Study of the sensitivity in measuring β_c, one of the angles of the charm unitarity triangle

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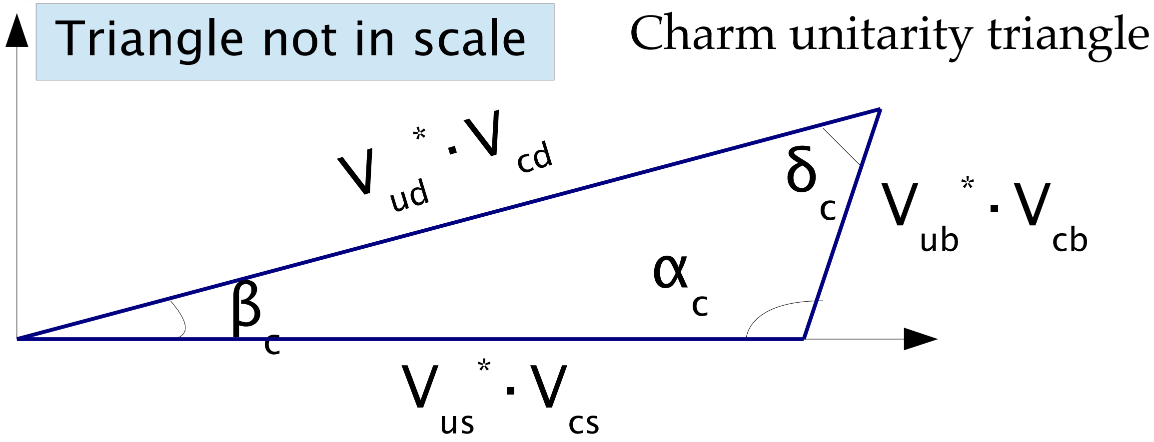
Plan of the thesis

1) study of CP asymmetry in D^0 decays with the next generation of Flavour Factories

2) tracking studies with PLUME

3) tracking performances in Belle II experiment

Study on the sensitivity in measuring β_c



$$V_{ud}^* \cdot V_{cd} + V_{us}^* \cdot V_{cs} + V_{ub}^* \cdot V_{cb} = 0 \qquad \lambda \lambda \lambda^5$$

Motivation:

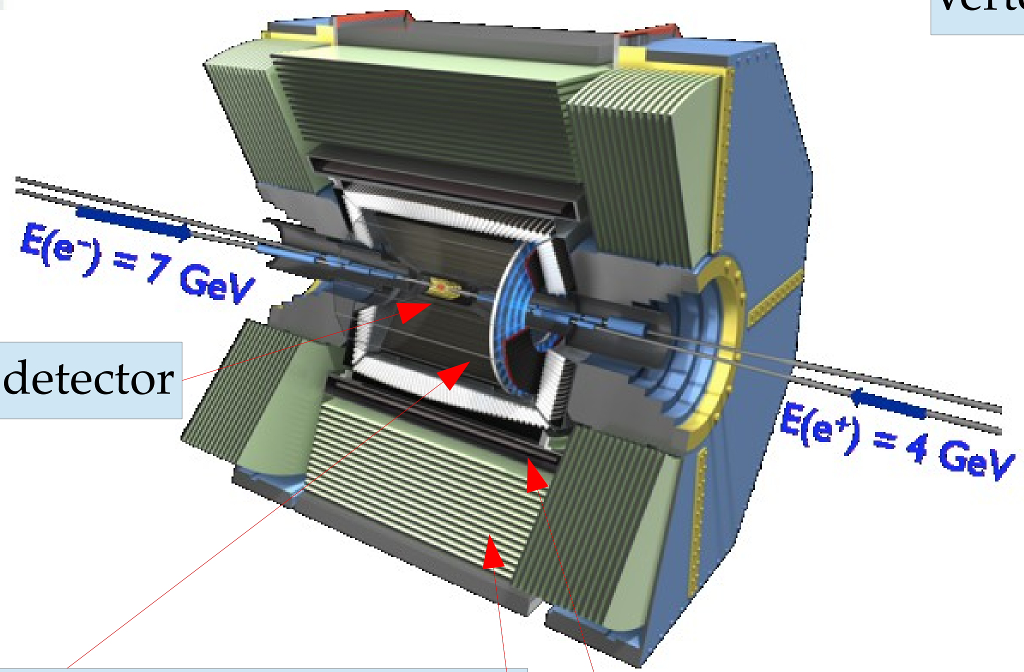
- CP asymmetry in charm sector is expected to be very small (10^{-3})

–any deviation from this value will signify **new physics**, or physics beyond the Standard Model (SM)

–the **charm unitarity triangle is unexplored**, because it is almost flat. One of this unitarity triangle angle is β_c

–LHCb has observed unexpected high asymmetry in D^0 decays

Belle II experiment at SuperKEKB



Vertex detector: 2 ladders PIXEL detectors (PXD)
4 Double Sided Si-Strip Detectors

-Located in Japan, upgrade of Belle and KEKB

- Its main goal is testing the SM and searching for new physics

Schedule: 2015 -> start of commissioning
2016 ->start of the physics run

Luminosity:
-instant: $8 \cdot 10^{35} cm^{-2} s^{-1}$
-integrated :50 ab^{-1} ~ 5 years

Beam pips radius = 1 cm

Time dependent asymmetry

Different collision scenarios at Flavour Factories :

1) $e^+e^- \to c\bar{c}$ (continuum) ← Belle II scenario (also SuperB)

$$c\bar{c} \to D^{(*)+} + X_c\ (D^-, \bar{D}^0, \Lambda_c, ..),\quad D^{(*)+} \to D^0 \pi^+$$

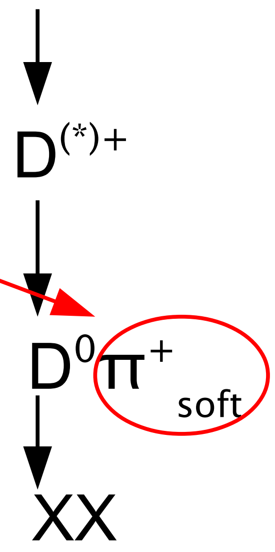
2) $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ ← Belle II scenario (also SuperB)

$$B\bar{B} \to D^{(*)+} + X_c\ (D^-, \bar{D}^0, \Lambda_c, ..),\quad D^{(*)+} \to D^0 \pi^+$$

