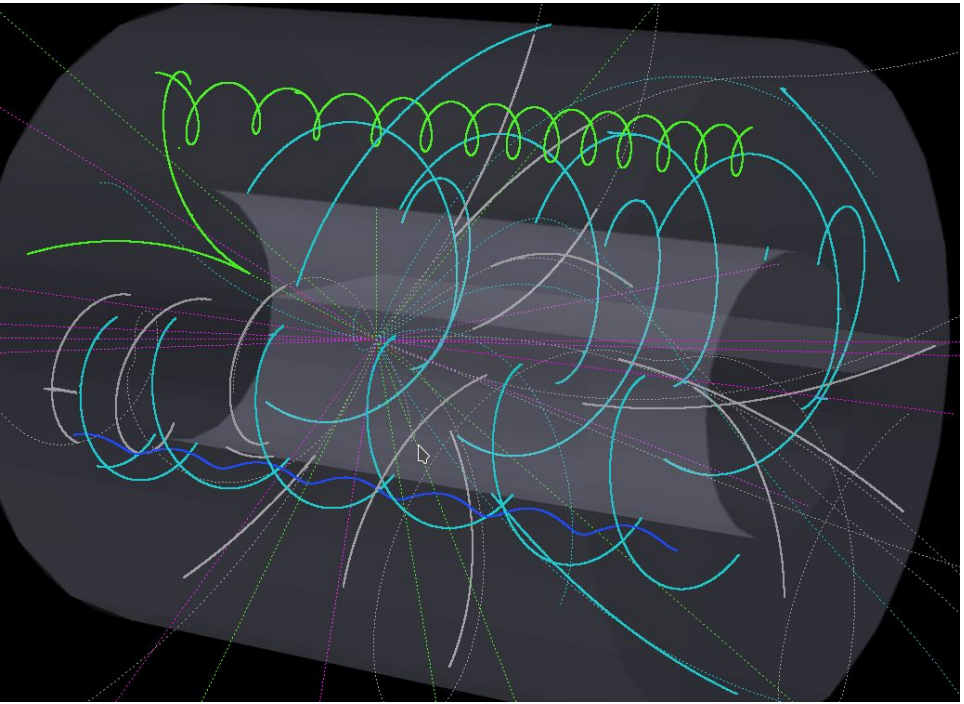


A tracking TPC for a future Belle II upgrade

Snowmass IF5 meeting

Peter M. Lewis

22 July 2022

UNIVERSITÄT BONN

Belle II

Resources

Bonn Master's thesis from Andreas Loeschcke Centeno
[https://docs.belle2.org/record/2631/files/BELLE2-MTHESIS-2021-073.pdf]

This whitepaper
[arXiv:2203.07287]

Belle II upgrade whitepaper
[https://arxiv.org/abs/2203.11349]

Timing layer
[https://arxiv.org/abs/2203.04847]

A TPC-based tracking system for a future Belle II upgrade

Andreas Löschcke Centeno[1], Christian Wessel[1], Peter M. Lewis *[1], Oskar Hartbrich[2], Jochen Kaminski[1], Carlos Mariñas[3], and Sven Vahsen[2]

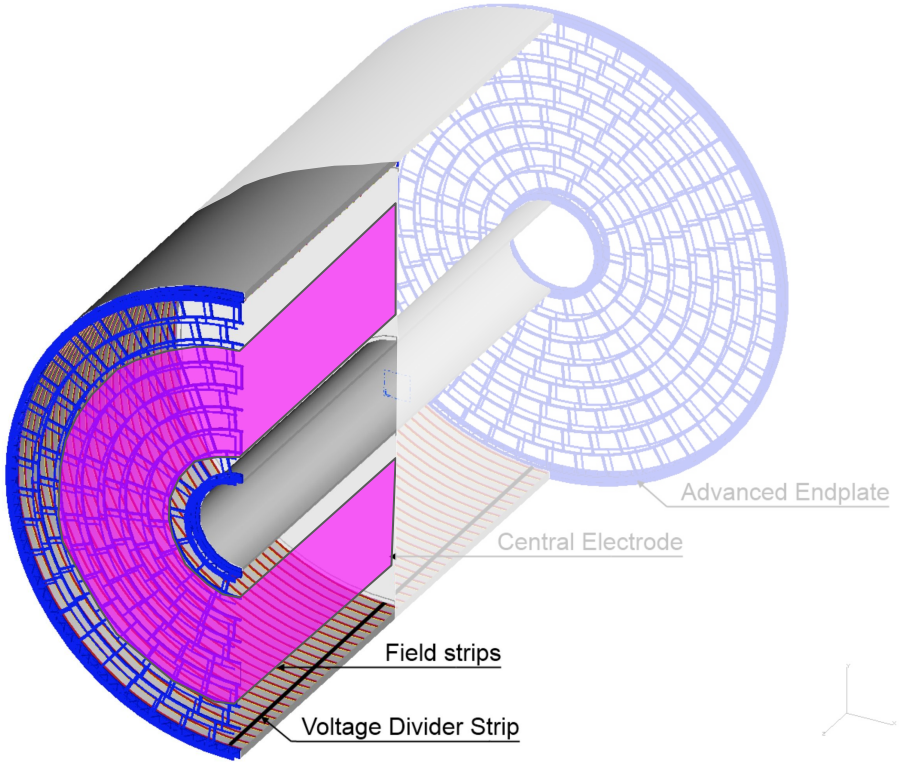
[1] *University of Bonn, Institute of Physics, Nußallee 12, 53115 Bonn, Germany*
[2] *University of Hawaii, Department of Physics and Astronomy, 2505 Correa Rd., Honolulu, HI 96822, USA*
[3] *University of Valencia - CSIC, Instituto de Fisica Corpuscular (IFIC), Spain*

