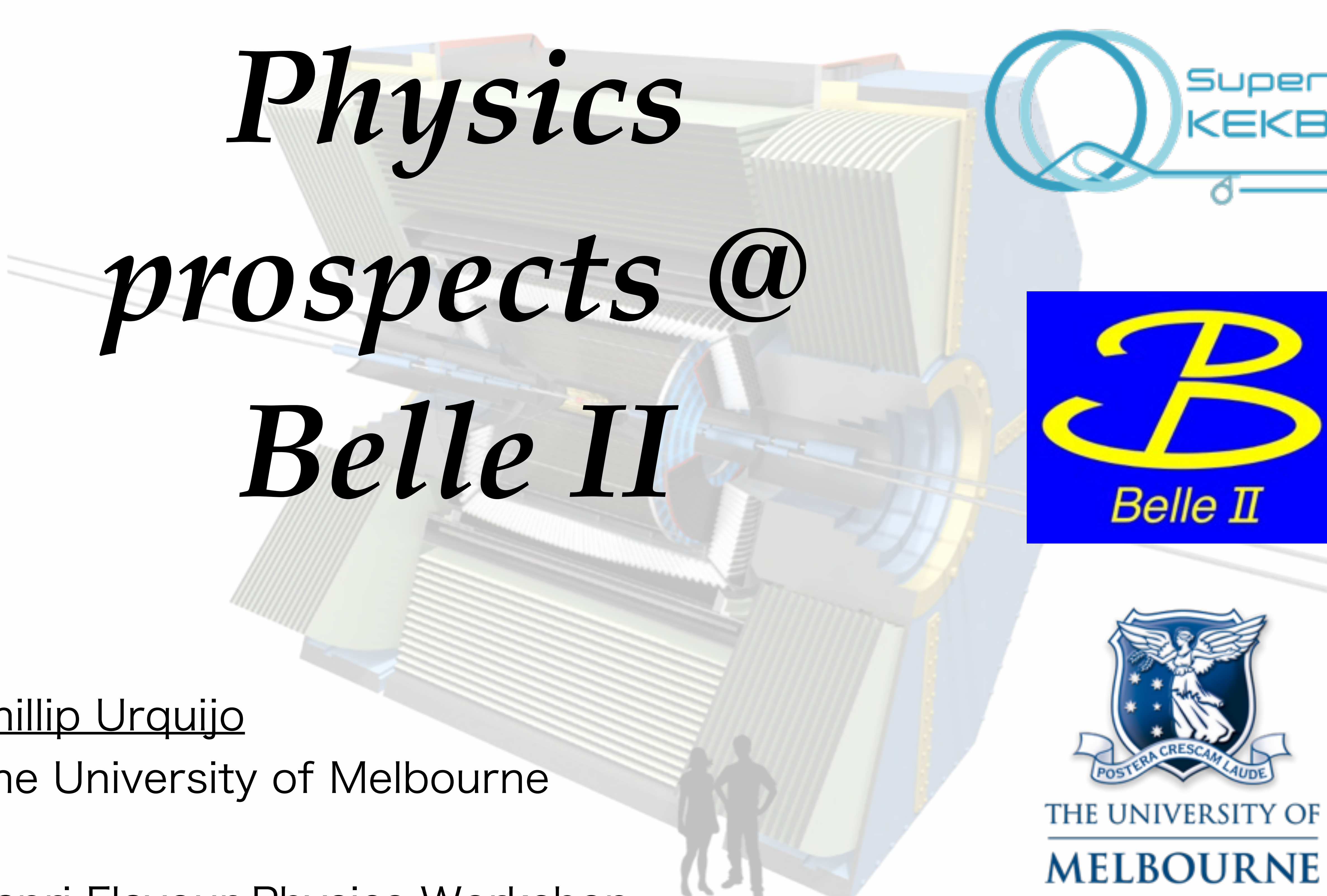


Physics prospects @ Belle II

Phillip Urquijo
The University of Melbourne

Capri Flavour Physics Workshop
May 2014

SuperKEKB & Belle II

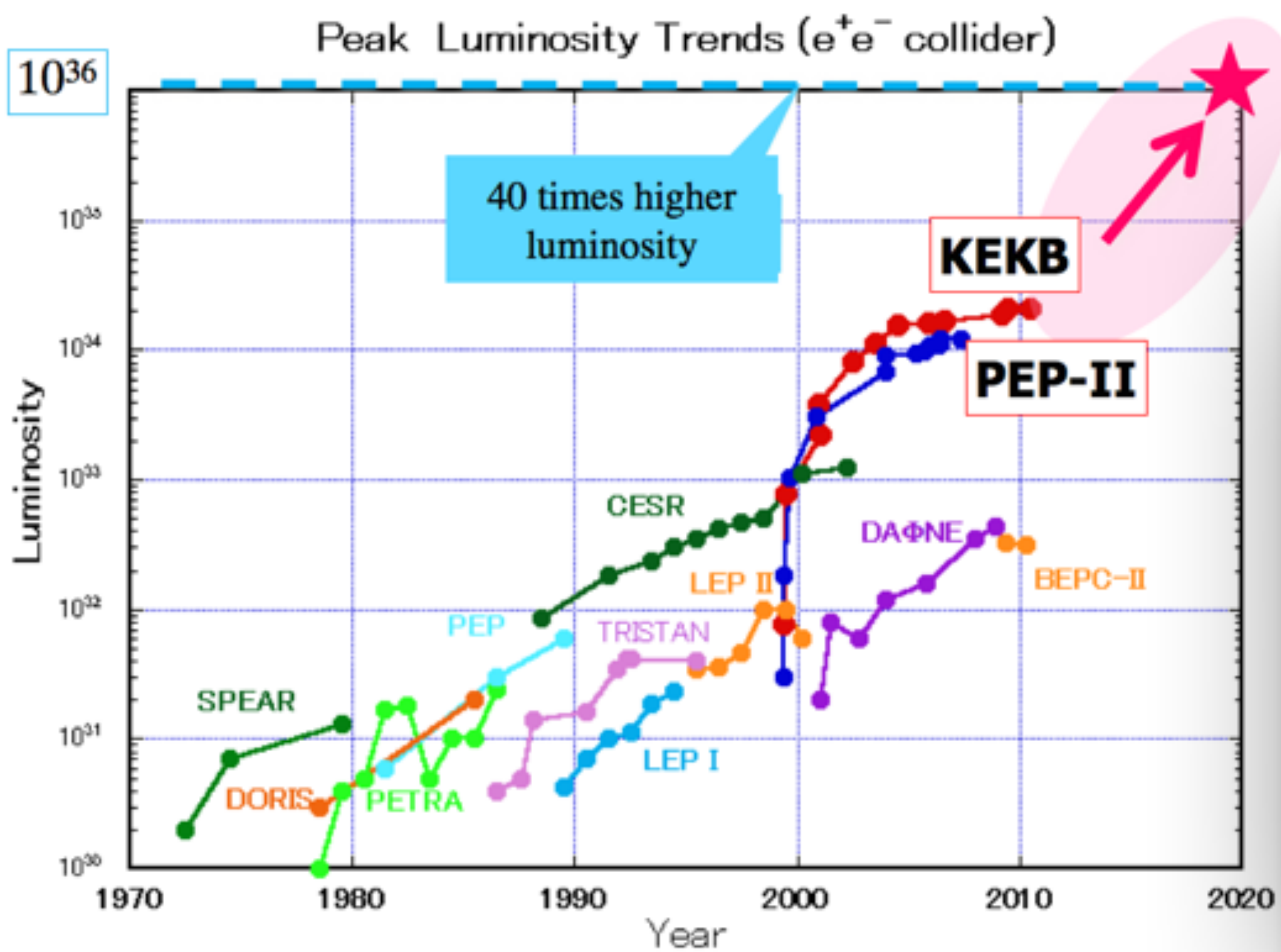
New intensity-frontier flavour facility

Target Luminosity:

$L_{peak} = 8 \times 10^{35}$ cm^{-2}s^{-1} **[40 x KEKB]**

$L_{int} > 50$ ab^{-1} by early 2020s **[50 x Belle II]**

Channel	Belle	BaBar	Belle II (per year)
$B\bar{B}$	7.7×10^8	4.8×10^8	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^6	–	6.0×10^8
$\Upsilon(1S)$	1.0×10^8		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^8	0.9×10^7	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^7	1.0×10^8	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^7	–	3.0×10^9
$\tau\tau$	1.0×10^9	0.6×10^9	1.0×10^{10}



Outline

1. **Case for a Super Flavour Factory**
2. **Upgrading KEKB to a "Super Flavour Factory"**
3. **Belle II Detector**
4. **Physics @ Belle II**
5. **LHCb Complementarity**

THE UNIVERSITY OF MELBOURNE

The case for new physics manifesting in BII

Issues (addressable at a Flavour factory)

- CP asymmetry in cosmology
  → CPV in quarks and charged leptons
- Quark and Lepton flavour & mass hierarchy
  → higher symmetry
  - 19 free parameters
    → Extensions of SM relate some, (GUTs). Study "NP DNA"

$$\mathcal{L}_{\text{Yukawa}} = g_u^{ij}\,\bar{u}_R^i\,H^T\,\epsilon\,Q_L^j - g_d^{ij}\,\bar{d}_R^i\,H^\dagger\,Q_L^j - g_e^{ij}\,\bar{e}_R^i\,H^\dagger\,L_L^j \quad + \text{h.c.}\,,$$

$$\mathcal{L}_{W^\pm\,\text{quark int.}} = \frac{g_2}{\sqrt{2}}\,W_\mu^+\,\bar{u}_L'\,\gamma^\mu\,V_{\text{CKM}}\,d_L' + \text{h.c.}\,,$$

- No (WIMP) candidates for Dark Matter
  → Hidden dark sector
- Finite neutrino masses
  → Tau LFV.

→ NP beyond the direct reach of the LHC

Searches for New Phenomena

- **Energy Frontier**: Production of **new particles** from *collisions* at high-***Energy*** (**LHC**)
  - *Limited by E_{Beam}*

- **Flavour Frontier**: **virtual production** to probe *scales* beyond energy frontier.
  - Often **first clues** about NP

- $\Gamma(K^0_L \to \mu\mu) \ll \Gamma(K \to \mu\nu) \Rightarrow$ Charm [GIM, 1970]
- $\Delta m_K \Rightarrow m_c \sim 1.5$ GeV [Gaillard-Lee, 1974]
- $\varepsilon_K \neq 0 \Rightarrow$ 3 generations [KM, 1973]
- $\Delta m_B \Rightarrow m_t \gg m_W$ [~1986]

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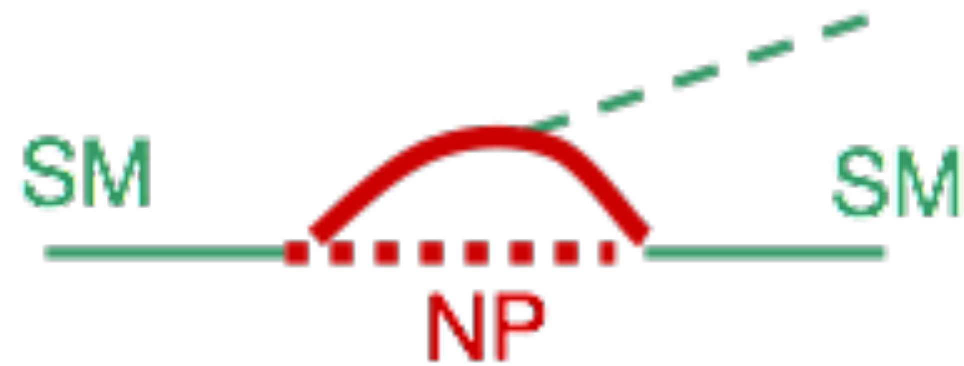

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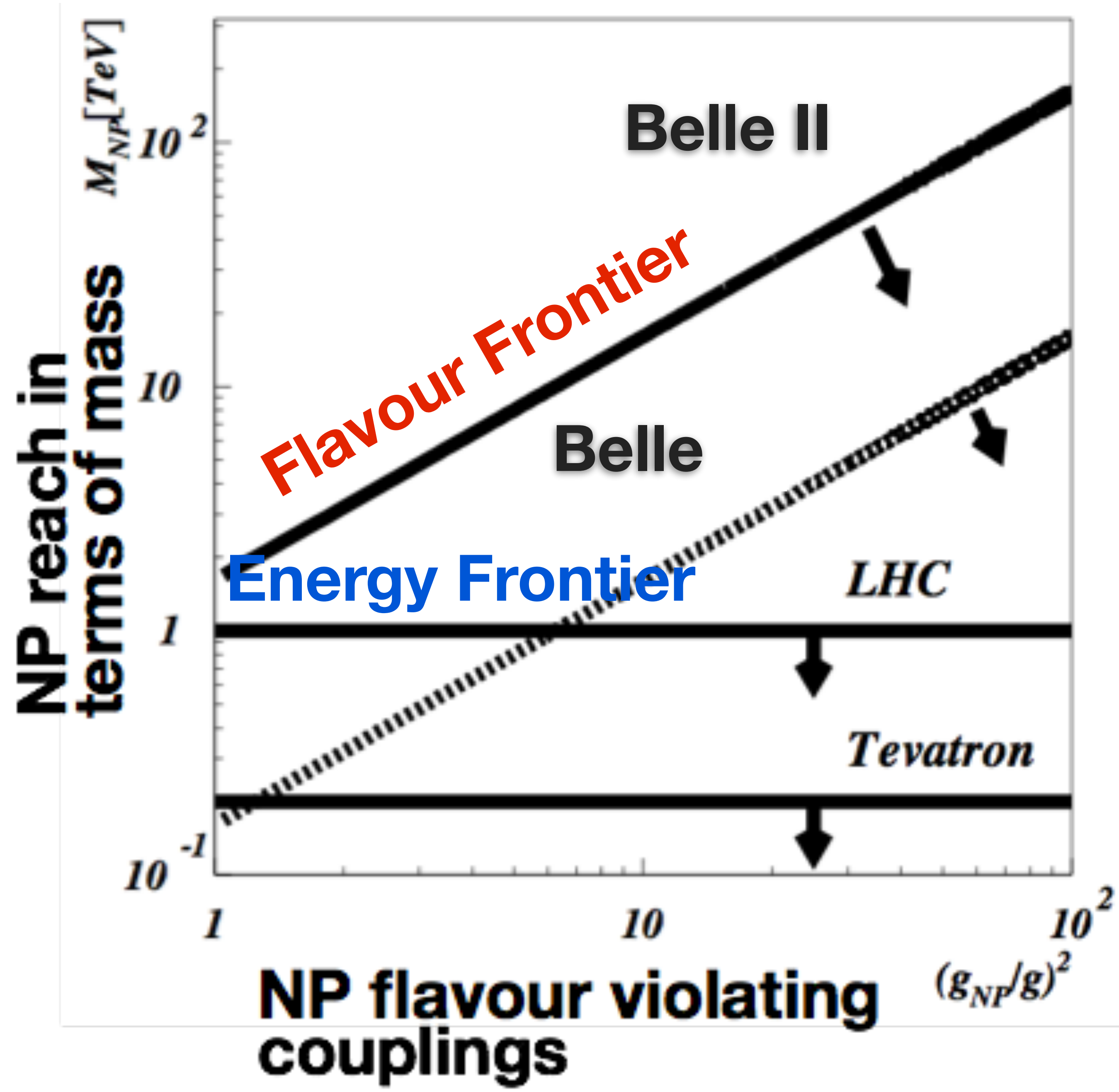

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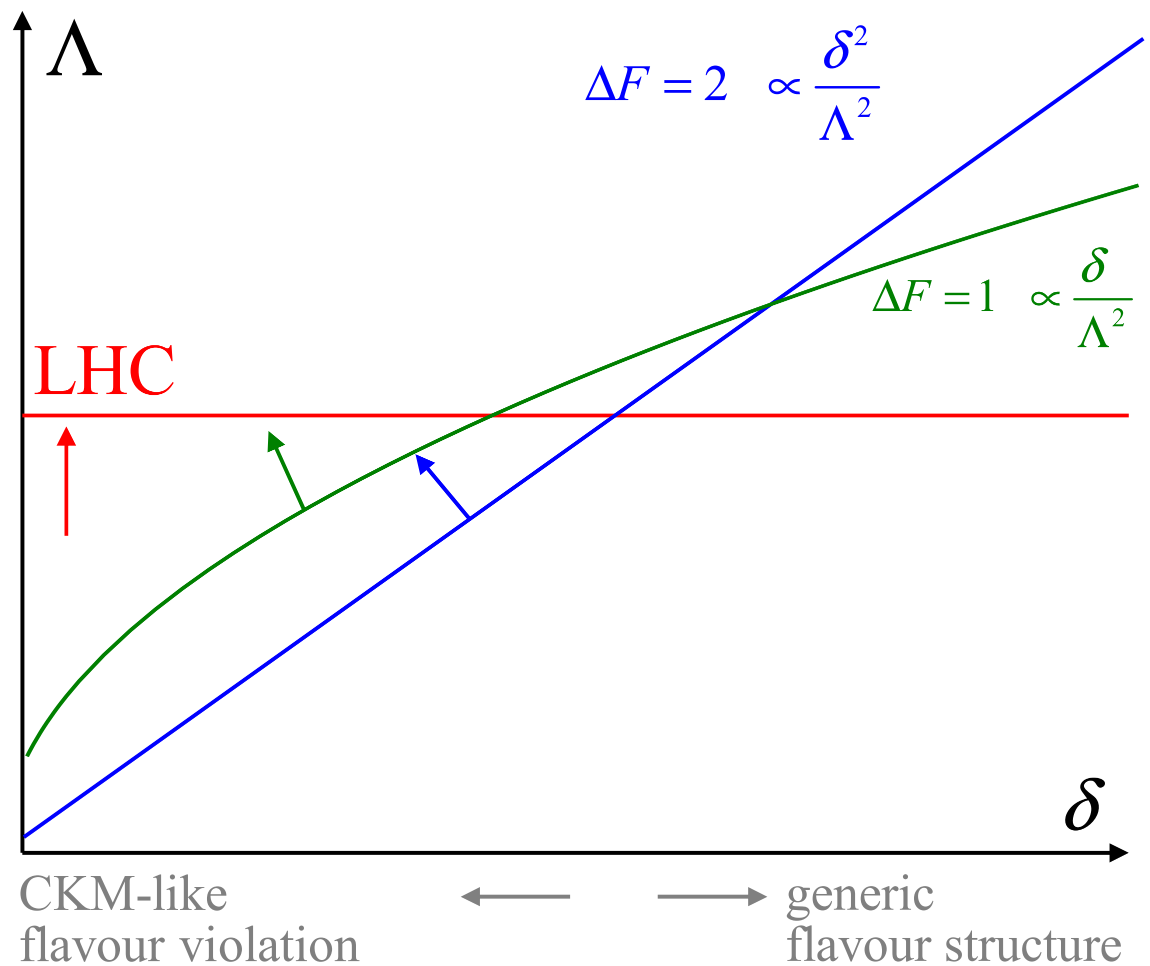

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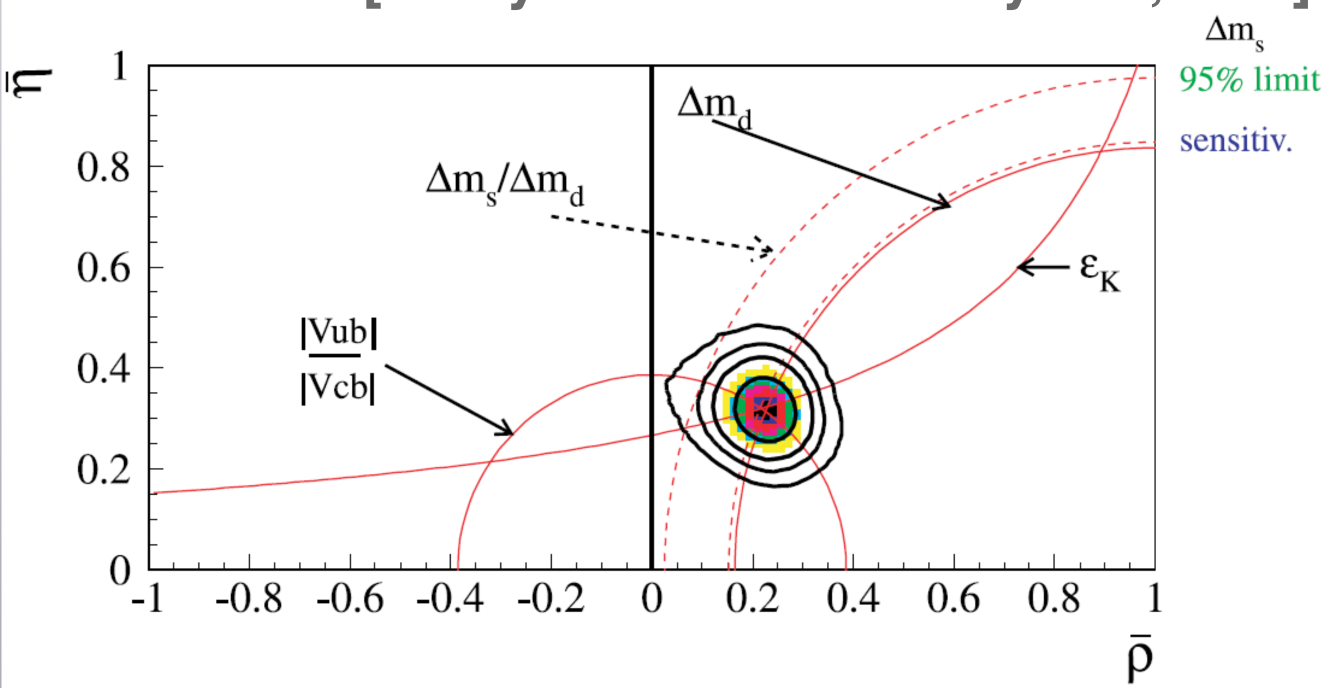
B factory Achievements

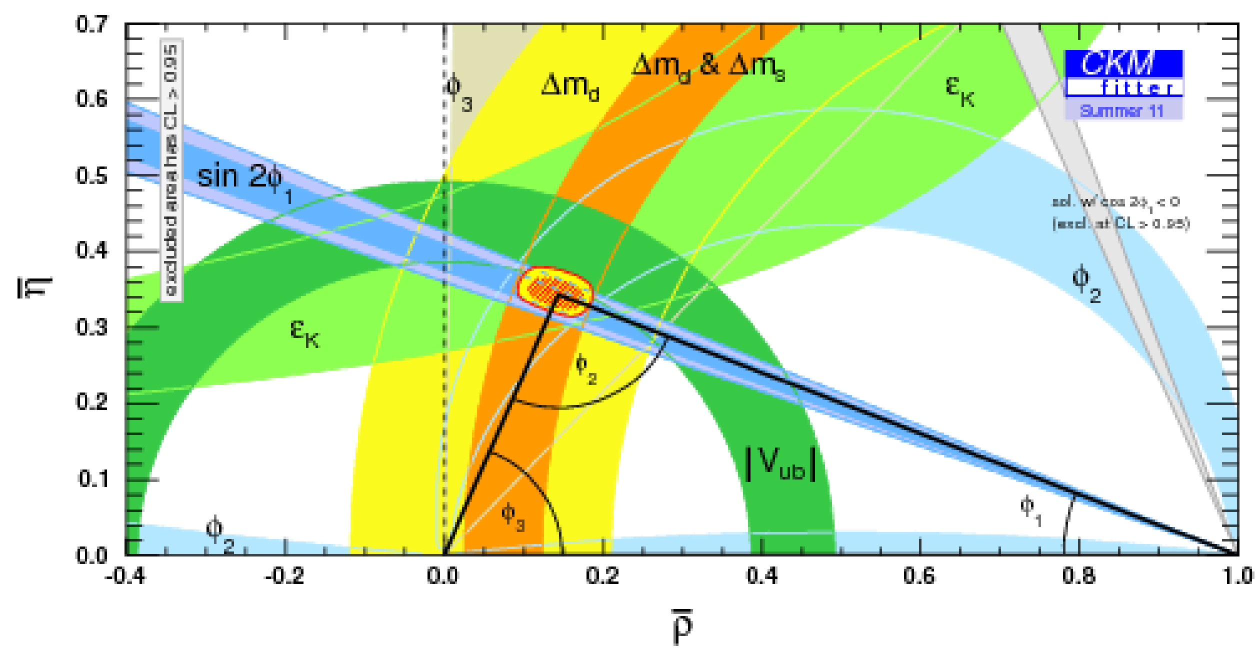
BaBar (**PEPII@SLAC**) and Belle (**KEKB@KEK**)
*Together recorded over **10^9 $e^+e^- \rightarrow Y(4S) \rightarrow BB$** events.*

- Discovery of CPV in *B*
- Measurements of UT sides and angles
- Rare *B* decays
- Mixing in charm
- Searches for rare τ decays
- New hadrons

UT @ 2000 [J.Phys.G:Nucl.Part.Phys.27,1101]



UT @ 2011 [CKMfitter]



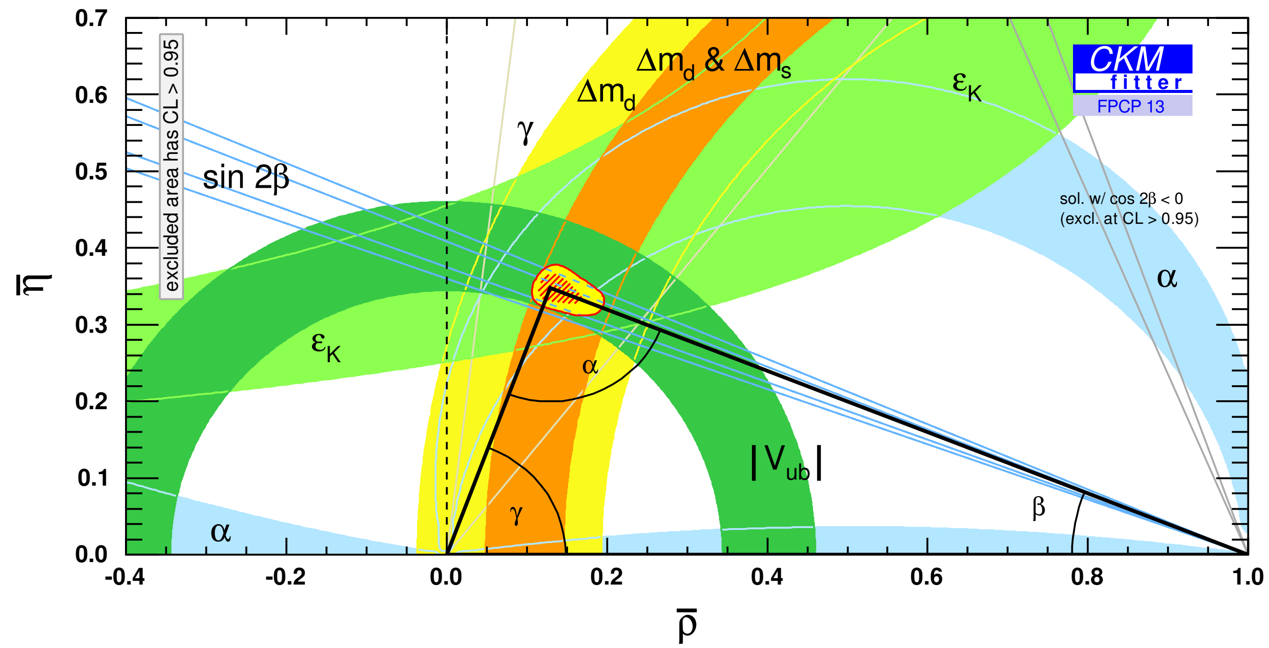
Flavour @ Belle II (SuperKEKB@KEK)

Driving Questions

- Are there new CPV phases?
- Right-handed currents from NP?
- Quark FCNCs beyond the SM?
- Sources of LFV beyond the SM?
- New operators with quarks enhanced by NP?
- Multiple Higgs bosons?

Flavour @ Belle II (SuperKEKB@KEK)

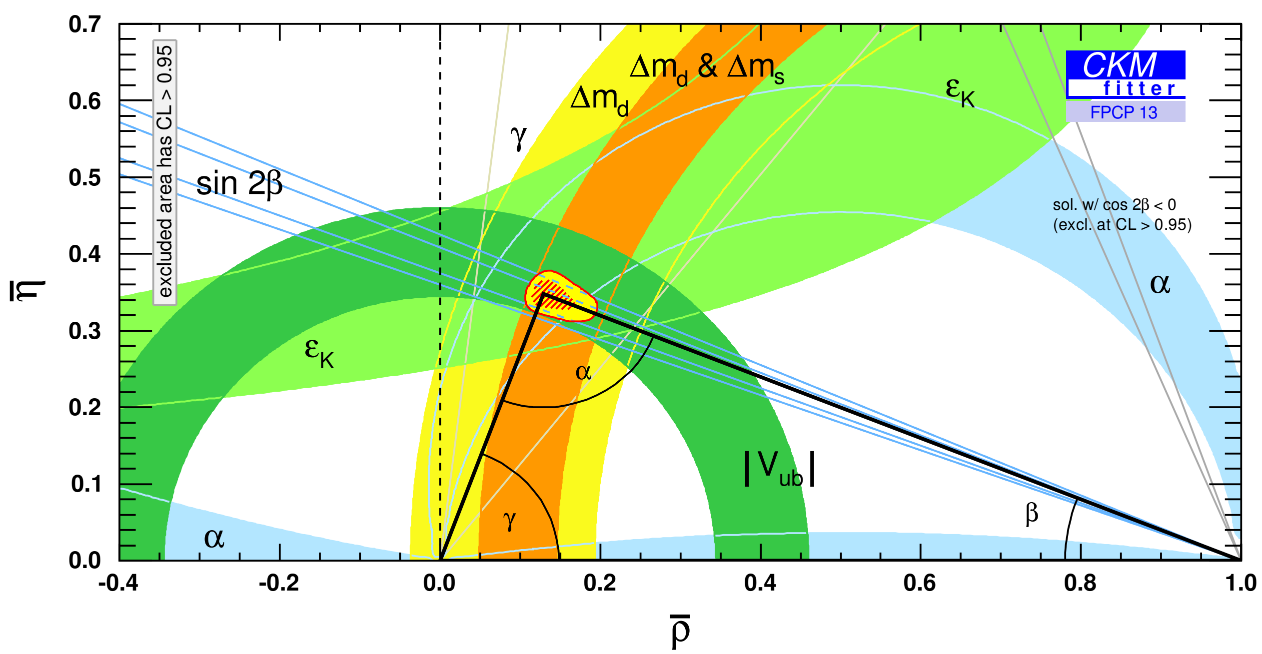
New physics amplitudes 10-20% the size of the Standard Model contributions allowed by data



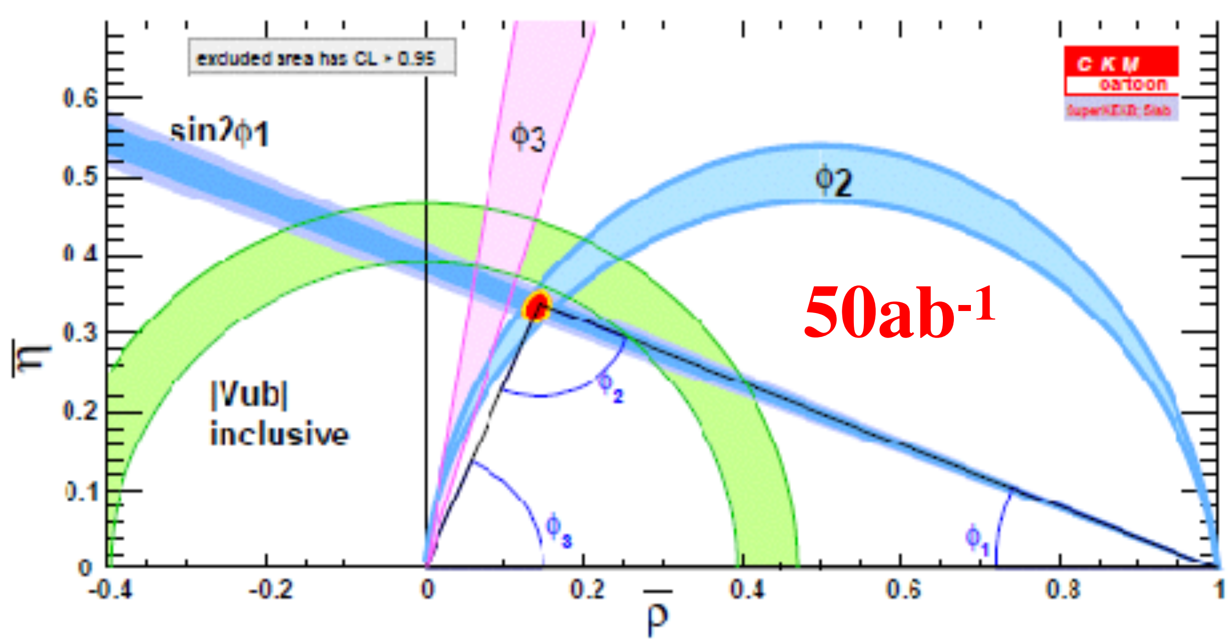
Still ~10% room for NP

Flavour @ Belle II (SuperKEKB@KEK)

New physics amplitudes 10-20% the size of the Standard Model contributions allowed by data



Still ~10% room for NP



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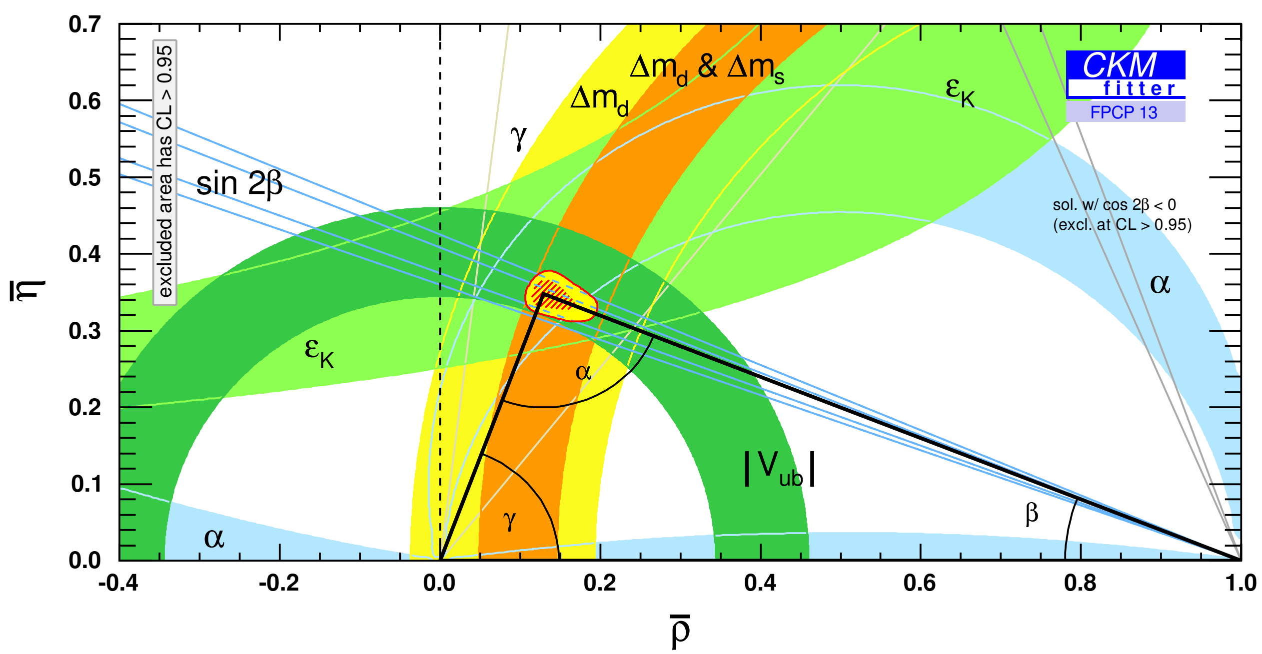

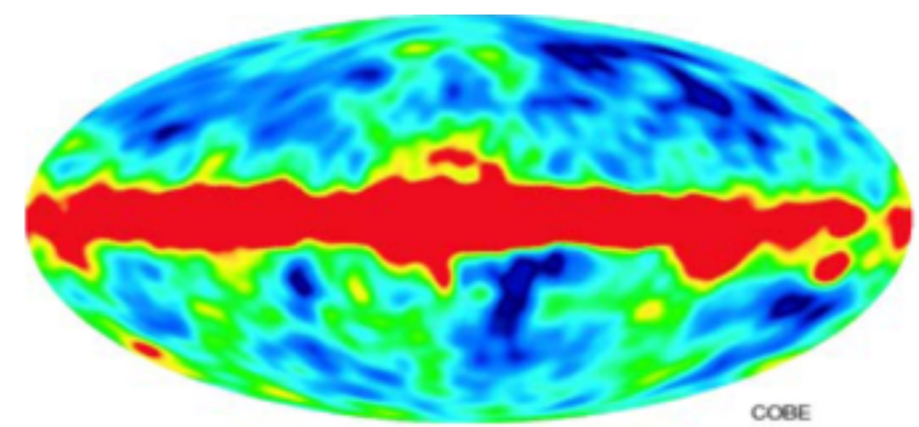

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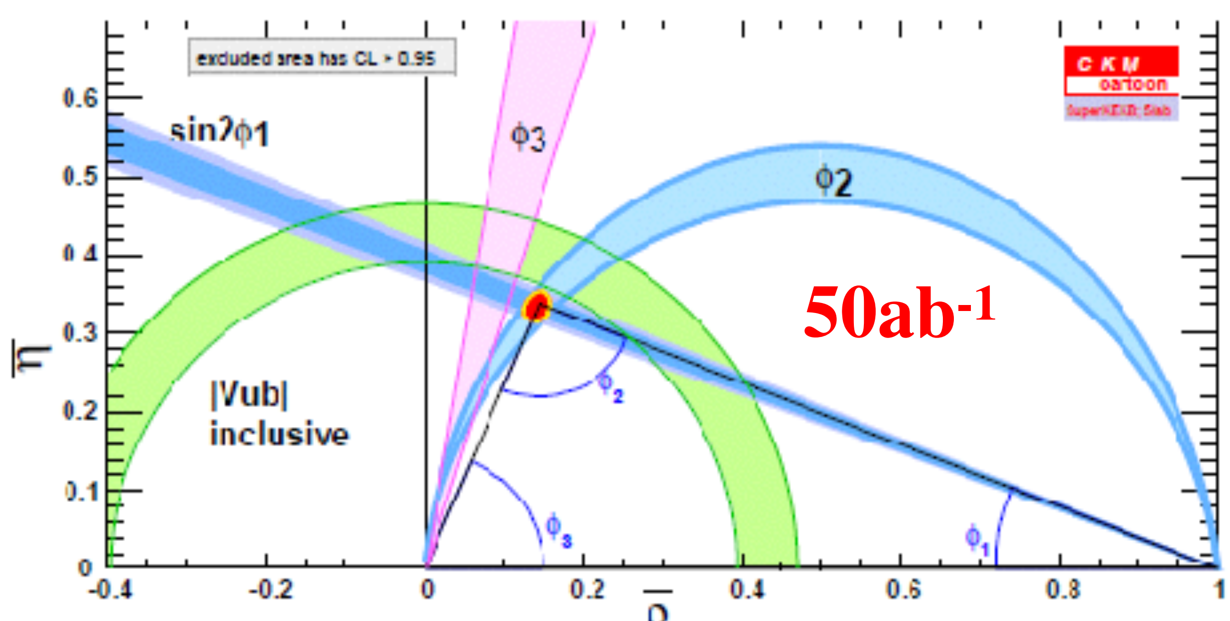

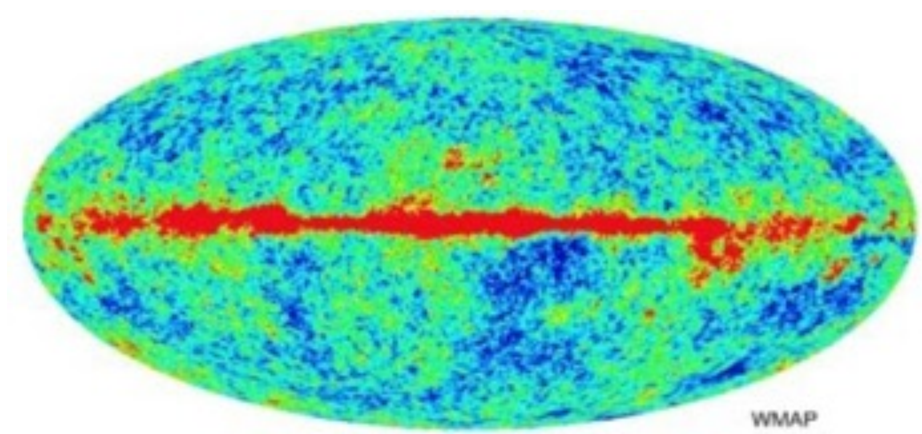

SuperKEKB Collider & Belle II

How to make a Super Flavour Factory

$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

Lorentz factor

Beam current

Beam-beam parameter

Lumi. reduction factor (crossing angle)&
Tune shift reduction factor (hour glass effect)
0.8 ~ 1
(short bunch)

Classical electron radius

Beam size ratio@IP
1 ~ 2 % (flat beam)

Vertical beta function@IP

Brute force: Increase beam currents by a factor of 5-10 ! Increase the beam-beam parameter by a factor of a few (crab cavities).
Too hard, too expensive (power, melt beam pipes)

How to make a Super Flavour Factory

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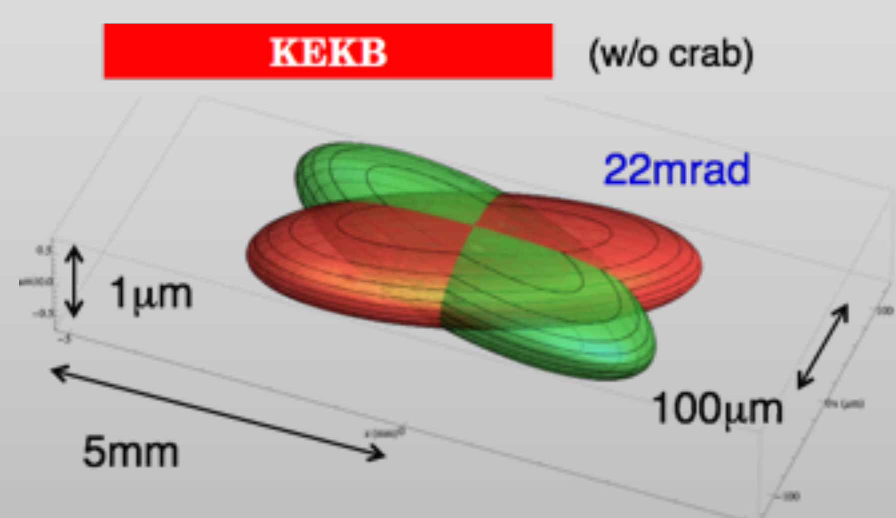
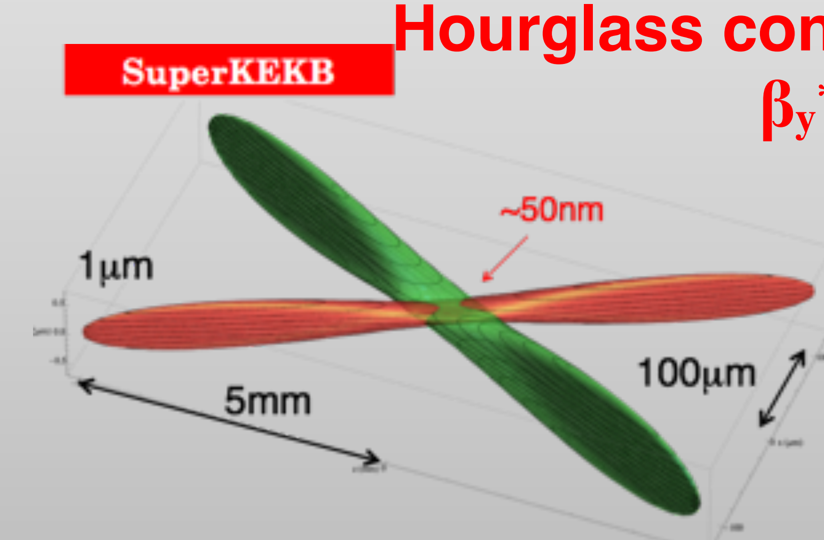
- Lorentz factor ($\gamma_{e\pm}$)
- Classical electron radius (r_e)
- Beam current ($I_{e\pm}$)
- Beam-beam parameter ($\xi_y^{e\pm}$)
- Beam size ratio@IP: 1 ~ 2 % (flat beam)
- Vertical beta function@IP (β_y^*)
- Lumi. reduction factor (crossing angle)& Tune shift reduction factor (hour glass effect): 0.8 ~ 1 (short bunch)

(1) Smaller β_y^* (20 x)

(2) Increase beam currents (~2-3x)





Hourglass condition:

$\beta_y^* >\sim L = \sigma_x/\phi$

How to make a Super Flavour Factory

Lorentz factor

Beam current

Beam-beam parameter

$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

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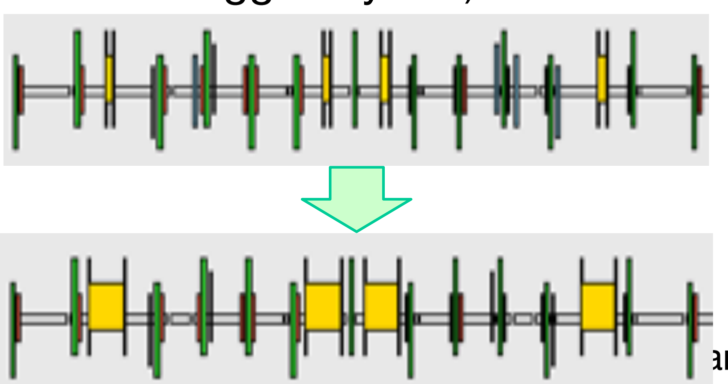
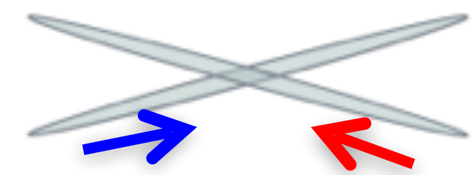
Hourglass condition:

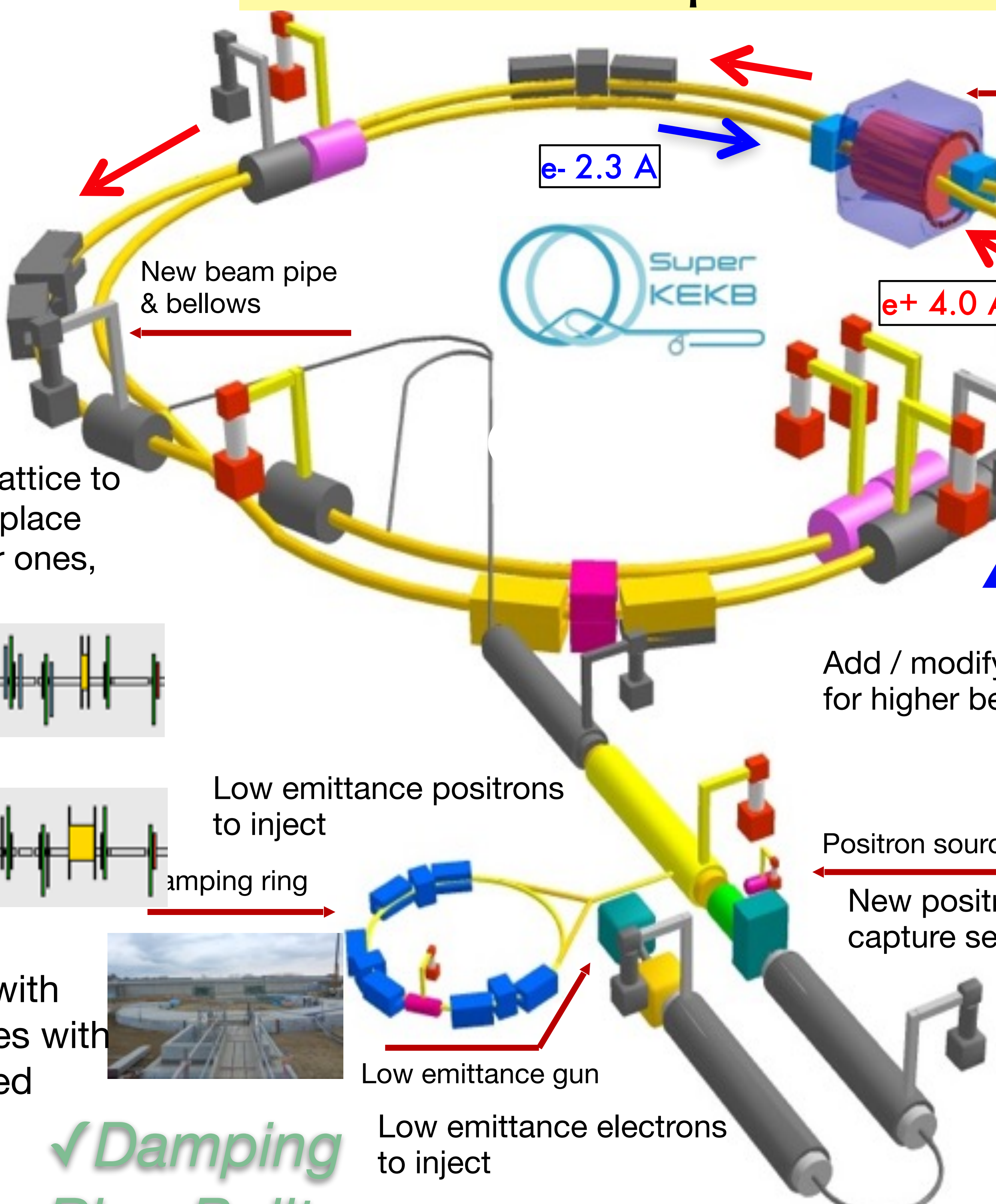
	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

KEKB to SuperKEKB

Redesign the magnetic lattice to reduce the emittance (replace short dipoles with longer ones, increase wiggler cycles)



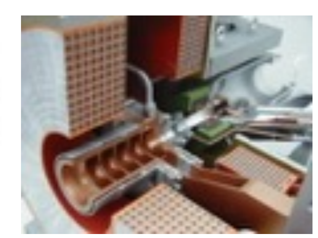




New superconducting / permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

New positron target / capture section



Replace beam pipes with TiN-coated beam pipes with antechambers (reduced Sync Rad.)

