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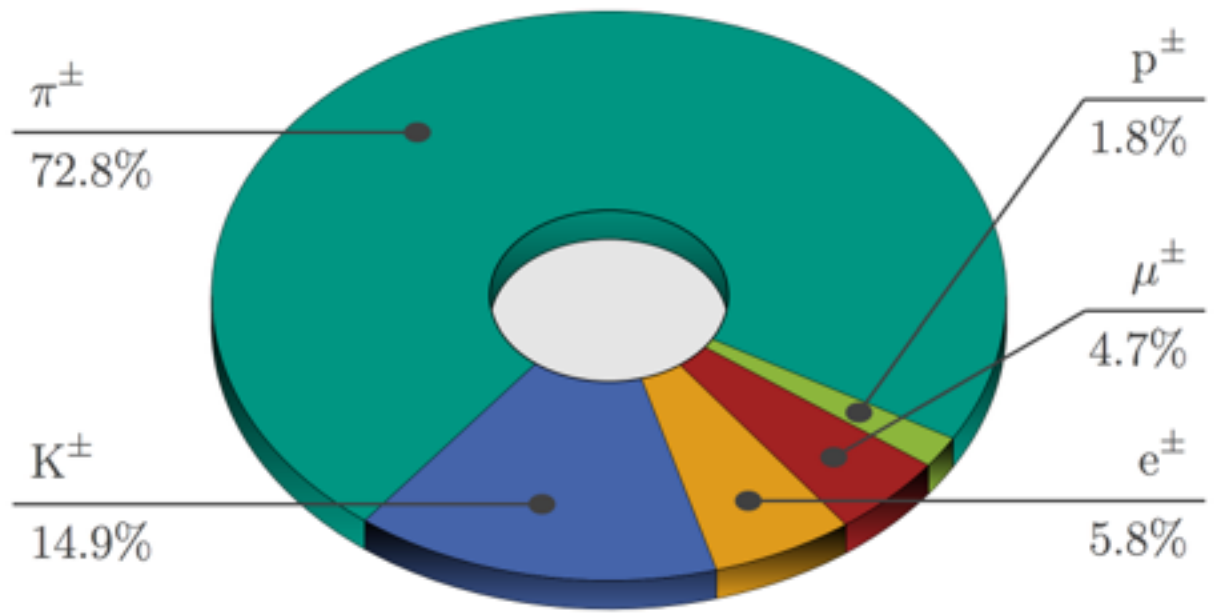
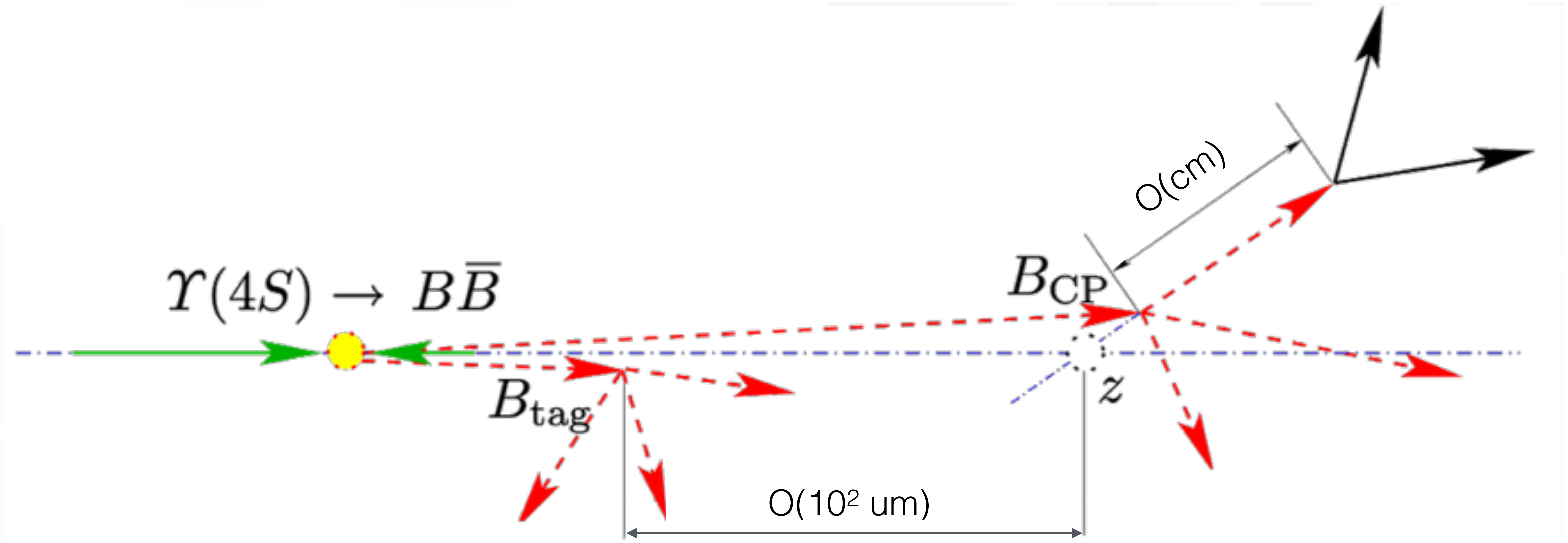
# Long-lived Particle reconstruction at Belle II

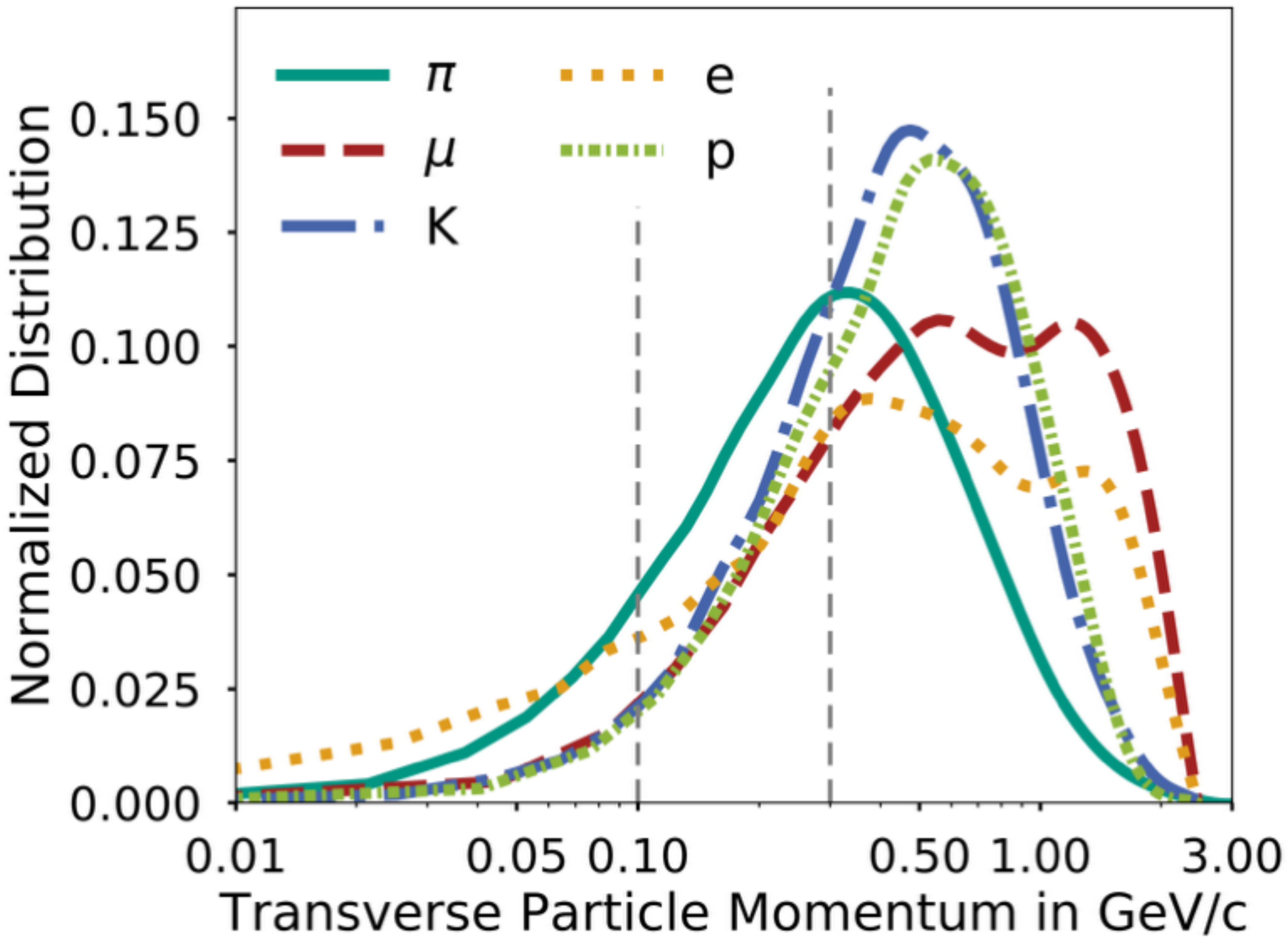
# Belle II: event properties and tracking challenges

- Typical Υ(4S) event:
  - On average 11 charged tracks with soft momentum spectrum
  - High machine background: number of background hits about 2 orders of magnitude larger than signal hits




- Operated at asymmetric collider SuperKEKB, CM boosted
- Precise measurement of primary and secondary vertices



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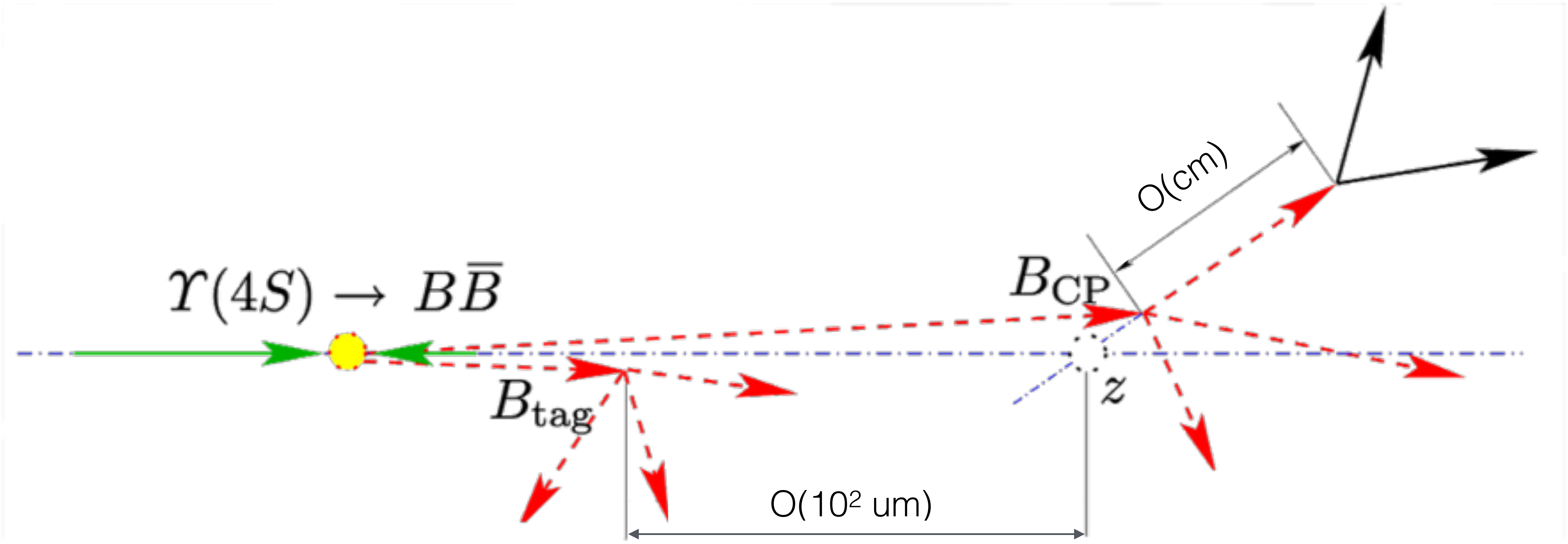
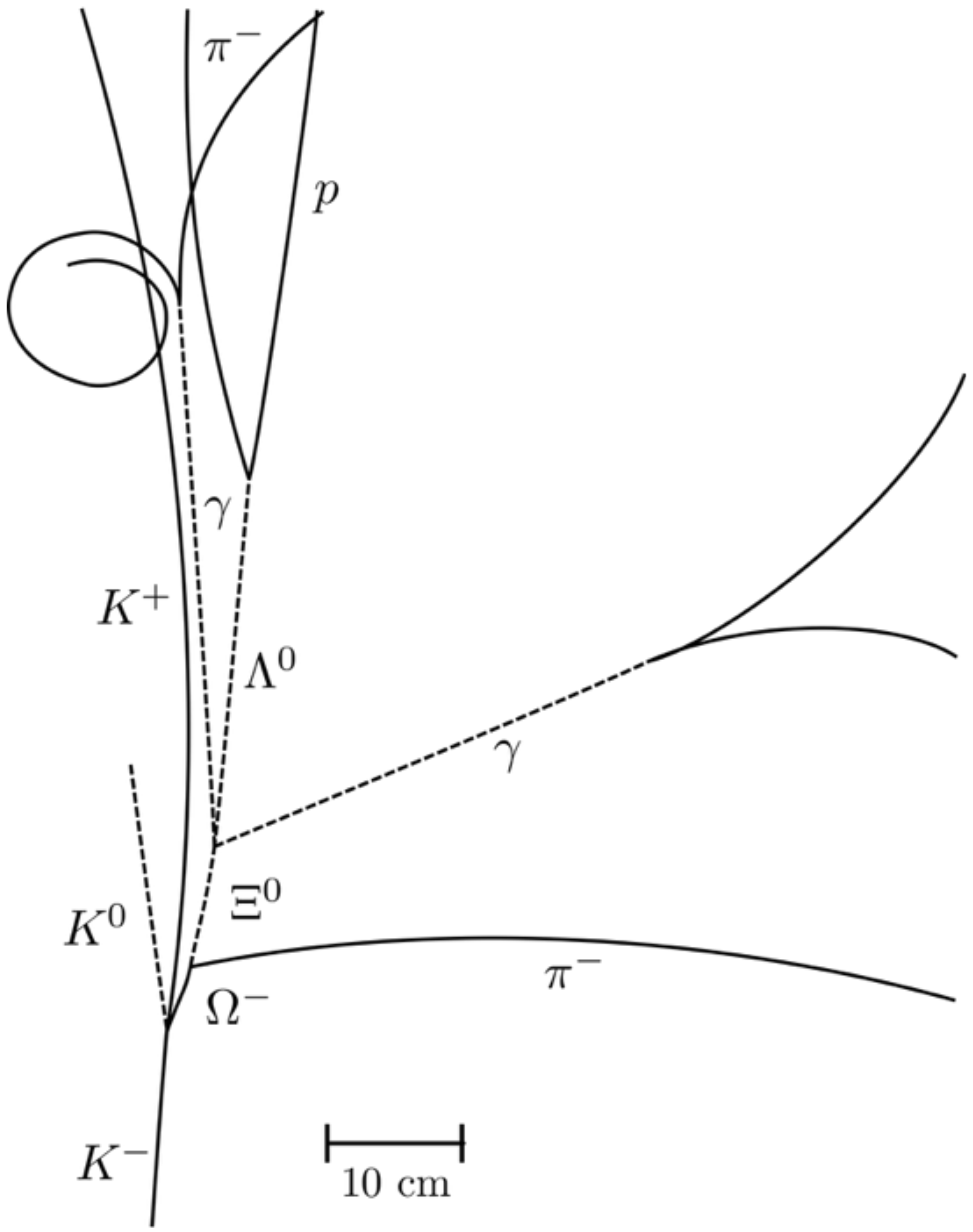



- Standard Model $V^0$s
  - $K_S$: cτ ~ 2.7 cm
  - Λ: cτ ~ 7.9 cm
- In some sense they are long-lived particles / can be used in benchmark studies for LLP
- …not without downsides
  - $K_S$: "short" LLP
  - Λ: asymmetric

# V0s: then and now

- Name "V0" derives from the peculiar signature in the detector
  - Two charged tracks appearing from nowhere
- We will refer in particular to 2 specific decays
  - Ks $\rightarrow \pi^+ \pi^-$ [ BR = 69.2 % ]
  - $\Lambda \rightarrow p \, \pi^-$ [ BR = 63.9 % ]
- Detection methods have changed with time
  - *Bubbles* became *hits*
- The signature of the signal is always the same
  - Two charged particles originating from a neutral one

*Fig: Bubble chamber trace of the first observed Ω baryon event at Brookhaven National Laboratory*



