COMMISSIONING OF THE Belle II SILICON VERTEX DETECTOR

Giulia Casarosa

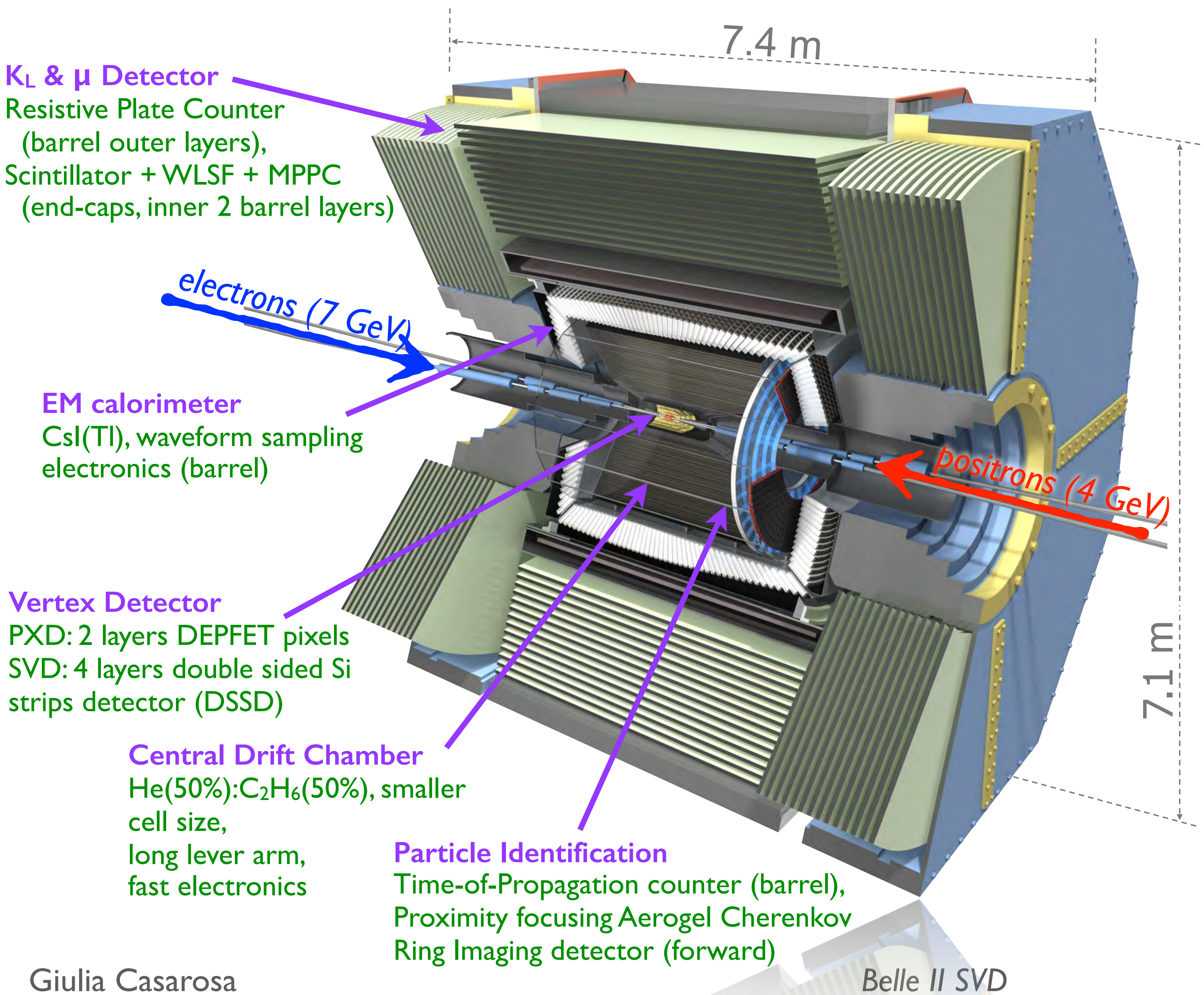
on behalf of the *Belle II* SVD Collaboration

Outline

- *The Belle II Silicon Vertex Detector*
- *SVD Commissioning*
  - *highlights from small-scale SVD operations in global data taking*
  - *final detector commissioning*
- *First Results from Global Cosmic Runs*

The *Belle II* Experiment

Belle II is a multi-purpose detector installed at the IP of the high-luminosity B-Factory SuperKEKB (design luminosity $8x10^{35} cm^{-2}s^{-1}$), located at the KEK Laboratory - Tsukuba, Japan



- 10 years operation will allow to collect 50/ab (x50 the Belle dataset) providing the analysts with a statistical-error-breaking dataset.
- Physics measurements will benefit from the increase of statistics if:
  1. the *resolution* is comparable with Belle, or better
  2. the *systematic* error is reduced too
- the *Belle II* sub-detectors, in particular the vertex detector, have been designed to achieve these goals

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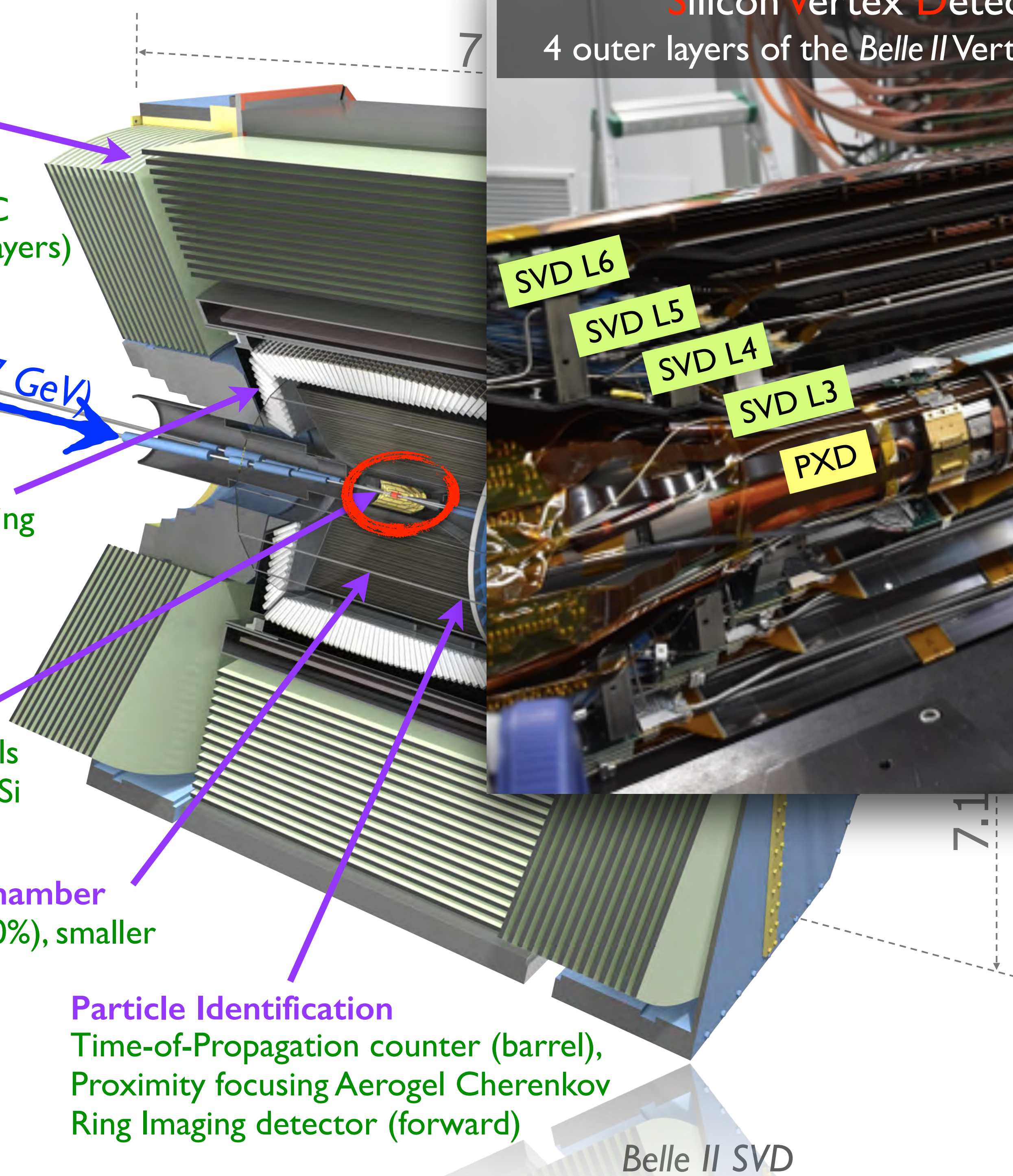

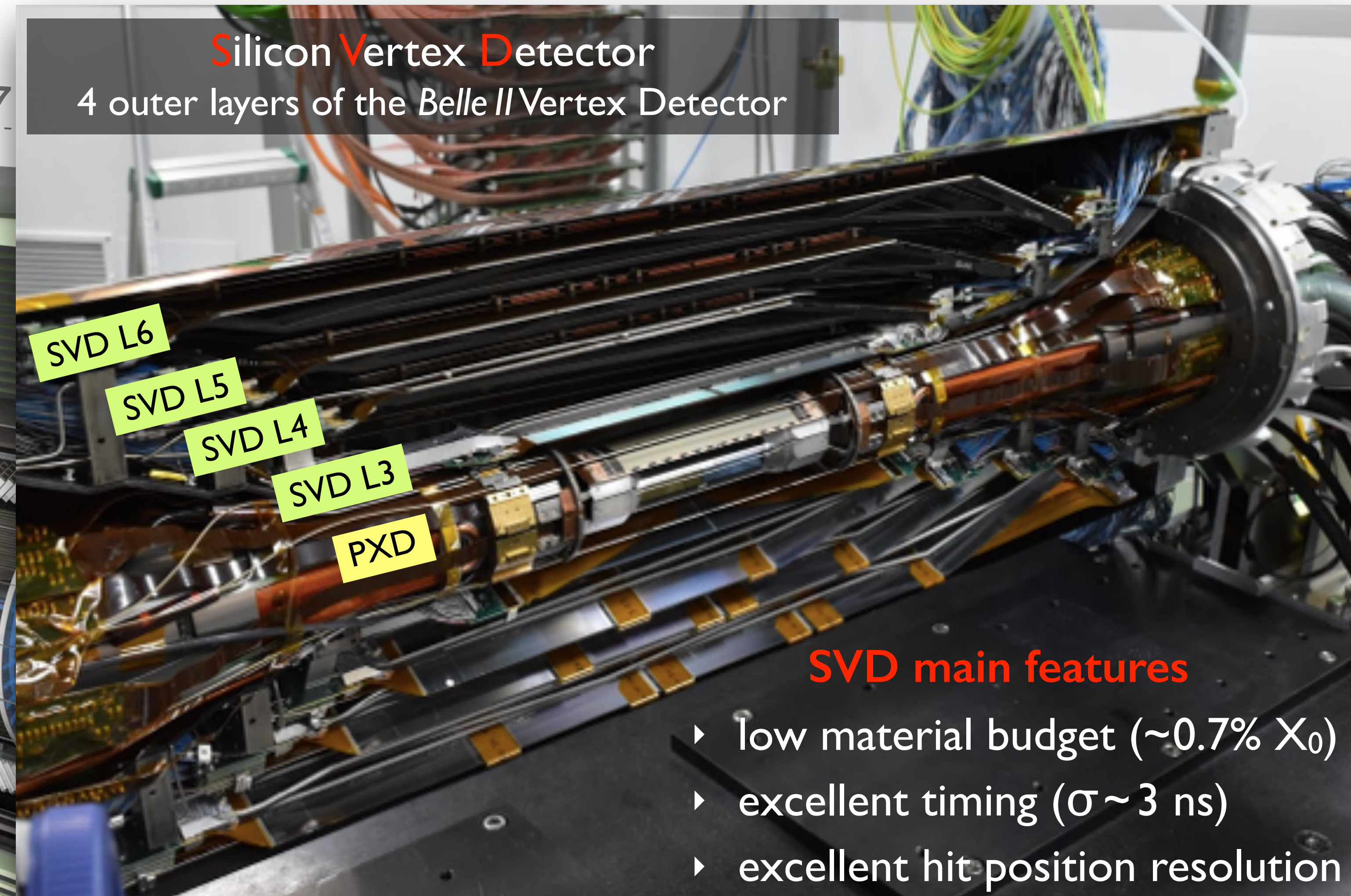

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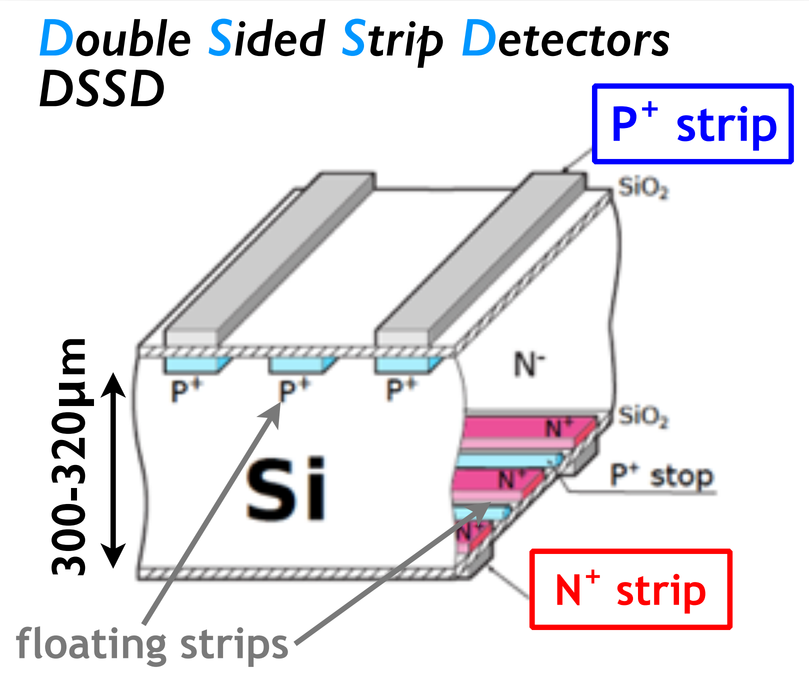
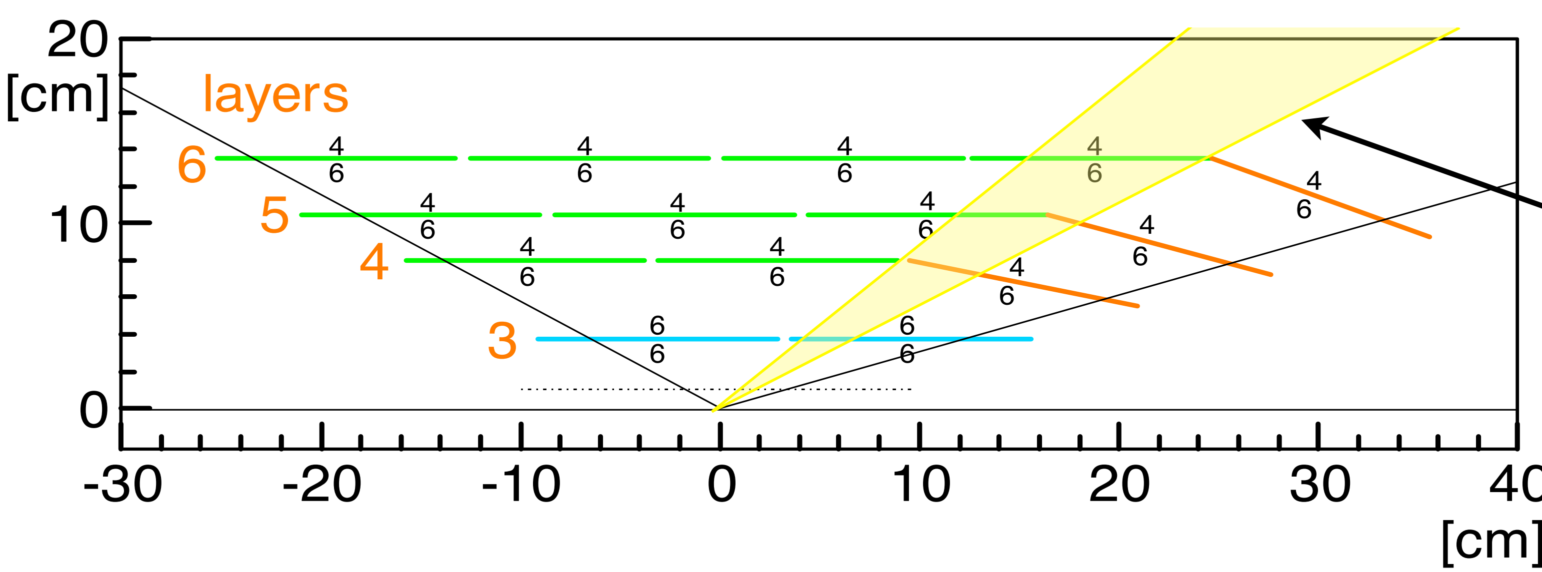
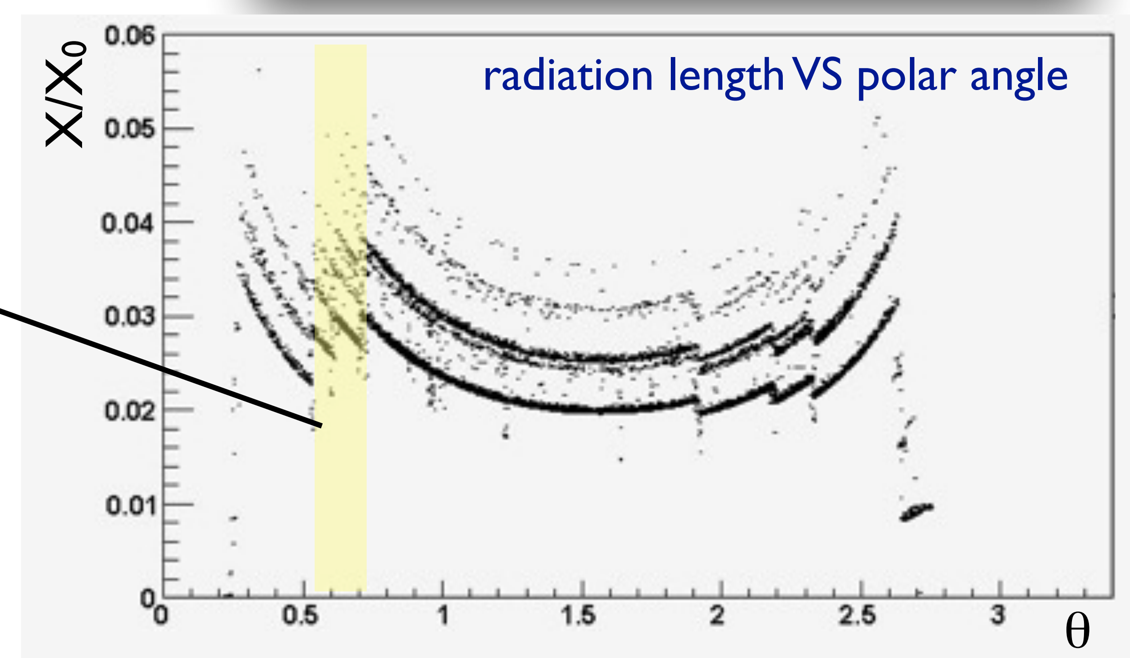
The SVD Silicon Sensors



