Status and Physics of Belle II

Sören Lange (University Gießen)

53rd International Winter Meeting on Nuclear Physics

Bormio, Italy, 26.01.2015

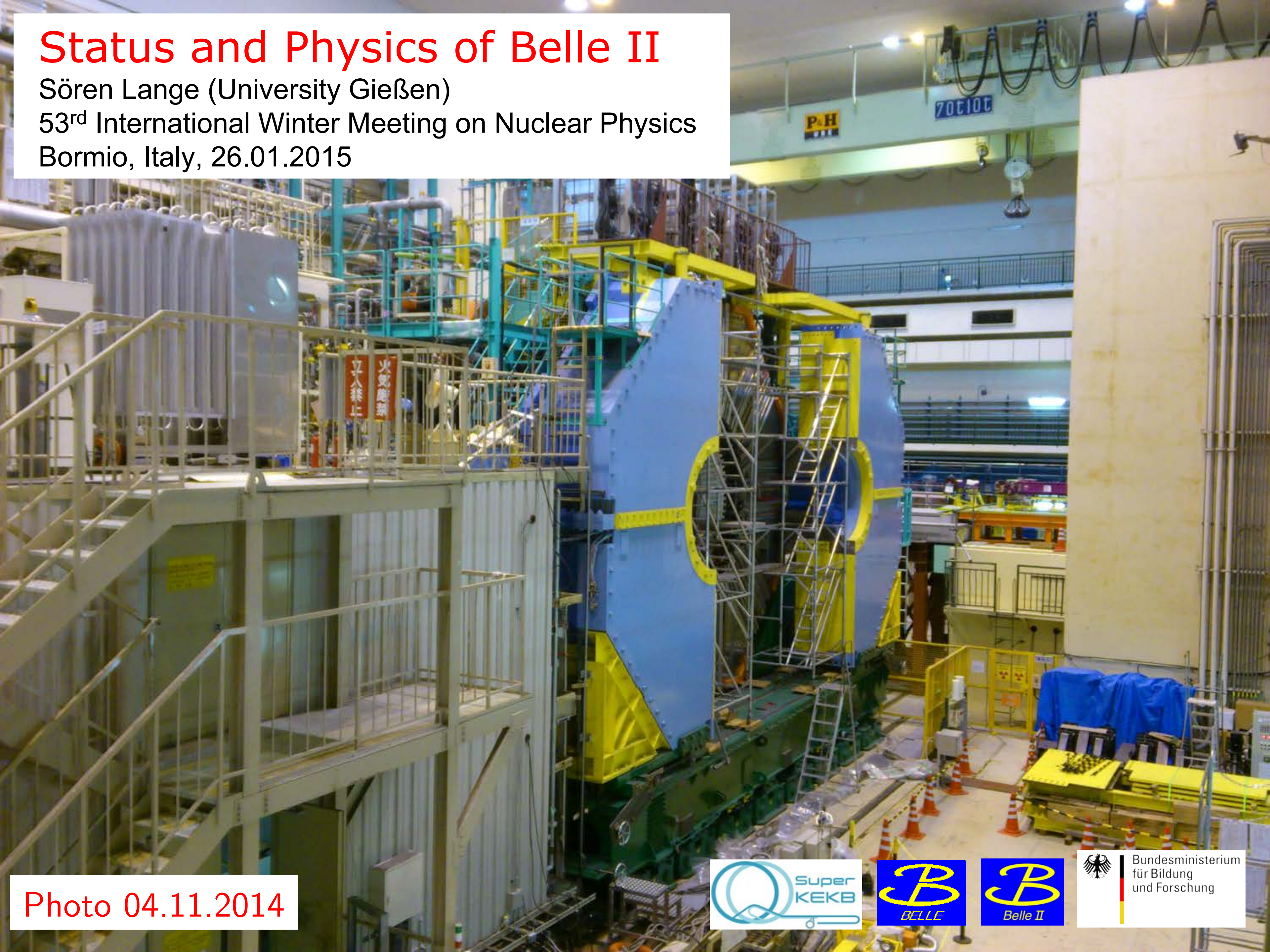


Photo 04.11.2014

Super KEKB

BELLE

Belle II

Bundesministerium für Bildung und Forschung

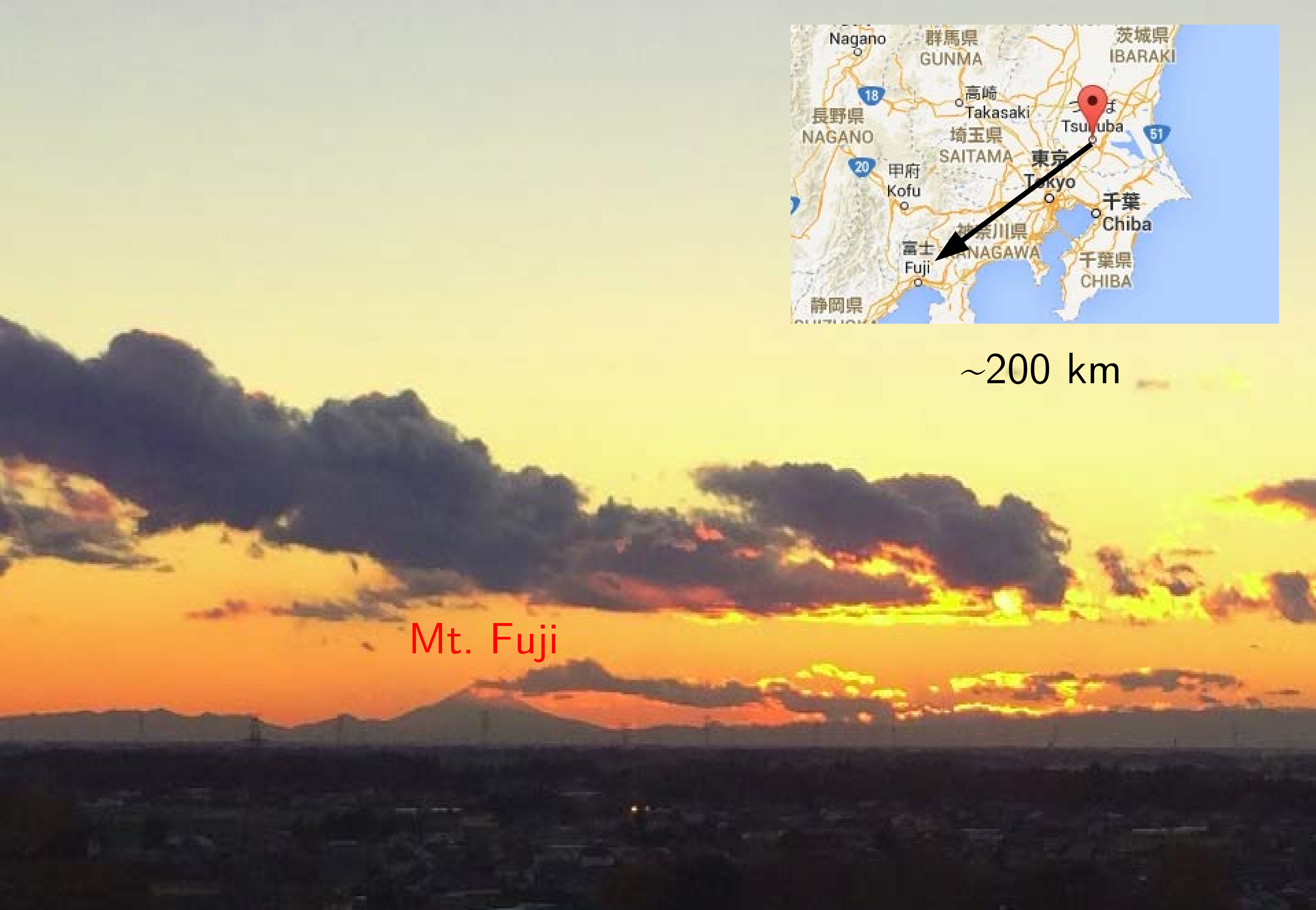
OUTLINE

- Introduction: SuperKEKB and Belle II
- Physics (achieved and extrapolated)
    - CP violation
        - Test of CPT invariance
        - Test of T invariance
    - $B \to K^*\gamma$ (flavor changing neutral current)
      $\to$ search for right-handed couplings
    - exotic, hadronic states: Z^+
- Status of detectors

SuperKEKB asymmetric B meson factory, e+ e– $\rightarrow$ $B\bar{B}$
adjusted to Y(4S) resonance, $\sqrt{s}$=10.6 GeV (7 GeV + 4 GeV)

Upgrade: luminosity peak x40, integrated x50

View from KEK, by Klemens Lautenbach (5.12.2014)



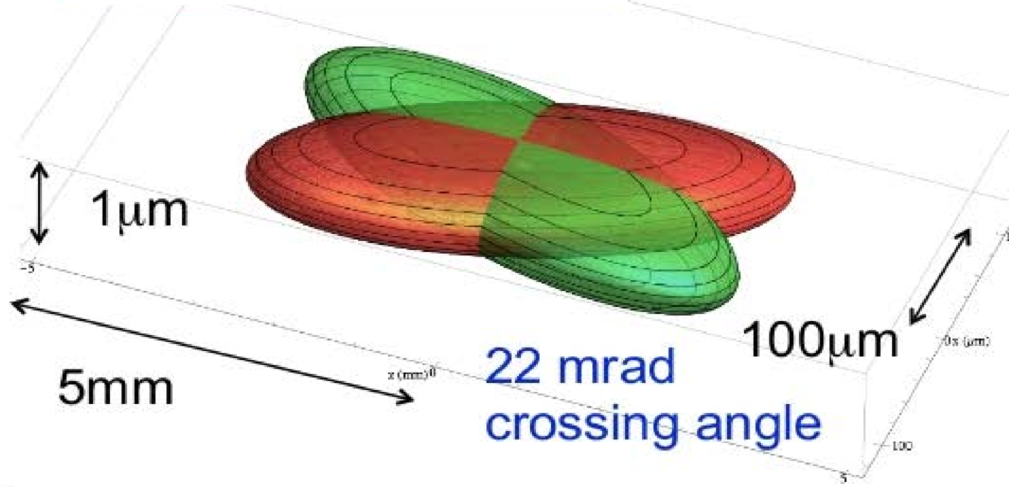
Nano-Beam Scheme

Belle → Belle II

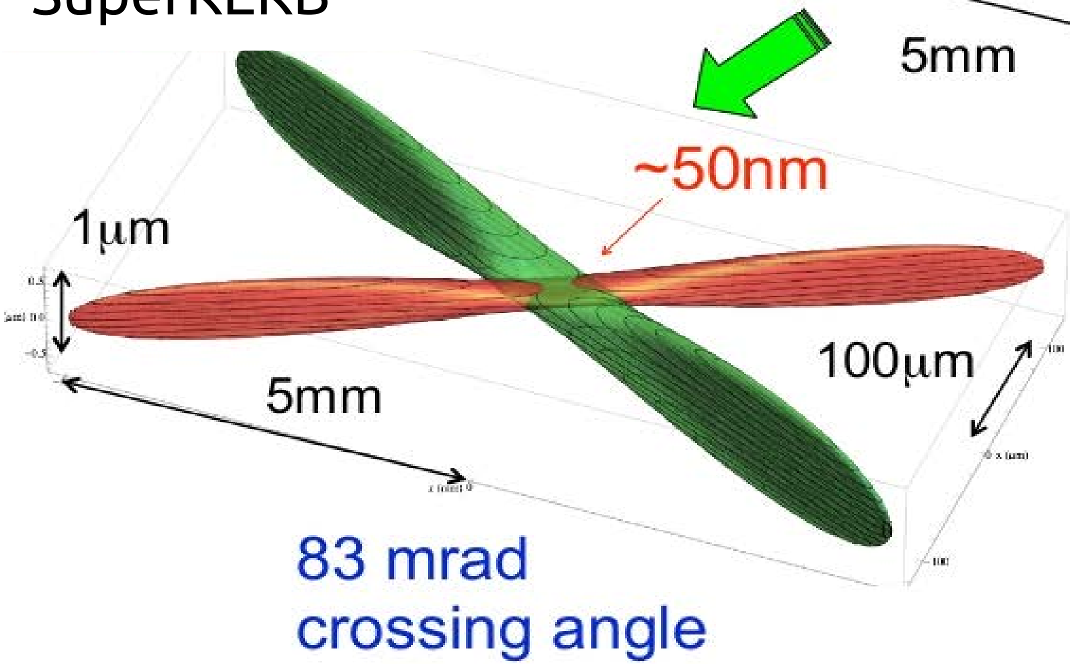
Luminosity x 40

$\mathcal{L} \leq 0.8 \times 10^{36}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

KEKB *(without crab)*



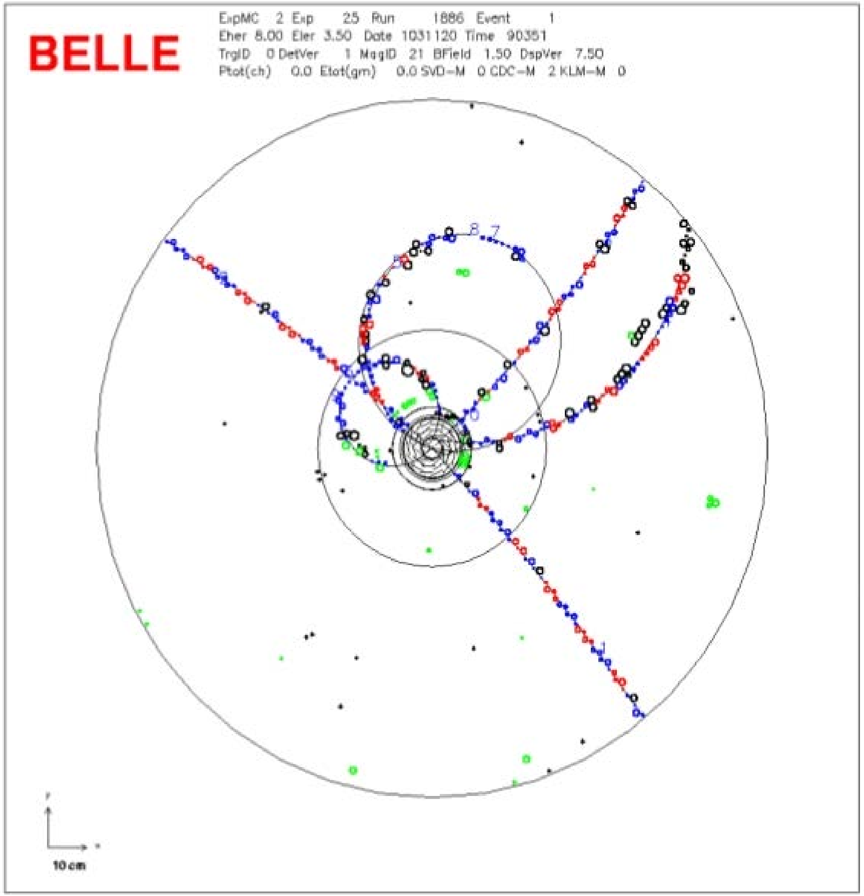
SuperKEKB

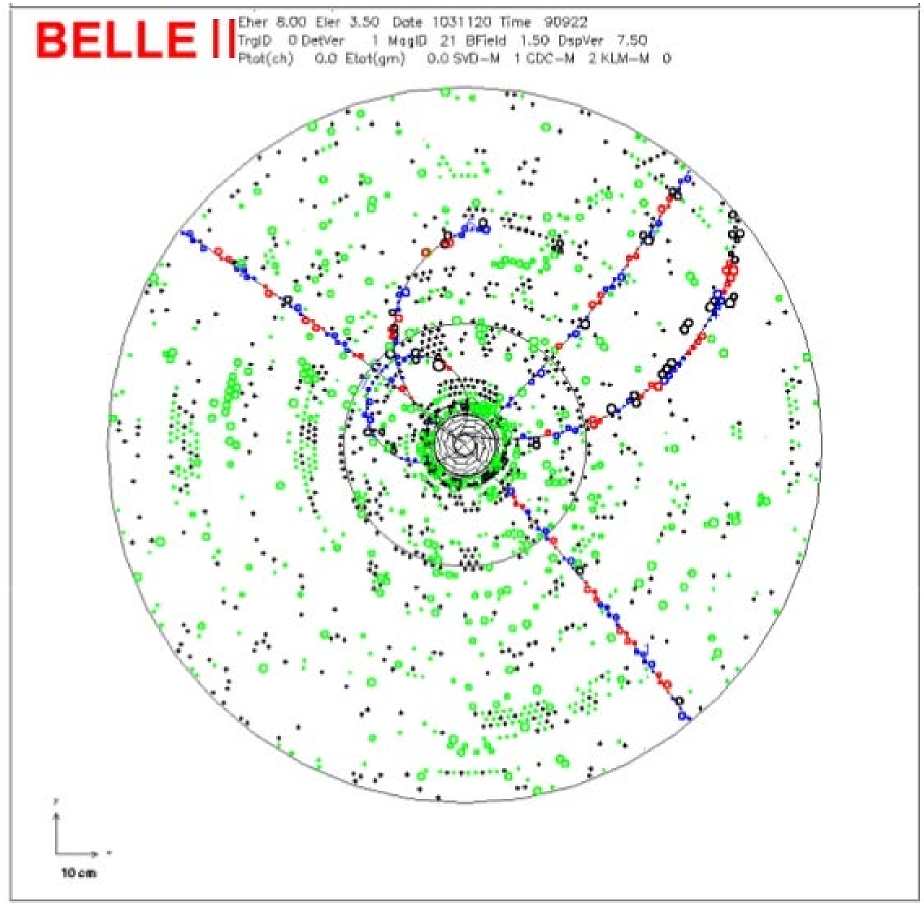


originally proposed for SuperB
by P. Raimondi (INFN)

graphics E. Paoloni (Pisa)

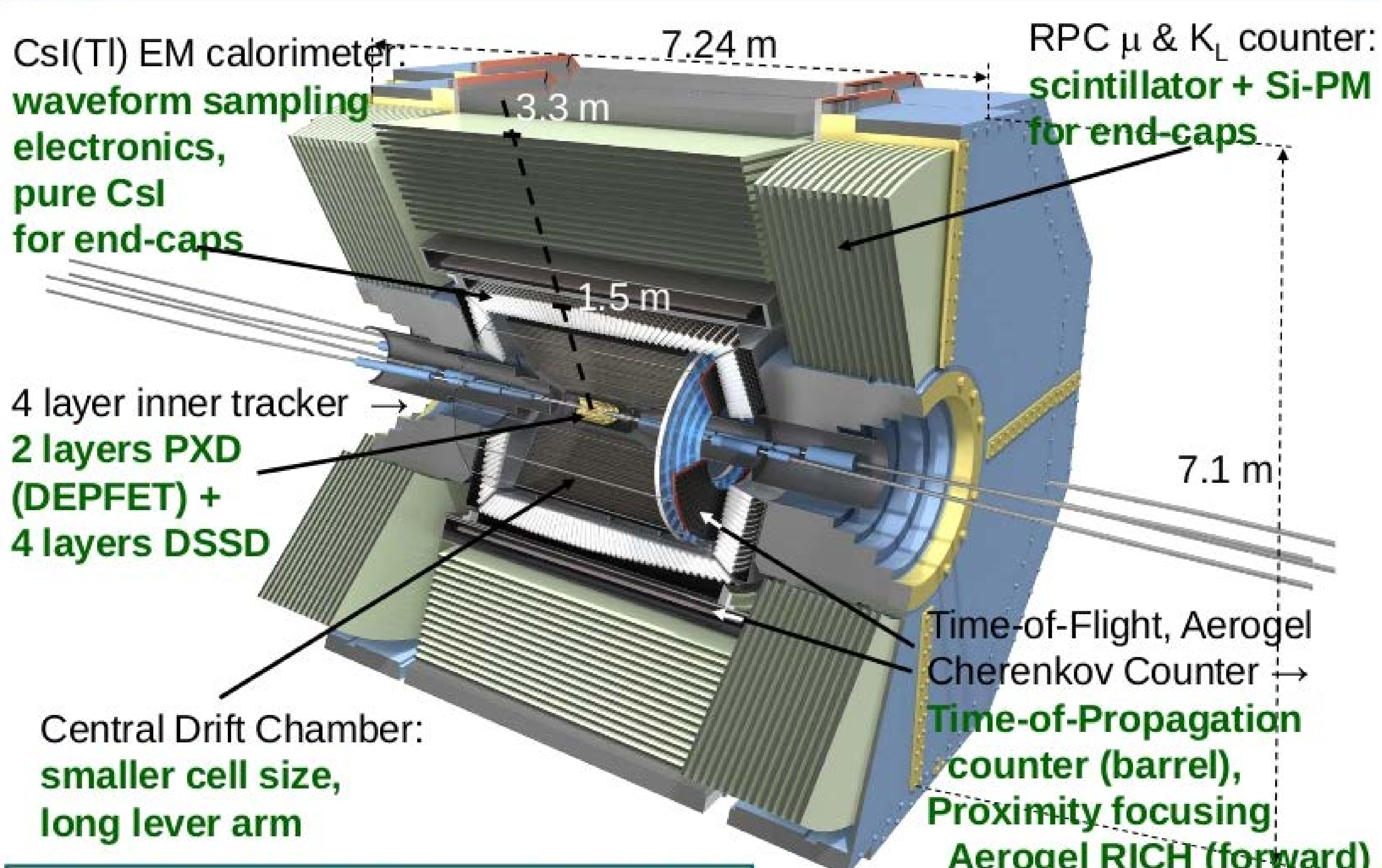
Background increase x factor 10–20





The Belle II Detector

(Upgrade of the Belle Detector)



Belle II Technical Design Report: arXiv:1011.0352

Belle II Collaboration

≥650 Members, 99 Institutes, 23 Countries

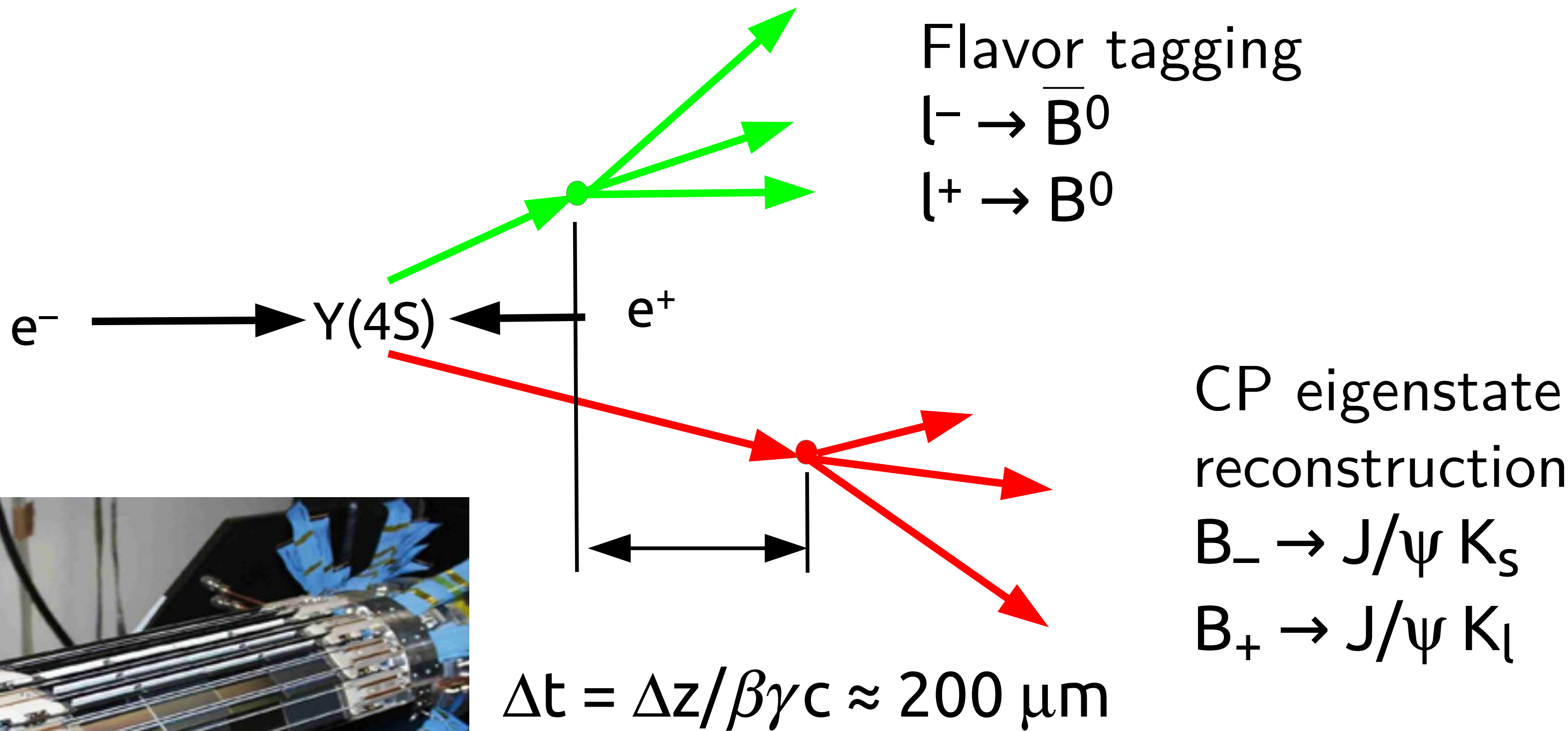
Achievement by Belle and BaBar:

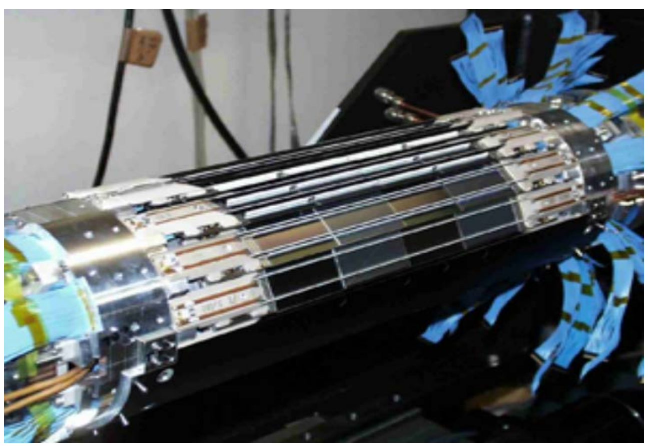
Observation of CP violation in the B meson system

C = charge conjugation symmetry
P = parity symmetry


e^-
e^+

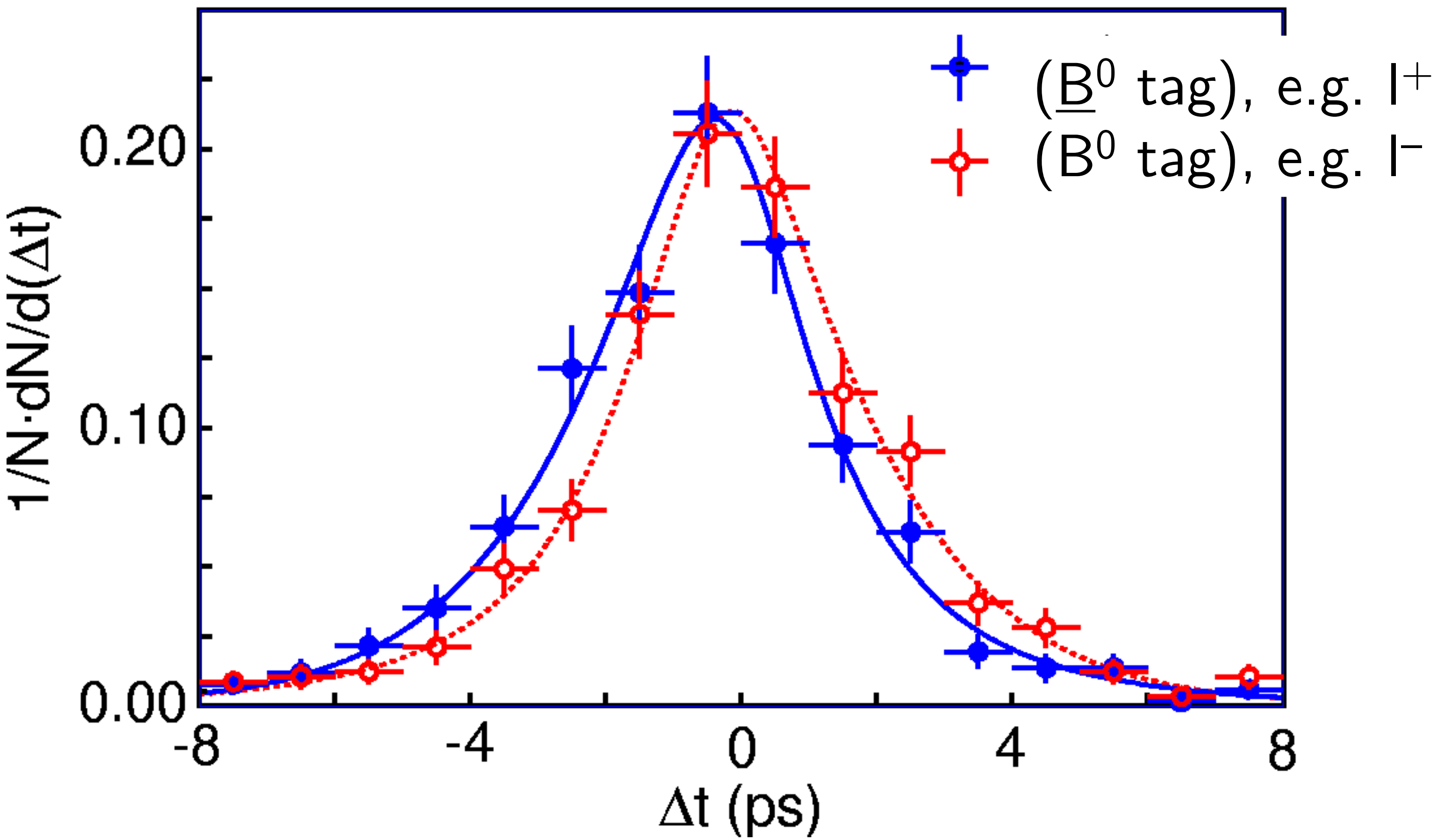
Measurement of CP violation at an asymmetric e^+e^- collider ($\sqrt{s}$=10.6 GeV)





Silicon Vertex Detector

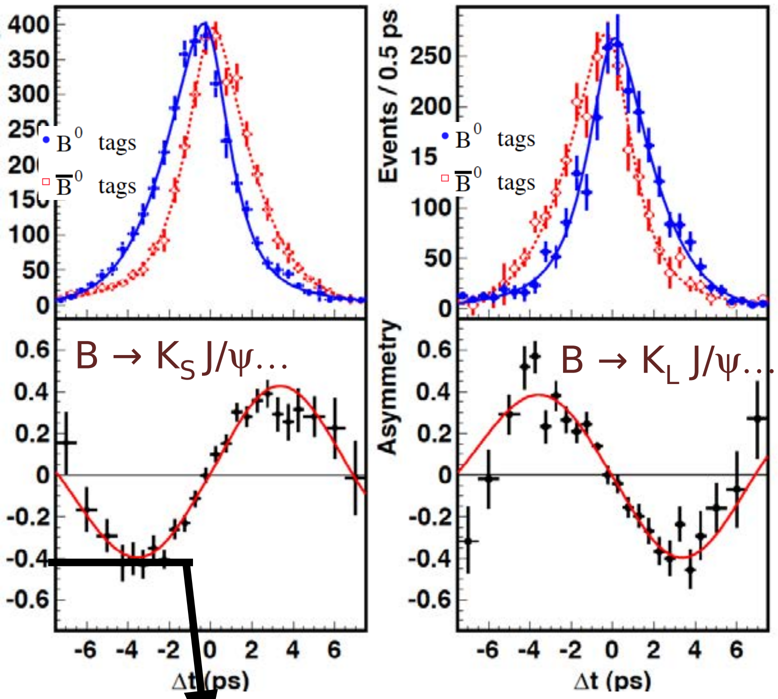
Red: B Mesons, Blue: Anti-B Mesons



CP violation is already visible in this plot!

