The Central Drift Chamber of Belle 2

Henrikas Svidras

5th Belle II Starterkit Workshop

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Brief introduction

Aims:

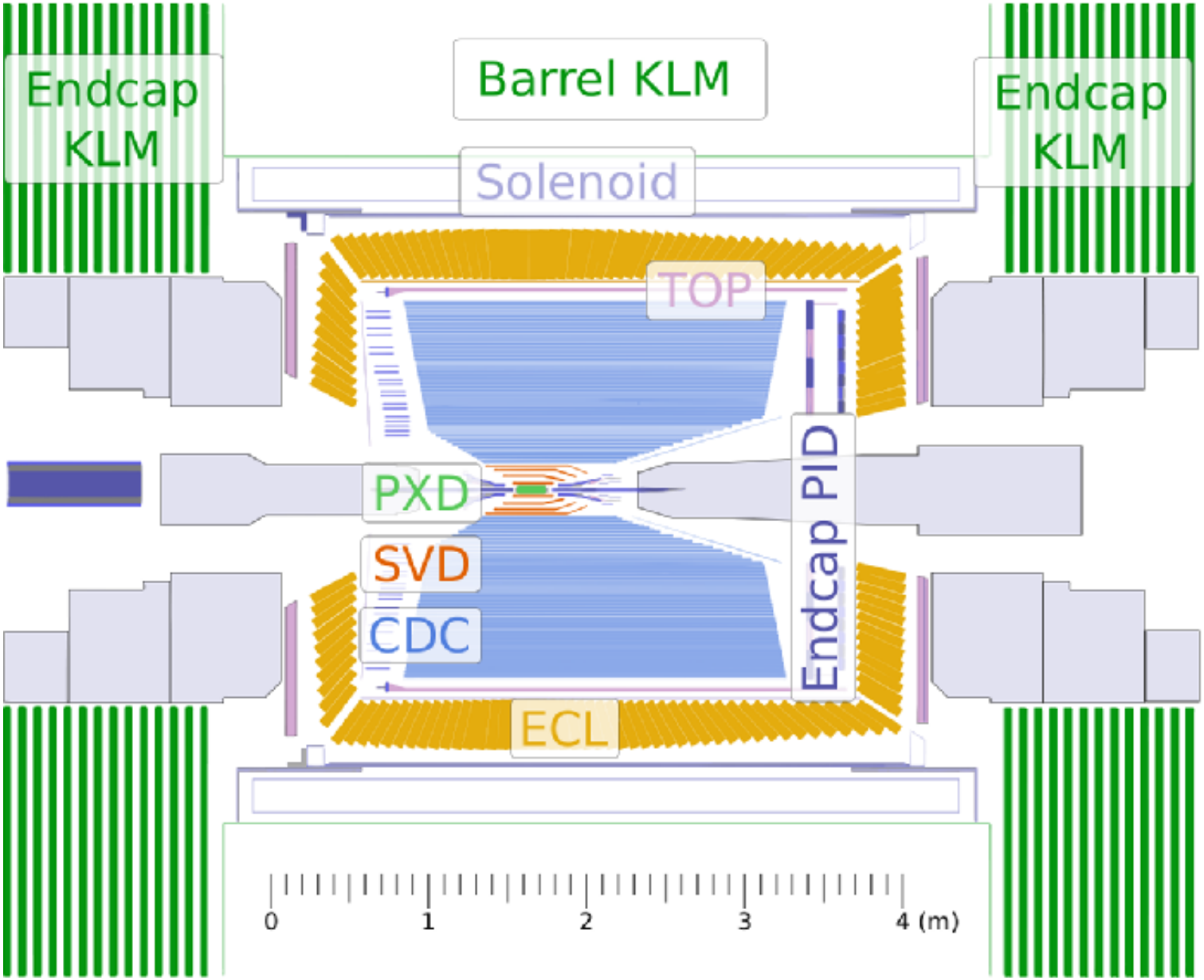
- Introduction to the Central Drift Chamber (**CDC**) of Belle 2.
- Familiarise with the terminology of the CDC.
- Show some performance numbers.

Goal:

- Lay the groundwork to understand CDC tracking and software better.

(Later sessions)

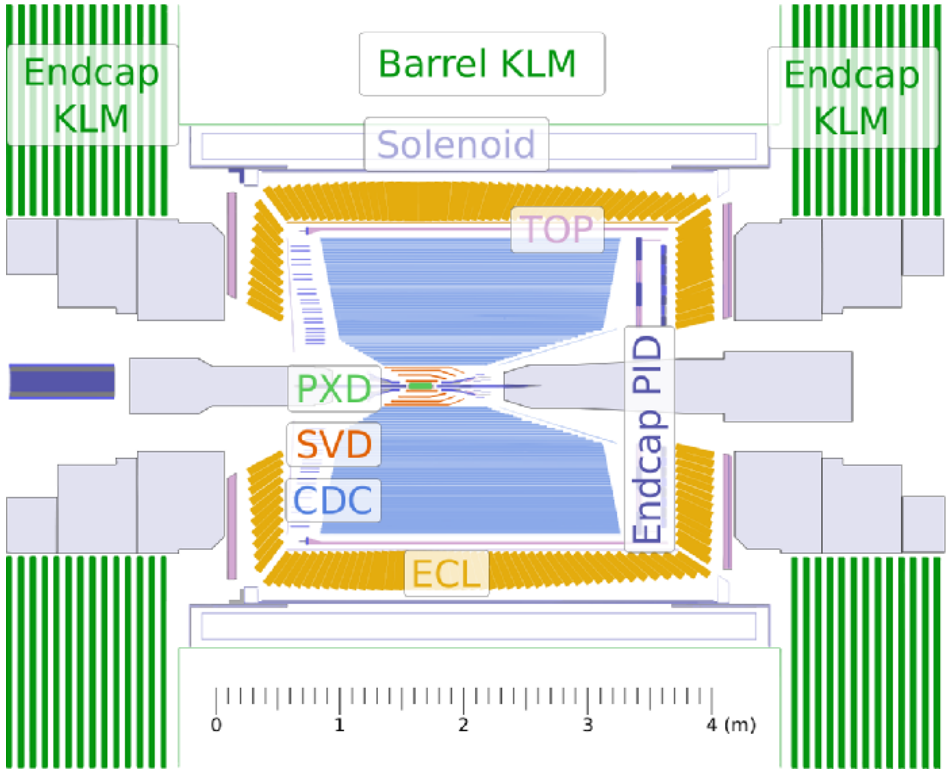
The Belle 2 detector



CDC structure

CDC is the main tracker of Belle 2:

- Measures particle momenta.
- Used in triggering.
- Particle identification.



CDC in Belle 2

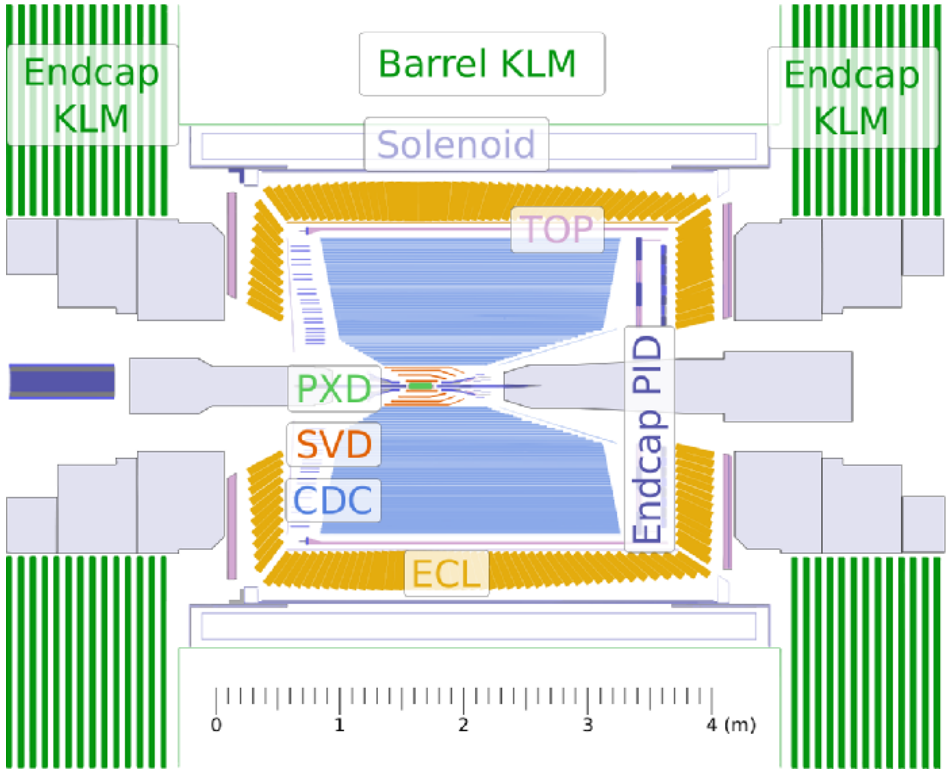
CDC is the main tracker of Belle 2:

- Measures particle momenta.
- Used in triggering.
- Particle identification.

