



# Muon Collider Synergies Workshop

## Neutrino Physics Session

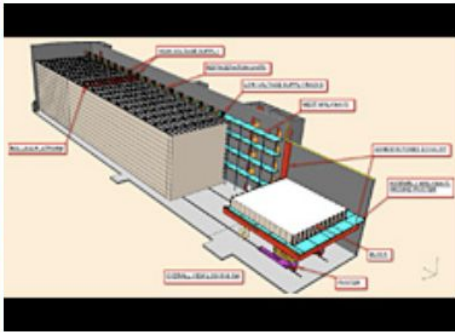
Conveners: Luis Alvarez-Ruso, Patrick Huber, Xianguo Lu, Francesco Terranova,

Question	By ~2040	Caveats
Neutrino mass ordering	Yes	Increasing significance and discovery
Delta CPV	Likely?	Depends on value of delta
Precision in oscillation parameters	Some	$\theta_{23}$ and delta with still some uncertainty
Sterile nus, NSIs, and other B3nu	Maybe	Surprises in store?
DSs: dark photons, HNLs,...	Maybe	Surprises in store?
Baryon asymmetry	Not really	Some hints if LNV and CPV

# Present/Future LBL exp

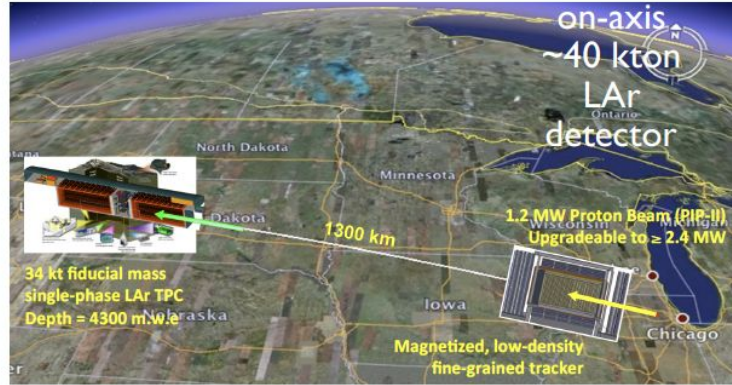
**DUNE:**  
1300 km

Silvia Pascoli



**NOvA:** 810 km off-axis  
~14 kton plastic scintillator detector

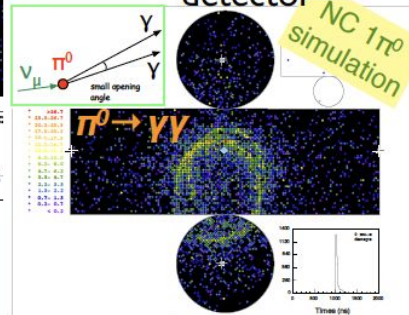
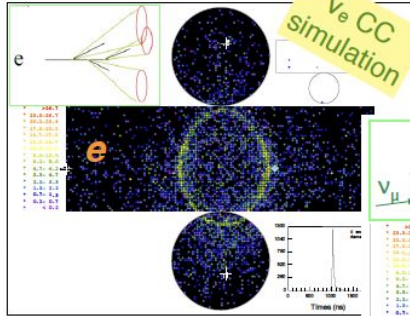
**T2K:** 295 km off-axis  
~22.5 kton WC detector



Flagship neutrino oscillation experiments

- L/E rules
- $E_{\nu}$  O(1 ~ 10 GeV)
- critical systematics: neutrino cross section

**T2HK:** 295 km off-axis  
~1 Mton WC detector



M. Shiozawa, for T2HK coll., NuPhys 2014



~1 BEuro for the neutrino facility including detector

**ESSnuSB:** 300-500 km  
~0.5 Mton WC detector  
second osc. maximum

# Strategic mid-term goal

Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders... *The technologies under consideration include* high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, *bright muon beams*, energy recovery linacs. The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. ...

