Neutrino Factory: EU+CH version

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CERN – PS/PP Division

Three family oscillation

Atmospheric Neutrinos | Phase δ ~~CP~~ | Solar Neutrinos

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix}\begin{pmatrix}c_{13} & 0 & s_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{-i\delta} & 0 & c_{13}\end{pmatrix}\begin{pmatrix}c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

- Super-K UP-DOWN
- **Maximal** mixing
- $\Delta m^2 \approx 3\ 10^{-3}\ eV^2$
- L/E = 1 GeV/500 km

- *Limit* from CHOOZ
- Goal of next generation of neutrino-beam
- If θ_{13} is zero, IMPOSSIBLE to observe CP violation

- SNO
- **Large** Mixing (LMA)
- Kamland
- L/E ≈ MeV/1.5 10^{11}m

CP violation in the leptonic sector ?

$$\frac{P(\nu_e \to \nu_\mu) - P(\overline{\nu}_e \to \overline{\nu}_\mu)}{P(\nu_e \to \nu_\mu) + P(\overline{\nu}_e \to \overline{\nu}_\mu)} = A_{CP} \propto \frac{\sin\delta \, \sin(\Delta m_{12}^2 L / 4E) \, \sin\theta_{12}}{\sin\theta_{13}}$$

~~CP~~ is observable IF:

- $\sin^2\theta_{12}$ and Δm^2_{12} are large (LMA) and $\sin^2\theta_{13}$ small
- Appearance experiment: $P(\nu_e \to \nu_\mu)$
  - $P(\nu_e \to \nu_e)$ is T invariant $\to$ CP is conserved
    (CP not observable from solar or reactor neutrinos)

Physics at a Nufact

- Measure θ_{13} via $P(\nu_e \rightarrow \nu_\mu)$ with a precision of 10^{-3} or setting a limit to 10^{-6}
- Determine via MSW the sign of Δm^2

- Discover and measure the
  CP violation in the leptonic sector (phase δ)

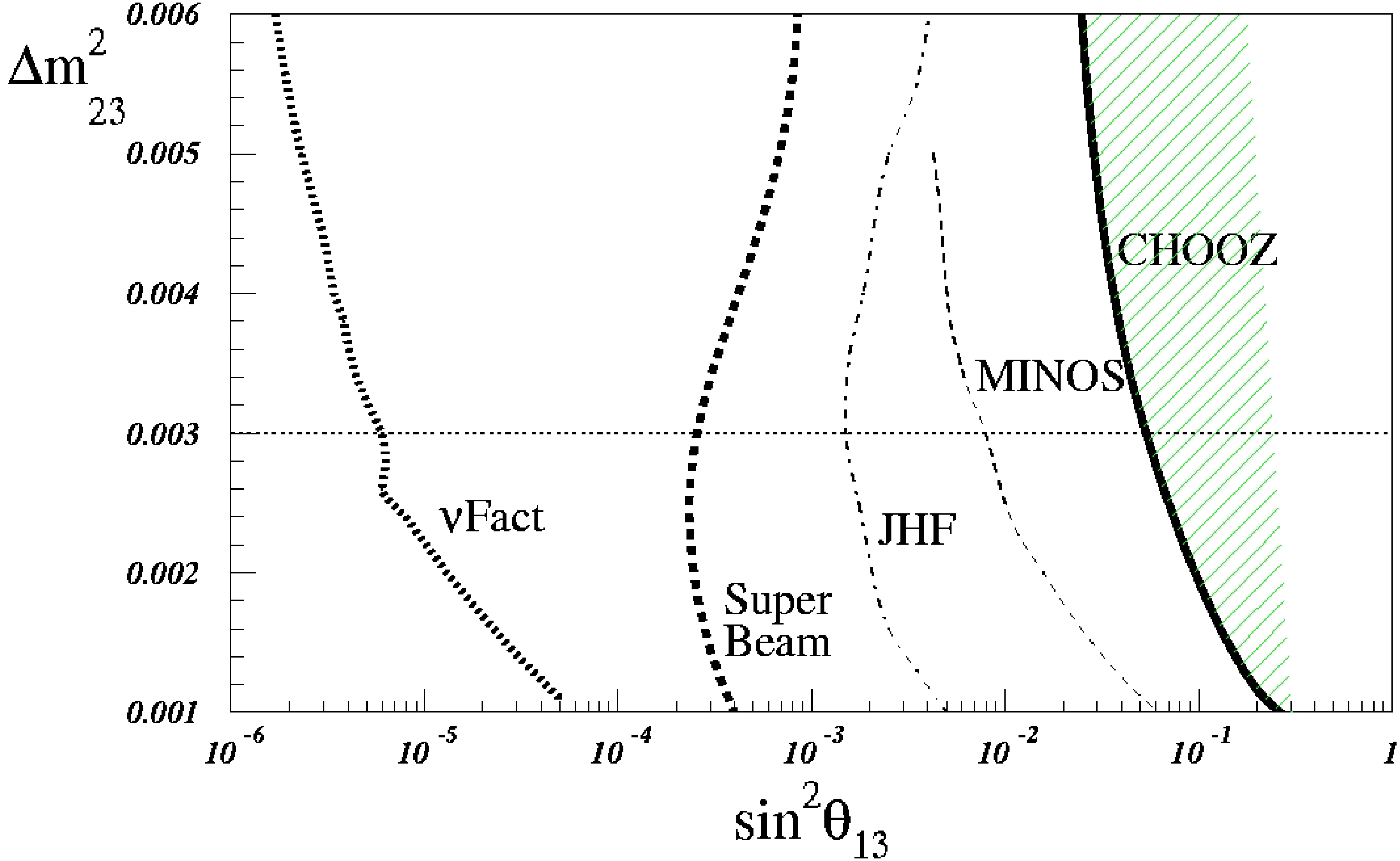
$$P(\nu_e \rightarrow \nu_\mu) \neq P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu)$$

