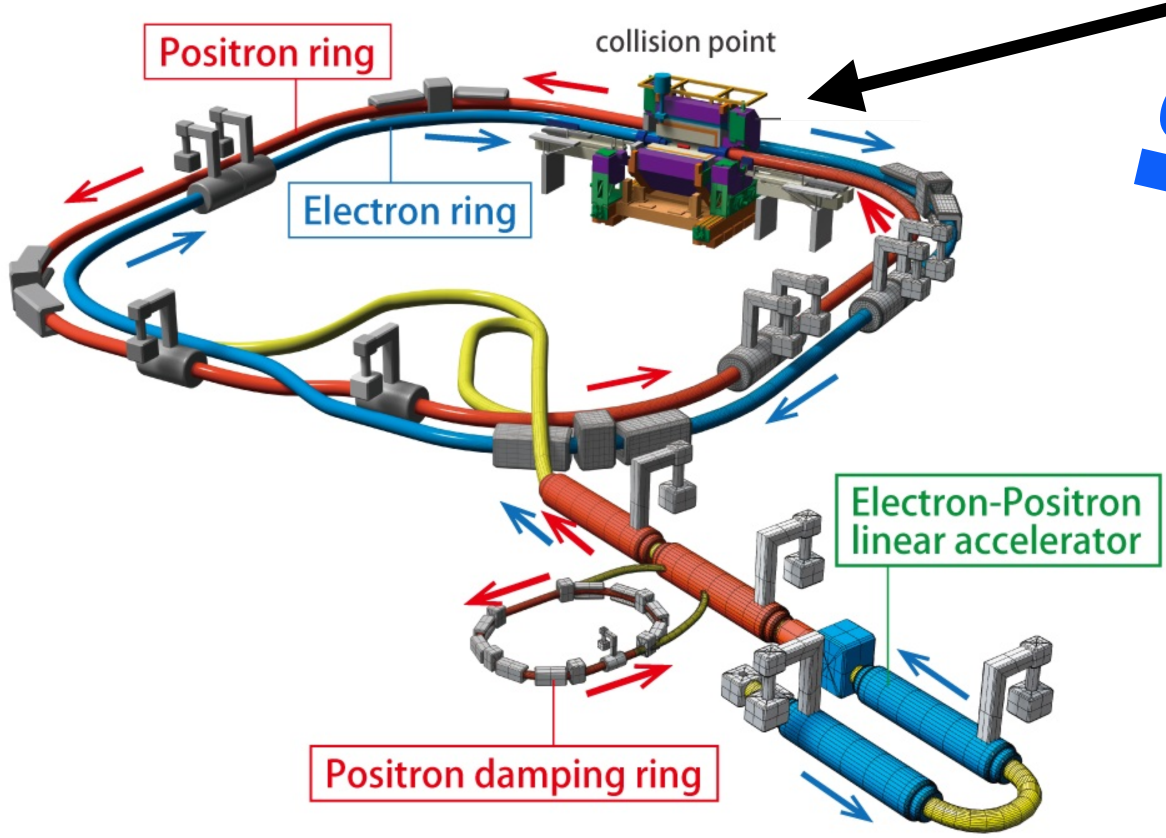
Central Drift Chamber for the Belle II experiment

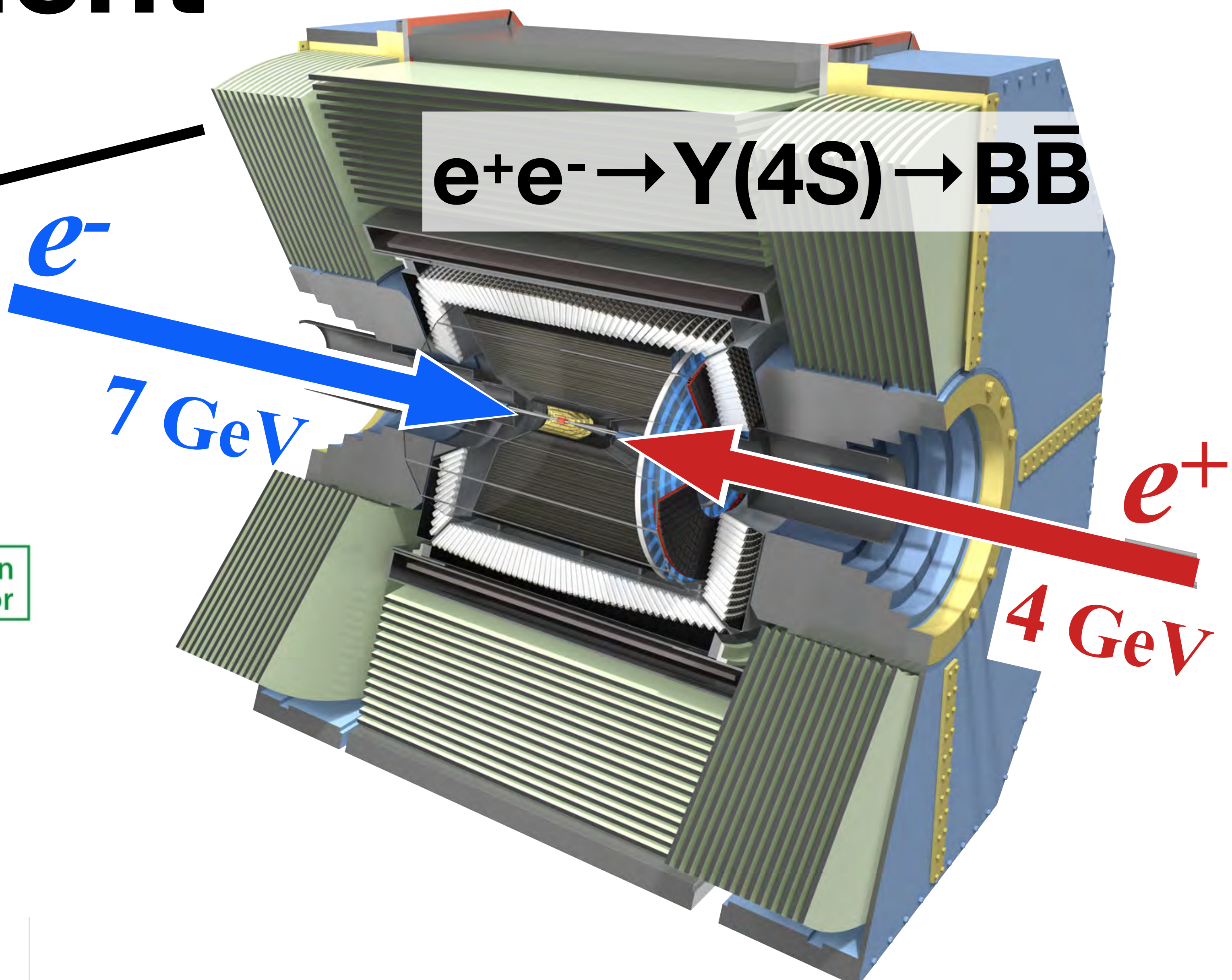
Kota Nakagiri (KEK)
on behalf of Belle II CDC group
2020 Feb. 25th, INSTR'20

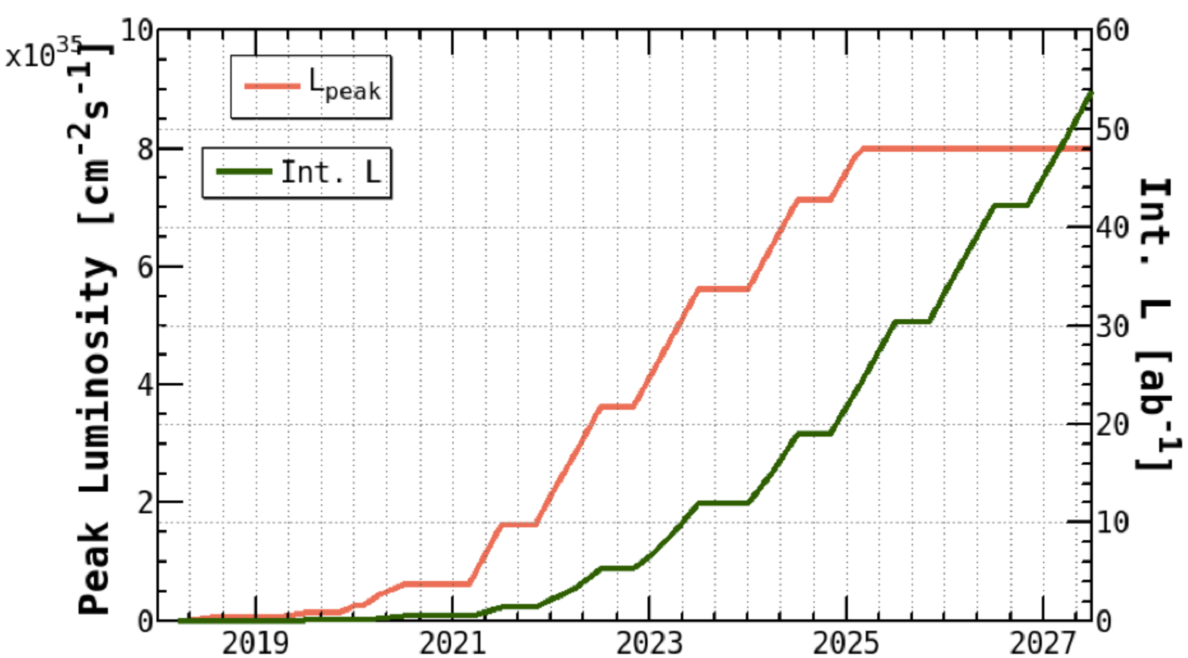
Belle II experiment

SuperKEKB



Belle II detector

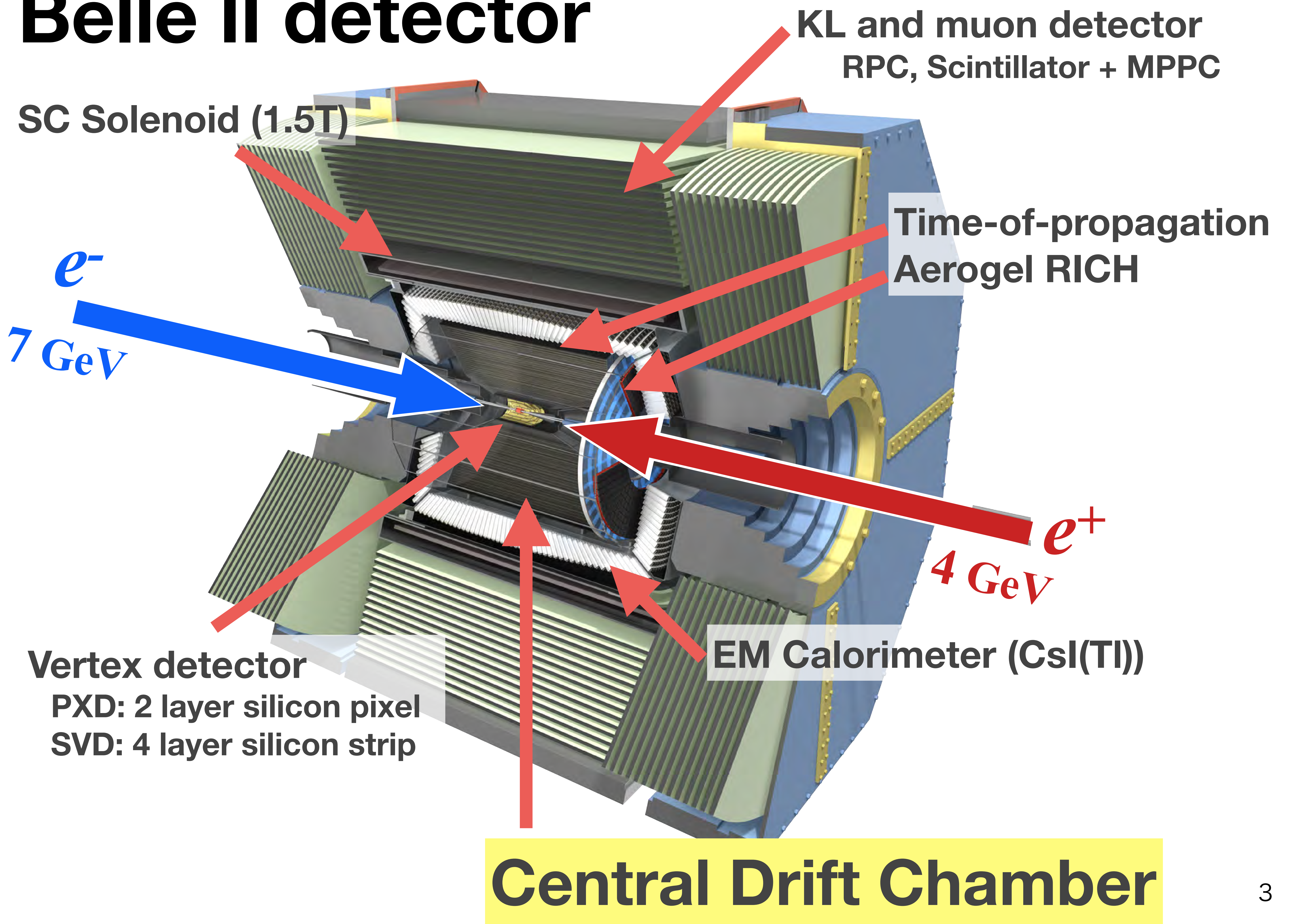




- design Lumi. : 8×10^{35} $cm^{-1}s^{-1}$
- integrated Lumi : 50 ab^{-1}

- Belle II started data taking in 2018
  - L = 1.14×10^{34} $cm^{-2}s^{-1}$ achieved
  - accumulated $\int L$ = 10.57 fb^{-1}

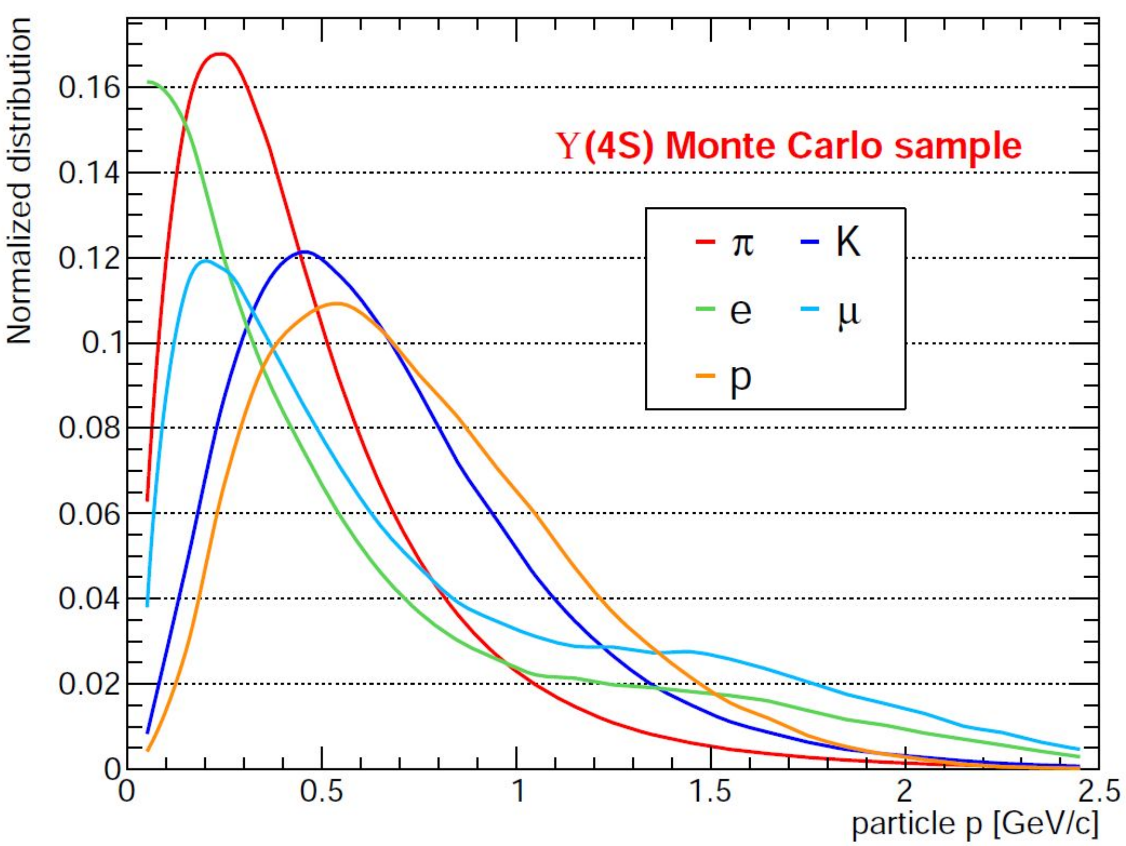
Belle II detector



Central Drift Chamber (CDC)

