Far forward neutrino detectors at the high luminosity LHC

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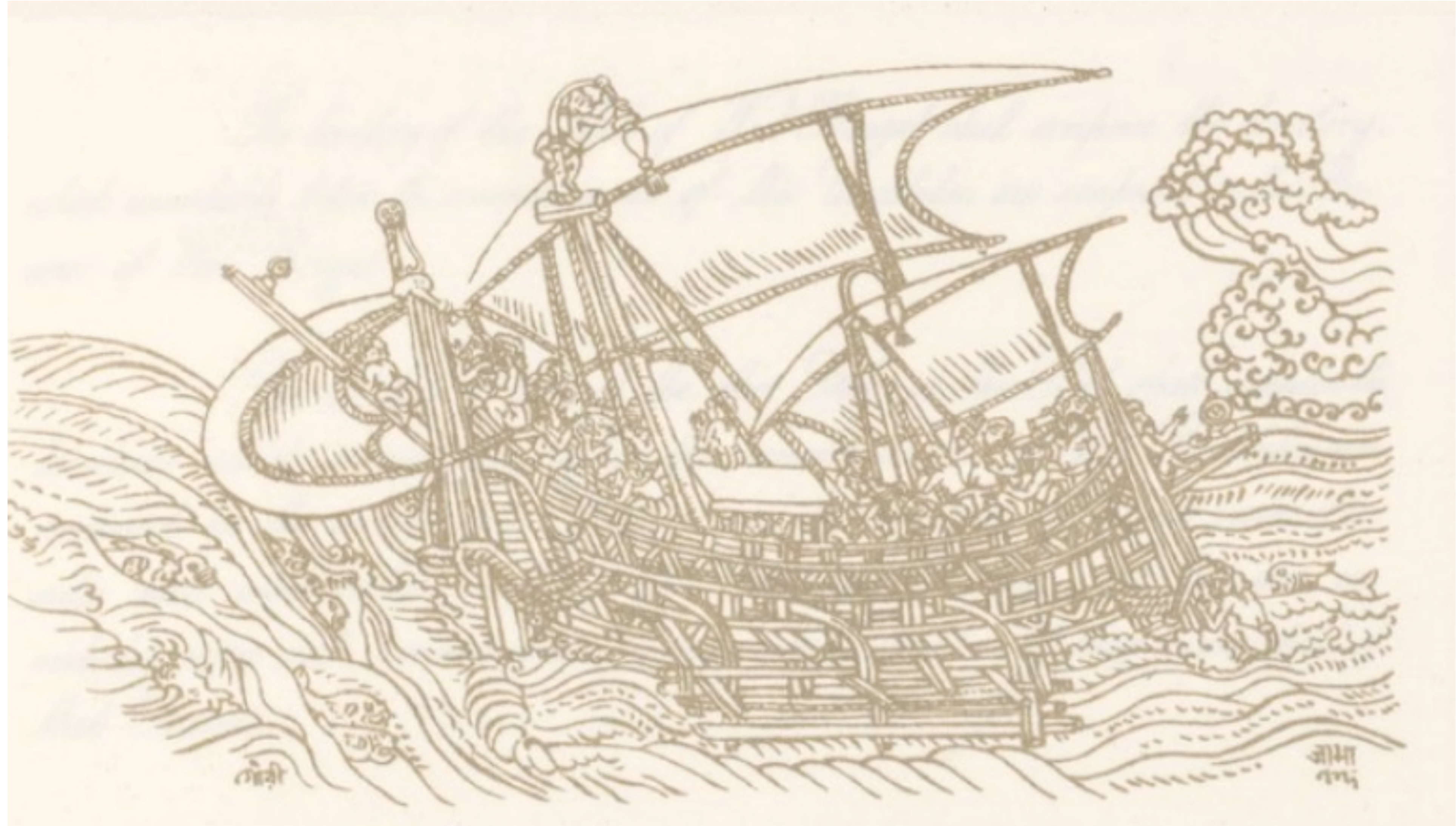
Physics Seminar, INFN, Laboratori Nazionali di Frascati



Gauri Bhanja, Jabha, and Nandalal

References for forward physics facility (FPF) and organization

- Snowmass LOI from 2020 (community study)
- Nov 2020 (FPF1), May 2021 (FPF2), Oct 2021 (FPF3), Jan 2022 (FPF4): 4 dedicated, interdisciplinary meetings to develop the FPF's potential. 5 physics themes: BSM, neutrinos, QCD, DM, and astroparticle physics.
- FPF Short Paper: 75 pages, 80 authors, Anchordoqui et al., 2109.10905, Phys. Rept. 968, 1 (2022).
- FPF Snowmass White Paper: 429 pages, 392 authors+endorsers, Feng, Kling, Reno, Rojo, Soldin et al., 2203.05090, J. Phys. G.
- Physics Beyond Colliders working group at CERN: PBC@CERN. There are many resources here.
- US working groups on FPF physics (Brian Battell, Sebastian Trojanowski, MVD) and FLArE Technical design (Steve Linden, Jianming Bian, MVD) group.
- There is modest funding in place with a mandate to produce a conceptual design report by early 2023.
- FPF-related talks at Snowmass in Seattle (July16-26). All are recorded.

Outline

The LHC and its parameters.

Geometry of the LHC

Geometry of the collision and the forward region.

Status of the plan for the Forward Physics Facility.

Possible schedule for FPF and its relation to the HL-LHC

Current program for forward physics.

Physics case and topics for the FPF:

dark matter,

neutrino physics.

Liquid argon detector for the forward physics facility.

Muon flux at the FPF.

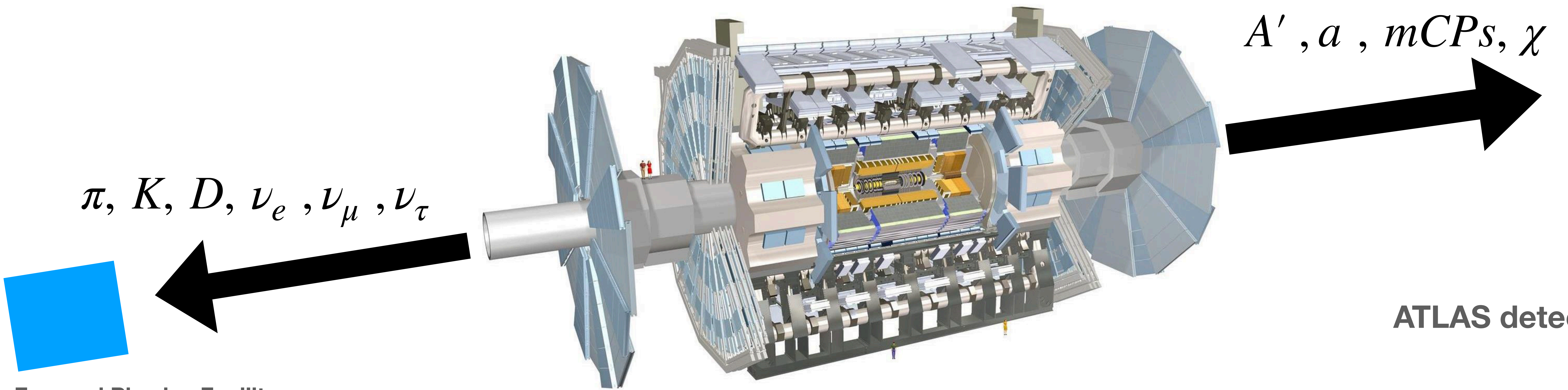
Detector requirements for a noble liquid detector.

Design options for a liquid argon TPC (Forward Liquid Argon Experiment)

Prospects.

The LHC, ATLAS and forward geometry

High luminosity LHC is a unique opportunity, and so what are we missing ?

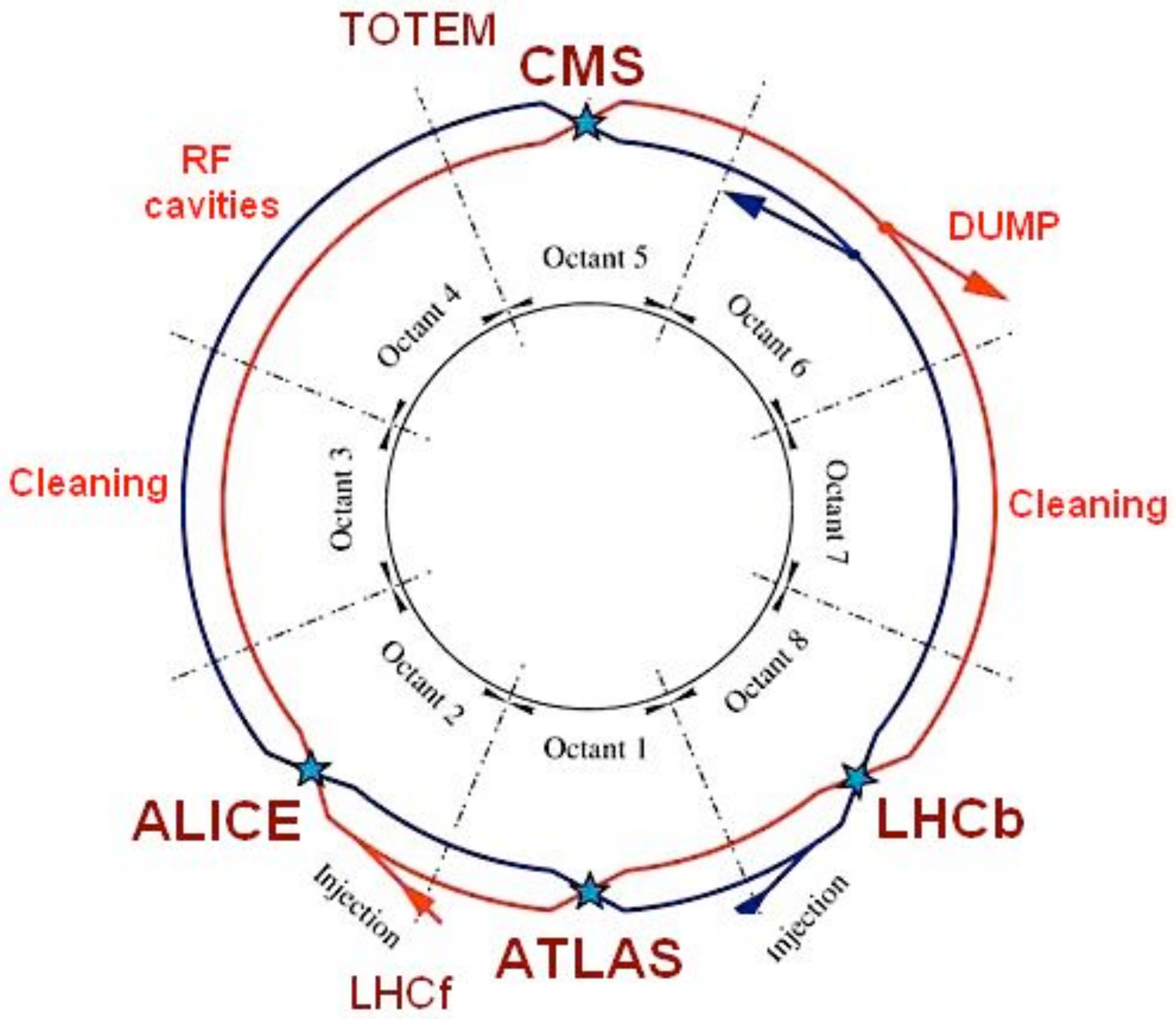


ATLAS detector.

Forward Physics Facility

- ***Most interesting physics is believed to be at high pT, and so are we missing physics in the forward direction ?***
- ***The largest flux of high energy light particles, pions, kaons, D-mesons, and neutrinos of all flavors is in the forward direction.***
- ***This could be true of new particles also: dark photons, axion-like particles, millicharged particles, light dark matter, etc.***
- ***The high laboratory energies (>100 GeV), and kinematically focused nature of the particles presents a unique opportunity (for modest sized detectors) that should not be missed with the high-luminosity LHC.***
- ***A program has started at LHC: 4 experiments are FASER, FASERnu, SND, and MilliQan. Please see Jonathan Feng's talk.***

The LHC description and operation for run 3 and (HL)-LHC

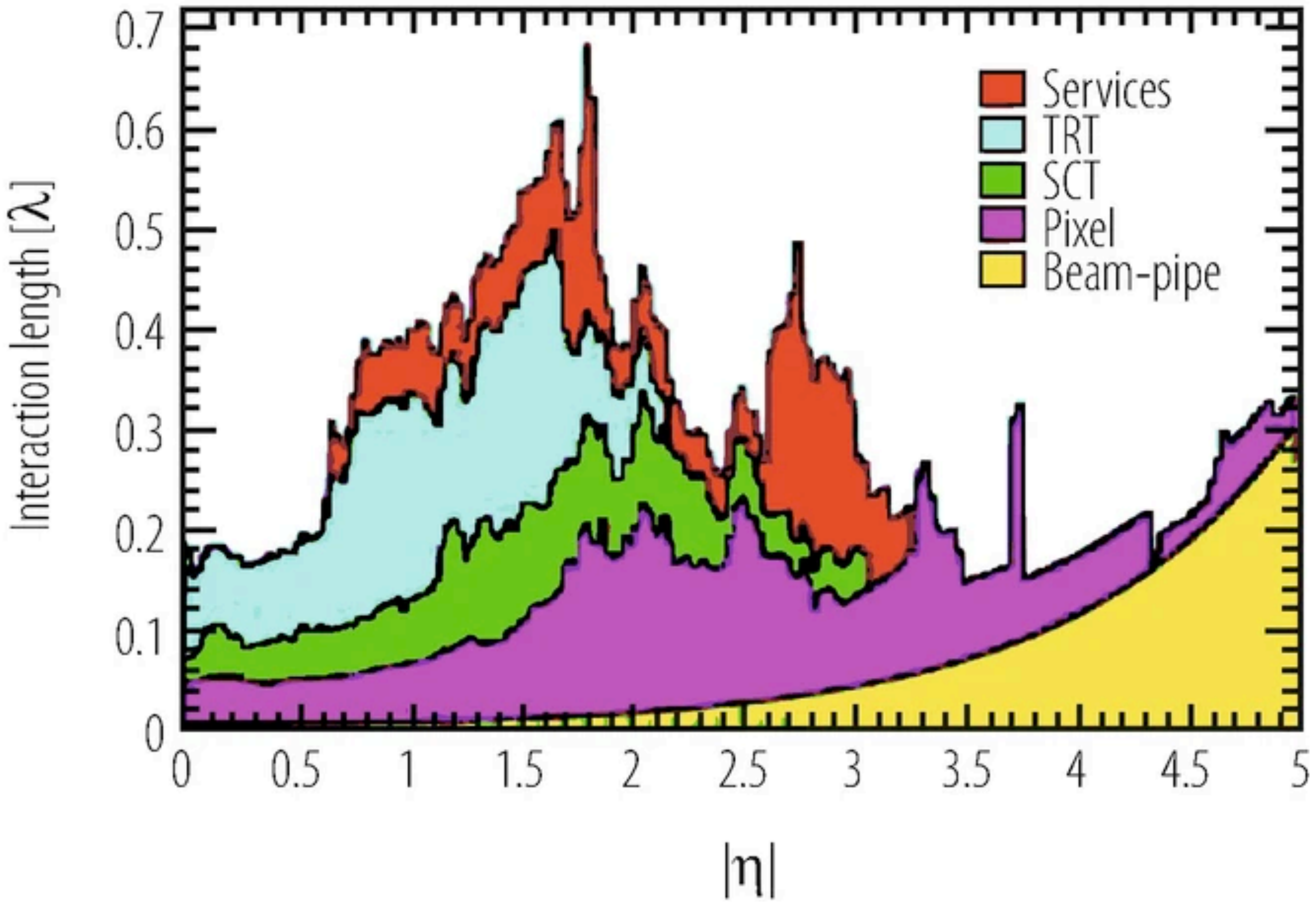


- For a forward experiment a ***well shielded location tangent*** to an IP must be found.
- The HL-Luminosity projections are to increase up to $7.5\ 10^{34}\ cm^{-2}\ s^{-1}$
- Source: Jamie Boyd (2001.04370)

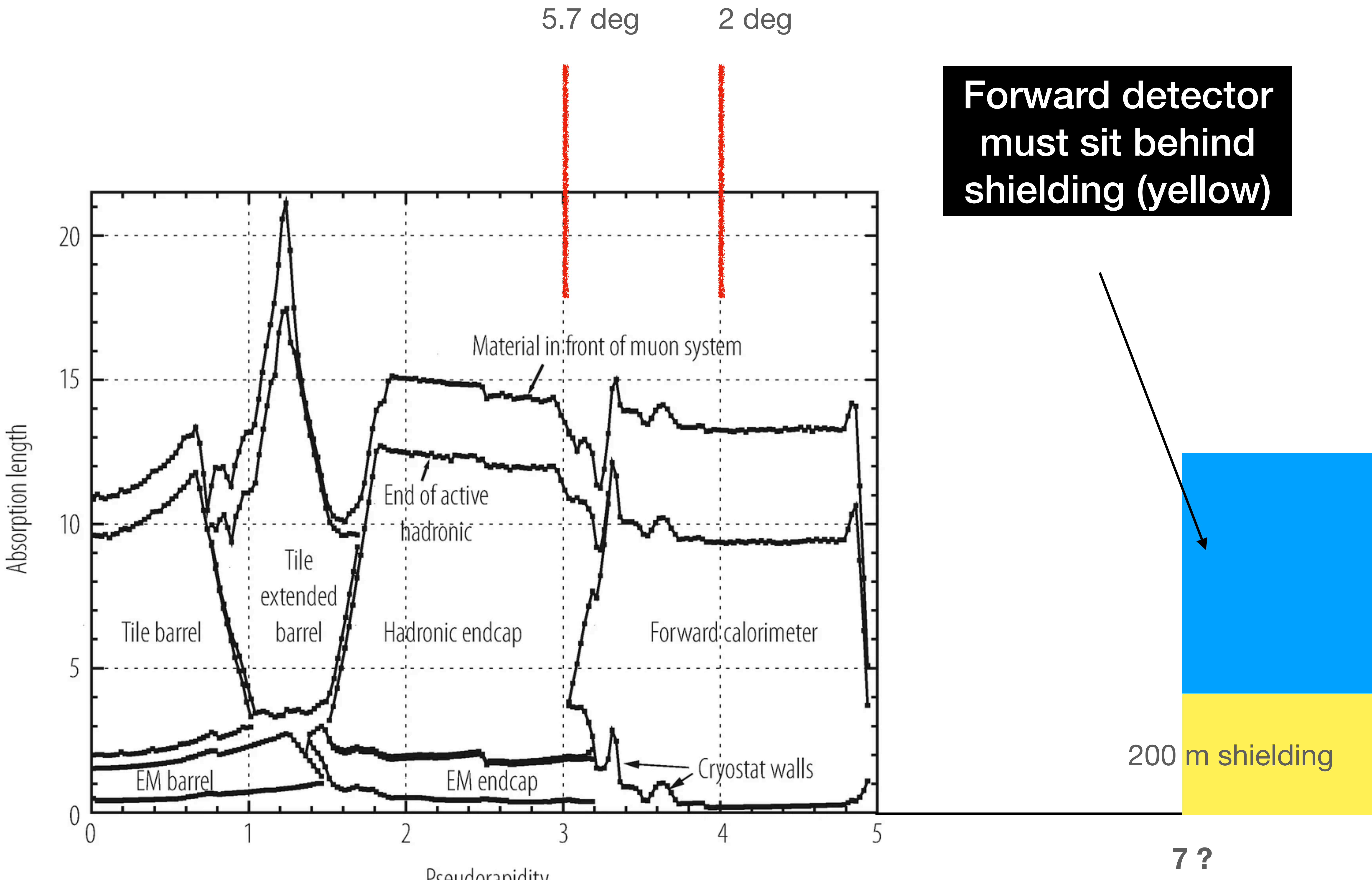
parameter	Design	Run-3	HL-LHC
Circumference	27 km (r=4243 m)		
depth	100 m		
arcs	8 arcs; each has 23 cells; cell is 106.9 m		
insertions	8 insertions: insertion is a straight section with transition regions at each end.		
energy	14 TeV	14 TeV	14 TeV
bunches	3550 (with 7.5 m/25 ns) spacing)		
effective bunches	2808	2808	2808
protons/bunch	1.15E+11	<1.8E+11	2.2E+11
crossing	40 Mhz (25 ns)	25 ns	25 ns
Peak Luminosity	$10^{34}\ cm^{-2}\ s^{-1}$	$2.\ 10^{34}\ cm^{-2}\ s^{-1}$	5. 10^34
Min-bias event rate	50/crossing=1.6 GHz	3.2 GMhz	8 Ghz
inelastic rate	~20/crossing = 0.6 GHz	1.2 GHz	3 Ghz
inelastic cross sec	60 mbarn		
bunch transverse size at IP	17 mu-m		
bunch length at 7 TeV	7.5 cm		
crossing angle	285 microrad	300-> 260	TBD
Peak pileup	25	55	150
Total plan		150 fb^{-1}	3000 fb^{-1}

ATLAS coverage

Physics coverage $\eta \leq 3.5$



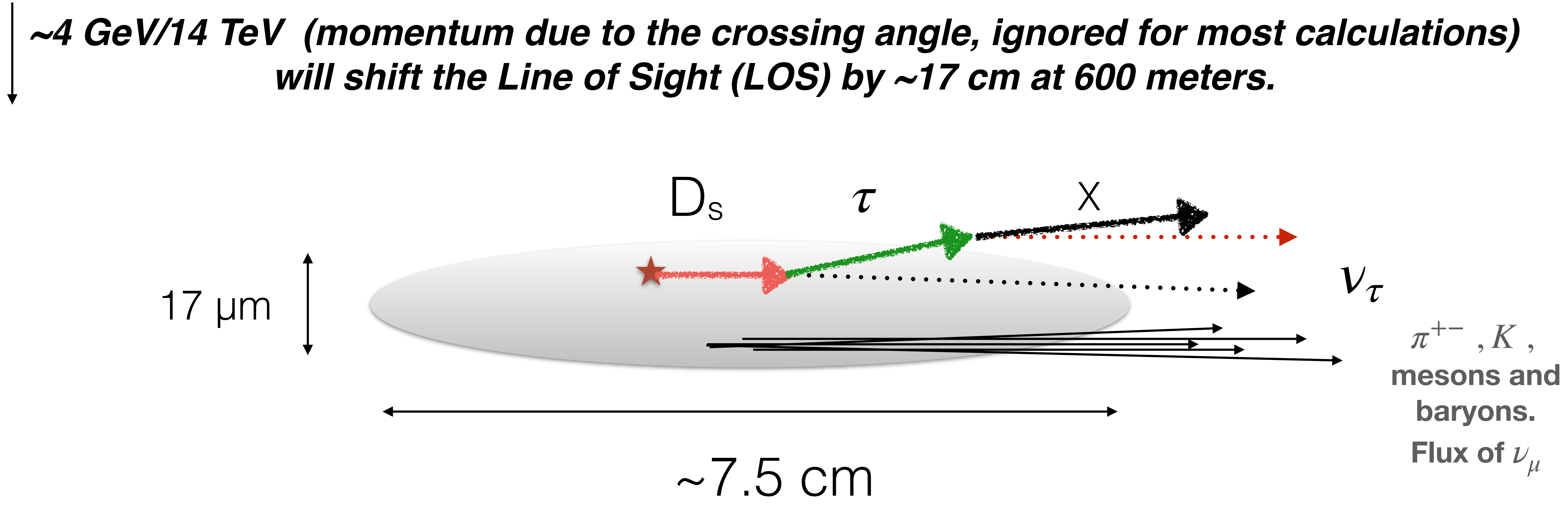
$\eta \equiv -ln[\tan(\theta/2)]$



Froidevaux, D. (2020). Integration of Detectors into a Large Experiment

Production geometry

~4 GeV/14 TeV (momentum due to the crossing angle, ignored for most calculations) will shift the Line of Sight (LOS) by ~17 cm at 600 meters.



For γ~100, decay distances will be ~1.5 cm for Ds and ~0.87 cm for tau lepton $\Longrightarrow$ size of the neutrino source for the LHC is ~7.5 cm. The LHC collision region is the most compact neutrino source ever made.

Recall heavy particles lile W, Z, Higgs do not contribute much here. Their decay products are at high PT

Neutrinos at FPF

Uncertainties are large. 2105.08270 (Kling) is standard simulations. 2002.03012 (Bai et al.) and 2112.11605 is deep analysis of the tau neutrino flux.

