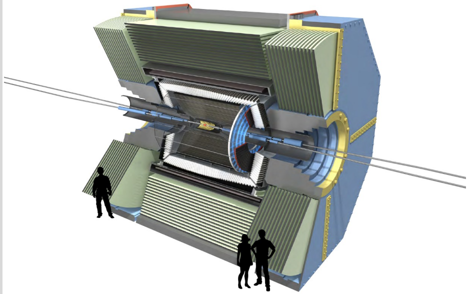
Karlsruher Institut für Technologie

Belle II – Plans & Prospects

WIN 2015

Martin Heck for the Belle II Collaboration | 09.06.2015
Institut für Experimentelle Kernphysik



Belle II

Overview

- Why Belle **II**?
- The Detector
- Reconstruction & Analysis
- Plans, Plans, Plans
- What can we expect?
- Summary & Encouragement

– Stuff, We Might Discover

– What is New Compared with Belle ?

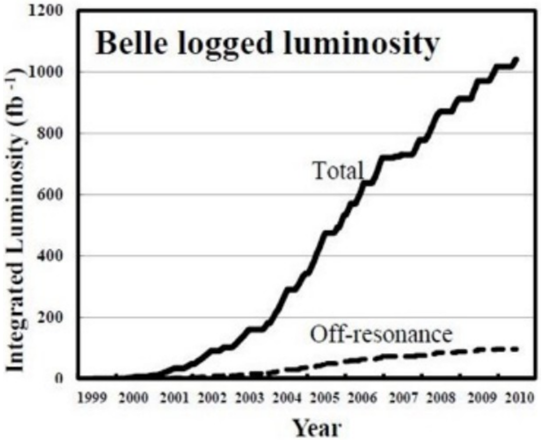
– New Algorithmic Approaches

– Commissioning and Running

– Some specific channels

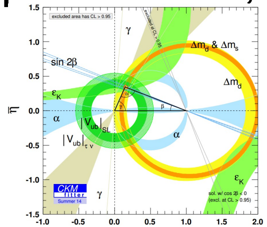
Why Belle II?

Belle@KEKB was very successful :



- ~ 1 ab^{-1} of integrated e^+e^- – Luminosity, mostly Y(4S);
- > 450 paper, 2014 one of strongest years;
- CPV in B mesons → Confirmation of the Kobayashi-Maskawa-mechanism

- Measurement of UT parameters;
- Rare B decays;
- Spectroscopy;



- Charm-, tau-physics (**LFV**,...)
- “Exotics” (Dark Photon, Axion,...)

Why Belle II? But plenty of stuff still improvable...

Issues, that could still be addressed by a flavour factory:

- Baryon asymmetry in cosmolgy
  → New Sources of CPV in quarks/charged leptons
- quark and lepton flavour & mass hierarchy
  → higher symmetry, massive new particles, extended gauge sector
- 19 free parameters
  → Extensions of SM might relate some (GUTs)
- Dark Matter, strong CP problem,...
  → hidden dark sector, axions,...
- finite neutrino masses, maybe SeeSaw
  → lepton flavour violation (tau)

Indirect searches for new physics

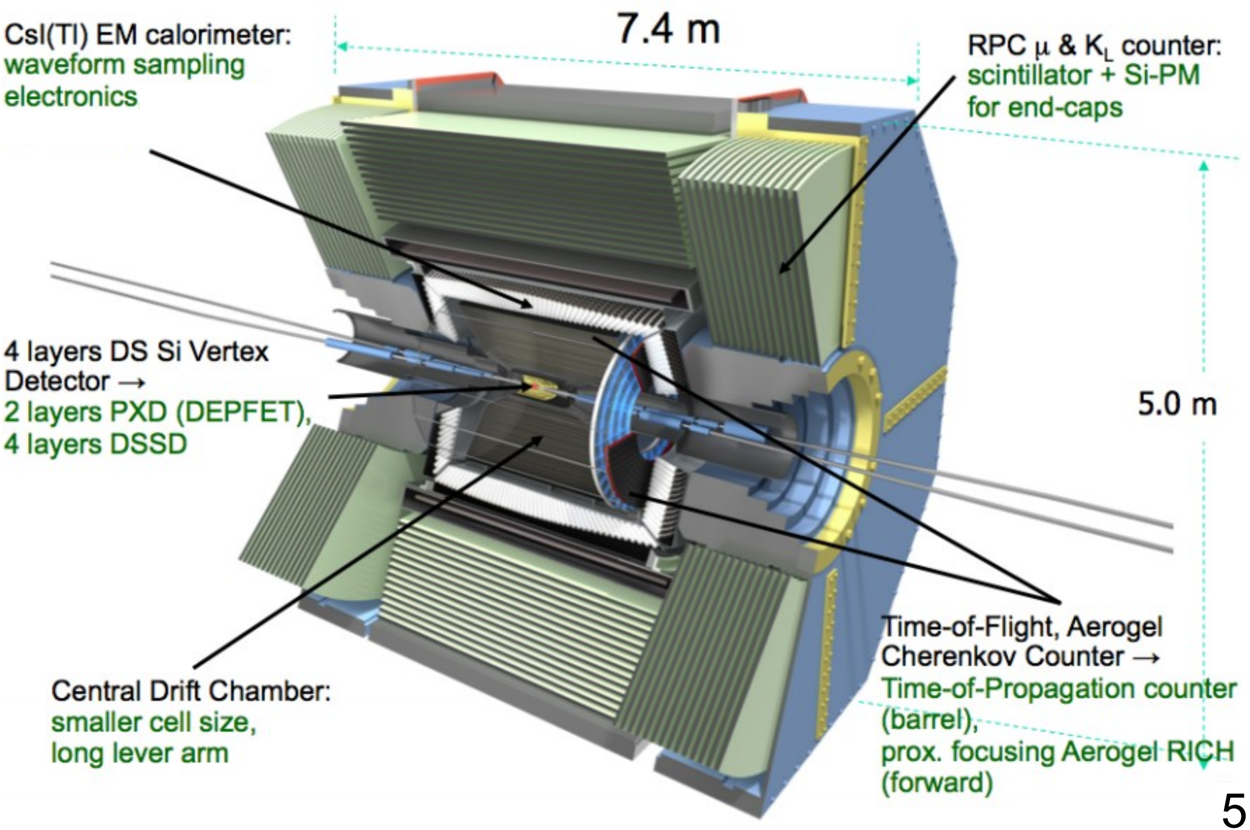
- nature of XYZ-states;
- decay structures (intermediate resonances, hadronisation,...) & excited states
- ...

Better handling of difficult to calculate QCD.

The Detector

Targeted improvements:

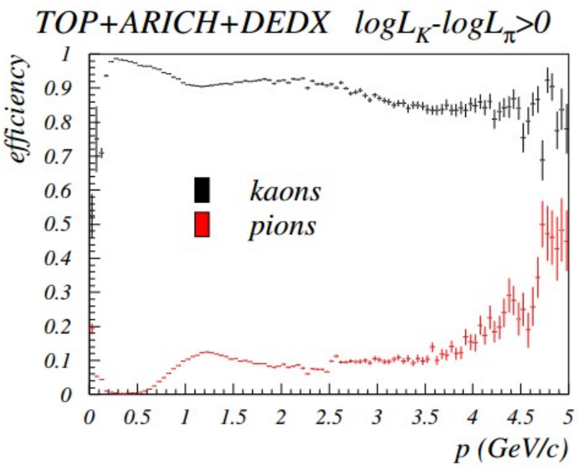
- *Increase hermiticity.*
- *Increase K_s^0 efficiency.*
- *Improve IP and secondary vertex resolution.*
- *Improve K/π separation.*
- *Improve π^0 efficiency.*
- *Add PID in endcaps.*
- *Add μ ID in endcaps.*
- Higher low momentum effieciency tracking