Roles of CDC

- track reconstruction and momentum measurement
  momentum of the final states particles: < O(1 GeV/c)
- particle identification using dE/dx information
- providing trigger signal



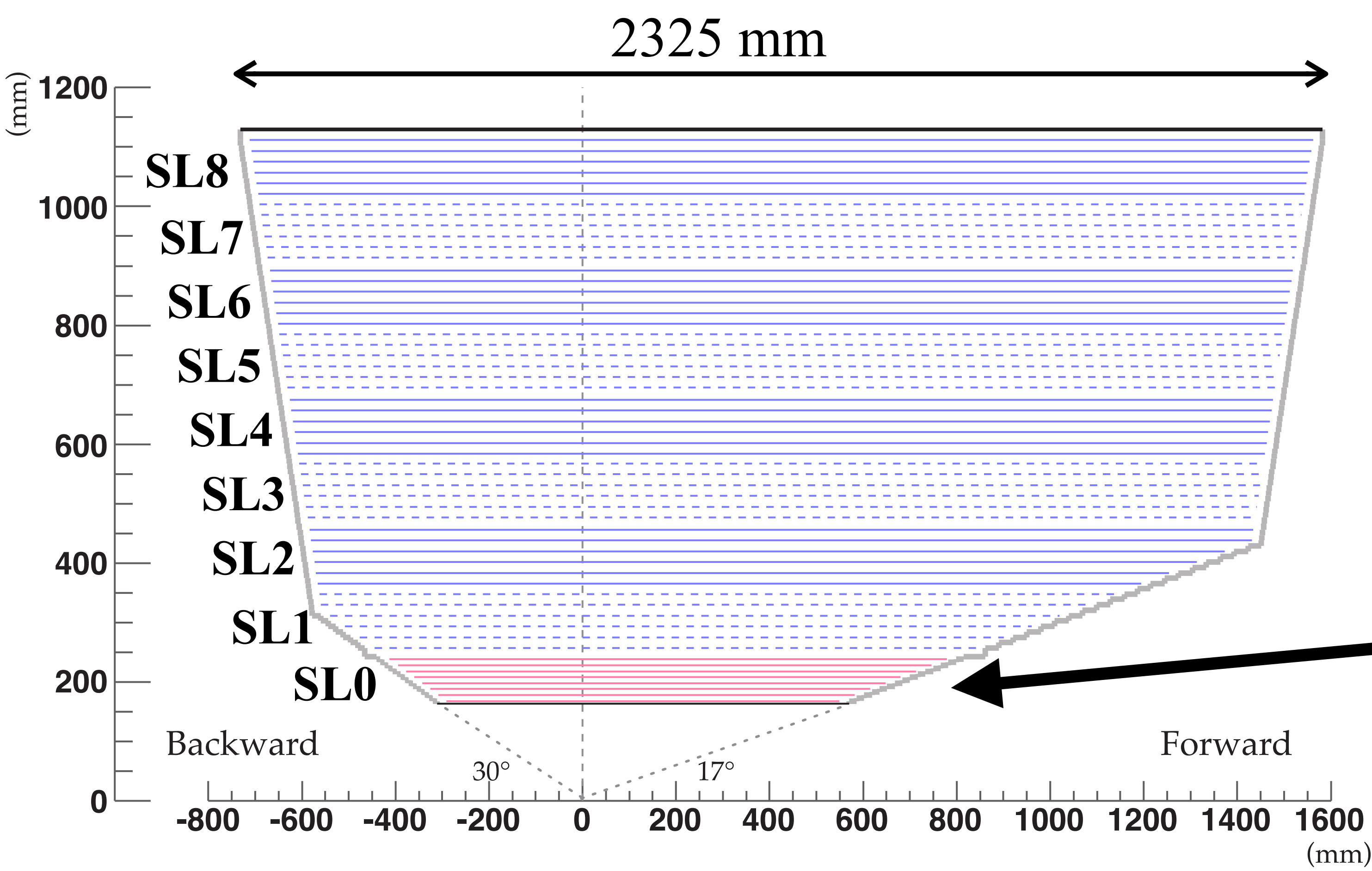
multiple scattering effect is dominant for momentum resolution for low momentum particles

→ drift chamber with $He:C_2H_6$ gas

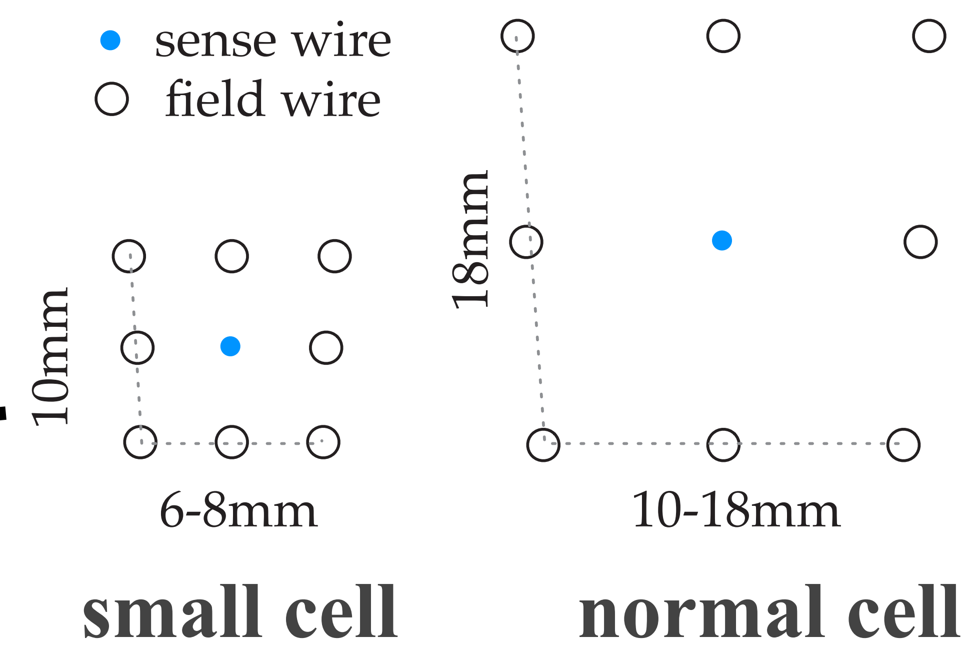
(low-Z gas, X_0 ~ 680m)

Structure of CDC

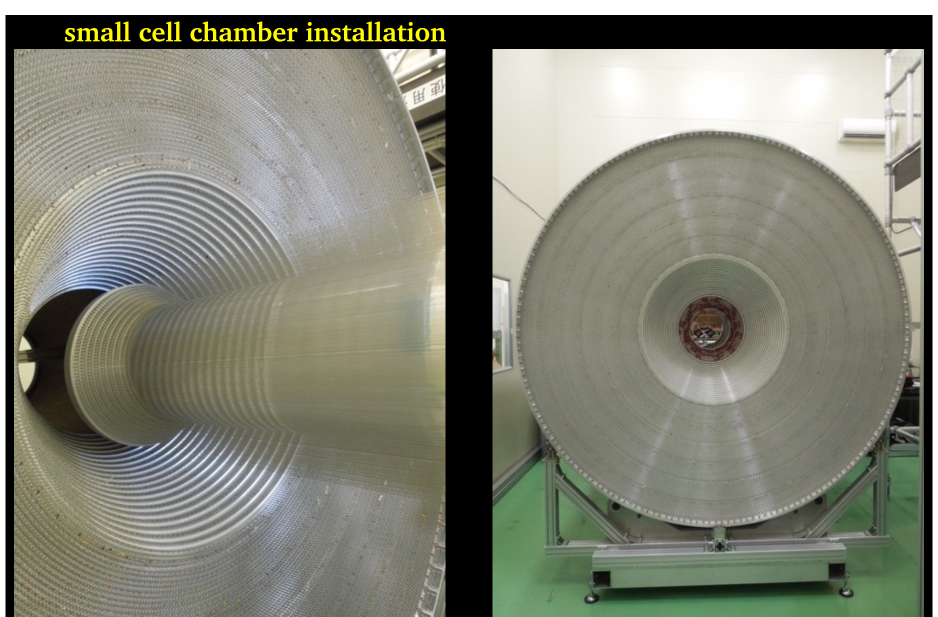
R of inner cylinder	160 mm
R of outer cylinder	1130 mm
length (Z)	2325 mm
angular coverage	17°<θ<150°



cell structure



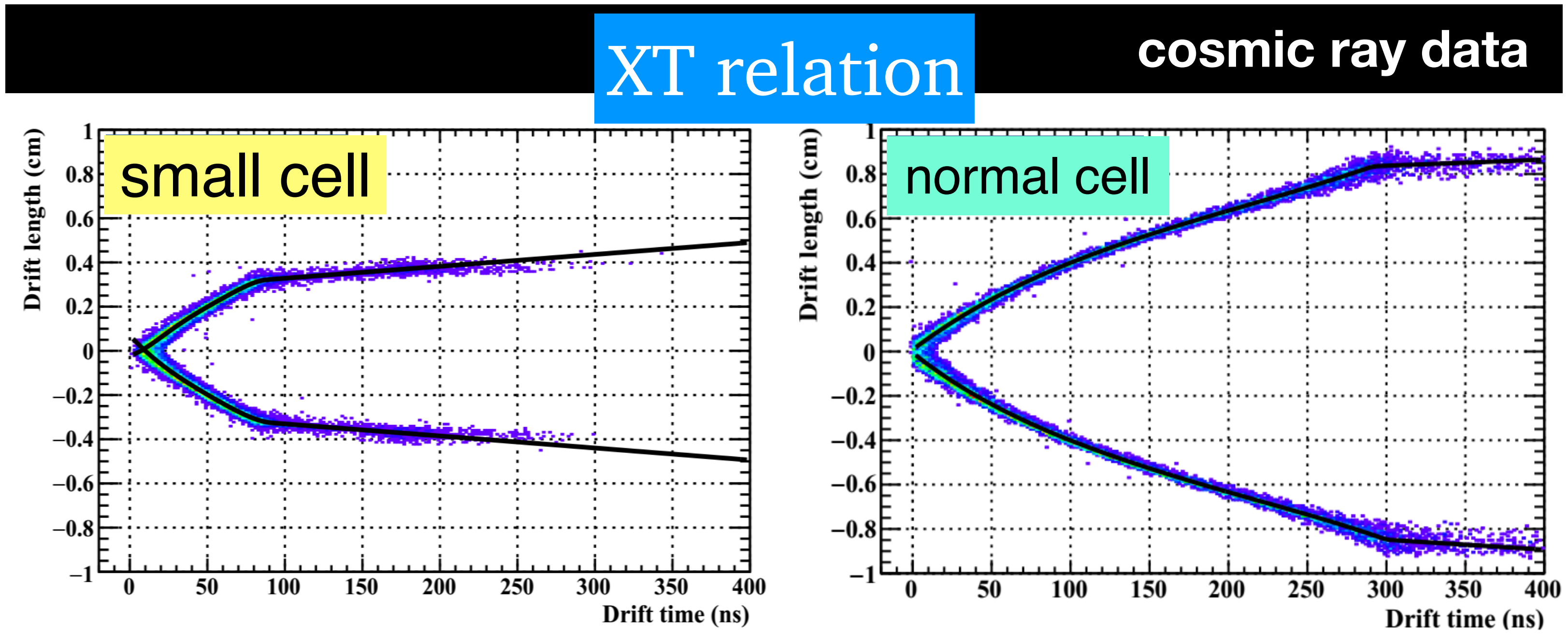
- 56 layers, arranged in 9 Super layers (SL)
- even SL: axial, odd SL: stereo → 3D reconstruction of tracks

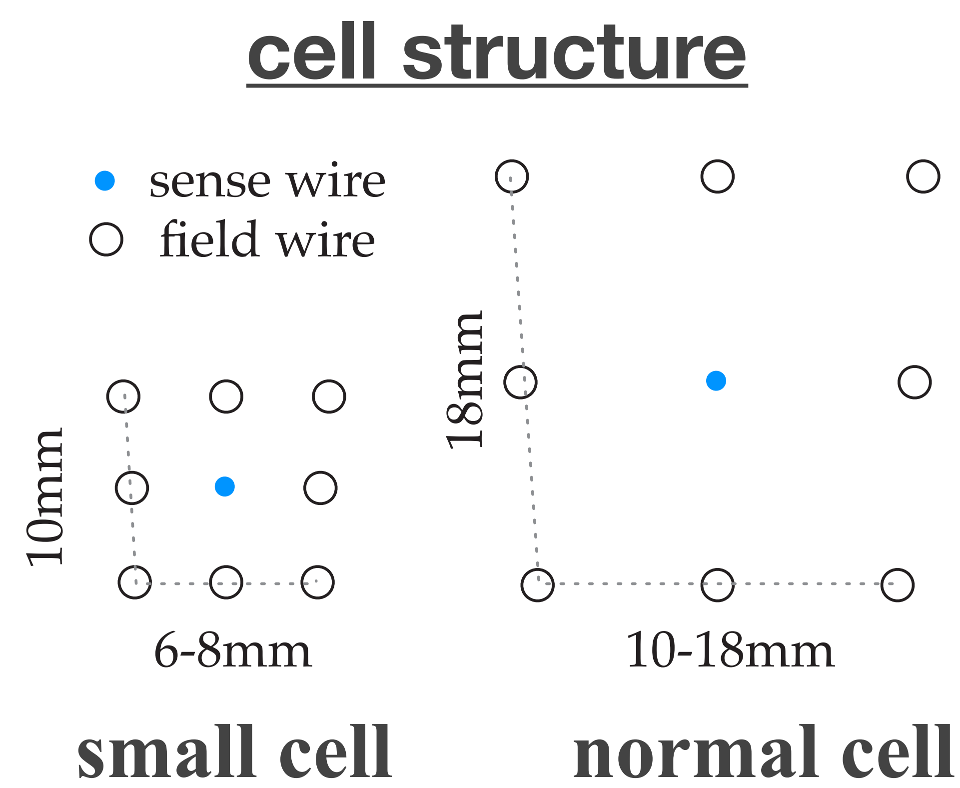


- smaller cell for innermost SL to mitigate the occupancy and shorten the drift time

