

Looking *Forward* to LLPs

Current and proposed forward LLP experiments

Carl Gwilliam

30th May 2022

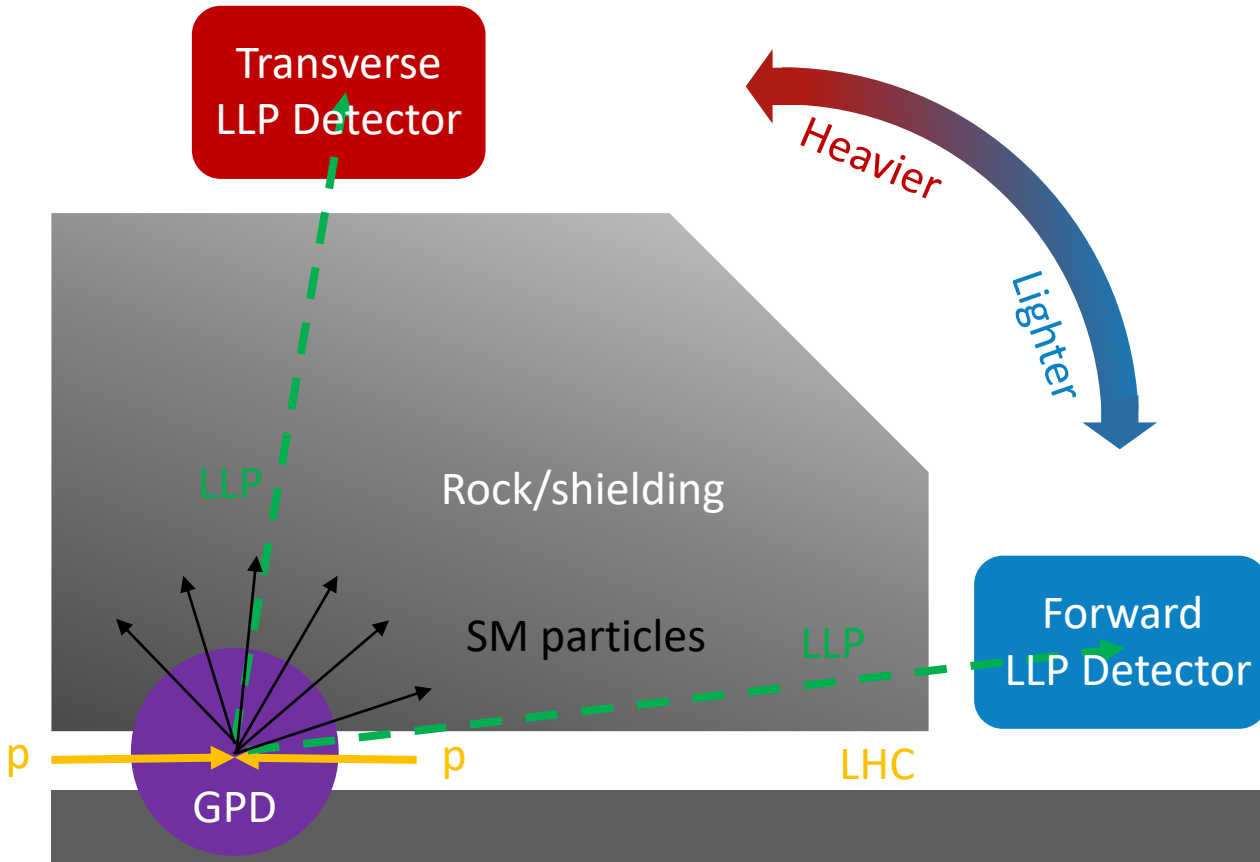
11th LLP Community Workshop



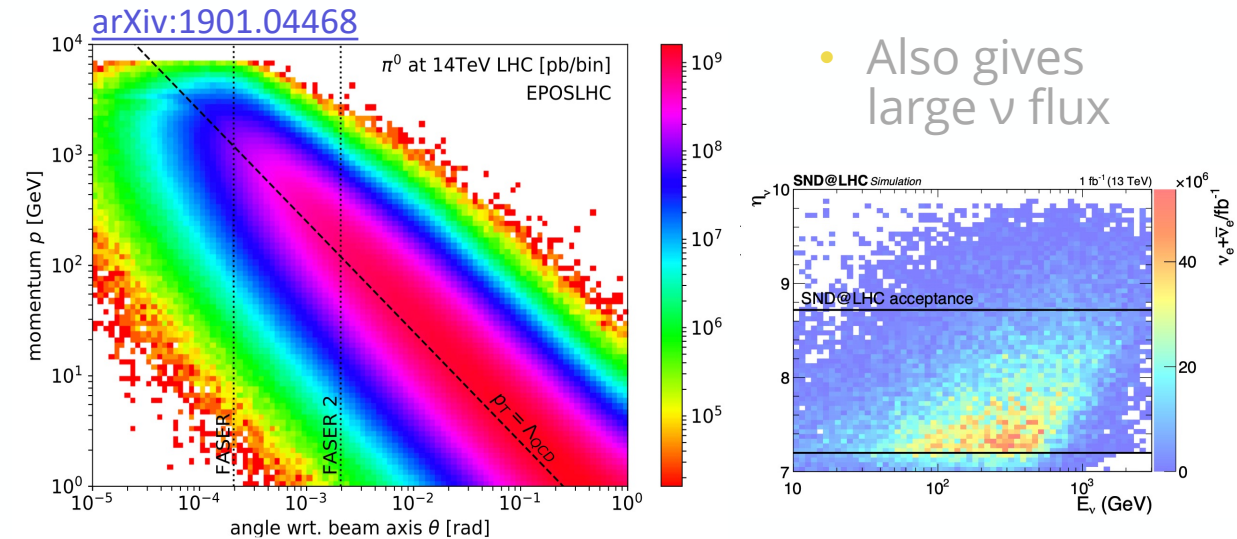
UNIVERSITY OF
LIVERPOOL

Motivation

- Dedicated LLP detectors mitigate several of the issues with searching for LLPs at GPDs
 - Background mitigated by rock/shielding
 - Simpler/no triggering
 - Targeted detector design
 - Specialised LLP reconstruction
- Optimal detector design and position are strongly dependent on targeted signature ...

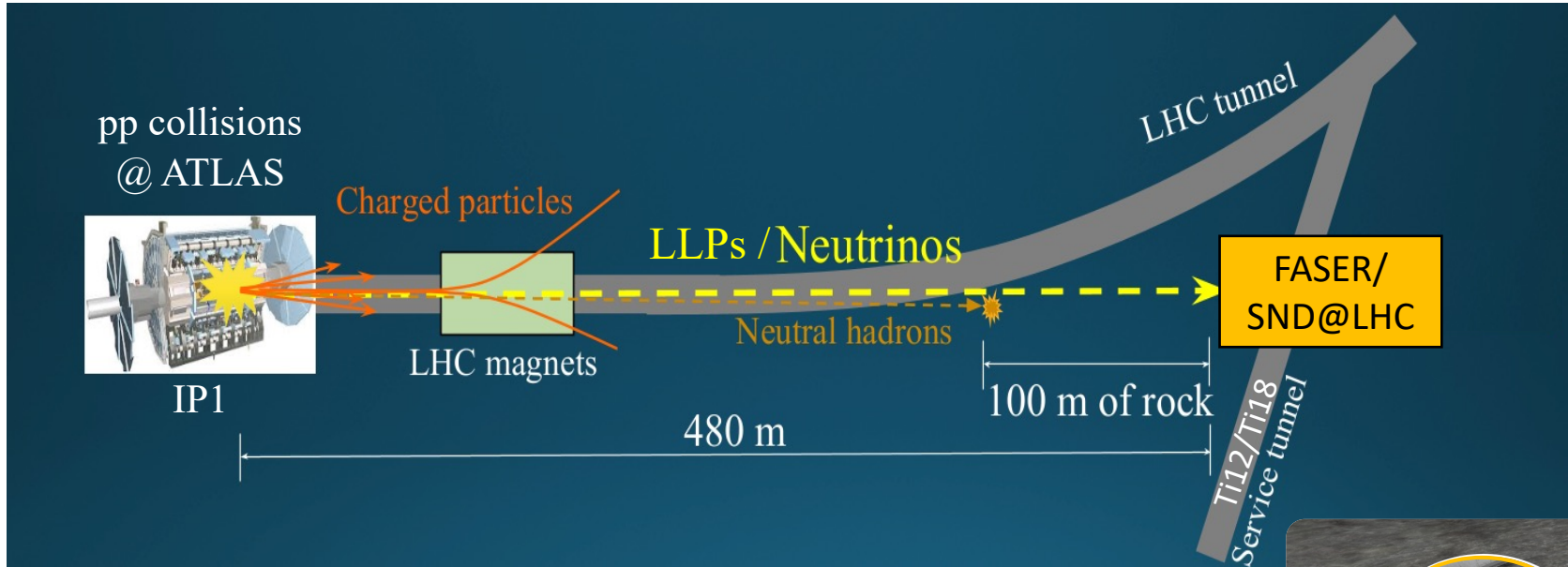


- Forward detectors target low-mass LLPs
 - Produced in forward-peaked light hadron decay



- Also gives large ν flux
- Generally able to target longer LLP lifetimes
 - Since detectors can be placed further from IP $_2$

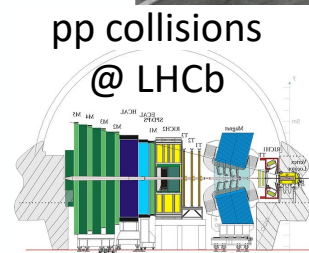
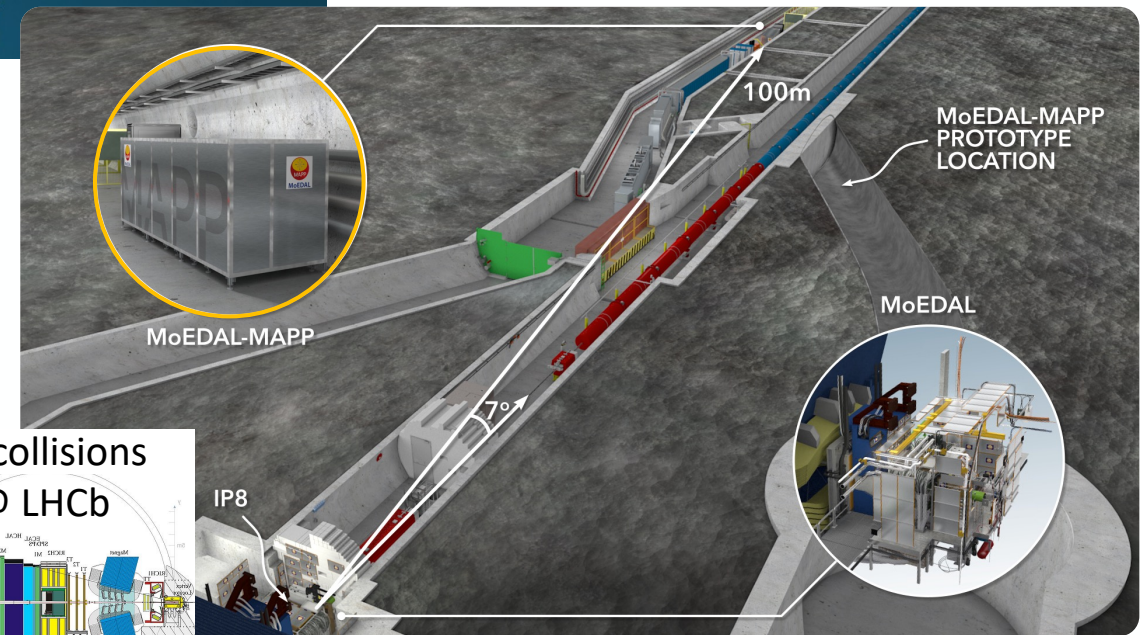
Run-3 Experiments



- **FASER**
 - Spectrometer + dedicated FASERν detector on LOS
 - 480 m from IP1 (Ti12)
- **SND@LHC**
 - Hybrid neutrino detector sited off-axis ($7.2 < \eta < 8.4$)
 - 480 m from IP1 (Ti18)

- **MoEDAL MAPP**

- MoEDAL's Apparatus for Penetrating Particles (MAPP) extends reach to LLPs
- Scintillator + PMT detector
- Located 100m from IP8 (UA83)
 - Previous prototype in UGC1 but moved as too long preparation time for run 3

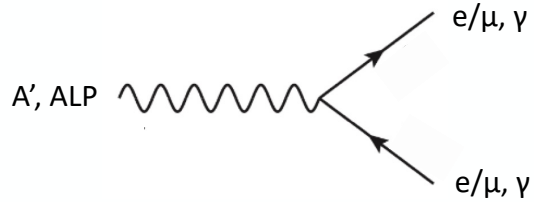


BSM Physics Sensitivity

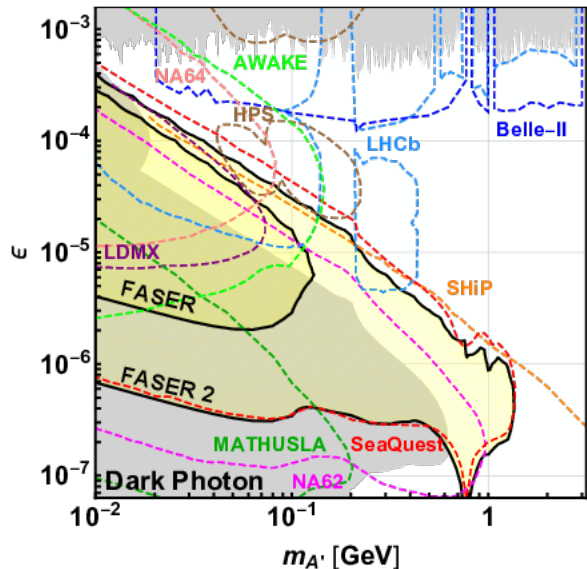
- LLP produced in pp collisions and then travels $O(100\text{ m})$ before being detected by experiment
 - Sensitive to masses in multi-MeV to low-GeV range

FASER

- LLP decays to SM
- ALPS, γ -dark (A'), ...

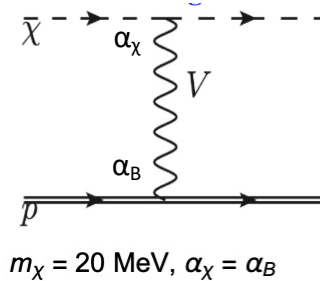


[arXiv:1811.12522](https://arxiv.org/abs/1811.12522)

