MEG II実験データの取得と μ→ eγ探索解析の現状 まとめと今後の展望

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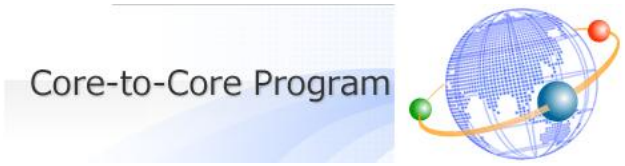
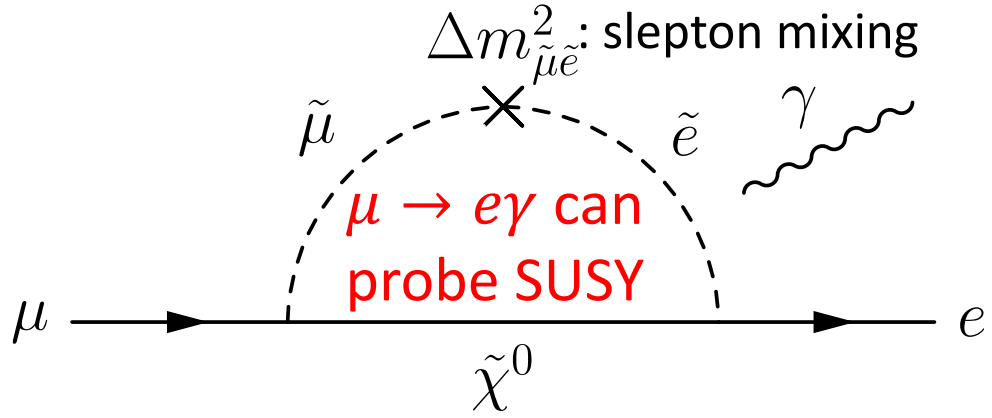
2025年日本物理学会春季大会



$\mu \to e\gamma$: Motivation and Principle

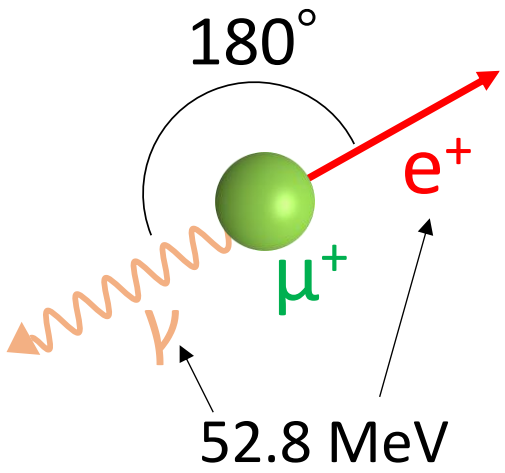
- $\mu \to e\gamma$ search by MEG II
  - $\mu \to e\gamma$: CLFV decay, forbidden in SM
  - Target sensitivity: Br($\mu \to e\gamma$) ~ $\mathbf{6 \times 10^{-14}}$
    → Can probe O(10 TeV) physics



- Search strategy

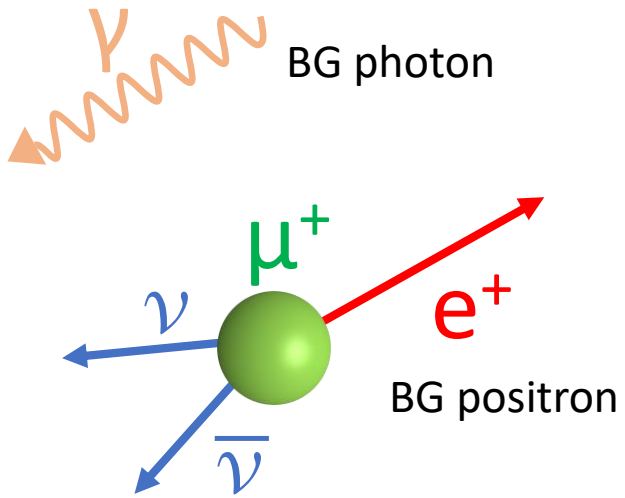
Signal

2-body kinematics



Background

Accidental coincidence



	Signal	Background
E_e	52.8	< 52.8
E_γ	52.8	< 52.8
$t_{e\gamma}$	0	Flat distribution
$\Theta_{e\gamma}$	180°	No correlation

Requirements to have high S/B

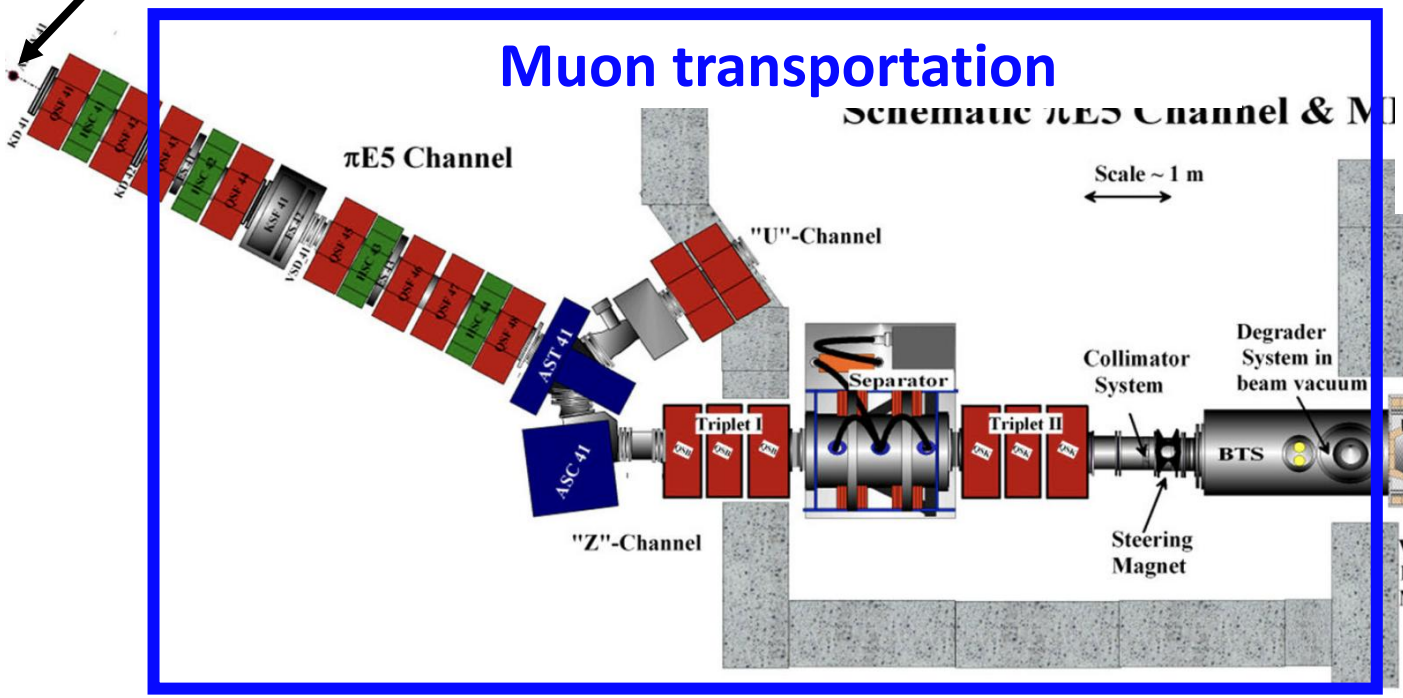
1. Continuous & High-rate muon beam
2. High resolution measurement

