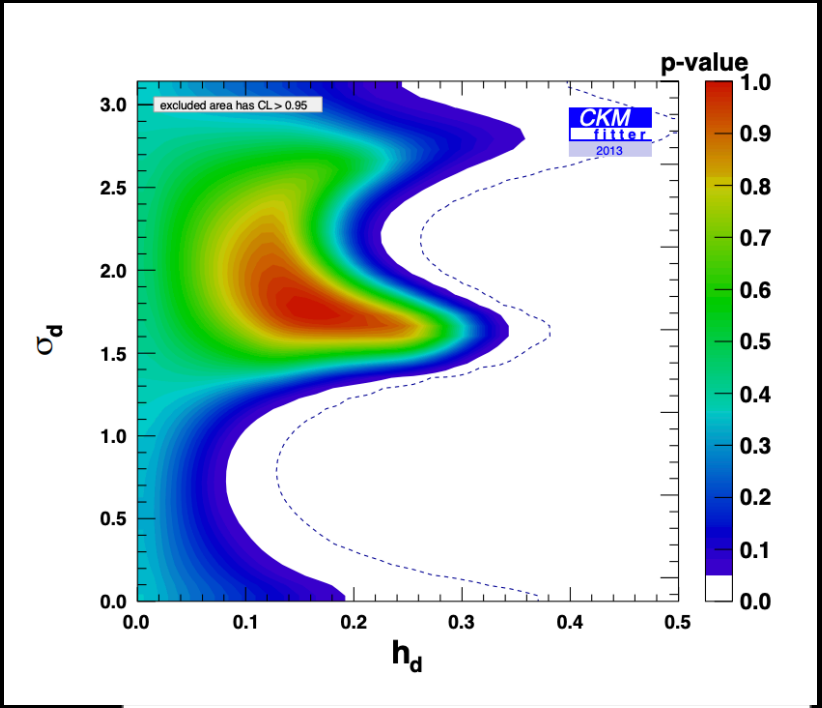
Instagram



@belle2collab (JP: @belle2japan)

Supplementary Material

CKM Improvement Projections



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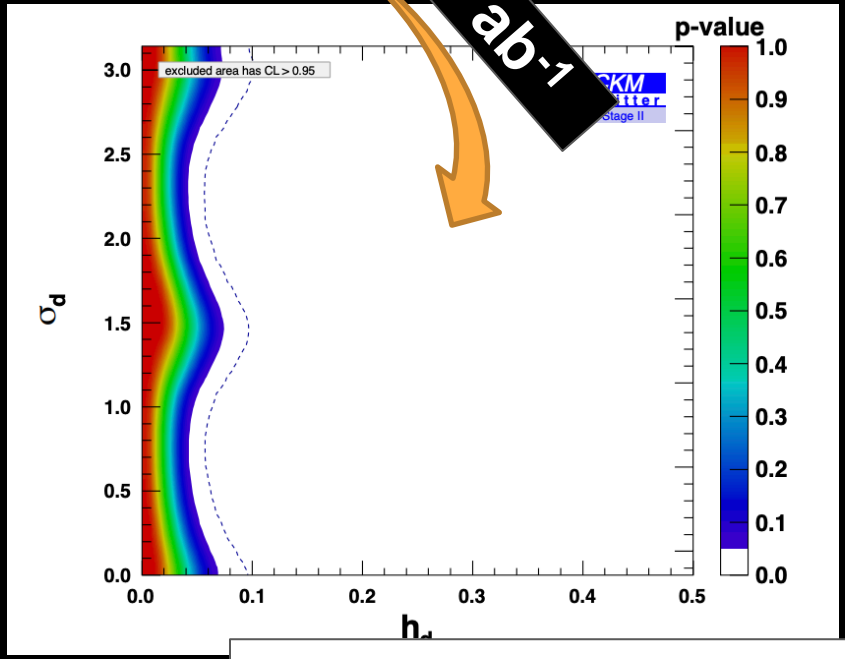
50 ab^{-1}

