Optimization studies of the Pixel Vertex Detector (PXD)

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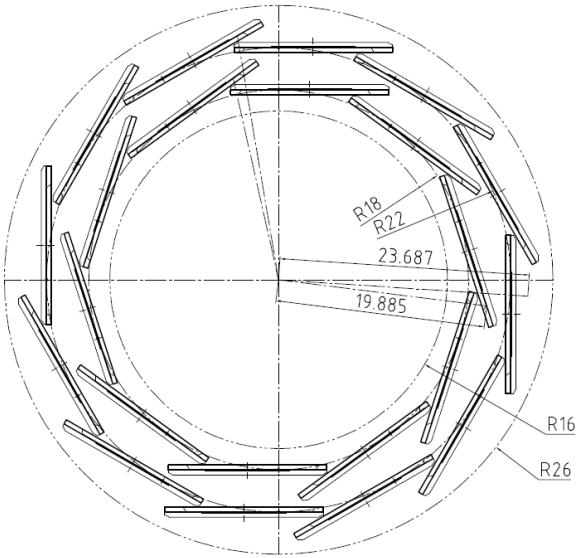
Overview

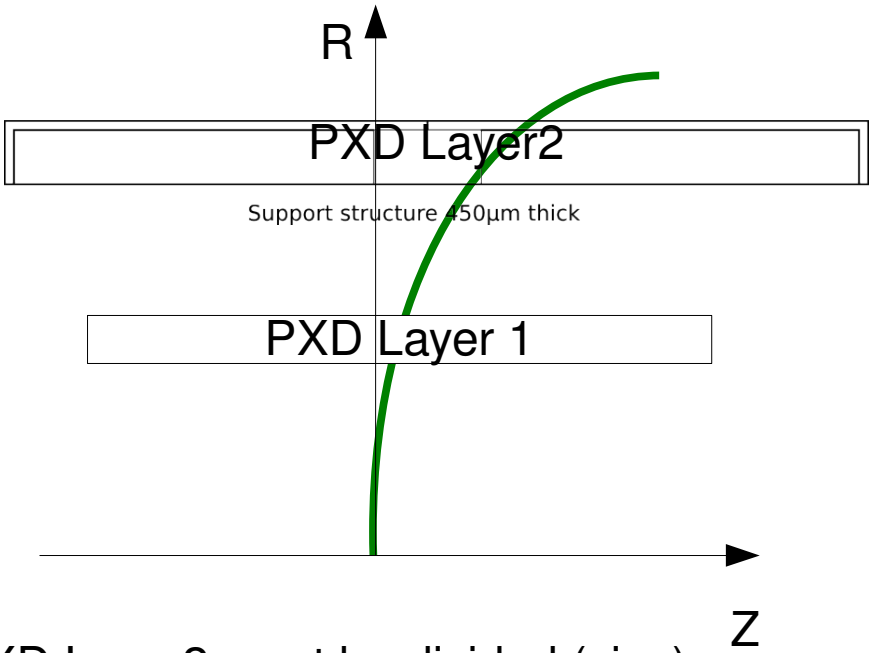
- Motivation for Optimization studies
- Simulation framework (ILC)
- Results on pixel arrangements
- Comparison of PXD Geometries for Highcurrent and Nanobeam options
- Summary

Aim of studies

- PXD Optimization for best physics performance
- Parameters to be varied
  - Beampipe radius (Nanobeam / Highcurrent option)
  - Pixel size (pitch) (10 or 20µs readout)
  - Pixel shape: constant pixel size (CPS), variable pixel size (VPS), bricked pixels (BP)
  - Material budget
    - Beampipe (influence of gold layer)
    - Thickness of active material (PXD sensors) [to be done]
- Studies in two frameworks (full / fast simulation)

PXD Geometry





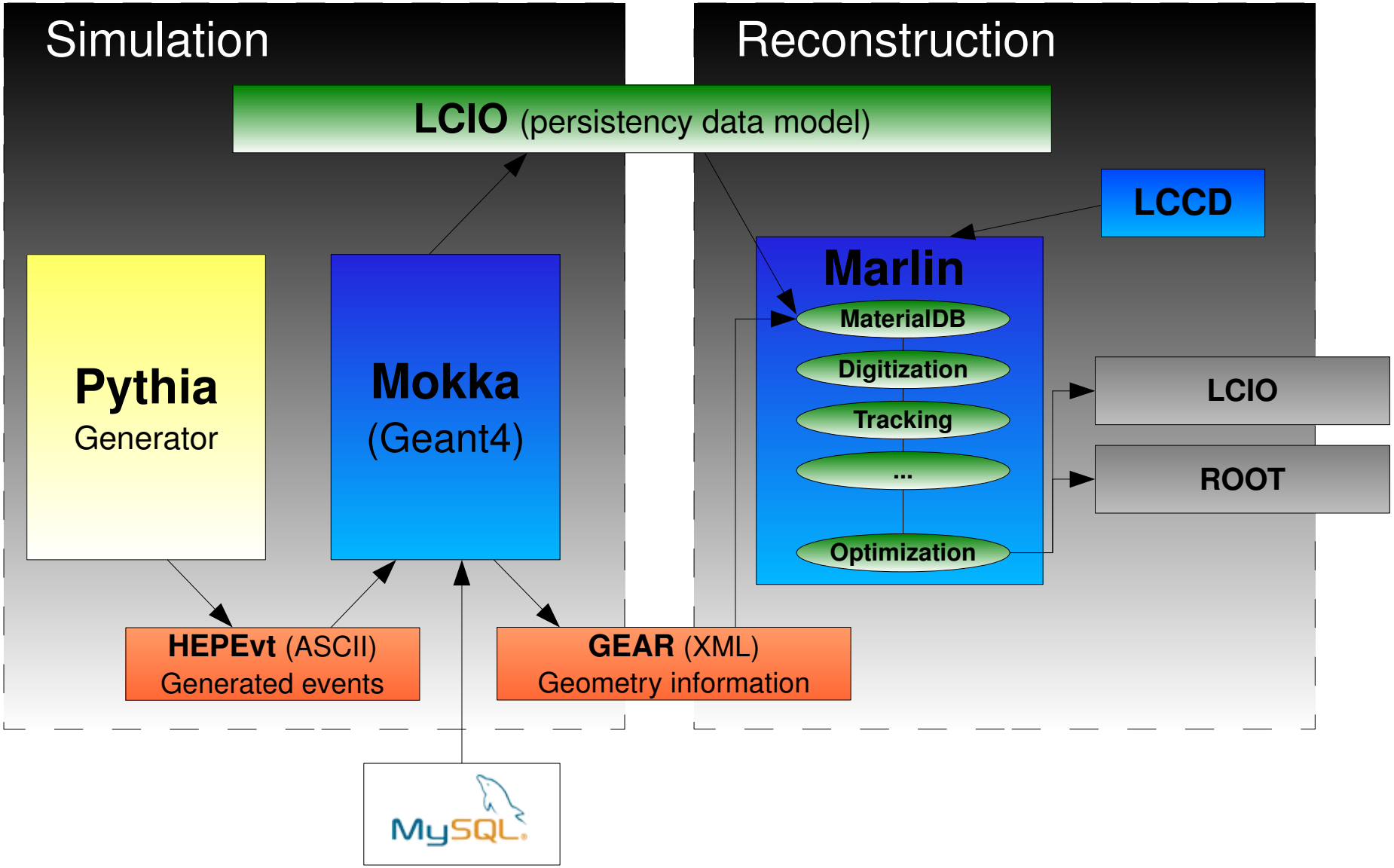
Windmill structure
Support structure challenging
(see talk Frank Simon)

PXD Layer2 must be divided (size)
Idea to divide PXD Layer1 (ground loops)

High current	R [mm]	ladders	support
PXD 1	18	10	no
PXD 2	22	12	yes

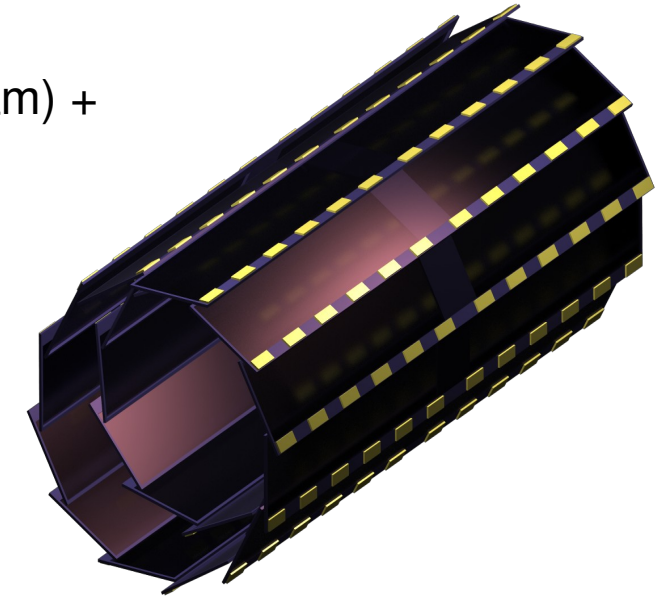
Nano beam	R [mm]	ladders	support
PXD 1	13	8	no/yes
PXD 2	22	12	yes

The ILC Framework



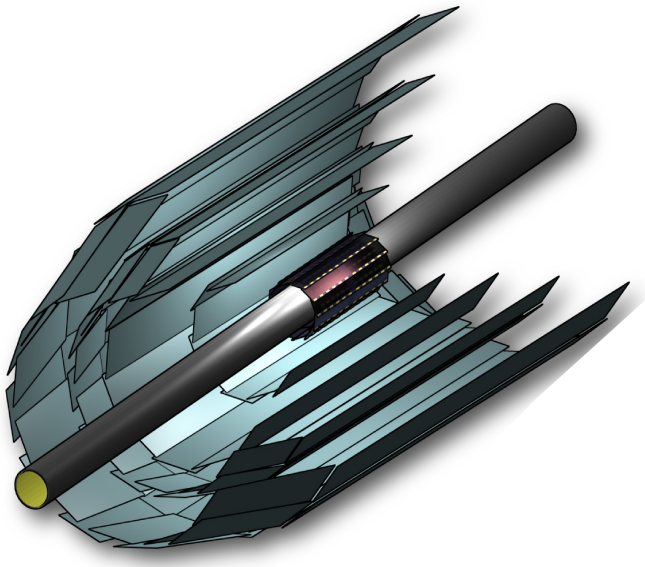
Mokka – Belle II Geometry - 1

- Mokka model: ***complete Belle II Tracker*** (beam pipe + PXD + SVD + CDC)
  - ***Beam pipe:*** cylindrical onion-like structure
    - inner golden layer + inner Be wall + cooling gap (paraffin) + outer Be wall
  - ***PXD:*** 2 layers of Si pixel detectors – DEPFETs
    - active part: layers → ladders → Si sensors (50µm)
    - passive part: Si rims (450µm) + 12 switchers (300µm) + Si support bridge @ 2nd layer (400 µm)



Mokka – Belle II Geometry - 2

- ***SVD:*** 4 layers of Si strip detectors (DSSDs) in barrel part
  - organized in stagger-like structure
  - active part: layers → ladders → Si sensors (300µm)



- ***CDC:*** Al cylinder with cone-shaped inner parts (as Belle)
  - active medium: gas He/C_2H_6 (50:50)
  - uses Gaussian smearing as digitization
  - geometry as of December 2008

