From Auger to FPF

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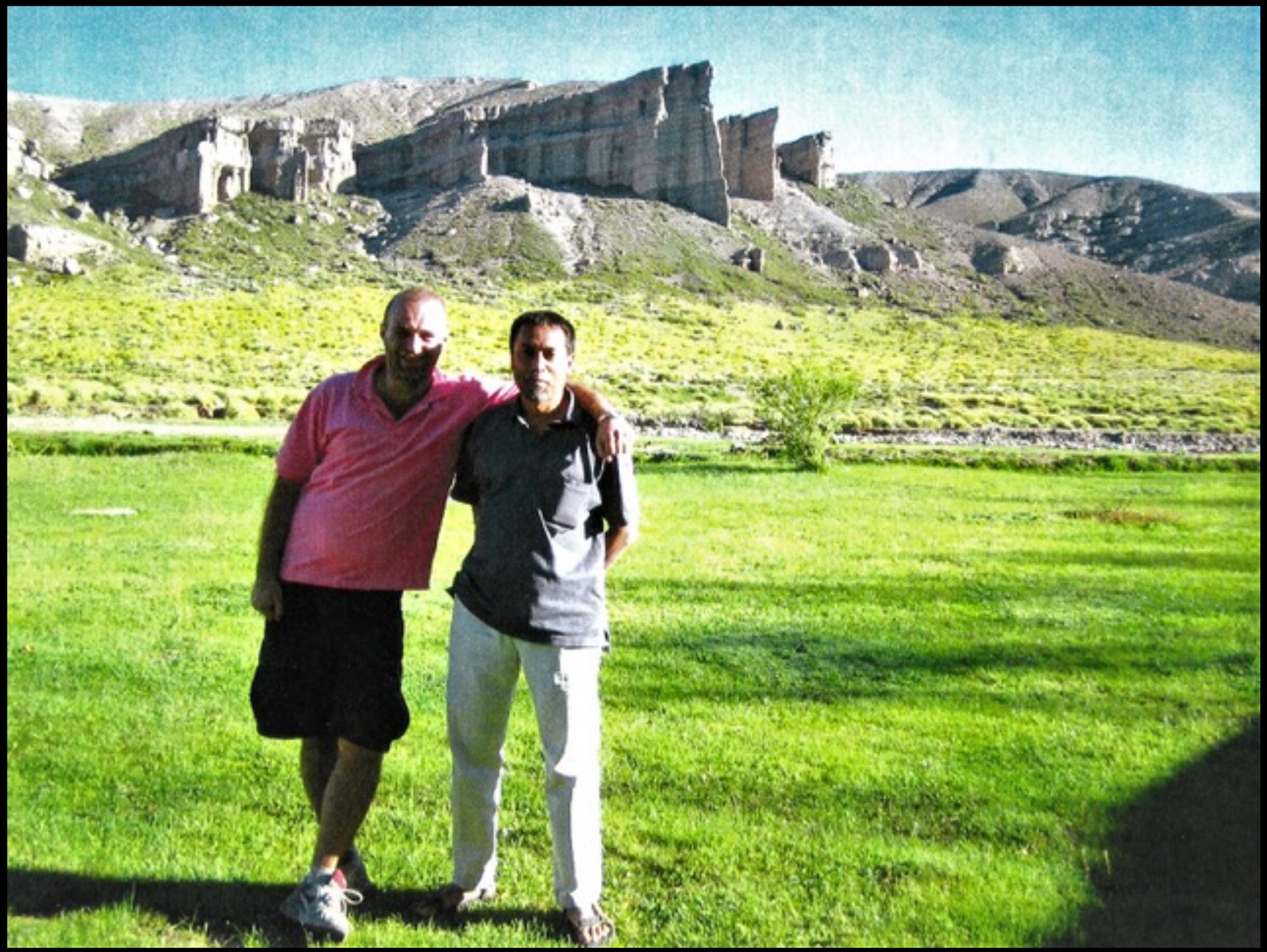
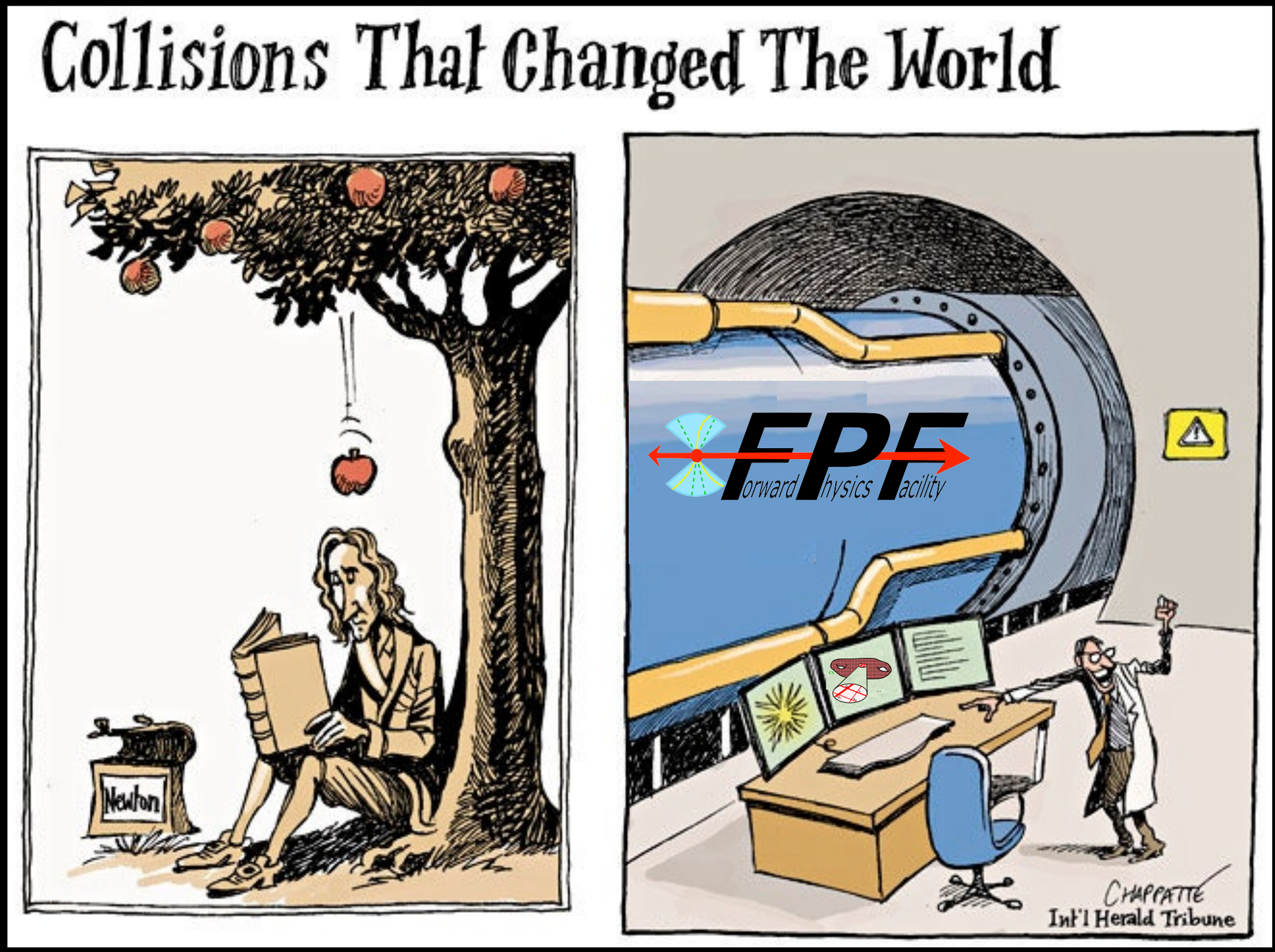


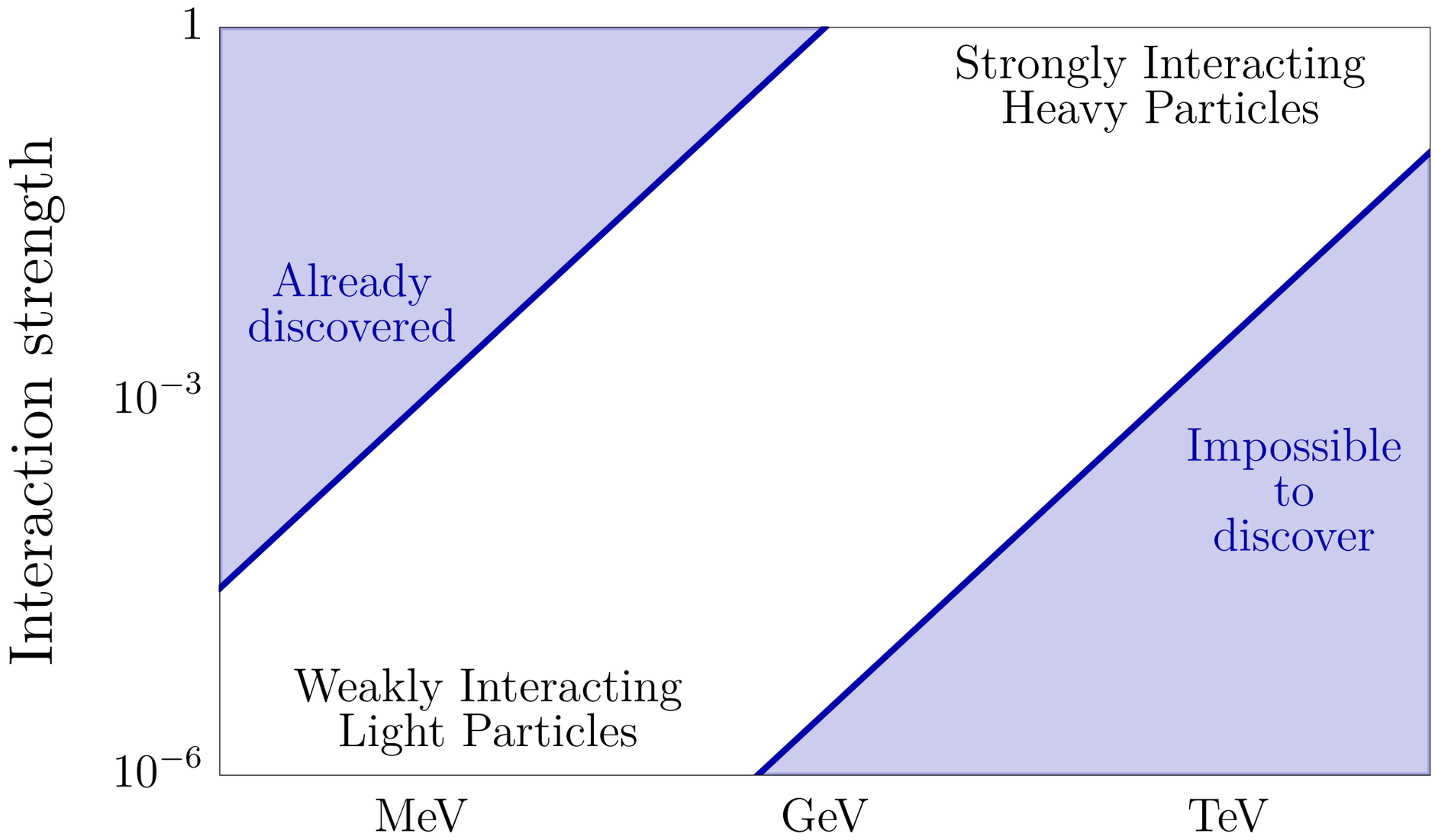
Asado @ Castillos de Pincheira

The Future...

