Tau physics at Belle II

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Outline:

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

How Mexico joined Belle II

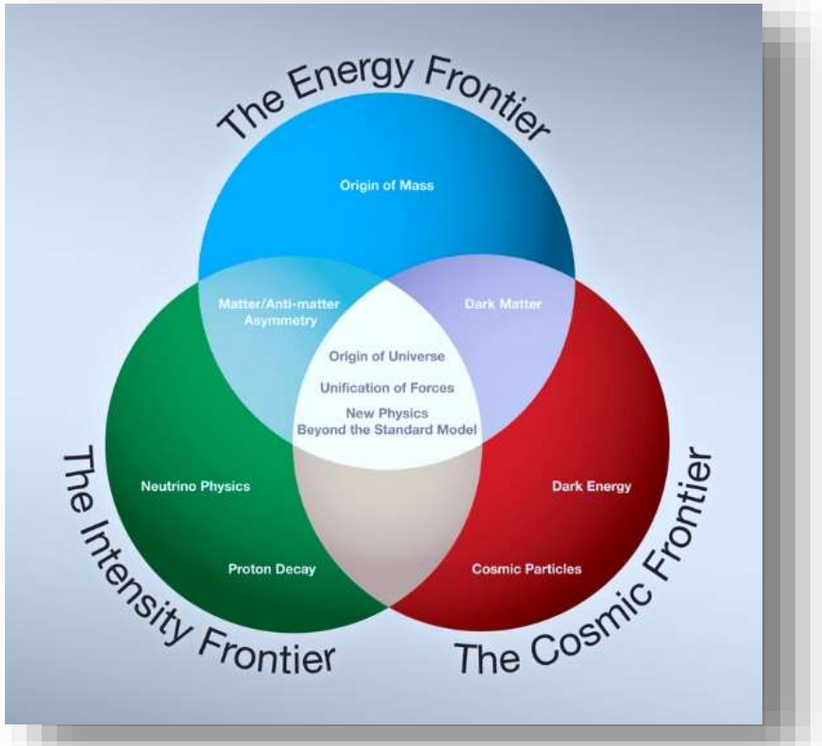
- In the context of the Mexican Network on HEP, in 2010-2011 after some national workshops a road map for HEP in Mexico was established.

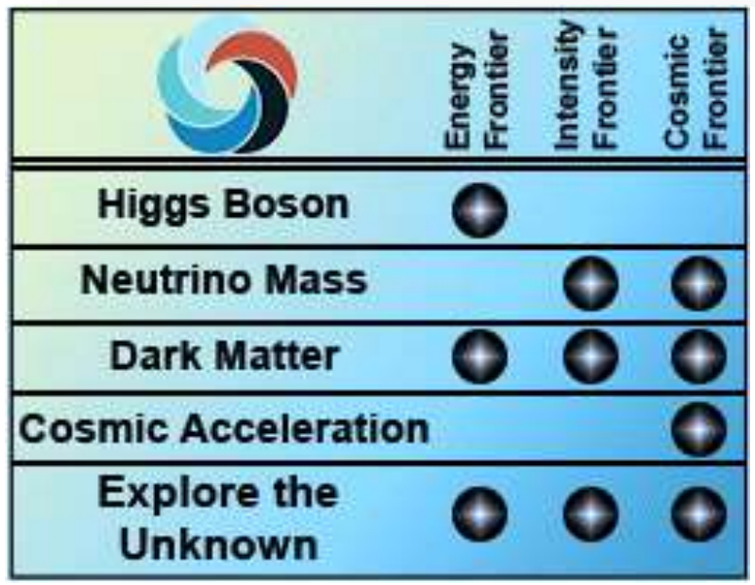
- In these workshops it was identified that Mexico needed to develop the experimental side in the intensity frontier.

- A group of Mexican institutions decided to join the SuperB Project in Italy, and funding was allocated for this.

- After SuperB was cancelled in 2012, an small group decided to continue this in SuperKEKB and joined Belle II in July 2013.

- To match the theoretical and experimental work in Mexico, the Mexican group at Belle II decided to concentrate mainly on tau lepton physics.

