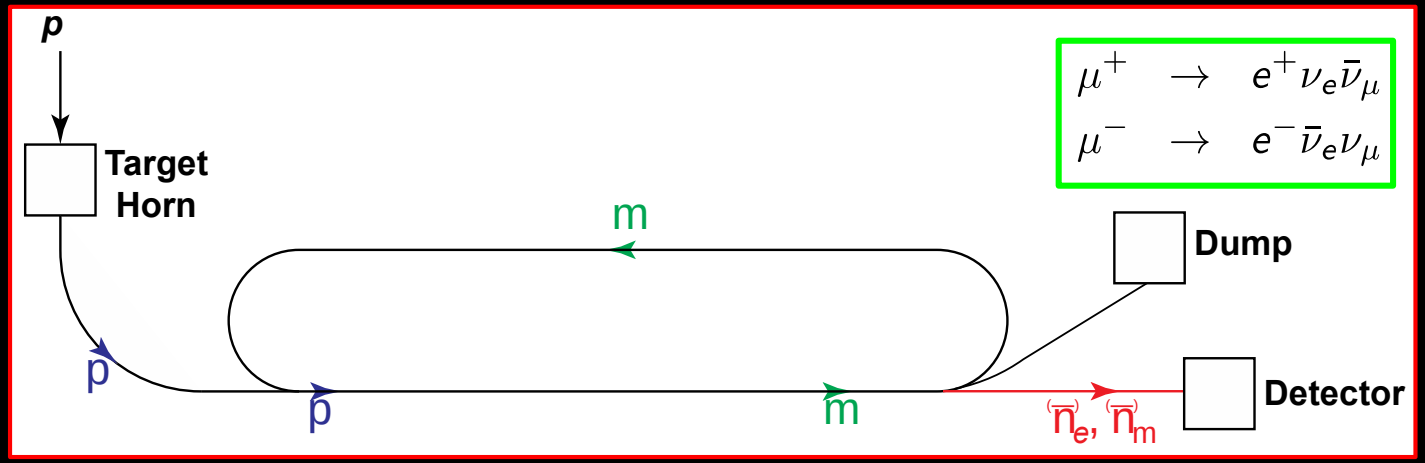
Imperial College London

Science & Technology Facilities Council

nuSTORM

K. Long, 22 November, 2017

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/flavour precise**
- **$\pi \rightarrow$ ↗injection pass:**
  - **"Flash" of ν_μ**

Elements of study

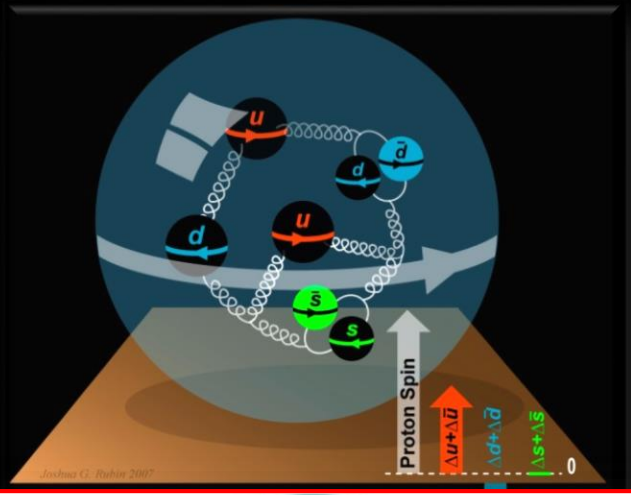
- Physics case:
  - Neutrino-scattering for:
    - Oscillation
    - Nuclear
- Specification:
  - Energy range:
    - Long- and short-baseline neutrino
    - Nuclear and particle physics
  - Acceptance:
    - Rate
    - Neutrino-energy calibration

