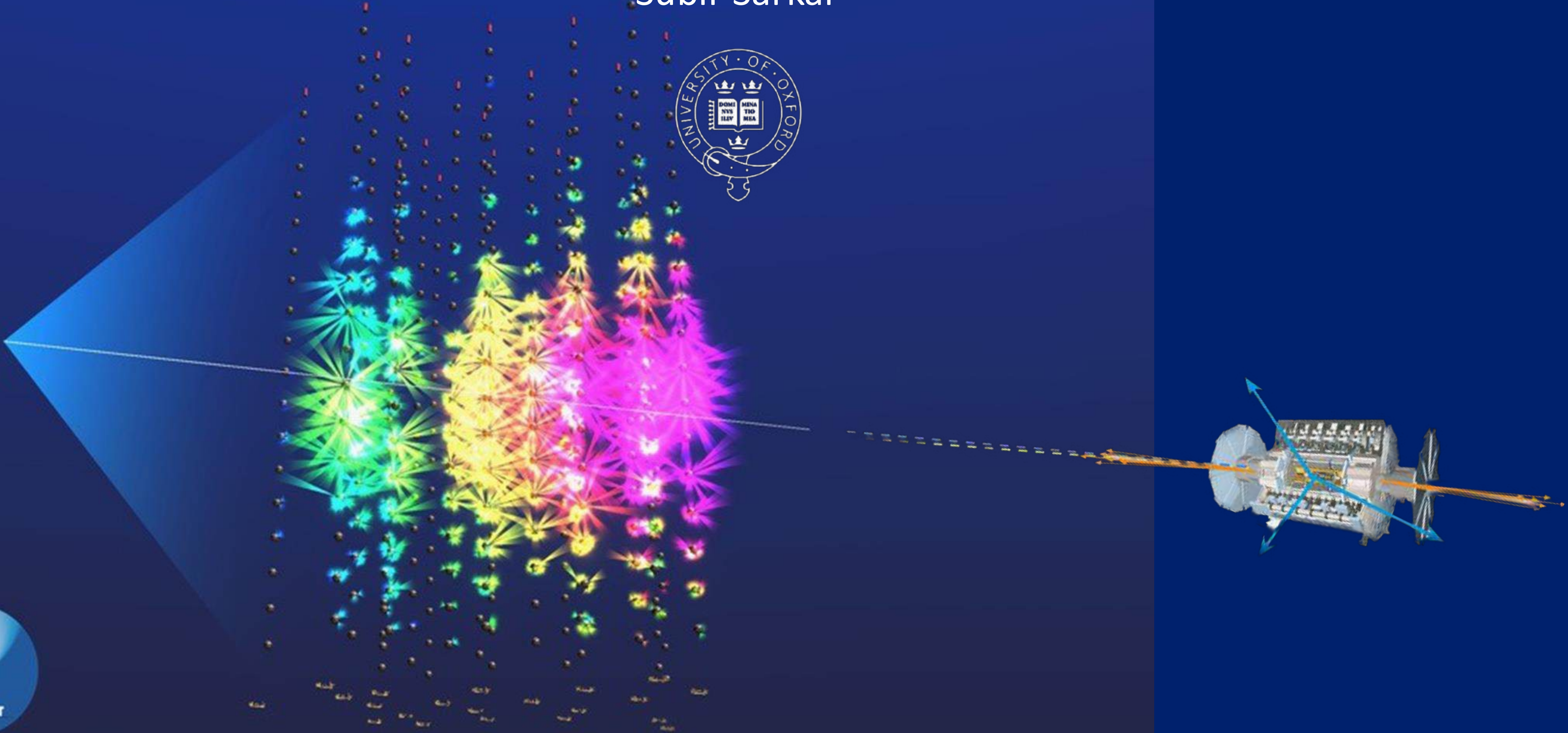
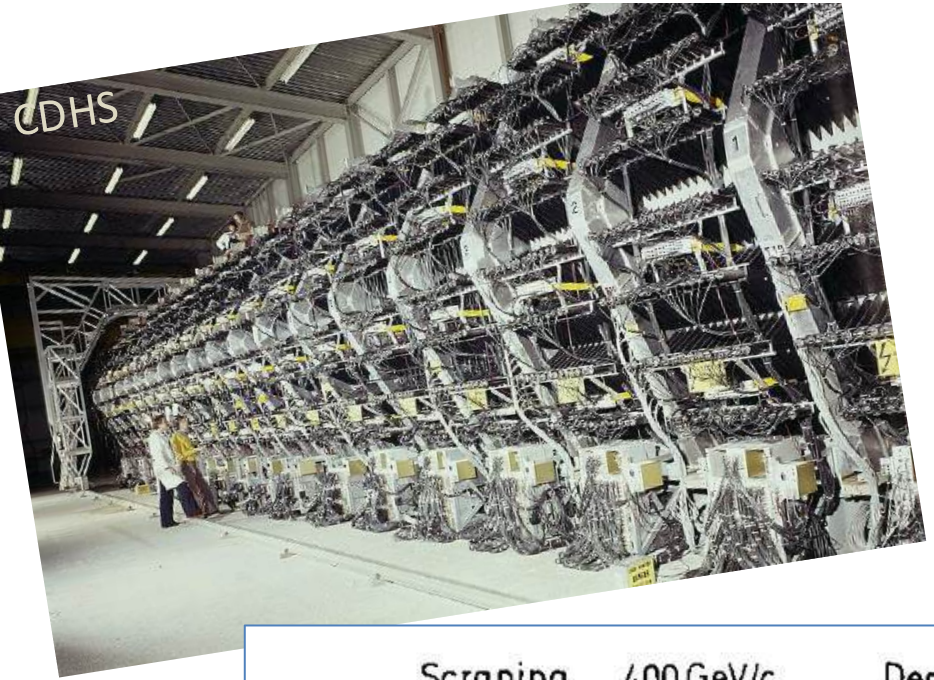
Forward Physics Facility @ CERN: The astroparticle connection

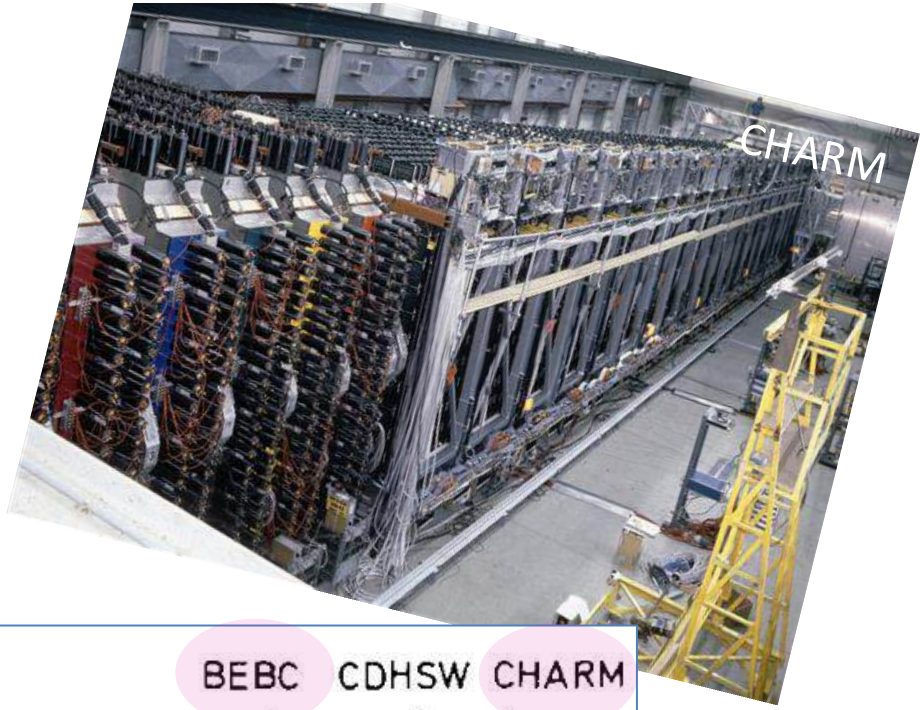
Subir Sarkar



International Workshop on New Opportunities for Particle Physics, IHEP Beijing, 14-16 August 2026

The 1970's-80's were a glorious era of pioneering neutrino experiments @ CERN





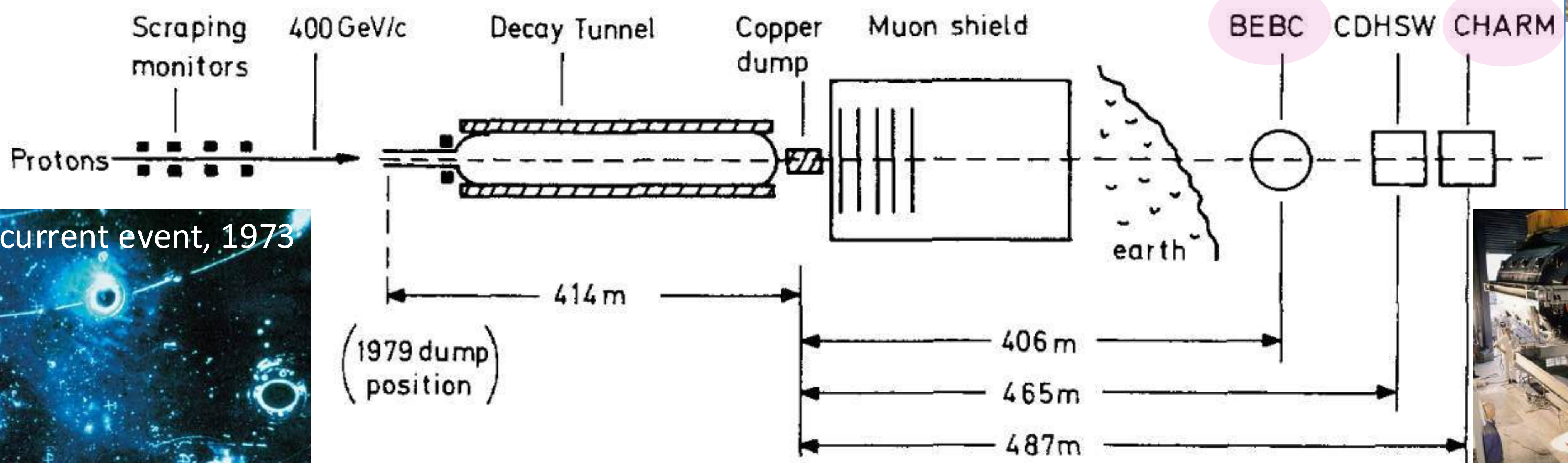
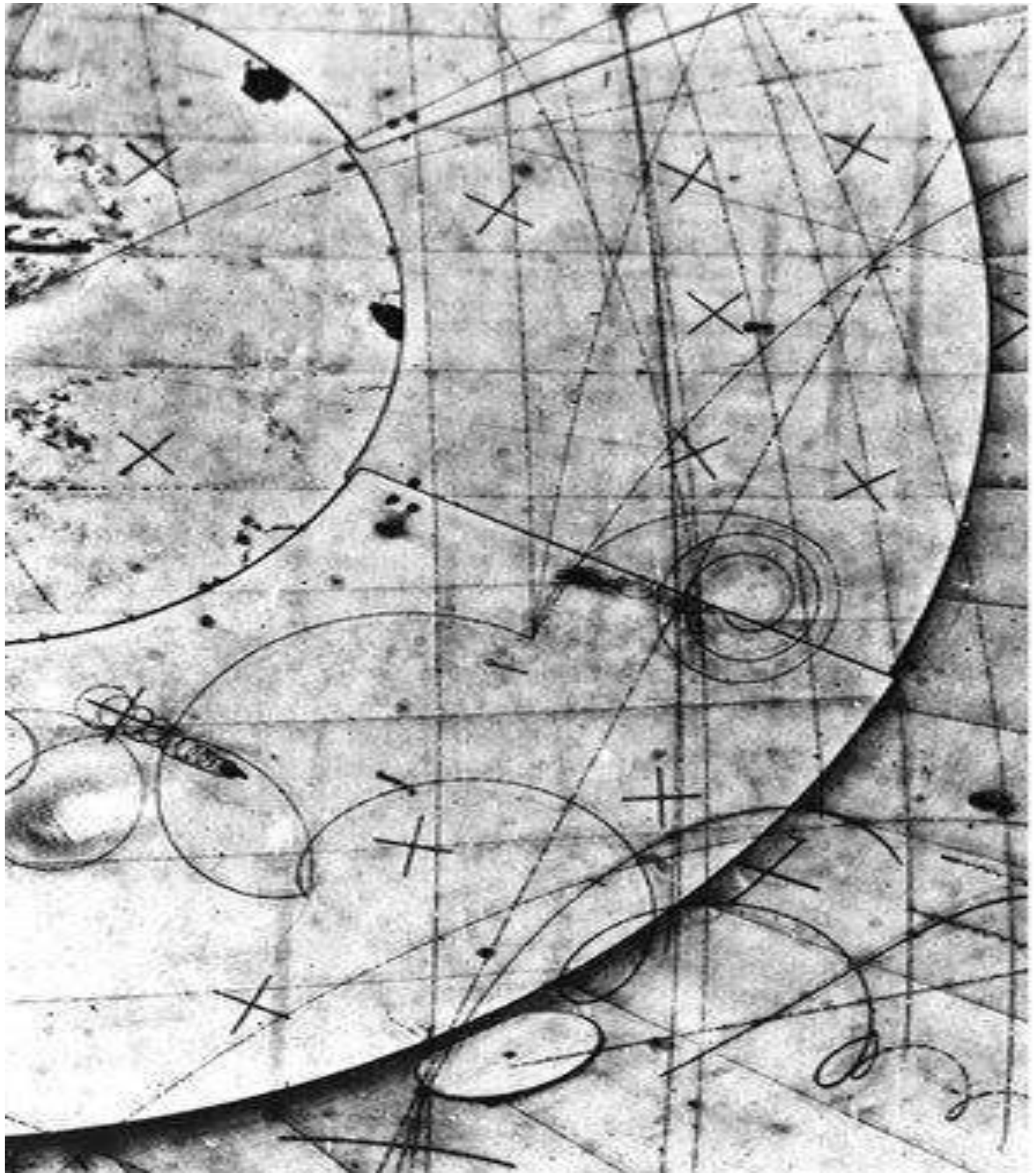
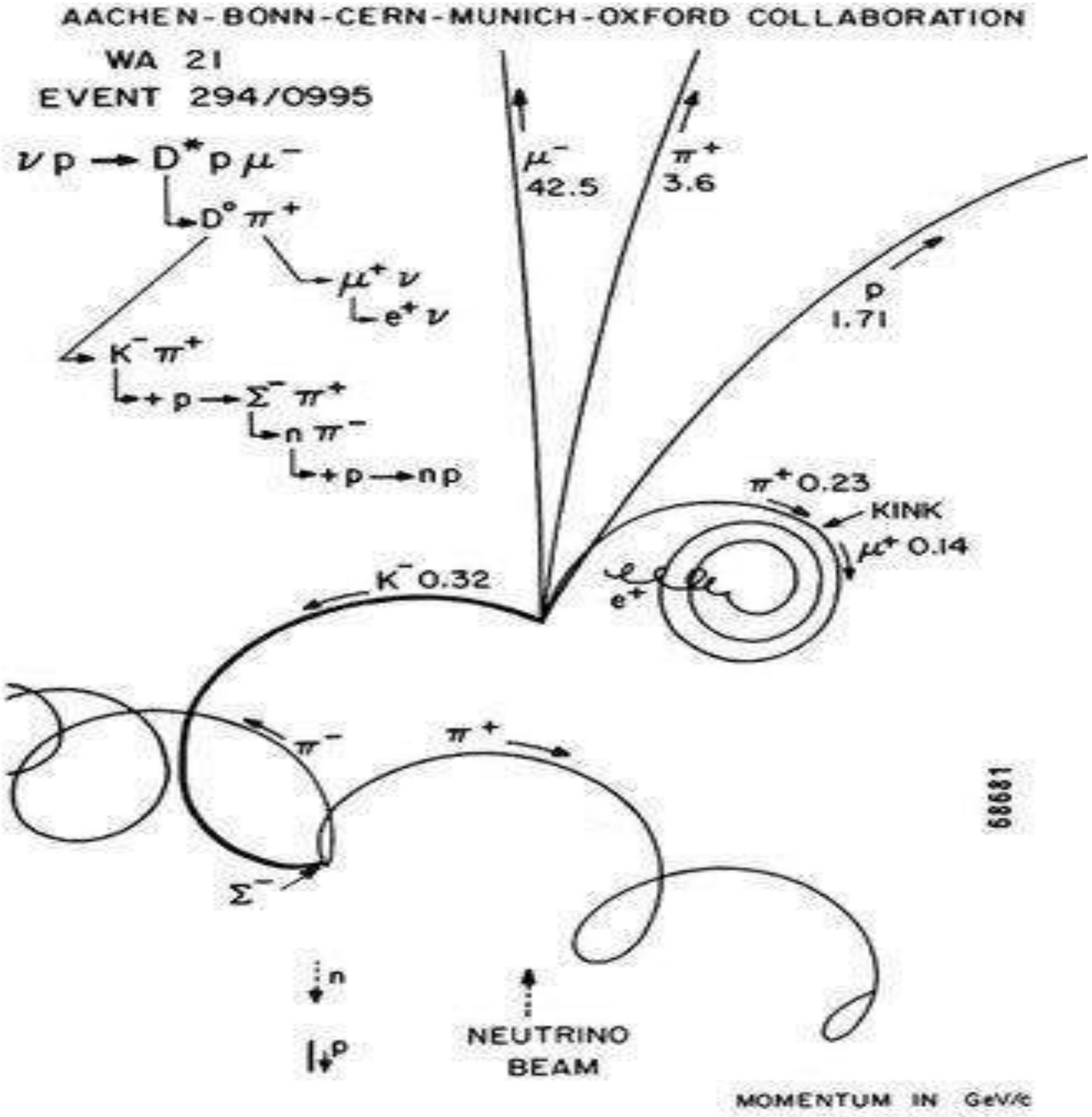


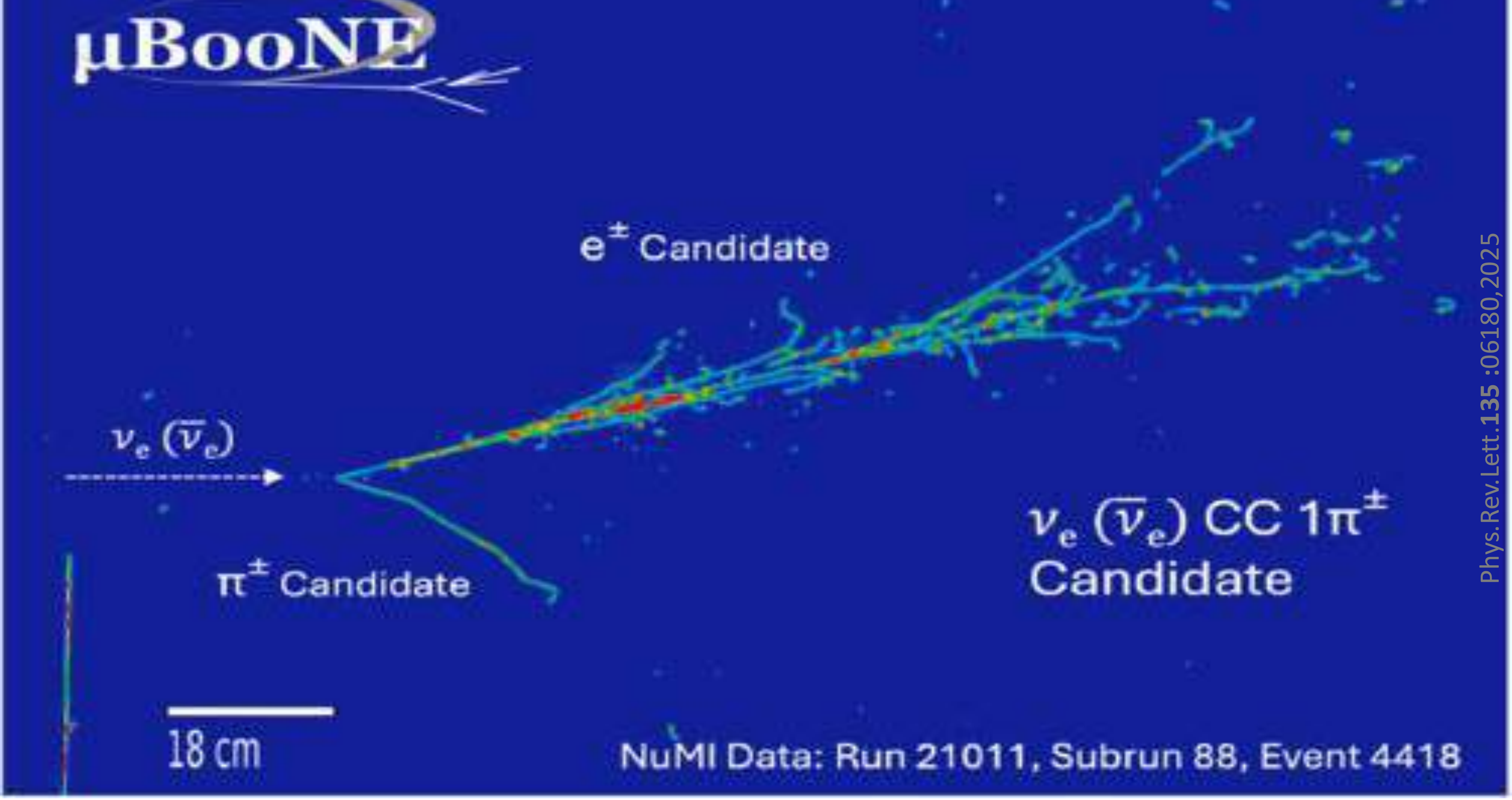
Fig. 1. Layout of the 1982 beam-dump area at the SPS, CERN.

Fully reconstructed neutrino interaction event in BEBC



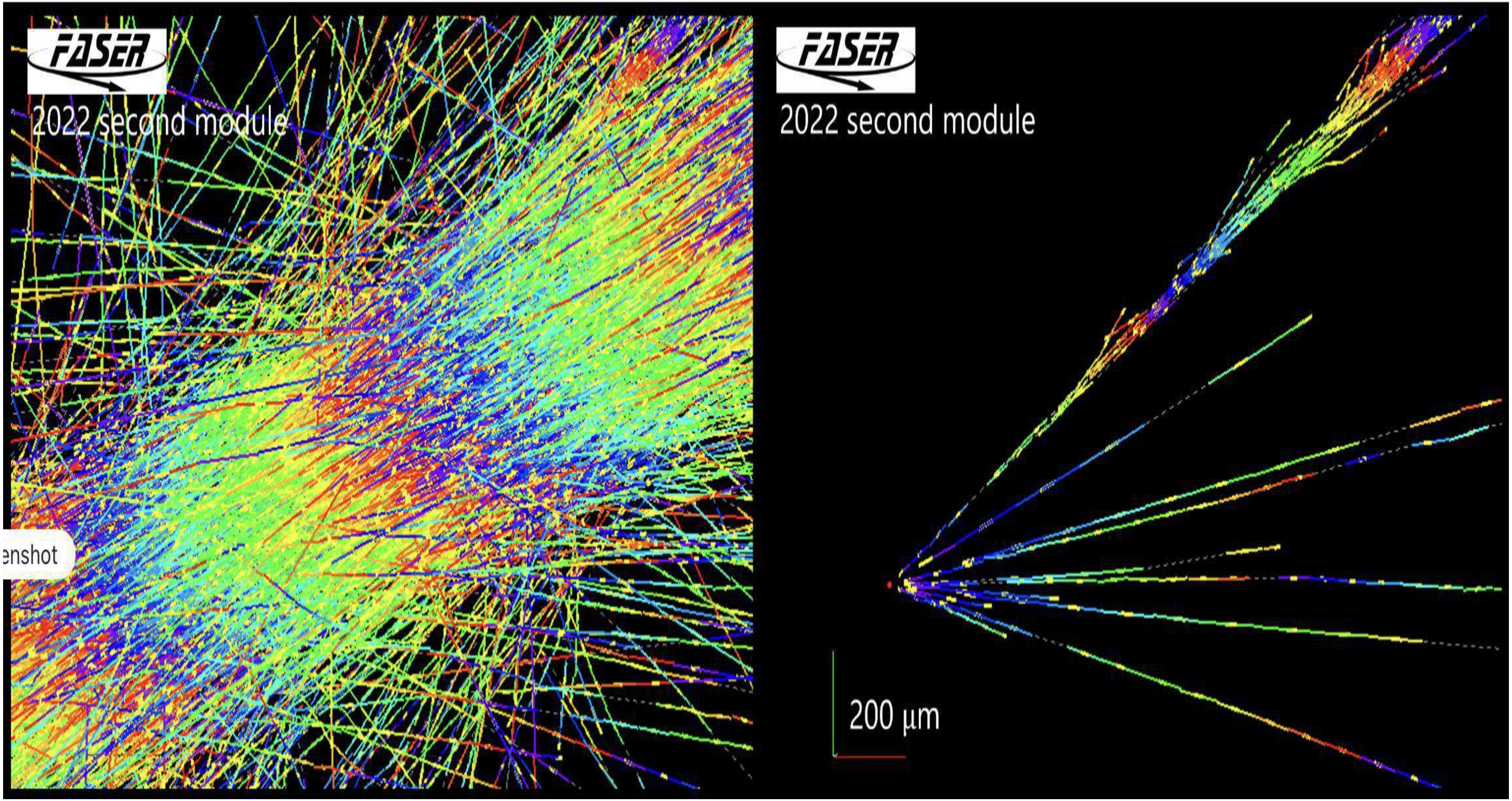


Resolution now matched by Liquid argon Time Projection Chambers



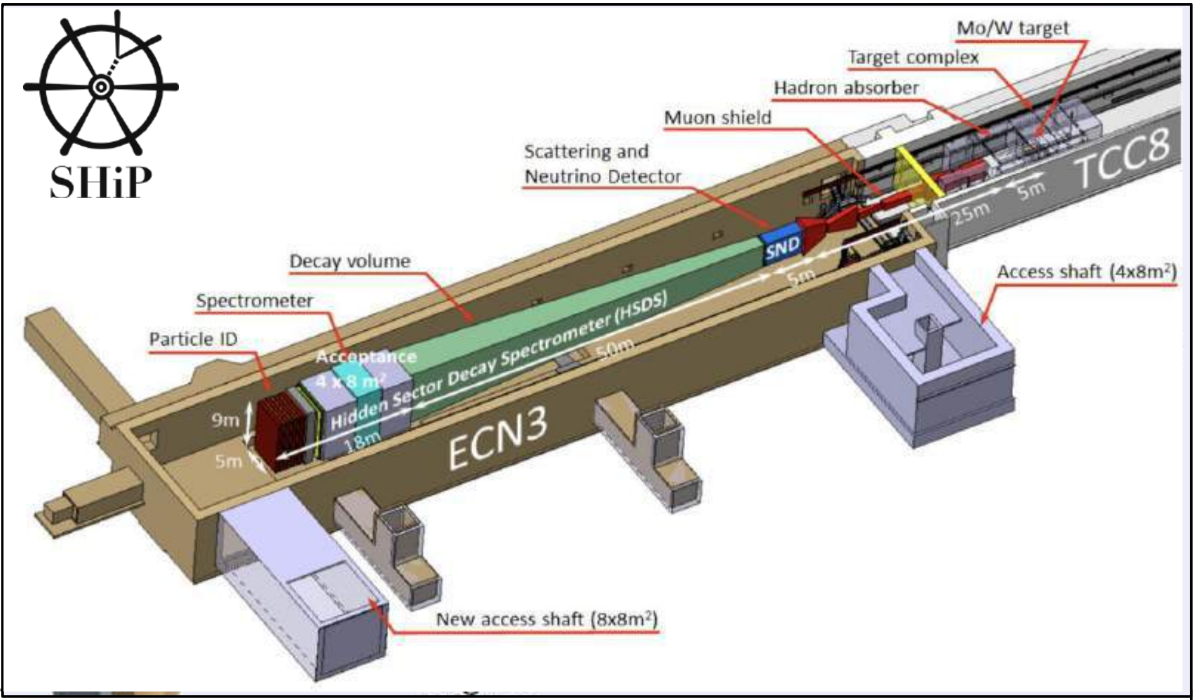
Phys.Rev.Lett.**135** :06180,2025

Although still not as good as nuclear emulsions!



FASER collab. *JINST* **20**:P12018(2025)

The renaissance of neutrino experiments @ CERN – at both the SPS & the LHC



2016

- Proposal for 'Search for hidden particles' (SHiP) @SPS
- Physics Beyond Colliders (PBC) initiative launched

2018

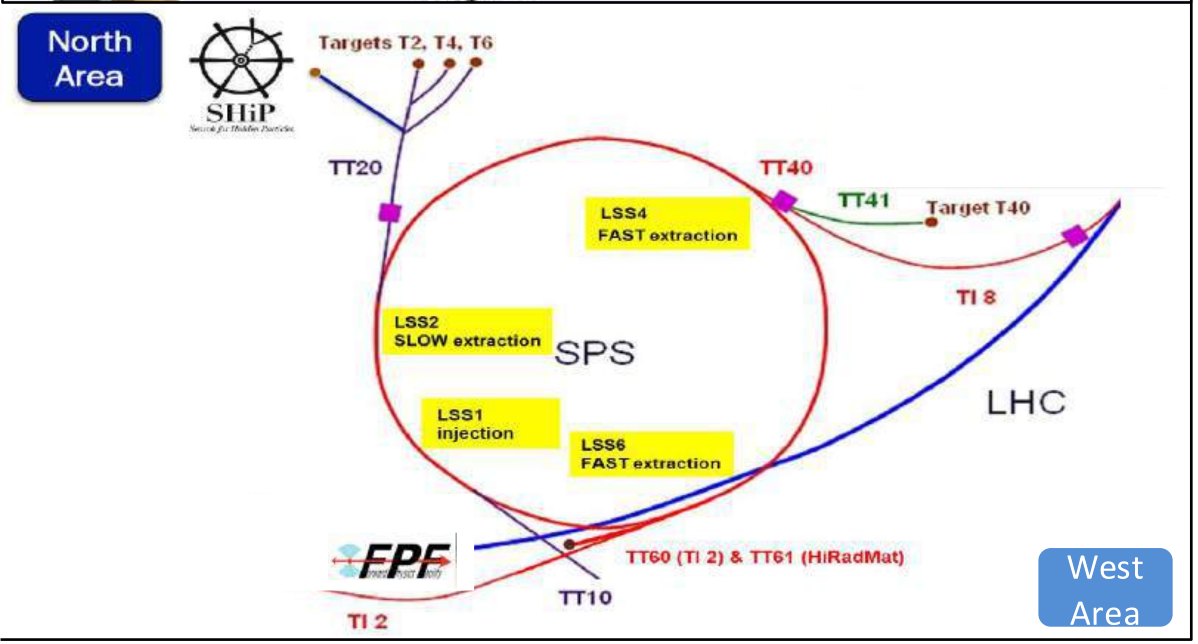
- FASER proposed to detect neutrinos from LHC P1

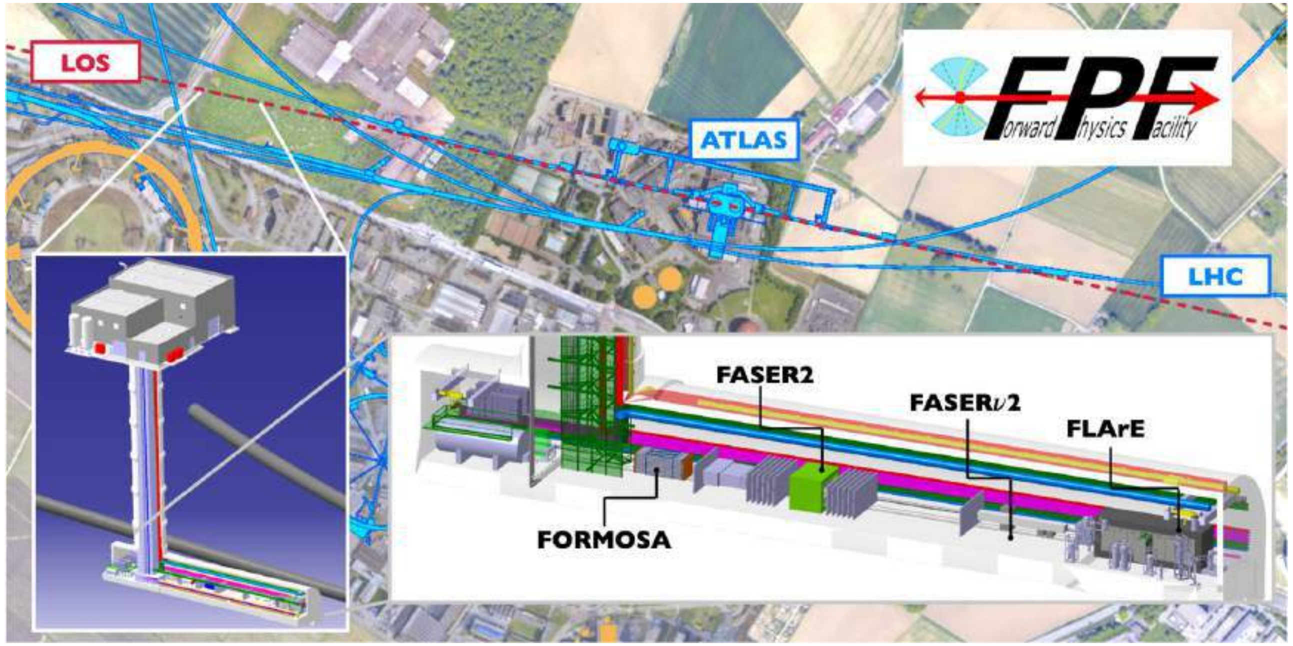
2023

- Detection of collider neutrinos by FASERν & SND@LHC

2024

- SHiP approved for construction
- Awaiting decision on Forward Physics Facility (FPF) @ LHC





LHC provides a collimated beam of TeV energy neutrinos in the far forward direction

NEUTRINO AND MUON PHYSICS IN THE COLLIDER MODE OF FUTURE ACCELERATORS *)

A. De Rújula and R. Rückl

CERN, Geneva, Switzerland

Proc. ECFA-CERN Workshop on large hadron collider in the LEP tunnel: 21-27 Mar 1984

ABSTRACT

Extracted beams and fixed target facilities at future colliders (the SSC and the LHC) may be (respectively) impaired by economic and "ecological" considerations. Neutrino and muon physics in the multi-TeV range would appear not to be an option for these machines. We partially reverse this conclusion by estimating the characteristics of the "prompt" ν_μ, ν_e, ν_τ and μ beams necessarily produced (for free) at the pp or $\bar{p}p$ intersections. The neutrino beams from a high luminosity (pp) collider are not much less intense than the neutrino beam from the collider's dump, but require no muon shielding. The muon beams from the same intersections are intense and energetic enough to study μp and μN interactions with considerable statistics and a Q^2-coverage well beyond the presently available one. The physics program allowed by these lepton beams is a strong advocate of machines with the highest possible luminosity: pp (not $\bar{p}p$) colliders.

