



# COMMISSIONING OF THE *Belle II SILICON VERTEX DETECTOR*

**VCI** VIENNA CONFERENCE ON INSTRUMENTATION

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**VCI 2019**



FEB 18-22, 2019



Istituto Nazionale di Fisica Nucleare

*Giulia Casarosa*

on behalf of the *Belle II SVD Collaboration*



# Outline

*The Belle II Silicon Vertex Detector*

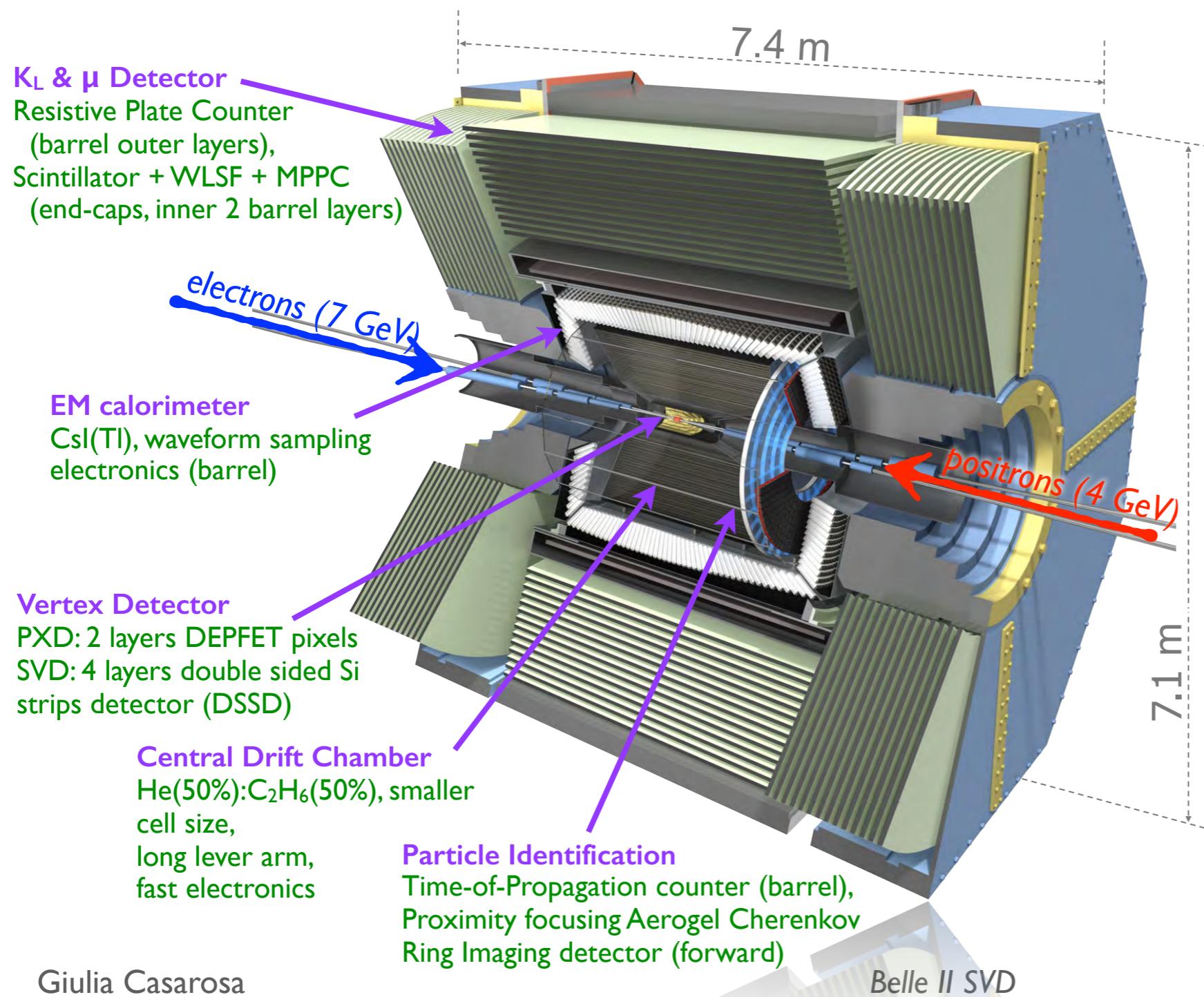
*SVD Commissioning*

- *highlights from small-scale SVD operations in global data taking*
- *final detector commissioning*

*First Results from Global Cosmic Runs*

# The Belle II Experiment

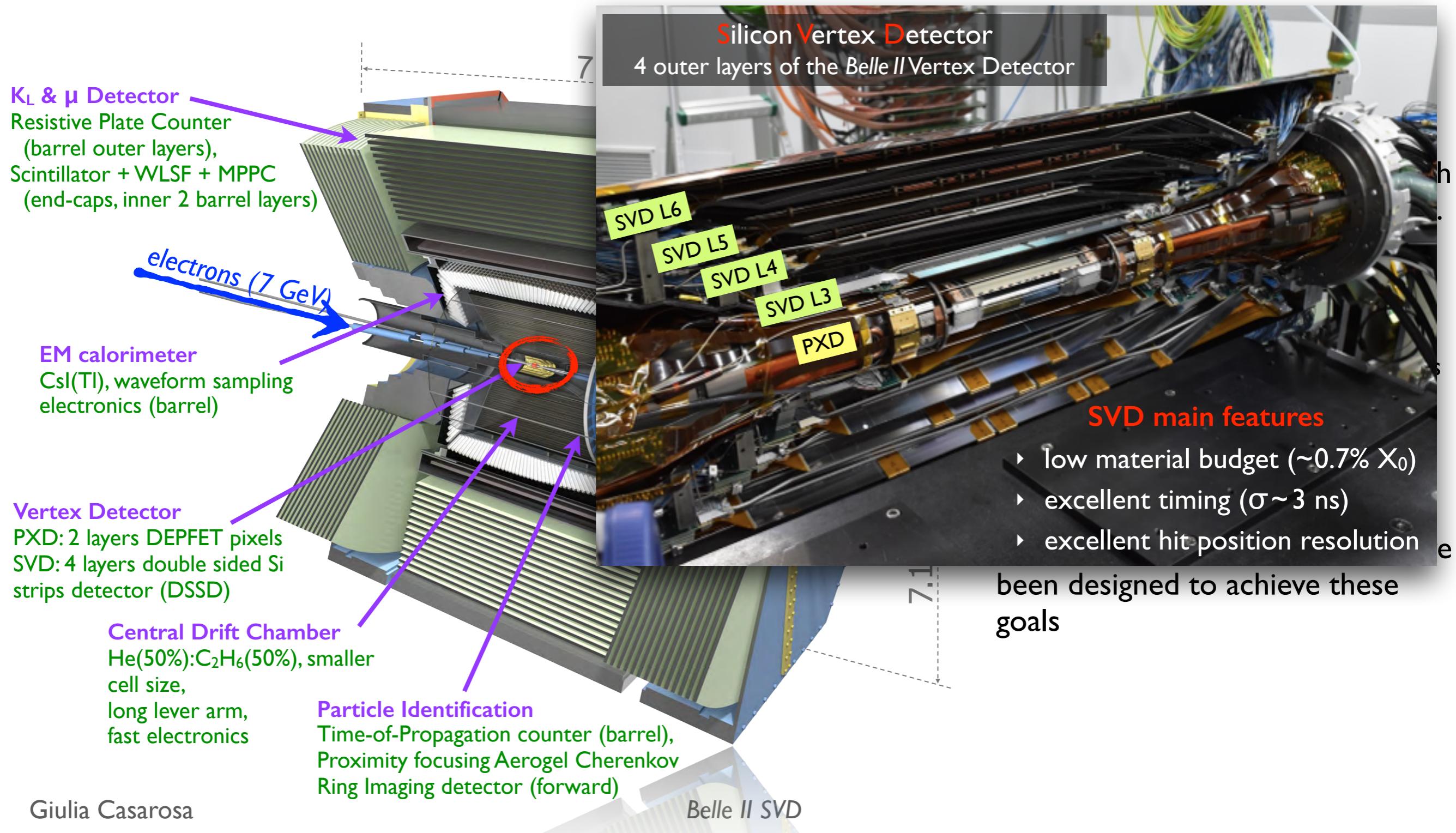
Belle II is a multi-purpose detector installed at the IP of the high-luminosity B-Factory SuperKEKB (design luminosity  $8 \times 10^{35} \text{ cm}^{-2} \text{s}^{-1}$ ), located at the KEK Laboratory - Tsukuba, Japan



- 10 years operation will allow to collect 50/ab ( $\times 50$  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

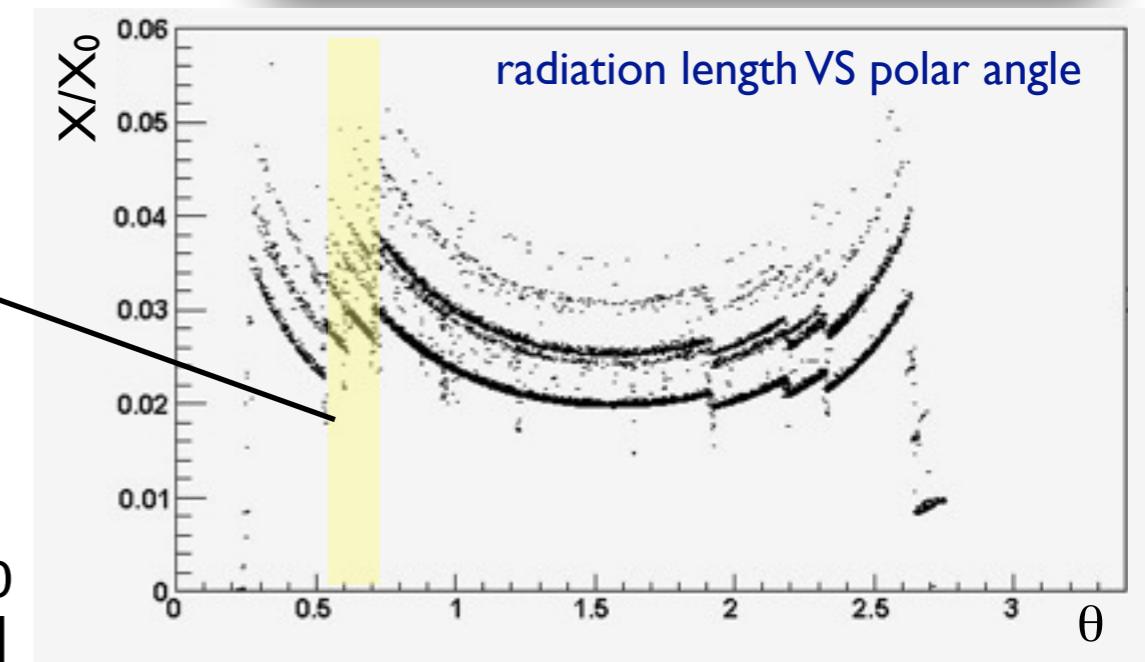
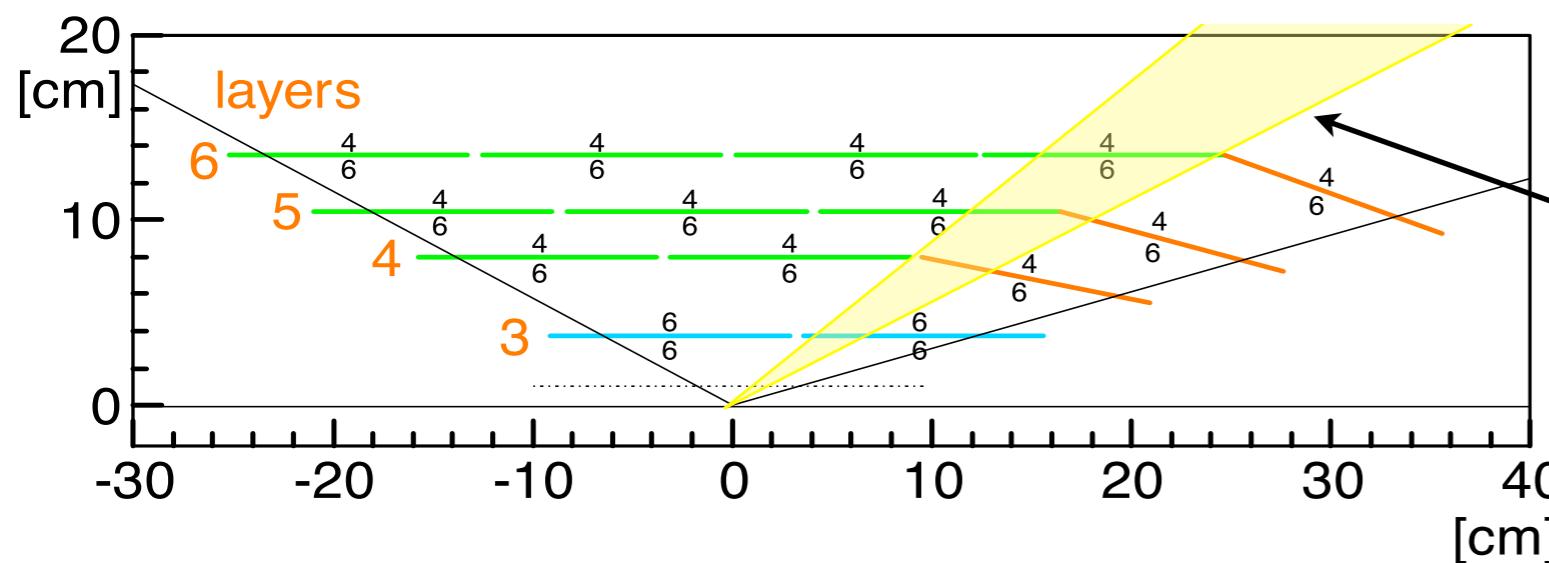
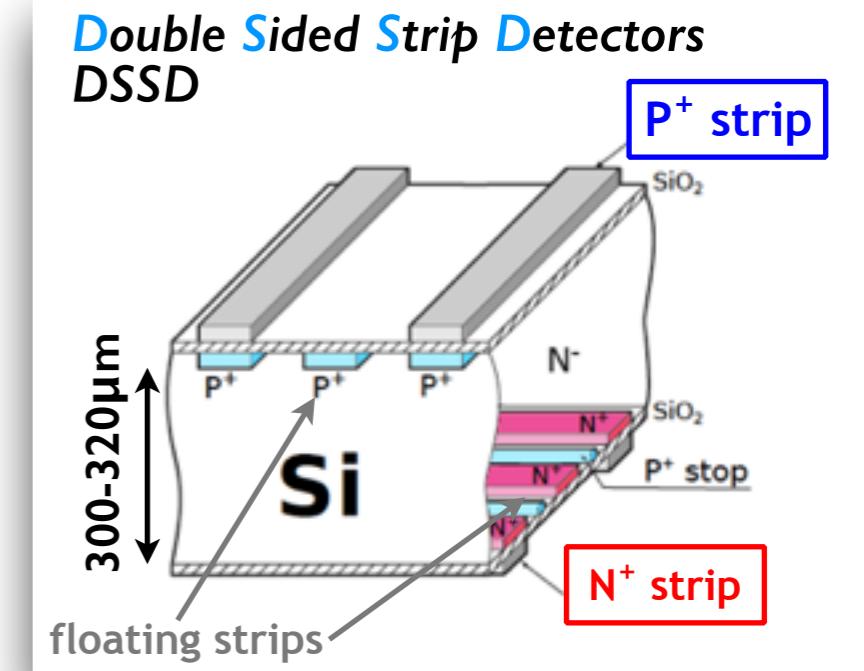
# The Belle II Experiment

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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 ( $\theta < 0.7$ )



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

layer	type	readout strip(p/r- $\phi$ )	readout strip(n/z)	strip pitch (p/r- $\phi$ )	strip pitch (n/z)	sensors # (+ spares)	active area (mm <sup>2</sup> )
4,5,6	large	768	512	75 $\mu\text{m}$	240 $\mu\text{m}$	120+18	122.90x57.72 = 7029.88
4,5,6 forward	trapezoidal	768	512	50-75 $\mu\text{m}$	240 $\mu\text{m}$	38+6	122.76x(57.59+38.42)/2 = 5893.09
3	small	768	768	50 $\mu\text{m}$	160 $\mu\text{m}$	14+4	122.90x38.55 = 4737.80

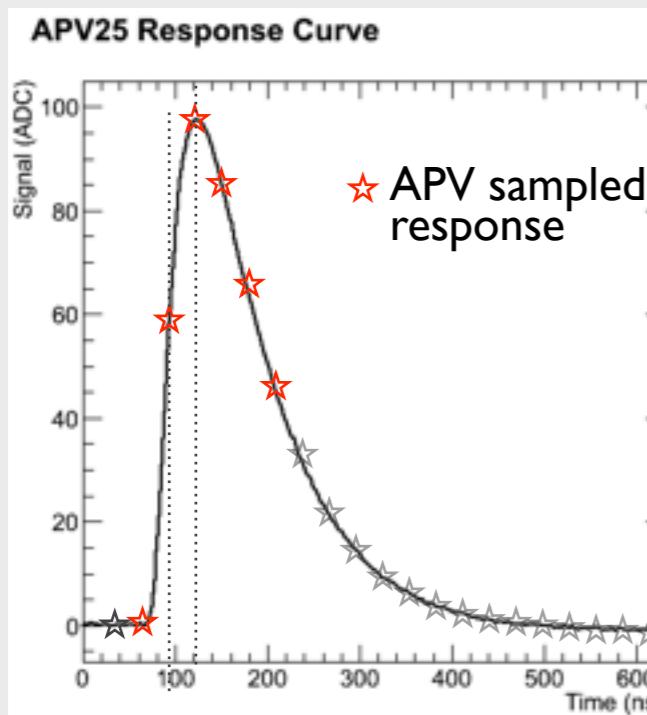
# SVD Readout System

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



the trigger arrives with a fixed latency of 5 µs

### APV25 (x1748 for 223744 channels)

- provides the 6 samples (corresponding to triggered event time!), of each of the 128 readout strips



