Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

The Belle II Experiment

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Pacific Northwest National Laboratory
Particle Physics Seminar, Brookhaven National Laboratory, Sep 20 2018

U.S. DEPARTMENT OF ENERGY

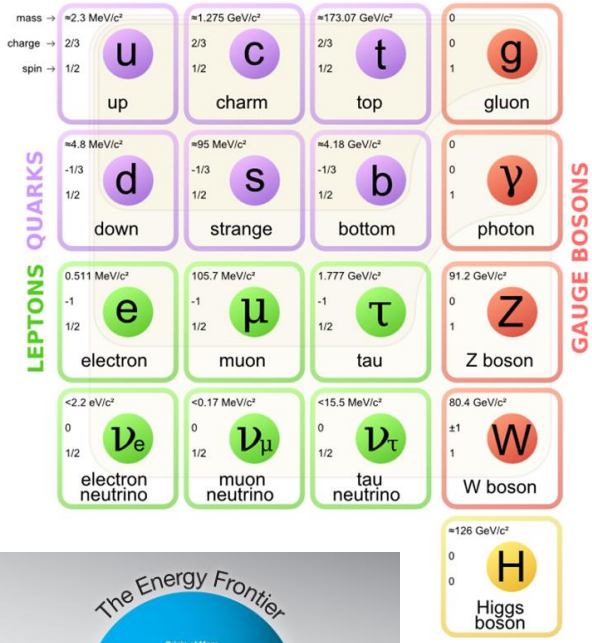
Outline

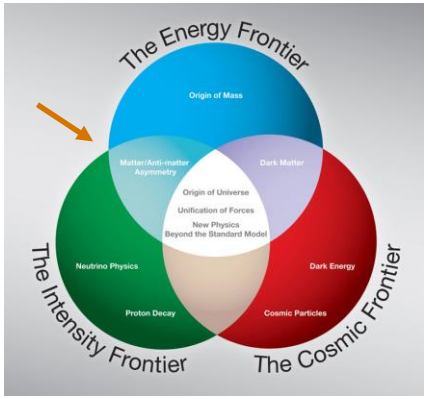
- Introduction to the B Factories
- Belle II: the next generation B Factory
- Belle II physics potential
- Quarkonium
- Early Belle II physics

THE B FACTORIES

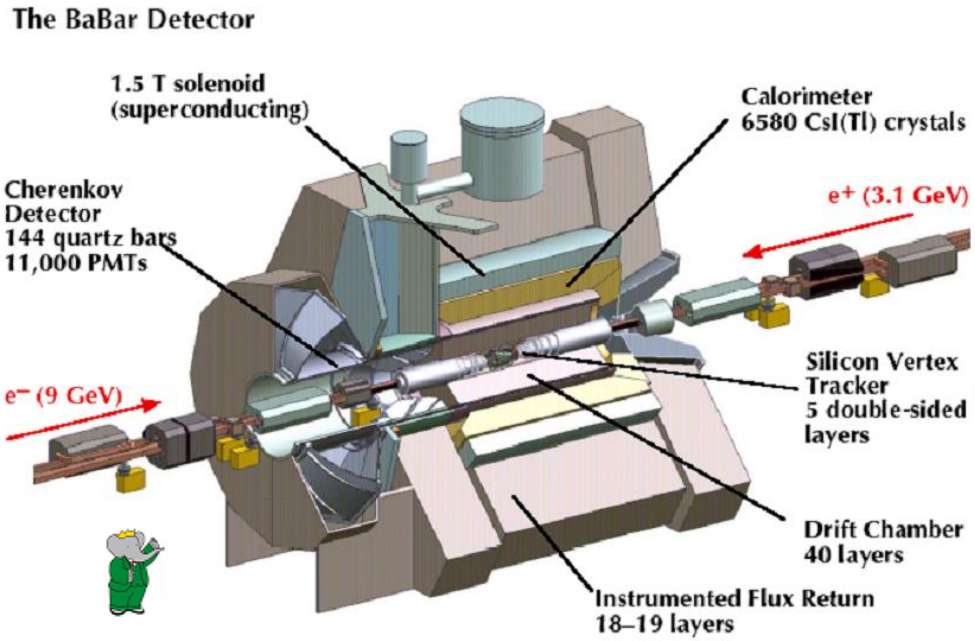
The Standard Model (SM) and Beyond

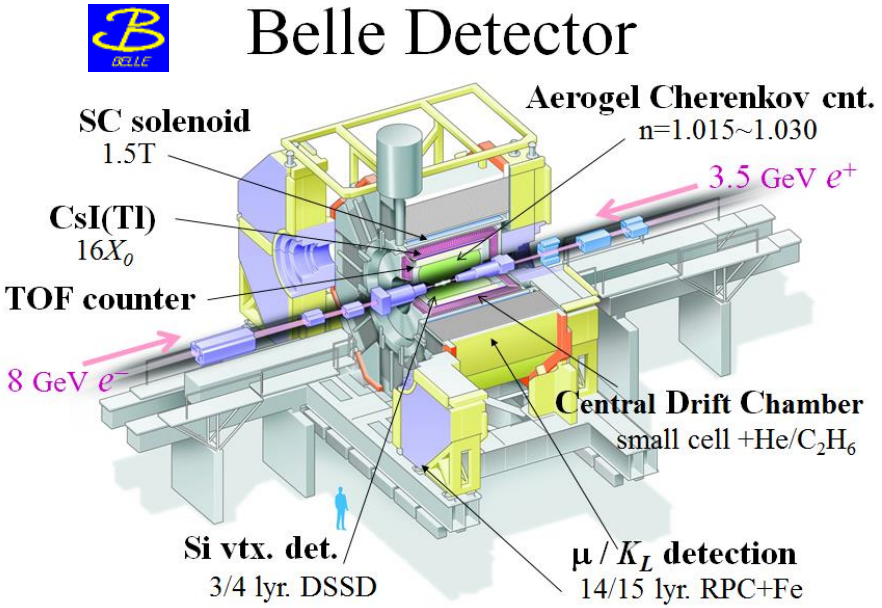
- SM: best-tested fundamental theory of nature
  - Matter: quarks and leptons
    - Baryons (3q), Mesons ($q\bar{q}$): B ($\bar{b}d$, $\bar{b}u$), ψ ($c\bar{c}$), Υ ($b\bar{b}$)
  - Forces: weak, EM, strong
  - Higgs boson: EM/weak symmetry-breaking, mass
- Some questions…
  - Single SM Higgs, or many (e.g. SUSY)?
  - Matter-antimatter symmetry and CP violation
  - Nature of Dark Matter
- Search for answers
  - Cosmic: Dark Matter from astrophysical sources
  - Energy: Direct high-energy accelerator searches
  - Intensity: Precision tests with high statistics
    - e.g.: e^+e^- collider "B Factories"  BaBar (SLAC),  Belle (KEK, Japan)





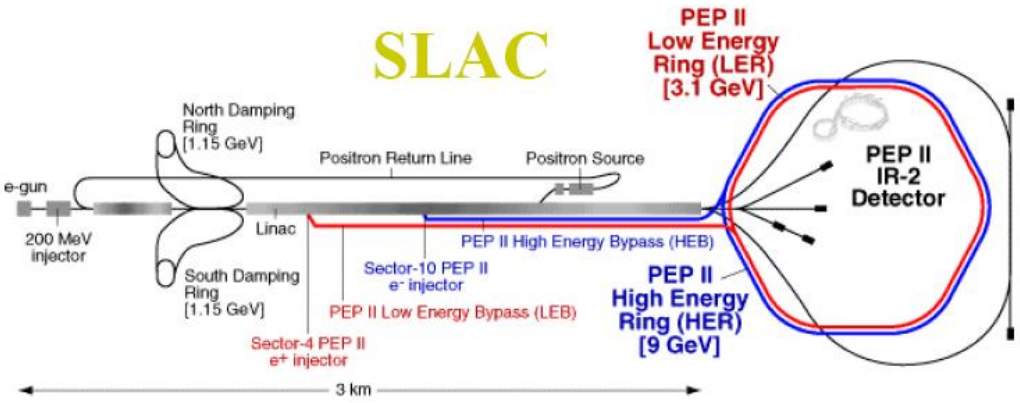
BaBar and Belle Detectors

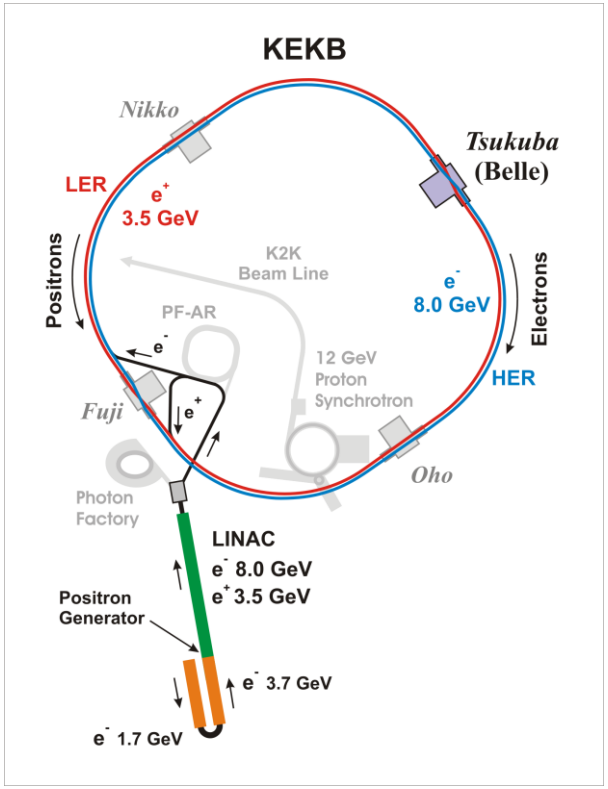




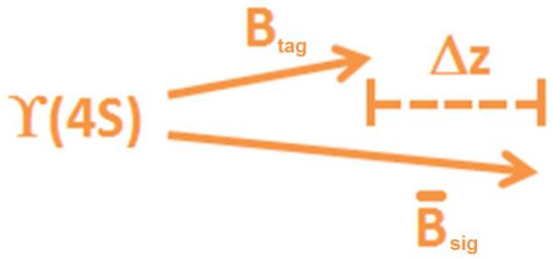
- BaBar (1999-2008)
  - SLAC, Stanford, USA
  - ~500 fb^{-1} collected
  - ~600 members, 13 countries
  - ~550 publications
- Belle (1999-2010)
  - KEK, Tsukuba, Japan
  - ~1 ab^{-1} collected
  - ~400 members, 18 countries
  - ~500 publications

The Accelerators

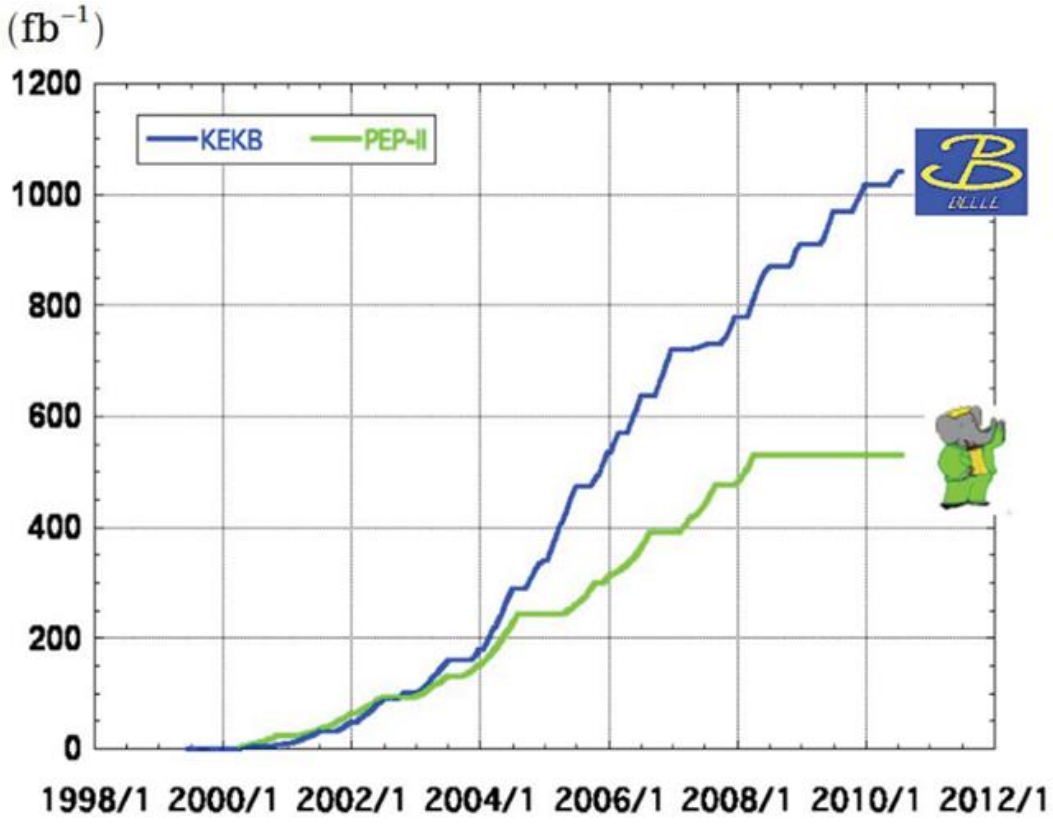


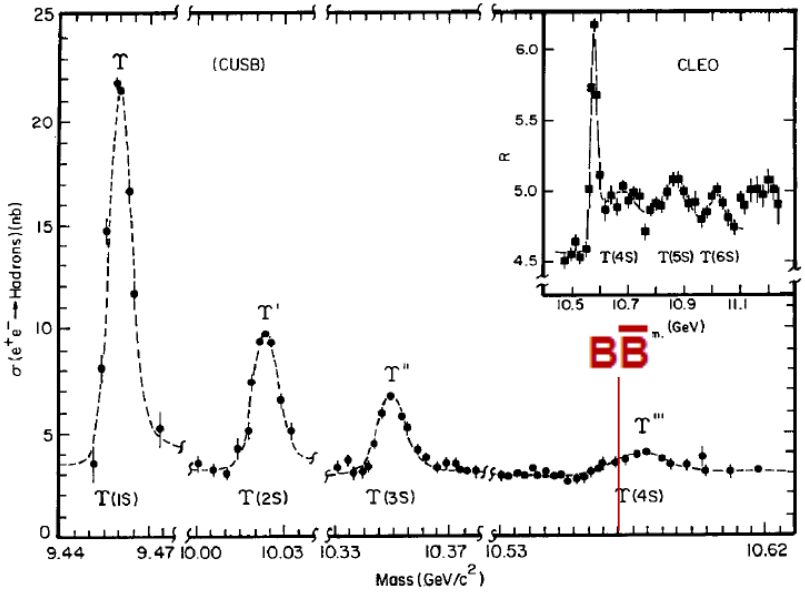


- Asymmetric B-Factories
  - PEP-II (BaBar): e- (9 GeV) e+ (3.1 GeV)
  - KEKB (Belle): e- (8 GeV) e+ (3.5 GeV)
  - Record luminosity: 2.1×10^{34} cm^{-2} s^{-1}



Integrated Luminosity





On resonance:
Y(5S): 121 fb^{-1} = 36 M
Y(4S): 711 fb^{-1} = 772 M
Y(3S): 3 fb^{-1} = 12 M
Y(2S): 25 fb^{-1} = 158 M
Y(1S): 6 fb^{-1} = 102 M
Off/scan: 100 fb^{-1}

On resonance:
Y(4S): 433 fb^{-1} = 471 M
Y(3S): 30 fb^{-1} = 122 M
Y(2S): 14 fb^{-1} = 99 M
Off/scan: 54 fb^{-1}

Legacy of the B Factories

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- **Flavor physics**
  - CKM matrix elements / unitarity triangle
  - CPV in B decays
- **Limits on BSM Physics**
  - Rare decays (e.g. $B \to \tau\nu$, $D\tau\nu$)
  - New physics search loops:
    $b \to s\gamma$, $b \to s\ell\ell$
  - Search for LFV τ decays
- **New particle discoveries**
  - "XYZ" four-quark states


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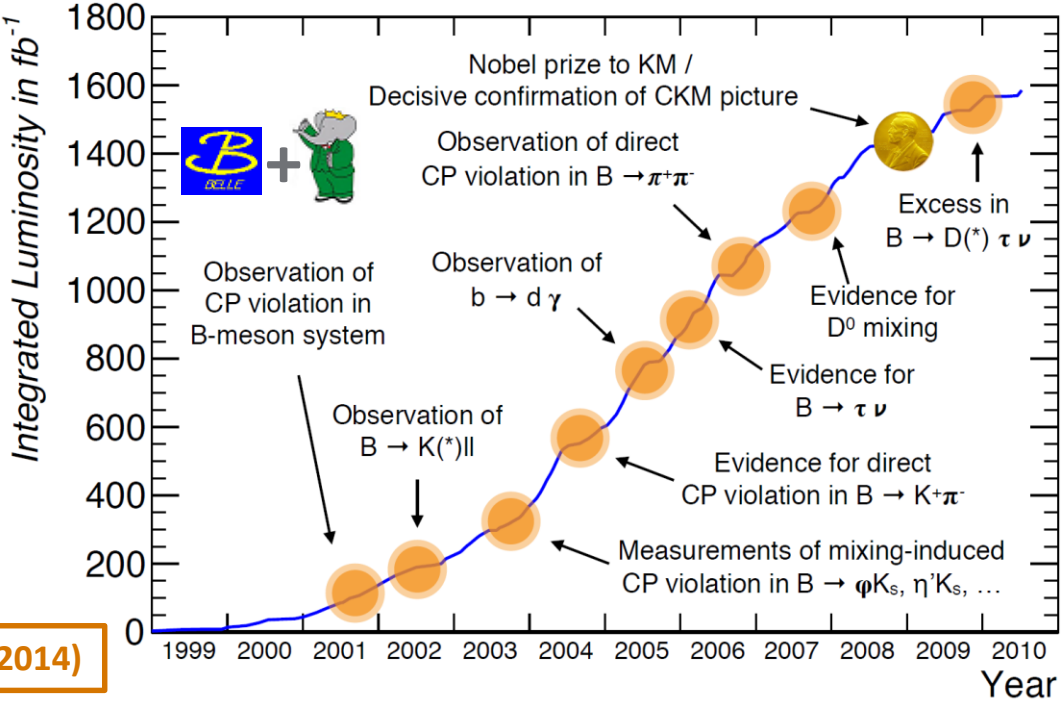
Toshihide Maskawa

2008



e.g.: "The Physics of the B Factories", EPJC 74, 3026 (2014)

Motivation for a next generation B Factory

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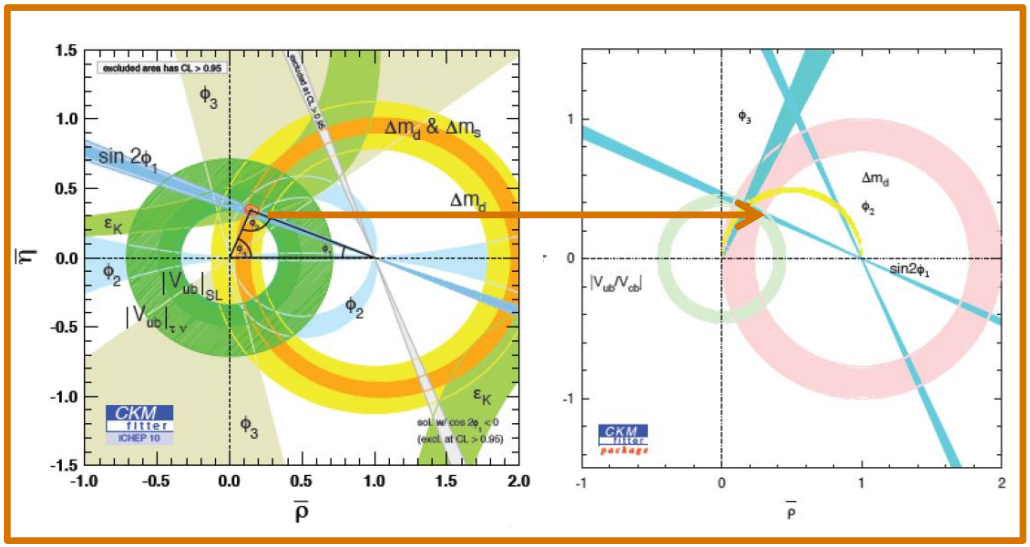
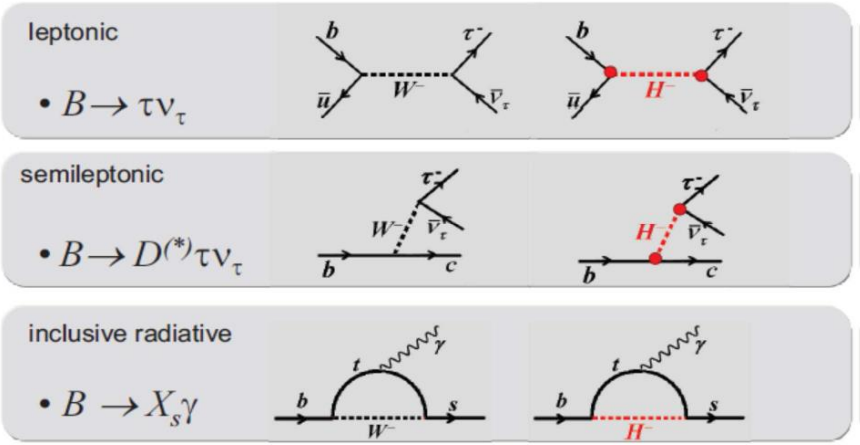
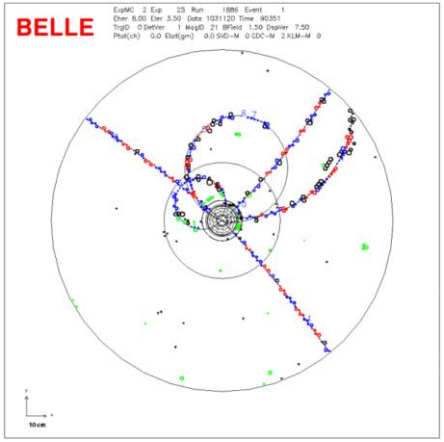
- **Search for New Physics via precision measurements**





