Measurement of the cluster position resolution of the Belle II Silicon Vertex Detector

The 30th International Workshop on Vertex Detectors

Robin Leboucher,
on behalf of the Belle II SVD group
leboucher@cppm.in2p3.fr

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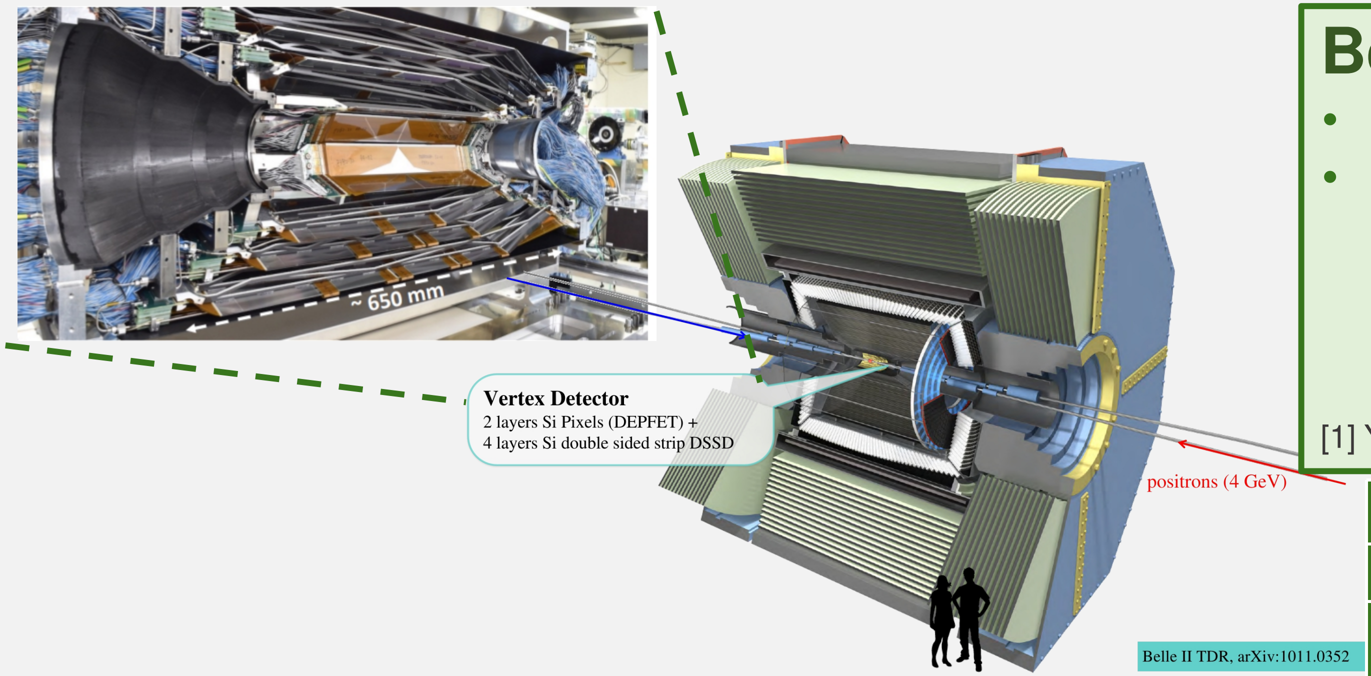
Belle II Silicon Vertex Detector



Belle II Vertex Detector @SuperKEKB:

- 2 pixel layers (PXD)
- 4 layers (SVD) of double-sided Si strip sensors (DSSD) [1]:
  - Side u/P in $r\phi$ direction
  - Side v/N in z direction

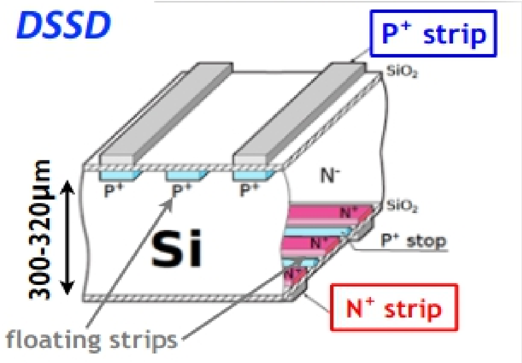
[1] Yuma's talk; https://indico.cern.ch/event/1047531/contributions/4510962/

Layer (Side)	3 (u/P)	456 (u/P)	3 (v/N)	456 (v/N)
Strip pitch (μm)	50	75	160	240
Digital resolution (with floating strips) $\frac{Pitch}{2\sqrt{12}}$ (μm)	7	10	23	34

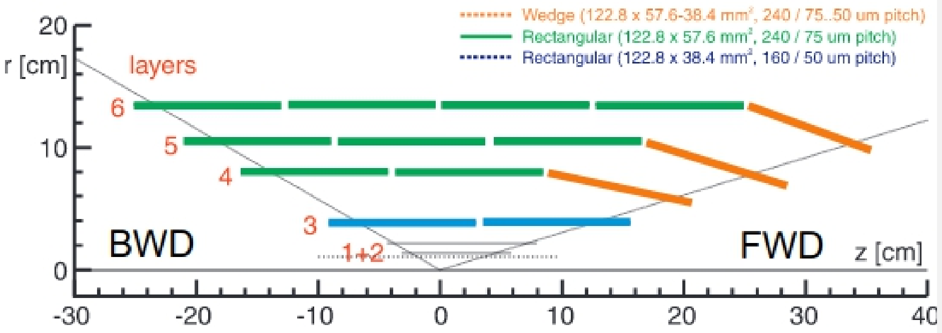
SVD roles:

- Provides tracking and PID for low momentum particles
- Extrapolates tracks to PXD (Region of interest)

Double Sided Strip Detector



3 shapes of DSSD used in ladders



Standard methods

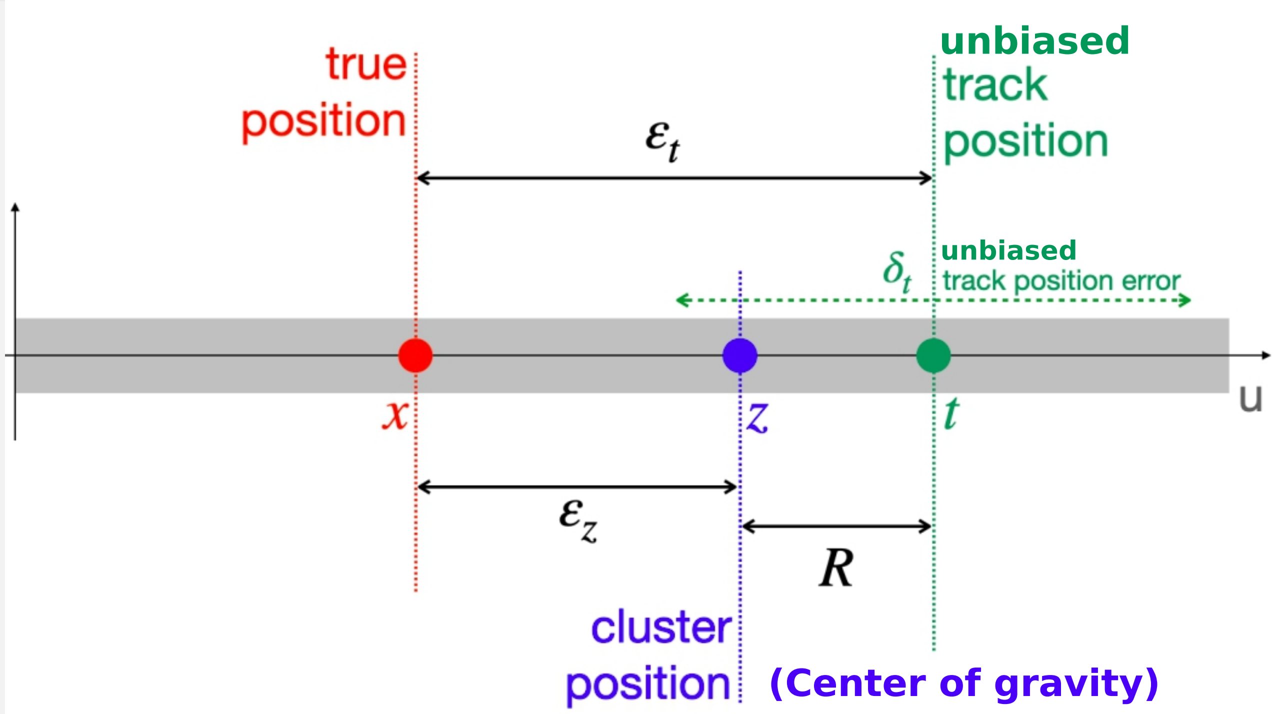
Cluster Position Resolution is crucial to:

- Provide best quality track reconstruction
- Correctly propagate uncertainty on hit's position to track parameters

Effect of the track extrapolation error subtracted

Residual R: difference between cluster position z and unbiased track position t

$$\boldsymbol{R = z - t}$$



Event by event method:

- For each event subtract in quadrature residuals (R) and errors on track extrapolation (δ_t)
- Quantile truncation optimized on simulation to match true resolution
- Resolution σ_{Cl}:

$$\sigma_{Cl} = \sqrt{\langle R^2 - {\delta_t}^2 \rangle}_{trunc}$$

Global method:

Global approach directly compare Residual width and track extrapolation error peak position and width:

