Prospects for τ lepton physics at Belle II

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On behalf of the Belle II collaboration

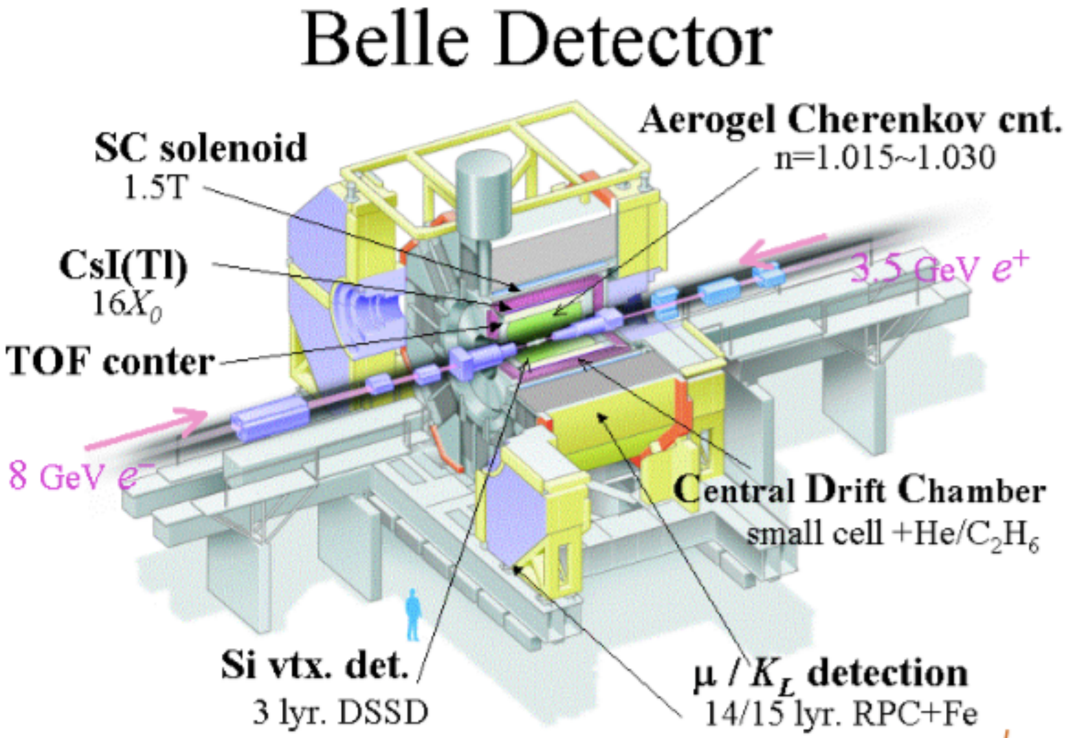
15th International Workshop on Tau Lepton Physics

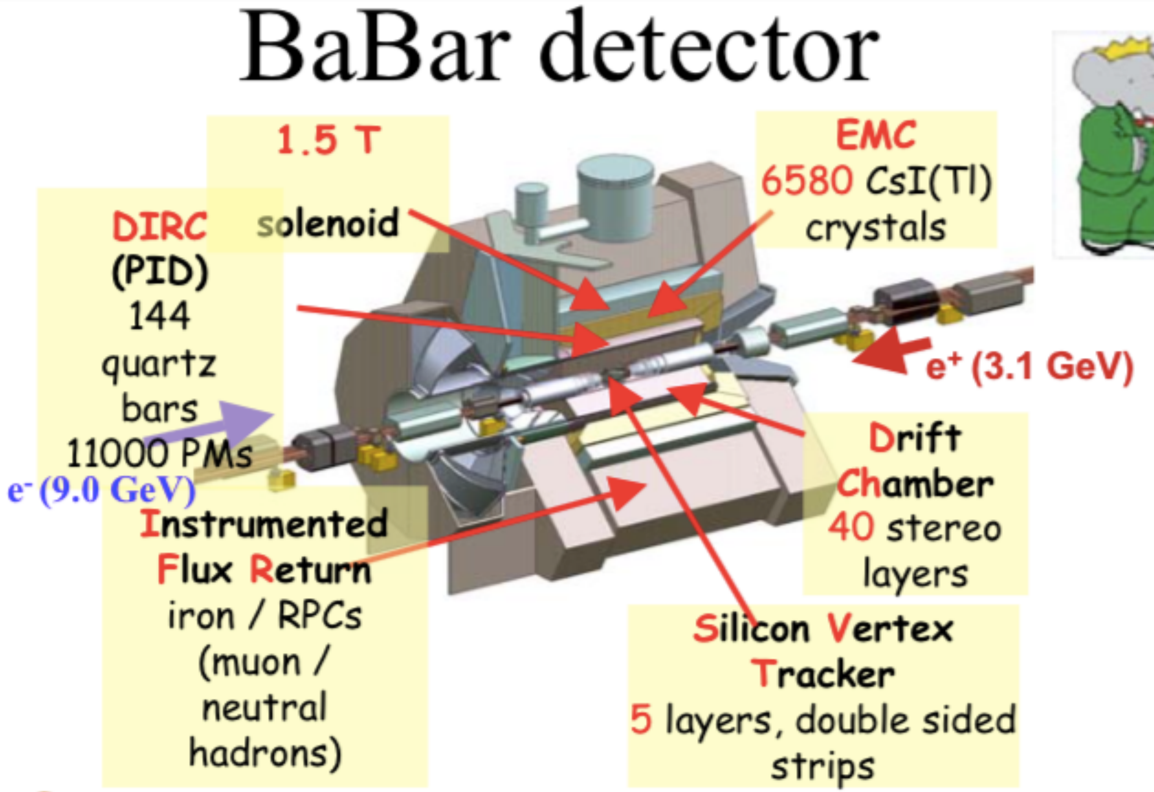
Amsterdam, Netherlands, Sep 24, 2018

Outline:

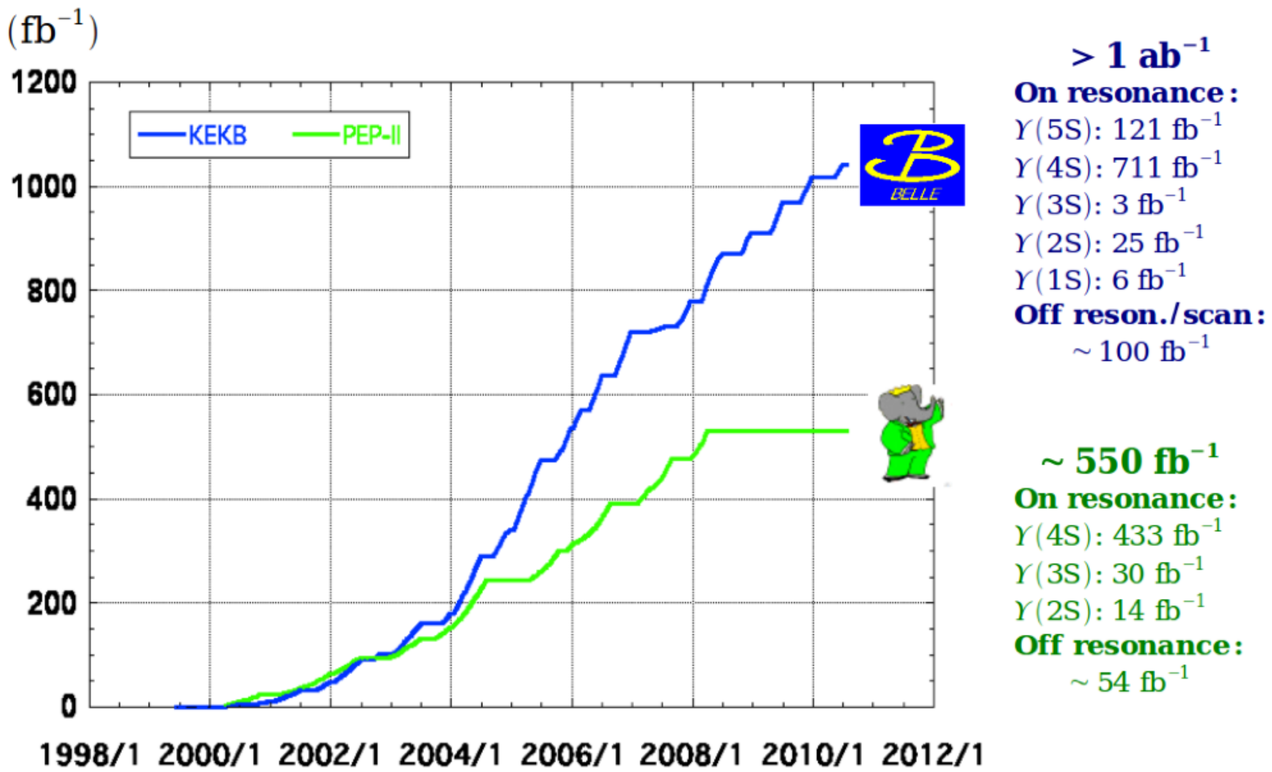
- Achievements of B-factories in τ lepton physics.
- The Belle II experiment.
- First results with early data.
- Prospects of τ lepton physics

B Factories



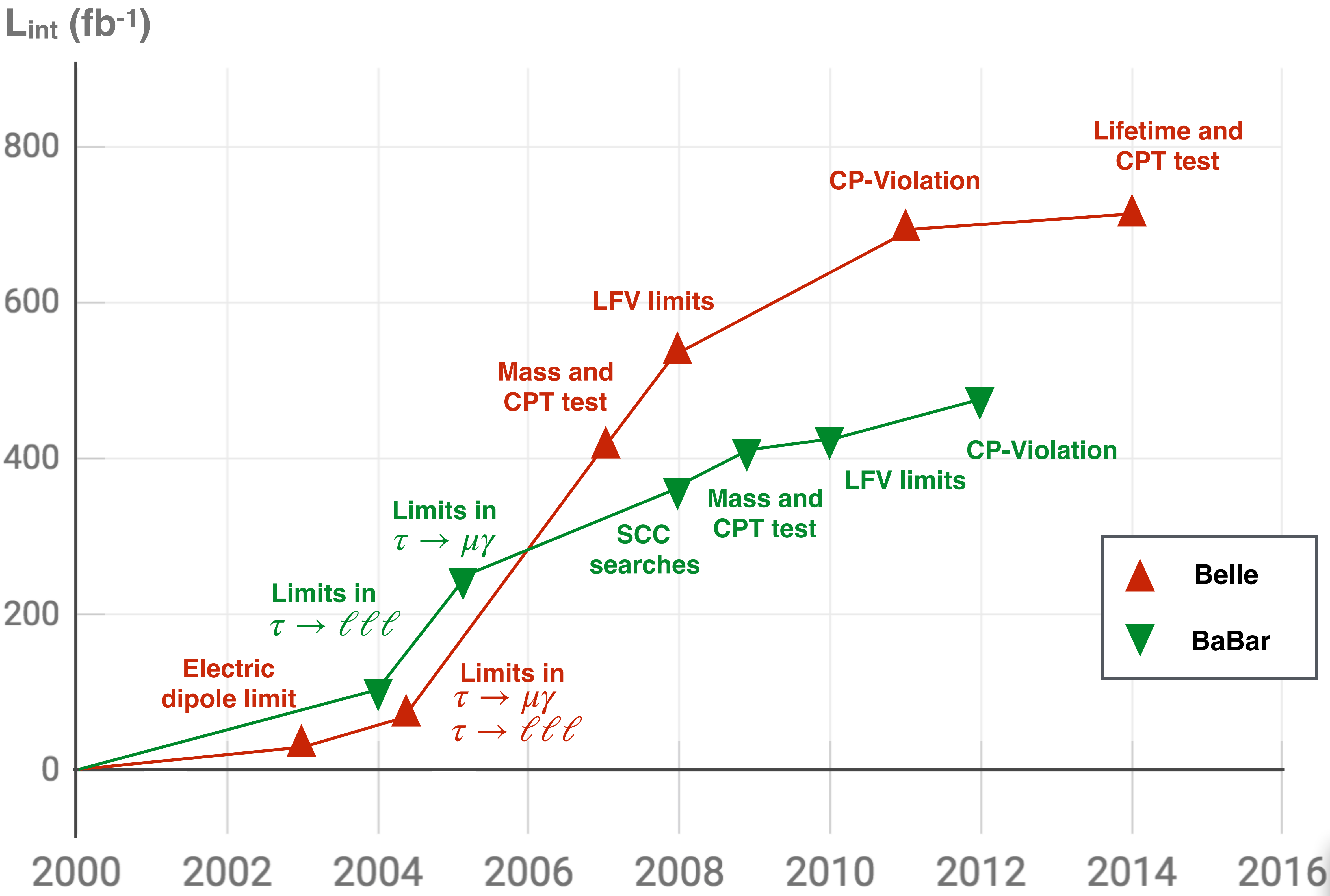


$\sqrt{s}$=10.58 GeV



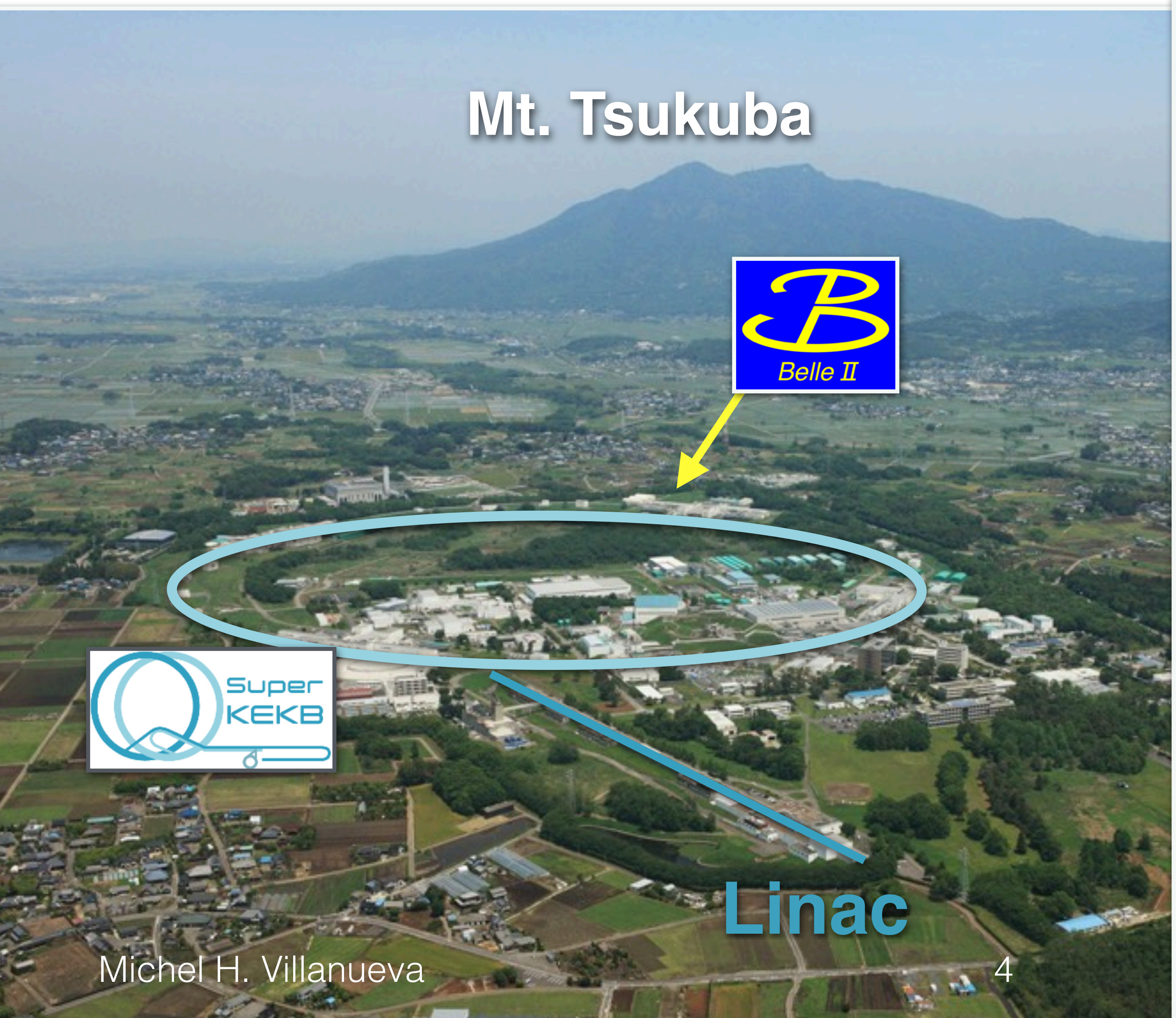
- B-Factory: Production of b pairs.
- τ factory too!
  $\sigma(e^+e^- \longrightarrow \Upsilon(4s))$ = 1.05 nb
  $\sigma(e^+e^- \longrightarrow \tau\,\tau)$ = 0.92 nb