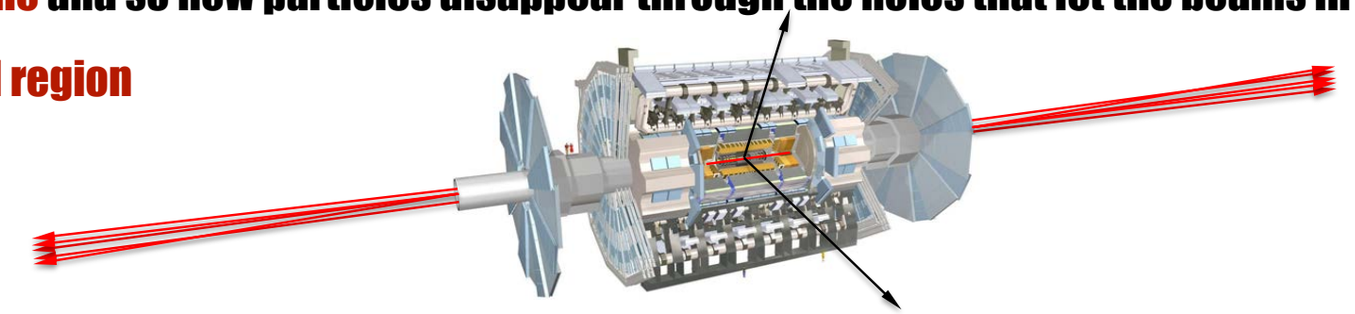


arXiv:2203.05090

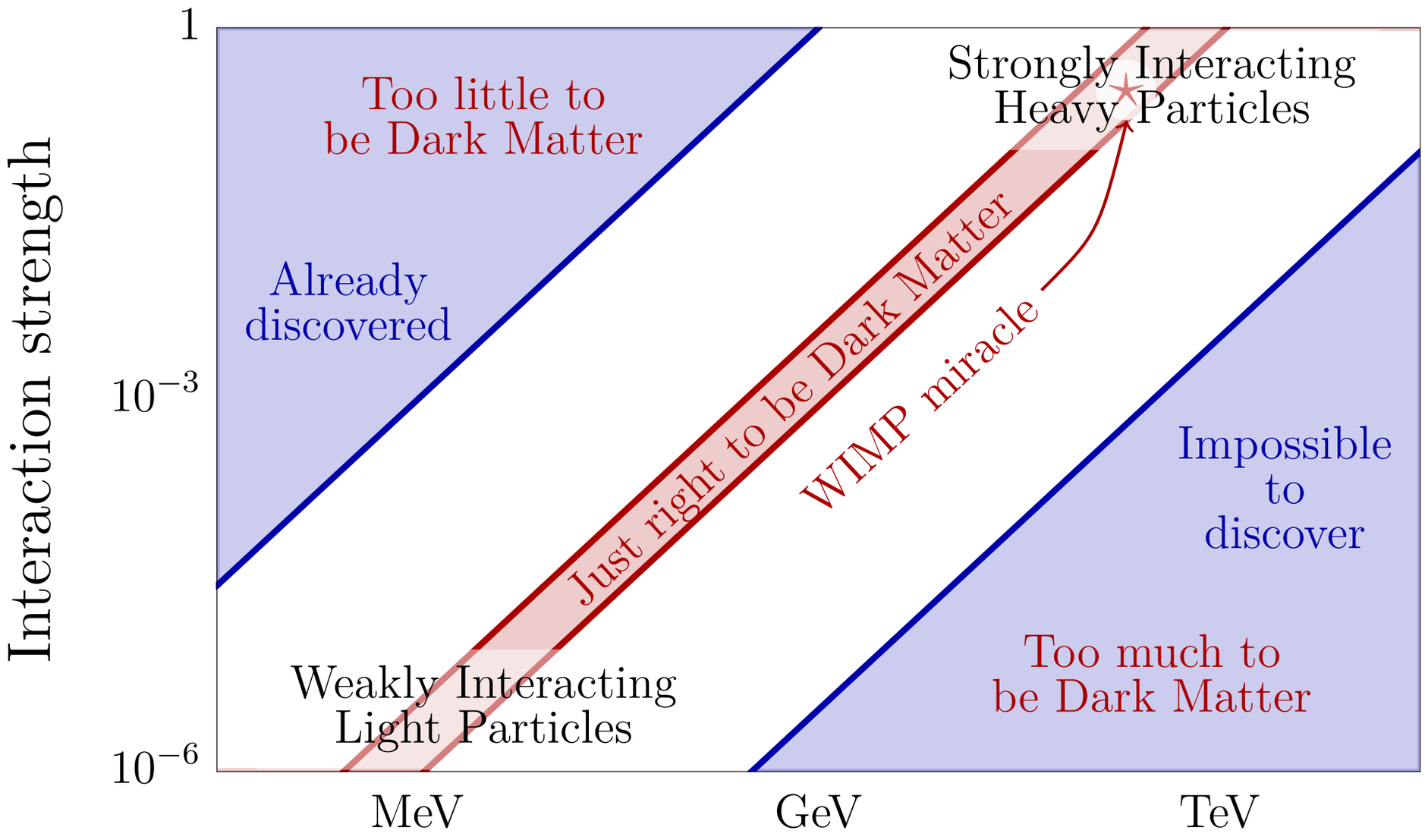
The New Particle Landscape

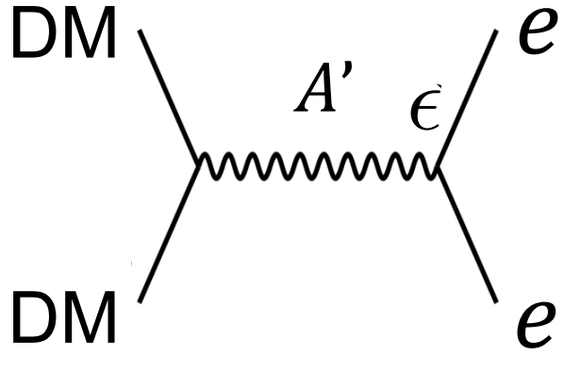


- **ATLAS and CMS detectors are designed to find new heavy particles which are produced almost at rest and decay isotropically**
- **New light particles are mainly produced along the beamline and so new particles disappear through the holes that let the beams in**
- **We need a detector to cover the blind spots in the forward region**



