FASER2 magnet

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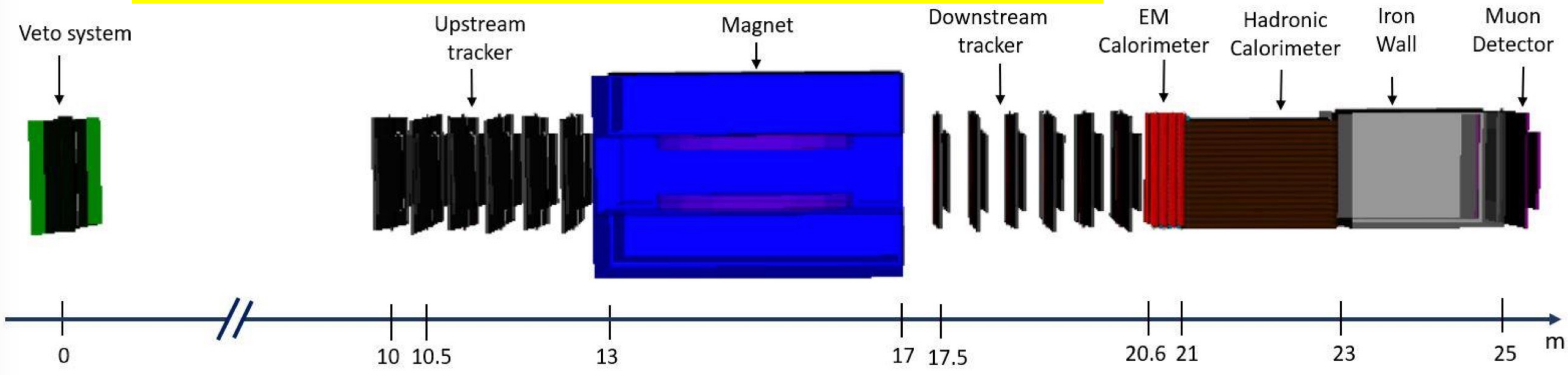
01/03/2024 FPF7 at CERN

Two options considered:

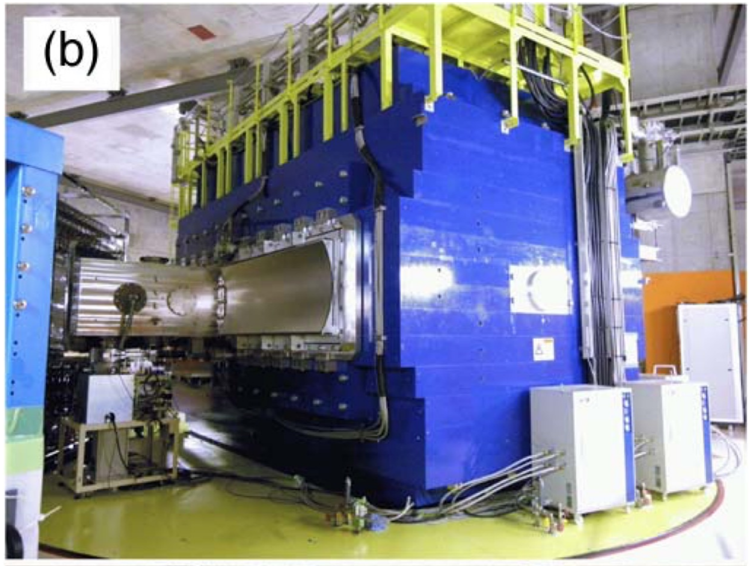
Similar senstivity for LLP
Similar muon acceptance for neutrino study
(see Olivier's talk yesterday)

Samurai-style magnet (1 m x 3 m aperture, 2 Tm on central axis)



Crystal puller magnet (1.6 m diameter, 2 Tm on central axis)

Samurai-style magnet



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SAMURAI magnet at RIKEN in JAPAN

- Aperture: 3 m x 0.88 m
- Integrated B filed at center: 7.05 Tm
- Construction started in 2008 and completed in 2011

First trial in 2022: SAMURAI-style magnet with 4.7 Tm for integrated B field

- Just reducing number of turn of SC coils and size of return yoke, while keeping other equipment
- Quotation: **10 MCHF** in November 2022