- 4 layers of DSSD on N-type silicon with AC coupled readout
- individual readout on each silicon sensor:
  - straightforward for sensors facing the non-tracking region
  - origami concept for all the other sensors (see backup)
- lamp-shade geometry for layers 4,5, and 6
  - optimize track incident angle
  - reduced material budget in the forward region (θ<0.7)





- three sensor layouts, to reduce the design and production cost:

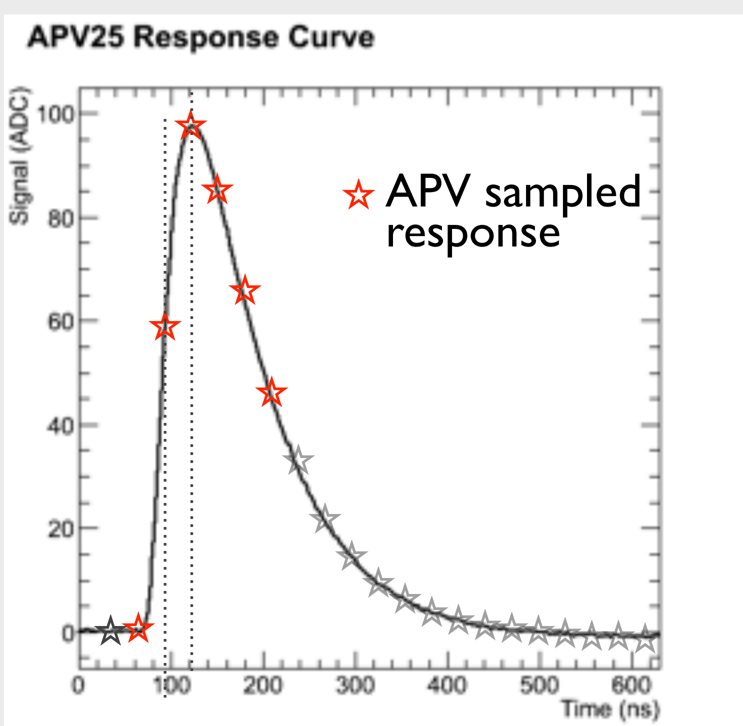
layer	type	readout strip(p/r-ϕ)	readout strip(n/z)	strip pitch (p/r-ϕ)	strip pitch (n/z)	sensors # (+ spares)	active area (mm^2)
4,5,6	large	768	512	75 μm	240 μm	120+18	122.90x57.72 = 7029.88
4,5,6 forward	trapezoidal	768	512	50-75 μm	240 μm	38+6	122.76x(57.59+38.42)/2 = 5893.09
3	small	768	768	50 μm	160 μm	14+4	122.90x38.55 = 4737.80

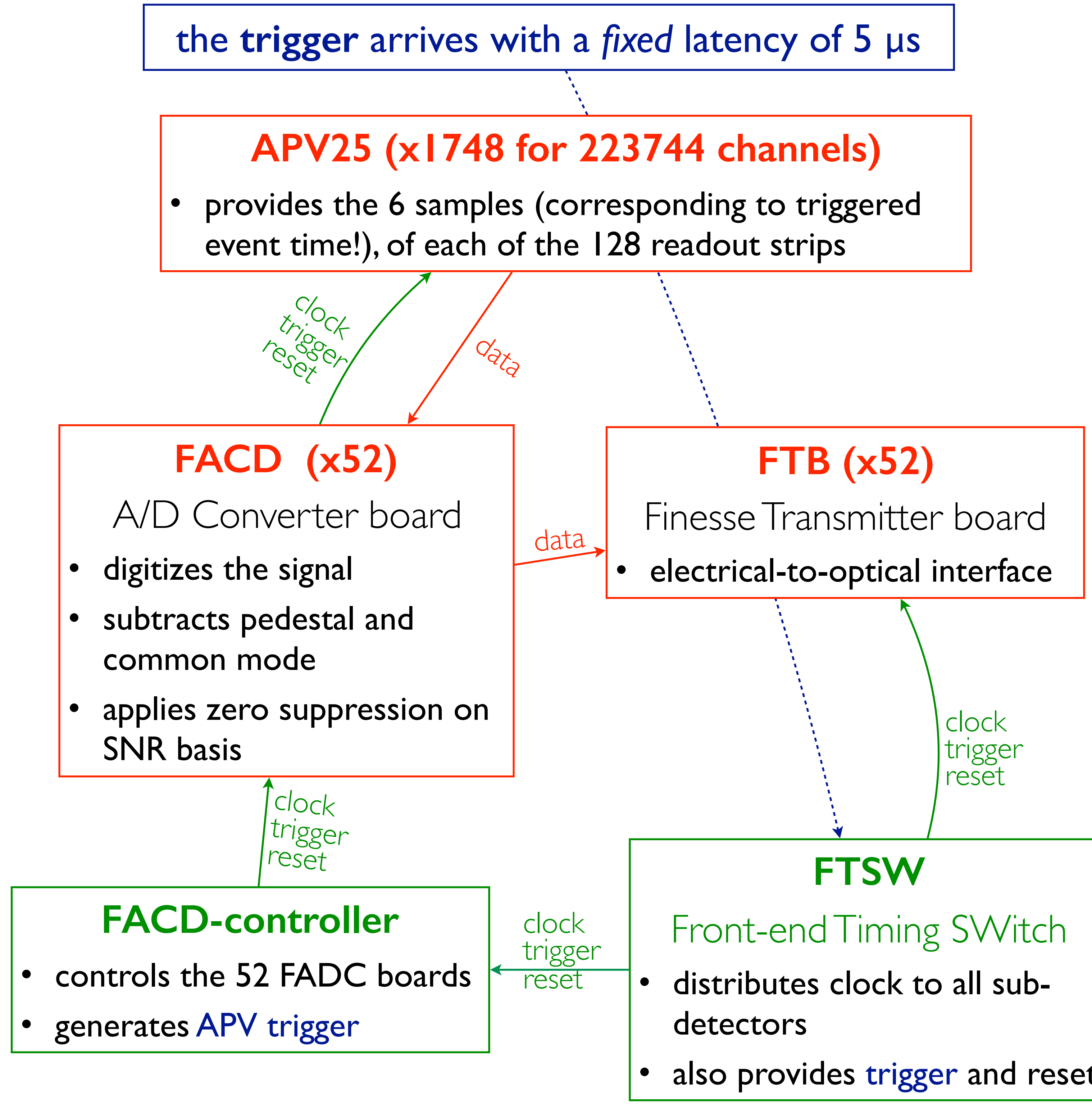
SVD Readout System

more details in Poster 67-B:
"Series Production Testing, Commissioning and Initial Operation of the Belle II Silicon Vertex Detector Readout System" by R. Thalmaier

The readout chip: APV25

- ➡ originally developed for CMS
- ➡ shaping time of 50 ns
  → low occupancy
- ➡ thinned to 100 μm
  → low material budget
- ➡ operated in multi-peak mode @ ~32 MHz, equipped with a 192 deep analog pipeline
- ➡ APV clock synchronised with bunch crossing frequency of ~ 8x32 MHz





SVD Timeline

more details on background in Poster 39-B:
"Measurements of Beam Background at SuperKEKB"
by L. Santelj

Phase2 SVD

Phase2 experiment

- data from e^+e^- collisions @ $\Upsilon(4S)$ energy
- with an incomplete *Belle II* detector (no final-version VXD)
- with a **reduced-scale vertex detector** and
- dedicated beam-background detectors

Phase2 main goals

- understand machine background
- understand detector performance
- detector subsystems commissioning
- detector calibration, …

focus of this talk is on detector performance

Phase2 collisions dataset

L = 500/pb

March 2019

collisions @ high luminosity

SVD

- **2008** – project started
- …
- **2017** september – beginning of +X half shelf ladder mount
- **2018** february – beginning of −X half shelf ladder mount
- july – SVD standalone commissioning of the two half shells
- october – PXD+SVD integration
- PXD+SVD commissioning
- november – PXD+SVD insertion
- **2019** mid january – *Belle II* global cosmics run

SVD

VXD

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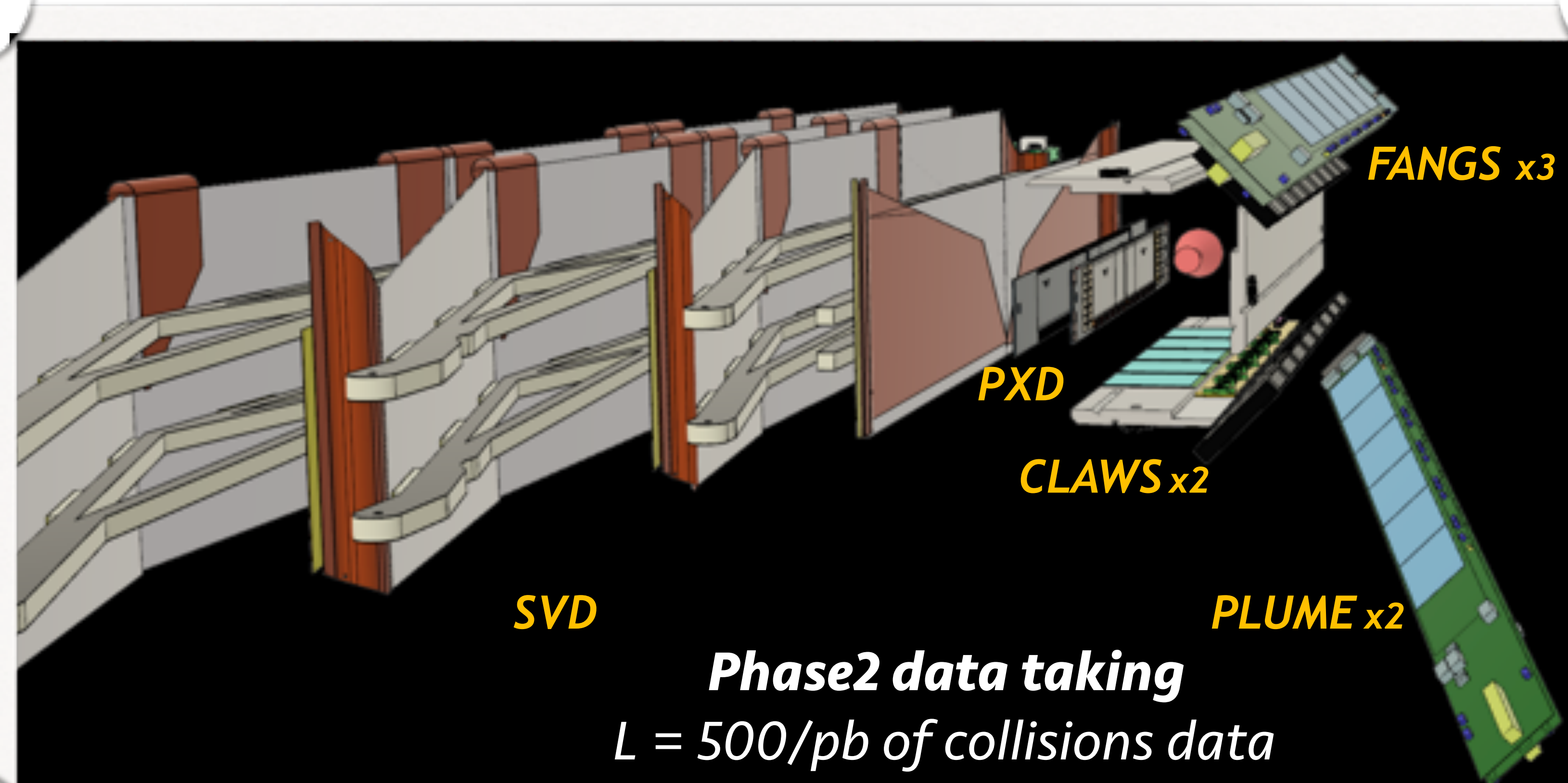
- ☑ The Belle II Silicon Vertex Detector
- ☑ SVD Commissioning
  - highlights from small-scale SVD operations in global data taking

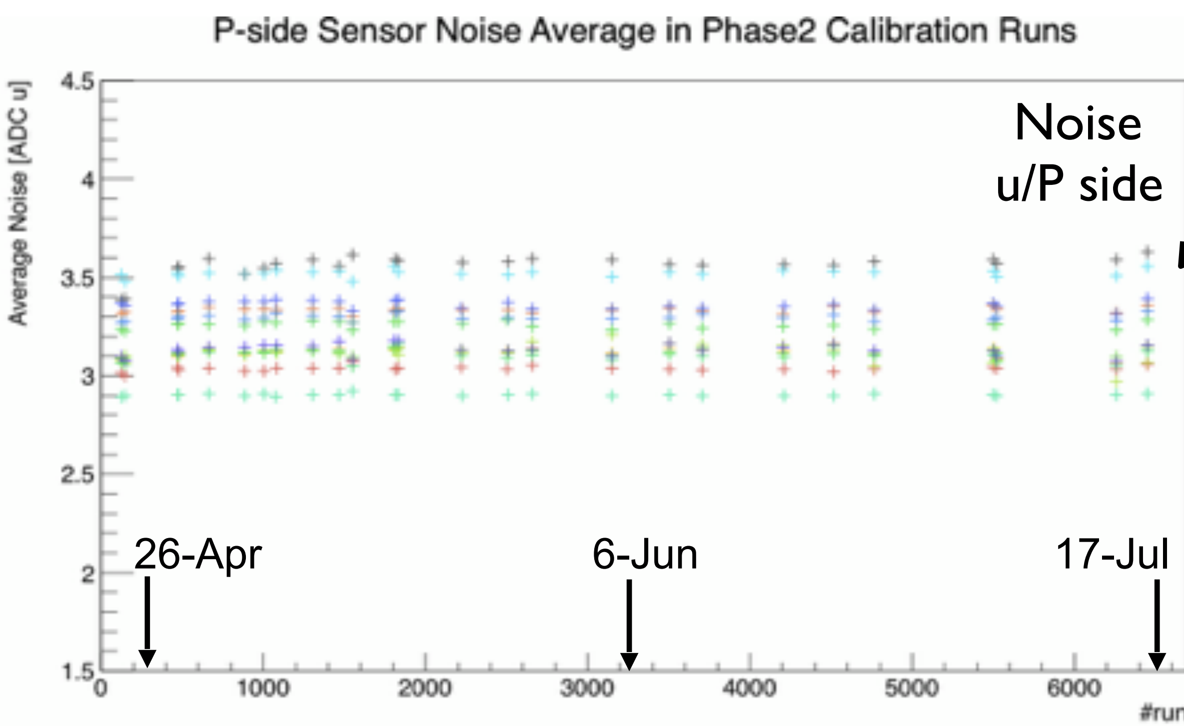


SVD in Phase2 Global Data Taking

☑ Phase2 SVD detector was operated since the beginning of Phase2, taking data in all runs

1. important experience gained in operating a *small-scale SVD* (14 vs 172 sensors) for what concerns **detector calibrations stability & subsystems commissioning**

