Recent Results from Belle and Prospects for Belle II

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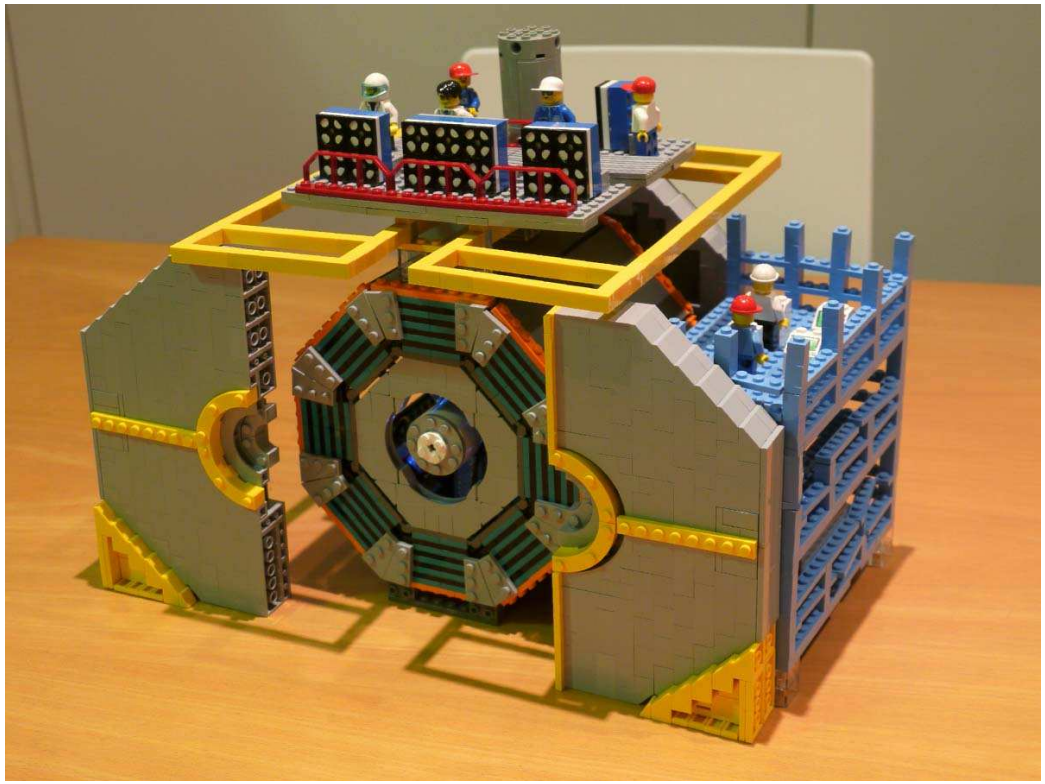
28 January 2015
Yongpyong/High1
Joint Winter Conference



Outline

(1) Introduction and Motivation

(2) Very Quick Tour of Selected Topics on Recent Results / On-going Studies / Belle II Sensitivities

- Precision measurement of Unitarity Triangle
- Pure leptonic decays $B \to \tau\nu$ and $B \to \mu\nu$
- τ lepton flavor violation (LFV)

(3) SuperKEKB / Belle II Status

(4) Summary

Belle data analysis is still on-going and many interesting results (not shown today) will be presented sooner or later

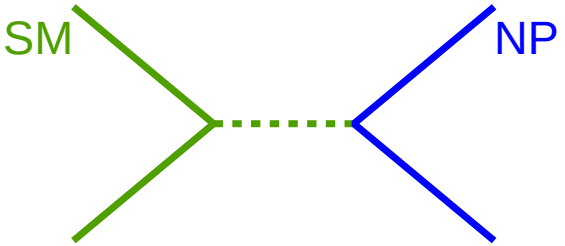
Introduction and Motivation

Role of Belle and Belle II

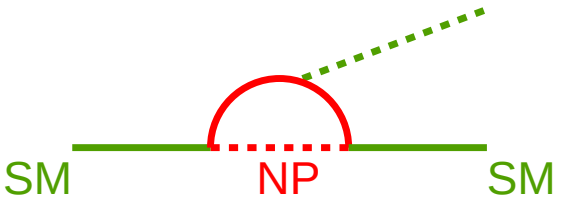
No established evidence (except for neutrino mass) **in HEP, but New Physics must be there to account for observations in cosmology and theoretical demands**

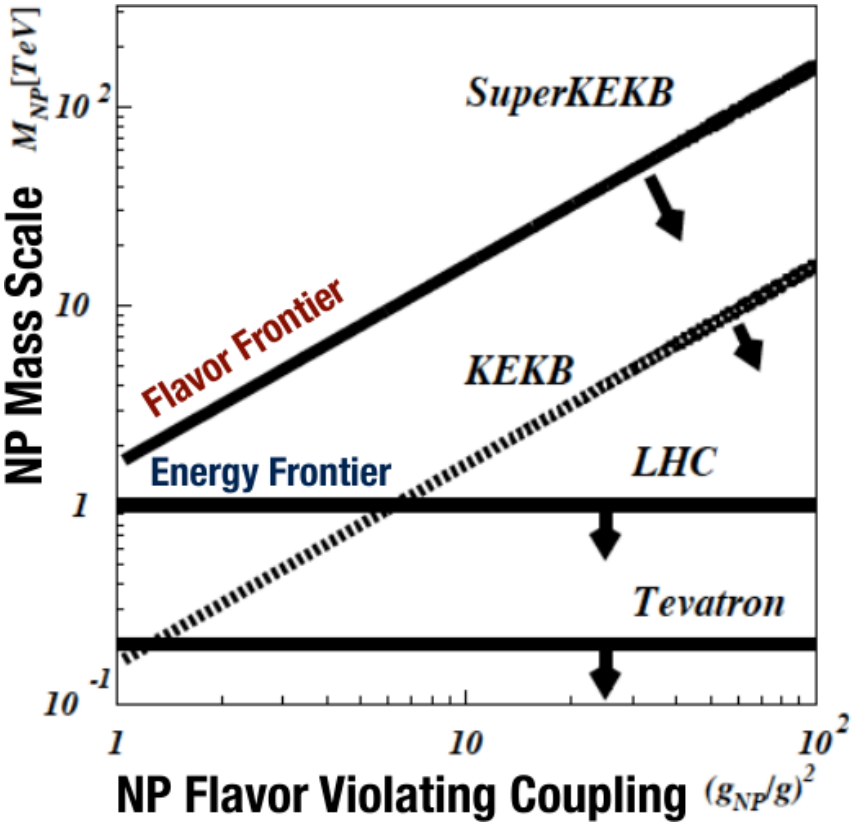
Flavor physics is able to access the mass scale beyond LHC

Energy Frontier: Pair production of new particle, limited by beam energy



Flavor Frontier: Virtual particles beyond 10 TeV is accessible

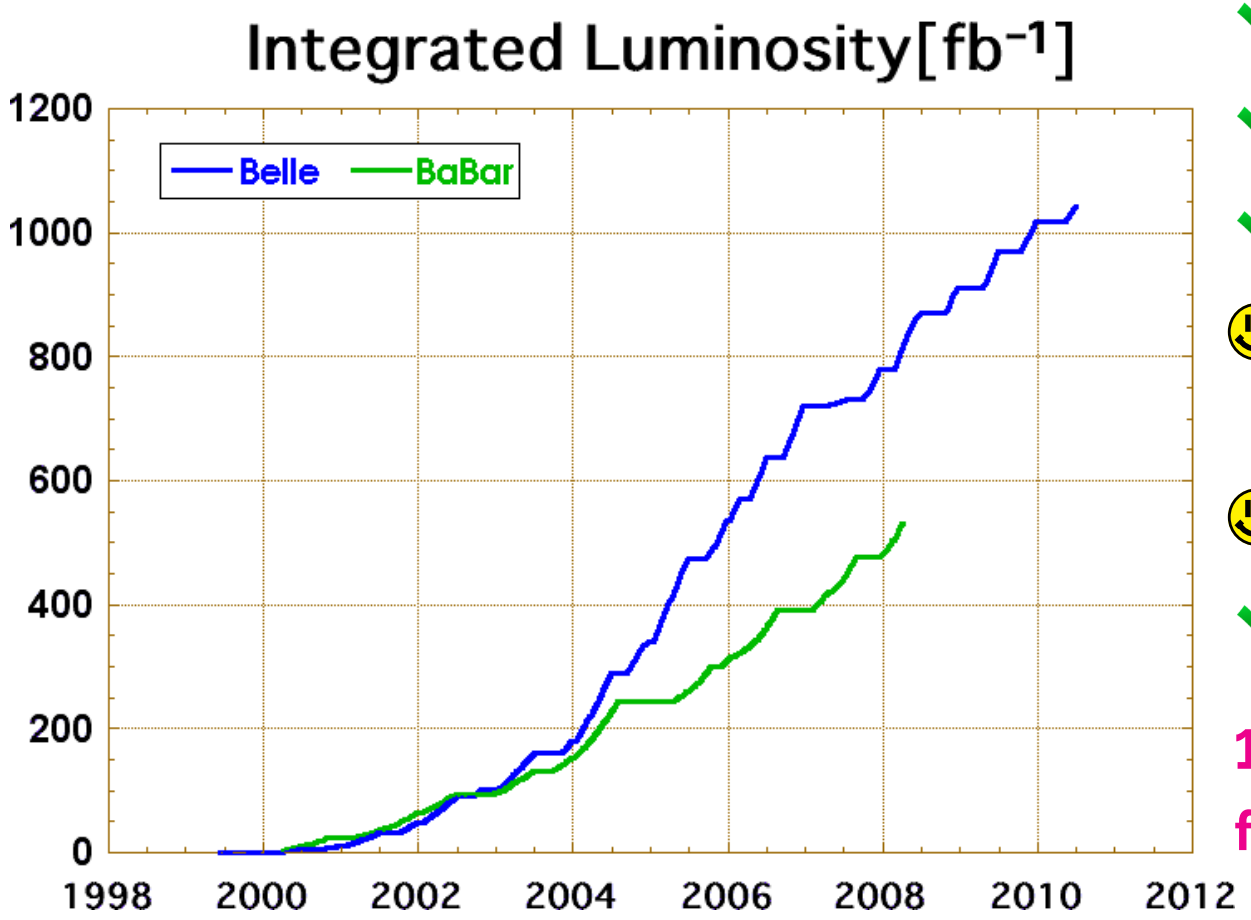




Complementarity: if LHC discovers SUSY, the next challenge is the symmetry breaking mechanism, for which the coupling to flavor is the key

Belle Datasets

1999.5.31 — 2010.6.1



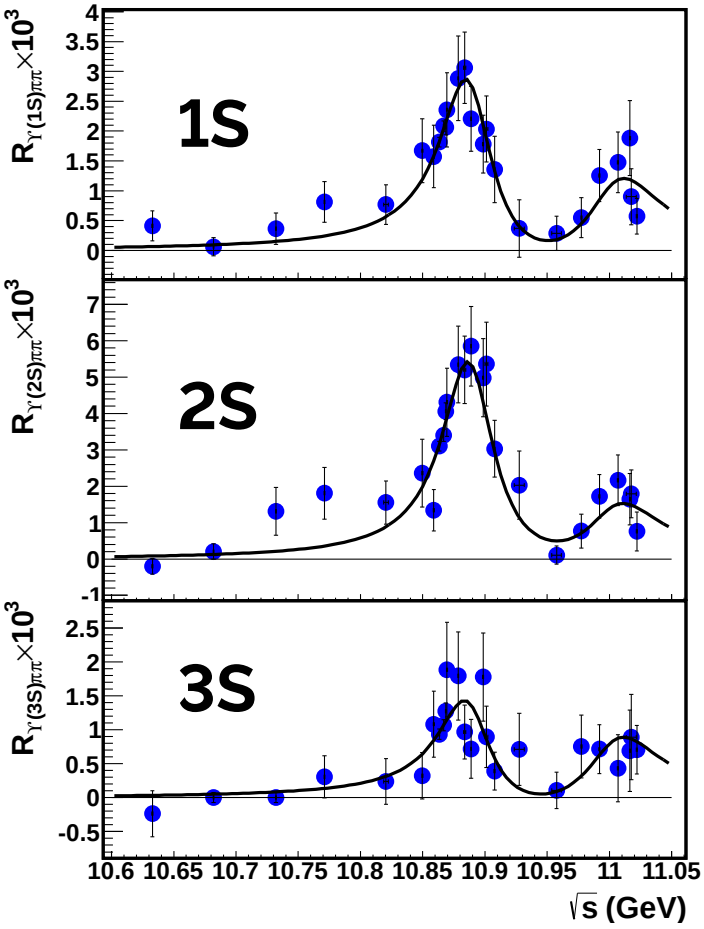
- ✔ $\Upsilon(1S)$ — 6 fb^{-1}
- ✔ $\Upsilon(2S)$ — 25 fb^{-1}
- ✔ $\Upsilon(3S)$ — 3 fb^{-1}
- 🙂 $\Upsilon(4S)$ — 711 fb^{-1}
  off-4S — 90 fb^{-1}
- 🙂 $\Upsilon(5S)$ — 121 fb^{-1}
- ✔ scan, off-nS

1041 fb^{-1} total, 988 fb^{-1} for analysis, 772M $B\overline{B}$

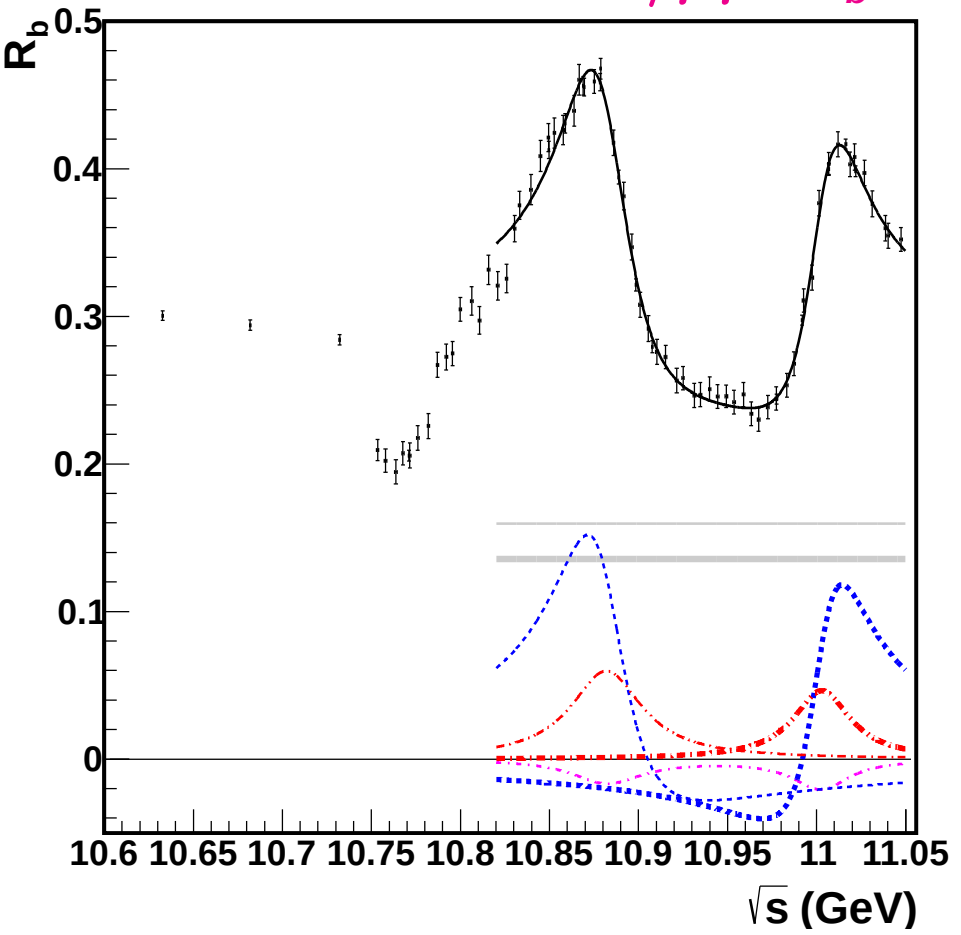
Scan around $\Upsilon(5S)/\Upsilon(6S)$

arXiv:1501.01137 submitted to PRL

$e^+e^- \to \Upsilon(nS)\pi^+\pi^-/\mu\mu$



$e^+e^- \to$ **hadrons**/$\mu\mu$ (R_b)



R_b model: $\left|A_{5S}e^{i\phi_{5S}}BW_{5S} + A_{6S}e^{i\phi_{6S}}BW_{6S} + A_r\right|^2 + |A_{nr}|^2$

$R_{\Upsilon(nS)\pi\pi}$: $|A^n_{5S}BW_{5S}|^2 + |A^n_{6S}BW_{6S}|^2 + 2k_nA^n_{5S}A^n_{6S}\mathrm{Re}(e^{i\delta}BW_{5S}BW^*_{6S})$

— assumptions in $\Upsilon\pi\pi$: no continuum, common phase in interference term

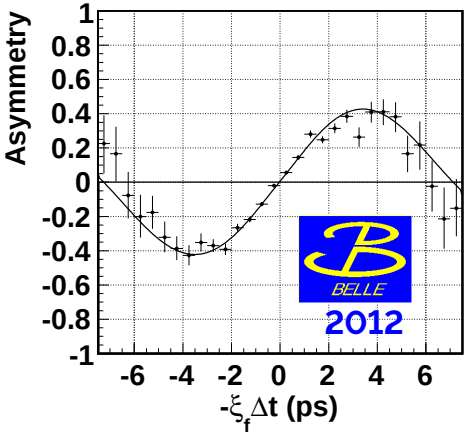
$\Upsilon(5S)$ still mysterious

arXiv:1501.01137 submitted to PRL

- ✔ Earlier Belle data showed possible shift in "$\Upsilon(5S)$" peak (?)
  - R_b has large continuum contribution and less reliable
  - Further update should be with more data on $\Upsilon(nS)\pi\pi$
- ✔ "Ali peak" at 10.9 GeV in BaBar dataset is not confirmed
- ⚠ **Z_b saturates $\Upsilon(5S)$ decay width (?)**
  - $\sum \Upsilon(nS)\pi^+\pi^-$: $17 \pm 1\%$ of R_b at $\Upsilon(5S)$
  - Assuming isospin, $\Upsilon(nS)\pi^0\pi^0$ contributes $0.5\times$ more
  - Almost all $\Upsilon(nS)\pi^+\pi^-$ is through $Z_b^{\pm}\pi^{\mp}$
  - Adding $\Upsilon(5S) \to Z_b\pi \to h_b\pi\pi \Rightarrow 42 \pm 4\%$ (including isospin)
  - Adding $\Upsilon(5S) \to Z_b\pi \to (B^*\overline{B}^{(*)}\pi)\pi \Rightarrow$ **$109 \pm 15\%$** (incl. isospin)
  - **Very little room left for $\Upsilon(5S) \to B_s^{(*)}\overline{B}_s^{(*)}$ (!?)**
- ⚠ $B_s^{(*)}\overline{B}_s^{(*)}$ from continuum only, or something from interference?
  $\Rightarrow$ Need more events for $e^+e^- \to B_s^{(*)}\overline{B}_s^{(*)}$ scan at Belle II

