The Belle II Experiment

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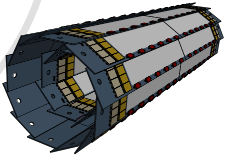
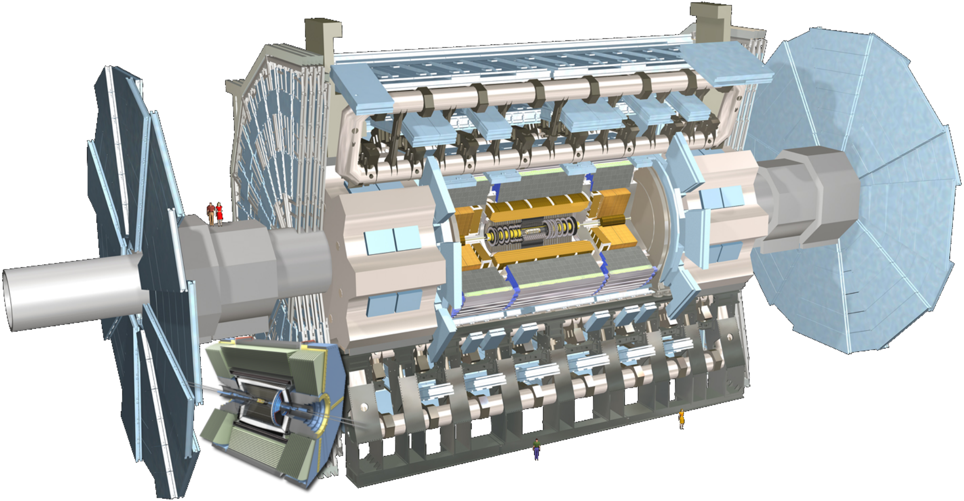
(Werner-Heisenberg-Institut)

DEPFET
Active Pixel Detector



The Detector – Size is not Everything

or: Look Who's Compensating for Something



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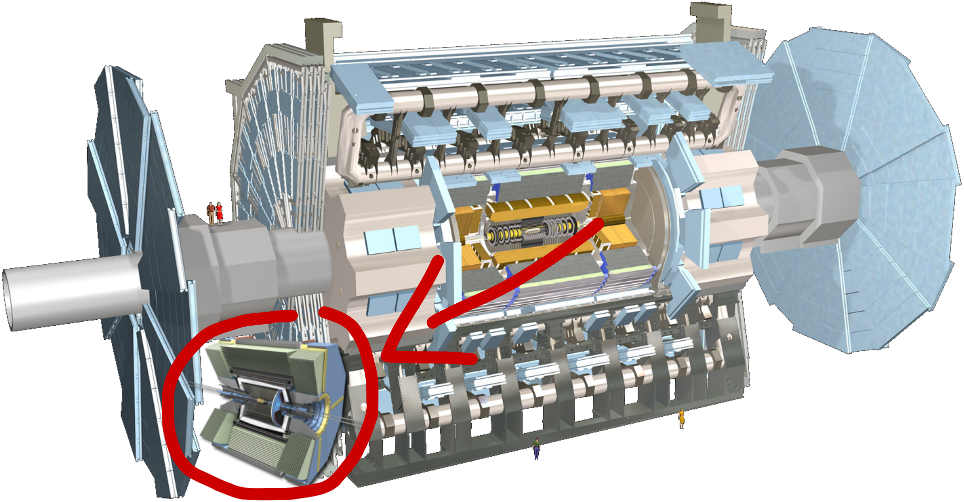


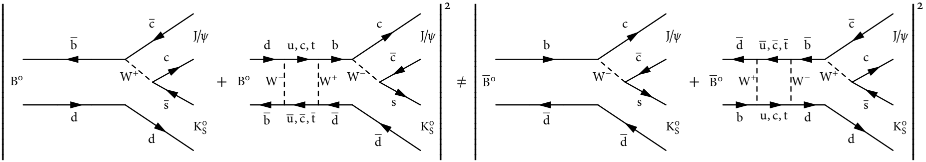
Measurement of CP Violation

Objective: Measure time dependent decay asymmetry of B and $\overline{\text{B}}$ going to the same final state

$$a_{CP}(t) = \frac{\Gamma\left(\overline{\text{B}}^0 \to f_{CP}; t\right) - \Gamma\left(\text{B}^0 \to f_{CP}; t\right)}{\Gamma\left(\overline{\text{B}}^0 \to f_{CP}; t\right) + \Gamma\left(\text{B}^0 \to f_{CP}; t\right)}$$