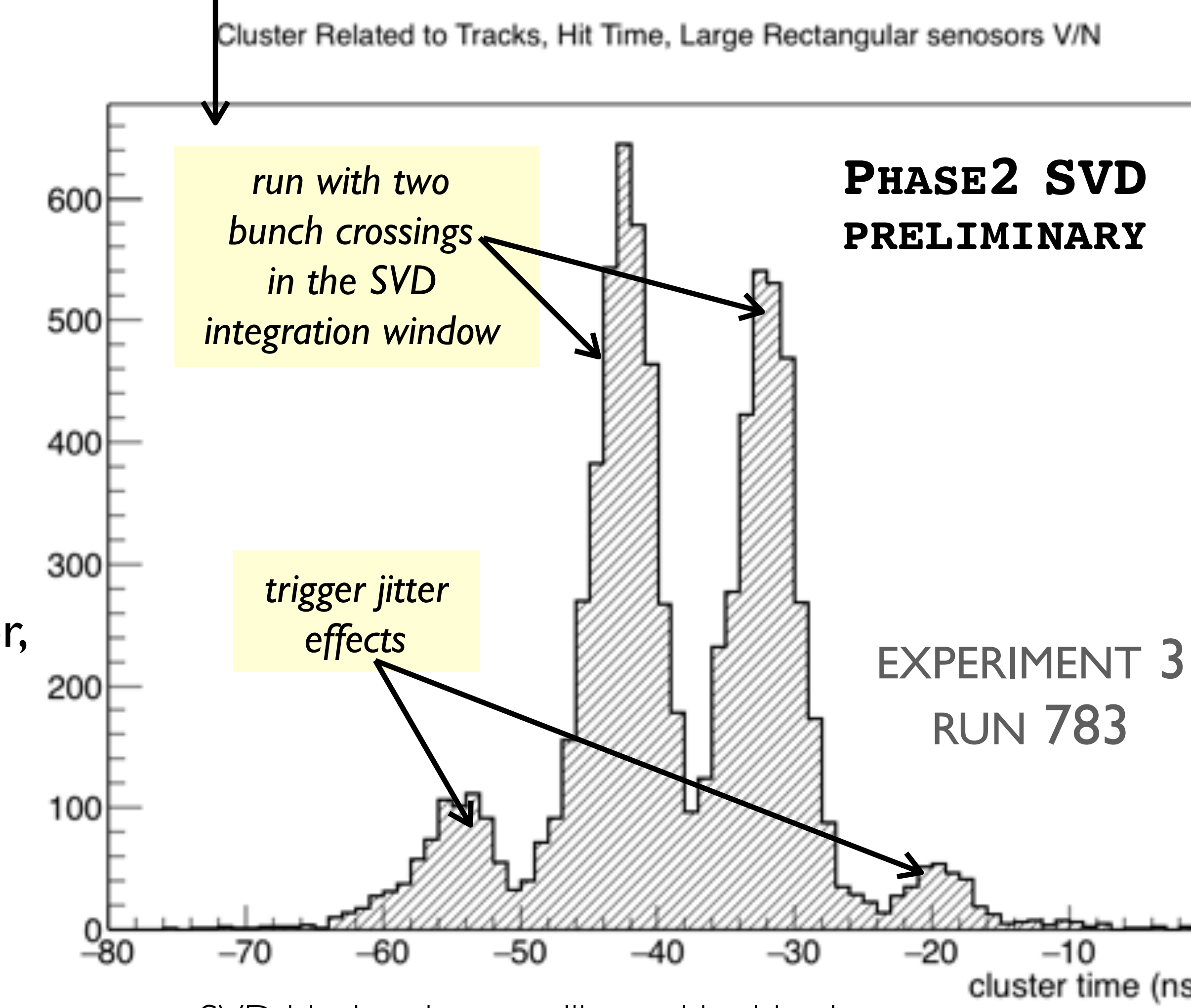
very stable calibration constants (gain, noise) of all sensors, over Phase2 running



2. test of **sensor response to MIPs from IP**
   - *sensor efficiencies above 97%* for all-except-one sensor, good considering class B sensors have been used

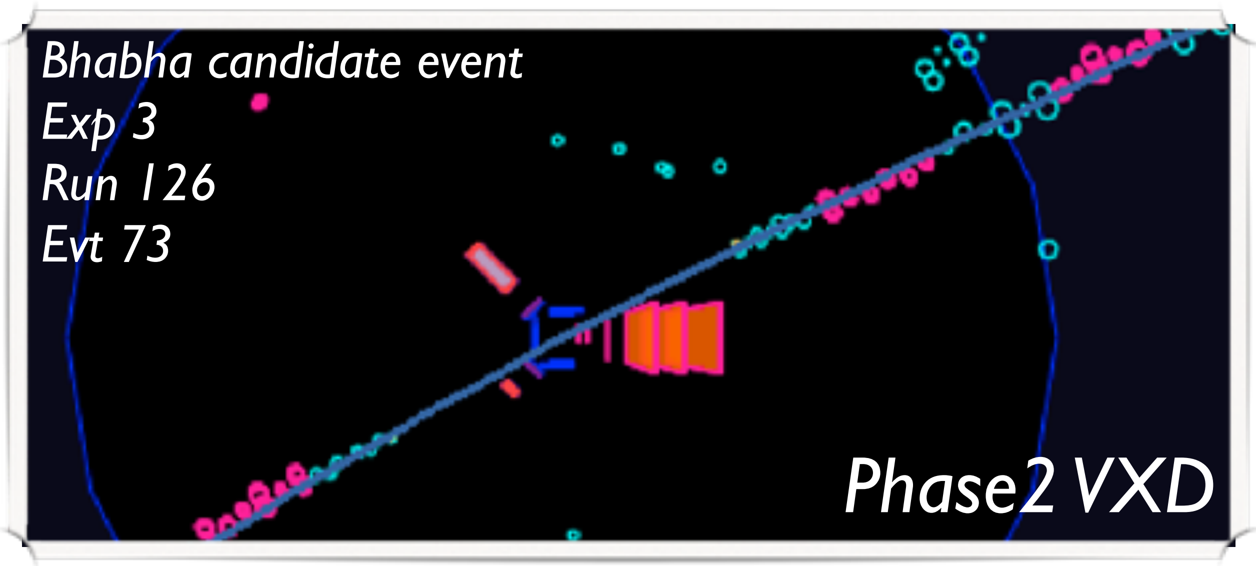
3. confirmed *impact of SVD reconstruction on tracking*, even if with only one ladder per layer

SVD sees bunch crossings 16 ns apart



note: SVD hit time is not calibrated in this plot

SVD Impact on Tracking in Phase2



➡ Phase2 SVD covers a small azimuthal, nonetheless measurements of tracks with SVD hits confirmed that:

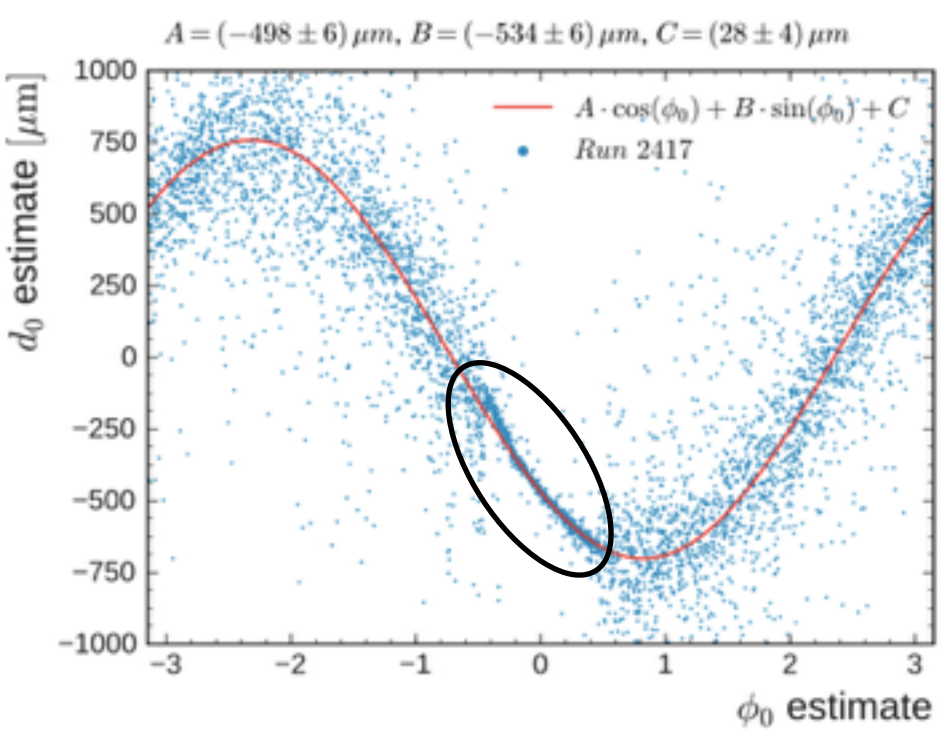
- svd-only tracking is working
- outward extrapolation from SVD is working

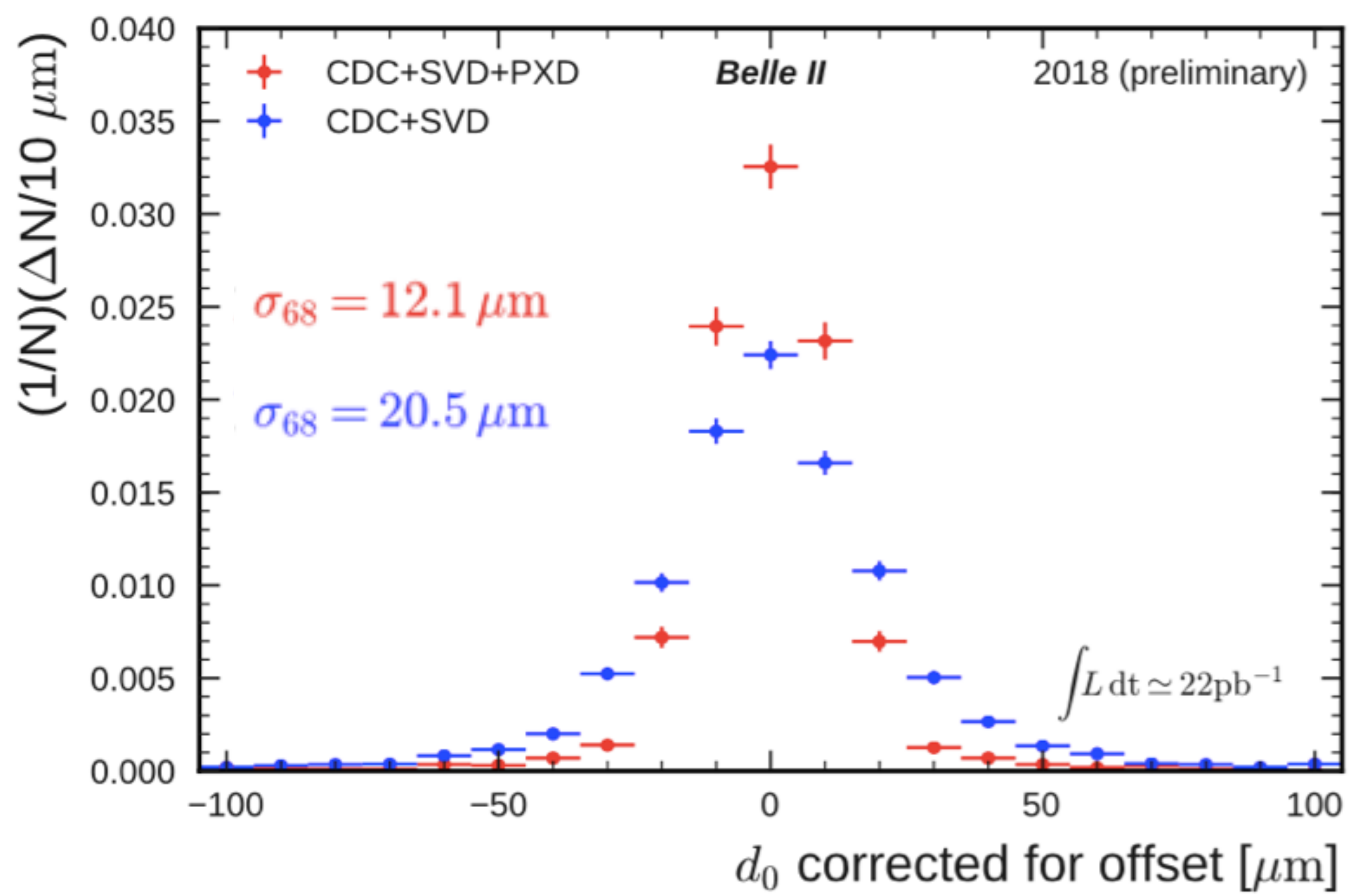
➡ track d_0 resolution ~ 20 μm (w/o PXD hits)

- innermost SVD layer at 3.9 cm from IP

➡ IP not in the nominal position, correlation between track parameters d_0 and φ_0

- evident improvement of the resolution in the VXD direction

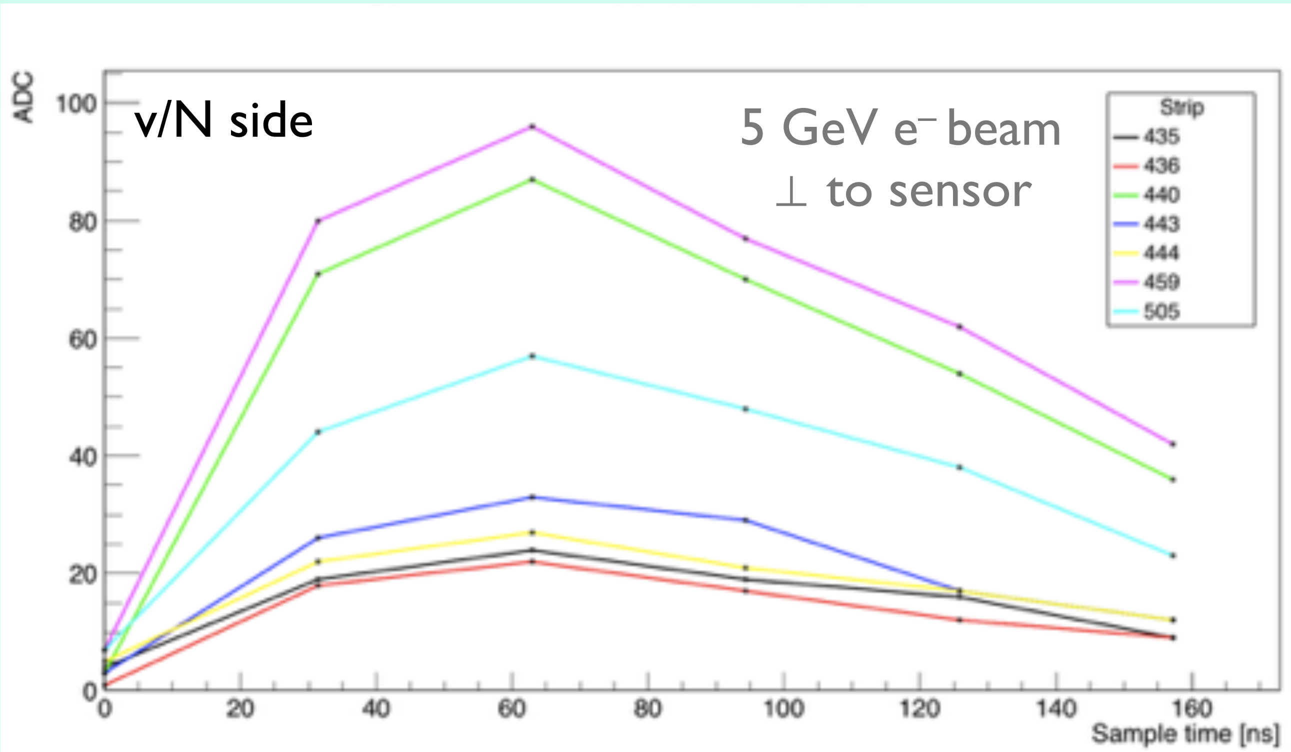




The SVD Hit Time Determination

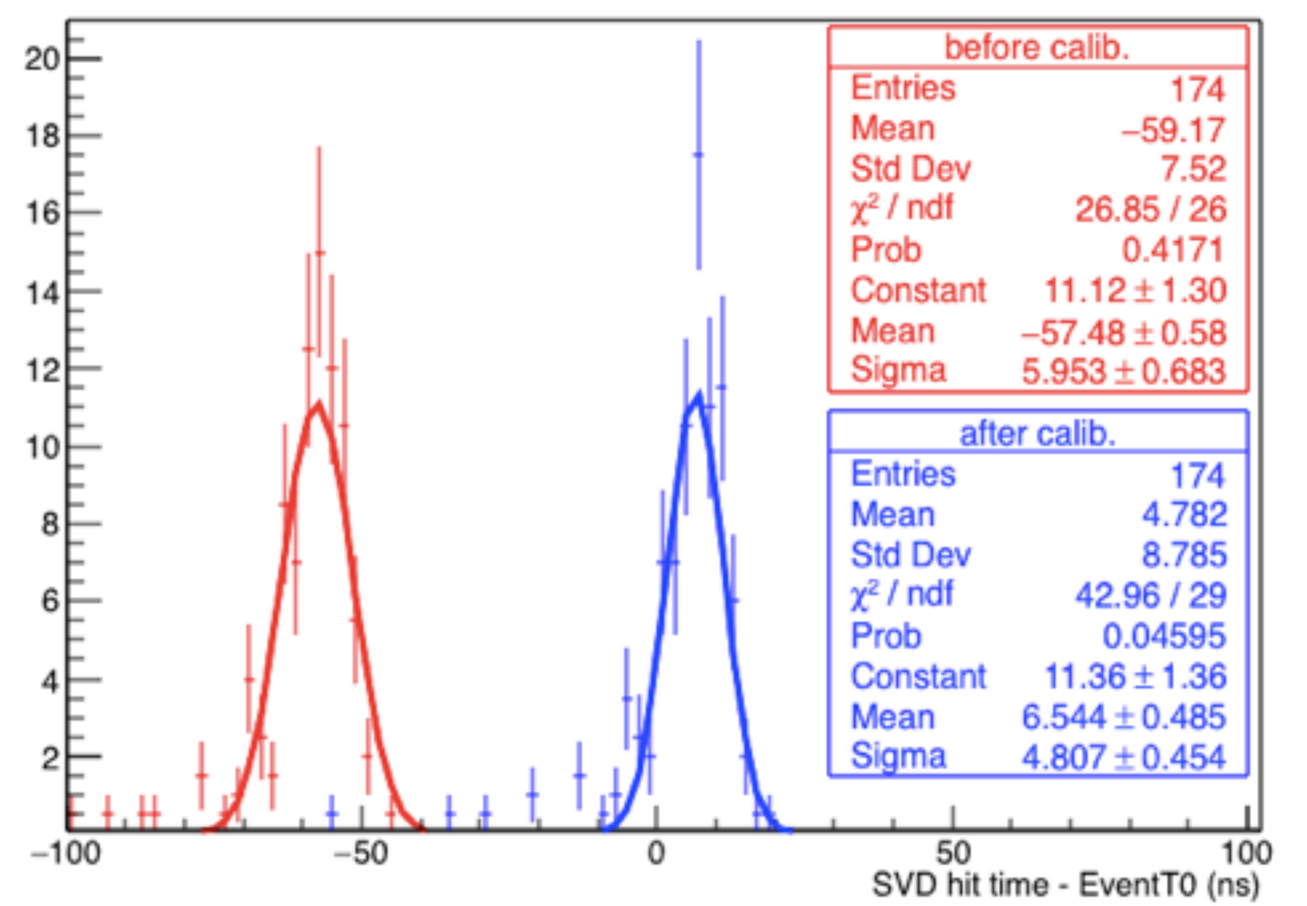
- Precise determination of the SVD hit time is crucial for the tracking performances at nominal luminosity
  - most of the beam background hits come from particles generated at past bunch-crossings with respect to the triggered event
  - rejection of off-time hits significantly reduces the beam background occupancy

main ingredient: 6 samples provided by the APV25, after digitisation, pedestal and CM subtraction



