Proposal of large tracking detectors for FASER II experiment

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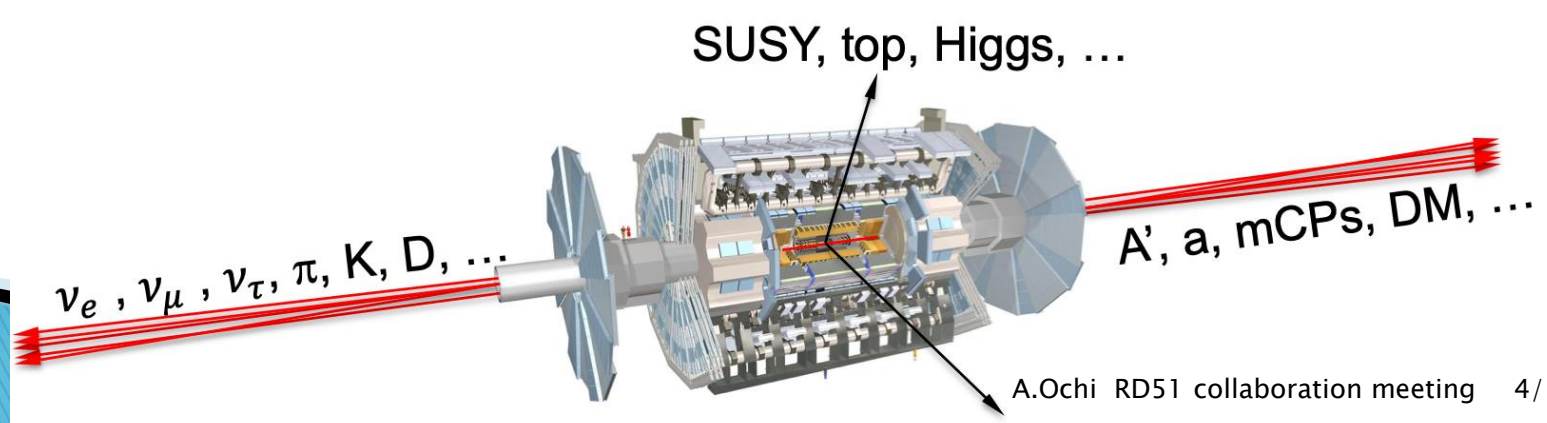
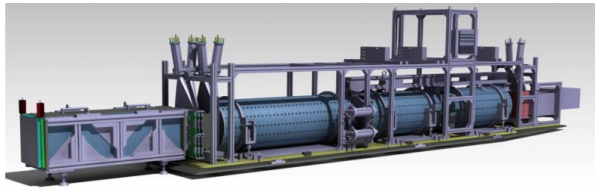
Exploring forward physics at the LHC

Copious hadrons (π, K, D, …) are generated toward forward direction of the LHC

- O(10^{15}) of π^0 in less than mrad from the beam axis for LHC-Run 3
  - New particles in MeV-GeV range could be produced and detected [paper]
    - Dark photon, Dark Higgs, Axion-like particle, …
  - TeV-energy collider neutrinos could be studied [paper]
    - All flavors of neutrinos including ν_τ which past accelerator experiments only observed 19 events
- FASER is the first experiment for these purpose
  - Need to cope with hash radiation environment in LHC nominal operation