τ lepton physics results at B factories

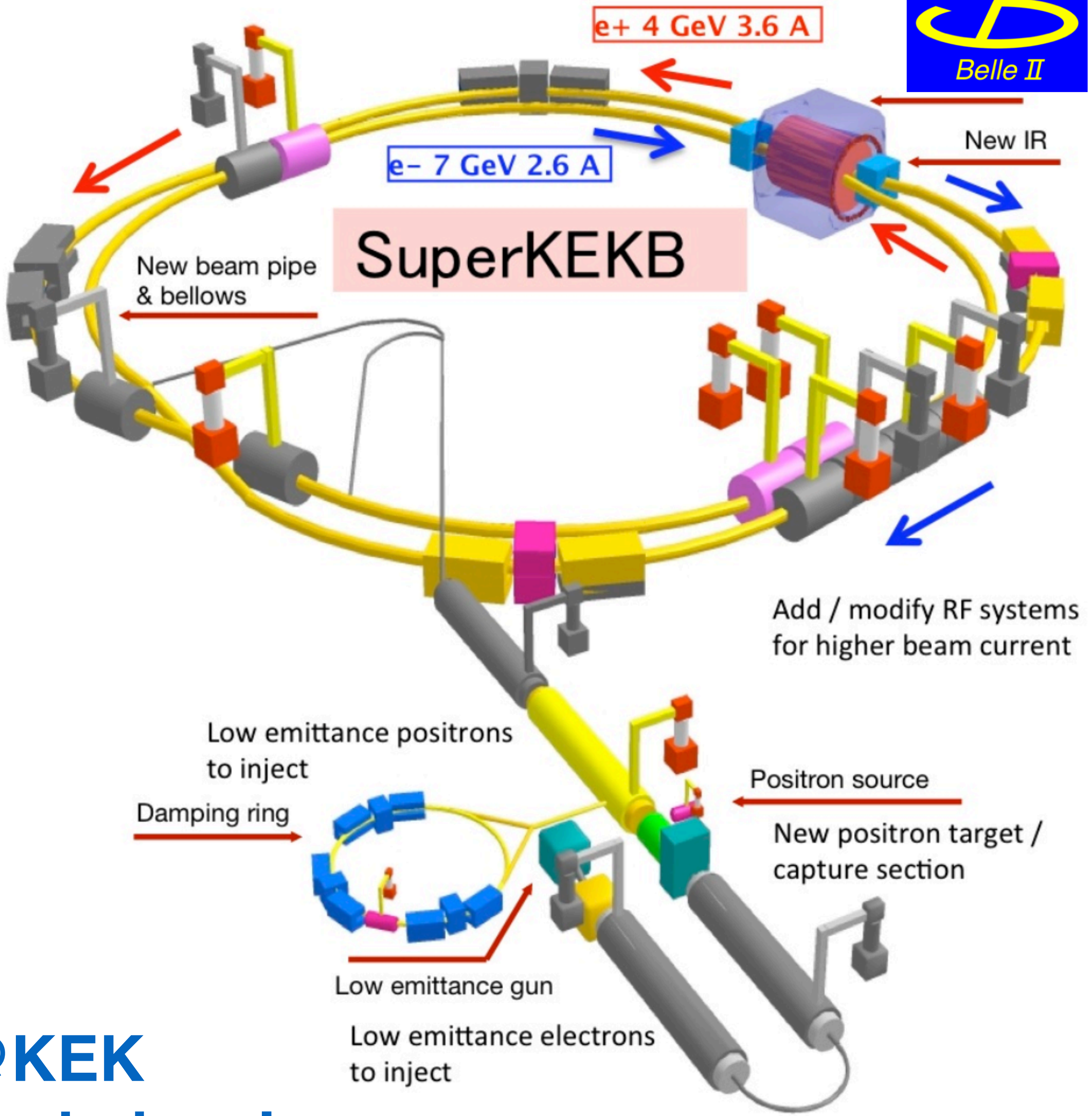


Next gen: Belle II collaboration

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



Next gen: SuperKEKB



- **Super B-Factory**
  (And τ factory too!)

  $\sigma(e^+e^- \longrightarrow \Upsilon(4s)) = 1.05$ nb
  $\sigma(e^+e^- \longrightarrow \tau\,\tau) = 0.92$ nb

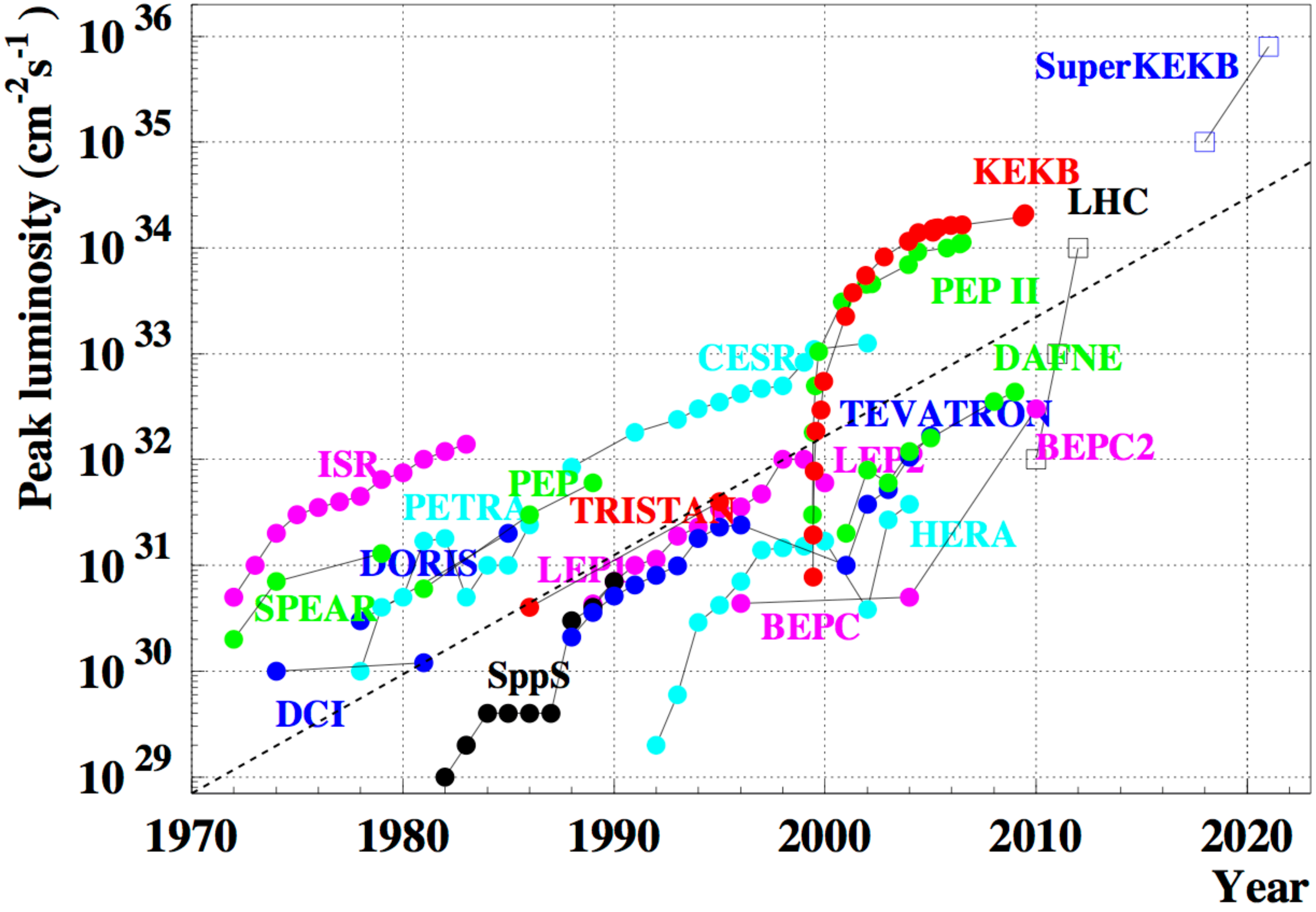
- Integrated luminosity expected:
  50 ab^{-1}

  (x50 than previous B factories)

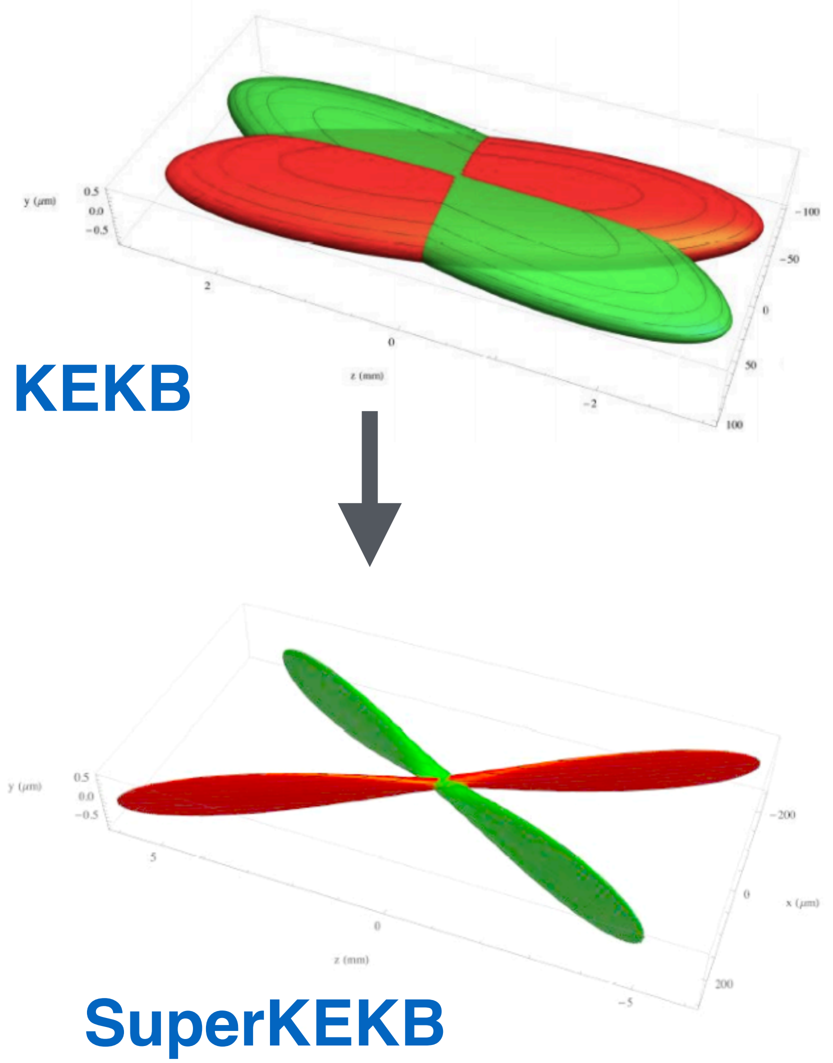
  4.6×10^{10} τ pairs

@KEK
Tsukuba, Japan

Next gen: SuperKEKB



“Nano-beams”: vertical beam size is 50nm at the IP.



KEKB

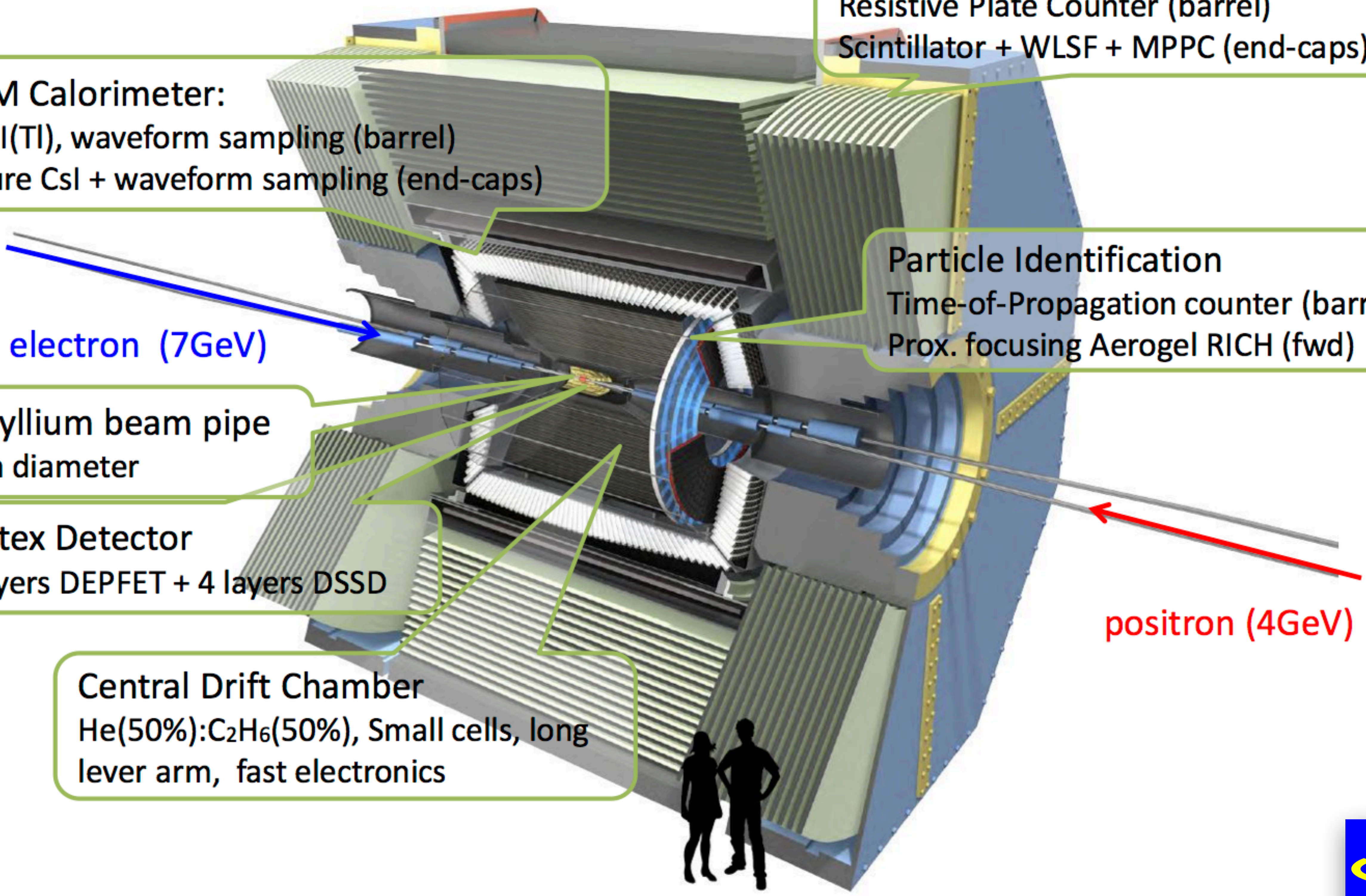
SuperKEKB

- Challenges at $L=8x10^{35}$ 1/cm^{2}/s:

  - Higher background (Radiative Bhabha, Touschek, beam-gas scattering, etc.).

