NUFACT 2014

25-30 August 2014

University of Glasgow

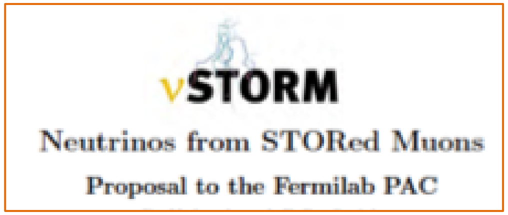
nuSTORM at CERN

Elena Wildner

CERN

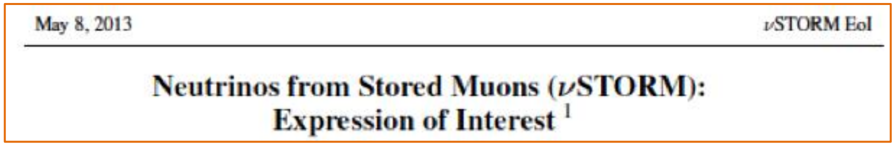
Material used

- Slides from several recent workshops:
  - 26-27 March 2013, CERN
  - 14-15 April 2013, Virginia Tech
  - 21-22 November 2013, Fermilab
  - ICFA, neutrinos, Paris January 2014
- Material in recent
  - Expression of interest to SPSC, CERN arXiv:1305.1419
  - Proposal to Fermilab PAC arXiv: 1308.6822, plus updates
  - Discussions at CERN around nuSTORM at CERN (K. Long, M.Nessi, E. Wildner)


νSTORM

Neutrinos from STORed Muons

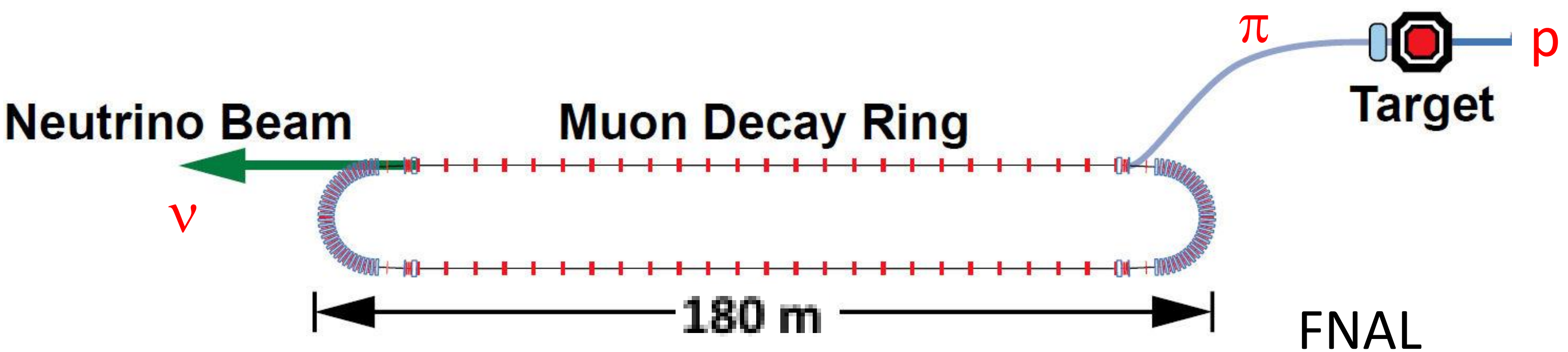
Proposal to the Fermilab PAC


May 8, 2013 νSTORM EoI

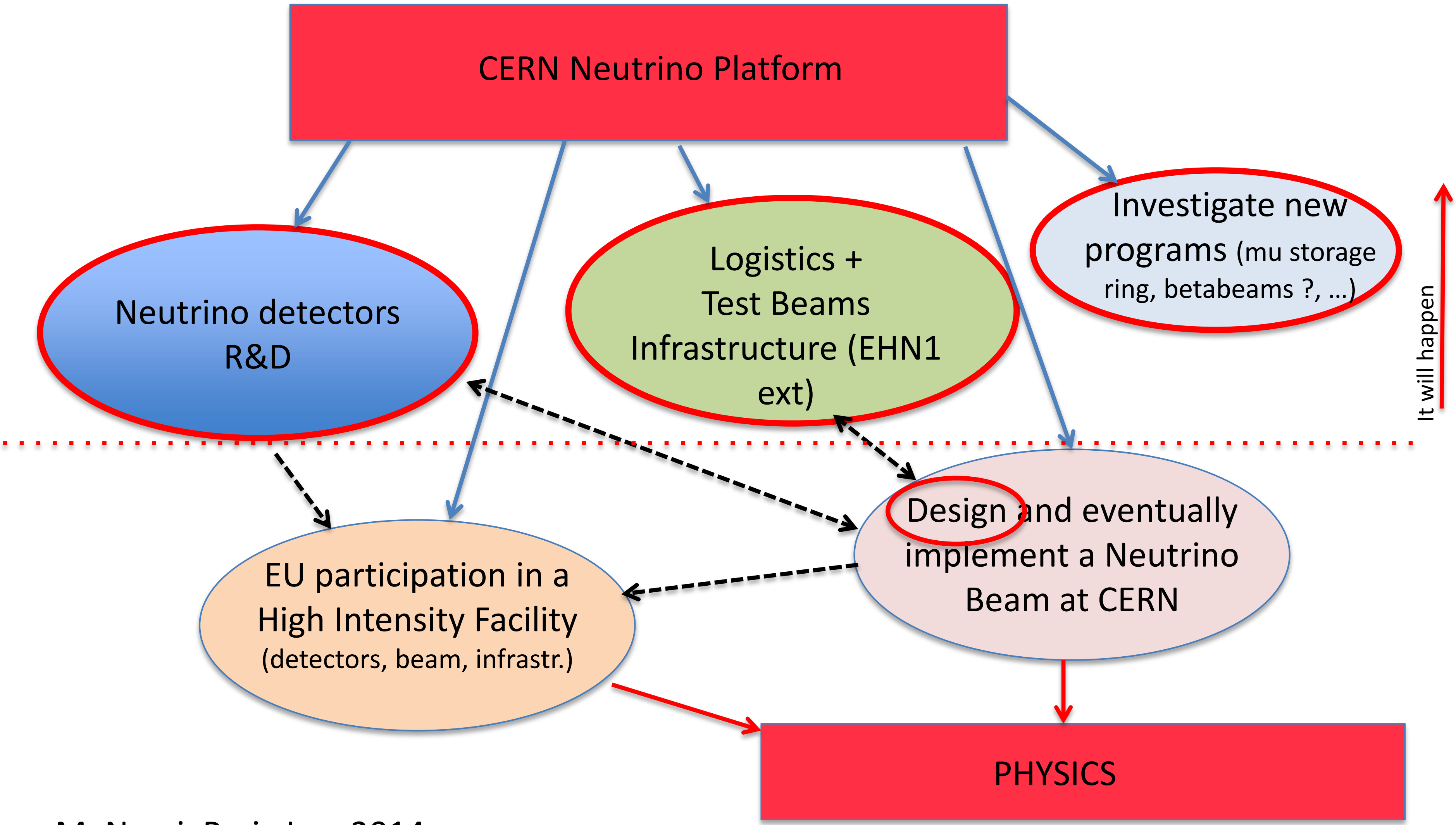
Neutrinos from Stored Muons (νSTORM):
Expression of Interest [1]

nuSTORM @ CERN

- Concept and design study: Fermilab (A. Bross et al.)
- Fit on CERN site (E. Wildner, Ken Long et al.)
- Existing Infrastructures
  - CERN SPS, North Area
- Add a small storage ring (FODO/FFAG racetrack)
- Several items can be developed independent of site
  - Lattice, instrumentation, magnets, horn and target …
- Some not
  - Civil engineering, safety, controls system, target station…
- Reuse/upgrade detectors
- Develop generic detector concepts and technologies (Laguna, …)