3) $e^+e^- \to \Psi(3770) \to D\bar{D}^0$ quantum correlated ← SuperB scenario

Flavour identification and D^0 oscillations

$e^+e^- \longrightarrow \Upsilon(4S) \longrightarrow B\bar{B}$

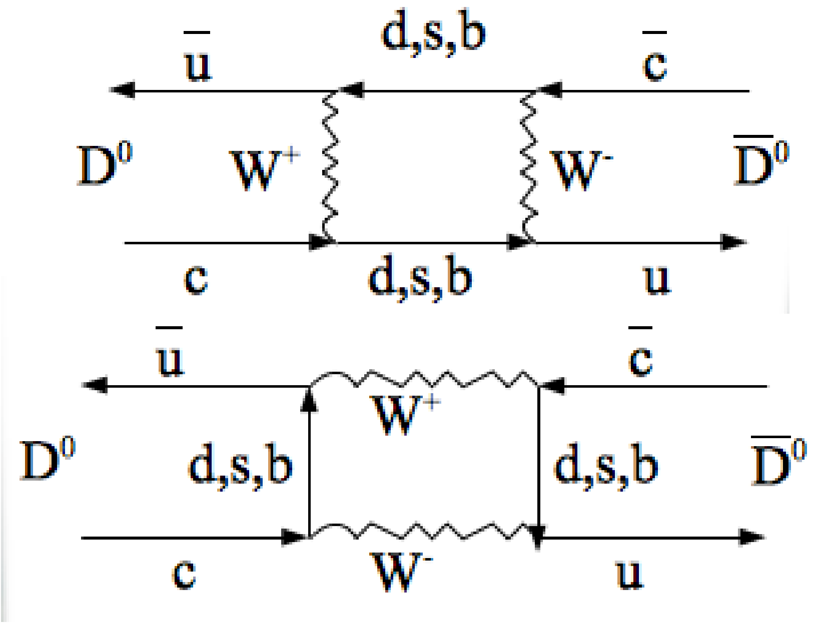


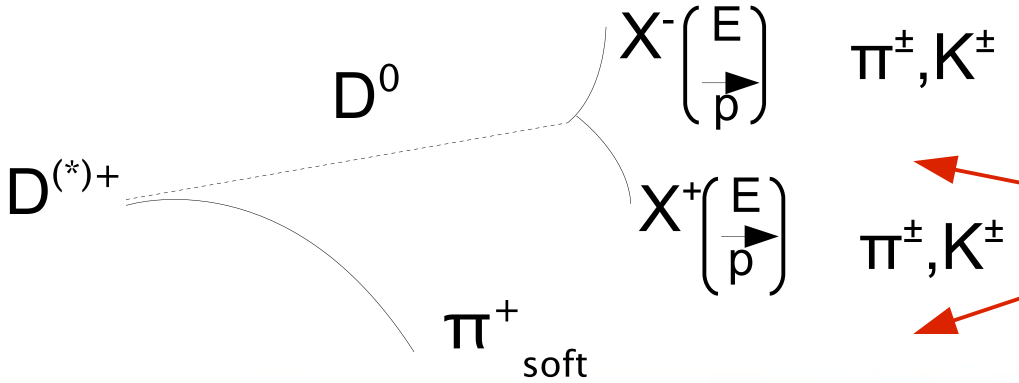
Identification of the D meson flavour

$\pi^+ \;\to\; D^0$

$\pi^- \;\to\; \bar{D}^0$

D^0 oscillations





Momentum reconstruction in the Belle II framework

How to estimate β_c

We reconstruct D^0 or $\overline{D}^0$ in a given CP final state :

$$D^0 \to \pi^+\pi^- \to \arg(\lambda_f) = \varphi_{mix} + 2\beta_{c,eff}$$

$$D^0 \to K^+K^- \to \arg(\lambda_f) = \varphi_{mix}$$

The time dependent asymmetry

$$A(\lambda_f,t,\Gamma,\Delta m) = \frac{N(\overline{D}^0\text{->}f) - N(D^0\text{->}f)}{N(\overline{D}^0\text{->}f) + N(D^0\text{->}f)}$$

Mixing and decay amplitudes are present

$$\lambda_f = \frac{q}{p}\frac{\overline{A}}{A}$$

$\frac{\overline{A}}{A}$ ← Direct CP violation

$\frac{q}{p}$ ← CP violation in mixing

The simulation

For the expected statistics with 50 ab^{-1} integrated luminosity (extrapolation from Belle results with 0.7 ab^{-1}):

$\sim 5 \cdot 10^6$ D^* tagged $D^0 \to \pi^+\pi^-$

$\sim 12 \cdot 10^6$ D^* tagged $D^0 \to K^+K^-$

Toy Monte-Carlo simulation (not a Full Simulation with Geant)

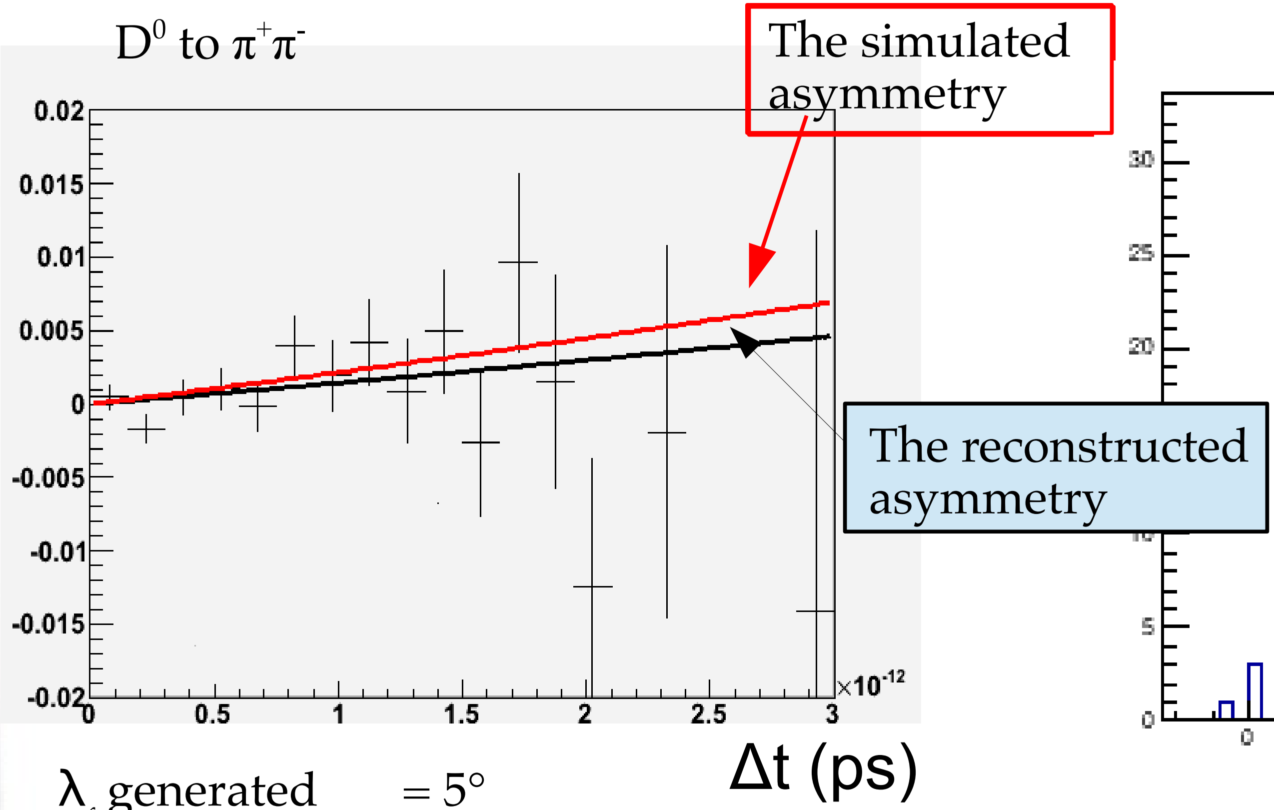
Data are simulated with a given λ_f CP parameter.

