Superbeams, beta-beams and neutrino factories

Mats Lindroos

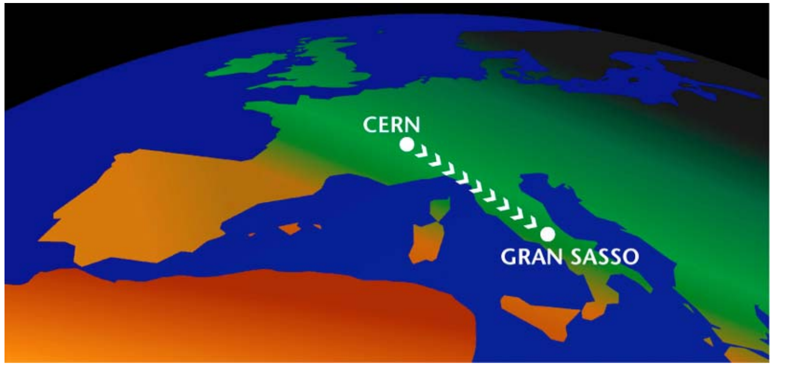
Outline

- Existing facilities
  - CNGS
- The super beam
- The neutrino factory
- The beta beam
- Conclusions

Acknowledgments

- CNGS
  - Konrad Elsener, CERN
- The Superbeam
  - Helmut Haseroth, Konrad Elsener, Tsuyoshi Nakaya
- The Neutrino Factory
  - The nufact study group
- The beta beam
  - The BENE beta-beam working group

CNGS



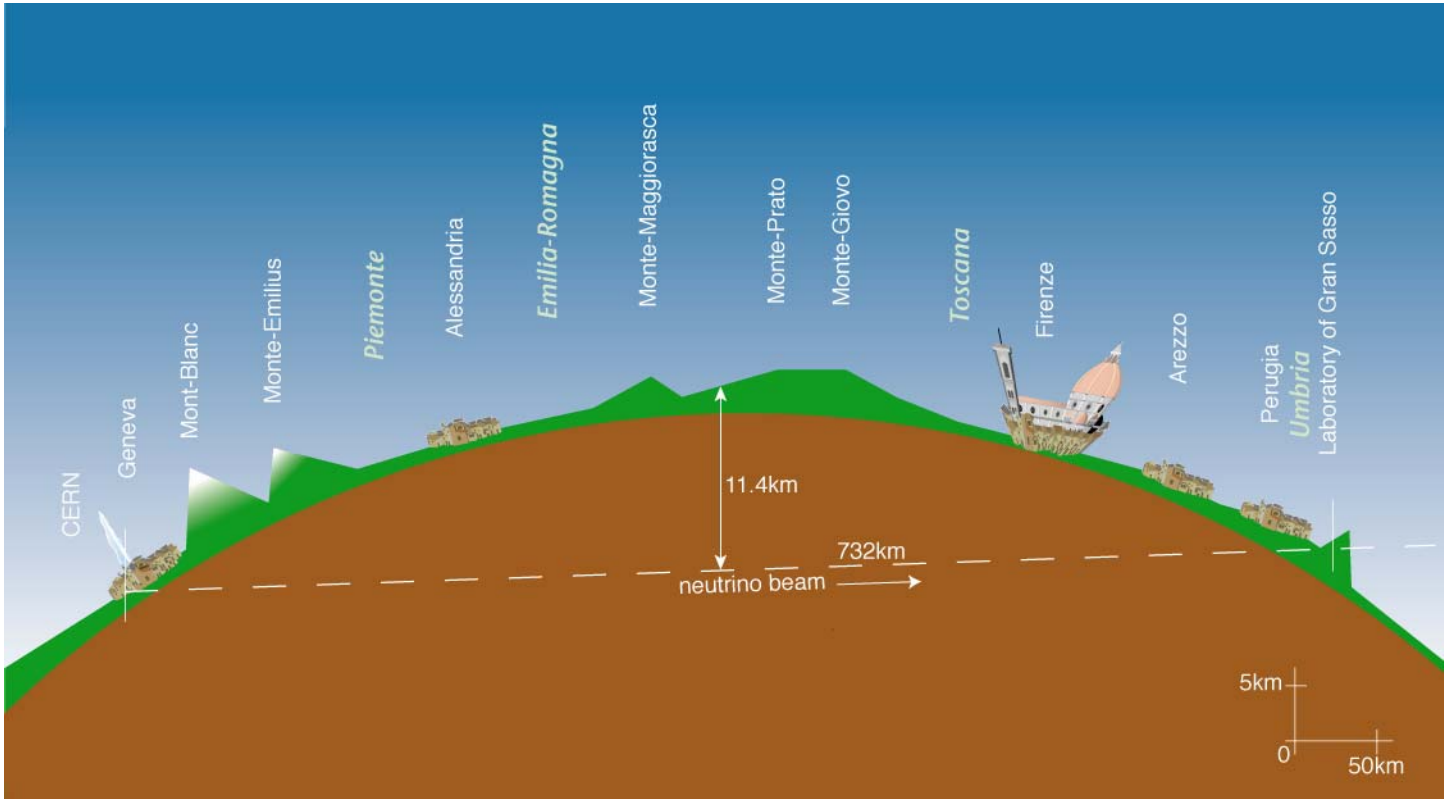
In Dec. 1999, CERN council approved the CNGS project:

- build an intense ν_μ beam at CERN-SPS
- search for ν_τ appearance at Gran Sasso laboratory (730 km from CERN)