### FADC (x52)

A/D Converter board

- digitizes the signal
- subtracts pedestal and common mode
- applies zero suppression on SNR basis



### FADC-controller

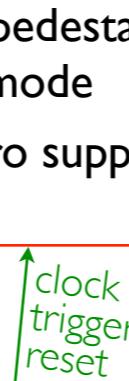
- controls the 52 FADC boards
- generates APV trigger



### FTB (x52)

Finesse Transmitter board

- electrical-to-optical interface



### FTSW

Front-end Timing SWitch

- distributes clock to all sub-detectors
- also provides trigger and reset

# 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 @ Y(4S) energy
- with an incomplete *Belle II* detector (no final-version VXD)
- with a **reduced-scale vertex detector** and
- dedicated beam-background detectors

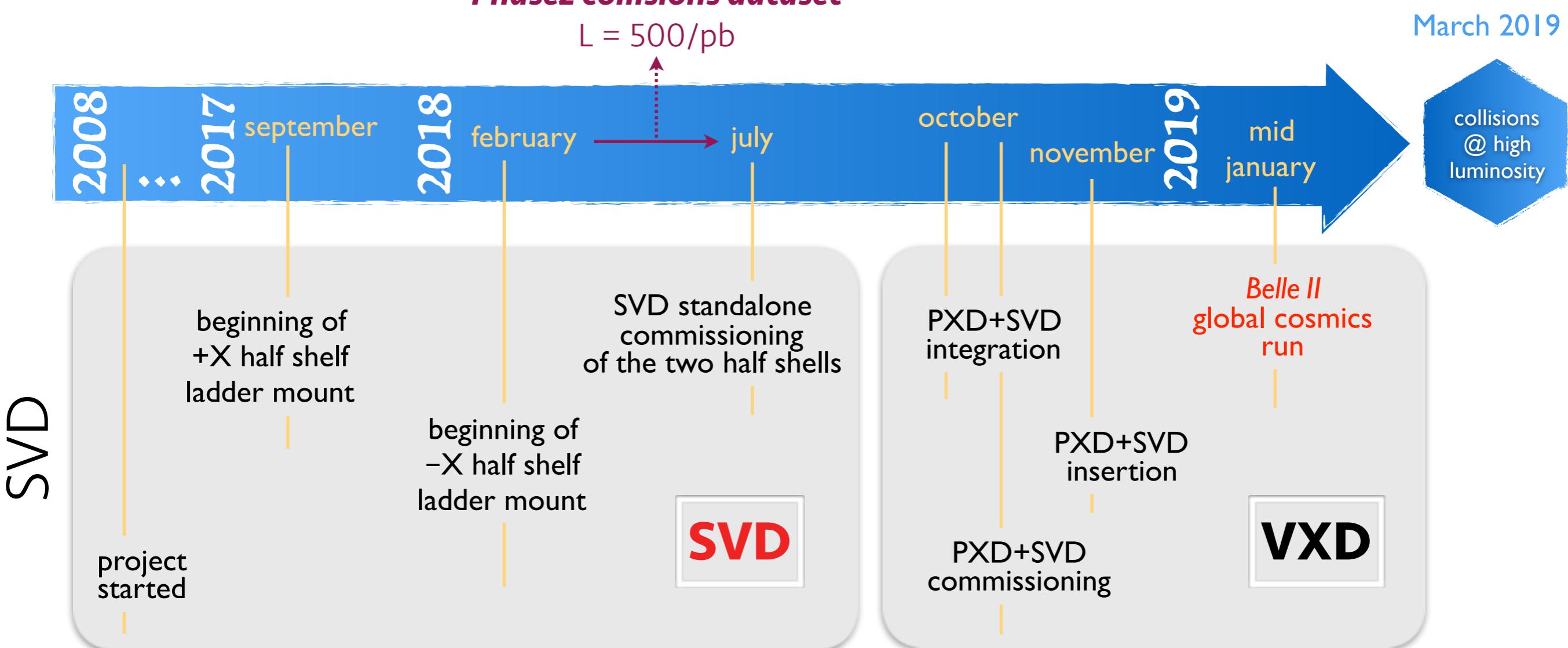
### Phase2 main goals

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

*focus of this talk  
is on detector  
performance*

### Phase2 collisions dataset

$L = 500/\text{pb}$

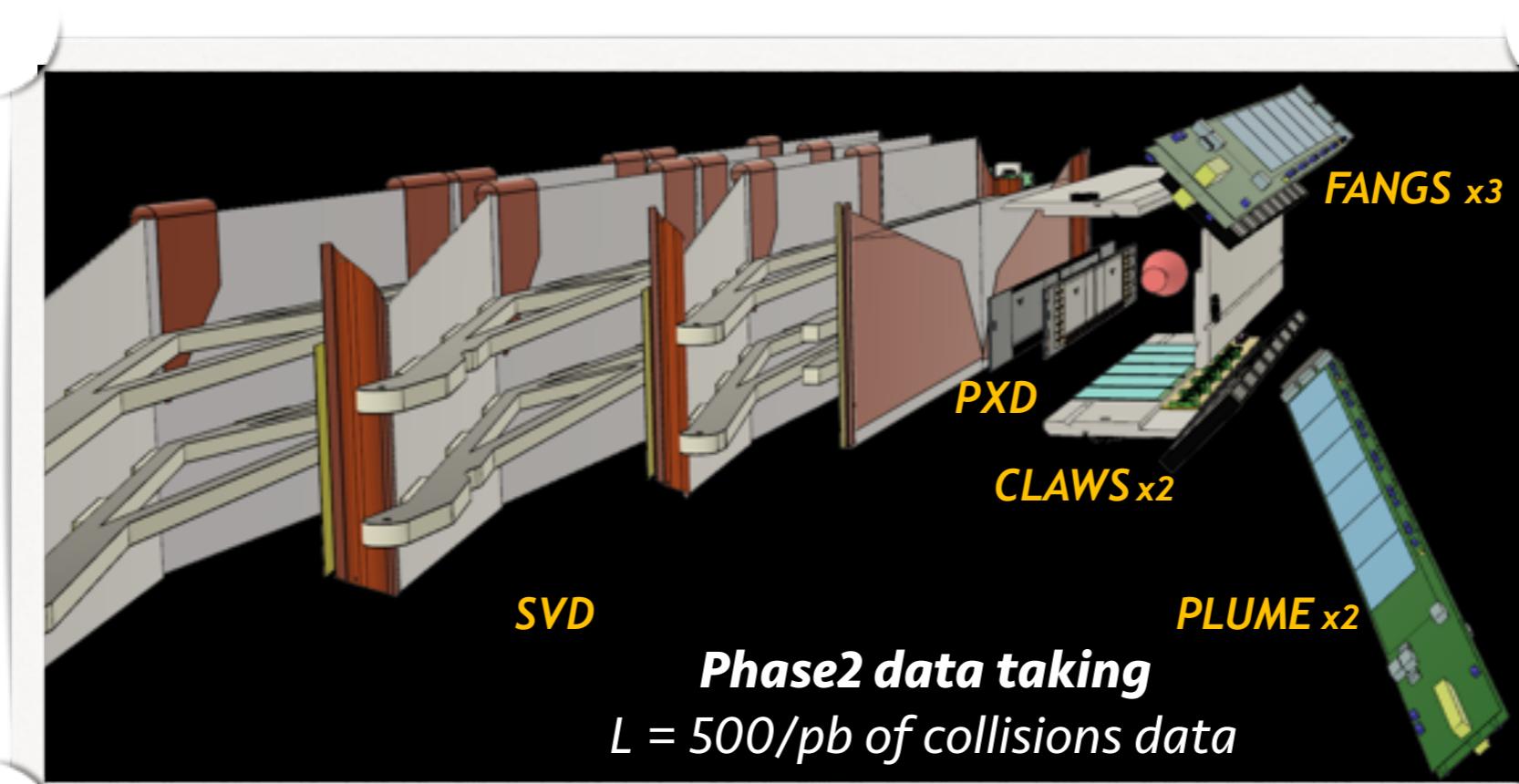


# Outline

The Belle II Silicon Vertex Detector

SVD Commissioning

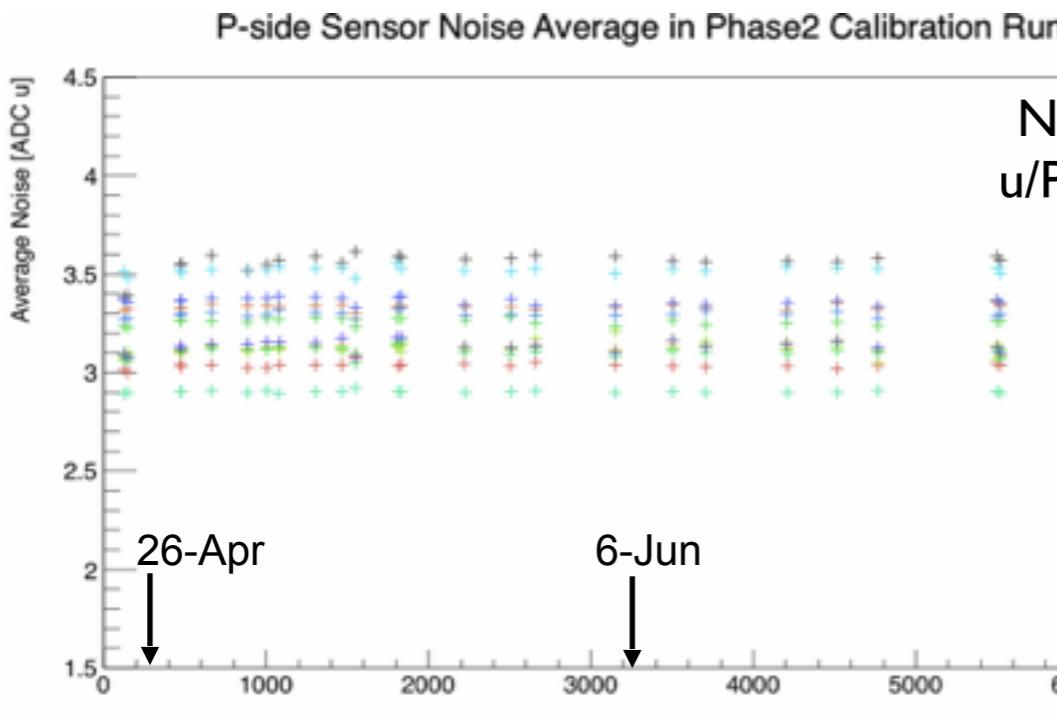
- *highlights from small-scale SVD operations in global data taking*



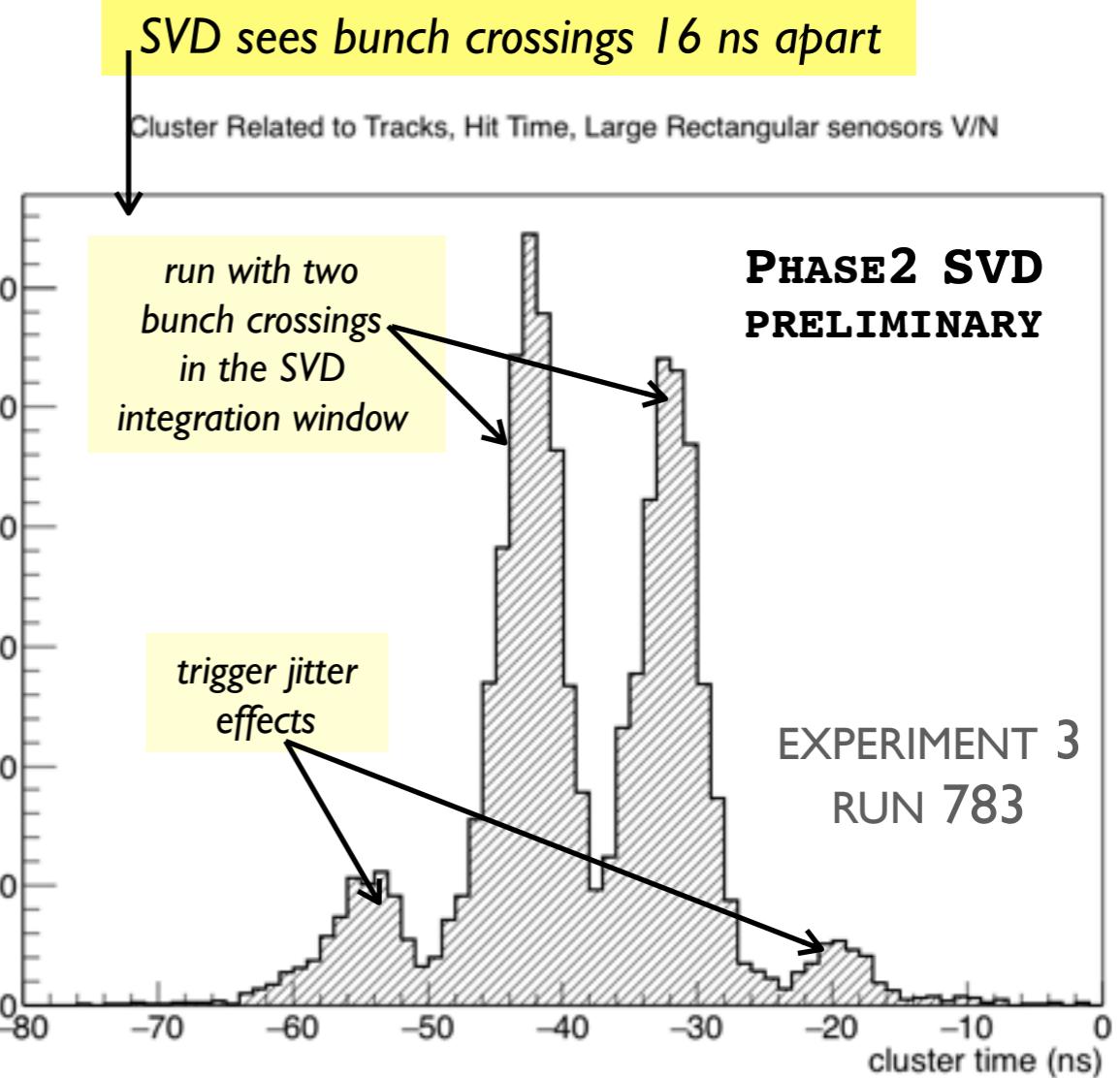
# SVD in Phase2 Global Data Taking

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*

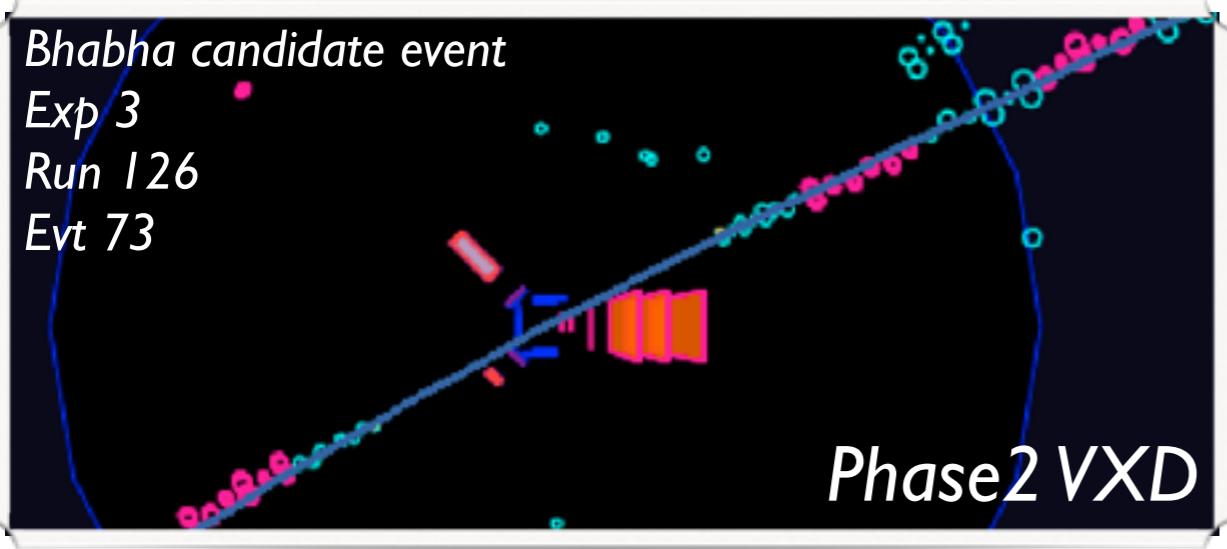


2. test of sensor response to MIPs from IP

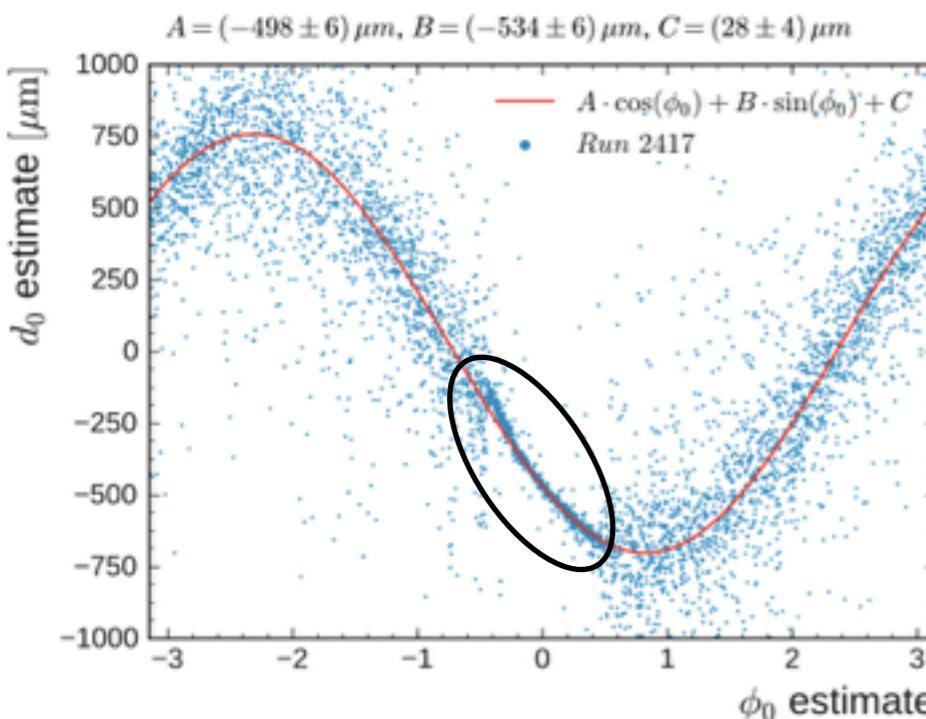
- *sensor efficiencies above 97% for all-except-one sensor, good considering class B sensors have been used*

