Report on WP1 activities
(Belle II software and physics case)

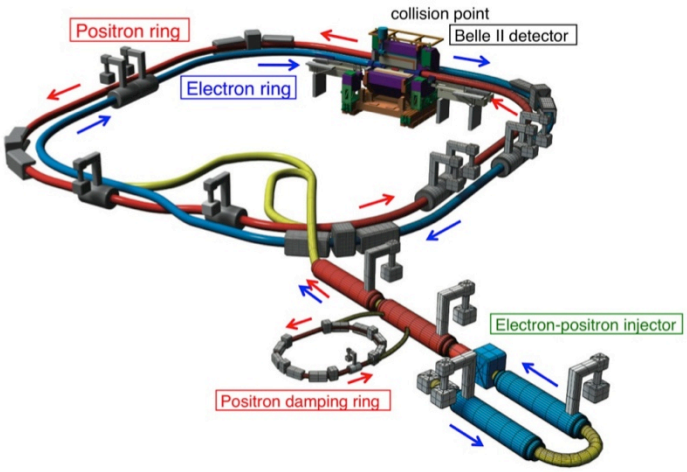
Christoph Schwanda
Austrian Academy of Sciences

EU grant n.644294

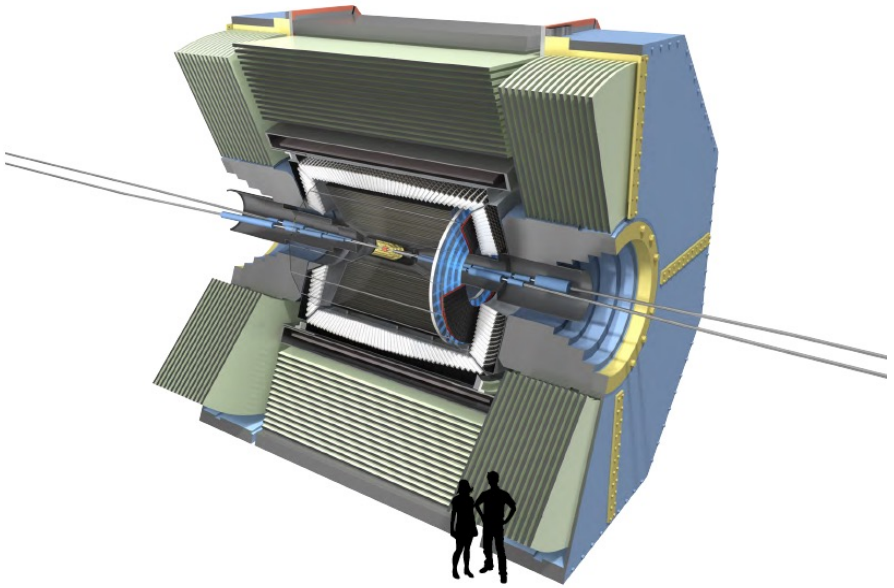
Introduction

- Belle II is particle physics experiment at KEK (Japan) that will explore the physics of B and charmed mesons and τ leptons from the year 2018 on

SuperKEKB



Belle II



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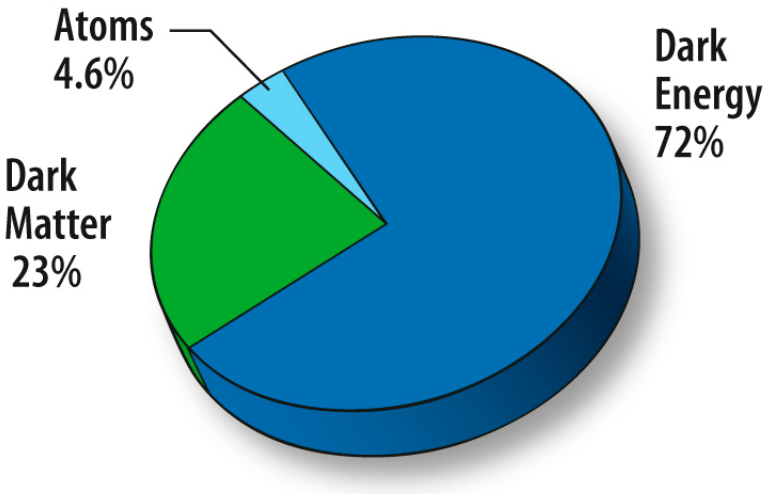
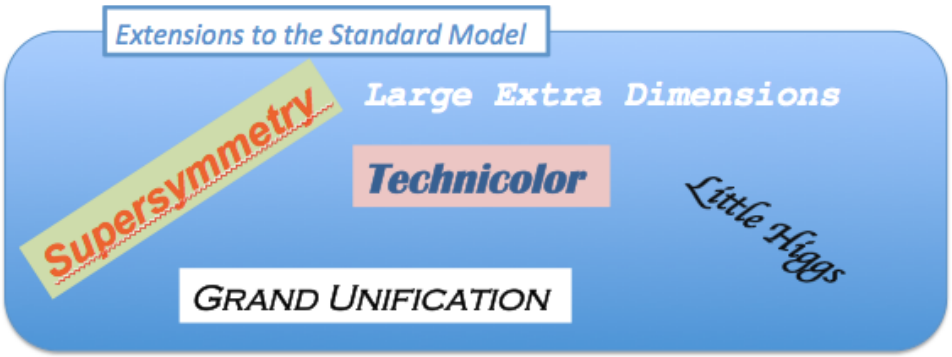
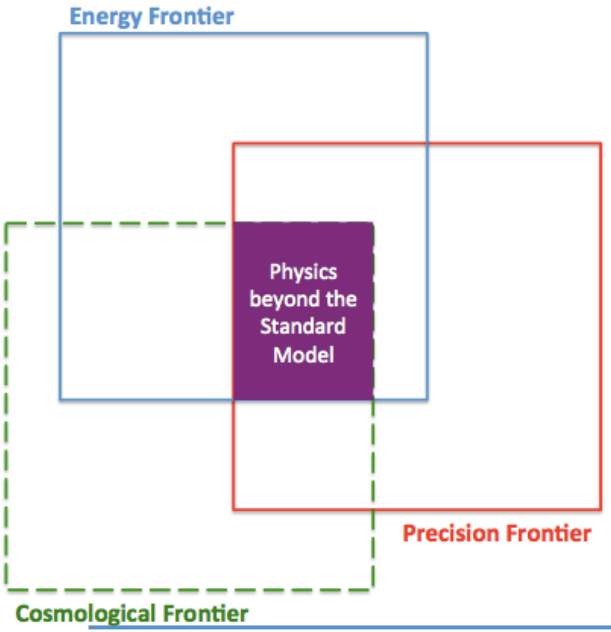
New Physics through precision







- Belle II is at the precision frontier – aims at accumulating 50 times more data than previous experiments (Belle/BaBar)