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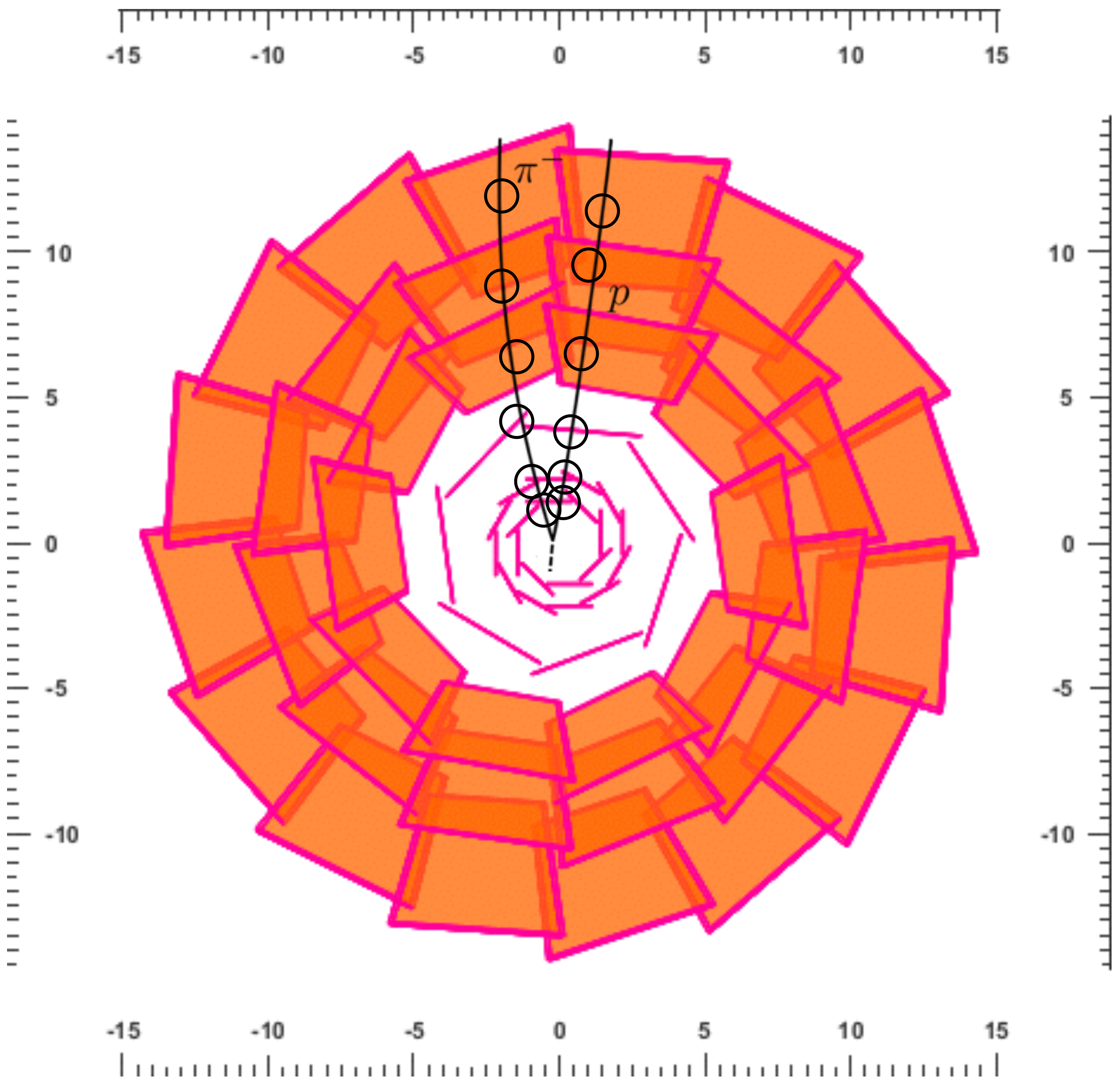
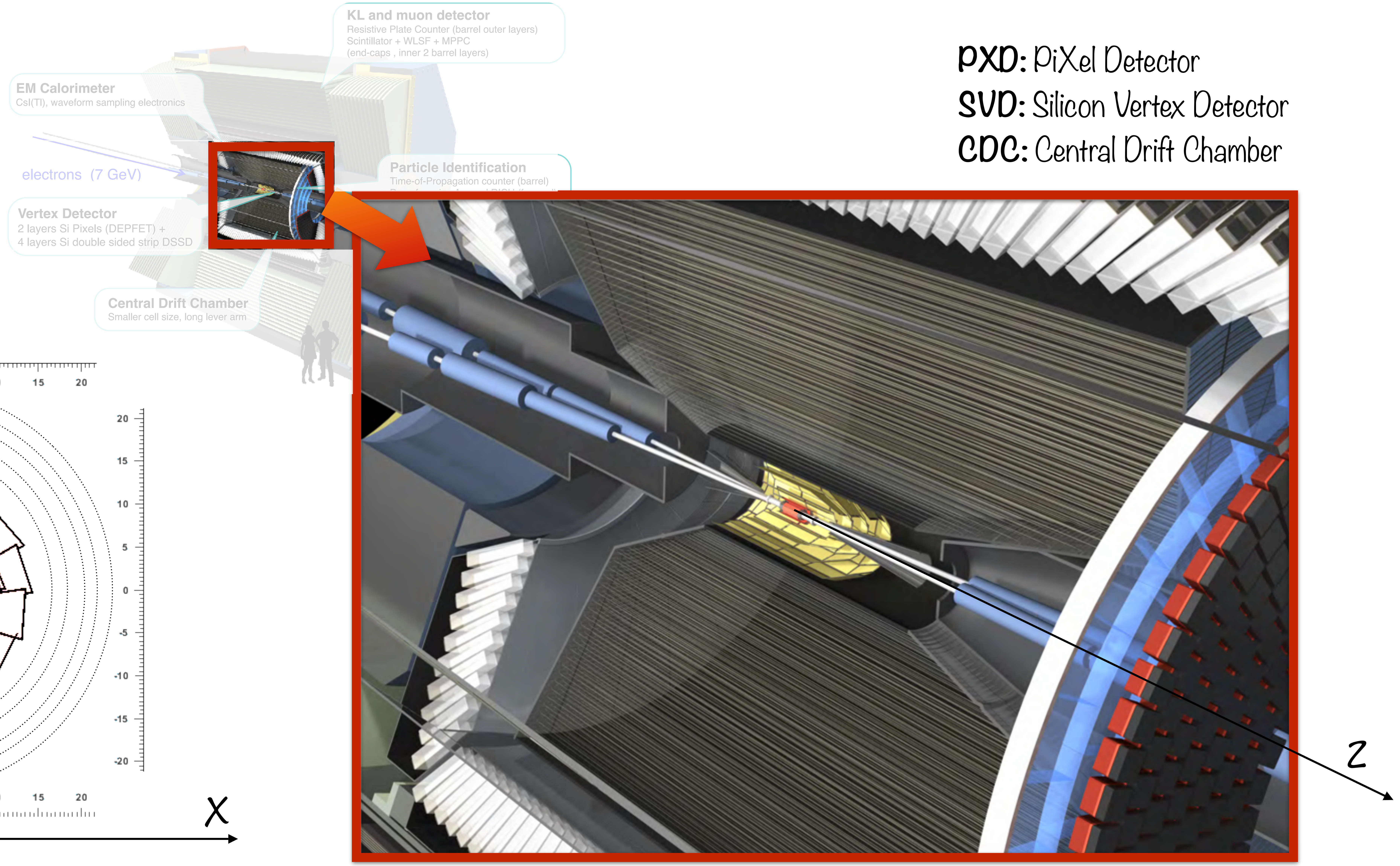
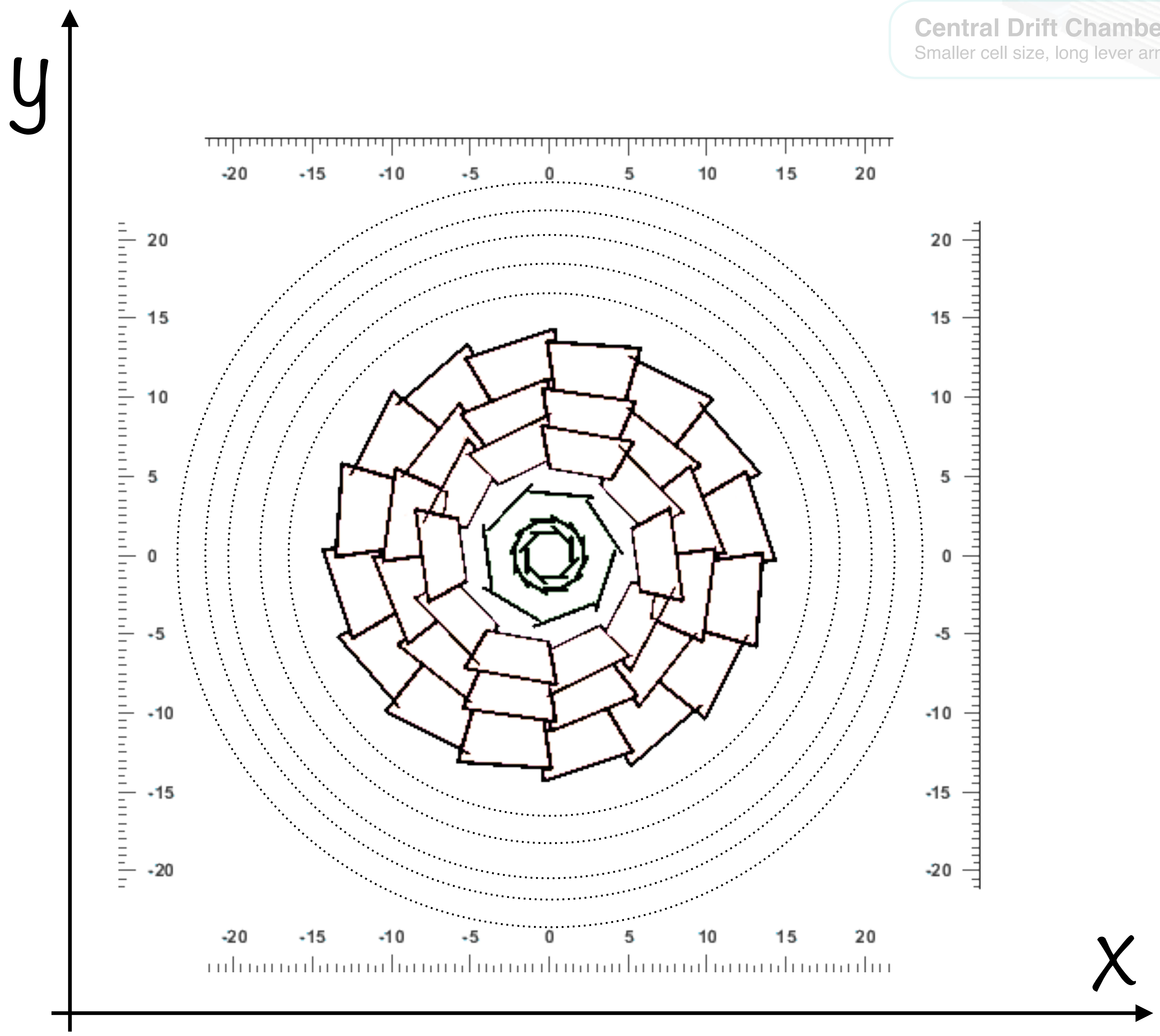


# Belle II detector – tracking systems




**PXD:** PiXel Detector
**SVD:** Silicon Vertex Detector
**CDC:** Central Drift Chamber

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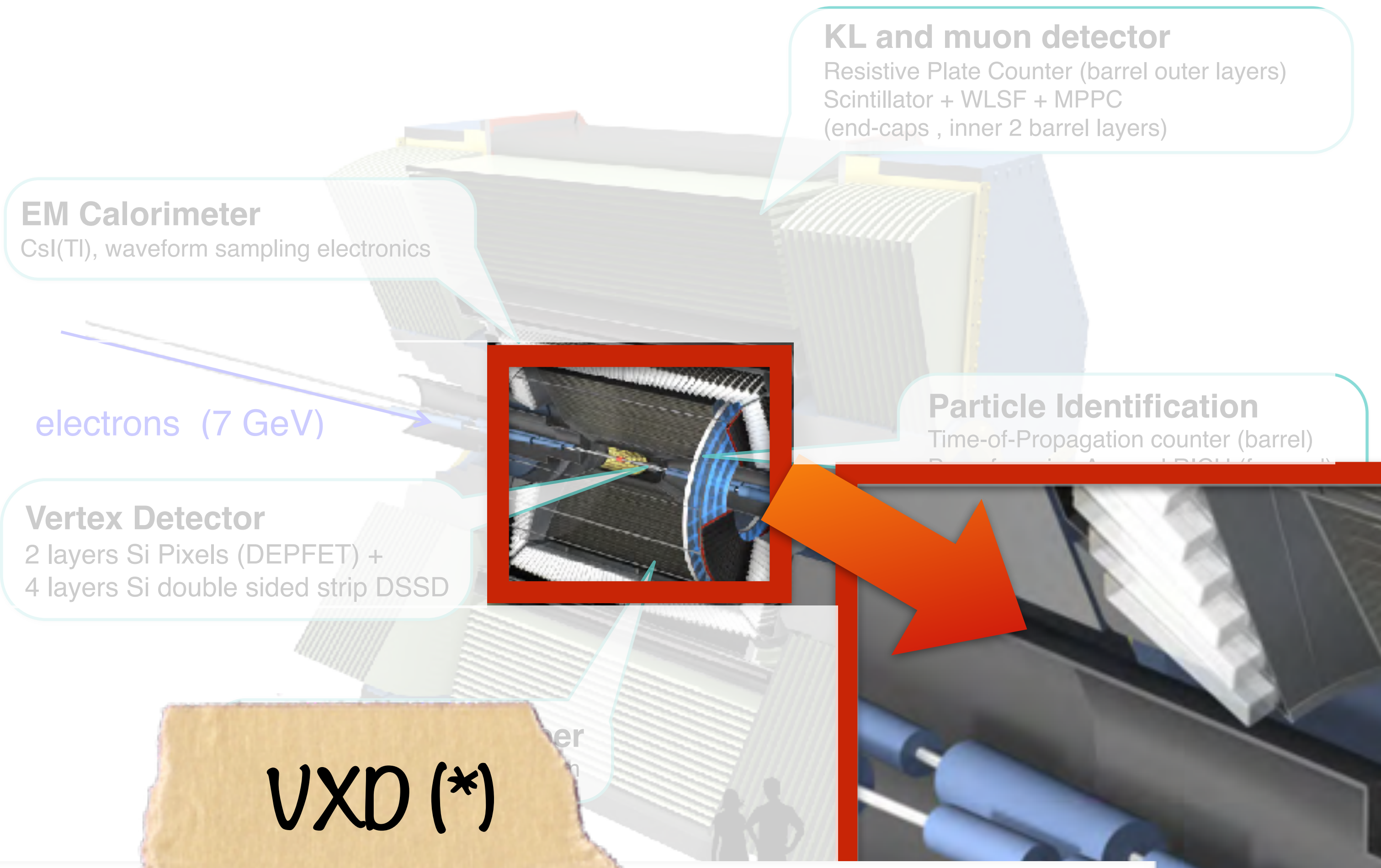
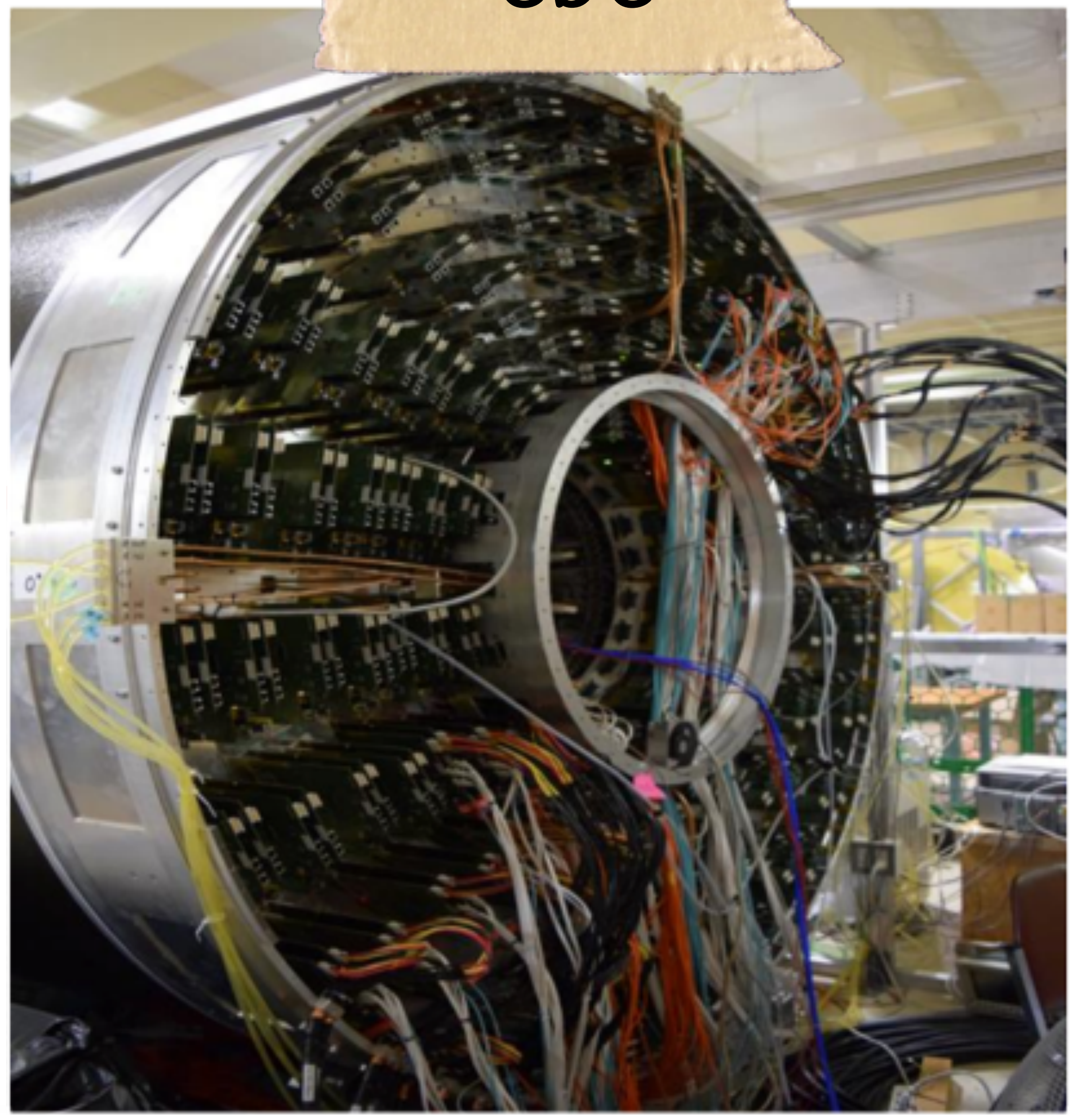
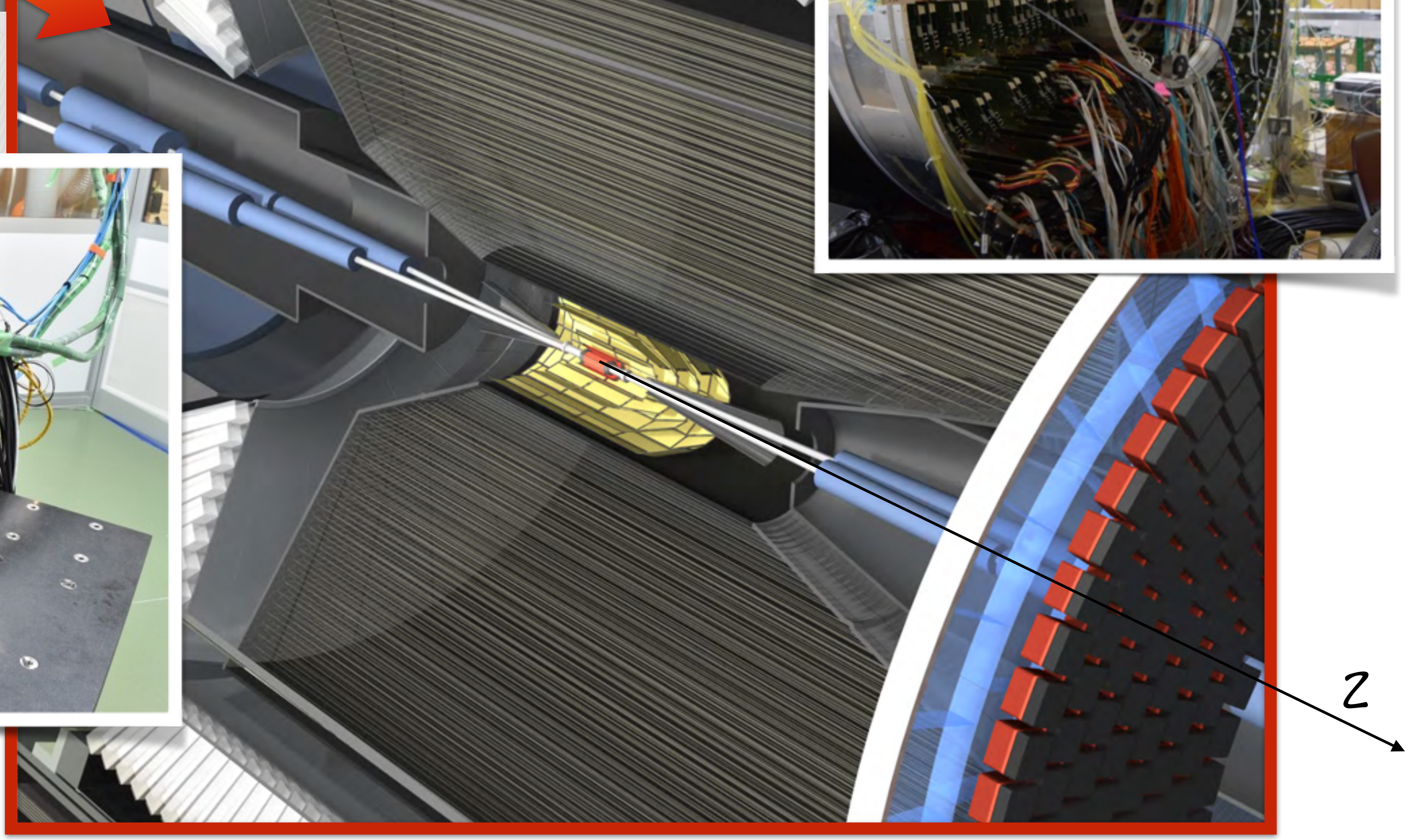
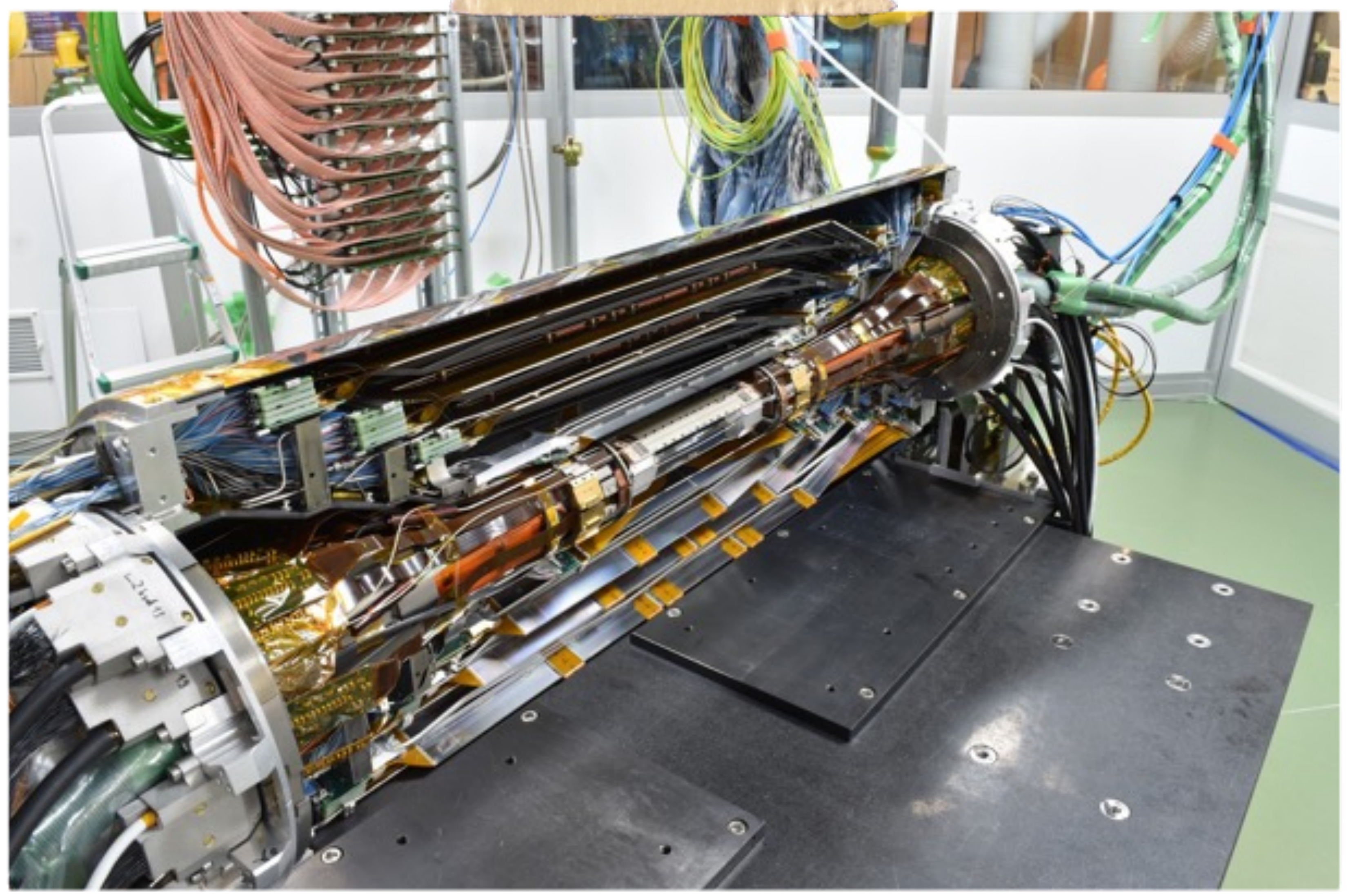