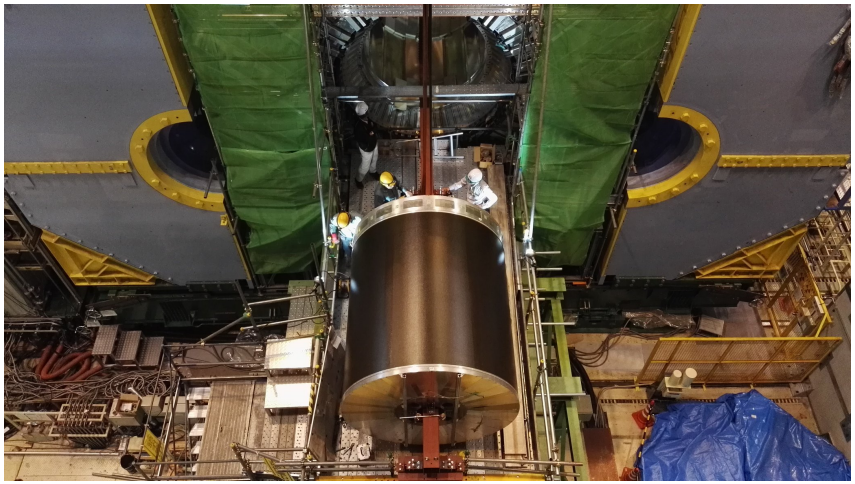
The particles in the travel in **helices**:

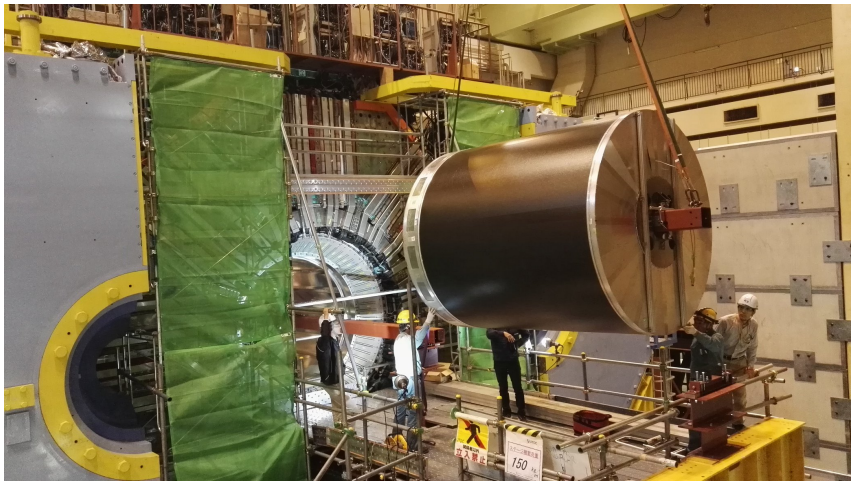
$$\frac{\mathrm{d}\vec{p}}{\mathrm{d}\tau} = q\gamma[\vec{\beta} \times \vec{B}] \qquad (1)$$

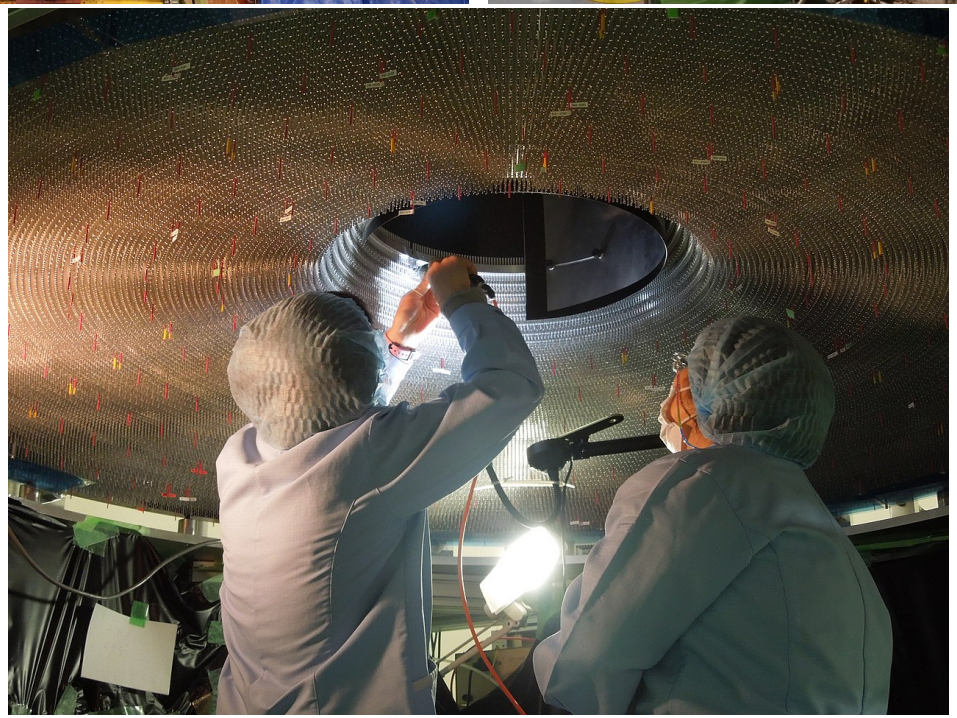
Covers $17° < \theta < 150°$ (polar angle).



CDC in pictures







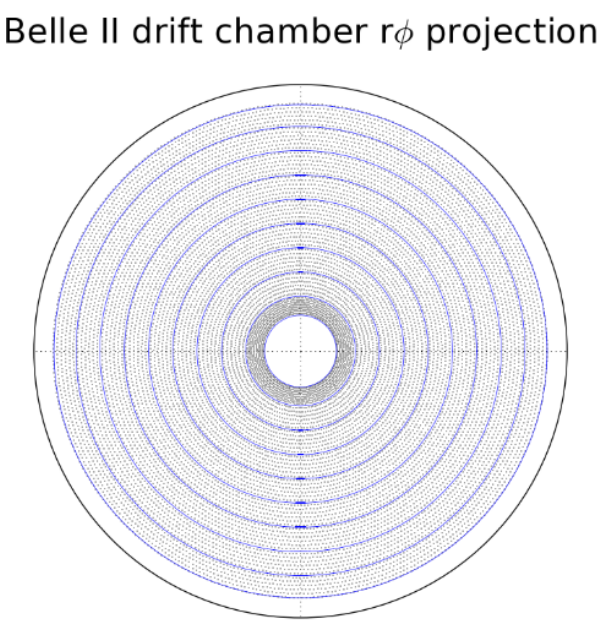
CDC and CDC wires

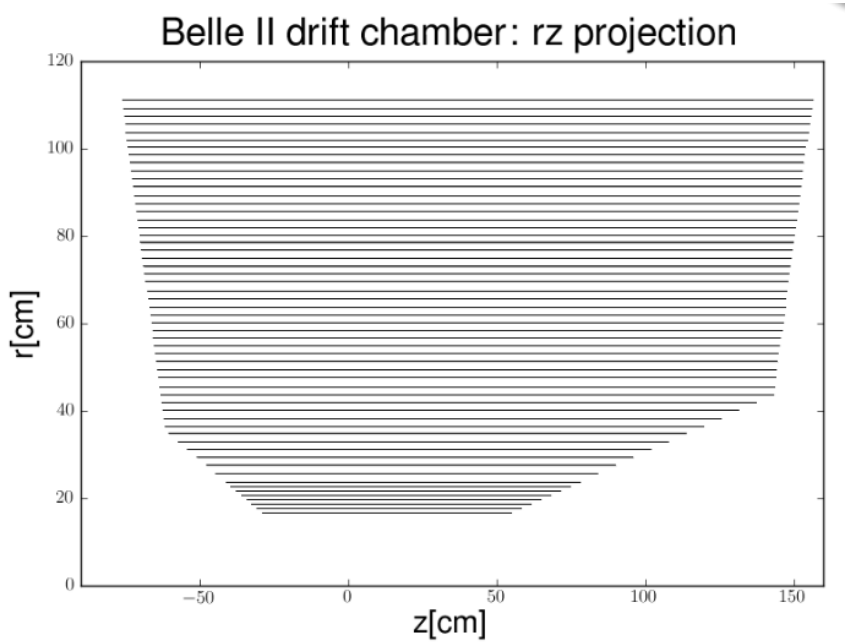
CDC is composed of:

- 9 super layers

which consist of

- 56 layers (grouped to 1x8 and 8x6)
- 14336 wires (160 - 384 wires in a layer).