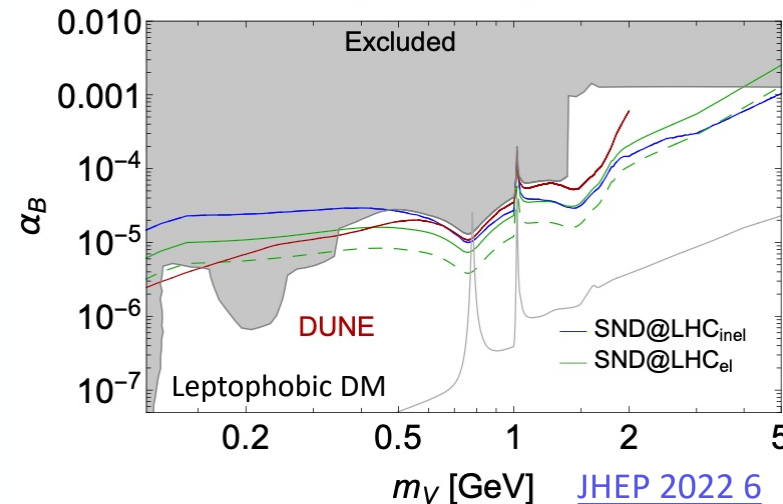


SND@LHC

- (In)elastic FIPS scattering or FIPS decay to $ee/\mu\mu$
- E.g. Light DM

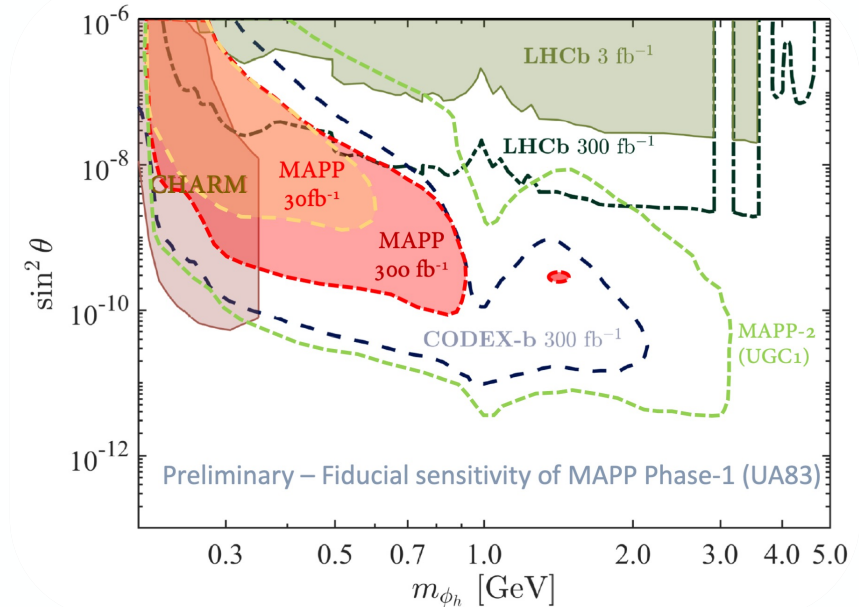


$$m_\chi = 20\text{ MeV}, \alpha_\chi = \alpha_B$$



MoEDAL-MAPP

- LLP decays and mCP
- LLP \rightarrow mCP, Dark Higgs



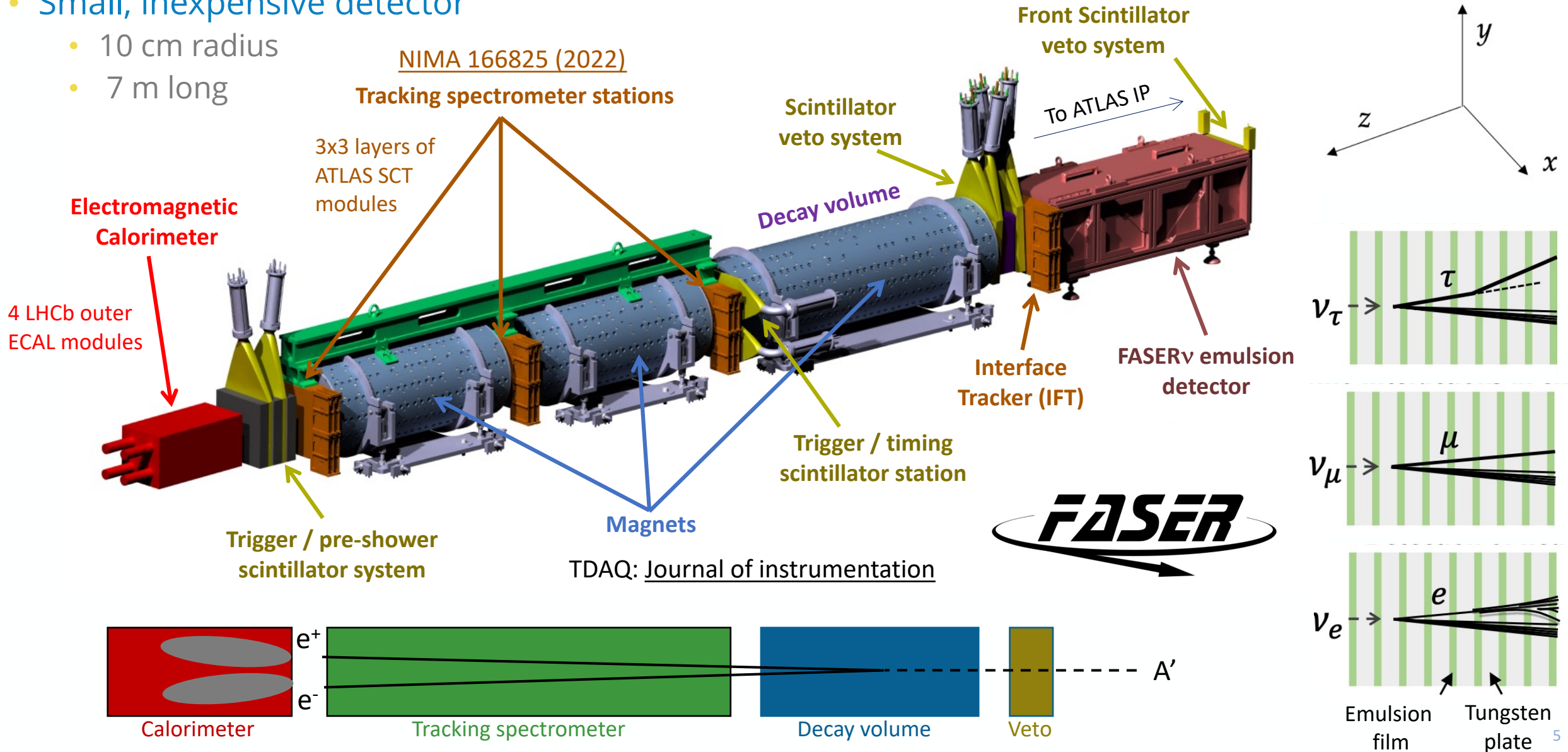
- Also, very LLP trapped in MoEDAL (see later)

FASER

- Small, inexpensive detector

- 10 cm radius
- 7 m long

NIMA 166825 (2022)



Successfully Installed in Ti12 in March

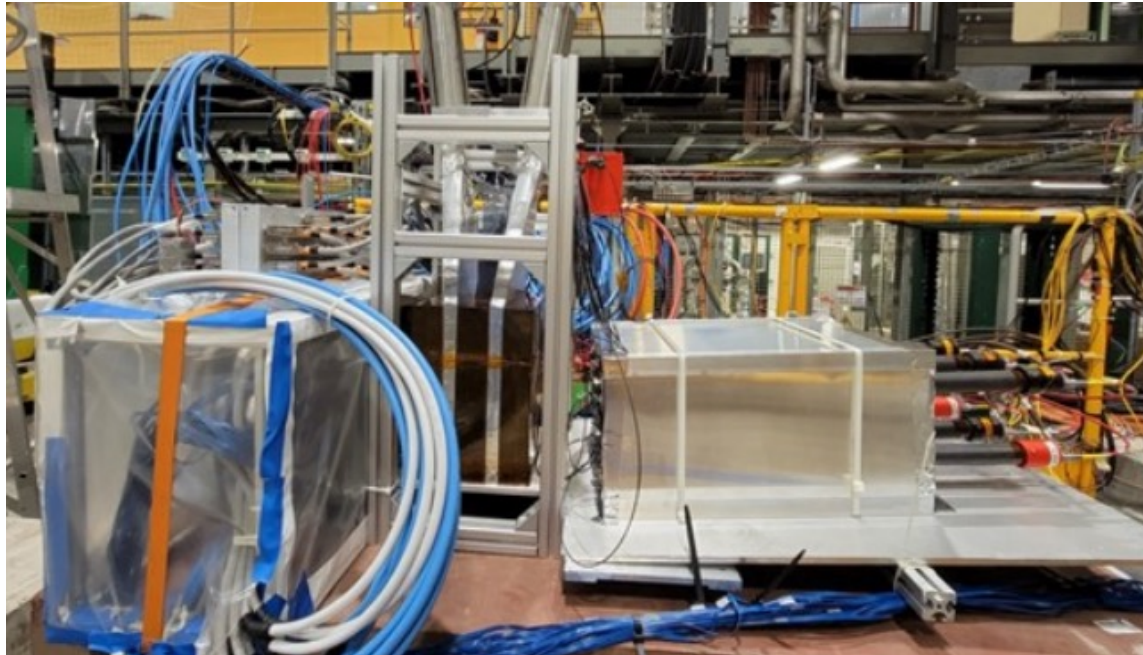
- Includes interface tracker, forward veto station and partial (30%) FASERv box



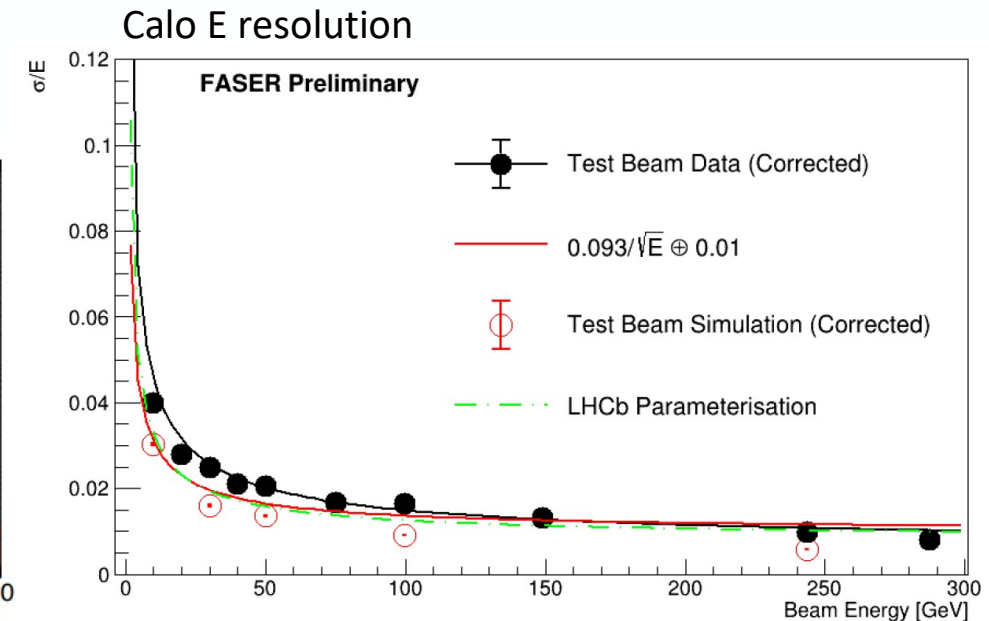
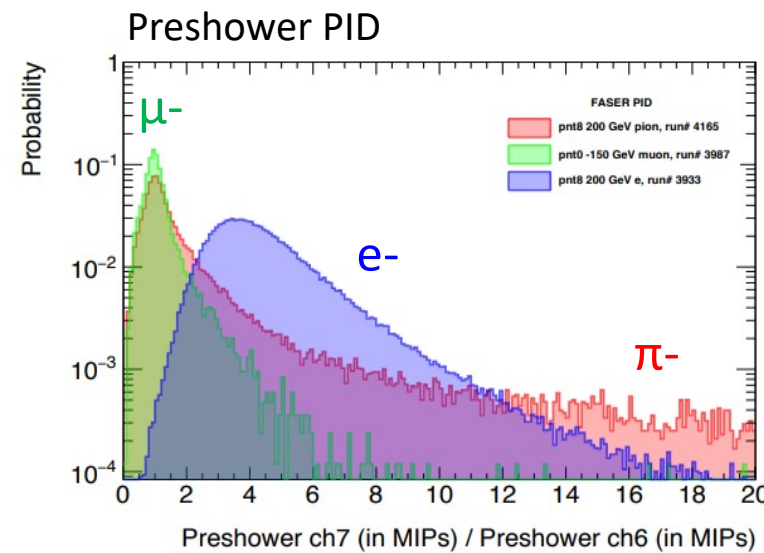
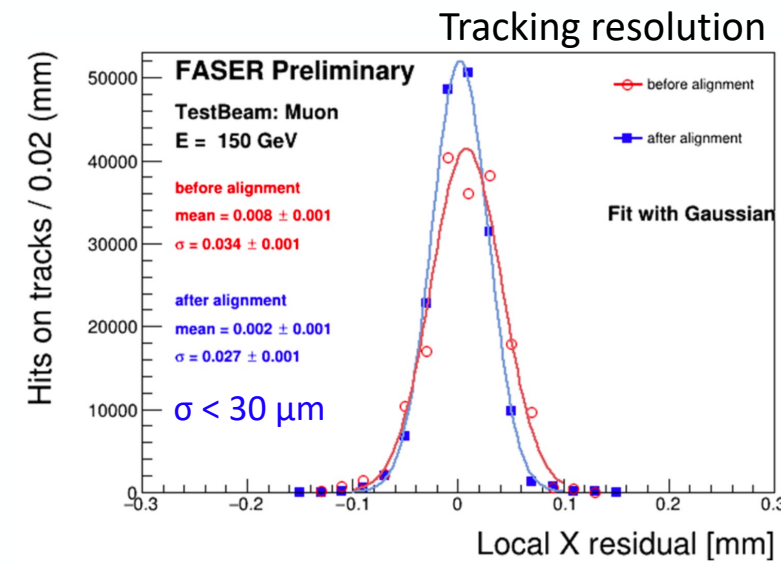
- Dedicated test beam

- Detector paper being finalised for publication
- In situ commissioning with cosmic events and beams since