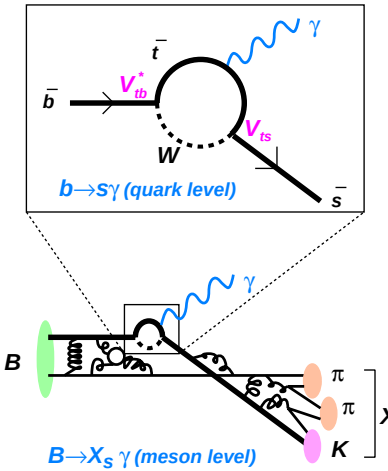
Belle Monuments

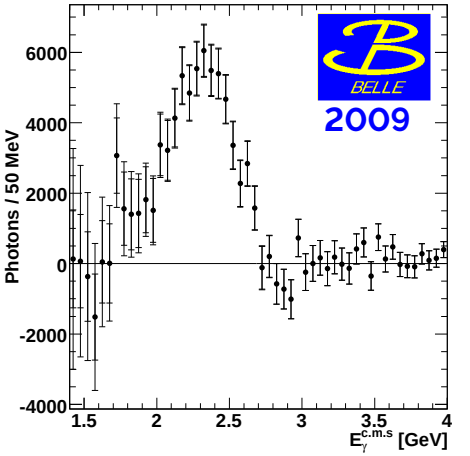
CP violation in $B \to J/\psi K_S$



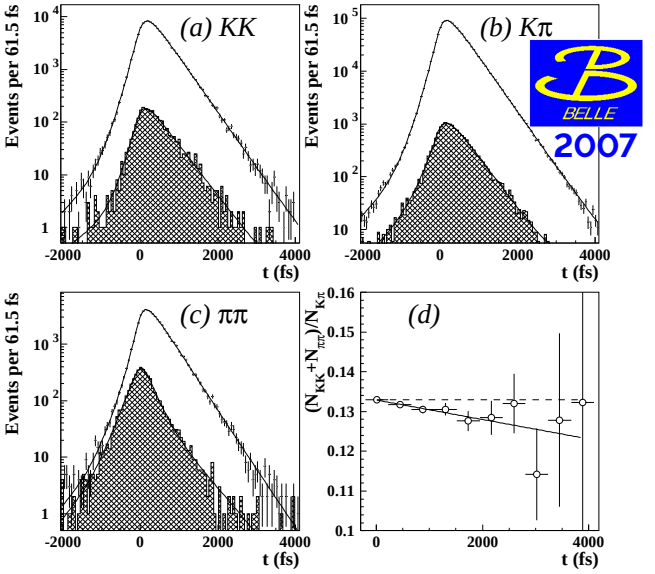
$$\sin 2\phi_1 = 0.668 \pm 0.023 \pm 0.013$$

Penguin decays $B \to X_s\gamma$

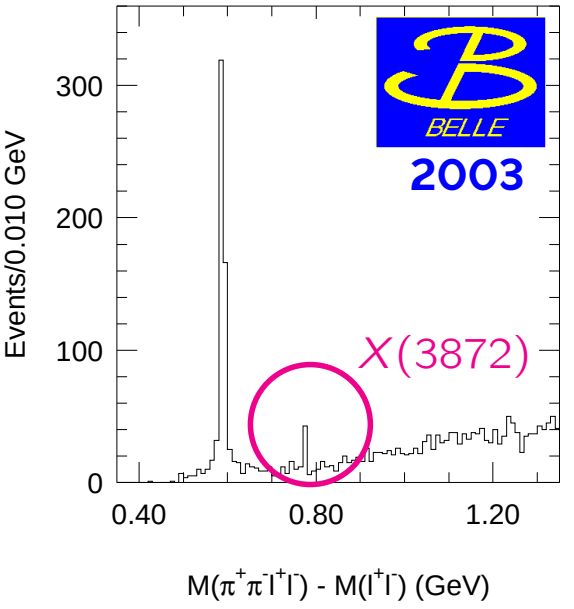


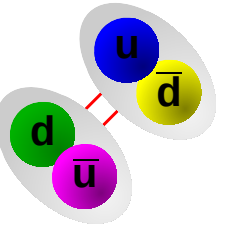


Charm mixing

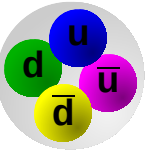


New Particles

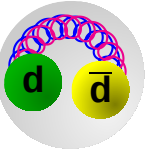




molecule?

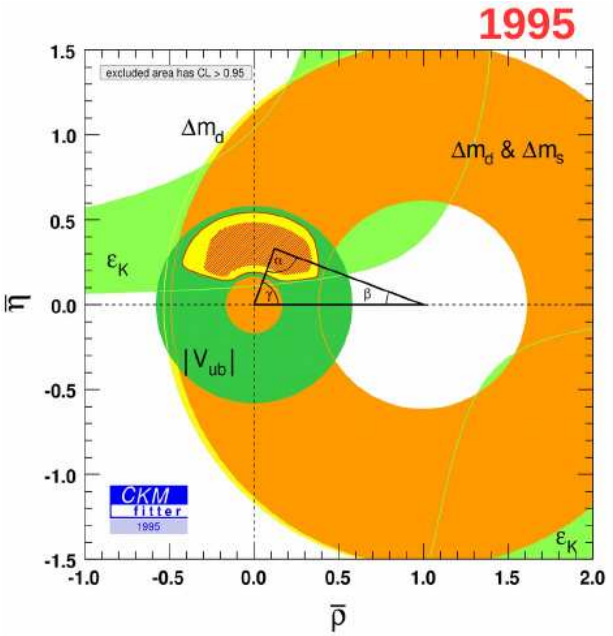


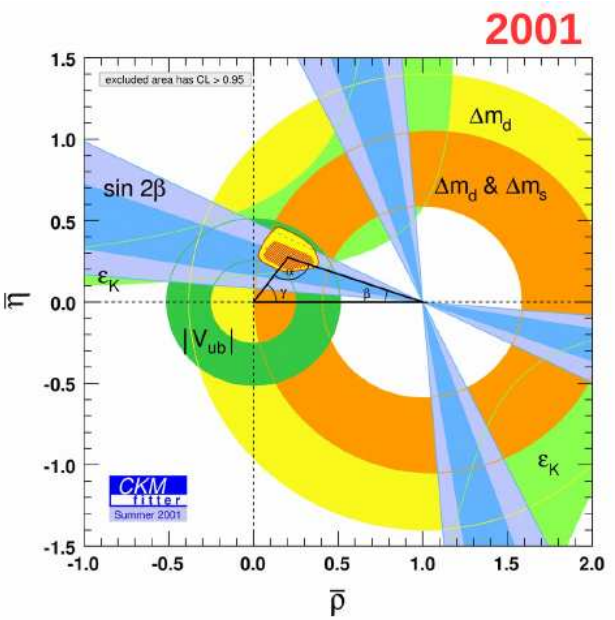
tetraquark?

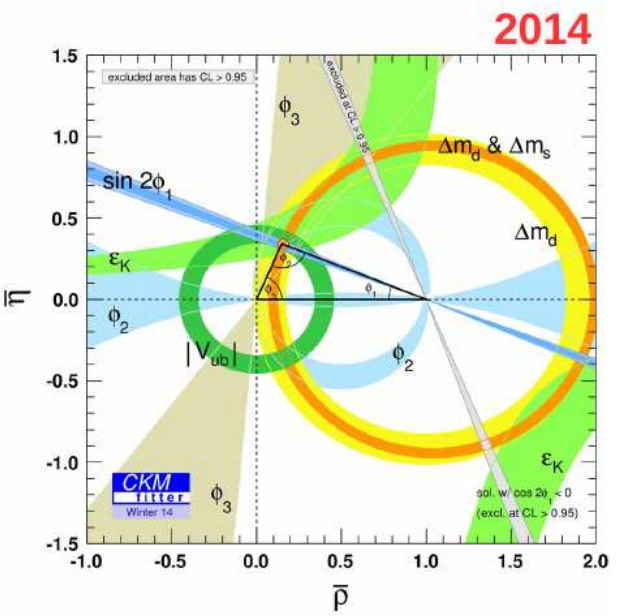


hybrid?

Unitarity Triangle



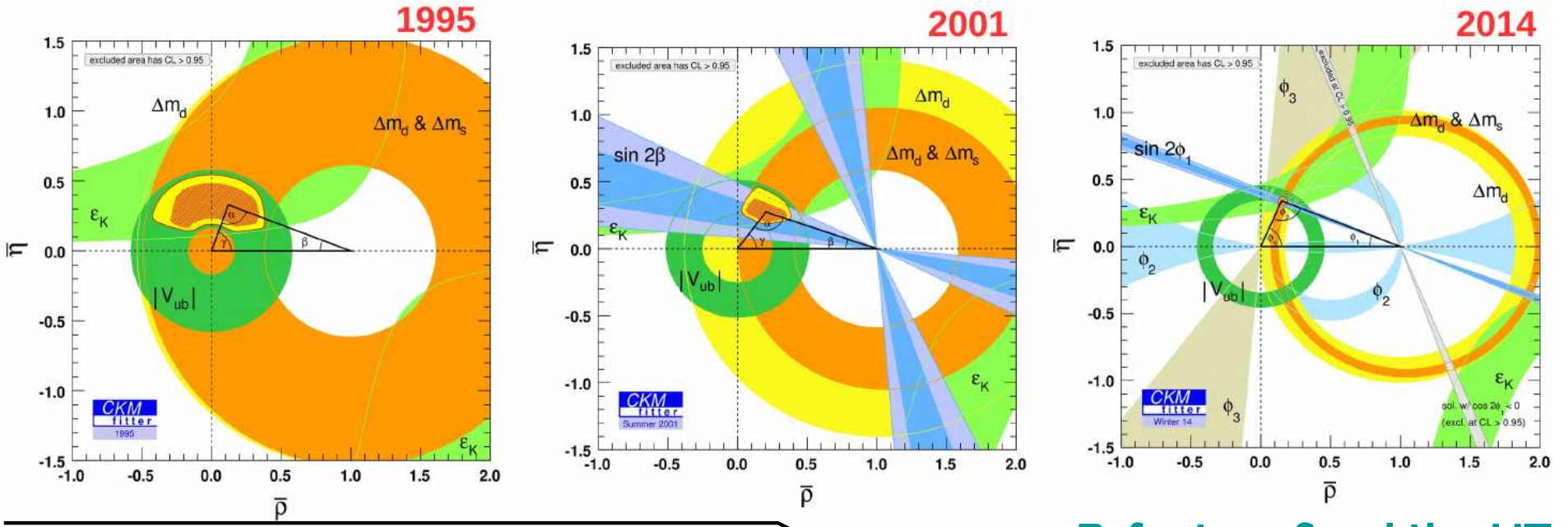




B-factory fixed the UT

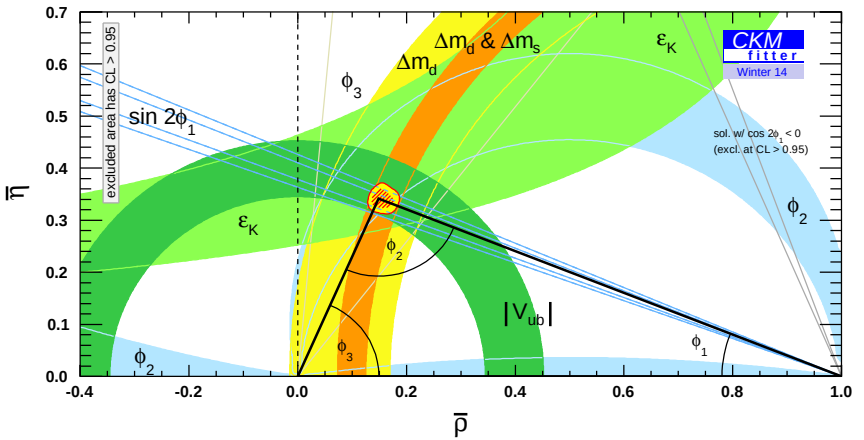
Non-trivial test of the SM — mission completed?

Unitarity Triangle



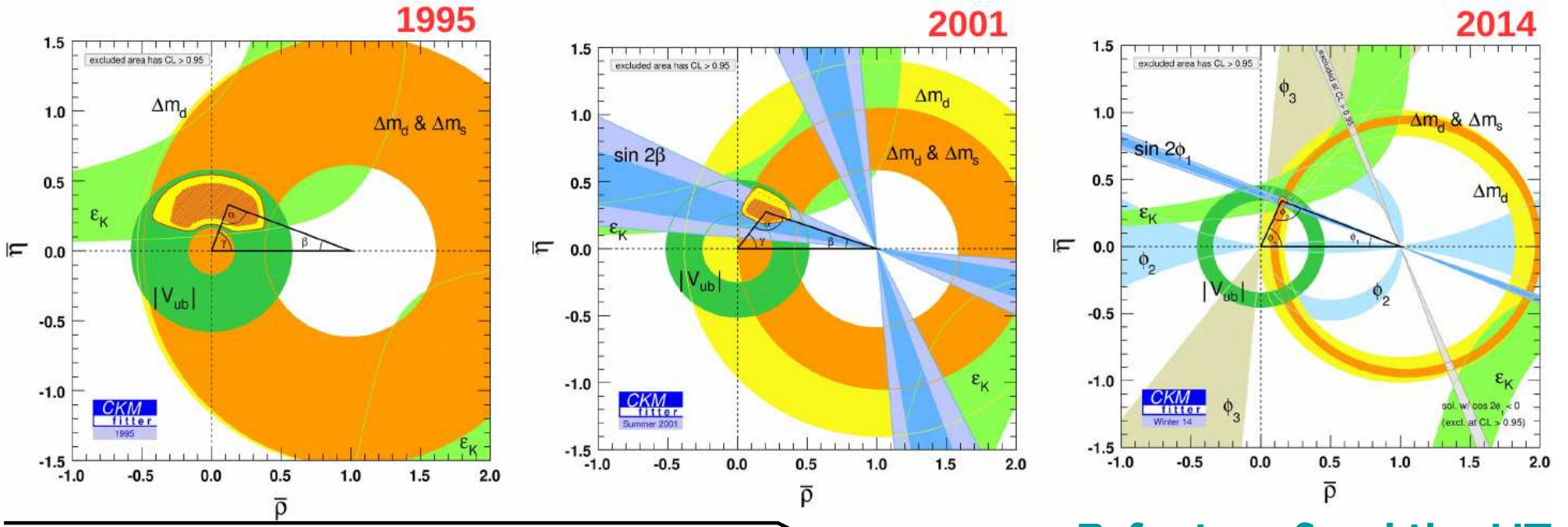
B-factory fixed the UT

But still coarse if magnified



Demand for more data!

Unitarity Triangle



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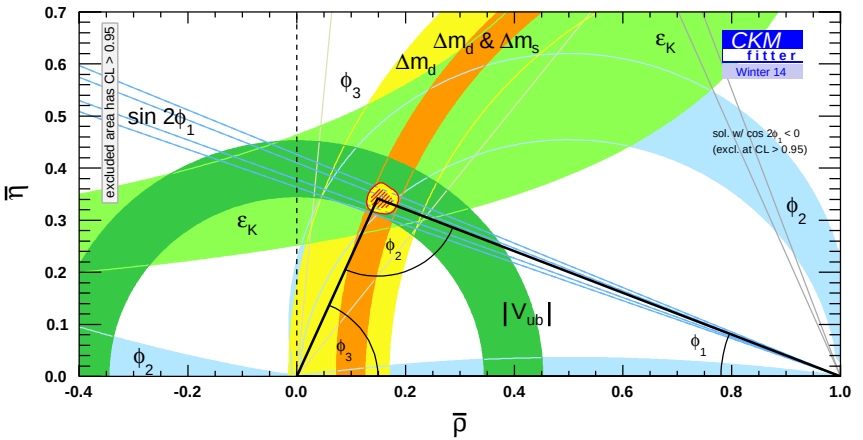
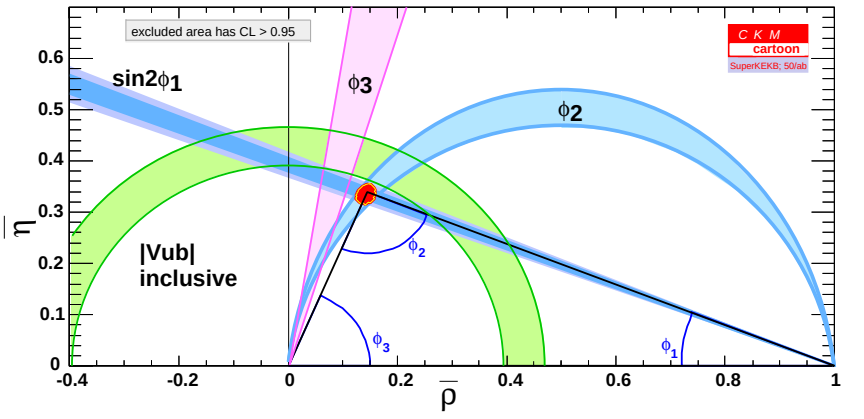


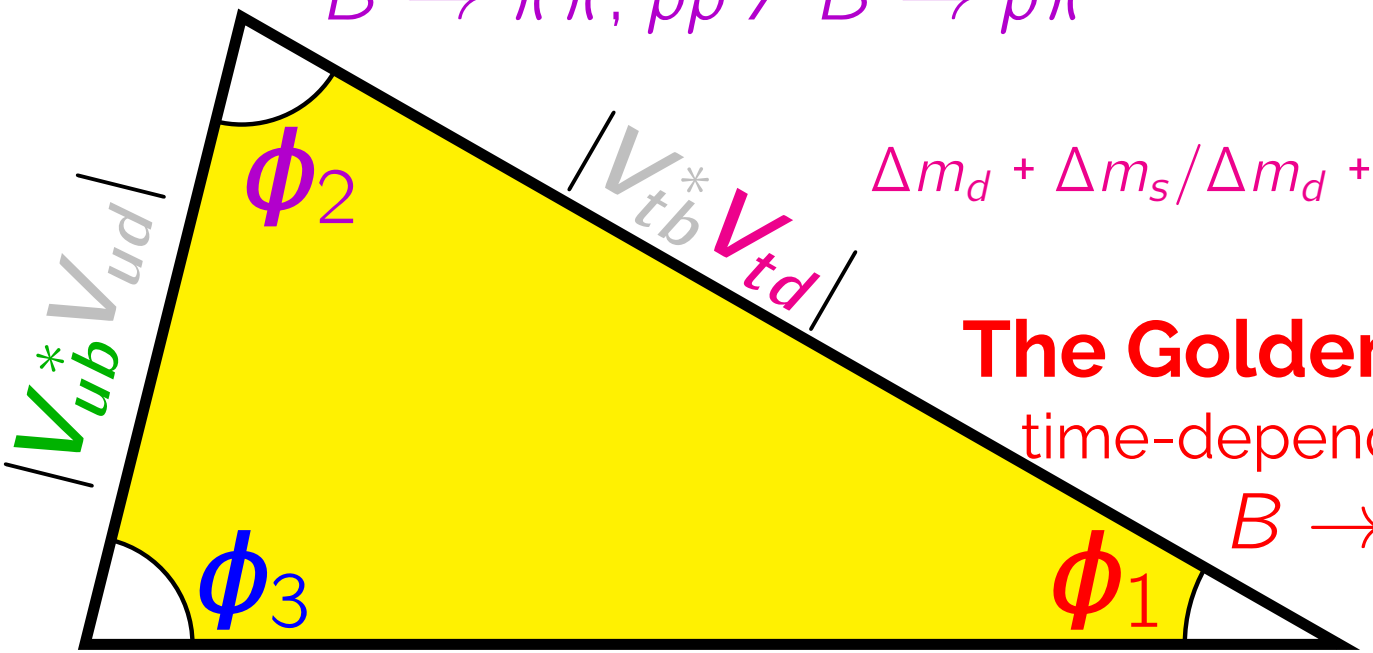


Belle II alone can push down to limit to overconstrain, or…

Unitarity Triangle

Inclusive $B \to X_u \ell\nu$ + OPE
Exclusive $B \to \pi\ell\nu$ + LQCD
Leptonic $B \to \tau\nu$ + f_B

time-dependent CPV + isospin/Dalitz analysis
$B \to \pi\pi,\ \rho\rho\ /\ B \to \rho\pi$



