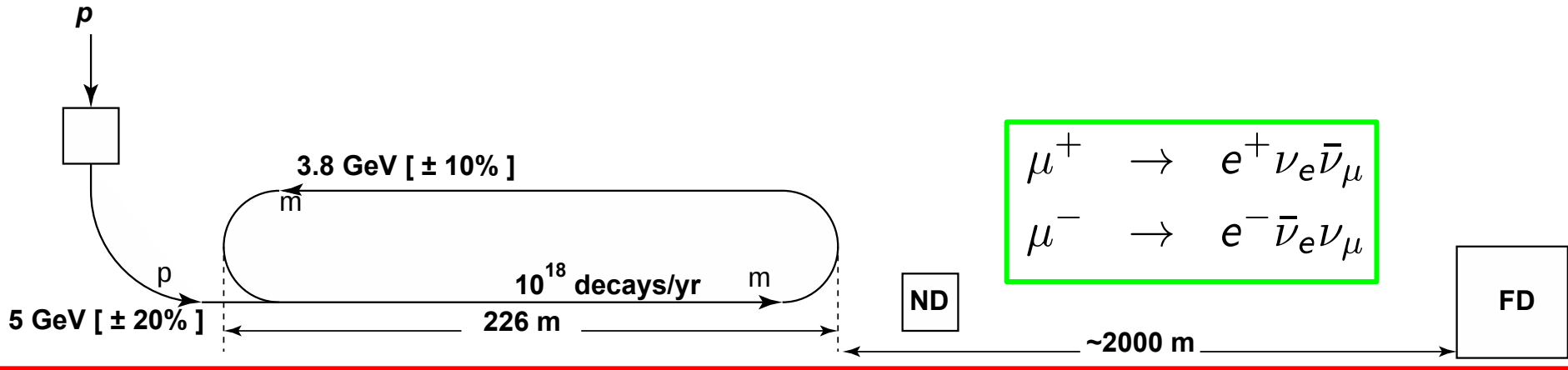
nuSTORM

P. Huber, K. Long; 5 July, 2018

WHAT IS nuSTORM?

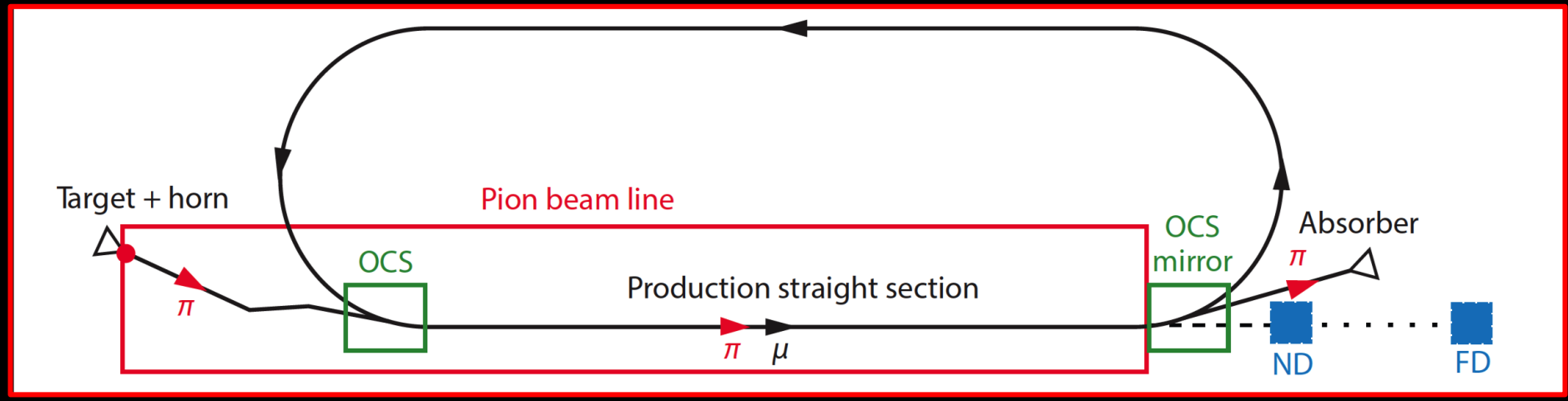
Neutrinos from stored muons



- **Scientific objectives:**
  1. **%-level ($\nu_e N$)cross sections**
     - **Double differential**
  2. **Sterile neutrino search**
     - **Beyond Fermilab SBN**

- **Precise neutrino flux:**
  - **Normalisation: < 1%**
  - **Energy (and flavour) precise**
- **π → ↗ injection pass:**
  - **"Flash" of muon neutrinos**