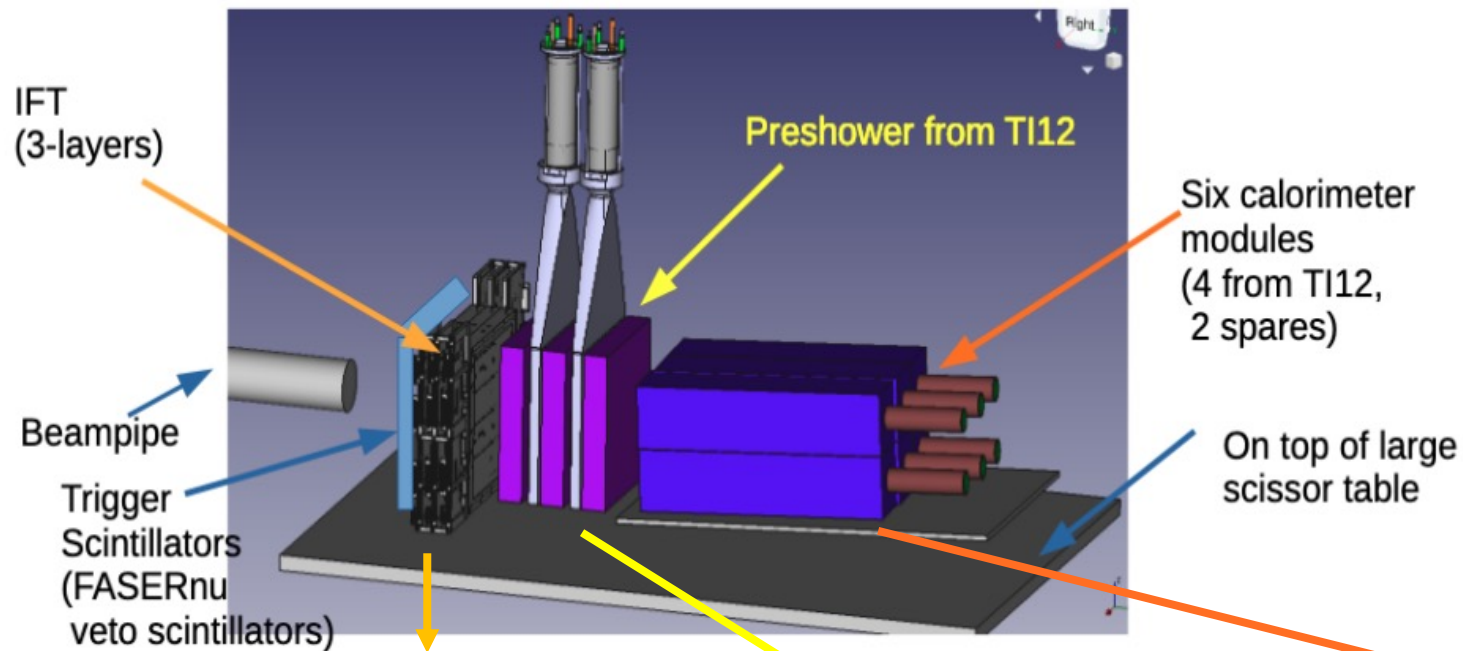
FASER Calorimeter Test Beam



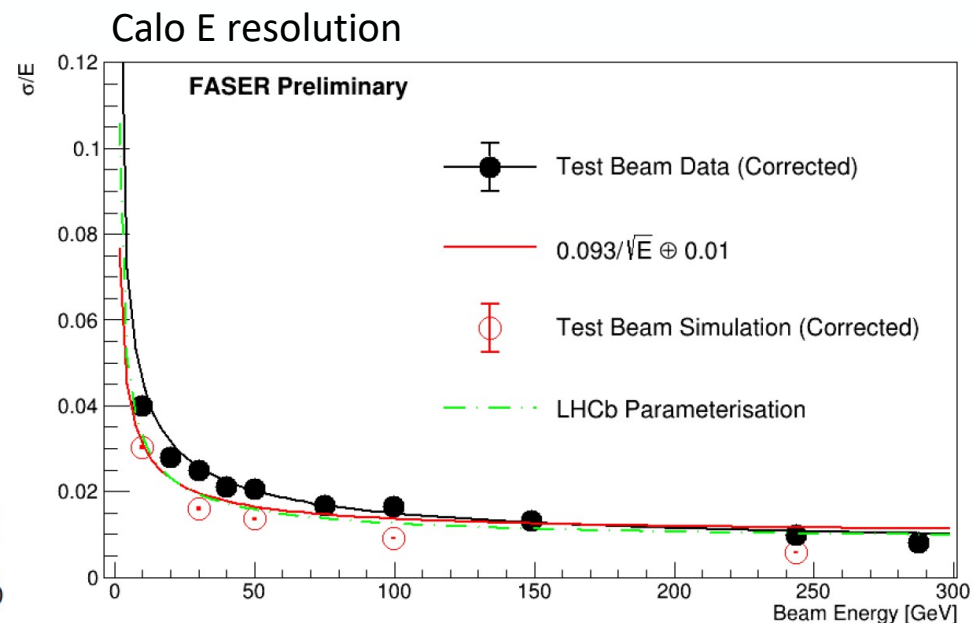
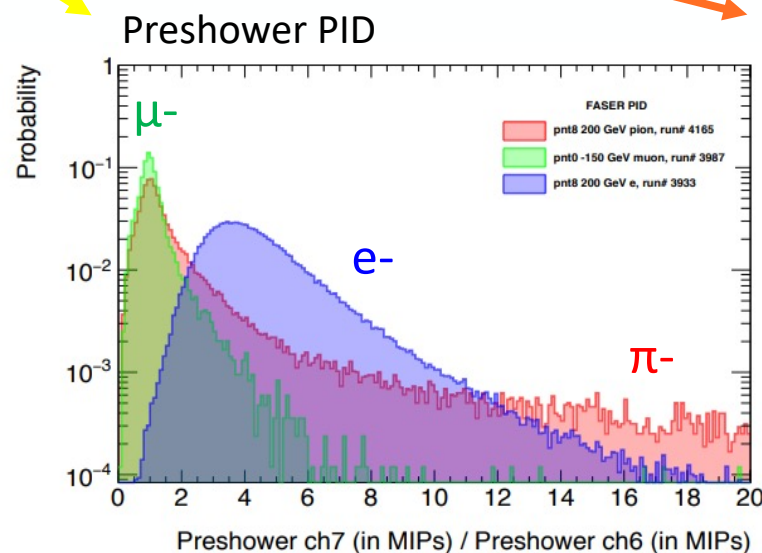
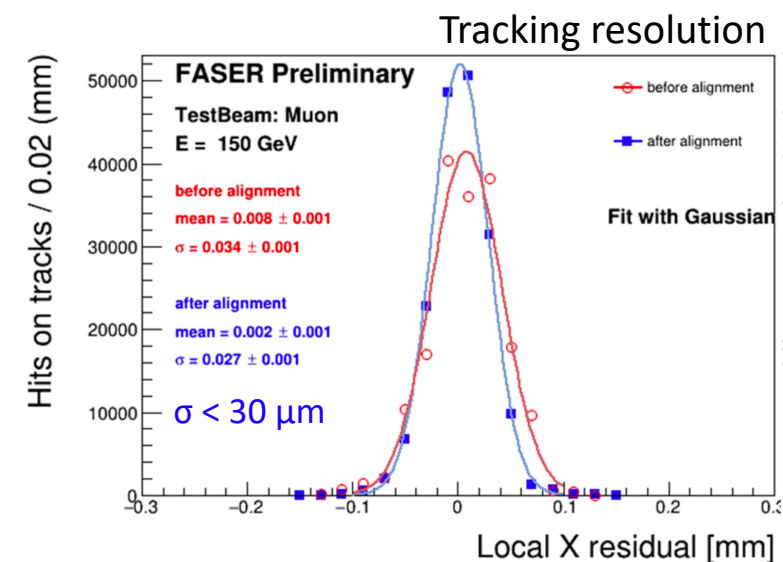
- TB @ CERN H2 beam (summer '21)
 - Electrons (5-300 GeV), muons (200 GeV) and pions (200 GeV)
- 6 ECAL modules (inc. spares)
 - Along with IFT and preshower
- Paper in preparation



FASER Calorimeter Test Beam

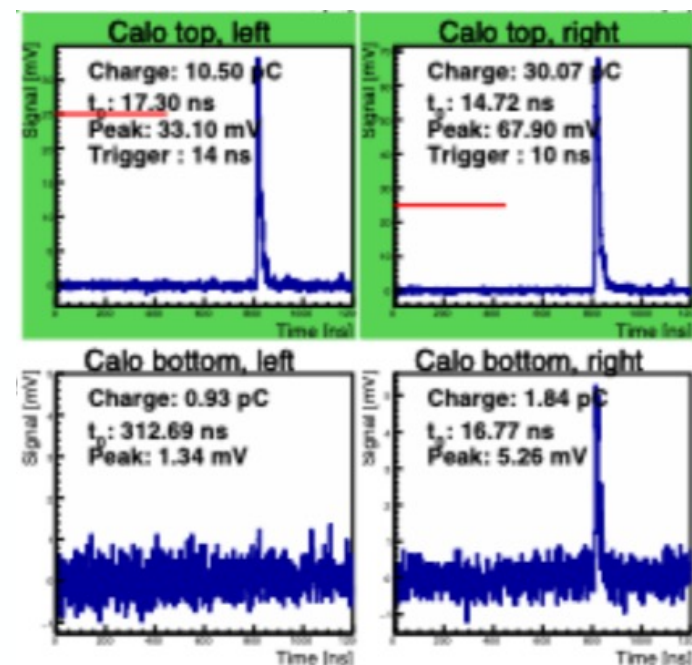
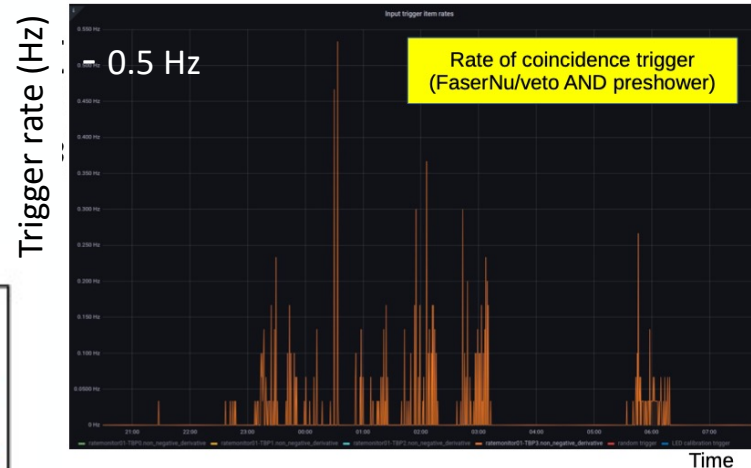
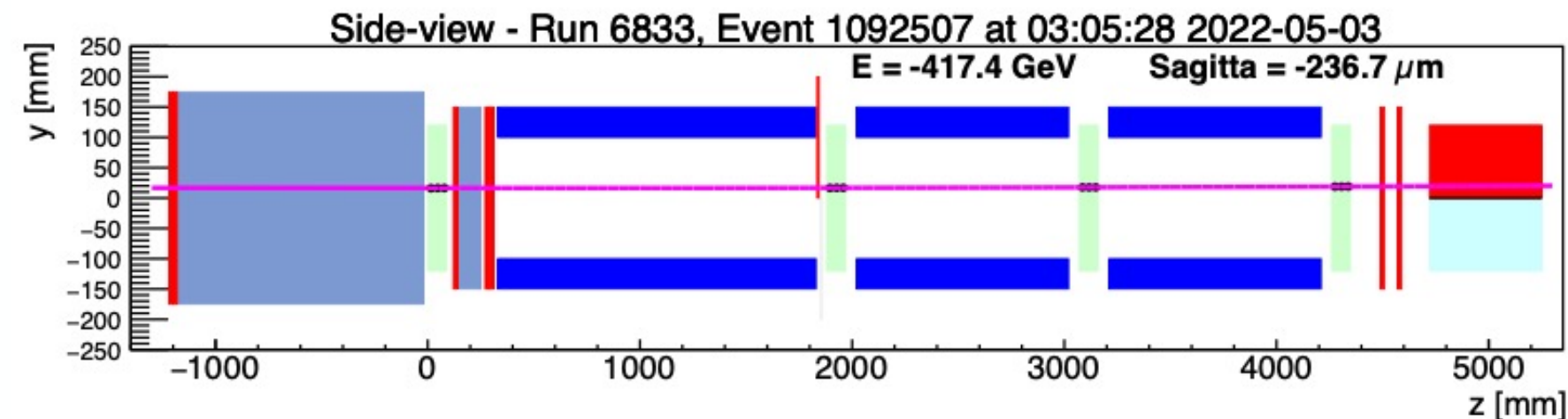
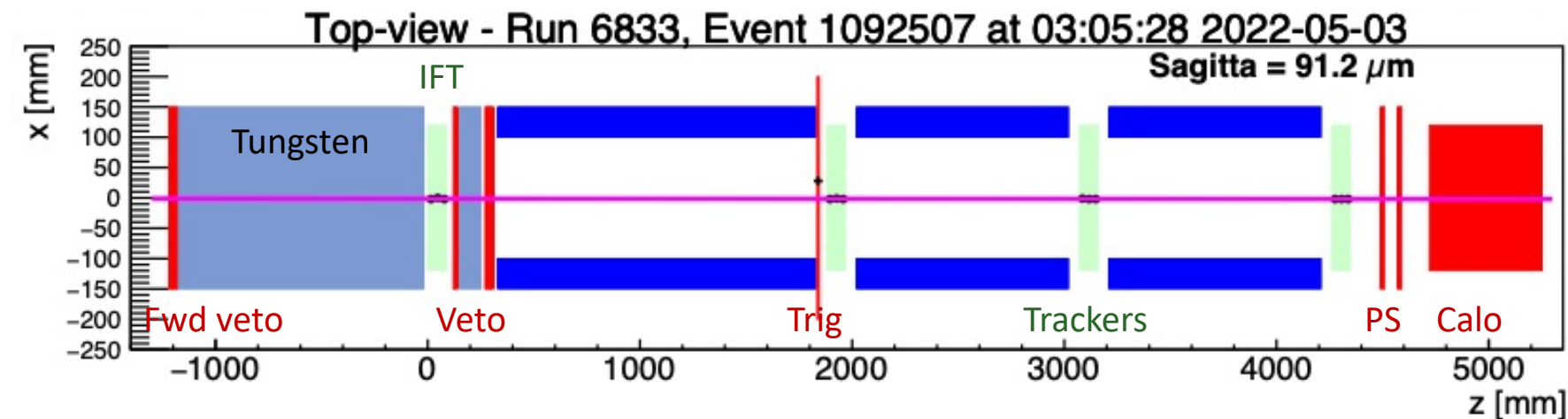


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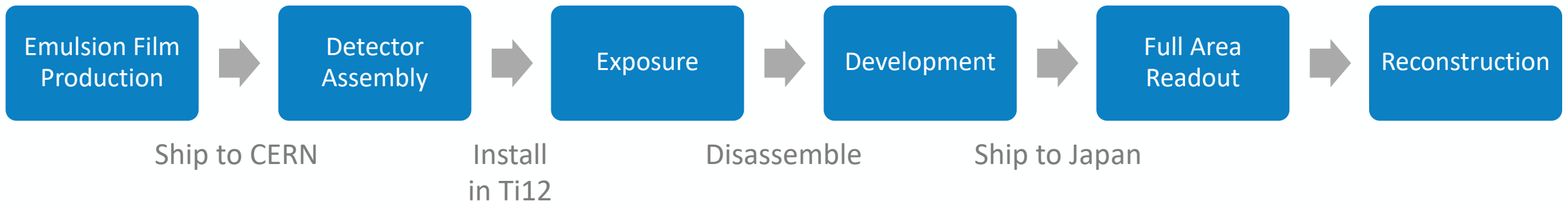
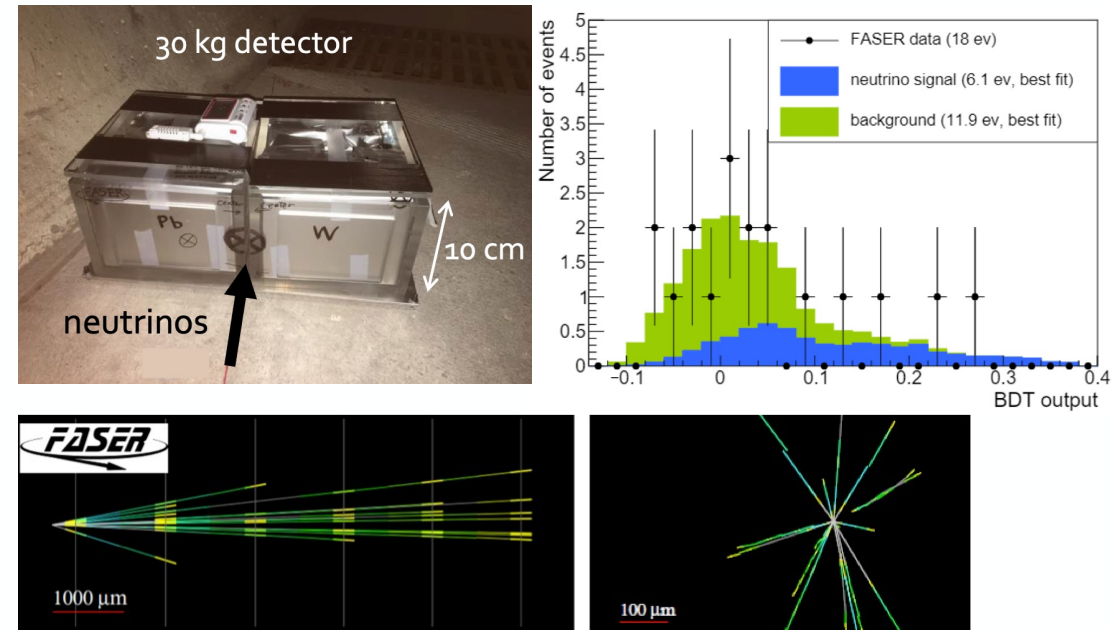
Ti12 Commissioning

- Saw first beam particles from recent 6.8 TeV beam optics tests!
 - First particles traversing full detector, including Fwd Veto and IFT
 - Of order 50 such events \rightarrow studying these in detail



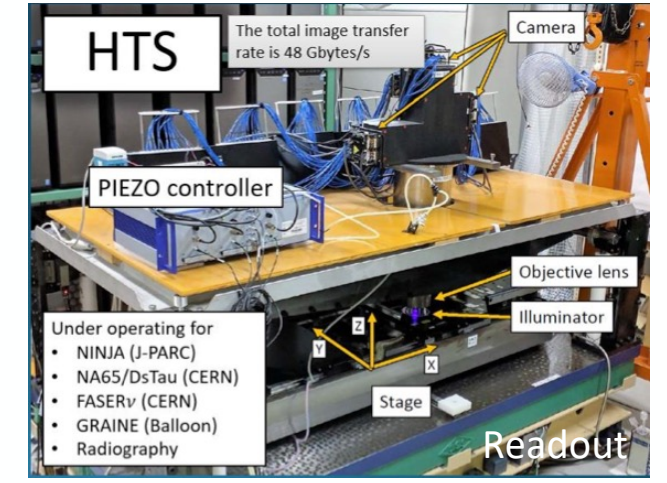
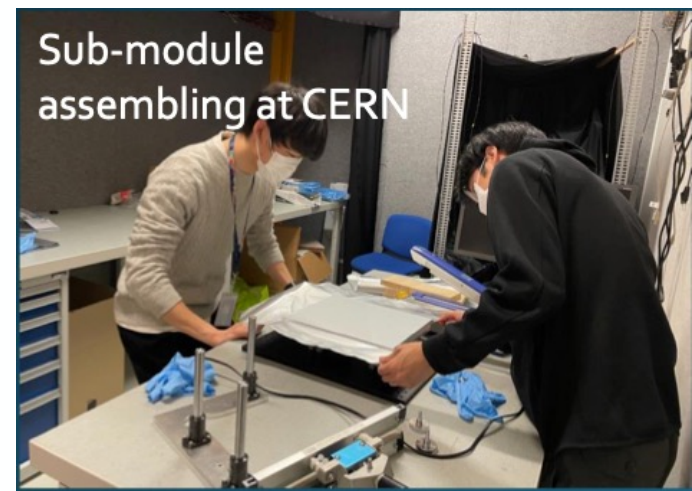
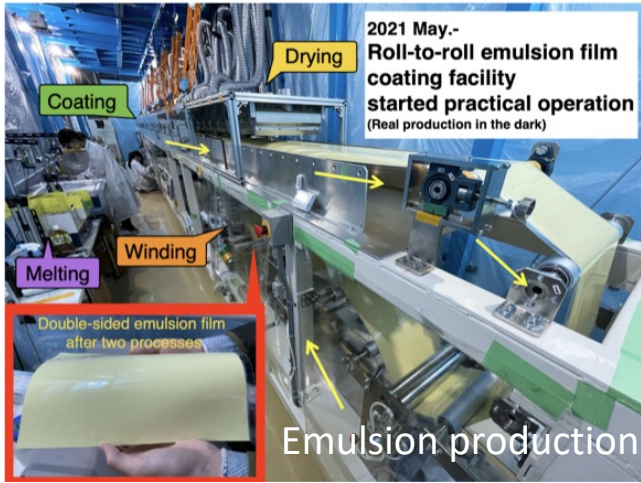
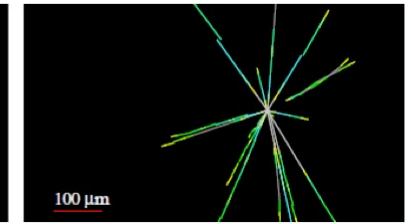
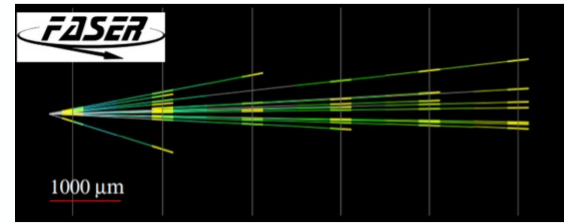
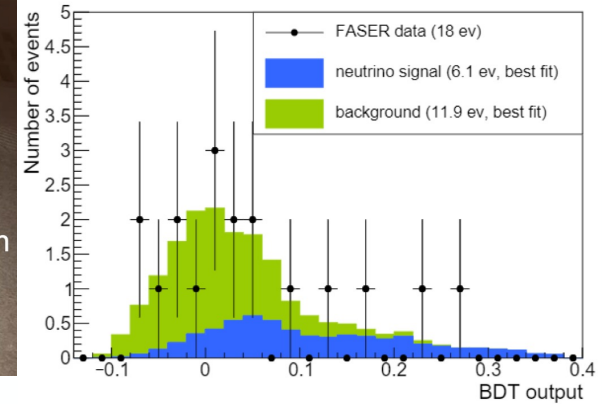
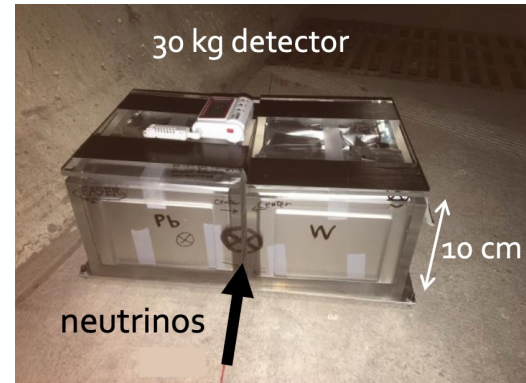
FASER ν