Precision Measurement of sin(2β) at Belle & BaBar

Belle, Phys. Rev. Lett. 108(2012)171802



Makoto Kobayashi

Toshihide Maskawa

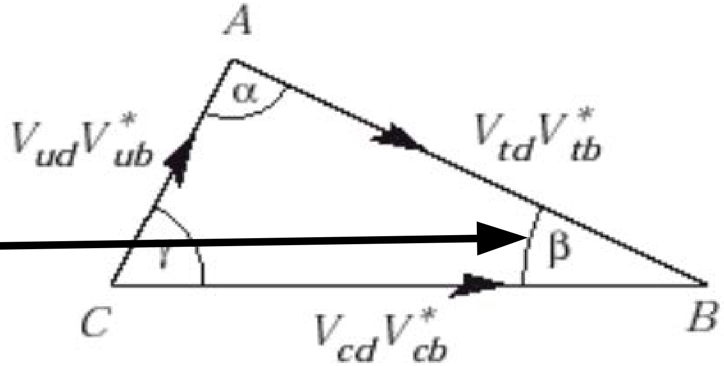
2008

V_{ij} are CKM matrix elements (Cabibbo-Kobayashi-Maskawa)

$A(\Delta t) \sim S_{CP} \sin(\Delta m \Delta t)$

in the SM

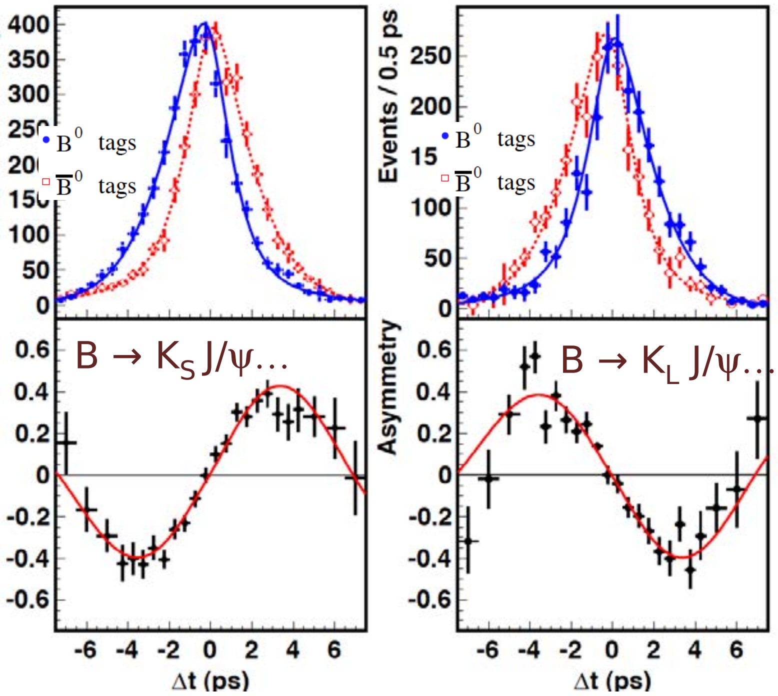
$S_{CP} = \pm\sin(2\beta)$



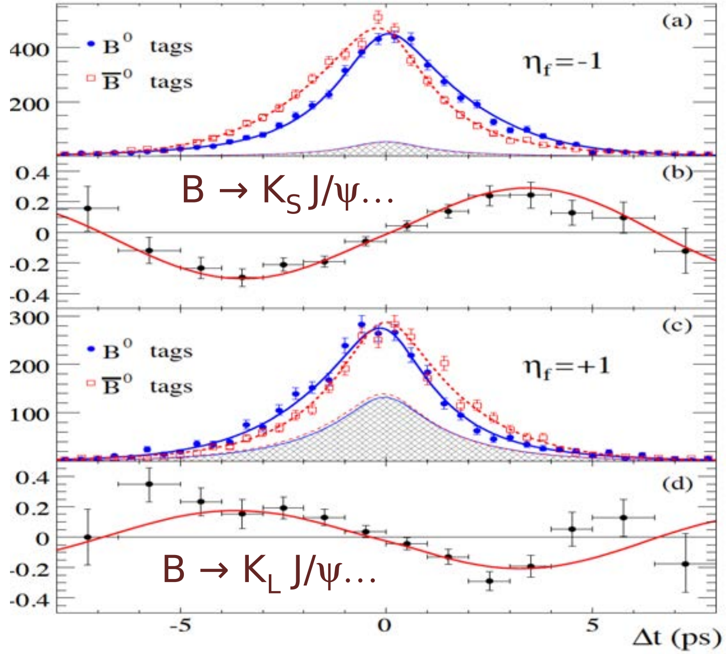
UNITARITY TRIANGLE

Precision Measurement of sin(2β) at Belle & BaBar

Belle, Phys. Rev. Lett. 108(2012)171802



BaBar Phys. Rev. D79(2009)072009



Belle and BaBar combined

$$S_{CP} = \sin(2\beta) = 0.679 \pm 0.024$$

error dominated by statistics $\rightarrow$ stat. error ±0.023 !

$\rightarrow$ can be largely improved by Belle II and LHCb

Test of CPT invariance

C = charge conjugation symmetry
P = parity symmetry
T = time reversal symmetry

Theorem: CPT is conserved* (Lüders, Pauli, 1954)
Violation is possible:
- quantum gravity
  (suppressed by m^2/M_{PLANCK}, M_{PLANCK}=1.2 x 10^{19} GeV)
- string theory (interactions of non-pointlike objects)
  Colladay, Kostecky, Phys. Rev. D55(1997)6760

*Any Lorentz invariant local quantum field theory with a Hermitian Hamiltonian must have CPT symmetry.

Test of CPT Invariance

Assuming CPT invariance

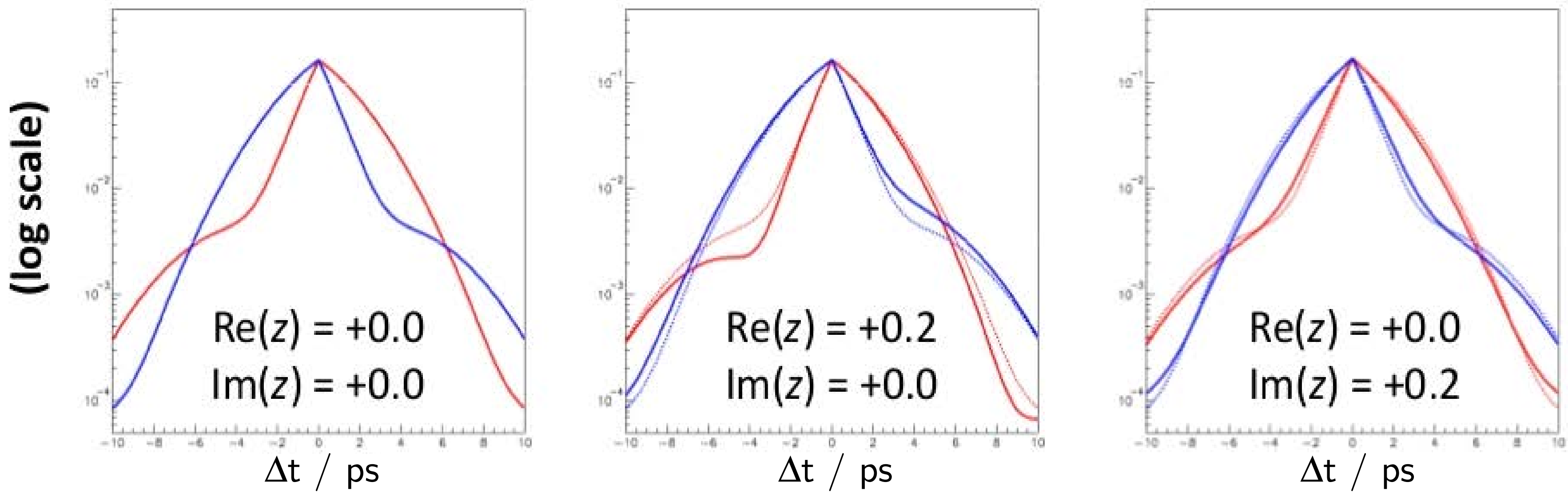
$$A = \frac{\Gamma(\overline{B}^0 \to J/\psi K_s^0) - \Gamma(B^0 \to J/\psi K_s^0)}{\Gamma(\overline{B}^0 \to J/\psi K_s^0) + \Gamma(B^0 \to J/\psi K_s^0)} = \sin(2\beta) \cdot sin(\Delta m \Delta t)$$

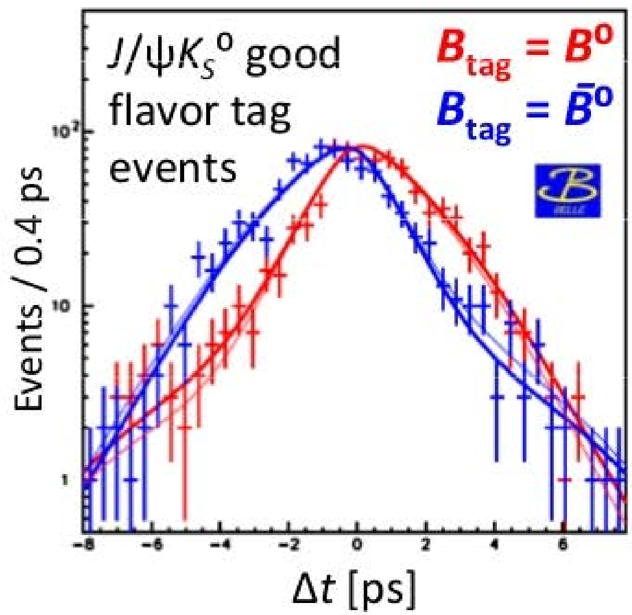
Not assuming CPT invariance

$$\begin{aligned} A &= \frac{\Gamma(\overline{B}^0 \to J/\psi K_s^0) - \Gamma(B^0 \to J/\psi K_s^0)}{\Gamma(\overline{B}^0 \to J/\psi K_s^0) + \Gamma(B^0 \to J/\psi K_s^0)} \\ &= \sin(2\beta) \cdot [cosh(\frac{\Delta\Gamma\Delta t}{2}) - 2\boxed{Re(z)}sinh(\frac{\Delta\Gamma\Delta t}{2}) \\ &\quad +2\boxed{Im(z)}sinh(\Delta m \Delta t) + sin(\Delta m \Delta t)] \end{aligned}$$

with a new, complex CPT violation parameter z

Test of CPT Invariance





Light lines indicate Re(z) = +0.2 Im(z) = +0.0 case.

Blue for q = +1 (B_{tag}=B^0)
Red for q = −1 (B_{tag}=B^0)
Bold solid lines for $z\neq0$,
thin dashed lines for z=0.

Belle, arXiv:1203.0930[hep-ex]
Phys. Rev. D 85(2012)071105(R)
535 x 10^6 BB pairs

Test of CPT Invariance

Belle, arXiv:1203.0930[hep-ex]
Phys. Rev. D 85(2012)071105(R)
535 x 10^6 BB pairs

$$\mathcal{R}e(z) = [+1.9 \pm 3.7(\text{stat}) \pm 3.3(\text{syst})] \times 10^{-2}$$

$$\mathcal{I}m(z) = [-5.7 \pm 3.3(\text{stat}) \pm 3.3(\text{syst})] \times 10^{-3}$$

can be improved by Belle II
by factor 10

translates to
$\Delta m_B/m_B=$
$(-1.3\pm2.6) \times 10^{-15}$
K. R. Schubert,
arXiv: 1409.5998[hep-ex]

compare to (anti)proton
$\Delta m_p/m_p=7 \times 10^{-10}$
PDG 2014

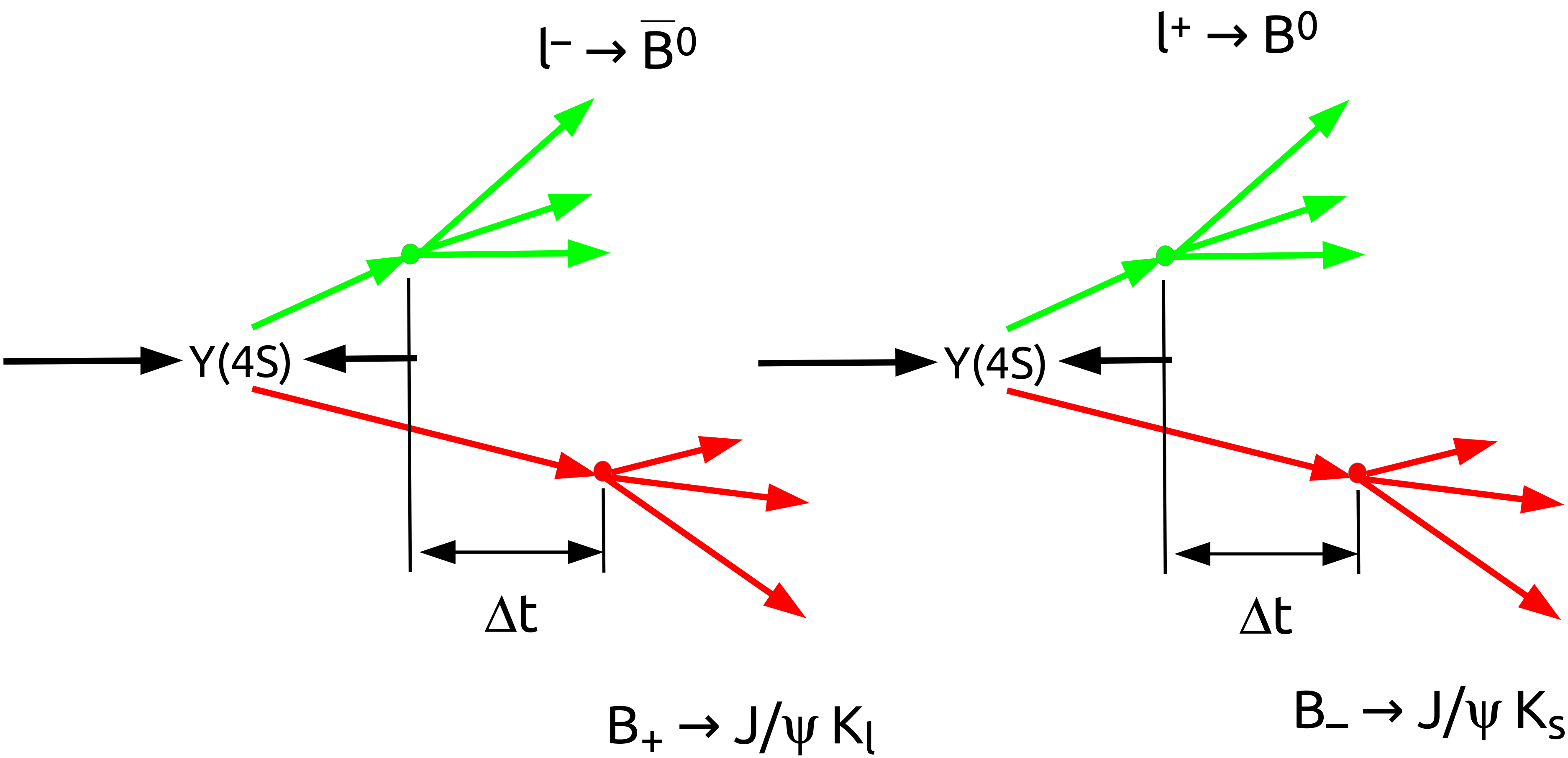
Source	$\delta(\mathcal{R}e(z))$	$\delta(\mathcal{I}m(z))$
Vertex reconstruction	0.008	0.0028
Δt-resolution function	0.003	0.0004
Tag-side interference	0.028	0.0006
CSD effect	0.004	0.0008
Fit bias	0.012	0.0013
Signal fraction	0.004	0.0002
Background Δt shape	0.005	0.0001
Others	0.001	<0.0001
Total	0.033	0.0033

sensitiv to
$(1/m_b^2)*\Delta m_B/m_B=$
$(-4.7\pm2.6) \times 10^{-17}$ GeV^{-1}

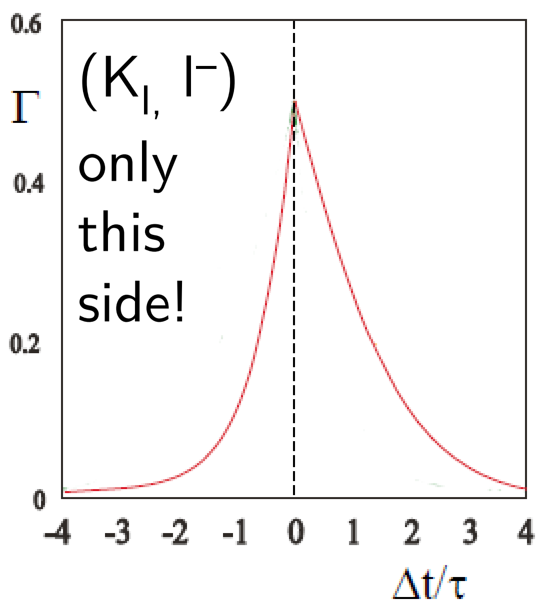
syst. error for Im(z),
$\rightarrow$ can be improved by factor 2
(new Belle II vertex detector)

Test of T invariance

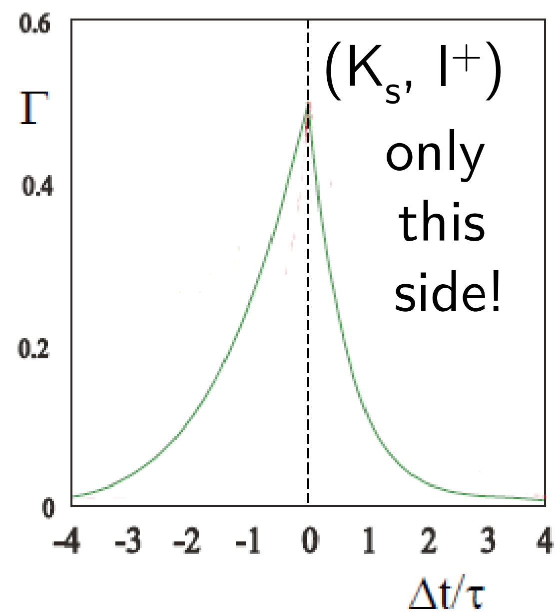
T Violation



T Violation

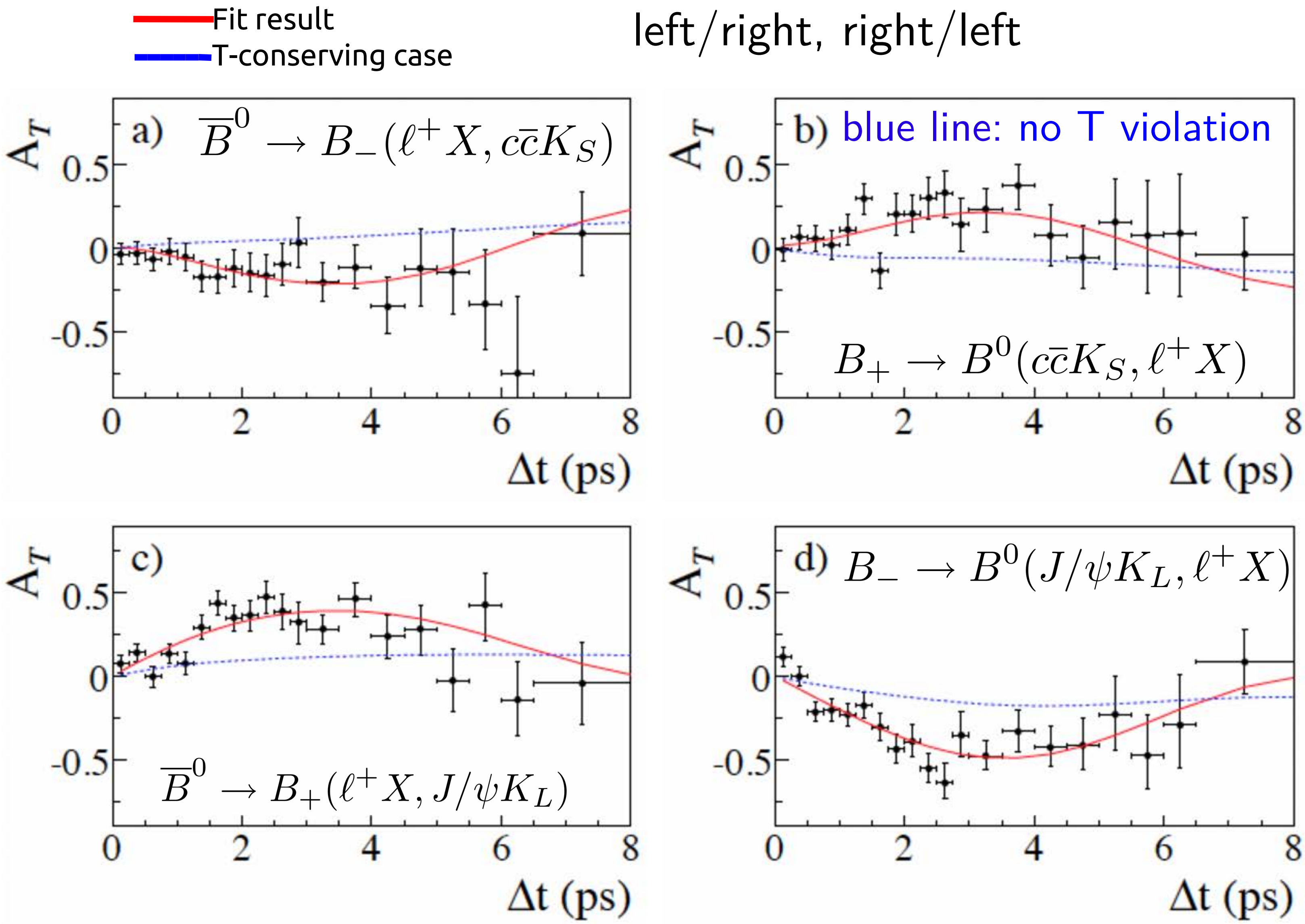


vs.