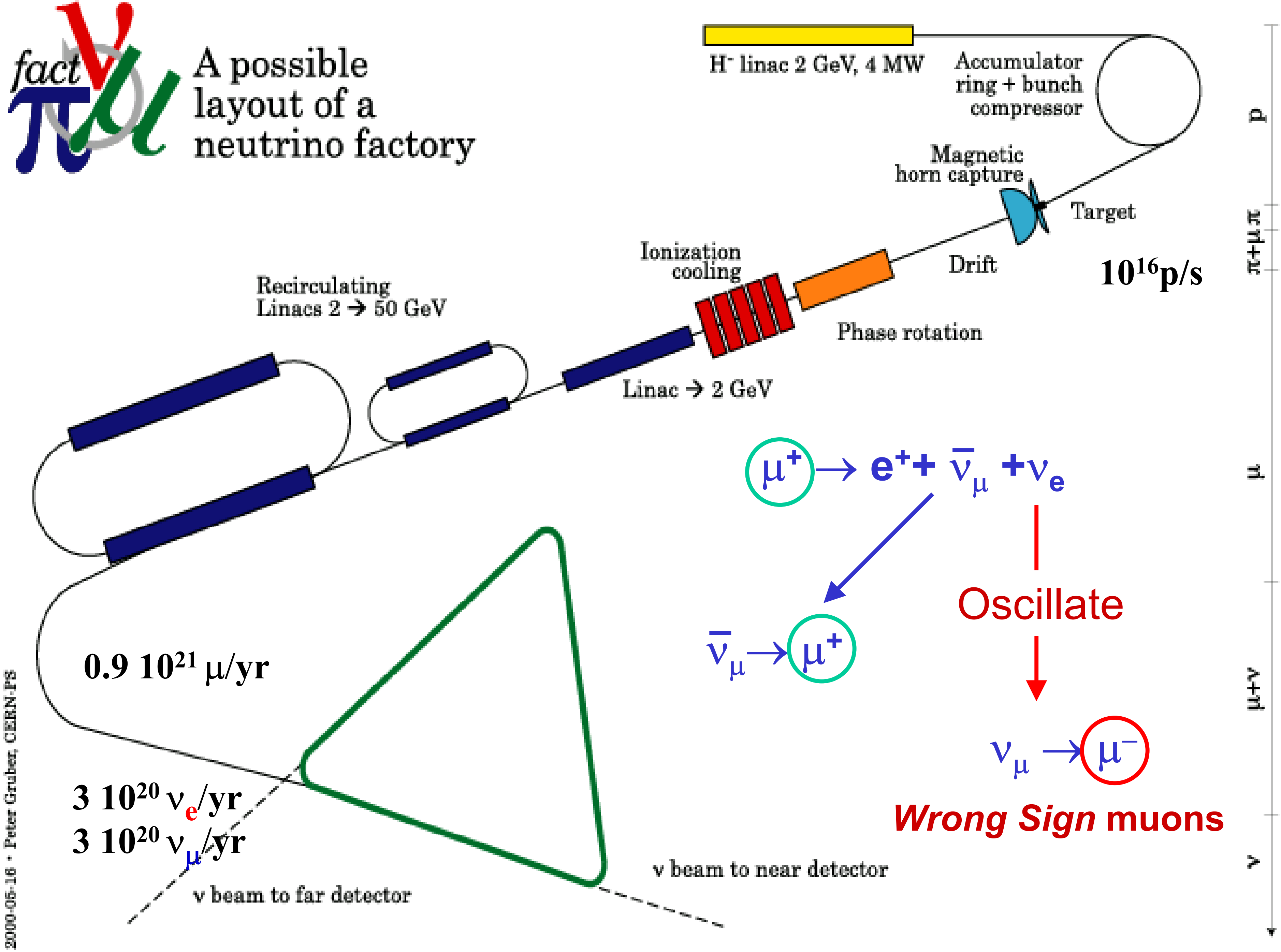
(If LMA is confirmed by Kamland…)

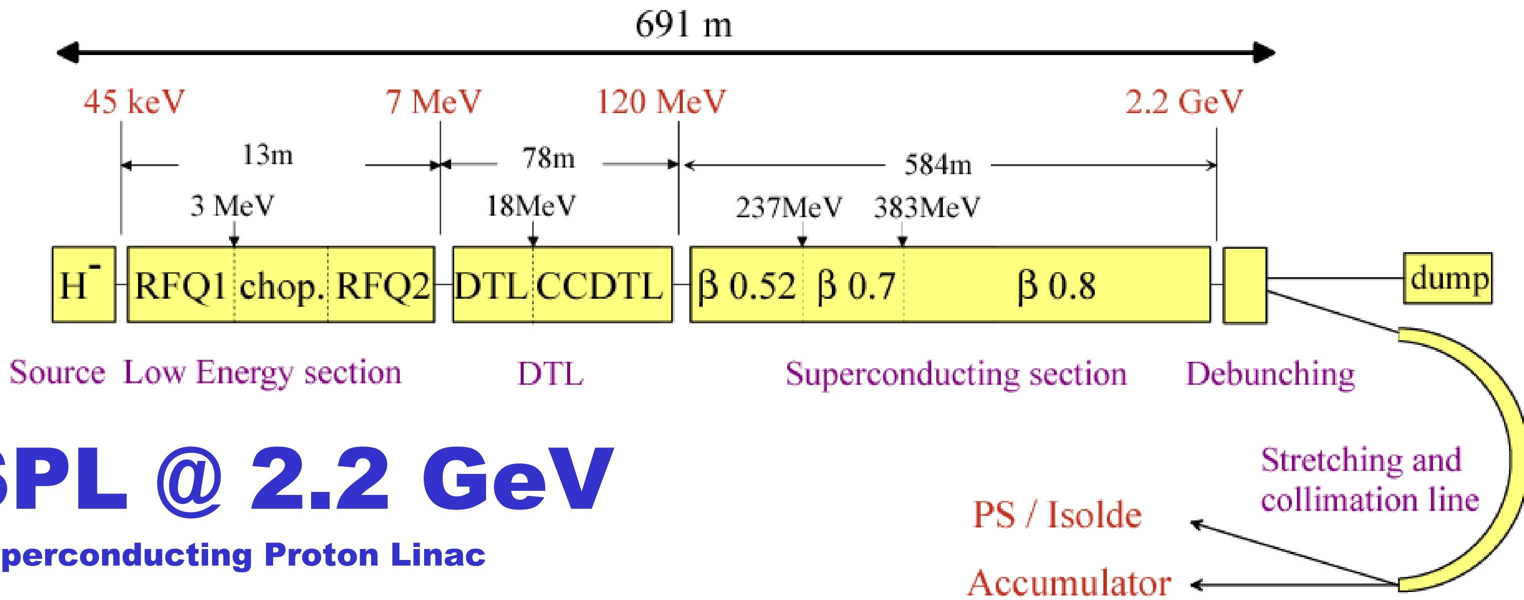
Need of high energy (~20 GeV) ν_e:

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Sensitivity of Nufact




A possible layout of a neutrino factory
H⁻ linac 2 GeV, 4 MW
Accumulator ring + bunch compressor
Magnetic horn capture
Target
10^{16}p/s
Drift
Phase rotation
Ionization cooling
Linac → 2 GeV
Recirculating Linacs 2 → 50 GeV
$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$
$\bar{\nu}_\mu \rightarrow \mu^+$
Oscillate
$\nu_\mu \rightarrow \mu^-$
Wrong Sign muons
0.9 10^{21} μ/yr
3 10^{20} ν_e/yr
3 10^{20} ν_μ/yr
ν beam to far detector
ν beam to near detector
p
π+μ π
μ
μ+ν
ν
2000-06-16 • Peter Gruber, CERN-PS



SPL @ 2.2 GeV

Superconducting Proton Linac

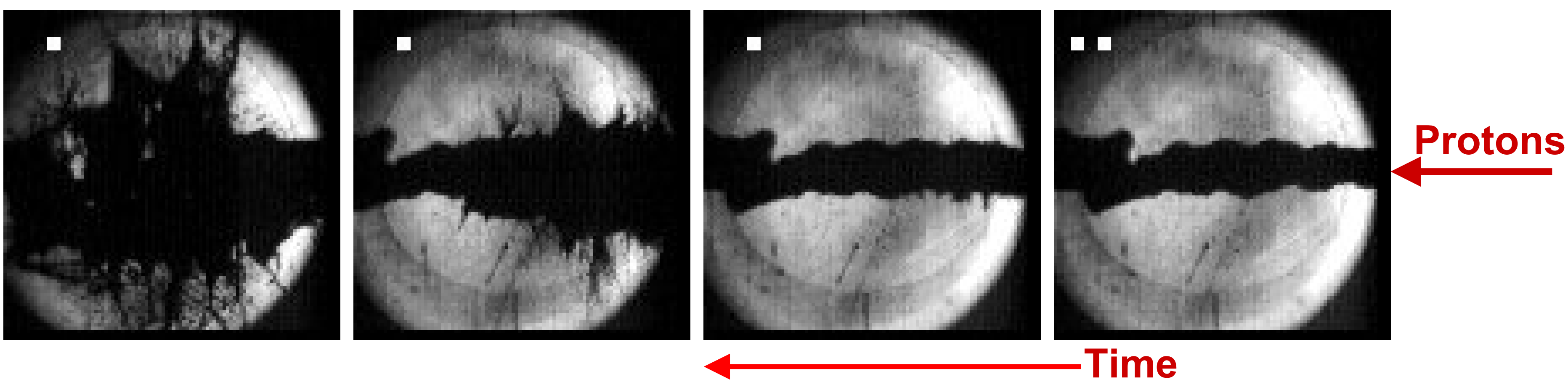
- High Power
  - LINAC @ 4 MW
  - Rep. Rate 50 Hz
  - 2.27 10^{14} p/pulse spaced by 22.7 nsec (44 MHz)
- Accumulator ring to reduce the pulse length
- CERN interested at least in the low energy part for the LHC upgrade and the improvement of CNGS