- Pilot detector (30 kg) exposed in UJ12 for 1 month
 - Observed (2.7σ) first collider ν candidates!
 - [Phys. Rev. D 1004, L091101](#)
- FASER ν will be exchanged frequently during run 3
 - Current partial detector till 25th July
 - First full detector (TS1): 26th July – 13th Sept
 - Emulsion already produced
 - Second detector (TS2): 13th Sept – 8th Nov
- Procedure:



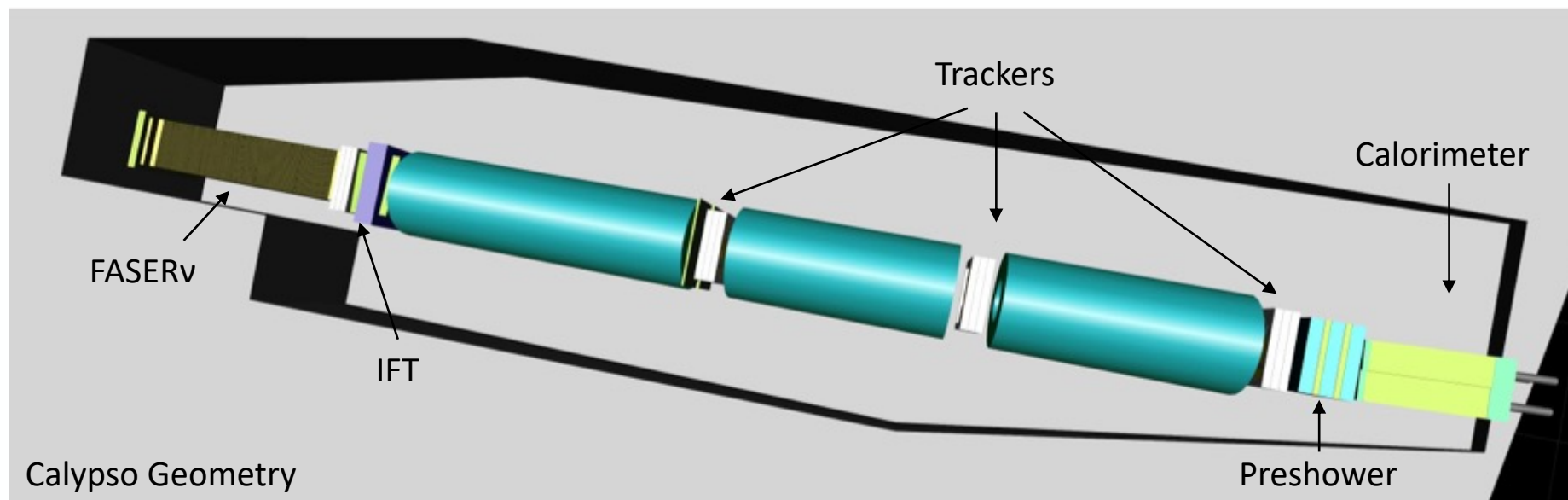
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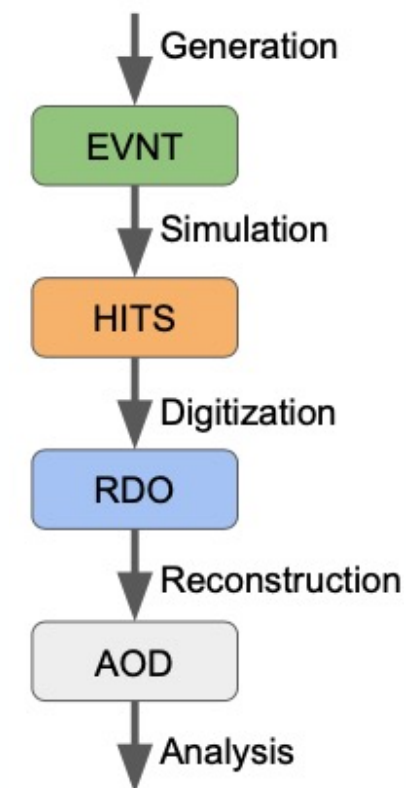


FASER Mock Data Challenge

- Ongoing Mock Data Challenge (MDC) to ensure readiness for data-taking
 - Test full production chain from generation all the way through to analysis
 - Additionally, exercise organisation structure & communication procedures
- Representative background and signal processes have been produced

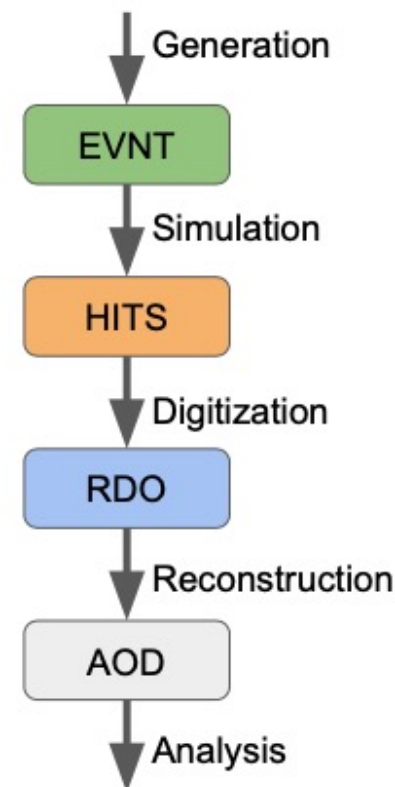
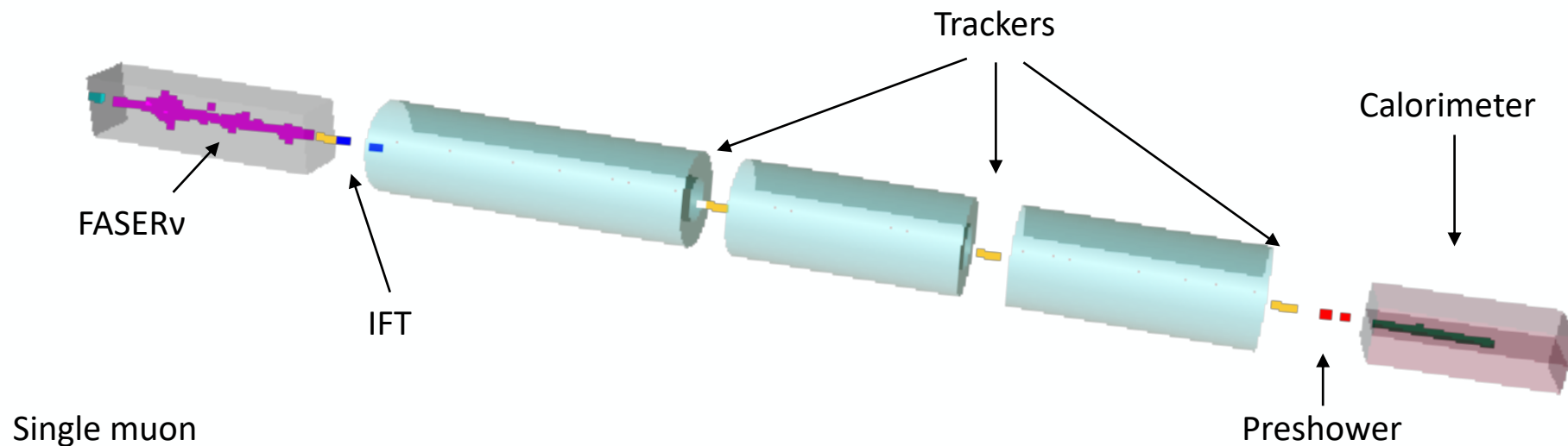


- Goal: demonstrate end-to-end analysis workflow
 - Finalise software: determine readiness & uncover missing pieces
 - In addition, jump start analysis effort already



FASER Mock Data Challenge

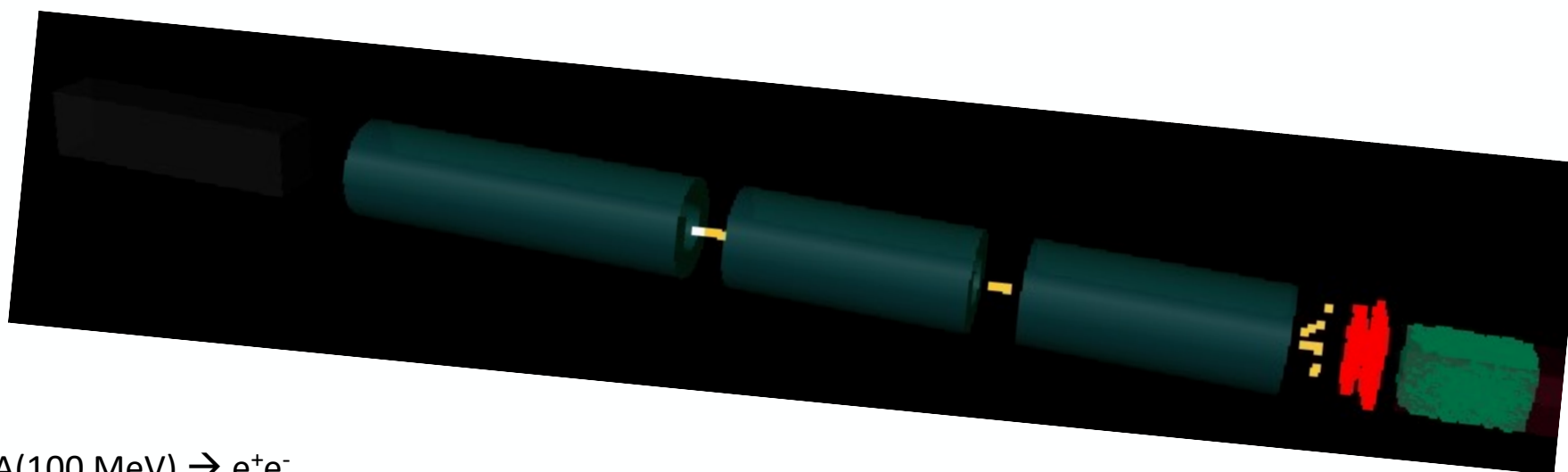
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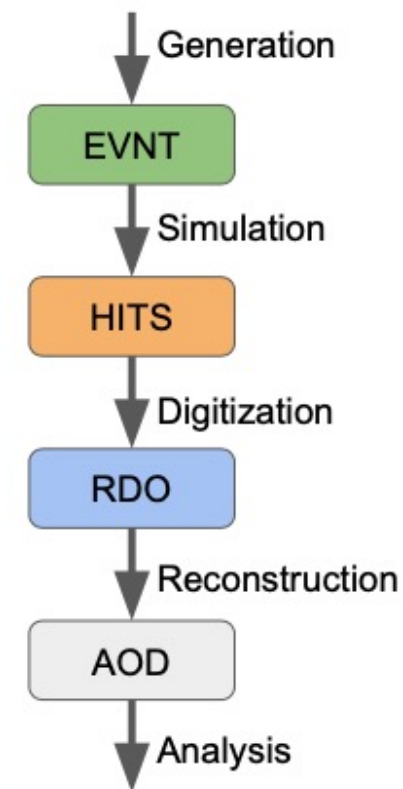
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$A(100 \text{ MeV}) \rightarrow e^+e^-$

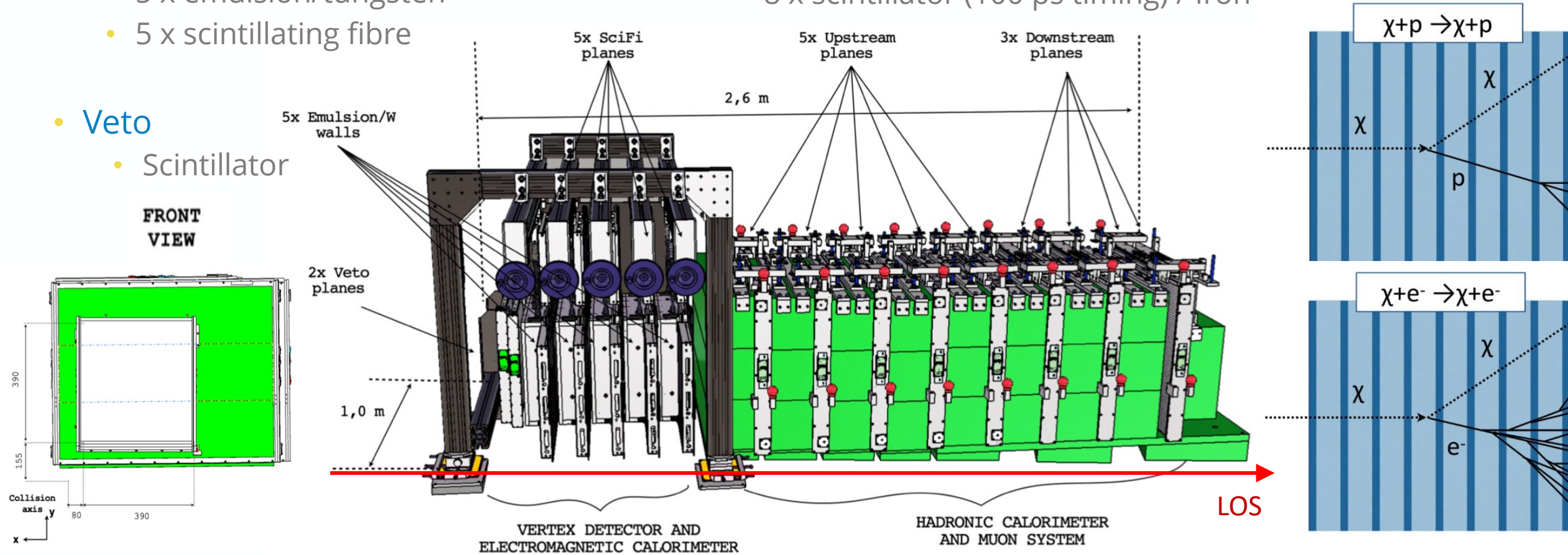
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- Hybrid off-axis (1 x 2.6 m) detector for ID of all 3 ν flavours and FIPS searches
 - Electronics detector (1st phase) combined with emulsion cloud chambers (2nd phase)
- Target: vertex/position + ECAL
 - 5 x emulsion/tungsten
 - 5 x scintillating fibre
- Muon + HCAL system
 - 8 x scintillator (100 ps timing) / Iron



- Veto
 - Scintillator



Successfully Installed in Ti18

- Electronic detector fully installed by end of 2021
- Neutron shield completed in March 2022