CDC



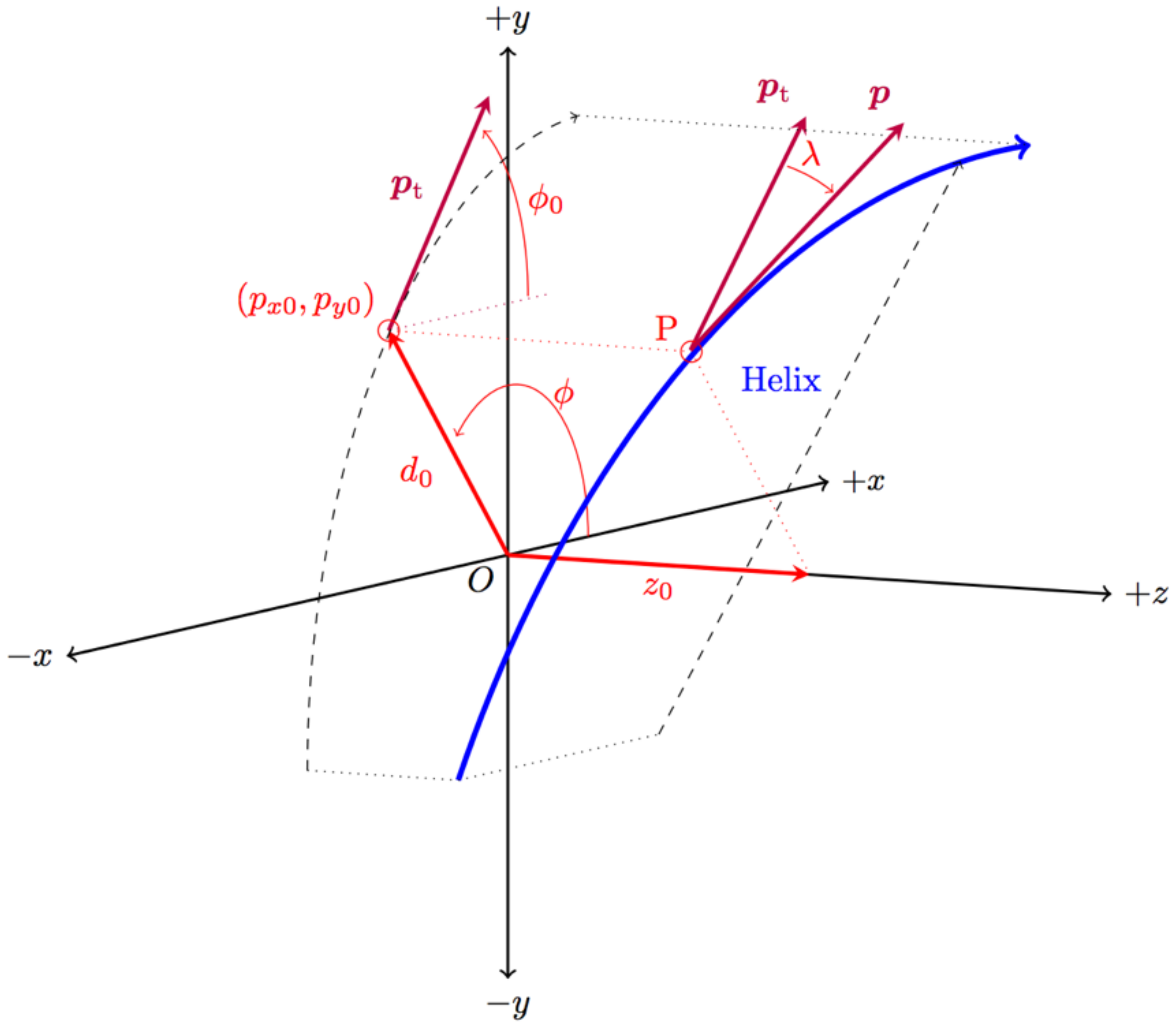



VXD (*)



(*) VXD = PXD + SVD

(*) POCA: Point Of Closest Approach

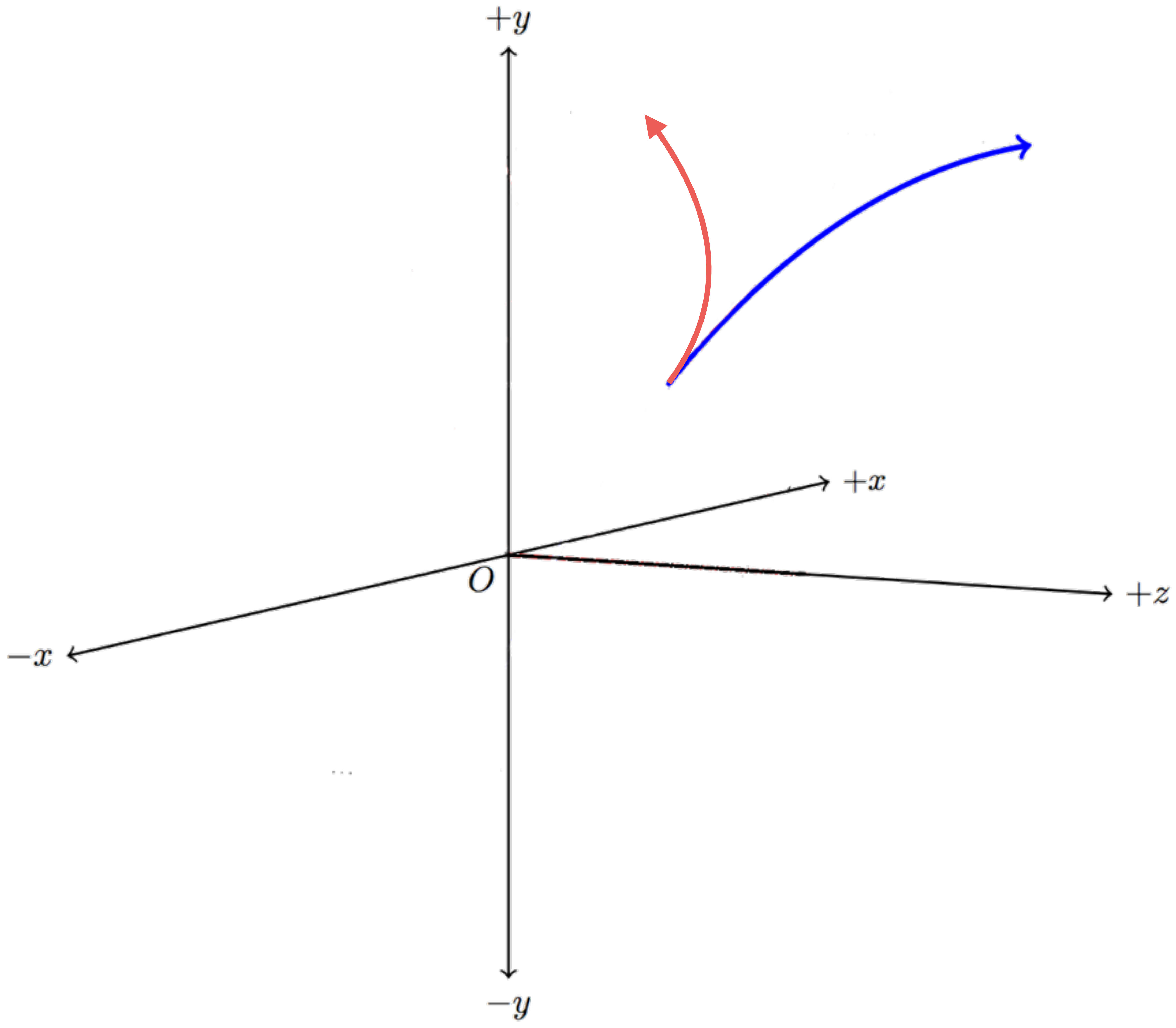



- After the reconstruction, the individual hit patterns are not available to the standard user
- The final object delivered to analysts is a *track*
  - Collection of 5 parameters at the POCA (*)

**track parameters = [d0, z0, tanλ, ϕ, ω]**

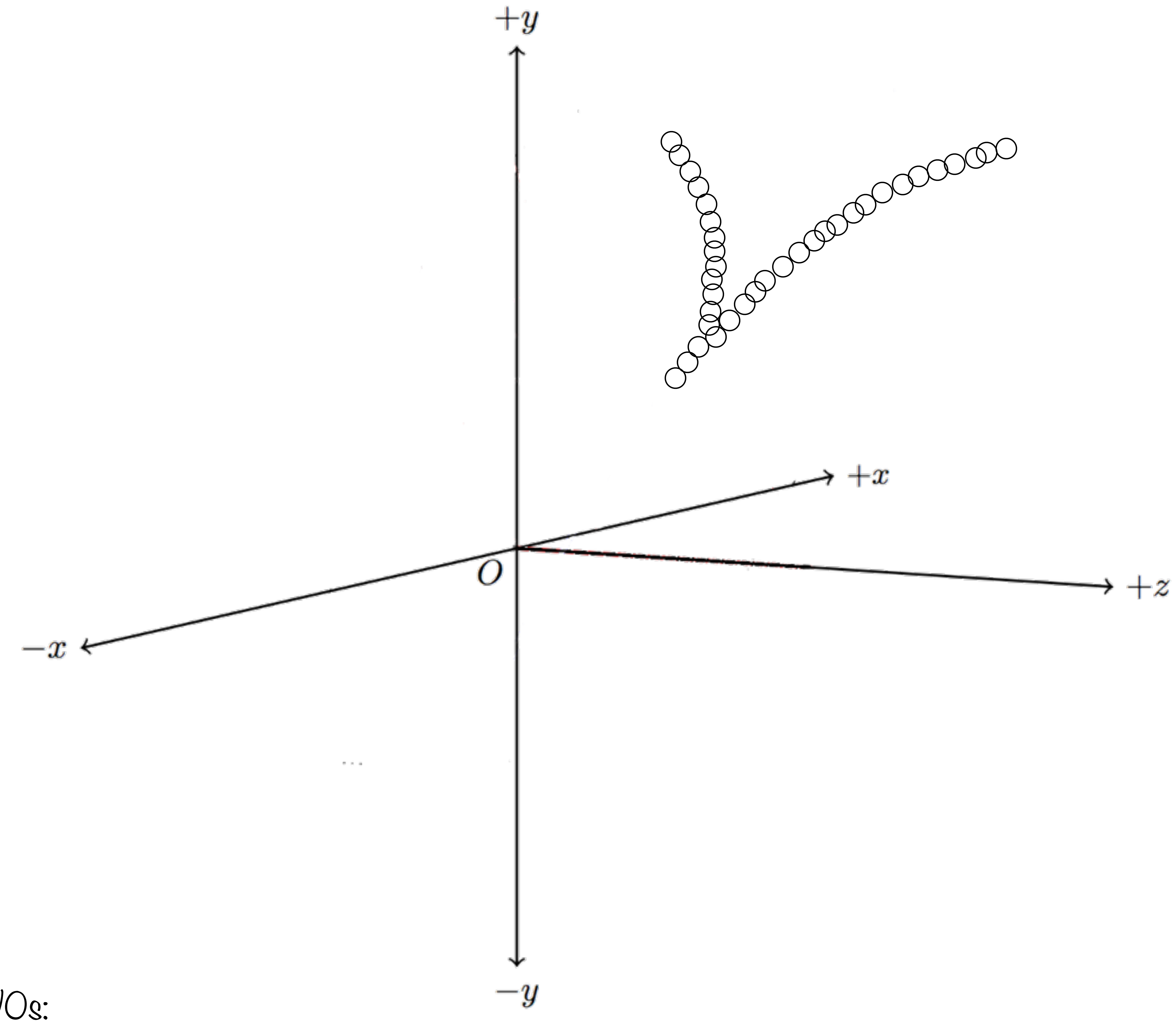
# Belle II V0s, theory

(*) POCA: Point Of Closest Approach




- After the reconstruction, the individual hit patterns are not available to the standard user
- The final object delivered to analysts is a *track*
  - Collection of 5 parameters at the POCA (*)
- V0s: two tracks with a common vertex and opposite charge
- Track description is not ideal for displaced vertices (and displaced tracks in general)
  - Material effects
  - Extrapolated to the IP, less precise

# Belle II V0s, theory



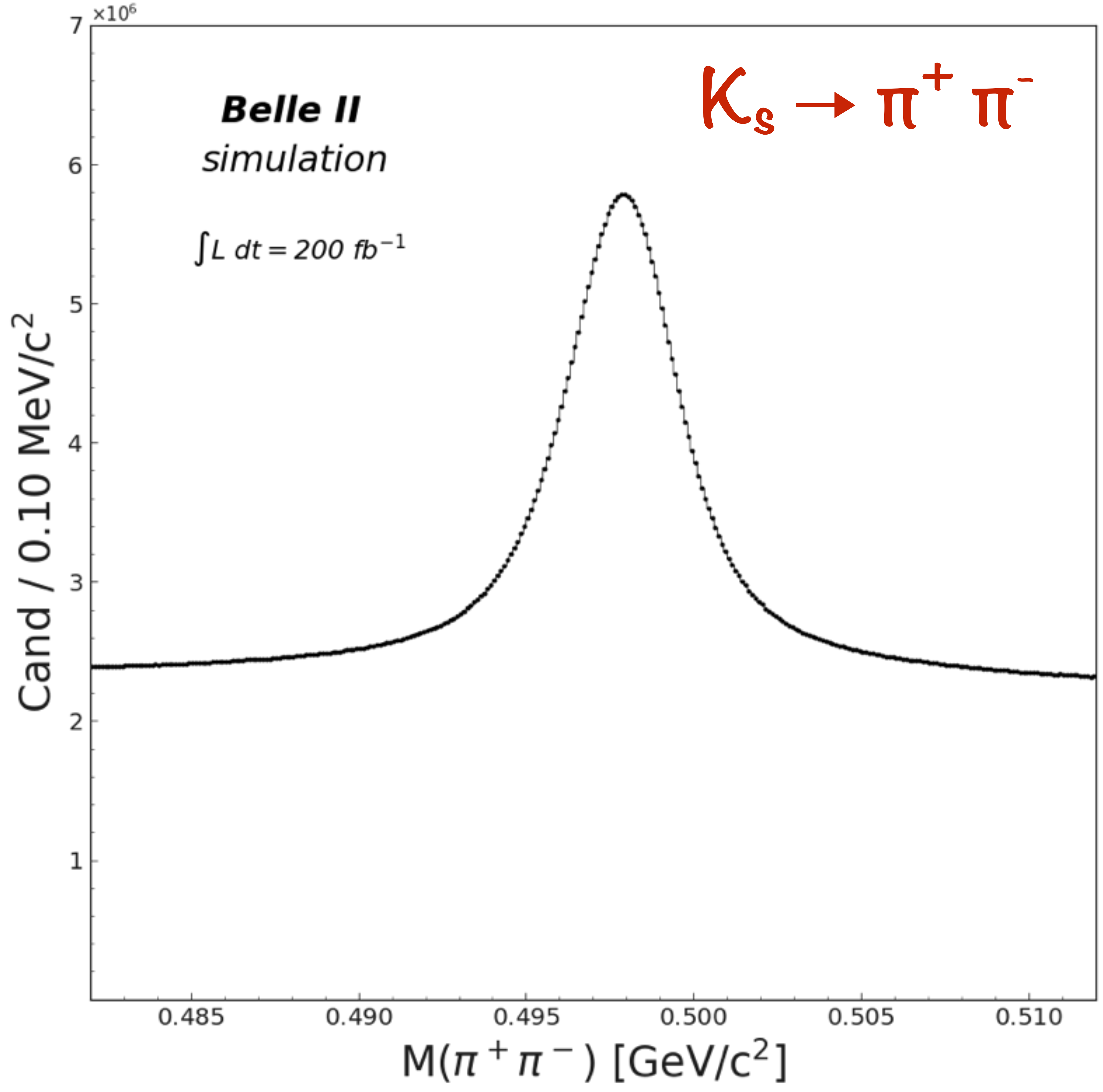

Offline V0s:
2 tracks combined w/ successful vertex fit

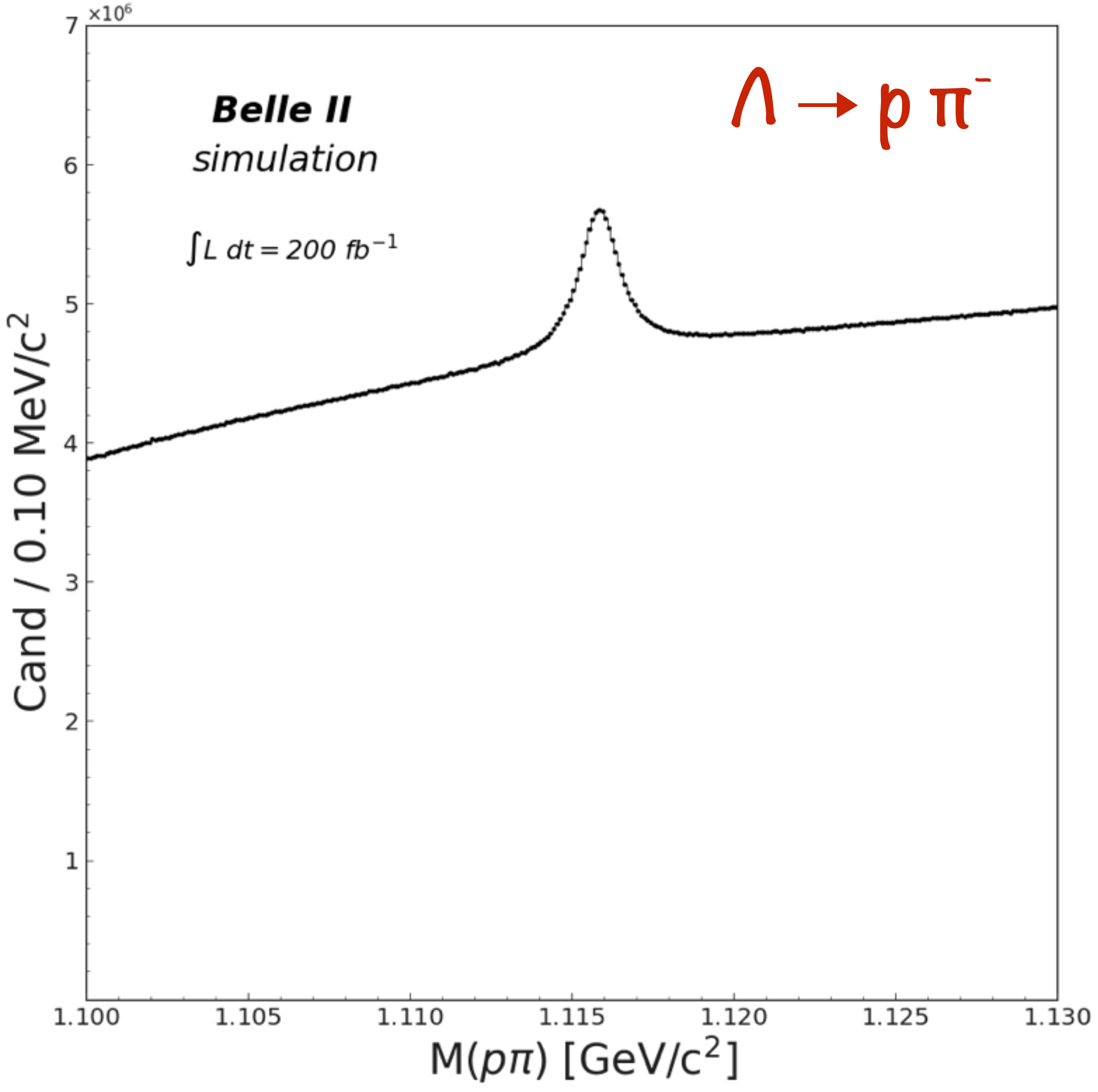
- During reconstruction we have a dedicated treatment for V0s
- Before throwing away the precious information from the hit patterns, we exploit it performing the vertex fit of possible V0 candidates
- When the fit succeeds, we store the object and deliver it to analysts
- ***Final "analysis" V0s: Combination of these objects and offline V0s***