March 15, 2022

Overview

A proof-of-concept project

- Can a **tracking TPC** work for Belle in a hypothetical **ultra-high luminosity** upgrade scenario? (2032+)
  - (drift chambers *cannot*)
- **Fine 3D segmentation** in principle is far more tolerant of high rates/high backgrounds

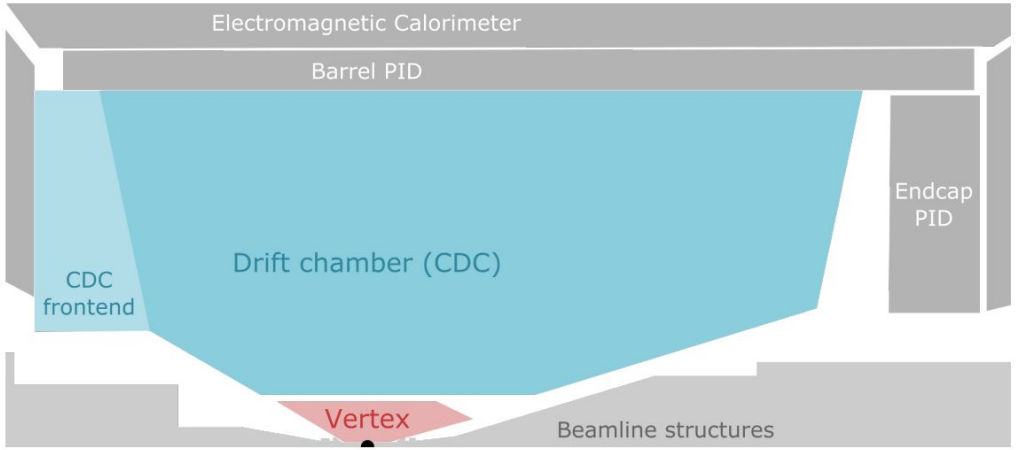


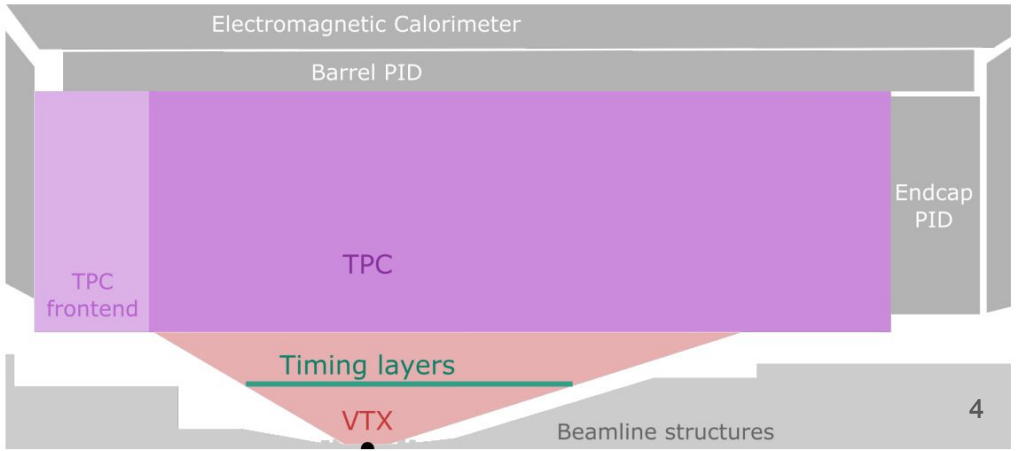
This project: demonstrate **proof-of-concept** for a tracking TPC in Belle II. Use **LCTPC** as a starting point with **Belle II** simulation.

Basic concept

Geometry constrained by Belle II layout (*top*)

- Abandon the inner volume to **silicon pixels (VTX)**
- Fill remaining volume with **single drift volume** and read out on BWD end
- Use T2K gas mixture Ar:CF_4 :iC_4H_{10} (95:3:2) at atmospheric pressure
- Readout via **GridPix**:
  - Silicon pixels with integrated MICROMEGAS
  - 55x55 µm pixels

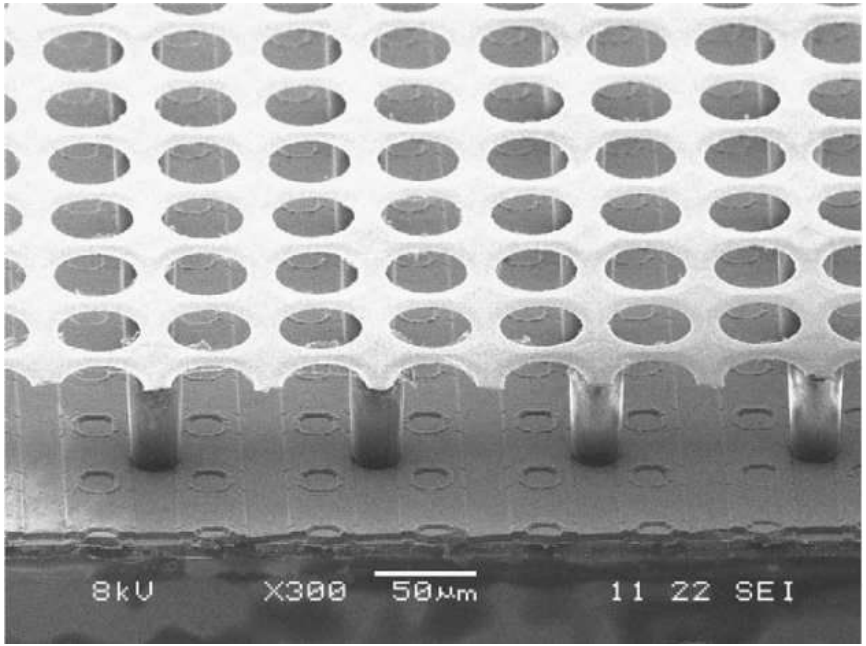




Why GridPix?

