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Physics potential and prospects at SuperKEKB/Belle II

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Pacific Northwest National Laboratory
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U.S. DEPARTMENT OF ENERGY

Motivation for Belle II

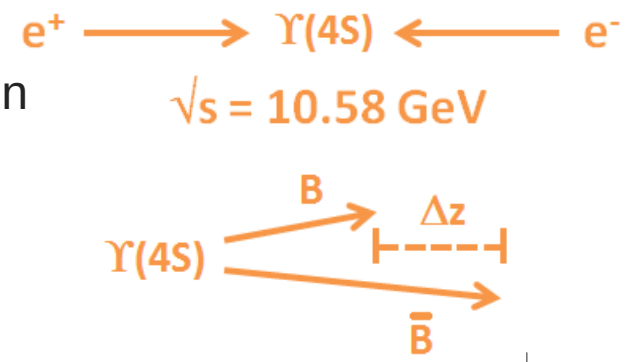
- Successes of the B-Factories (1999-2010)
  - CKM/unitarity triangle, CPV in B decays, rare decays ($B\to\tau\nu$, $D\tau\nu$), NP constraints in $b\to s\gamma$, A_{FB} in $b\to s\ell\ell$, D mixing, discovery of exotic/four-quark hadrons, …

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

2008

- **Next generation: Search for New Physics via precision measurements**
  - CPV, (semi-)leptonic/penguin decays, LFV, dark sector, …

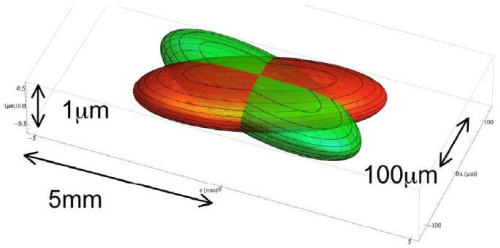
- Advantages of a B-Factory
  - Sensitive to NP mass ranges above direct production
  - "Clean" experimental environment
  - Reconstruction/flavour tagging capability
  - Tau decays and neutrals (γ, π^0, K_L, ν) in final state



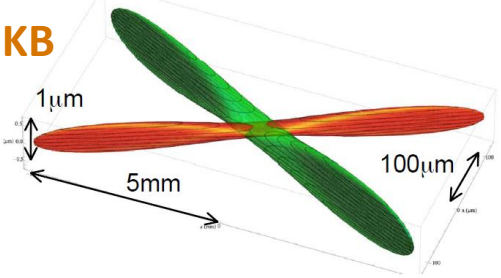
Accelerator Upgrade – SuperKEKB

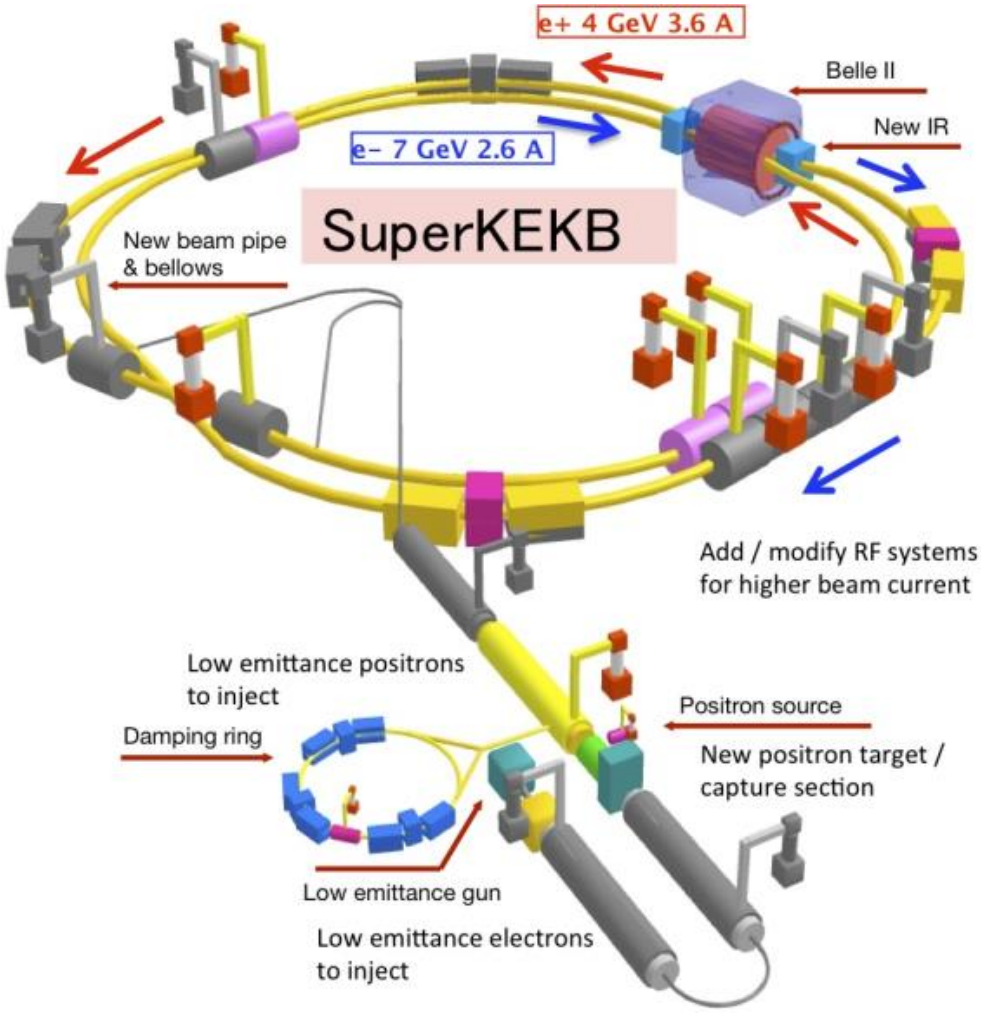
- **40x increase in luminosity**
- "Nano-beam" interaction point
- Increase in current

