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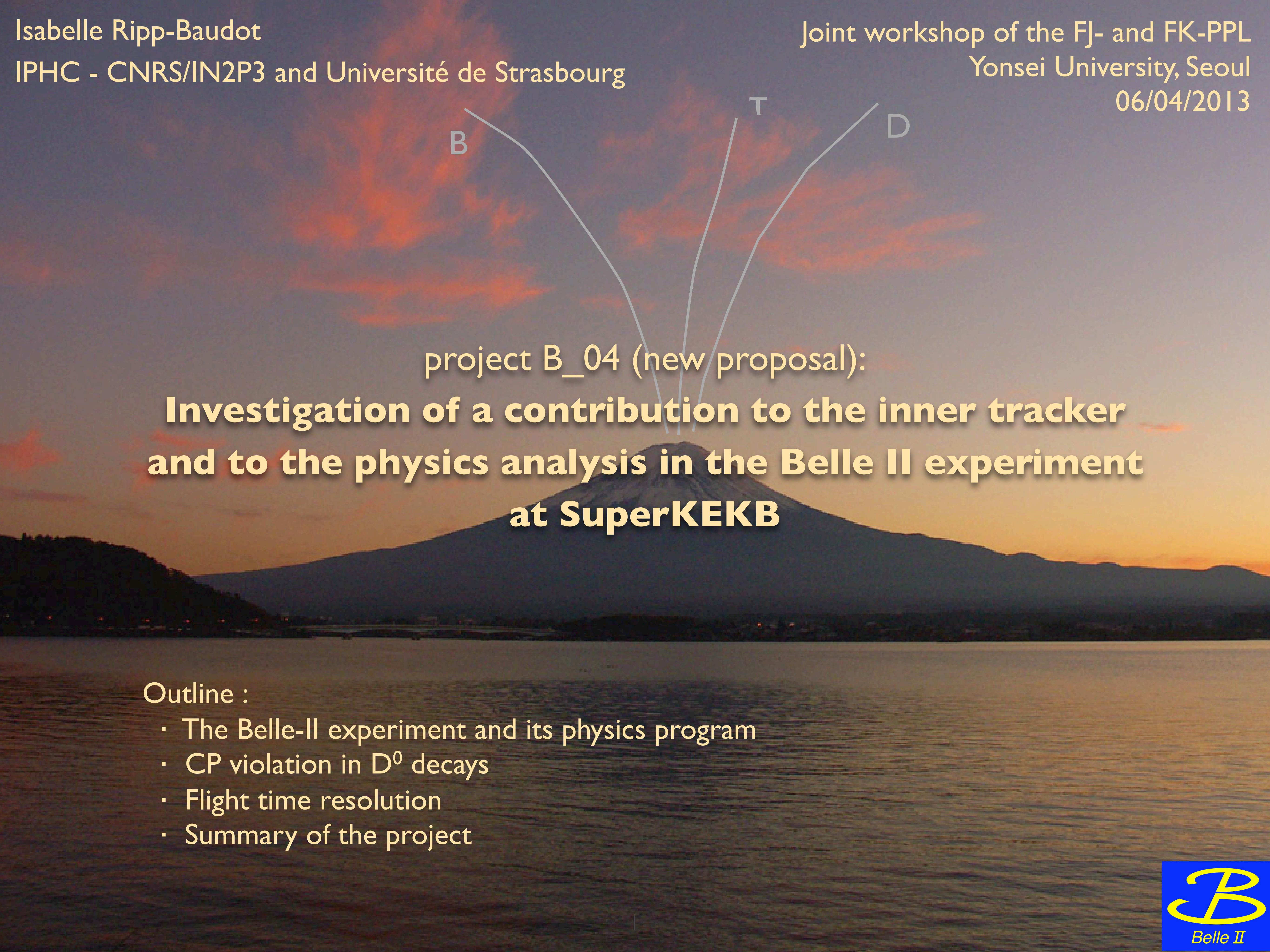
IPHC - CNRS/IN2P3 and Université de Strasbourg

Joint workshop of the FJ- and FK-PPL
Yonsei University, Seoul
06/04/2013



project B_04 (new proposal):

Investigation of a contribution to the inner tracker and to the physics analysis in the Belle II experiment at SuperKEKB

Outline :

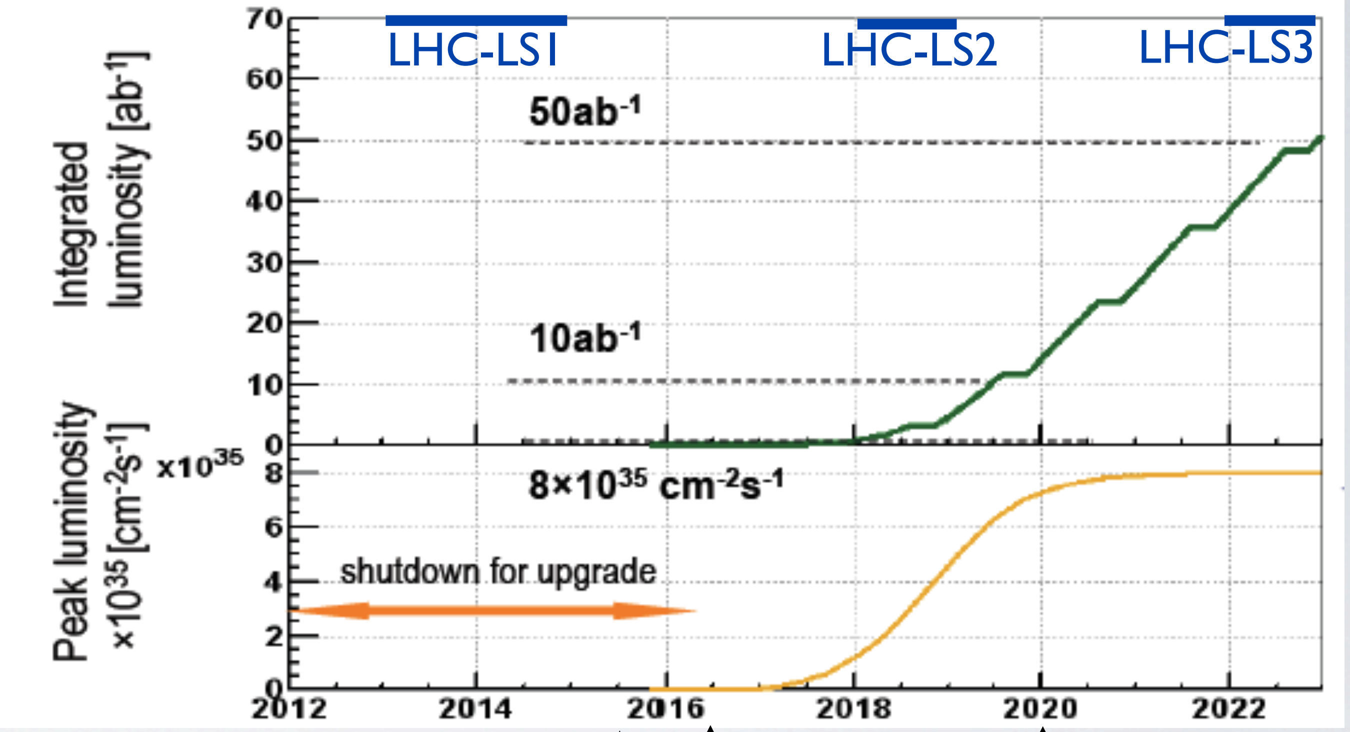
- The Belle-II experiment and its physics program
- CP violation in D^0 decays
- Flight time resolution
- Summary of the project

The SuperKEKB collider

- Asymmetric beams: e^- 7 GeV - e^+ 4 GeV.
  Collisions $E_{c.m.} = M_{\Upsilon(4S)}$ and $M_{\Upsilon(5S)}$.
- Moderate currents: ~2×KEKB to limit backgrounds.
- Small transverse beam size: ~KEKB/20 in y,
  $\sigma_x \times \sigma_y \sim 10\ \mu m \times 60\ nm$.
- Large Piwinski crossing-angle:
  22 mrad (KEKB) → 83 mrad (SuperKEKB)

➛ Instantaneous luminosity x40:

$0.8 \times 10^{36}\ cm^{-2}\ s^{-1}$

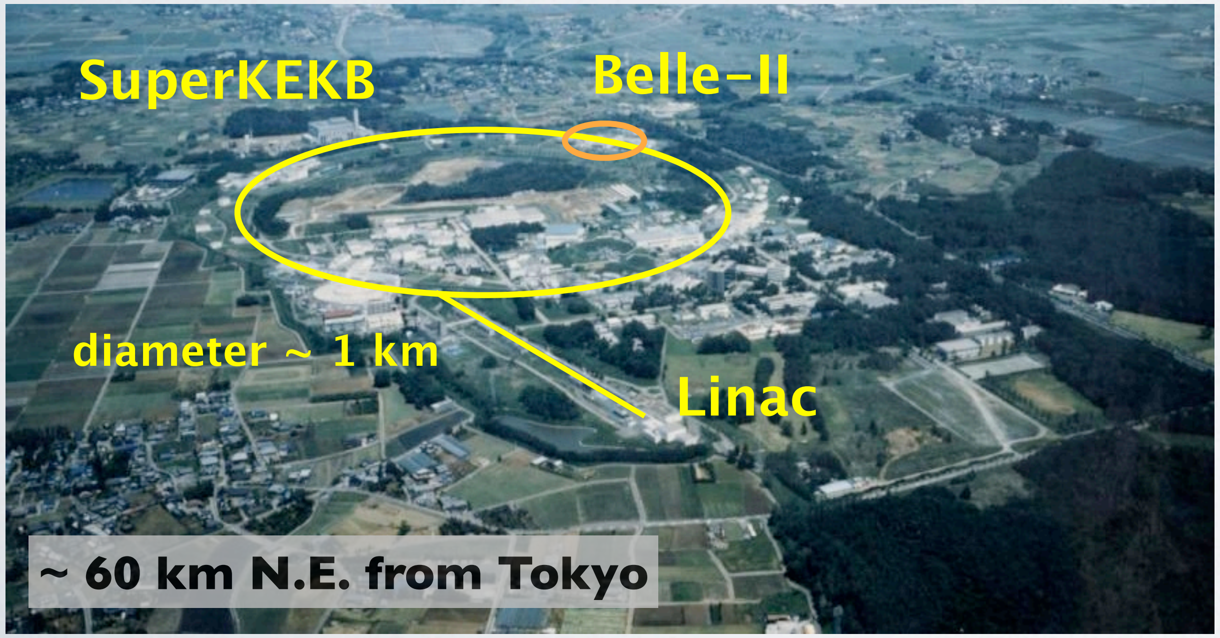


October 2016:
start of data taking

end 2022:
50 ab^{-1}
on tape

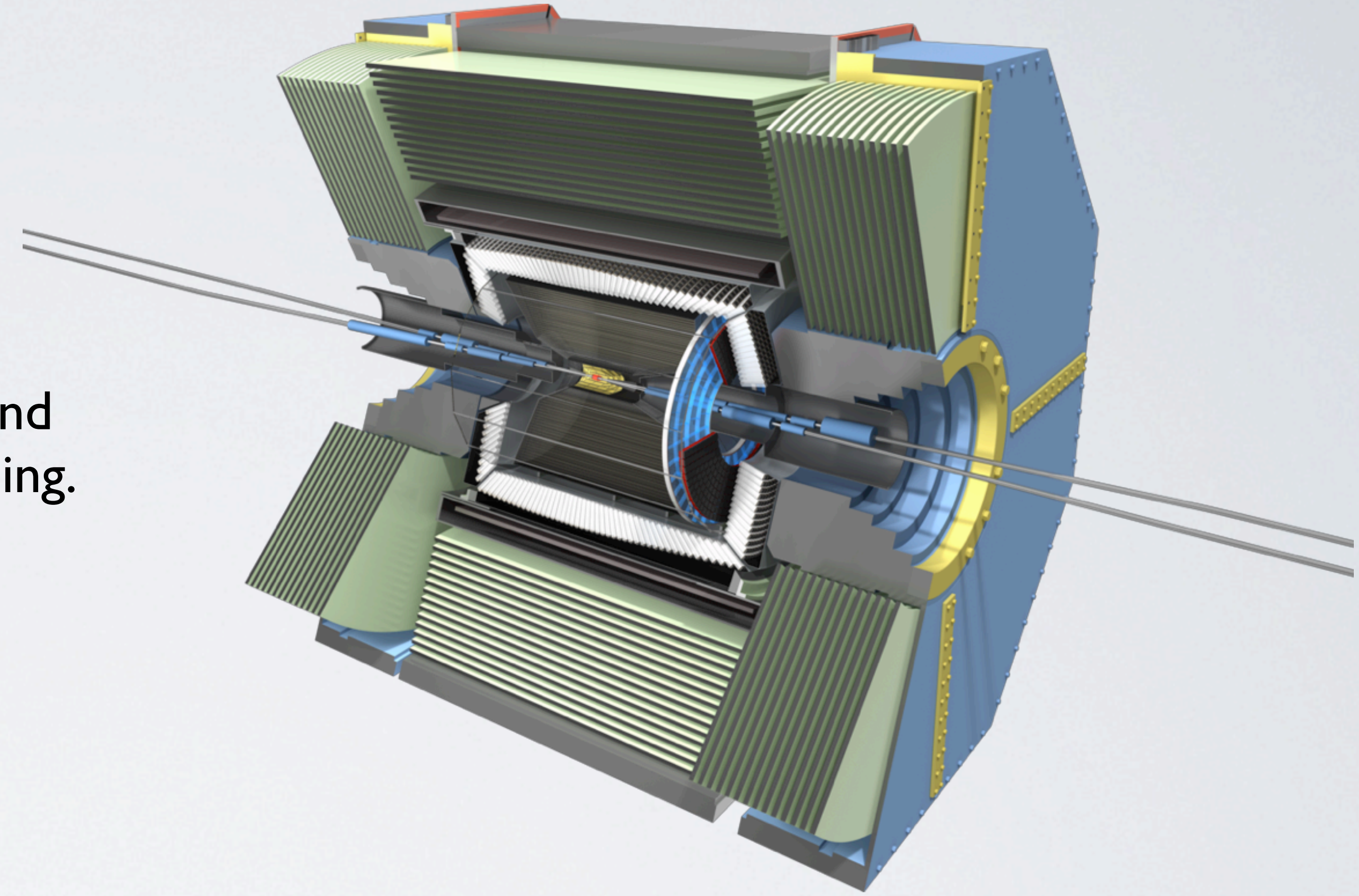
mid 2015: BEAST II
collider commissioning
until 10^{34} cm^{-2} s^{-1} reached.