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CKM Physics

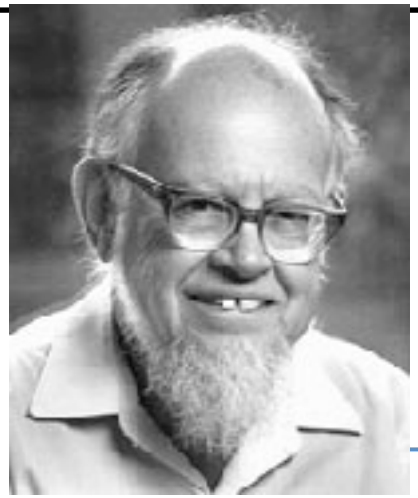
N. Cabibbo

M.Kobayashi

T.Maskawa

$$V_{\rm CKM} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

L. Wolfenstein (1923-2015)



to O(λ^3)

$$V = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

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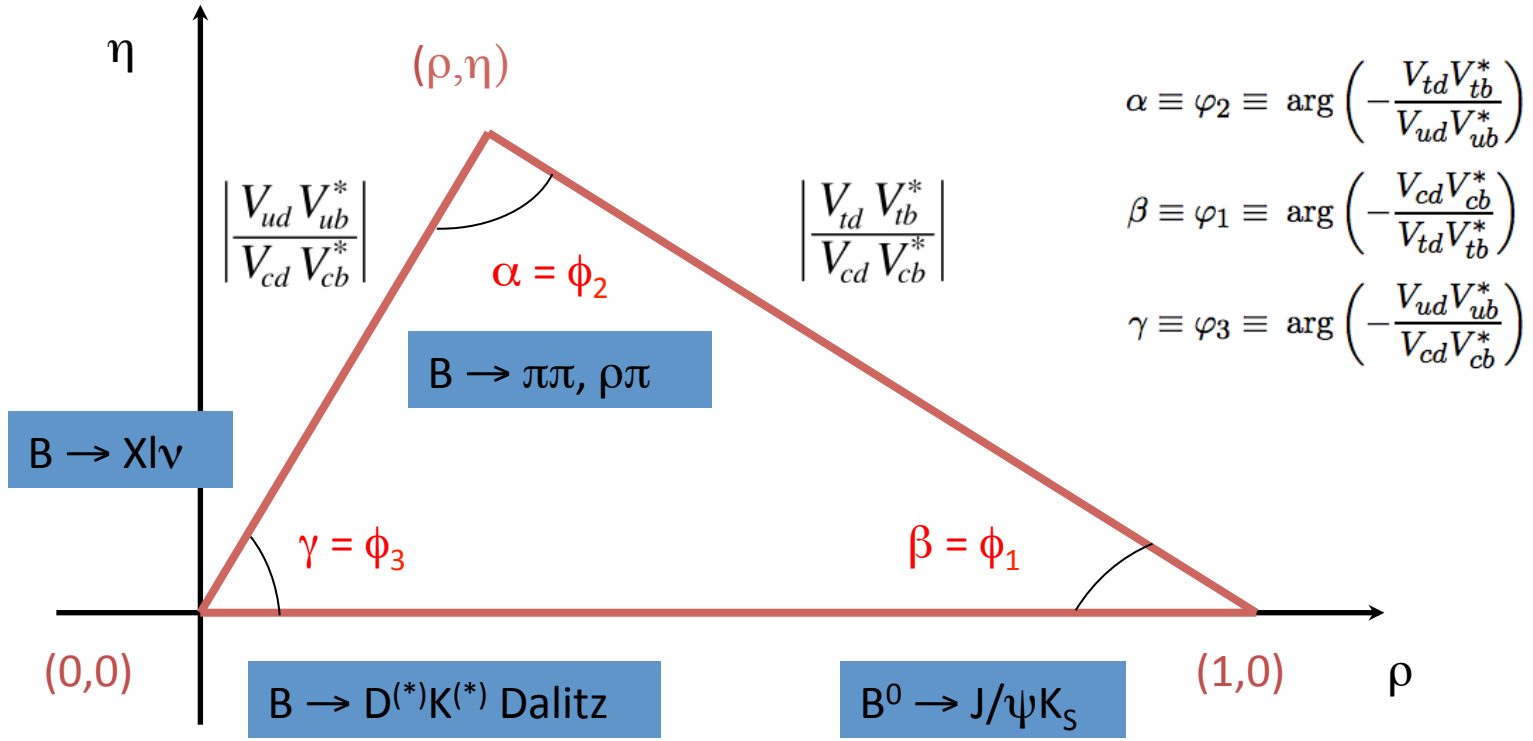
The CKM unitarity triangle

$$\sum_i V_{ij} V_{ik}^* = \delta_{jk} \quad \Rightarrow \quad V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0$$



$$\alpha \equiv \varphi_2 \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\beta \equiv \varphi_1 \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

$$\gamma \equiv \varphi_3 \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

Big Questions: *Are determinations of angles consistent with determinations of the sides of the triangle ? Are angle determinations from loop and tree decays consistent ?*

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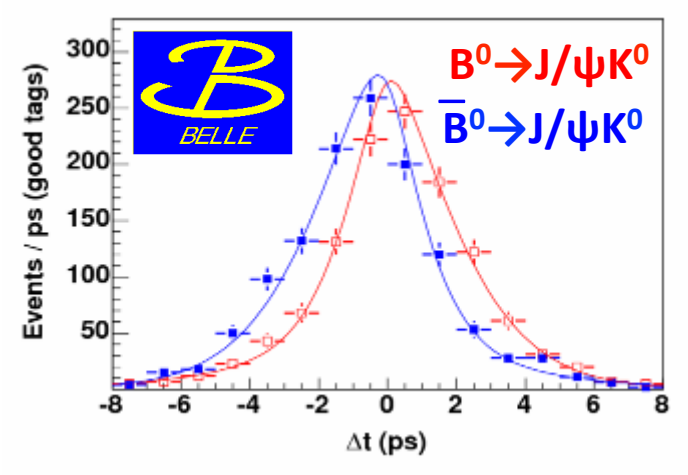
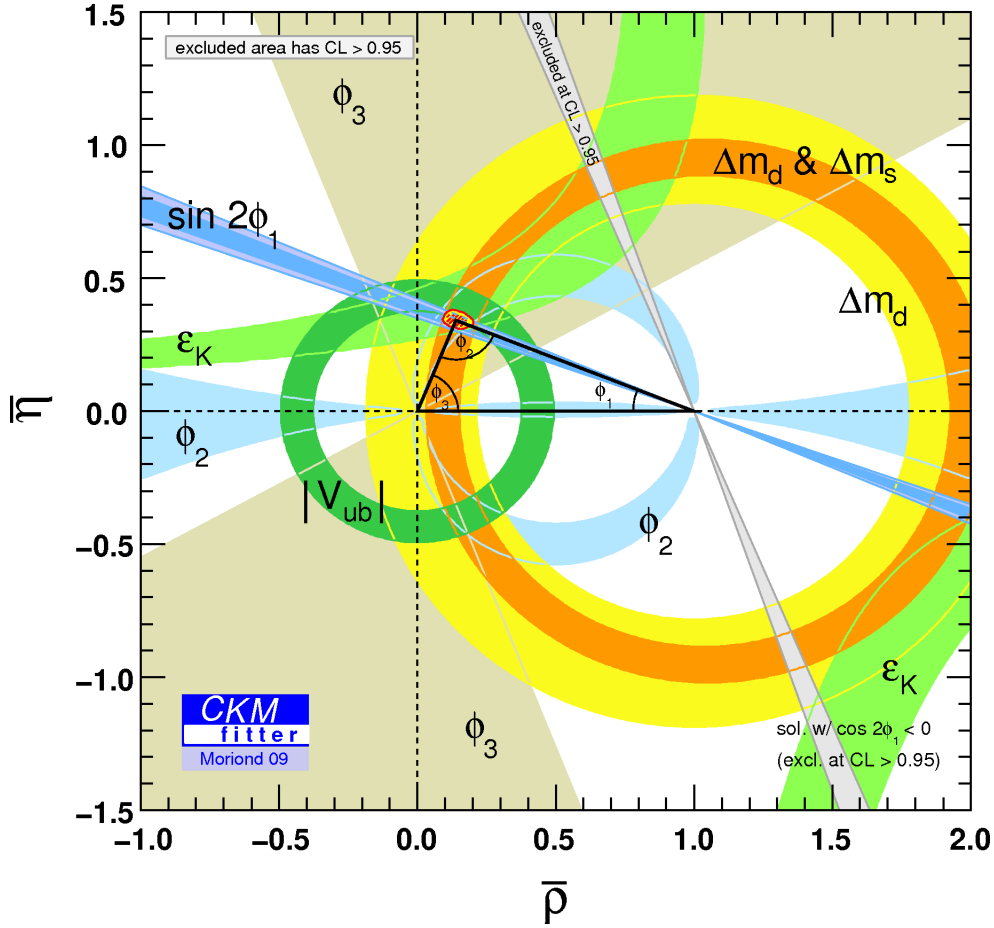
Belle/BaBar: a success story