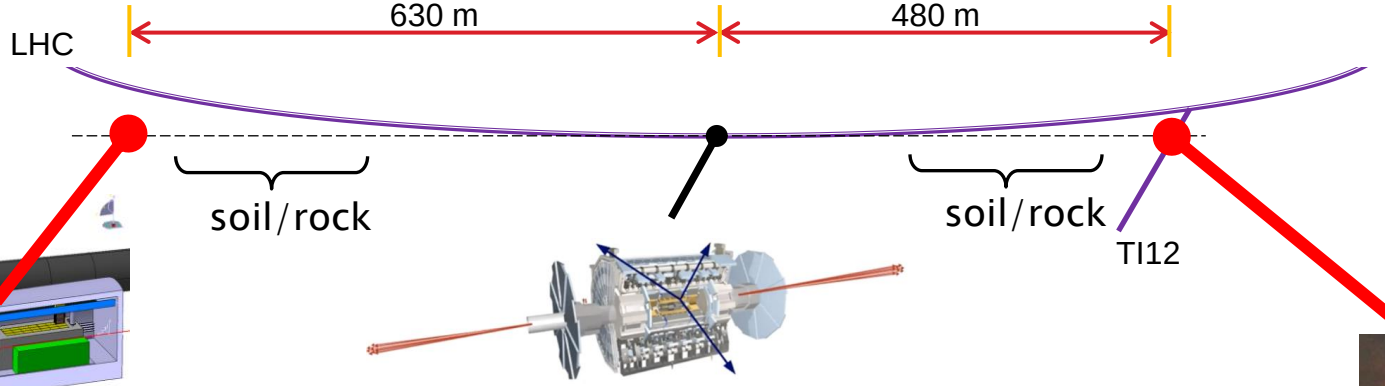




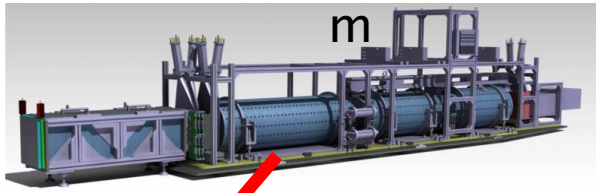
FASER and FASER 2

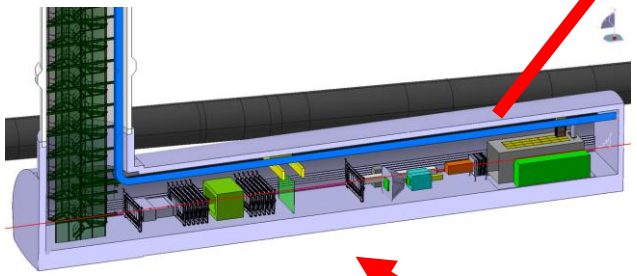
FASER is running in TI12 since 2022, aiming to start FASER 2 in Forward Physics Facility from 2031

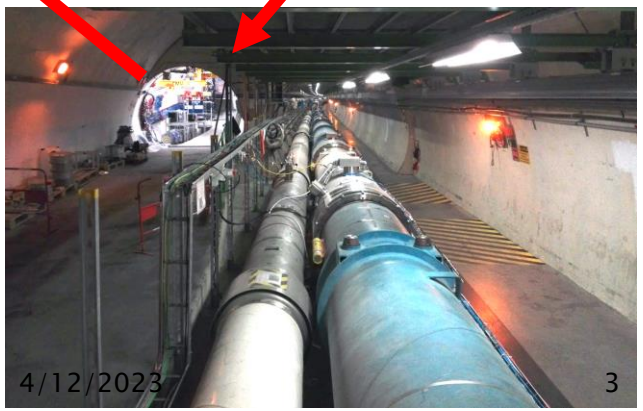
- Radiation is nicely shielded by natural soil/rocks, only trasmitting high-energy muon from IP at 1 Hz/cm^2
- TI12 is a small tunnel just next to LHC, while FPF is supposed to be a dedicated cavern decoupled from LHC