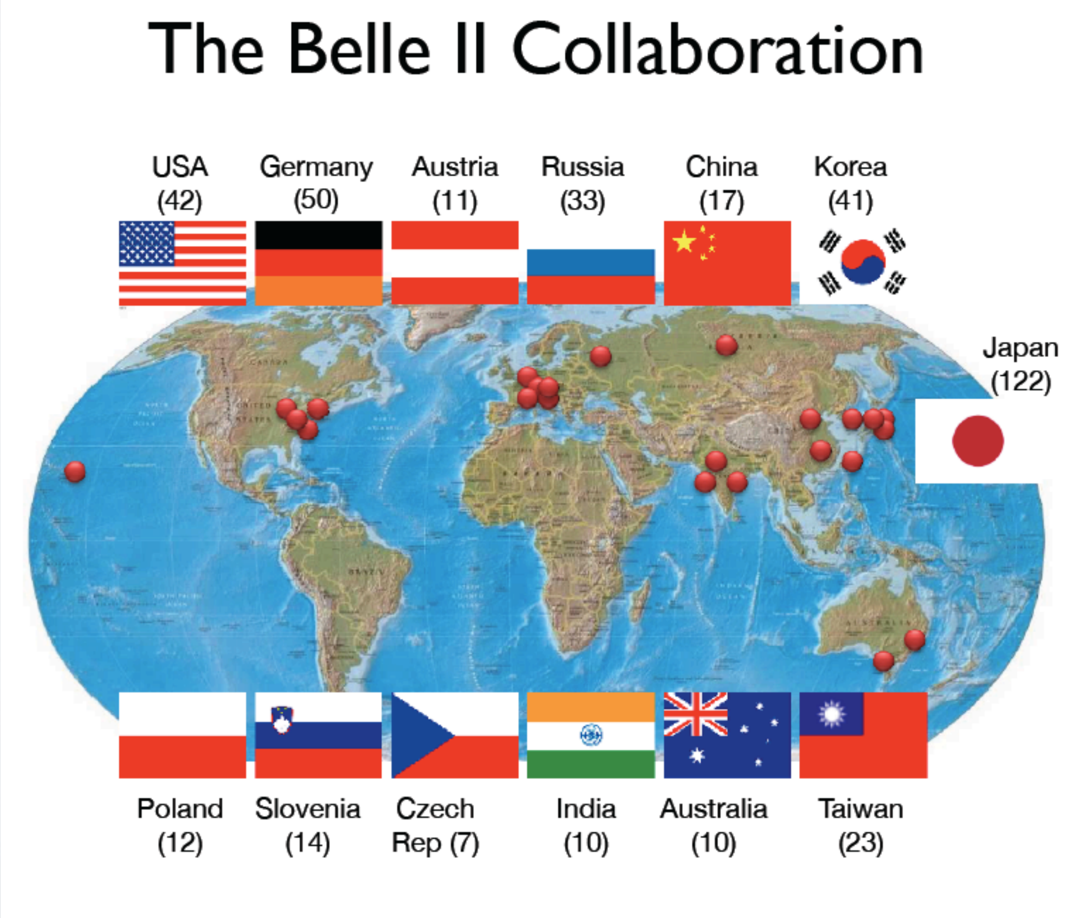
~2020:
10 ab^{-1} on tape



The Belle II experiment

- Project milestones:
  - Letter of Intent: 2004
  - Collaboration: Dec. 2008
  - TDR detector: 2010, arXiv:1011.0352,
    physics: 2010, arXiv:1002.5012.
- Experiment progress status: construction and delivery of accelerator and detector is ongoing.





- Collaboration:
  - Mid 2013: > 400 physicists from 17 countries.
  - Recent newcomers (2012-13): Turkey, Canada, Ukraine.
  - Next country to apply: Italy.

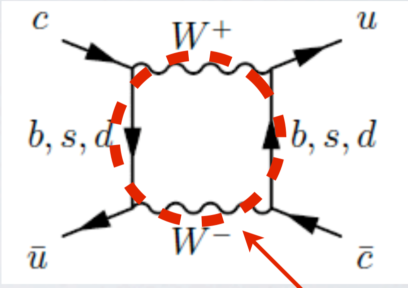
The Belle II physics case

- Where/what is the Beyond SM physics? Very few experimental indications.
  Finding and decoding NP will not be easy!
  A global effort based on different programs: energy frontier vs. intensity frontier ➛ enhanced sensitivity to NP.

- Two scenarios when Belle II starts taking data (2016):
  - NP is not found at the LHC: probe NP at multi-TeV scale through indirect search.
  - NP is found at the TeV scale: determine the detailed structure of NP couplings.

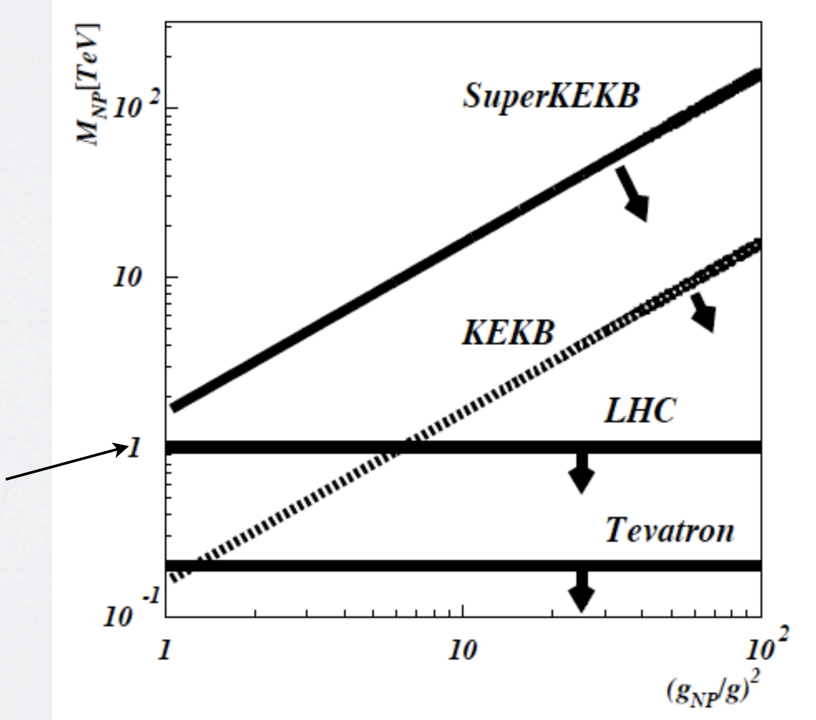
  ➛ crucial role of Belle II in all cases, with a program covering:

    - CKM parameters and unitarity triangles,
    - Rare B and D decays,
    - Mixing and CPV in beauty and charm,
    - B_s^0 physics,
    - Spectroscopy,
    - LFV τ decays,
    - Electroweak parameters,
    - Direct searches of new particles.



new physics?

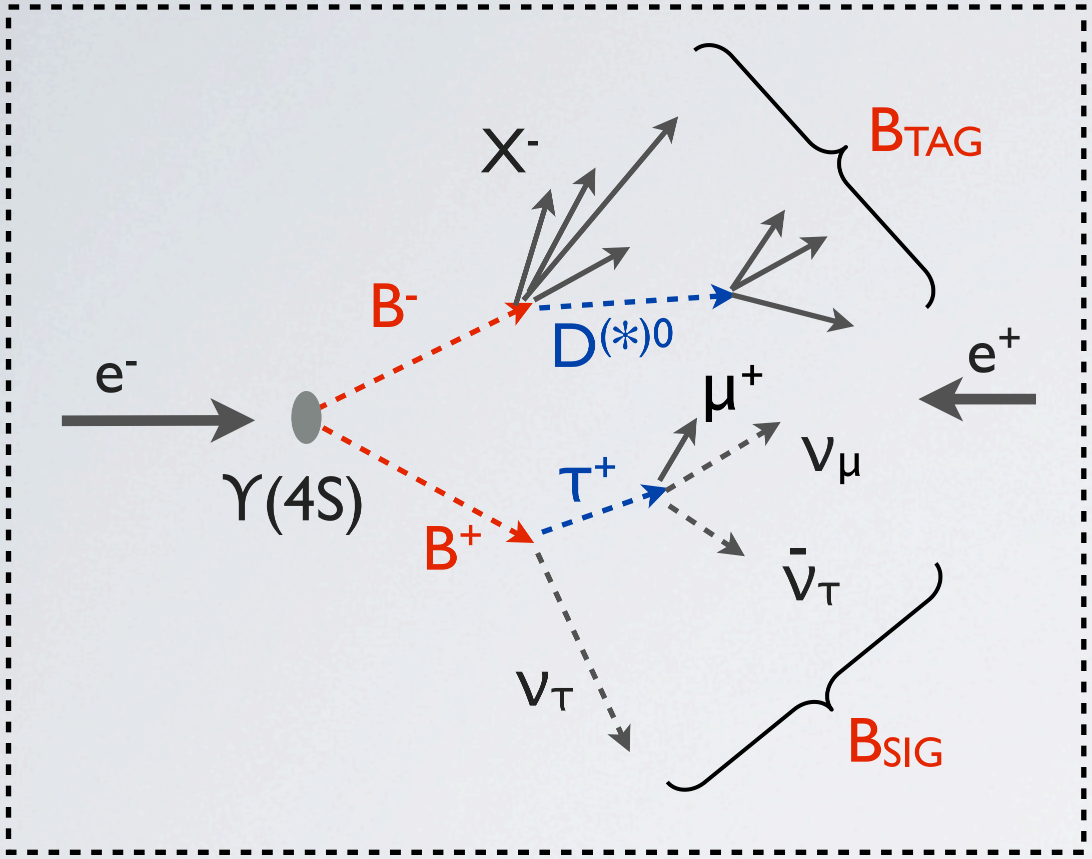
➛ double prong attack on the quark and lepton sectors



minimal flavour violation models

cf. arXiv:1002.5012, 2010
“Physics at Super B Factory”