KEKB



SuperKEKB



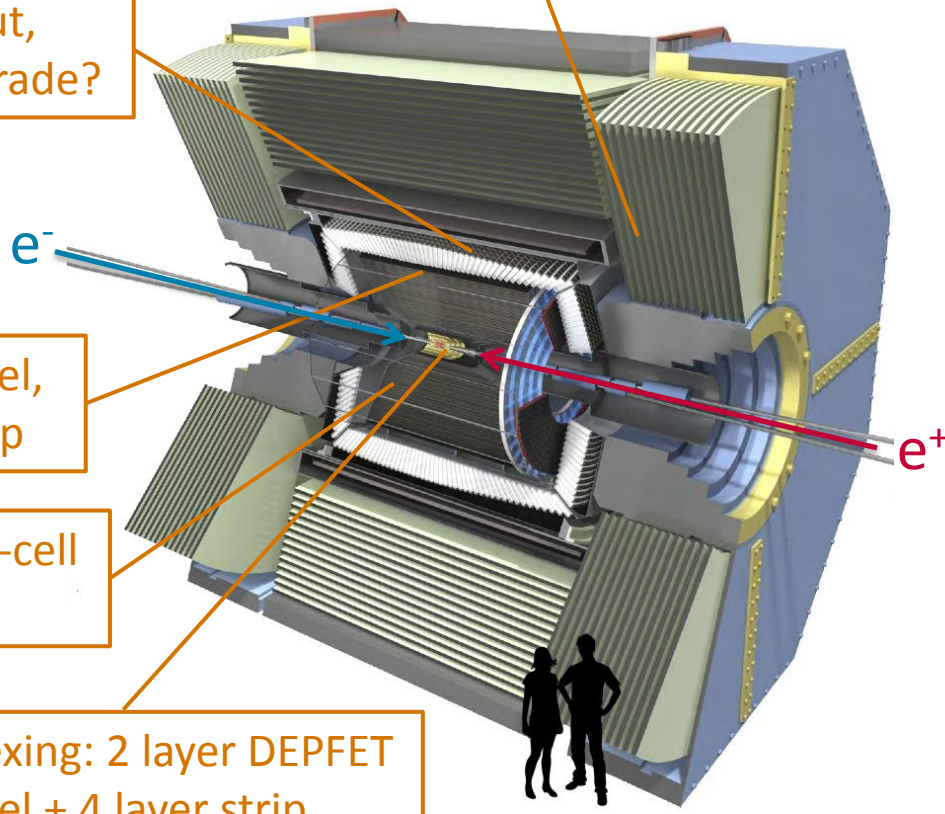


- **First turns achieved Feb 2016!**

See: Y. Onishi, ICHEP Highlights 08 Aug 12:10

Detector Upgrade – Belle II

- Order of magnitude luminosity increase:
  - Higher background
    - Radiation damage
    - Pile-up/ECAL hits
  - Higher event rate
    - Trigger, DAQ, computing
- **Significant detector upgrades required**



Further information
DEPFET: L. Andricek, Poster Aug 08 18:30
SVD: A. Paladino, Detector Aug 04 17:00
CsI: Y. Jin, Poster Aug 06 18:00
iTOP: A. Schwartz, Detector Aug 06 14:30
iTOP: K. Inami, Poster Aug 06 18:00
CPU: M. Schram, Computing Aug 04 12:50