A number of attractive features for us

- 1:1 mapping of electrons:pixels → optimal resolution
- Intrinsically low ion backflow
- Could be used in **binary readout** → reduction of data throughput
- In-house expertise at Bonn
- It is real, so we can confidently simulate it



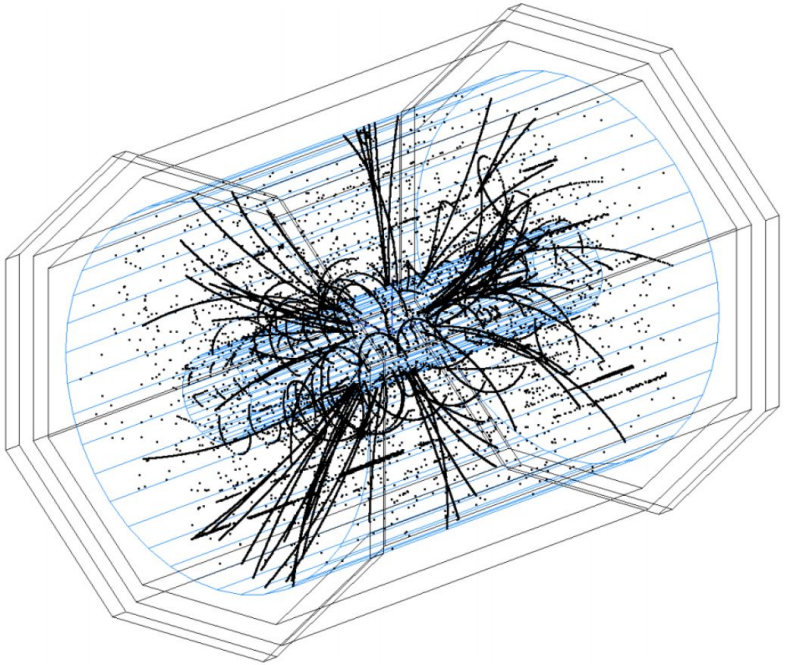
Ultimately, we would require a purpose-designed sensor, but we use GridPix for the proof-of-principle

Primary technical concerns

"This won't work at Belle because…"

- TPC can't provide a **trigger**
- Slow v_{drift} → large event/background **pileup**
- High event rates → no gating → bad **ion backflow** → decreased resolution
- Long drift length → high **diffusion** → decreased resolution
- No **dE/dx** for low-p_T tracks
- …

Today: address these one-by-one with simulation

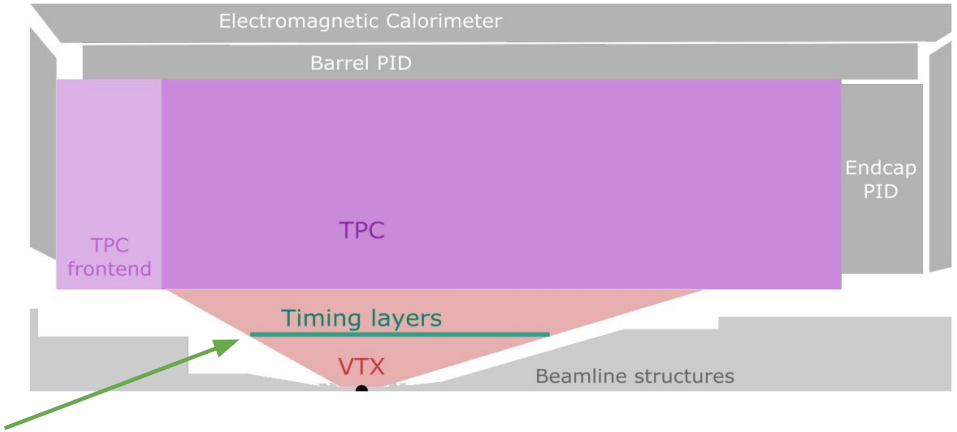


A **single** simulated LCTPC event with beam backgrounds

Concern 1: trigger

Solution: fast timing layers

- Fast silicon (assume **50 ps** resolution)
- At low radius (25 or 45 cm)
- Multilayer coincidence triggering (assuming 10 cm^2 coincidence regions)
- Based on U Hawaii technology development (arXiv: 2203.04847)
- Results currently based on toy simulation including beam-induced backgrounds at Belle II