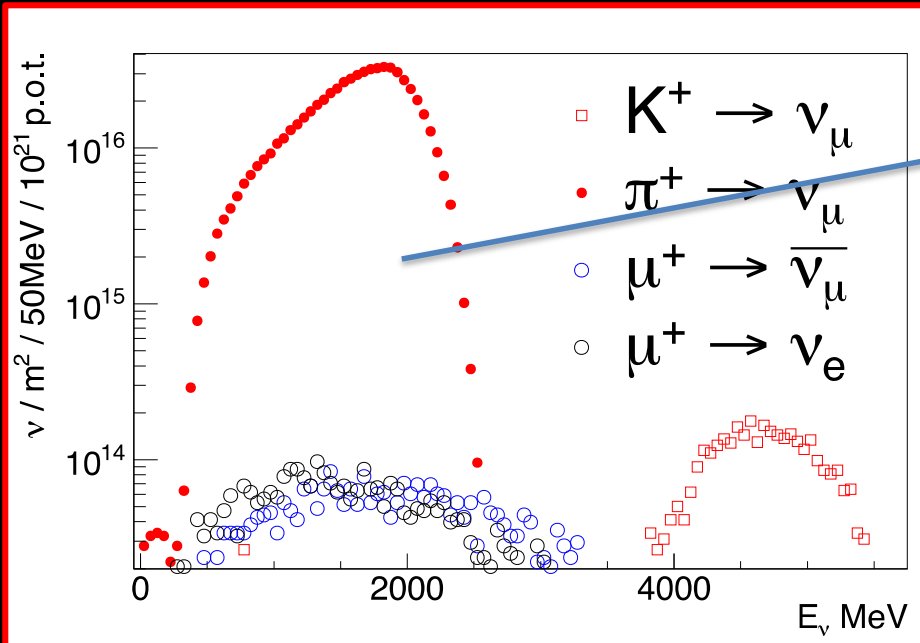
nuSTORM oveview

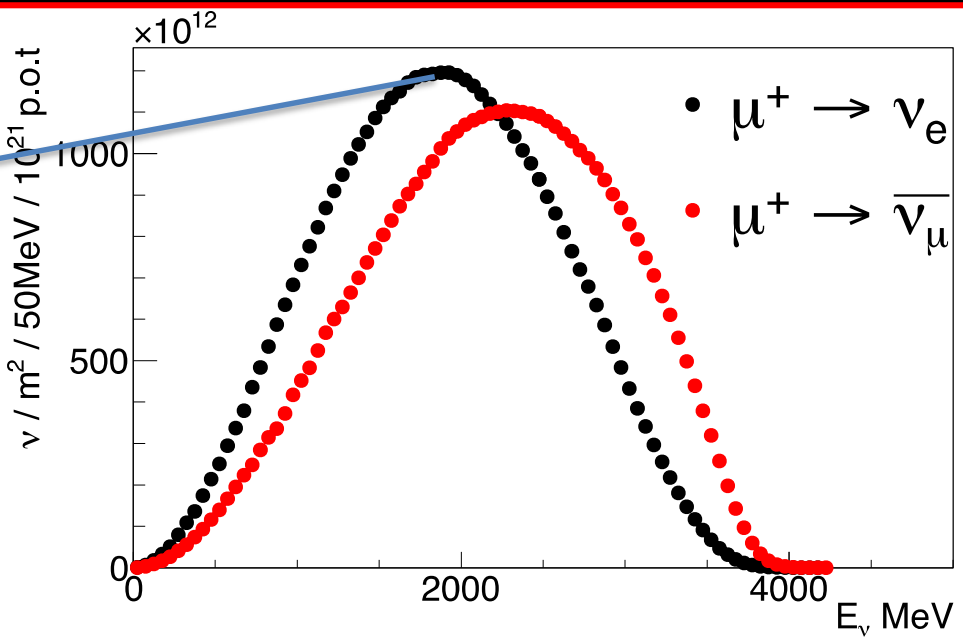


- Fast extraction at >~ 100 GeV
- Conventional pion production and capture (horn)
  - Quadrupole pion-transport channel to decay ring