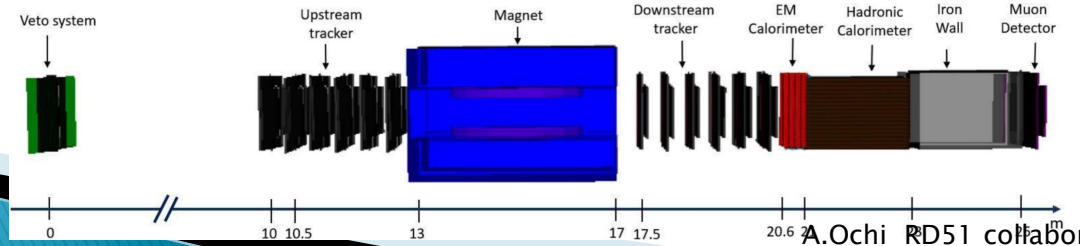
FASER in TI12
~ 0.5 m x 0.5 m x 6 m







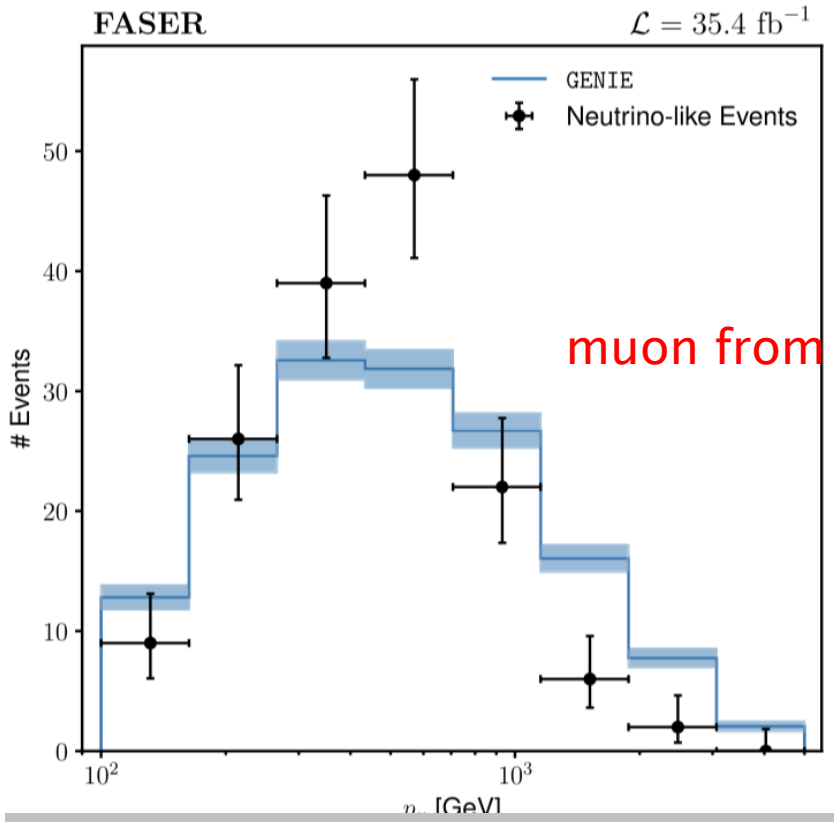
FASER 2 in FPF
~ 4 m x 3 m x 25 m



FASER physics result from 2022 data

The first collider neutrino observation

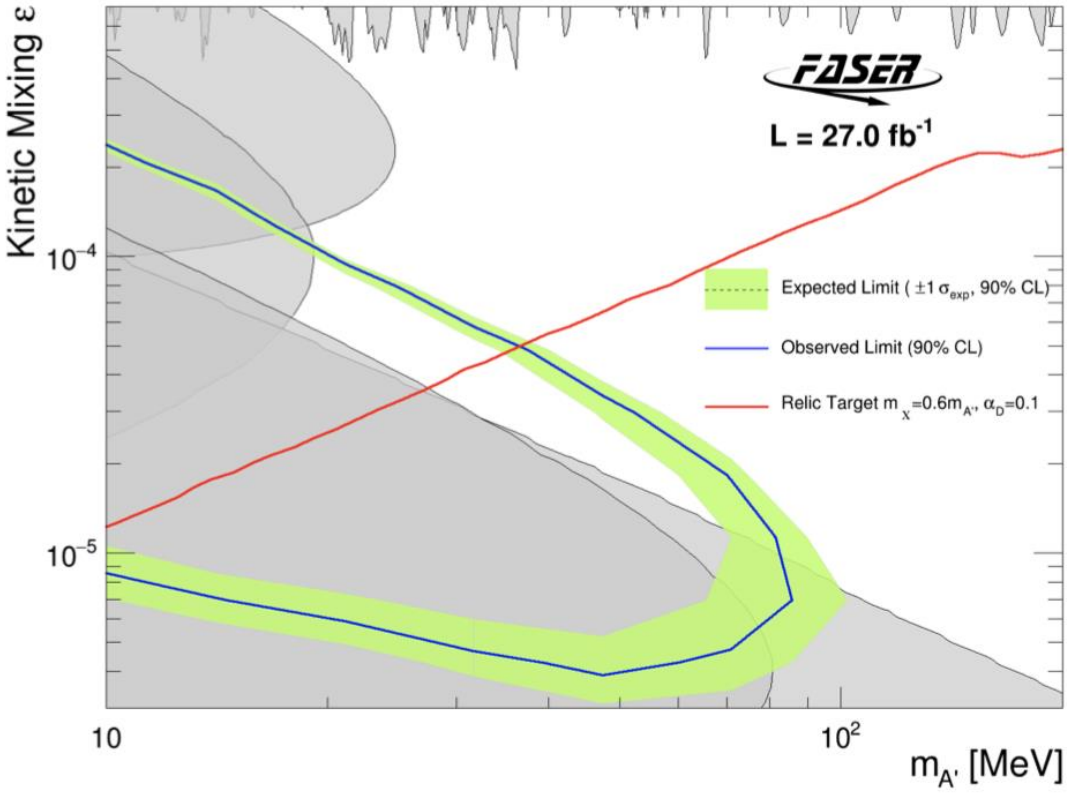
PRL 131, 031801 (2023)