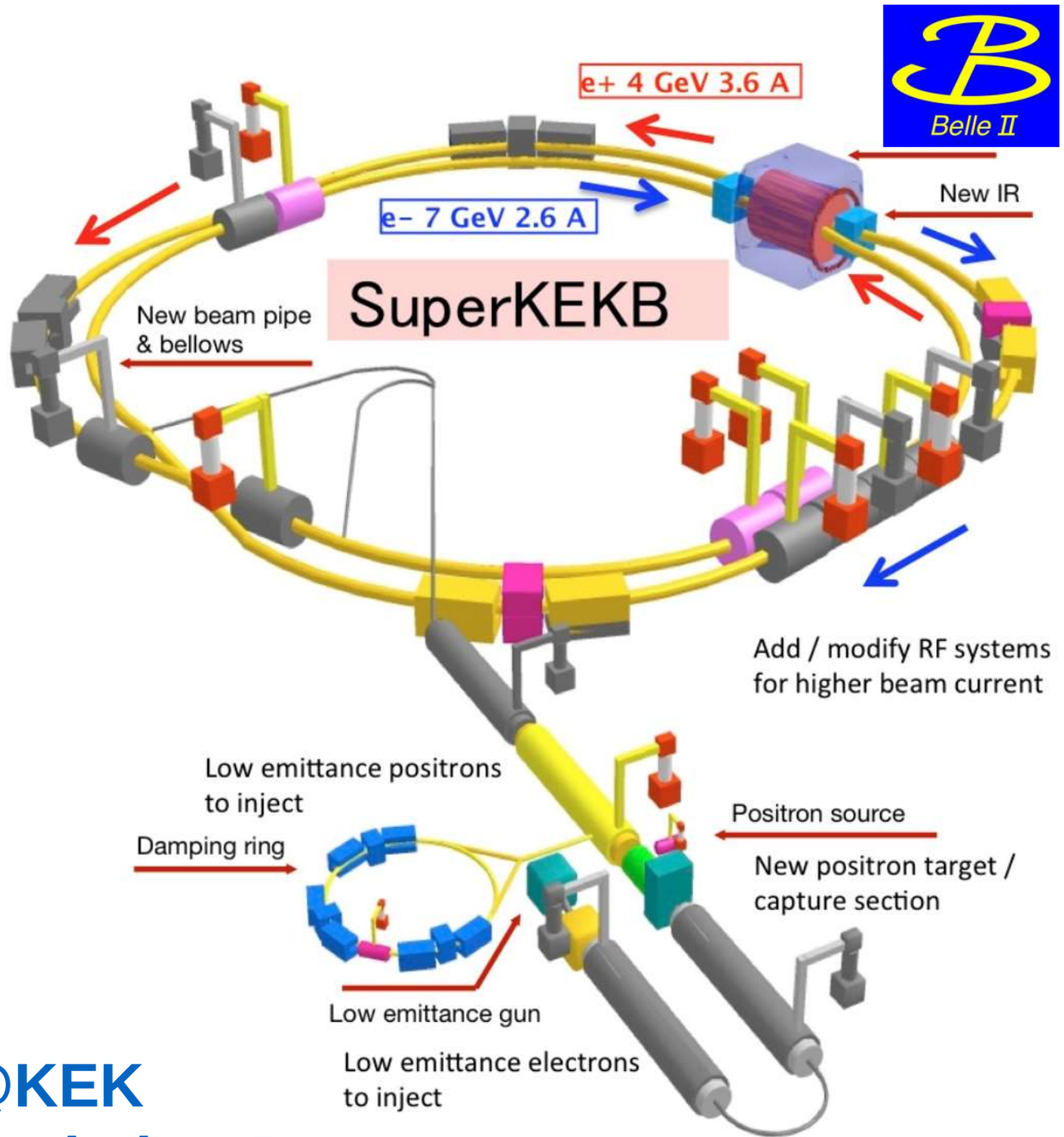




B-Factories

	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}

Next gen: SuperKEKB



@KEK
Tsukuba, Japan

- **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

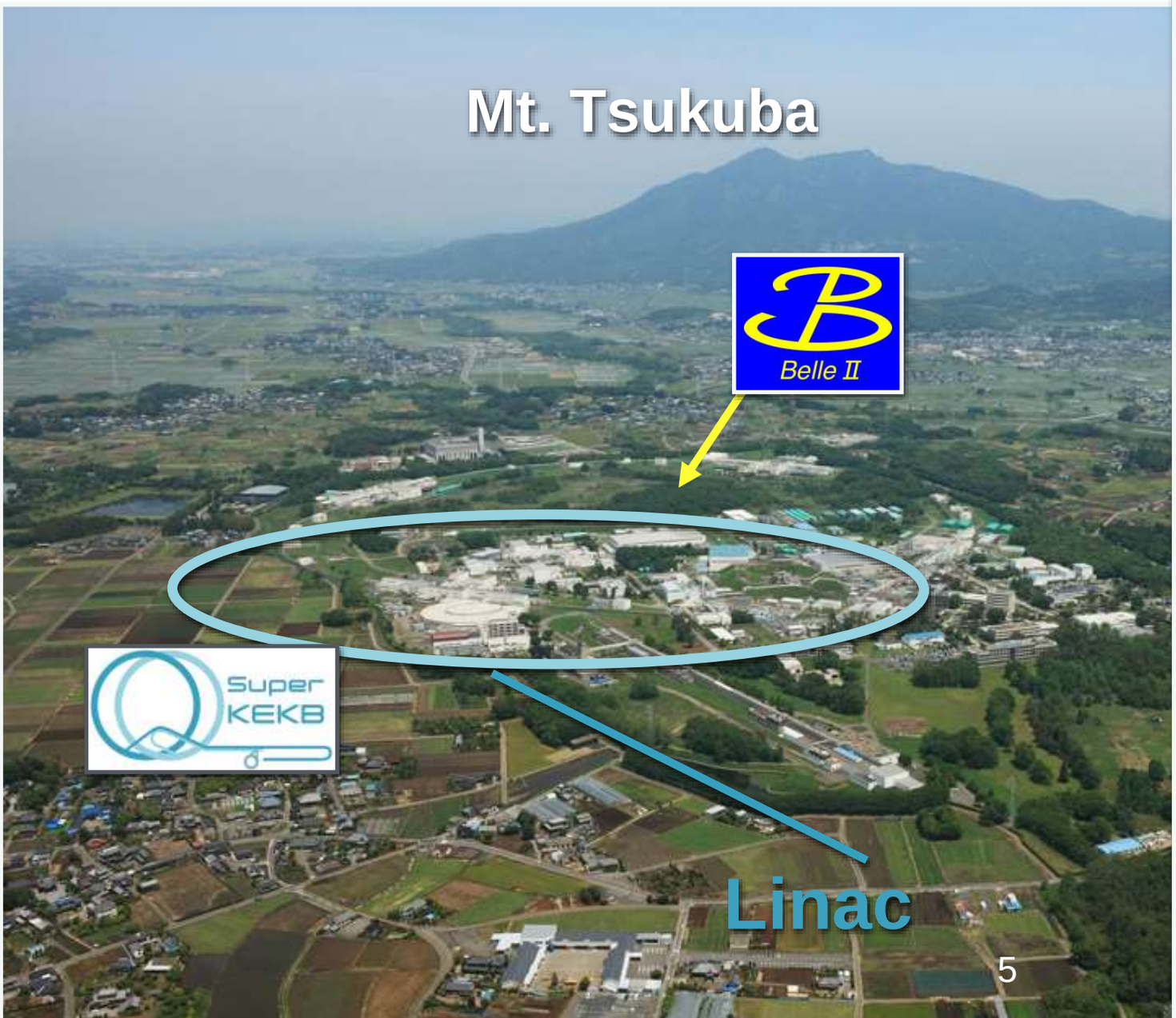
- Integrated luminosity expected:
  50 ab^{-1}

  (x50 than previous B factories)

4.6×10^{10} τ pairs

Belle II collaboration

- 1047 members (420 students), 119 institutions, 26 countries
- Located in KEK at Tsukuba, Japan



Mexico @ Belle II

- Mexico requested to join Belle II in 2013
- Currently three institutions: CINVESTAV IPN, UAS and UNAM (IF).
- Eight faculty researchers (6 exp. & 2 theo.)
- Six Ph.D. students

Commitments:

Hardware:

• Electronics for LABM (Large angle beamsstrahlung monitor)

Software:

• Grid support (the student graduated and moved to Mississippi)

Computing:

• Tier 2 cluster on GRID for Belle II

Mexican commitments

JAGUARLFIS.MX

- **Tier 2 center for Belle II online since May 2015.**

- **Mainly MC production, problems of bandwidth for data analysis.**

LABM detector

Installed and working, and the Mexican group plays a important role in its M&O.

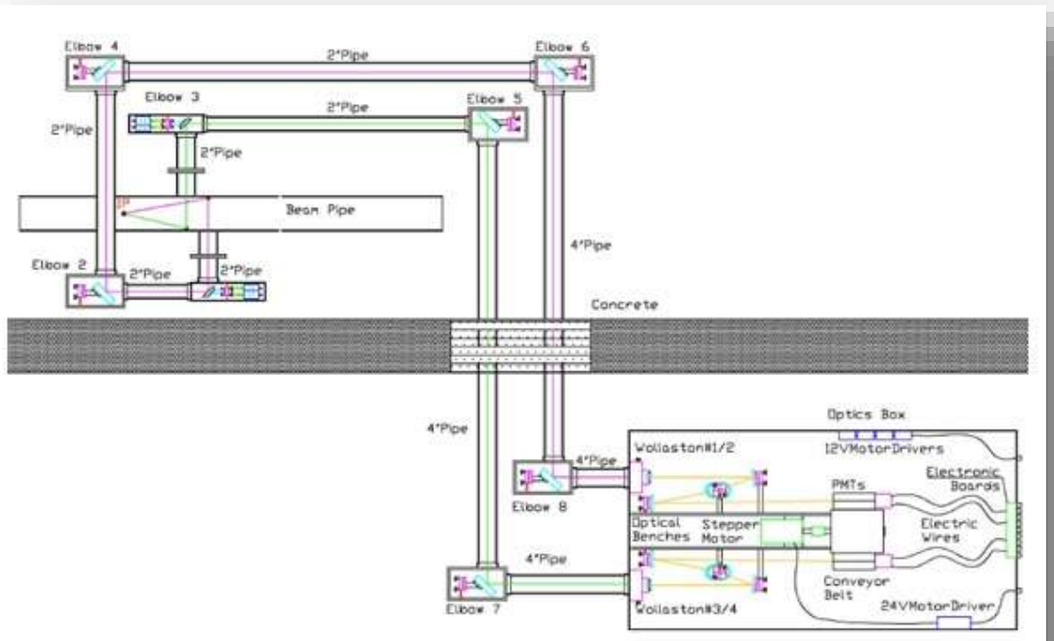
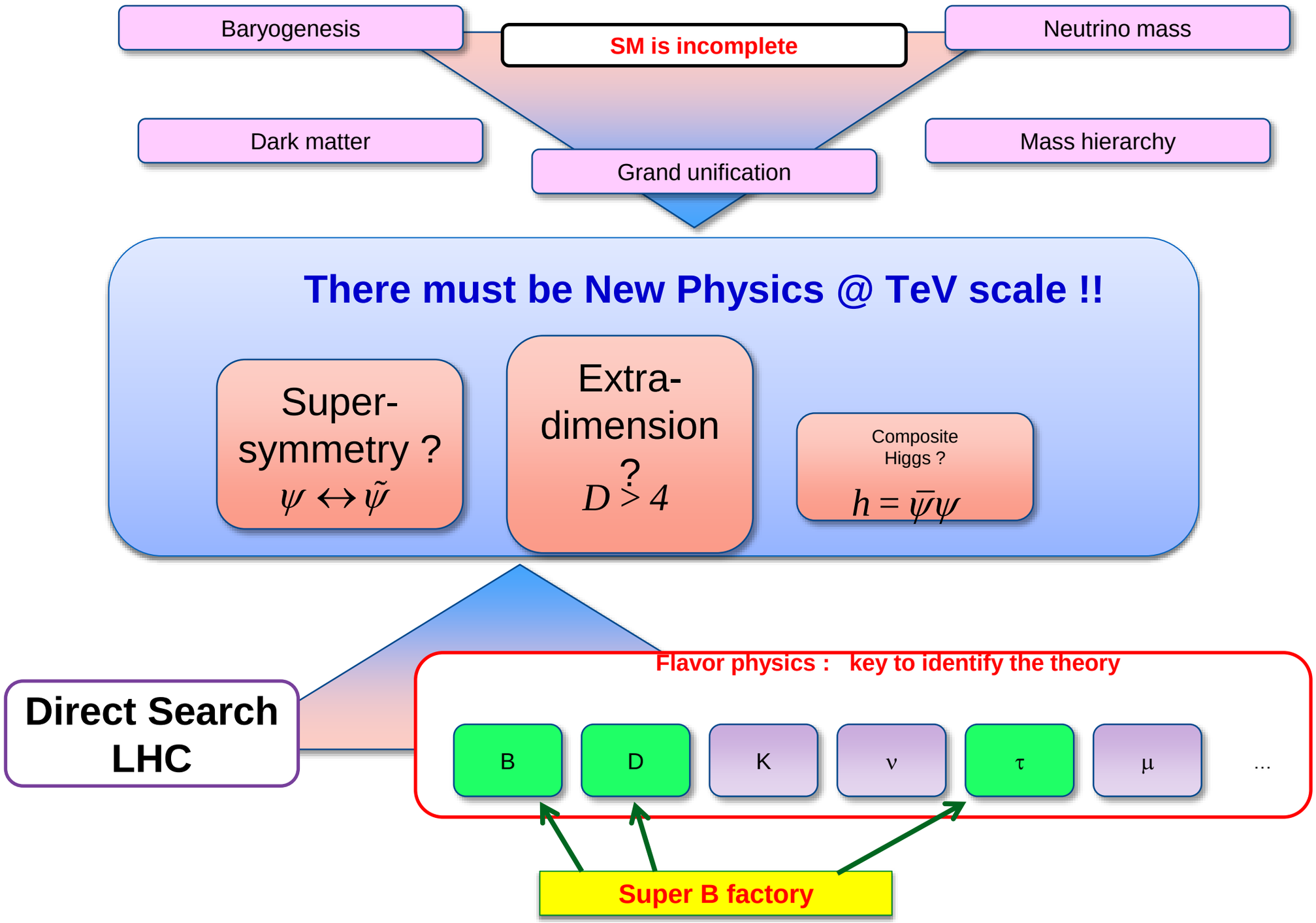


