

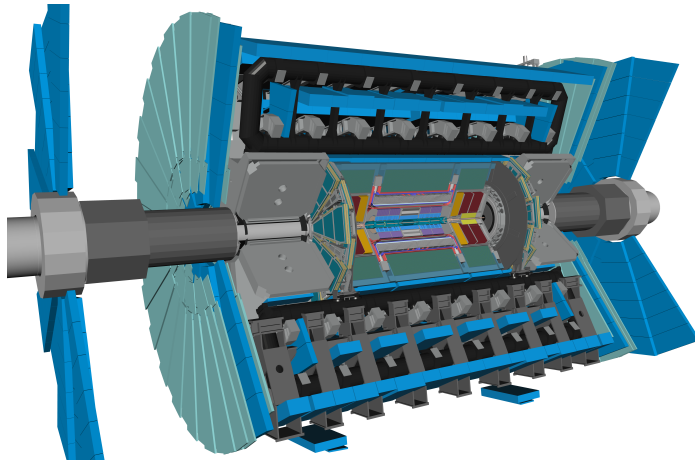


The FASER Experiment

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University of Oregon

2 July, 2024

ATLAS



- Huge
- Cost ~ \$1B to build
- ~3000 authors
- ~150 papers/year

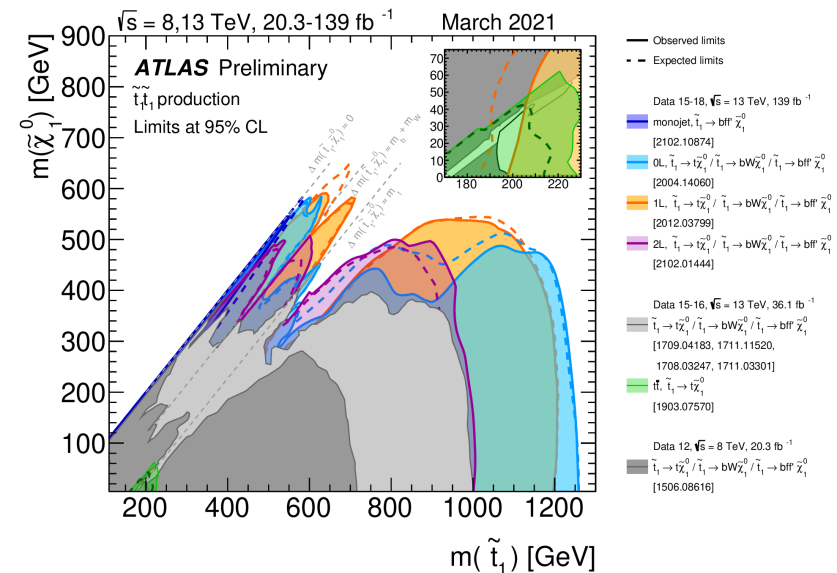
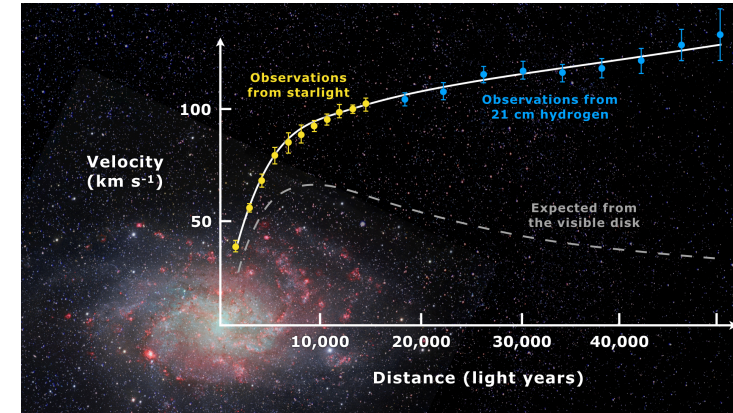
FASER

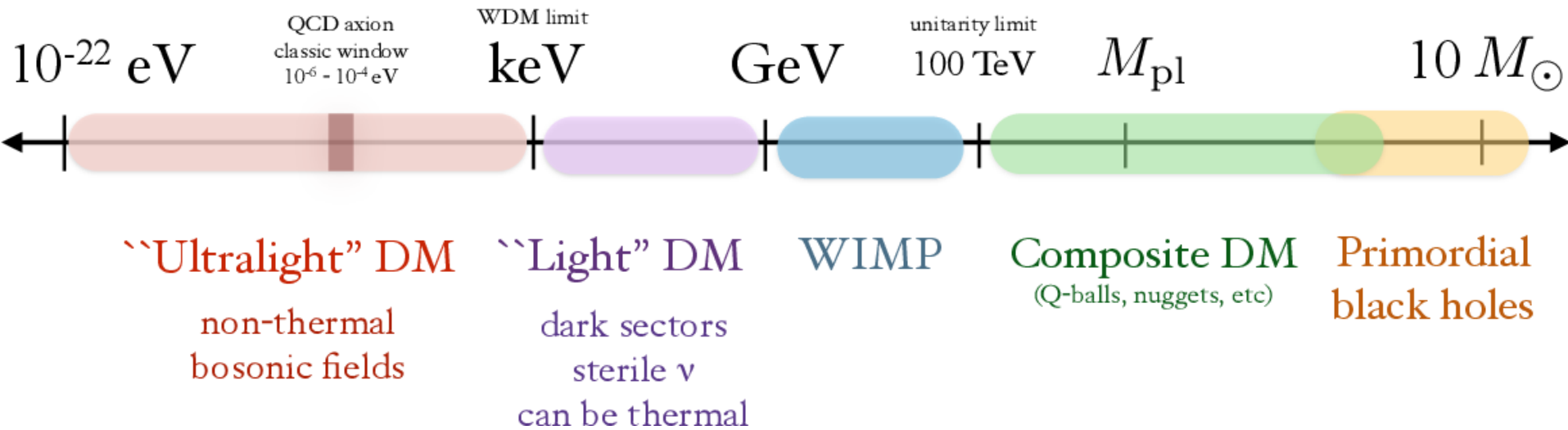


to scale(ish)

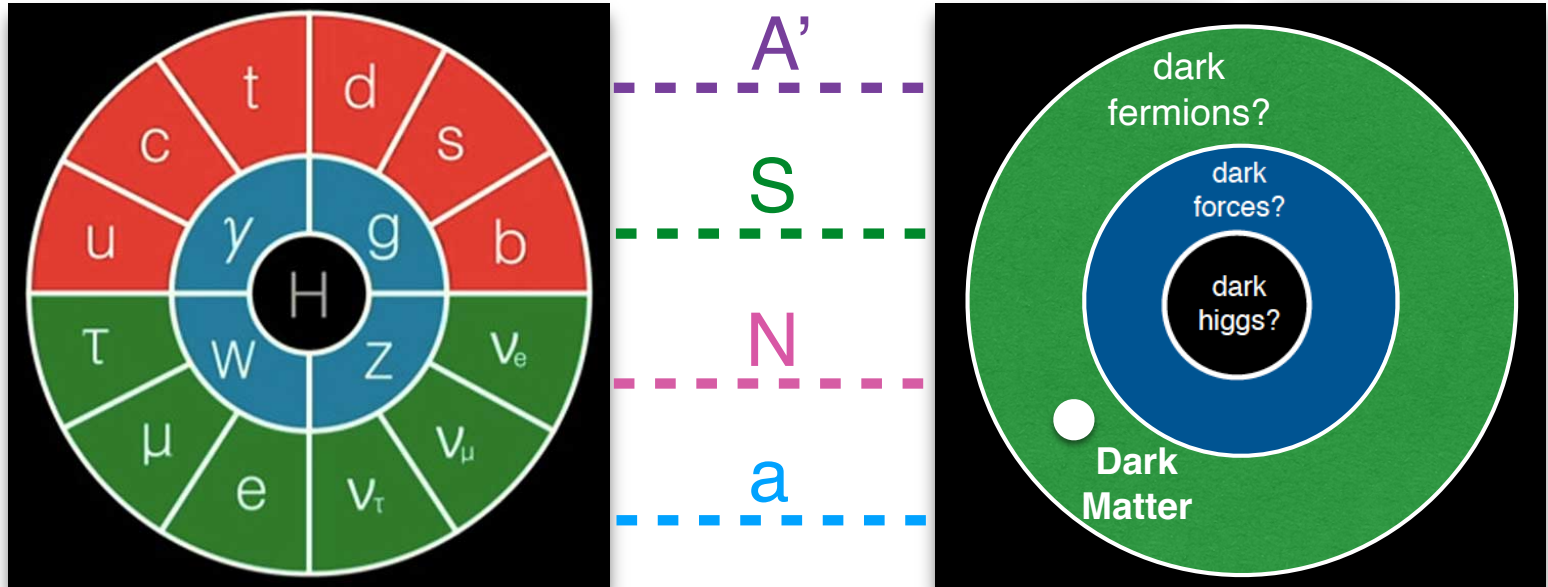
- Can trip over it
- Cost ~ \$1M to build
- ~70 authors
- several papers/year

- Lots of evidence for dark matter in our universe
 - Galactic rotation curves
 - Large-scale structure formation
 - Cosmic microwave background
 - ...
- Leading theory is weakly interacting, non-rel. particle (CDM or WIMPs)
- Searches at LHC have found nothing so far
- Perhaps we are looking in the wrong place?