Measurement: binned likelihood fit of the reconstructed asymmetry as a function of time

Study: impact from time resolution (spatial resolution on the vertex reconstruction) and mistag

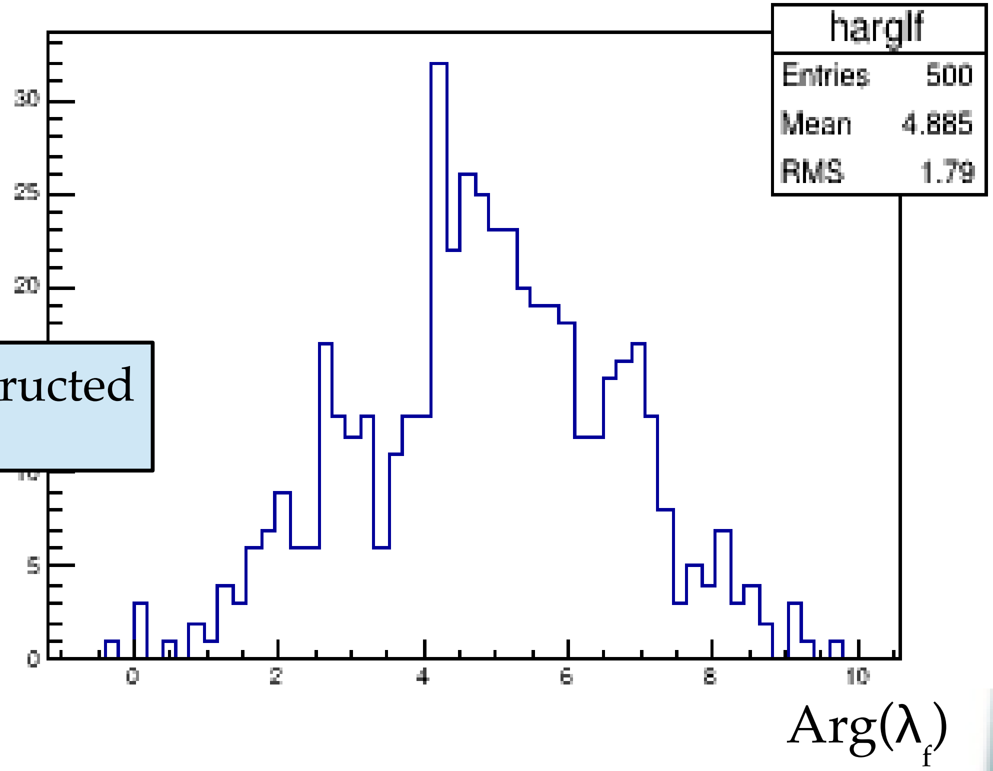
Some results

Reconstruction with perfect time resolution and no mistag



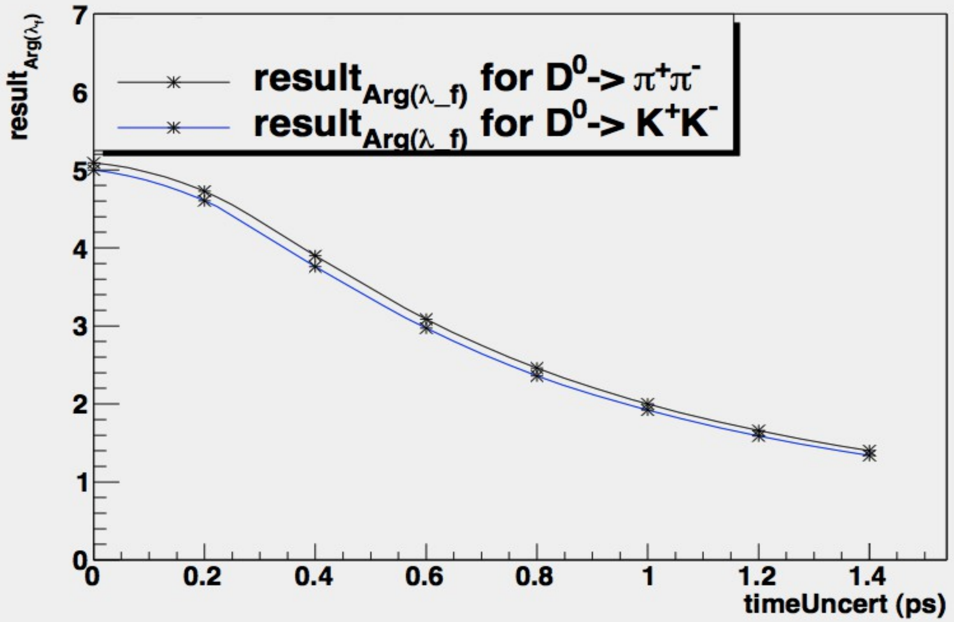
λ_f generated $= 5°$

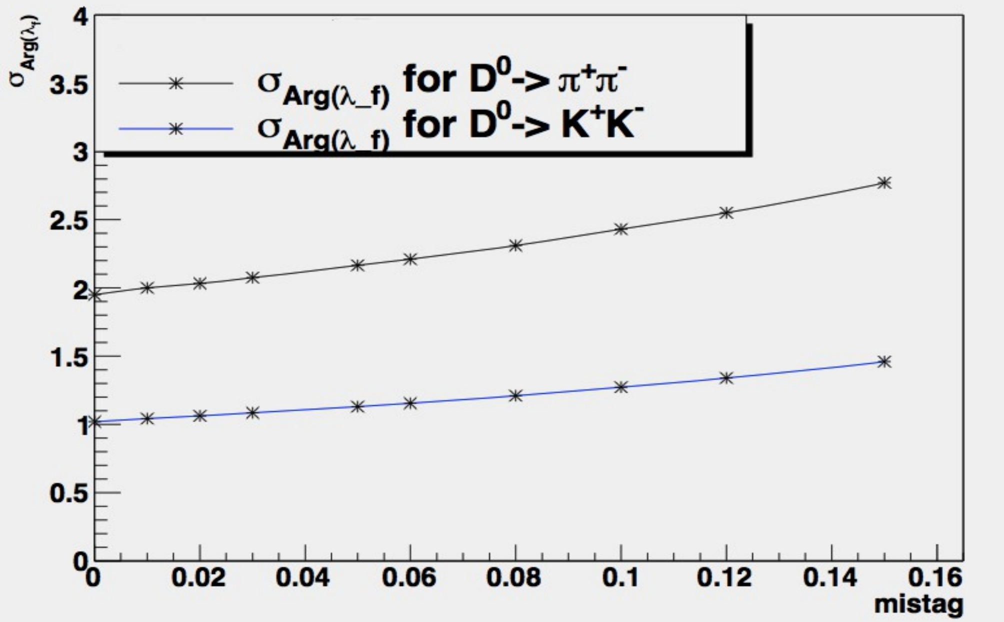
λ_f reconstructed $= 3.34 \pm 1.8°$

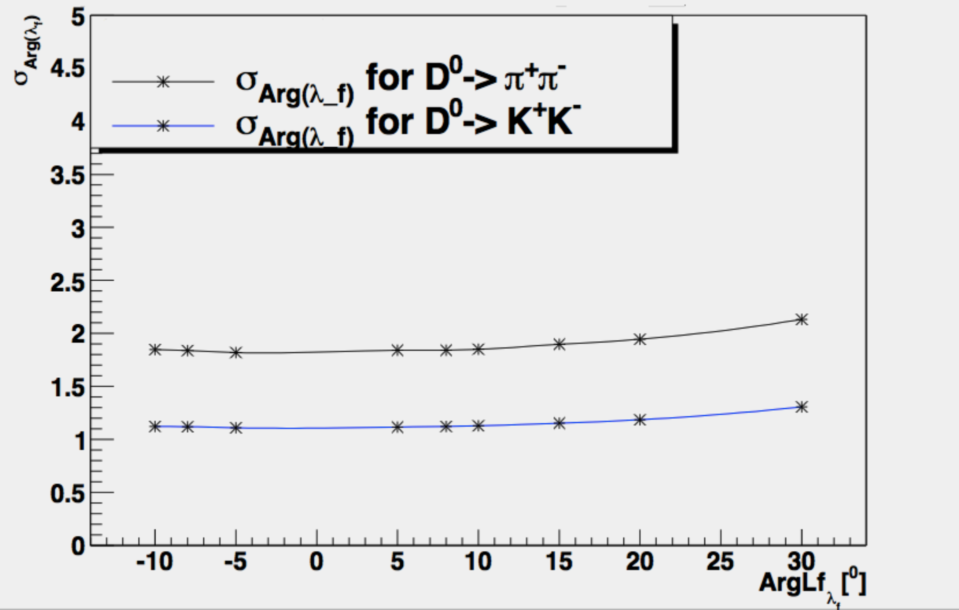


500 experiments with λ_f generated $= 5°$

Some results







Parameter	Uncertainty (^{0})
$\Phi(\pi\pi) = \arg(\lambda_{\pi\pi})$	1.9
$\Phi(KK) = \arg(\lambda_{KK})$	1.2
$\beta_{c,eff}$	1.1

Mistag used 0.01
Time uncertainty of the detector 0.2 ps

Outlooks