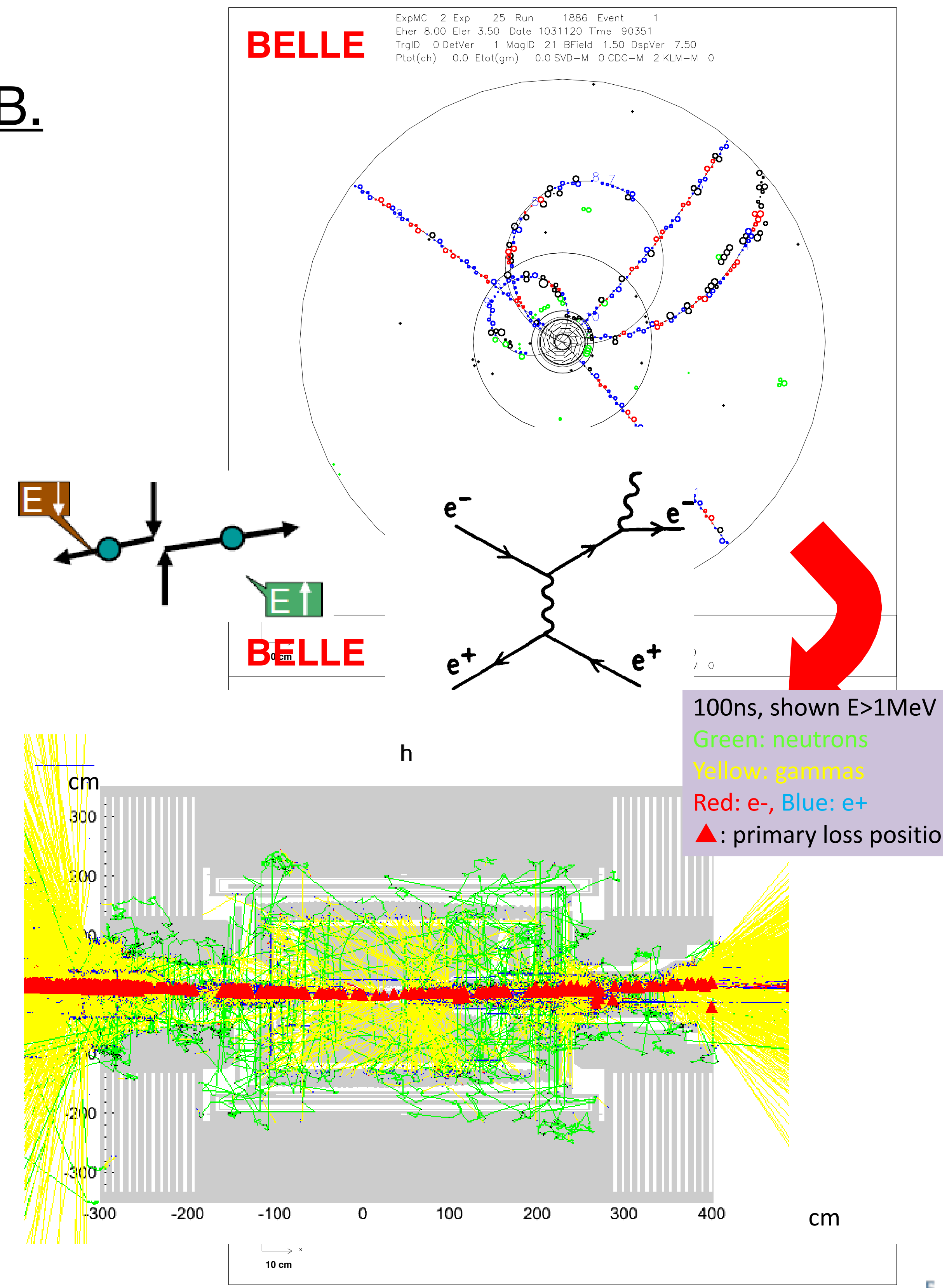
✓Damping Ring Built

$L=8\cdot10^{35}\ s^{-1}cm^{-2}$

Completion end of 2014

x 40 Gain in Luminosity

Belle II Detector Requirements



Beam-related backgrounds are 10-20 x KEKB.

- Touschek scattering
- Radiative Bhabha
- 2-photon

Fake hits, pile up, radiation damage

Higher trigger rate: L1 trigger rate: ~20kHz

Important improvements

- Hermeticity for full B reconstruction
- Vertex resolution
- K_S and π^0 ID efficiency
- K/π separation

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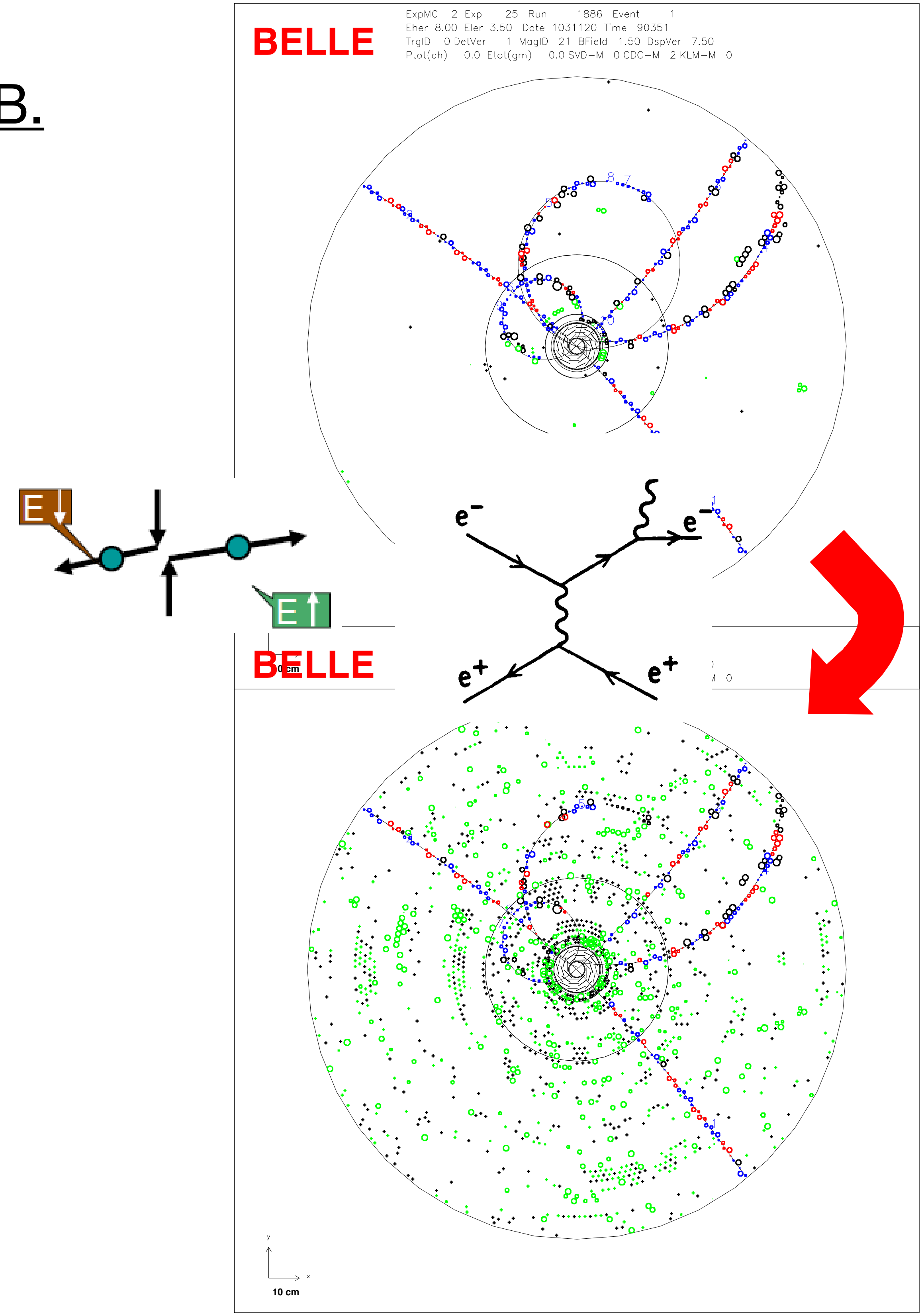

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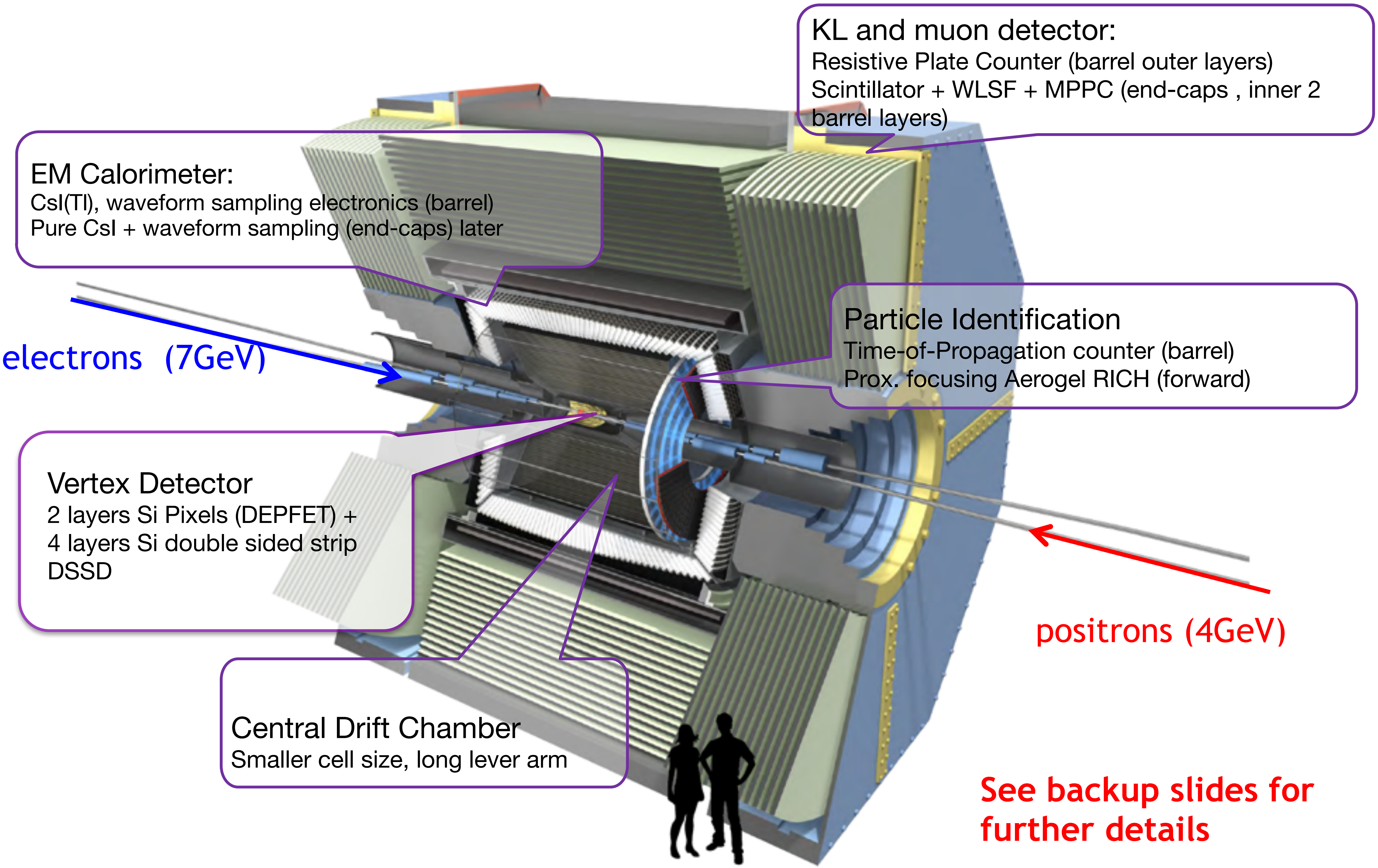


See backup slides for further details

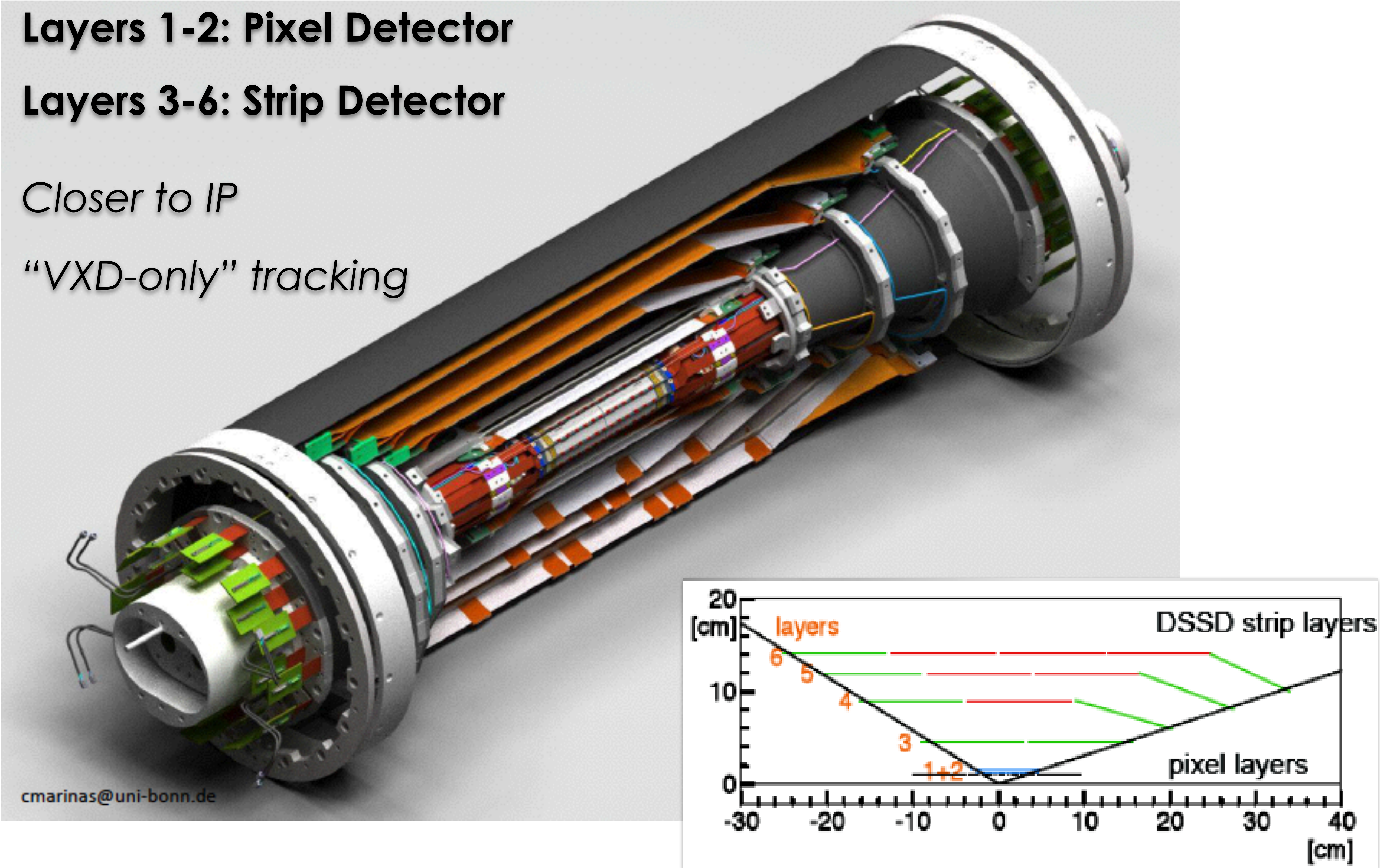
Vertex Detectors

Layers 1-2: Pixel Detector

Layers 3-6: Strip Detector

Closer to IP

“VXD-only” tracking



Belle II Vertex Detector

PXD: excellent spatial granularity (resolution ~15 μm)

low material (0.16%X_0 for layer 1)

but significant amount of background hits, huge data rate.

~10 million channels!

SVD: precise timing (2–3 ns RMS)

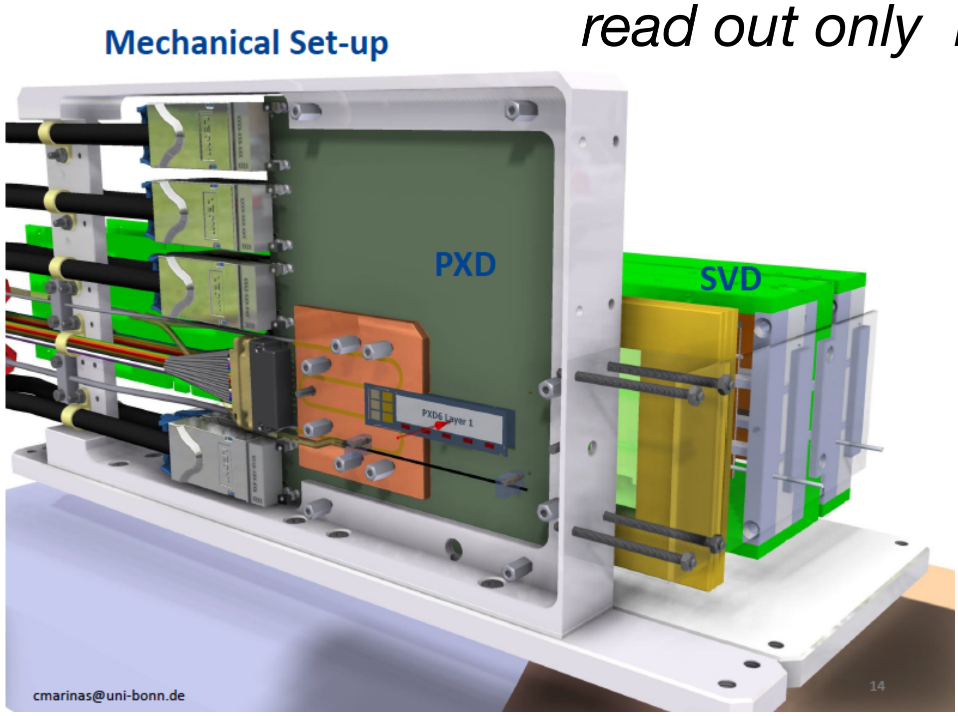
but has **ambiguities in space** due to 1D strip.

At much larger radius (~100->140 mm)

few 100k channels!

Combining both yields a very powerful device!

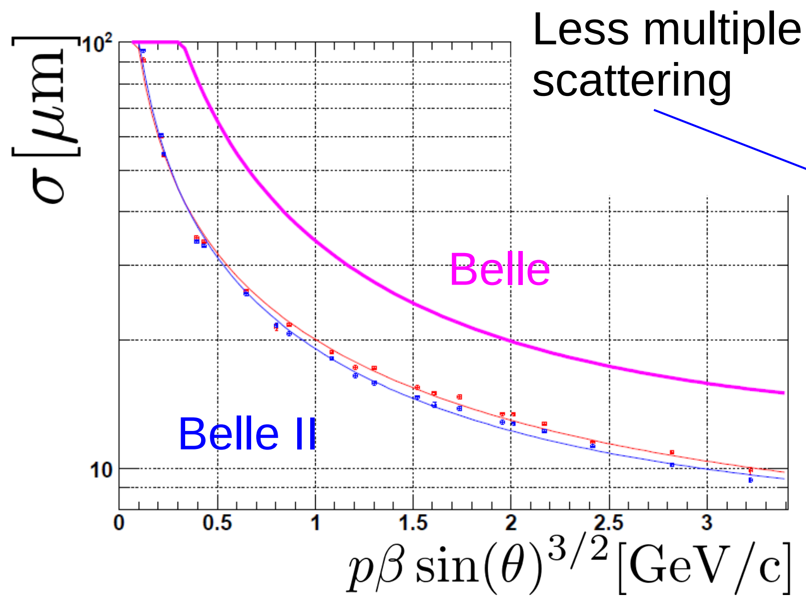
(Successful test beam January 2014) : To reduce Gbit/s data from PXD, read out only ***Regions Of Interest*** *from projected SVD tracks*



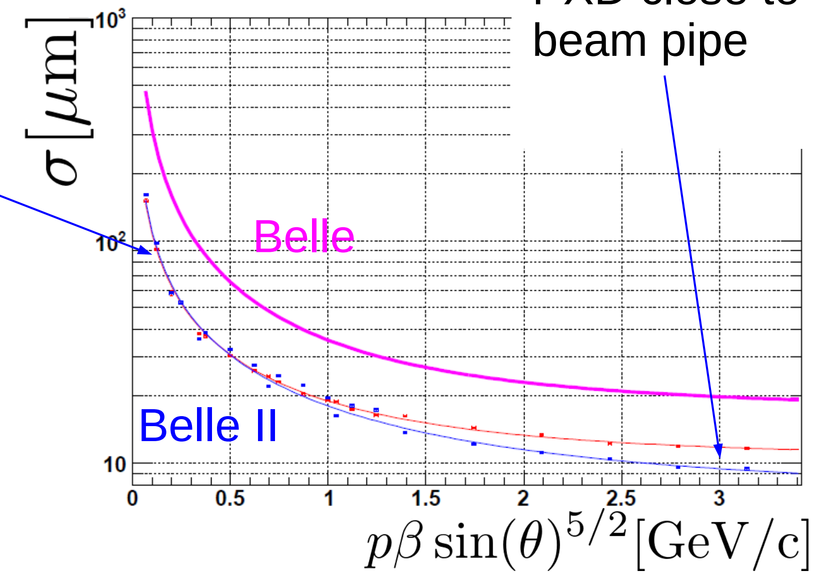
Performance

1)

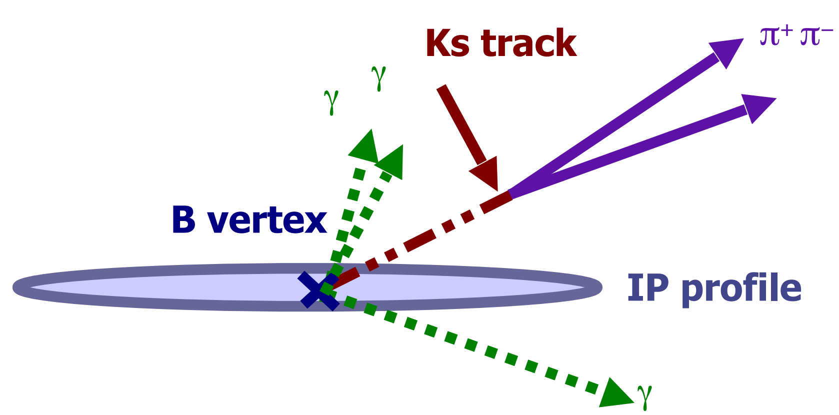
Closest approach resolution



Z resolution

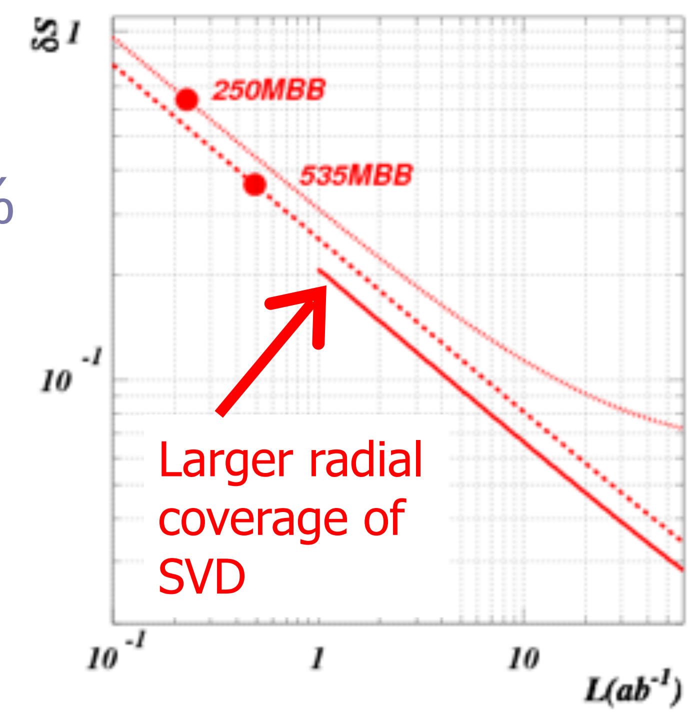


2) Larger acceptance (by 30%) for detection of pions from K_S decay →
e.g. improves Time Dependent CP Asymmetry $\delta S(K_S\pi^0\gamma)$



B decay point reconstruction
Using the K_S trajectory

30% -> ~2% precision



14

Particle Identification

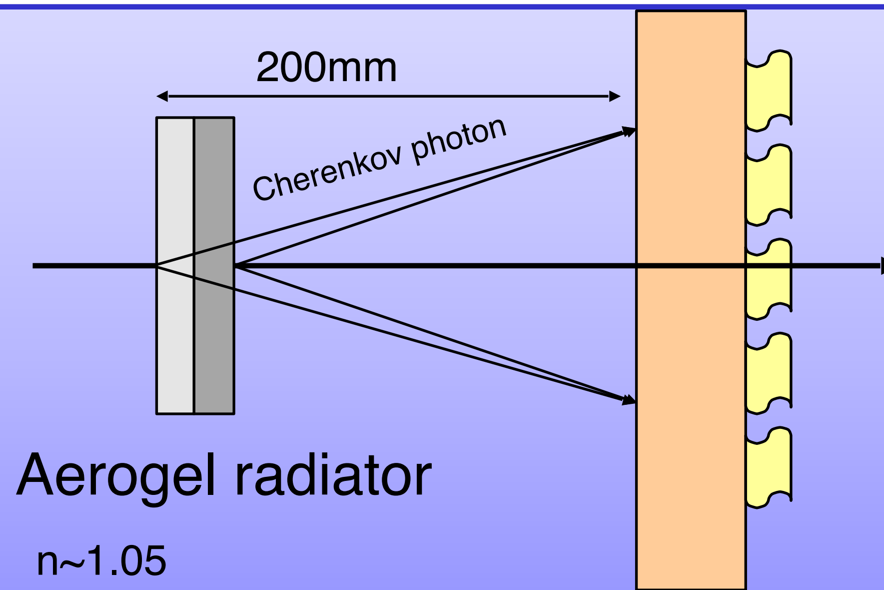
Barrel PID: Time of Propagation Counter (TOP)

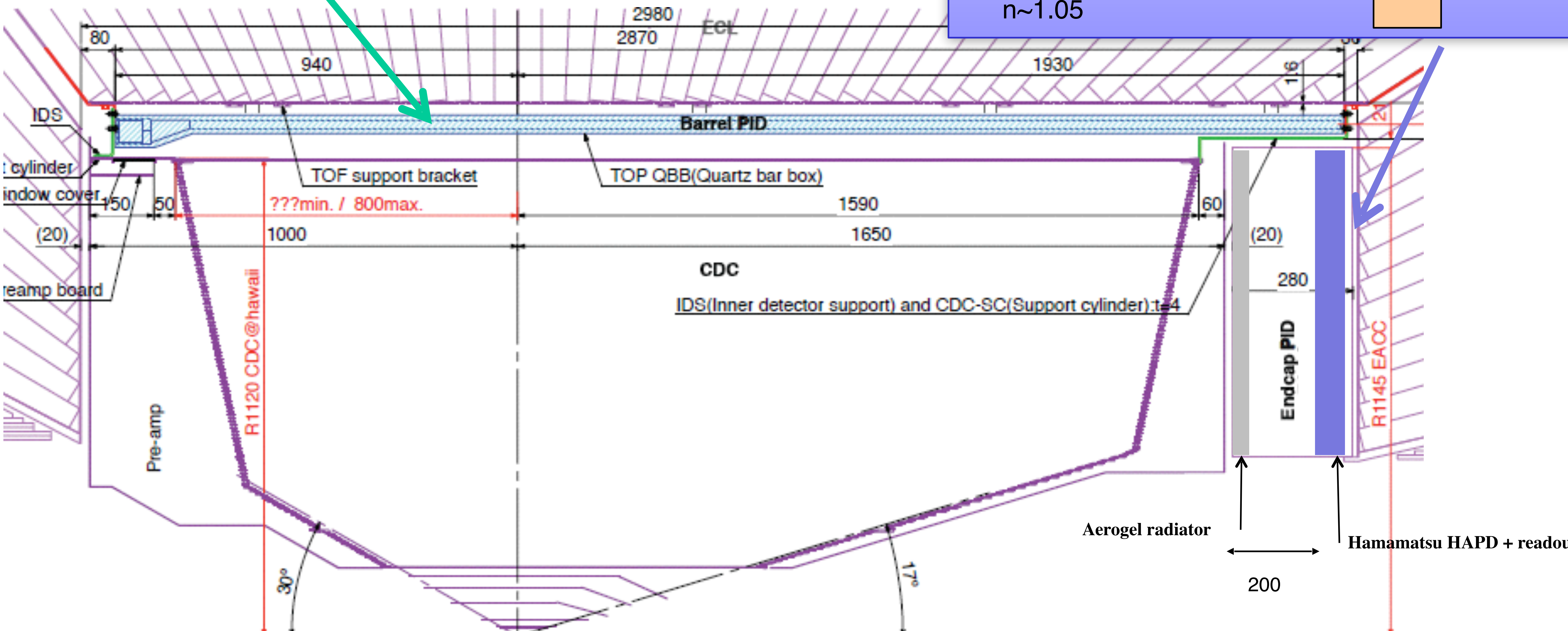
Quartz radiator

Focusing mirror

measure t, x and y

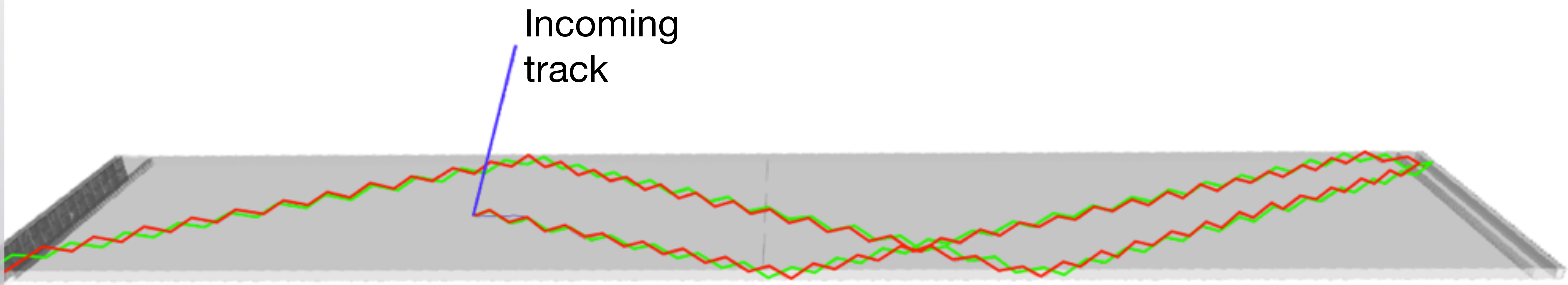
Endcap PID: Aerogel RICH(ARICH)

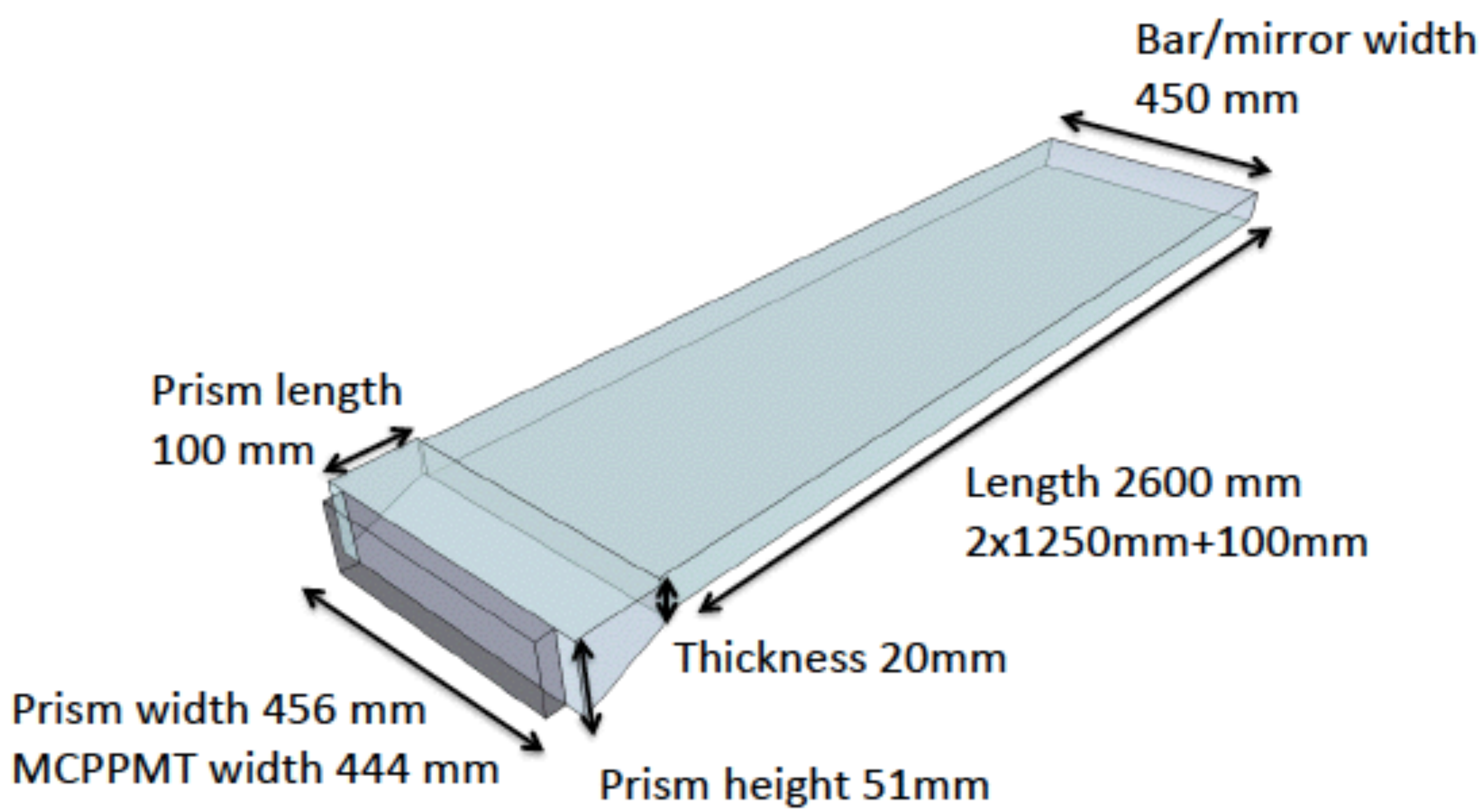


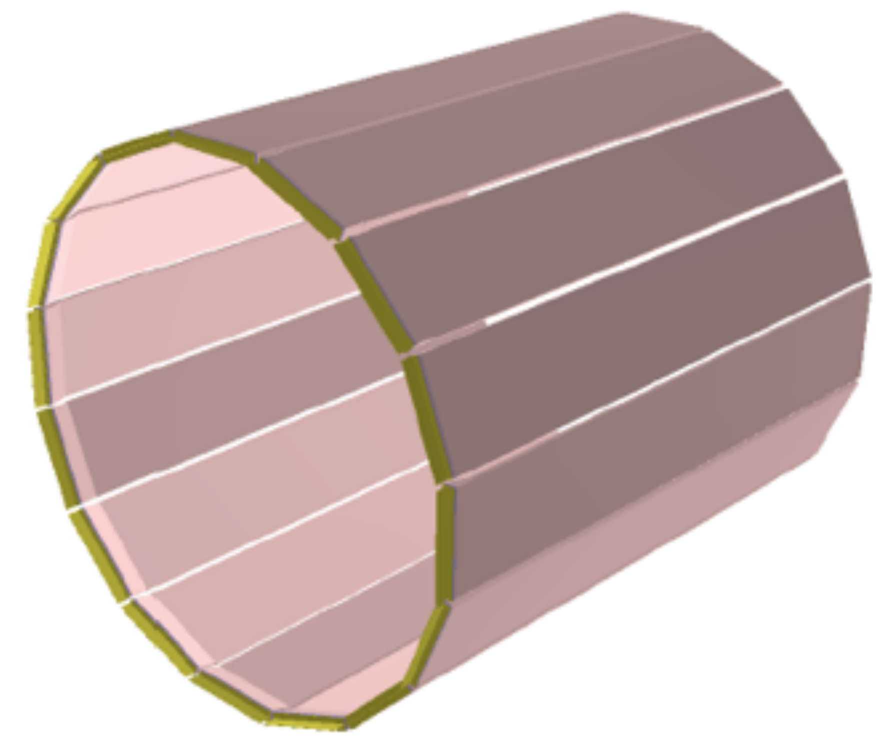


PID: Principle of operation of iTOP detector

Simulation of a 2 GeV pion and kaon interacting in a quartz bar.