3 possible contributions

- CP-Violation in decay (direct)
- CP-Violation in mixing (indirect)
- CP-Violation by interference of mixing and decay (mixing induced)

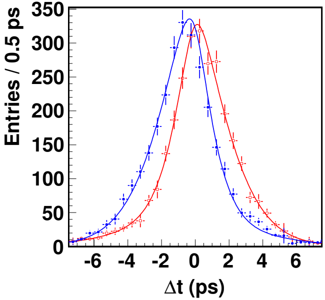


- For B mesons, contributions from indirect CP-Violation are negligible
- For many decays, loop diagrams contribute to the amplitudes
  ➡ possibility to indirectly detect new physics

Measurement of CP-Violation

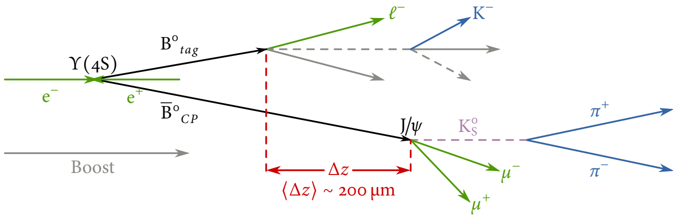
Experimental challenging task:

- lifetime of B mesons is 1.5 ps
- flavour of B meson has to be known

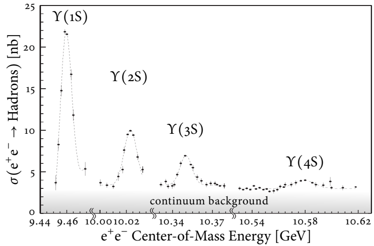


Solution

- $\Upsilon(4S)$: coherent B-meson pair production
- one B to determine flavour (tag side), other B for CP measurement (CP side)
- boost system using asymmetric beam energies $t \rightarrow \Delta t = \frac{\Delta z}{\langle \beta\gamma \rangle c}$



Experimental requirements



Best place to produce $B\overline{B}$ in a clean environment is at the $\Upsilon(4S)$:

- lowest energy with free B mesons
- 1/3 of all events are $B\overline{B}$
- possibility to “turn off” B production by lowering center of mass energy by 50 MeV

Differences to LHC

Energy is factor $\mathcal{O}(1000)$ smaller than for LHC:

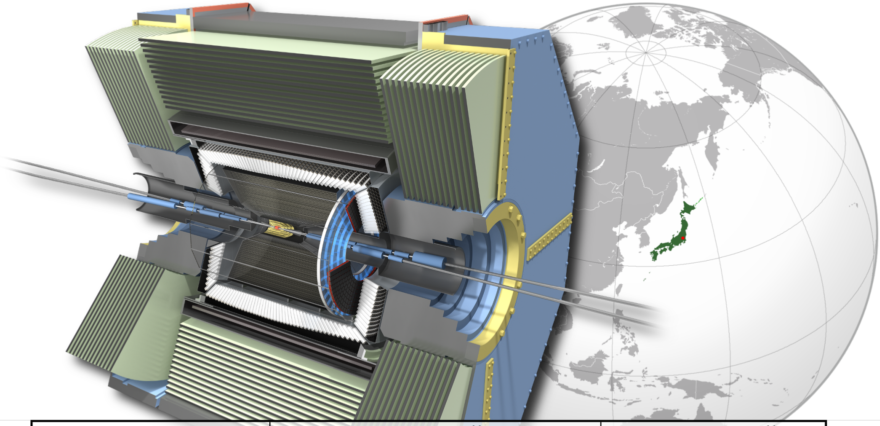
- there are no real “jets”: we see single particles
- mean momentum of charged particles is around 500 MeV

Electron Collider:

- full knowledge about the center of mass frame
- no underlying events
- but: low cross section (more than factor 100)

Belle/Belle II Experiment

Asymmetric e^+e^- experiment mainly at the $\Upsilon(4S)$ resonance (10.58 GeV)



	KEKB/Belle	SuperKEKB/Belle II
operation	1999 – 2010	2016 –
peak luminosity	$2.11 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$	$8 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
integrated luminosity	$1023\,\mathrm{fb}^{-1}$ (772 million $B\bar{B}$ pairs)	$50\,\mathrm{ab}^{-1}$