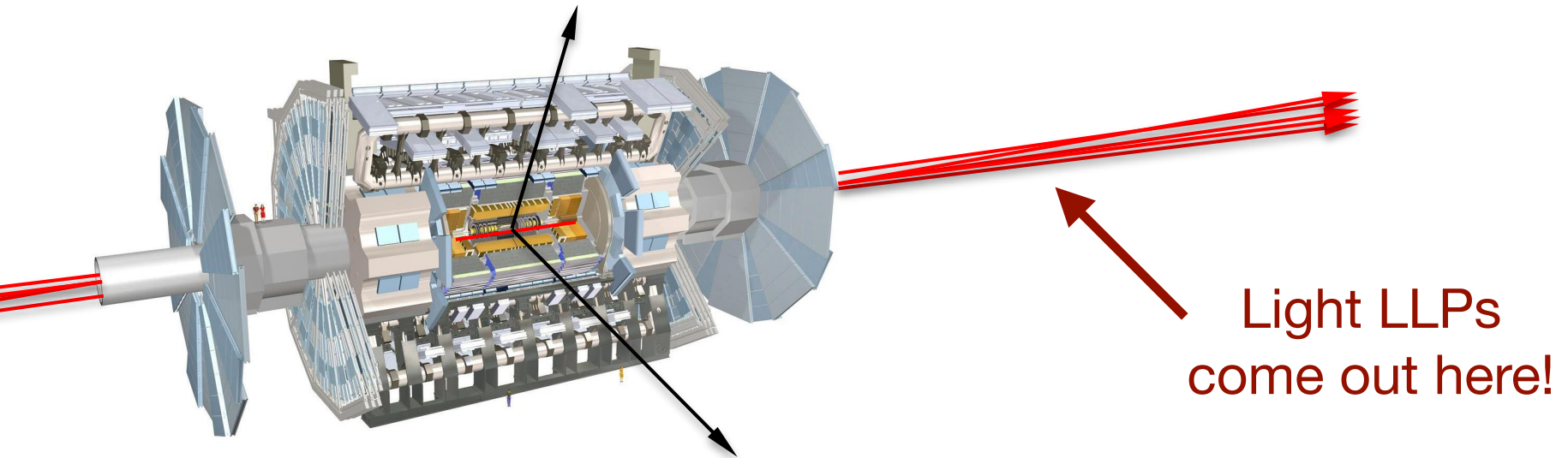




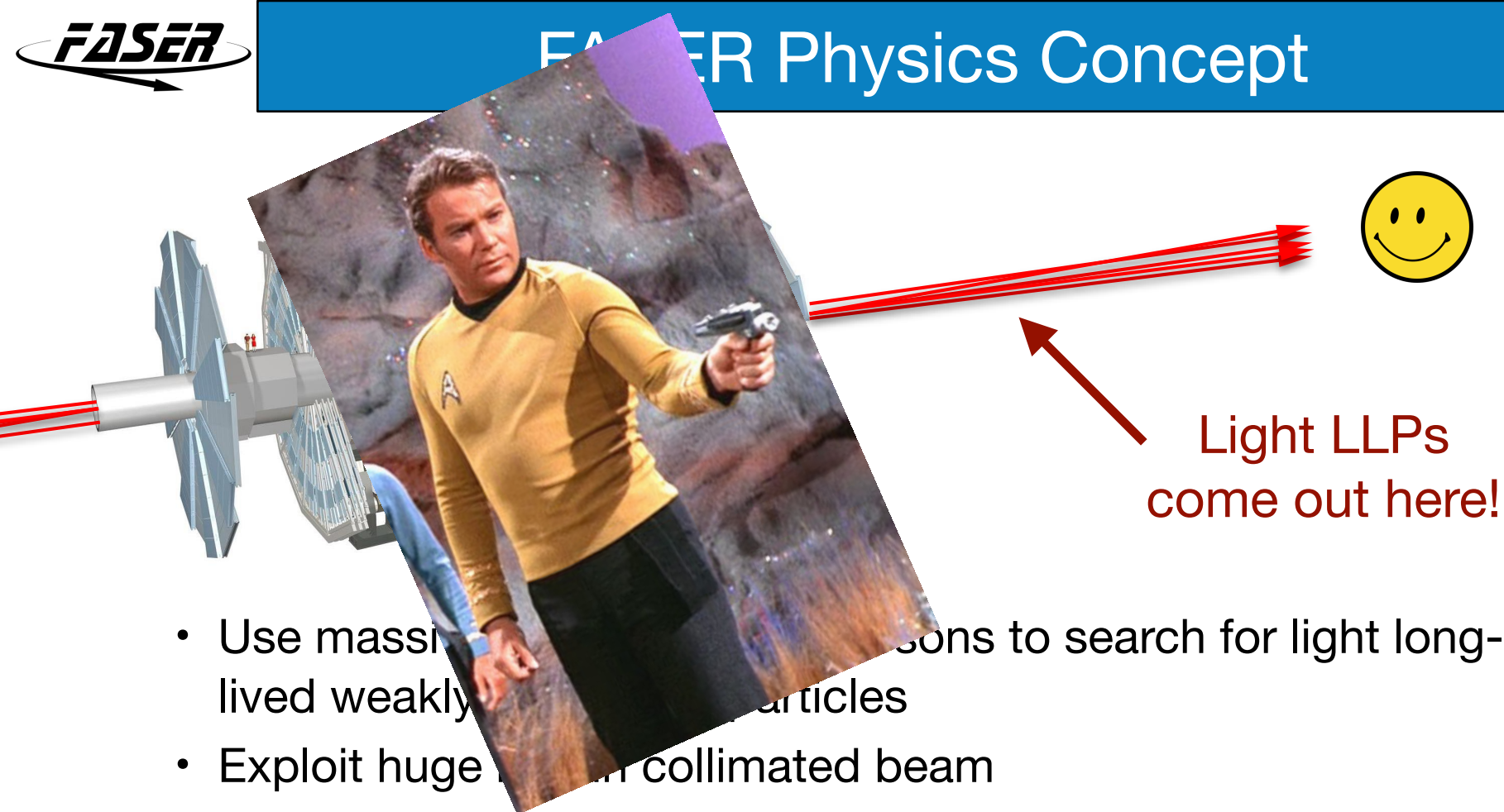
- Early theoretical bias towards $m_\chi \sim 100$ GeV
 - Abundance in early universe, “WIMP miracle”
- Lighter dark matter with smaller couplings could also be a solution
 - Long-lived weakly-interacting particles
- Perhaps DM doesn’t couple directly to SM, or only partly, must be some “portal” if there was coupling in the early universe



- Dark matter could just be a piece of an extended dark sector
- Perhaps we should look for the portal, not dark matter itself $\Rightarrow$ **dark photons**

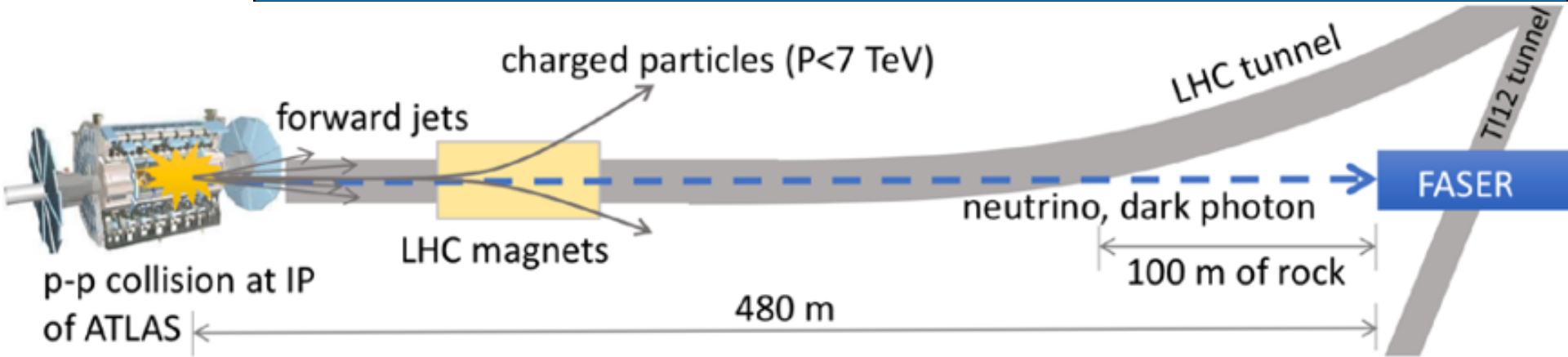


- Use massive rate of forward mesons to search for light long-lived weakly interacting particles
- Exploit huge rate in collimated beam
 - Inelastic pp cross-section: ~ 100 mb, $N \sim 10^{16}$ at Run3
 - Very forward production: $\theta \sim \Lambda_{\text{qcd}} / E \sim \text{mRad}$
 - Decay length: ~ 100 m for $m \sim 10\text{-}100$ MeV, $\epsilon \sim 10^{-5}$
- Put small detector on line-of-sight collision axis,
probe unexplored territory!