- Change from a binned likelihood method to an unbinned one (currently unsolved numerical issues)

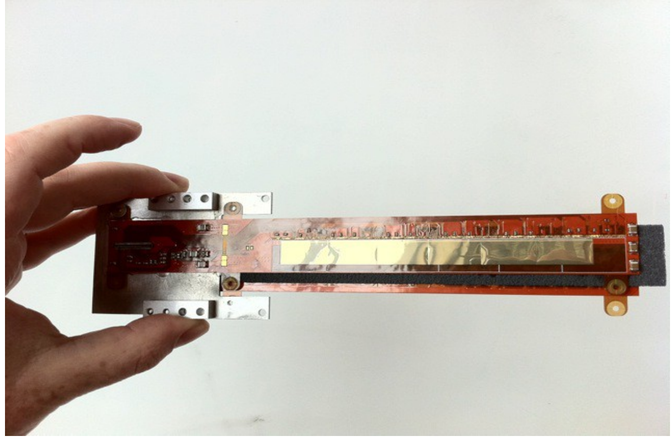
- Systematics with impact on the results: Δm, Γ

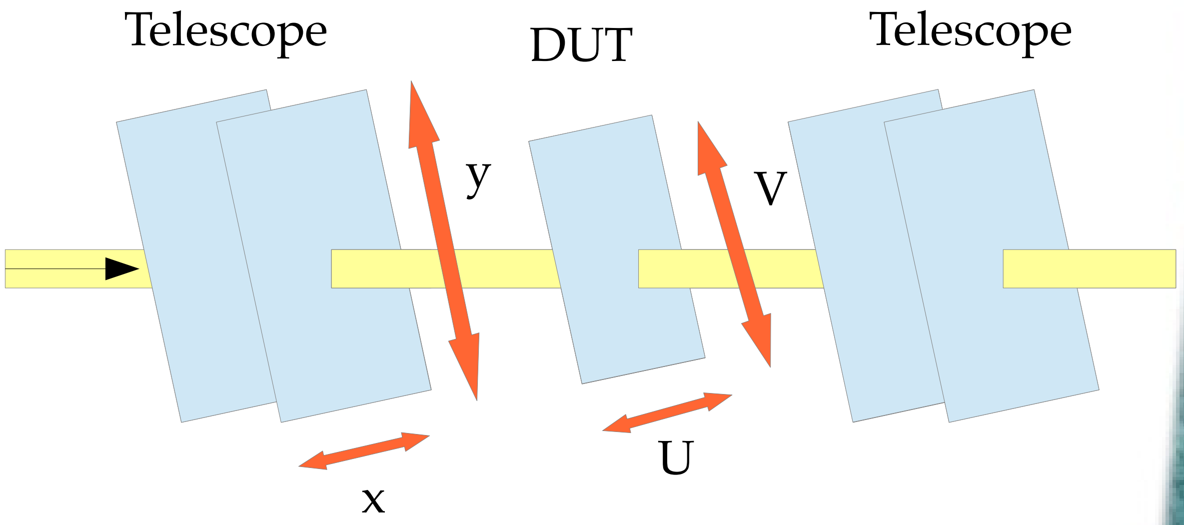
- Translation of time resolution into spatial resolution (because what is reconstructed is a flight distance)

- Ongoing work in the Belle II analysis framework to study D^0, π_{soft} momentum spectrum and vertex resolution

2) tracking studies with PLUME

PLUME (Pixel Ladder with Ultra Low Material Embedding) devices



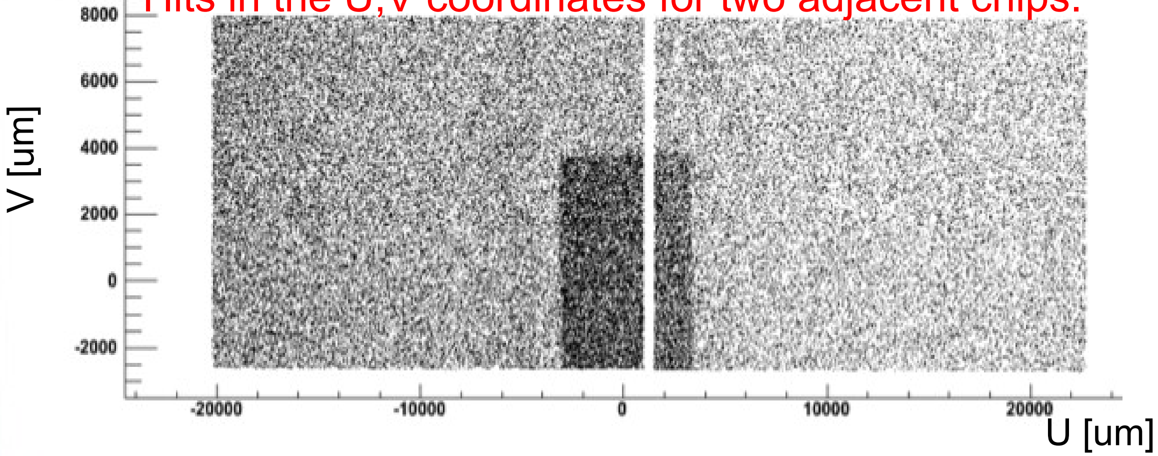


The Detector Under Test (DUT) is equipped with 2x6 CMOS pixel sensors (Mimosa26)
Size of the chip: 13,7 mm x 21,5 mm
Sensor matrix: 576x1152 pixels with 18.4 μm pitch
Trigger scintillator with 7x7 mm^2 area