The Thermal Relic Landscape

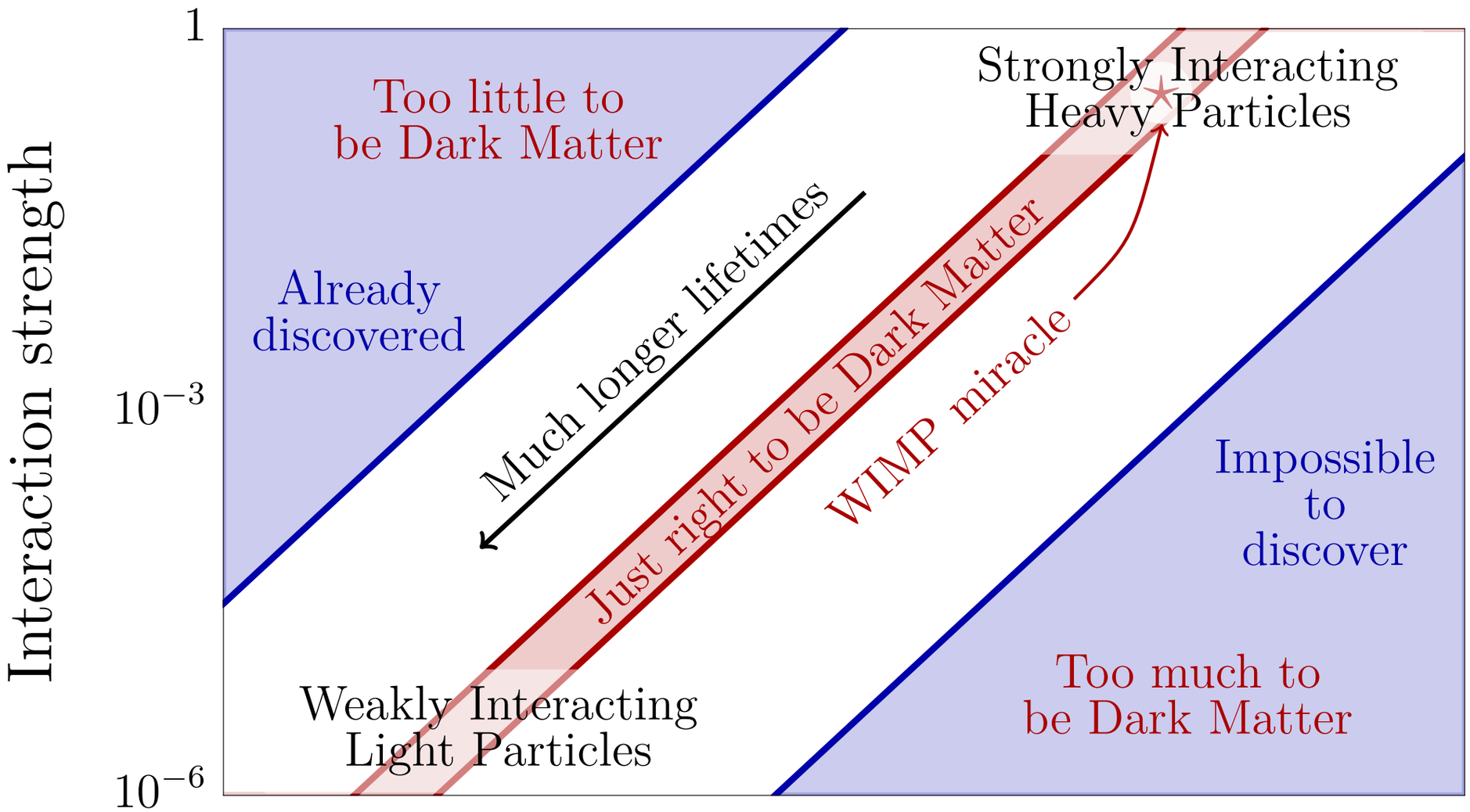




$$\langle \sigma v \rangle \sim \epsilon^2 / m_{A'}^2$$

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

Long Lived Particles



Velocity near the speed of light

$$v \sim 1$$

Rest lifetime enhanced by small mass, small ε

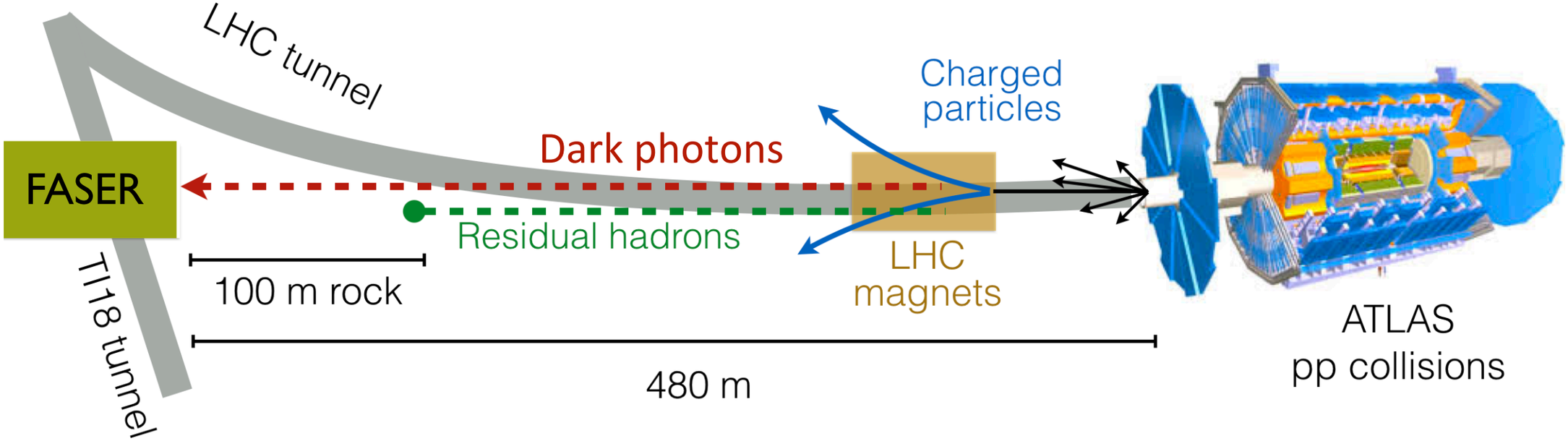
$$\tau \propto \frac{1}{\epsilon^2 m_{A'}}$$

Lifetime further enhanced by time dilation

$$\gamma \propto \frac{E}{m_{A'}}$$

$$L = v\tau\gamma \sim 100 \text{ m} \left(\frac{10^{-5}}{\epsilon}\right)^2 \left(\frac{100 \text{ MeV}}{m_{A'}}\right)^2 \left(\frac{E}{\text{TeV}}\right)$$

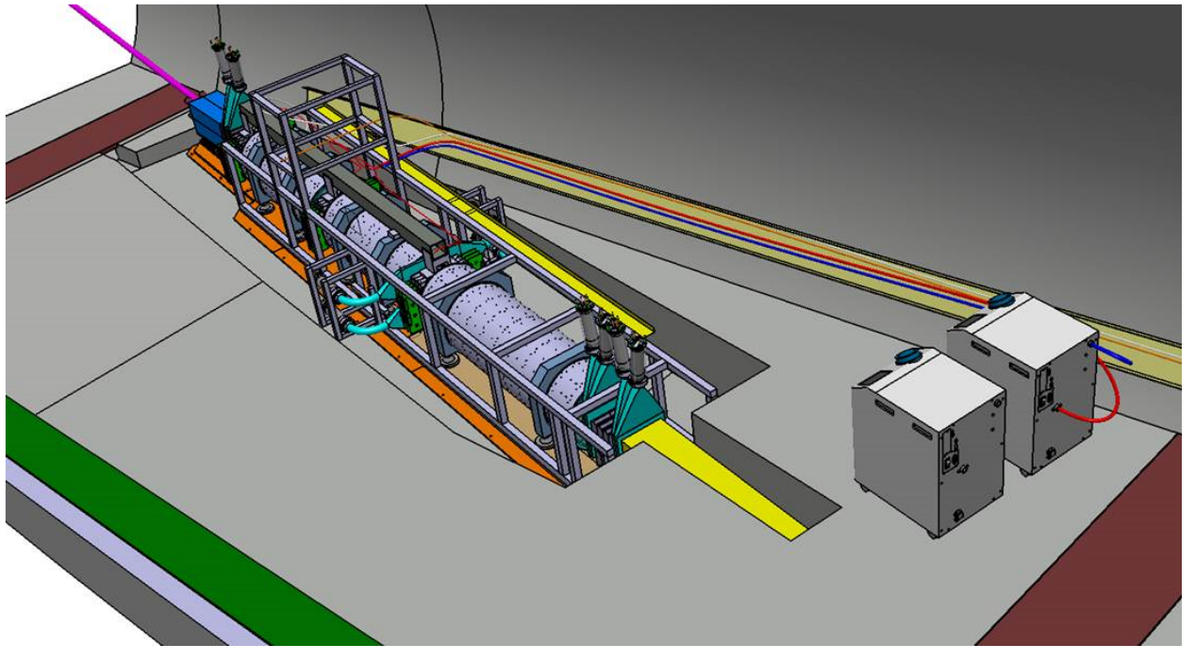
The ForwArd Search ExpeRiment (FASER)

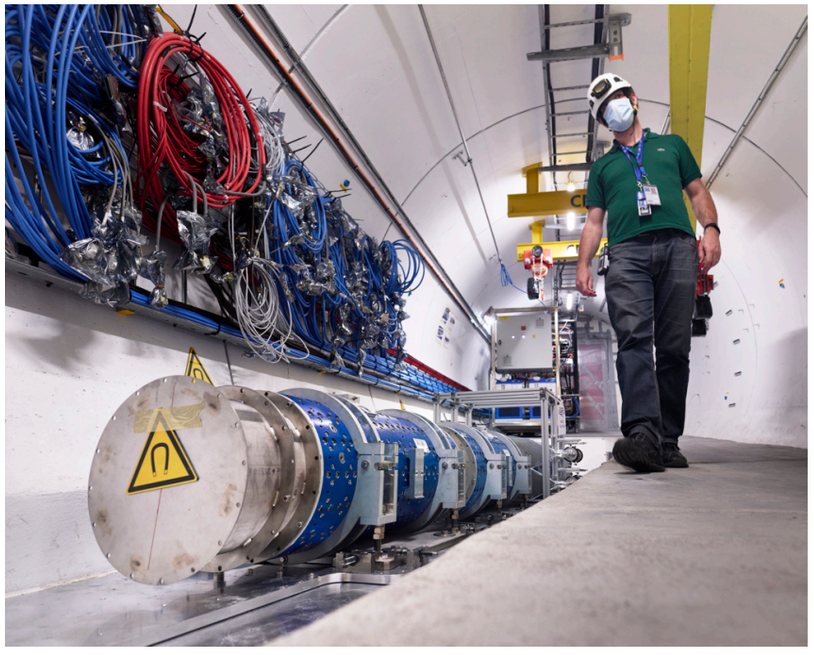


➢ FASER2 ☛ roughly 3 orders of magnitude increase volume

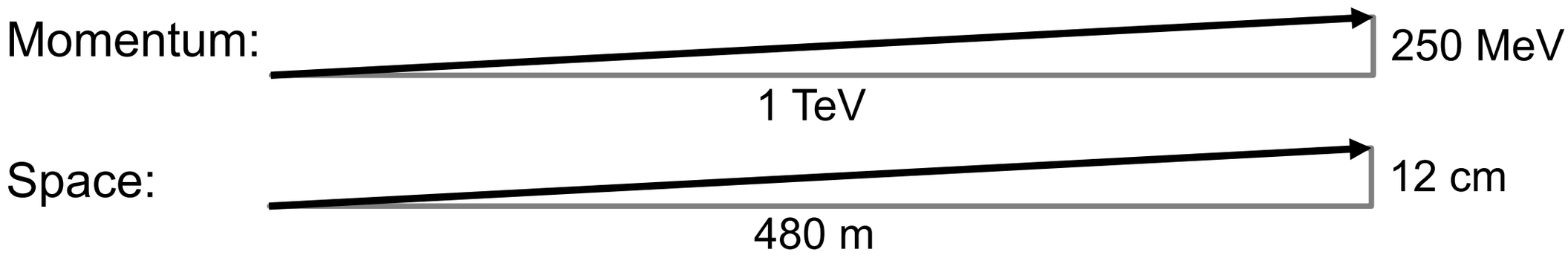
➢ The acronym recalls another marvelous instrument
that harnessed highly collimated particles
and was used to explore strange new worlds

How Big Does the Detector Have to Be?