Structure of CDC

drift time vs. distance from the sense wire





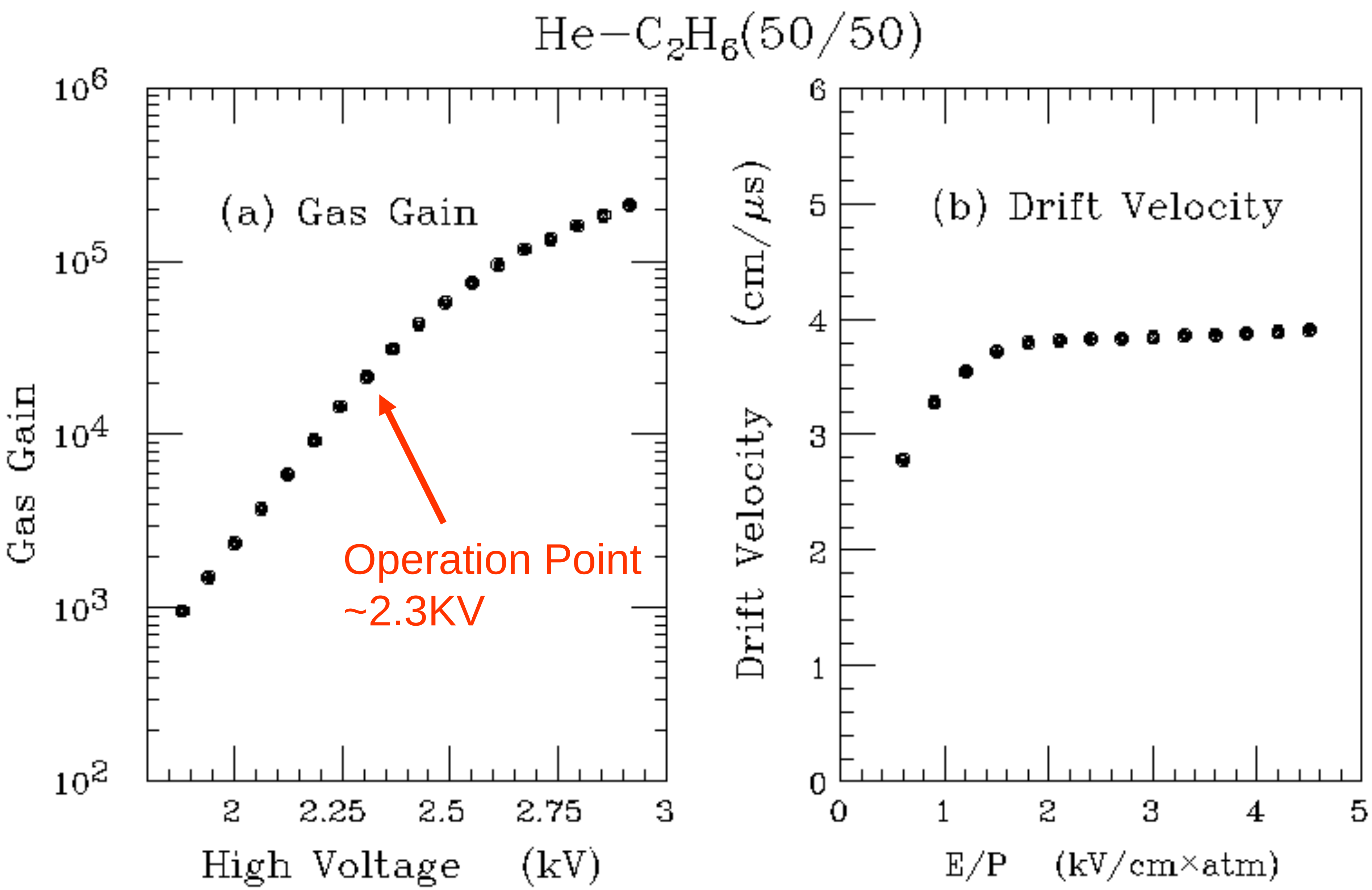
maximum drift time:

small cell: ~250 ns
normal cell: ~400 ns

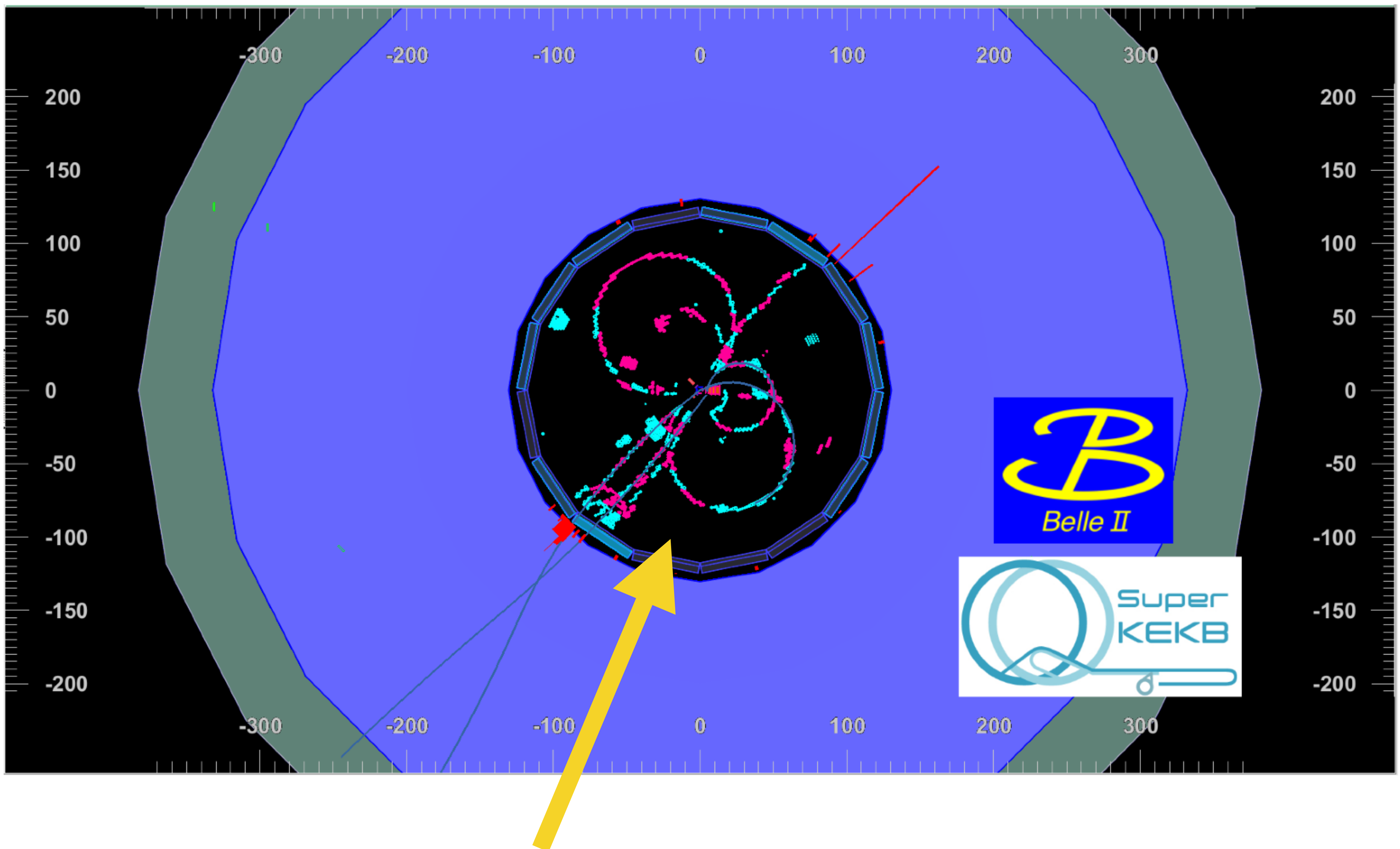
	sense wire	field wire
diameter	30 μm	126 μm
material	Tungsten (gold plated)	Aluminum
tension	50 gw	80 gw
# of wires	14336	42240

He-Ethane gas

- long radiation length (X_0 ~680 m)
- fast drift velocity (~3.3 cm/μs averaged in the cell)
- plateau of drift velocity
- good dE/dx resolution