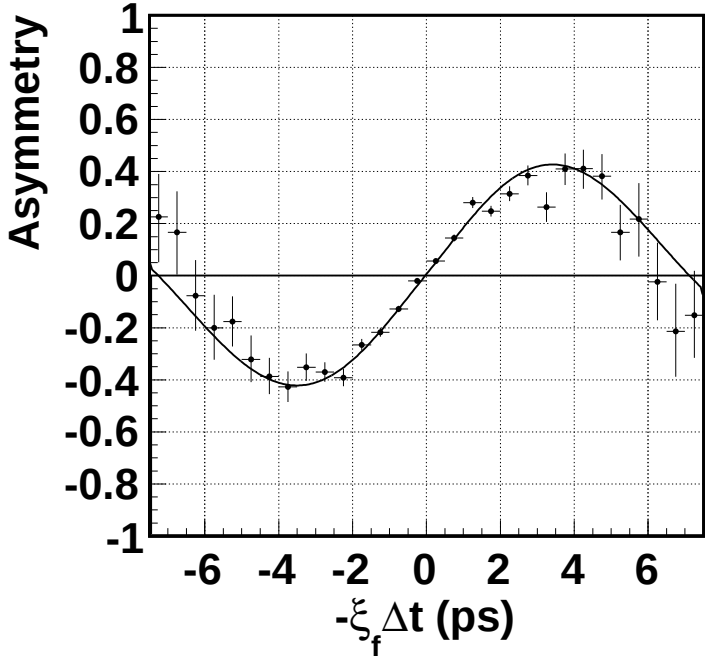
Δm_d + $\Delta m_s/\Delta m_d$ + LQCD

The Golden Mode
time-dependent CPV
$B \to J/\psi K_S$

$B \to DK$
GLW (D_{CP})
ADS (DCSD)
Dalitz ($K_S\pi^+\pi^-$)
(interference between D^0 and $\overline{D}^0$)

Inclusive $B \to X_c \ell\nu$ + OPE
Exclusive $B \to D^{(*)}\ell\nu$ + LQCD

ϕ_1 prospects



$\sin 2\phi_1 = 0.668 \pm 0.023 \pm 0.013$

Systematic error budget

	ΔS	ΔA
Physics parameters	± 0.001	< 0.001
Vertexing	$^{+0.008}_{-0.009}$	± 0.008
Resolution function	± 0.007	± 0.001
Flavor tagging	$^{+0.004}_{-0.003}$	± 0.003
Fit bias	± 0.004	± 0.005
$J/\psi K_S$ signal fraction	± 0.002	± 0.001
$J/\psi K_L^0$ signal fraction	± 0.004	$^{+0.000}_{-0.002}$
$\psi(2S) K_S$ signal fraction	< 0.001	< 0.001
$\chi_{c1} K_S$ signal fraction	< 0.001	< 0.001
Background Δt	± 0.001	< 0.001
Tag-side interference	± 0.001	± 0.008
Total	± 0.013	± 0.013

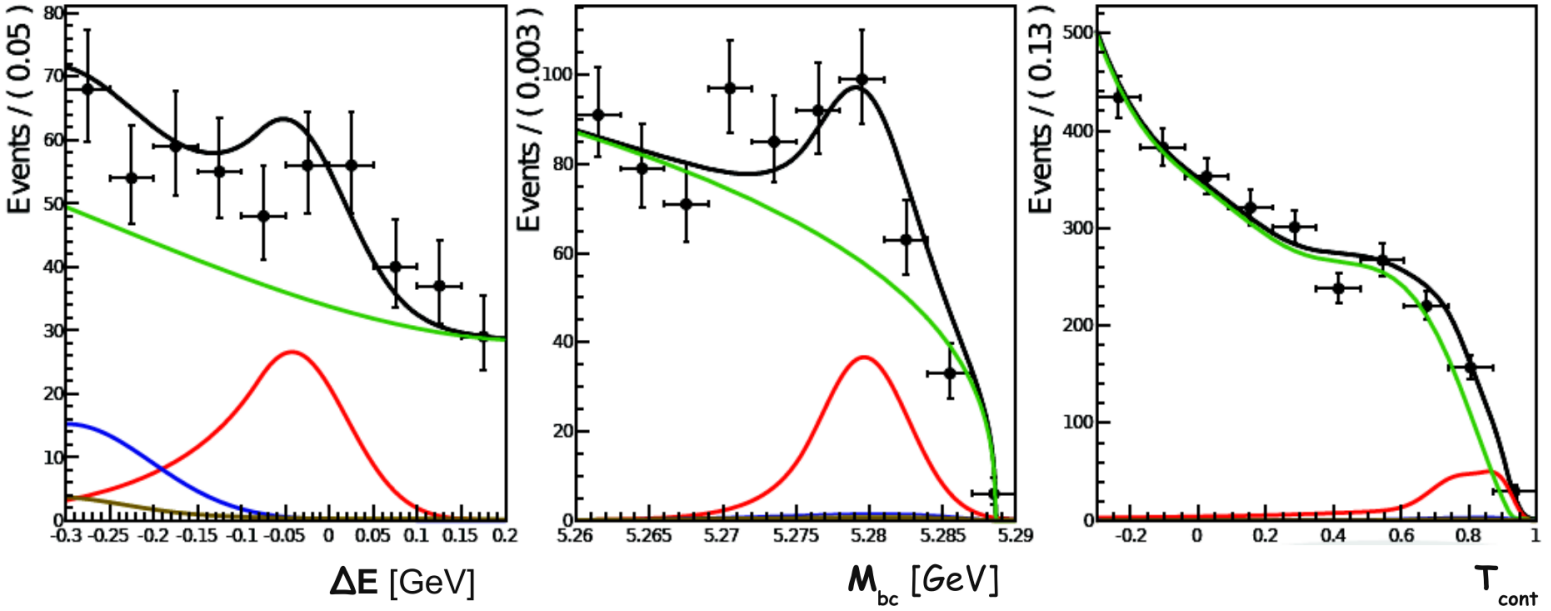
Belle analysis has completed for ϕ_1

- Belle II ultimate $\delta(\sin 2\phi_1) \sim 0.01$
  - Statistical error reach ~ 0.003
  - Better vertexing with Pixel + SVD **by a factor of ~two**

    (Systematic error ~ 0.012 in Belle II Physics Book should further decrease)

ϕ_2 status — new $B^0 \to \pi^0\pi^0$ result

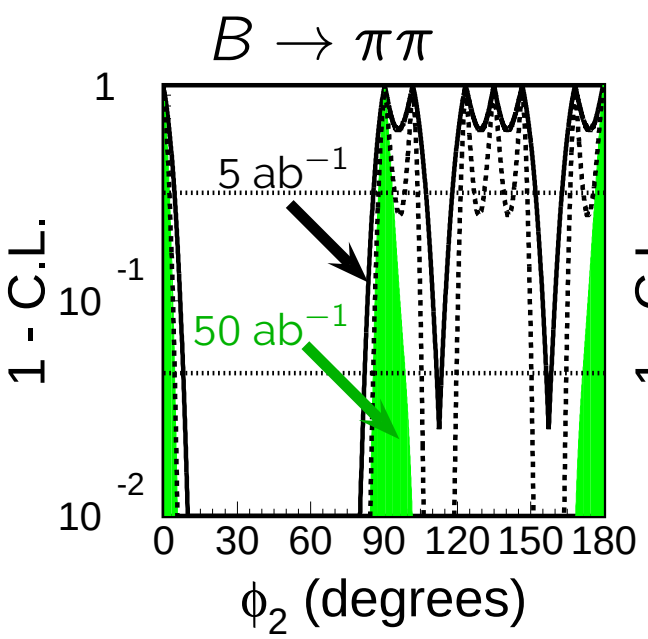
M.Petric at ICHEP2014

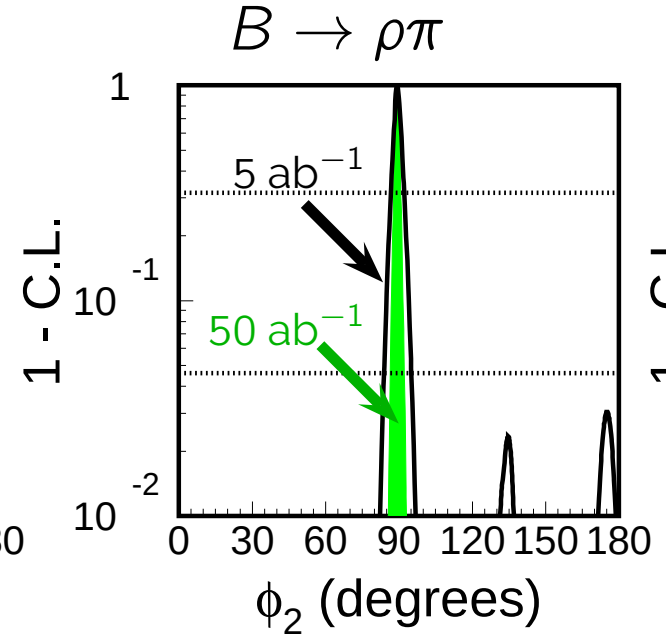


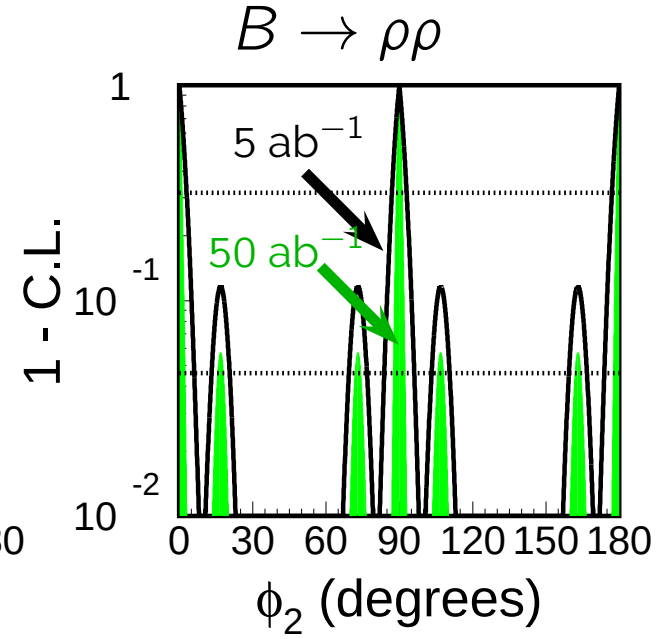
- Preliminary: $\mathcal{B}(B \to \pi^0\pi^0) = (0.90 \pm 0.12 \pm 0.10) \times 10^{-6}\ (6.7\sigma)$
  - Final results to include $A_{CP}(B \to \pi^0\pi^0)$
  - BF reduced from previous Belle $(2.3\,^{+0.4\ +0.2}_{-0.5\ -0.3}) \times 10^{-6}$, also smaller than BaBar $(1.83 \pm 0.21 \pm 0.13) \times 10^{-6}$
  - Getting closer to SM expectation
- On-going analysis for final Belle dataset: $B \to \rho\pi$, $B \to \rho^+\rho^-$

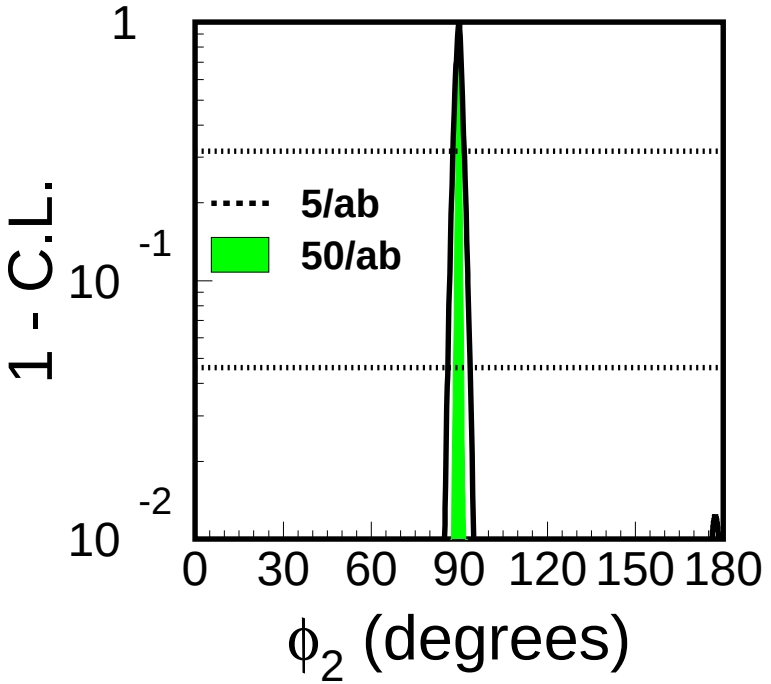
Belle analysis is still on-going for ϕ_2

ϕ_2 prospects









- Error on ϕ_2 combined reaches:
  5 ab^{-1} $\Rightarrow$ 2° / 50 ab^{-1} $\Rightarrow$ 1°
- Uncertainty on isospin relation $\sim 2°$
- Extra handle from time-dependent CPV in $B^0 \to \pi^0\pi^0$, using $\gamma \to e^+e^-$ conversion for vertexing

V_{ub} prospects

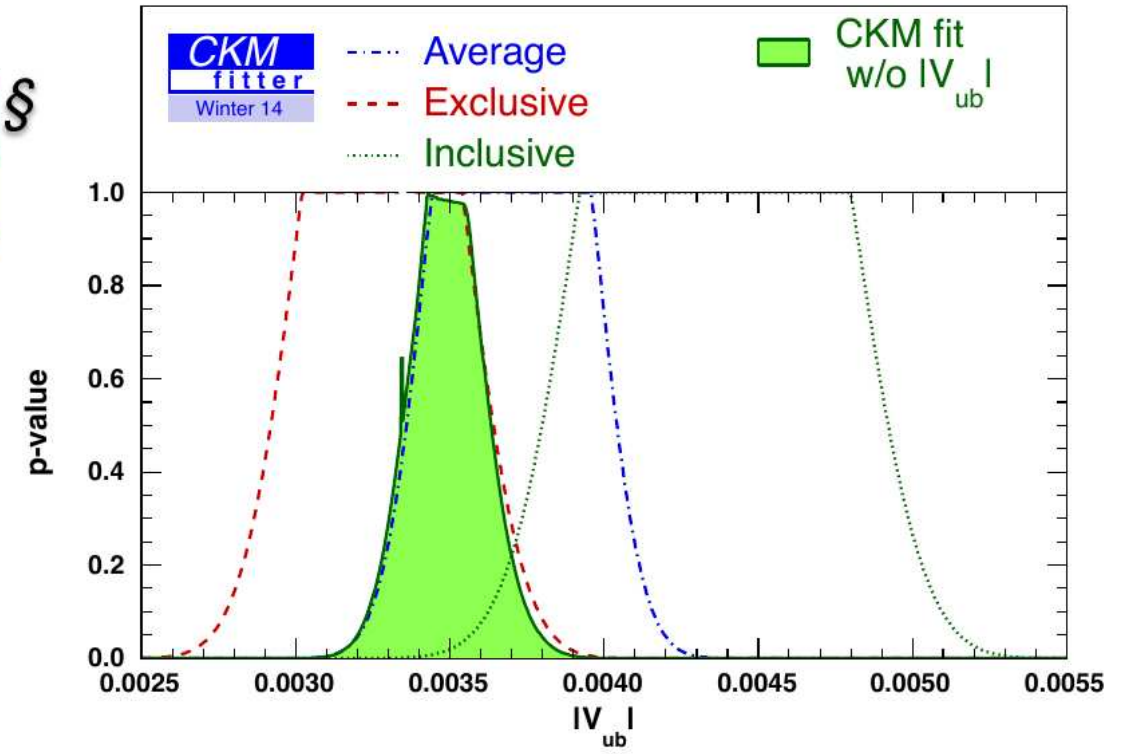
- Inclusive: b → u l ν + OPE / § Assign additional error on m_b, O(50 MeV).
- Exclusive: B → π l ν + Form factors (LQCD used)

[x10-3]

$$|V_{ub}|_{\text{Inc.}} = 4.36 \pm 0.18 \pm 0.44 \quad \S$$

$$|V_{ub}|_{\text{Exc.}} = 3.28 \pm 0.15 \pm 0.26$$

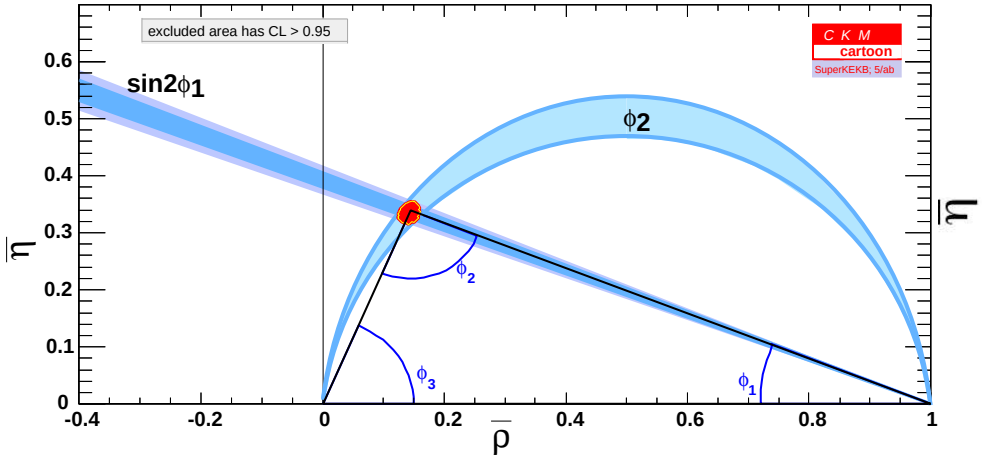
$$|V_{ub}|_{\text{Ave.}} = 3.70 \pm 0.12 \pm 0.26$$