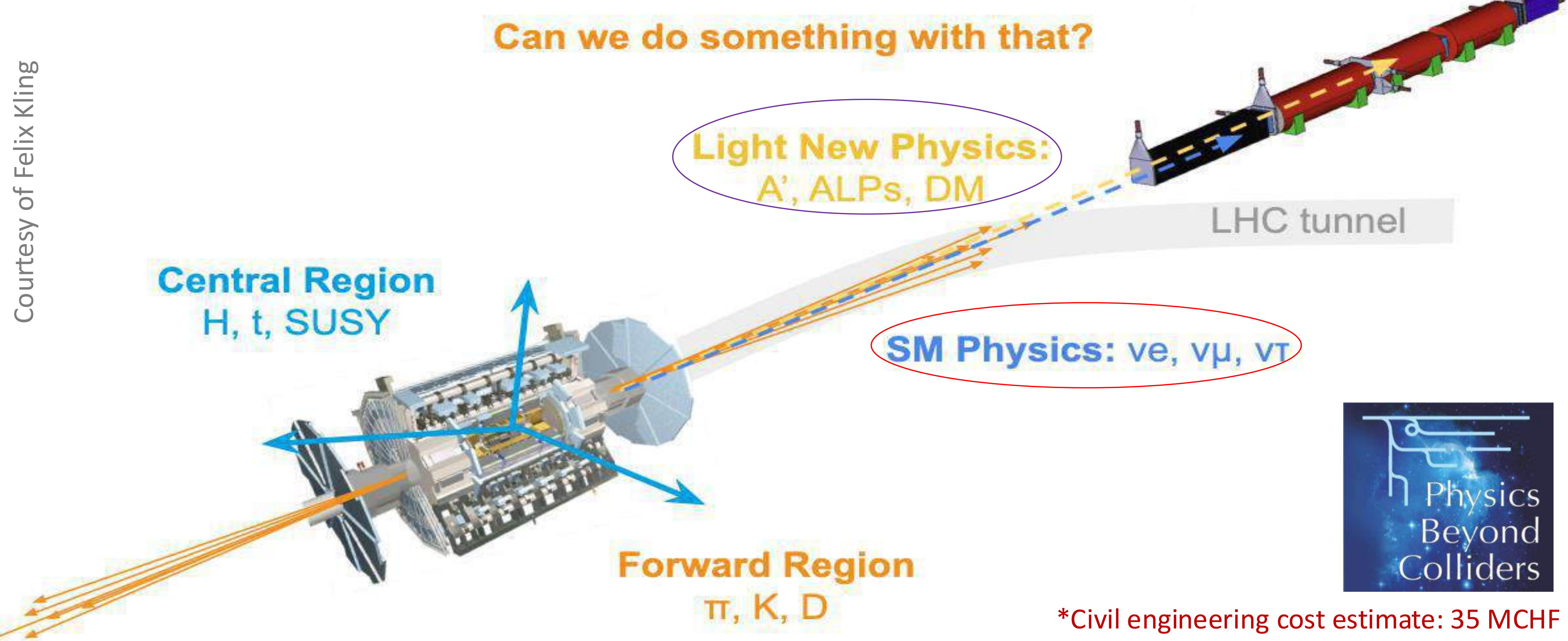
… Forty years later, this vision is being realized

While waiting for new physics at the LHC, can we explore the intensity frontier for free*?

The LHC produces an intense and strongly collimated beam of highly energetic particles in the forward direction.

10^{17} π0, 10^{16} η, 10^{15} D, 10^{13} B within 1 mrad of beam

Can we do something with that?

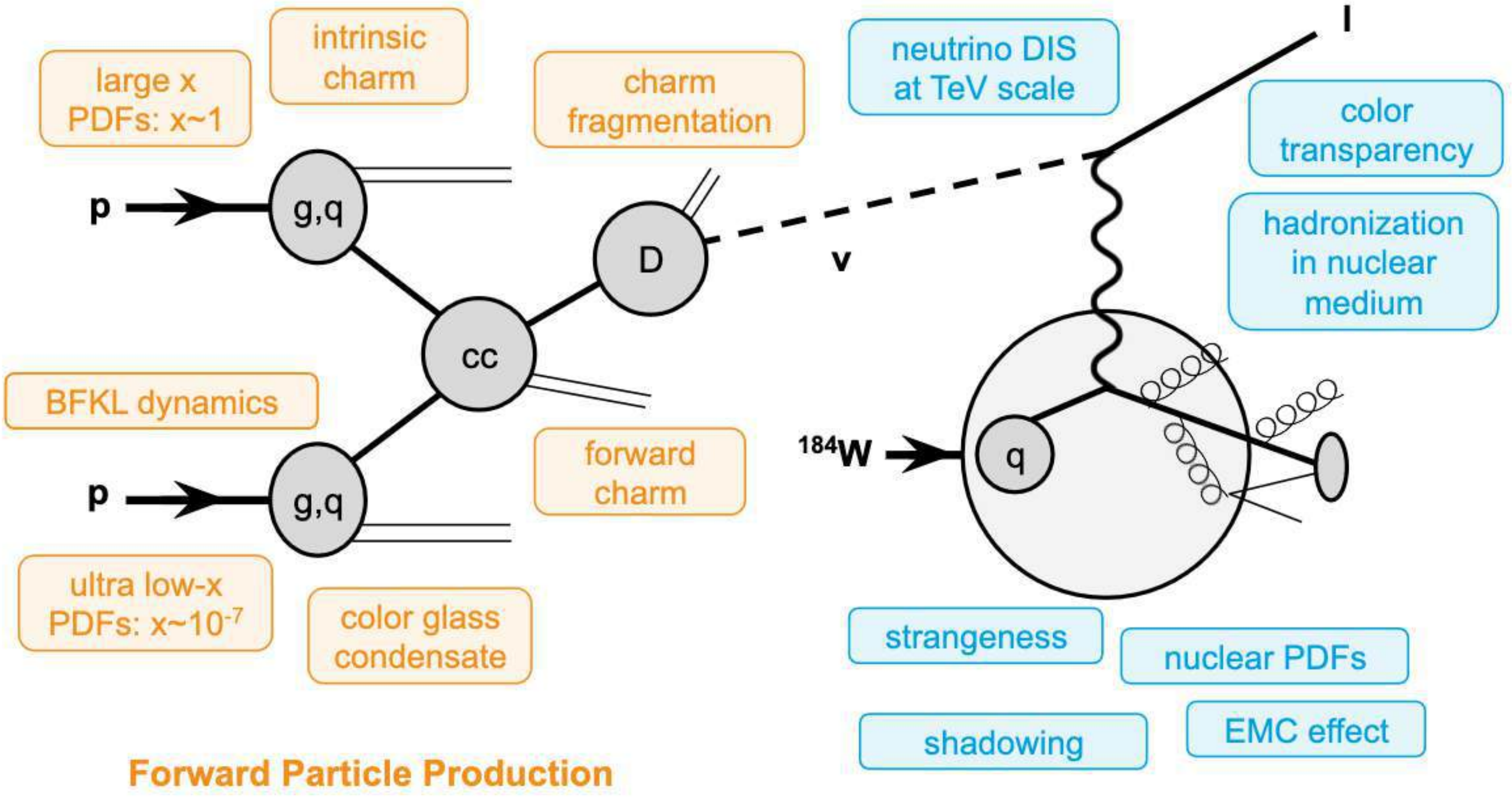


Courtesy of Felix Kling

Physics Beyond Colliders

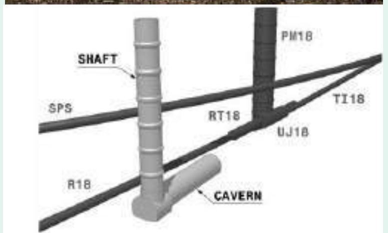
*Civil engineering cost estimate: 35 MCHF

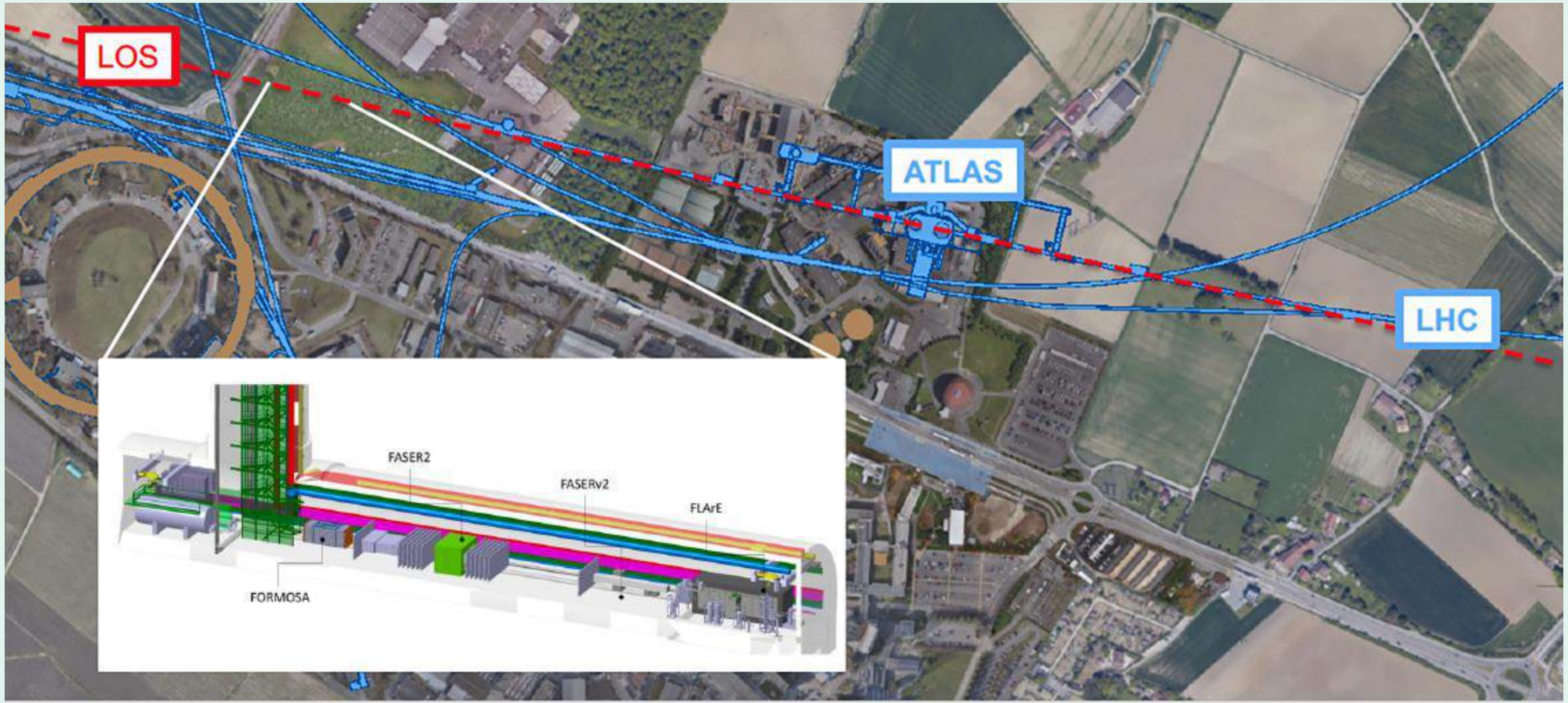
What can we do with an intense beam of TeV energy neutrinos?



Study interesting open issues in **QCD** – of relevance to **neutrino telescopes**; Study forward production of light hadrons – of relevance to **cosmic ray air shower arrays;** Search for **Beyond-Standard-Model** long-lived particles (axions, dark photons, heavy neutral leptons, milli-charged particles, scalar dark matter, quirks *etc*) – of relevance to **dark matter experiments.** Feng *et al*, *J.Phys.G* **50**:030501,2023

The Forward Physics Facility (FPF) is a proposal to create a cavern with the space and infrastructure to support a suite of far-forward experiments at the Large Hadron Collider during the High Luminosity era. Located along the beam collision axis and shielded from the interaction point by at least 100 m of concrete and rock, the FPF will house experiments that will detect particles outside the acceptance of all existing LHC experiments and will observe rare and exotic processes in an extremely low-background environment. In this work, we summarize the current status of plans for the FPF, including recent progress in civil engineering in identifying promising sites for the FPF; the FPF experiments currently envisioned to realize the FPF's physics potential; and the many Standard Model and new physics topics that will be advanced by the FPF, including searches for long-lived particles, probes of dark matter and dark sectors, high-statistics studies of TeV neutrinos of all three flavors, aspects of perturbative and non-perturbative QCD, and high-energy astroparticle physics. [*Phys.Rep.* **968**:1,2022, *J.Phys.G***50**:030501,2023]





FASER2: Magnetized spectrometer for BSM searches

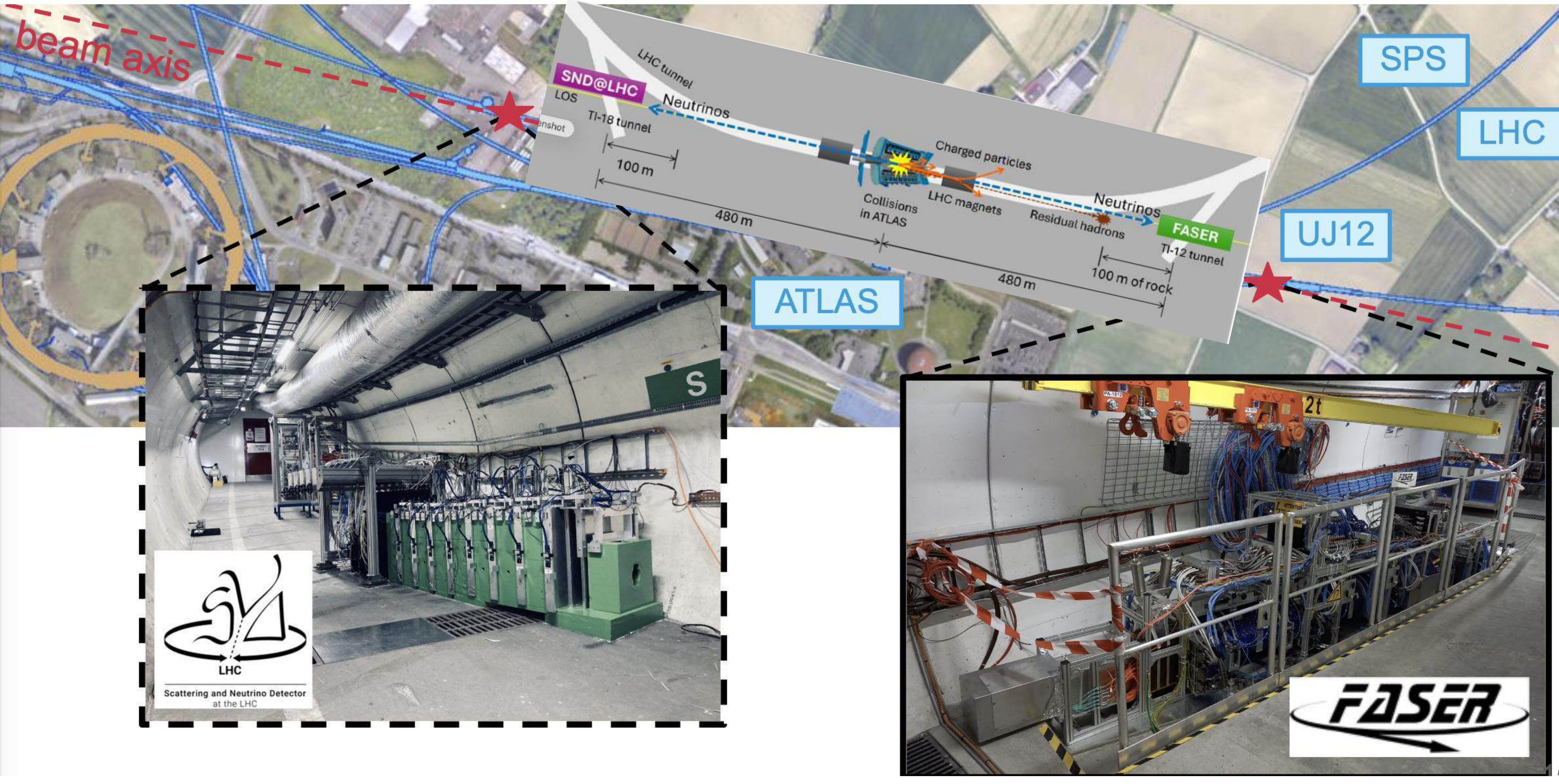
FASERν2: Emulsion-based ν detector

FORMOSA: Plastic scintillator array for BSM searches

FLARE: LAr ν detector

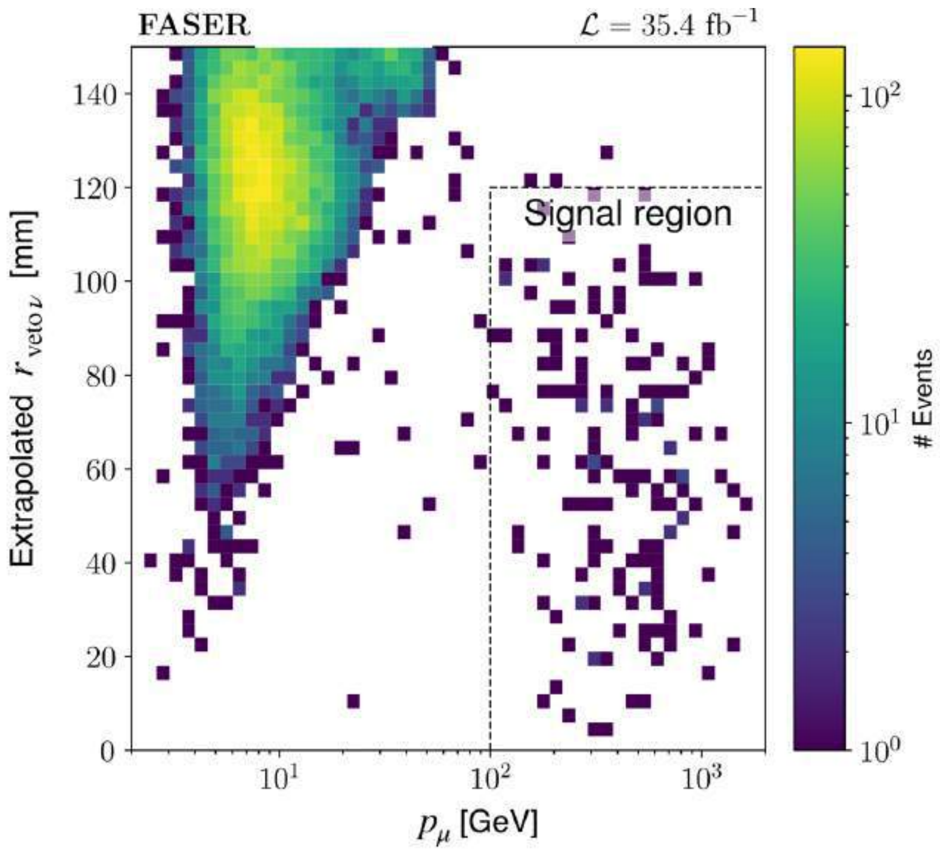
Proof-of-principle in 2022 when two new experiments started operation @ CERN:

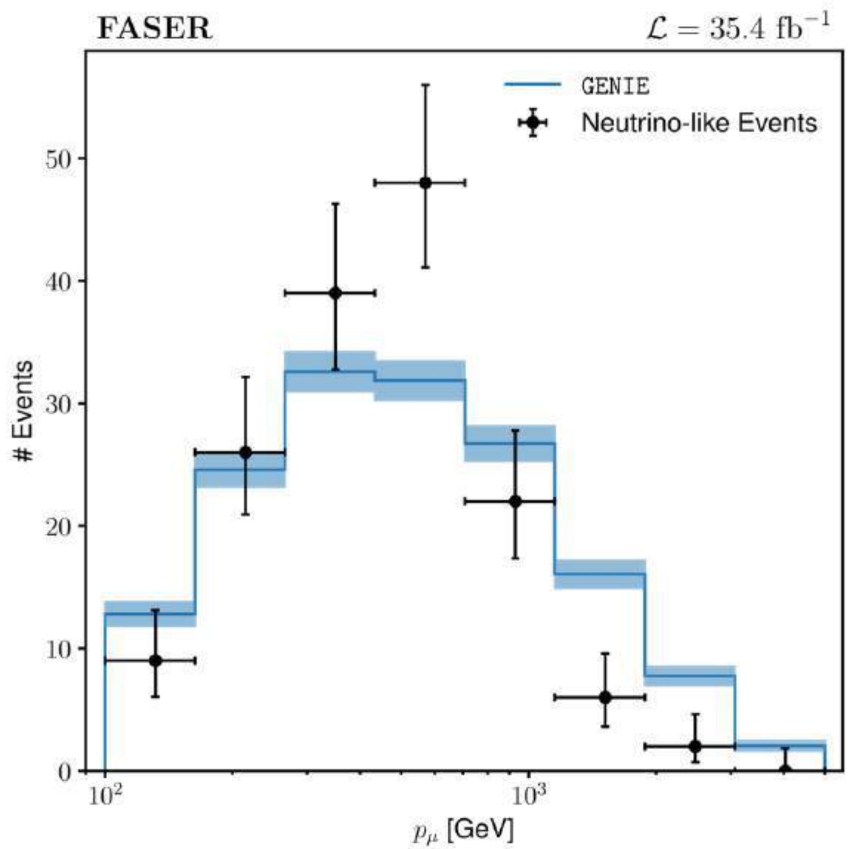
FASER [2207.11427] & SND@LHC [2210.02784]

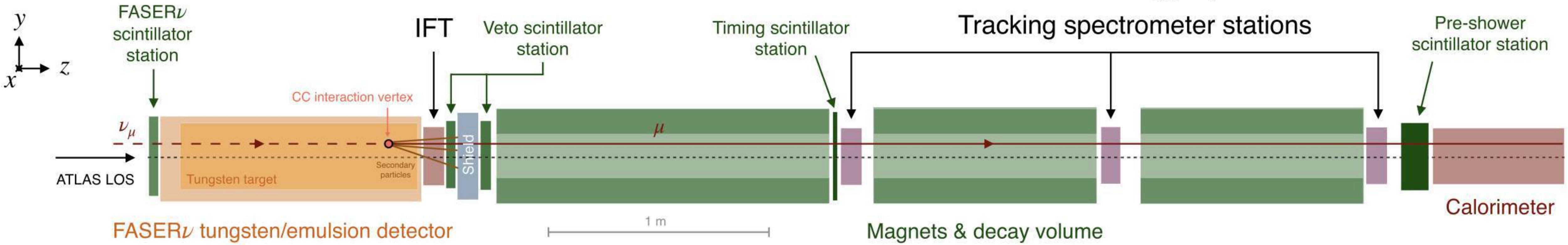


The dawn of collider neutrino physics

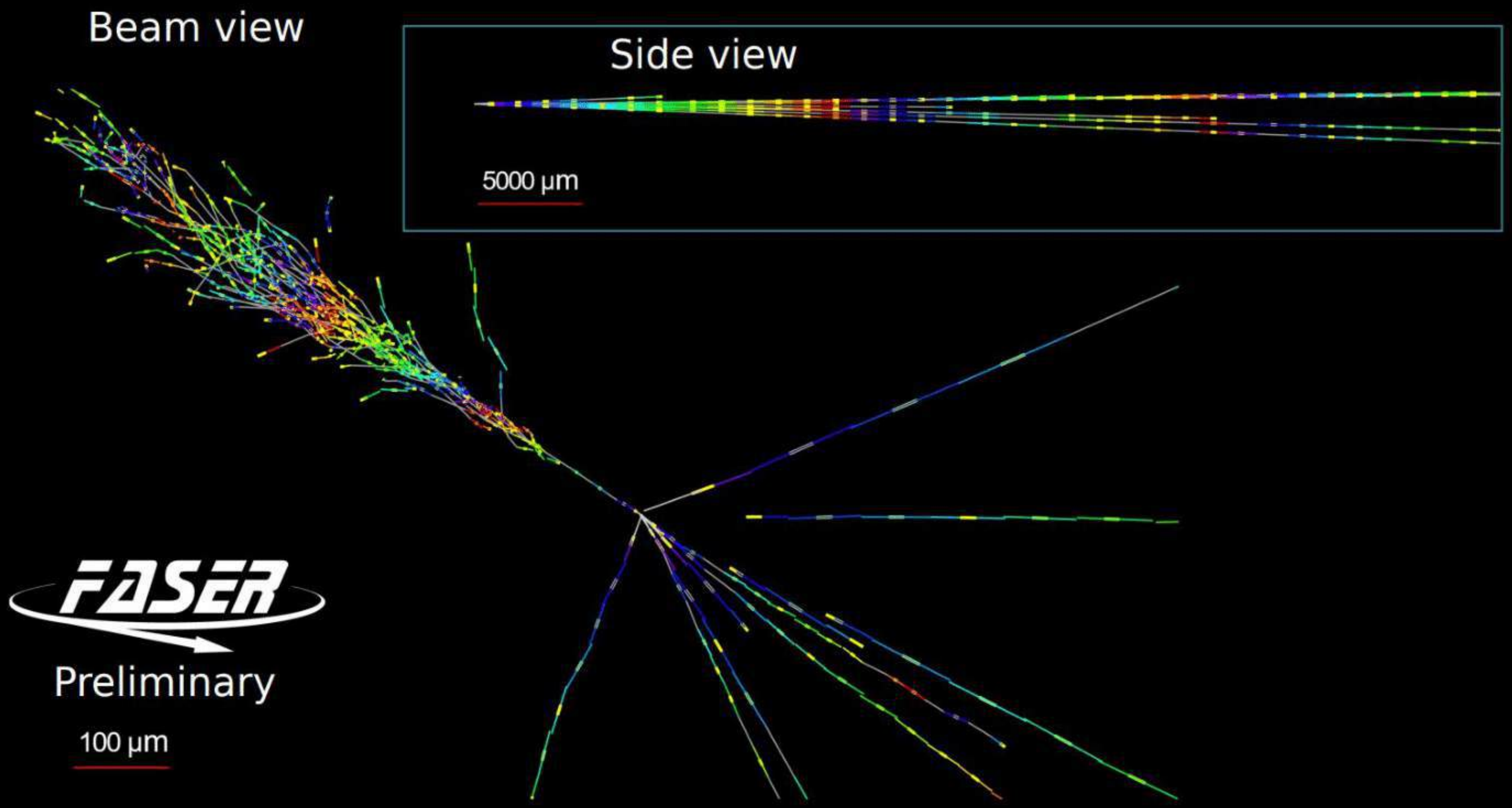
~0.2 background events expected in signal region … upon unblinding find 153 events with *no* veto







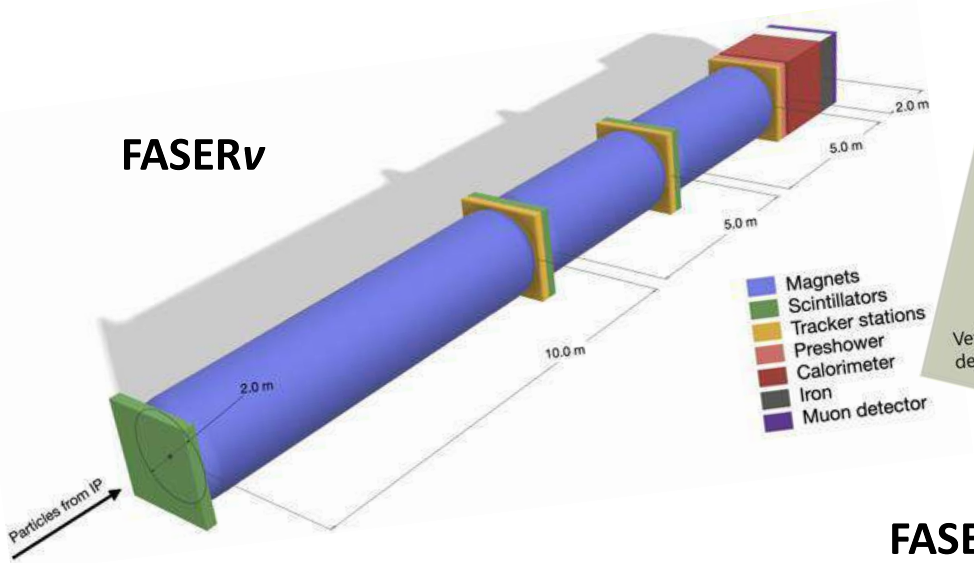
FASER collab., *PRL* **131**:031801,2023

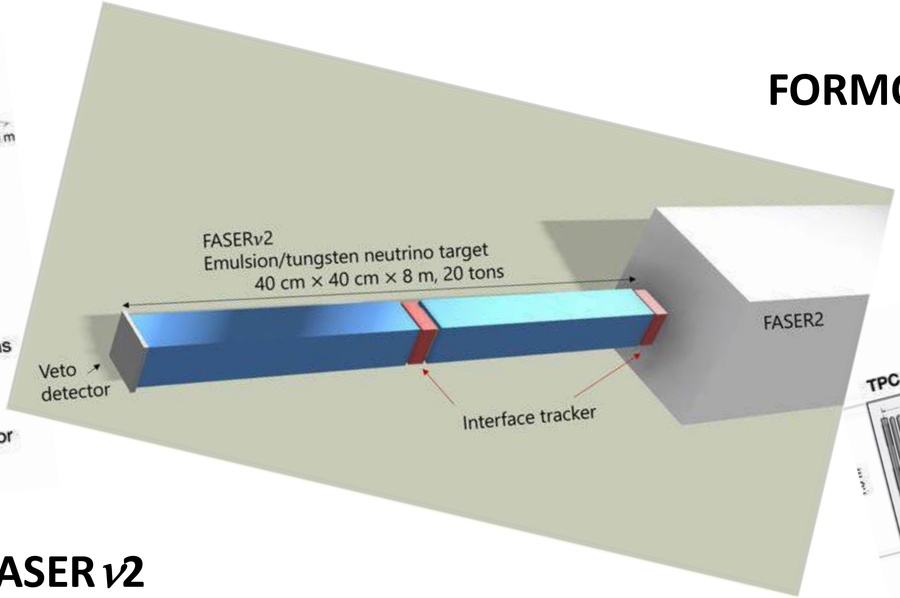

Beam view
Side view
5000 µm
Preliminary
100 µm

Expected Neutrino Fluxes at Forward Physics Facility experiments

Detector				Number of CC Interactions		
Name	Mass	Coverage	Luminosity	$\nu_e+\bar{\nu}_e$	$\nu_\mu+\bar{\nu}_\mu$	$\nu_\tau+\bar{\nu}_\tau$
FASERν	1 ton	$\eta \gtrsim 8.5$	150 fb^{-1}	901 / 3.4k	4.7k / 7.1k	15 / 97
FASERν2	20 tons	$\eta \gtrsim 8.5$	3 ab^{-1}	178k / 668k	943k / 1.4M	2.3k / 20k
FLArE	10 tons	$\eta \gtrsim 7.5$	3 ab^{-1}	36k / 113k	203k / 268k	1.5k / 4k
AdvSND	2 tons	$7.2 \lesssim \eta \lesssim 9.2$	3 ab^{-1}	6.5k / 20k	41k / 53k	190 / 754