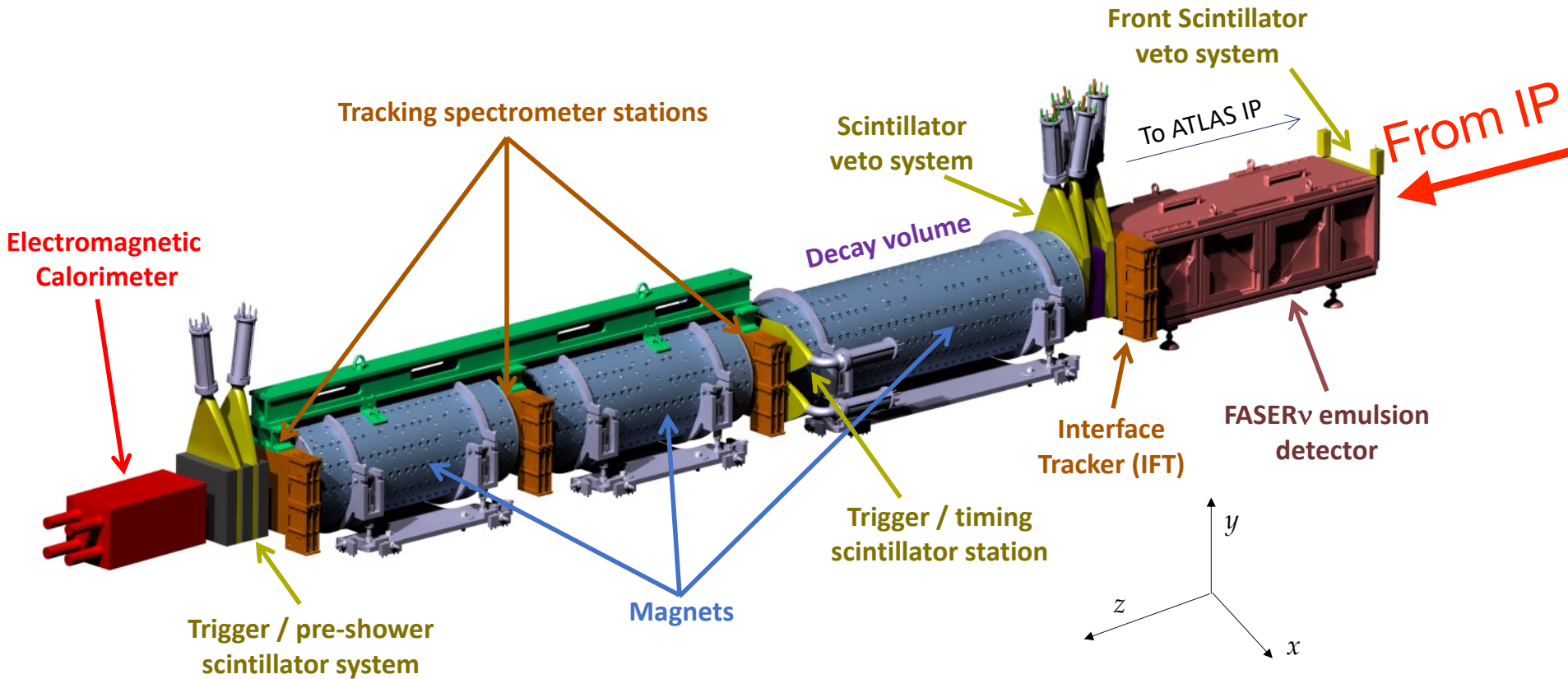
Light LLPs
come out here!

- Use massive collisions to search for light long-lived weakly interacting particles
- Exploit huge high collimated beam
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- FASER is 480m away from IP1 on the collision axis
 - 100m of rock shielding before detector
- Designed for a variety of long-lived, weakly interacting particles
 - New physics: Dark Photons, Axion-like particles, ...
 - Neutrinos: ν_e , ν_μ , ν_τ
 - Also observe SM muons
- Demonstrates small and cheap experiment
 - Proposed in 2017, installed and taking data in 2021!
 - Currently 96 members, 26 institutions, 10 countries

Tech Proposal: [CERN-LHCC-2018-036](#)
 Physics Prospects: [PRD99 095011 \(2019\)](#)



- Detector design constrained by **cost**, **space**, and **time**
- Scintillators w/ PMT readout for veto, trigger, and preshower (particle ID)
- 96 ATLAS SCT modules + 0.6T dipole magnets, **$r = 10$ cm aperture**
- 4 LHCb calorimeter modules
- 1.1 Ton Tungsten-emulsion target for additional neutrino sensitivity



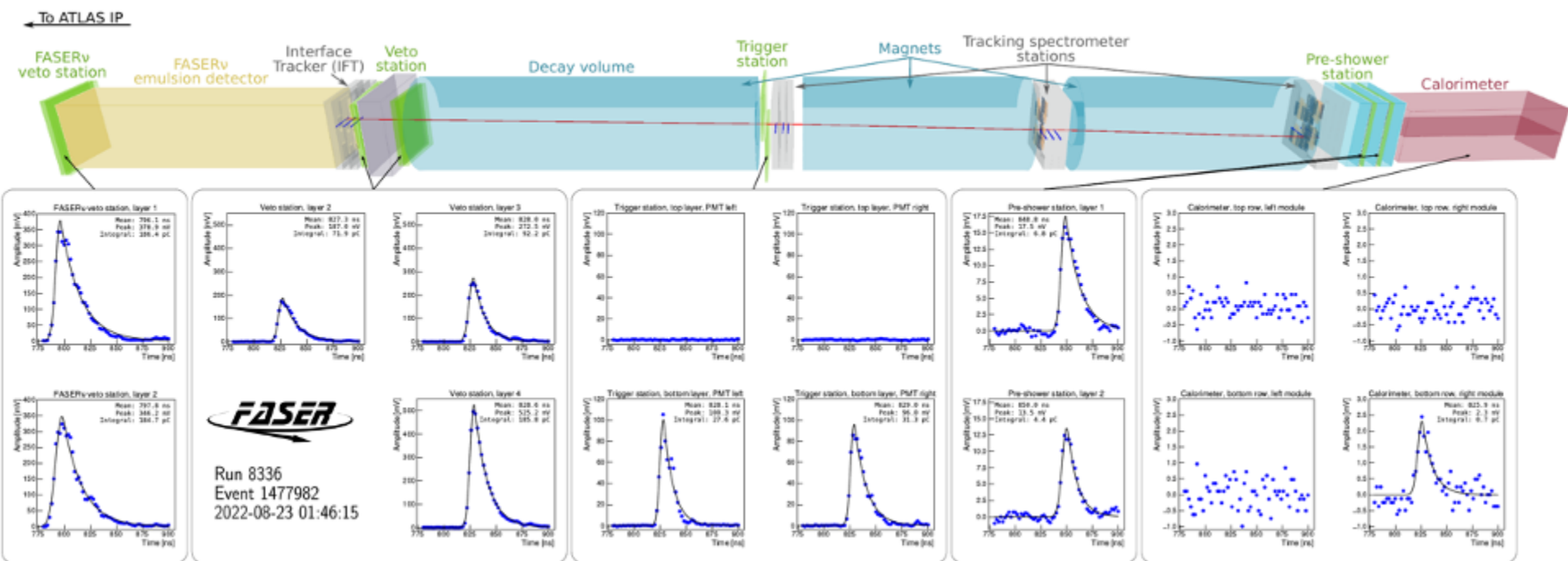
Installed in T112 tunnel

Detector Paper: [arXiv: 2207.11427](https://arxiv.org/abs/2207.11427)

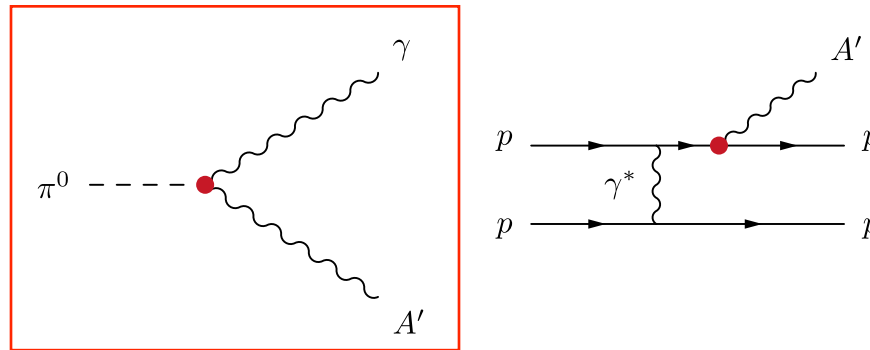
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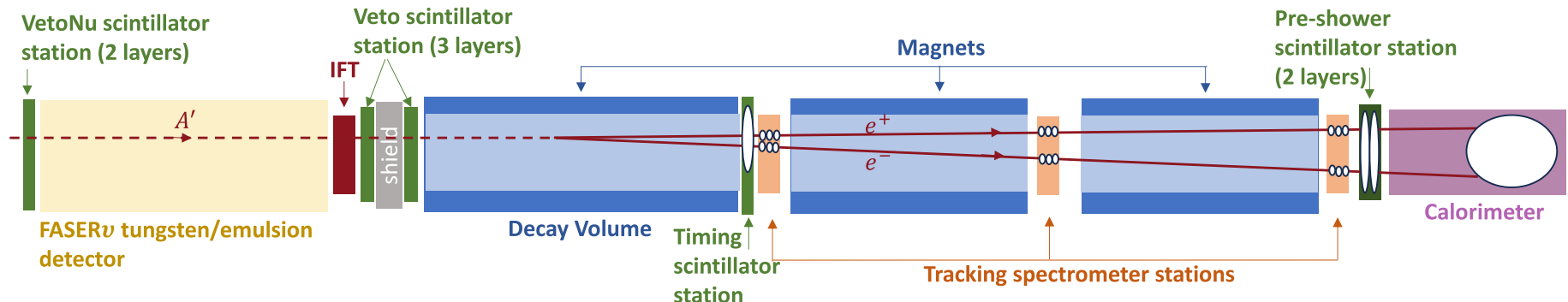
- ~250 Hz of muons from IP1 through $r=10$ cm dipole aperture (total trigger rate ~1 kHz)
- Rate highly correlated with luminosity (i.e. collisions)
- Important for tracker alignment/performance, calorimeter stability, veto station efficiency measurements, overall monitoring



