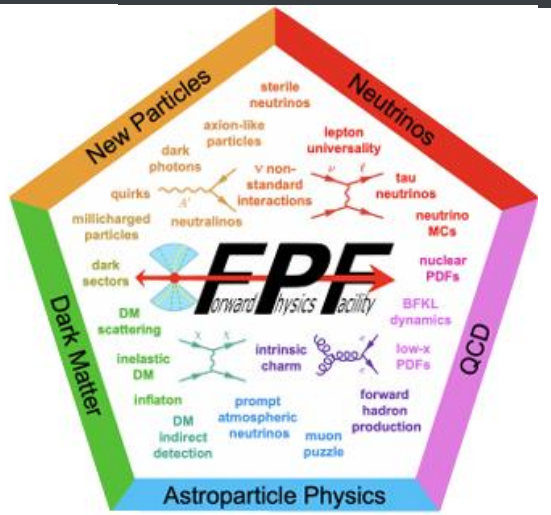


FASER2 Updates

FPF7 Workshop

29/02/2024

Olivier SALIN

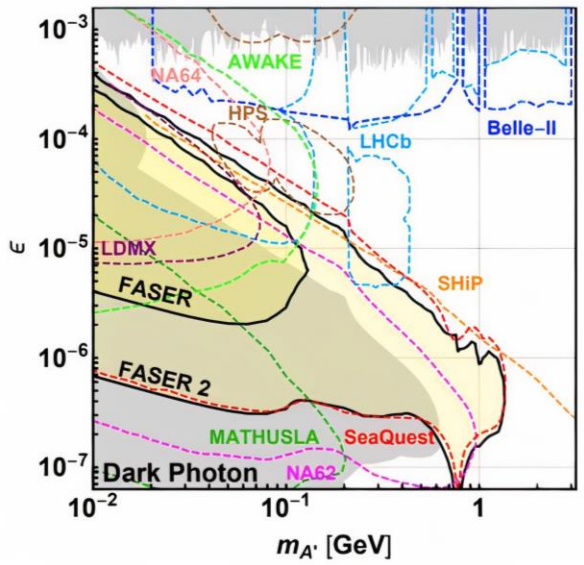
on behalf of the FASER2 collaboration

Olivier Salin - contact: olivier.salin@ens-paris-saclay.fr

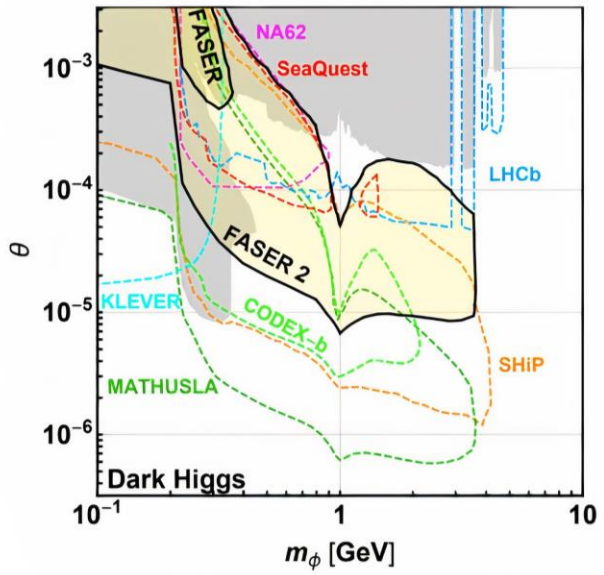
FASER2: Physics motivation

- Program for BSM physics
  - ➢ Search for long-lived particles

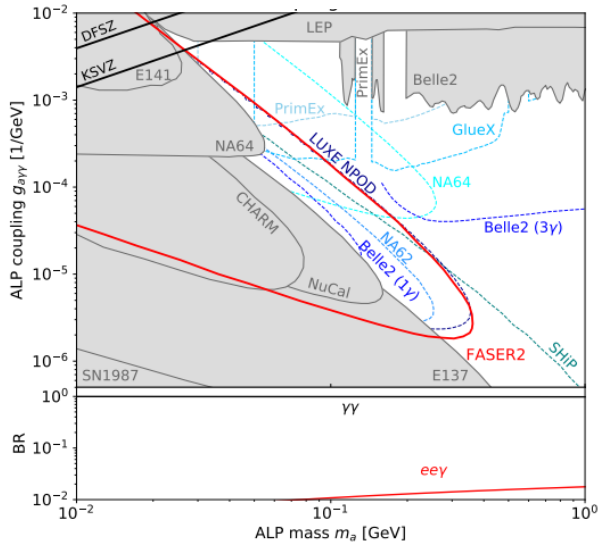
Dark Photon



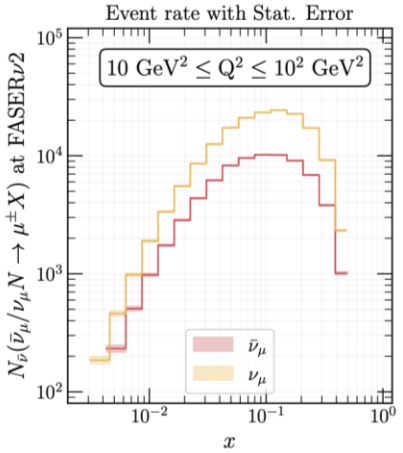
Dark Higgs



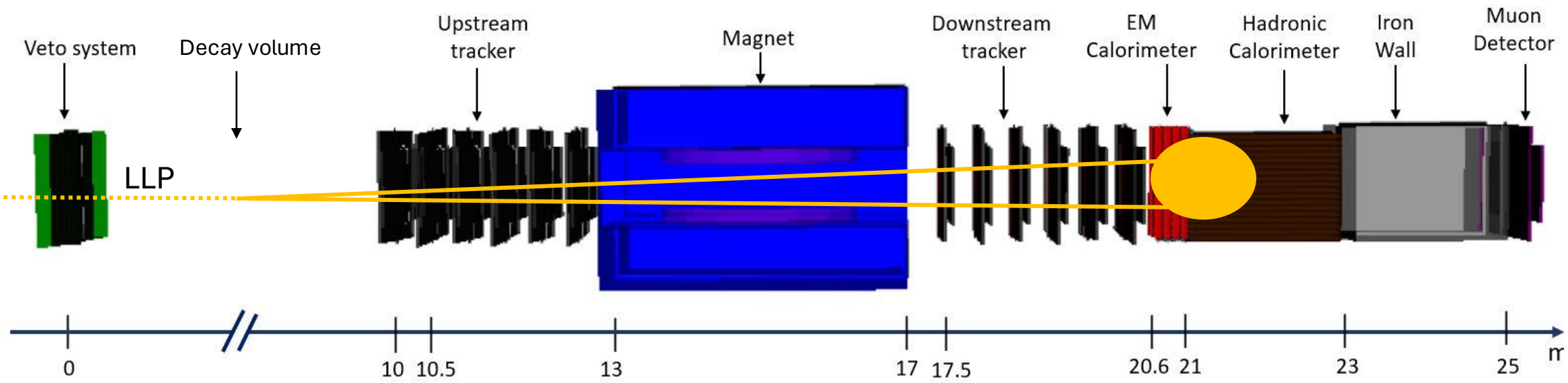
ALP coupling to photon



- Program for SM physics
  - ➢ Main spectrometer to neutrino experiments for the FPF (FLArE, FASERnu2)

