Influence of GLC to join Belle II

Eduard De La Cruz Burelo

Joining B factories

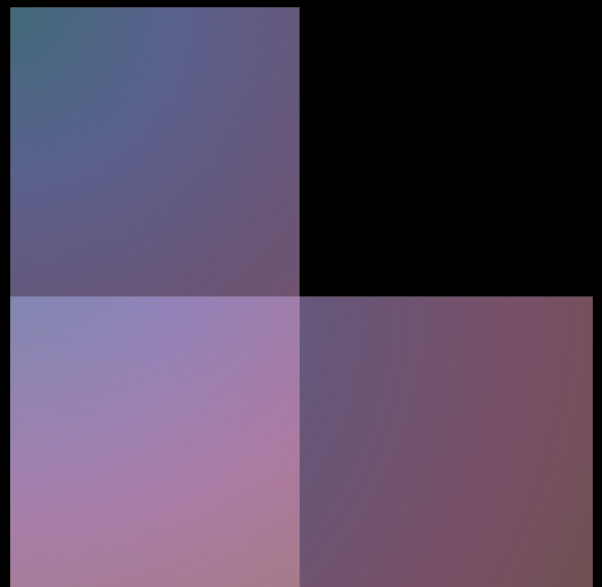
In 2010 (?) with the support of the Mexican Network of HEP a group of people started to discuss the necessity of Mexico to join the international experimental efforts on flavor physics (B factories).

Internationally there were two paths:

- Super B at Italy
- The upgrade of Belle and KEKB at Japan

In 2011 (?) a Mexican group joined the efforts of the Super B factory in Italy.

In 2012 Super B collider was cancelled.

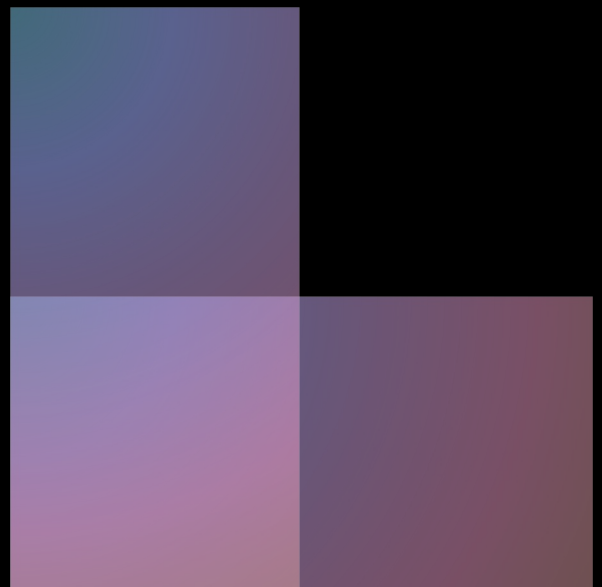


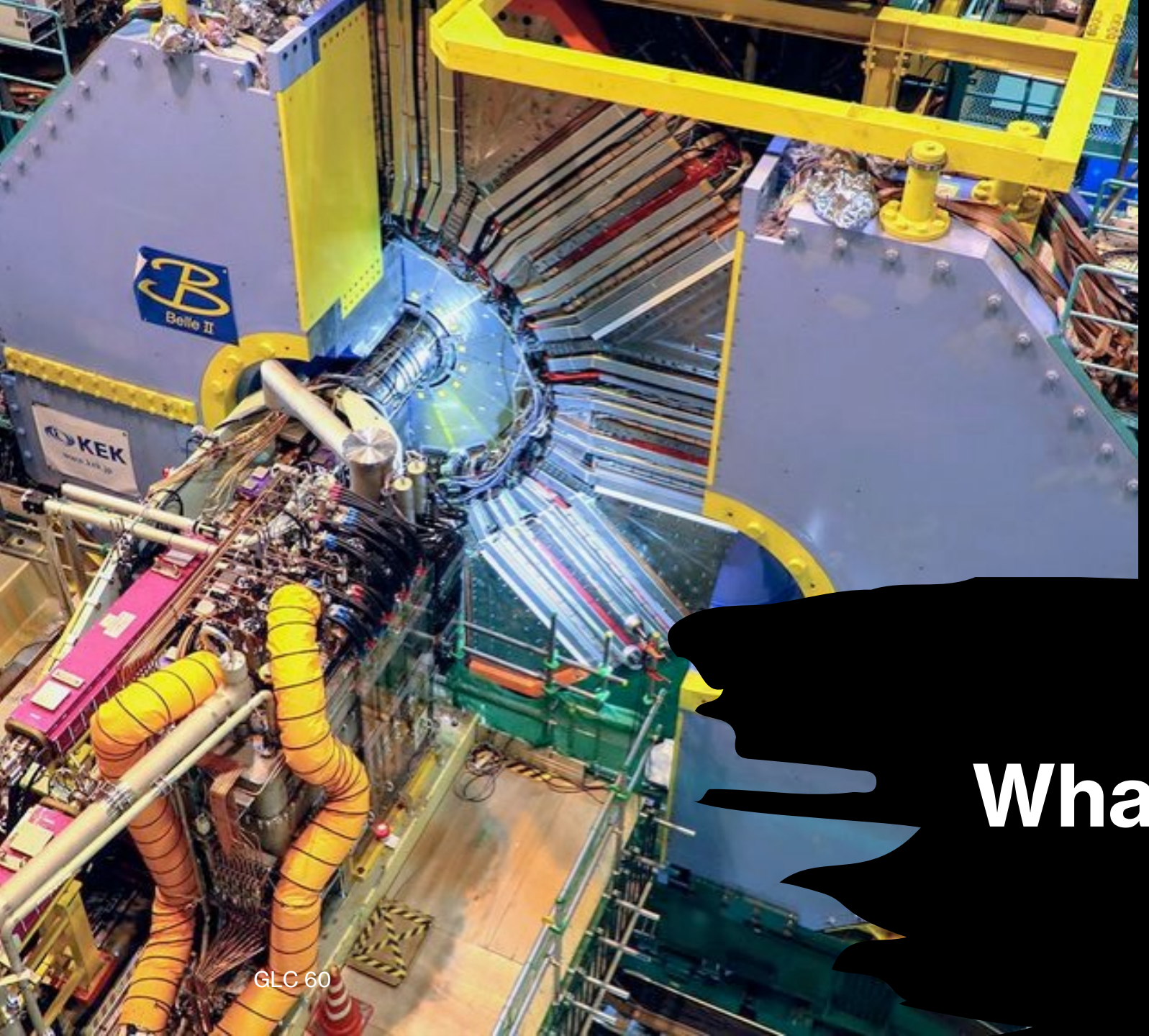
Joining B factories

The Mexican group had obtained a grant from Conacyt to support the work in Super B.

After Super B cancellation the group re-organized and several members decided not to continue.

In July of 2013 a Mexican group was accepted in Belle II.

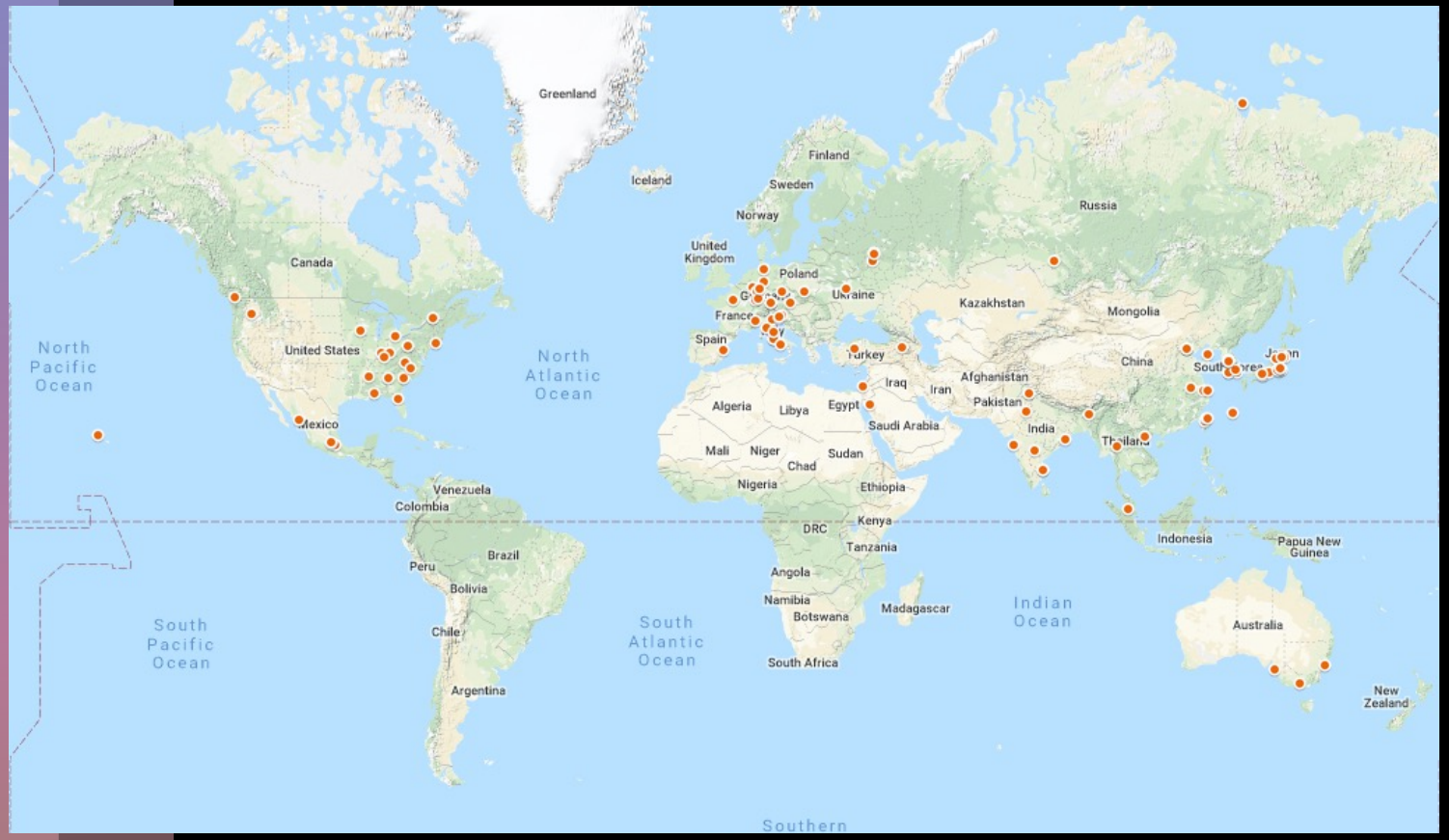




Belle II

What is Belle II?