- U(1) gauge boson, could provide portal to dark sector
 - Produced mainly by light mesons (π^0, η) via kinetic mixing

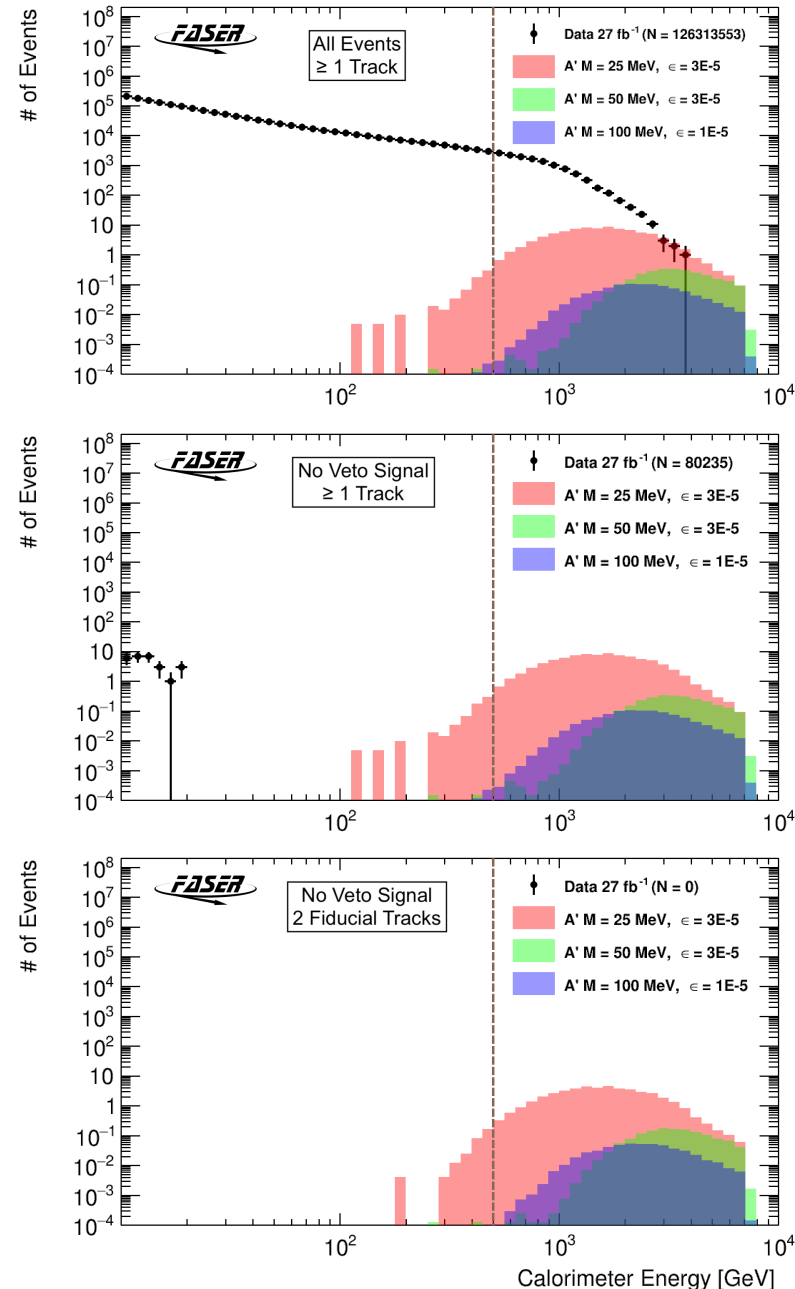


- Observed as $A \rightarrow e^+e^-$ pair appearing from ‘nothing’ with $\sim \text{TeV}$ of energy
 - Must decay in 1.5m decay volume - defines acceptance

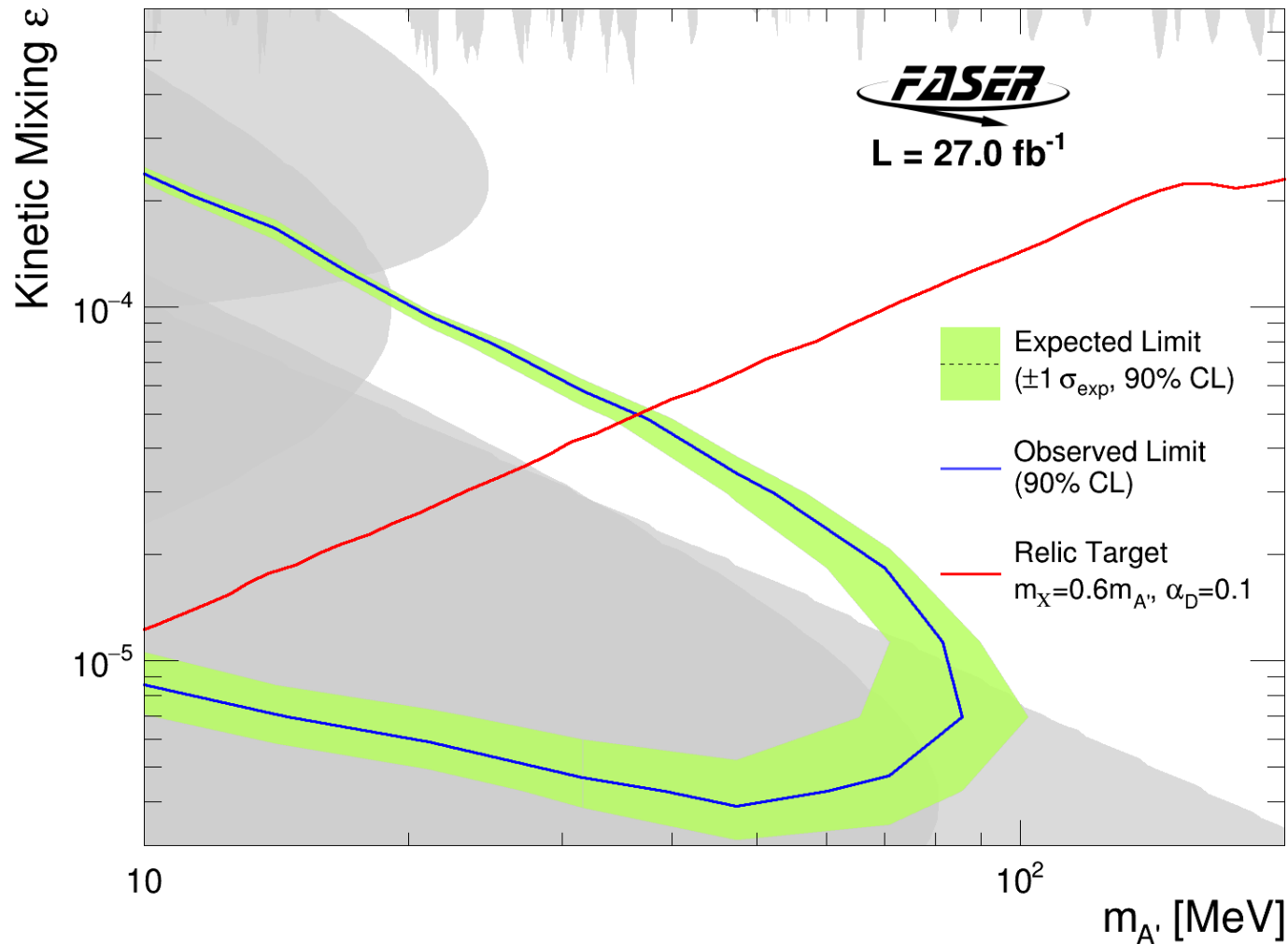


- Selection
 - 2 opposite-sign tracks within fiducial $r < 95$ mm
 - > 500 GeV in calorimeter
 - Nothing in all 5 veto counters
 - Something in downstream scintillators
 - In time with LHC collision
- Backgrounds Considered
 - Veto inefficiency
 - Neutrino interactions
 - Neutral hadrons
 - Large-angle muons
 - Non-collision / cosmics