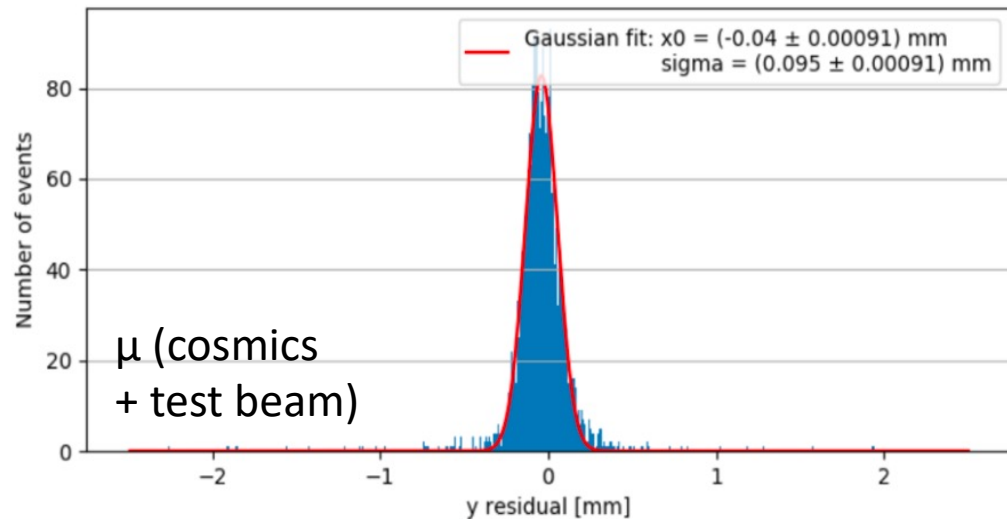
December 2021



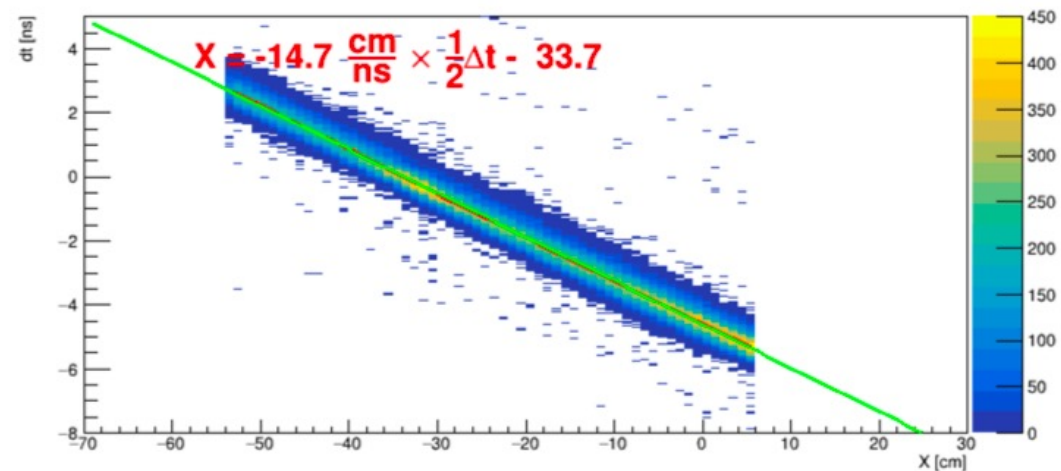
March 2021

SND@LHC Detector Performance

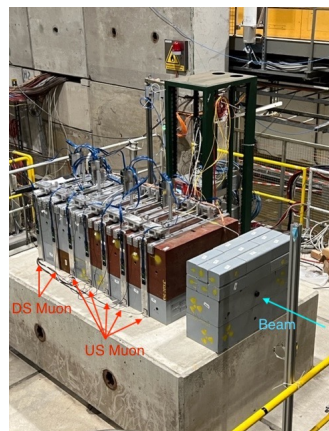
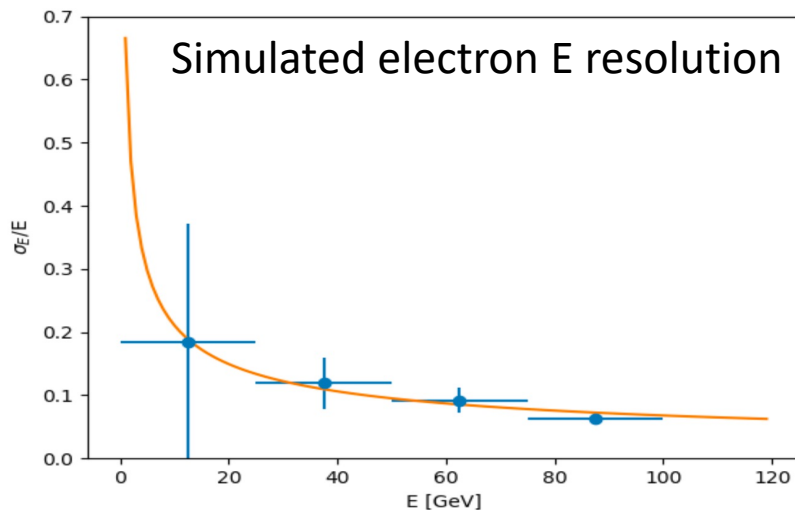
- SiFi resolution < 100 μm post alignment



- $\Delta t = 170$ ps between 2 ends of DS scintillators

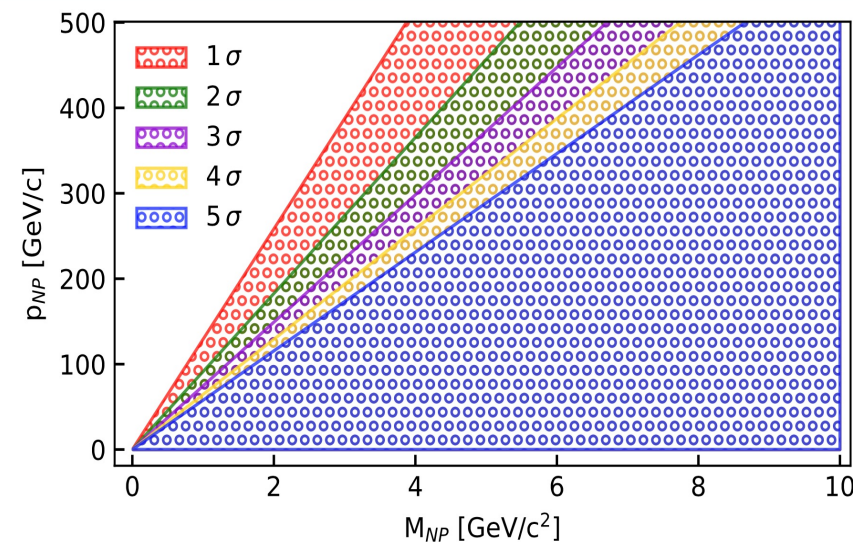


- Overall energy resolution ~ 20-30%



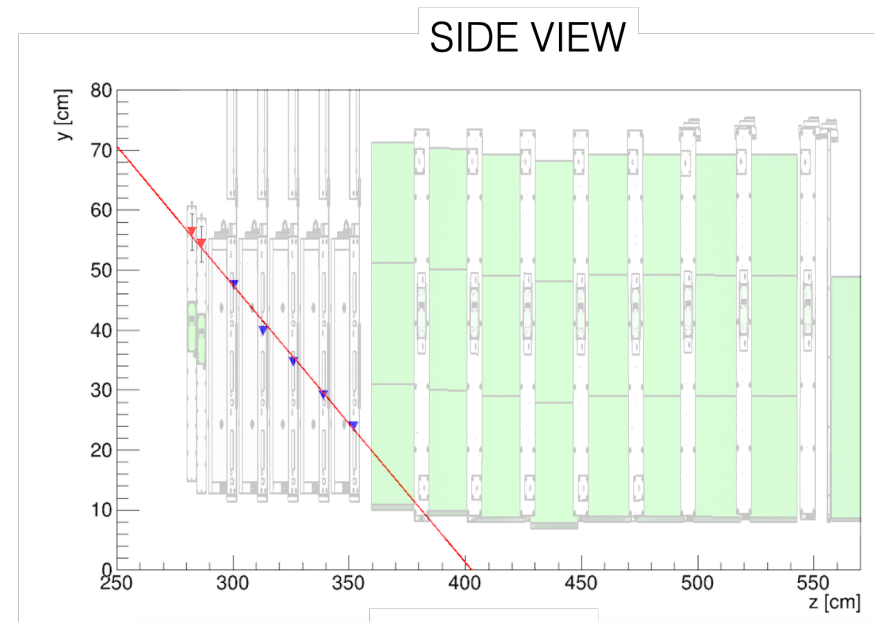
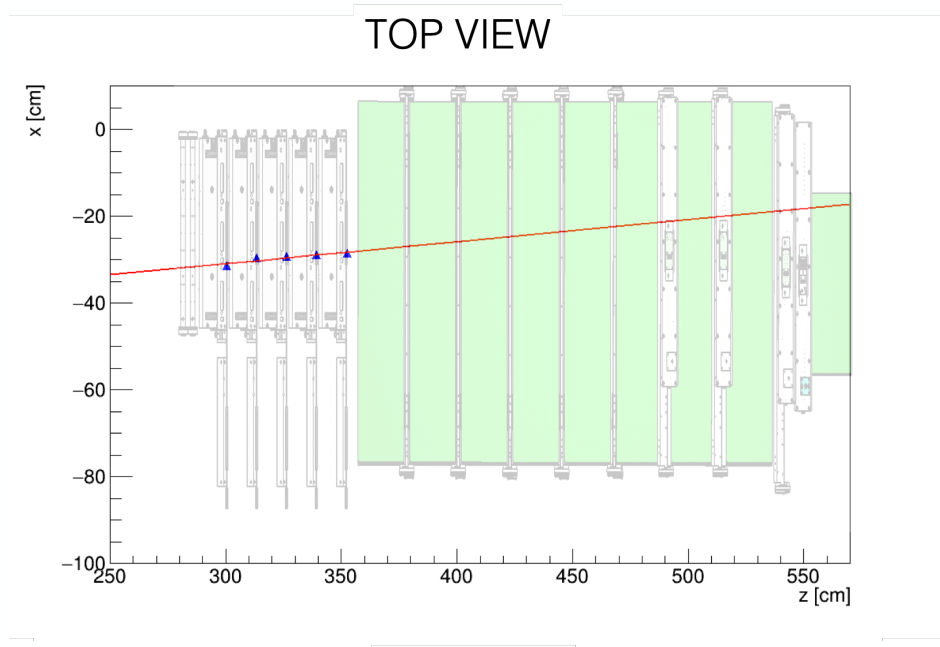
π test beam for E calib

- ToF can potentially push sensitivity to higher m

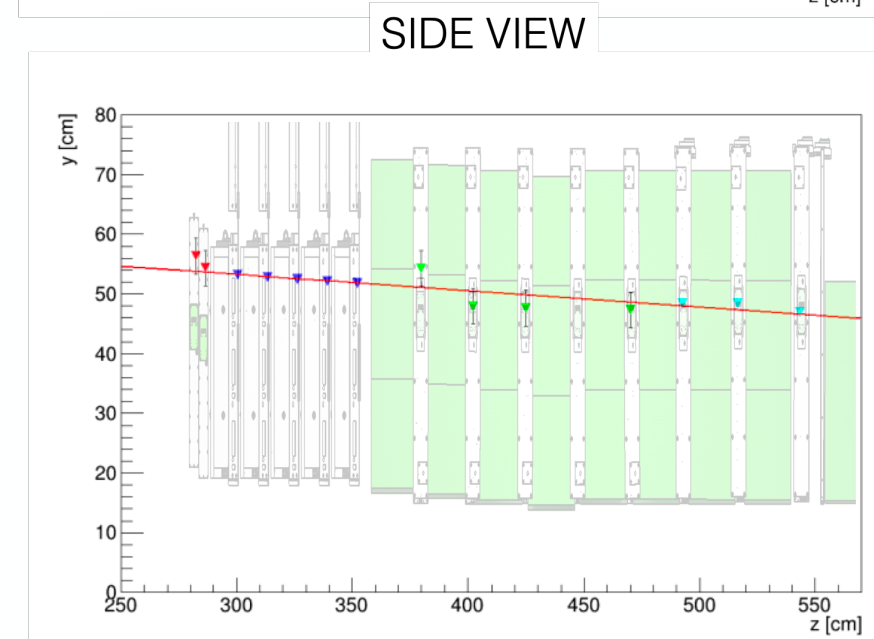
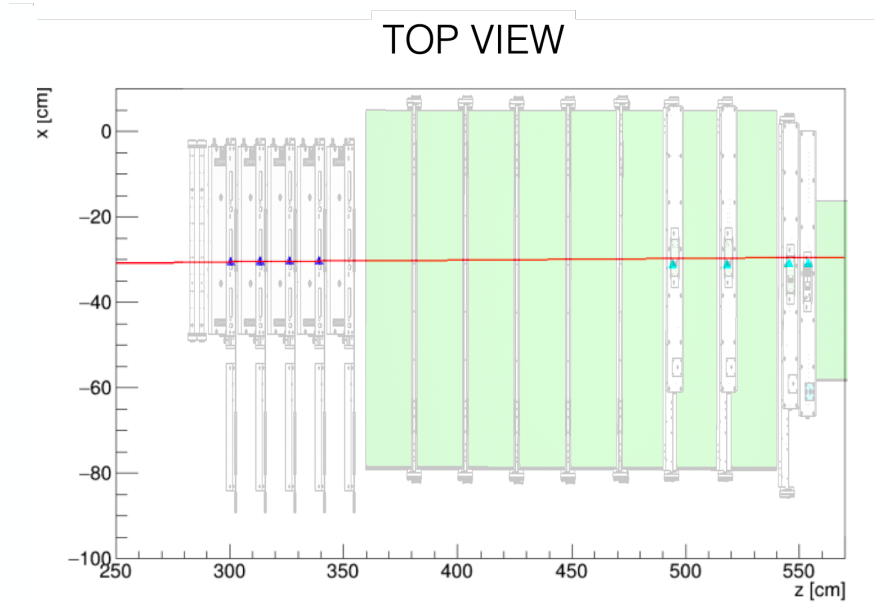


Ti18 Commissioning

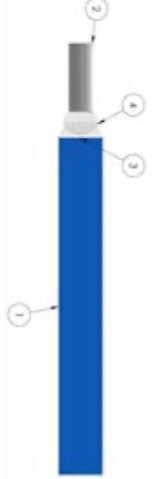
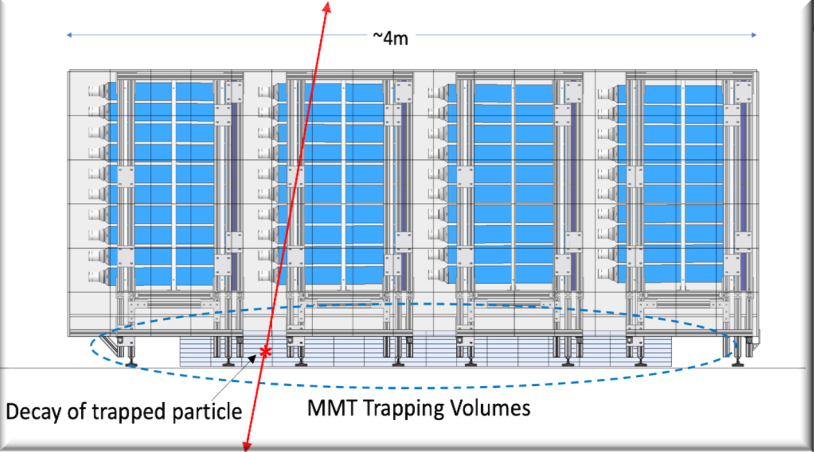
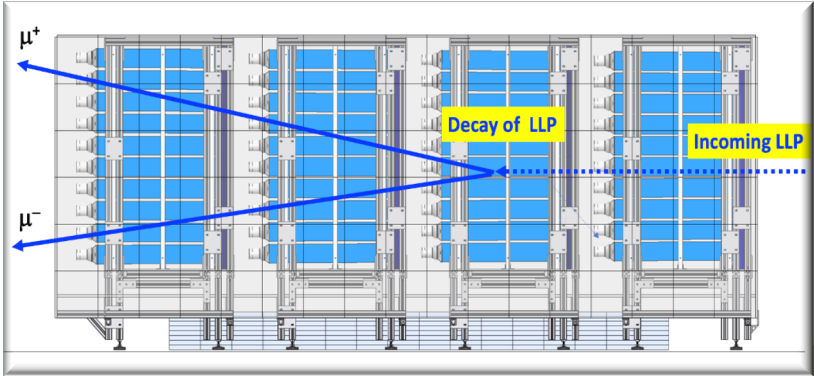
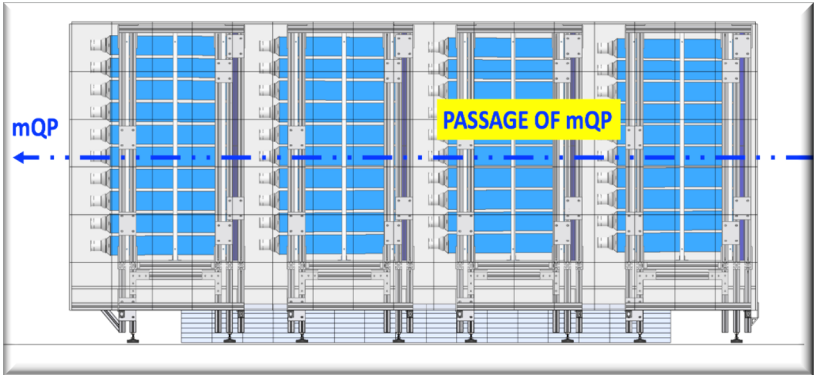
- Cosmic ray
 - March 2022