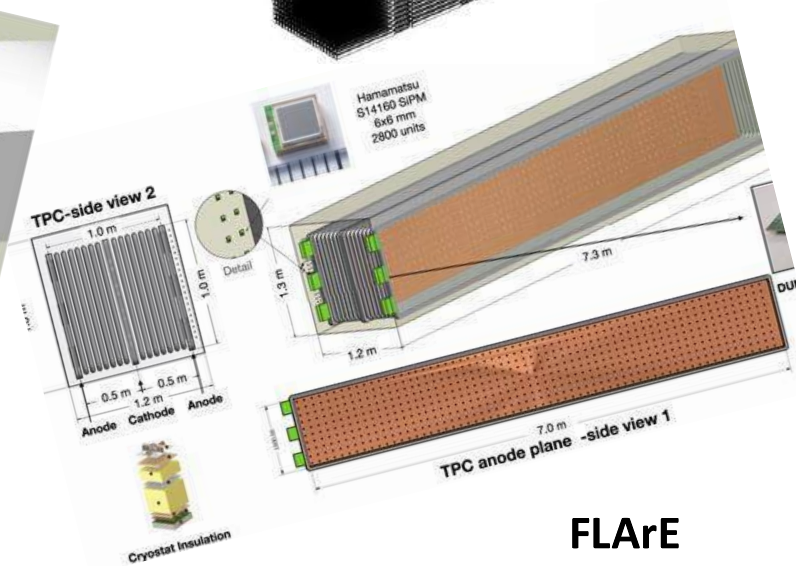
FASERν





FASER ν2

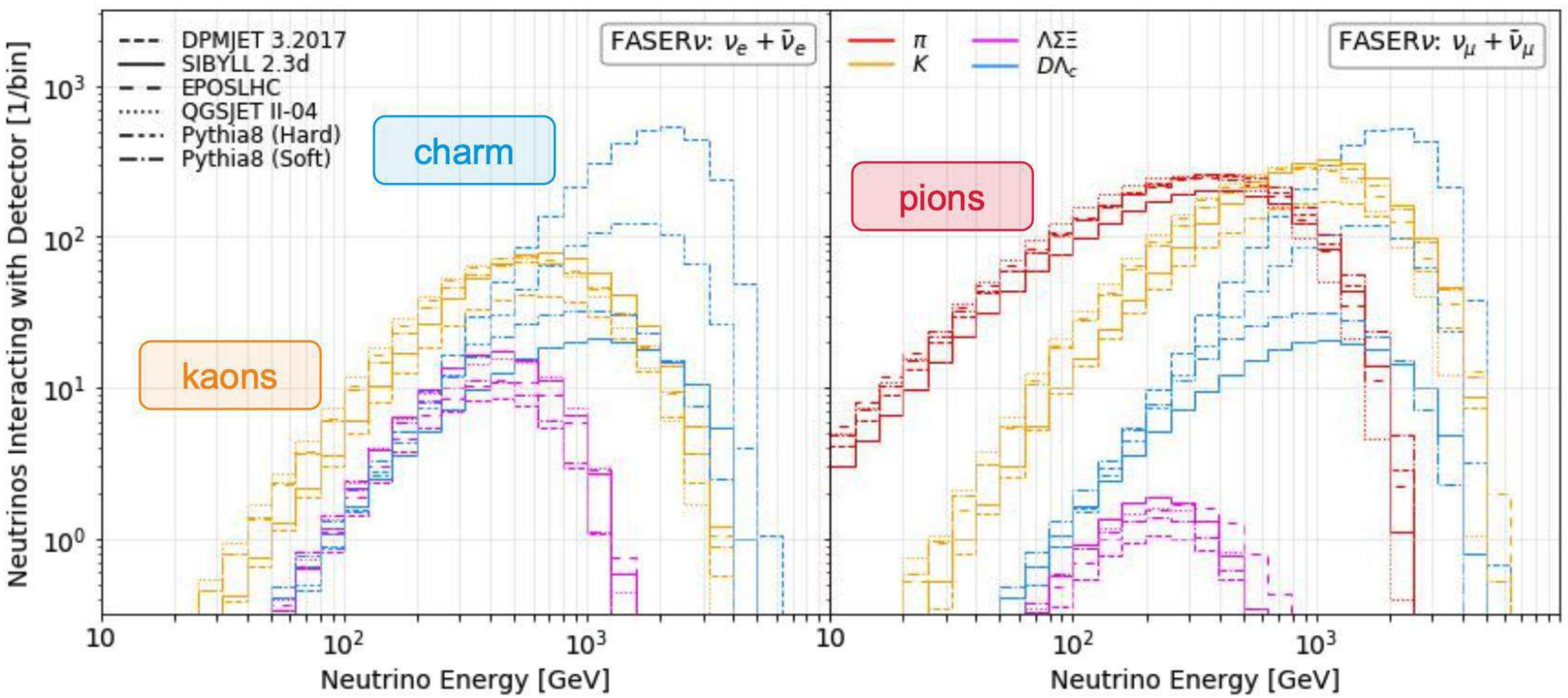
FORMOSA



FLArE

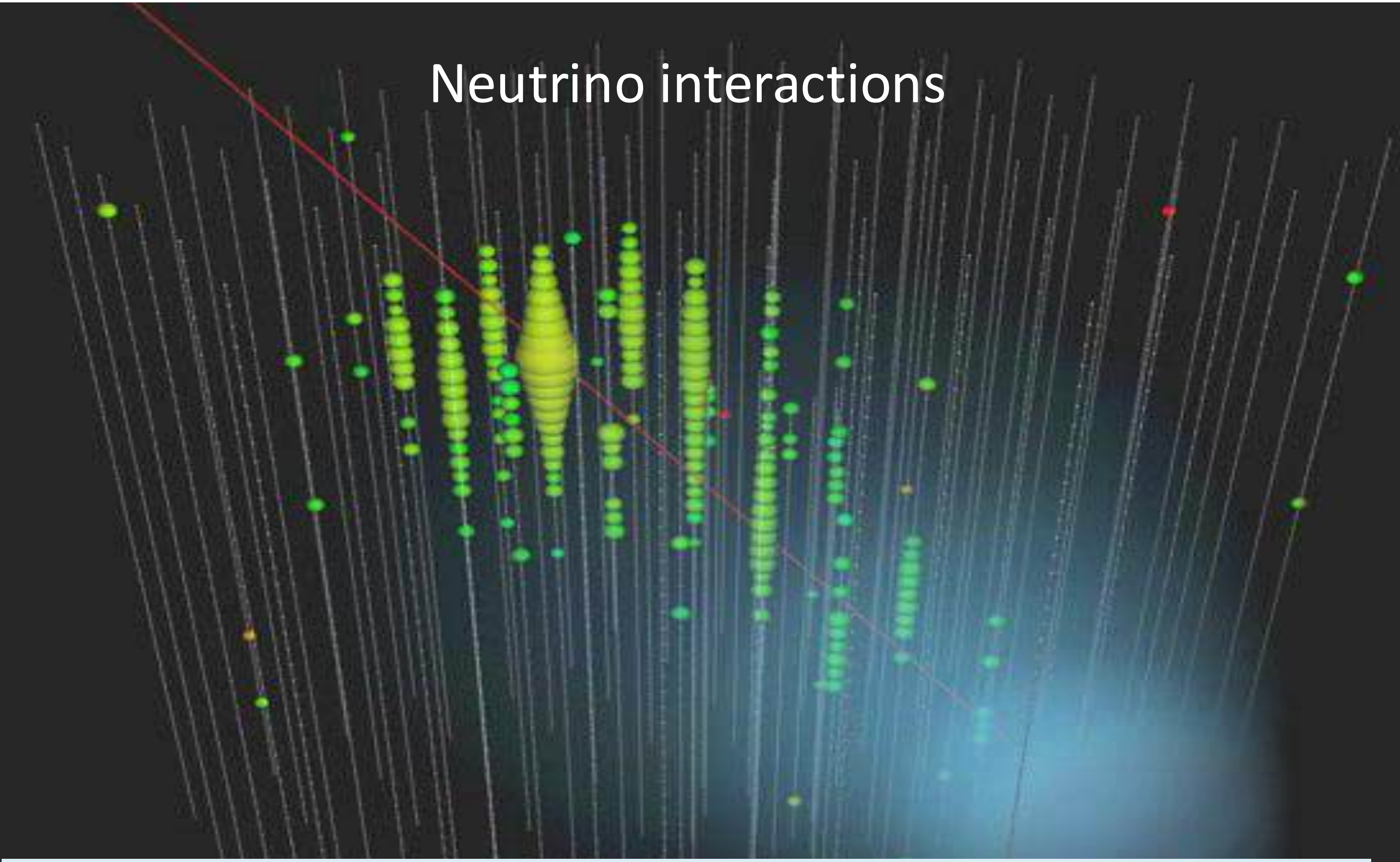
Feng *et al*, *J.Phys.***G50**:030501,2023

Expected spectrum of LHC neutrinos



Probe of forward particle production

Neutrino interactions



<u>Synergy with Neutrino Telescopes</u>:

Antares/***KM3NeT***, ***Baikal***/*GVD*, ***IceCube***/*Gen2*, … *P-One*, *Trident*,
… ***ANITA***, *PUEO*, *GRAND*, *Trinity*, … ***ARIANNA***, ***ARA***, *RNO-G*

At high energies, neutrinos interact via *ν-N* Deep Inelastic Scattering

This is calculable in the (perturbative) Standard Model, knowing the parton distribution functions (PDFs)

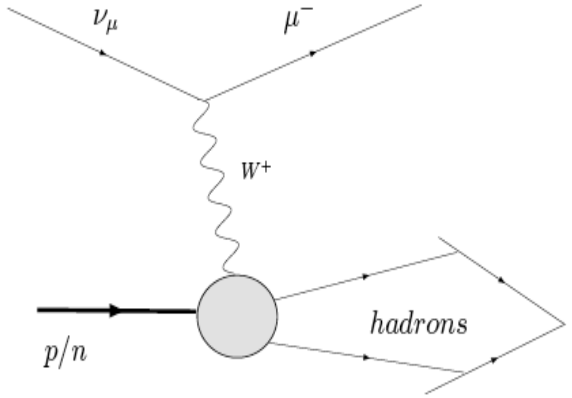
$$\frac{\partial^2 \sigma^{CC,NC}_{\nu,\bar{\nu}}}{\partial x \partial y} = \frac{G_F^2 M E}{\pi} \left(\frac{M_i^2}{Q^2 + M_i^2} \right)$$

$Q^2 \uparrow \Rightarrow$ propagator $\downarrow$

$$[\frac{1+(1-y)^2}{2} F_2^{CC,NC}(x,Q^2) - \frac{y^2}{2} F_L^{CC,NC}(x,Q^2)$$

$Q^2 \uparrow \Rightarrow$ parton distribution functions $\uparrow$

$$\pm y \left(1 - \frac{y}{2}\right) x F_3^{CC,NC}(x,Q^2)]$$



Most of the contribution to #-secn comes from:

$$Q^2 \sim M_W^2 \text{ and } x \sim \frac{M_W^2}{M_N E_\nu}$$

$$\text{At leading order (LO)}: F_L = 0, \quad F_2 = x(u_v + d_v + 2s + 2b + \bar{u} + \bar{d} + 2\bar{c}),$$

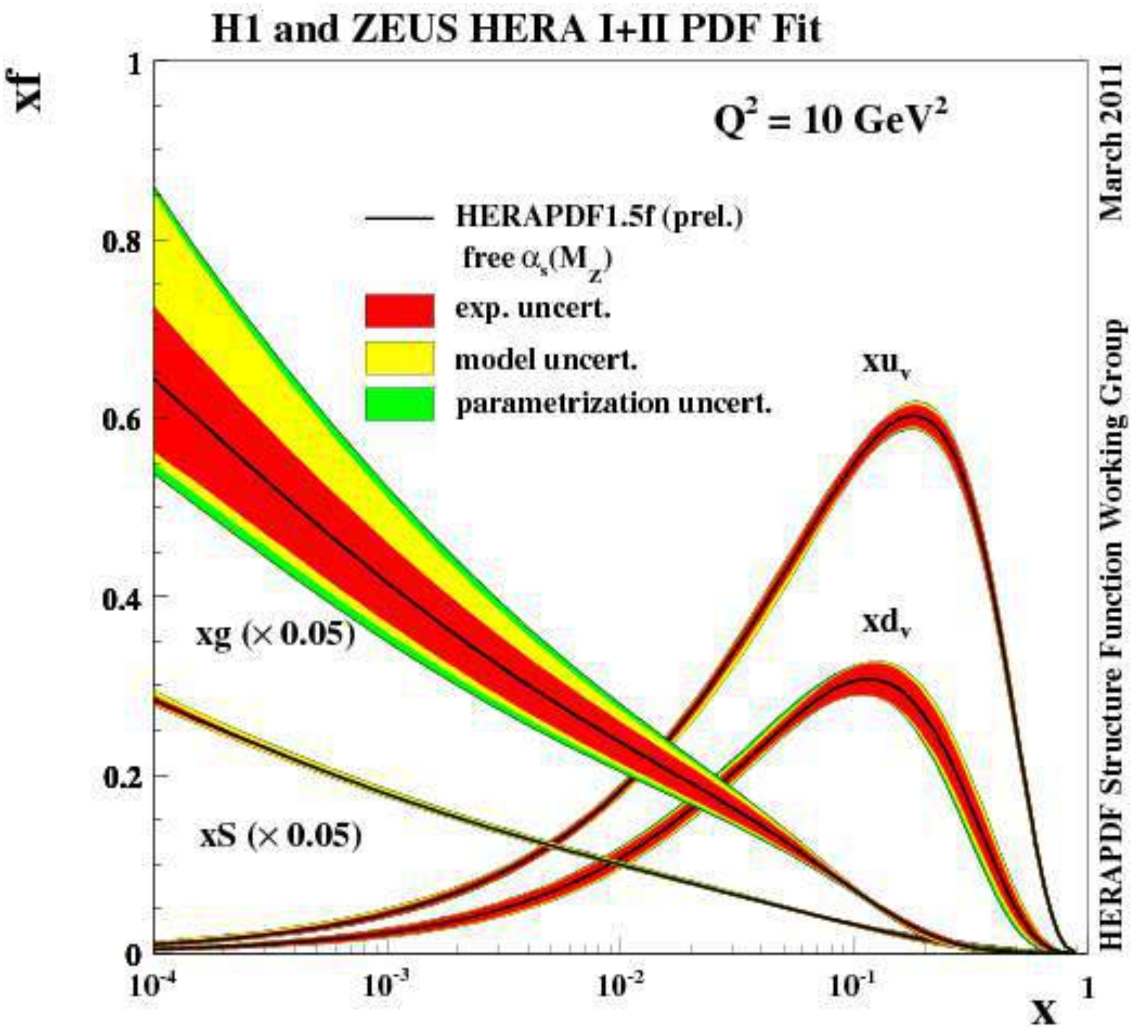
$$xF_3 = x(u_v + d_v + 2s + 2b - \bar{u} - \bar{d} - 2\bar{c}) = x(u_v + d_v + 2s + 2b - 2\bar{c})$$

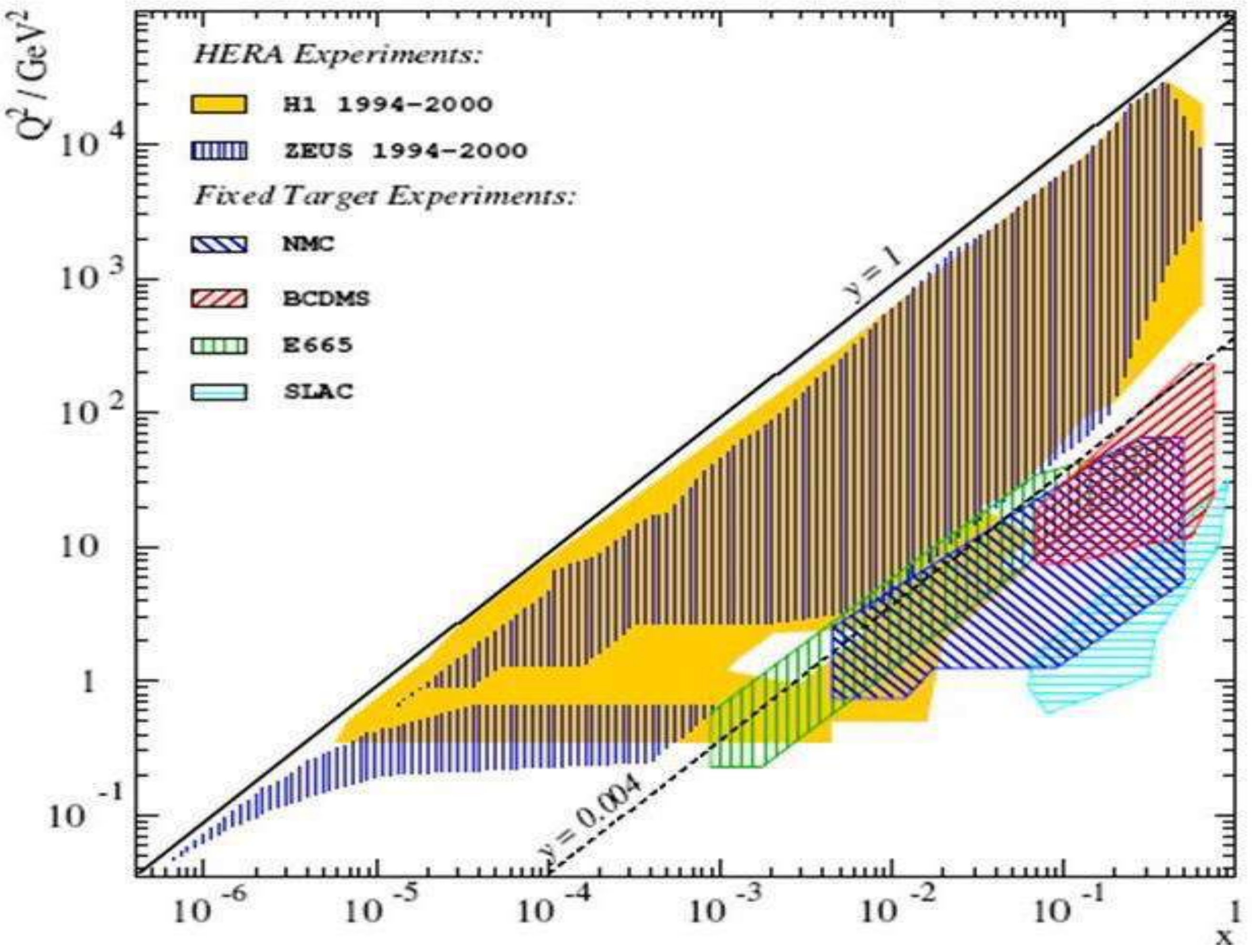
Can calculate numerically at Next-to-Leading-Order (NLO) … *no* significant further change at NNLO

For UHE neutrinos, need to perform DGLAP evolution of measured PDFs to (high) Q^2 and (low) Bjorken-*x*

Subtleties: heavy flavour thresholds, BFKL resummation, nuclear targets, shadowing …

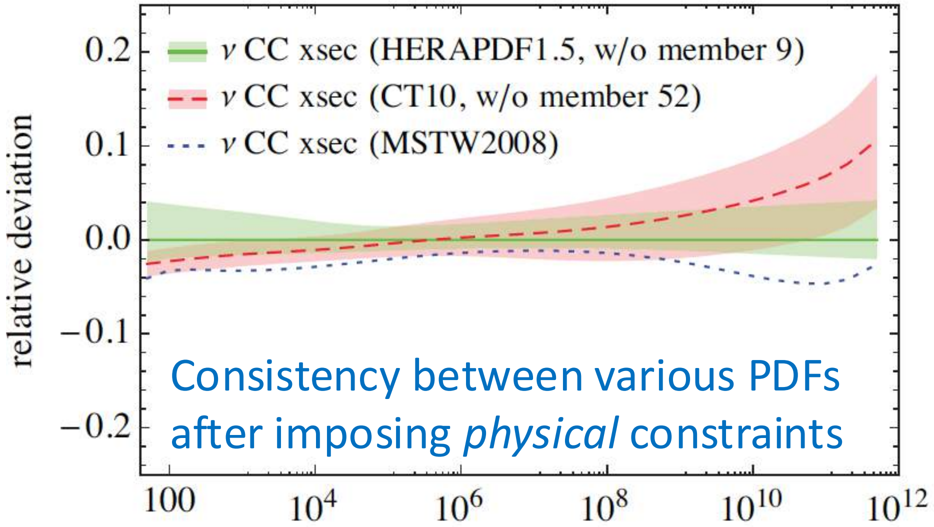
The H1 & ZEUS experiments at HERA were the first to measure DIS at high Q^2 and low Bjorken-x – an unexpected finding was the *steep* rise of the gluon PDF at low x which is particularly relevant for HE neutrino interactions



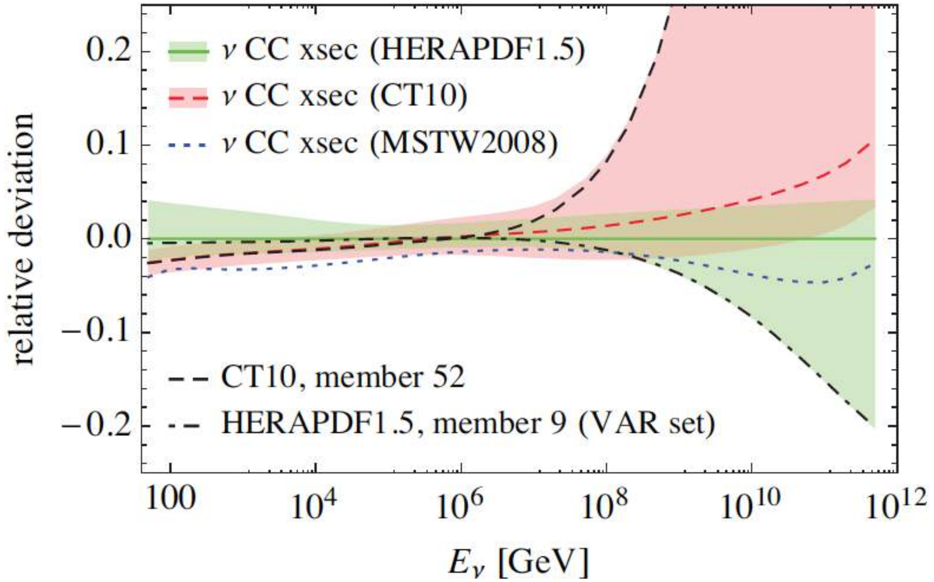


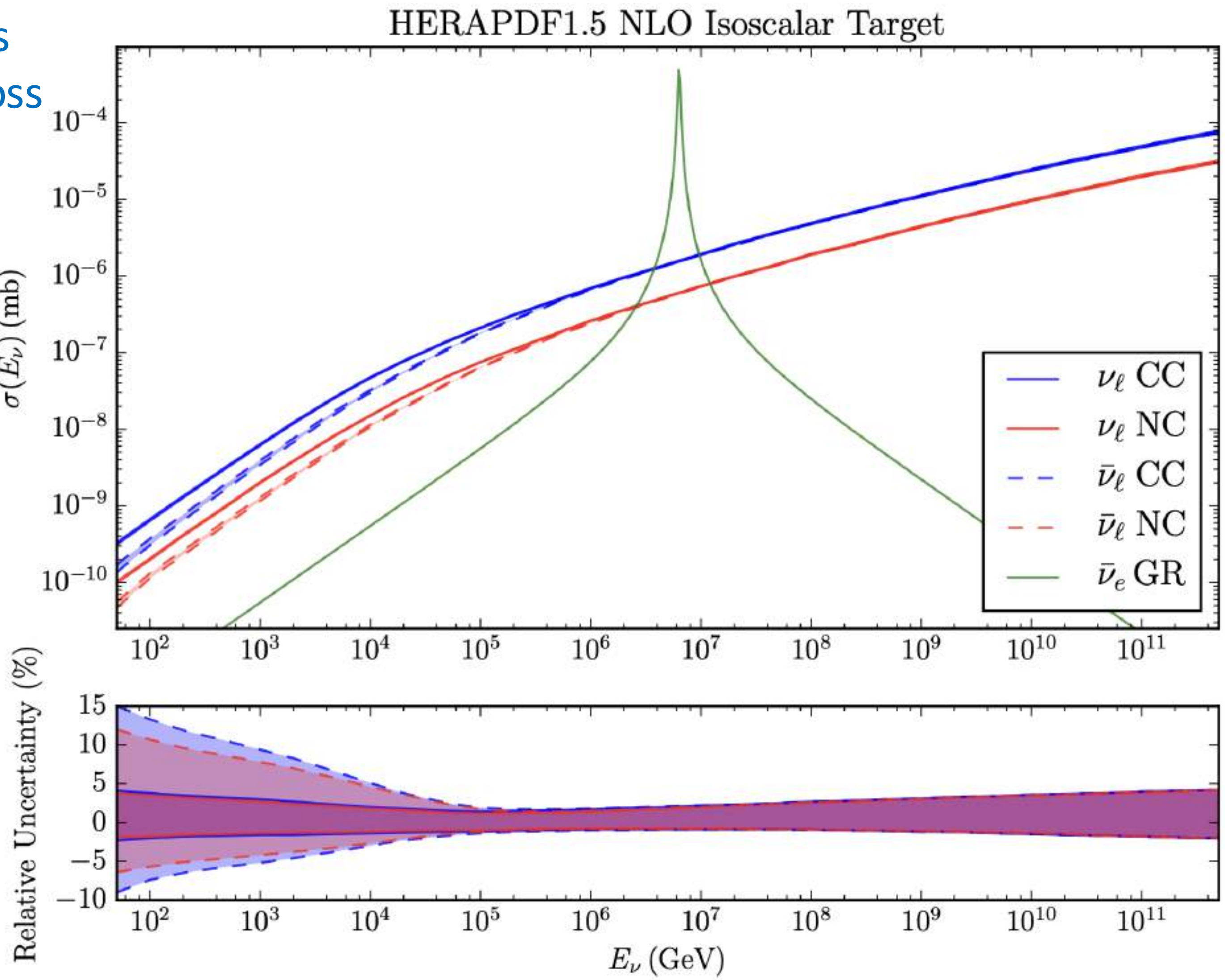
Subsequently data from the LHC (W, Z, ttbar, jets …) have led to more accurate PDFs and some new findings (low-x strange sea *less* suppressed than believed earlier, a hint of intrinsic charm …)

Neutrino telescopes like *IceCube* explore energies where there is no direct knowledge of the DIS cross section, so this must be estimated in pQCD from measured parton distribution functions



Consistency between various PDFs after imposing *physical* constraints



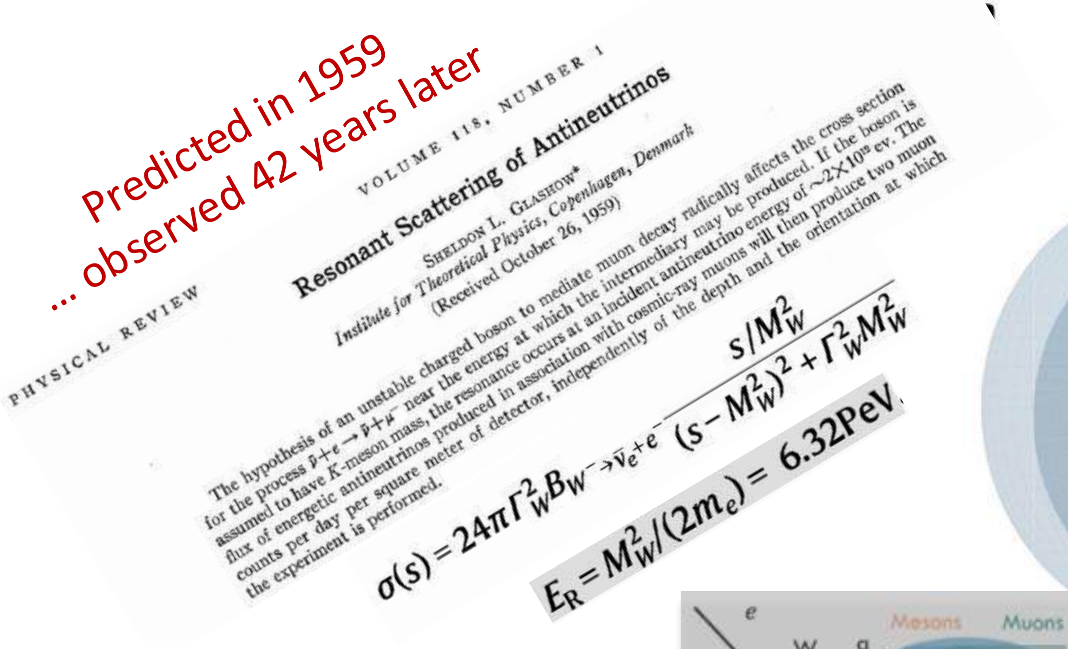


Our calculation @NLO using HERAPDF1.5 and incl. effect of heavy quarks on DGLAP evolution is incorporated in the neutrino event generator `NuGeN`
(and in `GENIEv3` via the `HEDIS` plugin module)
[Other calcs: Xie *et al*, 2303.13607, Weigel *et al*, 2408.05866]

Mertsch, Cooper-Sarkar, S.S., *JHEP* **08**:042,2011 ⇒ **CSMS**

Detection of a particle shower at the Glashow resonance with IceCube

Nature | Vol591 | 11March2021



PHYSICAL REVIEW VOLUME 118, NUMBER 1 APRIL 1, 1960

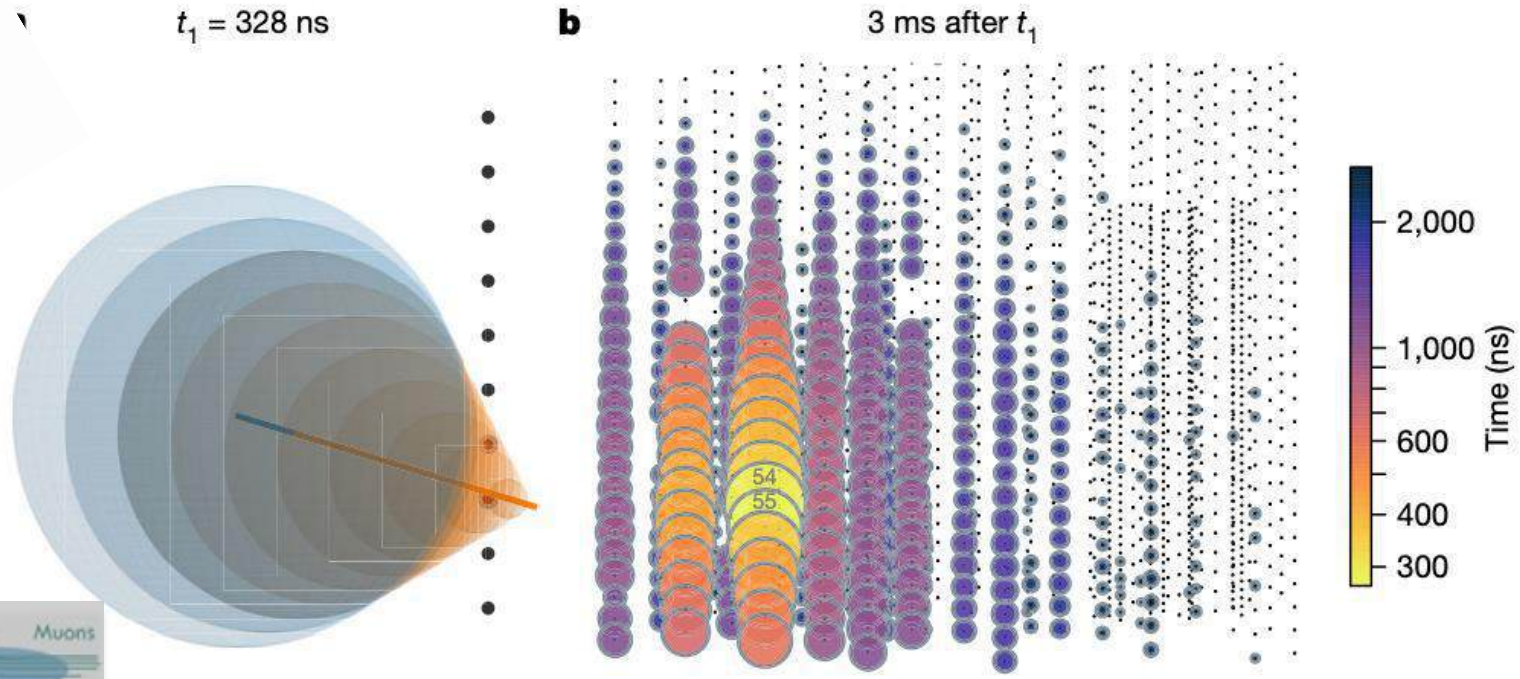
Resonant Scattering of Antineutrinos

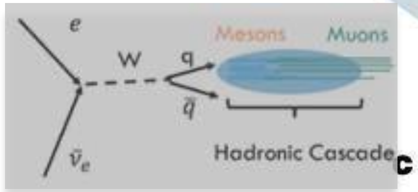
SHELDON L. GLASHOW*
Institute for Theoretical Physics, Copenhagen, Denmark
(Received October 26, 1959)