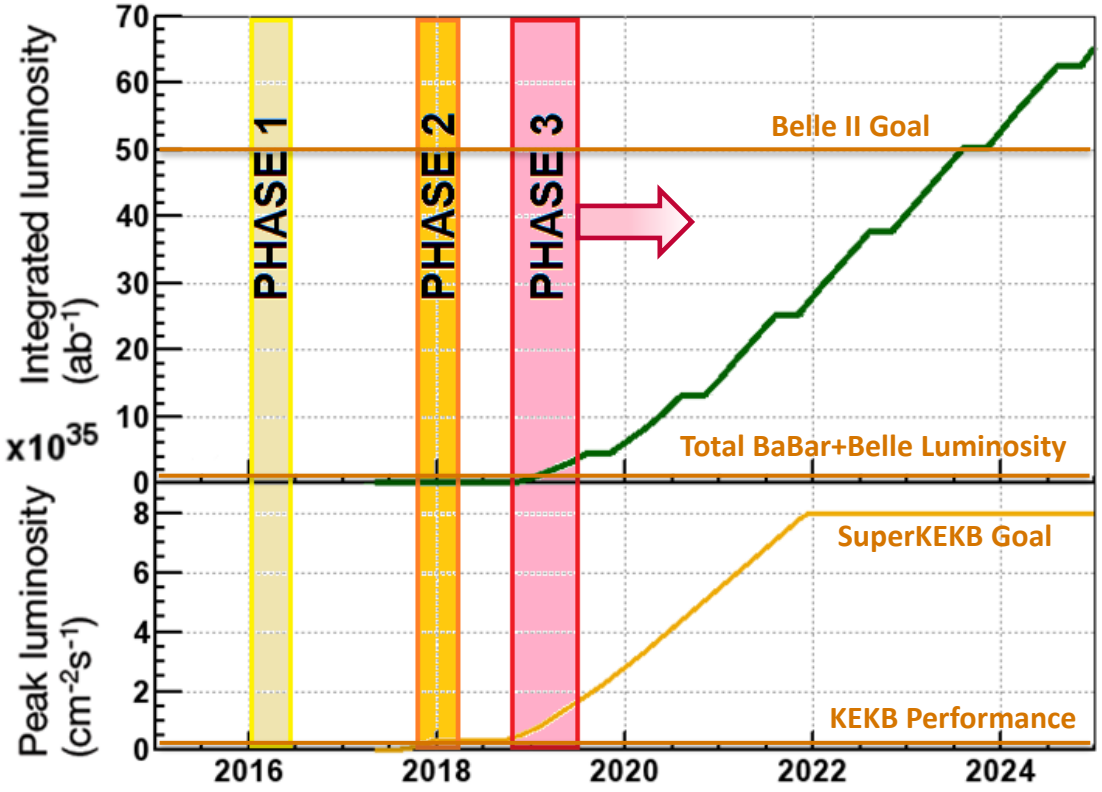
arXiv:1011.0352 (2011)

Current Status and Schedule

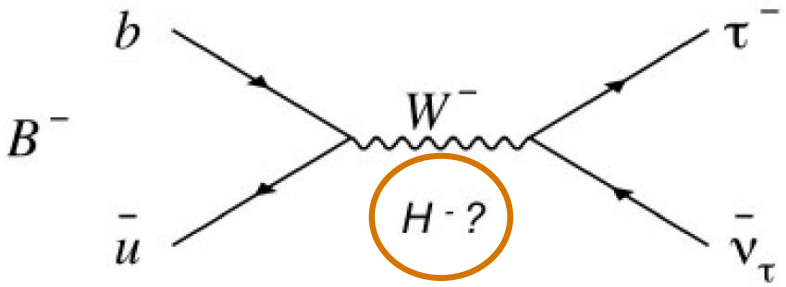
- Belle II Collaboration: ~700 members, ~100 institutions, 23 countries

- Phase 1 (complete)
  - Accelerator commissioning

  See: P. Lewis, Detector 05 Aug 09:20
- Phase 2 (2017)
  - First collisions
  - Partial detector
  - Background study
  - Physics possible
- Phase 3 (“Run 1”)
  - Nominal Belle II start
- **Ultimate goal: 50 ab^{-1}**



Leptonic B Decay: B → τν

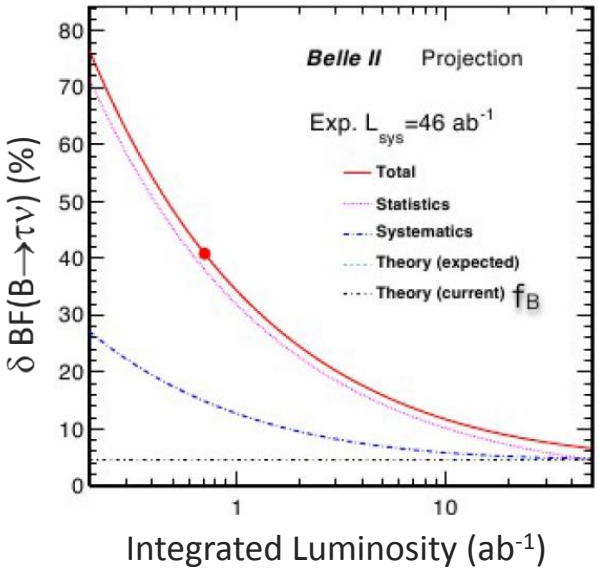


- Decay sensitive to charged Higgs NP contributions

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

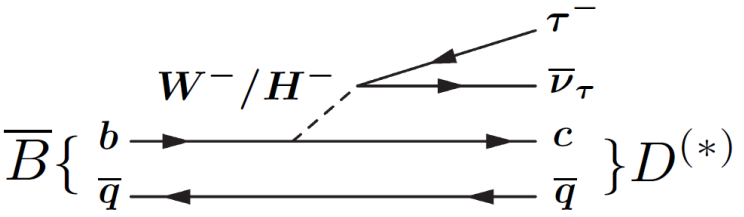
$$\mathcal{B}_{(B\to\tau\nu)} = \mathcal{B}_{SM} \times \left(1 - \tan^2\beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right) \quad \text{(2HDM)}$$