European Strategy for Particle Physics  
2020 update

High-priority future initiatives

To extract the most physics from DUNE and Hyper-Kamiokande, a *complementary programme of experimentation to determine neutrino cross-sections* and fluxes is required. Several experiments aimed at determining neutrino fluxes exist worldwide. The possible implementation and impact of a facility to measure neutrino cross-sections at the percent level should continue to be studied.

Opportunity ...

Exploit synergies with ENUBET:  
Articulate the need

Common requirement:  
Advanced neutrino detector

Other essential scientific activities for particle physics

Final

Neutrinos from Stored Muons (nuSTORM)  
Submitted to the Snowmass 2021 DPF Community Planning Exercise

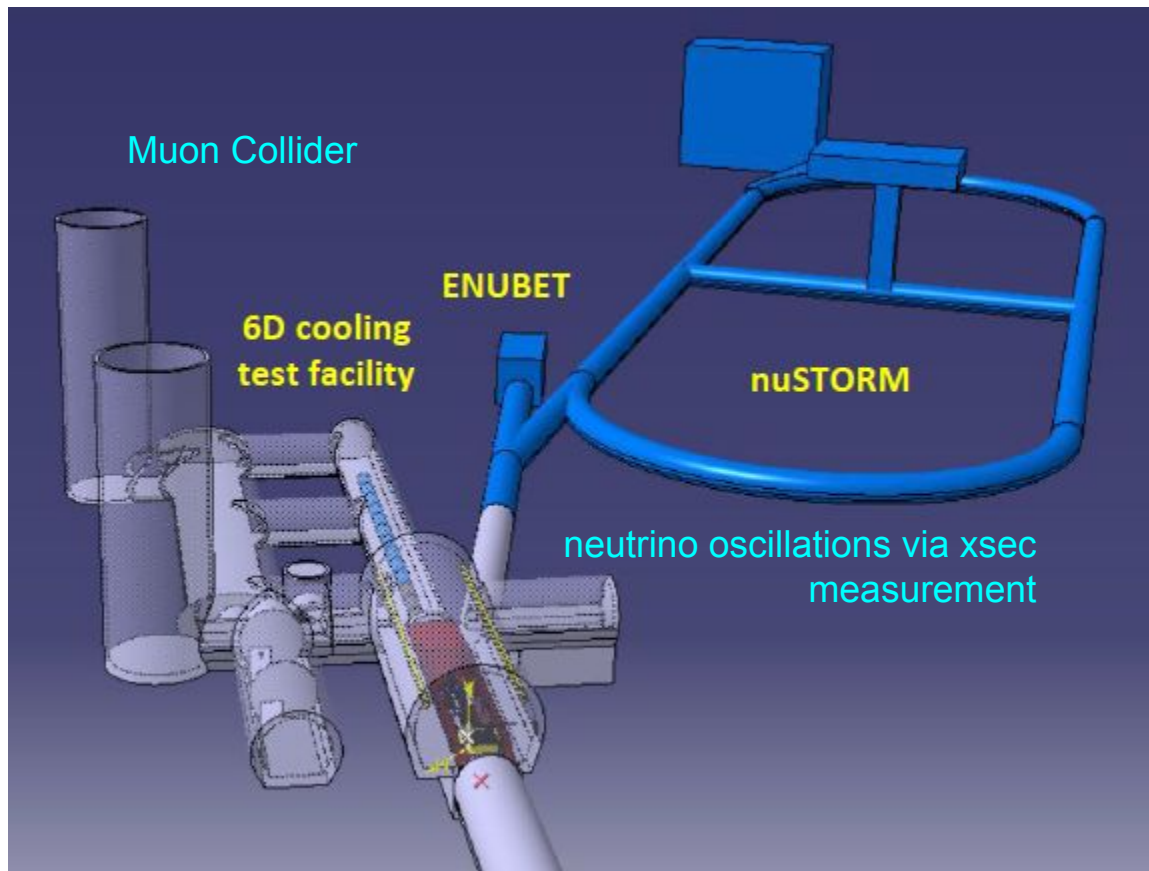
[arXiv:2203.07545](https://arxiv.org/abs/2203.07545)