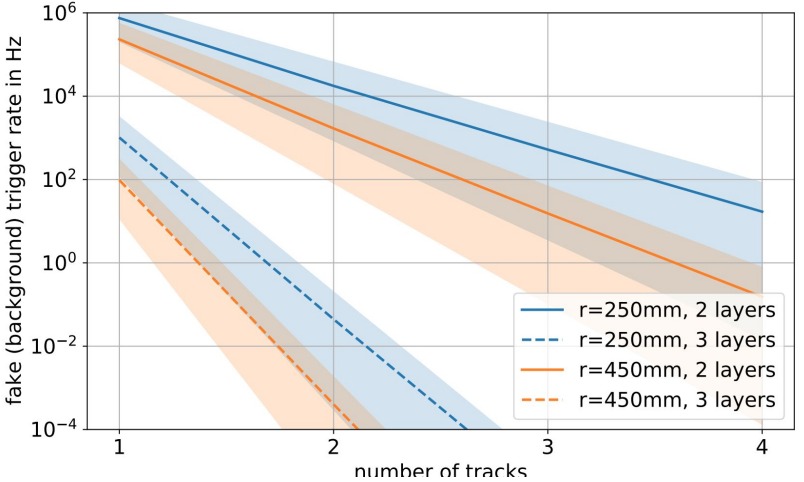


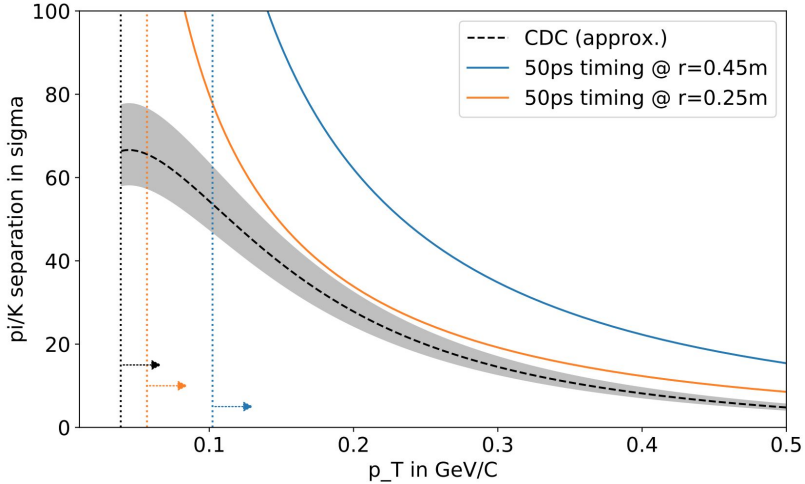
Concern 1: trigger

Timing layer findings

- Can replace trigger role of drift chamber with **tolerable fake trigger rate** (*top*)
- Major added bonus: PID via **time-of-flight**
  - *More than* replaces missing dE/dx info
  - Pion/kaon separation excellent for low-p tracks…
  - …could significantly improve efficiency of slow pion reconstruction in D* decays

Conclusion: existing technology can solve triggering issue of TPC, *and* missing dE/dx issue, with significant physics performance benefits



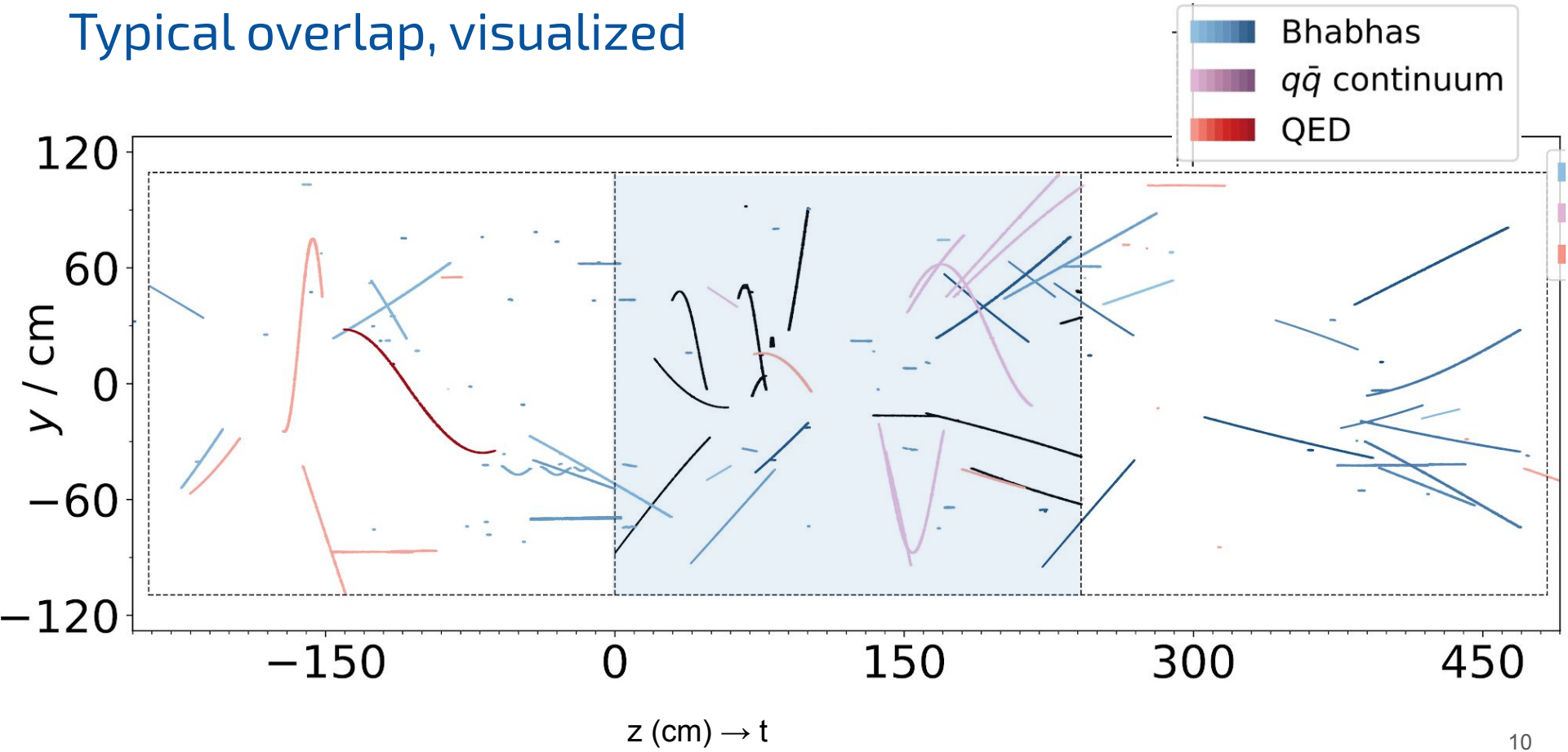


Concern 2: Pileup

First: event pileup

- High event rates + slow drift time → overlapping events
- **Untriggered** events like Bhabhas will still overlap physics and be read out
- With *continuous readout* and an *external trigger*, one "event" is like a **snapshot** of a continuous reel of tracks…

