ForwArd Search ExpeRiment (FASER)
Joint PhD opportunity with Liverpool + RAL

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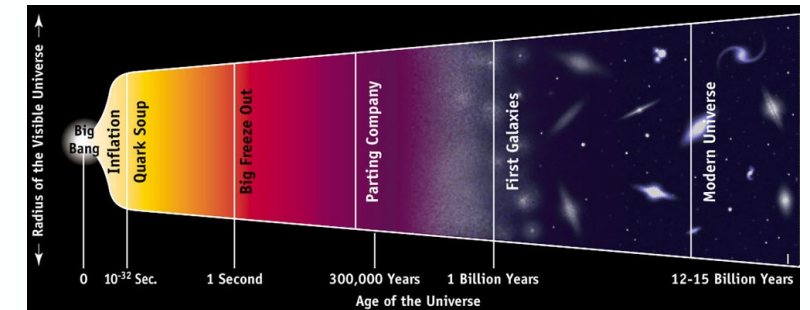
Large Hadron Collider

- 13 TeV proton-proton collisions
  - Study building blocks of matter
  - Probe conditions shortly after big bang

- 2 multipurpose experiments and 2 dedicated detectors
  - ATLAS and CMS
  - LHCb and ALICE
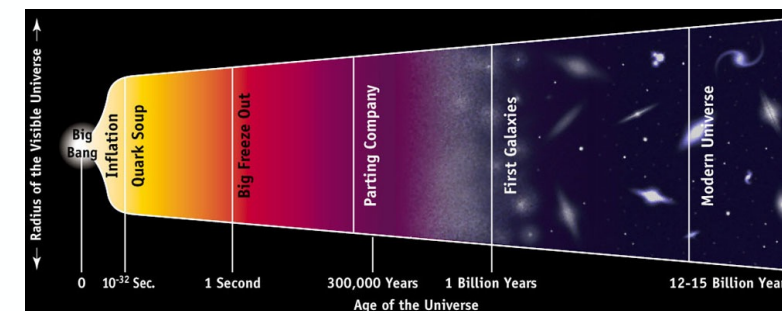
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- ## New for 2022 on (Run 3)
  - FASER experiment

