Online Data Reduction for the Pixel Detector at the Belle II Experiment

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Outline
- •Physics Motivation
- •Belle 2 Experiment
- •Pixel Vertex Detector
- •Data Reduction
- •Results

CP Violation

- CP symmetry is violated in weak decays
- non-vanishing complex phase in the weak mixing matrix (CKM matrix)
- B-physics: large CP violation in B system

$$\begin{pmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{pmatrix} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{V_{CKM}} \begin{pmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{pmatrix}$$

flavor eigenstates

mass eigenstates

<u>Precision Measurment of CP violation</u>

- verification of the CKM model (Nobel Price 2008 for Kobayashi and Maskawa)
- CPV in the Standard Model is not enough to describe the matter-antimatter asymmetry in the universe
- search for new sources of CP violation ➡ new physics

high energy (LHC)

high precision at low energy ("B-factor")

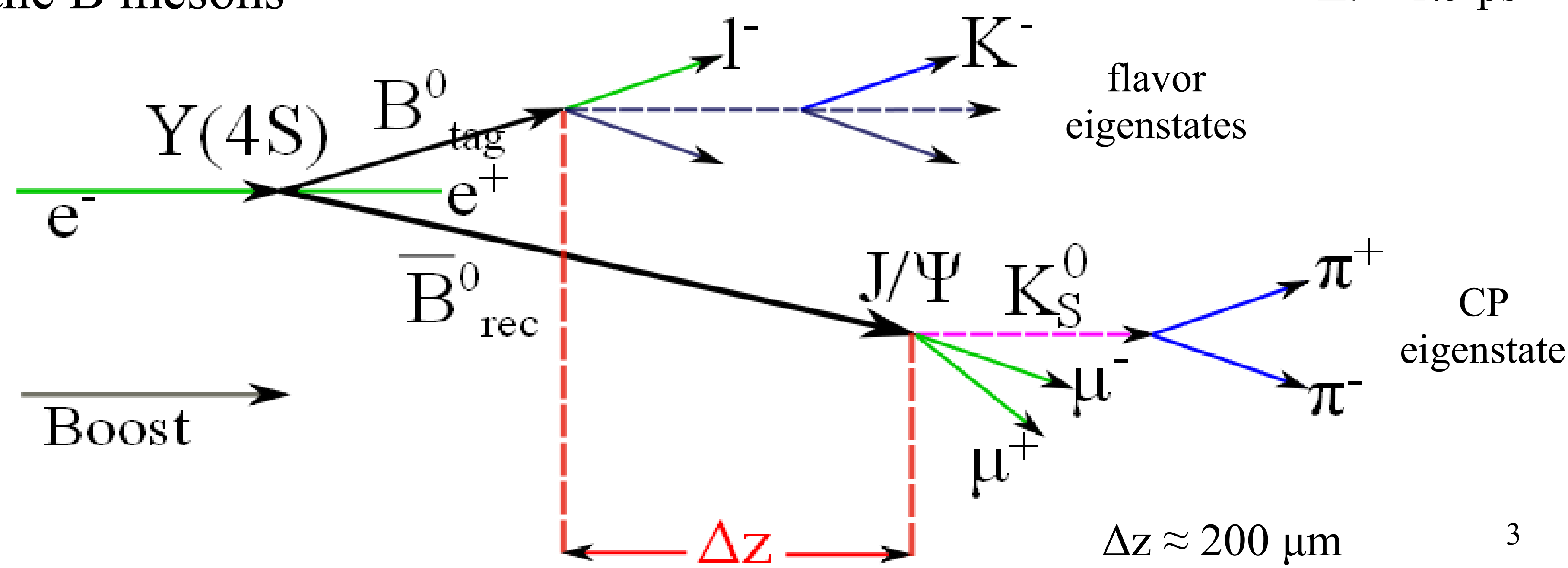
Measurement of CP Violation

measurement of differences between matter and antimatter decays

- production of $B\overline{B}$ pairs
- one B to determine the flavor, the other B for CP measurement
- boost of the system due to asymmetric beam energies
- measure Δz by determination of the decay vertices of the B mesons