- LHC beam!
 - April 2022



MoEDAL-MAPP

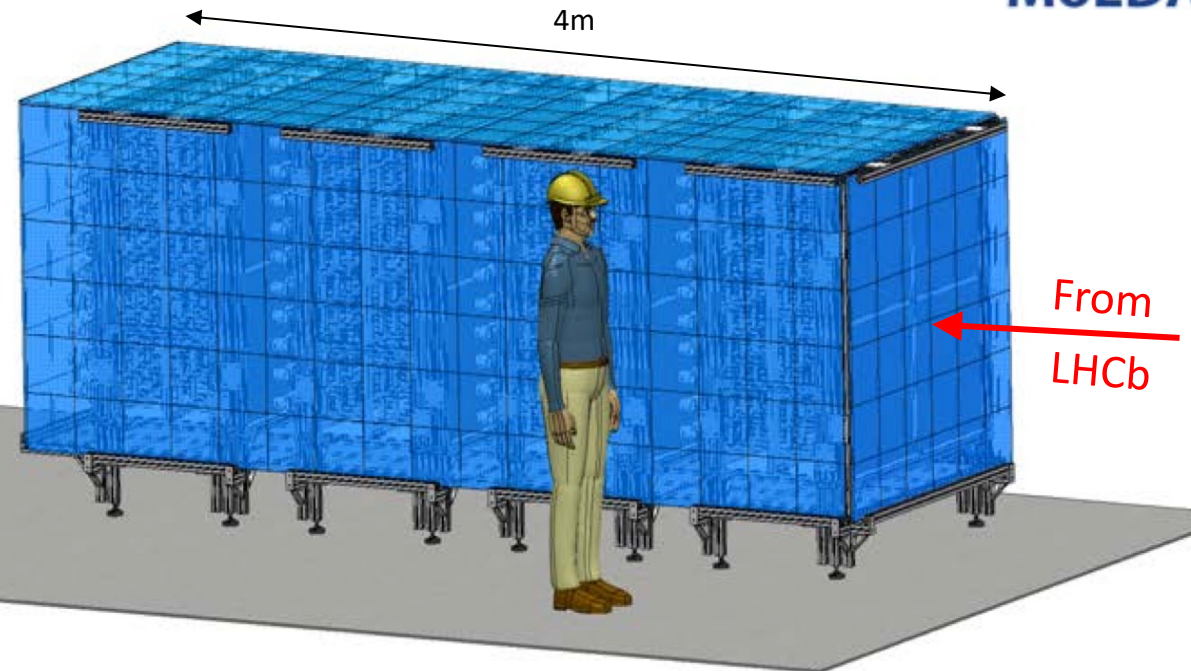


Basic unit



Electronics rack

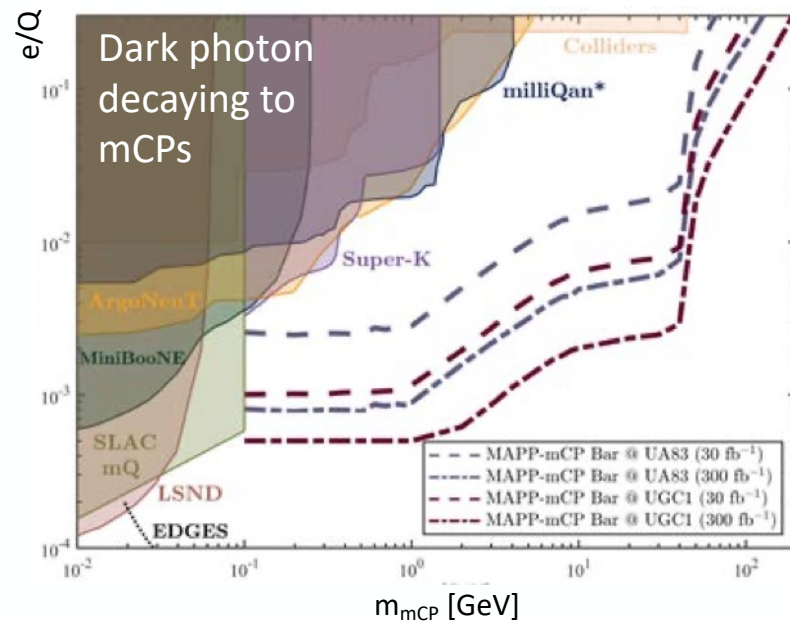
- Scintillating detector (~1.3 m x 1.8 m x 4 m)
 - 400 scintillating bars + PMTs in 4 sections
 - Surrounded by veto layer



- In addition to direct mCP and neutral LLP detection, monitors MoEDAL trapping volumes for charged LLPs with $\tau \sim 10$ years
 - Detector exposed for ~1 year then moved underground

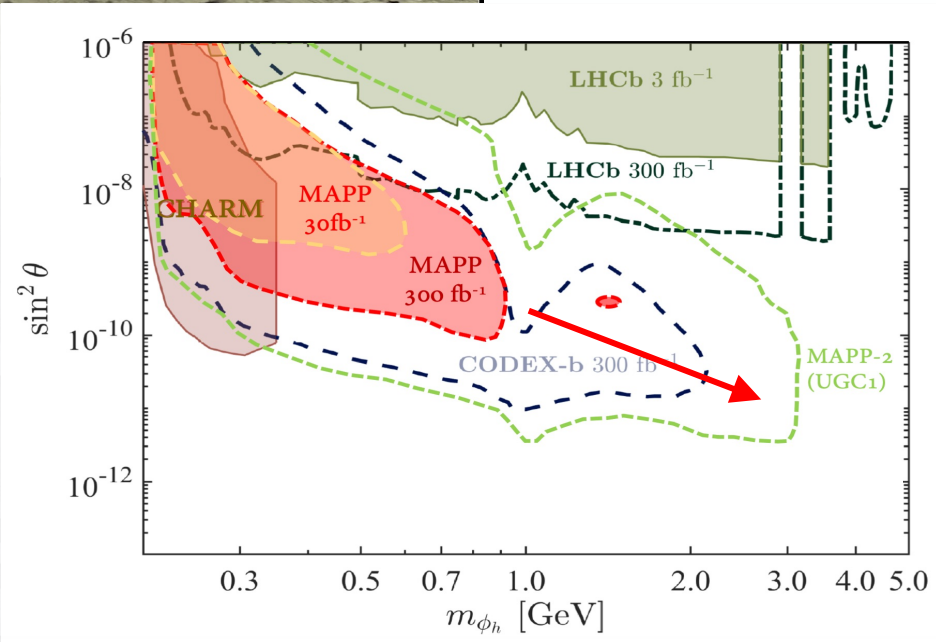
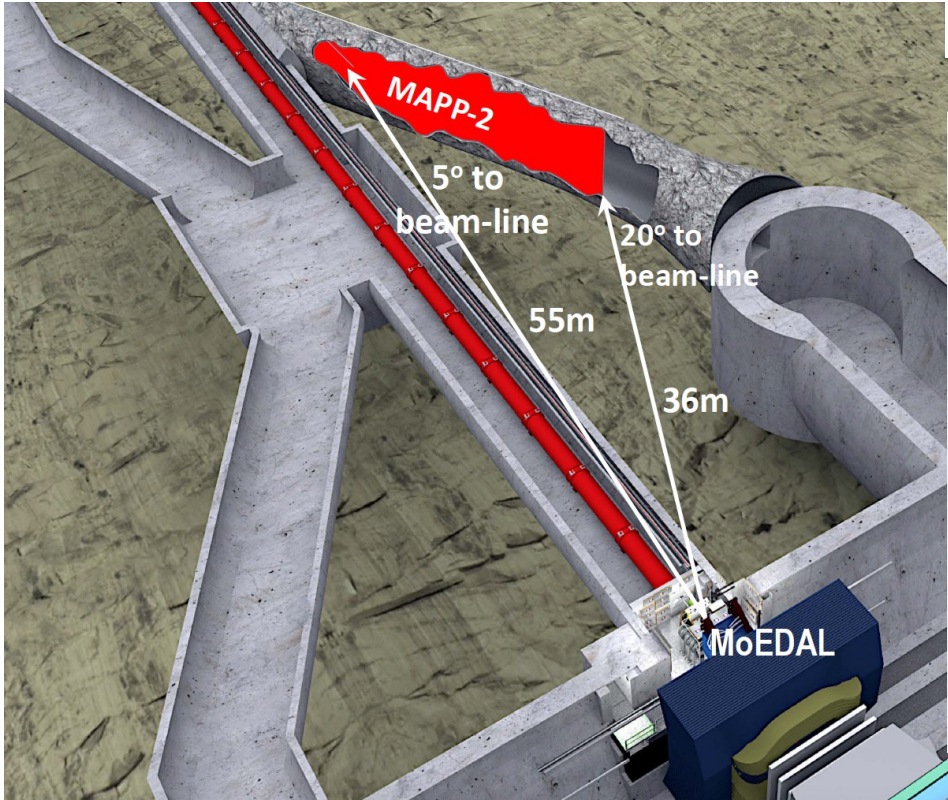
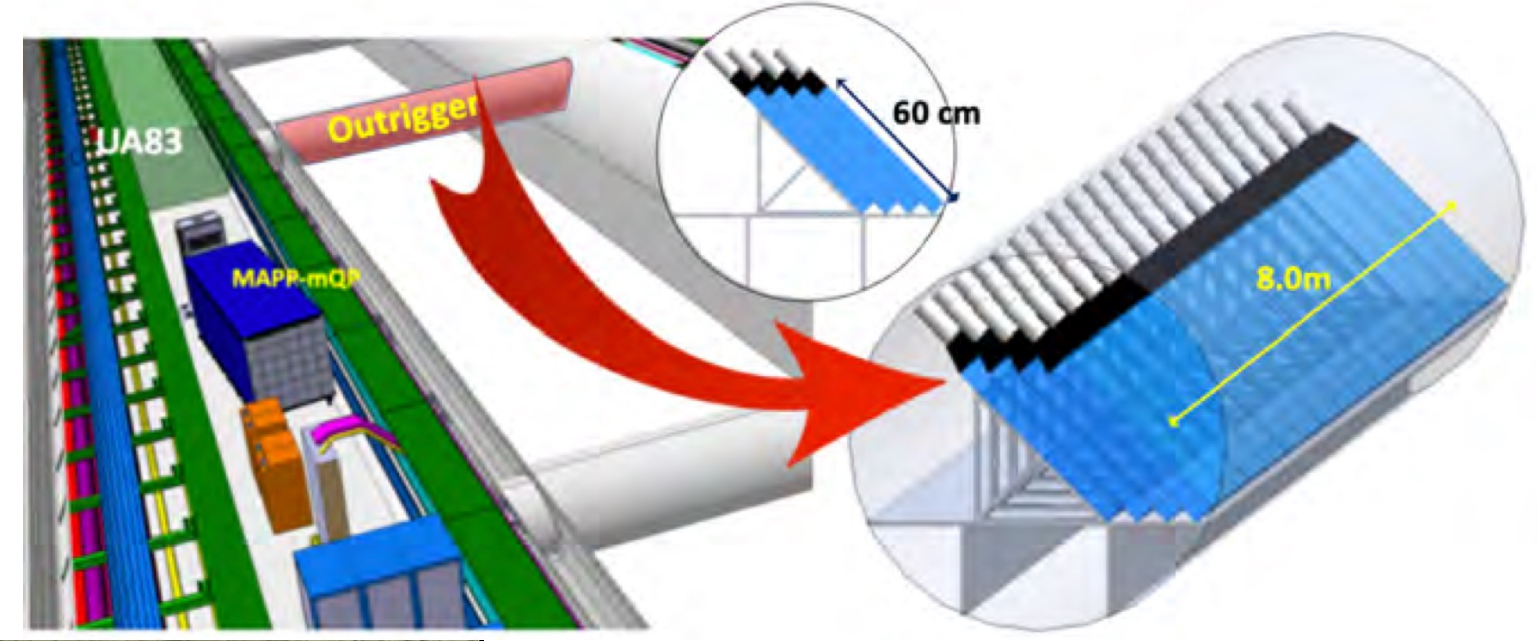
Installation in UA83

- Currently installed (Feb '22):
 - Support frame
 - Fraction of bars
 - Power + ethernet
 - LHC clock fibre optic
- Location change reduces mCP sensitivity (but inc. LLP τ reach)



MAPP Future Plans

- MAPP Outrigger (off axis)
 - 4 layers consisting of planks of 50 cm x 60 cm x 5cm scintillators
 - Increase sensitivity at high m & e/Q
 - Plan to install after run-3 detector

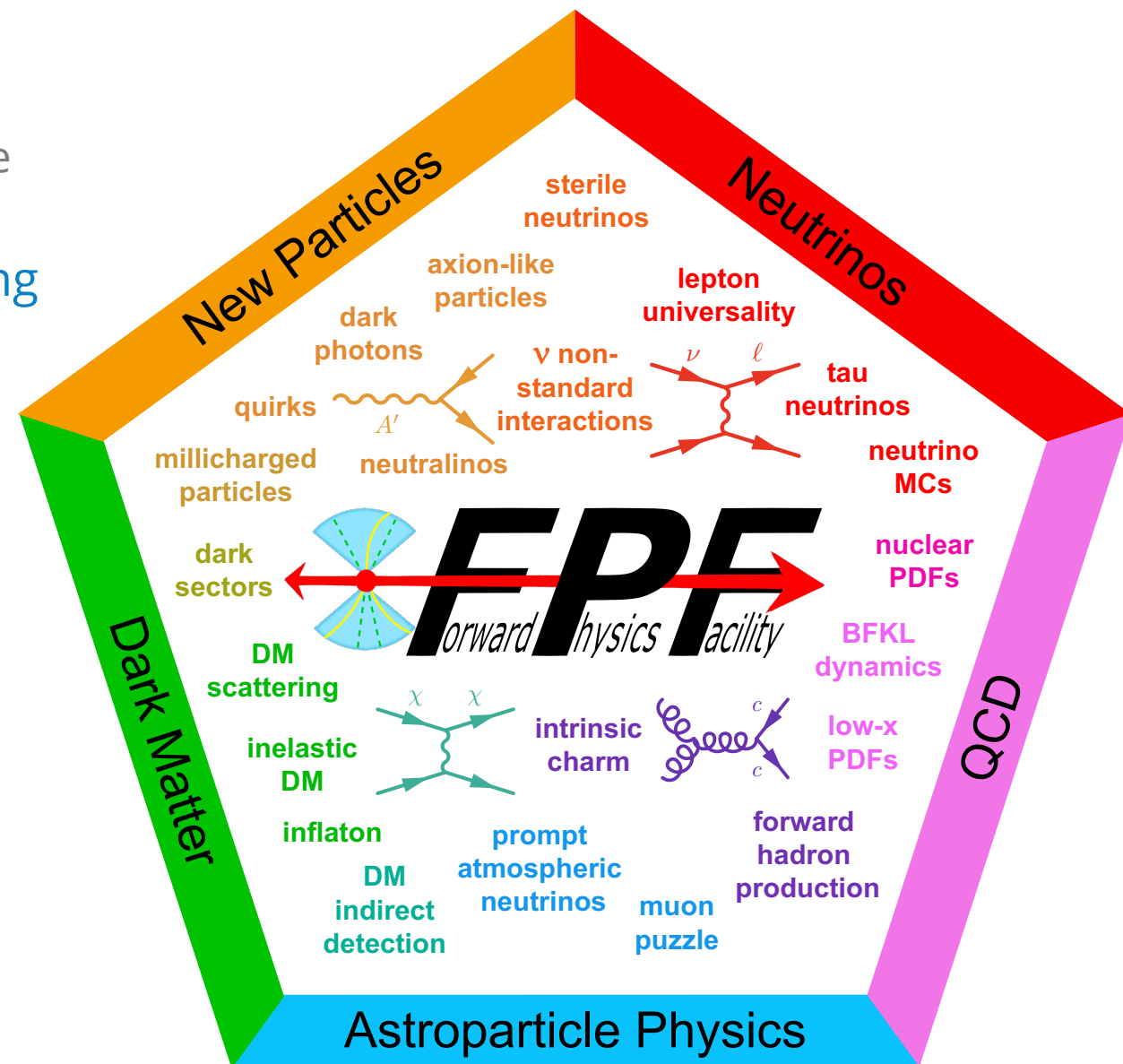


Dark Higgs to $\mu\mu$ sensitivity

- MAPP-2
 - Longer term for HL-LHC
 - In renovated UGC1 gallery
 - Lining wall
 - ~55 m from IP
 - Significant sensitivity inc.