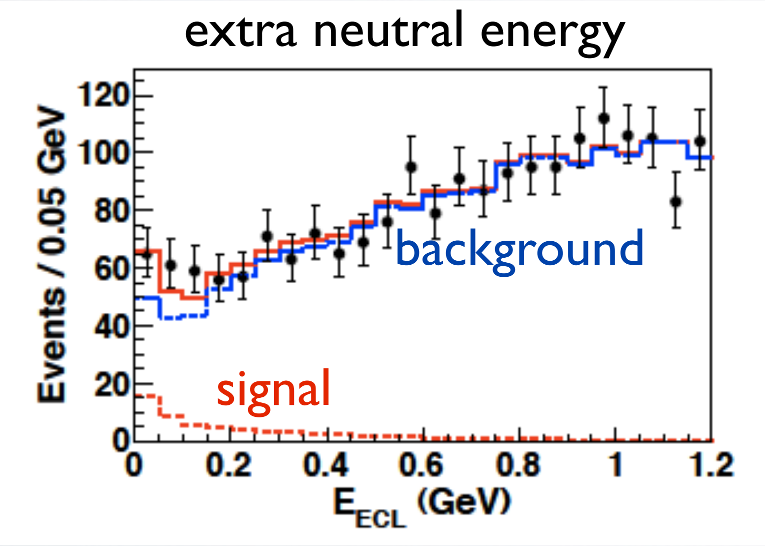
Belle II assets

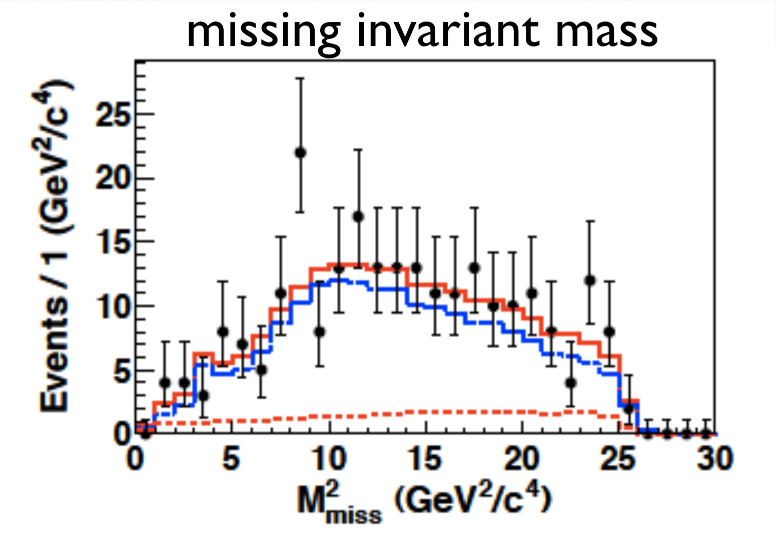


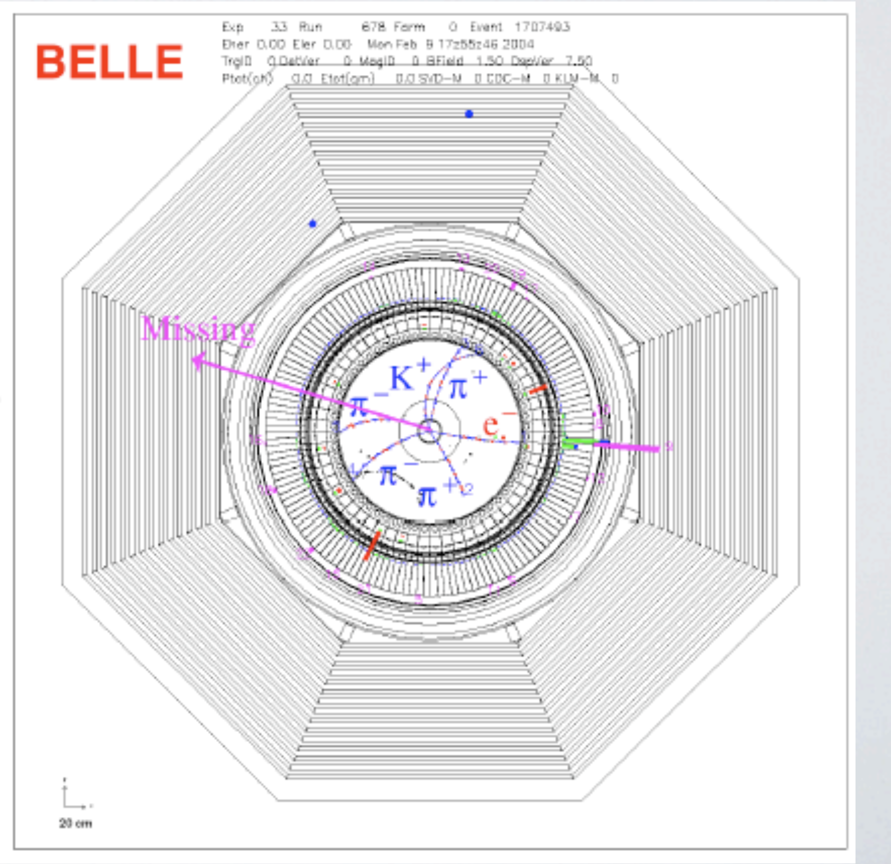
- Simplicity of the event topology (w.r.t. LHCb): only B_{TAG} and B_{SIG}.
  ➛ good capacity to study inclusive decays and decays including neutrals (γ, π^0, K_L^0) and missing energy (ν).
- Quantum correlation between B_{TAG} and B_{SIG} (w.r.t. LHCb):
  ➛ good flavour tagging.
- Reduced boost and better particle-id (w.r.t. Belle):
  ➛ improved acceptance.

- Example:

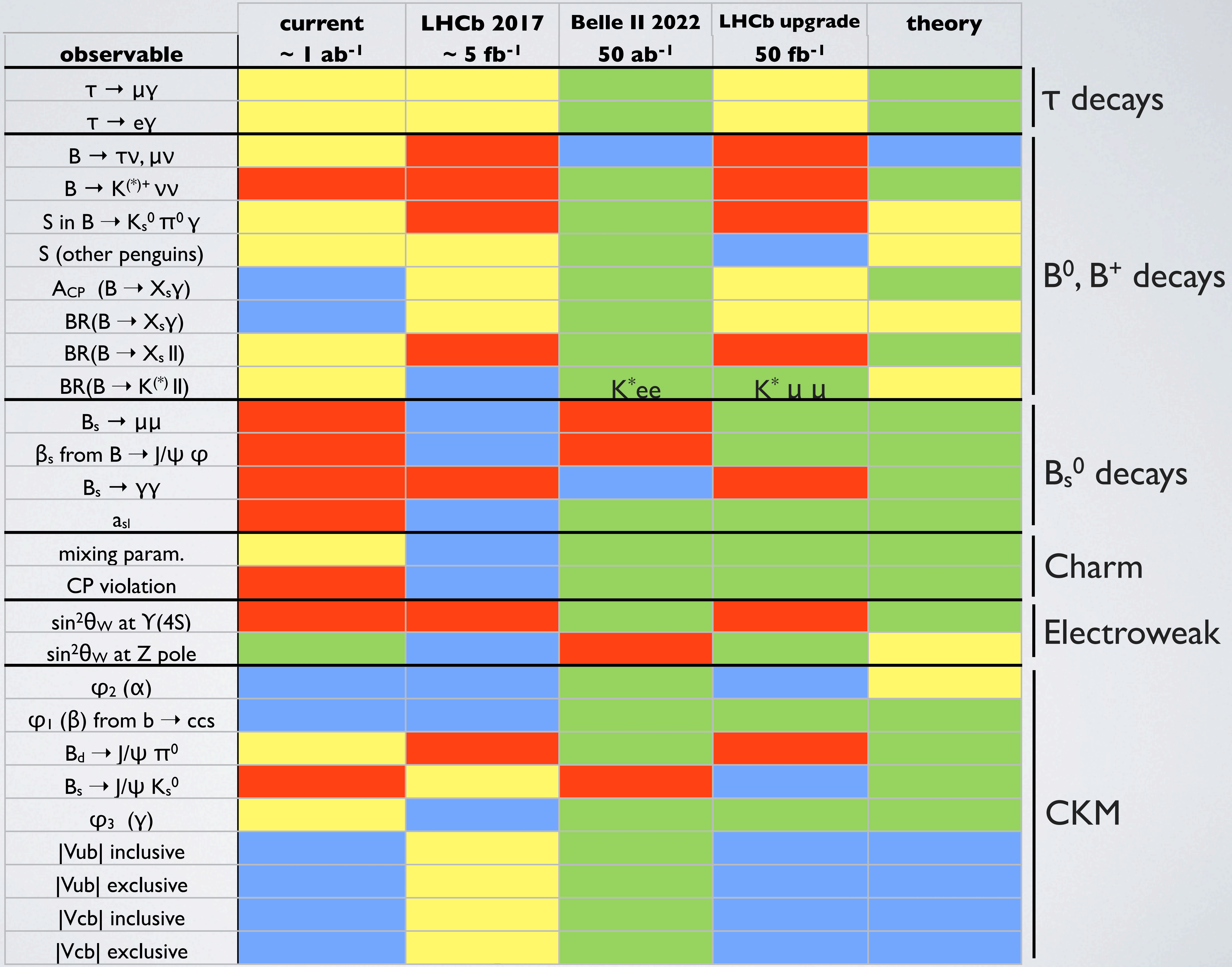
signal : $B^- \rightarrow \tau^- \bar{\nu} \rightarrow (e^- \nu \bar{\nu}) \bar{\nu}$ tag : $B^+ \rightarrow \bar{D}^0 \pi^+ \rightarrow (K^+ \pi^- \pi^+ \pi^-) \pi^+$