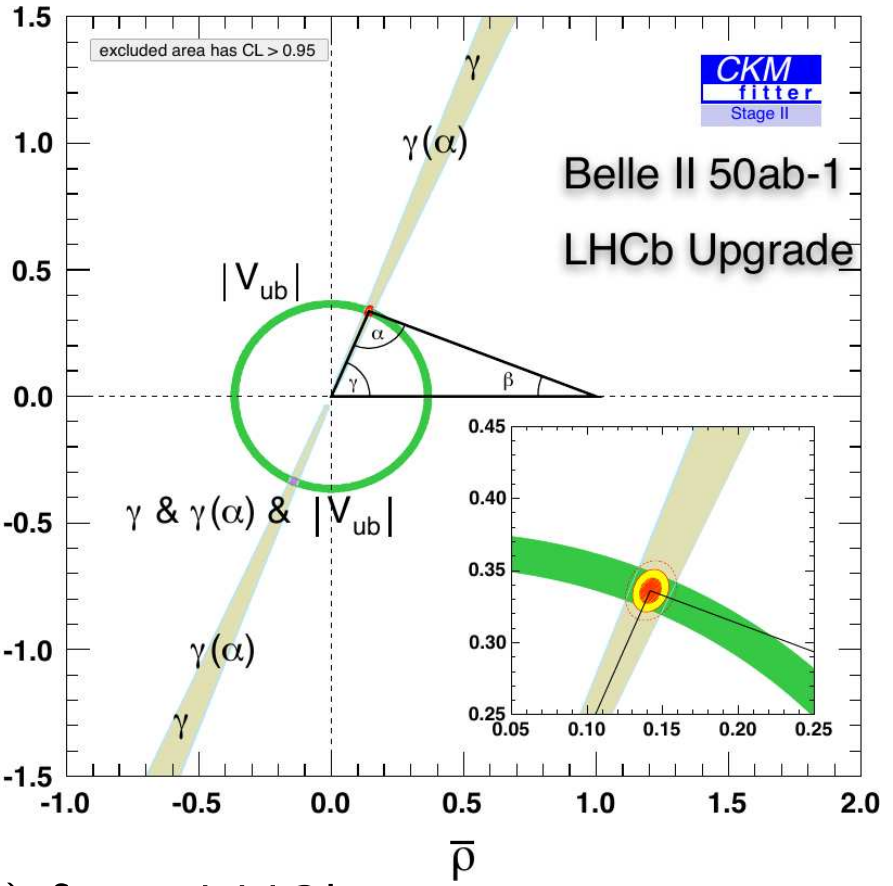
- Tension between inclusive and exclusive is not resolved yet
- Current 10% error ⇒ 3% by Belle II 50 ab^{-1}
- LHCb has no contribution, Lattice QCD progress is expected

UT comparison

Loop modes free from theory



Tree modes free from NP

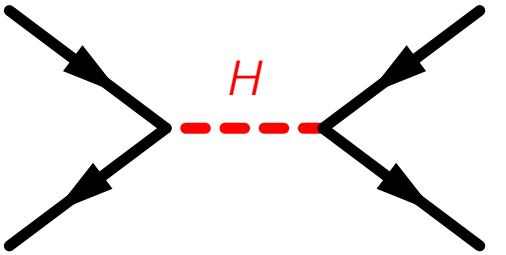


- Tree/loop comparison to search for NP in B-mixing
- Significant contribution to ϕ_3 (γ) from LHCb, but otherwise measurements will be dominated by Belle II
- More non-trivial constraints from Δm_d, ϵ_K (if LQCD improves), and $K_L \to \pi^0 \nu\bar{\nu}$ by E14(KOTO)@J-PARC

Belle II is the key to this non-trivial test

$B \to \tau\nu$, $B \to \mu\nu$

Charged Higgs in B Decays



- $B \to \tau\nu$ (and also $B \to \mu\nu$)

  SM: $\mathcal{B}_{\rm SM}(B^+ \to \tau^+\nu) = \dfrac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \dfrac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$

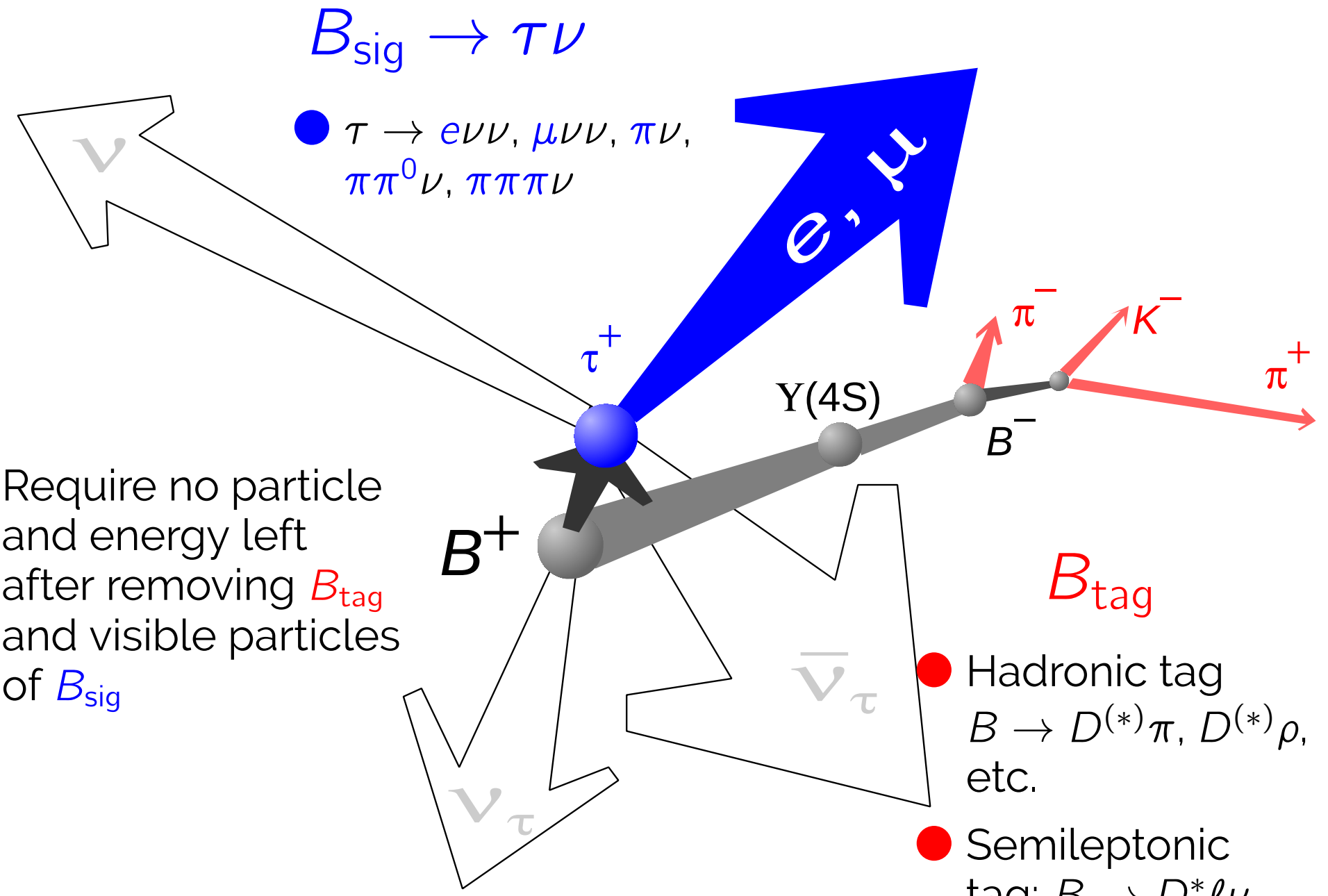
  2HDM: $\mathcal{B}(B^- \to \tau^-\overline{\nu}_\tau) = \mathcal{B}_{\rm SM}(B^- \to \tau^-\overline{\nu}_\tau) \times \left(1 - \dfrac{m_B^2}{m_{H^+}^2}\tan^2\beta\right)^2$

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

  2HDM: $\mathcal{B}(B \to D\tau\nu) = G_F^2 \tau_B |V_{cb}|^2 f(F_V,\ F_S,\ \dfrac{m_B^2}{m_{H^+}^2}\tan^2\beta)$

  Hadronic-tag analysis is almost ready, ***to be announced soon***
  and other analysis methods are also on-going, but not discussed today

Event reconstruction



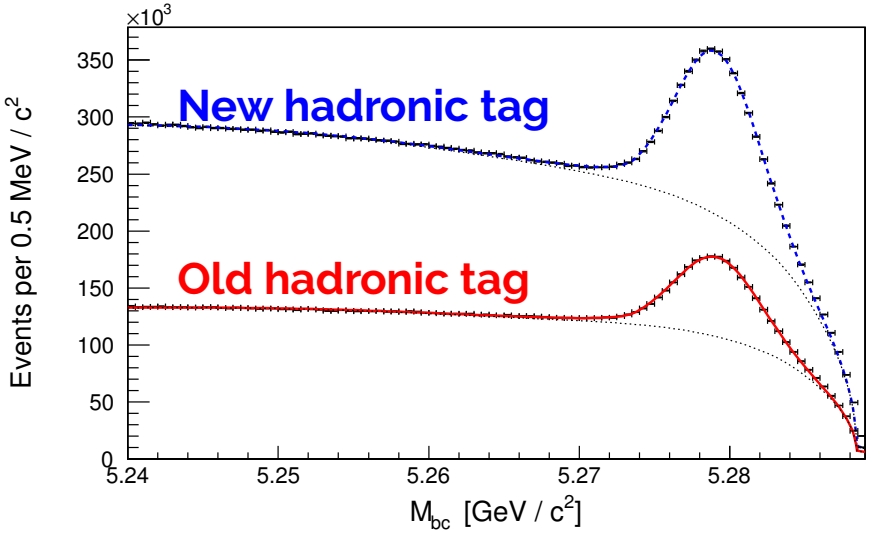
Require no particle and energy left after removing B_{tag} and visible particles of B_{sig}

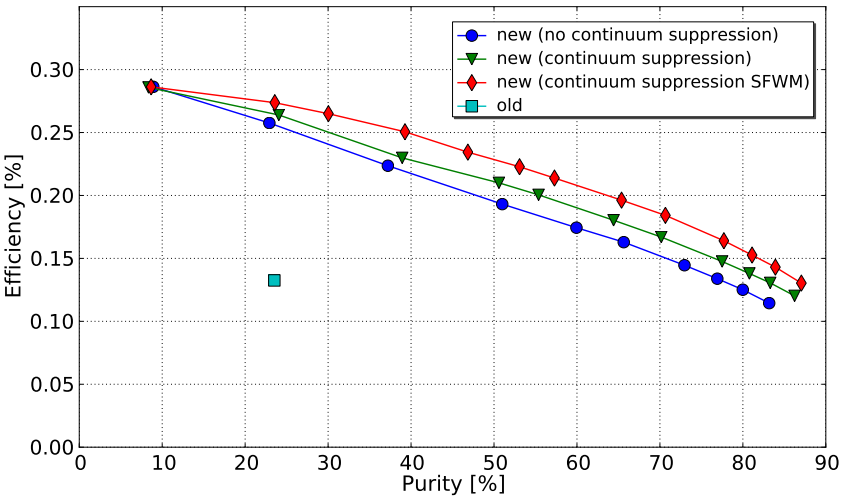
B_{tag}

- Hadronic tag $B \to D^{(*)}\pi$, $D^{(*)}\rho$, etc.
- Semileptonic tag: $B \to D^*\ell\nu$

B reconstruction tag

- **Hadronic Tag**
  - Sum of many many hadronic B decays
  - Neural-net based algorithm improved the efficiency by a factor of two
  - Not so high efficiency $\sim$ 0.2%
- **Semileptonic tag**
  - Reconstruct $B \to D^* \ell \nu$ in the other side (ν is missing)
- Possible only at $\Upsilon(4S) \to B\overline{B}$ + nothing



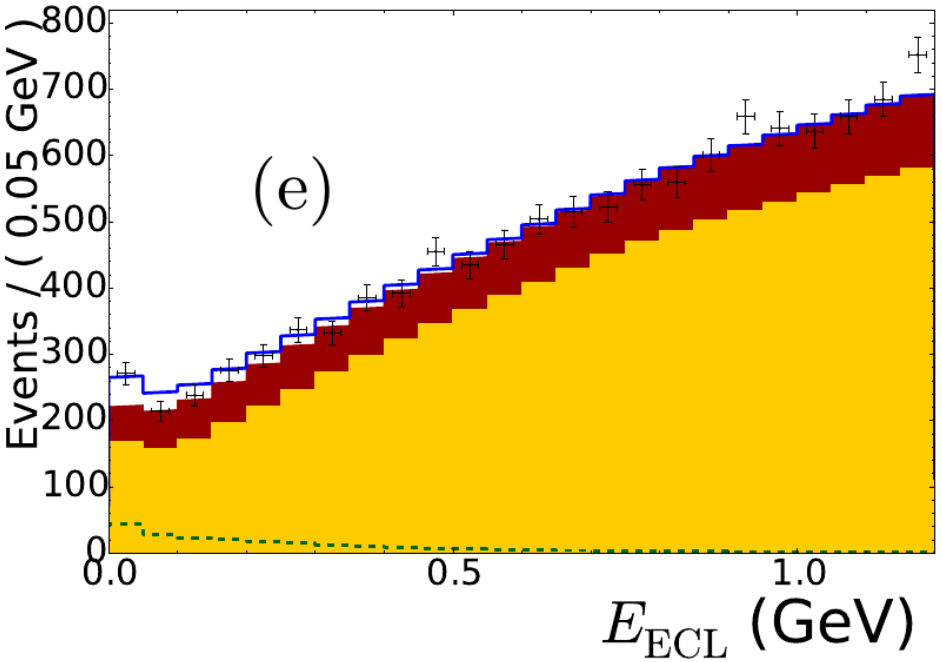


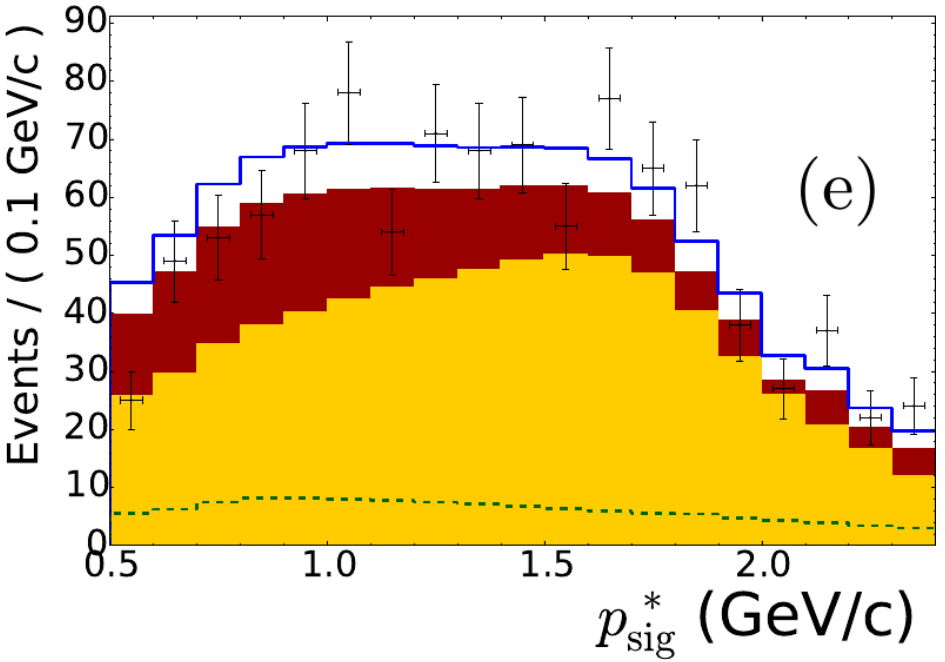
(M.Feindt et al, NIM A654,432(2011))

$B \to \tau\nu$ with SL-tag

arxiv:1409.5269 (preliminary)

- Update from 657M $B\overline{B}$ result to reprocessed 772M $B\overline{B}$
- $\tau \to \rho\nu$ mode added to $\tau \to e\overline{\nu}\nu$, $\mu\overline{\nu}\nu$, $\pi\nu$ modes
- SL tag improvement by neural net (similar to hadronic-tag)
- Improvement in selection, 2D fit to extract signal