# Belle II VOs, practice

- What does everything I just said mean *practically?*

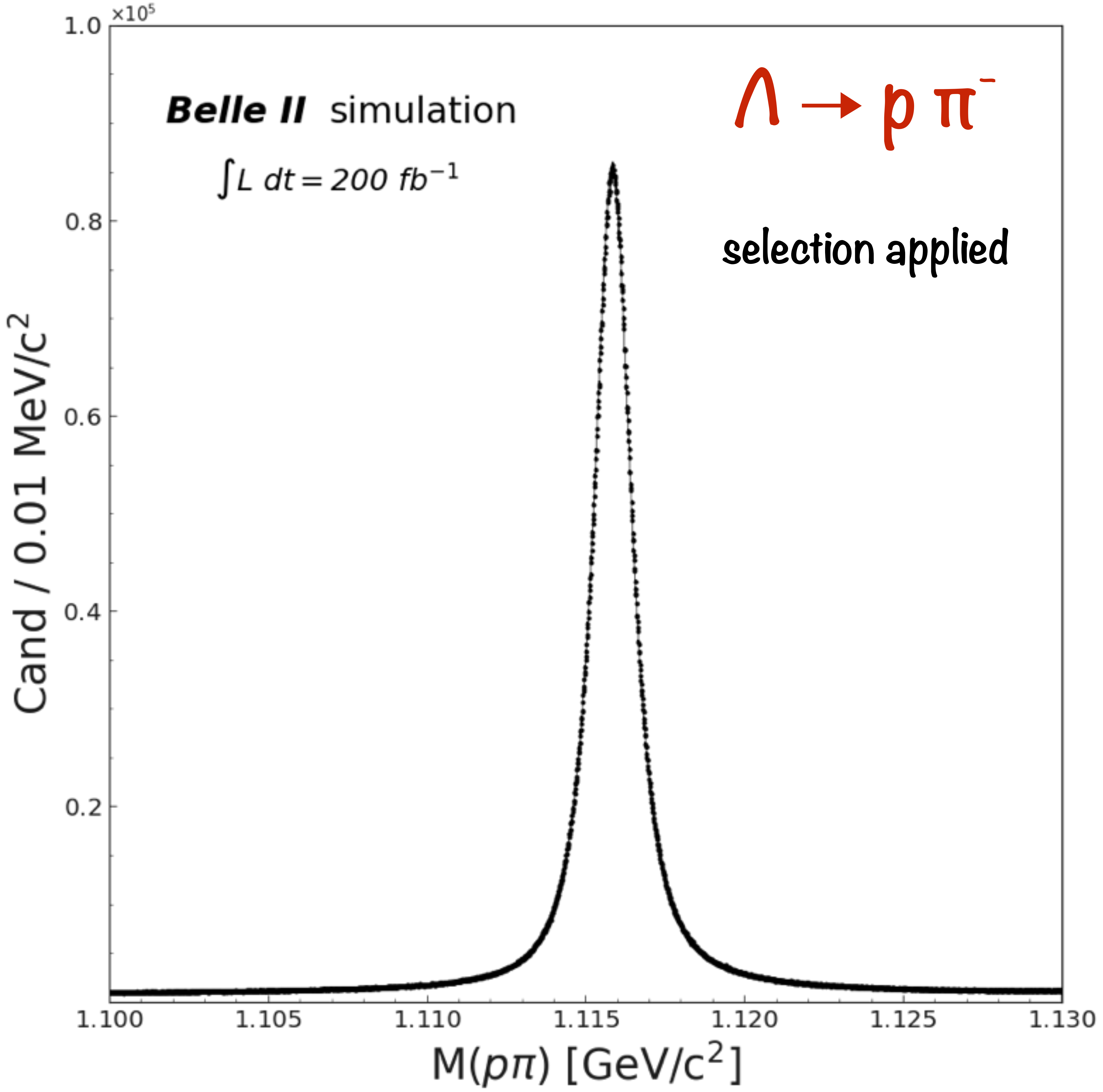
# Belle II V0s, practice



# Belle II V0s, practice

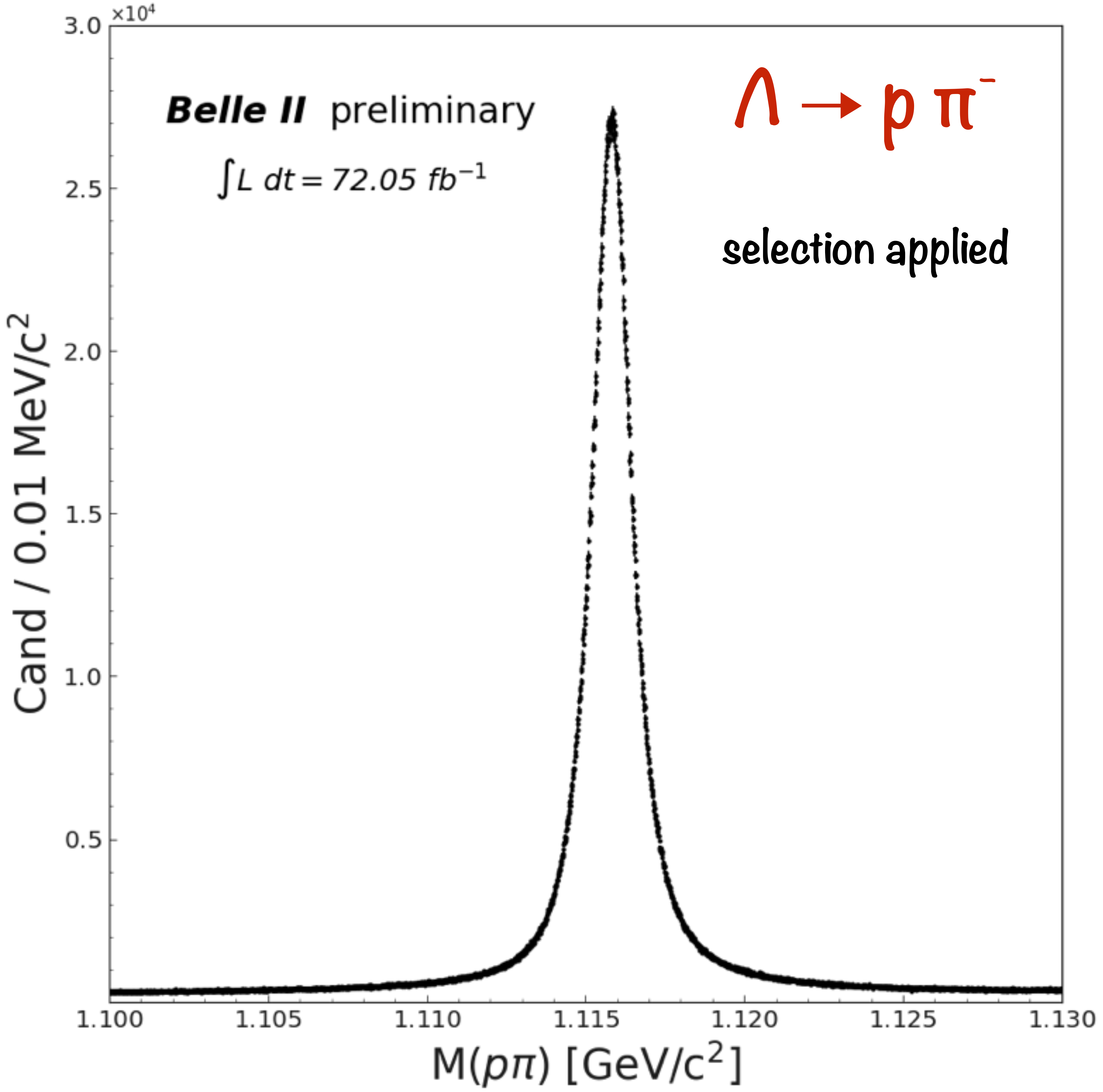
- The full samples are the most inclusive that one can get
  - Contain huge combinatorial background
- Adding kinematics cuts and exploiting PID information
  - We can get a cleaner peak




As a side note:
From now on I will focus on $\Lambda$, I am sorry for $K_s$ fans

# Belle II V0s, practice

- The full samples are the most inclusive that one can get
  - Contain huge combinatorial background
- Adding kinematics cuts and exploiting PID information
  - We can get a cleaner peak
- …also with data

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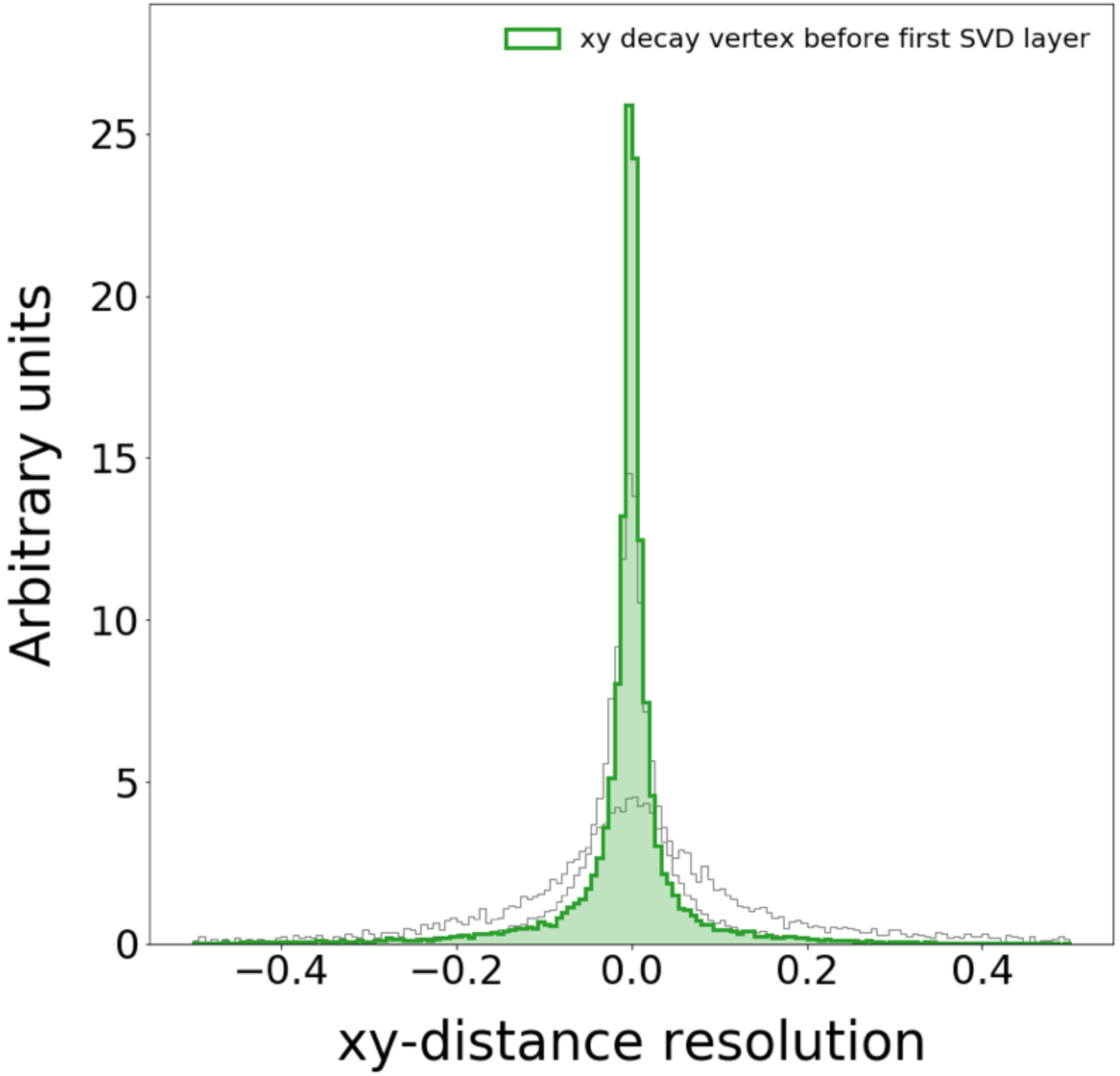
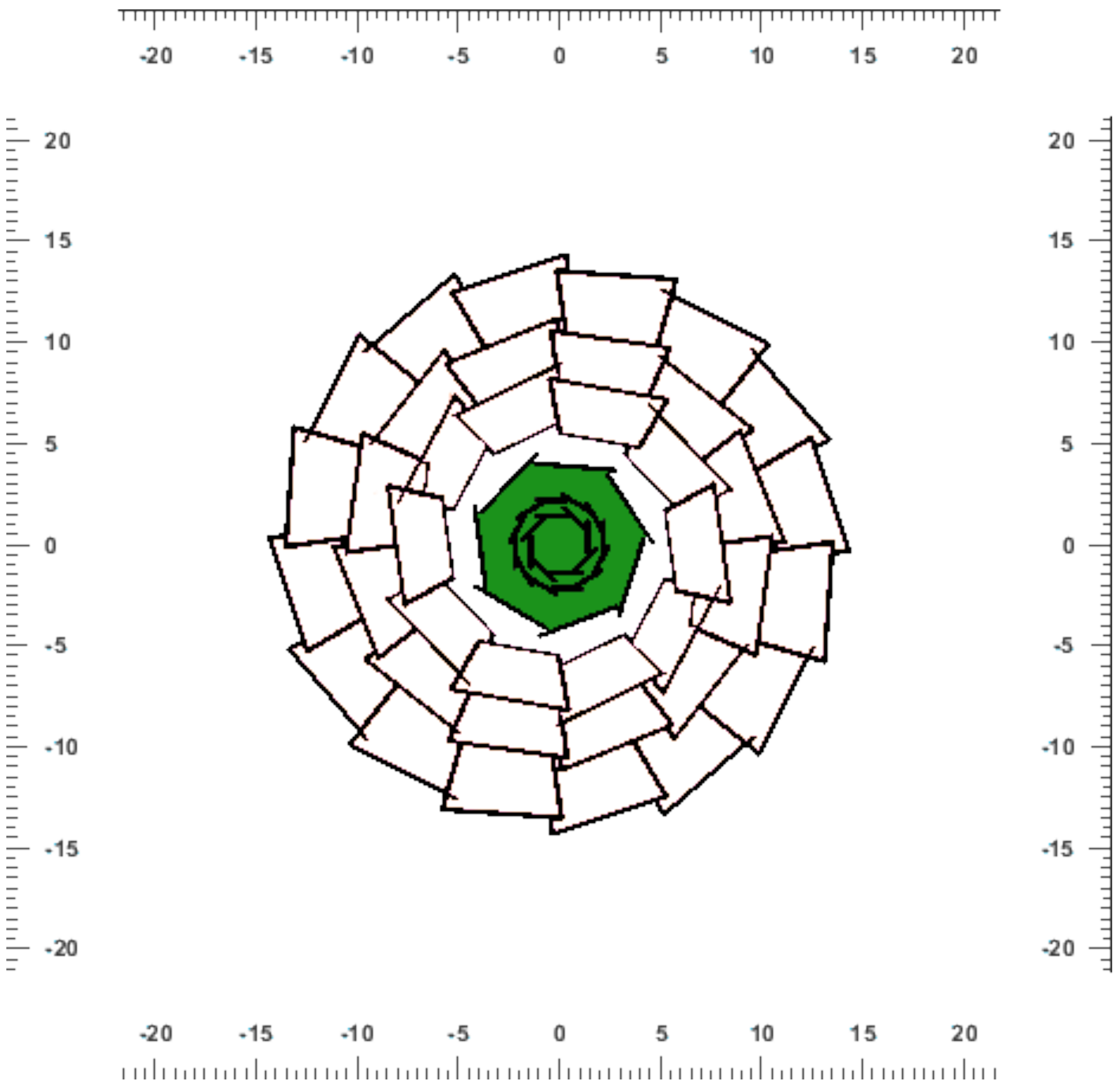
# Effect of the inner detectors on the resolution



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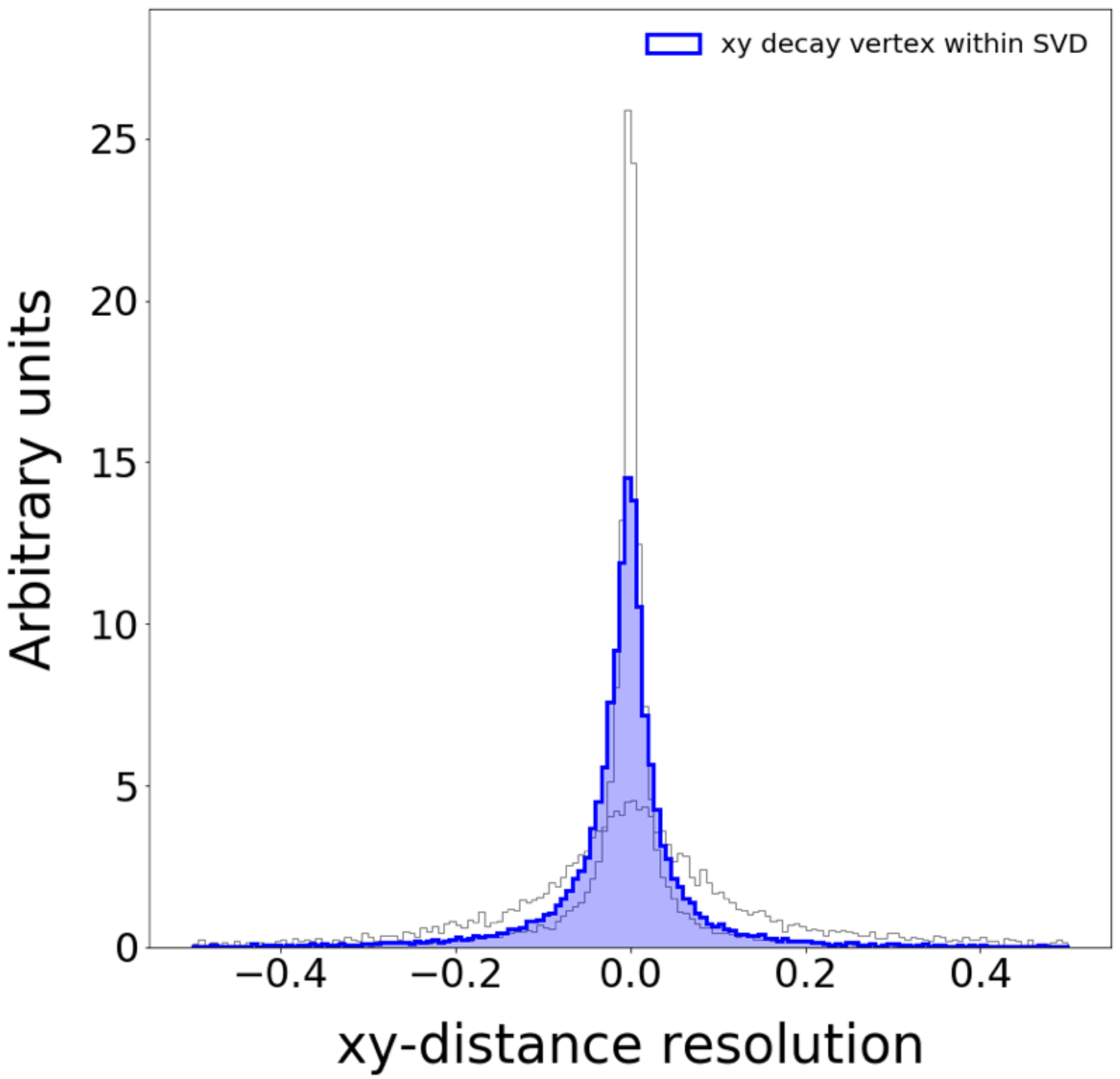