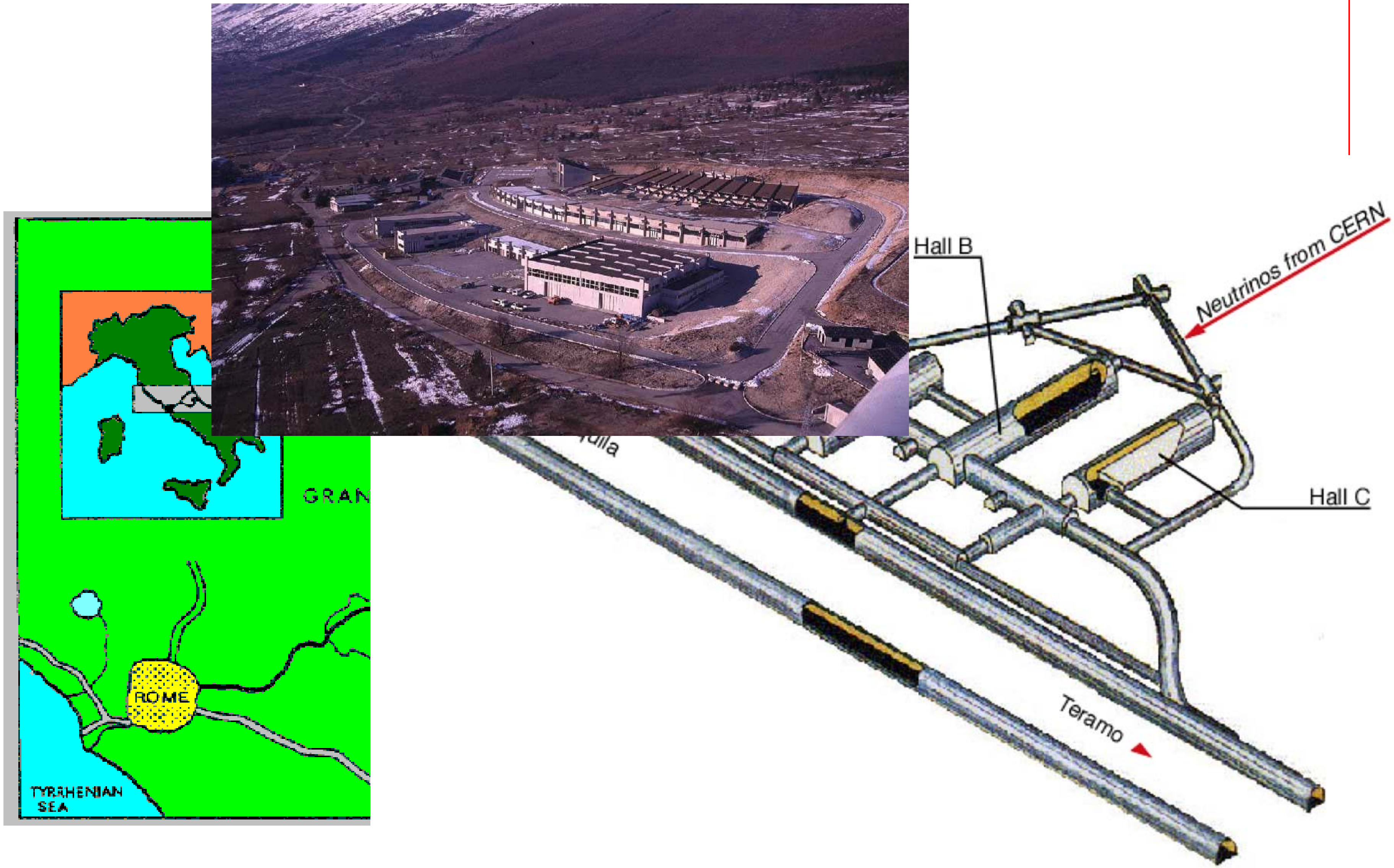
"long base-line" ν_μ -- ν_τ oscillation experiment

note: K2K (Japan) running; NuMI/MINOS (US) under construction

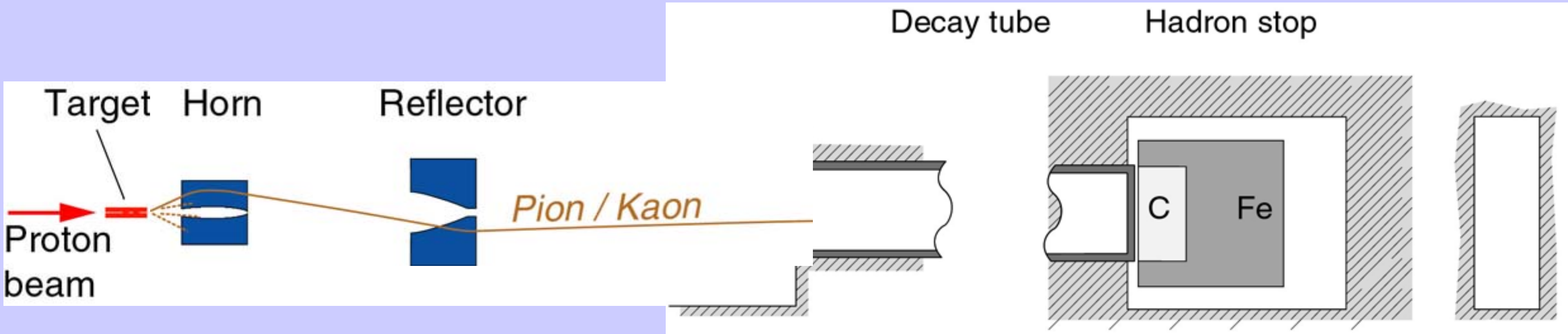
CERN to CNGS


CERN
Geneva
Mont-Blanc
Monte-Emilius
Piemonte
Alessandria
Emilia-Romagna
Monte-Maggiorasca
Monte-Prato
Monte-Giovo
Toscana
Firenze
Arezzo
Perugia
Umbria
Laboratory of Gran Sasso
11.4km
732km
neutrino beam
5km
0
50km

The Gran Sasso laboratory



The CERN part



$$p + C \rightarrow \text{(interactions)} \rightarrow \pi^+,\ K^+ \rightarrow \text{(decay in flight)} \rightarrow \mu^+ + \nu_\mu$$

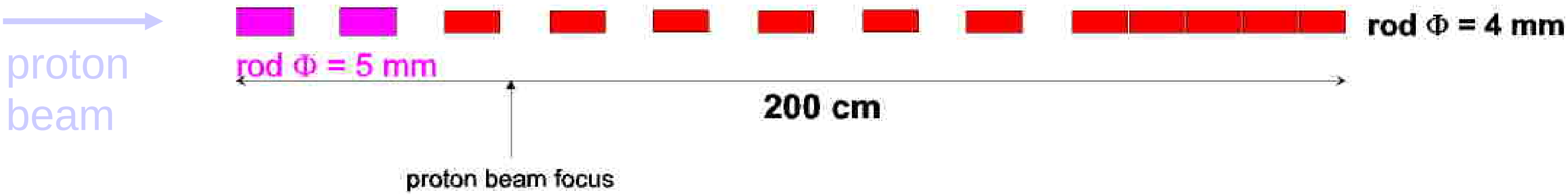
Polarity change foreseen!