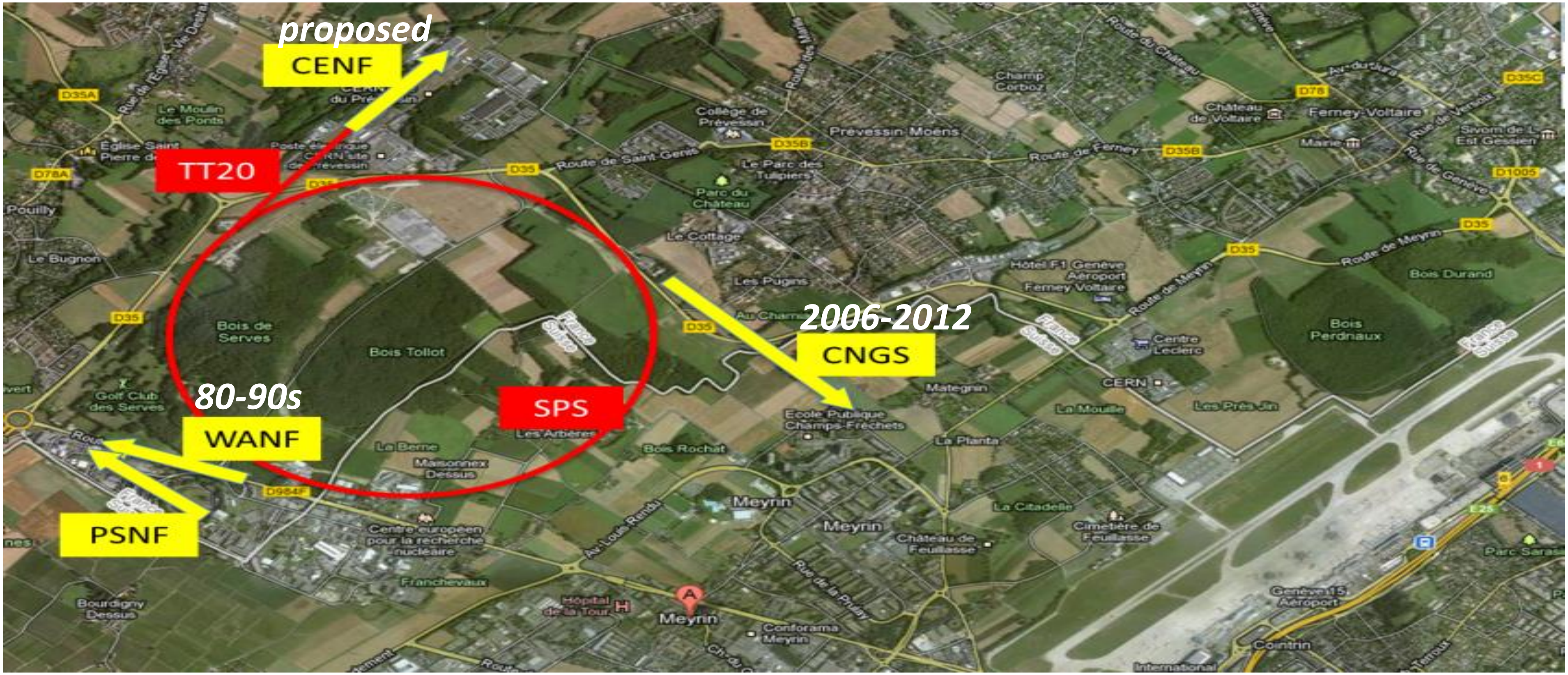


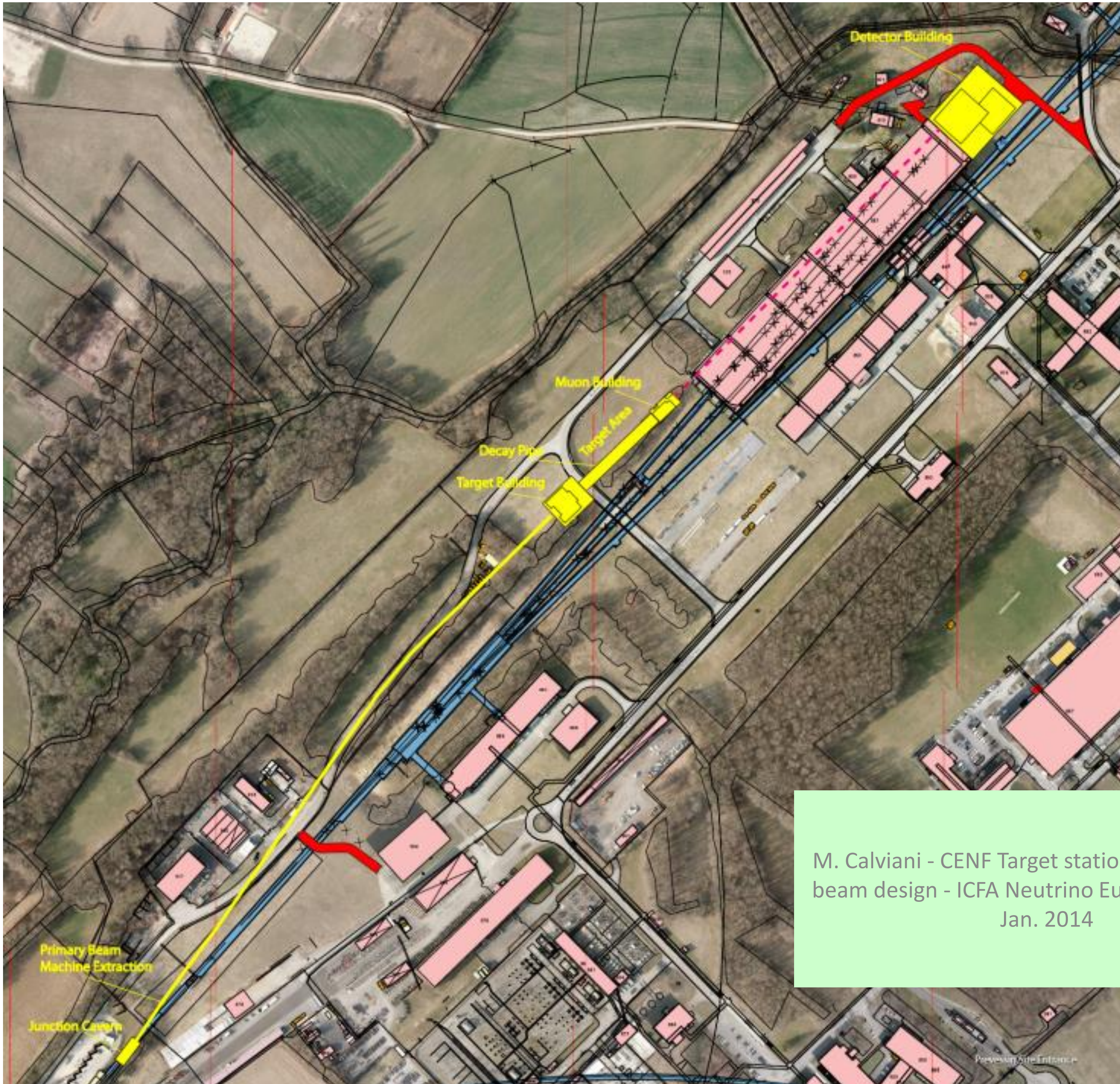
CERN Neutrino Project



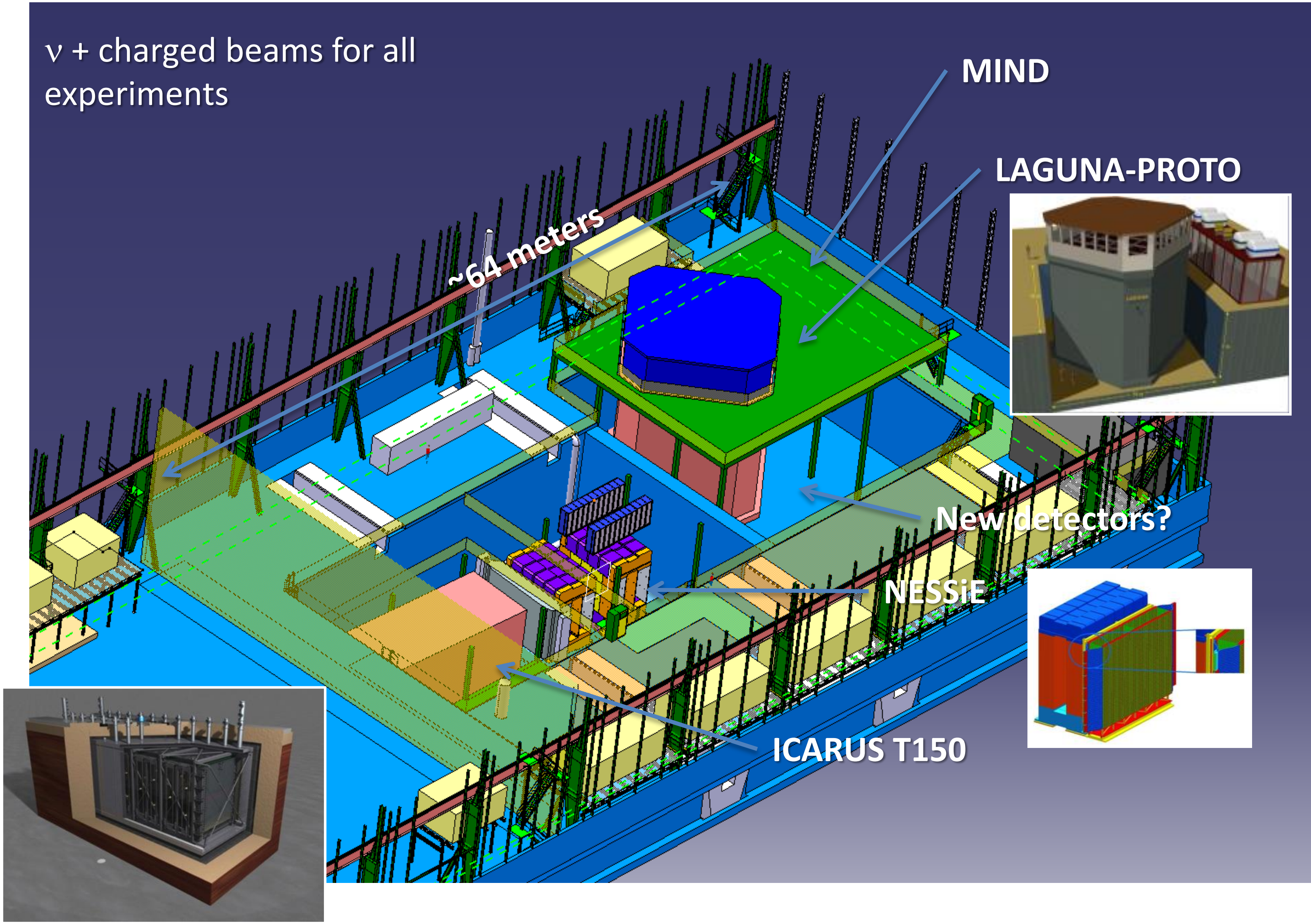
M. Nessi, Paris Jan. 2014

CERN Neutrino Platform

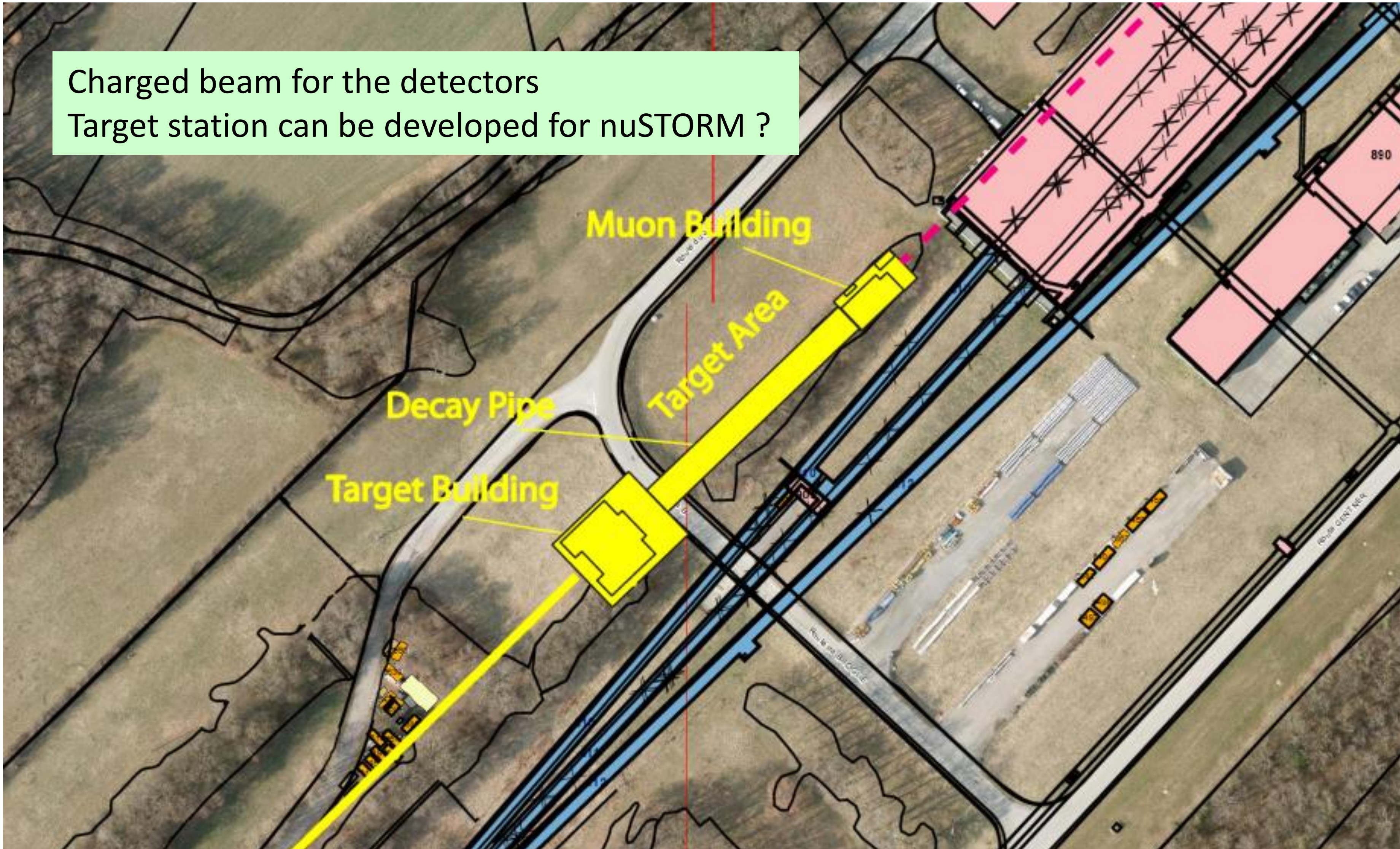



Detector Building
Muon Building
Target Area
Decay Pipe
Target Building