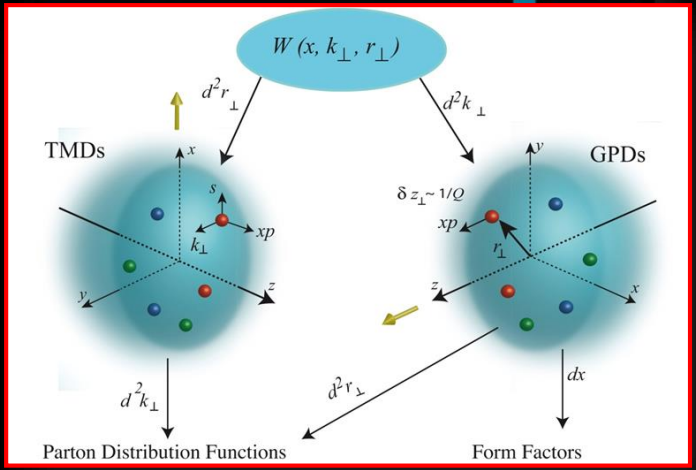
- Accelerator:
  - Full simulation that demonstrates <~1% flux precision
  - Energy range (i.e. sweep down from max)
- Implementation:
  - Feasibility at CERN (see next slide)
- Detector:
  - Others are “on this”, so:
    - Adopt performance of typical, or assumed, detector

WHY STUDY NEUTRINO INTERACTIONS?

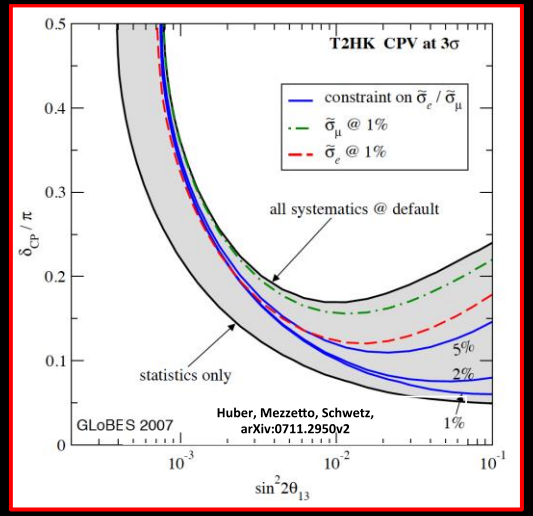
To understand the nucleon and the nucleus

- **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?**
  - To be studied!
- **Benefit of nuSTORM:**
  - Precise flux and energy distribution

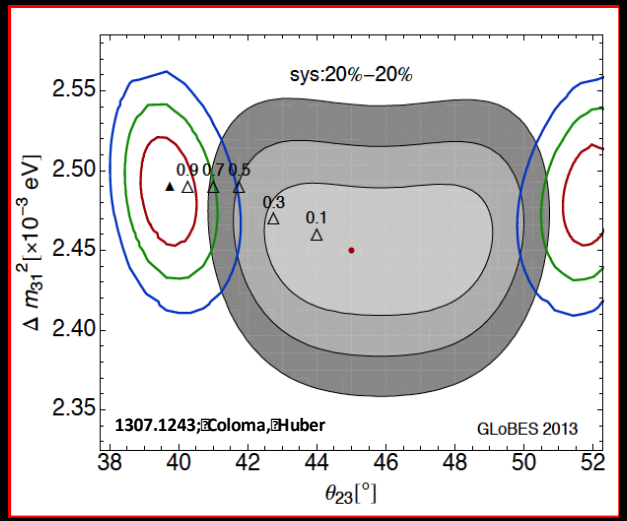




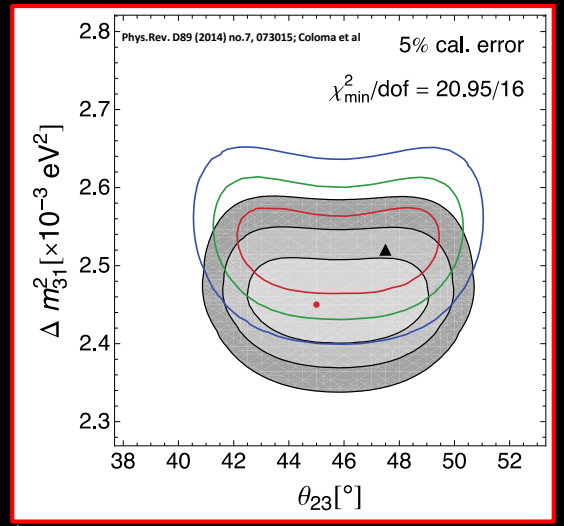
Systematic uncertainty and/or bias



Uncertainty
(cross section and ratio)