FASER Experiment and Collaboration

- New LHC run-3 experiment located 480 m downstream of ATLAS in Ti12 side service tunnel
  - Exploiting large LHC collision rate + forward-peaked light hadron production
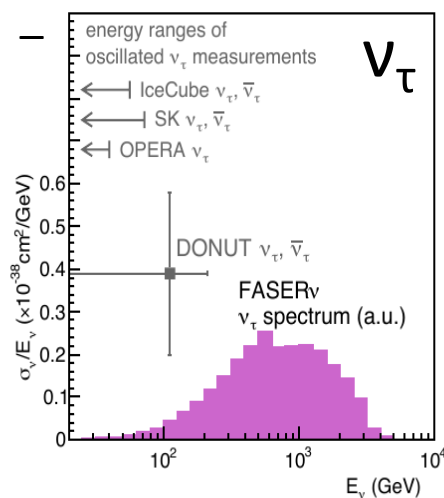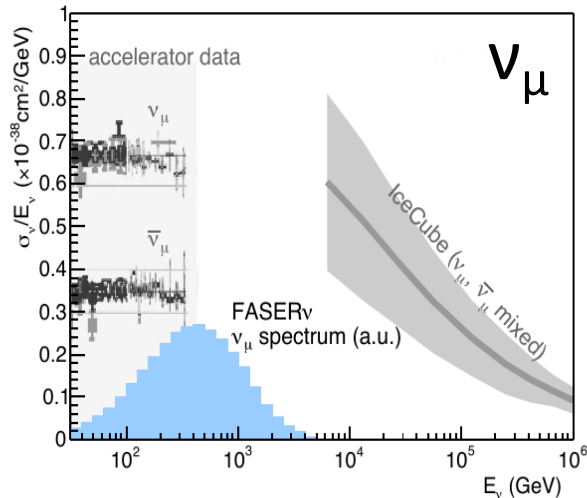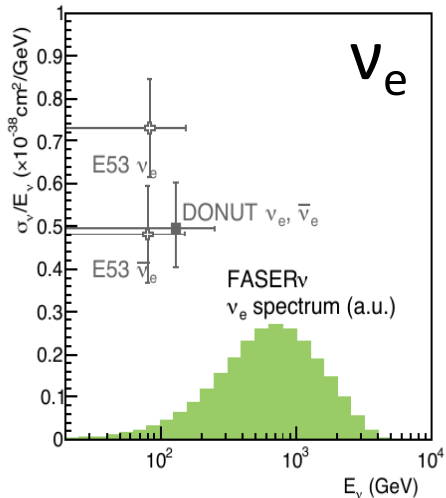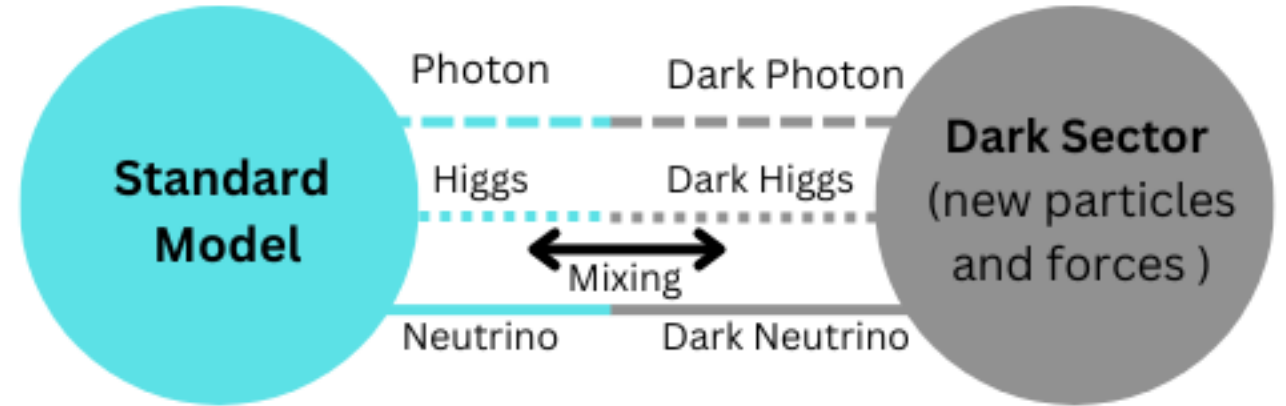 - Combination of LHC magnets and 100 m of rock shield most background
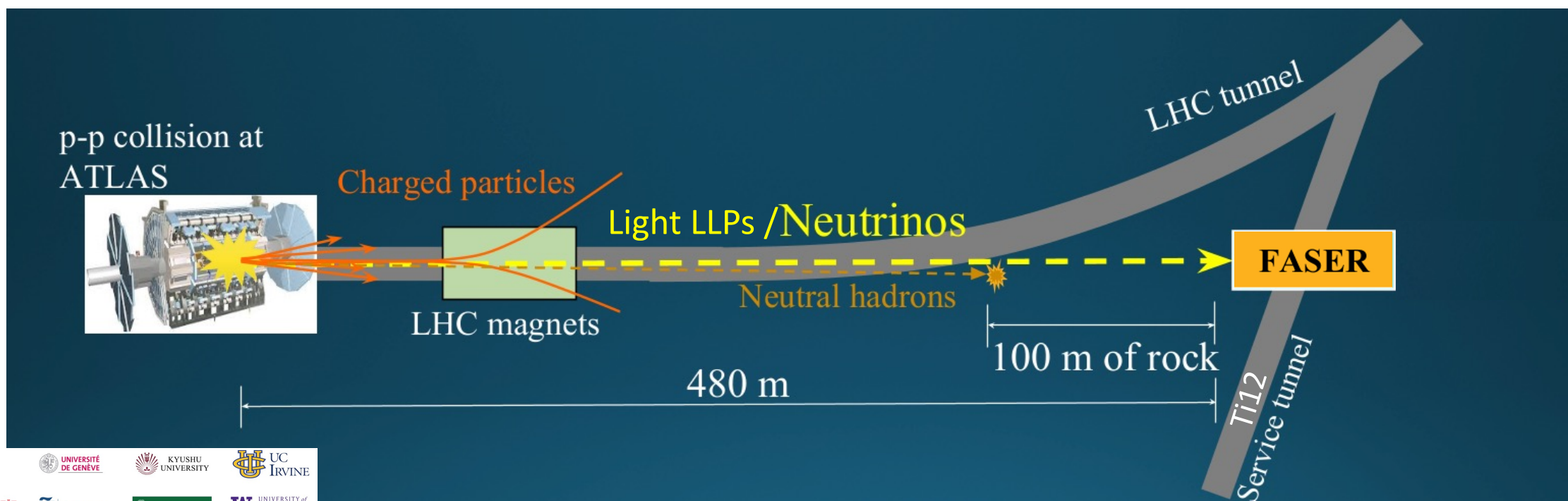
- 93 members from 26 institutes across 10 countries
  - 4 UK: Liverpool, Manchester, SUSSEX and RHUL
  - **Liverpool**: 2 academics and 2 PhD students (1st & 4th year)

