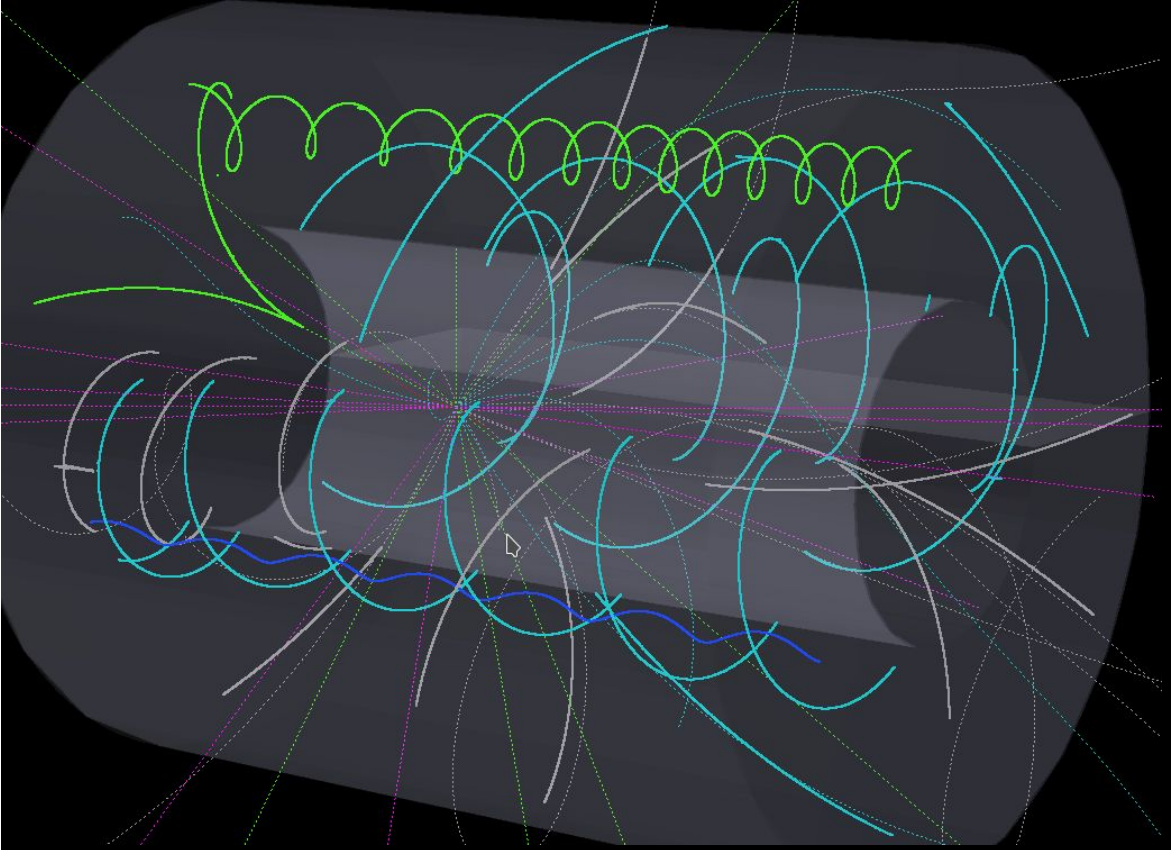

High-resolution gas TPCs for next-generation intensity frontier tracking

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Oskar Hartbrich, Carlos Mariñas, Sven Vahsen

CPAD 2023 | SLAC

Disclaimer

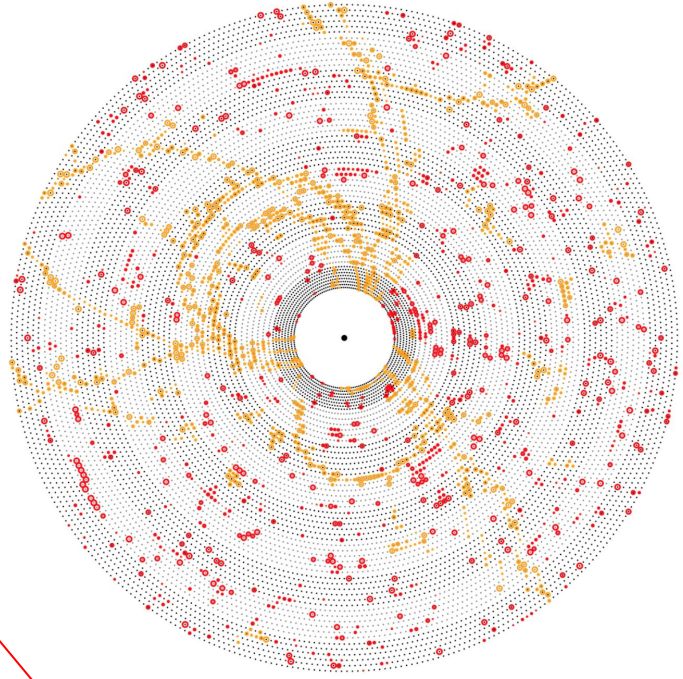
This is a *very* preliminary conceptual design based only on dreams and preliminary simulation