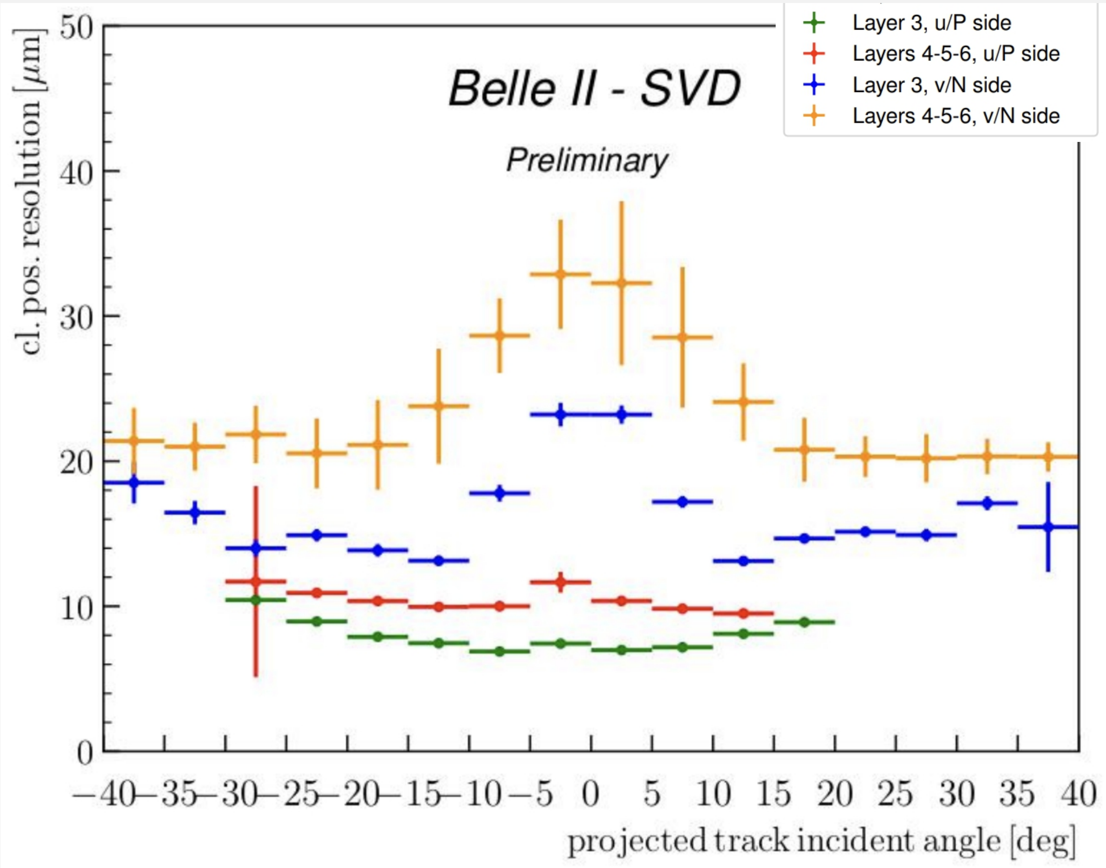
$$\sigma_{Cl} = \sqrt{mad(R)^2 - median(\delta_t)^2 - mad(\delta_t)^2}$$

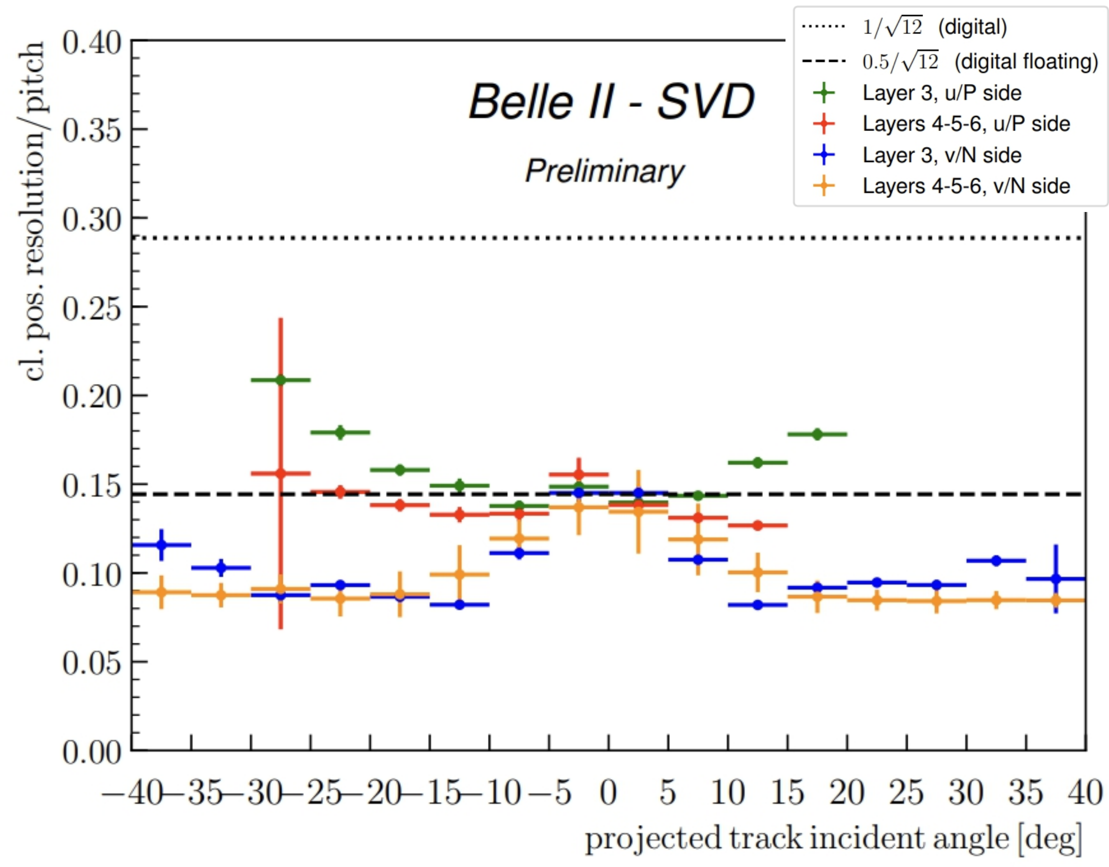
with $mad(y) = 1.4826 \times median(|y - median(y)|)$

Resolution results: Event by event

Event by event Method:

Results on collision data from $e^+e^- \to \mu^+\mu^-$ processes



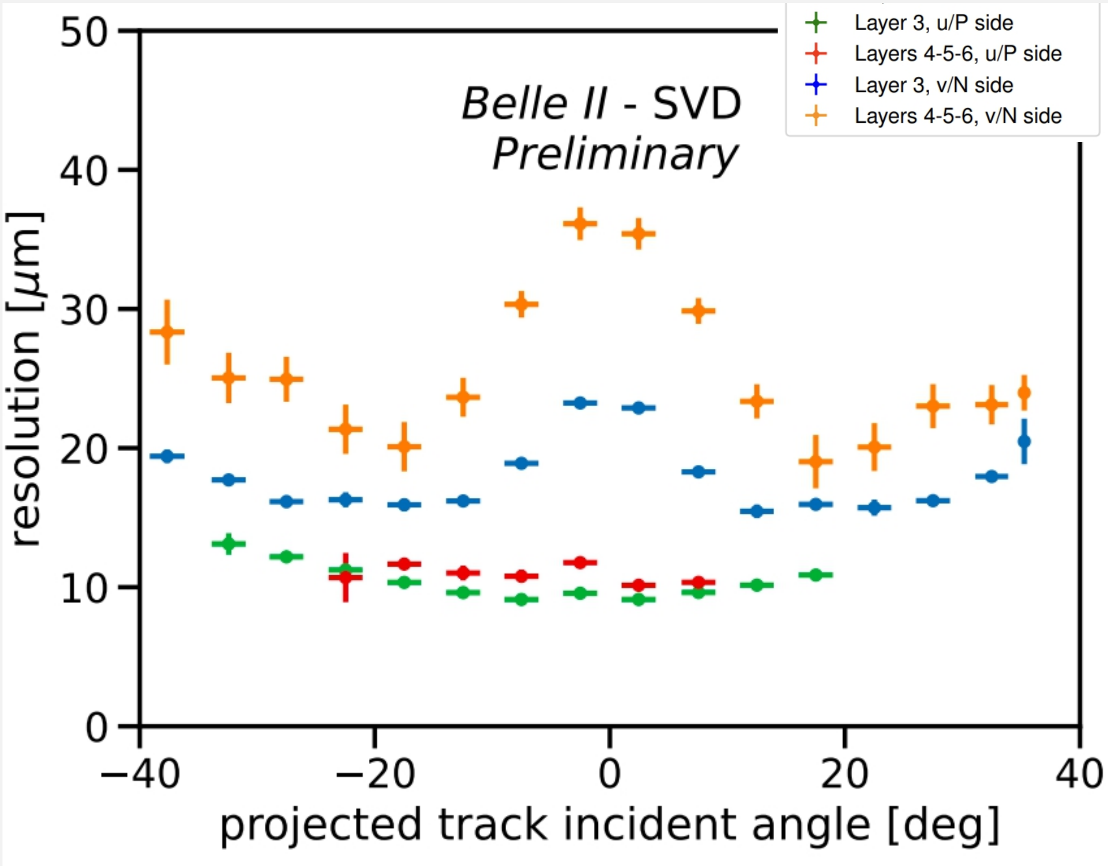


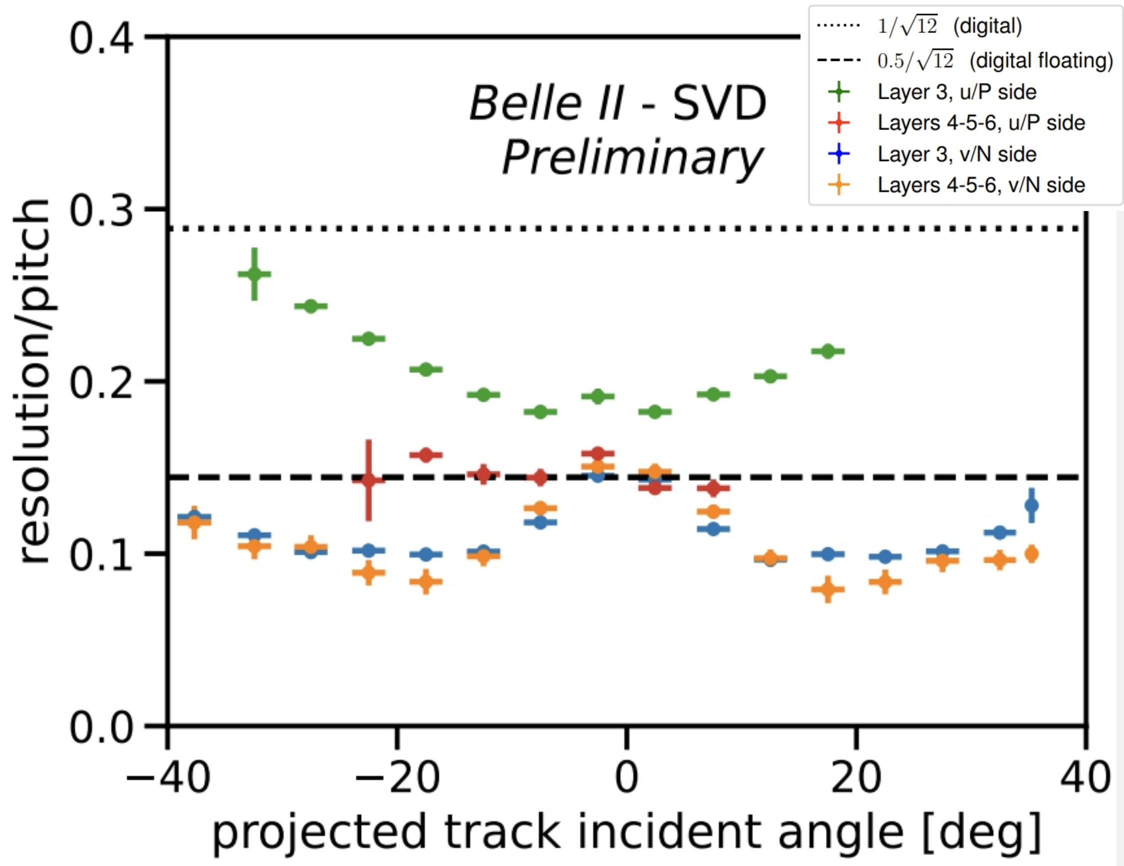
- Already reach digital resolution in v/N side for both Event by event and Global methods
- Still some room for improvements on u/P side