Drift chambers in general

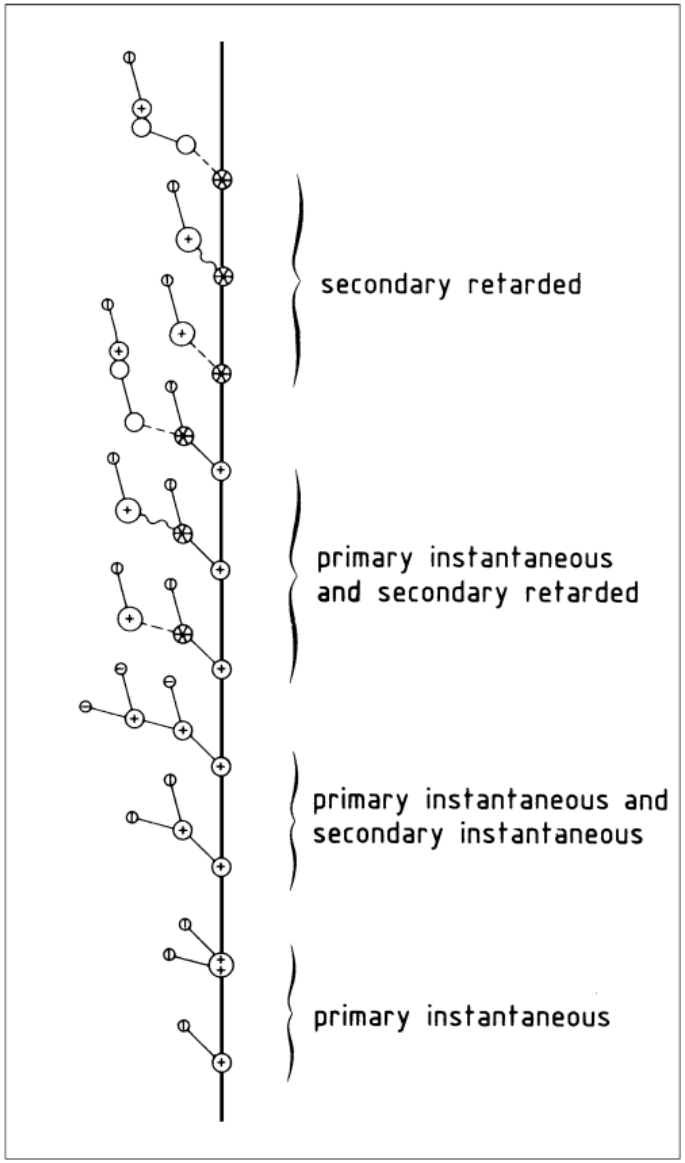
Drift chamber measures the trajectory of traversing particles through secondary ionisation it leaves:

- Primary particle **ionises** gas molecules.
- Secondary electrons create **avalanches**.
- Readout wires measure **drift time**.

$$pA \rightarrow pA^{+}e^{-}, pA^{2+}e^{-}e^{-}... \qquad (2)$$

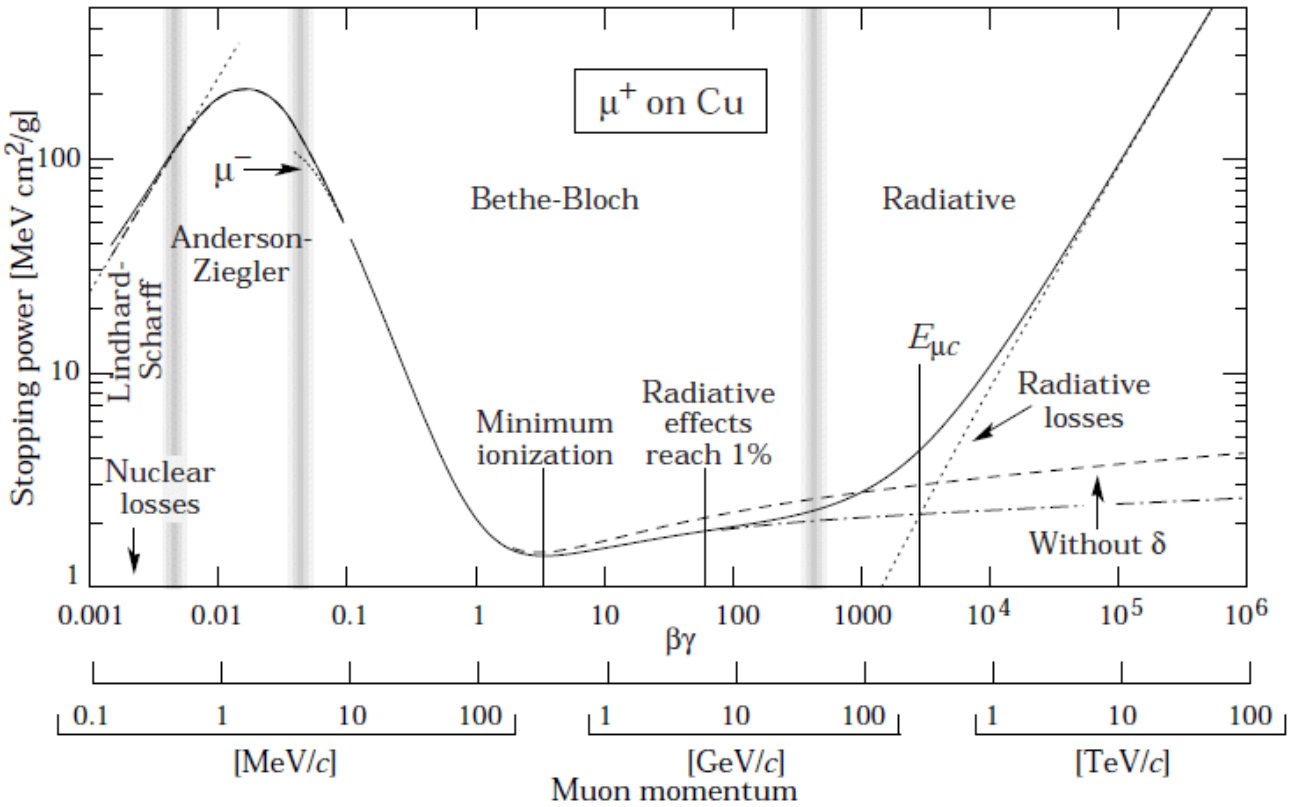
or in gas mixtures e.g.,

$$pA \rightarrow pA^{*}, \quad \text{and} \quad A^{*}B \rightarrow AB^{+}e^{-}, \qquad (3)$$



Rolandi, Luigi & Riegler, Werner & Blum, Walter. (2008). Particle Detection with Drift Chambers. 10.1007/978-3-540-76684-1.

Ionisation



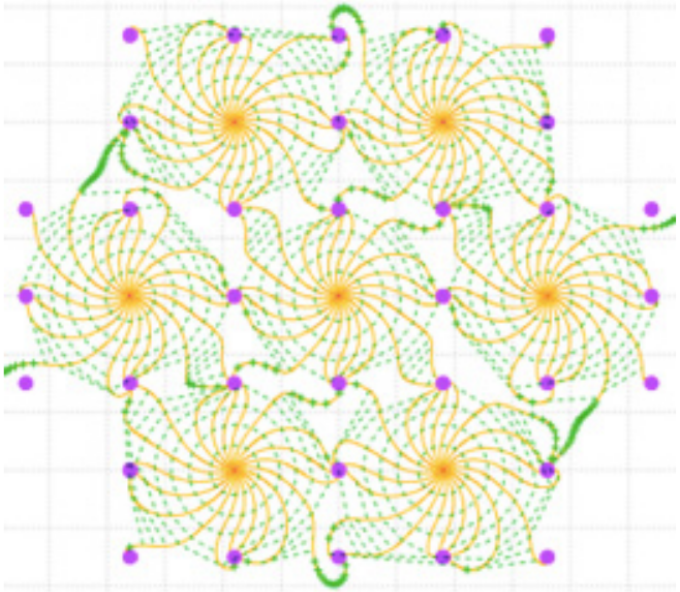
Bethe-Bloch formula:

$$\frac{\mathrm{d}E}{\mathrm{d}x} = \frac{4\pi N e^4}{mc^2\beta^2} z^2 \left(\ln \frac{2mc^2\beta^2\gamma^2}{I} - \beta^2 + \mathrm{corr} \right) \tag{4}$$

Drift chambers in general

To induce the drift **electric field** is needed.