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

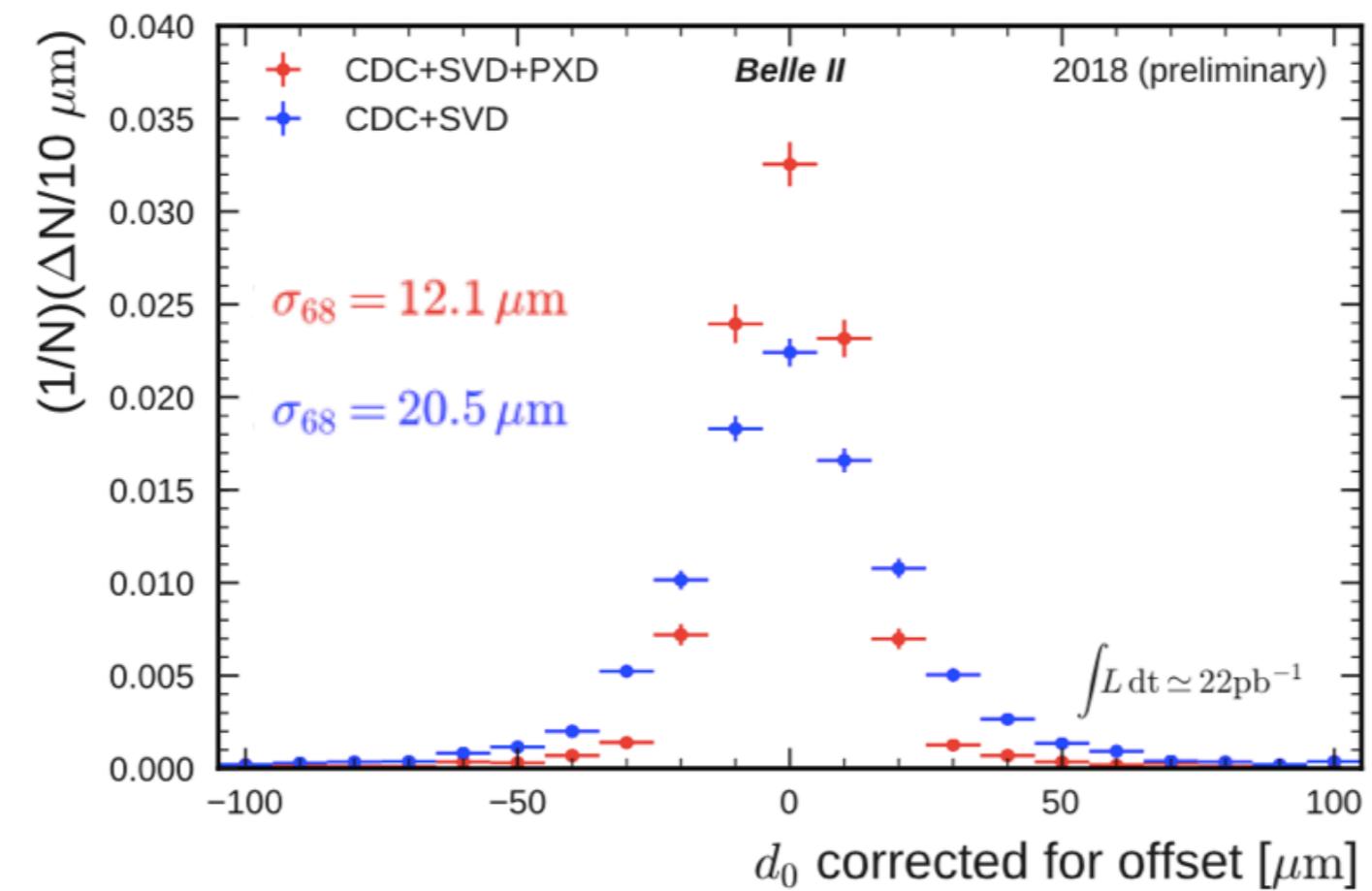
# SVD Impact on Tracking in Phase2



- IP not in the nominal position, correlation between track parameters  $d_0$  and  $\phi_0$ 
  - evident improvement of the resolution in the VXD direction



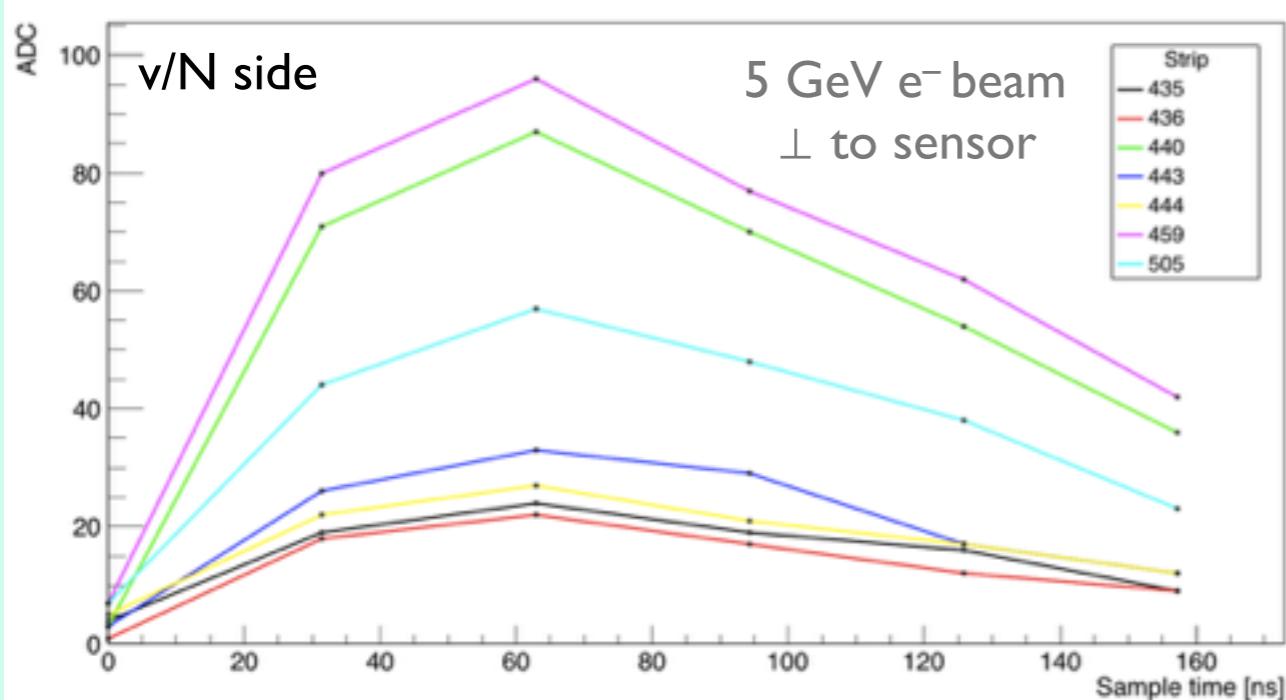
- Phase2 SVD covers a small azimuthal, nonetheless measurements of tracks with SVD hits confirmed that:
  - svd-only tracking is working
  - outward extrapolation from SVD is working
- track  $d_0$  resolution  $\sim 20 \mu\text{m}$  (w/o PXD hits)
  - innermost SVD layer at 3.9 cm from IP



# 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

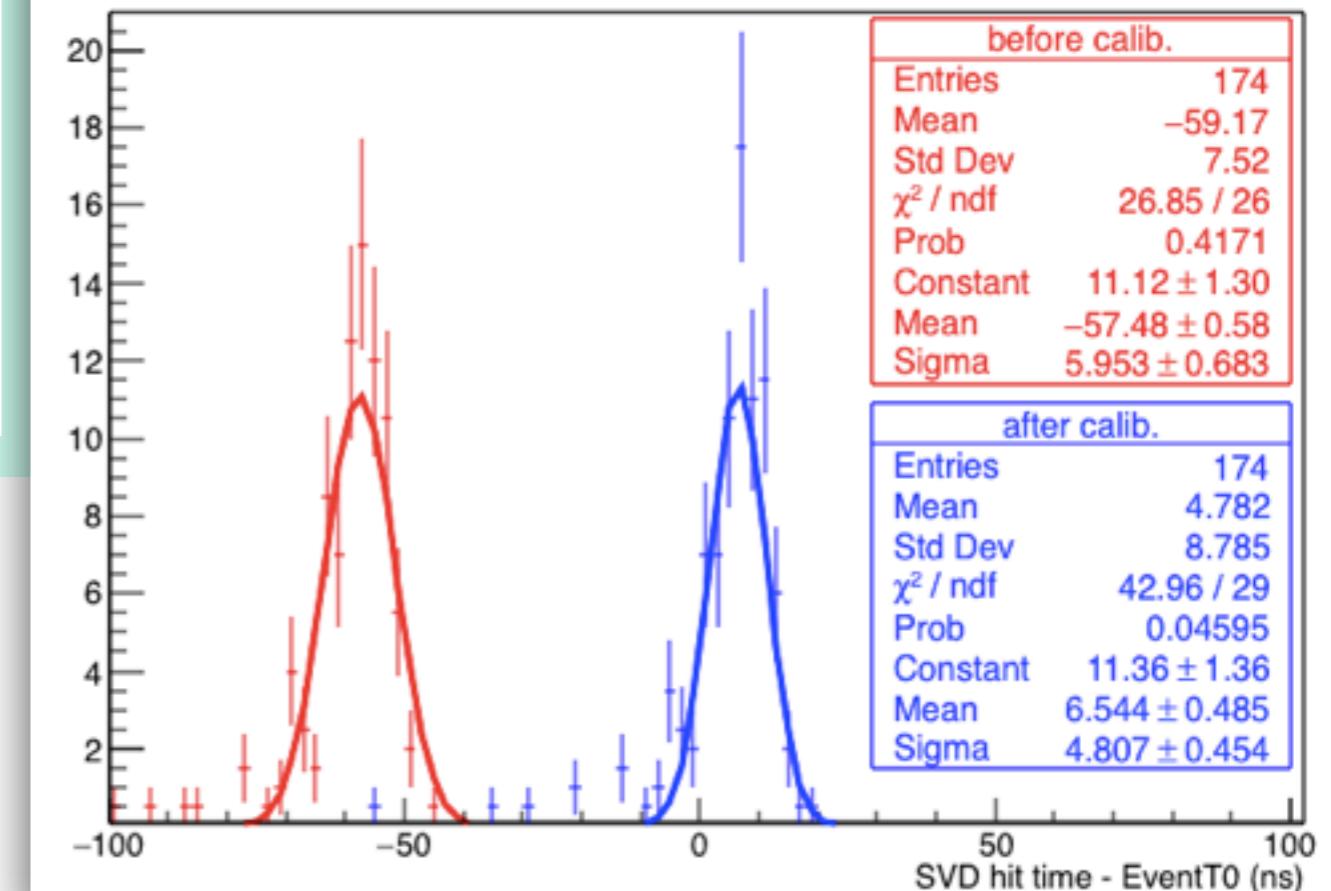


Strong indication of excellent time resolution of hits from tracks coming from the interaction point

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

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

SVD Hit Time – EventT0 provided by the drift chamber



# 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*

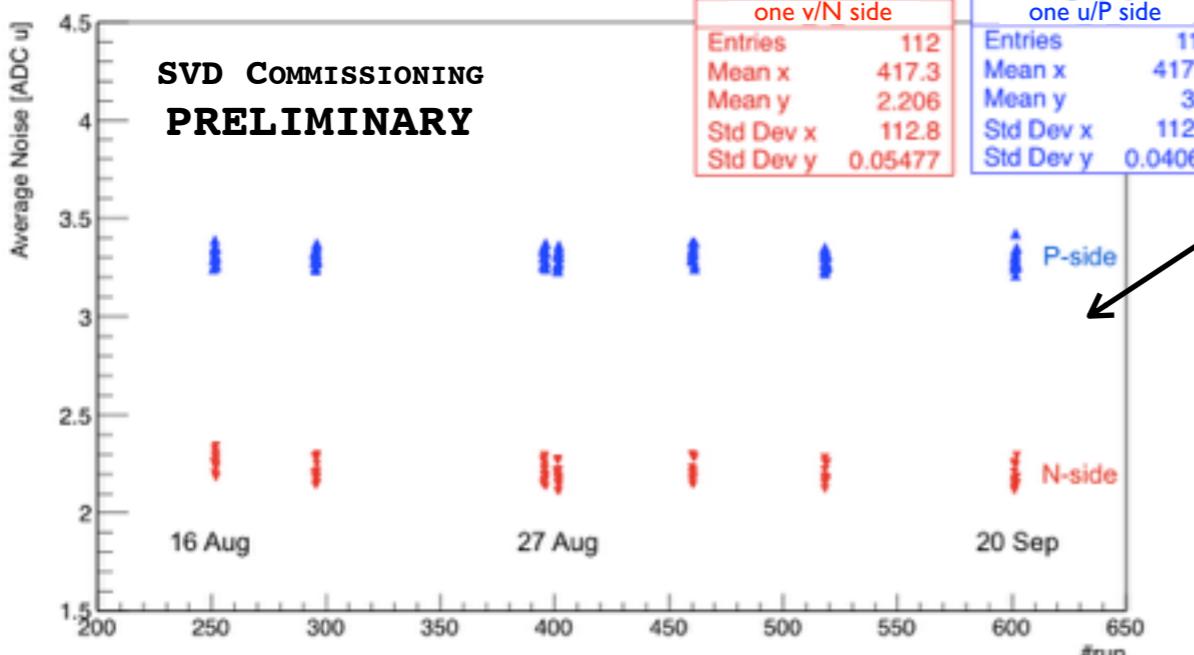
# SVD Standalone Commissioning

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

Noise Average L6.4 in Commissioning Calibration Runs



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

### SVD commissioning setup

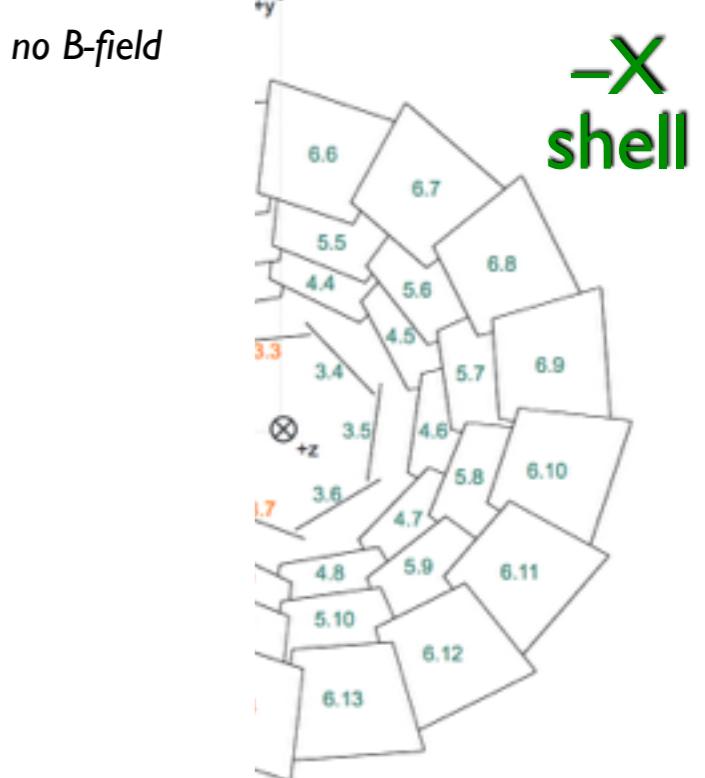
triggers provided by scintillators coincidence:

- ~jitterless
- asynchronous with respect to SVD readout clock

TOP scintillator #1



TOP scintillator #2

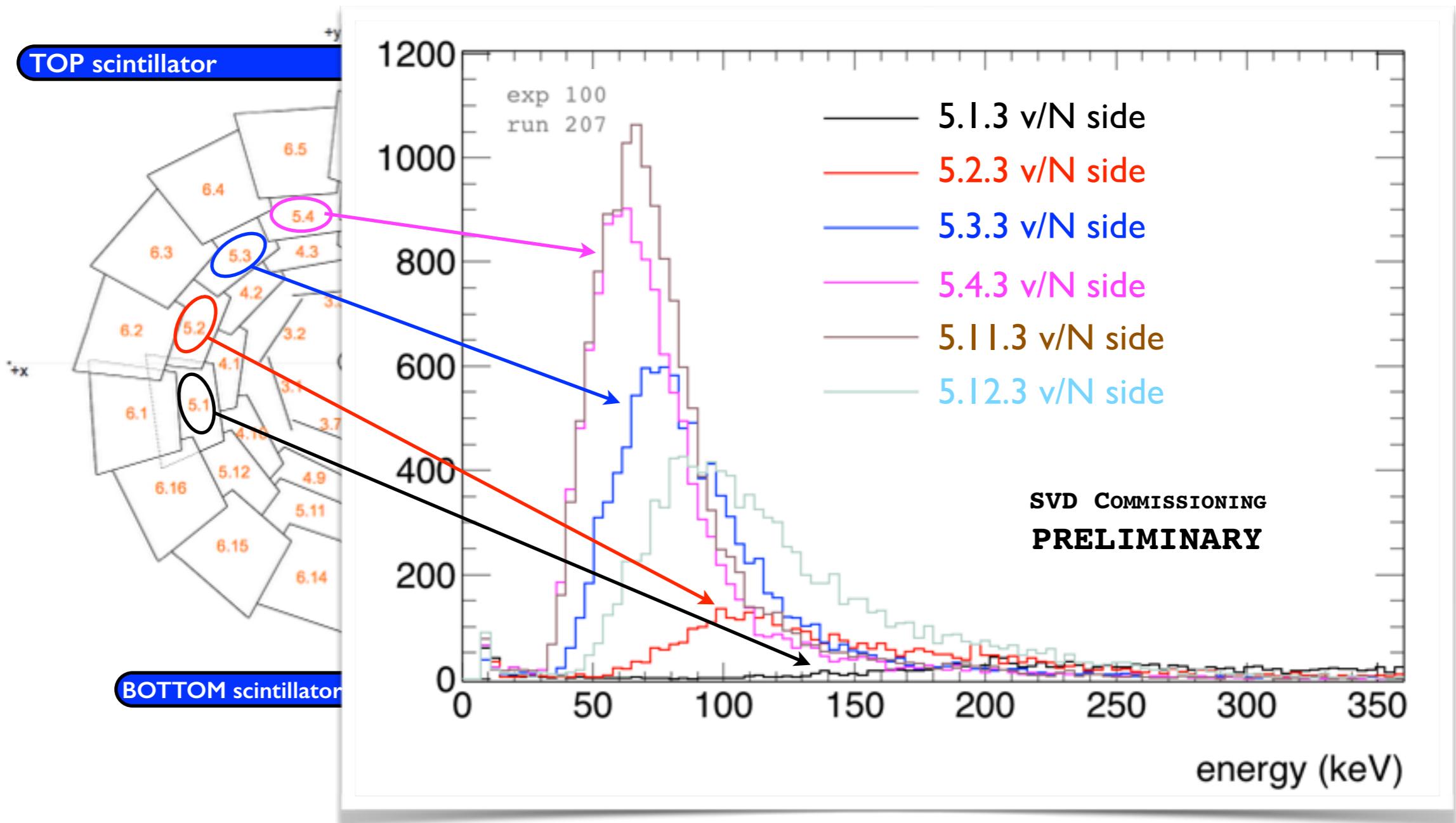


BOTTOM scintillator #2

BOTTOM scintillator #1

# Cluster Energy VS Azimuthal Angle

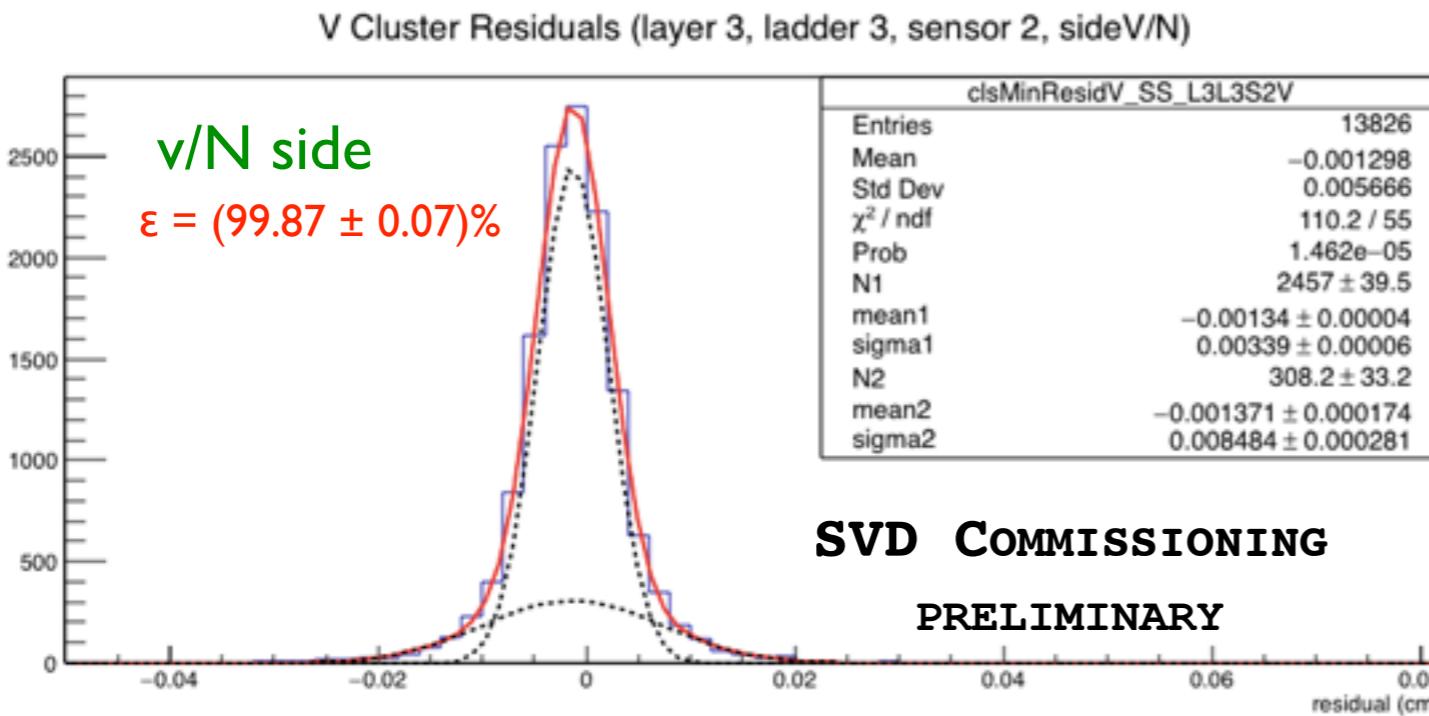
- Cosmic rays cross vertical layers with a larger incident angle with respect to horizontal layers



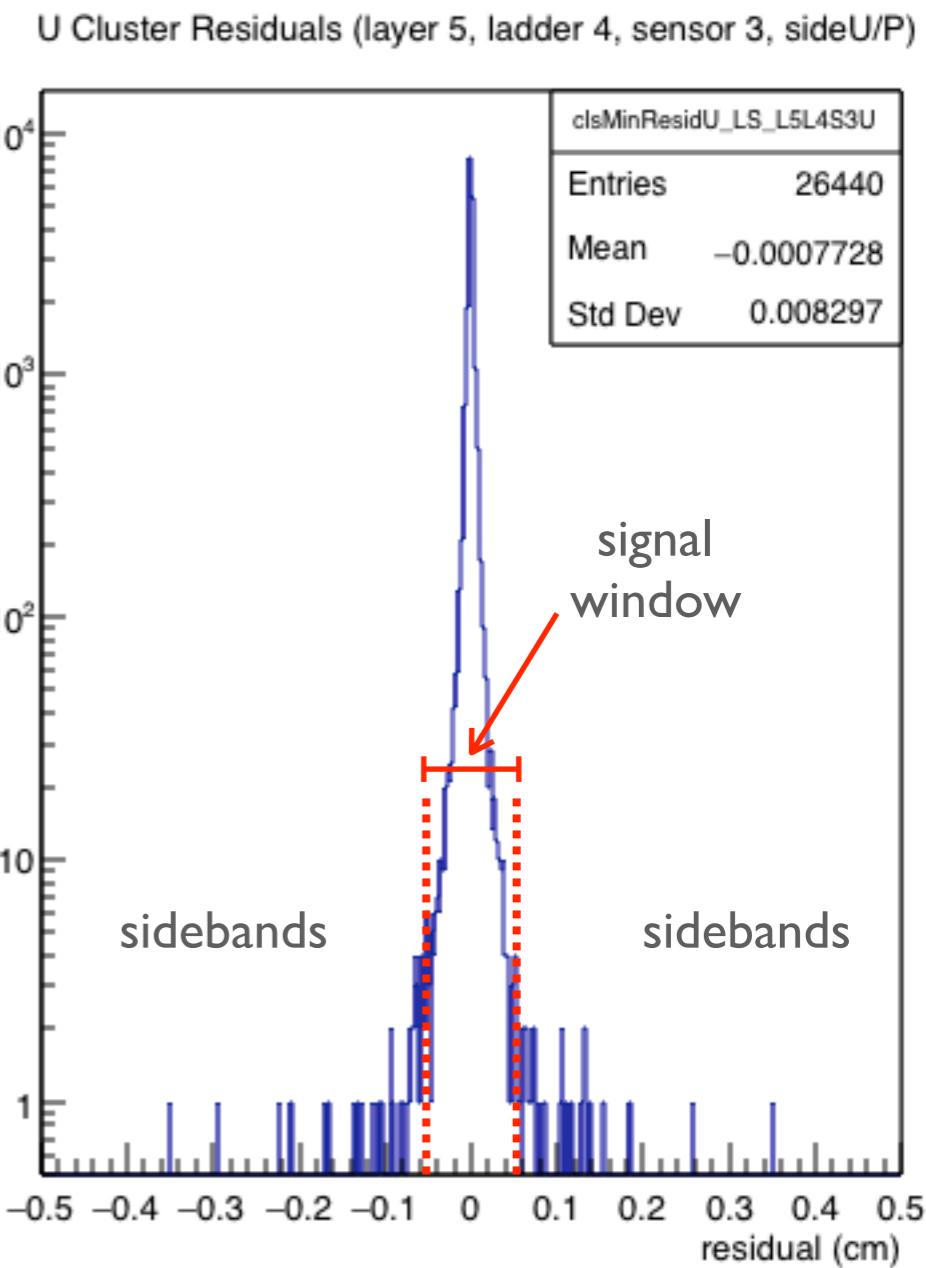
Concentrate on horizontal sensor to study the  $\perp$  track incident angle use-case

# Final SVD Sensor Efficiency with Cosmics

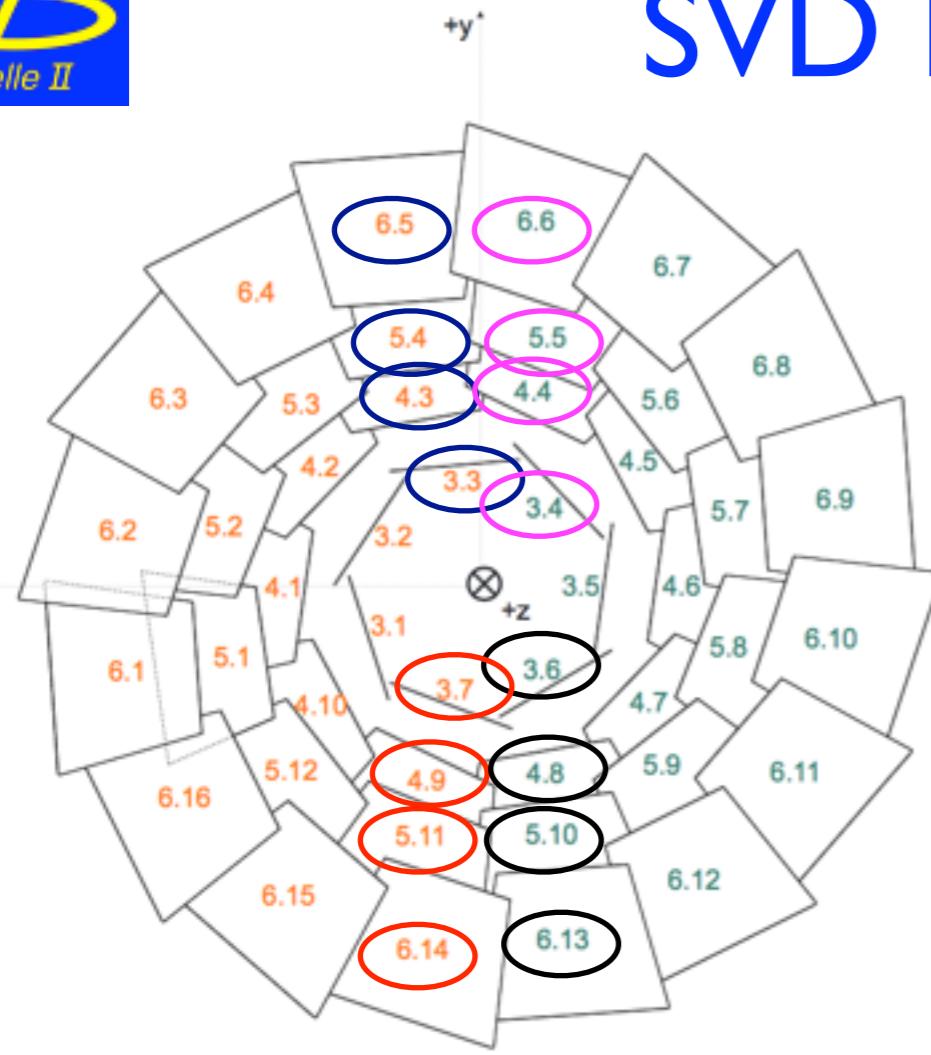
- Sensor efficiency estimated using cosmic tracks in  $\sim 10M$  events
- Tracking reconstruction excluding the sensors belonging to the layer under study, and applying quality cuts on clusters used in the pattern recognition and on the track
  - fiducial region for the extrapolation of the track to 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

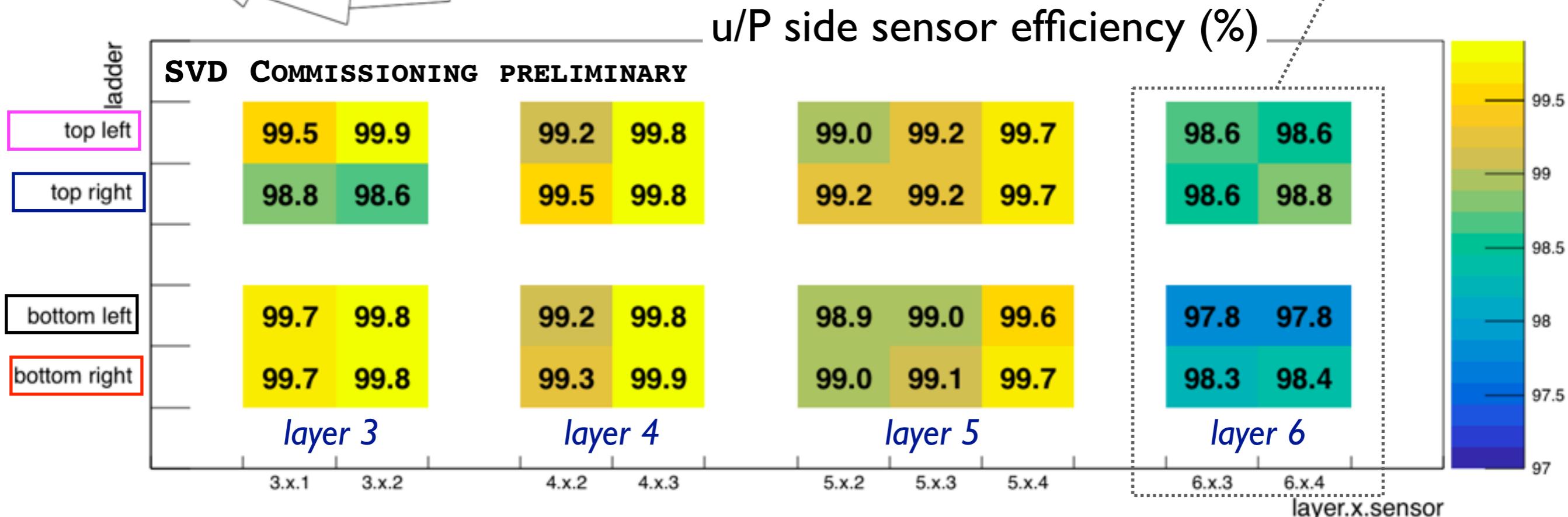


# SVD Efficiency, u/P side

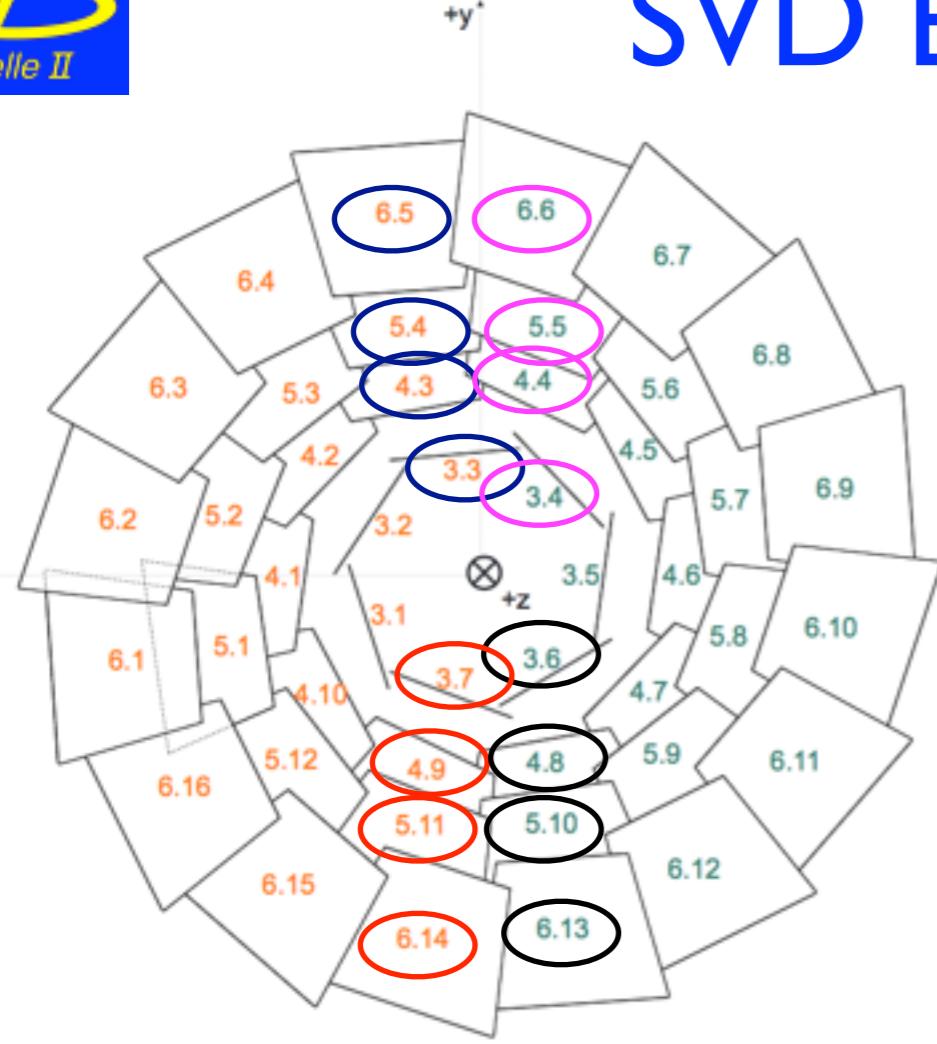


- efficiencies around/above 99% for sensors of the three innermost layers
- slightly lower efficiencies on layer6, but still around 98%, above 97.4%