T Violation

2 final states, but 4 asymmetries:
time-ordered → only positive Δt
left/right, right/left



BaBar, arXiv:1207.5832[hep-ex], Phys. Rev. Lett. 109(2012)211801

BaBar, arXiv:1207.5832[hep-ex], Phys. Rev. Lett. 109(2012)211801

T

$$\Delta S_T^+ = S^-_{\ell-,K^0_L} - S^+_{\ell+,K^0_S} \qquad -1.37 \pm 0.14 \pm 0.06$$

$$\Delta S_T^- = S^+_{\ell-,K^0_L} - S^-_{\ell+,K^0_S} \qquad 1.17 \pm 0.18 \pm 0.11$$

CP

$$\Delta S_{CP}^+ = S^+_{\ell-,K^0_S} - S^+_{\ell+,K^0_S} \qquad -1.30 \pm 0.11 \pm 0.07$$

$$\Delta S_{CP}^- = S^-_{\ell-,K^0_S} - S^-_{\ell+,K^0_S} \qquad 1.33 \pm 0.12 \pm 0.06$$

$\rightarrow$ another way to check for CPT invariance
(CP violation implies T violation, if CPT is conserved)

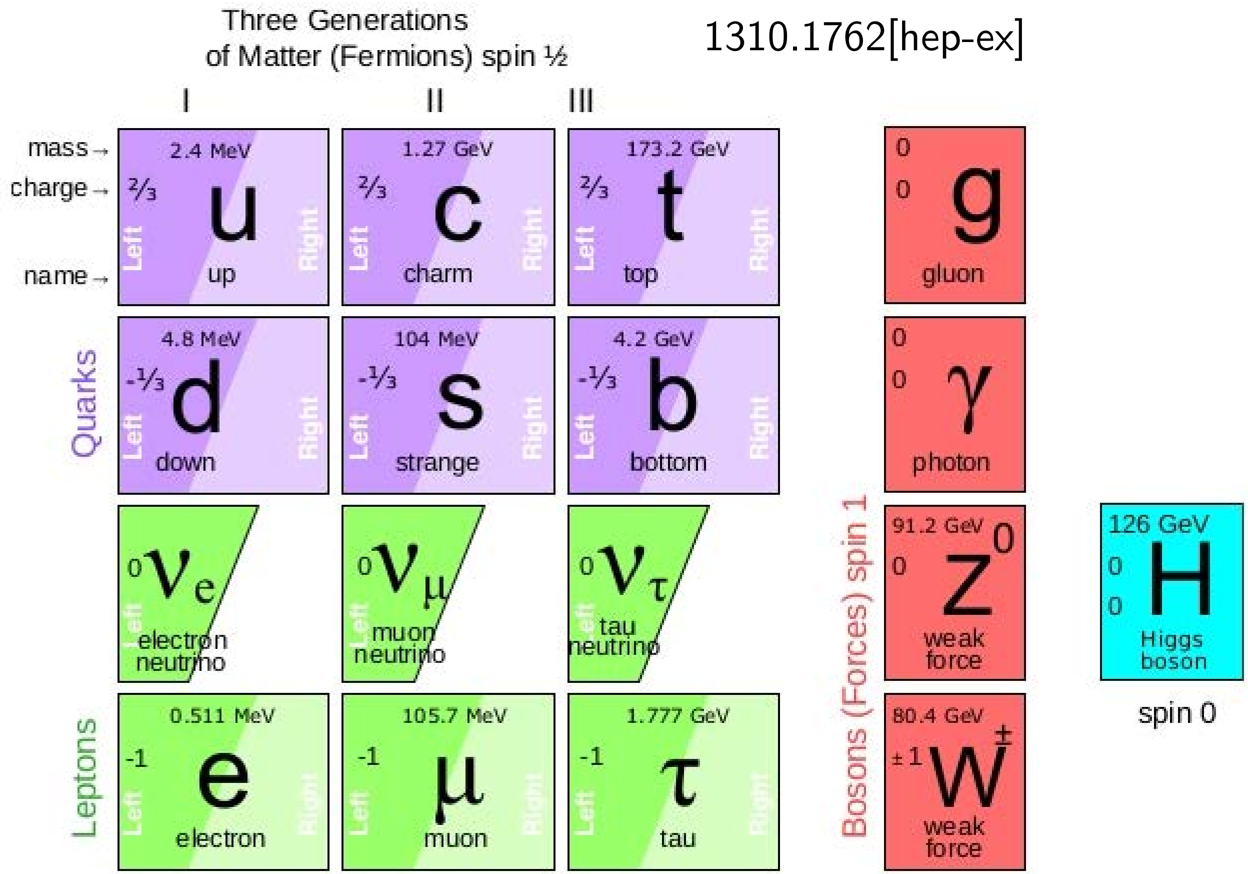
statistical error dominates
$\rightarrow$ improve by factor 10 at Belle II

T violation can be investigated in every decay with CP violation

Search for Right-Handed Couplings

The Standard Model (SM)

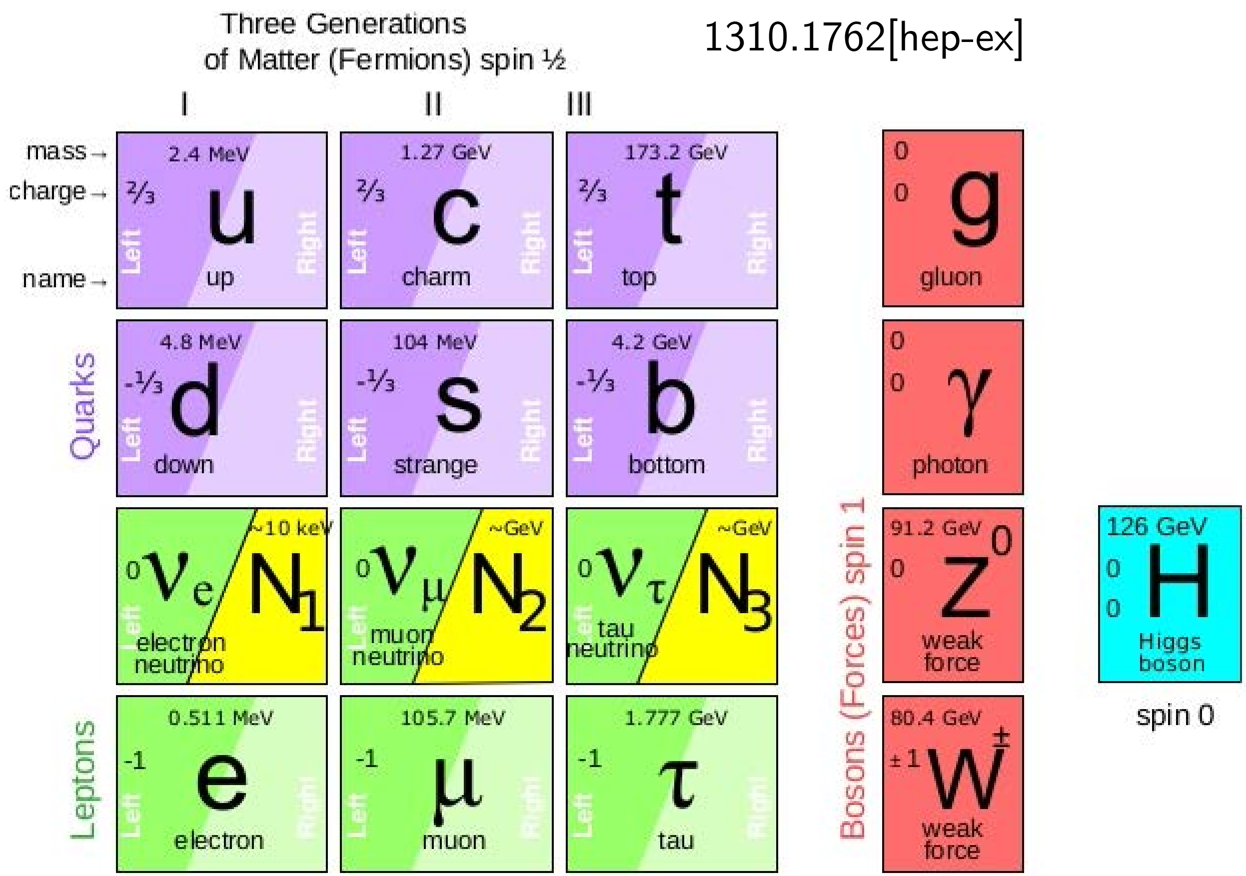
1310.1762[hep-ex]



in the SM:
neutrinos are left-handed, W bosons are left-handed

Beyond the Standard Model (BSM)

1310.1762[hep-ex]



Are there maybe right-handed neutral leptons, not observed yet?

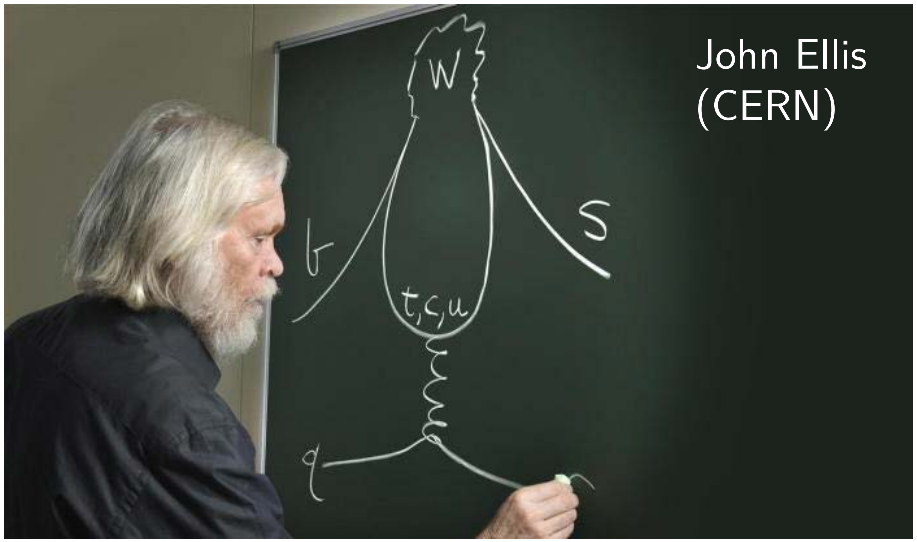
$\rightarrow$ right-handed currents

How do we know there is physics beyond SM ?

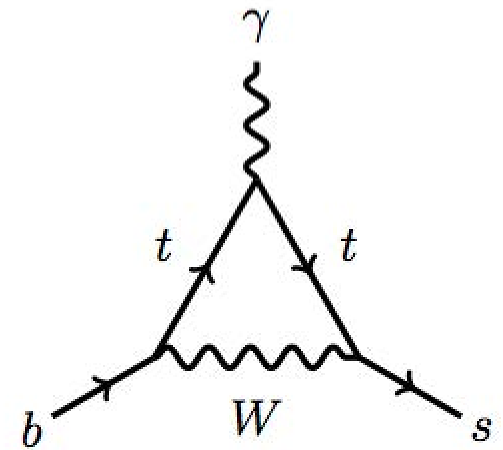
$\rightarrow$ neutrinos oscillate
$\rightarrow$ neutrinos have mass
$\rightarrow$ if $m \neq 0$, then $v < c$
$\rightarrow$ if $v < c$, then we can find a (faster) reference system, in which the helicity flips (left-handed $\rightarrow$ right-handed)
$\rightarrow$ conclusion: there should be a right-handed component (even if small)

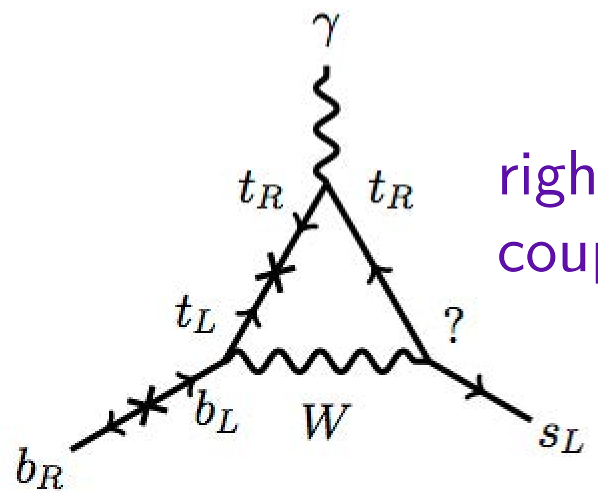
Penguin diagrams

Flavor Changing Neutral Current (FCNC)



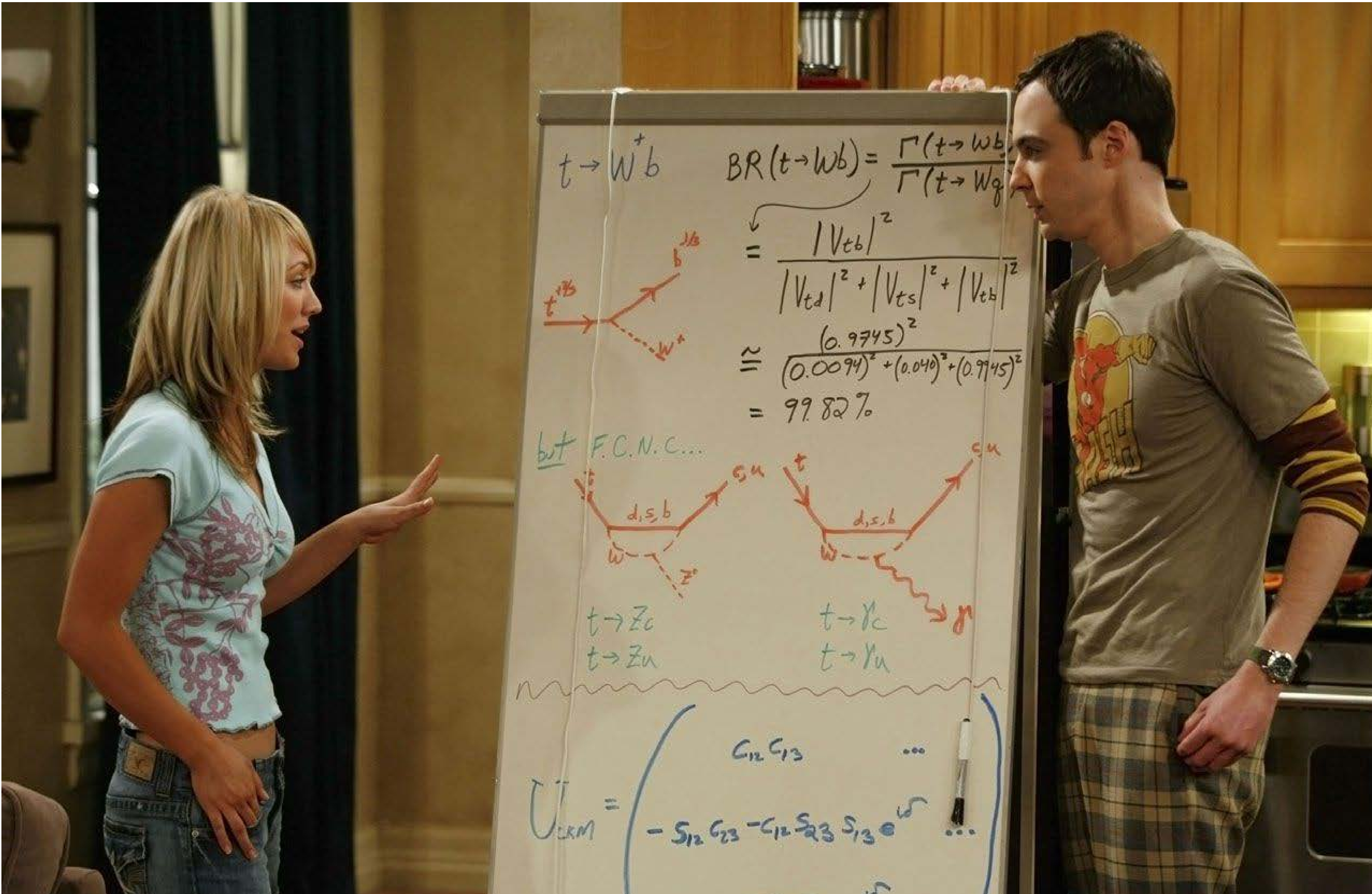
physicsforme.de





right-handed couplings

quantumdiaries.org
Flip Tanedo, 19.03.2013

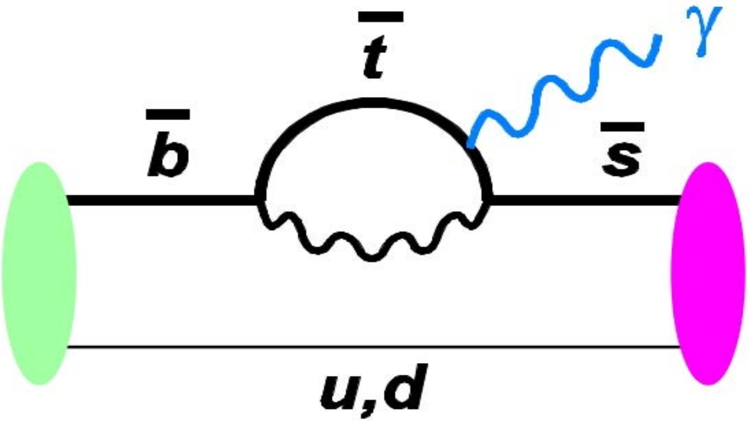

t → W+ b
BR(t→Wb) = Γ(t→Wb) / Γ(t→Wq)
= |Vtb|² / (|Vtd|² + |Vts|² + |Vtb|²)
≅ (0.9745)² / ((0.0094)² + (0.040)² + (0.9745)²)
= 99.82%
but F.C.N.C...
d,s,b
d,s,b
t→Zc
t→Zu
t→γc
t→γu
UCKM =
C12 C13
- S12 C23 - C12 S23 S13 e^iδ

The Big Bang Theory

FCNC $B \to K^* (K_s \pi^0) \gamma$

photon from $B(\overline{B})$ dominantly right(left)-handed
(because of W boson in the loop)

neutral B^0
(CP violation
requires
$B^0\overline{B}^0$ mixing)



resonant:
vector meson
e.g. K^*

non-resonant:
self-conjugate
$K_s \pi^0$

Advantages of Belle II:
- BB pair production
  (other side required for flavor tagging)
- neutrals:
  radiative photon and $\pi^0 \to \gamma\gamma$

FCNC $B \to K^* (K_s \pi^0) \gamma$

Belle, 486 fb^{-1}

Phys. Rev. D74(2006)111104(R)

CP violation in SM
is expected small

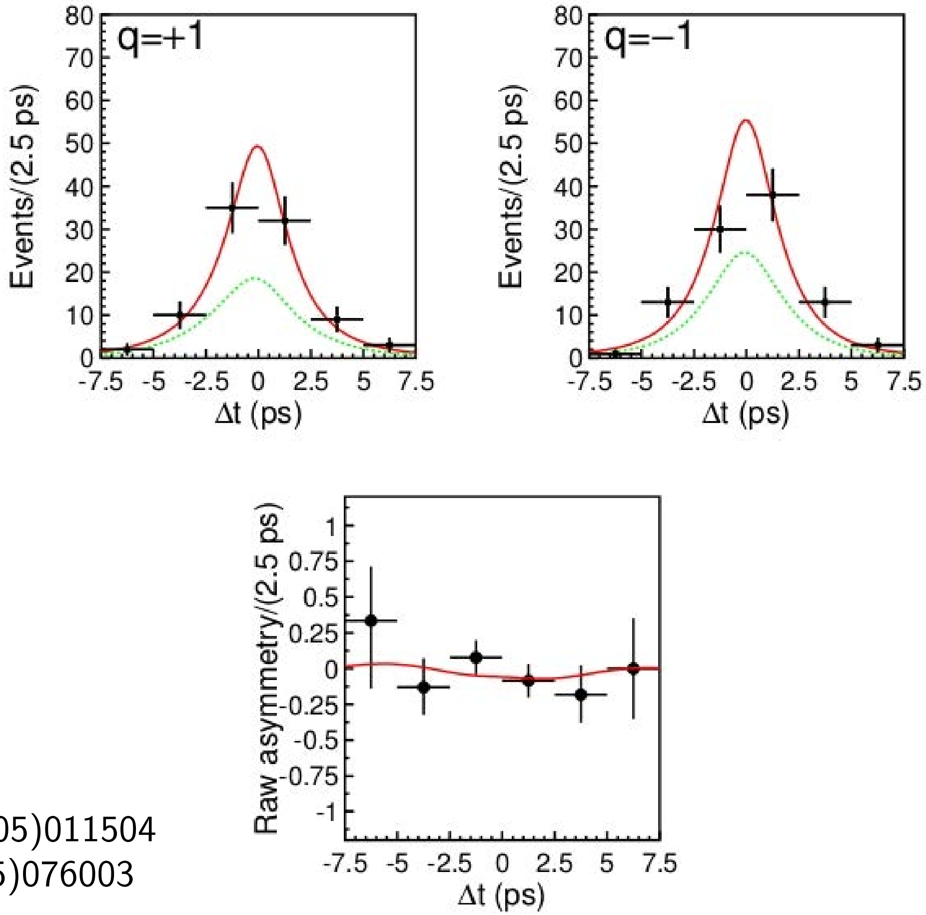
$S(K^*\gamma) = -(2m_s/m_b)$ $\sin 2\beta$ ~ 0.04

$S = -(3.5 \pm 1.7) \times 10^{-2}$

Matsumori, Sanda, Phys. Rev. D73(2006)114022

$S = -(2.2 \pm 1.5^{+0.0}_{-1.0}) \times 10^{-2}$

Ball, Zwicky, Phys. Lett. B642(2006)478



LR symmetric model

$S(K^*\gamma) = +0.67$ $\sin 2\beta$ $= 0.5$

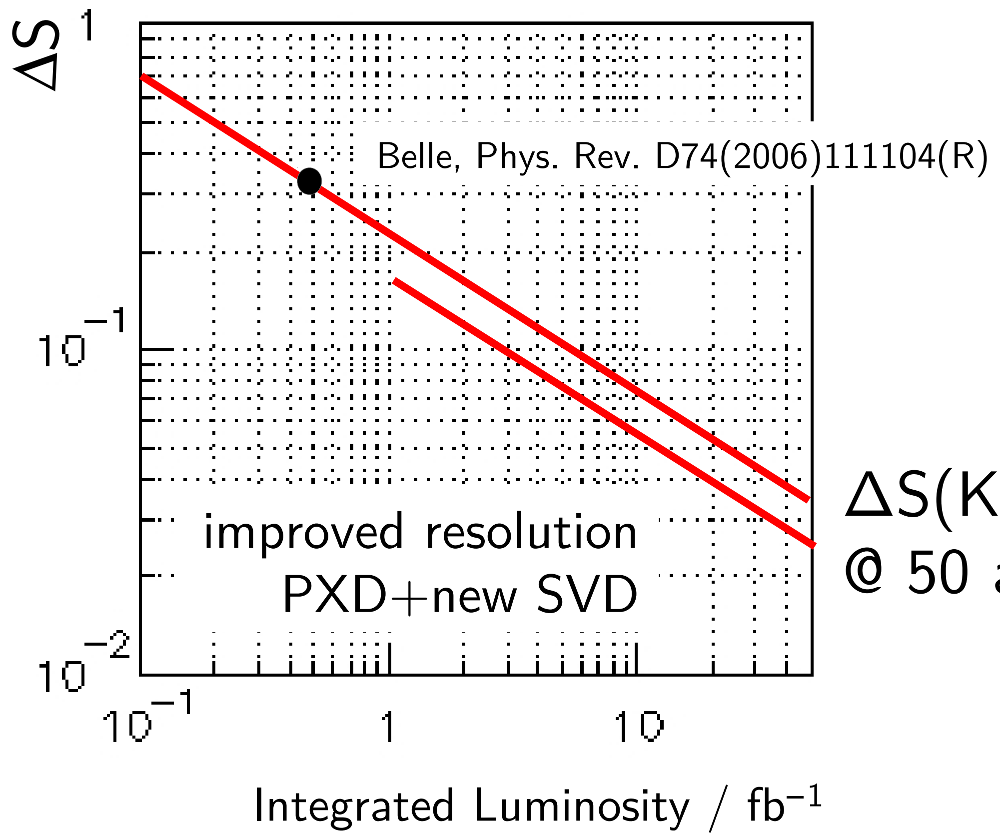
Atwood, Gronau, Soni, Phys. Rev. Lett. 79(1997)185

Grinstein, Grossmann, Ligeti, Pirjol, Phys.Rev.D71(2005)011504

Atwood, Gershon, Hazumi, Soni, Phys. Rev. D71(2005)076003

$$\mathcal{S}_{K^0_S \pi^0 \gamma} = -0.10 \pm 0.31(\mathrm{stat}) \pm 0.07(\mathrm{syst})$$

FCNC $B \to K^* (K_s \pi^0) \gamma$
Extrapolation for Belle II



$\Delta S(K^*\gamma) = 0.027$
@ 50 ab^{-1}

Bounds on scale of new physics based upon existing data

Isidori, Teubert, arXiv:1402.2844[hep-ph]

$$\mathcal{A}(\psi_i \to \psi_j + X) = \mathcal{A}_0 \left[\frac{c_{\rm SM}}{M_W^2} + \frac{c_{\rm NP}}{\Lambda^2} \right]$$

$\Lambda_{NP} \geq 10^2$ TeV

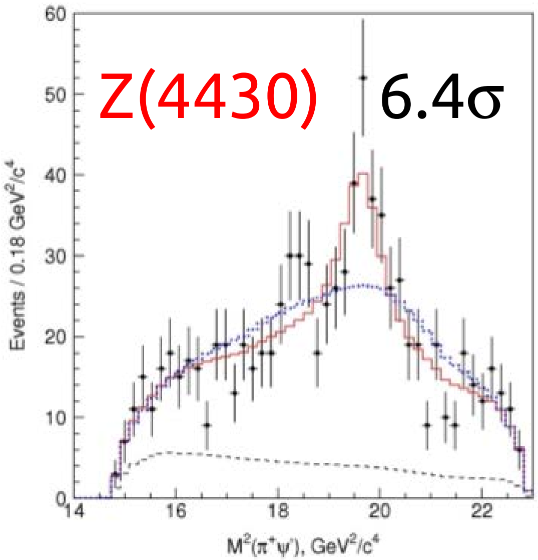
Factor 3–4 higher for b $\to$ sγ and right-handed currents

Operator	Bounds on Λ in TeV ($c_{\rm NP}=1$) Re	Im
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4
$(\bar{b}_L \gamma^\mu d_L)^2$	6.6×10^2	9.3×10^2
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	2.5×10^3	3.6×10^3
$(\bar{b}_L \gamma^\mu s_L)^2$	1.4×10^2	2.5×10^2
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	4.8×10^2	8.3×10^2

Z^+ States

Exotic hadronic states

$Z^+(4430)$



$$B^0 \rightarrow K^{\pm} \underbrace{\psi' \pi^{\mp}}_{\text{resonant state?}}$$

not confirmed by BaBar

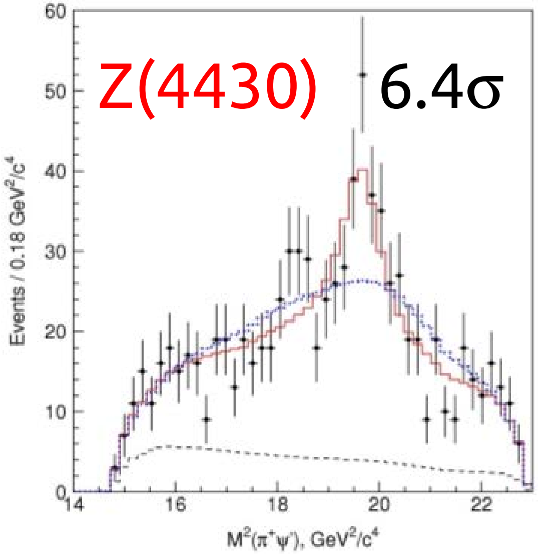
$$m{=}4433{\pm}4{\pm}2 \text{ MeV}, \ \Gamma{=}45^{+18+30}_{-13-13} \text{ MeV}$$

Belle, Phys. Rev D80(2009)031104

Steve Olsen

Soo-Kyung Choi

Photos: rare evidence from Belle barbecue parties (http://belle.kek.jp)



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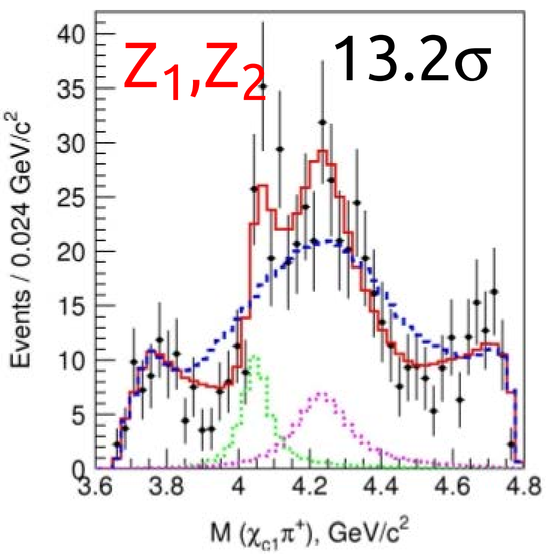
$$m{=}4433{\pm}4{\pm}2\ \text{MeV},\ \Gamma{=}45^{+18+30}_{-13-13}\ \text{MeV}$$

Belle, Phys. Rev D80(2009)031104



$$B^0 \to K^\pm \underbrace{\chi_{c1} \pi^\mp}_{\text{resonant state?}}$$

not confirmed by BaBar

$$m(\mathrm{Z}_1){=}4051{\pm}14^{+20}_{-41}\ \text{MeV},\ \Gamma(\mathrm{Z}_1){=}82^{+21+47}_{-17-22}\ \text{MeV}$$