extra neutral energy


missing invariant mass



Belle II vs. LHCb



observable	current ~ 1 ab^{-1}	LHCb 2017 ~ 5 fb^{-1}	Belle II 2022 50 ab^{-1}	LHCb upgrade 50 fb^{-1}	theory	
$\tau \to \mu\gamma$	🟨	🟨	🟩	🟨	🟩	τ decays
$\tau \to e\gamma$	🟨	🟨	🟩	🟨	🟩	
$B \to \tau\nu, \mu\nu$	🟨	🟥	🟦	🟥	🟦	B^0, B^+ decays
$B \to K^{(*)+} \nu\nu$	🟥	🟥	🟩	🟥	🟩	
S in $B \to K_s^0 \pi^0 \gamma$	🟨	🟥	🟩	🟥	🟨	
S (other penguins)	🟨	🟨	🟩	🟦	🟨	
A_{CP} $(B \to X_s\gamma)$	🟦	🟨	🟩	🟨	🟩	
$BR(B \to X_s\gamma)$	🟦	🟨	🟩	🟨	🟨	
$BR(B \to X_s ll)$	🟨	🟥	🟩	🟥	🟩	
$BR(B \to K^{(*)} ll)$	🟨	🟦	🟩 K^*ee	🟩 $K^* \mu\mu$	🟨	
$B_s \to \mu\mu$	🟥	🟦	🟥	🟩	🟩	B_s^0 decays
β_s from $B \to J/\psi\, \varphi$	🟥	🟦	🟥	🟩	🟩	
$B_s \to \gamma\gamma$	🟥	🟥	🟦	🟥	🟩	
a_{sl}	🟥	🟦	🟩	🟩	🟩	
mixing param.	🟨	🟦	🟩	🟩	🟩	Charm
CP violation	🟥	🟦	🟩	🟩	🟩	
$\sin^2\theta_W$ at $\Upsilon(4S)$	🟥	🟥	🟩	🟥	🟩	Electroweak
$\sin^2\theta_W$ at Z pole	🟩	🟦	🟥	🟩	🟨	
φ_2 (α)	🟦	🟦	🟩	🟦	🟨	CKM
φ_1 (β) from $b \to ccs$	🟦	🟦	🟩	🟩	🟩	
$B_d \to J/\psi\, \pi^0$	🟨	🟥	🟩	🟥	🟩	
$B_s \to J/\psi\, K_s^0$	🟥	🟨	🟥	🟦	🟩	
φ_3 (γ)	🟨	🟦	🟩	🟩	🟩	
|Vub| inclusive	🟦	🟨	🟩	🟦	🟦	
|Vub| exclusive	🟦	🟨	🟩	🟦	🟦	
|Vcb| inclusive	🟦	🟨	🟩	🟦	🟦	
|Vcb| exclusive	🟦	🟨	🟩	🟦	🟦	

🟥 no results

🟨 moderate precision

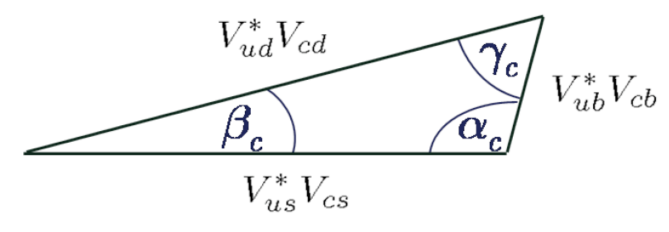
🟦 precise

🟩 very precise

CP violation in the charm sector

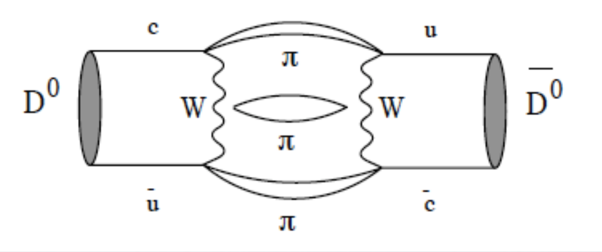
- Measurement of the *cu* UT:

$$V_{ud}^{*}V_{cd}+V_{us}^{*}V_{cs}+V_{ub}^{*}V_{cb}=0$$



prediction from CKM fit:
$\beta_c = (0.0350 \pm 0.0001)°$

- Important measurements while:
  - Unexpected direct CPV observation in D^0 decays by LHCb in 2011 (also by CDF and Belle, unconclusive results by LHCb in 2013);
  - Additional CP violation phases needed;
  - Only oscillating system involving down-type quarks in the box diagram.

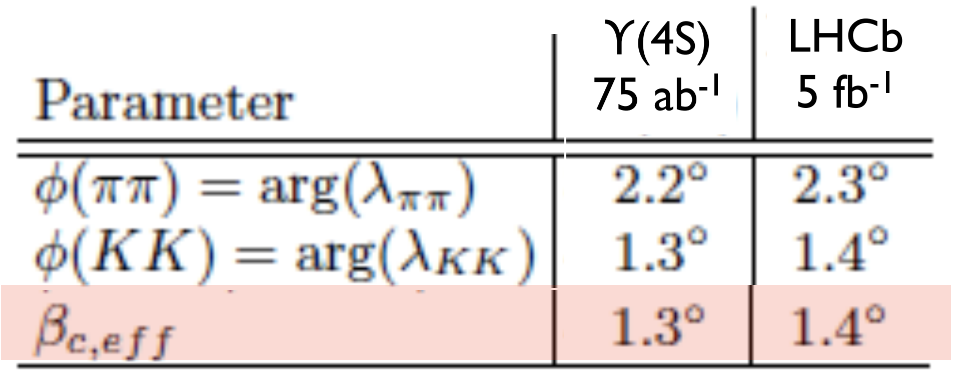


- New analysis : sensitivity to β_c through time dependent CP asymmetry in D^0 decays.

$$\text{asymmetry}\ \ A(t)=\frac{\Gamma(D^0(t)\rightarrow f_{CP})\ -\ \Gamma(\bar{D}^0(t)\rightarrow f_{CP})}{\Gamma(D^0(t)\rightarrow f_{CP})\ +\ \Gamma(\bar{D}^0(t)\rightarrow f_{CP})}=f(\lambda_f,t)$$

$$\text{with :}\quad \arg(\lambda_f)=\Phi_{mix}-2\beta_{c,\,eff.}$$

↗ ↗
$\Phi_{\pi\pi}$ Φ_{KK}



Parameter	Υ(4S) 75 ab^{-1}	LHCb 5 fb^{-1}
$\phi(\pi\pi)=\arg(\lambda_{\pi\pi})$	2.2°	2.3°
$\phi(KK)=\arg(\lambda_{KK})$	1.3°	1.4°
$\beta_{c,eff}$	1.3°	1.4°

A. Bevan *et al.*, Phys.Rev. D84 (2011) 114009

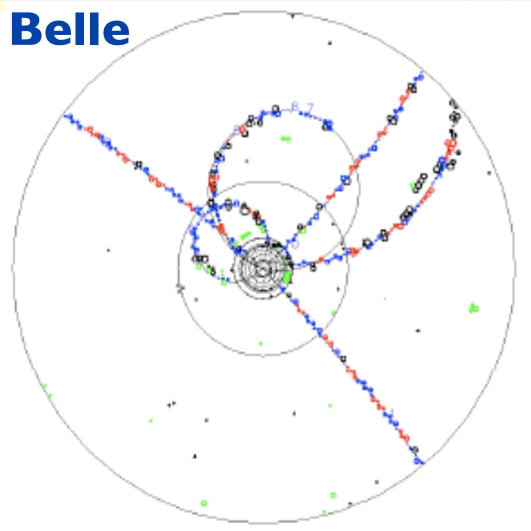
- Belle II vs. LHCb:
  - More statistics at LHCb but more background, lower trigger efficiency, and annoying trigger and cut decay time dependences.
  - Worse decay time resolution in Belle II. How to improve it: tracking algorithm, upgraded inner tracker?