Target Nufact

- Target: → **4 MW of proton into a pint of beer**
  - Mercury: Z = 80 → short target
    Liquid → easy to replace
    ($v_{//} \approx$ 20 m/s)
  - Dimensions: L $\approx$ 30 cm, R $\approx$ 1 cm

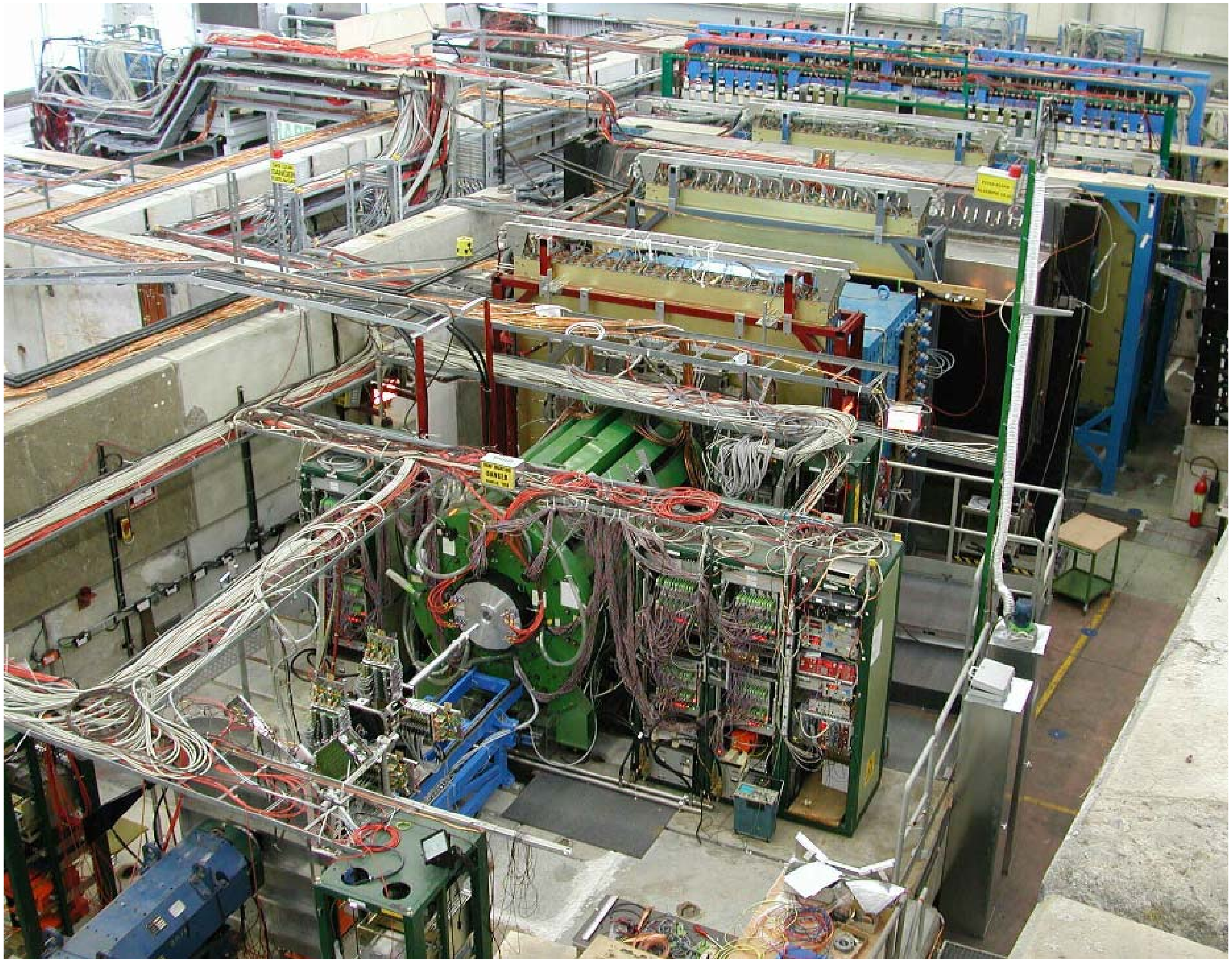
Jet test a BNL E-951

13.00 ms 4.50 ms 0.75 ms 0.00 ms