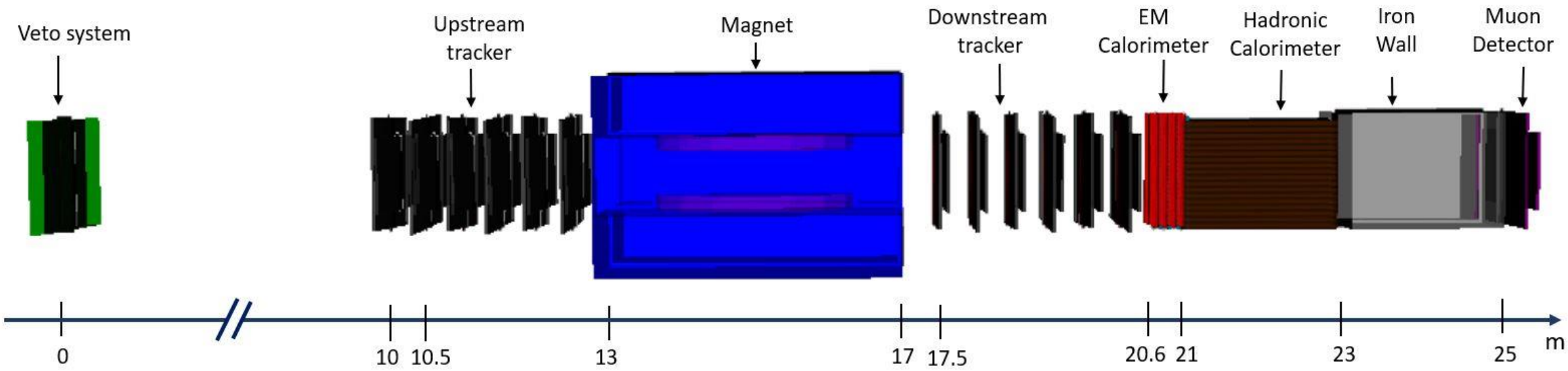


FASER2 Baseline detector



GDML/ Geant4 simulation of the detector created with pyg4ometry

FASER2 Baseline detector: Details



Tracker:

- Based on LHCb's SciFi tracker
- SiPM and scintillating fiber design
- Detector resolution: ~ 100 μm

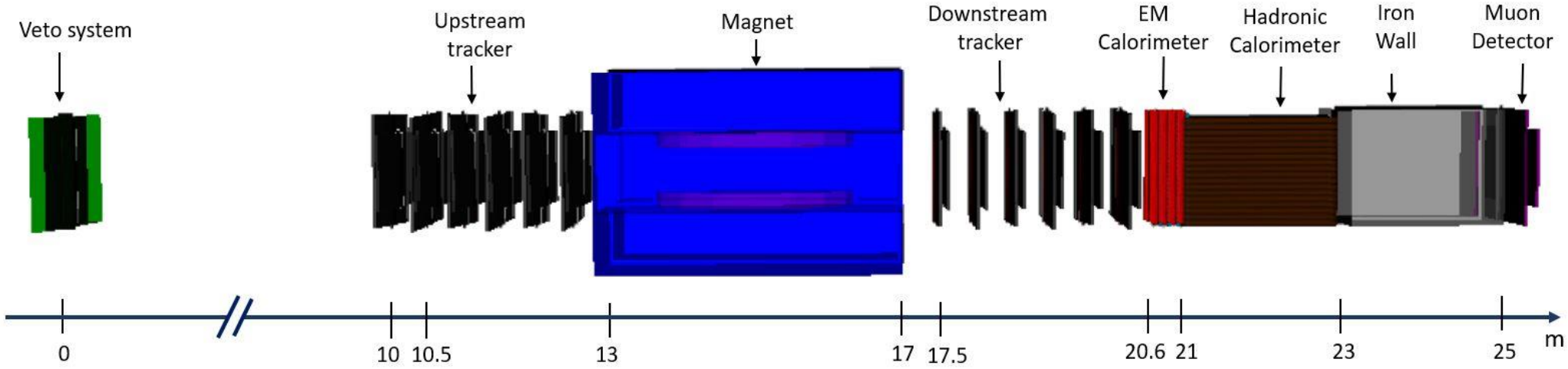
Magnet:

- Large aperture
- 3m wide X 1m gap
- Superconducting technology
- Magnetic Field : 2-4 Tm
- Based on the SAMURAI magnet

Calorimeter:

- Based on dual-readout calorimetery
- Spatial resolution: 1-10 mm

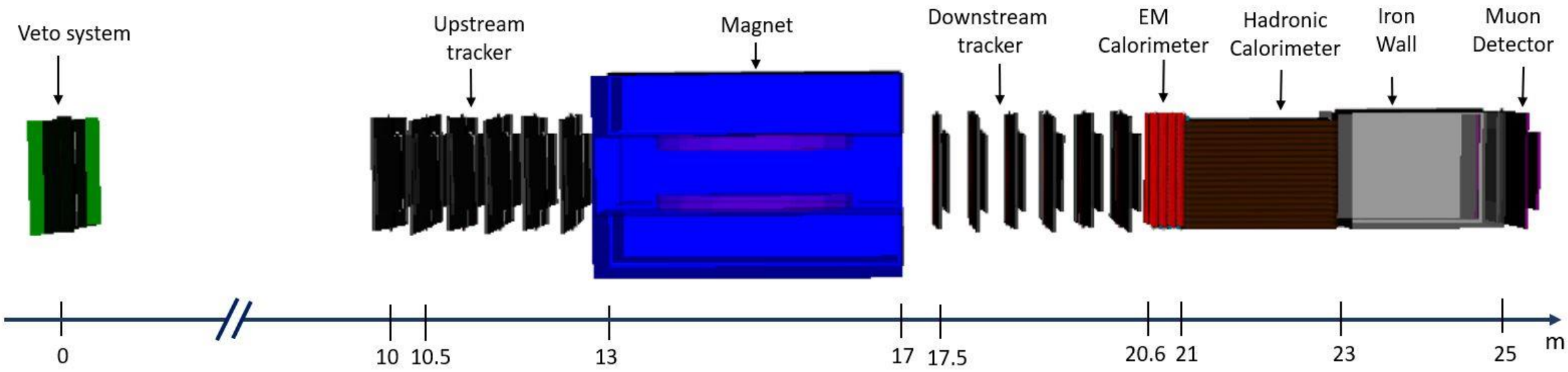
FASER2 Baseline detector: General consideration



Jamie Boyd

- Detector requirement and performance:
  - From well motivated physics benchmark
  - Aim to maintain high performance for model-independent physics
- Motivation for detector with less granularity and magnetic field at edge:
  - Near LOS: Particles highly boosted (O(1 TeV))
  - At 1m from LOS: Significant reduction in boost
- Motivation for detector squared shape detector :
  - Muon background increases with distance from LOS in the horizontal plane
  - More square-shaped detector (e.g., 1.7m x 1.7m) preferred over rectangular shapes (e.g., 3m x 1m)
  - Ongoing studies on optimizing detector shape for improved efficiency

FASER2 Baseline detector: Costing



- Previous costing estimation in the region of 20 MCHF
  - Cost mainly driven by magnet quotation (10 MCHF)

- Overall cost could be significantly lower than original estimate
  - Updated quotes for magnet is closer to 5 MCHF (Hidetoshi, KEK expert)
  - Investigation for reduced complexity for tracker and calorimeter

FASER2 Magnet: SAMURAI style magnet

- Presentation on FASER2 magnet by Hidetoshi Otono : link
  - Tomorrow at 11:30 (CERN time)