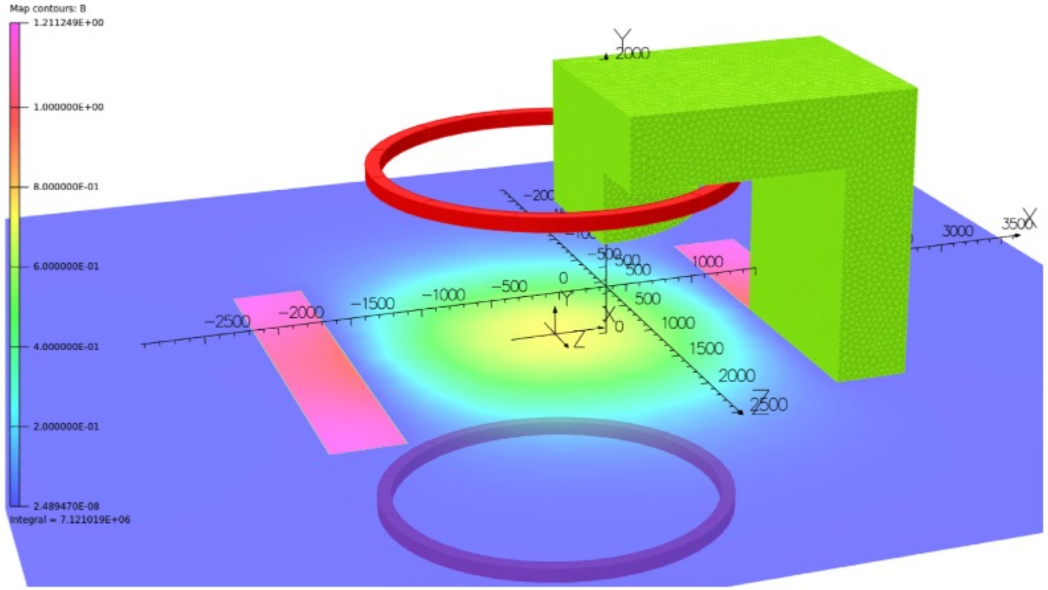
Second trial in 2023: SAMURAI magnet with 2 Tm for integrated B field

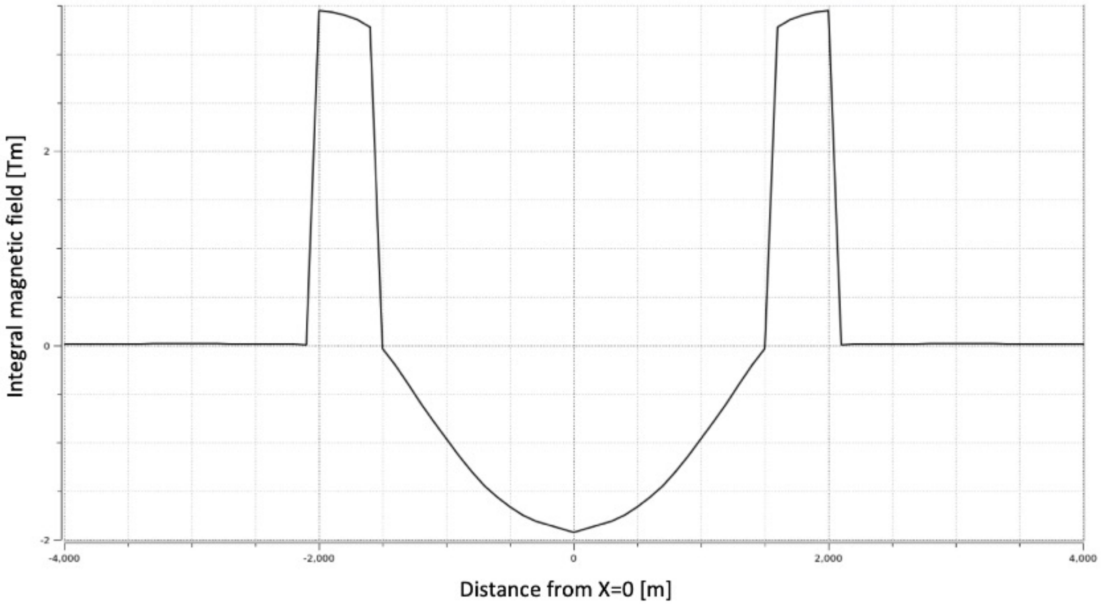
- Update cryogenics with recent products
- Remove the liquid He bath cooling method due to less stored energy compared to SAMURAI
- Quotation: **4.3 MCHF** in November 2023

Magnetic field simulation

Opera 3D has been used for the evaluation

- Coil diameter is 2.6 m (limited by the available winding machine in the company (Toshiba))
  - Apperture is **3 m x 1 m**
- Minimize thickness of the return yoke; 50 cm-thick is sufficient
  - Total width x height is **4 m x 3 m**





Magnet parameters

In addition, 3 m x 2 m aperture (wider gap) with 2 Tm is also tried

- 50 cm thick return yoke still work; total width is kept at 4 m, while total height increases to 4 m
- Stored energy still below 10 MJ, no need to use Liquid He bath cooling