All backgrounds found
to be very small



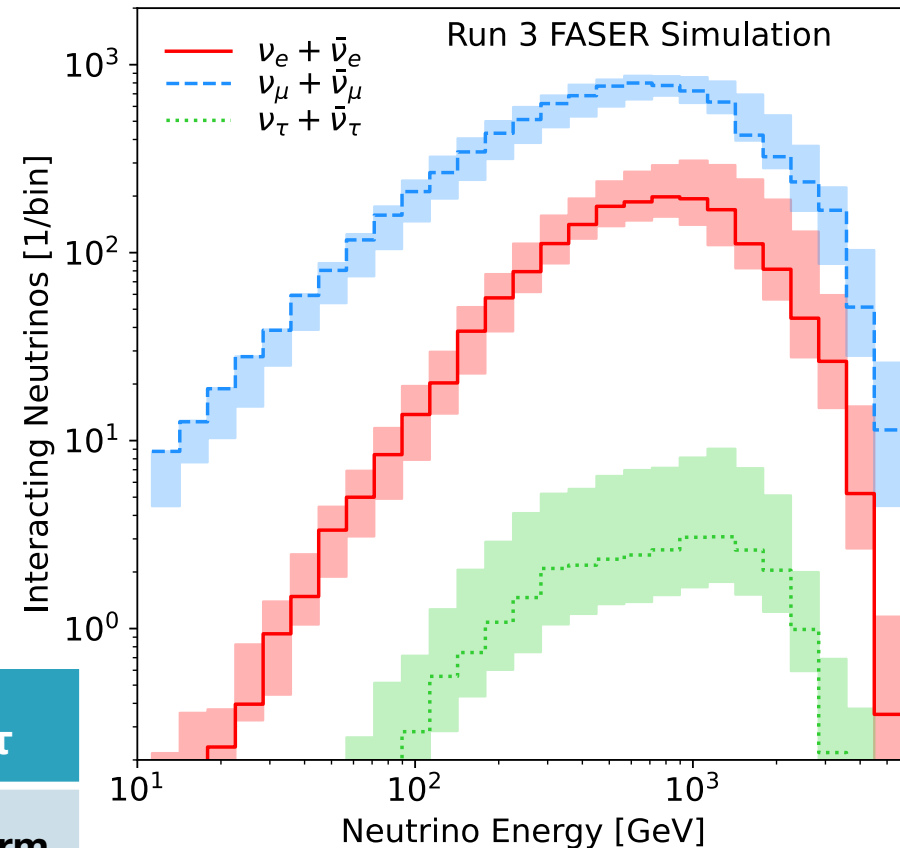
- Observed no events in 27 fb^{-1} from 2022 data, $(2.3 \pm 2.3) \times 10^{-3}$ background expected $\rightarrow$ place limits



- Copious production of **neutrinos** in forward region
- All species produced at $\sim$ TeV energy range
- Allows first direct observation of ν from collider

R3: 250 fb ⁻¹	ν_μ	ν_e	ν_τ
Primary Source	Pions	Kaons/ Charm	Charm
Traversing FASER	$\sim 10^{12}$	$\sim 10^{11}$	$\sim 10^9$
Interacting in FASERnu	8,500	1,700	30

Spectrum of interacting ν



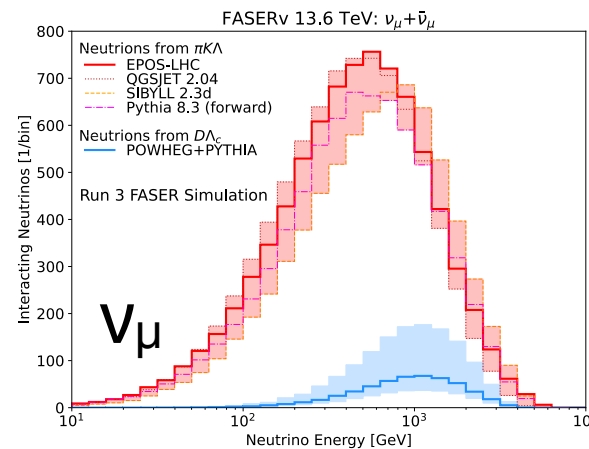
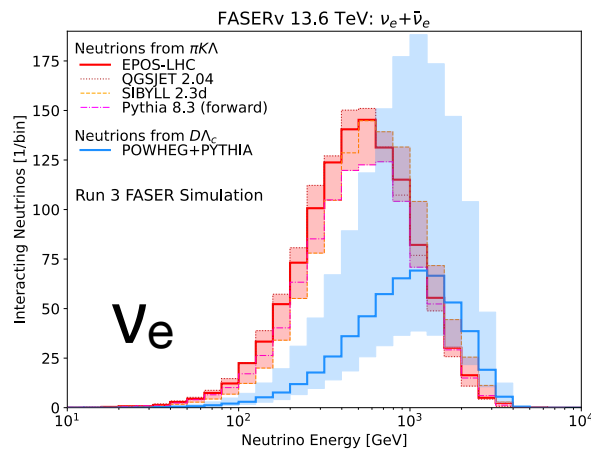
Rate Paper: [arXiv: 2402.13318](https://arxiv.org/abs/2402.13318)

Neutrinos are Interesting

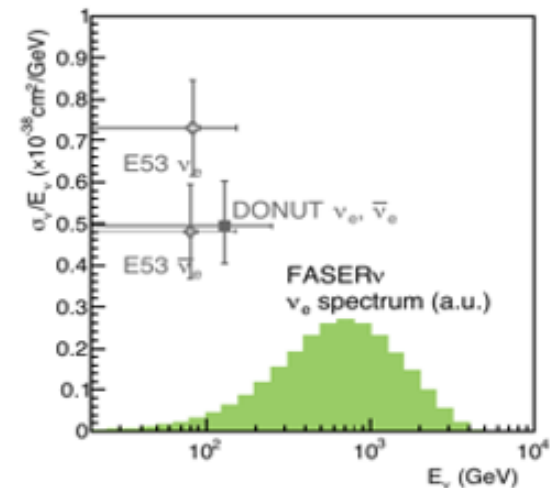
- Measure cross-section in uncovered TeV energy range
 - Highest man-made source, currently unconstrained
- Production rate measures forward hadron production
 - Novel input for PDFs, charm (ν_e) poorly constrained

Considerable interest for Neutrino telescopes, cosmic ray observatories, QCD, and measuring neutrino properties