- SVD time *before* the calibration:
  - $(t_{raw} - t_0)$ resolution ~ 6 ns
- SVD time *after* calibration (with event time t_0)
  - $(t_{SVD} - t_0)$ resolution ~ 5 ns

SVD Hit Time – EventT0 provided by the drift chamber



☑ Strong indication of excellent time resolution of hits from tracks coming from the interaction point

EventT0 estimation error included in the $(t_{SVD}$ - EventT0) width

Outline

- The Belle II Silicon Vertex Detector
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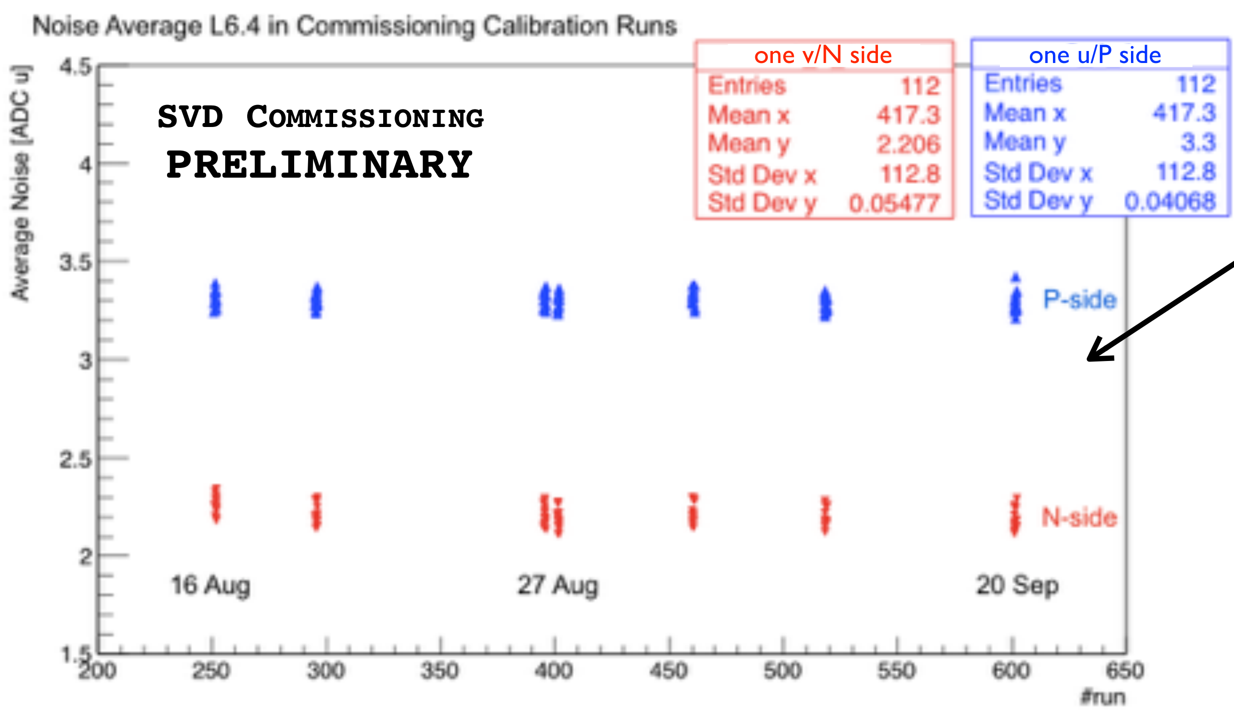
  - final detector commissioning
- First Results from Global Cosmic Runs

SVD Standalone Commissioning

☑ The Final SVD detector has been successfully commissioned summer last year

➡ Only minor problems observed, related to cooling, very few sensors showed some issues, not serious

1. **detector calibrations stability** confirmed as observed with small-scale SVD in Phase2



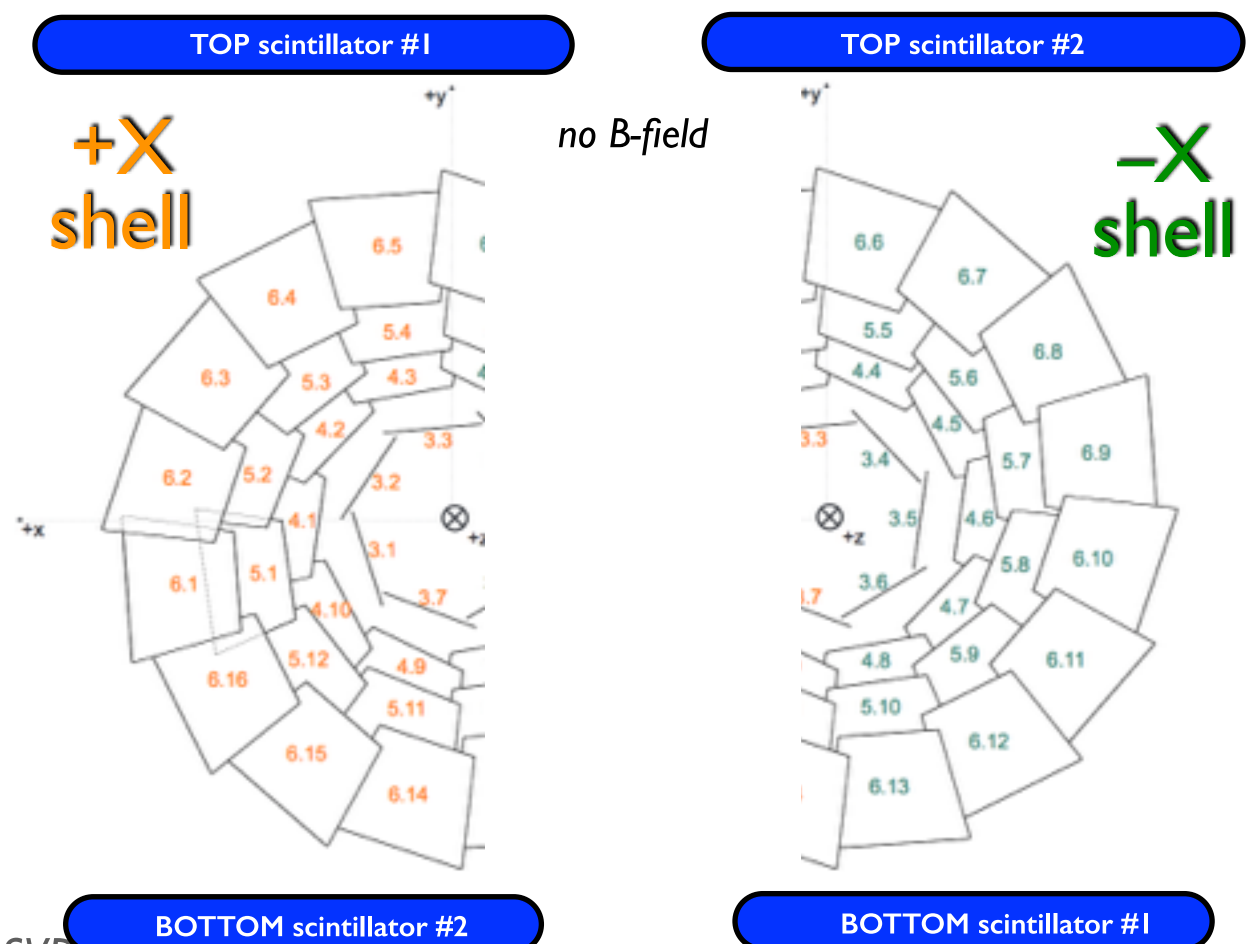
very stable calibration constants (gain, noise) of all sensors, over 2 months of running

note: one point represents a sensor of layer 6 ladder 4

SVD commissioning setup

triggers provided by scintillators coincidence:

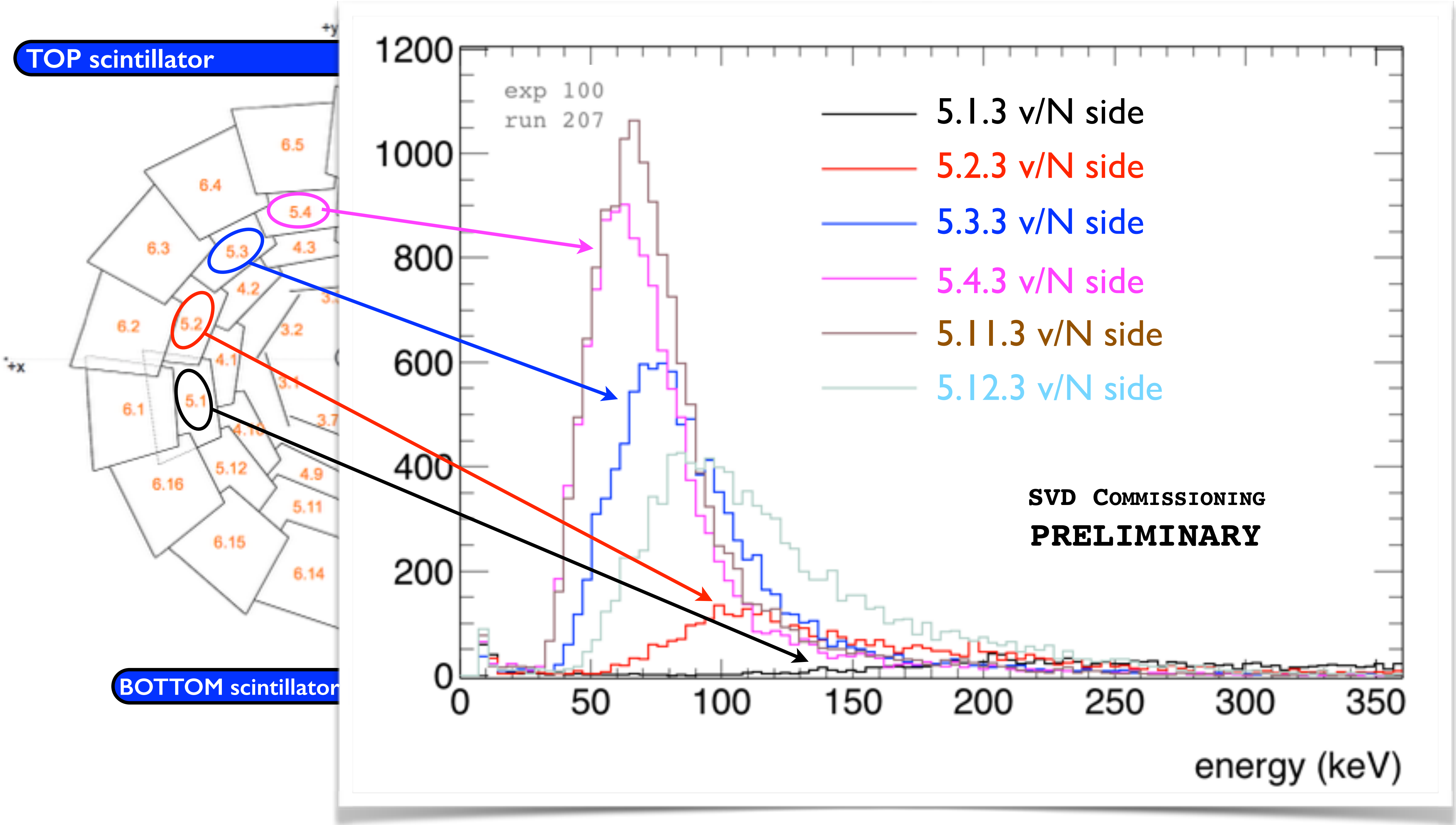
- *~jitterless*
- *asynchronous with respect to SVD readout clock*



2. useful dataset to test the final detector **sensors response to MIPs** (not from IP!)
   - reconstruction versus track incident angle
   - *sensor efficiencies above 99%* for most of the sensors, details later

Cluster Energy VS Azimuthal Angle

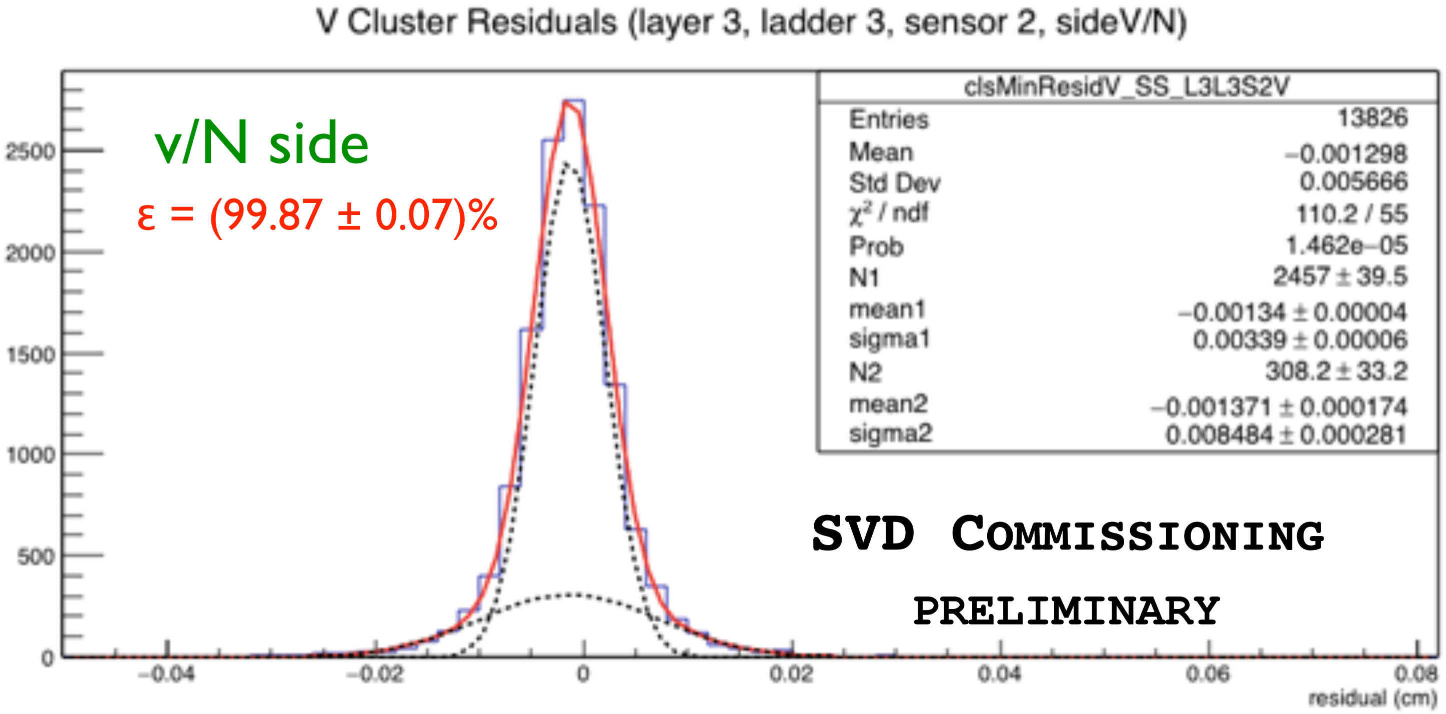
➡ Cosmic rays cross vertical layers with a larger incident angle with respect to horizontal layers