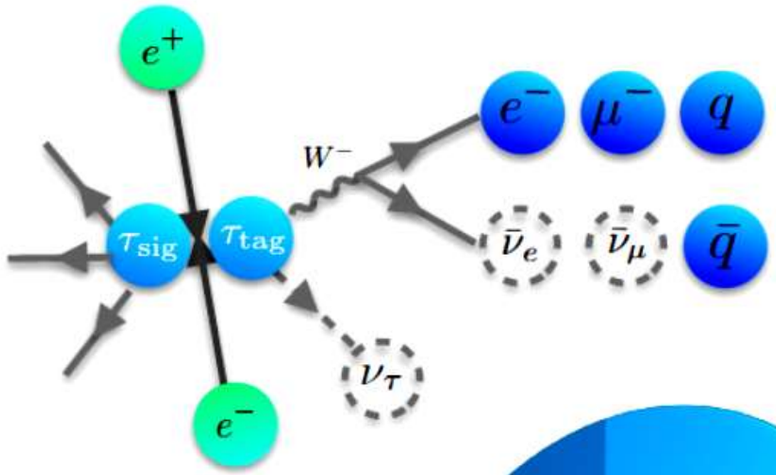
Figure 3.1: Schematic of the Beamstrahlung Detector That Will Be Used at BELLE II

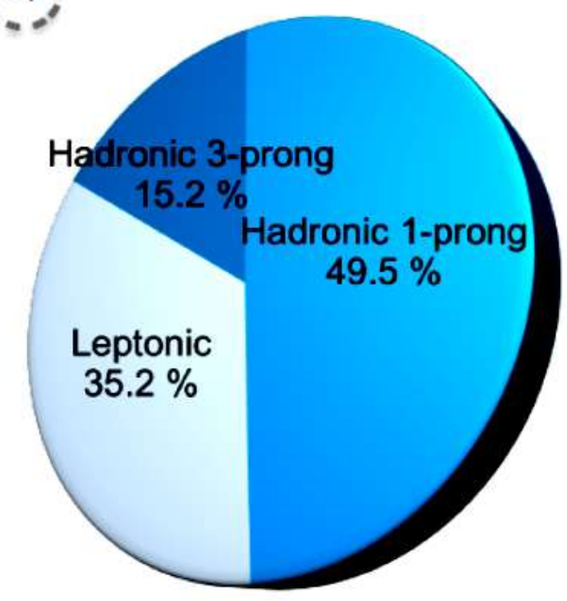
Physics goals of SuperKEKB

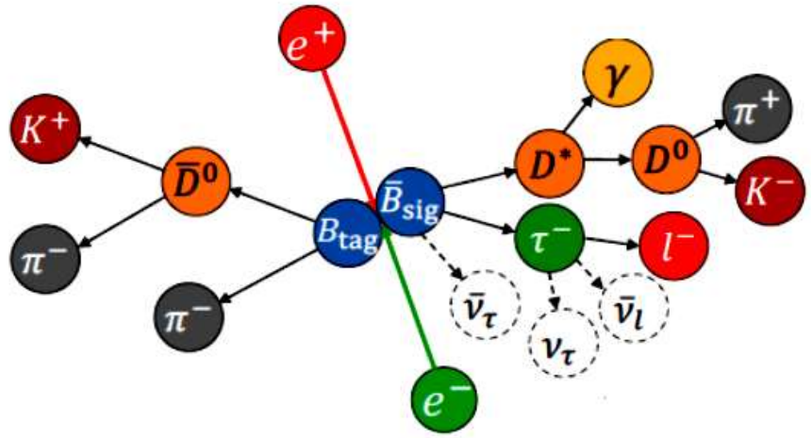


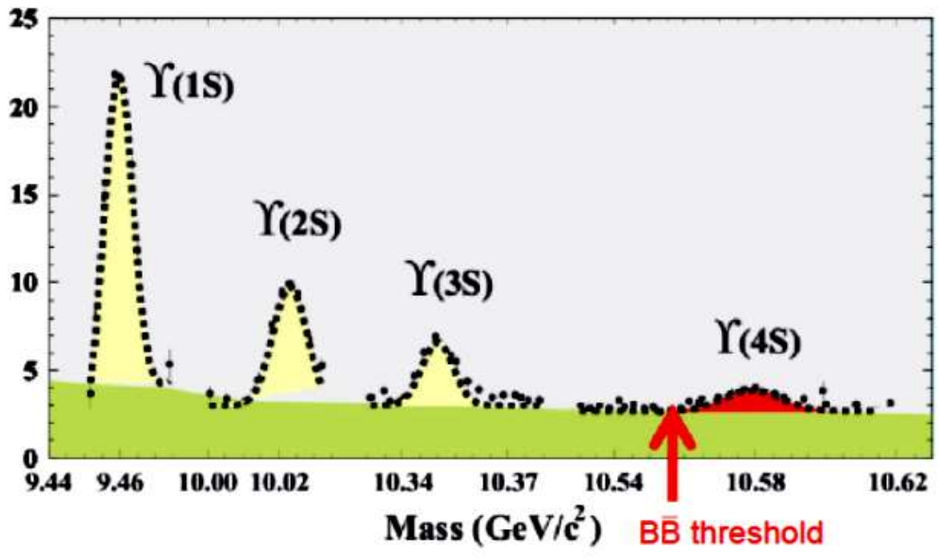
τ in Belle II

Not possible to fully reconstruct the full event









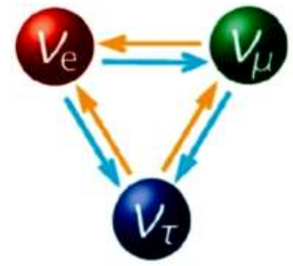
e^+e^- annihilation data is ideal for missing energy channels

- the kinematics of the initial state is precisely known
- the neutrino energy can be determined precisely

Lepton flavour and number ...

Conservation of the individual lepton-flavour and the total lepton numbers within the SM ($m_\nu = 0$)

$$G_{SM}^{global} = U(1)_B \times U(1)_{L_e} \times U(1)_{L_\mu} \times U(1)_{L_\tau}$$

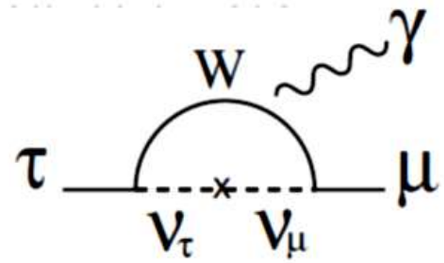


➡ The observation of neutrino oscillations as a first sign of LFV beyond the SM!

What about the charged leptons?

➡ The charged LFV processes can occur through oscillations in loops

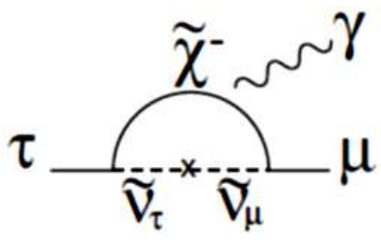
➡ Immeasurable small rates (10^{-54}-10^{-49}) for all the LFV μ and τ decays



$$\mathcal{B}(\ell_1 \to \ell_2\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\ell_1 i} U_{\ell_2 i} \frac{\Delta m^2_{i1}}{M_W^2}\right|^2$$

Observation of LFV will be a clear signature of the NP!