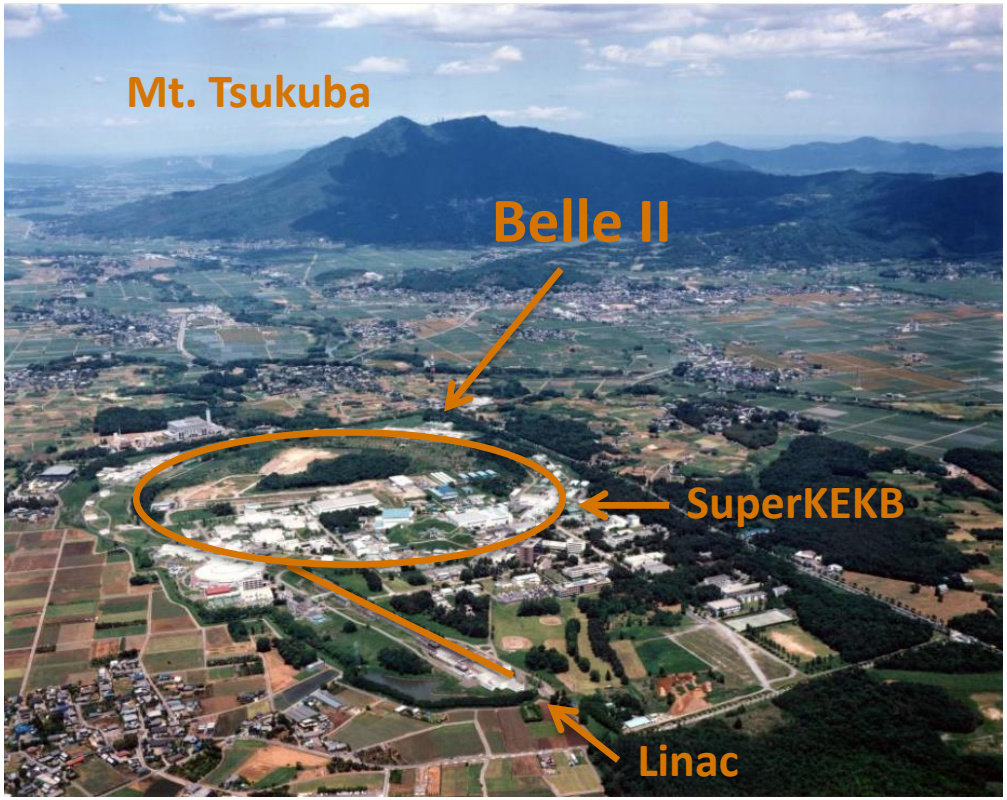
- Advantages of the B Factories
  - Sensitive to NP masses above direct production
  - "Clean" environment, full event reconstruction
  - Tau decays and neutrals (γ, π^0, K_L, ν) in final state
  - Complementary to LHC



BELLE II

The Belle II Collaboration

- 800+ members, 108 institutions, 25 countries
- Located at KEK in Tsukuba, Japan



Belle II US Involvement

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- US participation: ~90 members, 16 institutions

- Detector
  - Particle identification system
  - Readout electronics
  - Muon detector upgrade
  - Beam/background and commissioning
- Computing
  - Database development
  - Grid computing
- Physics
  - Working groups
  - “First Physics” program

2018 US Belle II Summer School

Accelerator Upgrade

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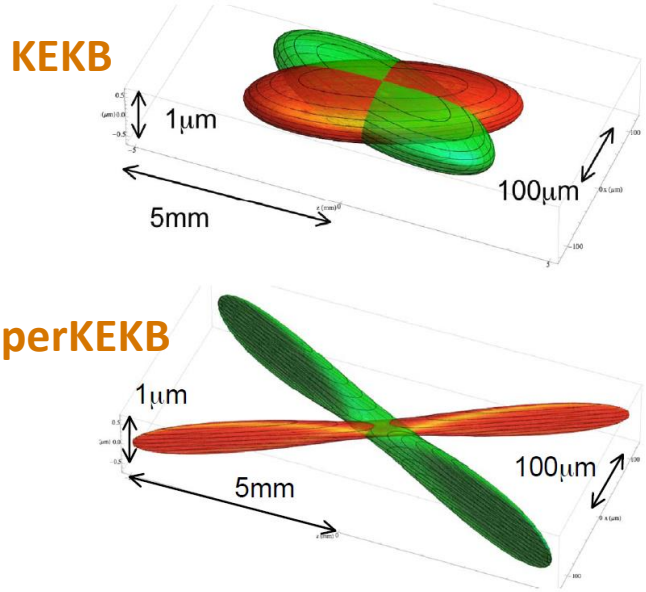
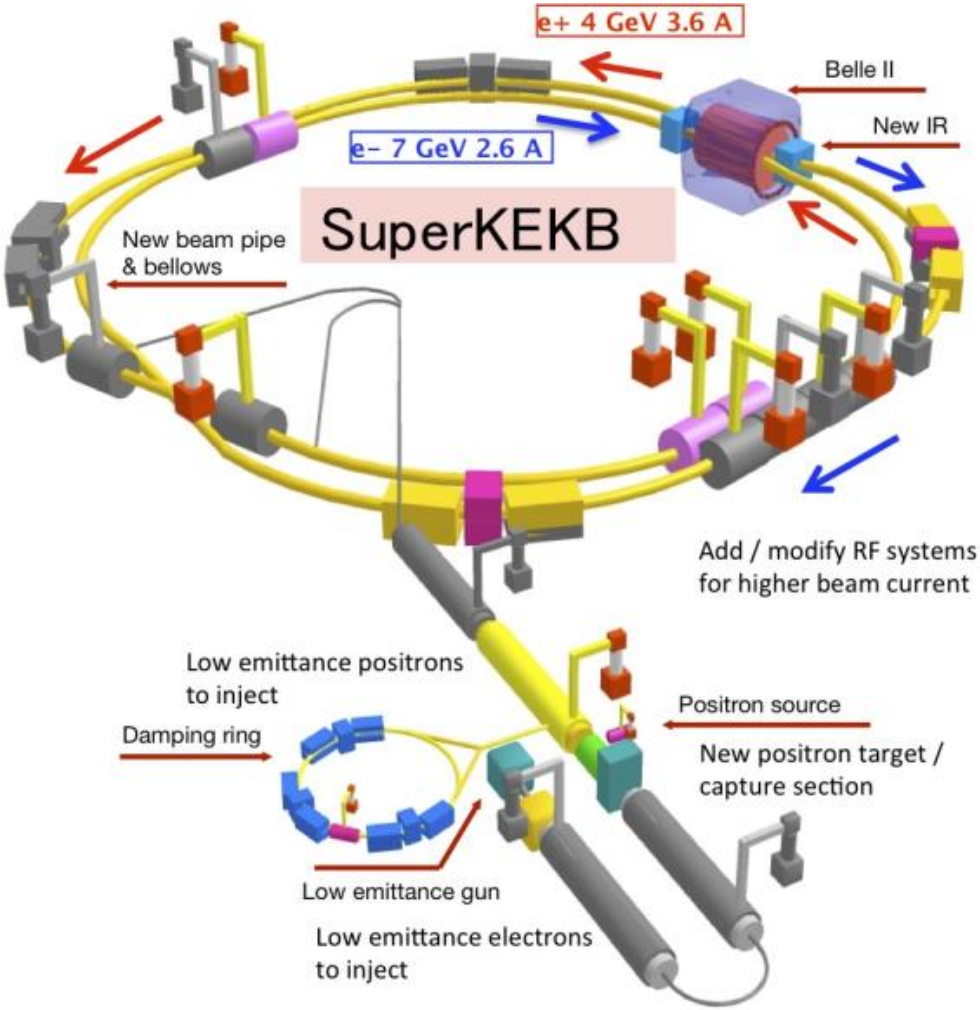
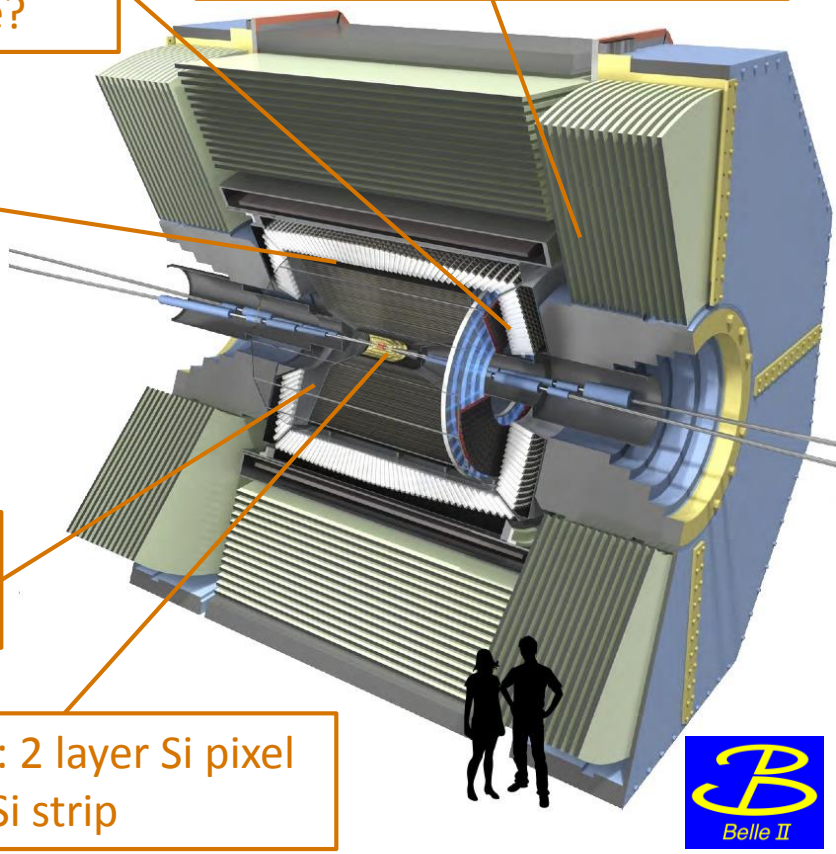
- SuperKEKB Upgrade
  - "Nano-beam" interaction point
  - Increase in current
  - Factor of 40x increase in luminosity
  - Energy: e^- (7 GeV) e^+ (4 GeV)





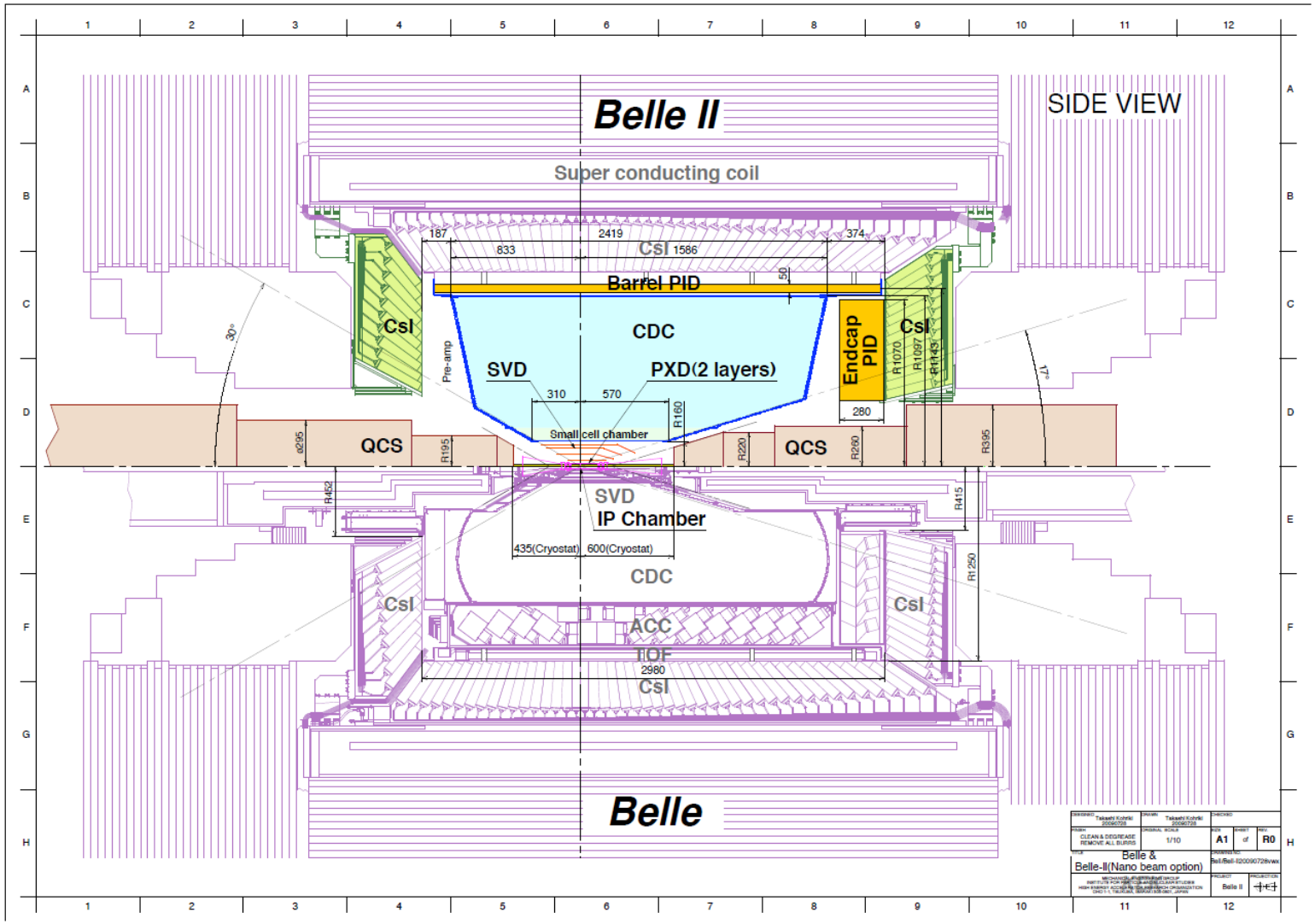
Detector Upgrade

- Order of magnitude luminosity increase means:
  - Higher background
    - Radiation damage
    - Detector readout
  - Higher event rate
    - Trigger, DAQ, computing
  - Boost change
    - Improve vertexing
- Significant detector upgrades required!



arXiv:1011.0352 (2011)

Detector Upgrade



Vertexing

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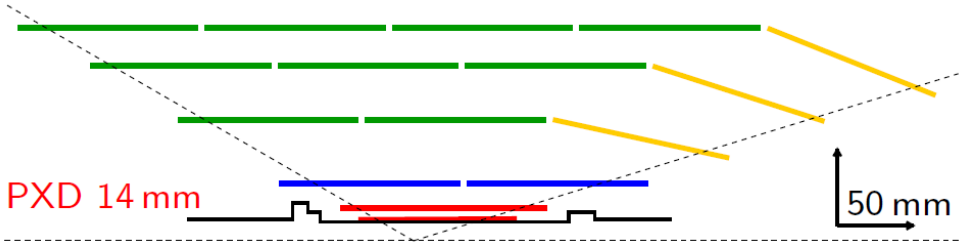
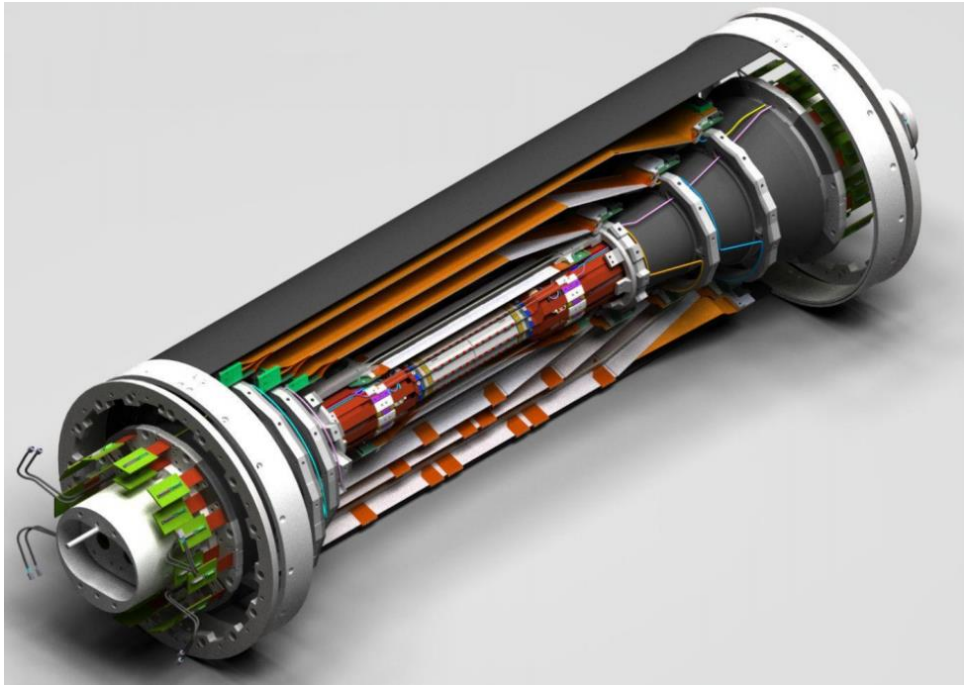
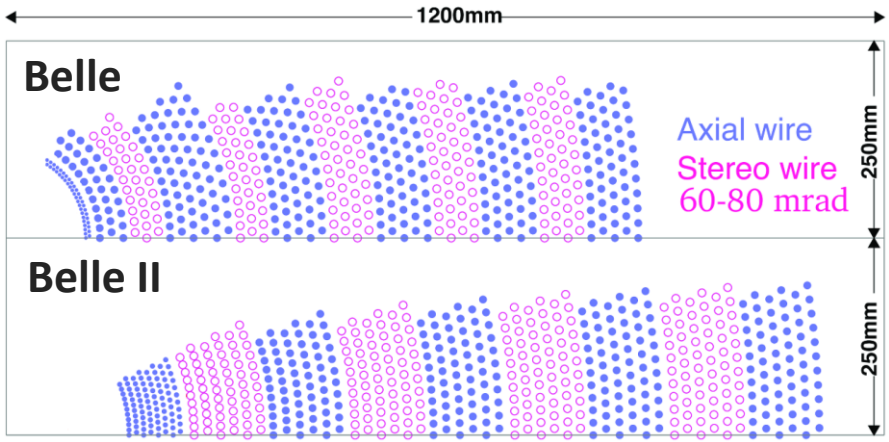
- VerteX Detector = PXD+SVD
- PiXel Detector
  - 40 DEPFET modules, 2 layers
  - Dimensions: 50x55, 50x85 μm^2
  - Thickness: 75μm (0.21% X_0)
- Silicon Vertex Detector
  - 172 double-sided strips, 4 layers
  - Slanted in forward region
  - 0.7% X_0 / layer
- Partial install early 2019

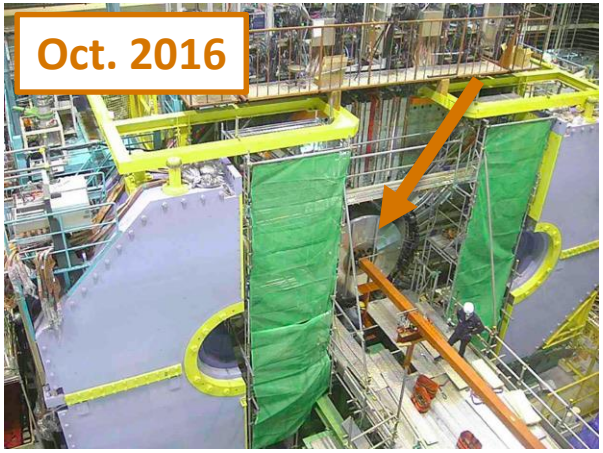


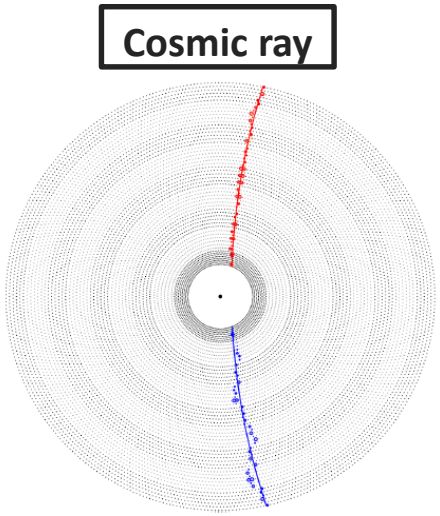


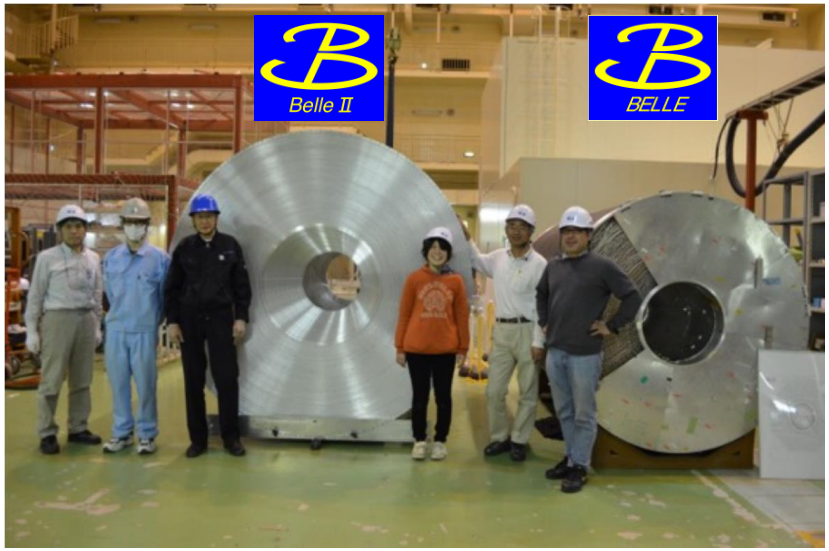
Tracking

- Central Drift Chamber
- 14336 sense wires, 56 layers
- He (50%) : C_2H_6 (50%)
- Smaller drift and increased size improves reconstruction and dE/dx
- Faster readout electronics