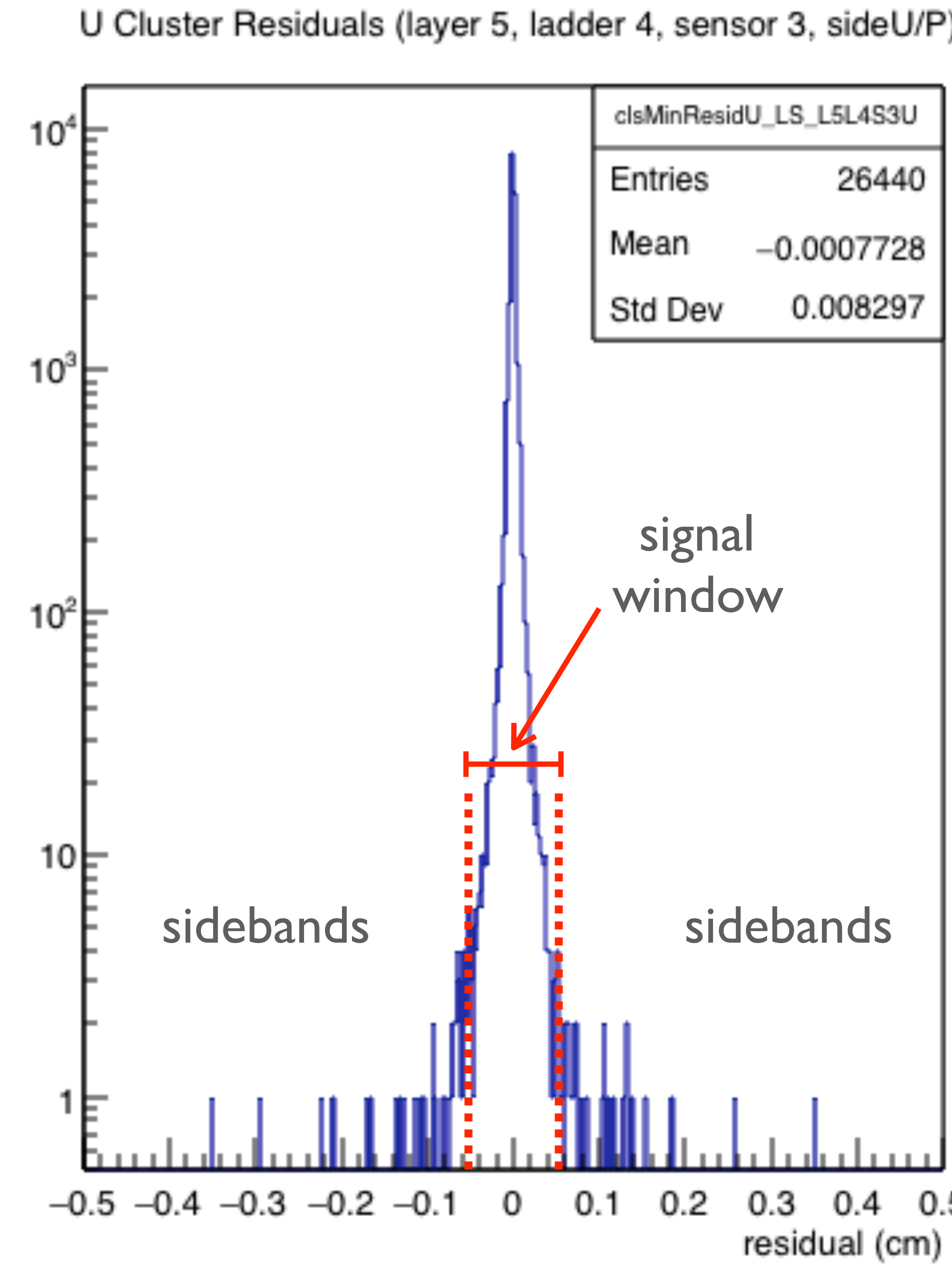


Concentrate on *horizontal sensor* to study the ⊥ track incident angle use-case

Final SVD Sensor Efficiency with Cosmics

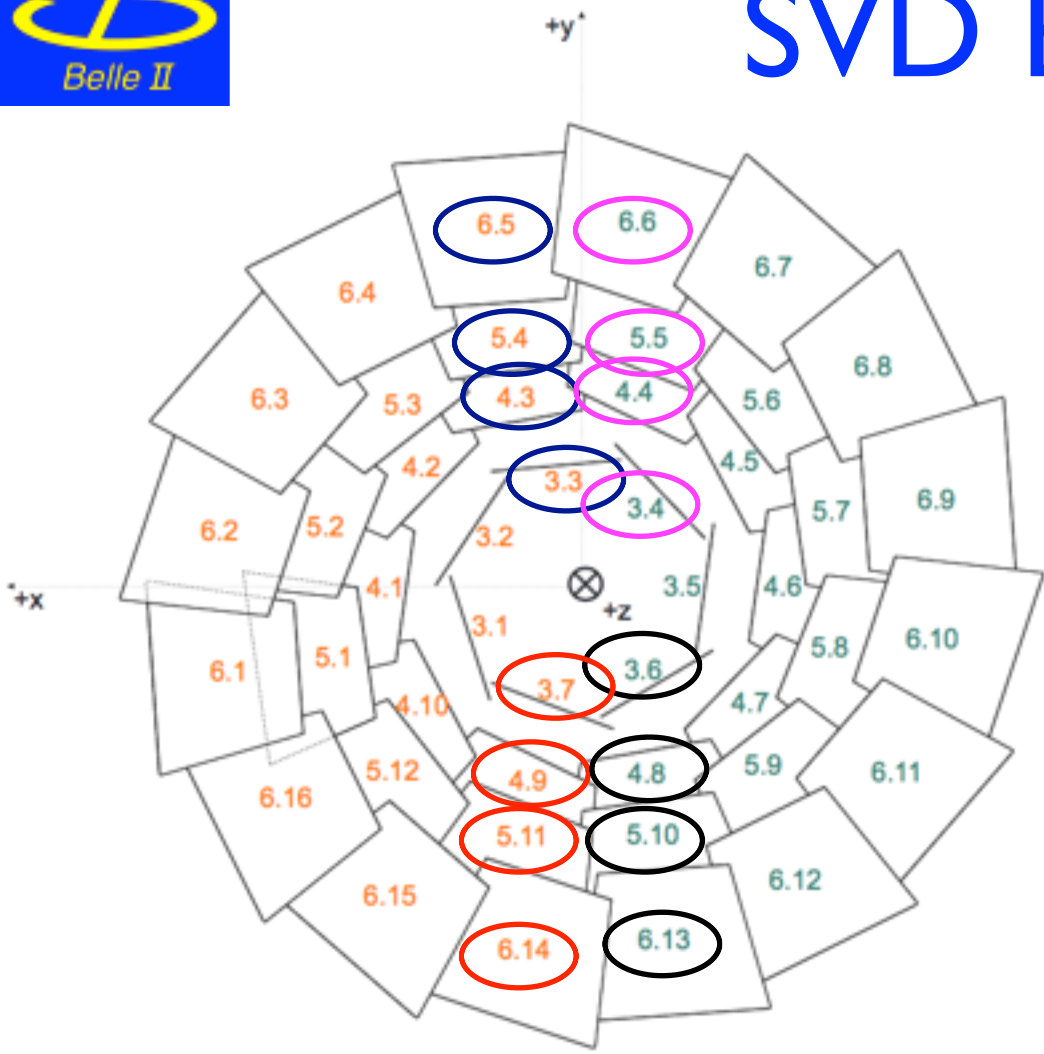
- Sensor efficiency estimated using cosmic tracks in ~10M events
- Tracking reconstruction *excluding* the sensors belonging to the layer under study, and applying quality cuts on clusters used in the pattern recognition and on the track
  - fiducial region for the extrapolation of the track to the sensor plane
- efficiency defined as the ratio between the background-subtracted clusters in the signal window (1mm wide) and the number of tracks extrapolated to the sensor plane
  - background clusters in the signal window estimated rescaling the number of clusters counted in the sidebands





- Cluster residuals distribution width *does not provide* a measurement of the cluster position resolution: the intercept extrapolation error contributes to the residuals but can't be determined without B-field

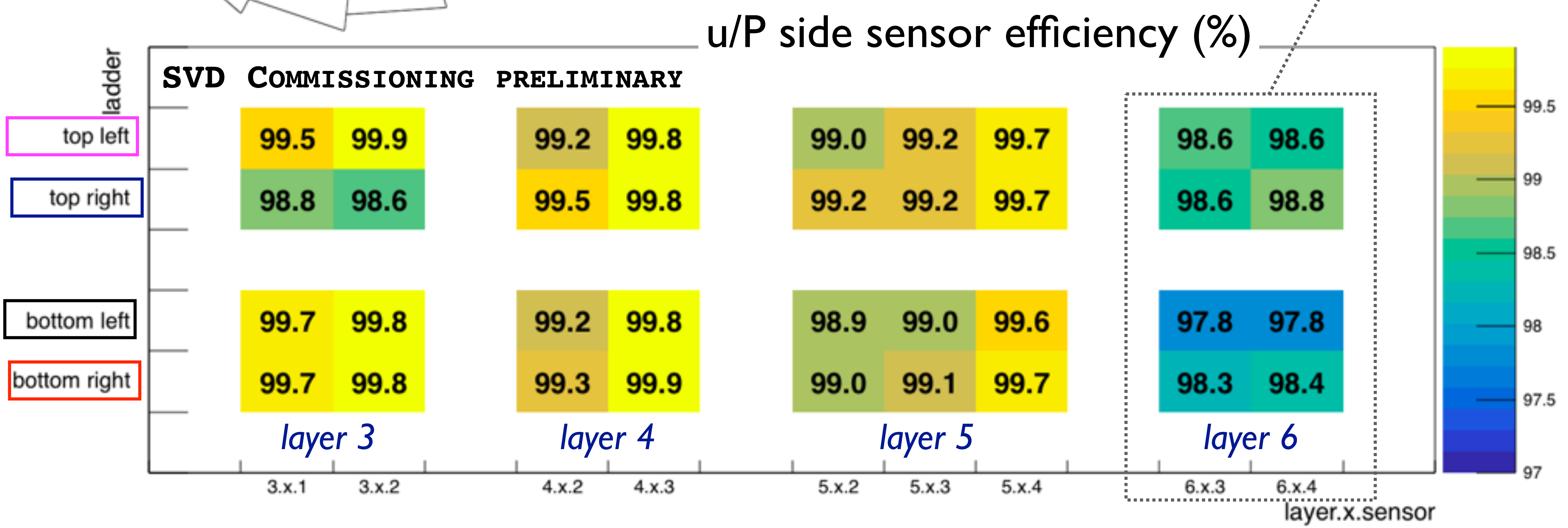
SVD Efficiency, u/P side



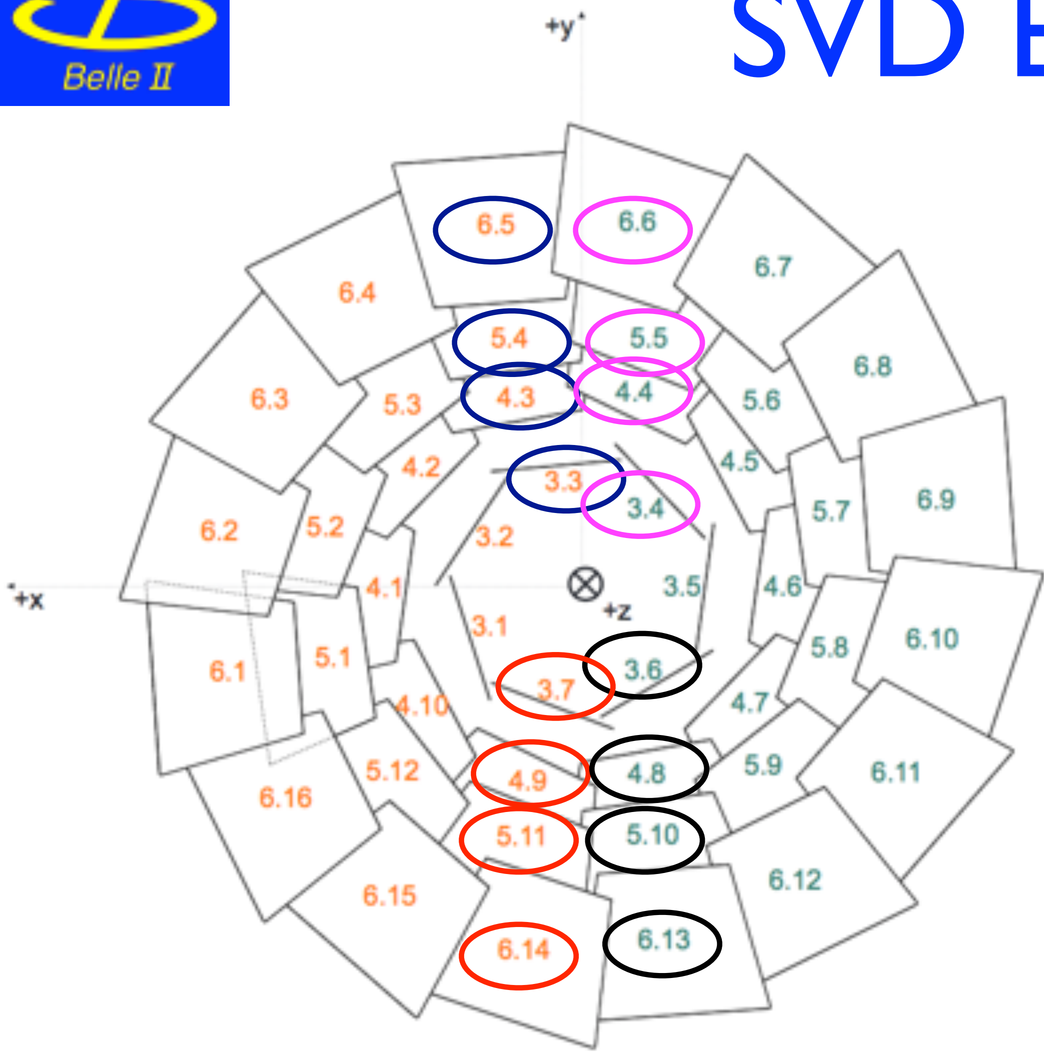
- ☑ efficiencies around/above 99% for sensors of the three innermost layers
- ☑ slightly lower efficiencies on layer6, but still around 98%, above 97.4%

- all sensors are expected to have efficiencies compatible with the one estimated estimated with horizontal sensors
- statistical-only error < 0.1 %

lower since no tracking device placed outside L6



SVD Efficiency, v/N side



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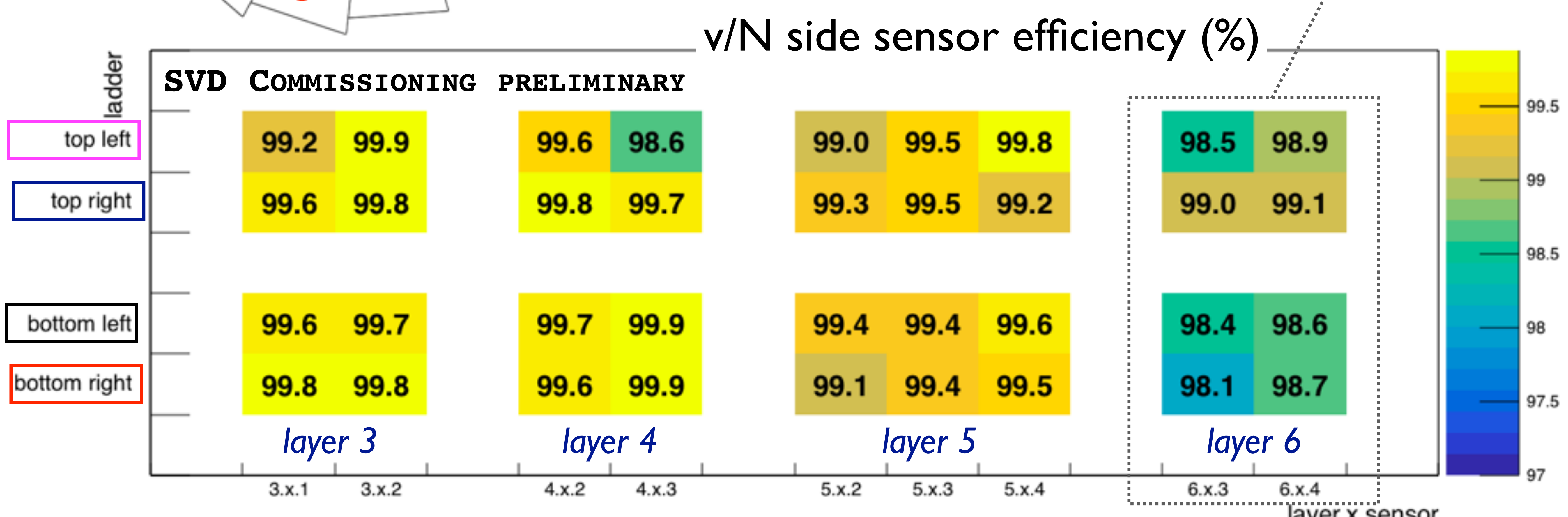

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- ☑ ***First Results from Global Cosmic Runs***

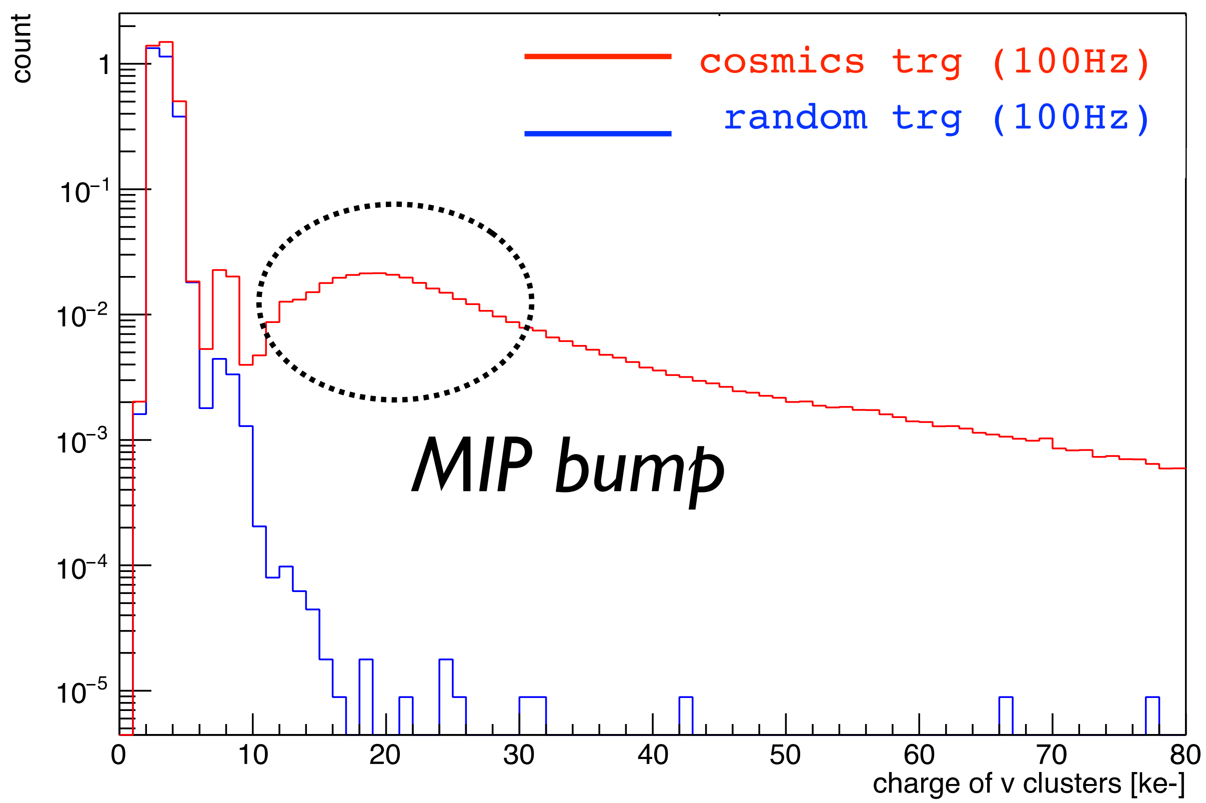
SVD Final Destination

☑ The *Belle II* vertex detector has been successfully installed and integrated in the *Belle II* DAQ