- $c\tau(\pi, K^{\pm}, K_L) = 7.8m,\ 3.7m,\ 15m$
- $\pi \to \nu_\mu, K \to \nu_\mu, K \to \nu_e$ will be affected by the LHC magnets and shielding

Needs detailed Monte Carlo

$D^{\pm} \to e/\mu$ (semi)leptonic (33%) m=1870MeV, $c\tau$=311 μm (decay to τ is very small)

$D^0 \to e/\mu$ (semi)leptonic (13%) m=1865MeV, $c\tau$=122 μm (no decay to τ due to mass)

$D_s^{\pm} \to e/\mu$ (semi)leptonic (6%) $m = 1968 MeV$, $c\tau = 150 \mu m$

$D_s^{\pm} \to \tau\nu_\tau$ (5.5%) p_{cm} = 182 MeV. This would be the main source of ν_τ

$B^{\pm} \to l^{\pm}\nu_l X$ (11 %) m=5279 MeV, $c\tau$=491 μm (most decays are to D which decay to neutrinos)

$B^{\pm} \to D\,X (> 95\%)$

$B^0, \bar{B}^0 \to l^{\pm}\nu_l X$ (11 %) m=5279MeV, $c\tau$=455μm

$B^0, \bar{B}^0 \to D\,X$ (>90%)

$\Lambda_c \to l\nu_l X (\sim 10\%)$ m=2286MeV, $c\tau$=60μm (e/μ modes only)

$\tau^{+} \to X\bar{\nu}_\tau$ (100%) m=1776 MeV, $c\tau$=87μm

Electron neutrino flux above 300 GeV is charm dominated.

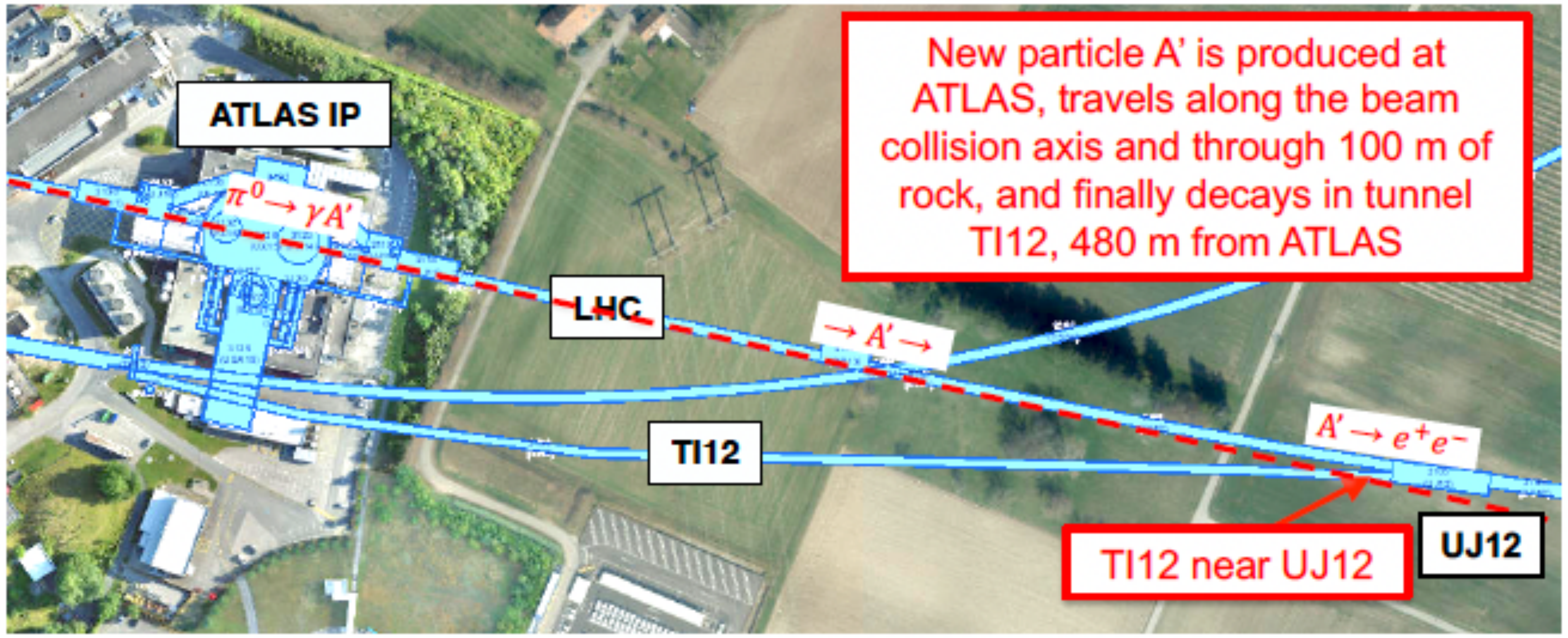
Needs modeling of forward production in the PP interaction

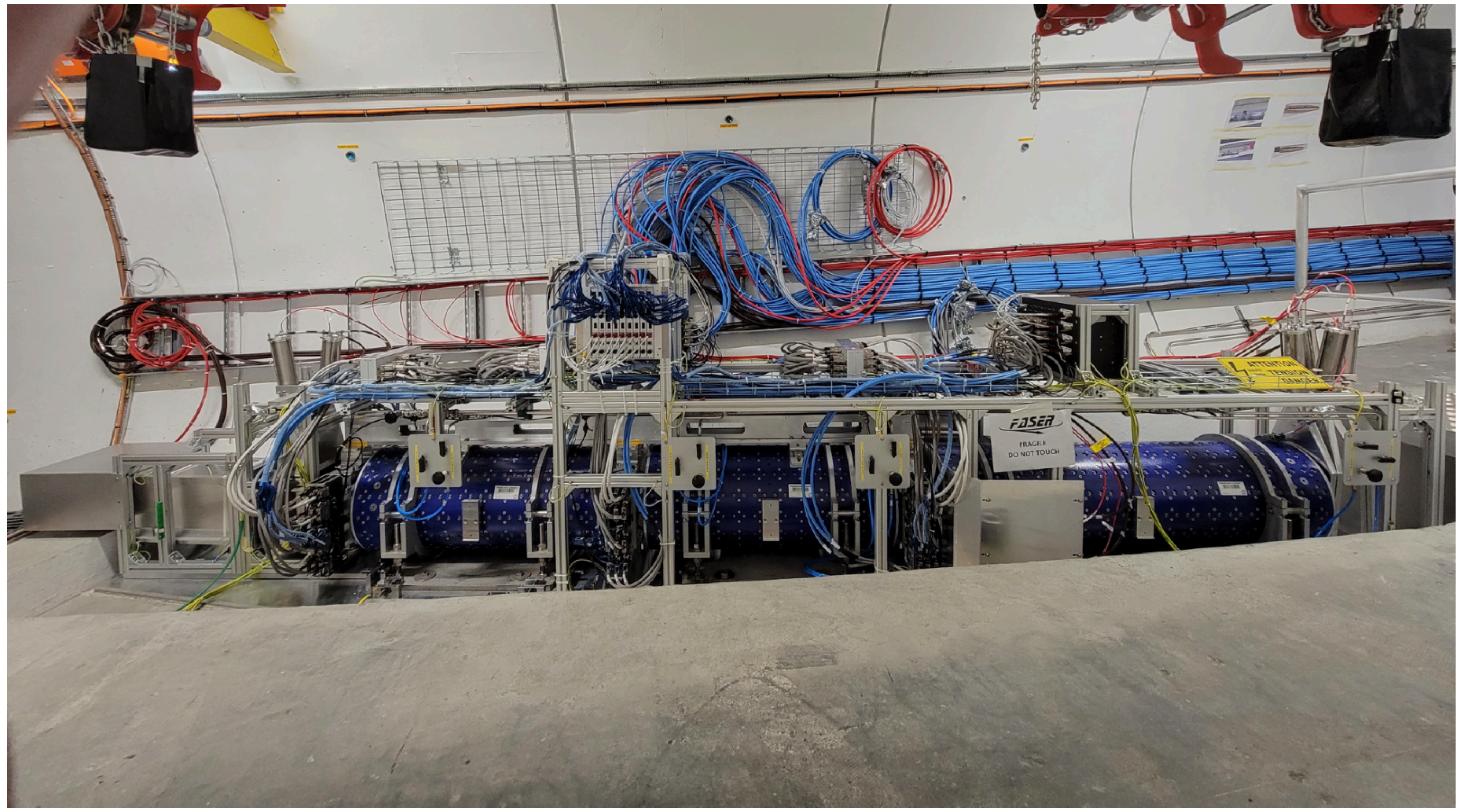
Current program

Current program with Run 3

Recent progress on forward physics

- 4 experiments in progress for LHC-run3 for 150fb^{-1} 2022-24.
- FASER (March 2019), Magnetic spectrometer for neutral decays.
- FASERnu (Dec 2019), Emulsion/ tungsten detector (~1 ton)
- SND@LHC (Mar. 2021) Hybrid Emulsion/active target. (~1 ton)
- Also MilliQan located near CMS (not forward); scintillation bars to see milli-charged particles.
- This program will provide excellent experience for the FPF.





FASERnu pilot run

First collider neutrinos detected at 2.7 sig

- 2018 pilot emulsion detector with 11 kg was deployed for 12.2/fb
- May 2021, announced 6 candidates with 12 backgrounds.
- Same stack able to measure the muon rate at that location.
- muon and neutrino rates in rough agreement with expectations.
- https://arxiv.org/abs/2105.06197

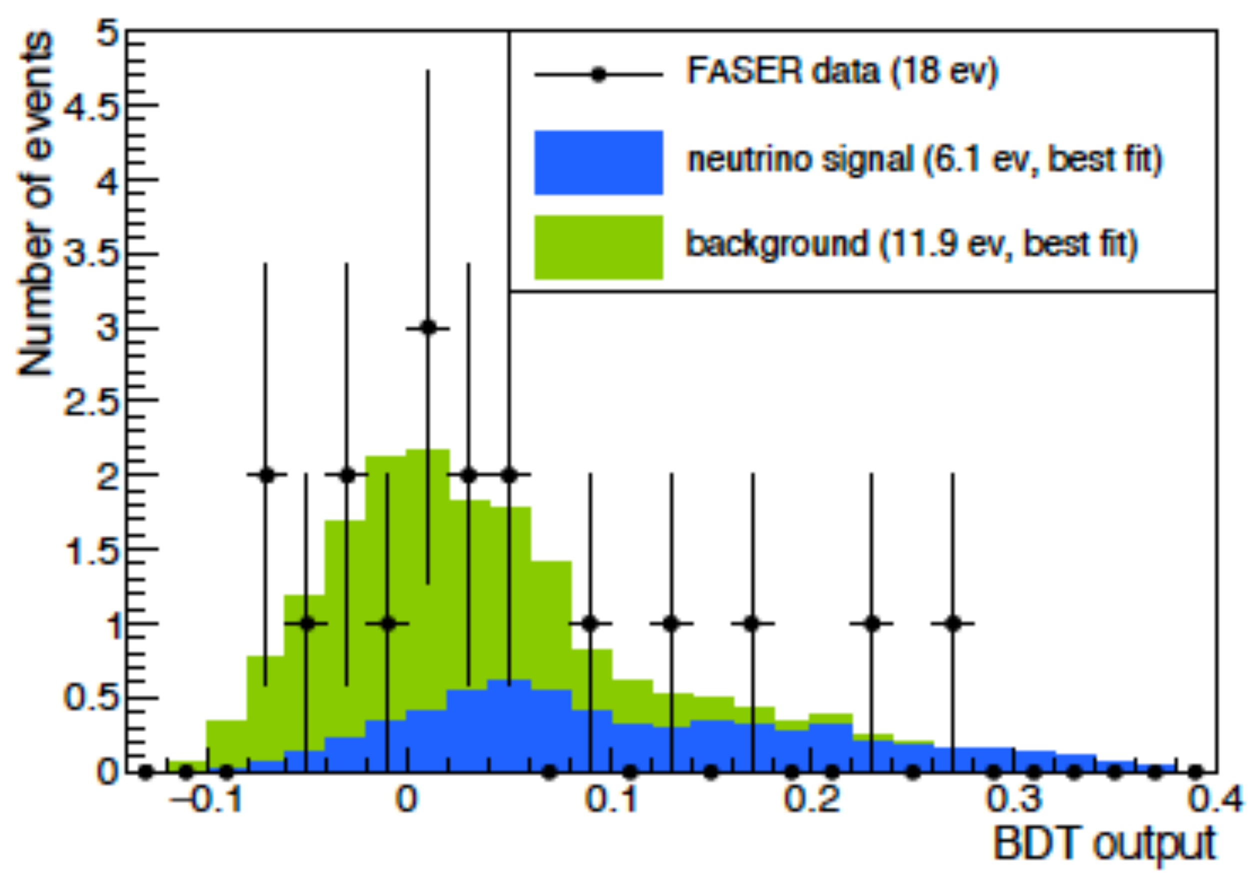
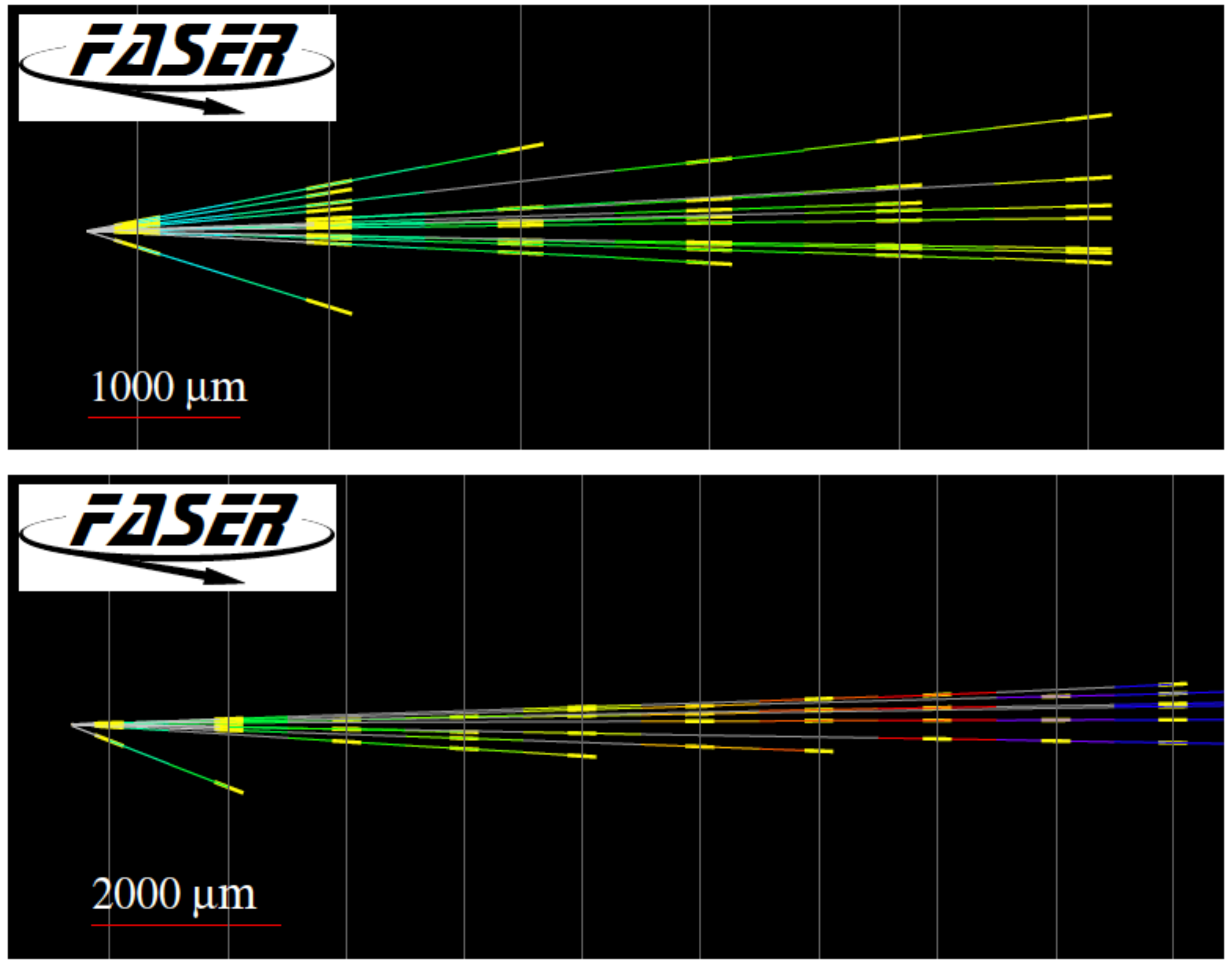


FIG. 6. The BDT outputs of the observed neutral vertices, and the expected signal and background distributions (stacked) fitted to data. Higher BDT output values are associated with neutrino-like vertex features.



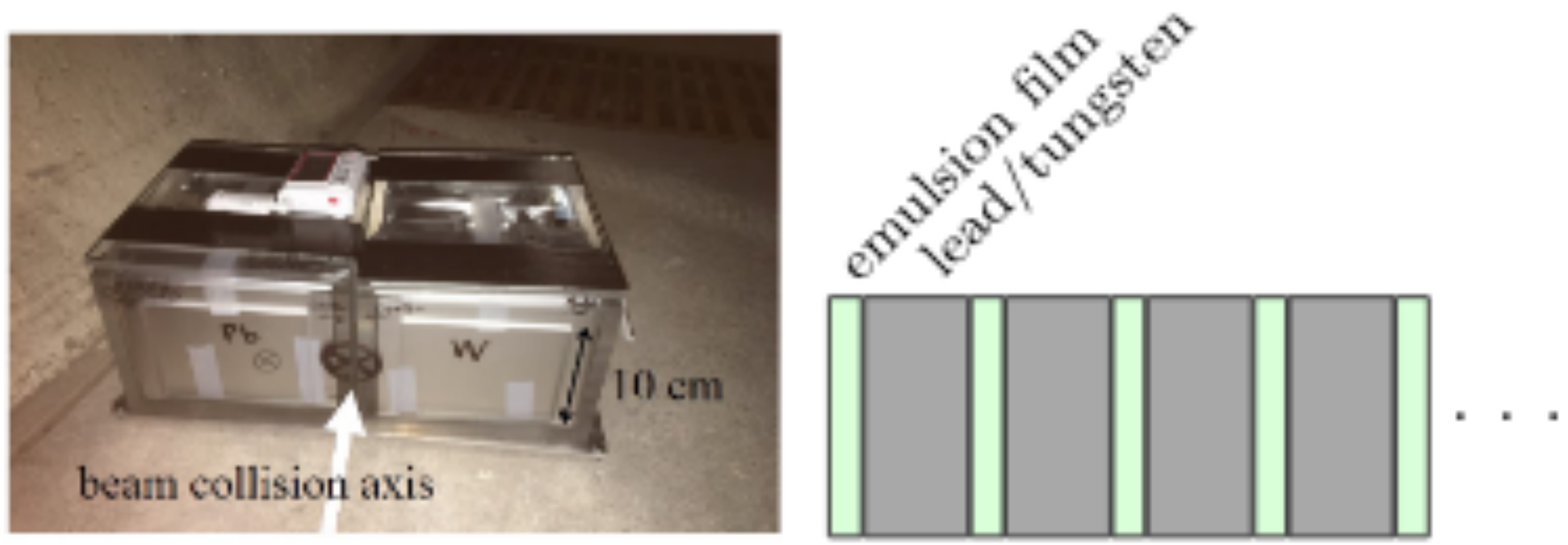


FIG. 1. Structure of the pilot emulsion detector. Metallic plates (1-mm-thick lead or 0.5-mm-thick tungsten) are interleaved with 0.3-mm-thick emulsion films. Only a schematic slice of the detector is depicted.

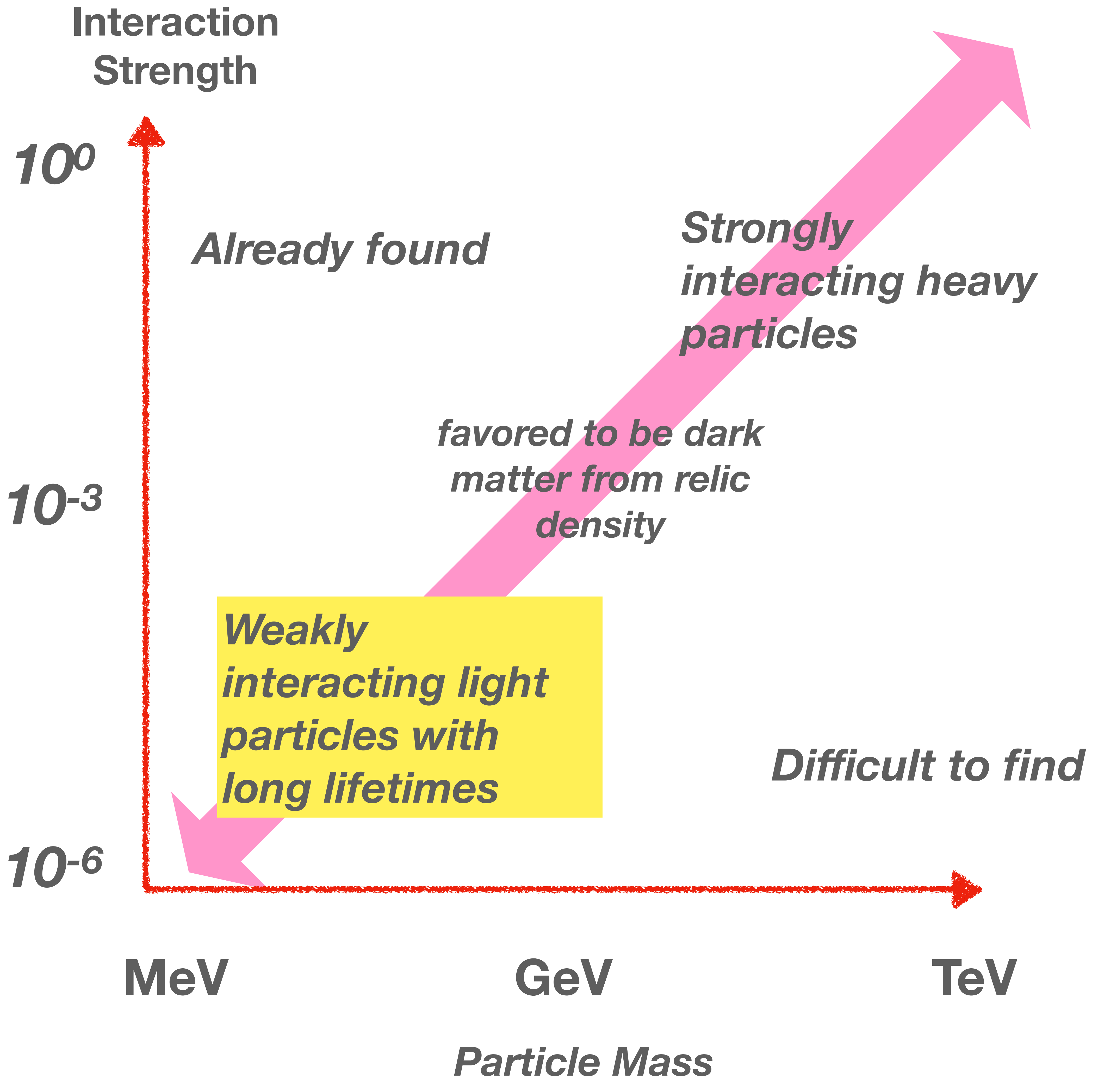
A forward program with much larger detectors is clearly well-justified.

Physics topics for a new program of forward physics.