Challenging environment

Challenging environment

Earthquake

Challenging environment

Eart

Tsunami

Challenging environment

Eart

Tsun

Nuclear meltdown

Challenging environment

Eartl

Tsun

Nucl

Tornado

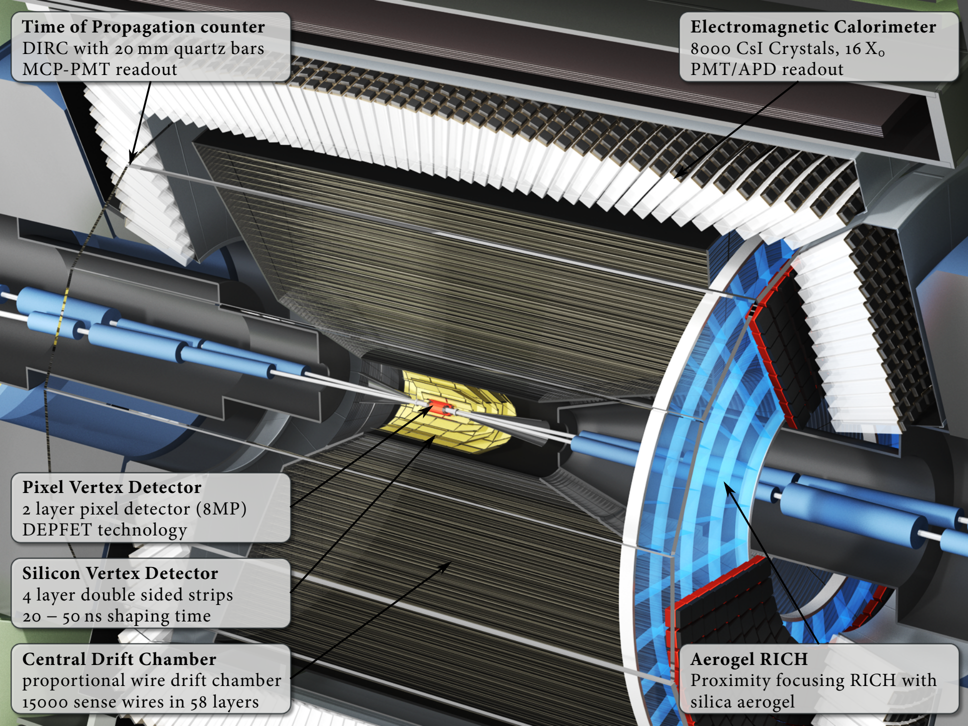
Challenging environment

Eartl

Tsun

Nucl

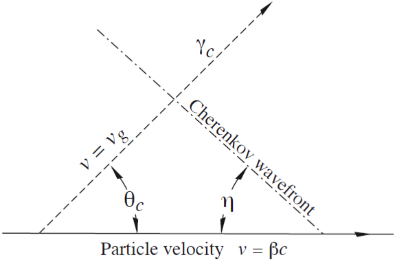
Torn


Time of Propagation counter
DIRC with 20 mm quartz bars
MCP-PMT readout
Electromagnetic Calorimeter
8000 CsI Crystals, 16 X_0
PMT/APD readout
Pixel Vertex Detector
2 layer pixel detector (8MP)
DEPFET technology
Silicon Vertex Detector
4 layer double sided strips
20 – 50 ns shaping time
Central Drift Chamber
proportional wire drift chamber
15000 sense wires in 58 layers
Aerogel RICH
Proximity focusing RICH with
silica aerogel

Particle Identification System

Good separation between Kaons and Pions is very important

- Momentum and dE/dx will be measured in the tracking system
- Use of Cherenkov detectors to measure speed of the particle

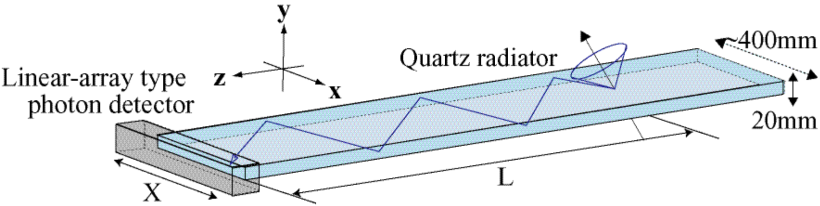


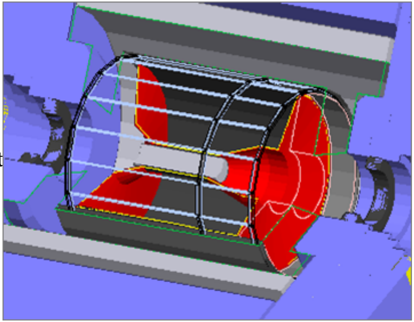
$$\cos\theta_c = (1/n\beta)$$

$$\text{or} \quad \tan\theta_c = \sqrt{\beta^2 n^2 - 1} \approx \sqrt{2(1 - 1/n\beta)}$$