$$\Delta t \approx \frac{\Delta z}{\langle \beta\gamma \rangle c}$$

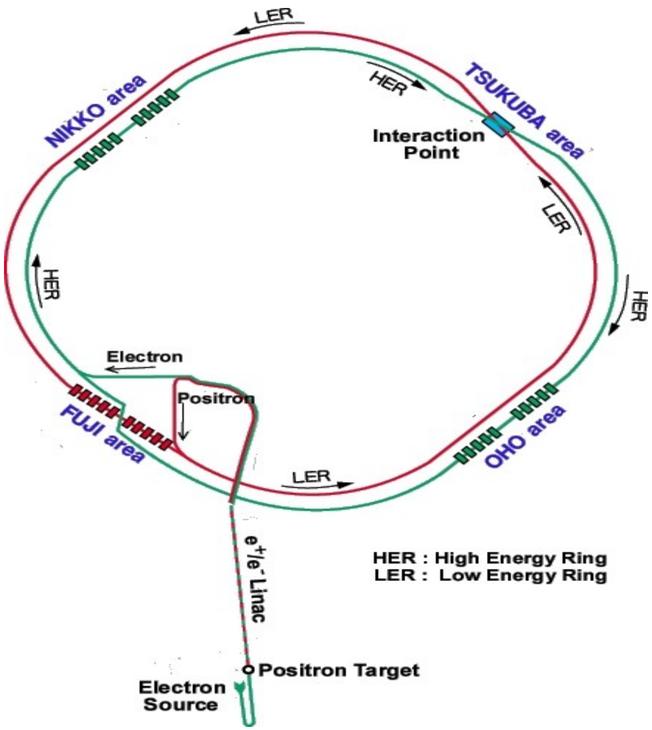
Δt ≈ 1.5 ps



SuperKEKB / Belle II

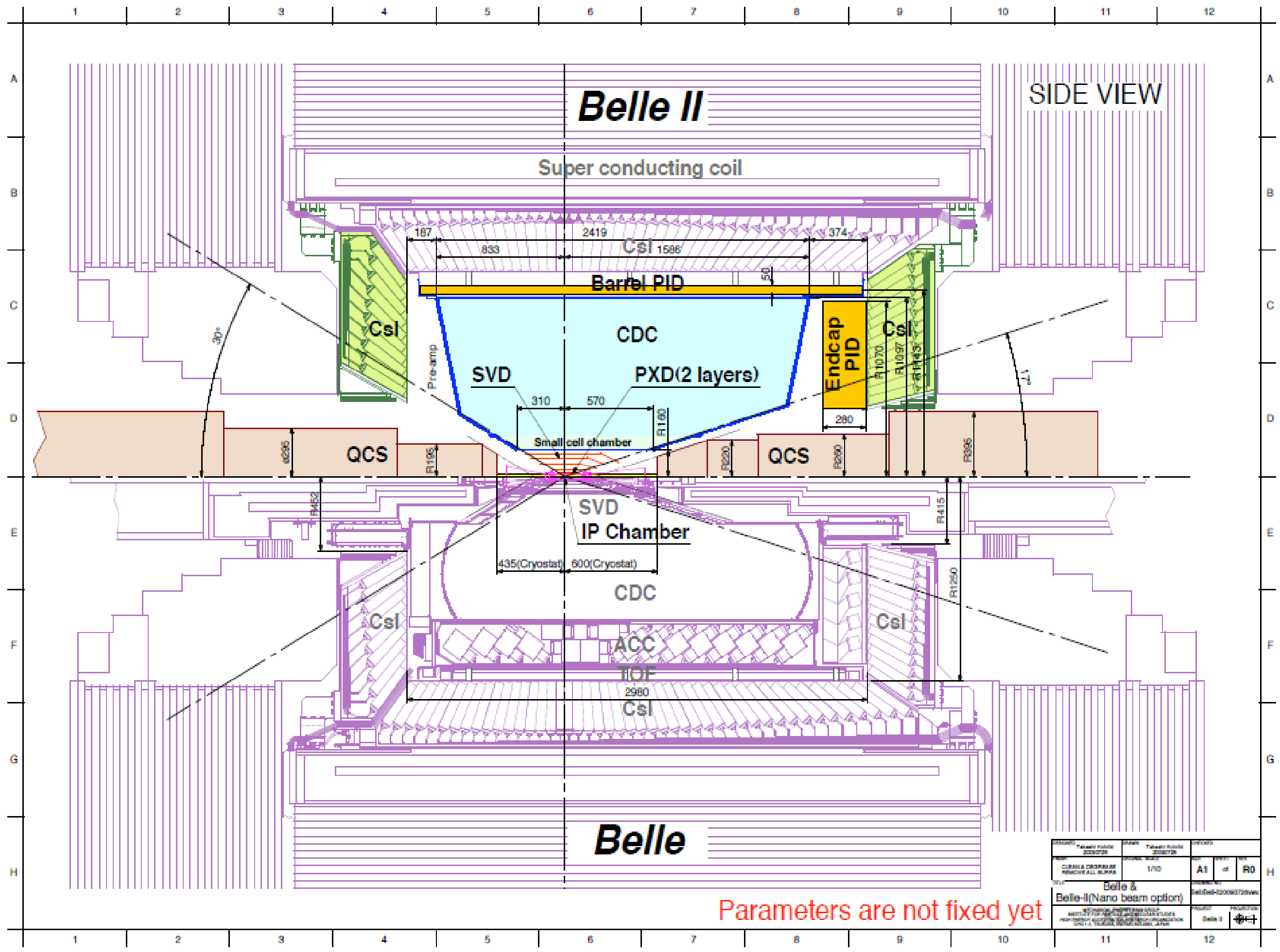
- Upgrade of KEKB collider ("B-factory") and the Belle Experiment at KEK in Tsukuba, Japan (start 2014)
- B-factory: asymmetric electron-positron-collider running at a center of mass energy of around 10.58 GeV
  Y(4S) Resonance
- SuperKEKB: 7 GeV e^- & 4 GeV e^+

  nano beam scheme: vertical beamsize 60 nm
- Design Luminosity 8 x 10^{35} cm^{-2} s^{-1}
  (40 x KEKB)



The Belle II Detector

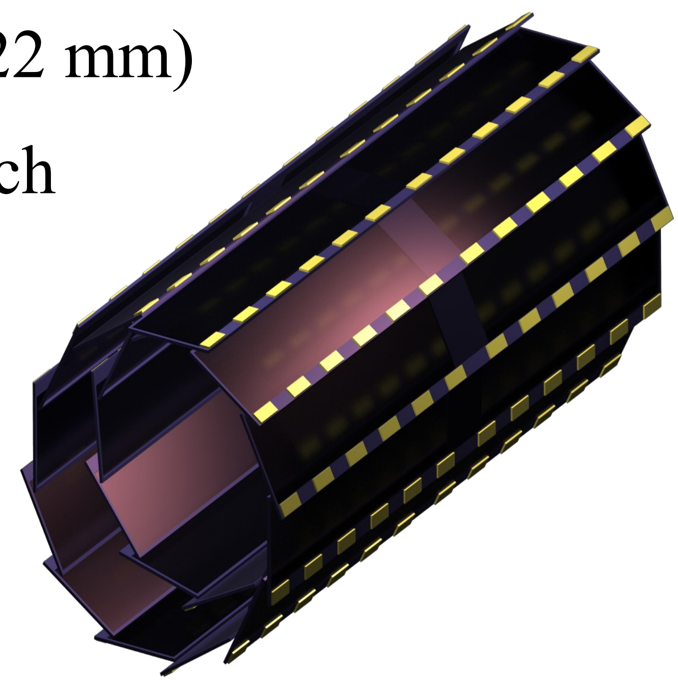
- Calorimeter
- Particle Identification
- Central Drift Chamber
- Silicon Vertex Detector
- Pixel Vertex Detector



Pixel Vertex Detector (PXD)

- close to the interaction region ➡ high occupancy at SuperKEKB ➡ no strip detector possible ➡ need pixel detector
- low momentum ➡ thin silicon (low multiple scattering)

- 2 layers of silicon modules (radii 14 mm, 22 mm)
- 20 modules with 400 000 Depfet pixels each
- Depfet: Depleted p-channel Field Effect Transistor
- row-wise readout from both ends



Why Data Reduction?

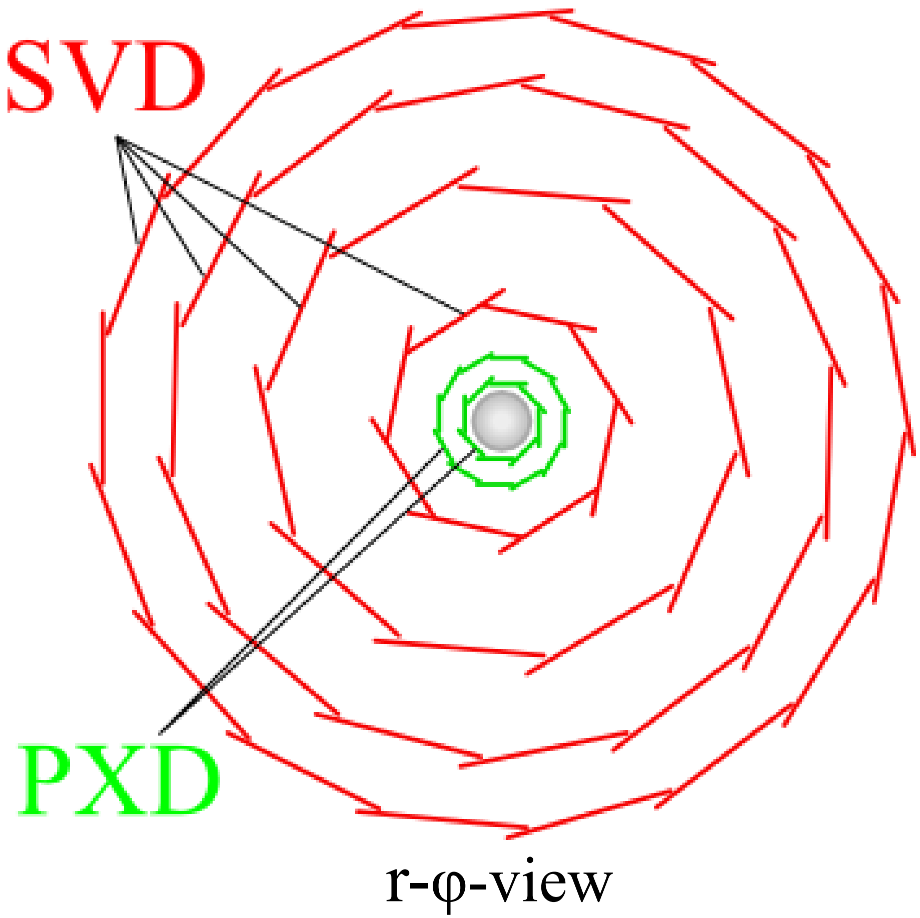
- High background environment: machine background, QED (Bhabha, 2-Photon) ➡ expected occupancy O(1%)
- Readout time 20 μs (1 event: 5000 tracks from background, only 10 physics tracks)
- Expected data rate: 1 MB / Event ➡ 25 GB / s
- Amount of data created by PXD is 10 times larger than the data collected by all other subdetectors of Belle II together
- PXD data cannot be stored on tape

➡ Online data reduction
Goal: reduction of the amount of data by a factor of 10 without losing physically relevant data