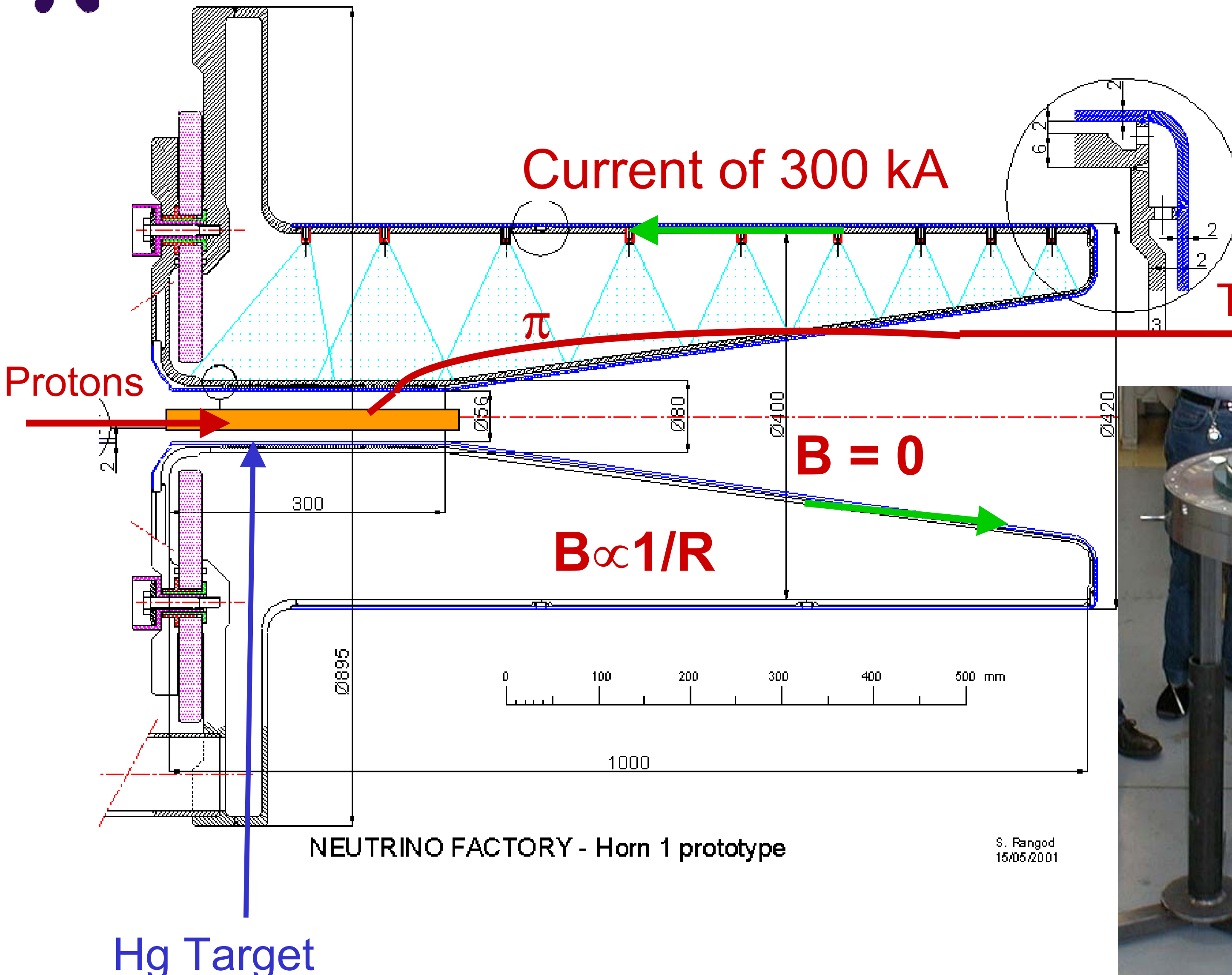


The Harp experiment

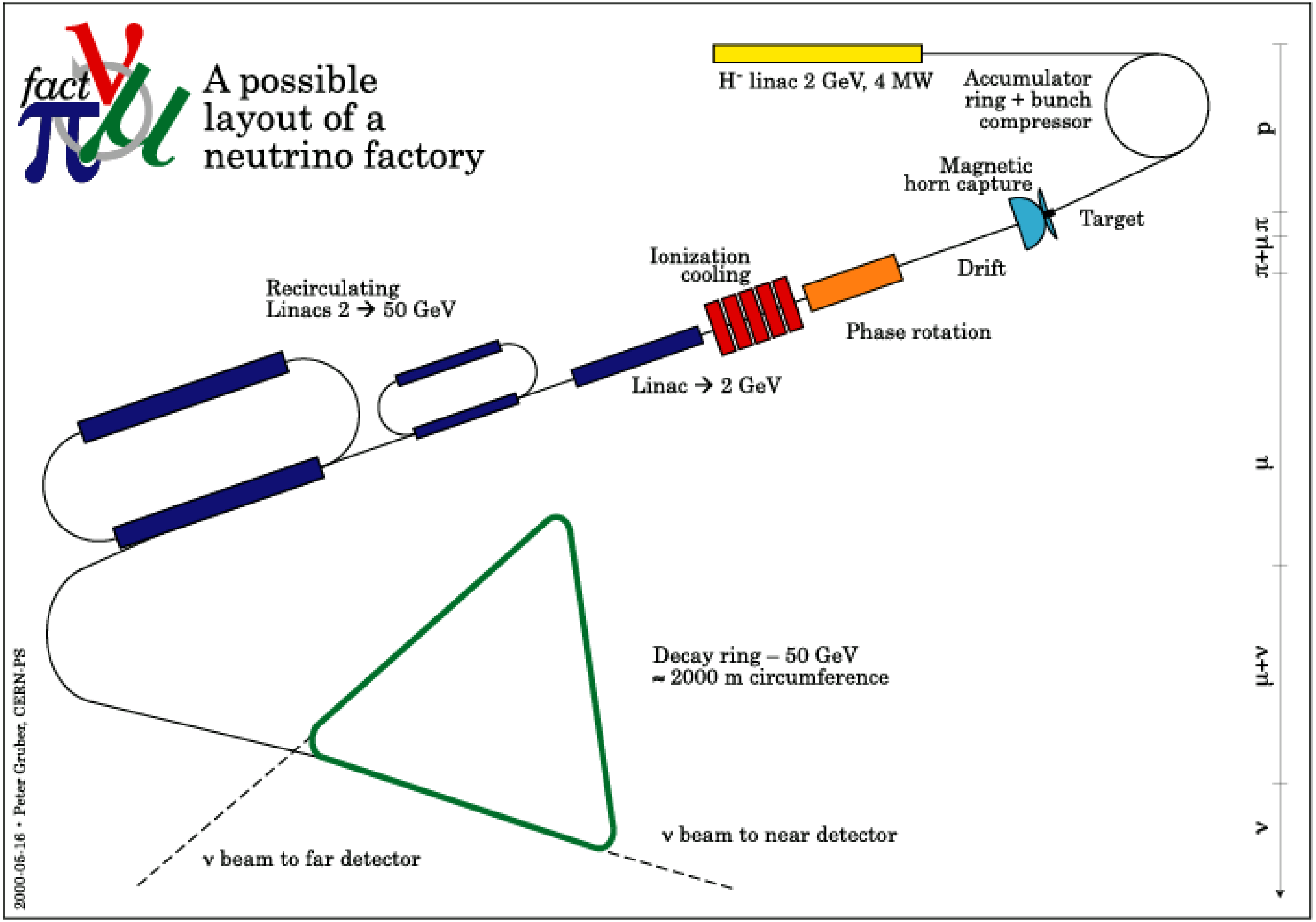
Hadron production cross section measurement



Magnetic horn



Nufact CERN layout

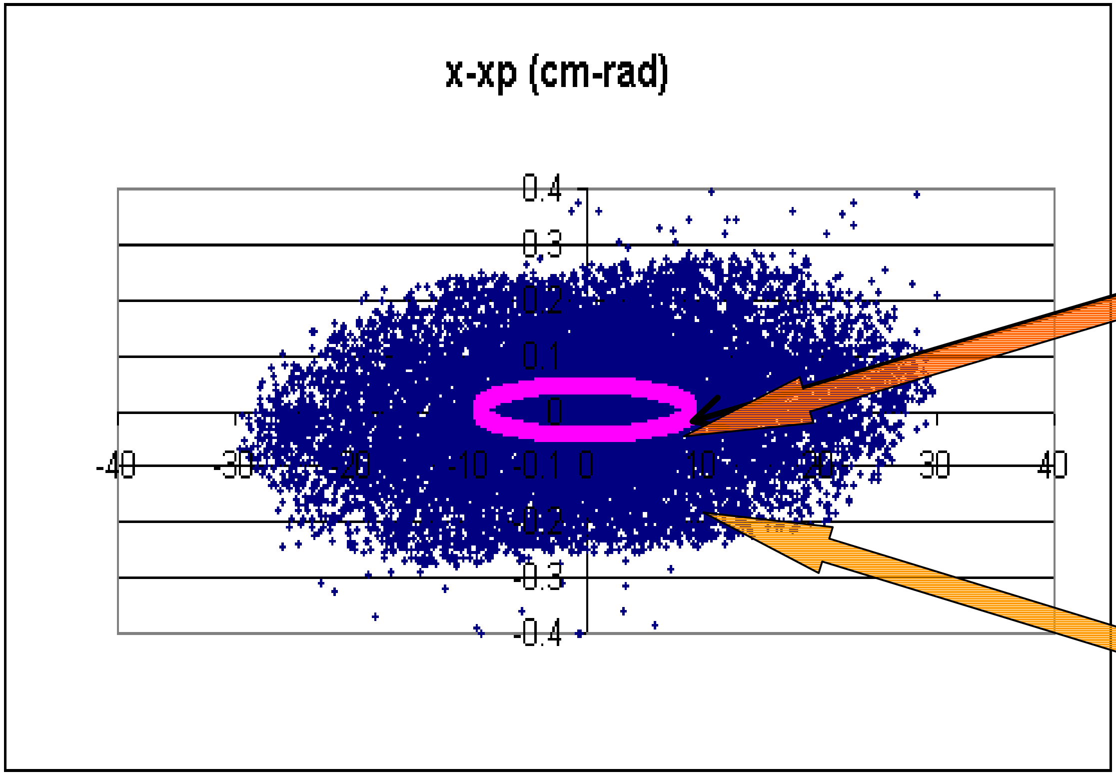


Cooling: the problem

(transverse phase space)