For $\eta \sim 9$ ☛ opening angle $\theta = 2\ \arctan(e^{-\eta}) \sim 0.25$ mrad



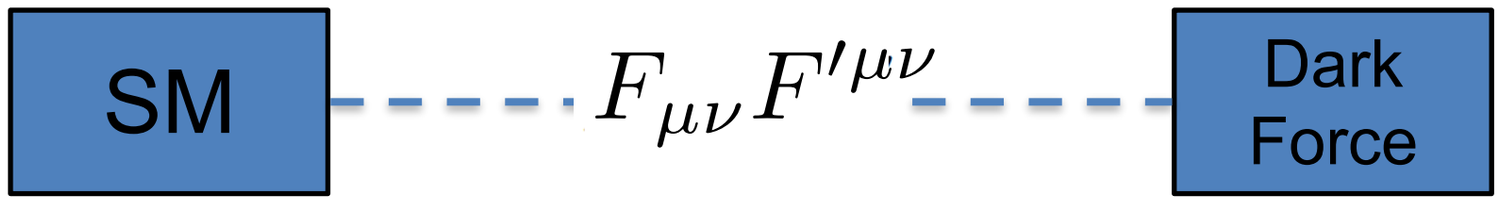
Most of the signal passes through one sheet of paper at 480 m

Portals

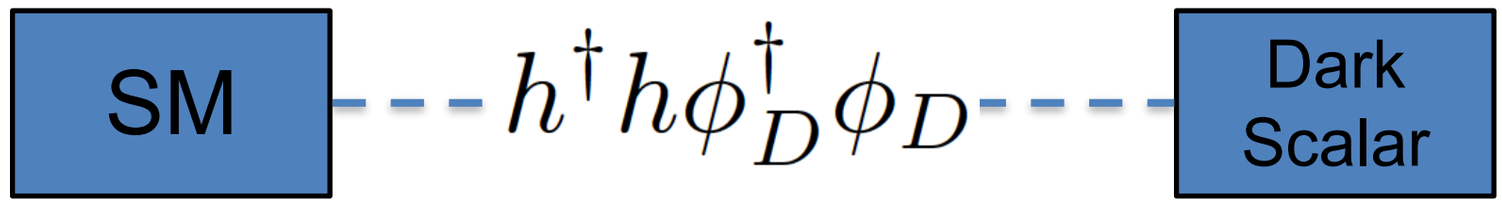
- Dark sectors need to talk to us
- But if they do ☛ what are the most likely non-gravitational interactions?

ORGANIZING PRINCIPLE THAT MOTIVATES SPECIFIC EXAMPLES

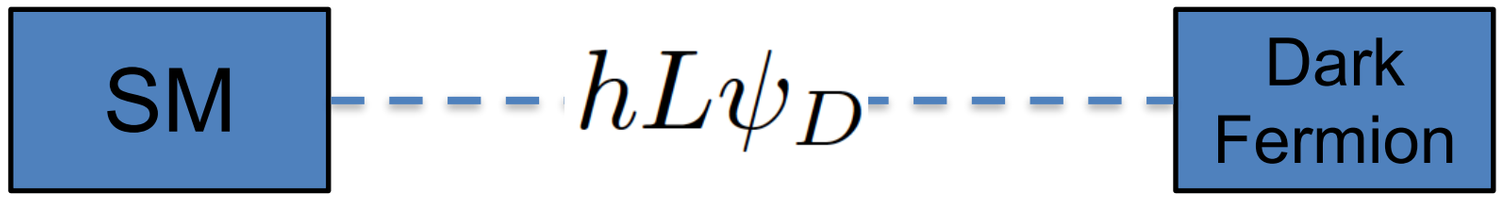
- spin-1 ☛ dark photon



- spin-0 ☛ dark Higgs

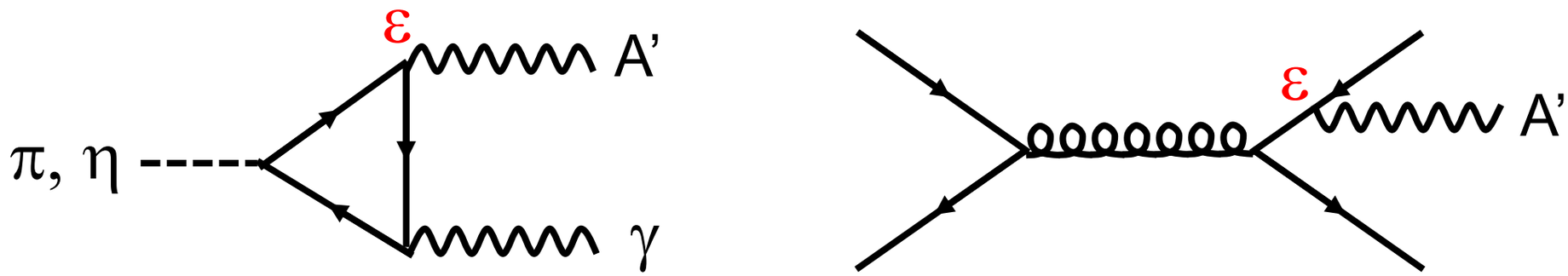


- spin-1/2 ☛ sterile neutrino

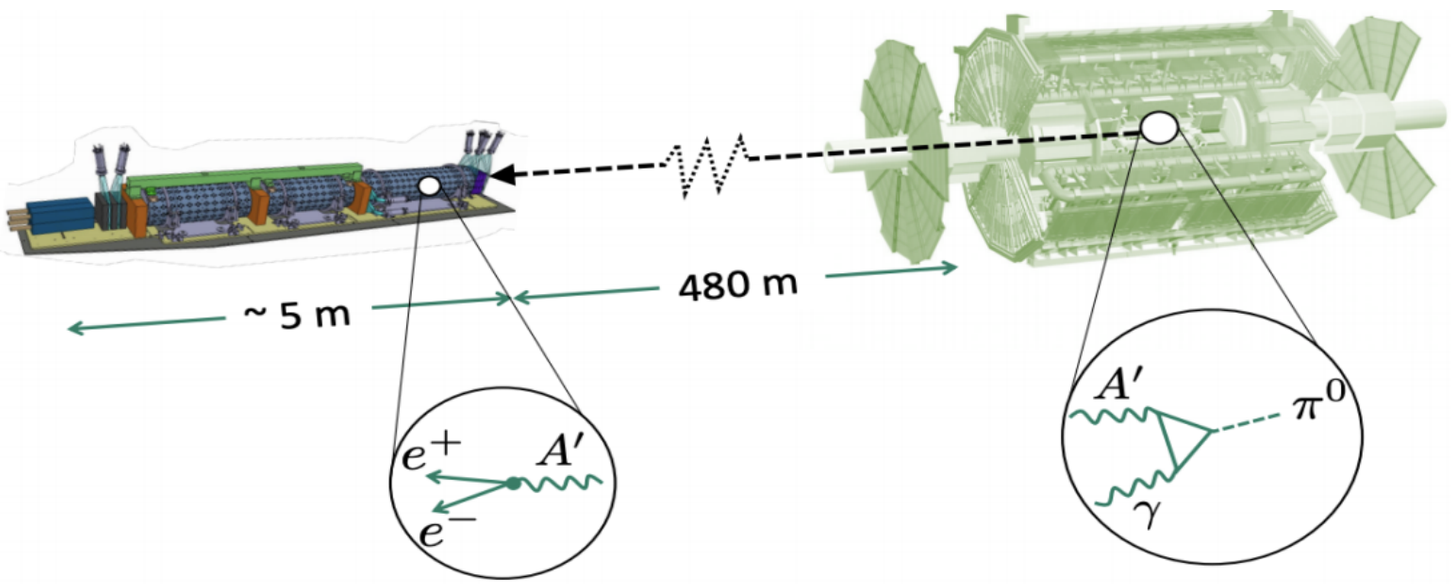


Dark Photon Properties

- **A priori 3 unknown parameters** ☛ $m_{A'},\ \epsilon,\ \mathcal{B}(A' \to \chi\bar{\chi})$
- **Consider 2 parameter model** ☛ $m_{A'} < 2m_{\chi}$
- **Production** ☛ through meson decay, dark bremsstrahlung…



- **Propagation** ☛ they pass through matter without interacting
  and they go straight unaffected by E and B fields
- **Decay** ☛ they decay to visible particles but after a long time