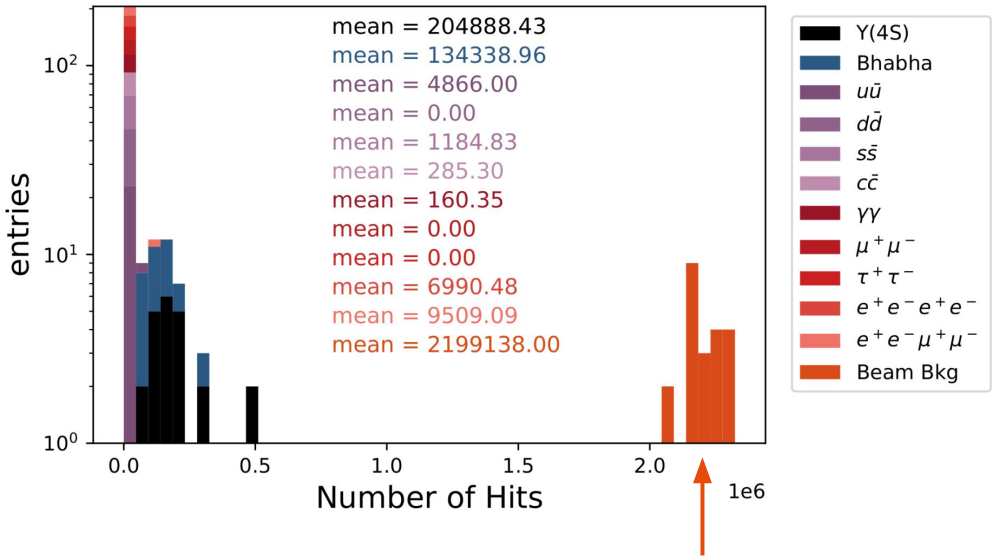
Typical overlap, visualized



Concern 2: Pileup

First: event pileup **findings**

- The mean number of background physics tracks per triggered event is **9** (compared to ~11 for Υ(4S) decays)
- These are overwhelmingly **Bhabha** tracks
- Overlapped Υ(4S) events are very rare
- **Easy to remove**: overlapped tracks do not point to the IP and have diffusion width incompatible with their drift time



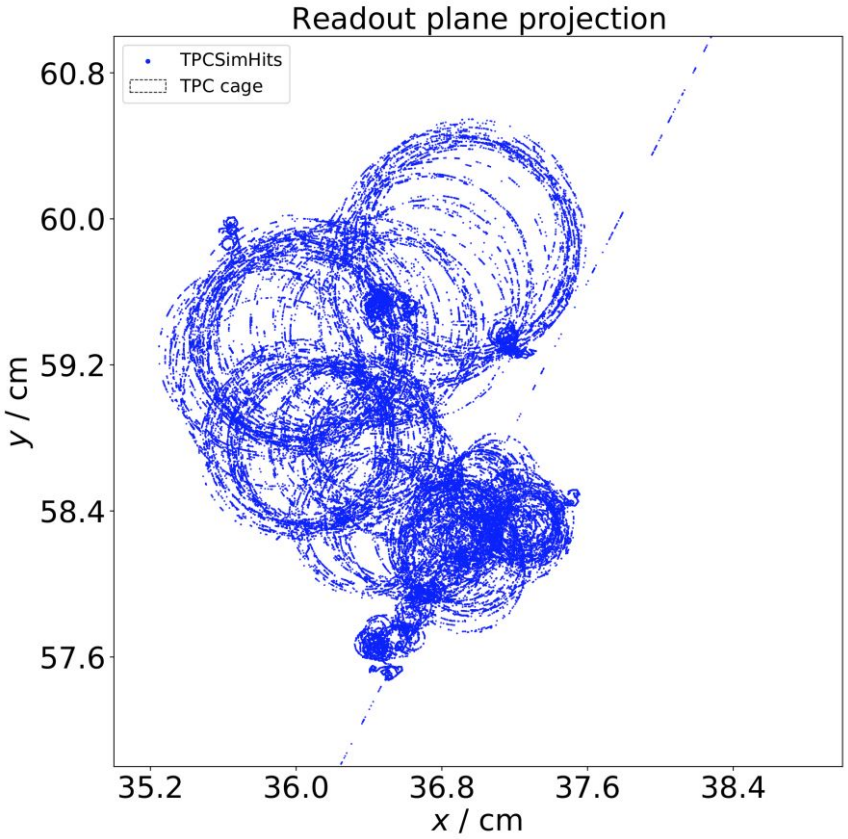
Event pileup should not be a major problem, but **beam-induced backgrounds** are…