muon from neutrino

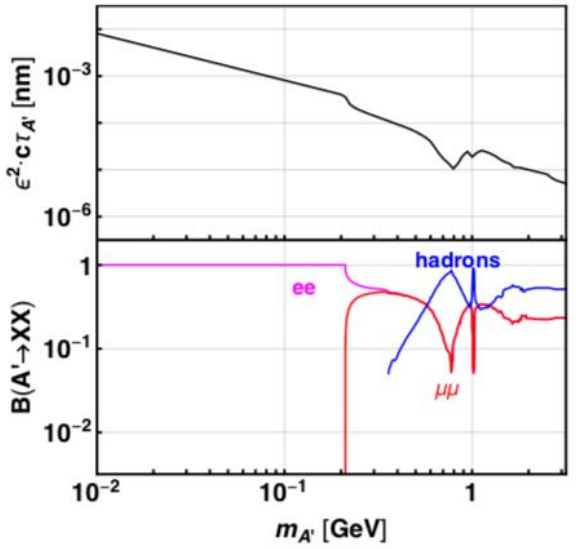
The first attempt of new particle search (null result)

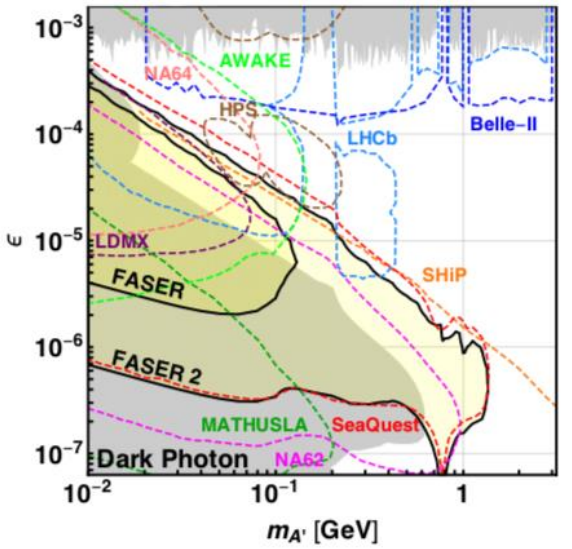
arXiv: 2308.05587



Quite active discussion toward FASER 2 in Forward Physics Facility (FPF) in HL- LHC era