Primary Beam
Machine Extraction
Junction Cavern

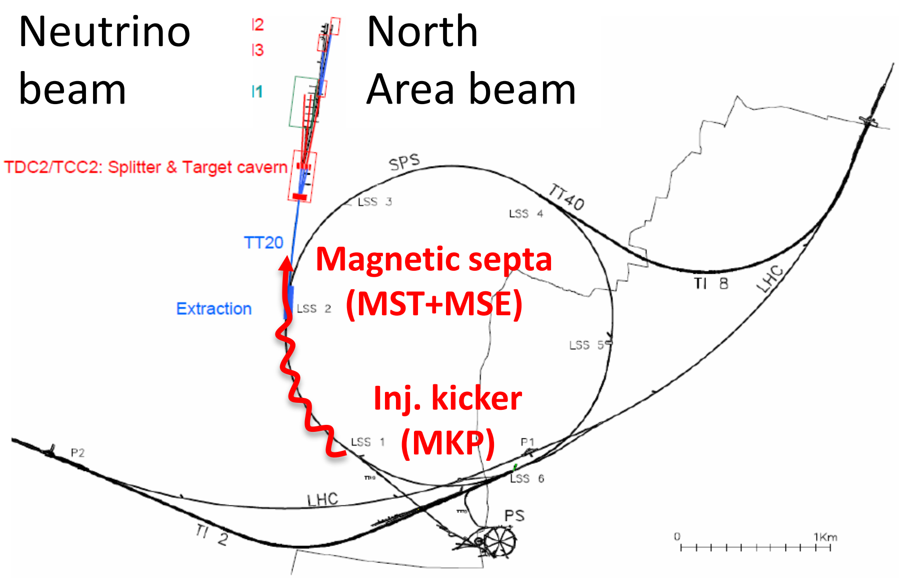
Detectors


ν + charged beams for all experiments
~64 meters
MIND
LAGUNA-PROTO
New detectors?
NESSiE
ICARUS T150

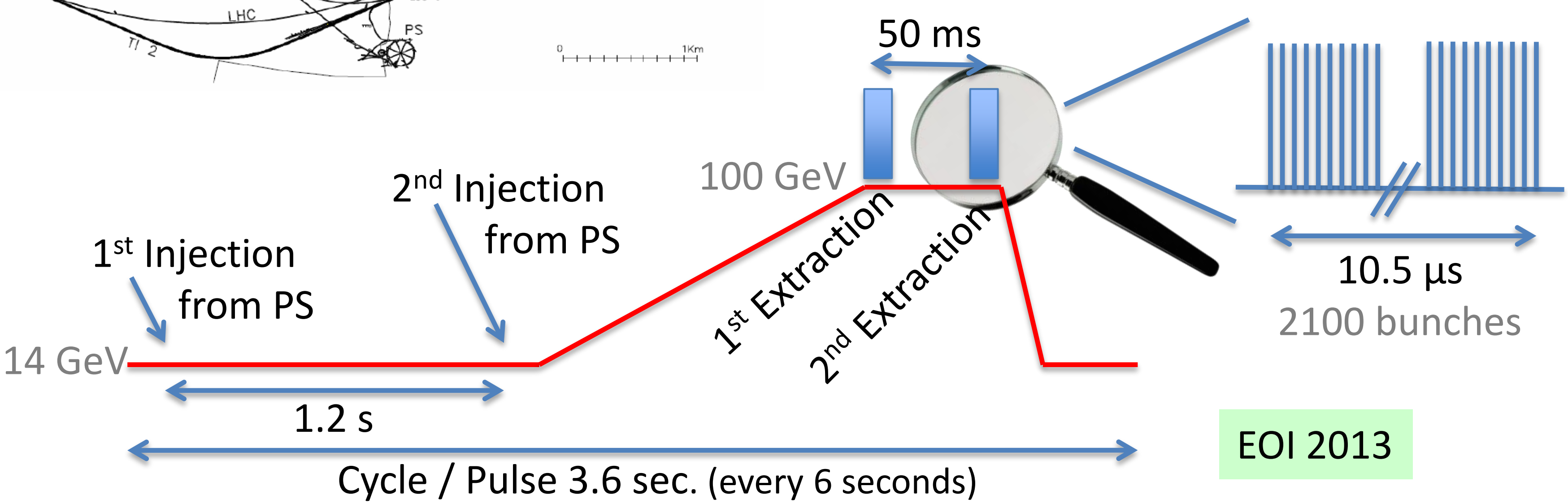
Charged beam for the detectors
Target station can be developed for nuSTORM ?