Concern 2: Pileup

Second: background pileup

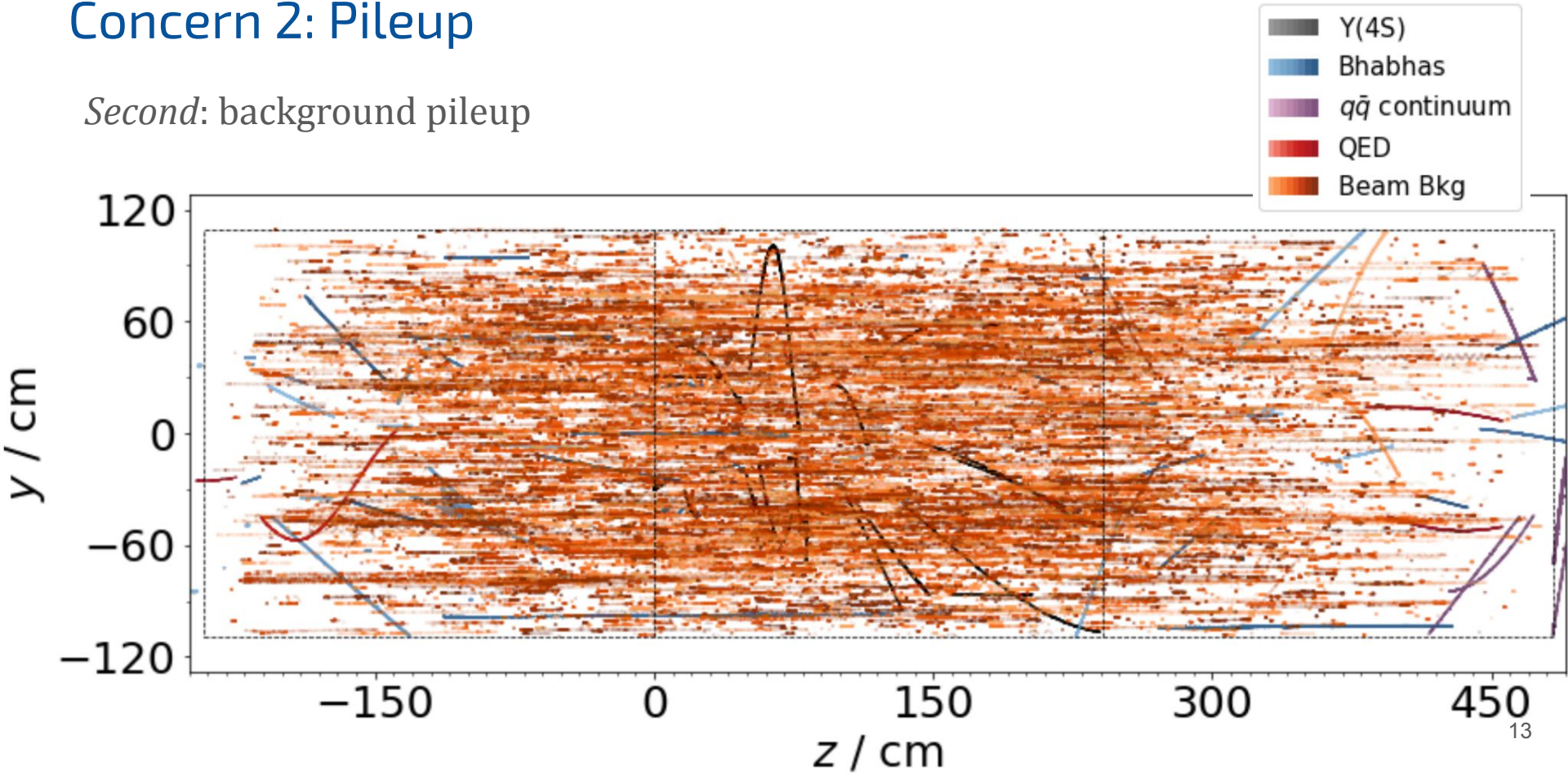
- Beam-induced backgrounds produce mostly **low-energy photons**
- These Compton-scatter to produce copious low-energy electrons in the drift volume…
- …***microcurlers***…
- …that ionize far more than MIPs over their path
- TPC would **integrate** these backgrounds over 2*30 μs drift time (over 7400 beam crossings)

Ultra-high luminosity necessarily means high beam-induced backgrounds… **is it tolerable?**



Concern 2: Pileup

Second: background pileup

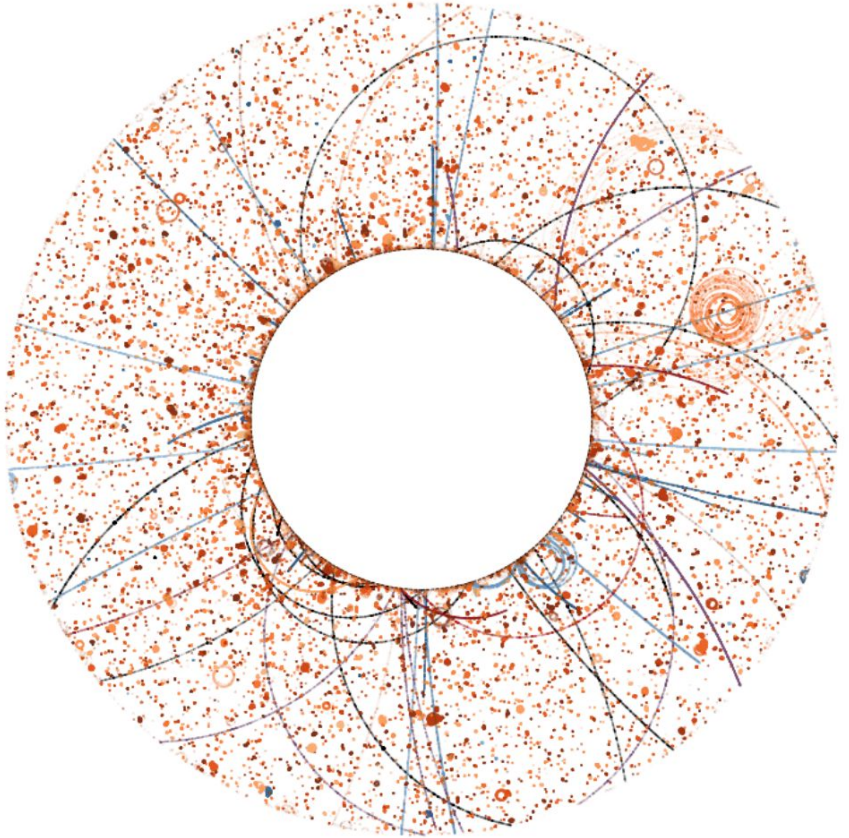


Concern 2: Pileup

Second: background pileup **findings**

- (*right*: end view of one triggered event with beam background overlay)
- The total ionization rate ≅ rate from beam-induced microcurlers
- However, the **voxel occupancy** is **low** ($\sim 10^{-5}$) due to fine 3D granularity provided by GridPix (assuming 55 x 55 x 200 μm^3)
- Microcurlers are also very *distinctive* and can be significantly reduced by chip-level logic