Spectrum of interacting ν



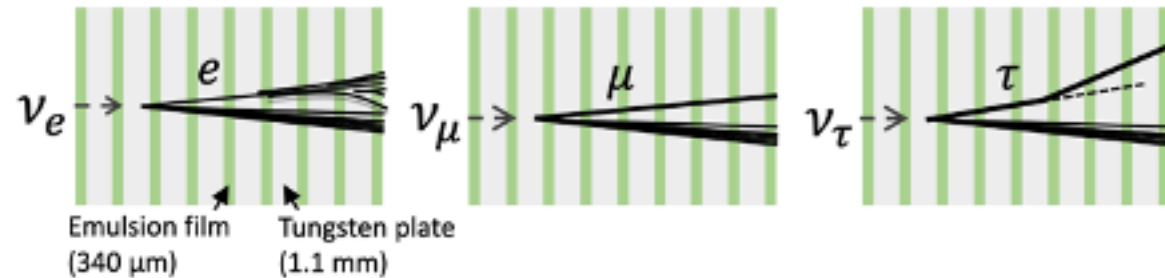
Measured σ_ν



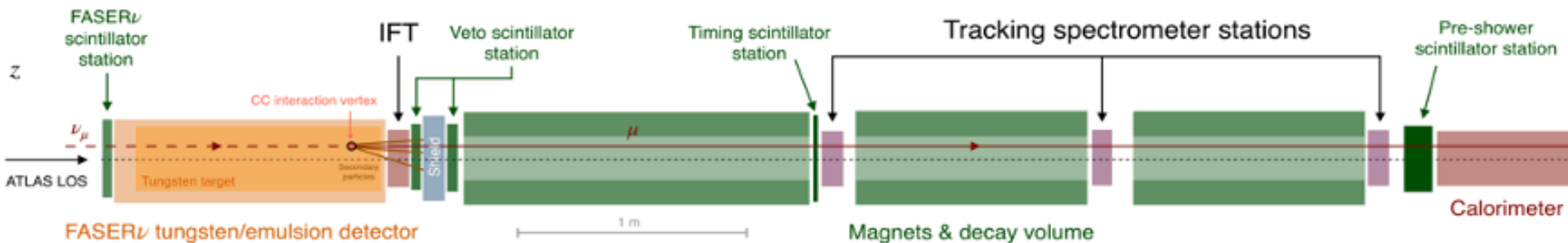
ν from π/K

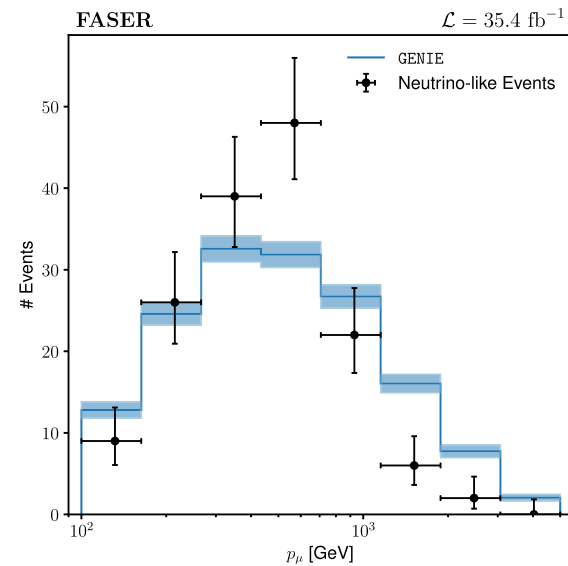
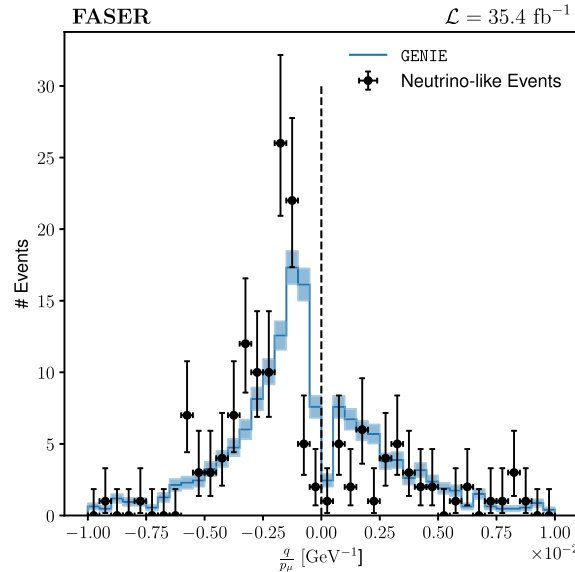
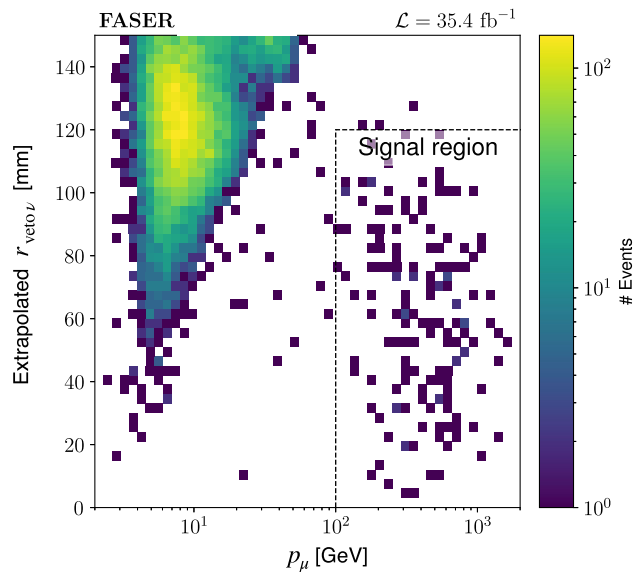
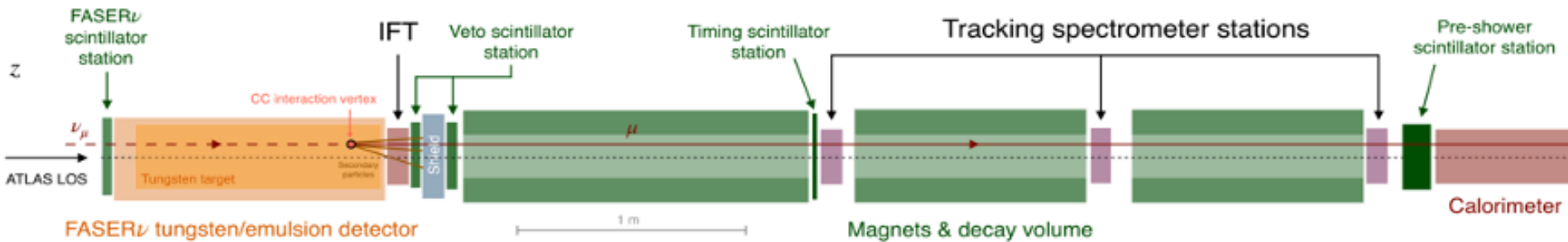
ν from charm

- Emulsion detector - FASERnu
 - Sensitive to all 3 species, no charge information
 - 1.1 Ton Tungsten target w/ 730 emulsion planes
 - Exquisite ~ 300 nm hit resolution



- Electronic detector - FASER
 - Sensitive to muon neutrinos, can separate ν_μ from $\bar{\nu}_\mu$





$$n_\nu = 153_{-13}^{+12}(\text{stat}) + 2_{-2}^{+2}(\text{bkg}) = 153_{-13}^{+12}(\text{tot})$$

(35.4 fb⁻¹)

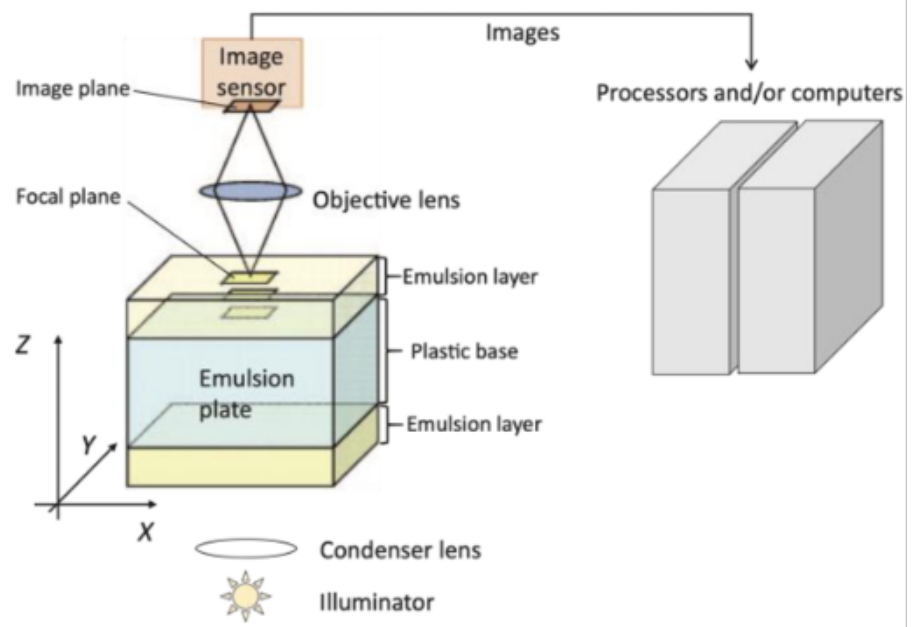
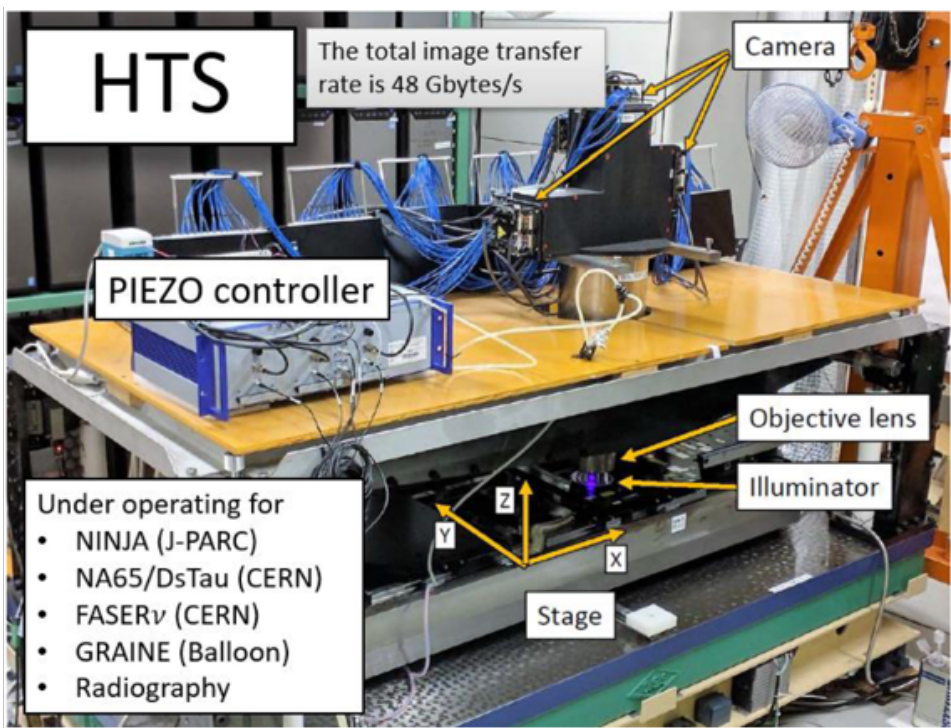
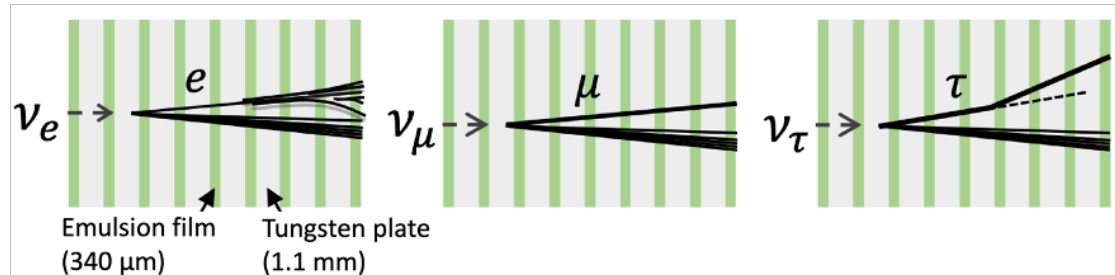
- Small background from neutral hadrons and large-angle muons

[PRL 131, 031801 \(2023\)](#)

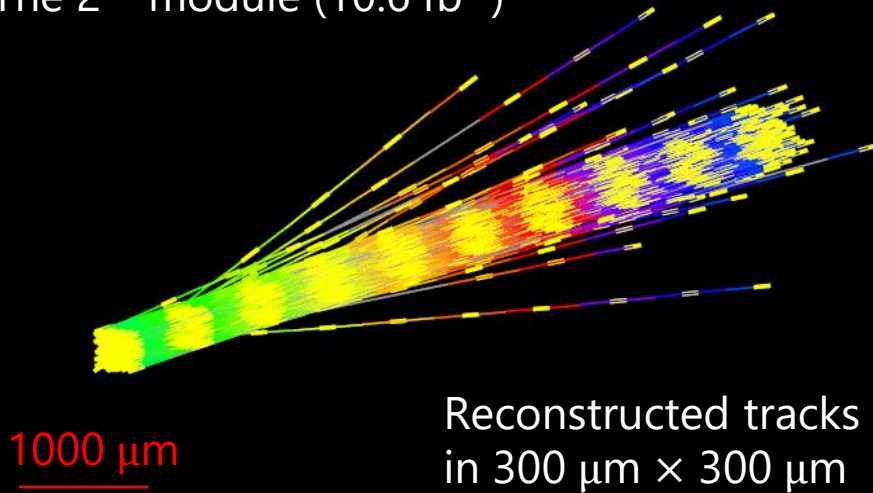
Stay tuned for update!