Standard model and BSM science program

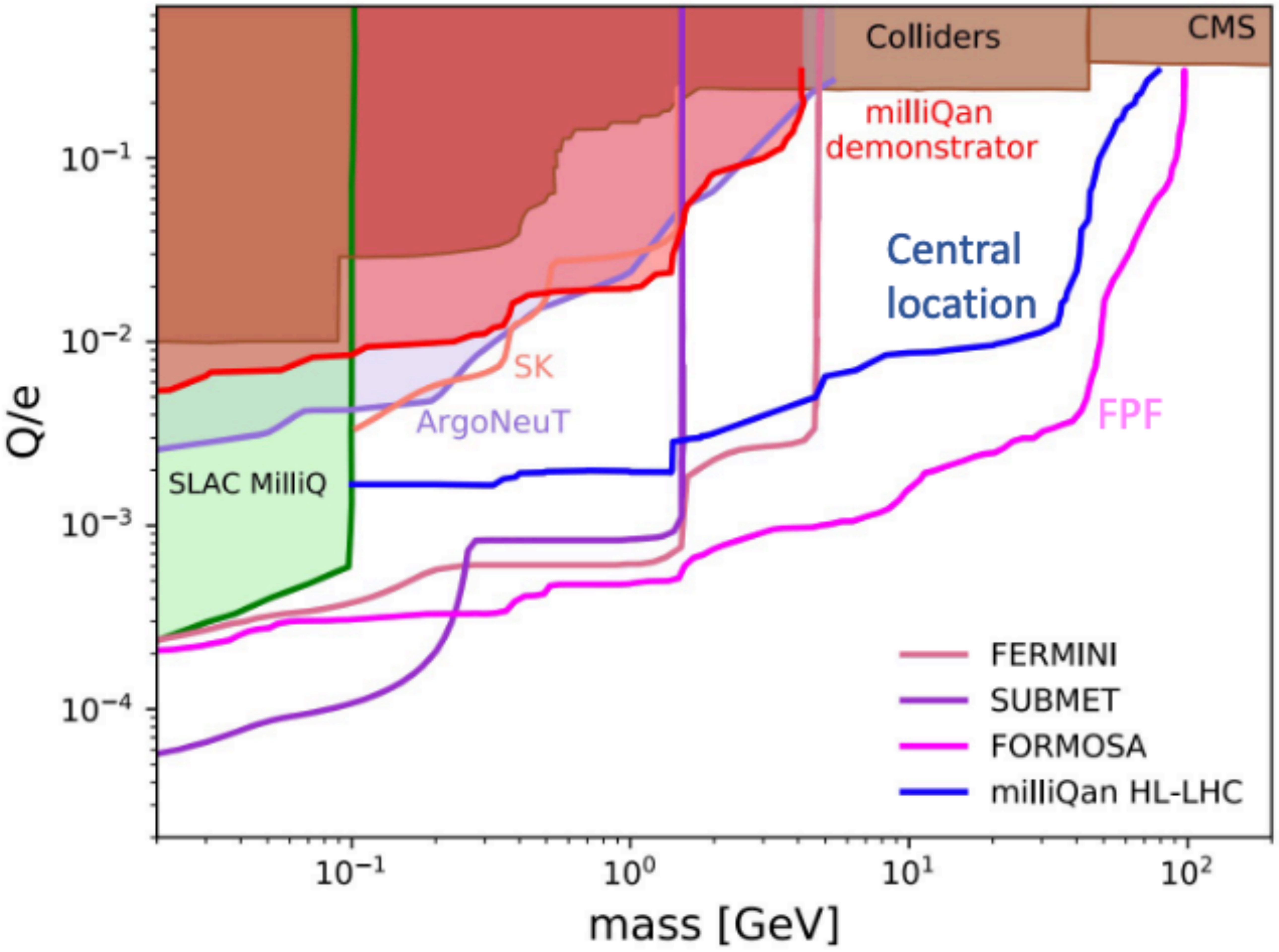
General considerations

- SM program - Focus on very high energy neutrinos and their interactions.
    - First large statistics for tau neutrino interactions.
- BSM program - Focus on weakly interacting light particles from the dark sector.
    - Produced in rare SM decays of copiously produced forward mesons
    - Particles are long lived and either decay or scatter in FPF detectors. Boost from the energy helps the sensitivity
- QCD program — Focus on prompt neutrinos (both tau and electron) to understand the charm content of the proton. Deep connections to nuclear physics and the EIC.



Milicharged particles

- These emerge in models with massless dark photons which couple weakly to dark particles.
- The idea is to see them using dE/dx in a low noise detector.
- Deep bars of scintillator coupled to PMTs: milliQan (central location) and FORMOSA (at FPF)
- The FPF sensitivity assumes high efficiency light sensitivity in 1 meter bars of plastic scintillator with coincidence of 4.
- How can we do better ? Is it possible to use a liquid argon TPC with very good single electron sensitivity (with 2phase)

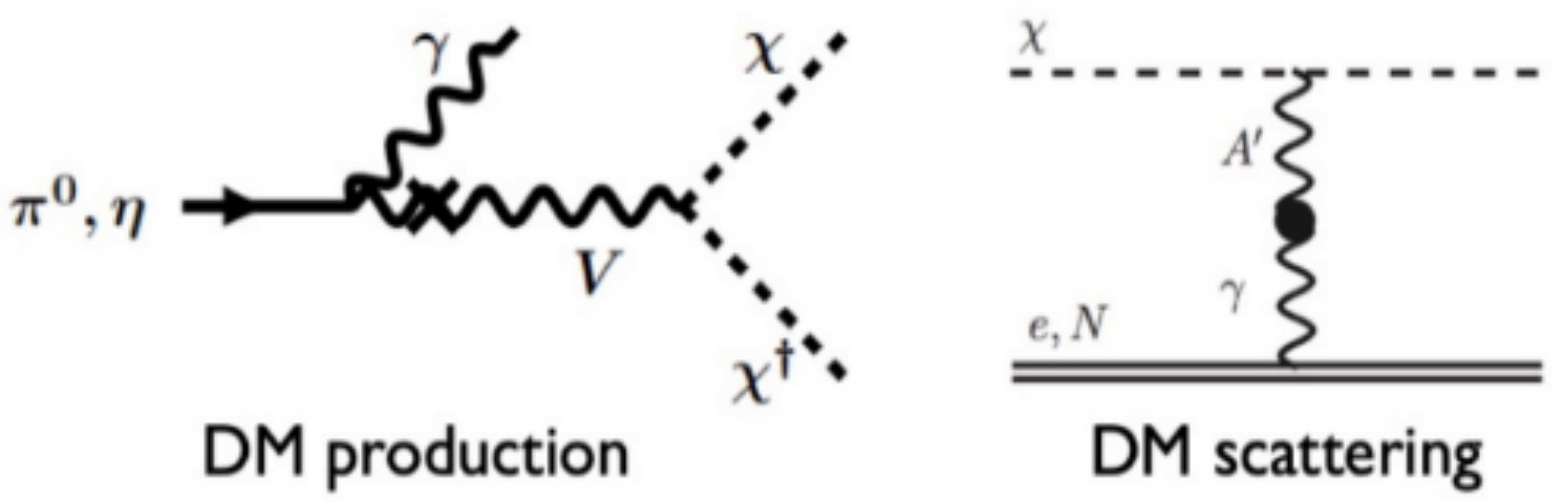


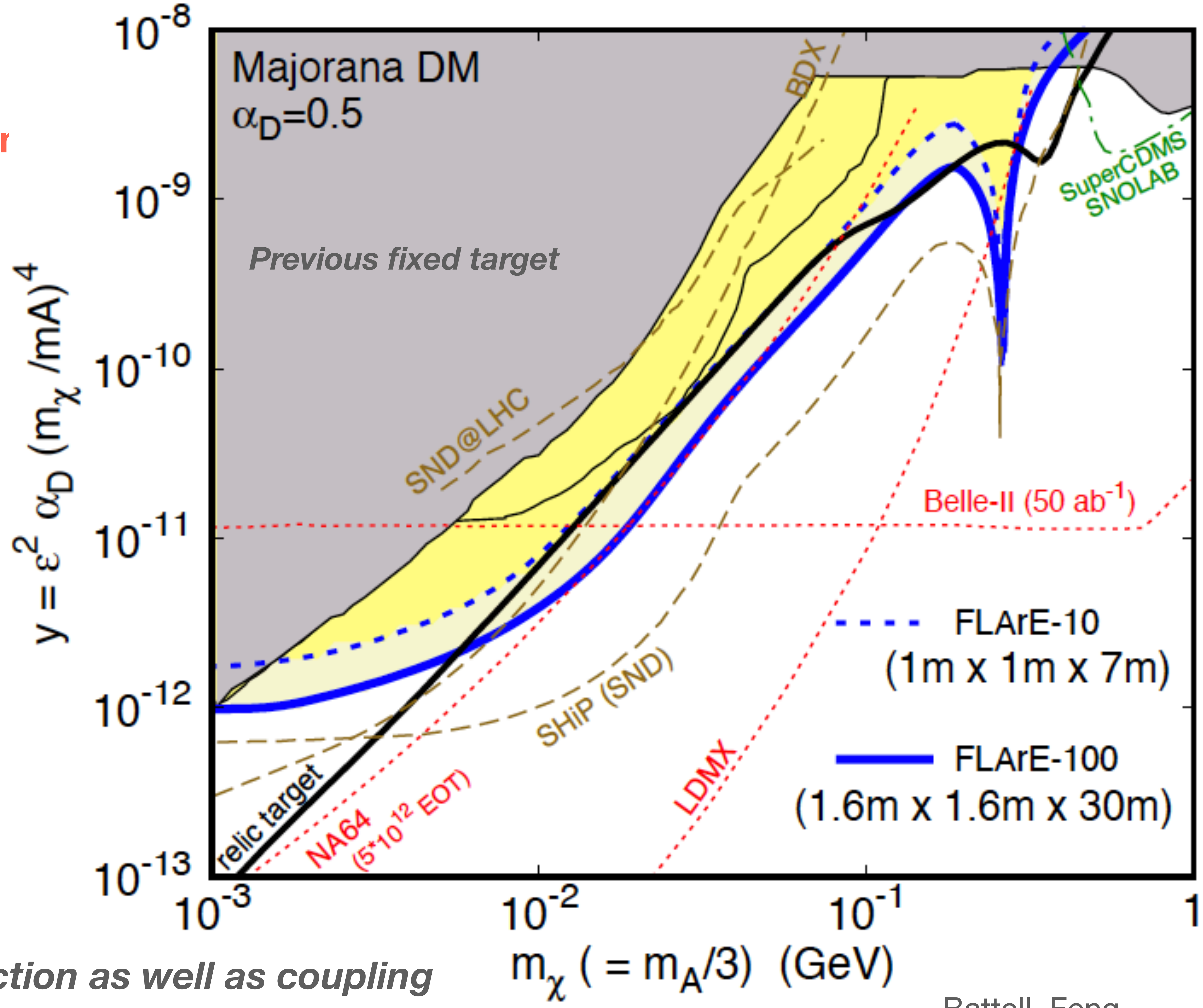
Foroughi-Abari-Kling (2020)

Light Dark Matter scattering (FPF@HL-LHC)

Direct detection with Elastic scattering from electrons or nuclei

- Mass of the χ alters the kinematics of the outgoing electron or nucleus.
- Signal is at low energy (~1 GeV). **Need high kinematic resolutior**
- Background is from neutrino interactions (elastic scattering) and muons.
- The sensitivity plot assumes reasonable cuts for background suppression
- ***10 ton detector will reach the target sensitivity indicated by Relic density.***





Plot attempts to compare both missing mass and direct detection as well as coupling with electrons and nucleons.

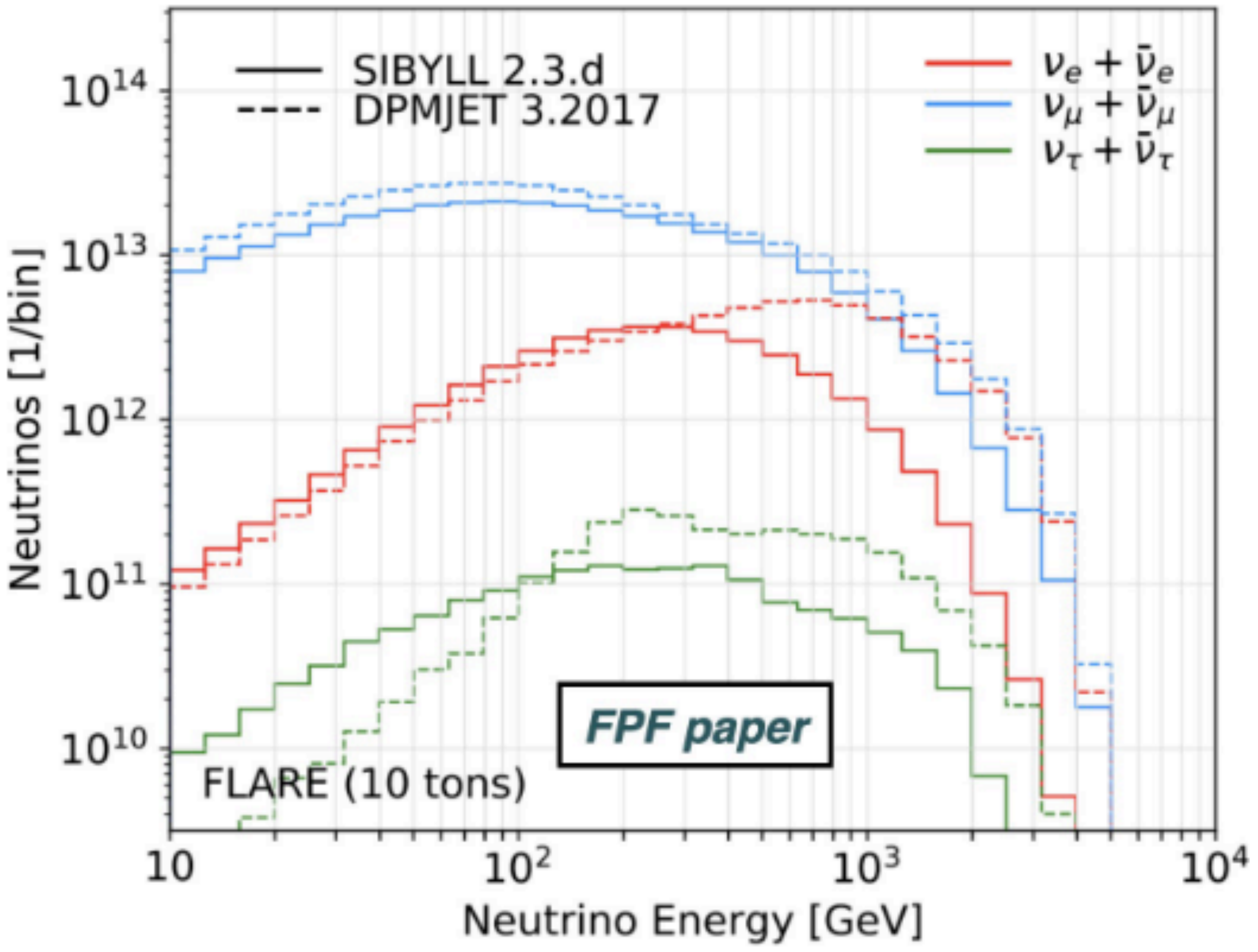
Battell, Feng, Trojanowski (2021)

Neutrino event rates @600 meters (with large uncertainties)

Muon and electron neutrino spectra require detailed simulation of the beam line. The tau flux requires deeper understanding of charm production in the pp collision.

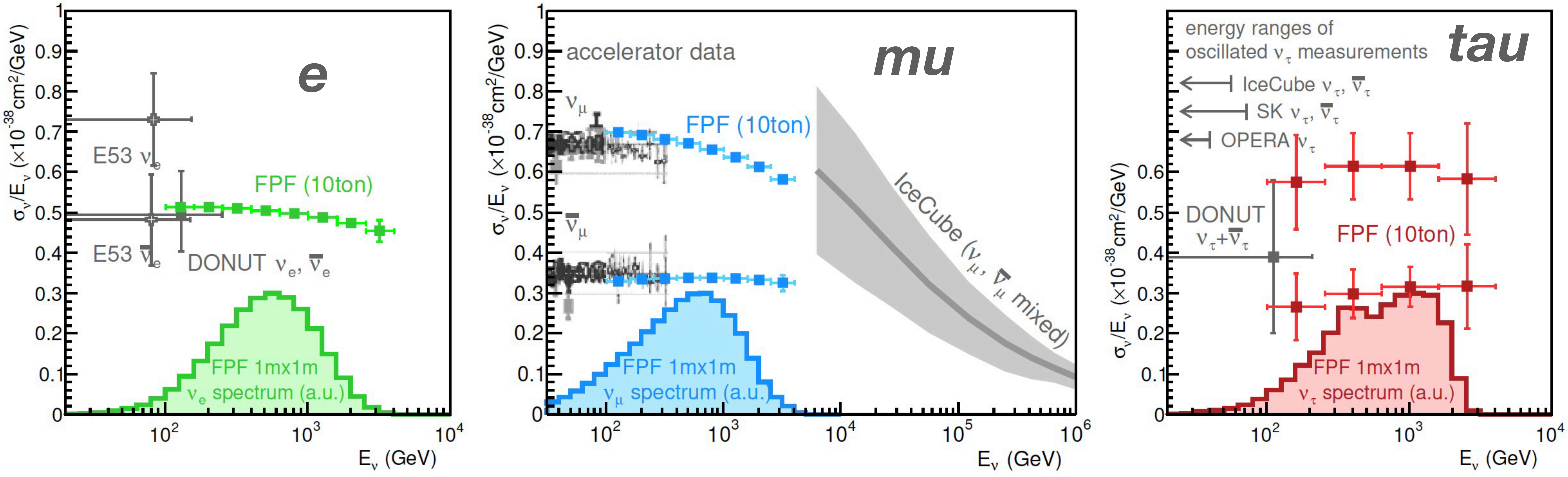
evts/ ton/fb-1	ν	$\bar{\nu}$	***Total***
e	*2.1*	*1.0*	*3.1*
mu	*15*	*5*	*20*
tau	*0.1*	*0.05*	*0.15*

During HL-LHC fb^{-1} is approximately per day.



Mean energy of interactions is ~500 GeV

Neutrino physics



- The current data from accelerators ends around 300 GeV. FPF would provide data that fills in the gap between accelerators and atmospheric neutrinos.
- There are three proposed detectors at 10 ton each: FASERnu2 (emulsion), SND(TBD), and FLARE.
- Total rate will be ~100k electron neutrinos, ~1M muon, and ~few thousand tau neutrino events.

Tau neutrino calculations

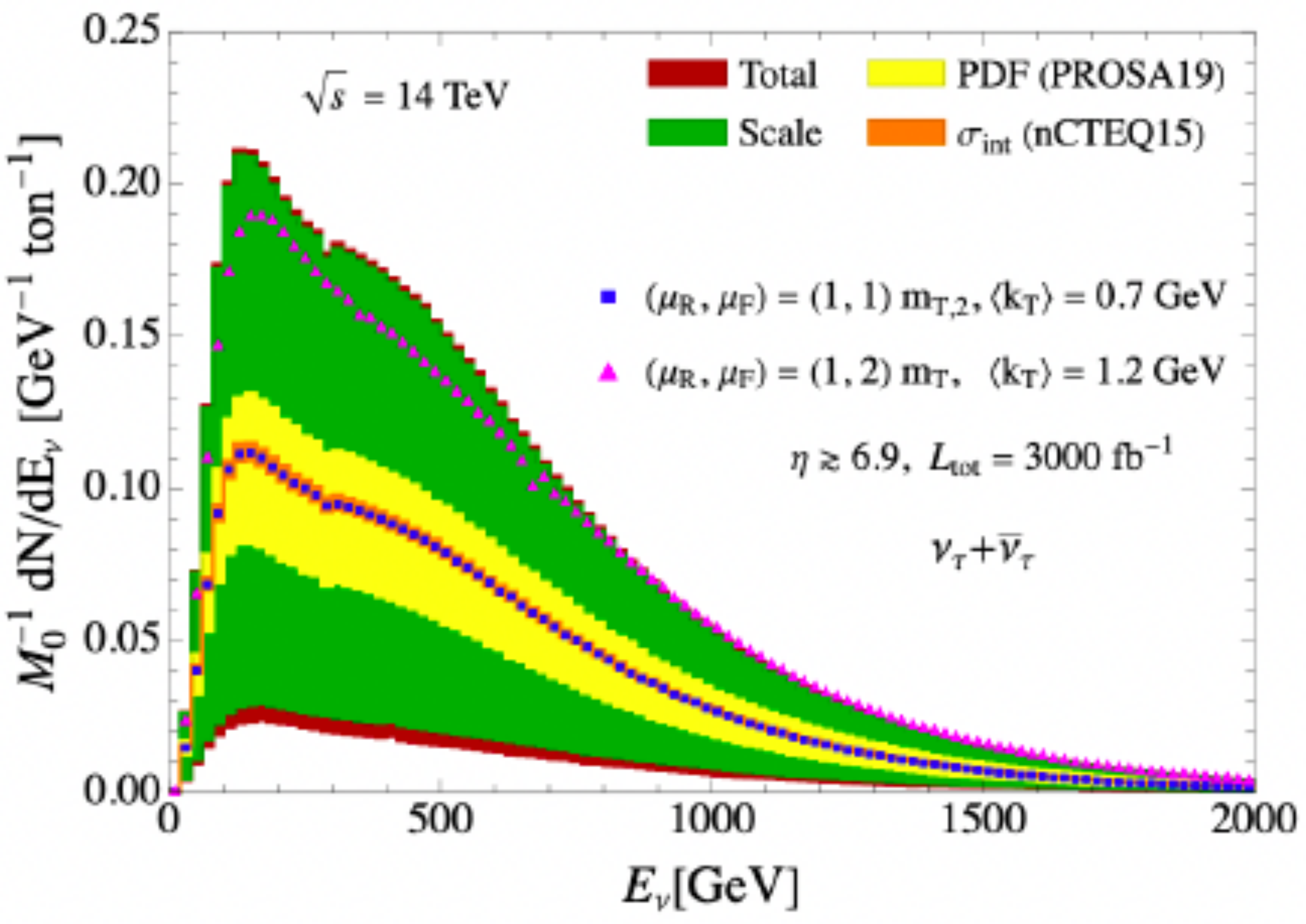
Parton distribution function uncertainties in theoretical predictions for far-forward tau neutrinos at the Large Hadron Collider,
Weidong Bai, Milind Diwan, Maria Vittoria Garzelli, Yu Seon Jeong, Karan Kumar, Mary Hall Reno,

https://arxiv.org/abs/2112.11605

$\mathcal{L} = 3000$ fb^{-1}, 1 m	ν_τ	$\bar{\nu}_\tau$	$\nu_\tau + \bar{\nu}_\tau$	$\nu_\tau + \bar{\nu}_\tau$		
$(\mu_R,\ \mu_F)$, $\langle k_T \rangle$	(1, 1) $m_{T,2}$, 0.7 GeV					
				scale (u/l)	PDF (u/l)	$\sigma_{\rm int}$
$\eta \gtrsim 6.9$	3260	1515	4775^{+4307}_{-3763}	+4205/-3494	+926/-1391	± 112
$(\mu_R,\ \mu_F)$, $\langle k_T \rangle$	(1, 2) m_T, 1.2 GeV			(1, 1) $m_{T,2}$, 0.7 GeV		
PDF	PROSA FFNS			NNPDF3.1	CT14	ABMP16
$\eta \gtrsim 6.9$	5877	2739	8616	4545	7304	5735