- Current measurements approach SM
  - $BR(B\to\tau\nu)_{SM} = (1.11 \pm 0.28) \times 10^{-4}$
  - $BR(B\to\tau\nu)_{CKMfitter2015} = \left(0.848^{+0.036}_{-0.055}\right) \times 10^{-4}$
- **Belle II at 50ab^{-1} will reduce uncertainty <5%**

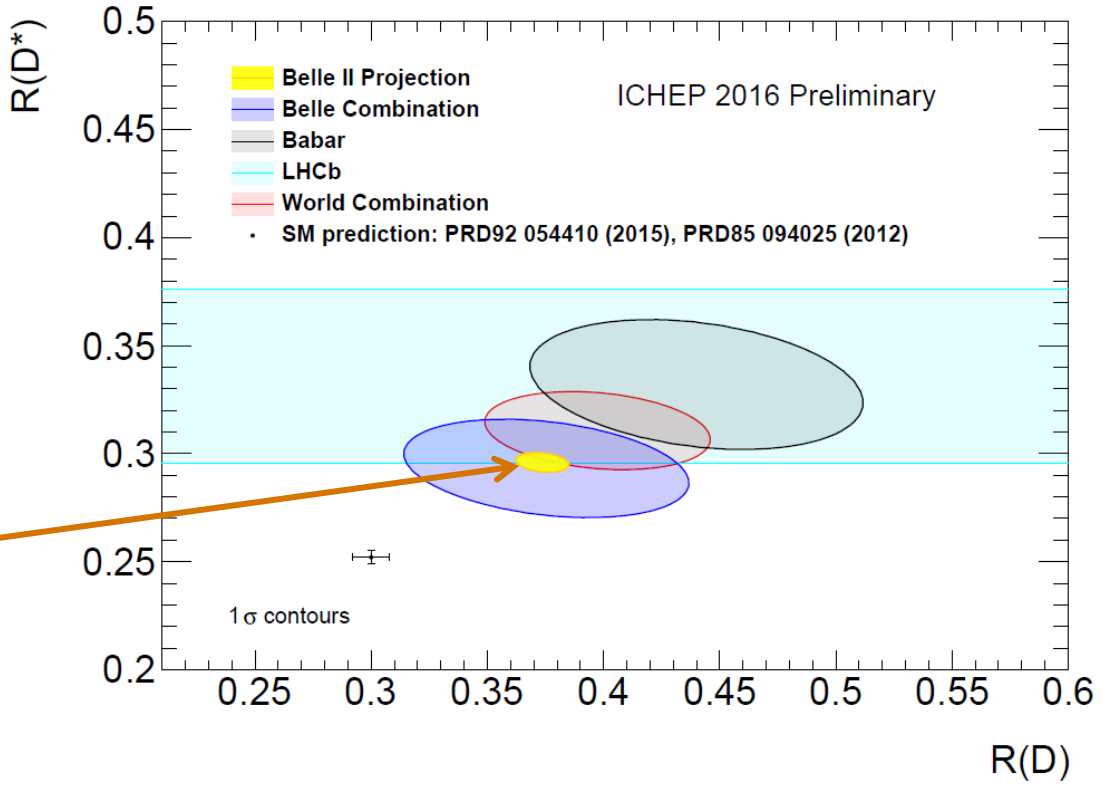


Semileptonic B Decay: $B \to D^{(*)}\tau\nu$

- Sensitive to charged Higgs contributions
- Compared to $B \to \tau\nu$
  - Larger BF(SM) O(~1%)
  - Less theoretical uncertainty