- Cherenkov light is the optical analogy to the sonic boom
- particles that are faster than the speed of light in a given medium emit cherenkov light
- direction of the light is dependent on β

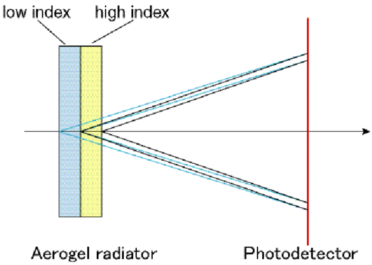
Time of Propagation Counter





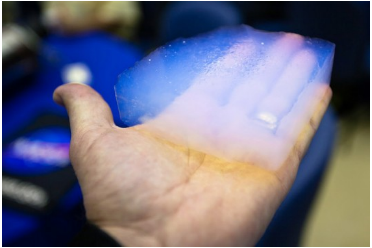
- array of rectangular quartz bars
- cherenkov light is reflected internally
- MCP-PMT array at the end will detect position and time
- 40 ps time resolution, 3σ K/π separation

Endcap A-RICH



RICH = Ring Imaging Cherenkov Detector

- silica aergoel radiators used to create Cherenkov light
- light will form in circle screen
- two layers of different refractive materials used to produced focussed ring
- 4σ K/π separation

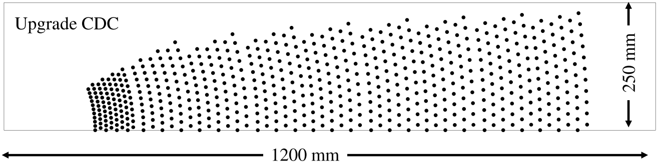


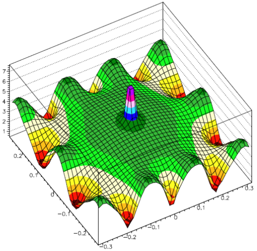
Silica Aerogel

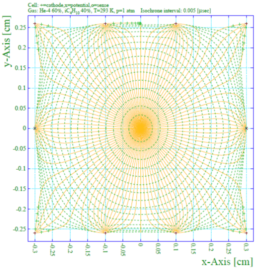
- produced by drying silica gel in a specific way
- holds 14 world records
- important for us: low density, low refractive index

Central Drift Chamber

Wire Configuration



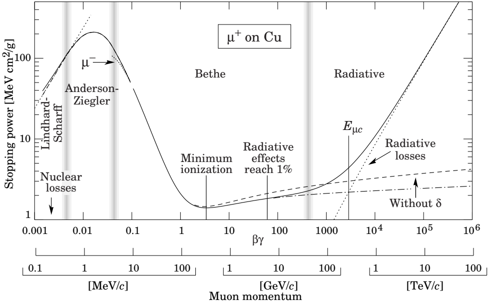


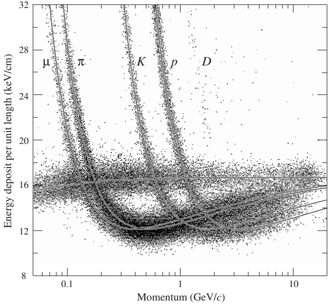


- wire chamber with ~ 15000 sense wires
- drift time ∝ distance to wire
- position resolution of $\mathcal{O}(100\,\mu\text{m})$
- stereo wires to get θ-information
- determination of particle momentum

Contribution to PID

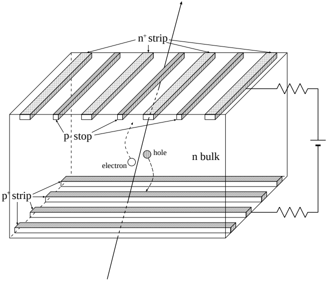
Drift chamber also contributes to particle identification due to different energy losses for different kind of particles