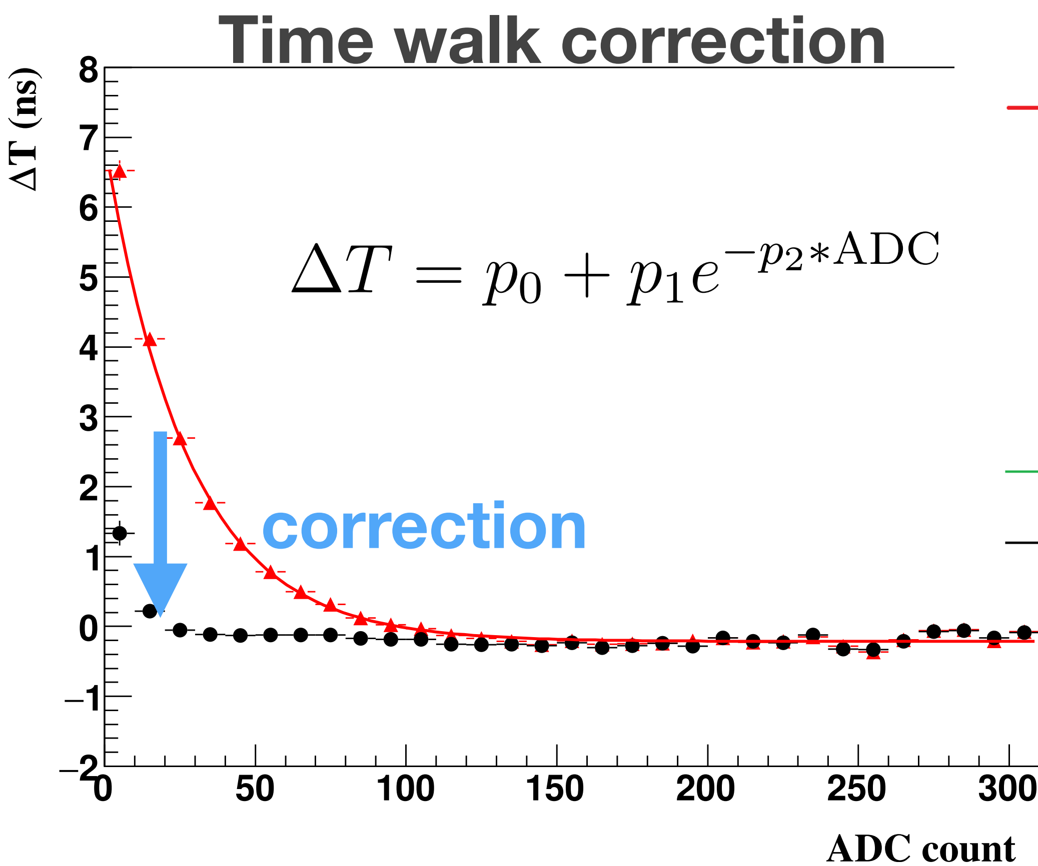
first collision, 2018 Apr. 26th 0:38

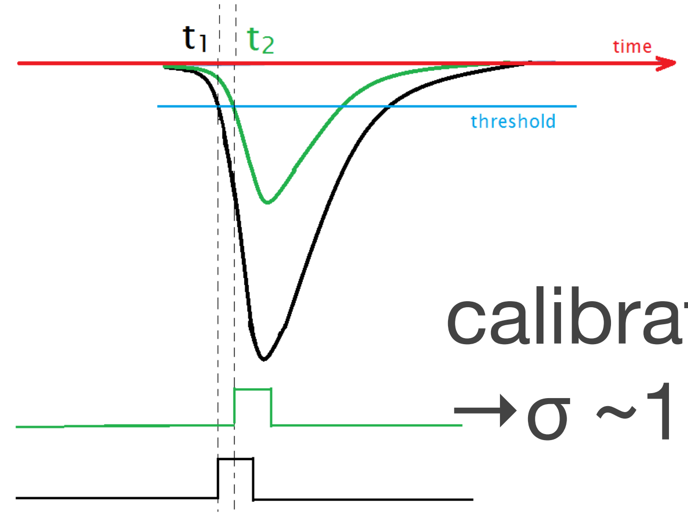


CDC

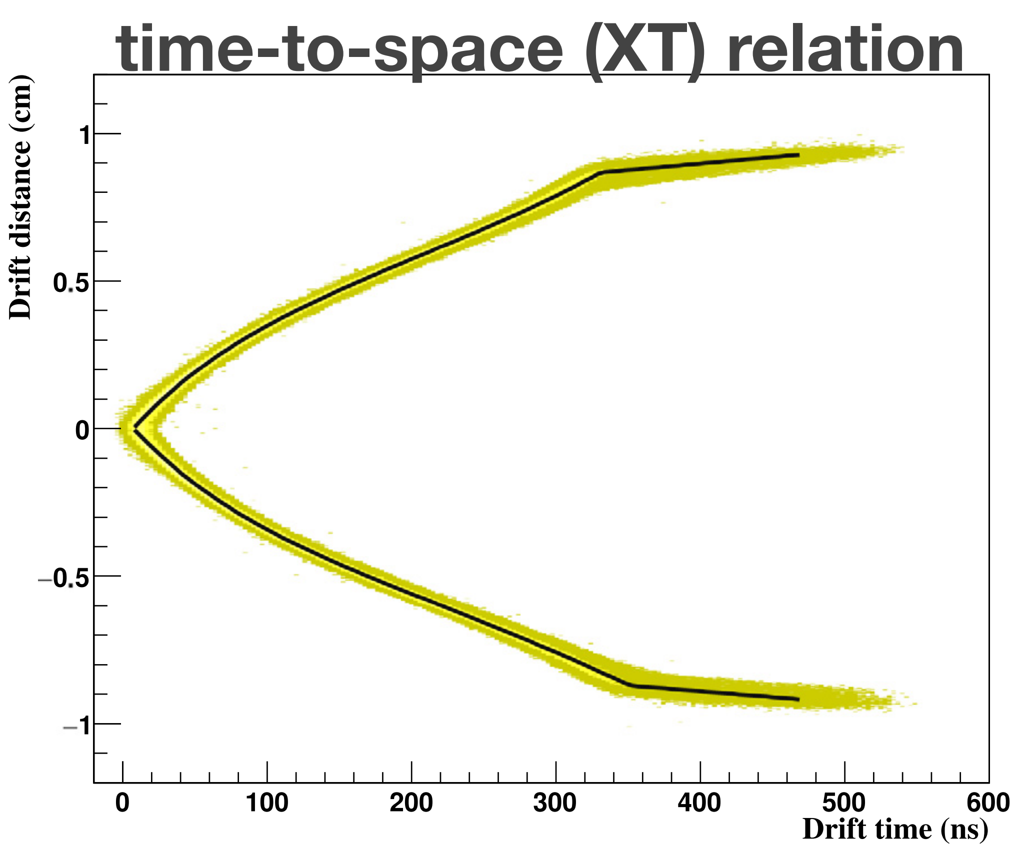
Position resolution

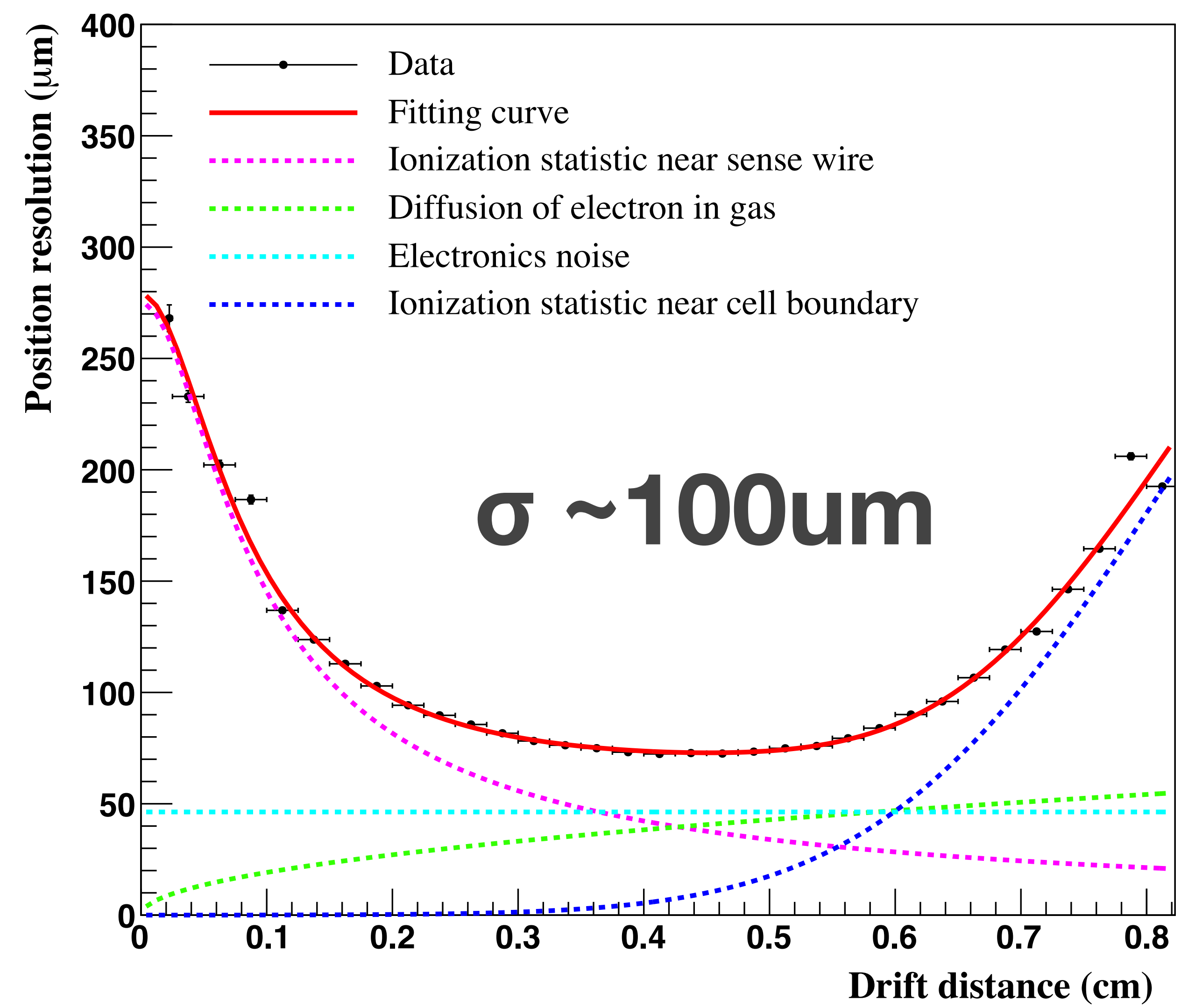
using cosmic ray data





calibration, alignment, correction
→σ ~100μm position resolution





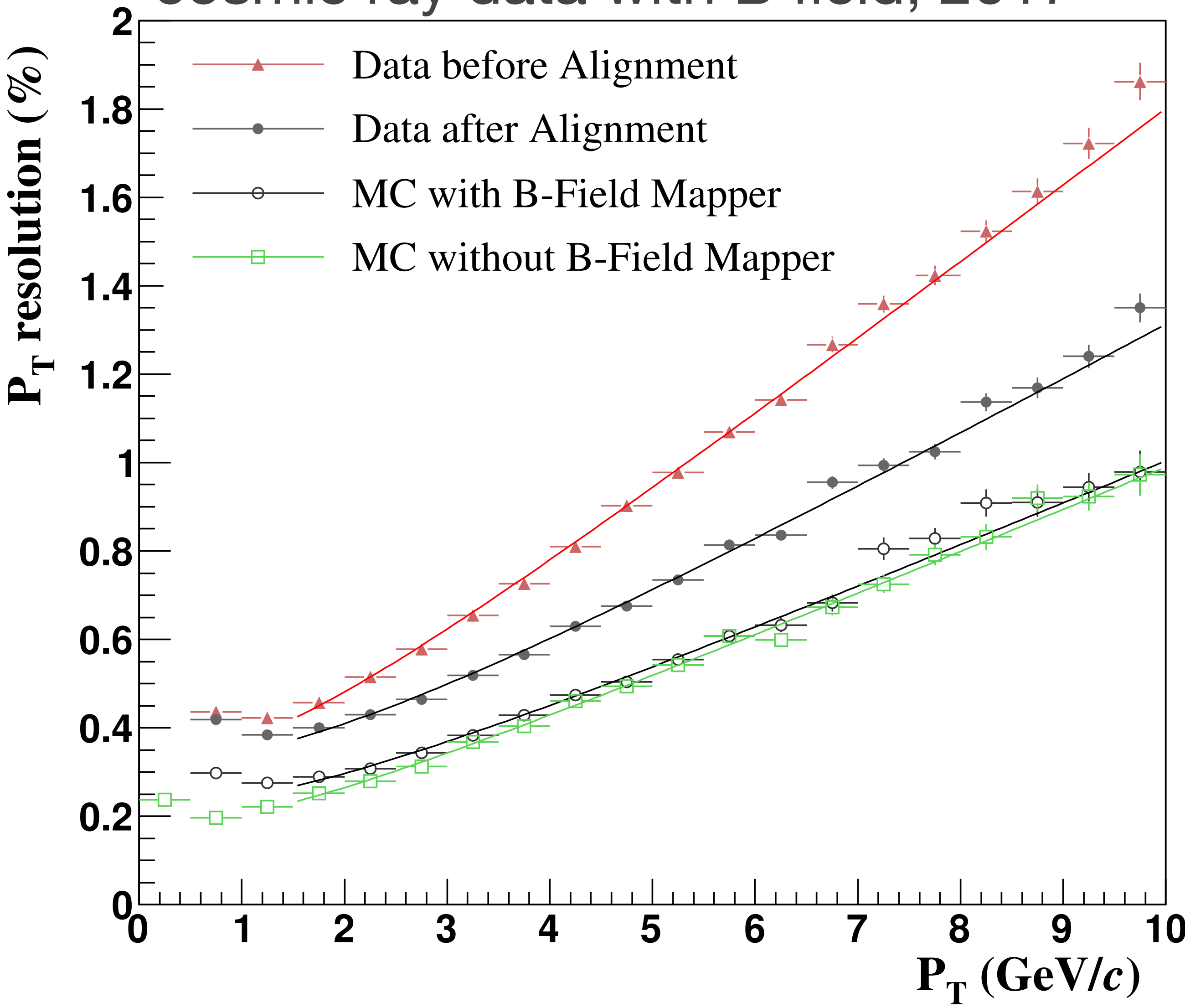
Pt resolution as a function of Pt

$$\frac{\sigma_p}{p} = \underbrace{\left(\frac{\sigma_p}{p}\right)_{\text{meas.}} \times p}_{} \oplus \underbrace{\left(\frac{\sigma_p}{p}\right)_{\text{MS}}}_{}$$

momentum measurement (position resolution)

multiple scattering

cosmic ray data with B field, 2017



before alignment

$$0.177 p_t[\mathrm{GeV}/c] \oplus 0.325\,\%$$

after alignment

$$0.127 p_t[\mathrm{GeV}/c] \oplus 0.321\,\%$$

MC

still worse than MC

- 20-30% discrepancy for slope term
- large discrepancy in constant term

possible sources:

- magnetic field in real and simulation
- remaining misalignment
- non-Gaussian components of pos. resol.

※ only CDC, VXD information not included

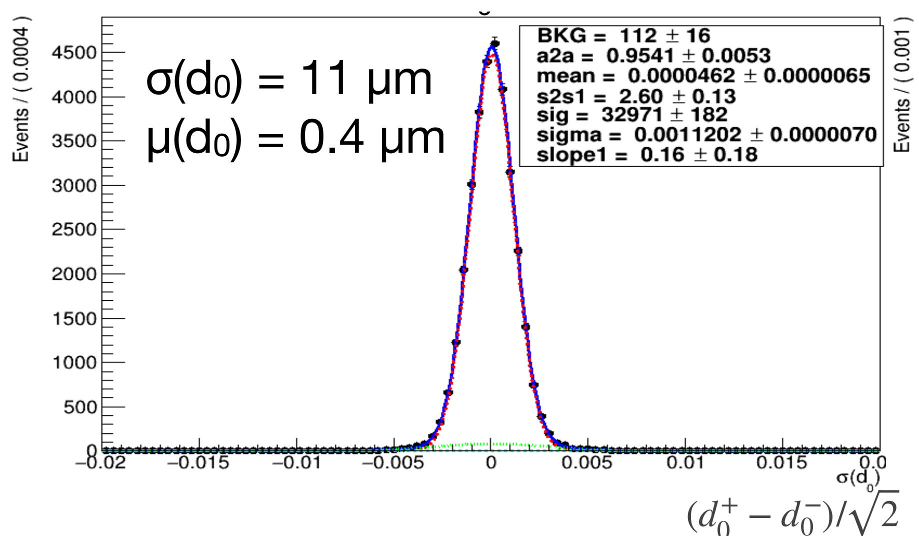
Vertex resolution

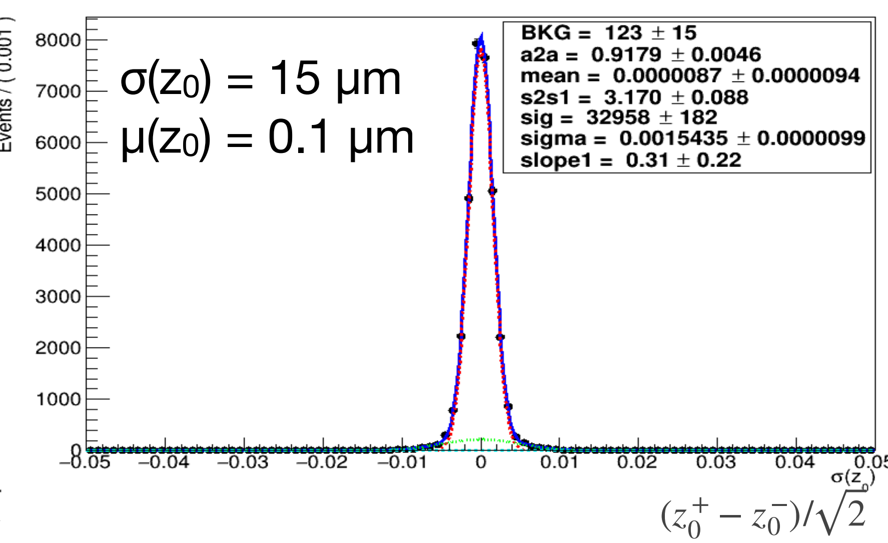
- 2019 spring run data
- $e^+e^- \rightarrow \mu^+\mu^-$ events

d_0 : impact parameter in r-φ plane ($= \sqrt{(x_0^2+y_0^2)}$)
z_0 : impact parameter in z

d_0 | **z_0**

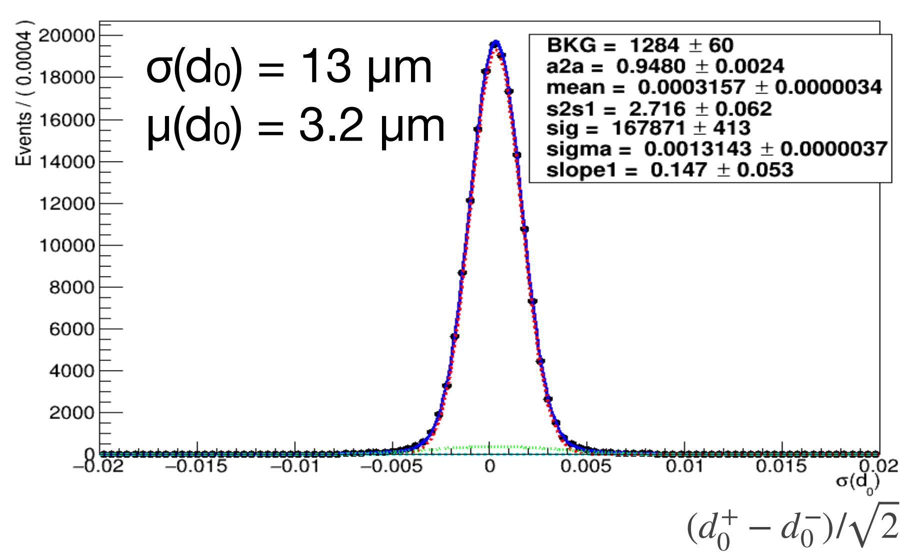
MC

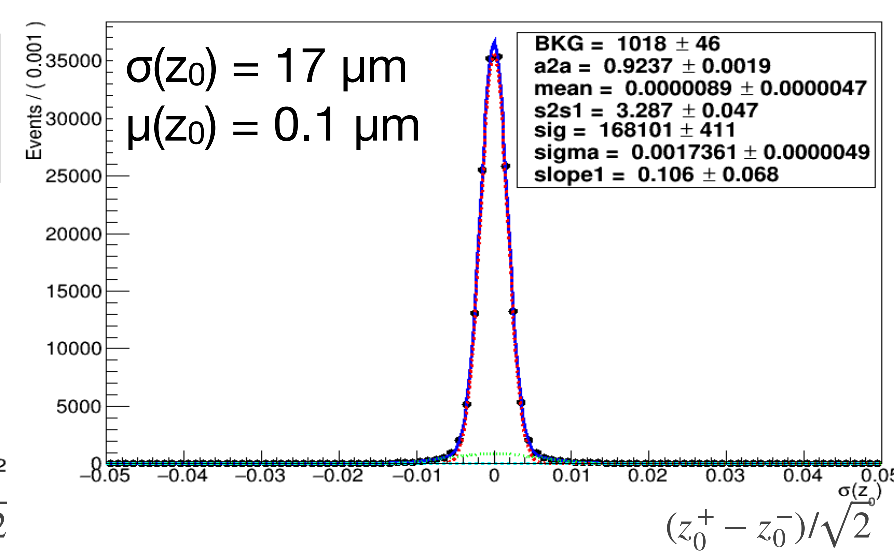




Exp7

Data





by R. Garg

good Data and MC agreement for sigma,
but mean shifts exist for Data

※ VXD information is used

CDC track-finding efficiency

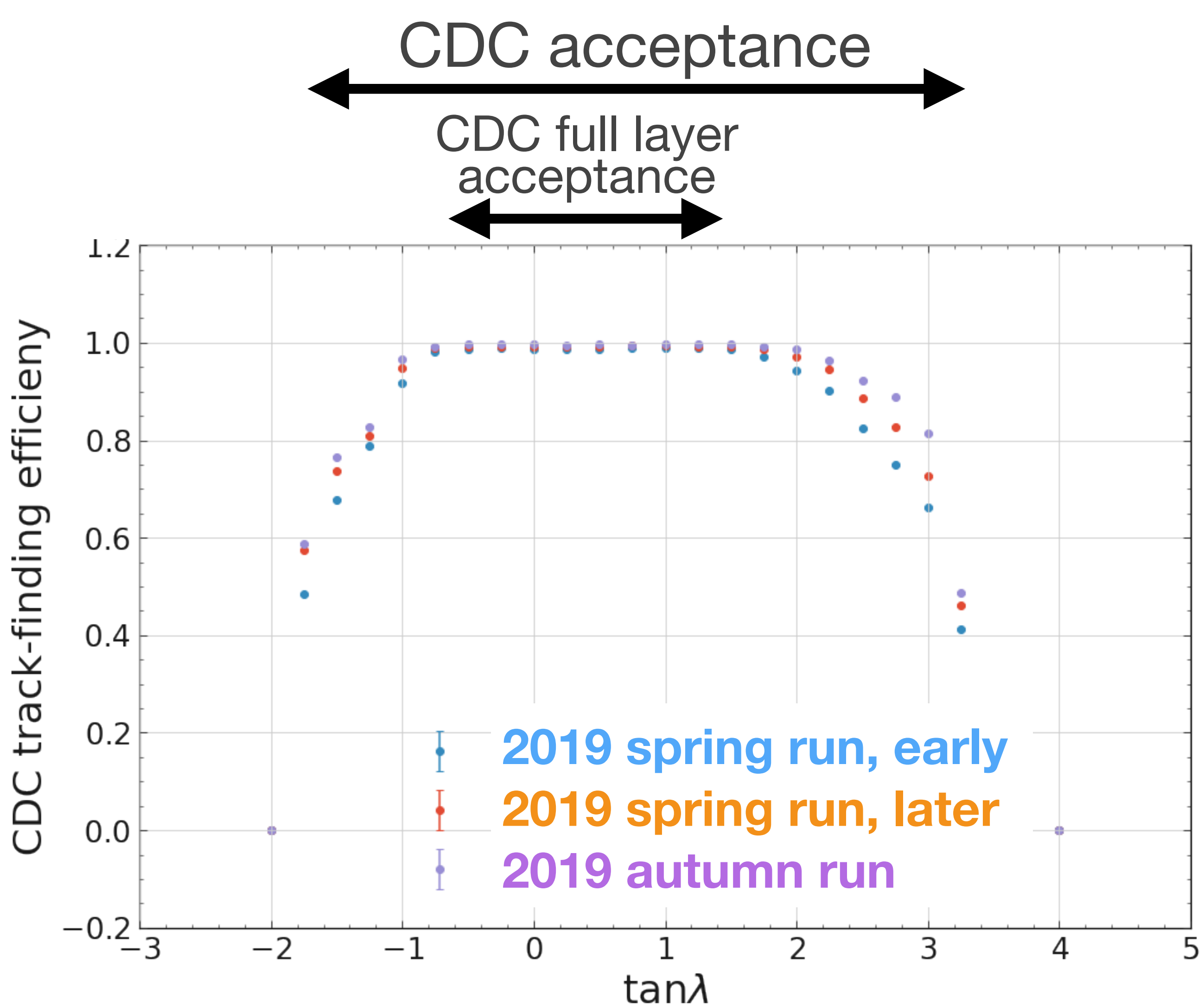
In our studies we define the **CDC tracking efficiency** as:

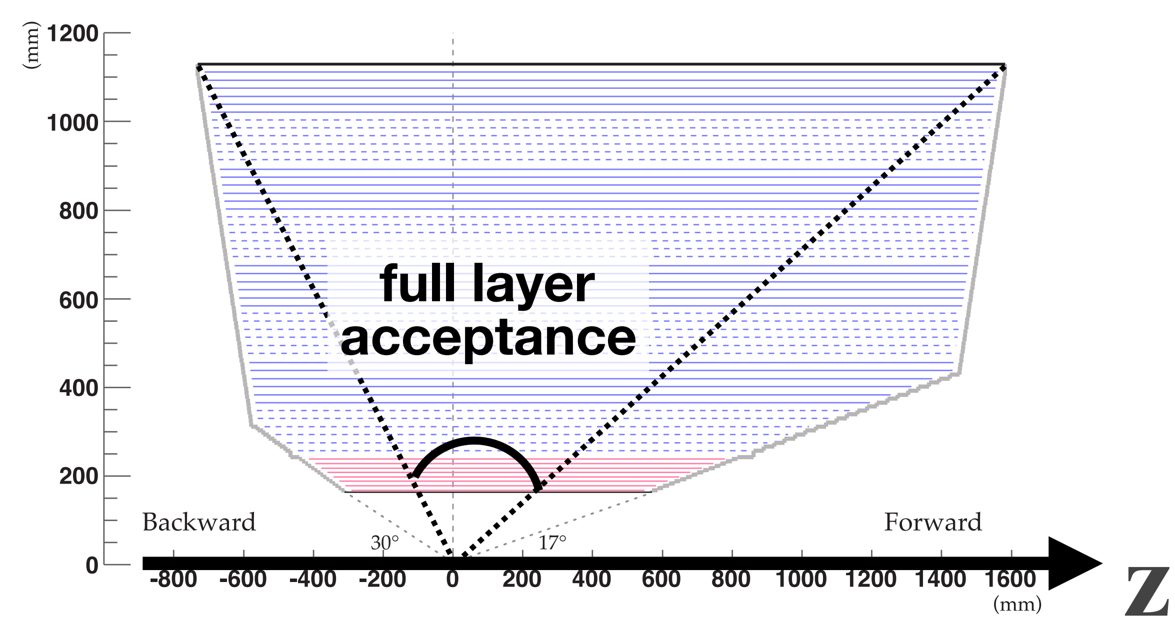
$$\epsilon_{CDC} \equiv \frac{N_{tracks}(\text{test cut})}{N_{tracks}(\text{reference cut})}$$

where:

- reference cut = SVD hits >= 8, |d0| < 2 cm, |z0| < 2 cm, pT > 0.8 GeV/c
- test cut = reference cut & CDC hits >= 10

$$\tan\lambda = \frac{p_z}{p_t}$$





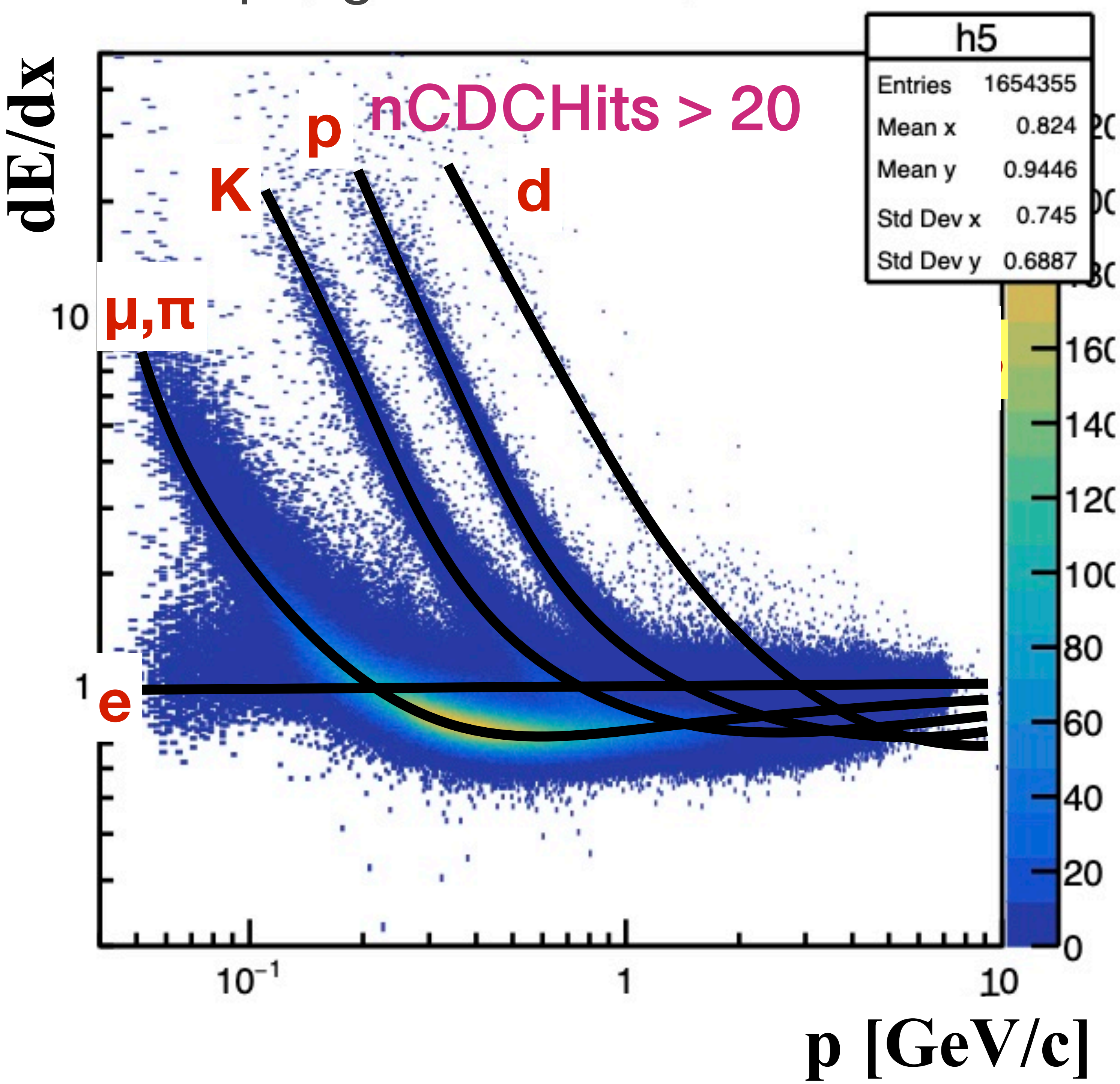
time dependence due to background level

using Bhabha-like events
($e^+e^- \rightarrow e^+e^-$)

by F. Dattola

dE/dx

- 2019 spring run data



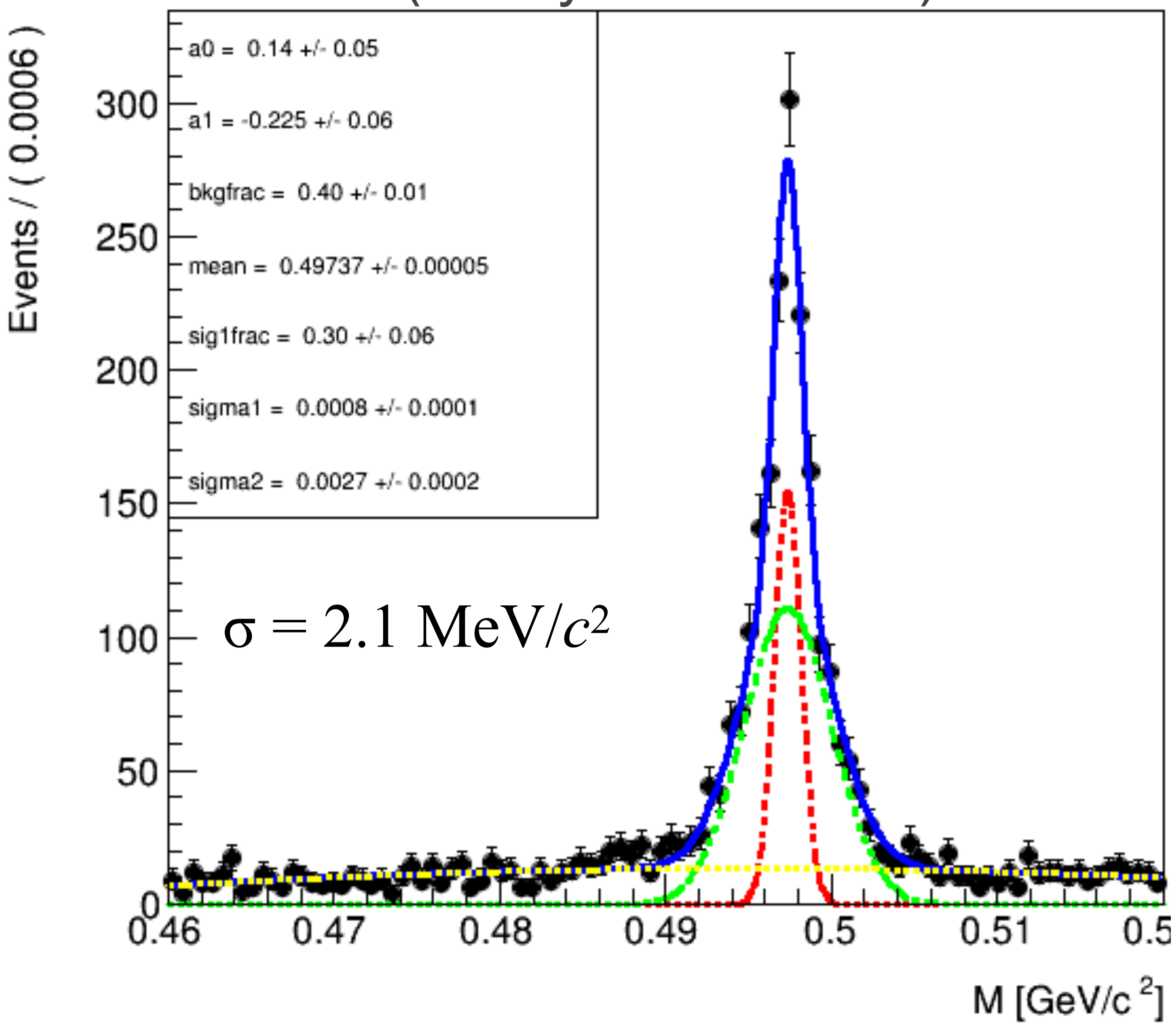
good separation is seen

by J. Kumar

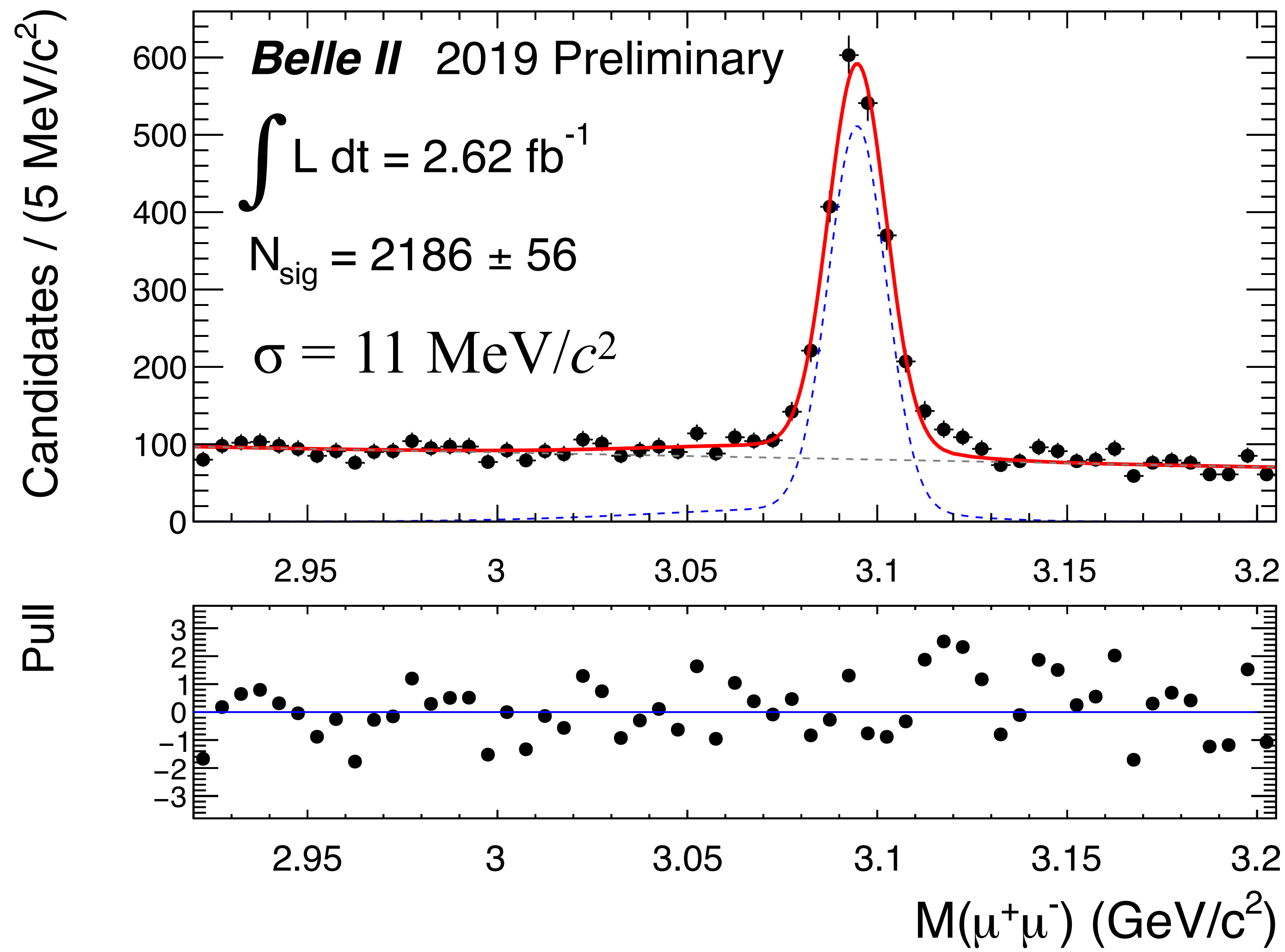
Mass distributions

$K_S \to \pi^+\pi^-$

(decay inside CDC)