Dark Photon Sensitivity Reach

Meson production @ HL-LHC

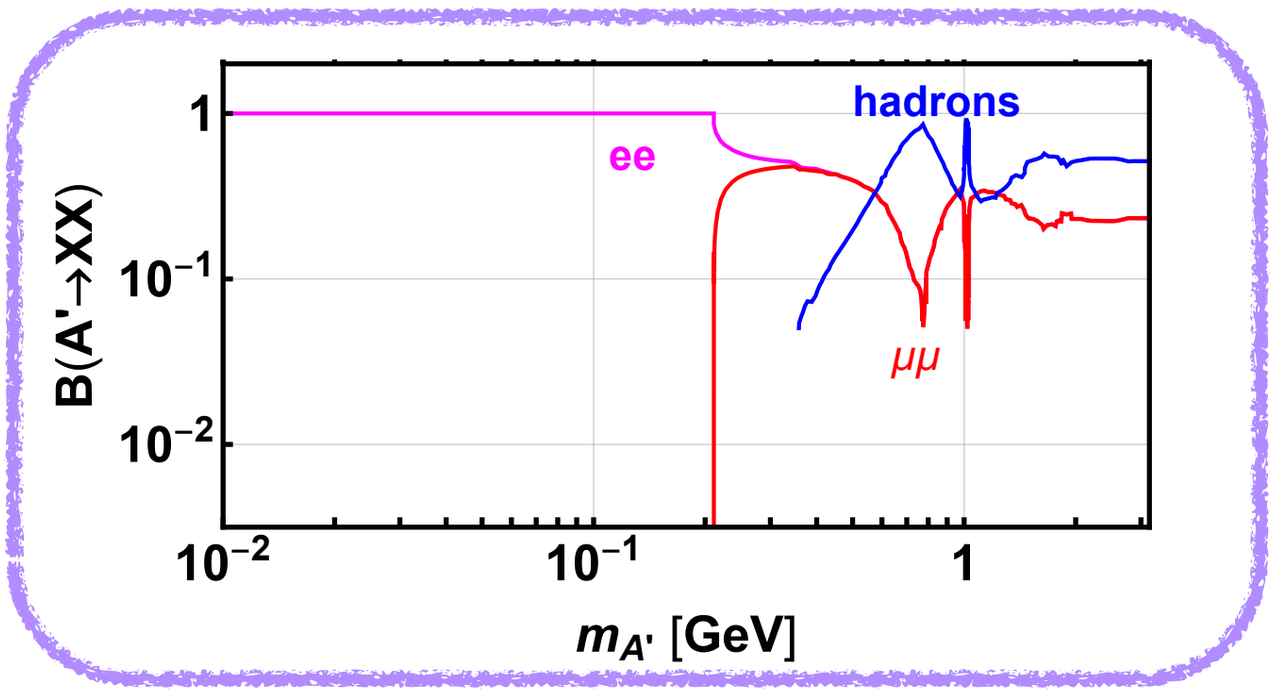
Luminosity ~ 3 ab^{-1}

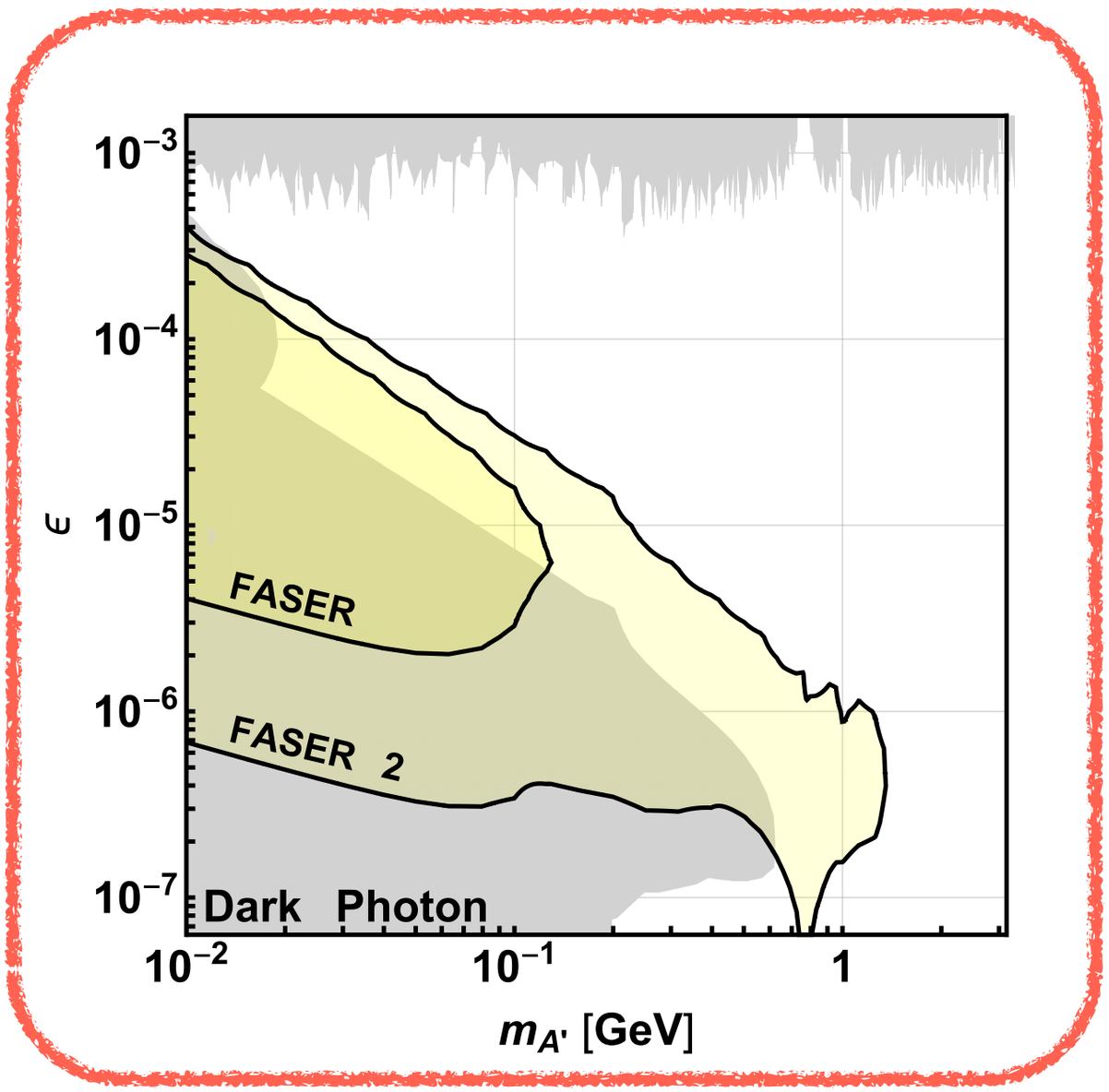
$\pi^0 \Rightarrow 4 \times 10^{17}$

$\eta \Rightarrow 6 \times 10^{16}$

$D \Rightarrow 2 \times 10^{15}$

$B \Rightarrow 10^{13}$





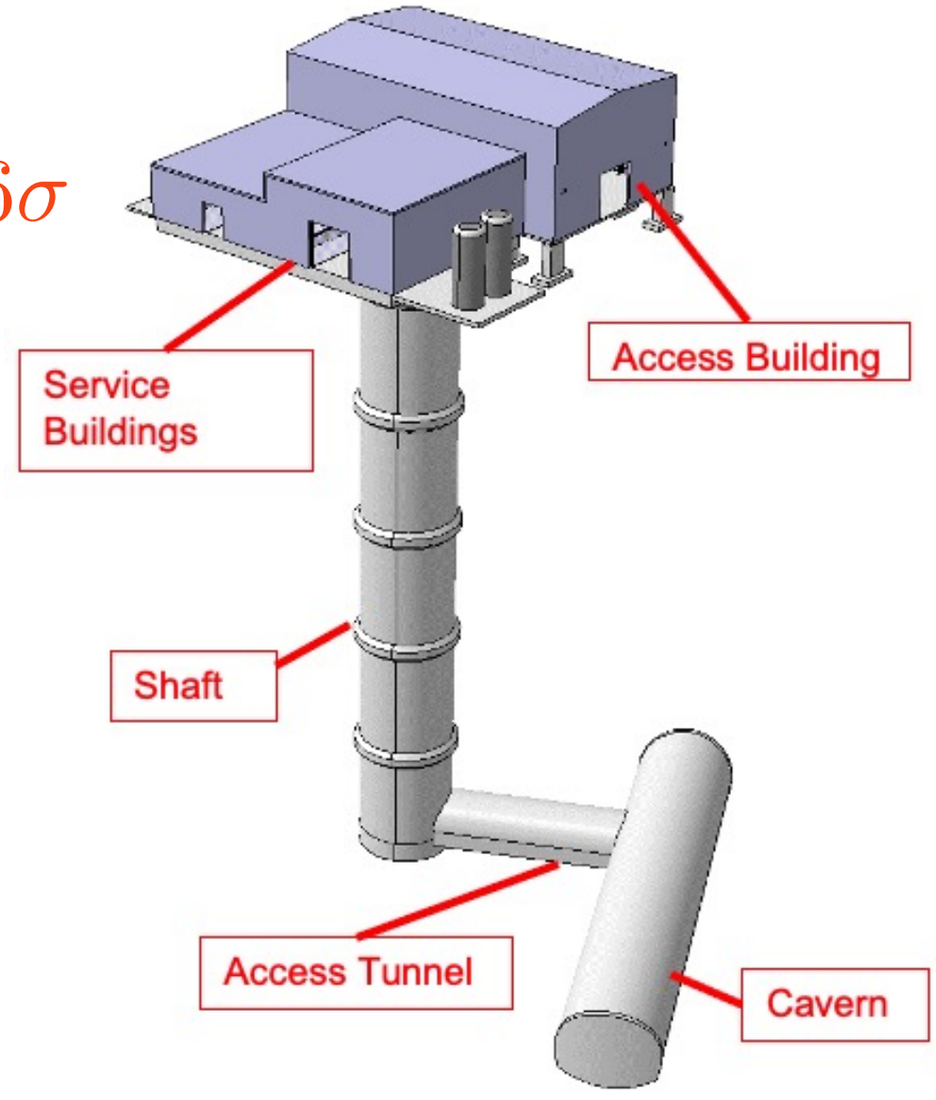
LHC Neutrinos!