Online Data Reduction

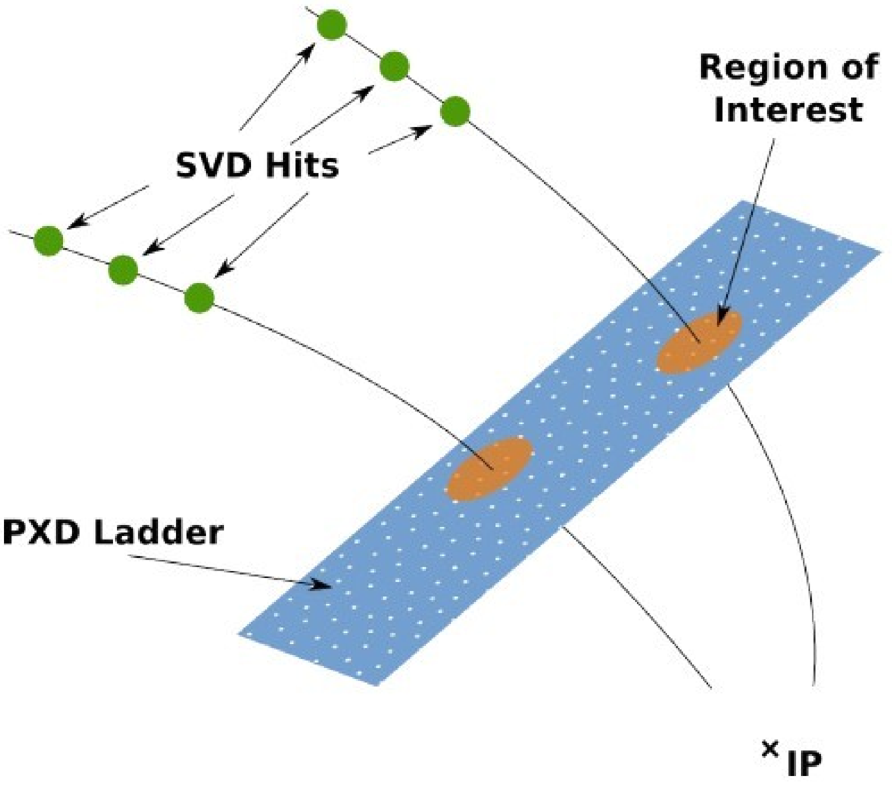
- Need fast and efficient way to reduce the data amount
- Cannot reduce data alone
- Use data from Silicon-Strip Detector (SVD)
  fast readout time (20 ns)
  SVD is clean
- 4 layers

  Radii = 38, 80, 115, 140 mm



General Idea for Data Reduction

- find all particle tracks from SVD hits (tracking)
- extrapolate the tracks into the direction of the interaction point through the PXD
- determine regions of interest (ROI) on the PXD modules from extrapolated SVD tracks
- Pixels inside the ROI's are stored



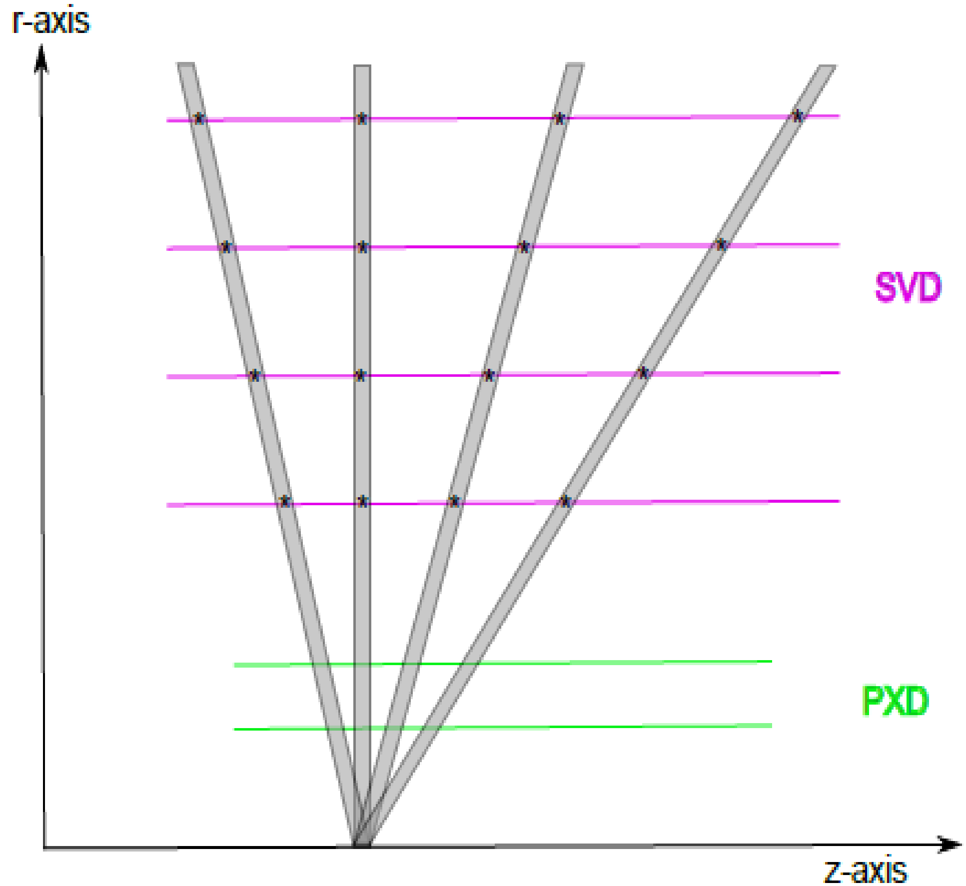
2D or 3D Track finding?

<u>3D track finding</u>

- was tried by collaborator
- efficiency of 50 % achieved not good enough

<u>2D pattern recognition</u>

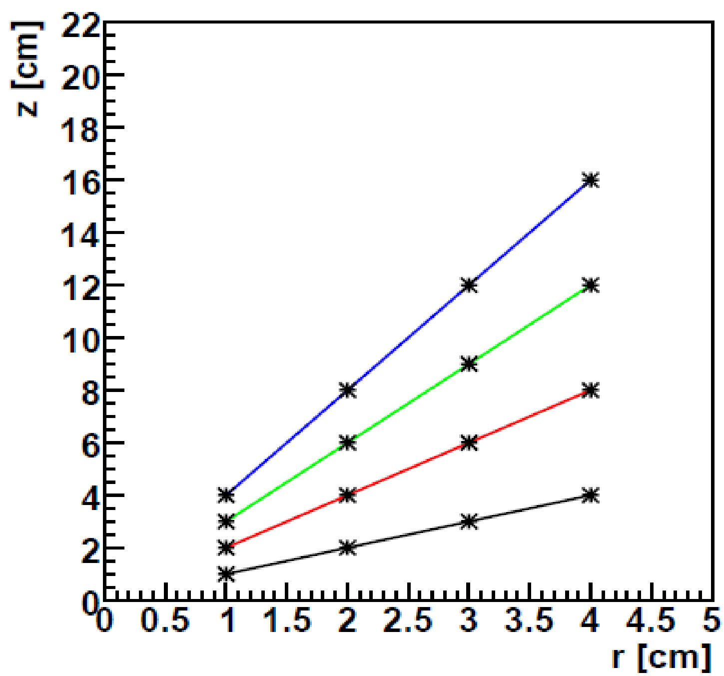
- r-z projection: sine curve
- approximation by a straight line for high p_T (p_T > 150 MeV)