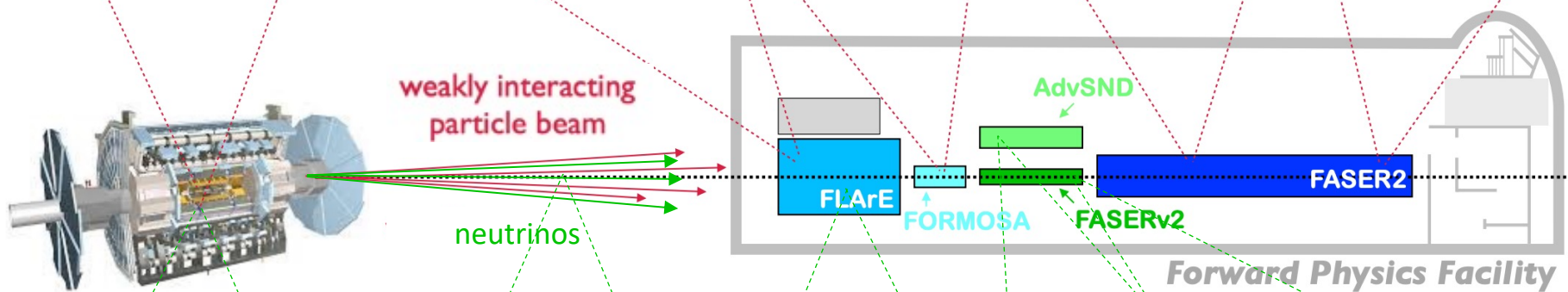
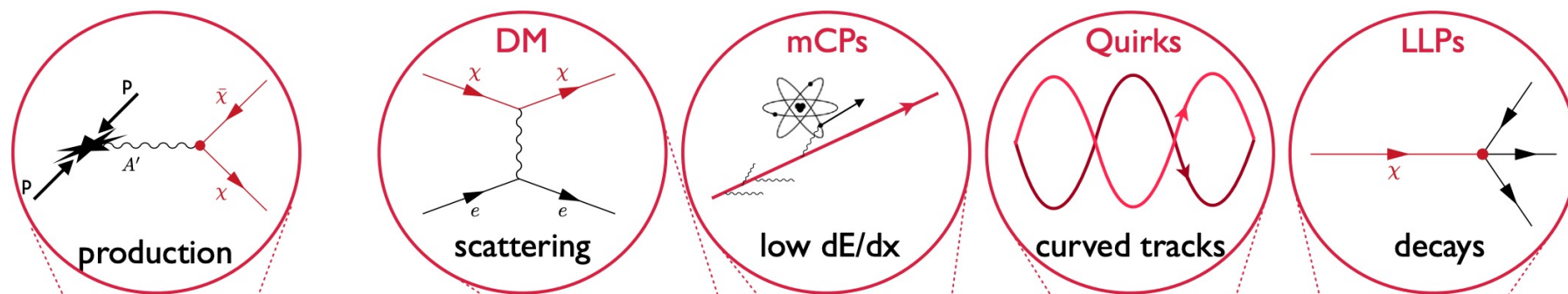
Forward Physics Facility (FPF)

- Proposal to build a new dedicated forward physics facility for the HL-LHC era
 - Rather than repurposing existing infrastructure
- Benefit from increased HL-LHC lumi by allowing
 - Longer detectors
 - Increased target/decay volume
 - Wider detectors
 - Increased sensitivity to HF production
 - New detectors
 - Complementary physics capabilities
- Rich and broad physics programs, particularly
 - BSM dark sector searches
 - Neutrino physics
 - QCD physics
- Since last LLP workshop: detailed [white paper](#)

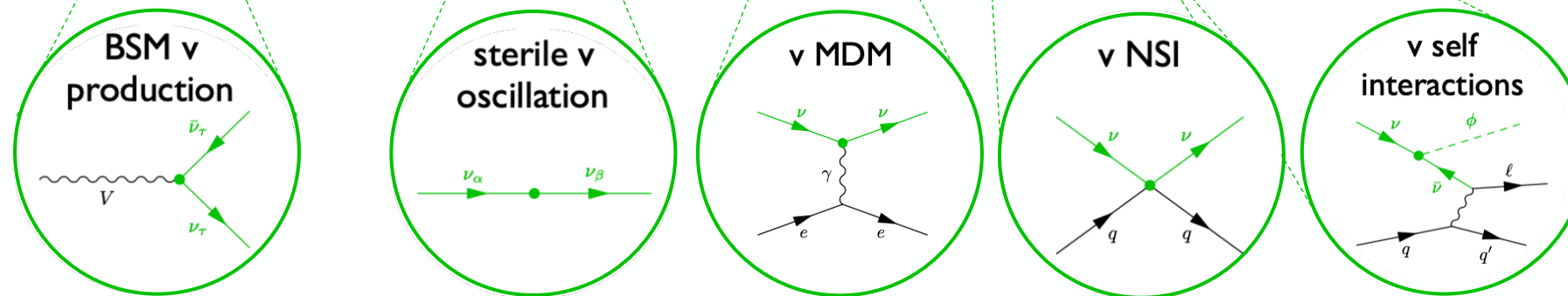


BSM Physics

- BSM particles can be detected in various ways
 - Giving access to wide range of models



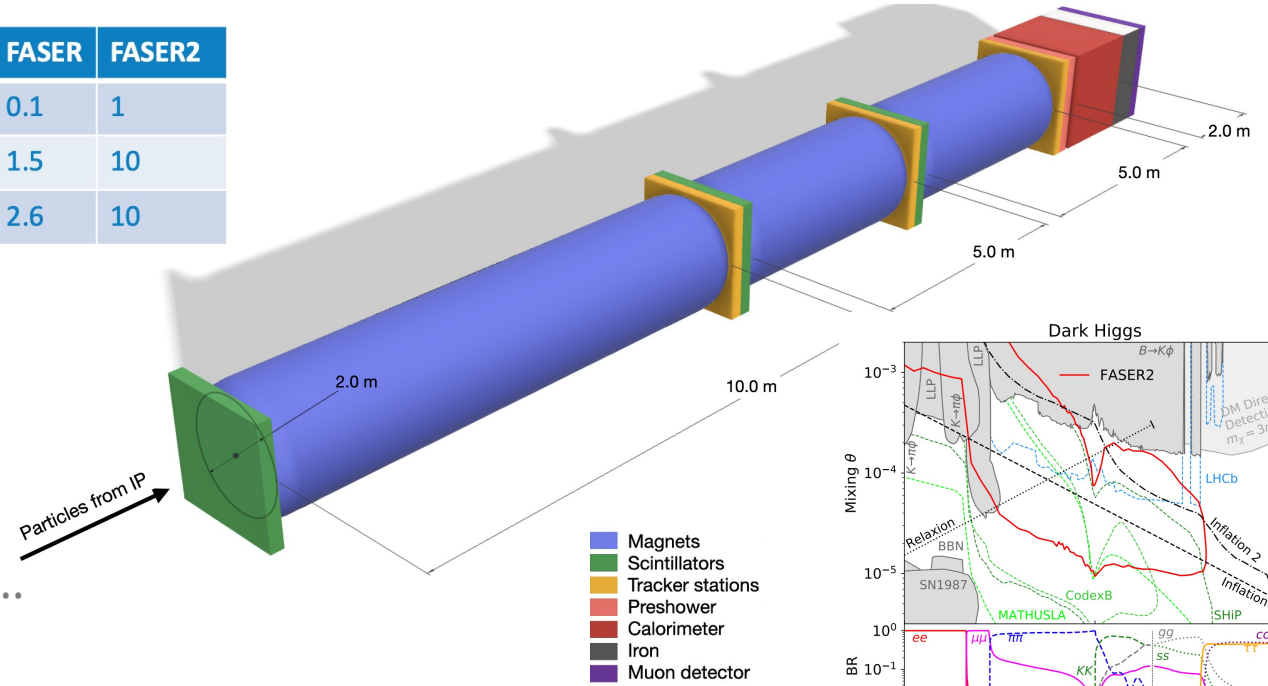
- Neutrinos can be used to search for BSM effects
 - Production
 - Propagation
 - Interaction



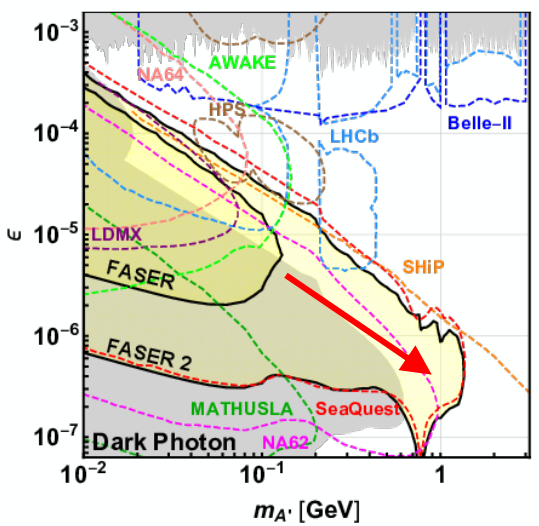
FASER2

- Conceptually a scaled up version of FASER2 with $\sim 100 \times$ active area
 - Veto: similar scintillator-based
 - Magnets: Superconducting w/ $B = 1 \text{ T}$
 - Tracker: much larger using e.g. SiFI/SiPM
 - Calo/Muon: enhanced PID & position resol.

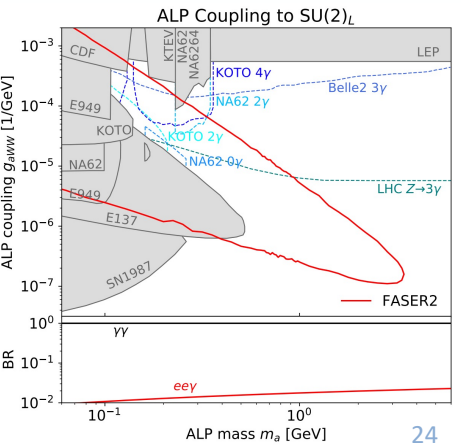
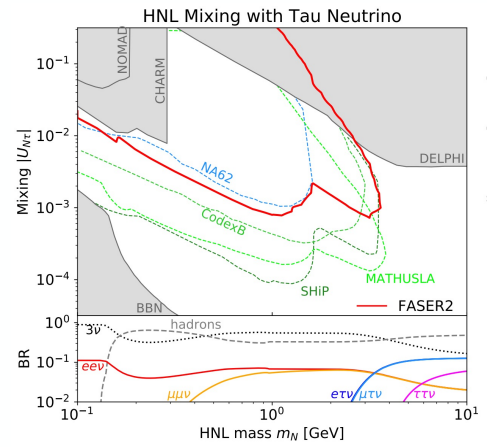
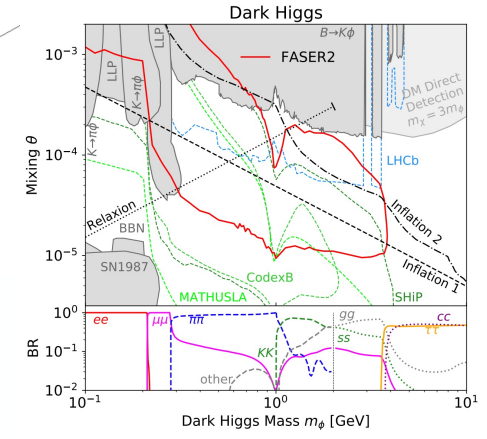
	FASER	FASER2
R [m]	0.1	1
DV [m]	1.5	10
TS [m]	2.6	10



- Wide LLP program probing many models
 - Dark vectors / (pseudo) scalars, ALPs, HNLs, ...
 - Extended sensitivity to higher mass



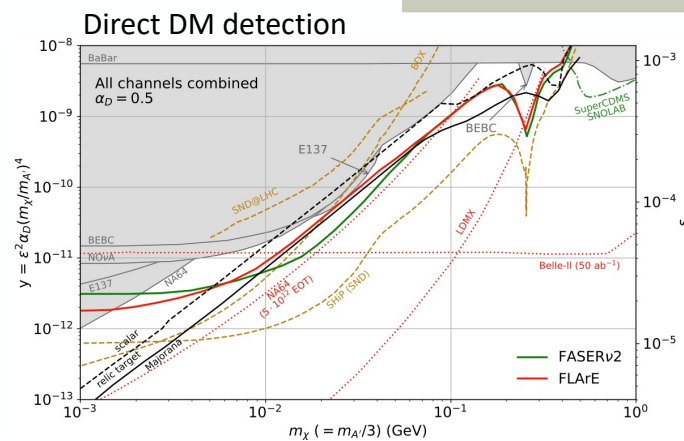
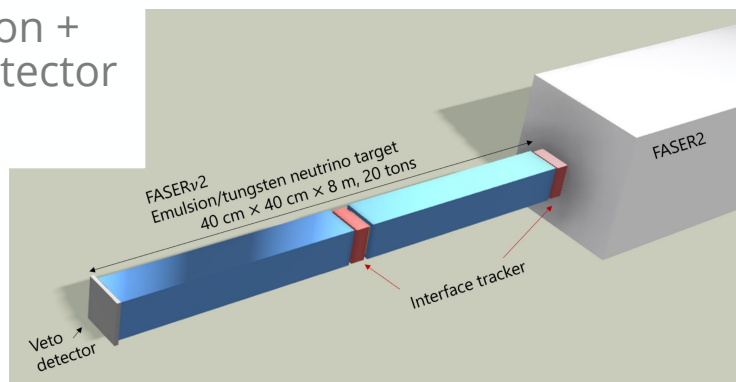
Benchmark Model	FASER	FASER 2
Dark Photons	✓	✓
$B - L$ Gauge Bosons	✓	✓
$L_i - L_j$ Gauge Bosons	—	—
Dark Higgs Bosons	—	✓
Dark Higgs Bosons with hSS	—	✓
HNLs with e	—	✓
HNLs with μ	—	✓
HNLs with τ	✓	✓
ALPs with Photon	✓	✓
ALPs with Fermion	—	✓
ALPs with Gluon	✓	✓
Dark Pseudoscalars	—	✓



Other Proposed Experiments

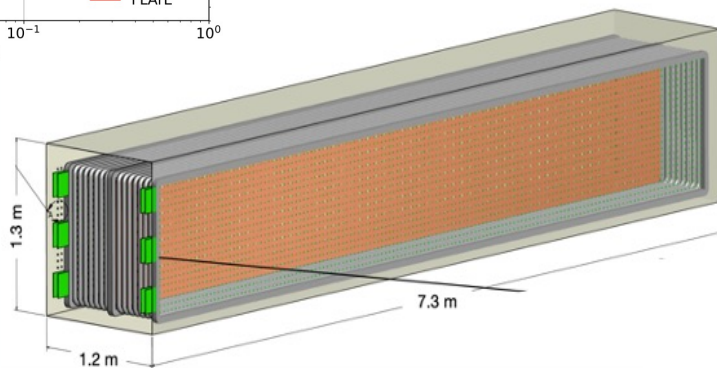
FASERv2

- ~20t emulsion + tungsten detector
- Focus on ν_τ



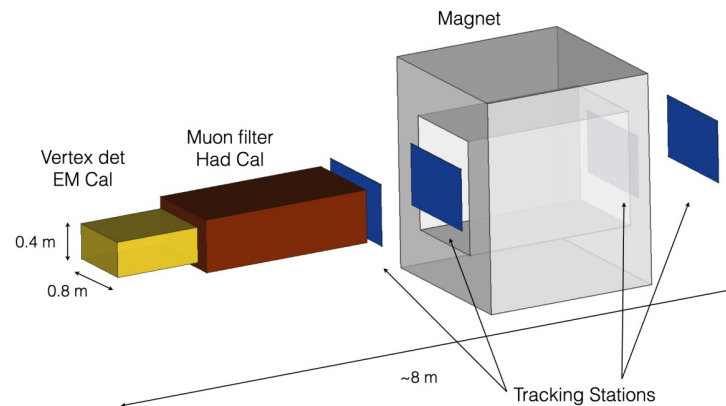
FLArE

- ~10t LAr TPC
- DM scatters + ν physics



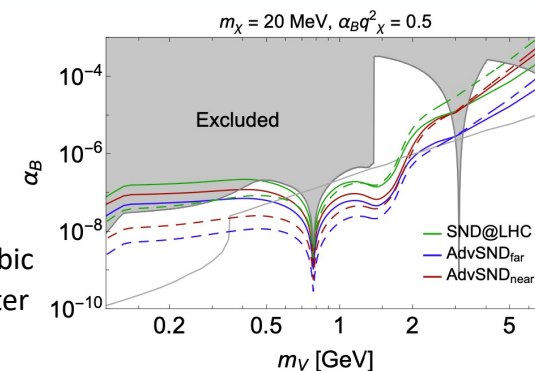
Currently proposed

- Two extended neutrino detectors
- Two completely new detectors



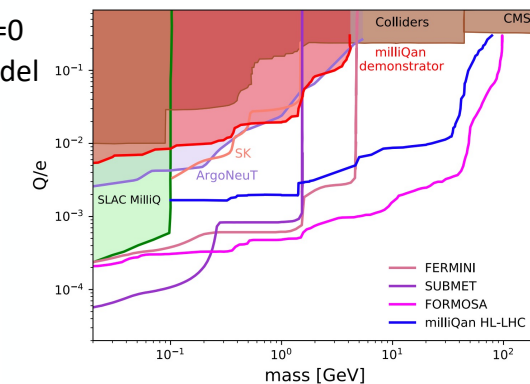
AdvSND (far)