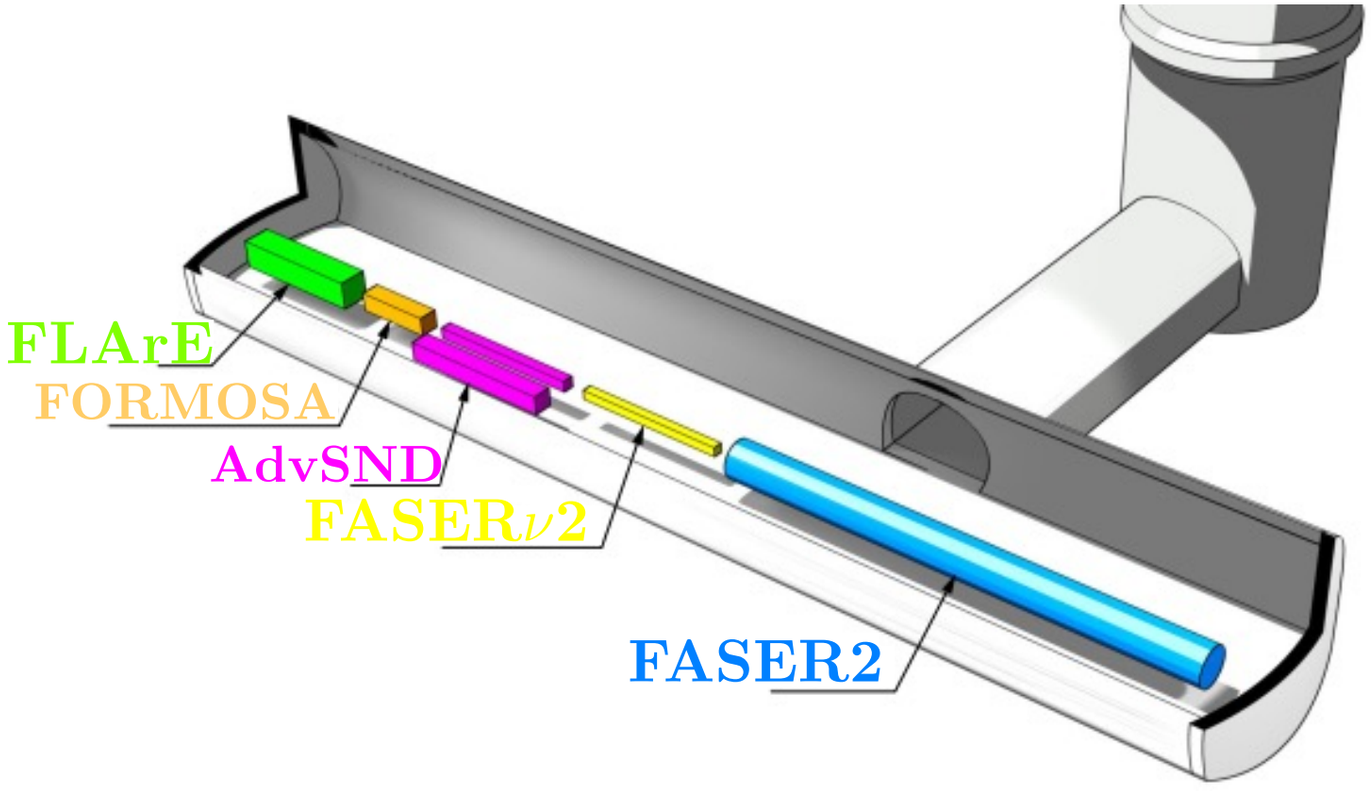
FASERν first contact

153^{+12}_{-13} neutrino interactions detected ☛ 16σ

arXiv:2303.14185

FASERν2 - AdvSND - FLArE





➢ millicharged particles ☛ **FORMOSA**

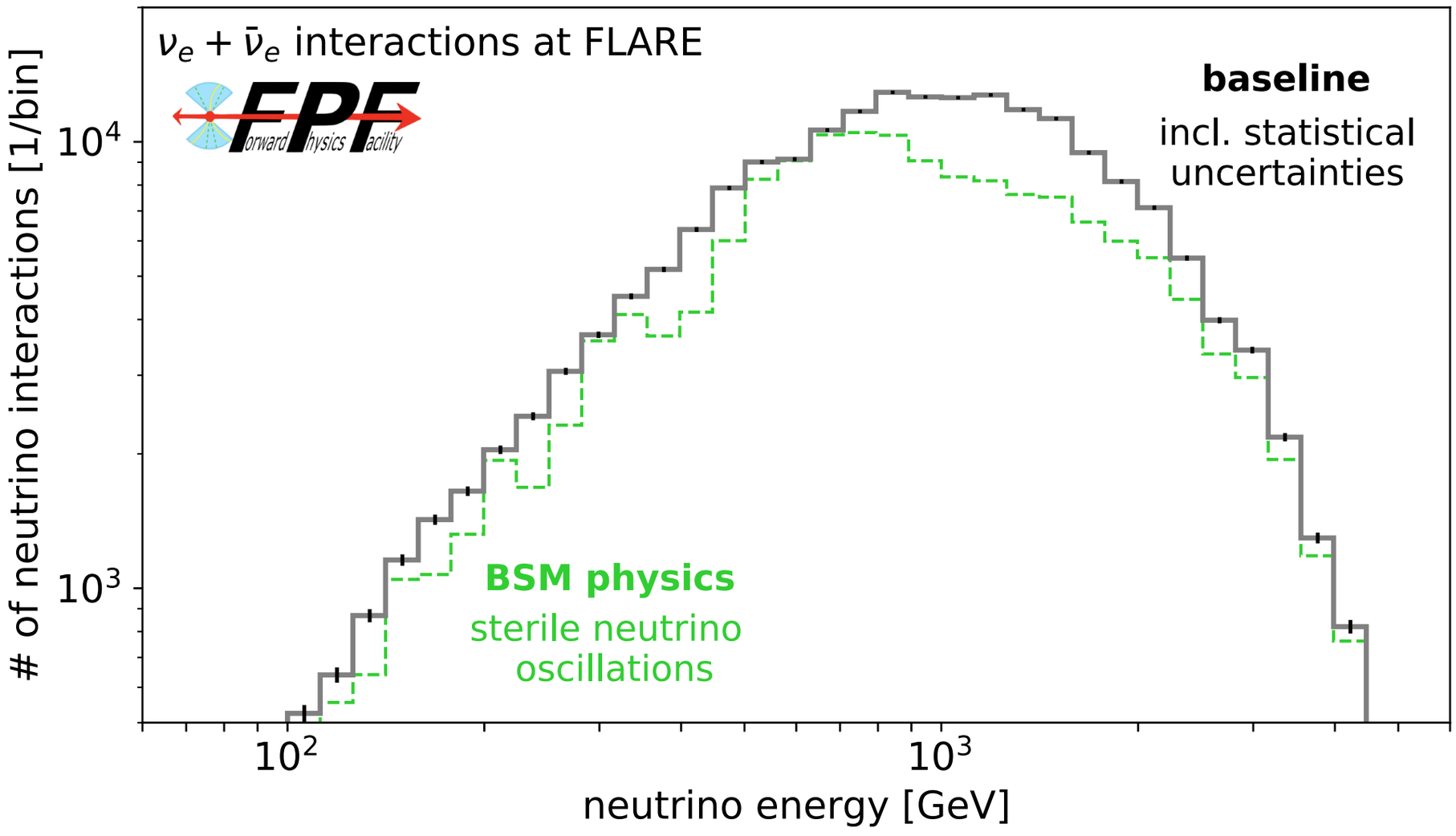
Sterile Neutrino Oscillations

3 + 1 scheme

$$P(\nu_\alpha \to \nu_\alpha) = 1 - 4|U_{\alpha 4}|^2(1 - |U_{\alpha 4}|^2)\sin^2\frac{\Delta m^2_{41} L}{4E}$$

➢ FLArE sensitive to neutrino square mass difference satisfying $\frac{\Delta m^2_{41} L}{4E} = \frac{\pi}{2}$

for $L \sim 620\ \mathrm{m}\ \wedge\ E \sim \mathrm{TeV} \Rightarrow \Delta m^2_{41} \sim 2000\ \mathrm{eV}^2$



Neutrino-Modulino Oscillations

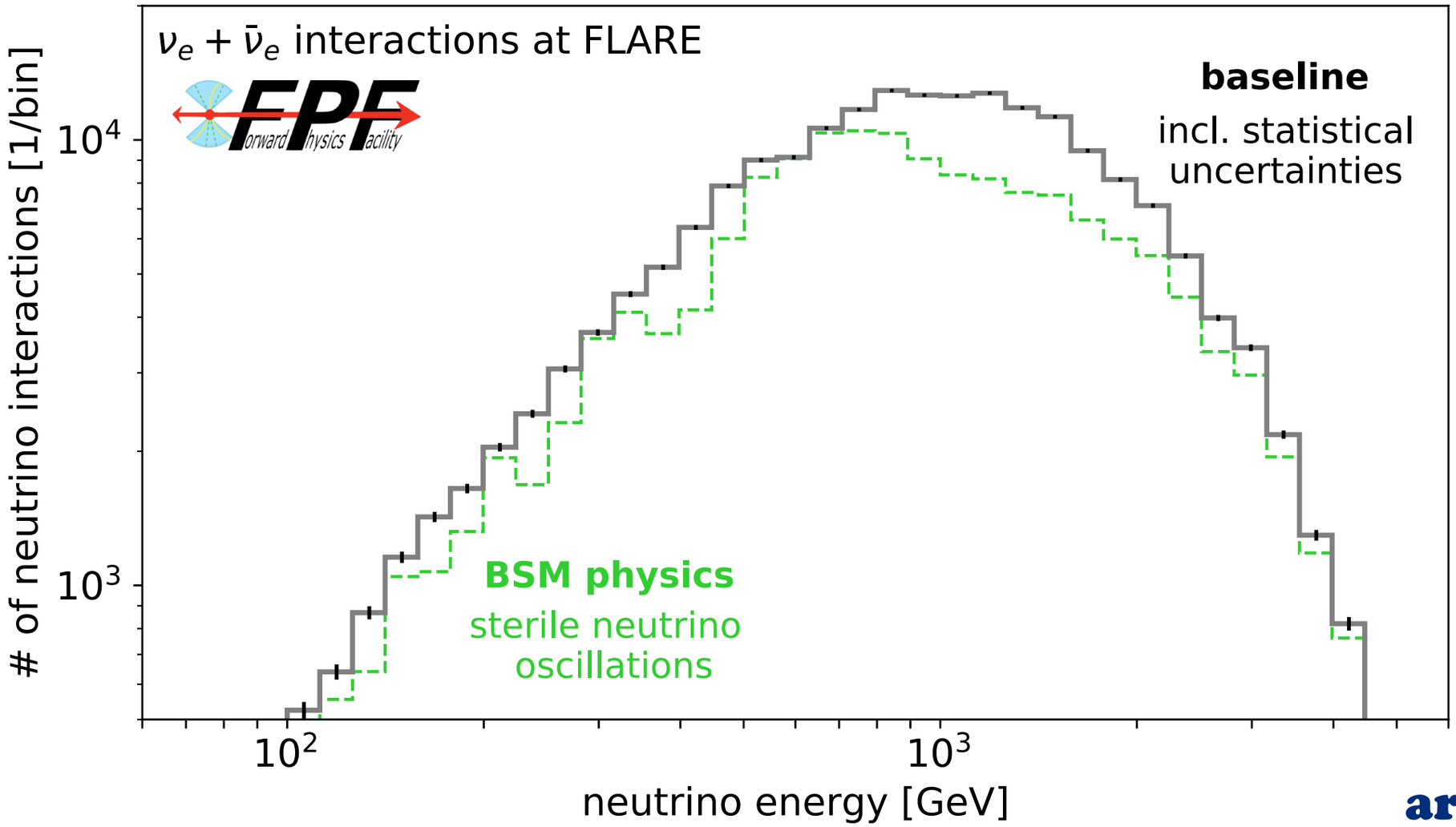
- Simple construct ☛ relevant light scale for SM singlets is $m_{3/2}$

  and dimensionless coupling constant with visible matter is $\lambda_i = \alpha_i \dfrac{m_{3/2}}{M_p}$