$J/\psi \to \mu^+\mu^-$

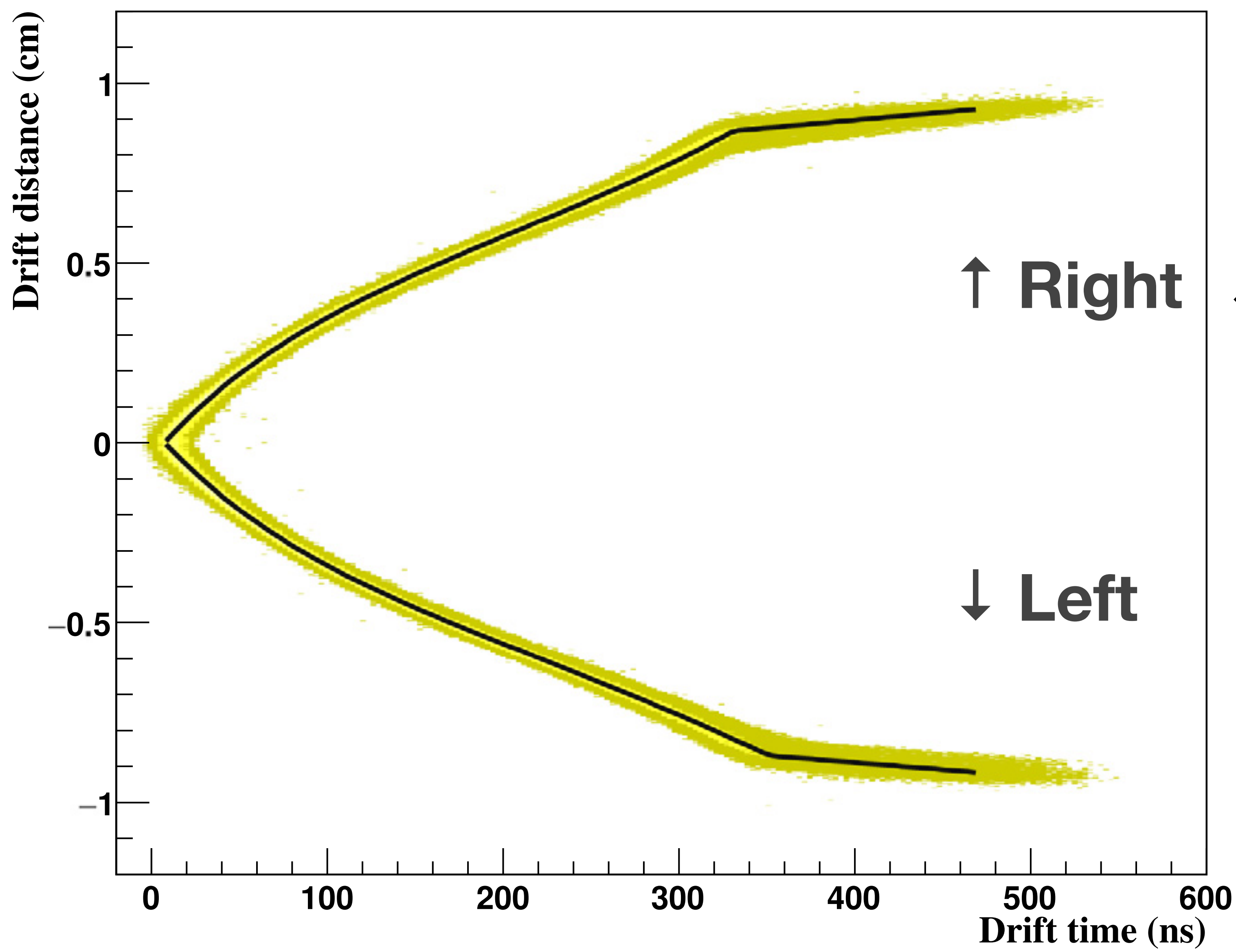


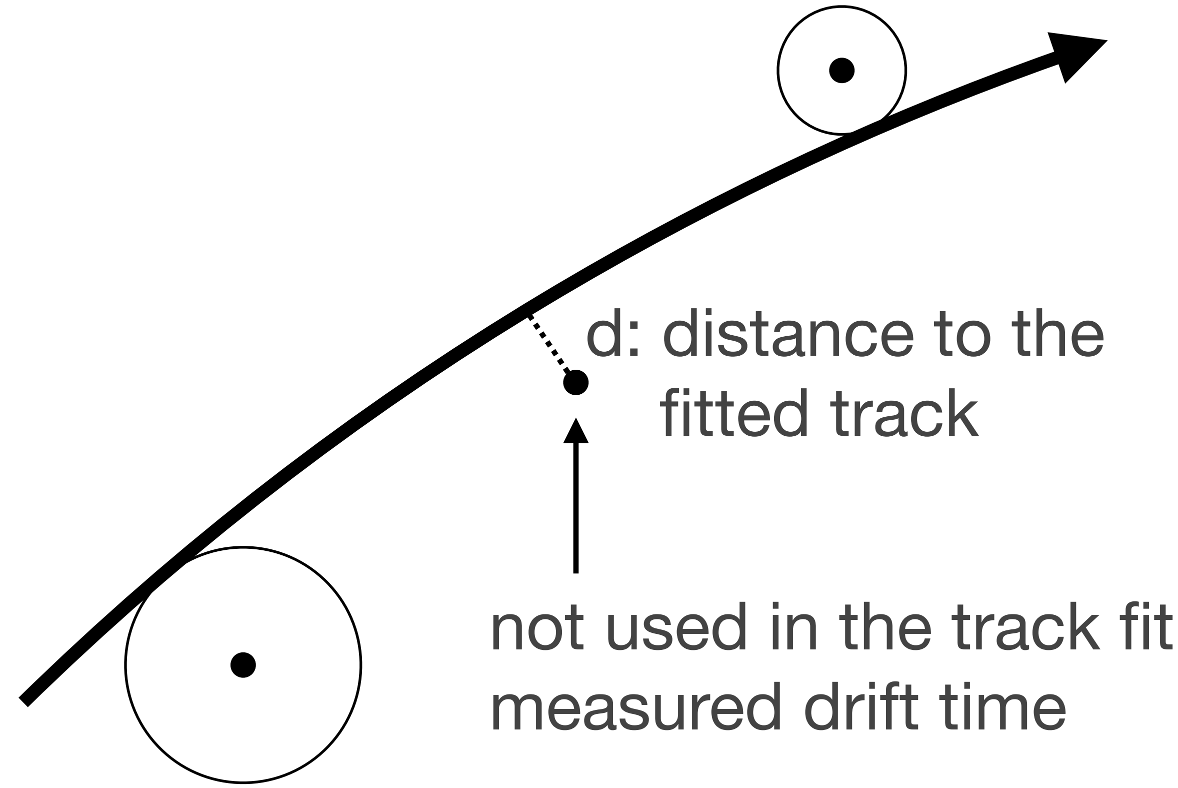
Summary

- Belle II CDC is working well
- vertex position resolution show good Data and MC agreement in di-muon events
    - mean shifts are seen in Data, though
    - Pt resolution vs. Pt needs more understanding

XT relation

"distance to the fitted track" vs.
"measured drift time" is plotted.

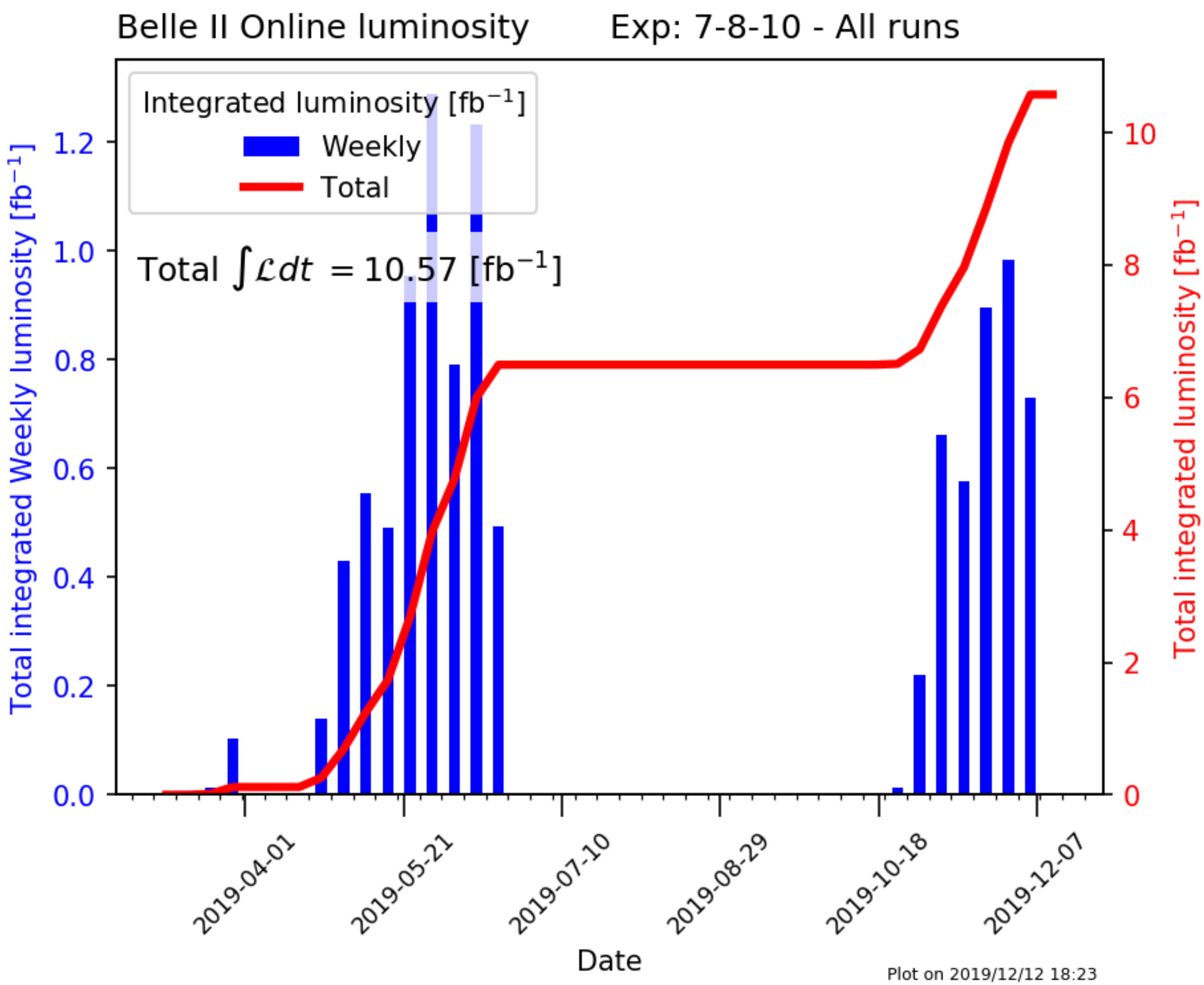




$56_{layer} \times 2_{RL} \times 18_{\alpha} \times 7_{\theta} = 14112$
→ 14112 XT relations

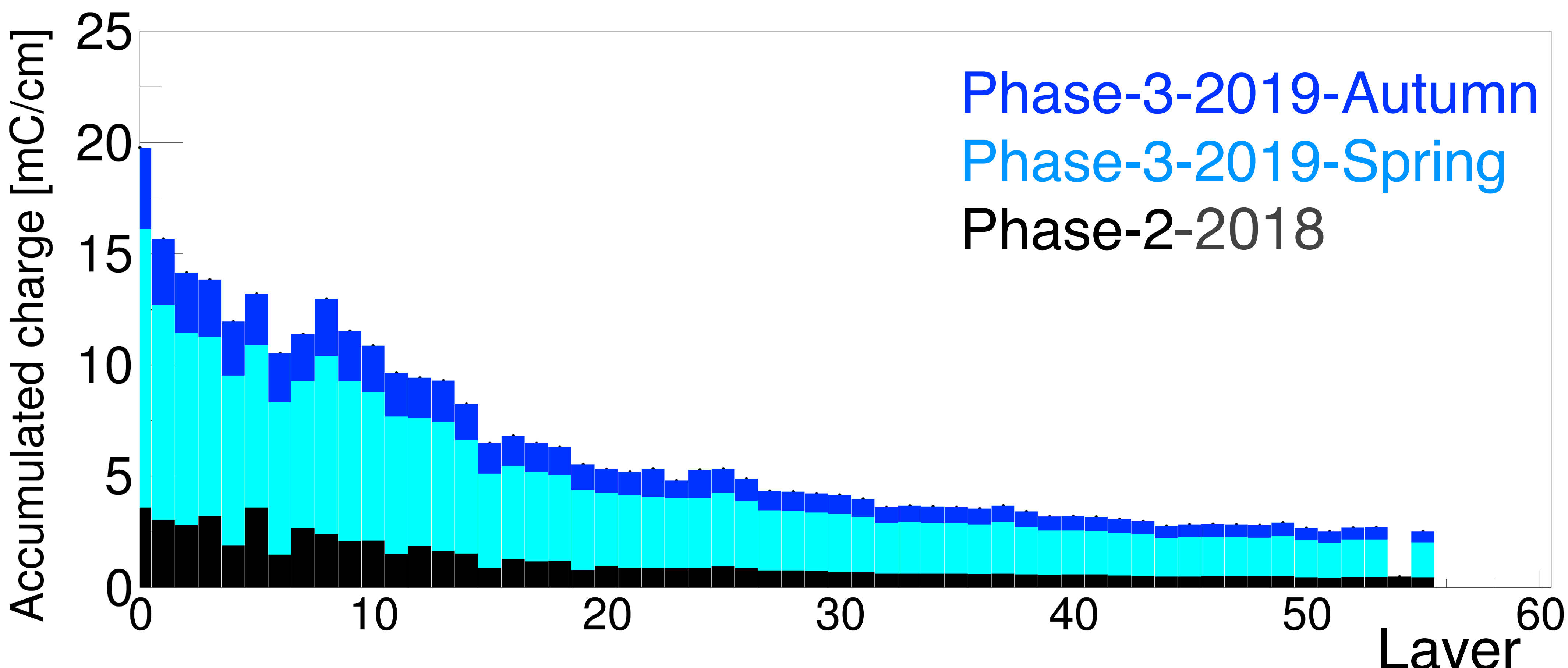
α: track incident angle in the r-ϕ plane
θ: track incident angle in the r-z plane

fit function: fifth-order Chebyshev polynomial + linear function(boundary region)


Belle II Online luminosity
Exp: 7-8-10 - All runs
Integrated luminosity [fb^{-1}]
Weekly
Total
Total $\int \mathcal{L} dt = 10.57$ [fb^{-1}]
Total integrated Weekly luminosity [fb^{-1}]
Total integrated luminosity [fb^{-1}]
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
2
4
6
8
10
2019-04-01
2019-05-21
2019-07-10
2019-08-29
2019-10-18
2019-12-07
Date
Plot on 2019/12/12 18:23

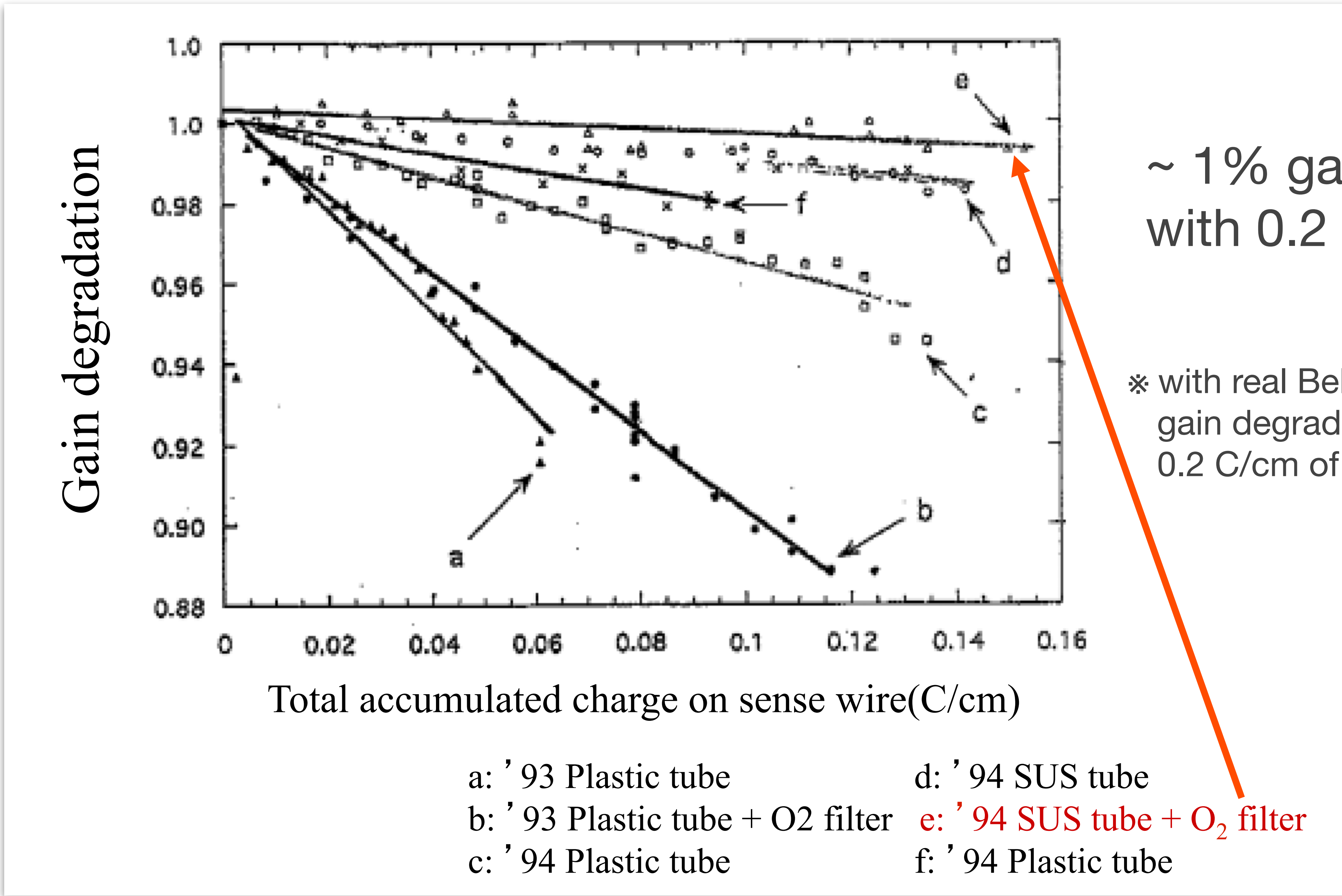
Accumulated charge on wires

- total accumulated charge
  10-20 mC/cm for inner layers
  ~5 mC/cm for outer layers



Gain degradation due to wire aging

https://www.phys.hawaii.edu/~superb04/talks/Uno.ppt



~ 1% gain degradation with 0.2 C/cm

※ with real Belle-1 CDC, no significant gain degradation was observed with 0.2 C/cm of accumulated charge

Layer configuration

SL	Type	N Layer	Layer	N cells / Layer	N FE / SL
SL-0	A	8	0 - 7	160	26.7
SL-1	U	6	8 - 13	160	20.0
SL-2	A	6	14 - 19	192	24.0
SL-3	V	6	20 - 25	224	28.0
SL-4	A	6	26 - 31	256	32.0
SL-5	U	6	32 - 37	288	36.0
SL-6	A	6	38 - 43	320	40.0
SL-7	V	6	44 - 49	352	44.0
SL-8	A	6	50 - 55	384	48.0
Total		56		14336	298.7