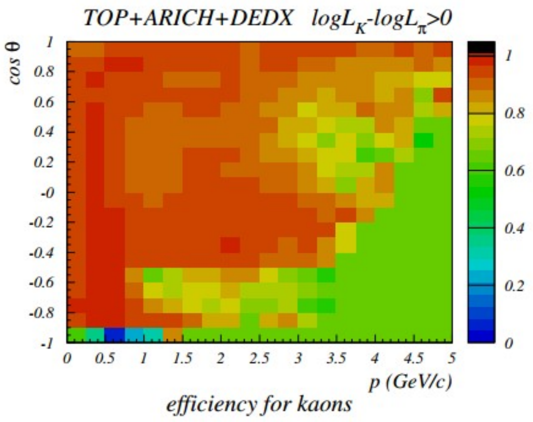


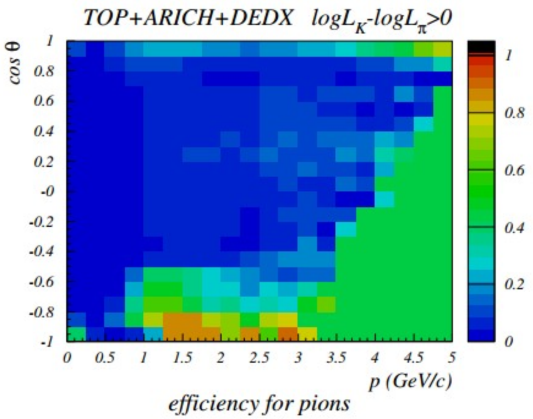
Two RICH systems covering full momentum range

- Barrel: Time of Propagation (TOP) counter (16 modules)
- Forward Endcap: Aerogel Ring Imaging Cherenkov detector (ARICH)

Plots from recent simulations





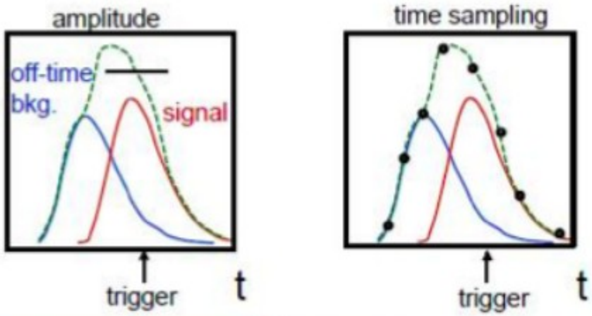


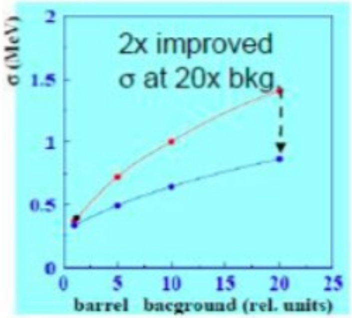
	Belle PID (%)	Belle II PID (%)
Ave. K efficiency	88	94
π fake rate	9	4

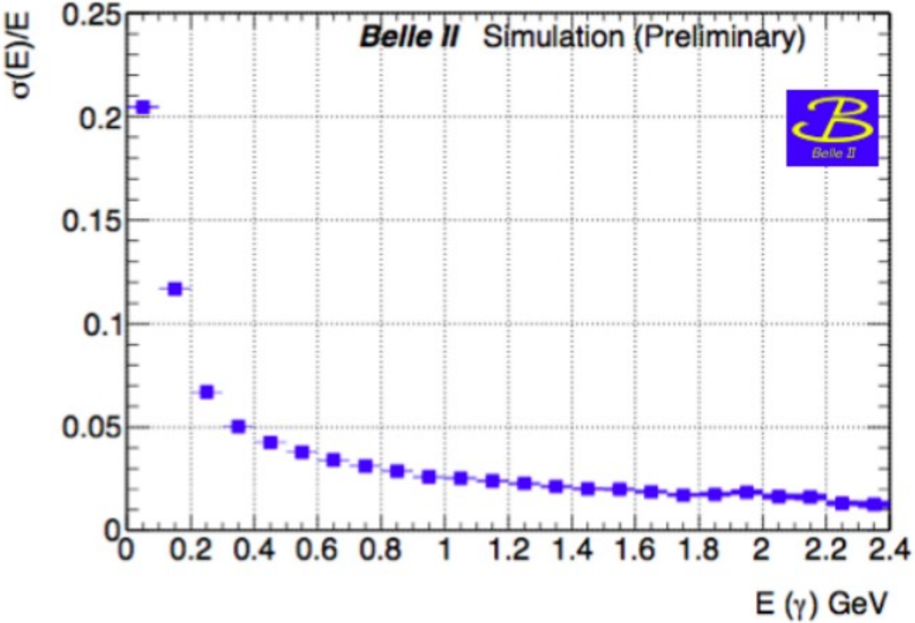
⇒ *Average K efficiency / π fake rate improved: Fake rate decreases by ≈ 2.5 for the same ε.*

Re-usage of Belle's CsI(TI) crystal calorimeter, but with new electronics with 2MHz wave form sampling to compensate for the larger beam-related backgrounds and the long decay time of CsI(TI) signals.

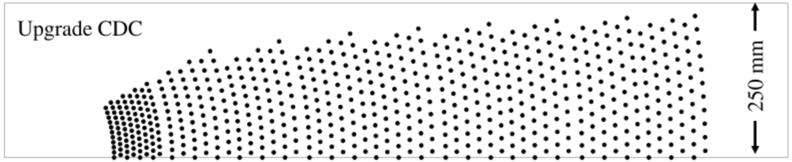
$\Rightarrow$ *Resolution much better at Belle II*