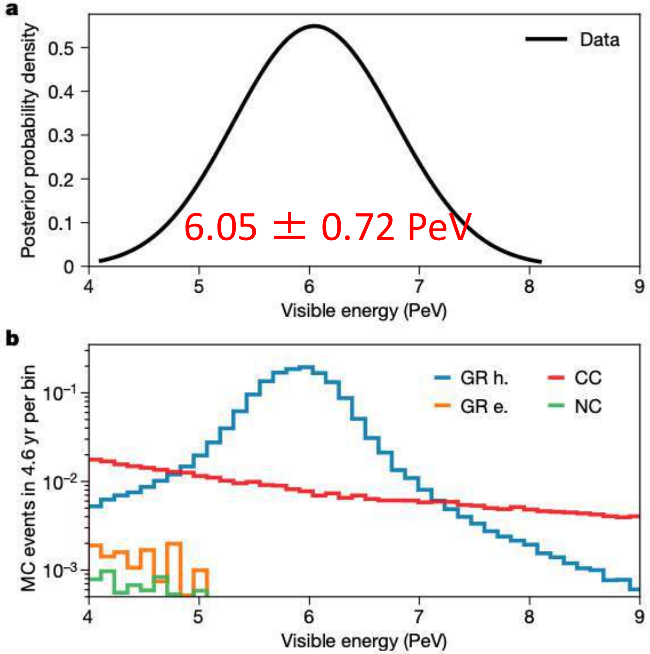
The hypothesis of an unstable charged boson to mediate muon decay radically affects the cross section for the process $\bar{\nu}+e \to \bar{\nu}+\mu^-$ near the energy at which the intermediary may be produced. If the boson is assumed to have K-meson mass, the resonance occurs at an incident antineutrino energy of $\sim 2\times10^9$ ev. The flux of energetic antineutrinos produced in association with cosmic-ray muons will then produce two muon counts per day per square meter of detector, independently of the depth and the orientation at which the experiment is performed.

$$\sigma(s) = 24\pi\Gamma_W^2 B_{W^-\to\bar{\nu}_e e^-}\frac{s/M_W^2}{(s-M_W^2)^2+\Gamma_W^2 M_W^2}$$

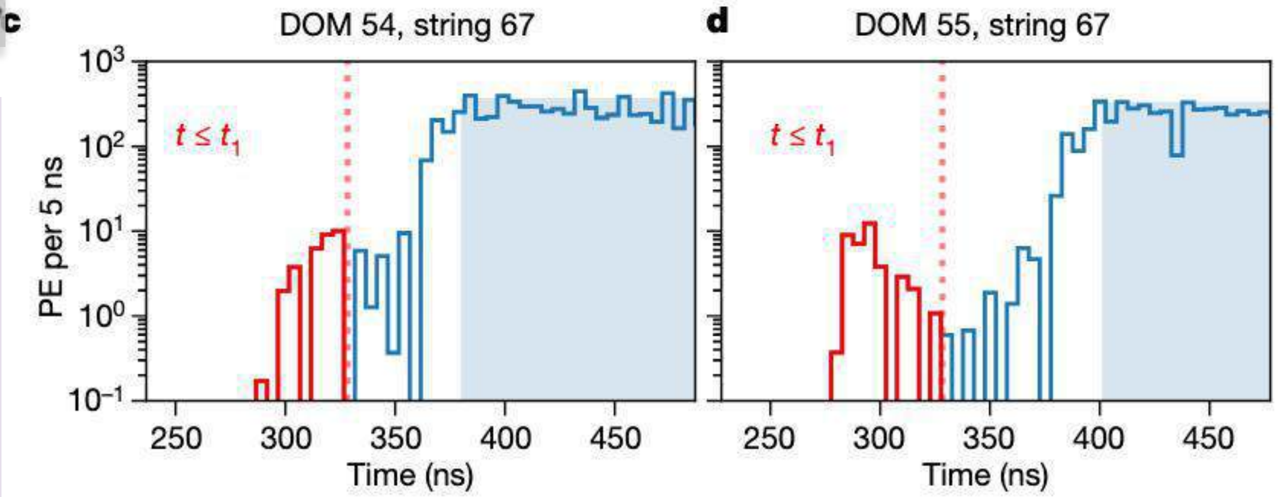
$$E_R = M_W^2/(2m_e) = 6.32\text{PeV}$$



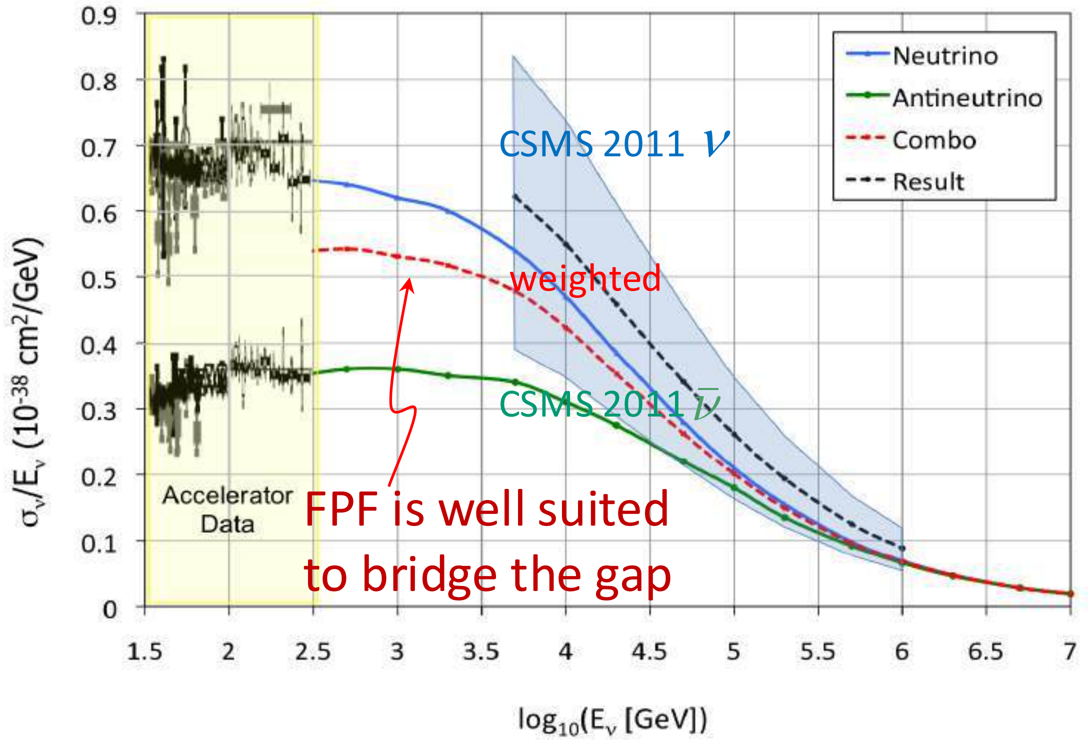


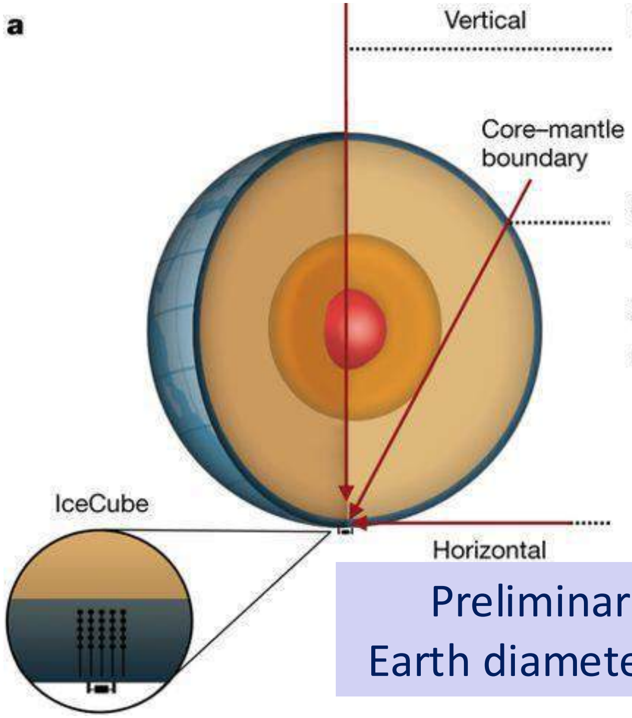


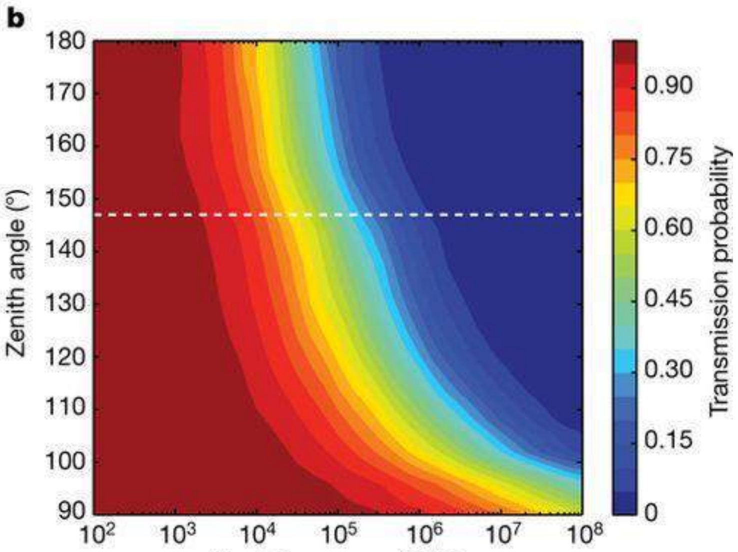
The precision with which the DIS #-secn can be *predicted* determines the C.L. of the GR identification



The predicted νN cross-section has been verified upto 10^3 TeV by ν absorption in the Earth

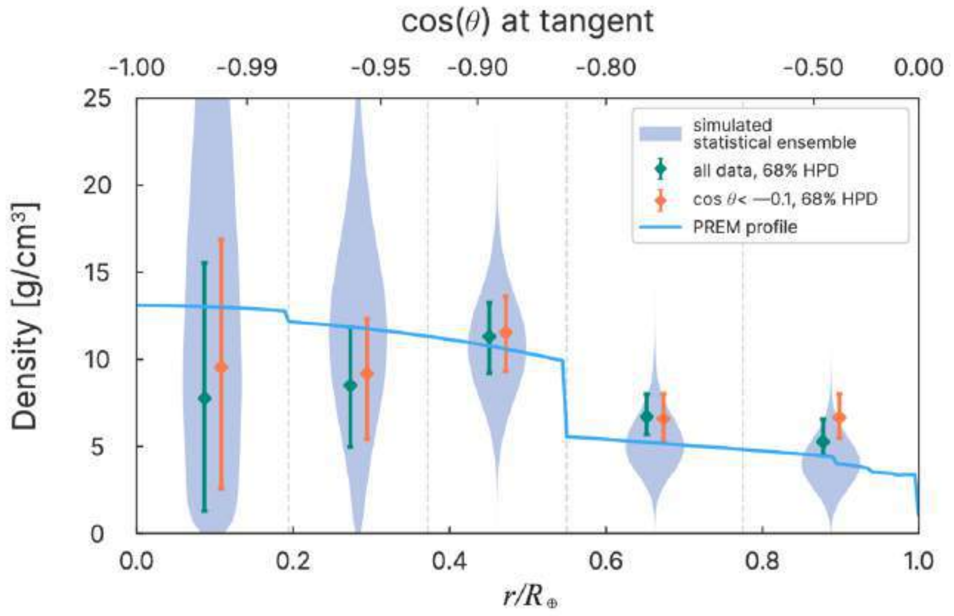






Preliminary Reference Earth Model (PREM)
Earth diameter = interaction length at $E_\nu \sim 40$ TeV

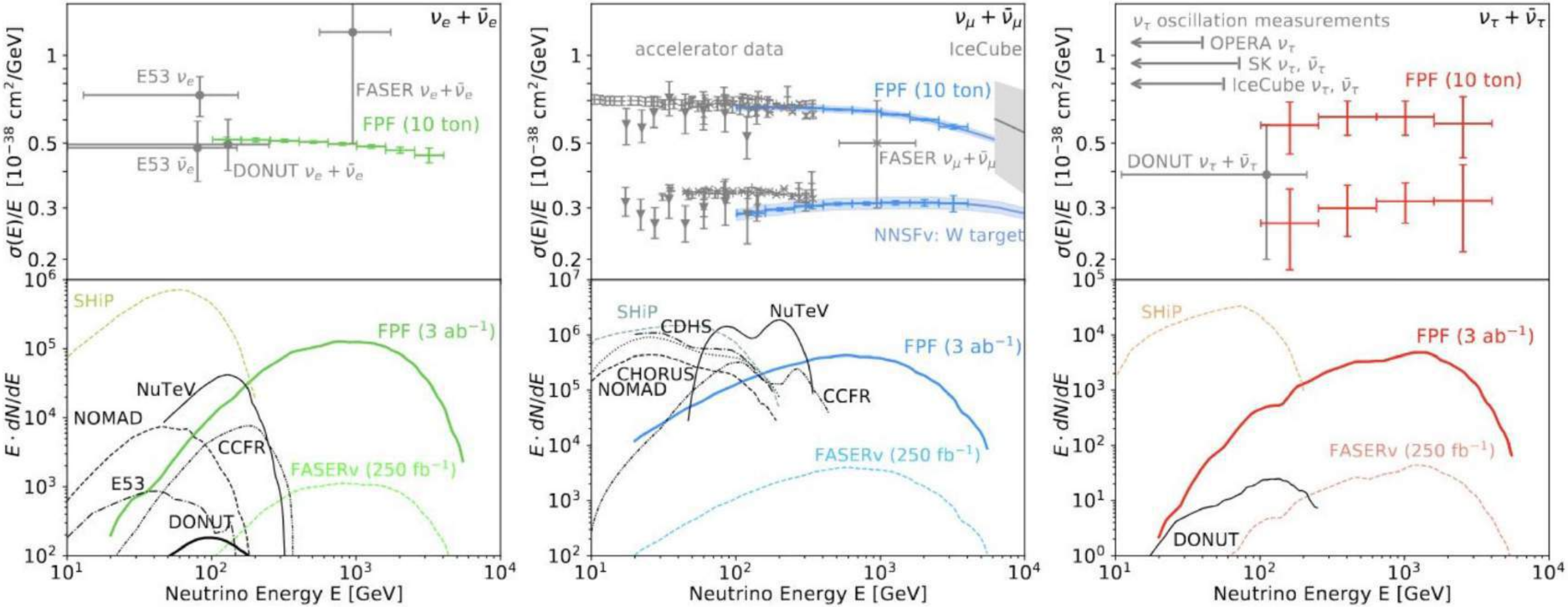
IceCube Collaboration, *Nature* **551**:596,2017



Can *invert* the argument to do tomography of Earth's interior (Donnini *et al*, *Nature Phys.* **15**:37,2019, IceCube collab. 2607.02644)

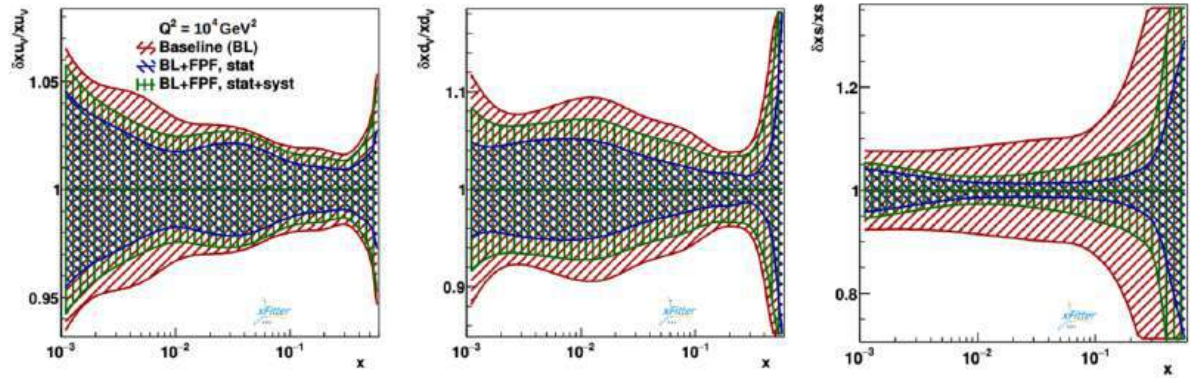
However the measurement uncertainty is large (~30%) and Earth absorption hapeens only above $E_\nu \sim 40$ TeV

SCIENCE AND PROJECT PLANNING FOR THE FORWARD PHYSICS FACILITY IN PREPARATION FOR THE 2024–2026 EUROPEAN PARTICLE PHYSICS STRATEGY UPDATE

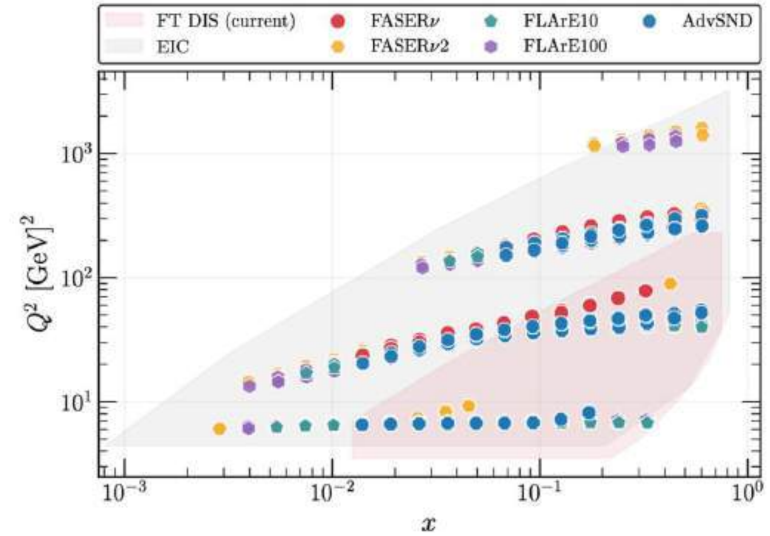


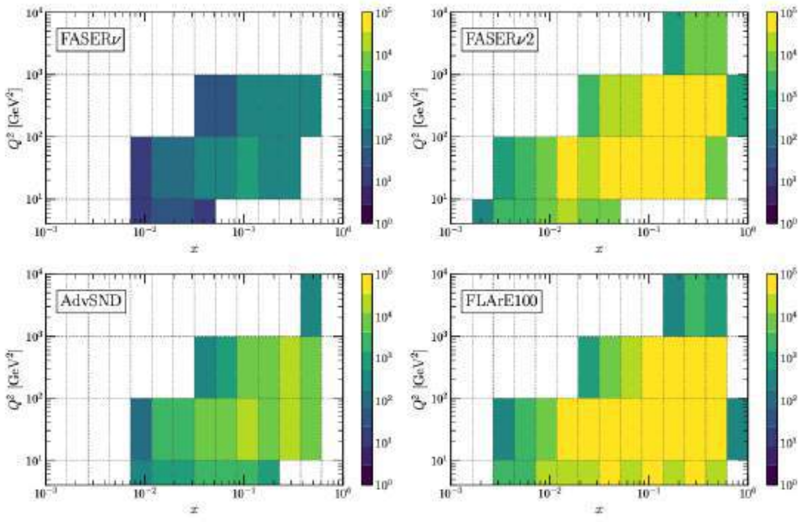
Neutrino flux as a function of energy for e neutrinos (left), μ neutrinos (middle), and τ neutrinos (right), with expected precision of FPF measurements - stat. uncertainties only (FPF collaboration, 2411.04175)

Impact on proton PDFs



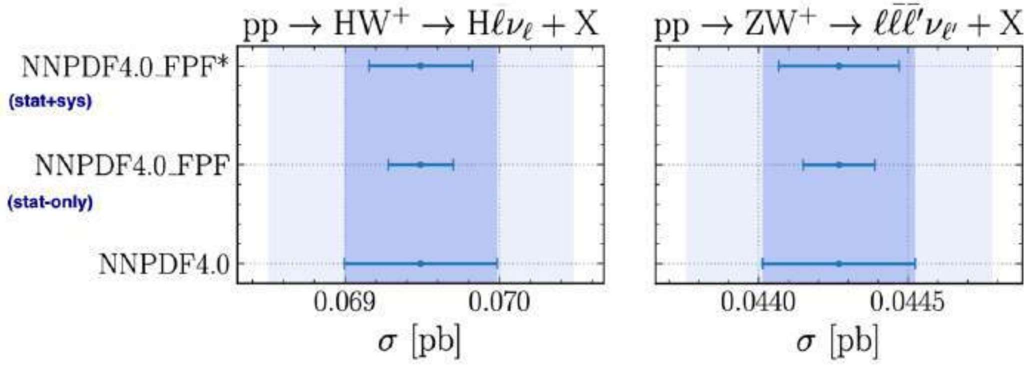
- Impact on proton PDFs quantified by the **Hessian profiling of PDF4LHC21** (xFitter) and by direct inclusion in the **global NNPDF4.0 fit**
- Most impact on **up and down valence quarks** as well as in **strangeness,** ultimately limited by systematics, but
- PDFs improved with LHC neutrino data **enhance precision HL-LHC measurements like *W* mass**

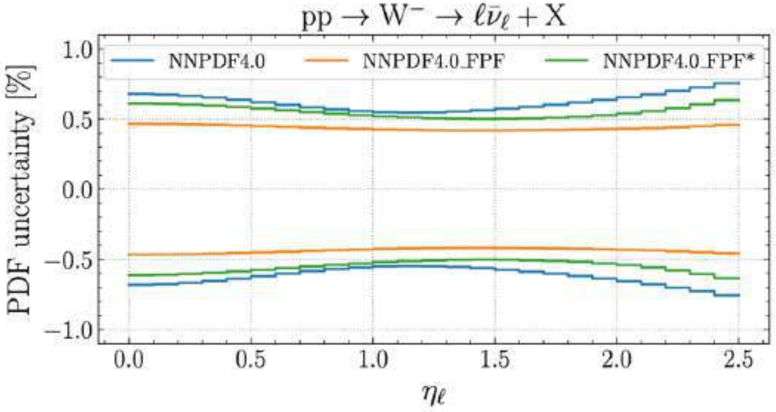




Cruz-Martinez *et al*, 2309.09581

Implications for the HL-LHC



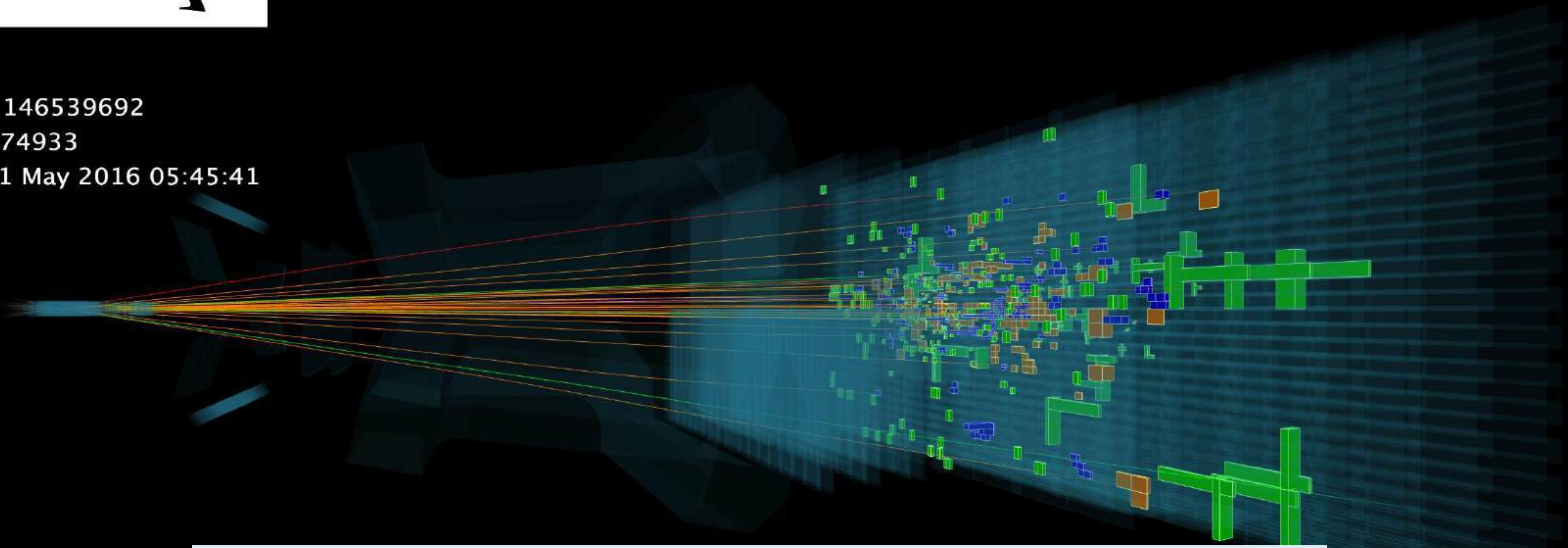


- Impact on **core HL-LHC processes** i.e. single and double weak boson production and Higgs production (VH, VBF)
- Also relevant for **BSM searches at large-mass** (via large-*x* PDFs)

Forward charm production

LHCb

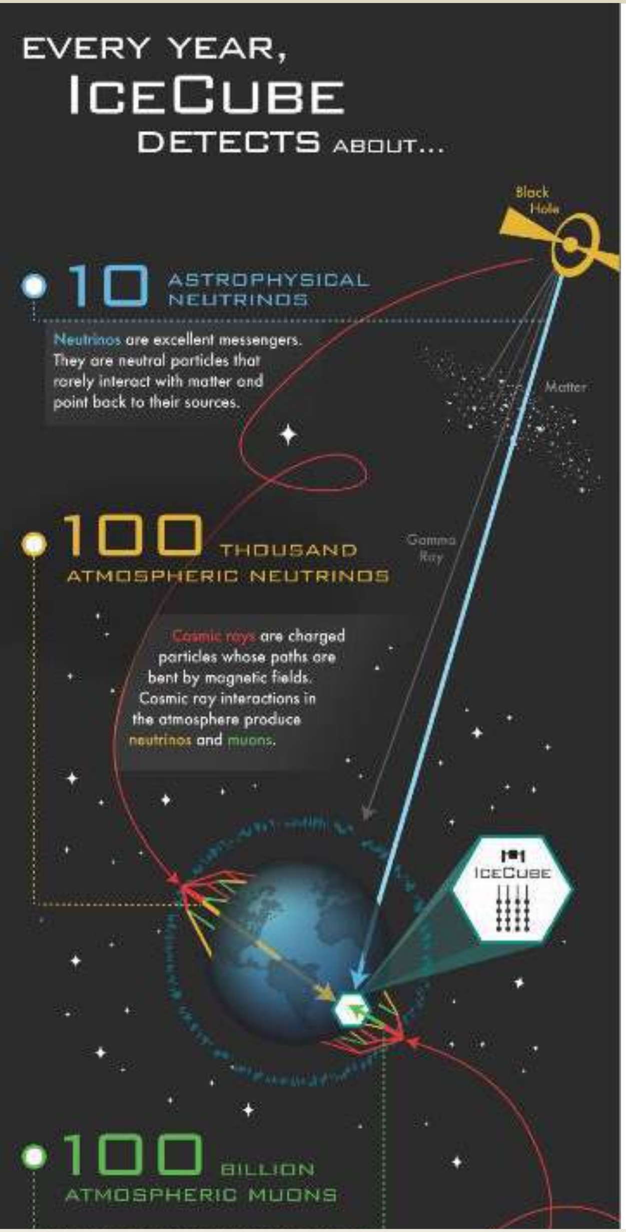
Event 146539692
Run 174933
Sat, 21 May 2016 05:45:41

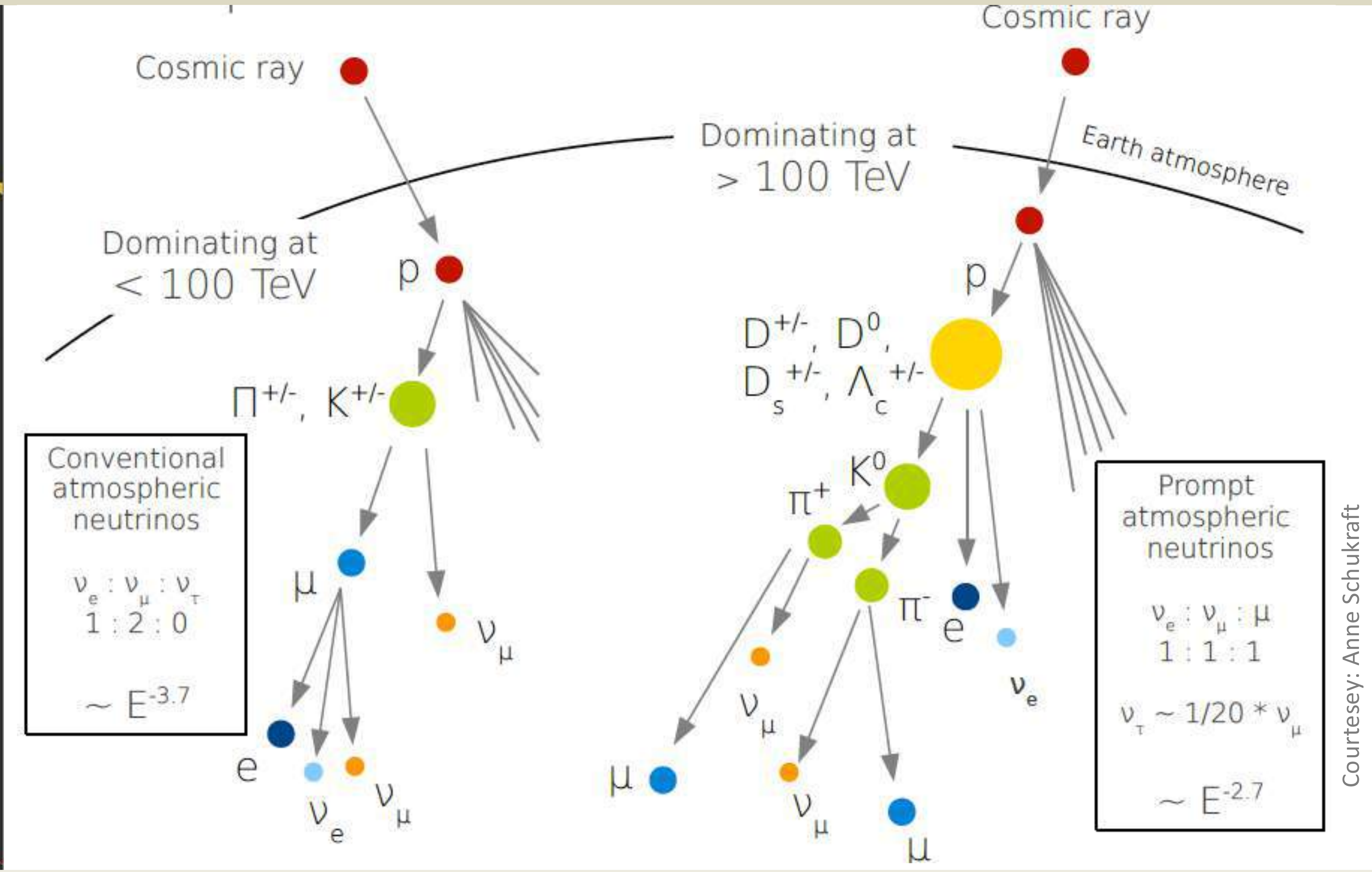


<u>**Synergy with Neutrino Telescopes**</u>:

Antares/***KM3NeT***, ***Baikal***/*GVD*, ***IceCube***/*Gen2*, … *P-One*, *Trident*,
… ***ANITA***, *PUEO*, *GRAND*, *Trinity*, … ***ARIANNA***, ***ARA***, *RNO-G*

Neutrino telescopes look for a cosmic signal buried in a huge background of atmospheric neutrinos



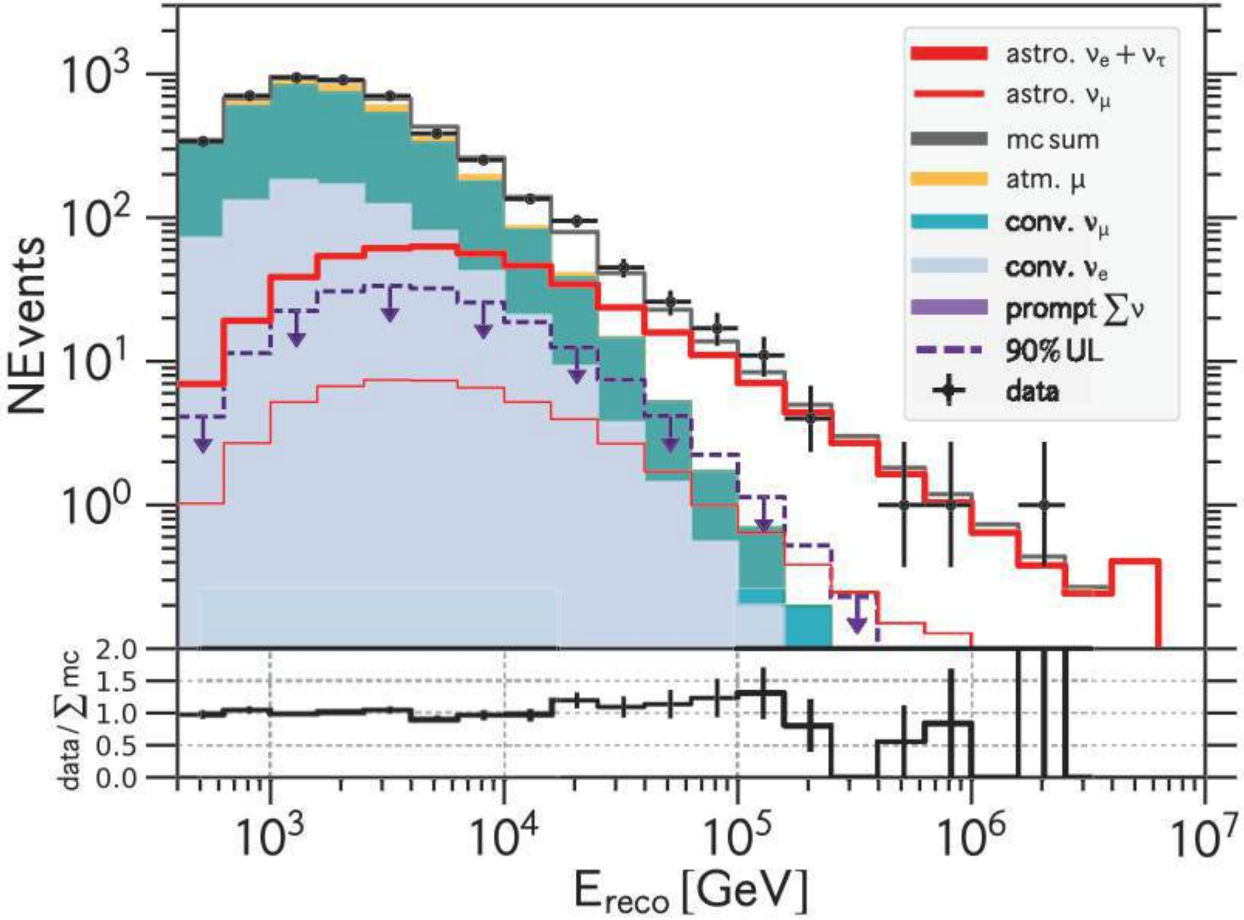


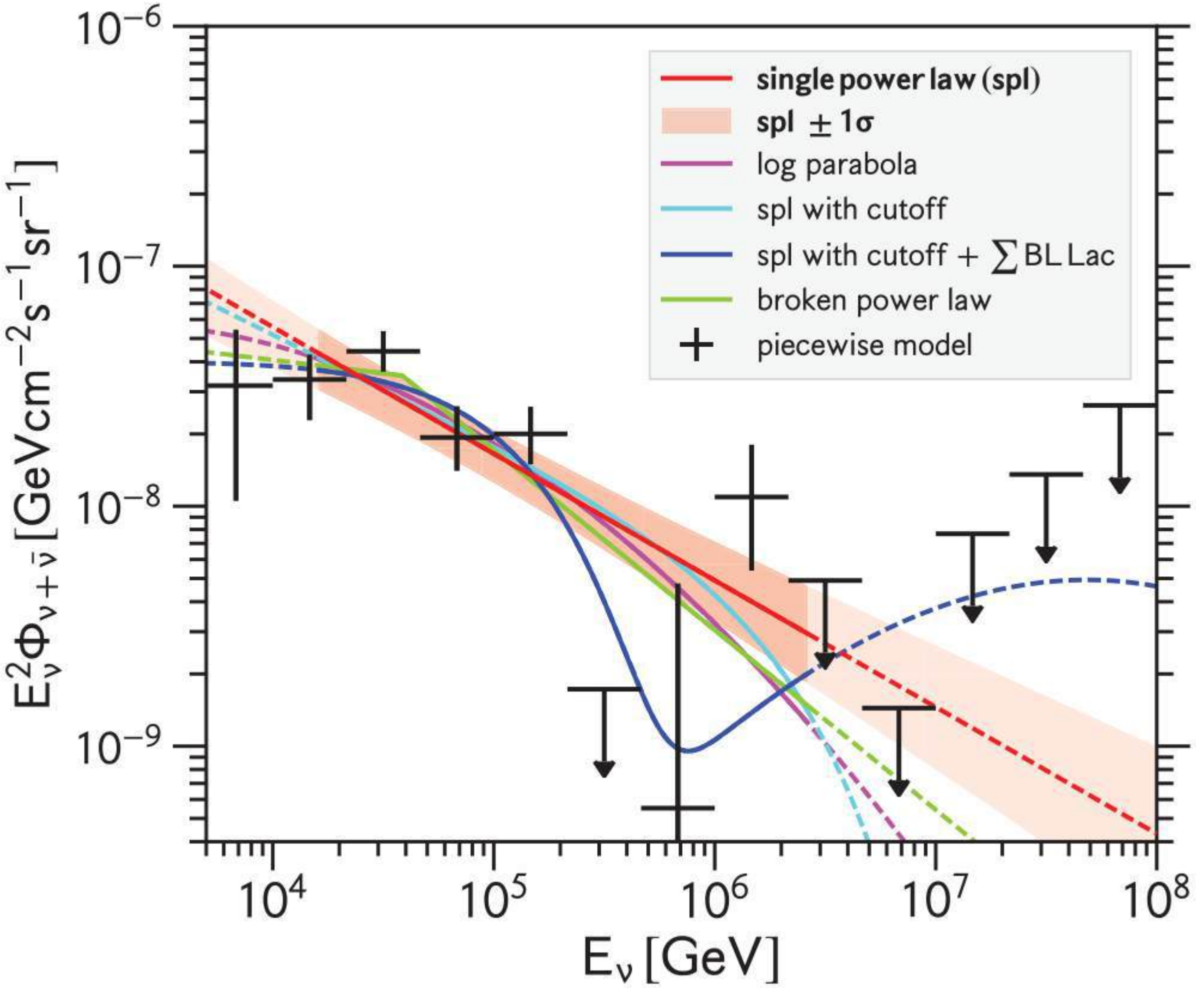
The ‘conventional flux’ is well understood as it is calibrated against many observations but uncertainties in charm production make the prompt flux less so although it is the most important background for the astrophysical flux!

the ν flux from atmospheric charm production is important for IceCube

The astrophysical ν flux can be fitted by a power-law, broken power-law, spline with a cut-off, log-parabola …

Need to discriminate between these in order to identify the source(s) – but this requires better estimate of atmospheric prompt ν background



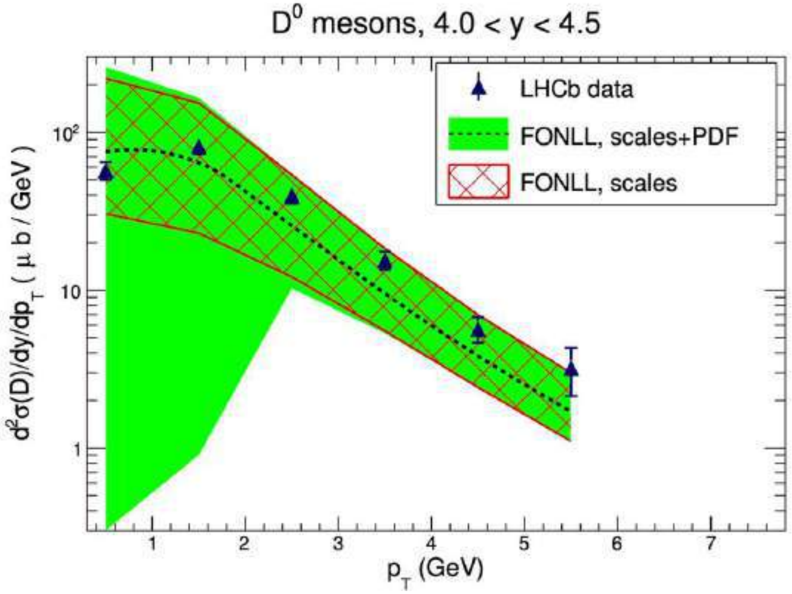


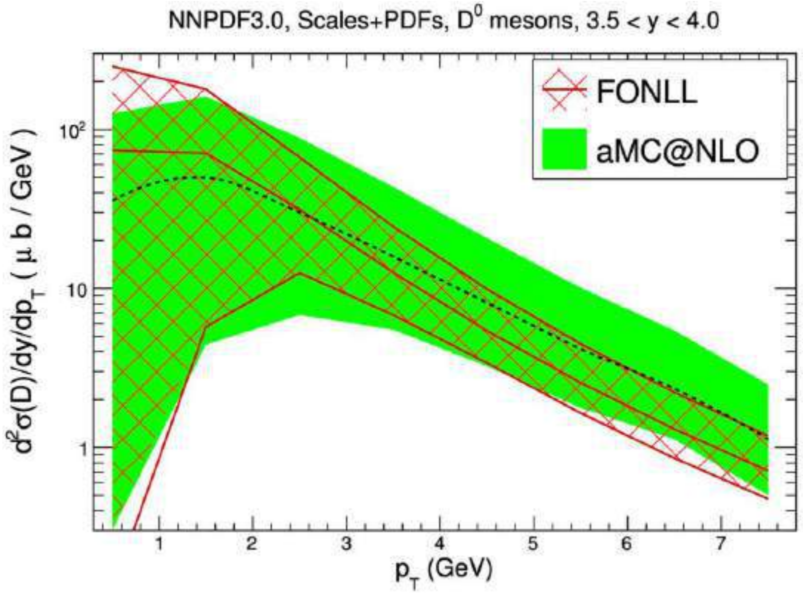
Aartsen *et al*, *PRL* **125**:121104,2020

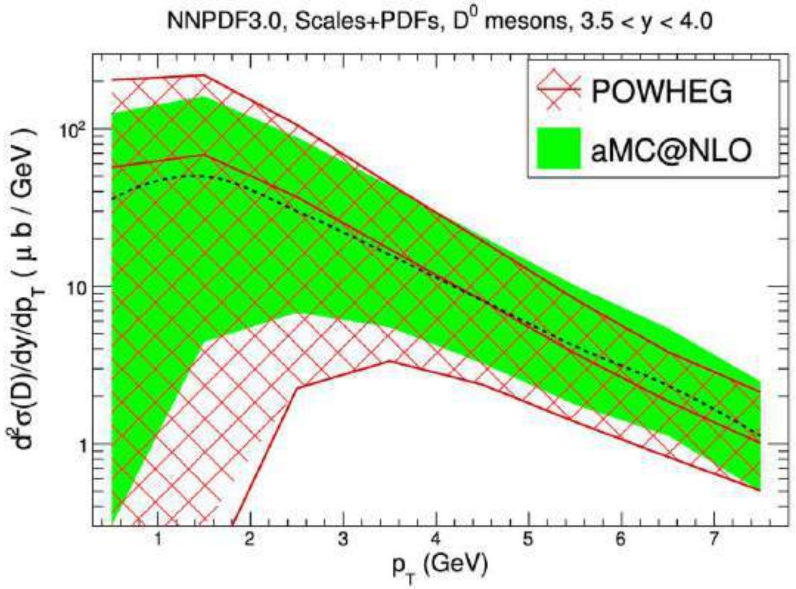
To measure this at an accelerator requires:
$\sqrt{s} = \sqrt{2E_\nu m_p} \simeq 10$ TeV, for $E_\nu \sim 10^7$ GeV: **LHCb**
and $x_{1,2} \sim (m_c/\sqrt{s})\, e^{\pm\eta} \Rightarrow \eta \sim 7\text{-}9$: requires **FPF**

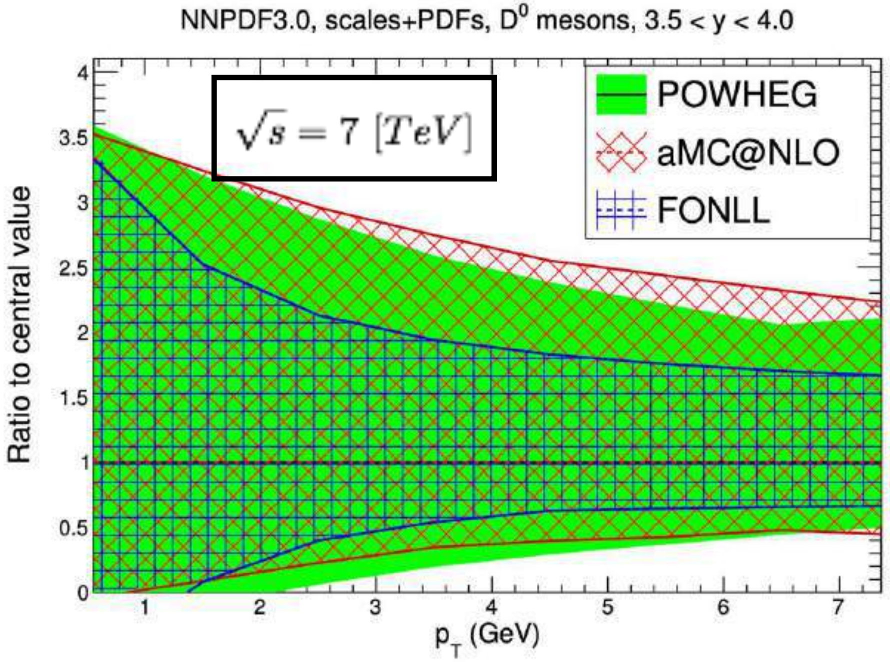
Forward Charm Production & LHCb

LHCb collab. *NPB* **871**:1,2013

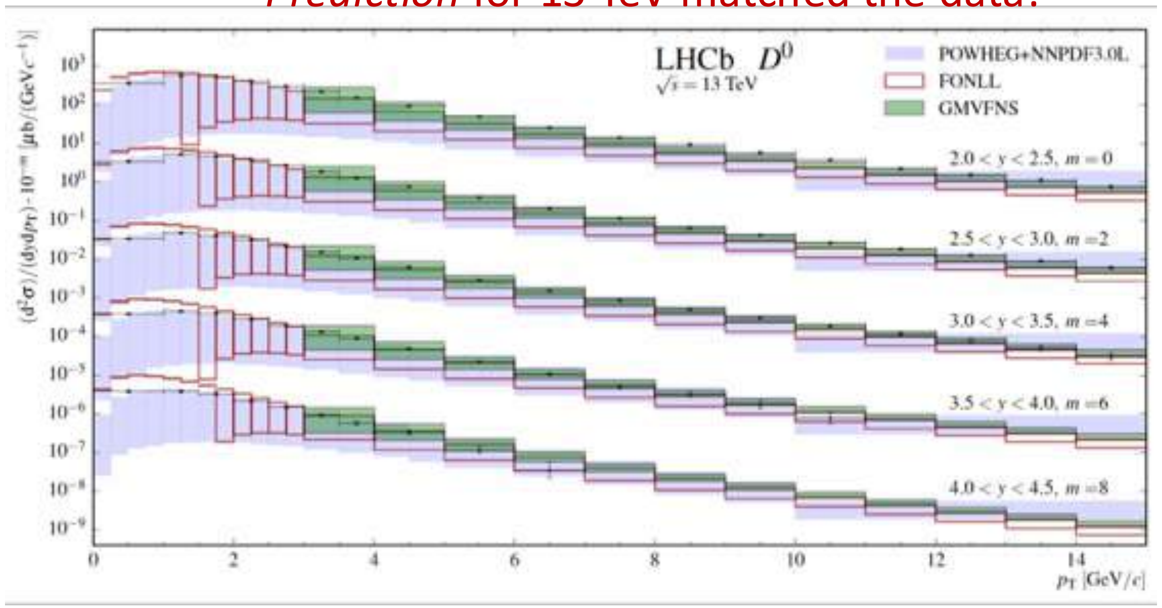






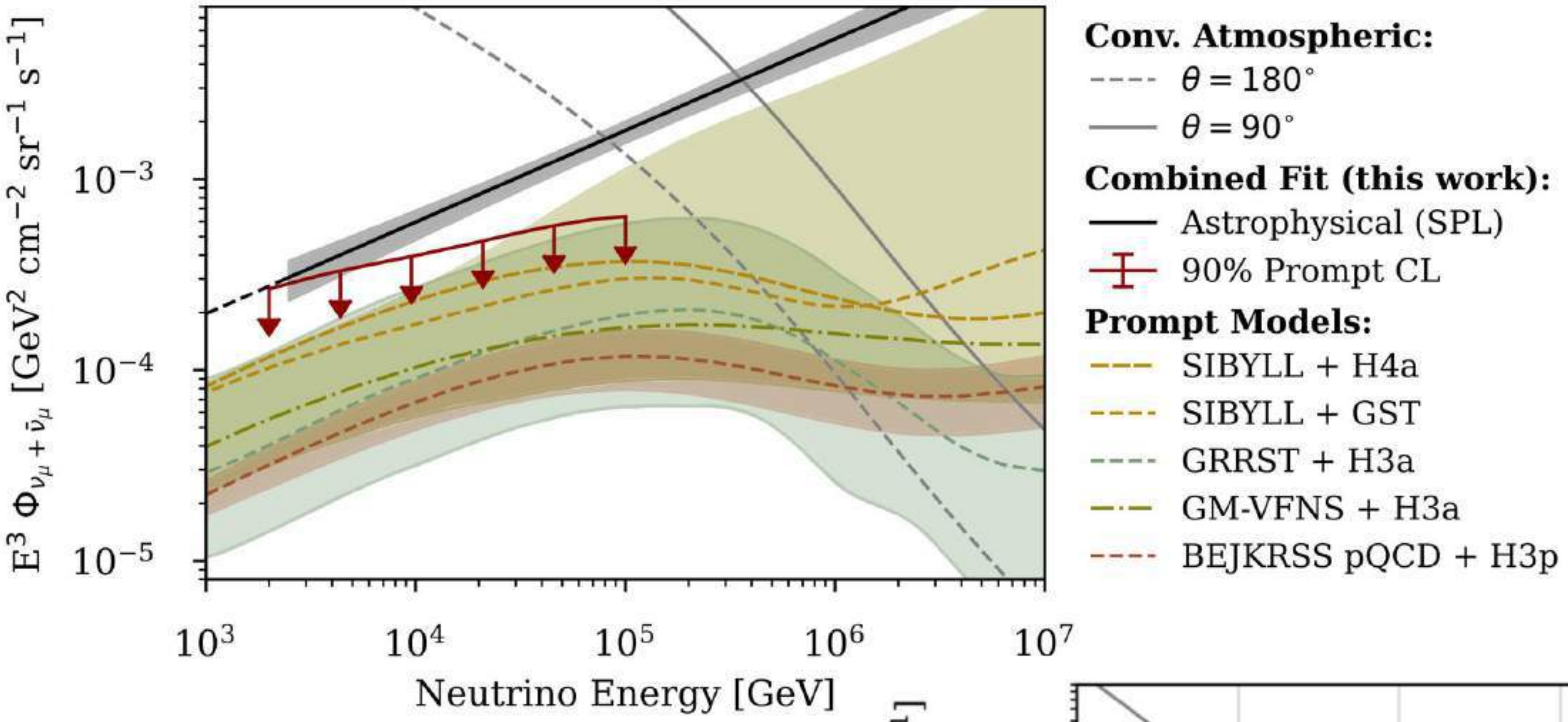


Prediction for 13 TeV matched the data!



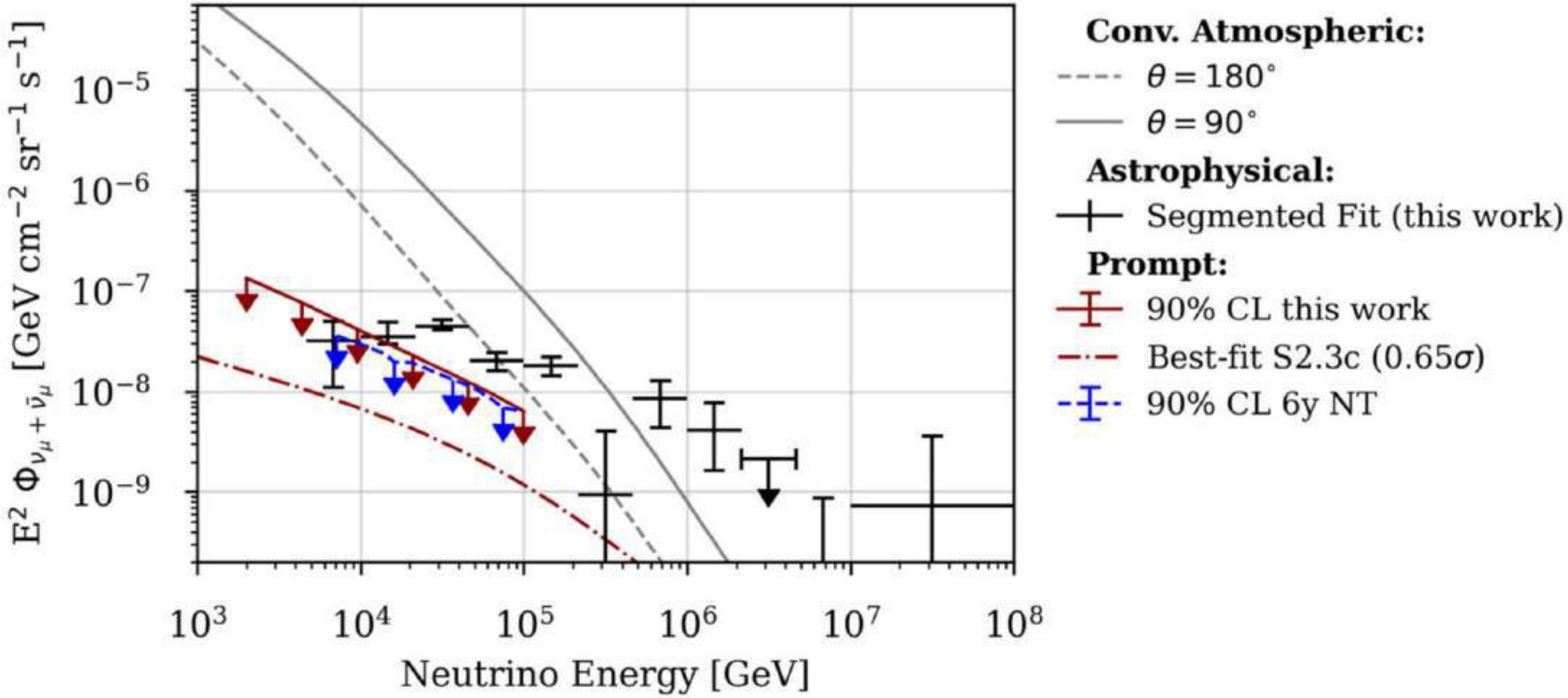
Gauld *et al*, *JHEP* **11**:009,2015

NLO predictions for forward charm production validated with LHCb data



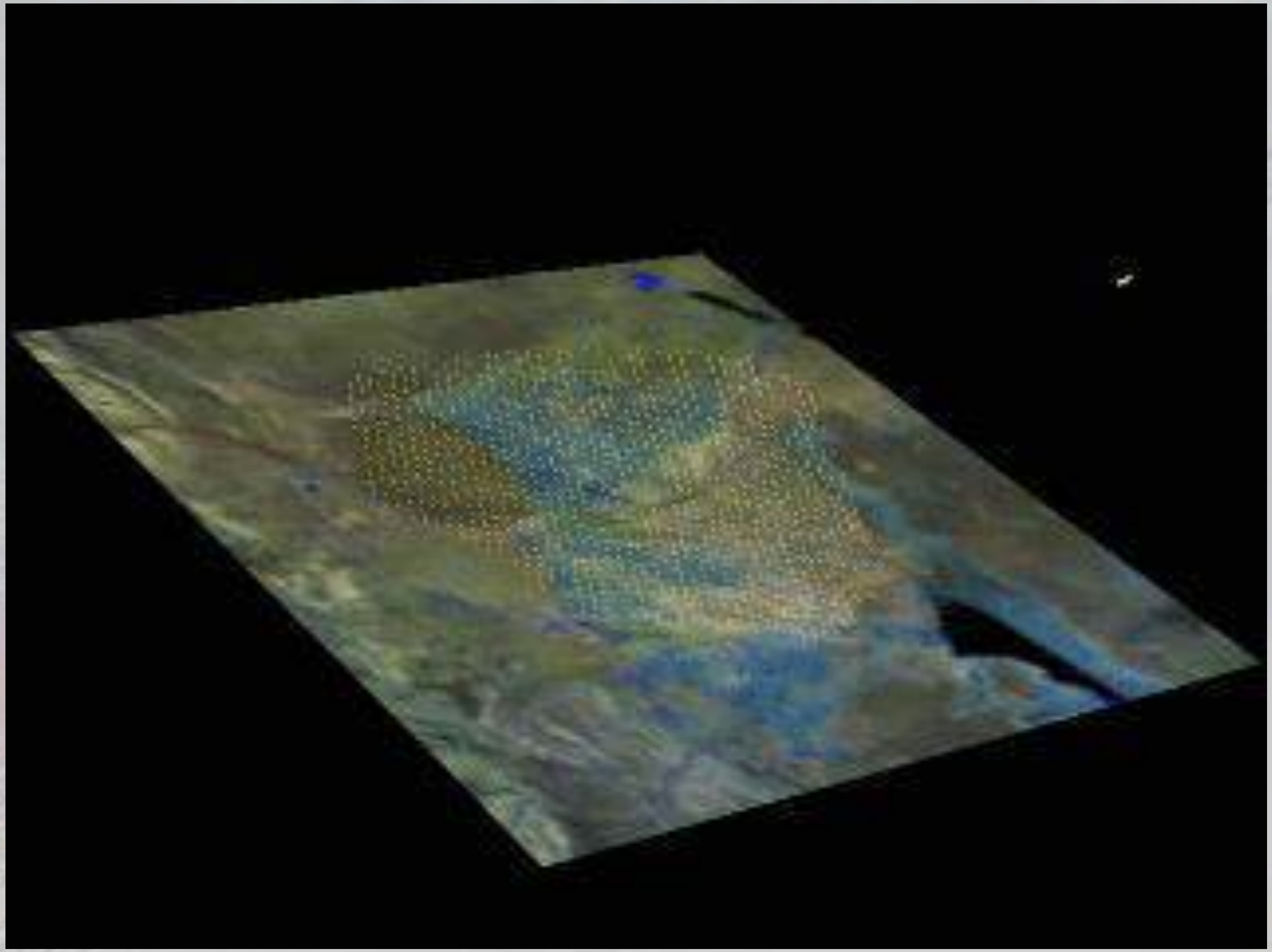
Range of prompt ν flux predictions are reduced with input from LHCb

IceCube, *EPJ C* **86**:814,2026



FPF will measure the prompt neutrinos even *more* forward ($|y| > 7.2$) than LHCb can access

Light hadron production

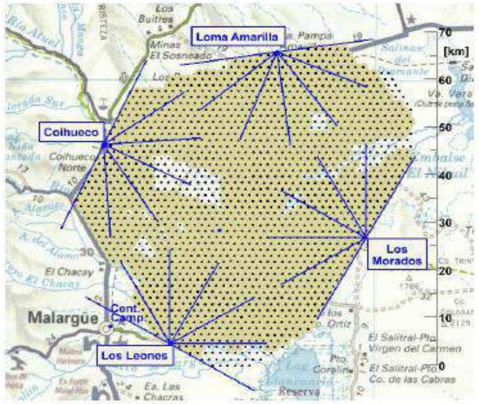


Synergy with Cosmic Ray Air Shower arrays:

Pierre Auger Observatory, ***IceTop***, *KASCADE-GRANDE*, ***LHASSO***,
NEVOD-DECOR, *SUGAR*, ***Telescope Array***, *TUNKA*, *Yakutsk* **…**

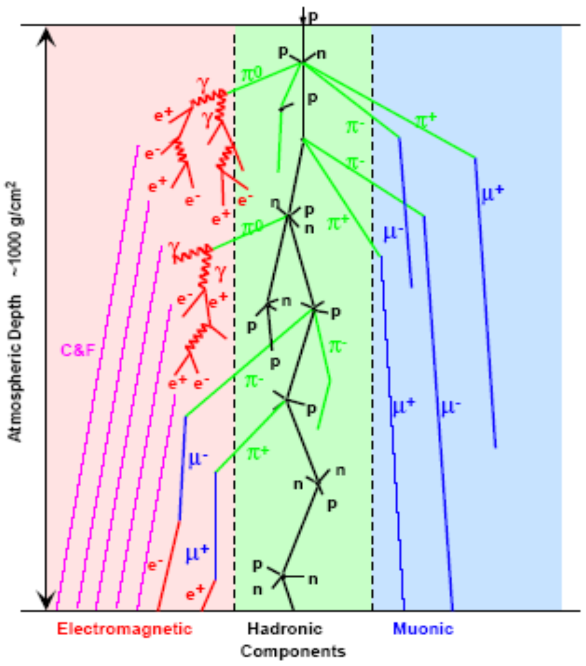
Pampa Amarilla, Argentina

The Pierre Auger Observatory



- 1600 water-cherenkov detectors
- Aperture $>$ 7000 km^2 sr yr $\equiv$ 70
- 4 $\times$ 6 telescopes

Schematic Shower Development



Fluorescence & Cherenkov-Light (isotropic) (forward peaked)

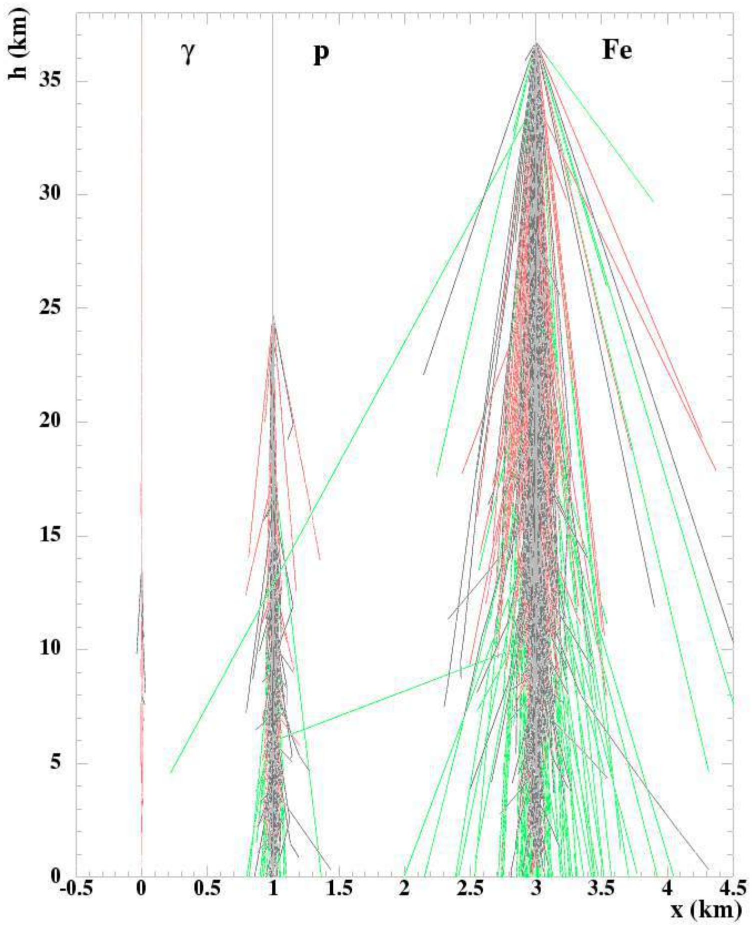
p, n, π : near shower axis
μ, e, γ : widely spread

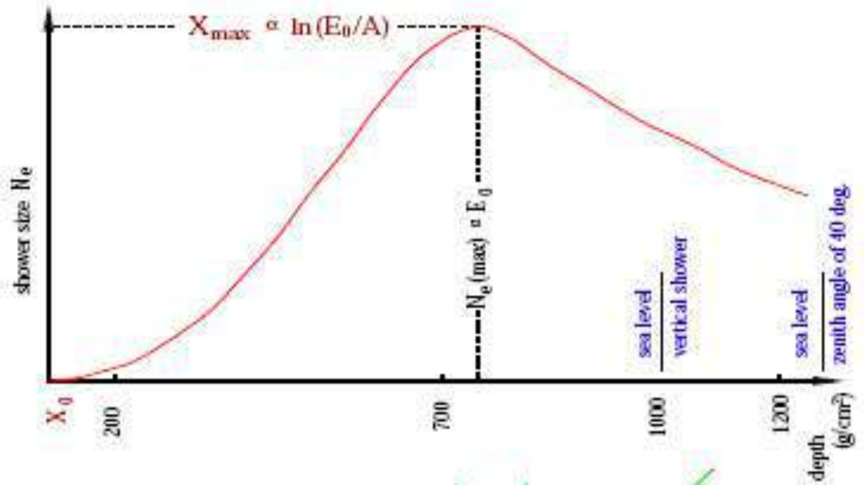
e, γ : from π^0, μ decays ~ 10 MeV
μ : from $\pi^\pm$, K, ... decays ~ 1 GeV

$N_{e,\gamma}$: N_μ ~ 10 ... 100 varying with core distance, energy, mass, Θ, ...