- 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



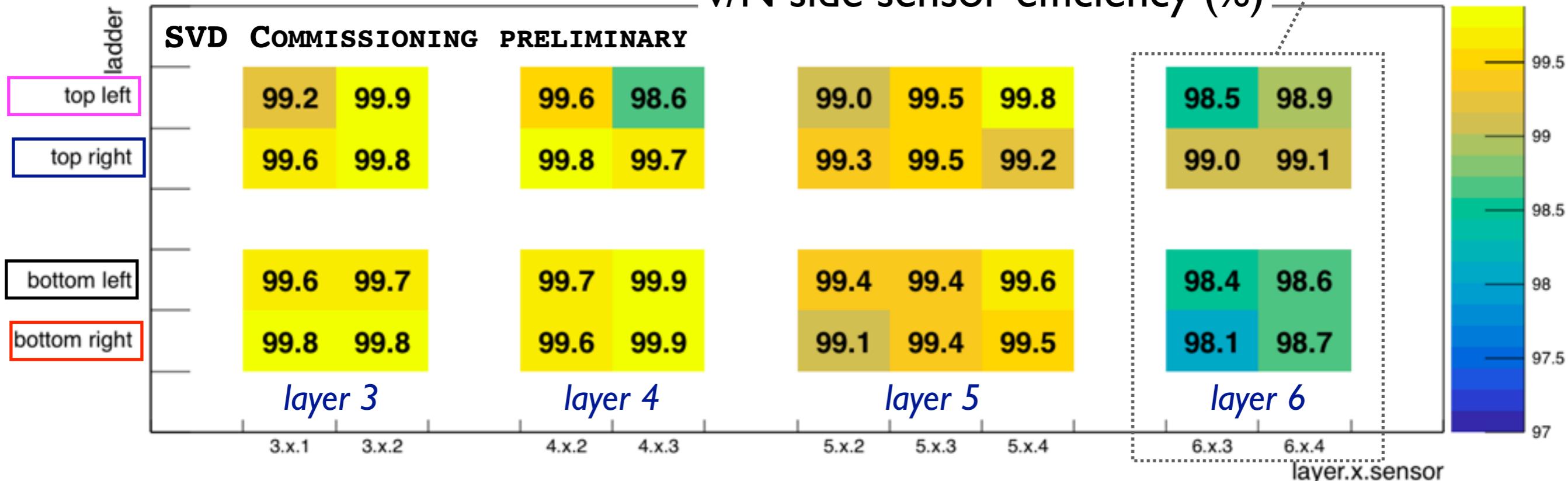
# SVD Efficiency, v/N side



- 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

v/N side sensor efficiency (%)



# Outline

*The Belle II Silicon Vertex Detector*

*SVD Commissioning*

- *highlights from small-scale SVD operations in global data taking*
- *final detector Commissioning*

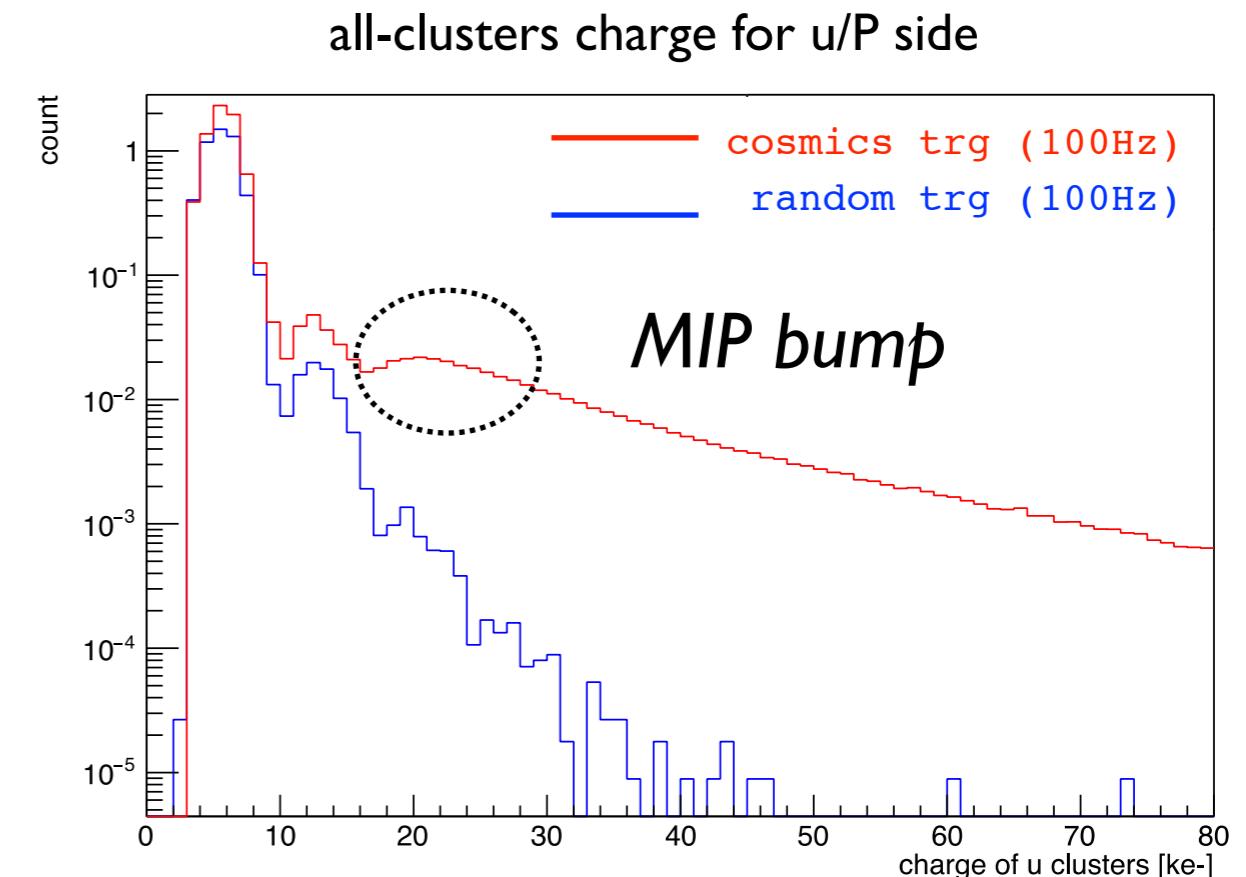
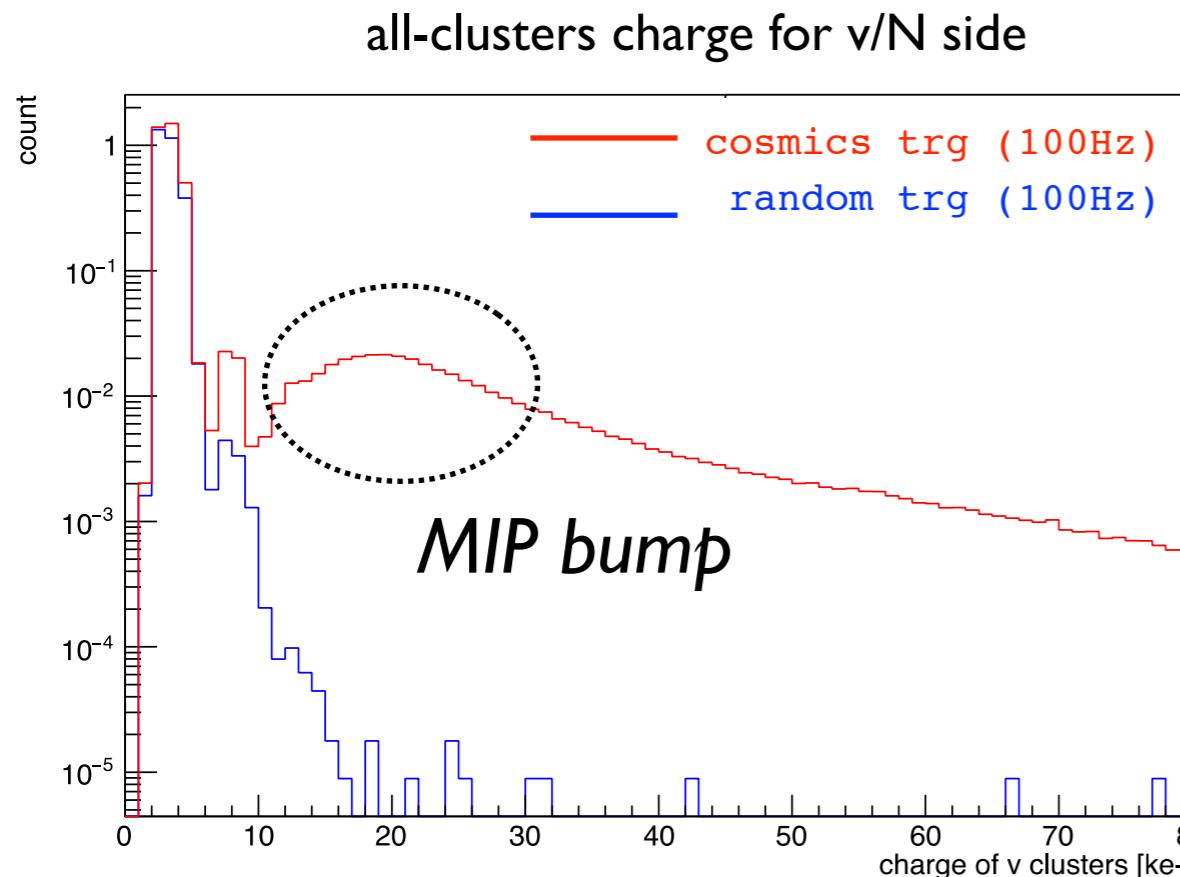
*First Results from Global Cosmic Runs*

# SVD Final Destination

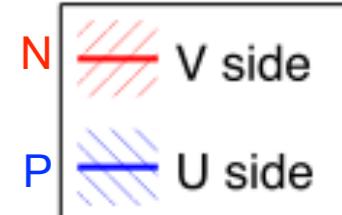
The *Belle II* vertex detector has been successfully installed and integrated in the *Belle II* DAQ

- Since mid January SVD is included in *Belle II* global runs:
  - random triggers with variable trigger rate, 1 - 30 kHz
  - cosmics triggers,  $\sim 150$  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

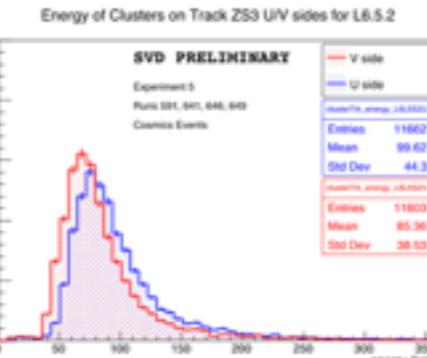
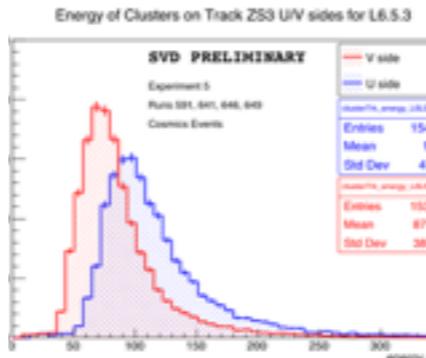
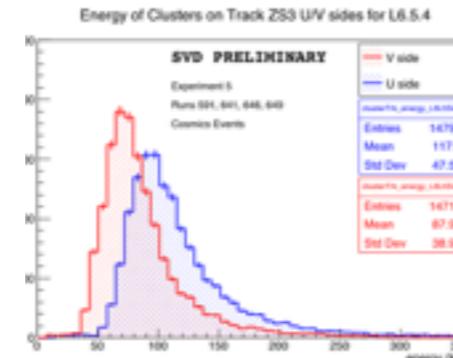


# Track-related Cluster Energy

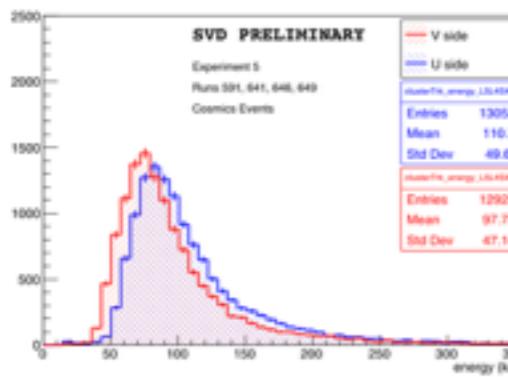


most probable cluster energy as expected from MIPs, around 80 keV

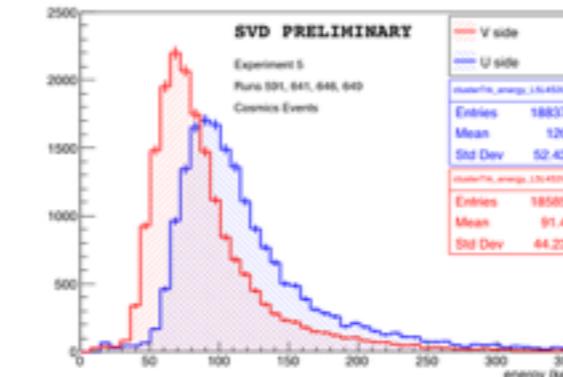
CDC



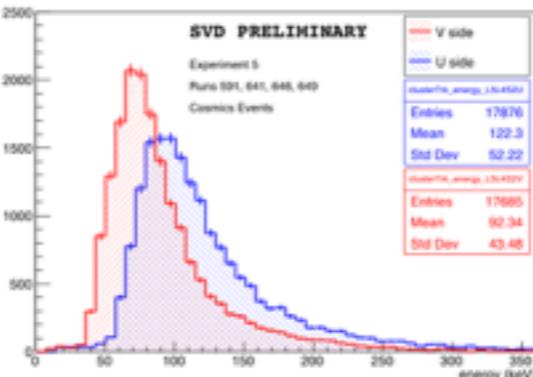
Energy of Clusters on Track ZS3 U/V sides for L5.4.4



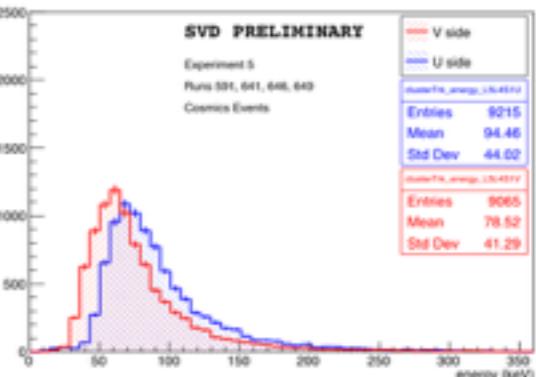
Energy of Clusters on Track ZS3 U/V sides for L5.4.3



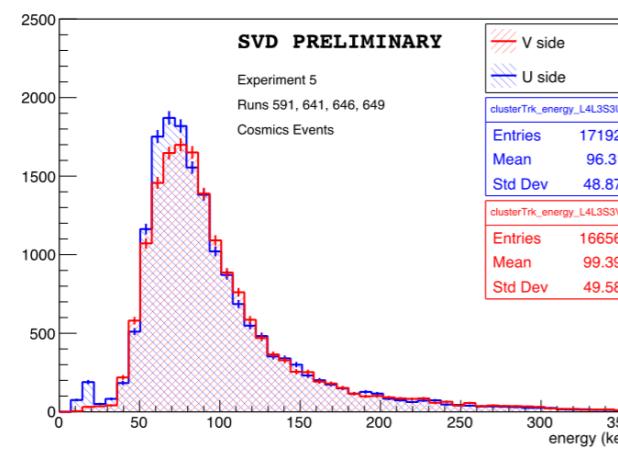
Energy of Clusters on Track ZS3 U/V sides for L5.4.2



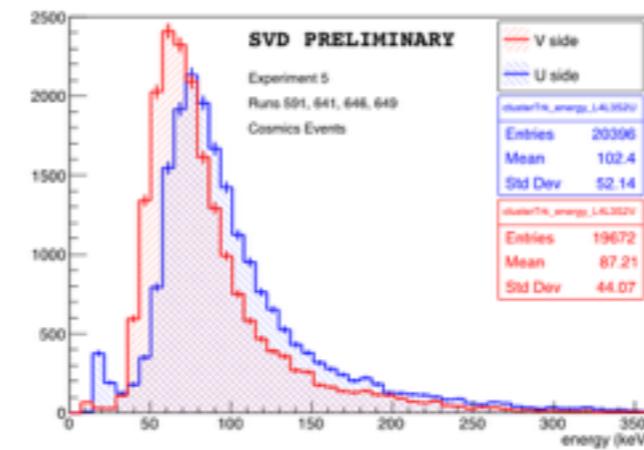
Energy of Clusters on Track ZS3 U/V sides for L5.4.1



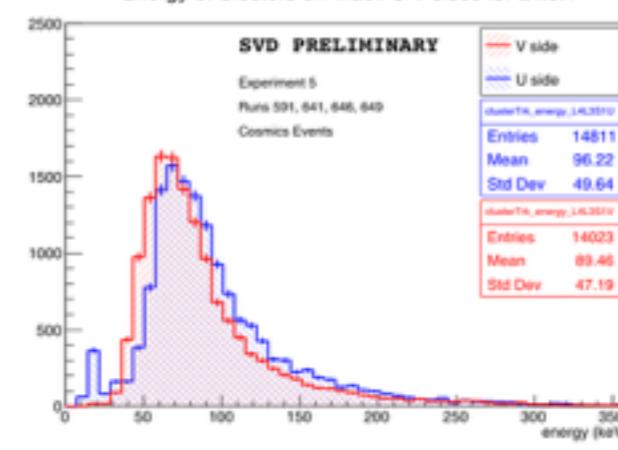
Energy of Clusters on Track U/V sides for L4.3.3