MEG II experiment @PSI

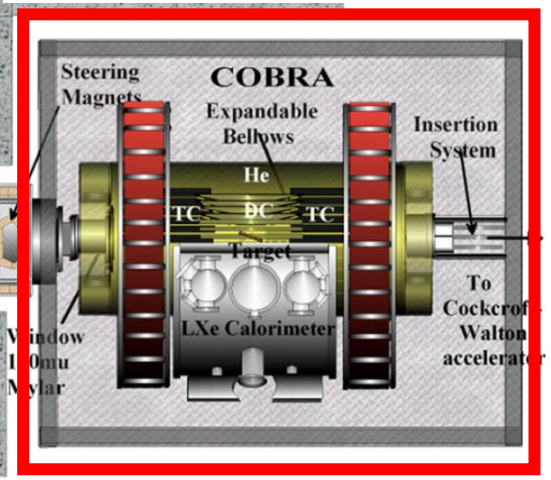
- Use of DC muon beam with availability of up to 10^8 μ/s rate
  - Detectors are operated at 4×10^7 μ/s due to rate capability (4×10^7 μ/s is the most optimal choice for sensitivity)

Muon production target
(Decay of π produced by proton reaction)

Proton beam

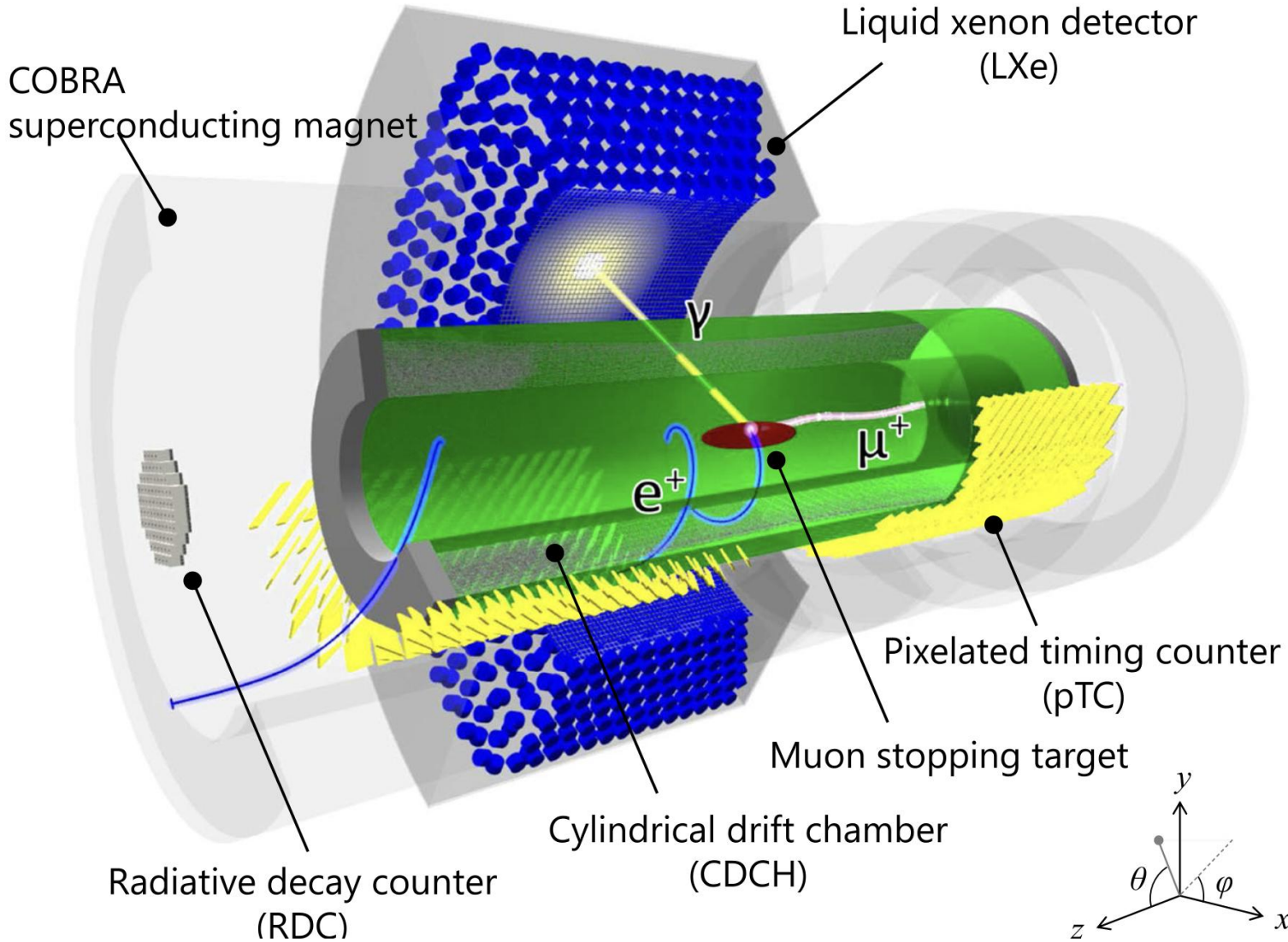


Main MEG II detector

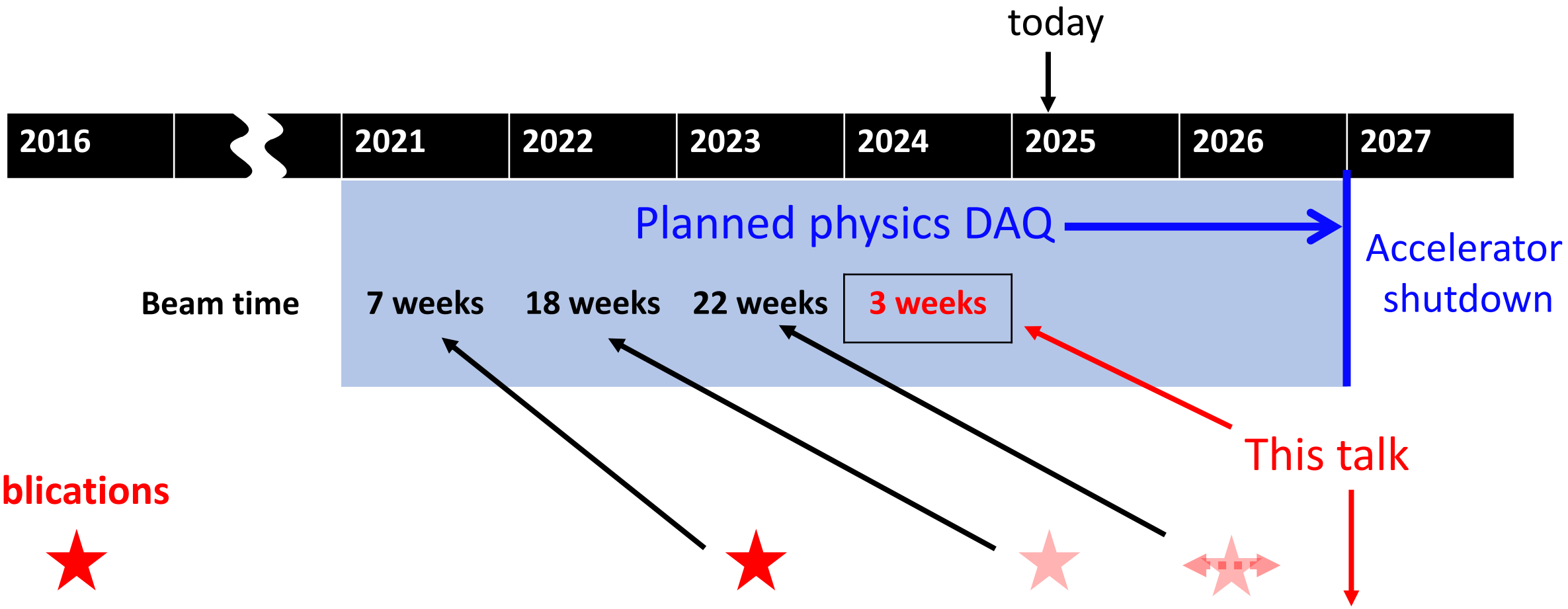


MEG II detector

- Photon detector
  - Use of liquid xenon (900 L)
  - Sensors limit μ rate to be less than 5×10^7 μ/s
- Positron tracker
  - Drift chamber
  - Track reconstruction makes 4×10^7 μ/s optimal
- Positron timing