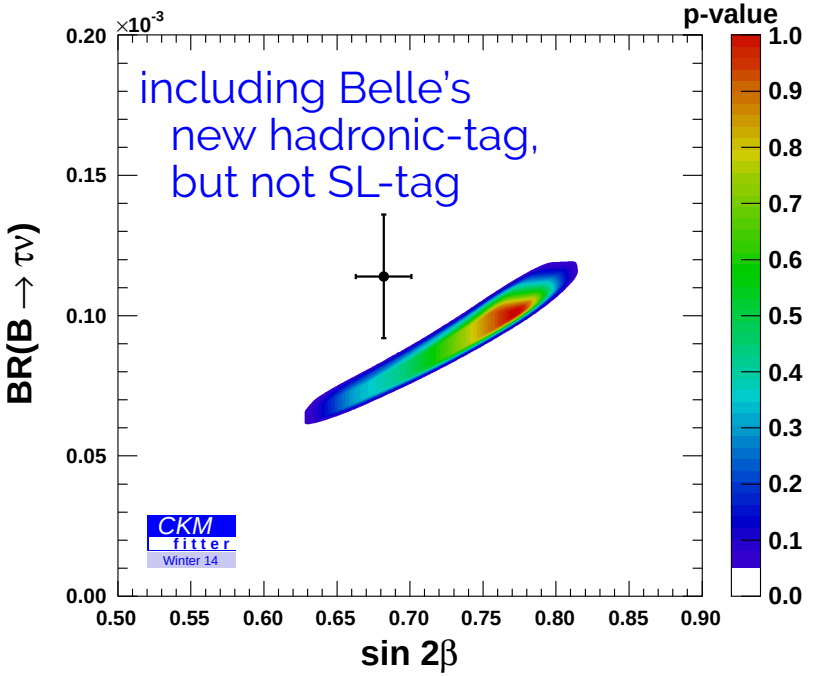


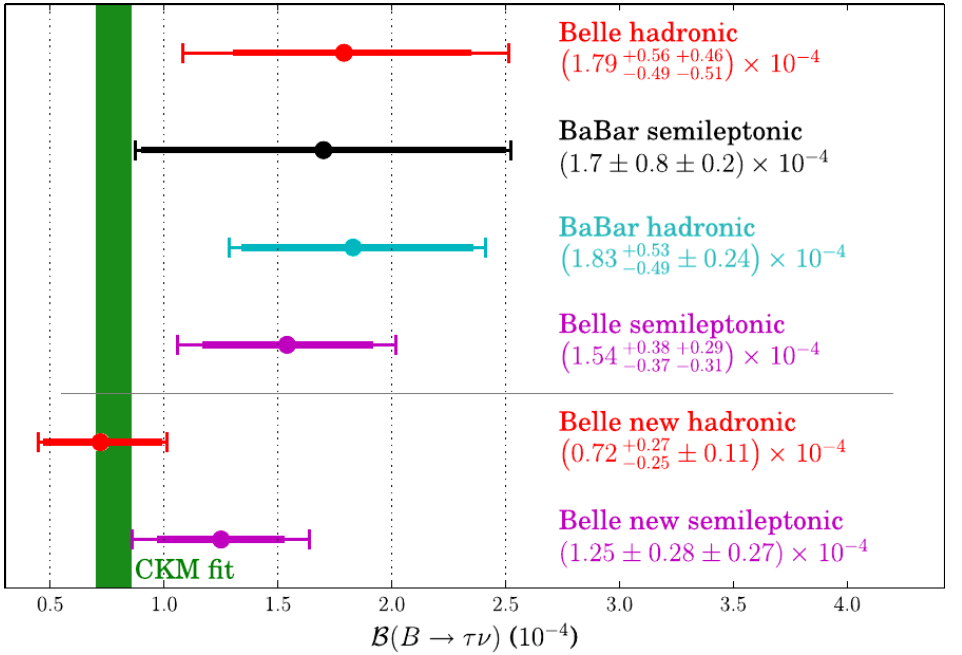


$$\mathcal{B}(B \to \tau\nu) = (1.25 \pm 028 \pm 0.27) \times 10^{-4}$$

$B \to \tau\nu$

- In 2012, Belle's hadronic-tag $\mathcal{B}(B \to \tau\nu)$ dropped significantly
- In 2014, Belle's SL-tag $\mathcal{B}(B \to \tau\nu)$ also somewhat dropped
- Tension in UT decreased by Belle's final results
- Belle+BaBar final results are all done, but still none of them exceeding 5σ, need Belle II for next step



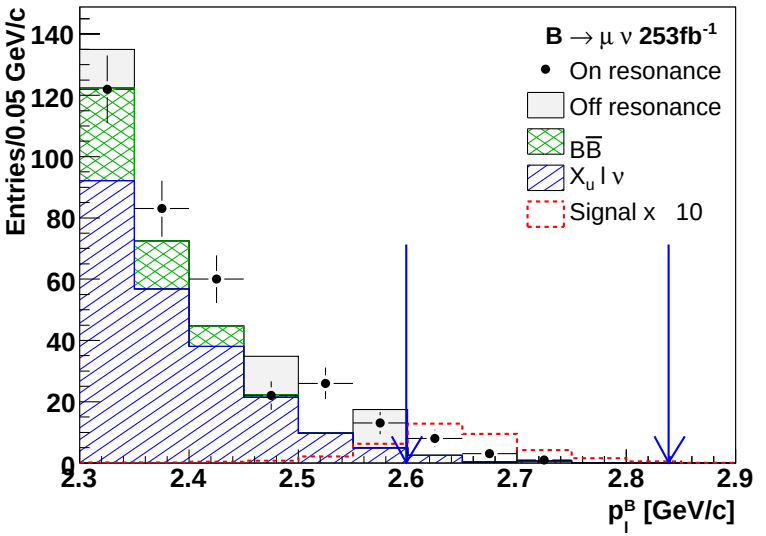


$B \to \mu\nu$

- Same formula as $B \to \tau\nu$ **— interesting if different!?**
  - charged Higgs and helicity suppression by the same amount
  - V_{ub} and f_B have the same effect
- Simple final state, no need to tag the other side (untag)
- Signal: high momentum monotonic lepton above $b \to u\ell\nu$ tail
- **Analysis of final dataset is on-going**,
  but most likely **to be measured in the early Belle II**

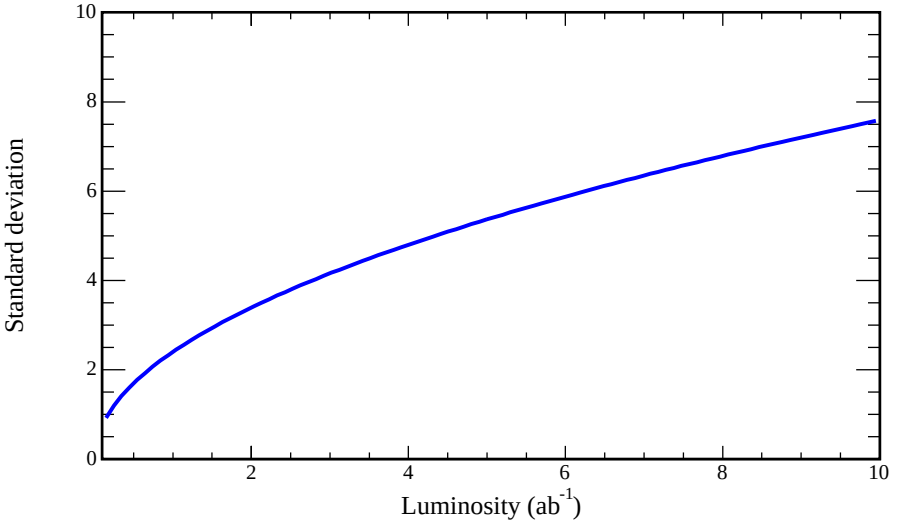
Belle 253 fb^{-1}

$\mathcal{B}(B \to \mu\nu) < 1.7 \times 10^{-6}$



Belle II sensitivity for

$\mathcal{B}^{\mathrm{SM}}(B \to \mu\nu) = 4.7 \times 10^{-7}$



$B \to \mu\nu$ with hadronic-tag

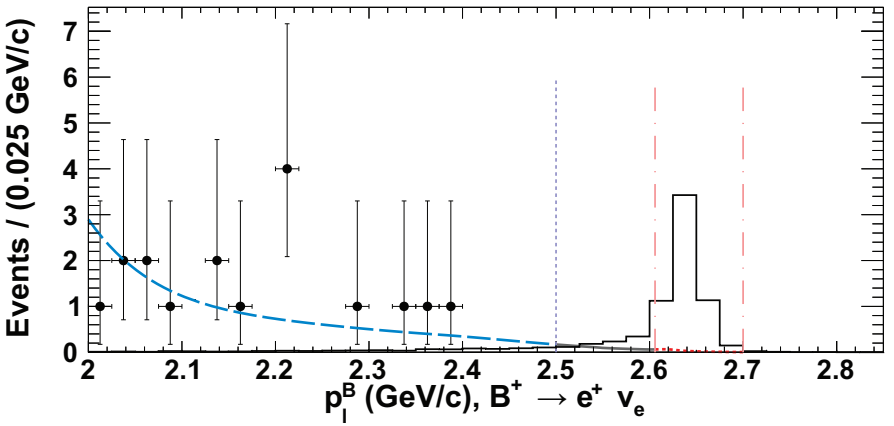
arXiv:1406.6356 submitted to PRD

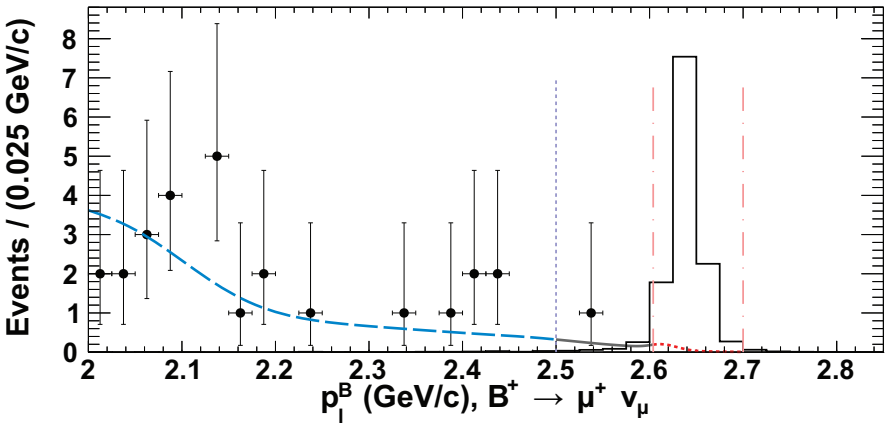
- Hadronic-tag cleans up almost all backgrounds
- Good p_ℓ resolution, also sensitive to massive hidden particle, $B^+ \to \ell X$ [talk by CS.Park/Yonsei on Friday]
- Efficiency is not competitive as untagged analysis

No events were found in Belle's full data, UL set at

$$\mathcal{B}(B \to \mu\nu) < 2.7 \times 10^{-6}$$
$$\mathcal{B}(B \to e\nu) < 3.4 \times 10^{-6}$$

Belle II data should be able to clearly observe at least $B \to \mu\nu$ mode



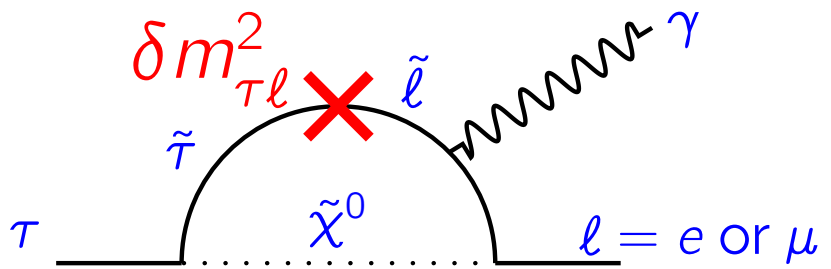


[Analysis by Y.Yook(Yonsei)]

τ LFV

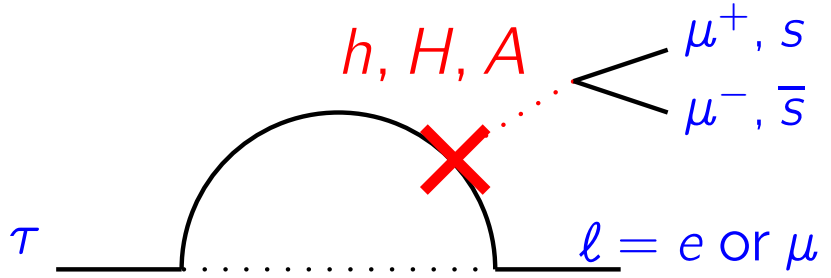
τ LFV

- Strongly forbidden in SM ($\mathcal{B} \leq 10^{-49}$ thru ν-mixing)
- **No theory uncertainty, firm evidence of new physics**
  - Radiative LFV ($\tau \to \mu\gamma$ and $\tau \to e\gamma$) thru slepton mixing



largest $\mathcal{B}$ in SUSY-seesaw / SUSY-GUT models

  - Higgs mediated LFV ($\tau \to \ell\mu^+\mu^-$, $\tau \to \ell h^0$)



Higgs coupling $\propto$ mass, $\mu^+\mu^-$ and $s\bar{s}$ (η, η', ...) are favored

- Separation power between SUSY models, difference between LFV measurements is crucial information

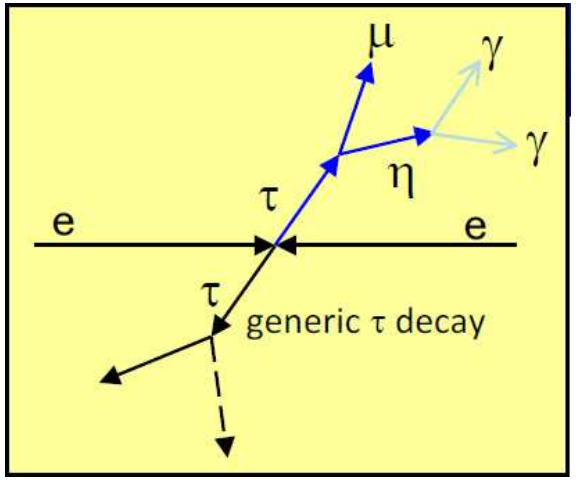
τ LFV analysis

$e^+e^- \to \tau^+\tau^-$

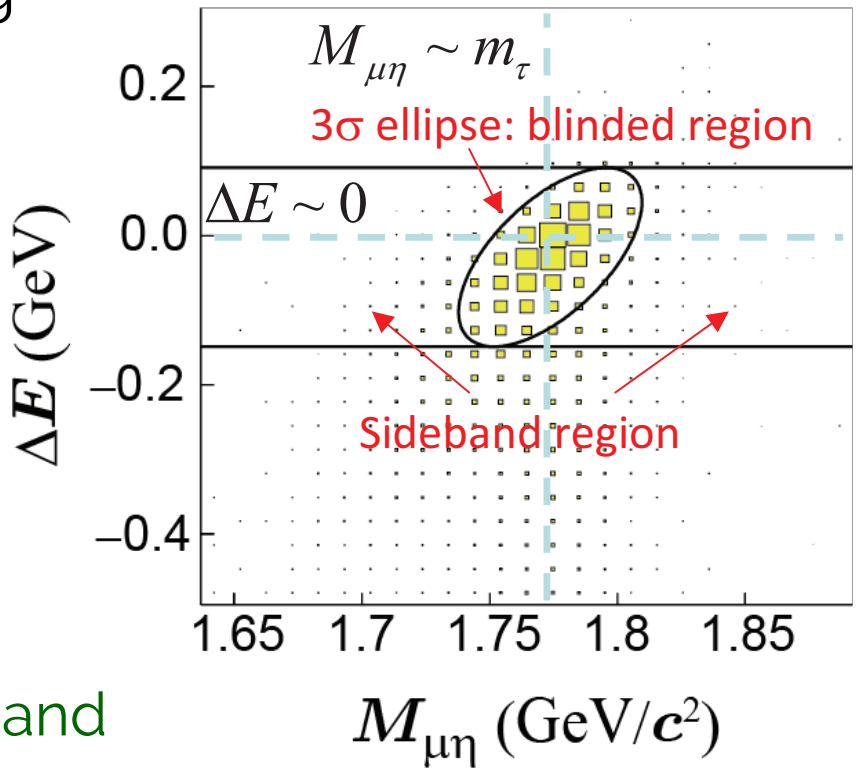
↳ 1 prong + missing (tag-side, $\mathcal{B}$ ~85%)

↳ $\mu^+\eta$ (signal)

↳ $\gamma\gamma$, no missing



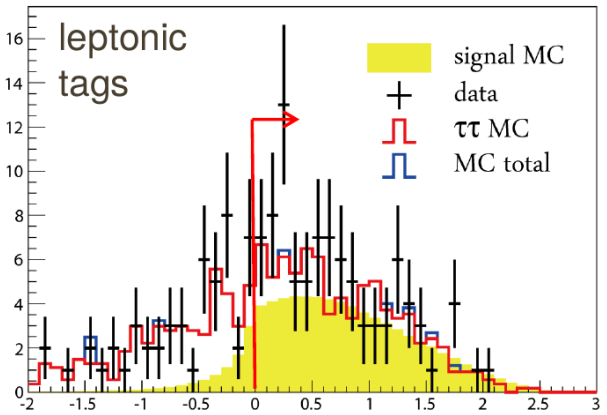
- Signal-side
  - $M_{\mu\eta} = \sqrt{E_{\mu\eta}^2 - p_{\mu\eta}^2}$
  - $\Delta E = E_{\mu\eta}^{\text{cm}} - E_{\text{beam}}^{\text{cm}}$
- Tag-side
  - p_{miss} & M_{miss}^2 (for hadronic- & leptonic-tag)

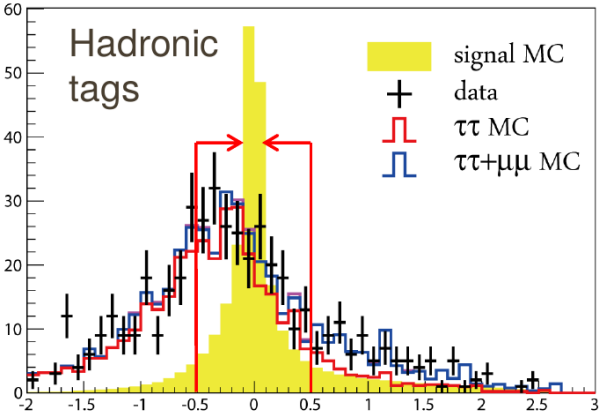


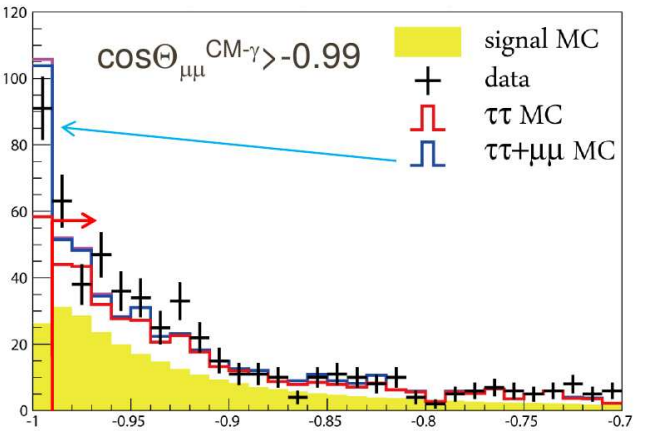
- Background-level fixed from sideband
  - In $\tau \to \ell\gamma$, ISR $e^+e^- \to \tau^+\tau^-\gamma \to (\tau^+)(\nu\ell^-)\gamma$ irreducible
  - Almost no background in $\tau \to \ell\ell\ell$ even at Belle II