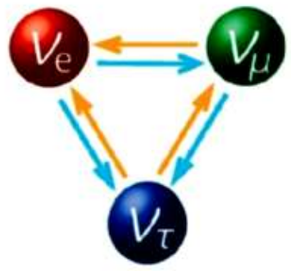
➡ Charged LFV enhanced in many NP models (10^{-10} - 10^{-7})



Lepton flavour conservation

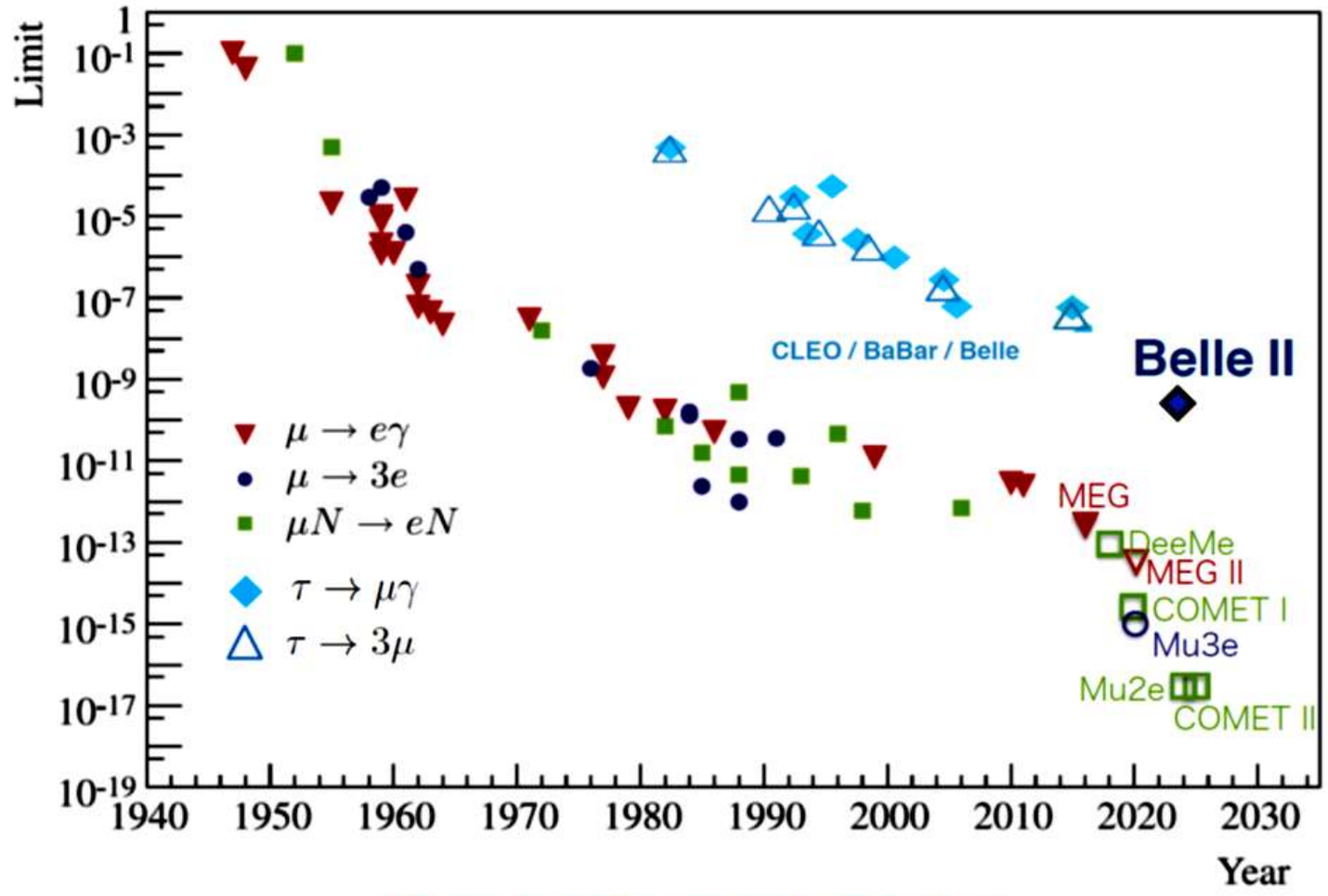
Conservation of the individual lepton-flavour and the total lepton numbers within the SM ($m_\nu = 0$)

$$G_{SM}^{global} = U(1)_B \times U(1)_{L_e} \times U(1)_{L_\mu} \times U(1)_{L_\tau}$$



➡ The observation of neutrino oscillations as a first sign of LFV beyond the SM!

What about the charged leptons?

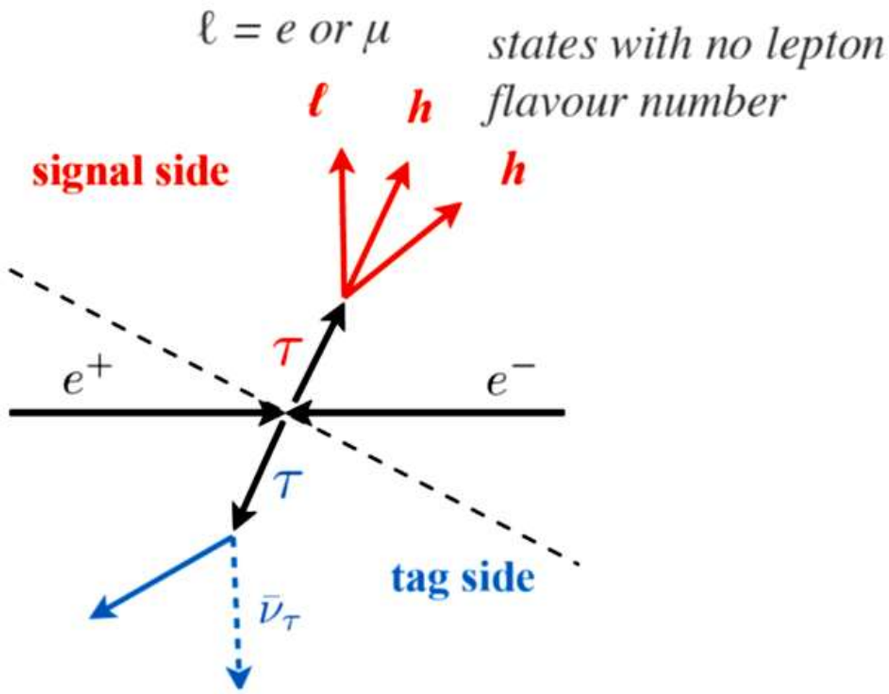


No success in searches so far!

LFV and LNV using τ´s

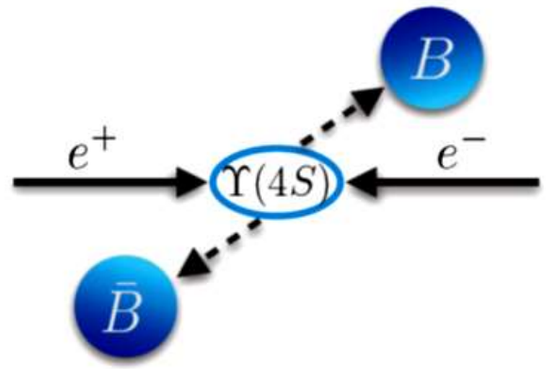
NP may favour the third generation!?