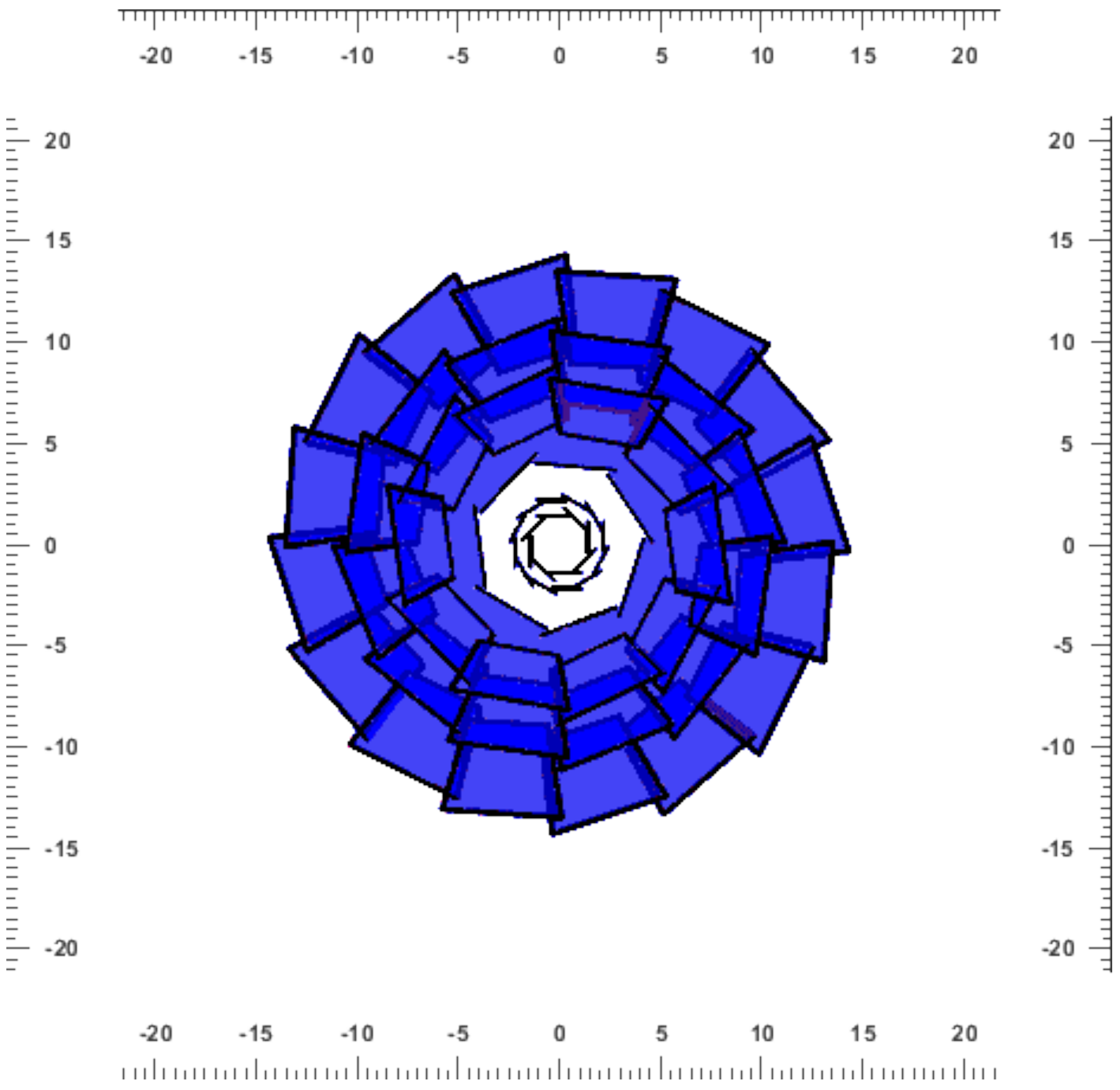

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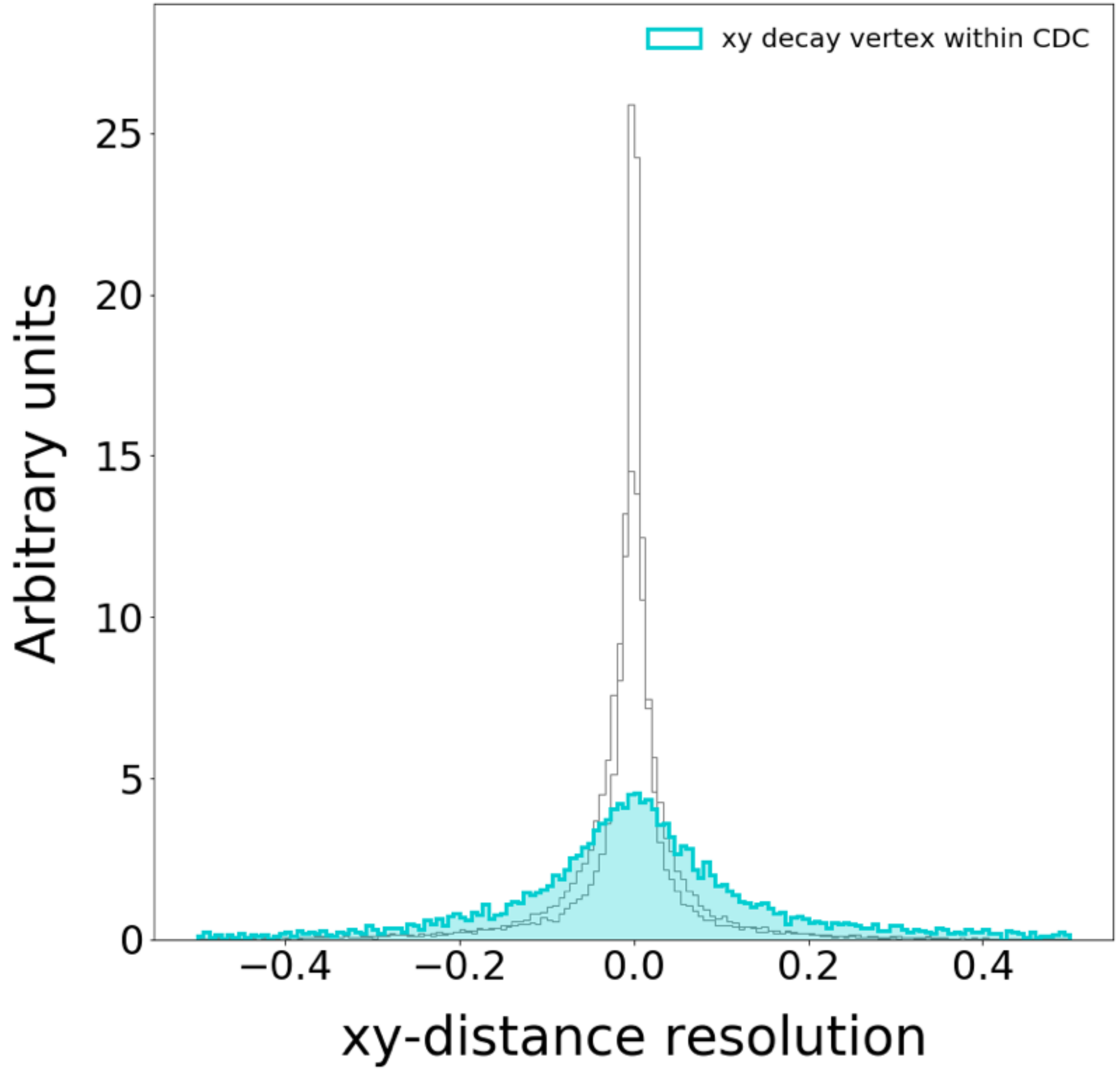
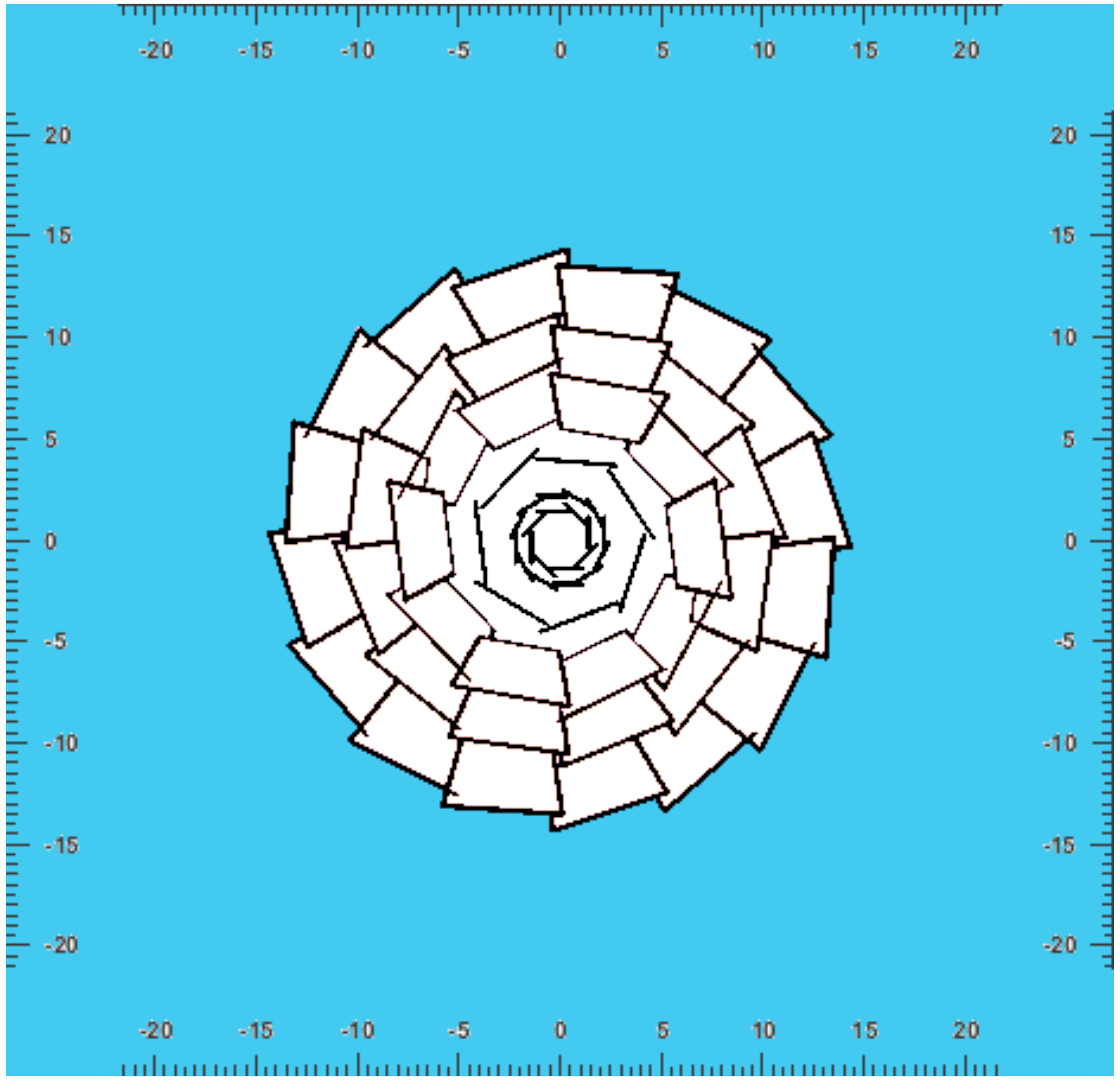
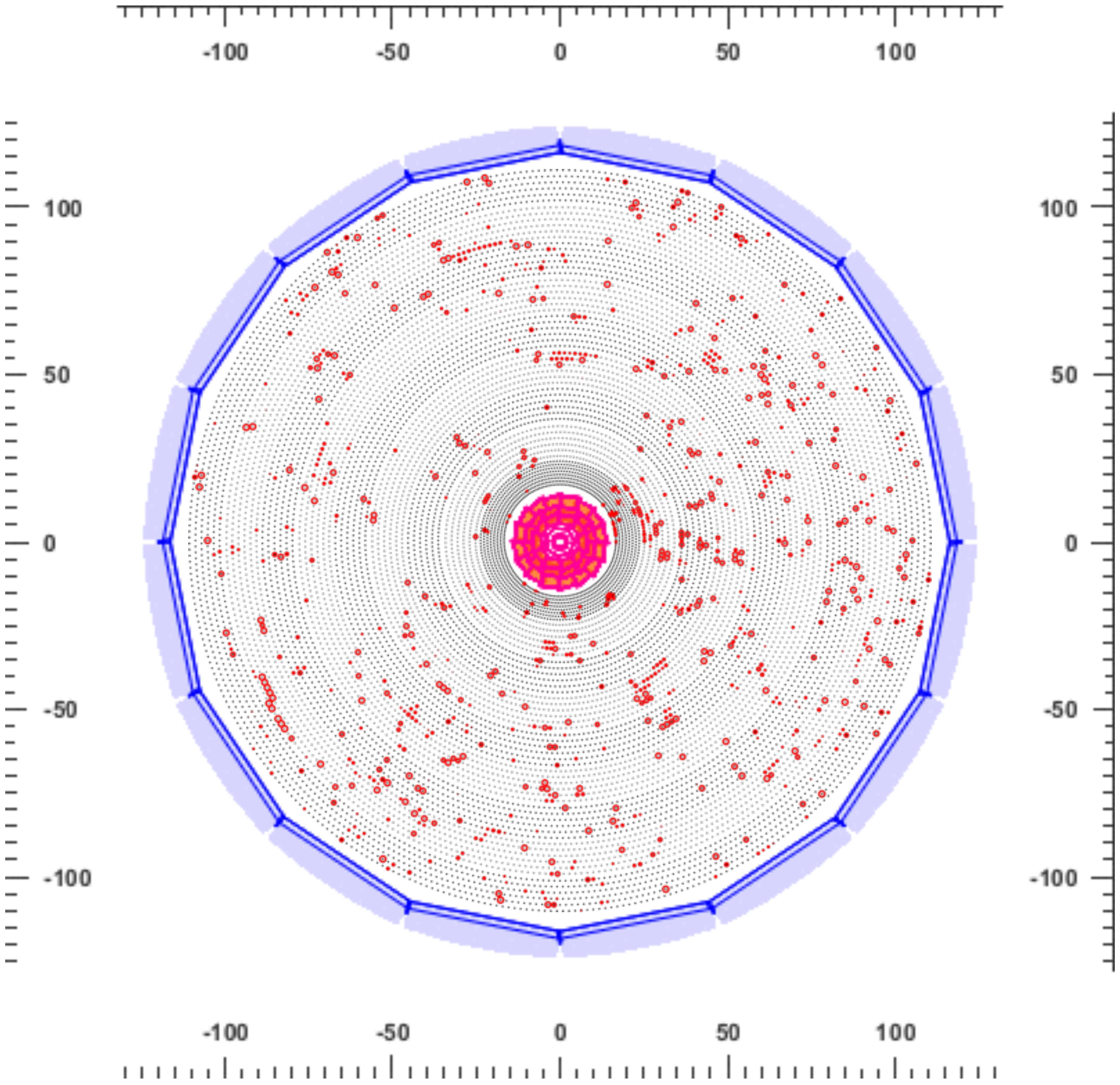


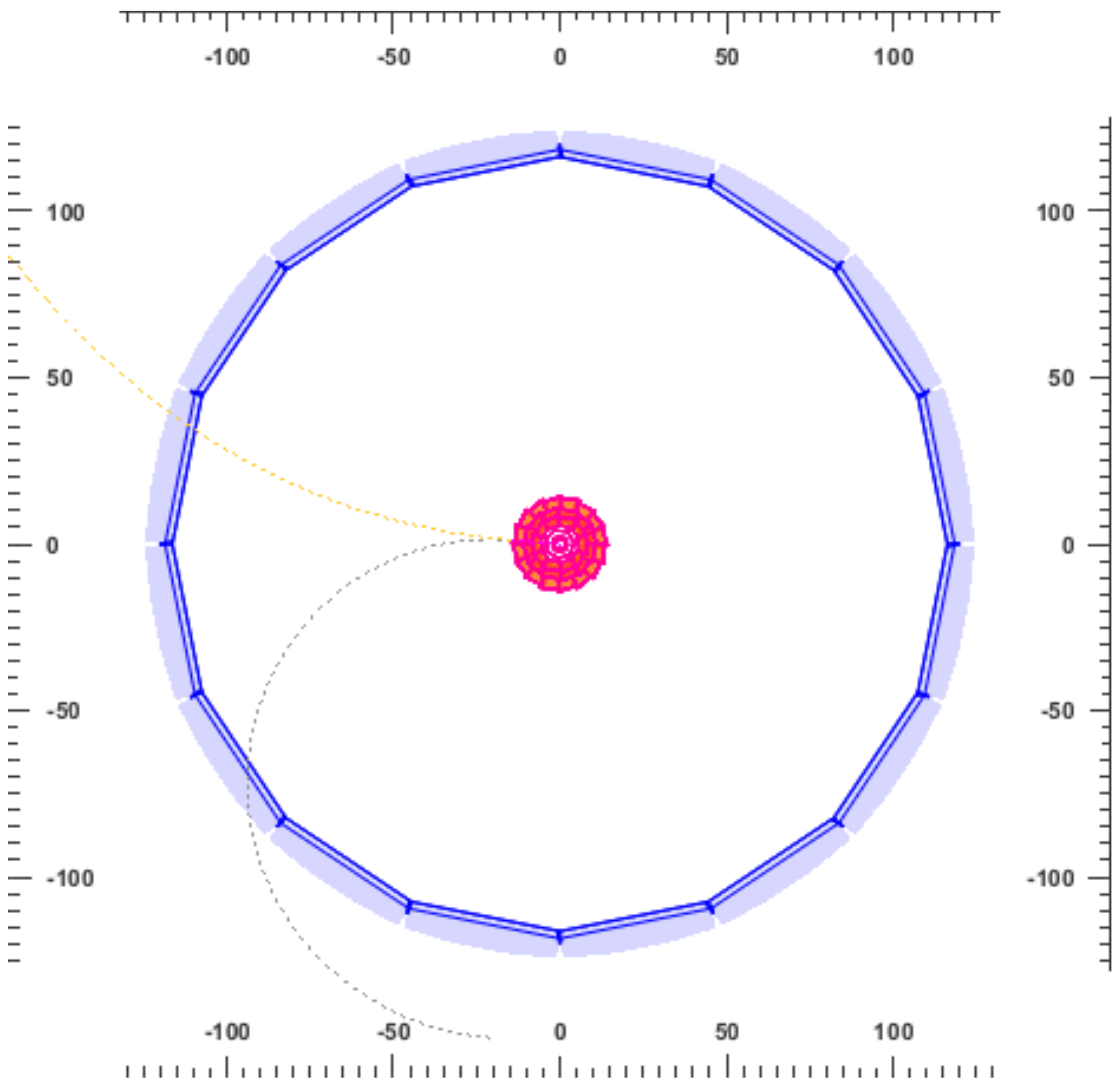
# Real life VS simulation: beam background

- Real life is not so easy
- We have to deal with high machine background
  - Random hits firing your detector that make the pattern recognition of real particles harder
- Not easy to simulate in a realistic way
- We use two different types of BG, a simulated one and random triggered events
- We also simulate higher background levels with respect to the "nominal" expected background (BGx1)
  - (BGx0,) BGx1, BGx2, BGx5



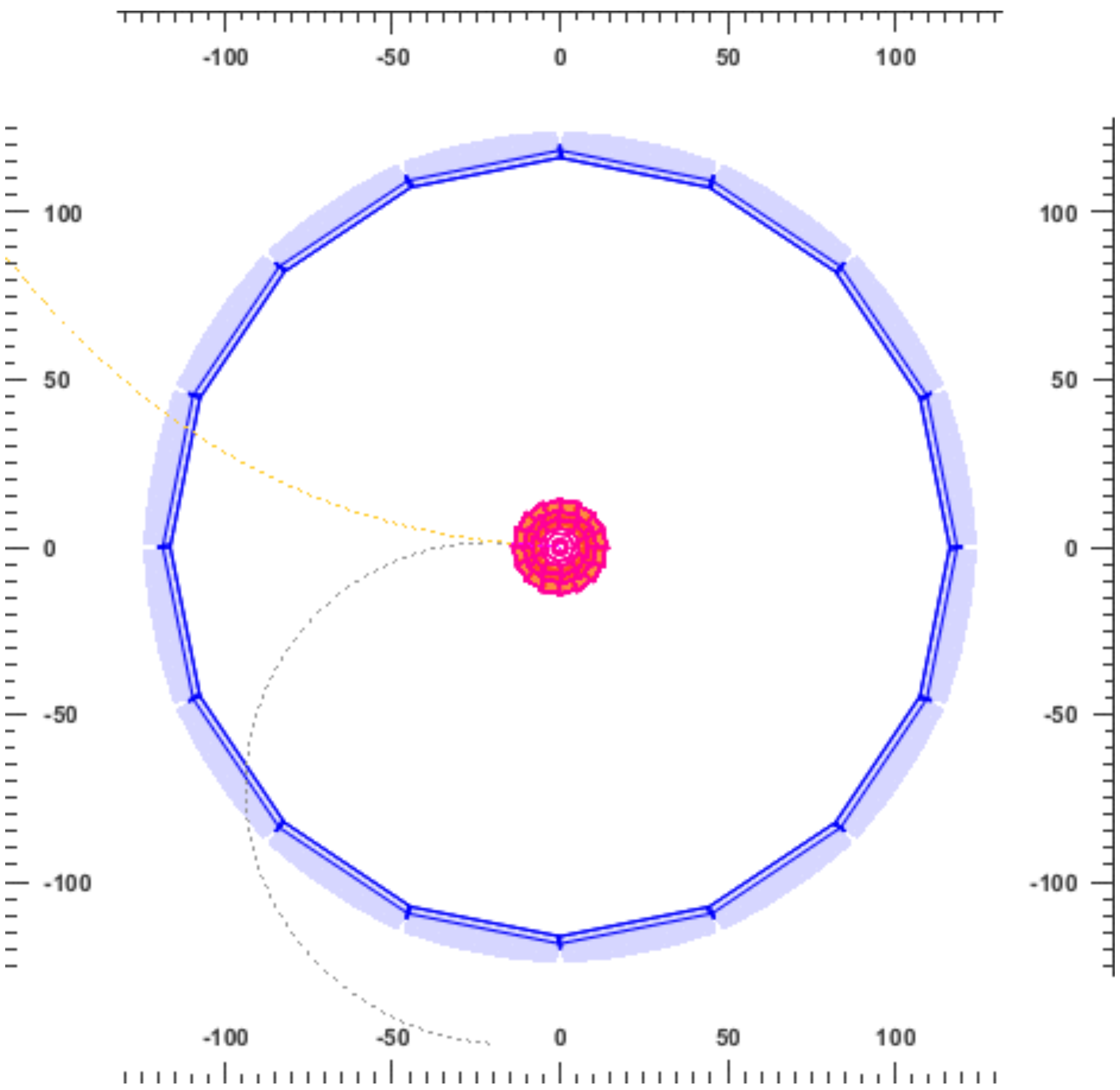
# Simple situation: particle gun

- Consider a very simple situation
  - 1 $\Lambda \to p\,\pi$ per event (generated with a particle gun)
  - Event display of Monte Carlo truth