$\tau \to \mu\gamma$ status

K.Hayasaka presented at TAU2014

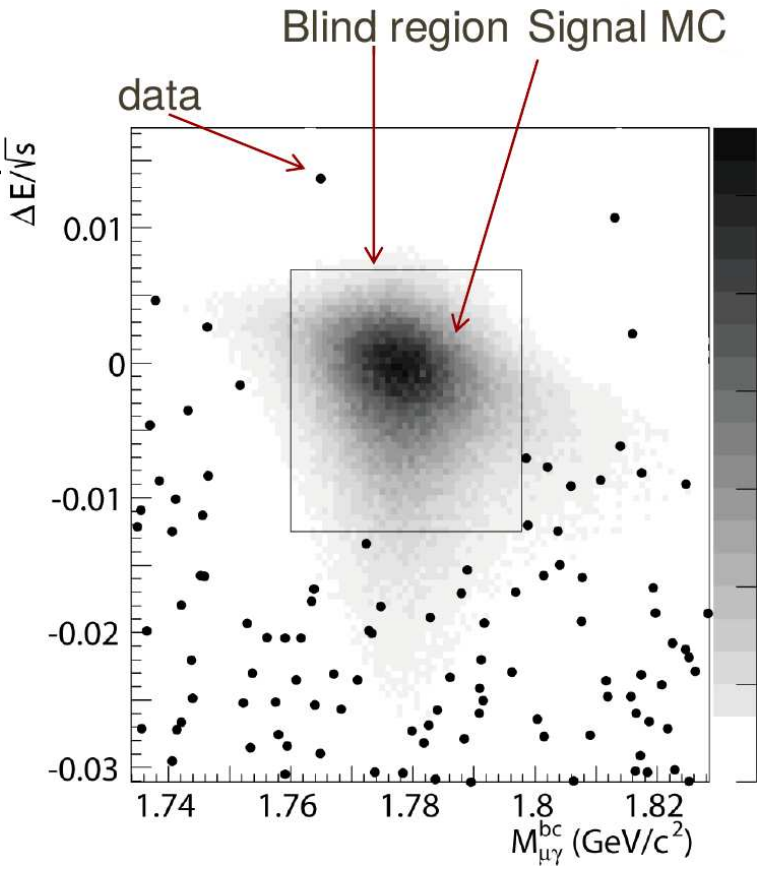






- New set of cuts reducing 33% background with the same efficiency
- Not unblinded yet
- Expected UL
  $\mathcal{B}(\tau \to \mu\gamma) < 5.3 \times 10^{-8}$
  including systematic error

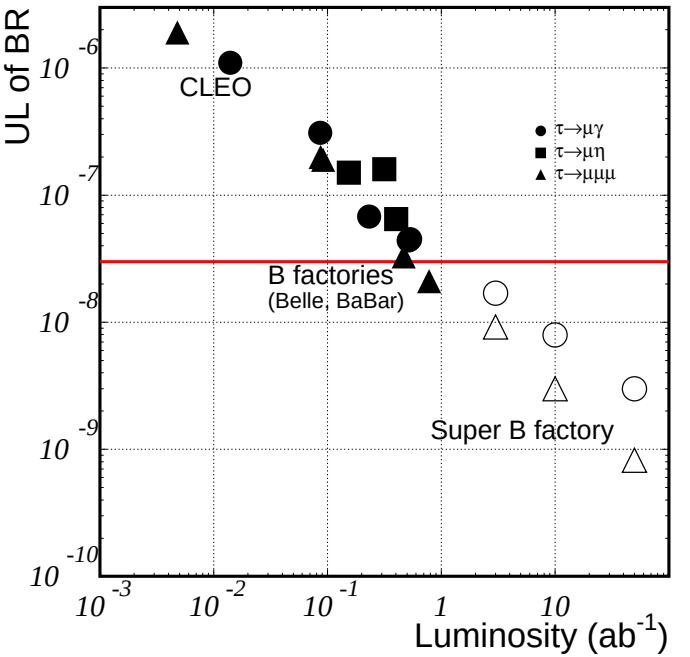
To be ready soon…



τ LFV Prospects

[Physics at SuperKEKB, arxiv:1002.5012]

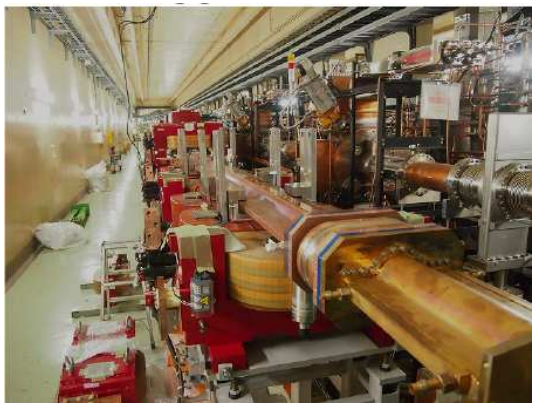
ratio of $\mathcal{B}$	little Higgs w/ T-parity	MSSM (no Higgs)	MSSM (w/ Higgs)
$eee/e\gamma$	0.4–2.3	~ 0.01	~ 0.01
$\mu\mu\mu/\mu\gamma$	0.4–2.3	~ 0.002	0.06–0.1
$e\mu\mu/e\gamma$	0.3–1.6	~ 0.002	0.02–0.04
$\mu ee/\mu\gamma$	0.3–1.6	~ 0.01	~ 0.01
$eee/e\mu\mu$	1.3–1.7	~ 5	0.3–0.5
$\mu\mu\mu/\mu ee$	1.2–1.6	~ 0.2	5–10

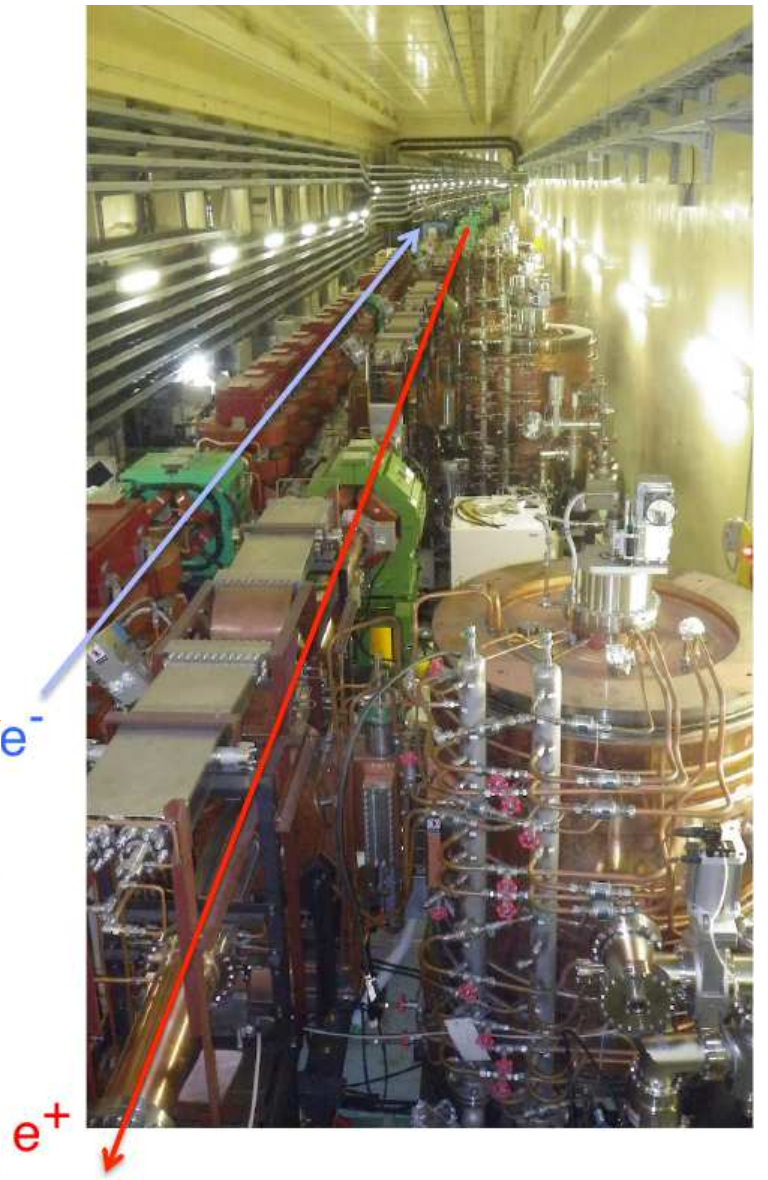


- Belle+BaBar has already reached existing BSM predictions
- $\tau \to \ell\gamma$ down to the 10^{-9} order (propotional to $1/\sqrt{\mathcal{L}}$),
  $\tau \to \ell\ell\ell$ down to the 10^{-10} order (propotional to $1/\mathcal{L}$)
- Predictions cover Belle II range, but also ranges further below
- τ LFV is in competition with $\mu \to e\gamma$ search

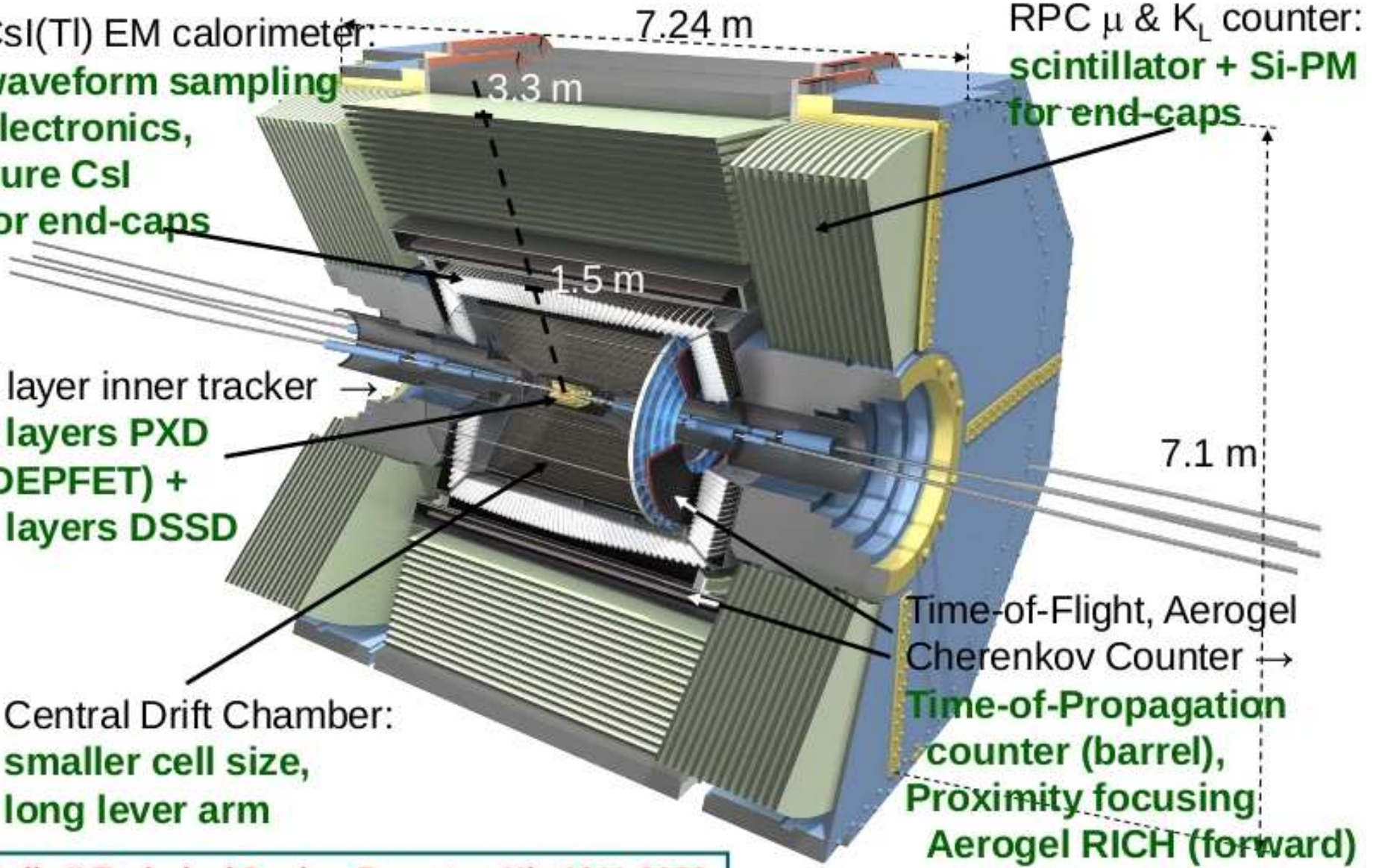
SuperKEKB / Belle II Status

SuperKEKB under construction



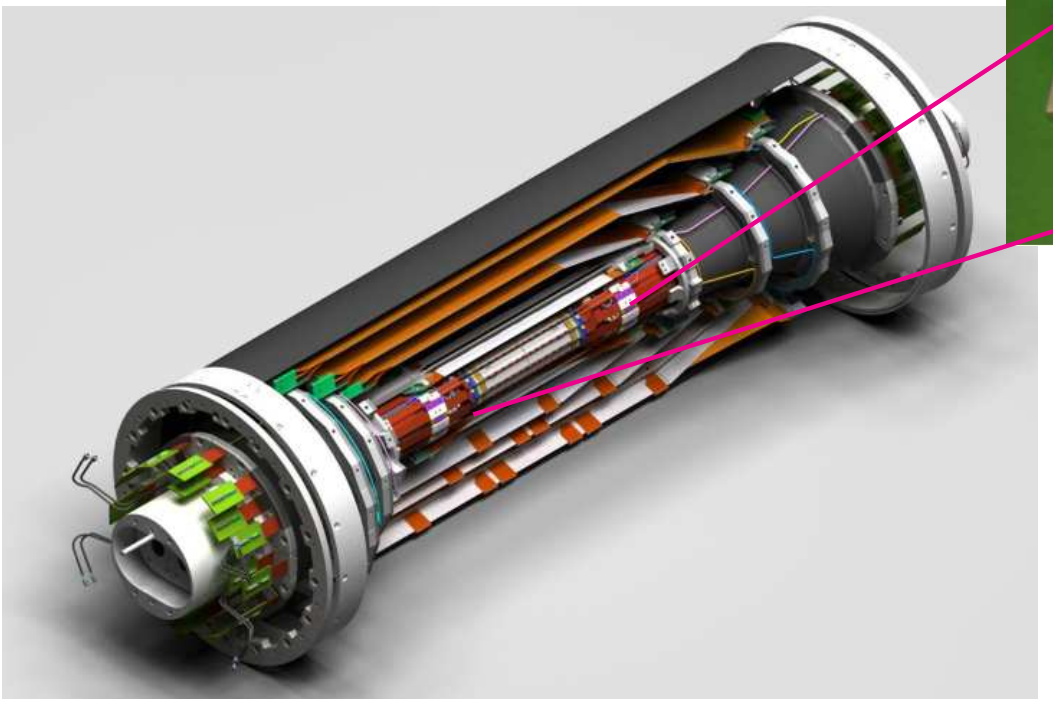


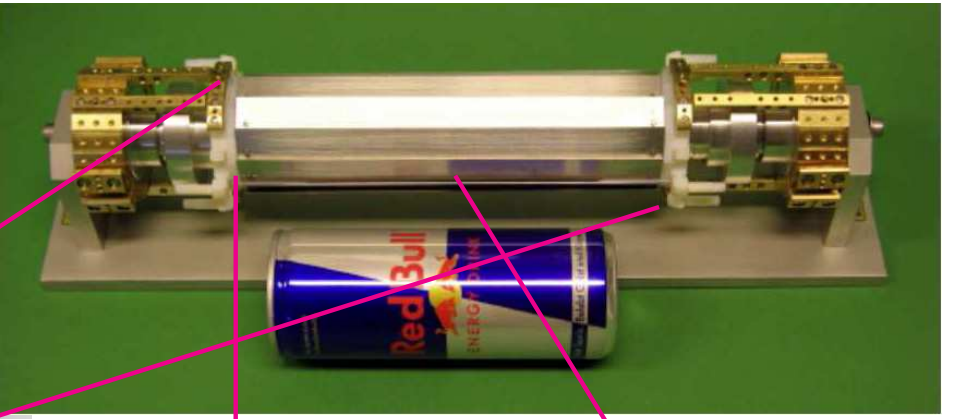
Belle II detector

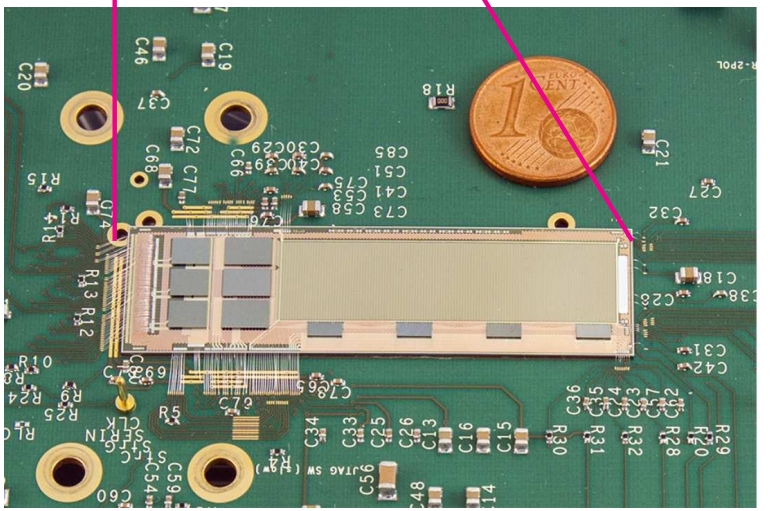


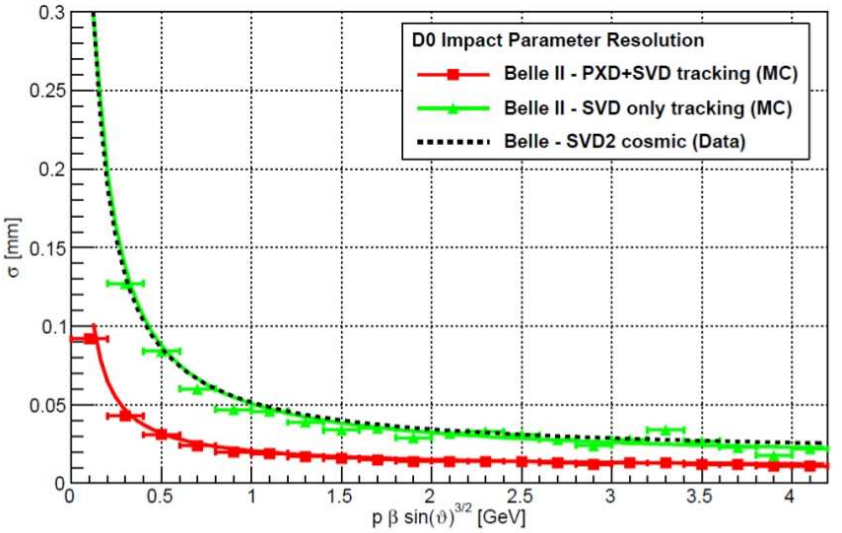
Belle II Technical Design Report: arXiv:1011.0352