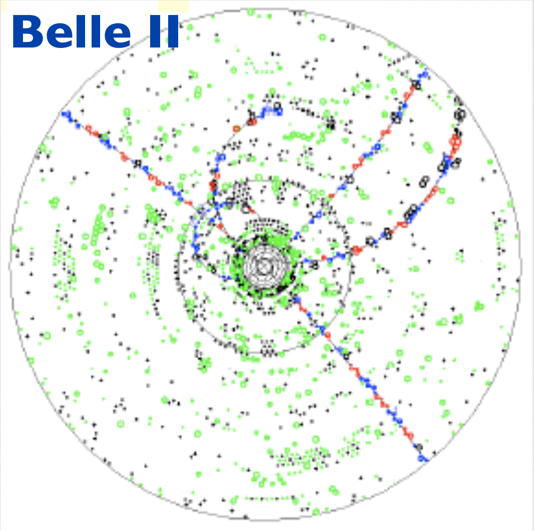
Flight time resolution

- Resolution on distance between the 2 decay vertices: crucial in all time dependent CPV studies in B and D decays.

- Increased machine induced backgrounds
  ➛ higher occupancy rate:
  impact on track reconstruction.

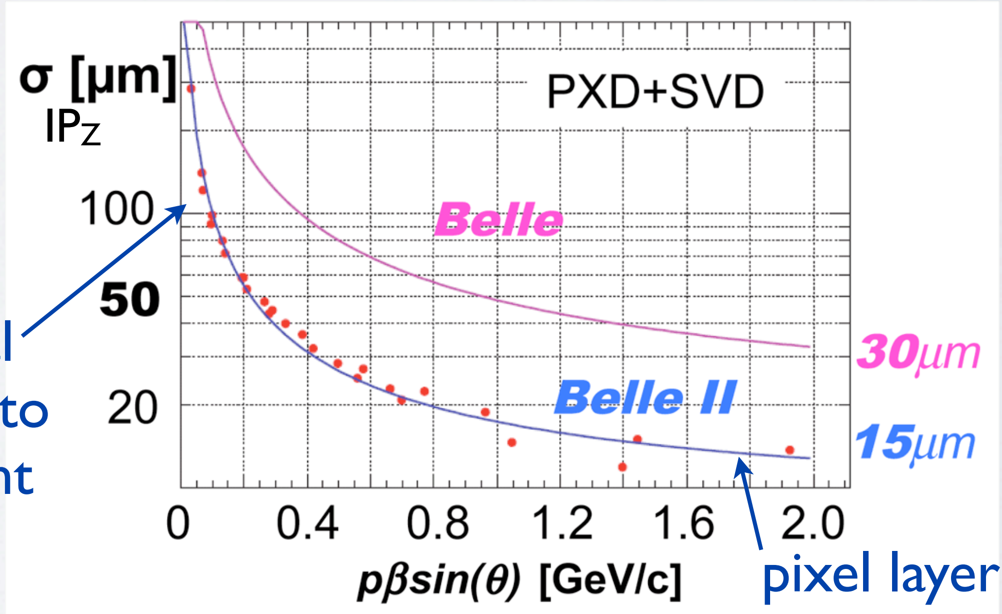
- Reduced beam asymmetry: βγ = 0.28
  (was 0.42 at KEKB)
  ➛ smaller Δz and worse σ(Δt)
  (but D mesons from continuum less impacted).





- Therapy:
  - Add 2 innermost layers of pixels close to IR,
  - Smaller beam spot,
  - Beam pipe radius decreased to 1 cm.

  ➛ Expected precision on Δt
  2× better than in Belle.



low material budget close to collision point

pixel layers close to collision point

- But also to be considered to further improve σ(Δt):
  - Improvement of tracking algorithms.
  - Investigate the added value of an upgraded pixellated light inner tracker taking data ~ 2020.

Which contributions are in discussion?

- Time dependent CPV studies in the Charm sector:

  R. Maria, I. Ripp-Baudot.

  Collaborator: K. Trabelsi (KEK).

  Reproduce and extend a preliminary study published in Phys.Rev. D84 (2011) 114009: sensitivity on the charm unitarity triangle β_c angle.

- Track reconstruction:

  J. Baudot, R. Maria, I. Ripp-Baudot.

  Collaborators: M. Heck (KIT), R. Frühwirth (HEPHY).

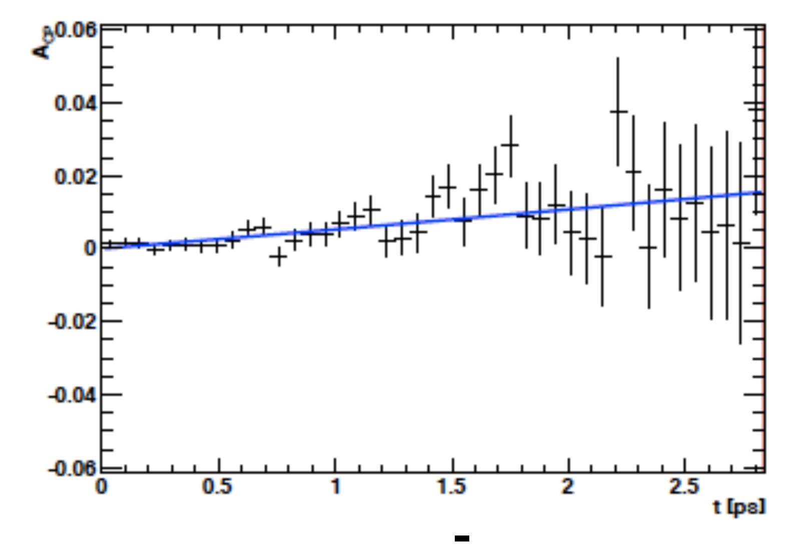
  Tracking performances for low momentum tracks (70-100 MeV) in a high hit occupancy environment.

- Commissioning of the SuperKEKB collider:

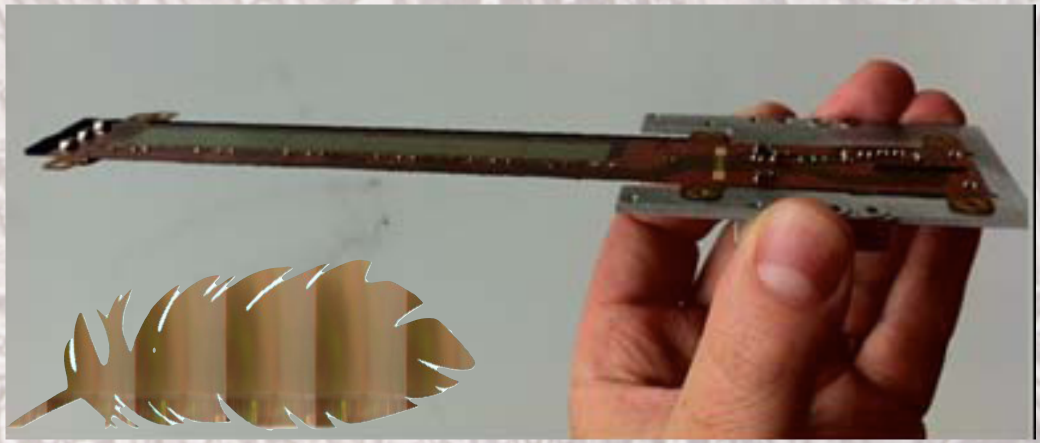
  J. Baudot, I. Ripp-Baudot.

  Collaborators: C. Marinas (Bonn Univ.), S. Vahsen (Hawaii Univ.), Y. Ushiroda (KEK), S. Tanaka (KEK).