Primary Beam: Production & Extraction

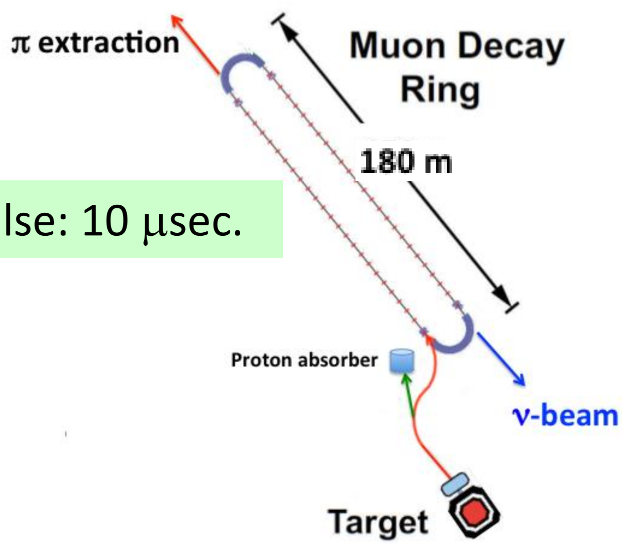


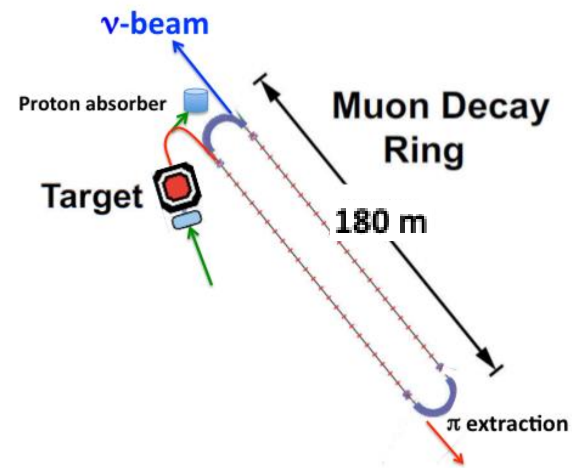
- Beam production scheme and beam structure similar to CNGS.
- Successfully tested non-local fast extraction from LLS1 & LSS2.
- Incompatible with simultaneous slow extraction → Time sharing.
- Major upgrade/consolidation of machine protection system (BIS) required.



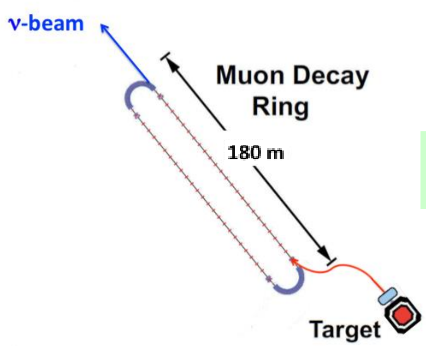
EOI 2013

Configurations





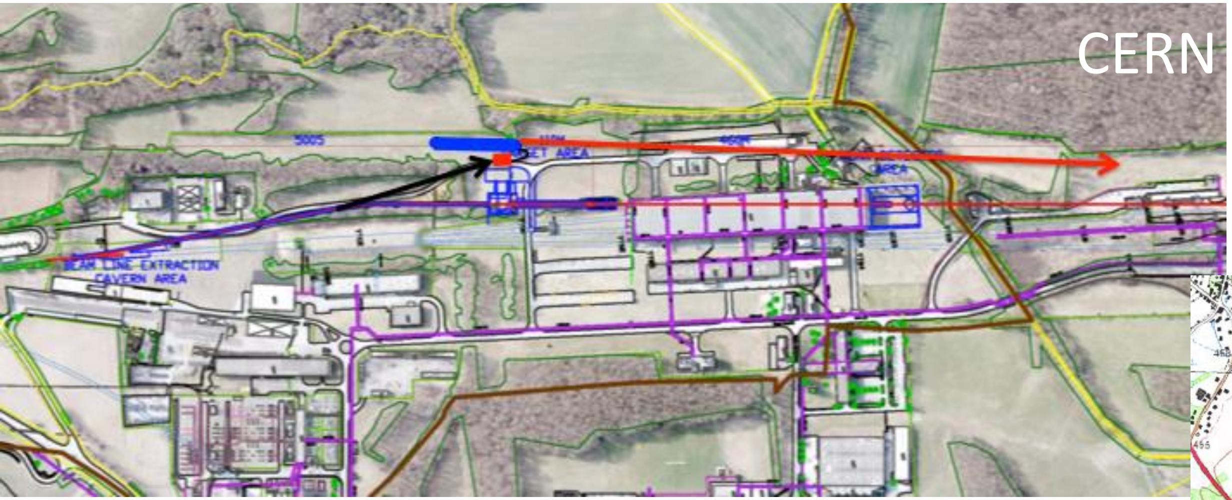
CERN SPS primary beam pulse: 10 μsec.



FNAL MI primary beam pulse: 1.6 μsec.

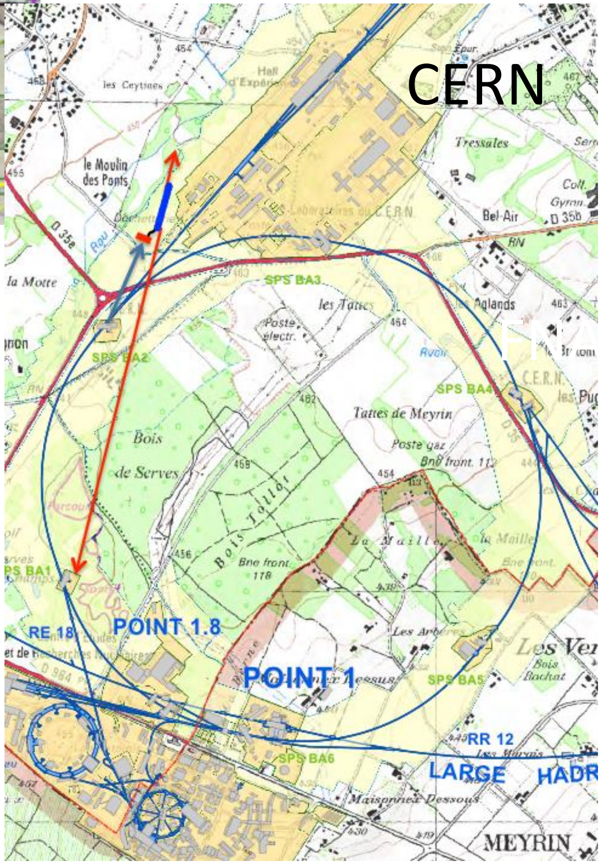
Best case is a pulse length = to the ring circumference. This gives best nu_mu from pion decay beam and most efficient use of the muon decays.

Siting (from EOI)