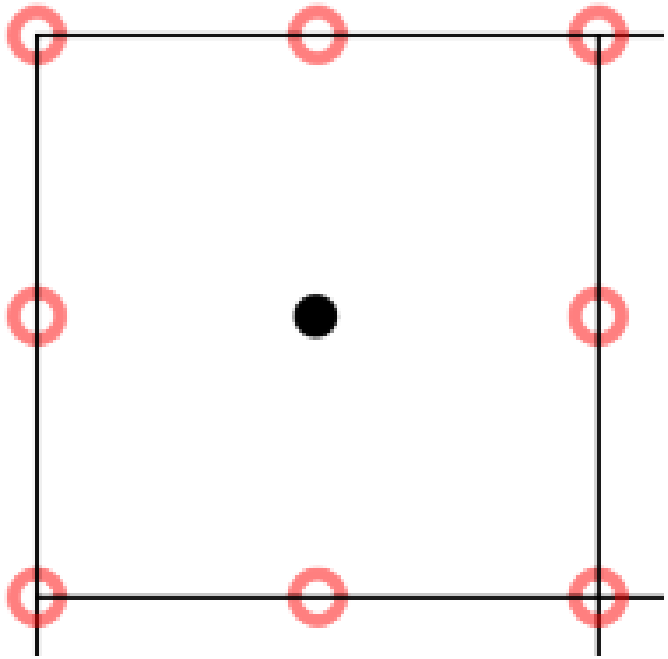
$\rightarrow$ Accelerated electrons create avalanches



In Belle2:

8 field wires

1 sense wire



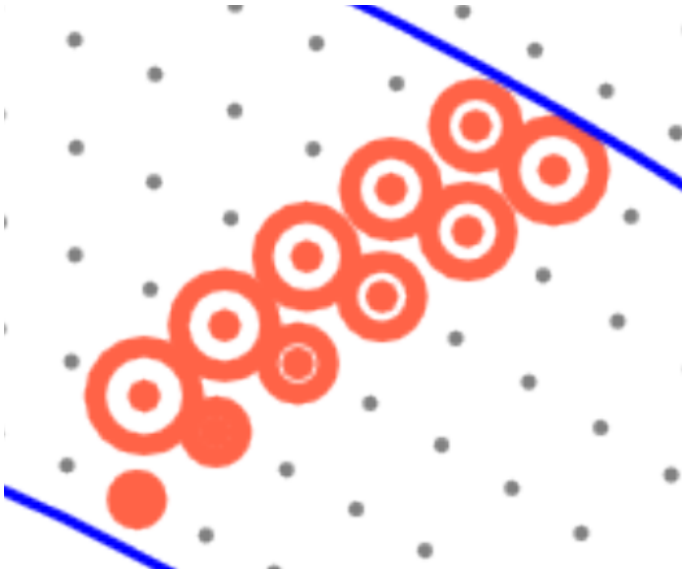
- Field wires generate electric field.
- Sense wires "sense" the signal

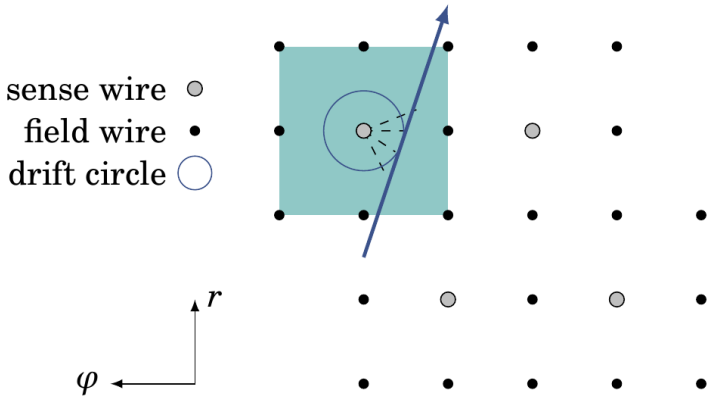
$$E \sim \frac{U}{r} \tag{5}$$

Drift chambers in general

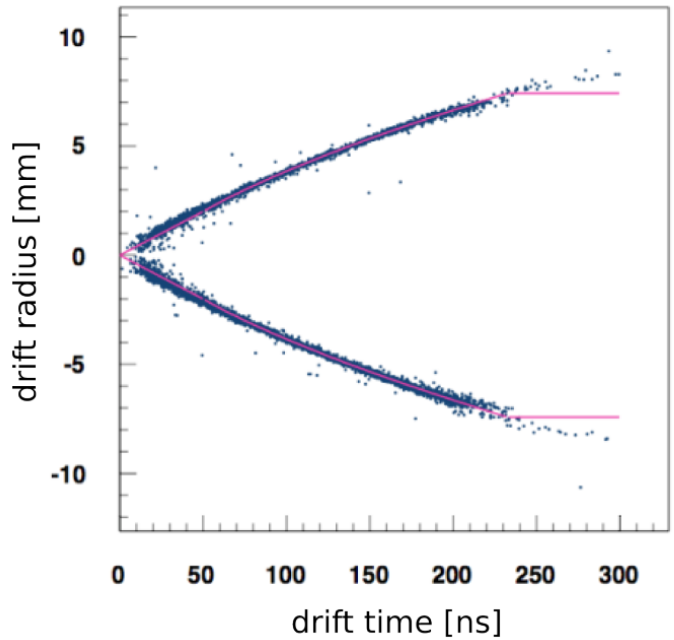
Once the electron avalanche reaches the sense wire a signal is generated. (**CDC Hit**)

The signal is readout by electronics: the signal is digitised by ADCs and TDCs.





Drift radius extracted from drift velocity:



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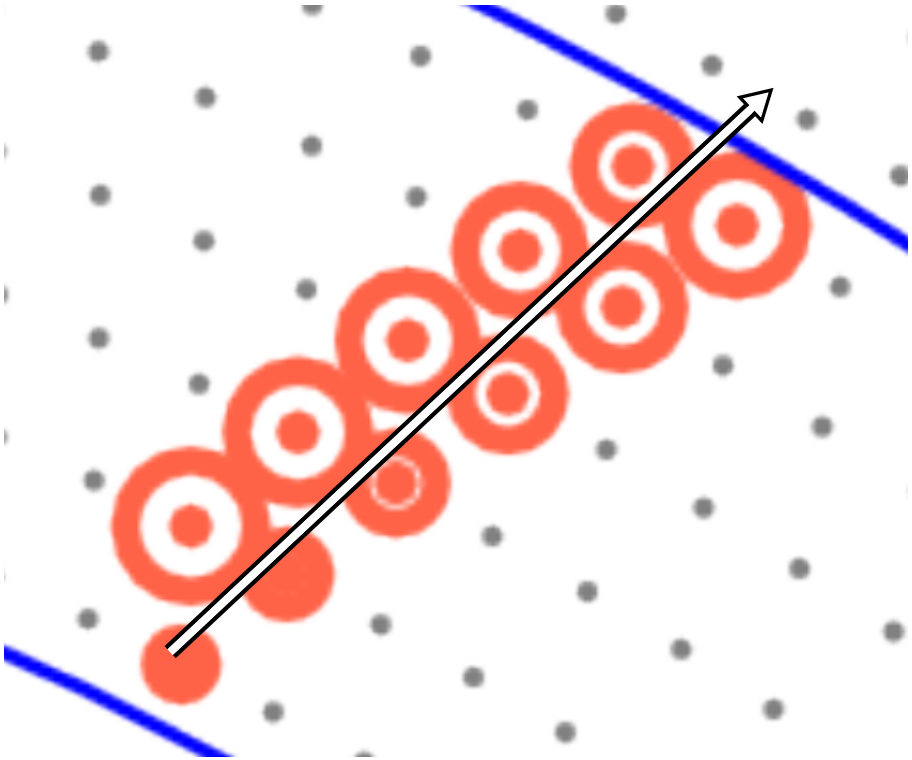