…but the intensity will go down and the contamination goes up

CERN underground

CNGS target

-> 10 cm long graphite rods, Ø = 5mm and/or 4mm

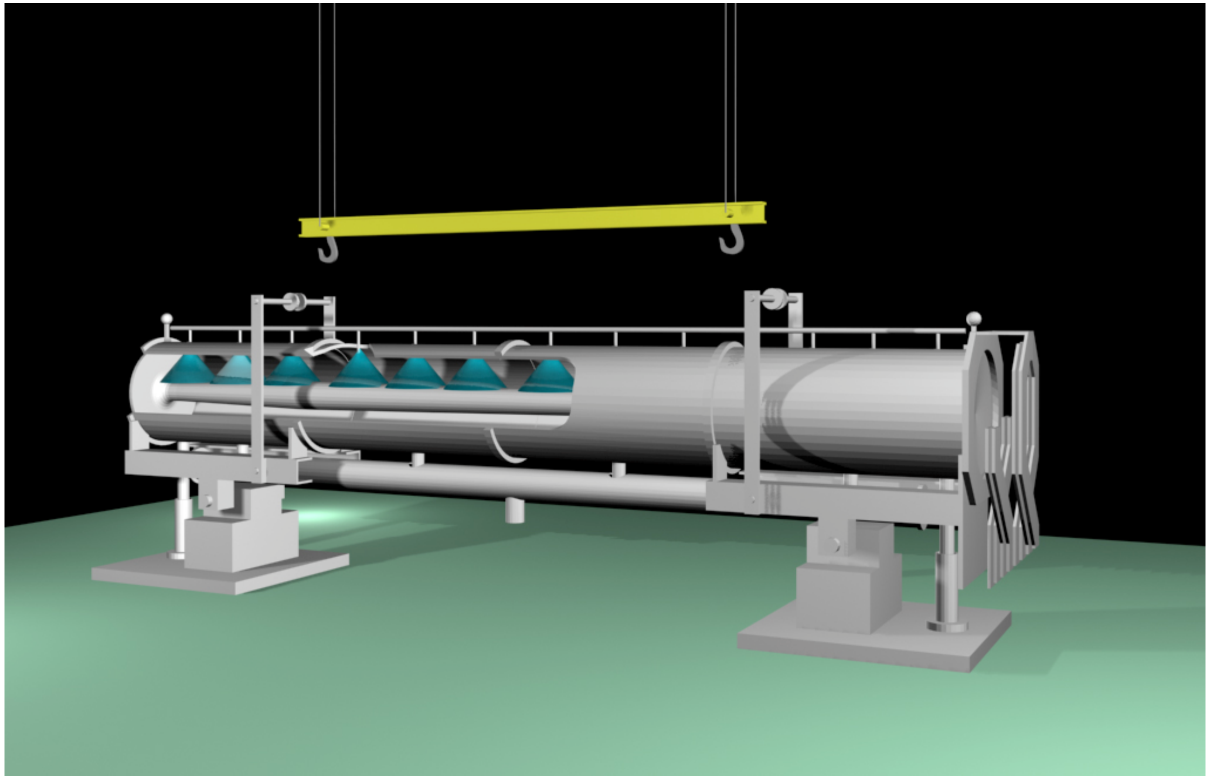


Note: - target rods interspaced to "let the pions out"

- target is helium cooled
(remove heat deposited by the particles)

CNGS focusing devices

"Magnetic Horn" (S. v.der Meer, CERN)