Options for future trackers

For *high event rate* (>100kHz) and *modest track momentum* (<1GeV)

- *Drift chamber*
  - effectively 2D → **high occupancies** from beam-induced backgrounds
- *Silicon tracker*:
  - **Expensive**
  - High X_0 → **degraded performance**
- *TPC*:
  - High-resolution 3D → **low occupancies**
  - **Far cheaper**
  - Minimal X_0 → **ideal performance**

But the case isn't so clear-cut…



Belle II drift chamber:
14,000 cells; 1% of hits are signal

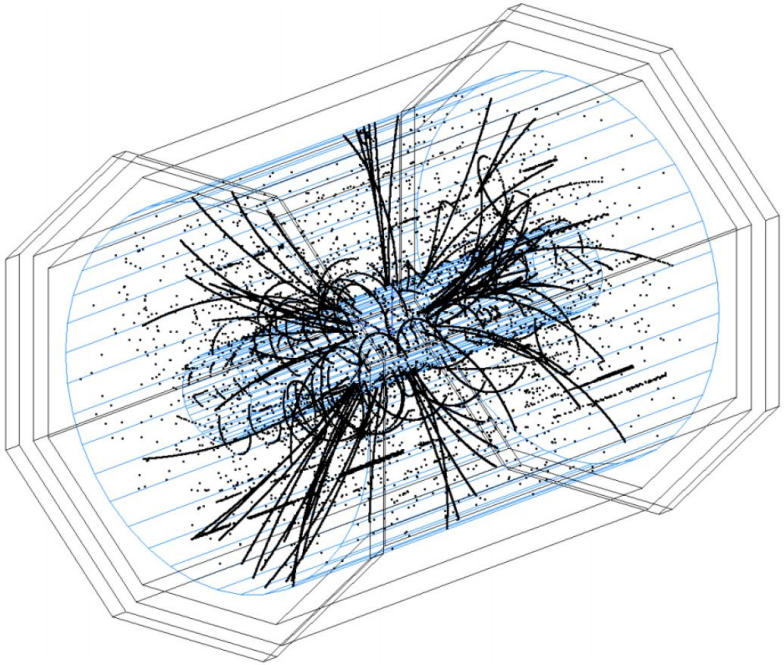
Same volume with 200μm^3 voxels:
10^{12} voxels

Primary technical concerns

"This won't work because…"

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

Today: address (two of) these one-by-one with simulation, with a proof-of-concept detector based on a **Belle II upgrade**