ESPPU  
202x

**Goal:** over next ~3 years, prepare for next ESPPU:

- Study and document the science case:
  - Cross sections, BSM, and MC demonstrator
- Prepare “pre-CDR” as input to the Strategy Update

Ken Long



# Take-away message #1

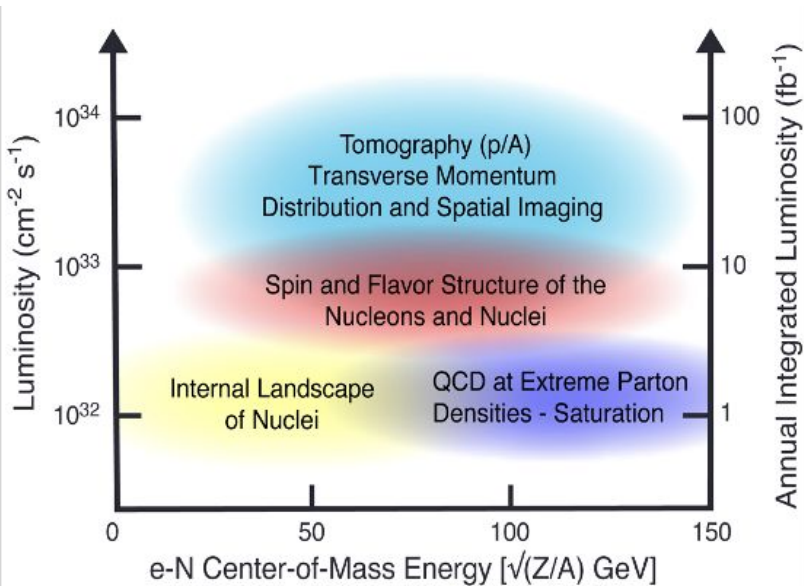
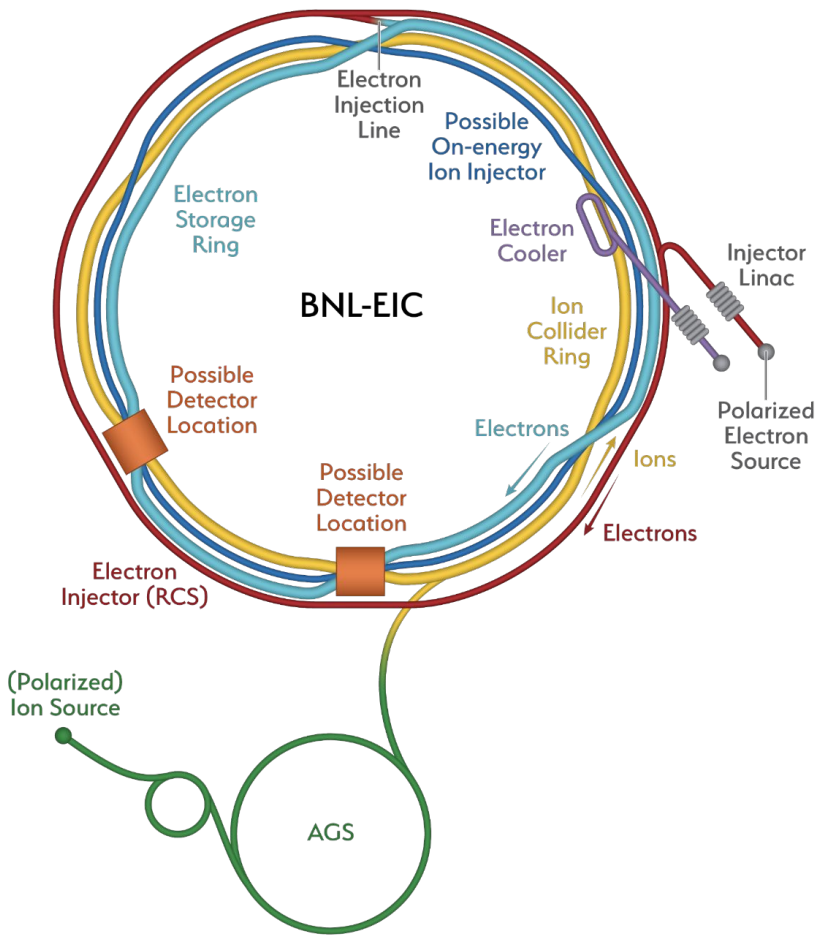
Muon Collider (TeV)  $\longleftrightarrow$  Neutrino Oscillation (GeV)