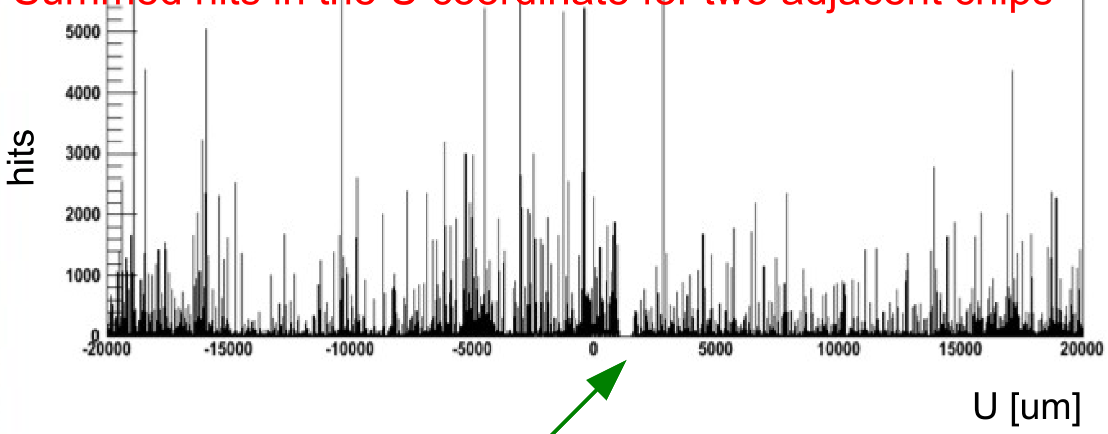
2 studies for the ability to reconstruct tracks with PLUME:
- The gap between 2 adjacent sensors
- Study on the tilted tracks

Study of the gap between two sensors for PLUME

Hits in the U,V coordinates for two adjacent chips.