10.1146/annurev-nucl-102014-021930

Neutrino flux



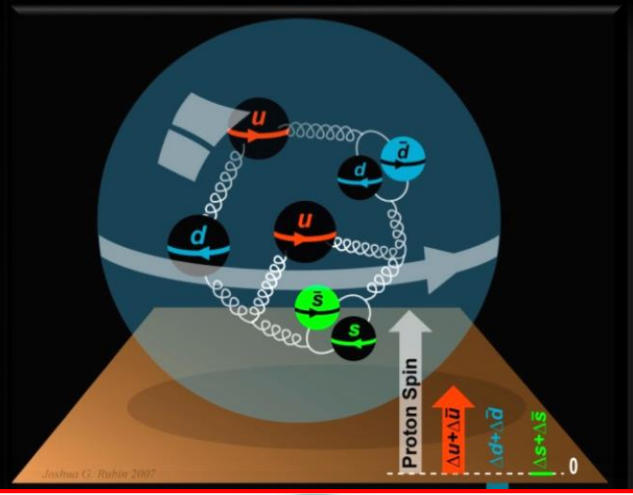


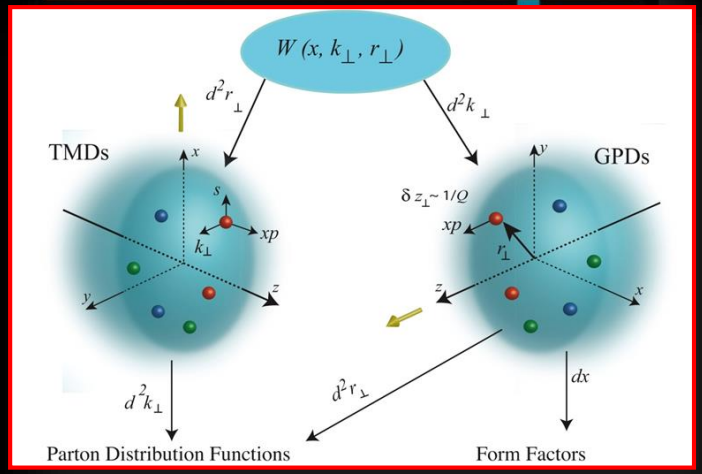
- ν_μ flash:
  - Pion: 6.3×10^{16} m^{-2} at 50m
  - Kaon: 3.8×10^{14} m^{-2} at 50m
    - Well separated from pion neutrinos
- ν_e and ν_μ from muon decay:
  - ~10 times as many ν_e as, e.g. J-PARC beam
  - Flavour composition, energy spectrum
    - Use for energy calibration

WHY STUDY NEUTRINO INTERACTIONS?

To understand the nucleon and the nucleus

- Neutrino unique probe: weak and chiral:
  - Sensitive to flavour/isospin and 100% polarised
- How could neutrino scattering help?
  - Nucleon (e.g.):
    - Spin puzzle
  - Nucleus (e.g.):
    - Multi-nucleon correlations
    - Precise determination of:
      - Model parameters or, better,
      - Theoretical (ab initio) description
- Can the neutrino's unique properties compete with the rate in, e.g. electron scattering?
  - Measure weak charge directly; rate and Q^2 dependence:
    - For e^- rely on interference with photon, 10^{-6}-level asymmetry
  - To be studied!
- Benefit of nuSTORM:
  - Precise flux and energy distribution

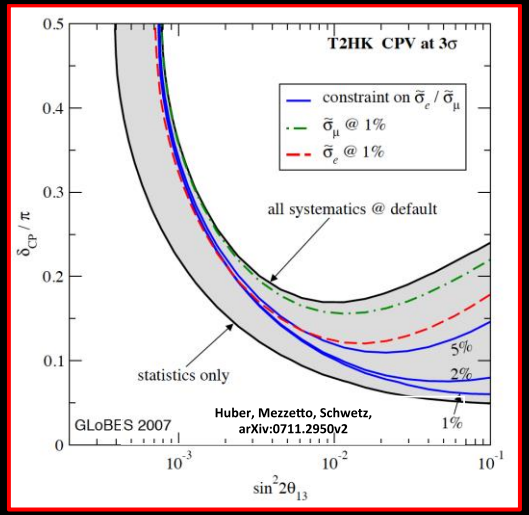




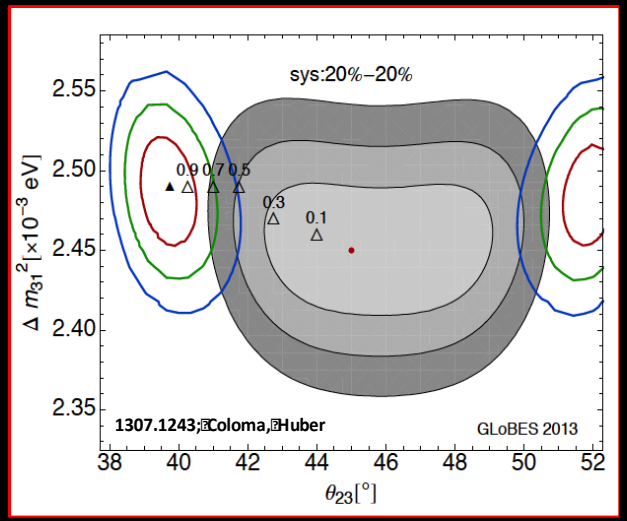
Search for CPiV in lbl oscillations

- Seek to measure asymmetry:
  - $P(\nu_\mu \rightarrow \nu_e) - P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$
- Event rates, convolution of:
  - Flux, cross sections, detector mass, efficiency, *E*-scale
    - Measurements at %-level required
  - Theoretical description:
    - Initial state momentum, nuclear excitations, final-state effects

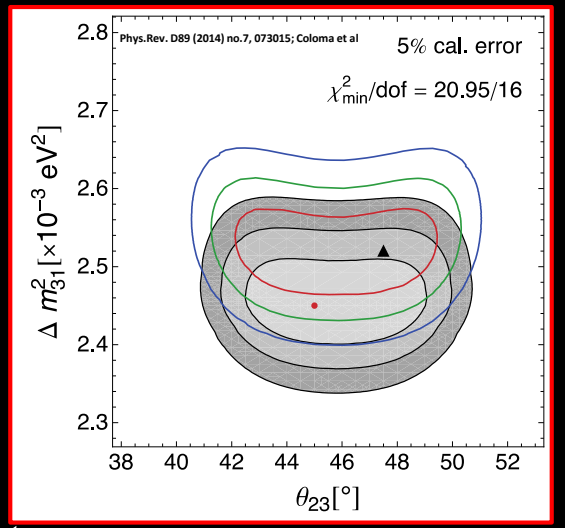
Systematic uncertainty and/or bias



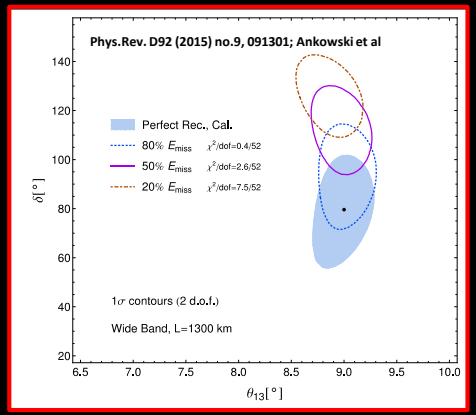
Uncertainty
(cross section and ratio)