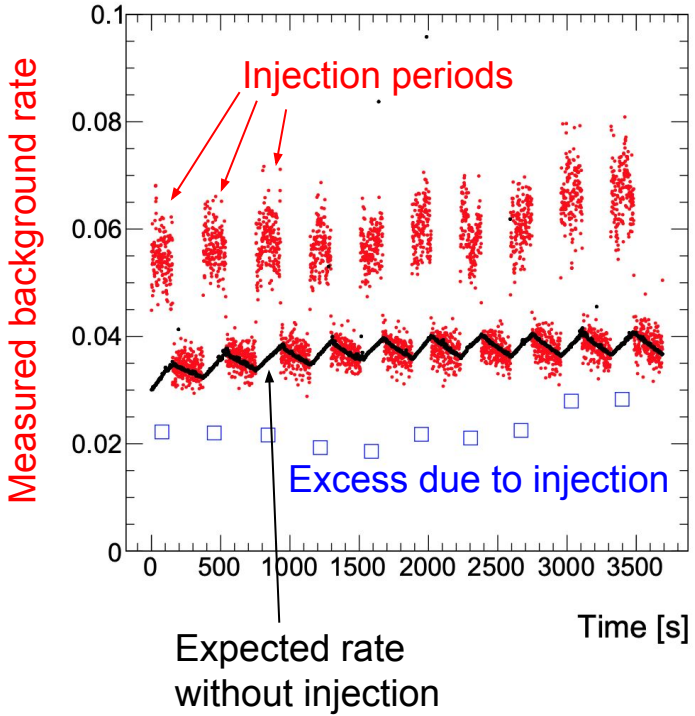
Beam-induced ionization appears to be a major technical challenge, but it also appears to be **manageable**



Concern 3: IBF

Ungated, continuous operation

- Event time occupancy is ~15% → gating is not possible
- GridPix are intrinsically low-IBF (~1% at a gain of 2000)
- Projected ion densities with 5x luminosity will be **comparable** to other tracking TPCs with similar tracking requirements…
- …however, our beam background simulation does not include **injection backgrounds**
- These are integrated over and may be *very* large due to continuous injection schemes

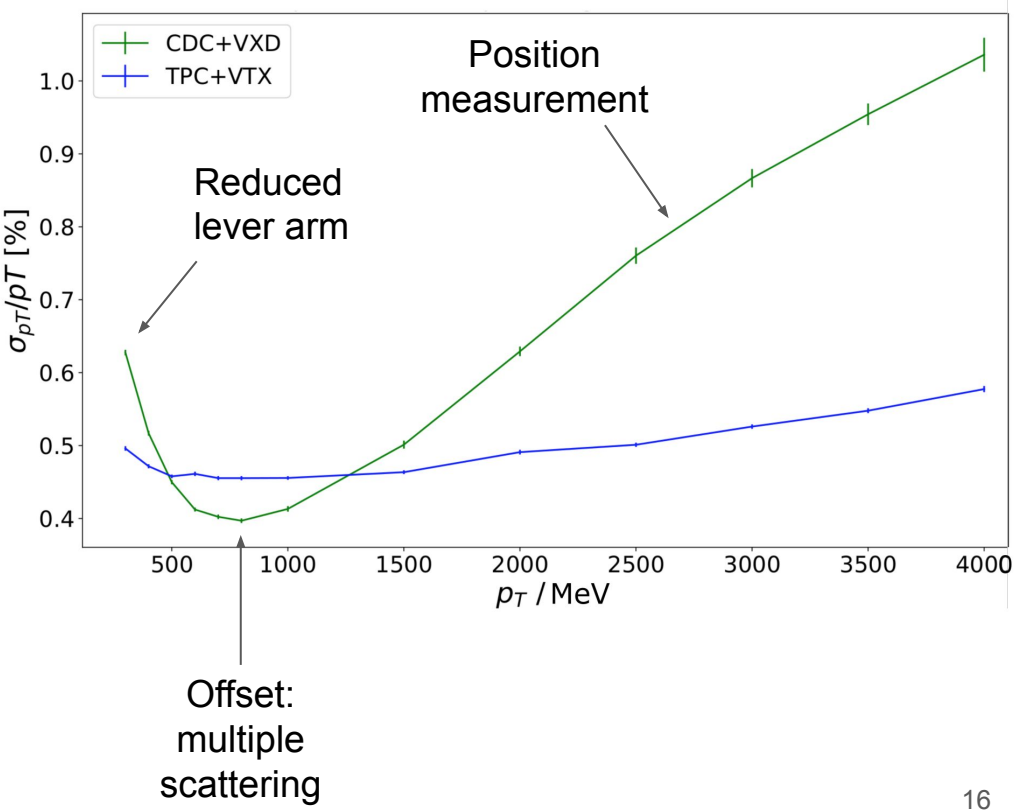


Ion backflow due to integrated backgrounds is **the** major unresolved technical challenge; solvable with clever design?

Concern 4: diffusion

Suitable tracking performance?