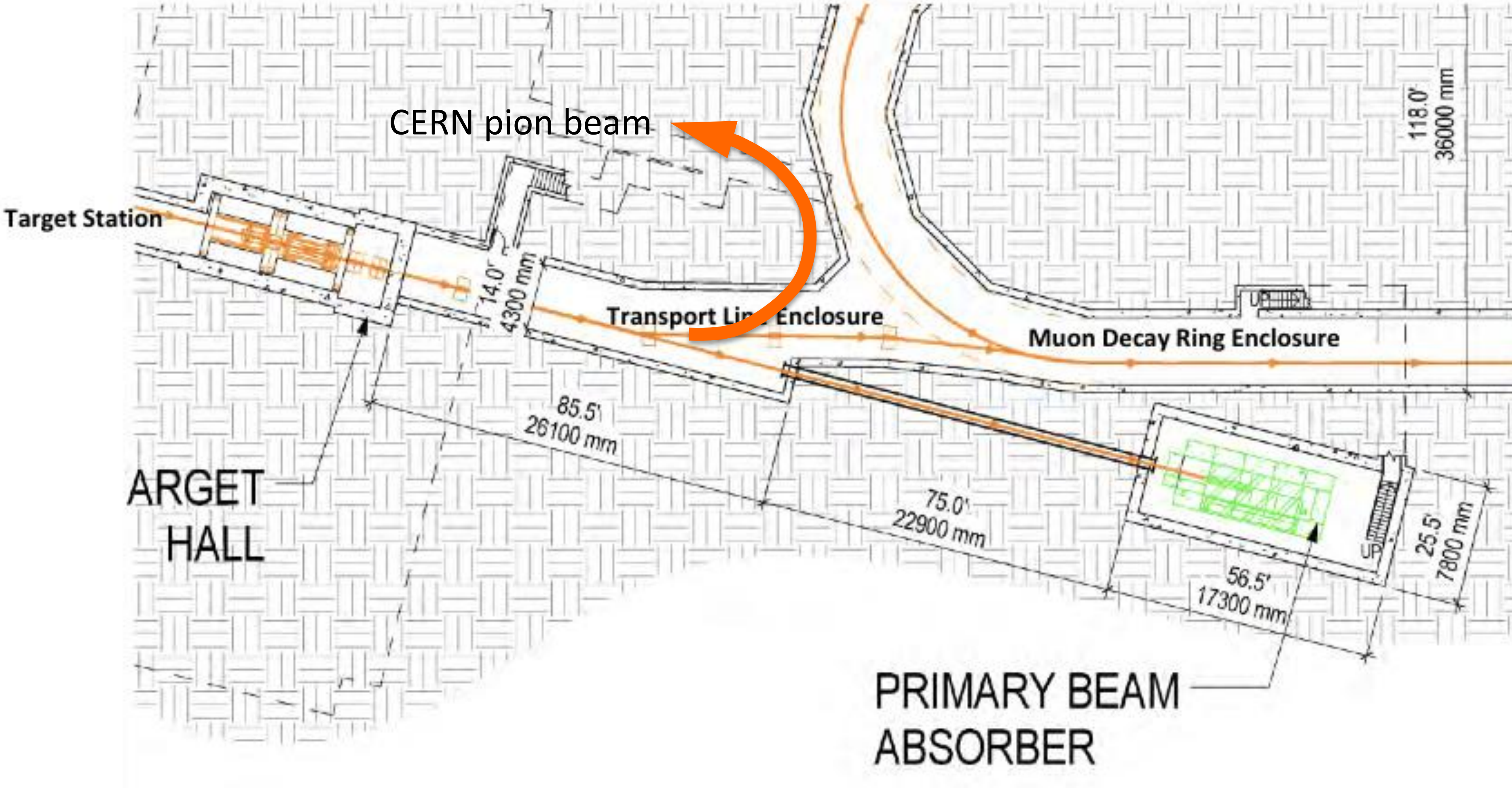


CERN North Area

Neutrino platform (CENF), from EOI



Target&injection region

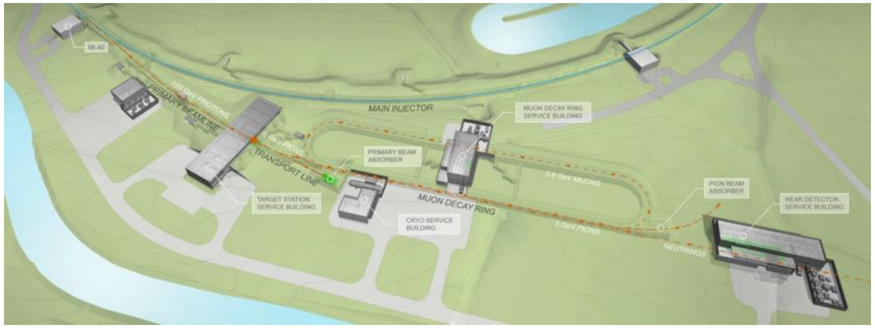


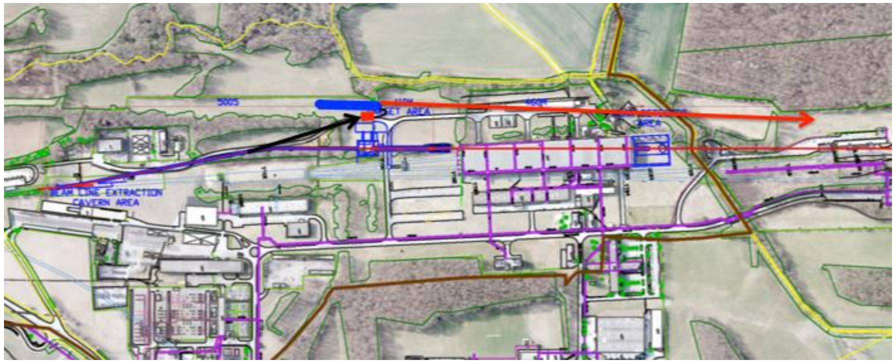
From project definition report [arXiv:1309.1389.](arXiv:1309.1389)

p-flux & ν-flux

- FNAL Proposal: 10^{21} 120 GeV POT/10yr -> ~ 1.9 X 10^{18} useful μ decays
  - In PIP era, extract one Booster batch/cycle (10^{20} POT/yr → 10 year run)
  - Baseline FODO ring, C target, NUMI style 1 horn
  - Inconel target + horn optimization + RFFAG → X5 (2 year run)

Alan Bross P5 Face-to-Face Meeting, Fermilab, Nov. 2013





CERN EOI, Nov. 2013

- CERN (EOI) 4.5 10^{20} 100 GeV POT/10yr
  - Assuming similar accelerator facility as FNAL (C target)
  - Beam from SPS as proposed for the CENF primary beam
  - Without any optimization

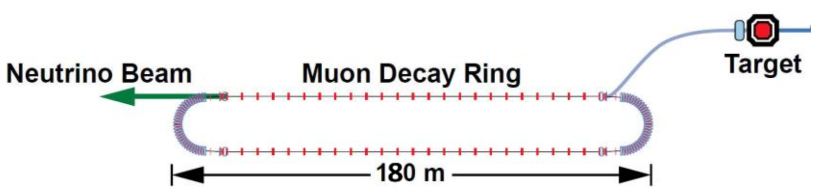
nuSTORM facility: parameters overview

- Collect and transport pions from target: 5 GeV/c $\pm$ 10%
- 60% decay on the first straight section to muons
- 40%, up to 5 kW, go to pion dump or pion degrader for cooling experiments
- Momentum of muons in ring 3.8 GeV/c $\pm$ 10%
- p-beam: FNAL 120 GeV/c, CERN SPS 100 GeV/c (baseline)
  - CERN SPS can deliver higher momentum, 450 GeV/c

nuSTORM Ring Parameters

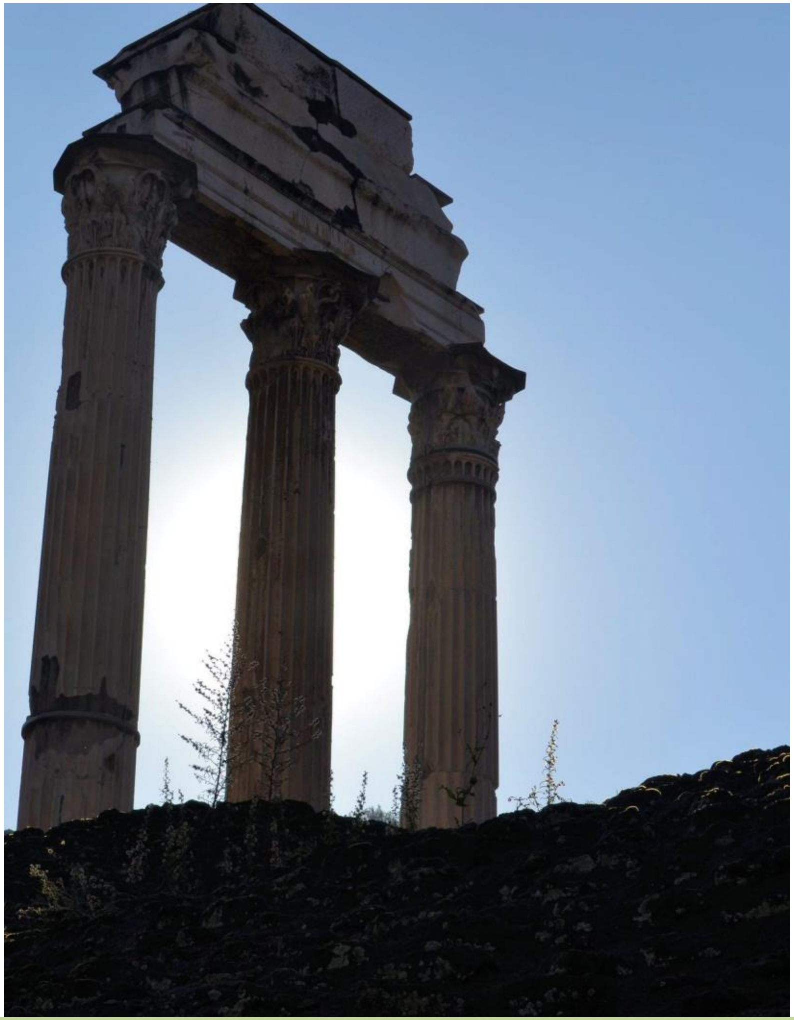
Parameter	Parameter Value
Design Momentum	3.8 GeV/c
Circumference	466.44 m
Production stright length	180 m
Total tune (H, V)	9.72, 7.88
Natural chromaticity (H, V)	-12.39, -9.24
Max Dipole field	4.14 T
Transission Gamma	28.51

Parameters for the DBA FODO decay ring (Preliminary). No full optimization has been studied yet. No nonlinear corrections applied yet.