Layer configuration

NIM A 930, 132 (2019), https://doi.org/10.1016/j.nima.2019.03.072

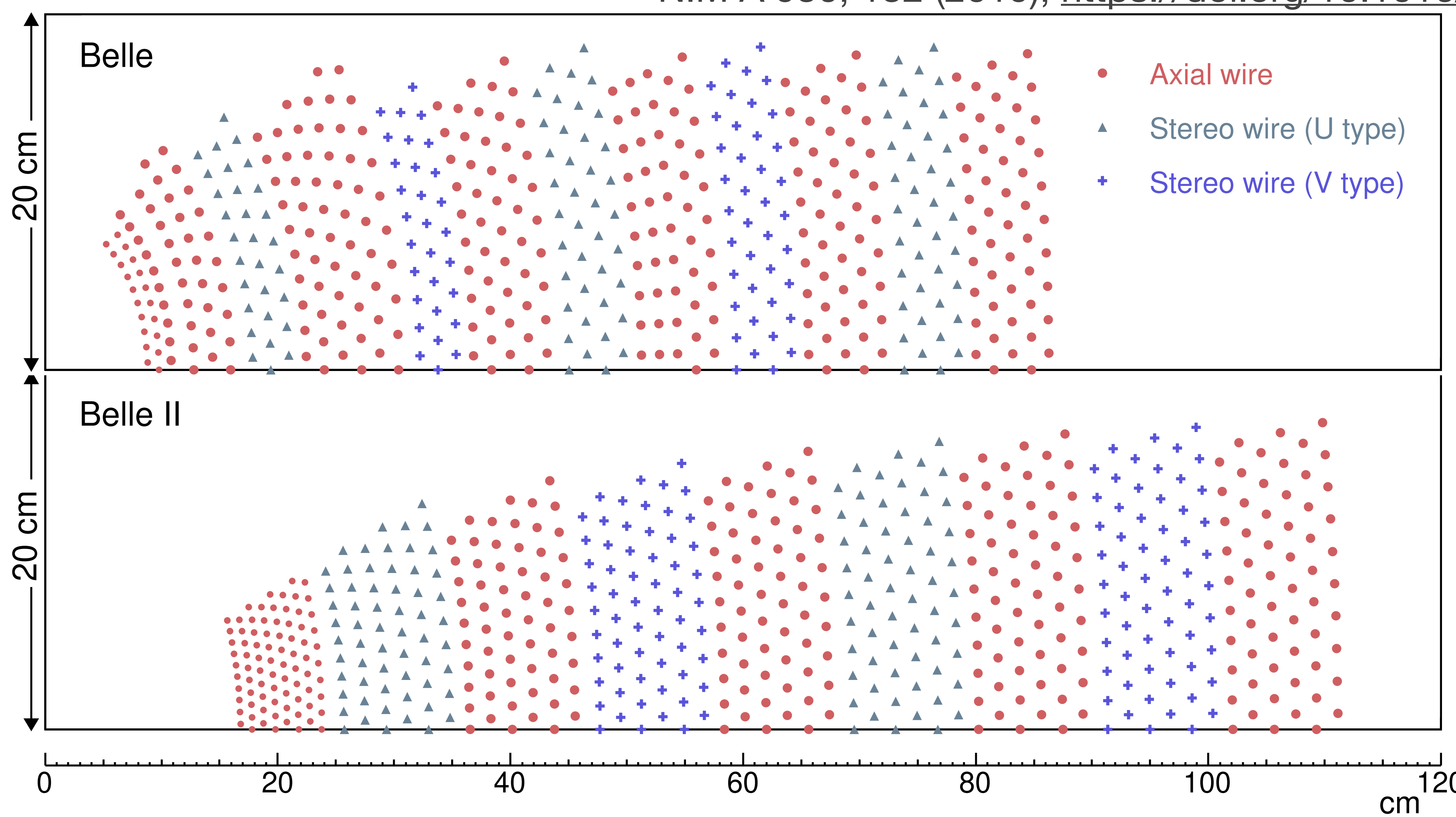


Fig. 2. Layer configuration of the Belle and Belle II CDCs.

R of the innermost layer (L0) : 88 mm → 168 mm
R of the outermost layer : 863 mm → 111.4 mm
# of sense wires: 8400 → 114336

Material budget inside CDC, X_0

XY cross-sections with approximations: cylinder, all axial wire (ignore stereo angle)

- total cross-section of CDC: $\pi(R^2-r^2) = \pi*(113^2-16^2) = 3.93e4\ cm^2$
  ※total volume: $\pi L(R^2-r^2) = \pi*232.5*(113^2-16^2) = 9.14e6\ cm^3$ (~9000ℓ)
- total cross-section of sense wires = $14336 * \pi * (0.0030/2)^2 = 0.101\ cm^2$
- total cross-section of field wires = $42240 * \pi * (0.0126/2)^2 = 5.27\ cm^2$

$$\frac{w[\mathrm{g}]}{X_0^{\mathrm{comp.}}[g/\mathrm{cm}^2]} = \sum \frac{w^i[\mathrm{g}]}{X_0^i[g/\mathrm{cm}^2]}$$

http://pdg.lbl.gov/2019/AtomicNuclearProperties/index.html
https://cds.cern.ch/record/1279627/files/PH-EP-Tech-Note-2010-013.pdf

	density (20°C,1 atm) [g/cm^3]	(He:C_2H_6=50:50) density [g/cm^3]	S [cm^2]	ρ*S [g/cm]	X_0 [g/cm^2]	ρS/X_0 [cm] (= w^i/X_0)
He	1.663E-04 →	8.315E-05	3.93E+04	3.27	94.32	0.03
C_2H_6	1.263E-03 → (1/2)	6.315E-04	3.93E+04	24.82	45.66	0.54
W	19.30	19.30	1.01E-01	1.96	6.76	0.29
Al	2.699	2.699	5.27E+00	14.22	24.01	0.59

	density (20°C,1 atm) [g/cm^3]	X_0 [g/cm^2]	X_0 [cm]	X_0 [m]
He:C_2H_6	7.147E-04	48.6	6.797E+04	**679.7**
total	1.126E-03	30.3	2.693E+04	**269.3**
wire + vacuum	4.114E-04	18.3	4.460E+04	**446.0**

momentum resolution

Overall momentum uncertainty (MS and sagitta independent):

$$\frac{\sigma_p}{p^2} = \frac{\sigma_x}{0.3B\ell^2}\sqrt{\frac{720}{N+4}} \oplus$$

$$\frac{0.0157\mathrm{GeV/c}}{0.3B\ell p}\sqrt{\ell/X_0}[1 + 0.038\ln(\ell/X_0)]$$

This can be seen as:

$$\frac{\sigma_p}{p^2} = [\text{detector construction}] \oplus [\text{material budget}]/p$$

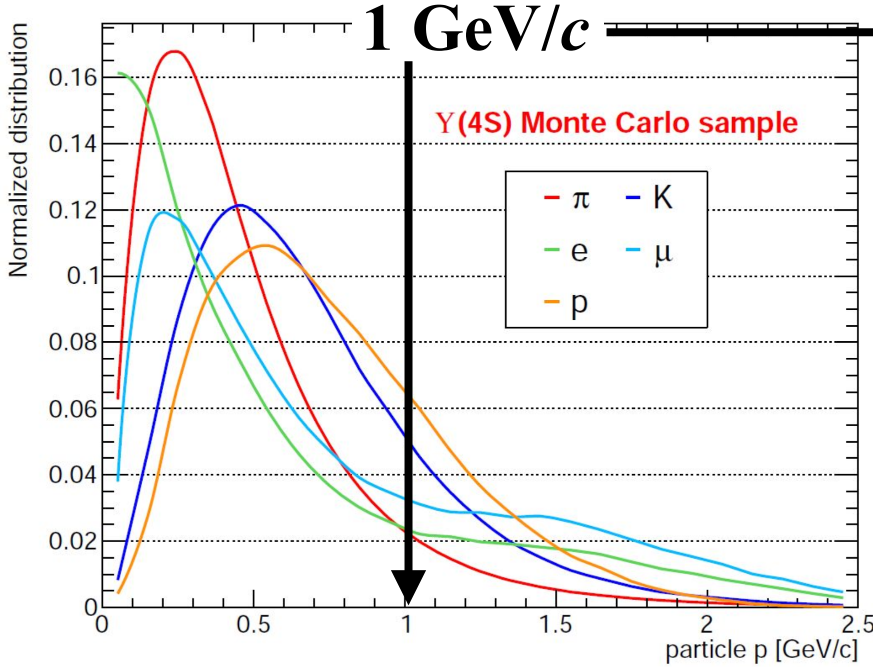
http://majorana.knu.ac.kr/resources/Teaching/PPEaHC/5-notes.pdf

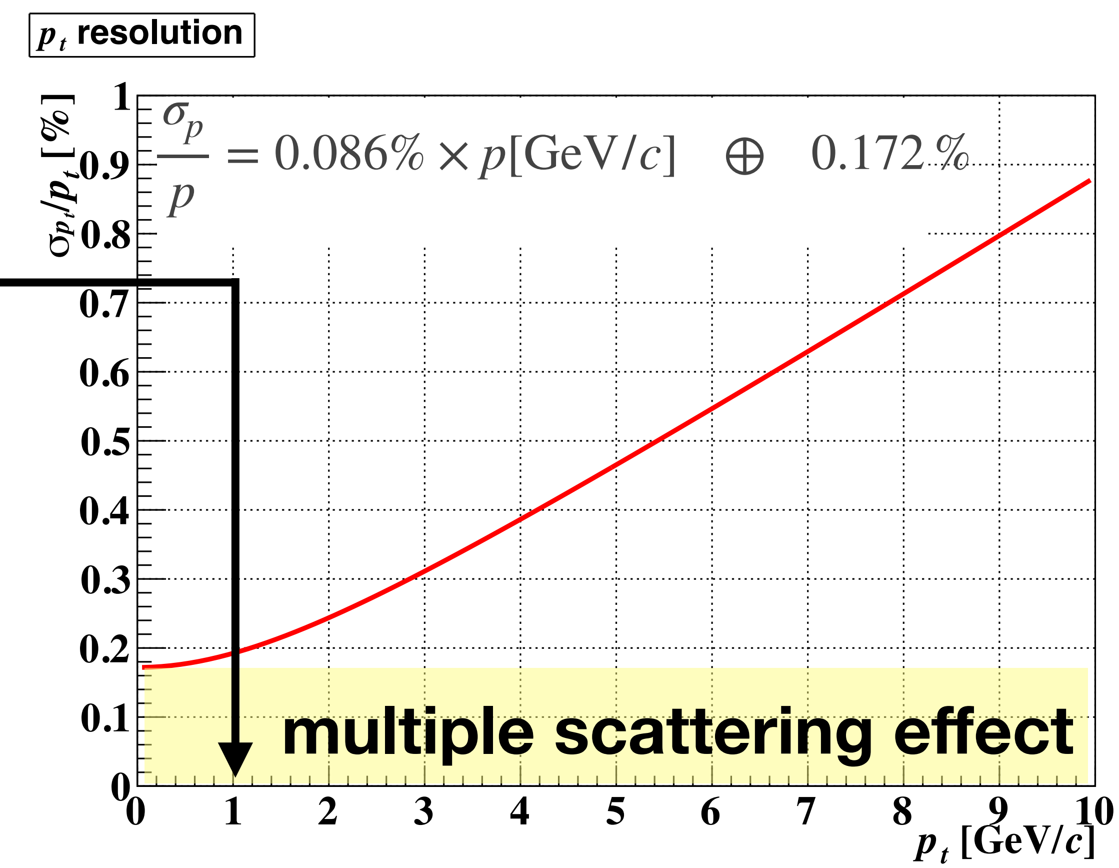
parameter	value
Lever arm: L [m]	0.9434
radiation length: X_0 [m]	269.3
B field: B [T]	1.5
position resolution: σ [m]	1E-04
# of meas. points	56

$$\frac{\sigma_p}{p} = \underbrace{\left(\frac{\sigma_p}{p}\right)_{\text{meas.}}}_{a} \times p \oplus \underbrace{\left(\frac{\sigma_p}{p}\right)_{\text{MS}}}_{b}$$

MS: multiple scattering

a	0.086%
b	0.172%





Structure

R of inner cylinder	160 mm
R of outer cylinder	1130 mm
R of innermost sense wire	168 mm
R of outermost sense wire	1111.4 mm
length (Z)	2325 mm
angular coverage	17°<θ<150°

\# of sense wires: 14336 (Au-W, ϕ30 μm)
\# of field wires: 42240 (Al, ϕ126 μm)

9 Super Layers (5-axial(A), 4-stereo(U/V))
SL = 6 layers of sense wires
※ exceptionally, SL0 (innermost) consists of 8 layers
→ **56 layers** in total

p[GeV/c] = 0.3 B[T] R[m], B=1.5T
→ p = 72 MeV/c with R = 0.16 m
p = 509 MeV/c with R = 1.13 m
p = 100 MeV/c → R = 0.222 m (~L5)

※ material effect (energy loss) is not considered

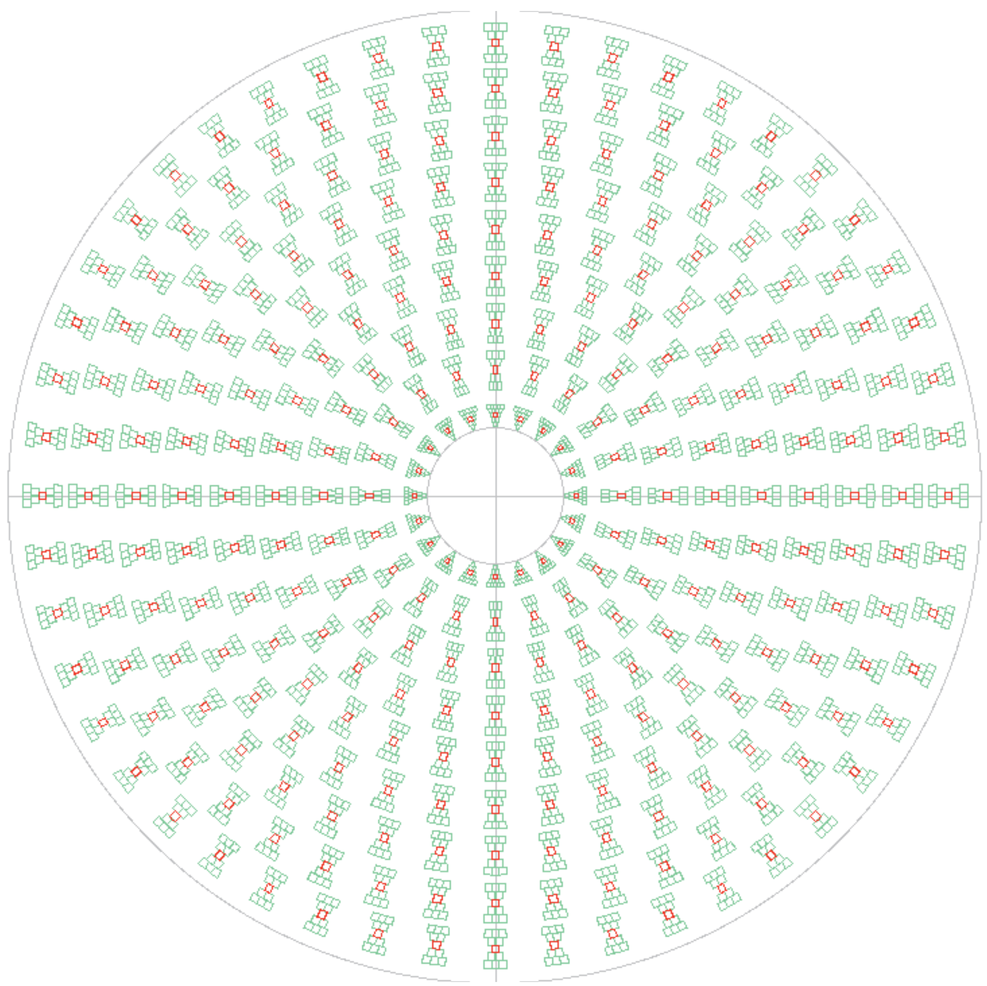
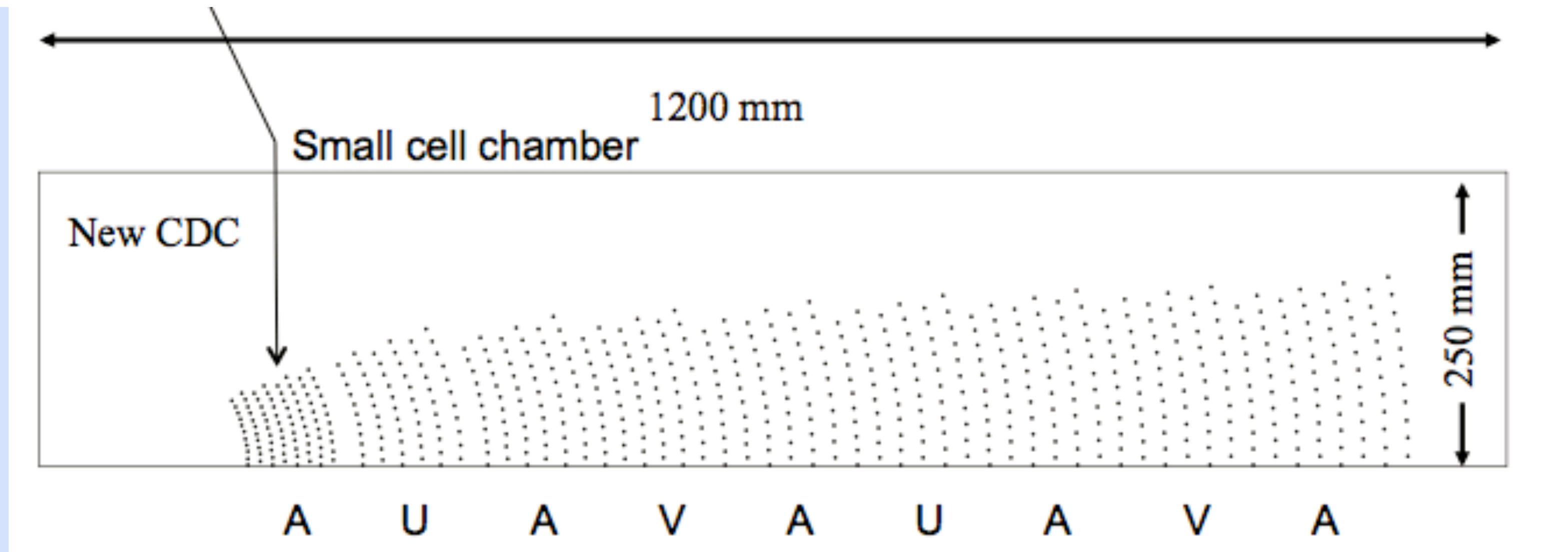