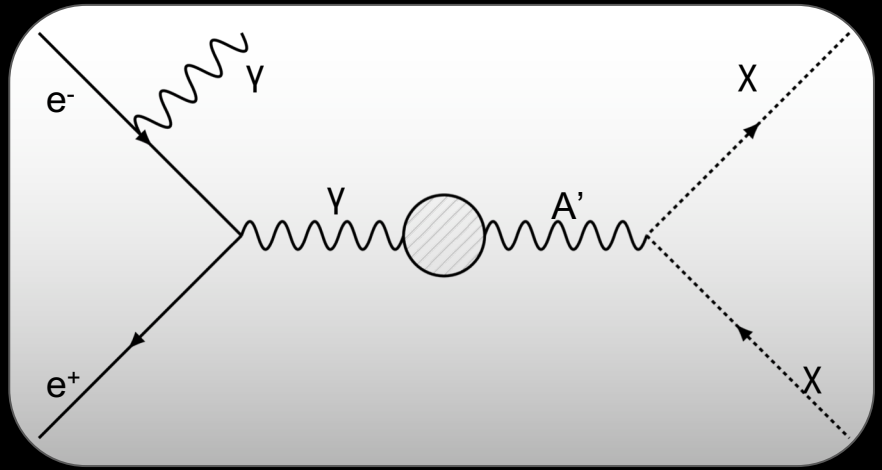


Belle II + LHCb Projection

Moving to Phase 3 - Vertex Detector Installation

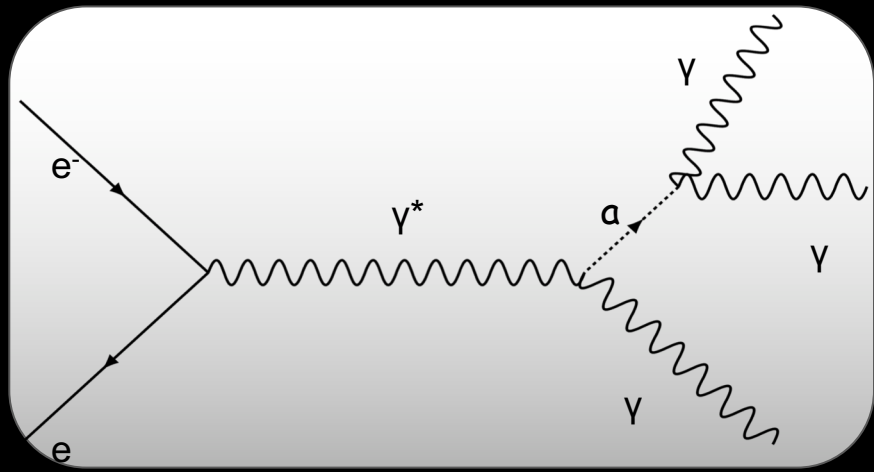
Dark γ→ Invisible

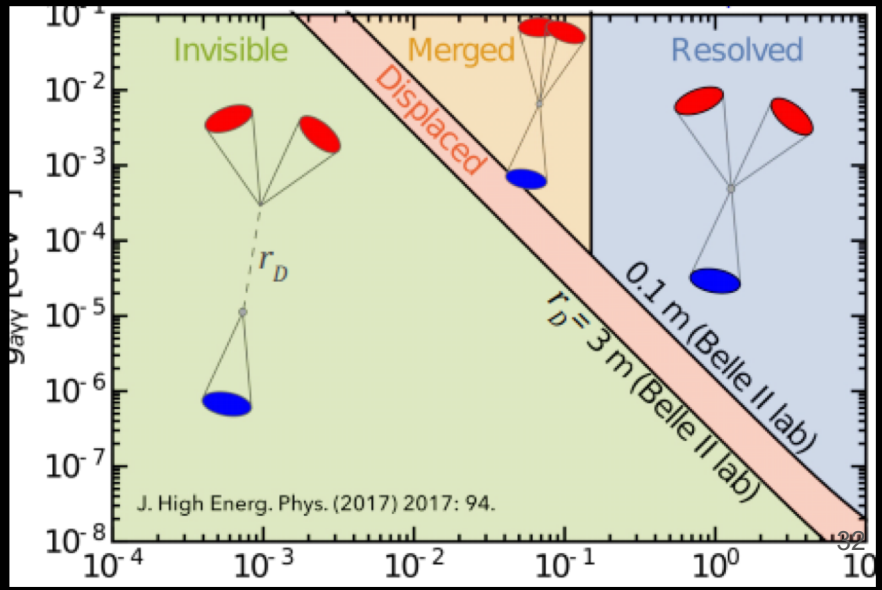
- Light (GeV scale) hidden dark sector weakly coupled to SM by dark photon A’
- Experimental signature: only 1 high-energy photon in detector
- Needs single photon trigger
  - Not present in Belle
  - Only present of ~10% of BaBar
  - Implemented for Phase 2
- ~No true physics backgrounds
  - Only missing particle backgrounds:
    - Radiative bhabha, γγ events with one γ not reconstructed