  - Scintillation counters (512 total)



Timeline of MEG II experiment



Publications

MEG I final result:
Br $< 4.2 \times 10^{-13}$
($S \sim 5.3 \times 10^{-13}$)
EPJC76, 434 (2016)

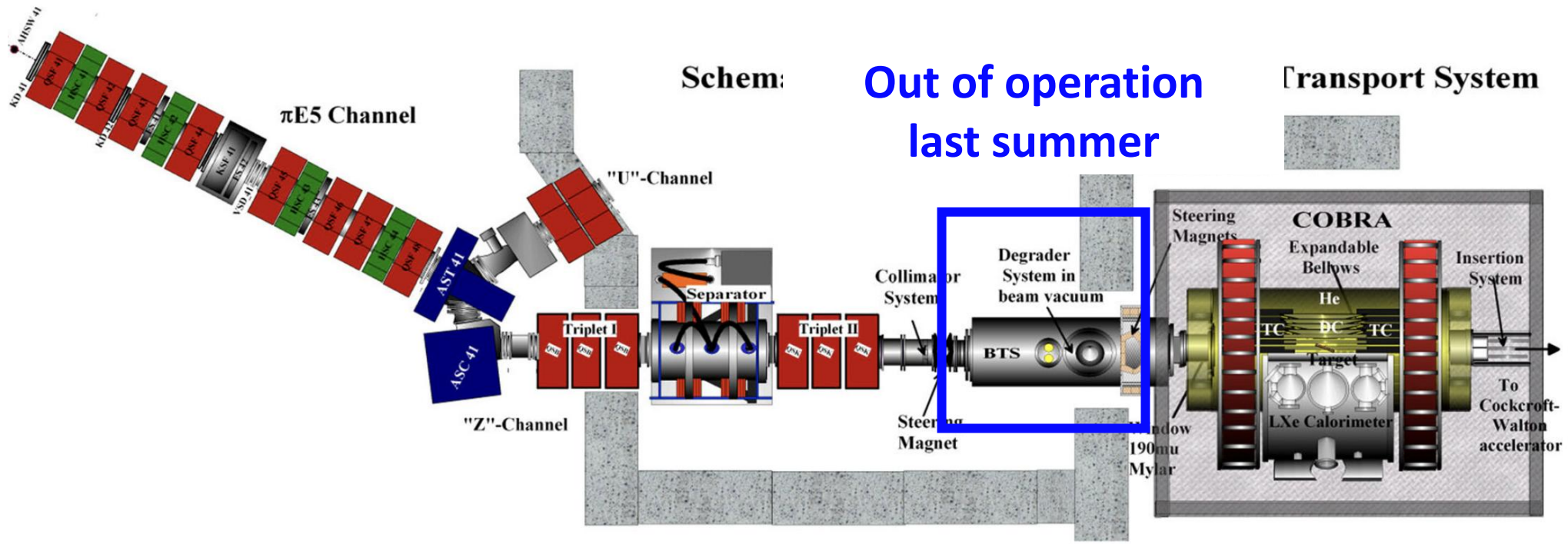
Br $< 7.5 \times 10^{-13}$
($S \sim 8.8 \times 10^{-13}$)
EPJC84, 216 (2024)

Coming soon
(Next talk)

Calibration in progress

Challenge in 2024: Beamline

- Beam collimation magnet runs on LHe supplied by PSI
  - Not having self-contained refrigerator
  - Last summer, LHe plant at PSI was out of service
  - So, start of DAQ was delayed until November
- Precautionary measure for coming years: Under discussion with PSI