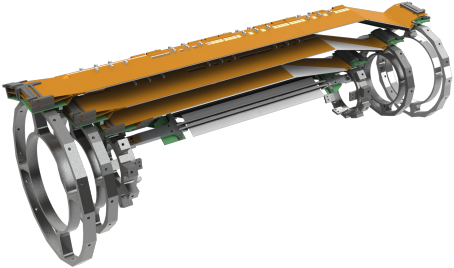


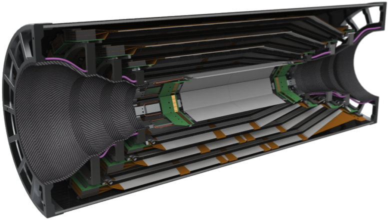
Particle Identification uses the combined information of all sub detectors the particle traversed

Strip Vertex Detector



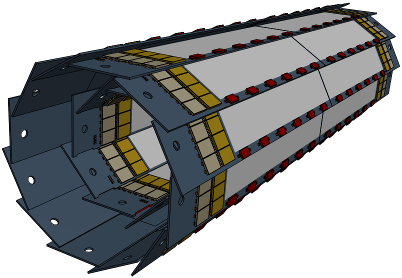
- charged tracks produce electron hole pairs which drift to the surface
- position of track intersection can be recorded
- 4 layer double sided strip detector
- pitch of 50 µm resp. 160 µm
- uses APV25 chips from CMS, time resolution of 20 – 50 ns

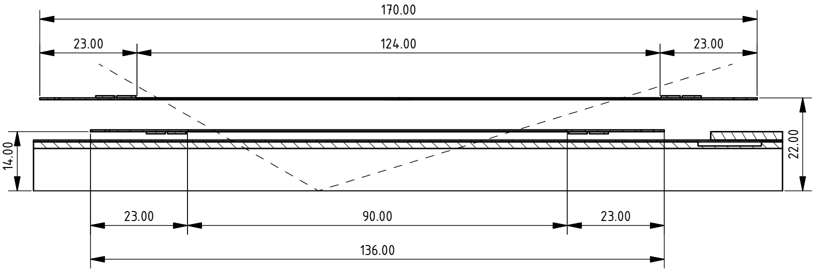




Pixel Vertex Detector

- innermost part of the detector
- 2 layer pixel detector (8M pixels)
- readout time of 20 ms
- data rate of 240 Gb/s = 30 GB/s
- pixel size of $50 \times 50\,\mu m$ and $50 \times 75\,\mu m$
- single track vertex resolution $\mathcal{O}(15 - 30\,\mu m)$





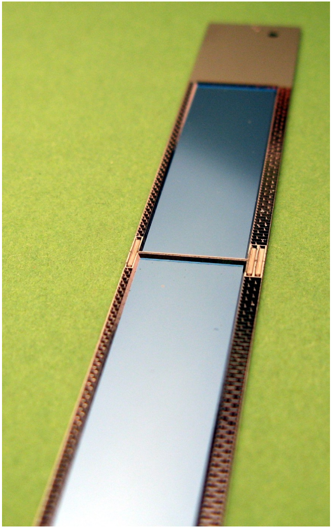
Material budget

PXD different design compared with existing Silicon detectors

- silicon sensors self supporting
- sensitive area will be thinned down to 75 µm
- almost no additional material inside of the acceptance

total material budget of 0.28 $\%X_0$

But: Silicon is very brittle: Once there is a small crack, this crack can grow very easily