- Problem: $\mu \rightarrow$ Beam pipe radius of storage ring

$P_\perp$ or x' and x reduction needed: COOLING

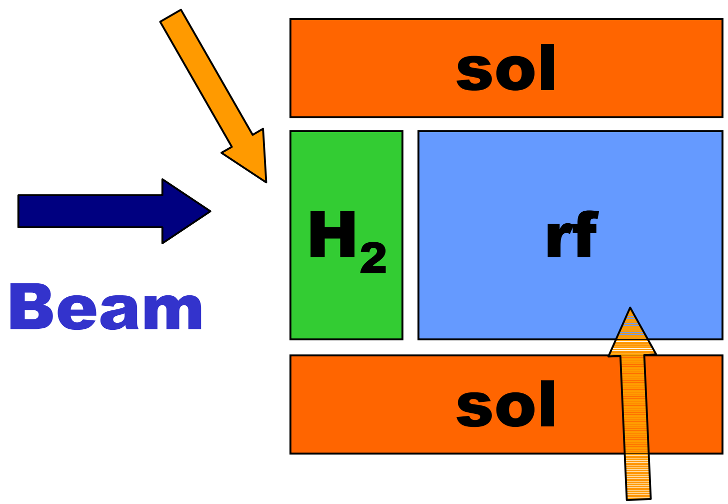


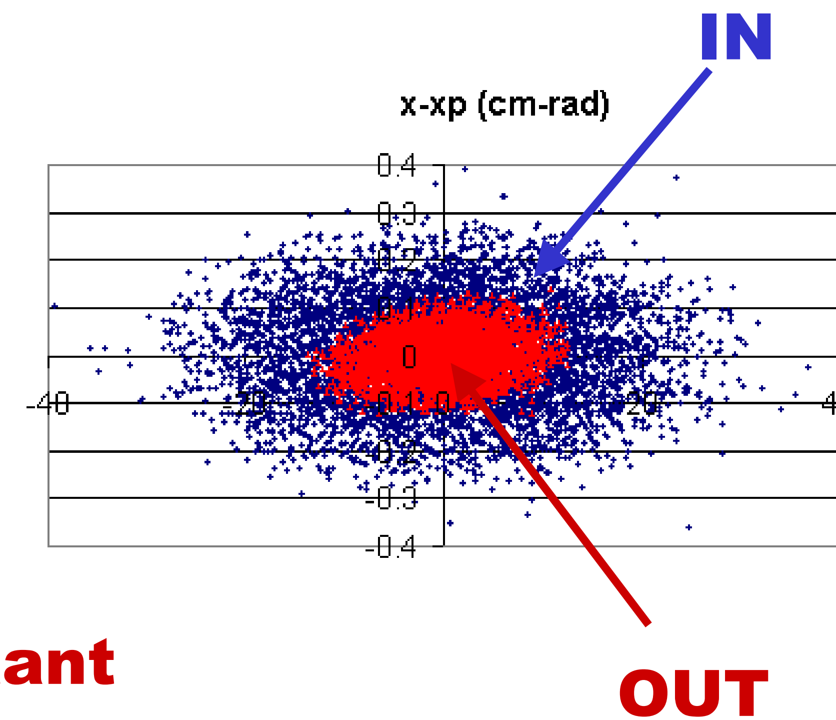
Accelerator acceptance
R ≈ 10 cm, x' ≈ 0.05 rad
rescaled @ 200 MeV

π and μ after focusing

Ionization Cooling : the principle

Liquid H_2: dE/dx



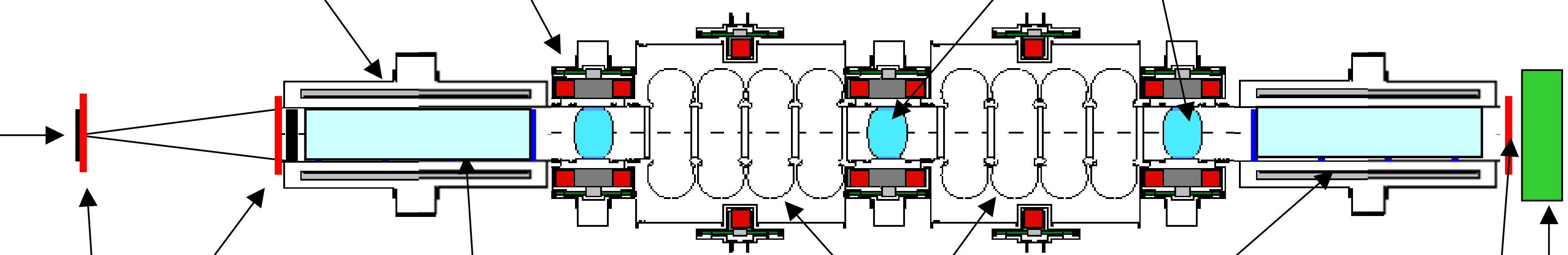


RF restores only $P_{//}$: E constant

Proposal to be submitted to RAL before end of the year

SC Solenoids;
Spectrometer, focus pair, compensation coil

Liquid H2 absorbers or LiH ?



201 MHz RF cavities

T.O.F. I & II
Pion /muon ID
precise timing

Tracking devices:
He filled TPC-GEM (similar to TESLA R&D) and/or sci-fi
Measurement of momentum, angles and position

T.O.F. III
Precise timing

Electron ID
Eliminate muons that decay

Participating Institutes (EU&US)

Contact person in parenthesis

Louvain La Neuve (G. Grégoire)

CERN** (H. Haseroth)

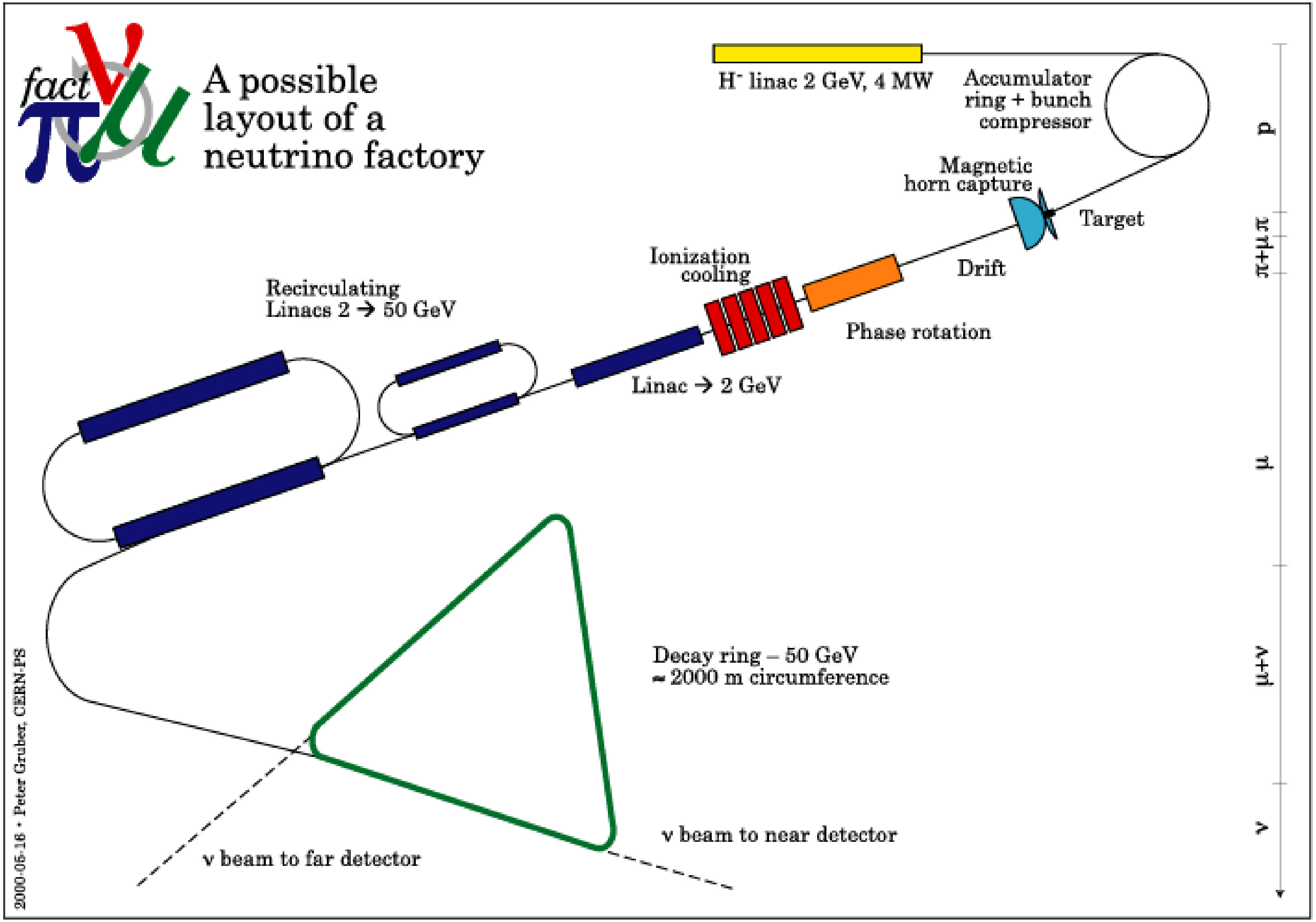
NESTOR Institute (L. Resvanis)
University of Athens (L. Resvanis)
Hellenic Open University (S. Tzamarias)