  - Higher trigger rates (High performance DAQ, computing).

Belle II Detector



KL and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps)

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

electron (7GeV)

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

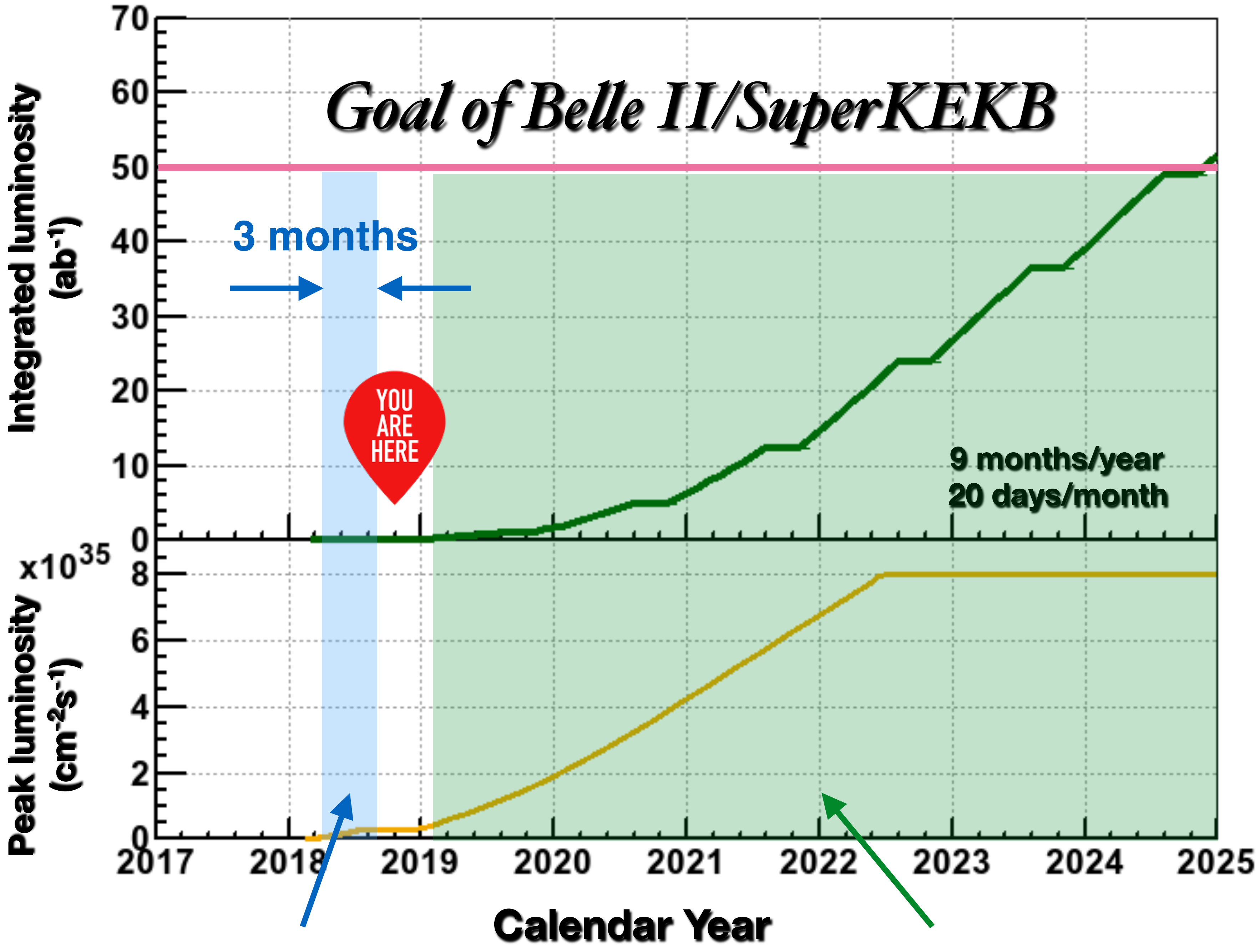
Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

positron (4GeV)

Central Drift Chamber
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

Belle II Schedule

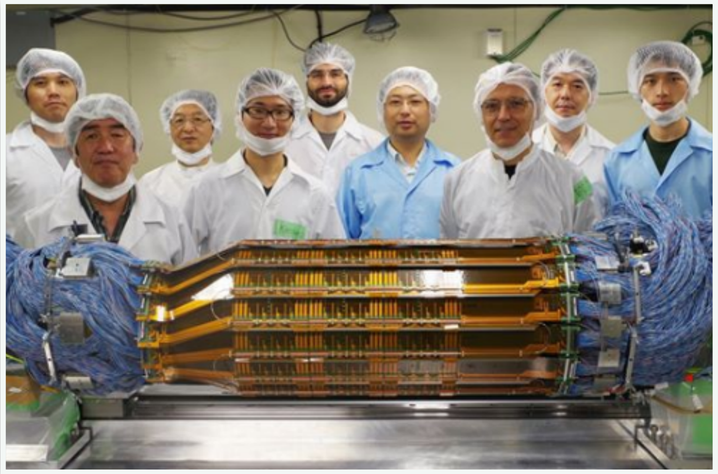


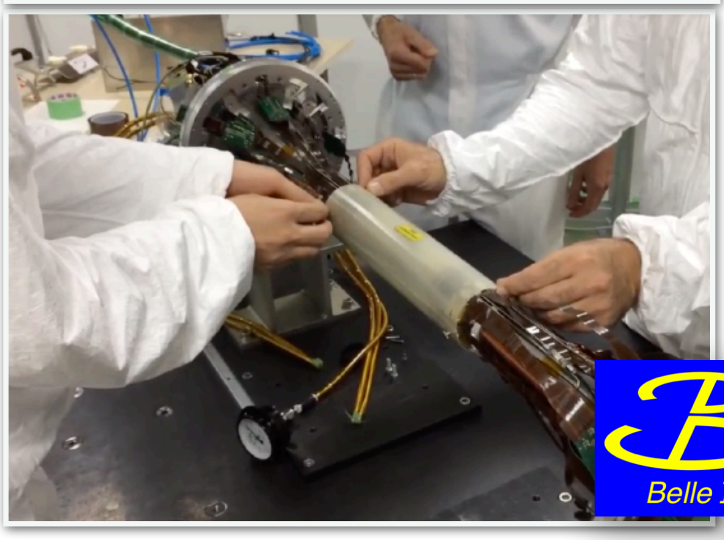
Phase II
(Partial Belle II)

Phase III
(Full Belle II)

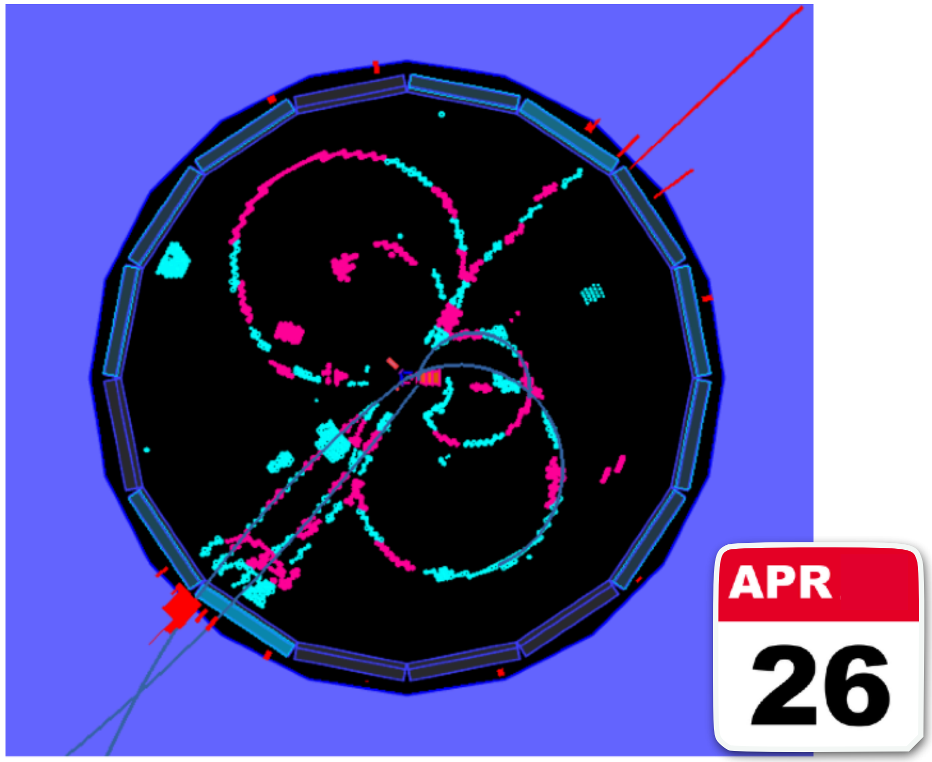
Data taking in phase II was performed with all subsystems, except vertex detectors.

They are being installed and they will be ready for phase III.



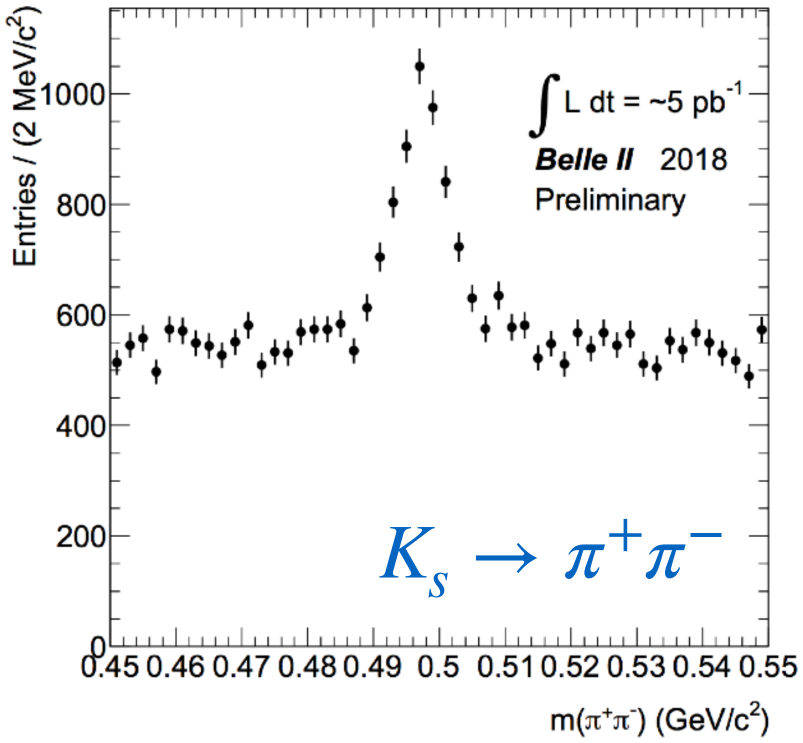


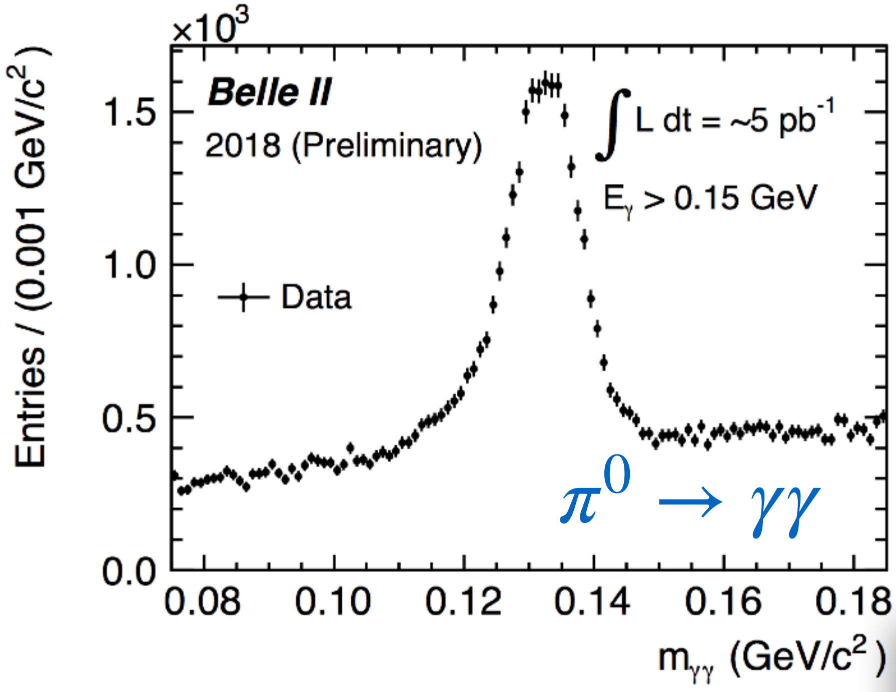
First collisions on Phase II



APR 26

Most of the Belle II detector subsystems are working well. We have signals involving photons and charged tracks.