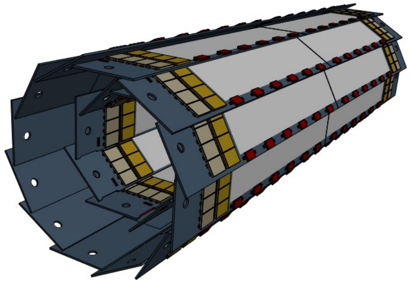


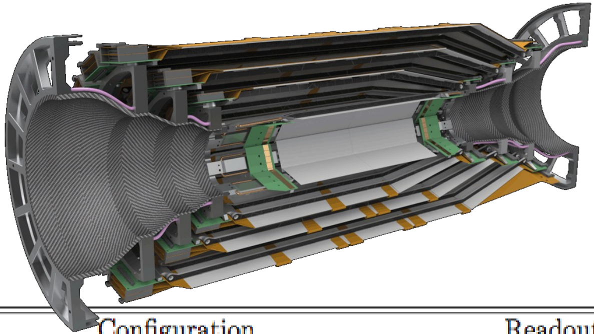


Tracking Hardware

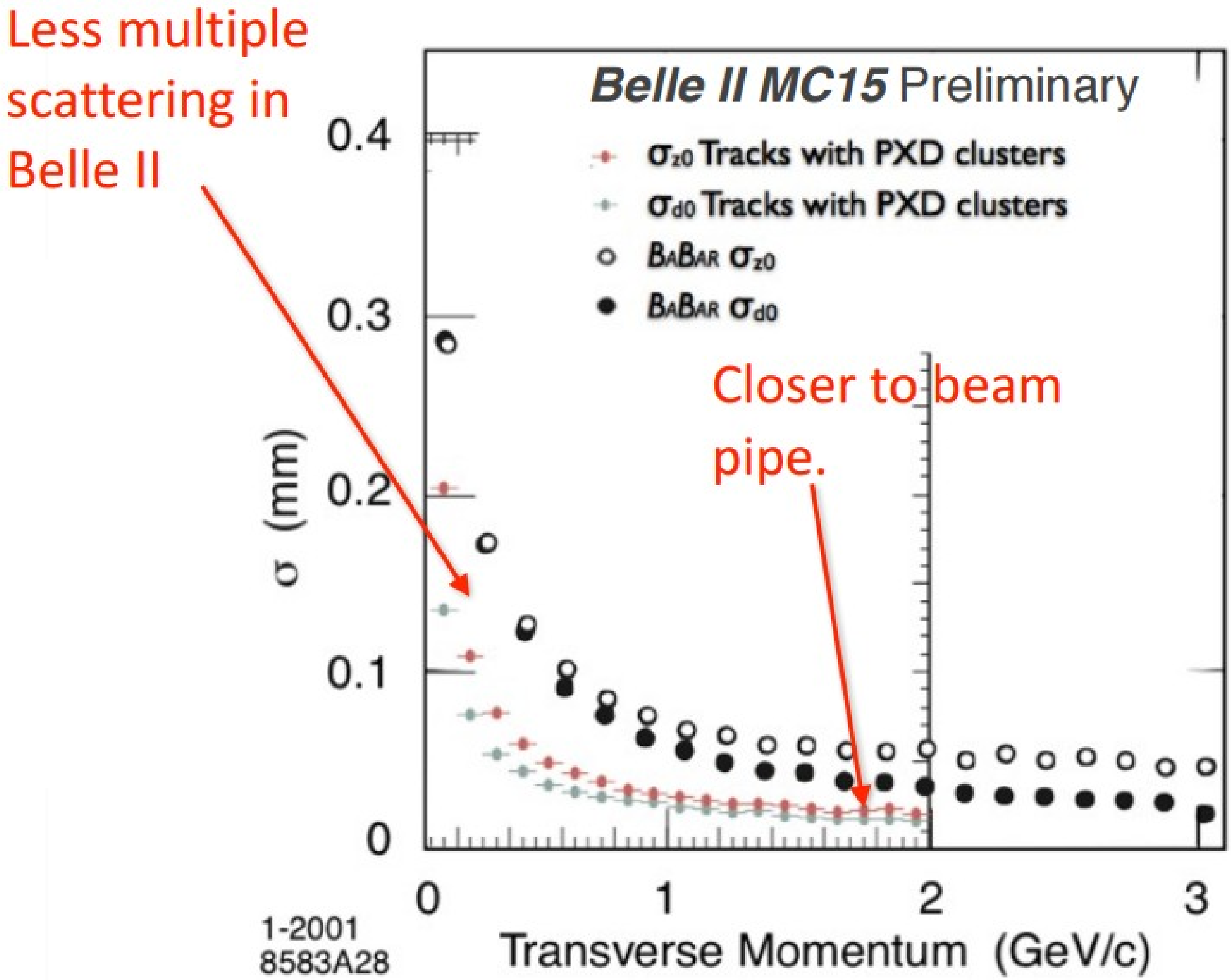


- Pixel (PXD), Strip (SVD), and drift chamber (CDC)





Component	Type	Configuration	Readout	Performance
Beam pipe	Beryllium double-wall	Cylindrical, inner radius 10 mm, 10 μm Au, 0.6 mm Be, 1 mm coolant (paraffin), 0.4 mm Be		
PXD	Silicon pixel (DEPFET)	Sensor size: 15×100 (120) mm^2 pixel size: 50×50 (75) μm^2 2 layers: 8 (12) sensors	10 M	impact parameter resolution $\sigma_{z_0} \sim 20$ μm (PXD and SVD)
SVD	Double sided Silicon strip	Sensors: rectangular and trapezoidal Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm 4 layers: 16/30/56/85 sensors	245 k	
CDC	Small cell drift chamber	56 layers, 32 axial, 24 stereo r = 16 - 112 cm $-83 \leq z \leq 159$ cm	14 k	$\sigma_{r\phi} = 100$ μm, $\sigma_z = 2$ mm $\sigma_{p_t}/p_t = \sqrt{(0.2\%p_t)^2 + (0.3\%/\beta)^2}$ $\sigma_{p_t}/p_t = \sqrt{(0.1\%p_t)^2 + (0.3\%/\beta)^2}$ (with SVD)



Less multiple scattering in Belle II
Belle II MC15 Preliminary
σz0 Tracks with PXD clusters
σd0 Tracks with PXD clusters
BABAR σz0
BABAR σd0
Closer to beam pipe.
0.4
0.3
0.2
0.1
0
σ (mm)
0
1
2
3
Transverse Momentum (GeV/c)
1-2001
8583A28

Design Rates

- 2ns bunch spacing;
- L1 Hardware Trigger @ 30 kHz;
- Software Trigger down to ~10 kHz; → less than the rate of 2 photon processes @ full design luminosity;
- B-event efficiency ~100%

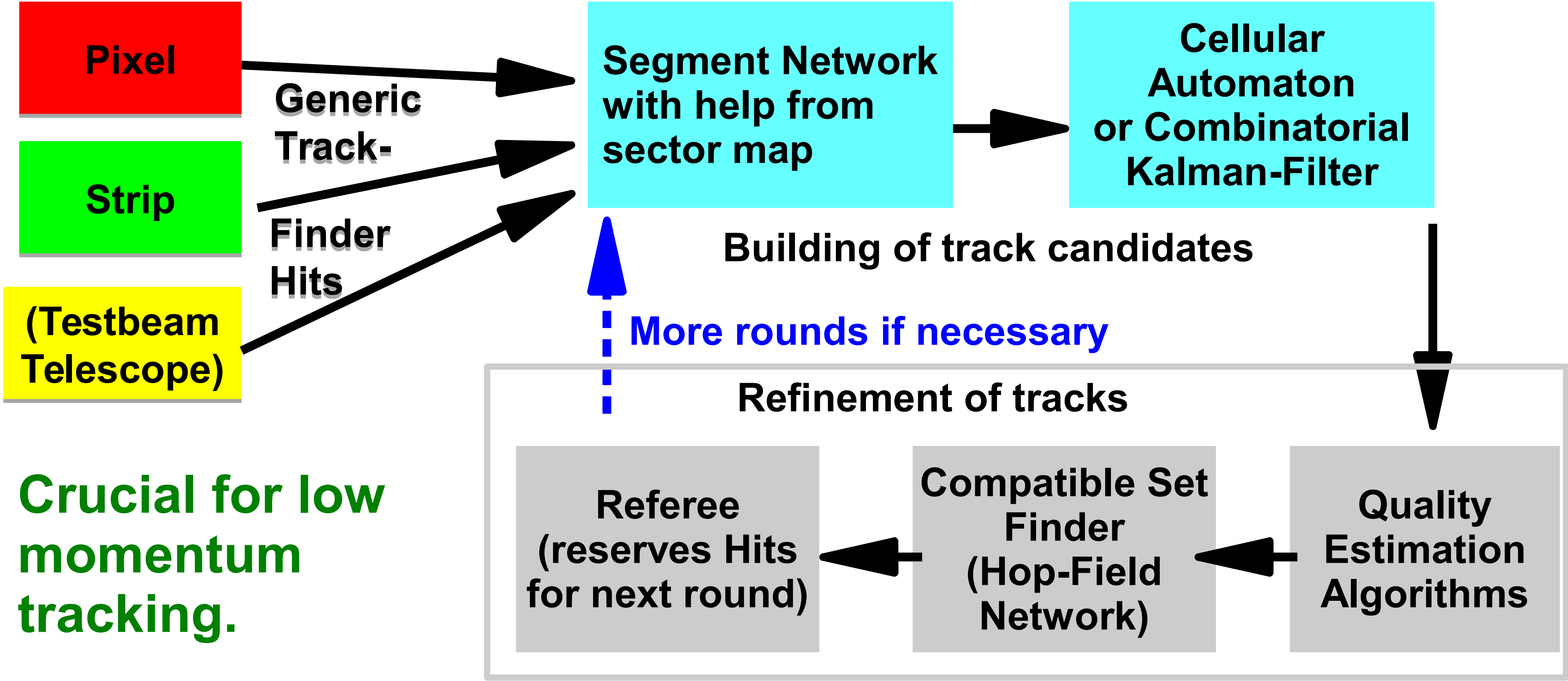
Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
$e^+e^- \to$ continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{\rm lab} \geq 17°$)	44	350 [a]
$\gamma\gamma$ ($\theta_{\rm lab} \geq 17°$)	2.4	19 [a]
2γ processes [b]	~ 80	~ 15000
Total	~ 130	~ 20000

[a] The rate is pre-scaled by a factor of 1/100.