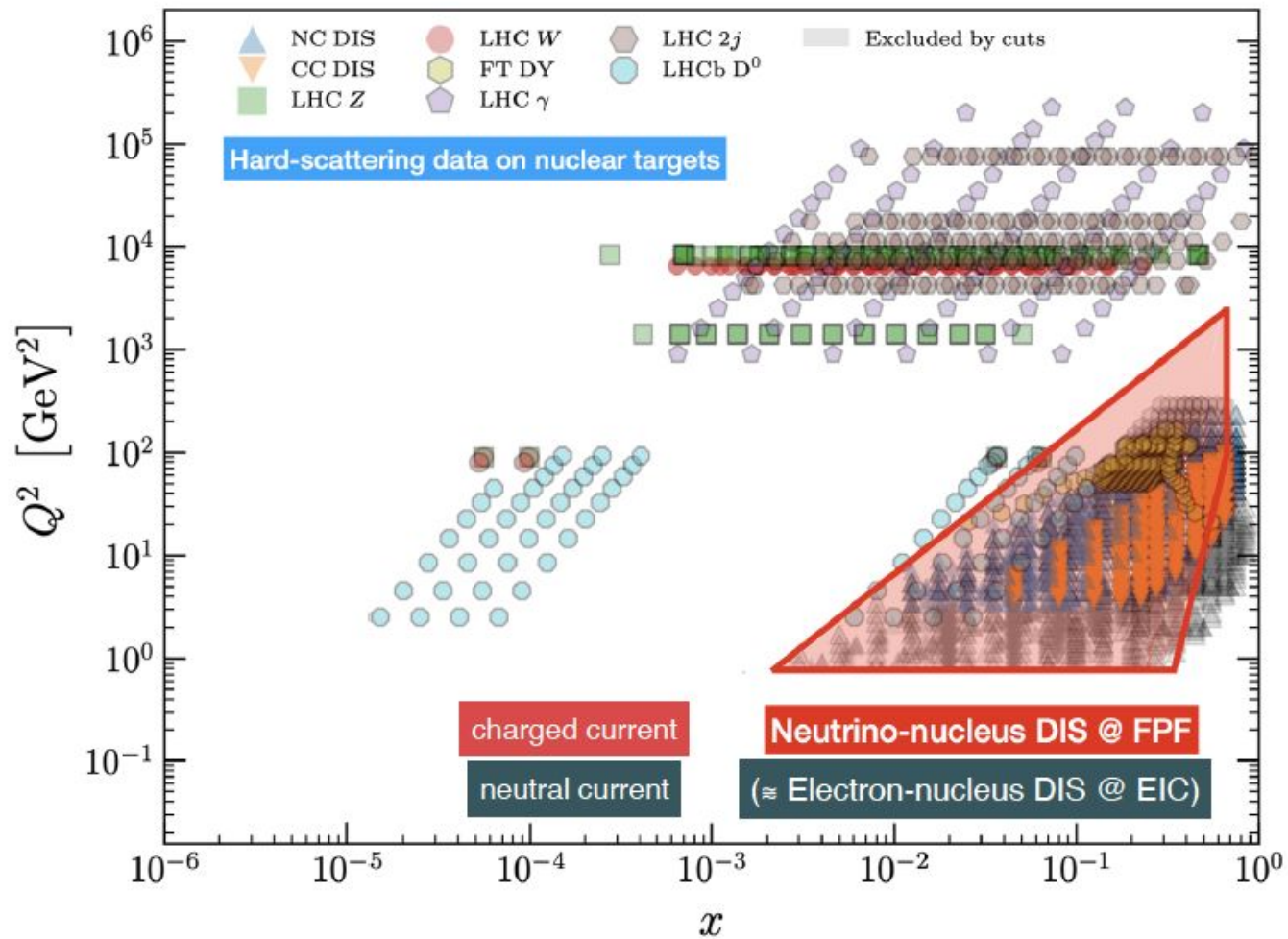
via demonstrator at CERN w/ ENUBET and nuSTORM