Energy of Clusters on Track U/V sides for L4.3.2



Energy of Clusters on Track U/V sides for L4.3.1



IP

backward

Giulia Casarosa

forward

note: layer 3 in slide 23

Belle II SVD

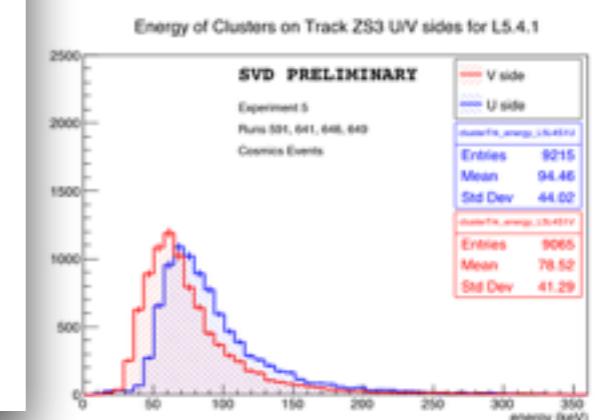
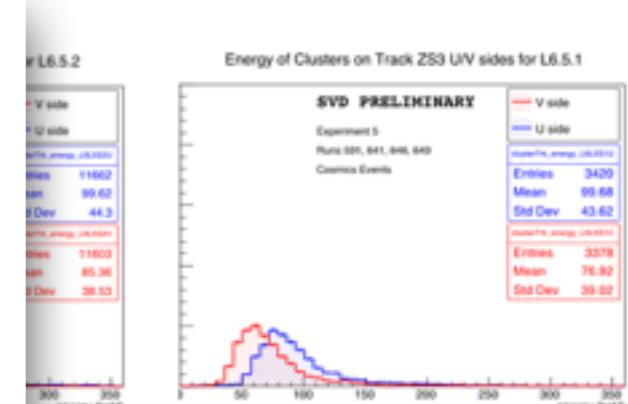
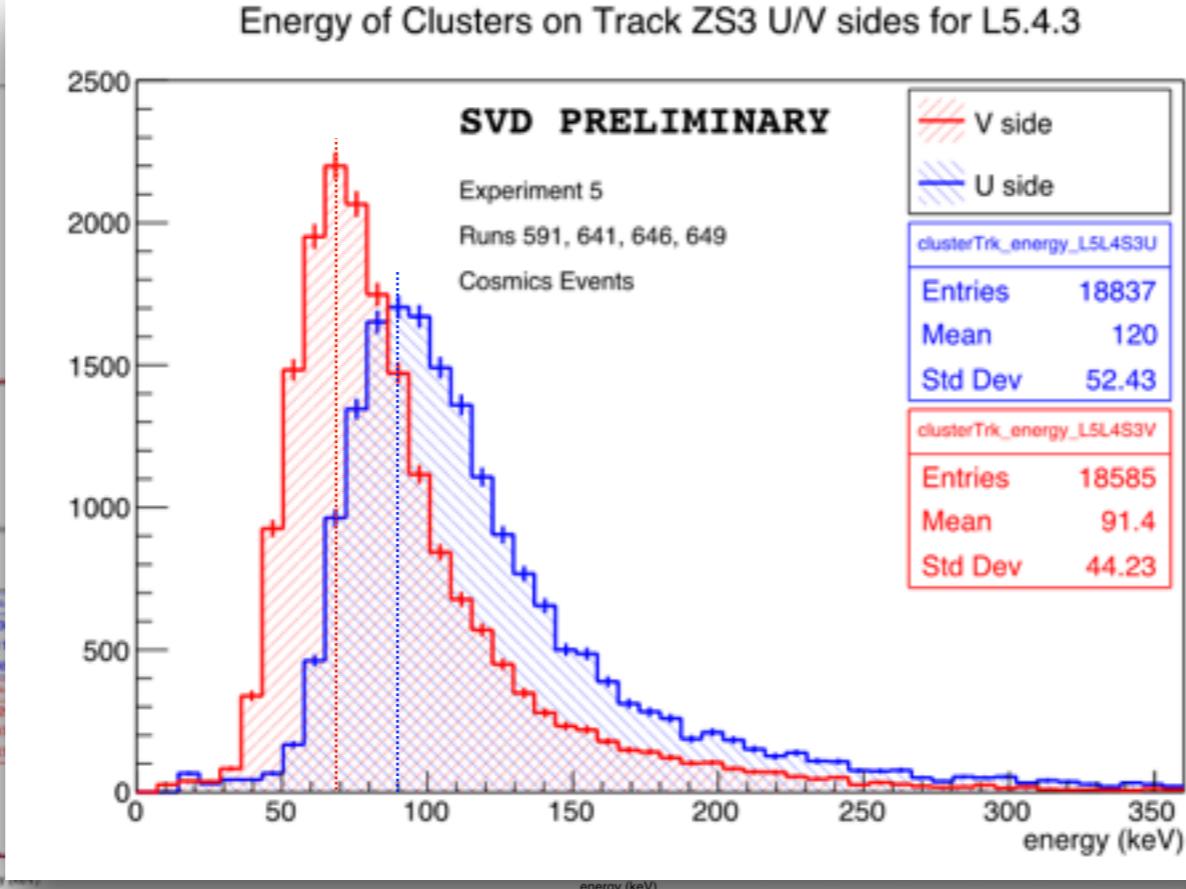
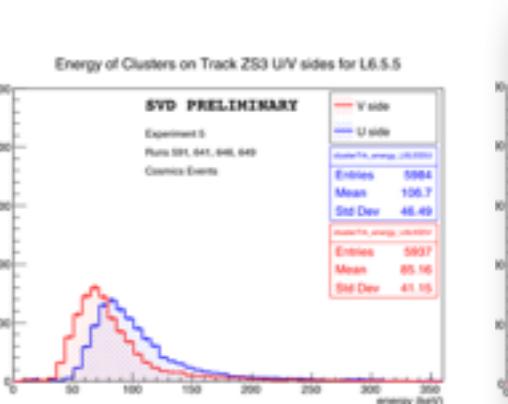
20

# Track-related Cluster Energy

N  V side  
P  U side

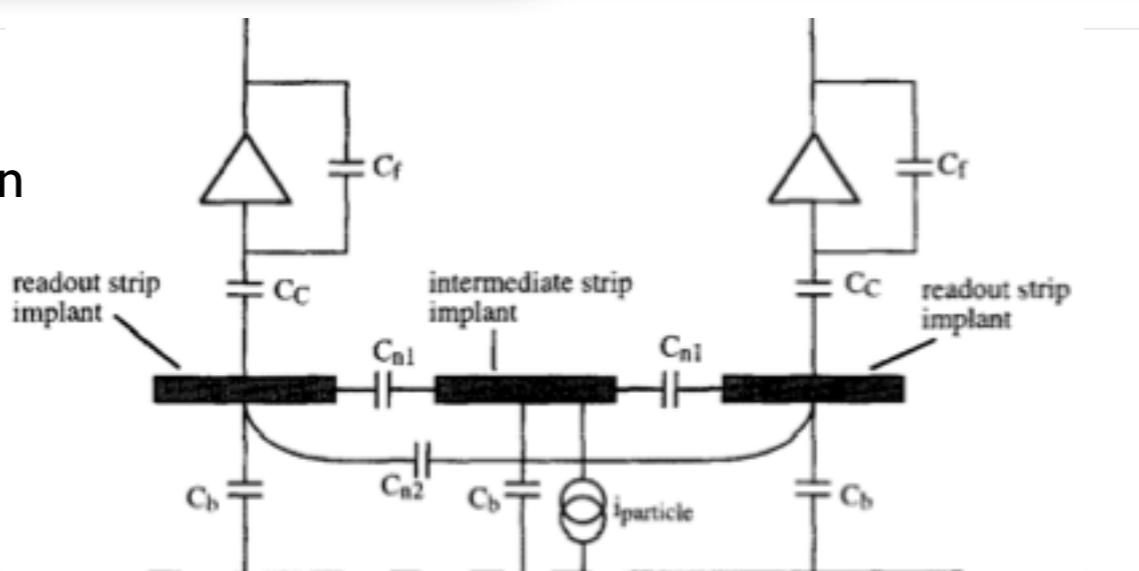
most probable cluster energy as expected from MIPs, around 80 keV

CDC



- 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:

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



IP

backward

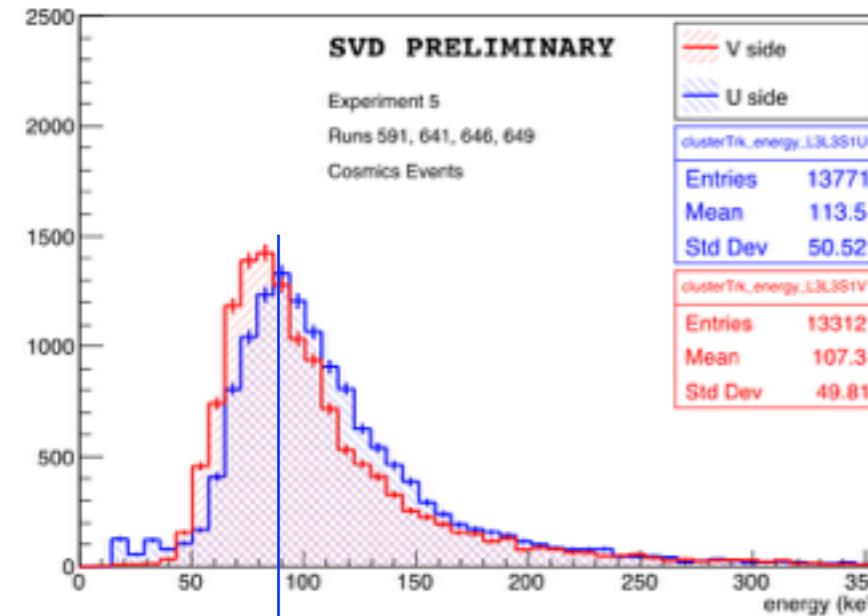
forward

note: layer 3 in slide 23

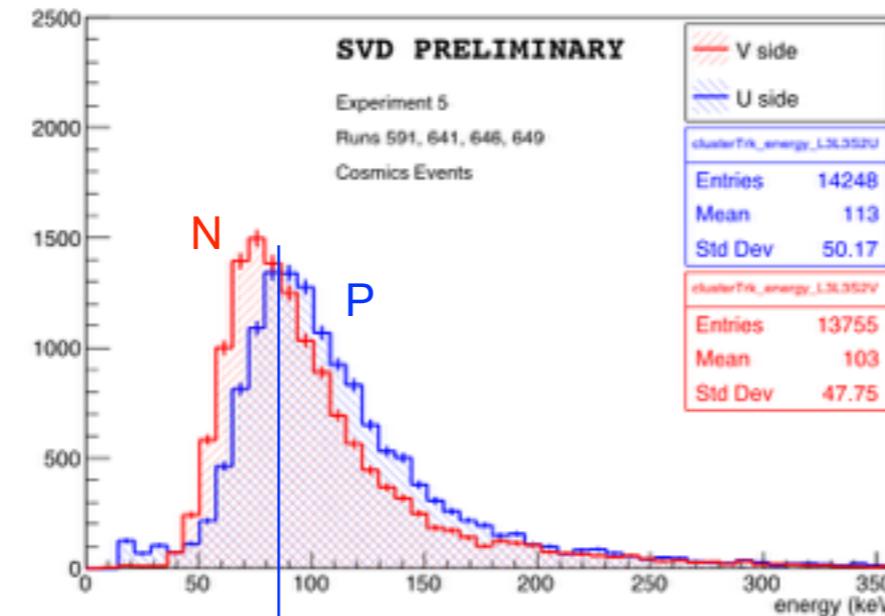
# Cluster Energy, Zero Suppression Effect

nominal online zero suppression, SNR cut = 3:

Energy of Clusters on Track ZS3 U/V sides for L3.3.1



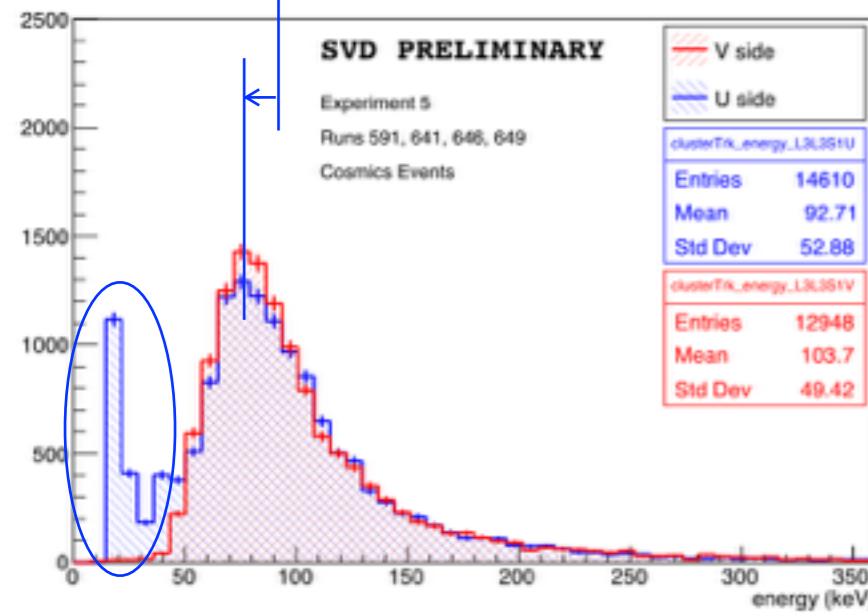
Energy of Clusters on Track ZS3 U/V sides for L3.3.2



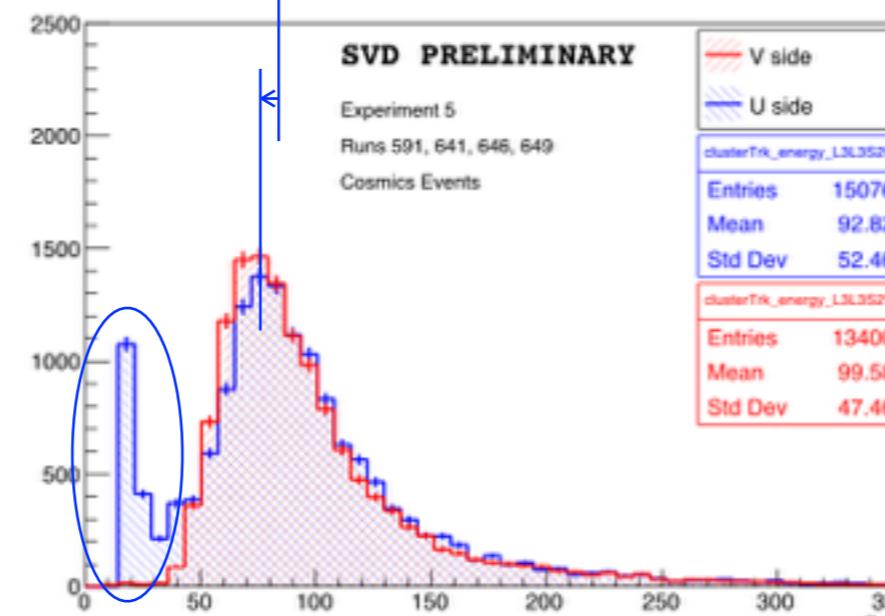
correct estimation of the cluster energy

higher online zero suppression, SNR cut = 5:

Energy of Clusters on Track U/V sides for L3.3.1



Energy of Clusters on Track U/V sides for L3.3.2



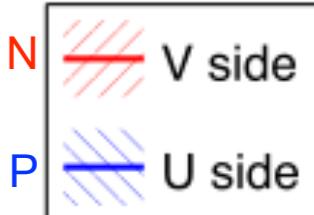
online zero suppression:  
SNR cut  
from 3 to 5