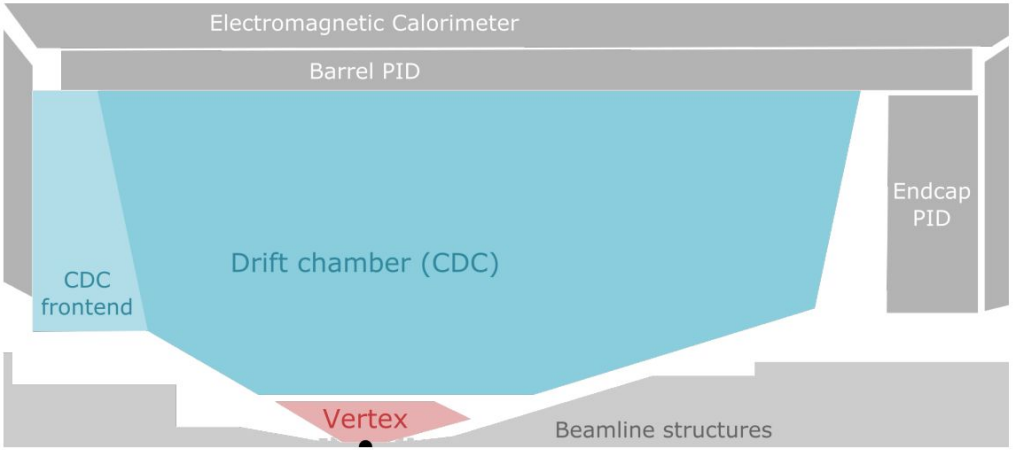


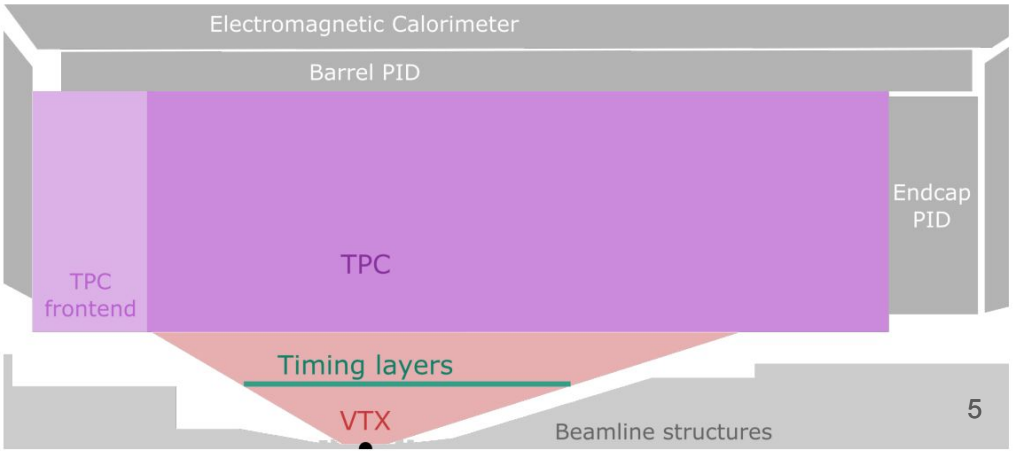
A **single** simulated LCTPC event with beam backgrounds

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 (Timepix3) with integrated MICROMEGAS
  - 55x55 µm pixels

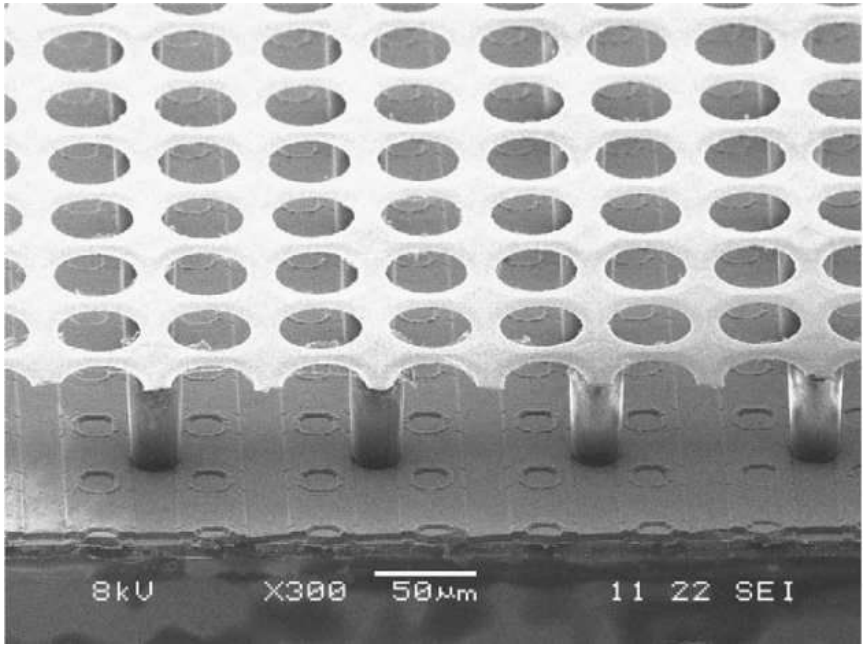




Why GridPix?