length: 6.5 m
diameter: 70 cm
weight: 1500 kg

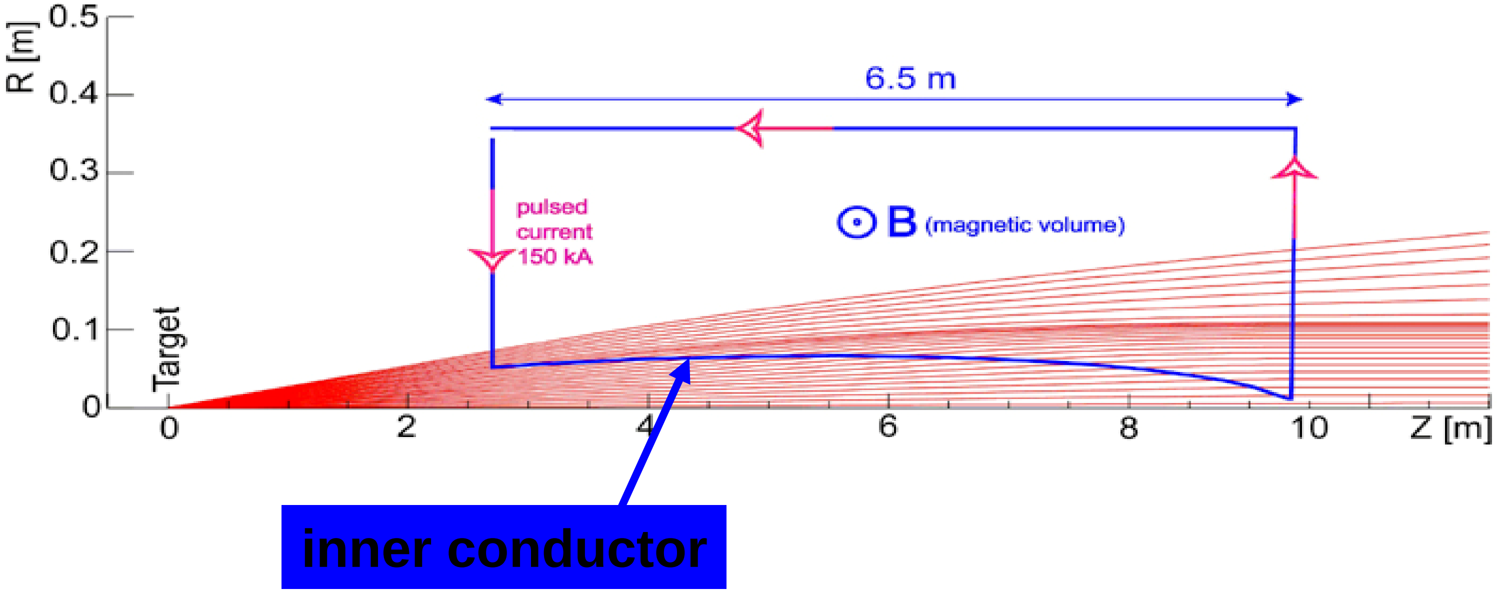
Pulsed devices:
150kA / 180 kA, 1 ms

water-cooled:
distributed nozzles

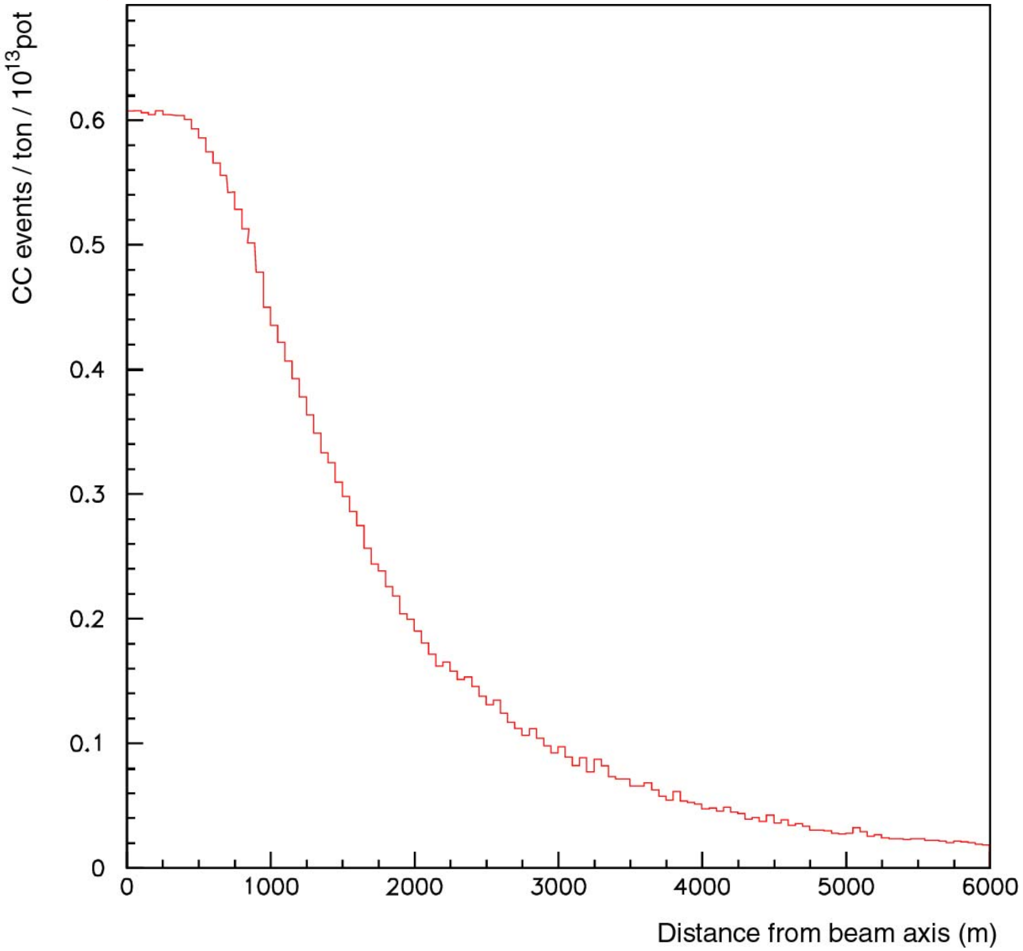
Principle of focusing with a Magnetic Horn

Magnetic volume given by "one turn" at high current:

- ♦ specially shaped inner conductor
- \- end plates
- ♦ cylindrical outer conductor



Radial distribution of the ν_μ- beam at Gran Sasso



Number of particles expected per year:

For <u>1 year of CNGS operation</u>, we expect:

(4.8x10^{13} protons in SPS, 55% efficiency -- 1997)

protons on target 4.5 x 10^{19}

pions / kaons at entrance to decay tunnel 5.8 x 10^{19}

muons in first / second muon pit 3.6 x 10^{18} / 1.1 x 10^{17}

ν_μ in 100 m^2 at Gran Sasso 3.5 x 10^{12}

Upgrade with a factor of 1.5 feasible but requires investment in CERN injector complex

Unwanted neutrino species

Relative to the main ν_μ component:

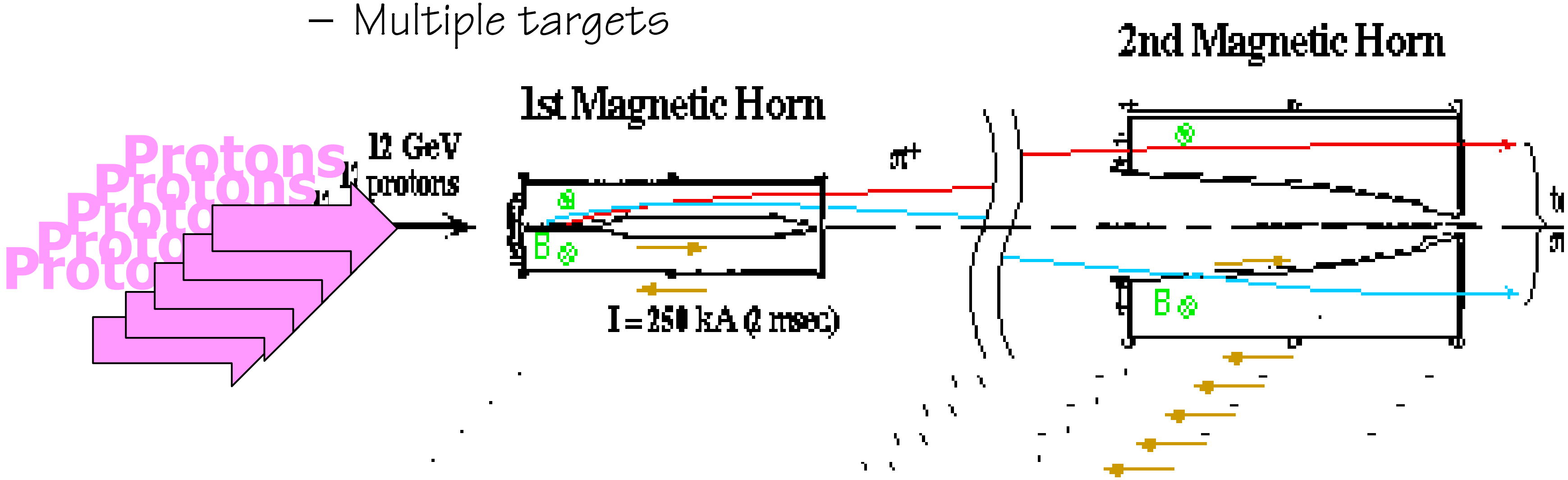
ν_e / ν_μ= 0.8 %

anti-ν_μ / ν_μ= 2.1 %

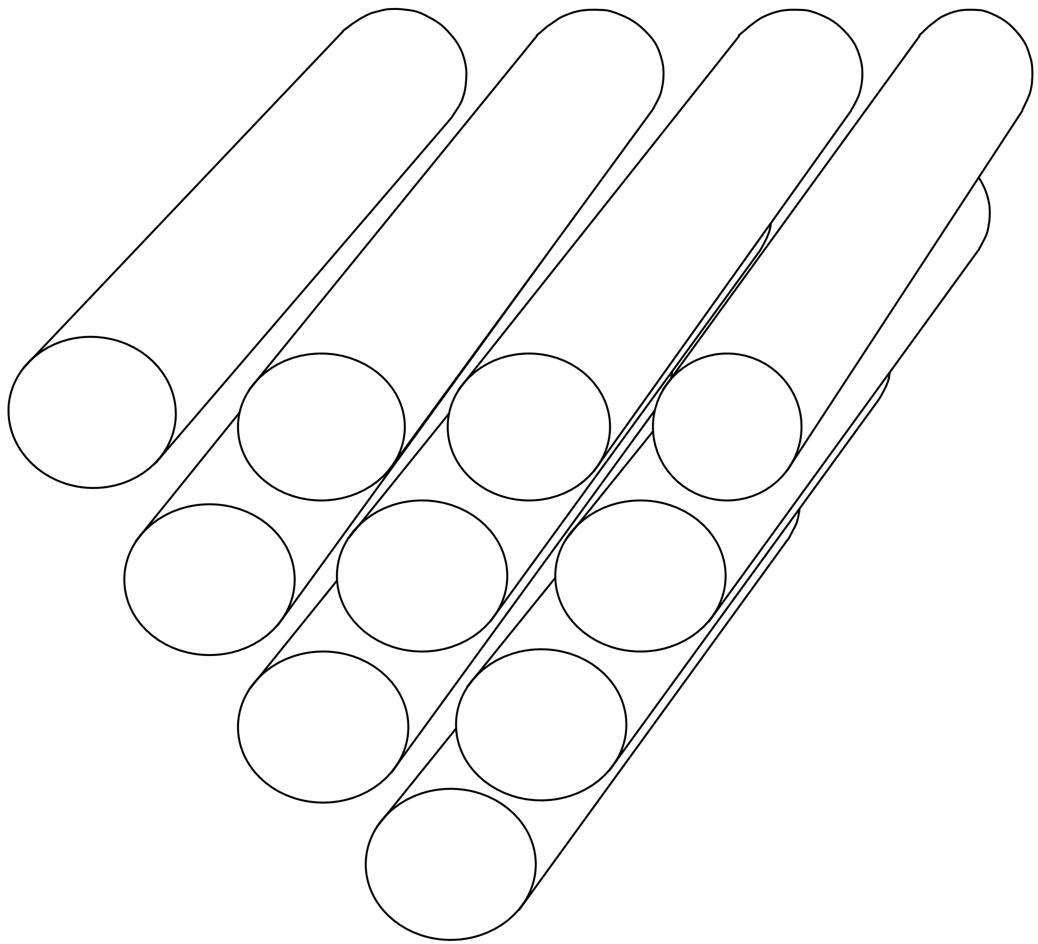
anti-ν_e / ν_μ = 0.07 %

What is the Super Neutrino Beam?

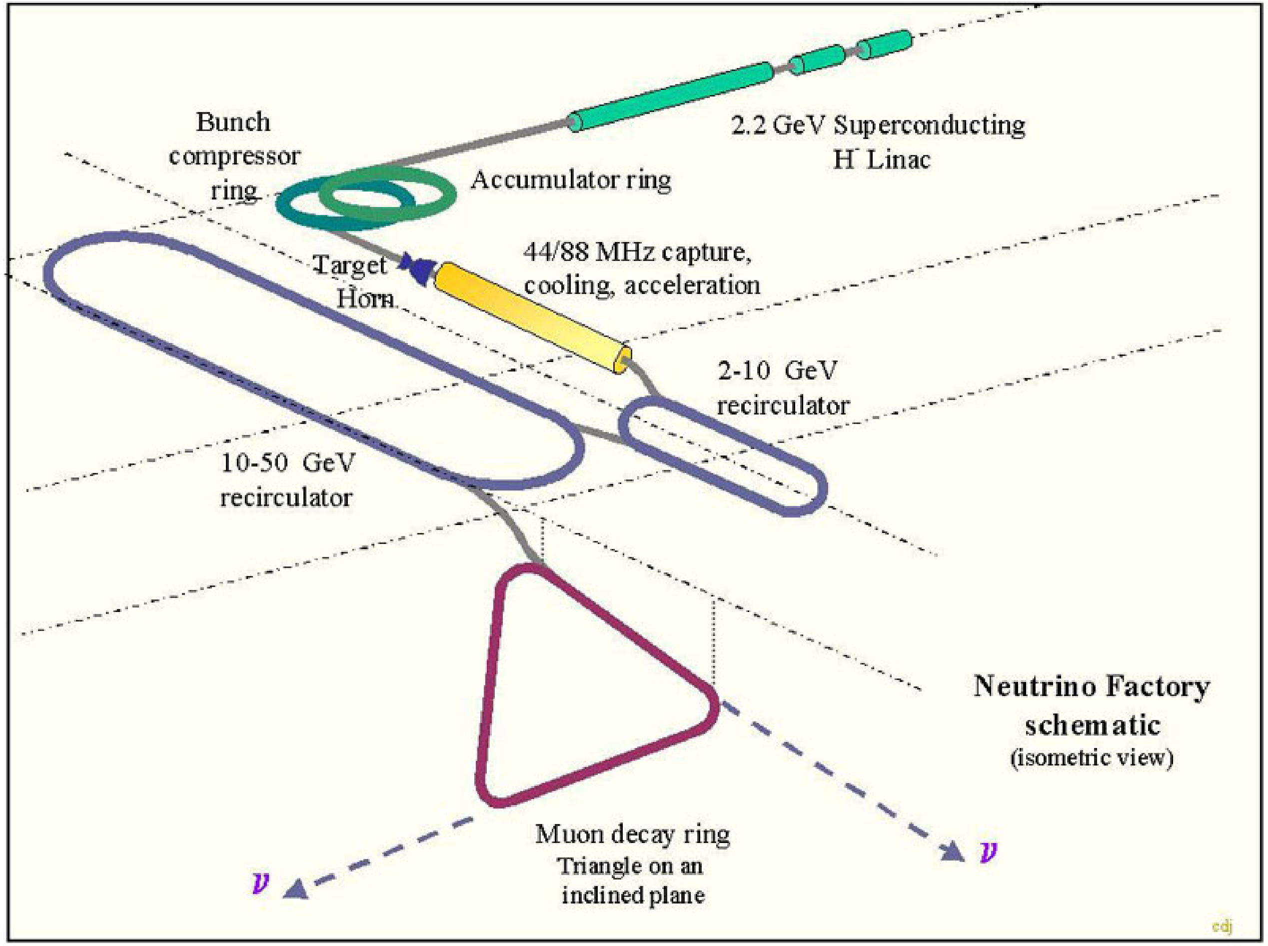
– No Clear definition, but it is a very intense neutrino beam produced by a high power (>1MW) accelerator.
  - A conventional method.
  - Still technically challenging due to the high power and the high radiation environment, but not impossible.
    – Multiple targets



Target stack?