The only lepton that decays into hadrons



- a large variety of **LFV** and **LNV** **semi-leptonic** decays ($\tau \to \ell h(h)$), in addition to radiative ($\tau \to \ell\gamma$) and leptonic decays ($\tau \to \ell\ell\ell$)
- $\tau \to \mu$ and $\tau \to e$: test of the lepton flavour structure

B mesons decay into e, μ, τ leptons



- modes used to test the lepton flavour universality

TREE

$B \to \ell\nu$

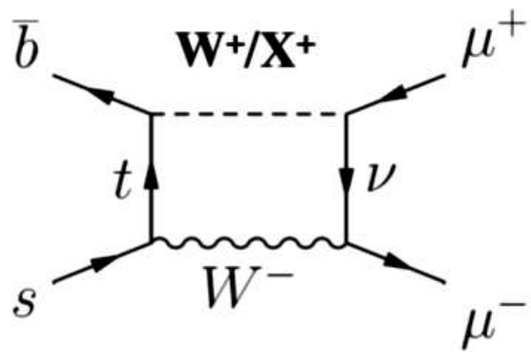
$B \to D^*\ell\nu$

LOOP

$B \to \ell\ell$

$B_s \to \ell\ell$

$B \to K^{(*)}\ell\ell$

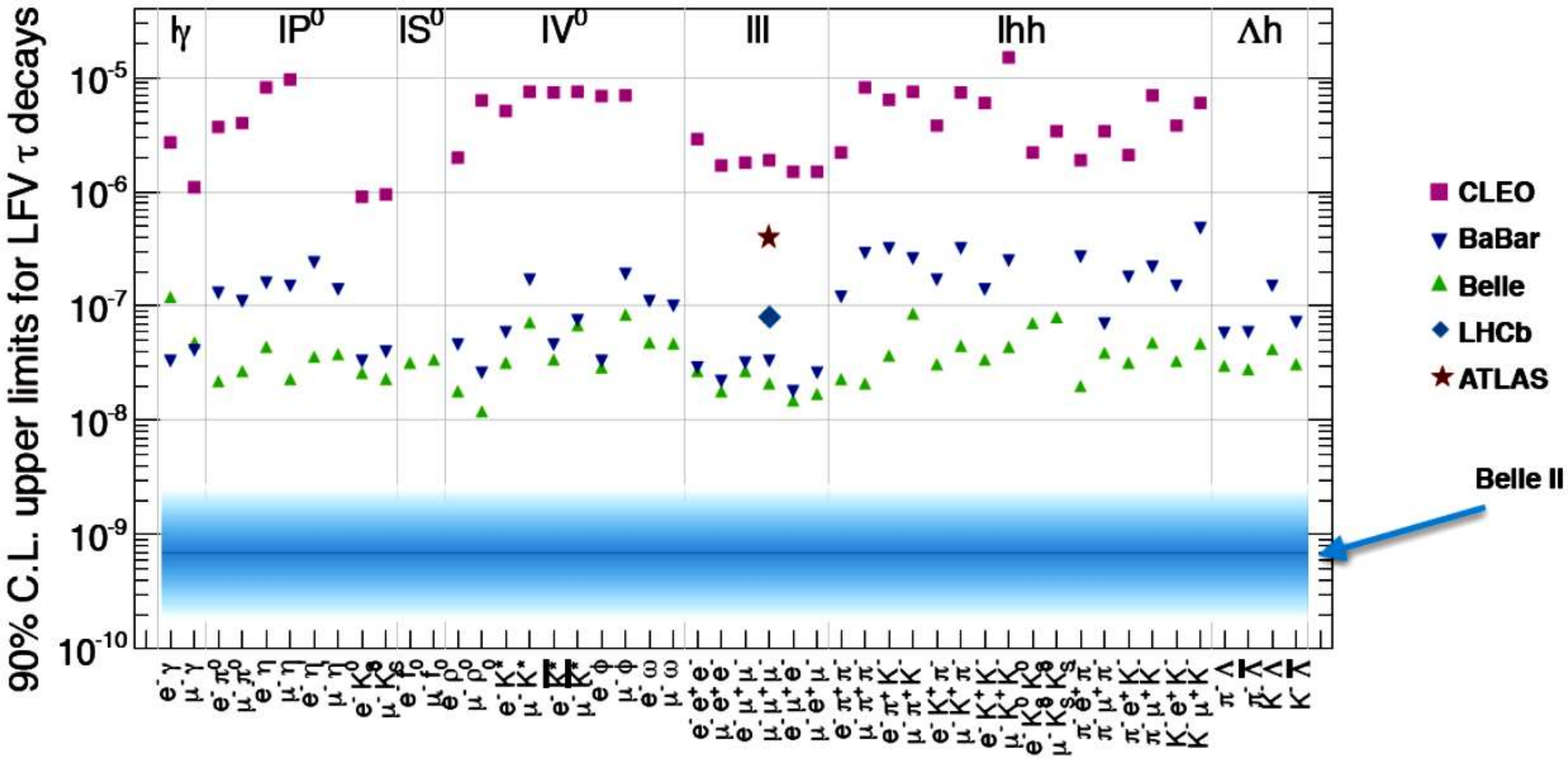


Test the SM in a variety of ways

Perspectives of LFV

LFV and LNV τ decays

➡ One of the factors pushing up the sensitivity of probes is the increase of the luminosity



➡ Equally important is the increase of the signal detection efficiency

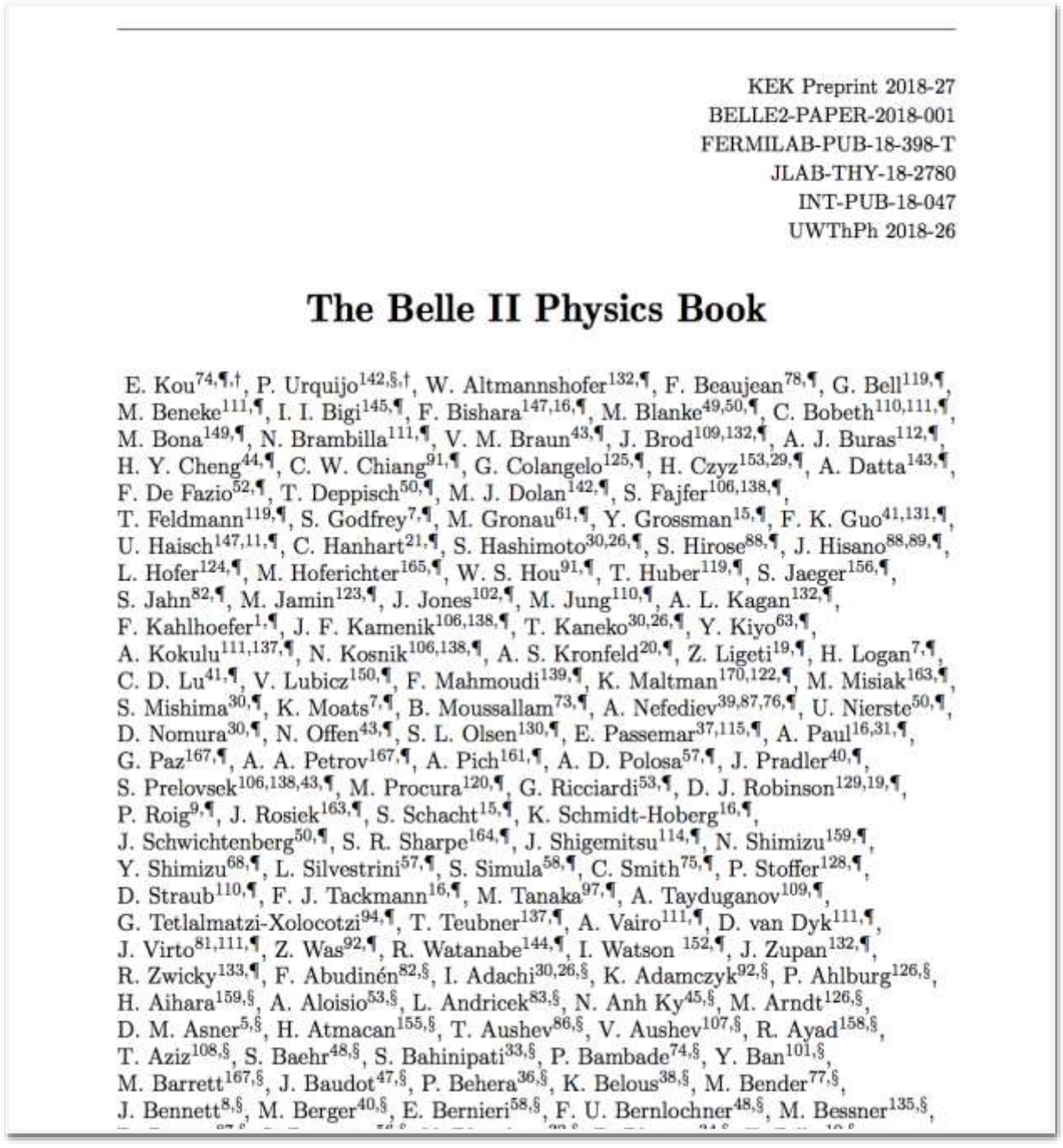
➡ high trigger efficiencies; improvements in the vertex reconstruction, charged track and neutral-meson reconstructions, particle identification, refinements in the analysis techniques…

The searches at Belle II will push the current bounds further by more than one order of magnitude

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



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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,§],