[b] $\theta_{\rm lab} \geq 17°$, $p_t \geq 0.1 {\rm GeV}/c$

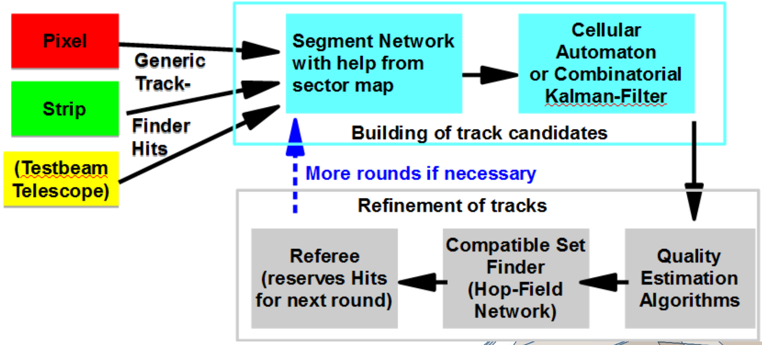
Reconstruction & Analysis

Vertex-Detector Stand-Alone Track-Finding Algorithm



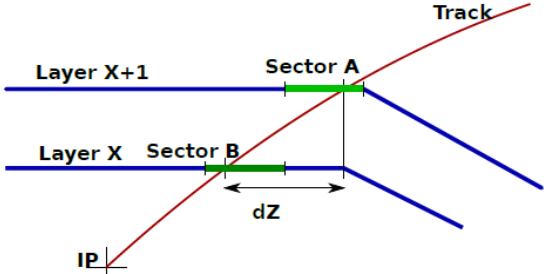
Crucial for low momentum tracking.

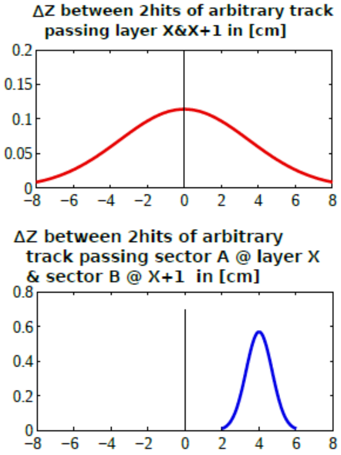
Why the Sector Map?

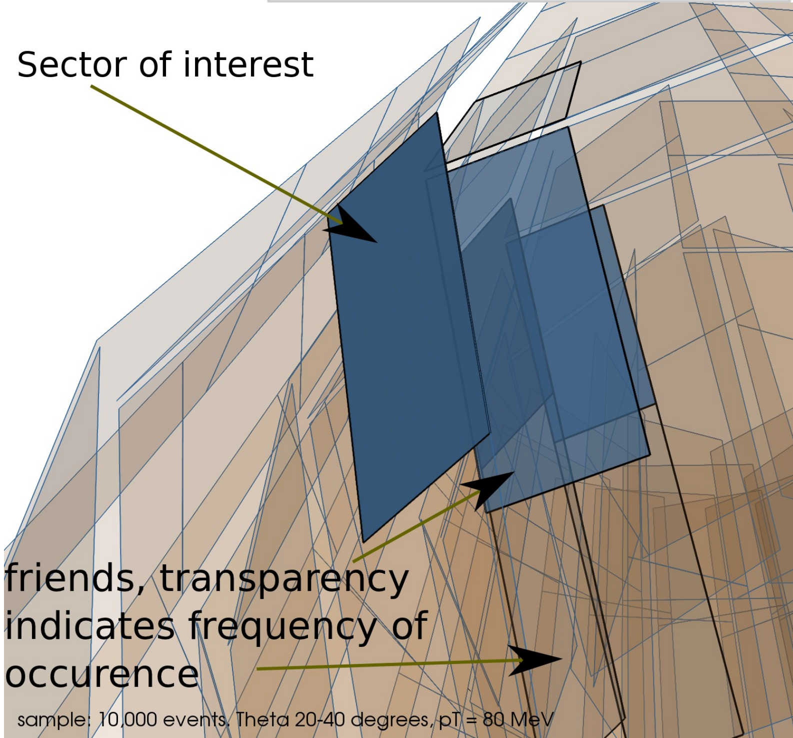


With the help from the sector map, we

- start the actual track finding only with somewhat reasonable combinations;
- avoid for the cellular automaton expensive extrapolation calculations;

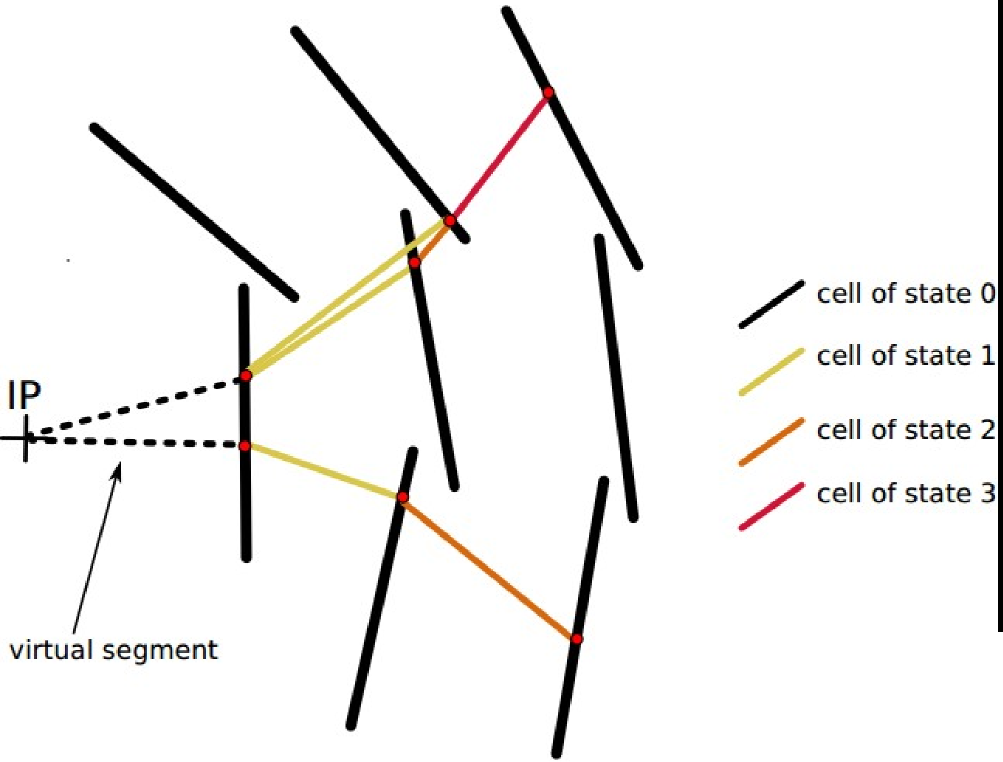


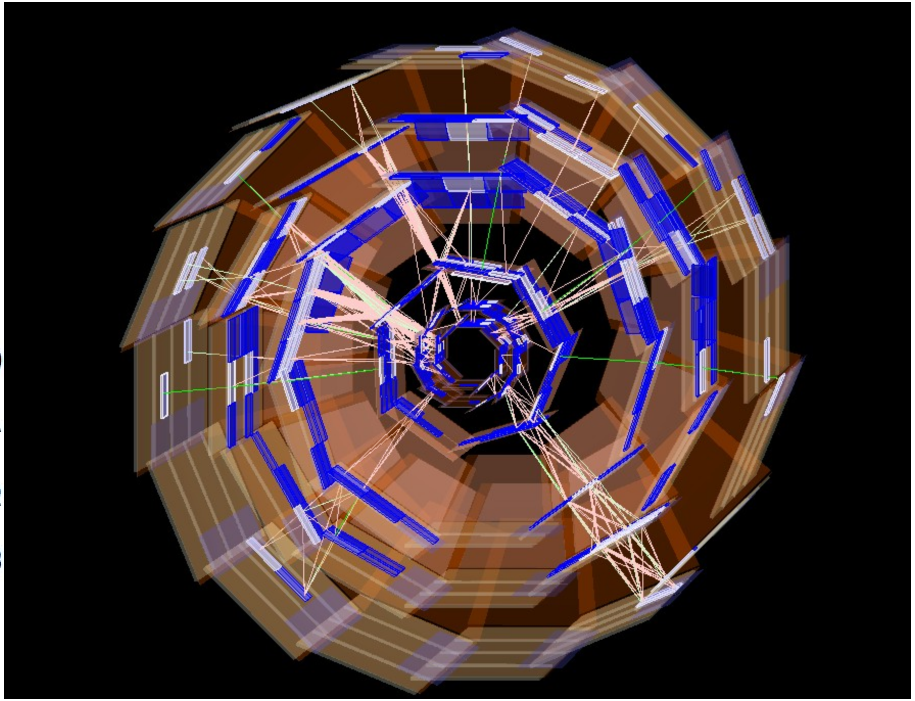




Additional to being in befriended sectors, there are sector-dependent 2-, 3-hit filters, that need to be passed to form a segment. 4-, 5-Hit Filters are Sector independent.