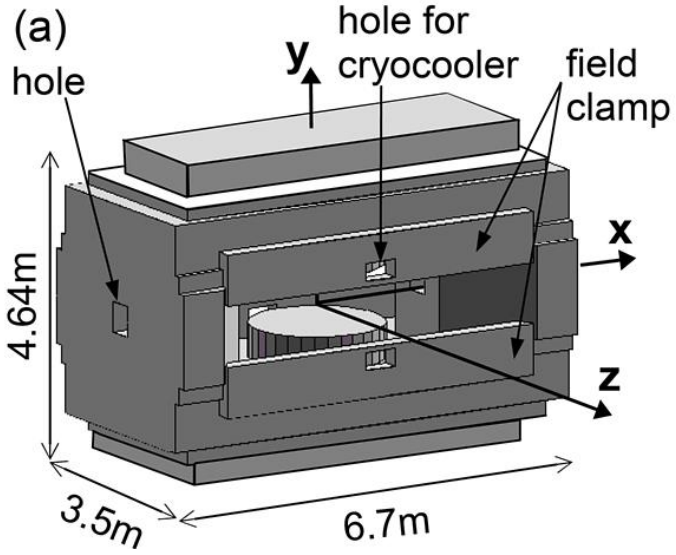
- SAMURAI Dipole Magnet as a reference
  - Aperture: 88cm X 340cm
  - Field integral 7 Tm

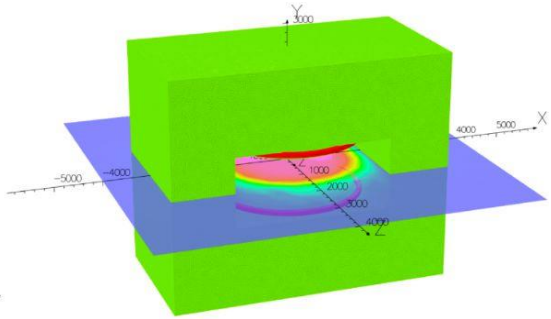
- FASER2 magnet based on SAMURAI:
  - **Dimension**: 3m wide X 1m gap X 4m along LOS
  - **Integrated field**: 4 Tm
  - **Stored energy:** 7 MJ
  - **Power consumption:** 36.2 kW
  - **Superconducting:** Cryogenic infrastructure needed

- On going study to optimise magnet design:
  - Reduce field strength: 2 Tm
  - Enlarging pole gap to 2 m with reduced width

- Discussion and study with KEK experts (Naoyuki SUMI)
  - Conceptual design, Field map, Current density, return yoke

Made by Toshiba for RIKEN

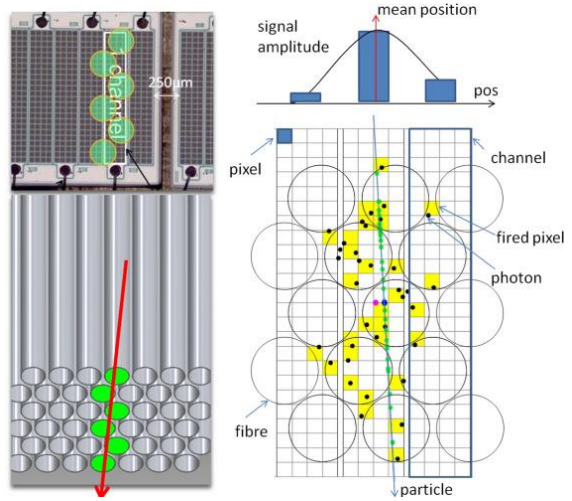




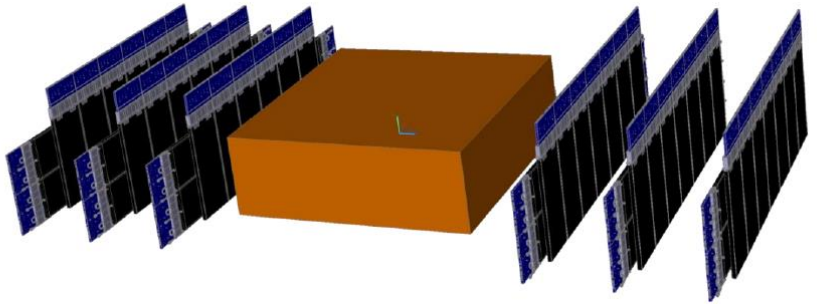
FASER2 Tracker: SciFi technology

Expert: Sune Jakobsen

- Based on SciFi detector installed in LHCb in LS2
  - SiPM + Scintillating fiber design
  - Resolution ~ 80 μm (fibers diameter 250 μm)
  - Each module consists mat of 4 fibers with > 99% efficiency
  - Power comsumption: 10 kW



- FASER2 tracking station layout
  - Active area of 3m X 1m
  - Composed of vertical and horizontal fiber layers
  - Stations relatively rotated e.g angle of 1°



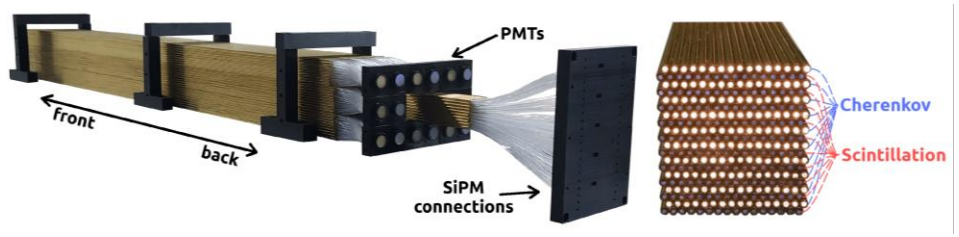
- Cost could be reduced by re-using tooling from LHCb if relevant institudes involved

- Possibility to directly use LHCb's SciFi modules (removed in LS4) for "free" (depend on schedule)

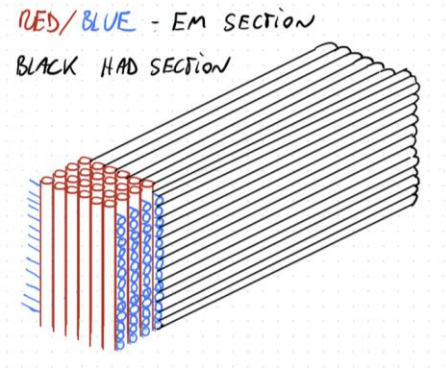
FASER2 Calorimeter: Dual-readout technology

Expert: Iacopo Vivarelli

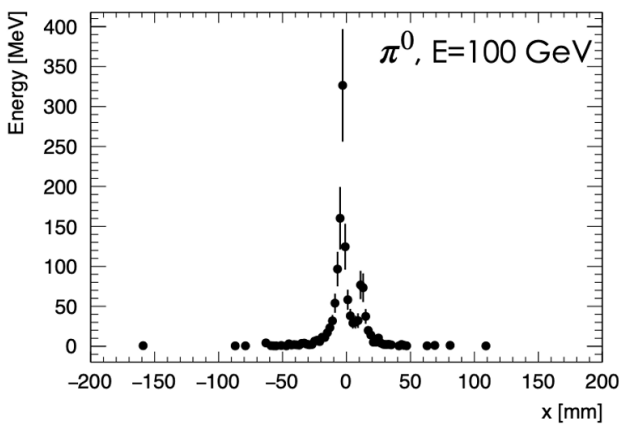
- Design based on dual readout calorimeter prototype
  - Prototypes for Higgs factory detector
  - EM prototype and HiDRa prototype – INFN: test beam