Discovery of *CP* violation in the B meson system (2001)



Rate of the decay B^0 ($\bar{B}^0$) $\to J/\psi K^0$ as a function of the decay time difference of the two Bs in Y(4S) $\to B\bar{B}$ events

Confirmation of CKM unitarity (~2005)



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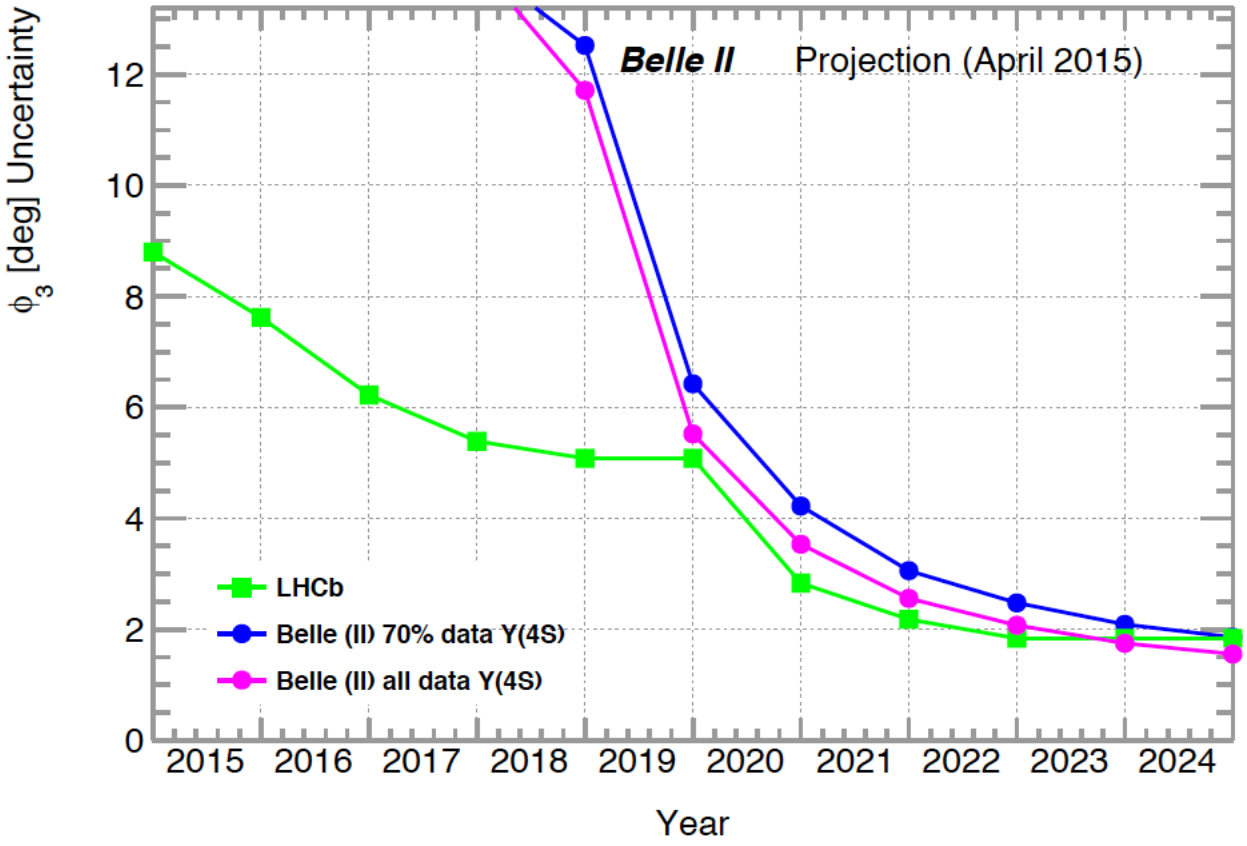
Will CKM unitarity hold at Belle II?



The angle γ/ϕ_3
A fierce competion between Belle II and LHCb

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Rare decays, charm physics, …

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\|V_{us}\|$ $[K \to \pi\ell\nu]$	**	0.1%	K-factory
$\|V_{cb}\|$ $[B \to X_c\ell\nu]$	**	1%	Belle II
$\|V_{ub}\|$ $[B_d \to \pi\ell\nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K^0_S$	***	$8 \cdot 10^{-3}$	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
$S(B_d \to K^*(\to K^0_S\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A^d_{SL}	***	0.001	LHCb
A^s_{SL}	***	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
$\|q/p\|_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

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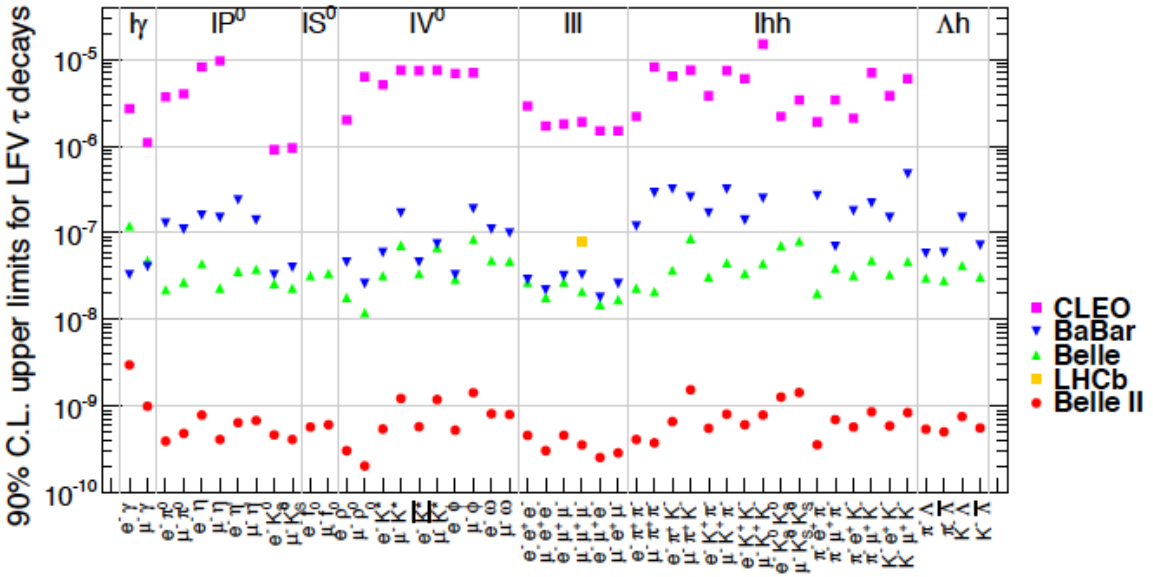
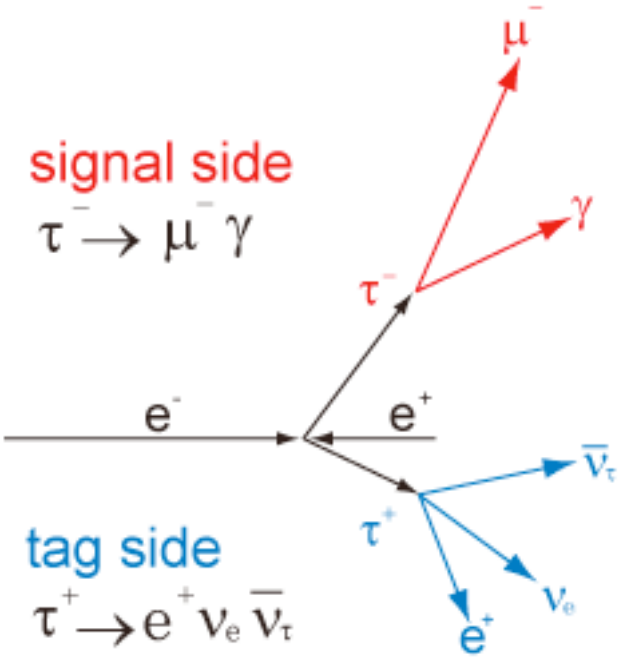
Tau lepton flavour violation