- Swapped every month or so, emulsion films developed, processed, shipped to Japan, scanned





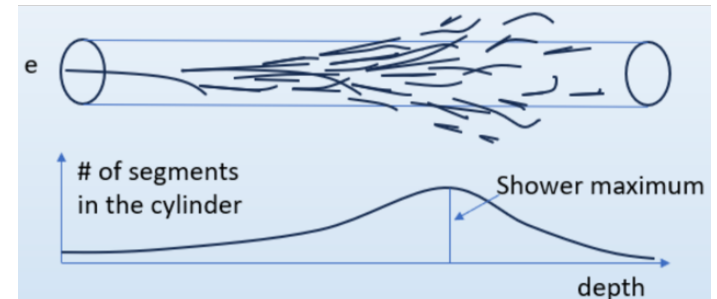
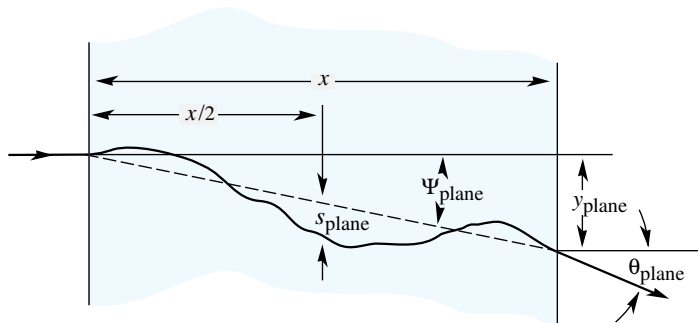
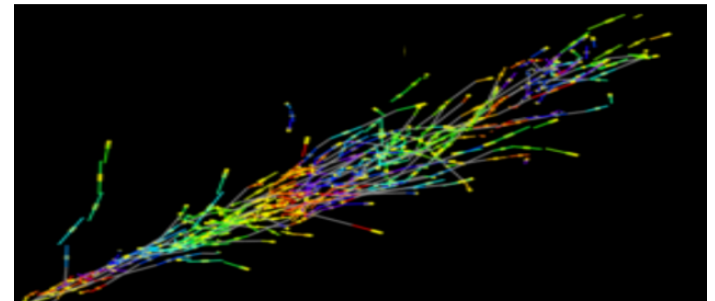
The 2nd module (10.6 fb⁻¹)

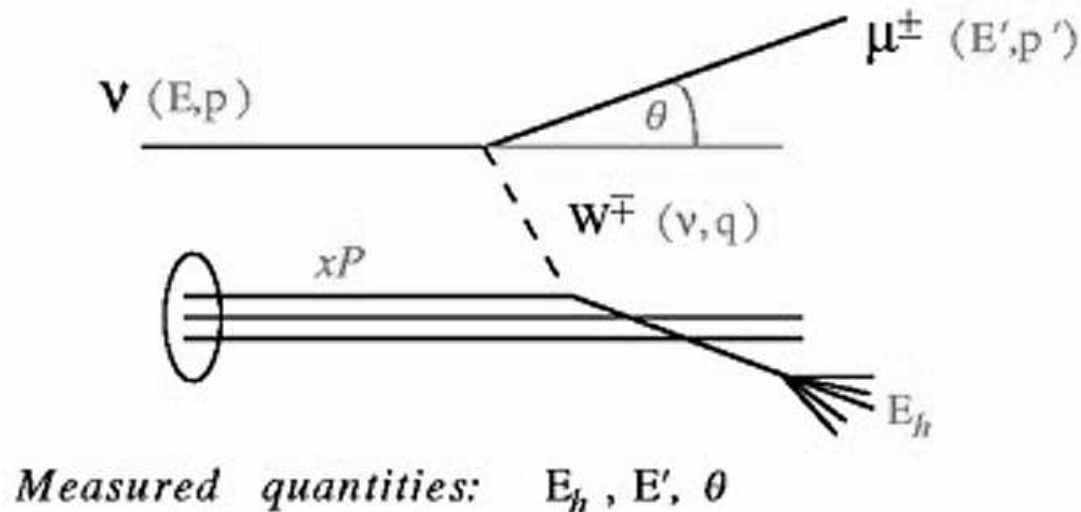


All events overlaid
from about ~1 month

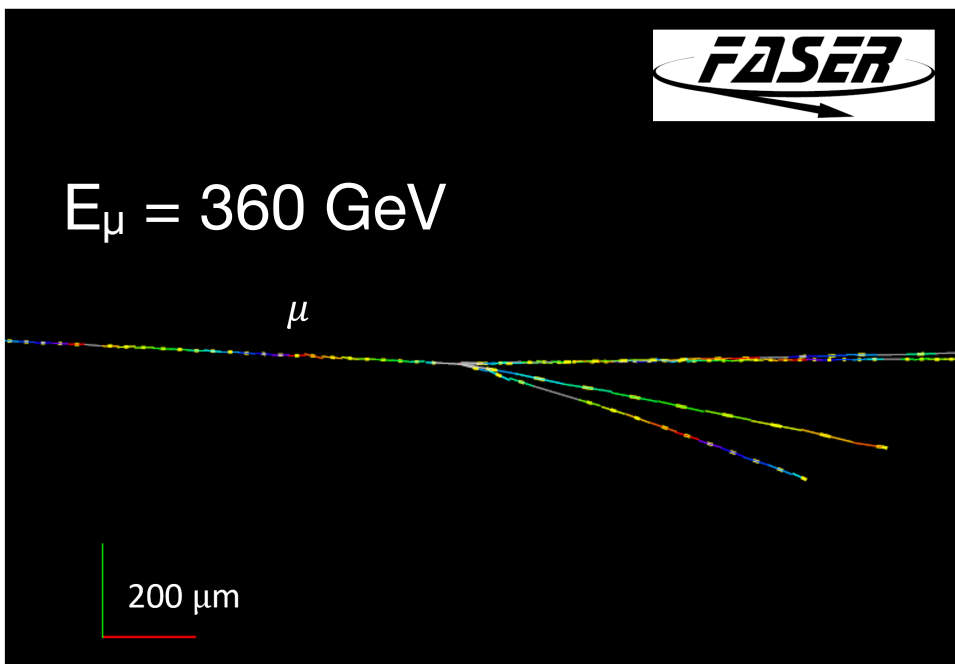
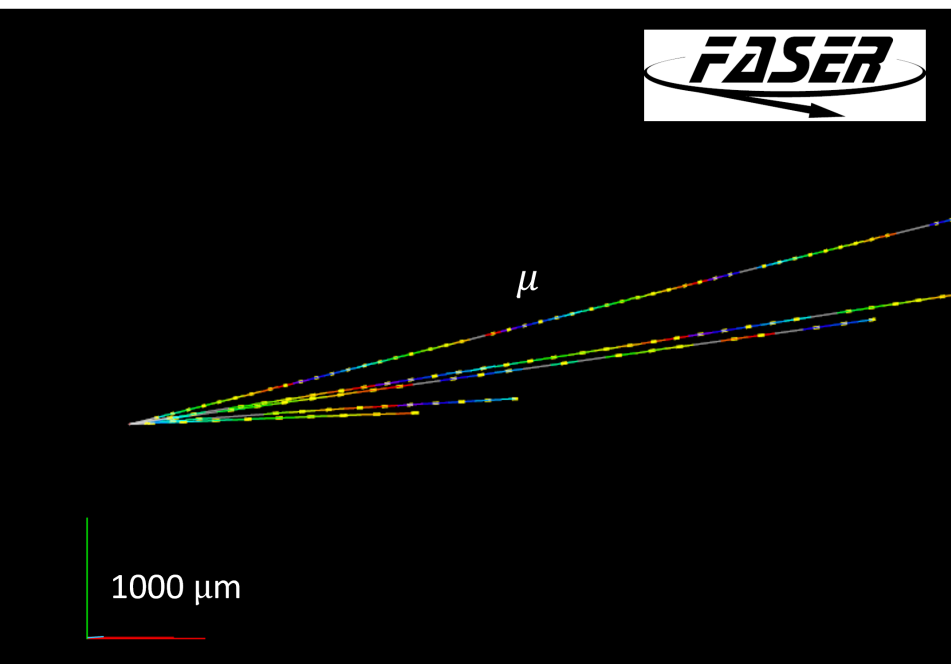
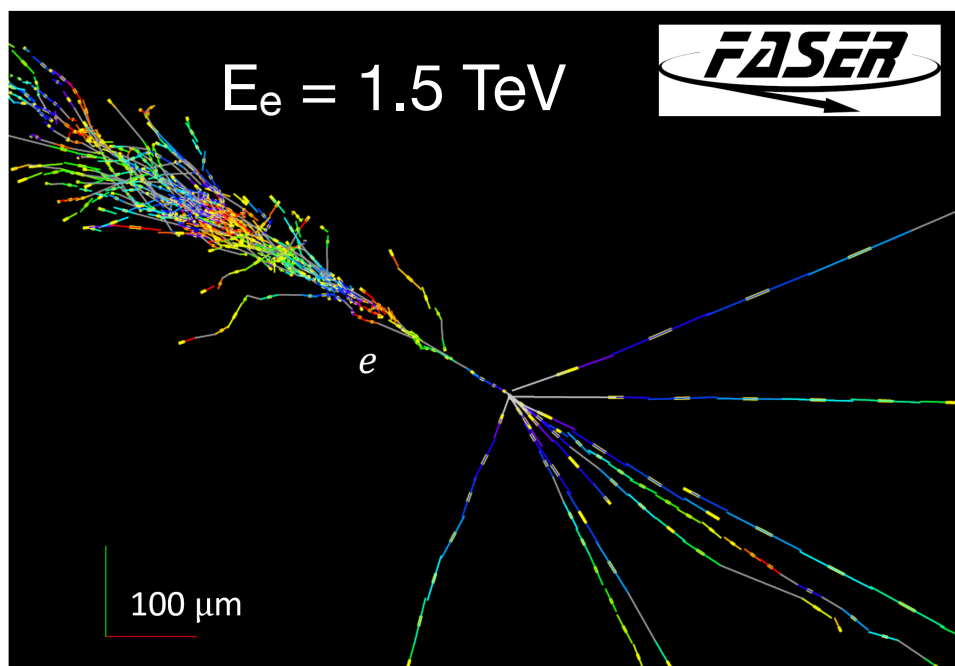
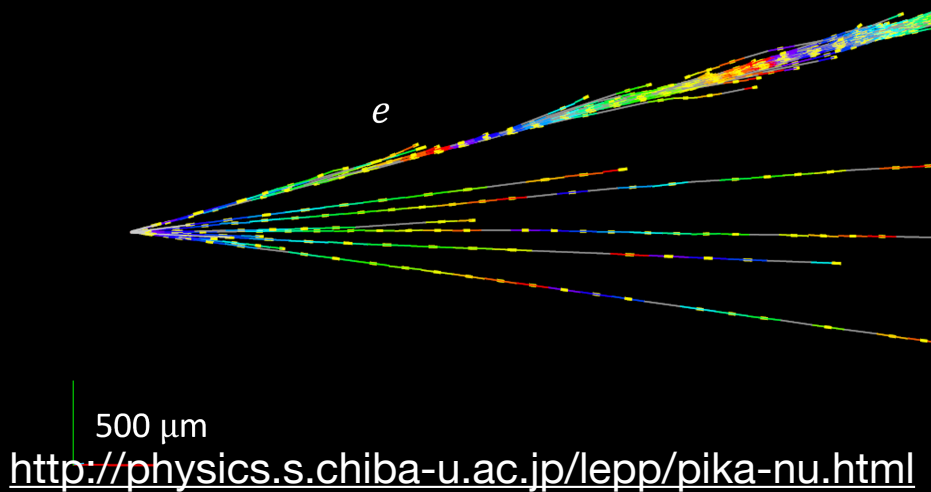
Exquisite resolution (~300 nm)
allows us to separate
individual interactions