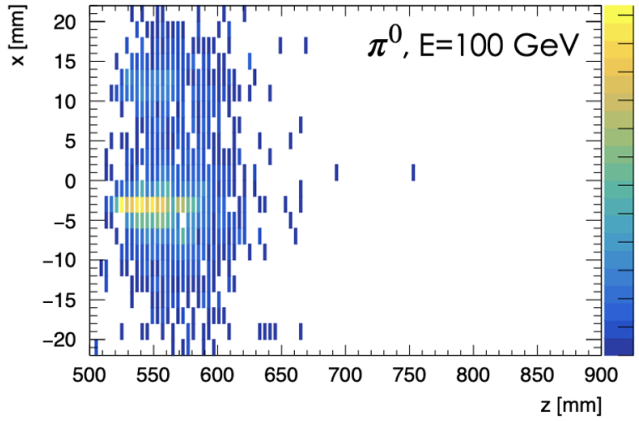


- FASER2 calorimeter design:
  - Fiber diameter 1 mm, 2 mm brass collar
  - Spatial resolution: ~ 5 mm
  - EM energy resolution: $\frac{\sigma}{E} = \frac{14.5\%}{\sqrt{E}} + 0.1\%$
  - Power consumption: ~ 3 kW (EM), ~ 1.3 kW (Hadronic)
  - Less granular for outer regions of the detector
    - Reduce number of chanels



- Calorimeter performances Geant4 simulation
  - Simulation π0 -> γγ

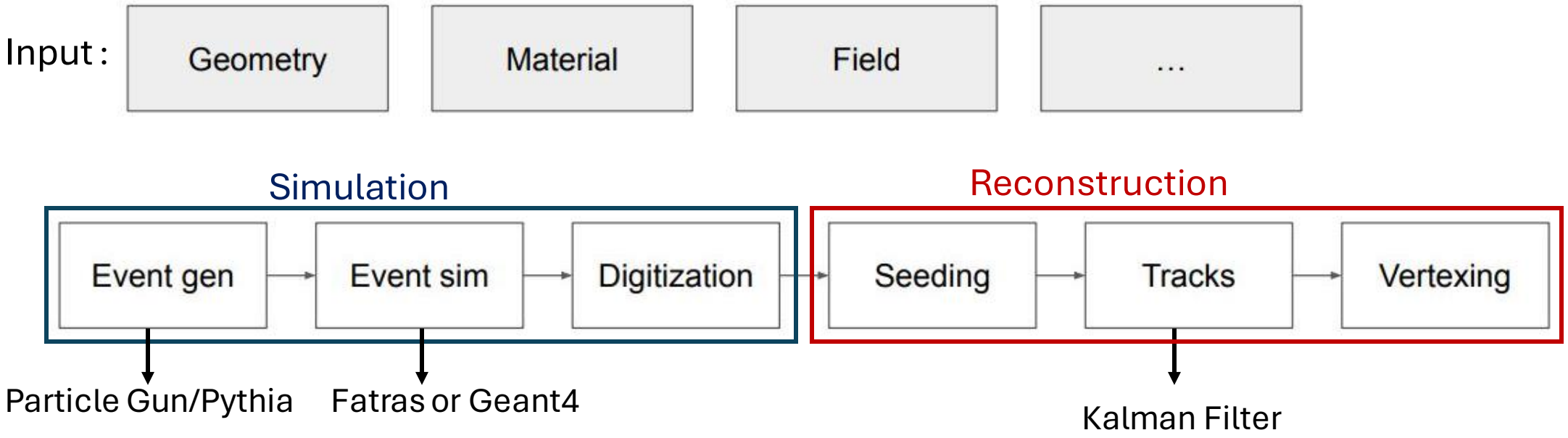




FASER2 Software: A Common Tracking Software (ACTS)

- ACTS: Modern tracking toolkit for detectors based on LHC tracking experience
- Implemented in experiments such as FASER, LDMX, ALICE

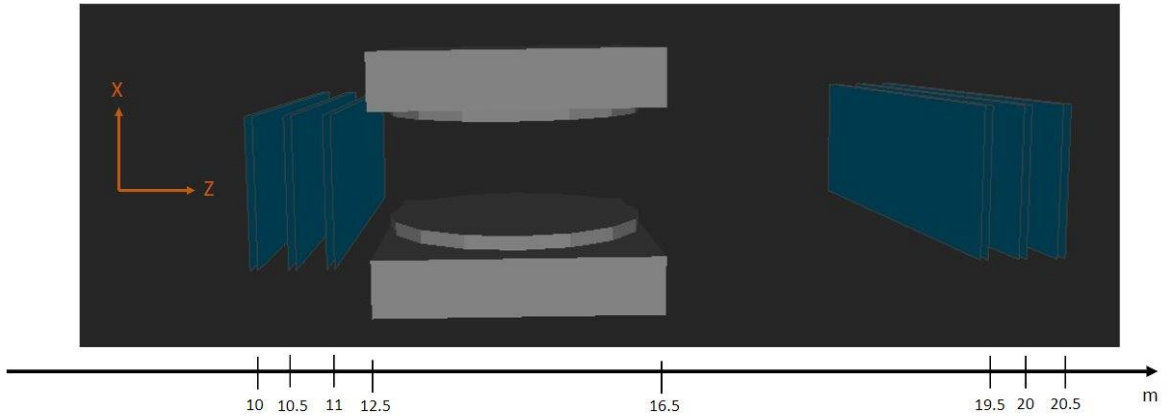
- Common algorithms for simulation and track reconstruction



- Could be used as main tracking software for the FPF (need adaptation forward region)
- Active and helpful communities of developpers

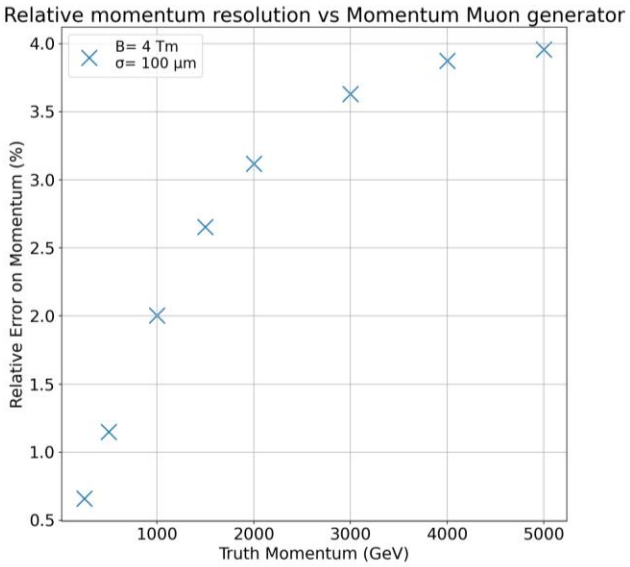
FASER2 Software: A Common Tracking Software (ACTS)

- Hypothesis for ACTS implementation:
  - Tracker with homogeous material and accurate X0
  - Tracker resolution digitized as 100 μm
  - Constant magnetic field within the magnet volume
  - No background
  - Truth track finding algorithm
  - Rotation of axis to avoid high eta region