Resolution results: Global

Global Method:

Results on collision data from $e^+e^- \rightarrow \mu^+\mu^-$ processes





- Already reach digital resolution in v/N side for both Event by event and Global methods
- Still some room for improvements on u/P side

Overlaps method

Overlaps method: [2]

- Select tracks in fiducial area with two hits on the same layer and on consecutive ladders
- Compare residuals computed for the pair of overlapping ladder, double residuals:

$$\Delta R = R_{int} - R_{ext}$$

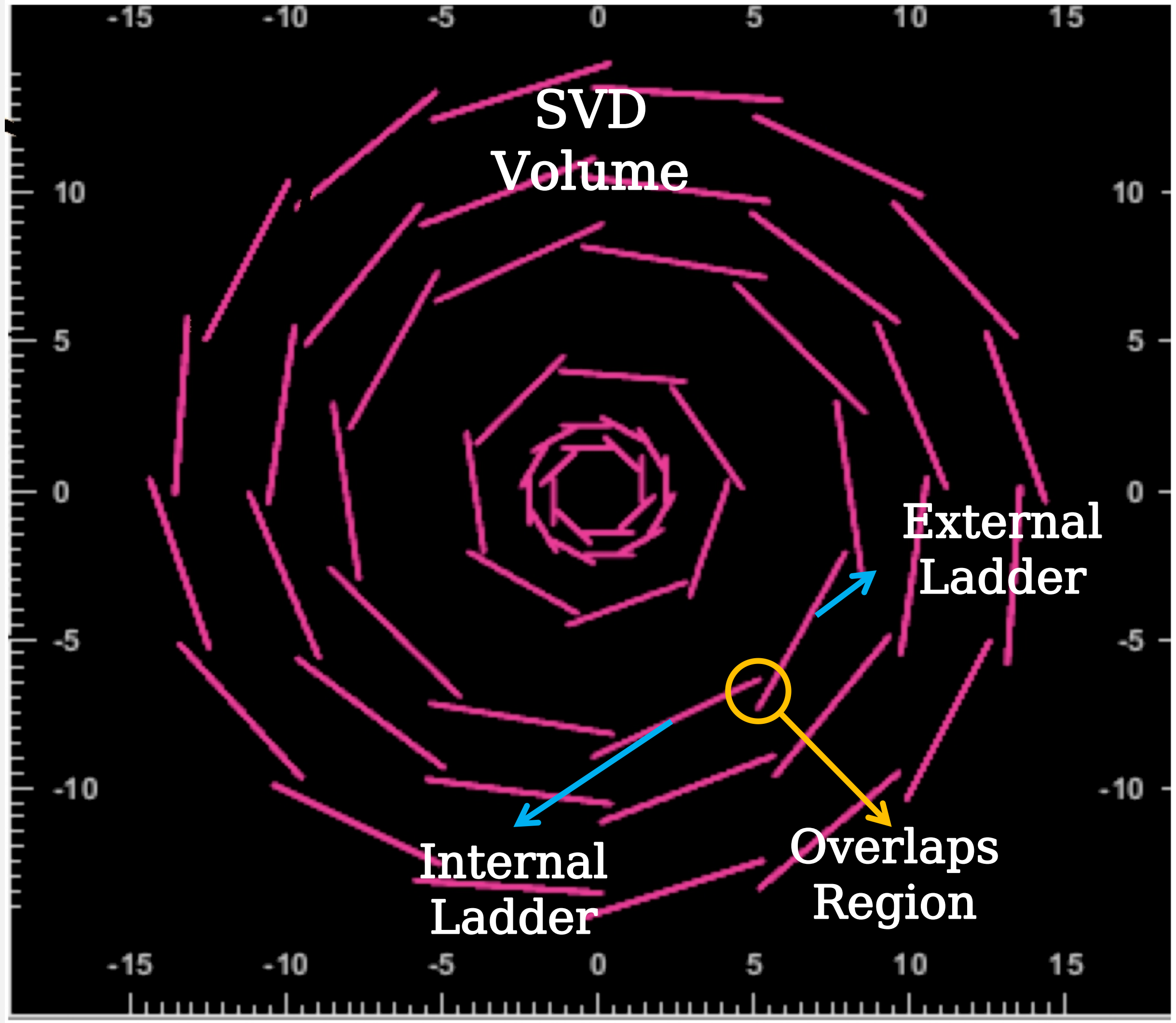
- Apply geometrical correction due to non-parallel sensors
- Resolution is the σ_{68} width of a Student-T distribution fit [p13]

[2] CMS Tracker Collaboration, 'Stand-alone Cosmic Muon Reconstruction Before Installation of the CMS Silicon Strip Tracker', J. Inst., vol. 4, no. 05, May 2009, doi: 10.1088/1748-0221/4/05/P05004.