Courtesy A. Liu

The Three Pillars of nuSTORM



- Can add significantly to our knowledge of ν interactions, particularly for ν_e
- Provides an accelerator & detector technology test bed for muons
- Delivers on the physics for study of sterile ν

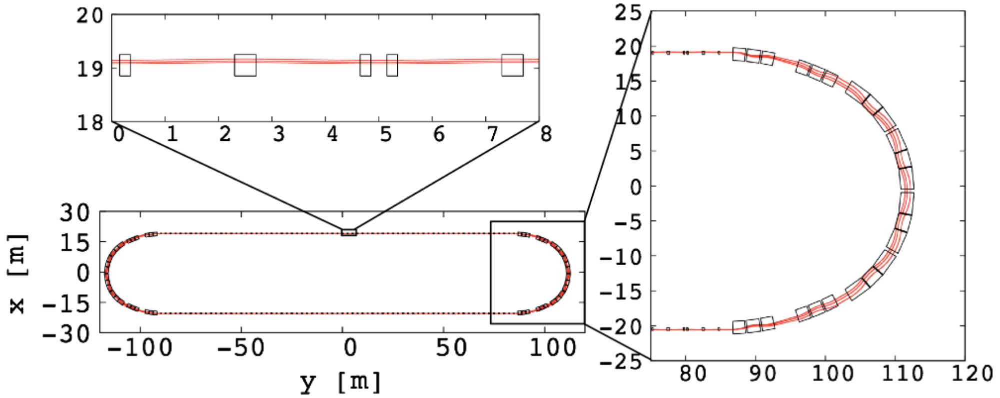
"European Strategy": LBL program & collaboration

Worldwide collaborative efforts

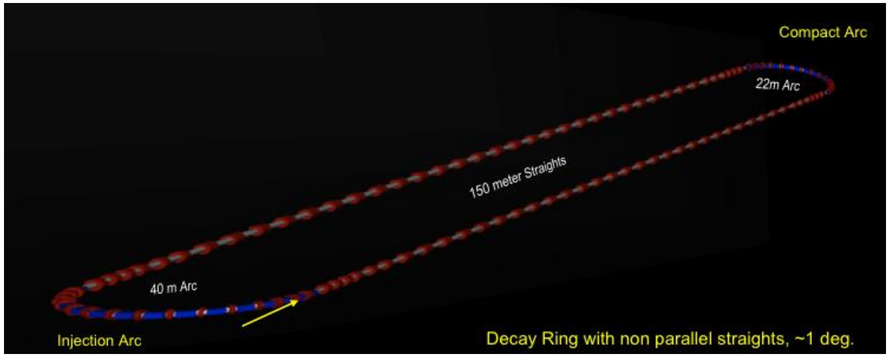
paves the way to a high precision neutrino/muon program

Lattice options

Racetrack FFAG



FODO



Fermilab layout drawings are for FODO
Dynamic aperture, tunes etc. still to be optimized.

Lattice option comparison

Parameters	FODO (Jun. 2013)	RFFAG "FODO-like"	RFFAG "low-cost"
$L_{straight}$ [m]	185	175	156
Circumference [m]	480	500	460
Dynamical acceptance A_{dyn}	0.6	0.95	0.95
Momentum acceptance	±10%	±16%	±16%
π/POT within momentum acceptance	0.094	0.171	0.171
Fraction of π decay in one straight (F_s)	0.48	0.47	0.43
Straight-circumference ratio (Ω)	0.39	0.35	0.34
A_{dyn} x π/POT x F_s x Ω	**0.011**	**0.027**	**0.024**

Paris, Jan. 2014

Workpackages @ CERN: SPS

Task Id	Task	Responsibility	Deliverable
1.1	Optimisation of extraction energy	Collaboration/ CERN	Report detailing choice of energy.
1.2	Optimisation of bunch structure	Collaboration/ CERN	Report specifying bunch structure and describing how this is achieved.
1.3	Design of extraction system	CERN	Report detailing extraction scheme.

Preliminary

Pion Production (FNAL)

- 120 GeV proton beam, beam radius – 1mm
- 5 GeV/c π+ yield optimization
  - Inconel, Tungsten, Graphite
  - Target length, radius, material and position inside horn. Horn current- 230 kA.
- Yield rises very little with target length. Dependence on target position inside horn is weak. Dependence of yield on target radius is opposite for heavy and light targets.
- Yields better for Inconel and Tungsten
- Realistic horn model slightly decreases predicted yield, but changes distribution is not so marginal (interactions in the horn itself)
- MARS model agrees well with exp. data on carbon in nuSTORM range of interest. MIPP and NA61/SHINE measurements for medium and heavy nuclei will be published in two years.
- Development at CERN?

WP2 @ CERN: Target and collection

Task Id	Item	Responsibility	Deliverable
2.1	Target station design	CERN	Report detailing design of a multipurpose target station.
2.2	Target and horn design	CERN	Design of the target/horn layout that maximises the pion yield.
2.3	Energy sweep study	Collaboration/ CERN	Evaluation of how the target/horn system will be affected by an energy sweep.

Preliminary

WP3 @ CERN: Collection and Transport

Task Id	Item	Responsibility	Deliverable
3.1	Transport and injection line	CERN	Design report on the transport and injection line.
3.2	The proton dump transport line	CERN	Design report on the proton transport line layout.
3.3	The proton dump	CERN	Report on the proton-dump design.

Preliminary

WP4 @ CERN: Decay Ring Layout

Task Id	Task	Responsibility	Deliverable
4.1	Definition of stored-muon energy range.	Collaboration/ CERN	Report detailing choice of energy range.
4.2	Review and finalisation of decay ring lattice.	Collaboration/ CERN	Report detailing lattice design.
4.3	Design of pion-injection system ring lattice.	Collaboration/ CERN	Report detailing injection scheme.
4.4	Design of pion-extraction system	Collaboration/ CERN	Report detailing extraction scheme.
4.5	Comparison of FODO and FFAG lattice solutions.	Collaboration/ CERN	Report detailing comparison and detailing baseline solution.

Preliminary

WP5 @ CERN: Pion Beam Dump

Task Id	Item	Responsibility	Deliverable
5.1	Pion-beam transport design	Collaboration/ CERN	Design report on the transport line layout
5.2	Pion-beam dump design	CERN	Design report on the beam dump

Preliminary

Preliminary magnet considerations, FODO Lattice

- Straights:
  - Resistive quite standard technology.
  - The apertures are quite large, prototyping needed
- Arcs:
  - Superconducting magnets. Most of them coil dominated, possibly a few quadrupoles in between could be iron dominated (superferric), also to avoid warm-to-cold transitions.
  - Lattice to be optimized for quadrupole feasibility (even with Nb_3Sn).

- Space for sextupoles / orbit correctors (in the arcs): large apertures is a challenge (large stored energies per unit length, large forces and significant cross-talk between the magnetic elements)

Courtesy A. Milanese

WP6 @ CERN: Magnets

Task Id	Item	Responsibility	Deliverable
6.1	Tune all optics to prepare for good magnets	Collaboration/ CERN	Optics file revised
6.2	Warm magnet choice and design	Collaboration/ CERN	Warm magnets and characteristics.
6.3	Cold magnet choice and design	Collaboration/ CERN	Cold magnets and characteristics.
6.4	Infrastructures	CERN	Cryogenic end electrical requirements.

Preliminary

Instrumentation

Determine the neutrino flux at the near and far end detectors with an absolute precision < 1%, which depends on the number of Neutrinos and their energy distribution.

If the circulating muon flux in the storage ring is known on a turn to turn basis together with the orbit and orbit uncertainties (uncertainty on the divergence), then the neutrino flux can be predicted:

1. Circulating muon intensity (on a turn by turn basis) to 0.1% absolute.
2. Mean momentum to 0.1% absolute
3. Width of momentum spread to 1% (FWHM)
4. Tune to 0.01

Accelerator commissioning and running: (turn by turn)

1. Trajectory
2. Tune
3. Beam loss
4. Profile

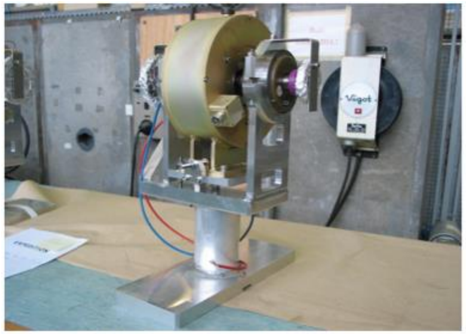


Figure 2: L4 Beam Current Transformer (BCT)

Intensity, large chamber, challenging precision (0.1%)

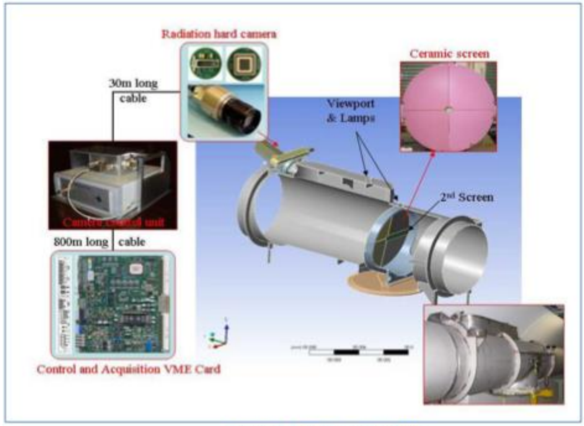


Figure 6: LHC dump line BTV

Profile, low intensities, short lifetime (100μs), IPM not feasible, Sc. Screens or SEM strips to be foreseen, wire scanners not possible. Figure : 2m long tank, 60cm diameter, to be adapted.