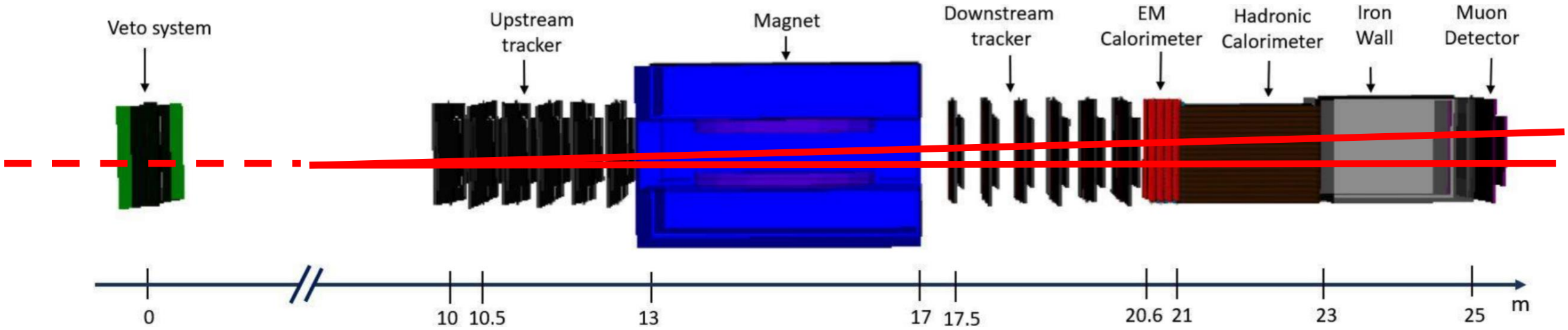
FASER 2





Bench mark process:

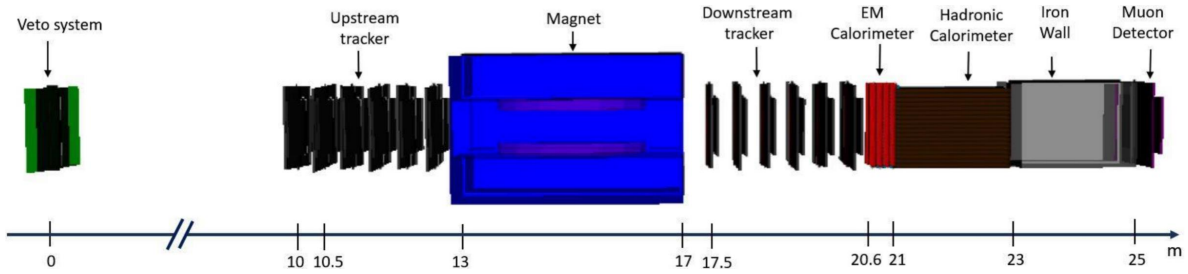
- $A' \rightarrow e^+e^-/\mu^+\mu^-/\pi^+\pi^-$ (A' = dark photon)
  - A' has a momentum of around TeV
  - Highly-collimated two charged particles should be separately reconstructed

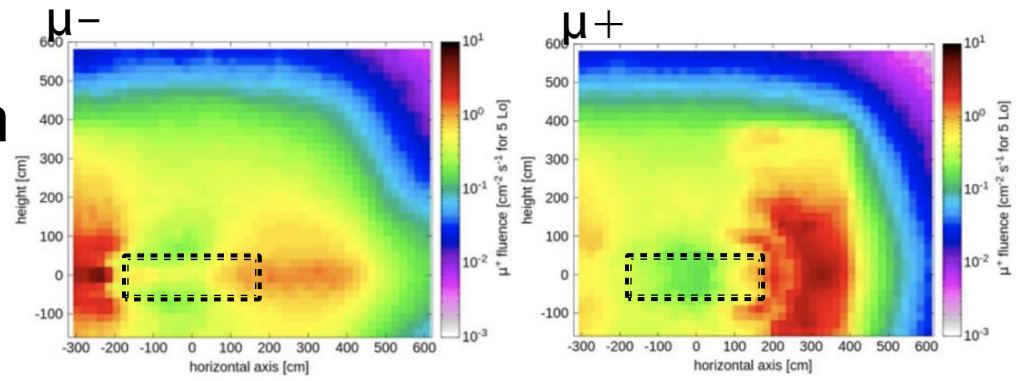


- $\nu_\mu + N \rightarrow \mu + X$
  - ν_μ also has a momentum of around TeV; momentum distribution of μ seen in the previous page

Requirments for FASER2 tracker

- Size: 1m x 3m, 10 layers
- Time resolution: < 25 ns
- Position resolution:
  - 100 um for horizontal axis
  - worse resolution acceptable for vertical axis
- Separation of two tracks with a few 100 um distance
- Material budget: 1% X_0 for each slice
- Rate: 50 kHz / layer dominated by muon
  - higher flux in the side
  - lower flux in the central region