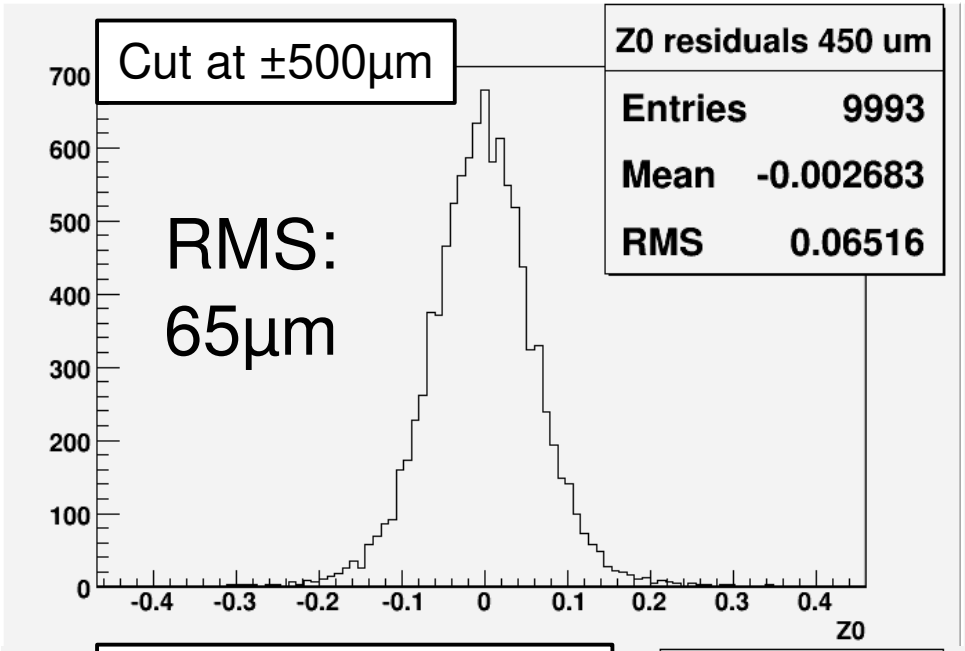
MarlinReco – Digitization for Belle II

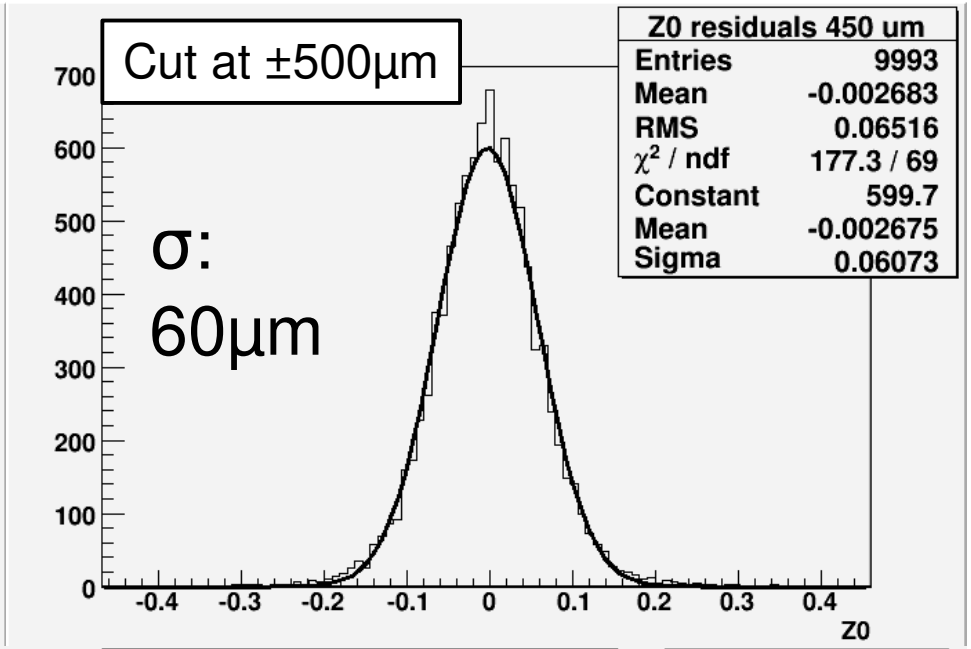
- Chain of Marlin reconstruction tools:
  - ***MaterialDB:*** (defines all materials – required by Kalman filter in the tracking code)
  - ***PXDDigitizer:*** (detailed PXD digitizer – both CPS & VPS options possible)
  - ***SiStripDigi:***
    - implemented (→ Zbynek Drasal)
  - ***CDCDigitizer:*** (digitizes data from central drift chamber)
    - simple gaussian smearing

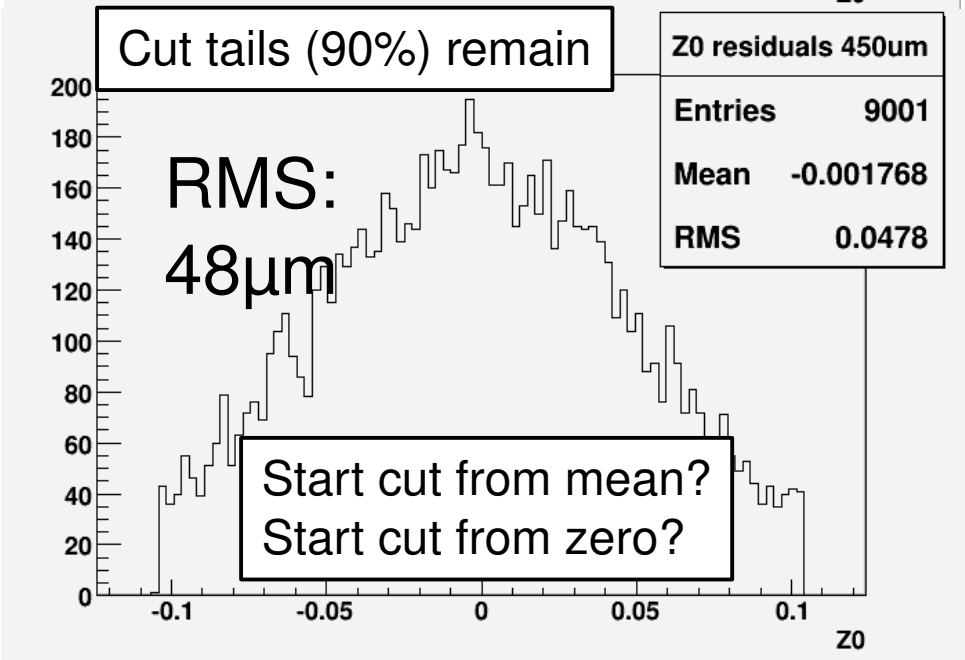
Details of simulation and reconstruction

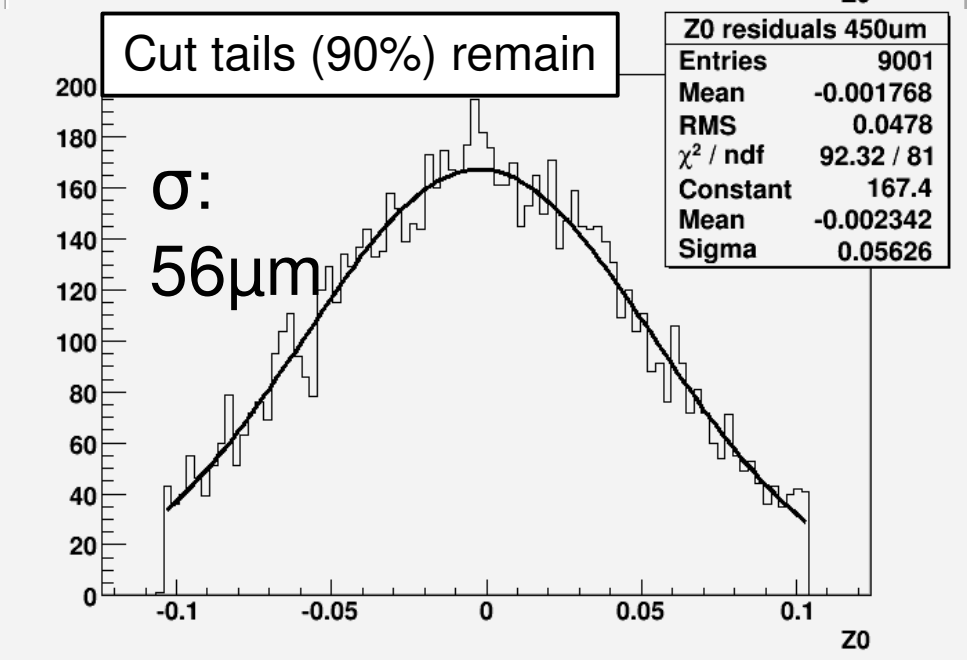
- particle gun: muons from origin
  - phi ∈ [0°,360°[
  - theta: 20°, 40°, 60°, 80°
  - energies: 0.1, 0.2, 0.4, 0.6, 1.0, 1.5, 2.0 GeV
- Stand alone tracking in PXD and SVD
- Stand alone tracking in CDC
- Refit of CDC and SVD/PXD tracks
- Detailed simulation including realistic PXD/SVD and material budget!

4 Procedures to obtain the resolution

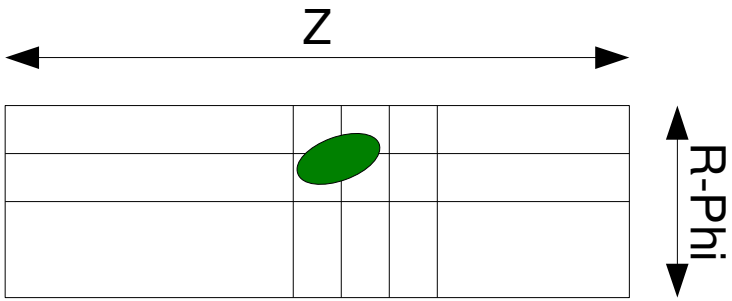








Data analysis for the spatial resolution



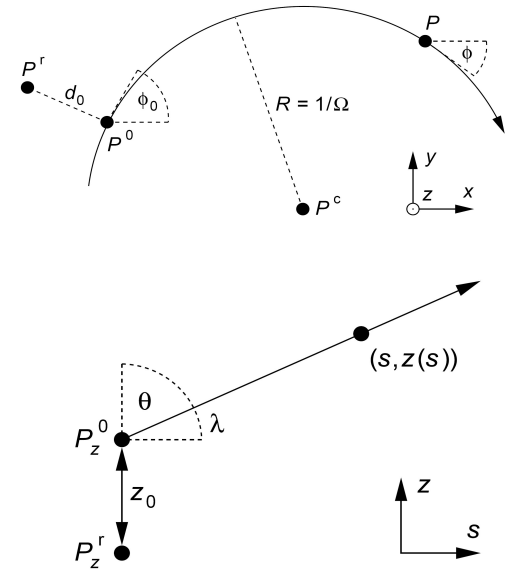
Clustering based on Center of Gravity algorithm
→ see talk Z.Drasal at last B2GM

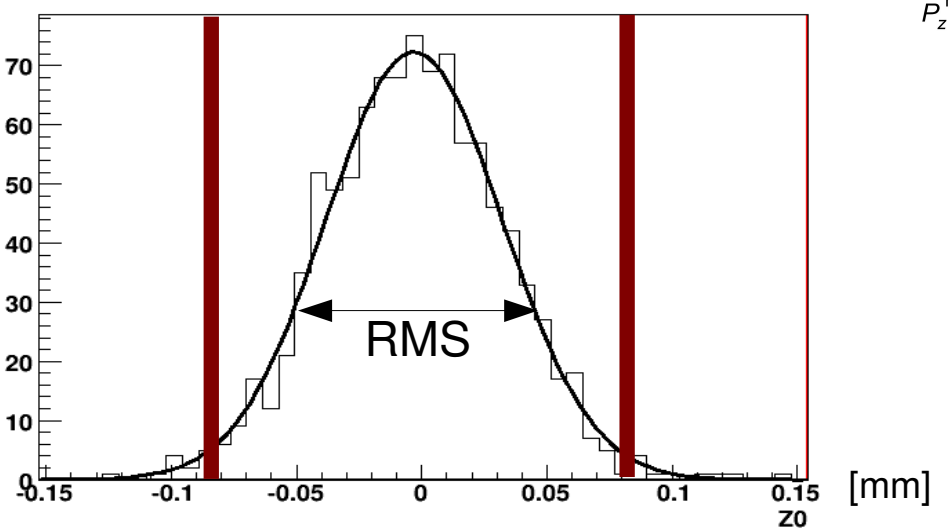
Residual plot is created (Monte-Carlo hit – reconstructed hit)

RMS of the residuals is used as the spatial resolution (pessimistic case)

Data analysis for Impact parameter resolution

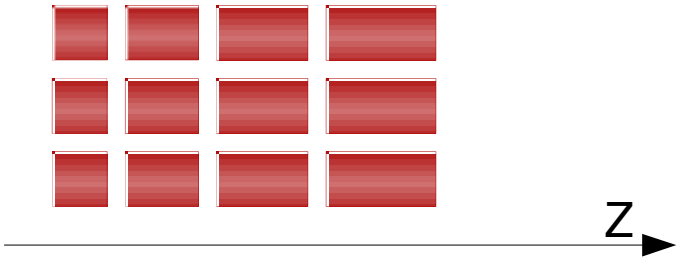
- Histogram of the D0 and Z0 Track parameters
  - D0: distance of closest approach in R-Phi
  - Z0: distance to point of closest approach in Z
- using **RMS 90** as a measure for the Impact Parameter Resolution (optimistic)