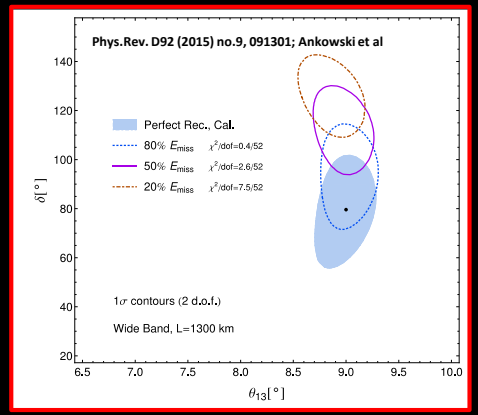


Event mis-classification



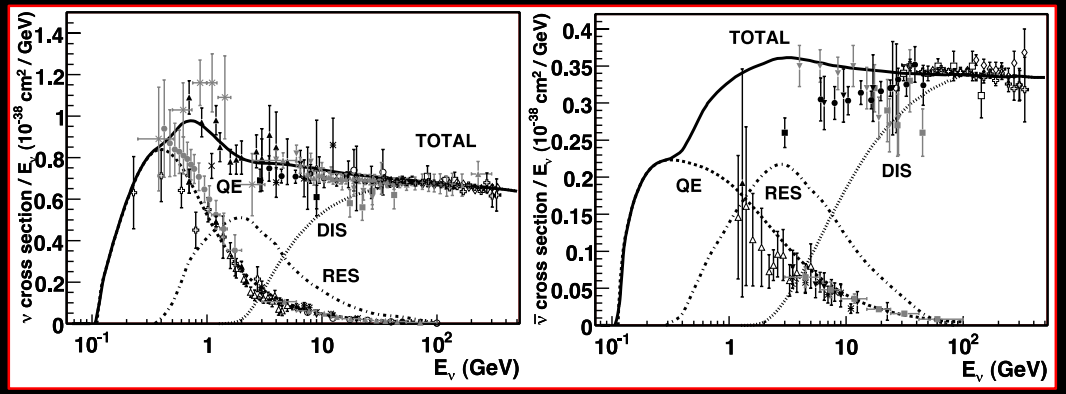
Energy scale mis-calibration

Missing energy (neutrons)

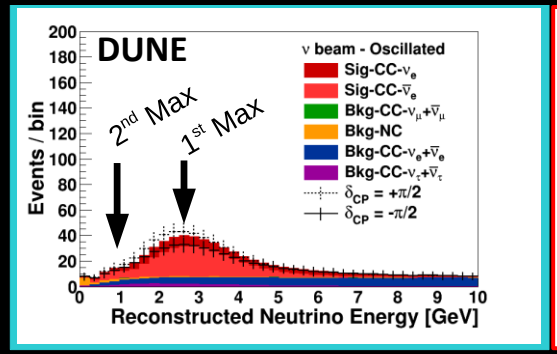


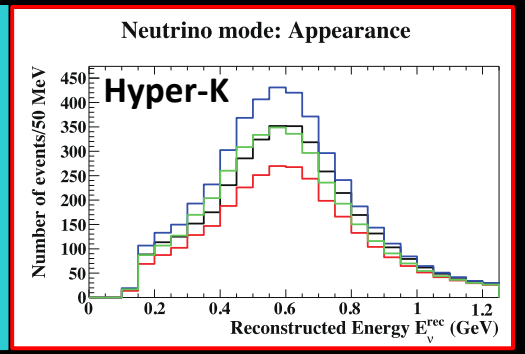
Energy range

- 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:

$$1 < E_\mu < 6 \text{ GeV}$$

Taking the physics study forward

- **IPPP:**
  - **Dan Watts (Edinburgh) and KL:**
    - ***"Bridging the gap between neutrino-nucleus and electro-nucleus scattering at nuSTORM and JLAB"***

- **"Organising committee" will meet Friday 24Nov17**

nuSTORM

PROGRESS IN FEASIBILITY STUDY

Participants/contributions:

- CERN:
  - W. Bartmann, S. Gilardone, B. Goddard, I. Efthymiopoulos, M. Lamont, J. Osborne, H. Vincke
- Imperial:
  - J. Pasternak
- Manchester/Cockcroft:
  - R. Appleby, S. Tygier