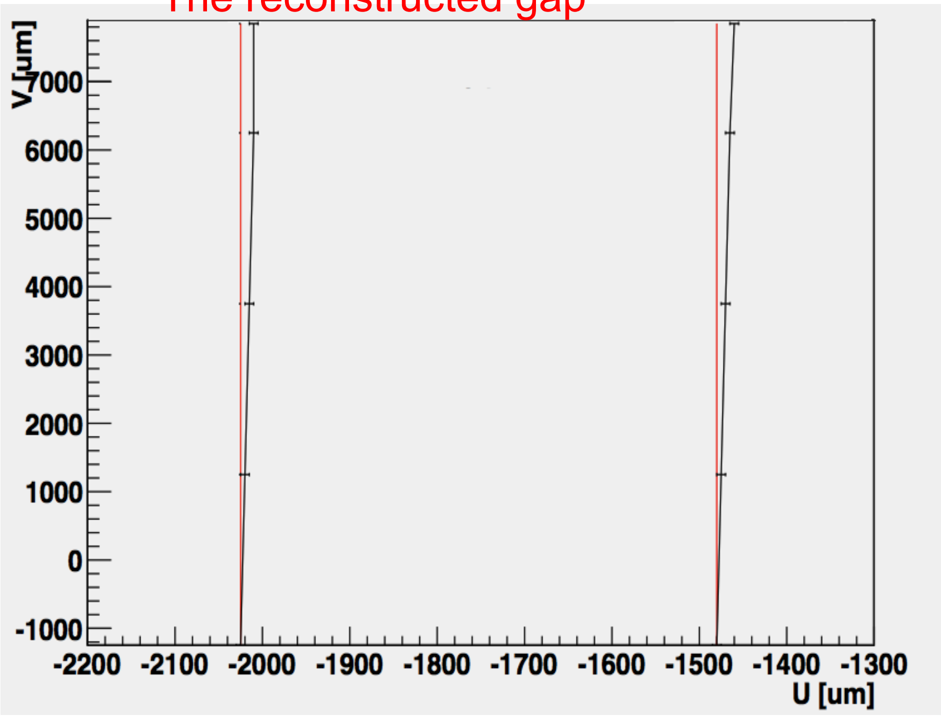


Summed hits in the U coordinate for two adjacent chips



Analysis on the region near the gap

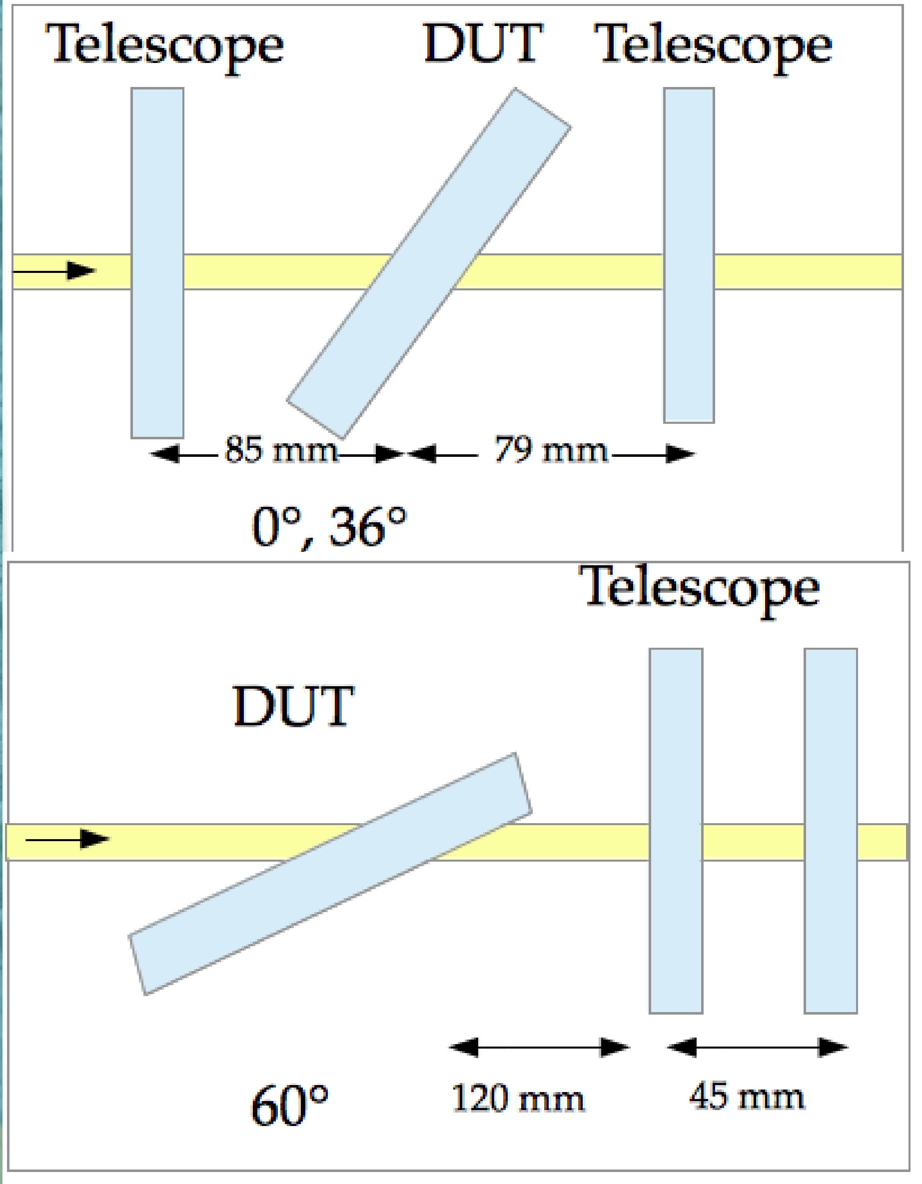
The reconstructed gap



The distance with no hits between different adjacent sensors

Sensors	1-2	3-4	5-6	7-8	9-10	11-12
Gap (um)	550	535	545	555	540	555

Study of non-perpendicular tracks



Finding the best possible resolution by aligning parts of the DUT

$$\sigma^2_{residue} = \sigma^2_{track} + \sigma^2_{hit}$$

Spatial resolution of the DUT

Computed ($\sigma^2_{telescope} + \sigma^2_{multiple\_scattering}$)

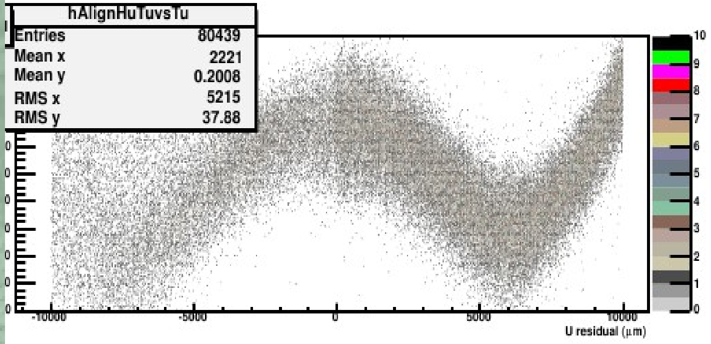
Measured from a gaussian distribution

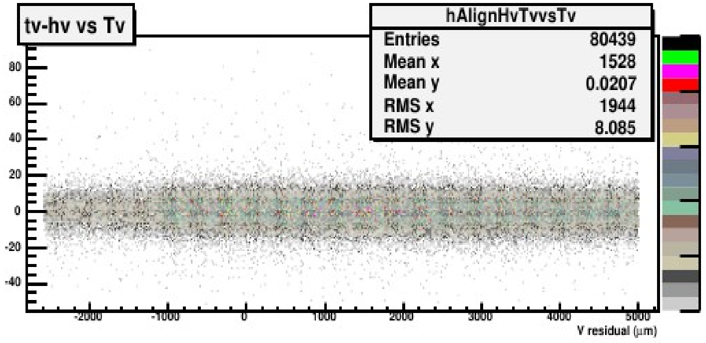
Tracks at 60°

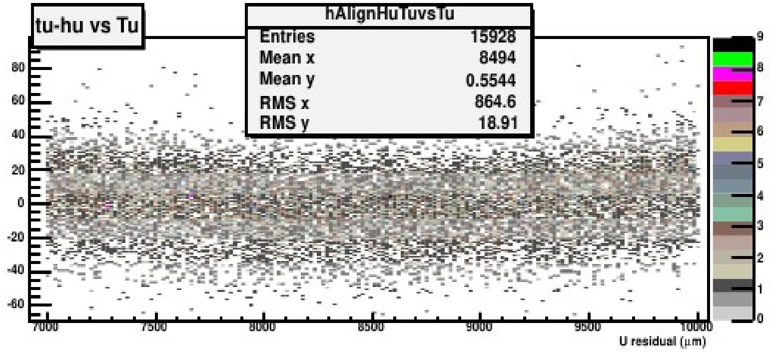
Deformations along the horizontal axis.