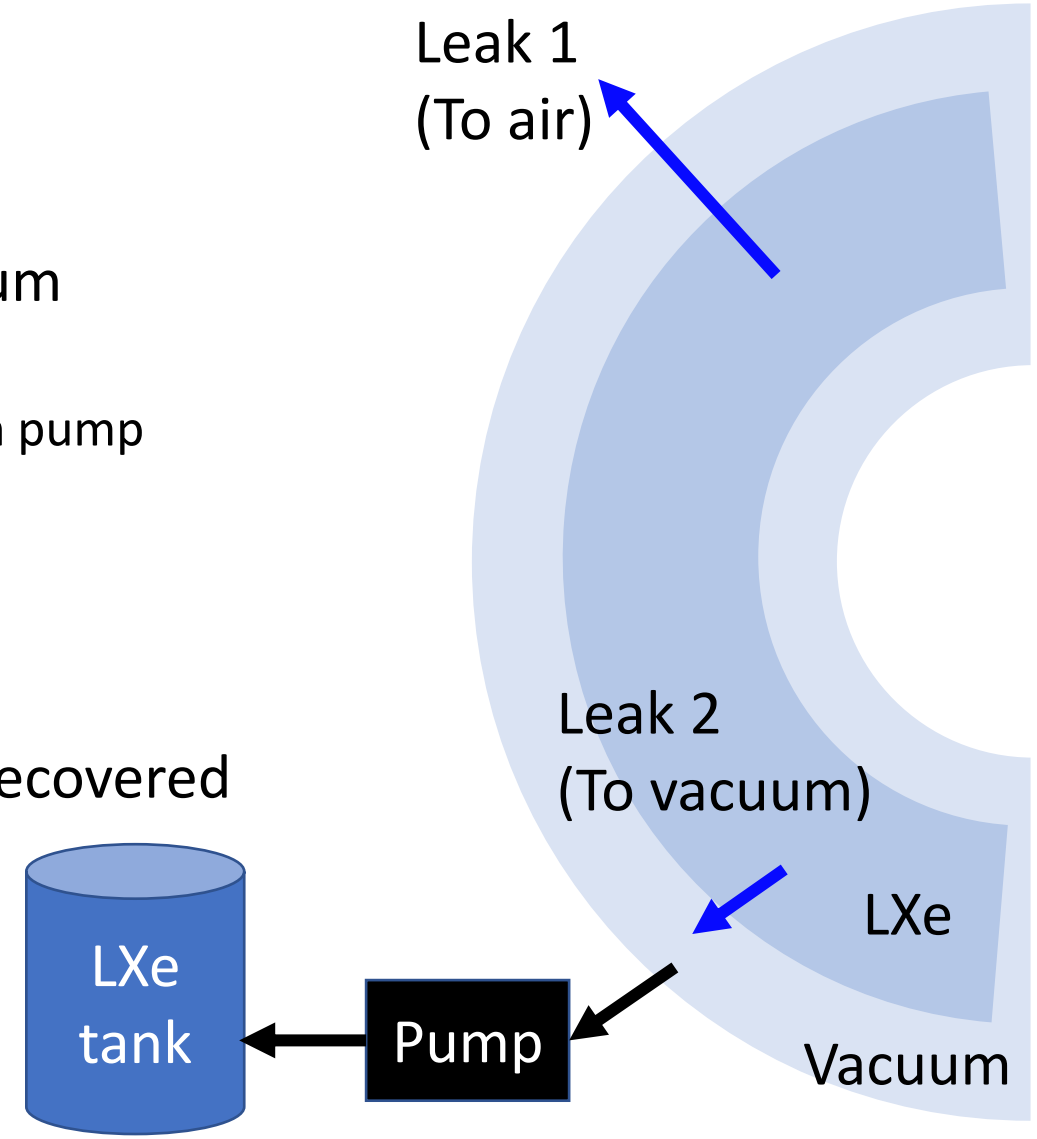
Challenge in 2024: Leak of LXe

※ Not to scale

- Imperfect leak-tightness of LXe cryostat
  1. Broken valve between LXe vessel and air
     - Broke in 2024
     - Fixed by replacing the broken valve
  2. Leak b/w LXe vessel & thermal insulation vacuum
     - (Probably) Existed for a few years
     - In 2024, started collection of leaked xenon via vacuum pump

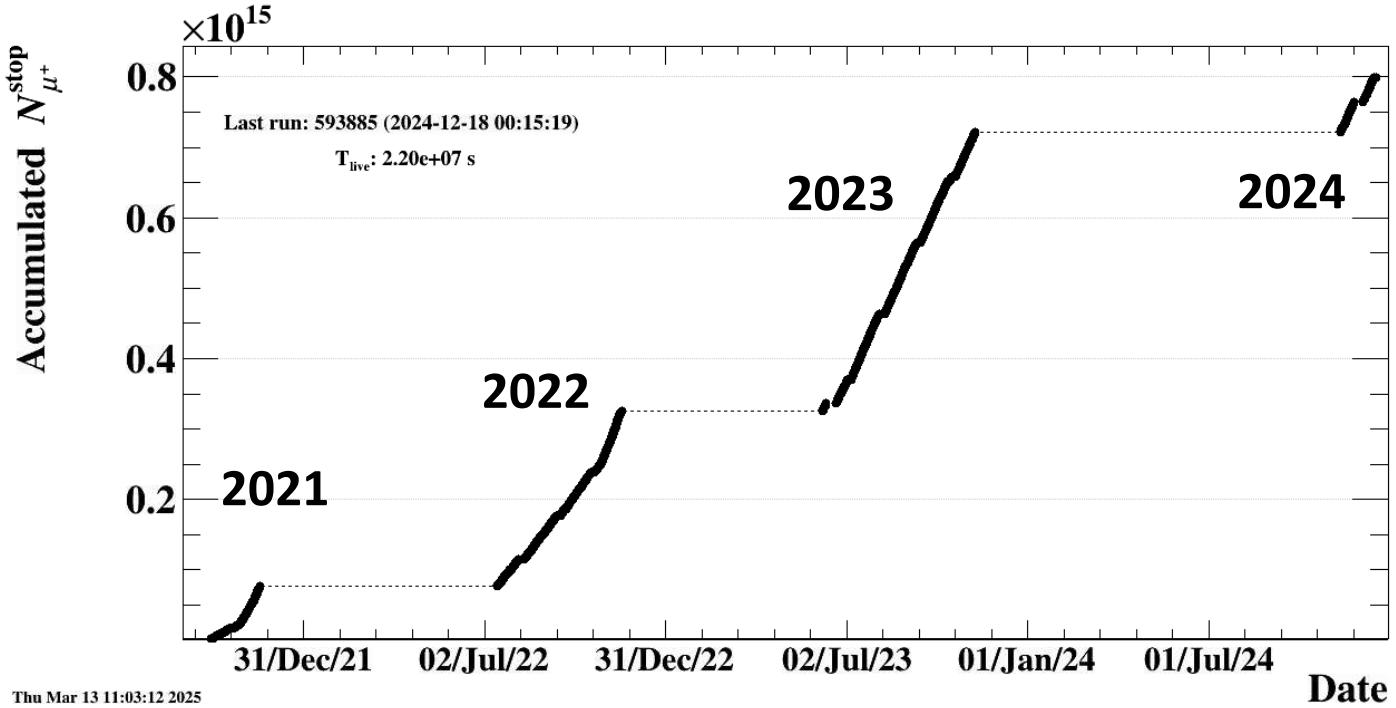
  → Lost XX litter of xenon

- Activities towards 2025 DAQ
  - After re-tightening vessels, leak-tightness looks recovered
  - Bought new xenon



DAQ summary and plan for 2025

- Beam time assigned from Jun – Dec in 2025



Assigned beam time for 2025 as long as 2023

Overview of analysis activities

- Now, finalizing analysis of data collected in 2022
  - Will be discussed in the next talk
  - To be published soon

  → Next talk by 山本, 18aT1-7

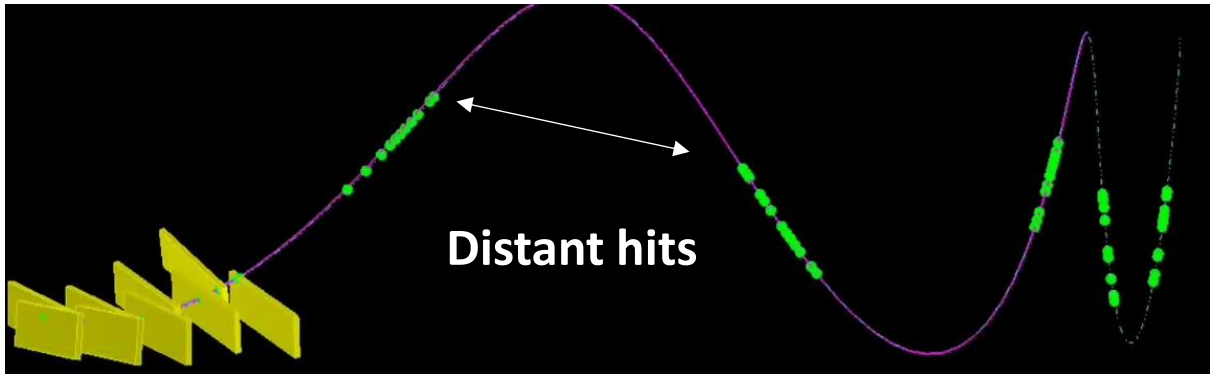
- **Ongoing studies on reconstruction for 2023 data**
  1. **Positron tracking improvement**
  2. **Systematics in positron timing calibration**
  3. Calibration of sensor saturation for LXe detector
     → By 藩, 19aT2-8