INFN Bari (G. Catanesi)
INFN LNF Frascati (M. Castellano, L. Palumbo)
INFN Legnaro (U. Gastaldi)
INFN Milano (M. Bonesini)
INFN Padova (M. Mezzetto)
INFN Napoli (G. Osteria)
INFN Roma I (L. Ludovici)
INFN Roma II (L. Catani)
INFN Roma III (L. Tortora)
INFN Trieste (M. Apollonio)

Argonne National Laboratory (J. Norem)
Brookhaven National Laboratory (R. Palmer)
Columbia University (A. Caldwell)
Fairfield University (D.Winn)
Fermi National Accelerator Laboratory (S. Geer)
Illinois Institute of Technology (D. Kaplan)
Lawrence Berkeley National Laboratory (M. Zisman)
Michigan State University (M. Berz)
Northern Illinois University (M. A. Cummings)
Princeton University (K. McDonald)
University of California Los Angeles (D. Cline)
University of California, Riverside/Indiana University
University of Chicago – Enrico Fermi Institute (K.-J. Kim)
University of Illinois at Urbana-Champaign (D. Errede)
University of Iowa (Y.Onel)
University of Mississippi (D. Summers)

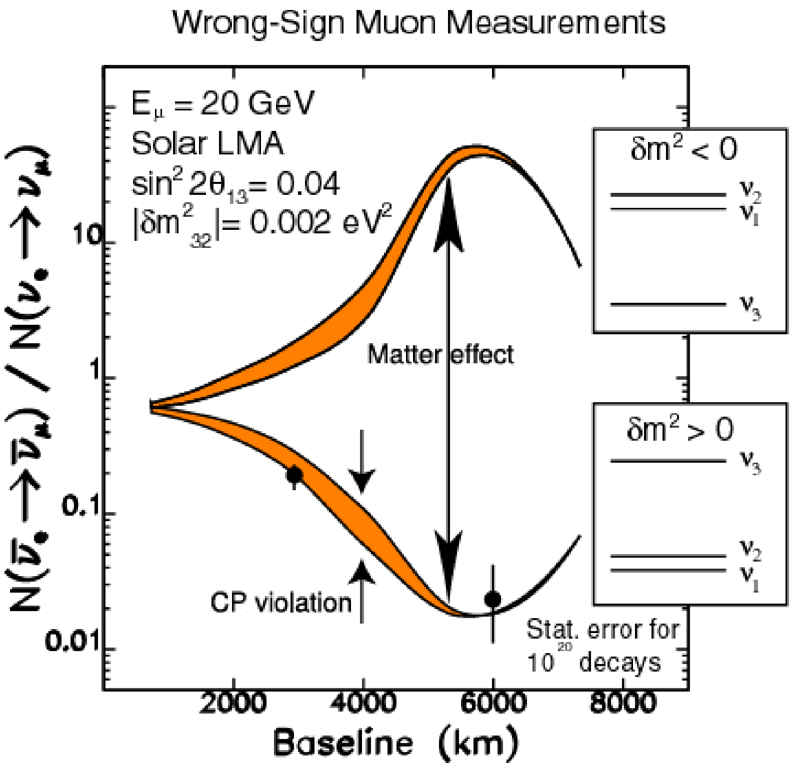
** limited participation to a few individuals and to the provision of re-furbished RF power sources.

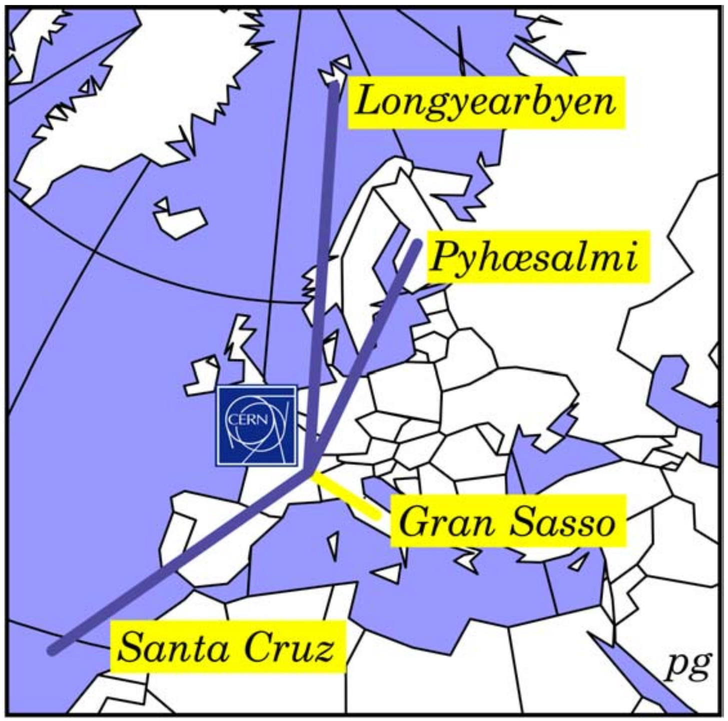
Nufact CERN layout



Around Europe...

- **First possible location:** Gran Sasso 732 km
- **Second location:** 3500 km away best
  Candidates: Svalbards (Norway)
  Gran Canaria (Spain)





EMCOG

European Muon Concertation and Oversight Group (EMCOG)