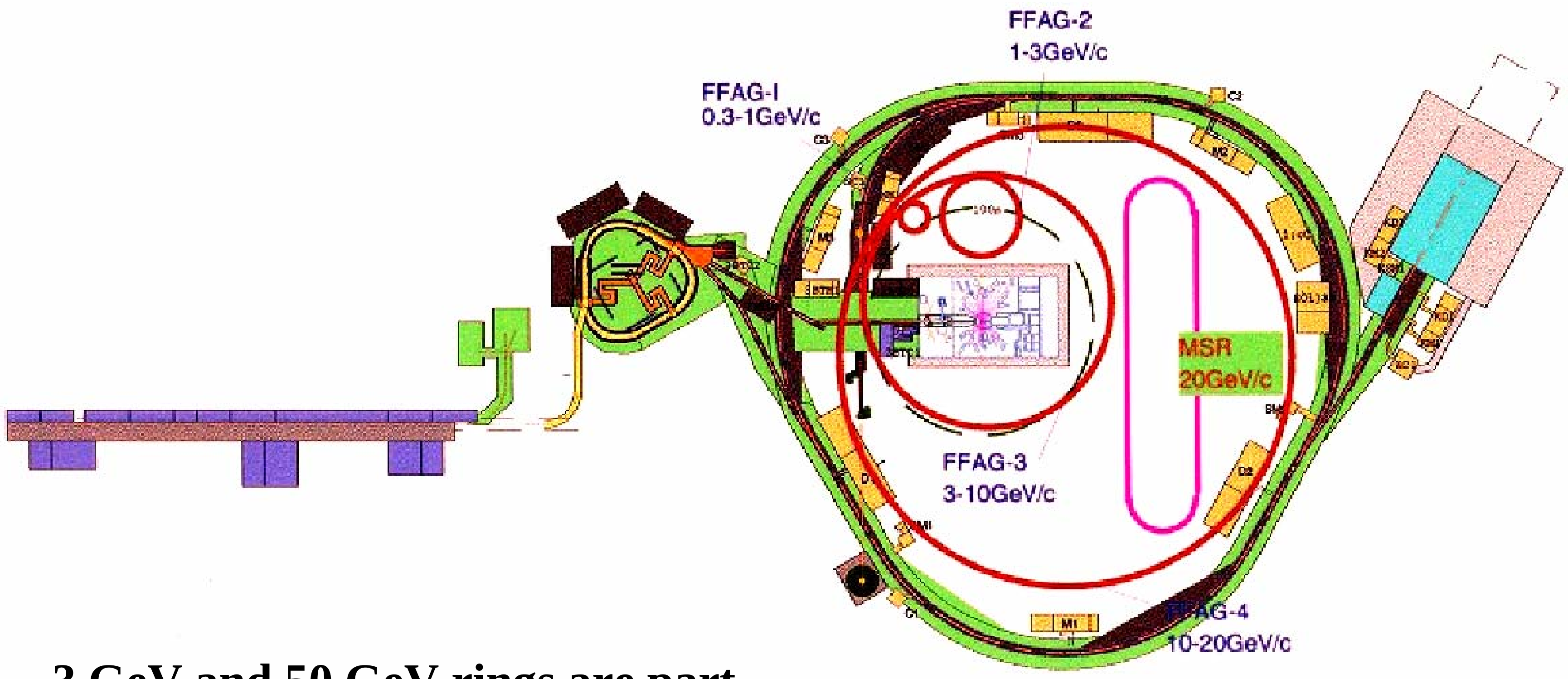


Neutrino factory CERN



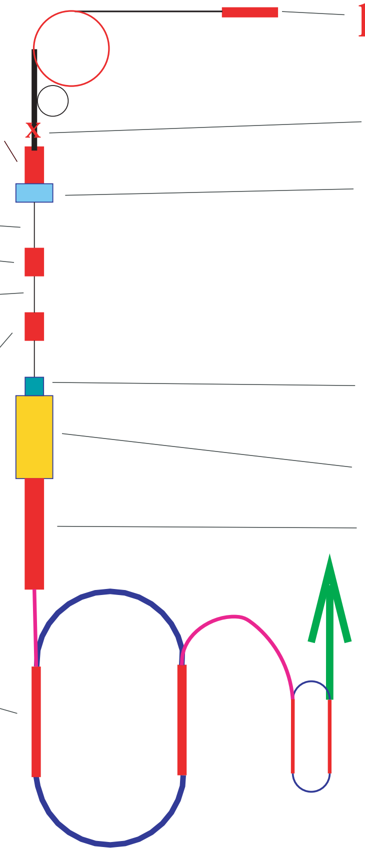
- Superconducting proton linac as driver
- Proton bunch train not longer than decay ring
- Bunch to bucket philosophy
- Longitudinal cooling using bunch rotation
- Transversal cooling using ionization cooling
- Recirculating linear accelerators
- Decay ring

Neutrino factory Japan



3 GeV and 50 GeV rings are part of JAERI-KEK Joint Project

American Study II



Targetry

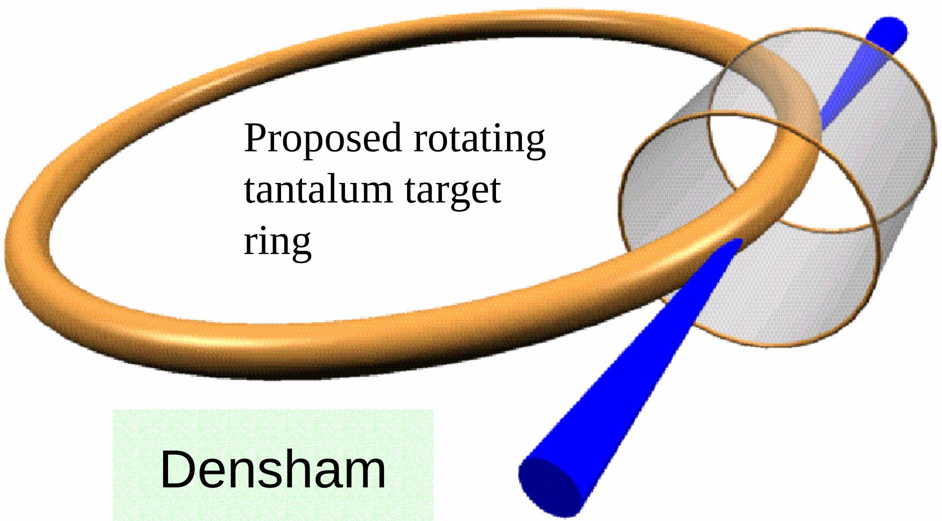
Many difficulties: enormous power density