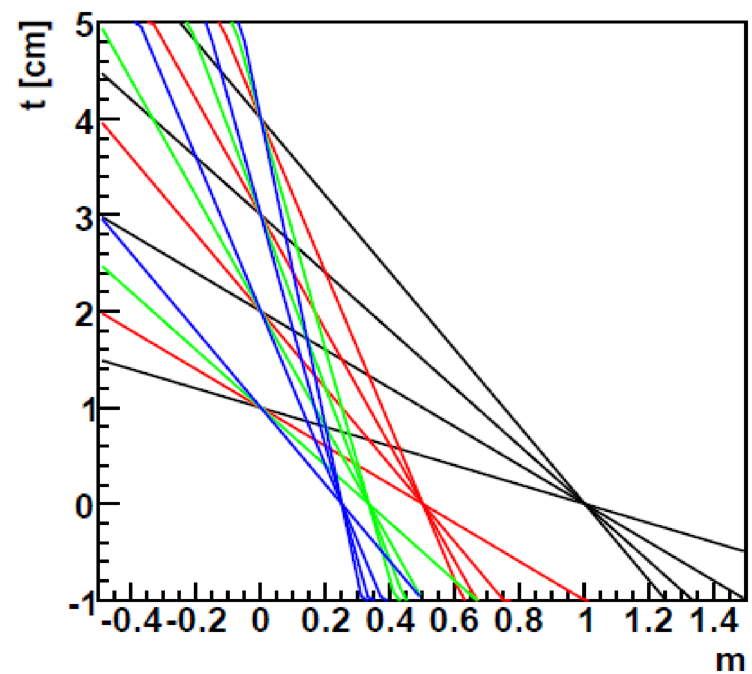
Track Finding: Hough Transform

- transformation into a 2D parameter space (Hough space)
- example: straight line $z = mr + t \longrightarrow t = z - mr$
- SVD hits are Hough transformed $\longrightarrow$ straight line for each hit
- intersections in Hough space correspond to parameters of the tracks
- algorithmic challenge: find intersections in Hough space