FIG. 5: LFV UL (90% C.L.) results from CLEO, BaBar and Belle, and extrapolations for Belle II (50 ab^{-1}) and LHCb updgrade (50 fb^{-1}).



Example of the decay topology



Belle II will push many limits below 10^{-9} ;
LHCb has very limited capabilities.

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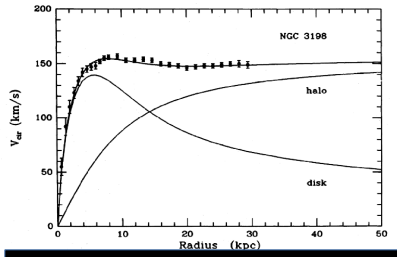
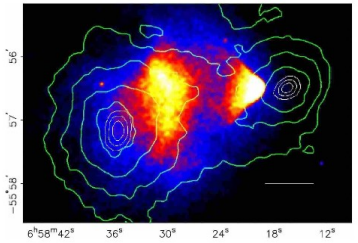
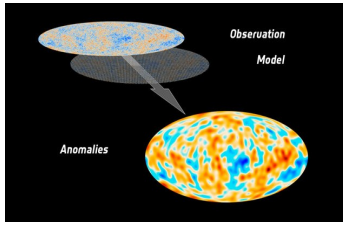
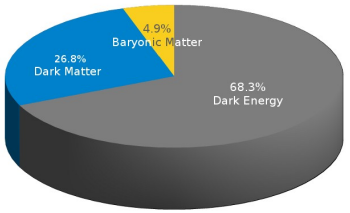
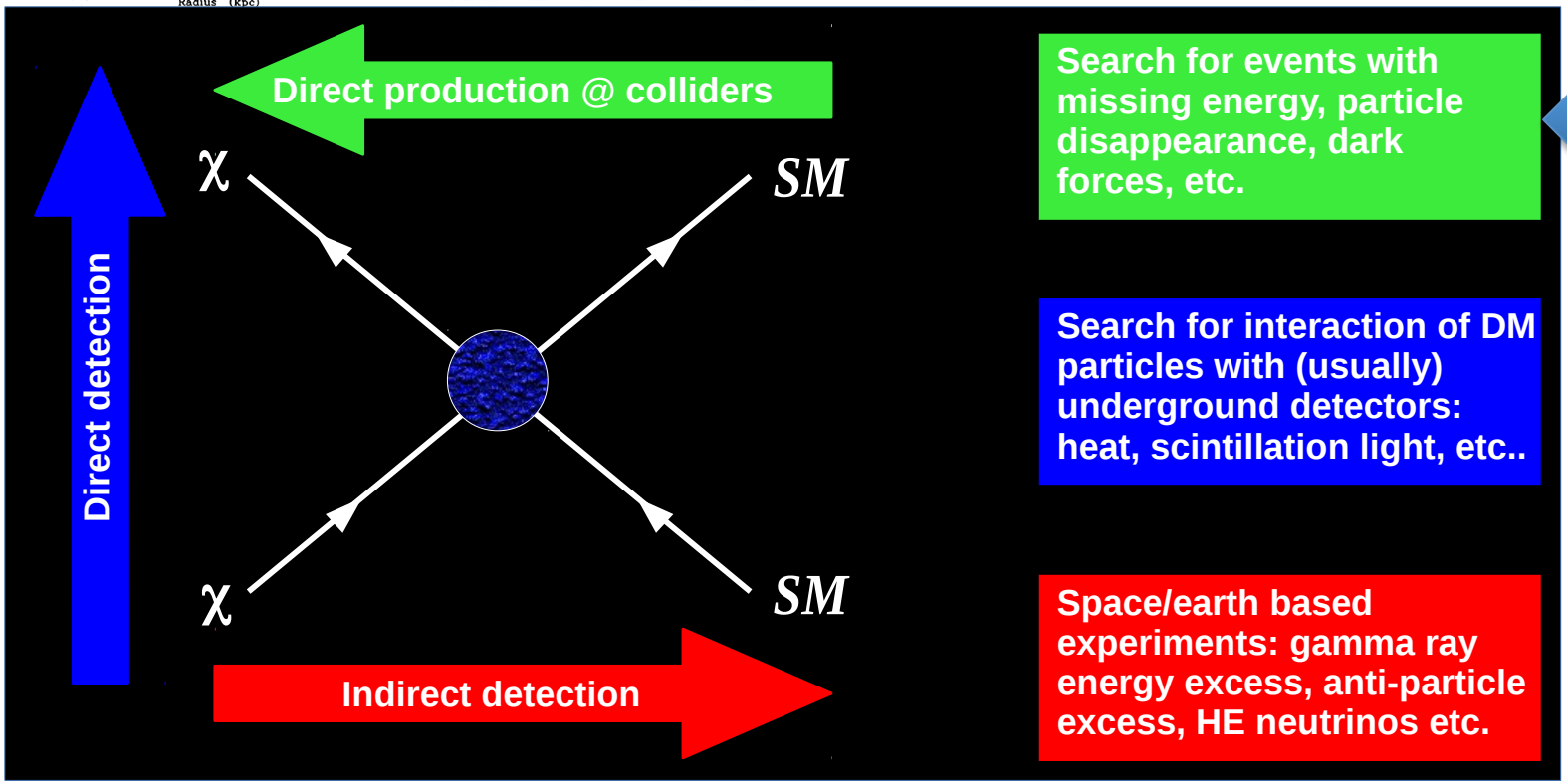
Searching for dark matter











Belle II

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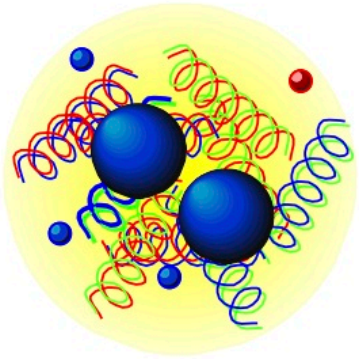
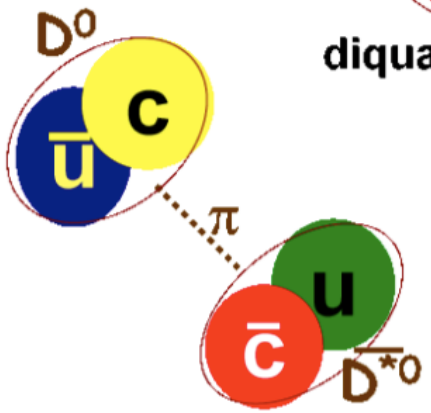
Quarkonium