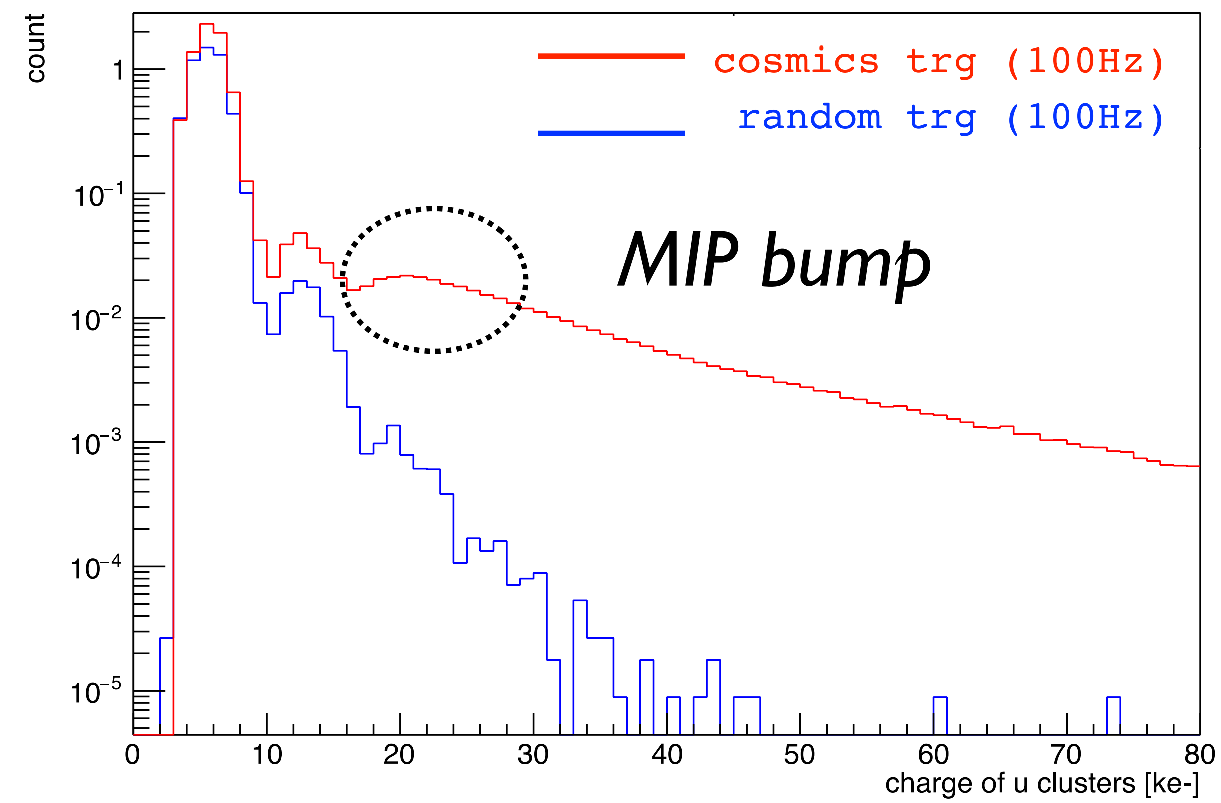
- Since mid January SVD is included in *Belle II* global runs:
  - random triggers with variable trigger rate, 1 - 30 kHz
  - cosmics triggers, ~ 150 Hz (actually 5 Hz for tracks in SVD acceptance)
  - cosmic + random triggers, variable trigger rate, 2 - 20 kHz
- Successful operations up to now:
  - all sensors are working, with cluster energy and SNR expected from MIPs

more details on SVD operations in Poster 66-A: "Run and Slow Control of the BelleII Silicon Vertex Detector" by C. Irmler

all-clusters charge for v/N side



all-clusters charge for u/P side



Track-related Cluster Energy

N — V side
P — U side

☑ most probable cluster energy as expected from MIPs, around 80 keV

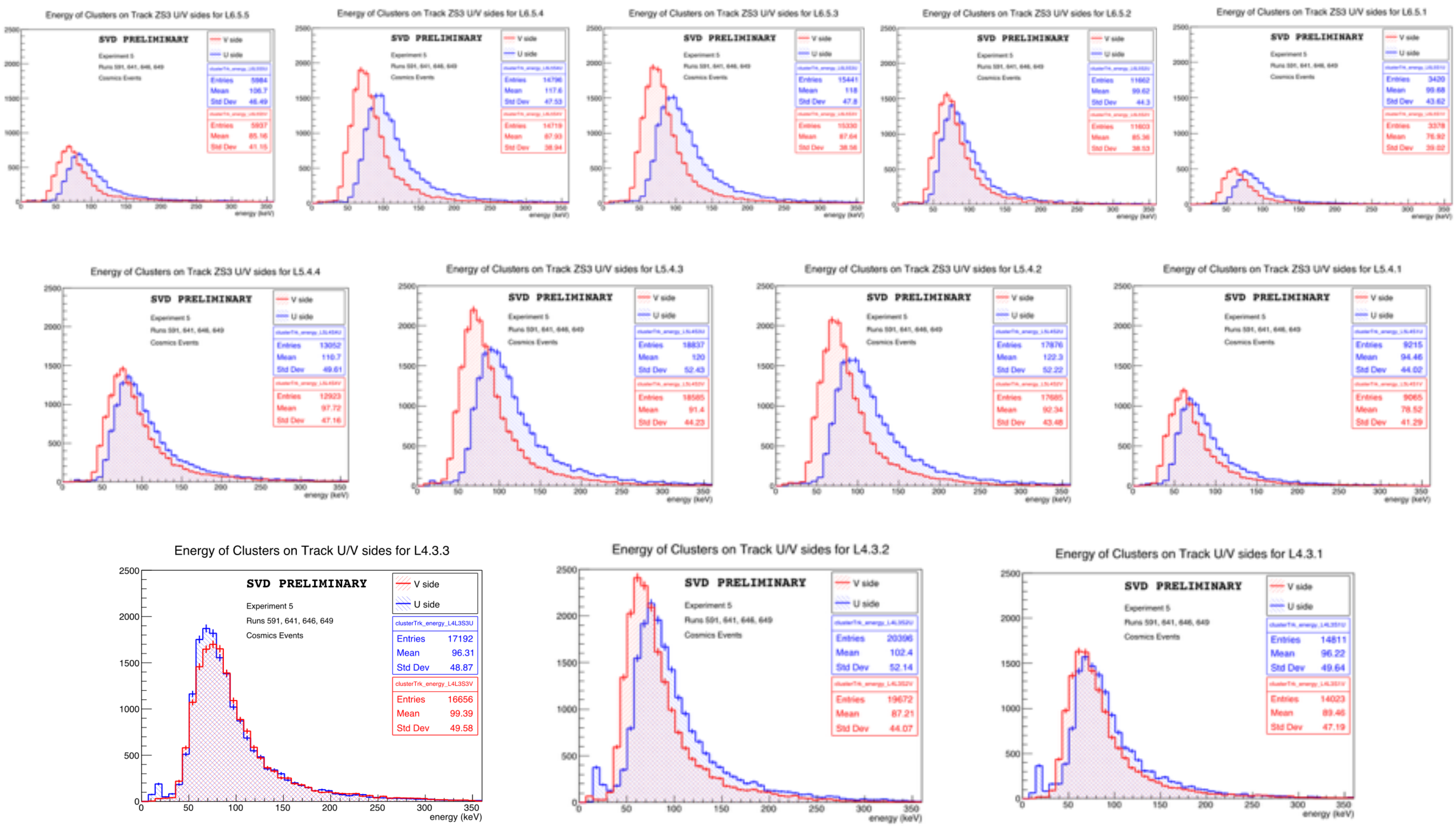
CDC

layer 6

layer 5

layer 4

IP



backward

forward

note: *layer 3 in slide 23*

Track-related Cluster Energy

N — V side
P — U side

most probable cluster energy as expected from MIPs, around 80 keV

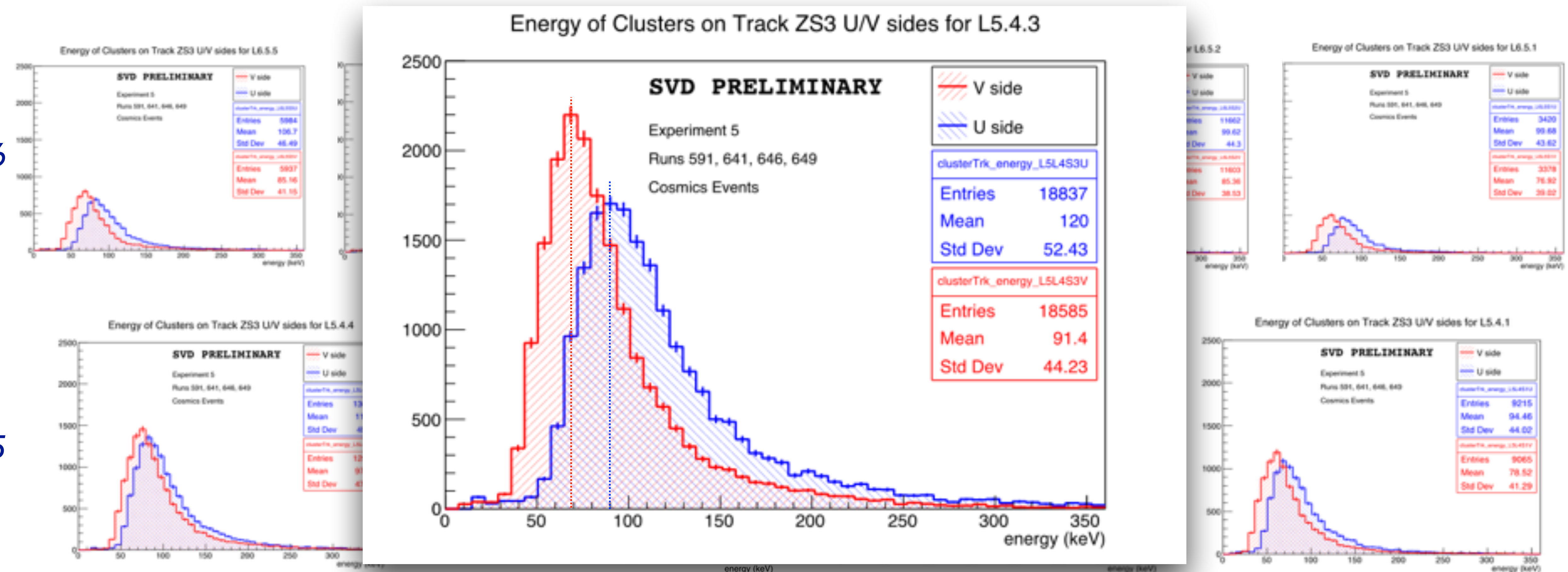
CDC

layer 6

layer 5

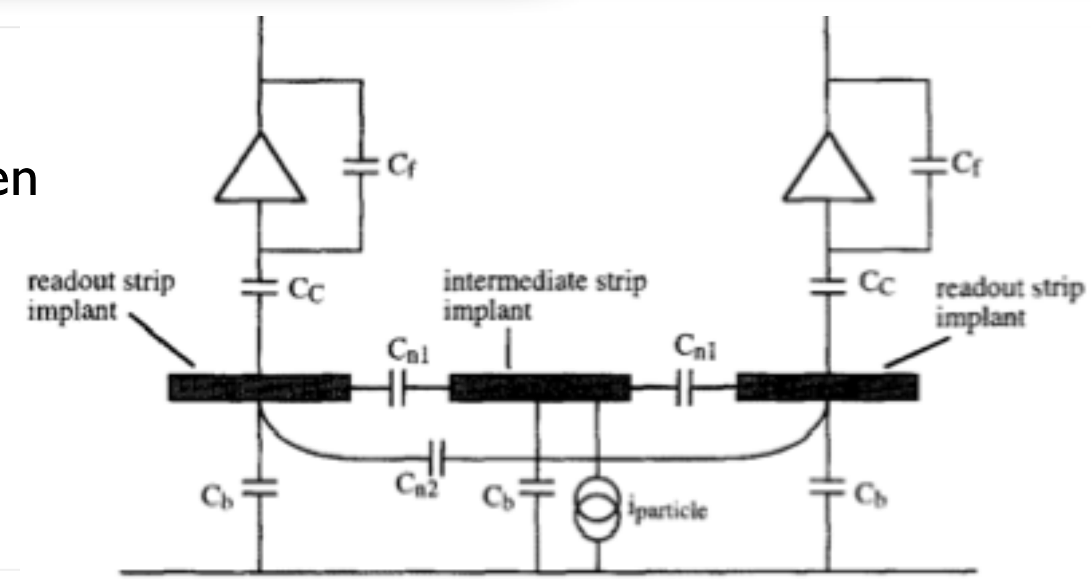
layer 4

IP



- ➡ Cluster energy *similar* for u/P and v/N sides
- ➡ 20% charge loss on N side due to coupling between floating and readout strip and large capacitance to the back side:
  - fraction of signal from floating strip to readout:

$$\frac{2C_i}{2C_i+C_b} \simeq 0.75(v/N), 0.9(u/P)$$



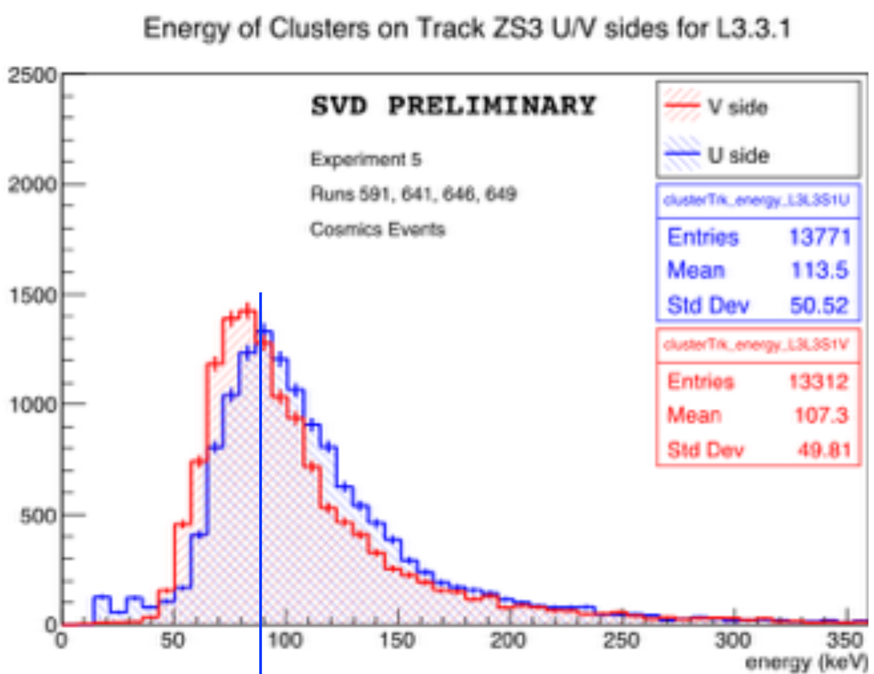
backward

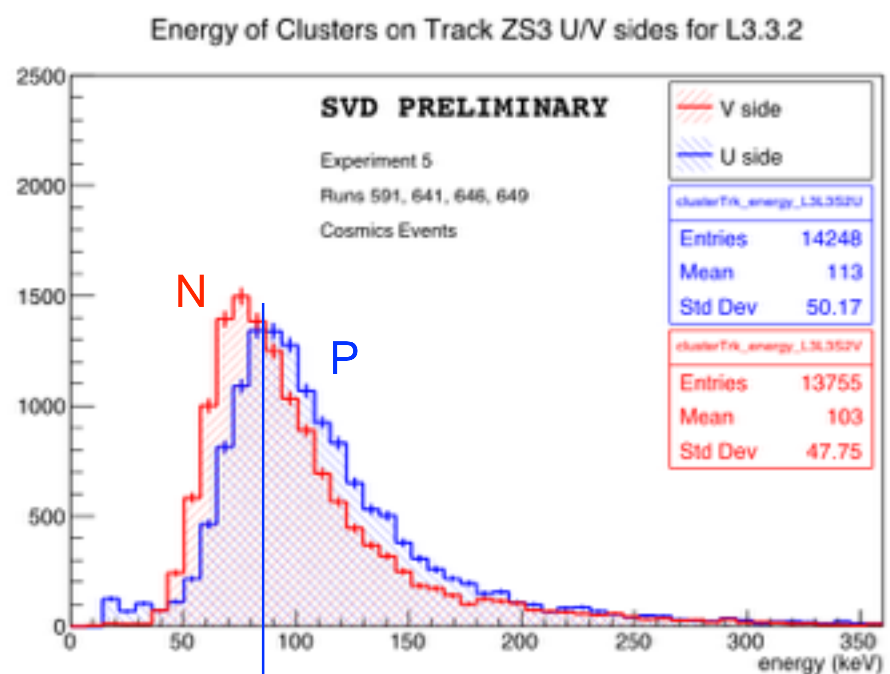
forward

note: *layer 3 in slide 23*

Cluster Energy, Zero Suppression Effect

nominal online zero suppression, SNR cut = 3:

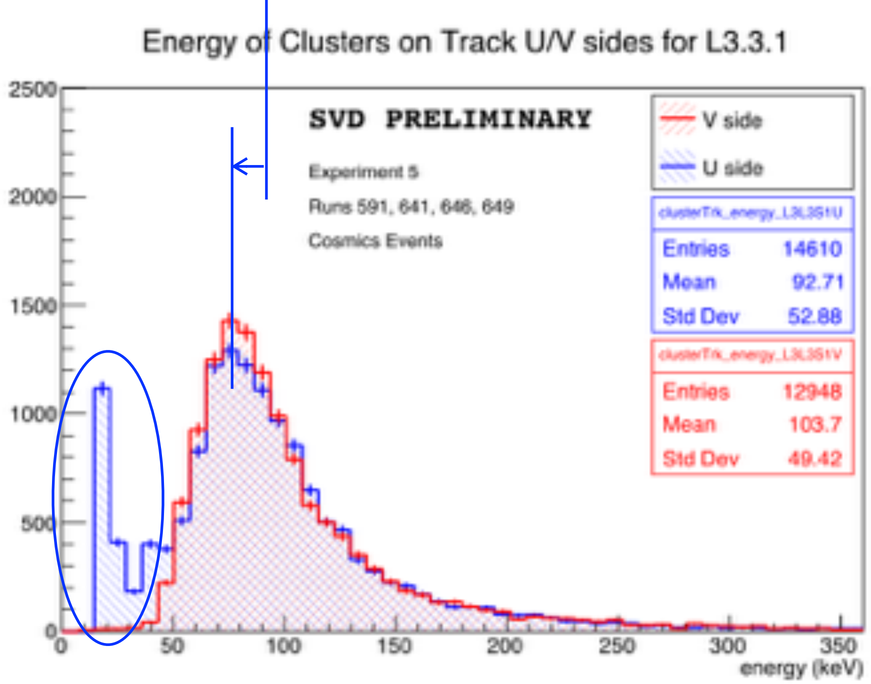


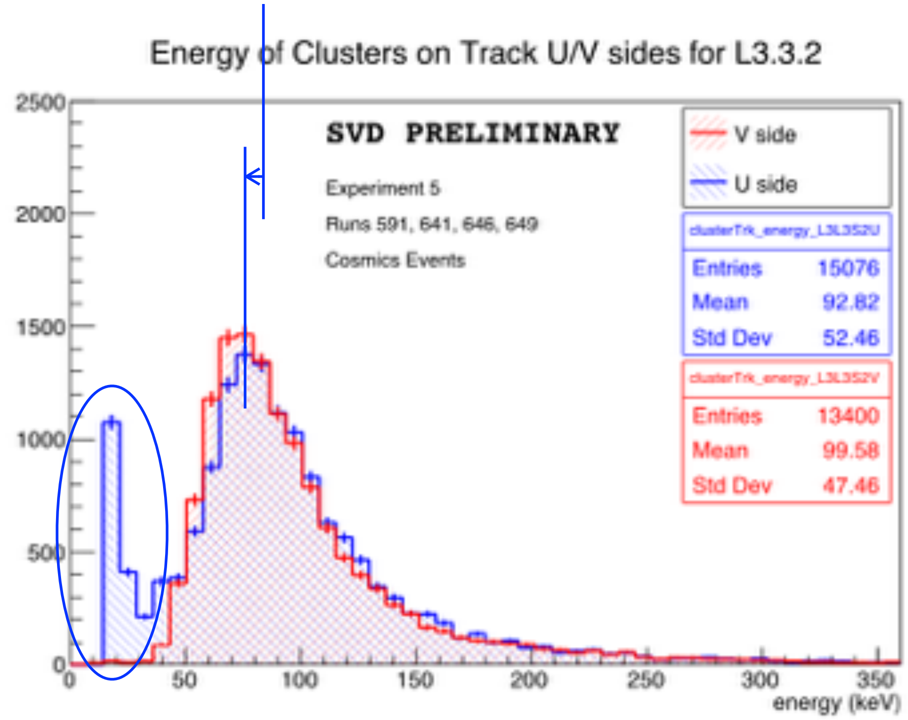


correct estimation of the cluster energy

online zero suppression: SNR cut from 3 to 5

higher online zero suppression, SNR cut = 5:



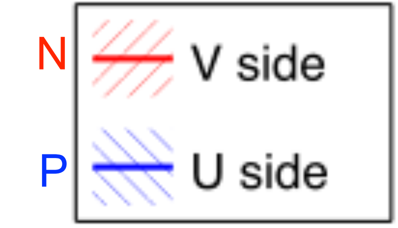


underestimation of the cluster energy of the u/P side:

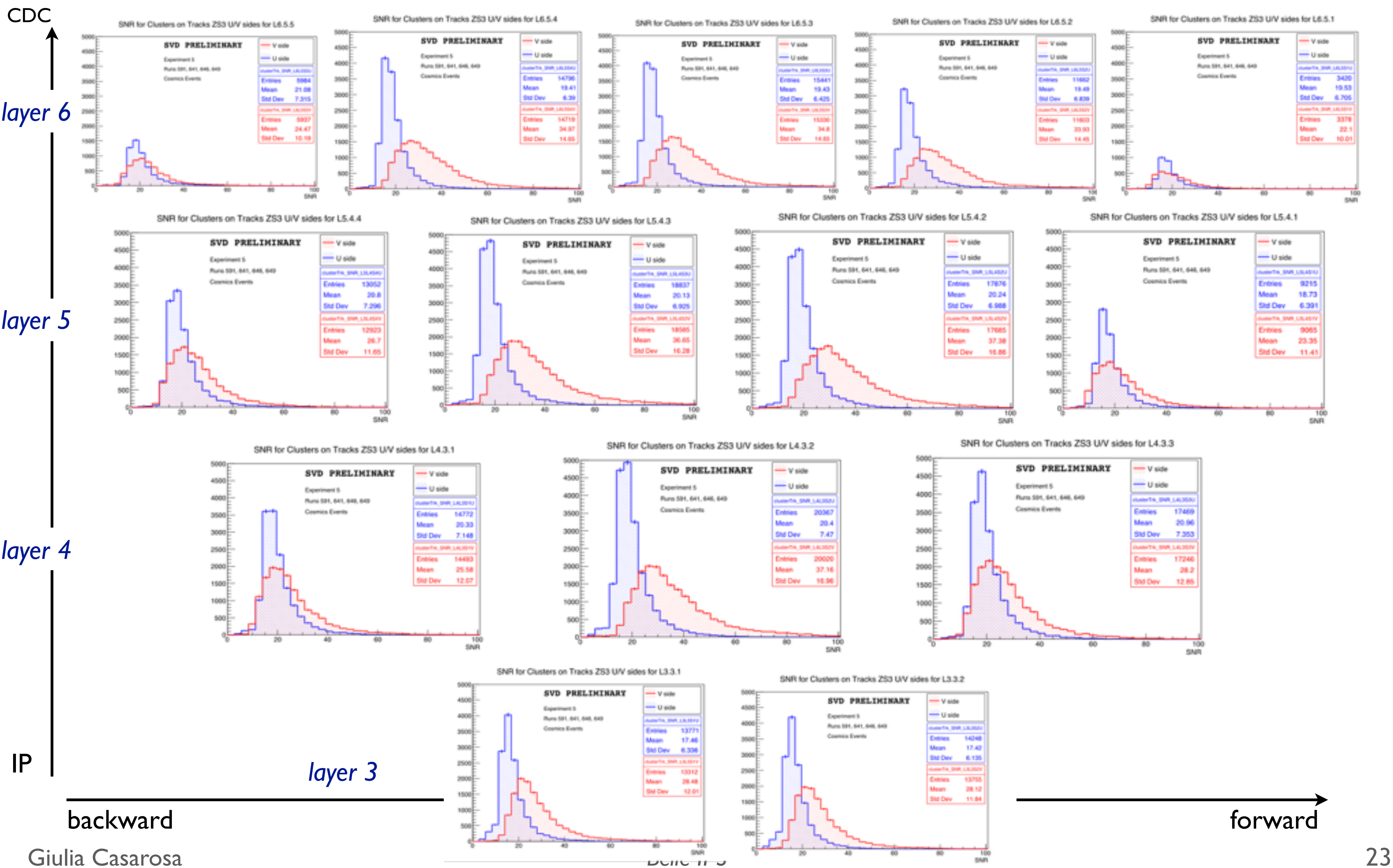
- MPV cluster energy shifted to lower energy
  - *loose strip(s) at the edge of the cluster*
- appearance peak at low energy
  - *cluster split effect*

note: effect observed in all players
note: higher SNR minimizes the effect on v/N side

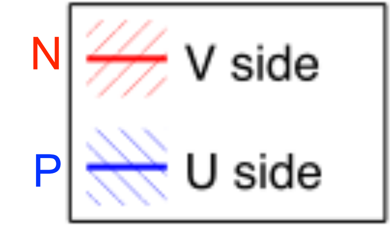
Track-related Cluster SNR



☑ good SNR for all sensors, as expected



Track-related Cluster SNR



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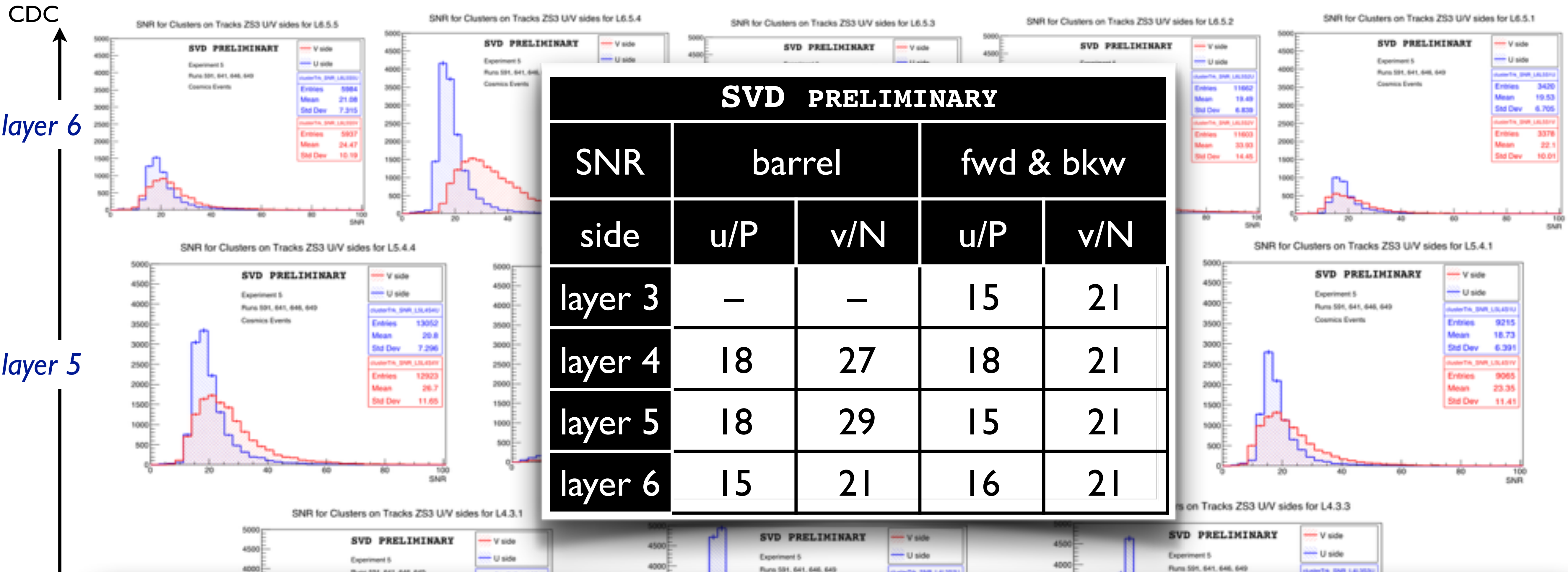


SVD PRELIMINARY

SNR	barrel		fwd & bkw	
side	u/P	v/N	u/P	v/N
layer 3	–	–	15	21
layer 4	18	27	18	21
layer 5	18	29	15	21
layer 6	15	21	16	21

$$SNR_{cls} = \frac{\sum_{strips} S_i}{\sqrt{\sum_{strips} N_i^2}}$$

- ➡ SNR depends on collected charge, strip noise ad cluster size
  - Noise u/P side (~900 e⁻) > Noise v/N side (~600 e⁻)
  - Signal u/P side > Signal v/N side
  - cluster size effect to be investigated
- ➡ The noise difference between the two sides is dominant with respect to cluster energy difference → higher SNR on v/N side

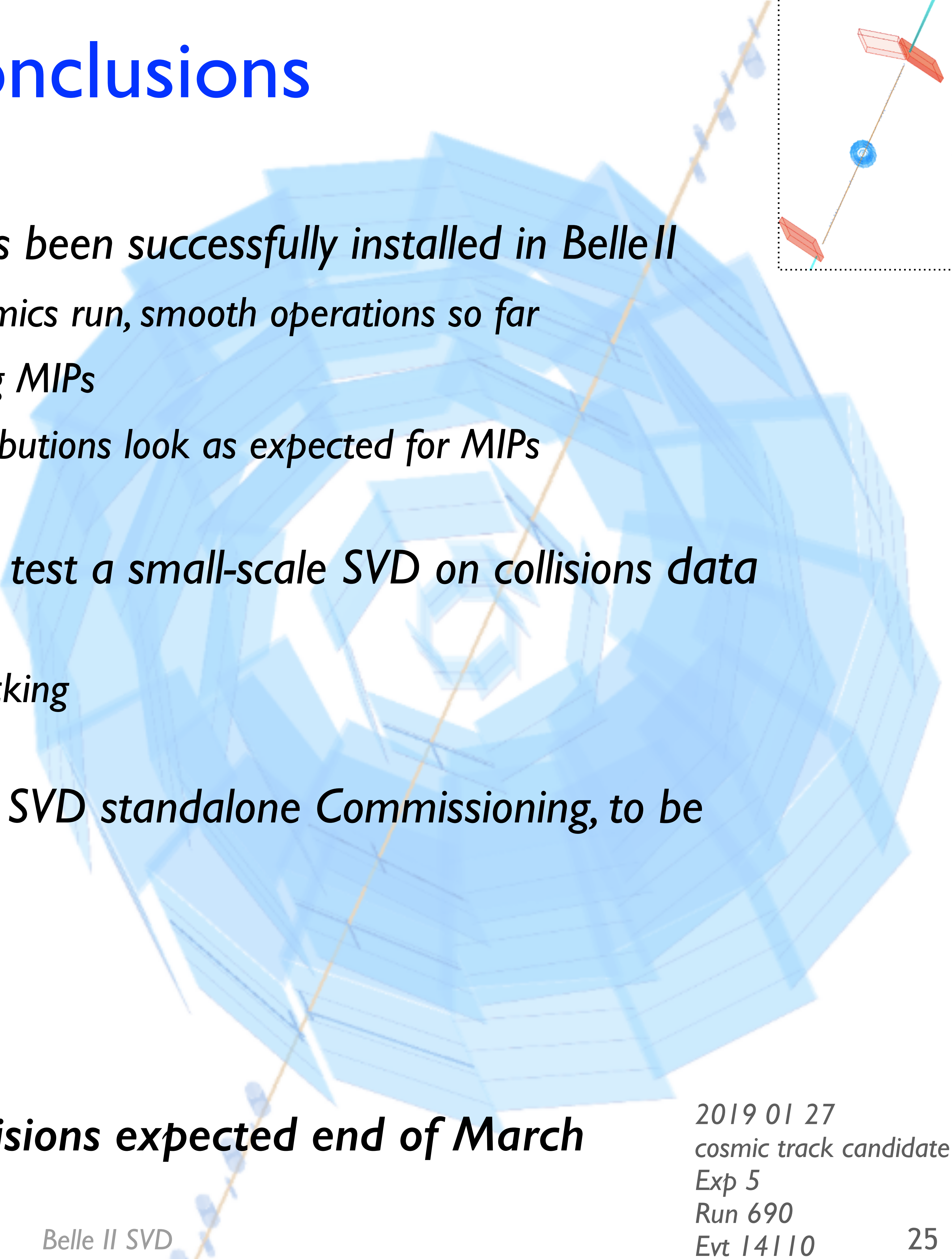
Conclusions

- *The Silicon Vertex Detector has been successfully installed in Belle II*
  - *SVD is included in global cosmics run, smooth operations so far*
  - *all sensors are alive, detecting MIPs*
  - *cluster energy and SNR distributions look as expected for MIPs*

- *Phase2 data taking allowed to test a small-scale SVD on collisions data*
  - *excellent time resolution*
  - *excellent feedbacks from tracking*

- *Promising indications from the SVD standalone Commissioning, to be checked in the next weeks*
  - *excellent sensor efficiency*
  - *excellent detector stability*

- ***Looking forward to first collisions expected end of March***

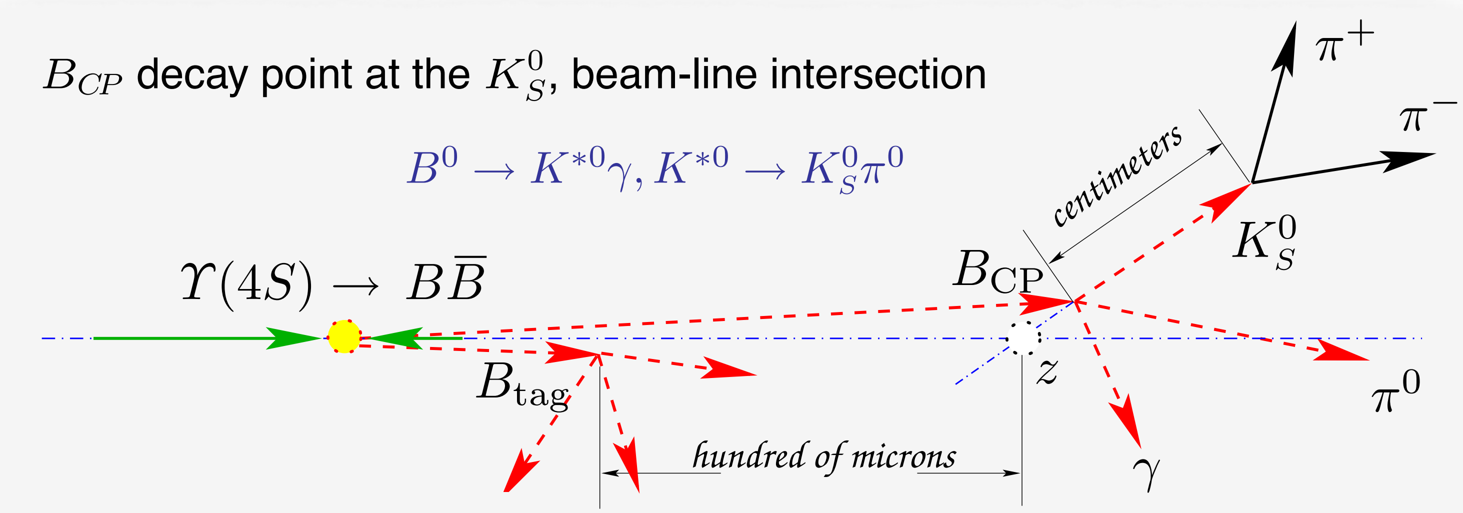


2019 01 27
cosmic track candidate
Exp 5
Run 690
Evt 14110

Thank you for your attention.