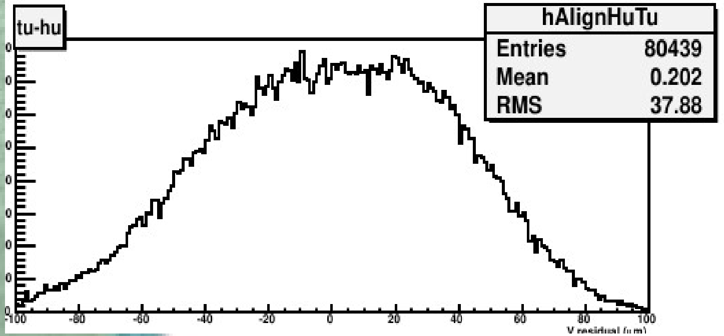
All the sensor surface

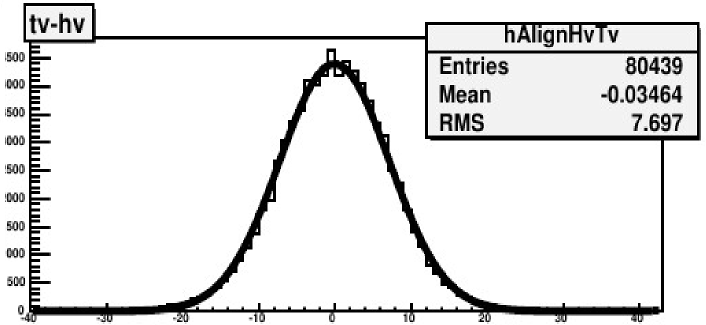
Aligned part of the sensor

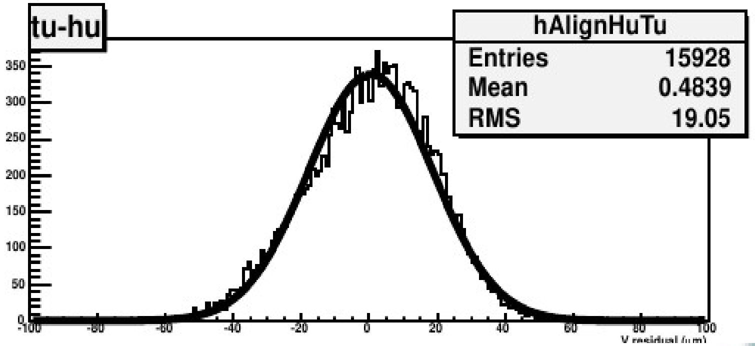








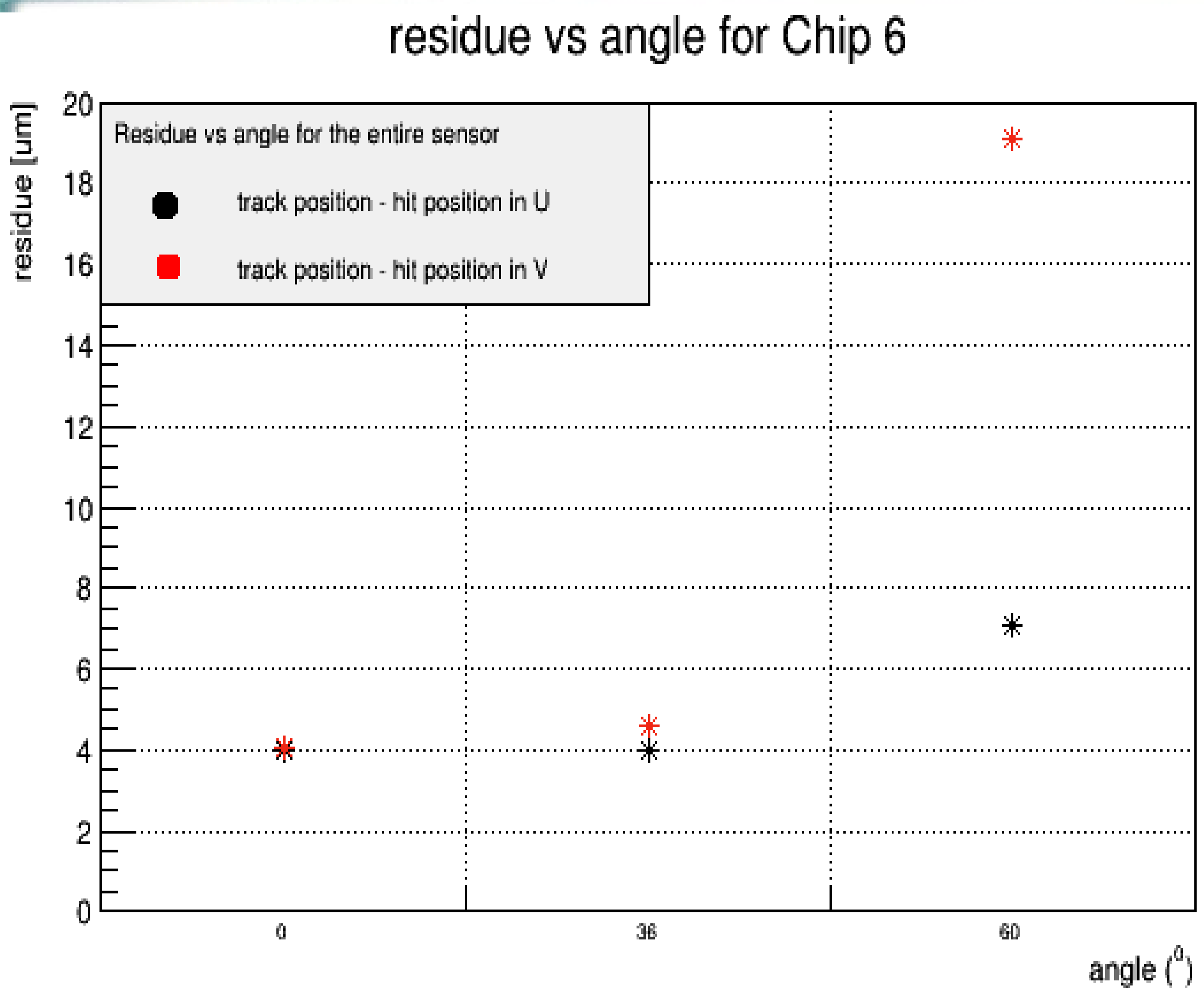




Track u position – hit u position

Track v position – hit v position

Track u position – hit u position



Outlooks of the study

For 50 μm thin sensors:

-no problems with perpendicular tracks or angles < 40^0

-for angles > 40^0 aligning individually sub-parts of the sensor (sensitive to sensor surface deformations)

-set up an automatic method to align all sensors by dividing them into sub-parts (reconstruction of the 3D shape of the surface)

-gap region → dead area from the tracking point of view

→ finding the impact on the track reconstruction

Outlooks of the thesis

- estimation of the momentum with energy deposit (dE/dx) in silicon sensors (PXD and SVD) for low momentum tracks (< 100 MeV) in Belle II

- low momentum tracks in Belle II do not reach the Central Drift Chamber, which is the central detector for track reconstruction.

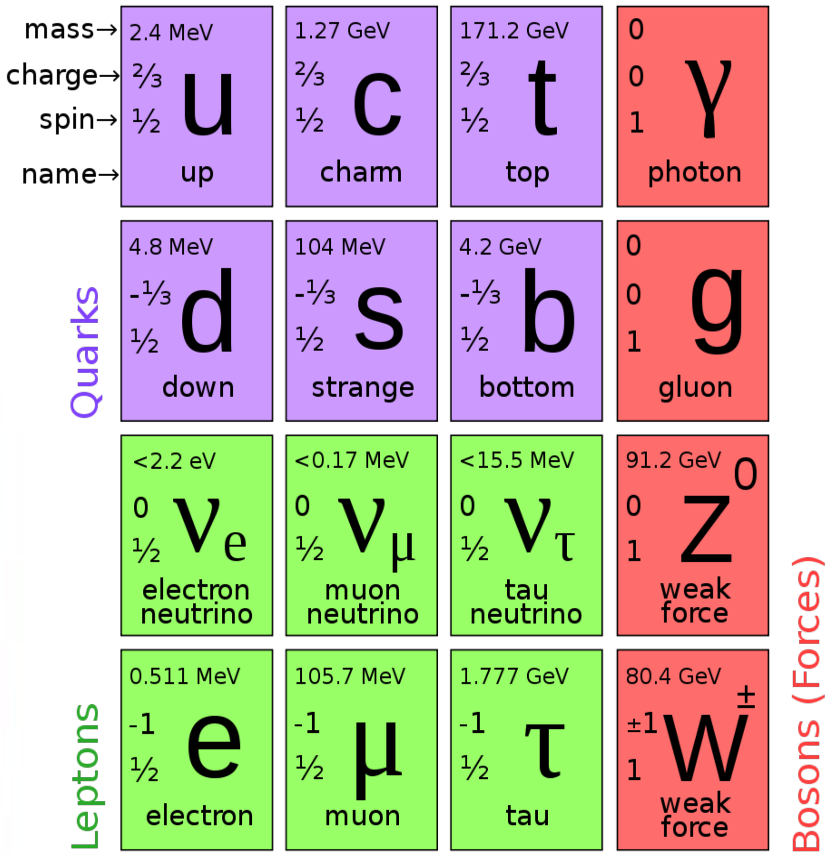
-> use another observable (different from helicoidal fit of the track) to estimate momentum -> dE/dx, which varies steeply with momentum at very low momenta

-> important for reconstructing the π_{soft} from the study on β_c

Thank you for your attention!