normalized for ~60 ton of tungsten

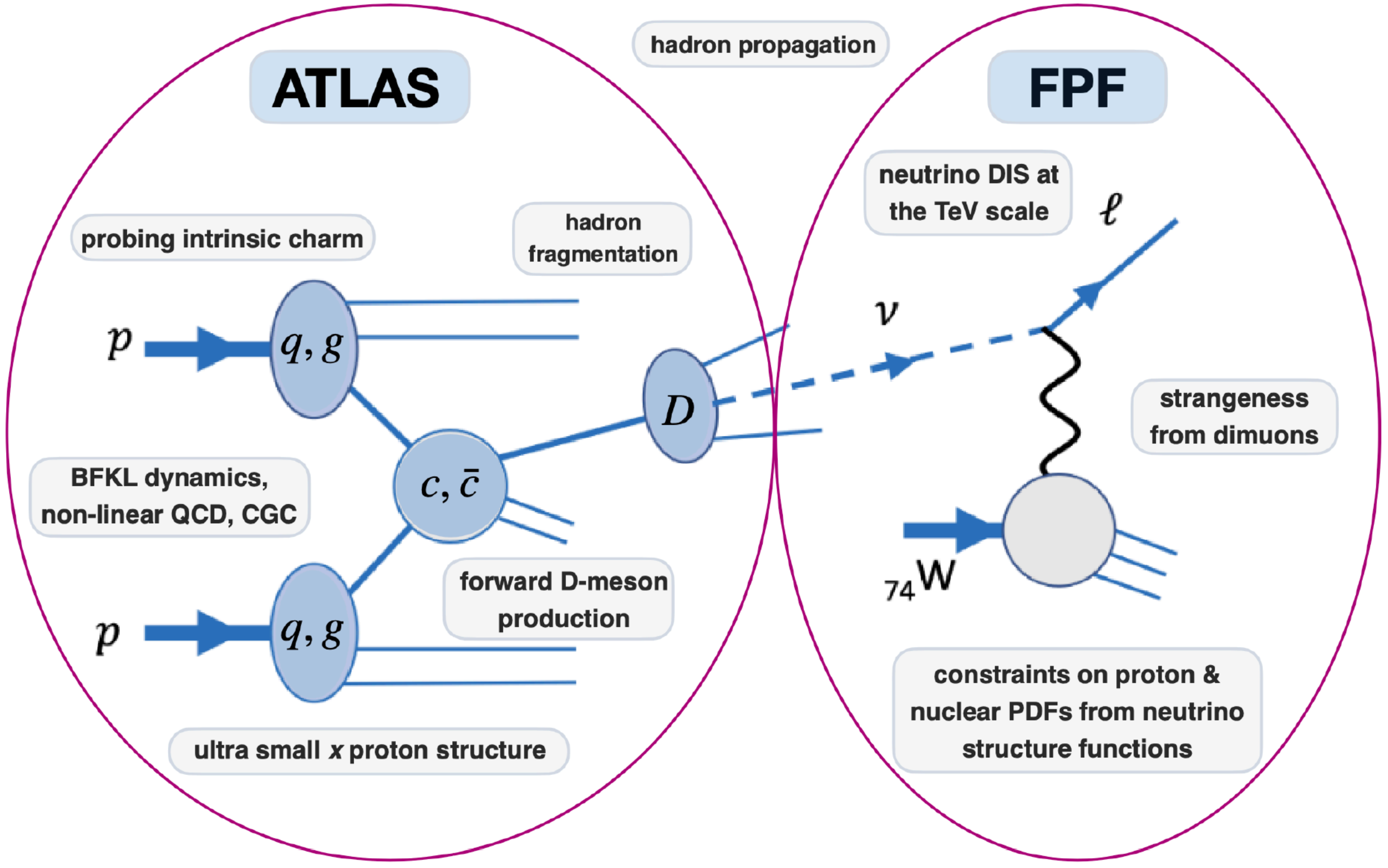
Events per GeV per ton

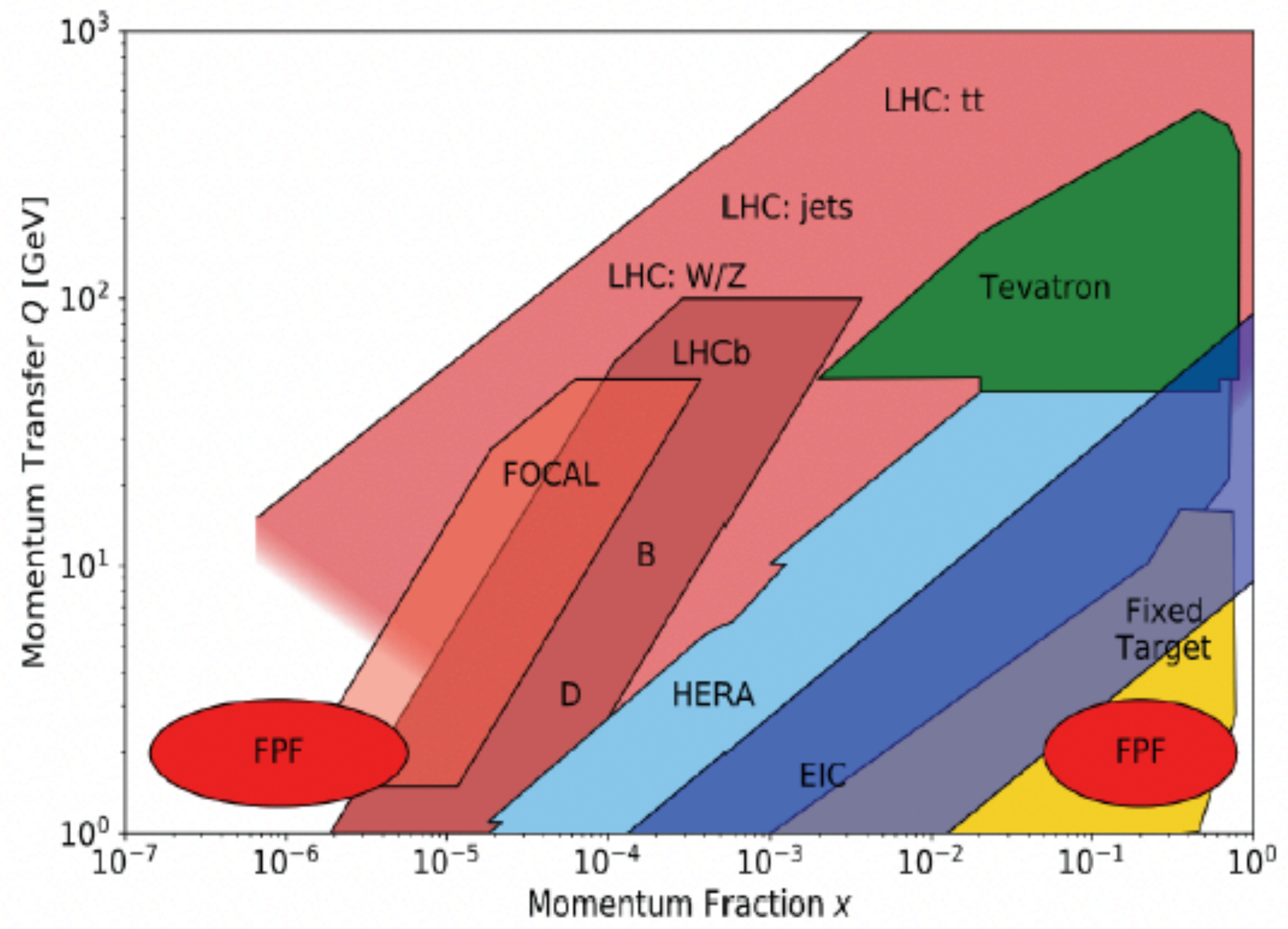


- Largest uncertainties are from scale variation.
- Measuring this rate could be important for forward charm production.

QCD interest

Neutrino interactions neutrino-ion collisions at $\sqrt{s} \approx 50GeV$





- ***Forward hadron production, instrinsic charm (large-x), ultra-small x proton structure***
- ***Extremely well motivated by the astrophysics UHE cosmic rays. New work shows significant reach for astrophysics with CM ~14 TeV***

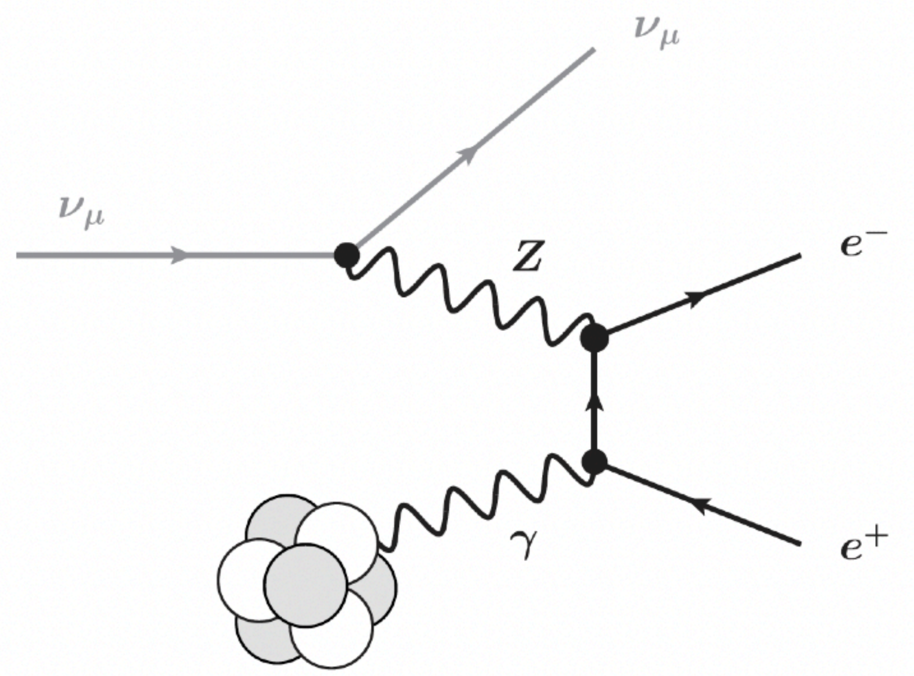
Flux and cross section errors.

How do we deal with unknown flux and cross sections ?

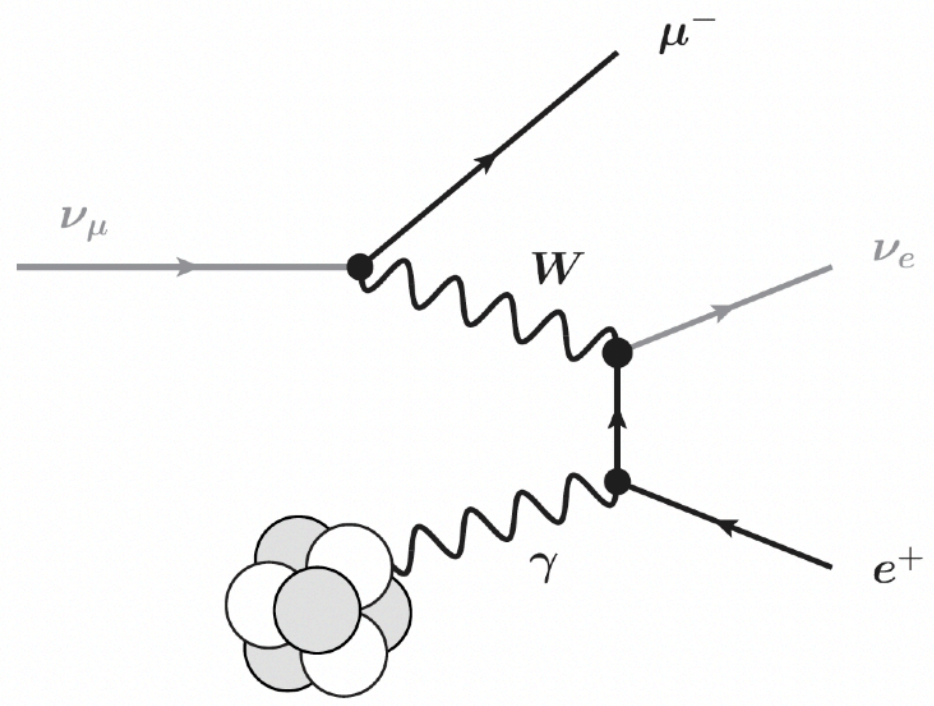
- The cross section and flux determination will be in a joint theoretical and experimental program. Evolving step by step like any other program.
  - Detailed simulations of the beam are needed for muon and electron components.
  - Well known cross sections (lo-nu and elastic scattering) can be used to extract flux.
  - The ratio of high energy electron and tau neutrinos can be well constrained.
  - Theoretical advances are needed in next to leading order calculations.
- External data will be needed on charm production
- ***FPF and EIC would be running at the same time and informing each other.***

Neutrino Tridents

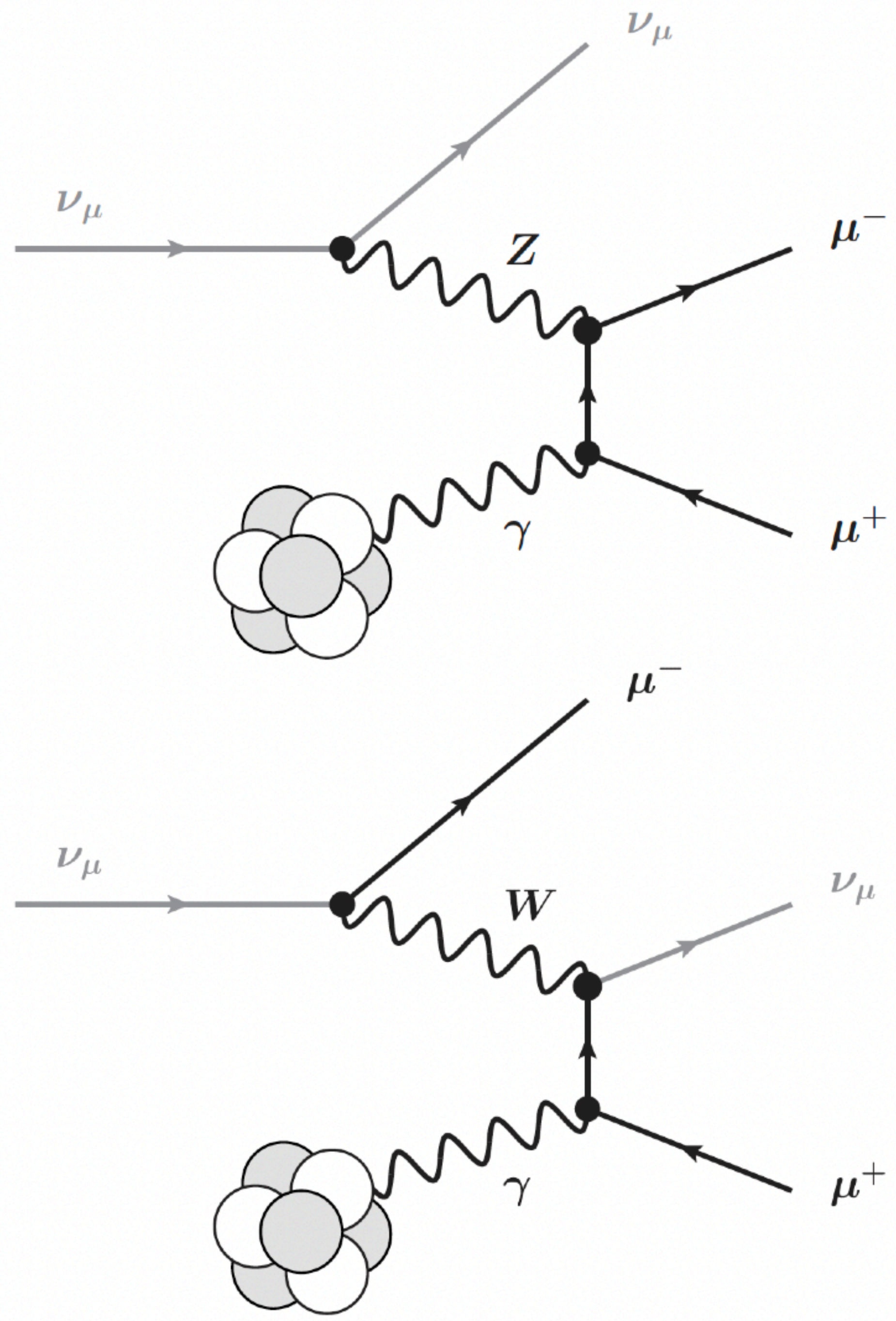
- *Neutrino induced production of charged lepton pairs in the presence of a nucleus.*
- *Mediated by electroweak interactions at tree level and sensitive to new physics.*
- *Rare process.   Mu+mu- has evidence from (CHARM-II) and CCFR.*
- *Coherent cross section strongly enhanced by Z and energy. The LHC flux would open up tau channels as well.*



ee



mue



mumu

$\sigma \approx 1\, fb$ at 200 GeV on Ar

Process	$g^V_{\rm SM}$	$g^A_{\rm SM}$
$\nu_e \to \nu_e e^+ e^-$	$1 + 4\sin^2\theta_W$	-1
$\nu_e \to \nu_e \mu^+ \mu^-$	$-1 + 4\sin^2\theta_W$	$+1$
$\nu_e \to \nu_\mu \mu^+ e^-$	2	-2
$\nu_\mu \to \nu_\mu e^+ e^-$	$-1 + 4\sin^2\theta_W$	$+1$
$\nu_\mu \to \nu_\mu \mu^+ \mu^-$	$1 + 4\sin^2\theta_W$	-1
$\nu_\mu \to \nu_e e^+ \mu^-$	2	-2

$$d\sigma_{\text{coh.}} \propto Z^2 \alpha_{\text{em}}^2 G_F^2 |F_N(q^2)|$$

See 1406.2332, Altmannshofer, Gori, Pospelov, Yavin
and 1902.06765, Altmannshofer, Gori, Martin-Albo, Sousa, Wallbank.

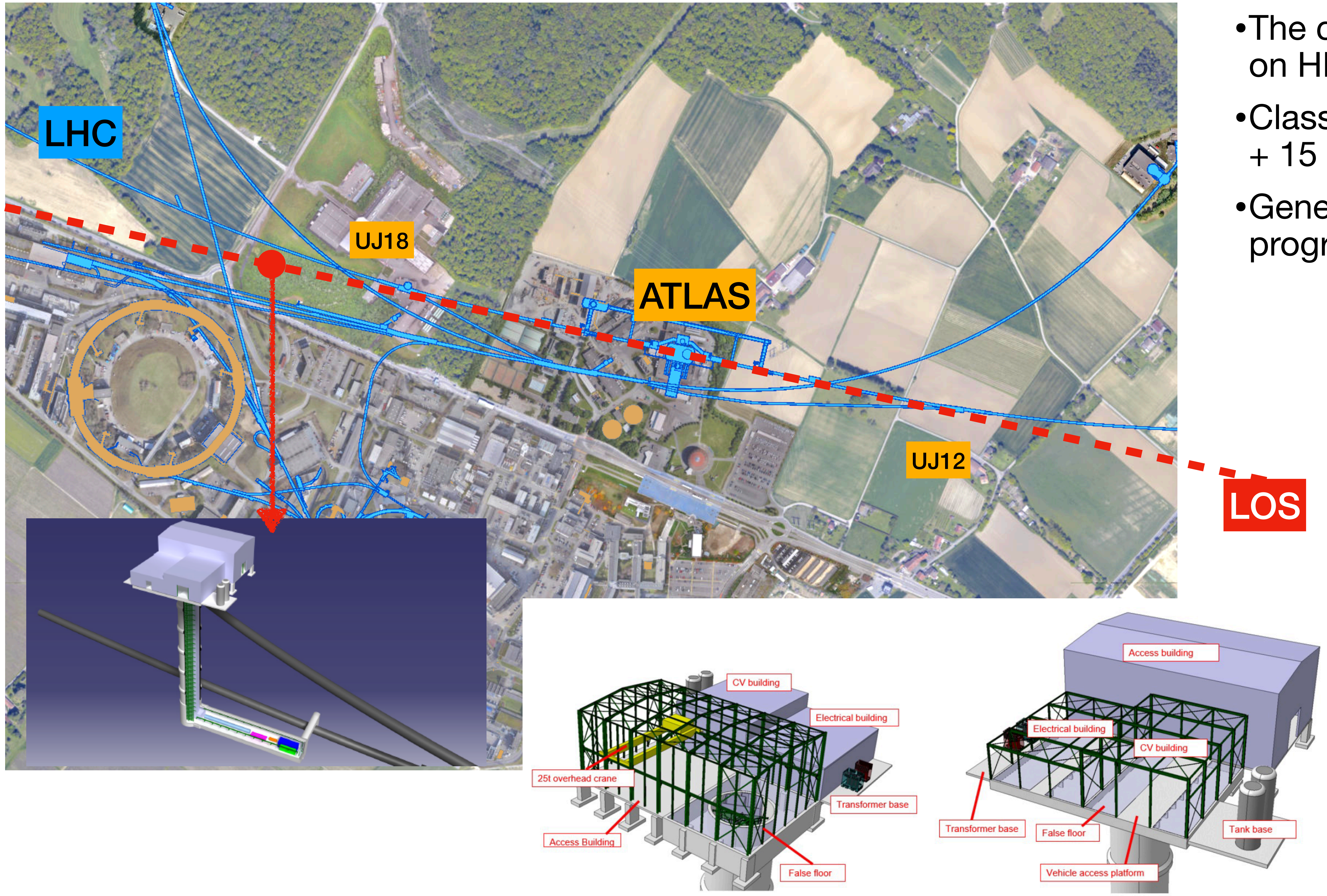
Forward Physics Facility and FLARE (forward liquid argon experiment)

Basic requirements for far forward detectors.

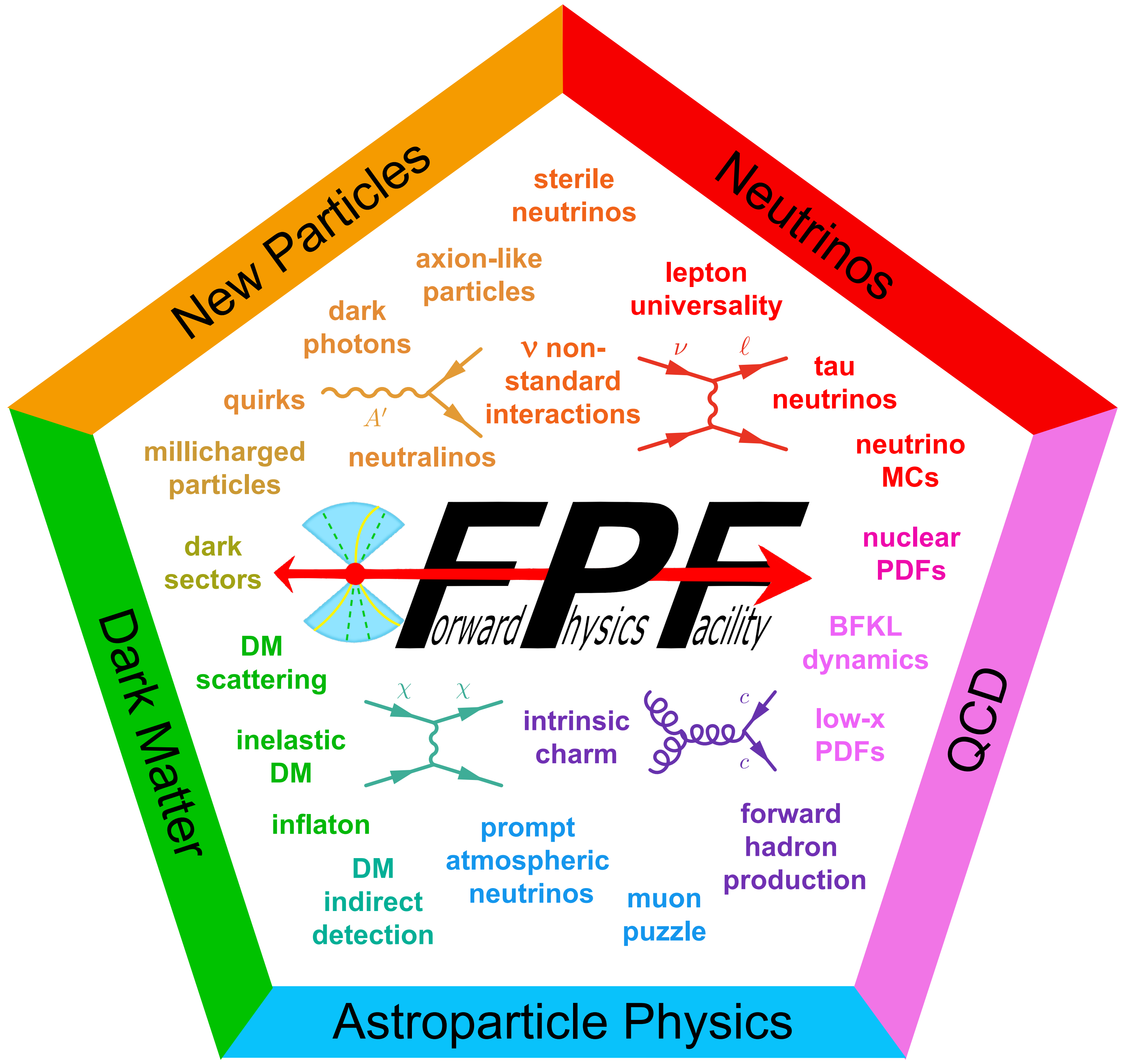
- Detector needs to be at 0 degrees to the collision axis.
- Some off-axis data might be very useful for neutrinos from high mass particles.
- Fiducial mass of 10 tons at few hundred meters is needed for good statistics and sensitivity to dark matter.
- Detectors need to have good energy containment (high density) and resolution (~10 interaction lengths, live detector) for neutrino physics.
- Detectors need low (~100 MeV) threshold for dark matter elastic scattering
- Detectors need <1 mm scale spatial resolution if we want to detect tau neutrinos with low backgrounds.
    - Only emulsion is guaranteed for this scale, but emulsion/tungsten stack will not have great total energy resolution. And it cannot be triggered.
    - The only other detector with this possibility is a liquid argon time projection chamber.

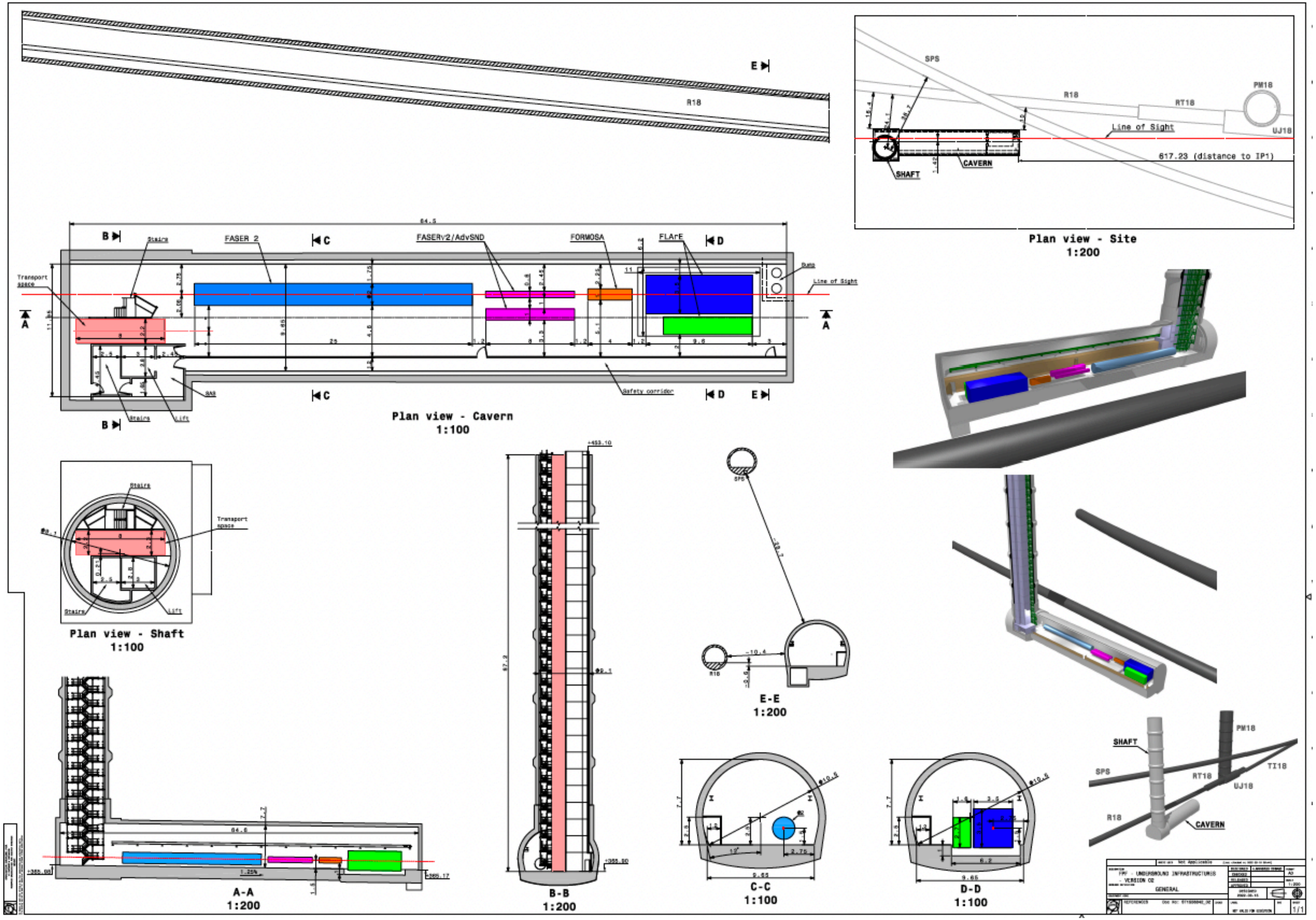
Forward Physics Facility (FPF)

Proposal to create forward underground space for experiments during HL-LHC. Expand the program that has started with FASER, FASERnu, SND, MilliQan.