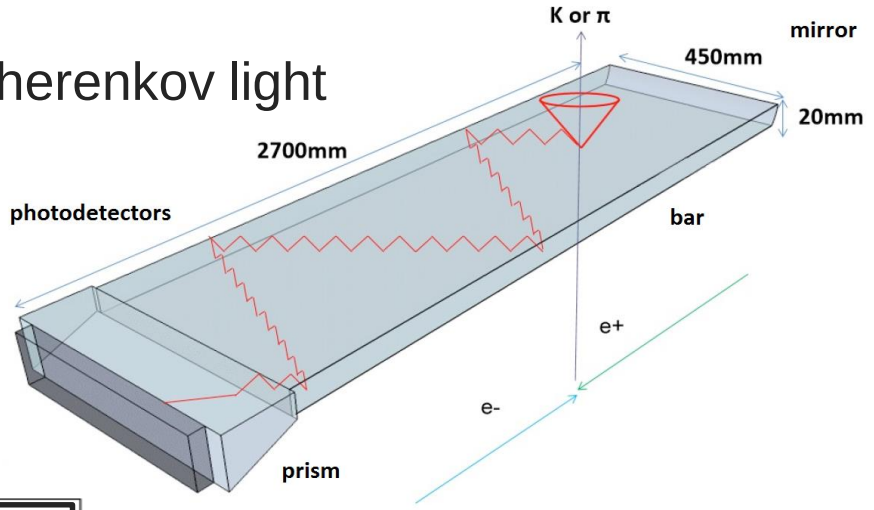


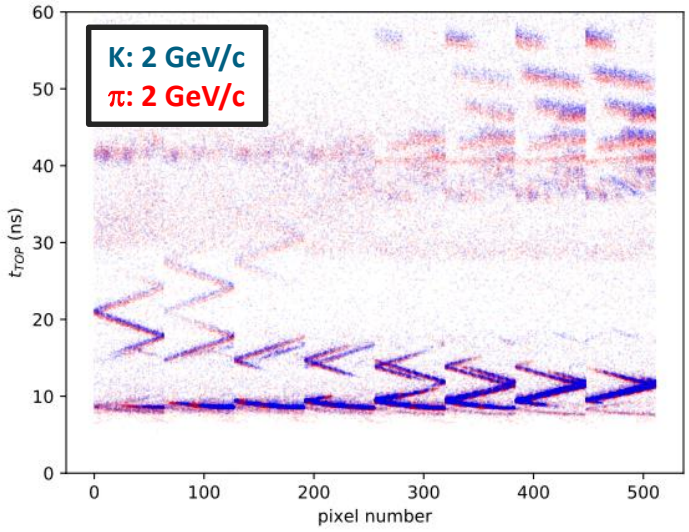


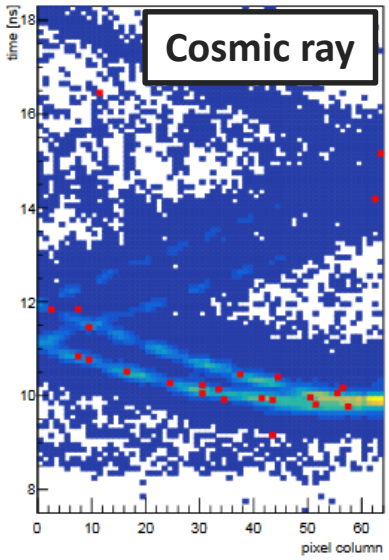


Particle ID: Barrel

- Measurement of internally-reflected Cherenkov light
- Time-Of-Propagation detector
  - 16 quartz bar coverage of barrel in ϕ
  - Custom MCP-PMTs (32/module)
  - FPGA feature extraction
- Used for π/K separation in barrel

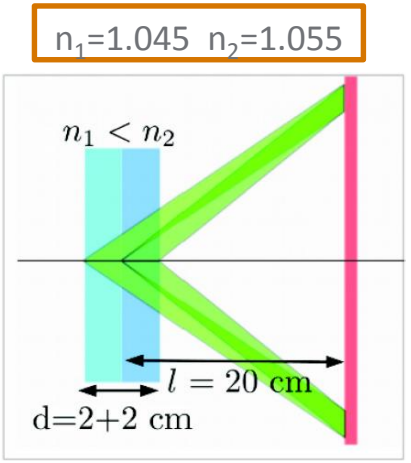


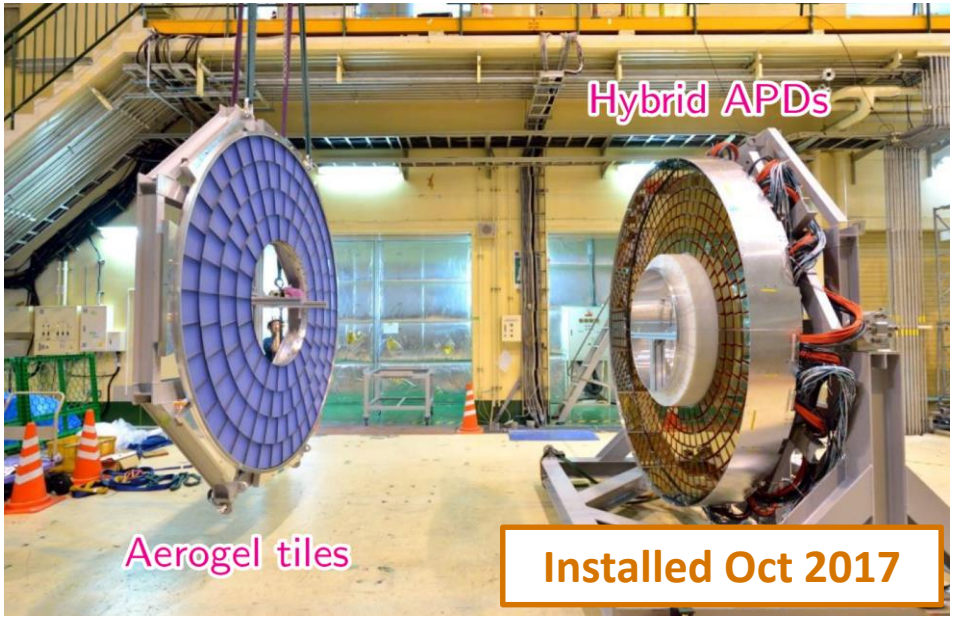


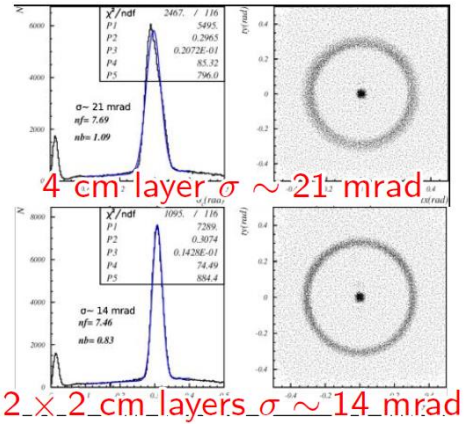


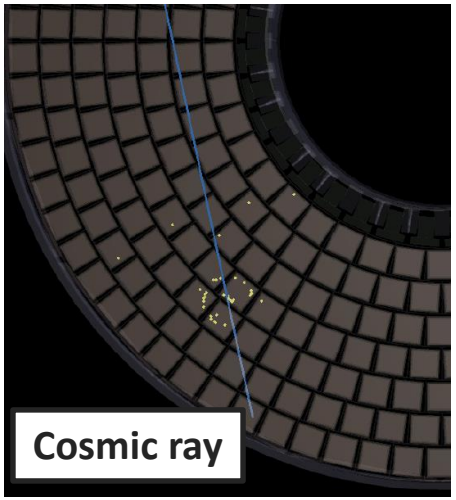
Particle ID: Endcap

- **A**erogel **R**ing-**I**maging **CH**ernkov detector
  - Non-homogenous 4 cm-thick aerogel radiator
  - 420 pixelated Hybrid Avalanche Photo Detectors
- Used for π/K separation in forward region



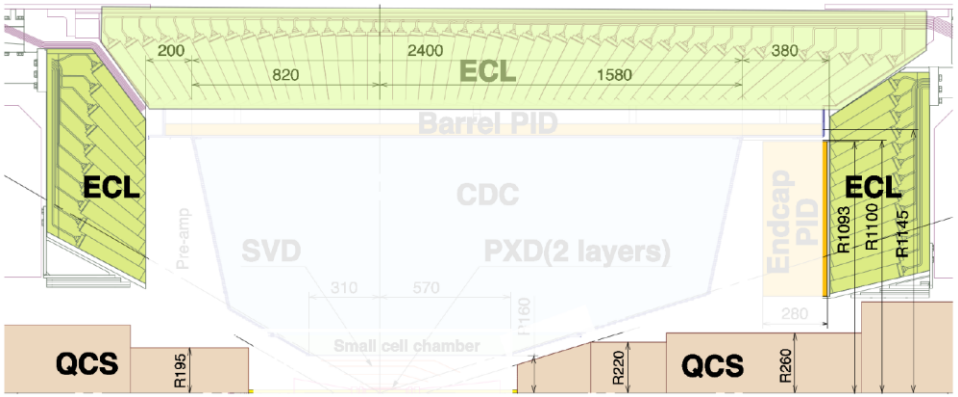


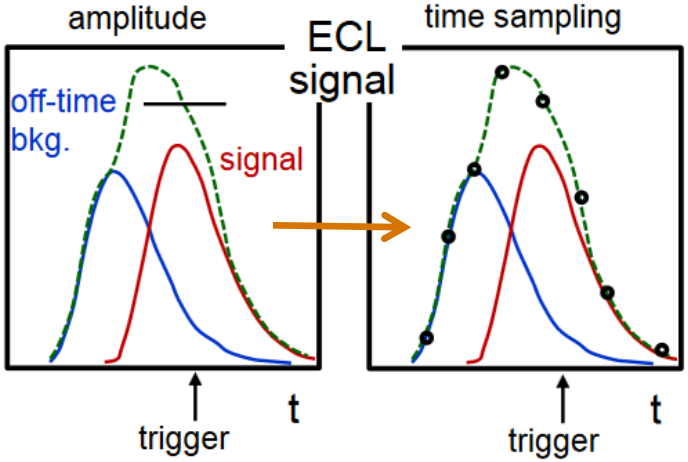


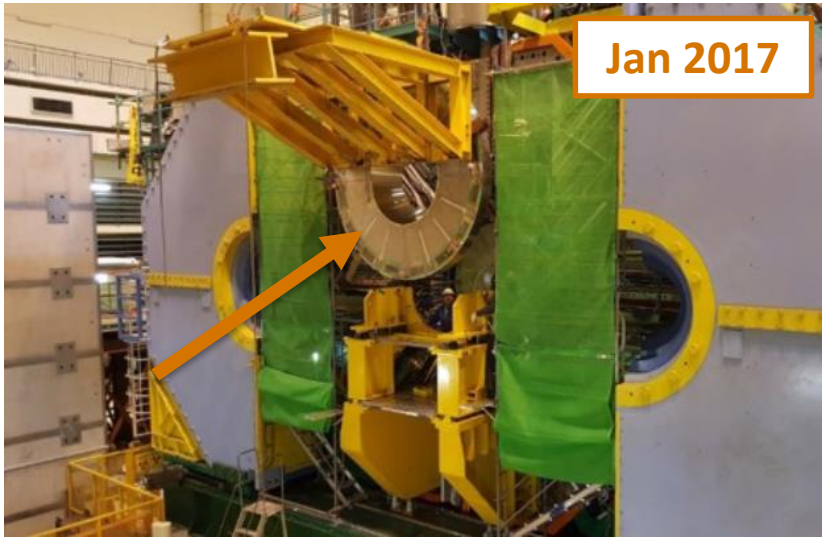


Energy

- **E**lectromagnetic **C**a**L**orimeter
  - Reuse Belle crystals and structure
  - 8736 CsI(Tl), 16 X_0
  - R&D for CsI endcap upgrade
- Electronics upgrade
  - FPGA analysis of waveform
  - Full waveform for commissioning run

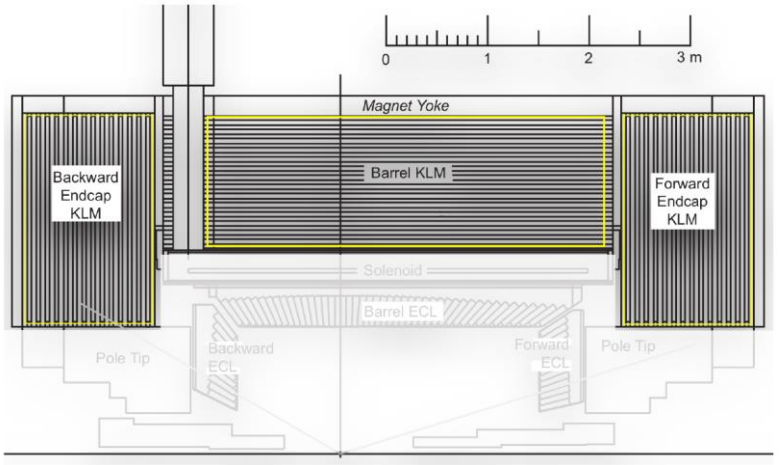


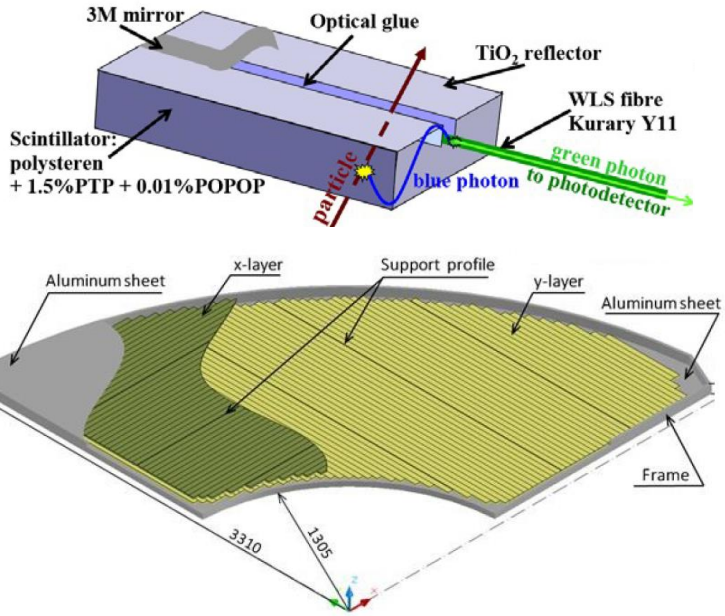


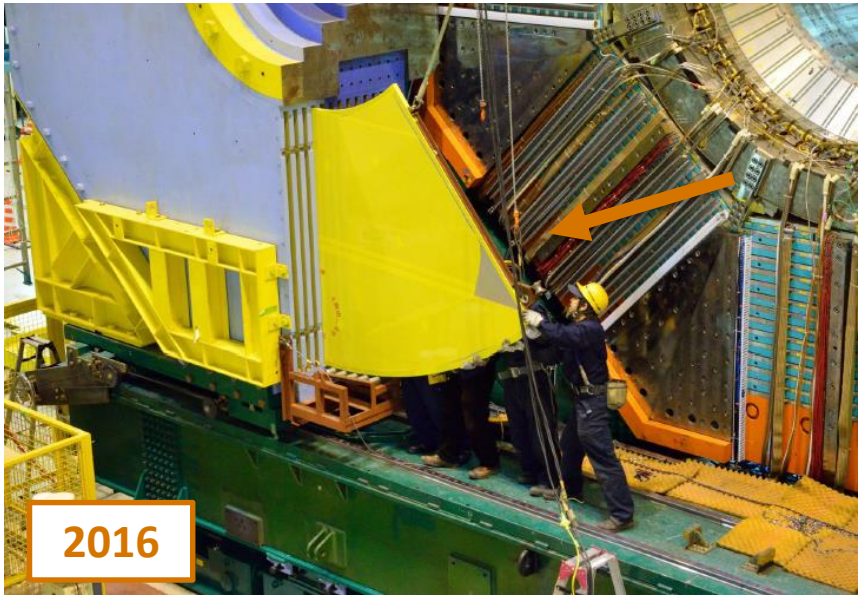


Muons

- **KL**ong and **M**uon detector
- Alternating iron / active layers
  - Barrel: 2 scintillator + 13 RPCs
  - Endcap: 14 scintillator
  - New for Belle II: PS strips + WLS + SiPM







Background monitoring

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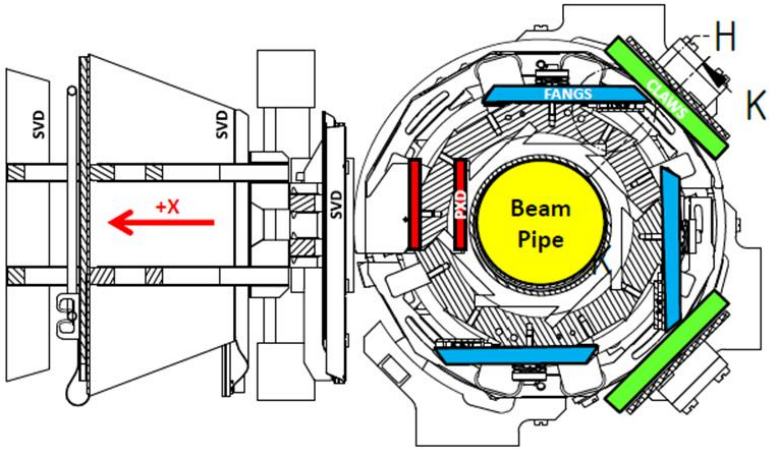
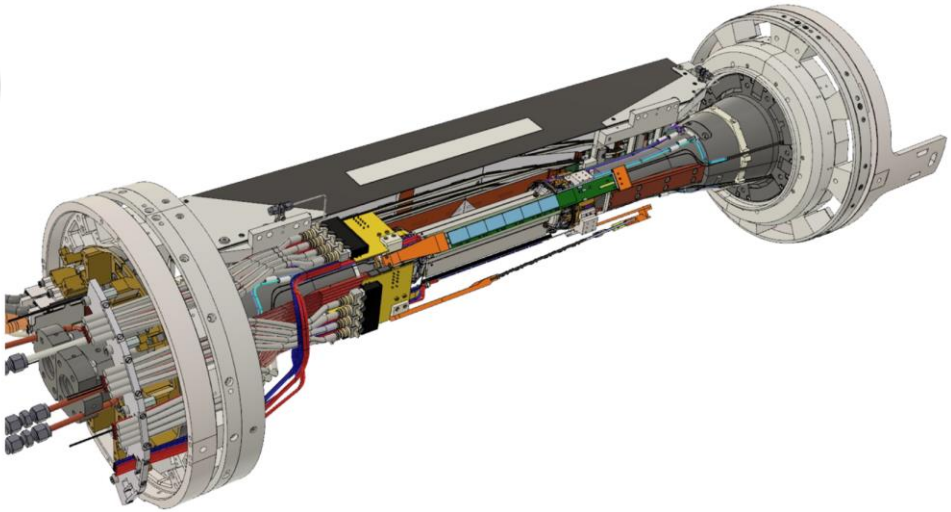
- **B**eam **E**xorcism for **A ST**able Belle **II**
  - Partial vertex detector
  - Radiation-monitoring detectors
  - Inner: “FANGS” “CLAWS” “PLUME”
  - Other: He3/TPCs, diamonds, PIN diode



arXiv:1802.01366 (2018)

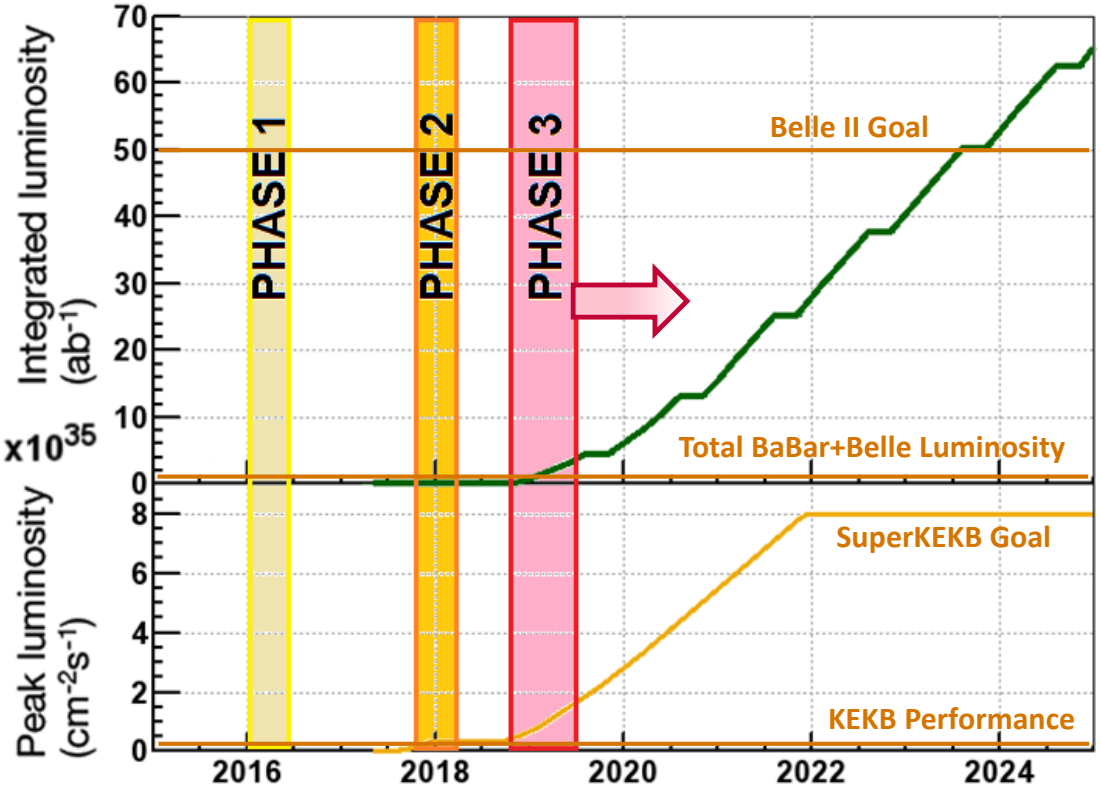
SuperKEKB Commissioning Detector
BEAST II
Belle II Collaboration

- Used only in initial phases
  - Machine commissioning
  - Ensure radiation-safe environment
- To be replaced by full VXD



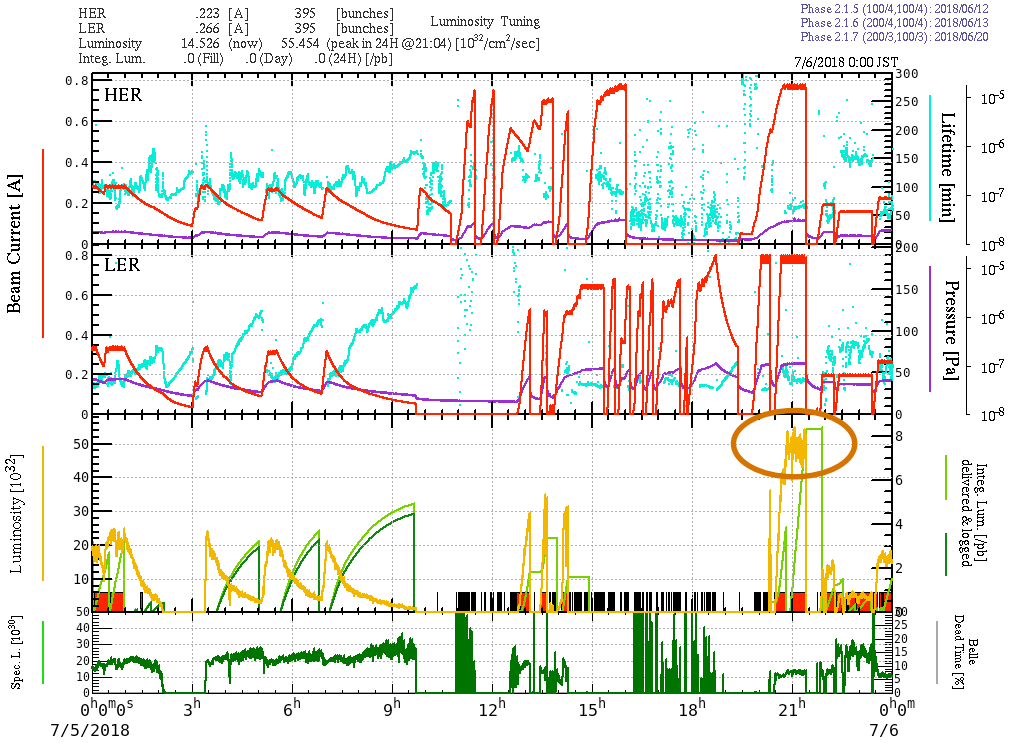
Belle II Schedule and Plans

- Phase 1 (complete 2016)
  - Accelerator commissioning
- Detector roll-in: April 2017
- Phase 2 (complete July 2018)
  - Partial detector
  - Background study
  - First collisions
  - First data collected
- Phase 3 (2019)
  - Nominal Belle II start
- **Ultimate goal: 50 ab^{-1}**