## Daria Sokhan

Flagship lepton-ion collider

- polarised lepton beam
- O(100 GeV) c.m.s. energy





Juan Rojo

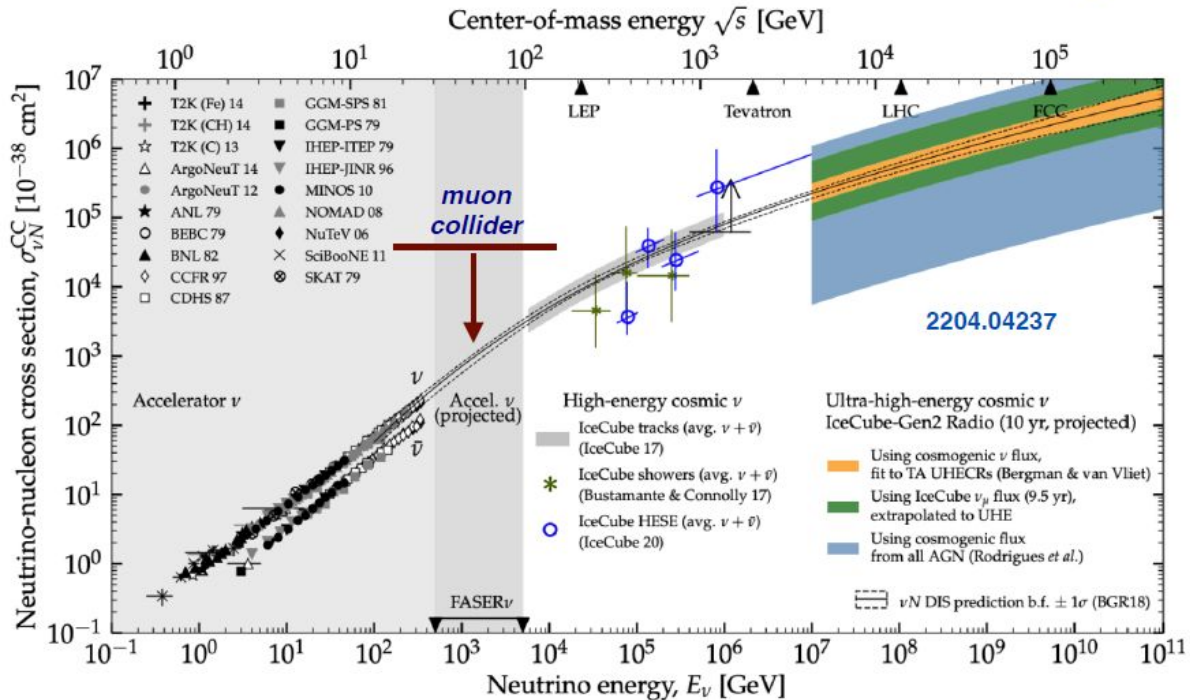


## Take-away message #2

Muon Collider (TeV beam fixed target)  $\longleftrightarrow$  Hadron/nuclear physics (100 GeV collider)

theoretically attractive due to strong overlap in kinematic region and complementary probes: polarised, charged current vs neutral current