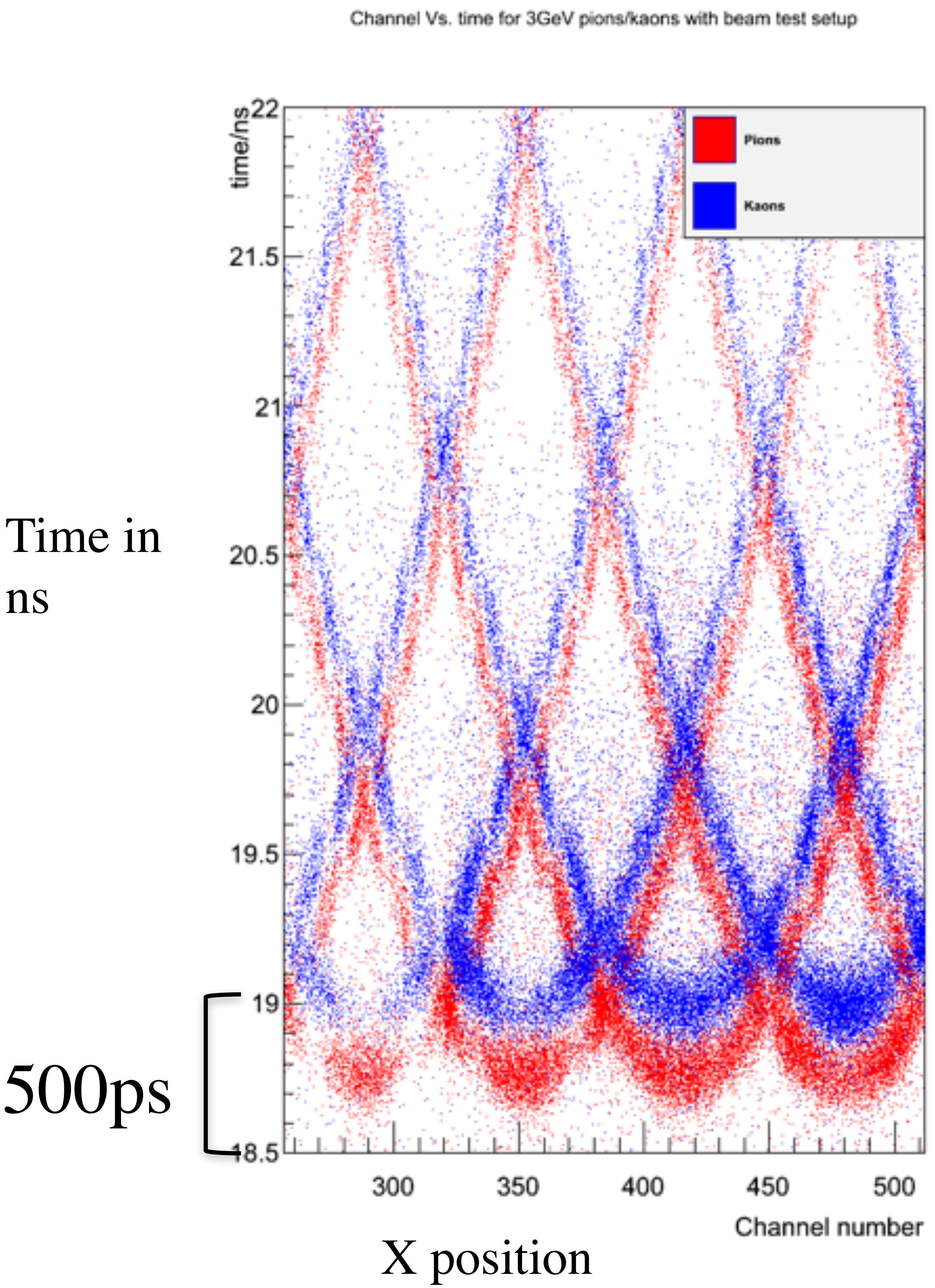




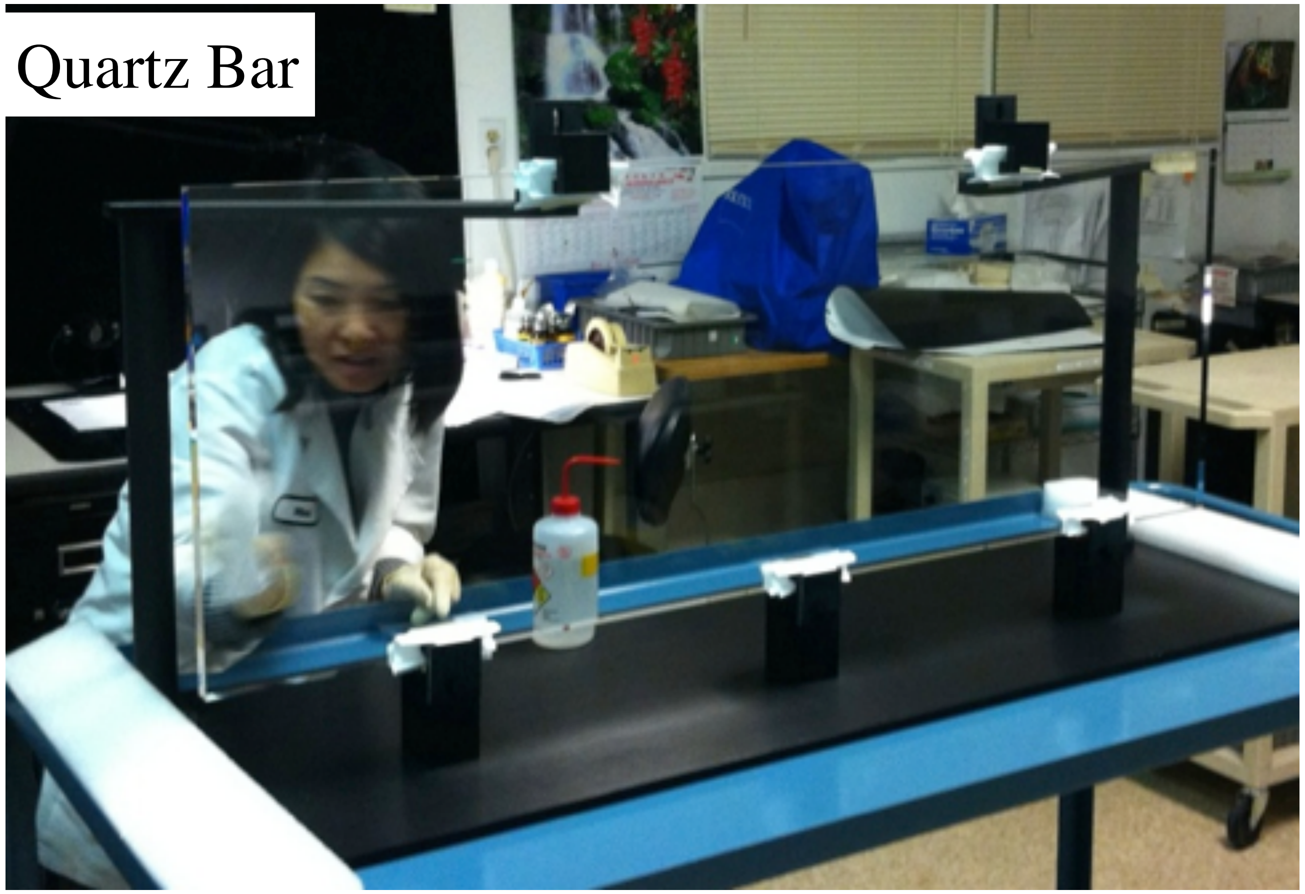


16 bar modules arranged in a "roman arch"

Kaons vs pions: Integrated distributions



At 3 GeV *Timing at the ~100 ps level is needed to separate pion and Kaon*



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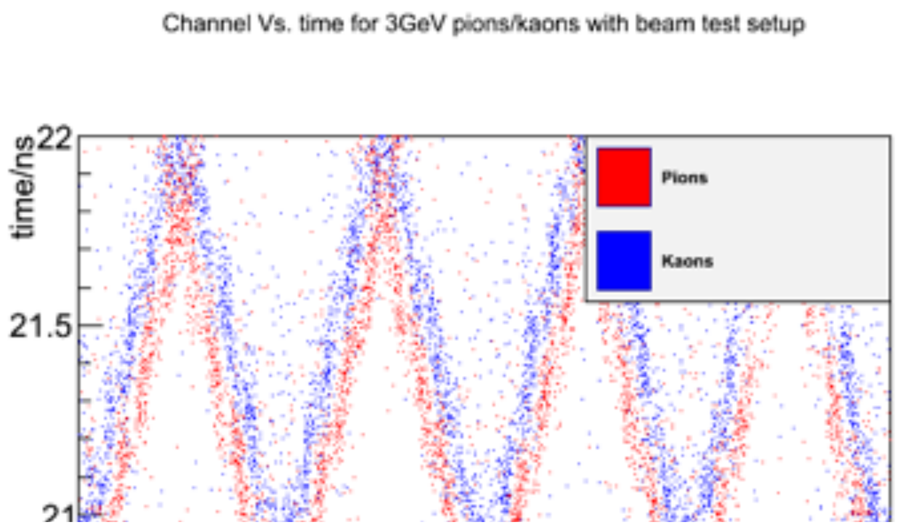

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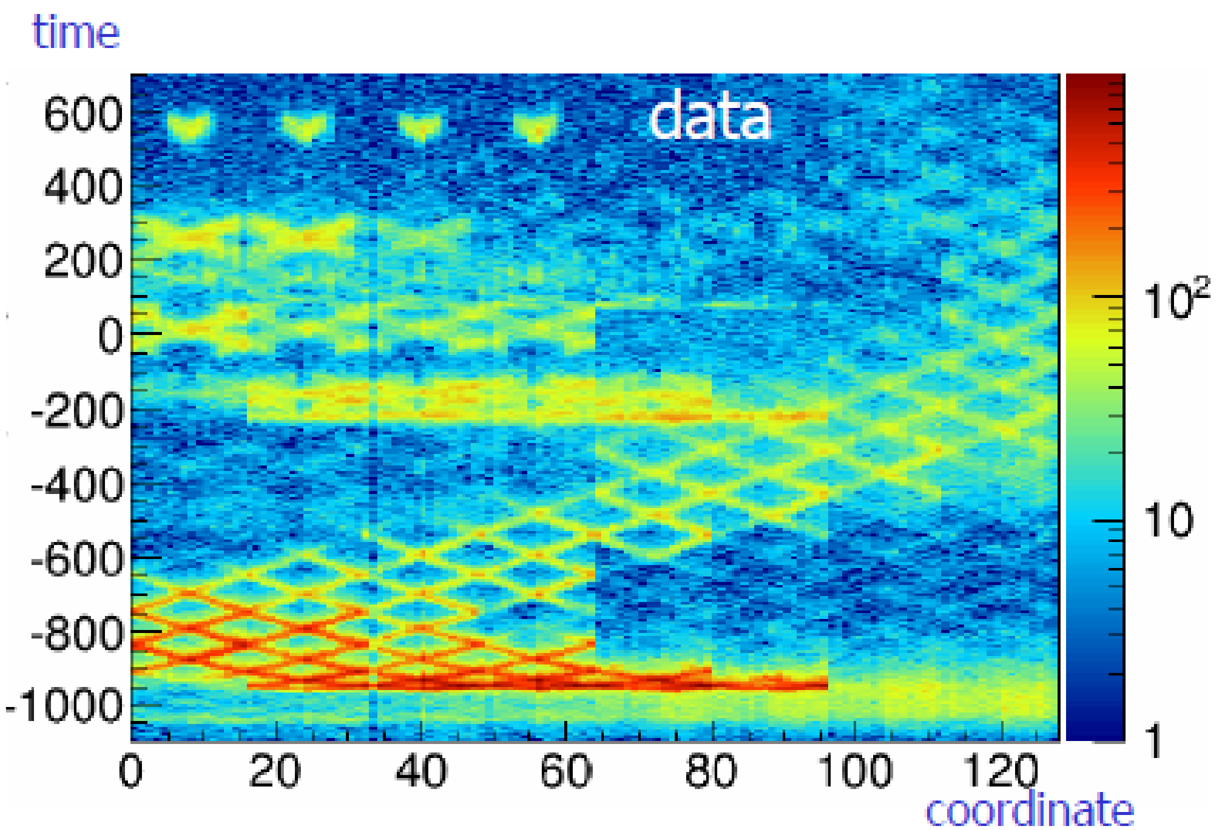
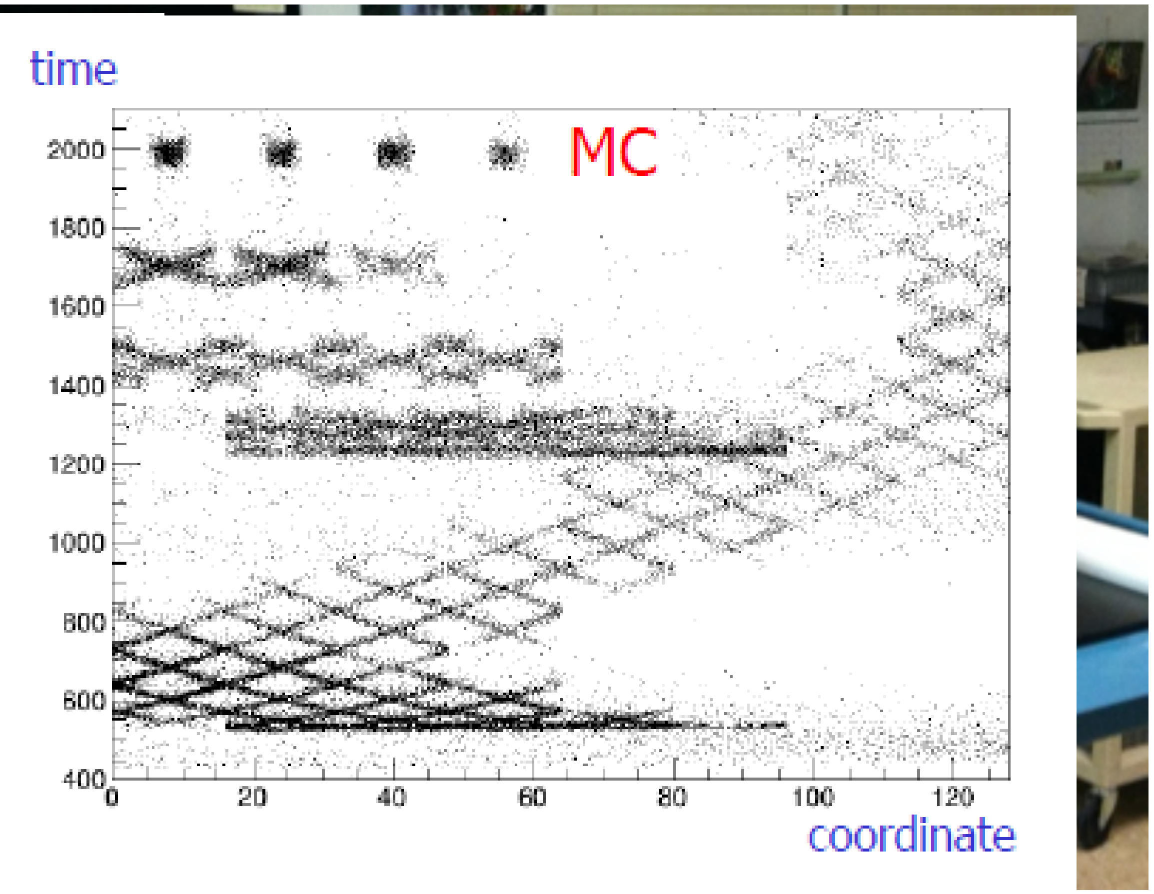
Time in ns





500ps

Excellent agreement between the test beam data and MC simulation

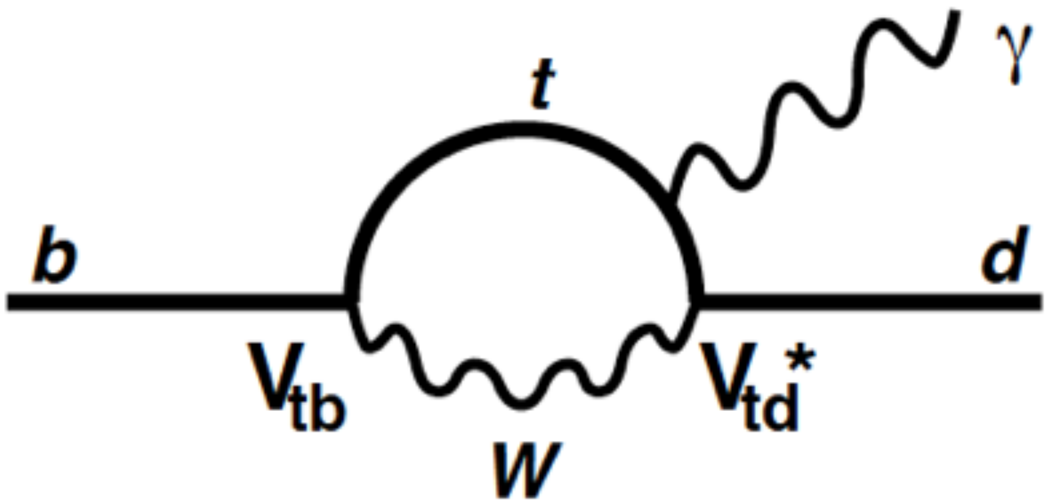
300 350 400 450 500

Channel number

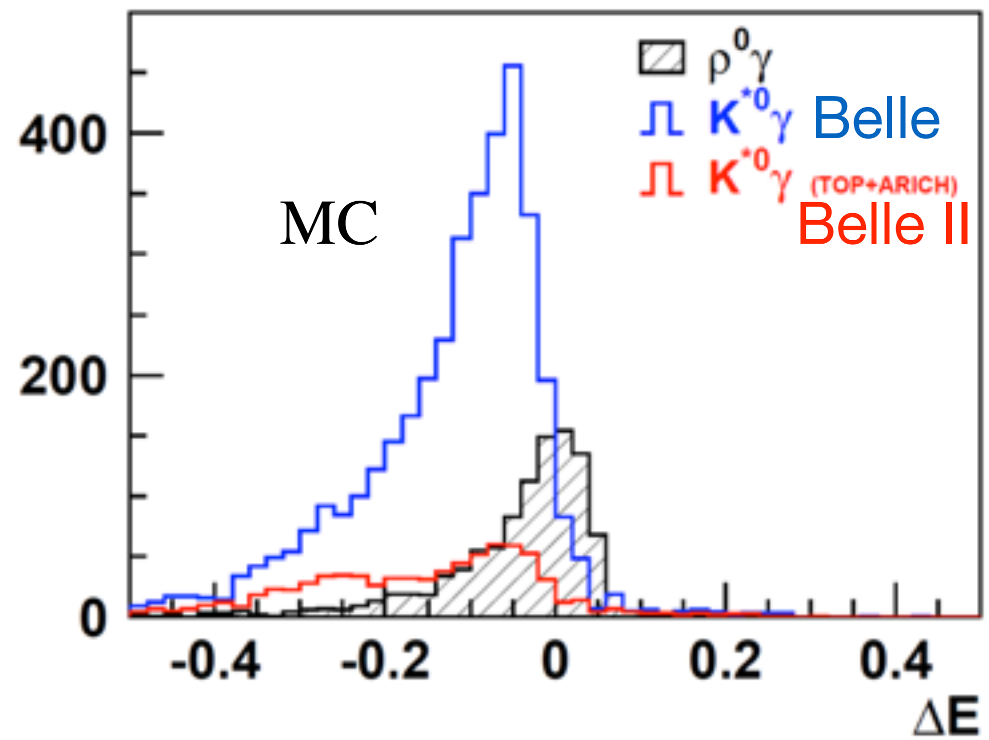
X position

iTOP impact on Rare b→d Penguins: $B \to \rho\gamma$, $K^* \gamma$

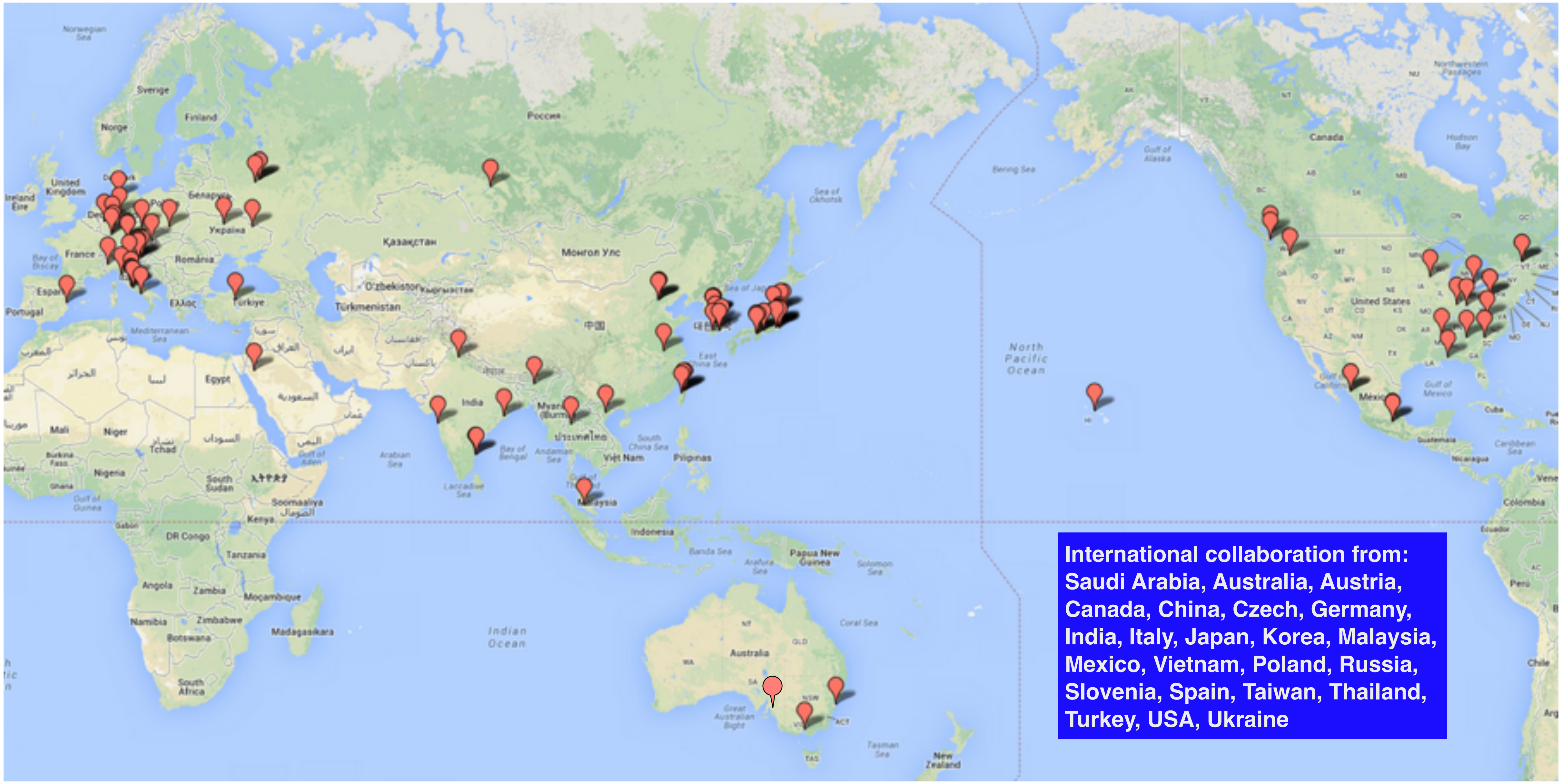
Rare leucistic penguin,
observed in a 2012 expedition



The Background
$B \to K^* \gamma$ (Belle / BelleII) ~30X more abundant than the signal **$B \to \rho\gamma$.**



The Belle II Collaboration



- **Belle** experiment@KEKB **(1999-2010)**

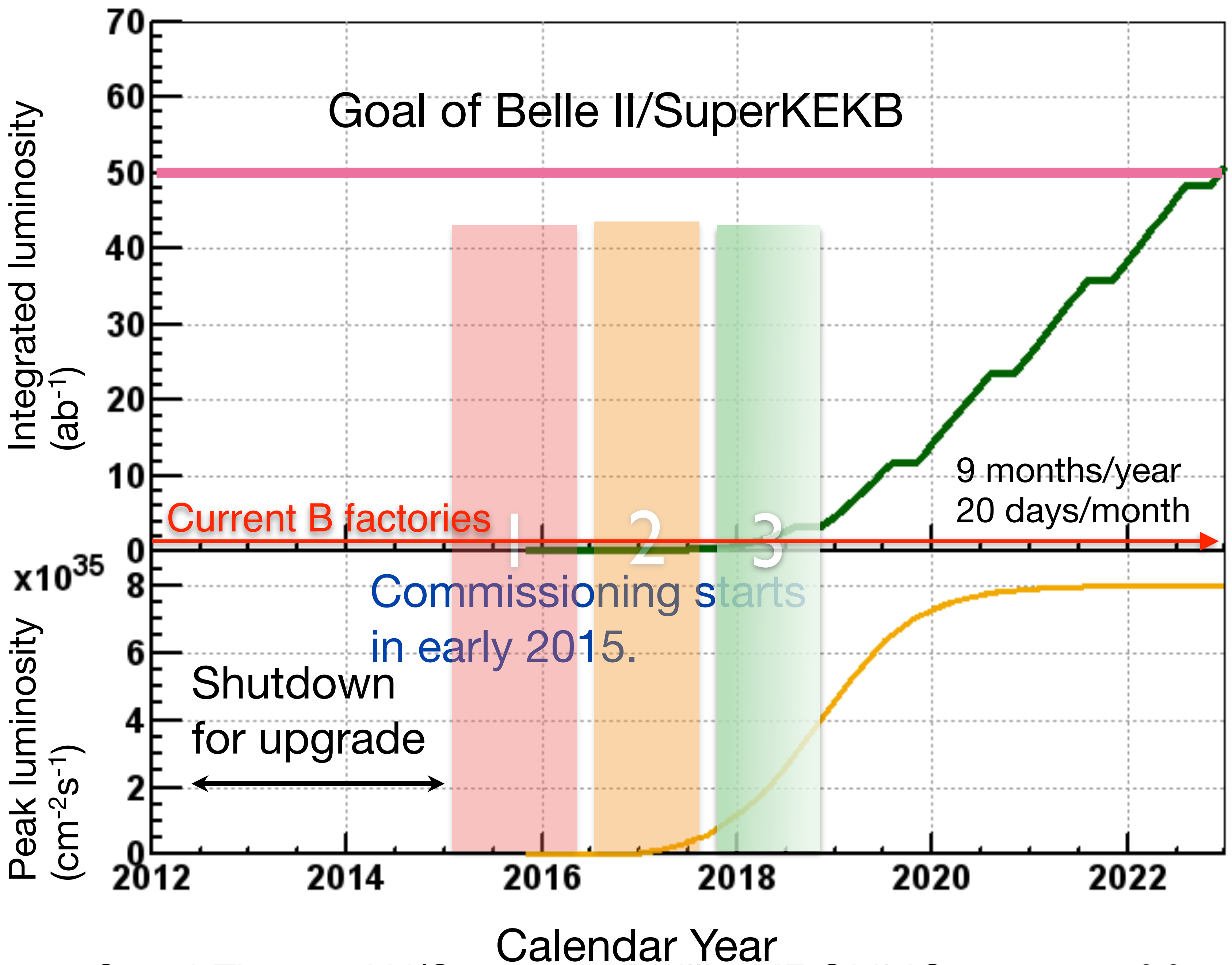
  [400 collaborators, 15 nations]

- **Belle II** experiment**@SuperKEKB** **(online in 2016)**

  [~600 collaborators, 96 institutions, 23 nations/regions]

Data collection timeline*

1	2015	Accelerator commissioning
2	2016	Belle II “Beast” and partial detector commissioning
3	2017	First runs with full detector



Golden modes of Belle II

- **Unique capabilities of Belle II:**
  - Exactly 2 B mesons produced (at Υ(4S))
    - High flavour tag efficiency (10 x better than LHC)
  - Detection of photons, π^0, $\rho^\pm$, $\eta^{(\prime)}$, K_L: complete strong phase surveys,
  - Clean ("see" decays with several neutrinos)

"Golden" modes?

- Sensitive to different NP
- Measurements to improve by **5-100 x precision.**
- Not limited by hadronic uncertainties

- Missing energy:
  - $B \to l\nu$, $l=e,\mu,\tau$
  - $B \to D^*\tau\nu$, $B \to X_{u,c}l\nu$, $B \to K^{(*)}\nu\nu$
- CPV in tree level decays Vs. penguins (inc. neutrals)
- A_{CP} in radiative decays, $S_{KS\pi 0\gamma}$
- Inclusive measurements, $b \to s\gamma$, $b \to sl^+l^-$,
- CPV in D^0 mixing
- Charged LFV, $\tau \to \mu\gamma$, $\tau \to eee$
- Improved CKM elements
- + Dark matter, new QCD states, Light Higgs.

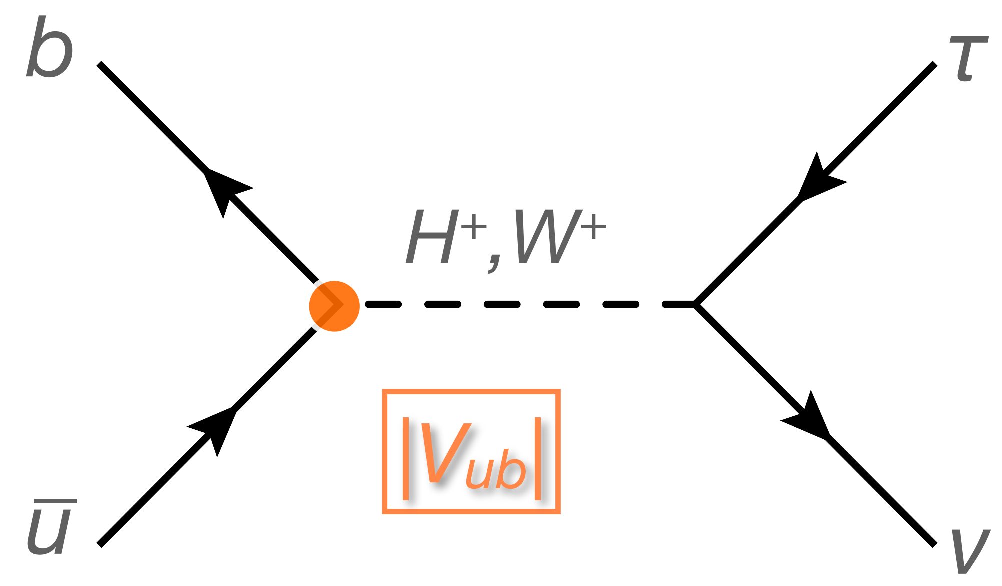
Semi(Leptonic)
B Decays

Extended Higgs & Gauge Sectors?
FCNCs with quarks?

H^+ Search: $B^+ \to \tau\,\upsilon$, $\mu\,\upsilon$

(Decays with *Large* Missing Energy)

Helicity suppressed - very small in SM.
NP could interfere *e.g.* **charged Higgs, and** *change* the branching fraction



BF$_{SM}$ **r$_H$**

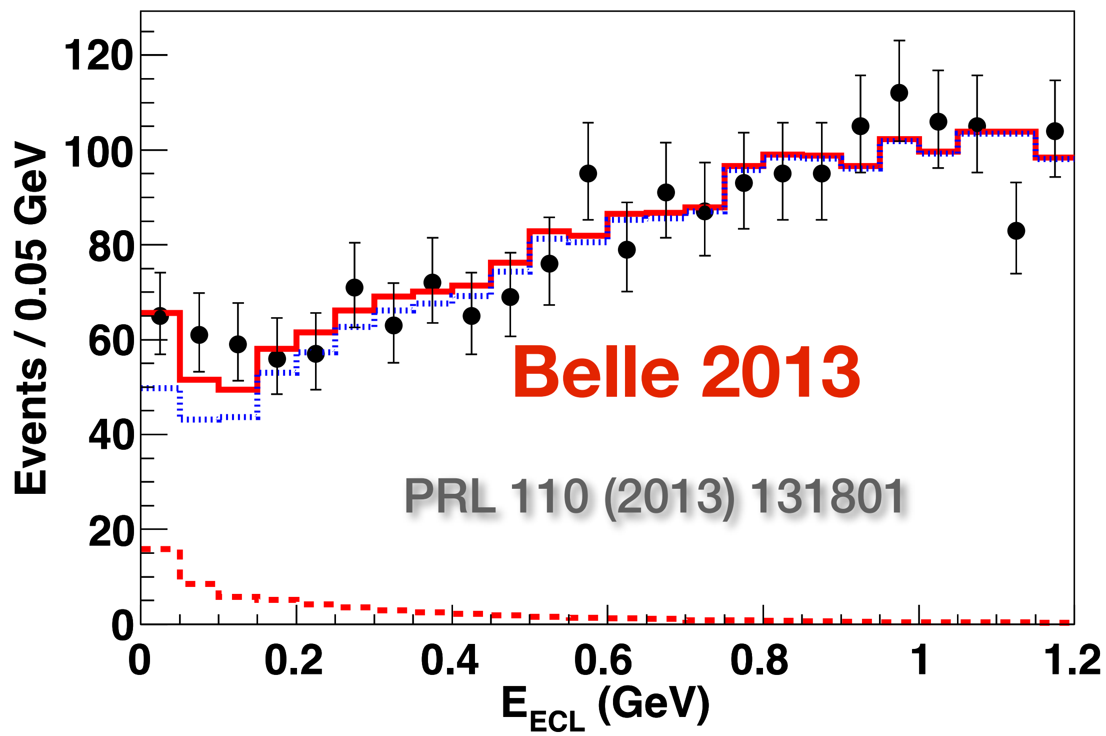
$$\mathrm{BR}(B_u \to \tau\nu_\tau) = \frac{G_F^2 f_B^2 |V_{ub}|^2}{8\pi} \tau_B m_B m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \left[1 - \left(\frac{m_B^2}{m_{H^+}^2}\right) \lambda_{bb}\lambda_{\tau\tau}\right]^2$$

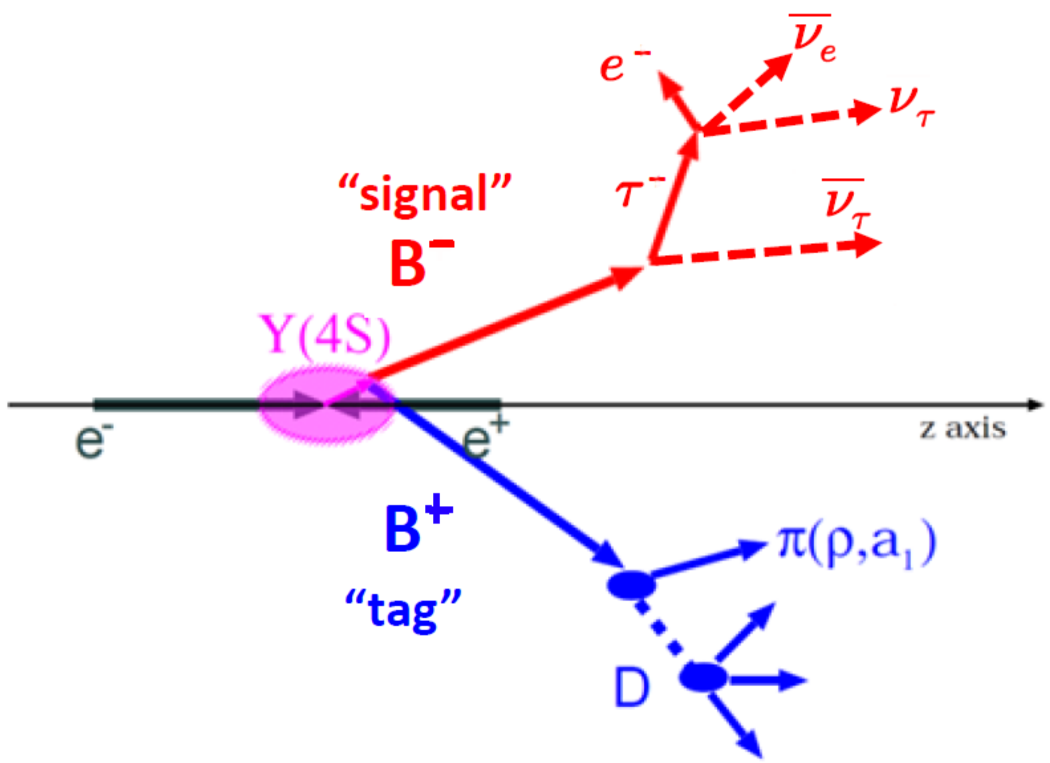
2HDM scenarios

Type	λ_{UU}	λ_{DD}	λ_{LL}
I	$\cot\beta$	$\cot\beta$	$\cot\beta$
II	$\cot\beta$	$-\tan\beta$	$-\tan\beta$
III	$\cot\beta$	$-\tan\beta$	$\cot\beta$
IV	$\cot\beta$	$\cot\beta$	$-\tan\beta$

B –> τ ν : Experimental Challenge

Reconstruct one B meson (Btag)
ε(B_{tag}) = 0.20 - 0.25% @
Purity(B_{tag}) = 20%



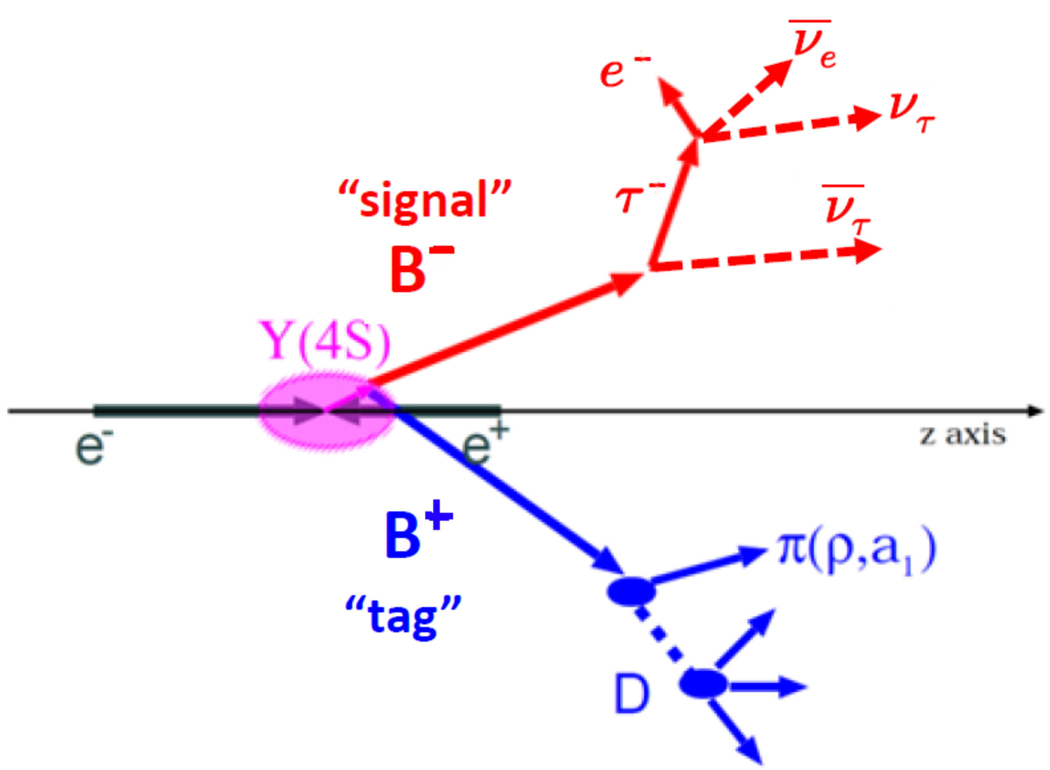


No residual activity (neutrinos)

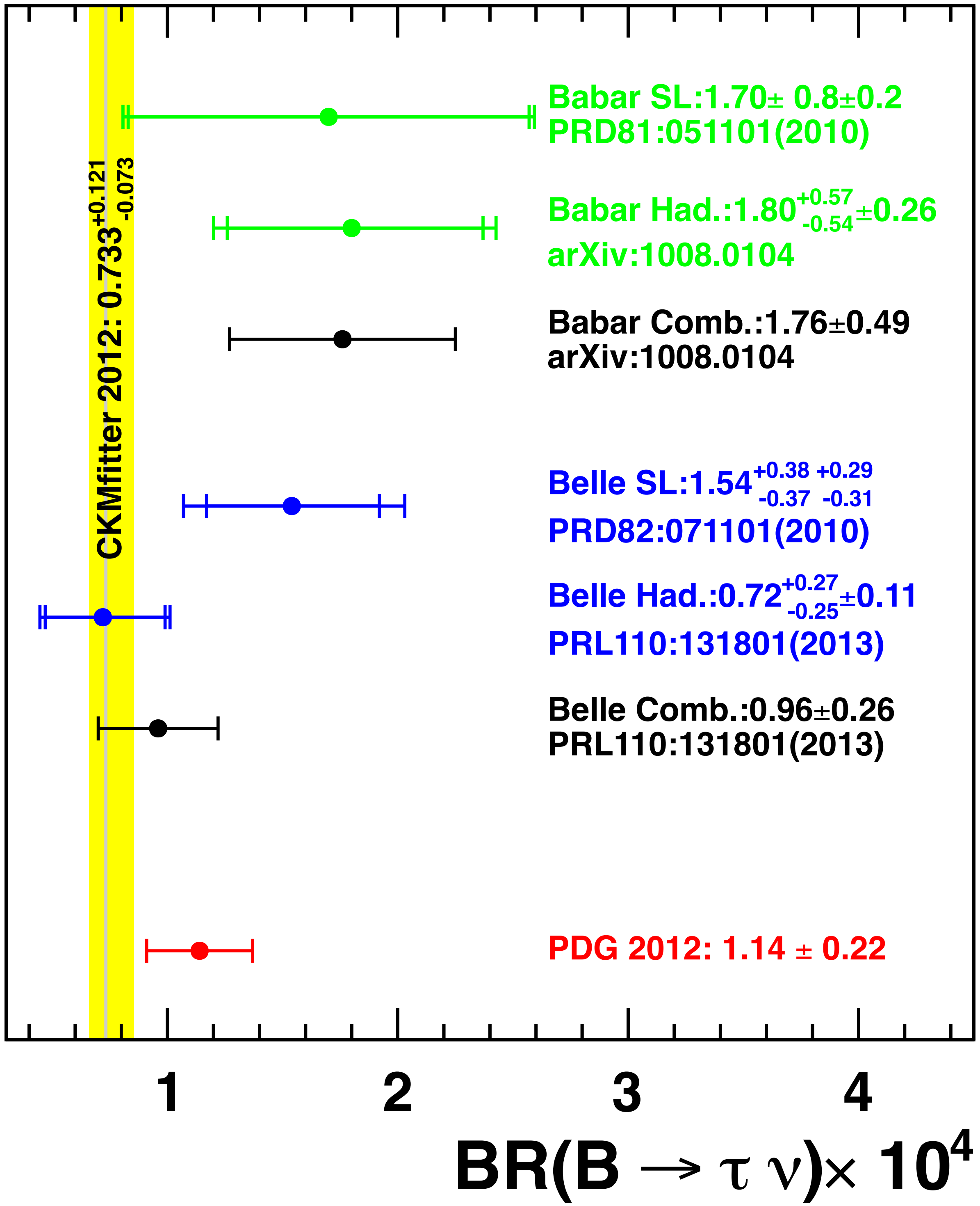
Signal (B→τν):
Zero or small value of E_{ECL} arising only from beam background
No residual tracks from the IP.

B –> τ ν : Experimental Challenge

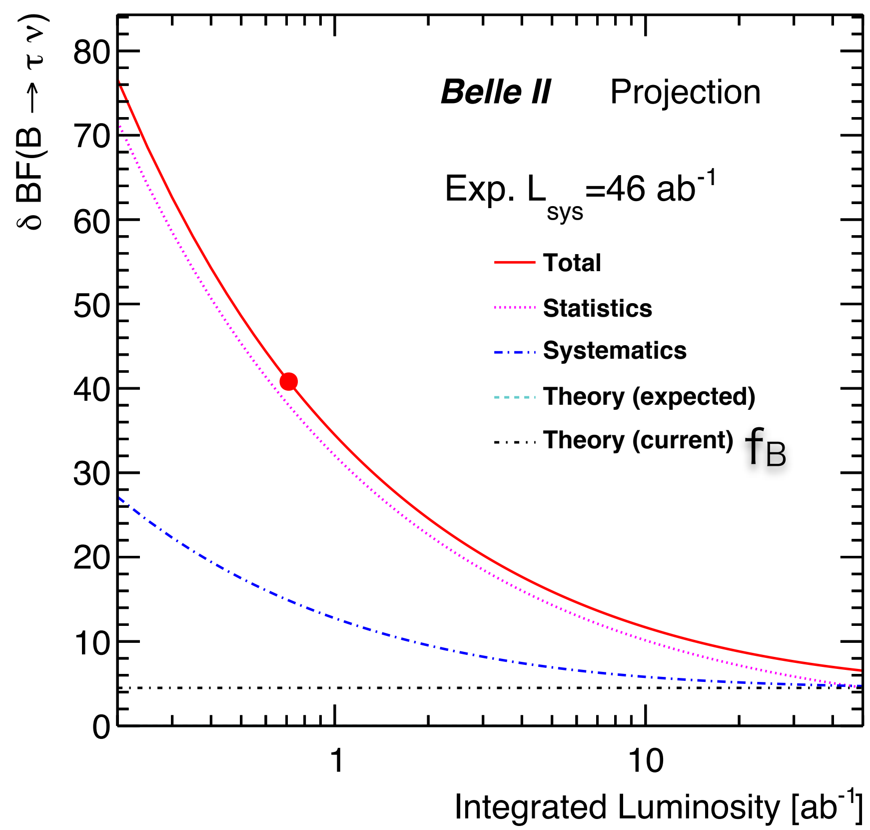
Reconstruct one B meson (Btag)
ε(B_{tag}) = 0.20 - 0.25% @
Purity(B_{tag}) = 20%



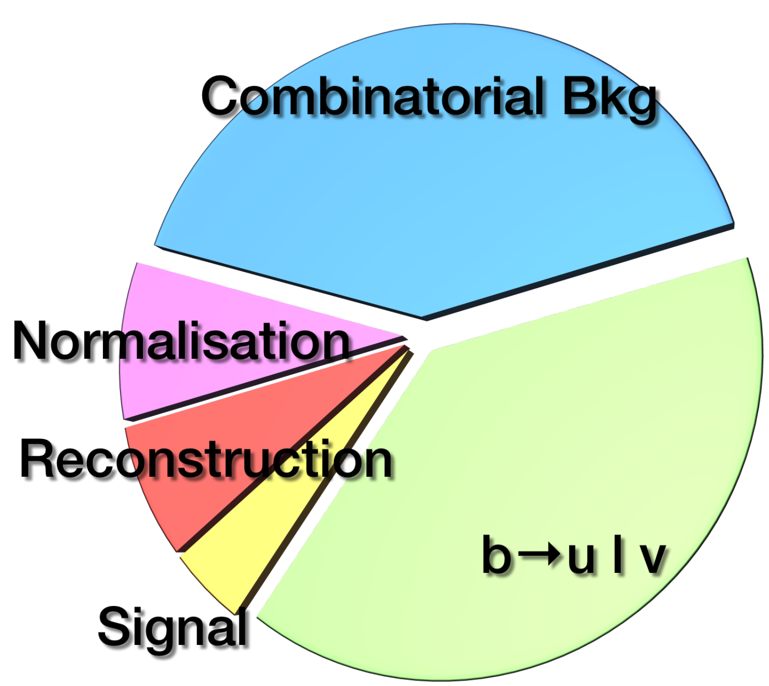
No residual activity (neutrinos)

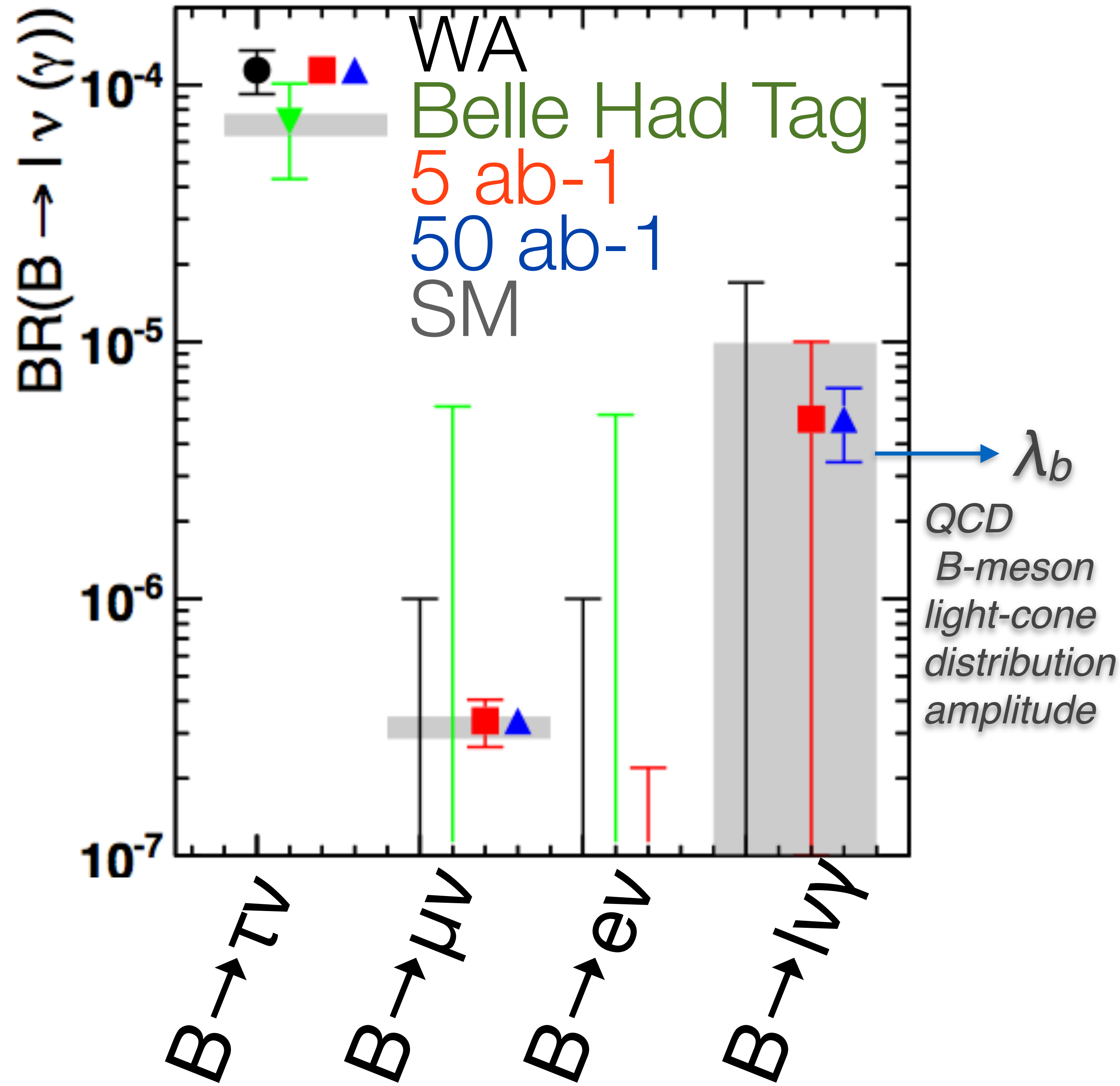


B→τ/e/μν(γ) Projections



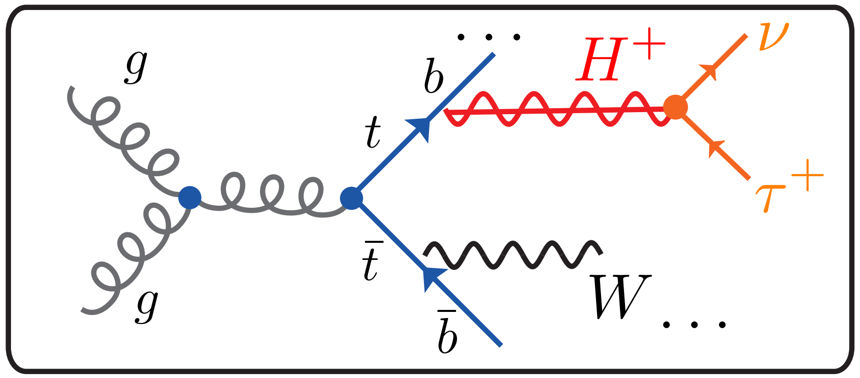
BF Systematics

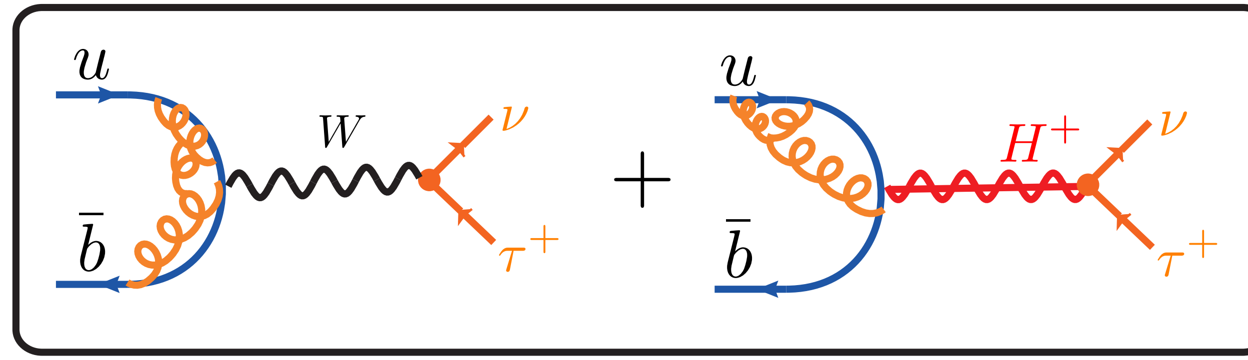


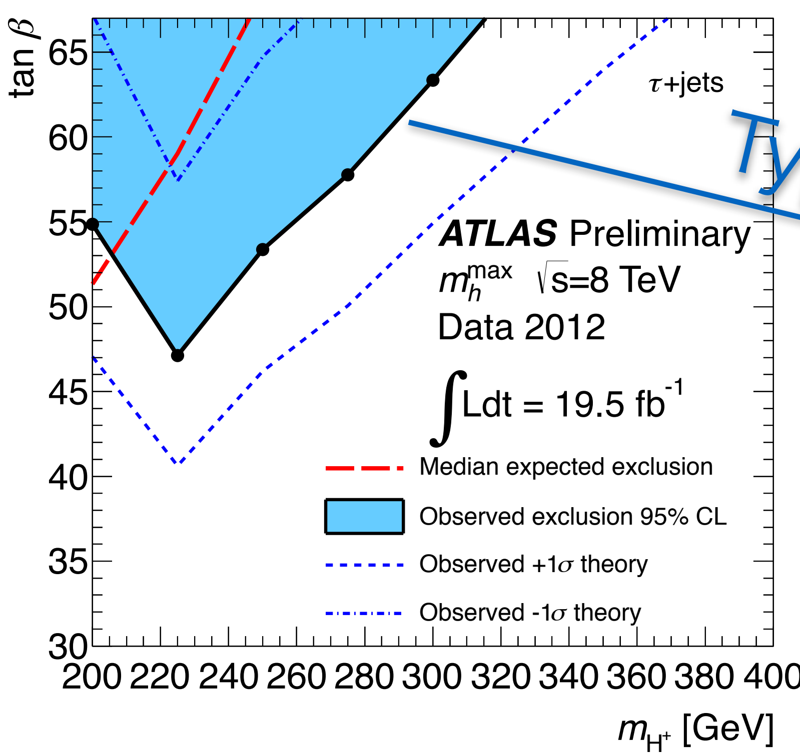


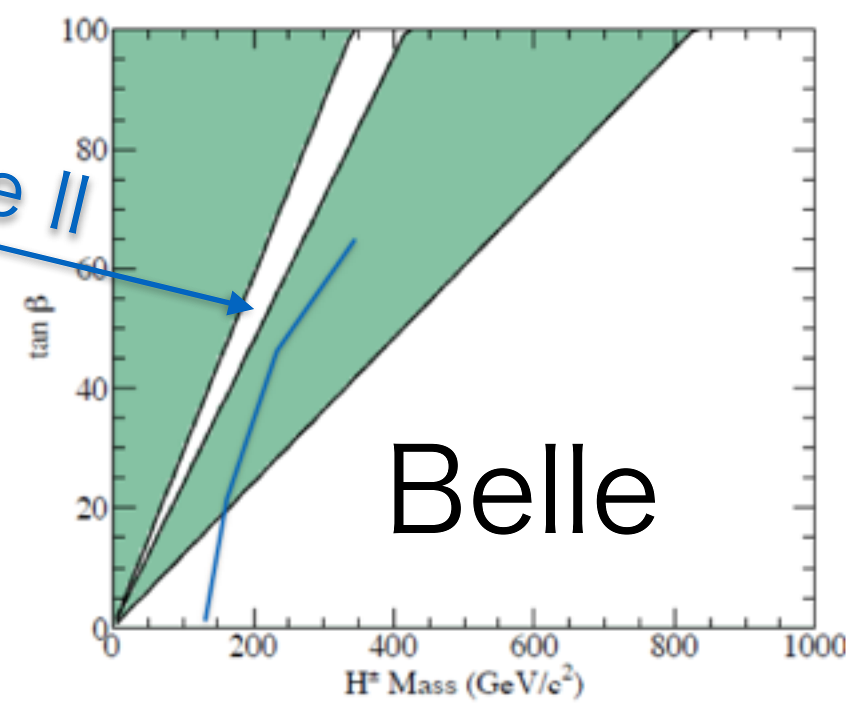
Charged Higgs $\sqrt{\lambda_\ell \lambda_d} \overset{\mathrm{TypeII}}{\Longrightarrow} \tan\beta$