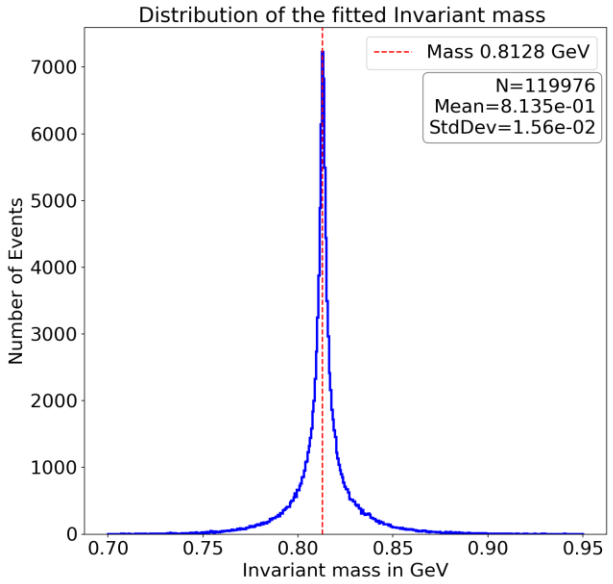


- Study of tracking performances for different metrics

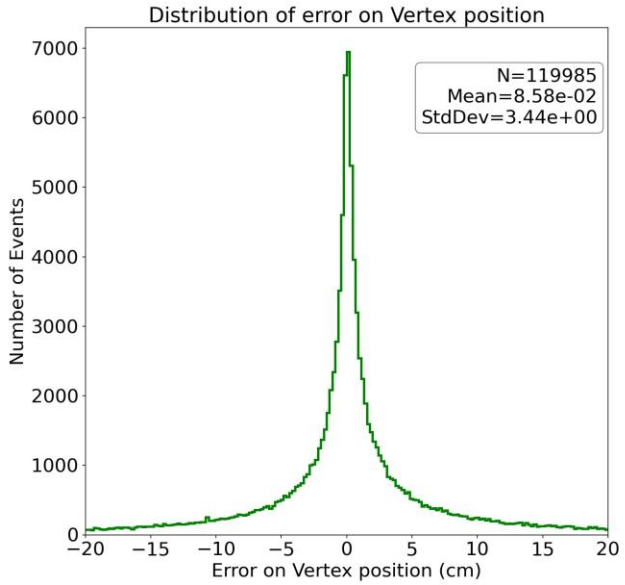
Momentum resolution



Mass resolution



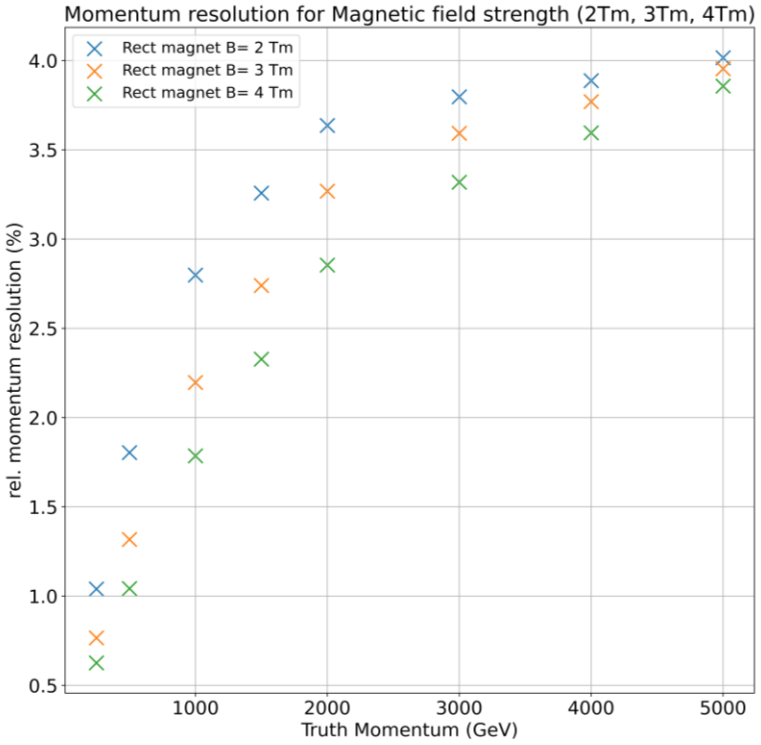
Vertex resolution



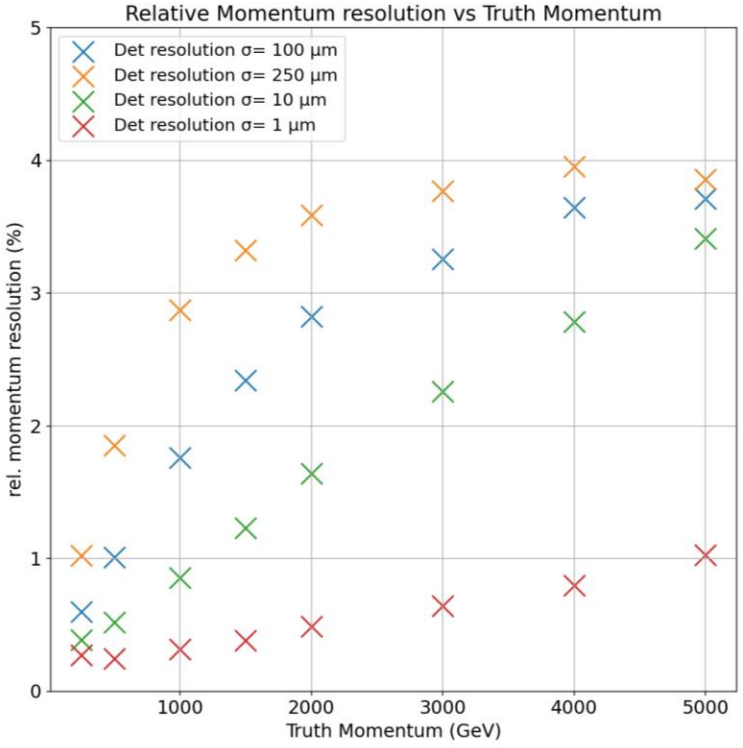
FASER2 Software: Performances

- ACTS performance plots for different FASER2 detector configurations/parameters

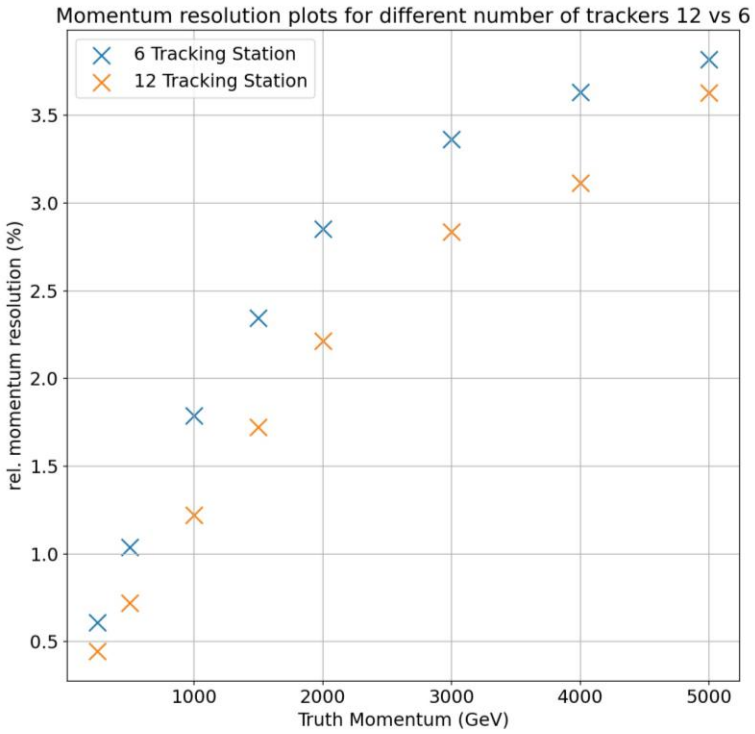
Field strength



Tracker resolution



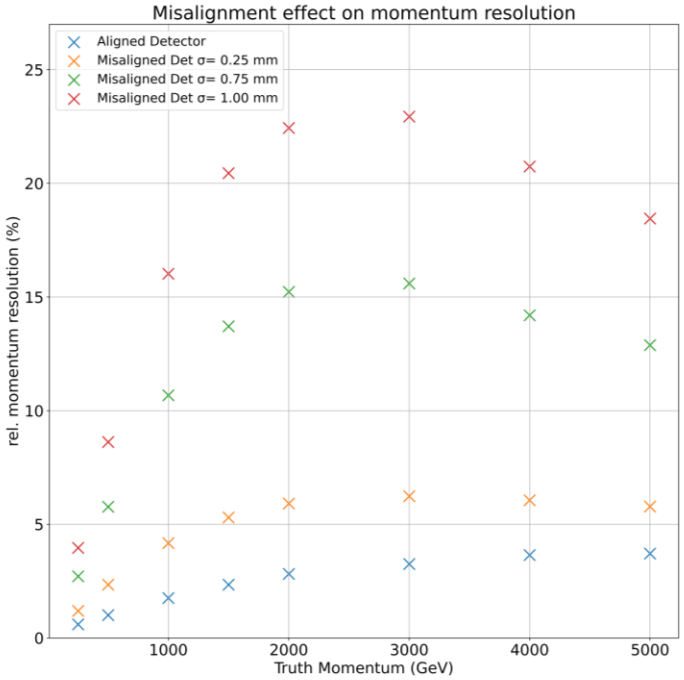
Number of tracking station

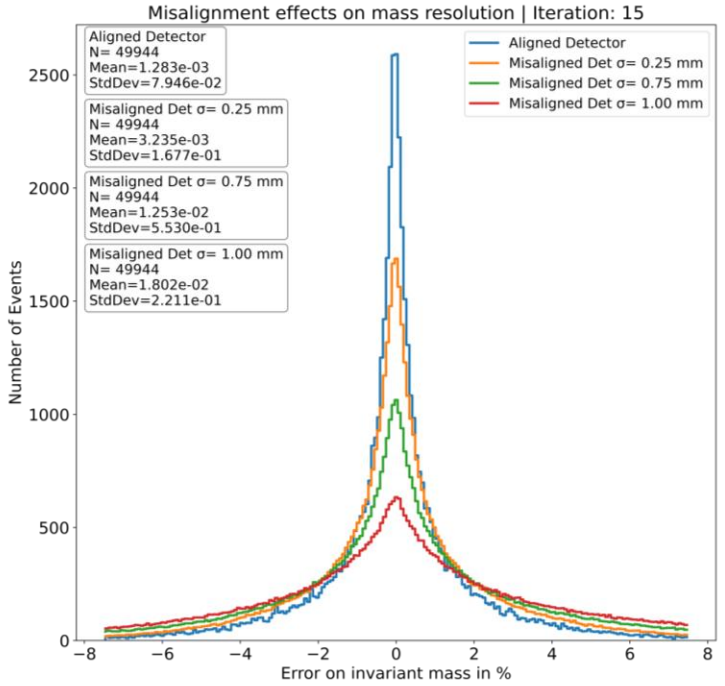


- Momentum resolution remains good while reducing magnetic field to 2 Tm
- Effect of tracker resolution on the momentum resolution
- Good performances with 6 tracking layers configuration

FASER2 Software: Alignment

- ACTS performance plots for detector toy misalignment of FASER2
- Study identifies the tracker alignment is a key performance driver





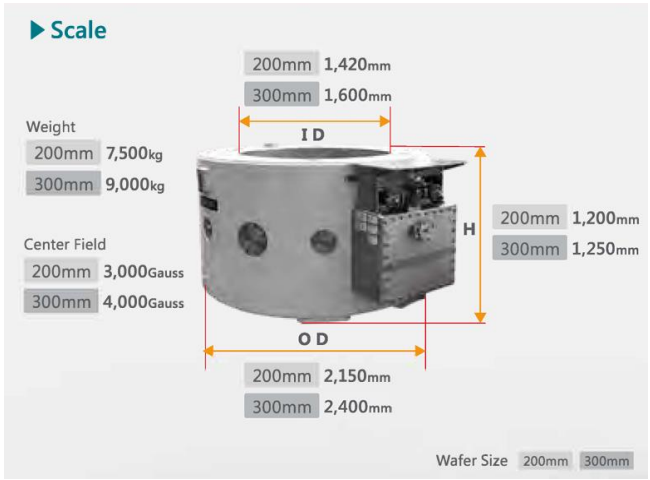