# The neutrino cross-section landscape

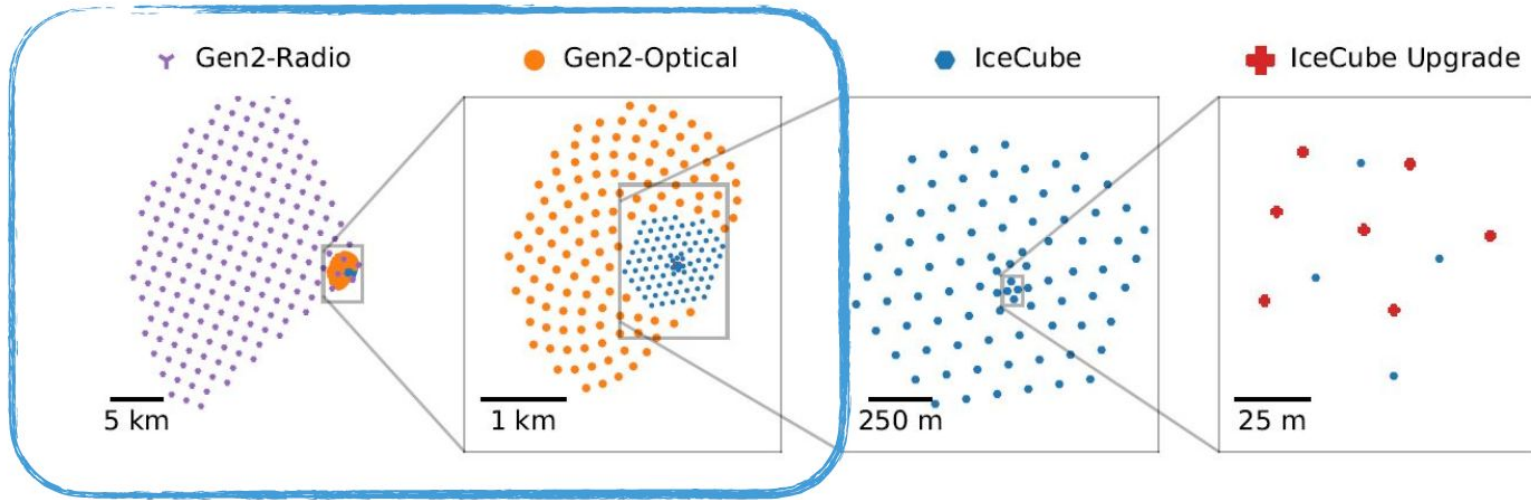


Juan Rojo

Precise measurements complementing EIC (Daria Sokhan), FASER, IceCube (Summer Blot)

- TeV-EeV neutrinos
- Driving towards TeV

## Extensions to the IceCube Neutrino Observatory



**IceCube Gen2 on longer timeline**

**Focus on TeV-EeV energy neutrinos**

[https://www.icecube-gen2.de/index\\_eng.html](https://www.icecube-gen2.de/index_eng.html)