Event mis-classification



Energy scale mis-calibration



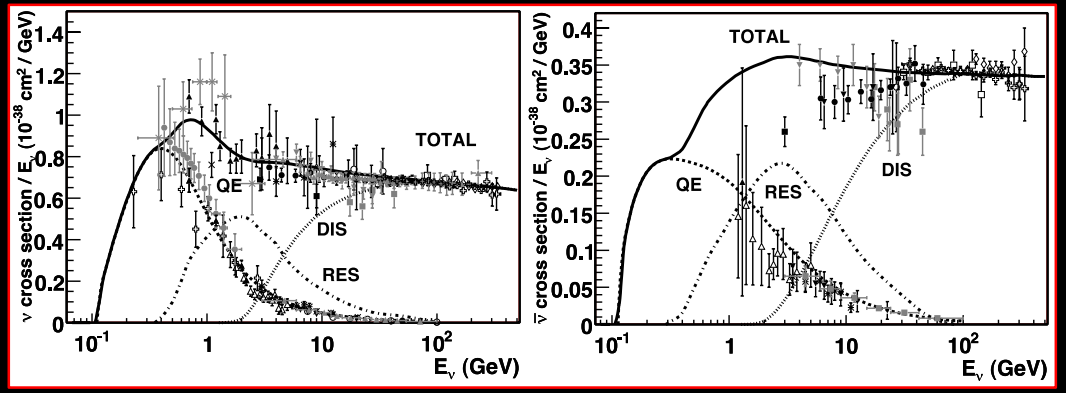
Missing energy (neutrons)

Search for CPiV in lbl oscillations

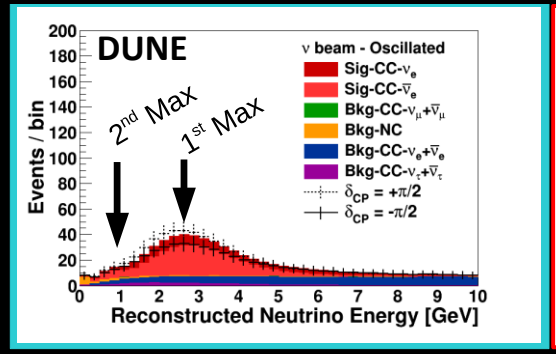
- Seek to measure asymmetry:
  - $P(\nu_\mu \rightarrow \nu_e) - P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$
- Event rates convolution of:
  - Flux, cross sections, detector mass, efficiency, *E*-scale
    - Measurements at %-level required
  - Theoretical description:
    - Initial state momentum, nuclear excitations, final-state effects
- Lack of knowledge of cross-sections leads to:
  - Systematic uncertainties; and
  - Biases; pernicious if ν and $\bar{\nu}$ differ

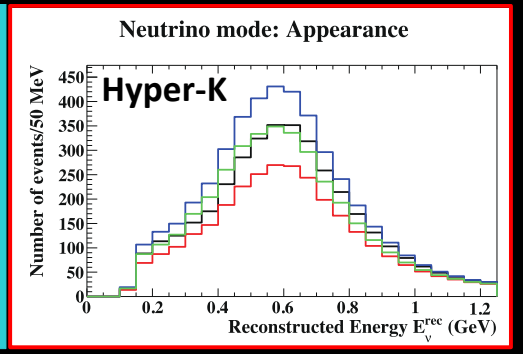
Specification: energy range

- Guidance from:
  - Models:
    - Region of overlap 0.5—8 GeV
  - DUNE/Hyper-K far detector spectra:
    - 0.3—6 GeV



- Cross sections depend on:
  - Q^2 and W:
    - Assume (or specify) a detector capable of:
      - Measuring exclusive final states
      - Reconstructing Q^2 and W
    - → E_μ < 6 GeV