  Include a double-sided PLUME ladder, equipped on both sides with CMOS pixel sensors, in the inner tracking volume, to do hit rate counting during BEAST II.



$$\frac{\Gamma(D^0(t)\rightarrow f) - \Gamma(\bar{D}^0(t)\rightarrow f)}{\Gamma(D^0(t)\rightarrow f) + \Gamma(\bar{D}^0(t)\rightarrow f)}$$

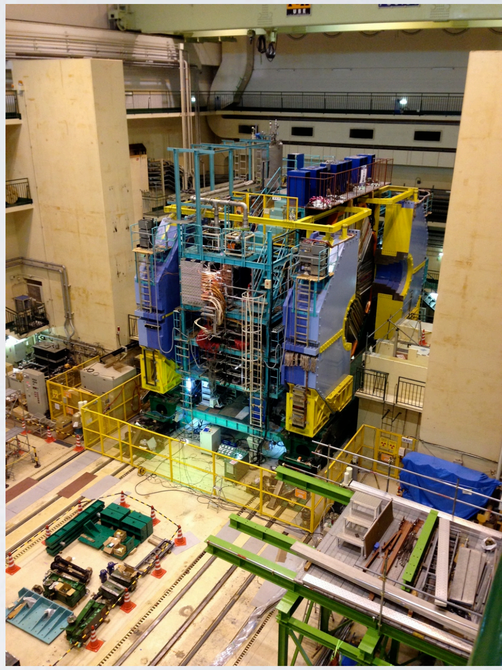


FJPPL (TYL) application

- Members:

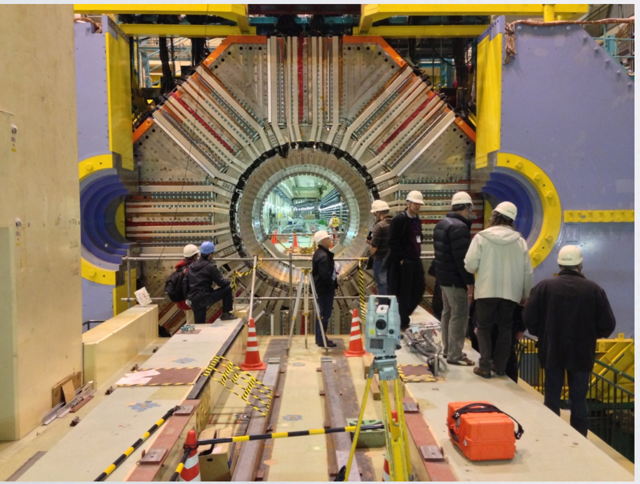
At IPNS/KEK:
  - Yutaka USHIRODA: technical coordinator,
  - Shuji TANAKA: inner tracking system coordinator (integration aspects),
  - Karim TRABELSI: physics coordinator.

At IPHC/IN2P3:
  - Isabelle RIPP-BAUDOT: principal investigator,
  - Marc WINTER: PICSEL group leader,
  - Christine HU: micro-electronic group leader,
  - Jérôme BAUDOT: tracking and CMOS pixel expert.
  - Robert MARIA: PhD student 2012-15.



- Funding requests:
  - IN2P3: 3 travels to Japan - 6600 €
  - KEK: 1 travel to France - 350 ¥

➛ actually 2 persons may travel to France (Fall 2013)



Conclusion

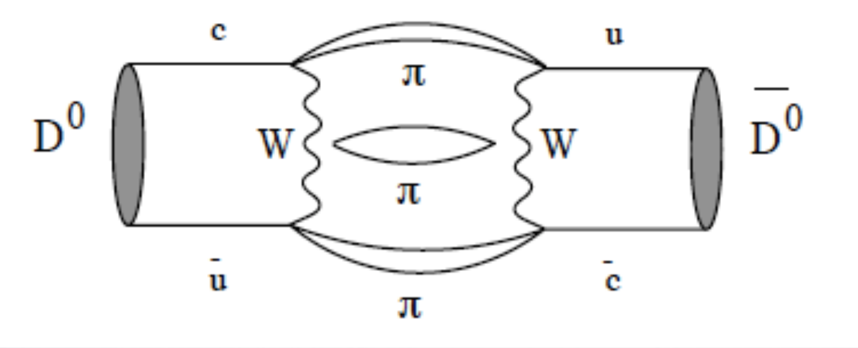
- SuperKEKB will deliver collisions with the highest instantaneous luminosity in the world.
- The Belle II detector and the SuperKEKB collider SuperKEKB are on the way to be delivered. Collider commissioning will start mid 2015 and data taking in Fall 2016.
- Belle II will play a crucial role in the discovery and the understanding of beyond SM physics.
- The Belle II physics program is complementary to energy frontier experiments, but also to LHCb and other intensity frontier experiments.
- There is currently a good opportunity to contribute to Belle II, aiming at analysing Belle II data in 2016, and also Belle data immediately.
- This project aims at initiating a French participation to Belle II with an interest focused on time dependant CPV studies in synergy with contributions to the track reconstruction and to the inner tracking system.
  Discussions with other French laboratories are ongoing to propose to join Belle II.

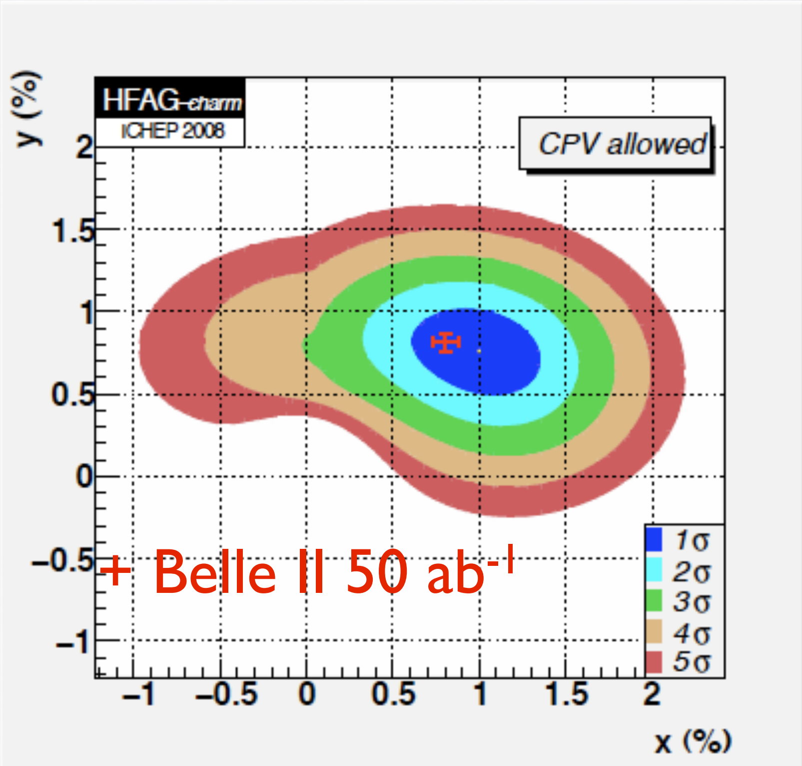
thank you for your attention!

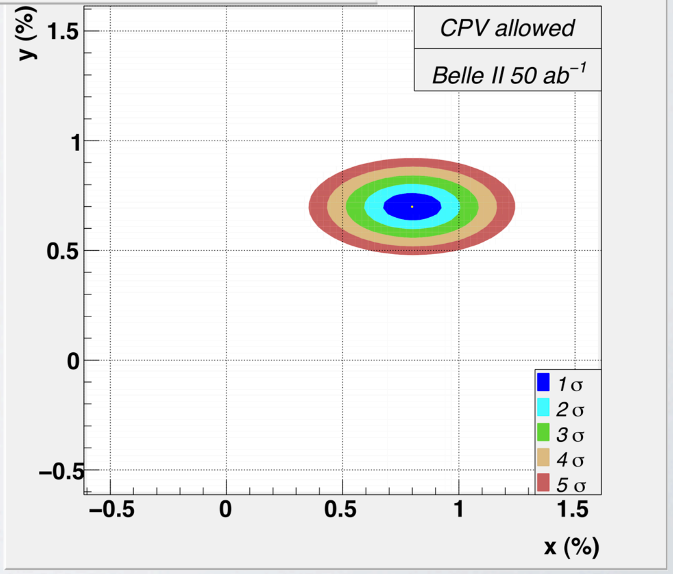
additional material follows

D^0 oscillation

- Recent experimental observation (2007): very slow oscillation w.r.t. D^0 lifetime.
- Measured oscillation parameters at the border of SM predictions :
  long distance contributions in the box diagram ☹.