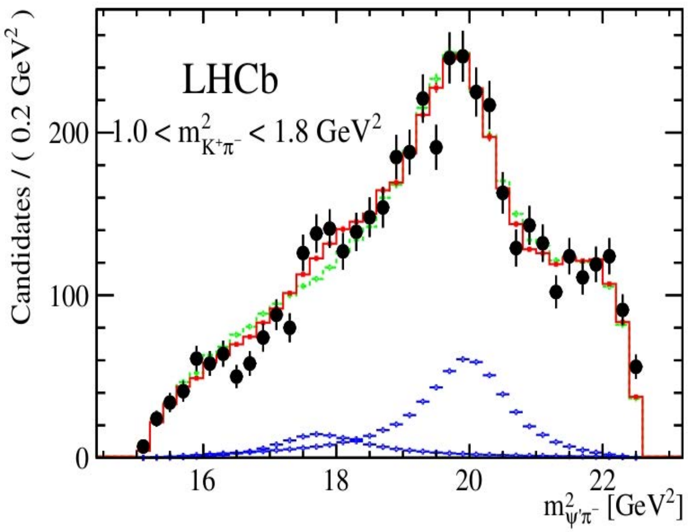
$$m(\mathrm{Z}_2){=}4248^{+44+180}_{-29-35}\ \text{MeV},\ \Gamma(\mathrm{Z}_2){=}177^{+54+316}_{-39-61}\ \text{MeV}$$

Belle, Phys. Rev D78(2008)072004

$J^P{=}1^+$ preferred in all cases

Confirmation of the $Z^+(4430)$ in $B^0 \to K^+ \psi' \pi^-$

LHCb, arXiv:1404.1903[hep-ex], Phys. Rev. Lett. 112(2014)222002



- data set 3 fb^{-1}, $\sqrt{s}$=7 and 8 TeV
- significance $>13.9\sigma$
- $J^P=1^+$ established (exclusion of 0–, 1–, 2+, 2– by 9.7σ, 15.8σ, 16.1σ and 14.6σ)
- mass and width consistent with Belle

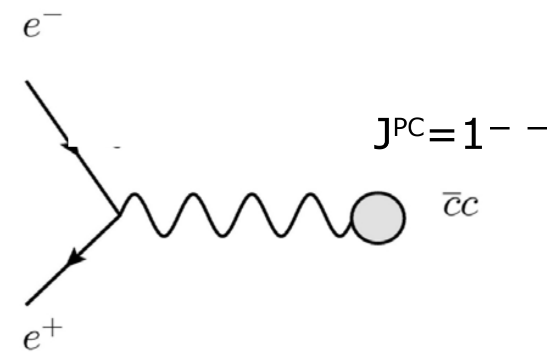
Product branching fraction $\sim 3 \times 10^{-5}$ $\to$ requires „B factories“

Search for Z^+ states in other processes

BESIII (IHEP Beijing)

$$e^+e^-(\sqrt{s}=4.26\ GeV) \rightarrow \underbrace{J/\psi\pi^\pm}_{\text{resonant state?}} \ \pi^\mp$$

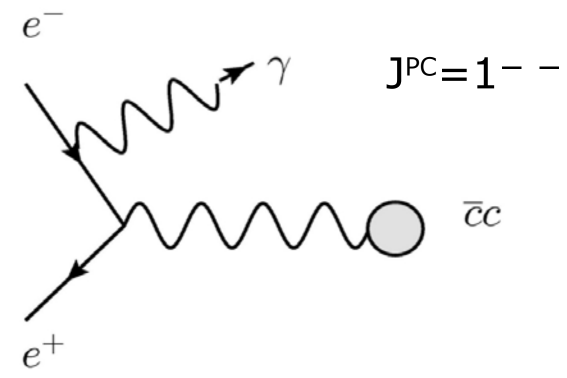
Direct Production



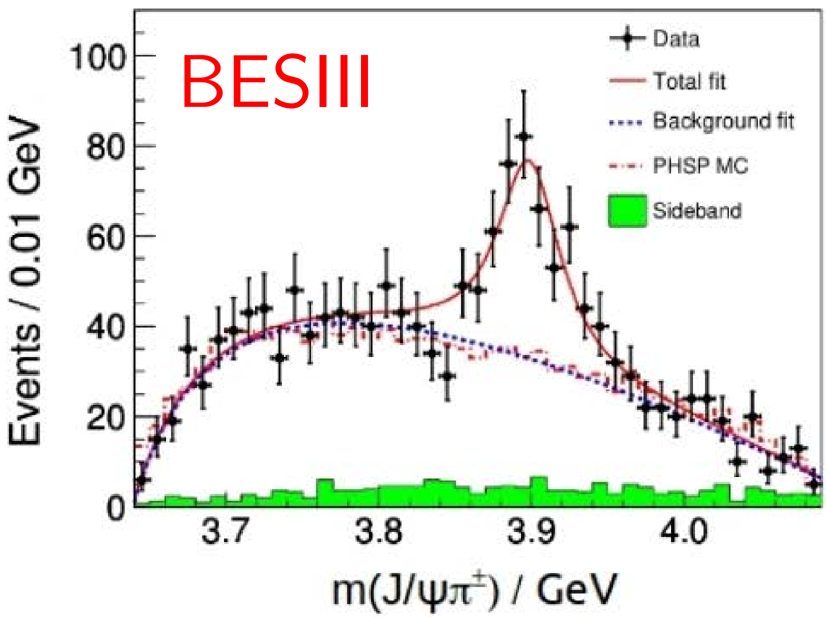
Belle

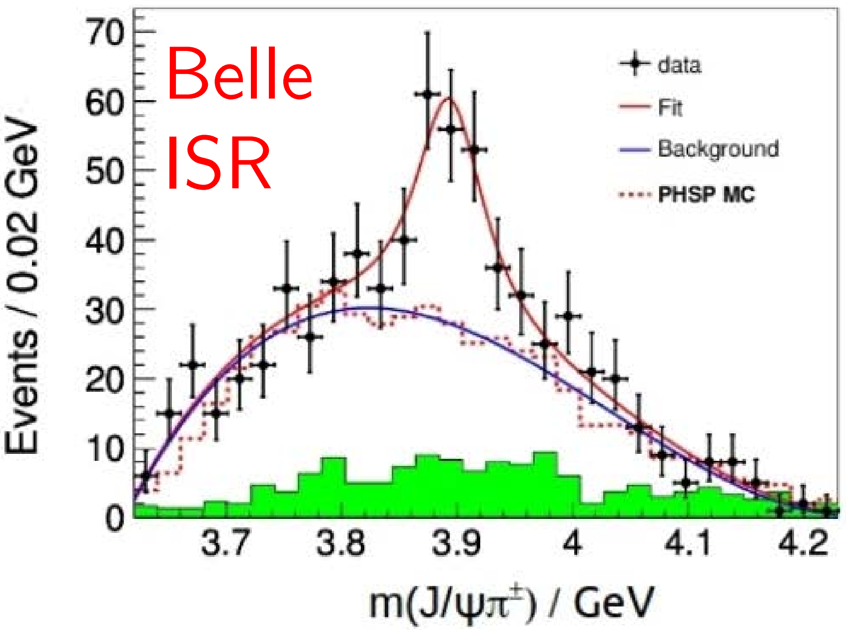
$$e^+e^-(\sqrt{s}=10.58\ GeV) \rightarrow \gamma_{ISR} \ \underbrace{J/\psi\pi^\pm}_{\text{resonant state?}} \ \pi^\mp$$

Initial State Radiation



$Z^+(3900)$





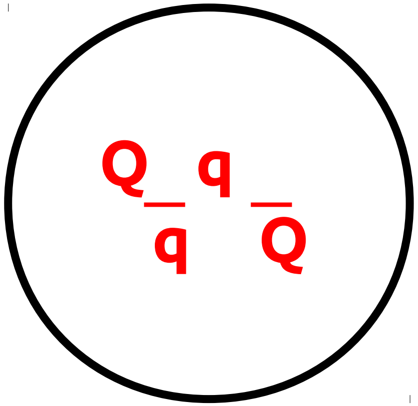
m = 3899.0±3.6±4.9 MeV
Γ = 46±10±20 MeV
307±48 events, >8 σ
arXiv:1303.5949, PRL 110(2013)252001

m = 3894.5±6.6±4.5 MeV
Γ = 63±24±26 MeV
159±49 events, >5.2 σ
arXiv:1304.0121, PRL 110(2013)252002

Confirmed with CLEO-c data, but different √s → not Y(4260)
S. Dobbs et al., Phys. Lett. B727(2013)366

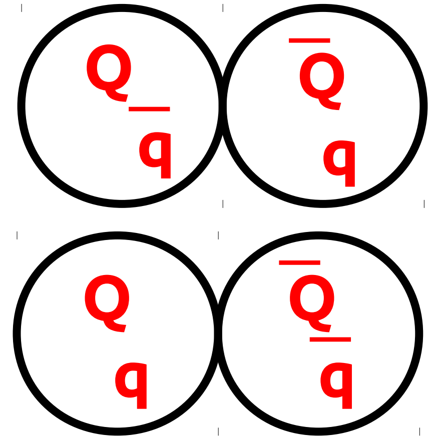
Charged states require minimum configuration of 4 quarks

TETRAQUARK (COMPACT)



Lattice QCD

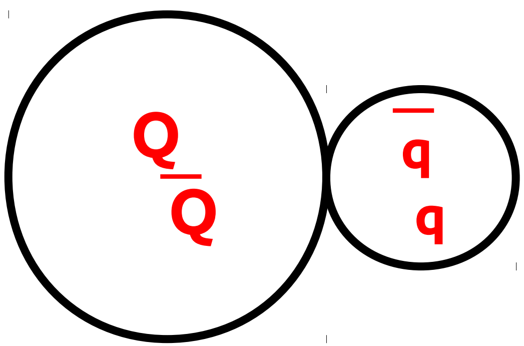
TETRAQUARK (DIQUARK- DIQUARK)



diquarks can be colored

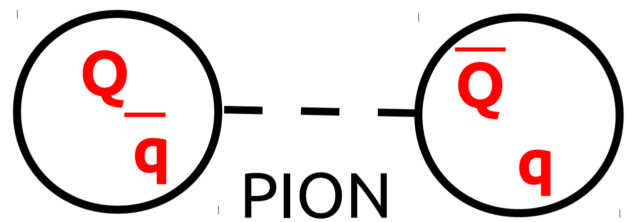
Maiani, Riquer, Piccinini, Polosa,
Burns; Ebert, Faustov, Galkin; Chiu, Hsieh;
Ali, Hambrock, Wang
Fischer, Heupel, Eichmann

HADRO-QUARKONIUM



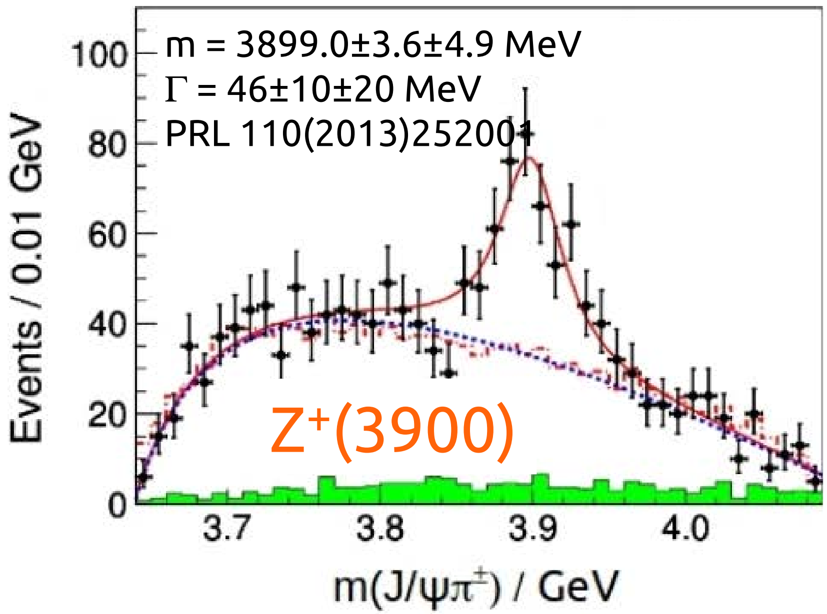
Guo, Hanhard, Meißner, Zhao

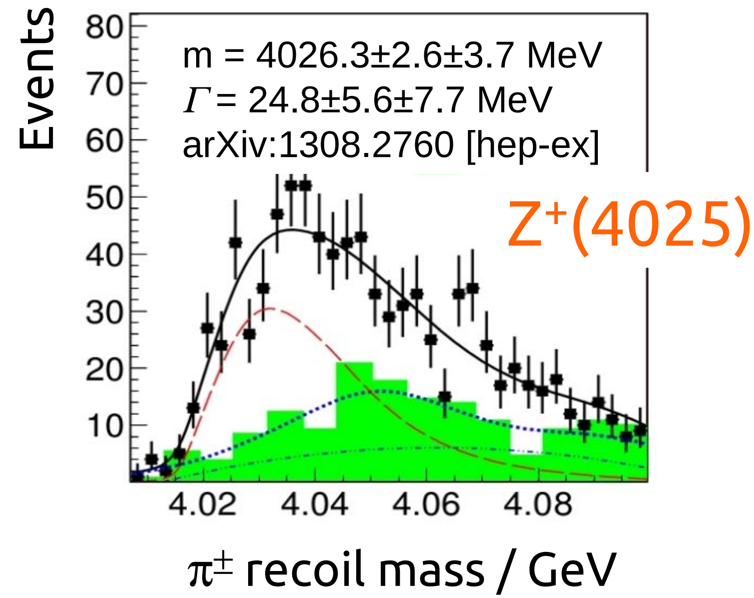
MOLECULE

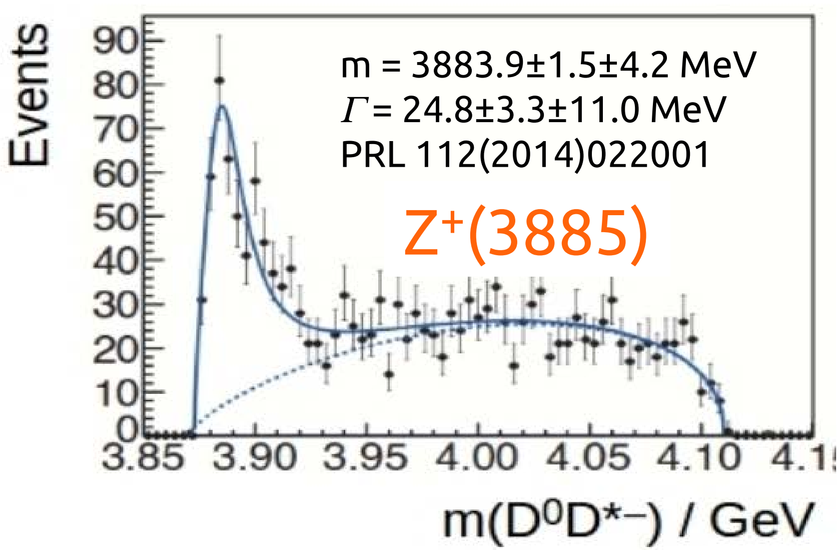


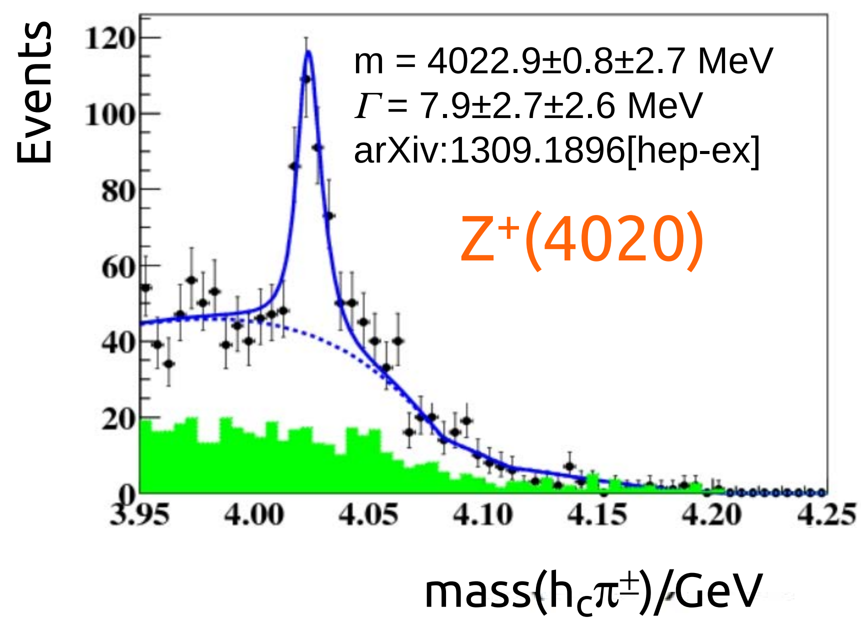
Tornqvist; Swanson; Braaten, Kusonoki,
Wong; Voloshin; Close, Page; Oset
Threshold CUSP: Bugg

Z^+ states at BESIII



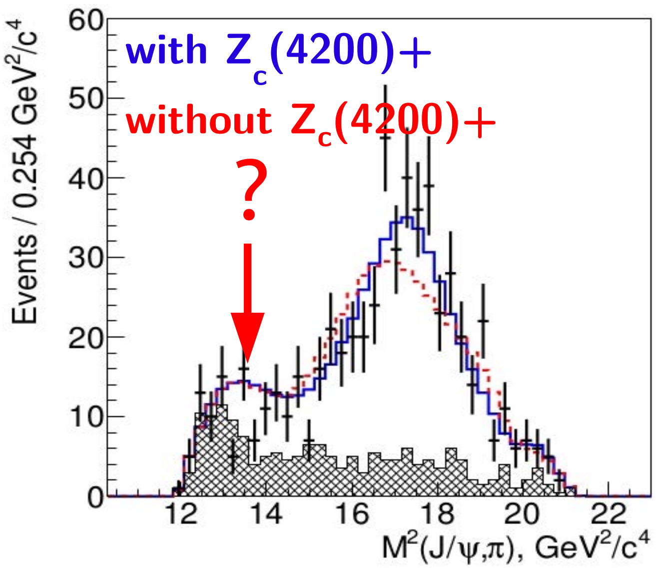






New 2014: $Z^+(4200)$ in B meson decays

Belle, arXiv:1408.6457[hep-ex], Phys. Rev. D90, 112009 (2014)



$$B^0 \to K^\pm \underbrace{J/\psi\pi^\mp}_{\text{resonant state?}}$$

$$M = 4196^{+31+17}_{-29-13}\ \text{MeV}/c^2, \quad \Gamma = 370^{+70+70}_{-70-132}\ \text{MeV}$$

significance 6.2σ

also $J^P = 1^+$ preferred

exclusion level ($J^P=0^-, 1^-, 2^-, 2^+$):

6.1σ, 7.4σ, 4.4σ, 7.0σ

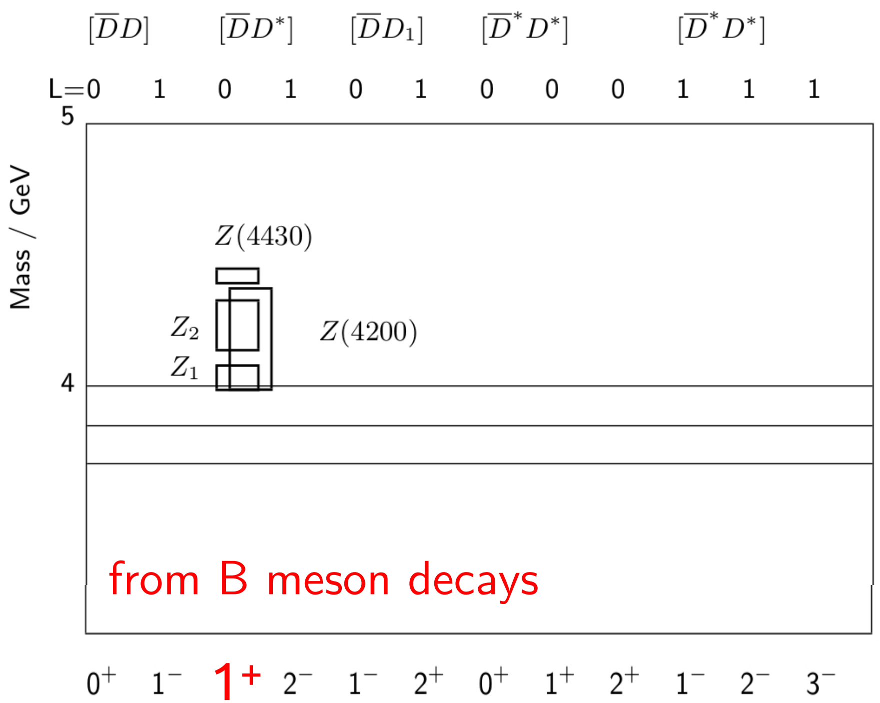
Important negative search result:

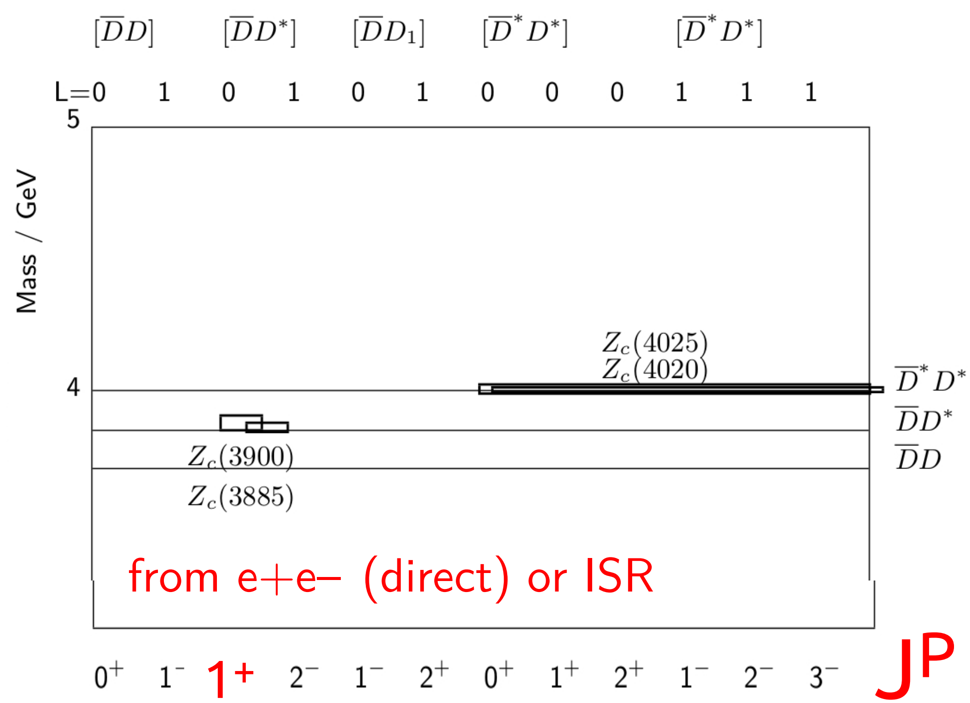
no evidence for $Z^+(3900)$ in B decays

$<0.1\sigma$ (if $J^P=1^+$)

Spectrum of Z+ States

Topic for Belle II → 2 different types?





– large widths
– not connected to thresholds?

– narrow widths
– near thresholds

Only Belle II can investigate both types in same experiment (high statistics → ~10.200 $Z^+(4430)$ in 50 ab^{-1})

Status of Belle II

Installation of 100 new LER Dipole Magnets

field measurement

move into tunnel

Installation of 100 new LER bending magnets done

carry on an air-pallet

Install over HER magnets

19

SuperKEKB Status, 7th BPAC, Mar. 11, 2013, K. Akai

B-KLM Installation

2013

Completed on November 16th

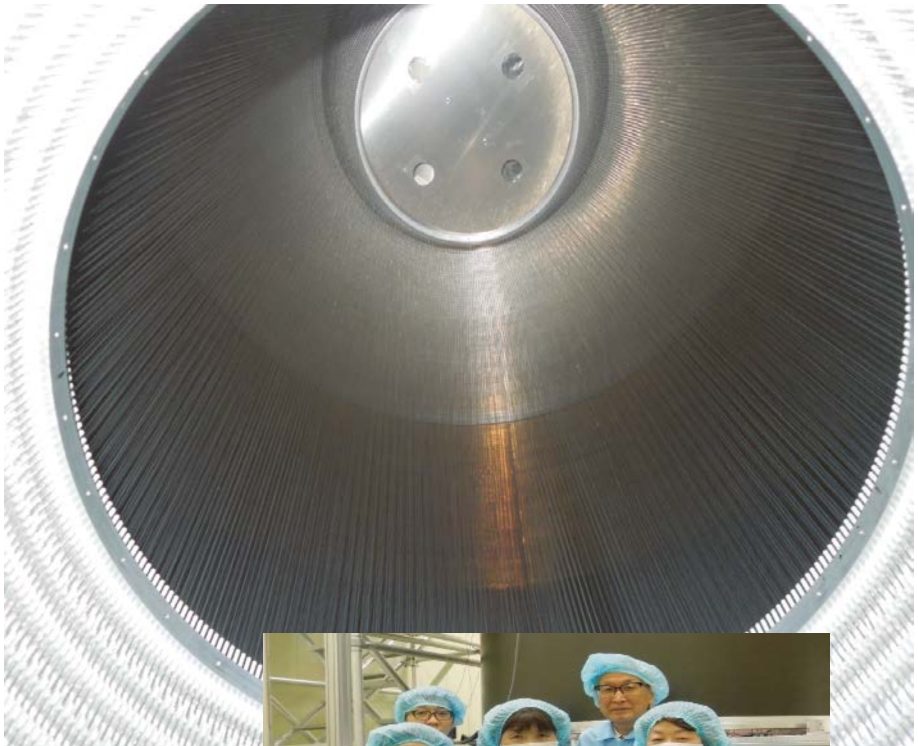
~2 months delay

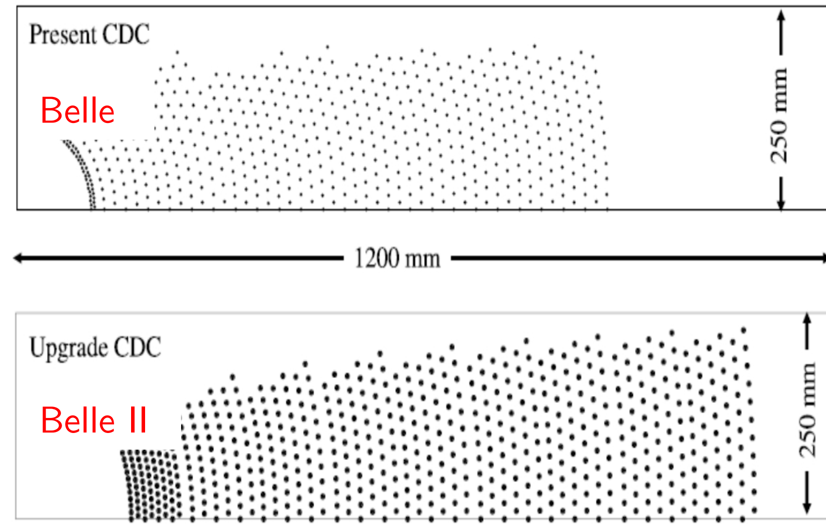
During installation, modules have been checked, found to be healthy.

The 1st New Detector Installed !!