Details depend on:
interaction cross-sections,
hadronic and el.mag. particle production,
decays, transport, ...
at energies well above man-made accelerators

Complex interplay with many correlations
requires MC simulations





Main sources of uncertainty

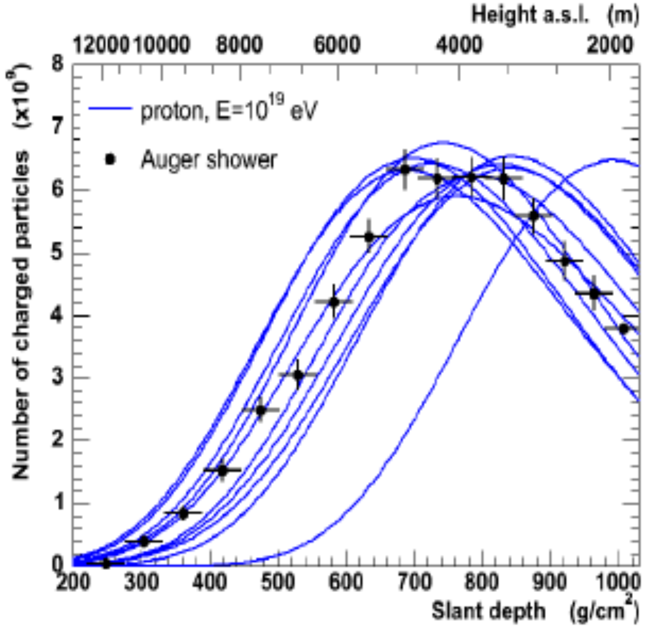
- Minijet cross-section (parton densities, range of applicability)
- Transverse profile function (total #-secn, multiplicity distribution)
- Energy dependence of leading particle production
- Role of nuclear effects (saturation, stopping power, QGP)

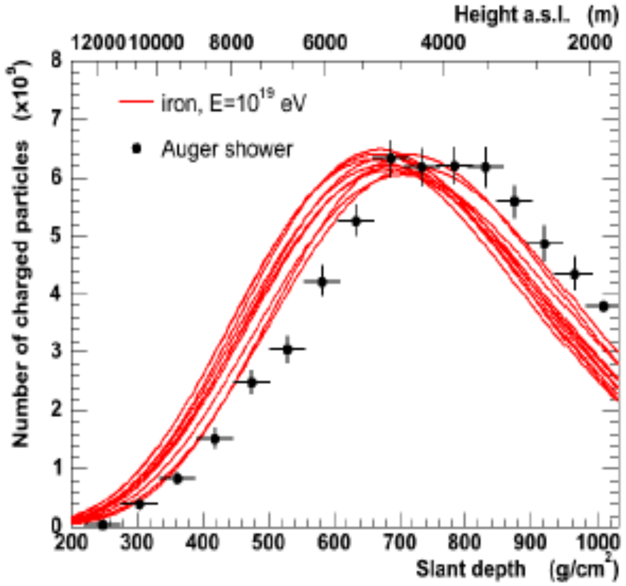
Need input from forward physics experiments

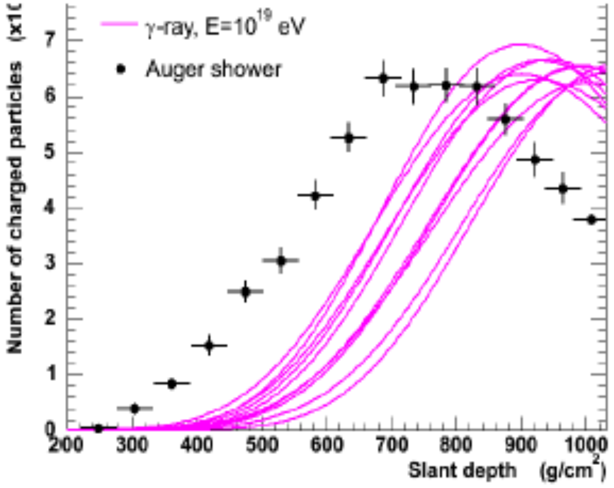
Energy/composition: shower profile

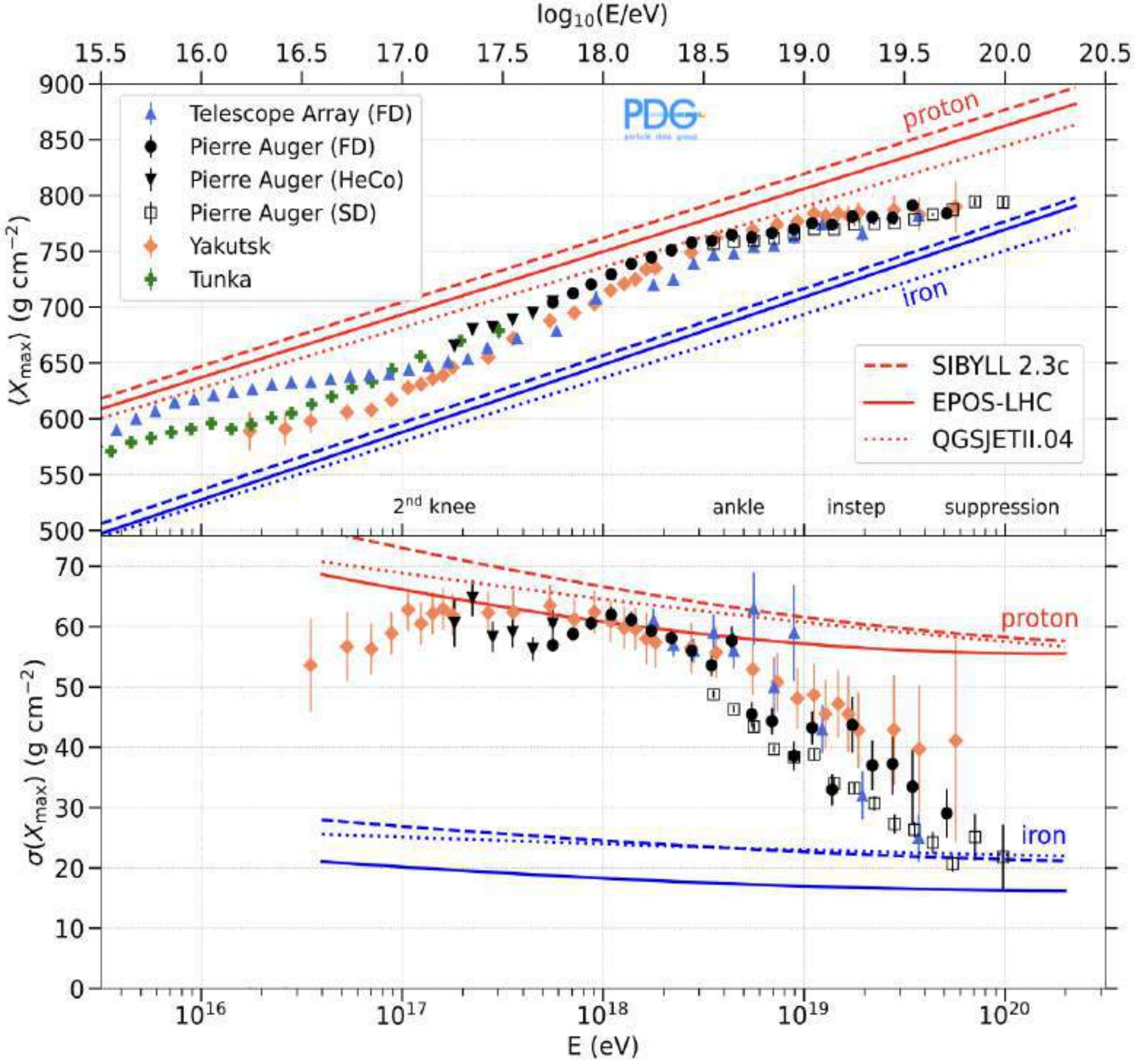
Trend of composition getting heavier with increasing energy

Detailed MC simulation: 10 showers
zenith angle 35°, QGSJET







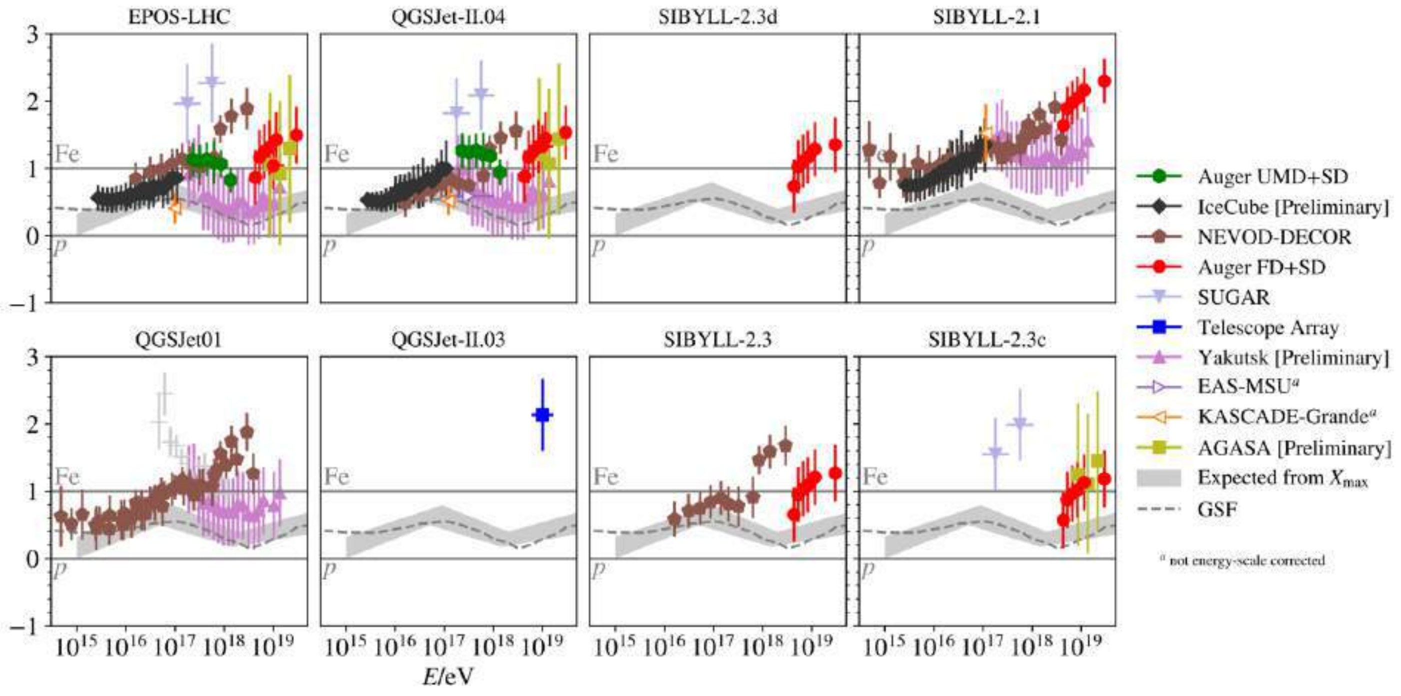


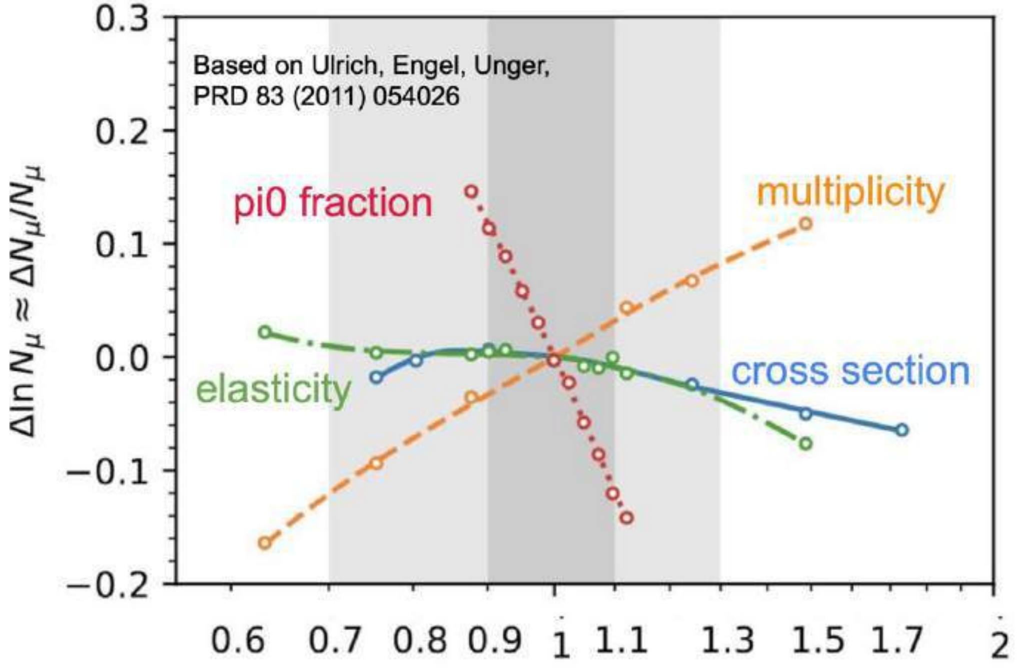
$$N_{max}^{A} = N_{max}, \qquad X_{max}^{A} \sim \lambda_e \ln(E_0/A)$$

Can discriminate between hadrons & photons …
harder to distinguish between p and Fe nuclei

PDG, Int.J.Mod.Phys.A**41**:2630011,2026

The Cosmic ray muon anomaly – new physics?



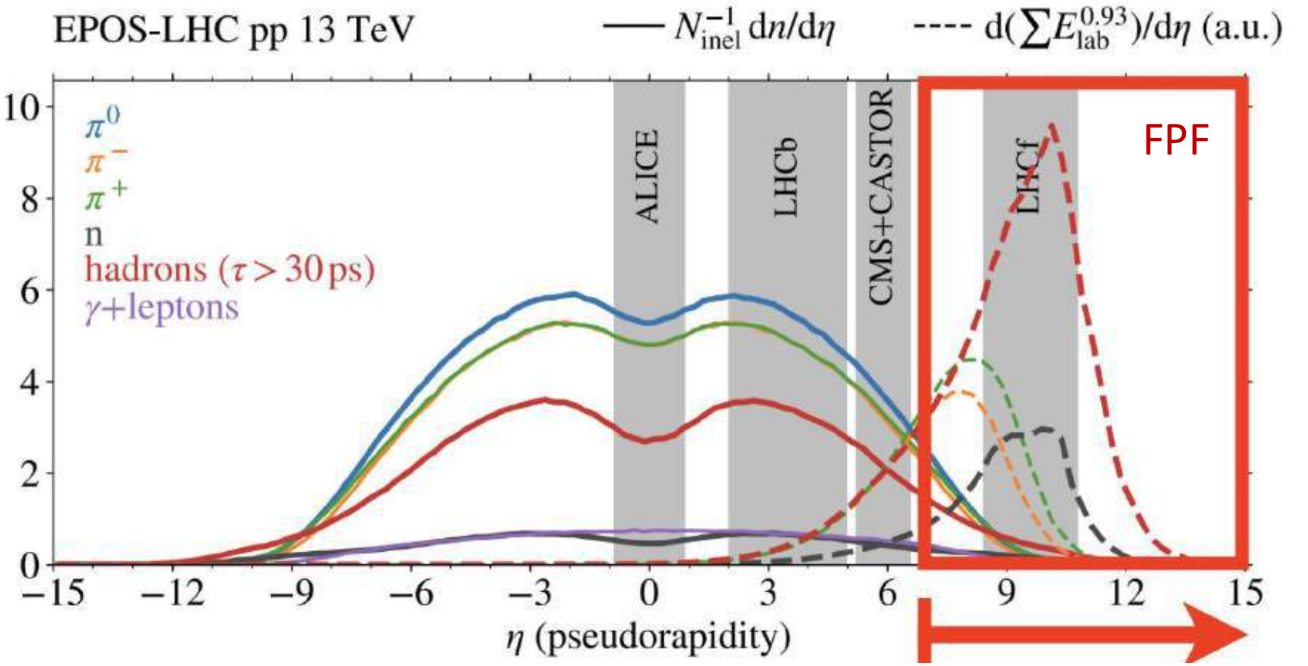


Albrecht *et al*, Astrophys.Space.Sci. **367**:27,2022

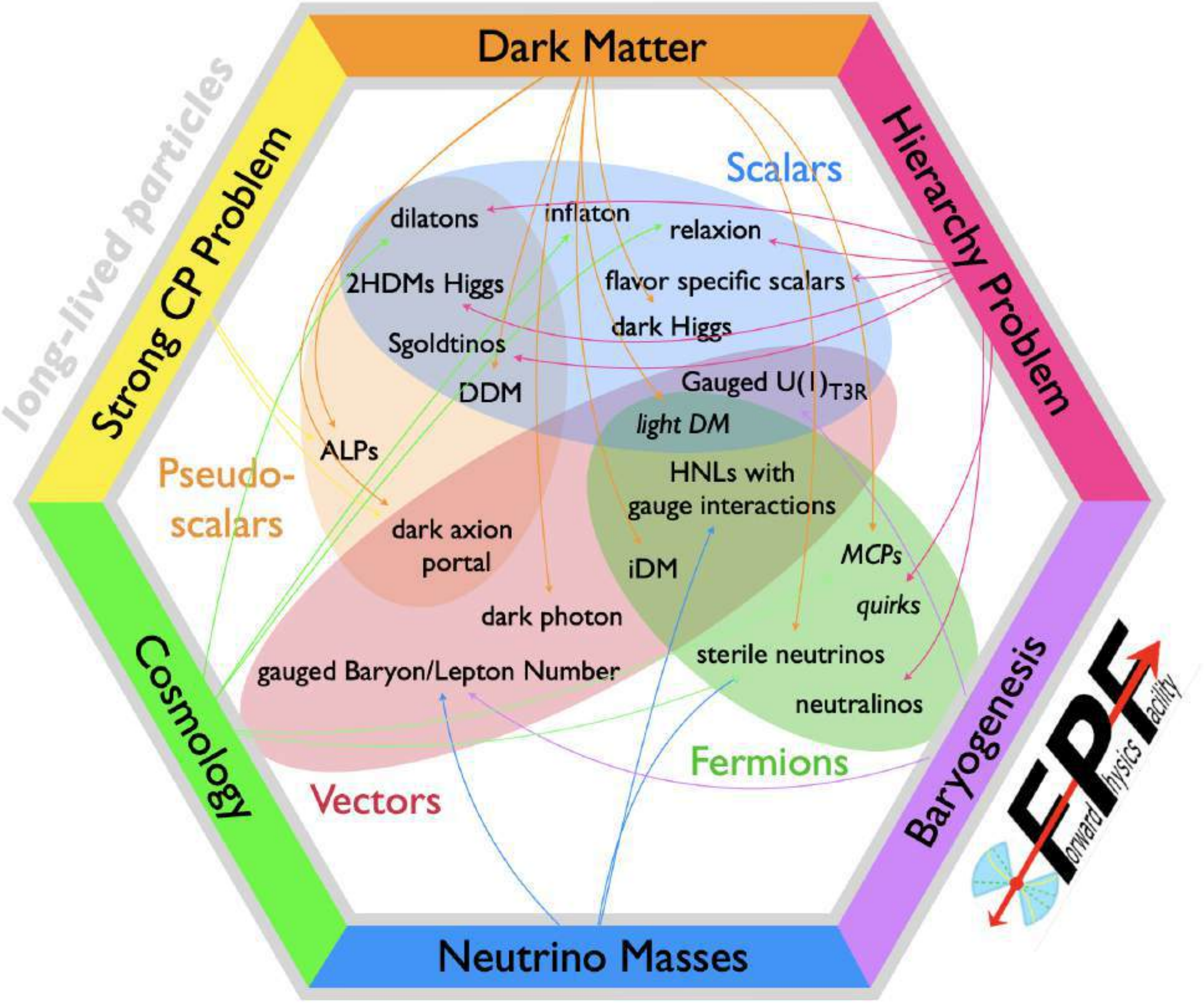
~30-60% mismatch between the observed muon flux and simulations

Difficult to explain away by tuning parameters without introducing other discrepancies with cosmic ray data

The FPF will measure forward light hadron production in a kinematic range never before explored and claify the issue

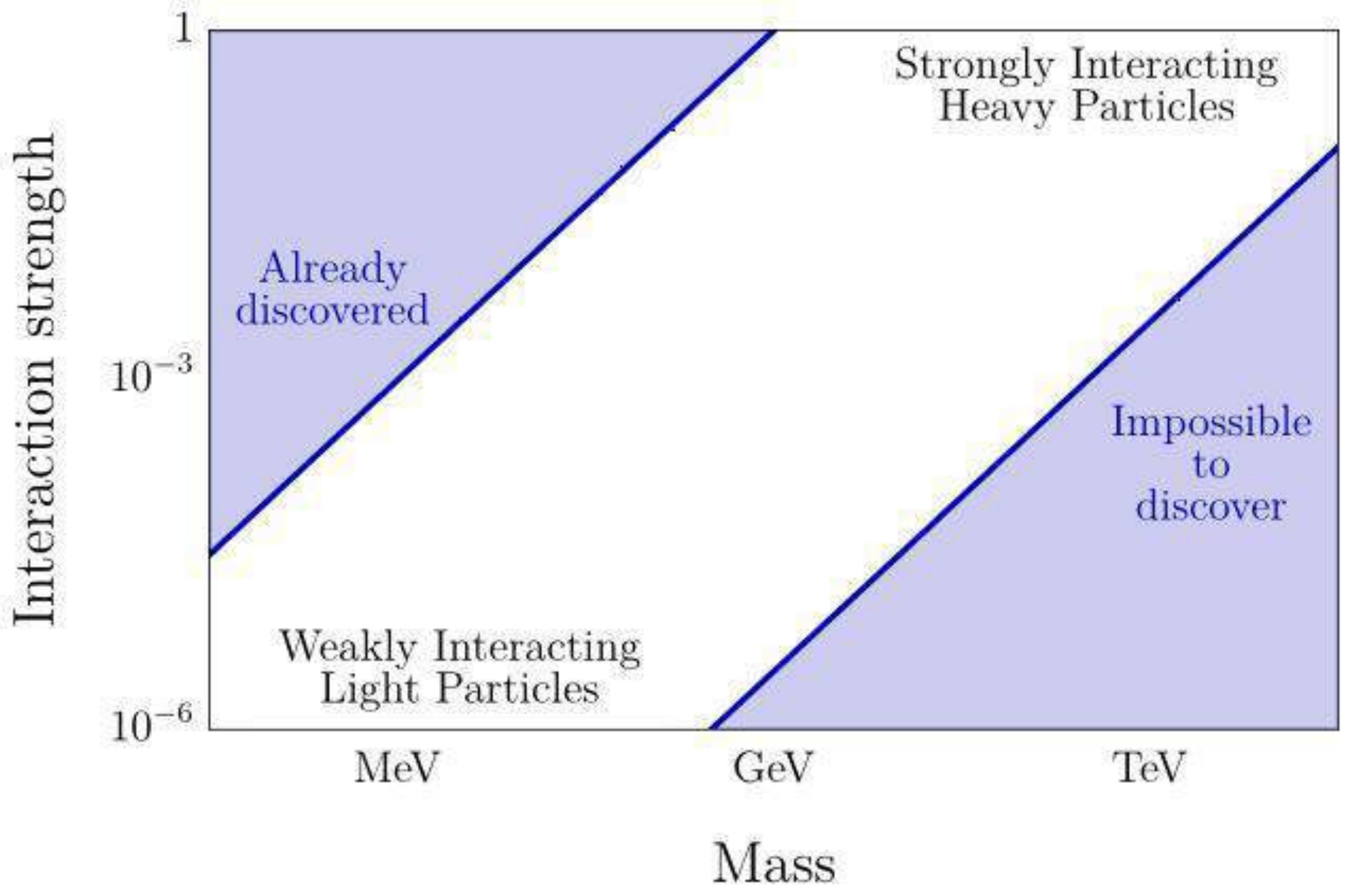


BSM physics



Synergy with dark matter experiments and γ-ray & neutrino telescopes

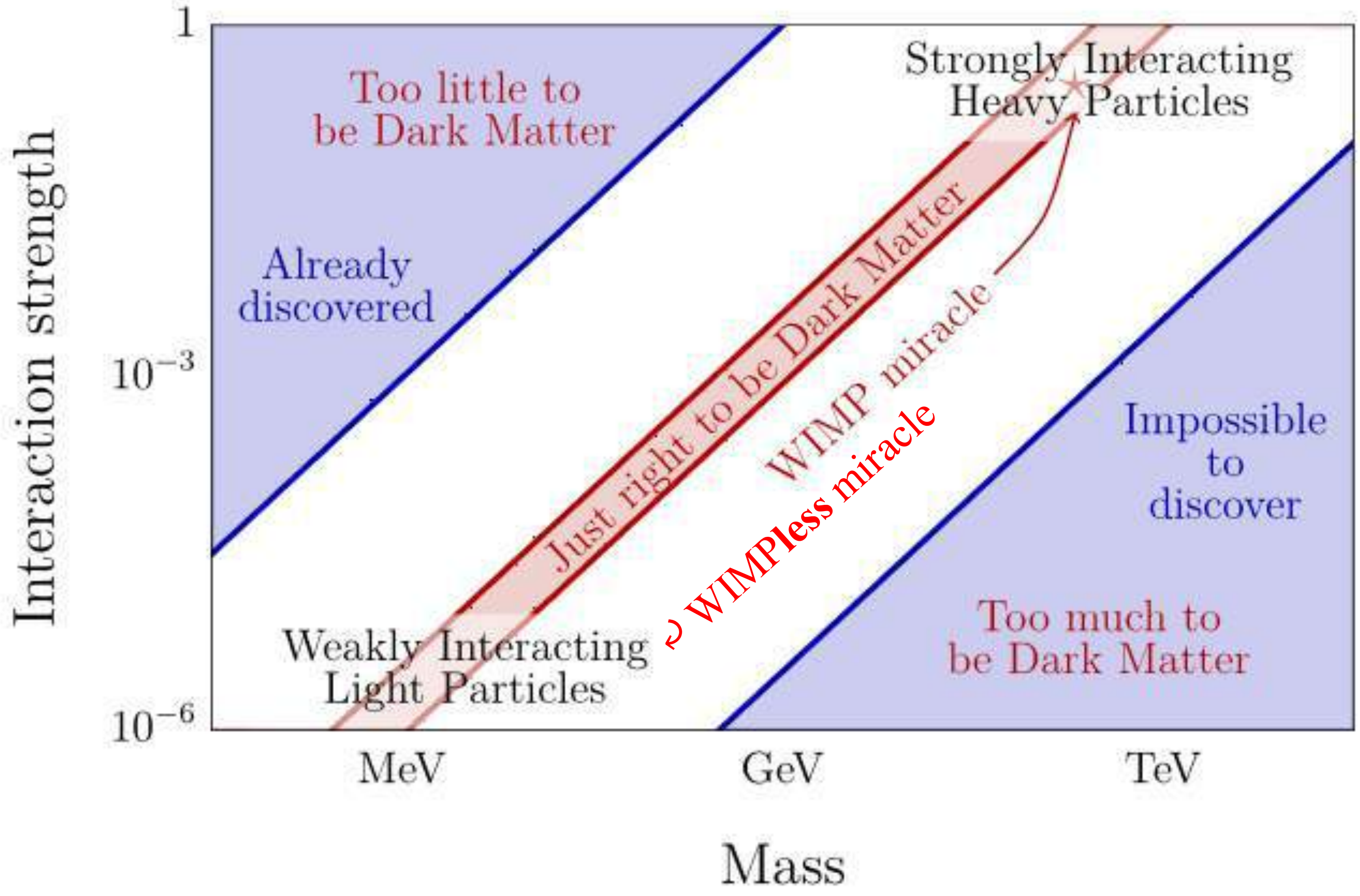
The new particle landscape

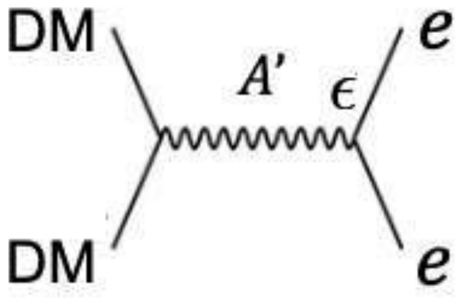


- ATLAS & CMS are designed to find new heavy particles which are produced nearly and rest and decay isotropically
- New light particles are produced mainly along the beam, so disappear through the holes that let the beams in …
- We need a detector to cover these blind spots in the forward region*

  * Or do a beam dump experiment

THE 'WIMP-LESS MIRACLE'