Image space

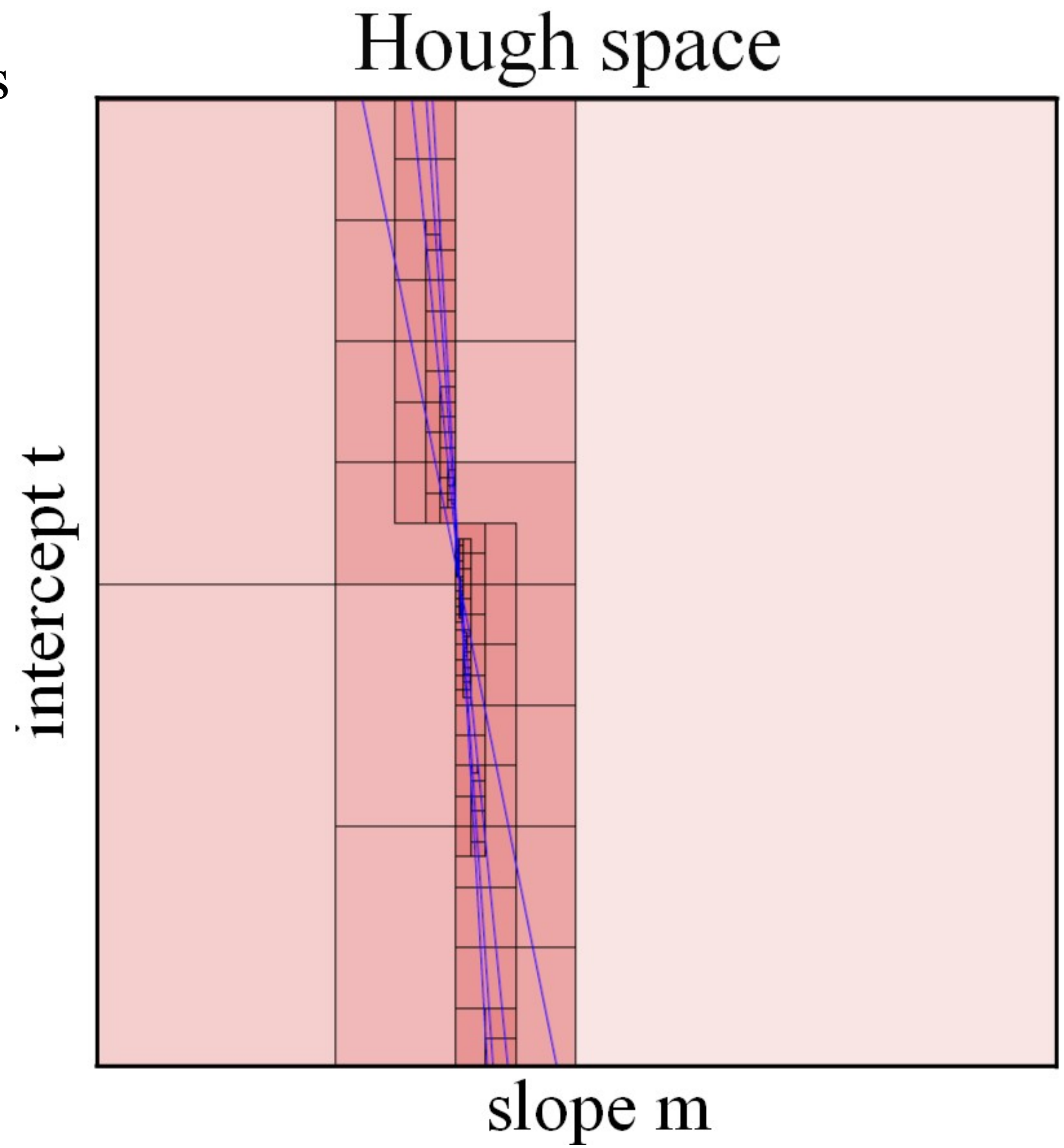


Hough space



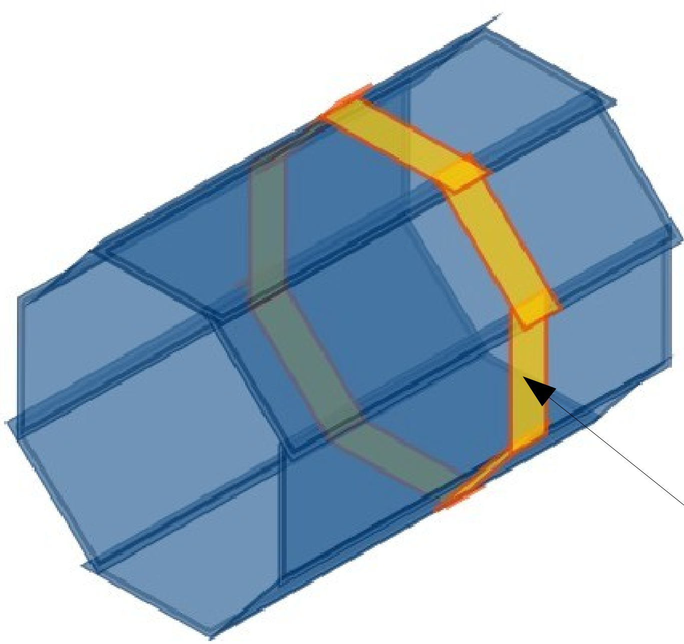
Find Intersections in Hough Space

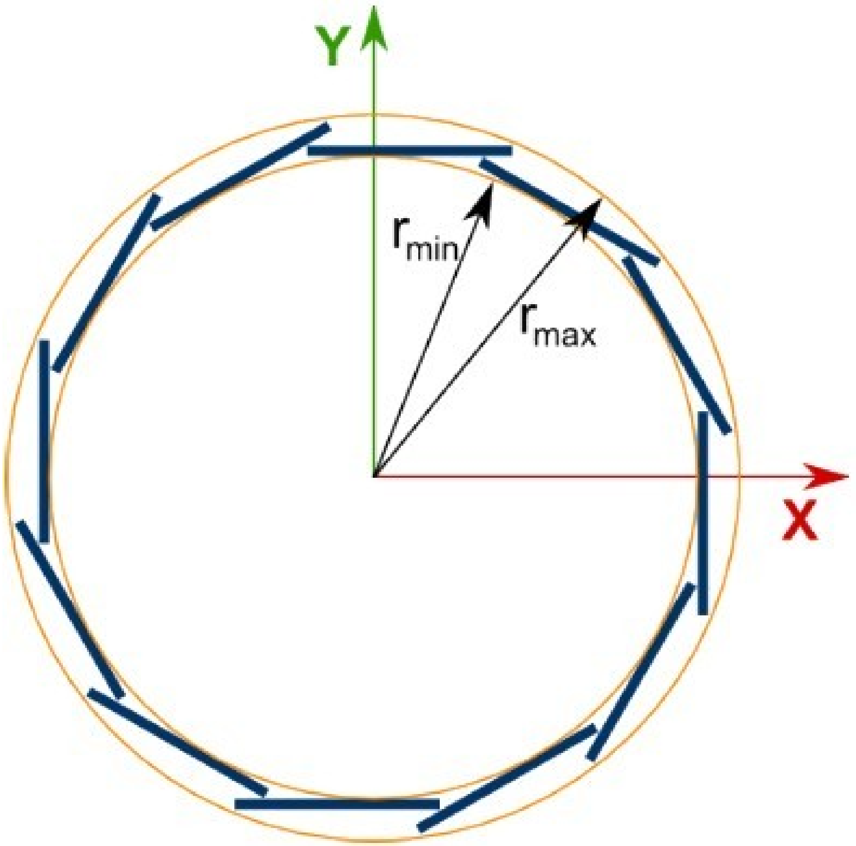
- division of the Hough space axes by 2 and thus subdivision into 4 rectangles
- calculate the number of lines in each rectangle
- keep only rectangles containing at least 3 lines
- repeat steps with remaining rectangles
- take parameter values in the middle of the remaining rectangles
- back transformation



Back Transformation

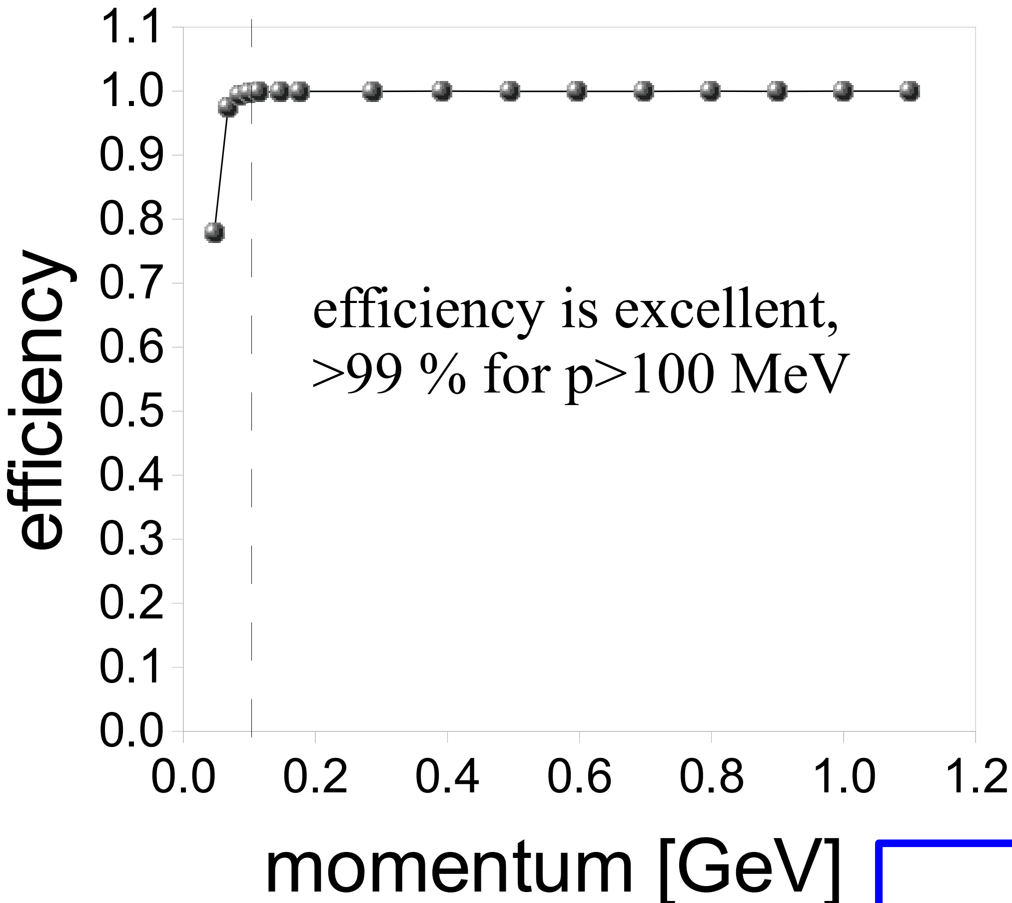
- $z = mr + t$
- Range of r [r_{min}, r_{max}]
- Calculate z_{min}, z_{max}
- Ring shaped areas on the PXD





areas are quite big

Efficiency of the Data Reduction



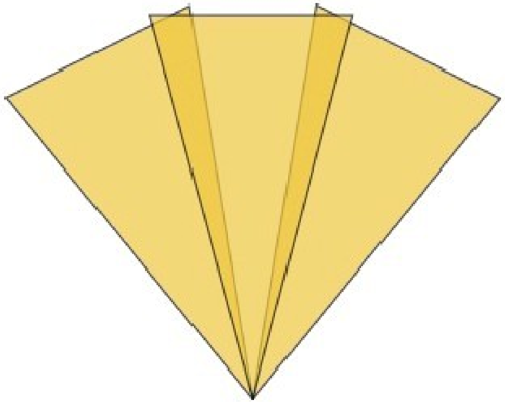
Test with single muons shot from the origin into the detector

Reduction factor below 2!

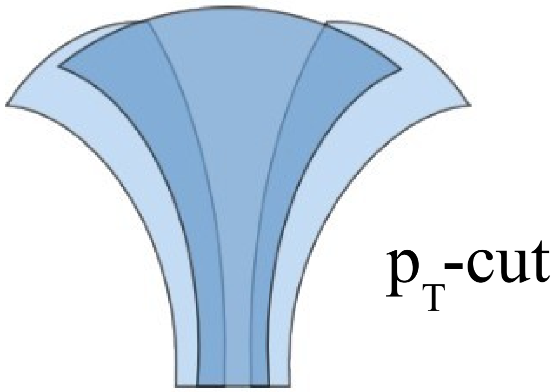
<u>Subdivision into sectors in azimuth (rφ)</u>
fast parallel computation

Sectors in r-φ

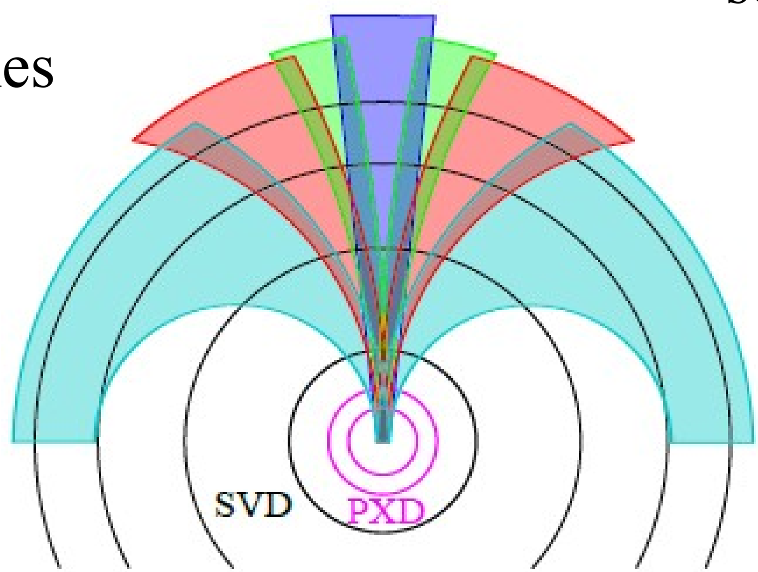
Differently shaped sectors for different transverse momenta of the particles