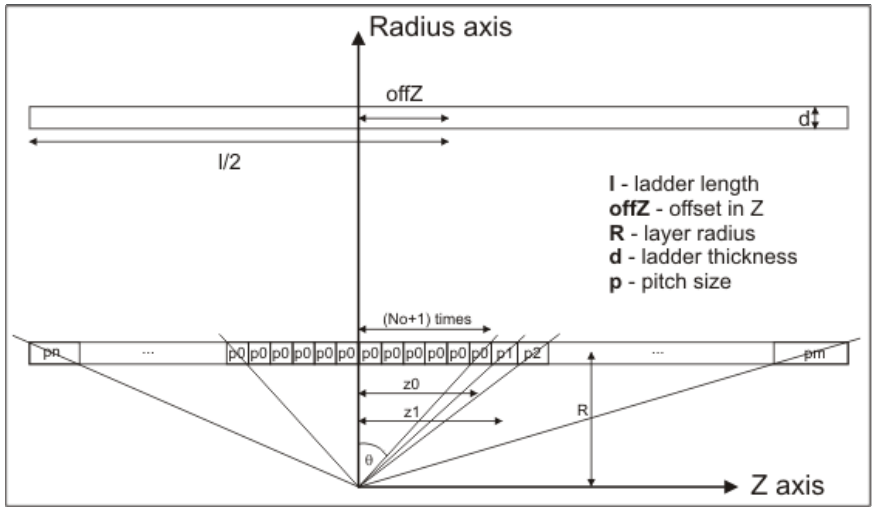


Variations of the pixel layout

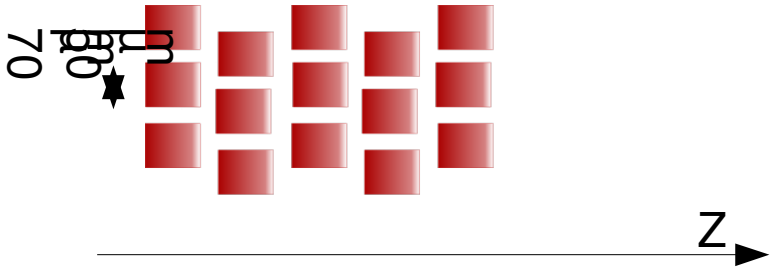
- Variable pixel size



- Idea: partition the PXD in steps of equal solid angle



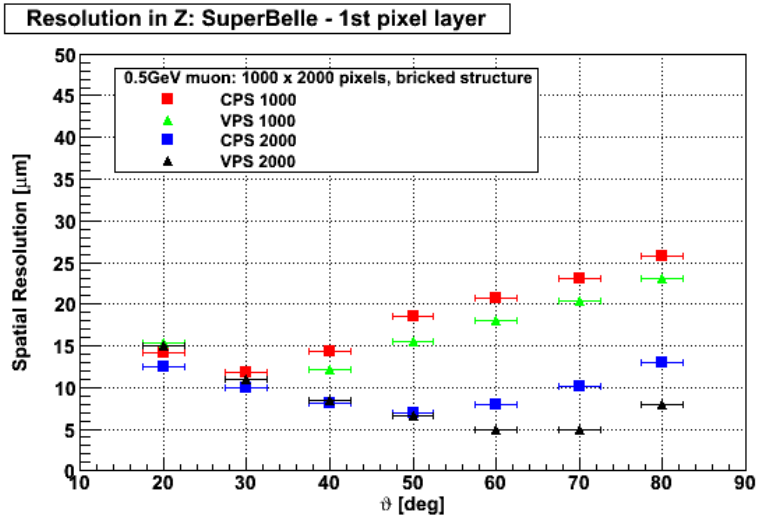
- Bricked pixel structure

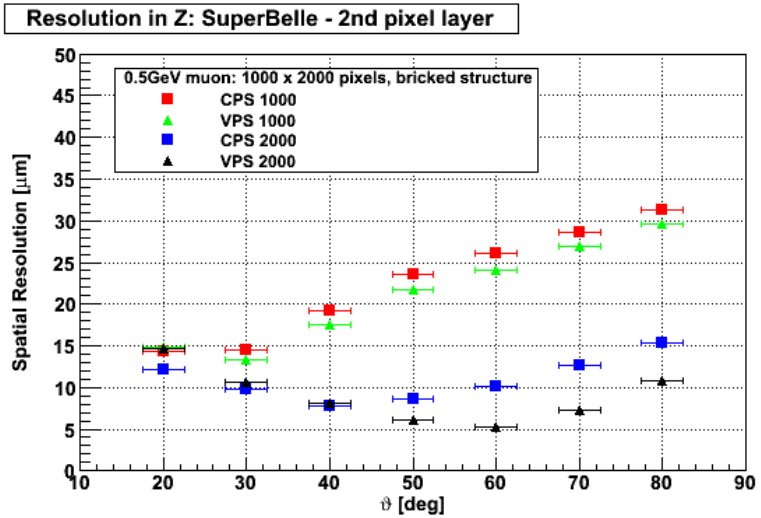


- Improvement in r-phi with minimal additional work
- Bricked structure only in R-Phi direction possible (readout lines)
- 50µm unbricked option (baseline)
- 70µm in max. for bricked option

VPS and CPS resolutions in Z

Configuration	R [mm]	L [mm]	P0 [µm]	Pn [µm]	Pm [µm]
CPS2000 l1	18	98	49.0	49.0	49.0
CPS2000 l2	22	117.4	58.7	58.7	58.7
VPS2000 l1	18	98	21.9	93.9	177.2
VPS2000 l2	22	117.4	35.6	91.9	174.0

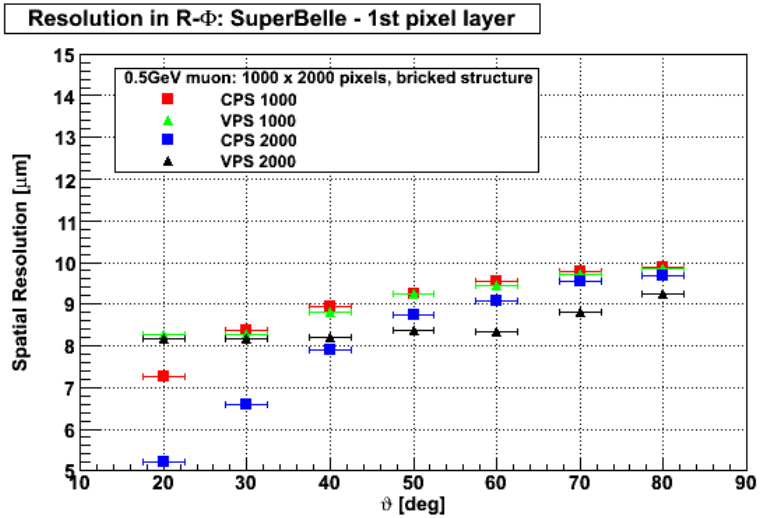


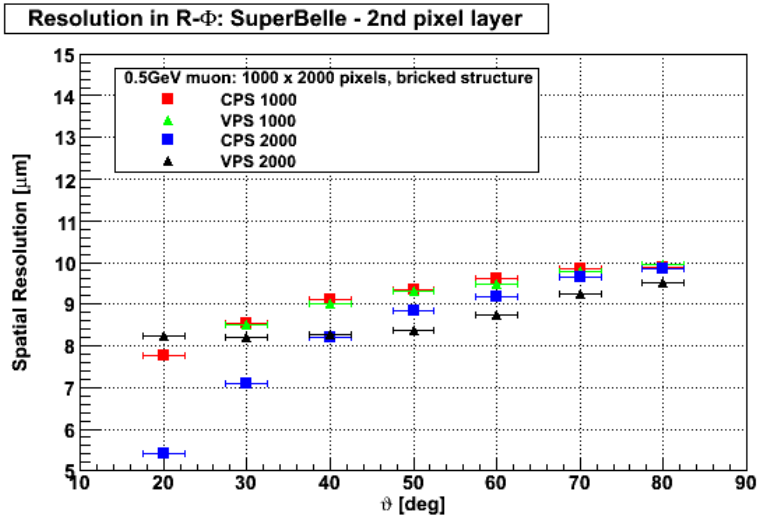


Effect of VPS (1st layer) starts at:

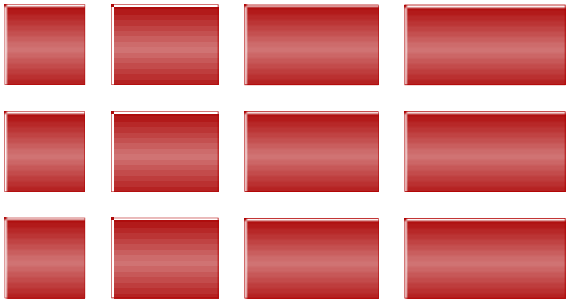
- 1600: $\theta = 52.6°$
- 2000: $\theta = 66.3°$
- for 2nd layer even smaller angles

VPS and CPS resolutions in R-phi





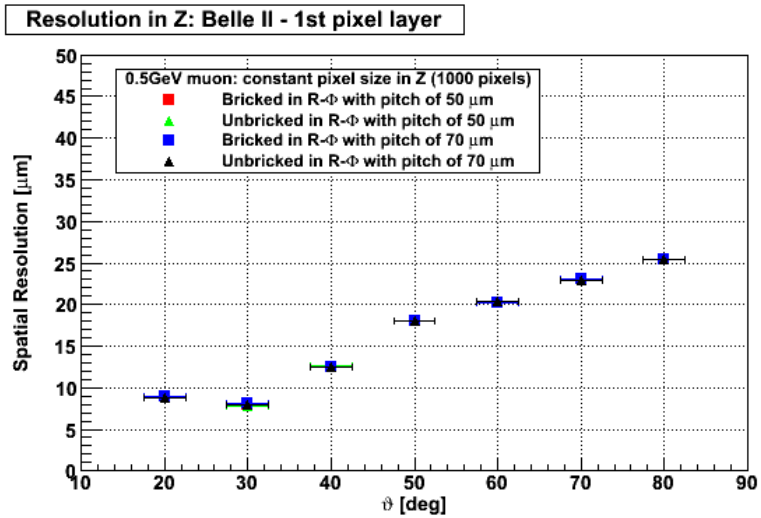
VPS or CPS

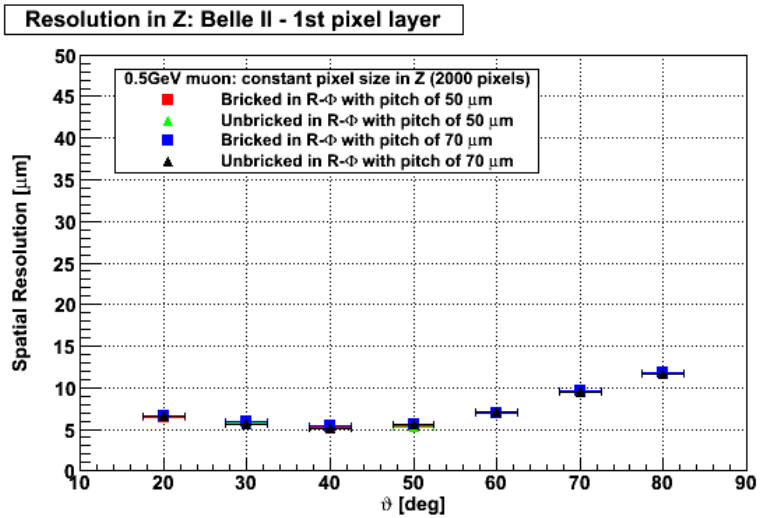


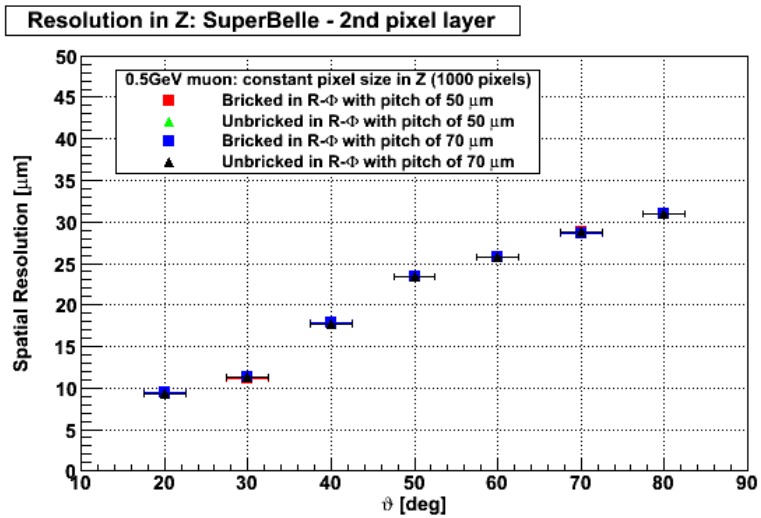
- VPS Z resolution better for $\theta > 50°$
- CPS R-Phi resolution better for $\theta < 40°$