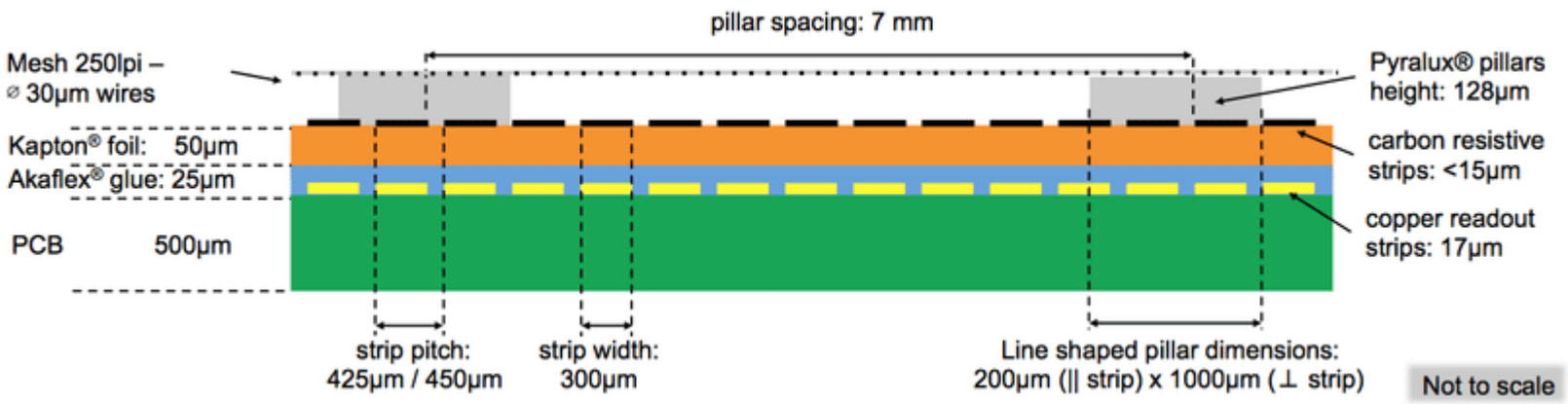


Gasous detector would be a good option for the FASER2 tracker

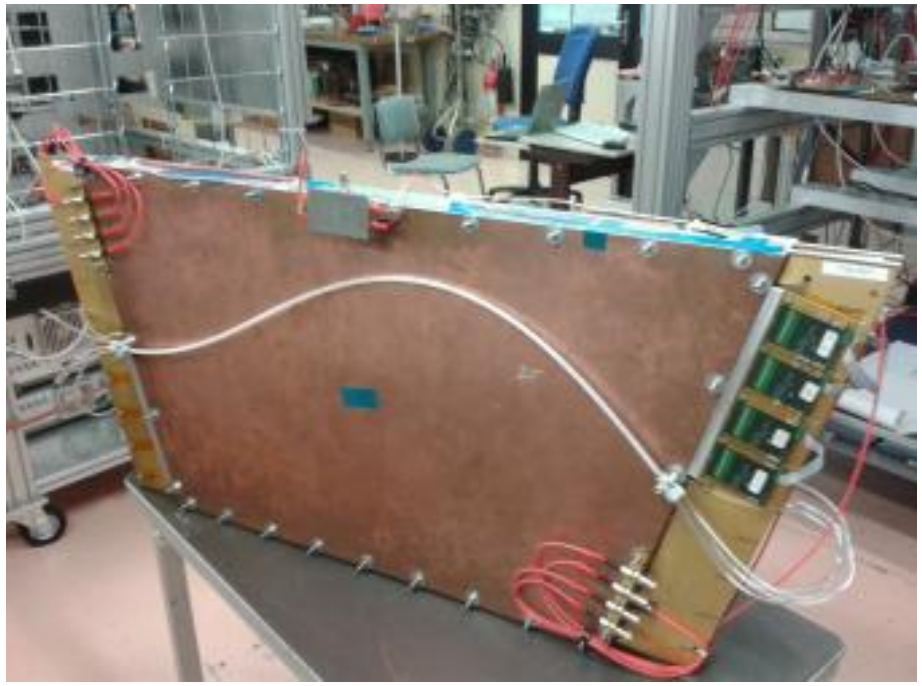
Candidates of Detector technology (Gas)