high transverse momentum
p_T >150 MeV
search for straight lines

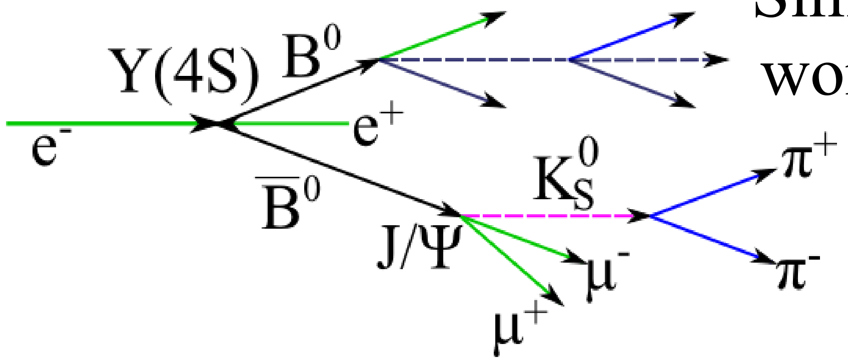


low transverse momentum
search for sine curves

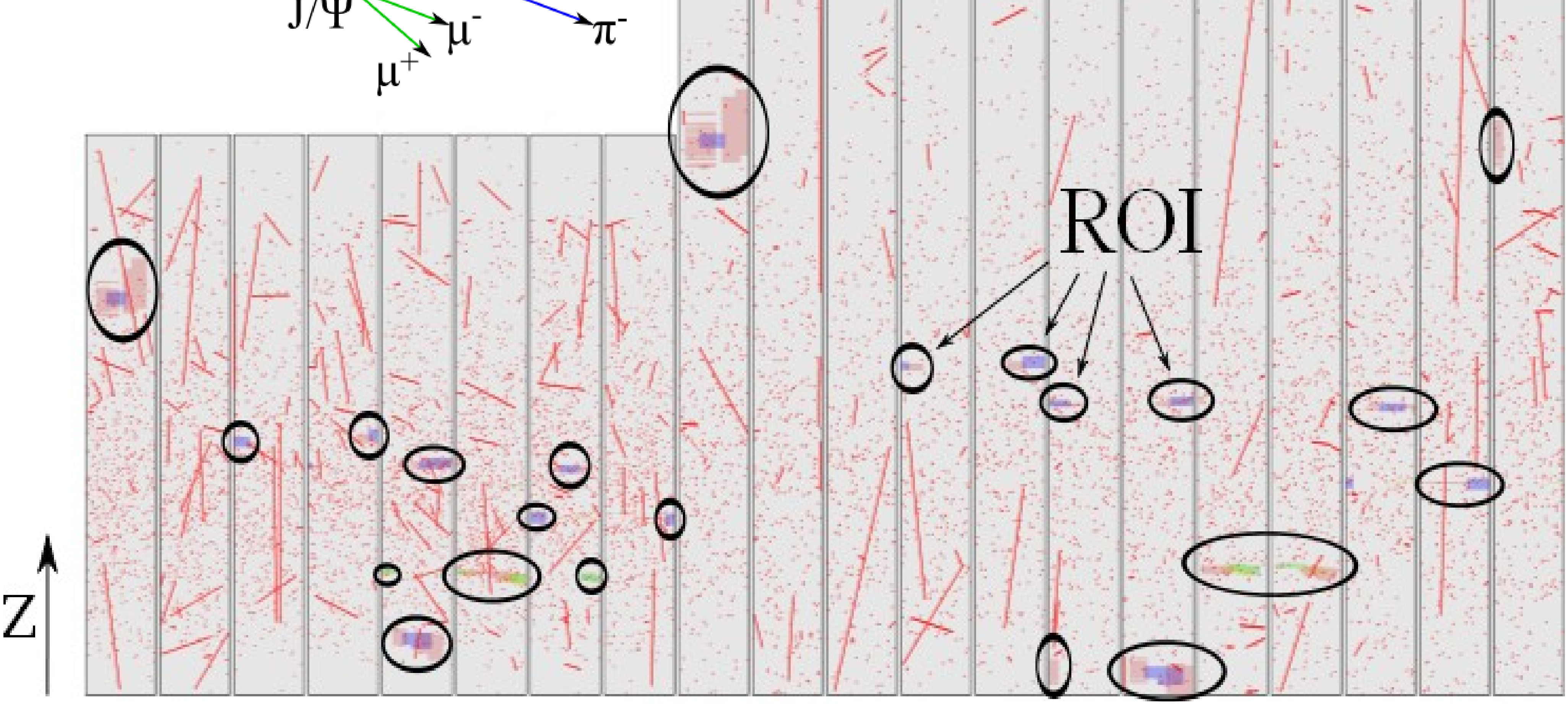


Rotation of the sectors to cover the complete φ-range with overlap

Test of the Data Reduction



Simulation of a typical event with background, worst case scenario (5000 background tracks)