Quarkonium-like states

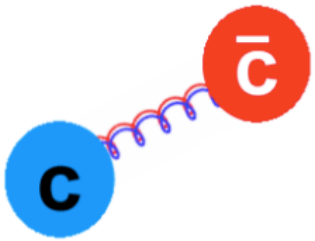


Exotic states

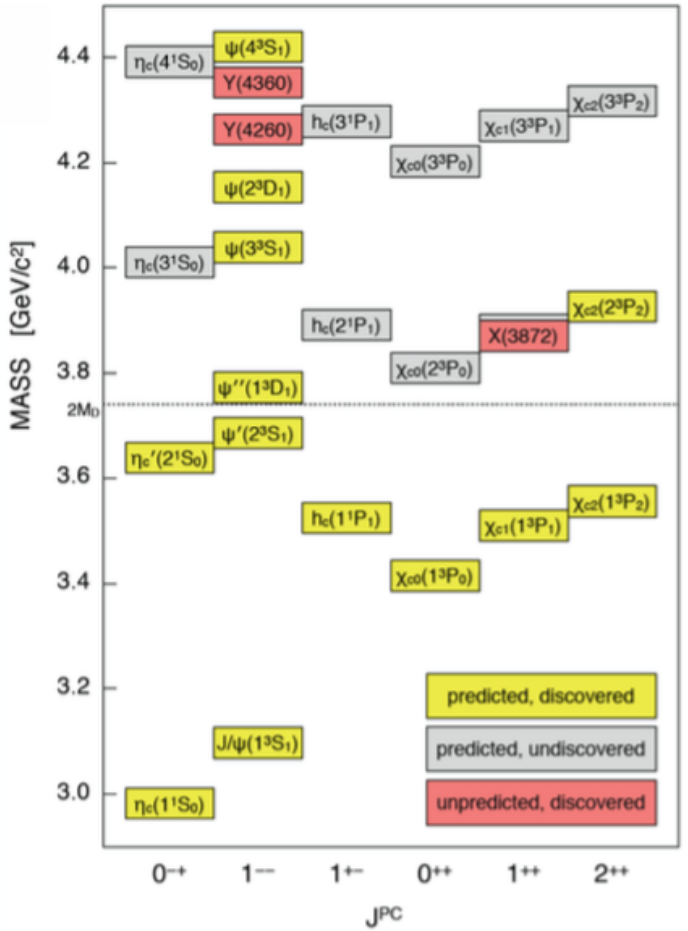
diquark-diantiquark



$D^0 - \bar{D}^{*0}$ "molecule"



$q\bar{q}$-gluon"hybrid"



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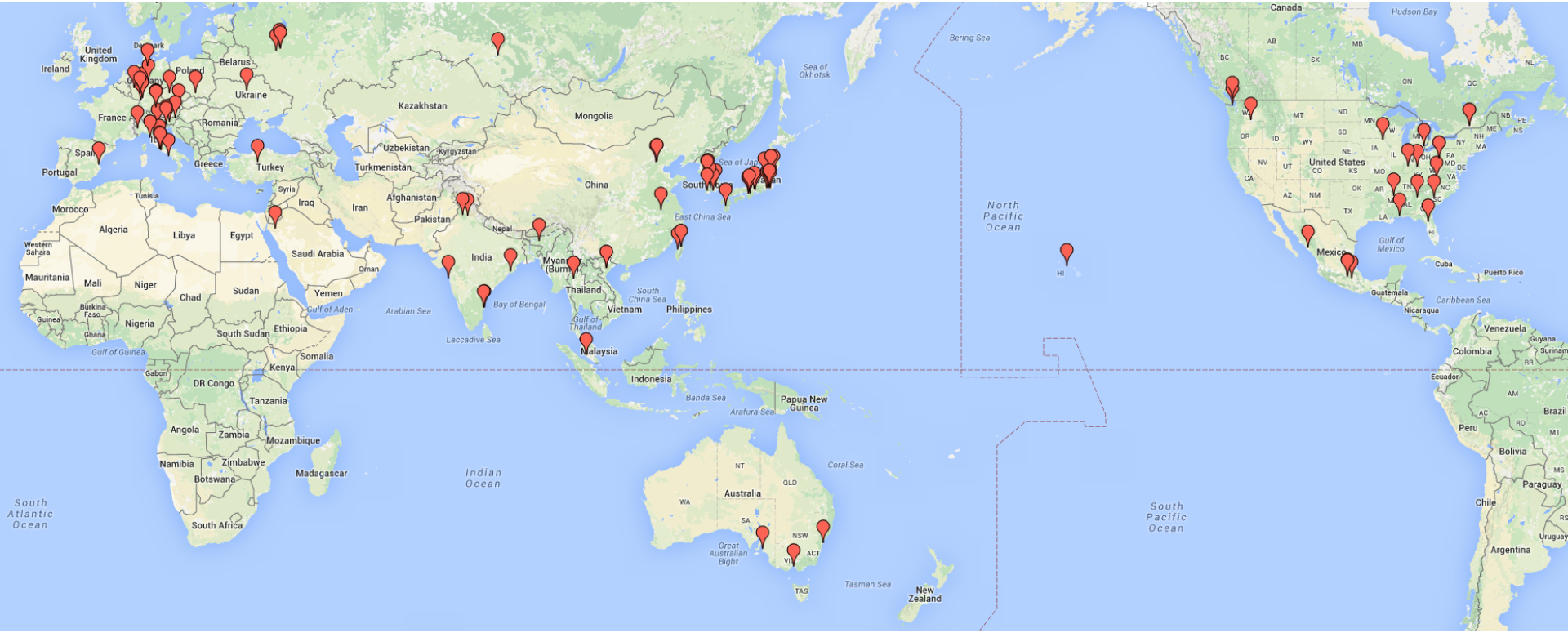
Objectives of WP1

Exploit the physics potential of Belle II by

- Task 1.1: Developing the detector-related software (charged track reconstruction, alignment, particle identification, …)
- Task 1.2: Implementing software tools for physics analysis
- Task 1.3: Identify the key measurements for Belle II (Belle II-theory interface platform)

Belle II collaboration map



- 100 Belle II institutions in 23 countries: WP1 typically uses secondments for attending collaboration meetings/workshops at KEK