Physics Motivation

- Designed to search for light, weakly interacting particles produced in LHC collisions at ATLAS
  - Can be either the neutrinos of the Standard Model (SM) or new physics beyond this (BSM)
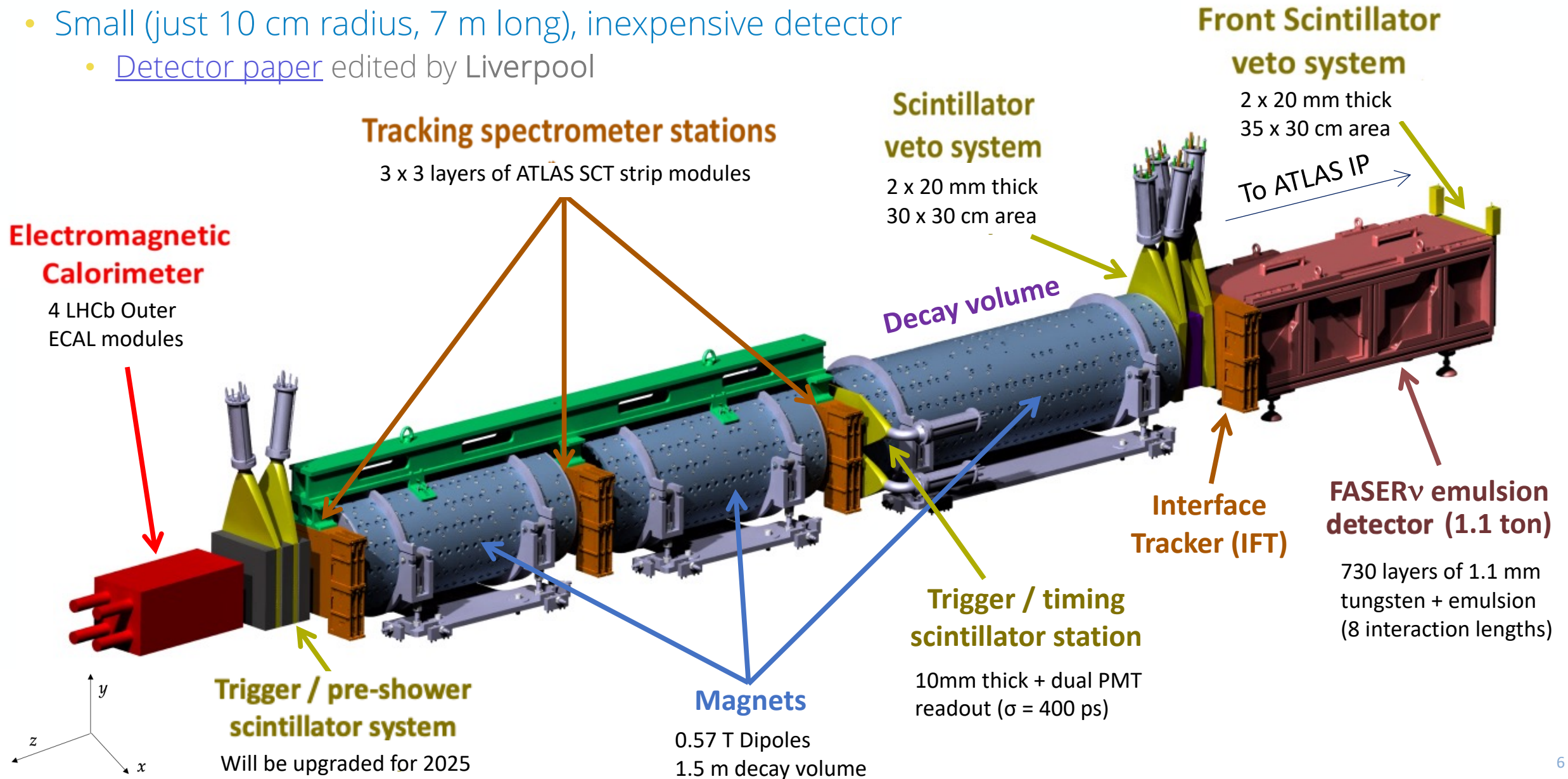
- Probes large range of BSM models that predict long-lived particles (LLPs)
  - Which may act as mediator to a dark sector

  pp → LLP, LLP travels ~480m, LLP → ee, γγ, μμ, ...

- Complementary to ATLAS/non-collider
  - Sensitivity to unique parameter space

Standard Model — Photon — Dark Photon — Dark Sector (new particles and forces)

Higgs — Dark Higgs

Mixing
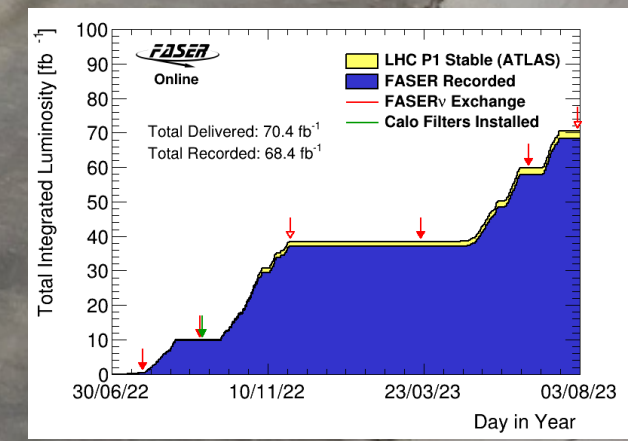
Neutrino — Dark Neutrino

ν_e

ν_μ

$\overline{\nu}_\tau$

- FASERν adds neutrino program
  - First detection of collider neutrinos

- Cross-section measurement in E range from ~ 100 GeV to ~1 TeV
  - Highest energy man-made neutrinos
  - Unexplored phase space region