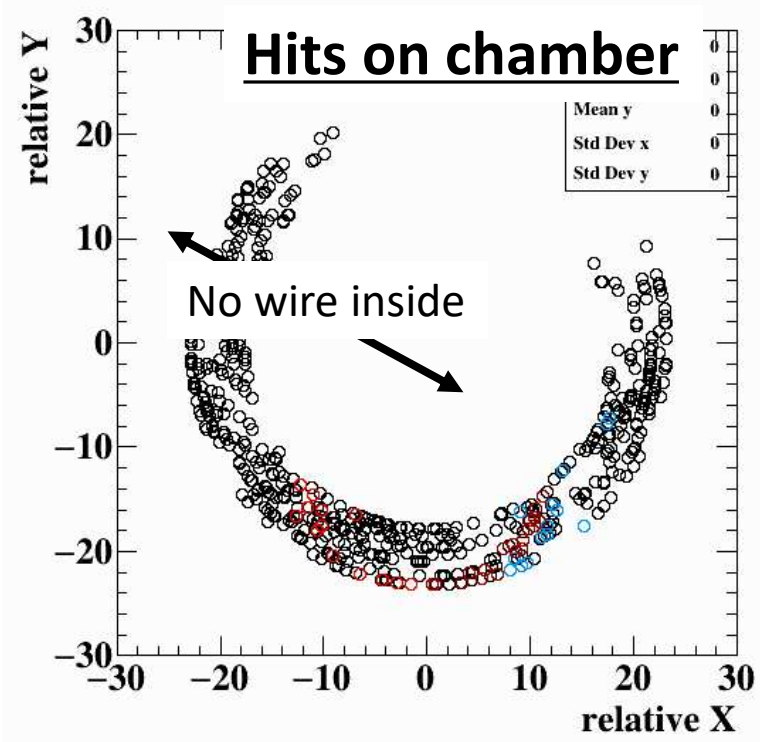
Positron tracking

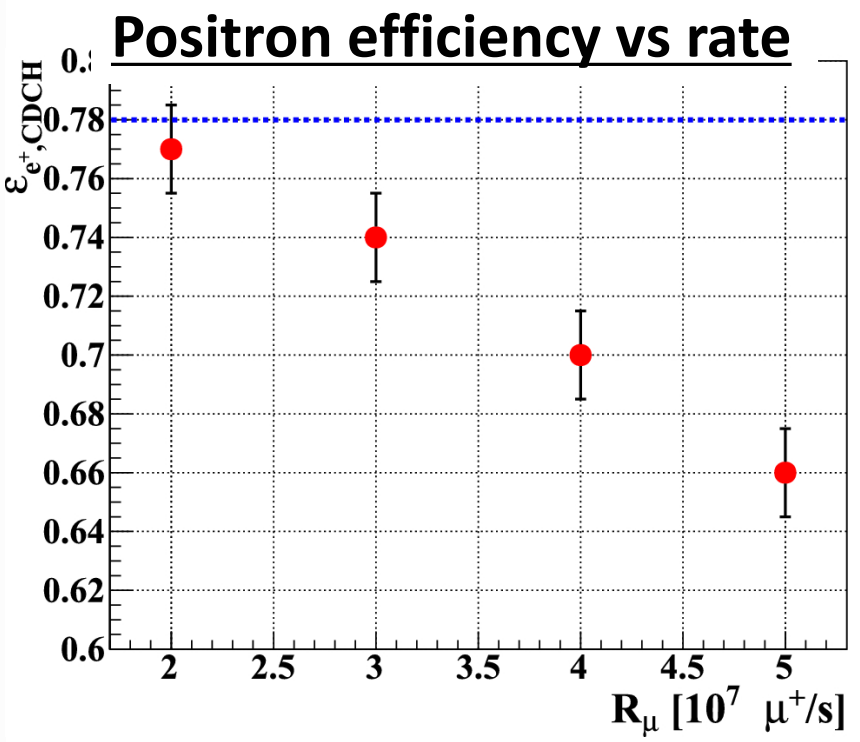
- Tracking challenges
  1. Efficiency loss in high pileup rate
     → So, 4×10^7 /s rate is optimal now
  2. Connection of distant hits
  3. CPU expensive

  → Challenge of track finding algorithm

… Can we improve this?