A number of attractive features for us

- 1:1 mapping of electrons:pixels → **optimal resolution**
- Intrinsically **low ion backflow** (IBF)
- Could be used in **binary readout** → reduction of data throughput
- It is *real*, so we can confidently (and easily) simulate it



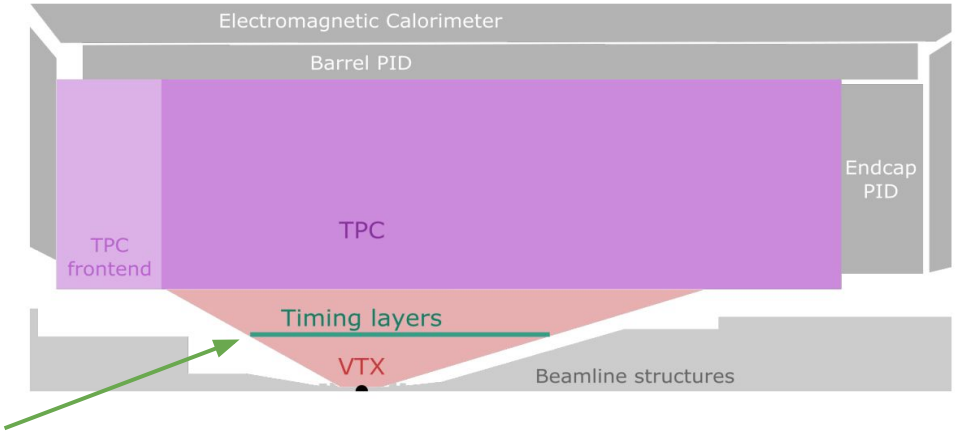
Ultimately, we would require a purpose-designed sensor, but we use GridPix for the proof-of-principle

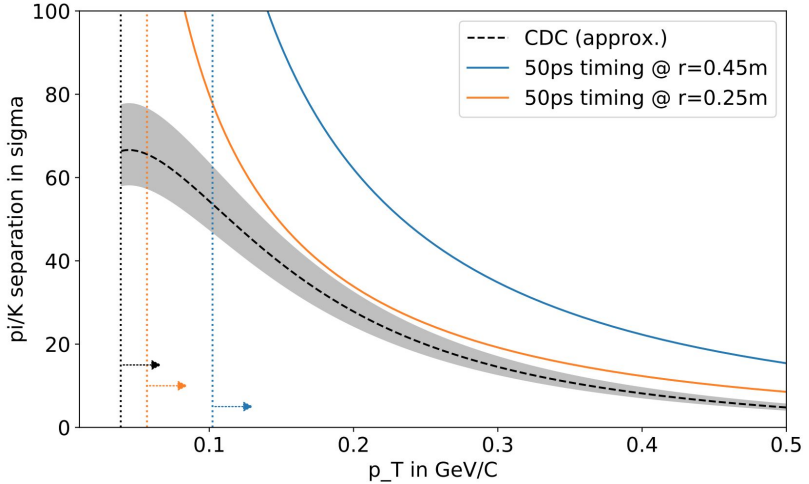
~~Concern 1: trigger~~

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)
- Results from toy simulation:
  - **Viable trigger option** with very low fake rate
  - *Bonus*: **far better PID** for low-p tracks (concern 5)