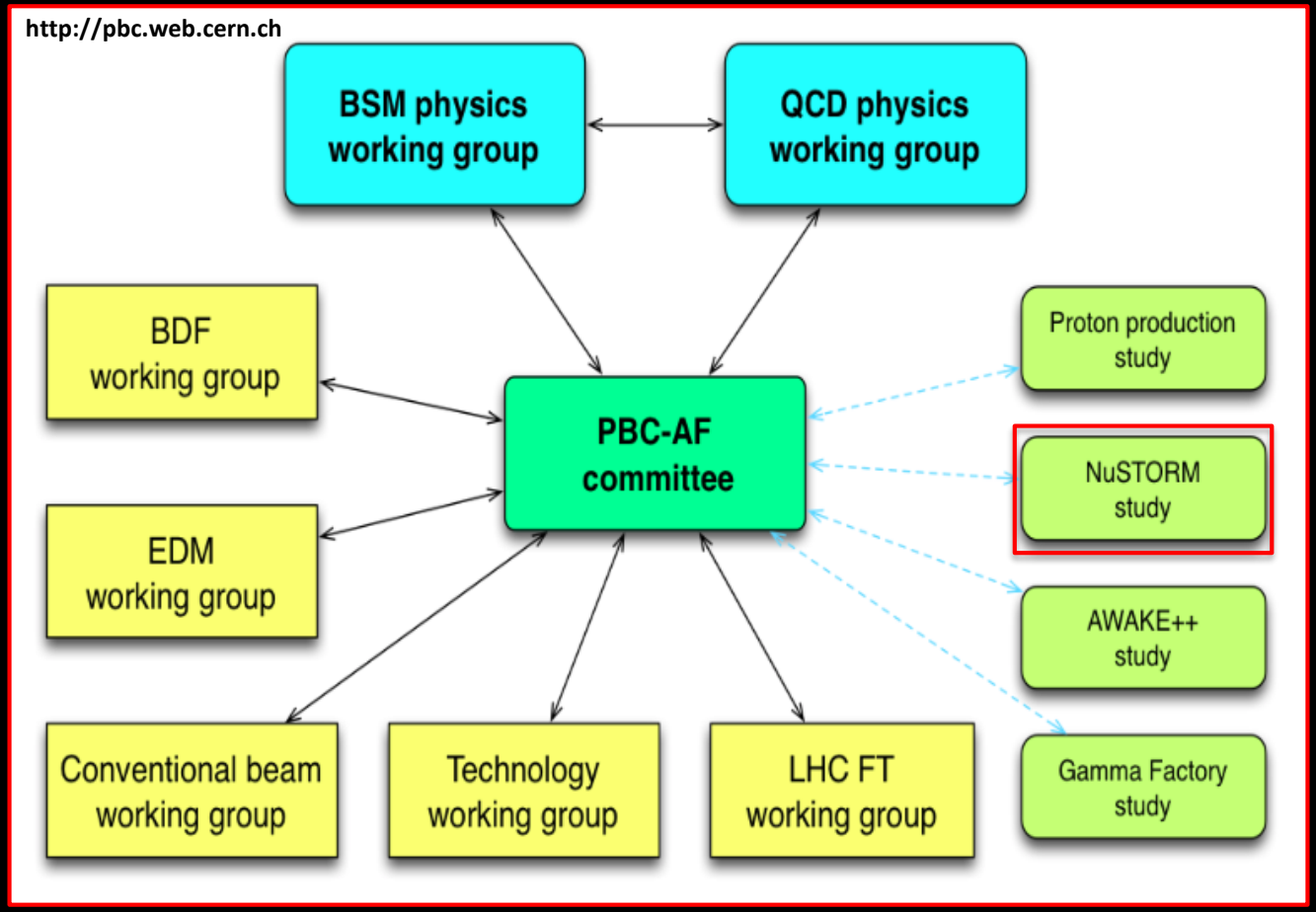


- So, stored muon energy range:

$1 < E_\mu < 6$ GeV

nuSTORM & THE CERN PHYSICS BEYOND COLLIDERS STUDY GROUP

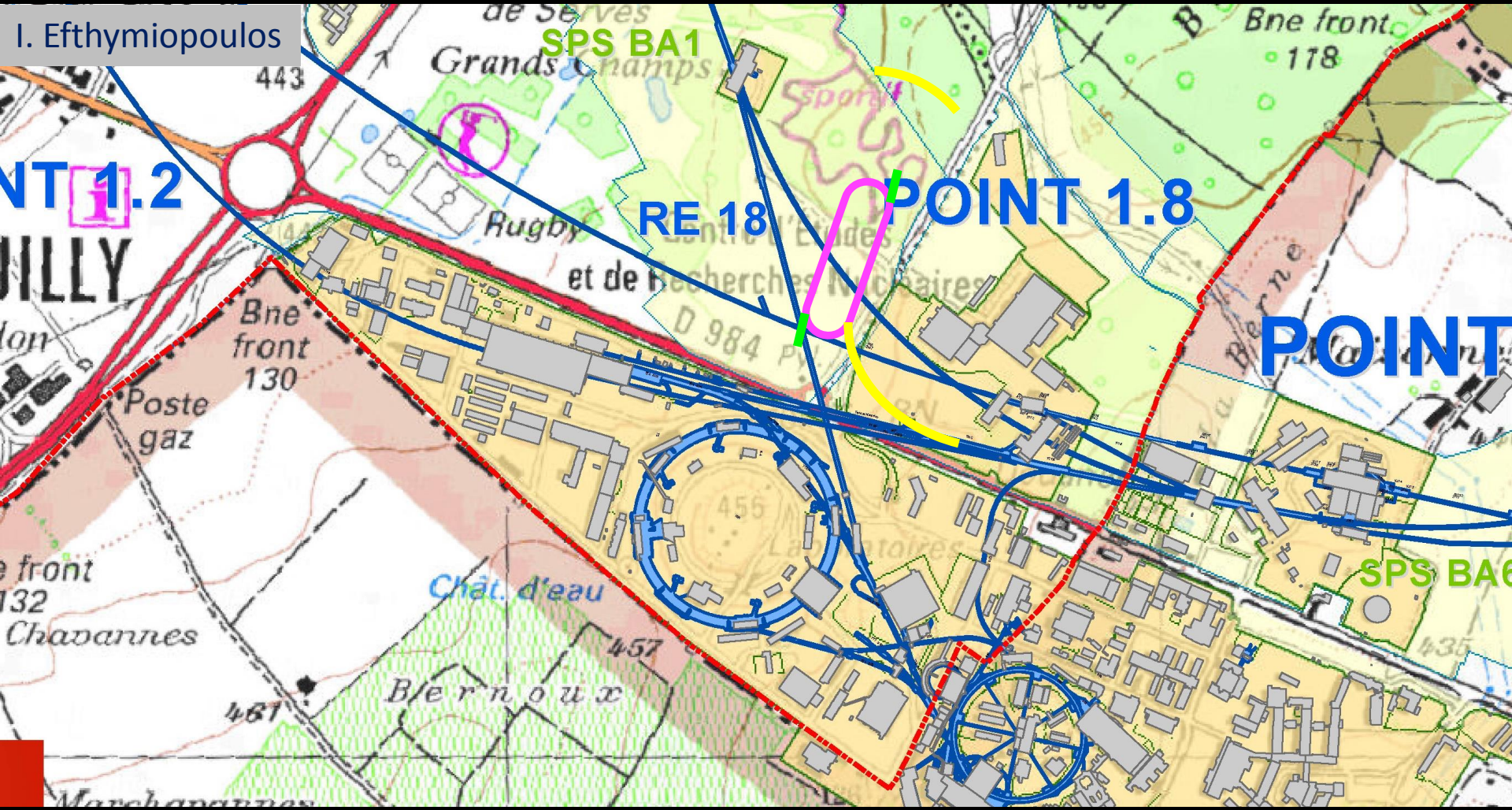
Physics Beyond Colliders study group



Implementation @ CERN Exploratory study

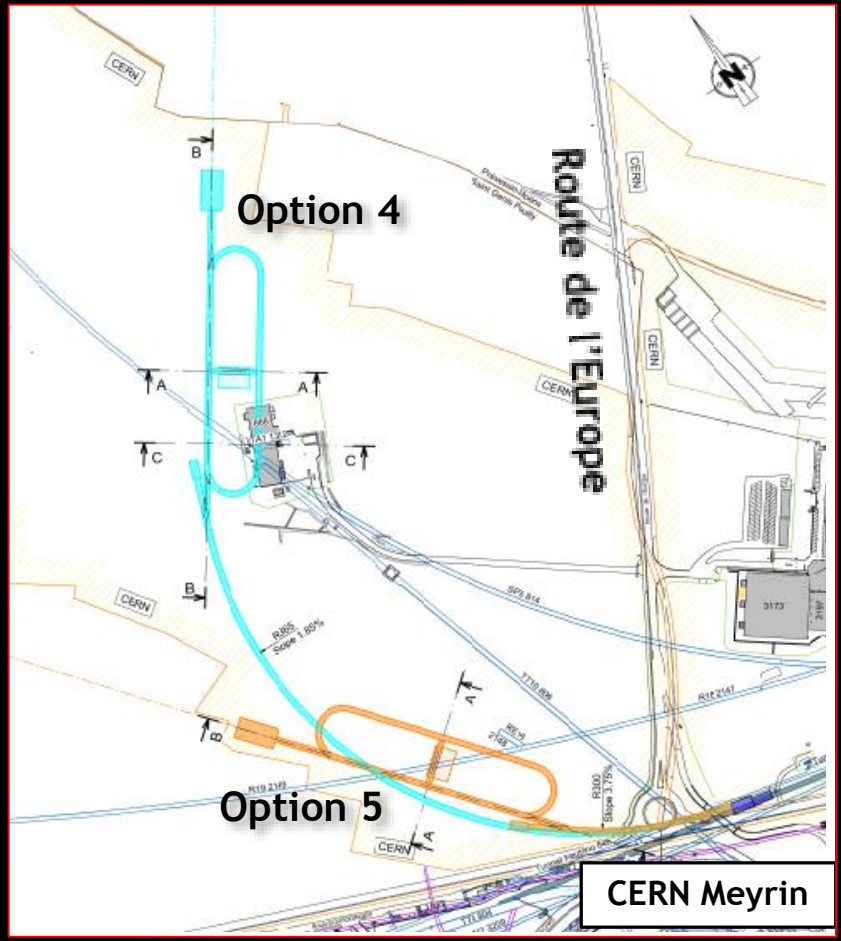
- A credible proposal for siting at CERN, including:
  - SPS requirements
  - Fast extraction, beam-line
  - Target and target complex
  - Horn
  - Siting
  - Civil engineering
  - Radio-protection implications