CDC (Charged Drift Chamber)

wire stringing finished (01/2014), 51456 wires





Improved resolution:

$\sigma(p_T)/p_T =$

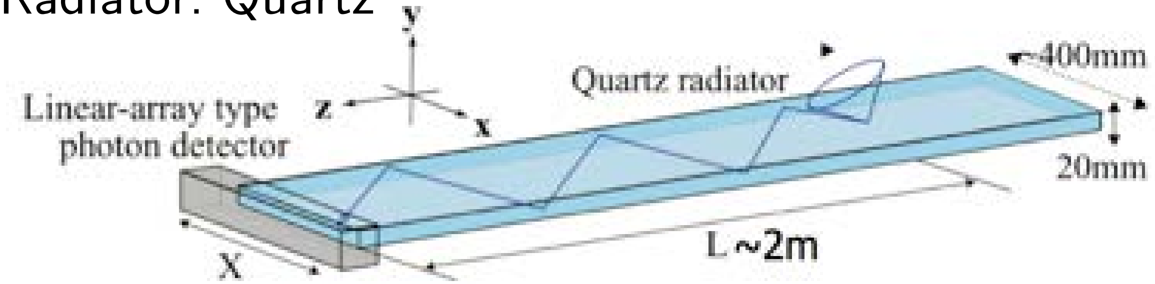
$0.19\ p_T \oplus 0.30/\beta$ (Belle)

$0.11\ p_T \oplus 0.30/\beta$ (Belle II)

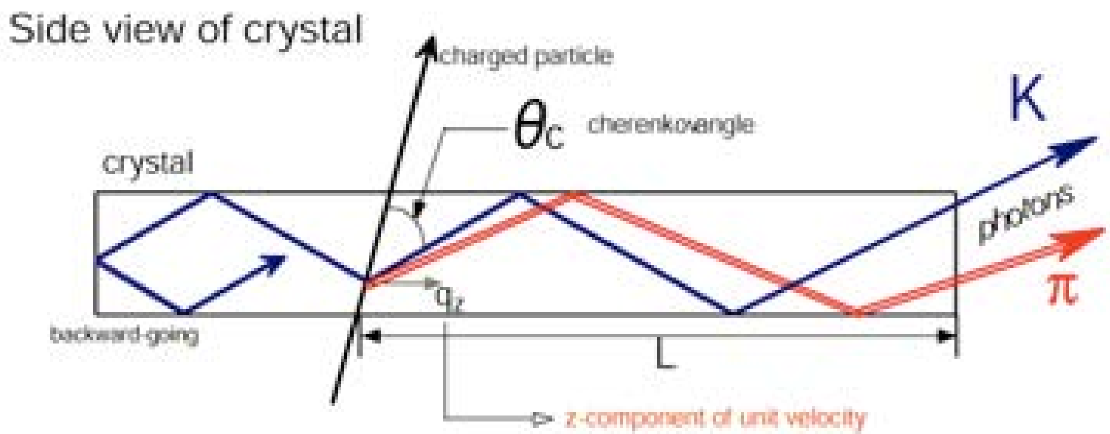
dE/dx 6.8% $\rightarrow$ 4.8%

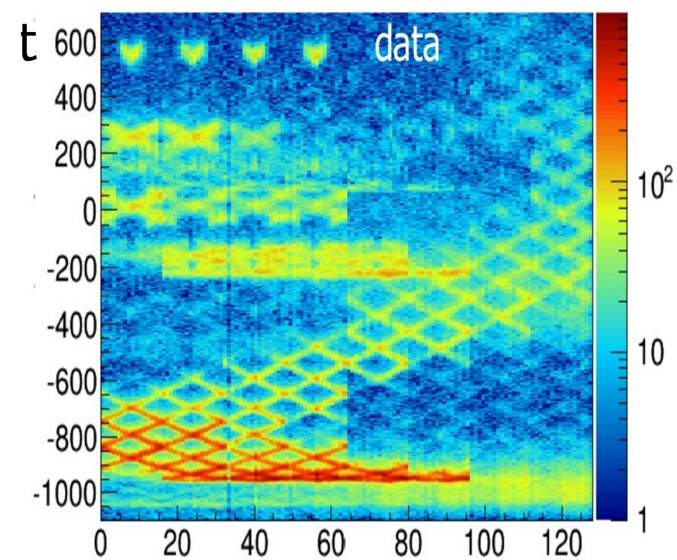
TOP (Time-of-Propagation Counter)

Radiator: Quartz



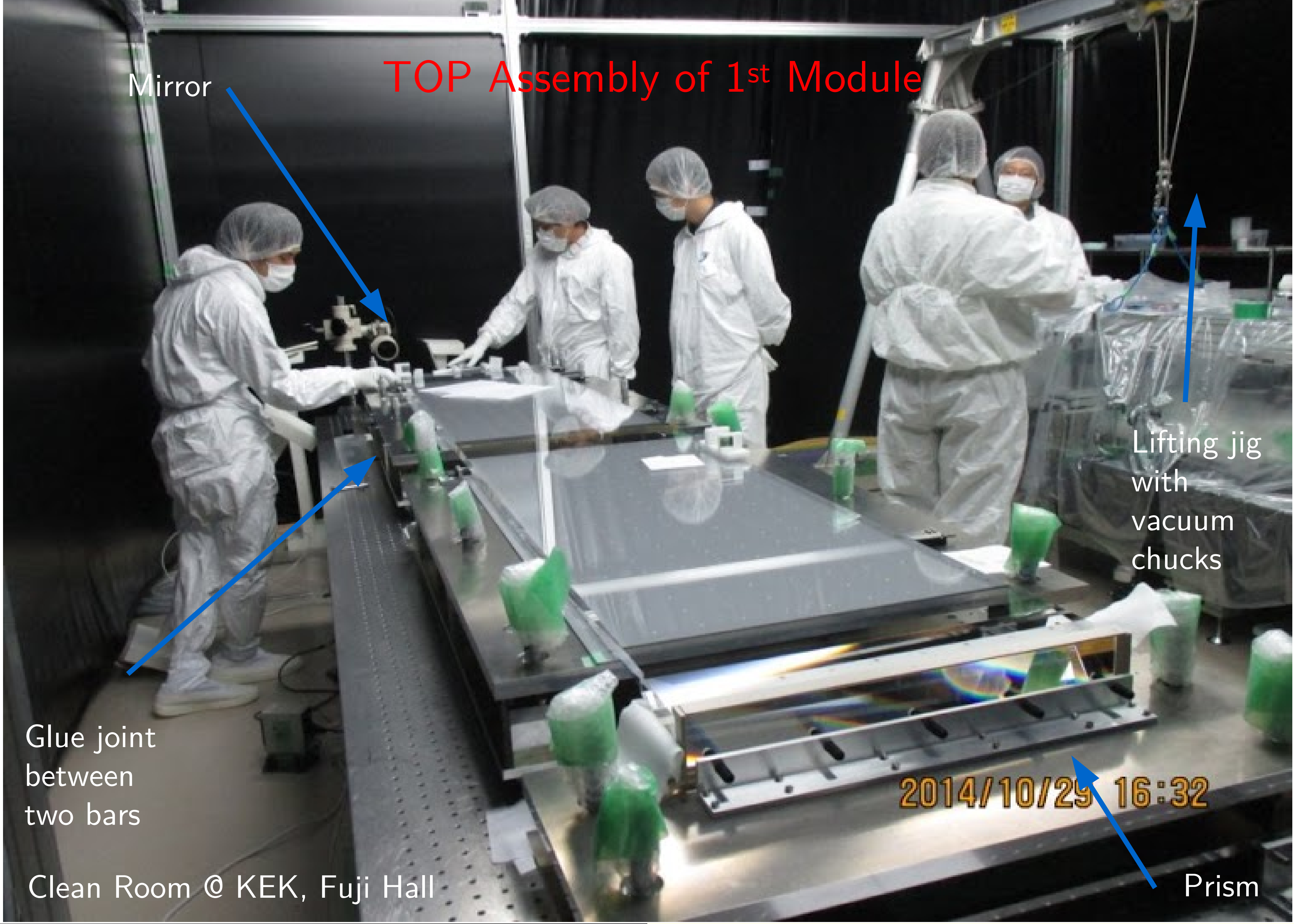
reconstruct Cherenkov angle from
- (X,Y)
- time of propagation





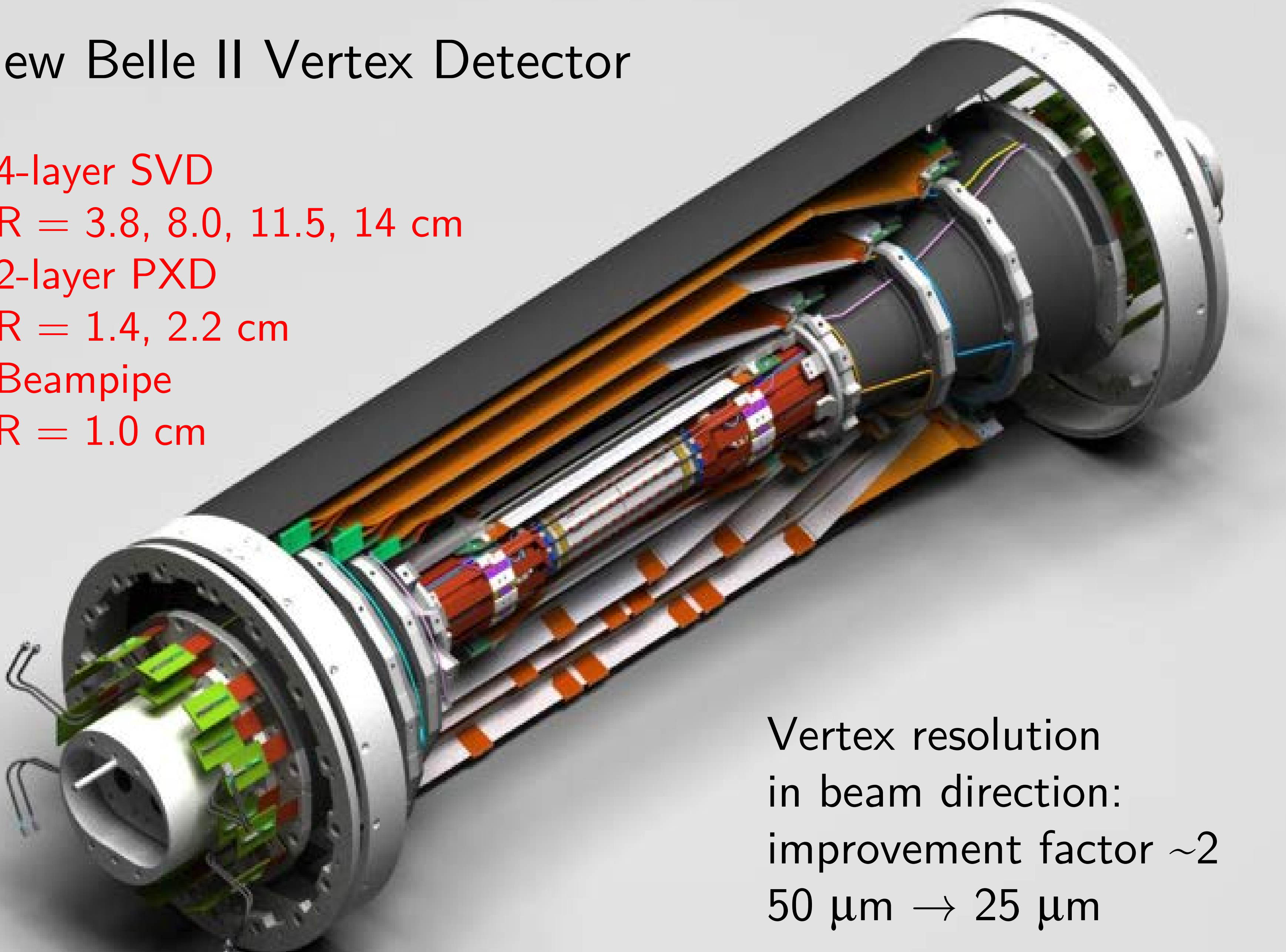
X

- Photon detector: Hamamatsu SL10 MCP-PMT
  - $\Delta t \leq 50$ ps
  - single photon sensitivity
  - operated in B=1.5 T field
- Estimated kaon fake rate factor 2-5 smaller than Belle (@ 95% kaon efficiency)

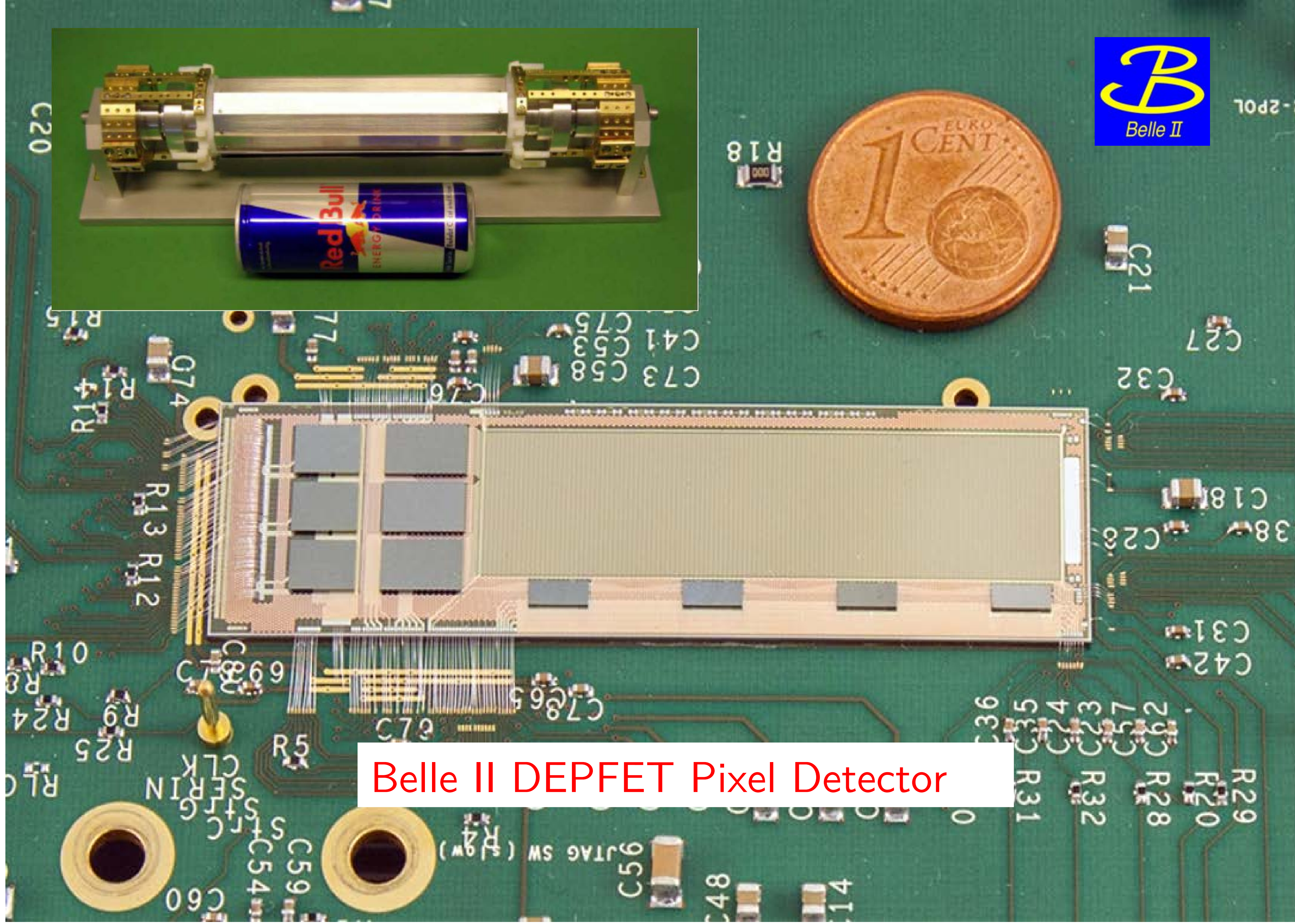

TOP Assembly of 1st Module
Mirror
Lifting jig with vacuum chucks
Glue joint between two bars
Clean Room @ KEK, Fuji Hall
Prism
2014/10/29 16:32

New Belle II Vertex Detector

- 4-layer SVD
  R = 3.8, 8.0, 11.5, 14 cm
- 2-layer PXD
  R = 1.4, 2.2 cm
- Beampipe
  R = 1.0 cm

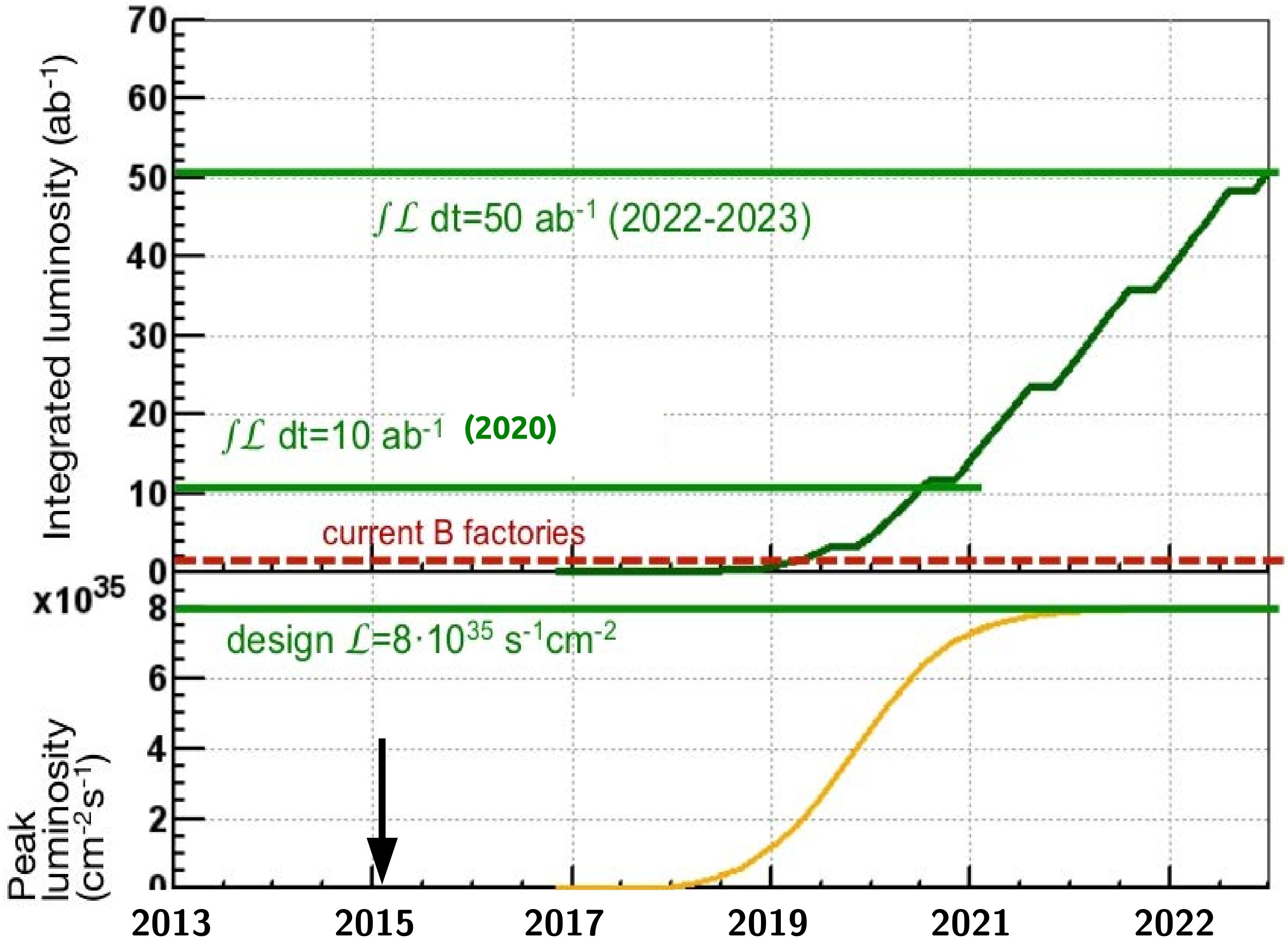


Vertex resolution
in beam direction:
improvement factor ~2
50 μm → 25 μm



Belle II DEPFET Pixel Detector

SuperKEKB Luminosity Extrapolation



SUMMARY

- Belle II envisaged start of physics data taking: 10/2017
- Test of symmetries:
  from CP to CPT and T
- CP asymmetries enable new physics search
  up to scales of $\geq 10^2$ TeV
  (in particular: right-handed currents)
- Investigation of
  - Z^+ in B meson decays
  - Z^+ in initial state radiation

  in same experiment with high statistics

BACKUP

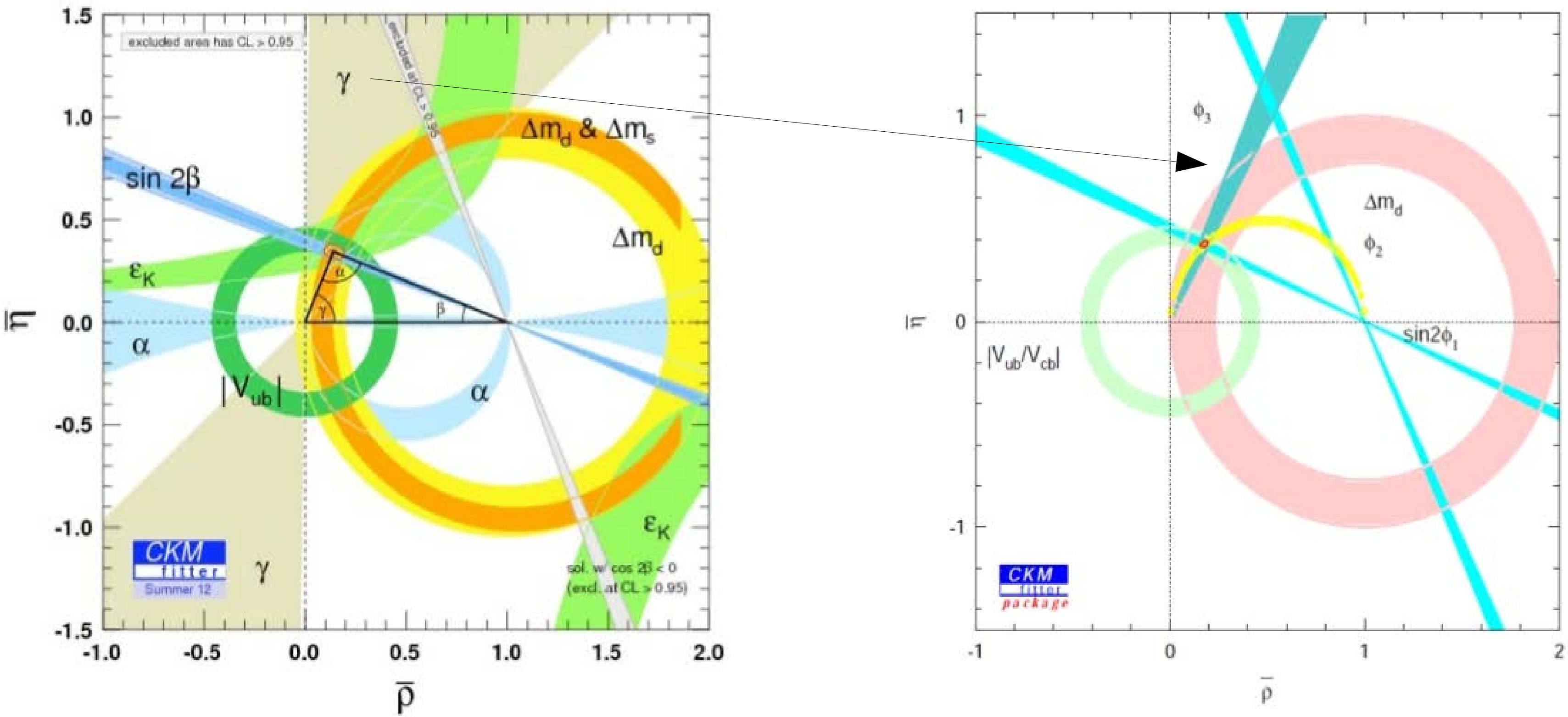
Unitarity Triangle – Present and Future

Belle and BaBar (2012, $\sim$1 ab^{-1}))

Super KEKB Letter of Intent, 2004

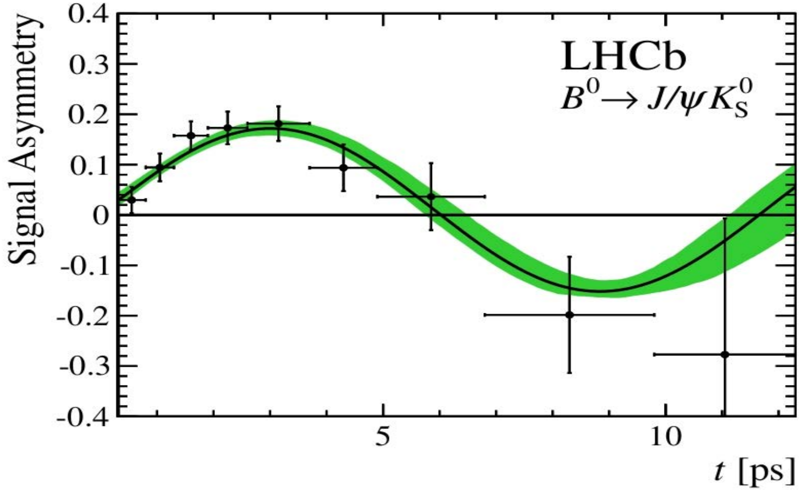
Belle II

Expected constraint at 50 ab^{-1}



phi1 old guess 0.014, recent estimate 0.010
phi2 old 0.9 deg (with rho phi), recent estimate also about 1 deg (rhorho dominated)
phi3 old 1.2 deg, recent estimate 1-1.5 deg
Vub old 4.4% (inclusive), recent estimate 3% inclusive and 2.5% exclusive

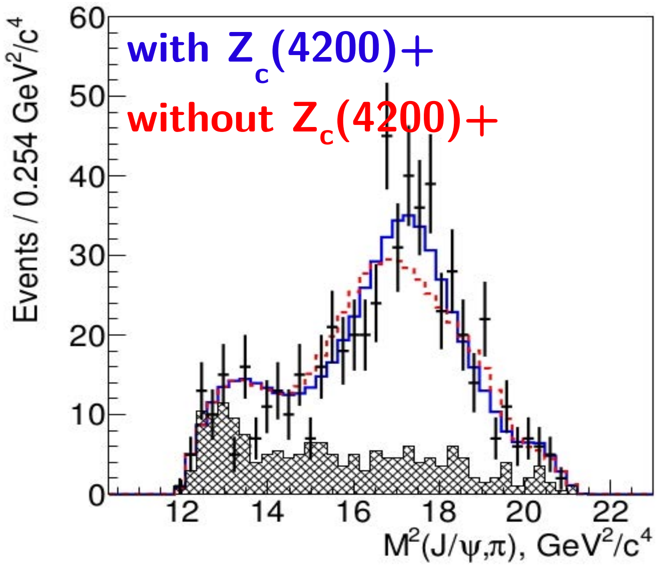
Precision Measurement of sin(2β) at LHCb



LHCb, Phys. Lett. B 721 (2013) 24
$\sqrt{s}$=7 TeV, 1.0 fb^{-1}
S=0.73 ± 0.07 (stat) ± 0.04 (syst)
stat. error factor ~3 larger than Belle and BaBar (combined)
syst. error factor ~40 larger than Belle and BaBar (combined)

New 2014: $Z_c(4200)^+$ in $[J/\psi\pi^\pm]$

Belle, arXiv:1408.6457[hep-ex], Phys. Rev. D90, 112009 (2014)



$$M = 4196^{+31+17}_{-29-13}\ \mathrm{MeV}/c^2, \quad \Gamma = 370^{+70+70}_{-70-132}\ \mathrm{MeV}$$

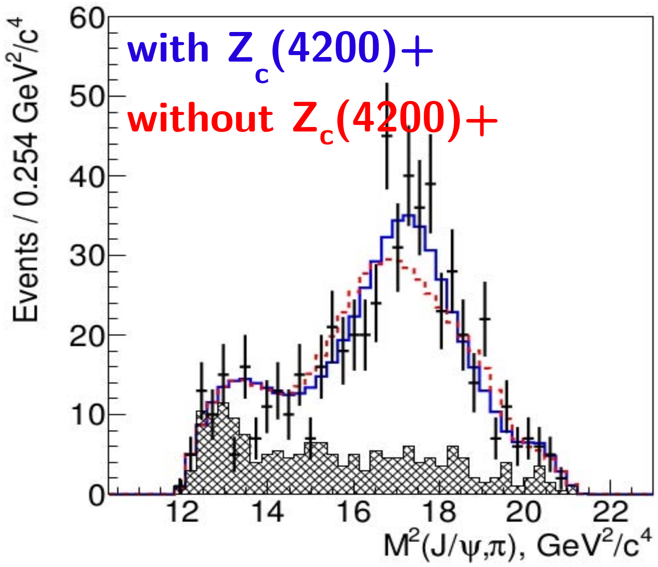
$Z_c(4200)^+$

TABLE I. Fit results in the default model. Errors are statistical only.