So: trigger isn't a problem but an **opportunity**



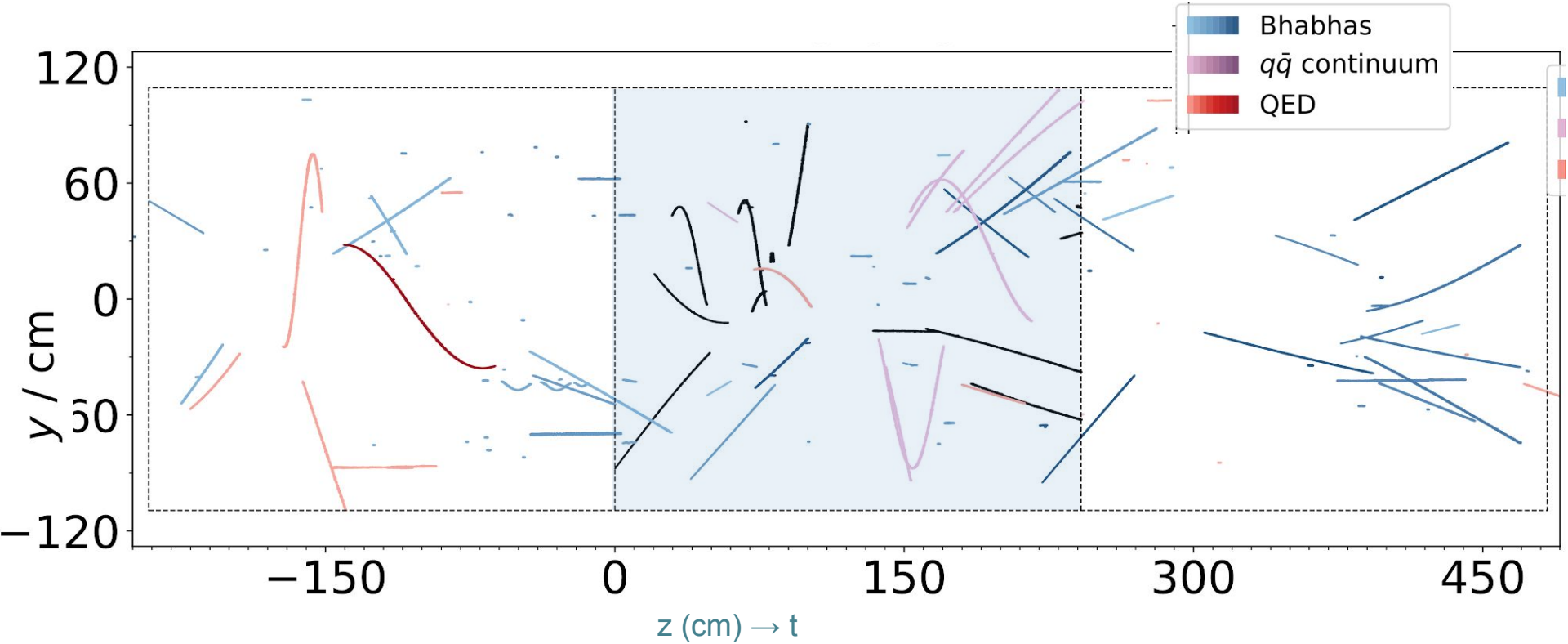


Concern 2: pileup

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…

Could a TPC work?



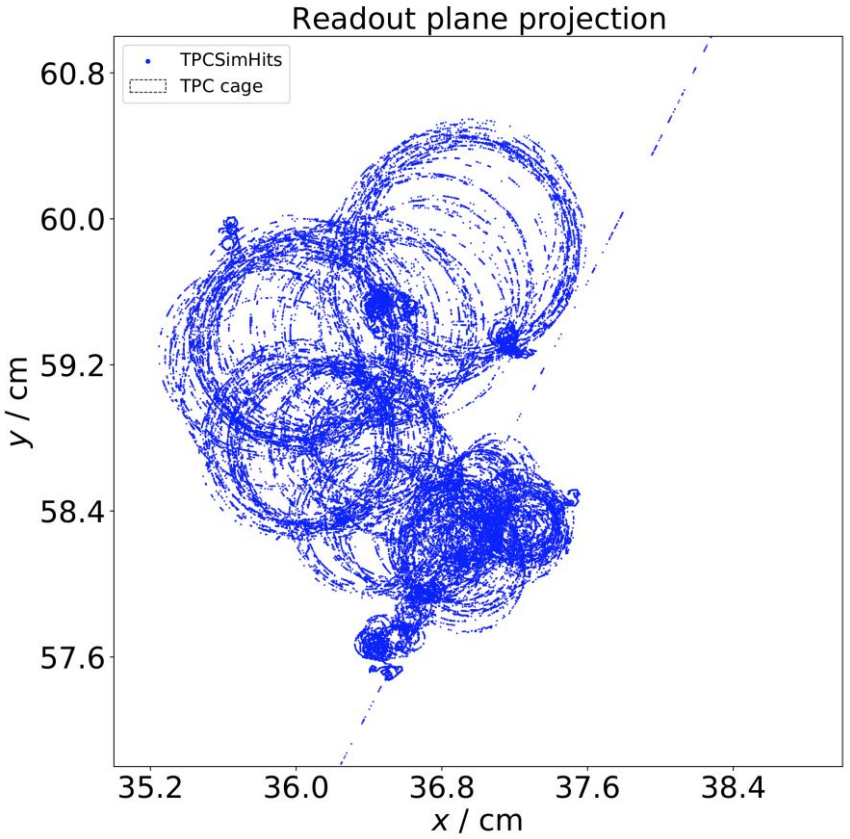
This is at 5x maximum Belle II lumi… “extra” tracks are easy to identify; **not a major issue**