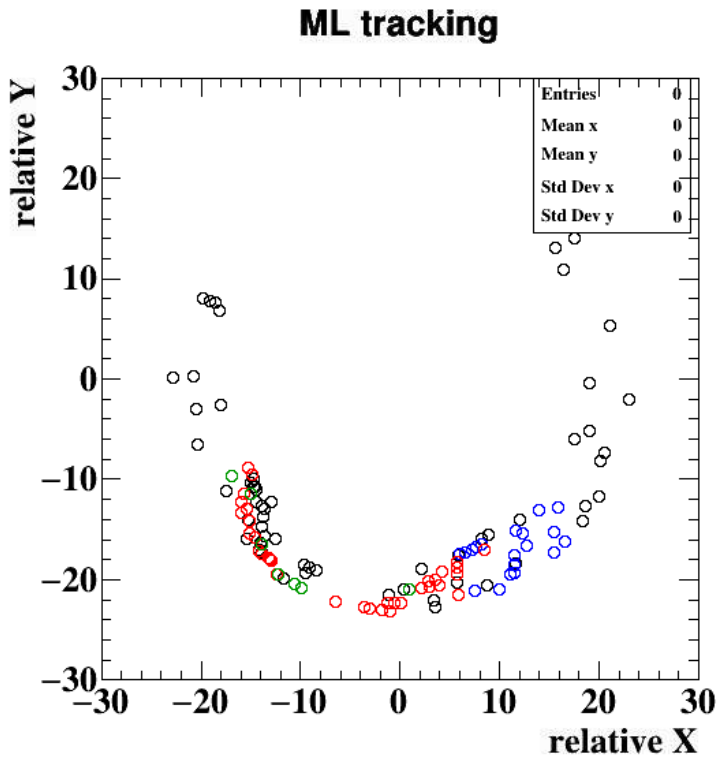


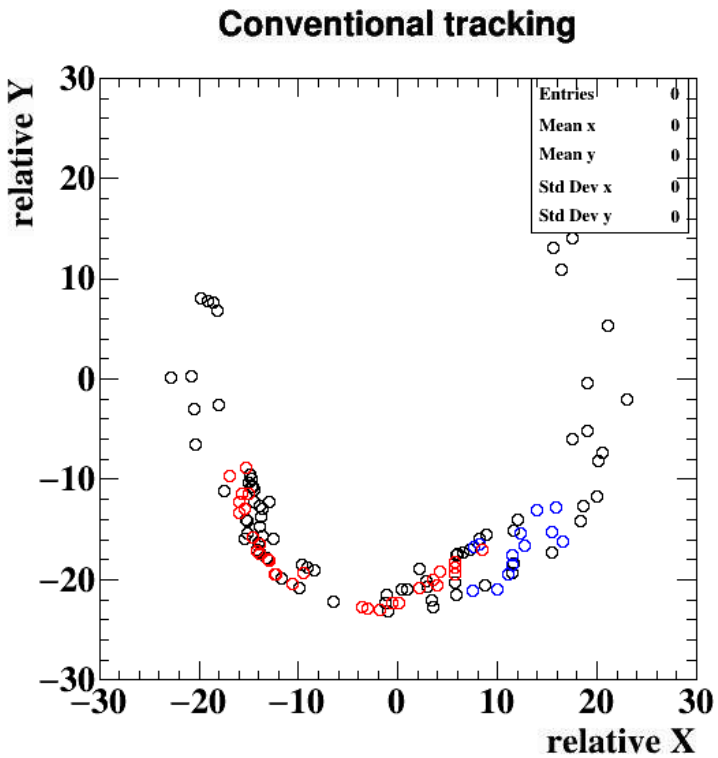


Study of ML-based tracking

- Started studies of Transformer-based tracking
  - Inspired by arxiv:2411.07149
  - Application of object-detection technique to particle tracking

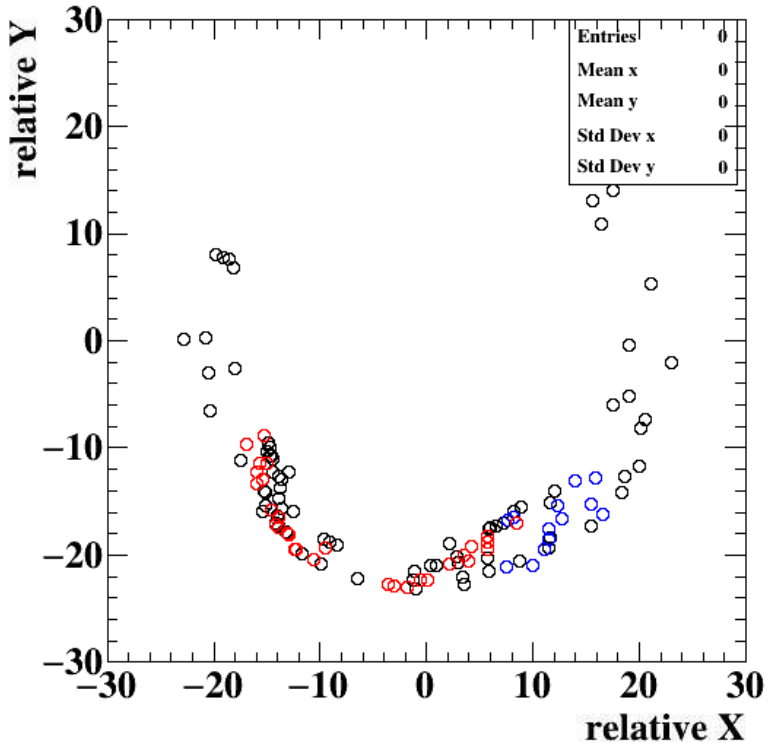
- Very preliminary test with low-intensity samples
  - Colored hits are hits identified by ML or conventional tracking
  - Looks ML can learn geometrical pattern of tracks





What's next?

- Performance in high-rate is not yet studied
- Time scale of this study
  - If we get promising result by May, we may consider increasing to 5×10^7 /s this year
  - To apply to 2023 dataset, need to get by summer anyway



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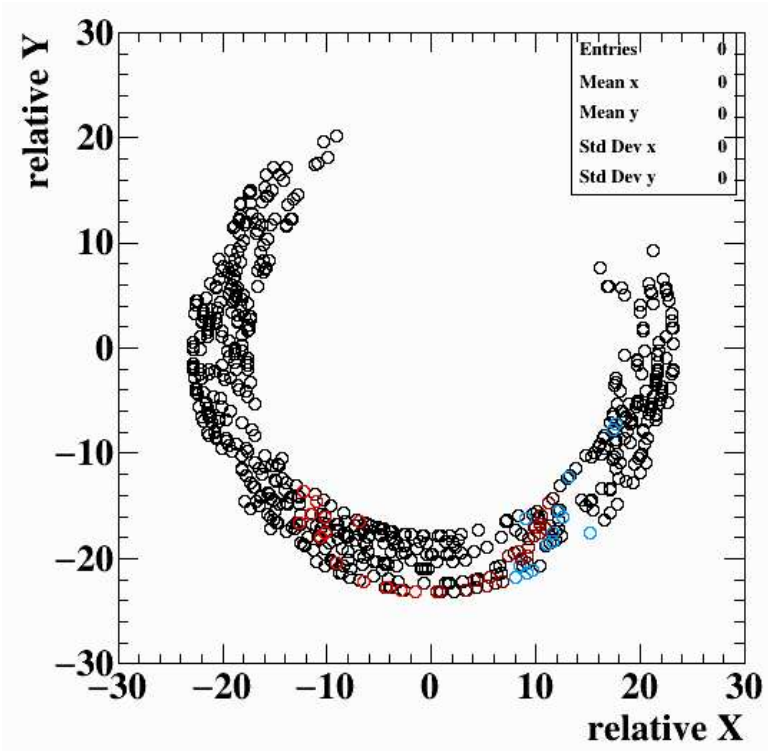
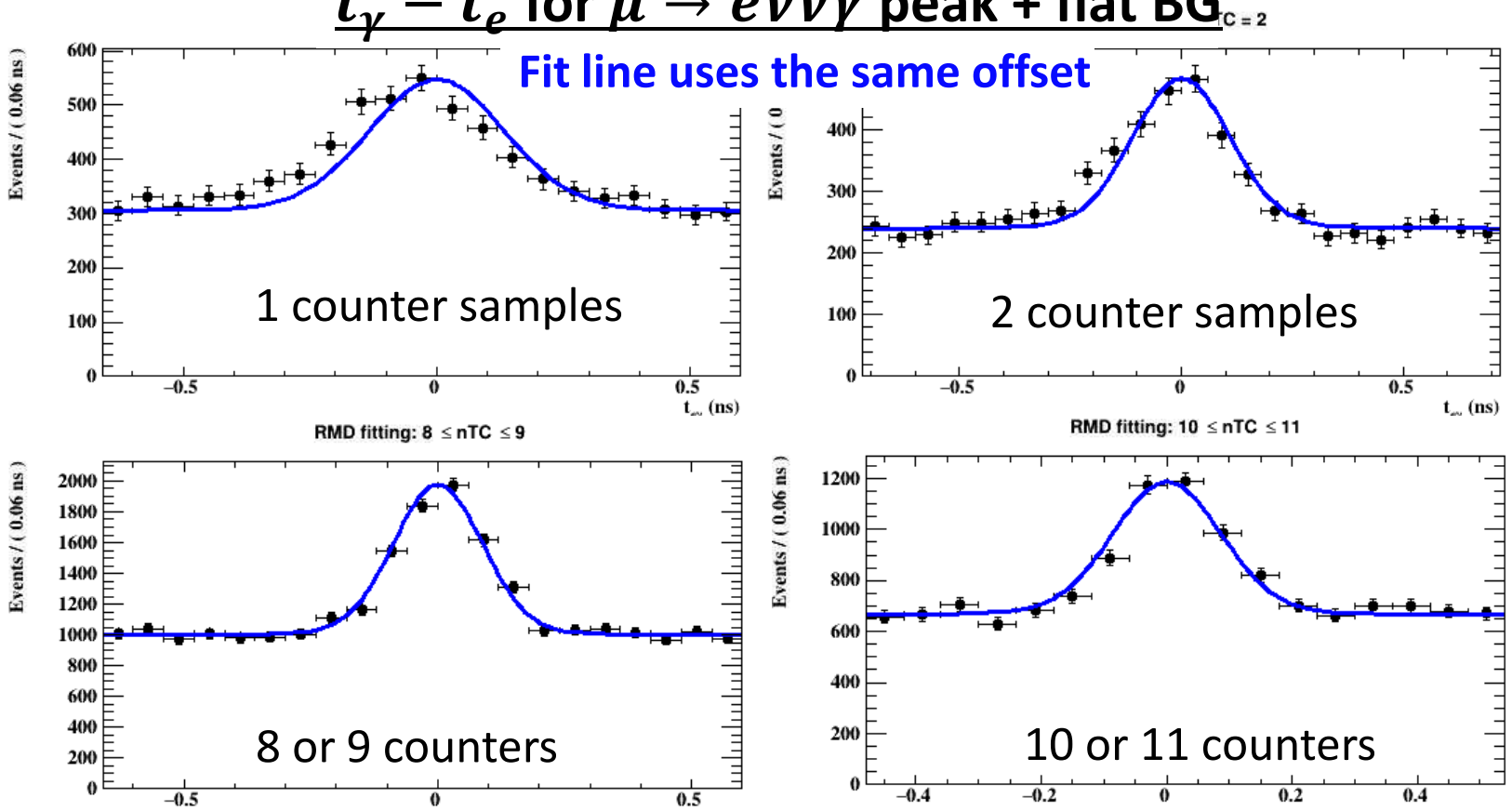