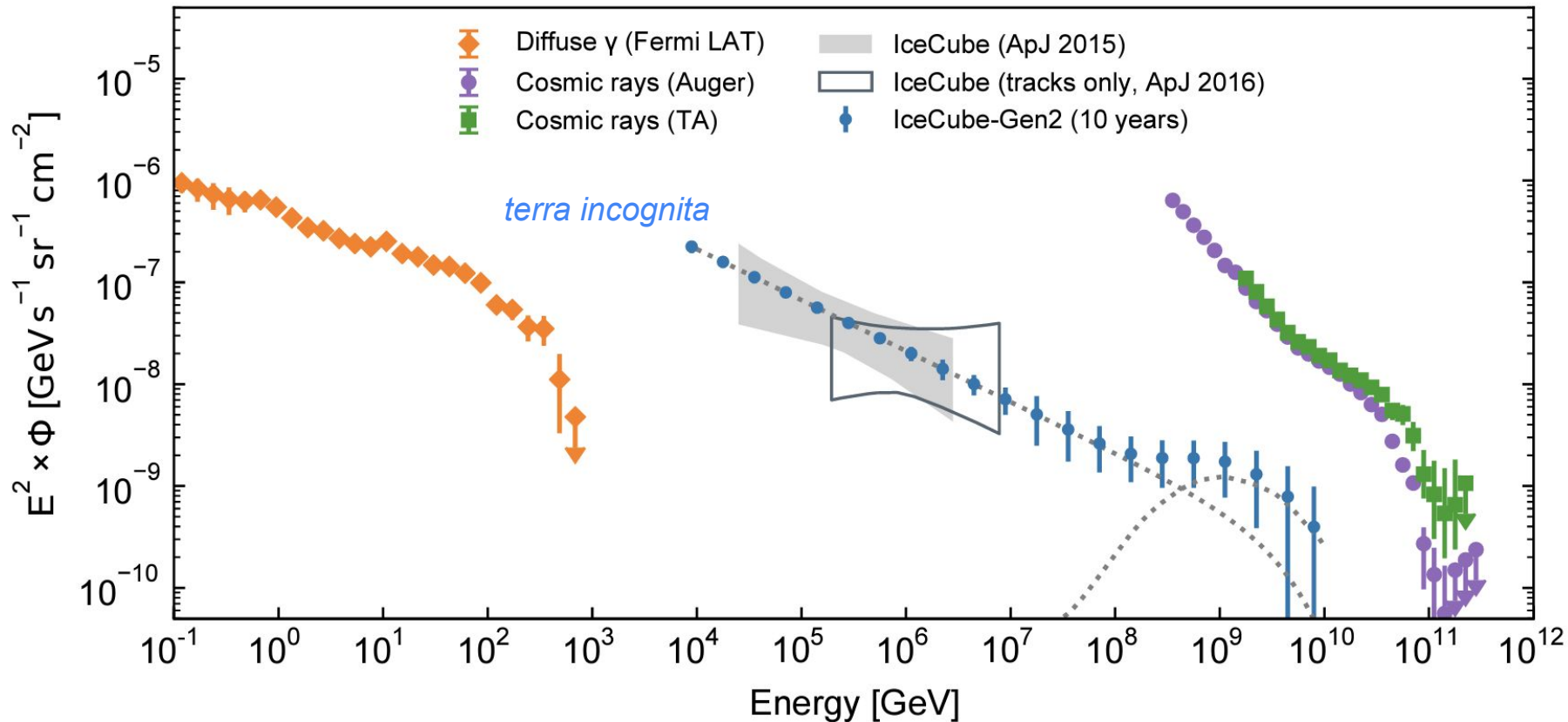
Learn more



# Summer Blot

## Particle astronomy

- TeV-EeV neutrinos
- Driving towards TeV



## Take-away message #3

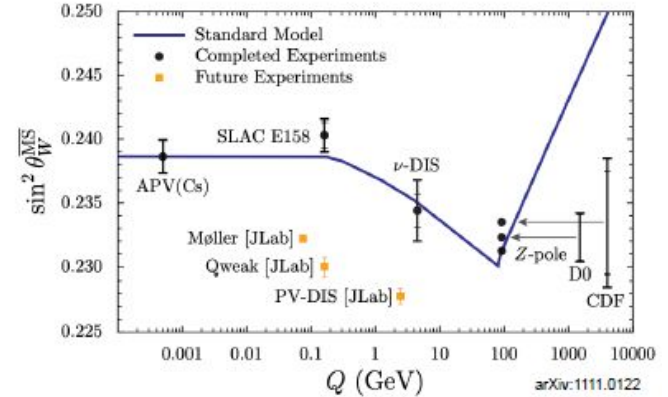
Muon Collider (TeV)  $\longleftrightarrow$  Particle astronomy (EeV-PeV-TeV)

Potential of discovery in  $\sim 20$  year, or systematics yet undiscovered? MC to provide precision benchmark measurements?

- NuTeV anomaly (3 sigma tension with SM)

$$R = \frac{\sigma_{NC}^{\nu A} - \sigma_{NC}^{\bar{\nu} A}}{\sigma_{CC}^{\nu A} - \sigma_{CC}^{\bar{\nu} A}} \approx 1/2 - \sin^2 \theta_W$$

- (Anti)neutrino-electron scattering
  - NuSOng



## Test EW



- NuSOng: [arXiv:0907.4864](https://arxiv.org/abs/0907.4864)
  - Four calorimeters+muon spectrometer separated by 15m.
  - Each calorimeter has 500 layers of glass and active detectors.

# Discussions

1. Community forming
  - a. organisation: communication, meetings, working groups, etc.
  - b. publication policy
2. Interface to IMCC
  - a. How can we get “official” neutrino fluxes?
  - b. How can we provide feedback on machine design?
3. AOB