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

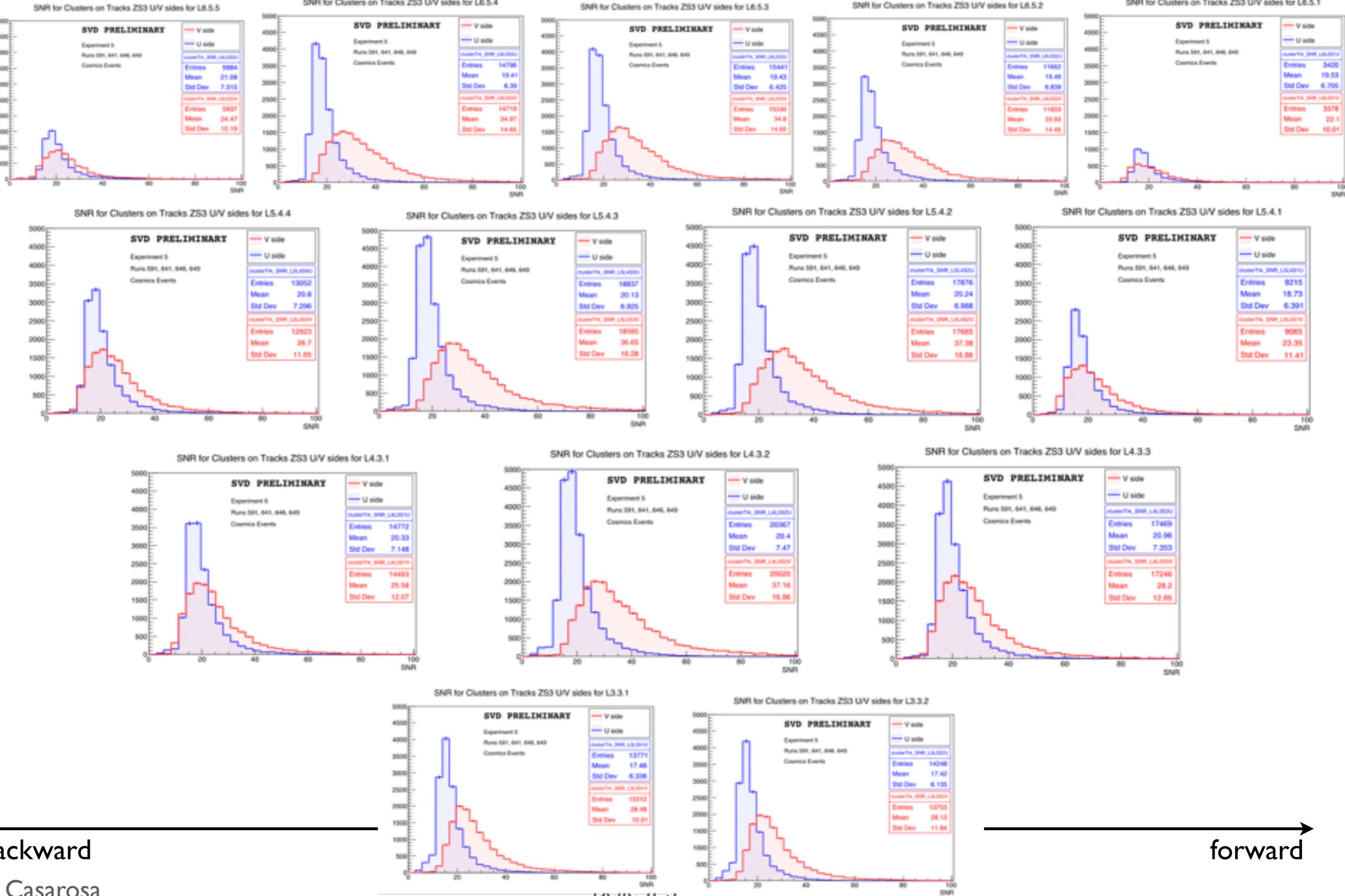
note: effect observed in all players  
note: higher SNR minimizes the effect on v/N side

# Track-related Cluster SNR



good SNR for all sensors, as expected

CDC



IP

backward

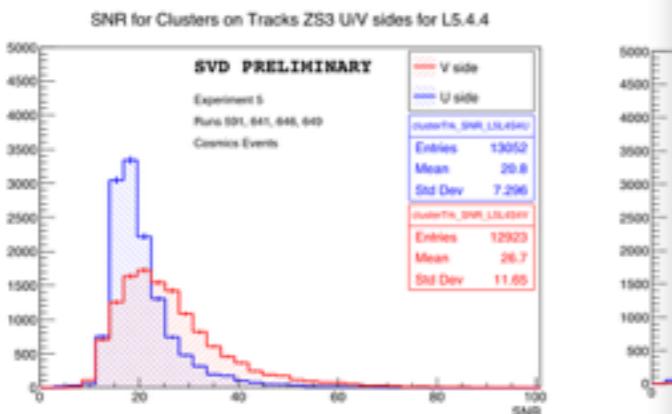
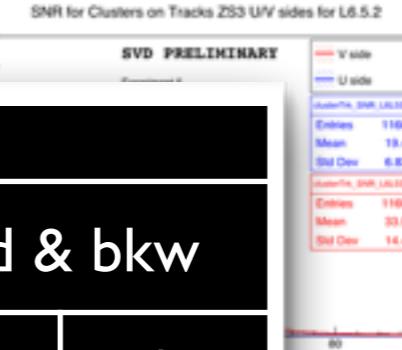
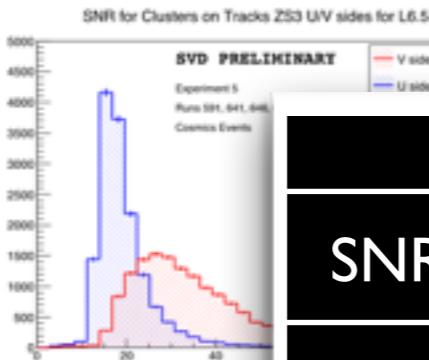
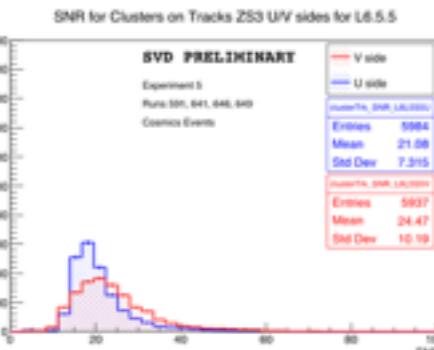
forward

# Track-related Cluster SNR

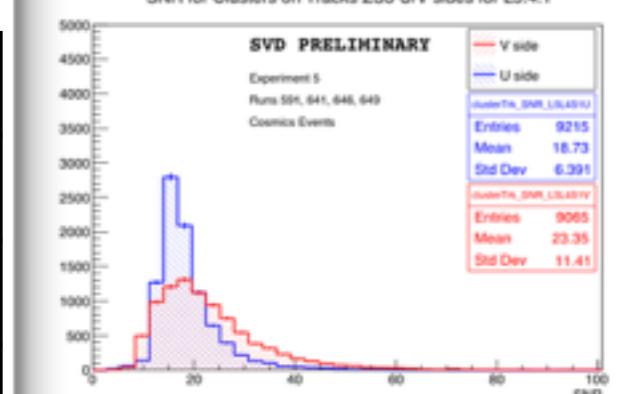
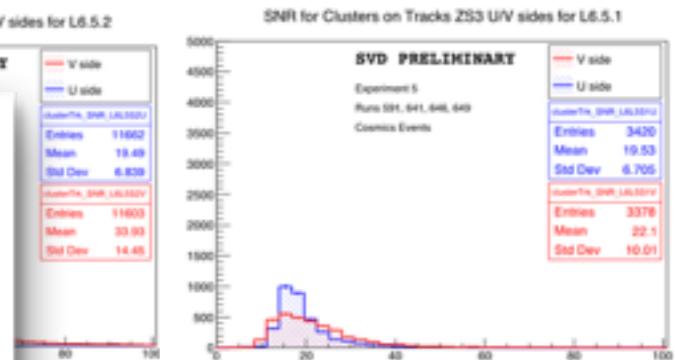


good SNR for all sensors, as expected

CDC



		barrel		fwd & bkw	
SNR	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	—



IP

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

- SNR depends on collected charge, strip noise ad cluster size
  - Noise u/P side ( $\sim 900 e^-$ ) > Noise v/N side ( $\sim 600 e^-$ )
  - 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

backward

forward

# Conclusions

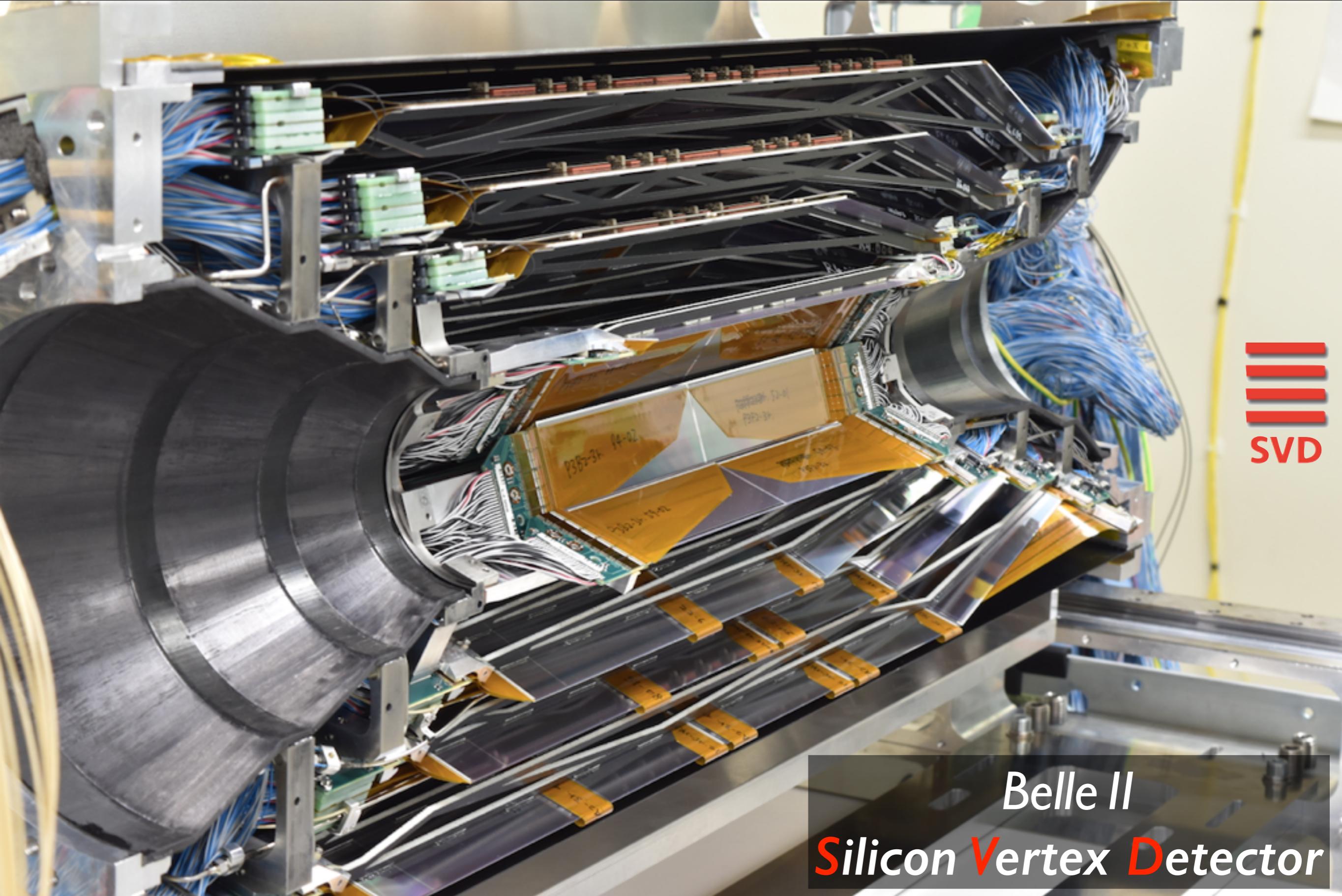
- The Silicon Vertex Detector has been successfully installed in BelleII**
  - SVD is included in global cosmics run, smooth operations so far
  - all sensors are alive, detecting MIPs
  - cluster energy and SNR distributions look as expected for MIPs
- Phase2 data taking allowed to test a small-scale 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