Belle II is an international collaboration



- Belle II detectors is based in Japan in the SuperKEKB collider
- Belle II now has grown to ~1000 researchers from 26 countries
- Around 330 are students
- Mexico joined Belle II in July 2013
- First collisions in 2018.

Mexico @ Belle II

- Cinvestav: 3+5
- Universidad Autónoma de Sinaloa: 2 + 1
- IF UNAM: 1+1


Mexico @ Belle II
Greenland
Iceland
Finland
Sweden
Norway
Russia
United Kingdom
Poland
Ukraine
Canada
France
Spain
Kazakhstan
Mongolia
China
United States
North Pacific Ocean
North Atlantic Ocean
Turkey
Iraq
Iran
Afghanistan
Pakistan
India
Algeria
Libya
Egypt
Saudi Arabia
Mali
Niger
Chad
Sudan
Nigeria
Ethiopia
Kenya
DRC
Tanzania
Angola
Namibia
Botswana
Madagascar
South Africa
Indonesia
Papua New Guinea
Australia
New Zealand
Venezuela
Colombia
Brazil
Peru
Bolivia
Chile
Argentina
South Pacific Ocean
South Atlantic Ocean
Indian Ocean

Counting particles or decays

$$N = L * \sigma * \left(\prod_{i=1}^{m} Br_i \right) * \varepsilon$$

- L : Luminosity
- σ : Cross section
- Br : Branching fractions
- ε : detector efficiency

Counting particles or decays

Detector

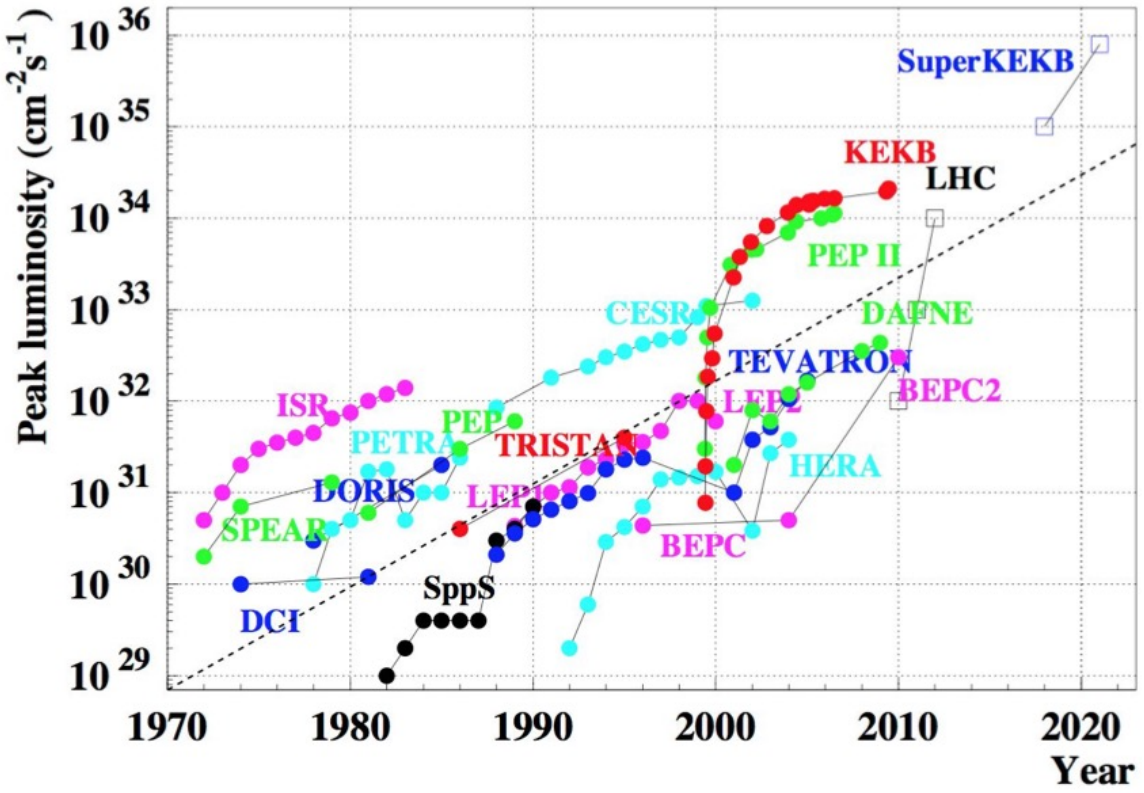
Accelerator

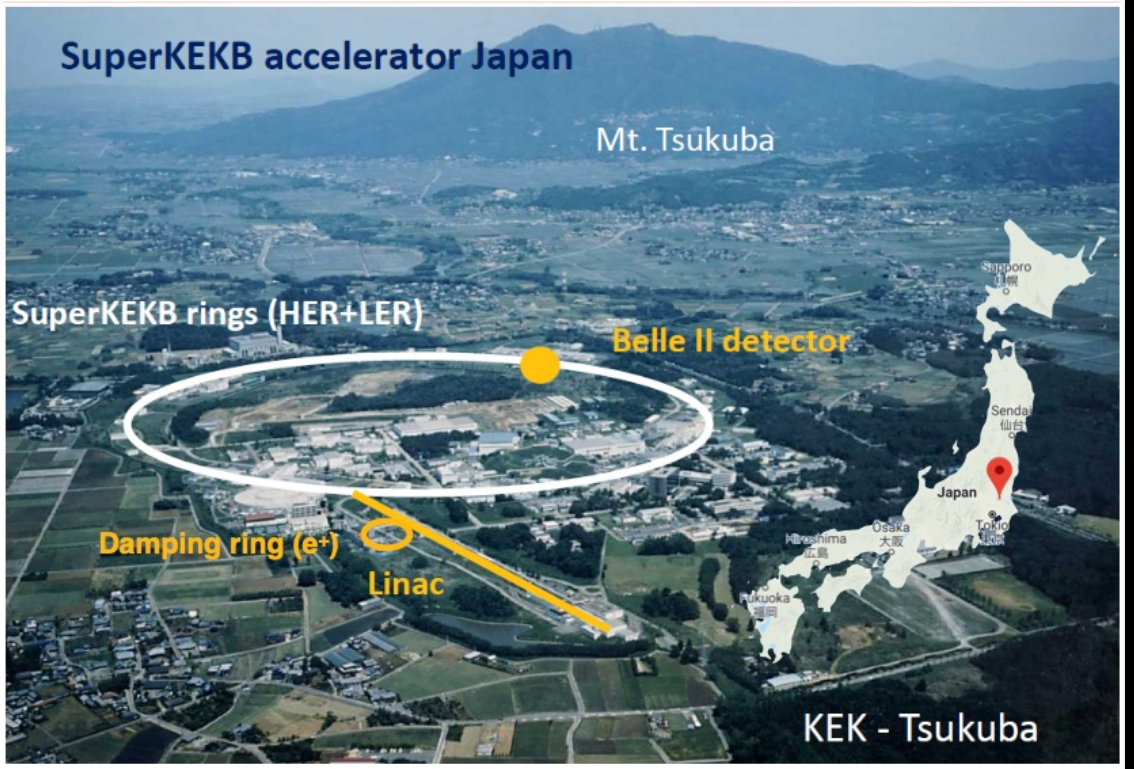
$$N = L * \sigma * \left(\prod_{i=1}^{m} Br_i \right) * \varepsilon$$

Nature

- L : Luminosity
- σ : Cross section
- Br : Branching fractions
- ε : detector efficiency

Ambitious Next Step at Luminosity Frontier: SuperKEKB





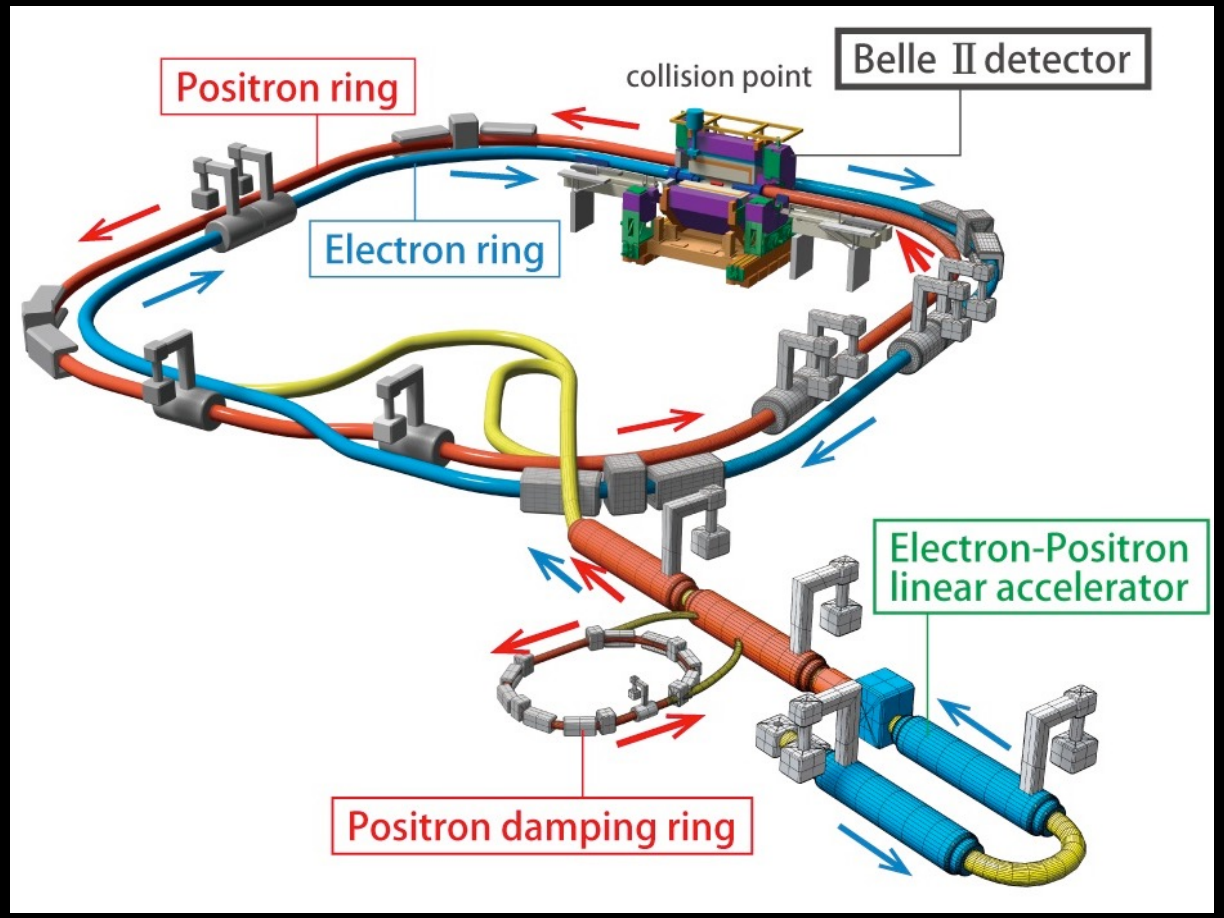
SuperKEKB, the first new collider in particle physics since the LHC in 2008 (electron-positron (e^+e^-) rather than proton-proton (pp)). Operates on the Upsilon(4S) resonance with 7 GeV(e-) on 4 GeV(e+) beams.