Vertexing at a B-Factory Experiment

➡ The Vertex Detector (VXD) provides the precise measurement of the primary and secondary vertices of short-lived particles



courtesy by E. Paoloni

➡ The most important factors affecting the *precision* of the vertex position determination are:

- the distance of the first measured hit
- the effect of multiple scattering

➡ Other important factors taken into account in the design are:

- single hit resolution
- impact of the machine background in terms of occupancy and radiation damage

Typical Υ(4S) Event

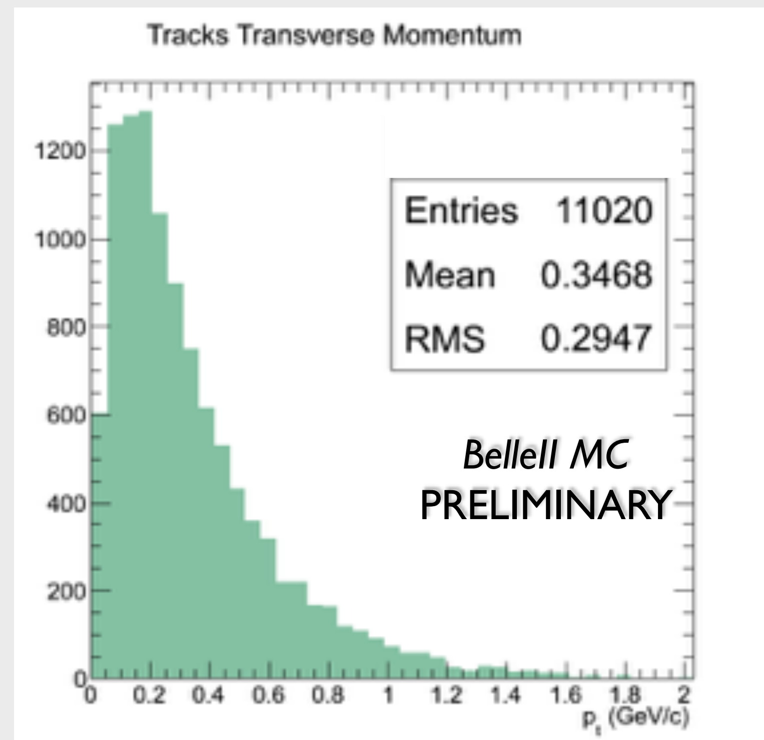
➡ Υ(4S) center of mass is boosted

- 7 GeV e^- on 4 GeV $e^+ \rightarrow \beta\gamma = 0.28$
- reduced boost w.r.t. Belle

➡ average multiplicities

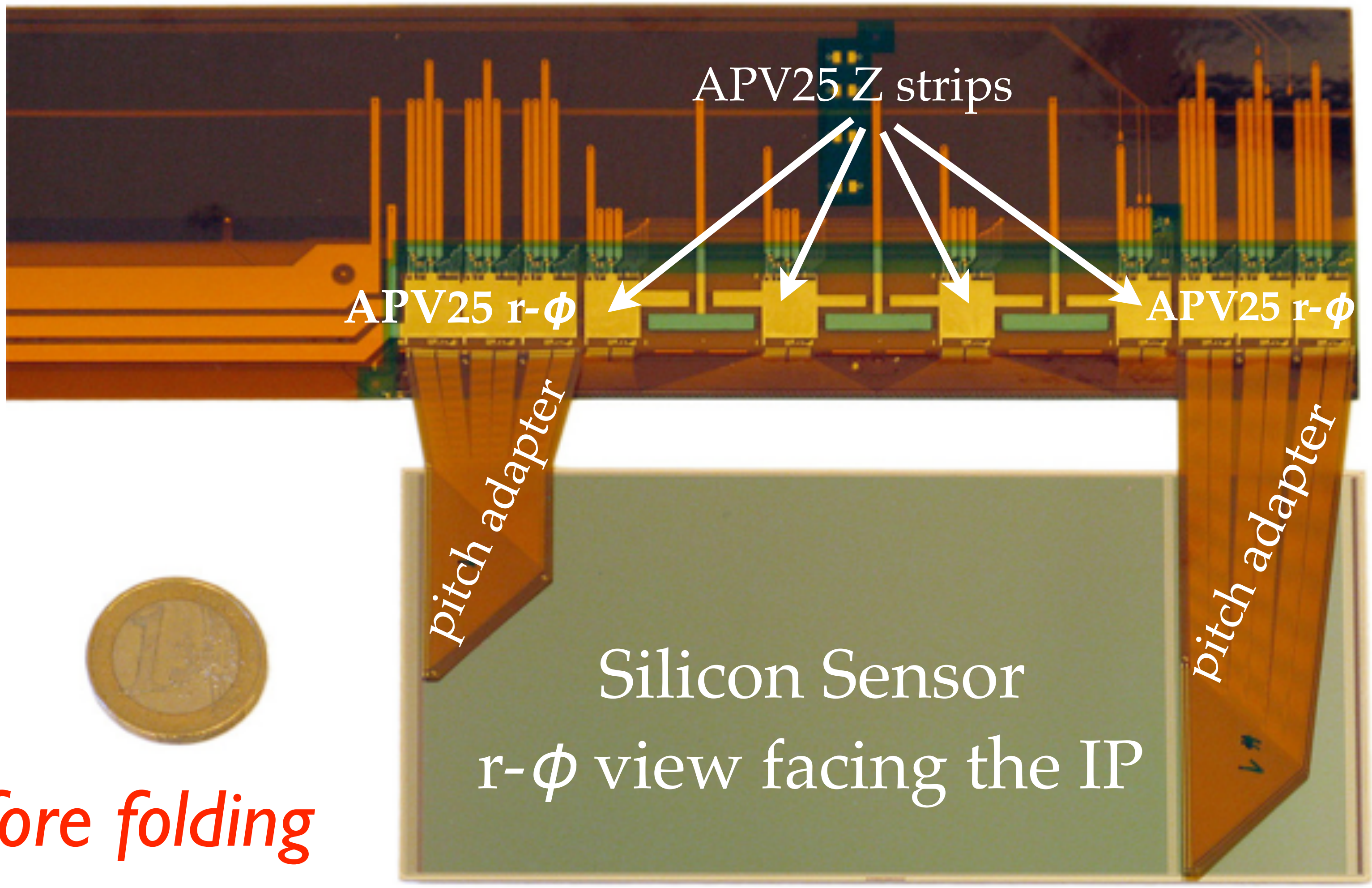
- 11 charged tracks
- 5 neutral pions
- 1 neutral kaon

➡ soft charged tracks momentum spectrum

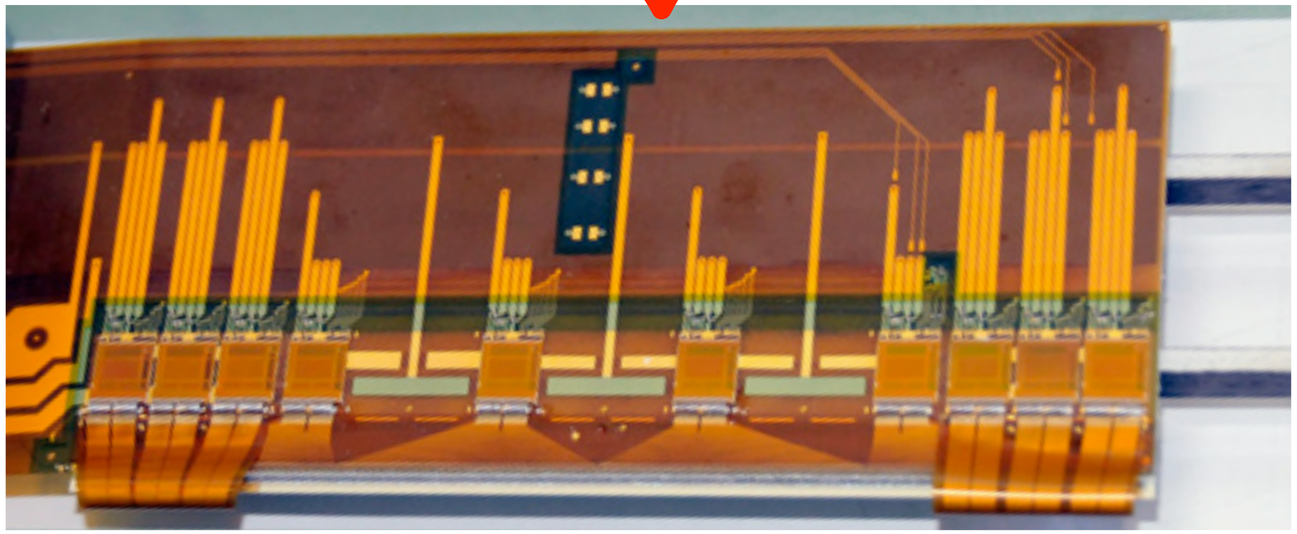


The Origami Concept

- ➡ SVD will operate at a high-luminosity machine ($8\times10^{35}cm^{-2}s^{-1}$)
- ➡ need short strips & short pitch adapters
  - reduce the occupancy
  - reduce the noise (lower capacitance at the charge preamplifier input)
- ➡ readout chips inside the tracking volume
- ➡ the "chip-on-sensor" Origami concept allows to minimise the analog path length

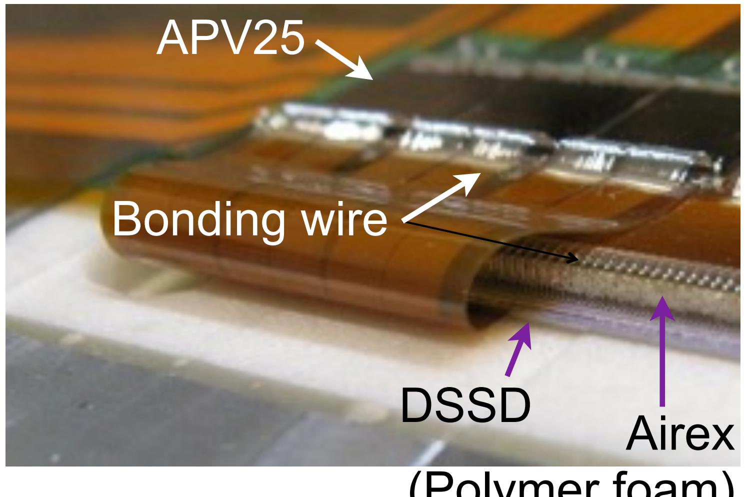


before folding



after folding

!! hidden micro bonding below the pitch adapter !!



Beam Background from Phase2

☑ It's safe to install the final SVD detector for early Phase3 data taking

➡ Use beam background estimation from Phase2 to get expected background on early Phase3:

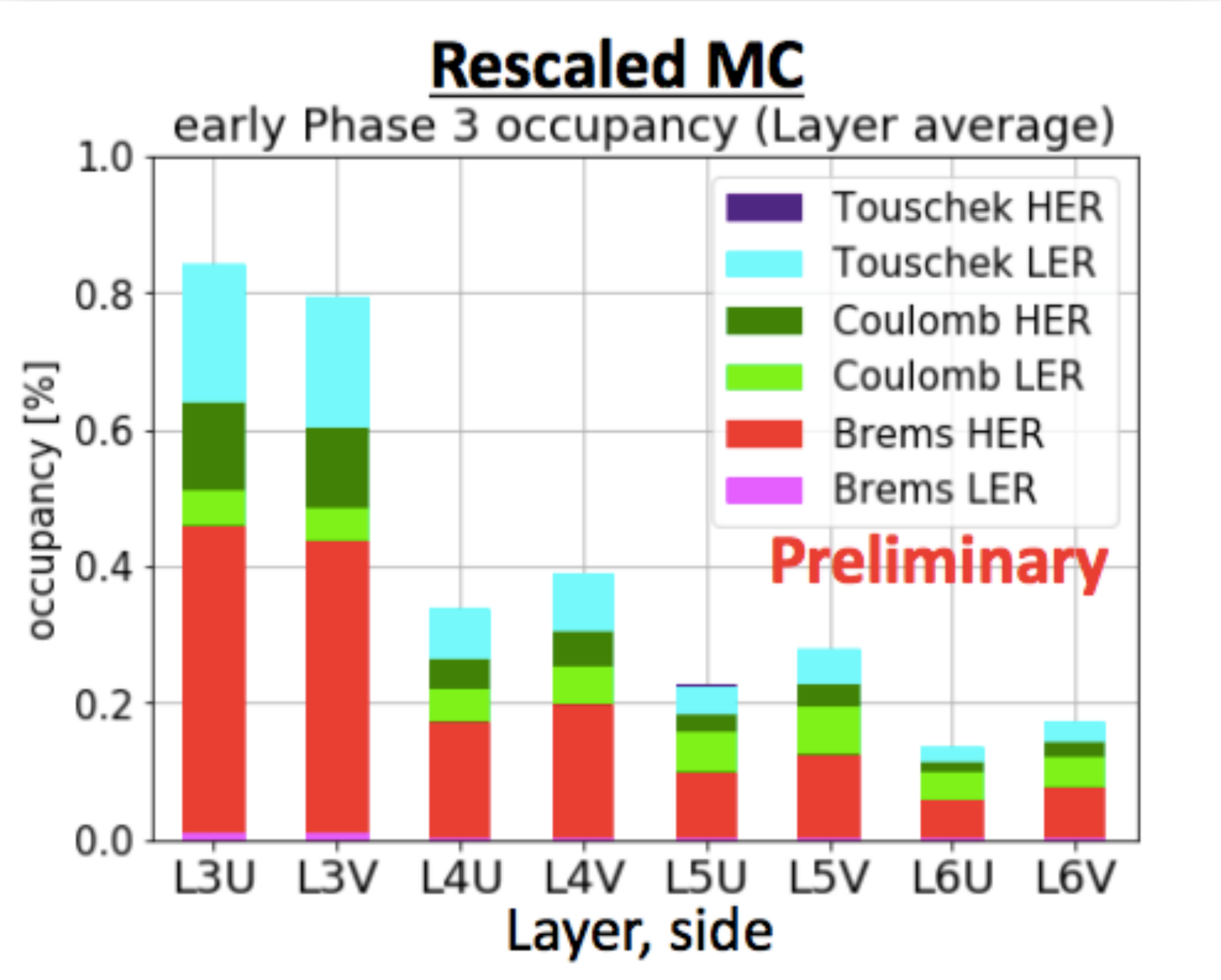
- decomposition of beam-induced backgrounds

occupancy — beam-gas rate — Touschek rate

$$O(I, P, \sigma_Y, n_b) = B \cdot PI + T \cdot \frac{I^2}{\sigma_y n_b}$$

- occupancy measured for different configurations of the beam parameters allows to extract B and T
- data MC comparison to extract scaling factors for beam-gas and Touschek rates:

$$Expected_{Phase3} = MC_{Phase3} \cdot \frac{Data_{Phase2}}{MC_{Phase2}}$$



➡ Background levels in earlyPhase3 will be acceptable for the final SVD detector

- occupancy limit from tracking ~3%
- luminosity background will be negligible in early Phase3

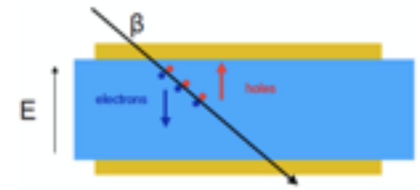
luminosity bkg = 1% at design luminosity & it scales with luminosity

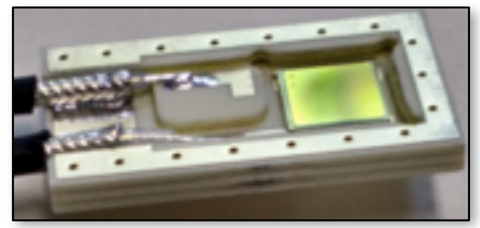
SVD Subsystems Commissioned in Phase2

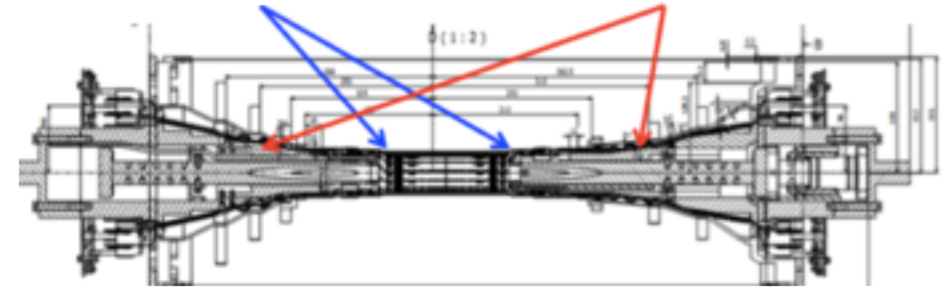
Radiation Monitor: essential to protect VXD from a large instantaneous or time-integrated dose by aborting the beams.

Diamond chambers:

- high radiation tolerance
- proper response to both rapid and slow increases of the radiation level
- reduced dependence of the leakage current on the total dose.





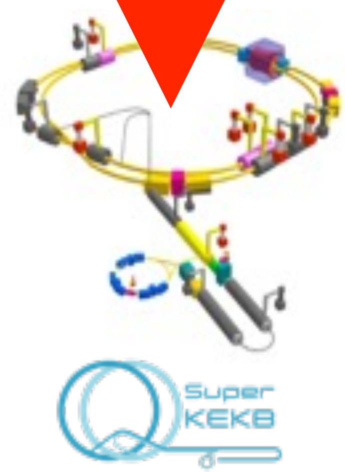


Phase2 highest dose 11.6 krad

Beam Abort System:

beam abort request to protect SVD and final focus magnets:

- fast abort: 1 rad/ms, (10μs reaction time) → 86 in Phase2
- slow abort: 100 mrad/s → 12 in Phase2
- thresholds adjustable



Dump the last second of data before the abort:

- Dump the last 100k samples in a R/O buffer (100kHz for 1s) to a memory.
- content of the R/O buffer correctly frozen and dump
- analysis of these data showed the abort was correctly issued

Interlock Systems: hardware and software interlocks to completely turn off the detector in case of problems

Environmental Monitors

- FOS & NTC temperatures
- humidity

- Minor but real instances happened during Phase2 operations.
- For each instance, the interlock system properly halted the SVD power supplies.