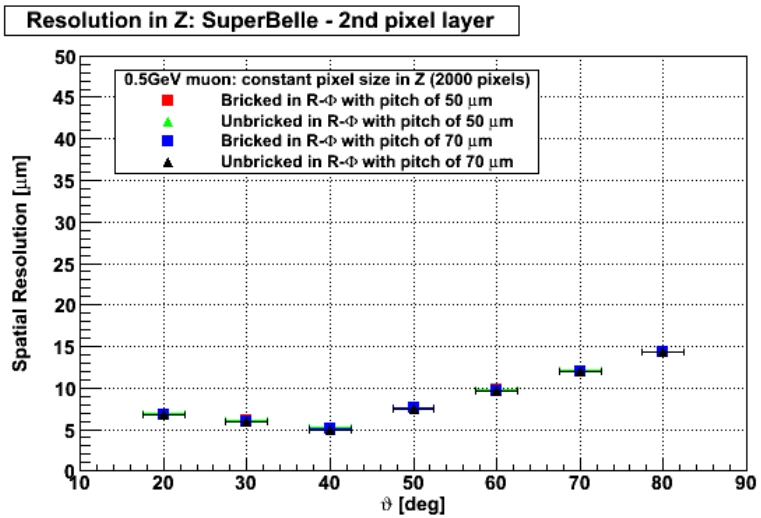
- Technical challenges
  - Pixel size can only be varied in steps of 4 pixels
  - Pixels bigger than 150µm have long drift times
- Constant pixel size is the favored option