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

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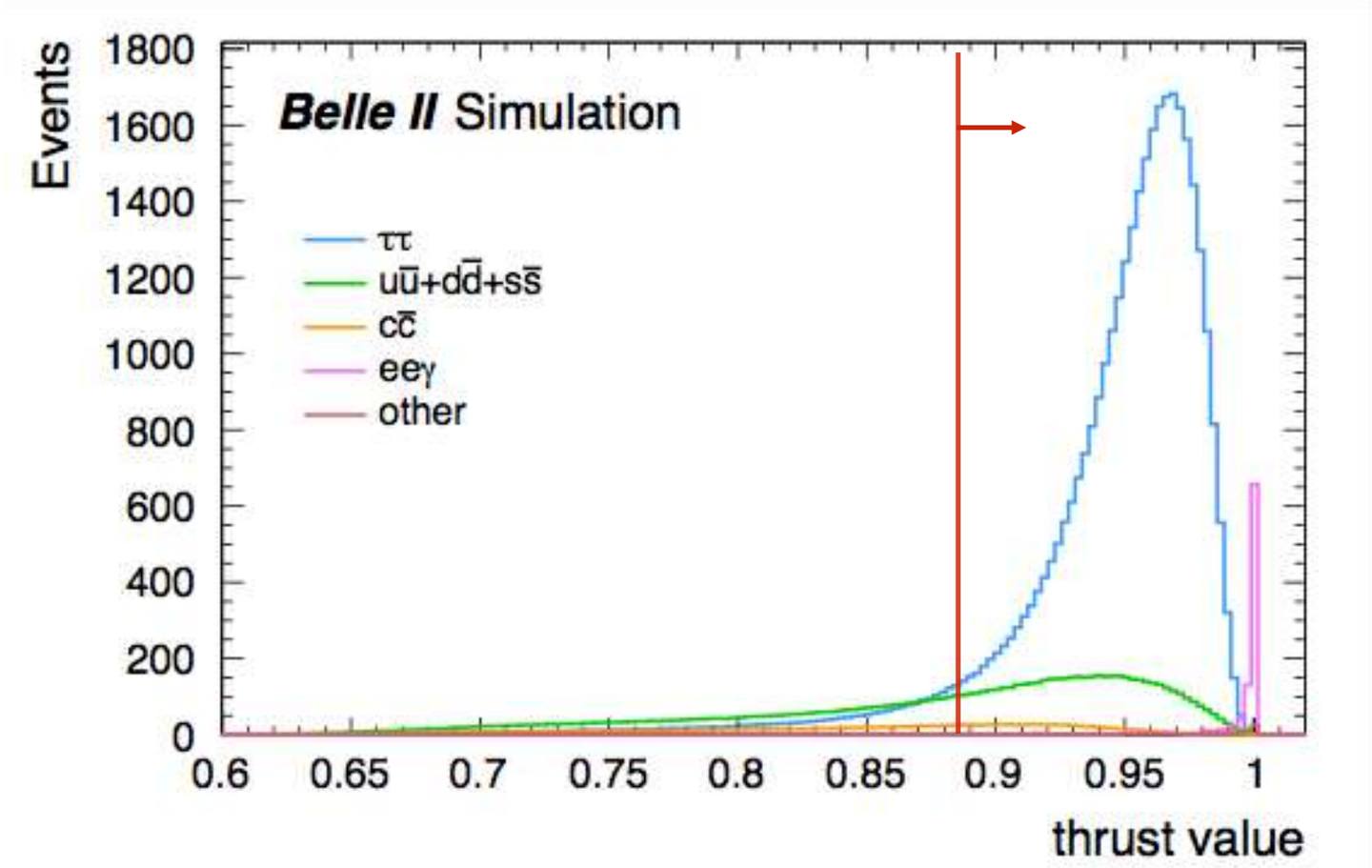
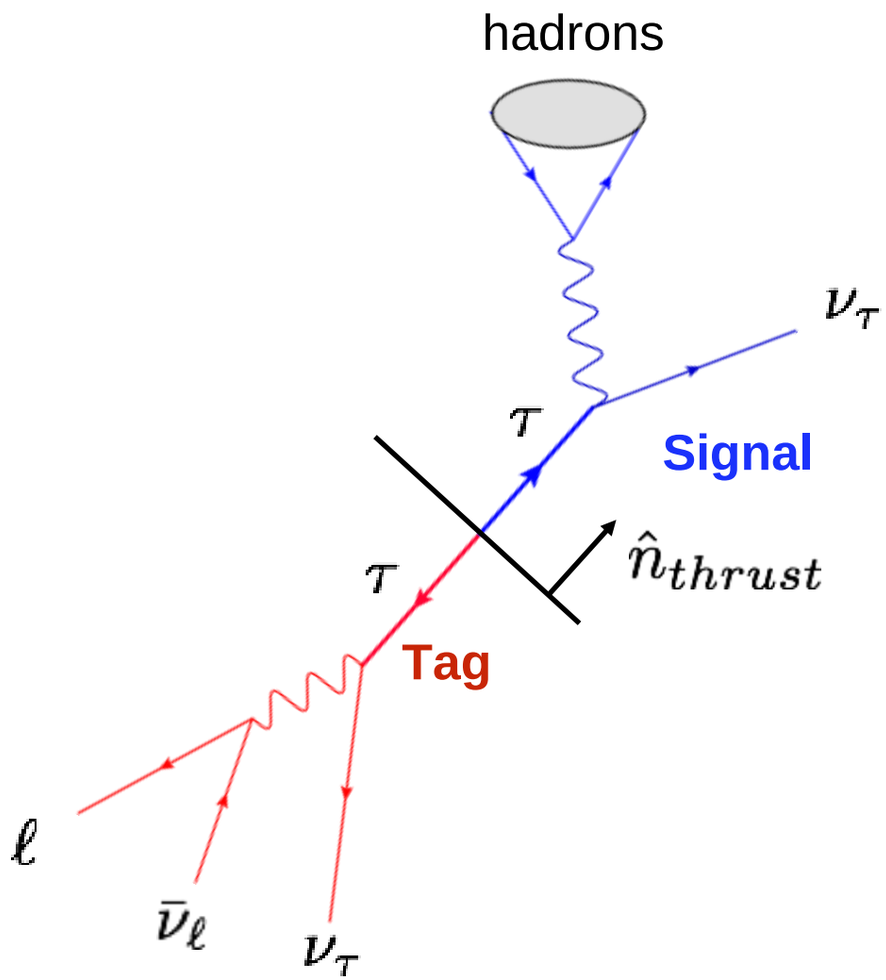
Candidates: 3 - 1 prong decay

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

We are assuming pion hypothesis in signal side.