Can measure electron energy
and muon momentum
in emulsion!





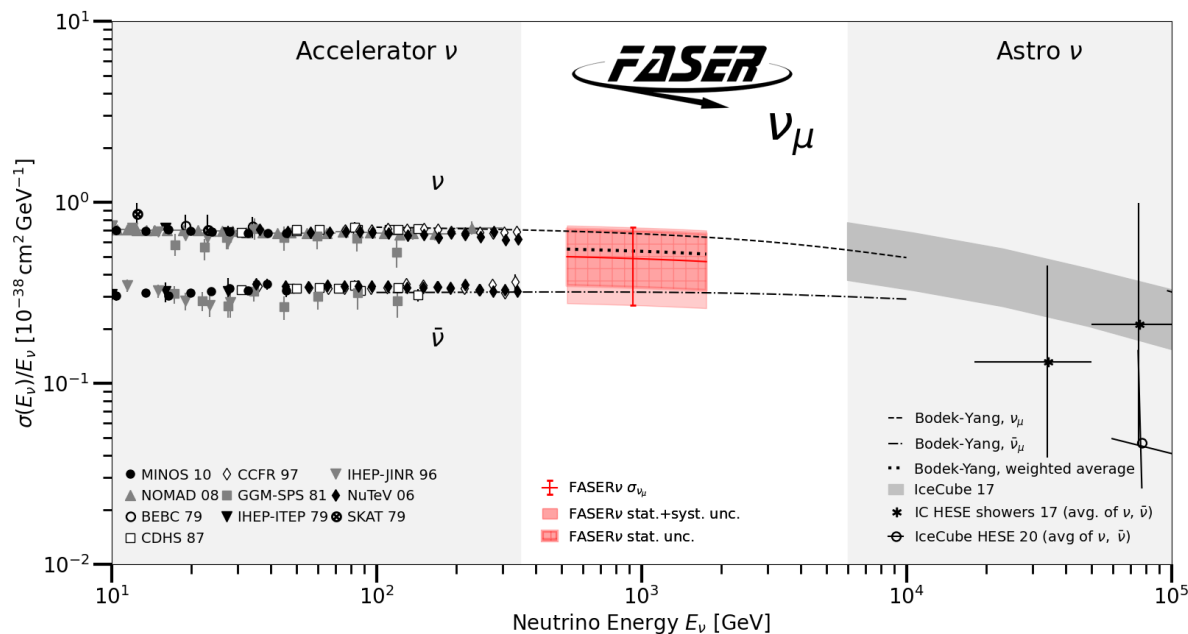
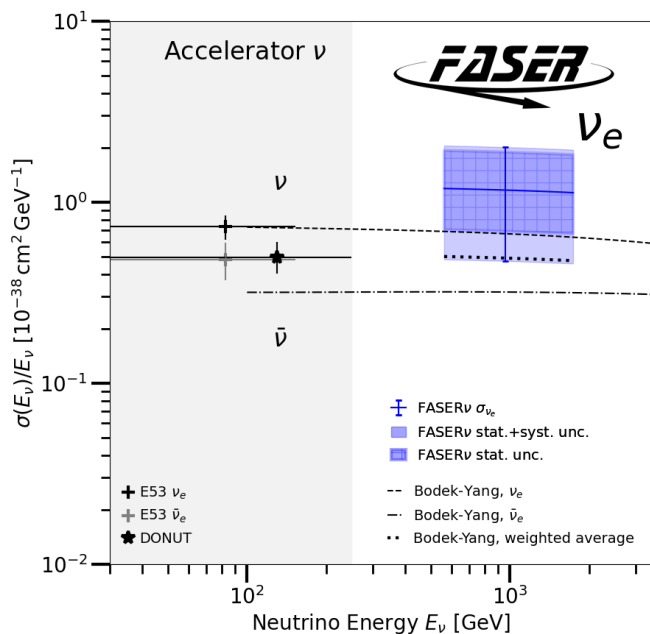
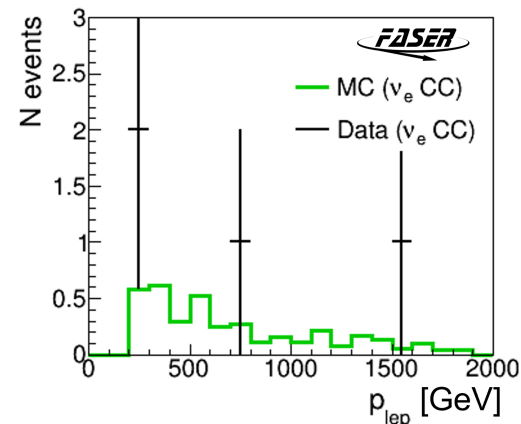
- Neutrinos interact very weakly, need lots of mass (lead, Tungsten, steel, water) for target
- Charged current interactions mean exchanging a W
- Observe charged lepton of same species
- Also see hadronic stuff from struck proton



After all vertex selection requirements:

	Obs	Exp	Bgd	Sig
ν_e	4	1.1-3.3	0.025 ± 0.012	5.2σ
ν_μ	8	6.5-12.4	0.22 ± 0.08	5.7σ

1.5 TeV!



The FASER Collaboration has 96 members from
26 institutes in 10 countries



International laboratory
covered by a cooperation
agreement with CERN



The FASER Collaboration gratefully acknowledges our funding agencies for their support:



Along with the tremendous institutional support from



- FASER is a new small experiment installed in the LHC
- FASER was installed in time for Run3
- First results on LLP (dark photons, ALPs)
- First cross-section measurement for ν_e and ν_μ
- More physics to come in Run3, including upgrades
- FASER will continue into Run4, pathfinder for future forward-physics experiments at the HL-LHC