- Misalignment of tracking station > 250 μm starts to have significant impact on momentum resolution
- Expected mechanical precision should have alignment precision of 250 μm
  - ➢ Achieving 250μm alignment precision across large detectors (~10m appart) is challenging
- On-going studies to use the muon background for track alignment (Luke Kennedy)

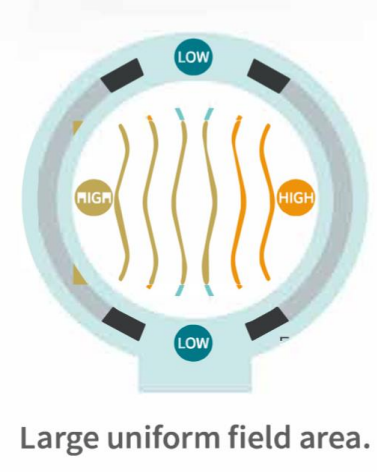
FASER2 Alternative design: Crystal puller magnet

- Possibility to use off-the-shelf crystall puller magnets from Toshiba (Japan) or TESLA electronics (UK)
  - Site visit to both Toshiba (Milind Diwan) and TESLA (Alan Barr) by FPF team

TESLA

Toshiba



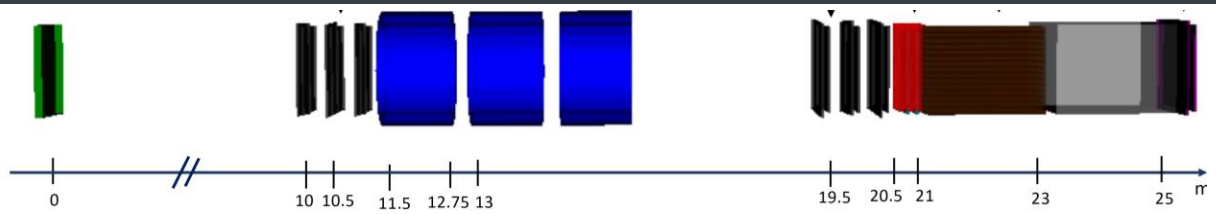


- Both of those Industrial Crystall puller magnet:
  - Central field of 0.4 - 0.5 T
  - Can be chained together to have incresead integrated magnetic field
  - Apperture diameter of 1.6 m (up to 2 m)
  - **Advantages**: Off the shelf, no R&D needed, cryo system integrated into design