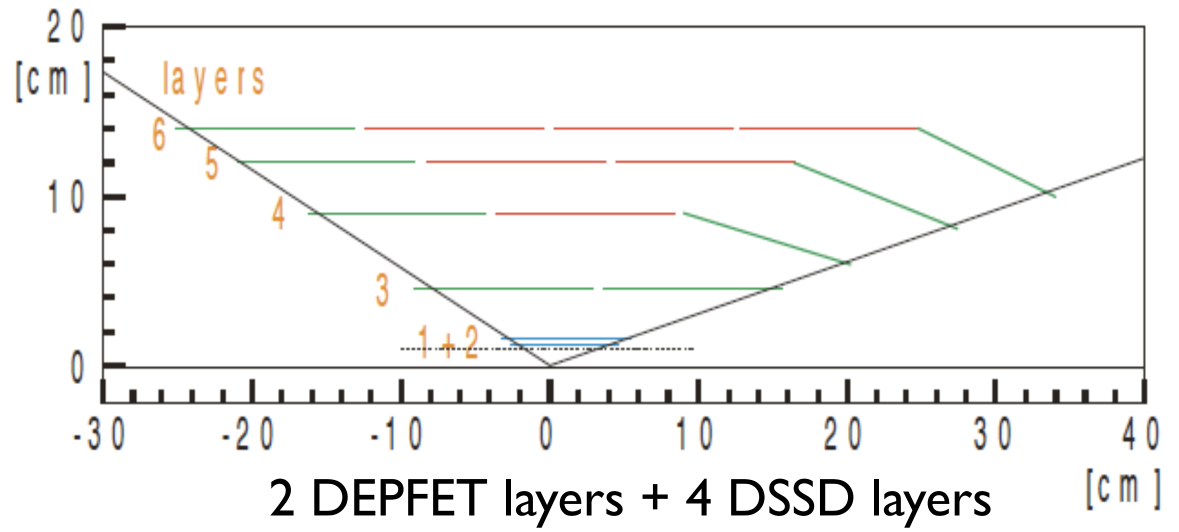
D^0-$\bar{D}^0$ mixing parameters

- $x_D = \Delta m/\Gamma$
- $y_D = \Delta\Gamma/2\Gamma$

can be measured with precision $< 10^{-3}$
with 50 ab^{-1} in Belle II.

Design of the inner tracker (1)

- Reduced boost at Belle II ➛ smaller Δz and worse $\sigma(\Delta t)$.
- Therapy:
  - Add 2 innermost layers of pixels close to IP,
  - Smaller beam spot,
  - Beam pipe radius decreased to 1 cm.



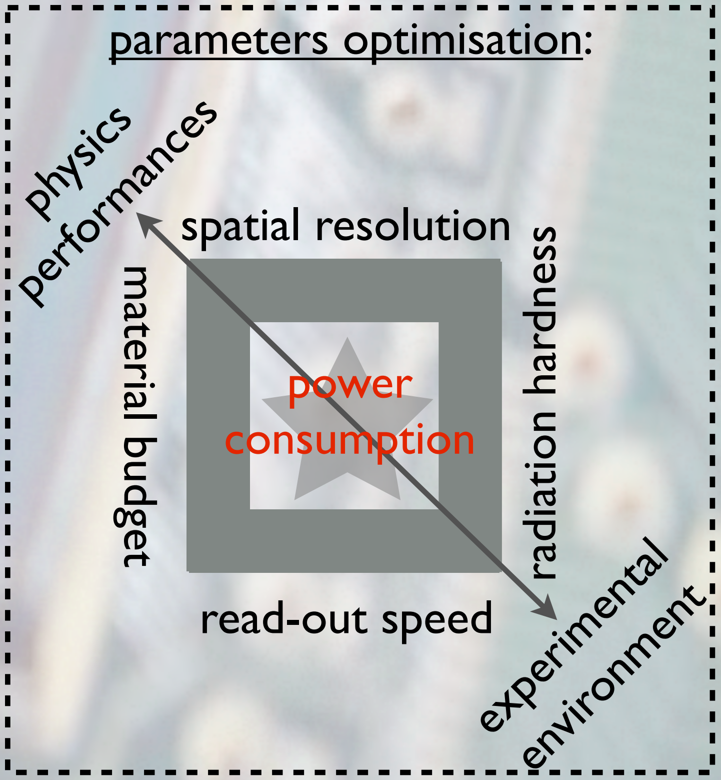
2 DEPFET layers + 4 DSSD layers

- Environmental constraints at r ~ 1.5 cm :
  - ionising radiations : 3 MRad /year,
  - non ionising rad. : 10^{13} $n_{eq}.cm^{-2}$ /year,
  - hit rate : 10 MHz.cm^{-2} dominated by machine induced backgrounds
  - data flow : 1 Gb s^{-1}
  - momentum spectrum < 1 GeV.

➛ imply *a priori* the need of a pixellated sensor with:

- material budget < 1 % X_0 /layer,
- spatial resolution in $R\varphi$ and z < 10 μm,
- sensor integration time ~ 1 μs.

➛



parameters optimisation:

physics performances

spatial resolution

material budget

power consumption

radiation hardness

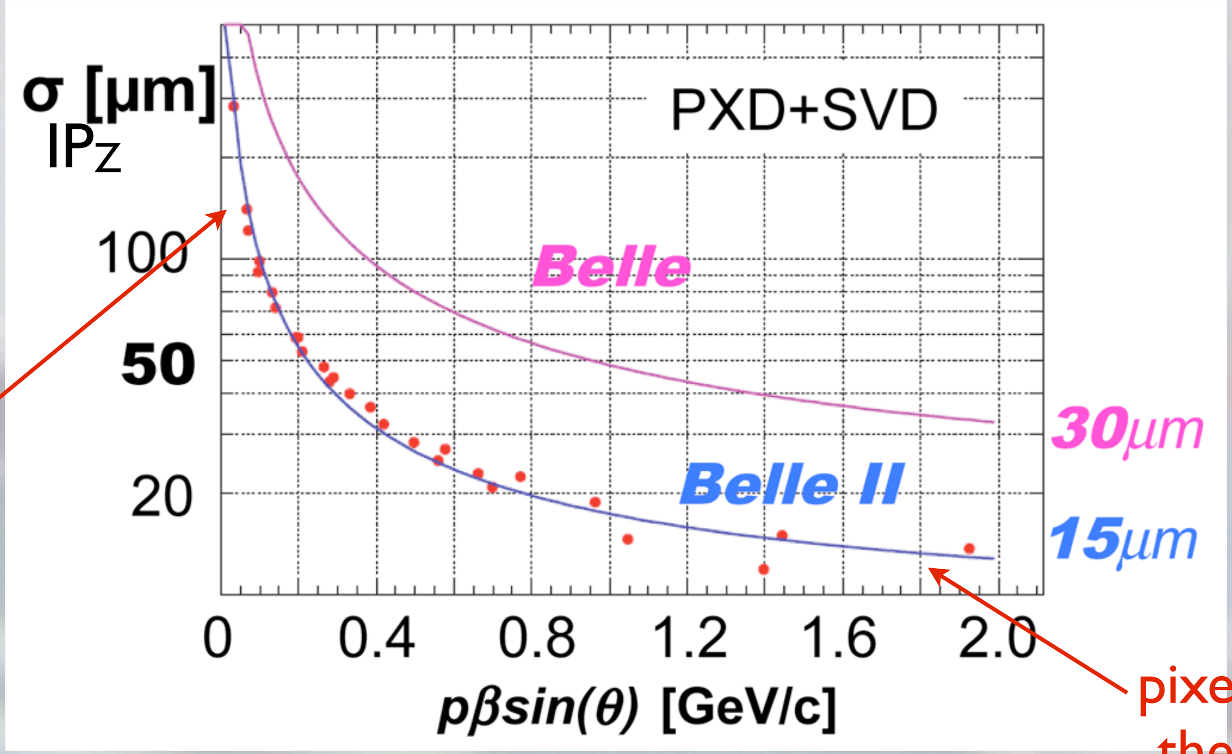
read-out speed

experimental environment

Design of the inner tracker (2)

- Technology chosen in Belle II : non-monolithic DEPFET pixels,
  - good radiation hardness,
  - material budget < 0.2 % X_0 /layer,
  - sensor integration time of 20 μs ➛ OK by taking benefit *on-line* from the track extrapolated outside-in from the SVD, with 3 ns time stamp, to reduce the impact of the high occupancy rate.

➛ The design is performed globally, by combining all layers performances and the tracking algorithm.



low material budget

pixel layers close to the collision point

➛ Expected precision on Δt 2× better than in Belle.