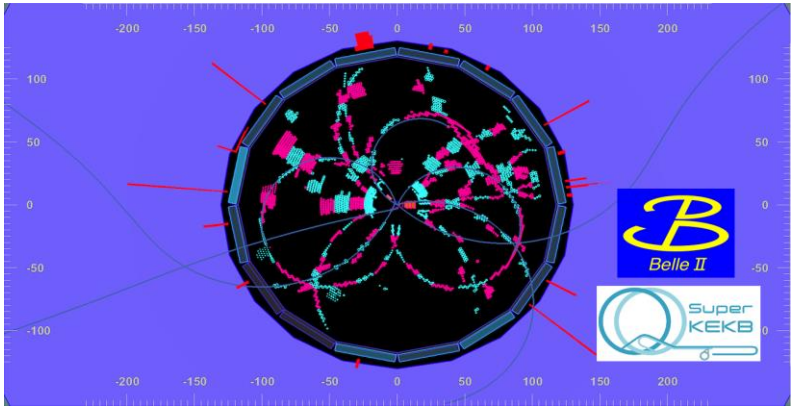


Belle II Achievements

- First collisions: April 26, 2018
- Peak luminosity: 5.5 x 10^{33} / cm^2 / s
- Total of ~500 pb^{-1} collected

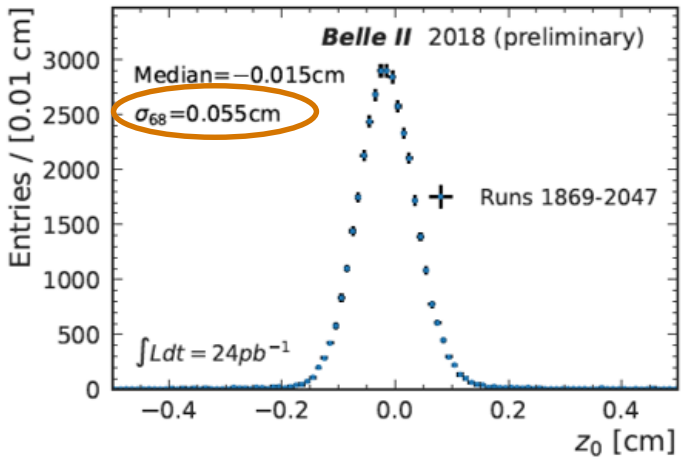


First $e^+e^- \rightarrow BB$ candidate

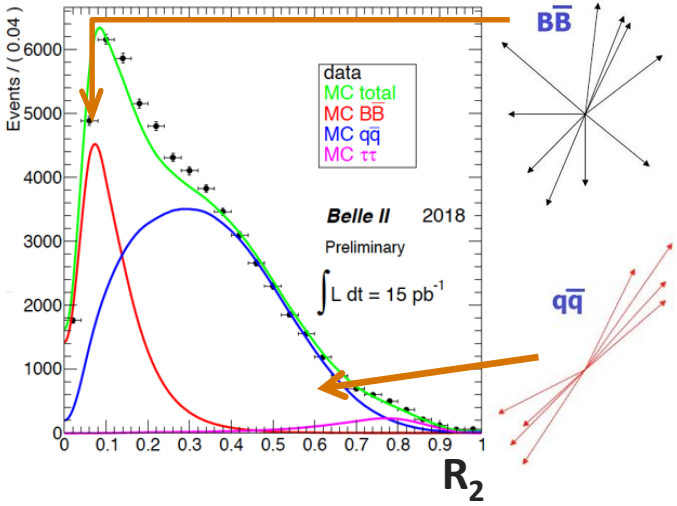


Early Belle II Performance

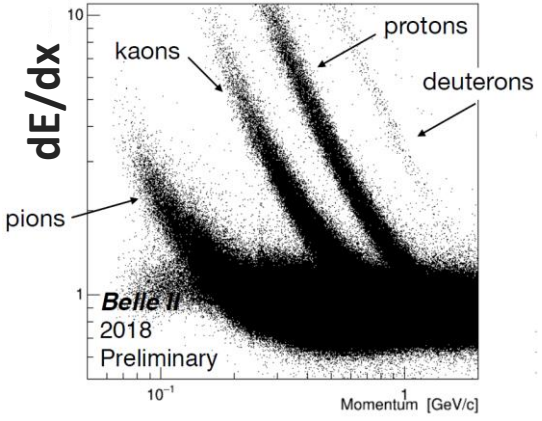
- Nano-beam scheme verified



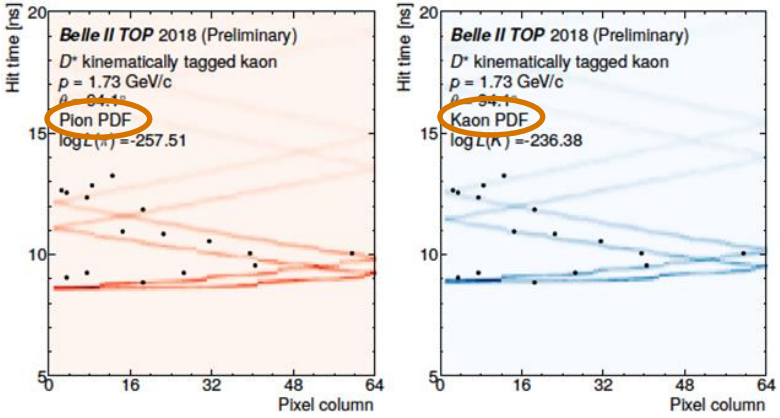
- $\Upsilon(4S)\rightarrow B\bar{B}$ operation



- Particle ID performance

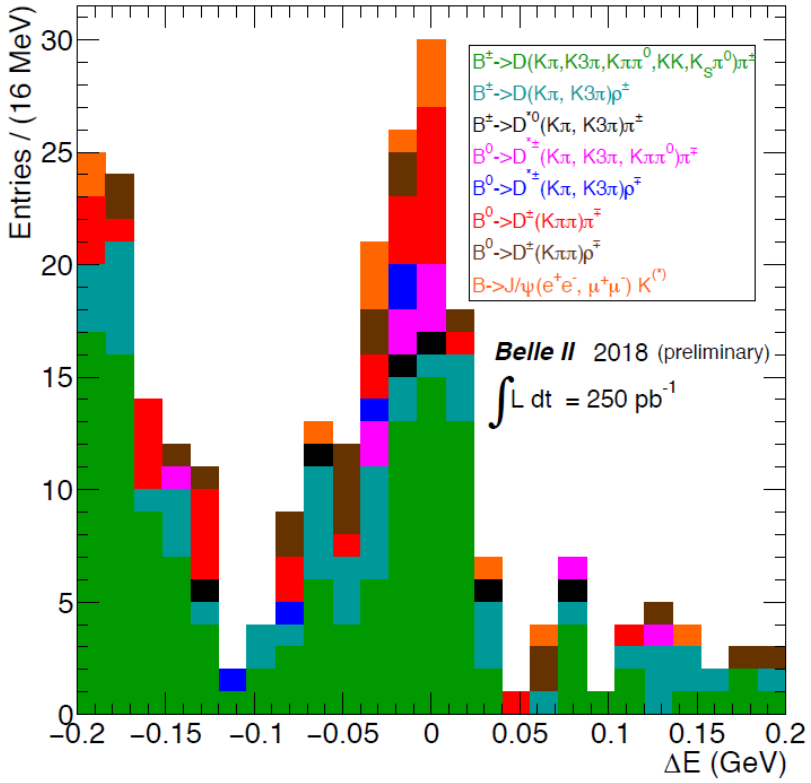


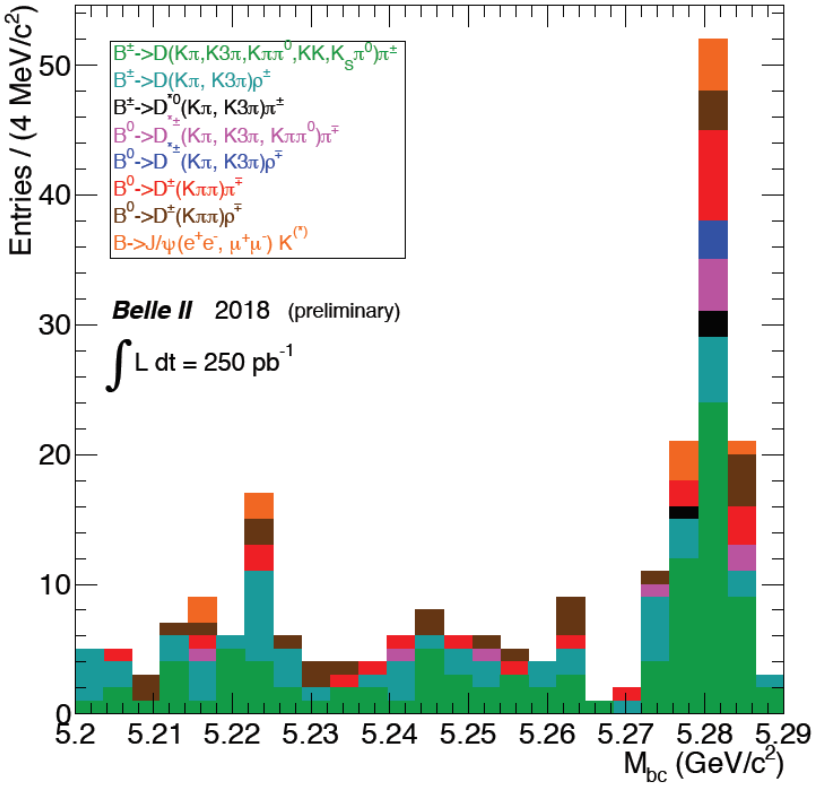
$D^{*+}\rightarrow\pi^+D^0(K^-\pi^+)$



First Belle II B mesons

- ~100 B meson candidates in hadronic decay modes





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

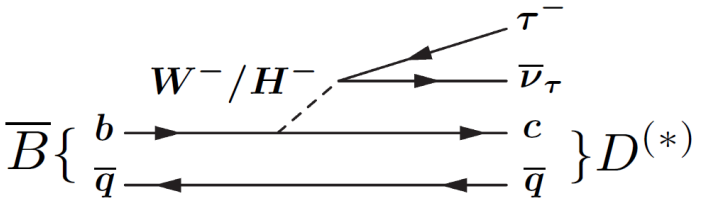
$$M_{bc} = \sqrt{(E_{cm}/2)^2 - p^2_{recon}}$$

BELLE II PHYSICS

"The Belle II Physics Book", arXiv:1808.10567 (2018)

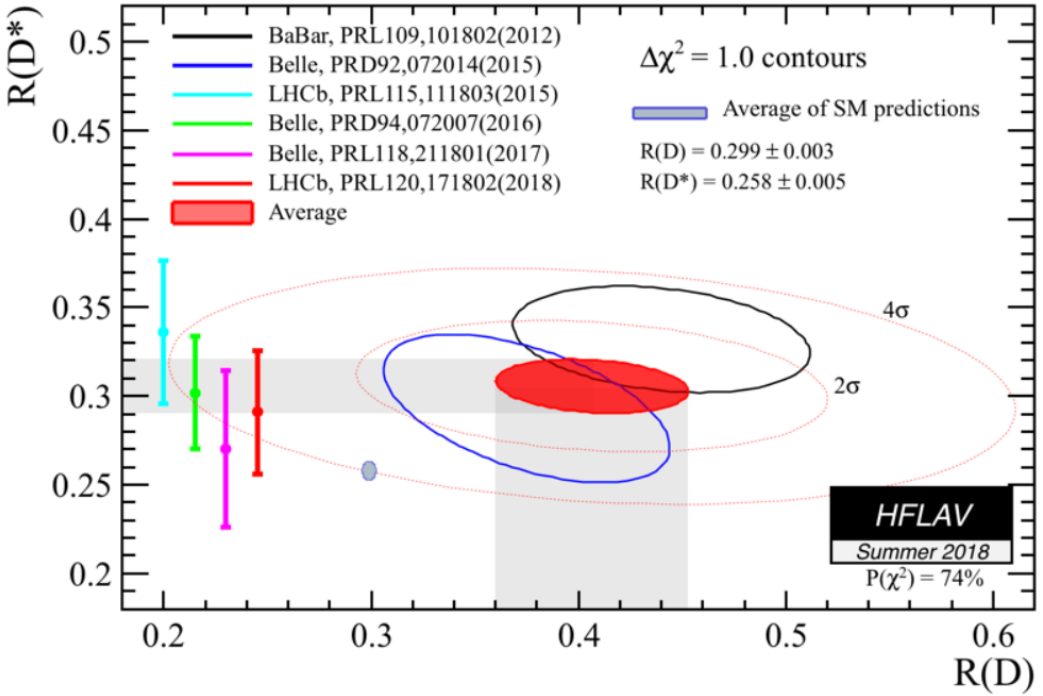
Leptonic B Decay: $B \to D^{(*)}\tau\nu$

- Sensitive to (e.g.) charged Higgs contributions
- Significant BF(SM) O(~1%)
- Cancelation of uncertainties



$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\overline{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\overline{\nu}_\ell)}$$

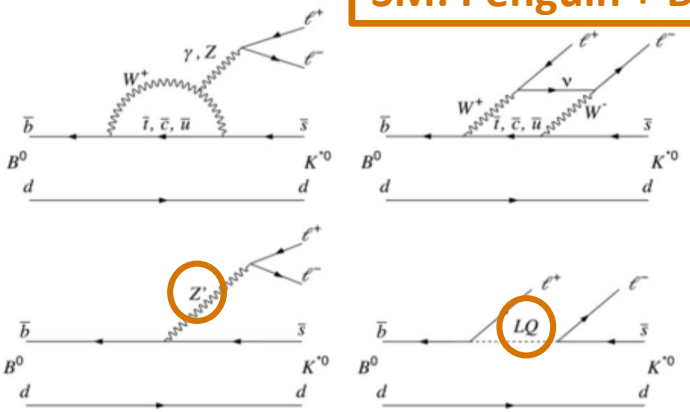
- **World average 3.8σ from SM**
- B-Factory uncertainty: 16 (9)%
- Belle II @ 50ab^{-1}: 2-3%
  - >5σ at ~5ab^{-1}



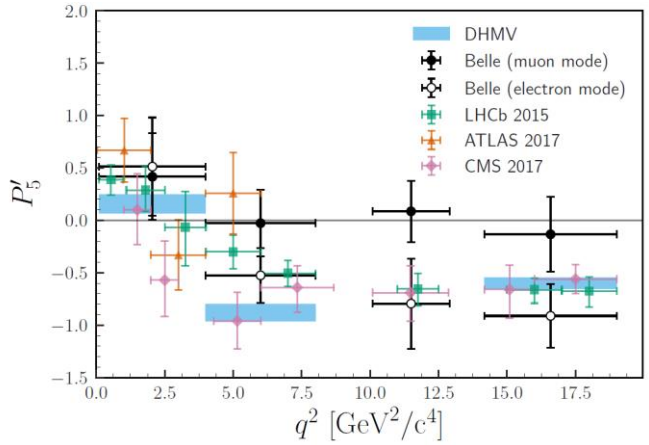
b→s Decays

- Rare SM decay: NP contributions?
- Deviations from SM in b→sℓℓ
  - >3σ tension globally
  - Complementary measures
    - LHCb: K*$\mu^+\mu^-$
    - Belle II: $\mathbf{X_s}(\mathbf{e^+e^-}, \mu^+\mu^-, \tau^+\tau^-)$

SM: Penguin + Box



- B→K$^{(*)}\bar{\nu}\nu$
  - SM prediction: ~4 (9) x 10^{-6}
  - Belle limit: ~<2 x 10^{-5}
  - Belle II uncertainty ~10%



- NP test via precise measurements in b→sγ ($X_s\gamma$) rates, …

Lepton Flavor Violation (τ)

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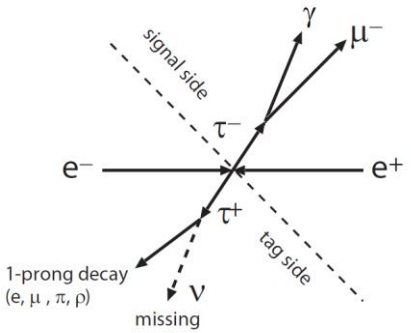
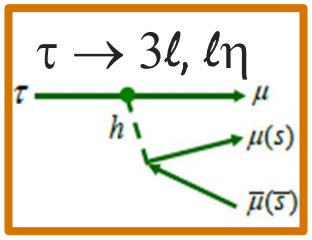
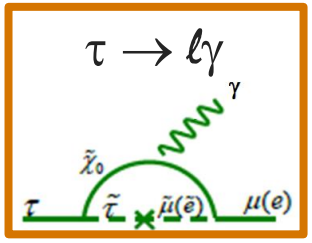
- Tau decay
  - Large ττ production cross section (σ ~0.9nb)
  - Coupling to NP due to m_τ
  - Flavor and lepton/baryon number violation



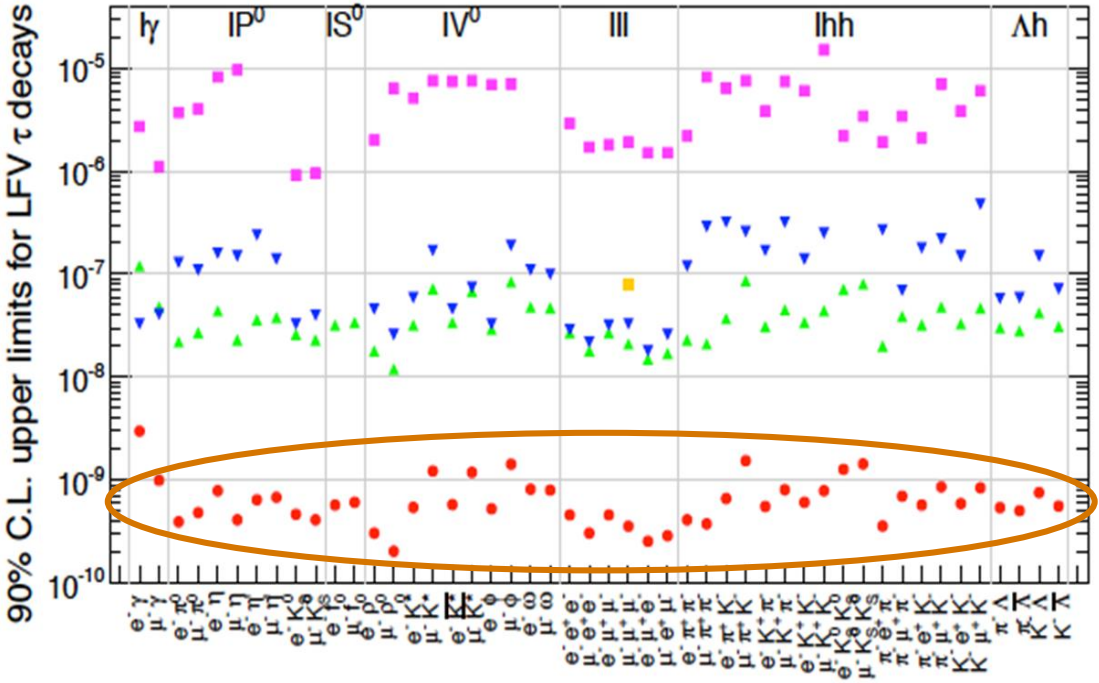
- CLEO (~10fb^{-1})
- BaBar (~0.5ab^{-1})
- Belle (~1ab^{-1})
- LHCb (3fb^{-1})
- Belle II (~50ab^{-1})

- LFV in SM ~O(10^{-25})
- NP enhancement ~O($10^{-(7-10)}$)



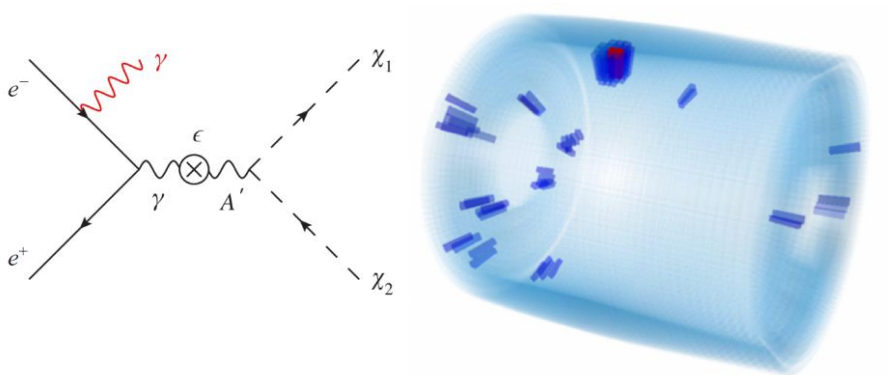


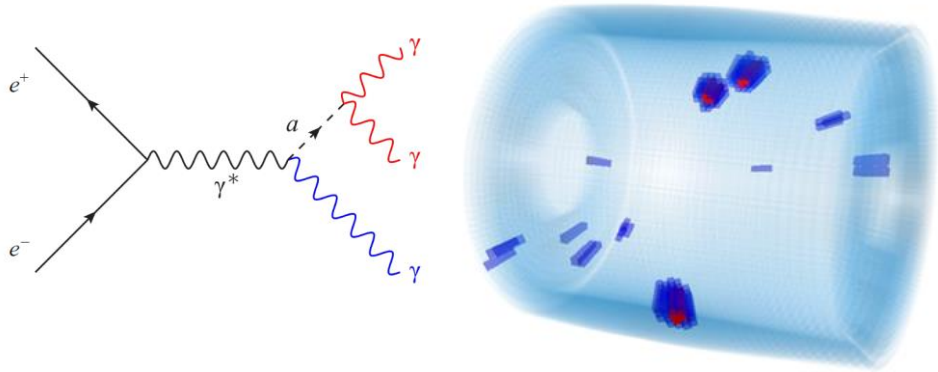
- **Belle II: Order of magnitude better for many modes**