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

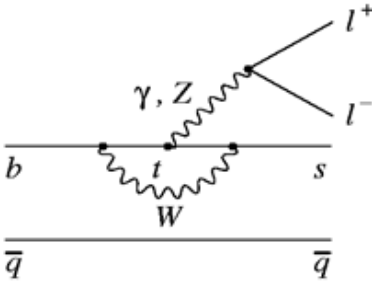


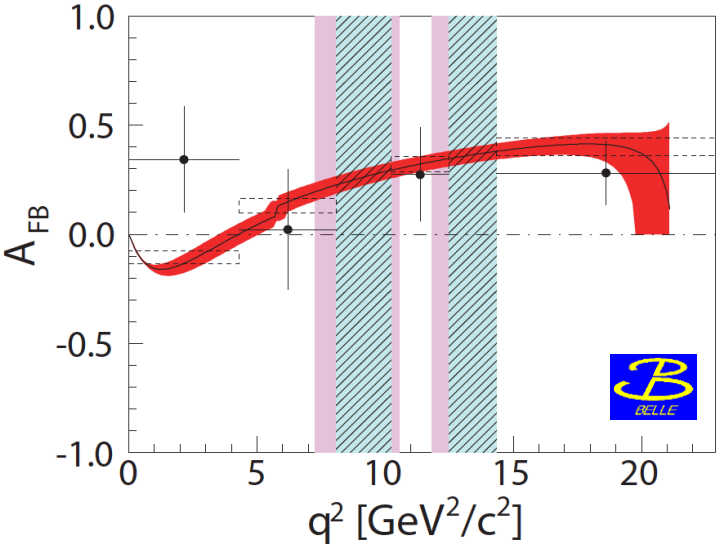
- **World average >3σ from SM**
- B-Factory uncertainty: 16 (9)%
- **Belle II @ 50ab^{-1}: 2-3%**

See: G. Inguglia, BSM 04 Aug 17:40

b→s Decays

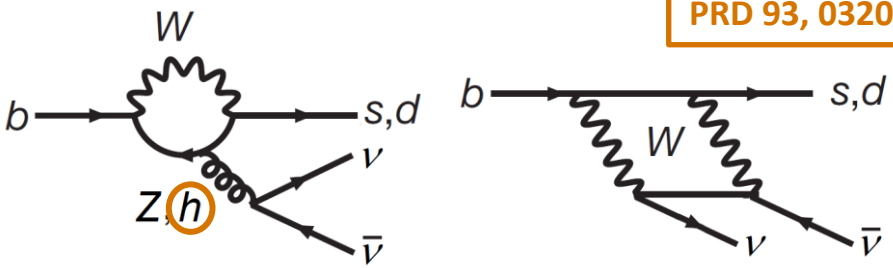
- Deviations from SM in $b \to s\ell\ell$ $A_{FB}(q^2)$
  - Tensions at low q^2
  - Complementary measures
    - LHCb: $K^*\mu^+\mu^-$
    - Belle II: $\mathbf{X_s}(\mathbf{e^+e^-}, \mu^+\mu^-, \tau^+\tau^-)$





PRD 93, 032008 (2014)

- $B \to K^{(*0)}\nu\bar{\nu}$ at SM expected rate
  - Prediction: ~4 (7) x 10^{-6}
  - Belle limit: <5.5 x 10^{-6}
  - Belle II uncertainty <20%

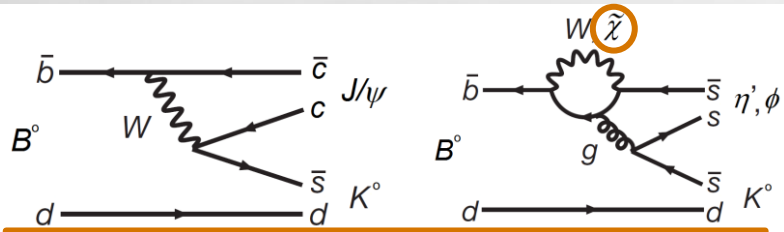


SM: Penguin + Box

- NP test via precise measurements in $b \to s\gamma$ ($X_s\gamma$) rates, A_{CP} asymmetry, …