- MM
  - Large size (0.5m x 2m) has already been available (ATLAS NSW)
  - 1 dimensional readout with 400 μm pitch (NSW)
  - 250 μm pitch will be available (there is small prototype)
- GEM
  - Large size (?? X ??) has already been available (CMS GE1/2)
  - 1 dimensional readout (should be check) with 300 μm pitch (CMS)
- μ-RWELL
  - Large size (0.5 m x 2m) is available in prototype (should be check)

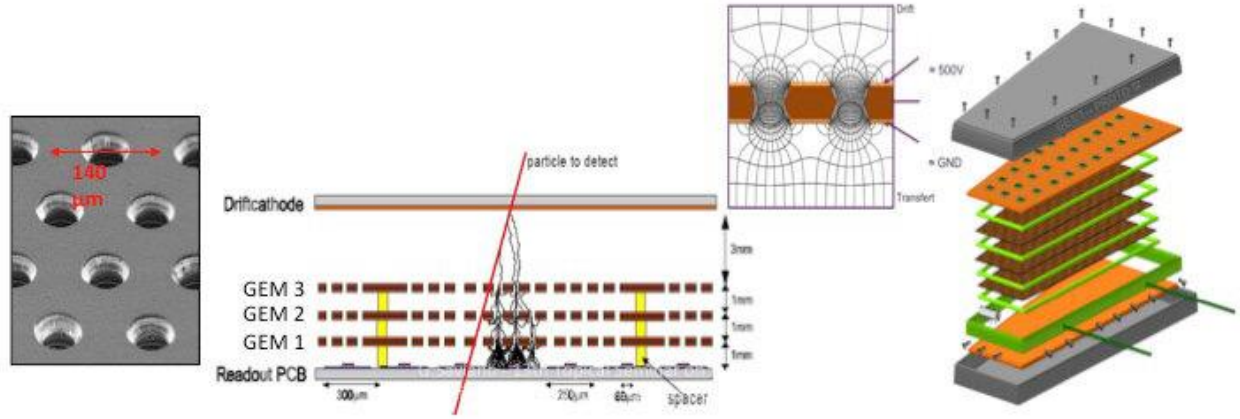
MM



- Large area … OK
- Granularity … > 250 um
- 2D readout … multi layer
- Material budget … may be OK

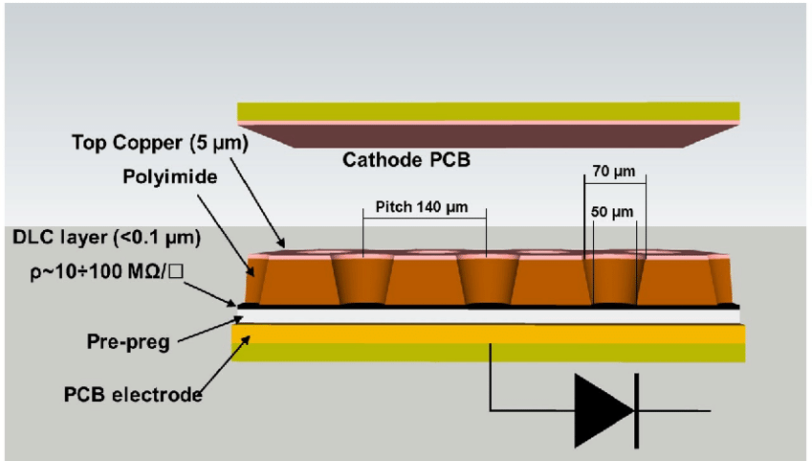


GEM



- Large area … OK
- Granularity … > 400 um ?
- 2D readout … OK?
- Material budget … depend on readout

μ-RWELL



- Large area … OK
- Granularity … > 140 um ?
- 2D readout … > OK (Top & PCB)
- Material budget … may be OK