- More information on FASER2 magnet talk by Hidetoshi Otono : link

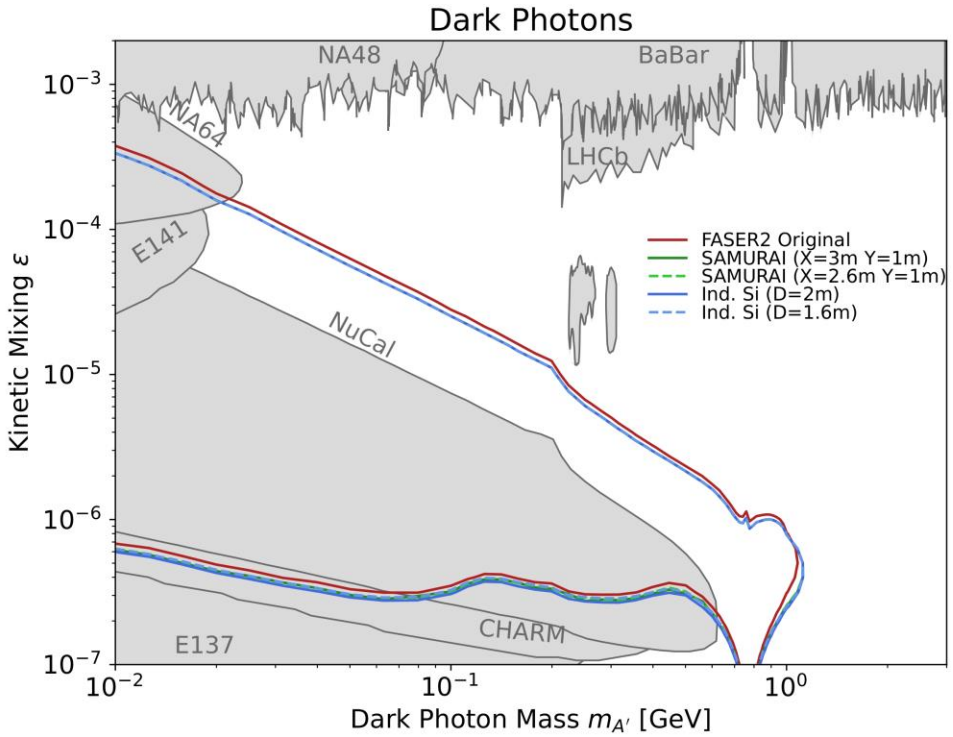
FASER2 Alternative design: Crystal puller magnet

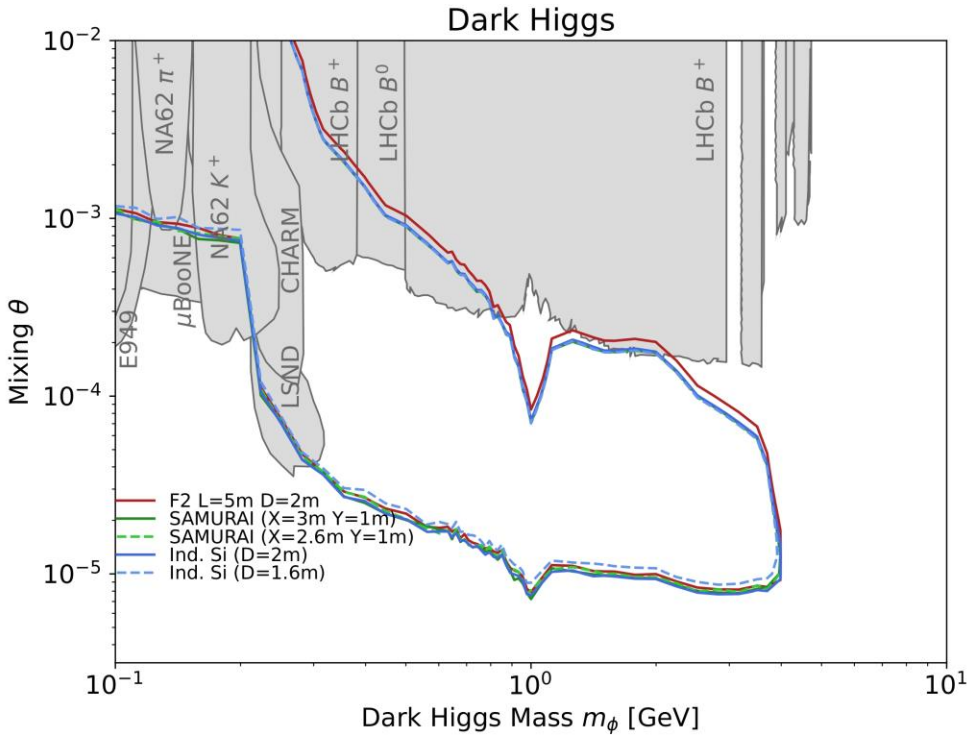
FASER2 design with
Crystal pulling magnet



Expert: Josh McFayden

- Sensitivity plots for Dark Photons and Dark Higgs comparison for FASER2 designs options



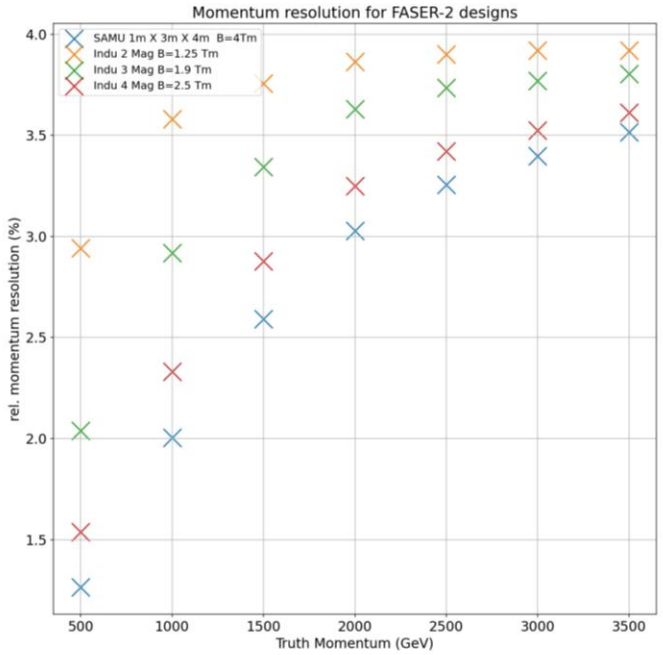


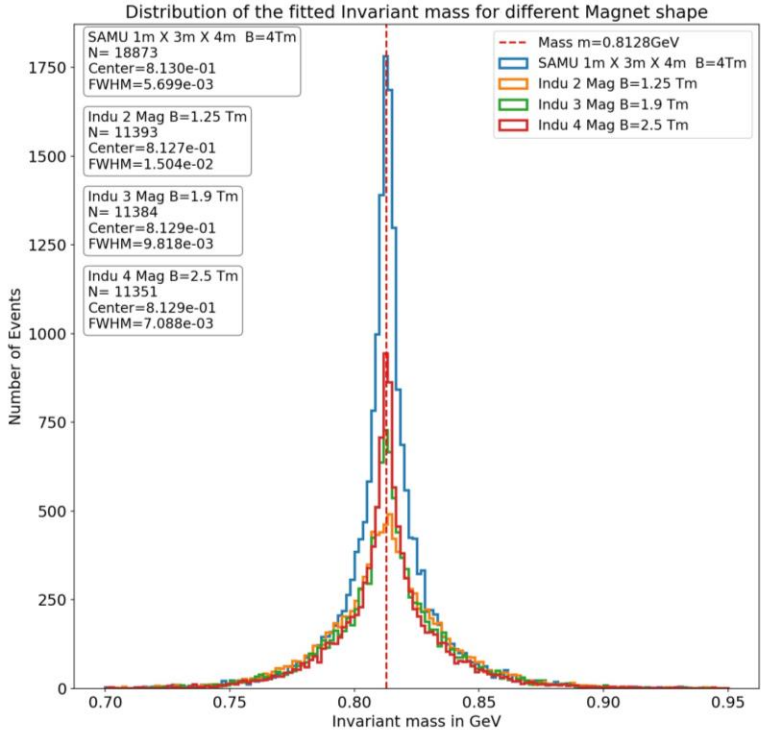
- Crytal puller magnet have similar sensitivity for LLP as SAMURAI style magnet aperture

FASER2 Alternative design: Crystal puller magnet

FASER2 design with
Crystal pulling magnet

- Track reconstruction resolution for FASER2 design options
  - Number of Crystal Puller magnets from 2 – 4 modules
  - Field strength: from 1.25 Tm to 2.5 Tm





- Crystal puller magnets keeps good performance on momentum resolution
- Performance for design with 3 or 4 Crystal puller magnets modules close to SAMURAI magnet