Charged Higgs in τ + jets at ATLAS & $B \to \tau\bar{\nu}_\tau$

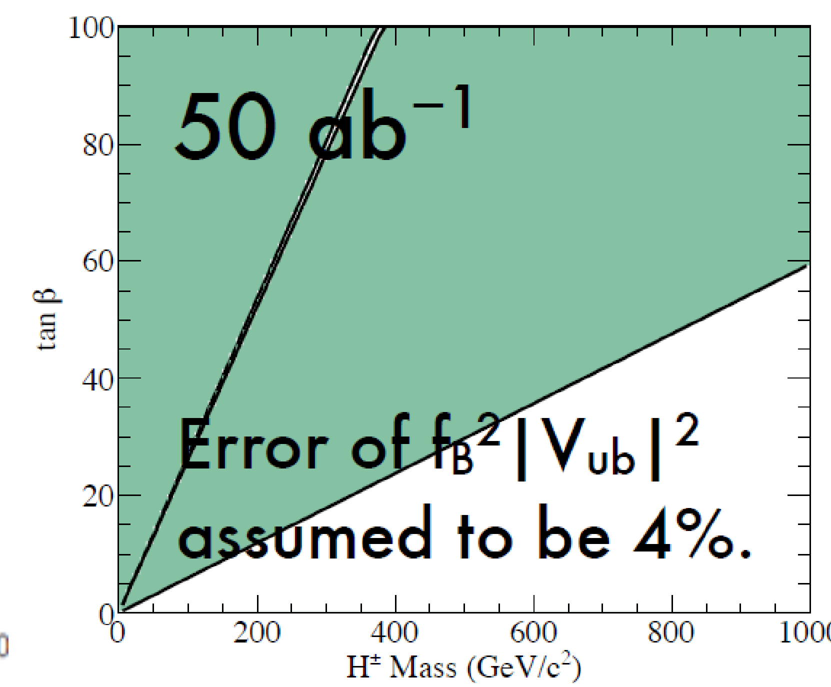






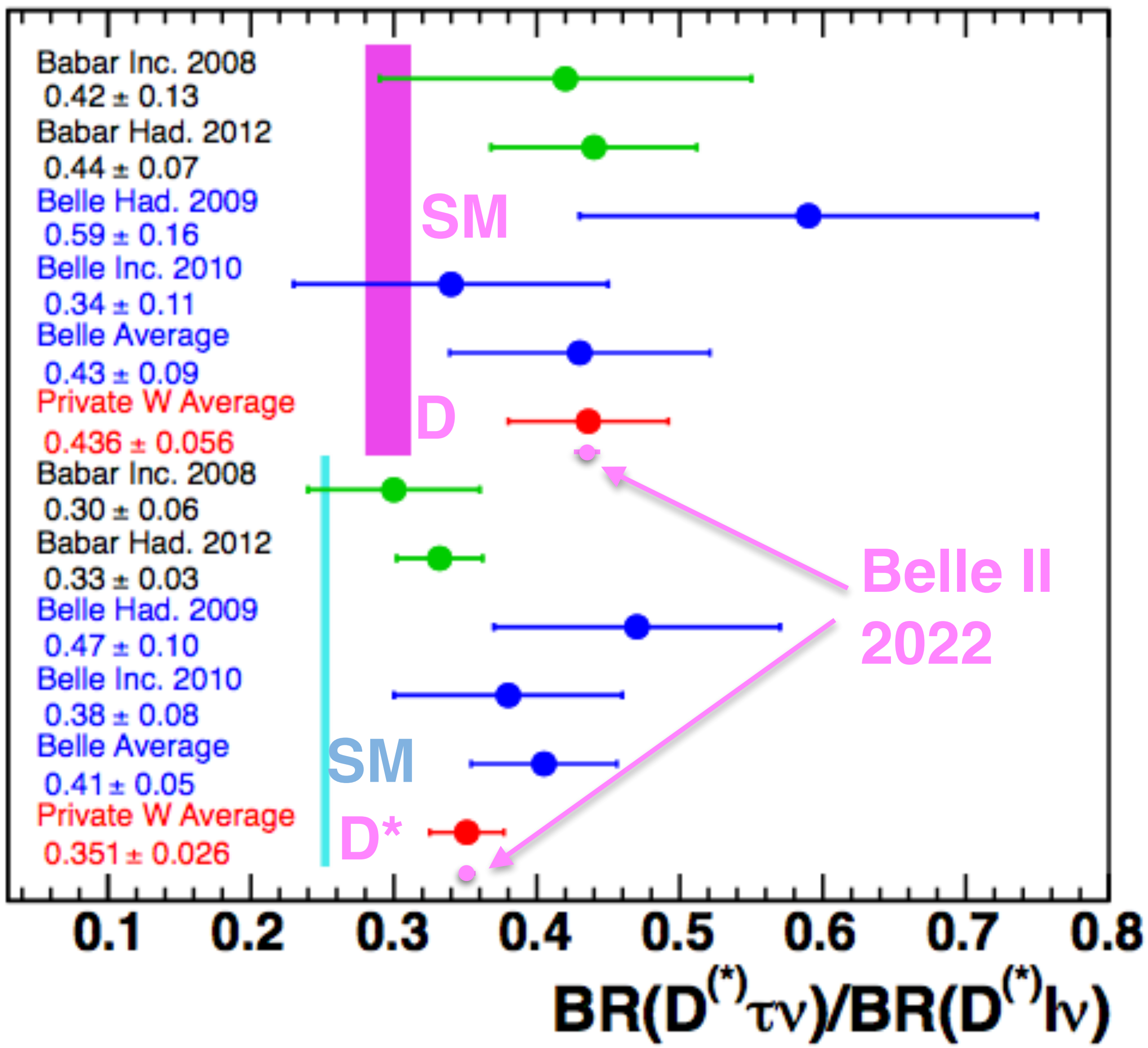


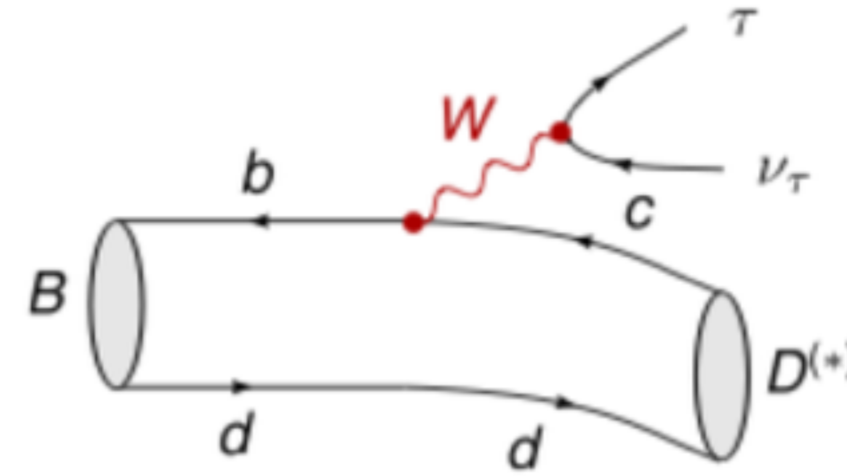
B-factories exclusion plot



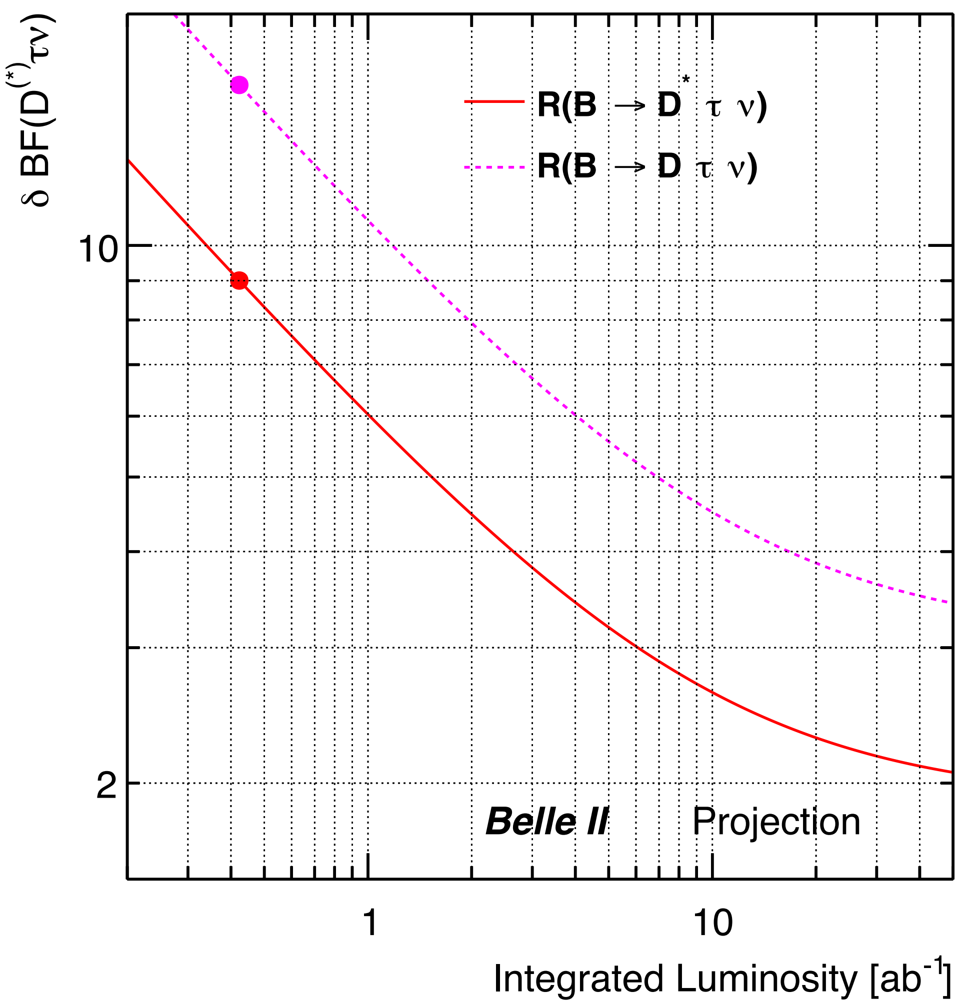
Super *B*-factory exclusion plot

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





➢Involves ≥ 2 ν (Missing E):

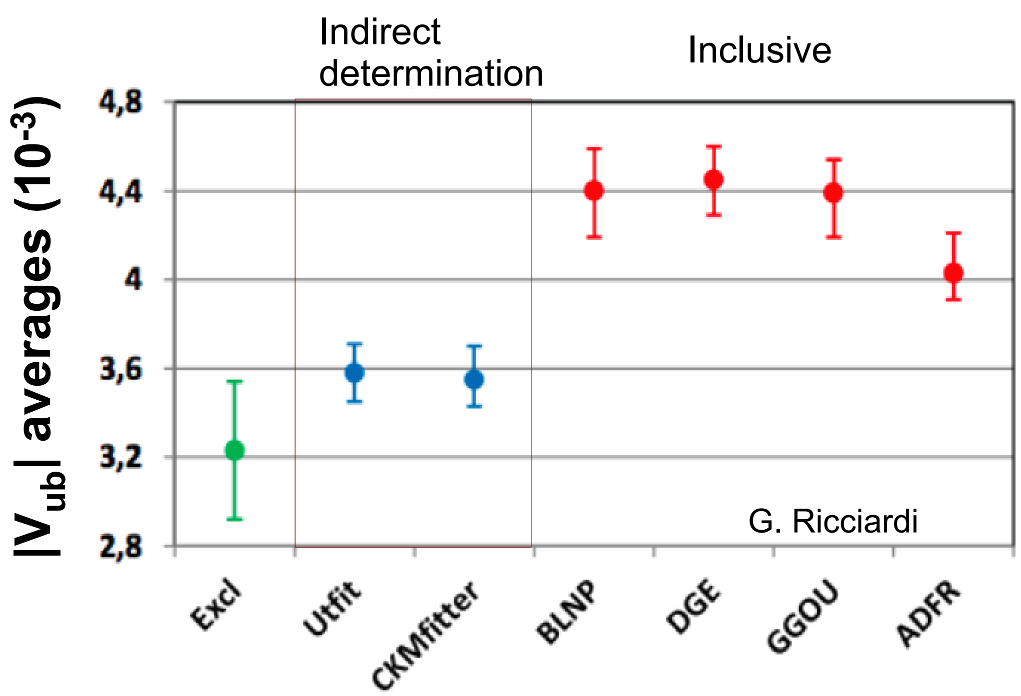


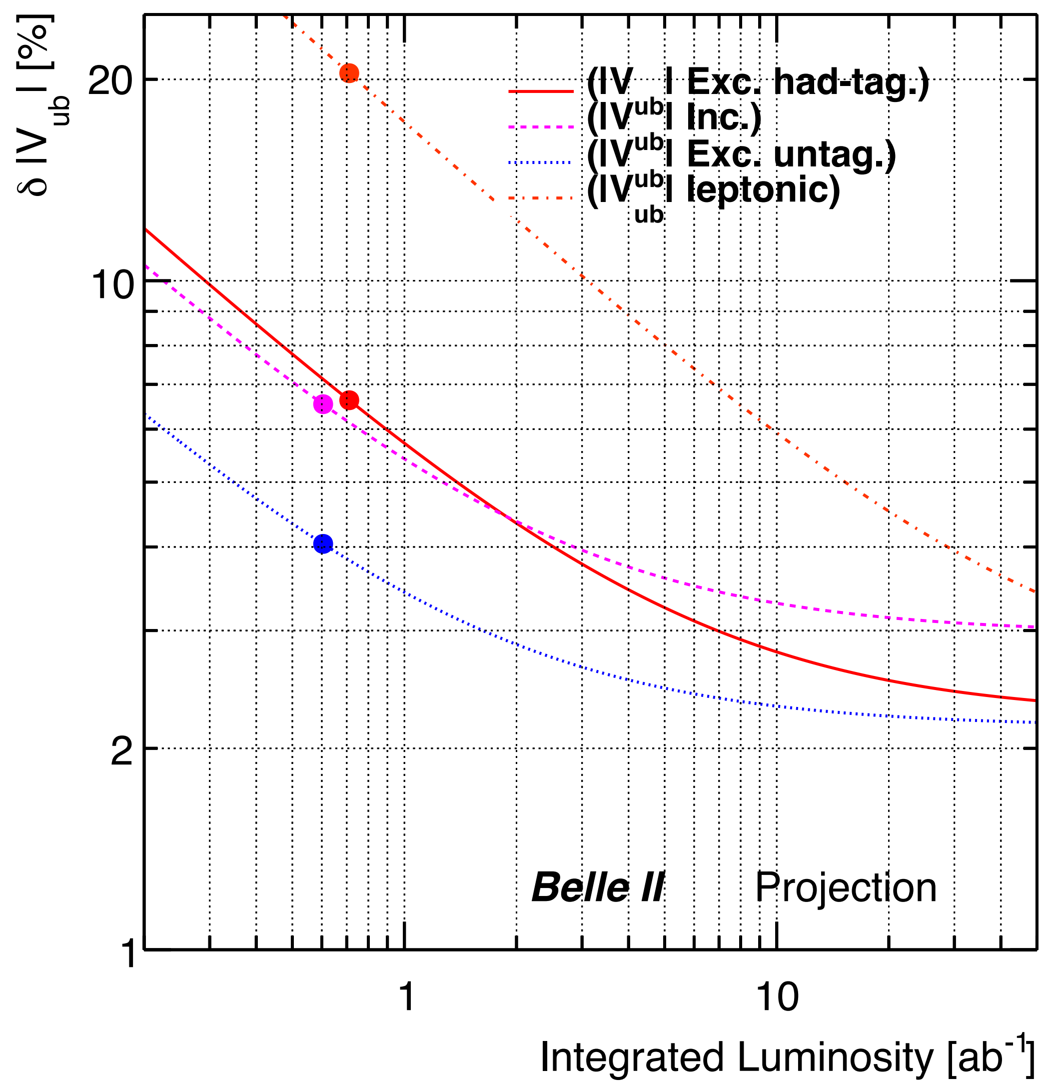
- *B → D*$^{(*)}$ τν : WA is ~5 sigma from the SM!
- ***Need differentials and more NP observables.***

But, large background ($D^{*(**)}l\nu$, D^*X)

|Vub| (& |Vcb|)

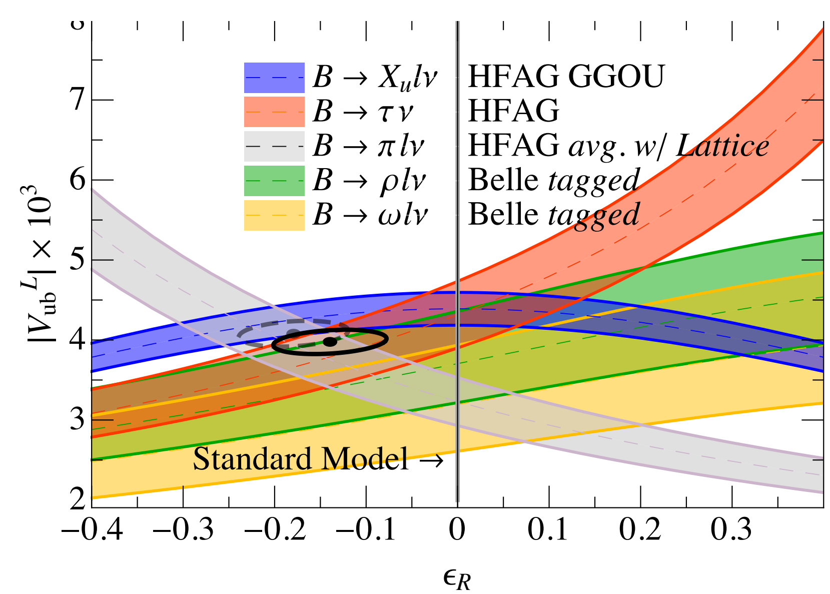
- Only Belle II can resolve |Vub/cb| exclusive/inclusive puzzles (or → NP). **Both 3 σ!**
  - → Measure decay differentials to test models & hadronisation in inclusive.
- |Vub| @ 2-3% precision for all approaches!





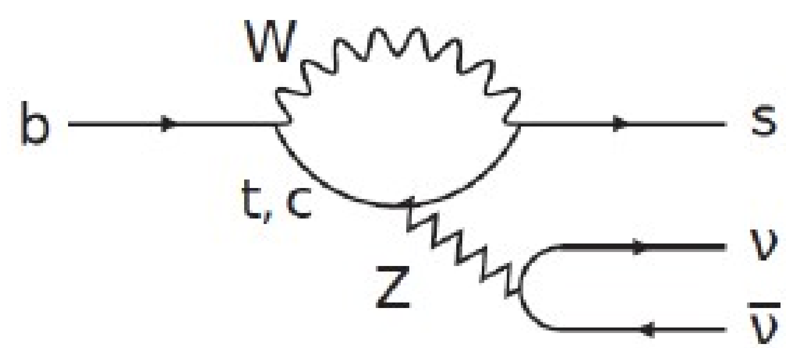
L & R current admixture

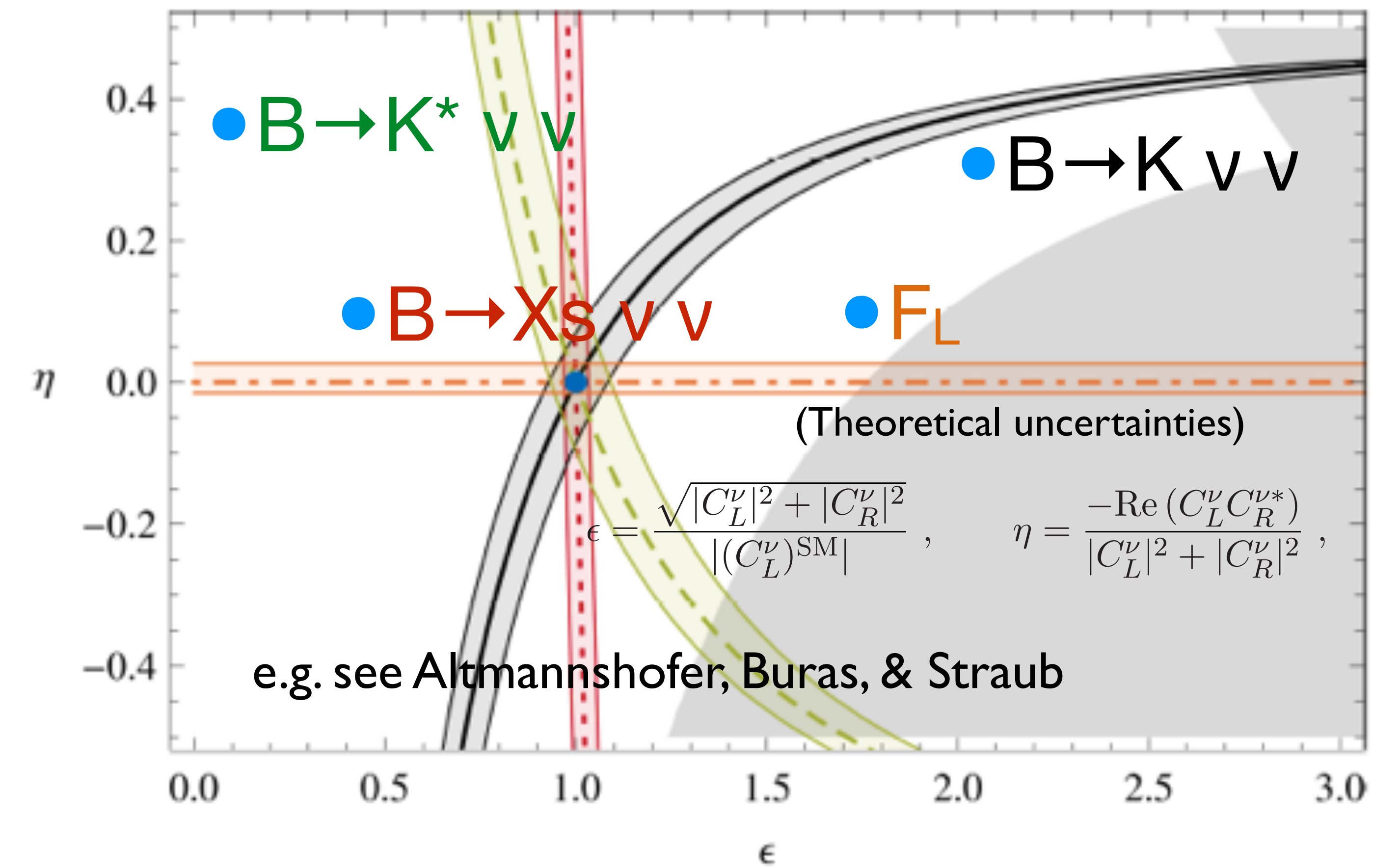
$$\mathcal{L}_{\rm eff}^{c.c.} = -\frac{4G_F}{\sqrt{2}}\,\bar{u}\gamma^\mu\left[(1+\epsilon_L)VP_L+\epsilon_R\widetilde{V}P_R\right]d\,(\bar{\ell}_L\gamma_\mu\nu_L) + \text{h.c.}$$



Favours ~TeV R handed with 15% coupling!

Di-neutrino EWP decays





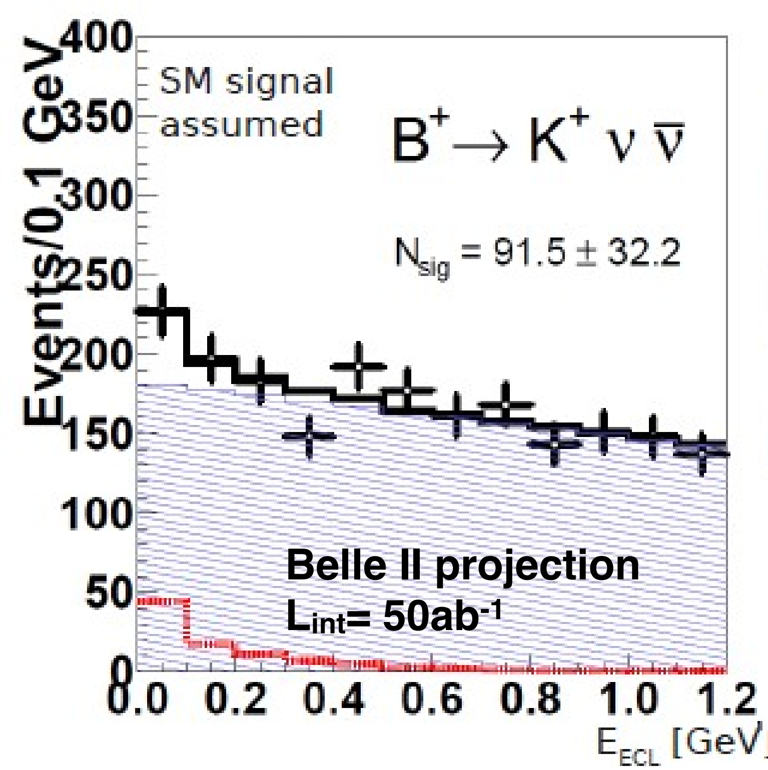
$BF(B^+ \to K^+ \nu \nu) = (4.4 \pm 0.7) 10^{-6}$

[Buchalla, NPPS 209, 137]

$BF(B^+ \to K^{*+} \nu \nu) = (6.8^{+1.0}_{-1.1}) 10^{-6}$

[Altmannshofer, JHEP 0904, 022]

- **Ultimate test of Belle II.** Further improvements to consider: tag efficiency, Calo. timing, better K_L ID.



Nsig @ Belle II ~ 100±30 based on Belle 2013 (had tag only)

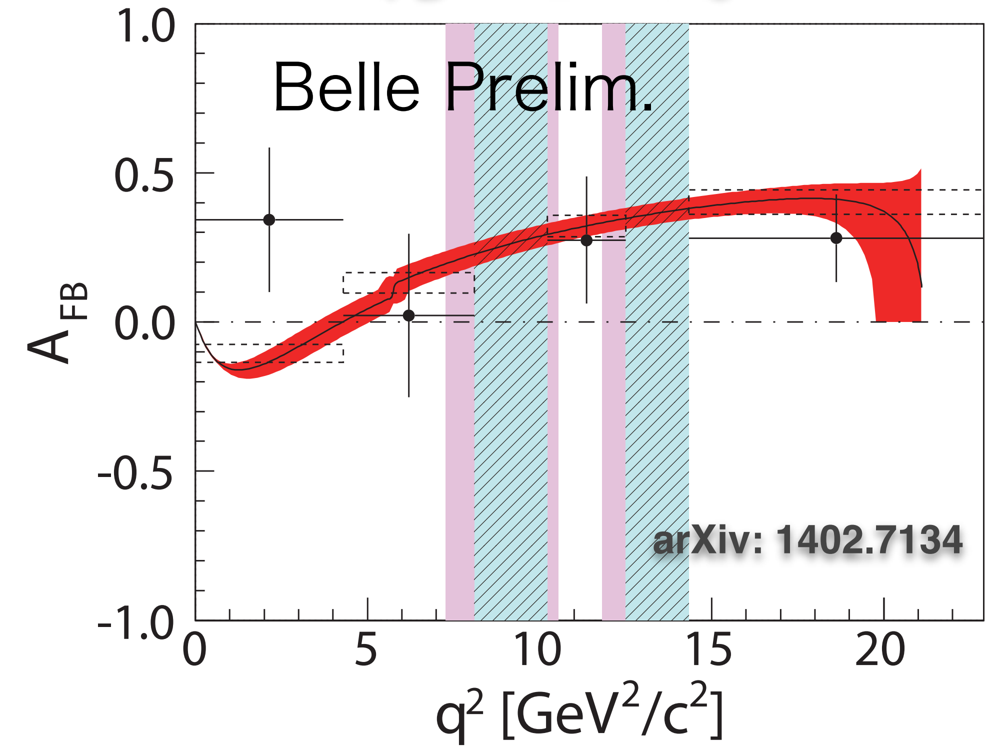
Leptonic EWP

1. **Inclusive $B \to X_s l^+ l^-$, l=e,μ**
   - More precise theory.
   - Sum of exclusive hadronic final states (BF, A_{CP}, A_I, F_L, A_{FB})

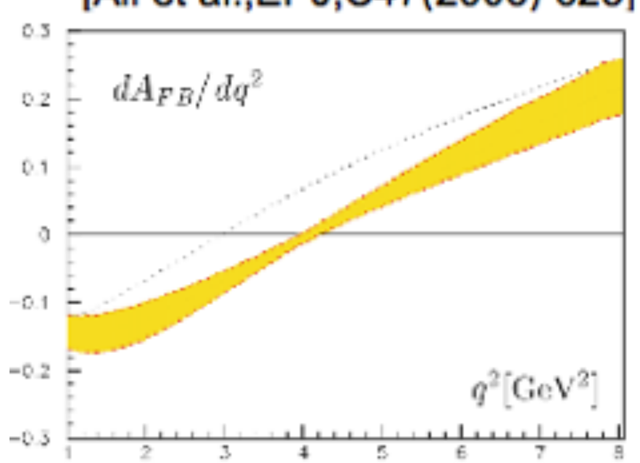
2. **$B \to \{K^*, K\} e^+ e-$**
   - Lepton Universality.
   - Photon Polarisation (low q^2).

3. **Third generation**
   - **$B \to K\tau\tau$** $<3 \times 10^{-4}$ in 50/ab
   - **$B_s \to \tau\tau$** $<2 \times 10^{-3}$ in 5/ab @ Y(5S)

A_{FB} in $B \to X_s l^+ l^-$

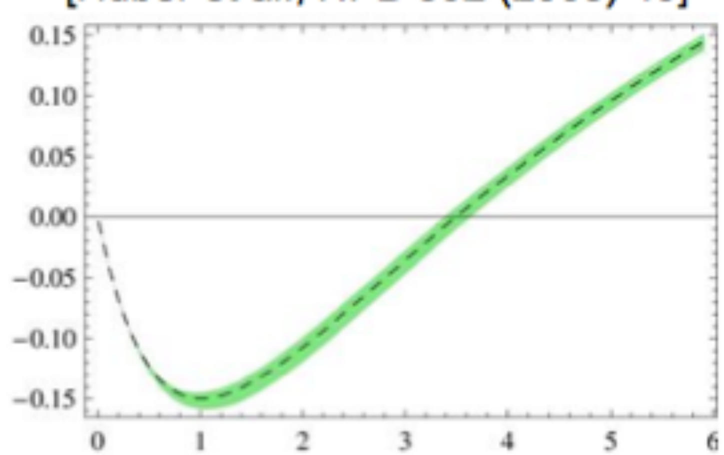


$K^* \ell^+ \ell^-$
[Ali et al.,EPJ,C47(2006) 625]



$$q_0^2 = (4.07^{+0.16}_{-0.13})\ \mathrm{GeV}^2$$

$X_s \ell^+ \ell^-$
[Huber et al., NPB 802 (2008) 40]



$$(q_0^2)_{\mu\mu} = (3.50 \pm 0.12)\ \mathrm{GeV}^2$$
$$(q_0^2)_{ee} = (3.38 \pm 0.11)\ \mathrm{GeV}^2$$

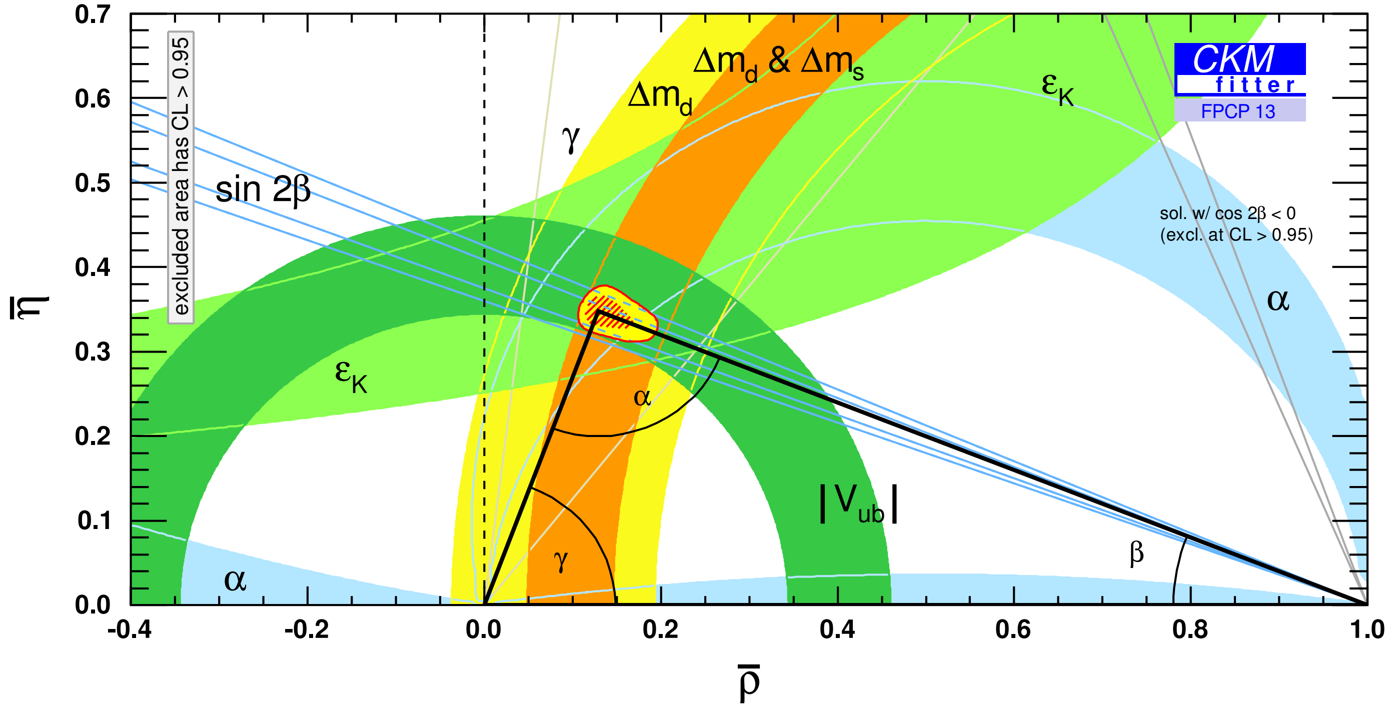
CP Violation
in B Decays

New sources of CPV?
Right handed currents?

CP Violation

in B Decays

New sources of CPV?
Right handed currents?



UT	2014	Belle II
α	4° (WA)	1°
β	0.8° (WA)	0.2°
γ	8.5° (WA) 14°(Belle)	1-1.5°

UT angle γ: Trees

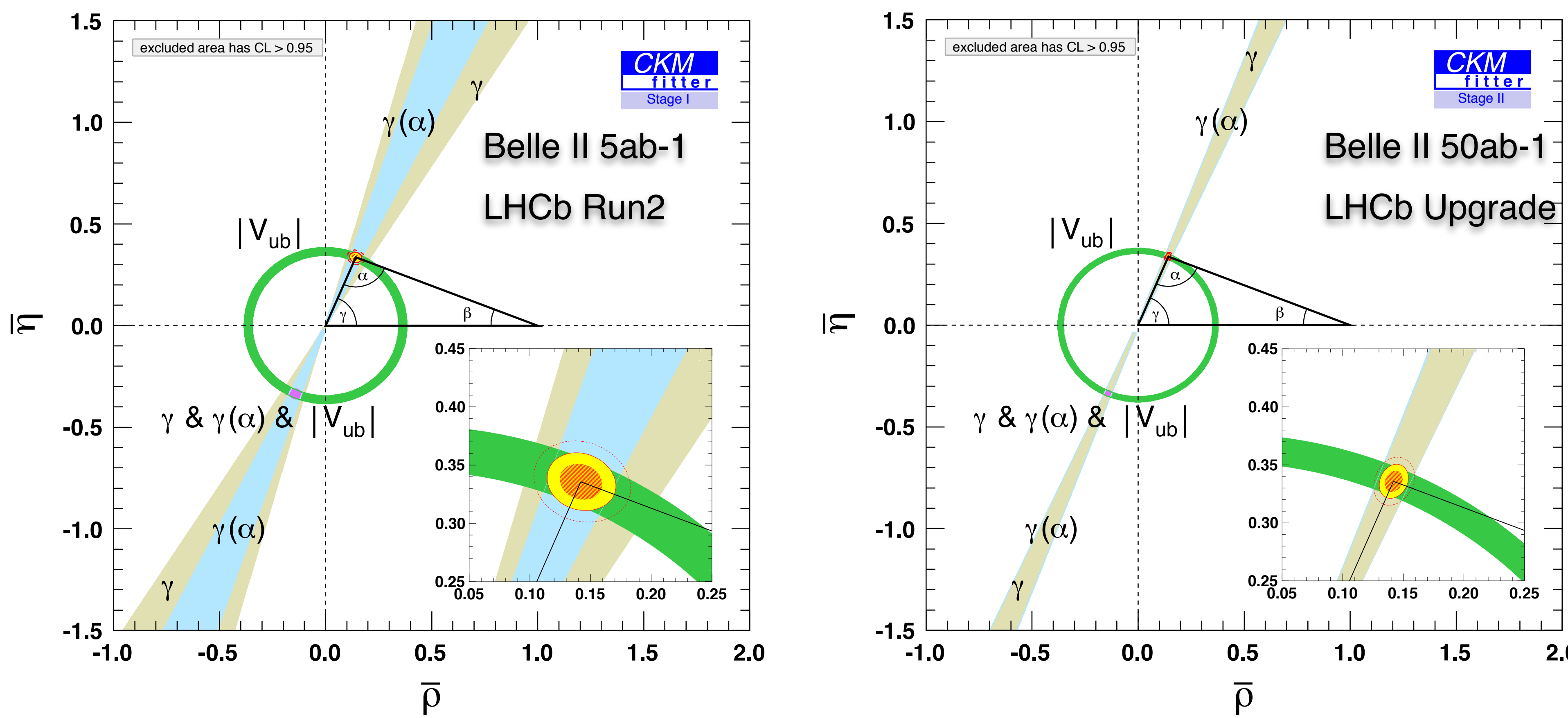
Least well measured mode:
Based on Tree-Level B→DK methods.