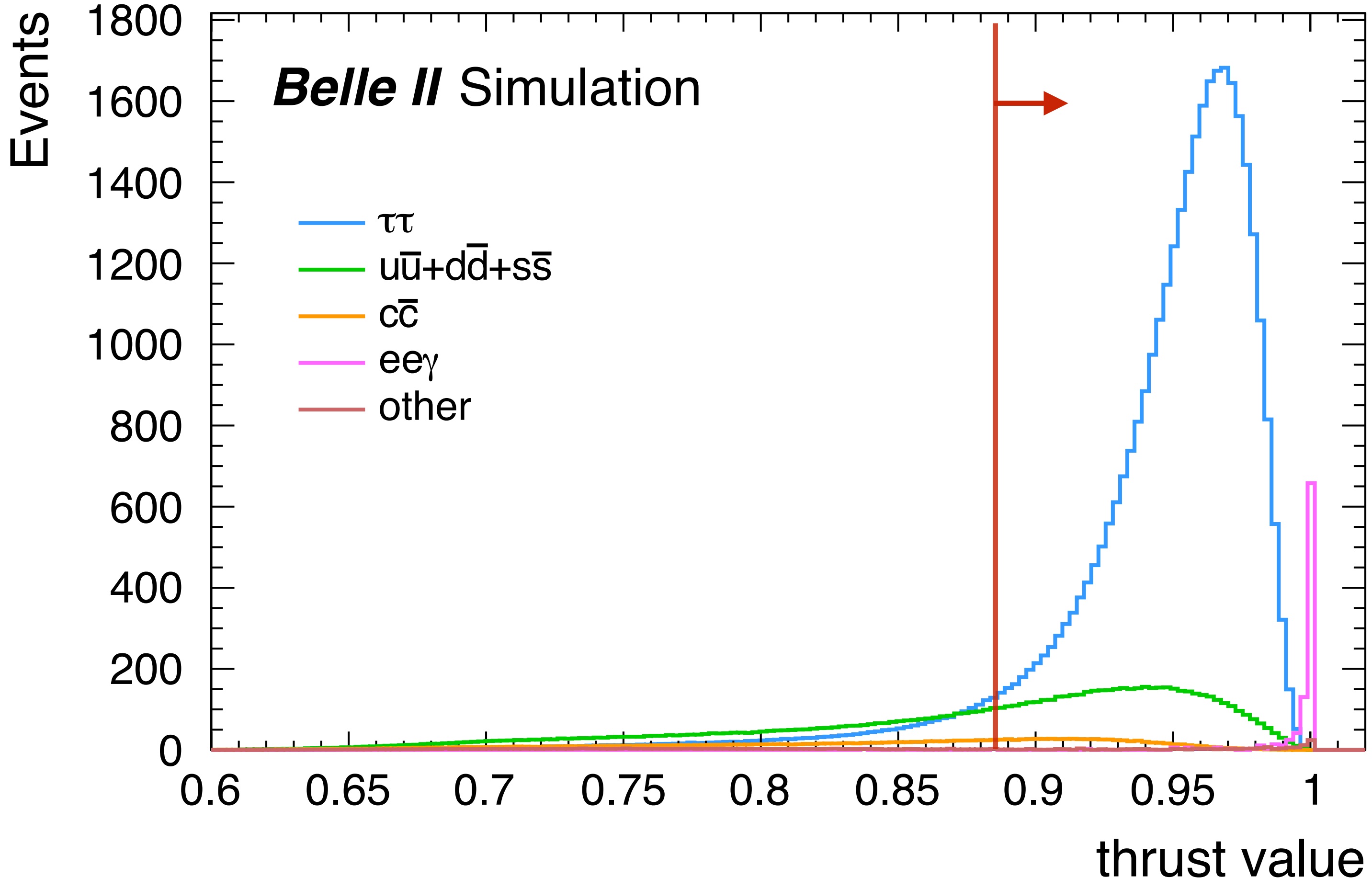
$\tau \to 3\pi\nu$ in Belle II early data

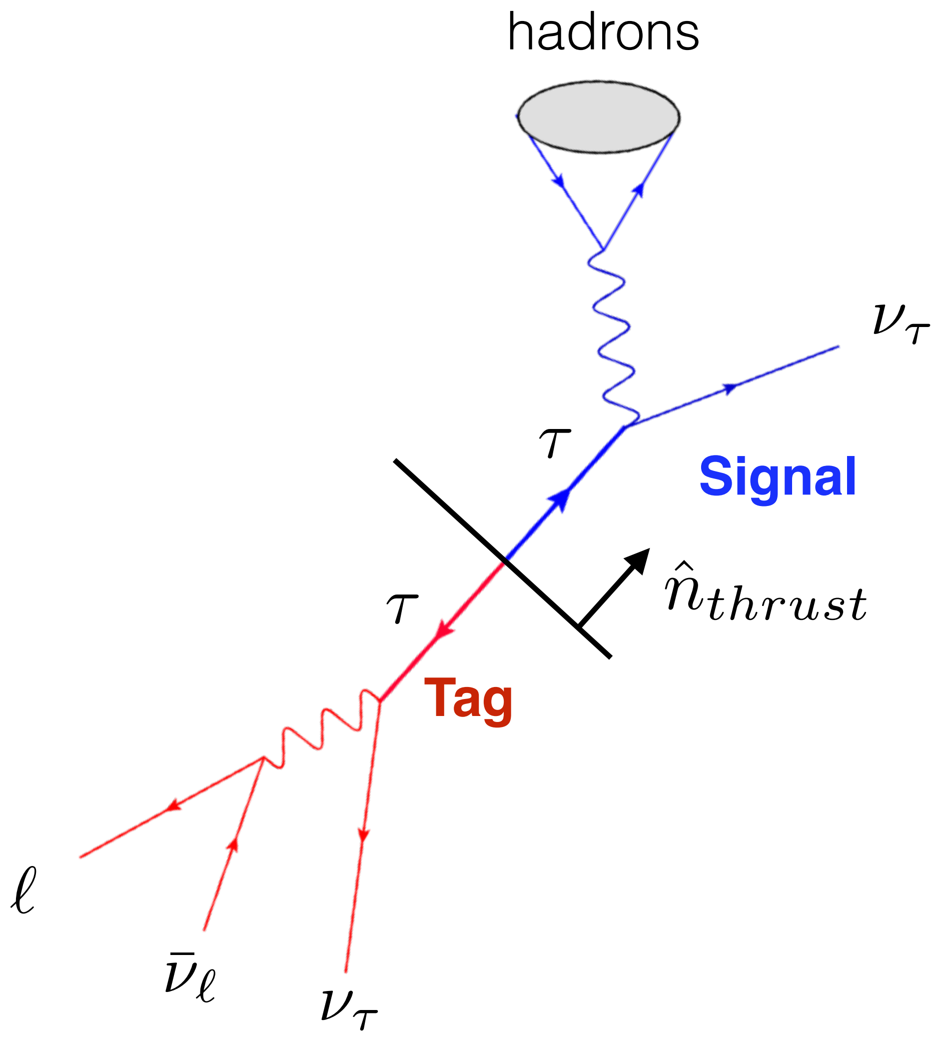
Candidates: 3 - 1 prong decay

$e^+e^- \to (\tau \to 3\text{ tracks})(\tau_{tag} \to \text{track})$

We are assuming pion hypothesis in signal side.

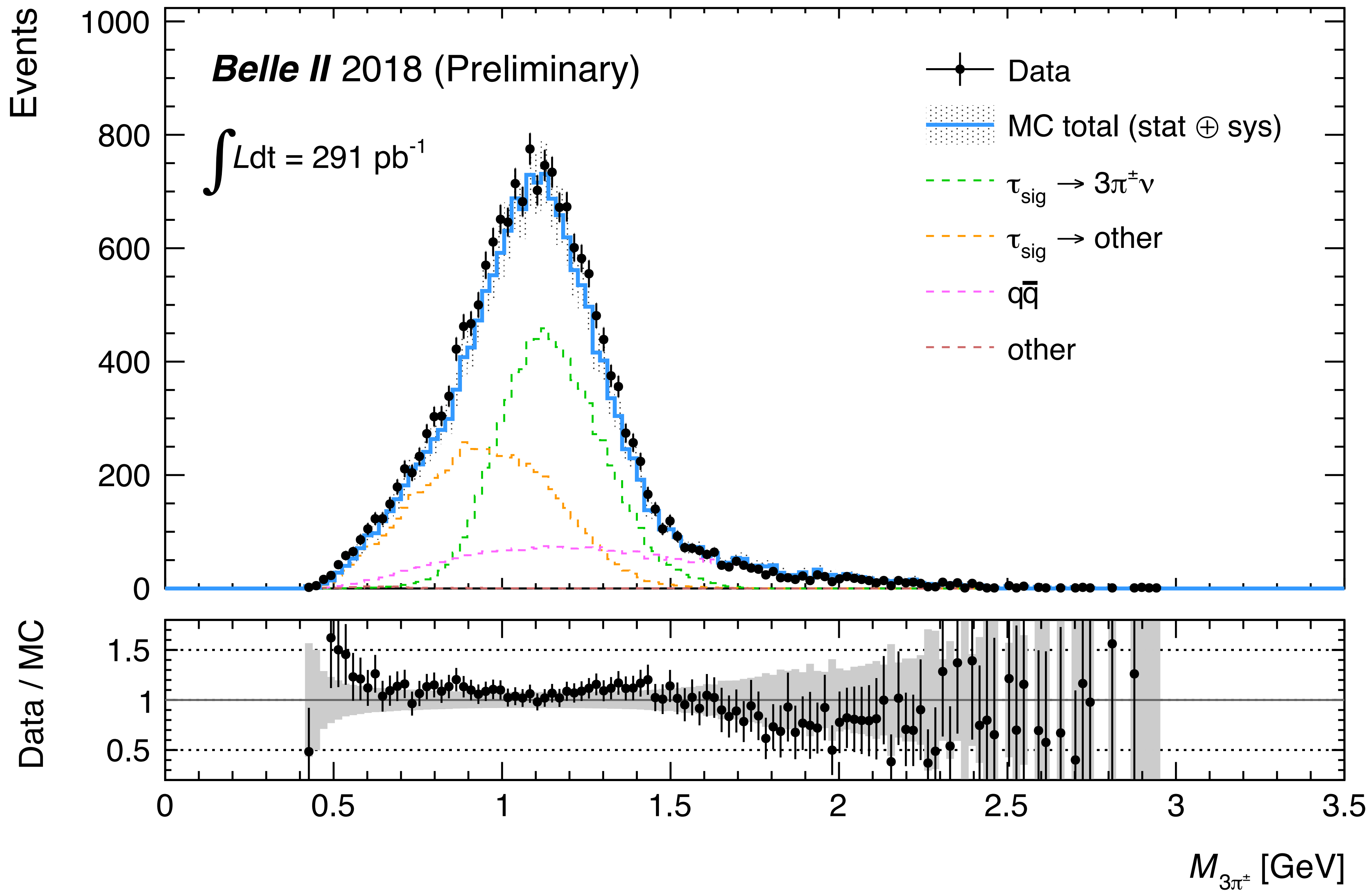
- Thrust axis: $\hat{n}_{thrust}$ such that V_{thrust} is maximum.





$$V_{thrust} = \frac{\sum_i |\vec{p}_i^{\,cm} \cdot \hat{n}_{thrust}|}{\sum_i |\vec{p}_i^{\,cm}|}$$

$\tau \to 3\pi\nu$ in Belle II early data

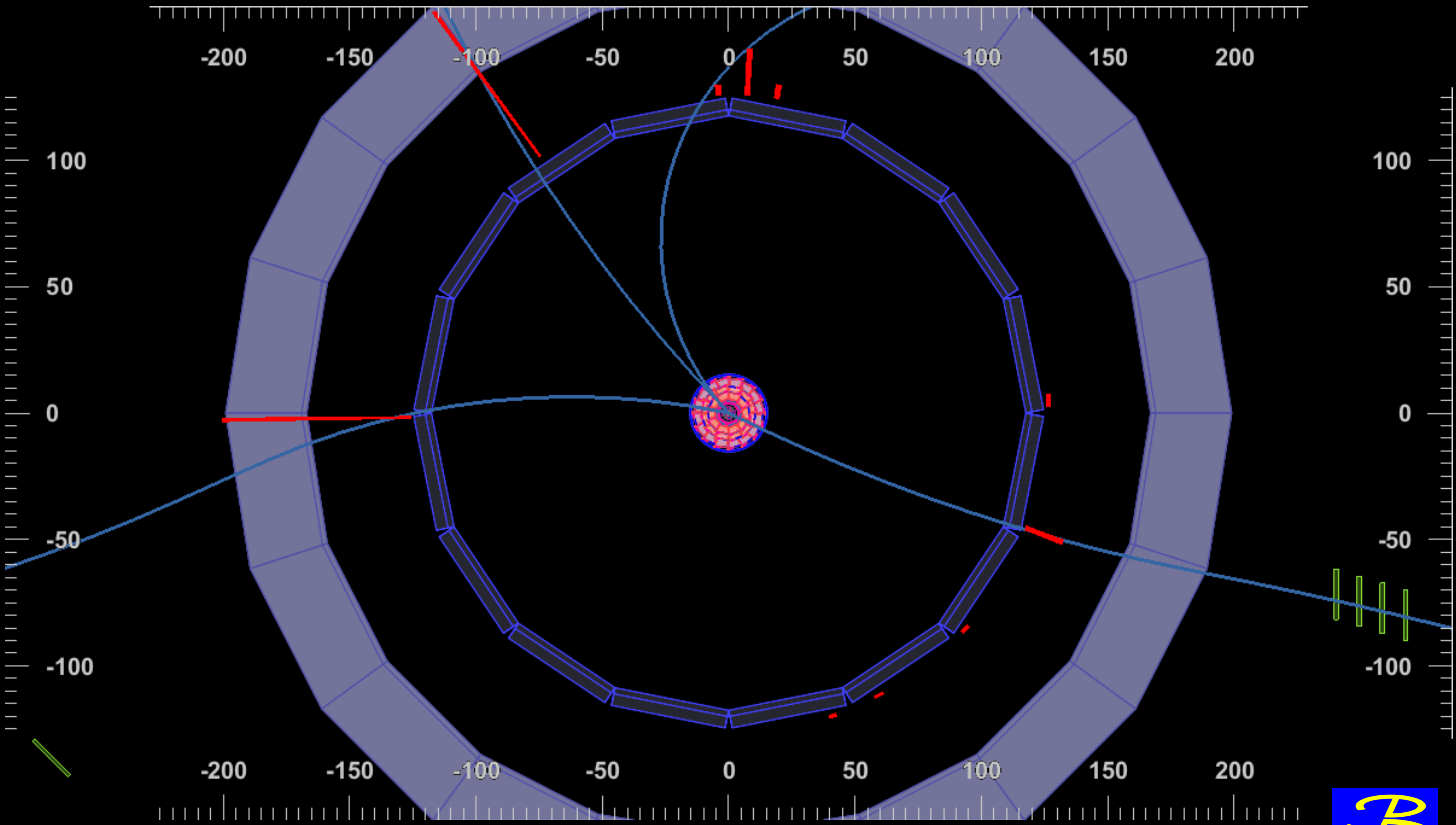


$M_{3\pi}$ distribution @ 291 pb^{-1}

After selection cuts, we have an agreement between distributions in data an MC.

Performance of the subsystems is good.