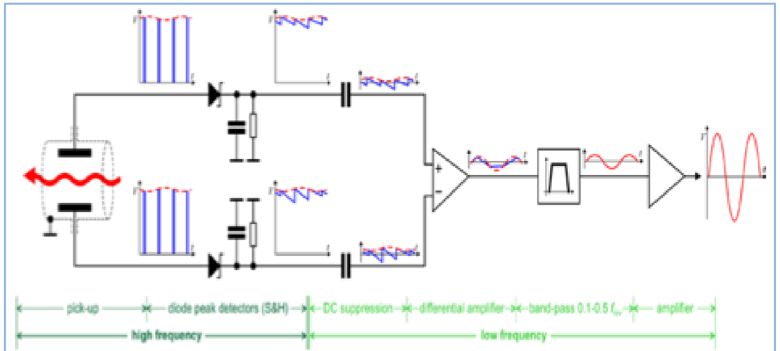


Figure 8: Base Band Tune measurement principle

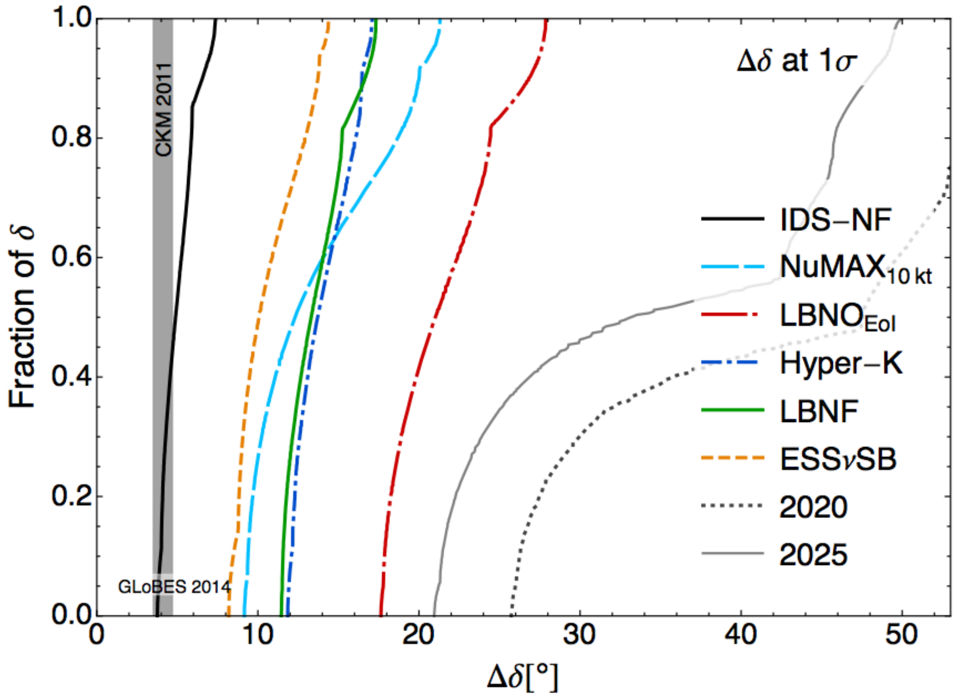
Direct Diode Detection Base-Band Q (3D-BBQ) developed at CERN, by M. Gasior

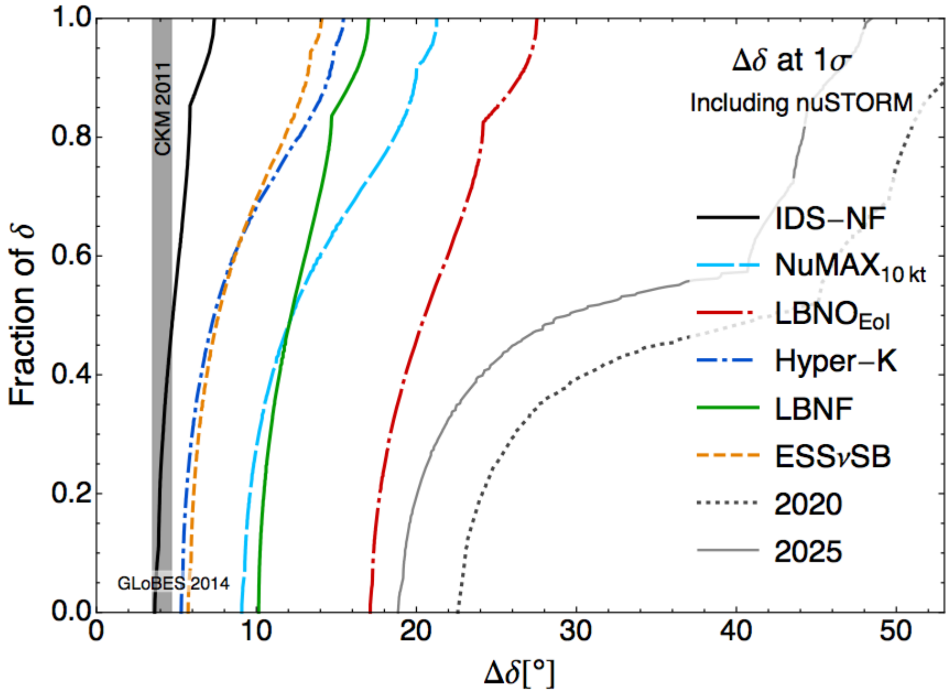
WP7 @ CERN: Instrumentation

Task Id	Item	Responsibility	Deliverable
7.1	Design of storage-ring instrumentation meeting nuSTORM precision requirements.	CERN/ Collaboration	Design report specifying instrumentation and cost.
7.2	Evaluate positron/electron collimation and shielding requirements.	CERN	Design report detailing necessary collimation and shielding.

Preliminary

Including nuSTORM results





Systematics is the same as before, only that including nuSTORM it is assumed that cross sections are determined at the 1% level of precision, removing the constraint between the cross sections for different flavors, they are all allowed to vary independently in the fit.

LBNF (40 kton detector, 1.2MW beam power)

Pilar Coloma et al.

Thank you for your attention !

Stay tuned:
a workshop will be held at CERN
Nov-Dec 2014

Backup

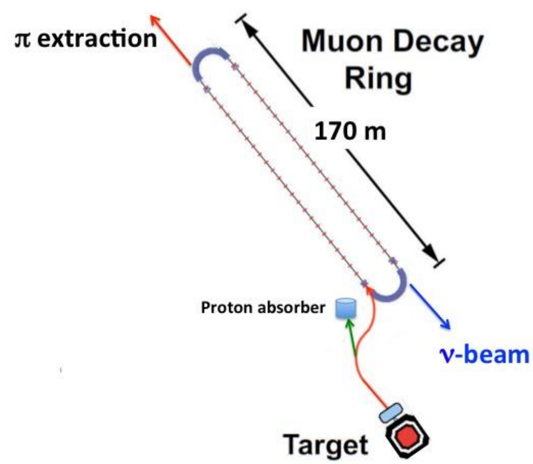
CERN Beams

Parameter	SPS operation		SPS record		After LIU 2020	
	LHC	CNGS	LHC	CNGS	LHC	νSTORM
Energy [GeV]	450	400	450	400	450	100
Bunch spacing [ns]	50	5	25	5	25	5
Bunch intensity [10^{11}]	1.6	0.105	1.3	0.13	2.2	0.17
Number of bunches	144	4200	288	4200	288	4200
SPS intensity [10^{13}]	2.3	4.4	3.75	5.3	6.35	7.0
PS intensity [10^{13}]	0.6	2.3	1.0	3.0	1.75	4.0
SPS Cycle length [s]	21.6	6.0	21.6	6.0	21.6	3.6
PS Cycle length [s]	3.6	1.2	3.6	1.2	3.6	2×1.2
PS beam mom. [GeV/c]	26	14	26	14	26	14
Beam Power [kW]	77	470	125	565	211	156

Beam parameters

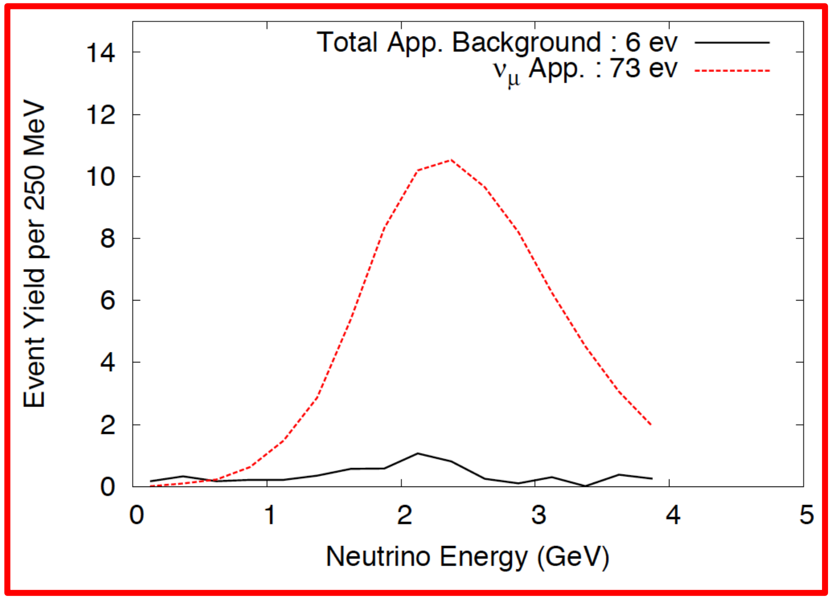
Parameter	Value	Comments
Muon energy	3.8GeV	
Total intensity	1 - 5E11?	Muon
Pulse length	10.5μs	From SPS
Bunch frequency	200MHz	Before injection
Nb of bunches	233-2100?	Phase at injection?
Bunch length	1-4ns?	Has to be simulated
Bunch intensity	5E7-2E9?	More precise data needed
Rev. frequency	851kHz	T = 1.17μs
Bunch current	2-80mA ?	Injection scheme?
Average current	14-68mA	At injection
Circumference	350m	
Beam size	30cm	Diameter
Aperture	40-60cm	
Beam life time	100 turns	
Vacuum	10E-7	