Belle II - Competitive with LHCb upgrade

e.g. GLW+ADS, DK, D*K, DK*

- No model error, expt. stat. error dominates @ $50ab^{-1}$
- **Combined with Dalitz, Gamma precision of 1.5°**

γ[BaBar] = $(69 \pm 17)°$
γ[Belle] = $(68 \pm 14)°$
γ[LHCb] = $(69^{+11}_{-13})°$
γ[combined] = $(68.0^{+8.0}_{-8.5})°$

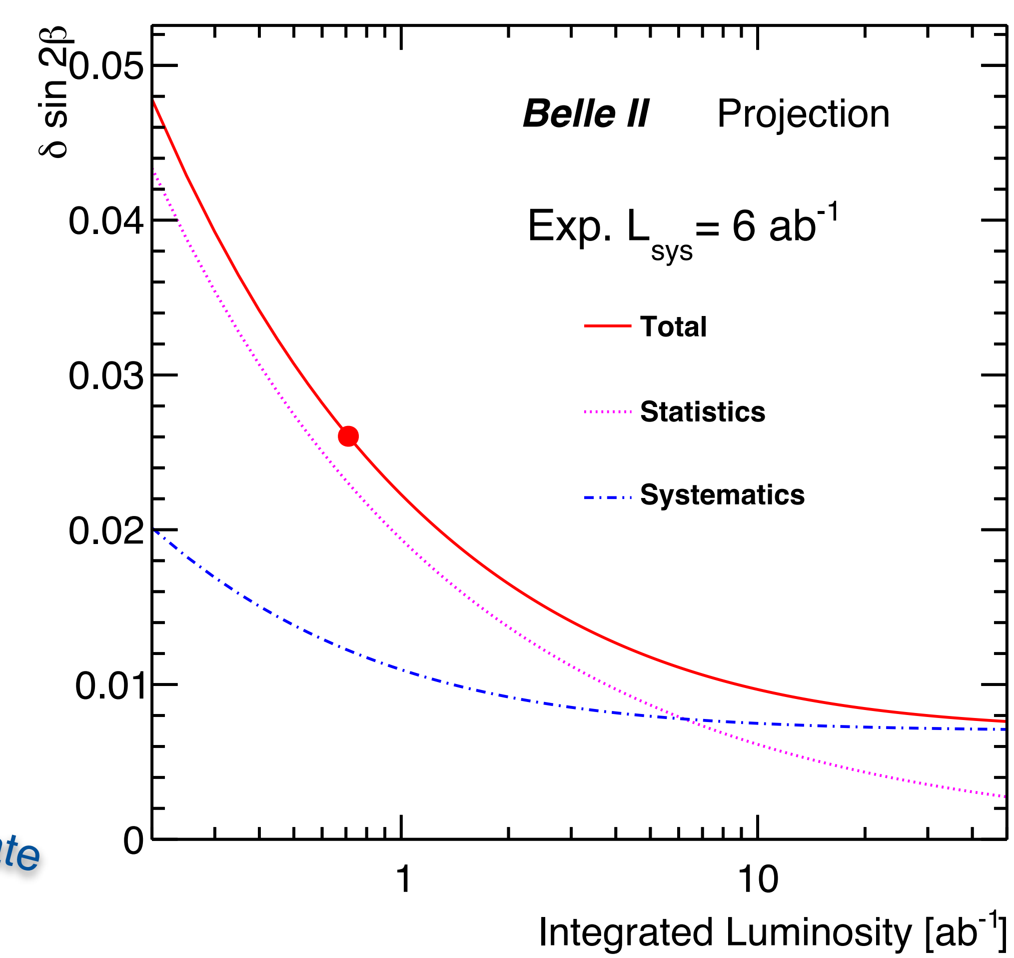


UT angle β: Loops

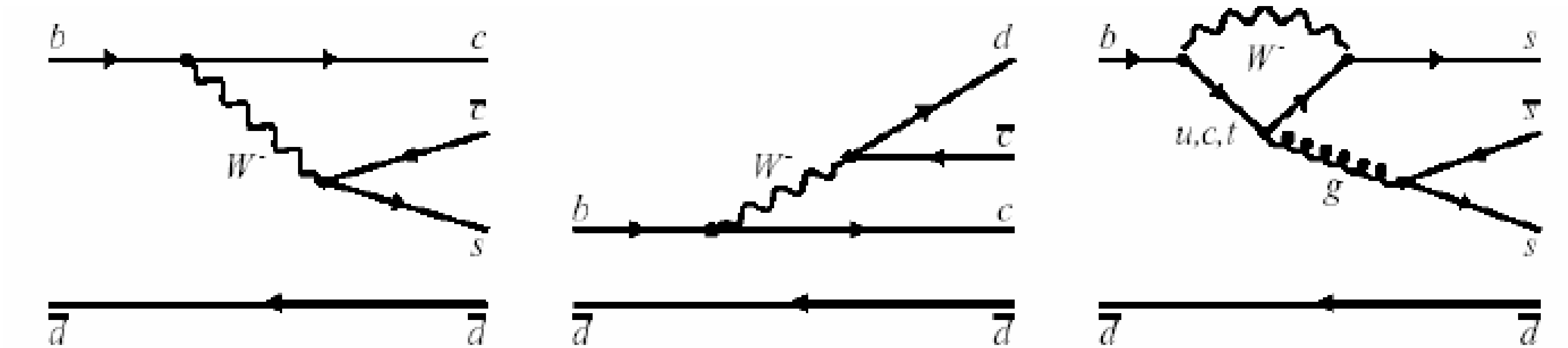
- The B-factory golden mode **stat.** limited - then **vertex** resolution
  - Improvements expected on both.
    *σ(z) on Vertex: Belle~**61μm** ⇣ Belle II~**18μm***

Source	Irreducible	Error on $\mathcal{S}$	Error on $\mathcal{A}$
Vertexing	X	± 0.007	± 0.007
Δt resolution		± 0.007	± 0.001
Tag-side interference	X	± 0.001	± 0.008
Flavor tagging		± 0.004	± 0.003
Possible fit bias		± 0.004	± 0.005
Signal fraction		± 0.004	± 0.002
Background Δt PDFs		± 0.001	< 0.001
Physics parameters		± 0.001	< 0.001
Total		± 0.012	± 0.012

Conservative estimate



New sources of CPV: b → sqq



$J/\psi K_S^0, \psi(2S)K_S^0, \chi_{c1}K_S^0,$ $\eta_c K_S^0, J/\psi K_L^0,$ $J/\psi K^{*0}(K^{*0} \to K_S^0 \pi^0)$	$D^{*+}D^-, D^+D^-$ $J/\psi\pi^0, D^{*+}D^{*-}$	$\phi K^0, K^+K^-K_S^0,$ $K_S^0 K_S^0 K_S^0, \eta' K^0, K_S^0\pi^0,$ $\omega K_S^0, f_0(980)K_S^0$

increasing tree diagram amplitude ←

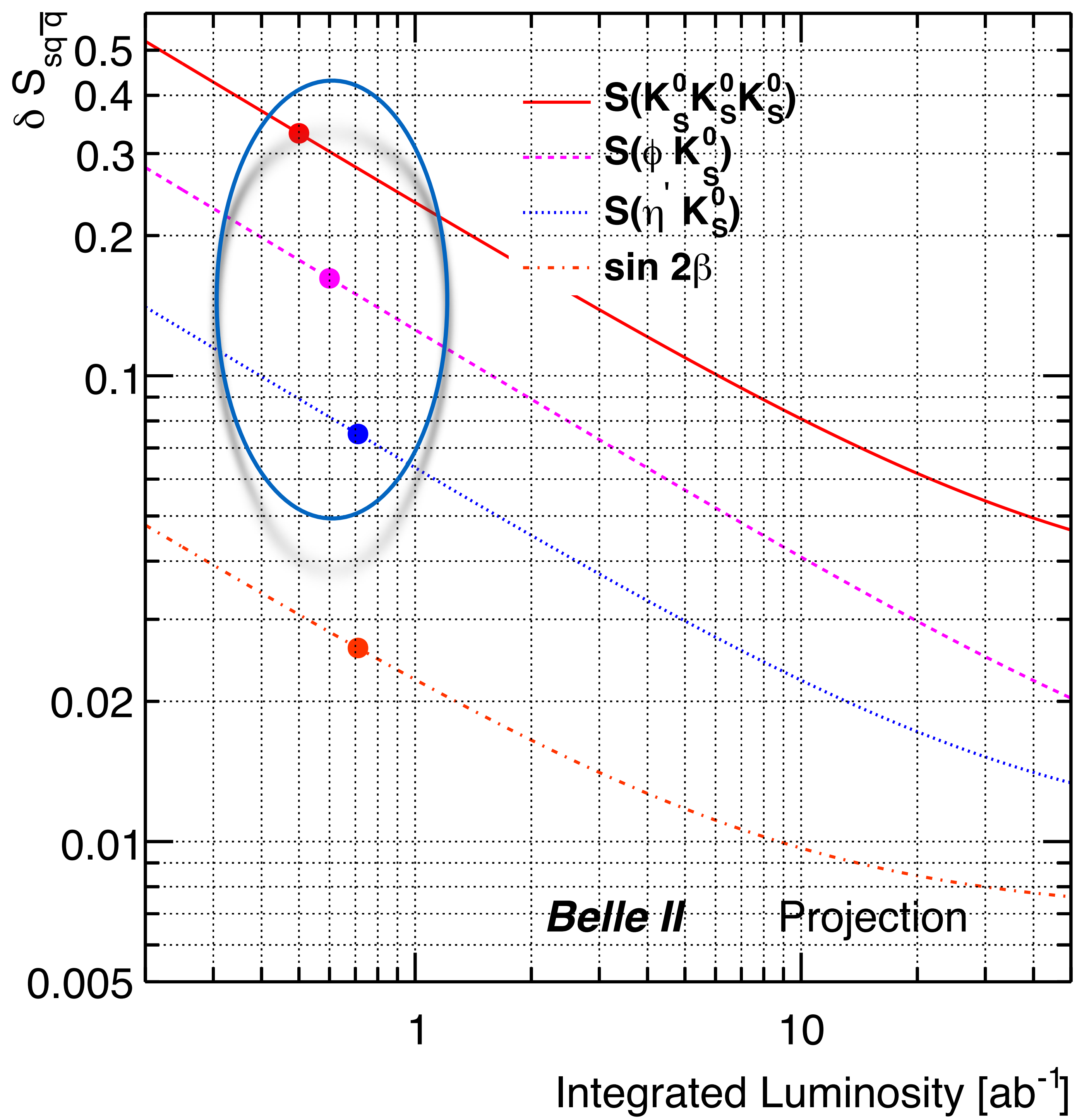
→ increasing NP sensitivity

SM: b→s Penguin
phase = $(c\bar{c})$ K^0

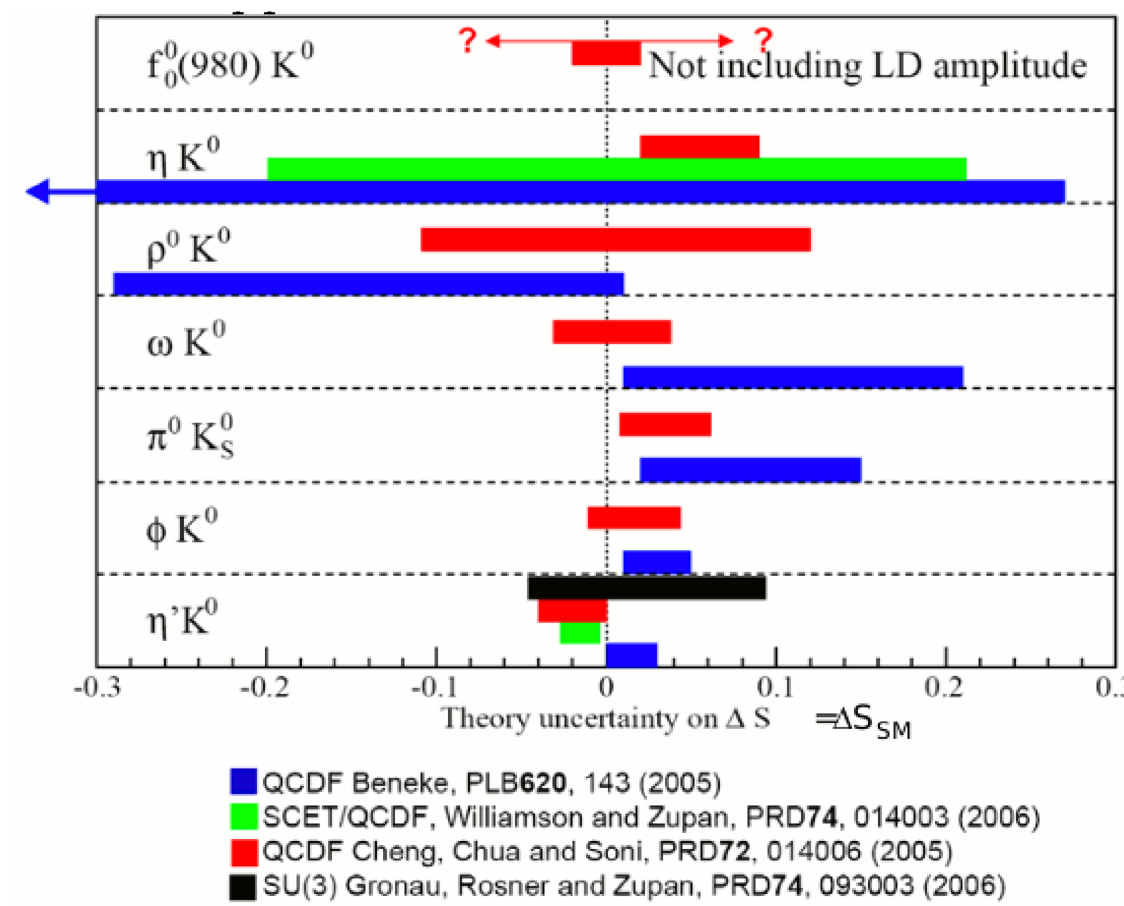
+ New Physics
with New Phase

Penguin β

New Sources of CP Violation



Firm SM upper bound required

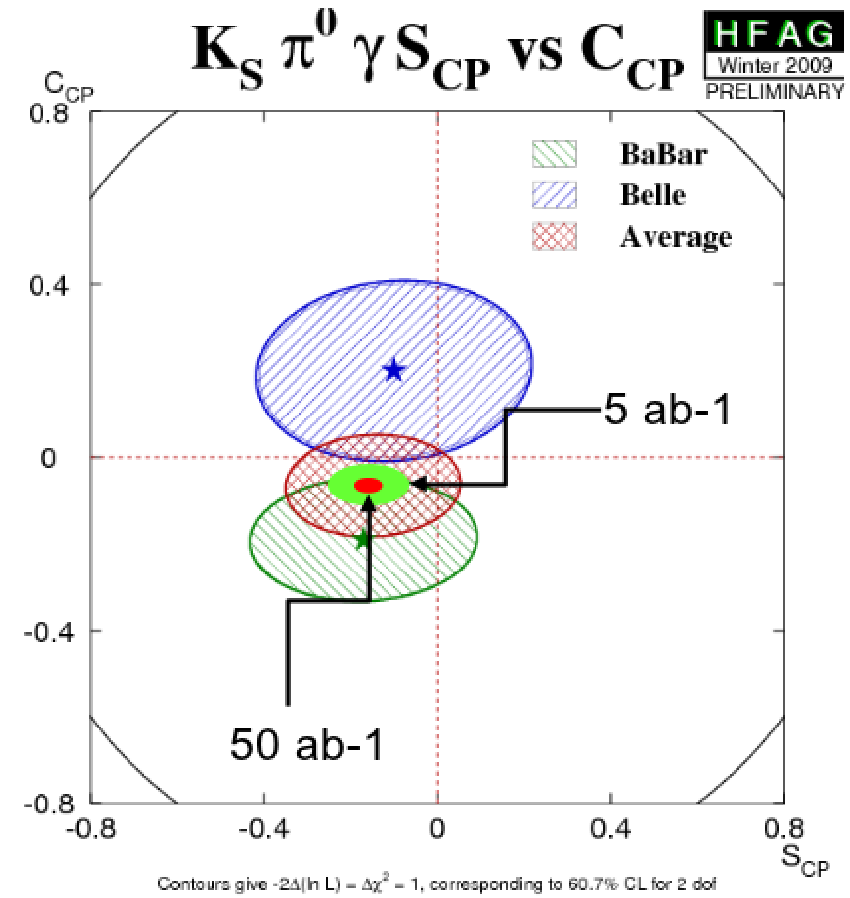


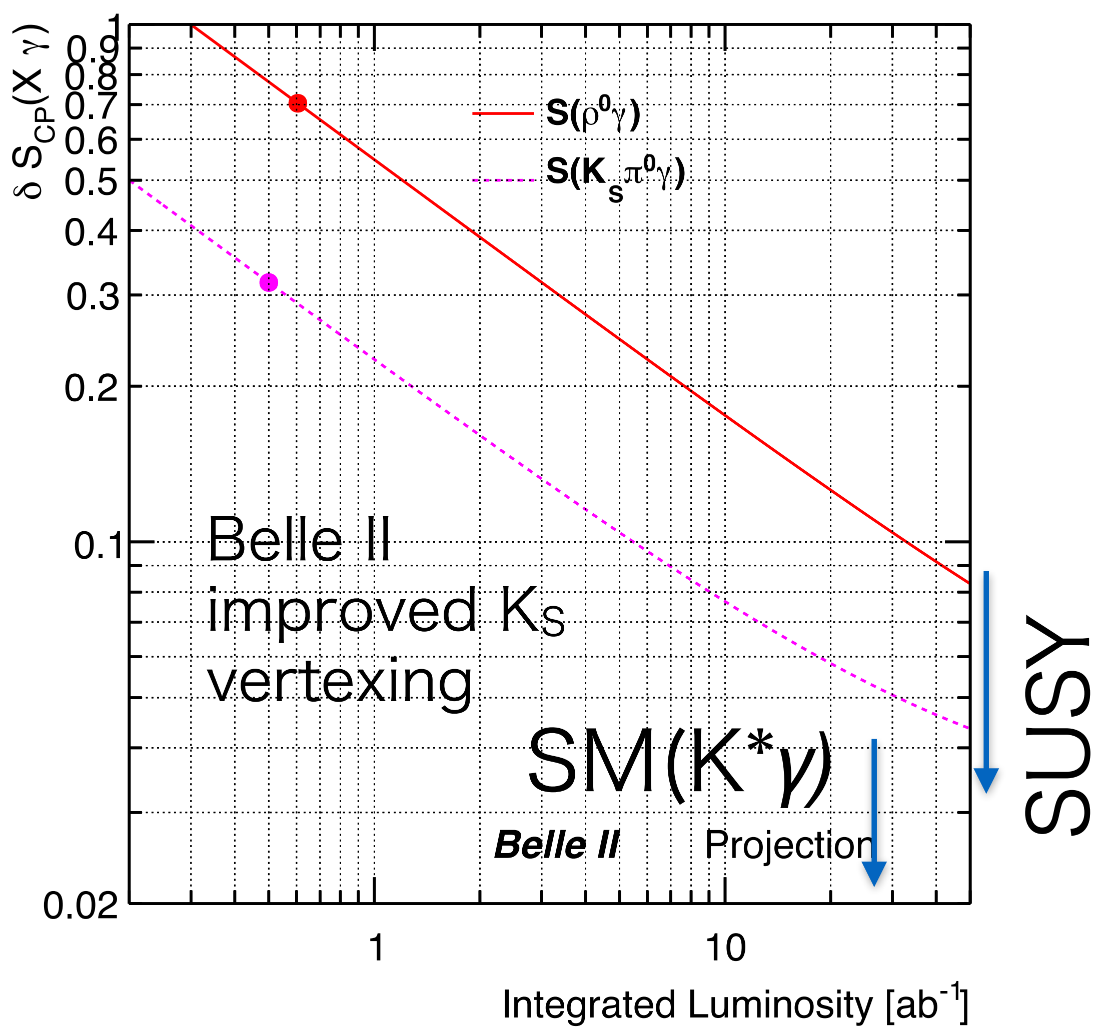
Prospect	$\delta(S_{b\to s})$ ~ 0.012 @ 50ab^{-1}

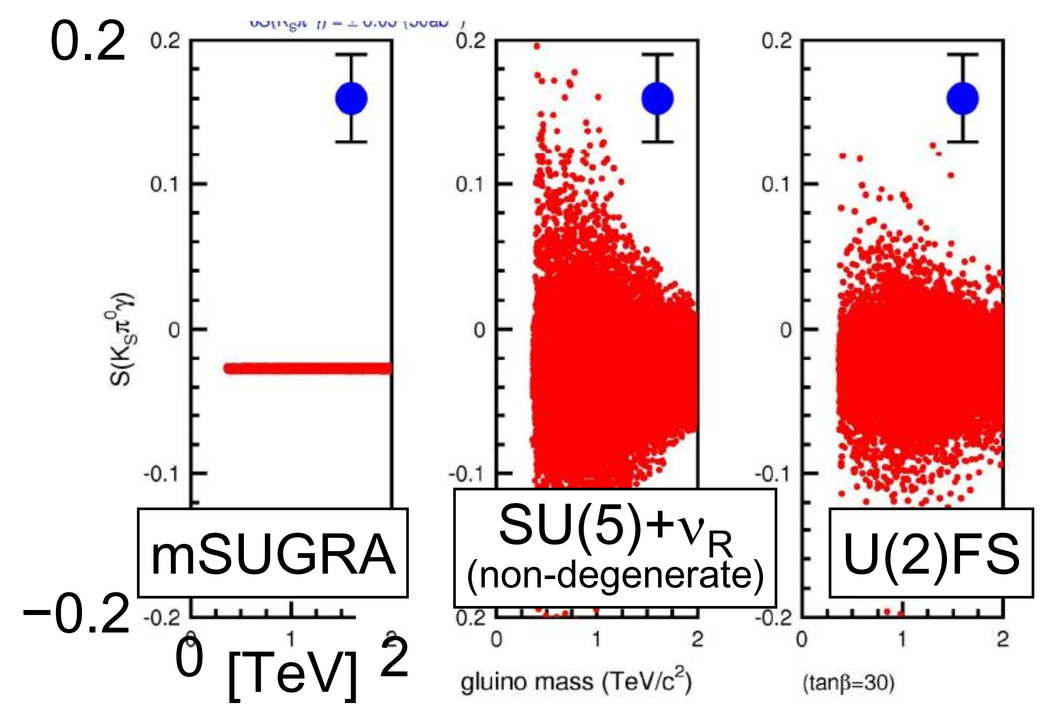
Mixing induced CPV in Radiative Penguins

$$\mathcal{A}(\Delta t) = S sin(\Delta m \Delta t) + A cos(\Delta m \Delta t)$$

- SM EW is purely L-handed.
- γ from b→s(d)γ is almost L-handed.
- R-handed current is a signature of NP
  $S=-2(m_s/m_b)\sin(2\phi_1)\sim-0.03 \rightarrow 0.5$ in NP







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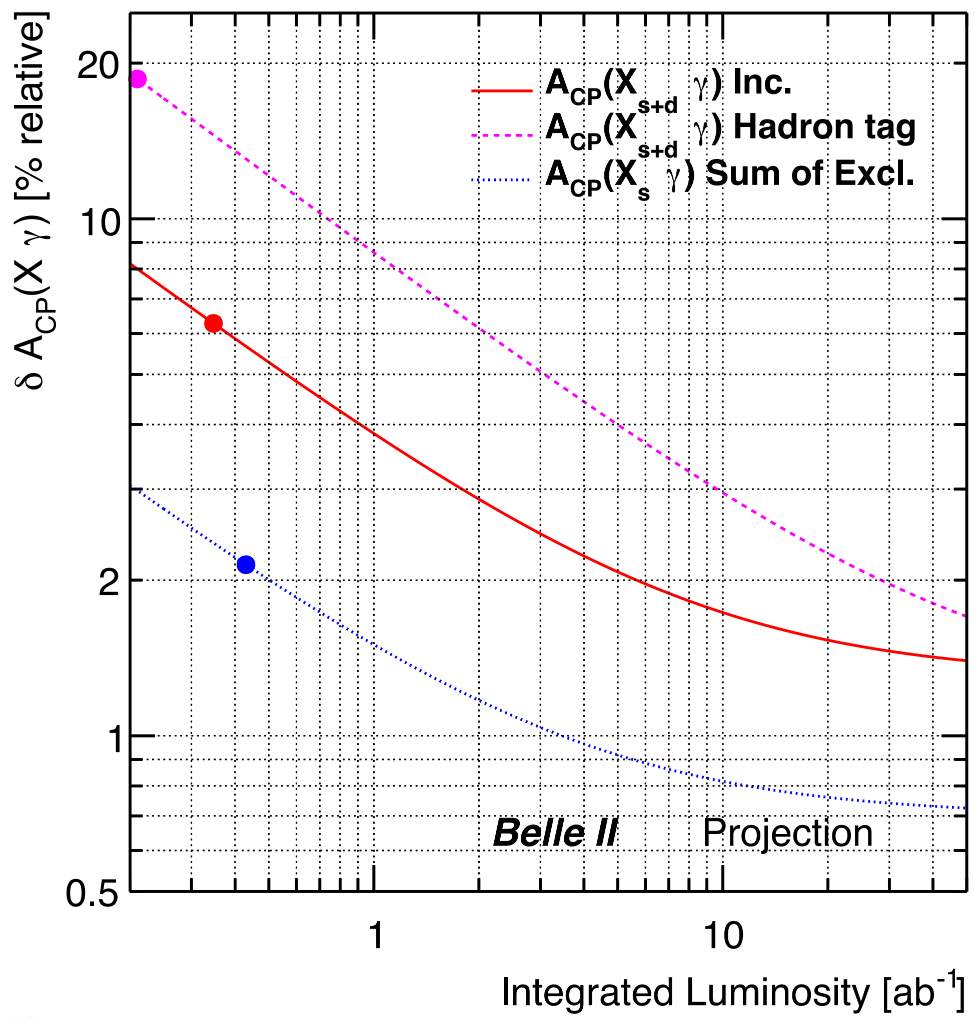
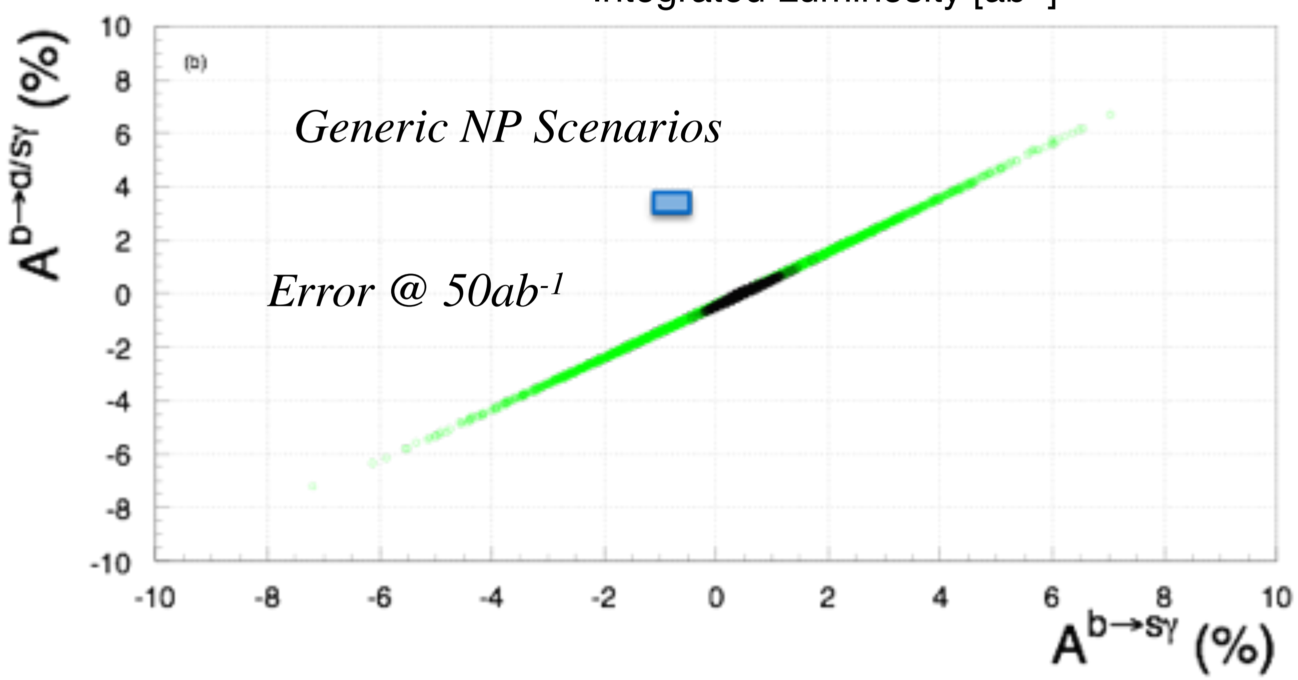
Direct CPV in Radiative B decays



Precise probes of CPV
Test flavour structure!

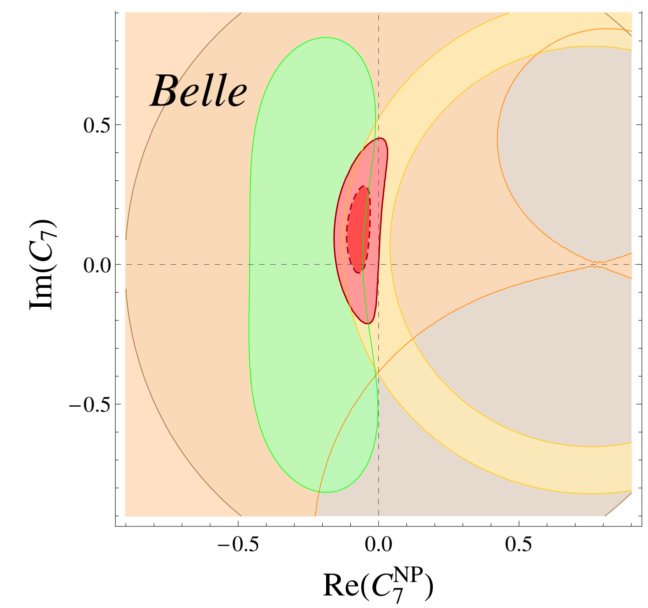


Dipole operators

$$O_7^{(\prime)} = \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_{R(L)}b)F^{\mu\nu}$$

Constraints on C_7^{NP}(160 GeV) from

$BR(B \to X_s\gamma)$, $A_{CP}(B \to X_s\gamma)$,
$B \to K^*\mu\mu$, $B \to X_s\mu\mu$

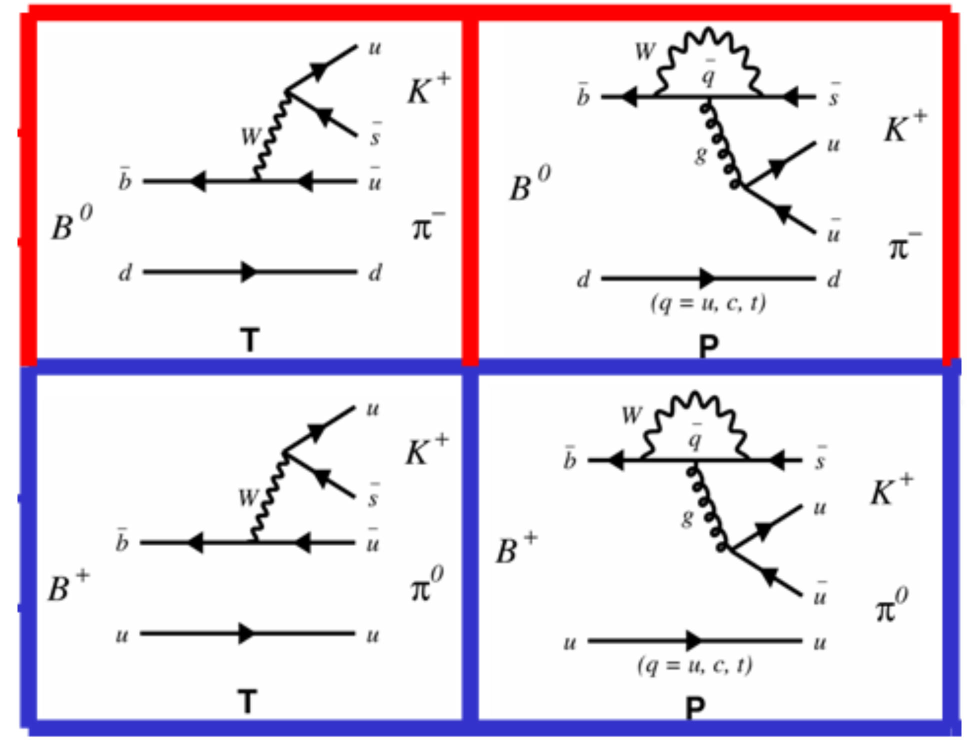


Direct CPV in B→Kπ (K$^{(0)}\pi^0$)

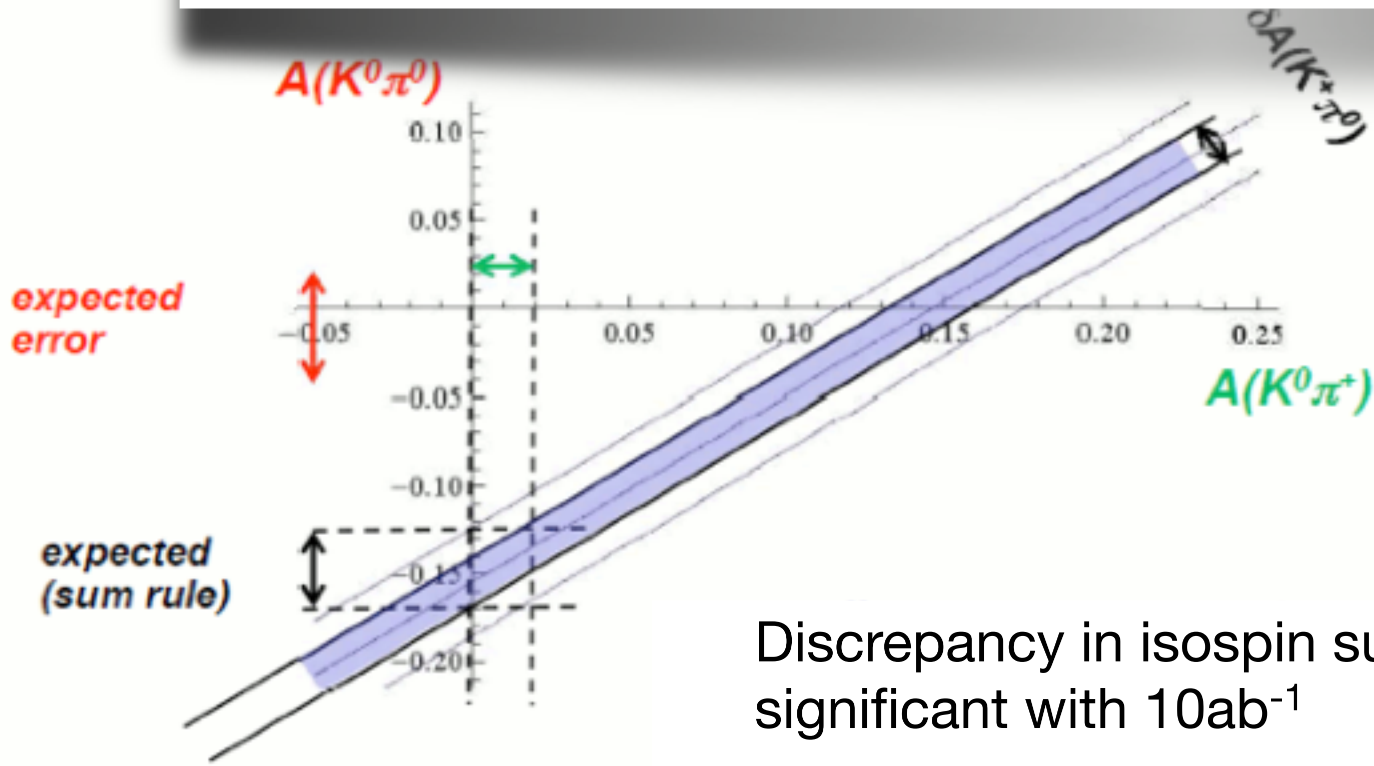
- A_{CP} in hadronic modes cannot be understood without complete isospin analyses.
- Sum rule approach needs neutrals

$B^0 \to K^+\pi^-$

$B^+ \to K^+\pi^0$



$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{Br(K^0\pi^+)}{Br(K^+\pi^-)}\frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0)\frac{2Br(K^+\pi^0)}{Br(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0)\frac{2Br(K^0\pi^0)}{Br(K^+\pi^-)}$$



Discrepancy in isospin sum rule may be significant with 10ab^{-1}

Direct CPV in B→Kπ (K$^{(0)}\pi^0$)

- A_{CP} in hadronic modes cannot be understood without complete isospin analyses.

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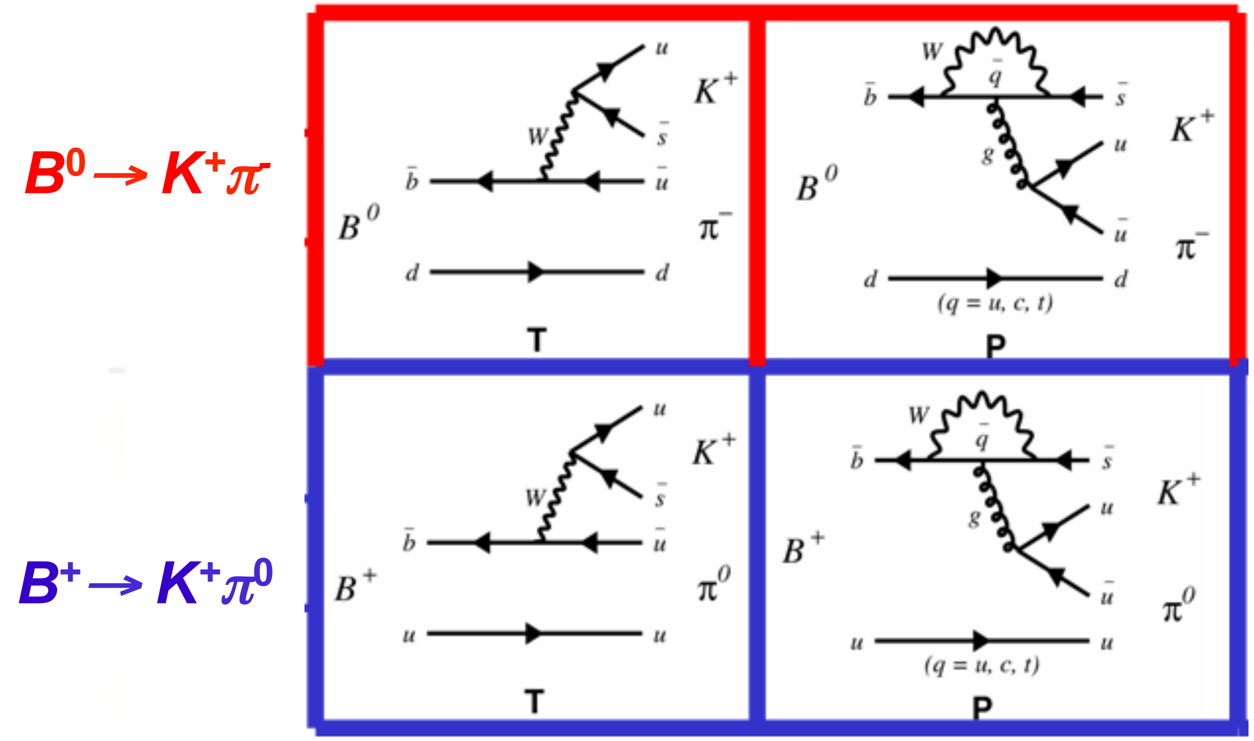
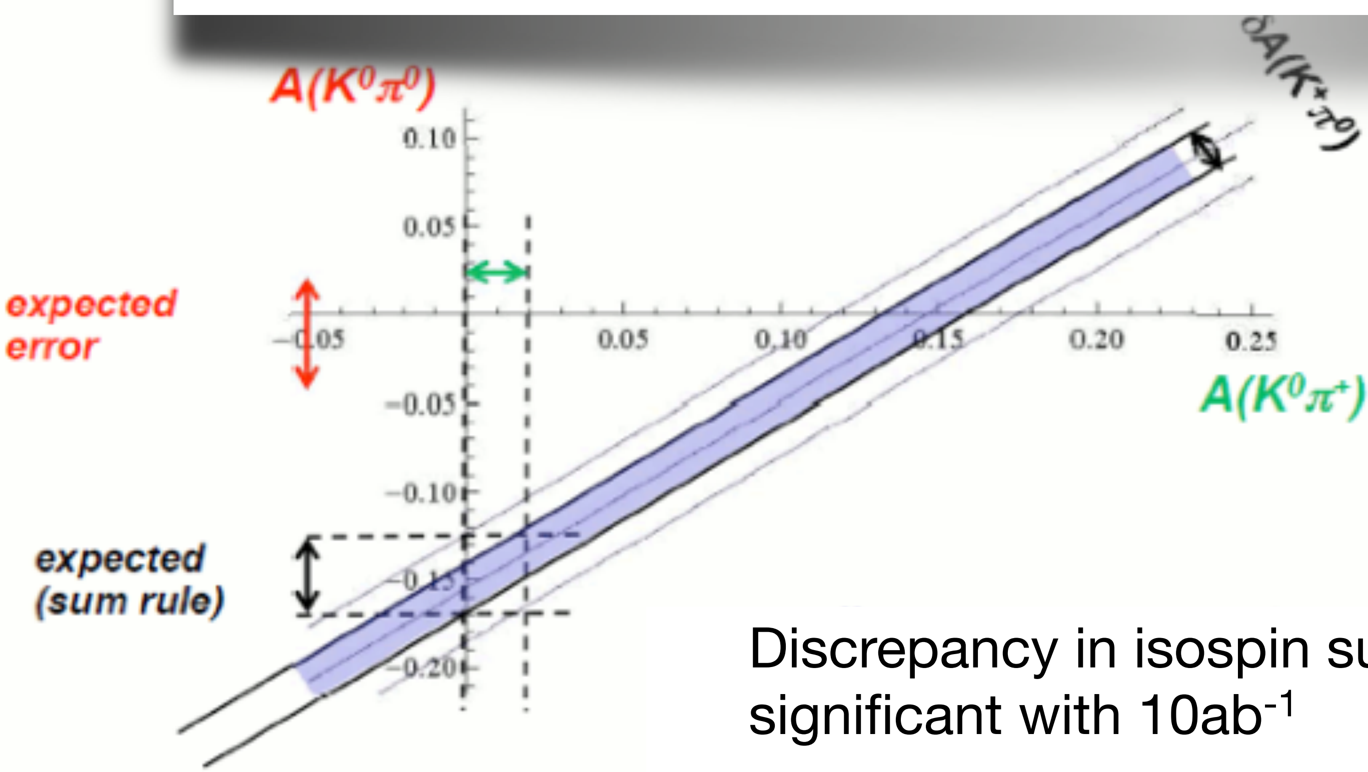


$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{Br(K^0\pi^+)}{Br(K^+\pi^-)}\frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0)\frac{2Br(K^+\pi^0)}{Br(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0)\frac{2Br(K^0\pi^0)}{Br(K^+\pi^-)}$$



$A_{CP}(K^+\pi^-) - A_{CP}(K^+\pi^0)$ = -0.122 ± 0.022

(5.6σ difference from zero)

$A(K^0\pi^0)$ = 0.006± 0.06 (stat limited

$A(K^0\pi^+)$ = -0.015± 0.019

$A(K^+\pi^0)$ = 0.040± 0.021

$A(K^+\pi^-)$ = -0.082± 0.006

Discrepancy in isospin sum rule may be significant with 10ab^{-1}

Charm

Analogous tests for up type NP.

Direct CPV in Charm

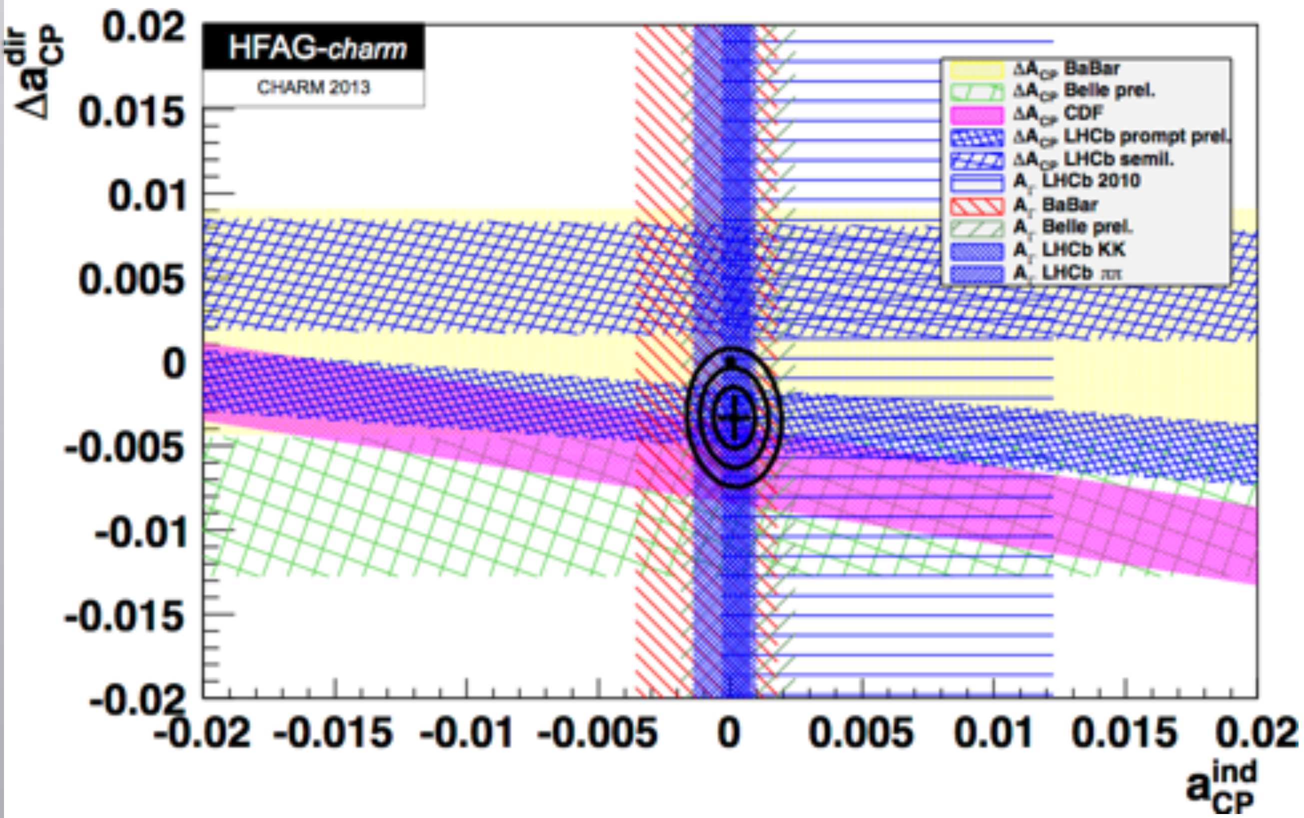
CPV from Production+detection+physics

$$A_{raw}(f)=A_{CP}(f)+A_D(\pi_s)+A_P(D^{*+})$$

LHCb measures the diff. to cancel systematics.

$$\Delta A_{CP} \equiv A_{CP}(K^- K^+) - A_{CP}(\pi^- \pi^+)$$

$=(-0.34 \pm 0.15 \pm 0.10)\%$, *π tagged*
$=(+0.49 \pm 0.30 \pm 0.14)\%$, *μ tagged*
$=(+0.14 \pm 0.16_{(stat)} \pm 0.08_{(syst)})\%$. *SLB*



SM prediction unclear however.

→Problems Analogous to DCPV in B system.

requires A_{CP} & measure of long distance effects.
e.g. $D\to\pi^0\pi^0$, $\pi^+\pi^0$, $D\to h^+h^-\gamma$

Using Belle(1 ab^{-1}),$\sigma(A_{\pi^0\pi^0})\sim 1\%$
⇒ o(0.1%) at Belle II

Direct CPV in Charm

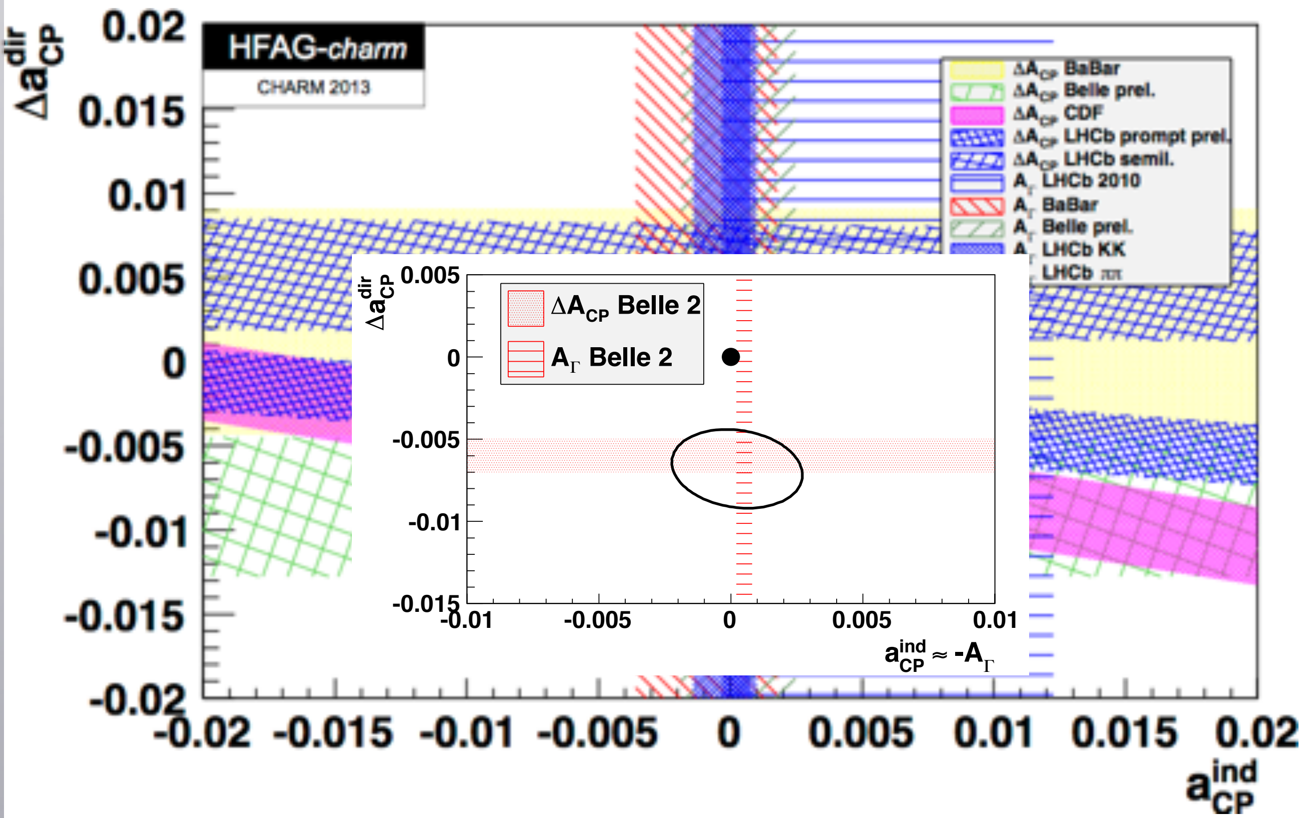
CPV from Production+detection+physics

$$A_{raw}(f)=A_{CP}(f)+A_{D}(\pi_s)+A_{P}(D^{*+})$$

LHCb measures the diff. to cancel systematics.

$$\Delta A_{CP} \equiv A_{CP}(K^- K^+) - A_{CP}(\pi^- \pi^+)$$

=(–0.34 ± 0.15 ± 0.10)%, π tagged
=(+0.49 ± 0.30 ± 0.14)%, μ tagged
=(+0.14±0.16$_{(stat)}$±0.08$_{(syst)}$)% . SLB



SM prediction unclear however.