Bricked Pixels (BP) spatial resolution in Z

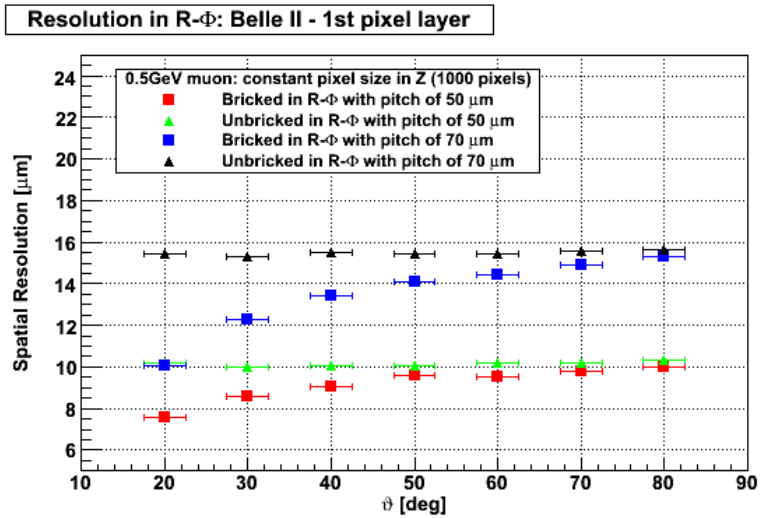


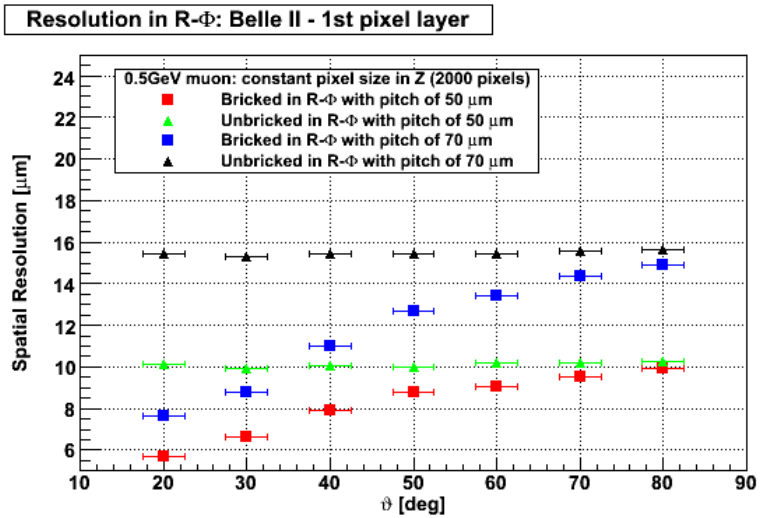


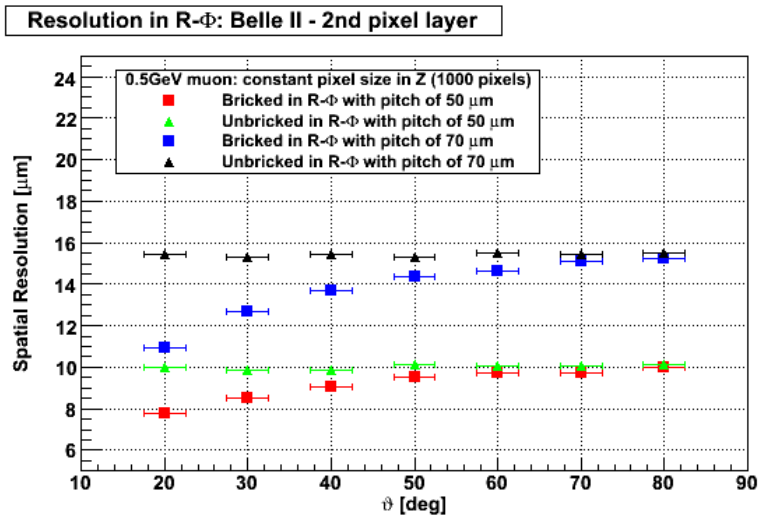


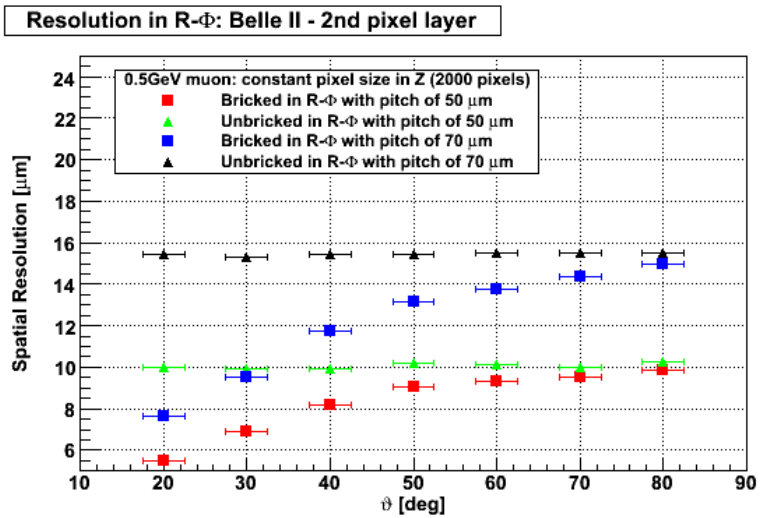


Bricked Pixels (BP) spatial resolution in R-phi

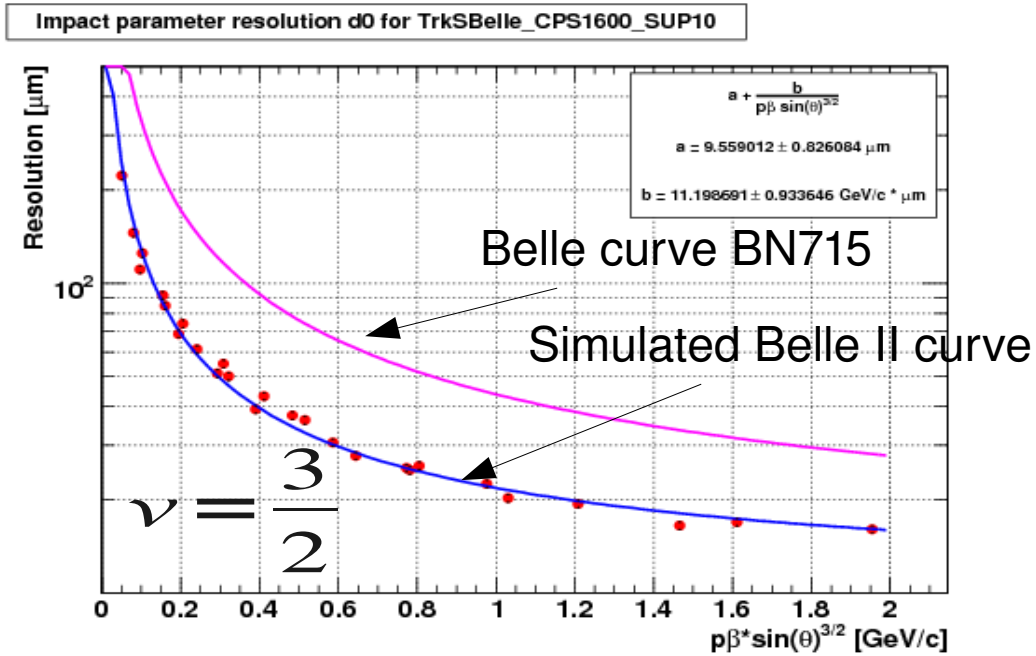


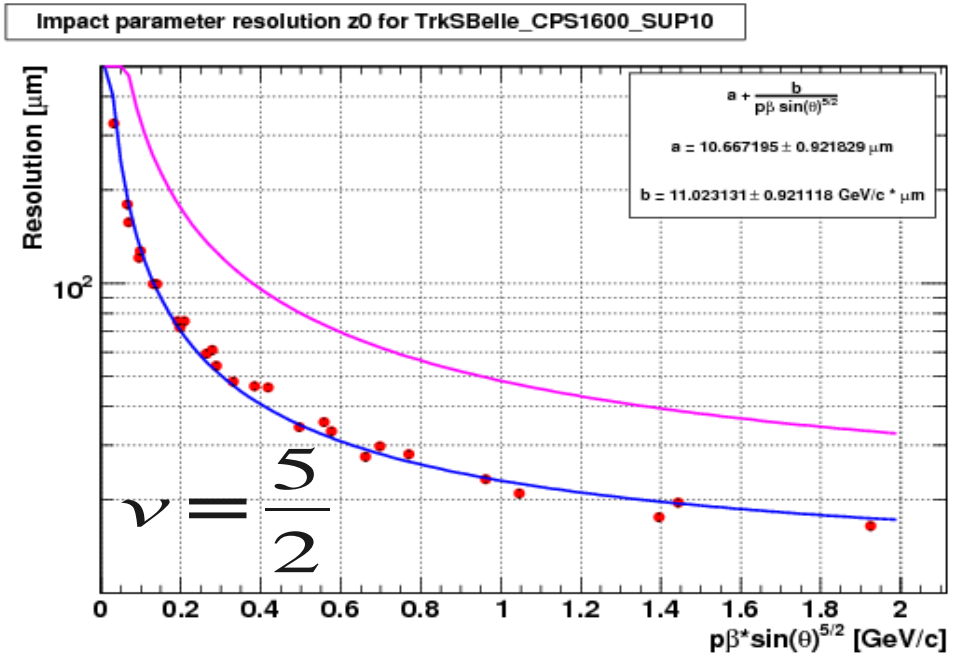






Impact parameter resolution using the 1600 pixel Highcurrent model



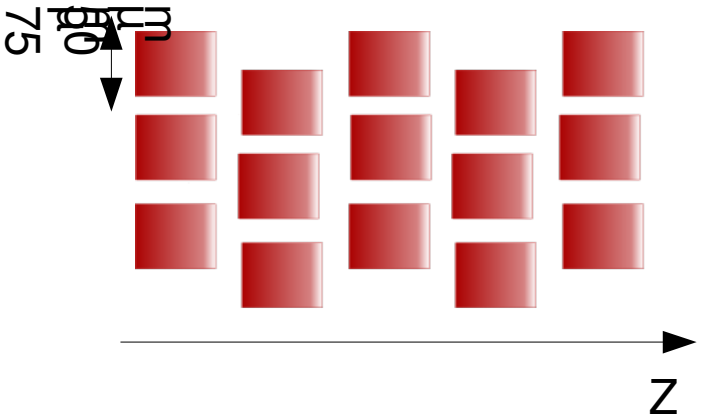


Fitting curve with multiple scattering formula

$$a + \frac{b}{p\beta \cdot \sin(\theta)^{\frac{5}{2}}}$$

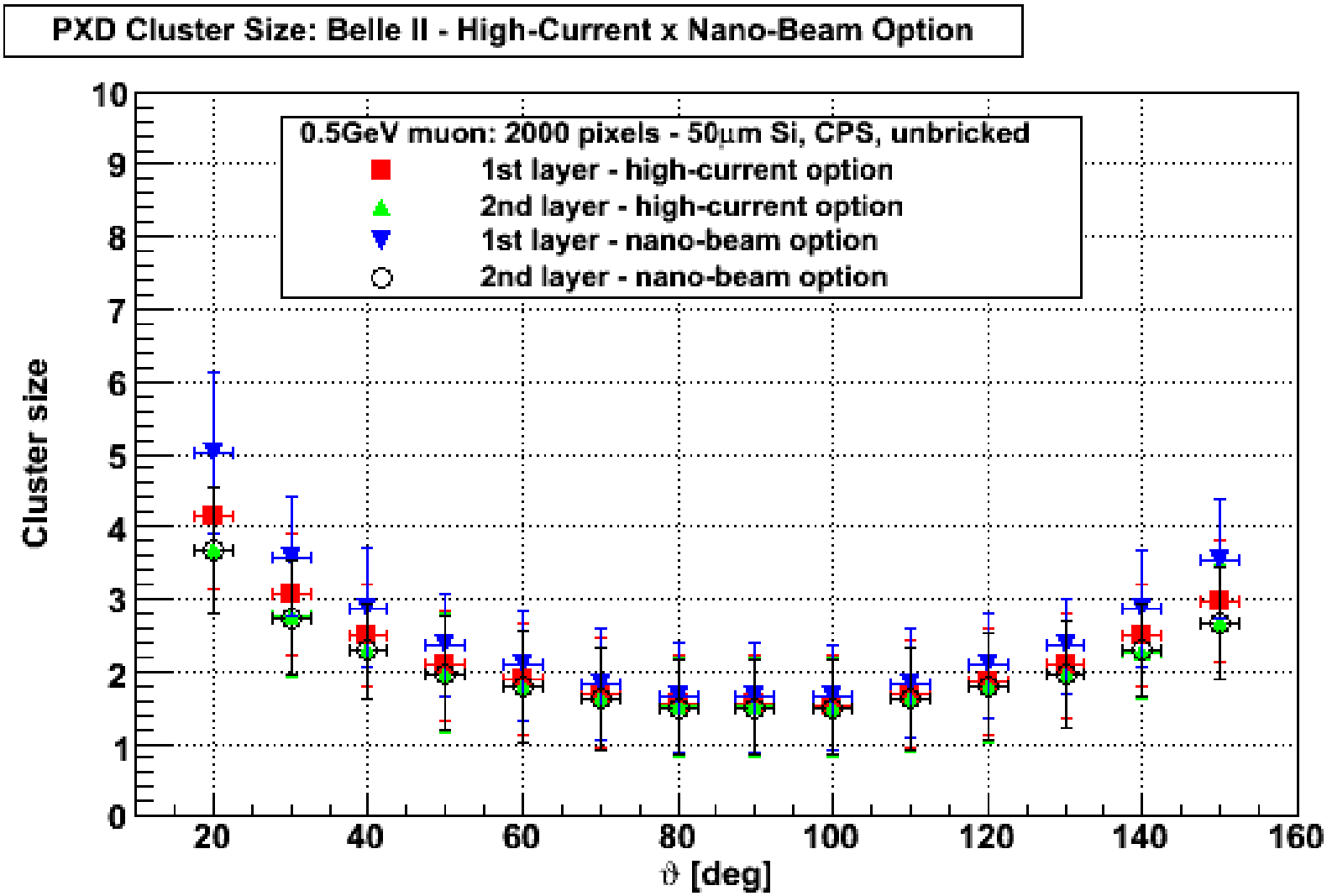
Parameter a: mostly geometry, pixel sizes …
Parameter b: mostly material budget

Bricked Pixels discussion

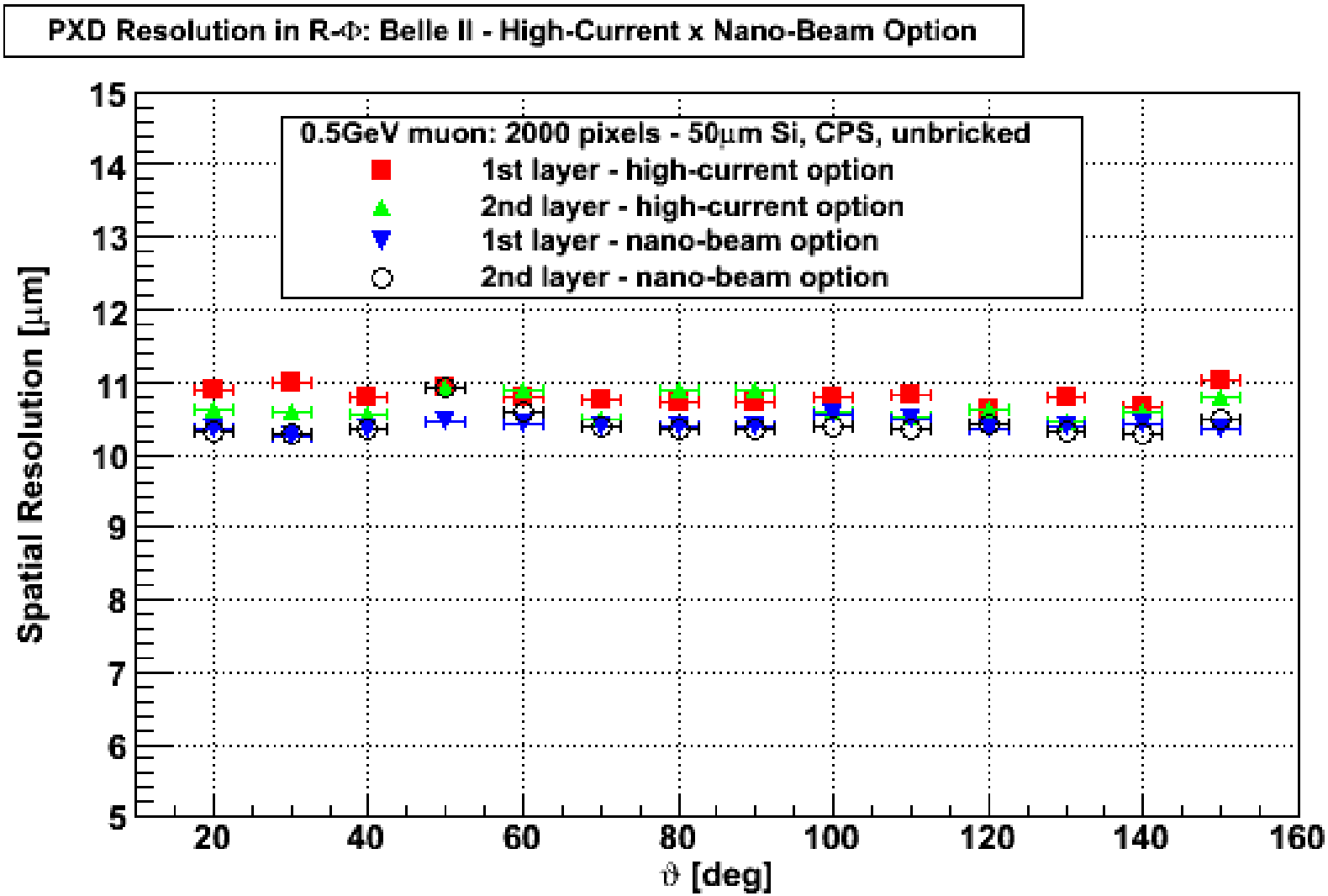


- Technically possible:
  - 50µm unbricked / 70µm bricked
- Bricked pixels
  - R-phi resolution
    - Unbricked 50 µm pixel option always better
    - Bricked 70 µm pixel option only better for θ <= 30° everywhere else resolution is worse
  - Z resolution
    - No effect
- Unbricked Pixels is the favored option

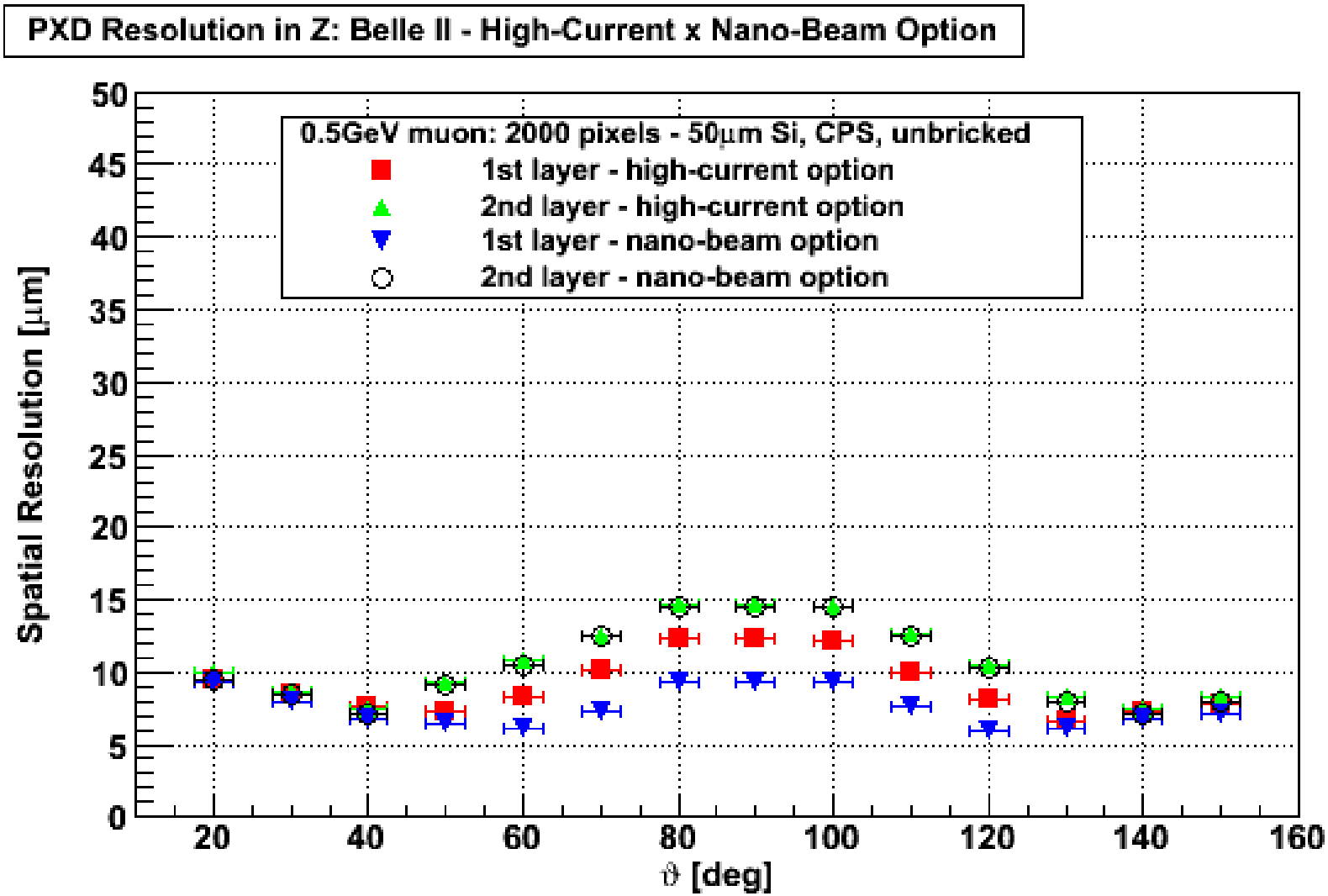
Nanobeam and Highcurrent option 2000 pixel