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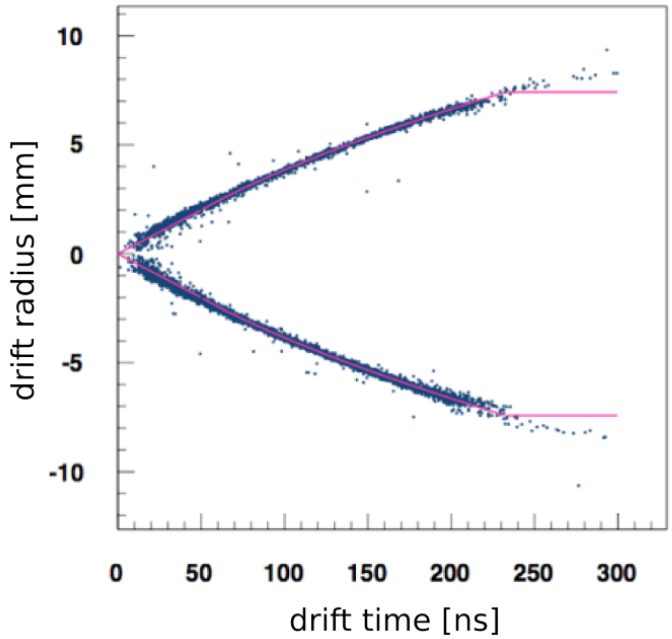
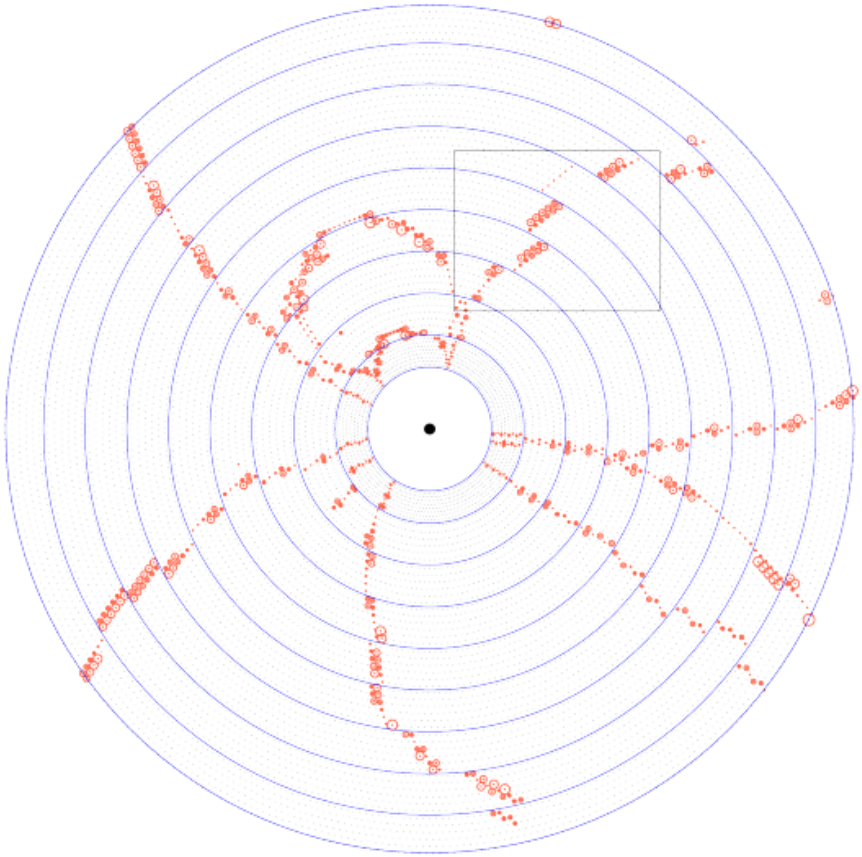


Typical event in the CDC

An example typical event of $\Upsilon(4S)$ decay (no beam background)



Can already easily get important info about particles:

$|\vec{p_T}| = R \cdot B \cdot |q|$ && $q > 0$ if clockwise, otherwise $q < 0$.

Axial and Stereo layers

If wire is along z (the beamline):
how to differentiate between $z = z_1$ and $z = z_2$?

Axial and Stereo layers

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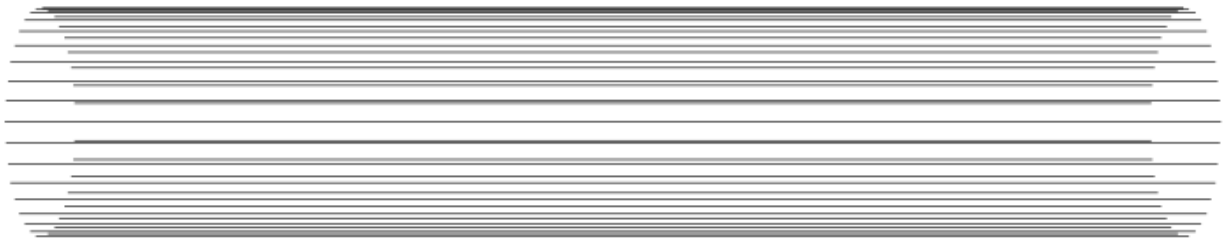
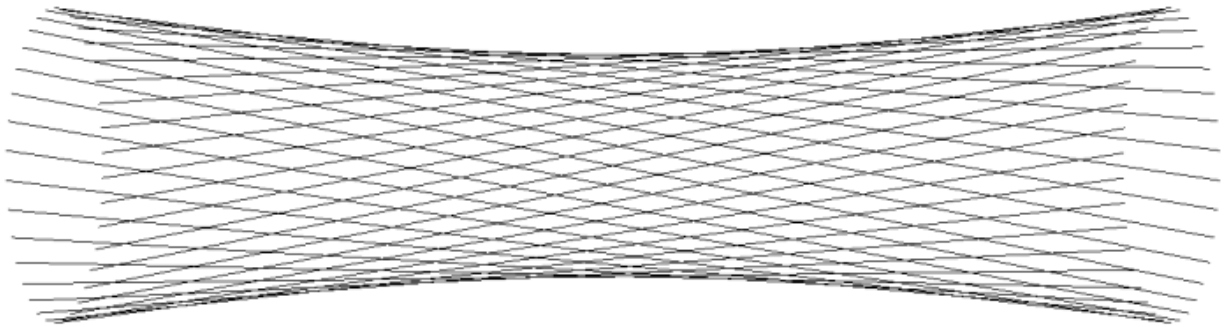


(a) An axial wire layer - sense wires are parallel to the beamline

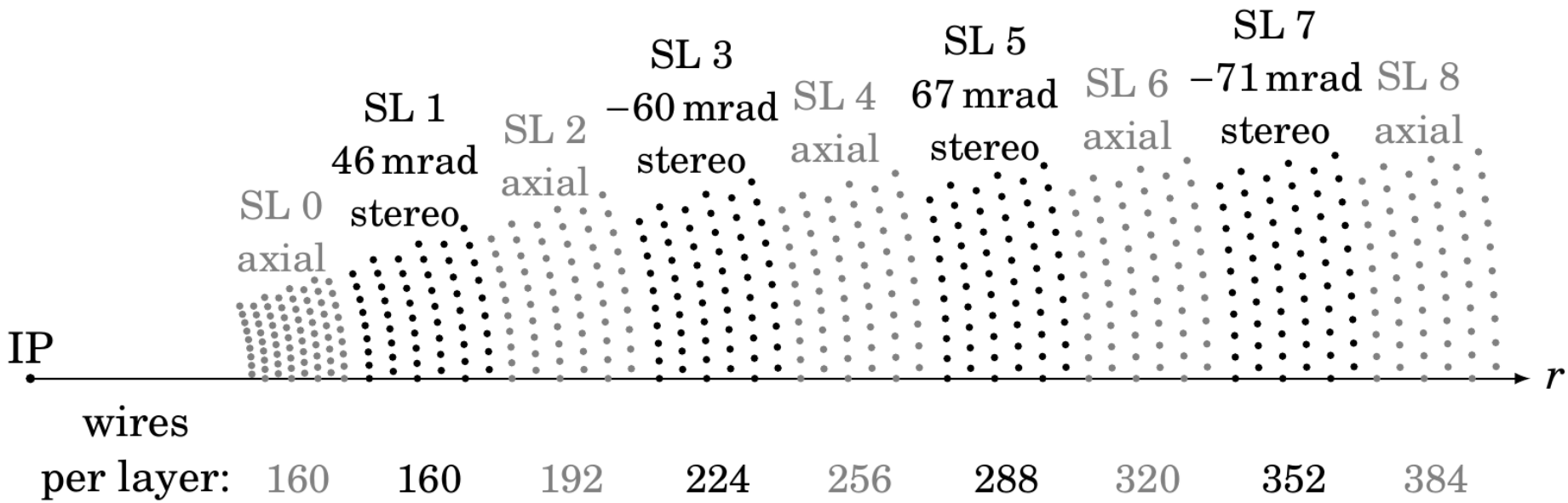


(b) A stereo wire layer - sense wires are skewed to the beamline (exaggerated)

$\rightarrow$ different combinations of wires are hit for different z, due to skew.