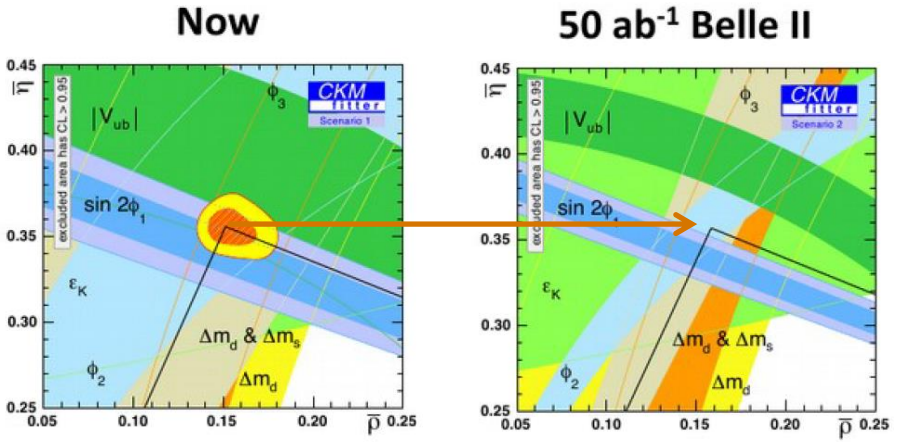
New Physics in CPV, CKM, and charm

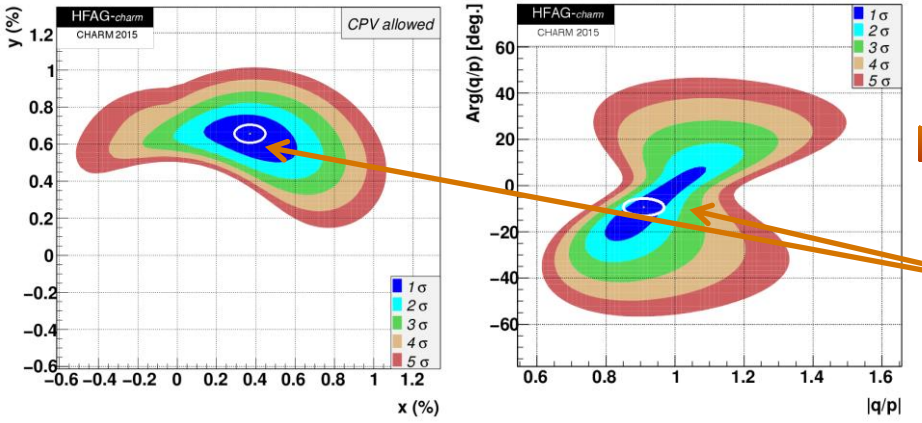
- sin(2β) in $c\bar{c}s$ vs. $sq\bar{q}$
  - Deviation possible from NP contributions
  - SM precision ~1% / Belle II 50ab^{-1} ~1.2%



+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°

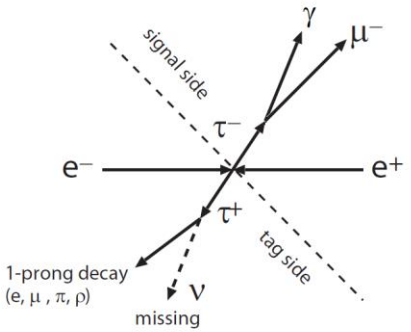




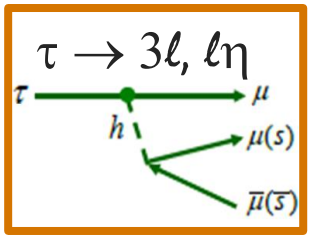
- Charm sector
  - $D^0\bar{D}^0$ mixing uncertainties @ 50 ab^{-1}
  - x~0.08%, y~0.05%, |q/p|~0.06, ϕ~0.07
  - Also CPV and rare decays

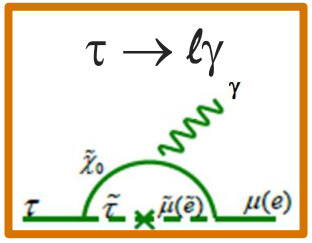
Lepton Flavour Violation (τ)

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



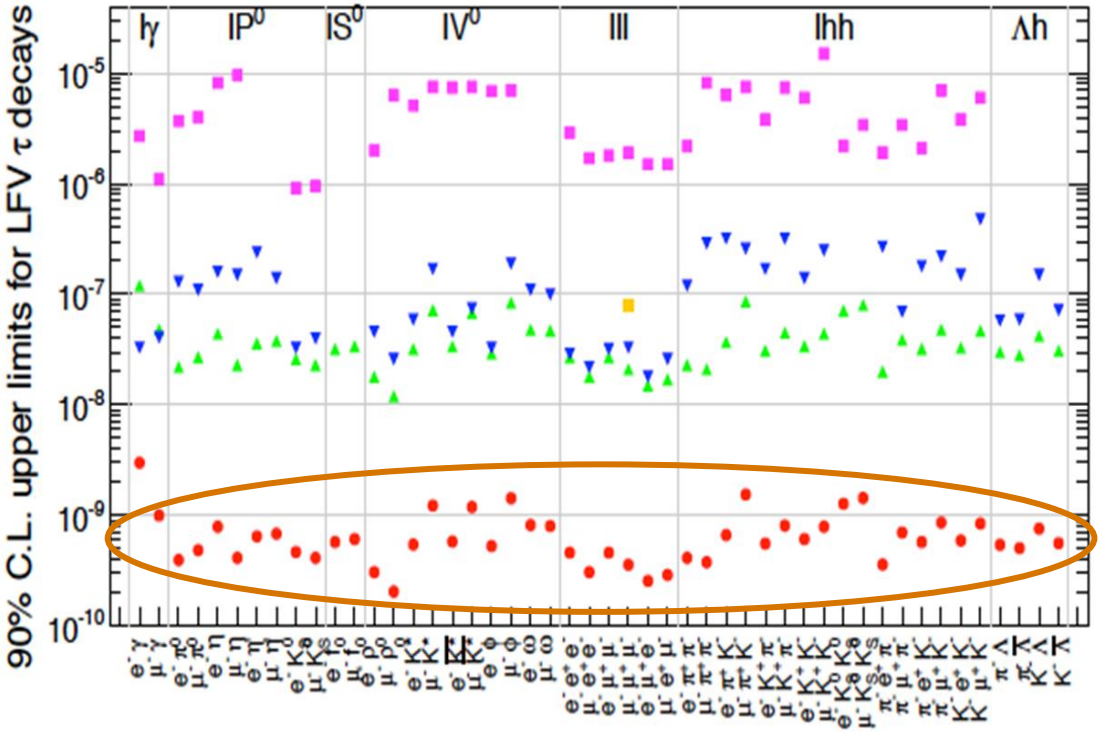
- LFV in SM ~O(10^{-25})
- NP enhancement ~O($10^{-(7\text{-}10)}$)