J^P	0^-	1^-	1^+	2^-	2^+
Mass, MeV/c^2	4318 ± 48	4315 ± 40	4196^{+31}_{-29}	4209 ± 14	4203 ± 24
Width, MeV	720 ± 254	220 ± 80	370 ± 70	64 ± 18	121 ± 53
Significance (Wilks)	3.9σ	2.3σ	8.2σ	3.9σ	1.9σ

New 2014: $Z_c(4200)^+$ in $[J/\psi\pi^\pm]$

Belle, arXiv:1408.6457[hep-ex], Phys. Rev. D90, 112009 (2014)



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Significance (Wilks)	3.9σ	2.3σ	8.2σ	3.9σ	1.9σ

NEW 2014

Neutral Z states

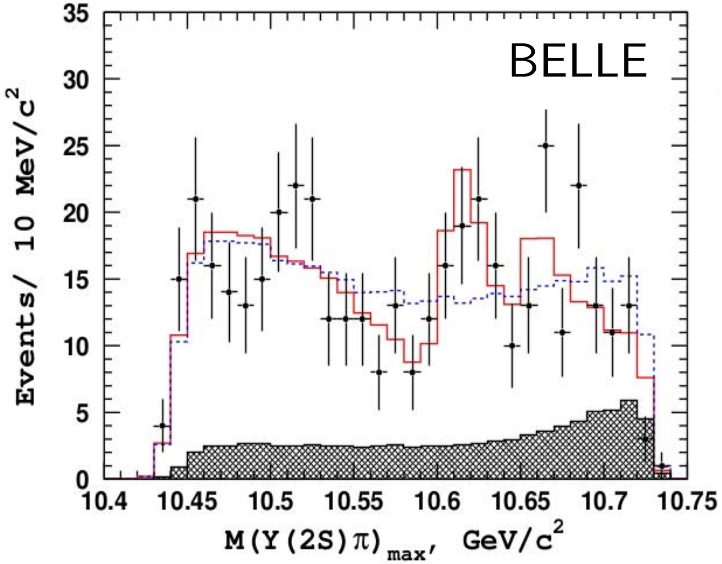
Neutral Z_b

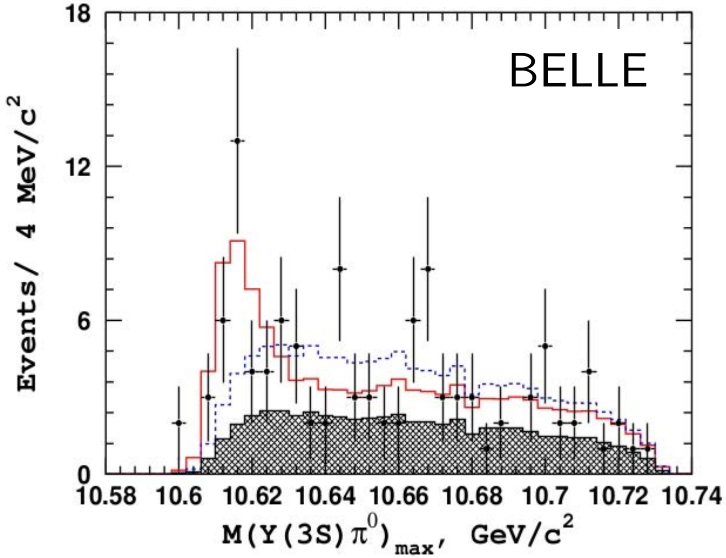
Belle, 1308.2646[hep-ex]
Phys. Rev. D88(2013)052016

121.4 fb–1 Υ(5S) decays
$Z_b(10610)^0$
decaying to $\Upsilon(2S)\pi^0$, $\Upsilon(3S)\pi^0$
significance 6.5σ

$$\sigma(e^+e^- \to \Upsilon(1S)\pi^0\pi^0) = (1.16 \pm 0.06 \pm 0.10)\,\text{pb}$$
$$\sigma(e^+e^- \to \Upsilon(2S)\pi^0\pi^0) = (1.87 \pm 0.11 \pm 0.23)\,\text{pb}$$
$$\sigma(e^+e^- \to \Upsilon(3S)\pi^0\pi^0) = (0.98 \pm 0.24 \pm 0.19)\,\text{pb}$$

cross sections are about factor ½ of p+p– → consistent with isospin scaling





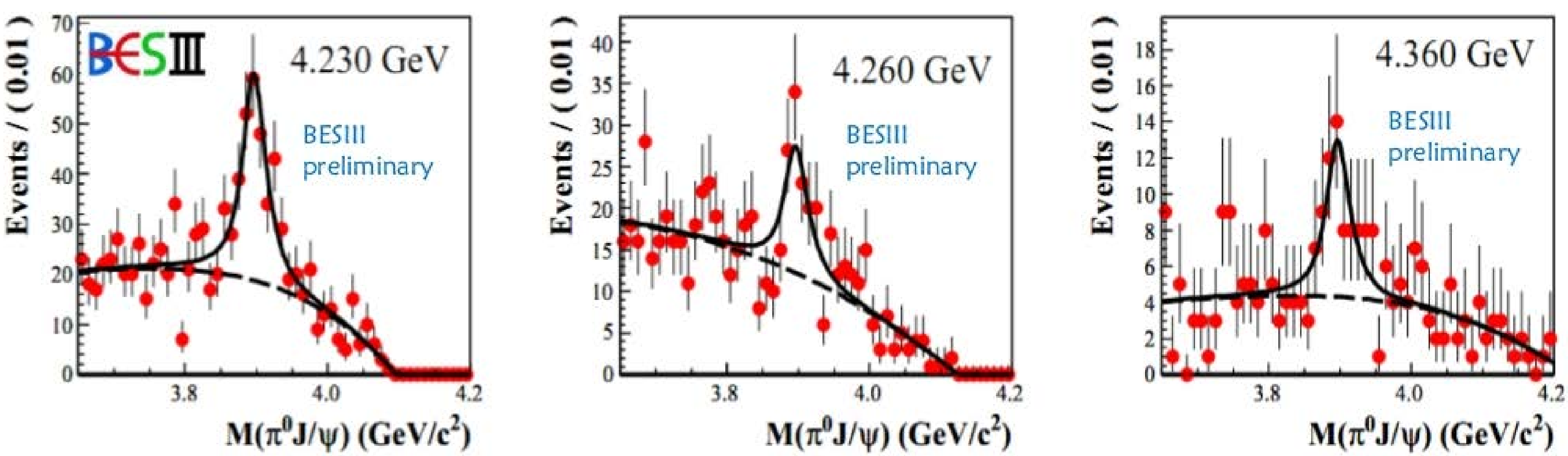
Neutral Z_b

first evidence in CLE0c data at $\sqrt{s}=4.17$ GeV (Phys. Lett. B727(2013)366)

BESIII preliminary, QWG2014

$e+e- \rightarrow J/\psi\pi^0\pi^0$
m=3894.8±2.3±2.7 MeV
Γ=29.6±8.2±8.2 MeV
significance 10.4σ

Reminder: charged Zc(3900)+
m = 3899.0±3.6±4.9 MeV
Γ = 46±10±20 MeV
arXiv:1303.5949, PRL 110(2013)252001



Notes:

- Isospin Triplet
  $\rightarrow$ these Z States are I=1

- Remember the connection
  decay Y $\rightarrow$ X, decay Y $\rightarrow$ Z

  but there is
  a neutral Z(3900) and a neutral X(3872),
  and they are different
  (width >20 MeV vs. width <1 MeV)

2nd neutral Z_c, near $D^*\overline{D}^*$ threshold

BESIII 1409.6577[hep-ex], Phys. Rev. Lett. 113, 212002 (2014)

$e^+e^- \rightarrow h_c\ \pi^0\pi^0$

hc $\rightarrow \gamma\, \eta_c$ with 16 reconstructed η_c decay channels

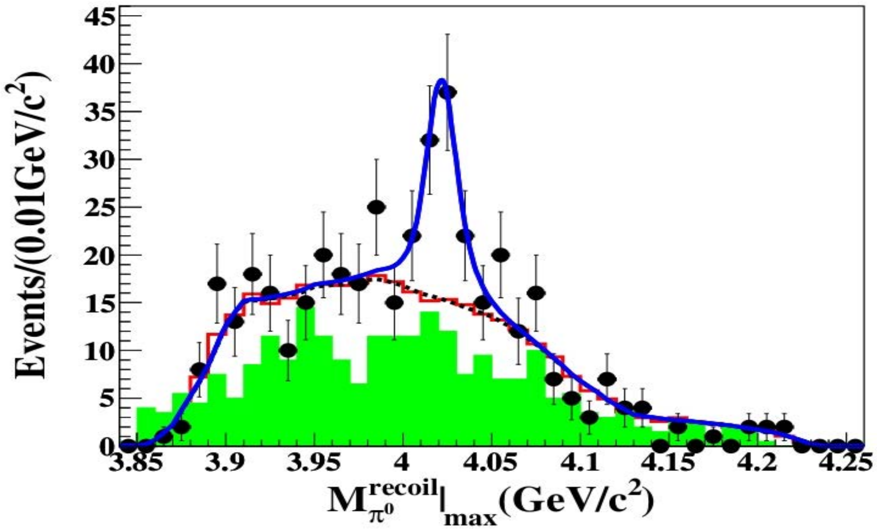
$Z_c(4020)^0$

$>5\sigma$

m=4023.9±2.2±3.8 MeV

no width measurement

width is fixed to charged Z



Isospin in $Z_c(4020)^0$ production

BESIII, 1409.6577[hep-ex], Phys. Rev. Lett. 113(2014)212002

$$\frac{\sigma(e^+e^- \to \pi^0\pi^0 h_c)}{\sigma(e^+e^- \to \pi^+\pi^- h_c)}$$

$\sqrt{s}$ (GeV)	$\mathcal{R}_{\pi\pi h_c}$
4.230	$0.54 \pm 0.11 \pm 0.06$
4.260	$0.63 \pm 0.14 \pm 0.10$
4.360	$0.73 \pm 0.14 \pm 0.10$

→ ratio ½, as expected from isospin scaling (similar to Y(nS) transitions)

$$\frac{\sigma(e^+e^- \to \pi^0 Z_c(4020)^0 \to \pi^0\pi^0 h_c)}{\sigma(e^+e^- \to \pi^\pm Z_c(4020)^\mp \to \pi^\pm\pi^\mp h_c)}$$

$\sqrt{s}$ (GeV)	$R_{\pi Z_c(4020)}$
4.230	$0.77 \pm 0.31 \pm 0.25$
4.260	$1.21 \pm 0.50 \pm 0.38$
4.360	$1.00 \pm 0.48 \pm 0.32$

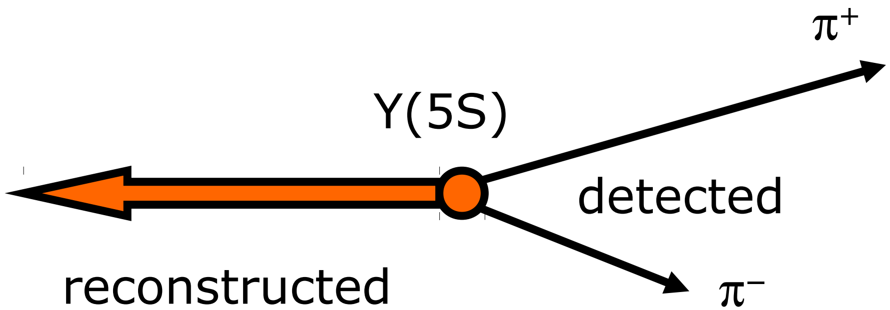
→ ratio closer to ~1 (?) (but ½ not excluded)

Z_b^+ in Υ(5S) decays

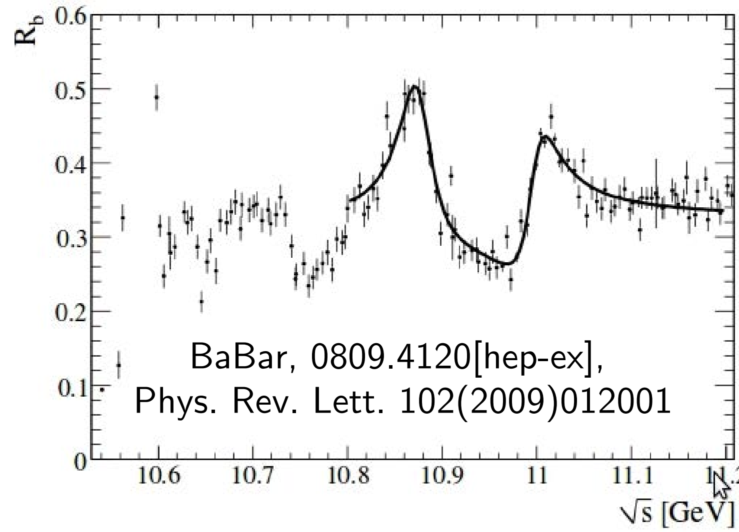
- Υ(5S)
  → adjust accelerator to $\sqrt{s}$=10.86 GeV

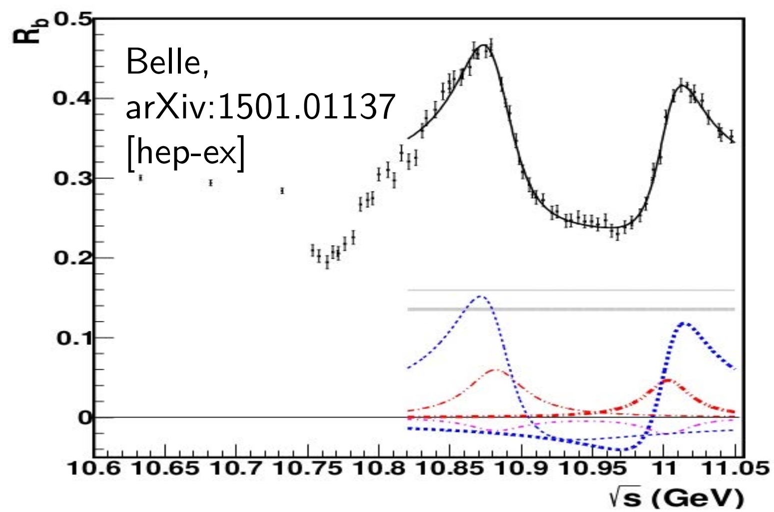
- „Υ(5S)“ maybe exotic itself
  $\Upsilon(5S) \rightarrow \Upsilon(1S)\,\pi^+\pi^-$
  factor ≥10^3 higher than expected

- Missing mass technique
  unique for e+e–
  (initial state precisely known)



$$M_{\rm miss}(X) = \sqrt{(E_{\rm c.m.} - E_X^*)^2 - p_X^{*2}}$$





Upsilon(5S) R_b event selection

Belle

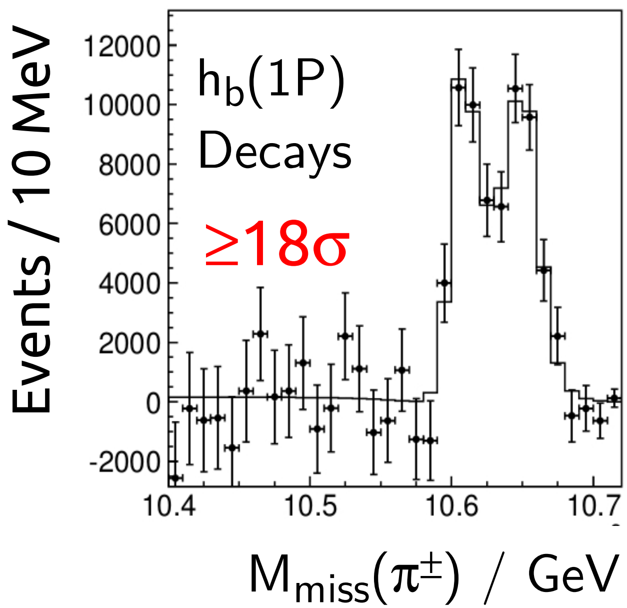
- $N_{track} \geq 3$
- one ECL cluster >100 MeV,
- total energy in the ECL between 0.1 and 0.8 x $\sqrt{s}$
- Evis > 0.5 × $\sqrt{s}$
- event vertex be within 1.5 (x) and 3.5 (y) cm of the IP
- $R_2 < 0.2$

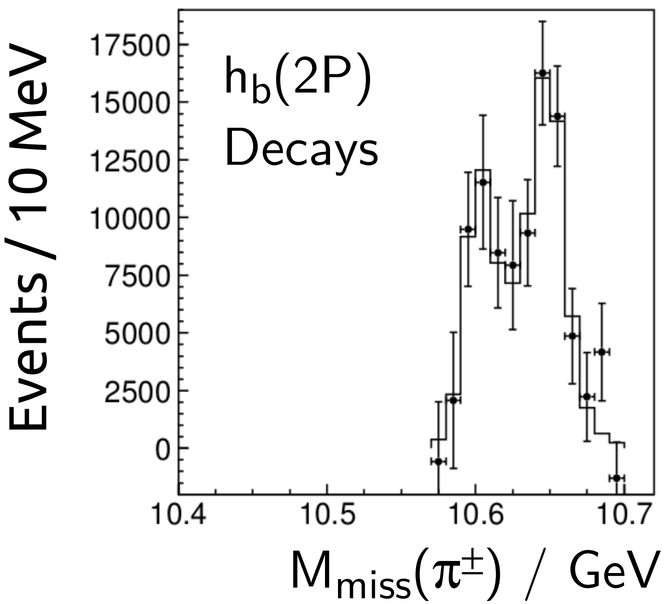
BaBar

- $N_{track} \geq 3$
- Evis>4.5 GeV
- $R_2 < 0.2$

Z_b states

$$e^+e^- \to \Upsilon(5S) \to \underbrace{h_b(mP)\pi^\pm}_{\text{resonant state?}} \pi^\mp$$





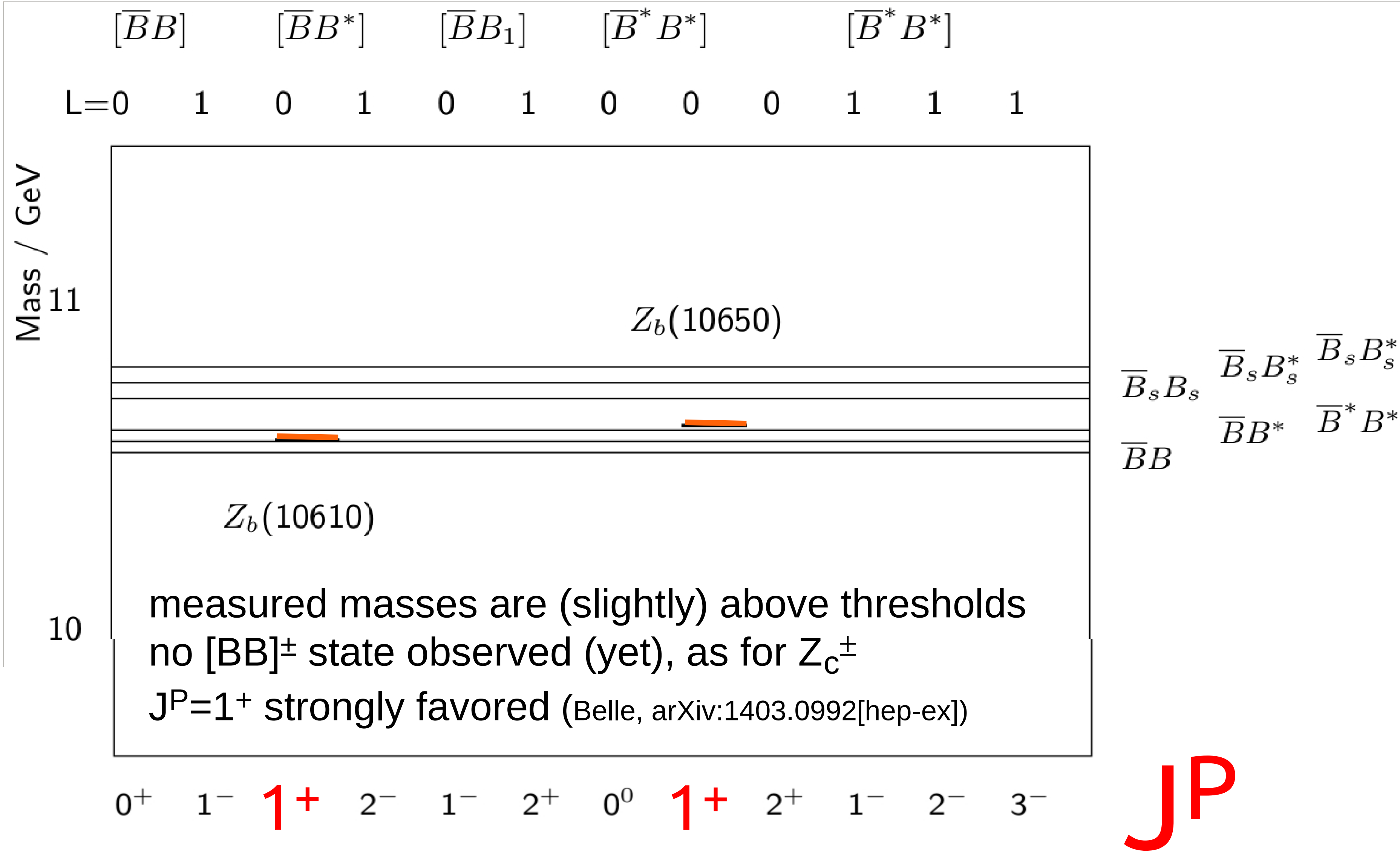
$Z_b(10610)^\pm$ $m=10607.2\pm2.0$ MeV , $\Gamma=18.4\pm2.4$ MeV

close to BB* threshold

$Z_b'(10650)^\pm$ $m=10652.2\pm1.5$ MeV , $\Gamma=11.5\pm2.2$ MeV

close to B*B* threshold

Spectrum of Z_b^+ states



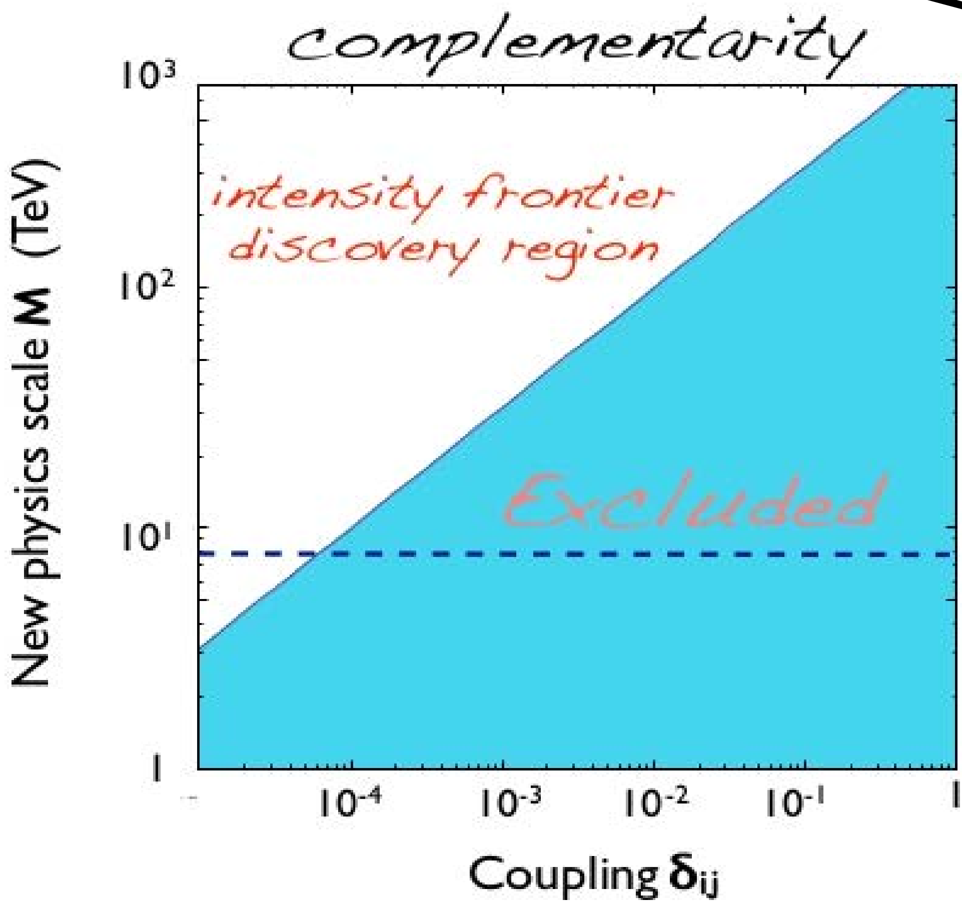
measured masses are (slightly) above thresholds

no $[BB]^\pm$ state observed (yet), as for $Z_c^\pm$

$J^P=1^+$ strongly favored (Belle, arXiv:1403.0992[hep-ex])

Belle II Search for New Physics

$$\Delta_{NP} = (\text{exp.} - \text{SM}) \pm \sqrt{(\sigma_{exp})^2 + (\sigma_{SM})^2}$$
$$= c/(M_{NP})^{n=2}$$



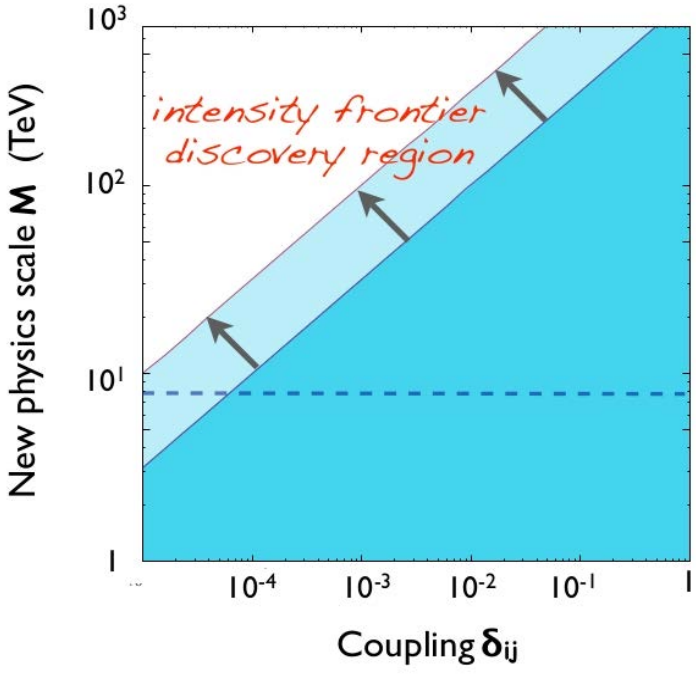
n=2
for box diagram
(e.g. $B^0\overline{B}^0$ mixing)

LHC direct search

E. Kou, Belle II Open Meeting 11/2014

$$\Delta_{NP} = (\text{exp.} - \text{SM}) \pm \sqrt{(\sigma_{exp})^2 + (\sigma_{SM})^2}$$

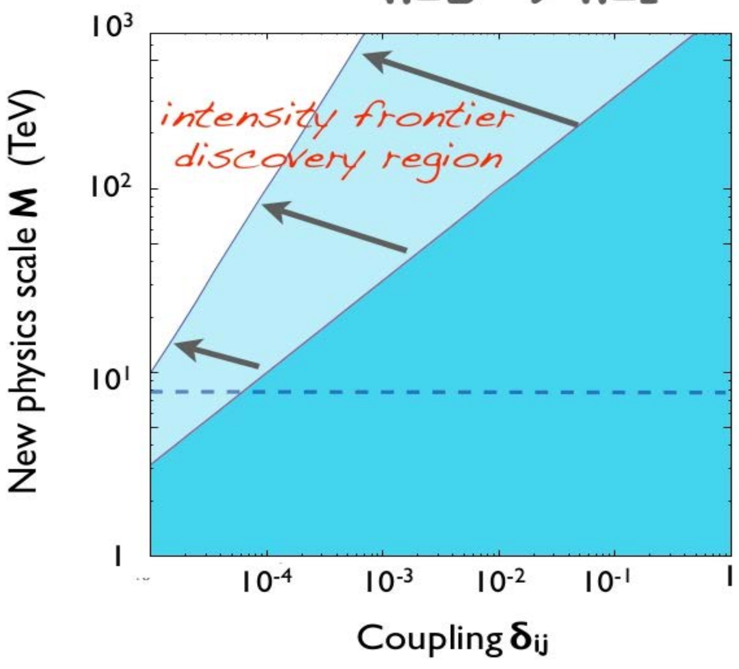
→ improve stat. and syst. errors



new detectors (PXD, TOP), reduce hadronic uncertainties (lattice QCD), ...

$$\Delta_{NP} = c/(M_{NP})^n$$

→ find decays with smaller n



e.g. penguin decays
n=1 for $b \to s\gamma$
m>~10^6 TeV in reach

E. Kou, Belle II Open Meeting 11/2014

Bounds on M_{NP} (or scale Λ) based upon existing data

Open Symposium on the European Strategy for Particle Physics
Isidori, Teubert, arXiv:1402.2844[hep-ph]

$M_{NP} \geq 140$ TeV (standard left-handed CKM couplings)

Operator	Bounds on Λ in TeV ($c_{NP}=1$) Re	Im	Bounds on c_{NP} ($\Lambda = 1$ TeV) Re	Im	Observables
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p \rvert_D$, ϕ_D
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	
$(\bar{b}_L \gamma^\mu d_L)^2$	6.6×10^2	9.3×10^2	2.3×10^{-6}	1.1×10^{-6}	Δm_{B_d}; $\sin(2\beta)$ from $B_d \to \psi K$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	2.5×10^3	3.6×10^3	3.9×10^{-7}	1.9×10^{-7}	
$(\bar{b}_L \gamma^\mu s_L)^2$	1.4×10^2	2.5×10^2	5.0×10^{-5}	1.7×10^{-5}	Δm_{B_s}; $\sin(\phi_s)$ from $B_s \to \psi\phi$
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	4.8×10^2	8.3×10^2	8.8×10^{-6}	2.9×10^{-6}	

Table 1. Bounds on representative dimension-six $\Delta F = 2$ operators [96, 97]. The bounds on Λ are evaluated assuming an effective coupling $1/\Lambda^2$ (i.e. setting $c_{NP} = 1$). Alternatively, the bounds on the respective c_{NP} are obtained assuming $\Lambda = 1$ TeV. In the last column we list the observables used to set such bounds; the observables related to CPV are separated from the CP conserving ones with semicolons.