Implementation @ CERN Exploratory study

- An initial proposal for siting at CERN, including:
  - Muon energy range
  - SPS requirements
  - Fast extraction, beam-line
  - Target and target complex
  - Horn
  - Siting
  - Civil engineering
  - Radio-protection implications

Towards a parameter table

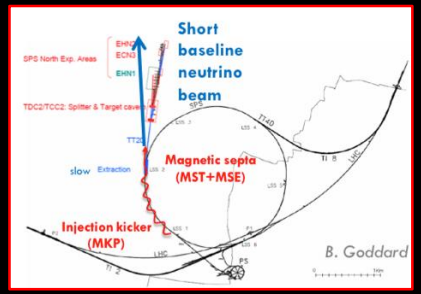
Preliminary!

Prepared for discussion

Parameter	Value or range	Unit	Comment
Primary proton beam Contact: M. Lamont			
Beam momentum (p)	100	GeV/c	
Total required POT	2.30E+20		
POT per year	4.00E+19		
SPS intensity	4.00E+13		
SPS cycle length	3.6	s	
Max. normalised horizontal beam emittance (1 sigma)	8	mm rad	
Max. normalised vertical beam emittance (1 sigma)	5	mm rad	
Number of extractions per cycle	2		
Interval between extractions	50	ms	
Duration per extraction	10.5	μs	
Number of bunches per extraction	2100		
Bunch length (4 sigma)	2	ns	
Bunch spacing	5	ns	
Momentum spread (dp/p 1 sigma)	2.00E-04		
Main primary beam parameters on target Contact: M. Lamont			
Nominal proton beam power	156	kW	
Maximum proton beam power	240	kW	
Horizontal beta (betax)	200	m	
Vertical beta (betay)	350	m	
Horizontal divergence (1 sigma)	1	mrad	
Vertical divergence (1 sigma)	1	mrad	
Nominal horizontal and vertical beam spot size (1 sigma)	2.1	mm	
Horiz. and vert. beam-spot size min./max. (1 sigma)	1.5/2.7	mm	
nuSTORM ring, including instrumentation Contact: K. Long			
Energy (E_μ)	$1 < E_\mu < 6$	GeV	See proc. NeuTel17
Energy acceptance	10 – 20	%	
Flux			
Intensity (accuracy/resolution)	0.1/0.01	%	See [1]
Position (accuracy/resolution)	5/1	mm	See [1]
Profile (accuracy/resolution)	5/1	mm	See [1]
Tune (accuracy/resolution)		0.01/0.001	See [1]
Beam loss (accuracy/resolution)	1/0.5	%	See [1]
Momentum (accuracy/resolution)	0.5/0.1	%	See [1]
Momentum spread (accuracy/resolution)	1/0.1	%	See [1]

Siting at CERN, options:

- **North Area:**
  - Kick @ LSS1; extract @ LSS2
  - Transport to North Area:
    - Issues:
      - Congestion, radio-protection, slow (rather than fast) extraction



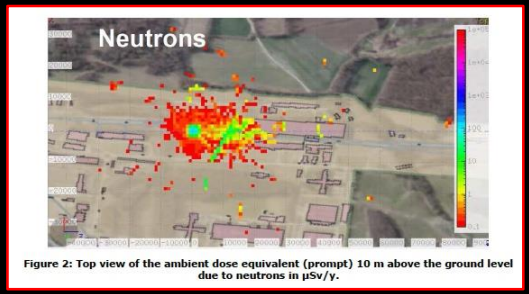
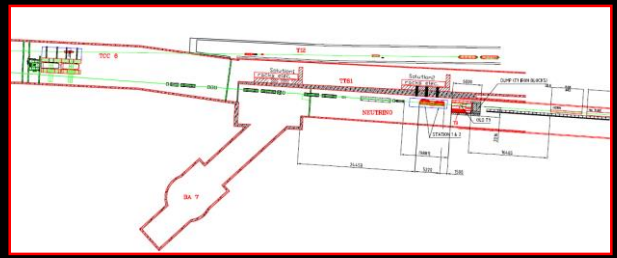
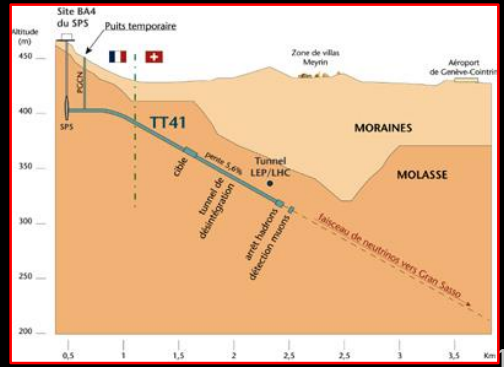


Figure 2: Top view of the ambient dose equivalent (prompt) 10 m above the ground level due to neutrons in μSv/y.