Hidden/Dark Sector

- Access to “hidden” sector via mixing/interaction with SM
  - Dark photon (A’) decaying to leptons (“visible”) or light DM (“invisible”)
  - Axion-like particle (ALP) decaying to two photons



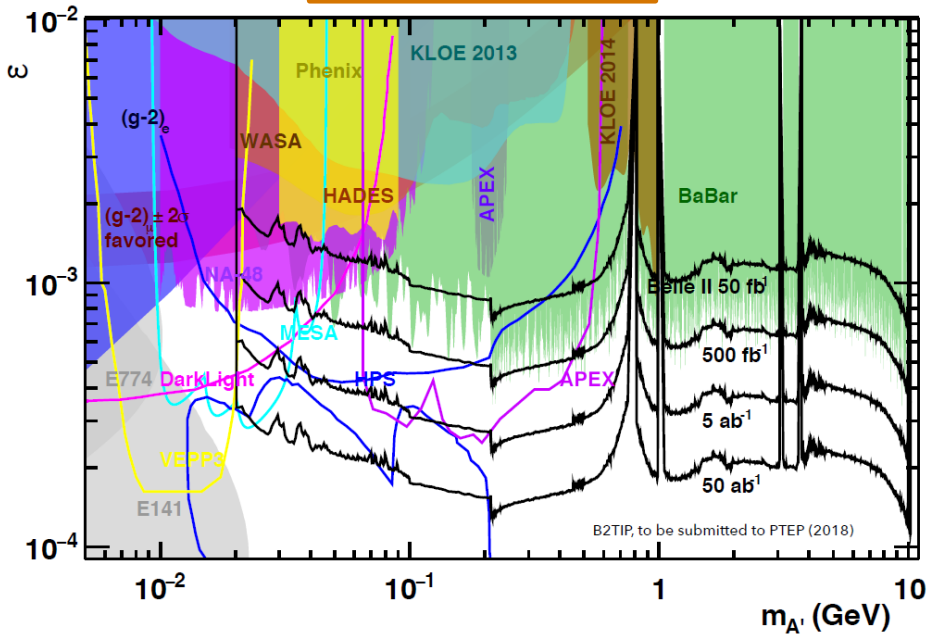


- Belle II considerations
  - Special topologies: mono-energetic photon / 3γ final state
  - Development of single-photon trigger
  - Calorimeter angular coverage and hermeticity

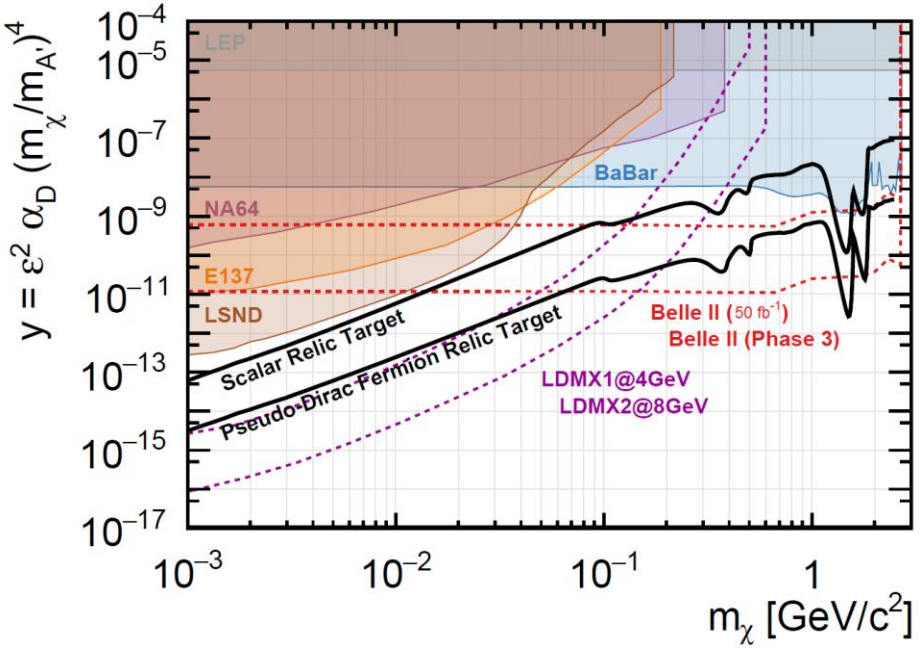
Dark Photon Search Capability

- Belle II potential reach versus luminosity

Visible decays



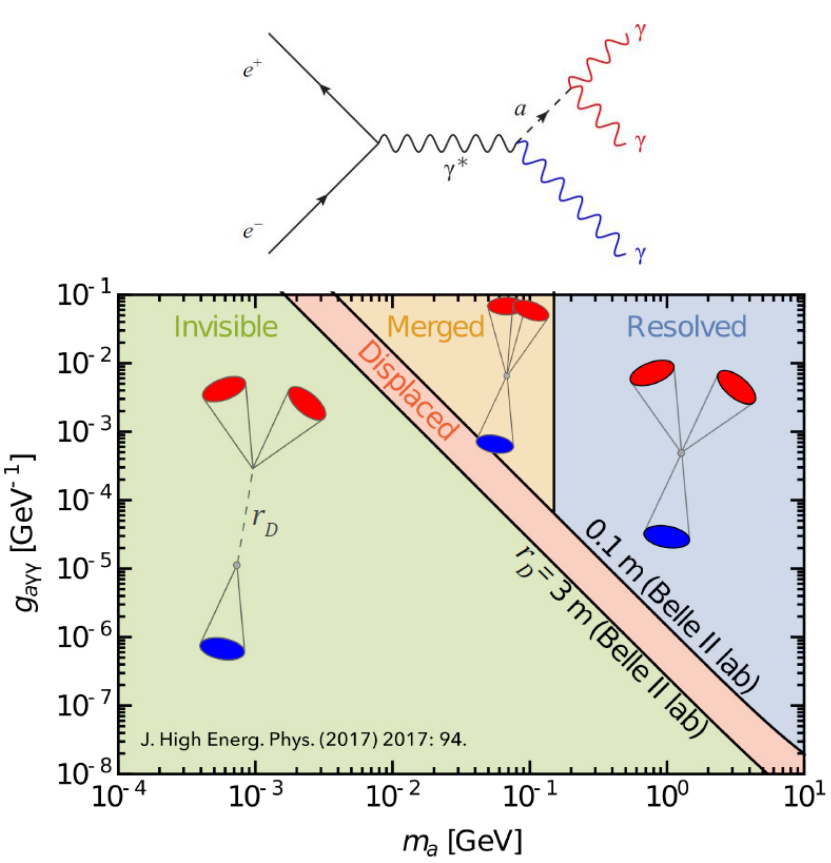
Invisible decays

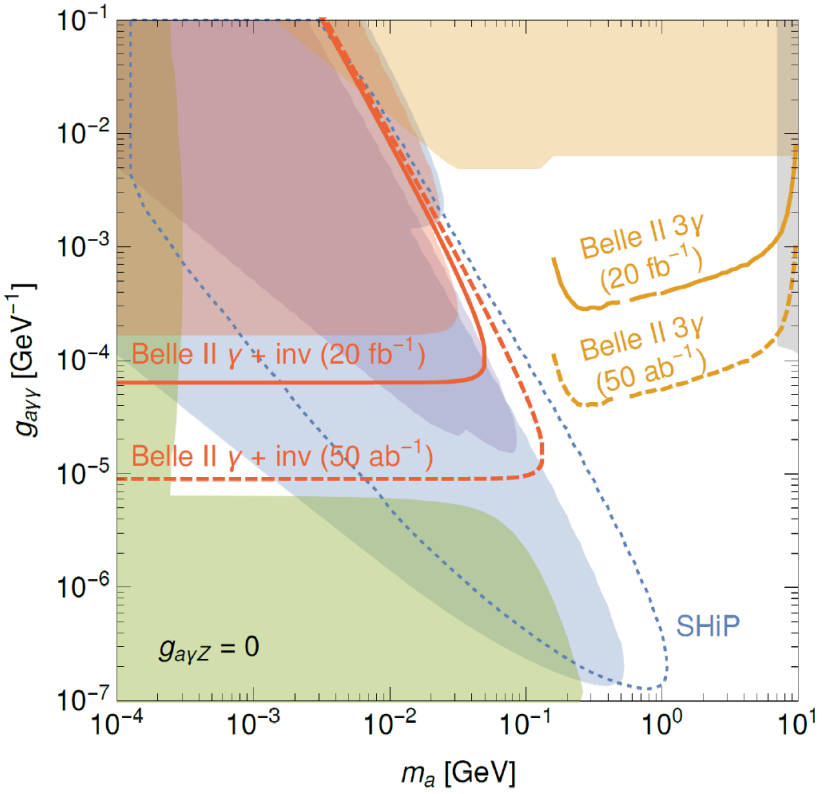


arXiv:1808.10567 (2018)

Axion-Like Particle Capability

- Parameter space affected by calorimeter photon reconstruction





M.J. Dolan et al., JHEP 2017, 94 (2017)

QUARKONIUM

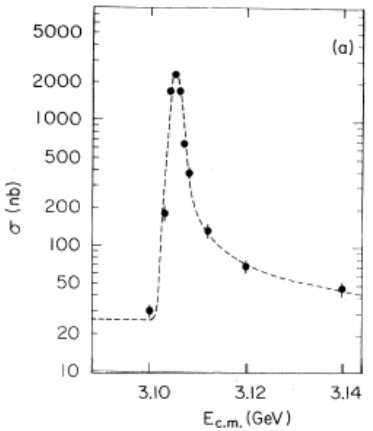
What is Quarkonium?

- **Bound state of heavy quark/anti-quark pair ($c\bar{c}$, $b\bar{b}$)**
- 1974: discovery of J/ψ, evidence of charm quark/quark model

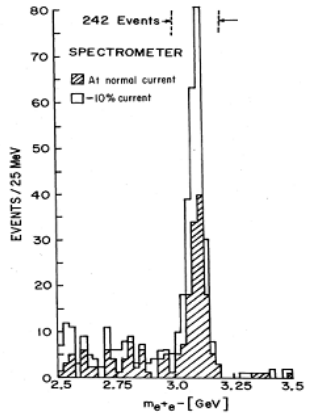
- Theoretical description
  - **Analogous to hydrogen/positronium (e^+e^-)**
  - Potential based on one-gluon exchange:

$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + br + \ldots$$

  - Now use effective field theories and lattice QCD



PRL 33, 1406 (1974)

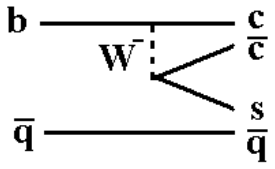


PRL 33, 1404 (1974)

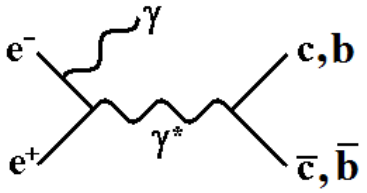
- Many (successful) predictions of properties for a whole family of particles
  - quantum numbers, masses/widths, production/decay mechanisms/rates
- **All are important tests of our theoretical understanding of QCD**

Quarkonium production at e^+e^- colliders

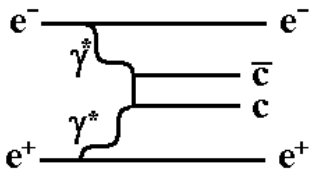
- B decays
  - Charmonium only
  - All quantum numbers available



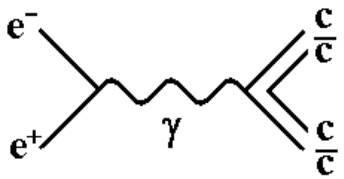
- Direct production / Initial State Radiation (ISR)
  - E_{CM} or below
  - $J^{PC}=1^{--}$



- Two-photon interaction
  - $J^{PC} = 0^{-+}, 0^{++}, 2^{++}$



- Double charmonium production
  - Seen for $J^{PC}=1^{--}$ (J/ψ, $\psi(2S)$) plus J=0 states



- Quarkonium transitions
  - Hadronic/radiative decays between states

Quarkonium Spectroscopy then…

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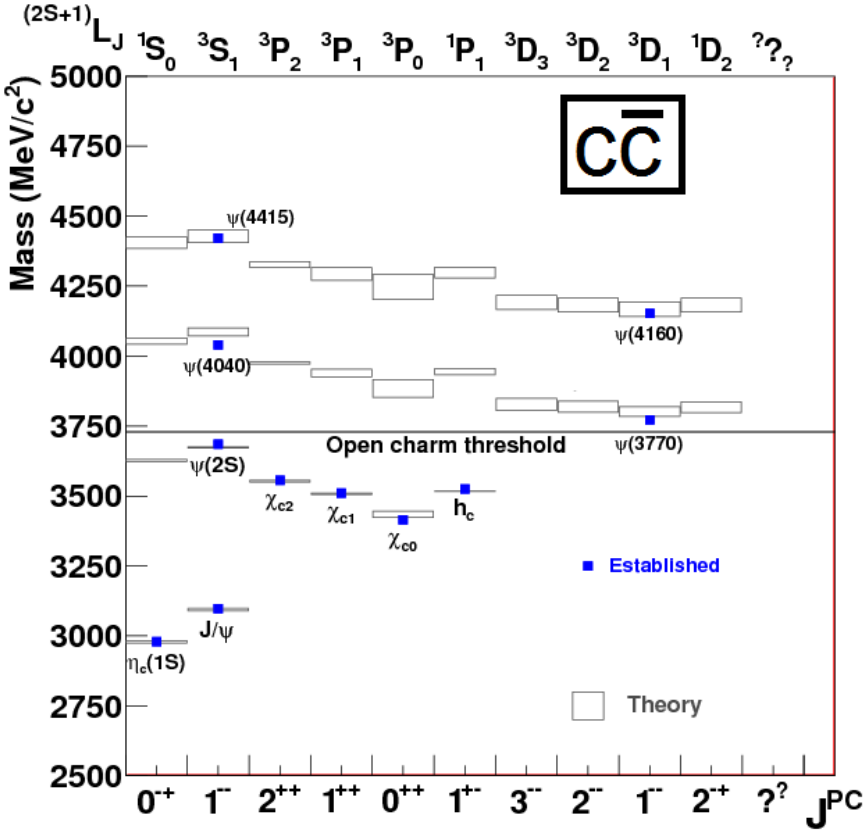
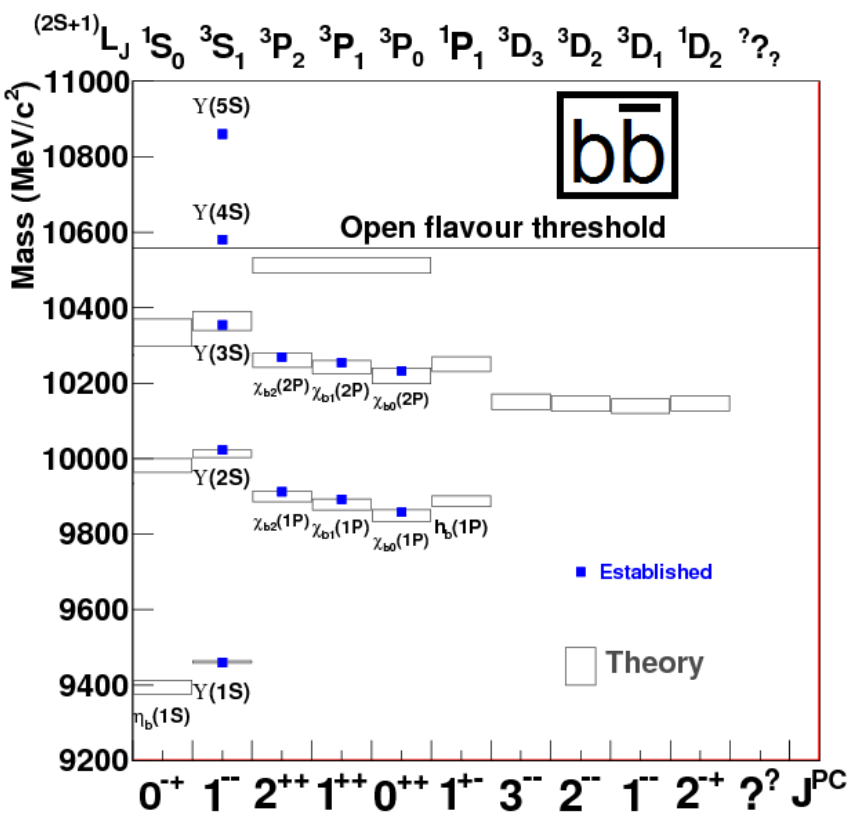
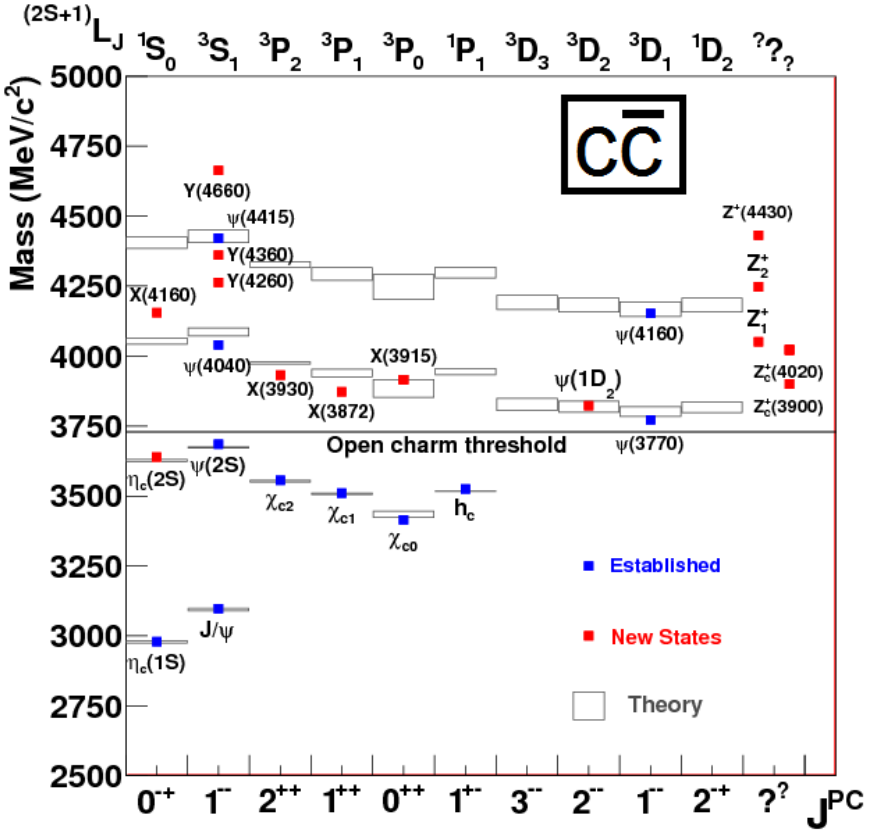
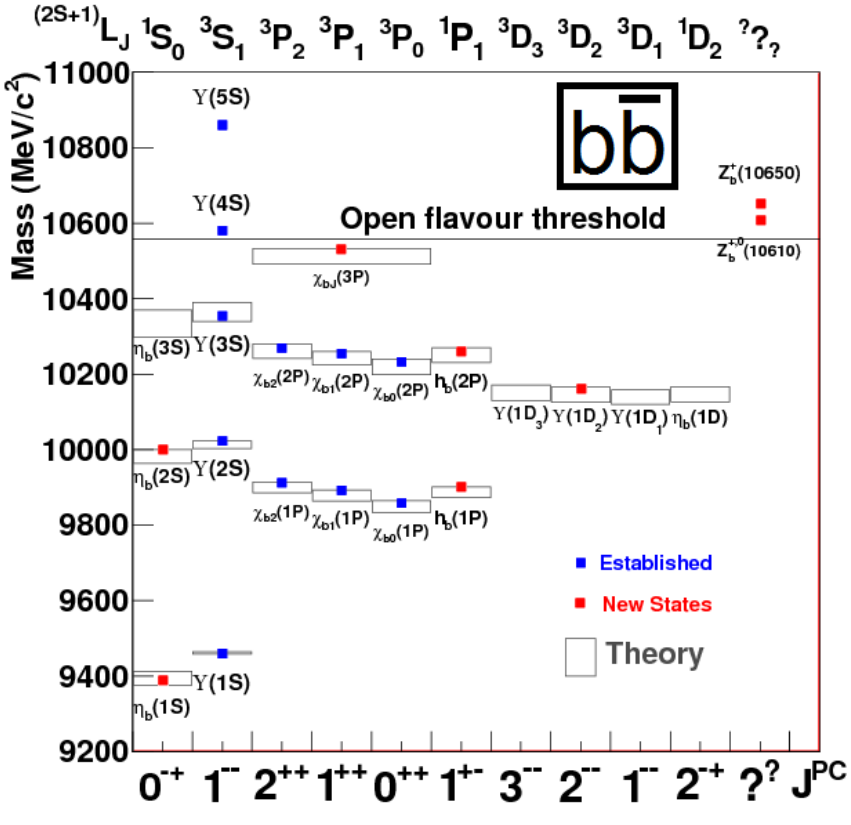




- Pre-B-Factories era (circa ~1999)

Quarkonium Spectroscopy … and now





- Post B-Factories

Quarkonium Spectroscopy

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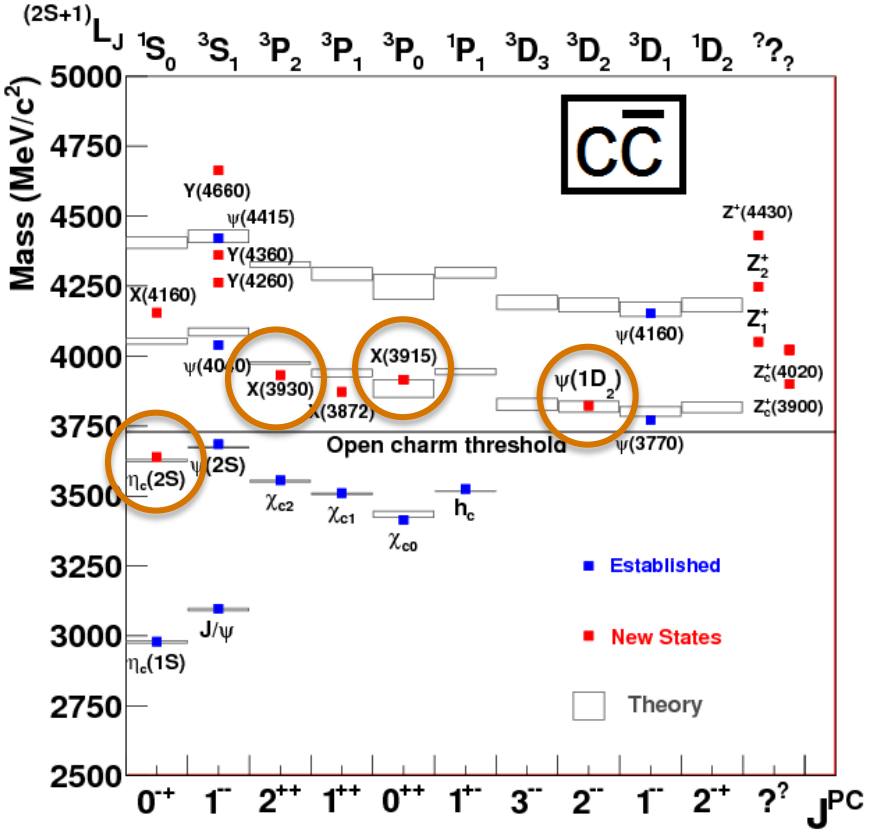