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WP1 results

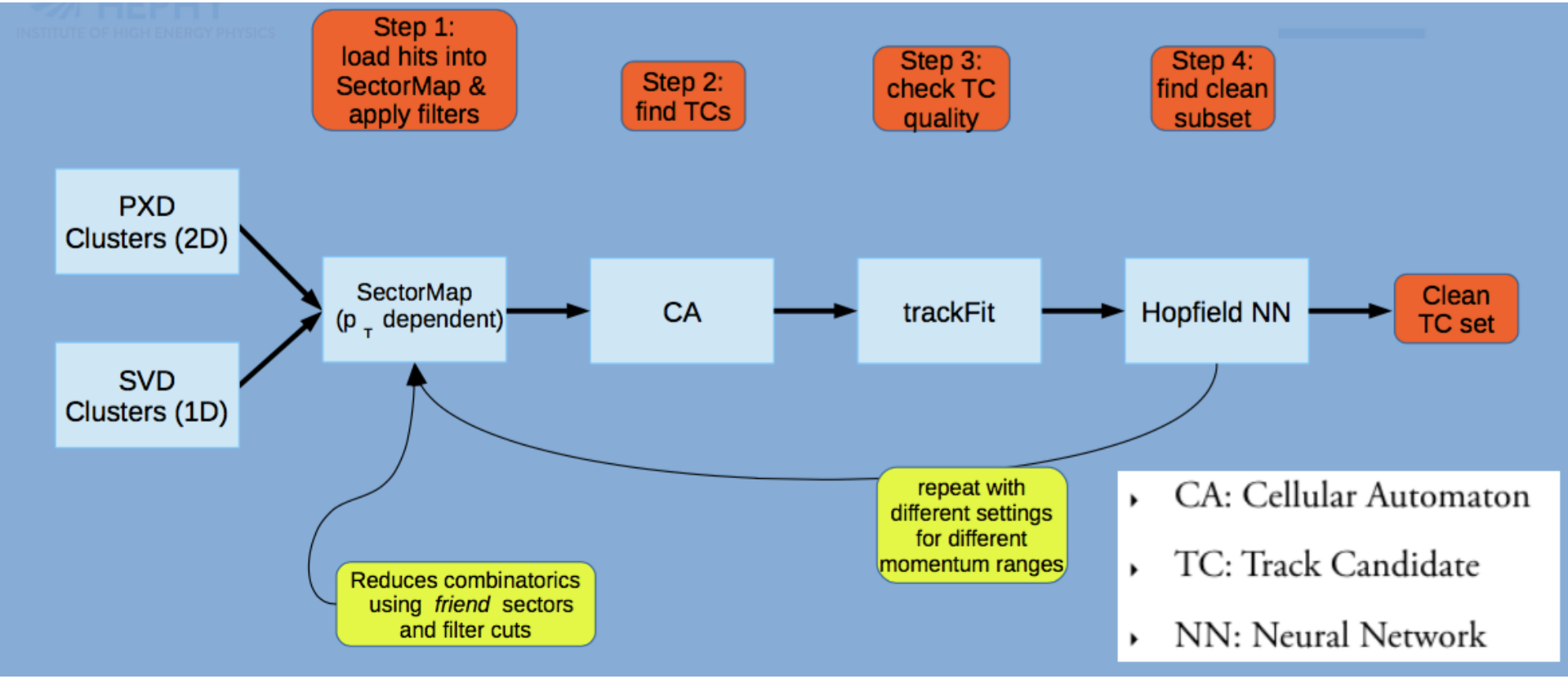
- Secondments
  - Total secondments: 259 days (8.6 months)
  - Started secondments (until August 2016): 15
  - Planned months (until August 2016): 19

	INFN	HEPHY	IFJ PAN	UKP	JSI	METU	CNRS
Seconded days	114	31	64	0	26	0	24
Planned (month)	5	2	3	2	3	2	2

- Deliverables D1.1 (offline workshop) and D1.2 (Belle II tutorials) achieved in time

VXDTF – track finder for low momentum particles

[HEPHY]



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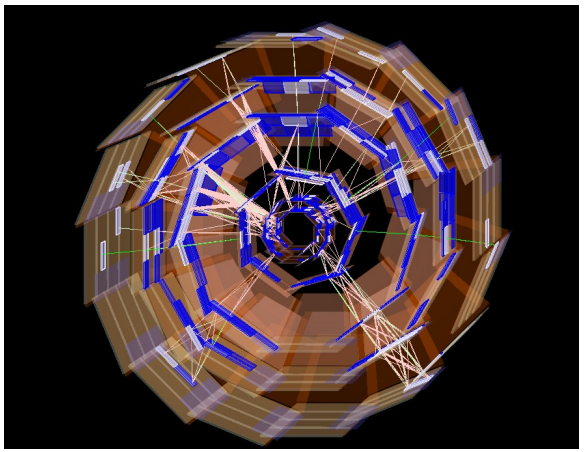
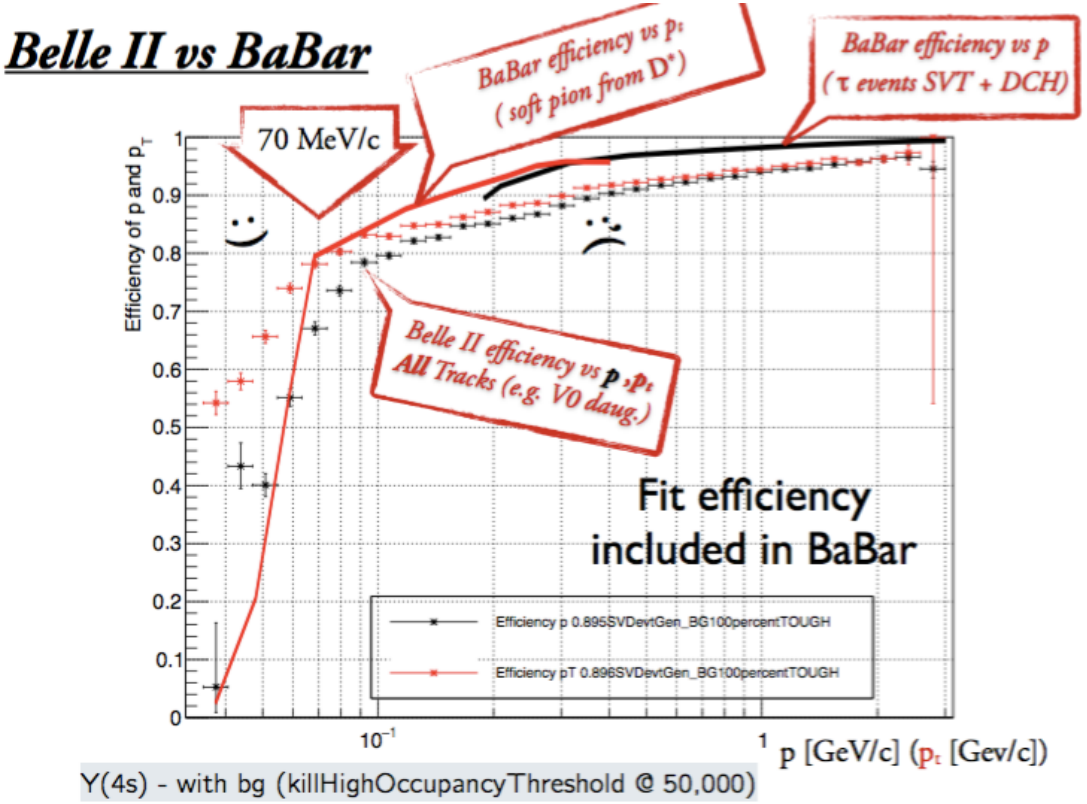
[HEPHY]