I. Efthymiopoulos

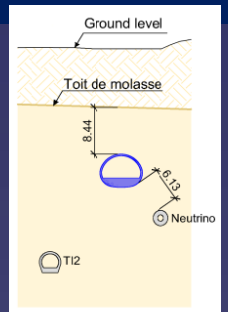


Status of study

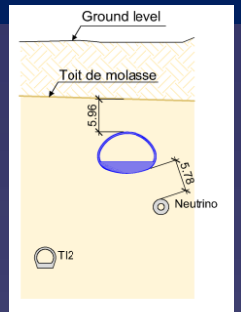
- Options:
  - Avoid existing tunnels;
  - Tunneling with mollase
  - Option 4:
    - Preserves possibility of detector at Prevesin site for sterile-neutrino experiment
  - Option 5:
    - Shorter transfer line
- Extraction from SPS:
  - Fast extraction into TT61 preferred
  - Two options for transfer line:
    - 1.6 T – easier magnets, longer
    - 1.8 T – stronger magnets, shorter
- Target and capture:
  - Initial ideas:
    - Prefer 'chicane' configuration used in AD
    - Similar requirements to ENUBET



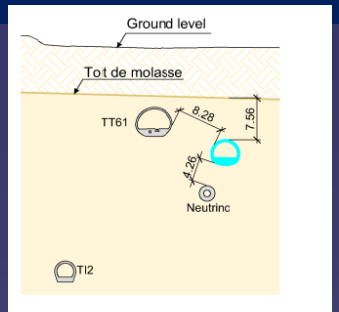
Civil engineering; example



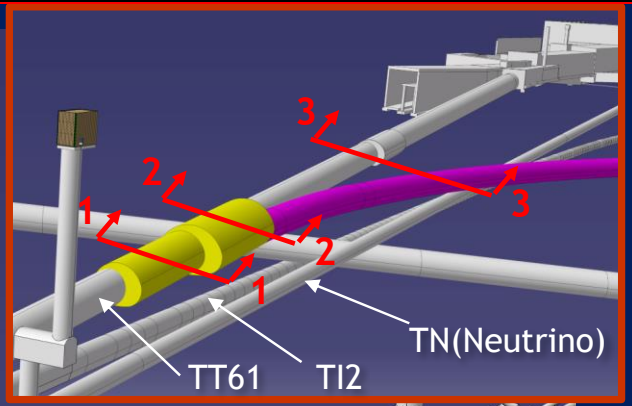
SECTION 1-1
OPTIONS 4 et 5
1:1000

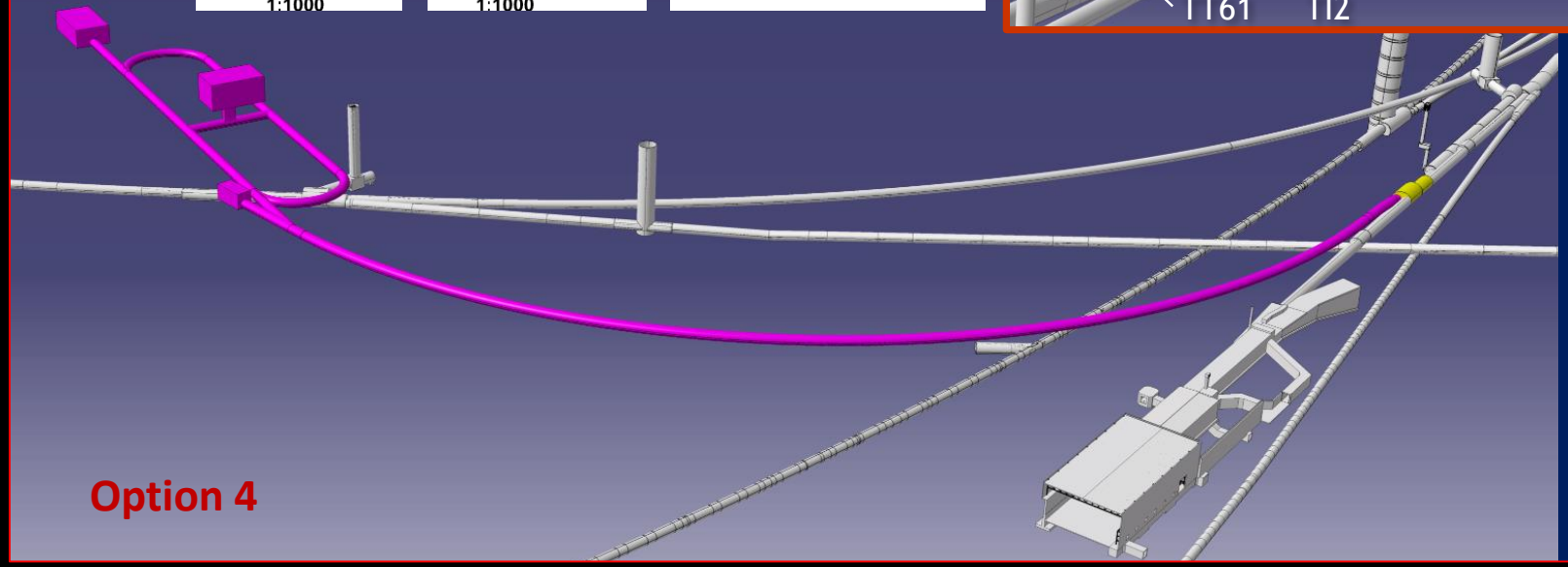


SECTION 2-2
OPTIONS 4 et 5
1:1000



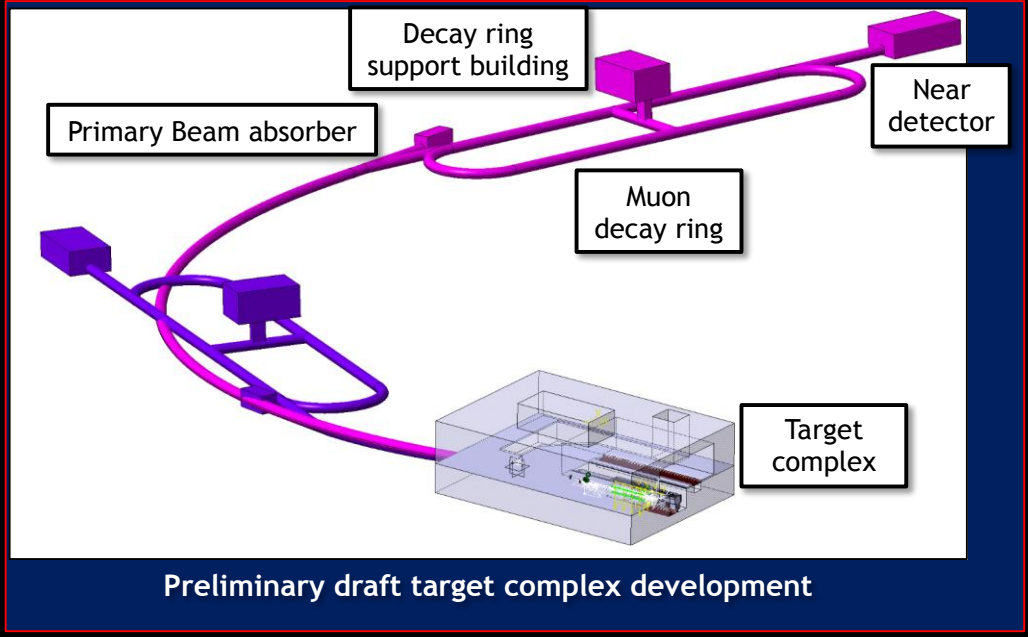
OPTION 4 - SECTION 3-3
1:500





Option 4

Target hall, detector hall, RP