Layer structure

Superlayer	Type	# of layers	# of wires /layer	Radius, mm	Stereo angle, mrad
1	A	8	160	168.0 – 238.0	0 – 0
2	U	6	160	257.0 – 348.0	45.4 – 45.8
3	A	6	192	365.2 – 455.7	0 – 0
4	V	6	224	476.9 – 566.9	-55.3 – -64.3
5	A	6	256	584.1 – 674.1	0 – 0
6	U	6	288	695.3 – 785.3	63.1 – 70.0
7	A	6	320	802.5 – 892.5	0 – 0
8	V	6	352	913.7 – 1003.7	-68.5 – -74.0
9	A	6	384	1020.9 – 1111.4	0 – 0



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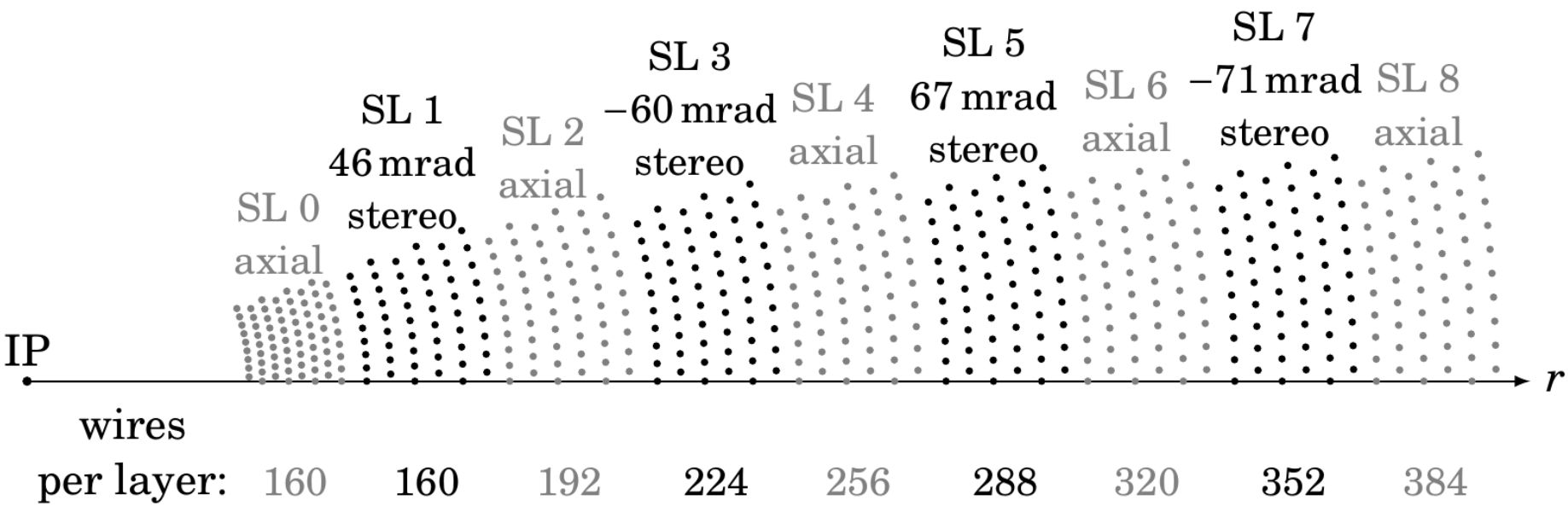

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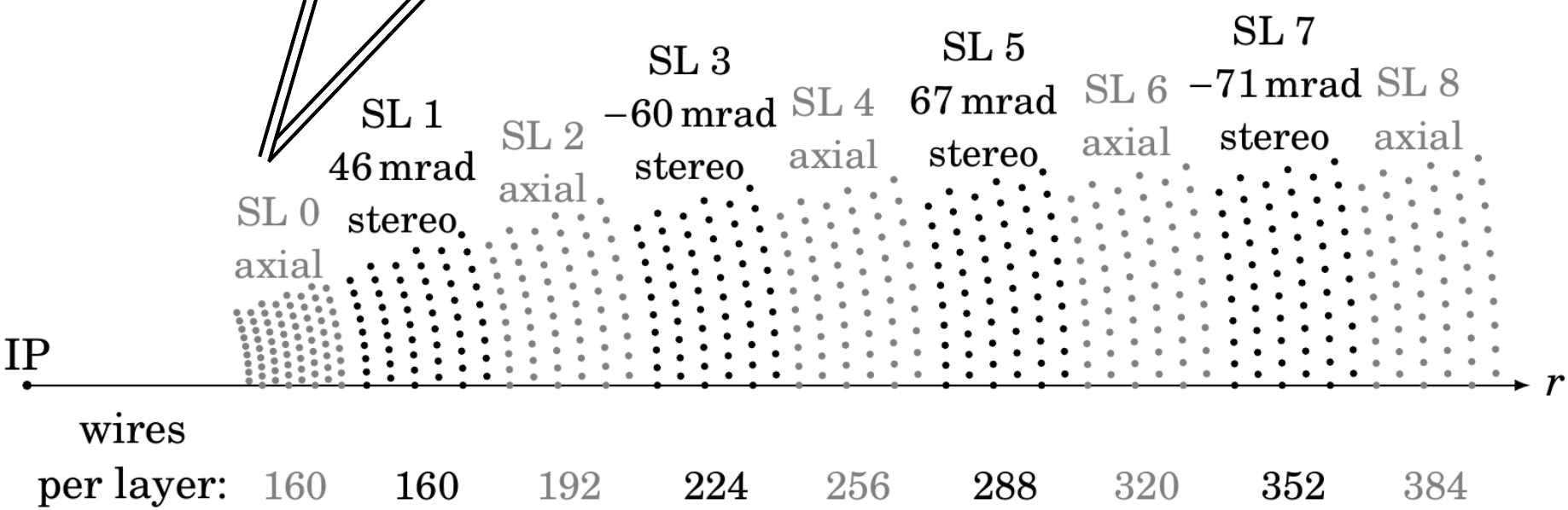


basf2 objects for CDC

Some important quantities that you actually "see" that characterise hits.

- **A**nalog-to-**D**igital-**C**onverter (ADC).

→ related to integrated charge deposited on the wire.

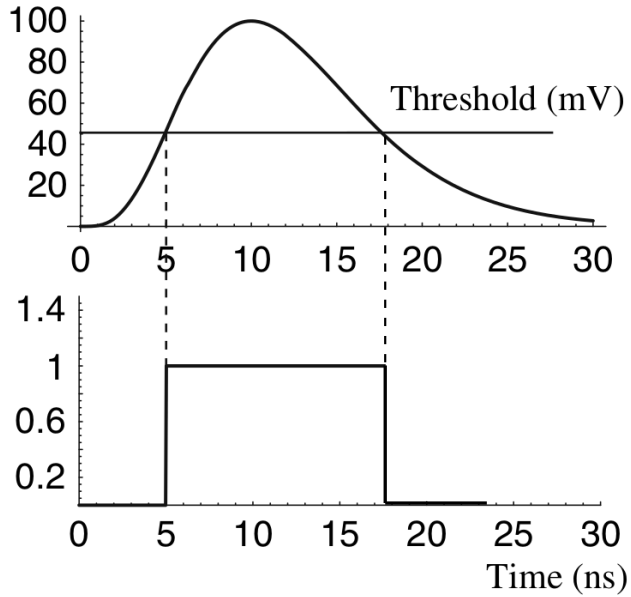
- **T**ime-**o**ver-**T**hreshold (TOT).

→ threshold for a hit to be registered as non-background/noise.

- **T**ime-to-**D**igital-**C**onverter (TDC).

→ related to drift time.

Very important in track reconstruction and correct hit selection!



Triggering

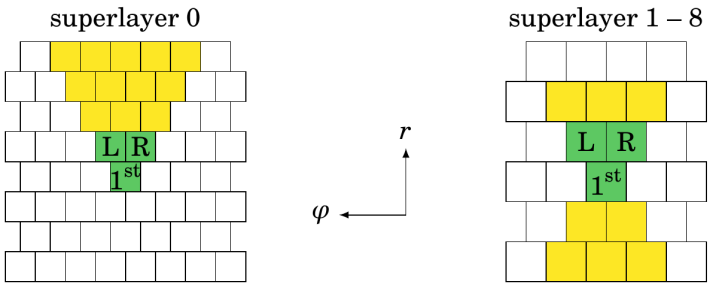
Belle II has a two-level trigger system.

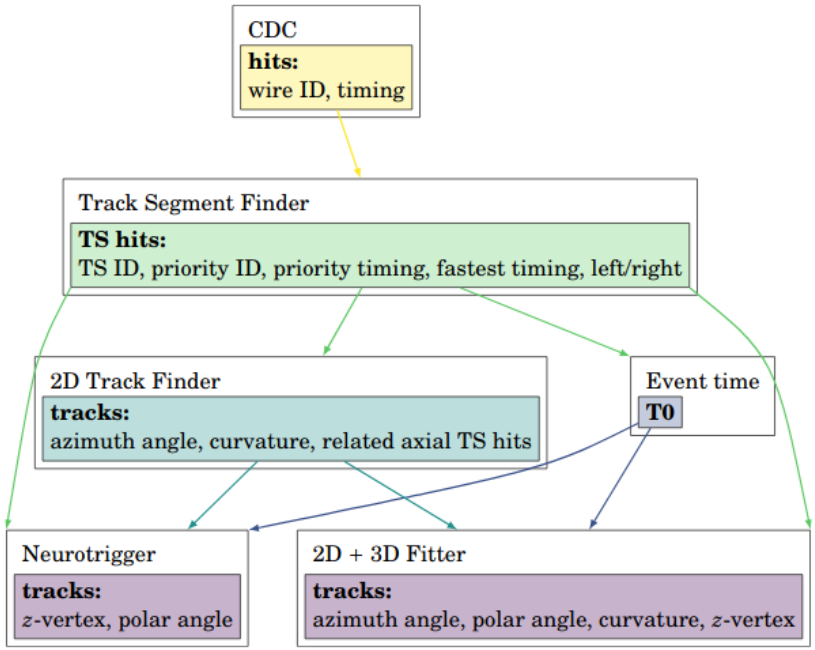
1st-level trigger implemented in FPGAs:

- Return trigger signal for data acquisition
- Trigger rate: 30 kHz, latency: 5 µs.