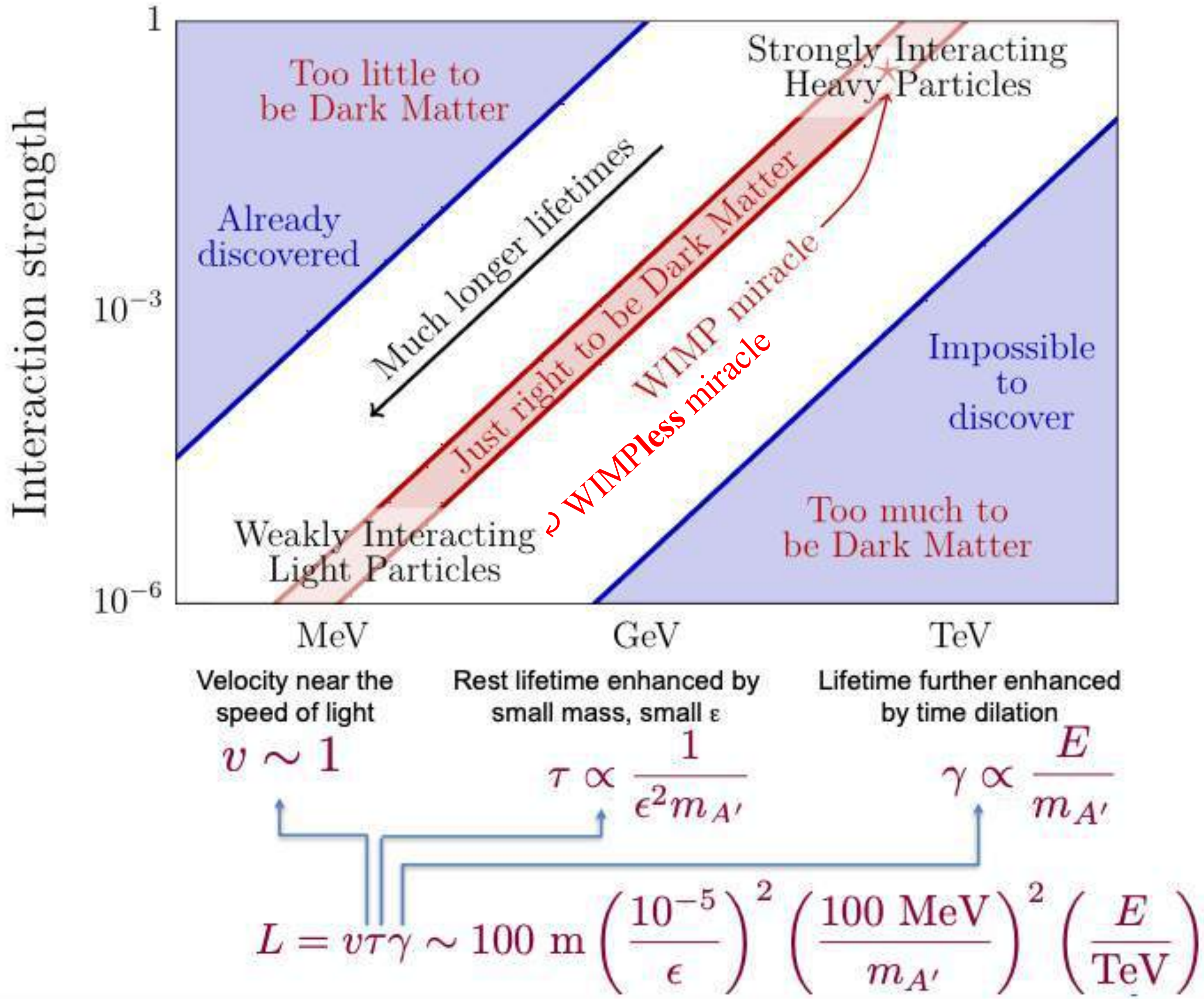


$$\langle \sigma v \rangle \sim \epsilon^2 / m_{A'}^2$$

$$\Omega_{DM} \propto 1/\langle \sigma v \rangle \sim m_{A'}^2/\epsilon^2$$

Feng & Kumar, *PRL* **101:231301**,2008

Long-lived particles



Theoretical motivations for New Light Feebly Interacting/Long-Lived Particles

Standard Model

Abelian, unbroken
Electromagnetism $U(1)_{EM}$

Abelian, spontaneously broken
Hypercharge $U(1)_{Y}$

Non-Abelian, spontaneously broken
Weak $SU(2)_{L}$

Non-Abelian, confined
QCD $SU(3)_{c}$

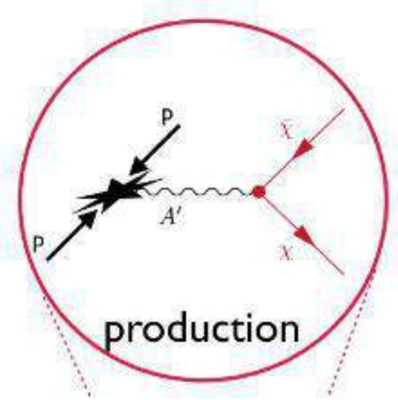
Dark Sector

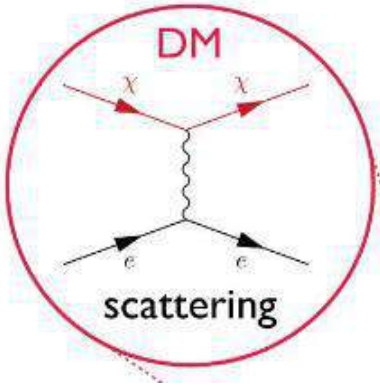
Abelian, unbroken
Millicharged particles (FORMOSA)

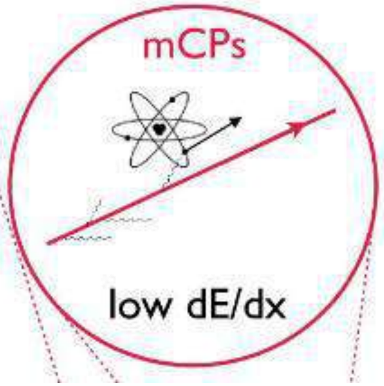
Abelian, spontaneously broken
Dark photon B-L, L_{μ}-L_{τ} gauge bosons
(FASER2, FASERn2, AdvSND, FLArE)

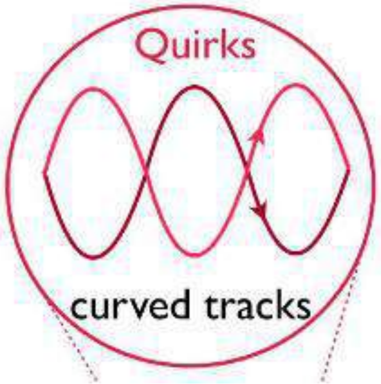
Non-Abelian, spontaneously broken ?

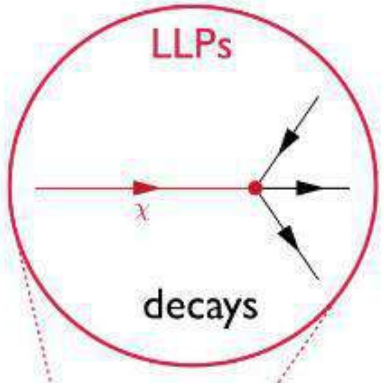
Non-Abelian, confined
Quirks (FASER2, FLArE)









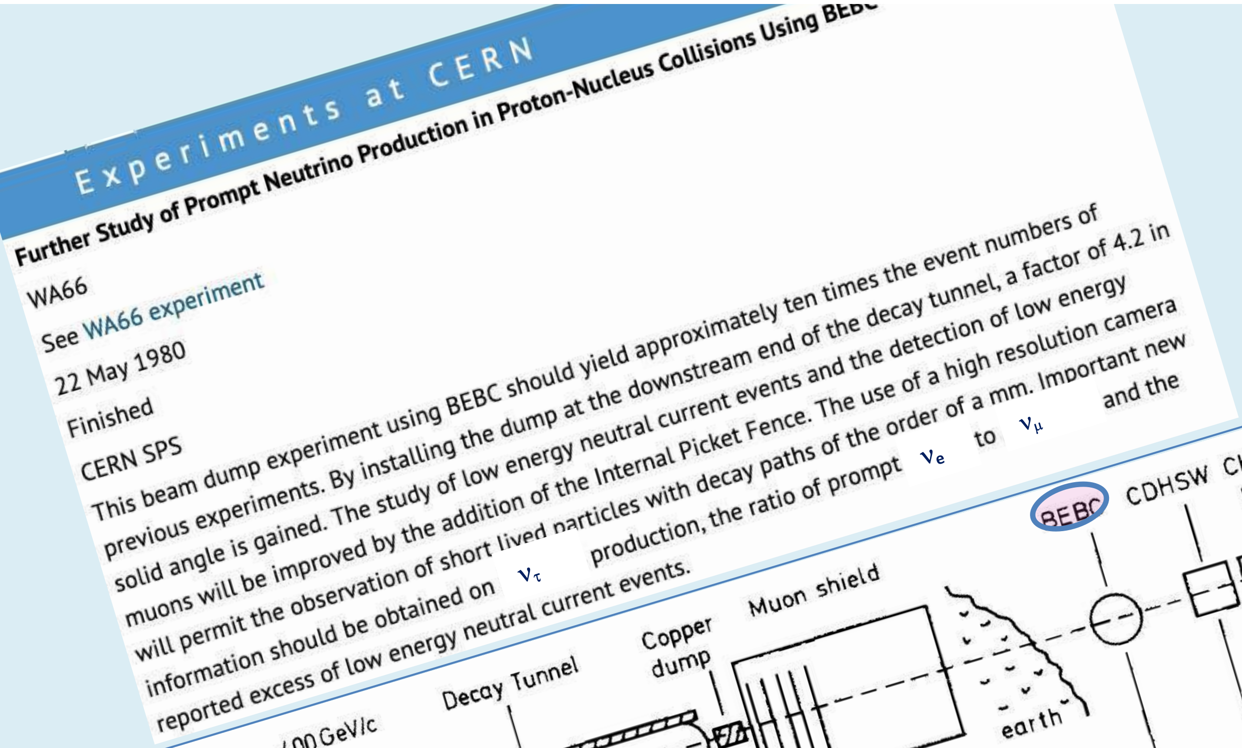


The Portal Formalism

$$\mathcal{L}_{\text{portal}} = \sum O_{\text{SM}} \times O_{\text{DS}}$$

Vector portal	$F'_{\mu\nu} F^{\mu\nu}$	
Scalar portal	$\phi H^\dagger H$	$\phi^2 H^\dagger H$
Neutrino portal	$L H N$	
Axion portal	$\frac{\partial_\mu a}{f_a} \bar{\psi} \gamma^\mu \gamma^5 \psi$	

Such searches were carried out ~40 years ago at CERN by the neutrino beam dump experiments at the SPS – I will focus on BEBC WA66 which searched for light neutralinos, heavy neutral leptons, neutrino magnetic moments *etc*


Experiments at CERN

Further Study of Prompt Neutrino Production in Proton-Nucleus Collisions Using BEBC

WA66

See WA66 experiment

22 May 1980

Finished

CERN SPS

This beam dump experiment using BEBC should yield approximately ten times the event numbers of previous experiments. By installing the dump at the downstream end of the decay tunnel, a factor of 4.2 in solid angle is gained. The study of low energy neutral current events and the detection of low energy muons will be improved by the addition of the Internal Picket Fence. The use of a high resolution camera will permit the observation of short lived particles with decay paths of the order of a mm. Important new information should be obtained on ν_τ production, the ratio of prompt ν_e to ν_μ and the reported excess of low energy neutral current events.

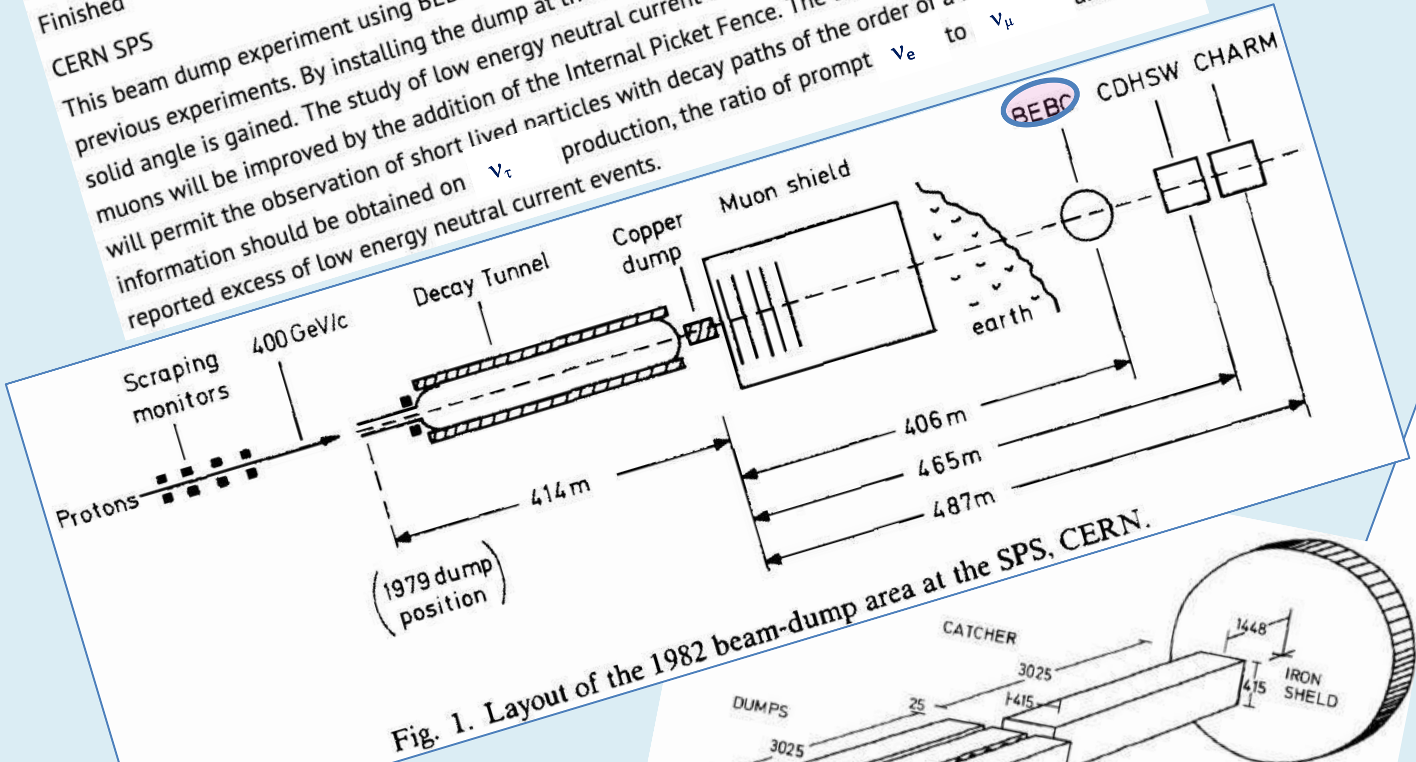
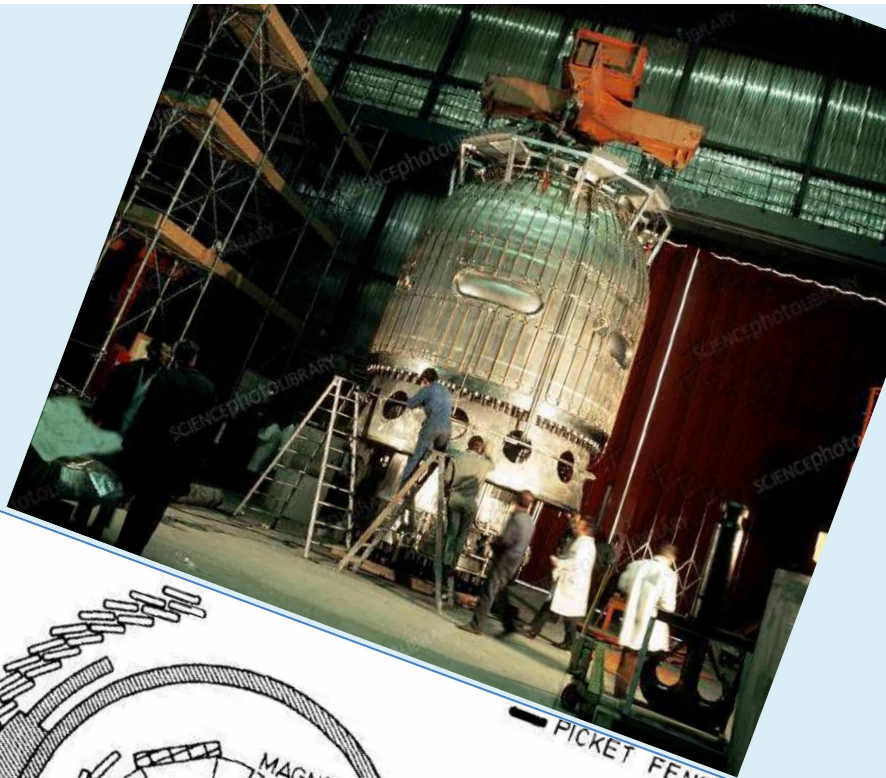
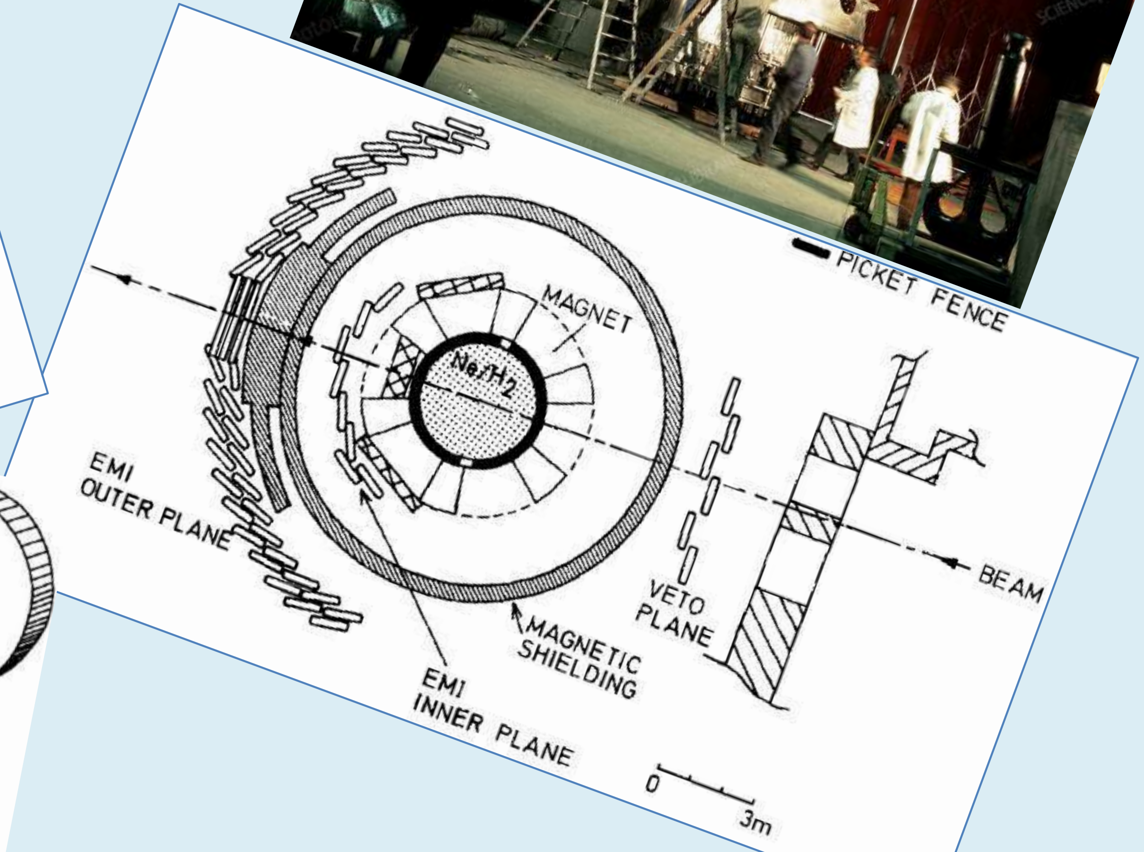
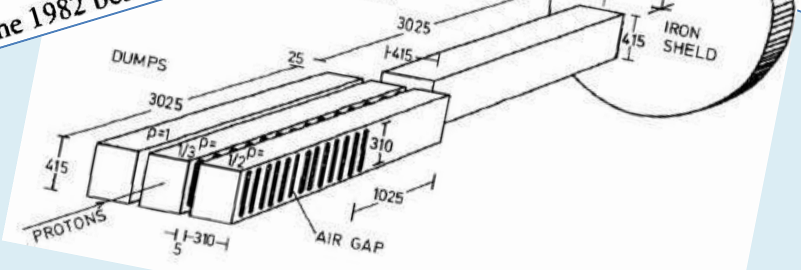


Fig. 1. Layout of the 1982 beam-dump area at the SPS, CERN.

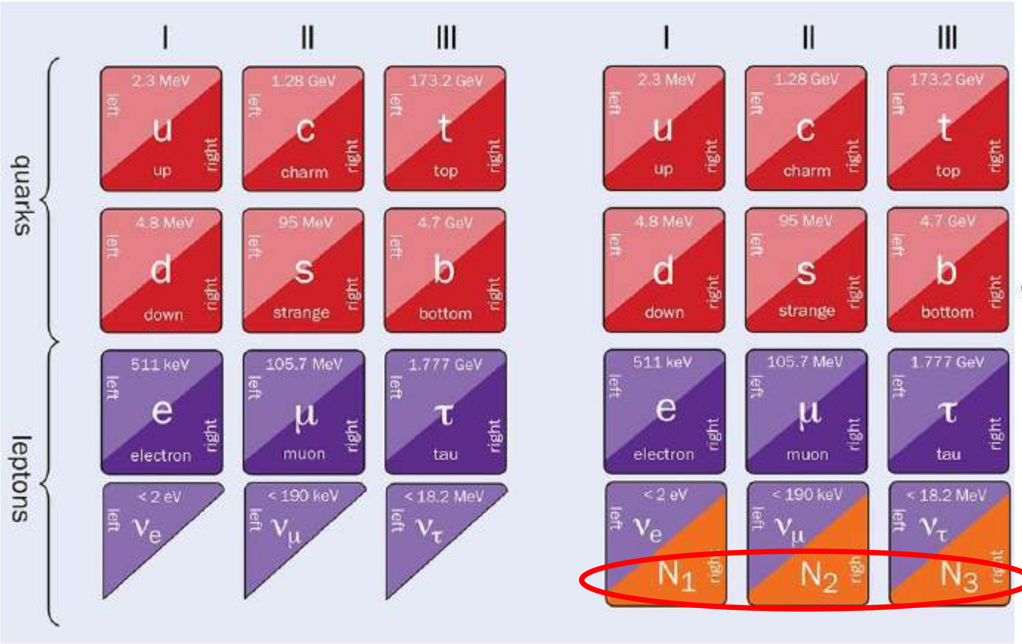


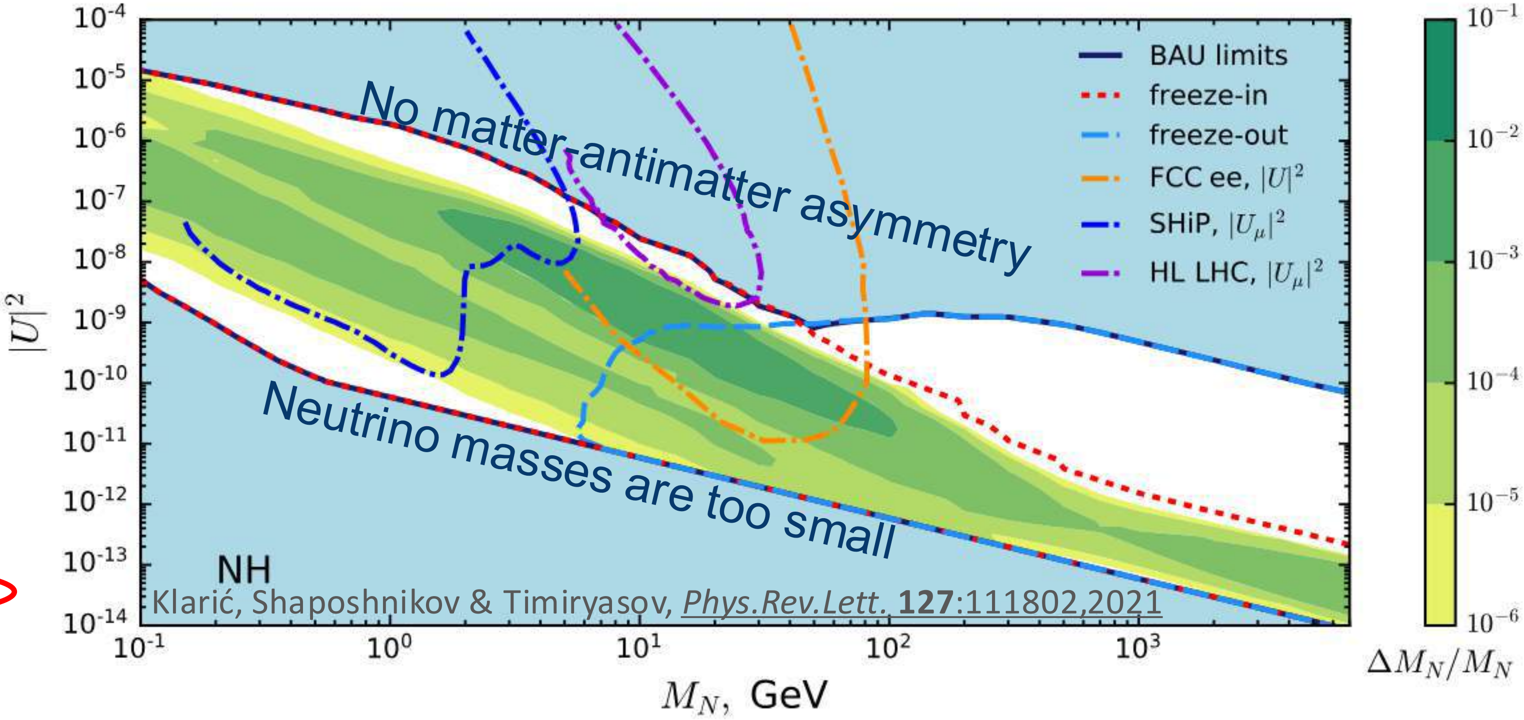




Subsequently neutrino oscillations were discovered … *first* sign of physics beyond SM

The simplest renormalisable extension of the SM which accommodates this, contains right-handed (RH) neutrinos





If in addition to (lepton-number conserving) Dirac masses due to interaction with the Higgs field, the RH neutrinos have (lepton-number *violating*) Majorana masses, then they can, *in principle* (Asaka, Shaposhnikov, Phys.Lett.B **620**:17,2005):

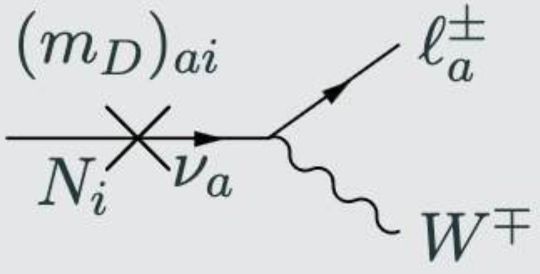
- ➢ Account for the baryon asymmetry of the Universe
- ➢ Provide a (warm) candidate for the dark matter

Test by searching for heavy neutral leptons (HNLs)
– SHiP@SPS, FPF@LHC (best below ~2 GeV)
– FCC, CEPC … (best above ~2 GeV)

Active neutrino masses

$$m_\nu = -m_D M_M^{-1} m_D^T$$

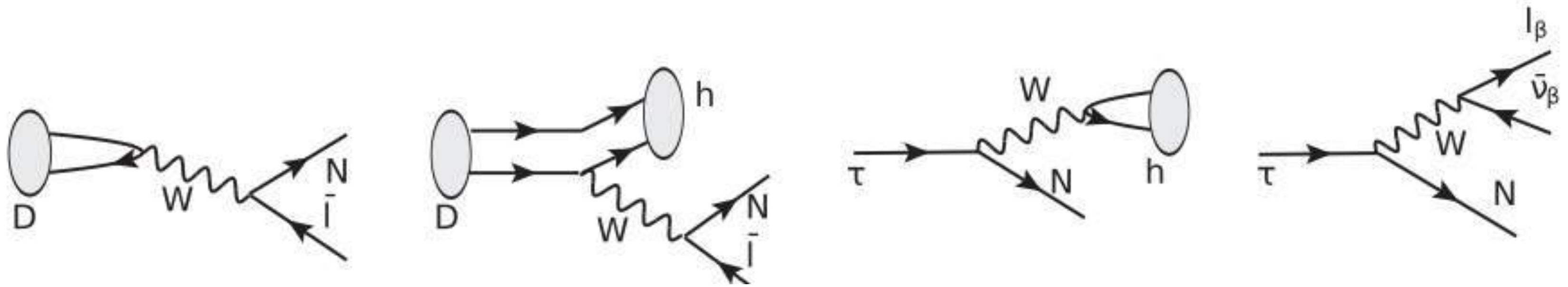
HNL mixing



$$U_{ai}^2 \equiv \left|\left(m_D M_M^{-1}\right)_{ai}\right|^2$$

$$U^2 = \sum_{a,i} U_{ai}^2$$

Heavy Neutral Leptons: Production & Decay



$$L_{lab,N} \simeq 30 \left(\frac{10^{-3}}{|U_{\tau 4}|^2}\right)\left(\frac{E_N}{10\ \mathrm{GeV}}\right)\ \mathrm{m}$$

For $\begin{cases} m_N \sim 1\ \mathrm{GeV} \\ |U_{e4}| = |U_{\mu 4}| = 0 \end{cases}$

Consider production in the beam dump of charmed mesons – decaying promptly to neutrinos whose mixings create a beam of HNL that decay in into **opposite sign charged charged particles** (*eeν, eμν, μμν*, or *eπ, μπ*)

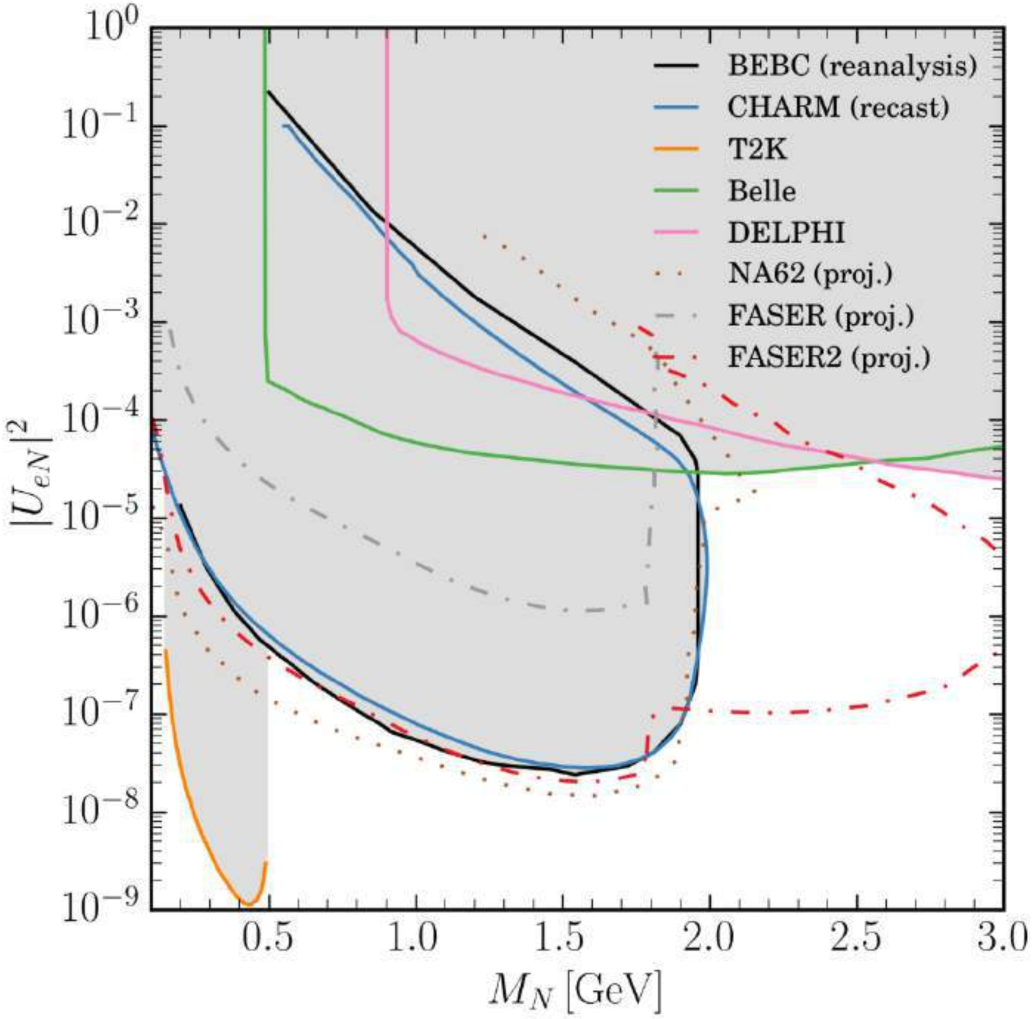
The number of HNLs produced, $\mathcal{N}_N$, can be directly related to the total number of detected active neutrinos of a particular species, $\mathcal{N}_{\nu_\ell}$, via:

$$\frac{\mathcal{N}_N}{\mathcal{N}_{\nu_\ell}} \simeq \frac{\sum_i \sigma(pN \to P_i + X)\mathrm{Br}(P_i \to N + Y)}{\sigma(pN \to D^+D^- + X)\mathrm{Br}(D^\pm \to \ell\,\nu_\ell + X) + \sigma(pN \to D^0\bar{D}^0 + X)\mathrm{Br}(D^0 \to \ell\,\nu_\ell + X)}$$

arXiv:2208.00416

The 40+ year old beam dump experiments @ CERN still provide *world-leading* sensitivity to HNLs