L(design,2020) = 6.5 x $10^{35}/cm^2/sec$

Phase 1:
Background, Optics Commissioning
Feb-June 2016.
Brand new
3 km positron ring.

Phase 2: Pilot run without VXD
Superconducting Final Focus,
add positron damping ring,
First Collisions (0.5 fb^{-1}).
April 27-July 17, 2018

Phase 3: → Physics running
(spring 2019 to present).
Have integrated 213 fb^{-1} so far.



Accelerator innovations: nano-beams and crab waist optics (*rather than large beam currents*)

Belle II Detector

Taken over from Belle

Super conducting solenoid
1.5 T B-field

KL and muon detector
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC
(end-caps , inner 2 barrel layers)

EM Calorimeter
CsI(Tl), waveform sampling electronics

Particle Identification
Time-of-Propagation counter (barrel) TOP
Prox. focusing Aerogel RICH (forward) ARICH
Central Drift Chamber

electrons (7 GeV)

Trigger
Hardware < 30kHz
Software < 10kHz

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers Si Pixels (DEPFET) +
4 layers Si double sided strip DSSD

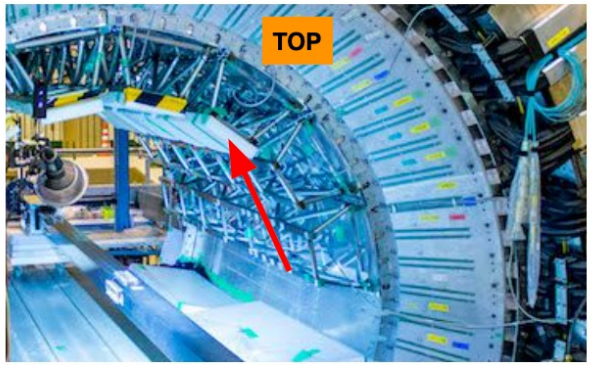
Final focus system QCS
Set of super conducting
magnets very close to the IP

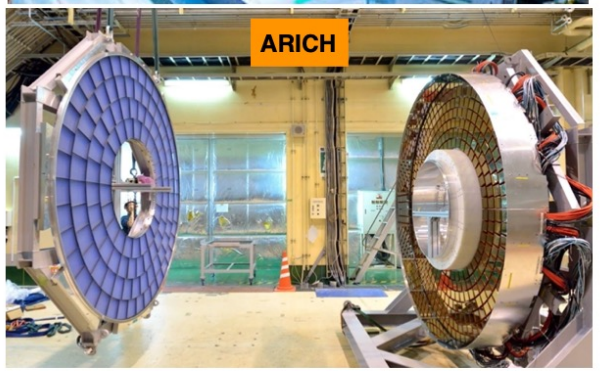
positrons (4 GeV)

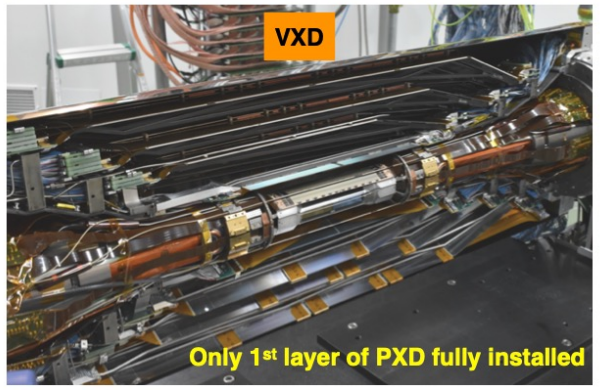
Central Drift Chamber
Smaller cell size, long lever arm

New for Belle II

Belle II TDR arXiv:1011.0352







Physics at Belle II

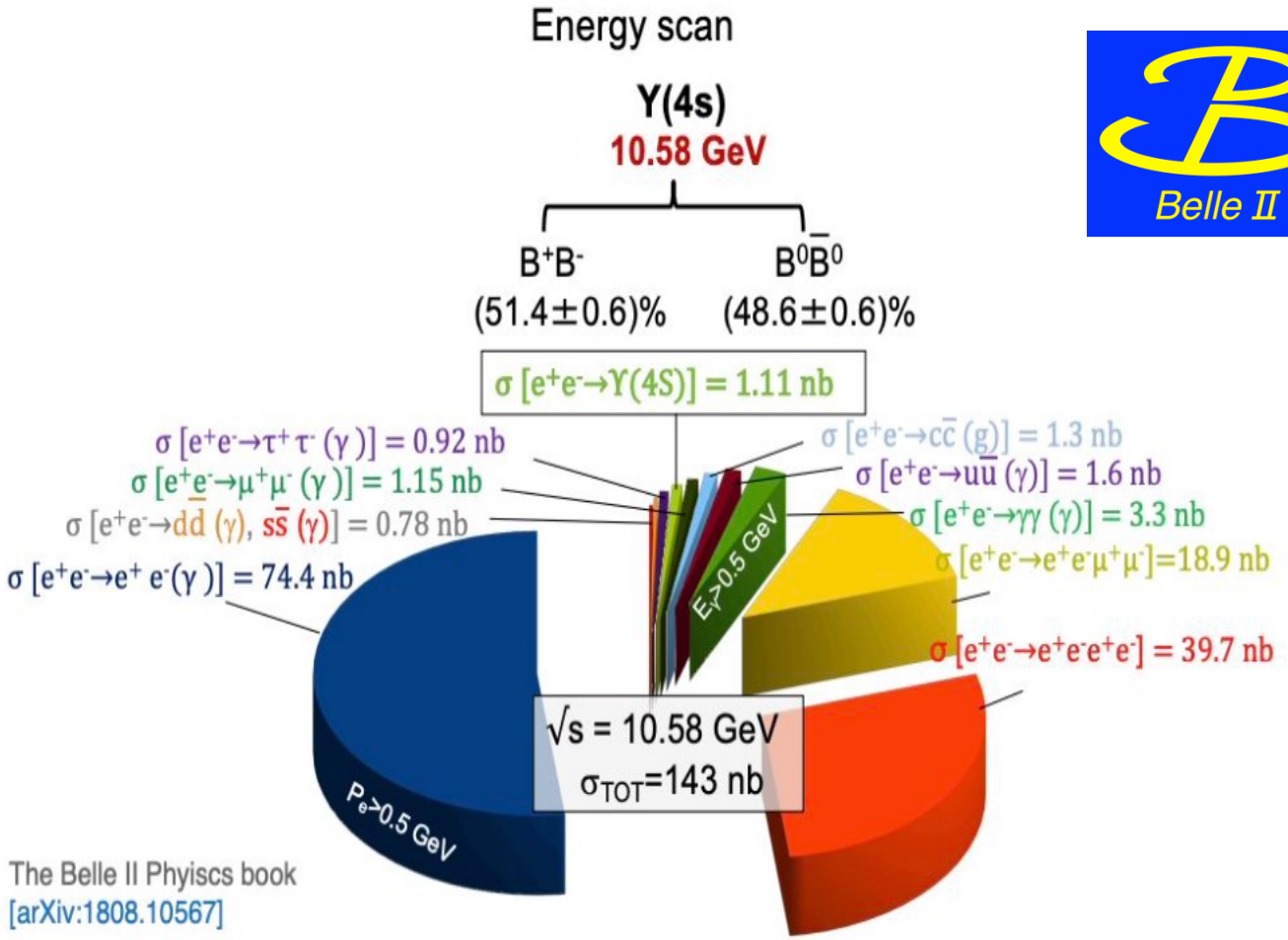
- Not *just* a B-factory!
  - τ, c, and b pairs have similar cross sections at $\sqrt{s}$ = 10.58 GeV