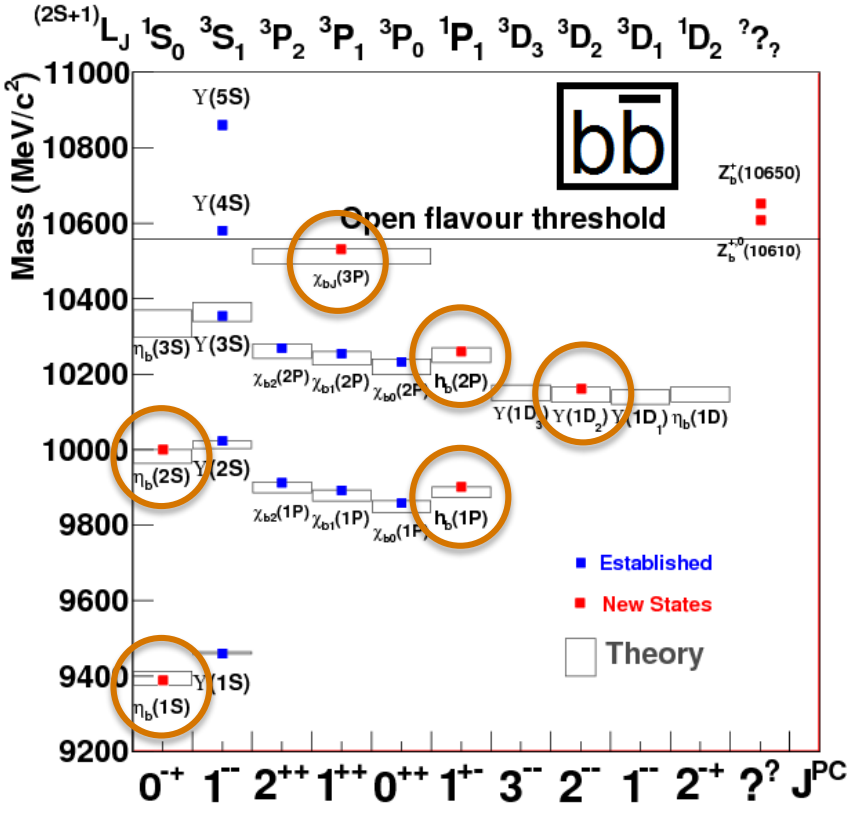

- First discoveries of long-predicted conventional quarkonia

Quarkonium Spectroscopy

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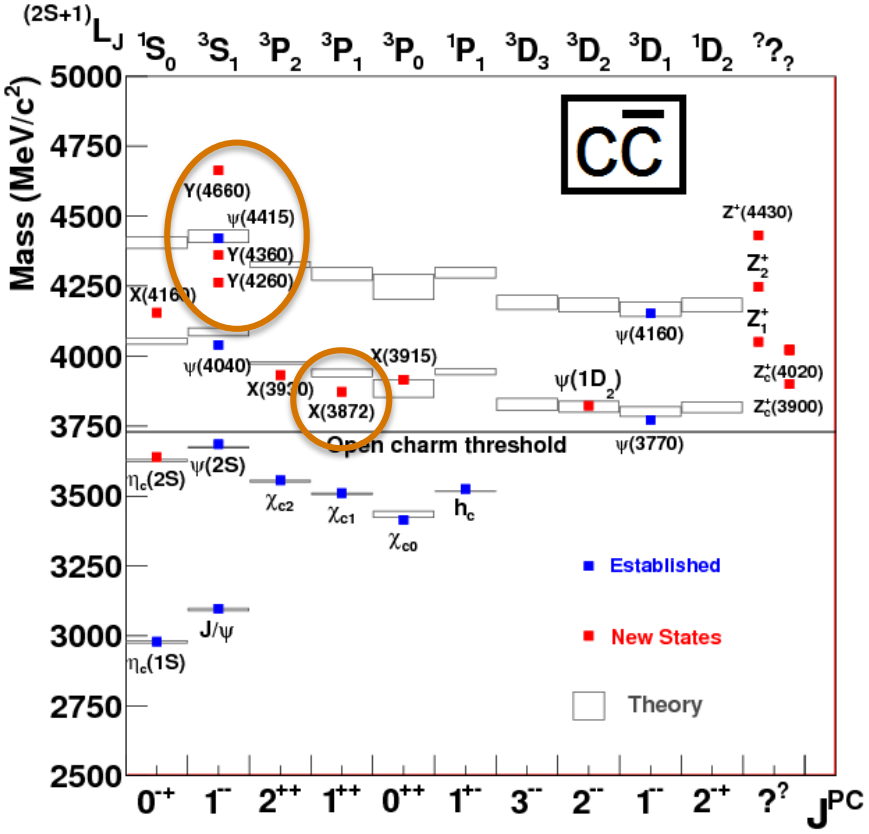
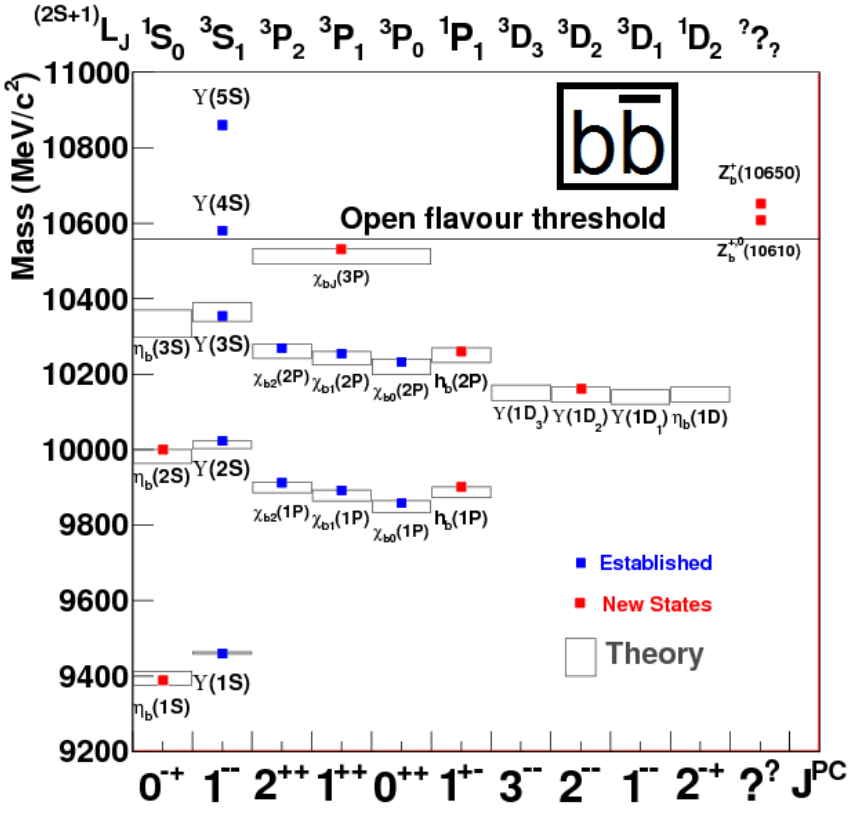
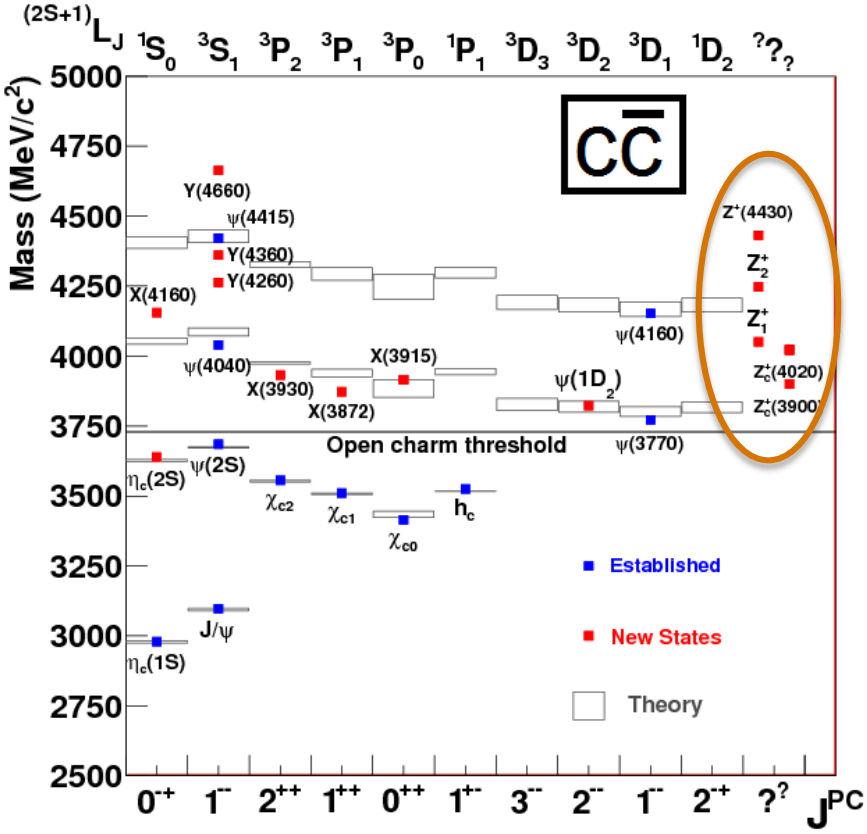
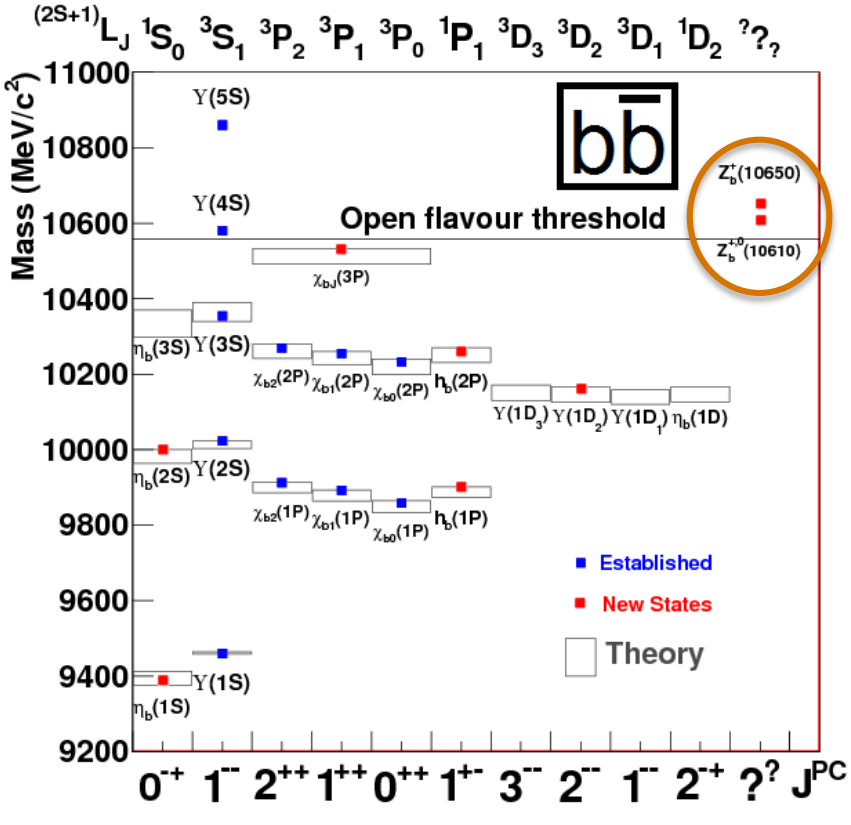




- First discoveries of long-predicted conventional quarkonia
- **Many discoveries are difficult to explain by quarkonium model**

Quarkonium Spectroscopy



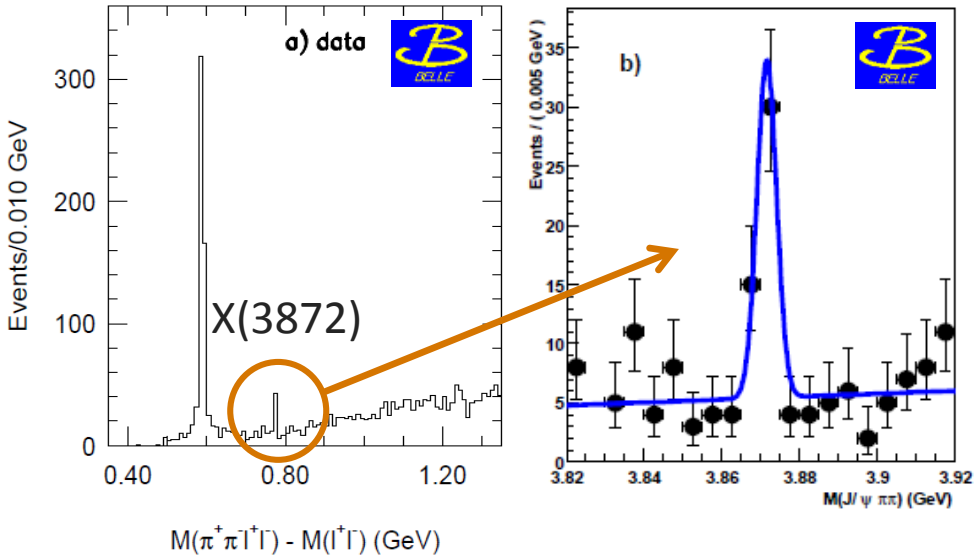


- First discoveries of long-predicted conventional quarkonia
- Many discoveries are difficult to explain by quarkonium model
- **Several states have non-zero charge, cannot be a $c\bar{c}$/$b\bar{b}$ pair**

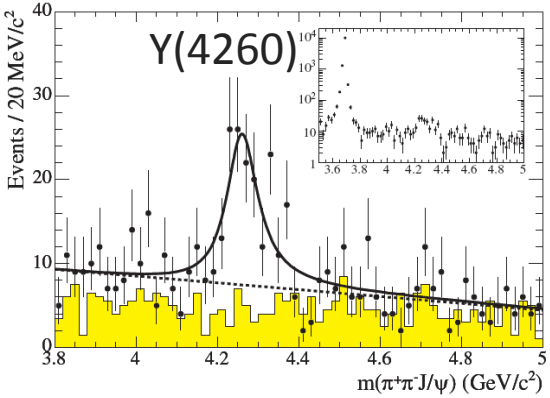
The New Alphabet: X, Y …

- X(3872)
  - Discovered by Belle in 2003
  - $B \to K\, X(3872) \to \pi^+\pi^-\, J/\psi(\ell^+\ell^-)$
  - Seen in all modern HEP expts.
  - **Most cited Belle publication**

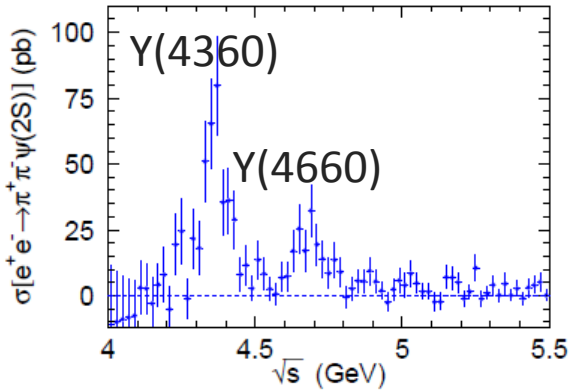
PRL 91, 262001 (2003)



- Y(4260) and friends
  - ISR-produced states decaying to $\pi^+\pi^-\,\psi(1S,2S)$
  - $J^{PC}=1^{--}$: **overpopulated for charmonium**!



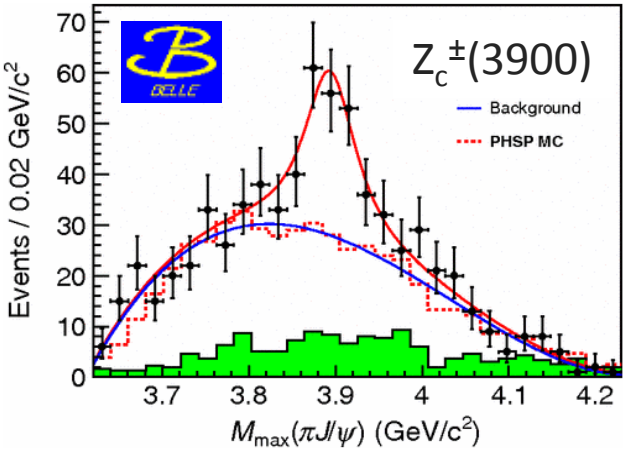
PRL 95, 142001 (2005)



PRD 91, 112007 (2015)

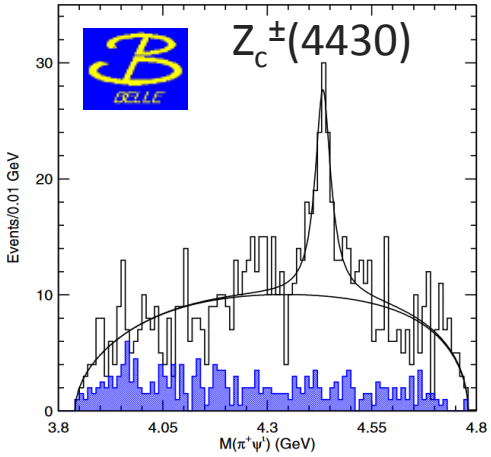
...and Z

- $Z_c^{\pm}(3900)$
  - Intermediate charged state in Y(4260) decay
  - $Y(4260) \rightarrow \pi^{\mp} Z_c^{\pm}(3900) \rightarrow \pi^{\pm} J/\psi$
  - Simultaneous discovery by Belle and BES-III
  - Others partners since seen by BES-III



PRL 110, 252002 (2013)

- $Z_c^{\pm}(4430)$
  - Discovered by Belle
  - $B \rightarrow K\pi^- Z^{\pm}(4430) \rightarrow \pi^+\psi(2S)$
  - Confirmed by LHCb
  - Partners seen in $\pi^+\chi_{c1}$ and $\pi^+ J/\psi$

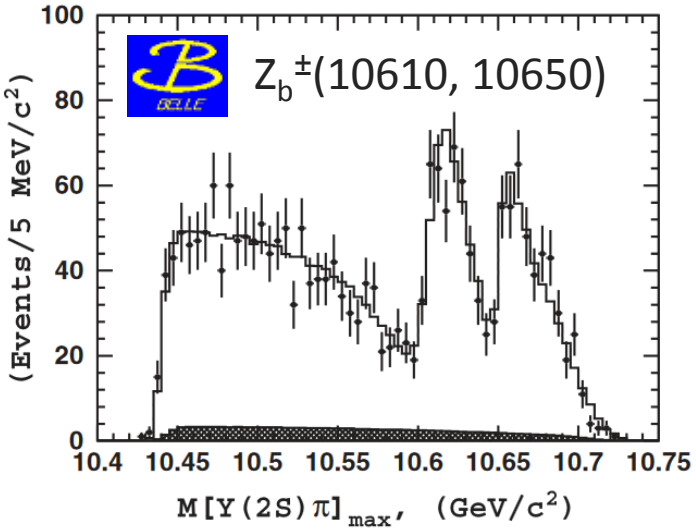


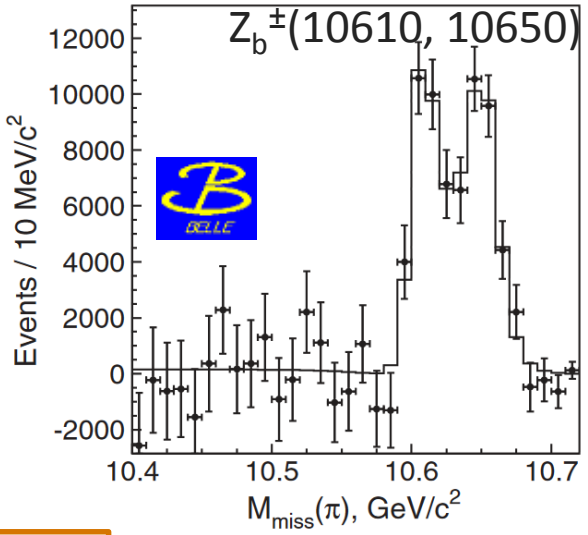
PRL 100, 142001 (2008)

- Non-zero charge cannot be $c\bar{c}$ = four quarks!

$Z_b^{\pm}$ states in the bottomonium system

- Anomalous dipion transition rate: $\Upsilon(5S) \to \pi\pi\, b\bar{b}$
- $\Upsilon(5S) \to \pi^{\mp} Z_b^{\pm} \to \pi^{\pm}\Upsilon(1S,2S,3S)$ and $Z_b^{\pm} \to \pi^{\pm} h_b(1P,2P)$
- Discovery of $h_b(1P, 2P)$, $\eta_b(2S)$, **indication of charged $Z_b^{\pm}$ states**
- **Analogous to Y(4260) decays and $Z_c^{\pm}$ in charmonium system!**





PRL 108, 122001 (2012)

A new form of matter?

- Meson Molecules
  - Weakly bound state of two mesons

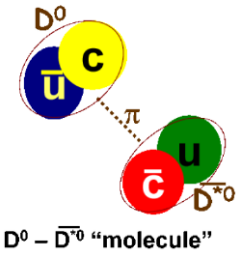
    e.g.: Tornqvist, PLB 590, 209 (2004)
- "Tetraquarks"
  - Color-singlet diquarks bound directly by strong force

    Polosa et al., PRD 89, 114010 (2014)
- Other exotica
  - Hybrids: quarkonium with bound excited gluon

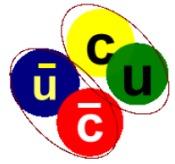
    Barnes et al., PRD 52, 5242 (1995)
  - Hadroquarkonium: qq-light hadron interaction

    Dubinskiy et al., PLB 671, 82 (2009)
- Nothing special
  - Kinematic effects / standard quarkonium

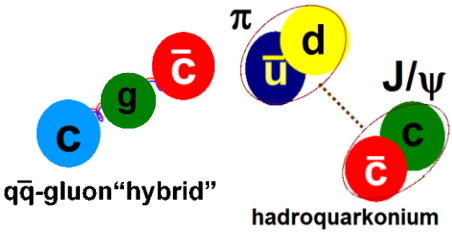
    e.g.: Swanson, PRD 91, 034009 (2015)



D⁰ – D̄*⁰ "molecule"



diquark-diantiquark



qq̄-gluon"hybrid"

hadroquarkonium

conventional quarkonium

A new form of matter?