Advance in the Cellular Automaton



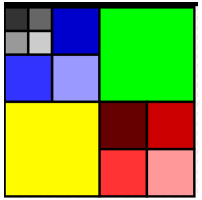


Drift Chamber Tracking

Using drift time in track finding helps handle higher background.

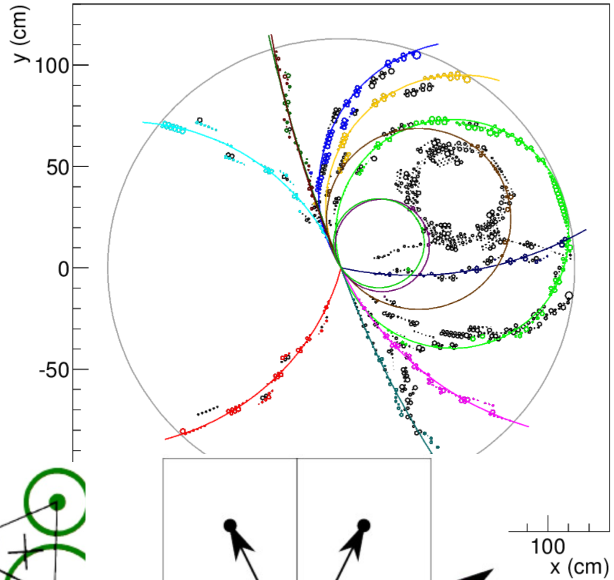
Two main algorithms

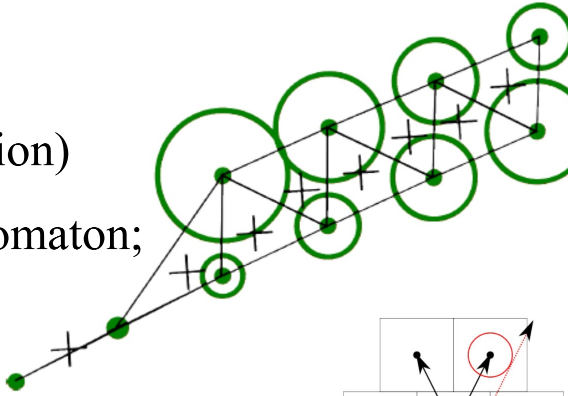
- One based on finding maxima in Legendre space (1) using a Quadtree;

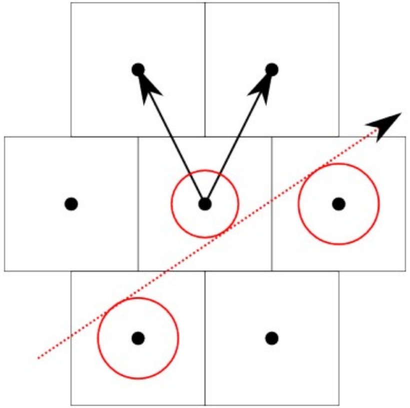


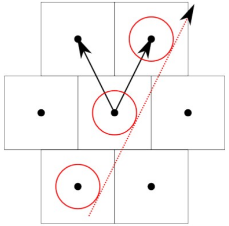
  (Iterative, but keeping the information)

- Based on hit following/cellular automaton;



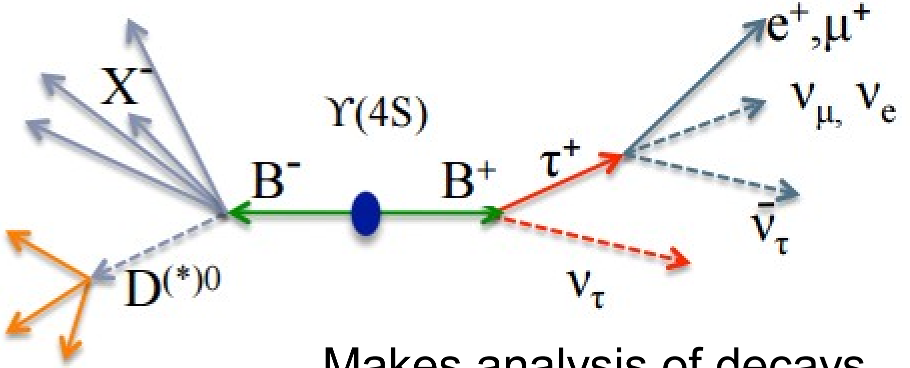






(1) T. Alexopoulos et al. “Implementation of the Legendre transform for the muon track segment reconstruction in the ATLAS MDT chambers” Nuclear Science Symposium Conference Record, 2007. NSS '07. IEEE

New Integrated Analysis Tools



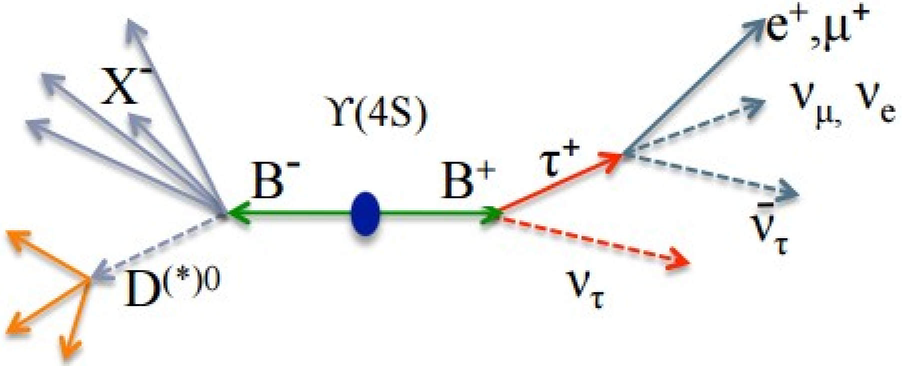
Specialty of B-factories: “Tagged” analysis:

Gaining info about signal side by analysing tag side

Makes analysis of decays with more than one neutrino possible at all.