- Modulino mass is generated by SUSY breaking as the coupling λ_i

  but @ 2nd order in $m_{3/2}$ ☛ $m_4 \sim \beta \dfrac{m_{3/2}^2}{M_p}$

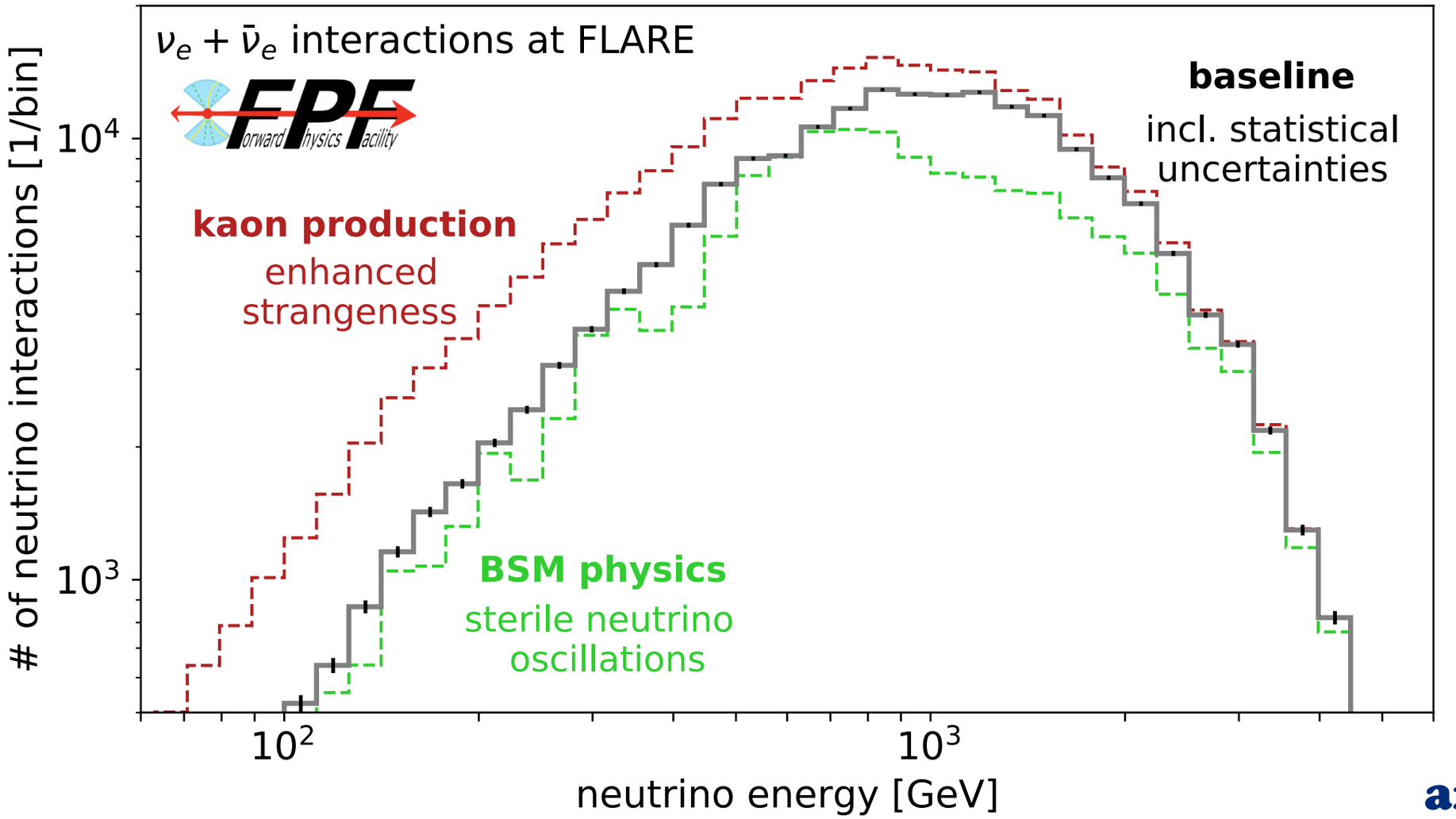
$$m_{3/2} \sim 250 \text{ TeV} \ \wedge \ \beta \sim 1.7 \Rightarrow \Delta m_{41}^2 \sim 2000 \text{ TeV}$$



arXiv:2105.06197

Forward Strangeness Production @ LHC

- Amount of forward strangeness production is traced by ratio of charged kaons to pions
  for which ratio of electron and muon neutrino fluxes is proxy that will be measured @ FPF
- Pions primarily decay into muon neutrinos
  but kaon decays lead to fluxes of electron and muon neutrinos
- Muon and electron neutrinos with different parent mesons populate different energy regions
  and so spectral shape can be used to disentangle neutrino origin