FASER Detector

- Small (just 10 cm radius, 7 m long), inexpensive detector
 - Detector paper edited by Liverpool

Tracking spectrometer stations

3 x 3 layers of ATLAS SCT strip modules

Front Scintillator veto system

2 x 20 mm thick
35 x 30 cm area

To ATLAS IP

Scintillator veto system

2 x 20 mm thick
30 x 30 cm area

Electromagnetic Calorimeter

4 LHCb Outer
ECAL modules

Decay volume

Interface Tracker (IFT)

FASERν emulsion detector (1.1 ton)

730 layers of 1.1 mm
tungsten + emulsion
(8 interaction lengths)

Trigger / timing scintillator station

10mm thick + dual PMT
readout (σ = 400 ps)

Trigger / pre-shower scintillator system

Will be upgraded for 2025

Magnets

0.57 T Dipoles
1.5 m decay volume

Virtual visit

- Successfully operated throughout 2022 + 23
- All detector components performing excellently

New Physics Searches

FASER
Simulation Preliminary
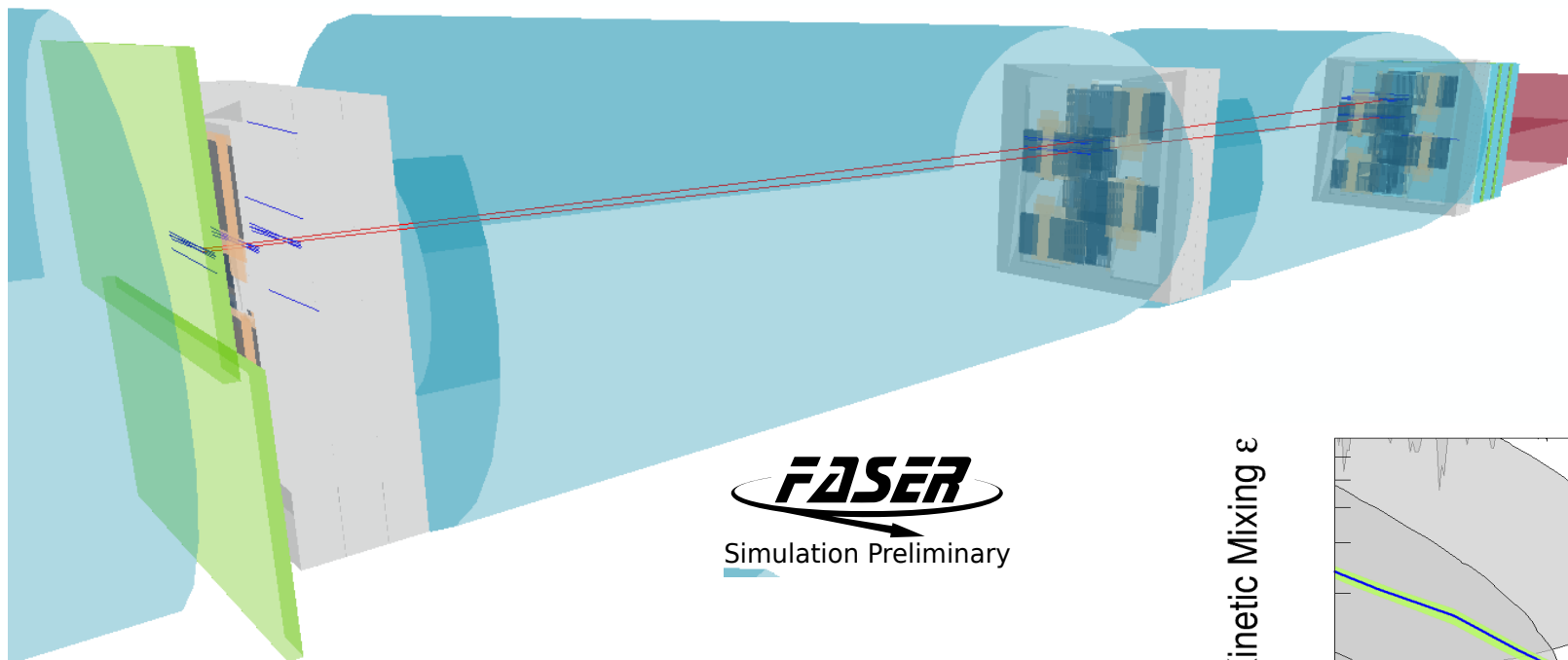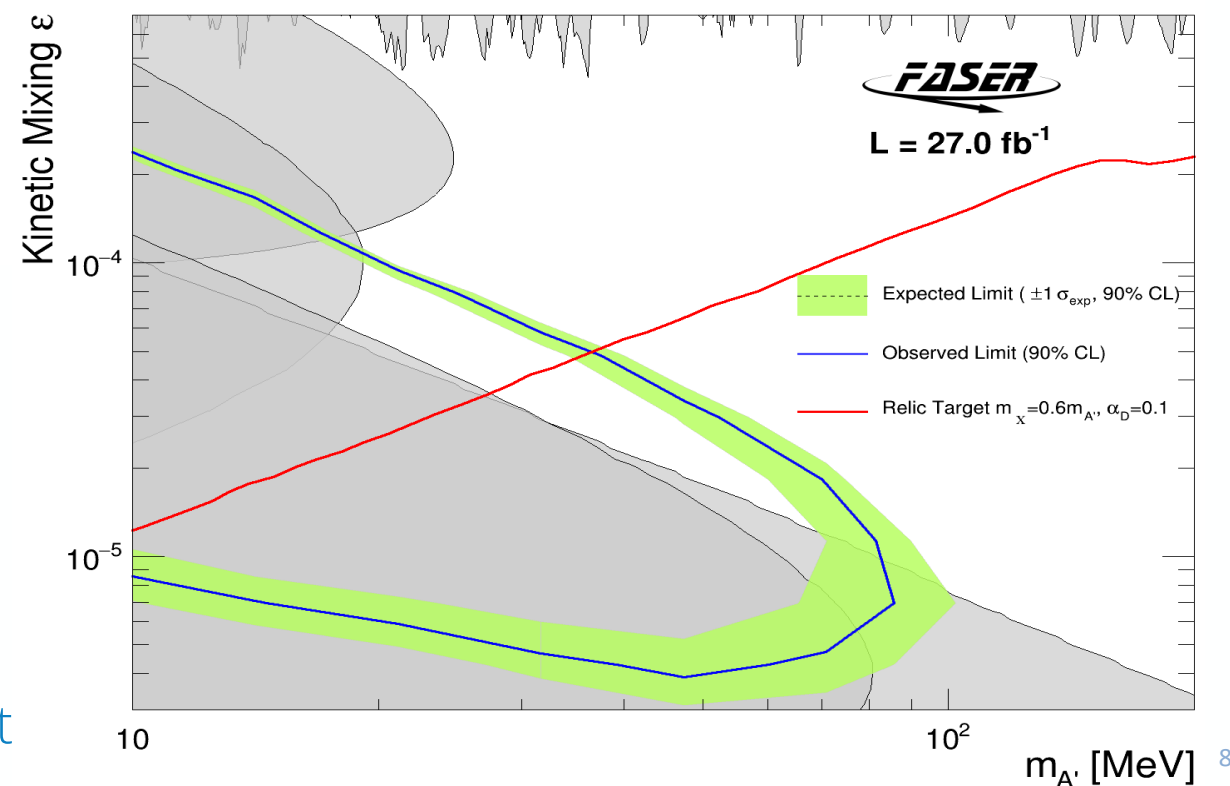
- First result: search for dark photons with 2022 dataset
  - Decaying into e^+e^- pair
- Analysis led by **Liverpool**
  - Limited by tracking efficiency