Nanobeam and Highcurrent option 2000 pixel



Nanobeam and Highcurrent option 2000 pixel

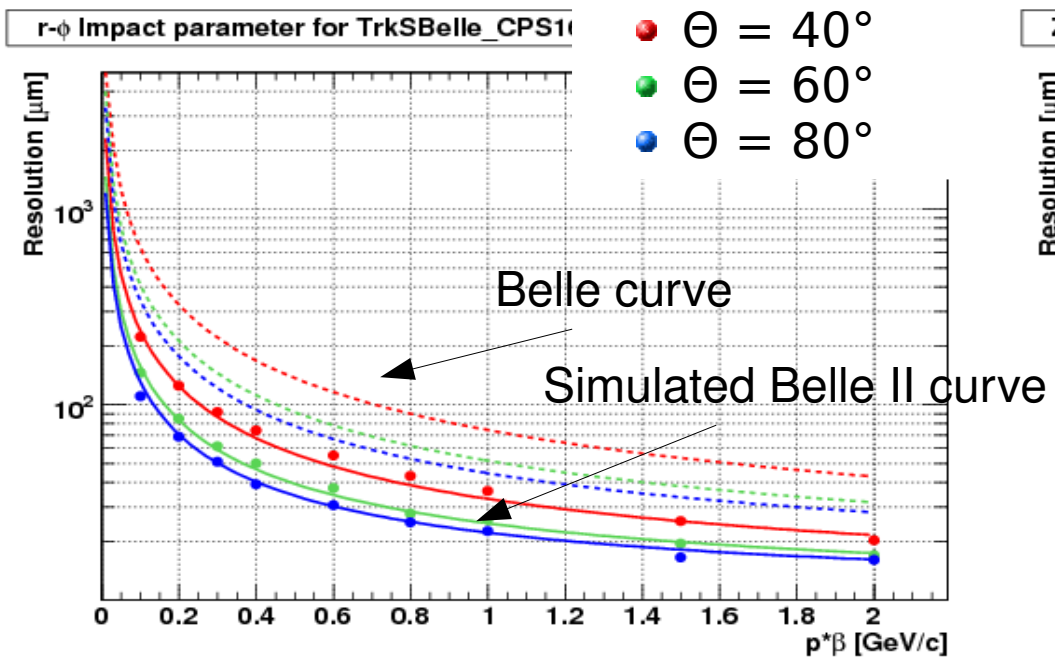


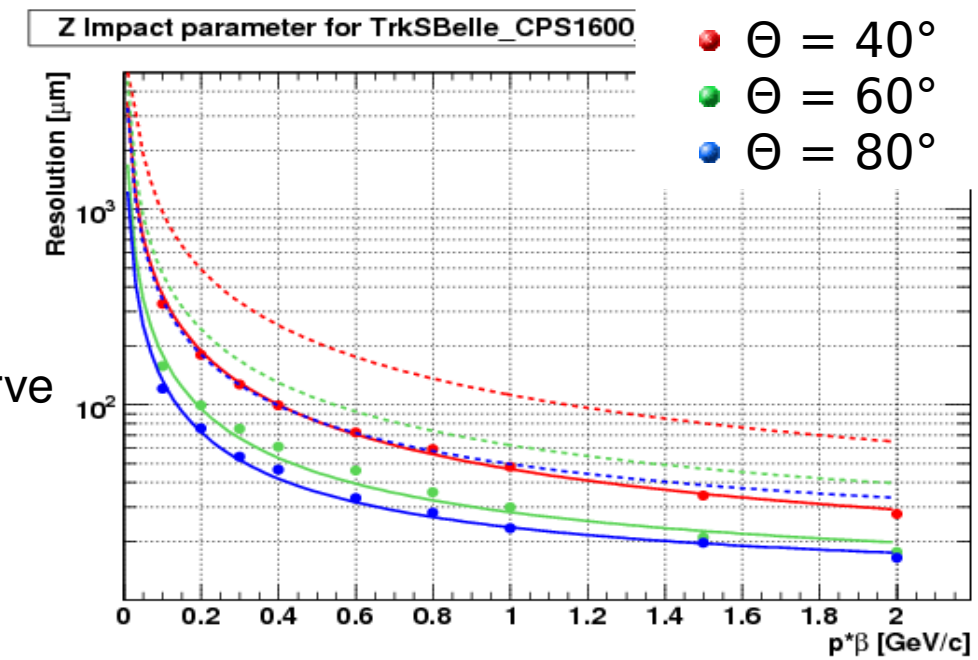
Conclusion

- Full simulation of PXD, SVD ready in the ILC framework
- Vienna LicDetectorToy running for rapid answers to design changes (not show)
- Optimization studies sorted out important parameters for the production
  - Favored option no bricked structure with constant pitch
- Nanobeam option will improve the PXD resolution because of reduced beam pipe radius
- Better background and error estimation

Backup

Impact parameter resolution compared for different angles and energies





Data points is simulated data

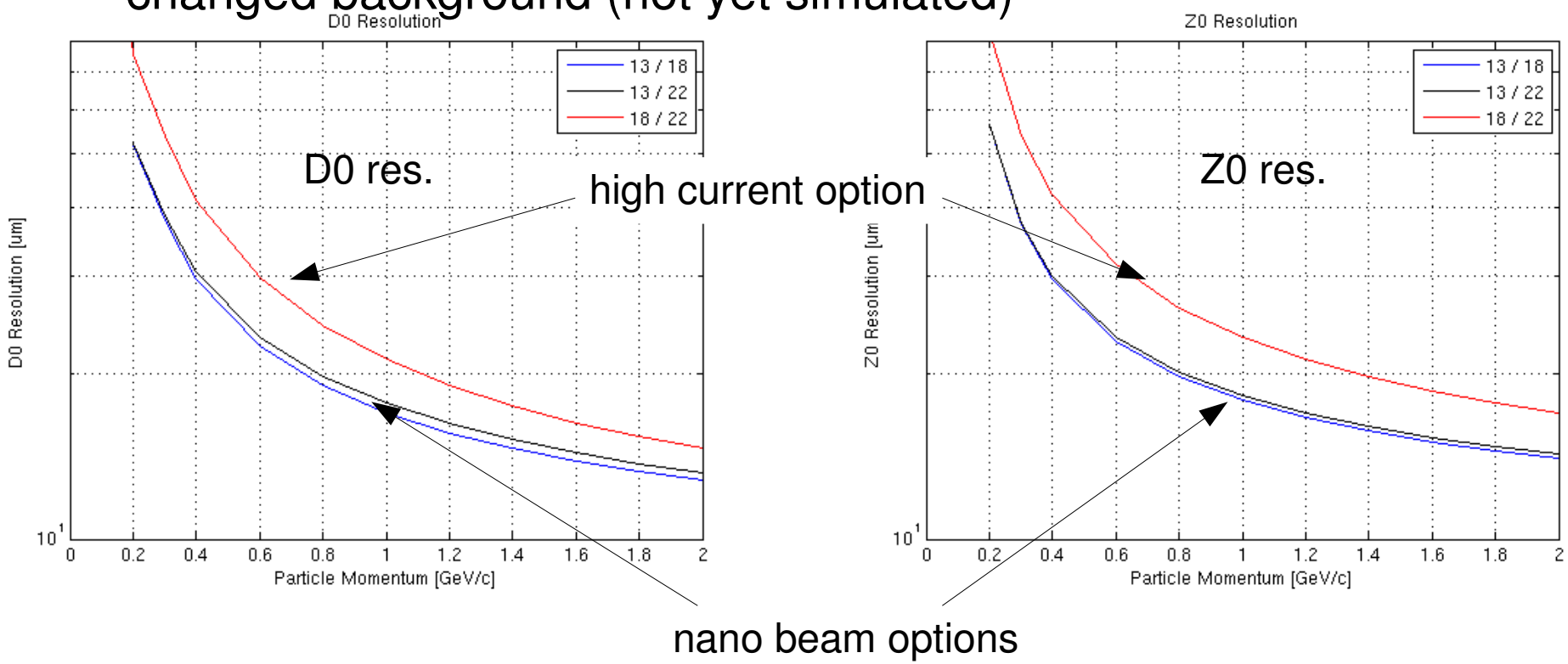
Solid lines taken from Impact Parameter fits
Dashed lines correspond to Belle resolution taken from Belle note 715

Lic Detector Toy 2.0 (LDT)

- Vienna Fast Simulation Tool for Charged Tracks
- Authors: Meinhard Regler, Manfred Valentan and Rudolf Frühwirth
- Geometry approximated as cylinders
- dE/dx and resolution specified for every layer
- Simulation: Gaussian smearing according to given resolutions
- Kalman tracking
- we wrote a module to convert the track parametrization to our common(LCIO) track model
- very fast / ideal for rapidly changing models
- impossible to study details of the detector implementation

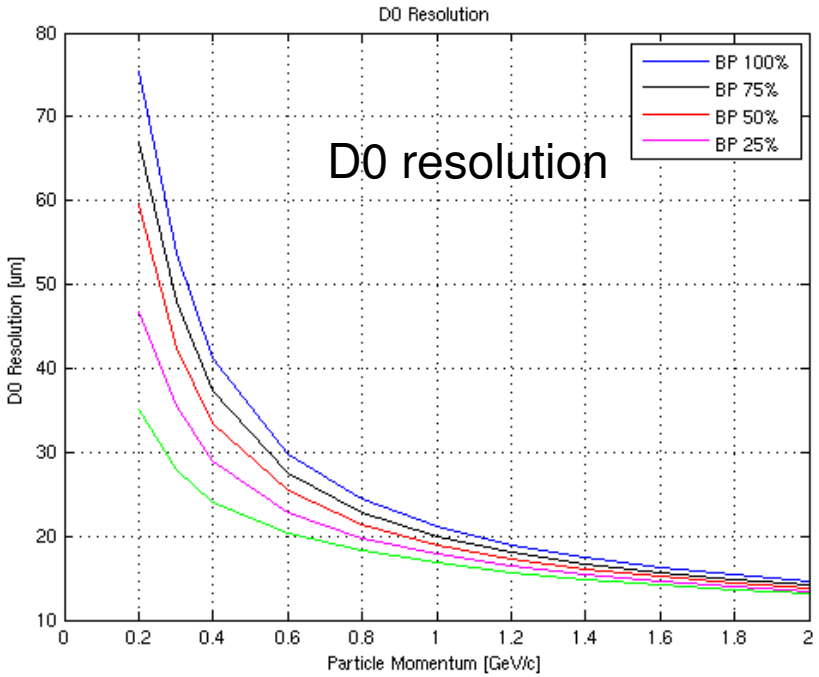
LDT: The Nanobeam Option

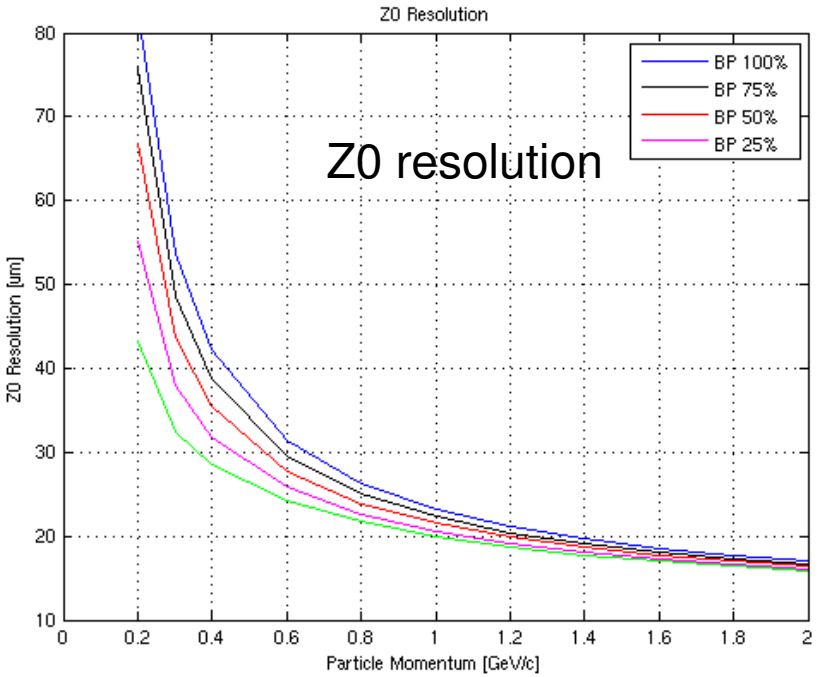
- Effects on PXD
  - smaller beampipe → reduced PXD radius → improves resolution
  - changed background (not yet simulated)