- **LSS6/West Area:**
  - "TCC6":
    - Served West Area Neutrino Facility
    - Now occupied by HiRadMat

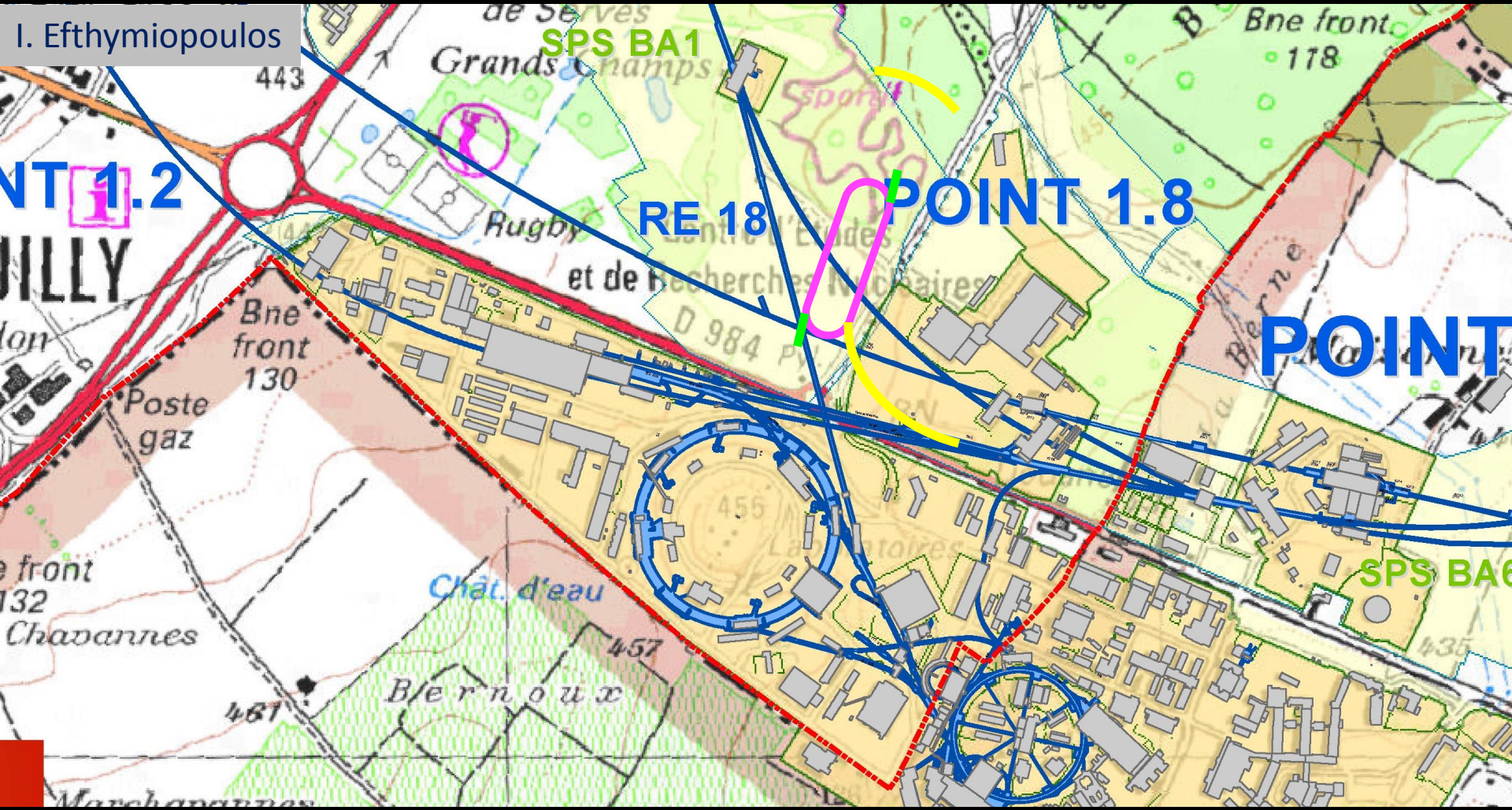


- **CERN to Gran Sasso beam line:**
  - Beamline directed "down hill" in molasse to serve Gran Sasso
  - Would put nuSTORM ring deeper than necessary
  - Existing target area hot



- **Preferred option "semi-greenfield" …**

I. Efthymiopoulos



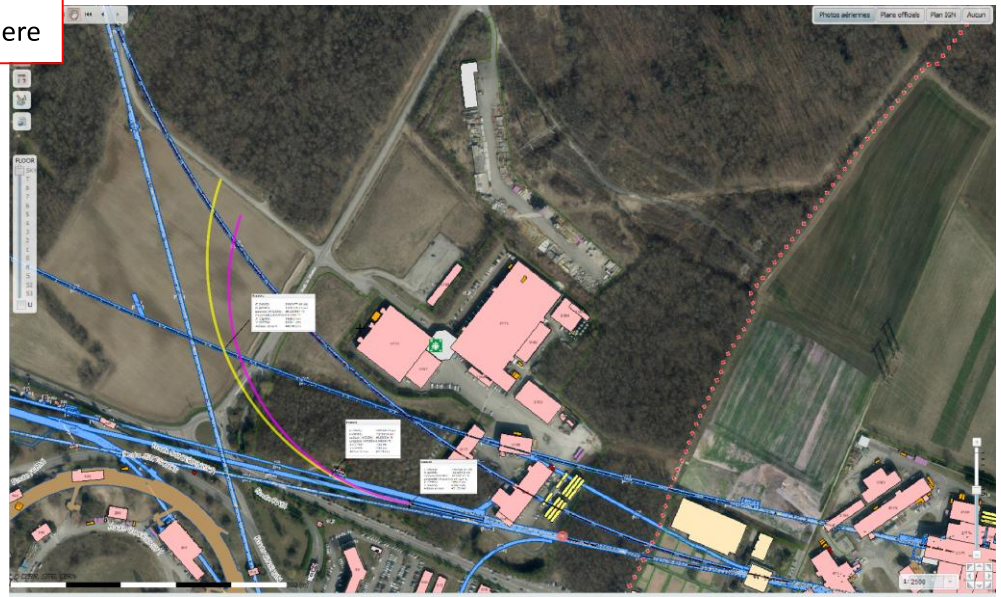
Extraction from SPS; transfer line to target

W. Bartmann, B. Goddard, C. Hessler

Extraction from LSS6

- 100 GeV protons, large emittance beams (FT beams in SPS)
- Switching dipoles MBS – ppm for SPS supercycle
- Aperture ok if branch off before TI 2
  - Might need replacement of several quads in TI 2 if line passes there

- Possible reach for 1.8 T (magenta) and 1.6 T (yellow) bending fields
- Coordinates of both lines being checked for CE feasibility