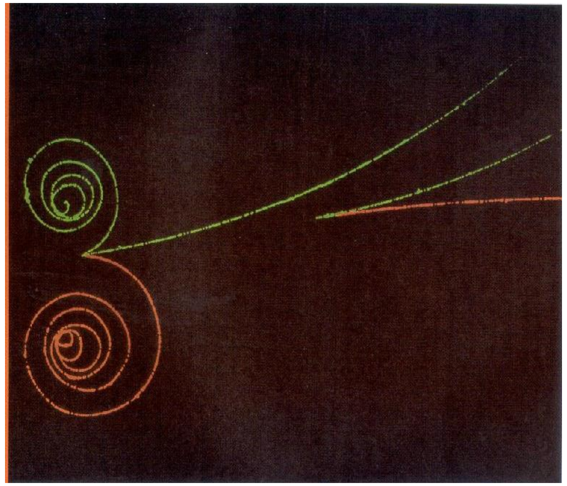
Backup slides

Frame and objective of the thesis:



← elementary particles that forms matter

proton = uud,
neutron = udd,
$D^0 = c\bar{u}$



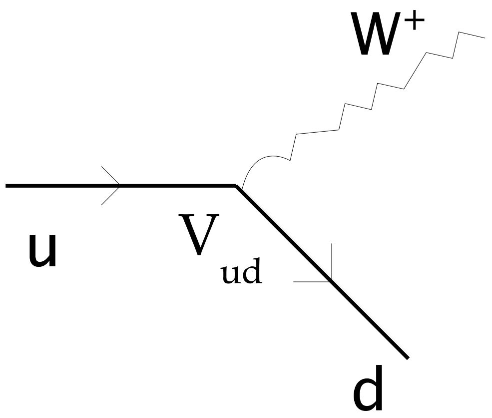
Charged particles in a detector

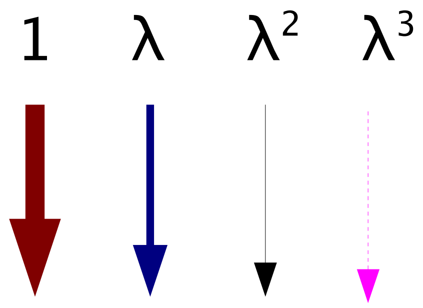
Why there is more matter than anti matter in the Universe?

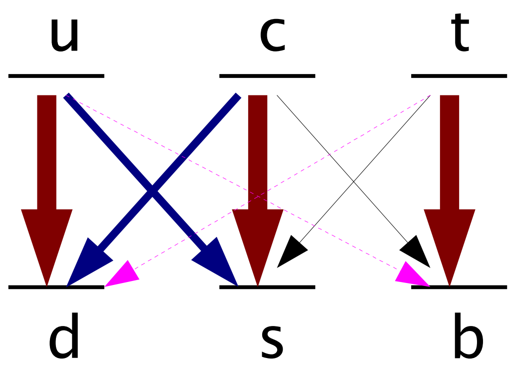
CP violation is one of the necessary conditions

The CKM matrix and the unitarity triangle

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}_{weak} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{\text{Cabibbo-Kobayashi-Maskawa matrix}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{mass}$$







Wolfenstein parametrization of the CKM matrix

$V_{us} \approx 0.22 = \lambda$

$V_{cb} \approx 0.06 = A\lambda^2$

Experimentally determined

$V_{ud} \sim 1 \quad V_{us} \sim \lambda \quad V_{ub} \sim \lambda^3$

$V_{cd} \sim \lambda \quad V_{cs} \sim 1 \quad V_{cb} \sim \lambda^2$

$V_{tb} \sim \lambda^3 \quad V_{ts} \sim \lambda^2 \quad V_{tb} \sim 1$

At the order of λ^3 →

$$\begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} - i\eta A^2\lambda^4 & A\lambda^2(1 + i\eta\lambda^2) \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

The charm unitarity triangle

$V_{CKM} \cdot V_{CKM}^T = V_{CKM}^T \cdot V_{CKM} = 1$ => 3 diagonal relations

6 out of diagonal relations

$$V_{ud}^* \cdot V_{us} + V_{cd}^* \cdot V_{cs} + V_{td}^* \cdot V_{ts} = 0 \qquad \lambda\ \lambda\ \lambda^5$$

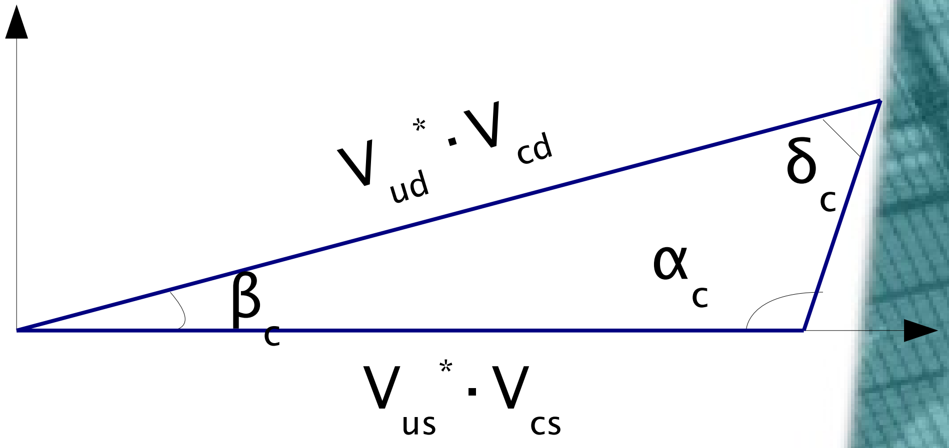
$$V_{ub}^* \cdot V_{ud} + V_{cb}^* \cdot V_{cd} + V_{tb}^* \cdot V_{td} = 0 \qquad \lambda^3\lambda^3\lambda^3$$

$$V_{us}^* \cdot V_{ub} + V_{cs}^* \cdot V_{cb} + V_{ts}^* \cdot V_{tb} = 0 \qquad \lambda^4\lambda^2\lambda^2$$

$$V_{ud}^* \cdot V_{td} + V_{us}^* \cdot V_{ts} + V_{ub}^* \cdot V_{tb} = 0 \qquad \lambda^3\lambda^3\lambda^3$$

$$V_{td}^* \cdot V_{cd} + V_{ts}^* \cdot V_{cs} + V_{tb}^* \cdot V_{cb} = 0 \qquad \lambda^4\lambda^2\lambda^2$$

$$V_{ud}^* \cdot V_{cd} + V_{us}^* \cdot V_{cs} + V_{ub}^* \cdot V_{cb} = 0 \qquad \lambda\lambda\lambda^5$$



Triangle not in scale

Study on the gap between two sensors for PLUME

Data taken from the PLUME beam test, November 2011
Only the runs with the beam between two sensors were analyzed