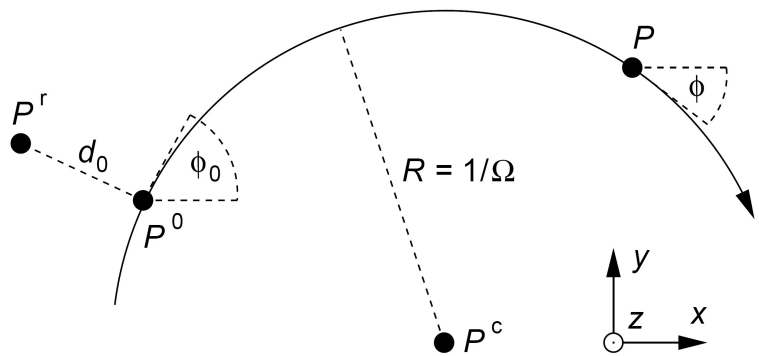
LDT: Beampipe variations

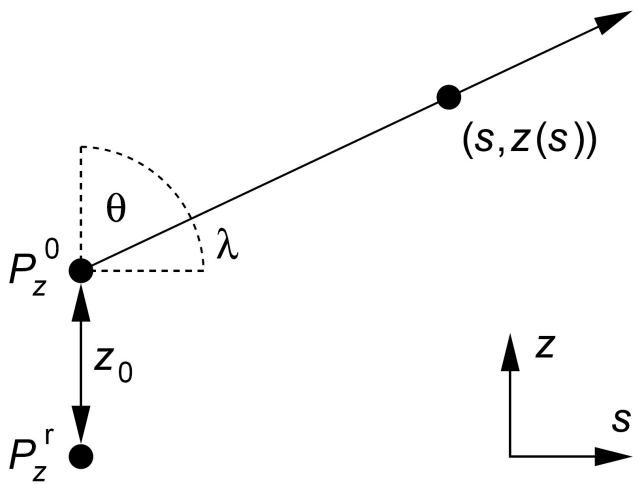
- influence of gold foil on vertex resolution
  - replace with low Z material
- big win for low momentum tracks





Global track parameterization





- P_r: arbitrary pivot point
- P_0: point of closest approach (p.c.a.) to P_r in x-y plane

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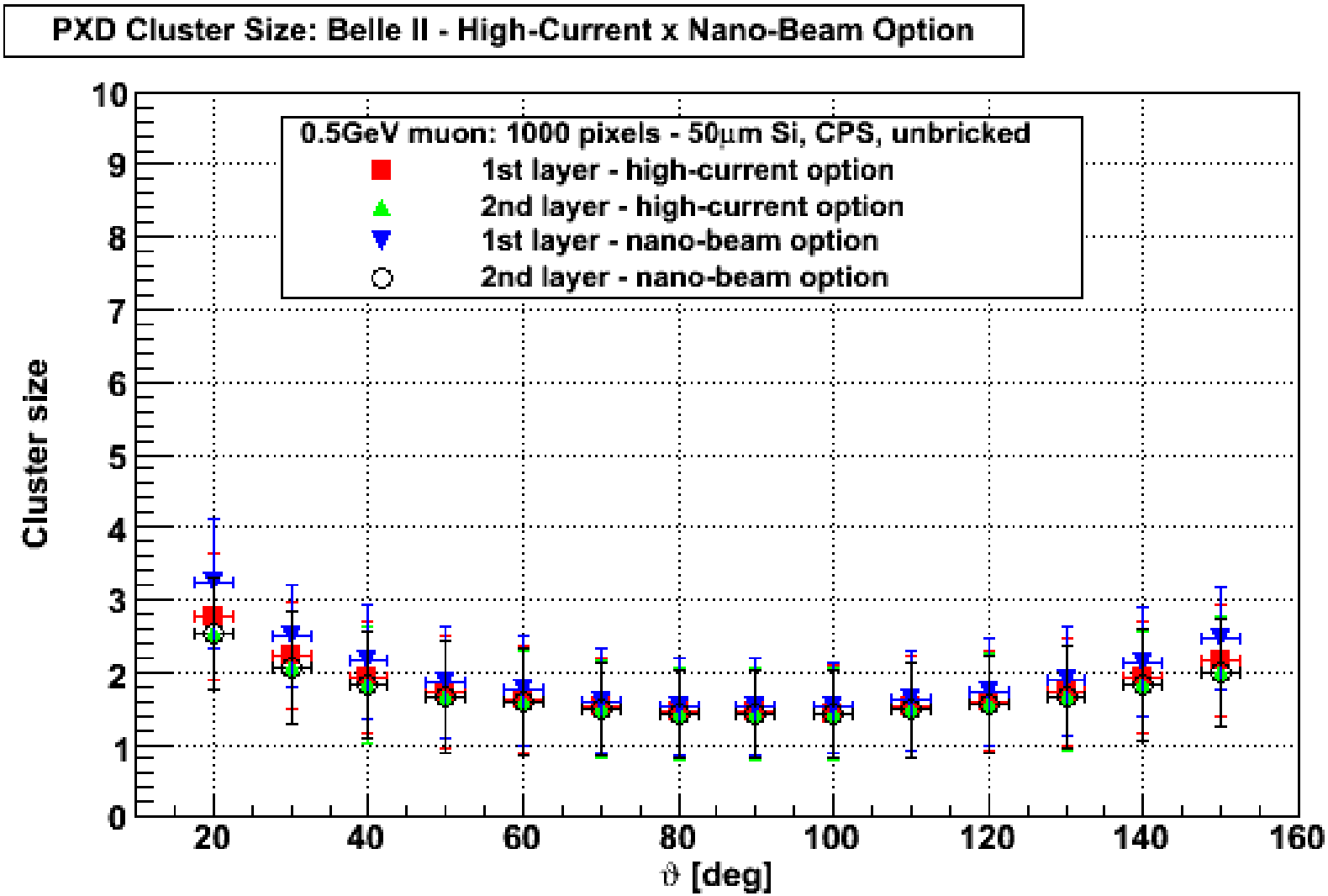
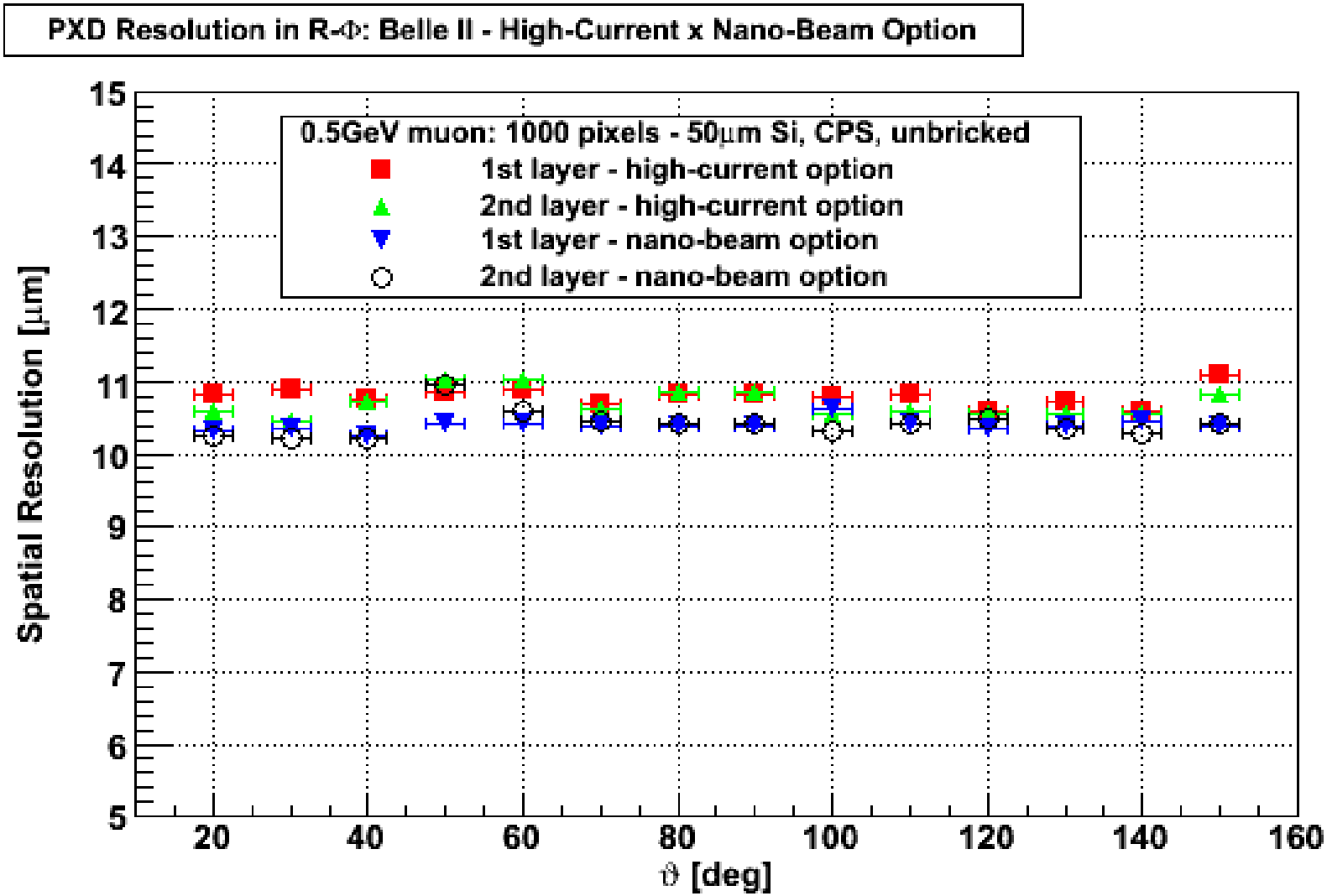
<u>Helix Parameters</u>

- d_0 distance P_0 to P_r
- Φ_0 angle at P_0
- Ω is 1/R
- $\tan \lambda = \cot \theta$ slope in s-z projection
- z_0 distance to p.c.a. in s-z projection

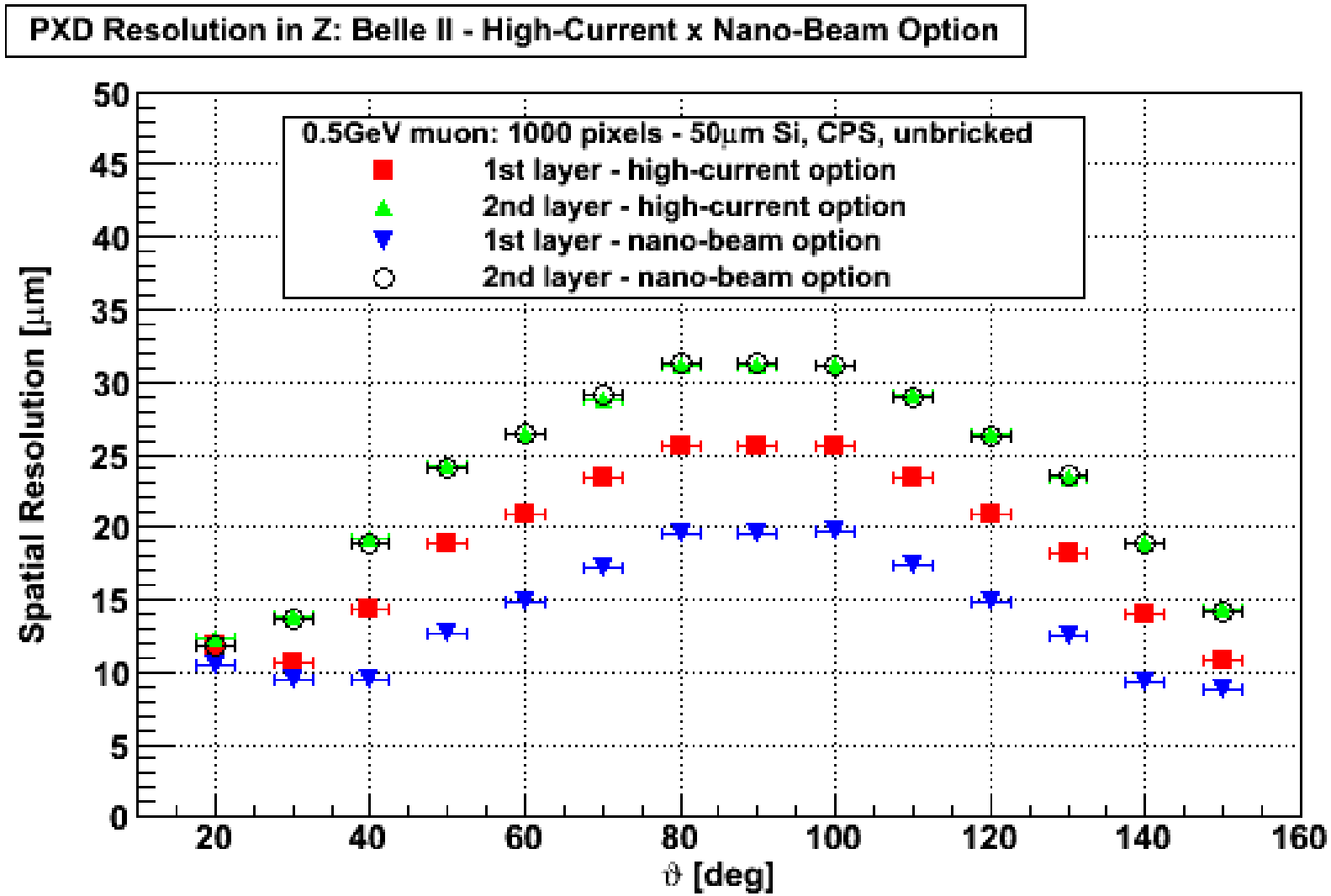
Nanobeam and Highcurrent option 1000 pixel