$\sigma(e^+e^- \rightarrow \Upsilon(4S)) = 1.11$ nb

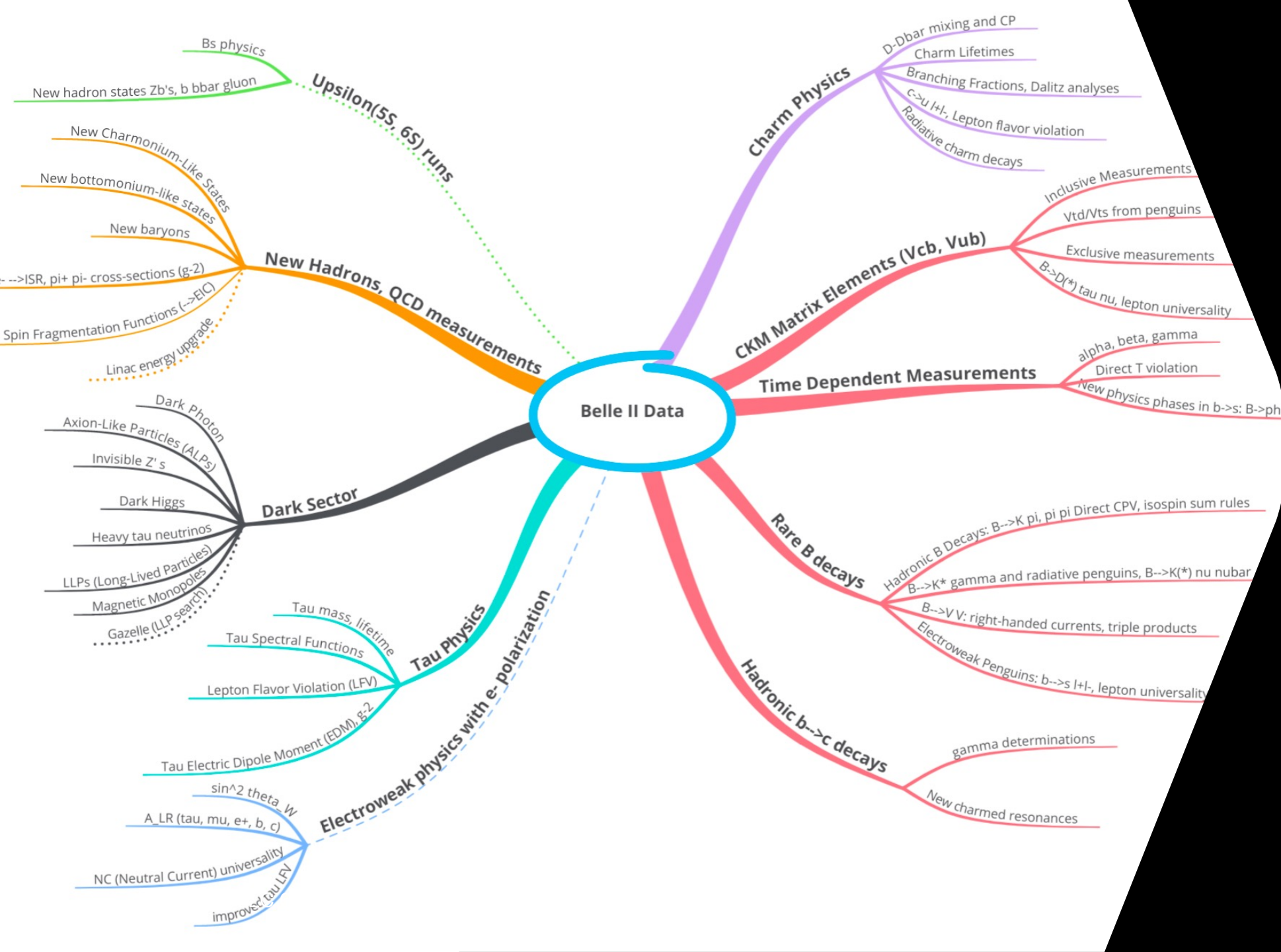
$\sigma(e^+e^- \rightarrow c\bar{c}) = 1.3$ nb

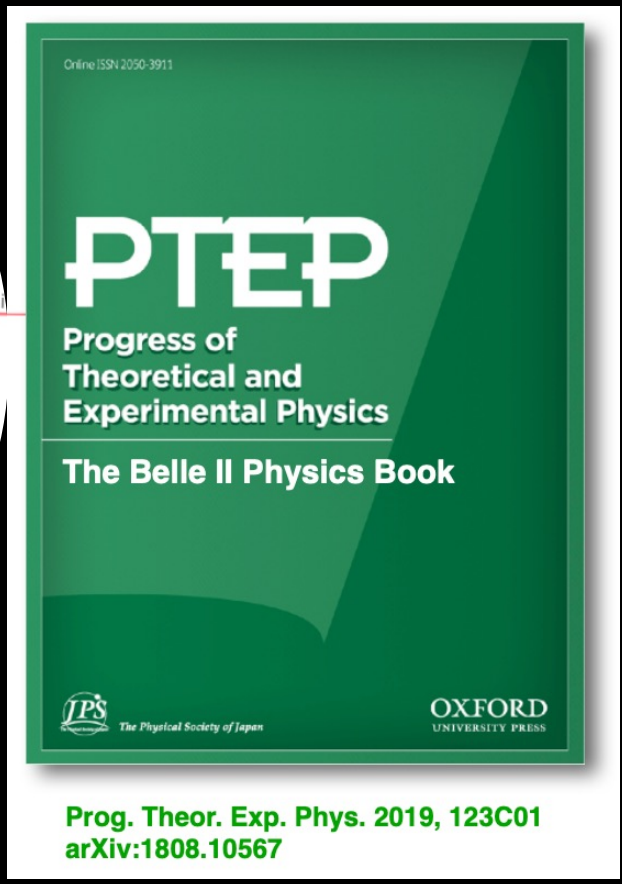
$\sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.92$ nb

- Wide physics program
  - precision measurements of time-dependent CPV and CKM parameters
  - searches for lepton flavor universality/number violations
  - dark-sector searches
  - and many more



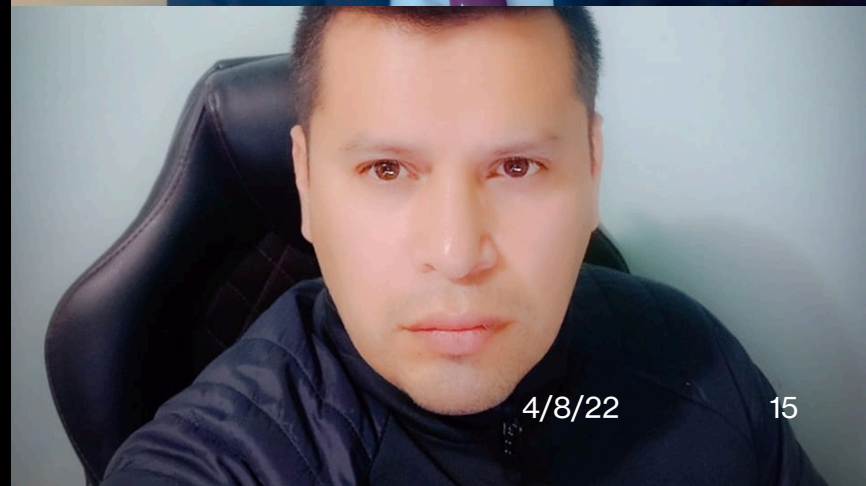
Belle II Physics mind map





Prog. Theor. Exp. Phys. 2019, 123C01
arXiv:1808.10567

Cinvestav group @ Belle II



Cinvestav group @ Belle II






Alejandro De Yta Hernández

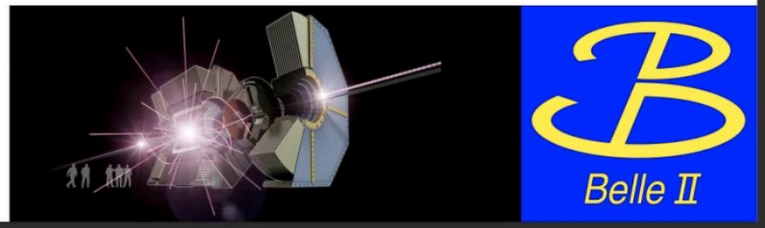
Search for the decay channel
$\tau \to l\alpha$
at the Belle II experiment

A. De Yta Hernández

Advisors:
E. De La Cruz-Burelo
I. Heredia De La Cruz

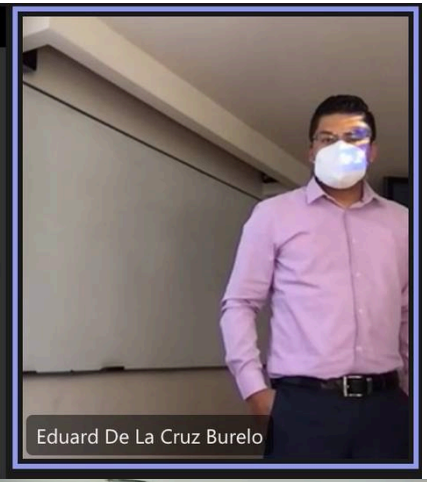
Feb 25th, 2022

Cinvestav



Belle II

Eduard De La Cruz Burelo



Eduard De La Cruz Burelo

Marcela García Hernández

Tema de doctorado:

“Search for new physics in charged lepton flavor violating processes at the Belle II experiment".

Asesor : Iván Heredia de la Cruz

El estudio se centra en la búsqueda de los canales que violan sabor leptónico:

- $\boldsymbol{\tau^{\pm} \rightarrow l^{\pm} + \alpha}$
  - **Objetivo**: Mejorar las cotas actuales que se tiene en **R** con datos del experimento Belle II.

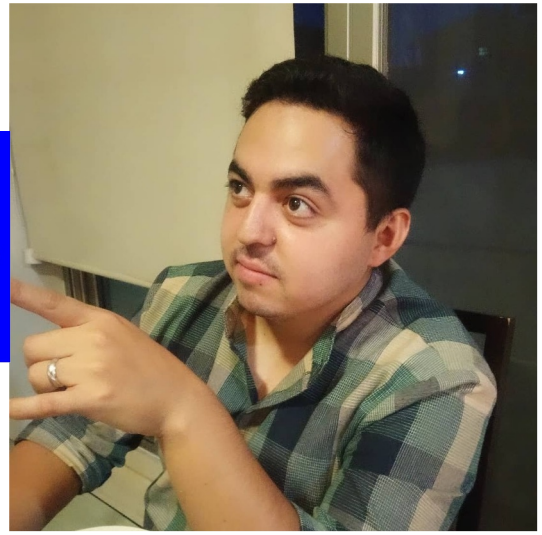
$$R \equiv \frac{Br(\tau \to \ell\alpha)}{Br(\tau \to \ell\nu\nu)}$$

- $\boldsymbol{\tau^{\pm} \rightarrow l^{\pm} + \gamma}$
  - **Objetivo**: Actualizar el cálculo del Branching ratio con datos de Belle II. Al incrementar la luminosidad integrada planeada para Belle II, se espera mejorar las cotas actuales por hasta dos órdenes de magnitud. $BR(\tau^{\pm} \to \mu^{\pm}\gamma) < \frac{n_{sig}}{2 \cdot L_{int} \cdot \epsilon_{sig} \cdot \sigma(e^+e^- \to \tau^+\tau^-)}$

Marcela García Hernández

- Miembro del grupo de Física del leptón tau en Belle II.
- Colaborador en el grupo de computo de Belle II.
- Colaborando en el grupo de software de Belle II.
    - Ha realizado trabajos como mentor en los cursos introductorios de los nuevos miembros del experimento.
- Colaborador en HEP Software Foundation.
    - Ha contribuido en la realización de los tutoriales de herramientas de análisis de datos que se utilizan comúnmente por la comunidad de HEP.

Norman Wilfrido Molina González



- Miembro del grupo de Física del leptón tau en Belle II.
- Colaborador en el grupo de computo de Belle II.

Tema de doctorado:

“Búsqueda de procesos raros del tau a 3 leptones cargados en el experimento Belle II".

Asesor : Iván Heredia de la Cruz $\tau^{\pm} \rightarrow l^{\pm} l'^{\mp} l''^{\pm}$

El análisis se especializa en decaimientos que violan sabor leptónico, esperando mejorar las cotas actuales de los Branching ratios.