VXDTF performance



Used for the analysis of the April 2016 testbeam data taken at DESY



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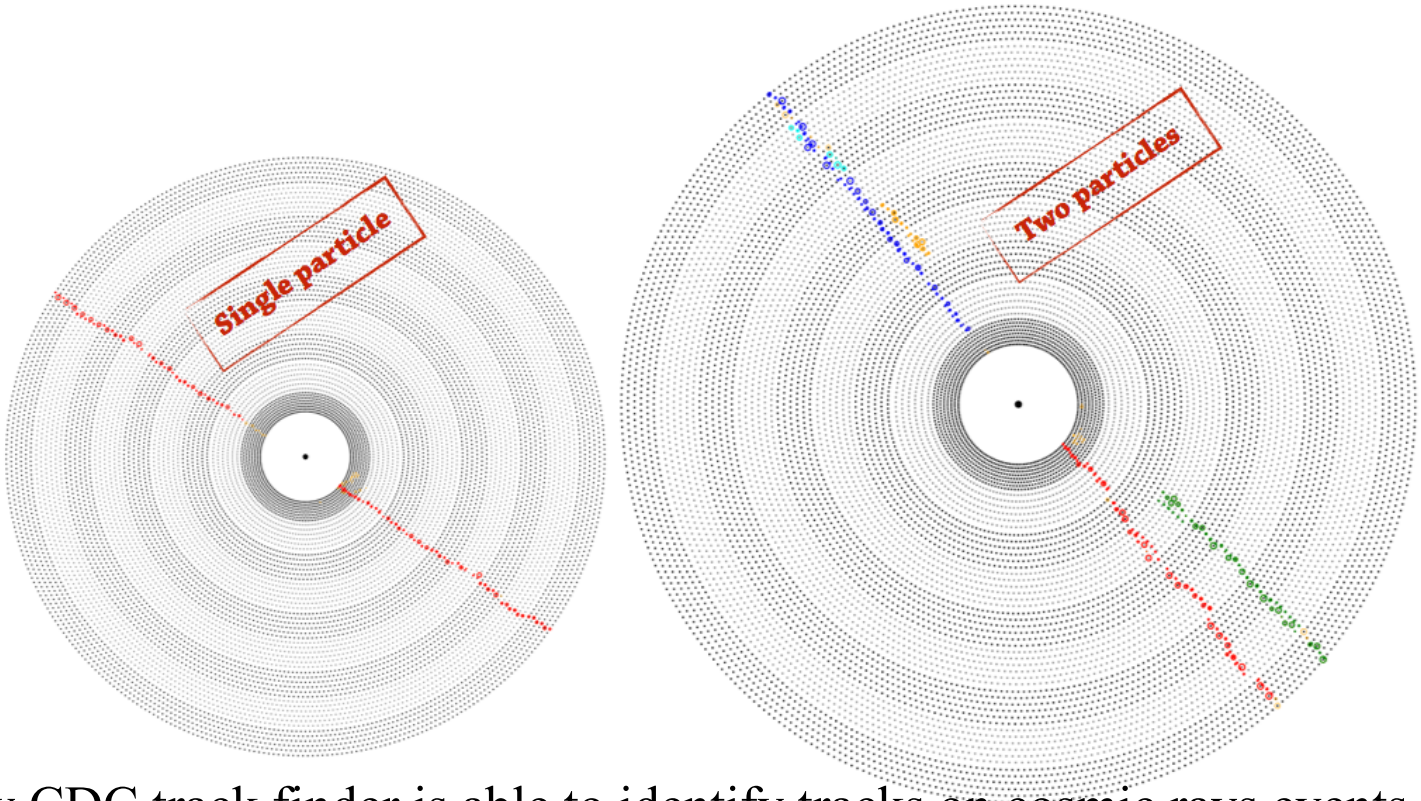
Legendre track finder for CDC [DESY]



The new CDC track finder is able to identify tracks on cosmic rays events with an efficiency close to 100% (i.e. each triggered event contains at least one track).
A few interesting events with more than one particles are also correctly reconstructed. All the CDC hits are represented.
The hits belonging to the same track are in same color.

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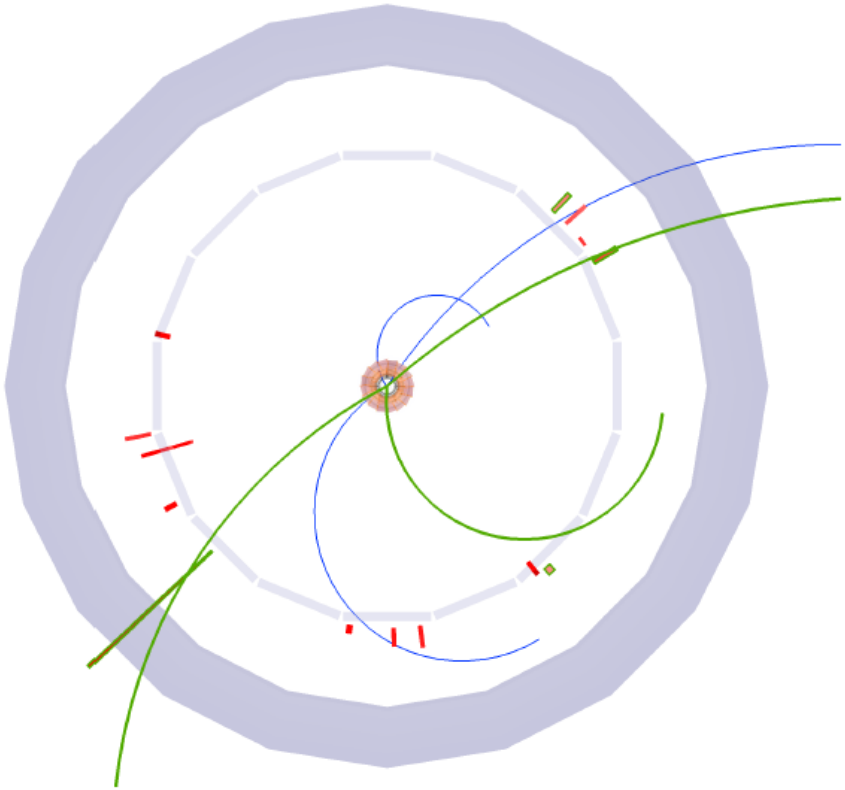
[DESY]

Full event interpretation

- C. Pulvermacher (PhD thesis http://doi.org/10.5445/IR/1000050704



(b) A correctly reconstructed tag-side $B^- \to D^{*0} e^- \bar{\nu}_e$ decay (with $D^{*0} \to D^0 \pi^0$ and $D^0 \to K^- \pi^+$). A low-energetic final-state-radiation photon from the D^0 decay was missed.

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B2TiP

- The “Belle II Theory Interface Platform” is a joint theory-experiment effort to define the Belle II physics program
- B2TiP is organized in 9 working groups
- The charge of each WG is to identify the “golden modes”, perform simulation studies and finally produce a chapter of the B2TiP report
- The activity is driven by a series of workshops

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B2TiP WG structure

WG1	Semileptonic & Leptonic B decays
WG2	Radiative & electroweak penguins
WG3	α (ϕ_2) and β (ϕ_1)
WG4	ϕ_3
WG5	Charmless hadronic B decays
WG6	Charm physics
WG7	Quarkonium-like states
WG8	Tau, low multiplicity and electroweak physics
WG9	New Physics (models)

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B2TiP workshop series

1. October 30-31, 2014 @ KEK
2. April 27-29, 2015 @ Krakow
3. October 28-29, 2015 @ KEK*)
4. May 23-25, 2016 @ Pittsburgh*)
5. November 15-17, 2016 @ MIAPP Munich (editorial meeting)

plus the kickoff meeting June 16-17, 2014 @ KEK and a few focused meetings

*) co-funded by JENNIFER

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Achievements (by May 2016)

- Identified priority modes and benchmarks for each group
- Developed advanced physics analysis framework: capable of full analysis
- FEI (B reconstruction), flavour tagging, missing energy software ready
- 5/ab MC delivered, O(30) analysts preparing sensitivity studies
- Accurate feasibility studies performed
- Performance of the detector and software measured and iterating
- Working versions of trigger tools for low multiplicity analyses available