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- Meson Molecules
  - Weakly bound state of two mesons
  - e.g.: Tornqvist, [illegible], 209 [illegible]4)
- "Tetraquarks"
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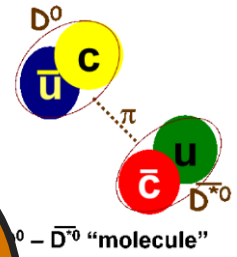
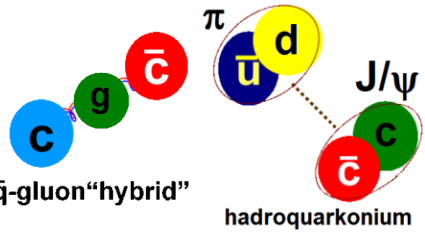
- Nothing specific
  - Kinematic effects / standard quarkonium
  - e.g.: Swanson, PRD 91, 034009 (2015)





EARLY BELLE II PHYSICS

Belle II Early Physics Prospects

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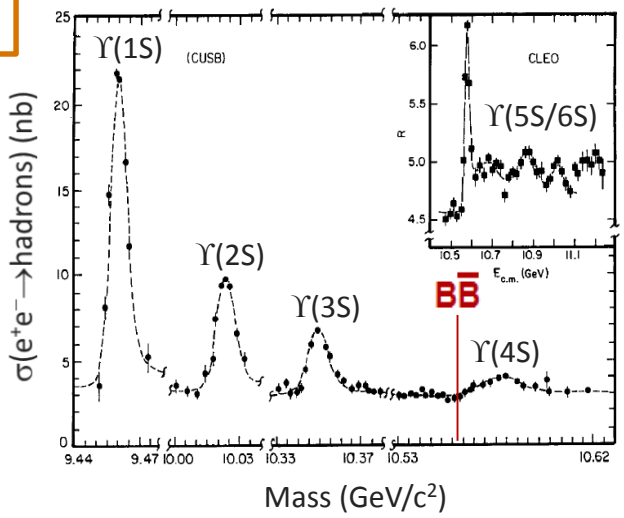
- Existing B-Factories ~1.5 ab^{-1}: opportunity for non-B physics results

Experiment	Scans / Off. Res. fb^{-1}	$\Upsilon(5S)$ 10876 MeV fb^{-1}	10^6	$\Upsilon(4S)$ 10580 MeV fb^{-1}	10^6	$\Upsilon(3S)$ 10355 MeV fb^{-1}	10^6	$\Upsilon(2S)$ 10023 MeV fb^{-1}	10^6	$\Upsilon(1S)$ 9460 MeV fb^{-1}	10^6
CLEO	17.1	0.4	0.1	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan		433	471	30	122	14	99	–	
Belle	100	121	36	711	772	3	12	25	158	6	102

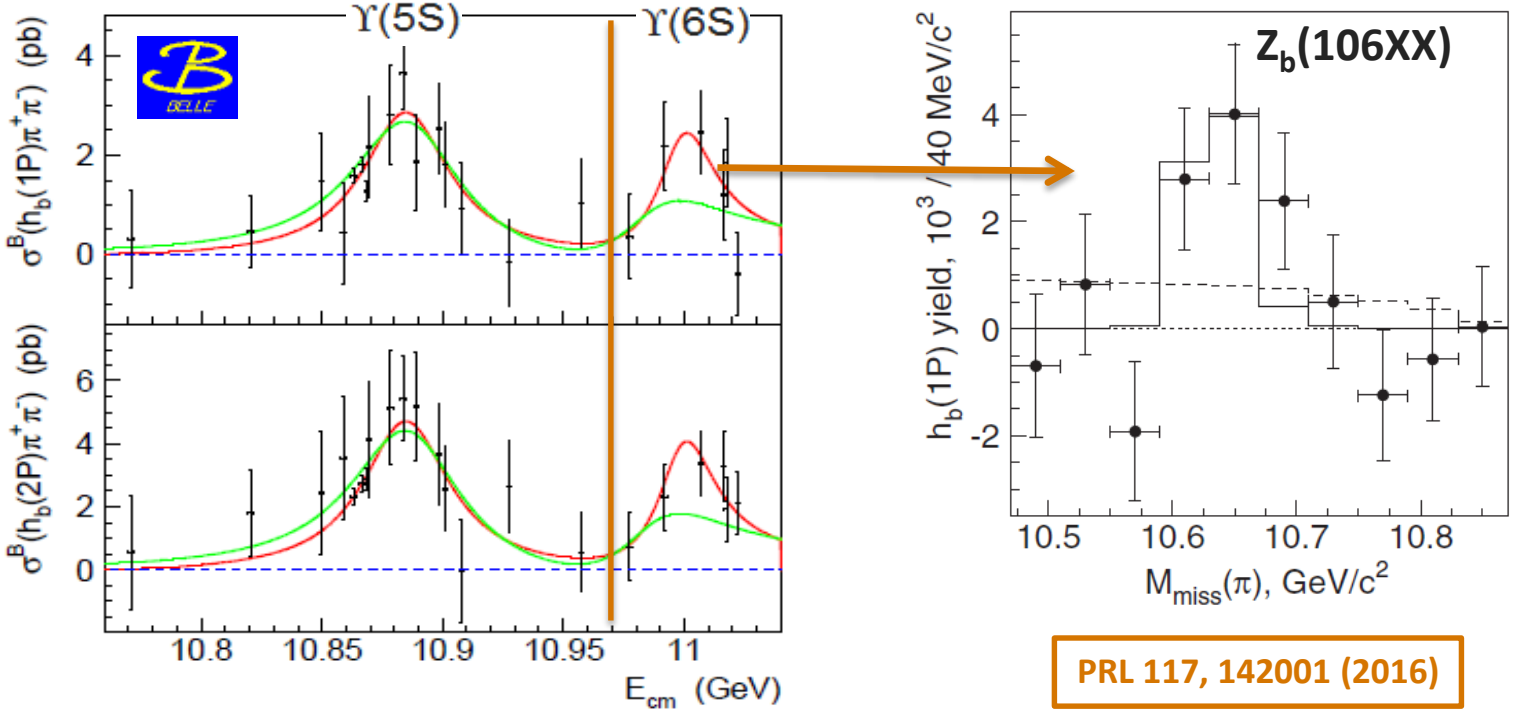
Potential impact with O(10-100) fb^{-1}

- Above $\Upsilon(4S)$
  - Study of exotic four-quark states
  - <6fb^{-1} accumulated by Belle at $E_{CM}=\Upsilon(6S)$
- Below $\Upsilon(4S)$
  - Bottomonium search/study, NP in decays
  - Scan for direct production of $\Upsilon(n^3D_1)$
- All energies: Dark Sector searches



Physics Potential at $\Upsilon(6S)$

- Discovery of $Z_b^{\pm}(106XX)$ via $\Upsilon(5S)\to\pi\pi\Upsilon(pS)$ transitions at Belle
- Preliminary evidence for $\Upsilon(6S)\to\pi\pi h_b(nP)$, via $\pi Z_b^{\pm}(106XX)$ decay



PRL 117, 142001 (2016)

- **Study nature of $\Upsilon(6S)$, exotic quarkonia, bottomonium discovery**

Above Υ(4S) / Υ(6S) Running

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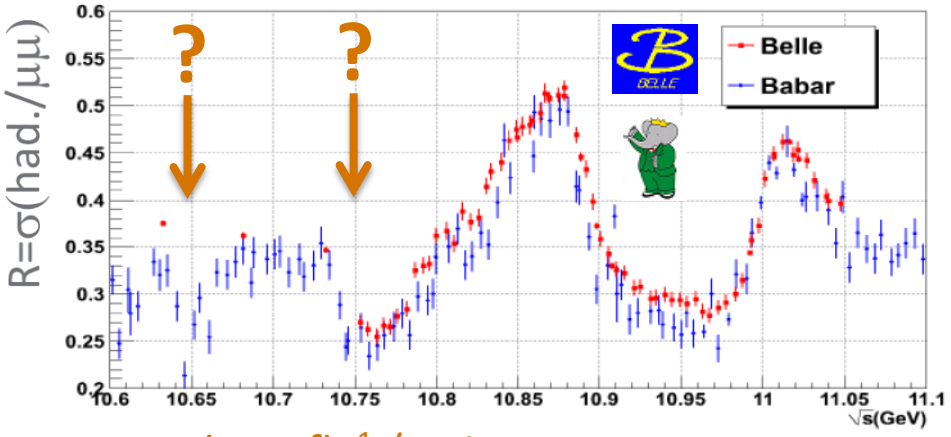
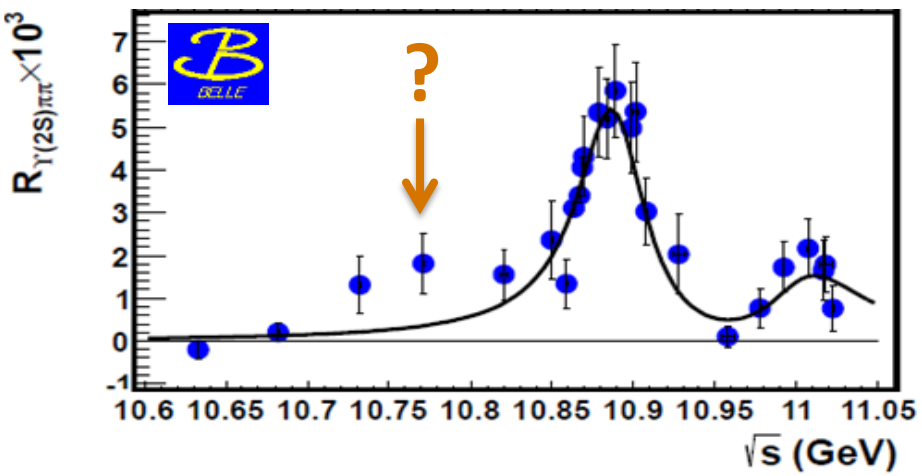
- Υ(6S) expectation from Υ(5S) and Y_c(4260)
  - Bottomonium transitions: $\pi\pi h_b$(1,2,3?P), $\pi\pi\Upsilon$(1,2,3S), $\eta\Upsilon$(1,2D)?
  - Resolve charged/four-quark intermediate states
  - Search for X_b("3872")?

- Other $B^{(*)}\bar{B}^{(*)}$ thresholds show potential
  - R_b dip versus $\pi\pi\Upsilon$ rise
  - Similar features as charm thresholds: sign of "Y_b" states?





Mostly <1 fb^{-1} / point

Υ(3S) On-Resonance: Bottomonium physics

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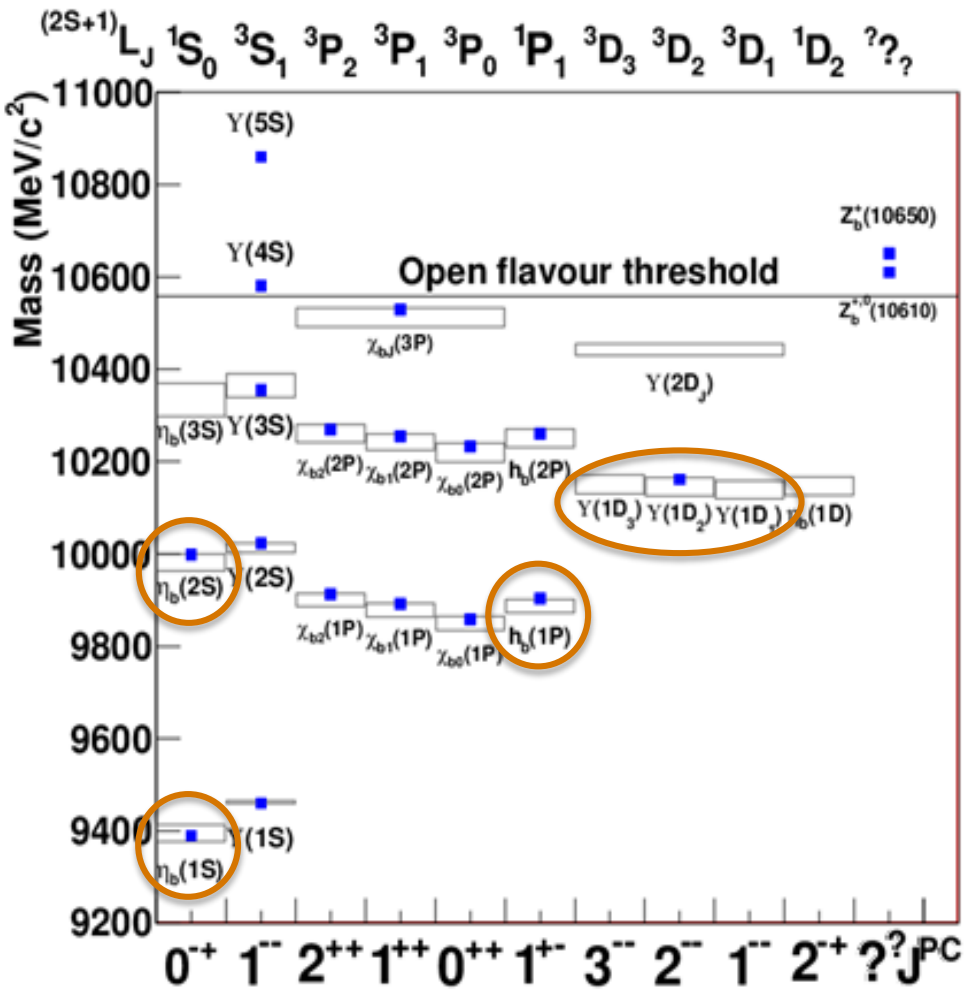
- **200fb^{-1} ~7xBaBar (Phase 3+)**
- Focus on conventional $b\bar{b}$ physics
  - $\Upsilon(1^3D_J)$ triplet
    - J=1,3 yet to be discovered
  - η_b(1S,2S)
    - Confirm m(η_b(1S,2S))?

    arXiv:1807.01201 (2018)
  - Hadronic (π^0,$\pi^+\pi^-$,η, ω) decays
  - Radiative transitions
- New Physics
  - Υ(1S, 2S) "invisible" decays
  - $\chi_{b0} \rightarrow \tau\tau$ light Higgs search
  - Dark sector decays $\gamma\chi\chi$



Belle II: Other long-term prospects for exotic hadrons

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- ISR-production of Y(4260, etc.)
  - BES-III limited <4.6 GeV, not observed at LHC
  - Belle II is the only way access to Y(4660) and scan in the b-sector
- Study of decay modes involving γ, π^0, η, soft pions
  - B decays with neutral final states, e.g. $X^{\pm}(3872) \to \pi^{\pm}\pi^0$ J/ψ, $Z(4430) \to \pi^0\psi(2S)$
  - Radiative transitions with soft photons
  - Structure in soft dipion decays (e.g. $\Upsilon(mS) \to \pi\pi\ b\bar{b}$)
- Revisit $\Upsilon(5S)$ resonance, increase from 100fb^{-1} to 1 ab^{-1}?
- Other surprises?
  - B Factories are exotics factories: the more we looked, the more we found!

CONCLUSIONS

Conclusions

- SuperKEKB / Belle II upgrade underway
  - First collisions 2018
  - Nominal start early 2019
- Next generation flavor factory
  - At least 50 times more data and improved detector capabilities
  - Clean environment with sensitivity complementary to LHC
- Wide-ranging physics program
  - Search for New Physics via high-statistics precision measurement
  - CPV, (semi-)leptonic/penguin decays, LFV, dark sector, etc.
  - Unique potential for further understanding of exotic hadrons and quarkonium

Conclusions

Pacific Northwest NATIONAL LABORATORY
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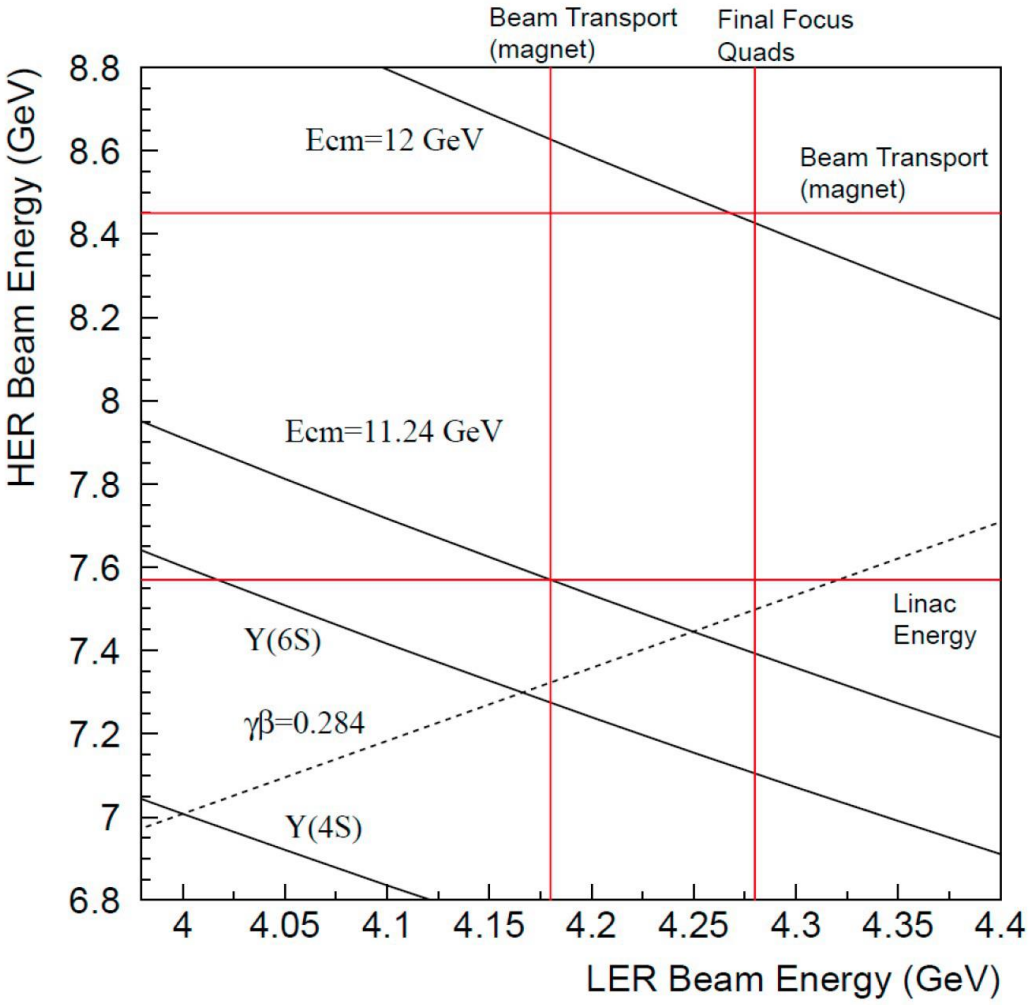
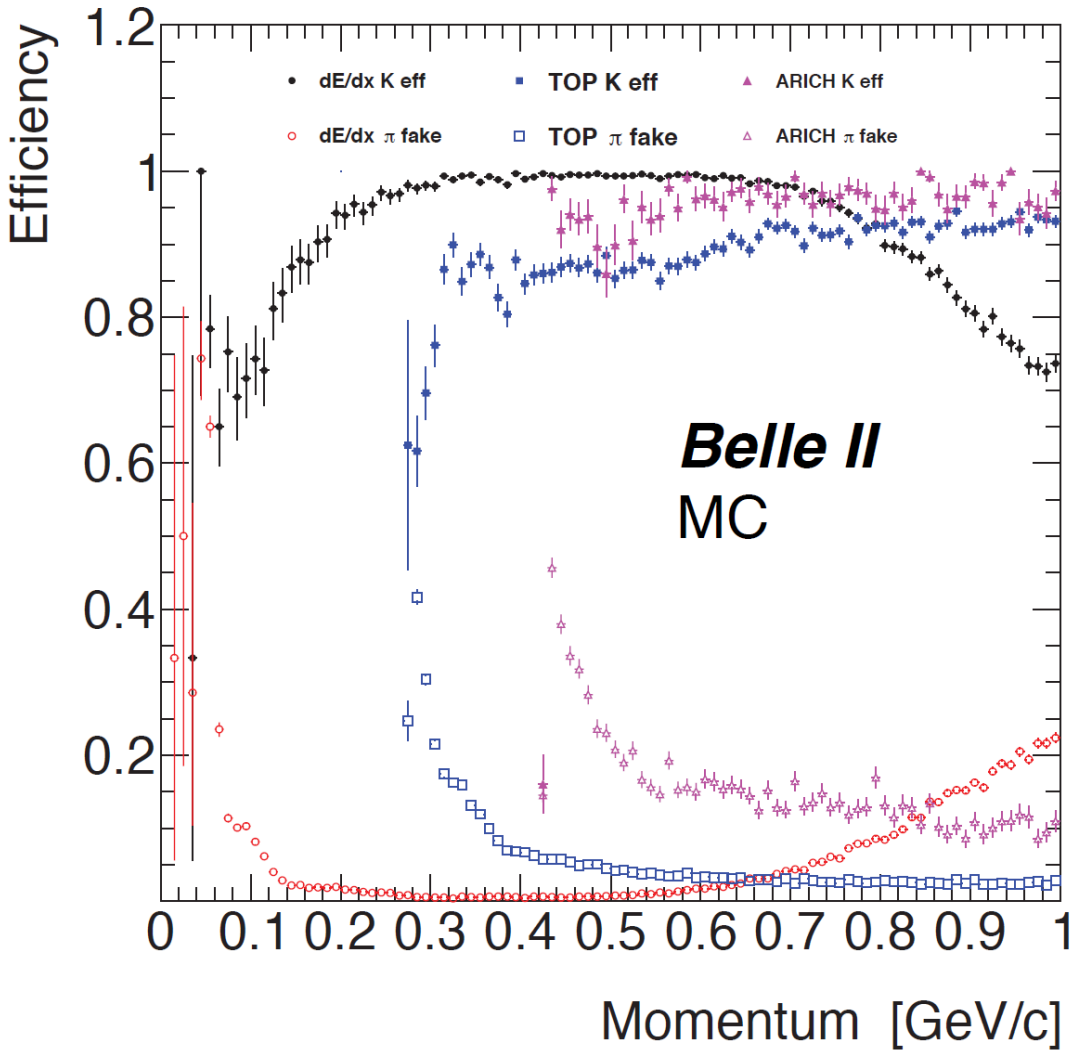
Thank you for your attention, and stay tuned!