$\tau \to 3\pi\nu$ in Belle II early data

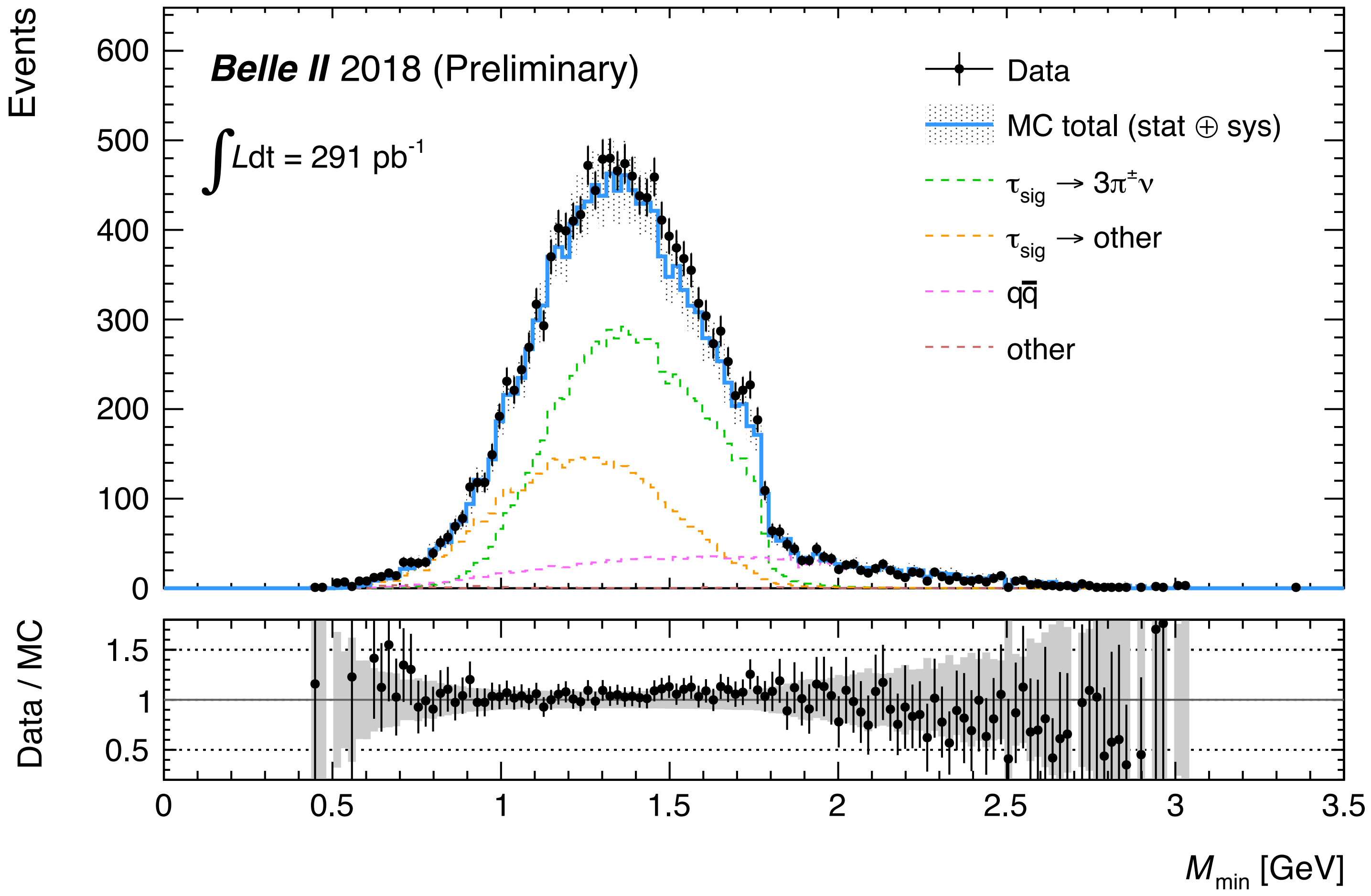


Michel H. Villanueva

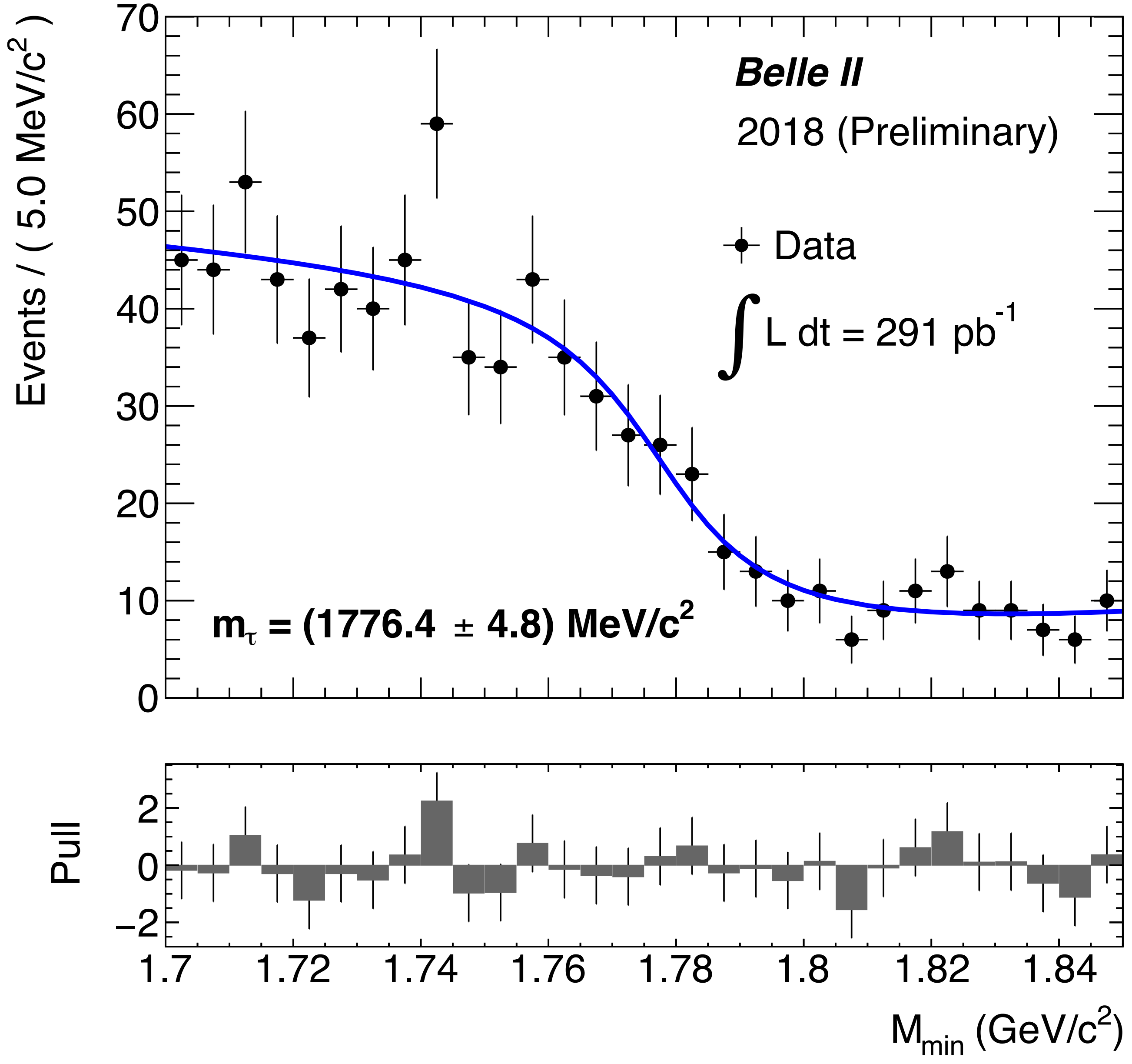
Measurement of τ mass

- Measured in the decay mode $\underline{\tau \to 3\pi\nu}$, using a pseudomass technique developed by the ARGUS collaboration:
- $$M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})}$$
- The distribution of the pseudomass is fitted to a empirical edge function.
- A first measurement of m_τ at Belle II is performed using the data collected during the Phase II.

M_{min} distribution @ 291 pb^{-1}:



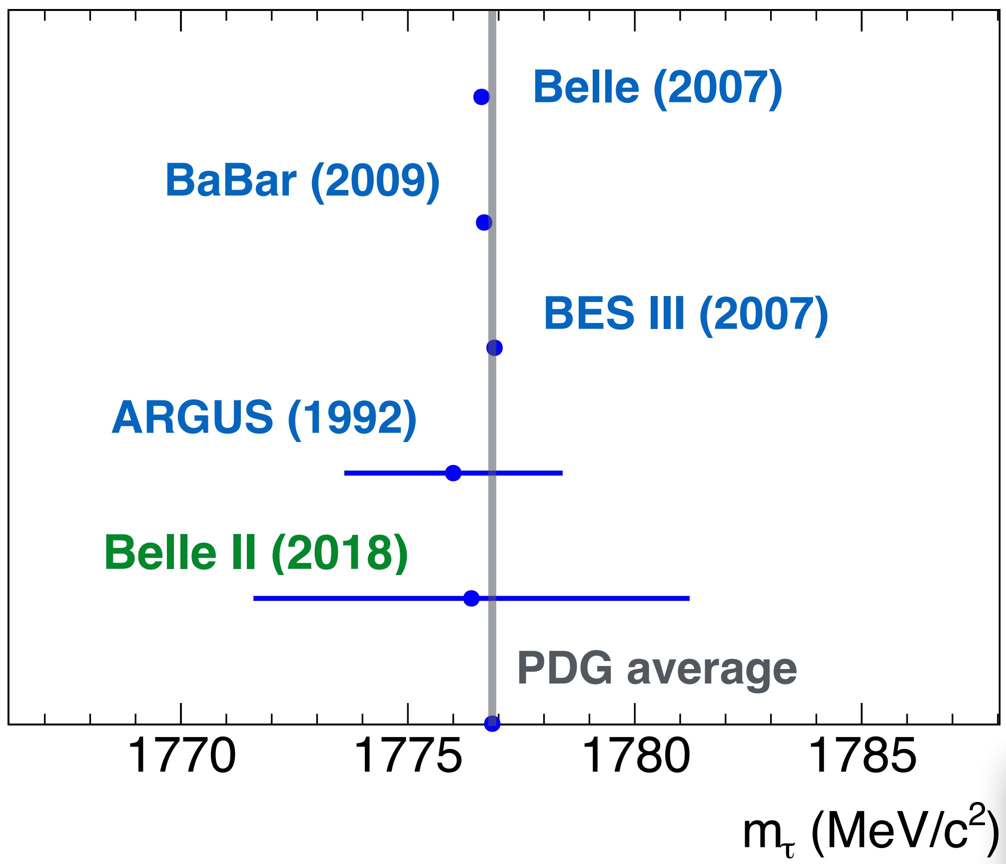
Measurement of τ mass



Our result, obtained from Belle II early data

m_τ = (1776.4 ± 4.8 (stat)) MeV/c^2

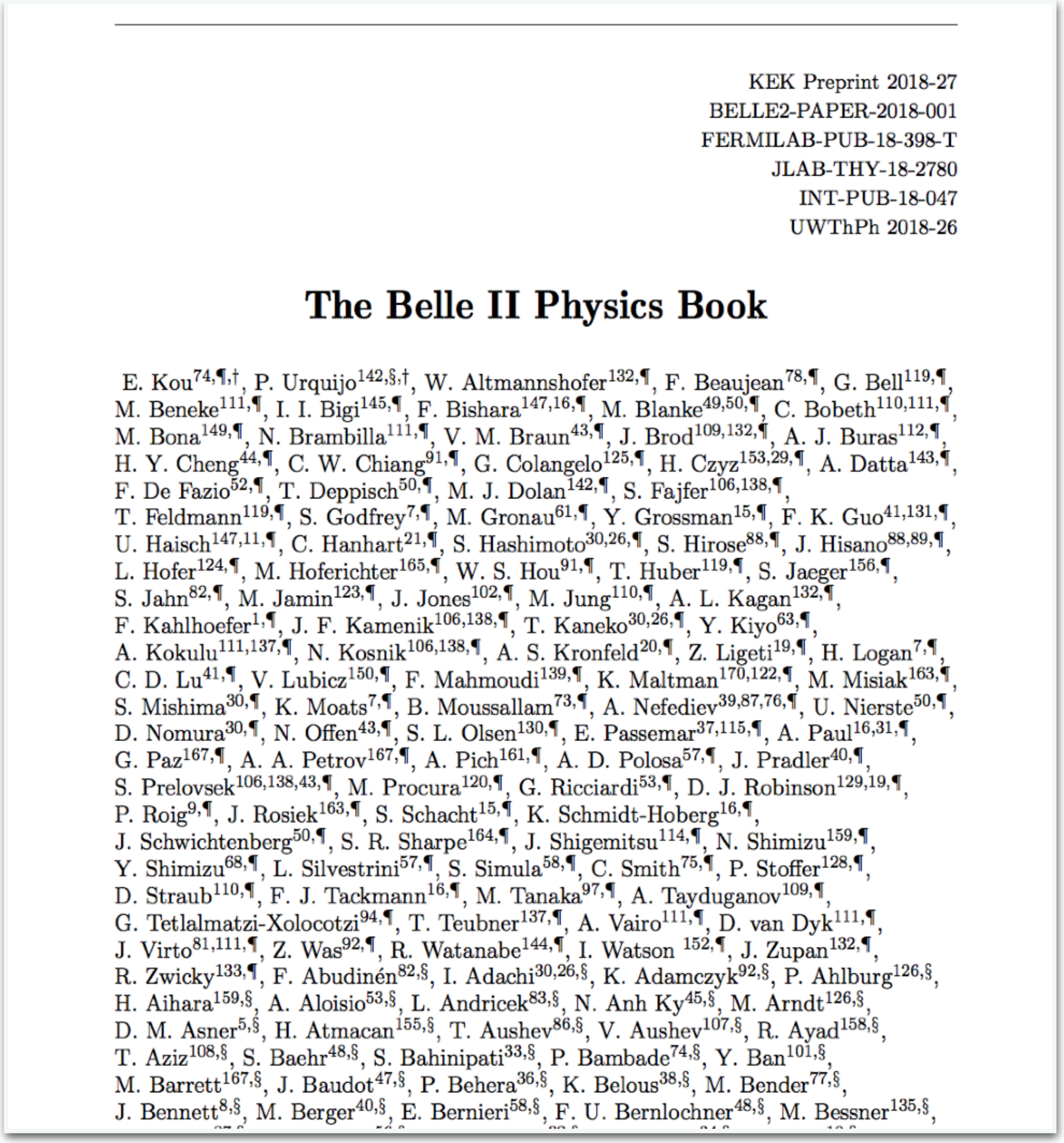
Is consistent with previous experimental results.



Prospects of τ lepton physics

- The enormous amount of e^+e^- collisions that are expected from the Belle II experiment features an unique environment for the study of τ physics with high precision.

- Further details can be looked at **"The Belle II Physics Book"**, which is now available at: arXiv:1808.10567



KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

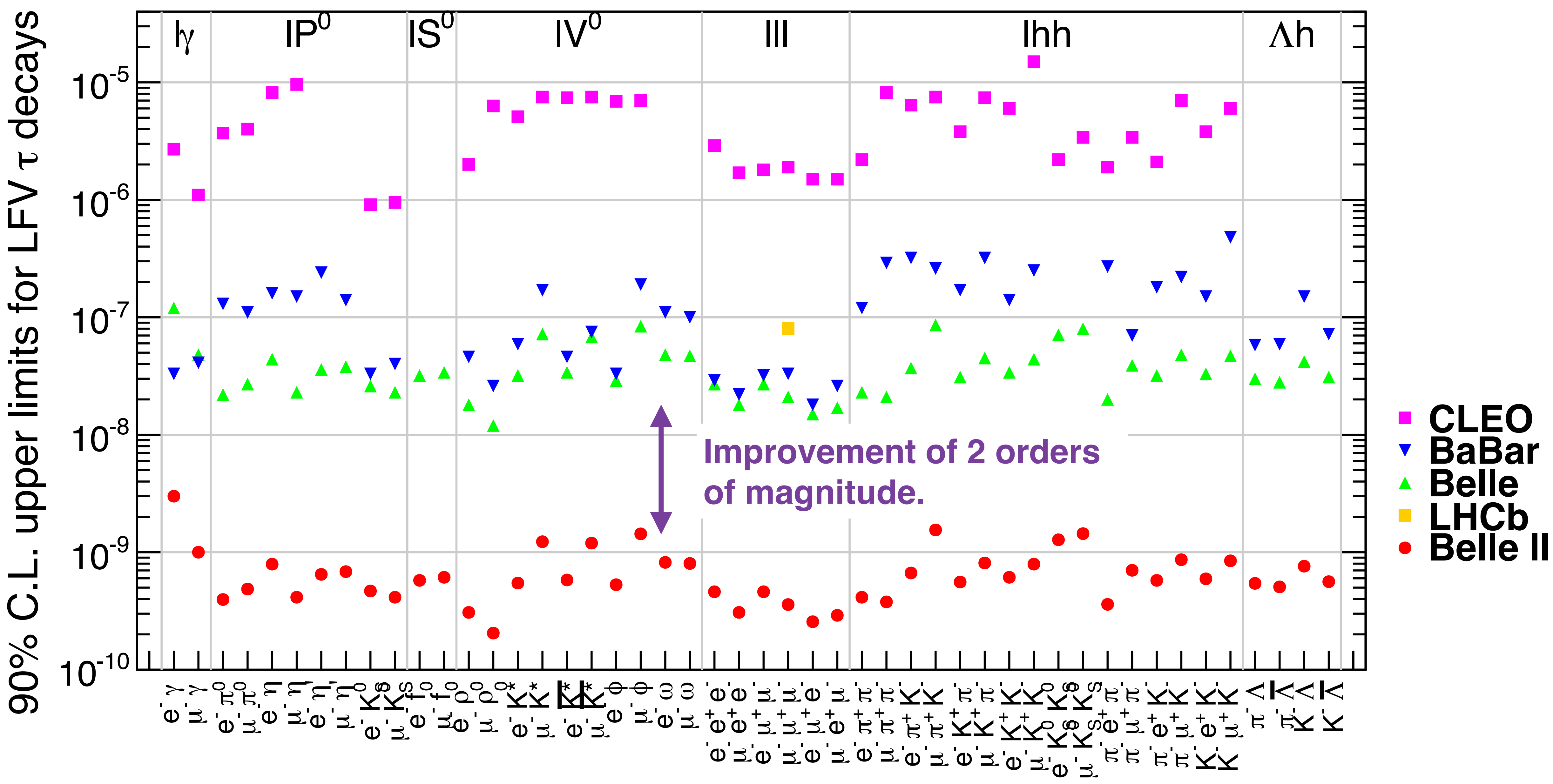
The Belle II Physics Book

E. Kou[74,¶,†], P. Urquijo[142,§,†], W. Altmannshofer[132,¶], F. Beaujean[78,¶], G. Bell[119,¶],
M. Beneke[111,¶], I. I. Bigi[145,¶], F. Bishara[147,16,¶], M. Blanke[49,50,¶], C. Bobeth[110,111,¶],
M. Bona[149,¶], N. Brambilla[111,¶], V. M. Braun[43,¶], J. Brod[109,132,¶], A. J. Buras[112,¶],
H. Y. Cheng[44,¶], C. W. Chiang[91,¶], G. Colangelo[125,¶], H. Czyz[153,29,¶], A. Datta[143,¶],
F. De Fazio[52,¶], T. Deppisch[50,¶], M. J. Dolan[142,¶], S. Fajfer[106,138,¶],
T. Feldmann[119,¶], S. Godfrey[7,¶], M. Gronau[61,¶], Y. Grossman[15,¶], F. K. Guo[41,131,¶],
U. Haisch[147,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[88,¶], J. Hisano[88,89,¶],
L. Hofer[124,¶], M. Hoferichter[165,¶], W. S. Hou[91,¶], T. Huber[119,¶], S. Jaeger[156,¶],
S. Jahn[82,¶], M. Jamin[123,¶], J. Jones[102,¶], M. Jung[110,¶], A. L. Kagan[132,¶],
F. Kahlhoefer[1,¶], J. F. Kamenik[106,138,¶], T. Kaneko[30,26,¶], Y. Kiyo[63,¶],
A. Kokulu[111,137,¶], N. Kosnik[106,138,¶], A. S. Kronfeld[20,¶], Z. Ligeti[19,¶], H. Logan[7,¶],
C. D. Lu[41,¶], V. Lubicz[150,¶], F. Mahmoudi[139,¶], K. Maltman[170,122,¶], M. Misiak[163,¶],
S. Mishima[30,¶], K. Moats[7,¶], B. Moussallam[73,¶], A. Nefediev[39,87,76,¶], U. Nierste[50,¶],
D. Nomura[30,¶], N. Offen[43,¶], S. L. Olsen[130,¶], E. Passemar[37,115,¶], A. Paul[16,31,¶],
G. Paz[167,¶], A. A. Petrov[167,¶], A. Pich[161,¶], A. D. Polosa[57,¶], J. Pradler[40,¶],
S. Prelovsek[106,138,43,¶], M. Procura[120,¶], G. Ricciardi[53,¶], D. J. Robinson[129,19,¶],
P. Roig[9,¶], J. Rosiek[163,¶], S. Schacht[15,¶], K. Schmidt-Hoberg[16,¶],
J. Schwichtenberg[50,¶], S. R. Sharpe[164,¶], J. Shigemitsu[114,¶], N. Shimizu[159,¶],
Y. Shimizu[68,¶], L. Silvestrini[57,¶], S. Simula[58,¶], C. Smith[75,¶], P. Stoffer[128,¶],
D. Straub[110,¶], F. J. Tackmann[16,¶], M. Tanaka[97,¶], A. Tayduganov[109,¶],
G. Tetlalmatzi-Xolocotzi[94,¶], T. Teubner[137,¶], A. Vairo[111,¶], D. van Dyk[111,¶],
J. Virto[81,111,¶], Z. Was[92,¶], R. Watanabe[144,¶], I. Watson [152,¶], J. Zupan[132,¶],
R. Zwicky[133,¶], F. Abudinén[82,§], I. Adachi[30,26,§], K. Adamczyk[92,§], P. Ahlburg[126,§],
H. Aihara[159,§], A. Aloisio[53,§], L. Andricek[83,§], N. Anh Ky[45,§], M. Arndt[126,§],
D. M. Asner[5,§], H. Atmacan[155,§], T. Aushev[86,§], V. Aushev[107,§], R. Ayad[158,§],
T. Aziz[108,§], S. Baehr[48,§], S. Bahinipati[33,§], P. Bambade[74,§], Y. Ban[101,§],
M. Barrett[167,§], J. Baudot[47,§], P. Behera[36,§], K. Belous[38,§], M. Bender[77,§],
J. Bennett[8,§], M. Berger[40,§], E. Bernieri[58,§], F. U. Bernlochner[48,§], M. Bessner[135,§],

Upper limits for the BR of τ LFV decays.

Assuming Belle II full dataset (50 ab^{-1}):

Observation of LFV is a clear signature of New Physics.



Improvement of 2 orders of magnitude.

See Ami's talk on Tuesday

CP violation in $\tau\to K_S\,\pi(\geq 0\pi^0)\nu$

- The decay of the τ lepton to final states containing a K_S meson will have a nonzero decay-rate asymmetry due to CP violation in the kaon sector.

$$A_\tau = \frac{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S^0 \bar{\nu}_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S^0 \bar{\nu}_\tau)}$$

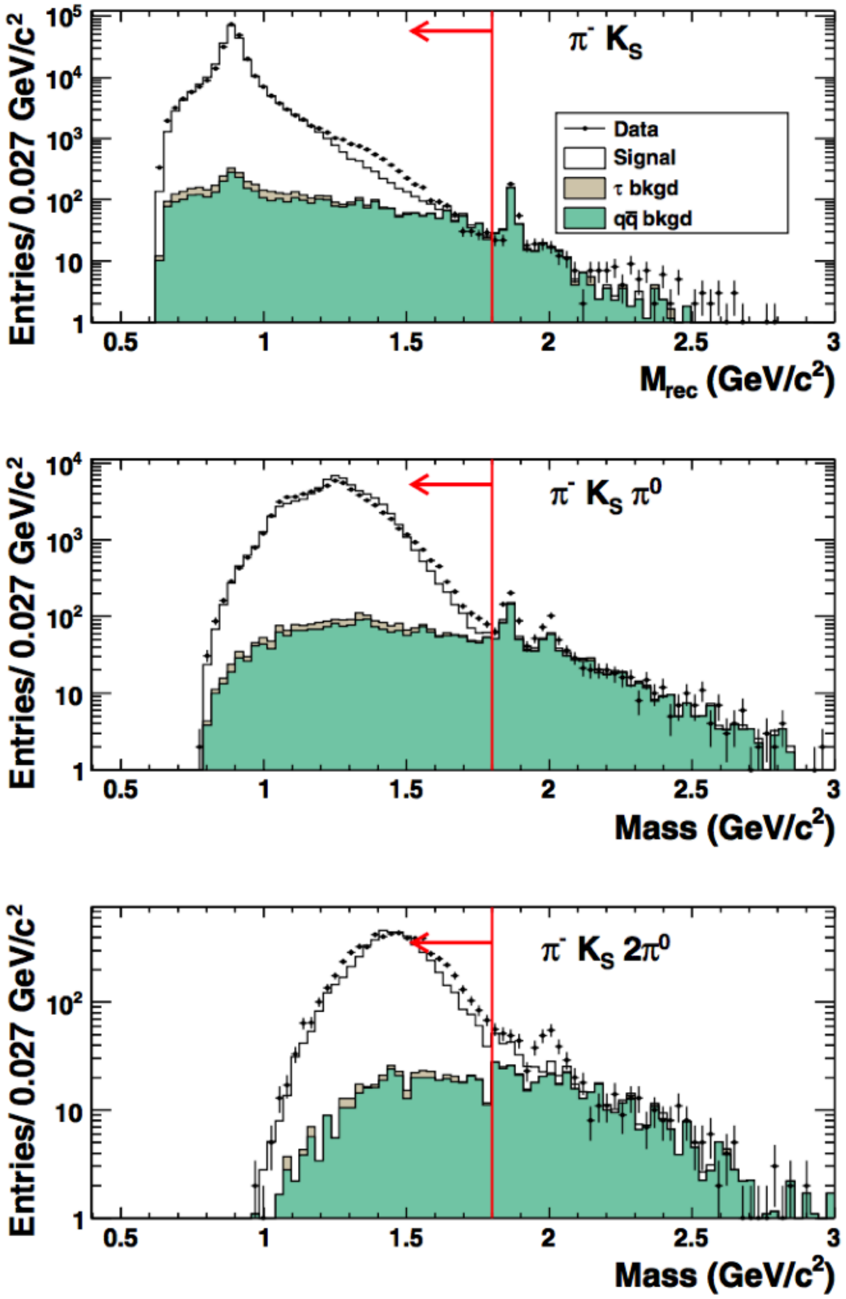
- The SM prediction[1,2] is

$$A_\tau^{SM} = (3.6 \pm 0.1) \times 10^{-3}$$

- BaBar measured:

$$A_\tau^{BaBar} = (-3.6 \pm 2.3 \pm 1.1) \times 10^{-3}$$

2.8 **σ** away from SM



J.P. Lees et.al (BaBar)
Phys.Rev D85 (2012) 031102

An improved measurement of A_τ is a priority at Belle II.

[1] I. I. Bigi and A. I. Sanda, Phys. Lett. B 625, 47 (2005).
[2] Y. Grossman and Y. Nir, JHEP 2012.4 (2012).

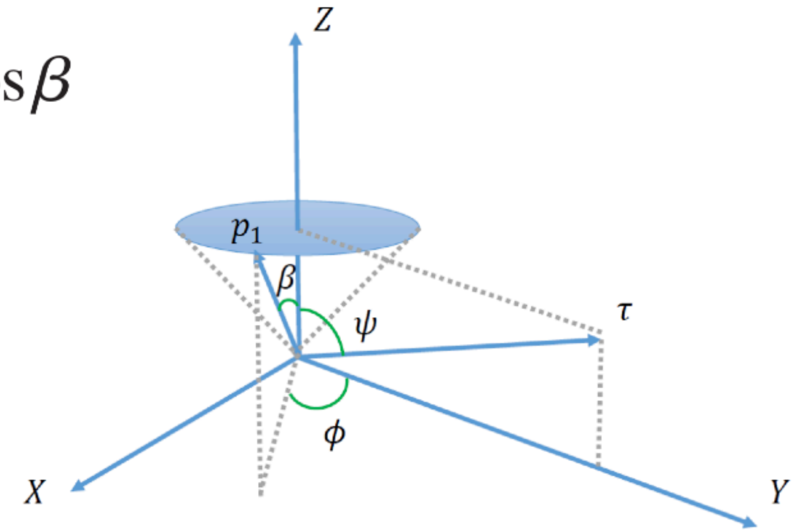
CP violation in $\tau \to K_S \pi \nu$

- CPV that could arise from a charged scalar boson exchange. It can be detected as a difference in the decay angular distributions

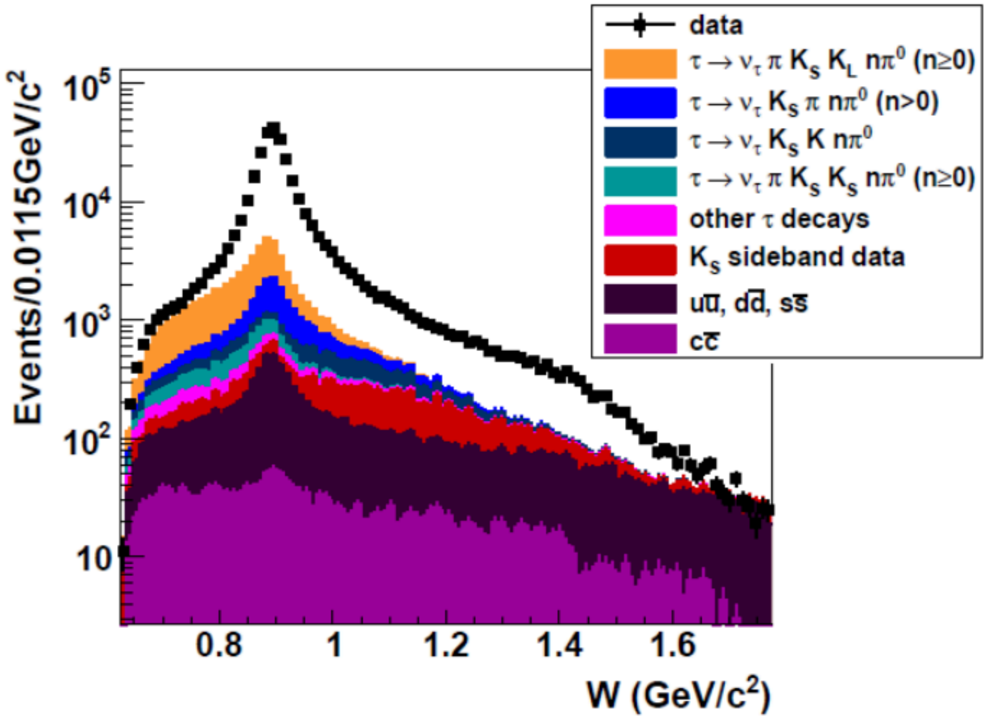
$$A_i^{CP} = \frac{\iint_{Q^2_{1,i}}^{Q^2_{2,i}} \cos\beta \cos\psi \left(\frac{d\Gamma_{\tau^-}}{d\omega} - \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega}{\frac{1}{2} \iint_{Q^2_{1,i}}^{Q^2_{2,i}} \left(\frac{d\Gamma_{\tau^-}}{d\omega} + \frac{d\Gamma_{\tau^+}}{d\omega}\right) d\omega}$$

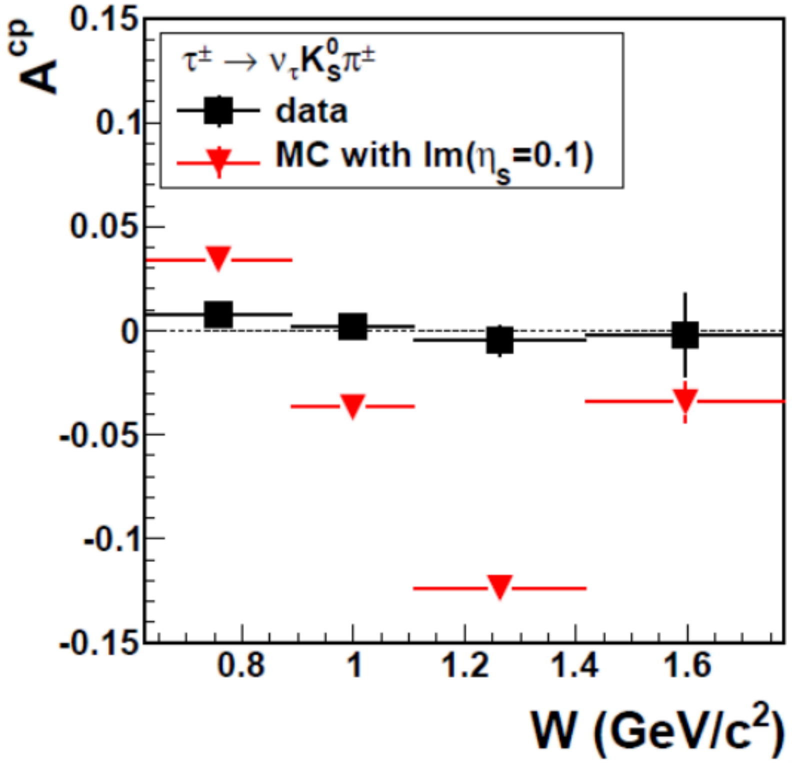
$$\simeq \langle \cos\beta \cos\psi \rangle^i_{\tau^-} - \langle \cos\beta \cos\psi \rangle^i_{\tau^+},$$

- $d\omega = dQ^2 d\cos\theta d\cos\beta$



- With 50 ab-1 data at Belle II, we expect 70 times improvement, i.e., **$|A^{CP}| < (0.5 - 3.8) \times 10^{-4}$**, at 90% C.L. assuming the central value $A^{CP} = 0$.