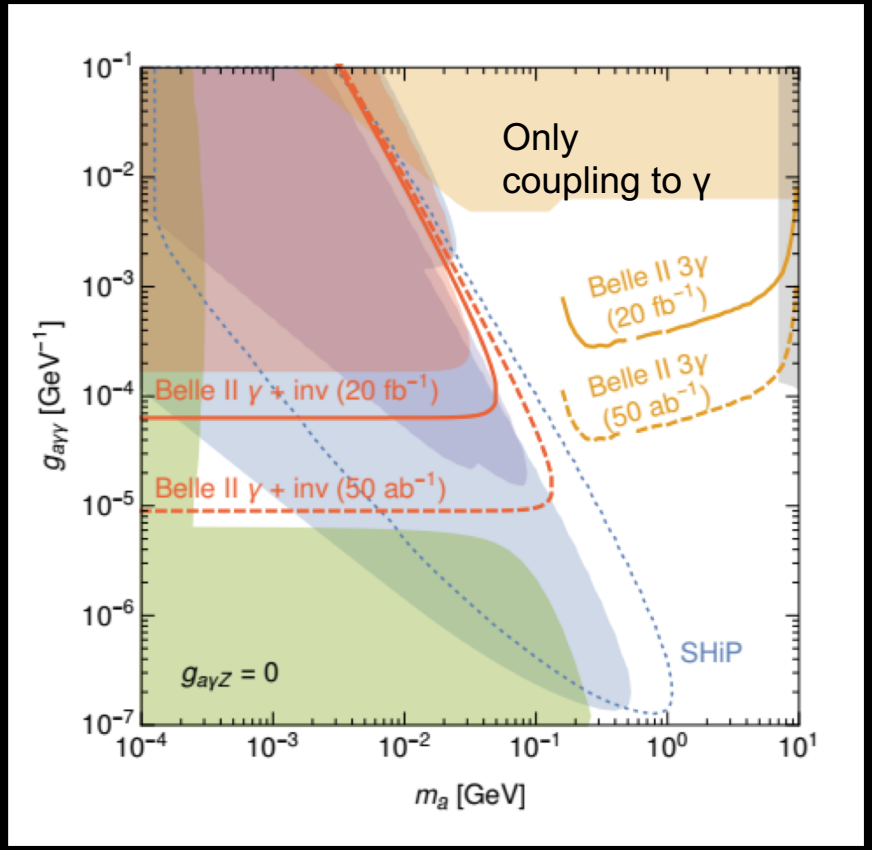
Axion-Like Particles (ALPs)