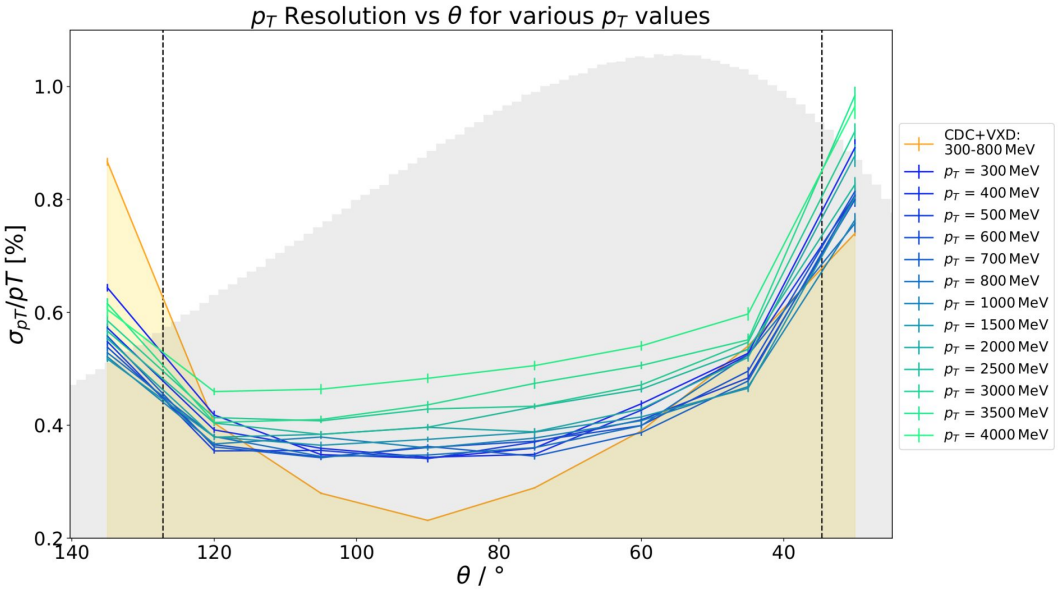
- Used modified basf2 track-finding and track-fitting algorithms fitting 3D space-points
- The key metric is p_T resolution (*right*)
- The high resolution of the TPC design gives better resolution everywhere…
- …but we still lack a realistic *mechanical* design, which will affect multiple scattering



Concern 4: diffusion

Suitable tracking performance?

- Forward/backward tracks have more hits (unlike CDC), improving resolution
- Overall, resolution is comparable to CDC



The short story: diffusion does not significantly degrade resolution due to large number of hits

Results and further work

Summary

- Our proof-of-concept is successful, with one caveat: **injection backgrounds** may be a major problem

What do we need to do next?

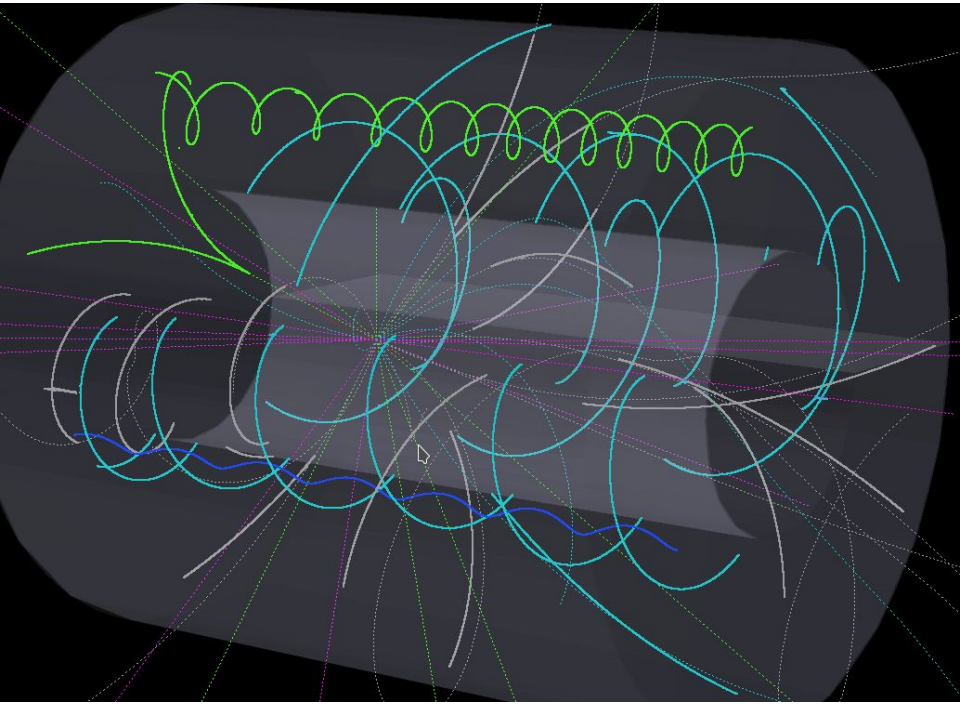
- A complete comparison of different amplification/readout options beyond GridPix
- Development of robust track-finding and track-fitting algorithms appropriate for TPCs
- Realistic estimate of effect of IBF

Implications for MPGD development

What would a purpose-built chip look like?

- Pixels with integrated MICROMEGAS
- 200 x 200 μm^2 pixels would be sufficient
- Time resolution of 25ns would be sufficient
- Binary readout
- Capable of continuous capture and triggered readout of a 30 μs buffer
- Capable of simple trigger and hit filtering logic

This is a *simpler* chip than GridPix; it will have to also be far *cheaper* to be viable for Belle II (needs to cover $\sim 3\ m^2$)



Thank you!