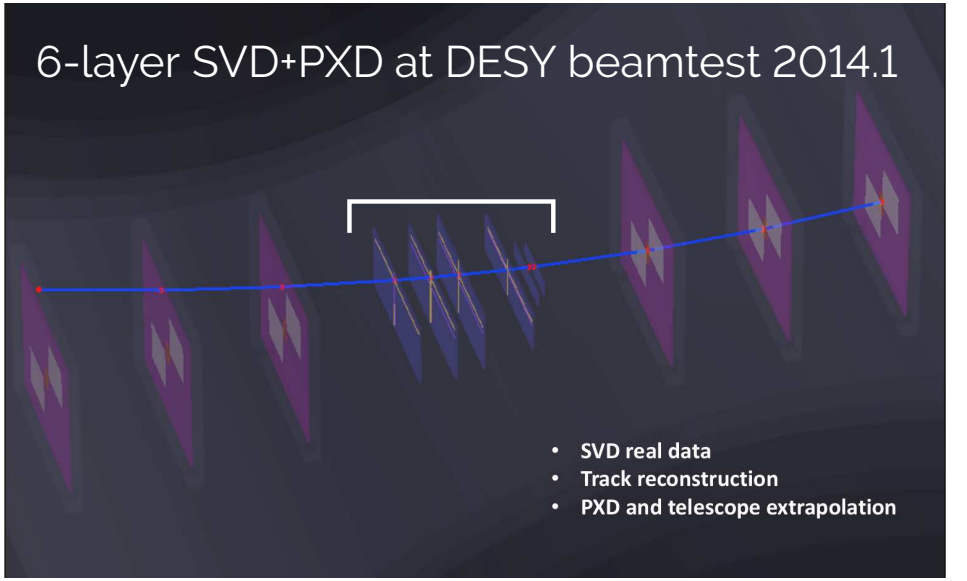
Vertex detector



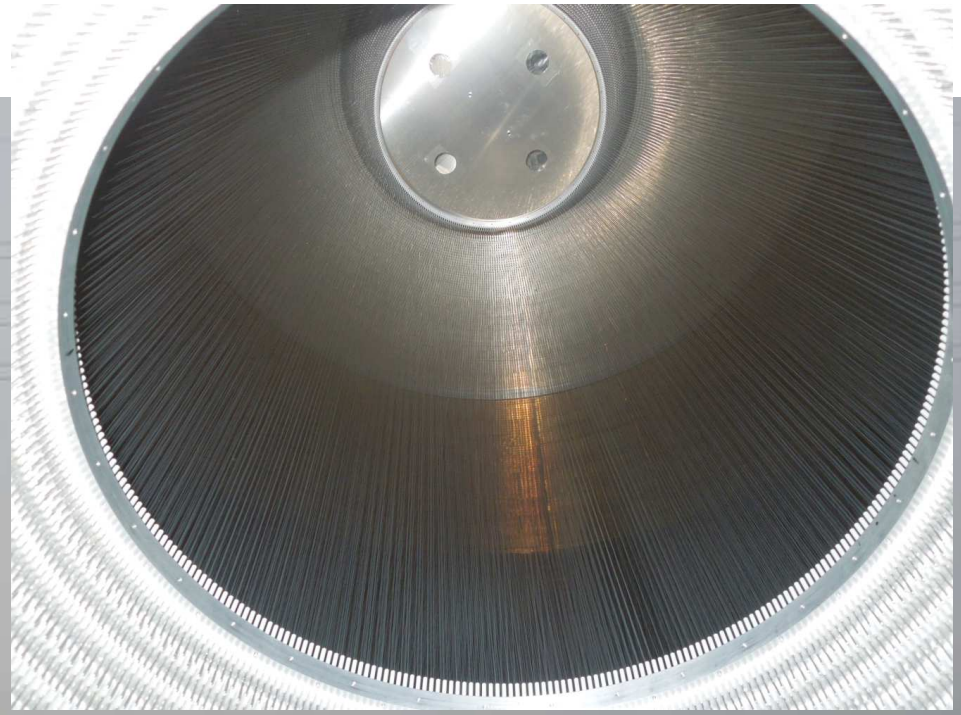








Central drift chamber

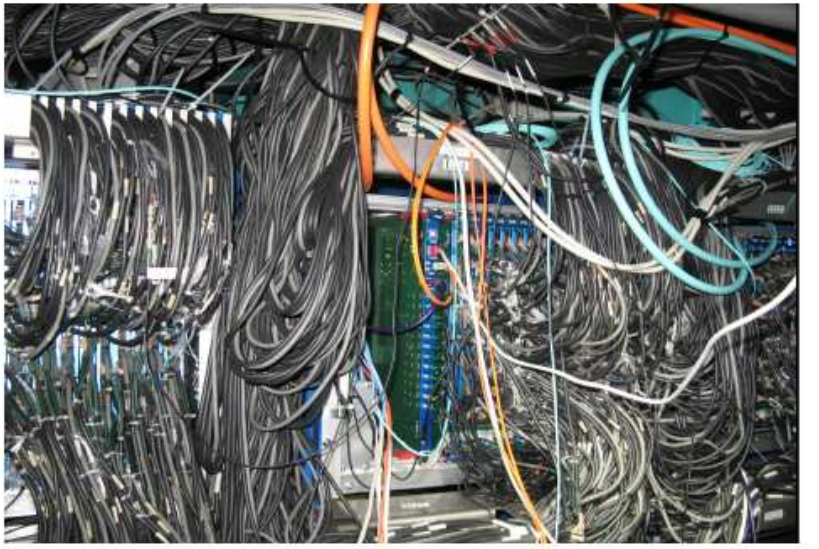


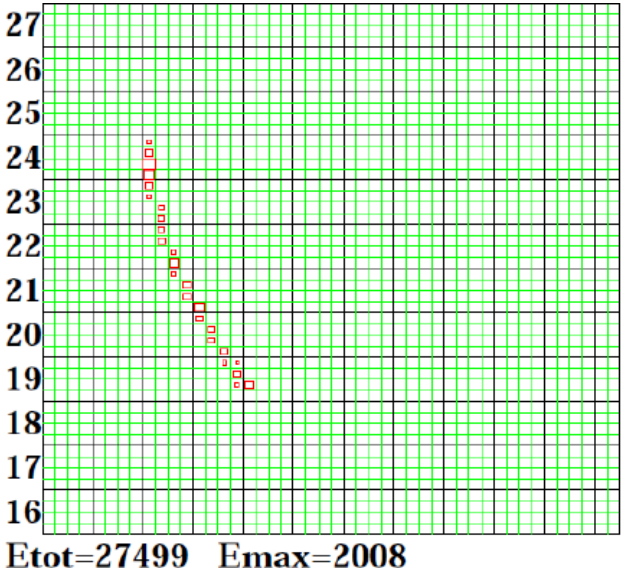
2014.1.14 Stringing 51,456 wires completed

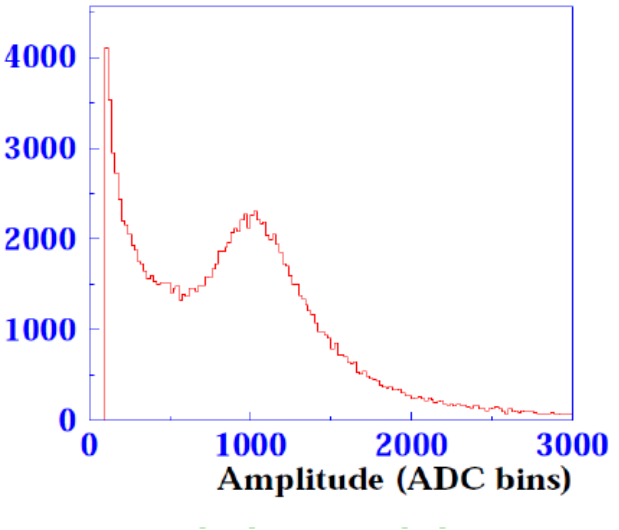
2015.1.21 Transpotation to Tsukuba hall

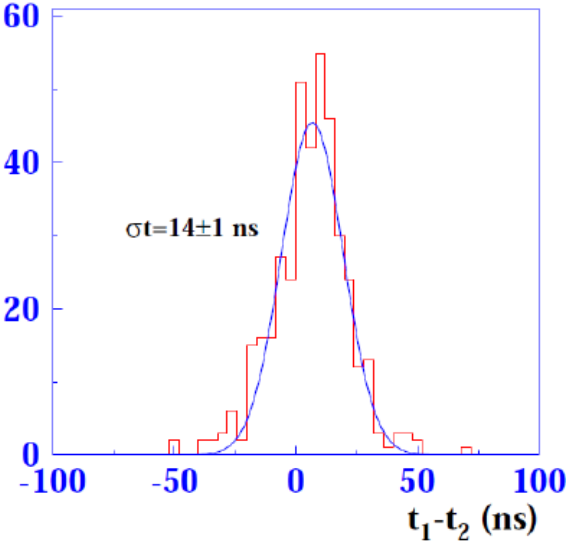
Time of projection counter

Electromagnetic Calorimeter

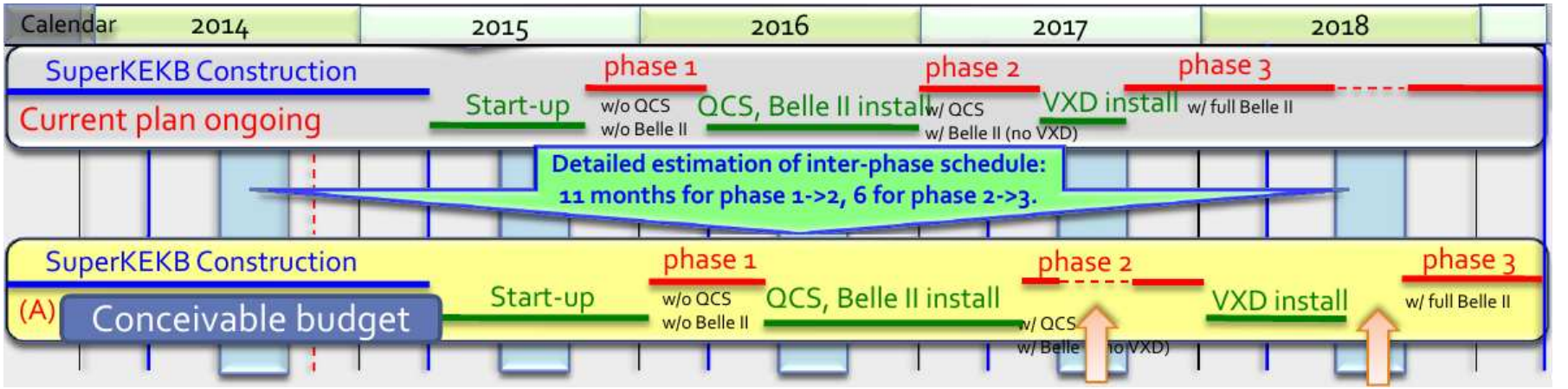




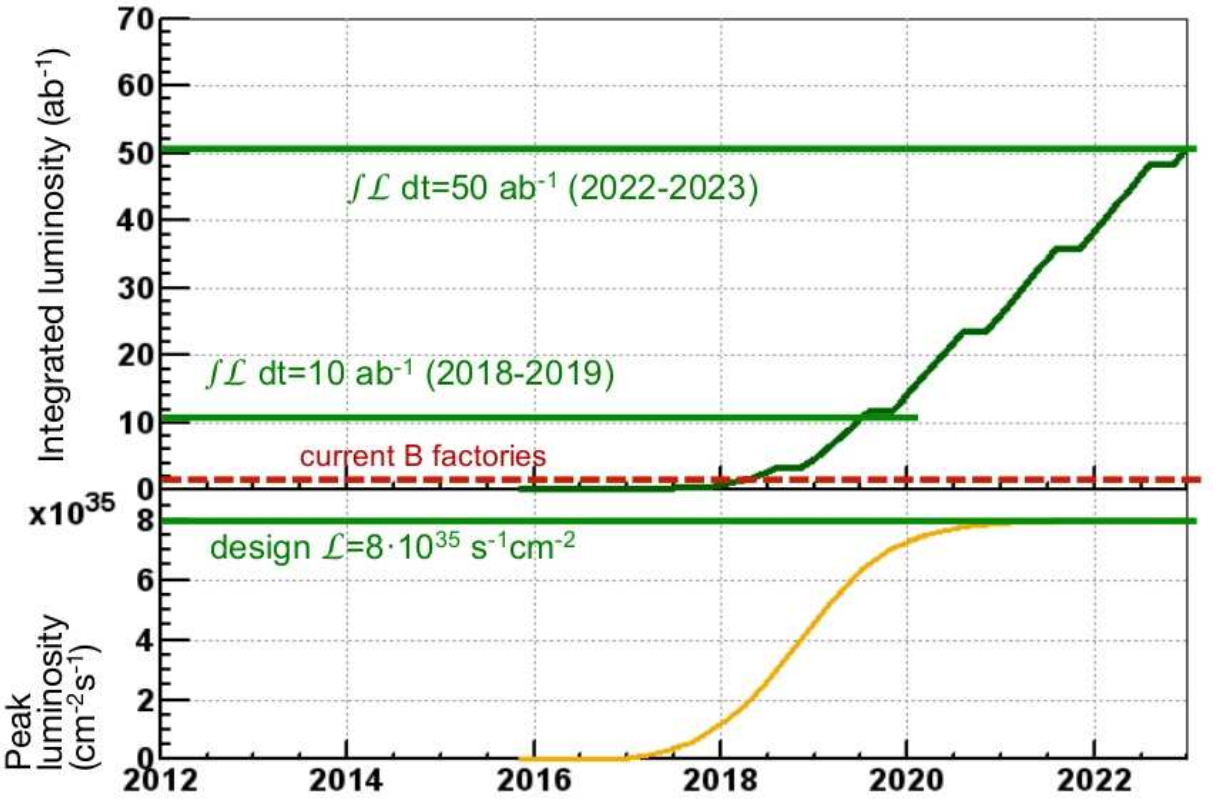




Timeline



(Y.Ushiroda, SVD-BPAC 2014.11)



Summary

Summary

- **Belle has established many historical measurements, still producing interesting results, and more to come soon**
- **Belle II physics program is extremely rich, can't be covered in one talk, and more topics not discussed today includes**
  - Radiative and electroweak B decays
  - Charm physics
  - New resonant structure
  - Search for dark sector ($\Rightarrow$ Y.Kwon's talk)
- **SuperKEKB / Belle II under construction, in good progress**

More Slides...

New Physics Wanted

No non-SM evidence found in HEP except for neutrino mass, but...

- **Observation (Cosmology)**
  - Matter-dominance $\Rightarrow$ non-SM CP violation, baryon number violation
  - Dark matter $\Rightarrow$ weakly interacting massive particle (WIMP)
  - Dark energy
- **Theory Demands**
  - Cosmological Constant
  - Hierarchy Problem $\Rightarrow$ SUSY, extra dimension, ...
  - Origin of Flavor Hierarchy $\Rightarrow$ lepton flavor violation, ...
  - Strong CP Problem $\Rightarrow$ axion
  - GUT

➡ Challenges to Energy and Intensity/Flavor Frontier

[KEKFF2014-fall Y.Grossman]

LHCb upgrade and Belle II

Do we need Belle II when LHCb upgrades and keeps taking data?

LHCb's modes (Belle II can't compete)

- Huge B, B_s, D, D_s production cross-section
- Time-dependent CPV of B_s (Too fast oscillation for Belle II)
- Charged-particle only mode (But somewhat degraded for K_S)
- Low momentum muons (due to boost)

Belle II's modes (LHCb can't do)

- Photons, π^0, η modes (Unless strong kinematic constraint works)
- Neutrino modes, especially those with τ
- Inclusive measurements

Both can do(?) (Partly because LHCb will have more data…)

- Time-dependent CPV of $B \to J/\psi K_S$ and $B \to \phi K_S$

Physics Sensitivity Comparison

LHCb's condition

- Now: 1 fb^{-1} or 3 fb^{-1} $\Rightarrow$ Run-2: 8 fb^{-1} $\Rightarrow$ goal 50 fb^{-1}
- Energy increase (7 $\Rightarrow$ 14 TeV) gains production cross-section $\times 2$
- New trigger system gains hadron and electron modes $\times 2$

Belle II's condition

- Now: 1 ab^{-1} $\Rightarrow$ goal 50 ab^{-1}
- Better detector may only compensating the increase of background

To compare

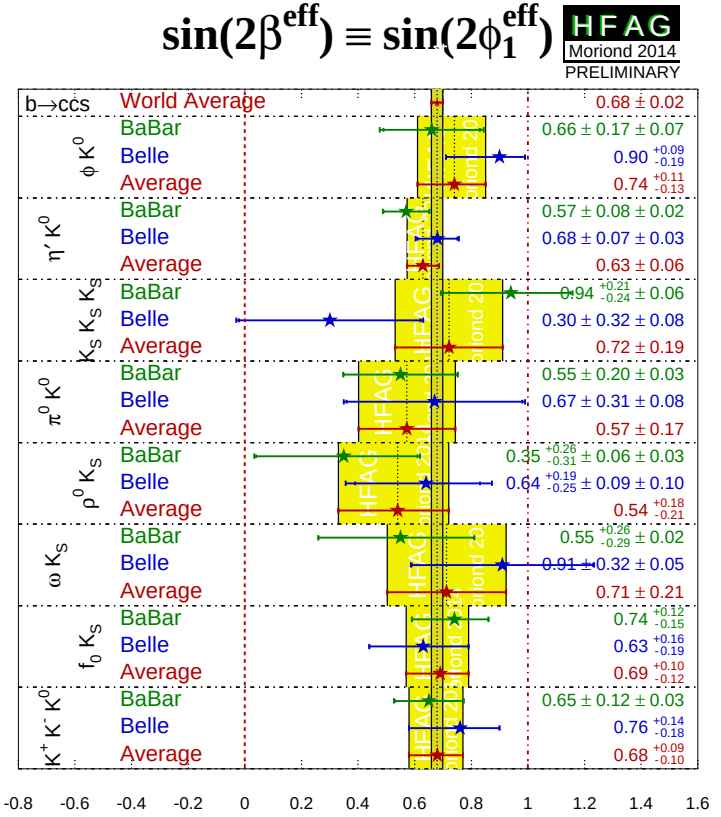
- Current sensitivity difference will simply scale to the final goal

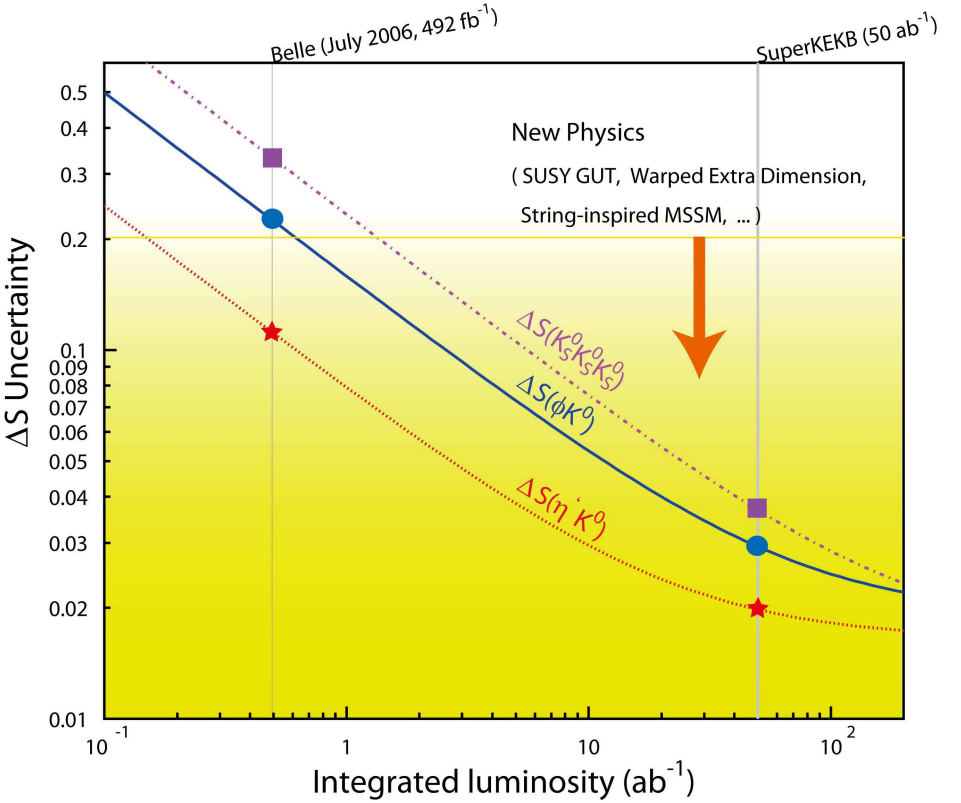
Physics Reach of Belle II and the LHCb upgrade