Systematics in positron timing

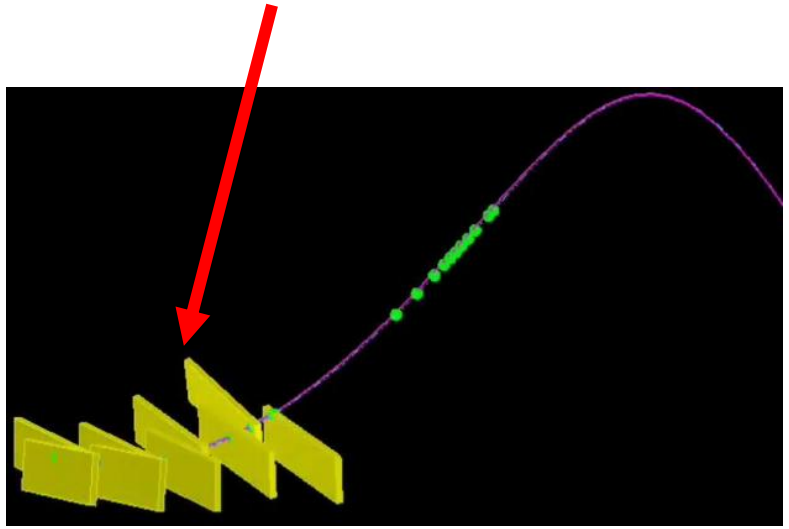
- In 2022 data, found systematics in $t_\gamma - t_e$ distribution for $\mu \to e\nu\nu\gamma$ samples
  - With $E_e > 45$ MeV & $E_\gamma > 45$ MeV, branching ratio $\sim 10^{-9}$
  - Systematics found depending on # of hits on scintillation counters

$t_\gamma - t_e$ for $\mu \to e\nu\nu\gamma$ peak + flat BG

Fit line uses the same offset



# of hits on scintillator depends event by event.

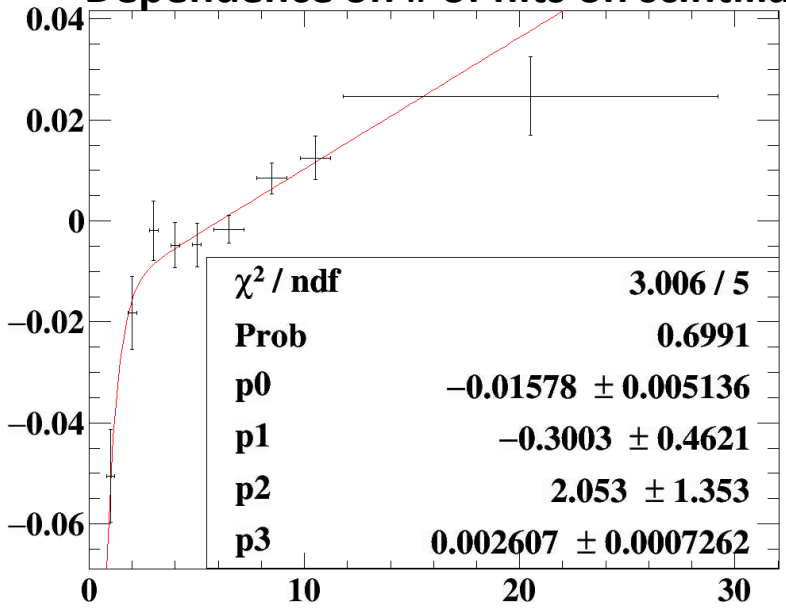


Systematics in positron timing

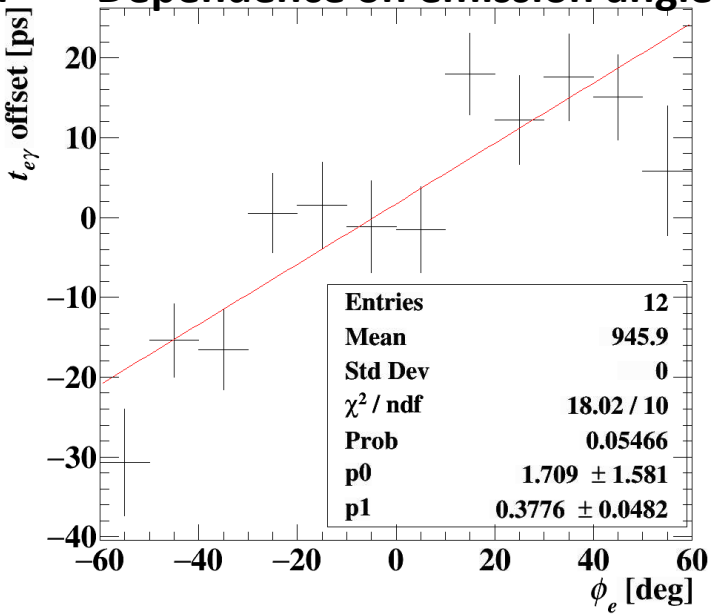
- Now, ad-hoc corrections are applied to positron timing to correct
  - ~ 70 ps dependence on # of hits
  - ~ 40 ps dependence on positron emission angle (also found in $\mu \to e\nu\nu\gamma$ samples)
- Possible candicate:
  - Bias in Time of Flight calculation
  - Systematic effects depending on hit position on counters