- Based on null result, FASER sets limits in previously unexplored parameter space!
  - Probing region of model that can explain the observed density of dark matter in the universe
  - Published in Physics Letters B
- Search for Axion-Like Particles (ALPs) in progress with 2022+23 data, led by **Liverpool** PhD student

FASER

L = 27.0 fb^{-1}

Expected Limit ($\pm 1\,\sigma_{exp}$, 90% CL)

Observed Limit (90% CL)

Relic Target $m_X = 0.6 m_{A'}$, $\alpha_D = 0.1$

Kinetic Mixing ε

$m_{A'}$ [MeV]

Collider Neutrino Observations

- First ever direct observation of neutrinos produced at a particle collider with 2022 dataset
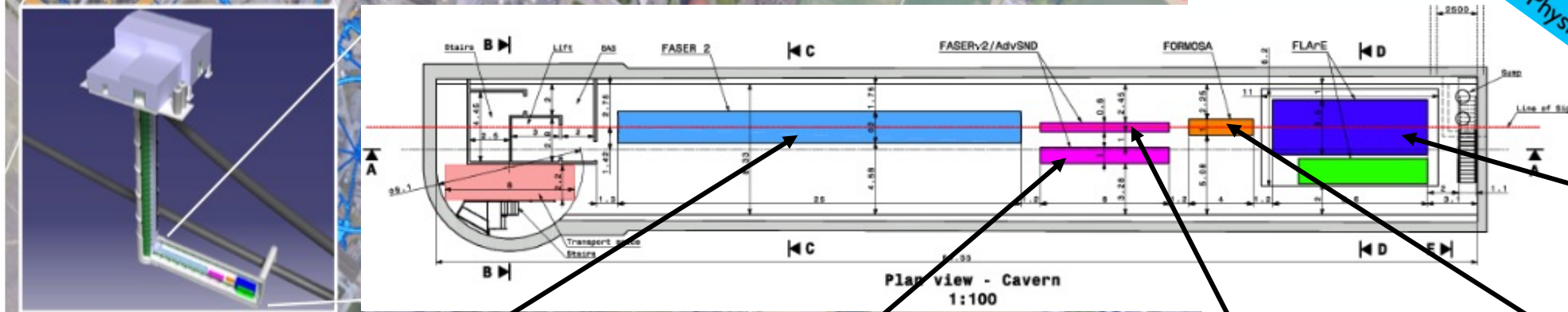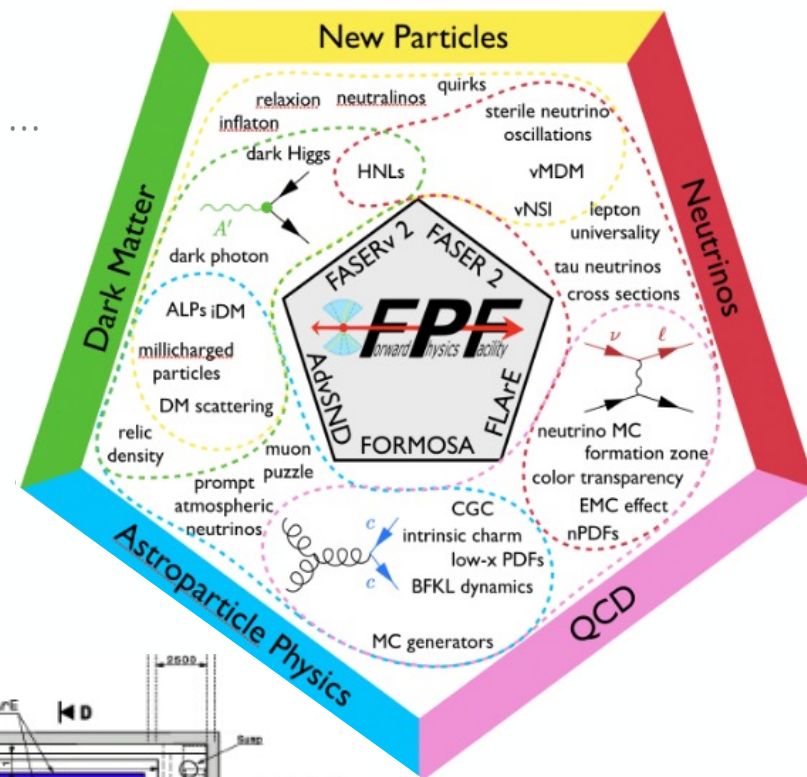 - Overseen by **Liverpool** as Physics Coordinator