Concern 2: pileup

Second: background pileup

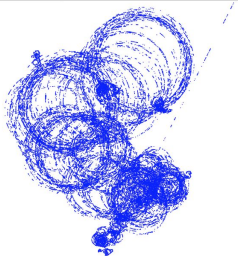
- Beam-induced backgrounds produce mostly **low-energy photons**
- These Compton-scatter to produce copious low-energy electrons in the drift volume…
- …***microcurlers***…
- …that ionize far more than MIPs over their path
- TPC would **integrate** these backgrounds over 30 μs drift time (over 7400 beam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

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

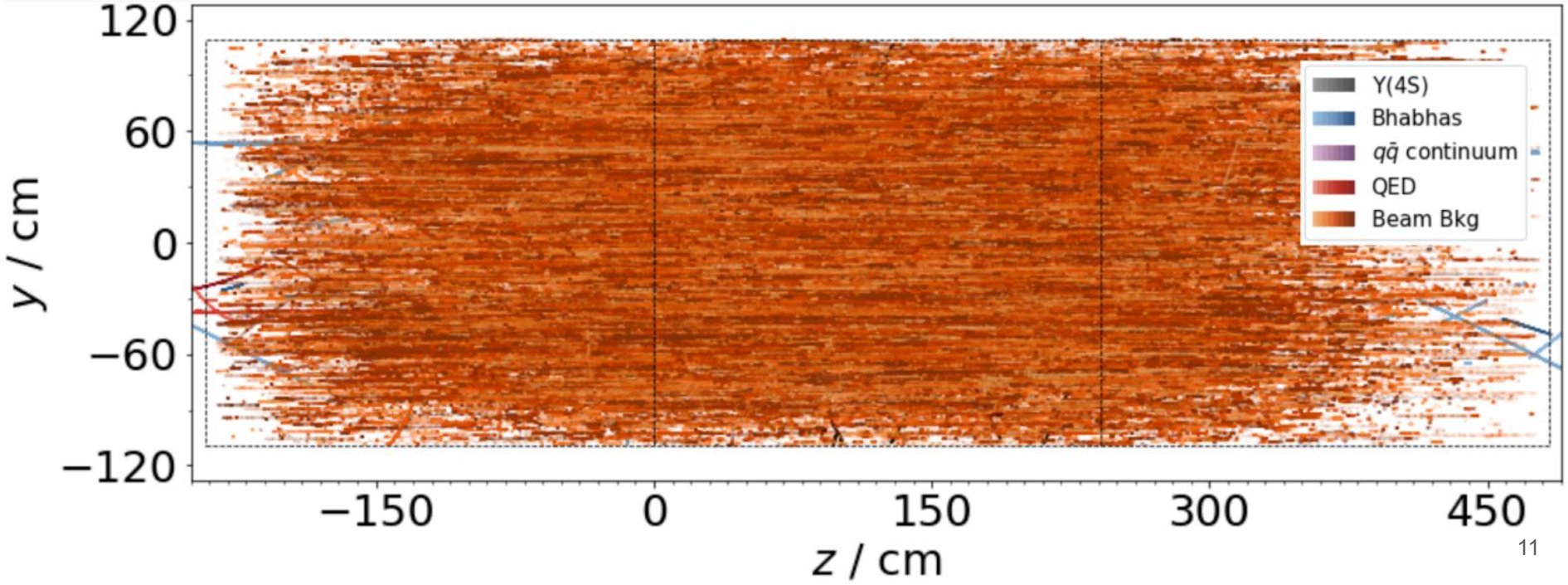


Could a TPC work?