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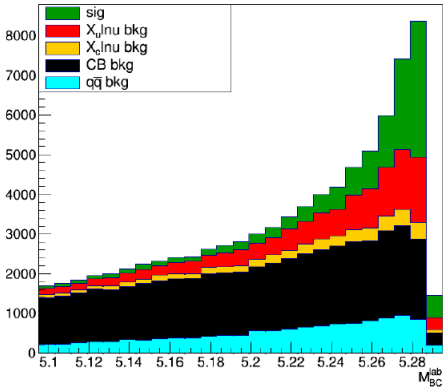
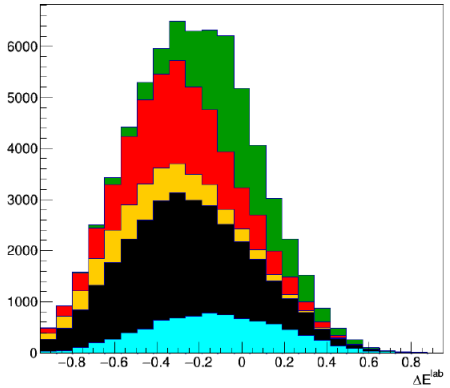
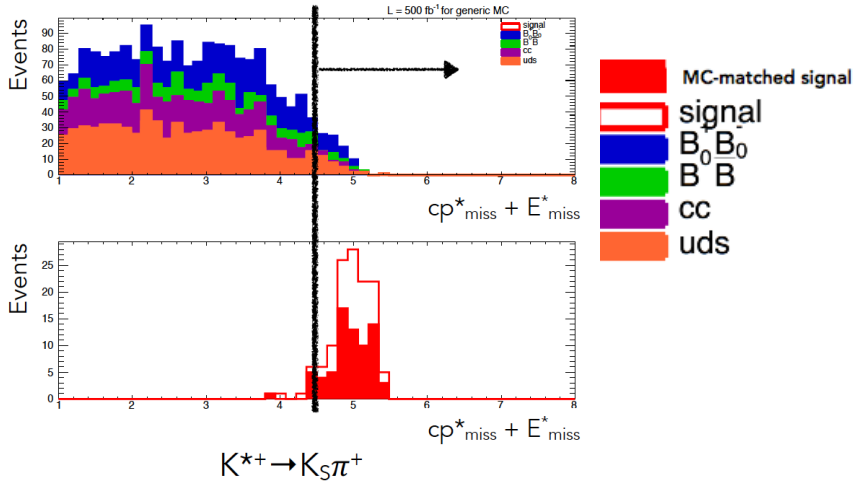
- Semileptonic & Leptonic WG 1&2 : 4 Full simulation studies *including beam background*@**B2TiP Pitt**

BR Stat Error [%] in 700 fb^{-1}	Belle/ *Babar	**B2BII MC**	**Belle II MC5**
B → π l ν untagged, M. Lubej	1.9	-	**1.3**
Bs → K l ν untagged @Υ(5S) A. Zupanc	-	**7.5**	-
B → τ ν Had tag, M. Merola	38		**34**
B → K^{*+} ν ν Had tag Cut&Count, E. Manoni	***<2.9·10^-4**		**<3.7·10^-4**







- **Analysis tools**: Rest-of-Event, Untagged SL, FEI/Full-recon, optimized γ/π^0 selection

WG3 Time Dependent CP Violation

- *Full simulation studies of 5 modes* @ **B2TiP Pitt.** Belle II *sensitivity improvements*.

Stat. Precision with 710 fb^{-1}	S_{CP}		A_{CP}		Δt [ps] resol.	
	Belle	**Belle II MC5**	Belle	**Belle II MC5**	Belle	**Belle II MC5**
$B \to K_S K_S K_S$, P. Jäger	0.27	**0.19**	0.17	**0.11**		
$B \to \eta'(\eta \to \gamma\gamma) K_S$, S. Lacaprara	0.15	**0.12**	0.10	**0.09**		
$B \to \Phi(KK) K_S$, A. Gaz					NA	0.75
$B \to J/\psi\ K_S$, L. Li Gioi					0.92	0.71
$B \to \pi^0 \pi^0 (\to ee\gamma)$, F. Abudinen					NA	1.5

Analysis tools: mdst K_S, flavour tagging, tag-vertex, continuum suppression.
Homework: K_L, e tracks, QED background, B2BII direct cross-check
Theory: Penguin pollution needs precision $\Gamma(B^+)/\Gamma(B^0)$.

- WG4 (Φ_3/γ) and 6 (Charm) *4 full simulation based studies* @ **B2TiP Pitt**
  - Φ_3 from $B \rightarrow D[K_S\pi\pi] K^{\pm}$, I. Watson
  - D semileptonics, J. Bennett
  - D tagging, G. de Pietro
  - D mixing and CPV, A. Schwartz, G. Casarosa

Preparation for first data

L1 Trigger Menu for Low Multiplicity Physics evaluated with L1 emulator.
https://d2comp.kek.jp/record/314/files/BELLE2-NOTE-PH-2015-011.pdf

Preparing for systematic uncertainty measurements
https://d2comp.kek.jp/record/345/files/BELLE2-NOTE-PH-2016-001.pdf

B2TiP report status (as a B2TiP May 2016)

Section	Exp editor(s)	Theory editor(s)	Support Documents	Draft/Outline	Svn	~ Draft status (April 2016)	Review status	Pages, Figures, Tables
Full Document			1, 2, 3					
1. Introduction & Data sets	Urquijo	Kou				60%, theory part missing		
2. Belle II Detector	Urquijo, Krizan	-				50%, update from Krizan coming		
3. Simulation	Ferber	-				80%		
4. Reconstruction	Bennett	-	1, 2			30%, need input on tracking, neutrals, v0, beamspot, eID		
5. Analysis software	Li Gioi, Zupanc, Goldenzweig	-	1			Rough outline (base on several theses)		
6. Theory overview	-	Nierste				40%		
7. WG1: Semileptonic & Leptonic B	De Nardo, Zupanc	Kronfeld, Tackmann, Watanabe	1			Rough outline		
8. WG2: Radiative and EWP B	Ishikawa, Yamaoka	Feldman, Haisch	1			20%		
9. WG3: Time dependent CPV B	Gaz, Li Gioi	Zupan, Mishima				Outline		
10. WG4: Phi 3	Libby	Blanke, Grossman	1			20%		
11. WG5: Hadronic B	Goldenzweig	Beneke, Chiang	1			20%		
12. WG6: Charm	Casarosa, Schwartz	Petrov, Kagan				Outline		
13. WG7: Quarkonium	Fulsom, Shen, Mizuk	Hanhart, Kiyo, Polosa, Prelovsek	1, 2, 3, 4, 5			30%, charmonium only, no simulation		
14. WG8: Low multiplicity & tau	Ferber, Hayasaka	Passemar, Hisano	1, 2, 3, 4			20%		
15. WG9: New physics	Bernlochner, Sato	Nierste, Silvestrini, Kamenik, Lubicz				Detailed outline		
16. Summary	Urquijo	Kou						

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B2TiP timeline

- 2016 key dates
  - **May** B2TiP Pittsburgh – presentation of 1/ab to 5/ab studies
  - **June** MC6 production based on software release 7 (removal of legacy tracking, more beam background processes); to be used in some studies
  - **July** First draft of each chapter sent for soft review **– VERSION 1**
  - **September** Deadline for response from reviewers
  - **Oct 31 Hard deadline for delivery of chapters for review prior to the MIAPP B2TiP workshop – VERSION 2**
  - **Nov 15-17** B2TiP Editorial meeting
  - **Dec-Feb** Editing and review; we will discourage new contributions in this period – **FINAL VERSION**
- Journal submission: March 31, 2017

Summary

- The Belle II experiment has a rich physics case and will study decays of B and charmed mesons and tau leptons from 2018
- WP1 is helping the exploitation of Belle II physics through supporting offline-software development, implementation of analysis tools and the B2TiP activity
- WP1 secondments are proceeding within schedule, deliverables D1.1 (offline workshop) and D1.2 (Belle II tutorials) have been achieved
- The preparation of the B2TiP report is on its way, aiming for journal submission by the end of March 2017

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