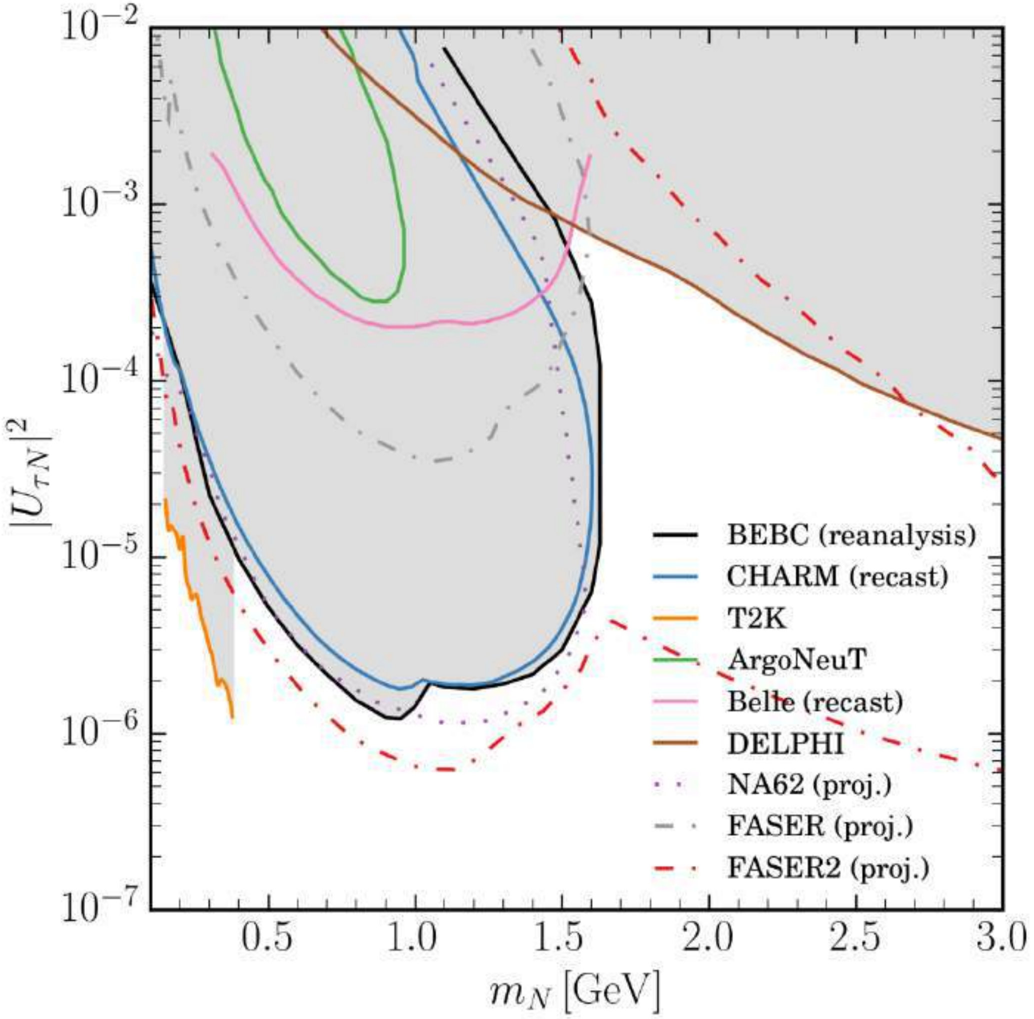
We revisit the search for heavy neutral leptons with the Big European Bubble Chamber in the 1982 proton beam dump experiment at CERN, focussing on those heavier than the kaon and mixing only with the tau neutrino, as these are far less constrained than their counterparts with smaller mass or other mixings. Recasting the previous search in terms of this model and including additional production and decay channels yields the strongest bounds to date, up to the tau mass. This applies also to our updated bounds on the mixing of heavy neutral leptons with the electron neutrino. Barouki, Marocco, S.S., *SciPost Phys.* **13**:118,2020 (Reanalysis of: Cooper-Sarkar *et al*, *Phys.Lett.*B**160**:207,1985)



Constraints on HNLs from BEBC & CHARM

FASER2 will do a factor of ~5 better up to m_c and a factor of ~100 better up to m_b

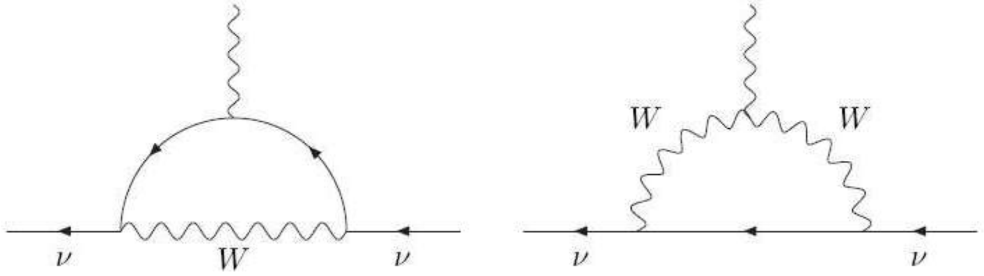
SHiP will do a factor of ~50 better upto m_c and a factor of ~1000 better upto m_b

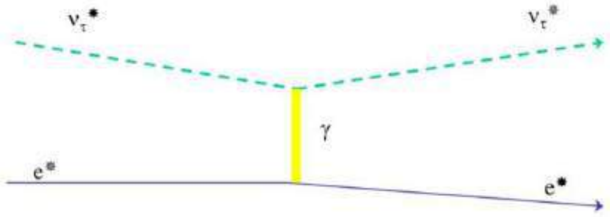


“With more than 50k ν_τ CC interactions in the SND, SHiP can constrain the ν_τ magnetic moment down to $9 \times 10^{-8}\mu_B$”

SHiP Collaboration + BDF Working Group, *BDF/SHiP at the ECN3 high-intensity beam facility*, CERN-SPSC-2023-033

The magnetic moment expected for a Dirac neutrino is $\boldsymbol{\mu_\nu = 3\text{x}10^{-19}\,(m_\nu/\text{eV})\,\mu_B}$ but can be enhanced by BSM physics





Bound on the tau neutrino magnetic moment from the BEBC beam dump experiment

A.M. Cooper-Sarkar *et al*, *Phys.Lett*.B**280**(1992)153

Scattering by a magnetic moment is strongly forward-peaked, so we considered production from $D_s \rightarrow \tau\nu_\tau$ and looked for elastically scattered events within the forward cone defined by the maximum scattering angle

$$\frac{d\sigma_\mu}{dT_e} \simeq \pi r_e^2 \left(\frac{\mu_\nu}{\mu_B}\right)^2 \left(\frac{1}{T_e} - \frac{1}{E_\nu}\right) \qquad \sin^2\theta_{\nu e} = \frac{2m_e}{T_e + 2m_e}\left(1 - \frac{T_e}{E_\nu} - \frac{m_e T_e}{2E_\nu^2}\right), \quad \theta_{\nu e}^2 \leqslant 2m_e/E_e$$

We found 1 candidate event, *cf.* expected background of 0.5 ± 0.1 ⇒ < 3.5 events @ 90% CL

This implies a bound of 5.4 x $10^{-7}\mu_B$ on the ν_τ magnetic moment

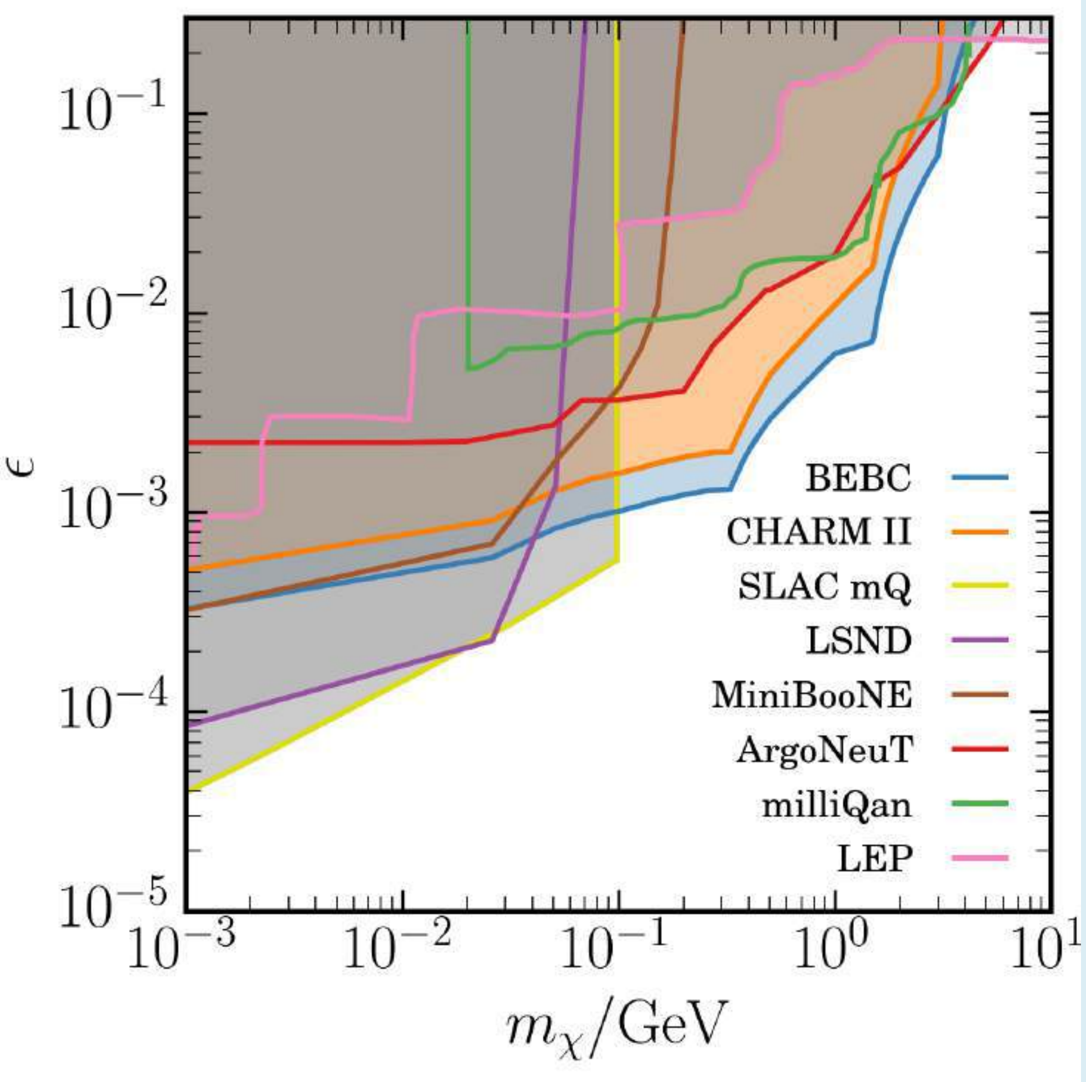
SciPost Phys. 10, 043 (2021)

Blast from the past: Constraints on the dark sector from the BEBC WA66 beam dump experiment

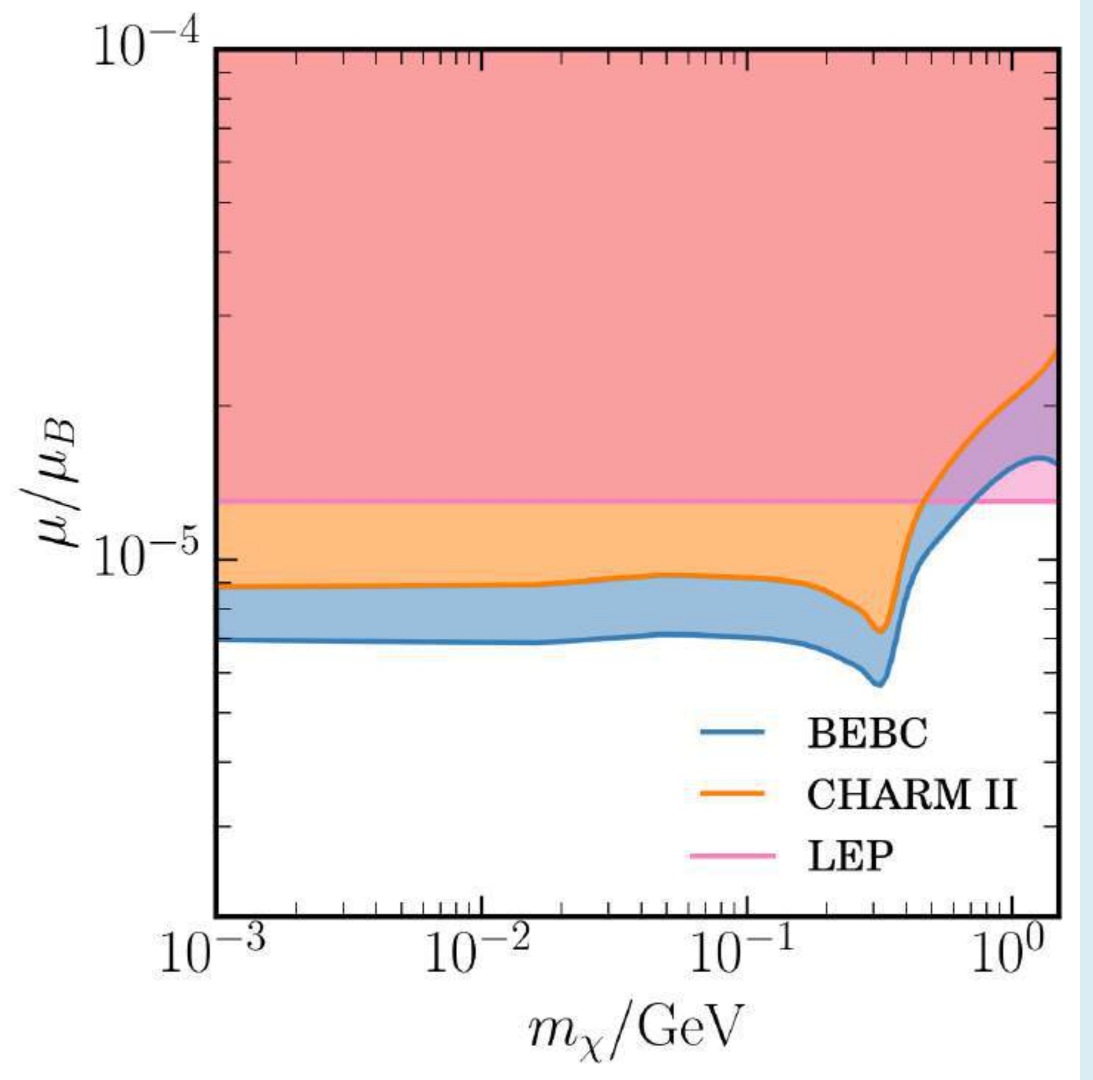
Giacomo Marocco * and Subir Sarkar

Rudolf Peierls Centre for Theoretical Physics, University of Oxford,
Parks Road, Oxford OX1 3PU, United Kingdom

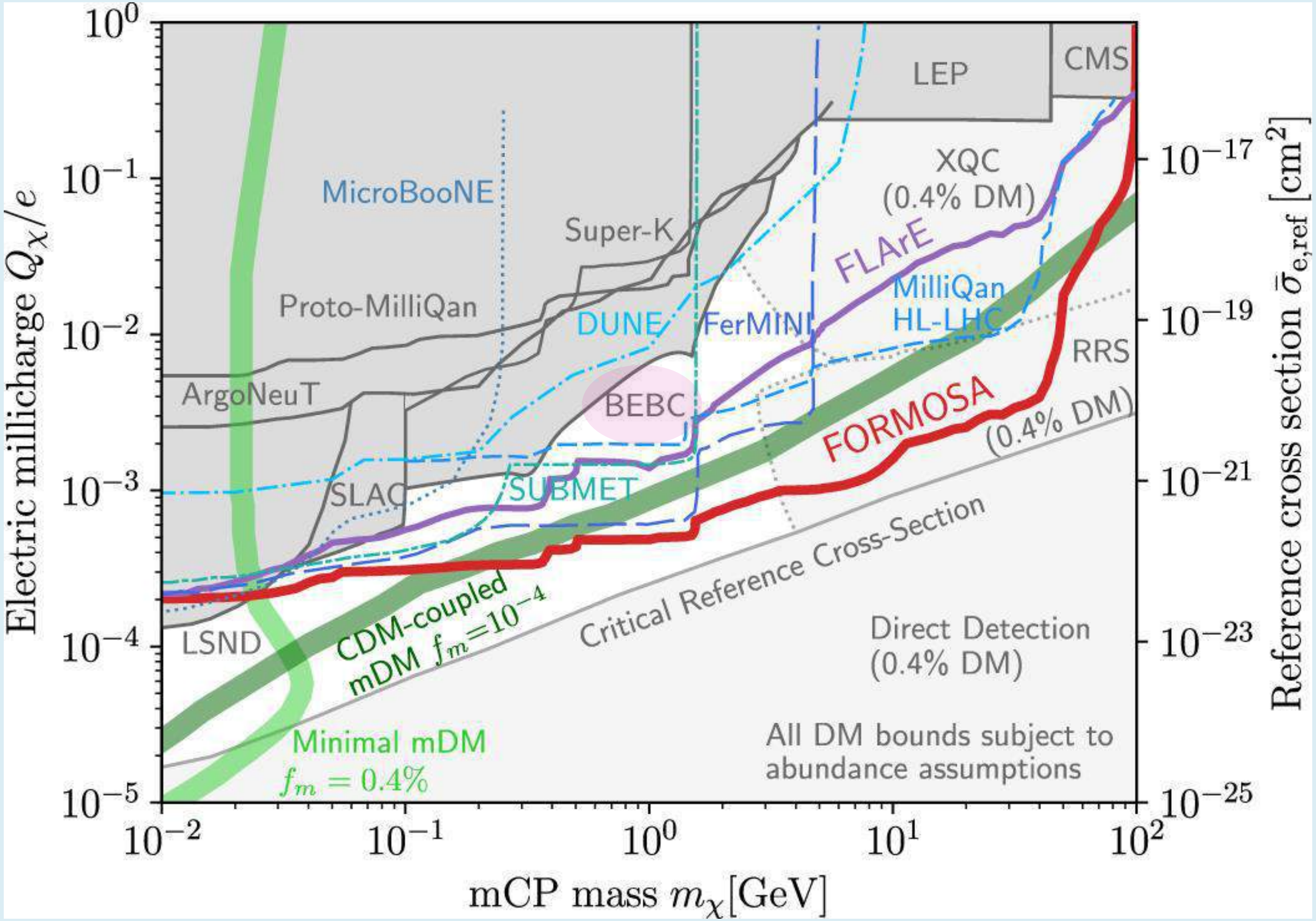
We derive limits on millicharged dark states, as well as particles with electric or magnetic dipole moments, from the number of observed forward electron scattering events at the Big European Bubble Chamber in the 1982 CERN-WA-066 beam dump experiment. The dark states are produced by the 400 GeV proton beam primarily through the decays of mesons produced in the beam dump, and the lack of excess events places bounds extending up to GeV masses. These improve on bounds from all other experiments, in particular CHARM II.



… this recast turns out to still be the most sensitive bound on milli-charged particles and on neutrino magnetic moments

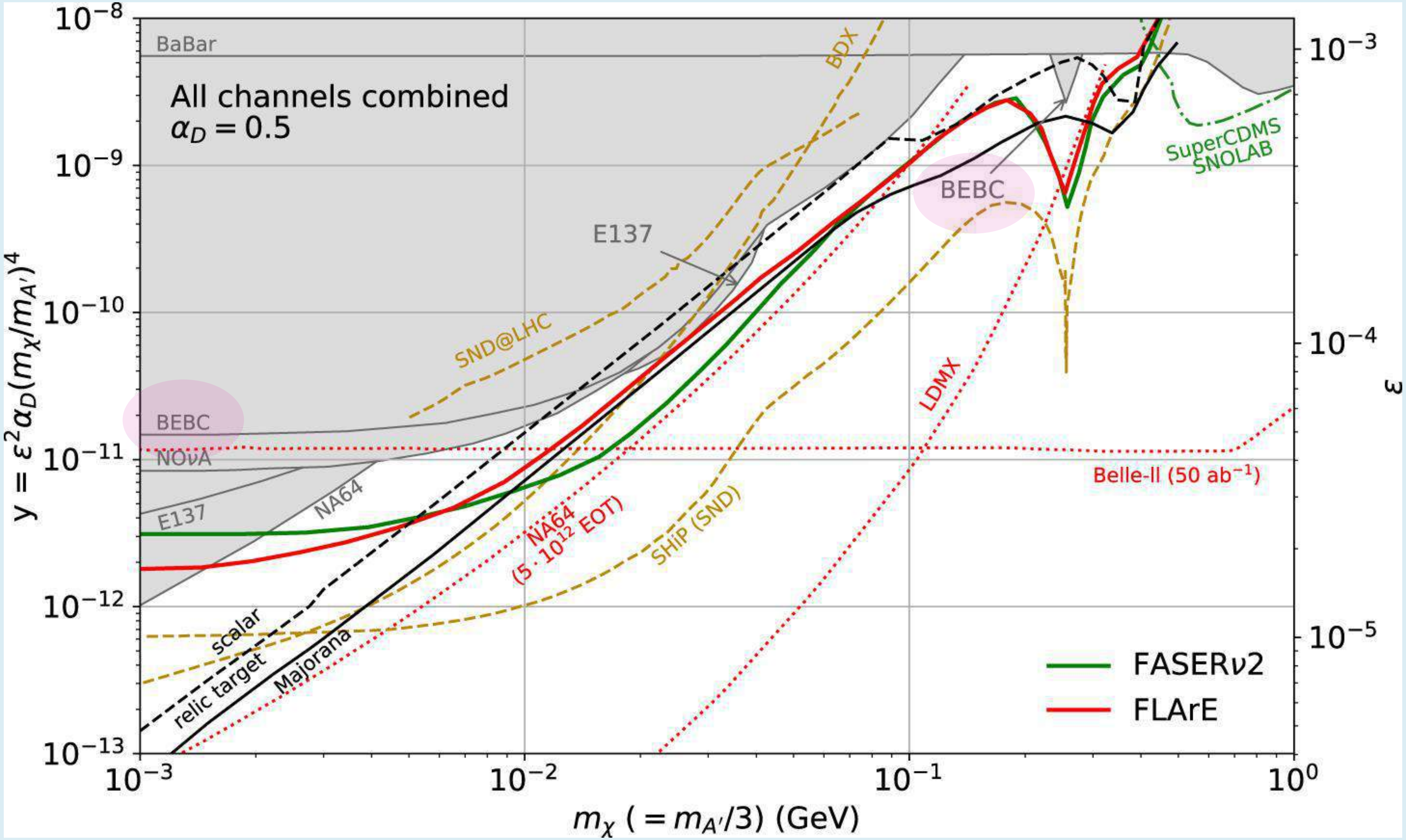


The reach will improve with FLArE & FORMOSA at the FPF [arXiv:2109.10905]



Present bounds on mCPs (grey): LSND, ArgoNeuT, SLAC, Super-K (limit on diffuse SN ν bkgd), LEP, CMS, BEBC
Expected sensitivities for FORMOSA, FLArE; **Projections** for SUBMET, FerMINI, MilliQan @ HL-LHC, DUNE,

The WA66 constraint on forward scattered electrons also translates into a competitive bound on scattering of ~MeV-GeV scalar dark matter (Buonocore *et al*, *PRD* **102**:035006,2020)



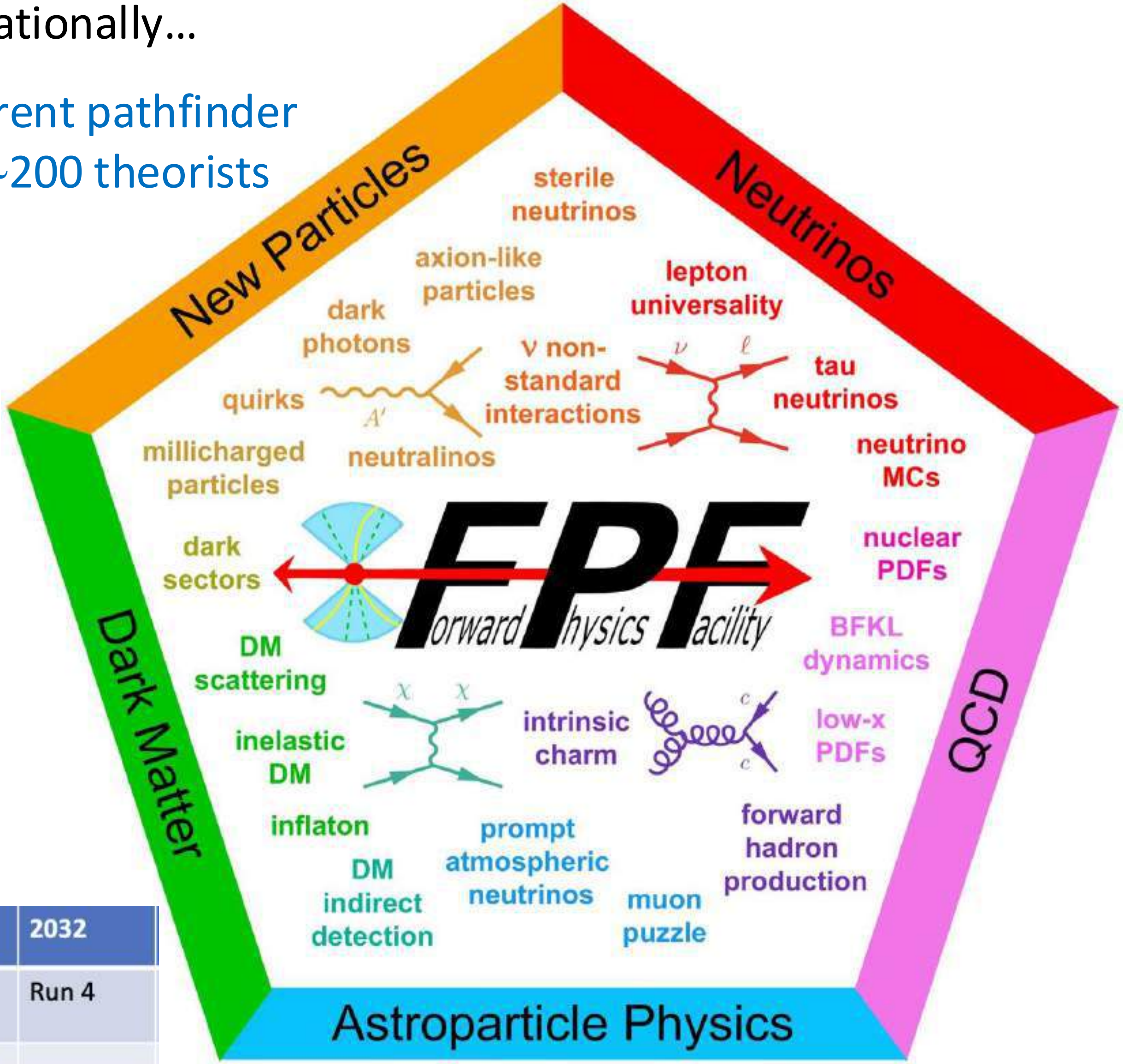
Projected exclusion bounds for **FASERν2** & **FLArE-10** detectors @ HL-LHC with 3 ab^{-1} integrated luminosity. Existing constraints (grey) & projected reaches from other expts [arXiv:2107.00666]

The FPF user community is large, vibrant, and growing internationally…

~300 people in over 60 institutions: collaborations of the current pathfinder detectors (FASER, FASERν, milliQan) + FLArE working group (~200 theorists participated in writing (or endorsed) the White Paper

- FPF Kickoff Meeting, 9-10 Nov 2020
- FPF2 Meeting, 27-28 May 2021
- FPF3 Meeting, 25-26 Oct 2021
- FPF4 Meeting, 31 Jan-1 Feb 2022
- FPF5 Meeting, 15-16 Nov 2022
- FPF6 Meeting, 8-9 June 2023
- FPF Theory Workshop, 18-19 Sept 2023
- FPF7 Meeting, 29 Feb-1 Mar 2024
- FPF8 Meeting, 21-22 Jan 2025
- FPF9 Meeting, 5-6 Mar 2026

	2024	2025	2026	2027	2028	2029	2030	2031	2032
LHC schedule	Run 3	Run 3	LS3	LS3	LS3	Run 4	Run 4	Run 4	Run 4
CE works	Design		Tender		Works				
Outfitting									
Detector	Design			Construction				Installation	
Physics								Physics	



https://pbc.web.cern.ch/fpf-mandate 80%

CERN Accelerating science

Physics Beyond Colliders

HOME WORKING GROUPS

Forward Physics Facility

https://fpf.web.cern.ch/

Introduction

The Forward Physics Facility (FPF) is a proposal to build a new underground cavern at the Large Hadron Collider (LHC) to host a suite of far-forward experiments during the High-Luminosity LHC (HL-LHC) era. The existing large LHC detectors have un-instrumented regions along the beam line, and so miss the physics opportunities provided by the enormous flux of particles produced in the far-forward direction. Without the FPF, the HL-LHC will be blind to neutrinos and many proposed new particles. However, small pathfinder experiments currently operating in the far-forward region at the LHC have recently directly observed collider neutrinos for the first time and demonstrated the potential for world-leading sensitivity to new physics. With the FPF, a diverse suite of experiments will realize this potential by detecting ~1,000,000 neutrino interactions at the highest energies from a human source, expanding our understanding of proton and nuclear structure and the strong interactions to new regimes, clarifying astroparticle data, and carrying out world-leading searches for light dark matter, dark sectors, and many other new particles.

Screenshot

PBC FPF Subgroup

Convener: Jamie Boyd (CERN) **Core Members**: Marco Andreini (CERN), Kincso Balazs (CERN), Jean-Pierre Corso (CERN), Jonathan Feng (UC Irvine), Anastasiya Magazinik (CERN), John Osborne (CERN)

Mandate and Objectives The PBC FPF Subgroup is mandated to provide a Conceptual Design of the facility after an analysis of the possible options and taking into account the impact on the LHC Machine during construction and installation and the HL-LHC operational scenario. The Subgroup's objectives are to

- Study the possible civil engineering scenarios for the construction of the Facility, their impact on the LHC machine and its infrastructure, and study the integration of the FPF and its experiments in the HL-LHC timeline.
- Determine the potential of FPF experiments to enhance the LHC physics program for both SM and BSM physics.
- Foster the development of experiments to realize this potential, and optimize their experimental setup within the FPF cavern based on the physics requirements identified by the Working Groups.
- Evaluate the performance of the FPF experiments based on the expected HL-LHC operational scenario.

Next Meeting

7th Forward Physics Facility Meeting

29 February, 2024

indico

Current Experiments

FASER/FASERnu

SND@LHC

milliQan

Steering Committee

Jamie Boyd (CERN), Albert De Roeck (CERN), Milind Diwan (Brookhaven), Jonathan Feng (UC Irvine), Felix Kling (DESY)

WG0 Facility Jamie Boyd (CERN)

WG1 Neutrino Interactions Juan Rojo (Nikhef)

WG2 Charm Production Anna Stasto (Penn State)

WG3 Light Hadron Production and Astroparticle Luis Anchordoqui (Lehman), Dennis Soldin (Karlsruhe)

WG4 New Physics Brian Batell (Pittsburgh), Felix Kling (DESY)

WG5 FASER2 Alan Barr (Oxford), Josh McFayden (Sussex), Hide Otono (Kyushu)

WG6 FASERnu2 Aki Ariga (Chiba), Tomoko Ariga (Kyushu)

WG7 FLArE Jianming Bian (UC Irvine), Milind Diwan (Brookhaven)

WG8 FORMOSA Matthew Citron (UC Davis), Chris Hill (Ohio State)

conclusions

- There is well-motivated new physics to be explored using high energy neutrinos
- These experiments cost very 'little' (< 100 MCHF) but are of great interest to a large (astro)particle community
- Beam dump experiments have been very successful in the past – SHiP will continue this tradition!
- The Forward Physics Facility will explore *both* SM and BSM physics at the HL-LHC … it should be part of the forward planning for proposed colliders (arXiv:2409.02163)

Message for ECFA

Seen at café outside Royal Tombs @ Αιγαί)