↳ Decouple contribution of tracking precision

↳ Marginally sensitive to Coulomb scattering

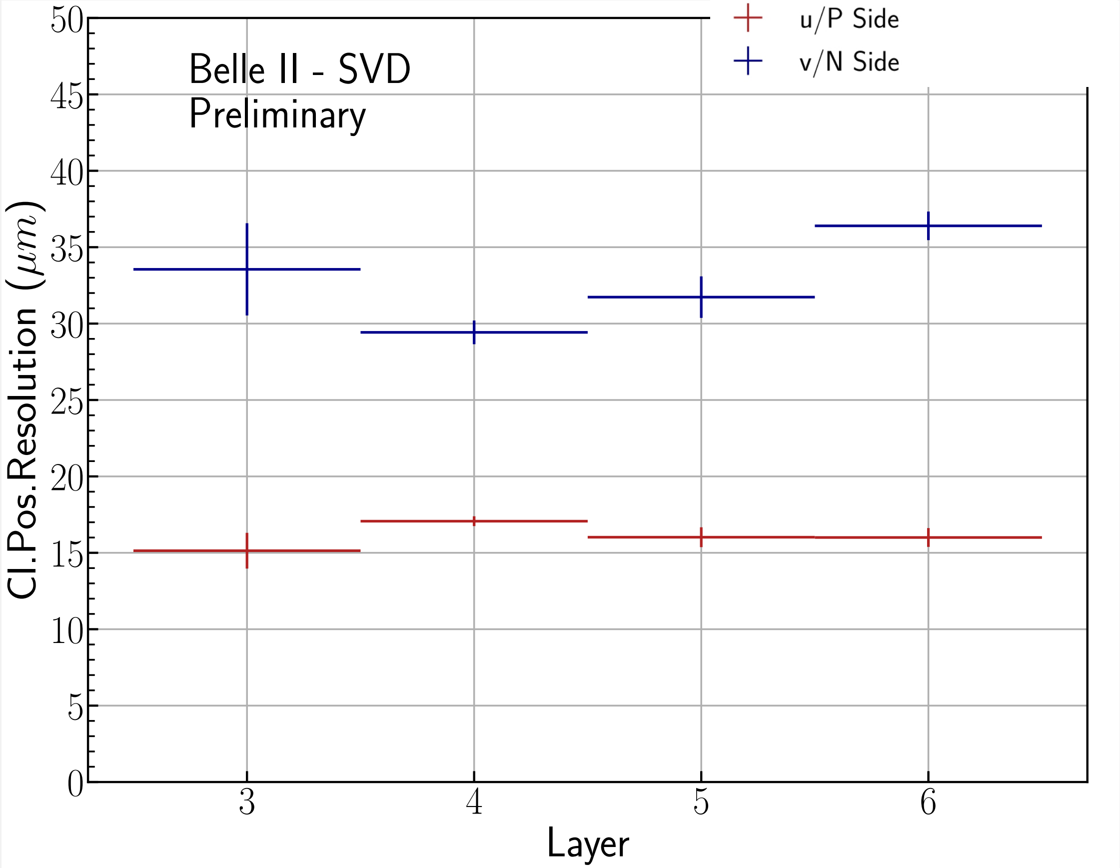
↳ But low statistic and limited angle range