# Simple situation: particle gun

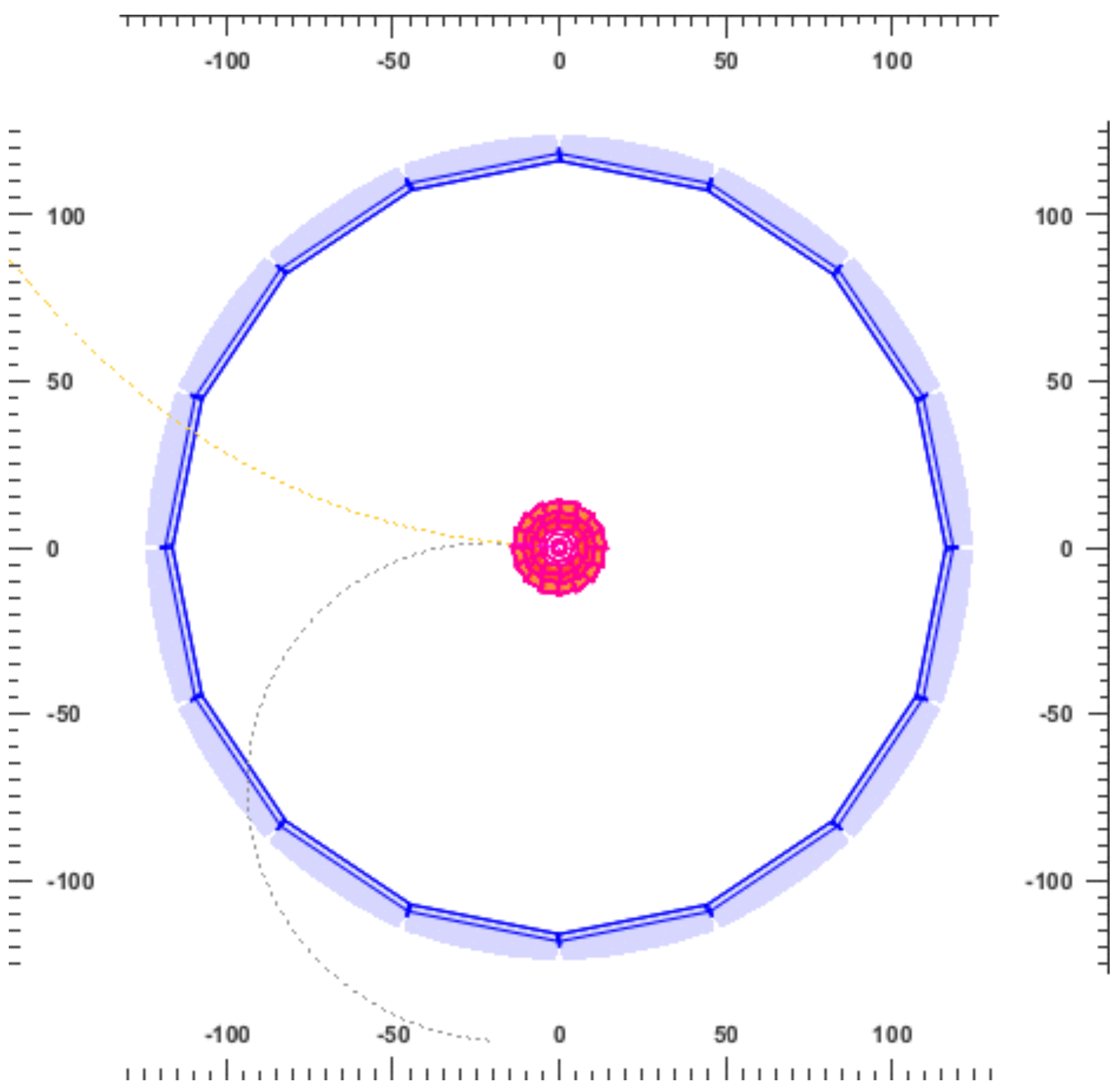
- Consider a very simple situation
  - 1 $\Lambda \to p\,\pi$ per event (generated with a particle gun)
  - Event display of Monte Carlo truth
- We take this same event and
  - Simulate the detector response including different levels of background (BGx0, BGx1, BGx2, BGx5)
  - Reconstruct the event
- Also, making use of the Monte Carlo truth, we compute the reconstruction efficiency (*) in such cases, as a function of the xy-distance of the vertex

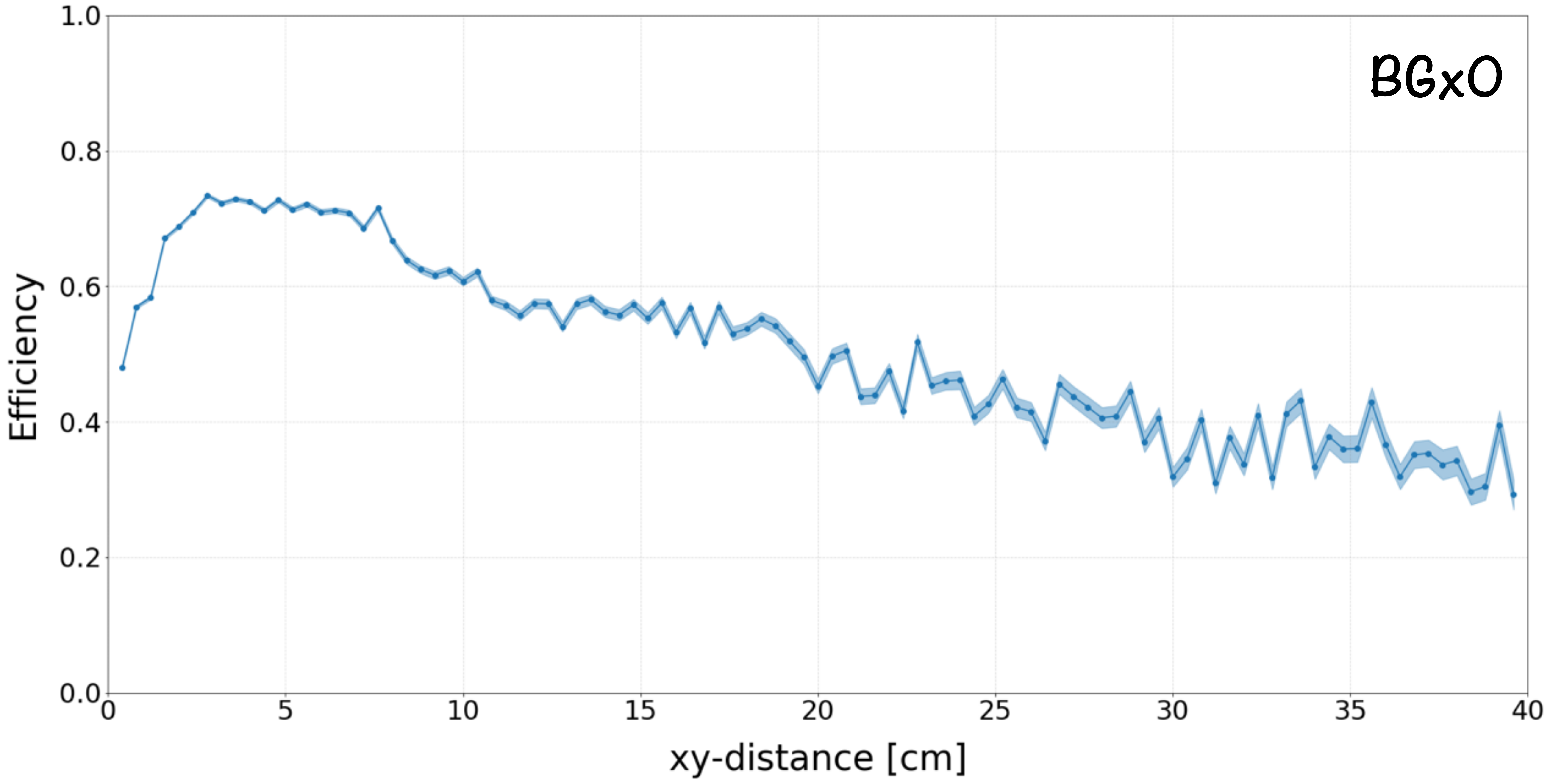



(*) # generated events = 20K

# Reconstruction efficiency for different background levels

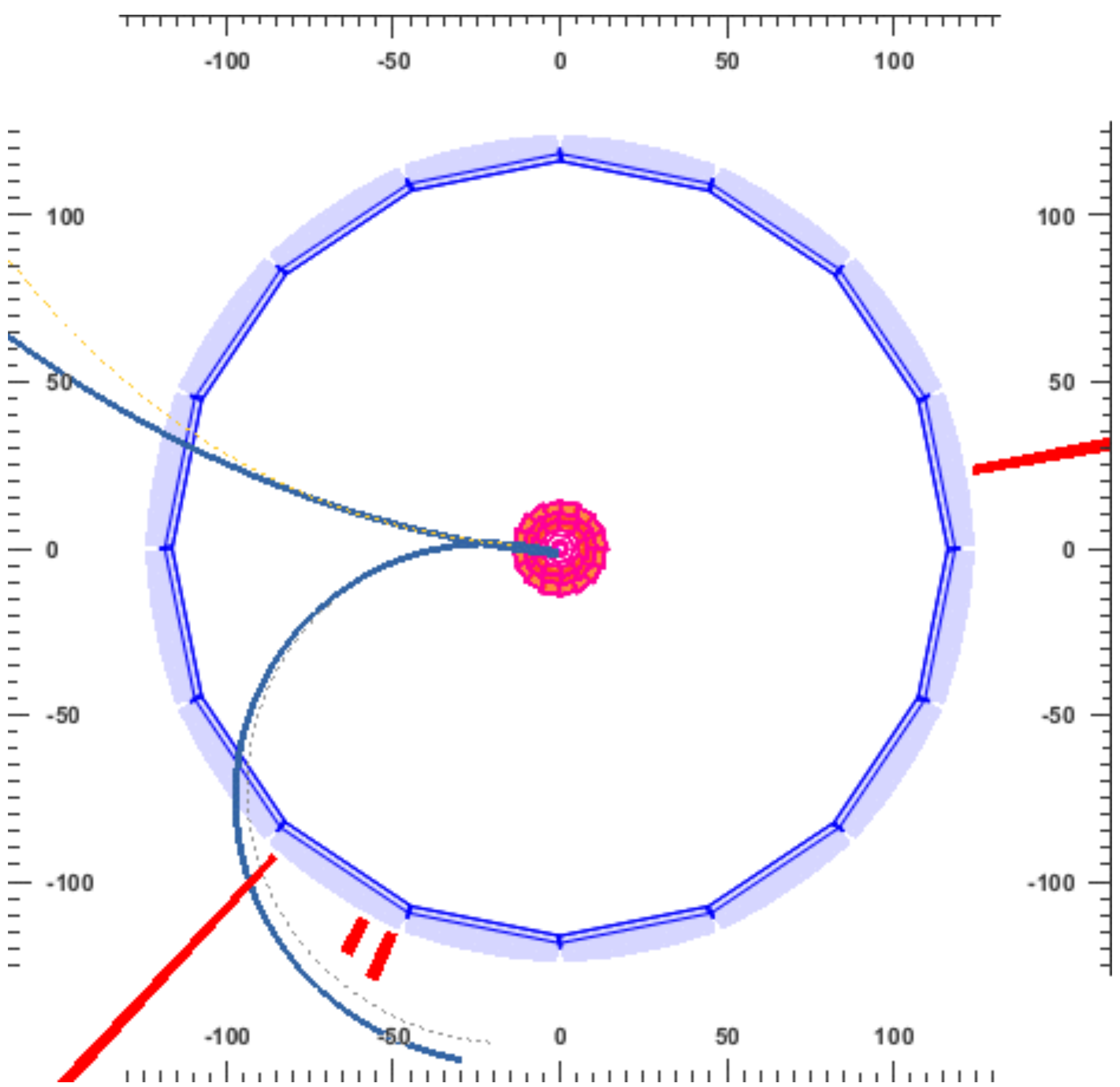
- Simulate the detector response and reconstruct the event in a background-free environment (BGx0)

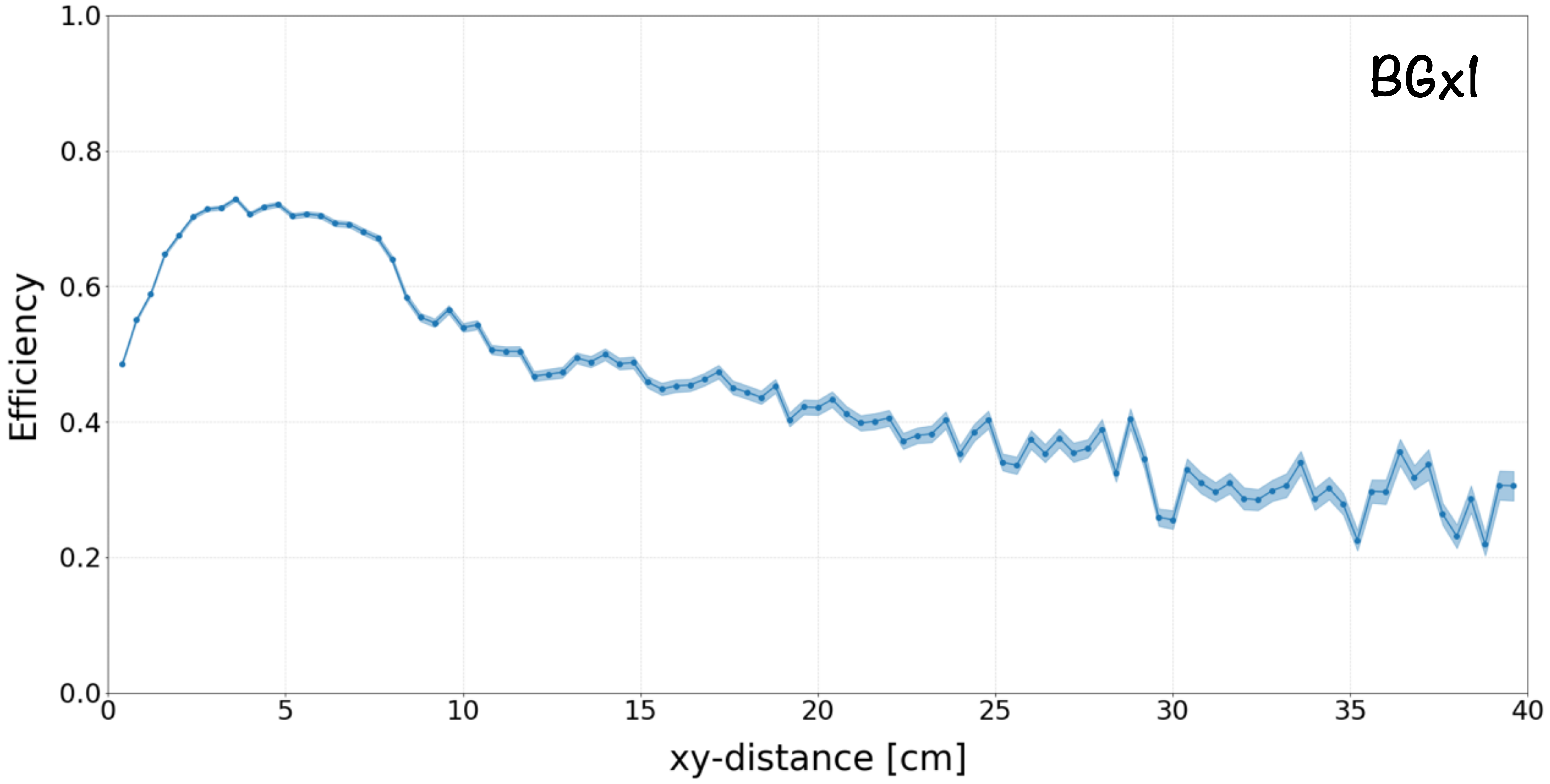


# Reconstruction efficiency for different background levels

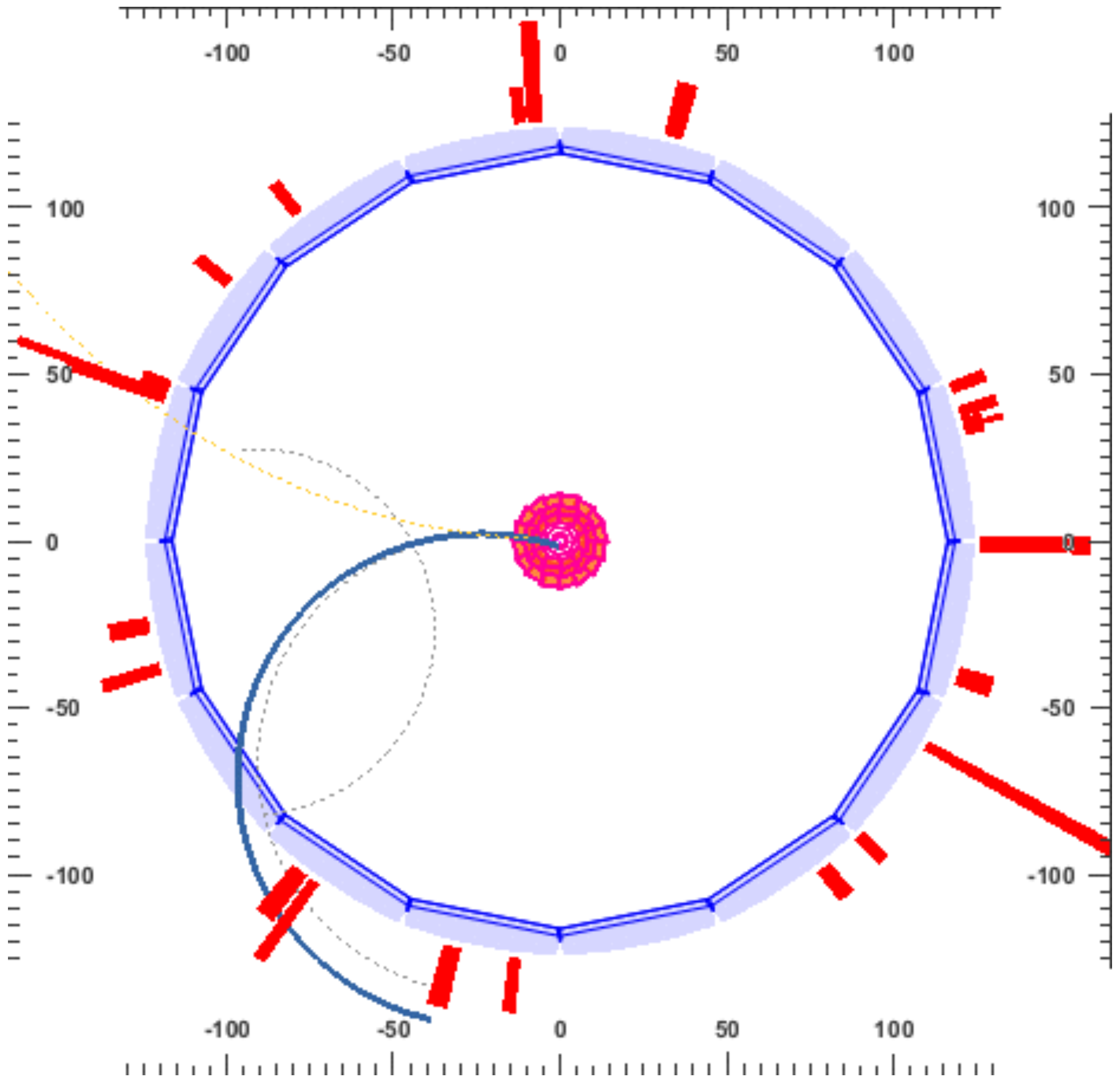
- Simulate the detector response and reconstruct the event with nominal background (BGx1)