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

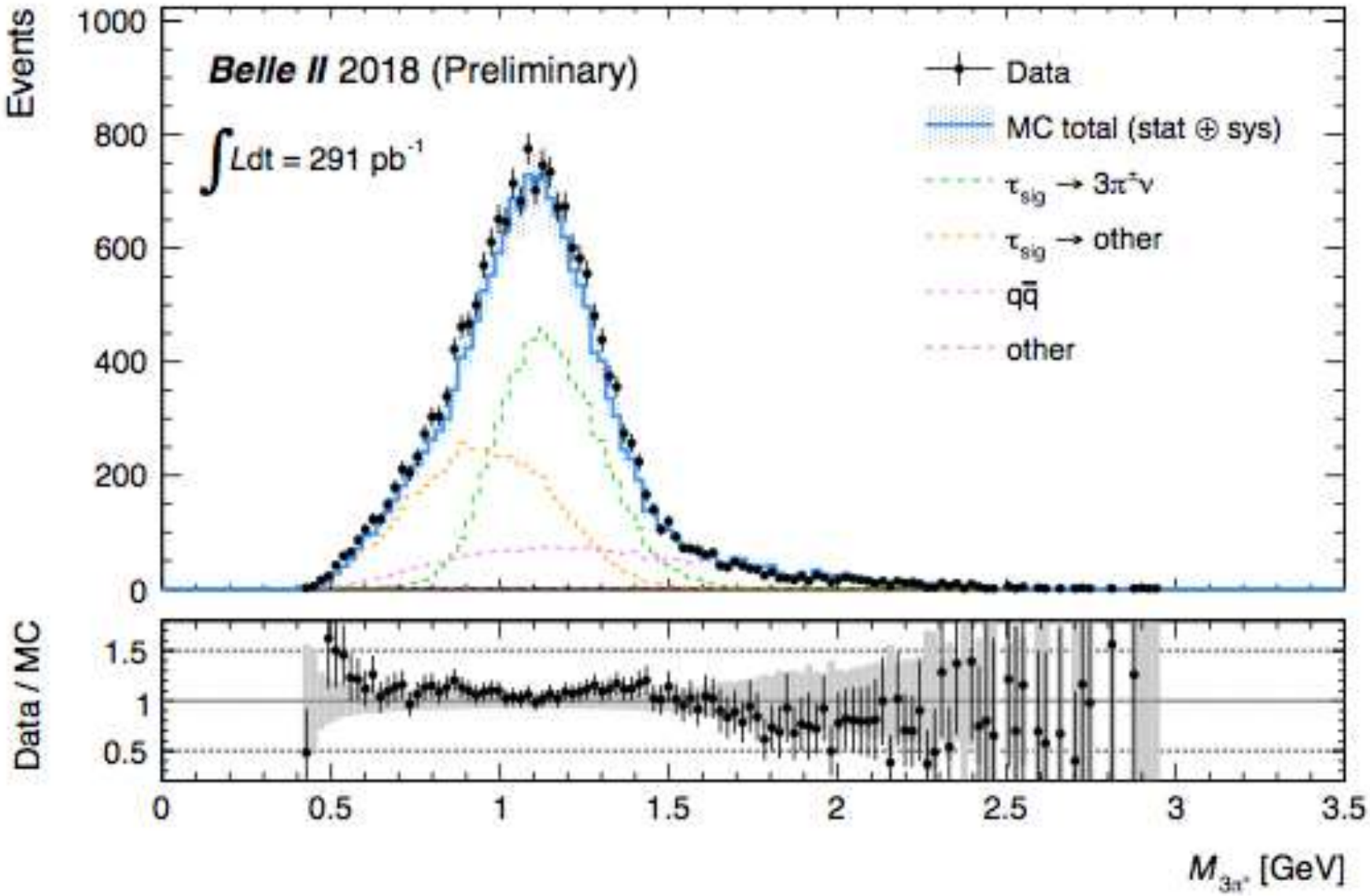




$$V_{thrust} = \frac{\sum_i |\vec{p}_i{}^{\,cm} \cdot \hat{n}_{thrust}|}{\sum_i |\vec{p}_i{}^{\,cm}|}$$

Belle II

$\tau \to 3\pi\nu$ 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.

Measurement of τ mass

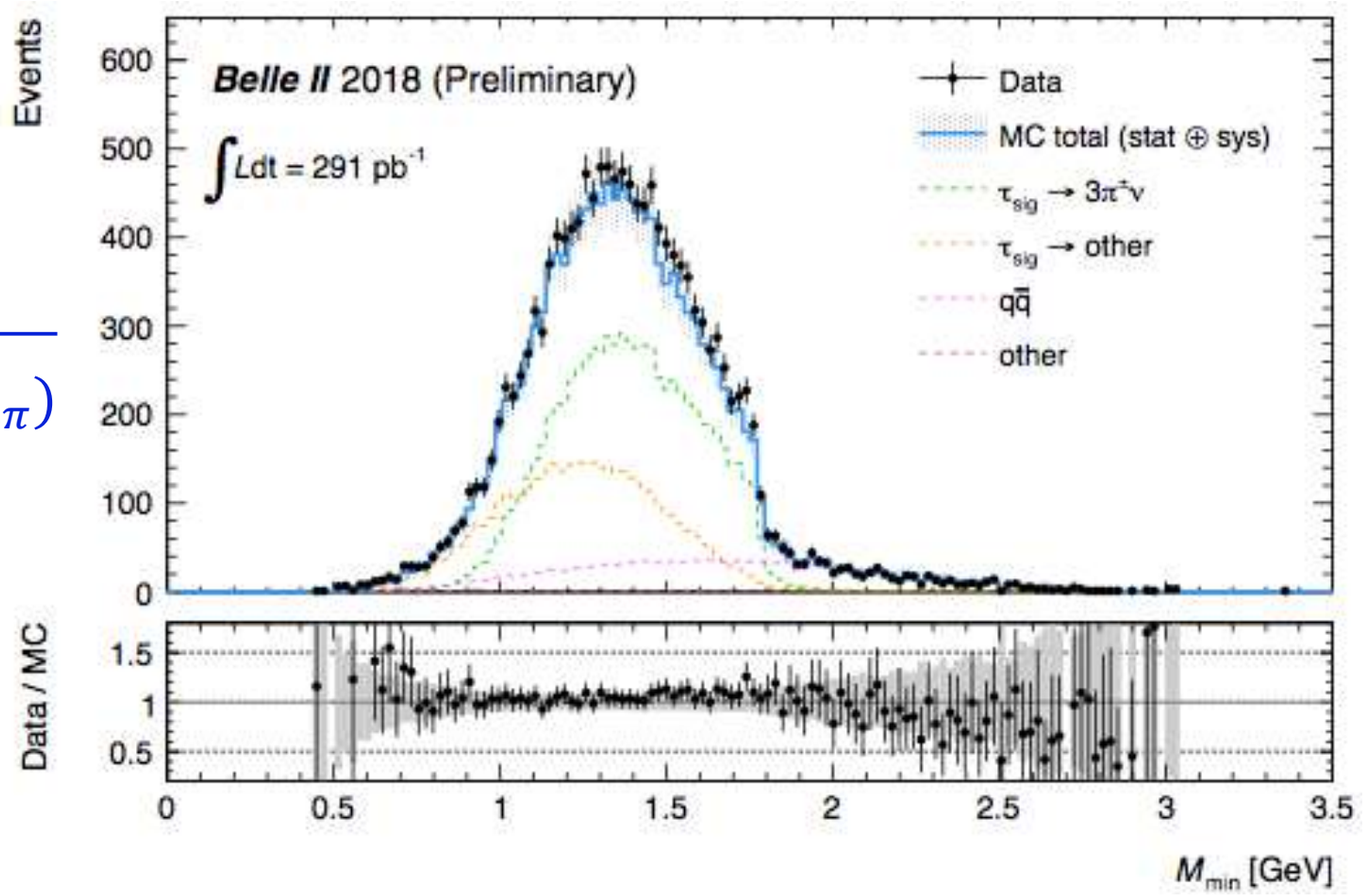
- Measured in the decay mode $\tau \rightarrow 3\pi\nu$, using a pseudomass technique developed by the ARGUS collaboration:

- $$M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})}$$

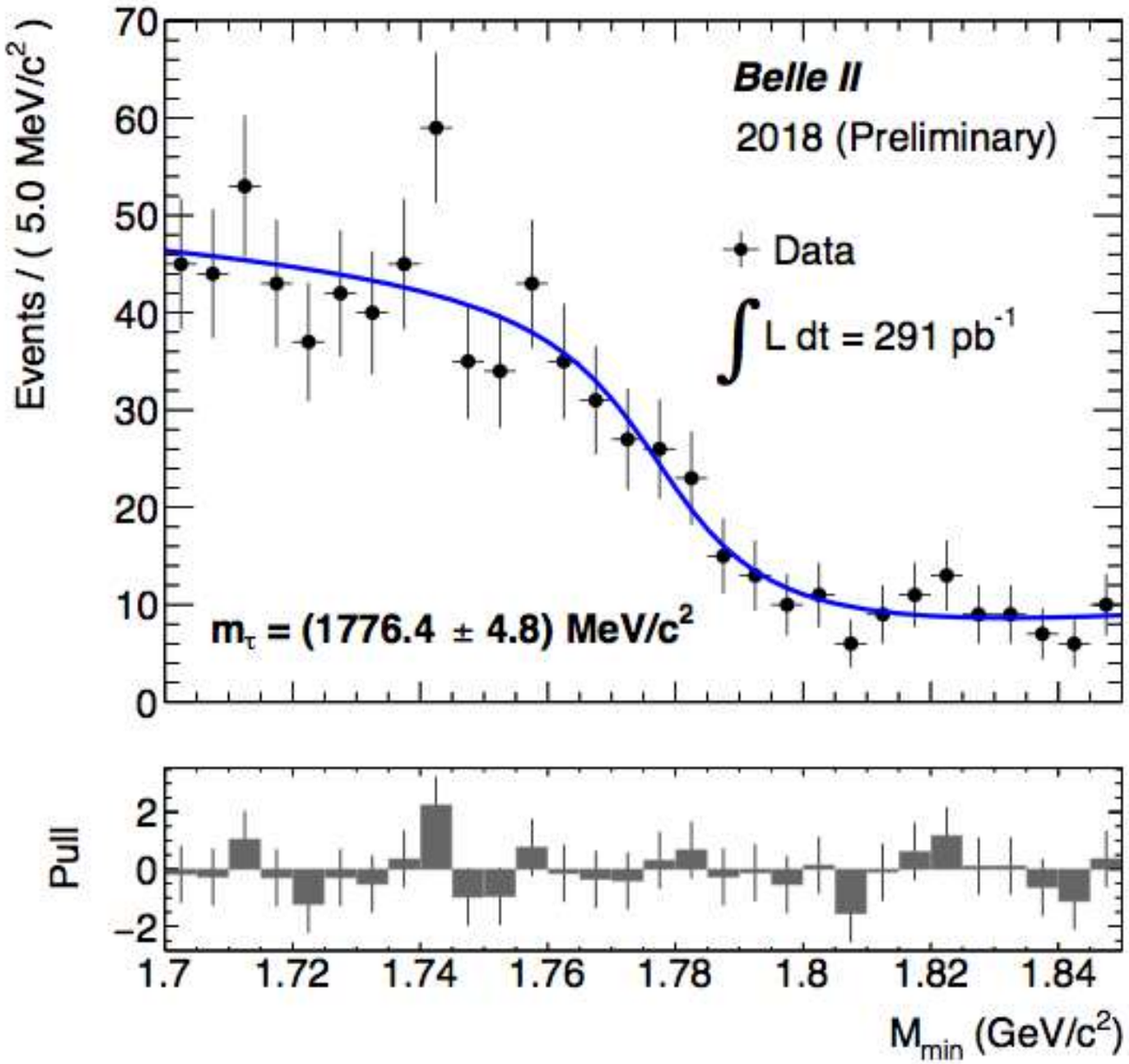
- The distribution of the pseudomass is fitted to a empirical edge function.