Typical *background* pileup



These are almost entirely *microcurlers*



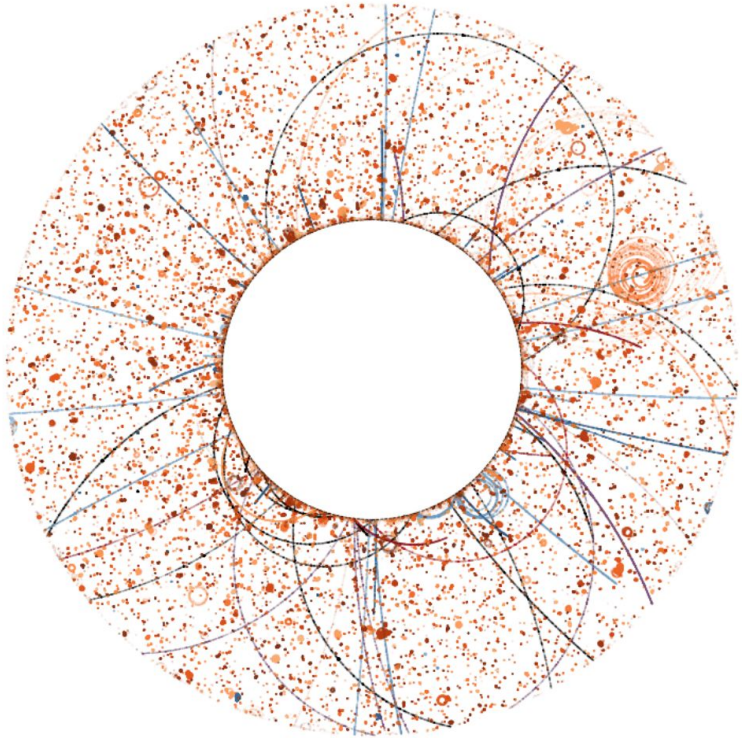
Concern 2: Pileup

Remember

- CDC is 2D, TPC is 3D
- CDC is triggered, TPC integrates all backgrounds

So *which one wins?* **The TPC does**, because **1T is a *lot* more than 10K**

However, **injection backgrounds** are not simulated and *very large*



So: pileup is a technical challenge but not a showstopper

Concern 3: IBF

Ungated, continuous operation

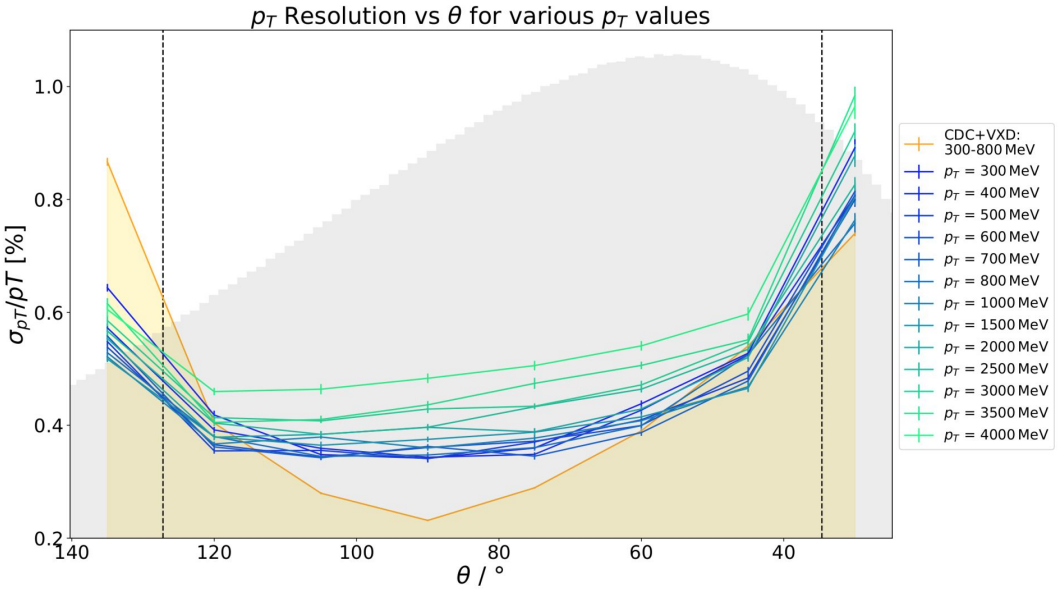
- Event time occupancy is ~15% → gating is not possible
- GridPix are intrinsically low-IBF (~1% at a gain of 2000)
- Projected ion densities with 5x luminosity will be **comparable** to other tracking TPCs, but:
  - our tracking requirements are more stringent
  - our beam background simulation does 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?

- Forward/backward tracks have more hits (unlike CDC), improving resolution
- Overall, resolution is comparable to CDC
- The material budget of the inner detectors is more relevant than diffusion in the TPC



So: diffusion does not significantly degrade resolution due to **large number of hits**

So, *could* a TPC work?