Consists of subtrigger systems:

- track (CDC) trigger & ECL trigger.
- additional TOP & KLM triggers.

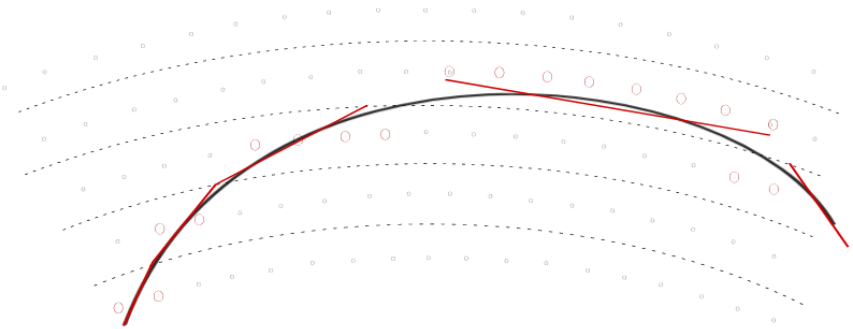




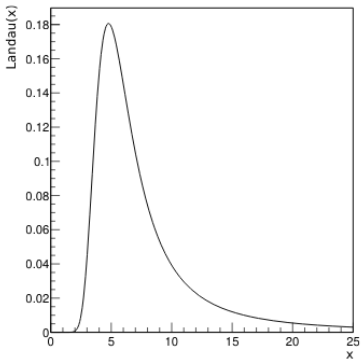
dE/dx measurements and PID

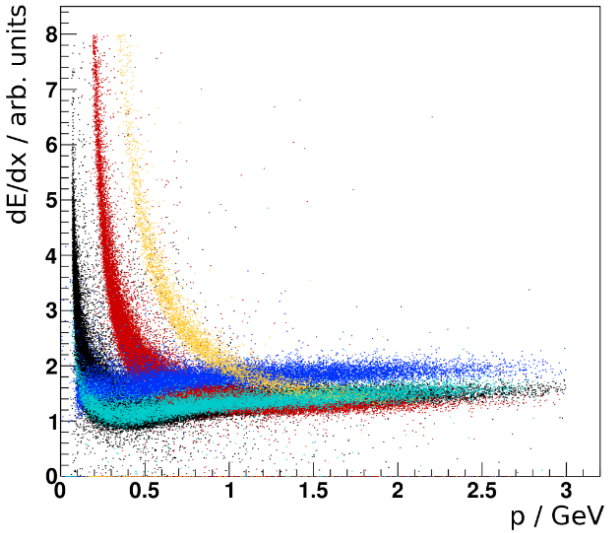
Ionisation is $\sim$ distance traversed, so charge/distance is used:

- Charge in each layer summed.
- Distance approximated as straight line to next layer.



$\mathrm{d}E/\mathrm{d}x$ - extracted as avg ionisation:





electrons, muons, pions, kaons, protons.

$\rightarrow$ PID possible by comparing with distributions.

& combining with $\mathrm{d}E/\mathrm{d}x$ from PXD/SVD.

Expected CDC Performance

Majority of charged particles below 2 GeV

$$\left(\frac{\sigma_{p_T}}{p_T}\right)_{\text{meas}} \rightarrow \text{measurement error}$$

Dominating:

$$\left(\frac{\sigma_{p_T}}{p_T}\right)_{\text{MS}} \rightarrow \text{error due to multiple scattering}$$

Expected CDC Performance

Majority of charged particles below 2 GeV
$\rightarrow$ mom. resolution will be dominated by multiple scattering.

- low-Z gas (50% He, 50%-C_2H_6).
- low-mass Au plated, W sense wires.
- low-mass Al field wires.

$\rightarrow$ assuming $\sigma_{r\phi} \sim 100$ µm:
Ideally, measurement error:

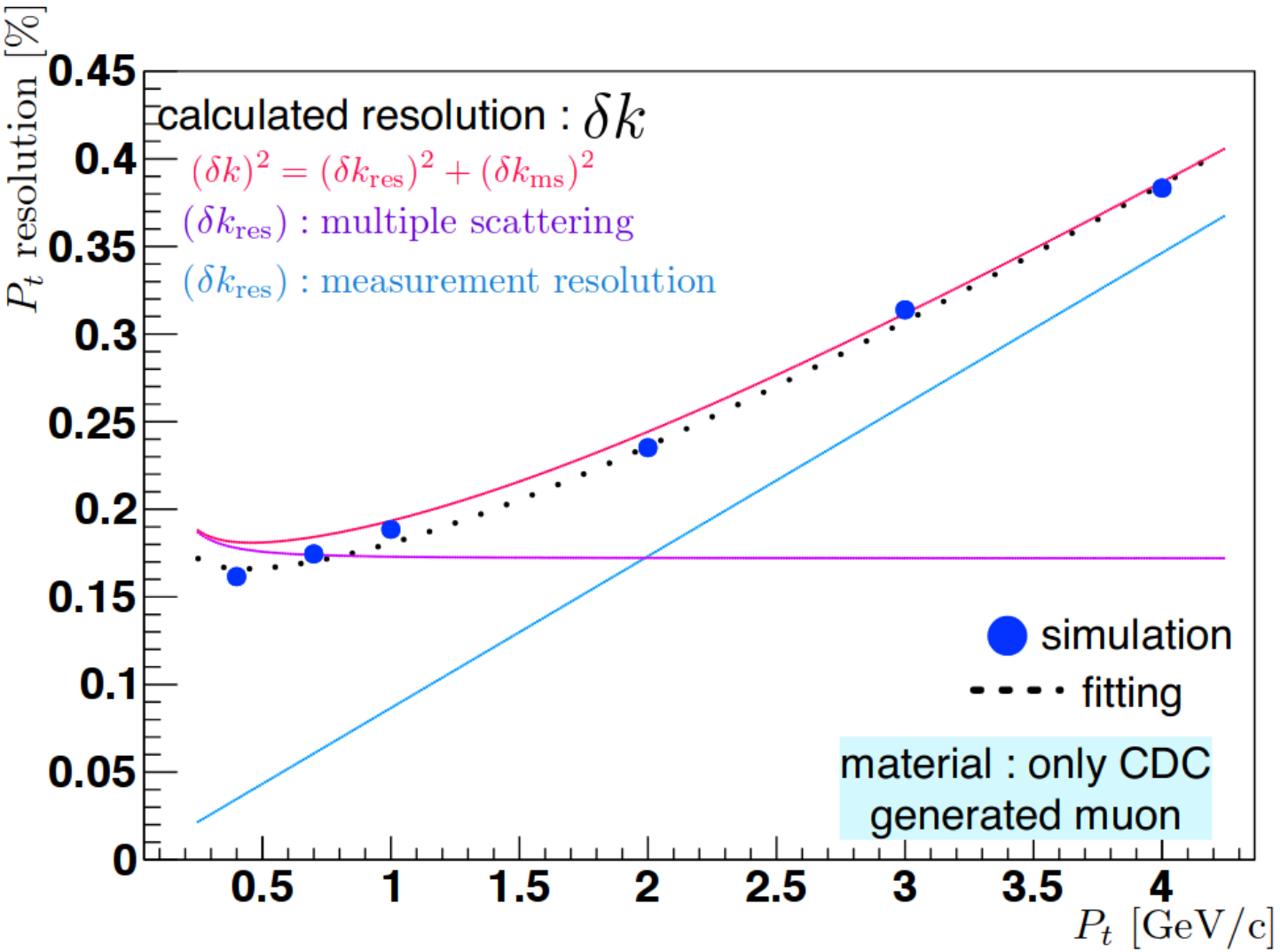
$$\left(\frac{\sigma_{p_T}}{p_T}\right)_{\text{meas}} \approx 0.1\% p_T \quad \text{(Belle 1: } \approx 0.2\% \ p_T \text{)} \tag{6}$$

Ideally, error due to multiple scattering:

$$\left(\frac{\sigma_{p_T}}{p_T}\right)_{\text{MS}} \approx 0.2\%/\beta \quad \text{(Belle 1: } \approx 0.3\%/\beta\text{)} \tag{7}$$

for equations and Belle numbers see: https://doi.org/10.1016/S0168-9002(00)00513-1

Expected CDC Performance



Summary

- CDC is the main tracker of the Belle 2 experiment.
- It is used in tracking, triggering and for PID.
- The resolution is expected to improve over Belle.