Isidori, Teubert, arXiv:1402.2844[hep-ph]

→ Λ_{NP} scales with at most $N^{1/4}$,

where N is relative increase of number of events

1 ab^{-1} → 50 ab^{-1} ($50^{0.25} = 2.65$)

e.g. Λ_{NP}=100 TeV (Belle) → 265 TeV (Belle II)

If physics beyond the SM respects the SM gauge symmetry, as we expect from general arguments, the low-energy amplitudes describing the transition of a fermion ψ_i to a fermion ψ_j (of different flavour) can be decomposed in the following general form

$$\mathcal{A}(\psi_i \to \psi_j + X) = \mathcal{A}_0 \left[\frac{c_{\rm SM}}{M_W^2} + \frac{c_{\rm NP}}{\Lambda^2} \right] , \qquad (16)$$

where Λ is the energy scale of the new degrees of freedom and the SM result is recovered in the limit $c_{\rm NP} \to 0$. This structure is completely general: the coefficients $c_{\rm SM(NP)}$ may include appropriate CKM coefficient factors and eventually a $\sim 1/(16\pi^2)$ suppression if the amplitude is loop-mediated. Given our ignorance about the $c_{\rm NP}$ coefficients, the values of the scale Λ probed by present experiments vary over a wide range. However, the general result in Eq. (16) allows us to predict how these bounds will improve with future experiments: increasing the statistic on a given observable, the corresponding bound on Λ scales at most as $N^{1/4}$, where N is the relative increase in the number of events used to measure the observable.[2] From Eq. (16) it is also clear that indirect searches can probe NP scales well above the TeV for models where ($c_{\rm SM} \ll c_{\rm NP}$), namely models which do not respect the symmetries and the symmetry-breaking pattern of the SM.

Direct searches for W' at LHC (lljj)

ATLAS, arXiv:1203.5420[hep-ex], 2.1 fb^{-1}, $\sqrt{s}=7$ TeV
mass WR $<$ 2.3 TeV
(under some conditions)

CMS, arXiv:1407.3683[hep-ex], 19.7 fb^{-1}, $\sqrt{s}=8$ TeV
2.87 TeV (3.00 TeV) for electron (muon)

Yu, Kou, Lü, arXiv:1305.3173 [hep-ph], JHEP12(2013)102

$$S_{K_S\pi^0\gamma} \simeq \frac{-2Re\left[C'_{7\gamma}/C_{7\gamma}\right]\sin 2\beta + 2Im\left[C'_{7\gamma}/C_{7\gamma}\right]\cos 2\beta}{1 + Re\left[C'_{7\gamma}/C_{7\gamma}\right]^2 + Im\left[C'_{7\gamma}/C_{7\gamma}\right]^2}$$

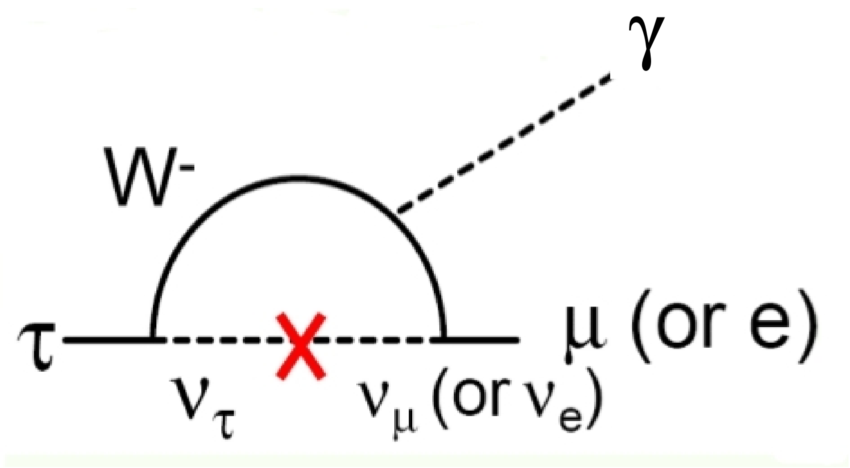
$$|C'_{7\gamma}/C_{7\gamma}|$$

=0.5 for right-handed M_w=2.0 TeV
=0.3 for right-handed M_w=2.5 TeV

Lepton Flavor Violation

flavor changing neutral currents in the lepton sector

Lepton flavour violation in τ decays



SM predictions are small

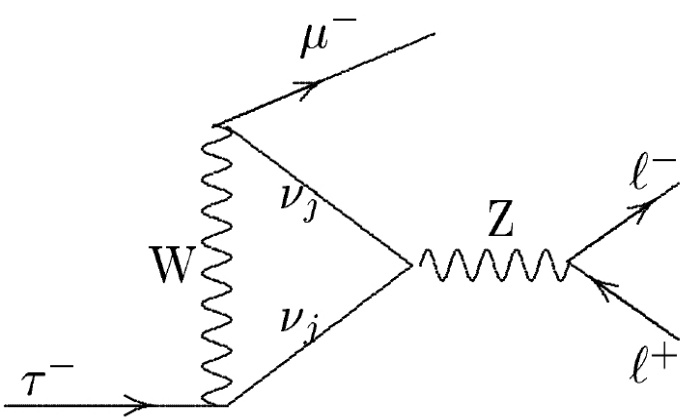
$Br(\tau \rightarrow \text{lepton } \gamma) \sim 10^{-54}$

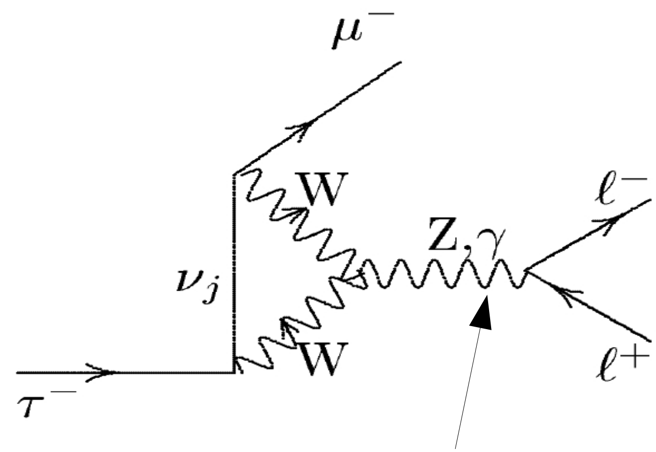
$Br(\tau \rightarrow 3 \text{ leptons}) \sim 10^{-14}$

SM predictions are small

Br(τ → lepton γ) ~ 10^{-54}

Br(τ→ 3 leptons) ~ 10^{-14}





photon only here (requires electrical charge of W bosons)

CKM Matrix and PMNS Matrix

CKM: (quarks)

1	0	0	→	1.0	0.2	0.0
0	1	0		0.2	1.0	0.0
0	0	1		0.0	0.0	1.0

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 0.97427 \pm 0.00014 & 0.22536 \pm 0.00061 & 0.00355 \pm 0.00015 \\ 0.22522 \pm 0.00061 & 0.97343 \pm 0.00015 & 0.0414 \pm 0.0012 \\ 0.00886^{+0.00033}_{-0.00032} & 0.0405^{+0.0011}_{-0.0012} & 0.99914 \pm 0.00005 \end{pmatrix}$$

PMNS: (neutrinos)

1	1	0		0.8	0.5	−0.2
0	1	1	→	−0.3	0.7	0.6
0	0	1		0.4	−0.4	0.8

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 0.817 & 0.557 & -0.149 e^{-i\delta} \\ -0.413 - 0.084 e^{i\delta} & 0.605 - 0.057 e^{i\delta} & -0.673 \\ -0.383 + 0.090 e^{i\delta} & 0.562 + 0.061 e^{i\delta} & 0.725 \end{pmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

F. Potter, Prog. Phys. 10(2014)146

Why SM + m_ν prediction is so small ?

$$Br(\tau \to \mu\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=1,2} U^*_{\tau i} U_{\mu i} \frac{\Delta m^2_{li}}{m^2_w}\right|^2 < 10^{-54}$$

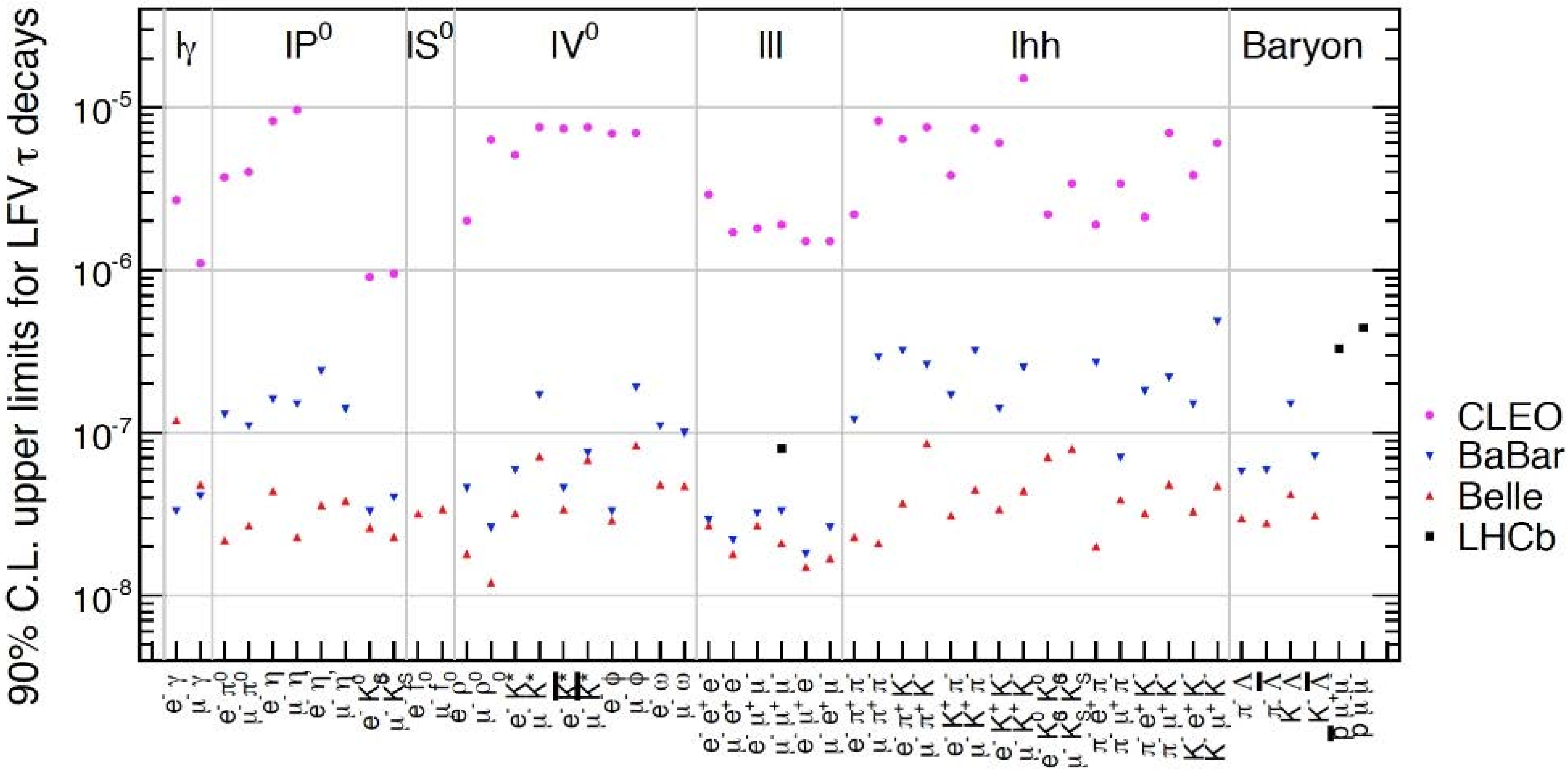
U : PMNS neutrino mixing matrix

$\Delta m^2_{ij} = m^2_{\nu i} - m^2_{\nu j}$:Neutrino mass square difference

-Lepton Flavor is conserved accidentally.

T. Iljima, TAU2014

Lepton Flavour Violating Tau Decays

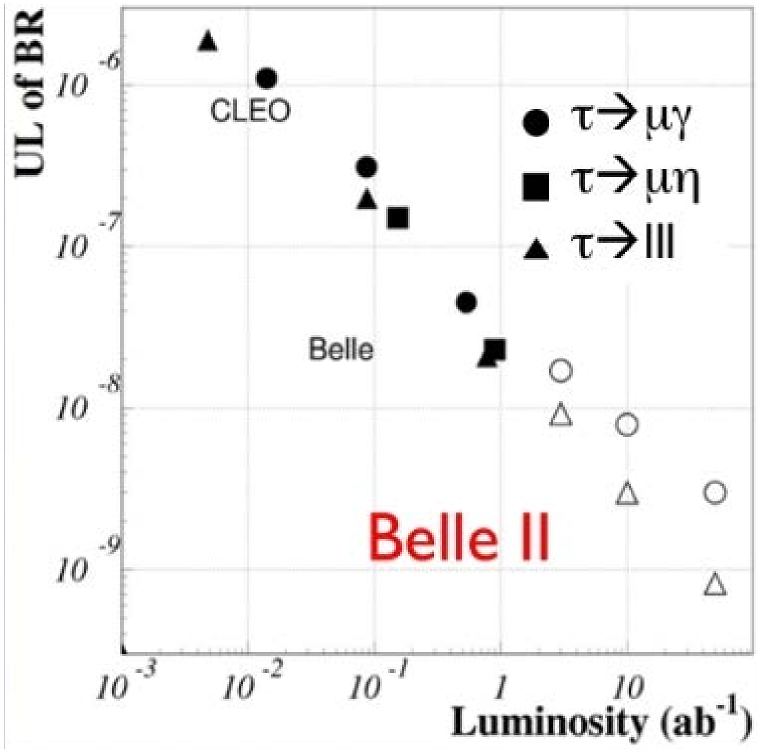


Future prospects for LFV in t decays

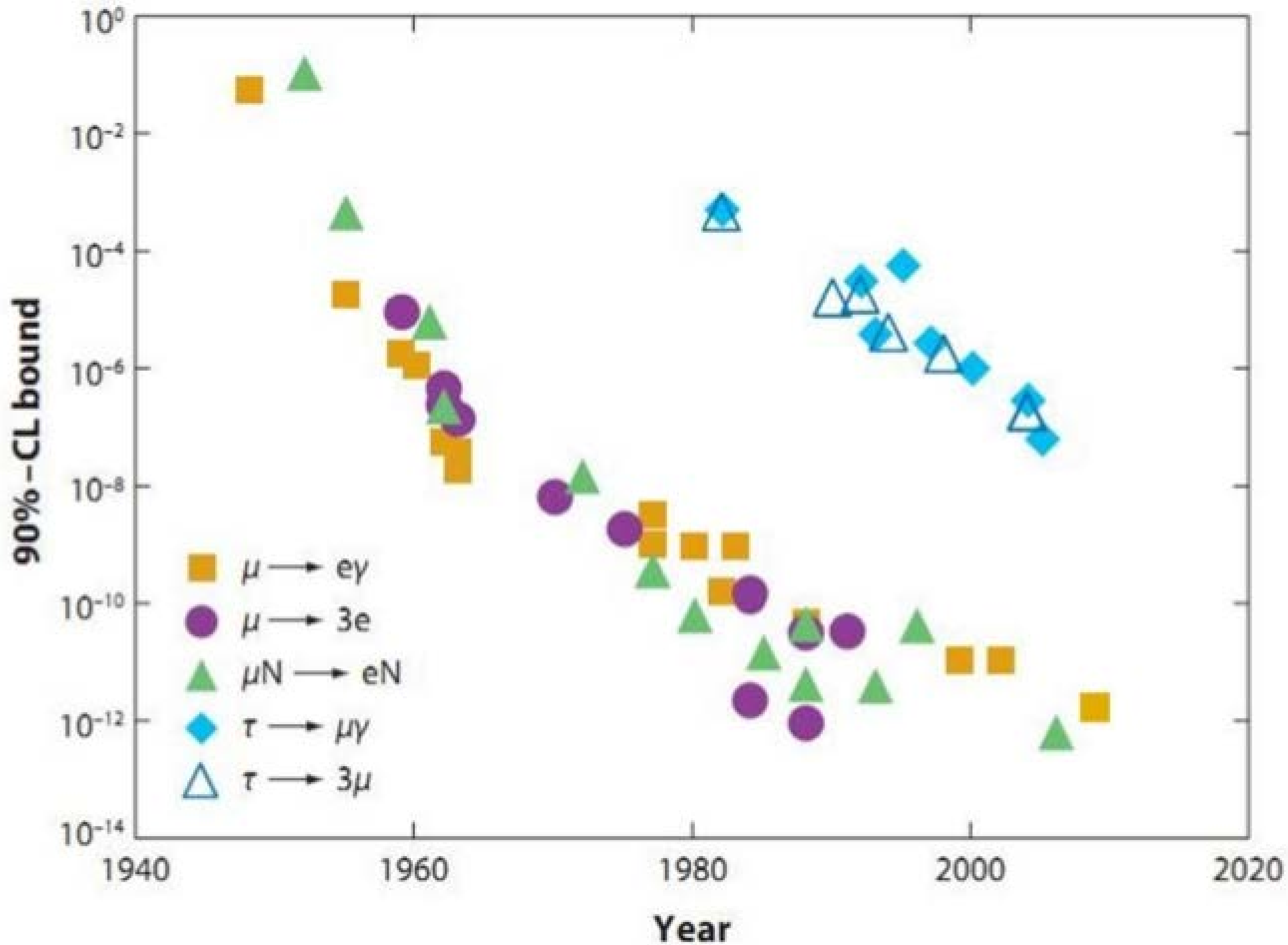
Sensitivity extrapolation

$\tau \to \mu\gamma$
BG non-free
$\sim 1/\sqrt{N_\tau}$
expected limit
$B(\mu\gamma) \sim O(10^{-9})$

$\tau \to \mu\mu\mu$
BG free
$\sim 1/N_\tau$
expected limit
$B(\mu\mu\mu) \sim O(10^{-9})–O(10^{-10})$
LHCb may also be able to reach $O(10^{-9})$ with 10 fb^{-1}



5.7 x 10^−13
MEG, Phys.Rev.Lett. 110 (2013) 201801
but scales

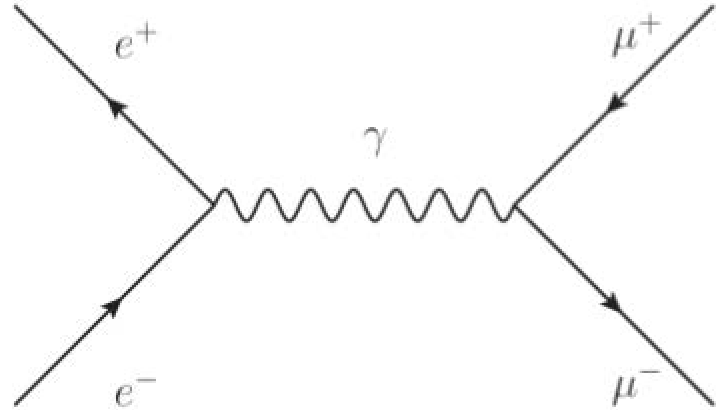


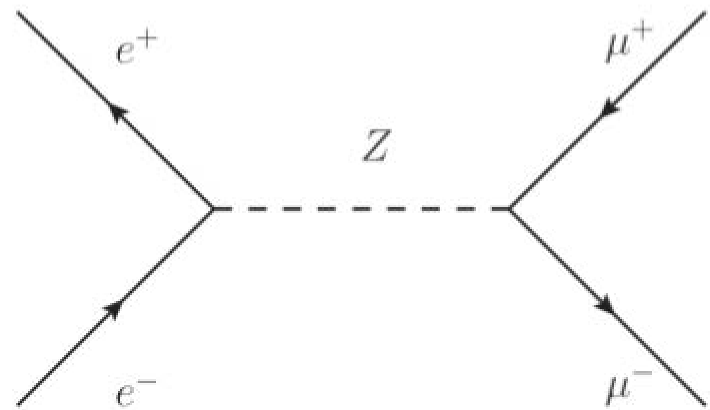
MEG Upgrade Proposal, arXiv:1301.7225[hep-ex]

A_{FB}
(weak mixing angle)

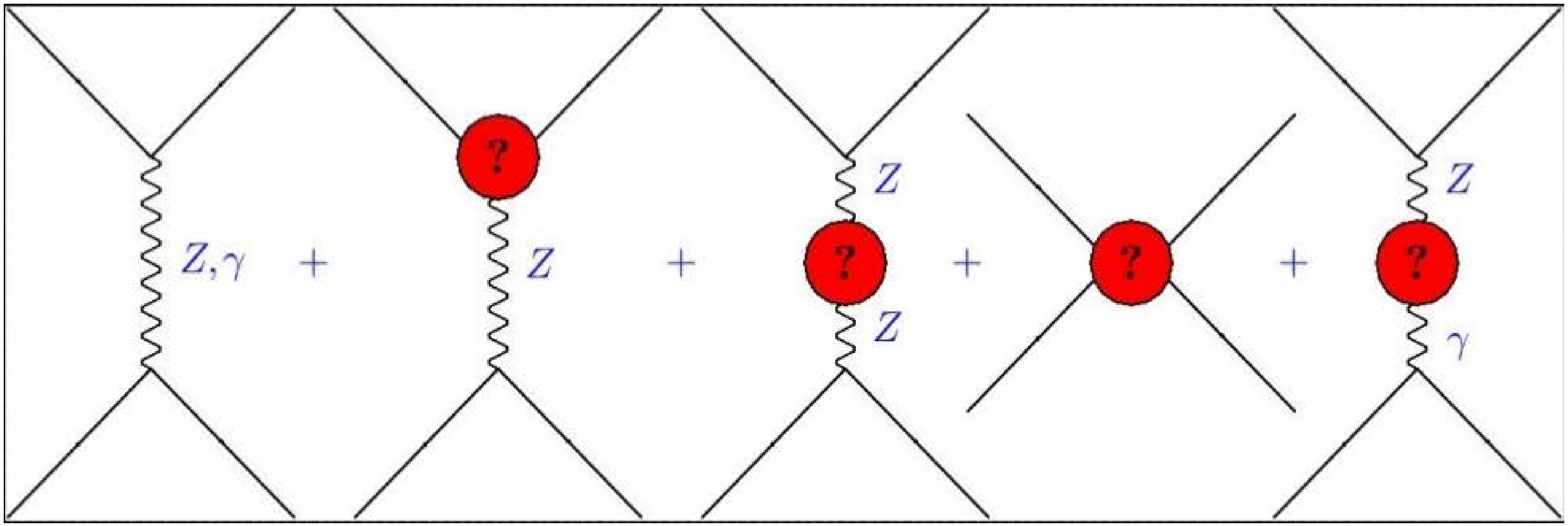
Electroweak Unification

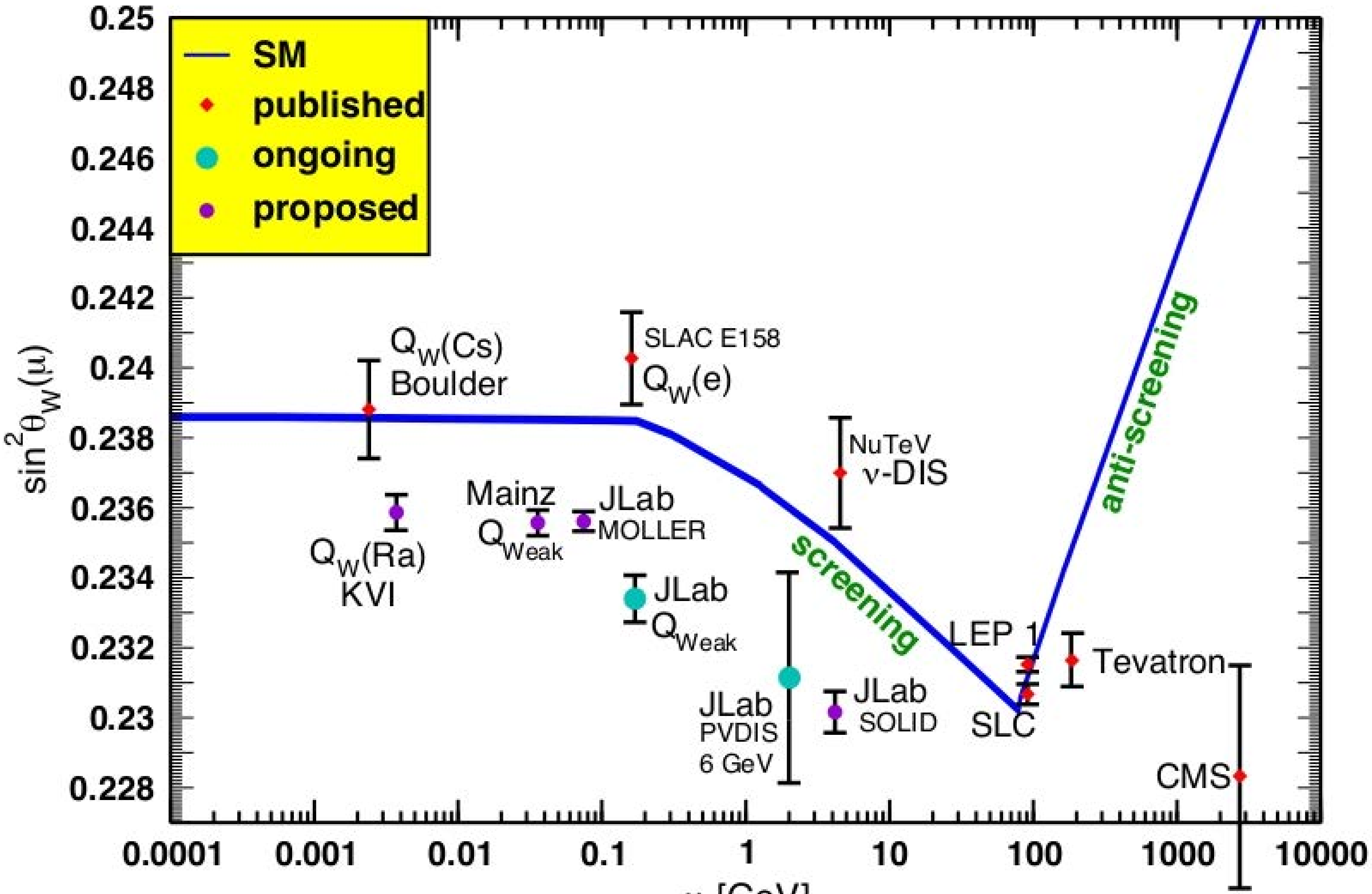
$$\begin{pmatrix} \gamma \\ Z^0 \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} B^0 \\ W^0 \end{pmatrix}$$