- The cavern is not connected to the LHC and no impact on HL-LHC running is foreseen.
- Class 4 cost of this has been estimated: 23 MCHF (CE) + 15 MCHF (services) +additional items = 40 MCHF
- General purpose facility with broad SM and BSM program; spans all HEP frontiers.





Class 4 cost of this has been estimated: 23 MCHF (CE)+ 15 MCHF (services) + additional items
= 40 MCHF

Class 4 means: -30% +50%

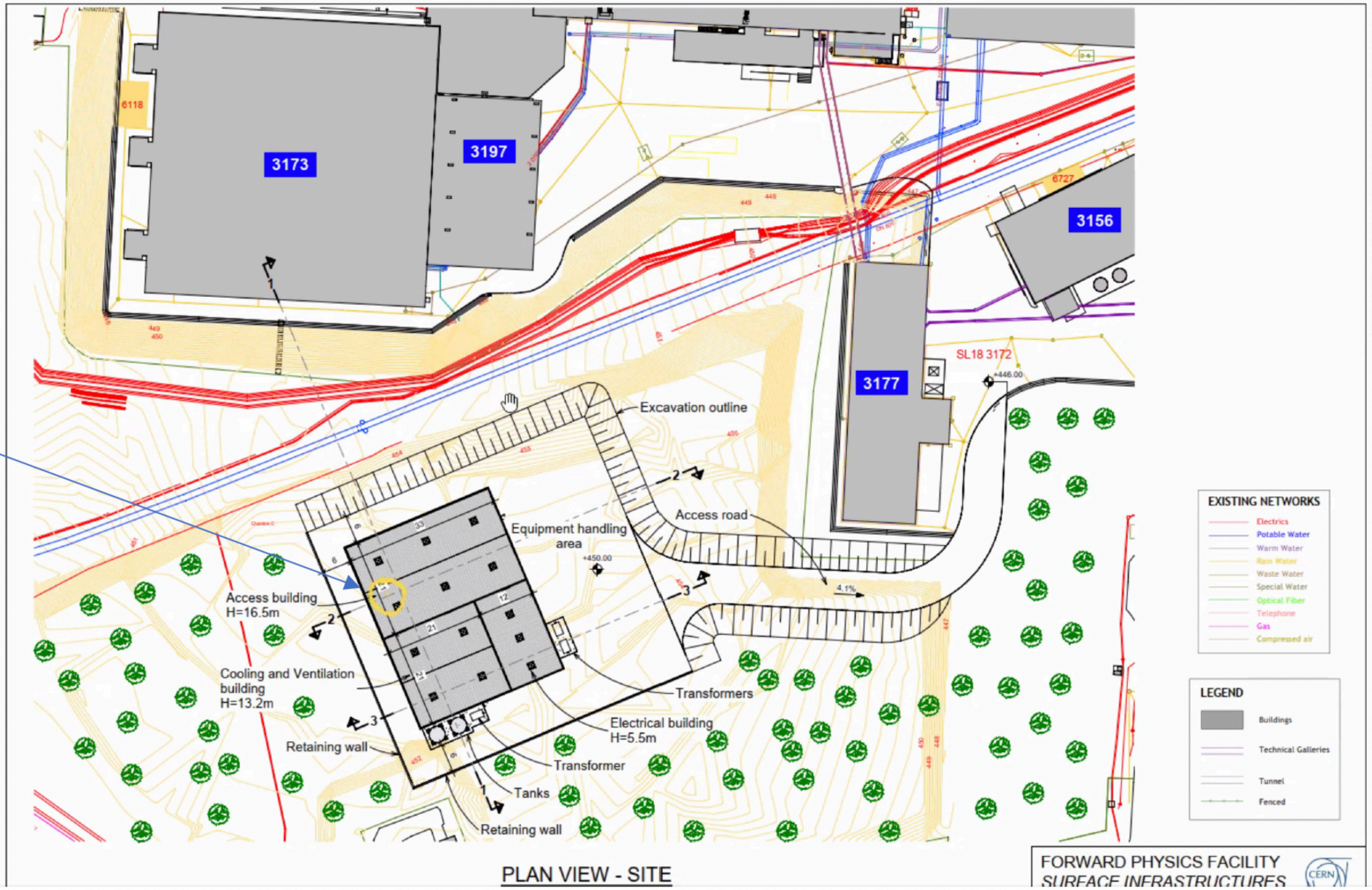
Important development April 22:

- safety gallery allows no connection to the LHC for secondary exit.

Civil Engineering: Site Investigation

Civil engineering team are starting a site investigation study.
With external consultant are planning to drill a core down to proposed FPF cavern level (90m) at location of shaft.
Will provide important information on on the structural strength of the rock at the cavern location, as well as understanding any contaminates in the rock, and would be fed into a revised design/costing.
Hope to have drilling and analysis carried out before the end of the year.

Planned drilling location



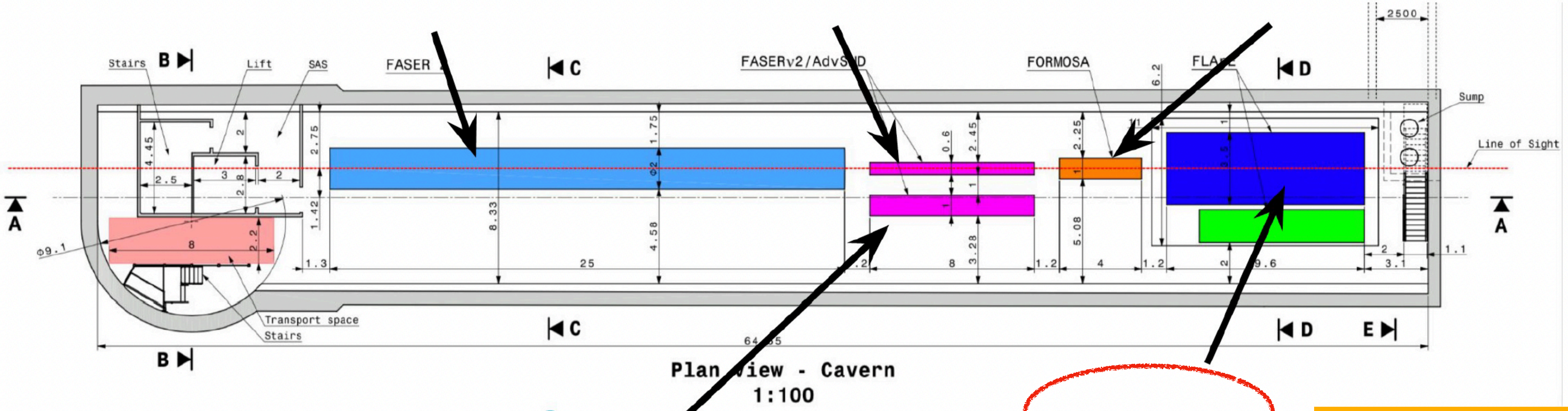
- At present there are 5 experiments being developed for the FPF.
- Pseudo-rapidity coverage in the FPF is $\eta > 5.5$, with most experiments on the LOS covering $\eta > 7$.

A strong experimental program is needed to make a decision on the FPF

FASER2
magnetized spectrometer for BSM searches

FASERν2
emulsion-based neutrino detector

FORMOSA
plastic scintillator array for BSM searches



AdvSND
electronic neutrino detector

FLArE
LAr based neutrino detector

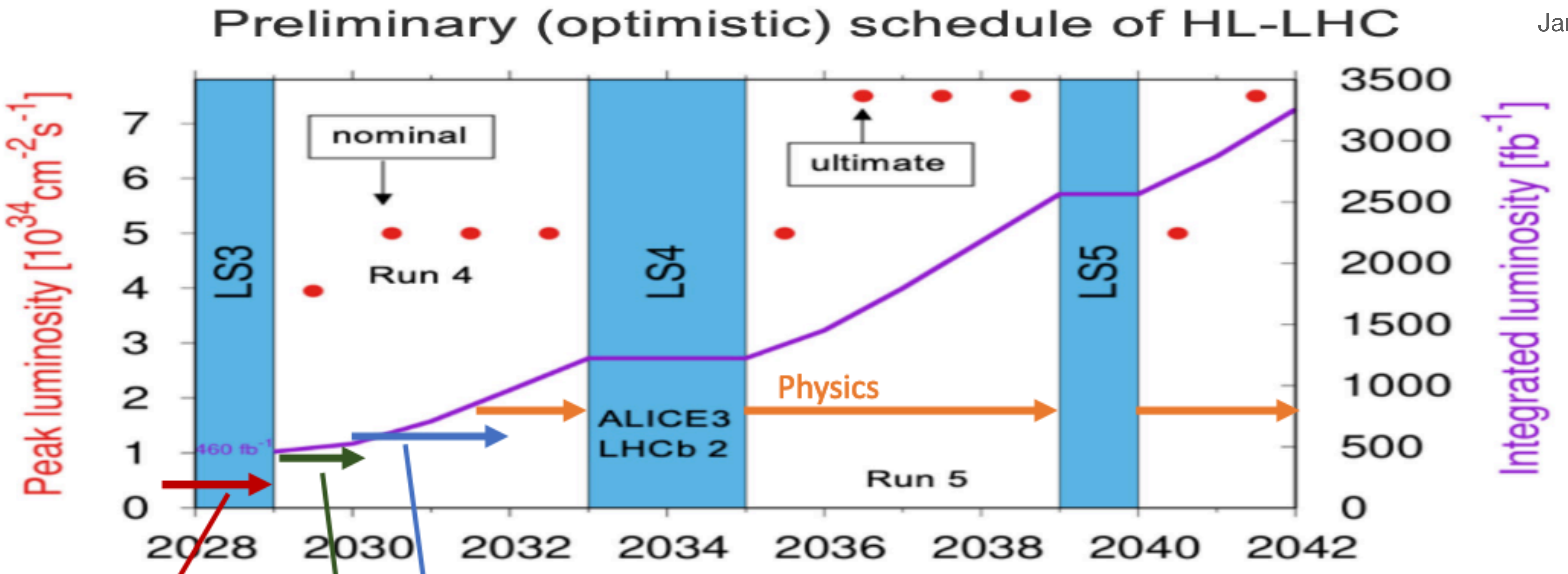
MVD will focus on technical issues of FLARE.

Kling 2022

Possible FPF schedule

HL-LHC schedule from DG presentation, New-Year (on-line) meeting, 13/1/22

Jamie Boyd



Pure CE works (including ~~connection to LHC)~~

Installation and commissioning of the experiments

Installation of services (CERN technical teams, busy during LS3)

Such a schedule would:

- Allow physics data taking for most of the luminosity of the HL-LHC
- Not overload CERN technical teams during LS3
- Design of facility would allow different experiments to come online at different times

Requirements:

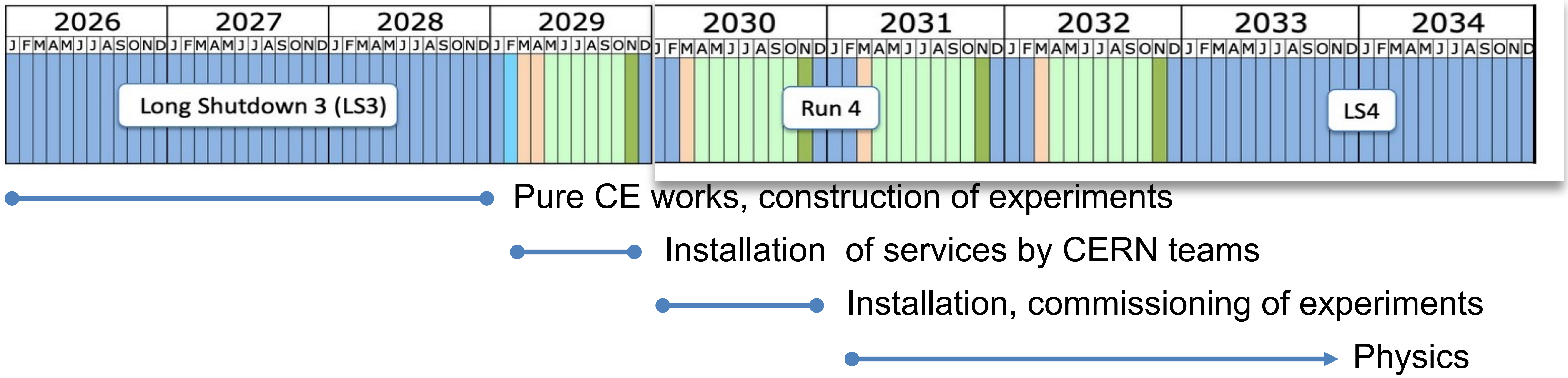
- Can access the facility during LHC operations (RP study ongoing)
- Can complete CE works before the end of LS3

COST AND TIMELINE

- Very preliminary (class 4) cost estimate: 23 MCHF (CE) + 15 MCHF (services) $\approx$ 40 MCHF (+50%/-30%), not including experiments.

- Conceptual designs for the FPF and its 5 experiments ready by mid-2023.
  - FASER2, FASERnu2, AdvSND, FORMOSA build on existing experiments and collaborations.
  - FLArE R&D is currently supported by BNL LDRD and Heising-Simons Foundation funds.

- Timeline: begin CE works, installation of services in LS3, followed by installation and commissioning of experiments in early Run 4. Physics begins in Run 4 and continues to the end of the HL-LHC era (~2031-42).

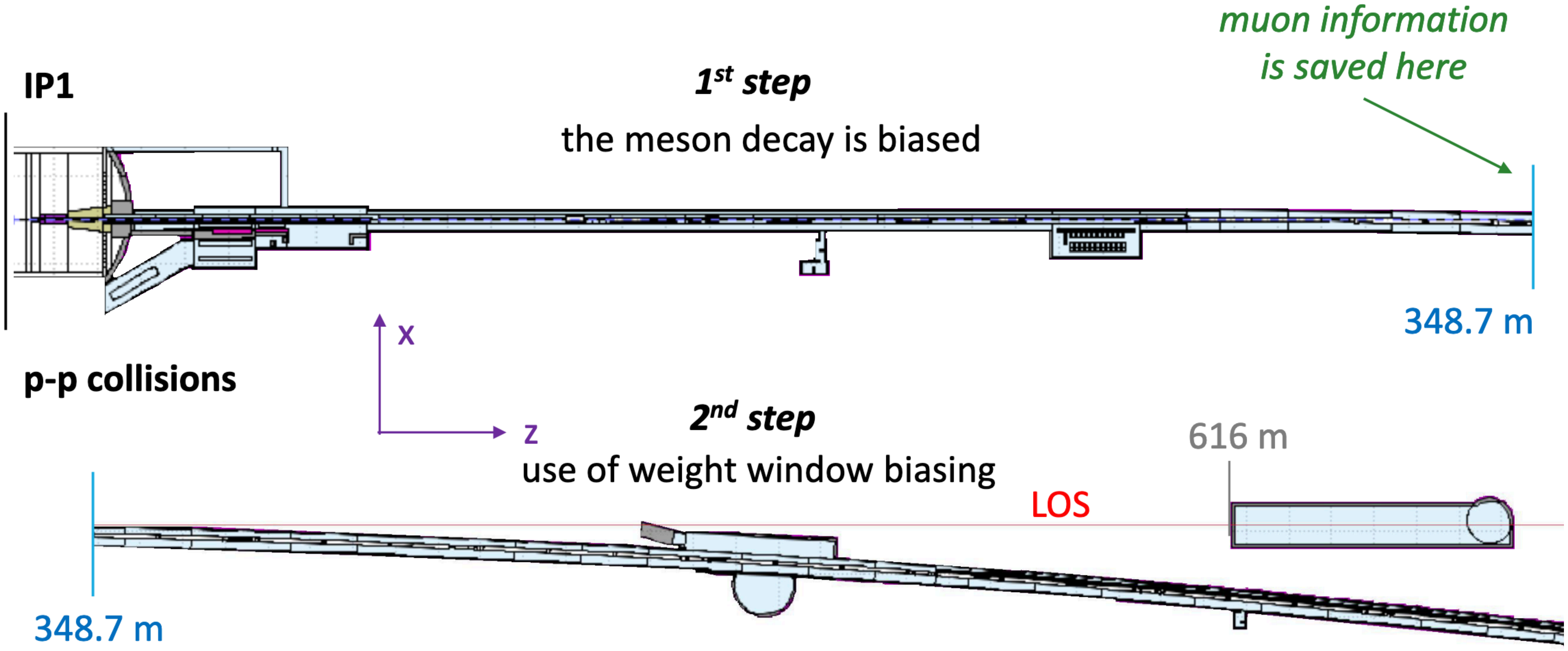


Radiation issues.

FLUKA simulations overview

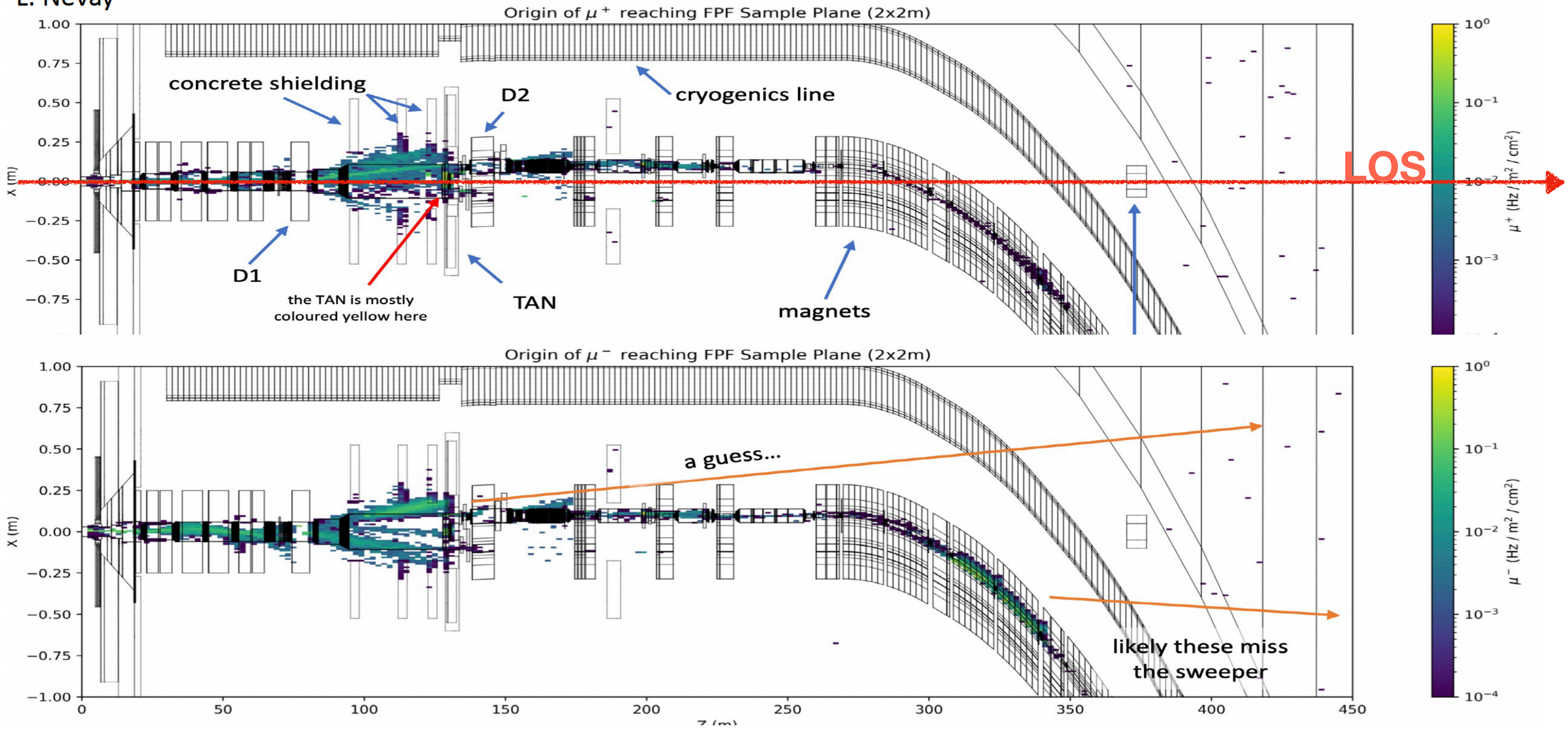
IR1 - HL-LHC
Horizontal crossing
+250 μrad half crossing angle

- In order to get the muon fluence in the FPF cavern:



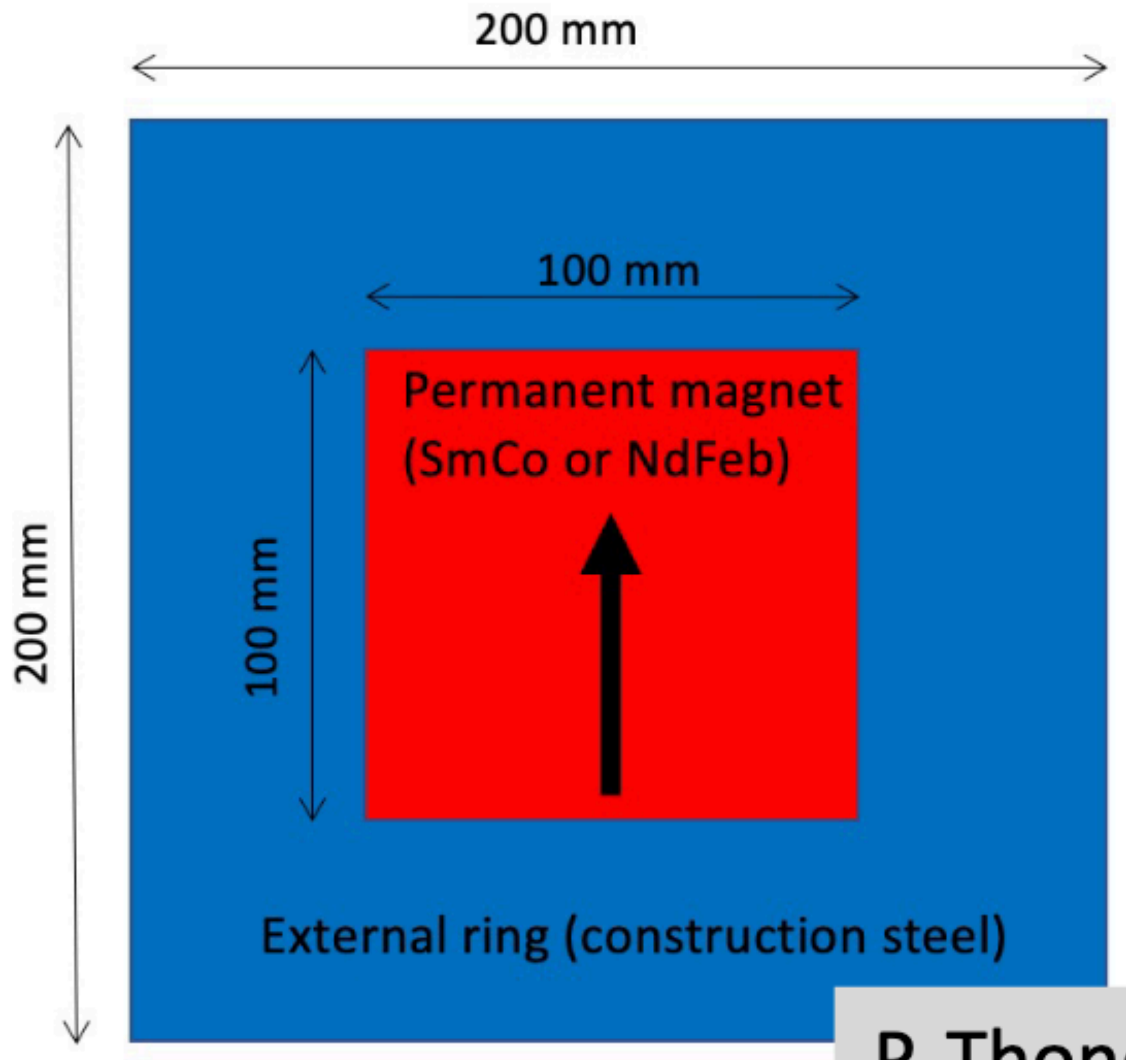
New HL-LHC geometry BDSIM simulation. Where to place a sweeper magnet ?
Any Placement requires movement of cryogenic lines and other services. But so far possible.