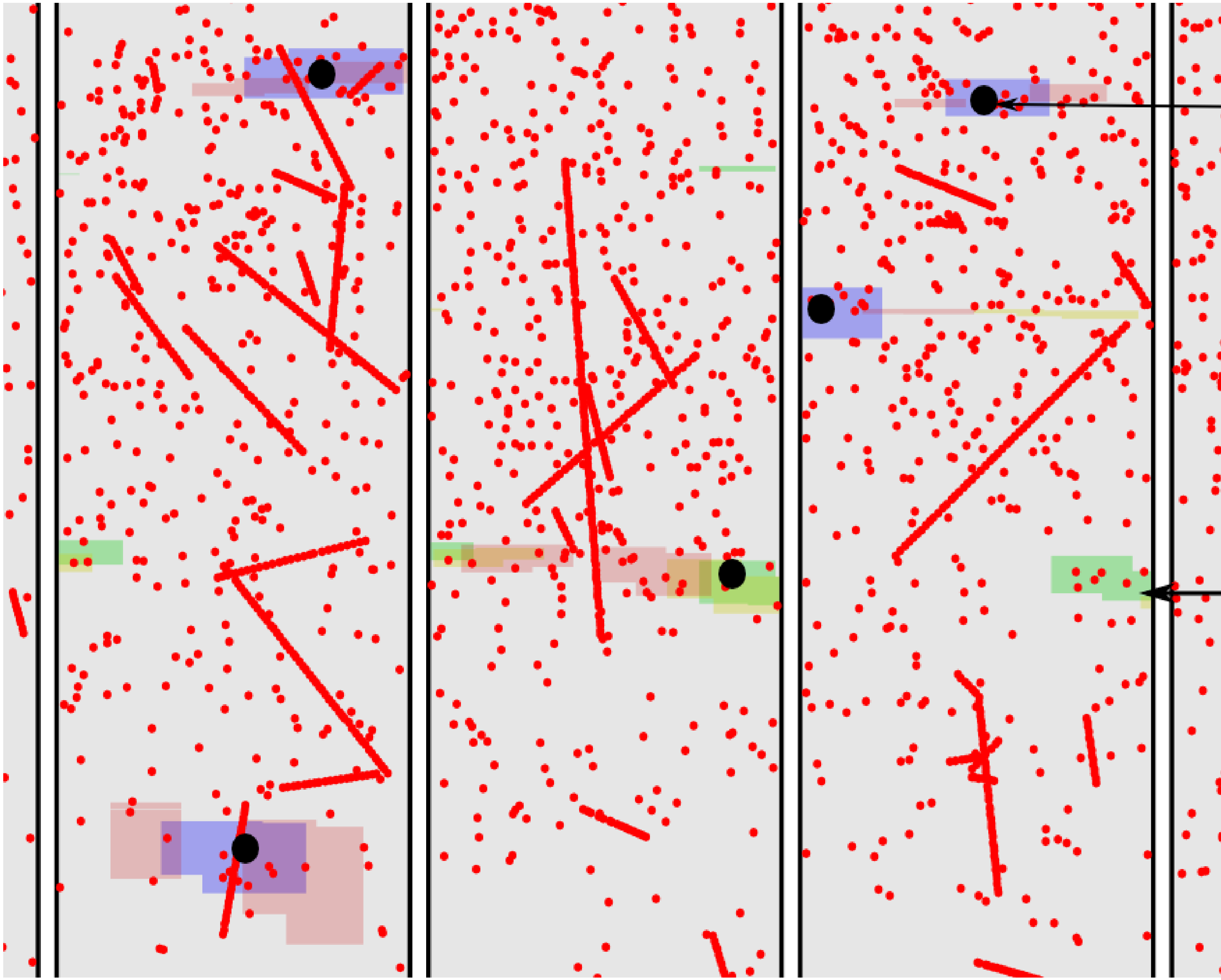


8 inner layer modules

12 outer layer modules

Reduction factor of 13 achieved

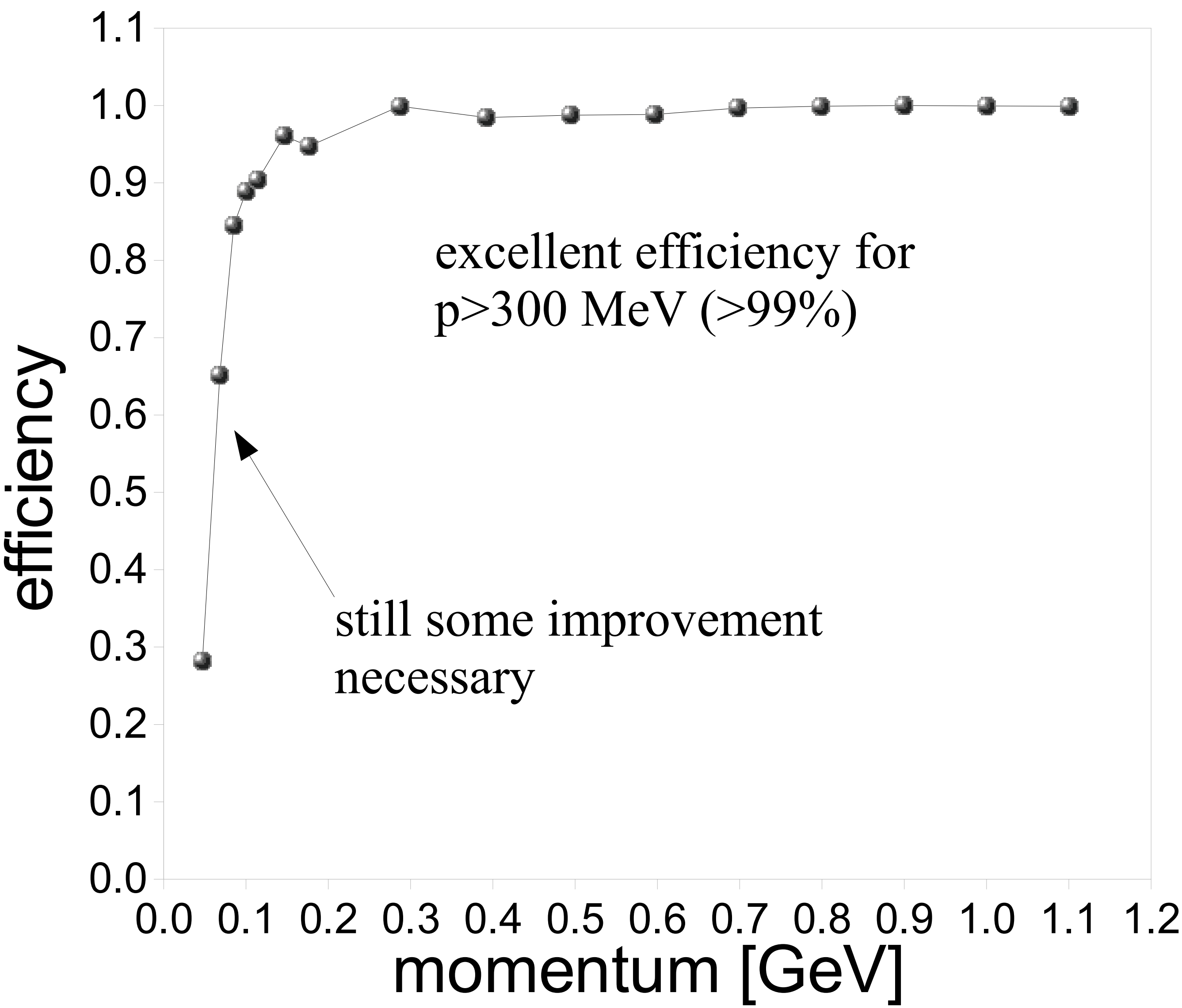
Test of the Data Reduction: Zoom



real PXD Hit

small number of additional ROI's generated by ghost tracks

Efficiency of the Data Reduction with Sectors



test with single muons shot from the origin into the detector

average reduction factor of 10 achieved

Conclusion and Outlook

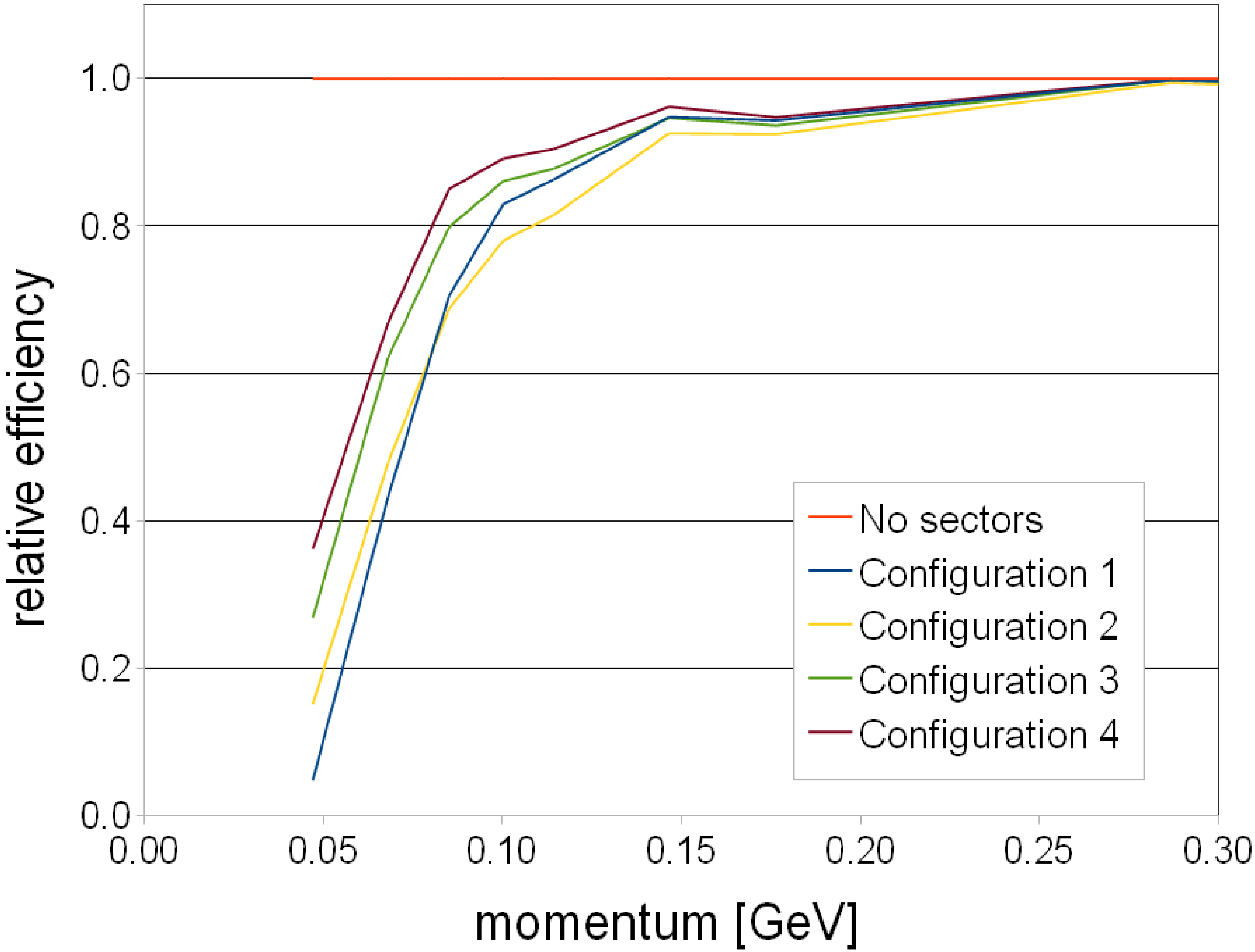
- Tests with physics background look very promising
- Efficiency of 99 % down to 300 MeV
- Average data reduction of factor 10 achieved