- Off-axis ν detector
- Forward charm prod. + low-x gluon PDF



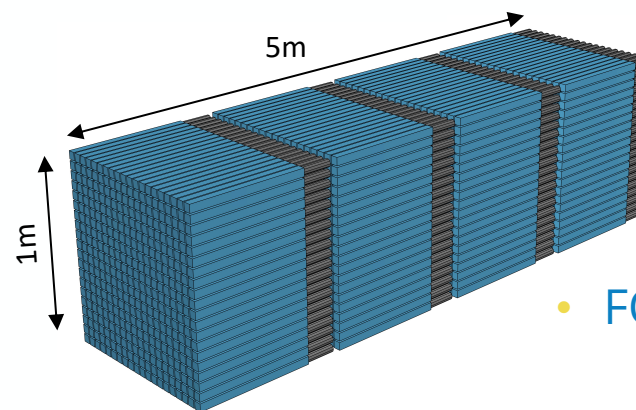
Leptophobic
Dark matter

mCP in m=0
 γ -dark model



FORMOSA

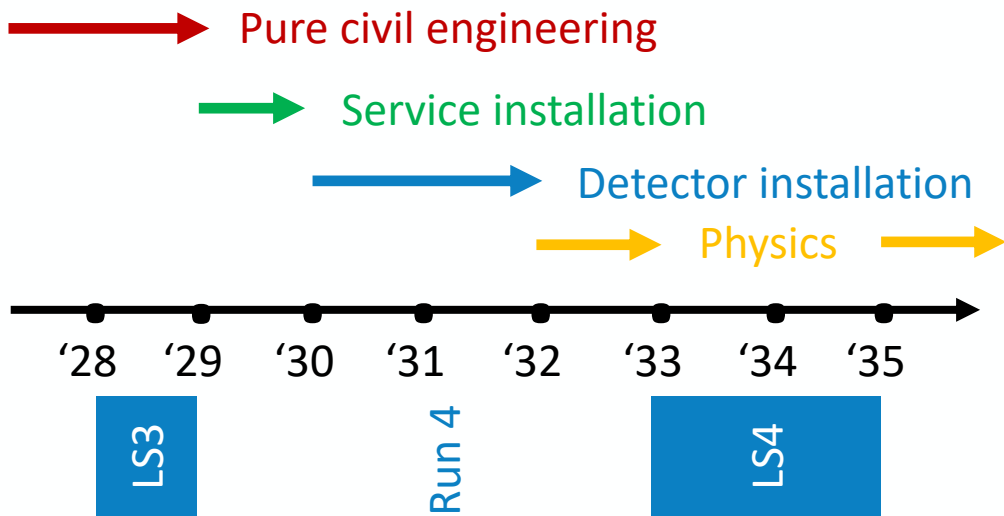
- Scintillator/tungsten detector
- For milli-charged particles ²⁵



Facility

- Baseline is new dedicated facility ~600 m to west of ATLAS (IP1)
 - Based on several studies from CERN civil engineering (CE) team
- Very preliminary cost: ~40 MCHF
 - 23 MCHF CE + ~15 MCHF services
 - Plus experiments on top

• Tight schedule:



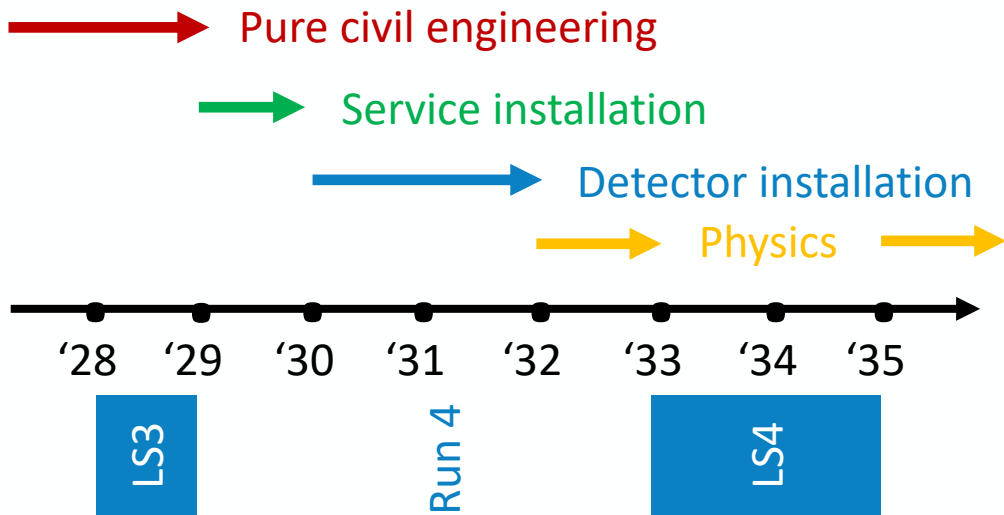
- Need to move to CDR/TDR soon



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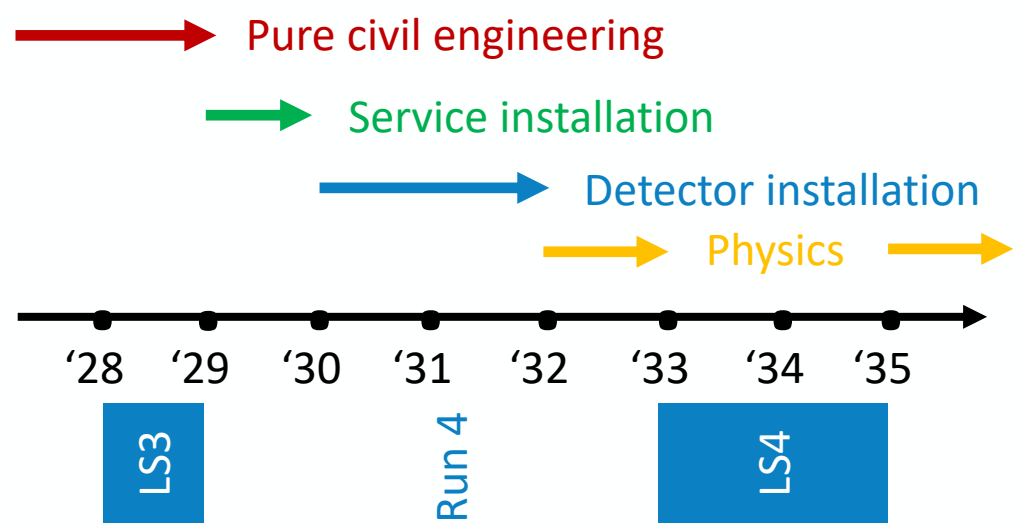
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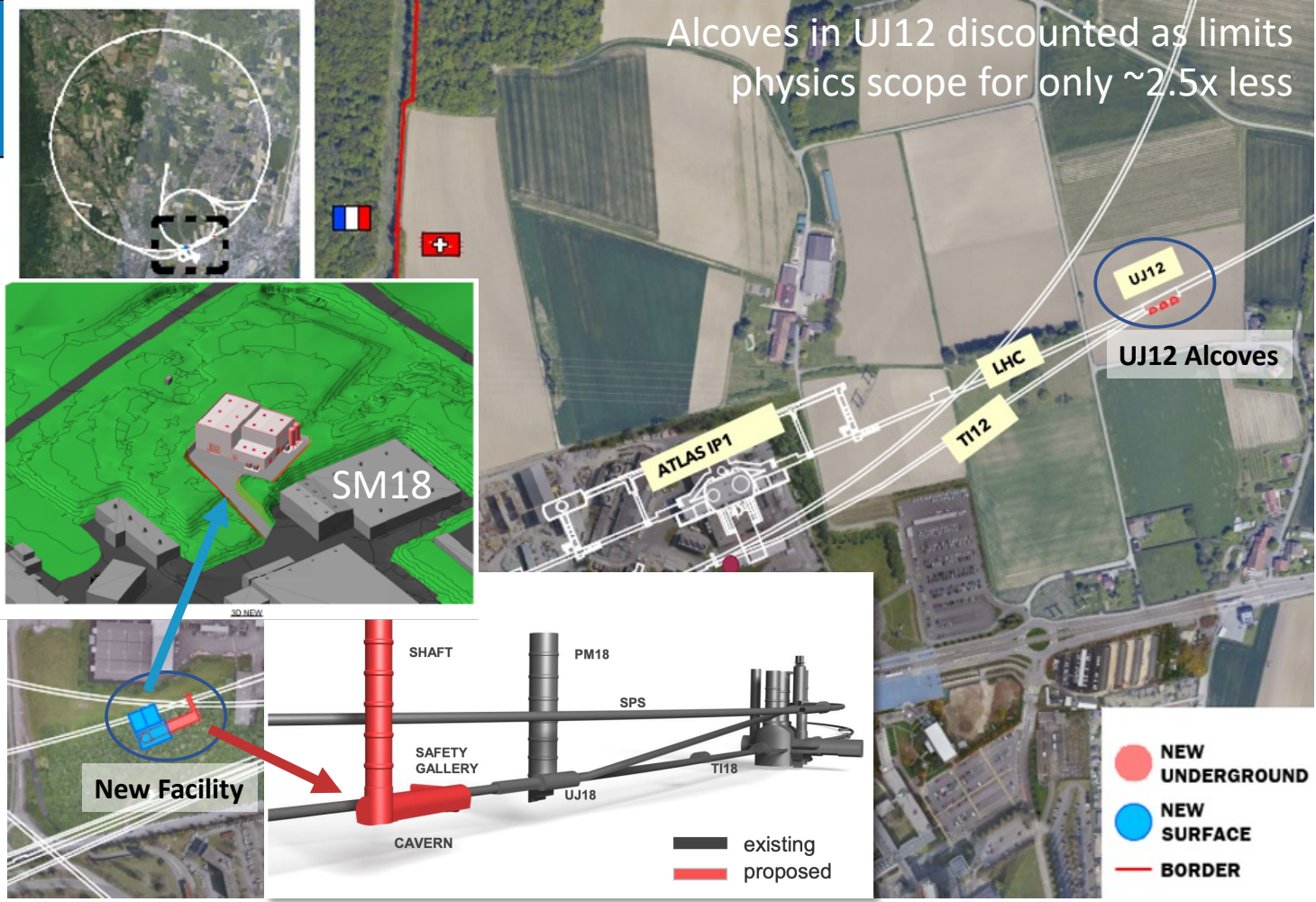
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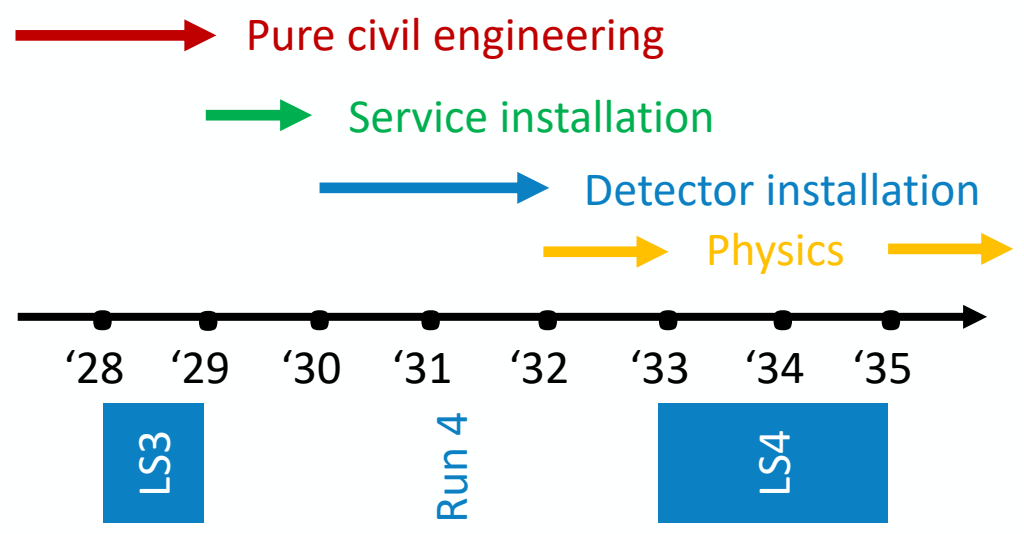


Alcoves in UJ12 discounted as limits physics scope for only ~2.5x less

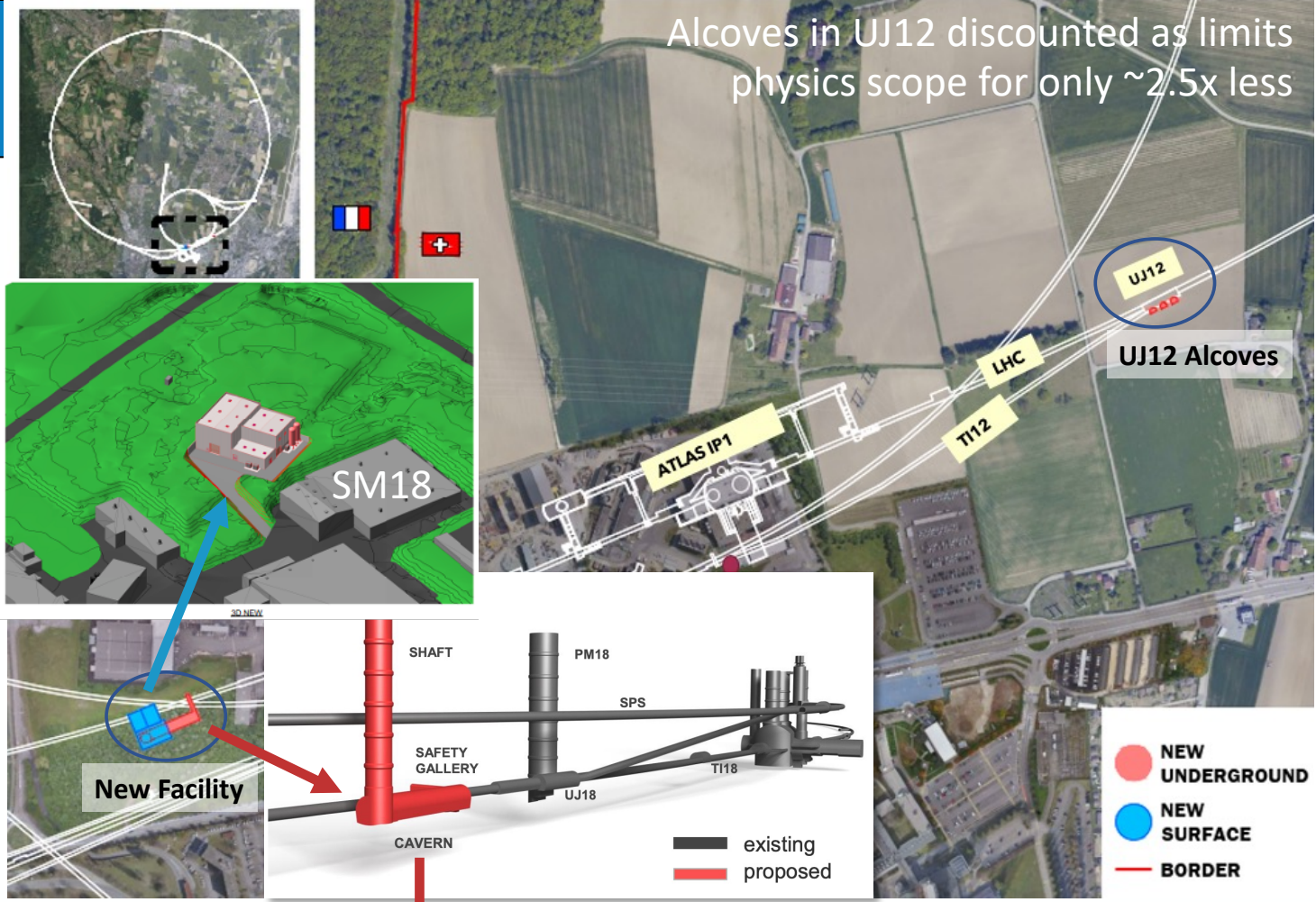
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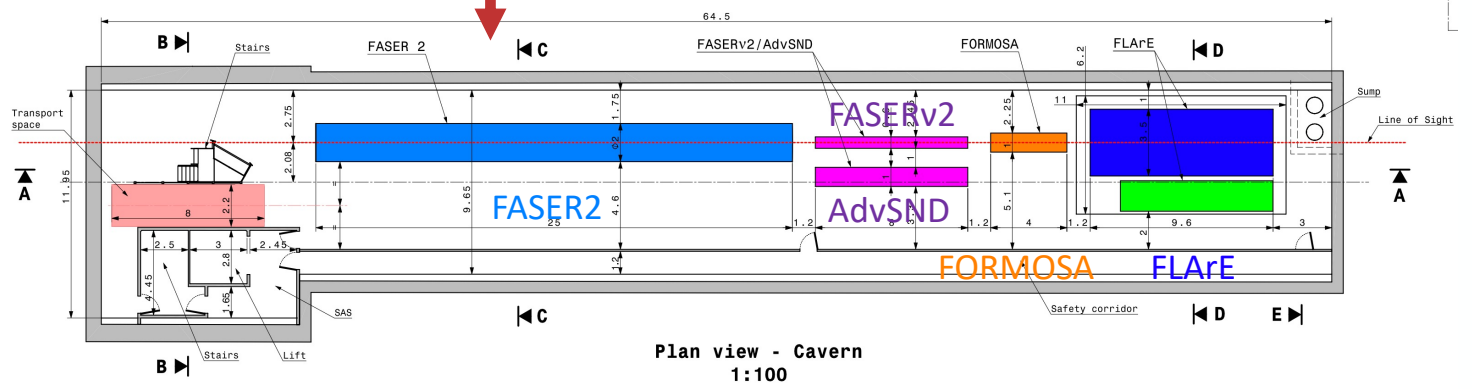
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Summary

- Forward detectors give access to light, weakly-interacting particles with significant lifetime
 - Even small, inexpensive detectors can have a strong, complementary physics case
- Provide sensitivity to a wide range of BSM physics models (dark γ , ALPS, HNL, light DM, mCP etc)
 - Probing uncovered regions of phase space, even with 2022 data already in some cases
- Three new detectors making great progress towards imminent run-3 data taking
 - Stay tuned for first physics!
- Longer term, proposal for dedicated forward physics facility to take advantage of HL-LHC
 - Would give a rich and broad physics programme
 - Tight timeline so please contribute to studies if interested