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\|V_{us}\|$ $[K \to \pi\ell\nu]$	**	0.1%	K-factory
$\|V_{cb}\|$ $[B \to X_c\ell\nu]$	**	1%	Belle II
$\|V_{ub}\|$ $[B_d \to \pi\ell\nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K^0_S$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K^0_S\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A^d_{SL}	***	0.001	LHCb
A^s_{SL}	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $A_{FB}(B \to K^*\mu\mu)$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})
$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\|q/p\|_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

(T.Browder ICHEP2014)

ϕ_1^{eff} from Penguins



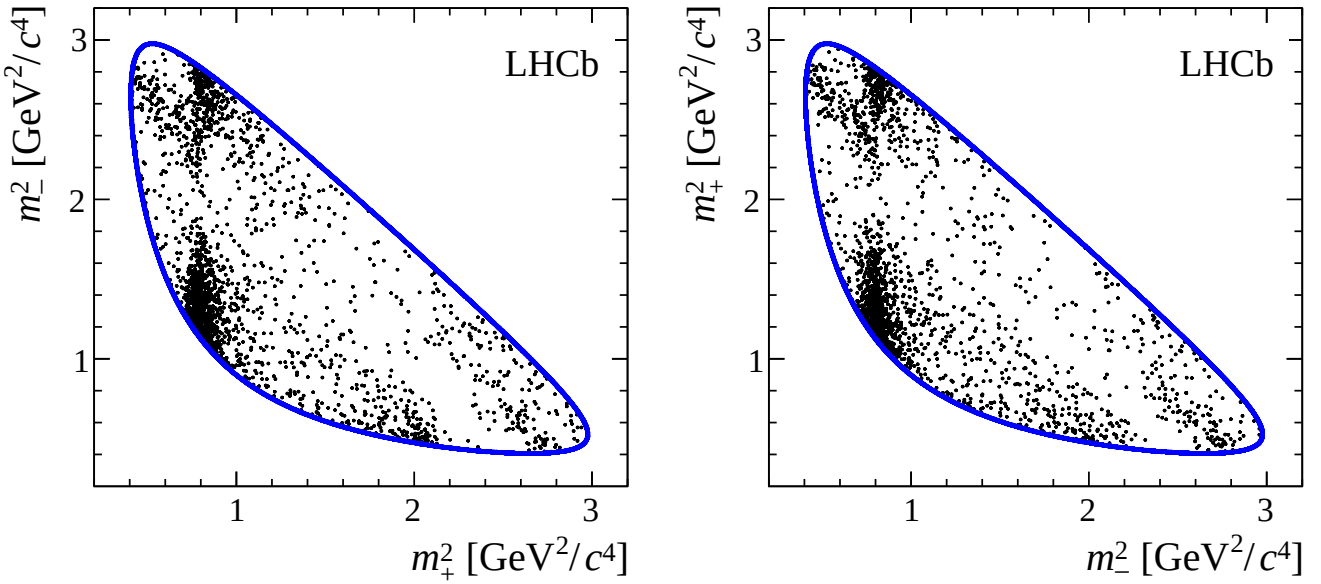


- ϕ_1 is no more deviated from $J/\psi K_S$
- Belle II sensitivity $\Delta\mathcal{S}_{\phi K_S} \sim 0.03$ similar to current $J/\psi K^0$
  (30% smaller error than above plot (LoI) by analysis improvement)

ϕ_3 from $B \to DK$

GGSZ (Dalitz): $D \to K_S\pi^+\pi^-$ Dalitz plot directly gives ϕ_3

- Best precision
- Similar sensitivity for Belle (0.7 ab^{-1}) and LHCb (3 fb^{-1}) ($\delta\phi_3 \sim 15°$)



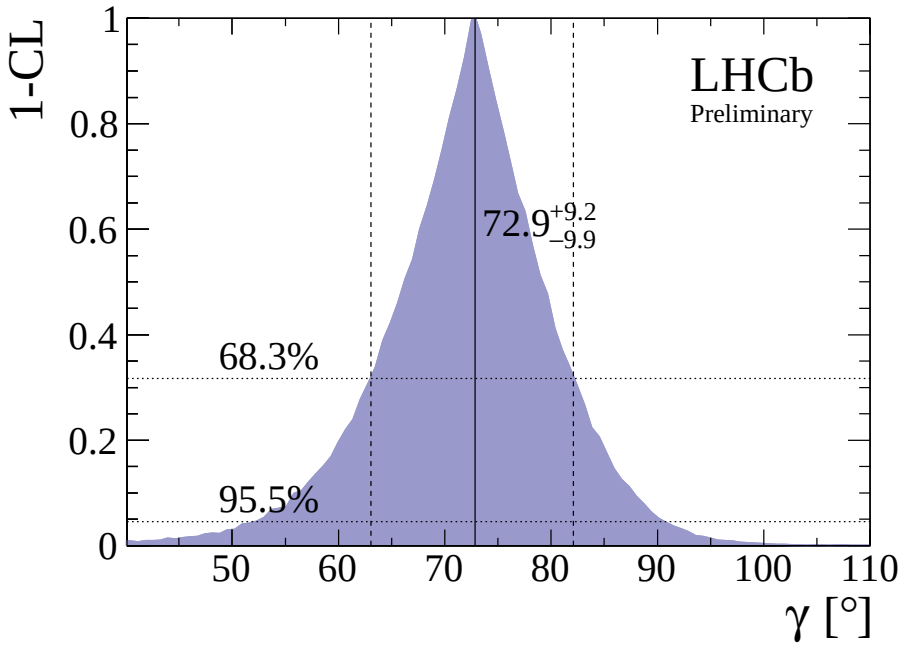
GLW: decays to CP final states such as $D \to K^+K^-$

ADS: doubly Cabibbo suppressed decays such as $D^0 \to K^+\pi^-$

- Charged-particle only modes benefits LHCb
- Belle II can use π^0 modes, $D^{*0} \to D^0\pi^0$ and $D^{*0} \to D^0\gamma$

ϕ_3 sensitivity

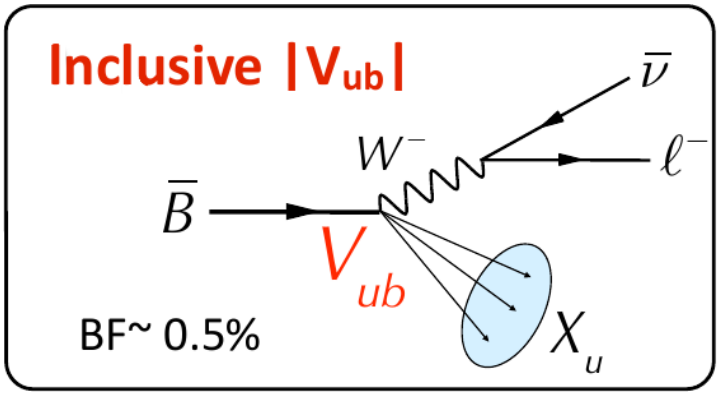
- ϕ_3 is only from tree diagram and is not affected by new physics — important reference

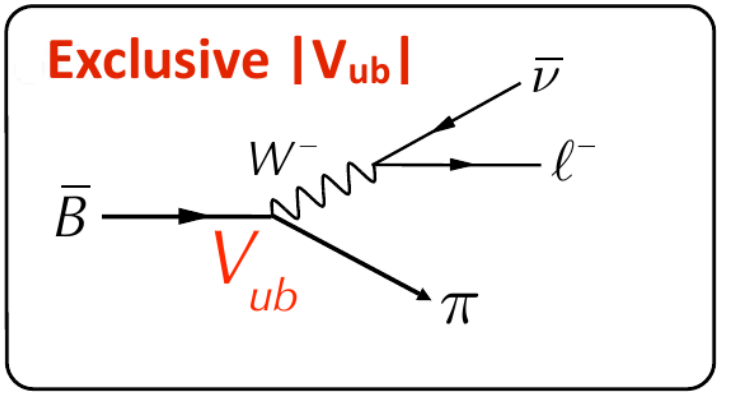


- Current LHCb only $\delta\phi_3 < 10°$
  (no WA yet including LHCb's latest result?)
- LHCb Run-2 $\Rightarrow \delta\phi_3 \sim 4°$
- LHCb upgrade (50 fb^{-1}) $\Rightarrow \delta\phi_3 \sim 0.9°$

- LHCb dominates for the time being
- Belle II 50 fb^{-1} is competitive, $\delta\phi_3 \sim 1.5°$

V_{ub} from $b \to u\ell\nu$





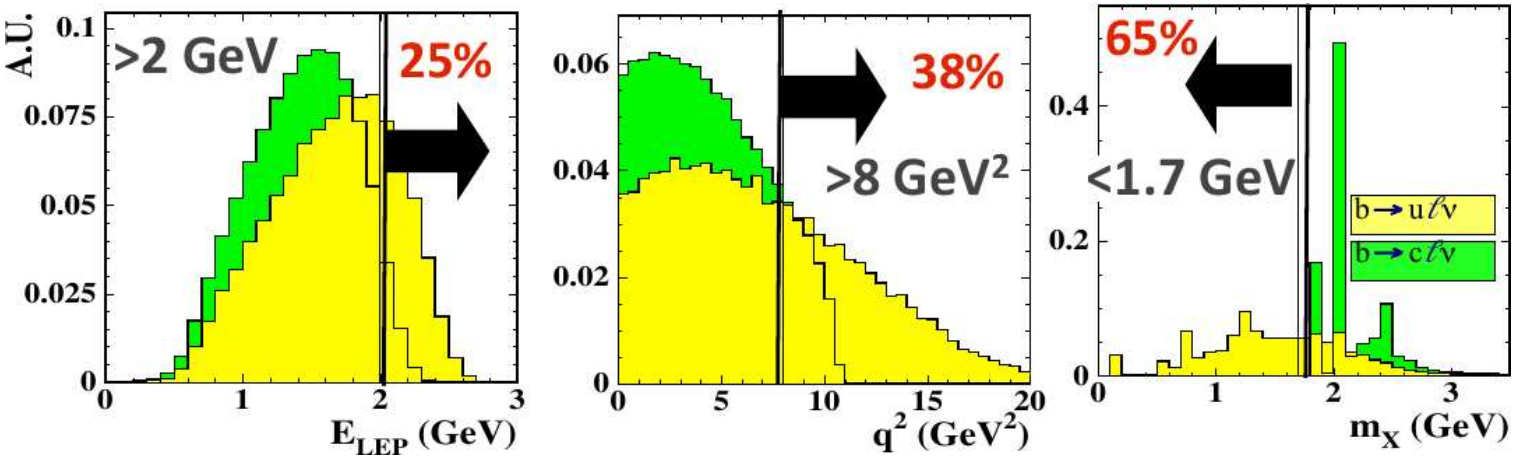
Inclusive (sum of all final states)

- $1/m_b$ operator expansion (OPE)
- $B \to X\ell\nu$ and $B \to X_s\gamma$ spectra fixes nonperturbative parameters

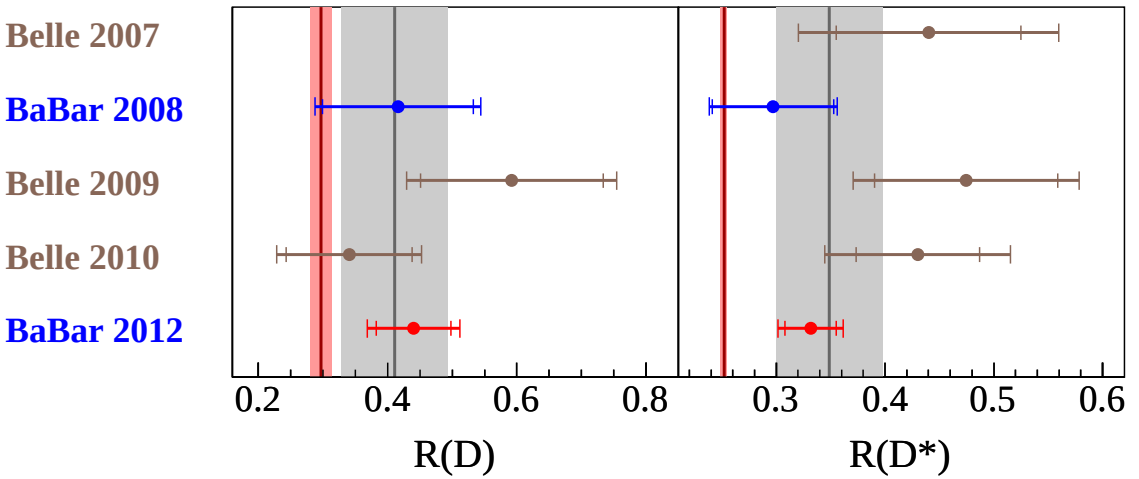
Exclusive

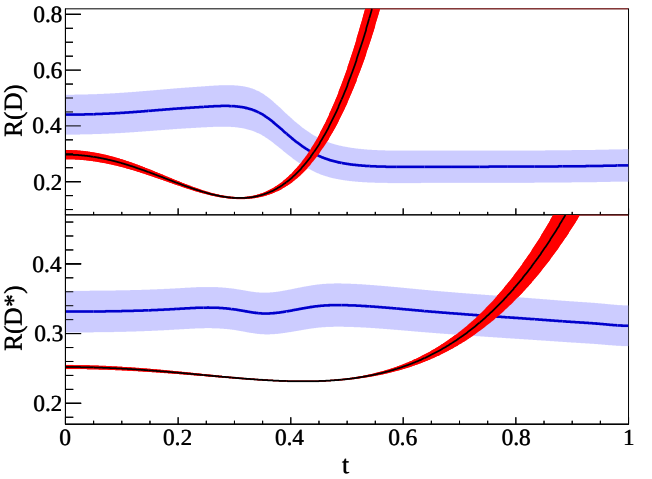
- π (or ρ etc) is required
- Lattice QCD or QCD sum rule needed for form factor $f_i(q^2)$

Cuts needed for inclusive measurements



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

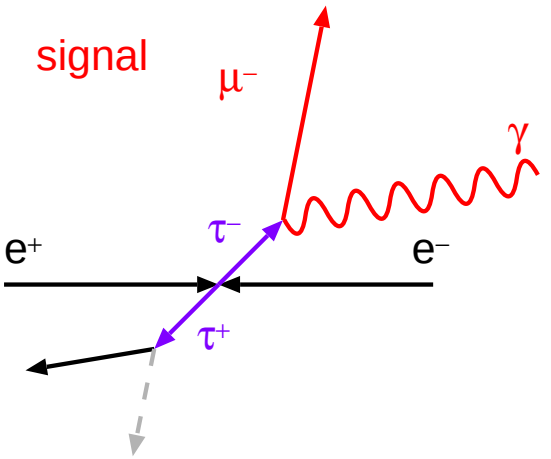


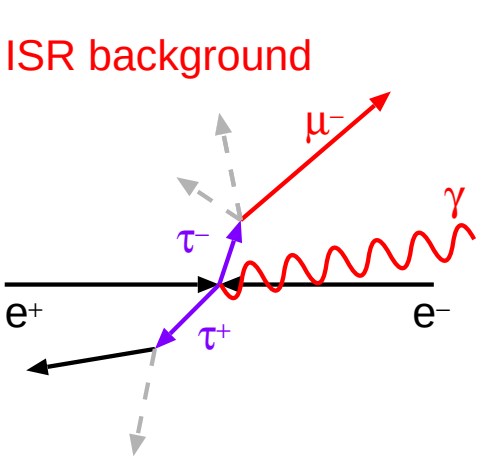


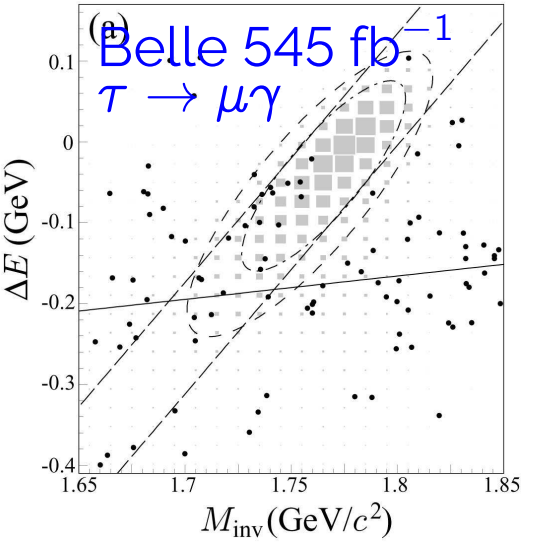
- BaBar has the most precise result
  - Both $B \to D\tau\nu$ and $B \to D^*\tau\nu$ deviate from SM
  - 2HDM charged Higgs cannot explain both at the same time — more complex Higgs?
- Belle's hadronic-tag results will be announced soon, but it will not resolve the problem
- Belle II data is needed

$\tau \to \ell\gamma$ and $\tau \to \ell\ell\ell$

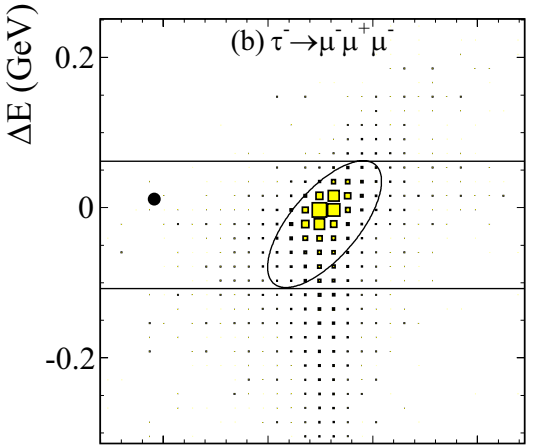
- In $\tau \to \ell\gamma$, ISR $e^+e^- \to \tau^+\tau^-\gamma \to (\tau^+)(\nu\ell^-)\gamma$ irreducible







- Almost no background in $\tau \to \ell\ell\ell$ at Belle II



← Belle 0.8 ab^{-1}

$\mathcal{B} < 2.1 \times 10^{-8}$