Next Steps:

- Improve the efficiency for low momenta
- Find optimal sector configuration
- Hardware implementation (FPGA) by collaborators to check for sufficient speed (<20 μs required)

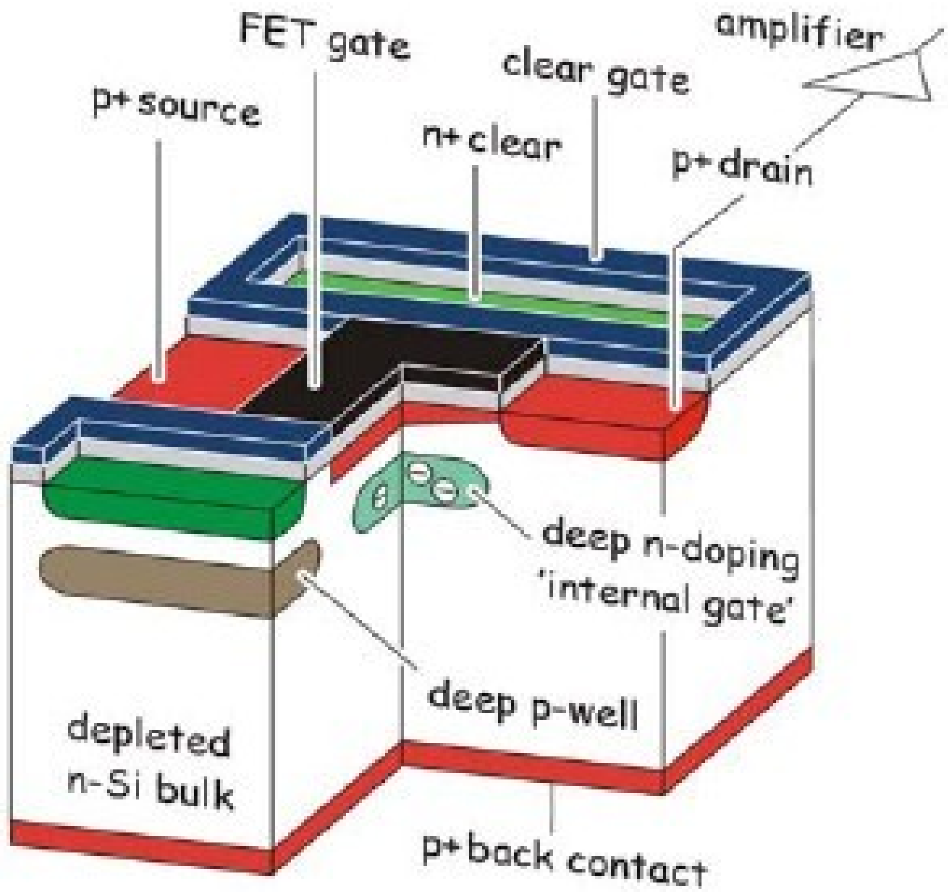
Backup

Efficiency progress



Efficiency of different sector configurations relative to the efficiency without sectors

Schematic of the Depfet Pixel

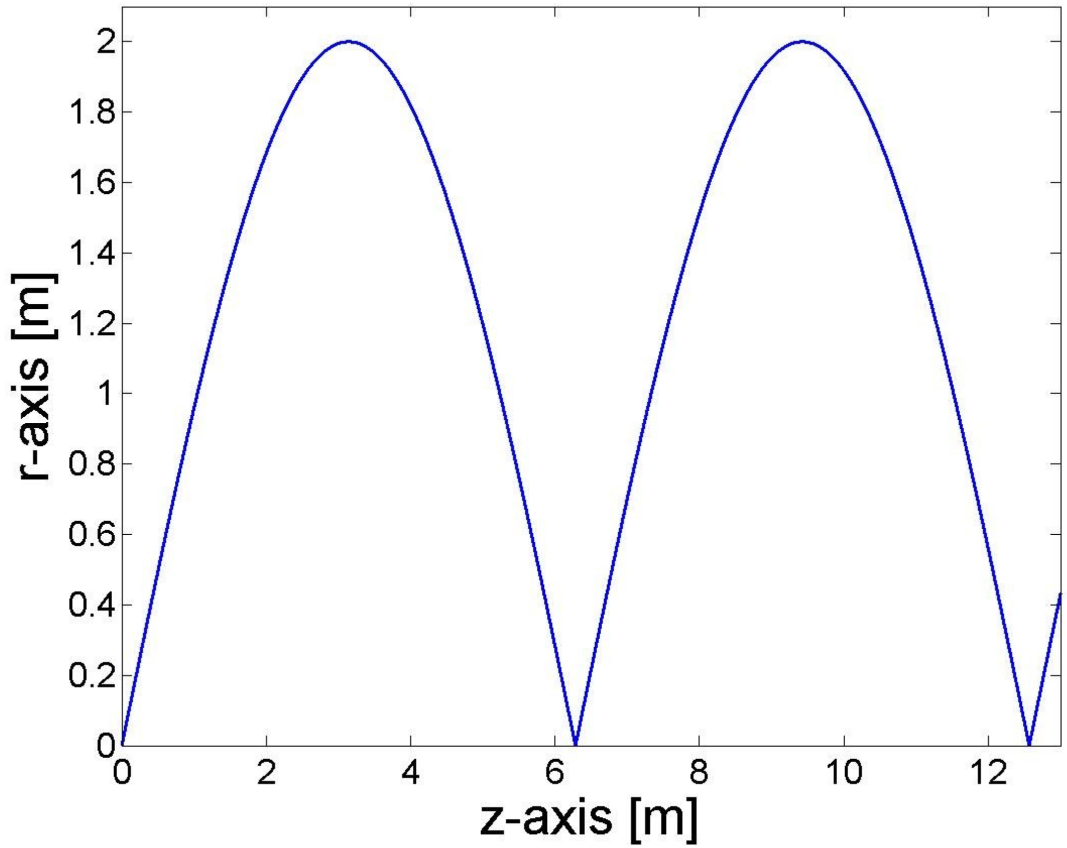


2D Projection

r-z-projection of a helix going through the origin:

$$r = \left| \frac{1}{b} \sin(az) \right|$$

$$a = \frac{qB}{2\mathrm{p}_L} \qquad b = \frac{qB}{2\mathrm{p}_T} = \frac{1}{2\mathrm{R}}$$



magnetic field
B=1.5T

particle charge q