- $p(B_{sig}) = - p(B_{tag})$,
- all reconstructed particles remaining in the detector after removing tag side have to stem from signal side (veto), ← ε < 1%, strong improvement expected
- Flavour B_{sig} @ T (decay of B_{tag}) = inverse of Flavour B_{tag}, ← $\varepsilon D^2 > 30\%$
- improved B_{tag}-vertexing with detailed kinematic understanding → better estimate of decay length difference

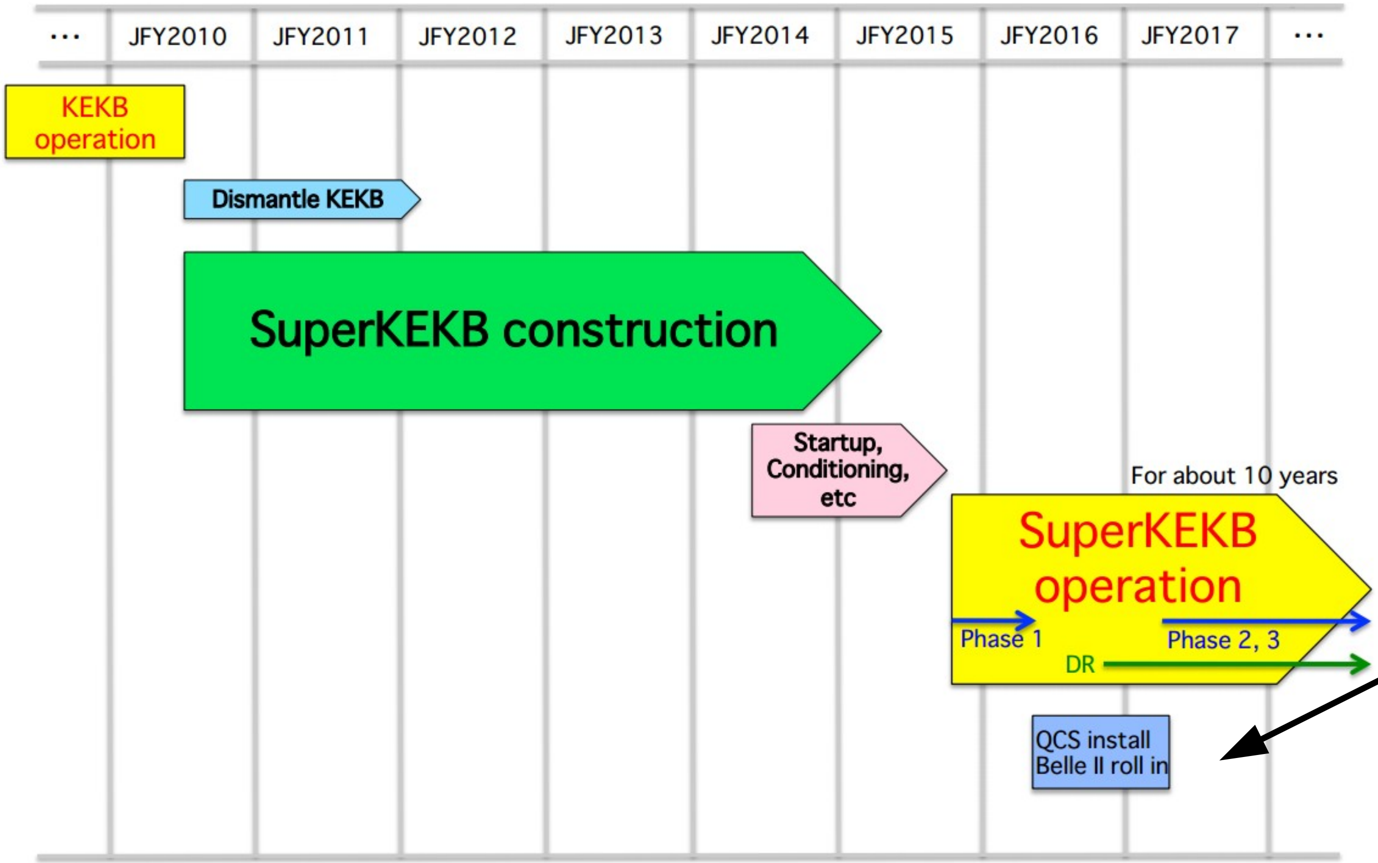
New Integrated Analysis Tools



Reasons for strong improvement of full tag side recombination:

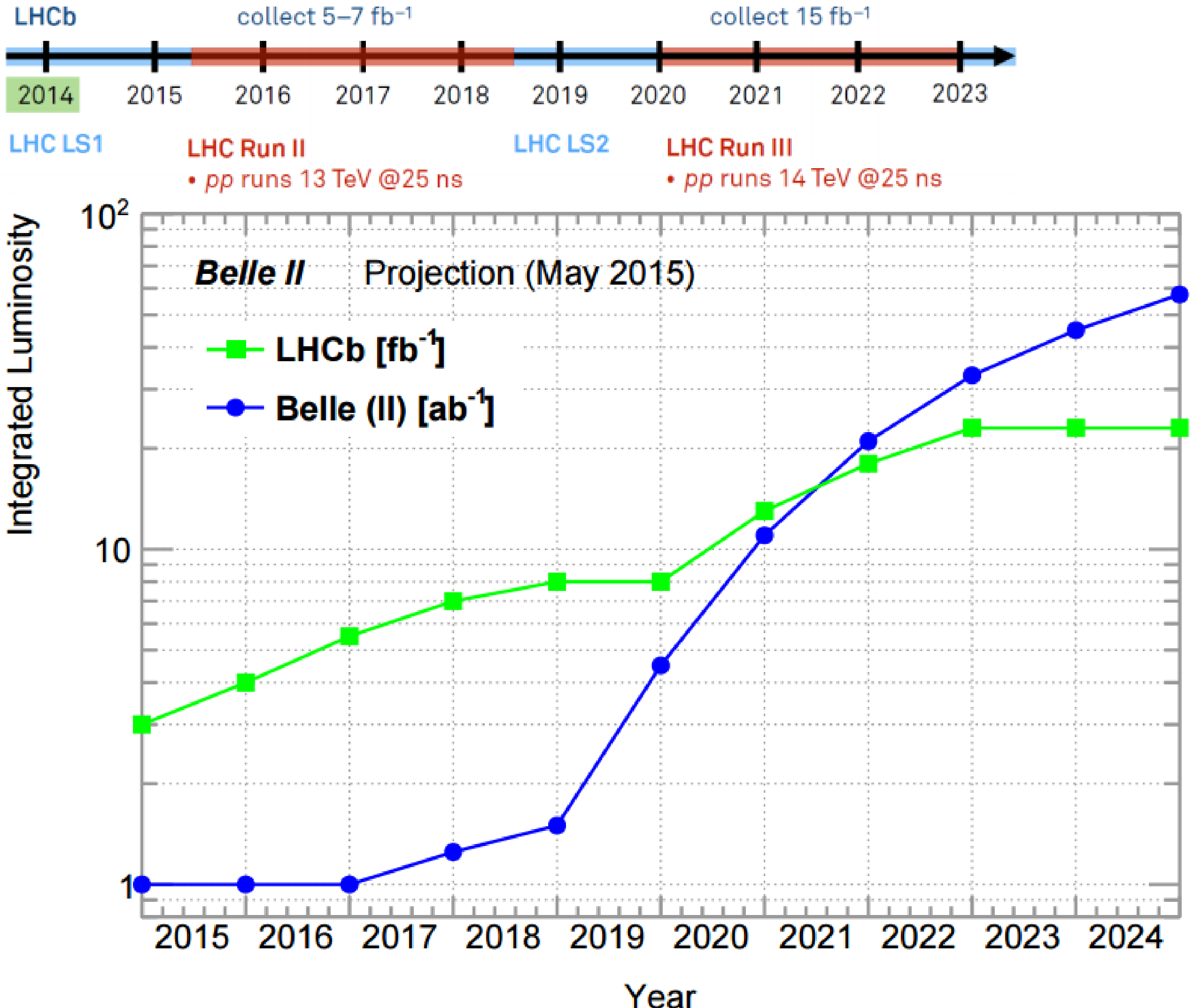
- lower boost → fewer particles outside detector acceptance;
- better detector, better reconstruction software (see above);
- per analysis training of tag side recombination with prior signal side picking;
- More inclusivity with new approaches to battle information loss (especially for semileptonic decays and decays with a loss of a photon);
- rethinking of decay features;
- improved simulation, especially of multi-body decays;

Plans, Plans, Plans



First roll-in without silicon detectors; physics program for data taken in that mode is under investigation;

Silicon roll-in in 2018;



Anticipated data taking profile;

LHCb "nearest competitor", but as well numerous decays, where no real competition exists;

Run on different resonances/ energy scan at the beginning
(no vertex detector needed for most analysis, easier to supersede existing experiments)

Experiment	Scans/Off. Res.	$\Upsilon(5S)$ 10876 MeV		$\Upsilon(4S)$ 10580 MeV		$\Upsilon(3S)$ 10355 MeV		$\Upsilon(2S)$ 10023 MeV		$\Upsilon(1S)$ 9460 MeV	
	fb^{-1}	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6
CLEO	17.1	0.4	0.1	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan		433	471	30	122	14	99	–	
Belle	100	121	36	711	772	3	12	25	158	6	102

Dark γ to Leptons	Radiative production of A' via ee→γA'
Dark Light Higgs	Y(2S,3S)→A^0 γ, A^0→ invisible, single γ trigger.
Dark Matter	Non-resonant production in ee→A' γ, A^0→*invisible*
Dark Higgs-strahlung	ee → A'h', h'→ A'A'(*), l+l- or hadrons.