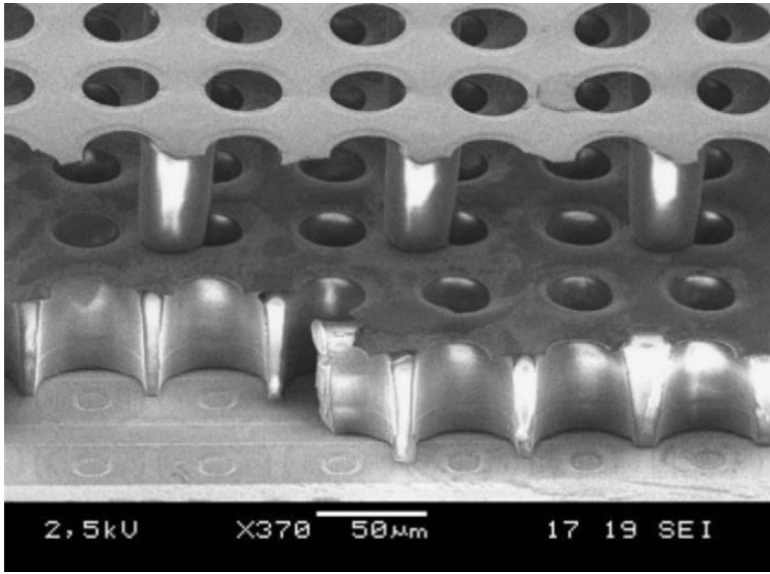
Yes!

But it will require some technology development…

Technical opportunities

Amplification and detection

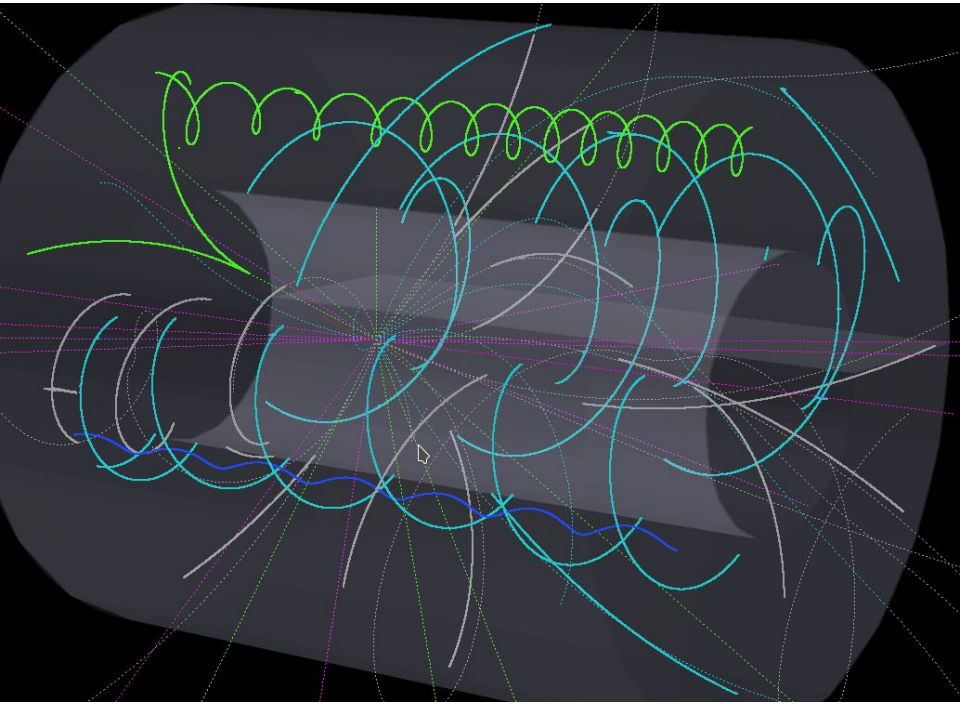
- High-efficiency, high-resolution, low-throughput, **ultra-low-IBF** sensors with continuous readout required
- **TwinGrid pixels** perhaps ideal for this (?)
- The same technology could be ideal for low-*E* nuclear recoils, neutrinos, …



Frontend

- Online microcurler rejection would be an excellent application for **frontend ML/AI**
- Online hit-event association and event-building, etc…

Huge potential for innovation and many synergies here!



Thank you!

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 whitepaper
[https://arxiv.org/abs/2203.04847]

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

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