Estudio extra: “Observación de decaimientos del tau a 3 leptones cargados con neutrinos (SM)”

$$\tau^{\pm} \rightarrow l^{\pm} l'^{\mp} l'^{\pm} \nu_{\tau} \nu_{l}$$

Esperamos mejorar la medición actual (CLEO) de los Branching ratios.

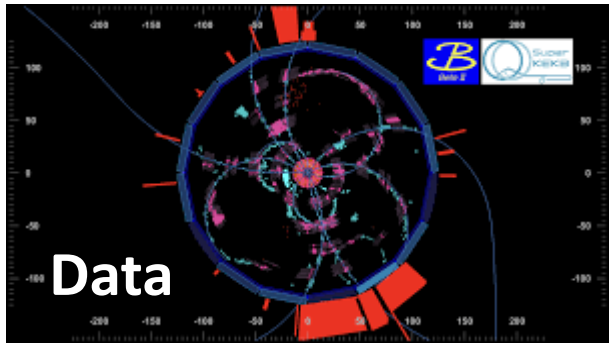
PhD. Leonardo Ismael Salinas Maya

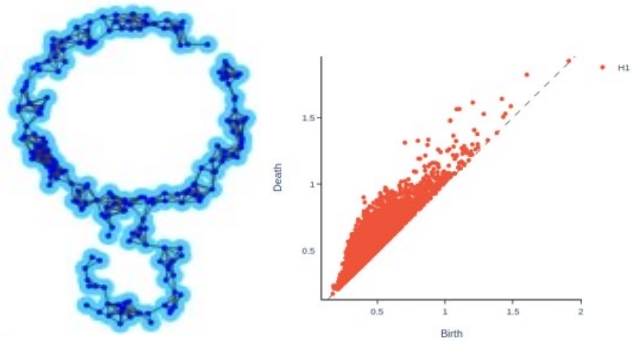
Tema de Doctorado: Nuevas técnicas de análisis en estudios de Física del experimento Belle II

Asesor: **Dr. Eduard De La Cruz Burelo**

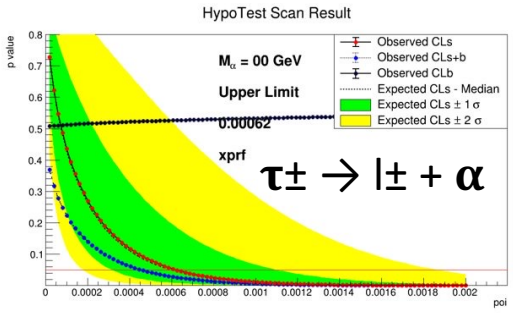
La investigación busca aplicar **Análisis Topológico de Datos** en la búsqueda de nueva física, mediante la caracterización topológica de los datos recolectados por la colaboración Belle II.

También dentro de la colaboración, apoyo al desarrollo de software (BASF2) y estudio del skimming de datos para el grupo de taus.





Análisis Topológico de datos



Mediciones Físicas en Belle II

Jordan Camilo Correa Rozo

Tema de doctorado:
"Search for charged exotic hadrons in $B \to J/\psi\pi^+\pi^0 K$ decays at the Belle II experiment".

- Colaborador en el grupo de Computo de Belle II

Asesor:
Iván Heredia de la Cruz

Objetivos:

- Caracterizar estructuras *like-resonant* en todo el espectro $m(J/\psi\pi^+\pi^0)$, empleando un análisis de amplitudes.
- Calcular y actualizar el *upper limit* para $Br(B^{\{+,0\}} \to X^+ K^{\{0,-\}}, X^+ \to J/\psi\pi^+\pi^0)$ en las regiones donde no se observen estas estructuras.

* Estas mediciones contribuyen en la determinación de la naturaleza exótica de estos hadrones.
** Tema de investigación asignado en el grupo de Quarkonium en la colaboración Belle II.

Carlos Lizama

Estudiante de Doctorado Directo

Asesorado por: Dr. Eduard De La Cruz Burelo

Trabajo actual y futuro:

- Combinación de tests estadísticos independientes aplicados al experimento Belle II
- Generalización del artículo: "Statistical approach to determine the production distribution for "$\tau \rightarrow l$ + *invisible*" decays in the pseudo-rest-frame"

Work service: Skimmings para el Tau Generic, Thrust y LFV

- Objetivo: Lograr una reducción del retention rate de los canales de ruido, correspondiente a cada caso.

Johan Andres Colorado Caicedo

Asesorado por: Dr. Eduard De La Cruz Burelo

Trabajo:

- Comenzó el doctorado en Marzo 2022
- Tesis de maestría:
  - "Medición de la masa del Leptón tau en estados finales semi-invisibles en topología 1x1 en la colaboración Belle II"

Work service: Corrección de brehmstralung para Belle II

Students

- Ph.D:
  - 2 graduated:
    - Michel E. Hernández Villanueva (2019)
    - Alejandro De Yta Hernández (2022)
  - Currently 5 Ph.D. students
- Master:
  - Graduated: 10
    - Michel, Alejandro, Marcela, Hugo, Norman, Leo, Saulo, Carlos, Johan, Diego,

Belle II physics by Mexican groups

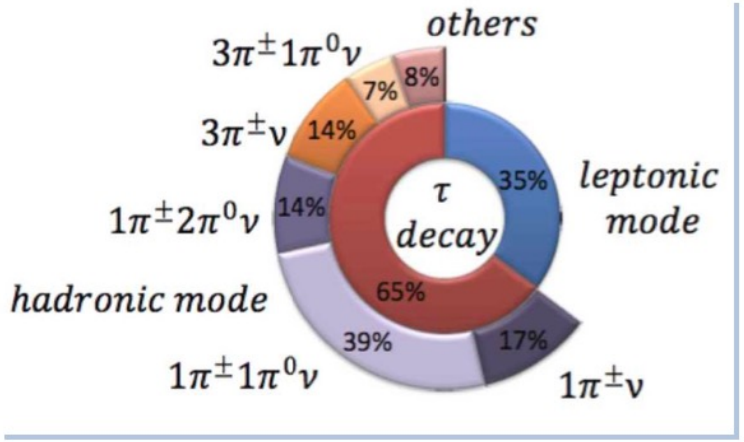
- Tau physics
- Exotics
- Rare decays

Mexican measurements involvement

- Tau lepton mass
- LFV tau to lepton + boson
- LFV tau to 3leptons
- LFV tau to mu gamma

τ -Physics at Belle II

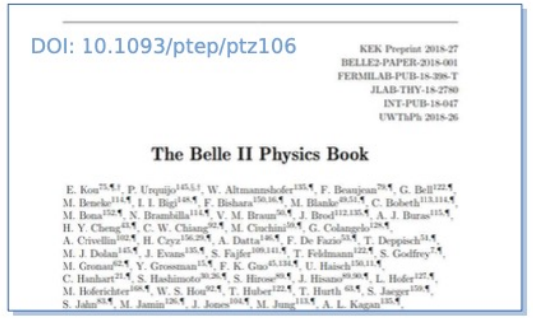
- Why τ ***physics***?
  - Large production cs:
    $\sigma(e^+e^- \to \tau^+\tau^-)$ = 0.9 nb (τ –factory)
  - The τ is the only lepton massive enough to decay into hadrons:
    - Leptonic decays: BR ~ 35%
    - Hadronic decays: BR ~ 65%



- τ **physics** program
  Rich program of precision SM measurements and new physics searches @ Belle II

Some ongoing physics analyses @ Belle II:

- Precision SM measurements / Indirect NP searches (deviations from the SM)
  - Mass
  - Lifetime
  - Lepton universality in $\tau \to l\nu\nu$ decays
  - τ EDM and MDM
  - $\tau \to eee\nu\nu$
  - CP violation $\tau \to K_S\pi\nu$
- Direct NP searches (forbidden / strongly suppressed decays)
  - $\tau \to l\,\alpha$
  - $\tau \to l\,\phi$
  - $\tau \to l\,\gamma$
  - $\tau \to \mu\mu\mu$
  - $\tau \to l\pi^0$
  - $\tau \to lhh$


DOI: 10.1093/ptep/ptz106

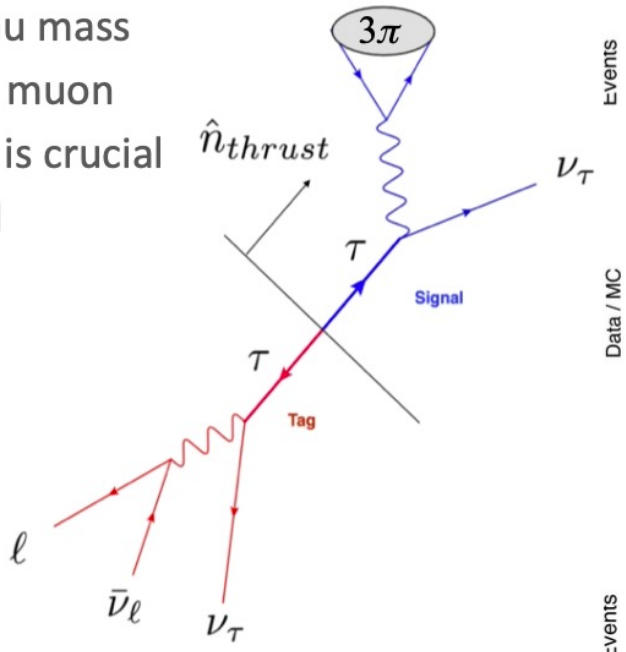
KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