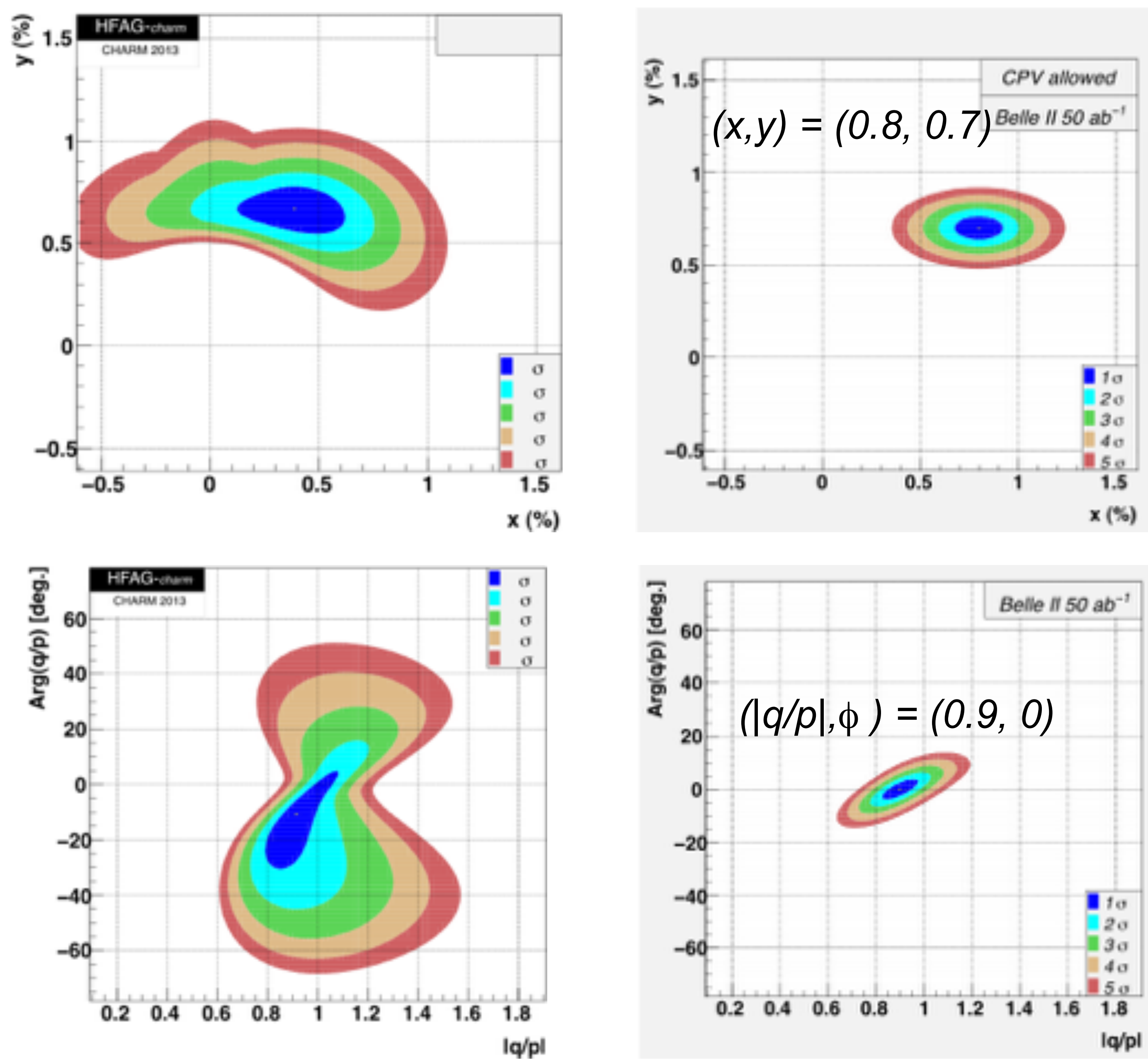
→Problems Analogous to DCPV in B system.

requires A_{CP} & measure of long distance effects.
e.g. $D\to\pi^0\pi^0$, $\pi^+\pi^0$, $D\to h^+h^-\gamma$

Using Belle(1 ab^{-1}),σ($A_{\pi 0 \pi 0}$)~1%
⇒ o(0.1%) at Belle II

Charm mixing and CPV in mixing

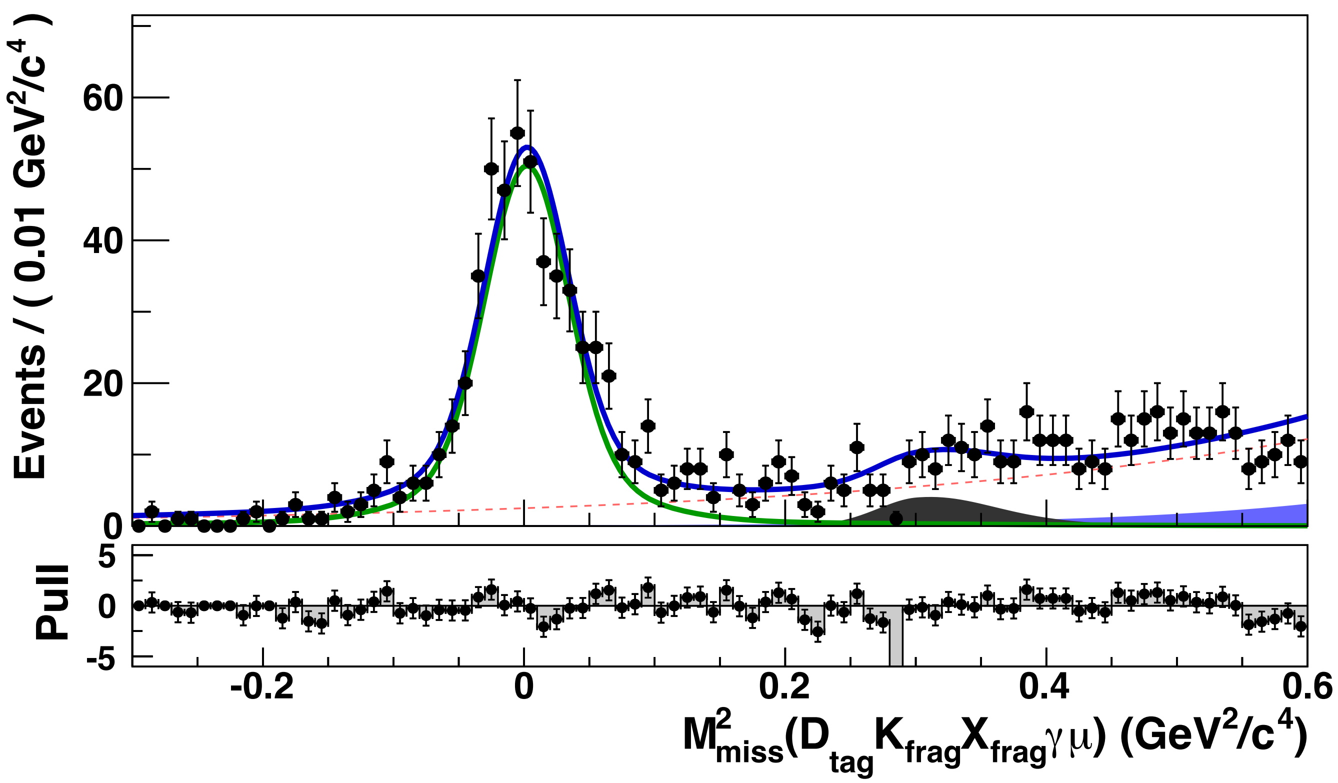
- Belle II **good in A_{CP}** due to symmetric D-meson production; sensitivity would reach 0.03% level. (LHCb may provide competition, arXiv:1405.2797)
  - Belle II **competitive in x'^2, y' and y_{CP}**



Charm Recoil Techniques

- Based on B-beam techniques.
- Powerful, precise tests of LQCD and NP in (semi)leptonics.

$$e^+e^- \rightarrow c\bar{c} \rightarrow \overline{D}_{\rm tag} X_{\rm frag} D^{(*)}_{\rm recoil}$$



- Many modes to explore, e.g.
  - **$D_s \rightarrow \mu\nu$(@1%), $\tau\nu$(@3%) precision**
  - **$D \rightarrow \nu\nu$:** New scalars (e.g. Dark Matter).
  - **$D \rightarrow \gamma\gamma$:** Expect to reach ~$10^{-7}$ (Measures long distance contributions to 2-μ mode.)

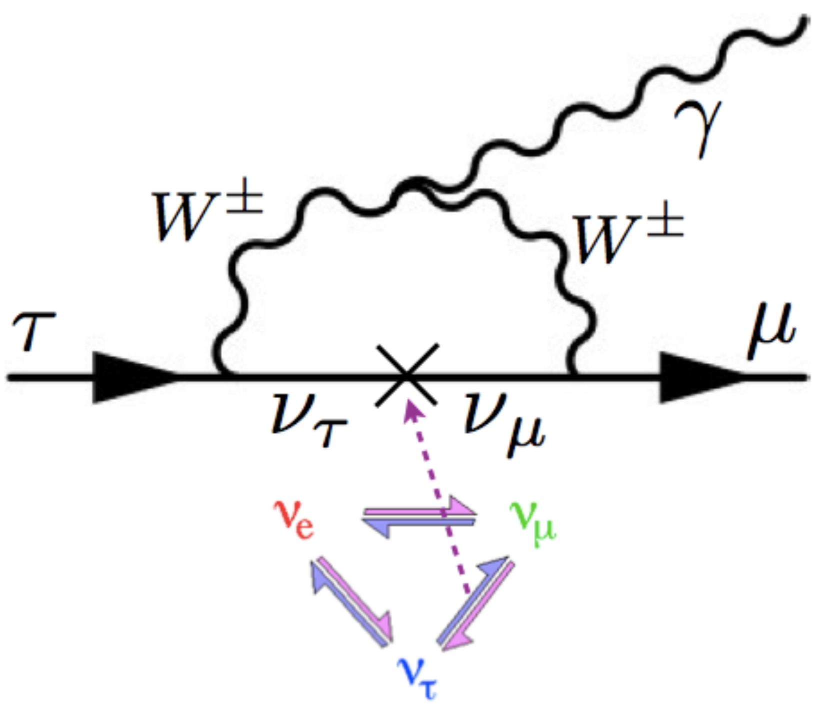
- Rare modes: ργ, Φγ → 1% (NP up to 10%)

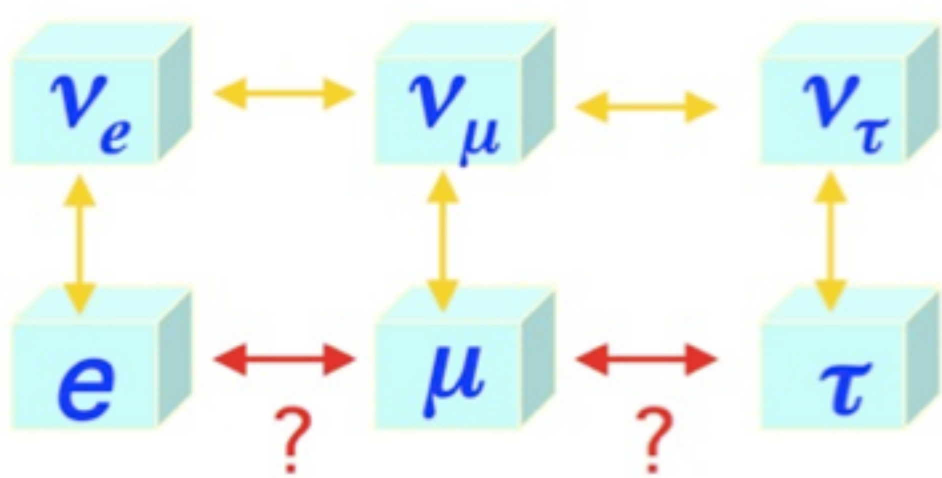
τ-lepton

Sources of LFV?
New sources of CPV?

τ Lepton Flavour Violation: m→mGUT

- LFV is a **theoretically clean** null test of the SM: BF~10^{-25}
- 2 / 3 lepton “mixing” types studied at **Belle II.**

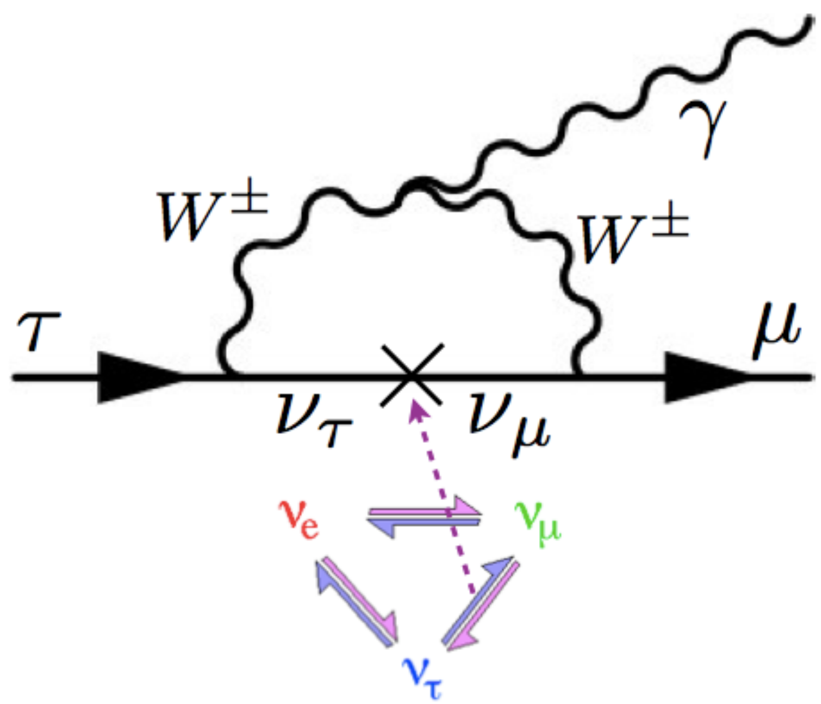




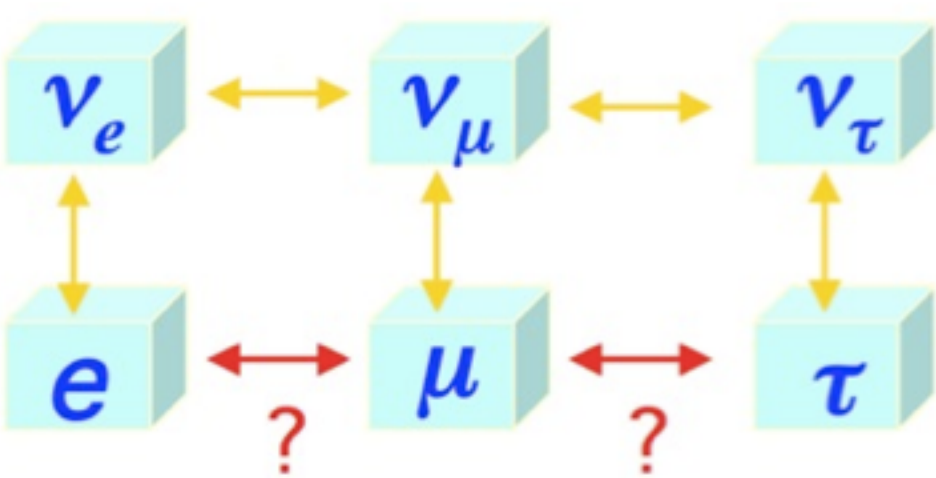
Tau LFV

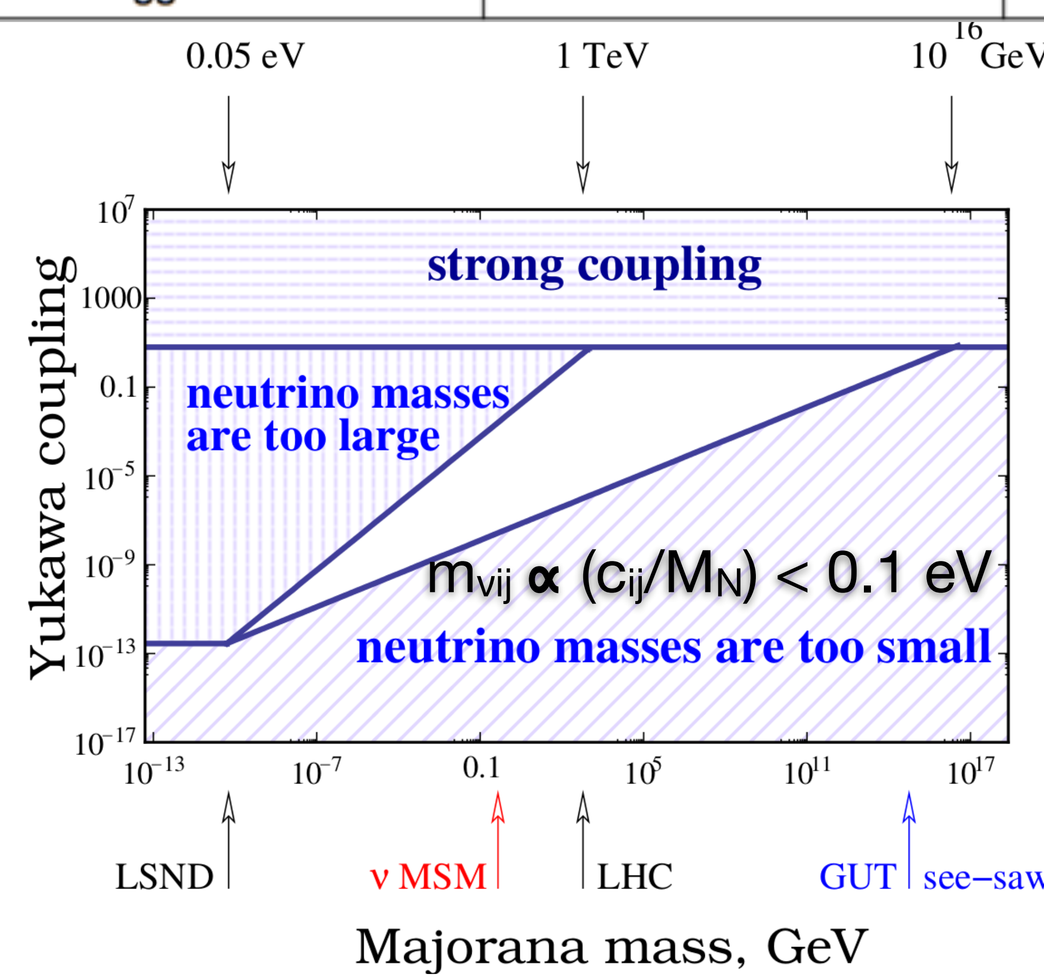
τ Lepton Flavour Violation: m→mGUT

- LFV is a **theoretically clean** null test of the SM: BF~10^{-25}
- 2 / 3 lepton "mixing" types studied at **Belle II.**



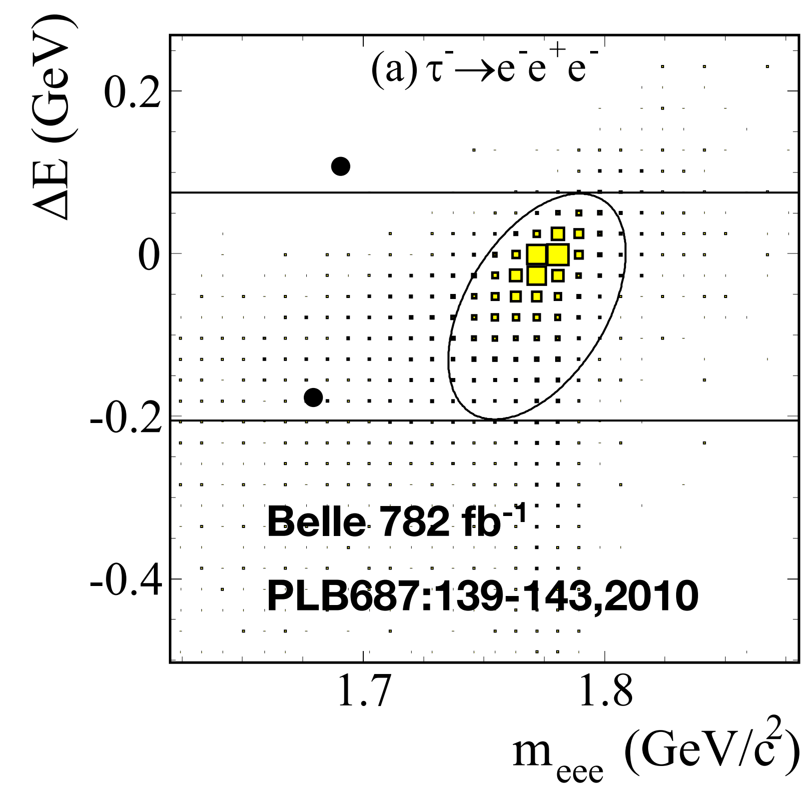
	reference	$\tau\to\mu\gamma$	$\tau\to\mu\mu\mu$
SM + heavy Maj ν_R	PRD 66(2002)034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547(2002)252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68(2003)033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66(2002)115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566(2003)217	10^{-10}	10^{-7}

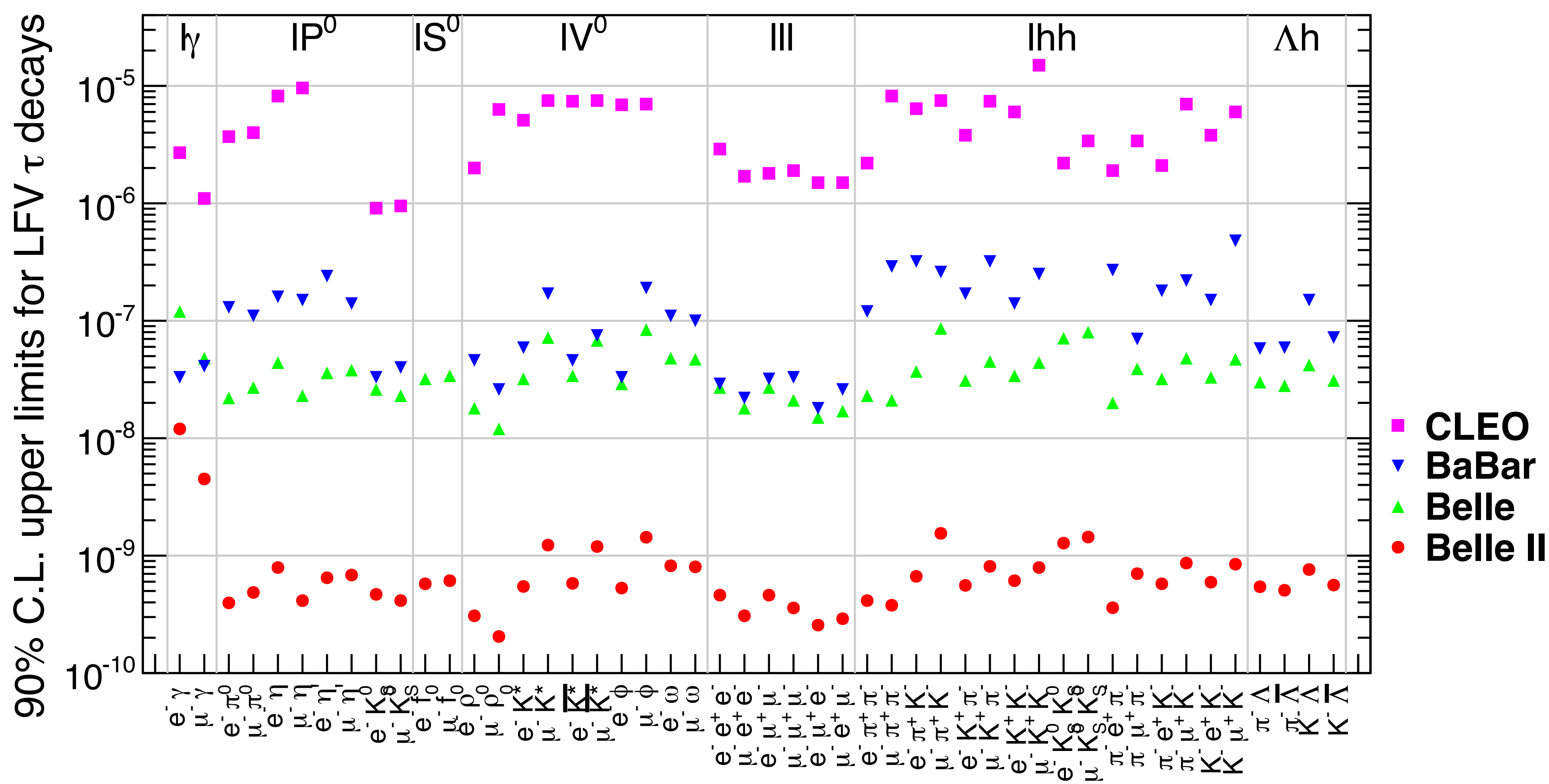




LFV decays

- Up to 50x improvement: very clean!
- LHC not so competitive- trigger and track p_T limiting (even μμμ).
- CPV in τ: comparable limits on NP.





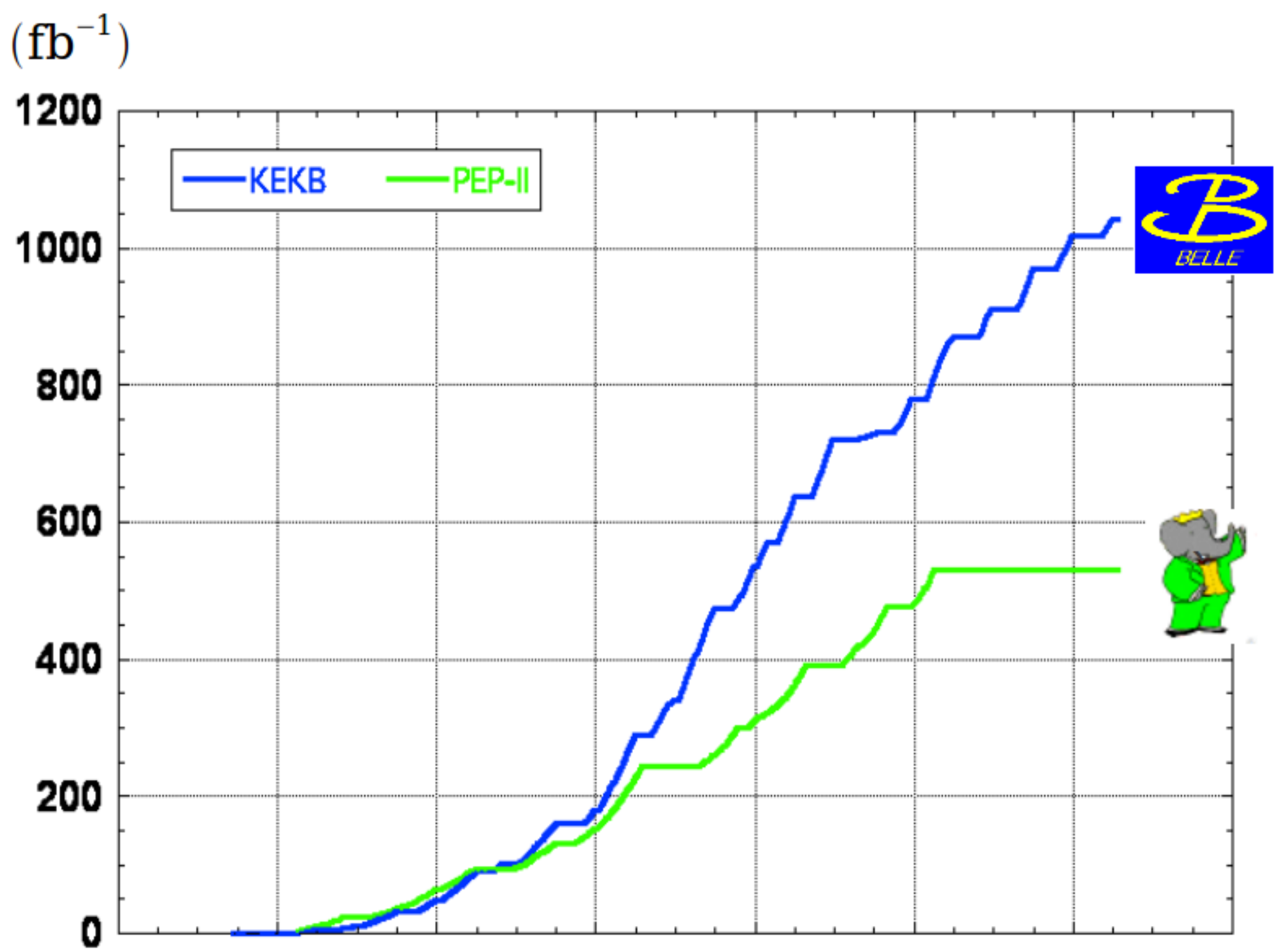
Tau LFV

First year physics plans

First year Physics Plan (2016-2017)

- May not have full PID. B physics requires PID more than other topics. *Considering alternatives to Y(4S) for the first run, Maybe few hundred fb^{-1}.*
- **Y(2S)**: dark forces, light Higgs
- **Y(3S):** conventional bottomonium
- **Scan** around Y(5S) and *b* quark mass determination
- **Y(6S):** bottomonium, $\mathbf{r_B}$ scan

beyond Y(4S)



> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

Early impact with unique data-sets
(ideas welcome)

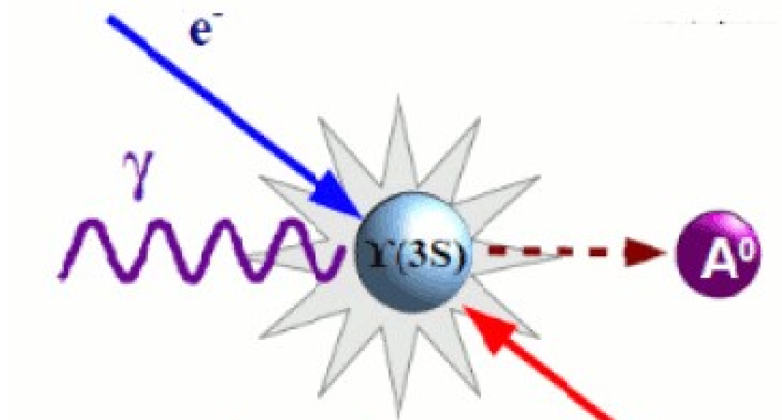
Dark Sector (Aside)

Dark photon A', motivated be in MeV – GeV mass

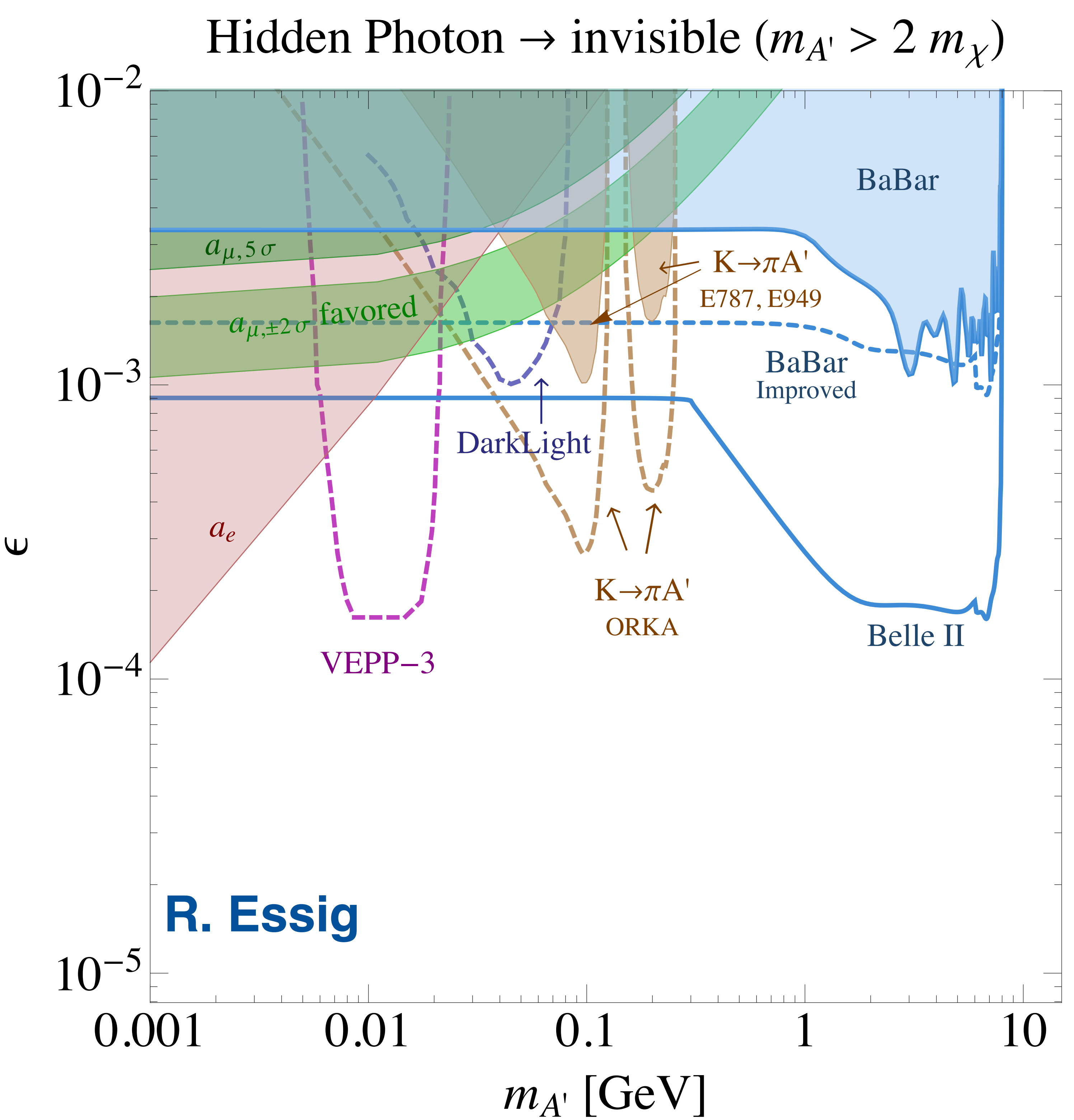
1. Probe leptonicaly decaying dark photons through mixing

2. Probe sub-GeV dark matter in invisible decays

Radiative decays of Υ(2S), Υ(3S)



$$E^*_\gamma = \frac{m^2_\Upsilon - m^2_{A^0}}{2m_\Upsilon}$$



Summary

- Rich physics program at SuperKEKB/BelleII (mostly complementary to LHCb)
  - Extended Higgs sectors
  - New sources of CPV
  - Lepton Flavour Violation
  - Precision CKM
  - Dark Sectors
  - QCD exotics
- **Belle II full physics program to start in 2017! precision 10-100 times better than B-factories!**

Supplementary material

Belle II Theory Interface Platform

https://belle2.cc.kek.jp/~twiki/bin/view/Public/B2TIP

Inviting Theorist Participation: ***Kickoff in June, 1st Workshop in Nov.***

Belle II Theory Interface Platform (B2TIP)

Overview

The "Belle II-Theory Interface Platform" is an initiative to coordinate a joint theory-experiment effort to study the potential impacts of the Belle II program.

We plan to organize meetings twice a year gathering theory experts and Belle II members, starting from June 2014 until the end of 2016.

One of the expected outcomes of the project is a "KEK Report", summarizing all the important observables which will be measured at Belle II, their experimentally achievable precision and their impact on our understanding of the theory (Standard Model and New Physics). This report should also include a "milestones table" clarifying the targets for the first 5 to 10 ab-1 of data as well as for the final goal at 50 ab-1.

This project is an official activity of Belle II, approved by the executive board of the Belle II Collaboration, in February 2014.

Workshop Dates

The 2014 meetings will be held at KEK in June and November, as a satellite meeting of the Belle and Belle II General meetings. There is a possibility of holding one workshop in 2015 at an external location. Individual working groups may choose to hold additional meetings. Please register for the meetings on the linked indico pages.

B2TIP Meeting	Meeting Agenda	Belle (II) associated meetings
2014 June 16-17 at KEK	workshop indico	B2GM June 18-21, BGM June 22-23
2014 November/December		B2GM November 3-6, BGM November 7-8
2015 June (External Workshop)		
2015 November (KEK)		
2016 June (External Workshop)		

Committees

Organising Commitee

Toru Goto	KEK
Emi Kou	LAL
Karim Trabelsi	KEK / Lausanne
Phillip Urquijo (B2 Physics Coord.)	Melbourne

Ex Officio

Hiroaki Aihara (B2 EB Chair)	Tokyo
Thomas Browder (B2 Spokesperson)	Hawaii
Marco Ciuchini (KEK FF Advisory)	Rome
Thomas Mannel (KEK FF Advisory)	Siegen

Report Editors

Christoph Schwanda	HEPHY Vienna
Theory TBC	

Advisory Committee

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Shoji Hashimoto	KEK
Francois Le Diberder	LAL
Zoltan Ligeti	LBL
Hitoshi Murayama	IPMU
Matthias Neubert	Mainz
Yoshihide Sakai	KEK
Junko Shigemitsu	Ohio

(Semi)Leptonic, EWP & Radiative

LHCb (upgrade)

Type	Observable	Current precision	LHCb 2018	**Upgrade** (50 fb^{-1})
Right-handed currents	$2\beta_s^{\rm eff}(B_s^0 \to \phi\gamma)$	–	0.09	0.02
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.08 [68]	0.025	0.008
	$s_0 A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [68]	6 %	2 %
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.25 [77]	0.08	0.025
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [86]	8 %	2.5 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [13]	0.5×10^{-9}	0.15×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~100 %	~35 %

Belle II

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
UT sides	$\lvert V_{cb}\rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 1.8\%)$ [8]	1.2%	
	$\lvert V_{cb}\rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\rm ex.} \pm 2.7\%_{\rm th.})$ [10]	1.8%	1.4%
	$\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\rm ex.} \pm 2.5\%_{\rm th.})$ [5]	3.4%	3.0%
	$\lvert V_{ub}\rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 8.2\%)$ [7]	4.7%	2.4%
Missing E decays	$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$96(1 \pm 27\%)$ [26]	10%	3%
	$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7 [67]	20%	7%
	$R(B \to D\tau\nu)$	$0.440(1 \pm 16.5\%)$ [29]†	5.2%	2.5%
	$R(B \to D^*\tau\nu)^\dagger$	$0.332(1 \pm 9.0\%)$ [29]†	2.9%	1.6%
	$\mathcal{B}(B \to K^{*+}\nu\overline{\nu})$ $[10^{-6}]$	< 40 [30]	< 15	30%
	$\mathcal{B}(B \to K^+\nu\overline{\nu})$ $[10^{-6}]$	< 55 [30]	< 21	30%
Rad. & EW penguins	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%
	$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	$2.2 \pm 4.0 \pm 0.8$ [68]	1	0.5
	$S(B \to K_S^0\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$ [20]	0.11	0.035
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$ [21]	0.23	0.07
	C_7/C_9 $(B \to X_s\ell\ell)$	~20% [36]	10%	5%
	$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	< 8.7 [42]	0.3	–
	$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	–	< 2 [44]‡	–

CPV & mixing

LHCb (upgrade)

Type	Observable	Current precision	LHCb 2018	**Upgrade** (50 fb^{-1})
B_s^0 mixing	$2\beta_s(B_s^0 \to J/\psi\phi)$	0.10 [139]	0.025	0.008
	$2\beta_s(B_s^0 \to J/\psi f_0(980))$	0.17 [219]	0.045	0.014
	a_{sl}^s	6.4×10^{-3} [44]	0.6×10^{-3}	0.2×10^{-3}
Gluonic penguins	$2\beta_s^{eff}(B_s^0 \to \phi\phi)$	–	0.17	0.03
	$2\beta_s^{eff}(B_s^0 \to K^{*0}\overline{K}^{*0})$	–	0.13	0.02
	$2\beta^{eff}(B^0 \to \phi K_S^0)$	0.17 [44]	0.30	0.05
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	∼10–12° [252, 266]	4°	0.9°
	$\gamma(B_s^0 \to D_s K)$	–	11°	2.0°
	$\beta(B^0 \to J/\psi K_S^0)$	0.8° [44]	0.6°	0.2°

Belle II

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$ [64]	0.012	0.008 [0.2°]
	α [°]	85 ± 4 (Belle+BaBar) [24]	2	1
	γ [°]	68 ± 14 [13]	6	1.5
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$ [19]	0.053	0.018
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$ [65]	0.028	0.011
	$S(B \to K_S^0 K_S^0 K_S^0)$	$0.30 \pm 0.32 \pm 0.08$ [17]	0.100	0.033
	$\mathcal{A}(B \to K^0\pi^0)$	$-0.05 \pm 0.14 \pm 0.05$ [66]	0.07	0.04

Charm and Tau

LHCb (upgrade)

Type	Observable	Current precision	LHCb 2018	**Upgrade** (50 fb^{-1})
Charm *CP* violation	A_{Γ}	2.3×10^{-3} [44]	0.40×10^{-3}	0.07×10^{-3}
	$\Delta \mathcal{A}_{CP}$	2.1×10^{-3} [18]	0.65×10^{-3}	0.12×10^{-3}

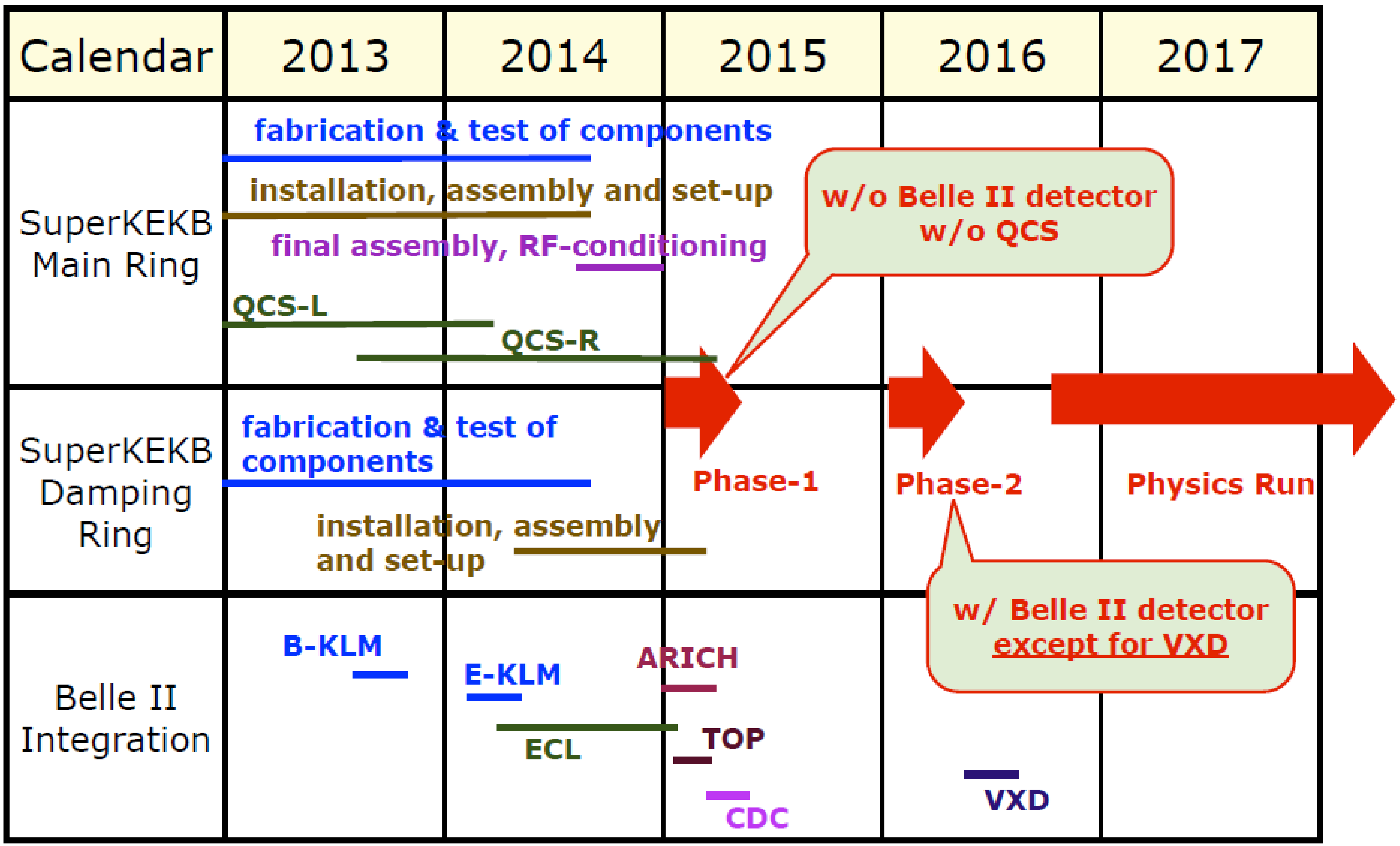
Belle II

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$ [46]	2.9%	0.9%
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$ [46]	3.5%	3.6%
	$\mathcal{B}(D^0 \to \gamma\gamma)$ $[10^{-6}]$	< 1.5 [49]	30%	25%
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ $[10^{-2}]$	$-0.32 \pm 0.21 \pm 0.09$ [69]	0.11	0.06
	$A_{CP}(D^0 \to \pi^0\pi^0)$ $[10^{-2}]$	$-0.03 \pm 0.64 \pm 0.10$ [70]	0.29	0.09
	$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$ [70]	0.08	0.03
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$ [52]	0.14	0.11
	$y(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$ [52]	0.08	0.05
	$\lvert q/p \rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$ [52]	0.10	0.07
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ $[^\circ]$	$-6 \pm 11 \pm {}^{4}_{5}$ [52]	6	4
Tau	$\tau \to \mu\gamma$ $[10^{-9}]$	< 45 [71]	< 4.6	< 0.5
	$\tau \to e\gamma$ $[10^{-9}]$	< 120 [71]	< 12	< 1.2
	$\tau \to \mu\mu\mu$ $[10^{-9}]$	< 21.0 [72]	< 4.5	< 0.5

Backup

Construction & Commissioning Schedule

Feb 2014

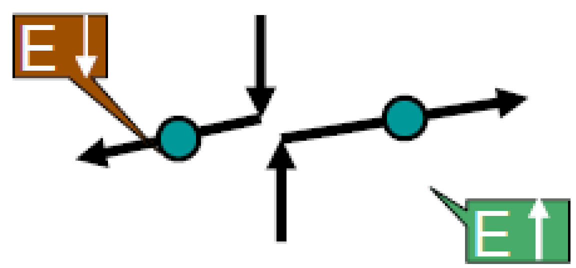


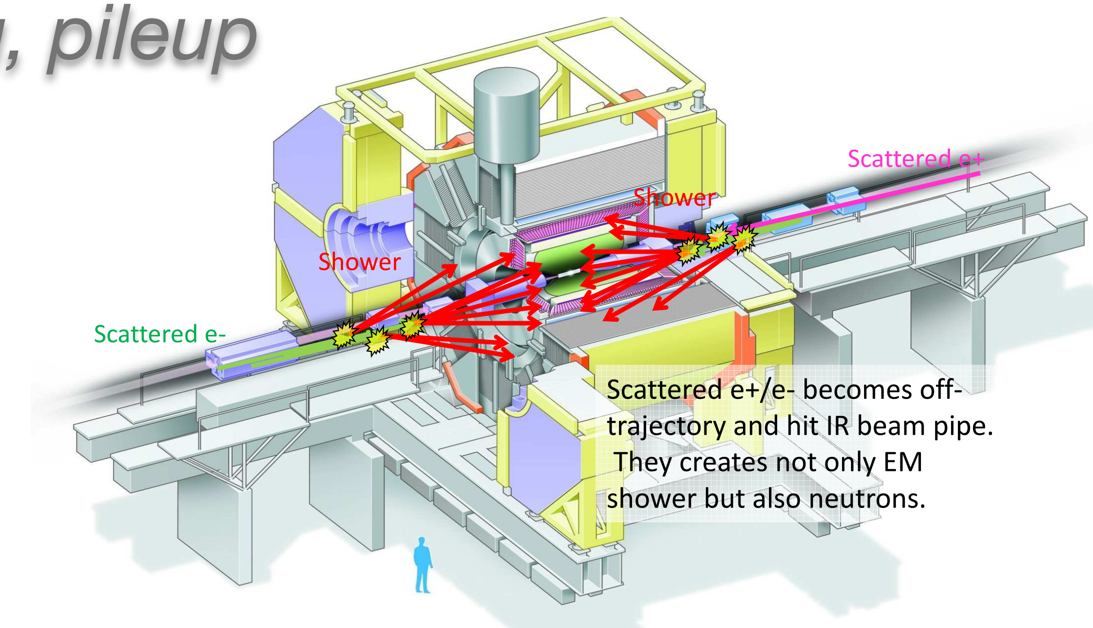
Beam Backgrounds

At SuperKEKB with x40 larger Luminosity, beam background will also increase drastically.