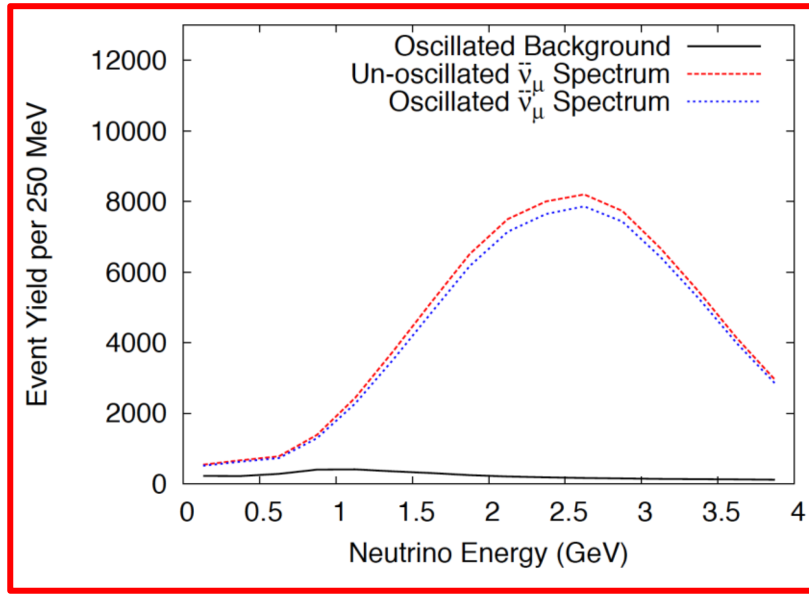
1. **Continuous multi turn (~9 turns) injection.**
2. **No RF**
3. **Injecting on top of circulation bunches NOT foreseen yet, i.e. 200MHz plus any frequency above is possible.**
4. **Structure in beam unknown for the moment**

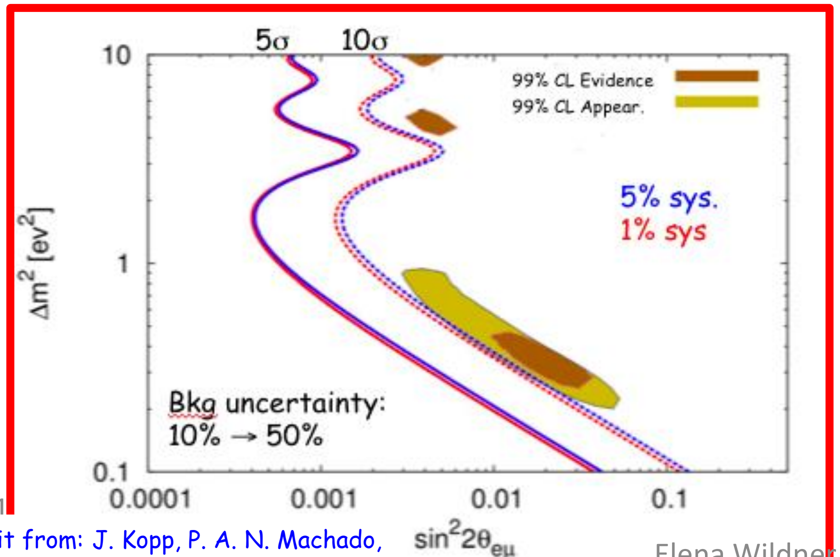


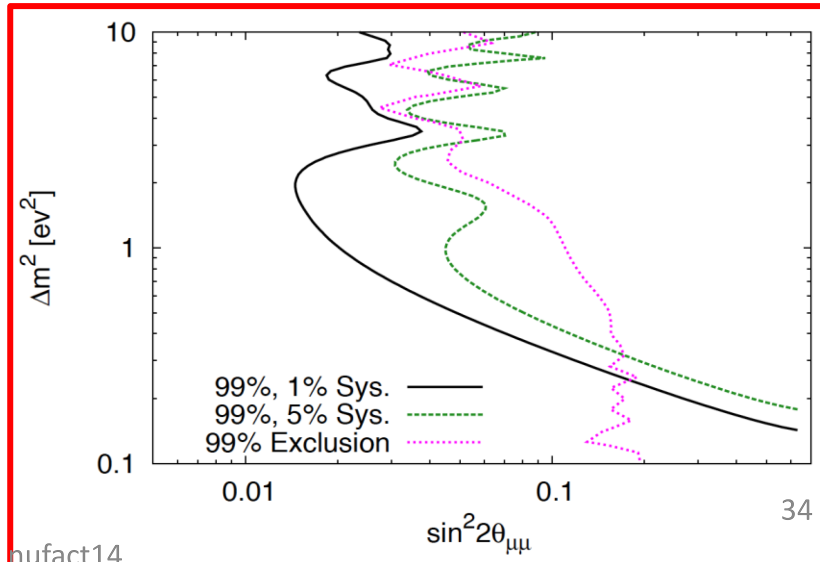
Elena Wildner, nufact14

Sterile-neutrino search sensitivity





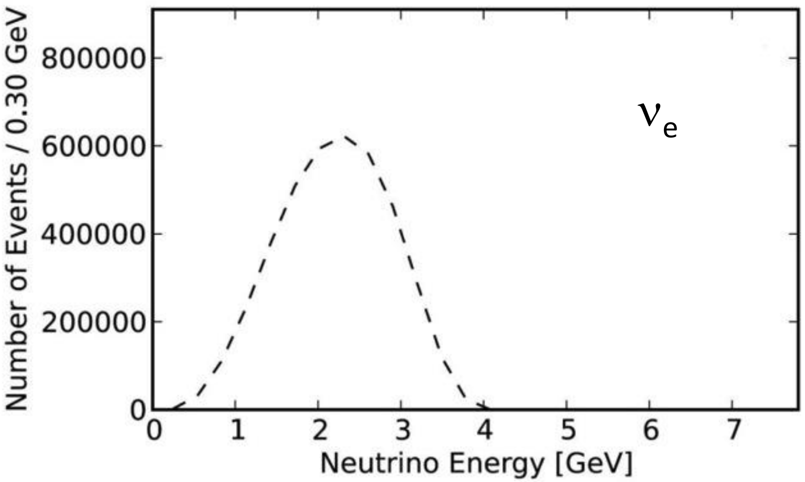


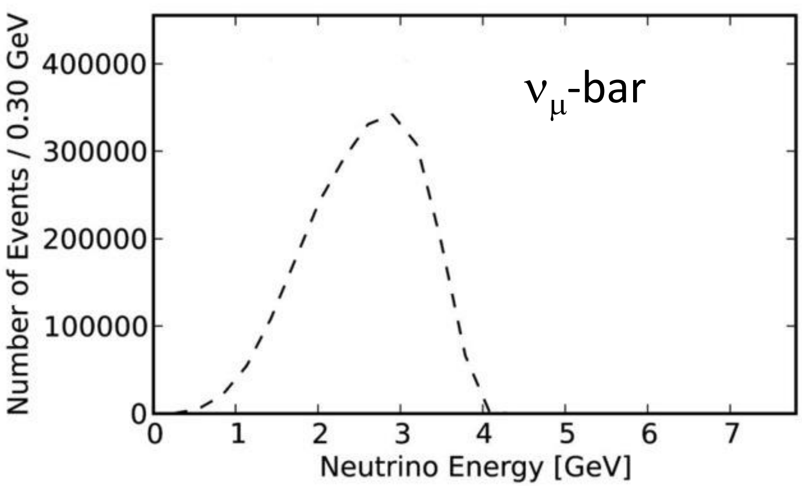


Global fit from: J. Kopp, P. A. N. Machado, M. Maltoni, and T. Schwetz (2013)

Spectra X cross-section (3.8 GeV/c μ^+)

$m^+ \rightarrow e^+ \bar{n}_m n_e$





Event rates /100T at ND hall 50m from straight with μ^+ stored for 10^{21} POT exposure

Channel	N_{evts}
$\bar{\nu}_\mu$ NC	844,793
ν_e NC	1,387,698
$\bar{\nu}_\mu$ CC	2,145,632
ν_e CC	3,960,421

Channel	$N_{\text{osc.}}$	N_{null}	Diff.	$(N_{\text{osc.}} - N_{\text{null}})/\sqrt{N_{\text{null}}}$
$\nu_e \rightarrow \nu_\mu$ CC	332	0	∞	∞
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ NC	47679	50073	-4.8%	-10.7
$\nu_e \rightarrow \nu_e$ NC	73941	78805	-6.2%	-17.3
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ CC	122322	128433	-4.8%	-17.1
$\nu_e \rightarrow \nu_e$ CC	216657	230766	-6.1%	-29.4