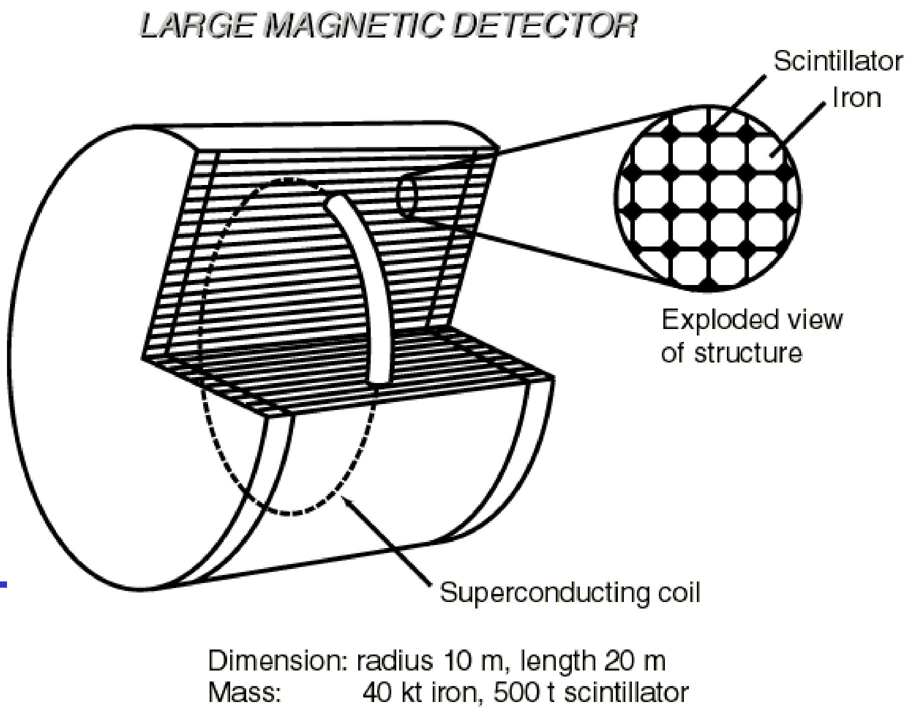
CERN:	Carlo Wyss (chair), Helmut Haseroth, John Ellis
CEA-DAPNIA:	Alban Mosnier, François Pierre
IN2P3:	Stavros Katsanevas, Marcel Lieuvin
INFN:	Marco Napolitano (Napoli), Andrea Pisent (Legnaro)
GSI:	Oliver Boine-Frankenheim, Ingo Hofmann
PSI:	Ralph Eichler
Geneva:	Alain Blondel (secretary)
RAL:	Ken Peach

- **The long-term goal is to have a Conceptual Design Report for a European Neutrino Factory Complex by the time of LHC start-up, so that, by that date, this would be a valid option for the future of CERN.**

- **Cooling is on the critical path for the neutrino factory itself; there is a consensus that a cooling experiment is a necessity.**

Detector (one option)

- Iron calorimeter
- Magnetized
  - Charge discrimination
  - B = 1 T
- R = 10 m, L = 20 m
- Fiducial mass = 40 kT



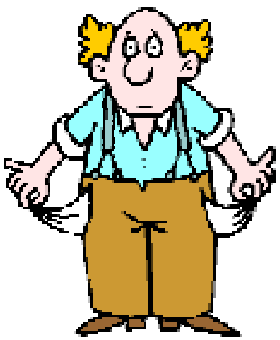
Baseline	$\bar{\nu}_\mu$ CC	ν_e CC	ν_μ signal
732 Km	3.5×10^7	5.9×10^7	1.1×10^5
3500 Km	1.2×10^6	2.4×10^6	1.0×10^5

Events for 1 year

Where do you prefer to take shifts?

Last question: about financing?

- For the time being our situation is not so good….



BUT….. Some ideas are developing…

hep-ph/0111247
TUM-HEP-446/01

Could One Find Petroleum Using Neutrino Oscillations in Matter?

Tommy Ohlsson[1,*] and Walter Winter[1,†]

[1]Institut für Theoretische Physik, Physik-Department, Technische Universität München, James-Franck-Straße, 85748 Garching bei München, Germany

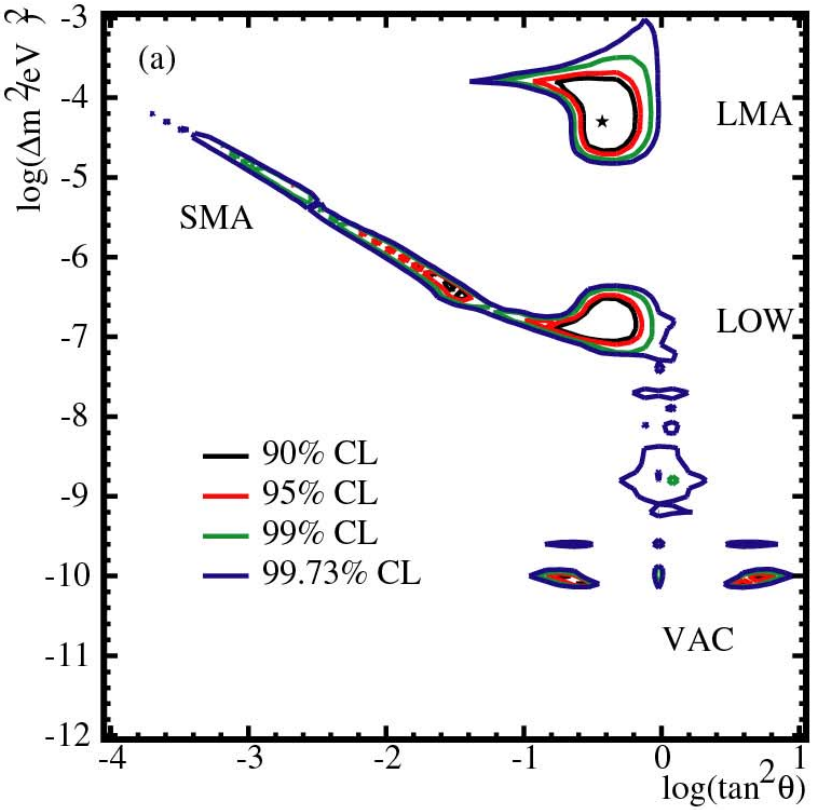
(Dated: November 20, 2001)

It is now widely believed in neutrino physics that neutrino oscillations are influenced by the presence of matter, modifying the energy spectrum produced by a neutrino beam traversing the Earth. Here, we will discuss the reverse problem, *i.e.*, what could be learned about the Earth's interior from a single neutrino baseline energy spectrum, especially about the Earth's mantle. In the end of the paper, we will finally investigate if one could really find petroleum using this method.

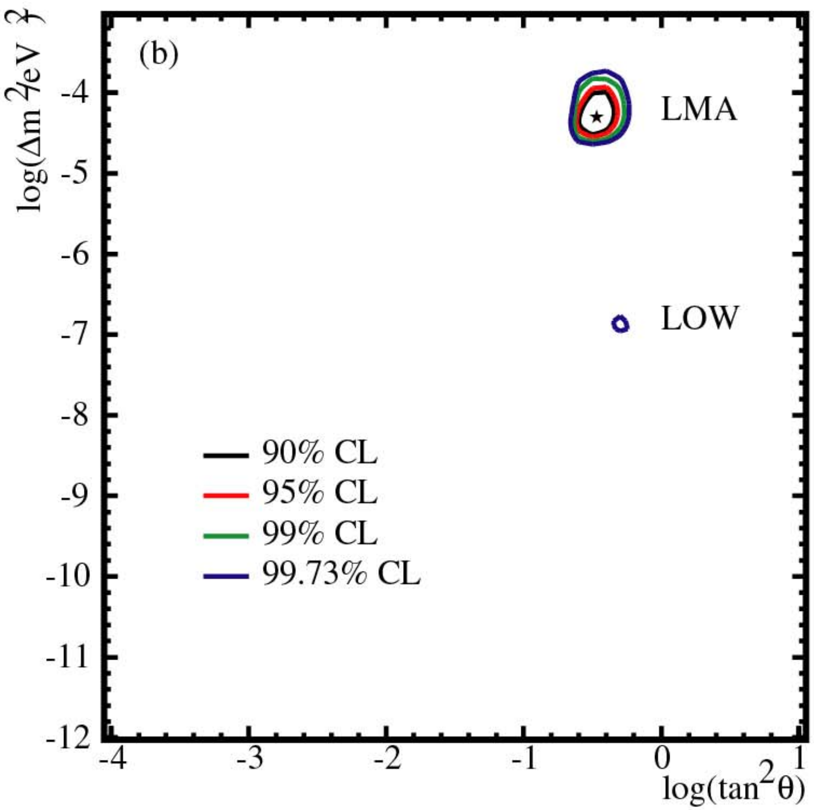
PACS numbers: 14.60.Lm, 13.15.+g, 91.35.-x