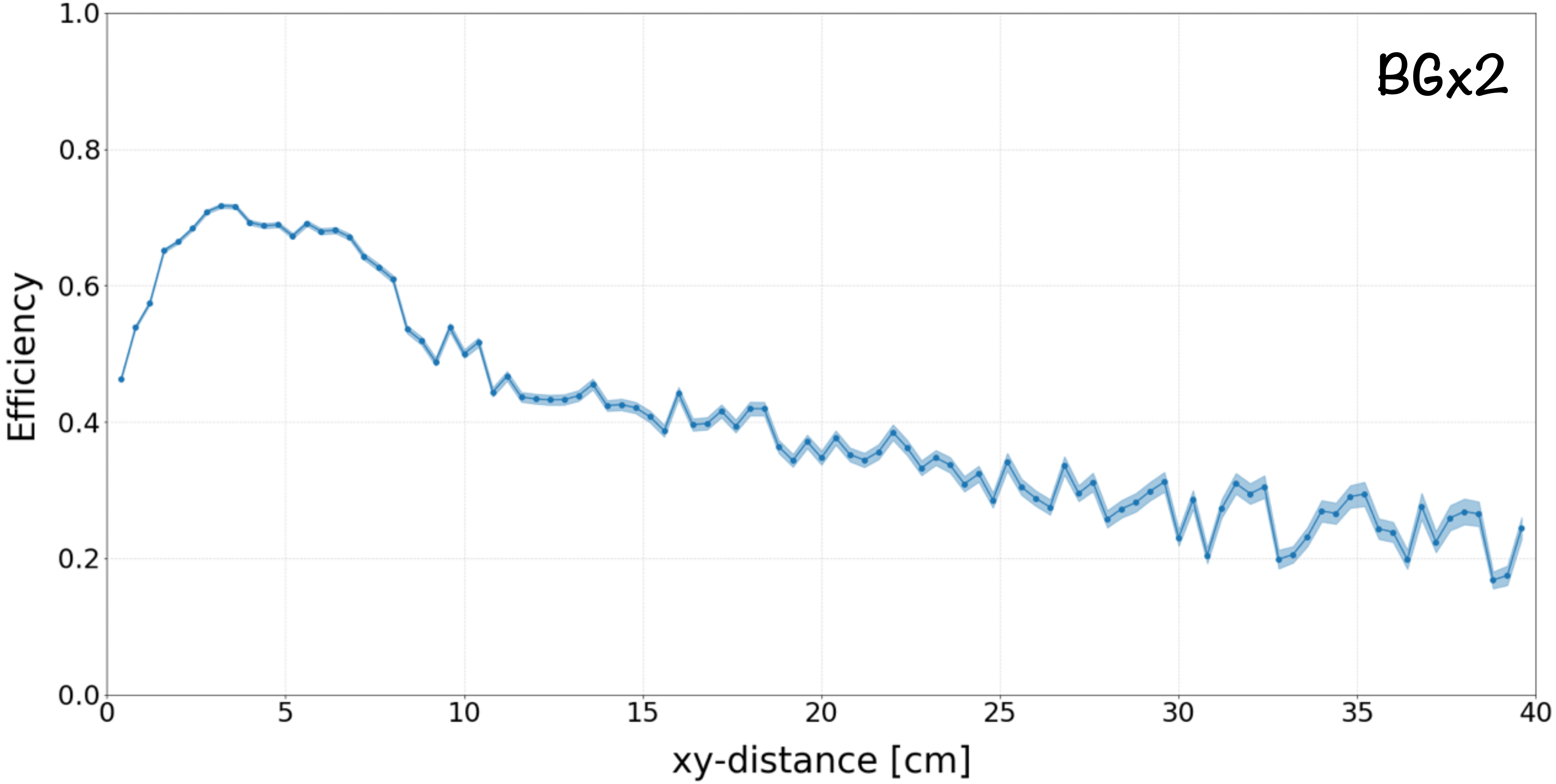


# Reconstruction efficiency for different background levels

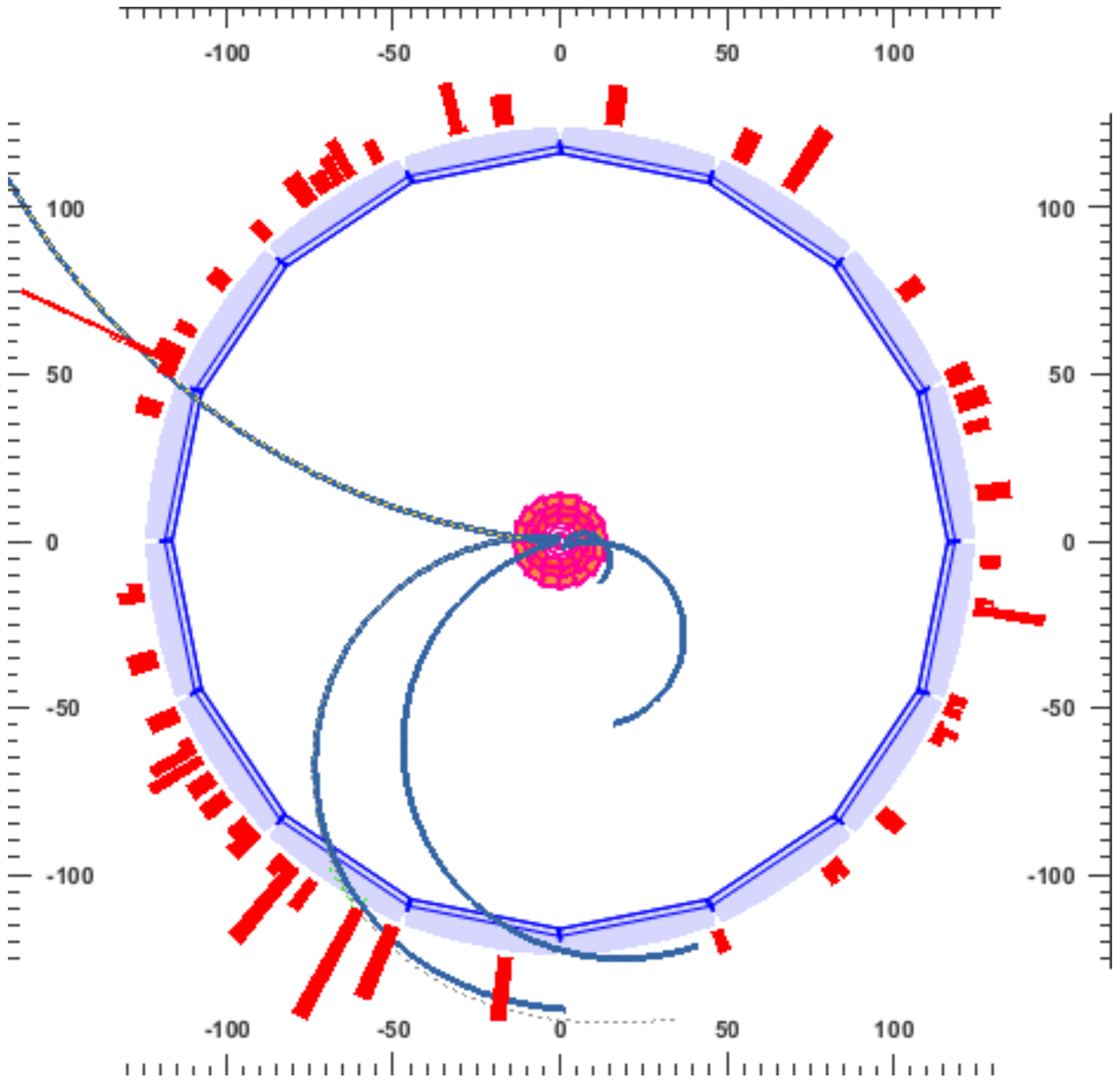
- Simulate the detector response and reconstruct the event with 2x nominal background (BGx2)

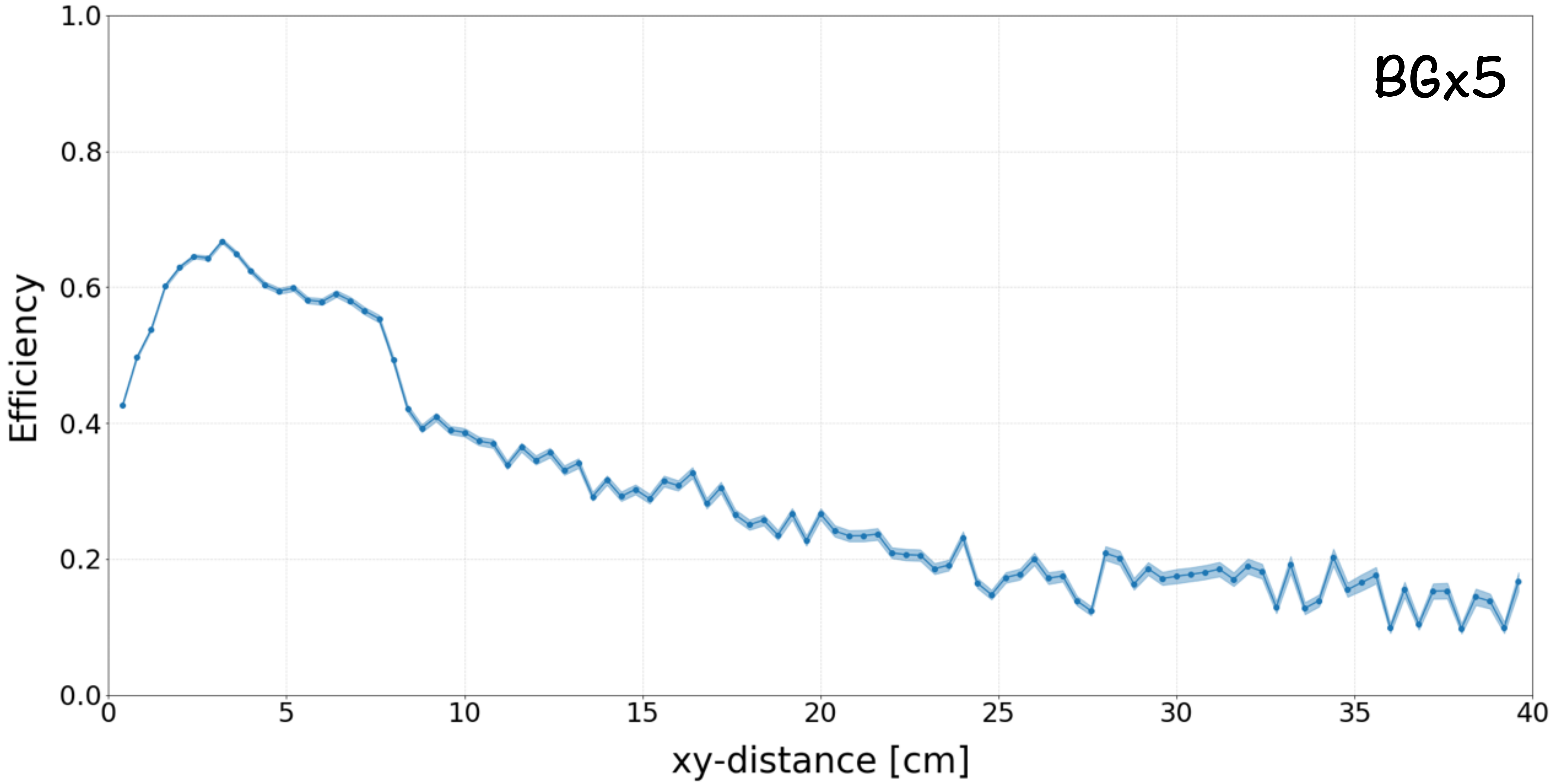


# Reconstruction efficiency for different background levels

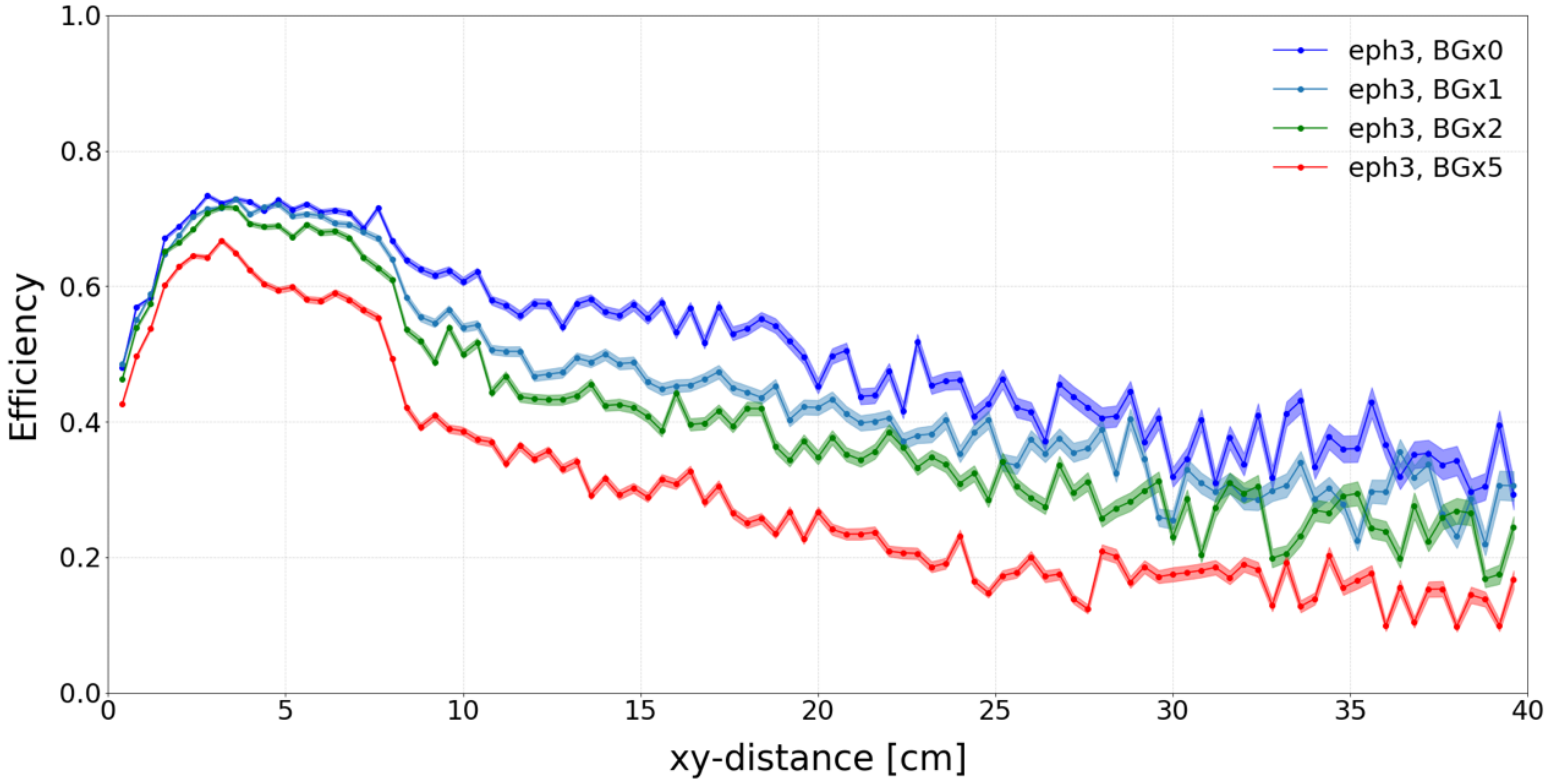
- Simulate the detector response and reconstruct the event with 5x nominal background (BGx5)



# Reconstruction efficiency for different background levels

- Drop in efficiency (vs xy-distance) as a function of BG level is more severe for Λ decaying far from the interaction point

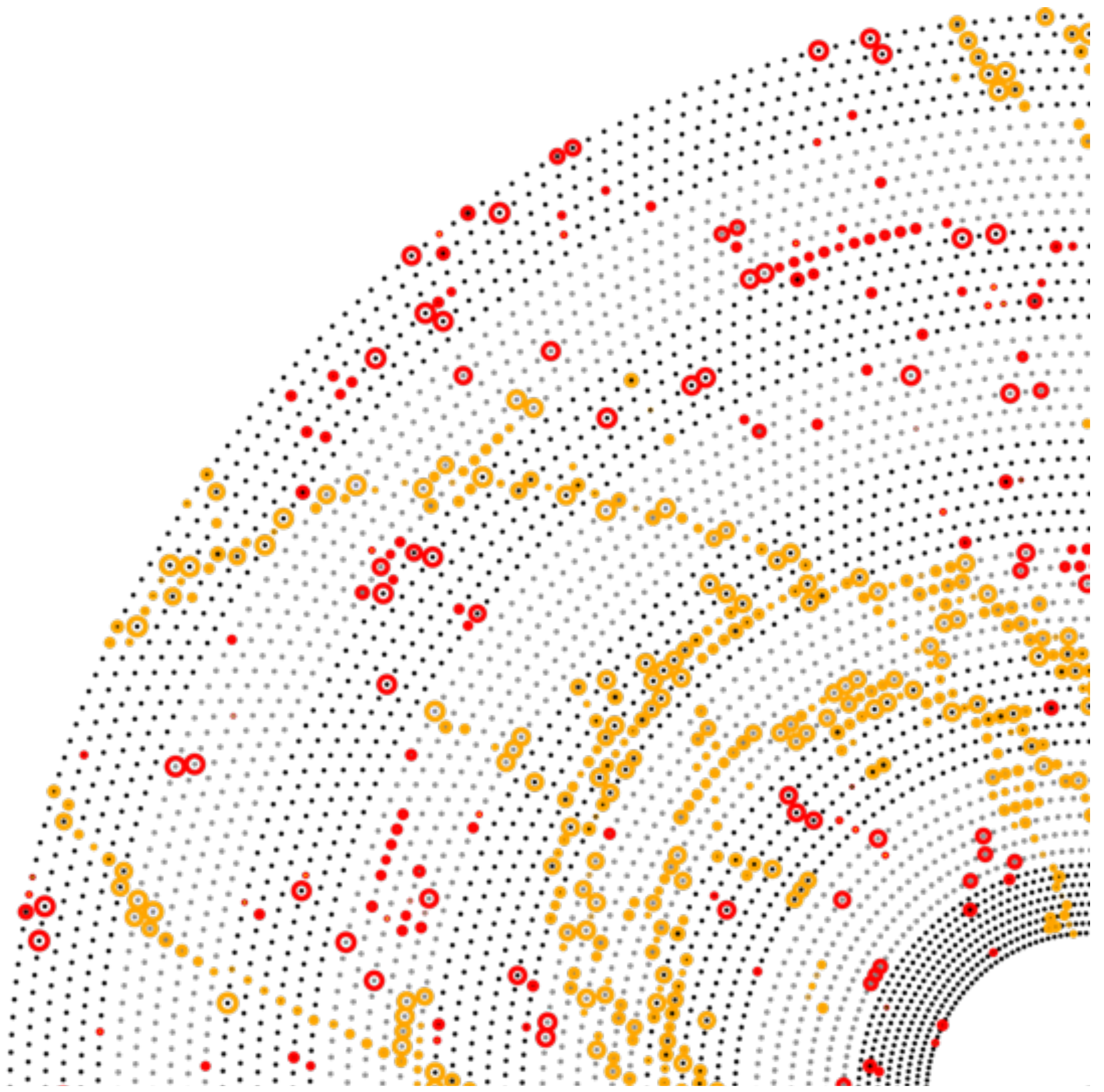


# Monitoring the background in data

- ***We need a way to monitor the background effects on data***
  - In simulation everything is easy to monitor, we know the Monte Carlo truth

- For this we rely on two observations:
  - Drop in efficiency (vs xy-distance) as a function of BG level is more severe for $\Lambda$ decaying far from the interaction point
  - Some event-based measured quantities depend on the background level

- Example: ***nExtraCDCSegments***
  - Number of *segments* reconstructed using CDC informations and not used in any of the tracks in the event
  - Very intuitively:
    - In a clean environment all segments would belong to a track
    - Increasing the number of backgrounds hits will increase the number of fake segments