Belle II  
**Silicon Vertex Detector**

*Thank you for your attention.*

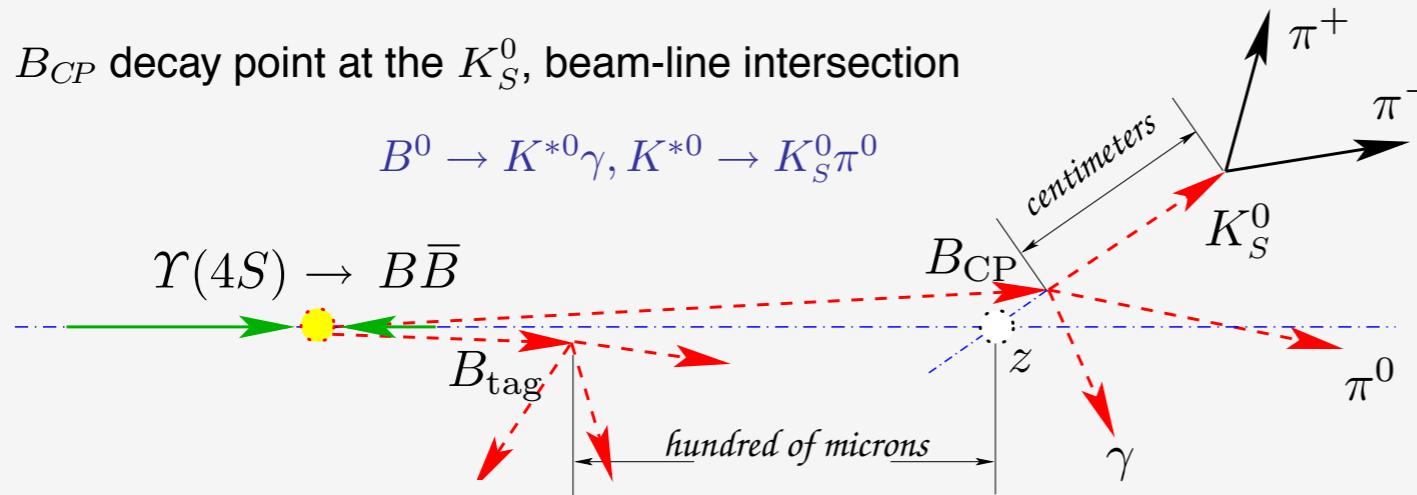




# Vertexing at a B-Factory Experiment

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

$B_{CP}$  decay point at the  $K_S^0$ , beam-line intersection

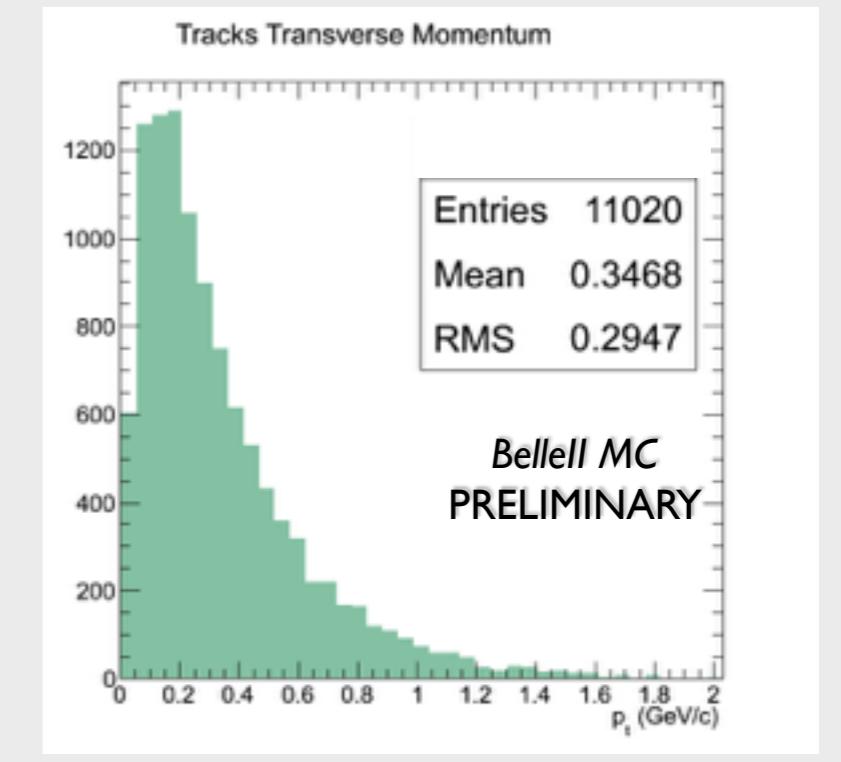


courtesy by E. Paoloni

- 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

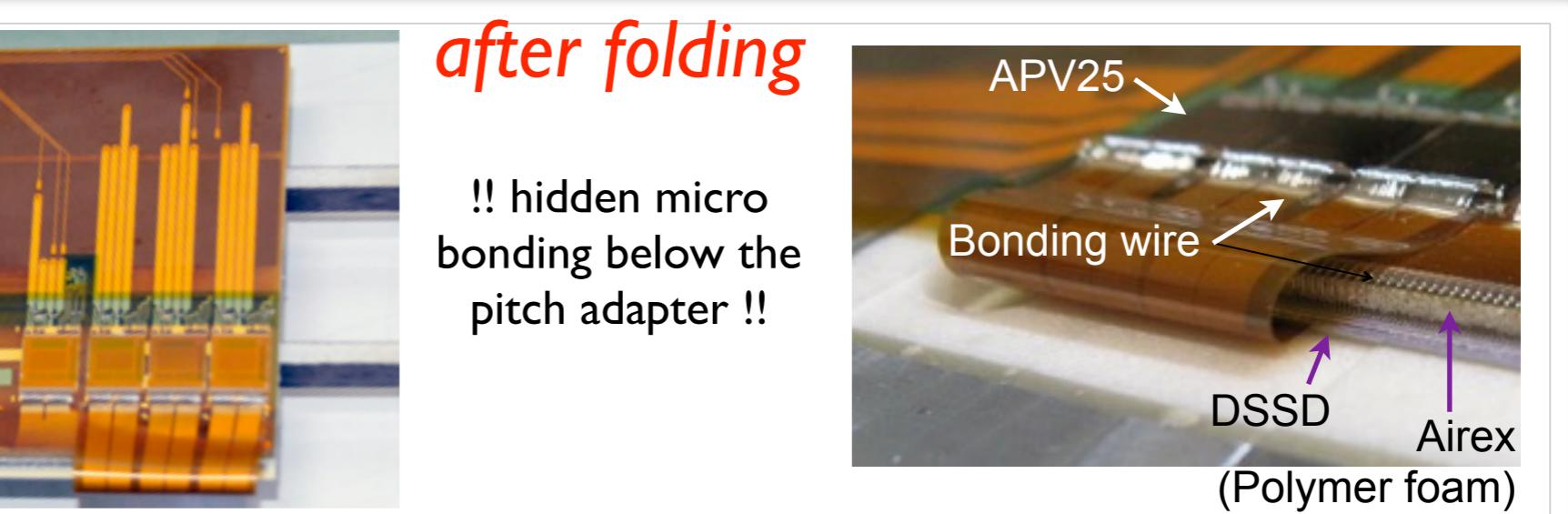
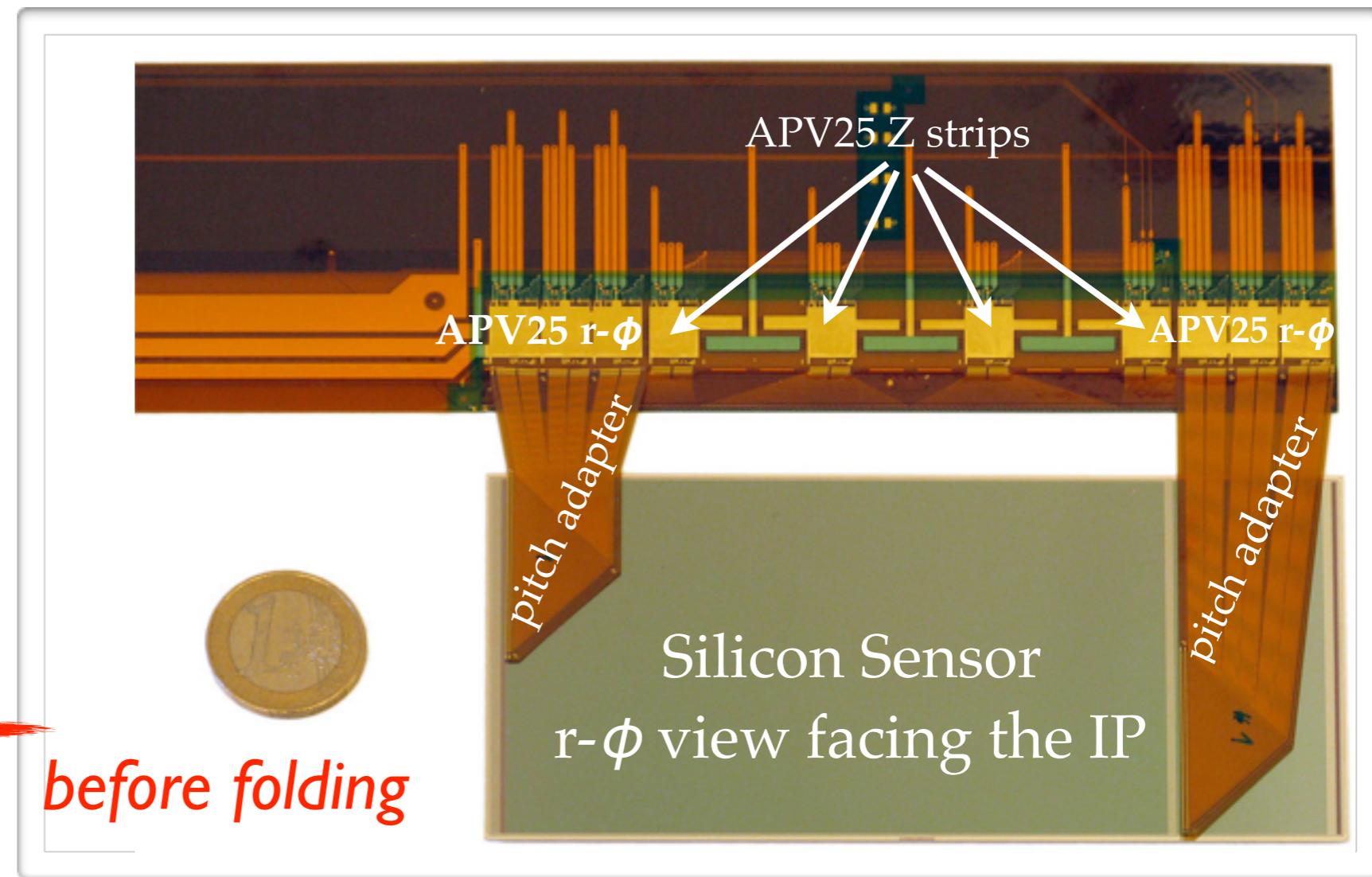
## Typical Y(4S) Event

- Y(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



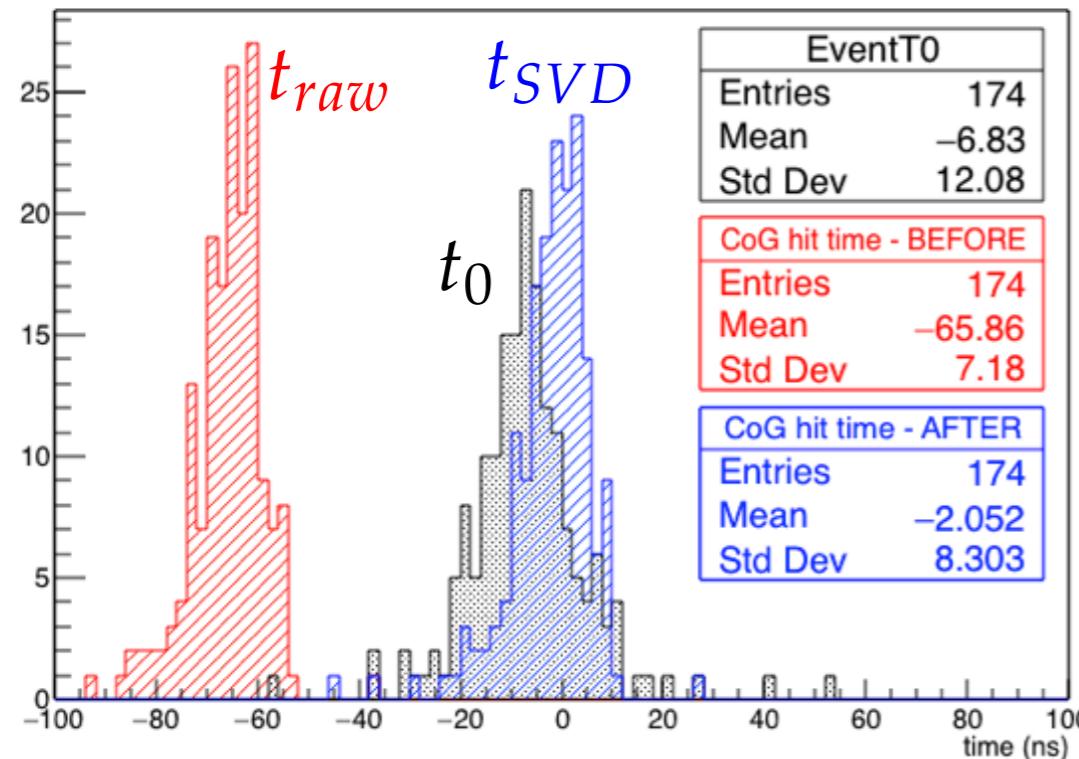
# The Origami Concept

- SVD will operate at a high-luminosity machine ( $8 \times 10^{35} \text{cm}^{-2}\text{s}^{-1}$ )
- 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



# Results on SVD Hit Time in Phase2

Time for sensor 3.1.2, V side, trigger bin = 1



sensor →  
trigger-bin →

$$t_{SVD} = \alpha(s, tb) \cdot t_{raw} + \beta(s, tb) + B$$

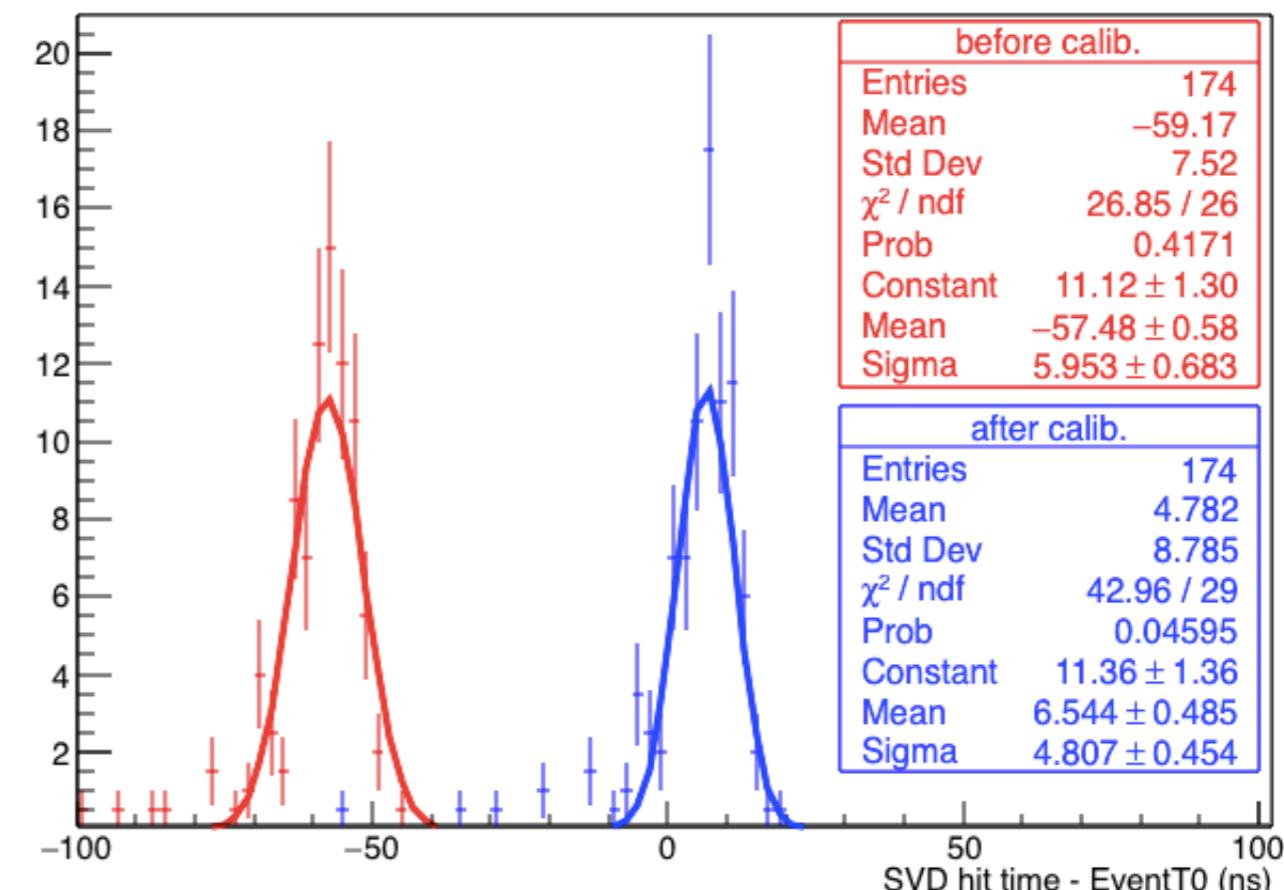
- $\alpha$  and  $\beta$  determined using  $t_0$  estimation, depend on sensor side and trigger bin
- $B$  single shift to center  $t_{SVD}$  distribution in 0



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

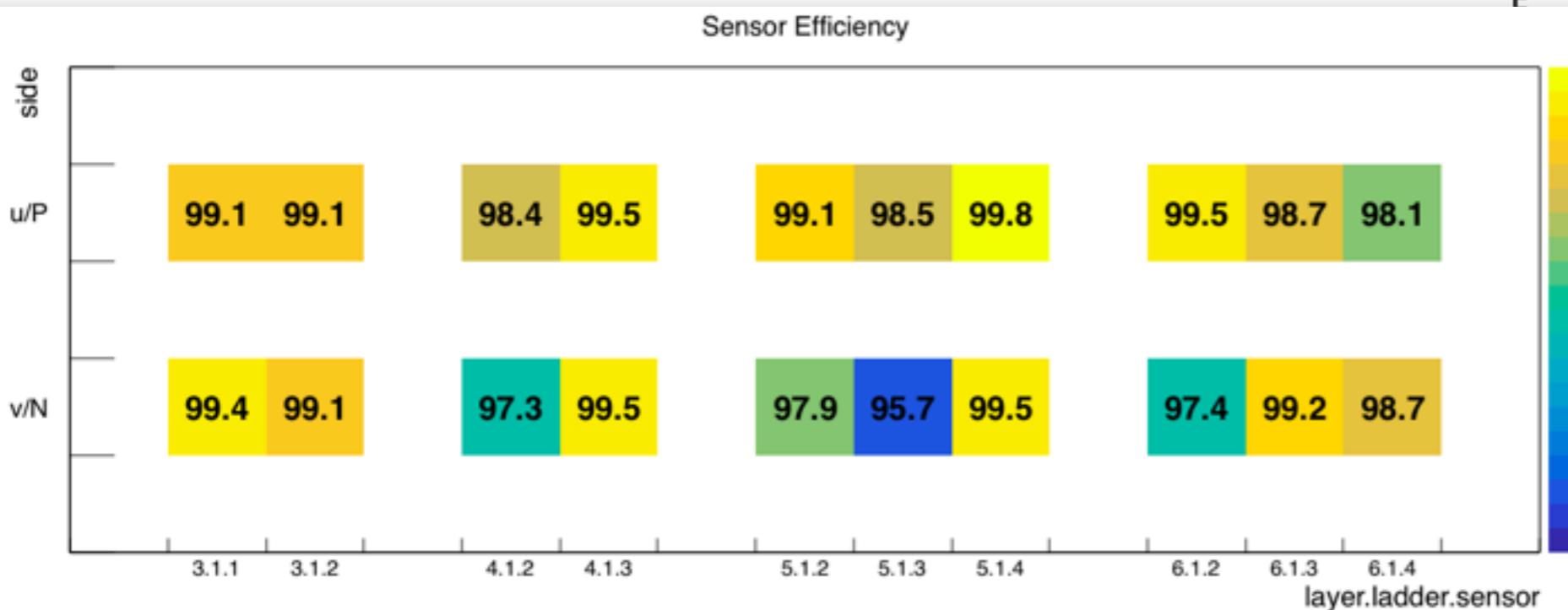
- event time ( $t_0$ ) determined by the drift chamber
  - estimated  $t_0$  error  $\sim 2\text{-}3$  ns
- SVD time before the calibration:
  - $(t_{raw} - t_0)$  resolution  $\sim 6$  ns
- SVD time after calibration (with event time  $t_0$ )
  - $(t_{SVD} - t_0)$  resolution  $\sim 5$  ns

SVD hit time - EventT0 for sensor 3.1.2, V side, trigger bin = 1

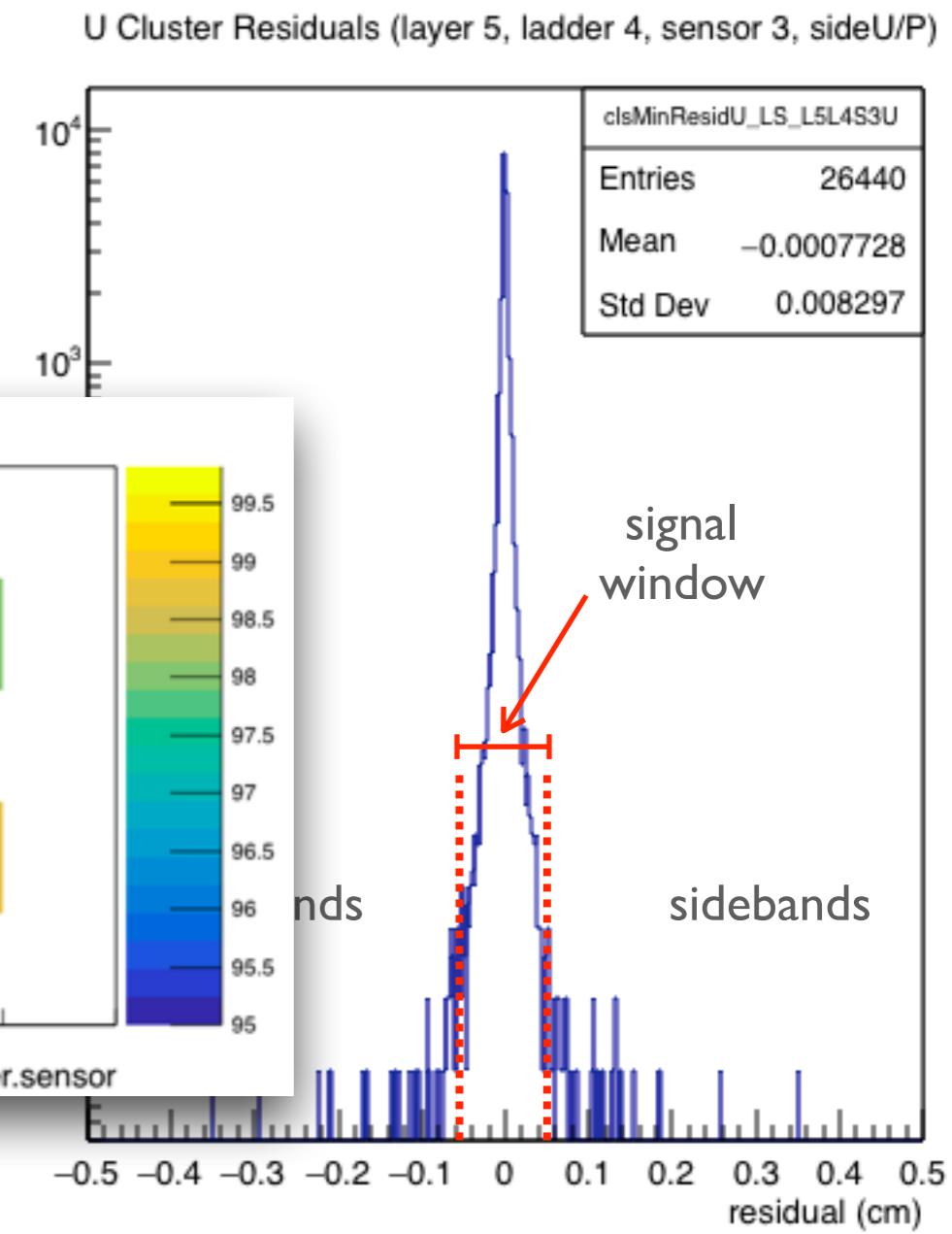


# SVD Phase2 Detector Efficiency

- Sensor efficiency estimated using Bhabha skimmed events with the complete Phase2 dataset.
- Tracking reconstruction *excluding* the sensors belonging to the layer under study, and applying two additional requirements on the tracks:
  - at least one hit in PXD and one hit in SVD
  - extrapolation to the DUT within 20 strips from sensor edge
- 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



✓ efficiencies above 97% for all-except-one sensor despite class B sensors have been used for the Phase2 SVD detector



# The Alignment Effect

U Cluster Residuals (layer 5, ladder 4, sensor 3, sideU/P)