FASER Preliminary

FASER Preliminary $\mathcal{L} = 35.4 \text{ fb}^{-1}$
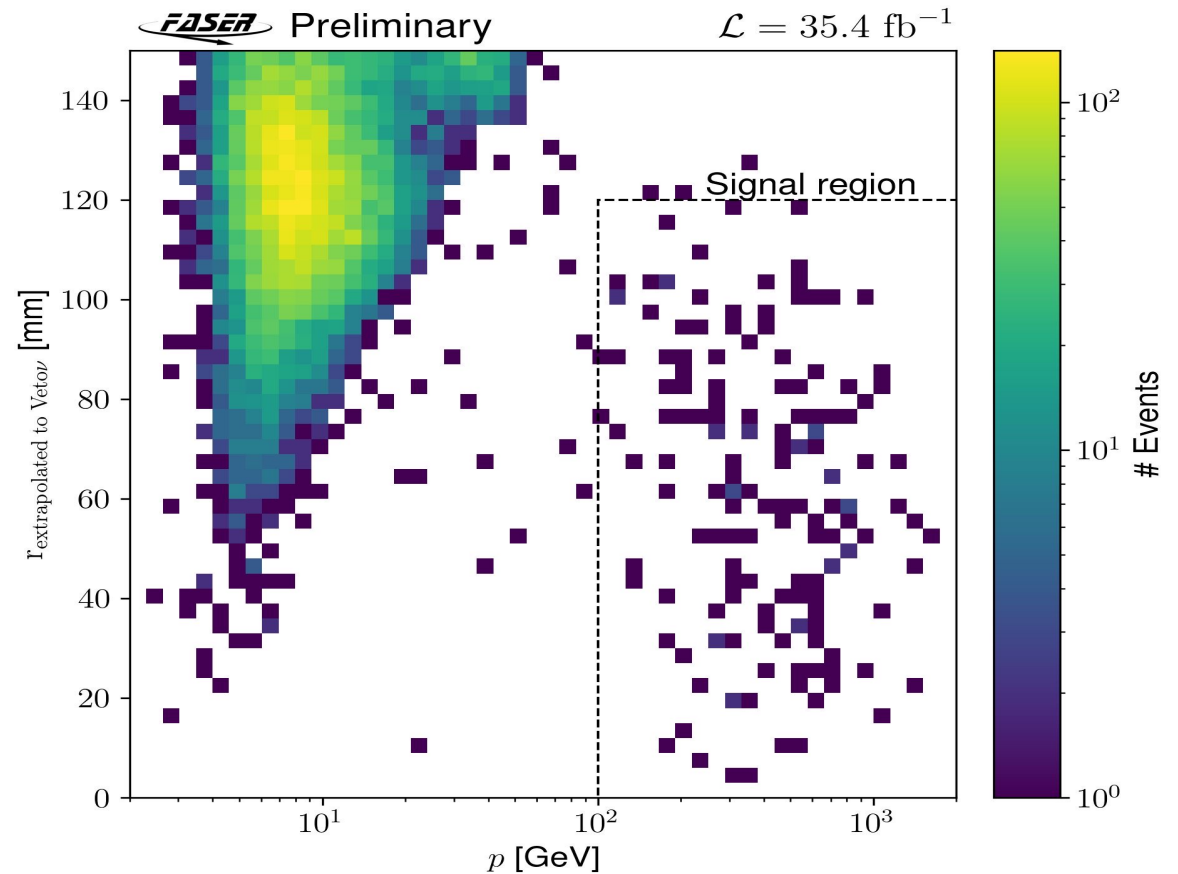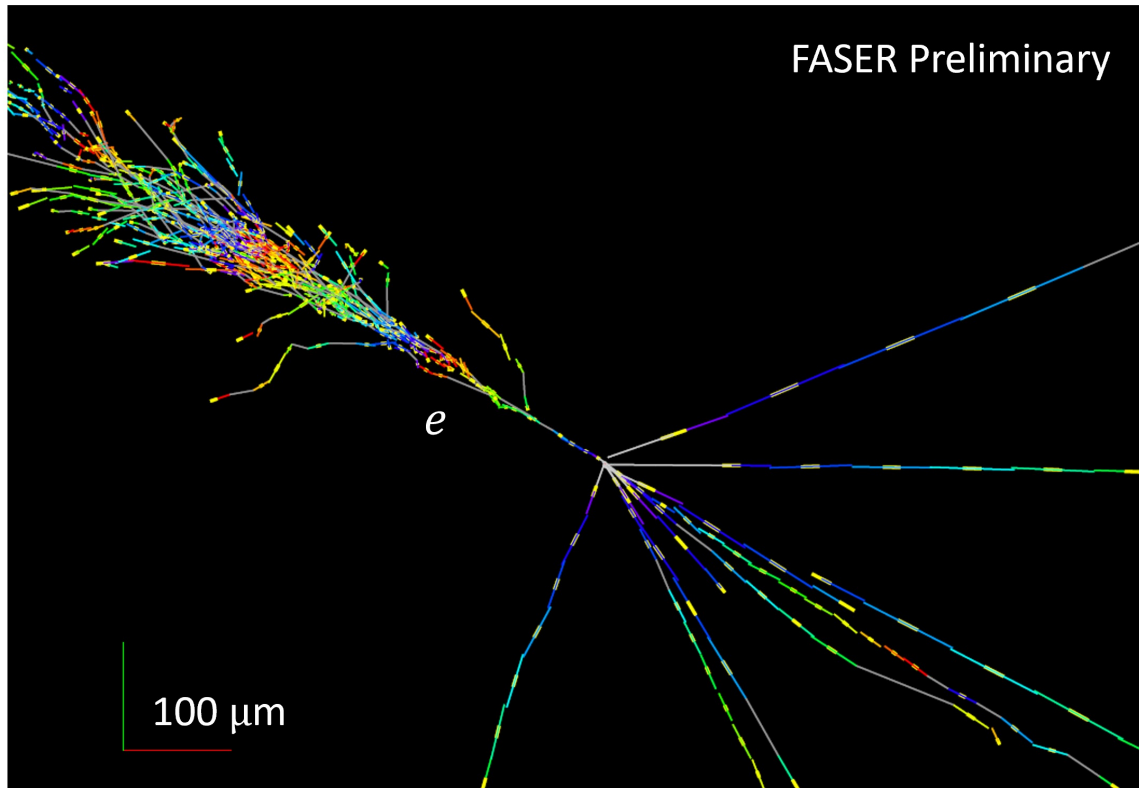
- Emulsion detector: electron neutrinos
  - 3 candidates ➔ 5σ significance!
  - Preliminary result released

- Electronic detector: muon neutrinos
  - 153 candidates ➔ 16σ significance!
  - Published in Physics Review Letters

Forward Physics Facility (FPF)

- Proposed new dedicated forward physics facility at HL-LHC
  - Broad physics program: BSM searches, ν physics, QCD measurements, …