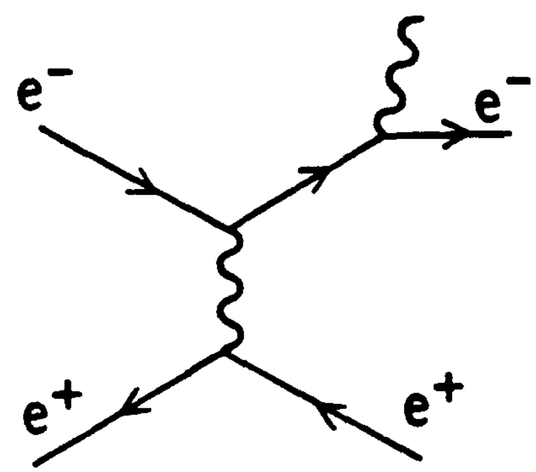
radiation damage, photosensor ageing, pileup

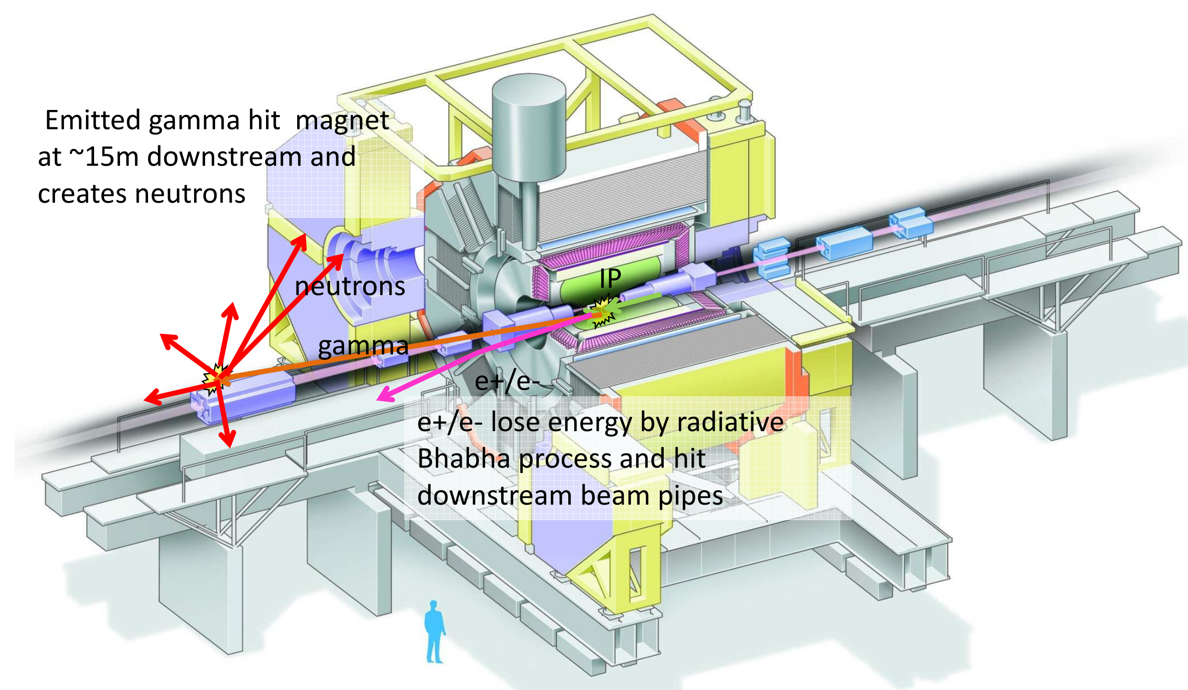
Touschek scattering
Beam-gas scattering
Synchrotron radiation





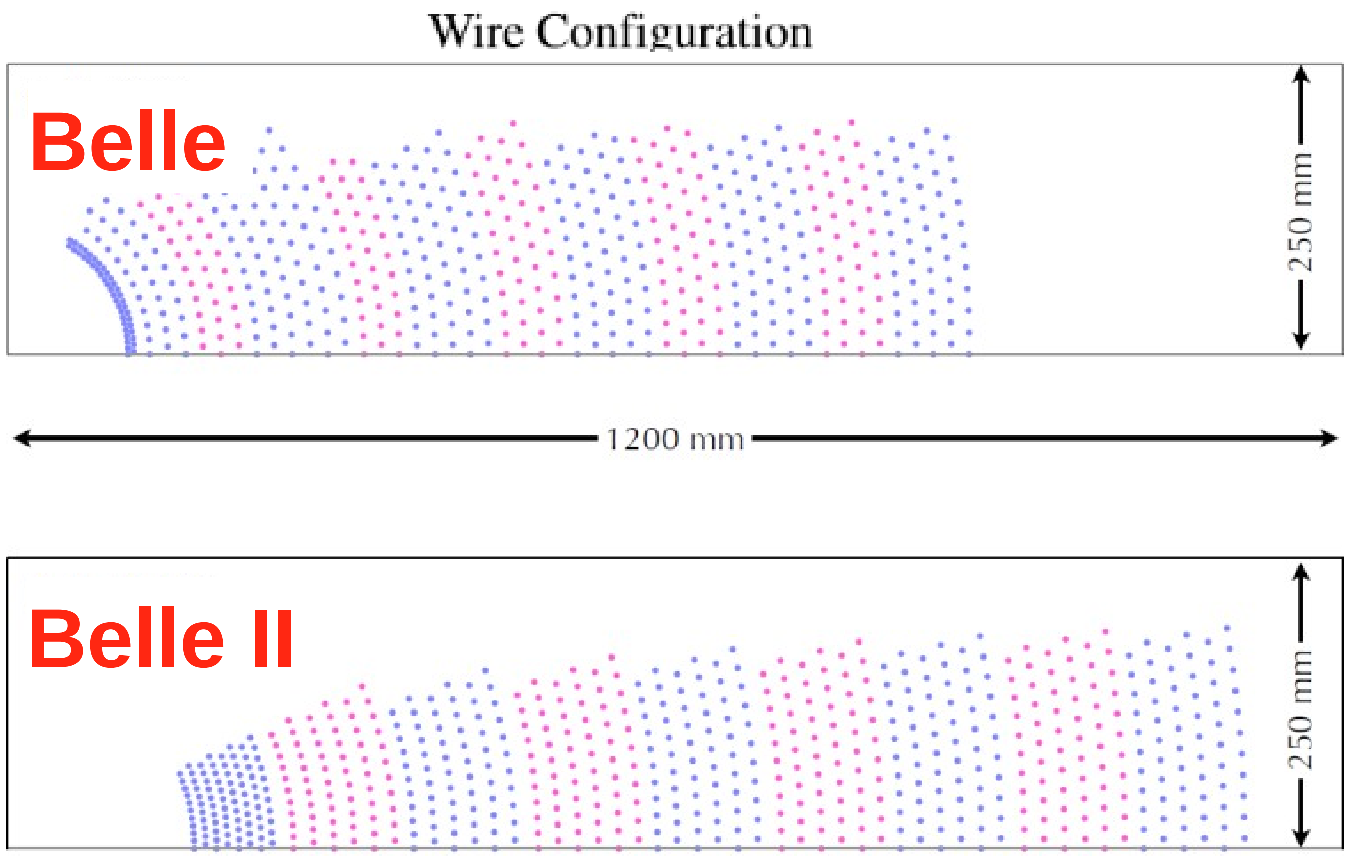
Radiative Bhabha
emitted photons
spent electrons

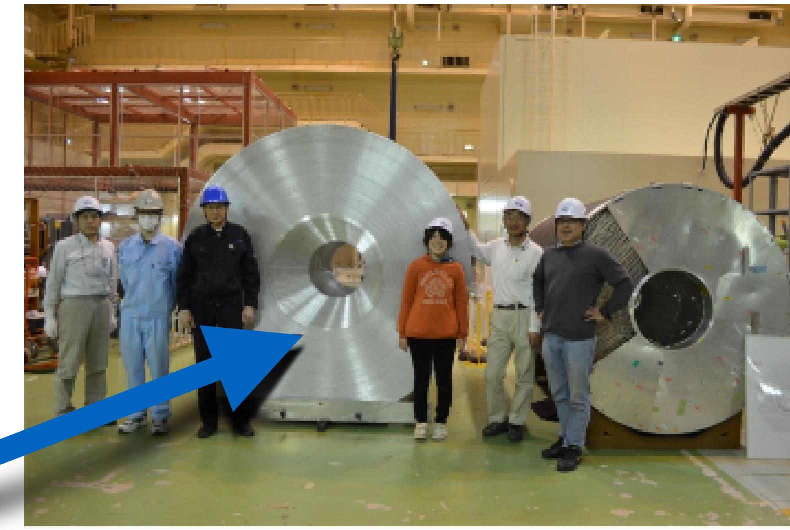




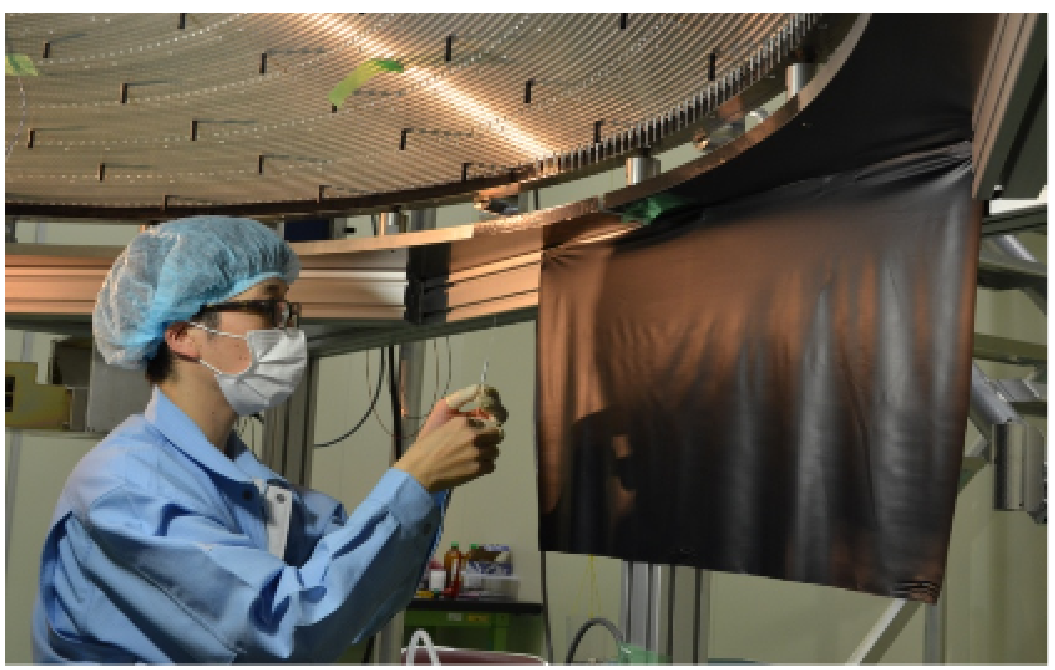
2-photon process: $e^+e^- \rightarrow e^+e^-e^+e^-$

Central Drift Chamber





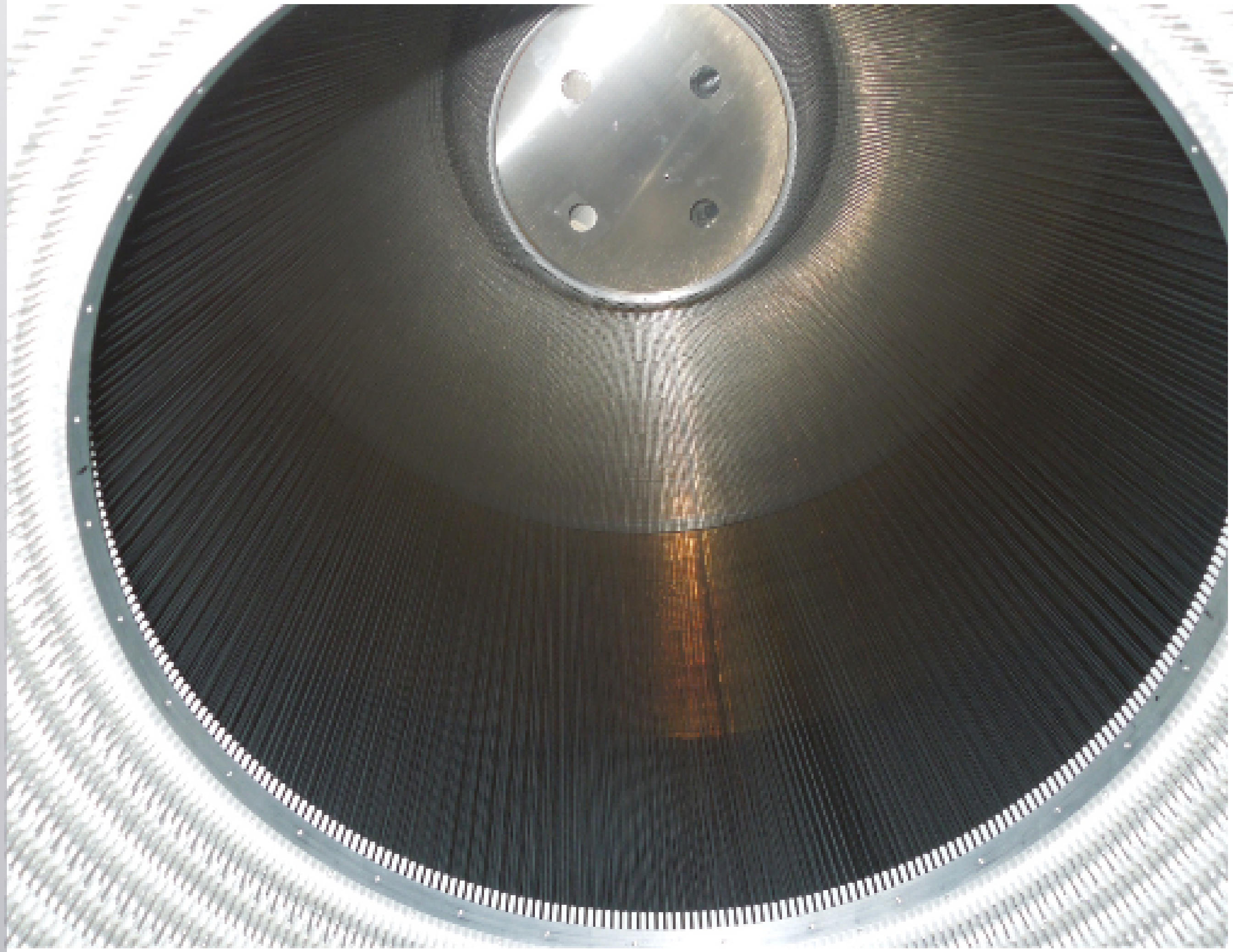
Longer lever arm than in Belle



Wire stringing in a clean room in Fuji Hall

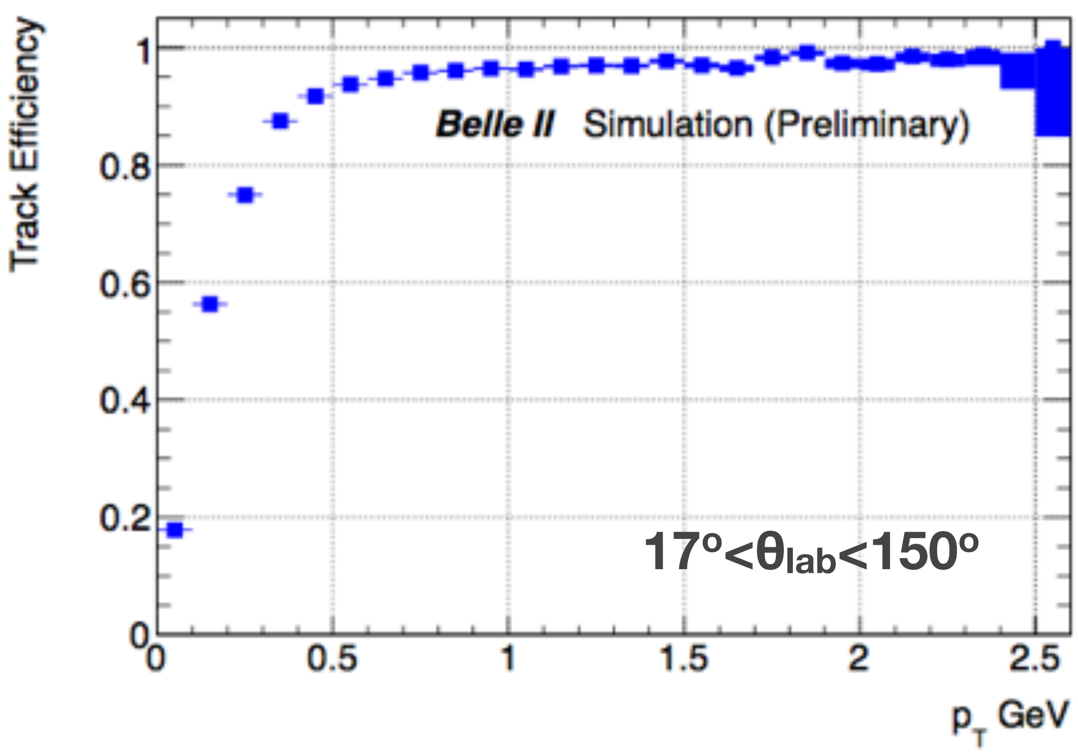
Central Drift Chamber

CDC wire stringing is complete (~51k wires)



CDC viewed from the backward side

Expected performance using a Kalman filter and GEANT4



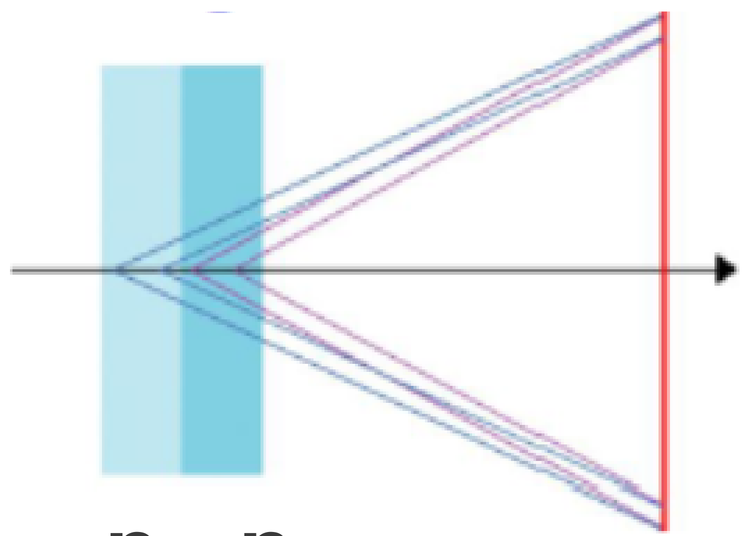
$\sigma_p/p \sim 0.3\% + 0.1\% \times p(\mathrm{GeV})$ in $B = 1.5\mathrm{T}$

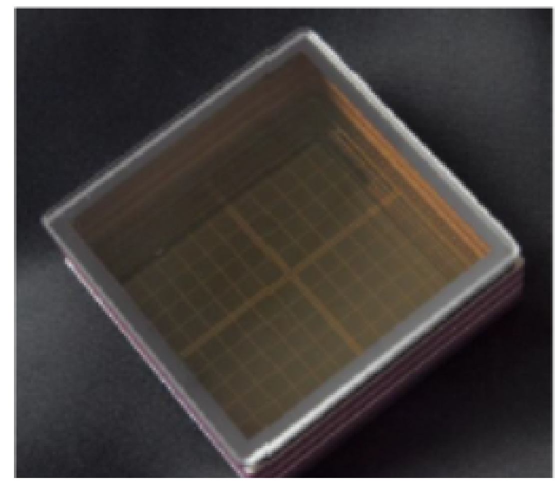
$\sigma(\mathrm{d}E/\mathrm{d}x) \sim 6\%$

Aerogel RICH: Endcap PID

2-layer Aerogel

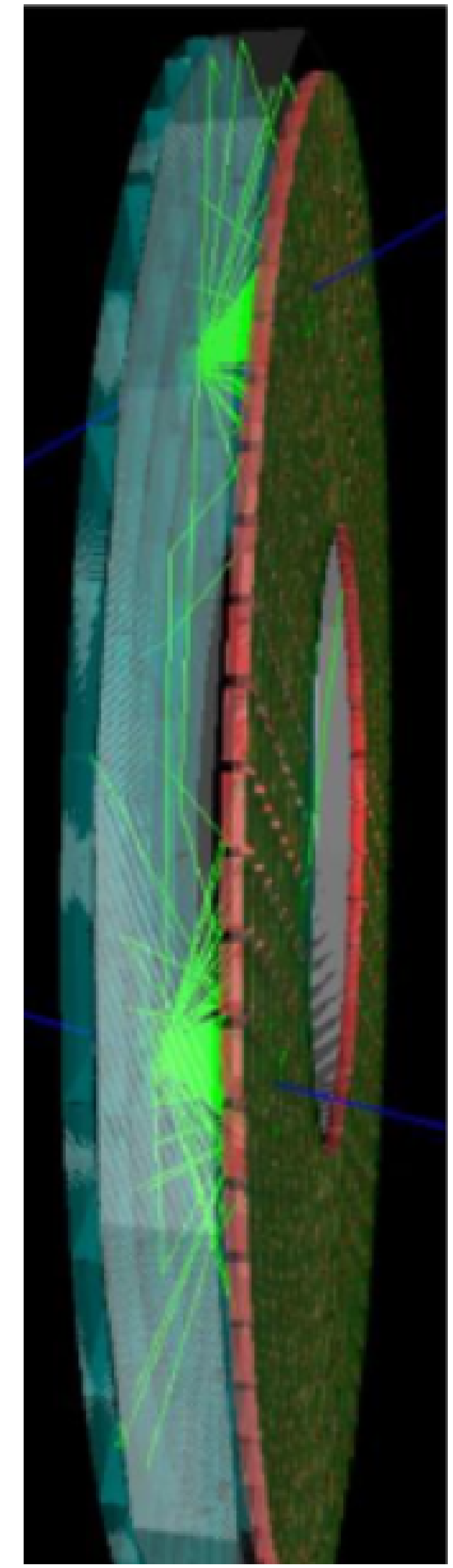
HAPD Photo-detector





n_1 n_2

$(n_1 < n_2)$



PID in the forward endcap

2-layer aerogel radiator

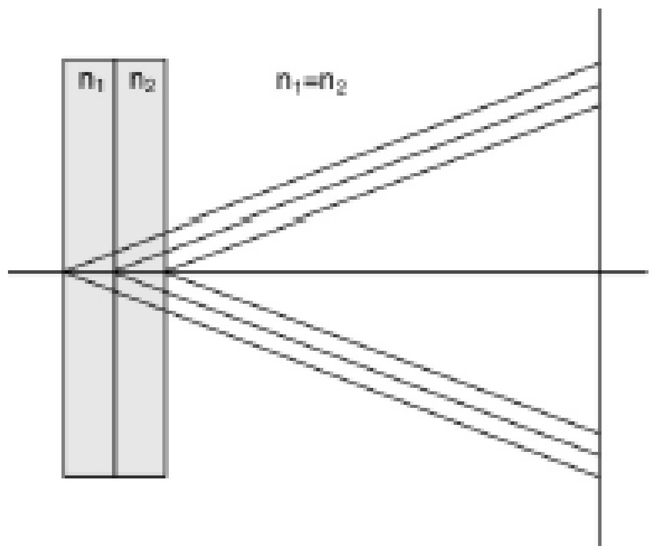
420 × *144*-channel Hybrid-Avalanche Photo-detectors (HAPD)

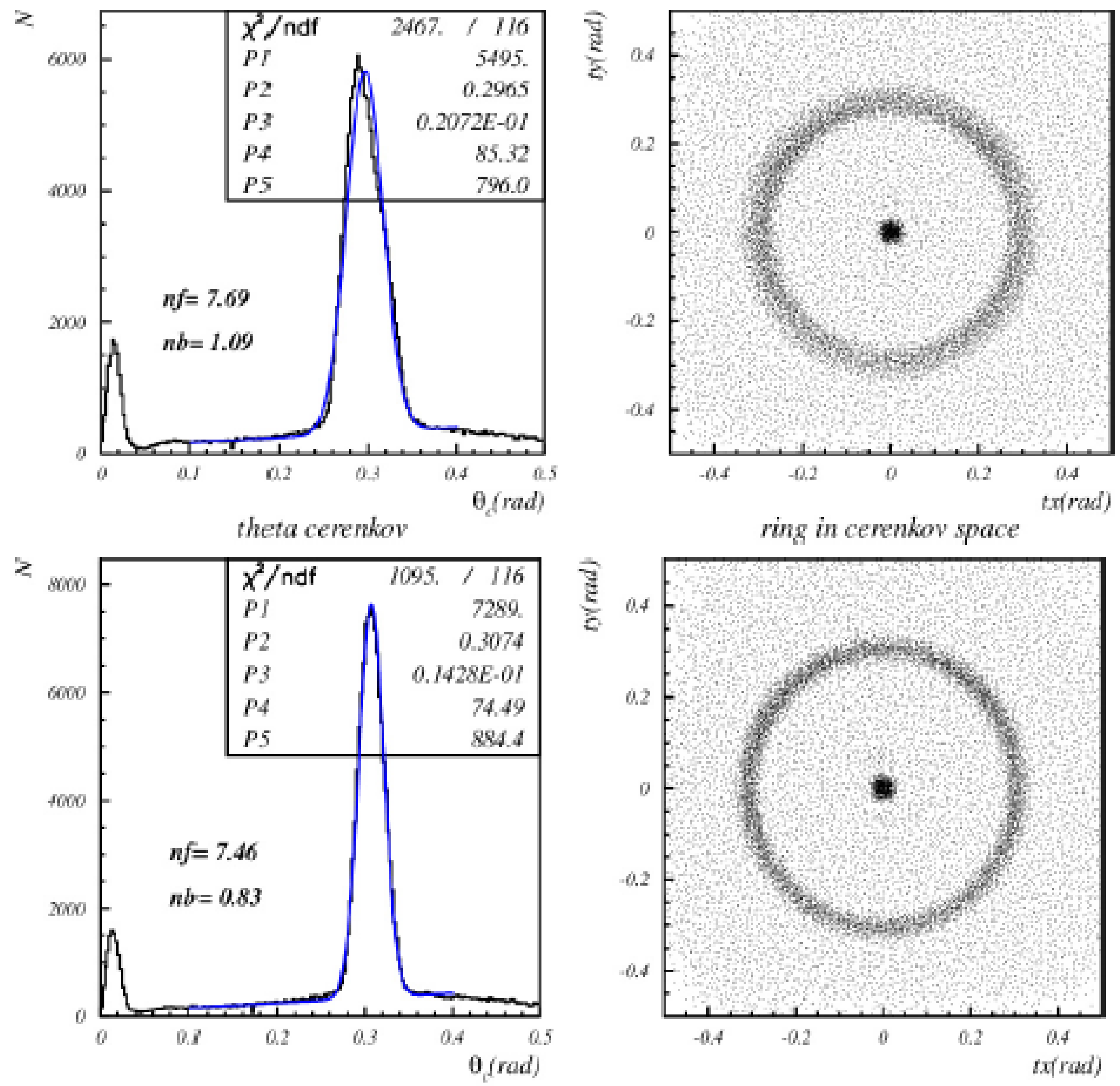
Aerogel RICH: Endcap PID

2-layer radiator

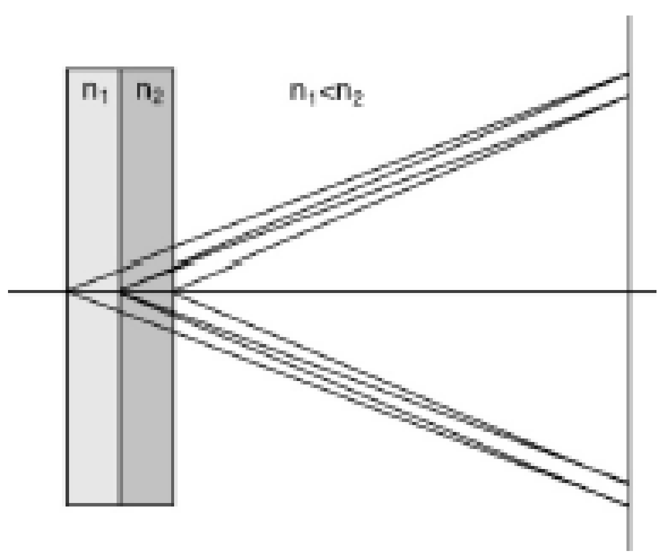
Increases the number of photons without degrading resolution

4cm aerogel single index





2cm+2cm aerogel



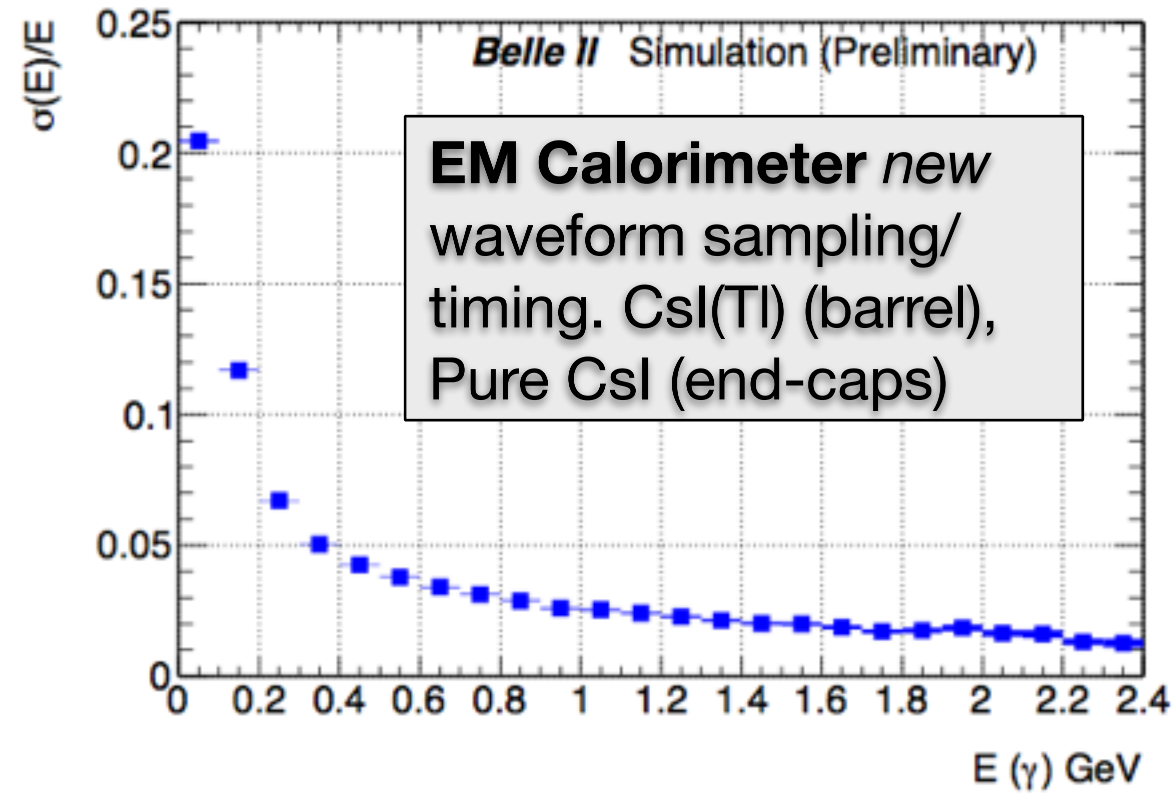
NIM A548 (2005) 383

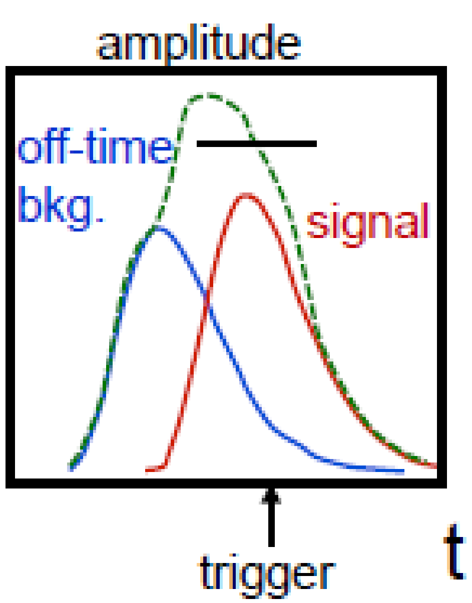
Calorimeter

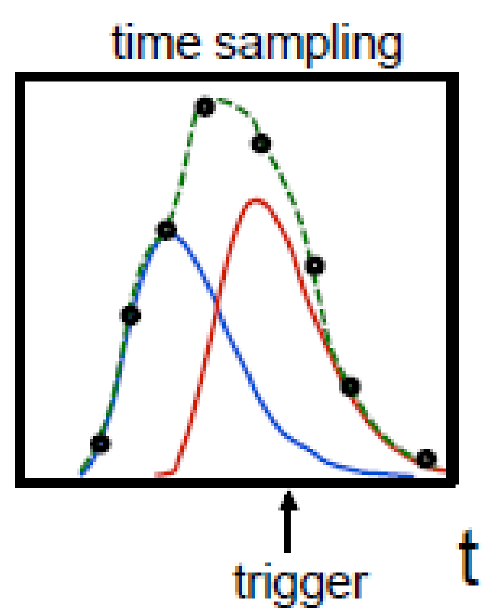
Re-use of Belle's CsI(Tl) crystals, *plus*

barrel: 2MHz wave form sampling to compensate for larger beam-backgrounds & the slow decay time of CsI(Tl) signal:

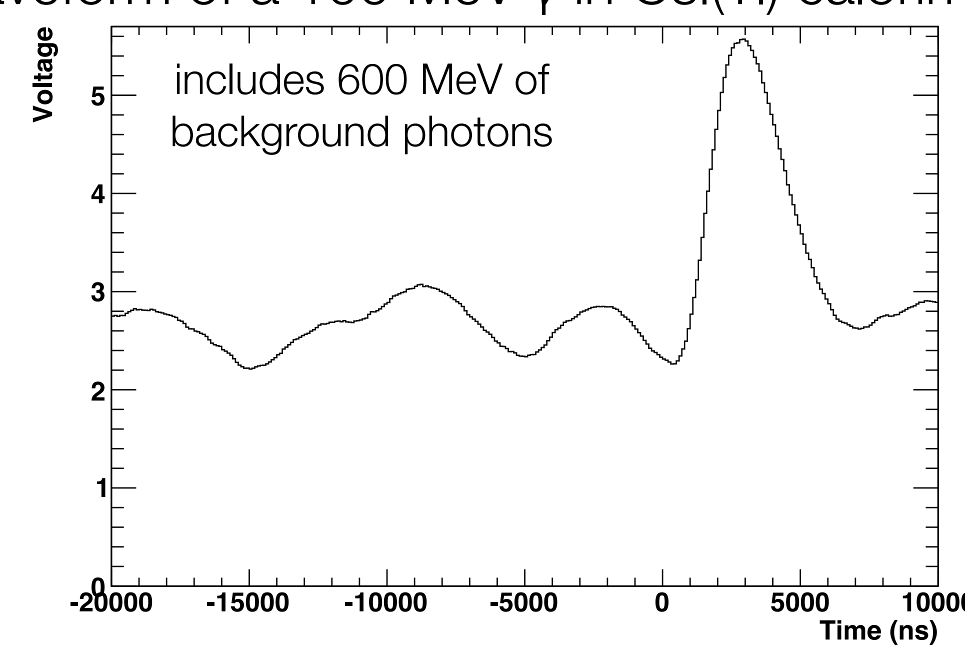
2x better resolution at 20x background!







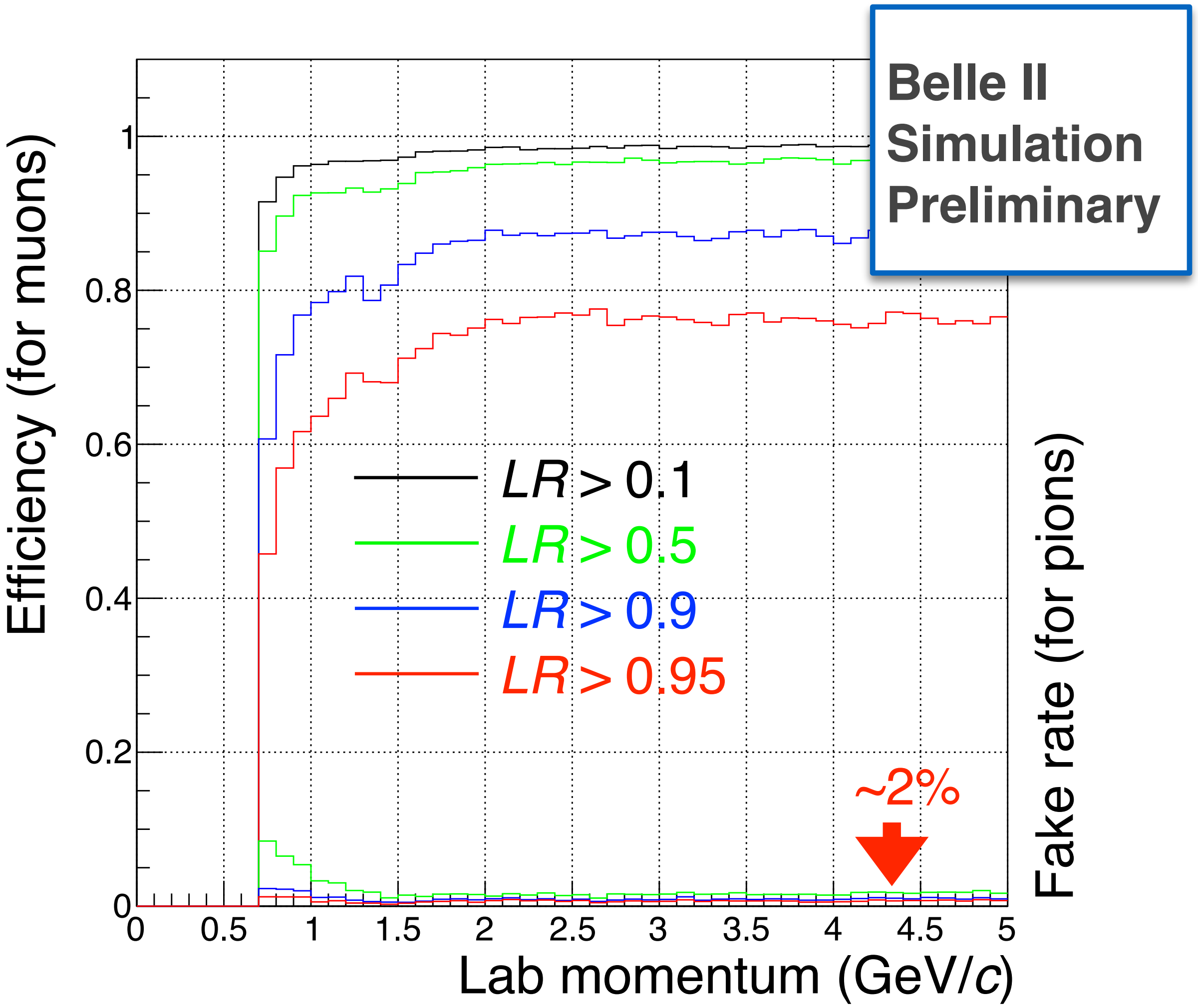
Waveform of a 100 MeV γ in CsI(Tl) calorimeter



forward endcap: CsI(Tl) ⇒CsI for faster performance and better radiation hardness (not from the beginning of data-taking)

Muon/K_L Detector

Endcap RPCs and two layers of the barrel have to be replaced with scintillators to handle higher backgrounds (mainly from neutrons)
K_L* *momentum measured by layer timing coincidence.



Barrel KLM installation complete - first Belle II sub detector ready!