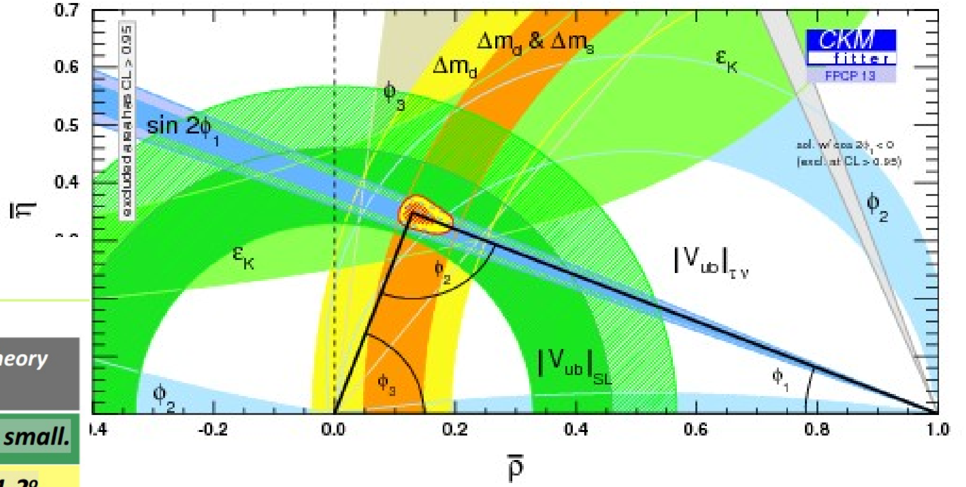
What Can We Expect?

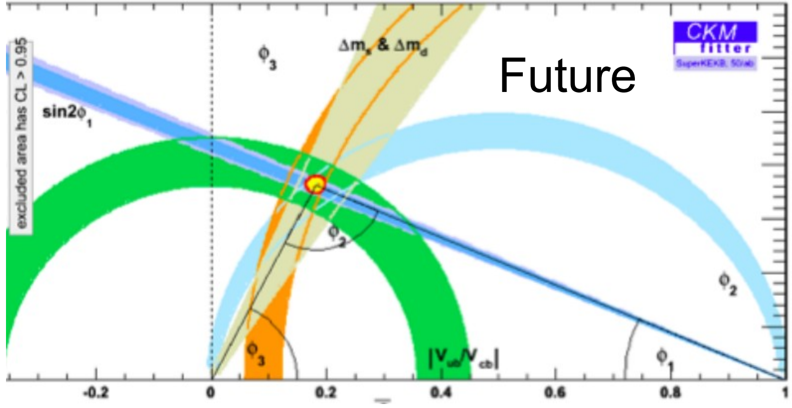
Summary of CKM Metrology

	Belle	BaBar	Global Fit CKMfitter	LHCb Run-2	Belle II 50 ab^{-1}	LHCb Upgrade 50 fb^{-1}	Theory
φ_1: ccs	0.9°		0.9°	0.6°	0.3°	0.3°	v. small.
φ_2: uud	4° (WA)		2.1°		1°		~1-2°
φ_3: DK	14°		3.8°	4°	1.5°	1°	negl.
$\|V_{cb}\|$ inclusive	1.7%		2.4%		1.2%		
$\|V_{cb}\|$ exclusive	2.2%				1.4%		
$\|V_{ub}\|$ inclusive	7%		4.5%		3.0%		
$\|V_{ub}\|$ exclusive	5.5%			7.2%	2.4%		
$\|V_{ub}\|$ leptonic	14%				3.0%		

Experiment
No result
Moderate precision
Precise
Very Precise

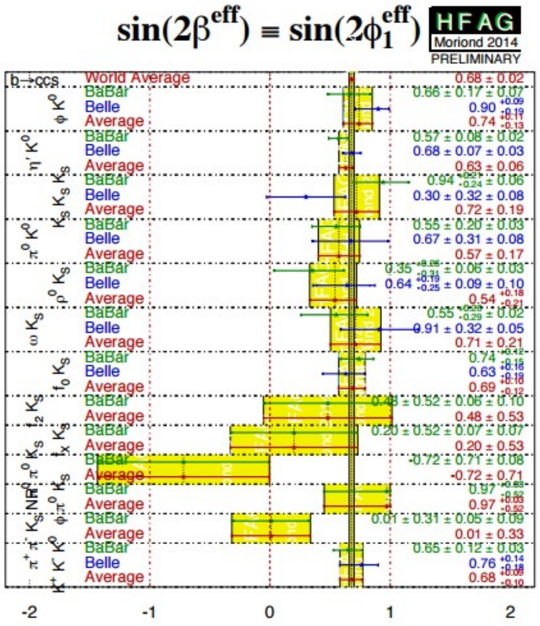
Theory
Moderate precision
Clean / LQCD
Clean

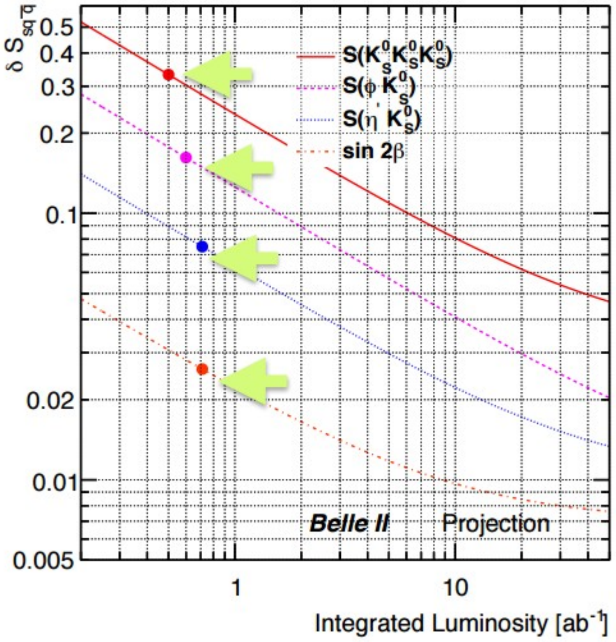




b→s Penguin ϕ_1

Belle, $B \to \eta' K0$, JHEP 1410, 165 (2014)
Belle, $B \to \omega Ks0$, PRD 90 012002 (2014)



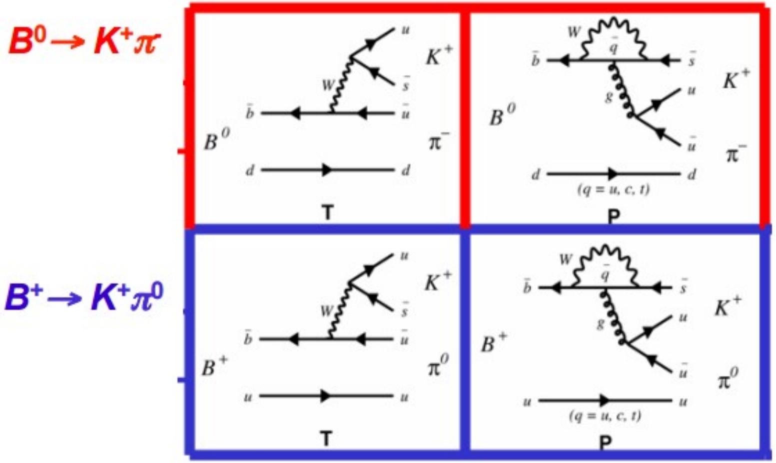


These analyses are currently totally dominated by the statistical uncertainty!