Proposal published

FASER2: spectrometer for BSM LLP searches

+

FASERν2: emulsion neutrino detector

AdvSND: electronic neutrino detector
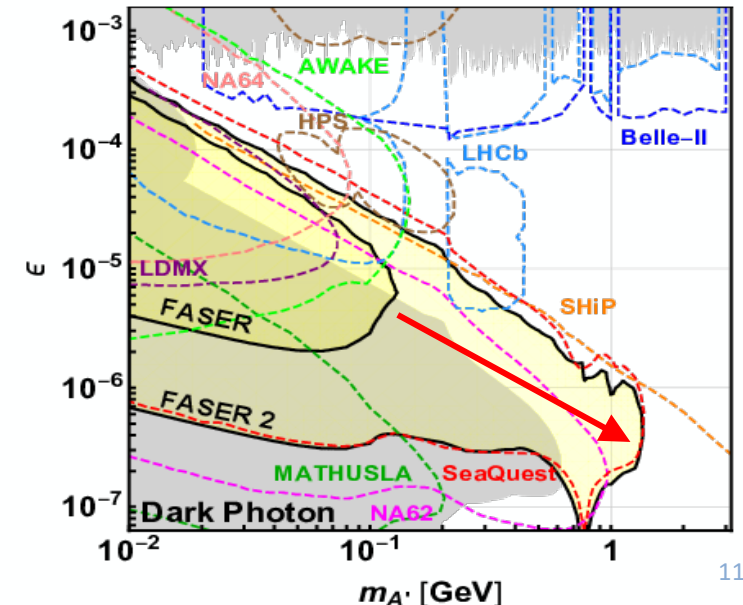
FORMOSA: Plastic scintillator for BSM

FLArE: LAr-based neutrino detector

FASER2

- On-axis spectrometer with 4 Tm superconducting magnet
  - Longer: increased target and decay volume (L =1.5 m ➔ 10 m)
  - Wider: increased sensitivity to HF production (R = 0.1m ➔ 1 x 3 m)

- Wider LLP physics program
  - Probing up 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	—	√
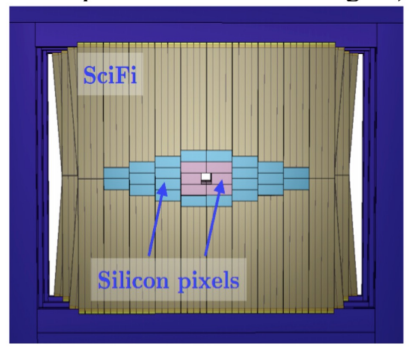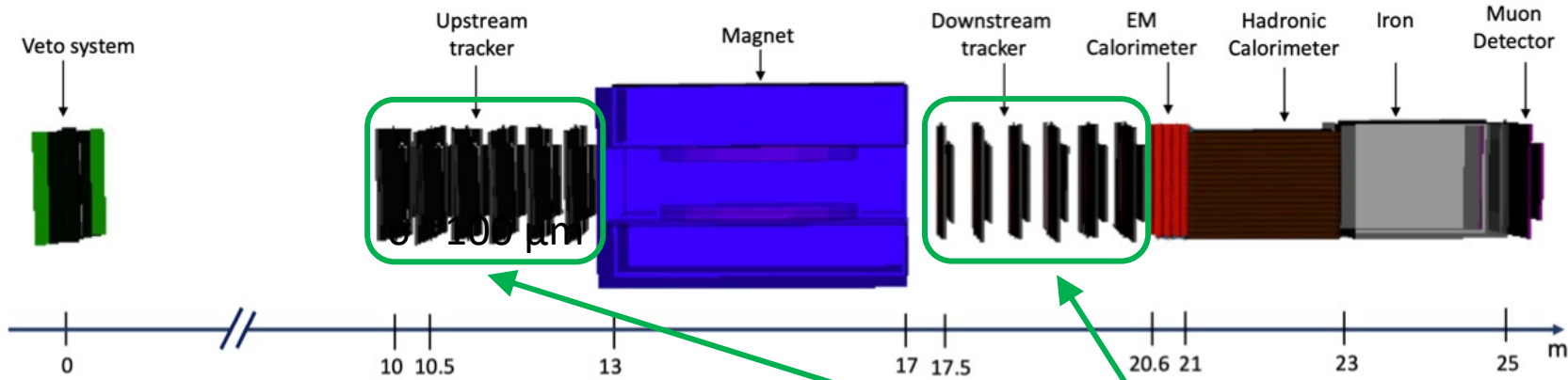
- Liverpool + RAL interested in tracking detector:
  - Baseline proposal is LHCb-like scintillating fibre (SciFi) detector but potential higher resolution silicon detector for 1st layer / central region
  - Currently contributing to layout optimisation

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PhD Project Outline

- Project will run from Oct 2024 - Mar 2027, giving access to full LHC run-3 dataset (~250 fb^{-1})
  - Start in Liverpool for ≈1 year, then move to RAL, before coming back to Liverpool to write up
  - Potential for long-term attachment (LTA) at CERN

1. Develop and improve FASER tracking software
   - Significant efficiency improvements possible for searches below
   - RAL has significant tracking expertise from ATLAS

2. Using tracking expertise, optimise tracking detector for FPF
   - Crucial input into decision on FPF and FASER2 layout

3. Search for long-lived particles with the full run-3 data
   - Flexibility on potential model(s) to probe e.g. dark photon/higgs
   - RAL have expertise in BSM searches on ATLAS

- If you're interested pop by to talk to us in Interview Room 2