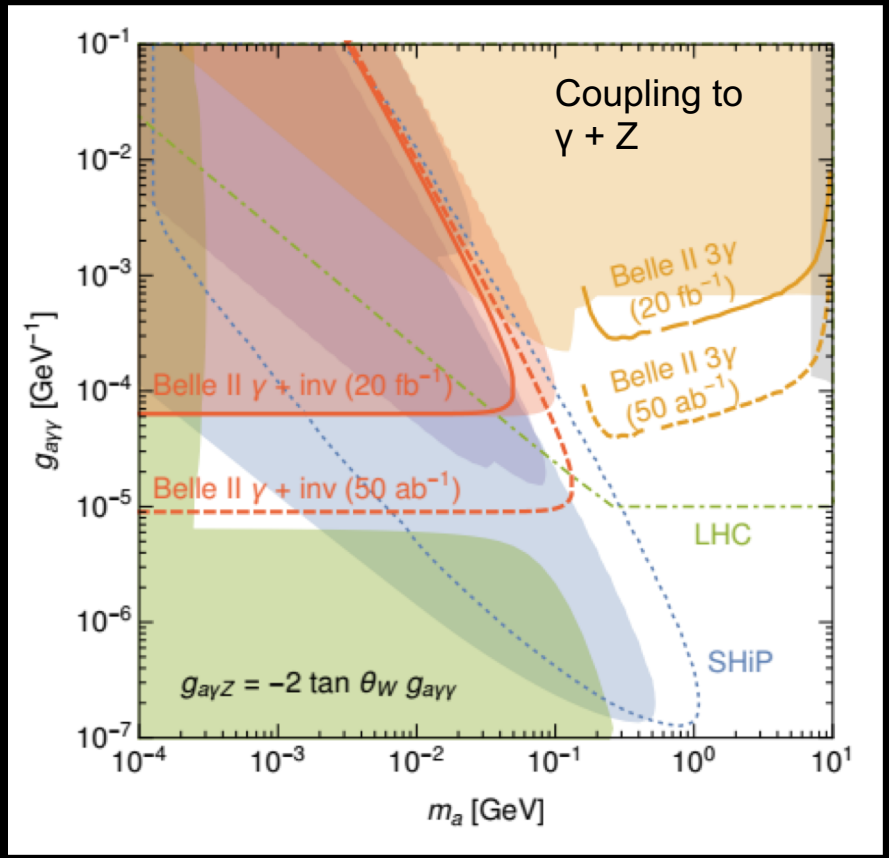
- Pseudoscalars that couple to bosons
  - Can target photon coupling $g_{a\gamma\gamma}$
- Coupling not related to mass
  - Different from QCD axions
- Three-Photon signature
  - One γ from recoil
  - Pair from a->γγ
- Four calorimeter signatures
  - (Determined by displacement, θ of photon pair)



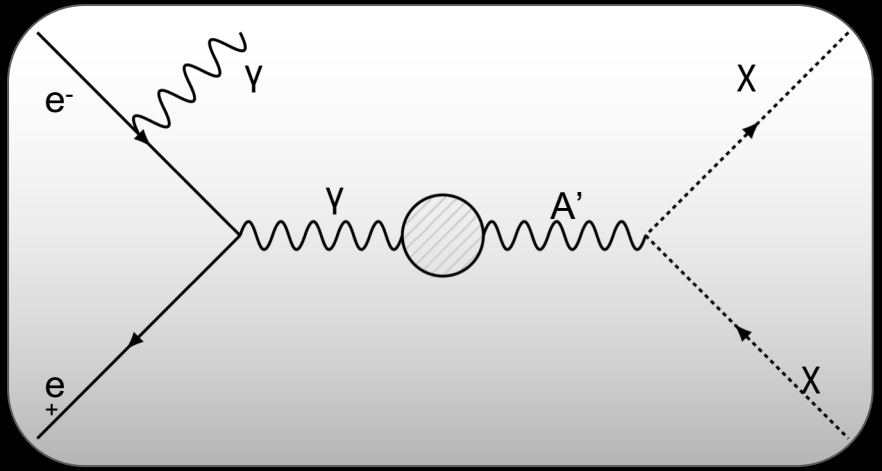


ALPs: Dark Sector Pseudoscalar Portal

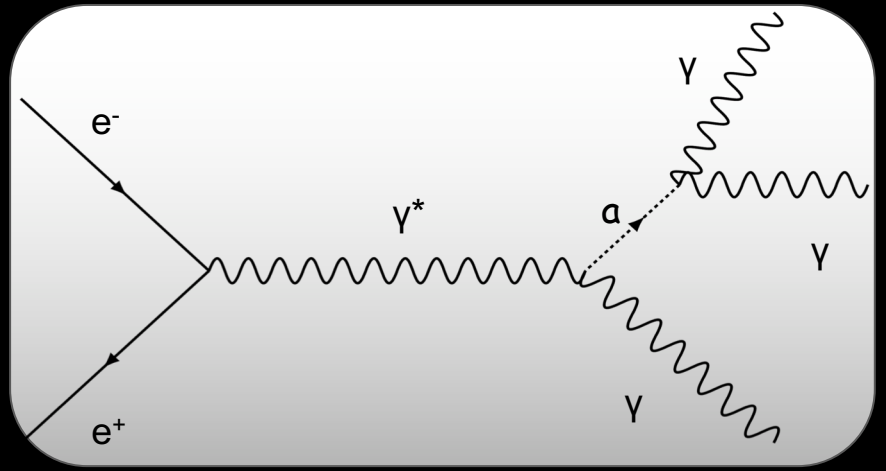




Dark Sector Searches: Invisible Dark γ and ALPs



Vector: Dark γ → Invisible



Pseudoscalar: Axion-Like Particles

Dark Sector Searches: Invisible Dark γ and ALPs

Other searches possible!