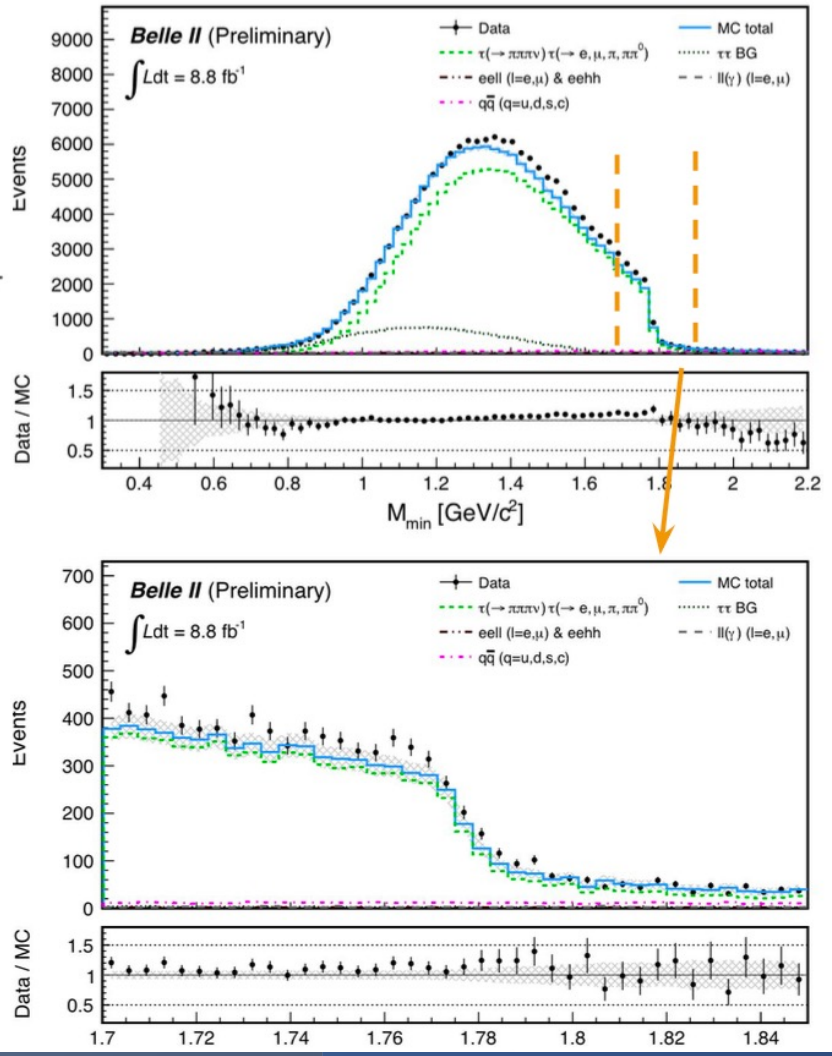
The Belle II Physics Book

Tau lepton mass measurement:

- Motivation:
  - ~10^3 worse relative precision in tau mass compared to that of electron and muon
  - A precise tau mass measurement is crucial for lepton universality tests of SM
- Topology:
  - 3x1 decays of the τ are used
  - signal: $\tau^- \to \pi^+\pi^-\pi^+\nu_\tau$
  - tag: $\tau^- \to \ell\nu_\ell\nu_\tau$, $\pi^-\nu_\tau$, $\pi^-\pi^0\nu_\tau$
- Pseudomass variable (M_{min}) :
  - calculated from 4-momentum of the 3π system
  - kinematic edge exploited to extract the mass:

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



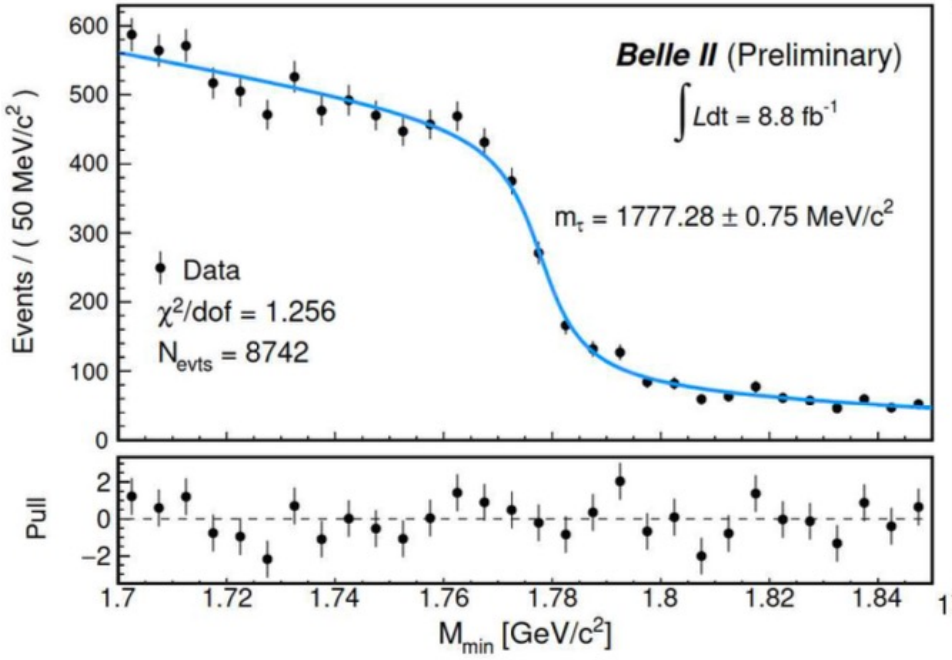


Tau lepton mass measurement

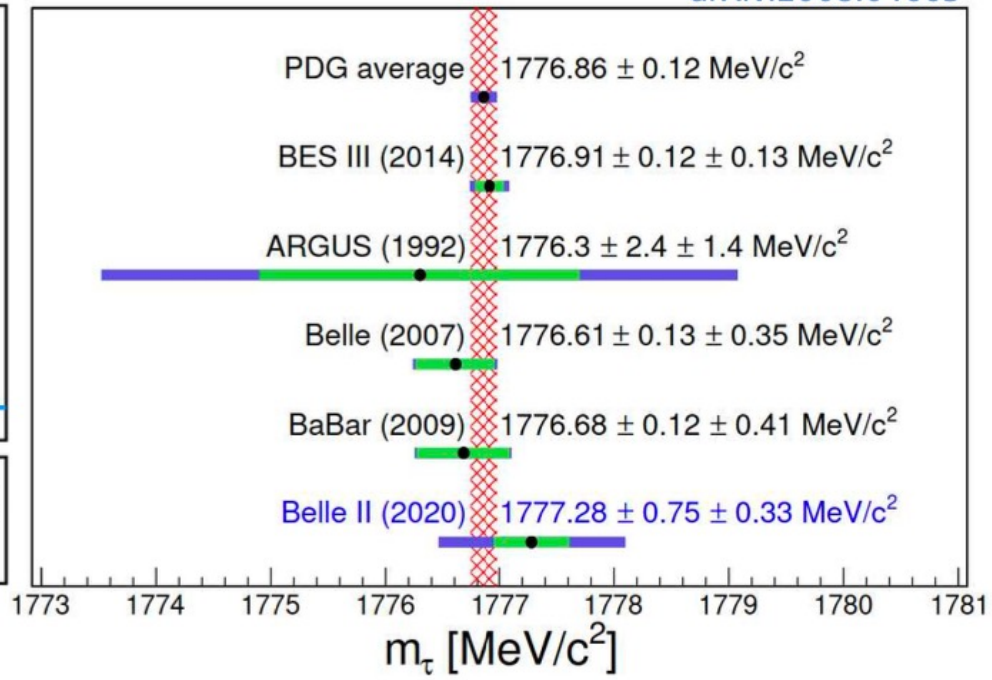
- An empirical p.d.f. is used to estimate the τ lepton mass, m_τ:

$$F\left(M,\vec{P}\right)=\left(P_3+P_4\cdot M\right)\cdot\tan^{-1}\left[\left(M-P_1\right)/P_2\right]+P_5\cdot M+1$$

  - P_1 is the estimator of the τ lepton mass.



arXiv:2008.04665



$m_\tau = 1777.28 \pm 0.75_{stat} \pm 0.33_{sys}$ MeV/c²

- Consistent with previous measurements!
- Belle II has similar systematic error as Belle

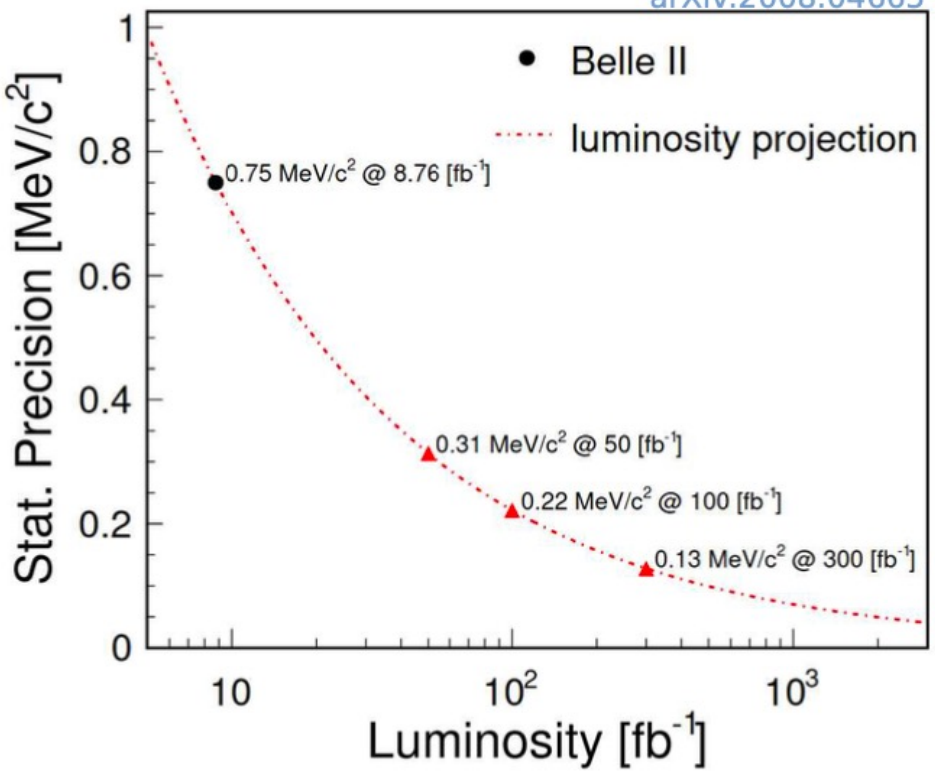
Tau lepton mass measurement

- Dominant systematic uncertainty due to the track momentum scale, but it is expected to be reduced