BACKUP

SuperKEKB Energy Range



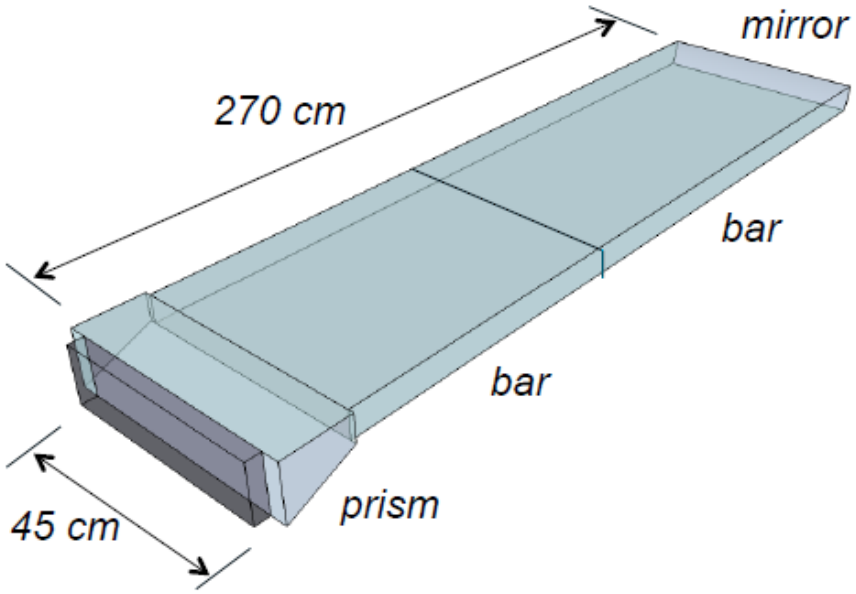
PID Expectations

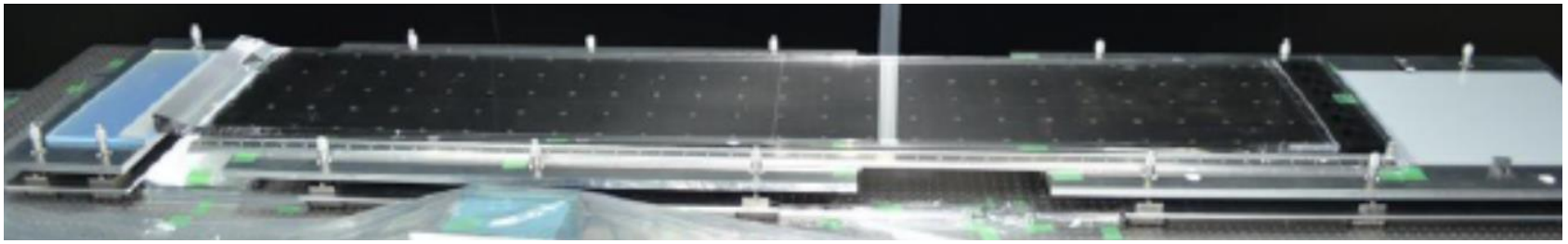


Belle II TOP Optics

- US responsibility: optics procurement, assessment, gluing/assembly
- 16 modules for barrel phi coverage

- Focusing mirrors
  - Correct chromatic dispersion
- Quartz bars
  - Radiator/reflector
- Expansion prisms
  - Increased resolution





Belle II TOP Microchannel Plate PMTs

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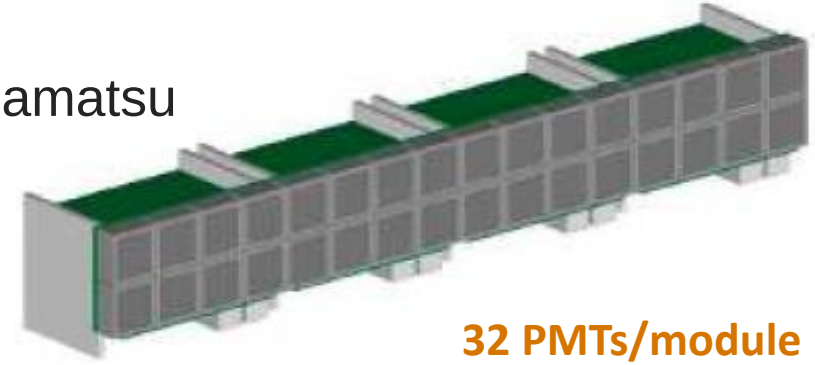
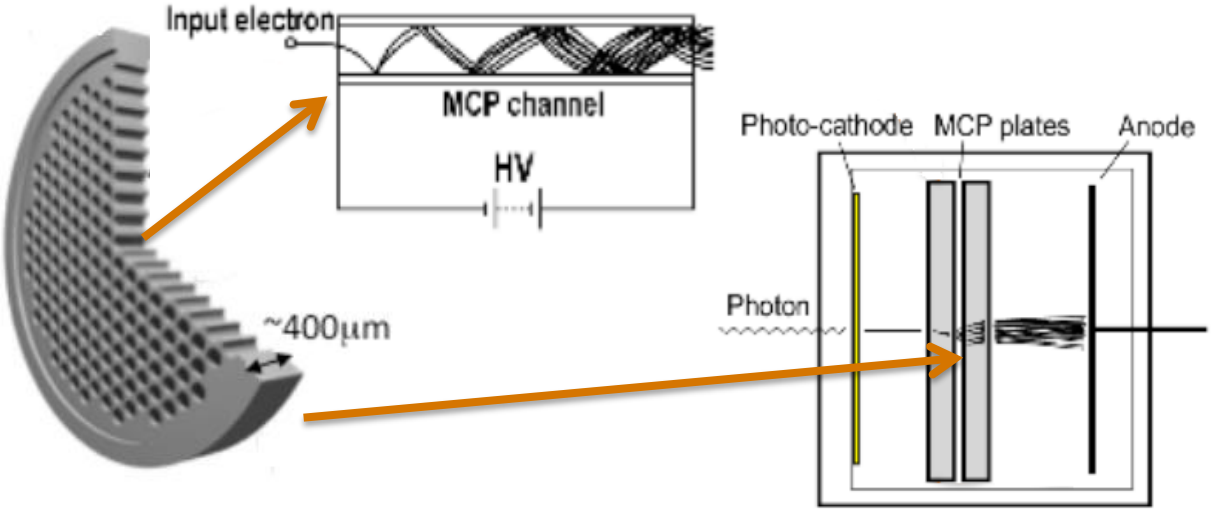
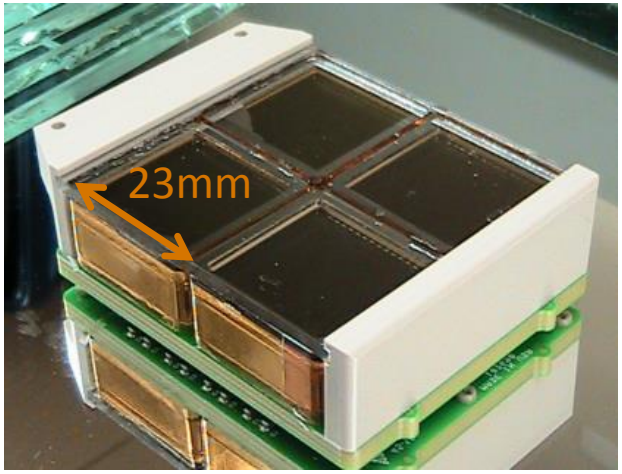
- Joint development with Nagoya and Hamamatsu
- Single photon detection
- Fast signal response (<50ps TTS)
- Average QE~28%
- Lifetime ~20ab^{-1}, to be replaced by ALD-PMTs



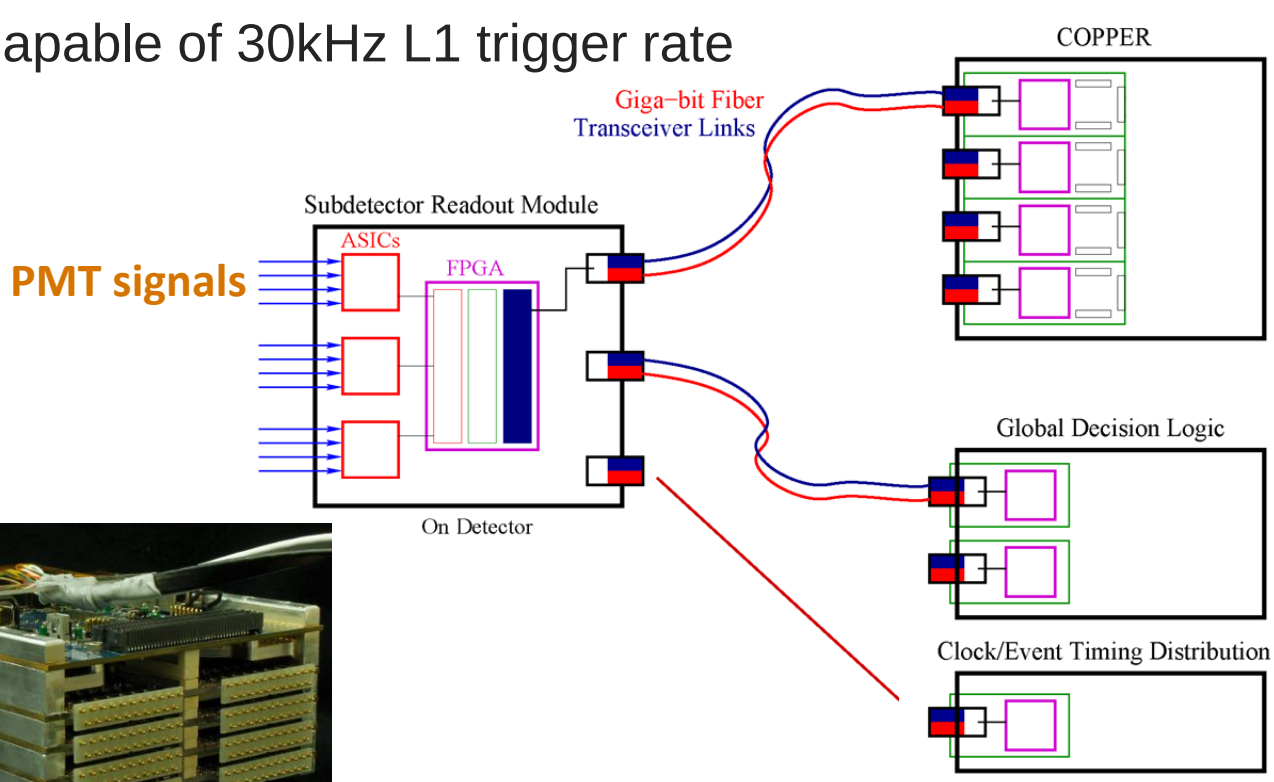
32 PMTs/module

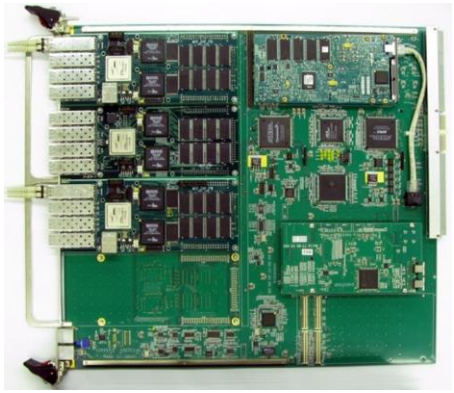




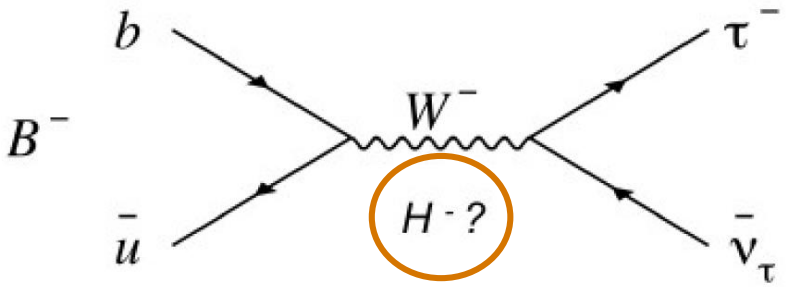
TOP and Belle II Readout

- Signal readout via four boardstacks per module
- On-board FPGA fast feature extraction
- Fiber connection to common readout electronics, clock/trigger
- Capable of 30kHz L1 trigger rate





Leptonic B Decay: B → τν

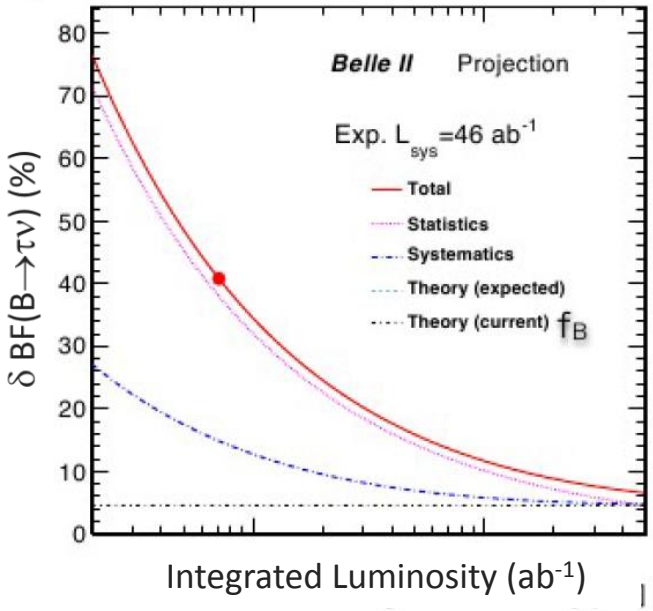


- Decay sensitive to charged Higgs NP contributions

$$\mathcal{B}(B^- \to \tau^- \nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

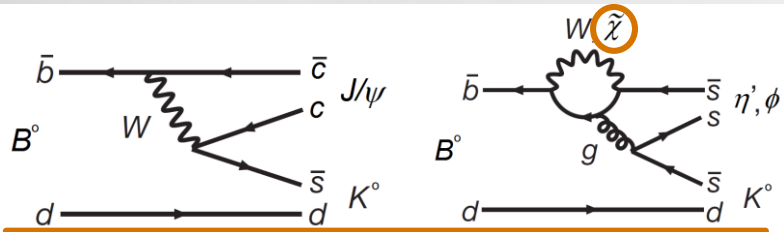
$$\mathcal{B}_{(B\to\tau\nu)} = \mathcal{B}_{SM} \times \left(1 - \tan^2\beta \frac{m_{B\pm}^2}{m_{H\pm}^2}\right) \quad \text{(2HDM)}$$

- Current measurements approach SM
  - $BR(B\to\tau\nu)_{PDG} = (1.09 \pm 0.24) \times 10^{-4}$
  - $BR(B\to\tau\nu)_{SM} = (1.11 \pm 0.28) \times 10^{-4}$
  - $BR(B\to\tau\nu)_{CKMfitter2016} = \left(0.851^{+0.035}_{-0.038}\right) \times 10^{-4}$
- **Belle II at 50ab^{-1} will reduce uncertainty <5%**



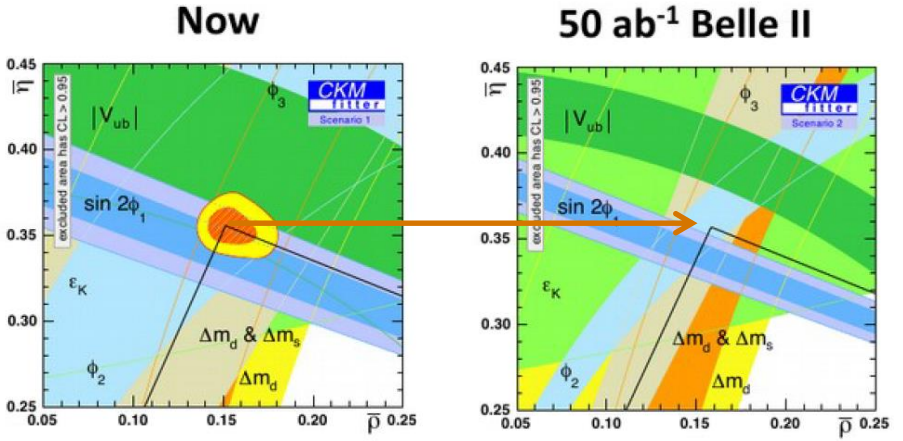
Precision measurements in CPV, CKM, and charm

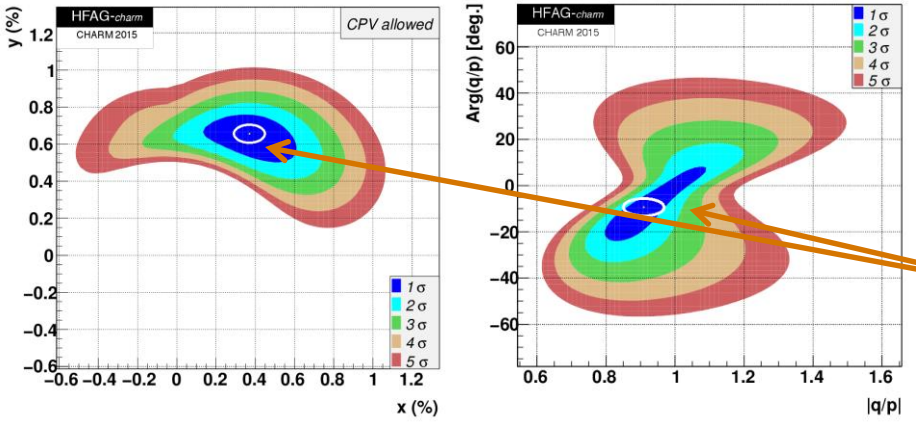
- sin(2β) in $c\bar{c}s$ vs. $sq\bar{q}$
  - Deviation possible from NP contributions
  - SM precision ~1% / Belle II 50ab^{-1} ~1.2%



+0.682±0.019 sin(2β) +0.64±0.03

- Unitarity triangle: α+β+γ = 175°±9°
- Belle II combined reach:
  - δα~1°, δβ~0.3°, δγ~1.5°

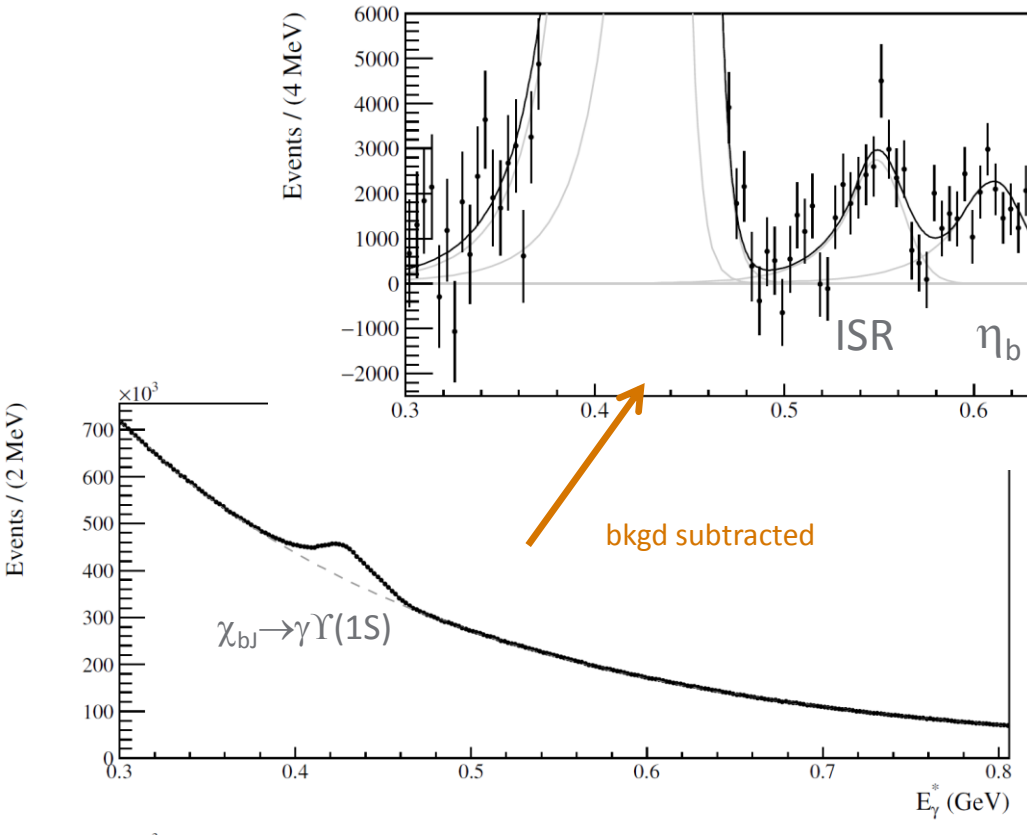


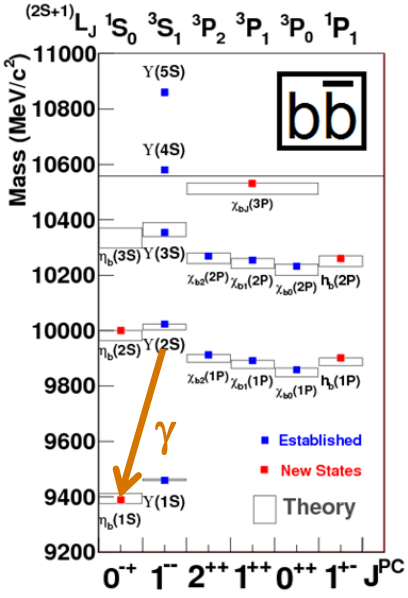


- Charm sector
  - $D^0\bar{D}^0$ mixing uncertainties @ 50 ab^{-1}
  - x~0.08%, y~0.05%, |q/p|~0.06, ϕ~0.07
  - Also CPV and rare decays

$\Upsilon(2S)\to\gamma\,\eta_b(1S)$ Summary arXiv:1807.01201

- Measurement of hyperfine splitting and transition rate
- Fit of the inclusive photon spectrum





Results: $\Upsilon(2S) \to \gamma\eta_b(1S)$

$$\mathcal{B}(\%) = (6.1^{+0.5+0.7}_{-0.7-0.4})\times10^{-2}$$

$$E^*_\gamma(\mathrm{MeV}) = 606.1^{+2.5+1.3}_{-2.4-1.4}$$

-1st observation of this mode (>7σ)
-consistent with PDG
-χ_b and ISR match expectation

Context of $\Upsilon(2S) \to \gamma\, \eta_b(1S)$ Results