Candidate, other than gaseous detector

Tracker | SciFi technology

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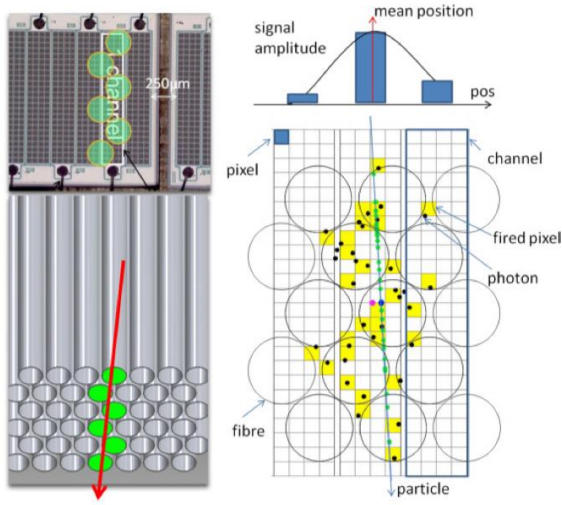
- Based on SciFi detector installed in LHCb in LS2.
  - SiPM+scintillating fibre design
  - Fibres 250um diameter => 80um resolution.
- Each module consists of a mat of 4 fibres, with >99% efficiency.
- Costing done by scaling LHCb detector to the FASER2 design, and includes readout.
- Cost could be reduced by re-using tooling from LHCb if relevant institutes were involved.



Candidate, other than gaseous detector

Tracker | Layout

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The upstream tracker

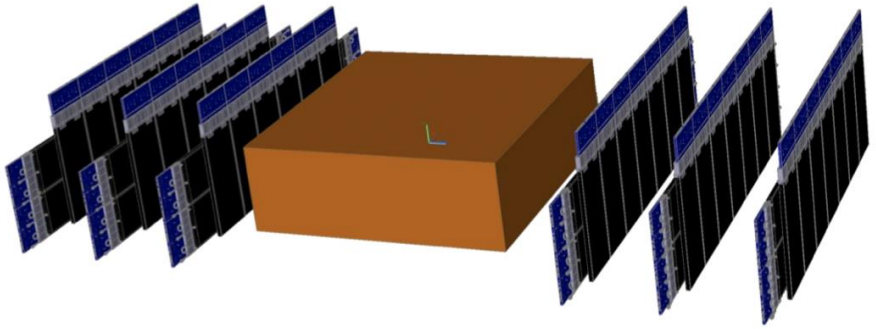
6 vertical + 2 horizontal modules makes up a station.

3 stations.

The downstream tracker

7 vertical + 2 horizontal modules makes up a station.

3 stations.



Sune Jakobsen

- The stations should be relatively rotated e.g. 1 degree to maximize performance for multi tracks etc.
- Cost: ~3.8M CHF

10 Josh McFayden I FPF6 I 6/6/2023

Electronics

Number of channel : (1m + 3m) / 400 um = 10 k channel per layer

- XY configuration with 90 degrees assumed
- 100 k channel in total expected for 10 layer
  - could be reduced by coarse pitch in the edge region, while finer pitch in the central region
  - could be reduced by having less number of layers

VMM (readout card with ASICs) + SRS (Scalable Readout System)

- Total ~ 700 k CHF assuming 100 k channel
  - VMM: 128ch / card (~ 400 CHF)
    - 1000 VMM cards -> ~400k CHF
  - SRS: 2kch / module (~5k CHF)
    - 50 modules -> ~ 250k CHF
    - 3 VME crate is needed ~ 50k CHF

Power supply

- To be estimated, hoping O(200-300k) CHF

1 MCHF or less would be a current guess for electronics

Schedule

2023

2024 Physics Beyond Collider (PBC) review early 2024

2025 LoI will be submitted early 2025, hopefully followed by TP submission

2026

2027 Detector Development/Production

2028

2029

2030 Detector installation

2031 Start the experiments

Summary

- We are starting the design of detector for FASER II experiment
- Large area (1m x 3m) with high granularity (sub mm) area detector is needed for separate multiple tracks.
- MPGDs are thought as ideal detectors for this purpose, and we are researching the technology choice.
- We will decide the technology by 2024 and write LOI in 2025
- Commissioning and Installation will be 2030, and Physics run will be start from 2031. Then we have 5 years for development and production.
- We welcome your idea and participation !