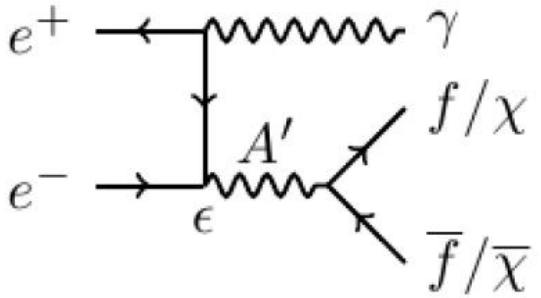
- **Belle II: Order of magnitude better for many modes**

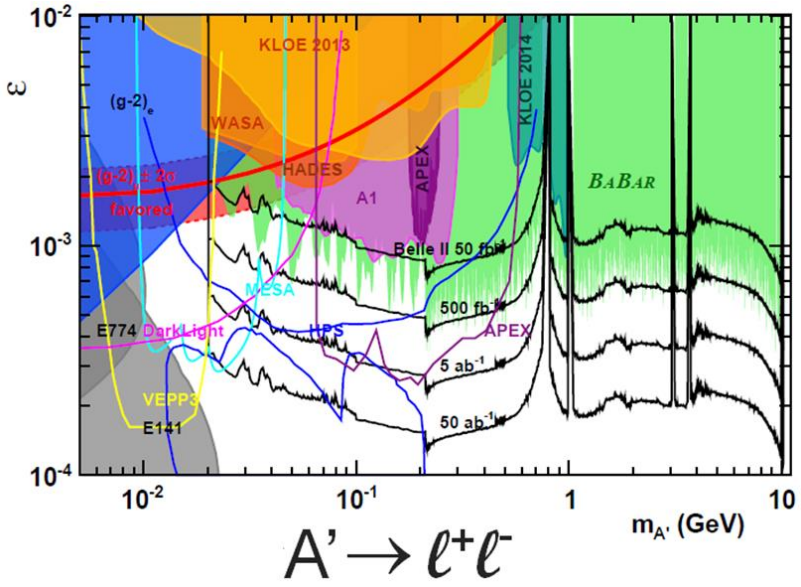
See: K. Inami, Flavor 05 Aug 18:45

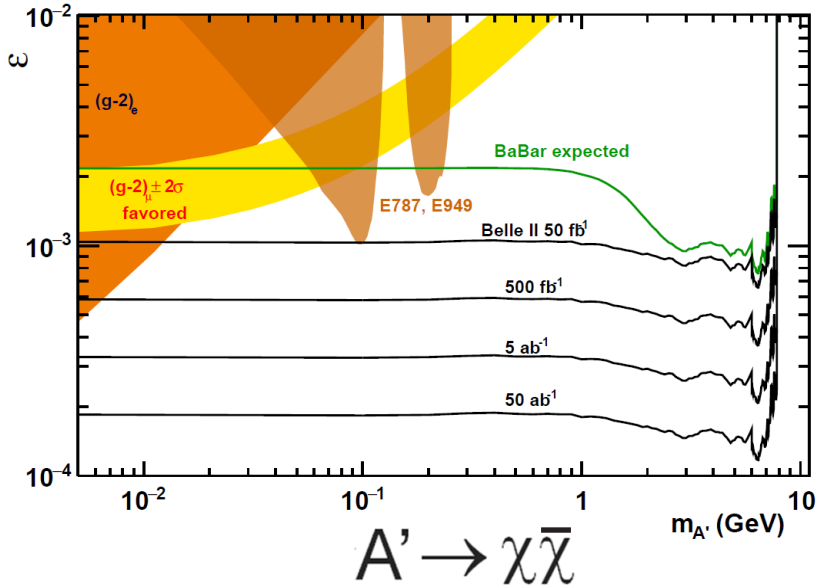


New Physics with low multiplicity

- Dark photon (A') mixing with SM, light Higgs candidates, et al.
- Search strategies
  - Invisible decay $\gamma A'(\chi\bar{\chi})$: monoenergetic photon search
  - Development of specialized (single photon) triggers
  - Consider also $\Upsilon(2S,3S)\rightarrow\pi^+\pi^-\Upsilon(1S)\rightarrow\gamma A'$
- Belle II only way to extend reach in certain parameter space