FASER2 muon acceptance from FLArE

- Study made by Matteo Vicienzi (BNL) and Wenjie Wu from (UCI) from FLArE collaboration: more details
- Muon from neutrino interaction in FLArE simulated in detailled Geant4 simulation

FPF options to bring FASER2 and FLArE closer

Muon acceptance for FASER2 configurations

	SAMURAI 1 m gap x 3 m	SAMURAI 1.5 m gap x 2 m	Crystal puller 1.6 m diameter
37 m	40 %	51%	50%
30 m	45%	56%	58%
17 m	60%	71%	72%

- To maximise the muon acceptance from FLArE (and FASERnu2) into FASER2
  - ➢ Minimising distance between FASER2 and FLArE
  - ➢ Increasing the pole gap of the SAMURAI magnet option is prefered
  - ➢ Crystal puller magnet alternative offer good muon acceptance

FASER2 performance documentation

Contents

Josh McFayden, Alan Barr
Jamie Boyd, Olivier Salin

- FASER2 physics studies and detector performance documentation in preparation
  - Requirement for the detector
  - Summarise performance studies
  - Sensitivity plots, Track reconstruction, neutrino acceptance
  - Benchmark detectors performances comparison

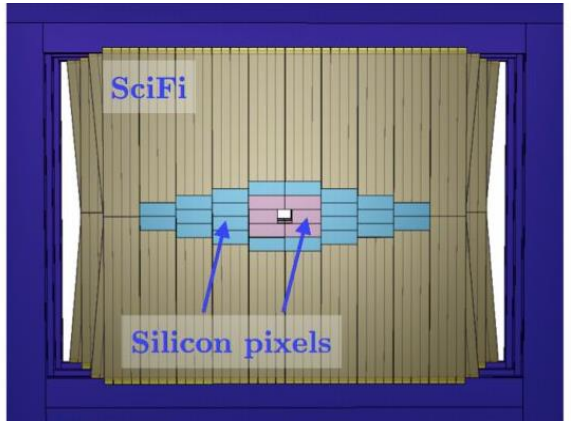
- Basis of our input for PBC document (summer 2024) and FPF LoI

FASER2 Alternative design: Tracker proposals

Proposition: Pixel Mighty tracker (LHCb Run 5 upgrade)

Monica D'Onofrio, Carl Gwilliam
Eva Vilella-Figueraz

- Mighty pixels modules in central region of tracking layers:
  - Achieve better resolution on layer before magnets ~ 50 μm
  - Better separation for close-by tracks in central region
  - Interest of UK institutes (Liverpool, Manchester, RAL)

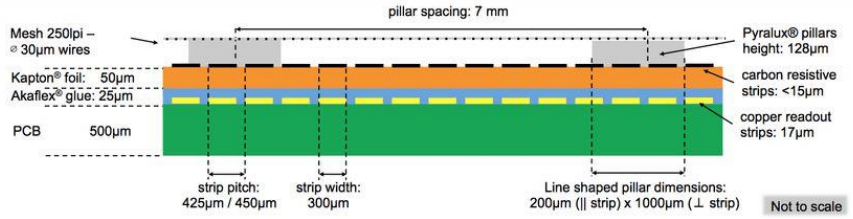


Proposition: Gaseous trackers

Hidetoshi OTONO, Atsuhiko Ochi

- MPDG tracker option for FASER2:
  - ATLAS Micro Megas, CMS GEM, μ-RWELL
  - Less than 1 MCHF for 10 layers
  - Less than 1 MCHF for the electronics
  - For MGTD option discussion within RD51 collaboration
  - Studies needed for reconstruction of closely separated tracks

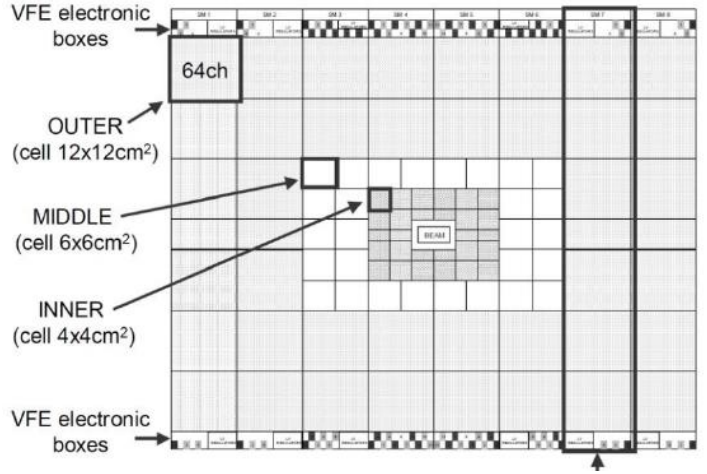
ATLAS Micro Megas

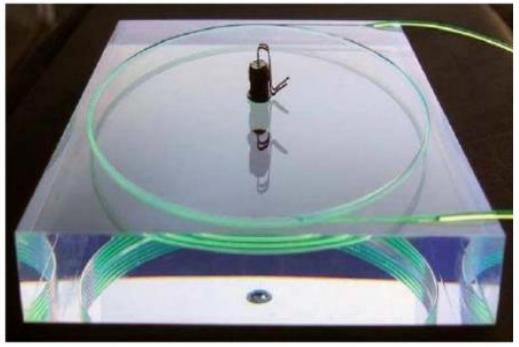


FASER2 Alternative design: LHCb preshower

Jamie Boyd, Sune Jakobsen
Iacopo Vivarelli, Josh McFayden

- Possibility to reuse old LHCb Preshower and Scintillating Pad Detector for part of the FASER2 calorimeter (outer region of the calorimeter)
- Considerable possible cost saving
- Simulation studies in progress to investigate feasibility and performance





FASER2 community

- We are working to build and consolidate the community and possible funding routes for FASER2

- **UK interest and involvement** – FPF UK meeting (11/10/23):
  - Oxford, Sussex, Liverpool, Manchester, RAL, Sheffield
  - Dual Readout/ Tracking/ Support structures/ Simulation and data analysis
  - Preparing statement of interest with STFC

- **Geneva:** Investigating options within Switzerland

- **Japan**: FASER2 & FASERnu2 in process of being included in one of Grand Vision summarised by Science Council of Japan

- **US**: FASER groups to look at applying for NSF funds for FASER2 work
  - UCI, Washington, Oregon

- **Serbia**: Activities on FASER2 studies
  - Belgrade group: Marija Vranješ Milosavljević, Nenad Vranješ, Darko Brunet

- Expected increased involvement from existing FASER collaboration

Future studies

- Expected trigger rate
  - ➢ Effect on DAQ system design for acceptable physics deadtime
- Expected background from neutrino interaction:
  - ➢ Possible mitigation of this effect
- Study on detector material effect on electron and photon reconstruction performance
- Study on ALPs reconstruction and performance of the detector

Summary

- Studies on detector and magnet technology made significant progress:
  - Magnet – FASER2 magnet talk by Hidetoshi Otono : link:
    - Extended discussion with KEK experts on SAMURAI style magnet conceptual design
    - Contact and visit for industrial crystal puller magnet (Toshiba, TESLA)
    - Good performance expected for both options
  - Tracker:
    - Design and costing advanced building on experience from LHCb SciFi
    - Advanced simulation and track reconstructions studies
    - Alternative tracker: Gaseous tracker, hybrid SciFi and Mighty tracker
  - Calorimeter
    - Design and costing from existing prototype
    - Performance from Geant4 simulation
- Work toward the PBC document (summer 2024)
    - Physics studies with benchmark models to asses detector performances
    - Detector options with more or less cost/complexity
- Several avenues for funding being pursued in UK/US/Japan