M. Bischofberger et. al (Belle)
PRL 107 (2011) 131801

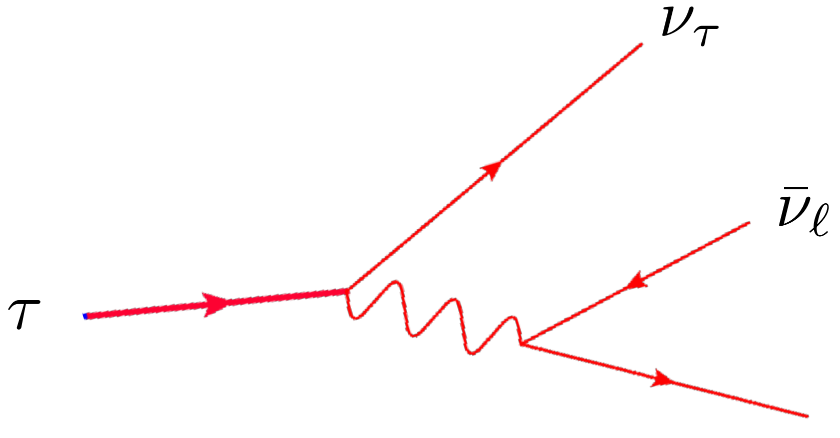
Michel Parameters

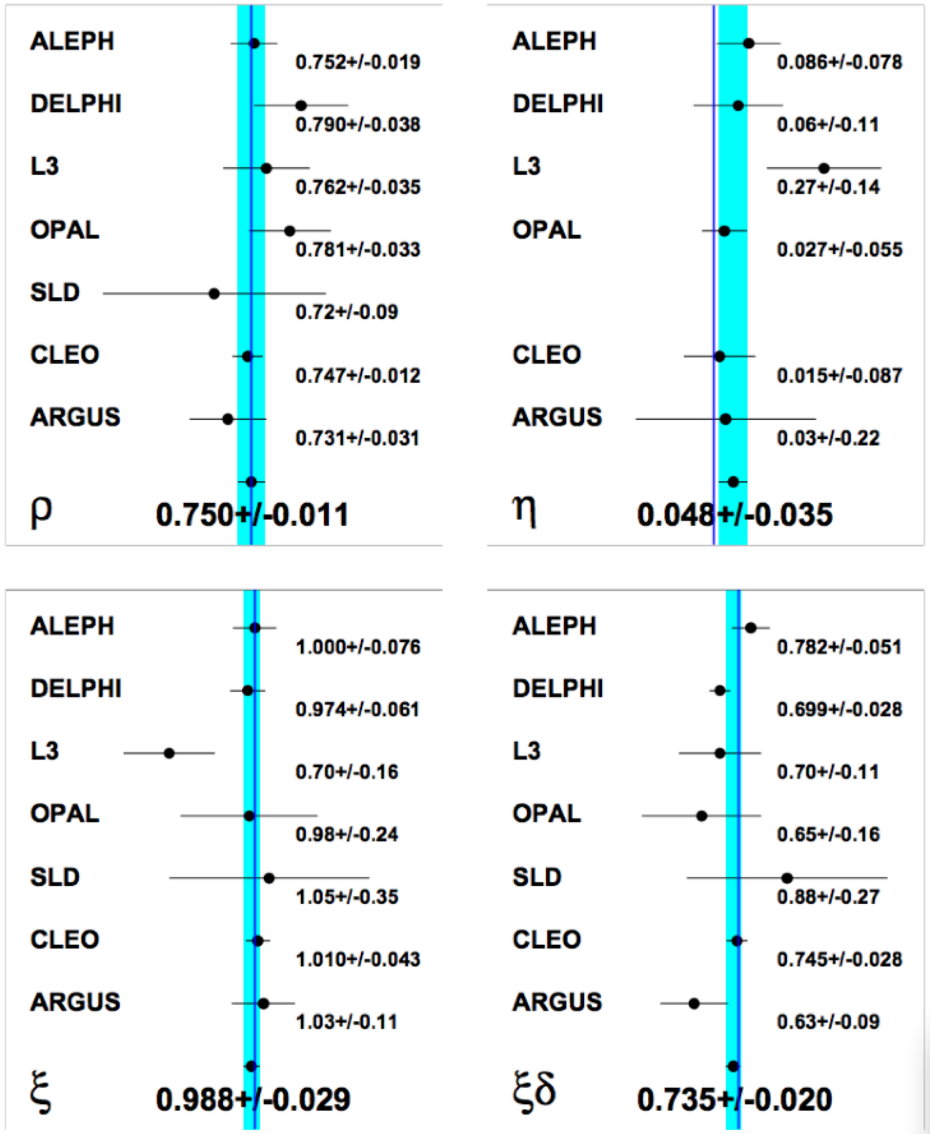
When spin of τ lepton is not determined, ρ, η, ξ and δ are the experimentally accessible parameters used in describing the phase space distribution of τ leptonic decays.

In SM:
ρ = $^3/_4$, η = 0, ξ = 1 and δ = $^3/_4$.

With full dataset (50 ab^{-1}), the statistical uncertainty is expected to be **~10^{-4}**.

Comparing with current Belle performance[1] , systematic uncertainties will be challenging at Belle II **(~10^{-3})**.



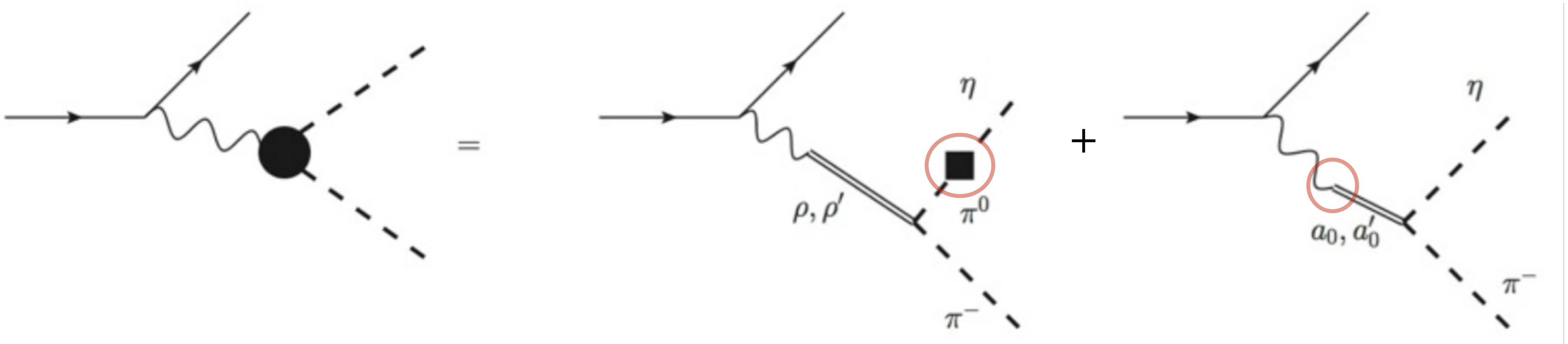


[1] D. Epifanov, Nucl.Part.Phys.Proc. 287-288 (2017) 7-10

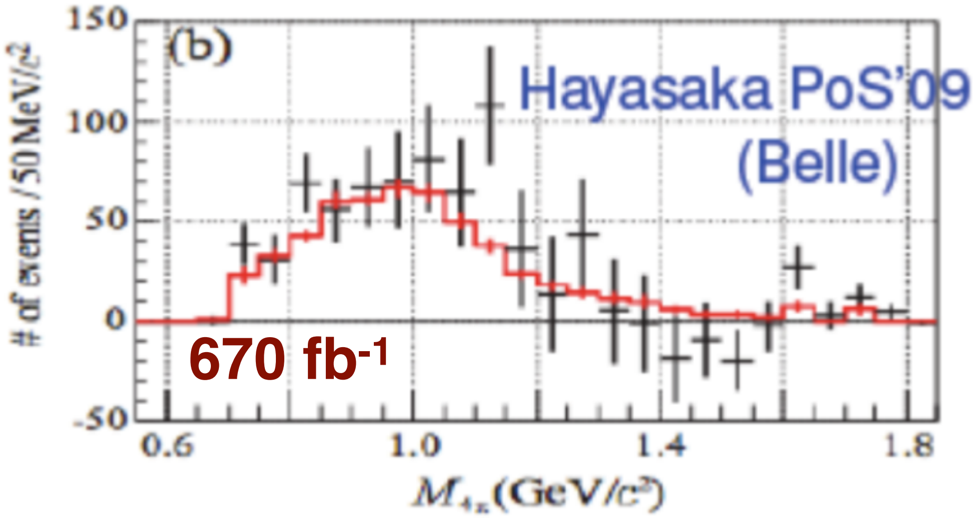
Second class currents: $\tau\to\eta\pi\nu$ decay

- Mechanisms in the SM: isospin violation

$$\epsilon_{\eta\pi} = \frac{\langle\pi^0|H|\eta\rangle}{m_\eta^2 - m_{\pi^0}^2} = \frac{\sqrt{3}}{4}\,\frac{m_d - m_u}{m_s - \bar{m}} \sim 1.5\times 10^{-2}$$

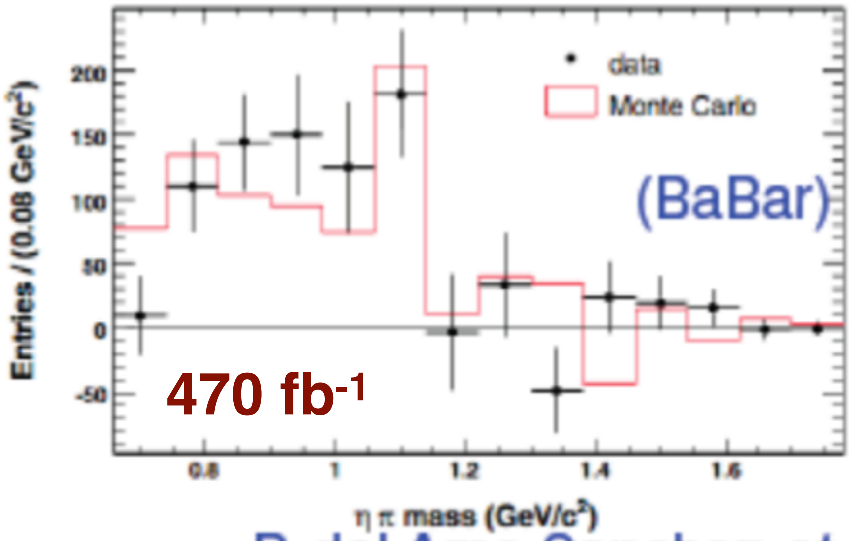


- The corresponding suppression of the SM contribution can make new physics visible.



Hayasaka PoS'09
(Belle)

670 fb^{-1}



(BaBar)

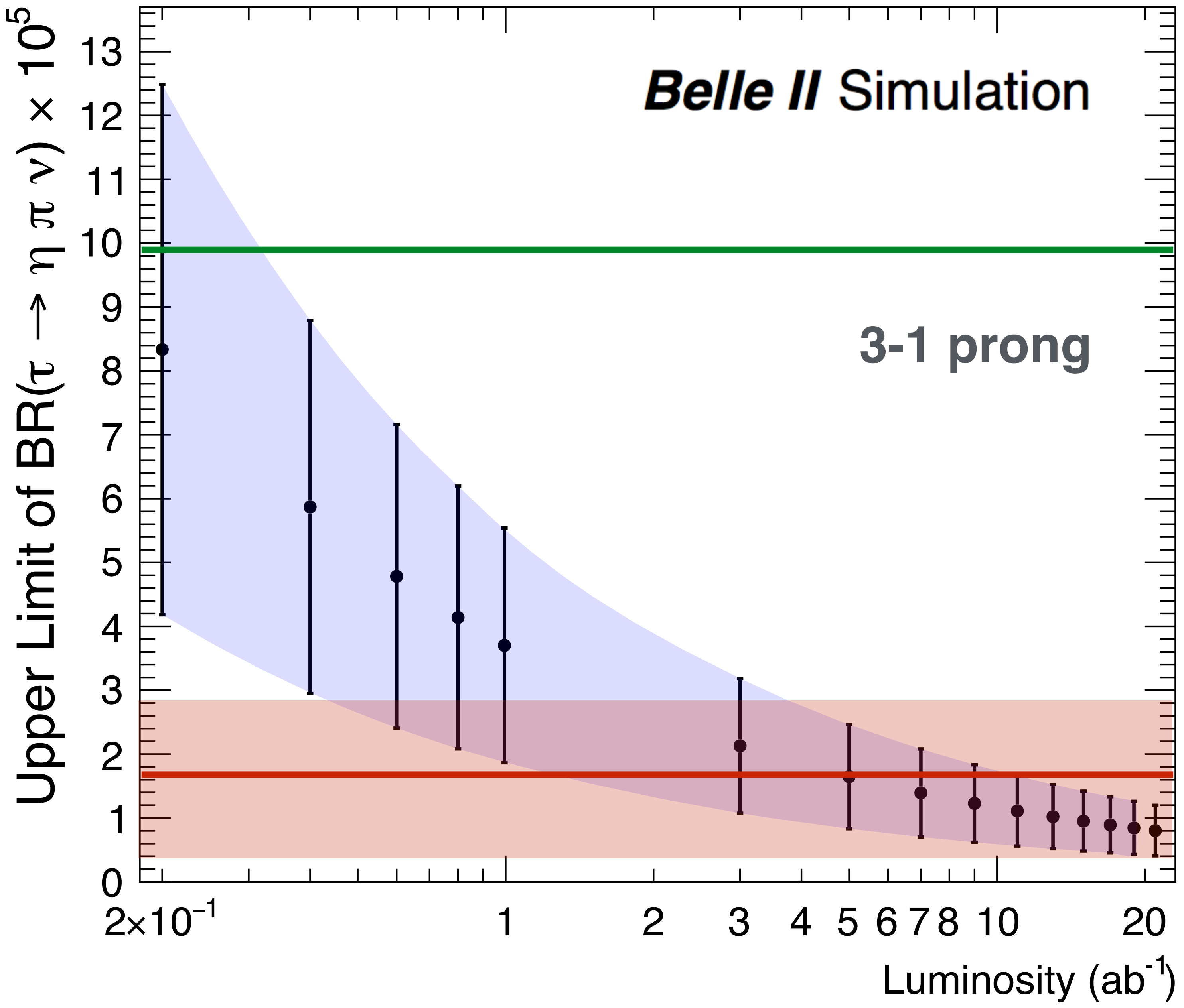
470 fb^{-1}

P. del Amo Sanchez *et.al*
(PRD 83 032002 '11)

$BR^{Belle}_{exp} < 7.3\cdot 10^{-5}$ 90% CL

$BR^{BaBar}_{exp} < 9.9\cdot 10^{-5}$ 95% CL

Estimated Upper Limits for $\tau \to \eta \pi \nu$



🟩 BaBar Upper Limit

🟥 3 coupled channels model

▨ Other models

SM predictions: $BR(\tau \to \eta \pi \nu) \sim 10^{-5}$

BR$_V$ (x10^5)	BR$_S$ (x10^5)	BR$_{V+S}$ (x10^5)	Model
0.36	1.0	1.36	MDM, 1 resonance
[0.2, 0.6]	[0.2, 2.3]	[0.4, 2.9]	MDM, 1 and 2 resonances
0.44	0.04	0.48	Nambu-Jona-Lasinio
0.13	0.20	0.33	Analiticity, Unitarity
0.26	1.41	1.67	3 coupled channels

We have the capability of testing models in the first years of data taking.