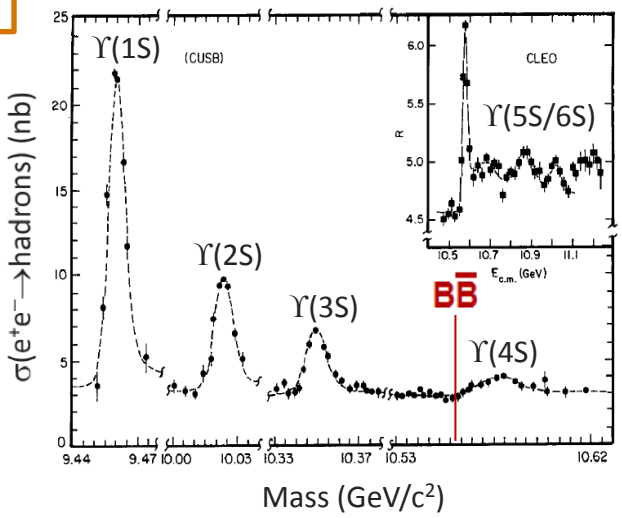
Early Physics Prospects

- Existing B-Factories ~1.5 ab^{-1}: **opportunity for other results in Phase 2/3?**

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}

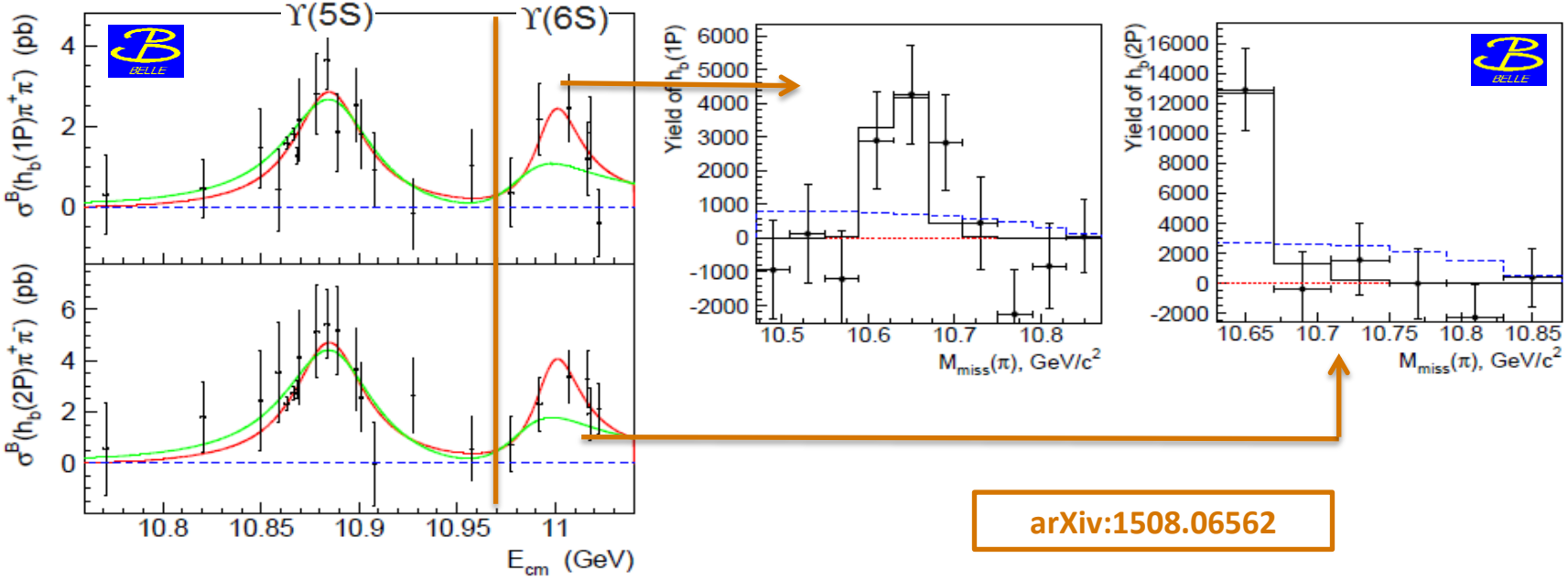
- Below $\Upsilon(4S)$
  - $\Upsilon(2S,3S)$ access to bottomonium and dark sector
  - Scan for direct production of $\Upsilon(n^3D_1)$
- Above $\Upsilon(4S)$
  - Study of exotic four-quark states
  - <6fb^{-1} accumulated by Belle at $E_{CM}=\Upsilon(6S)$



See: D. Besson, Poster 06 Aug 18:00

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



- **Study nature of $\Upsilon(6S)$, exotic quarkonia, bottomonium discovery**
- Continued study of "XYZ" states planned for all energies

Conclusion

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- **SuperKEKB / Belle II upgrade well underway**
  - **First turns achieved Spring 2016**
  - **Commissioning Fall 2017**
  - **Nominal start Fall 2018**
- **Next generation flavour Factory**
  - **50x more data and improved detector capabilities**
  - **Clean environment with sensitivity to neutrals complementary to LHC**
- **Wide-ranging physics program**
  - **Search for New Physics via high-statistics precision measurement**
  - **CPV, (semi-)leptonic/penguin decays, LFV, dark sector, exotic hadrons, etc.**