See how this CDC geometry and outputs are used in tracking
$\rightarrow$ upcoming seminars

Further reading

About drift chambers in general:

- Rolandi, Luigi & Riegler, Werner & Blum, Walter. (2008). Particle Detection with Drift Chambers. 10.1007/978-3-540-76684-1.

About Belle2:

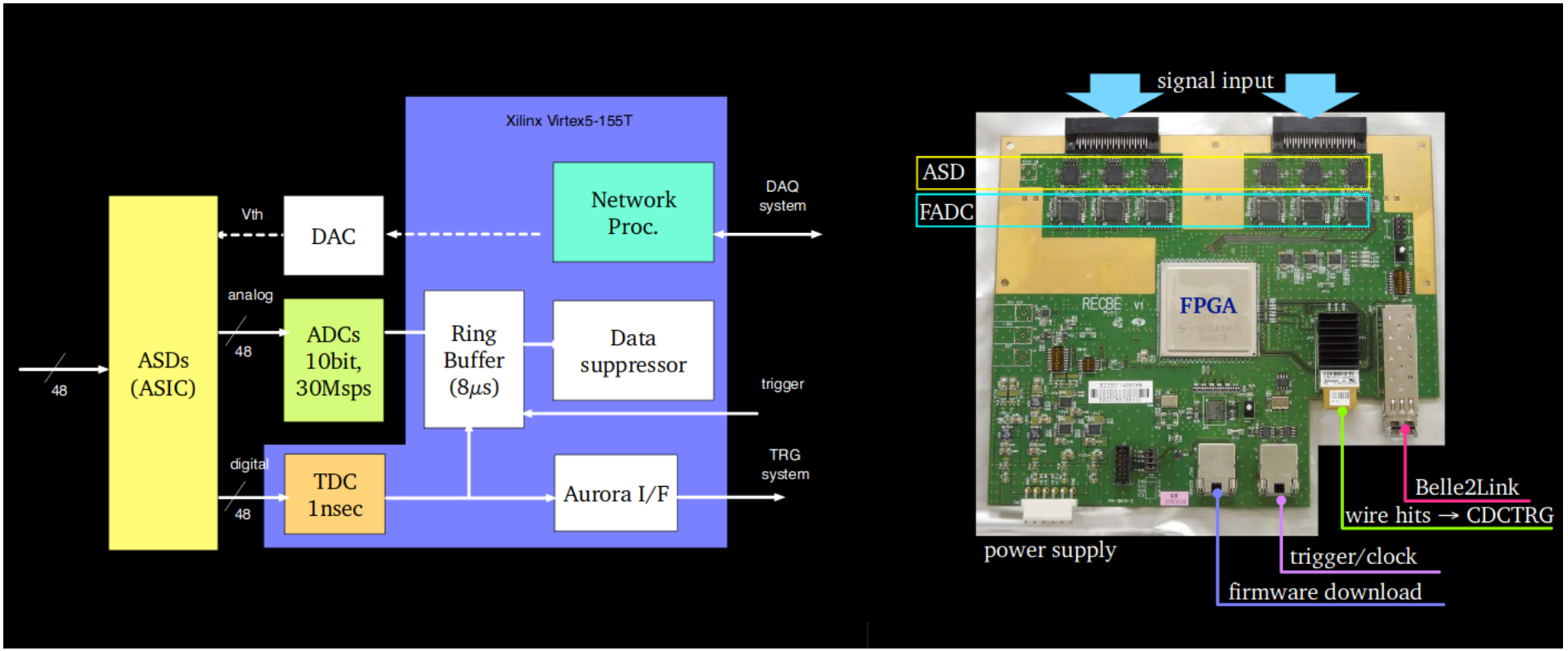
- Belle 2 TDR: arXiv:1011.0352
- Belle 2 Expected CDC performance: N. Taniguchi 2017 JINST12 C06014
- Belle literature: `https://belle.kek.jp/` (still relevant)
- Belle 2 Physics Book: BELLE2-PAPER-2018-001
- Technical/CDC software PhD Theses, e.g. IEKP-KA/2013-06, BELLE2-PTHESIS-2018-001, IEKP-KA/2012-9
- Belle 2 examples and software documentation!

Backup: Hit selection

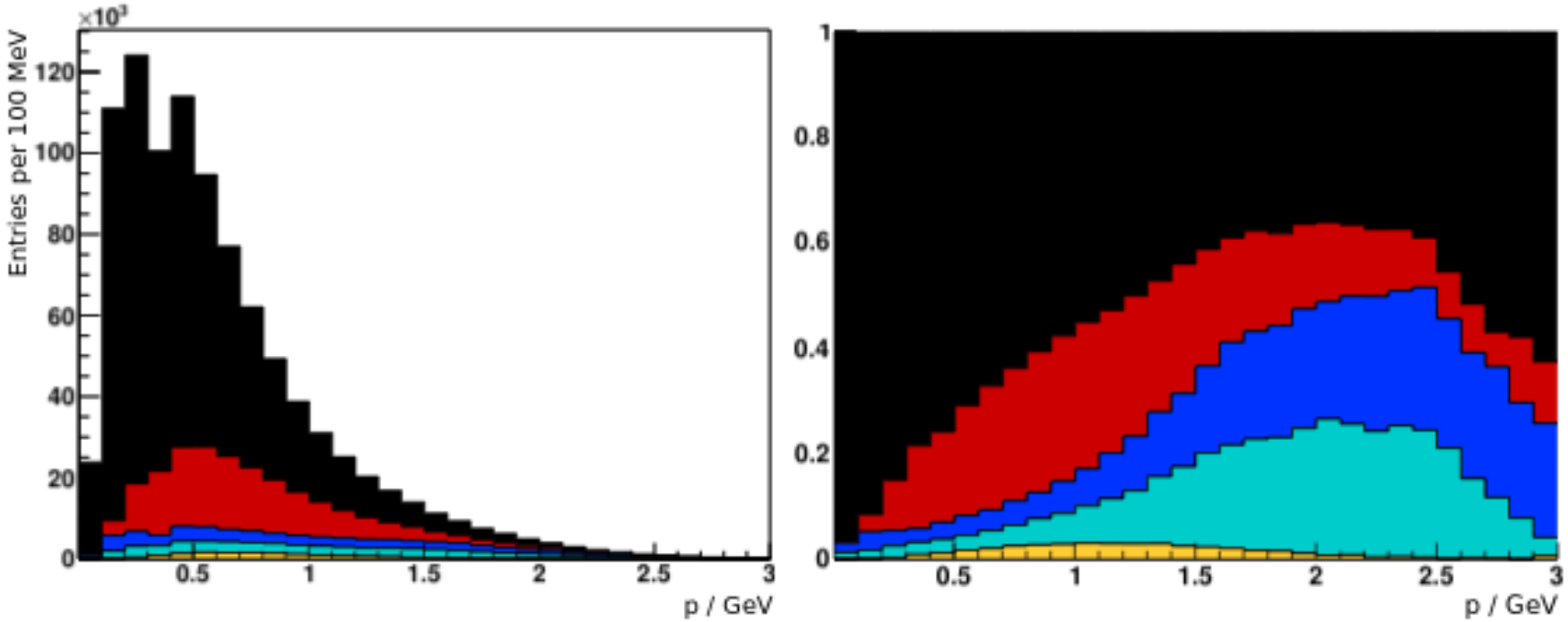
Selected based on ADC/TOT requirements, depending on experiment/run:

ADC (outer SLs/inner SL)	TOT	ADC/TOT
$\geq 15/ \geq 12$	≥ 2	≥ 4
$\geq 18/ \geq 15$	≥ 2	≥ 3

Backup: Readout



Backup: particle fractions



Top to bottom:

- pion
- kaon
- electron
- muon
- proton

Backup: CDC structure methods

The numbering scheme is conventionalised: numbering starts at 0!

ID	Range
Superlayer ID	0 – 8
Layer ID	0 – 7, for superlayer 0
	0 – 5, for superlayer 1–8
Continuous layer ID	0 – 55
Wire ID	0 – [159;191..;383] for superlayers [0 and 1;2;...;8]
Encoded wire ID	0 – 35711 (discontinuous!)

CDCHit objects in basf2

https://b2-master.belle2.org/software/development/classBelle2_1_1TrackFindingCDC_1_1CDCWireHit.html

https://b2-master.belle2.org/software/development/classBelle2_1_1CDCHit.html

https://b2-master.belle2.org/software/development/classBelle2_1_1CDCRawHit.html