L. Nevay



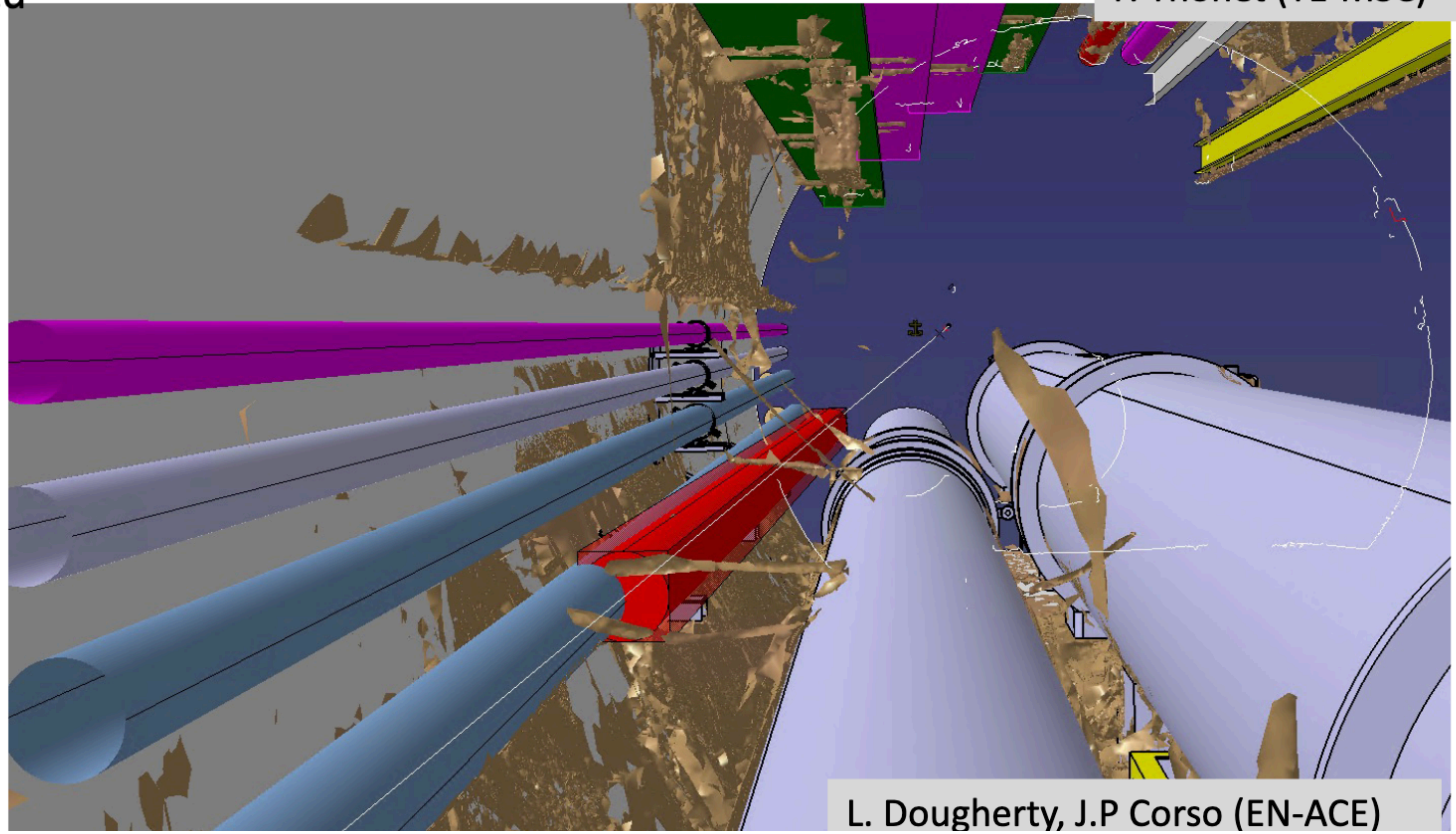
The MU+ and MU- have very different spatial distributions. And the rate is actually higher away from the LOS. We have to assume that this will be solved with ultimate rate of << 1 Hz/cm2 at the FPF. it will need more people !

Sweeper Magnet: Ongoing Studies



- Preliminary design of sweeper magnet by TE-MSC
  - Based on permanent magnet to avoid power converter in radiation area
  - Consider 7m long (20x20cm^2 in transverse plane) magnet, 7Tm bending power
- To install such a magnet would require some modifications to cryogenic lines in relevant area
  - Possibility of modifications to be investigated with LHC cryo
  - Integration/installation aspects to be studied
- FLUKA and BDSIM studies ongoing to assess effectiveness of such a magnet in reducing the muon background in the FPF

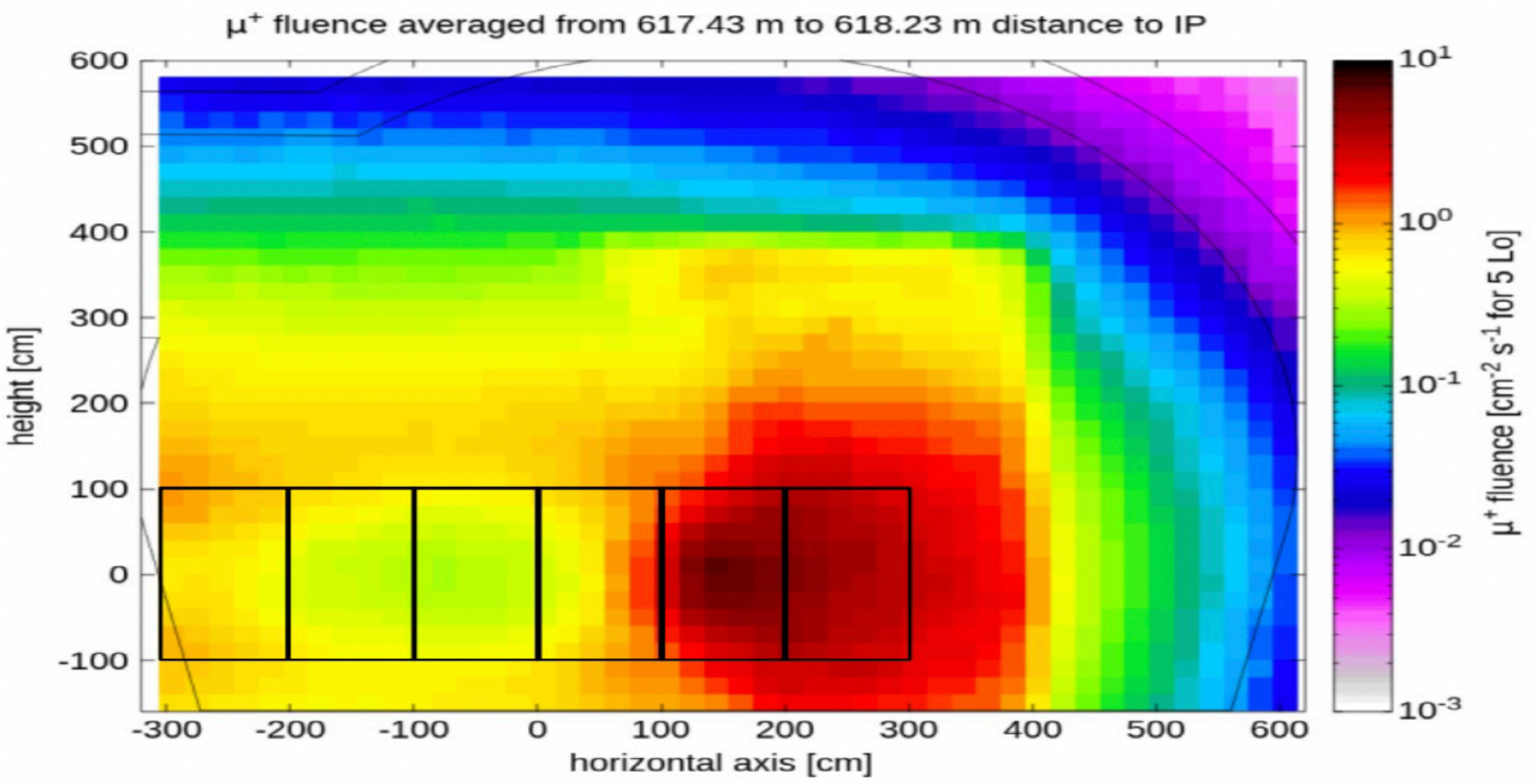
P. Thonet (TE-MSC)

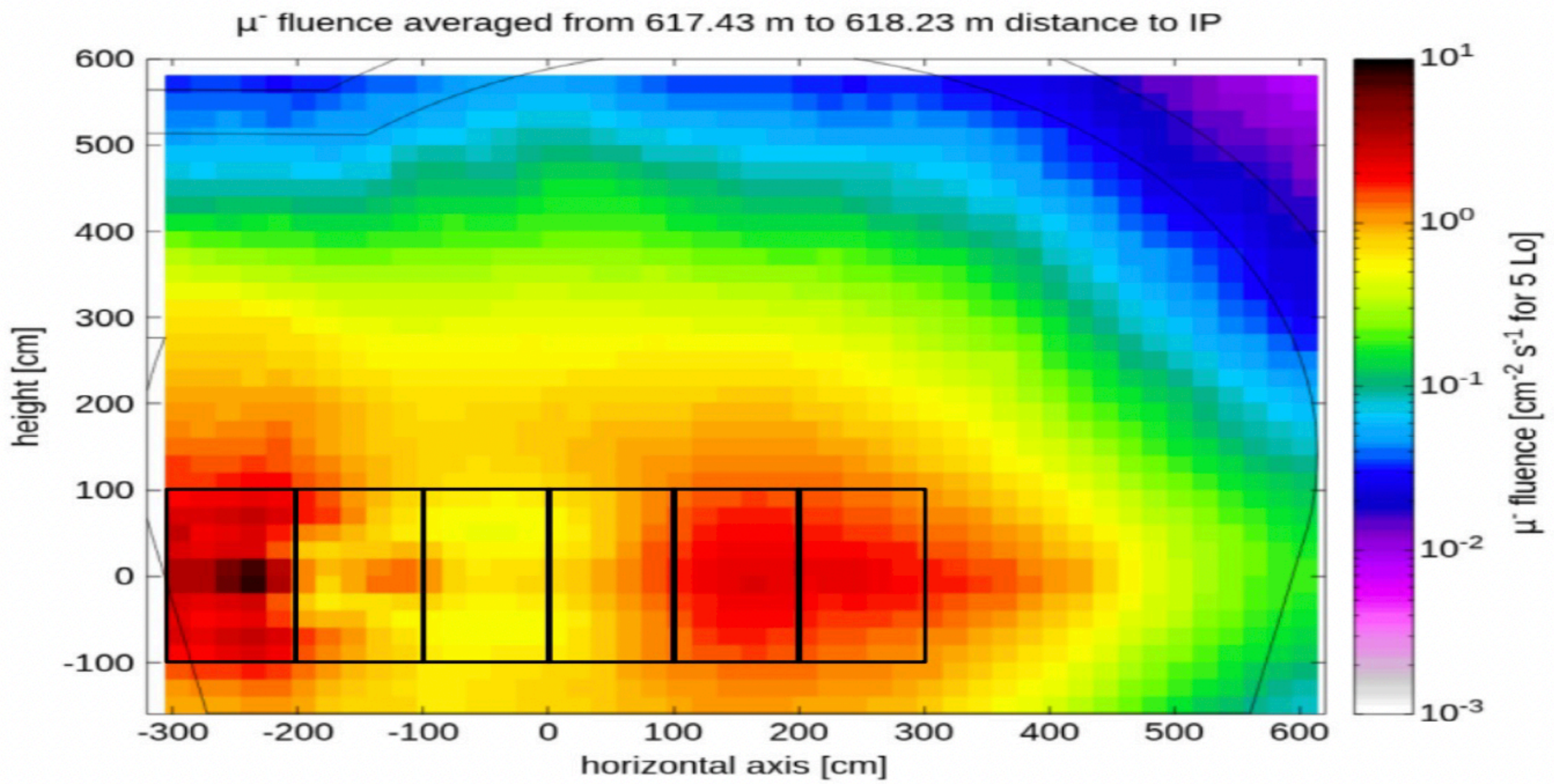


L. Dougherty, J.P Corso (EN-ACE)

Muon fluence estimates

Jamie Boyd June 27, 2022





First FLUKA results shown at last meeting. Flux in ~1m from LOS <1.5Hz/cm^2.

Ongoing FLUKA studies:

- Using the full magnetic field maps of Q4 and D2 had some impact on the results, so the full magnetic field maps of Q5/6/7 will be considered in further simulations as soon as they are available from the magnet group
    - Likely to slightly reduce flux

- The sweeping magnet is now implemented in the simulations, placed on the line of sight. Preliminary calculations show a

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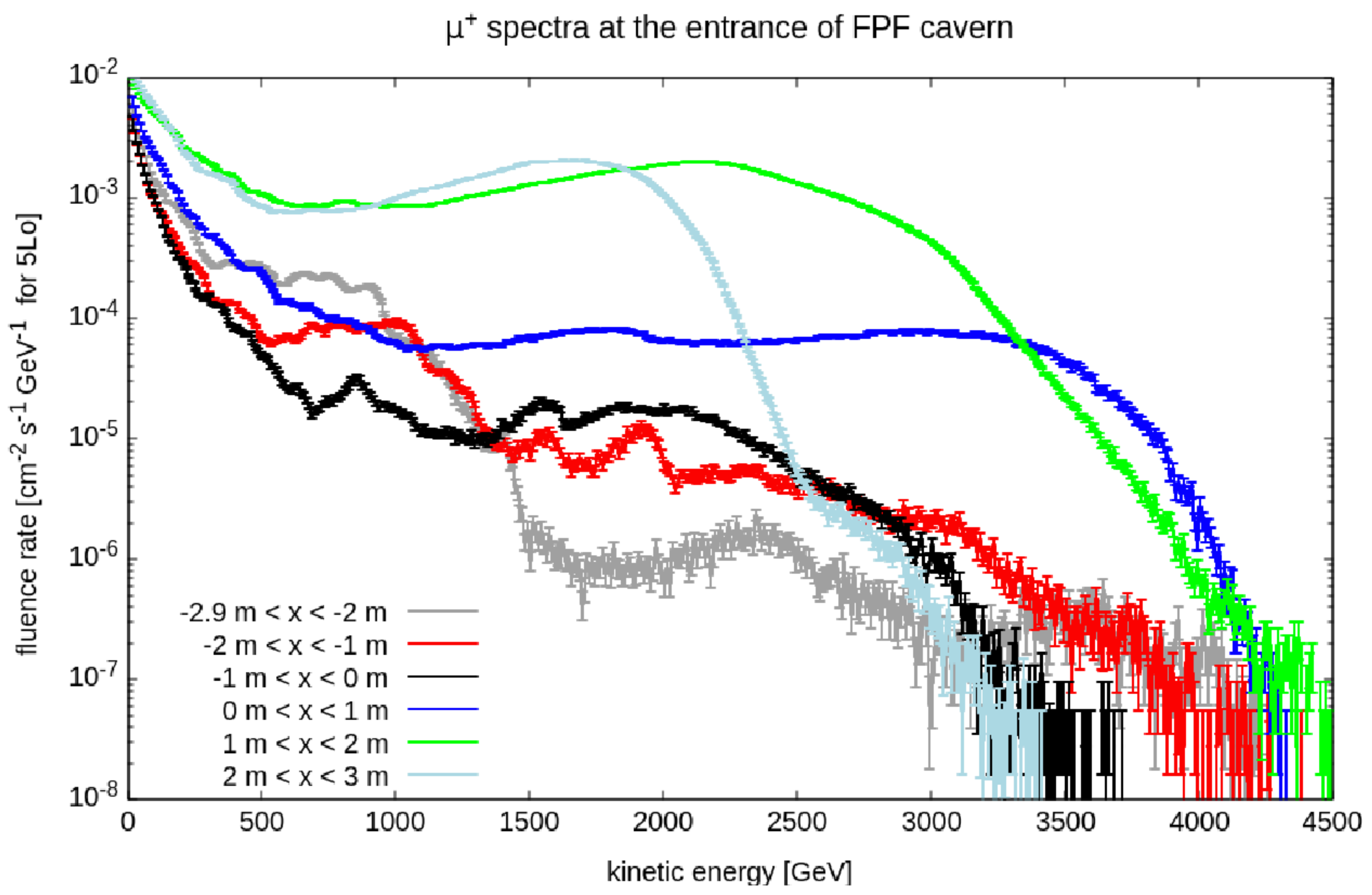
Conclusion from RP study: Given that the study was at 7.5e34 luminosity and assumed HL-LHC operations for 100% time in year, it should be possible to access the cavern during operations. Especially in first year(s) of Run 3 (for finishing CE works, installation of services and experiments) when luminosity will be lower. Some specific local areas of the cavern (corresponding to the muon hot spots) could be inaccessible during HL-LHC operations.

Experimental conditions (without sweeping magnet)

Approximate fluxes, rates of backgrounds



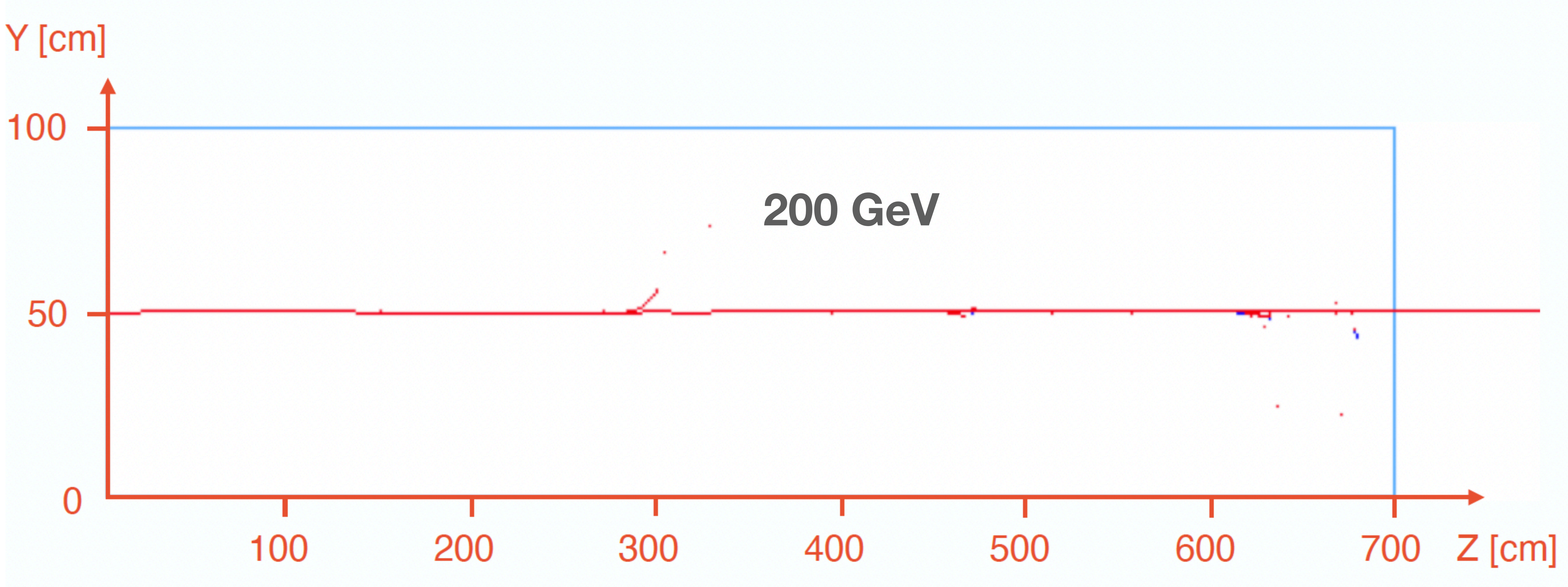
Sabate-Gilarte, Cerutti

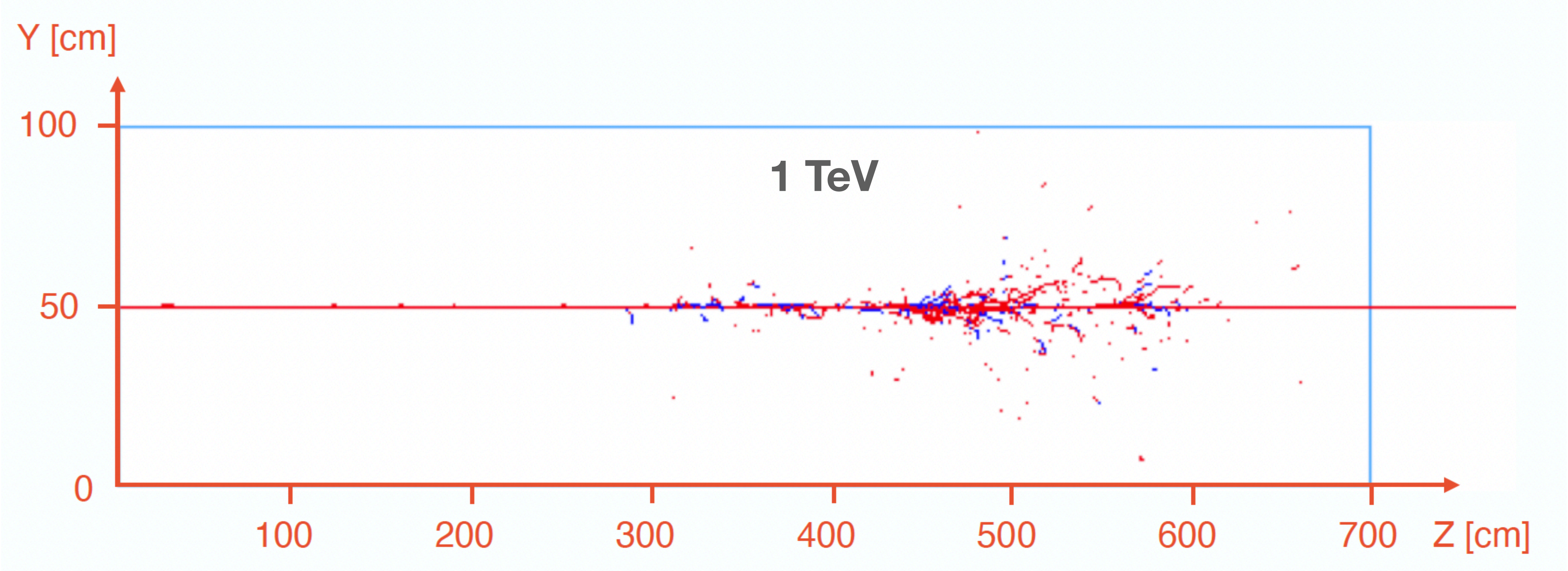
- **Muon flux at FPF is calculated to be 1.5/cm2/sec at HL-LHC**
- **Mean muon energy ~300 GeV**
- **Both charged and neutral hadron interactions present significant background.**
- **Total neutrino interaction rate normalized to per ton per fb^{-1}**
- **Observed nu rate from pilot run: ~45/ton/fb^{-1} at 480 m**

Minimum distance	612 m
LHC collision energy	14 TeV
LHC bunch crossing	25 ns (40 MHz)
LHC crossing angle	280 micro-rad (TBD for HL-LHC)
Total Lumi/max lumi	3000/fb ; 5x10^{34} /cm2/sec
Lumi per day	~1 /fb assuming 10 year running
pseudorapidity coverage	>6.4, (~5.4-6.0 for off-axis)
track density (from pilot data)	1.7x 10^{4}/cm^{2}/fb^{-1}
max track density per sec (per crossing)	~1.5/cm^{2}/sec (3.75x10^{-8}/cm2/ crossing)
Tracks in detector/1 ms	~15/m^2/1msec
Neutral hadron flux > 10 GeV (10^{-4} of muons)	~few /cm^{2}/fb^{-1}
Total neutrino rate (all flavors)	~25-50/ton/fb^{-1}

updated with new information on HL-LHC configuration 2105.06197

Muon simulation in liquid argon.