図 2: CDC の断面図 (x-y 平面図)。図中小さな四角形がセンスワイヤーのセルを表す。濃色 (赤) がプライオリティーセルを示しており，このワイヤーのドリフト時間がトラッキングに使用される。セルの塊一つ一つが TSF を表し，全 TSF のうち 1/8 のみを表示している。

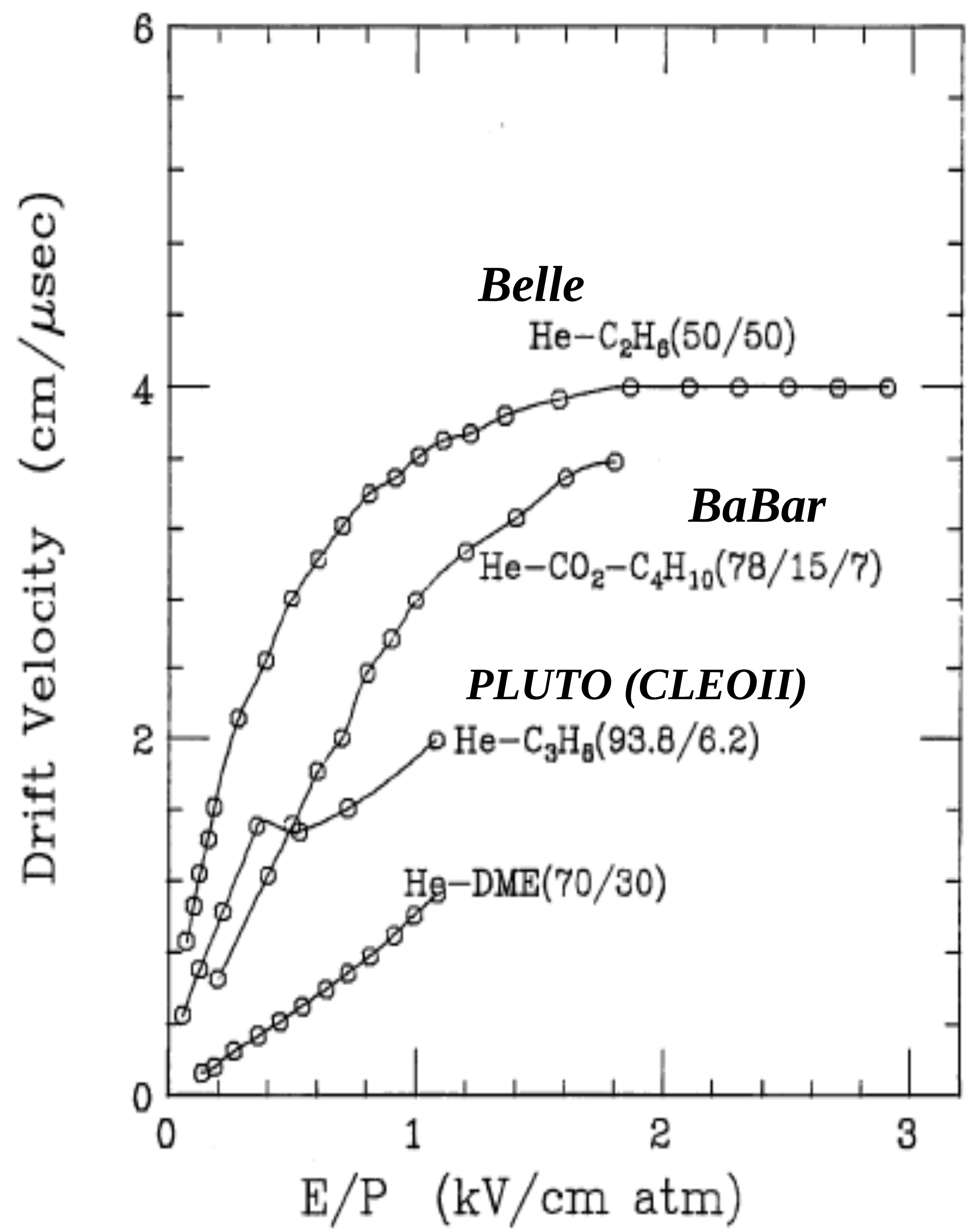


Gas

https://indico.mpp.mpg.de/event/1747/contributions/2050/attachments/1929/2180/BelleII-CDC.pdf

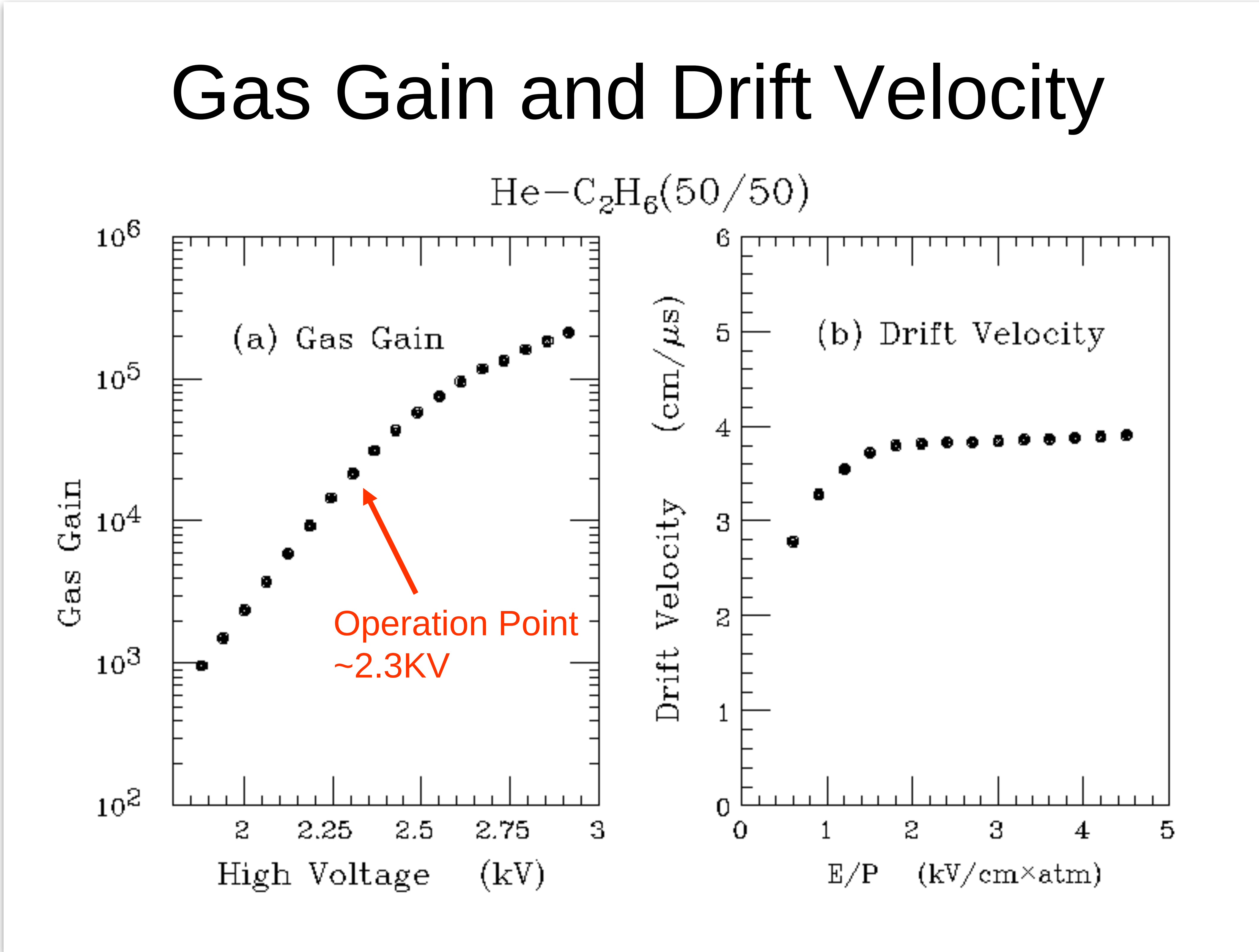
Chamber Gas

- He(50%)-C_2H_6(50%)
  - Longer radiation length(680m).
  - Drift velocity is higher than other He-based gas.
    - Average drift velocity : ~3.3cm/μsec in the chamber cell.
    - Maximum drift time : ~350nsec for 17mm cell size.
  - Good dE/dx resolution.



Gas

https://indico.mpp.mpg.de/event/1747/contributions/2050/attachments/1929/2180/BelleII-CDC.pdf

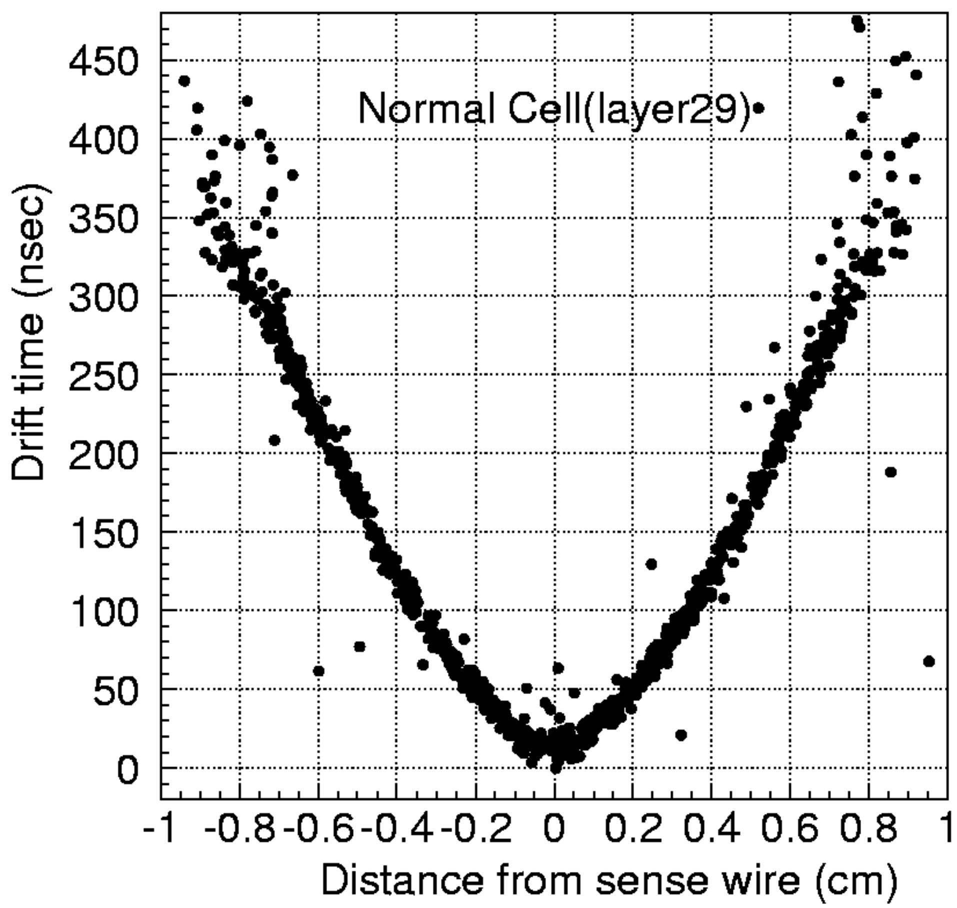


Gas

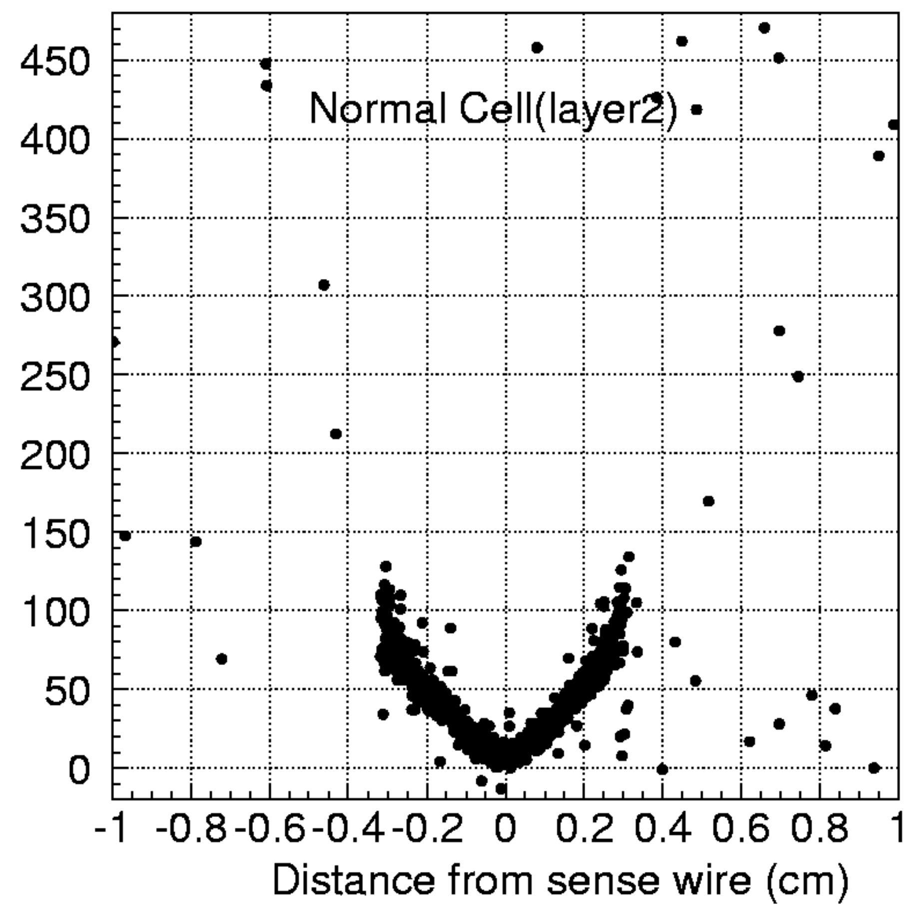
https://indico.mpp.mpg.de/event/1747/contributions/2050/attachments/1929/2180/BelleII-CDC.pdf

XT Curve & Max. Drift Time

- He(50%)-C_2H_6(50%), B=1.5Tesla, HV : 2.3KV
- Rather shorter maximum drift time



Normal cell(17.3mm)



Small cell(5.4mm)

Gas

https://indico.mpp.mpg.de/event/1747/contributions/2050/attachments/1929/2180/BelleII-CDC.pdf

dE/dx Resolution

- The pulse heights for electron tracks from ^{90}Sr were measured for various gases.
- The resolutions for CH_4 and He(50%)-C_2H_6(50%) are same.
- The resolution for He-CF_4 is worse than Ar-based gas(P-10).