LQCD

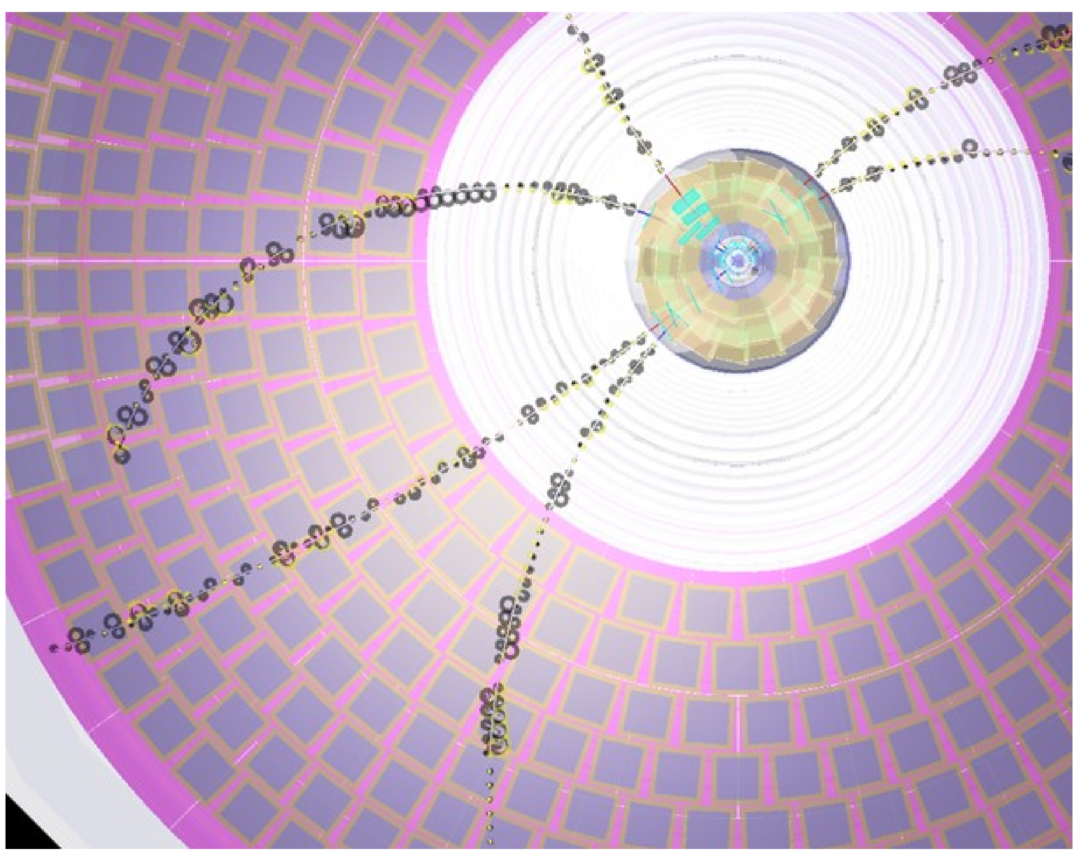
- Lattice QCD promises important improvements in precision.
- USQCD "Lattice QCD at the Intensity Frontier"
  http://www.usqcd.org/documents/13flavor.pdf

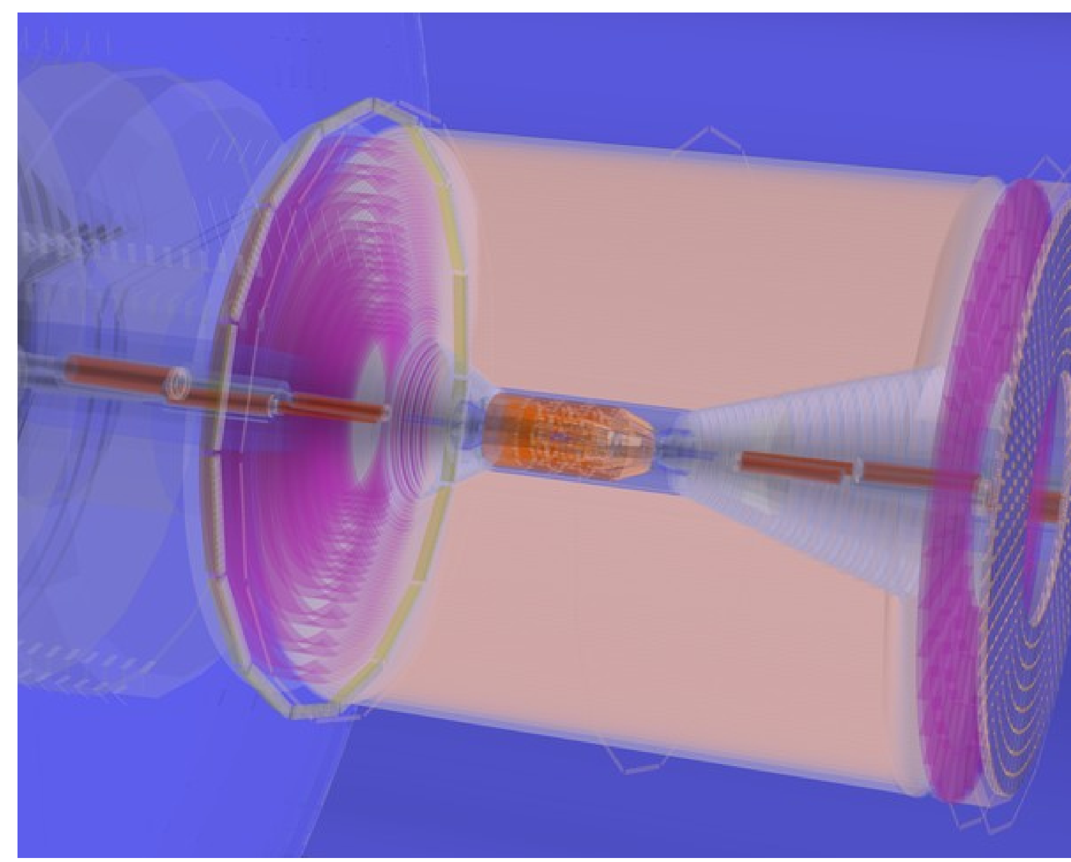
Quantity	CKM element	Present expt. error	2007 forecast lattice error	Present lattice error	2018 lattice error
f_K/f_π	$\|V_{us}\|$	0.2%	0.5%	0.5%	0.15%
$f_+^{K\pi}(0)$	$\|V_{us}\|$	0.2%	–	0.5%	0.2%
f_D	$\|V_{cd}\|$	4.3%	5%	2%	$< 1\%$
f_{D_s}	$\|V_{cs}\|$	2.1%	5%	2%	$< 1\%$
$D \to \pi\ell\nu$	$\|V_{cd}\|$	2.6%	–	4.4%	2%
$D \to K\ell\nu$	$\|V_{cs}\|$	1.1%	–	2.5%	1%
$B \to D^*\ell\nu$	$\|V_{cb}\|$	1.3%	–	1.8%	$< 1\%$
$B \to \pi\ell\nu$	$\|V_{ub}\|$	4.1%	–	8.7%	2%
f_B	$\|V_{ub}\|$	9%	–	2.5%	$< 1\%$
ξ	$\|V_{ts}/V_{td}\|$	0.4%	2-4%	4%	$< 1\%$
ΔM_s	$\|V_{ts}V_{tb}\|^2$	0.24%	7–12%	11%	5%
B_K	$\text{Im}(V_{td}^2)$	0.5%	3.5–6%	1.3%	$< 1\%$

- + other rare processes, e.g. $B \to K^*\gamma$, $B \to K^* l^+ l^-$

Belle Software Framework

- New framework with dynamic module loading, parallel processing, python steering, root I/O, and use of GRID with Dirac
- Full detector simulation with Geant4
- Tracking with GenFit
- Alignment with Millepede II
- Employed for test beam studies

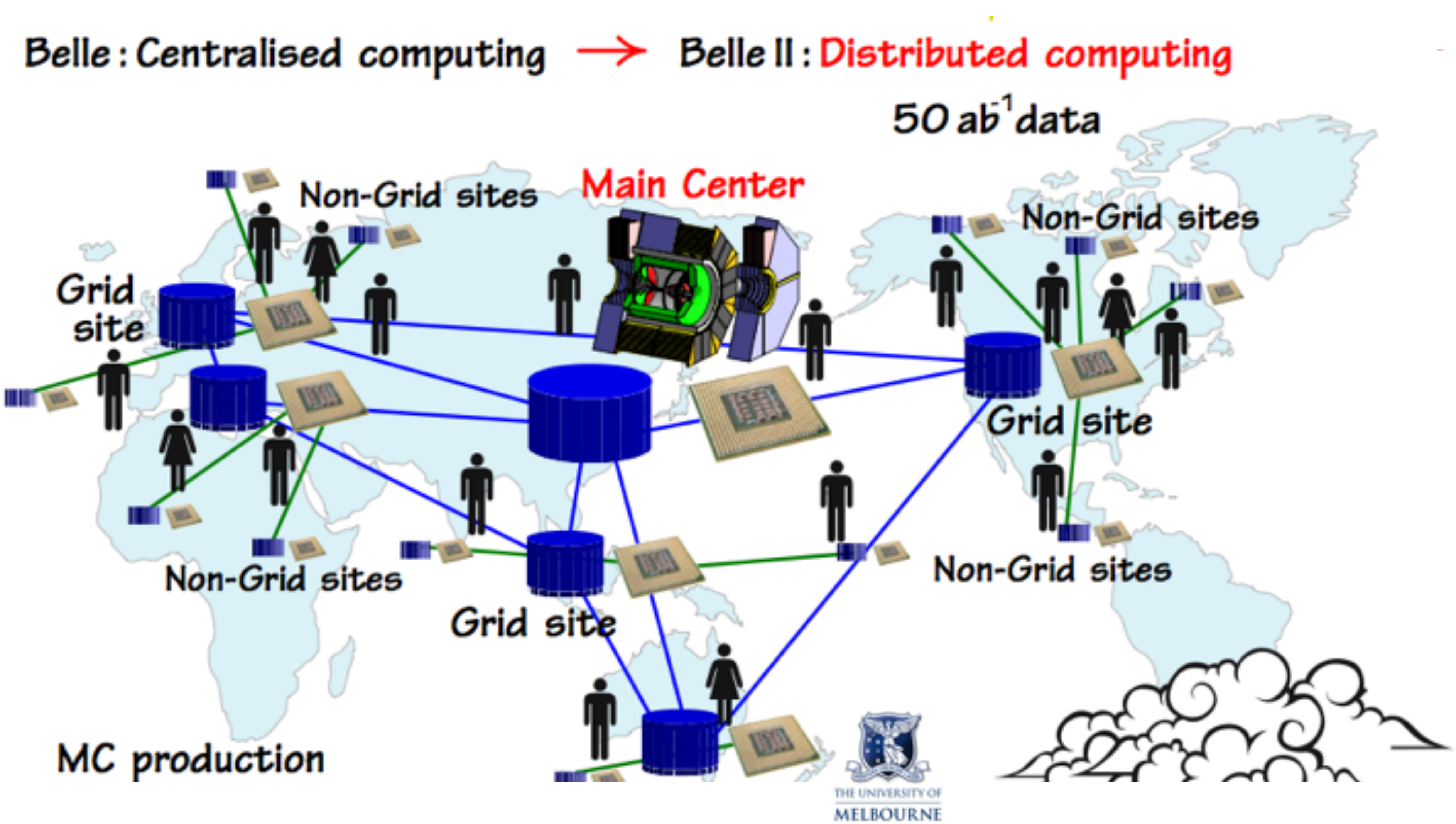




Computing

	Hardware Trigger rate	Physics output rate	event size
Belle	500 Hz	90 Hz	300kB (max)
Belle II	30 kHz	3.6kHz	300kB (max)
ATLAS		0.2kHz	1.6MB

~similar amount of **raw** data to ATLAS!



Computing

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Belle	500 Hz	90 Hz	300kB (max)
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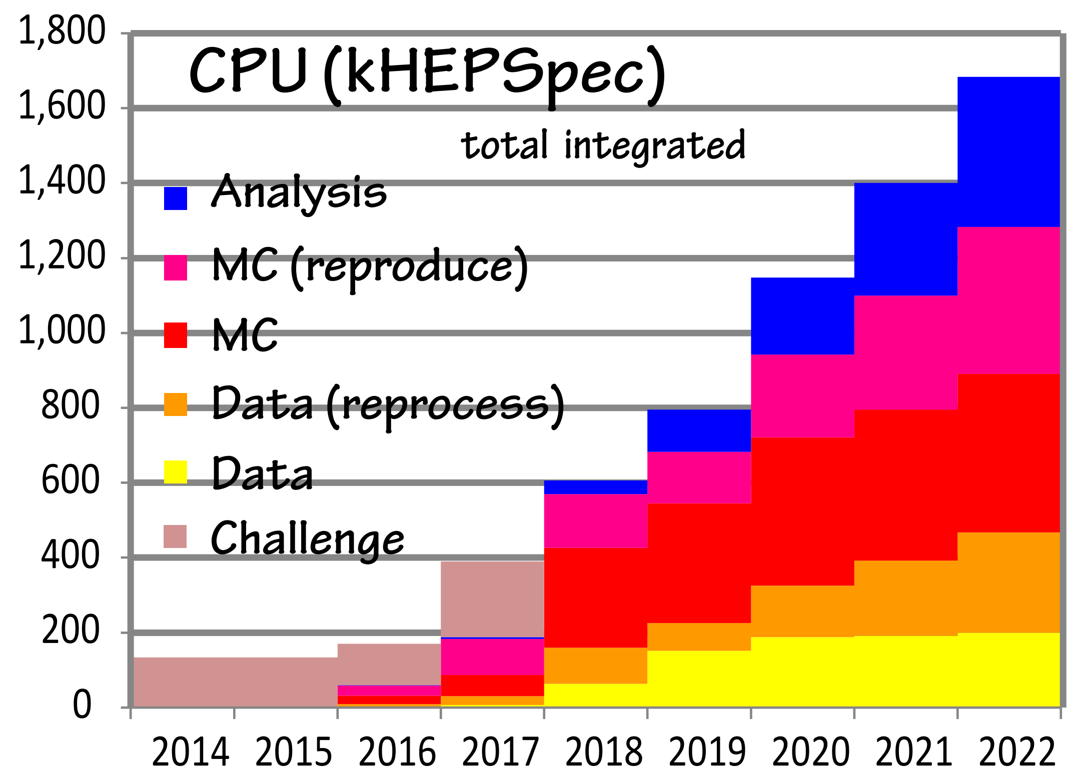
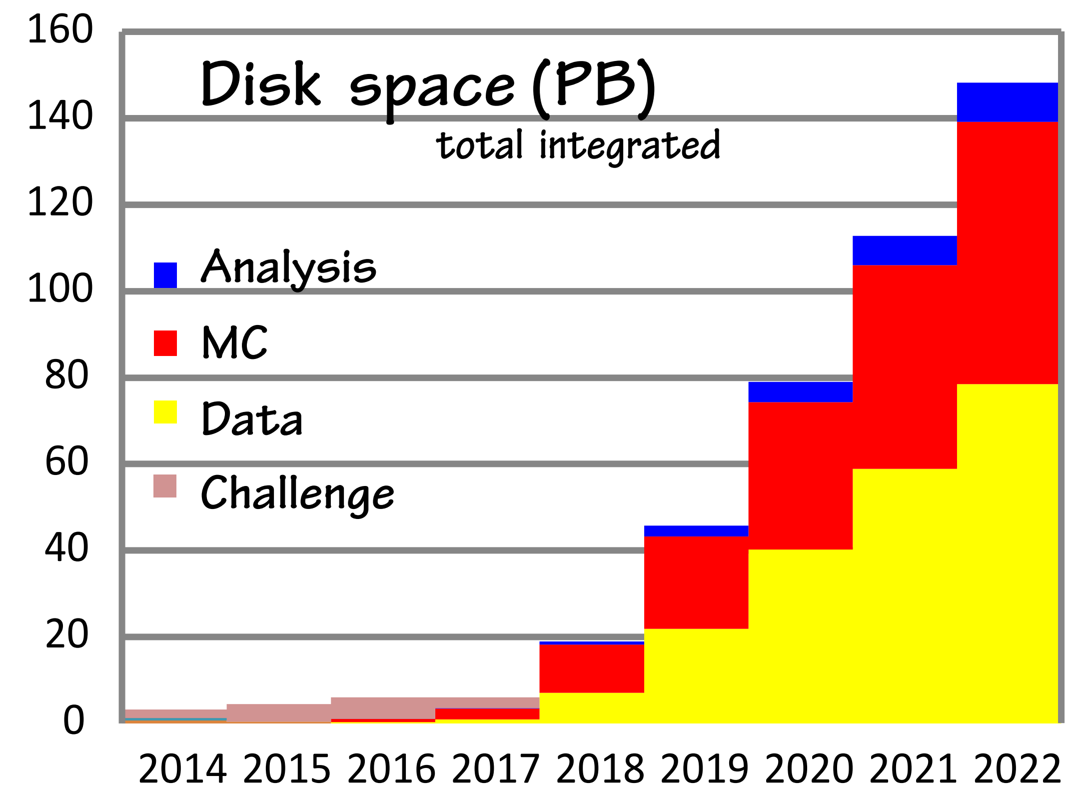
ATLAS		0.2kHz	1.6MB

~similar amount of **raw** data to ATLAS!

Belle : Centralised computing → Belle II : Distributed computing

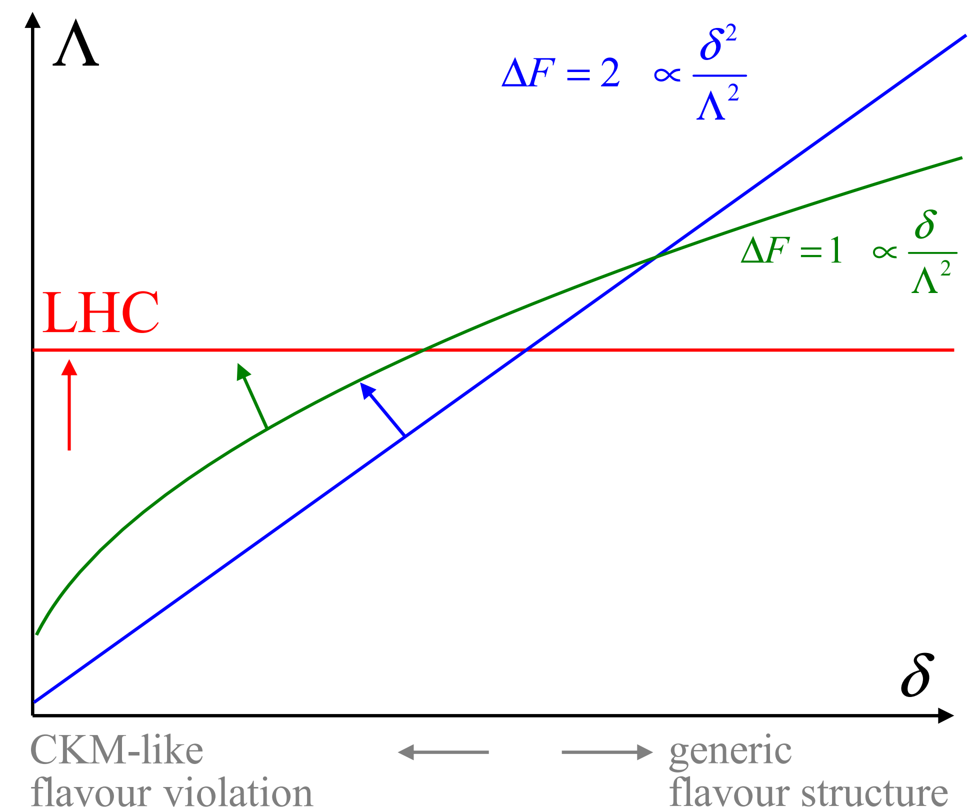
50 ab^{-1} data



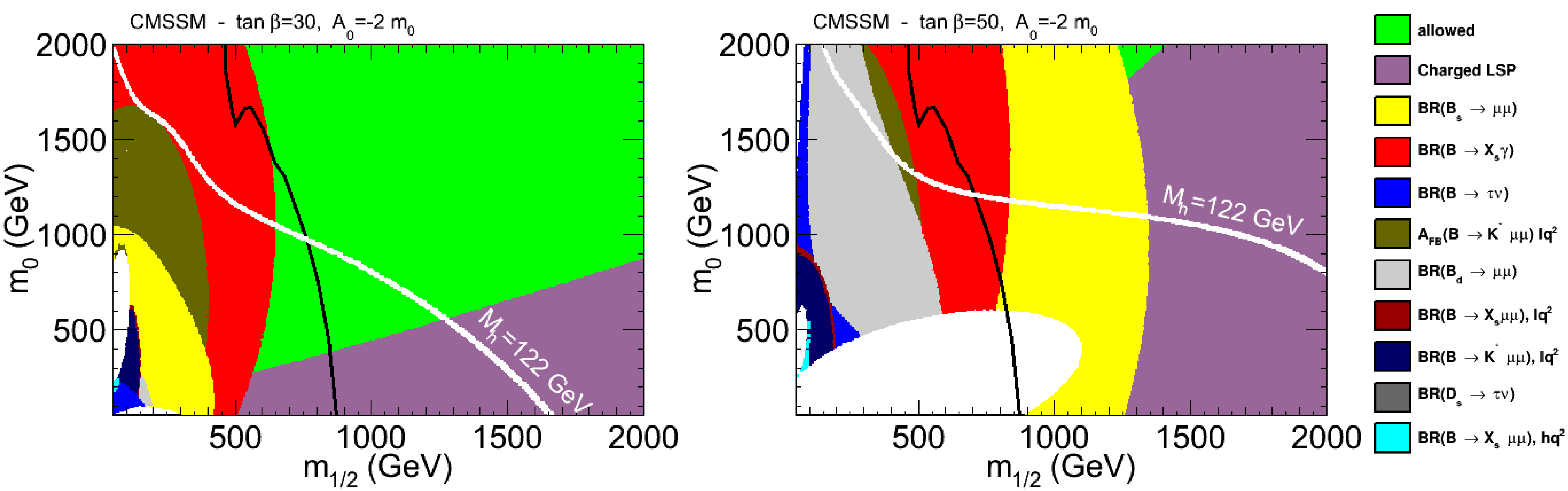


Complementarity to High p_T

- Clearly demonstrated sensitivity to scales beyond EW that complement LHC direct searches.



Flavour constraints in CMSSM in ($m_{1/2}$, m_0)
[F. Mahmoudi, 1310.2556]



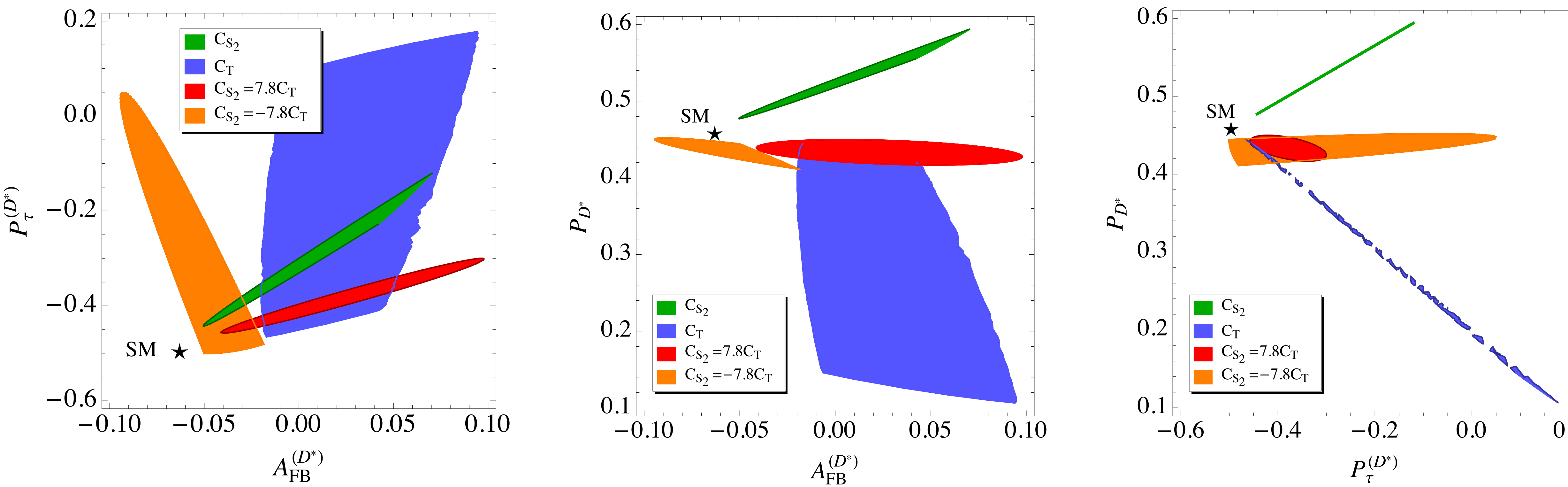
Deciphering NP @ Belle II (Aside)

M. Tanaka et al., PRD 88, 094012 (2013)

- Only resolved through decay differentials & New observables: **Polarisation, A_{FB}...**

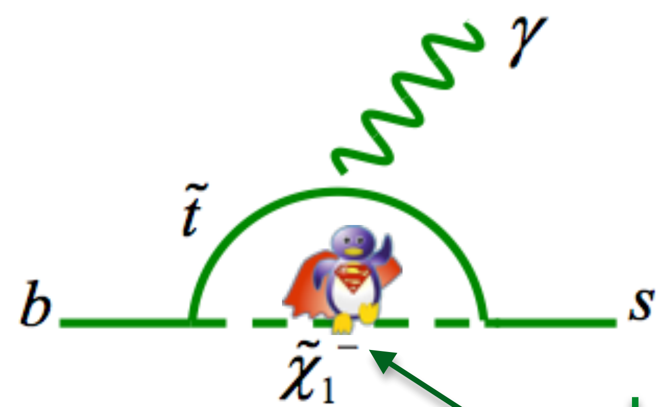
- Explore new Scalar, Vector or Tensors & CPV!
  - "flavour blind" Type II 2HDM ruled out.
  - Wilson Coefficients $C_n \sim \Lambda/m^2$

$$
\begin{aligned}
\mathcal{O}^l_{V_1} &= \bar{c}_L \gamma^\mu b_L \, \bar{\tau}_L \gamma_\mu \nu_{Ll} \,, \\
\mathcal{O}^l_{V_2} &= \bar{c}_R \gamma^\mu b_R \, \bar{\tau}_L \gamma_\mu \nu_{Ll} \,, \\
\mathcal{O}^l_{S_1} &= \bar{c}_L b_R \, \bar{\tau}_R \nu_{Ll} \,, \\
\mathcal{O}^l_{S_2} &= \bar{c}_R b_L \, \bar{\tau}_R \nu_{Ll} \,, \\
\mathcal{O}^l_{T} &= \bar{c}_R \sigma^{\mu\nu} b_L \, \bar{\tau}_R \sigma_{\mu\nu} \nu_{Ll} \,,
\end{aligned}
$$



Inclusive Radiative B decays: Archetypal NP mode

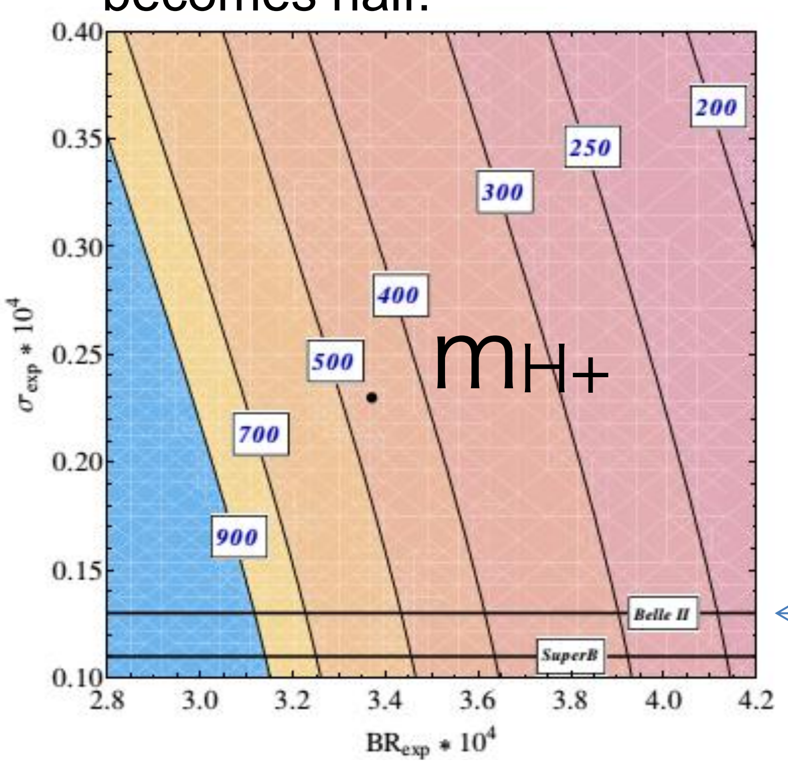
Many new particles may enter loop: e.g. H+
Theory precision near experimental precision in b→s, b→d may be fragmentation error limited.



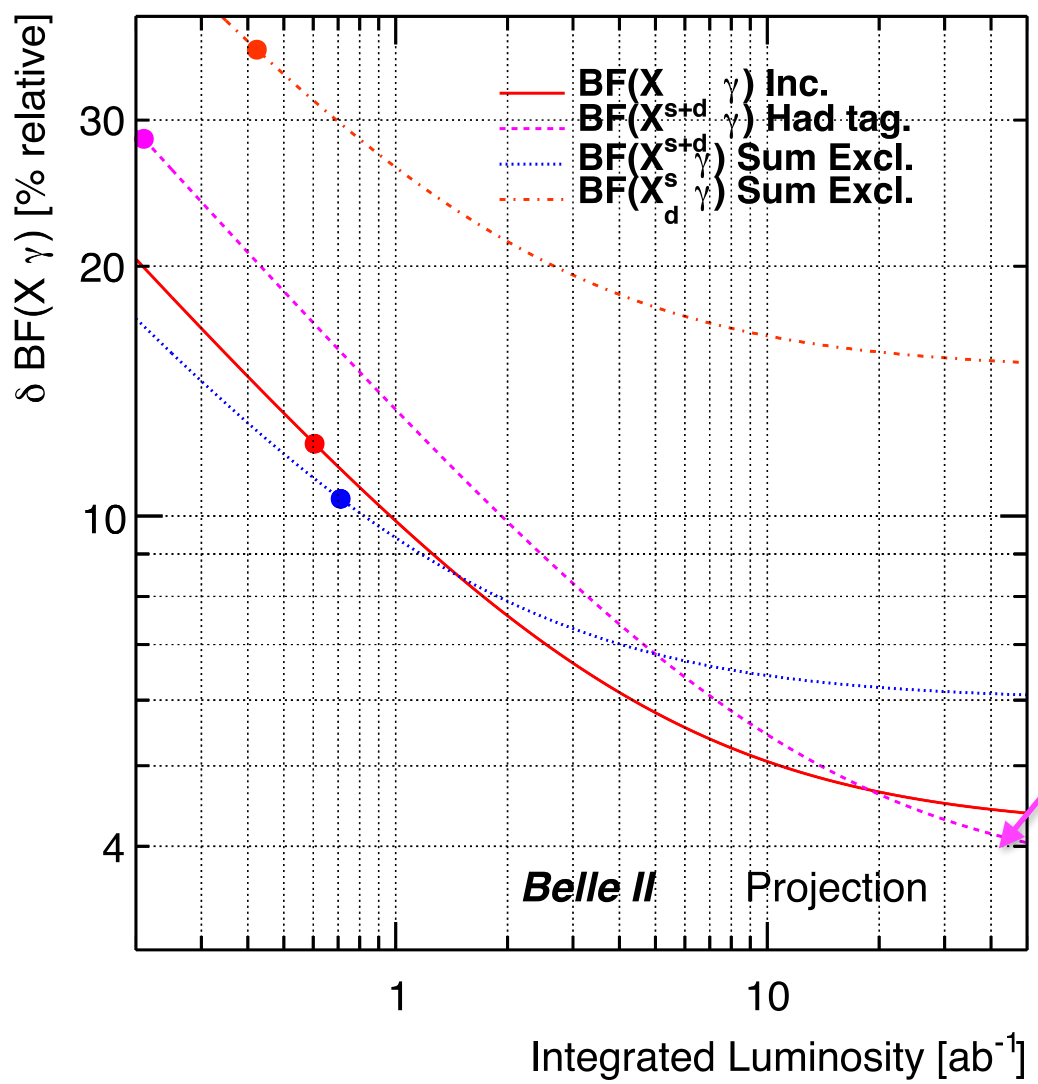
Large CPV source!

Limit to charged Higgs mass.

Assuming theoretical uncertainty becomes half:



← Belle II



B-full recon. tag ultimately performs best! (minimal qq continuum background!)

D^0-anti-D^0 mixing and CPV (global fit via HFAG)

Charm

10 parameters: x, y, δ, $\delta_{K\pi\pi}$, R_D, A_D, A_π, A_K, $|q/p|$, ϕ

41 observables: y_{CP}, A_Γ, $(x, y, |q/p|, \phi)_{\text{Belle } K^0_S \pi^+\pi^-}$, $(x, y)_{\text{BaBar } K^0_S h^+ h^-}$, $(R_M)_{Kl\nu}$, $(x'', y'')_{K^+\pi^-\pi^0}$, $(R_D, x^2, y, \cos\delta, \sin\delta)_{\psi(3770)}$, $(R_D, A_D, x'^{\pm}, y'^{\pm})_{\text{BaBar}}$, $(R_D, A_D, x'^{\pm}, y'^{\pm})_{\text{Belle}}$, $(R_D, x', y')_{\text{CDF}}$, $(R_D, x', y')_{\text{LHCb}}$, $(A_{CP}^K, A_{CP}^\pi)_{\text{BaBar}}$, $(A_{CP}^K, A_{CP}^\pi)_{\text{Belle}}$, $(A_{CP}^K - A_{CP}^\pi)_{\text{CDF}}$, $(A_{CP}^K - A_{CP}^\pi)_{\text{LHCb}(D^*)}$, $(A_{CP}^K - A_{CP}^\pi)_{\text{LHCb}(B\to D^0\mu X)}$

$$R_M = \frac{1}{2}(x^2 + y^2)$$

$$2y_{CP} = \left(|q/p| + |p/q|\right) y\cos\phi - \left(|q/p| - |p/q|\right) x\sin\phi$$

$$2A_\Gamma = \left(|q/p| - |p/q|\right) y\cos\phi - \left(|q/p| + |p/q|\right) x\sin\phi$$

$$x_{K^0\pi\pi} = x$$
$$y_{K^0\pi\pi} = y$$
$$|q/p|_{K^0\pi\pi} = |q/p|$$
$$\mathrm{Arg}(q/p)_{K^0\pi\pi} = \phi$$

$$\begin{pmatrix} x'' \\ y'' \end{pmatrix}_{K^+\pi^-\pi^0} = \begin{pmatrix} \cos\delta_{K\pi\pi} & \sin\delta_{K\pi\pi} \\ -\sin\delta_{K\pi\pi} & \cos\delta_{K\pi\pi} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

$$A_M = \frac{|q/p|^2 - |p/q|^2}{|q/p|^2 + |p/q|^2}$$

$$x'^{\pm} = \left(\frac{1 \pm A_M}{1 \mp A_M}\right)^{1/4} (x'\cos\phi \pm y'\sin\phi)$$

$$y'^{\pm} = \left(\frac{1 \pm A_M}{1 \mp A_M}\right)^{1/4} (y'\cos\phi \mp x'\sin\phi)$$

$$\frac{\Gamma(D^0\to K^+\pi^-) + \Gamma(\overline{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^-\pi^+) + \Gamma(\overline{D}^0\to K^+\pi^-)} = R_D$$

$$\frac{\Gamma(D^0\to K^+\pi^-) - \Gamma(\overline{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^+\pi^-) + \Gamma(\overline{D}^0\to K^-\pi^+)} = A_D$$

$$\frac{\Gamma(D^0\to K^+K^-) - \Gamma(\overline{D}^0\to K^+K^-)}{\Gamma(D^0\to K^+K^-) + \Gamma(\overline{D}^0\to K^+K^-)} = A_K + \frac{\langle t\rangle}{\tau_D} A_{CP}^{\text{indirect}}$$

$$\frac{\Gamma(D^0\to \pi^+\pi^-) - \Gamma(\overline{D}^0\to \pi^+\pi^-)}{\Gamma(D^0\to \pi^+\pi^-) + \Gamma(\overline{D}^0\to \pi^+\pi^-)} = A_\pi + \frac{\langle t\rangle}{\tau_D} A_{CP}^{\text{indirect}}$$

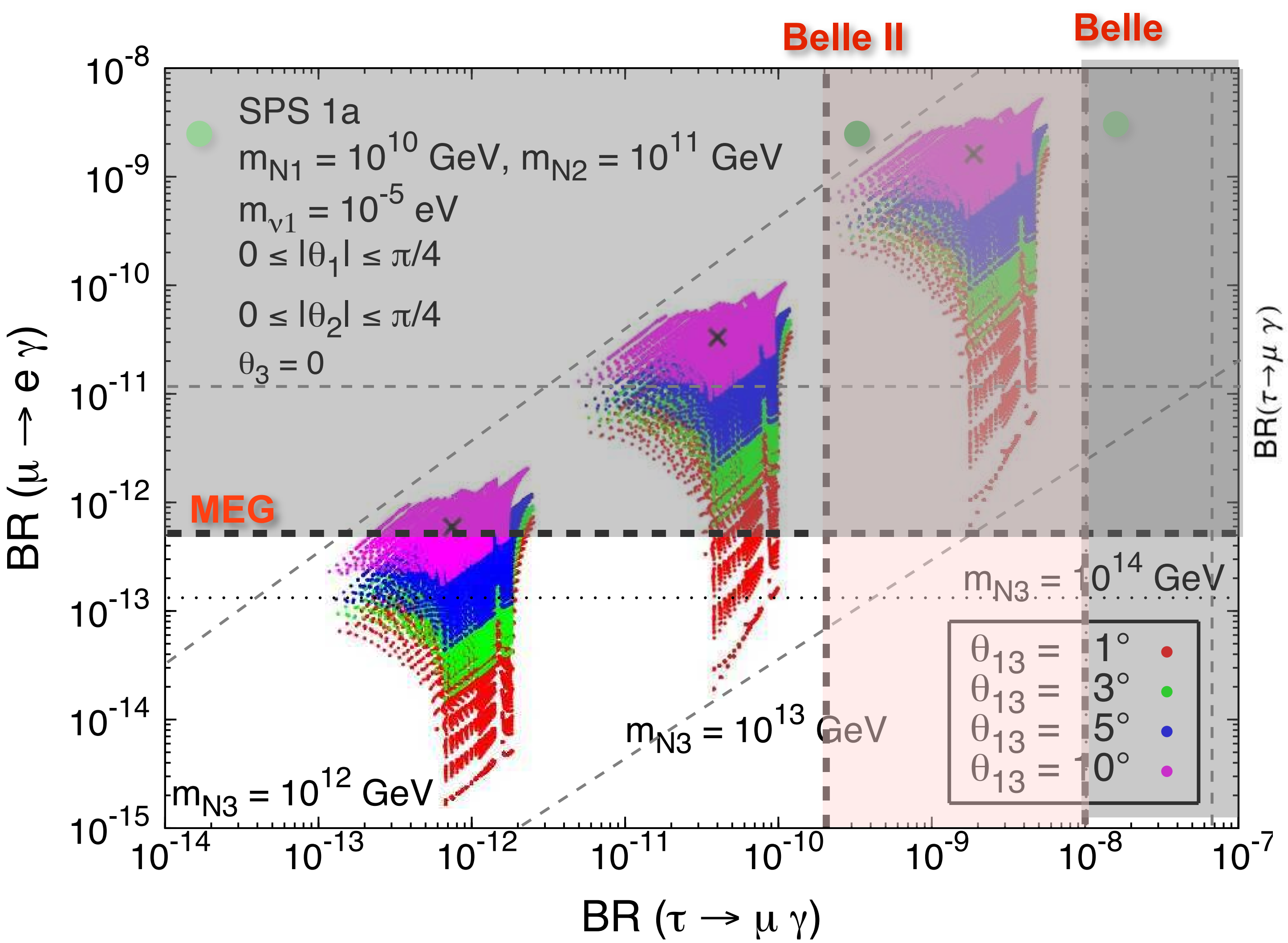
$$2A_{CP}^{\text{indirect}} = \left(|q/p| + |p/q|\right) x\sin\phi - \left(|q/p| - |p/q|\right) y\cos\phi$$

LFV Impact On Models

Tau

Seesaw

CMSSM model point with 3 massive RH N for various $m(N_3)$ and θ_{13}



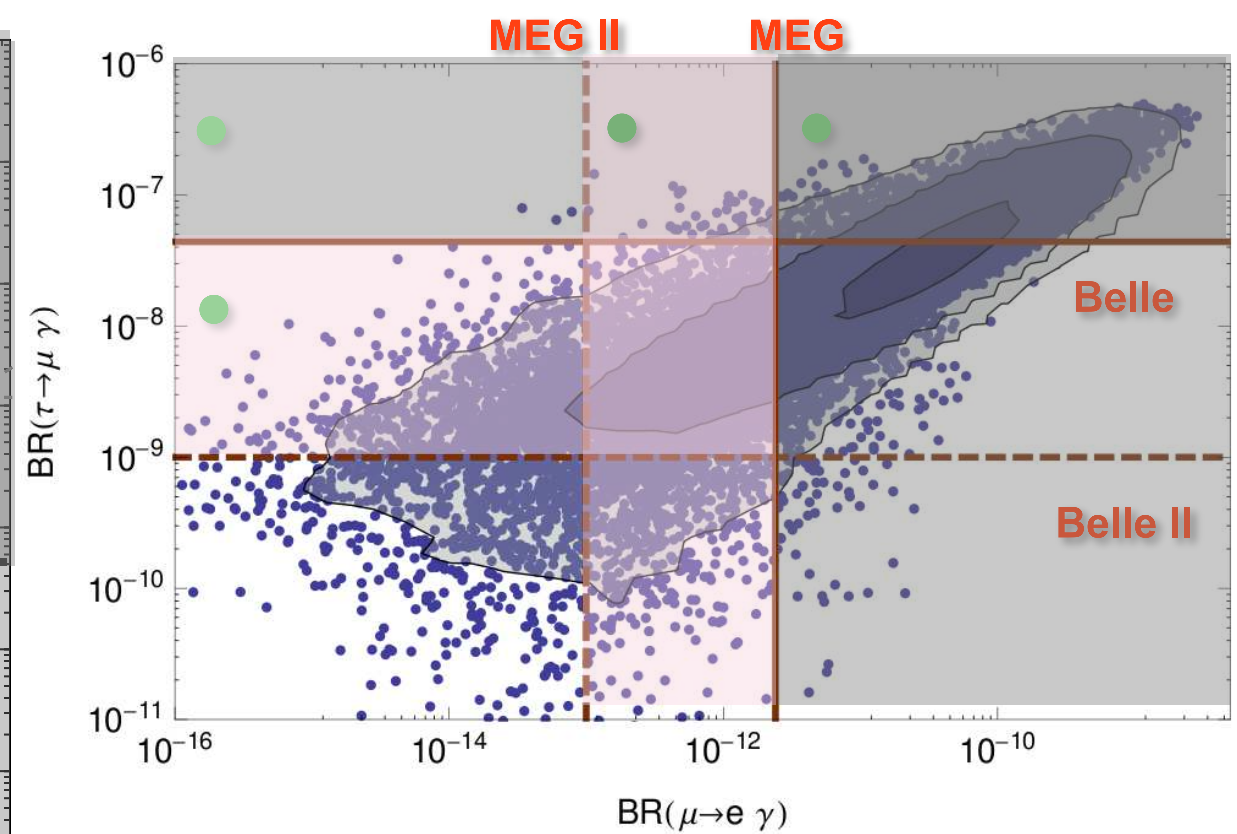
MEG Phys. Rev. Lett. 110, 201801 (2013)

S. Antush et al. JHEP, 11:090 (2006)

SUSY

TeV scale slepton

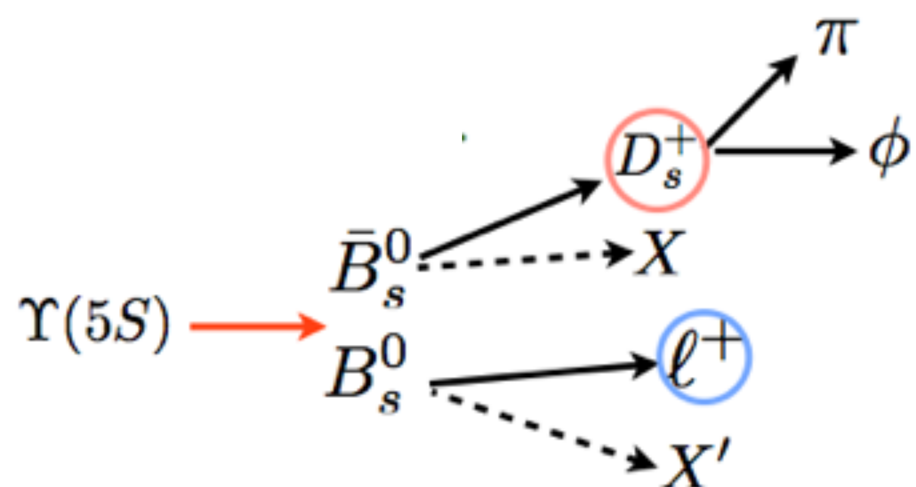
$m_{l3} \ll m_{l1,2}$



Eur.Phys.J. C72 (2012) 2126

B_s Physics

- **5 ab^{-1}** B_S SL or Full recon. @ Υ(5S) similar precision to B^0 studies / **325 fb^{-1}** of Υ(4S)
- f_s will be well measured: WA=**(19.9±3.0)%**
- **SU(3) Symmetry heavily relied upon at LHC, but needs to be rigorously tested.**

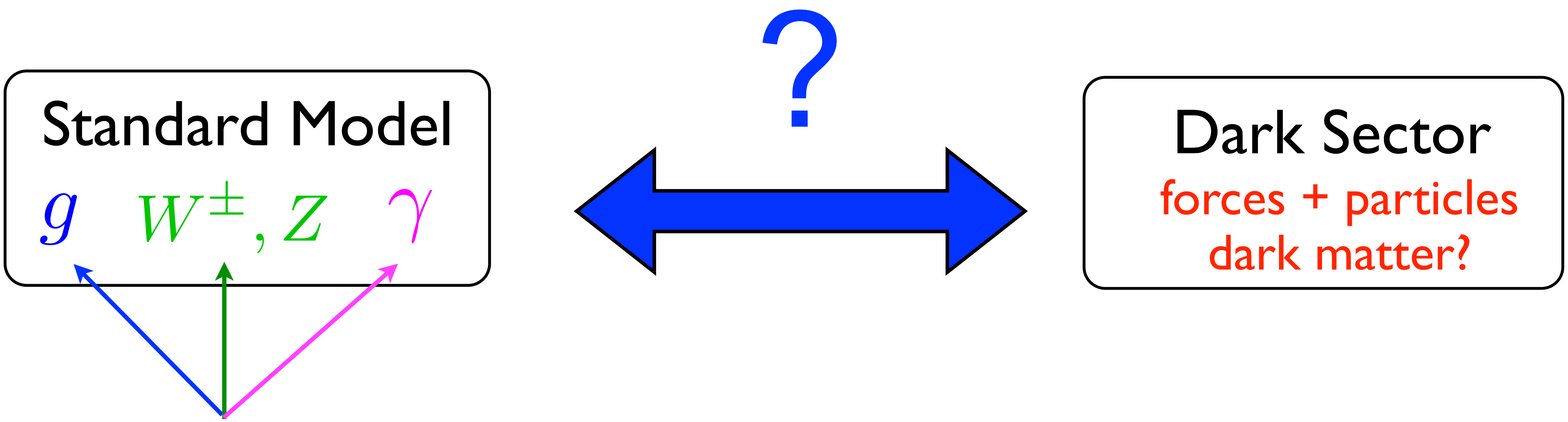


Tag Method	Tag Eff.	NB_s/NB	B_s Yields 121/fb	B_s Yields 5/ab
Untagged	2.000	$f_s/f_{d,u} \simeq 0.25$	1.4E+07	**6.0E+08**
Lepton tag	0.100	$f_s/f_{d,u} \simeq 0.25$	7.0E+05	**3.0E+07**
D_s:Φπ,K_SK,K^*K	0.040	$10 \cdot f_s/f_{d,u}$	2.8E+05	**1.2E+07**
B_s Full Recon.	0.004	$\gg 10$	2.8E+04	**1.2E+06**

$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	< 8.7 [42]	0.3	–
$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	–	< 2 [44]‡	–

Dark Sector

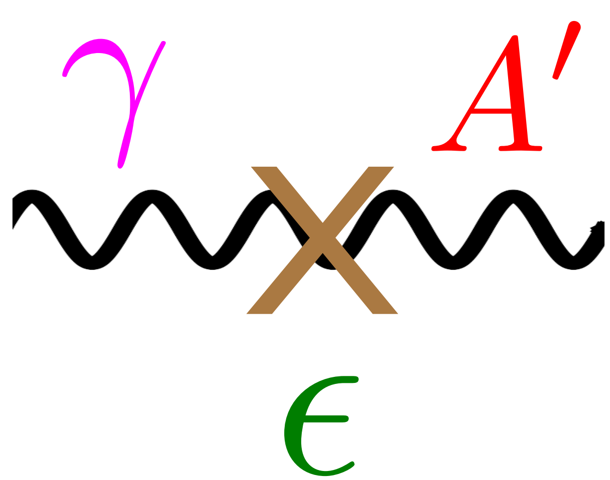
Dark matter suggests the presence of a dark sector, neutral under all Standard Model forces (i.e. non-WIMP)



Known Forces

strong, weak, EM

One way:
Dark Photons.



$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

"Kinetic Mixing"

Holdom
Galison, Manohar