SNO: the Puzzle solution

SNO Day and Night Energy Spectra Alone



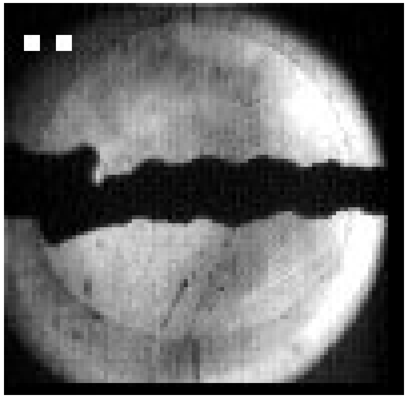
Combining All Experimental and Solar Model information

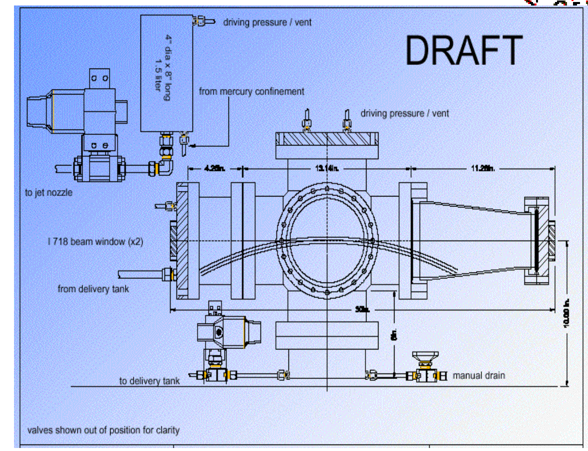


LMA (Large Mixing Angle) is the preferred solution

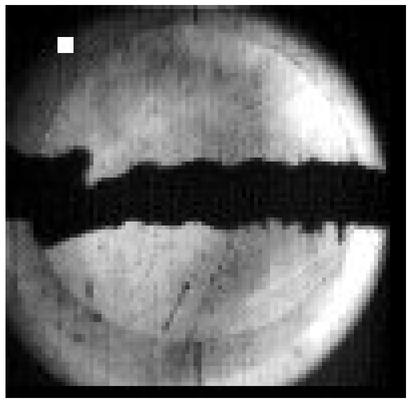
Jet test a BNL E-951

Event #11   25th April 2001





Protons ←



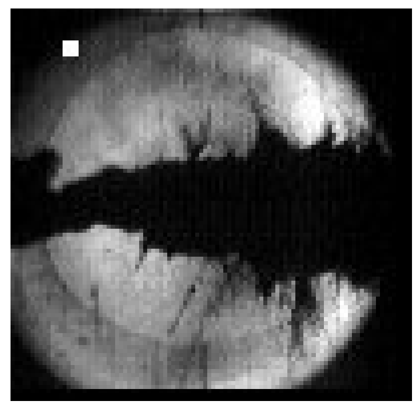
Picture timing [ms]

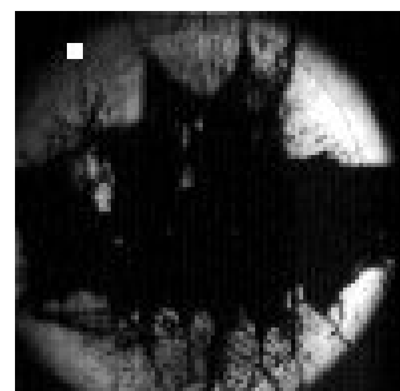
0.00

0.75

4.50

13.00



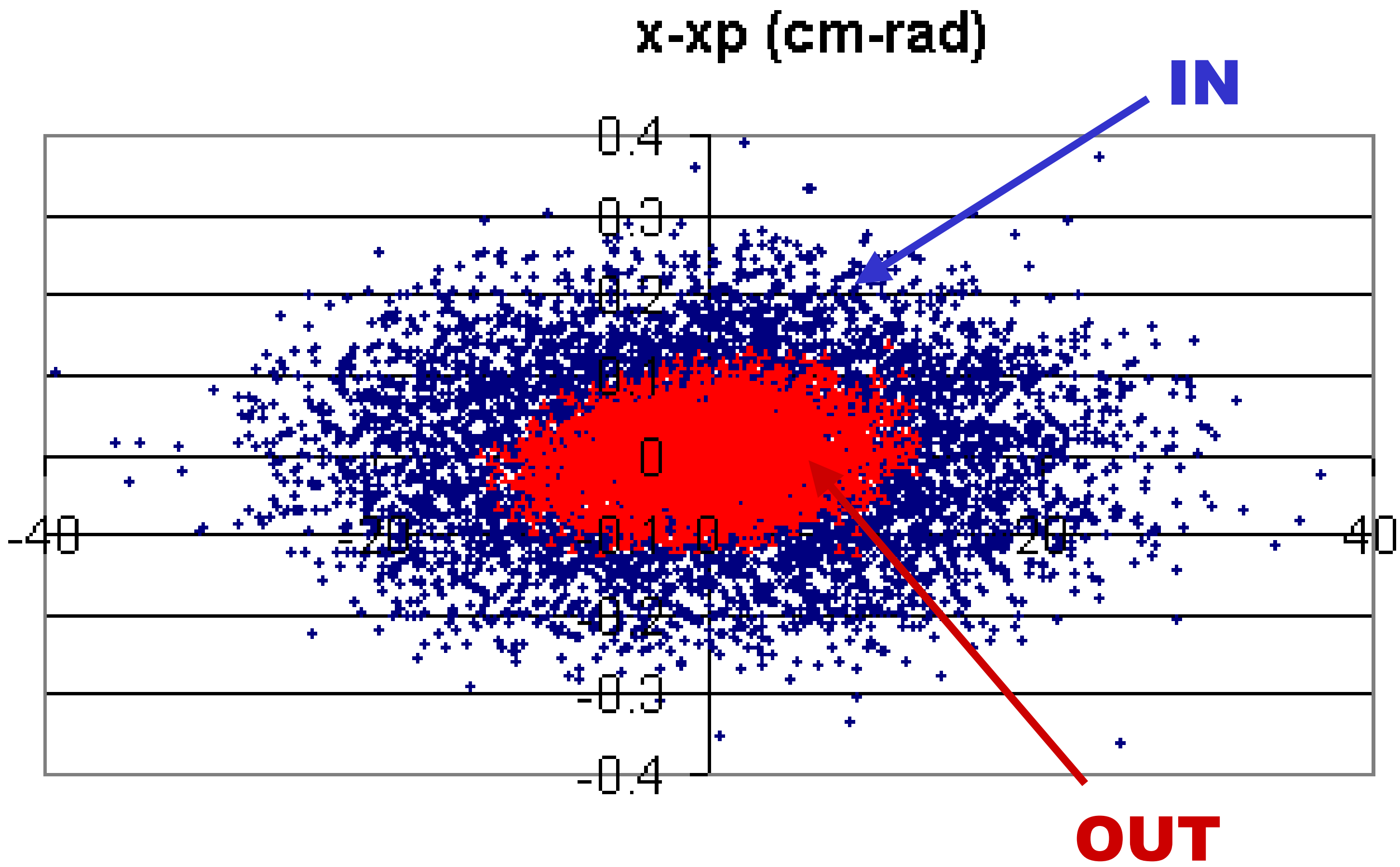


P-bunch: 2.7×10^{12} ppb
100 ns
t_o = ~ 0.45 ms

Hg- jet : diameter 1.2 cm
jet-velocity 2.5 m/s
perp. velocity ~ 5 m/s

K. Mc Donald, H. Kirk, A. Fabich

Cooling: the results



Results: **phase space density increased by 16**
(Cooling rate for MICE: 16%)