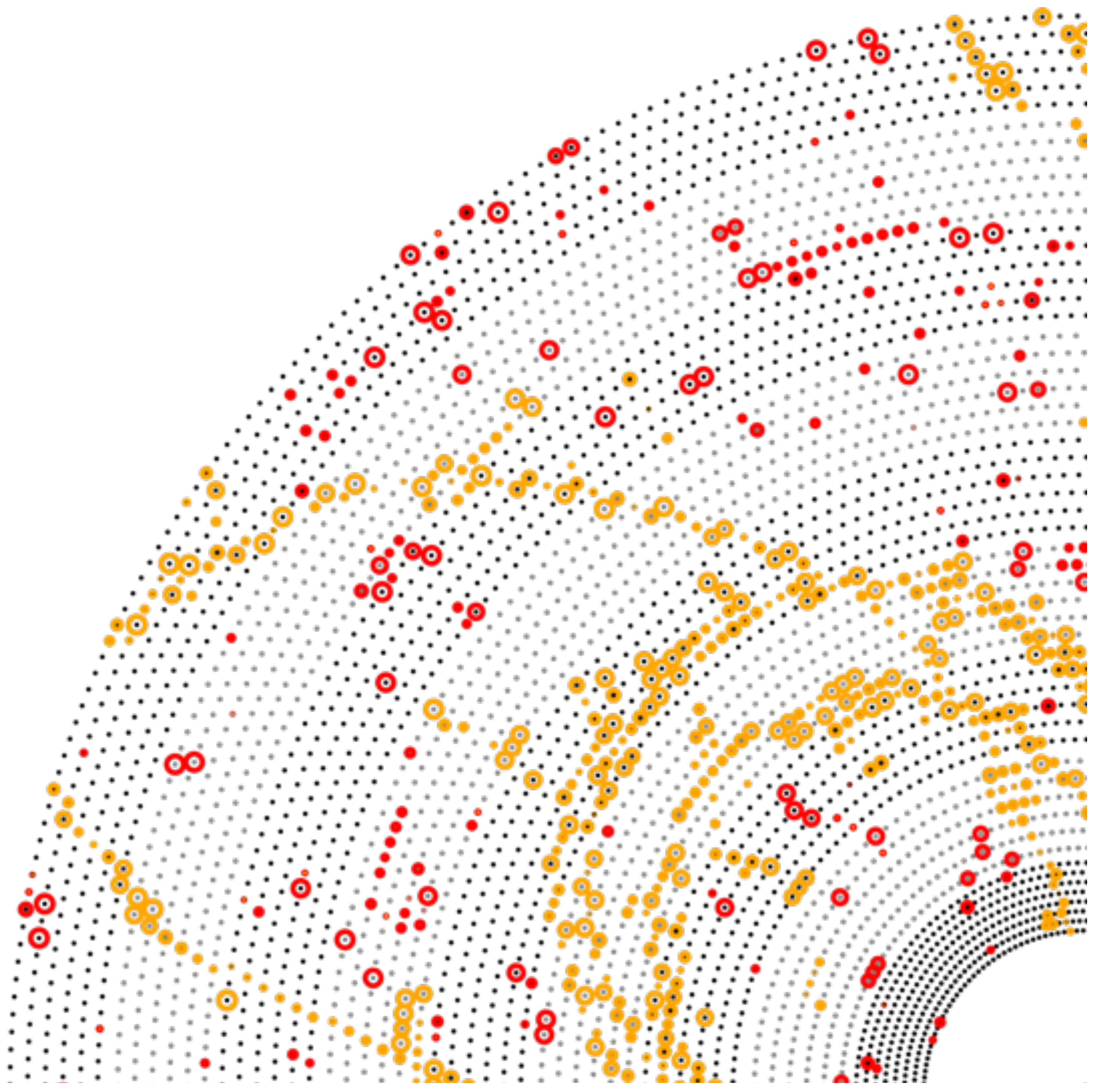
# Monitoring the background in data

- ***We need a way to monitor the background effects on data***

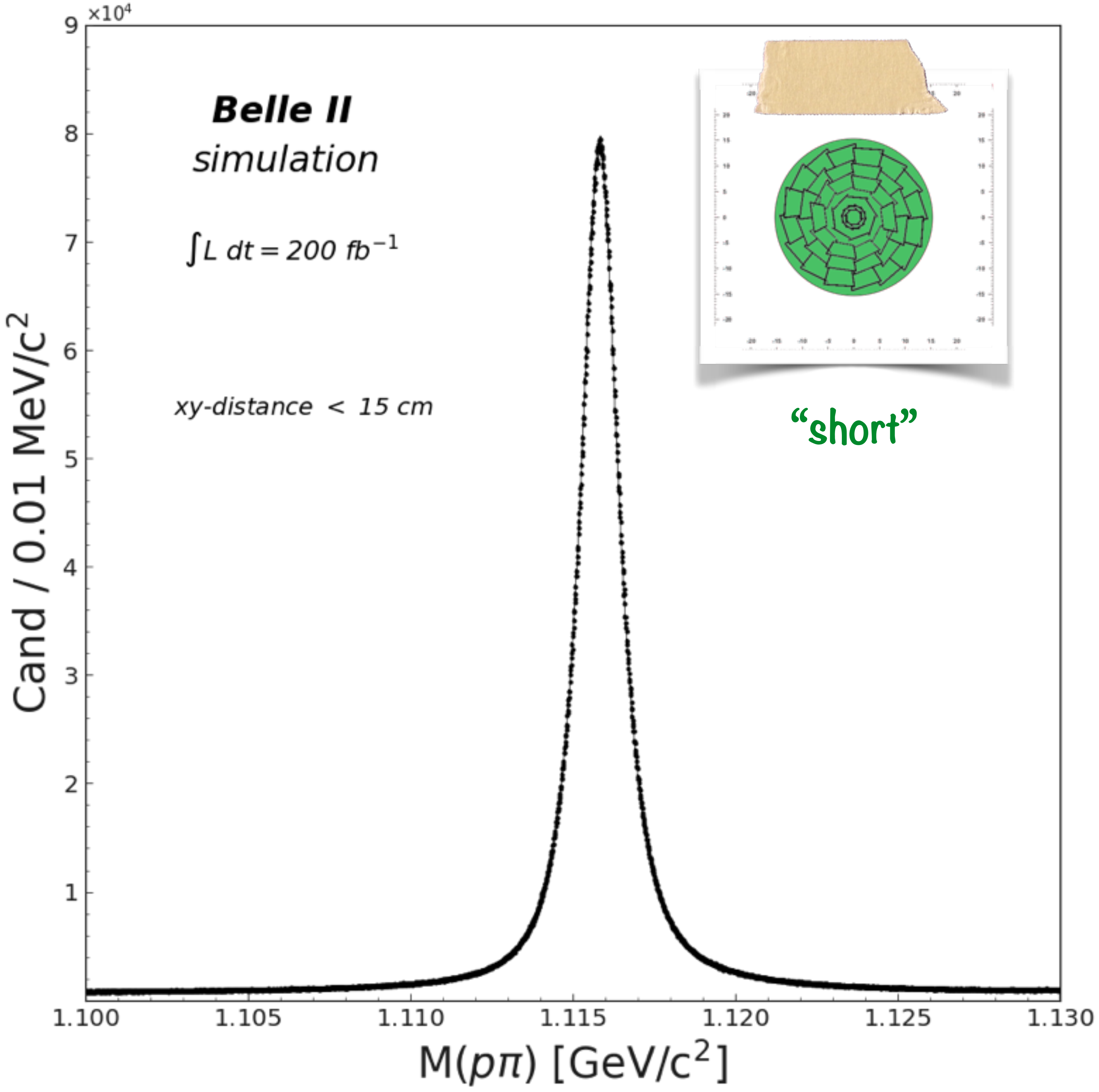
- Divide the Lambda sample in two categories, “short” and “long”
  - “short” Lambda: xy-distance < 15 cm
  - “long” Lambda: xy-distance ≥ 15 cm (decaying outside the SVD volume)

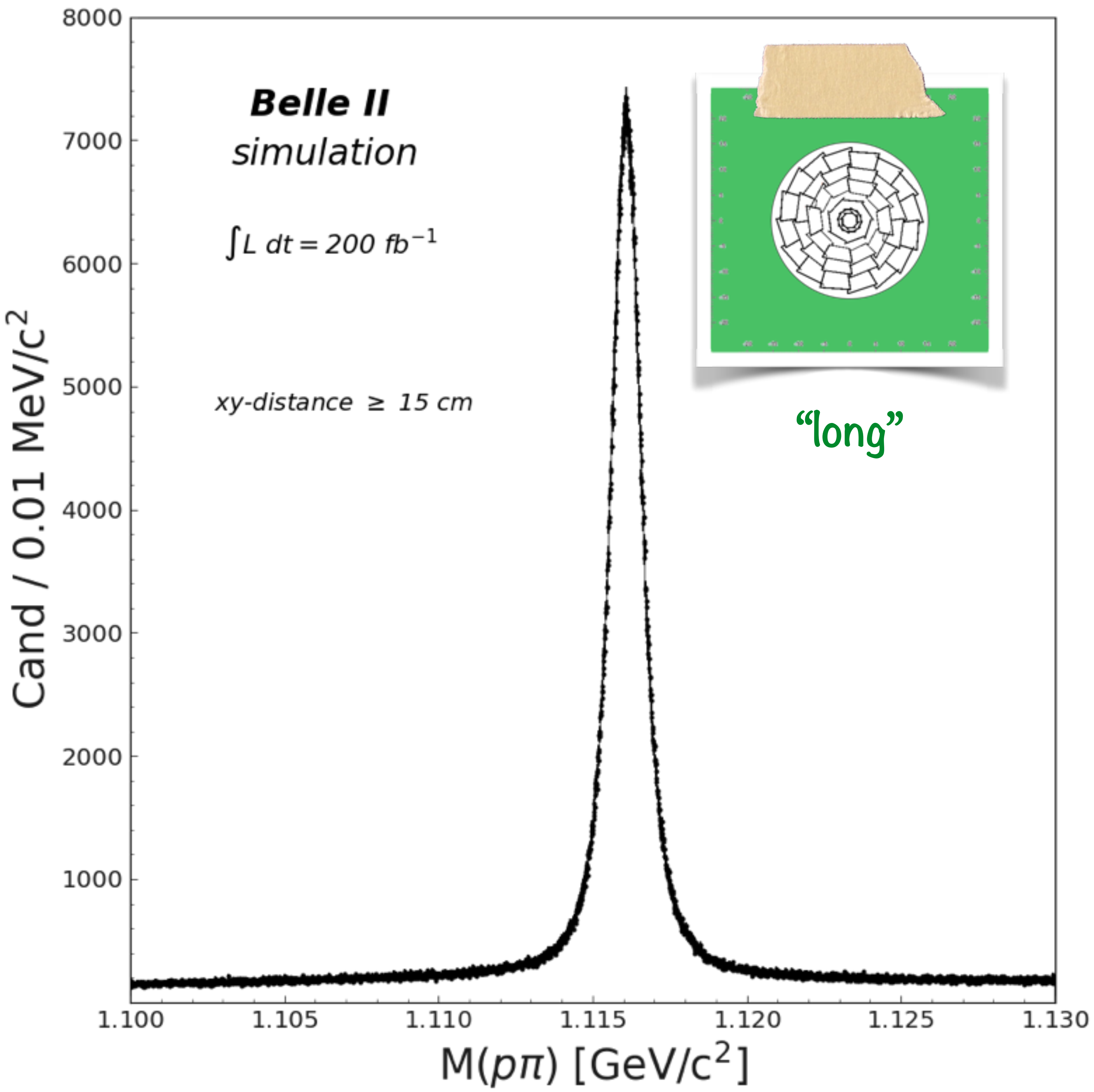
- Divide the considered background-dependent variable in bins

- For each bin count the number of long and short $\Lambda$ and plot the ratio between long and short

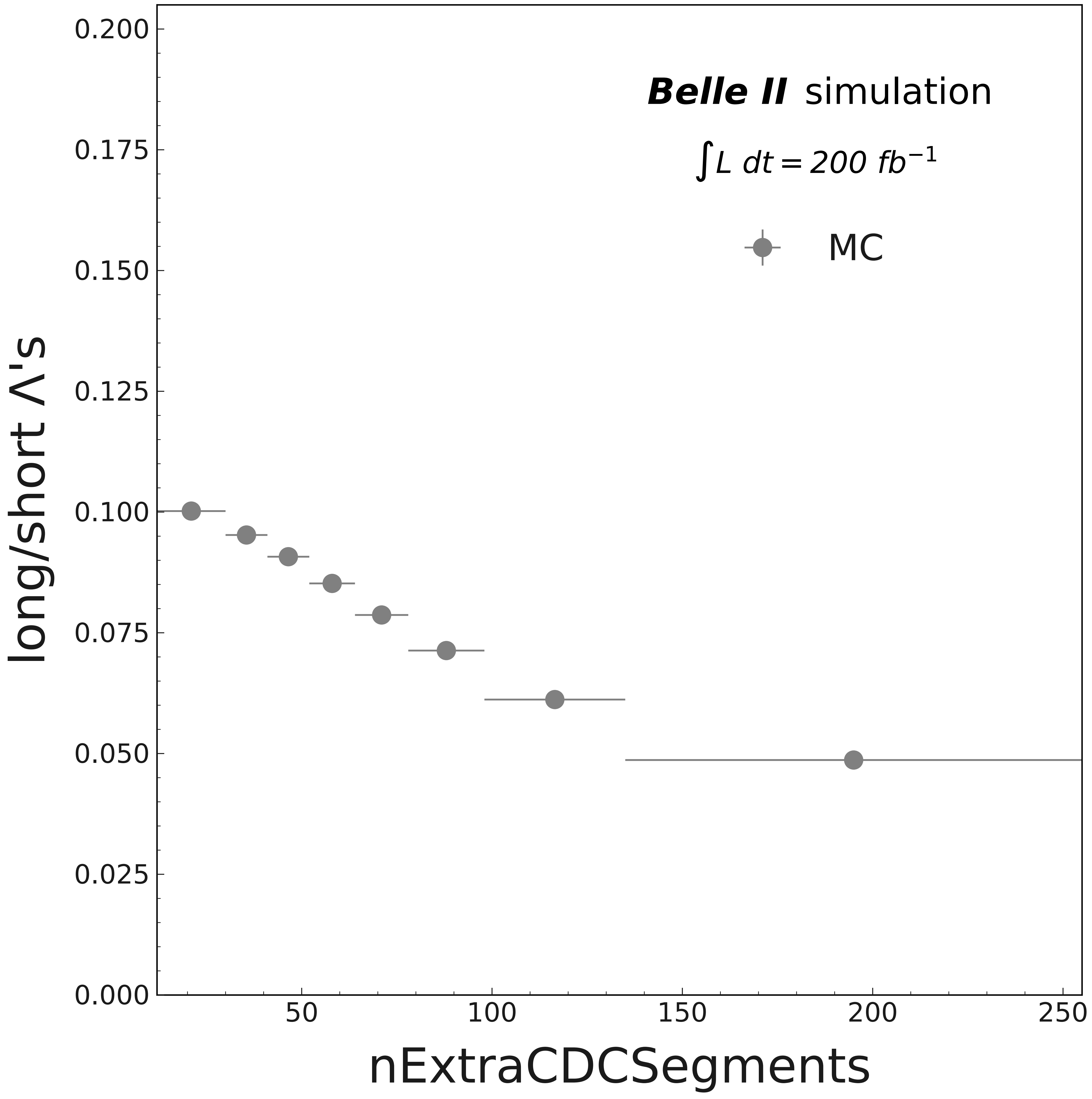


# Short and long Λs



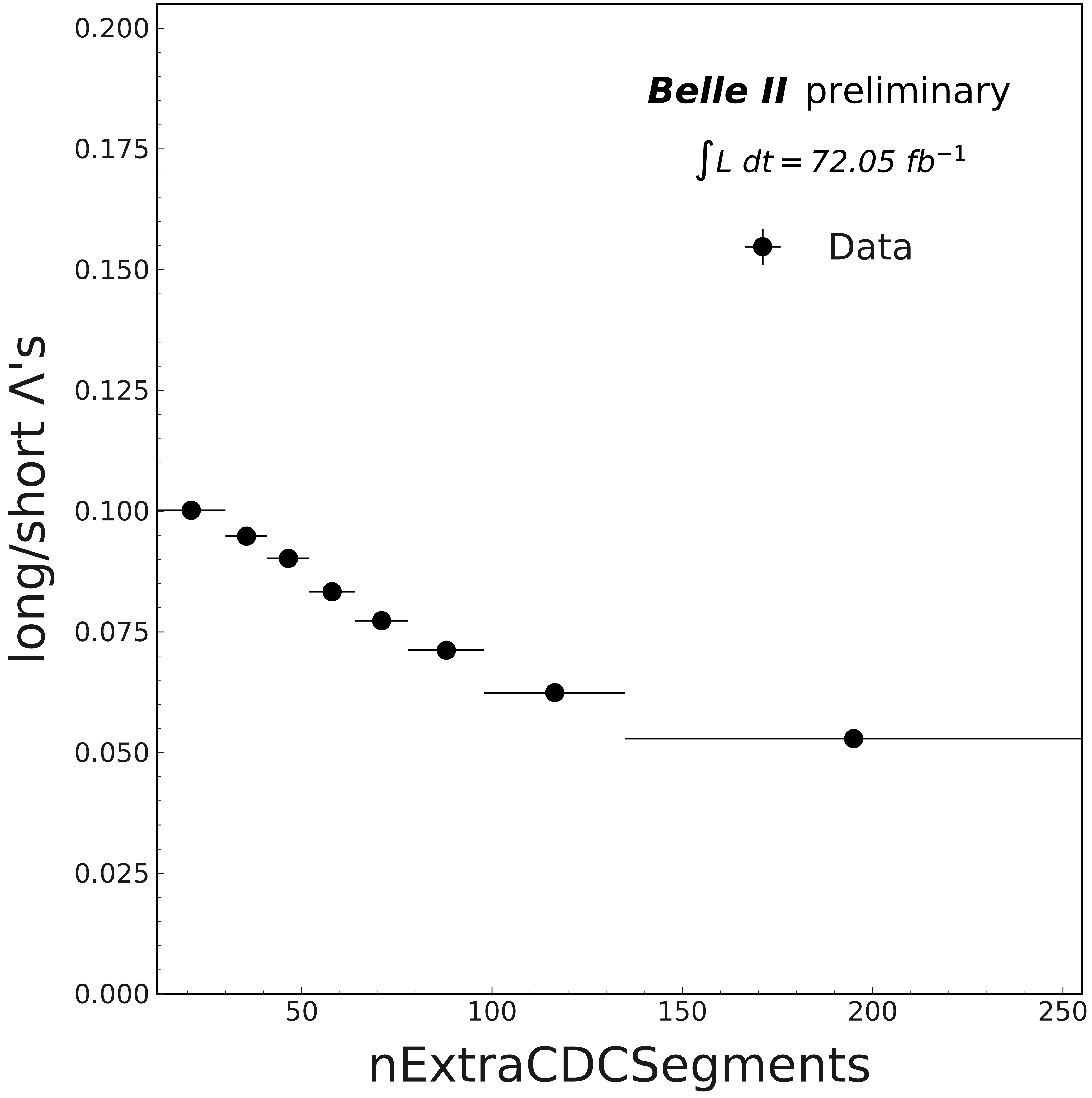



# Long/short ratio VS nExtraCDCSegments




- long/short VS nExtraCDCSegments in simulation
- We see a clear dependence of the long/short ratio on the nExtraCDCSegments
- The study is ongoing, we are double checking the results with different samples
  - $K_S$ from B decays
  - Exclusive Λ sample (from $\Lambda_c^+$ decay)

# Long/short ratio VS nExtraCDCSegments

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- The study is ongoing, we are double checking the results with different samples
  - $K_S$ from B decays
  - Exclusive Λ sample (from $\Lambda_c^+$ decay)
- Data and simulation are in fair agreement

# Summary

- The Belle II experiment is optimized for B physics
- (SM) long-lived particles not originally considered priority
  - Nevertheless the interest is alive and we do have dedicated tools

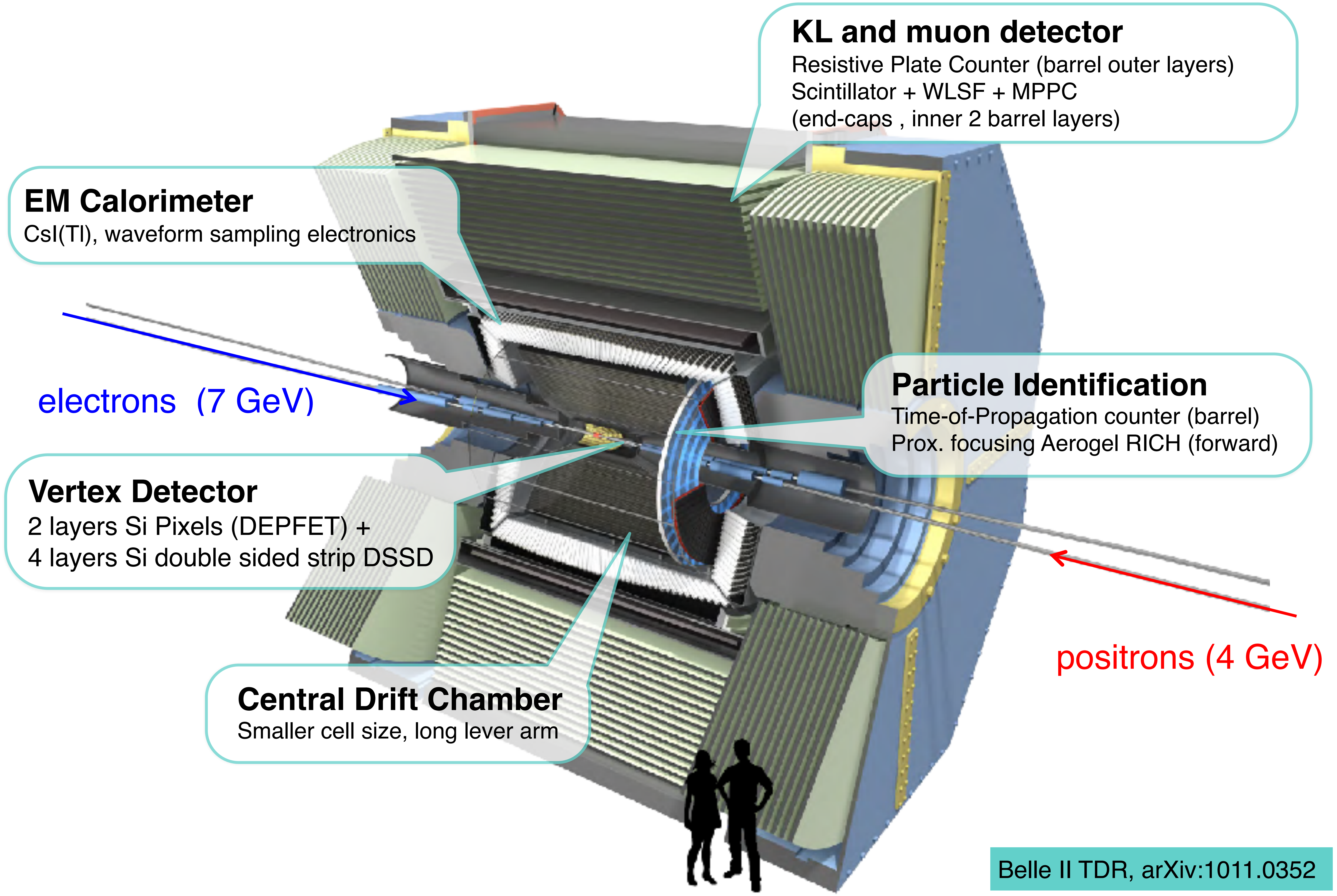
- For LLP, high background level is a problem
  - Clear degradation of the performance as a function of the xy-distance of the vertex from the interaction point

- We are developing a way to monitor the background impact directly on LLP using data (without relying on the Monte Carlo truth)
  - The study is ongoing, data and Monte Carlo show fair agreement

- Last thing worth mentioning (not part of this talk):
  - There are ideas and possibilities to improve the tracking algorithms specifically for LLP

# Backup slides

# Belle II detector




Belle II TDR, arXiv:1011.0352