Nanobeam and Highcurrent option 1000 pixel



Nanobeam and Highcurrent option 1000 pixel



Different models tested

- VPS – variable pixel size
- CPS – constant pixel size

Configuration	R [mm]	l [mm]	N_{pixels}	p_0 [μm]	p_n [μm]	p_m [μm]
CPS0800_B_layer1	18.0	98.0	800	122.5	122.5	122.5
CPS1000_B_layer1	18.0	98.0	1000	98.0	98.0	98.0
CPS1600_B_layer1	18.0	98.0	1600	61.3	61.3	61.3
CPS2000_B_layer1	18.0	98.0	2000	49.0	49.0	49.0
CPS0800_B_layer2	22.0	117.4	800	146.8	146.8	146.8
CPS1000_B_layer2	22.0	117.4	1000	117.4	117.4	117.4
CPS1600_B_layer2	22.0	117.4	1600	73.4	73.4	73.4
CPS2000_B_layer2	22.0	117.4	2000	58.7	58.7	58.7
VPS0800_B_layer1	18.0	98.0	800	117.1	117.1	177.5
VPS1000_B_layer1	18.0	98.0	1000	87.8	93.9	177.2
VPS1600_B_layer1	18.0	98.0	1600	38.2	93.9	177.2
VPS2000_B_layer1	18.0	98.0	2000	21.9	93.9	177.2
VPS0800_B_layer2	22.0	117.4	800	145.2	145.2	174.2
VPS1000_B_layer2	22.0	117.4	1000	111.6	111.6	174.2
VPS1600_B_layer2	22.0	117.4	1600	56.0	91.9	174.0
VPS2000_B_layer2	22.0	117.4	2000	35.6	91.9	174.0

- R = layer radius
- l = ladder length
- p_o = minimal pixel size in Z
- p_n = minimal pixel size in $-Z$
- p_m = minimal pixel size in $+Z$
- for CPS $p_o = p_n = p_m$
- for VPS $p_o \neq p_n \neq p_m$

Lic Detector Toy parameters and analysis

	Beampipe	PXD	SVD	CDC
Number of Layers	1	2	4	35
Radii (mm)	15	18/22	45/70/100/137	356/1155
Thickness per Layer (% of X0)	0.0065	0.000468 0.0015 avg.	0.003 0.0105 avg.	0.0000125

50 µm silicon

300 µm silicon

Comparison ILC and LDT

- PXD Model CPS 1600 pixel 18/22mm radius

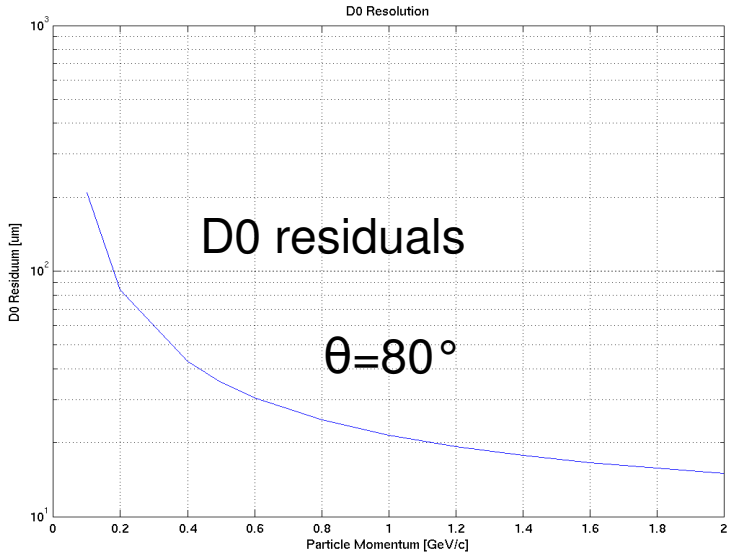
Model	Energy (GeV)	D0 (µm)	Z0 (µm)
ILC frame	0.2	69	75
ILC frame	0.4	39	47
ILC frame	1.0	23	23
LDT	0.2	75	83
LDT	0.4	41	42
LDT	1.0	21	23

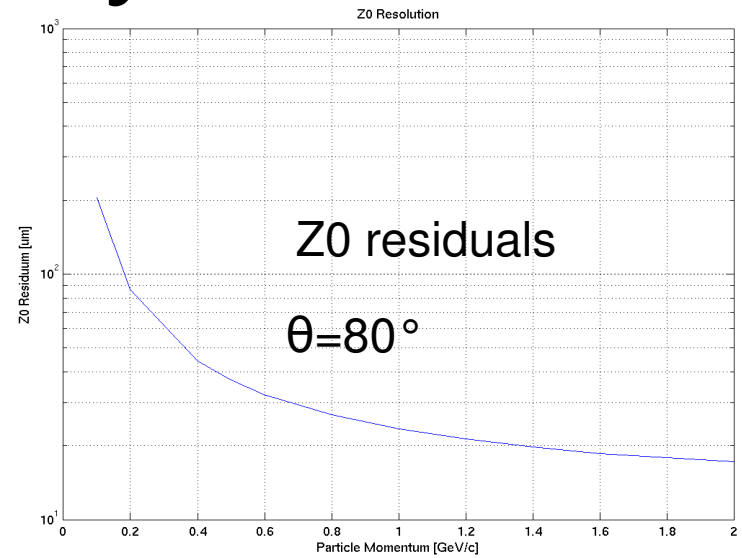
Difference LDT to ILC Frame

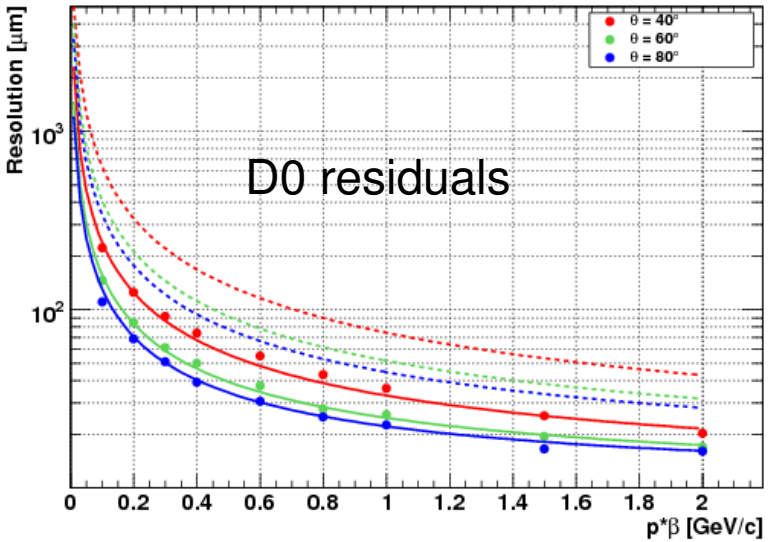
Energy (GeV)	D0	Z0
0.2	-10.0%	-10.6%
0.4	-5.3%	9.3%
1.0	6.2%	0.5%

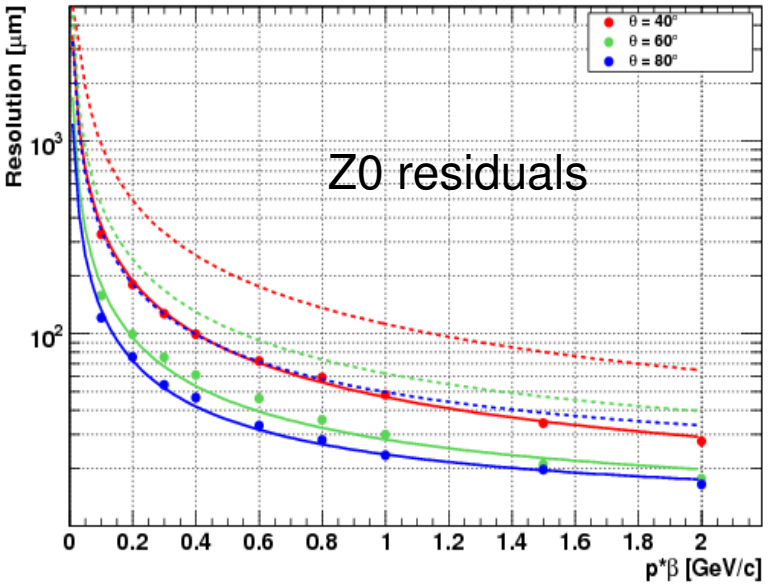
Big differences at low momentum are due to differences in the reconstruction software

Comparison of Mokka/Marlin with Lic Detector Toy results



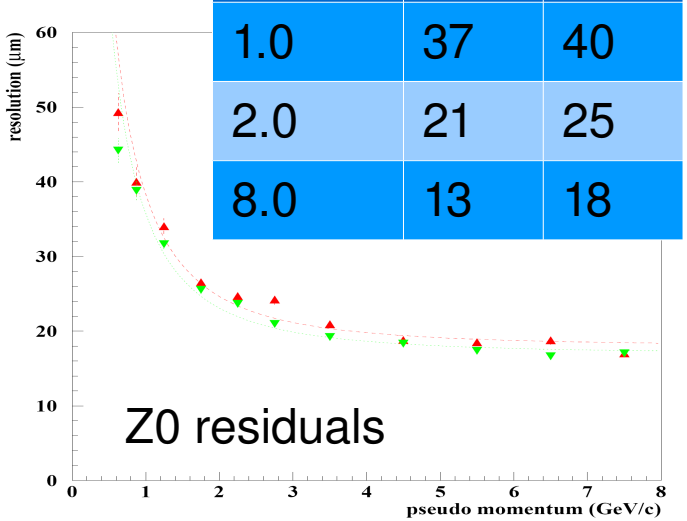




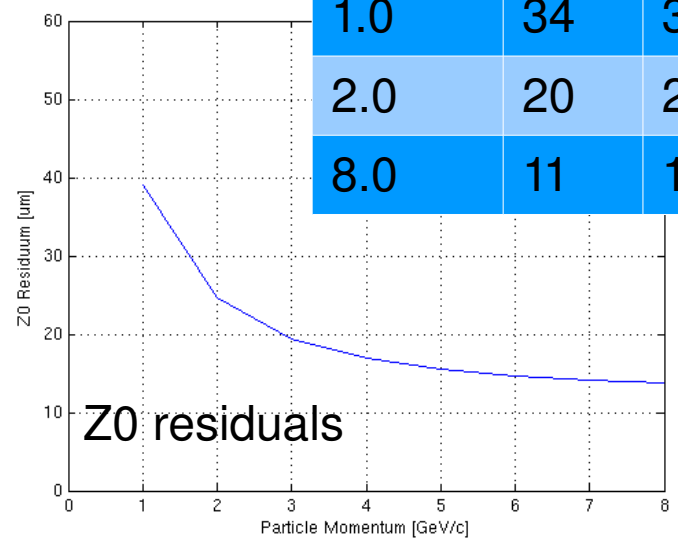


Comparison of Belle note 715 with Lic Detector Toy

Energy (GeV)	D0 (µm)	Z0 (µm)
1.0	37	40
2.0	21	25
8.0	13	18



Energy (GeV)	D0 (µm)	Z0 (µm)
1.0	34	39
2.0	20	25
8.0	11	13



	Beampipe	PXD	SVD	CDC
Number of Layers	1	2	4	35
Radii (mm)	15	18/22	45/70/100/137	356/1155
Thickness per Layer (X0)	0.0065	0.000468	0.003	0.0000125