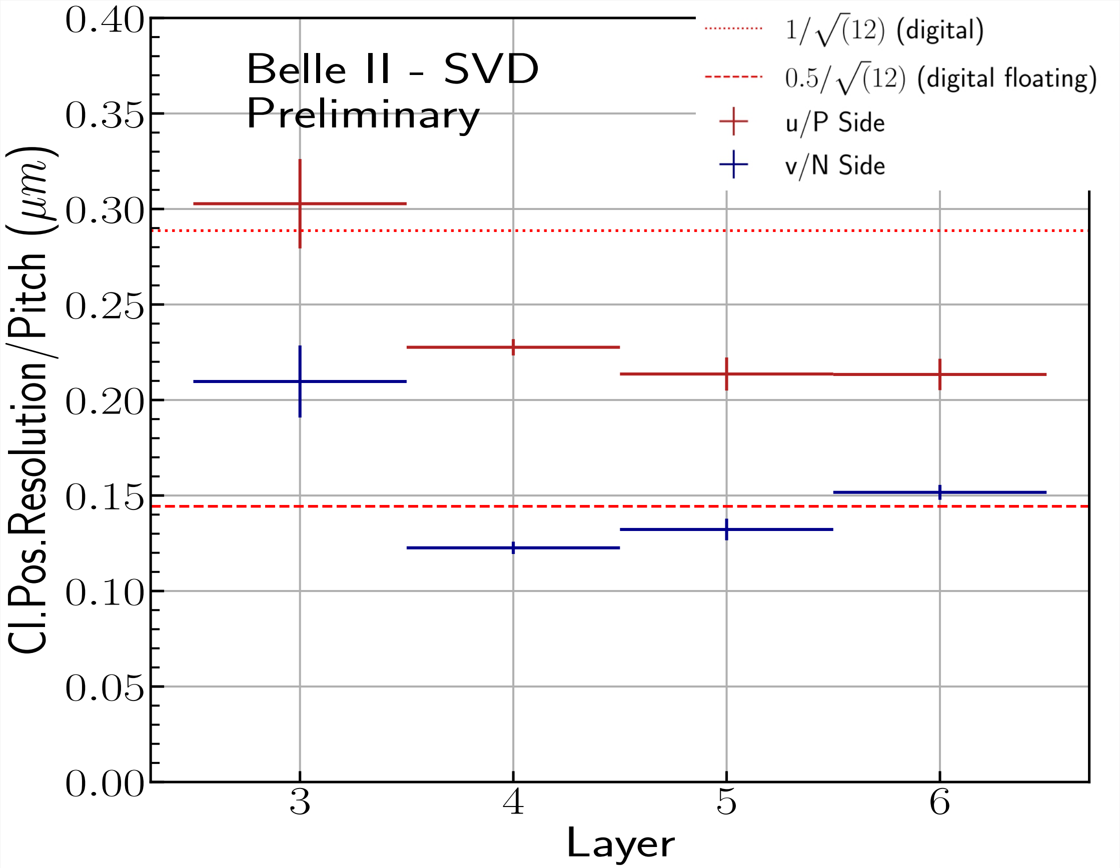


Resolution results: Overlaps

Overlaps Method:

Results on collision data from $e^+e^- \rightarrow \mu^+\mu^-$ processes





- Overlaps method reaches digital resolution with outermost v/N layers
- Further investigation for better understanding and possible improvements on u/P side ongoing

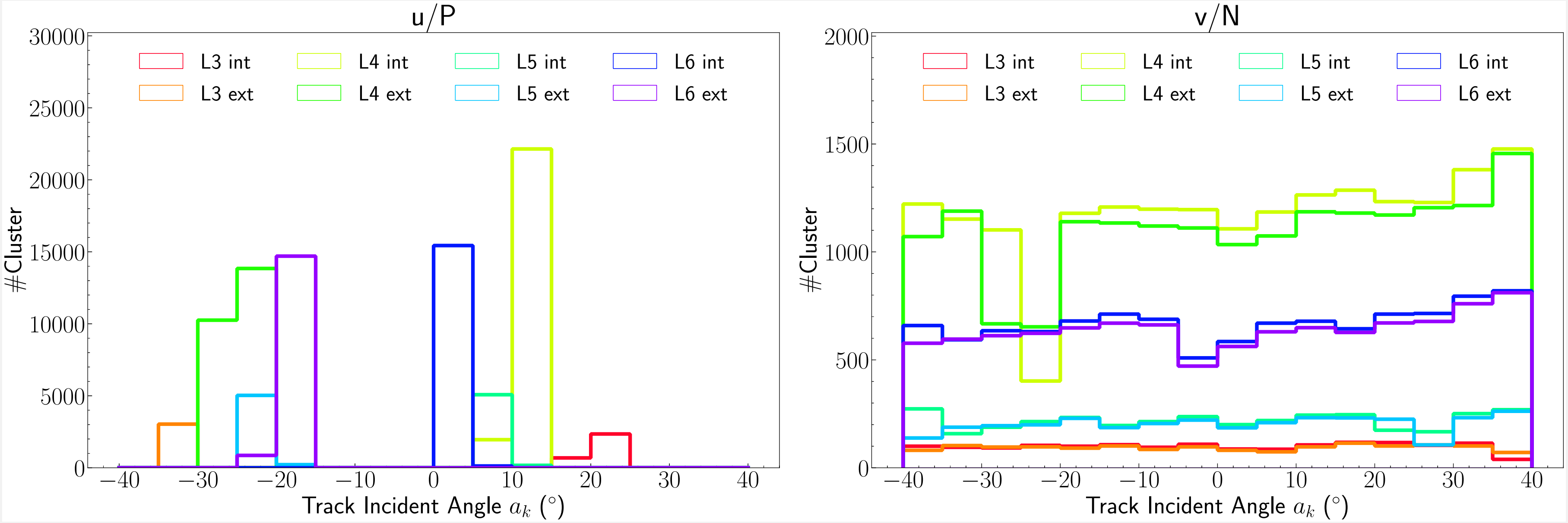
Resolution results: Overlaps (II)

Overlaps Method:

	u/P Side		v/N Side	
Layer	Overlaps (µm)	Event by envent (µm)	Overlaps (µm)	Event by event (µm)
3	15.1 +/- 1.1	12.5	33.5 +/- 3.0	16.4
4	17 +/- 0.3	10.4	29.4 +/- 0.7	23.6
5	16 +/- 0.6	10.3	31.7 +/- 1.3	23.6
6	16 +/- 0.6	10.5	36.4 +/- 0.9	23.6

Overlaps method on u/P side sensitive only to a **limited incident track angle range**, differential measurement not possible→ u/P side comparison applies only in some angular bins of the event by event method (*reported average resolution*)

- Overlaps show larger resolutions than event by event method
- Differential measurement as a function of the incident track angle on v/N side statistically limited



Summary

Cluster position resolution are estimated with different methods:

Event by event	Global	Overlaps

- **Excellent position resolution in agreement with the expectations from the pitch**
- **Still room for improvement for the u/P side (work ongoing)**

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Thanks for your attention

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Backups Slides

Errors estimation on Event by event & Global methods

Errors estimation in Event by event method:

1. **Statistical uncertainties**
   Taking variance of resolution squared as variance of sample mean

$$\Delta\sigma_{Cl} = \frac{1}{2\sigma_{Cl}}\sqrt{\frac{\langle(R^2 - {\delta_t}^2)^2\rangle - \sigma_{Cl}^4}{N}}$$

2. **Systematic uncertainties**
   Adding in quadrature:
   - Variation in resolution measurement with and without selection on residual
   - Variation in resolution measurement with quantile truncation at $\mp 0.2\%$ (step) between optimal quantile

Errors estimation in Global method:

1. **Statistical uncertainties**
   - For median $\frac{mad}{\sqrt{N}}$
   - *For mad* $\sqrt{2}\frac{mad}{\sqrt{N-1}}$

2. **Systemac uncertainties:**
   Difference with another robust estimator that should give the same result for Gaussian distributions
   - For median $|median - midhinge|$ (average of the first and third quartiles)
   - For mad $|mad - \sigma_{68}|$

Detailled Overlaps Method

Method for estimate resolution with overlapping:

1. Apply geometical correction factor on double residuals:

$$\Delta R = \frac{R_{int} - R_{ext} * C}{\sqrt{1 + C^2}}$$

with $C = \frac{\cos a_{ext}}{\cos a_{int}}$

2. Fit double residual with a Student-T distribution:

$$T(X, \nu, \mu, \sigma) = \frac{exp\left(\Gamma(\frac{\nu+1}{2}) - \Gamma(\frac{\nu}{2})\right)}{\sigma\sqrt{\pi\nu}}\left(1 + \frac{(X-\mu)^2}{\sigma^2\nu}\right)^{-\frac{\nu+1}{2}}$$

normalisation parameter N
number of degree of freedom ν
mean μ
variance σ²

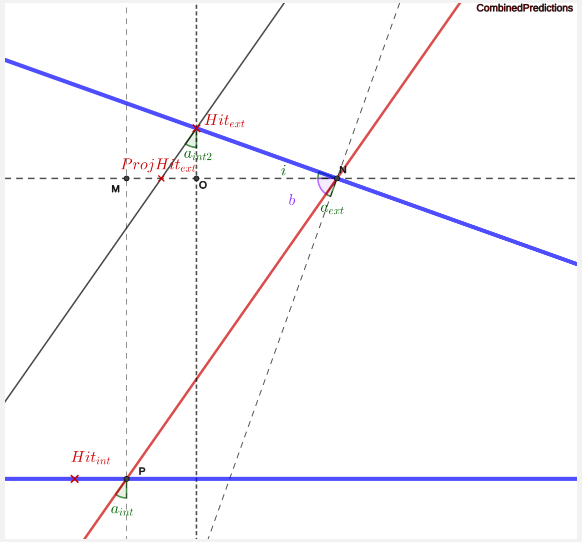
3. The resolution is the σ_{68} of the fitted Student-T distribution T

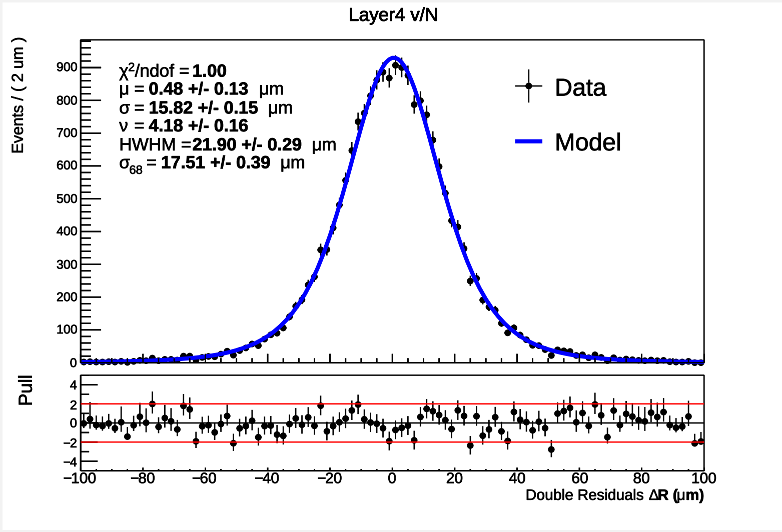
$$r = \sigma_{68}(T(X, \nu, \mu, \sigma)) = \frac{\chi_{84}(T(X,\nu,\mu,\sigma)) - \chi_{16}(T(X,\nu,\mu,\sigma))}{2}$$

True Resoltion in Monte-Carlo:

$$\sigma_{68}(z - x)$$

Cluster position x_{Cl}
True position x_{True}





Method for estimate resolution uncertainties:

1. Vary fitted parameters (N, μ, ν, σ) within the fit uncertainties (+/- Fit errors)
2. Compute Student-T distribution with new parameters
3. Taking σ_{68} resolution of this new model
4. Take as resolution uncertainty for each layer half the maximal variation of the recomputed σ_{68}:

$$\frac{max(r_{\sigma 68}) - min(r_{\sigma 68})}{2}$$