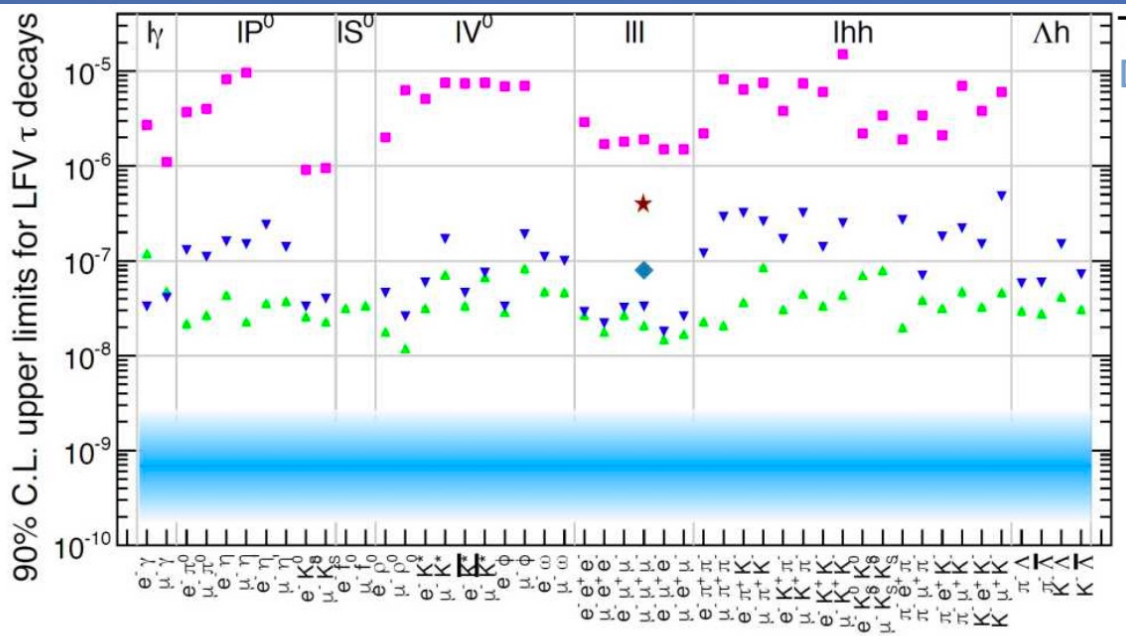
Systematic uncertainty	MeV/c^2
Momentum shift due to the B-field map	0.29
Estimator bias	0.12
Choice of p.d.f.	0.08
Fit window	0.04
Beam energy shifts	0.03
Mass dependence of bias	0.02
Trigger efficiency	$\leq$ 0.01
Initial parameters	$\leq$ 0.01
Background processes	$\leq$ 0.01
Tracking efficiency	$\leq$ 0.01

- A scenario with a total systematic uncertainty reduced is expected in the near future

arXiv:2008.04665



- With the present level of systematic uncertainties, this measurement is expected to be statistically dominated until around 50 fb^{-1} of data.
- With around 300 fb^{-1} of data, systematic uncertainties would dominate the measurement.



The Belle II Physics Book,
DOI: 10.1093/ptep/ptz106

- Thanks to the large mass of the τ, we have an extensive variety of decay modes to explore

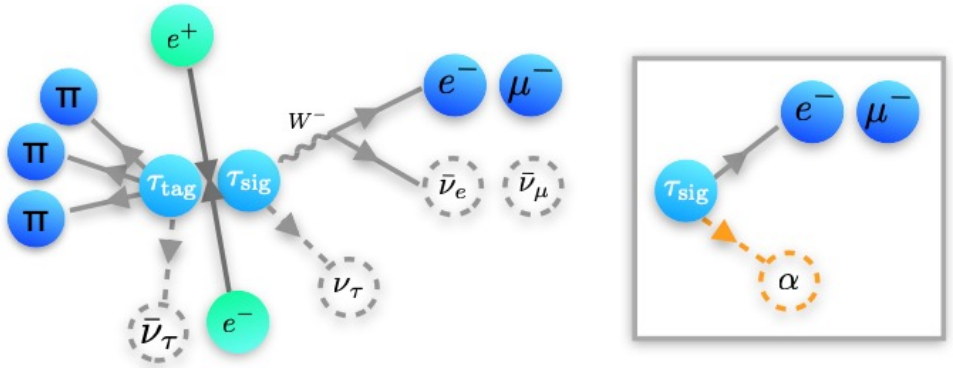
- LFV decays of the τ are strongly suppressed in the SM
  Br ~ O(10^{-54})
- Many NP models predict LFV decays of the τ at a measurable rate
  Br ~ O(10^{-10}) - O(10^{-7})
- Any observation of LFV is a clear indication of NP

- Golden channels:
  - τ→μμμ
  - τ→μγ

  } Work in progress
- Belle II is expected to push the current bounds further by more than one order of magnitude.

LFV decay $\tau \to \ell + \alpha$(invisible)

- Search for the two body decay $\tau \to e/\mu + \alpha$ where α is an unobserved particle (missing energy).

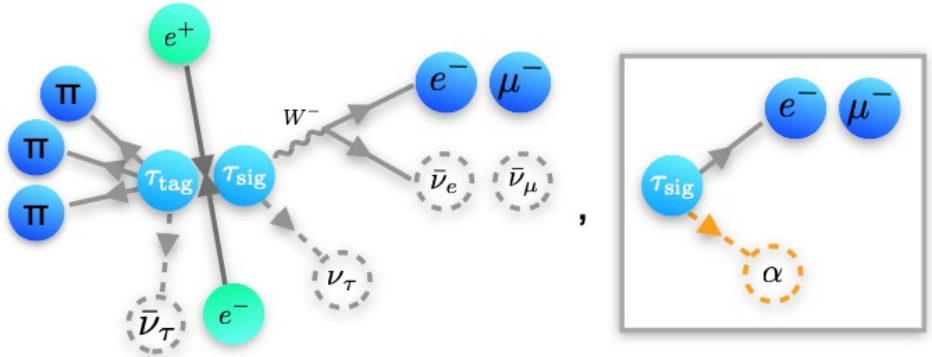


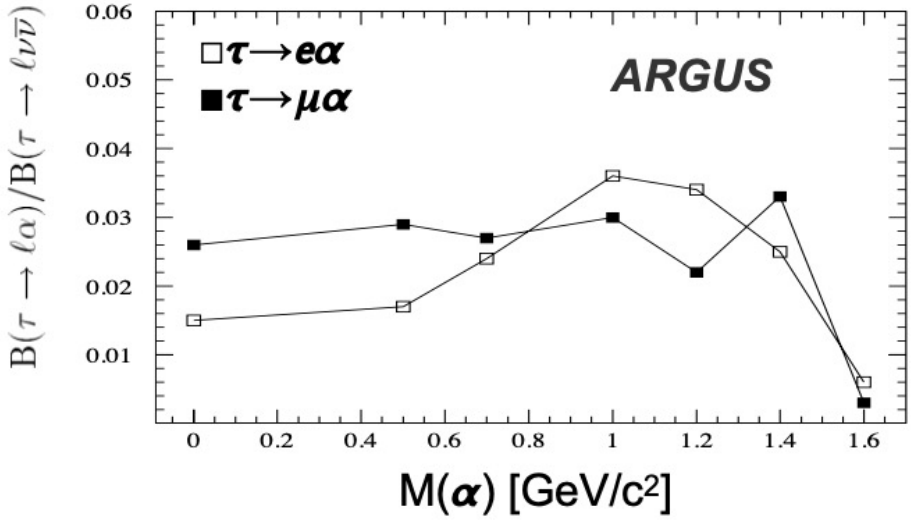
- LFV process which is not present in the SM but appears in several NP models e.g. as a Goldstone boson.

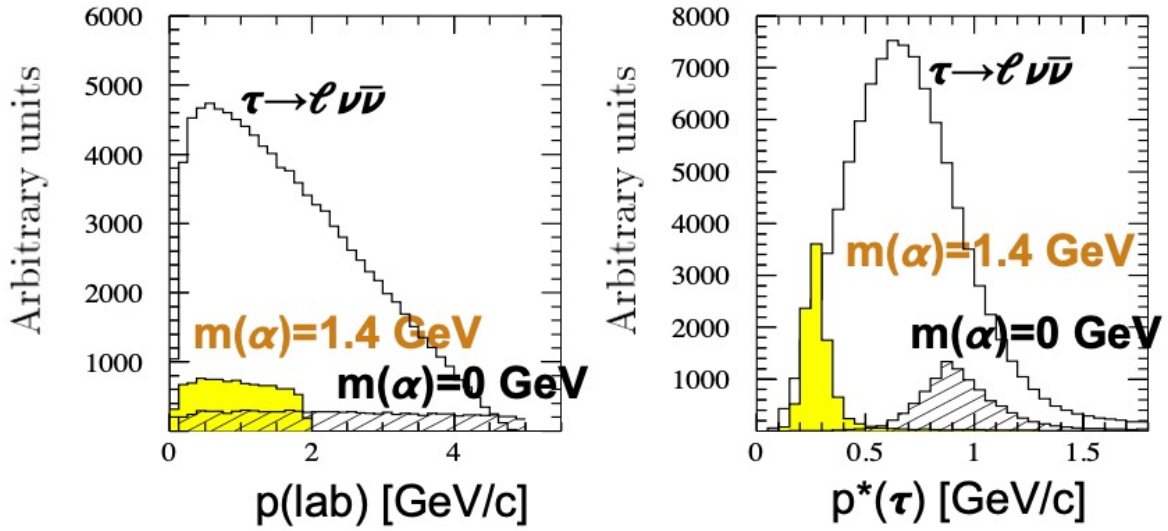
- Model independent search - minimal assumptions are made on the nature of α.
- We present preliminary MC studies and provide UL(95% CL) projections for the $\tau \to e\alpha$ channel measurement at Belle II.

Previous Searches

- **Mark III (1985, 9.4 pb^{-1})**
- **ARGUS (1995, 476 pb^{-1})**
- Here the lepton momentum is studied in the τ rest frame, where it manifests as a peak against the SM $\tau \to \ell\nu\nu$ background.