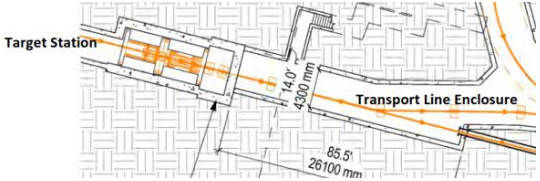


Pion-production target and capture

M. Calviani

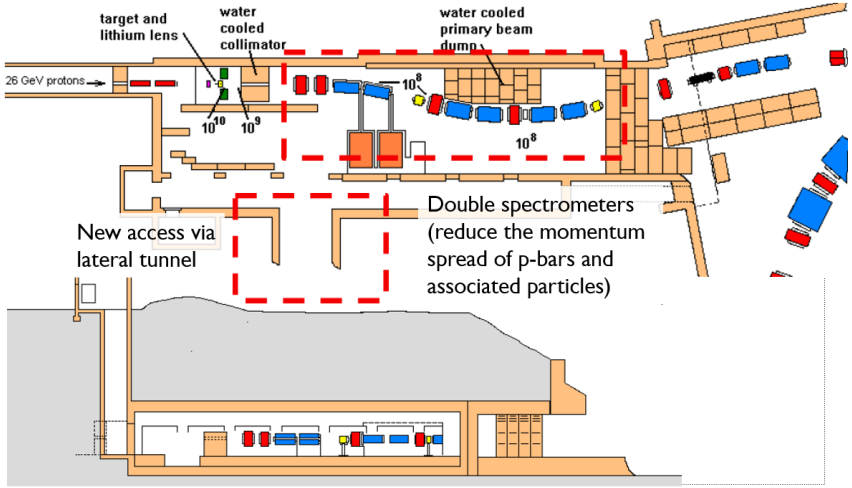
Ideas for nuSTORM

- A target area based on AD-T concept with vertical handling (a-la-CENF/NuMI) might be possible alternative
  - Target area much smaller and dose rate confined
- ~Site independent… could be even at a depth
- ENUBET requiring a very similar infrastructure



EN Engineering Department

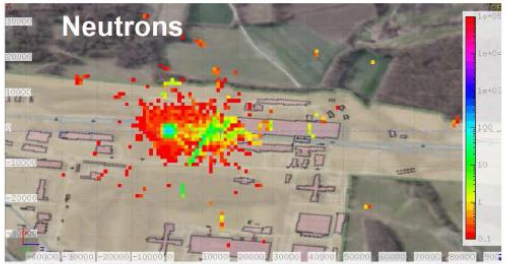
Present configuration of the AD-target area



Radio-protection issues

H. Vincke

beyond the fenced areas of the Organization. Stray radiation fields have been extensively studied in Ref. [2] under the assumption of 200 kW beam power at 100 GeV and during 180 days of operation (1.9×10^{20} primary protons in one year).



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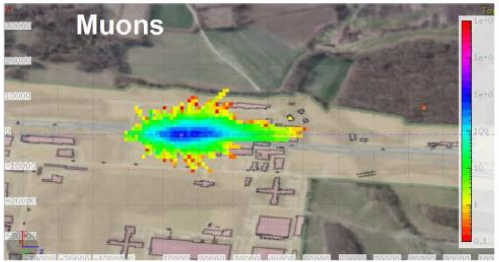

Figure 3: Top view of the ambient dose equivalent (prompt) 10 m above the ground level due to muons in µSv/y.

Initial guidance …

RP issues

H. Vincke
HSE/RP

nuSTORM meeting
18/10/2017

- **ALARA (optimization) starts already at the design phase -** The design of the entire facility must not only respect legal dose limits but must also satisfy the optimization principle (ALARA) with respect to individual and collective doses for workers and the public. The design goals for individual and collective doses are valid for commissioning, normal beam operation, maintenance and accidents.
  At CERN: Design goal of **100 uSv** per **year** for persons exposed because of their own professional activity or **10 uSv** for circumstances not linked with their own professional activities and for **members of the general public.**

nuSTORM

CONCLUSIONS

Muon Colliders: a working/discussion group [L. Rivkin (PSI)]

- Panel:
  - N. Pastrone (INFN, Chair)
  - M. Diemoz (INFN)
  - A. Skrinsky (BINP)
  - K. Long (Imperial/STFC)
  - J-P. Delahaye (CERN)
  - D. Schulte (CERN)
  - A. Wulzer (CERN)
  - B. Mansoulie (IRFU)

- Panel has now met once:
  - Discussed scope and mode of operation
  - Will include "studied" and "novel" approaches
  - Accepted that near-term *physics* with such beams should be part of the discussion:
    - nuSTORM will be considered in this context

Conclusions

- First steps in the nuSTORM feasibility study:
  - Muon energy range identified;
  - Preferred site identified;
  - Initial review of siting issues carried out:
    - Extraction, beam-to-target, target, radio-protection
      - No “show-shoppers” identified
  - Work-packages/sections of chapter for PBC report identified

- The physics of nuSTORM:
  - Joint nuclear-/particle-physics study initiated:
    - Modest resources secured from IPPP
  - Output of physics study:
    - Document potential of scattering programme:
      - Sister publication to the evaluation of the sterile-neutrino-search programme