Possible new physics (NP) contributions





J. Erler, arXiv:1209.3324[hep-ph]

Forward-Backward Asymmetry in e+e− → μ+μ−

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4s}(C_1(1+\cos^2\Theta^*) + C_2\cos\Theta^*) \qquad A_{FB} = \frac{3C_2}{8C_1} = -\frac{3}{2}\chi$$

$$C_1 = 1 + 2v_e v_\mu \chi + (v_e^2 + a_e^2)(v_\mu^2 + a_\mu^2)\chi^2 \quad v_\mu$$

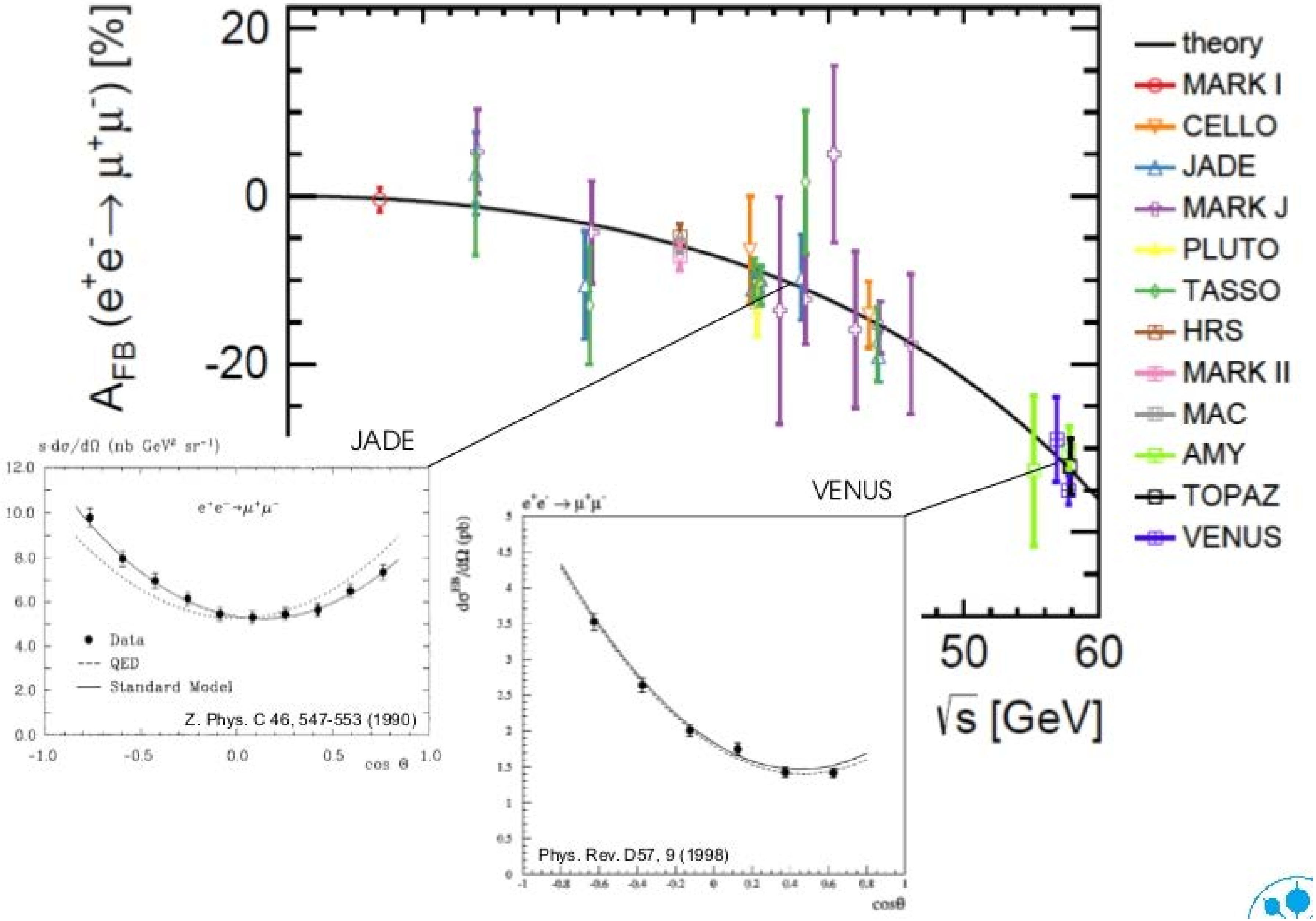
$$C_2 = -4a_e a_\mu \chi + 8v_e a_e a_\mu \chi^2$$

at Belle II energies,
χ is small (<<1)
→ little dependence
on Weinberg angle!

$$v_{e,\mu} = -1 + 4\sin^2\Theta_W \qquad a_{e,\mu} = -1$$

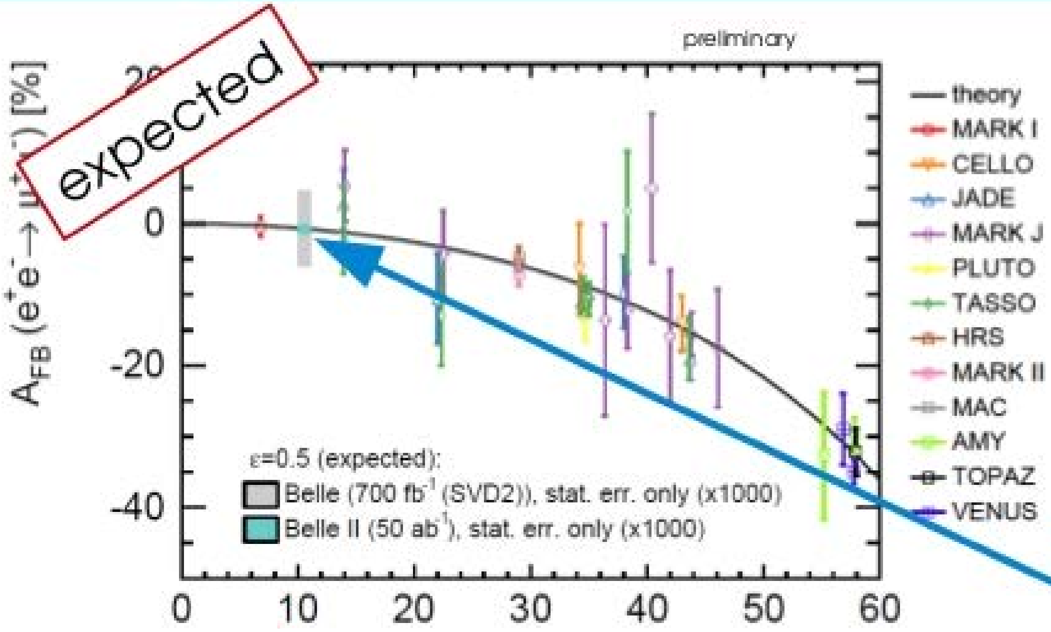
$$\chi = \frac{1}{16\sin^2\Theta_W\cos^2\Theta_W}\frac{s}{(s-M_Z^2)} = \frac{\rho G_F M_Z^2}{8\pi\alpha\sqrt{2}}\frac{s}{(s-M_Z^2)}$$

Akeroyd et al., arXiv:1002.5012[hep-ex[



$A_{FB}(e^+e^- \to \mu^+\mu^-)$ [%]
20
0
-20
50
60
$\sqrt{s}$ [GeV]
theory
MARK I
CELLO
JADE
MARK J
PLUTO
TASSO
HRS
MARK II
MAC
AMY
TOPAZ
VENUS
JADE
s·dσ/dΩ (nb GeV² sr⁻¹)
$e^+e^- \to \mu^+\mu^-$
Data
QED
Standard Model
Z. Phys. C 46, 547-553 (1990)
cos θ
VENUS
$e^+e^- \to \mu^+\mu^-$
Phys. Rev. D57, 9 (1998)
cosθ

Measurement of A_{FB}



$$A_{FB}(s) \approx \rho \frac{3G_F}{4\sqrt{2}\pi\alpha} \frac{sM_Z^2}{s - M_z^2} g_A^e g_A^\mu$$

stat. errors are x1000 (otherwise not visible)

Belle 2: $\sigma_{stat}(A_{FB})/A_{FB} \approx 0.1\%$

Limit on new physics → contact interaction ansatz

$$\mathcal{L}_{eq} = \left[\frac{G_F}{\sqrt{2}} g_{VA}^{eq}(\mathrm{SM}) + \frac{g^2}{\Lambda^2} \right] \bar{e}\gamma_\mu e \, \bar{q}\gamma^\mu\gamma^5 q$$

Belle II will reach Λ<33 TeV

2.2 Oscillation Phenomenology

An unstable meson can be described by the non-relativistic Schrödinger equation $i\partial_t\psi = (m - \frac{i}{2}\Gamma)\psi$, with the solution

$$|\psi\rangle = |\psi_0\rangle e^{-imt} e^{-\frac{1}{2}\Gamma t} \tag{2.15}$$

which reproduces the exponential law of radioactive decay, since $|\psi_0|\psi\rangle|^2 = e^{-\Gamma t}$.

The four meson pairs $K^0/\overline{K}^0$, $D^0/\overline{D}^0$, $B^0/\overline{B}^0$, and $B_s/\overline{B}_s$ can be described as decaying two-component quantum states obeying the Schrödinger equation

$$i\partial_t\psi = \mathbf{H}\psi$$

with a general Hamiltonian

$$\mathbf{H} = \mathbf{M} - \frac{i}{2}\mathbf{\Gamma} = \begin{pmatrix} m_{11} - \frac{i}{2}\Gamma_{11} & m_{12} - \frac{i}{2}\Gamma_{12} \\ m_{12}^* - \frac{i}{2}\Gamma_{12}^* & m_{22} - \frac{i}{2}\Gamma_{22} \end{pmatrix} \tag{2.16}$$

where $\mathbf{M}$ and $\mathbf{\Gamma}$ are **hermitian**, but $\mathbf{H}$ is not [19]. If the $B^0/\overline{B}^0$ system is taken as a representative to illustrate the behaviour of oscillating meson pairs, the indices 1 and 2 correspond to base vectors $|B^0\rangle$ and $|\overline{B}^0\rangle$, respectively. These states are assumed to be normalized, i.e. $\langle\overline{B}^0|\overline{B}^0\rangle = \langle B^0|B^0\rangle = 1$.

R. Waldi, Maria Laach 1997

Oscillation Phenomenology

$$\eta_m := \frac{q}{p}$$

$$|\psi(t)\rangle = ae^{-imt-T/2}\left[\cos(x-iy)\frac{T}{2}|B^0\rangle + i\eta_m \sin(x-iy)\frac{T}{2}|\overline{B}^0\rangle\right]$$

scaled time variable

$$T := \Gamma t$$

Γ = 1/T

$$x = \frac{\Delta m}{\Gamma}, \qquad y = \frac{\Delta\Gamma}{2\Gamma} = \frac{\Gamma_H - \Gamma_L}{\Gamma_H + \Gamma_L} = \frac{\tau_L - \tau_H}{\tau_L + \tau_H}$$

CPT Parameter z

$$\mathrm{Re}\,\delta = -\frac{\mathrm{Re}\,z}{2} = \frac{m_{22} - m_{11}}{2\,\Delta m}\,, \quad \mathrm{Im}\,\delta = -\frac{\mathrm{Im}\,z}{2} = -\frac{\Gamma_{22} - \Gamma_{11}}{4\,\Delta m}$$

Eigenstates

- Mass Eigenstates

$$|B_L\rangle = p|B^0\rangle + q|\overline{B}^0\rangle$$
$$|B_H\rangle = p|B^0\rangle - q|\overline{B}^0\rangle$$

$$\delta := \langle B_H|B_L\rangle = |p|^2 - |q|^2$$

- Flavour Eigenstates

$$|B^0\rangle = \frac{1}{2p}\left(|B_L\rangle + |B_H\rangle\right)$$
$$|\overline{B}^0\rangle = \frac{1}{2q}\left(|B_L\rangle - |B_H\rangle\right)$$

- CP Eigenstates

$$|B^0_+\rangle = \frac{1}{\sqrt{2}}\left(|B^0\rangle + \mathrm{CP}\,|B^0\rangle\right), \qquad |B^0_-\rangle = \frac{1}{\sqrt{2}}\left(|B^0\rangle - \mathrm{CP}\,|B^0\rangle\right)$$

$$\mathrm{CP}\,|B^0_+\rangle = |B^0_+\rangle \text{ and } \mathrm{CP}\,|B^0_-\rangle = -|B^0_-\rangle$$

T Violation

$$\lambda = \frac{q}{p}\frac{A(\bar{B}^0 \to f)}{A(B^0 \to f)}$$

- Assuming $\Delta\Gamma=0$ (good for B_d decays)

$$C^{\pm}_{\alpha,\beta} = \frac{1-|\lambda|^2}{1+|\lambda|^2} \qquad S^{\pm}_{\alpha,\beta} = \frac{2Im\lambda}{1+|\lambda|^2}$$

$$g^{\pm}_{\alpha,\beta}(\Delta t) \propto e^{-\Gamma\Delta t}\left[1 + C^{\pm}_{\alpha,\beta}\cos(\Delta m\Delta t) + S^{\pm}_{\alpha,\beta}\sin(\Delta m\Delta t)\right]$$

$$\alpha \in \{\ell^+, \ell^-\} \qquad \beta \in \{K_S, K_L\} \text{ i.e. } CP = \pm 1$$

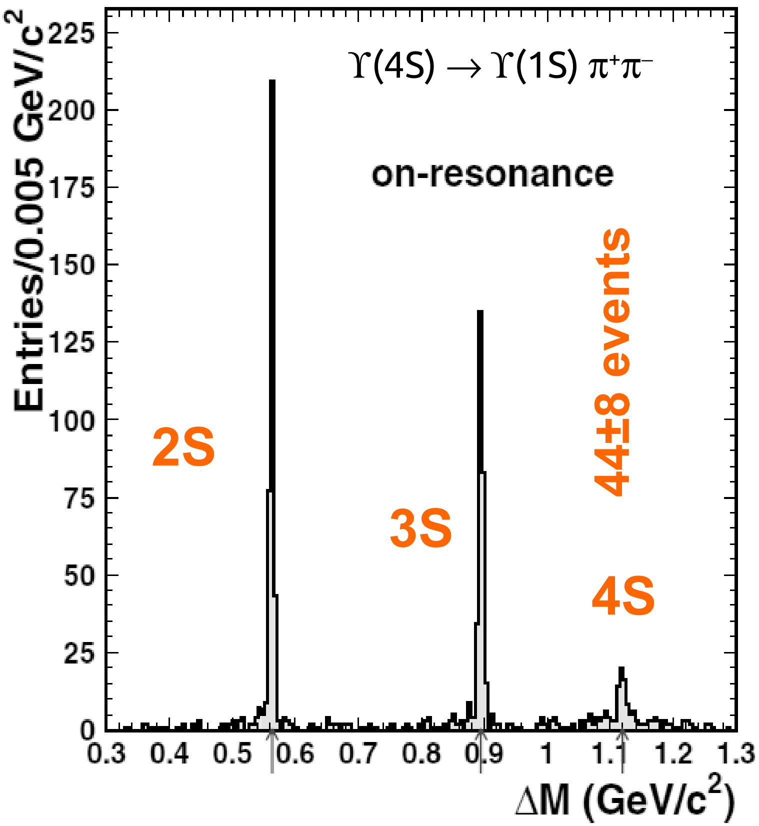
Adrian Bevan, Queen Mary University of London

CKM matrix			
$\lvert V_{us}\rvert$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\lvert V_{cb}\rvert$ $[B \to X_c \ell \nu]$	**	1%	Belle II
$\lvert V_{ub}\rvert$ $[B_d \to \pi \ell \nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K_S^0]$	***	$8 \cdot 10^{-3}$	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
$S(B_d \to K^*(\to K_S^0\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A_{SL}^d	***	0.001	LHCb
A_{SL}^s	***	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
$\lvert q/p\rvert_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

G. Isidori et al., Ann.Rev.Nucl.Part.Sci. 60, 355 (2010)
B. Golob, KEK FF Workshop, Feb. 2012

Γ[Y(5S)→ππY(nS)] is huge

Y(4S)→ππY(1S)
477 fb^{-1}

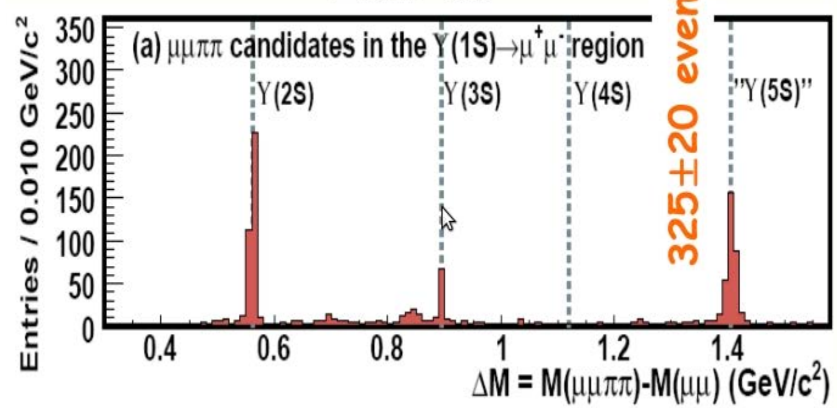


Phys. Rev. D75(2007)071103

8 times as many events integrated for Y(nS)

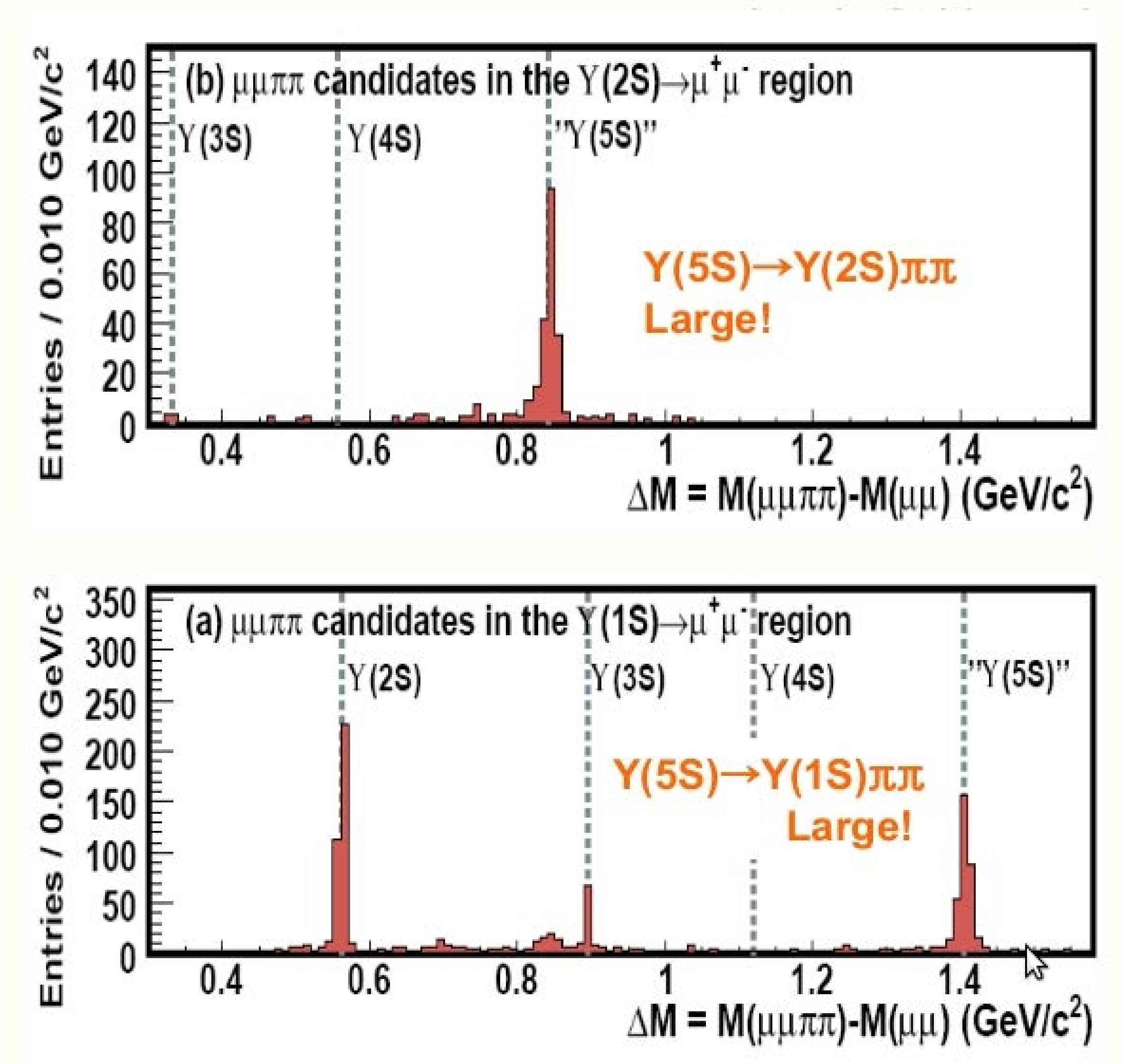
1/20 times the data & ~1/10th the crosssection

Y(5S)→ππY(1S)
21.7 fb^{-1}



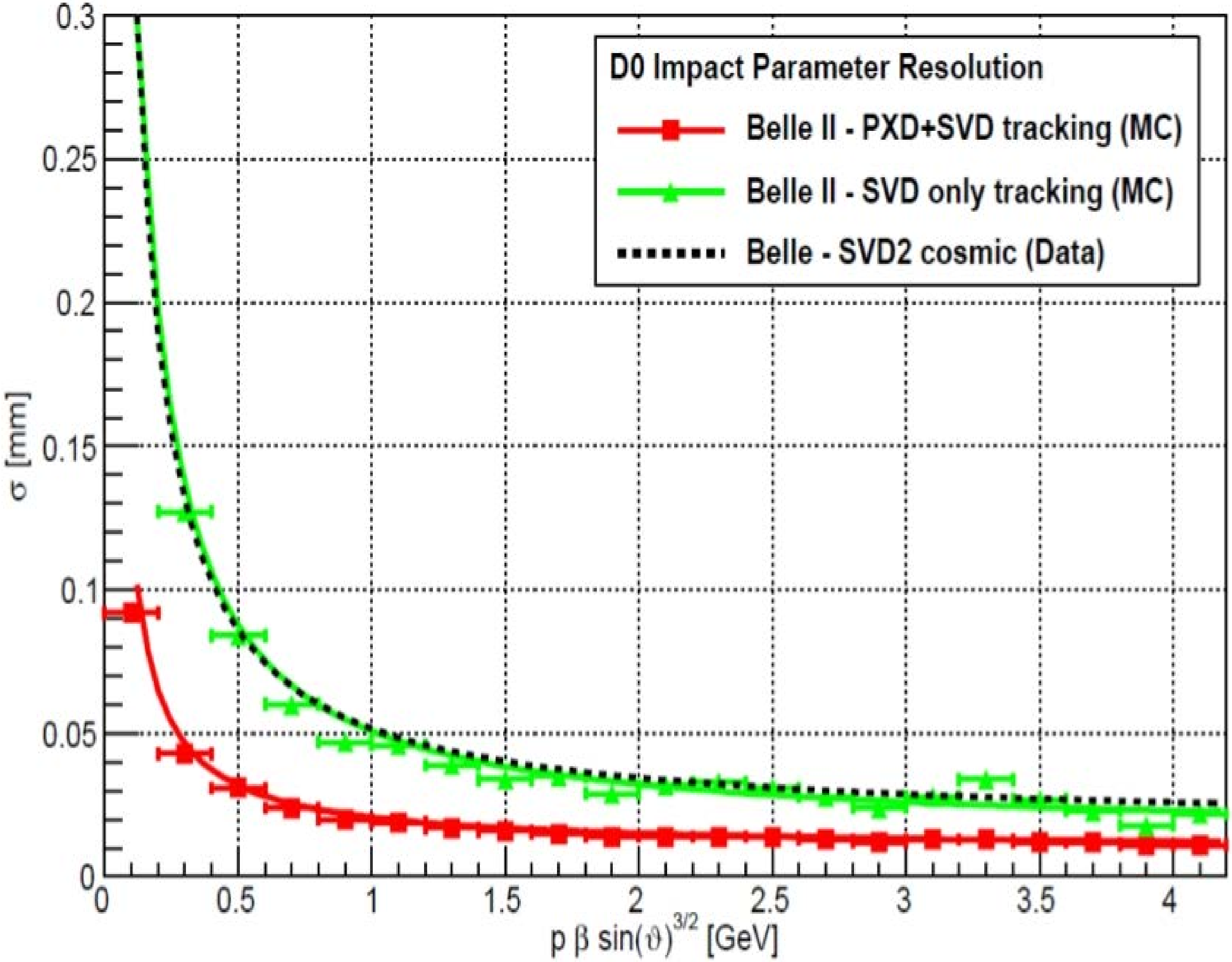
Belle Phys. Rev. Lett. 100, 112001 (2008)

Not only Υ(5S) → Υ(1S)ππ is large, but also Υ(5S) → Υ(2S)ππ



Accelerator	CESR	KEKB	PEP-II	SuperKEKB
Laboratory	Cornell	KEK	SLAC	KEK
Detector	CLEO III	Belle	*BABAR*	Belle II
	(achieved)	(achieved)	(achieved)	(planned)
Circumference (km)	0.768	3.0	2.2	3.0
Energy e^-/e^+ (GeV)	5.3/5.3	8.0/3.5	9.0/3.1	7.0/4.0
Lorentz boost $\beta\gamma$	0	0.43	0.56	0.28
Beam current e^-/e^+ (A)	0.5/0.5	$1.6/1.2^\dagger$	3.2/2.1	3.6/2.6
Number of bunches	45	5120	1732	2500
Crossing angle (mrad)	± 2.3	± 11	0	83
Luminosity $(10^{33}/\mathrm{cm}^2\mathrm{s})$	1.55	21.08	12.07	800
σ_x (μm)	n.a.	103-116	120	7.2-8.9
σ_y (μm)	n.a.	0.94	4	36×10^{-3}
σ_z (mm)	n.a.	6	11	5

† with crab cavity


D0 Impact Parameter Resolution
Belle II - PXD+SVD tracking (MC)
Belle II - SVD only tracking (MC)
Belle - SVD2 cosmic (Data)
σ [mm]
p β sin(ϑ)^3/2 [GeV]
0.3
0.25
0.2
0.15
0.1
0.05
0
0.5
1
1.5
2
2.5
3
3.5
4

CDC transport from Fuji Hall to Tsukuba Hall, 21.01.2015