- 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}:



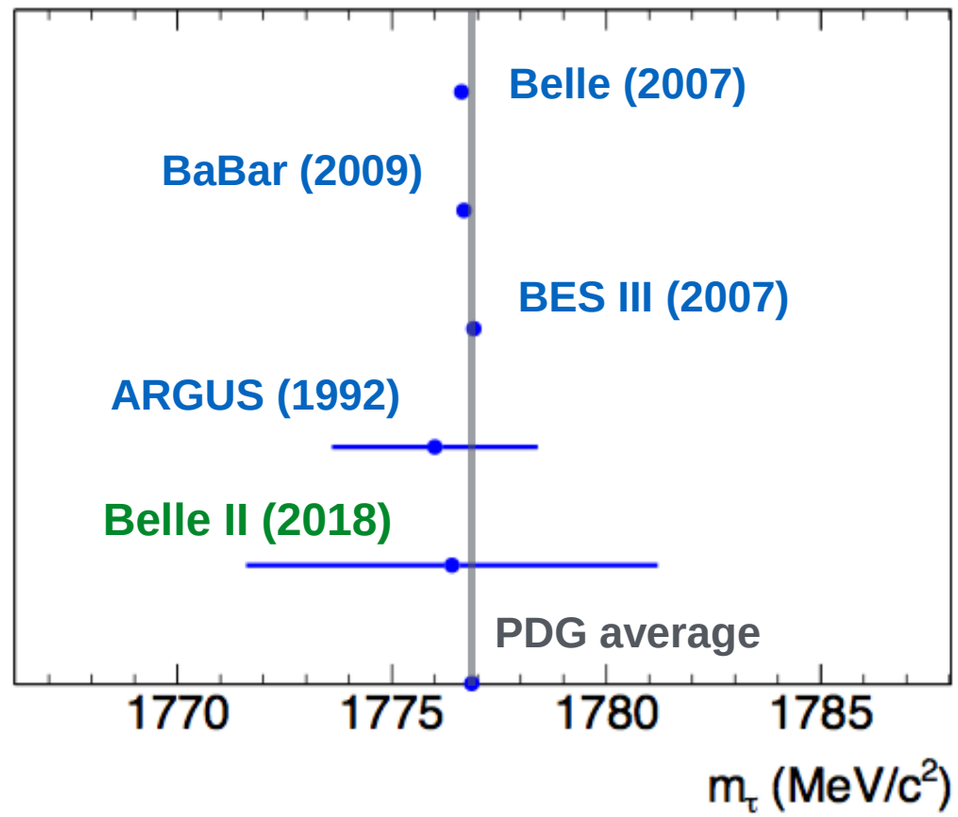
Measurement of τ mass



Our result, obtained from Belle II early data

m_τ = (1776.4 ± 4.8 (stat)) MeV/c^2

Is consistent with previous experimental results.



Summary and status

- The performance of the detector in data taking is good. Belle II is reconstructing $e^+e^- \rightarrow \tau^+\tau^-$ events.
- From July to October Belle II is in shutdown for maintenance
- So far two publications and more coming on soon
- SuperKEKB will produce a sample of τ pairs 50 times larger than previous B-factories. Precision studies with τ leptons involved will be performed.
- With the incoming data, the Mexican group is concentrating in the search for LFV tau decays.
- τ decays @ Belle II will provide very interesting results in the next decade. See “The Belle II Physics Book” at arXiv:1808.10567.

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

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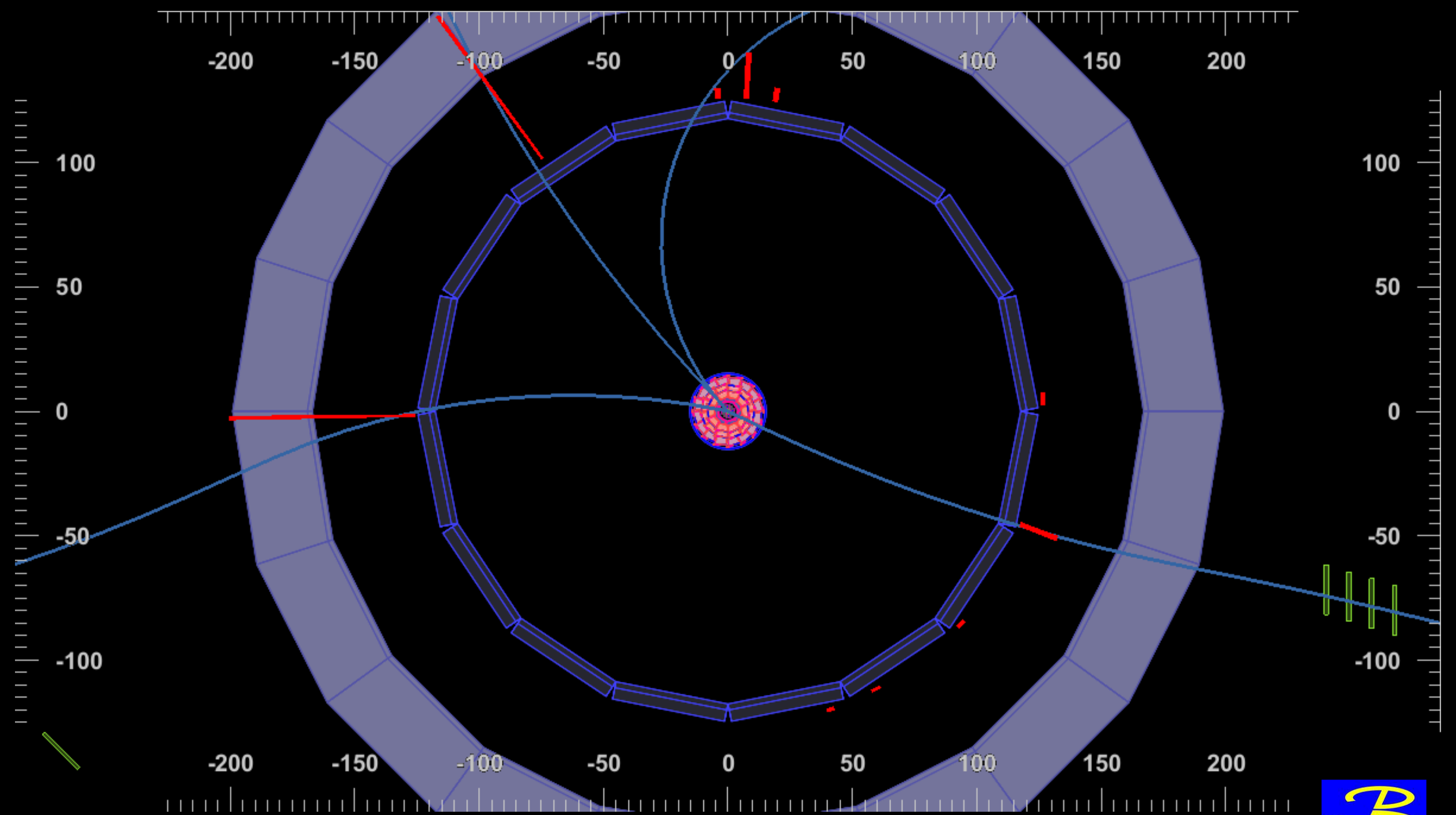

Belle II