arXiv:2105.06197

UHECR Muon Conundrum

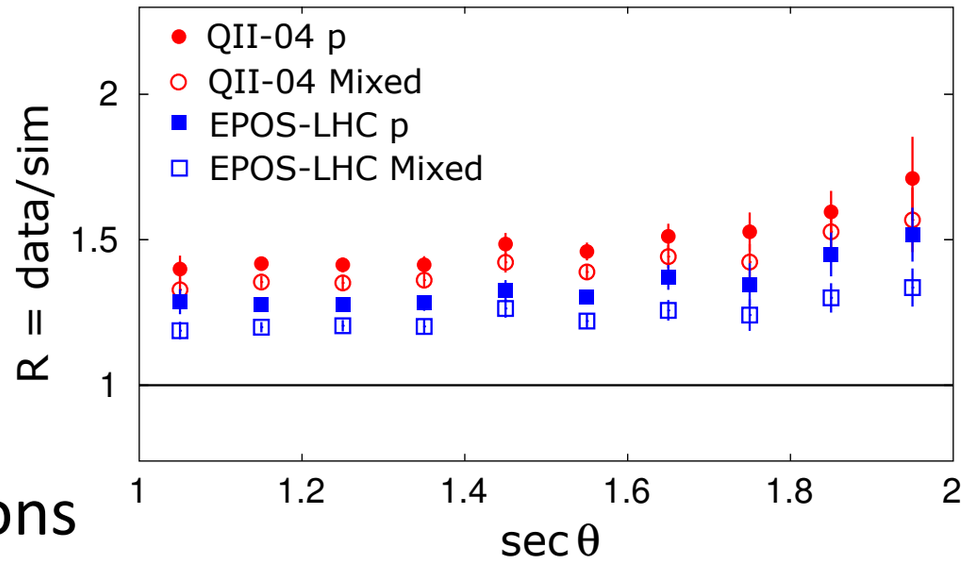
- Hints in ALICE data

  arXiv:1606.07424

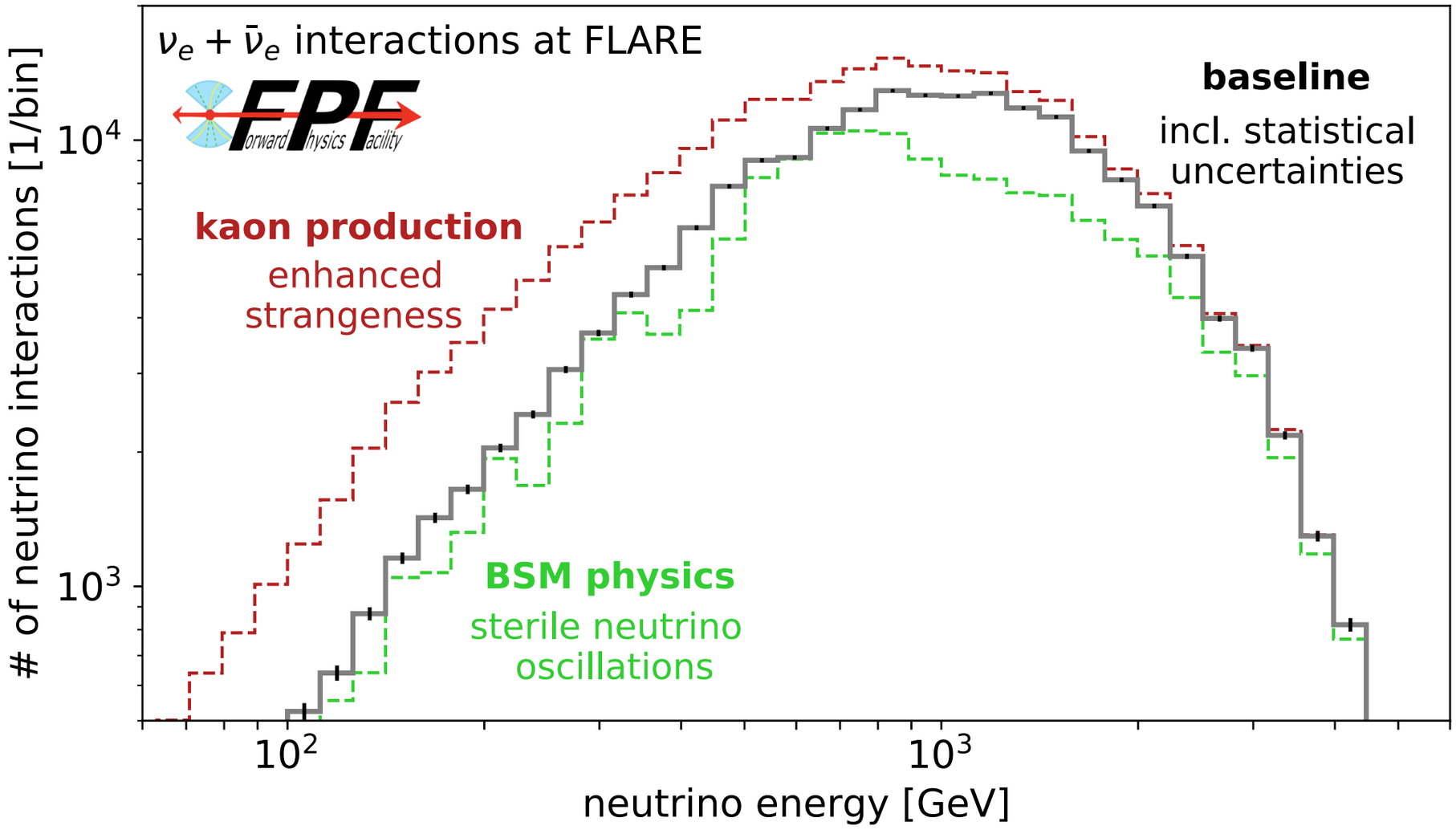
- Hadronic component of showers

  with $10^{9.8} < E/\mathrm{GeV} < 10^{10.2}$

  contains more muons than expected from simulations

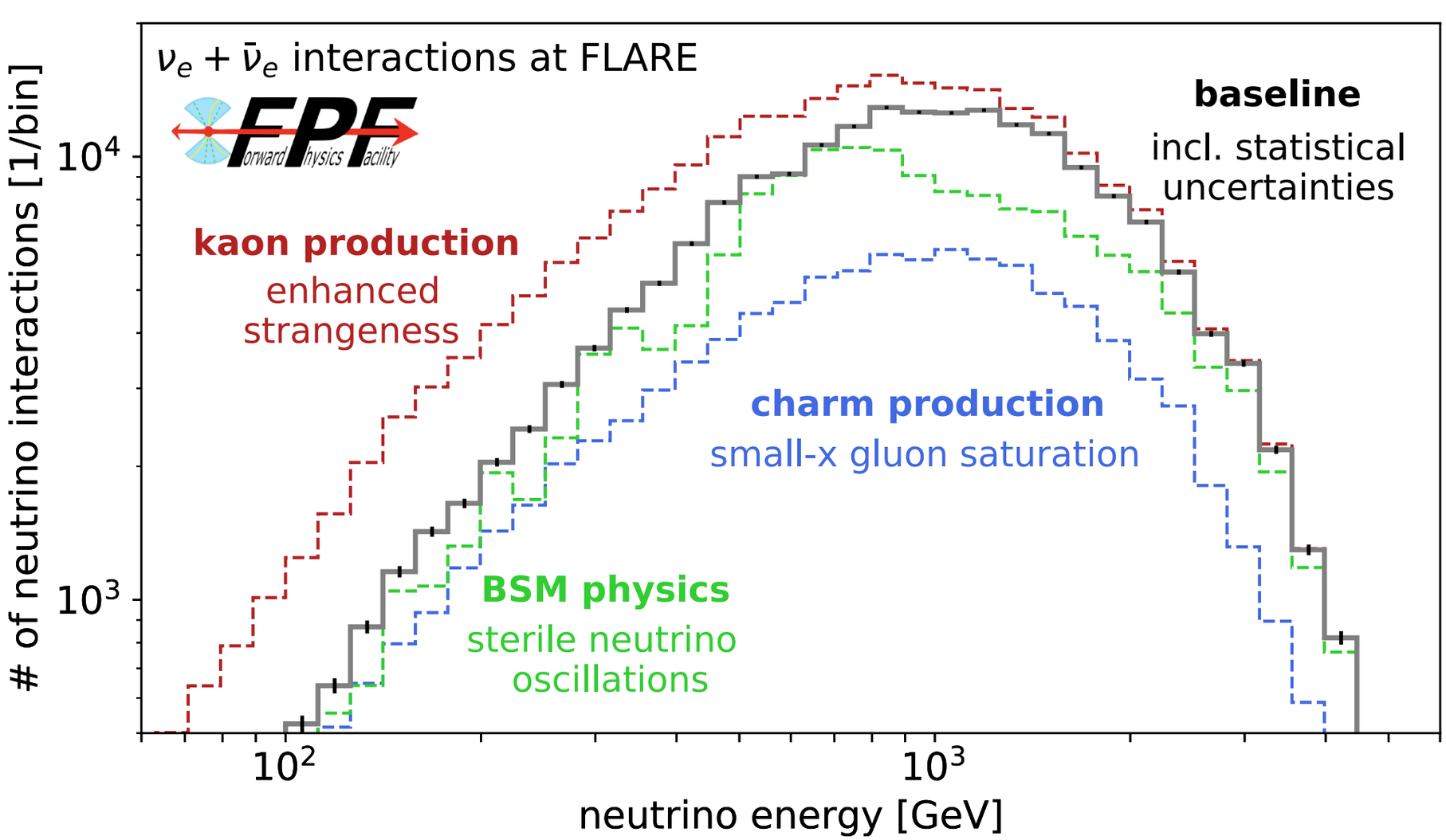


arXiv:1610.08509



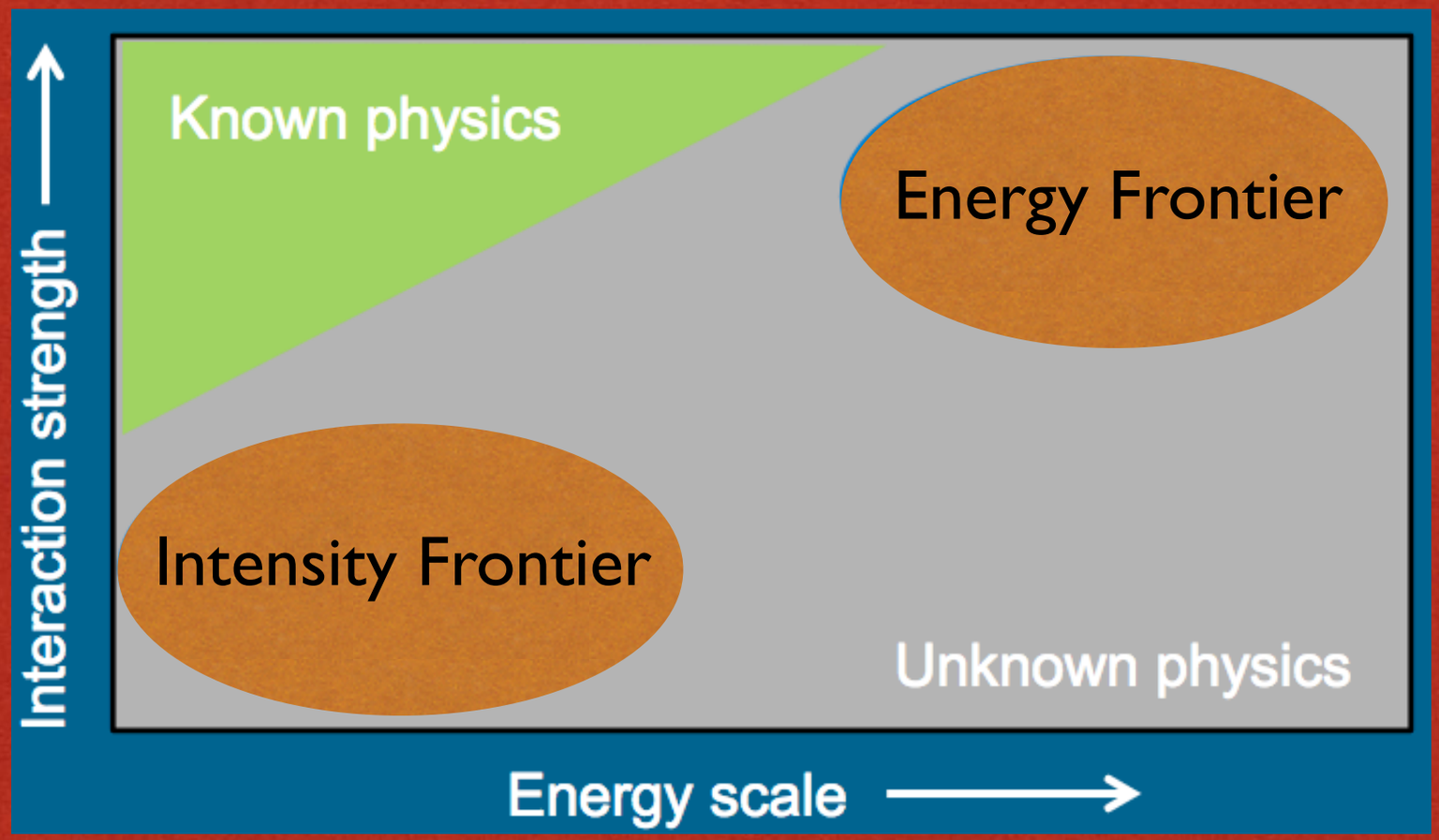
PDFs and Forward Charm Production

- Neutrinos above 1 TeV are mainly produced in charm hadron decays
- Production of charm quarks dominated by gluon fusion
- FLArE measurements of neutrino flux can probe both very high-x and very low-x regions of colliding protons
- Gluon recombination $(gg \to g)$ is expected to be relevante for $x \sim 10^{-7}$ and would tame growth of gluon PDF in this region



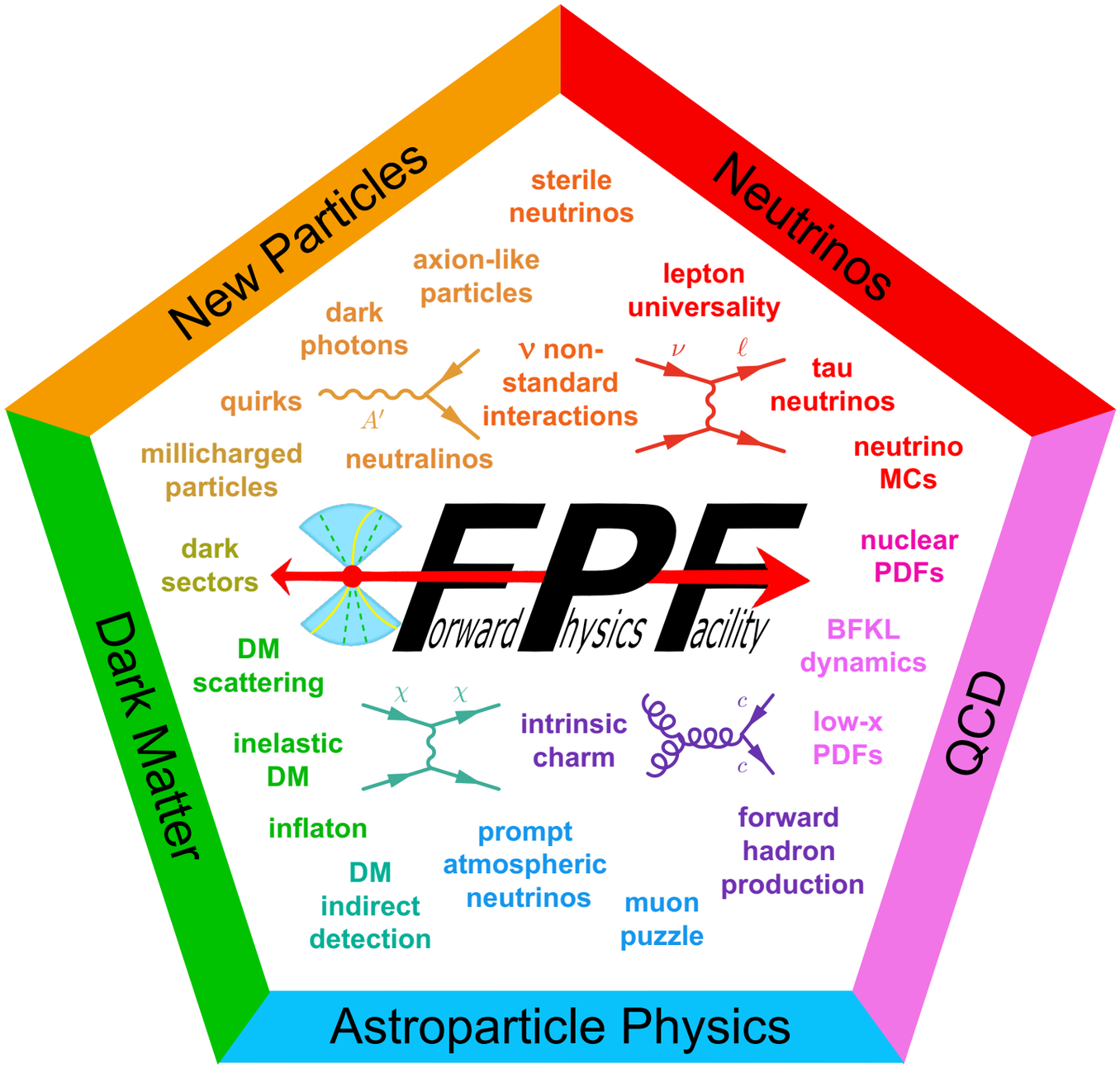
Take Home Message

- Next breakthrough in particle physics is likely to involve long-lived particles



- FPF experiments operating at the HL-LHC will be sensitive to unexplored phase space for broad range of LLP hidden sector physics

- FPF neutrino measurements will improve modeling of high-energy hadronic interactions and help to reduce uncertainties in air shower measurements



Forward Physics Facility Theory Workshop

Subir's highlight talk: FPF Connection to Astro-Particle Physics

September 19, 14:30 (CERN time zone)


NASA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