Summary

- The performance of the detector in the first months of data taking is good. Belle II is reconstructing $e^+e^- \rightarrow \tau^+\tau^-$ events.

- Semileptonic τ decays provides a clean environment to study SM processes with QCD involved.

- SuperKEKB will produce a sample of τ pairs 50 times larger than previous B-factories. Precision studies with τ leptons involved will be performed.

- Systematic uncertainties will become dominant. Improvements with respect to the last generation of B-factories are required.

- τ decays @ Belle II will provide very interesting results in the next decade. See “The Belle II Physics Book” at arXiv:1808.10567.

Thank you

Backup

B-Factories

	PEP-II	KEKB	SuperKEKB
Detector	BaBar	Belle	Belle II
Start date	1999	1999	2016
End of operations	2008	2010	-
Beam Energy (GeV)	e-: 9.0 e+: 3.1	e-: 8.0 e+: 3.5	e-: 7.0 e+: 4.0
Int luminosity	550 fb^{-1}	1 ab^{-1}	50 ab^{-1}

$\tau \to 3\pi\nu$ Event Selection

- **Tracks**
  - pT > 0.1 GeV
  - |dz| < 5 cm
  - |dr| < 1 cm
  - $-0.8660 < \cos(\theta) < 0.9565$
  - E/p < 0.8

- **γ's**
  - E > 200 MeV
  - nHits > 1.5
  - $E_9E_{25} > 0.9$
  - $-0.8660 < \cos(\theta) < 0.9565$

- **Event**
  - 3 - 1 prong
  - thrustValue > 0.87
  - visibleEnergyCMS < 9.7
  - $-0.8660 < \cos(\theta) < 0.9565$
  - E_τ signal at CMS < 5.29
  - E_τ tag at CMS < 5.22

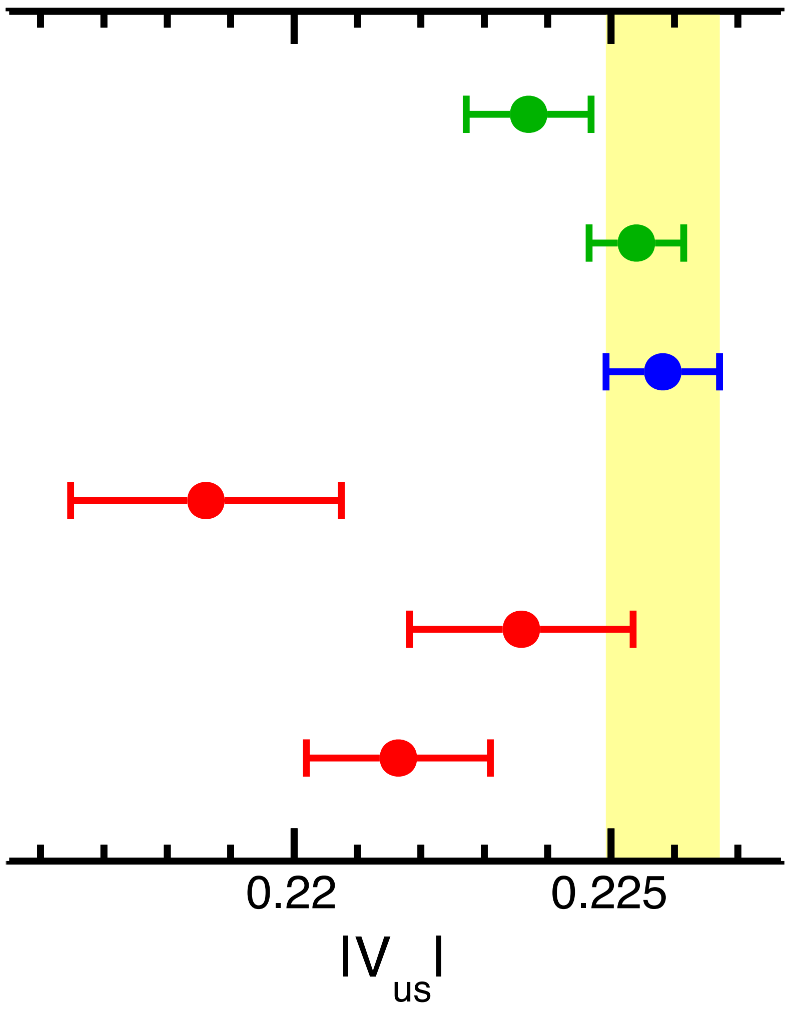
- π^0 - veto in signal side.
- $\pi^0 < 3$ in tag side.
- $N\gamma \leq 1$ in signal side.
- $N\gamma \leq 5$ in tag side.

- We require data to fire the L1 CDC trigger.

V_{us} from inclusive τ decays

$$|V_{us}|_{\tau s} = \sqrt{R_s / \left[\frac{R_{VA}}{|V_{ud}|^2} - \delta R_{\text{theory}} \right]}$$

- At present, the total V_{us} error is strongly dominated by the uncertainties in the weighted flavor spectral integrals.
- Significantly reduced V_{us} errors should be possible through improvements of the strange mode branching fractions.



K_{l3}, PDG 2016
0.2237 ± 0.0010

K_{l2}, PDG 2016
0.2254 ± 0.0007

CKM unitarity, PDG 2016
0.2258 ± 0.0009

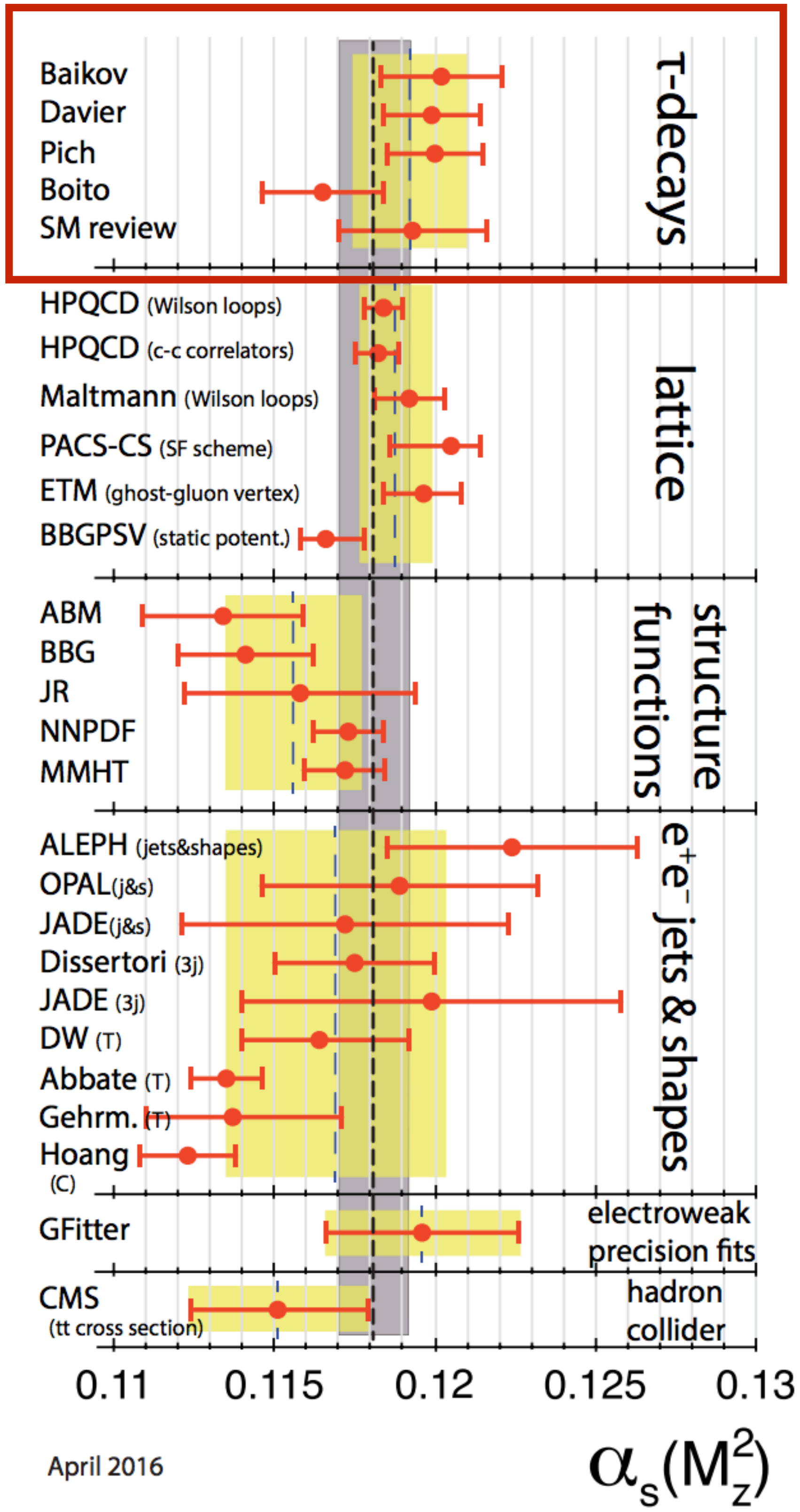
$\tau \to s$ incl., HFLAV Spring 2017
0.2186 ± 0.0021

$\tau \to K\nu$ / $\tau \to \pi\nu$, HFLAV Spring 2017
0.2236 ± 0.0018

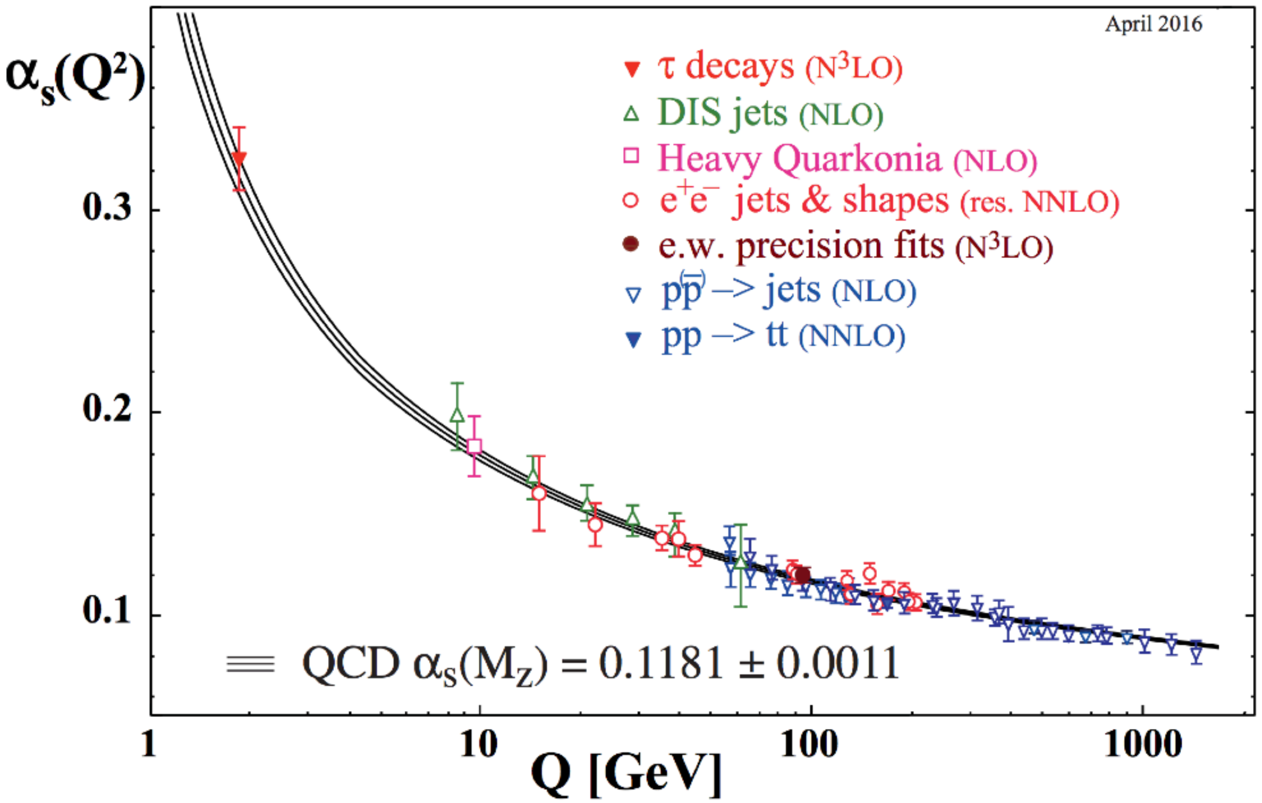
τ average, HFLAV Spring 2017
0.2216 ± 0.0015

HFLAV
Spring 2017

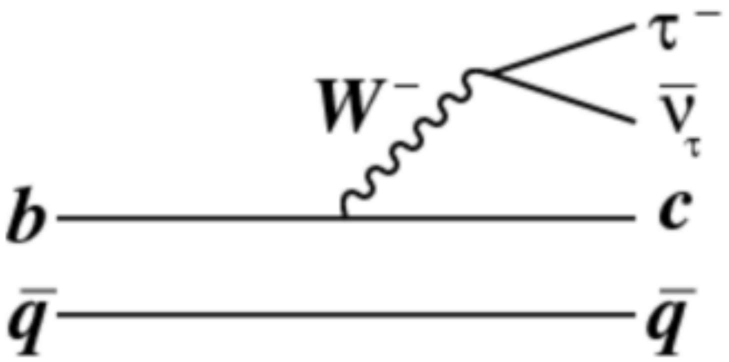
Measurement of $\alpha_s(m_\tau)$



- Analyses of the τ hadronic decay width and spectral functions have been performed, leading to precise determinations of α_s.
- They are based on different approaches to treat perturbative and non-perturbative contributions.



Sensitivity of R(D$^{(*)}$)



Uncertainties at Belle II

	5 ab^{-1}	50 ab^{-1}
R_D	$(\pm 6.0 \pm 3.9)\%$	$(\pm 2.0 \pm 2.5)\%$
R_{D^*}	$(\pm 3.0 \pm 2.5)\%$	$(\pm 1.0 \pm 2.0)\%$
$P_\tau(D^*)$	$\pm 0.18 \pm 0.08$	$\pm 0.06 \pm 0.04$

- Current measurements are dominated by statistical uncertainty.
- Dominant systematic: limited signal MC samples (Larger at Belle II).