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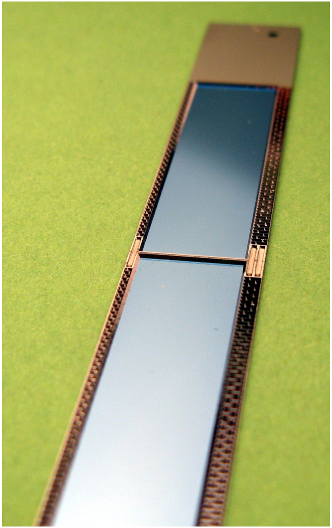
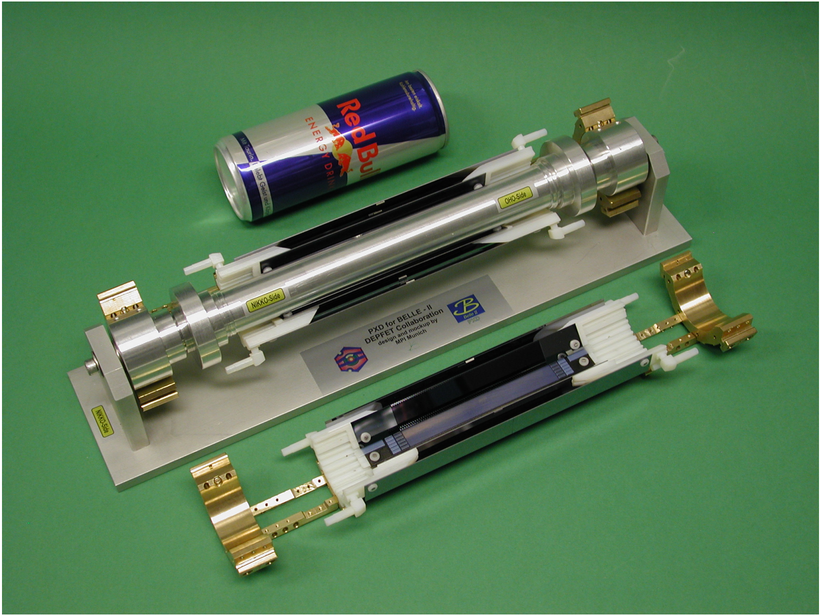



Red Bull
OHO-Side
NIKKO-Side
PXD for BELLE - II
DEPFET Collaboration
design and mockup by
MPI Munich
NIKKO-Side

Conclusions

Belle/Belle II is a precision measurement focusing on the production of B mesons

- Center of Mass energy of 10.58 GeV
- boosted system to transform lifetime difference between the two B mesons into vertex difference
- very good vertex detector
- good identification of final state particles (K,π)

Belle II will increase the data sample of $B\overline{B}$ Events by a factor of 50

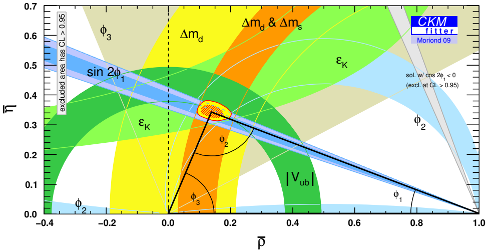
- opens possibilities to examine very rare decays
- will push sensitivity of CP measurements to a level to really challenge SM

Thank you
for your attention

Unitarity Triangle

- unitarity of CKM matrix leads to column constraints $\sum_k V_{ik} V_{jk}^* = 0$
- triangles in complex space
- almost degenerate in Kaon system, large angles in B meson system

$$\underset{\mathcal{O}(\lambda^3)}{V_{ud} V_{ub}^*} + \underset{\mathcal{O}(\lambda^3)}{V_{cd} V_{cb}^*} + \underset{\mathcal{O}(\lambda^3)}{V_{td} V_{tb}^*} = 0$$

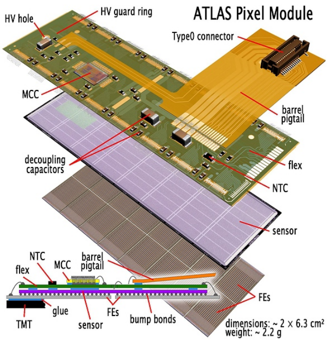


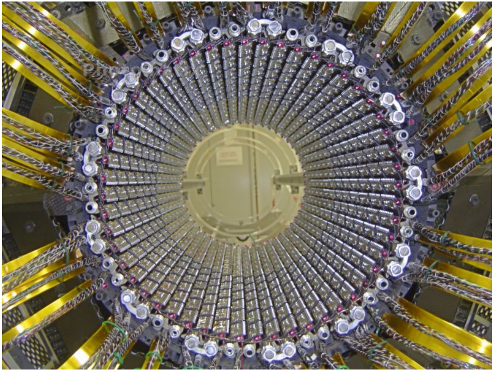
$$\bar{\rho} = \left(1 - \frac{\lambda^2}{2}\right)\rho \qquad \bar{\eta} = \left(1 - \frac{\lambda^2}{2}\right)\eta$$

$$\phi_1 = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right) \qquad \phi_2 = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

Standard Silicon Detector
for example ATLAS





- multiple sensitive modules are glued on support ribs which provide mechanical stability
- support, cooling and cables inside acceptance region (between 5% and 30 $\%X_0$)

→ too much material for Belle II (10 GeV CM energy)