	Observables	Belle or LHCb (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.053	0.018	0.2	0.04
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.028	0.011		
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	0.100	0.033		
	$\beta_s^{\rm eff}(B_s \to \phi\phi)$ [rad]	± 0.18			0.12	0.03
	$\beta_s^{\rm eff}(B_s \to K^{*0}\bar{K}^{*0})$ [rad]	± 0.19			0.13	0.03
Direct CP in hadronic Decays	$\mathcal{A}(B \to K^0\pi^0)$	$-0.05 \pm 0.14 \pm 0.05$	0.07	0.04		

- A_{CP} in hadronic modes cannot be understood w/out full isospin analysis.

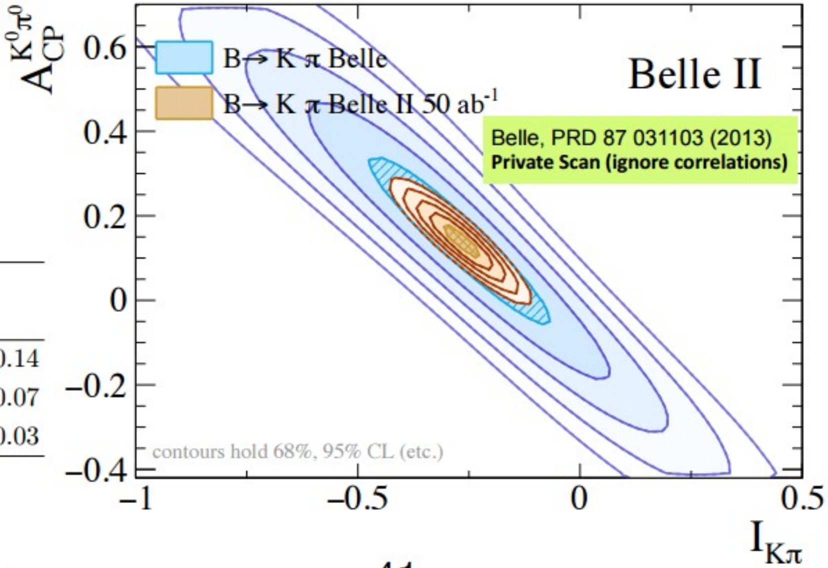
➡ Need neutral modes.

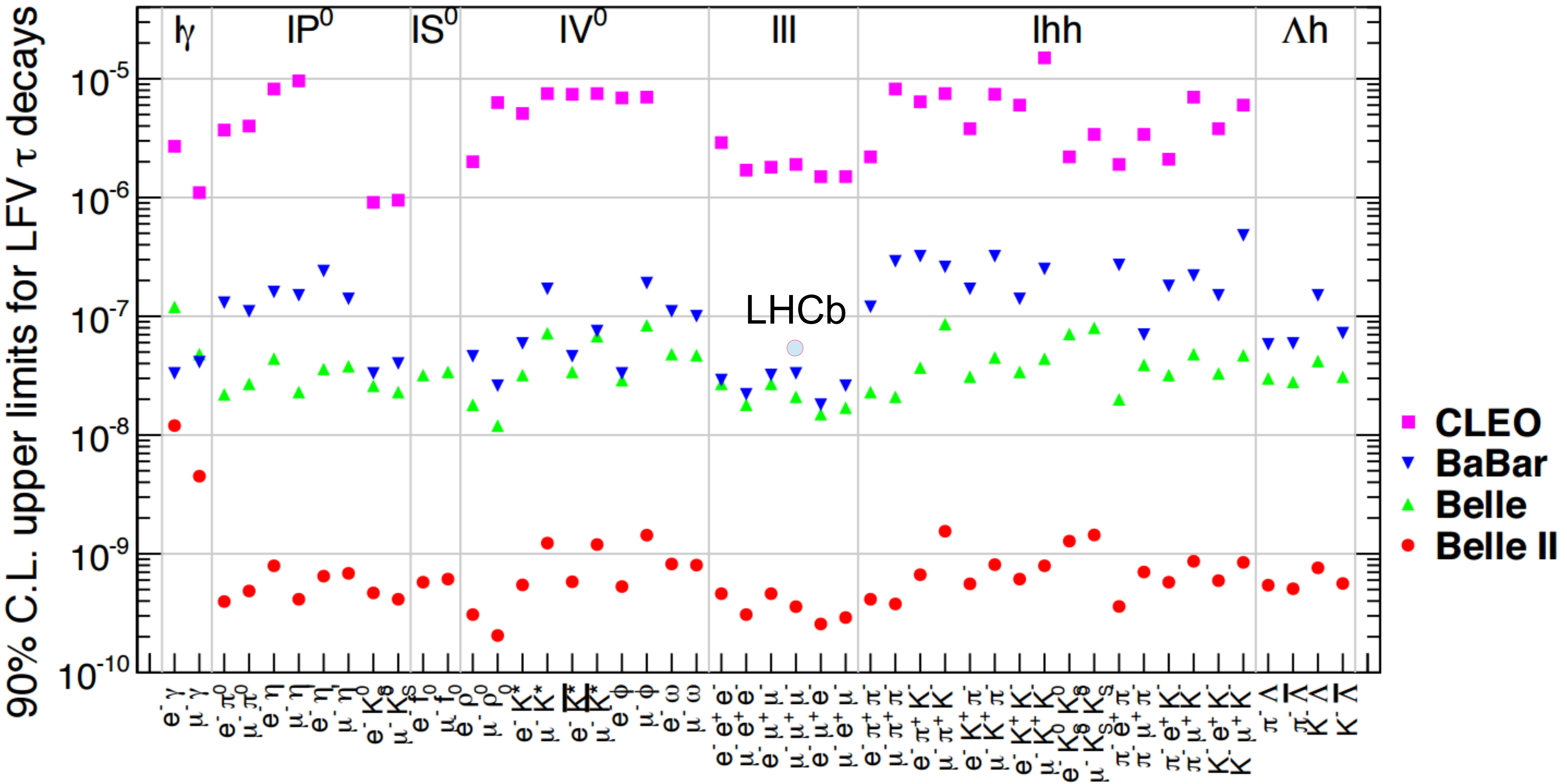


$$I_{K\pi} \cdot \mathcal{B}(B^0 \to K^+\pi^-)$$
$$= A_{CP}^{K^+\pi^-} \cdot \mathcal{B}(B^0 \to K^+\pi^-) + A_{CP}^{K^0\pi^-} \cdot \mathcal{B}(B^+ \to K^0\pi^-)\frac{\tau_{B^0}}{\tau_{B^+}}$$
$$- 2A_{CP}^{K^0\pi^0} \cdot \mathcal{B}(B^0 \to K^0\pi^0) + 2A_{CP}^{K^+\pi^0} \cdot \mathcal{B}(B^+ \to K^+\pi^0)\frac{\tau_{B^0}}{\tau_{B^+}}$$

Scenario	$A^{K^0\pi^0}$			$I_{K\pi}$
	Value	Stat.	(Red., Irred.)	
Belle	0.14	0.13	(0.06, 0.02)	0.27 ± 0.14
Belle + $B \to K^0\pi^0$ at Belle II 5 ab^{-1}		0.05	(0.02, 0.02)	0.27 ± 0.07
Belle II 50 ab^{-1}		0.01	(0.01, 0.02)	0.27 ± 0.03

Explore this for πK^*, ρK, ρK^*!





We will have lots of tau-leptons!

Summary & Encouragement

- Lots of New Physics ideas have signatures, that might be visible in a B-factory.
- Belle II is more than Belle with higher luminosity, we improve the detector, reconstruction, and analysis techniques to reach beyond.
- Start in 2017 will focus on non-B measurements.
- Lots of different measurements can be performed (B, D, tau, …)
- If you think, you could profit from synergies, you may contact the B2TIP (Belle II Theory Interface Platform), which includes (besides Belle II people), theory, lattice, and some LHCb people.
  (https://belle2.cc.kek.jp/~twiki/bin/view/B2TiP)