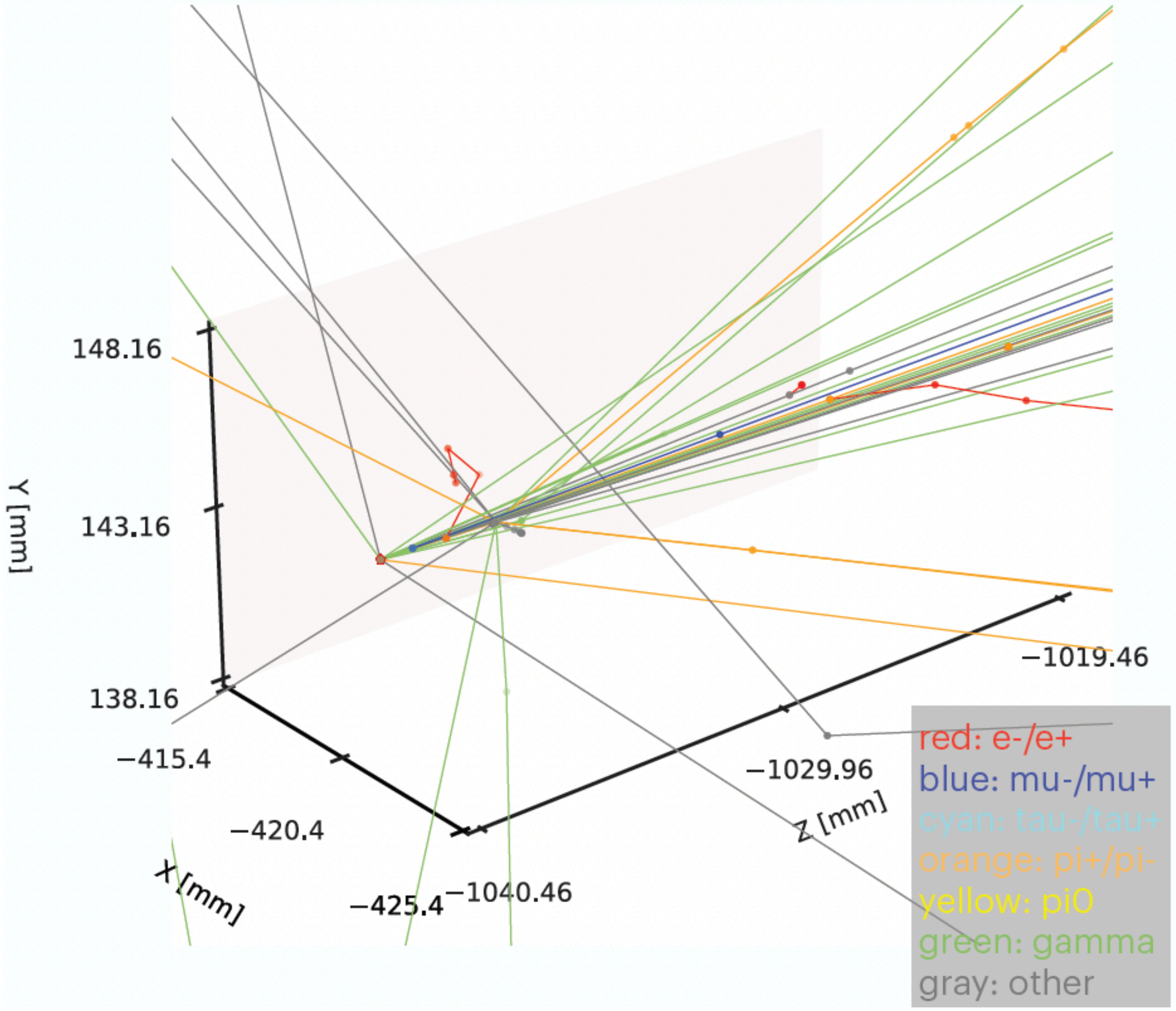
- *Muon flux above 1 Hz/cm2 presents a difficult problem for all detectors.*
- *For Liquid argon TPC, the flux also presents a space charge problem for large gaps.*
- *Showering muons will also present a trigger problem since if the incoming muon is missed the event will look like a neutrino.*

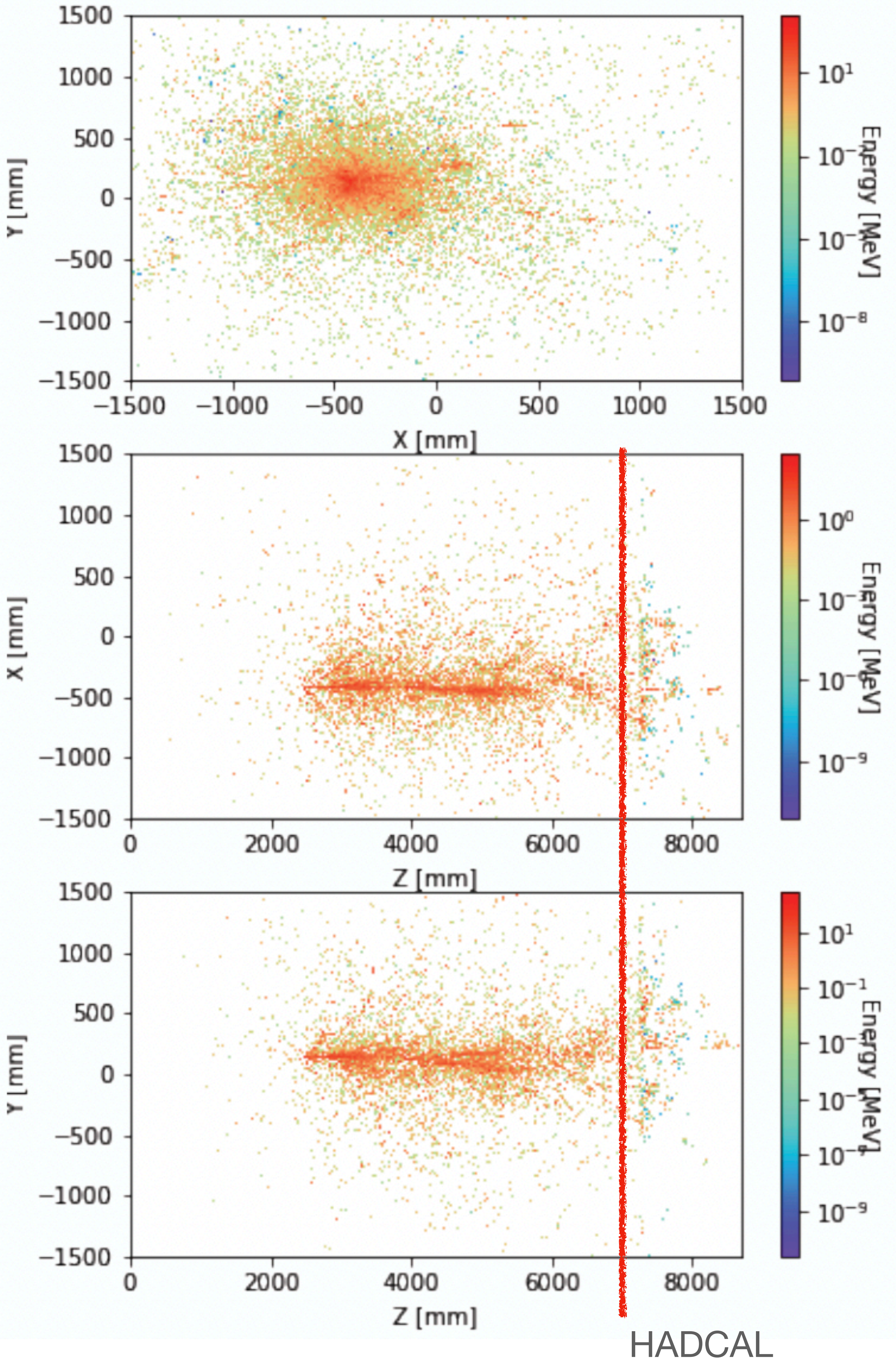
Wenjie Wu (UCI)

Tau Neutrino event simulation in a LAR TPC. Kinematic separation combined with high vertex resolution seems to be very promising. But a lot of work is needed.

ν_τ CC (E_ν = 230.7 GeV)

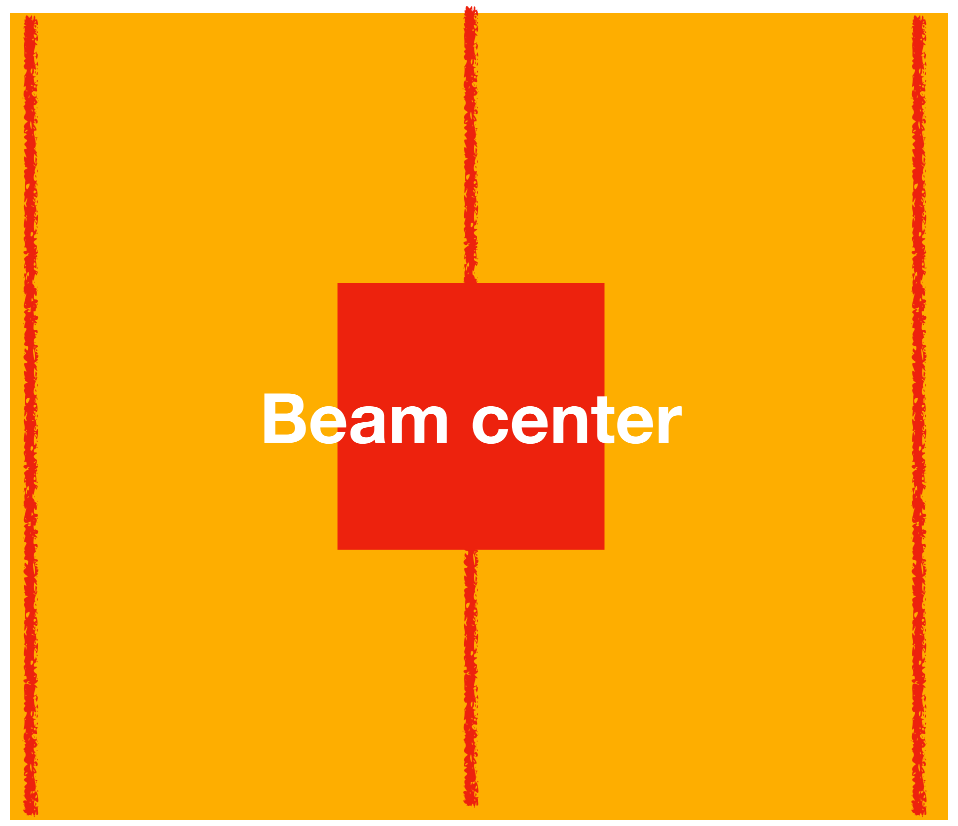
$$\tau^-(102.9\ \mathrm{GeV}) \rightarrow \nu_\tau + \bar{\nu}_\mu + \mu^-(74.7\ \mathrm{GeV})$$





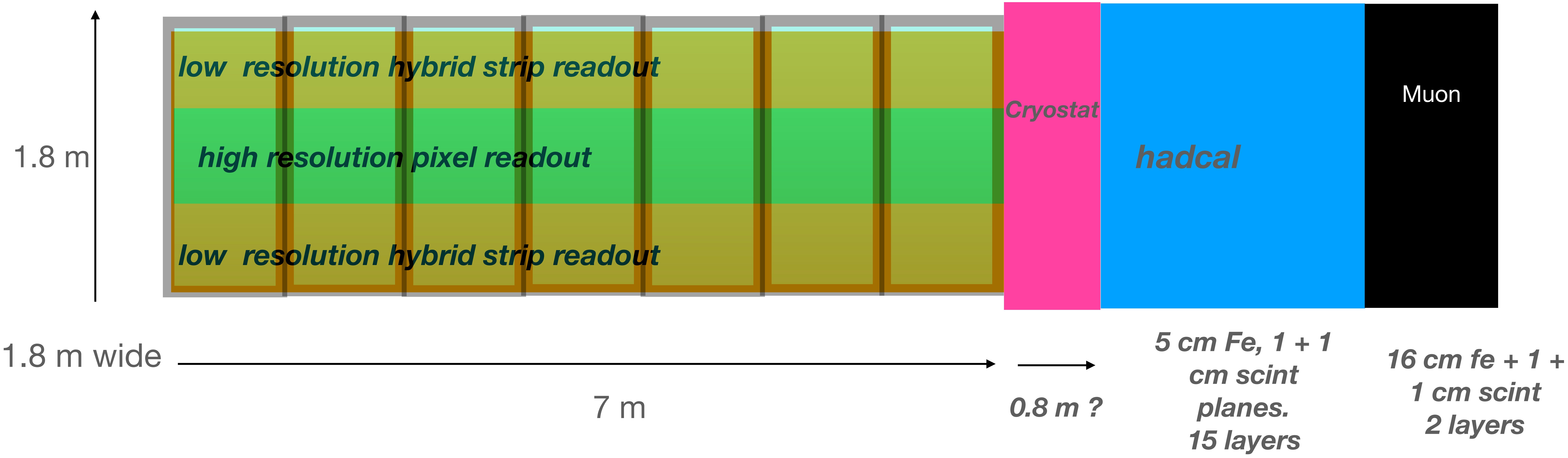
1. 1.8 X 1.8 to contain transverse events in fiducial of 1m x 1m x 7m.
2. Hadronic calorimeter to contain showers that start downstream.
3. Even a modest energy resolution is sufficient.
4. Excellent muon identification results in quick selection of nutau events.
5. We will combine spatial resolution in drift dimension with kinematics to get good S/N.

Wenjie Wu/ Jianming Bian UCI



Simulations have confirmed that these dimensions allow reasonable containment of neutrino events in LAr and total energy measurement.

They also fit within the cryostat allowed transverse space.



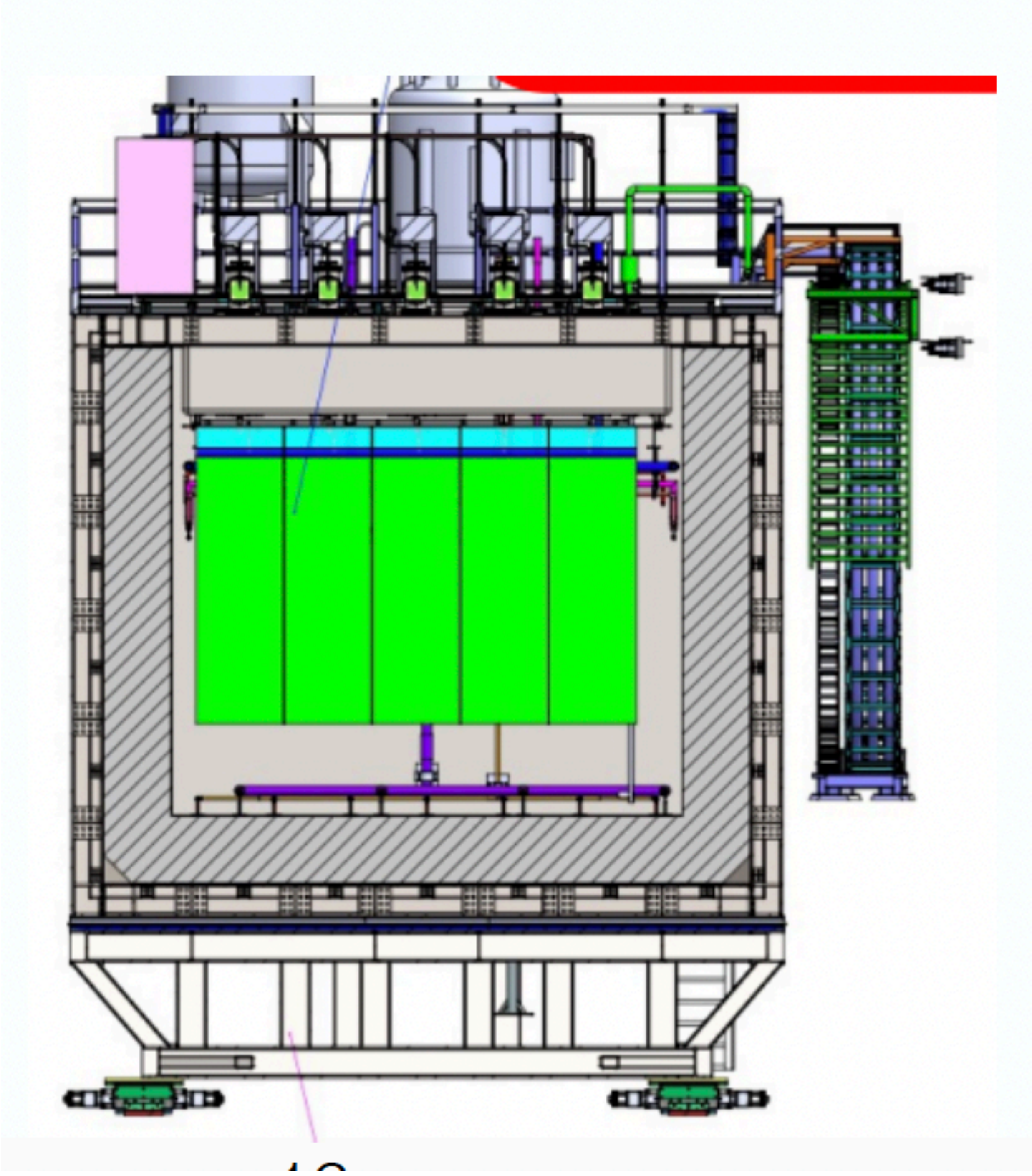
Carry two options into Conceptual Design

either 2 X 7 vertical modules with 0.45 m gap
or 3 x 7 vertical modules or with 0.3 m gap

None of this is optimized

Cryostat options

Very important for space considerations.

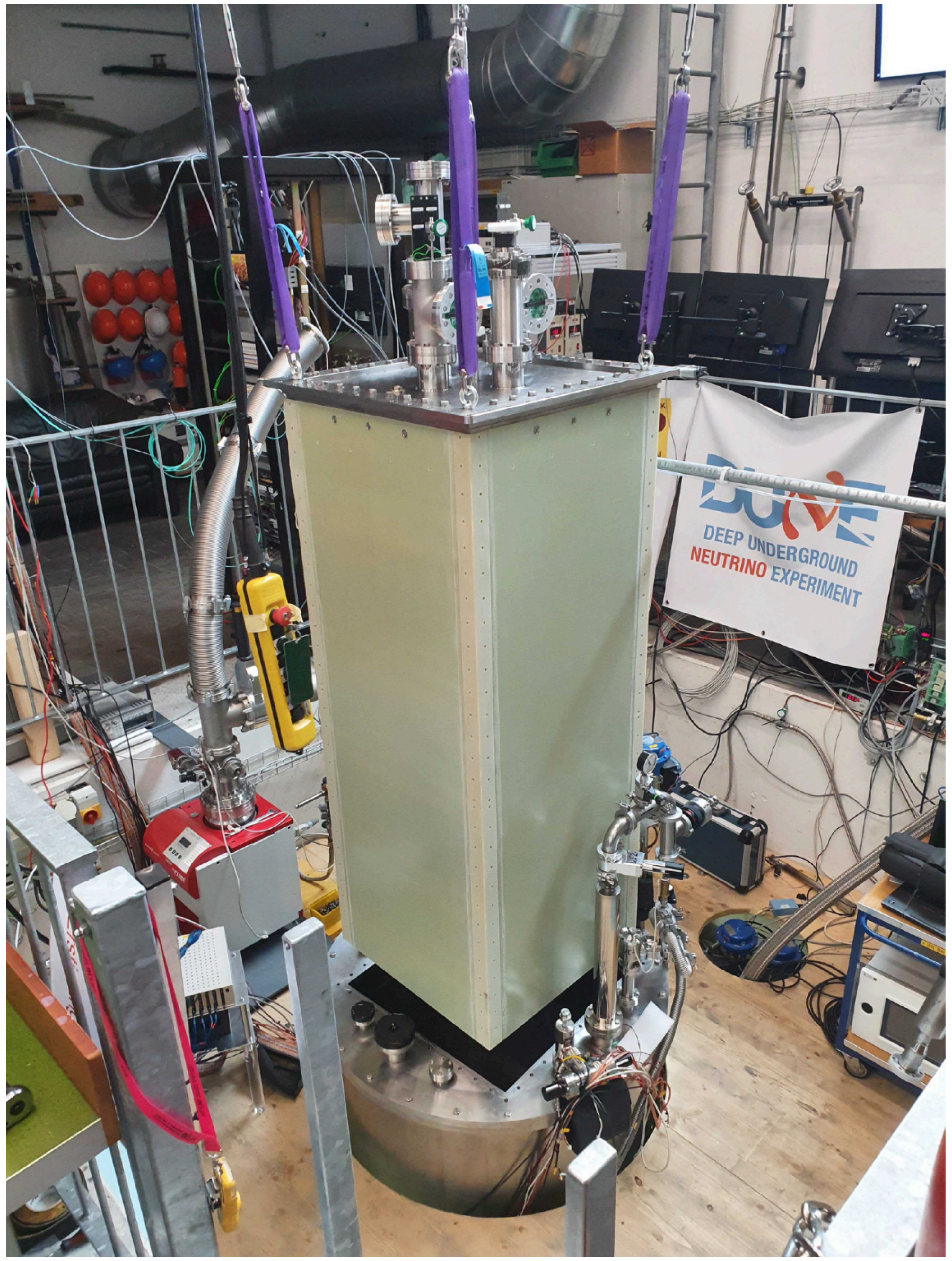


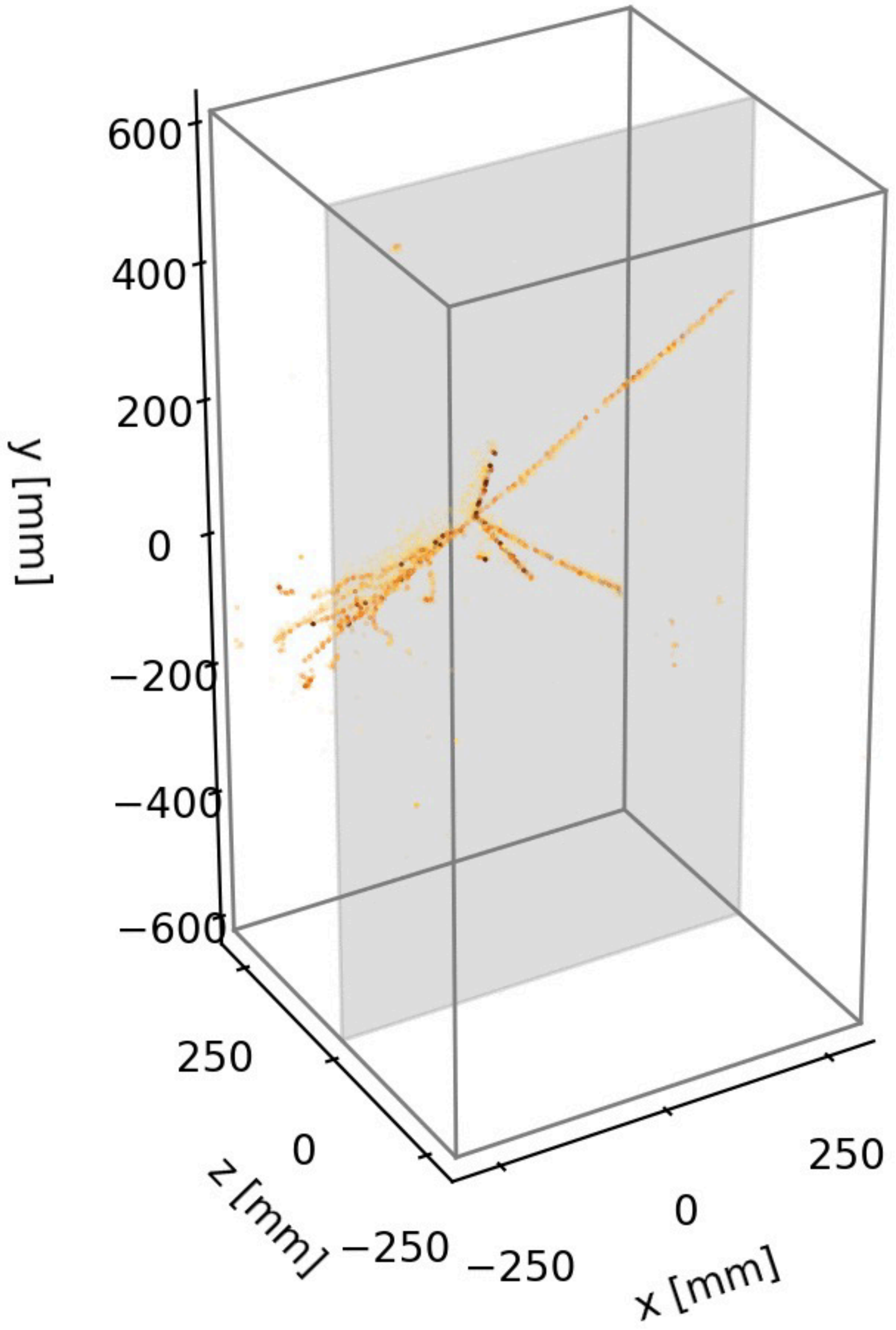
	Cryostat Inner Dimensions	Insulation Type	Insulation Thickness	Insulation density	Heat leak	Cold shield
MicroBooNE	3.8m dia x 12 m	Polyurethane Foam	**400mm**	32 kg/m³	**~13 W/m²**	No
ICARUS-GS	3.9m x 3.6m x 19.6m	Nomex honeycomb+perforated Al	**665 mm+ (combined)**	25-35 kg/m³	**7-22 W/m²**	Yes
ICARUS-SBN	3.9m x 3.6m x 19.6m	Al extrusion+GTT foam	**665 mm+ (combined)**	25-35 kg/m³	**10-15 W/m²**	Yes
ProtoDUNE	7.9m x 8.55m x 8.55 m	GTT membranc	**800mm**	90 kg/m³	**~8 W/m²**	No
ND-LAr	3m x 5m x7m	GTT membrance	800mm	90 kg/m³	**~8 W/m²**	No
FLArE	~(1m x 1m x 7m)					No?