Preliminary draft target complex development

- Detector hall taken from FNAL design
- Radio-protection (RP):
  - Evaluation based on LBNO studies
  - Requires appropriate engineering; not viewed as 'in principle problem'

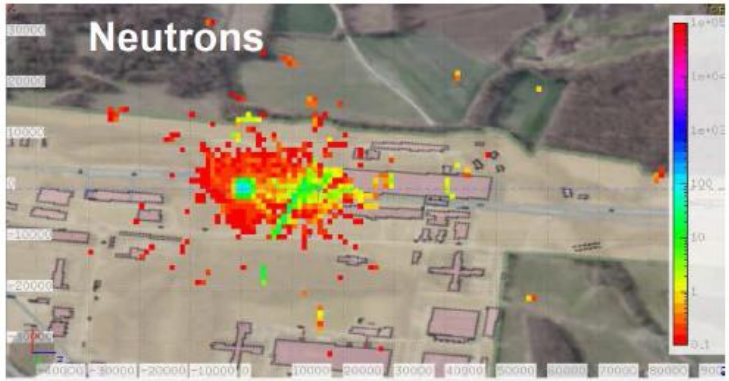


Figure 2: Top view of the ambient dose equivalent (prompt) 10 m above the ground level due to neutrons in µSv/y.

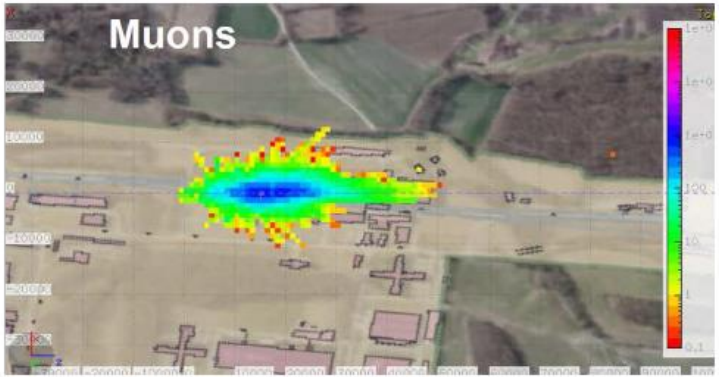


Figure 3: Top view of the ambient dose equivalent (prompt) 10 m above the ground level due to muons in µSv/y.

nuSTORM

Conclusions

Conclusions

- nuSTORM can deliver:
  - νN scattering measurements with precision required to:
    - Serve the long- and short-baseline neutrino programmes
    - Provide a valuable probe for nuclear physics

- CERN PBC study: opportunity to define innovative programme:
    - nuSTORM:
      - Delivers critical measurement: ν_e/ν_μ *N* scattering;
      - Has discovery potential: sterile neutrinos;
      - Potential for 6D ionization-cooling programme to follow MICE