	SAMURAI	2 Tm gap 1 m	2 Tm gap 2 m
Coil diameter [m]	2.6	2.6	2.6
Coil cross section [mm^2]	180 × 160	100 × 100	100 × 100
Current density [A/mm^2]	66.74	37	86
Coil current for Φ1.2 mm cable [A]	563	48	112
Total width [m]	6.7	4	4
Total height [m]	4.64	3	4
Iron yoke thickness [m]	1.65	0.5	0.5
Iron weight [t]	566	167	190
Gap [m]	0.88	1	2
Coil center field [T]	3.08	0.89	0.75
Max field in coil [T]	5.4	1.5	2.9
Integral magnetic field at center [Tm]	7.05	2.20	1.92
Stored energy [MJ]	27.4	2.2	8.2

4.3 MCHF   + ~1 MCHF [TBC]

1.7 m x 1.7 m aperture will be tried in the next iteration

Peripheral equipment

- Cryocooler
  - 1.5W @ 4K x 4 units
  - Attached to the SC coils in the cryostat
- Vacuum pump unit
  - 2.2 kW for rotary pump
  - 1 kW for turbomolecular pump
  - Attached to the cryostat
- Water cooled compressor
  - 8 kW x 4 units
  - 1 m x 1 m x 1 m for each
  - Distance from cryocooler should be less than 25 m
- Power source with quench detector and also monitoring system
  - 1 m x 1 m x 2 m, equivalent to 3 x 19-inch rack
  - 1 kW during ramping

At Riken, 30A on 200V breaker are used for each compressor

36.2 kW is expected for the maximum power comsumption

Cost and Timeline

Work	Months	Comments
Designing	9	
Procurement	12	could be started before designing
Winding wire	6	could be done while designing
Assembly	12	
Test	3	
Dismantlement, Delivery	2	
	44 (3.6 years)	could be 35 (2.9 years)

3-4 years expected before commissioing

	JPY [MJPY]	CHF [MCHF]
Material	**384**	**2.2**
Superconducting wire	6.3	0.04
Yoke material	88	0.51
Yoke manufacturing	106	0.62
Vacuum chamber, shield, etc	130	0.76
Coil winding jig, assembly jig	51	0.30
Testing instruments	2.7	0.02
Commercial product (cryogenics, power supply, etc)	**73**	**0.43**
Manufacturing and assembly	**102**	**0.60**
Others (Designing, testing, etc)	**174**	**1.02**
	733	**4.29**

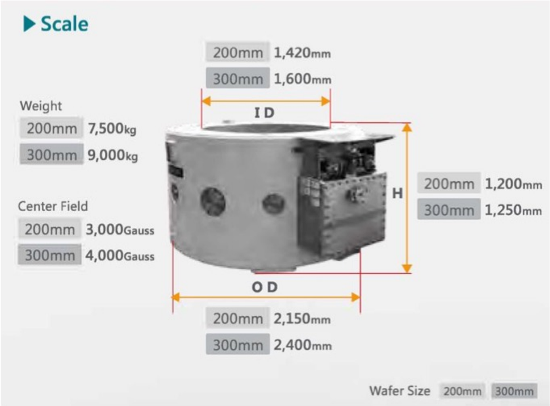
Transportation fee is not included

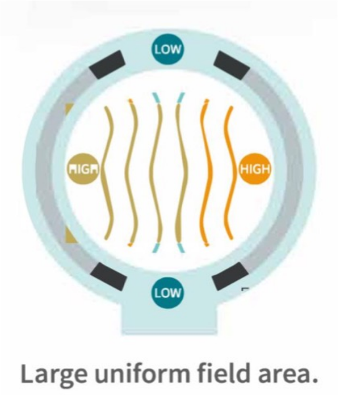
FASER2 Alternative design: Crystal puller magnet

- 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

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Need more iteration with the company on price and leadtime

Summary

FASER2 magnet is a key component in FPF

- Provide charge and momentum of muon for other experiments
- Occupy large area in FPF, constrained by shape of the FPF
- Give requirement for infrastructures, e.g, crane

Two options considered, both of them have similar performance for physics

- Samurai-style magnet
  - 3 m x 1 m (2 m) aperture with 2.6 m diameter coil; cost/leadtime evaluated for today
  - 1.7 m x 1.7 m aperture with 1.4 m diameter coil will be tried for the report to PBC
- Crystal puller magnet
  - 1.6 m diameter, possibly larger diameter (2 m?)
  - Cost/leadtime will be collected for the report to PBC