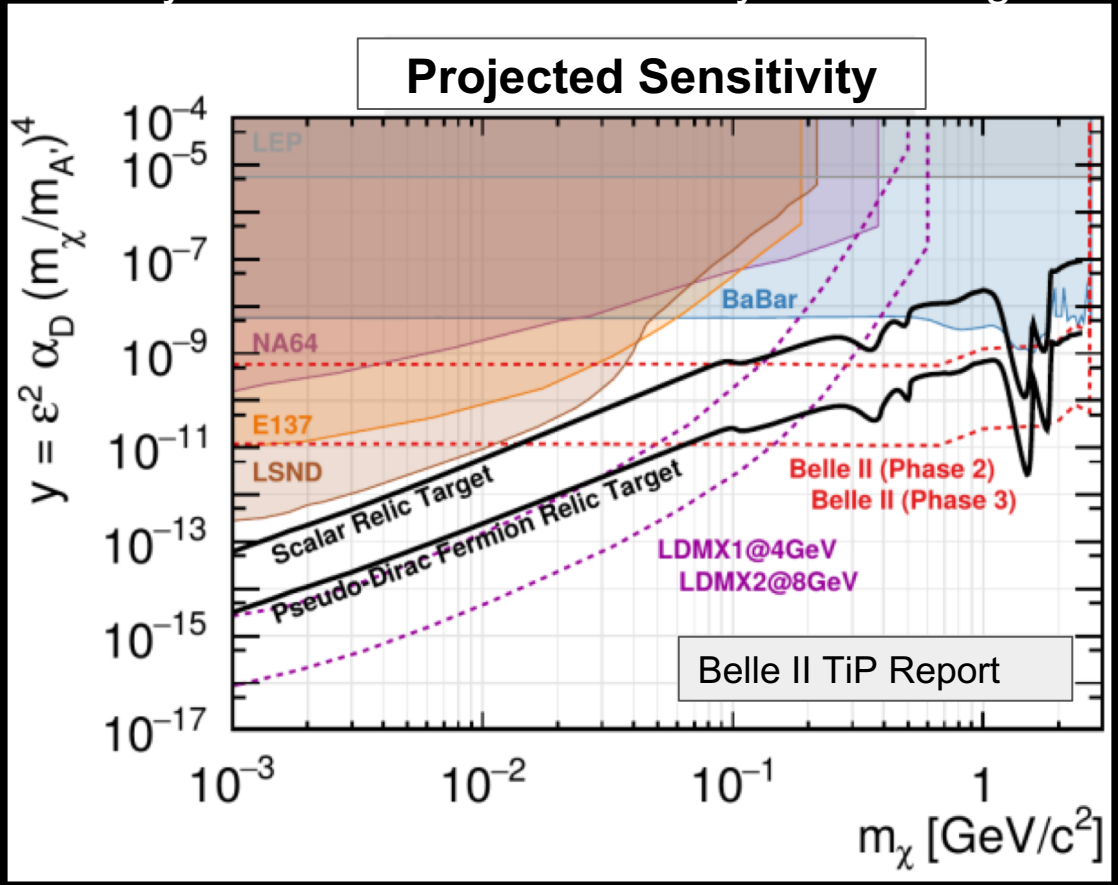
- Magnetic Monopoles
- Invisible Z', Z' → LFV (e -μ coupling)
- Dark scalars
- Dark Higgs
- Off-shell A' decays
- Even more…

Vector: Dark γ → Invisible

Pseudoscalar: Axion-Like Particles

Dark γ→ Invisible: Prospects

Improved luminosity and calorimeter hermiticity can allow great improvement!



Dark γ→ Visible dileptons: Heavier DM