} Work in progress to understand

Dependence on # of hits on scintillator



Dependence on emission angle



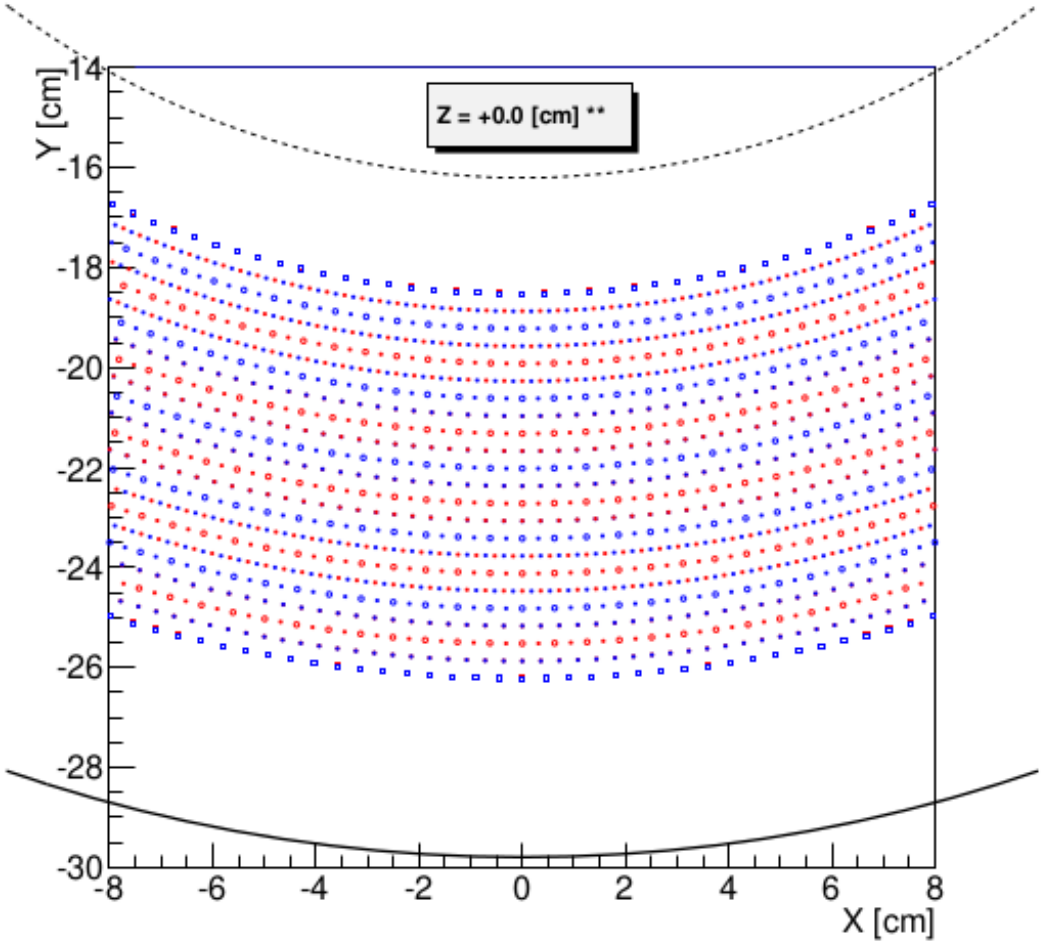
Summary

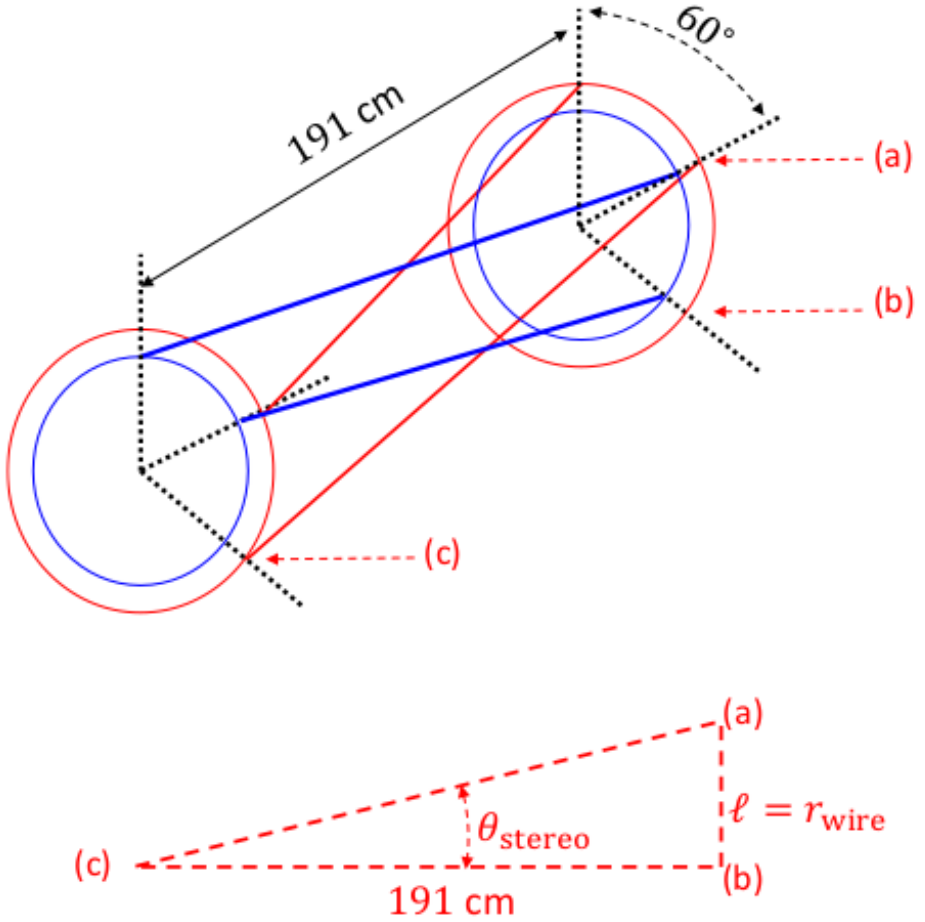
- DAQ
  - Despite several challenges, collected 3 weeks of data in 2024
  - LXe leak tightness has recovered and ready for 2025 DAQ
  - Improvement of LHe supply from PSI is under discussion

- Ongoing reconstruction works
  - Study of ML-based track finding algorithm:
    Aiming to increase the muon beam rate, as well as to better exploit already taken data
  - Study of systematics in calibration of positron timing:
    Room for improvement in time resolution

Backup

Chamber geometry

- 



Conventional tracking

- aa