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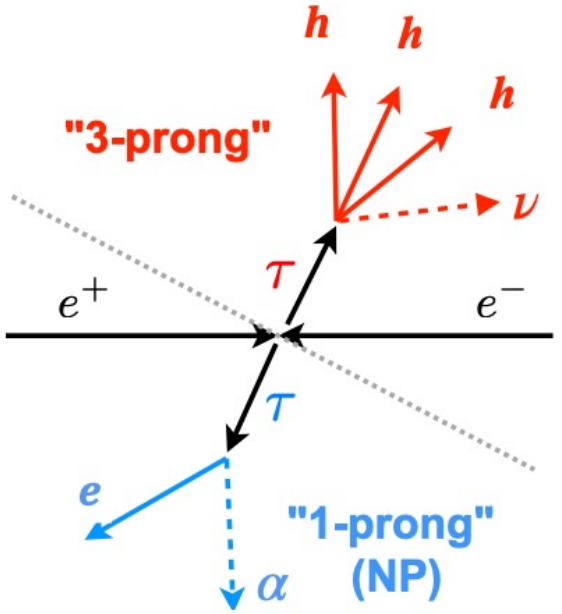
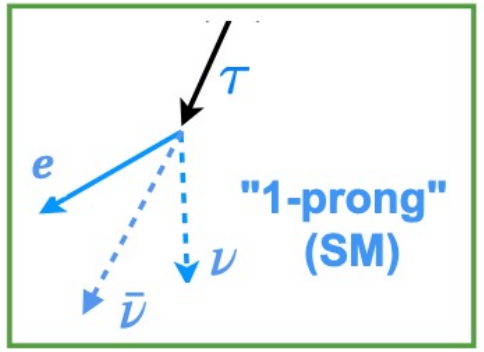
Event Reconstruction

- 3x1-prong decay: $\tau \rightarrow e\alpha$ **(signal)** , $\tau \rightarrow 3\pi\nu$ **(tag)**
  - Exactly 4 good tracks required.
  - Hemisphere separation using thrust vector $\vec{T} = max\left(\sum_i \frac{\vec{p_i} \cdot \hat{T}}{|p_i|}\right)$
- Dominant background: SM $\tau \rightarrow e\nu\nu$ **(irreducible)**
  - Since we don't know **M(α)** we optimise for the SM.
- Other BG: $\tau\tau$ (non-3x1), BBbar, qqbar, ee(γ), μμ(γ), ee$\ell\ell$, beam
- Initially rejected by:
  - **Vertex fit** of the 3-prong tag (reject displaced vertices).
  - **Veto** neutral pions and gamma (qqbar, beam bg).





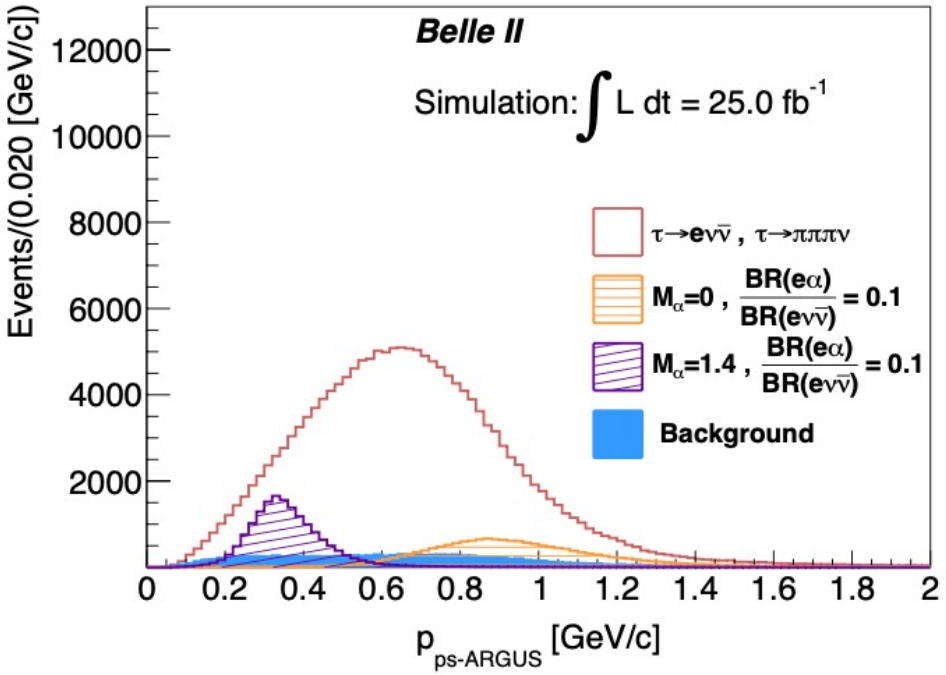
Tracks
-3< dz<3 cm
dr < 1 cm

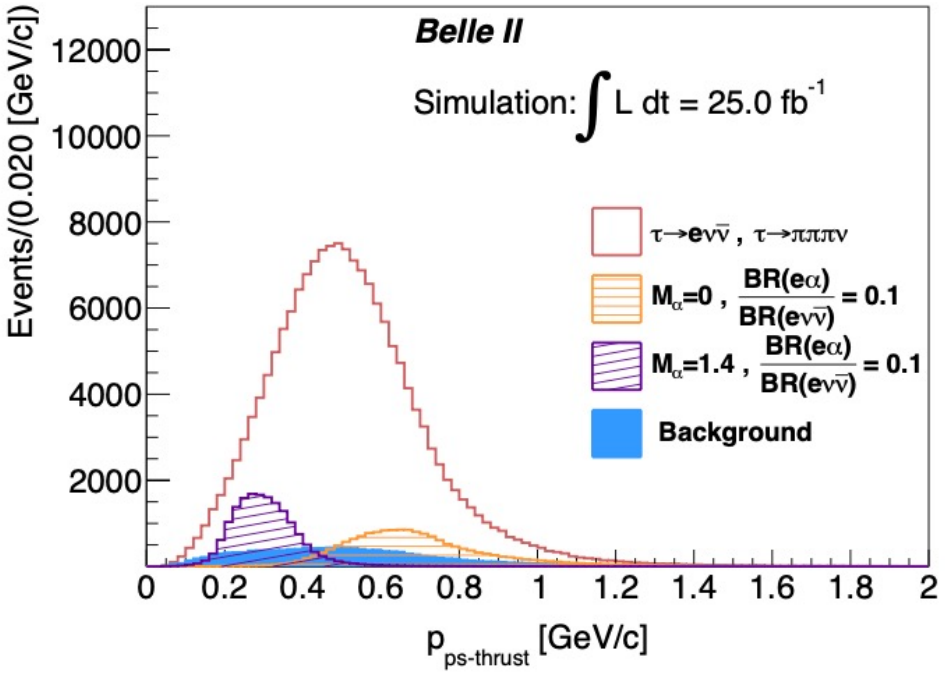
PID
e: E/p > 0.8
π: E/p < 0.8

Photons
Within tracking acceptance and
E(γ) > 100 MeV
115<M(γγ)<152 MeV
or
E(γ)>200 MeV

Spectrum in the Pseudo-Rest Frame

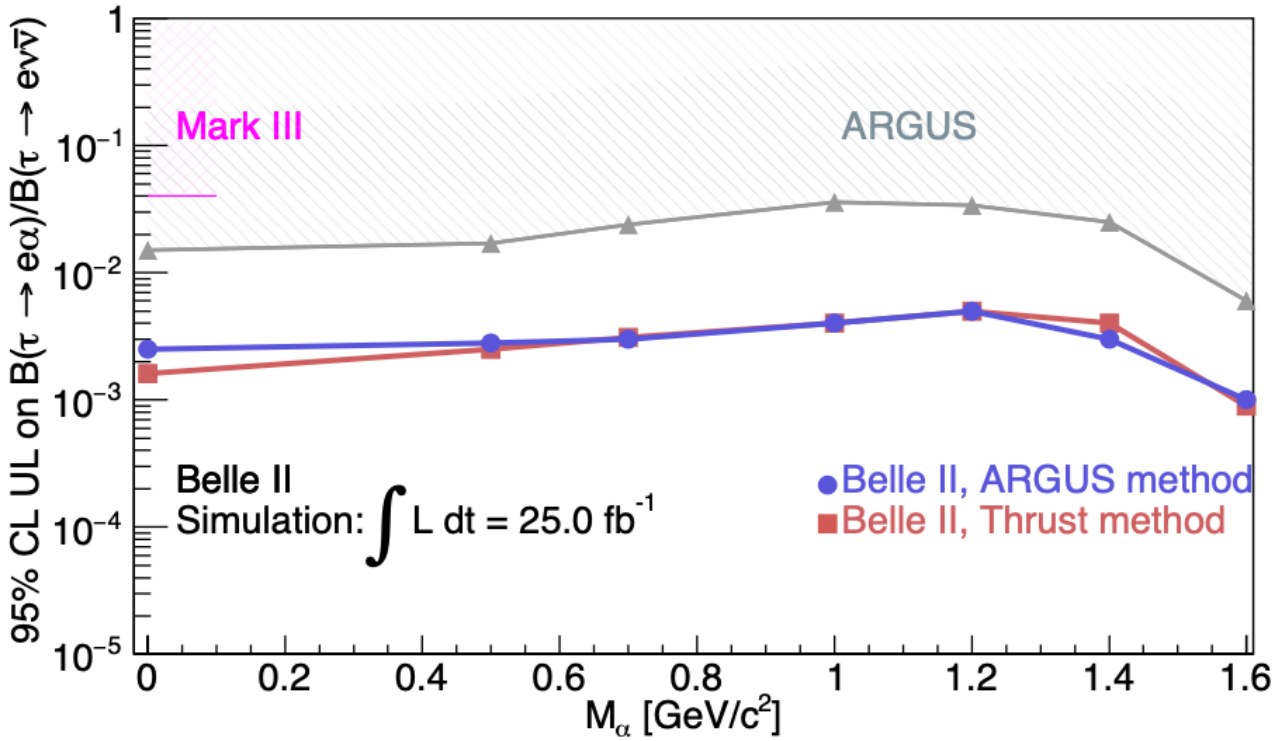
- In the signal τ rest frame, the **e** momentum for $\tau \rightarrow e\alpha$ will be a monoenergetic peak; the boost to the τ frame is unknown, so we approximate:
- $E_\tau = \sqrt{s}/2$
- ARGUS method: $\hat{p}_\tau \approx -\hat{p}_{3\pi}$
- Thrust method: $\hat{p}_\tau \approx \hat{T}$





Previous Measurements and MC Estimations

- UL is provided for the ratio $Br(\tau \to e\alpha)/Br(\tau \to e\nu\nu)$



	UL(95% c.l.)		
$M(\alpha)$ [GeV/c^2]	ARGUS (1995)	Argus method	Thrust method
0	0.015	0.0025	0.0016
0.5	0.017	0.0028	0.0025
0.7	0.024	0.003	0.0031
1.0	0.036	0.004	0.004
1.2	0.034	0.005	0.005
1.4	0.025	0.003	0.004
1.6	0.006	0.001	0.0009

- No systematics effects are taken into account at this stage.

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Summary ...

- 2013 ... it has been almost 9 year already since joining Belle II
- It took until 2018 to have first collisions
- It took until 2019 to have first data for analysis
- Currently our team is involved in analyses in the tau group that are heading to publications. Hopefully we will have the first tau group publication in Belle II.
- The group has grown and it more mature and participative than ever.