Yichen Li

- *Space in FPF hall currently is limited to 3.5 m X 3.5 m X 9.6 m for FLARE.*
- *80 cm GTT membrane occupies 1.6 m out of 3.5 m. More space might be needed for corrugations.*
- *But despite the installation for th GTT membrane would be much easier.*
- *The DUNE ND-LAR design has installation from top. This would also simplify things.*
- *Further engineering might be needed, but we can settle on this option for now.*

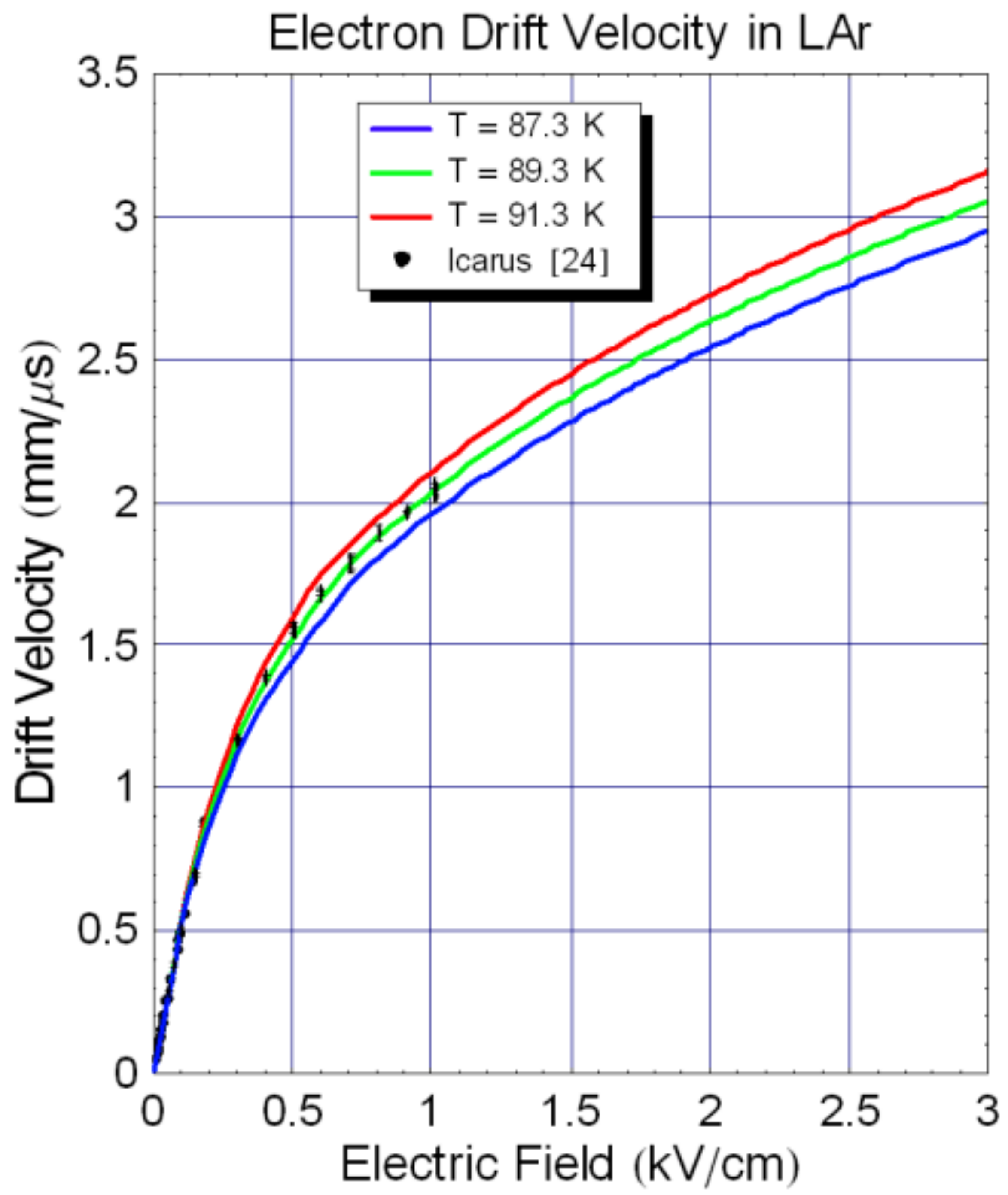
FLARE will Benefit from the DUNE near detector concepts.





Drift velocity and diffusion

Electron drift velocity [22, 23, 24, 25]



Electron transverse diffusion coefficient: . D_t = 13 cm² /s

Electron longitude diffusion coefficient: D_l = 5 cm² /s

t = 500 [mm] / 2.0 [mm/us] = 250 us

T = 250 [mm] / 2.5 [mm/us] = 100 us

1D case $\sigma_l = \sqrt{2D_l t}$ = 0.5 [mm]

2D case $\sigma_t = \sqrt{4D_t t}$ = 1.1 [mm]

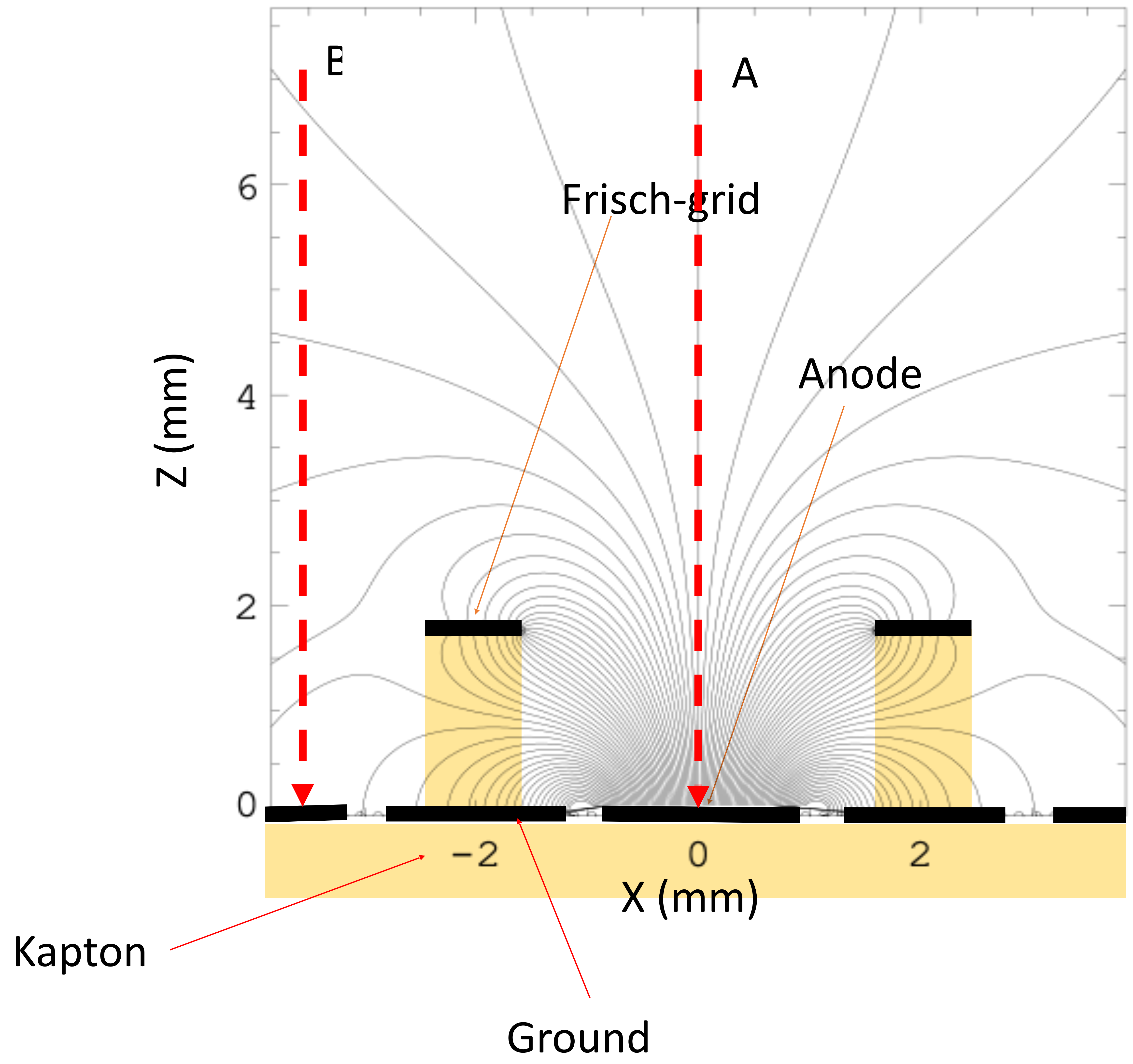
	500 mm at 1 KV/cm, 250 us	250 mm at 2 KV/cm, 100 us
Long. (FWHM)	0.5 (1.2) mm	0.3 (0.7) mm
Transverse (FFHM)	1.1 (2.6) mm	0.7 (1.7) mm

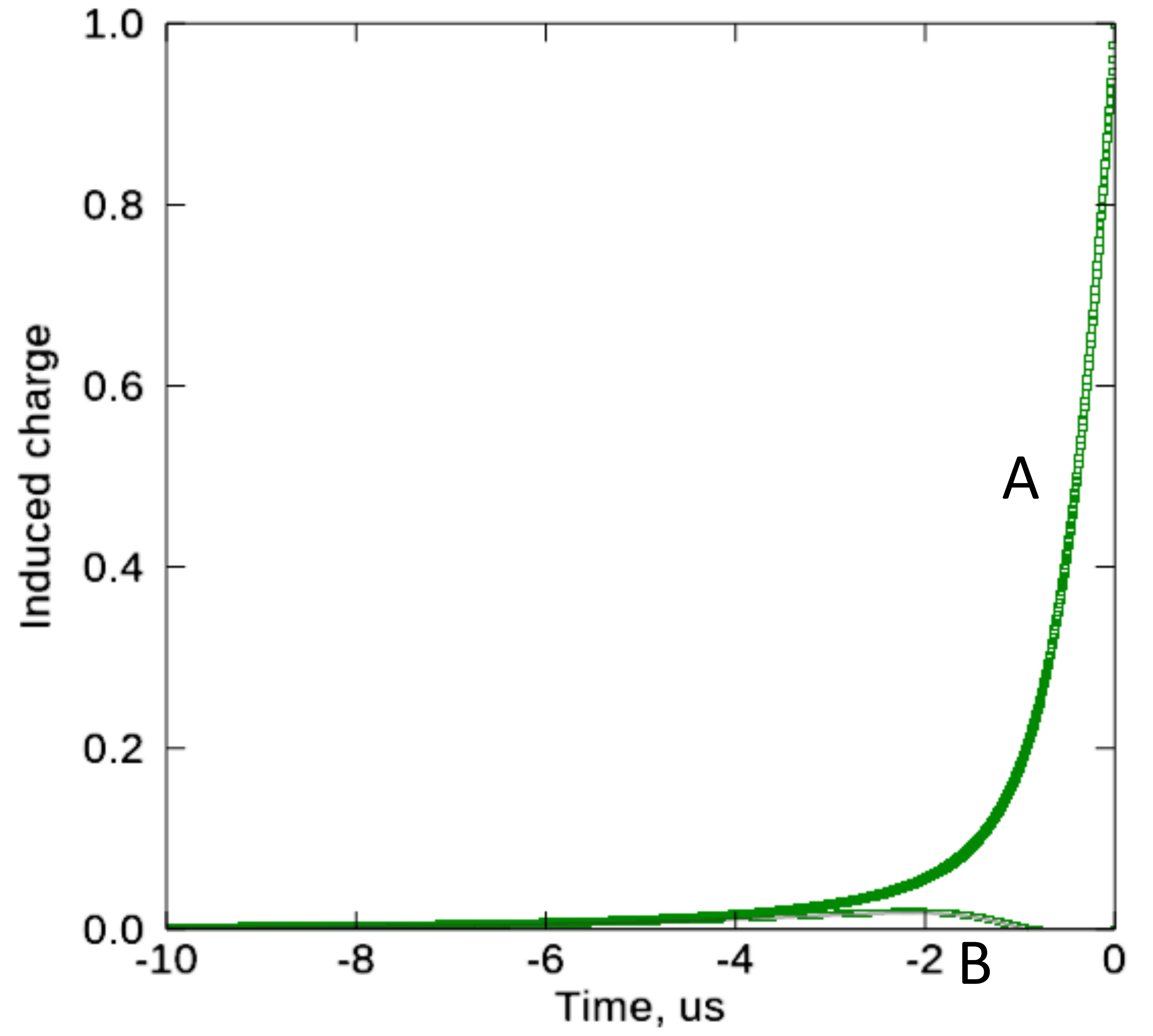
There should be no fundamental limit to getting < 1 mm resolution

Bolotnikov

Use Frisch-grid

Weighting field for GEM-like structure with pixel anode, 4 mm pitch



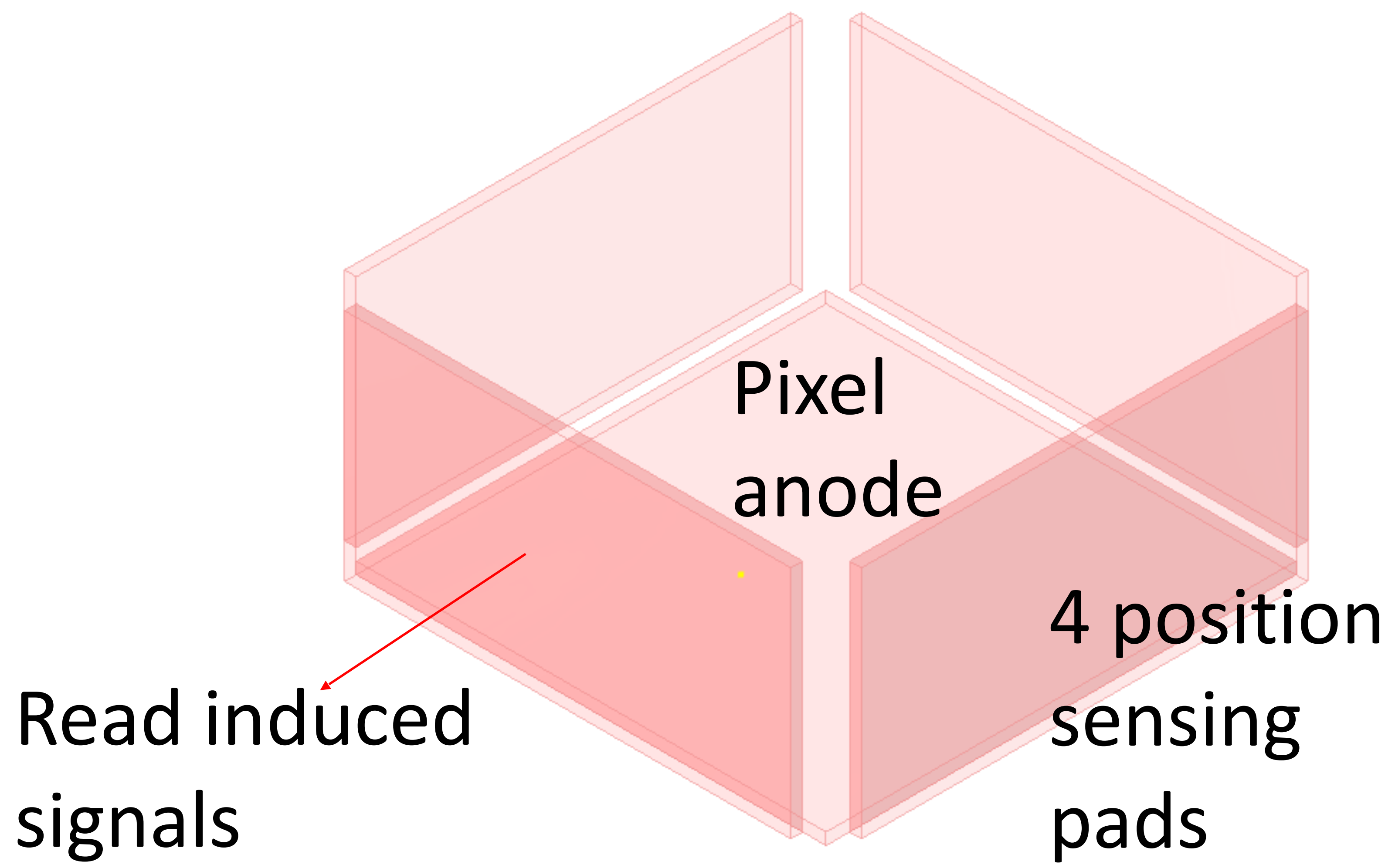


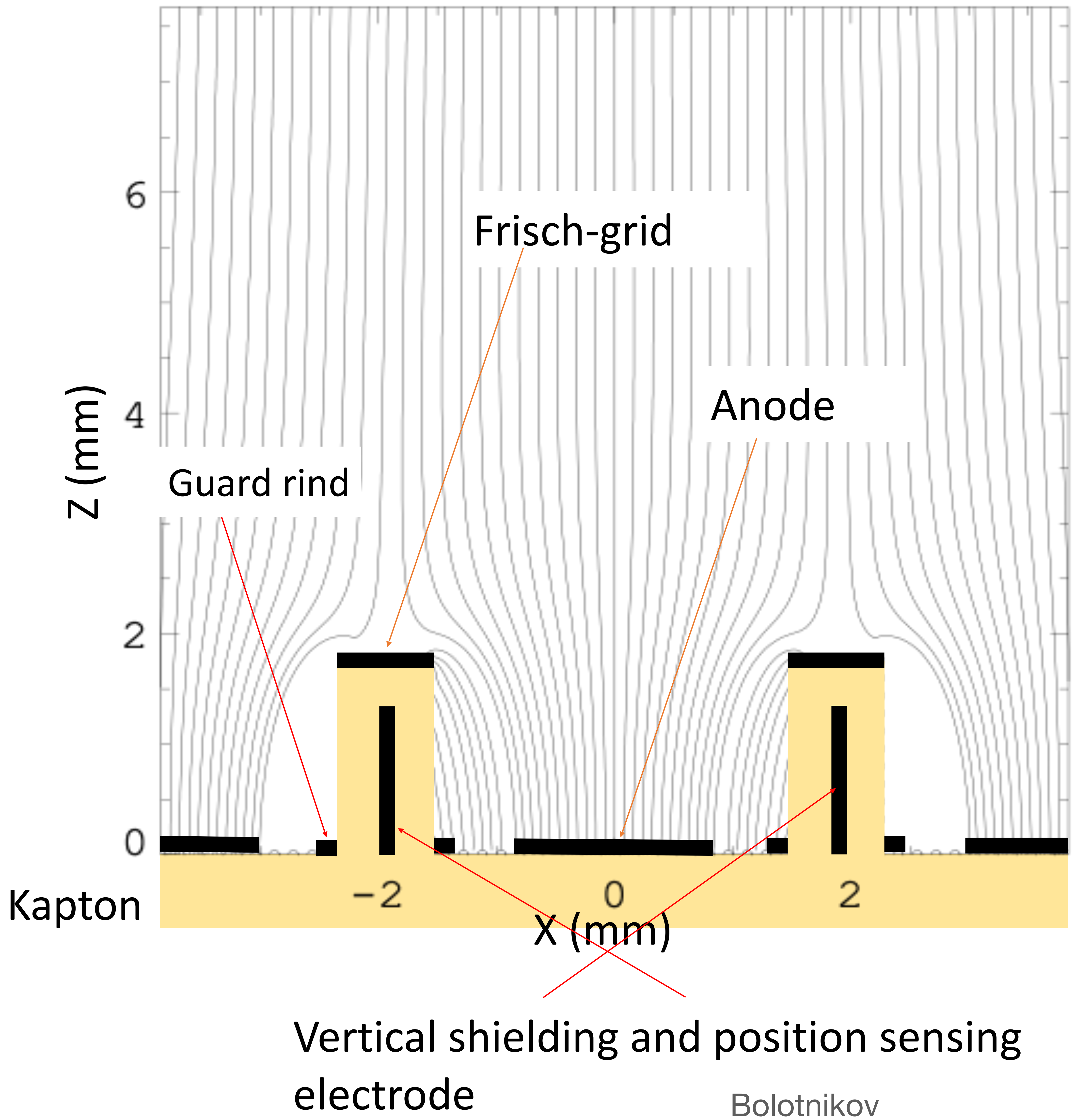
Most of the field lines terminate on the grounding electrodes

Bolotnikov

Using the Frisch-grid or GEM-like structure with pixelated anode (cont.)

- Vertical shielding electrodes
- They can also be used as position sensitive electrodes to refine position withing a pixel -- position resolution of < 100 um was demonstrated in the case of 8-mm pitch for a point-like charge





Bolotnikov

Basic detector requirements for FLARE from studies

Item	Choice	Comments
Liquid fill	LAr or LKr or LAr/LXe mix	LKr allows compact events and EM showers, but radioactivity may limit utility.
Cryostat and TPC dimensions	Keep the total to active volume ratio small. Need to fit into FPF space.	Cryostat, field cage, HV design must be integrated.
Cathode/anode and gap size	Central cathode with two anode planes. (makes two drift volumes). Gap < 0.5 m	more channels, better for HV safety and space charge. cathode must be transparent to light
Photon readout	SiPM's. Cannot use PMTs to keep the unused volume small.	Will need large number of channels.
Wavelength shifter for scintillation light	LAr: 128 nm, LKr: 150 nm, LXe: 170nm	DUNE development of ARAPUCA.
SiPM density, timing resolution and trigger	This requires detailed simulations and R&D. **A minimum density is needed for recognizing contained events versus muons for trigger.** Timing resolution is needed to associate with LHC bunch.	
Anode electrode design	Pixels versus wires	Simple wire geometry may not be possible because of straight thru muons. Need Simulation input.
Anode readout pitch	1-2 mm	Depends on kinematic resolution needed and also signal to noise.
Electronics	Cold electronics for low noise; how do we optimize for best drift resolution	Need < 1 mm resolution in drift dimension

Conclusion

- A forward physics facility(FPF) is being considered at CERN for neutrino and dark matter physics. It will unlock a new source of neutrinos => the LHC.
- HL-LHC will start running in 2029-2030. The FPF is decoupled from the LHC sufficiently that its schedule could be independent of the HL-LHC upgrades.
    - The headline physics interest is
        - Neutrinos in the 1 TeV range: ~20-50 events/ton/day
        - Tau neutrino flux and associated heavy flavor physics: ~0.1-0.2 events/ton/day
        - Light dark matter search with decays and interactions.
- Noble liquid detector for FPF is being considered along with other technologies.
- Preliminary examination of event rates and backgrounds suggests that a LAr detector is feasible and ground-breaking.
- Muon backgrounds, and engineering considerations necessitates a modular TPC detector.
- A LAr TPC requires much more advanced readout for ultimate spatial resolution, and a trigger system that can find contained events in the presence of muons. Timing could associate events with the ATLAS bunch crossing (studies are needed).
- Cost ? We now have a very modest funding to produce a conceptual design by mid-2023. DUNE R&D investment has made this much easier.

Backups

Nominal configuration

To be detailed in a spread sheet and developed into a detail for a conceptual design parameters.

Cryostat outer	**3.5 m X 3.5 m X 9.6 m**	**Membrane**
Insulation thickness	0.8 m	including corrugations
Detector dimension	1.8 m X 1.8m x 7 m	good for >90 % containment
Fiducial volume	1 m x 1m x 7 m (10 tons)	Length may be adjusted later
TPC Modules	2 X 7 or 3 X 7	Keep two options
Module opt1 dimensions	0.9 m (W) X 1.8 m (H) X 1 m (L)	Central cathode: gap: 0.45 m
Module opt2 dimensions	0.6 m (W) X 1.8 m (H) X 1 m (L)	gap: 0.3 m
Anode design fiducial region	5 mm x 5 mm for 1 m x 1 m	80000 chan/mod
Anode design containment region	10 mm x 10 mm for 0.8 m x 1 m	16000 chan/mod
photon sensor	Bare SiPM or X-ARAPUCA	~50 chan/mod
Downstream cryo wall	80 cm	Can it be thinned down
HADCAL	2 m x 2 m x (5 cm Fe + 1+1 cm scint, 15 layers) x (1.05 m)	Optimize for resolution
Murange	•2 m x 2 m x (16 cm Fe + 1 + 1 cm scint, 2 layers) x (0.36 m)	Increase to 1 m to get clean muID