⇒ lifetime problems

pion capture

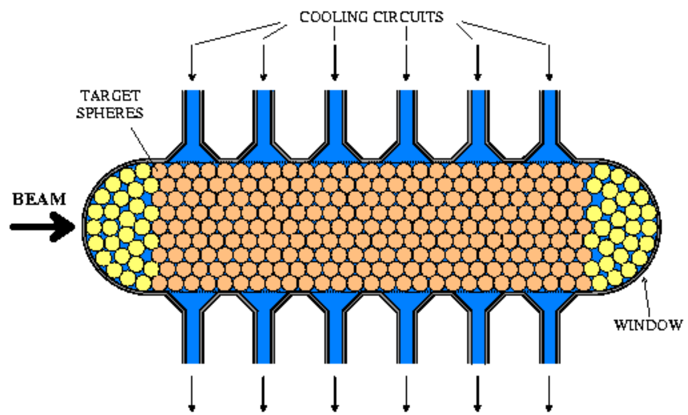
Replace target between bunches:

Liquid mercury jet or rotating solid target

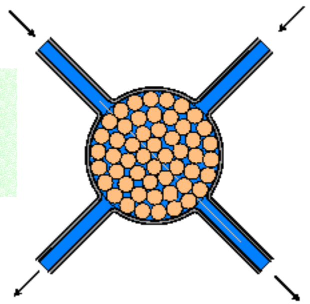


Densham

Stationary target:

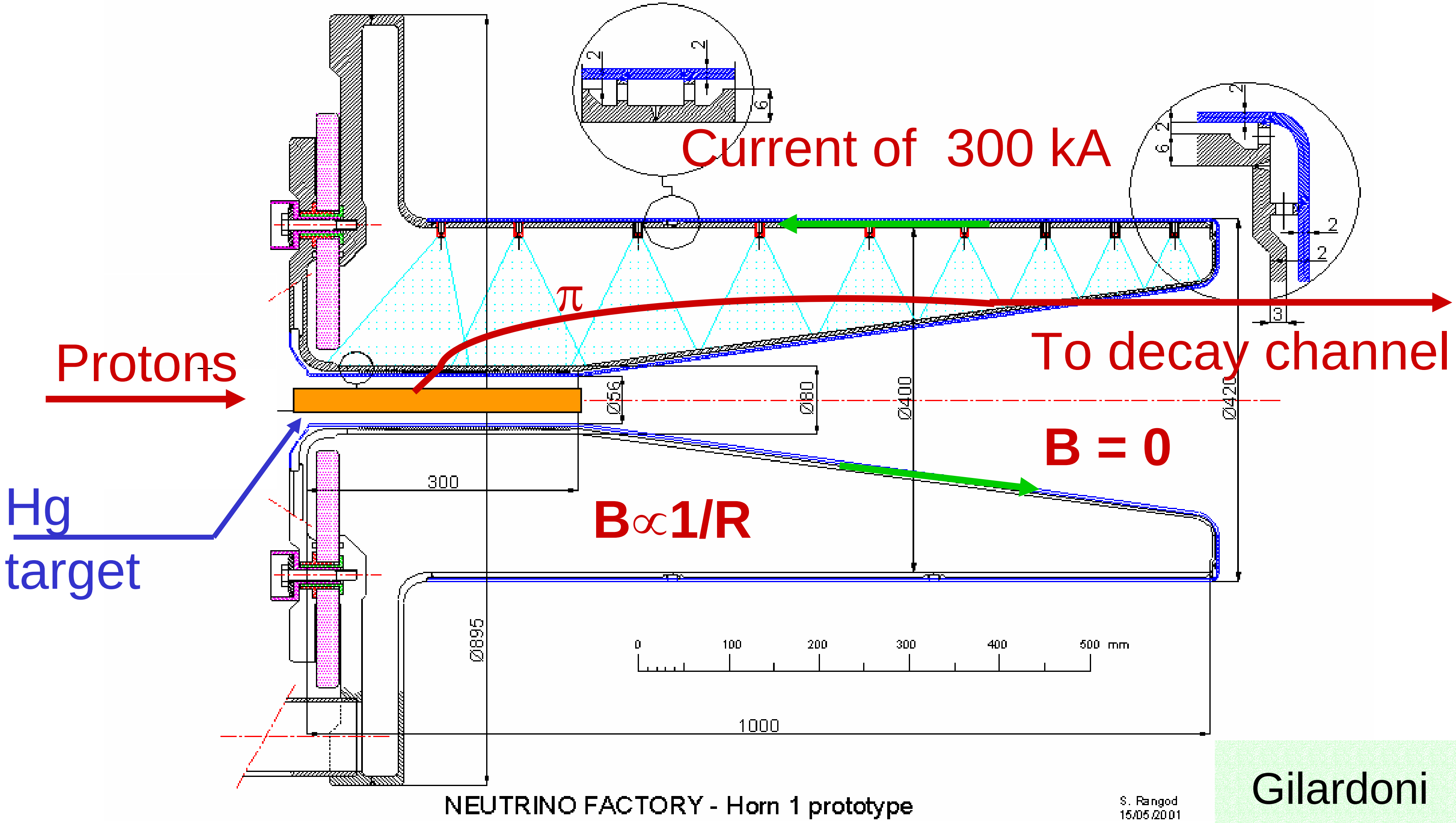


Sievers



eting

Target and pion capture
liquid jet+Horn



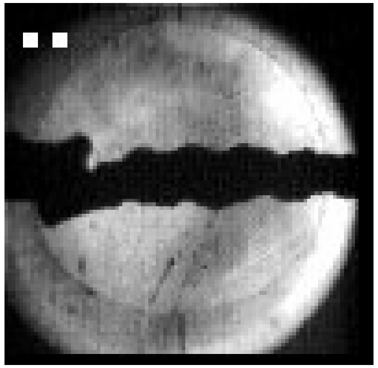
Gilardoni

ECT* meeting

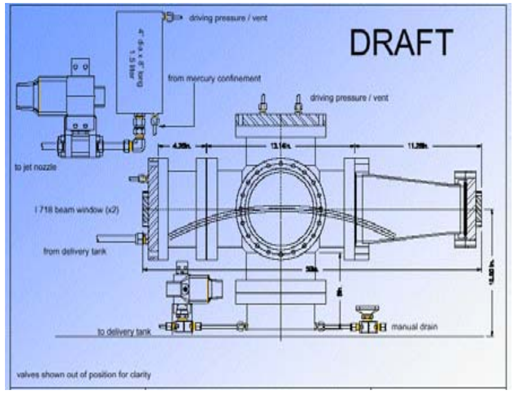
Jet test at BNL

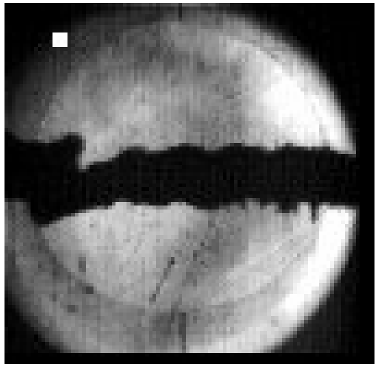
Event #11   25th April 2001

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

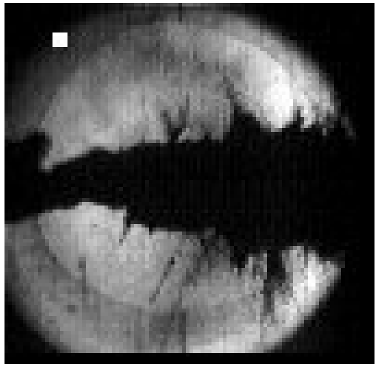


Protons



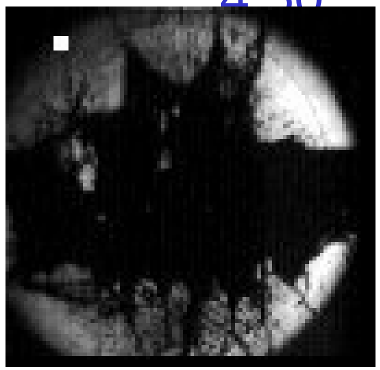


Picture timing
[ms]
0.00
0.75
4.50

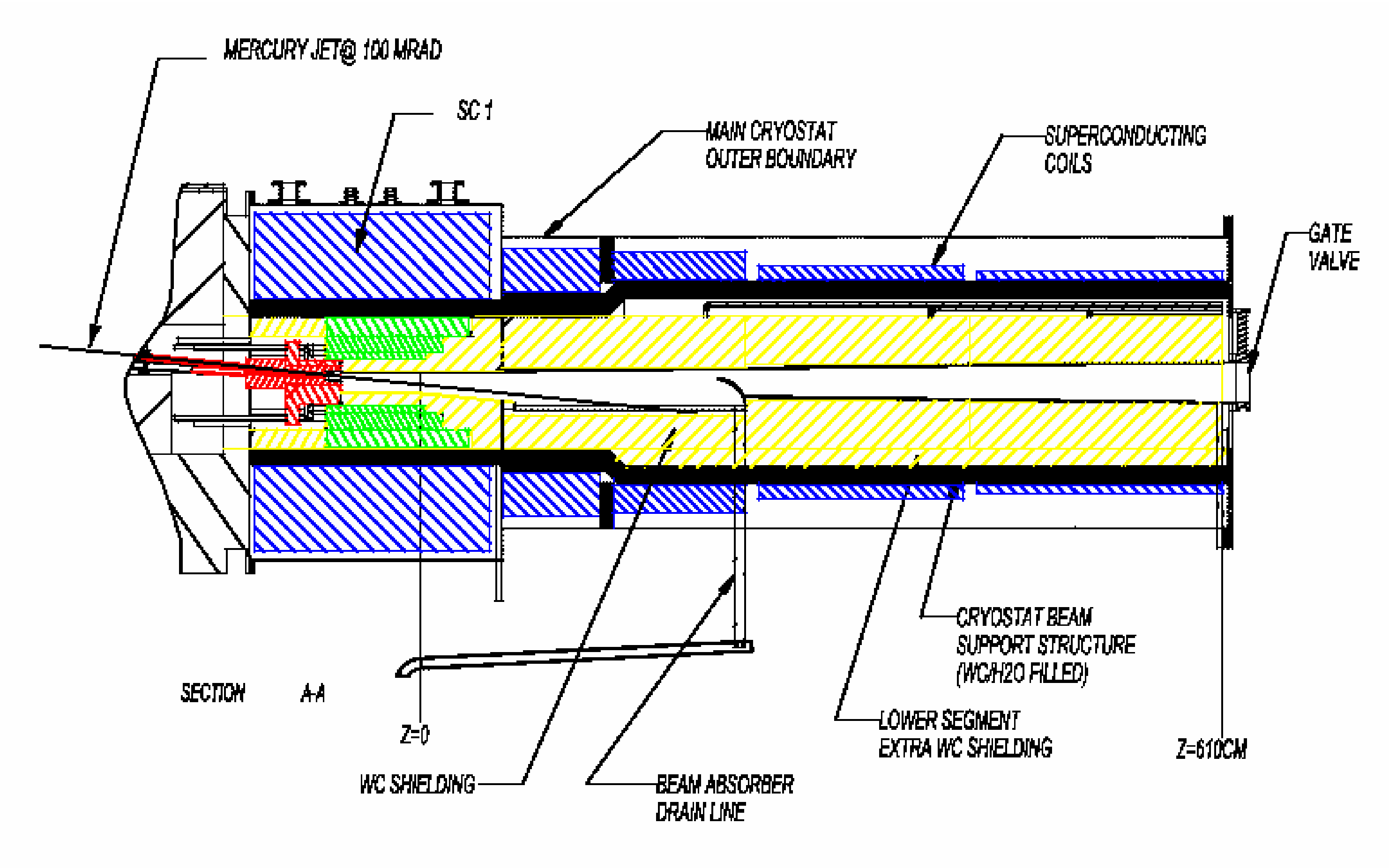


P-bunch: 2.7×10^{12} ppb
100 ns
t_o = ~ 0.45 ms

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



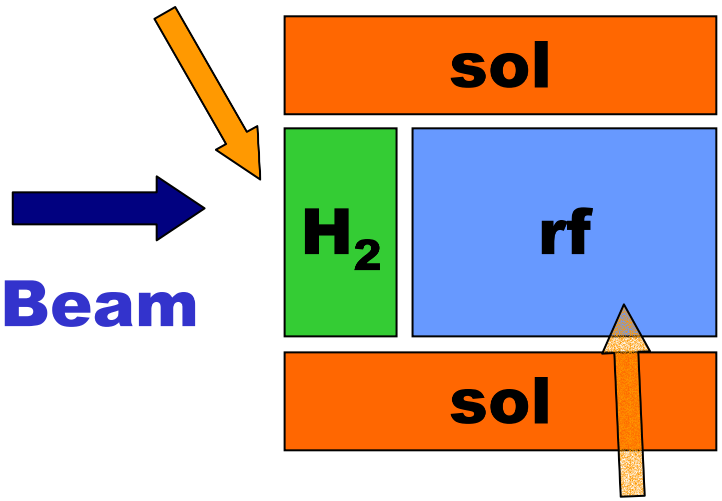
Pion Capture: Solenoid



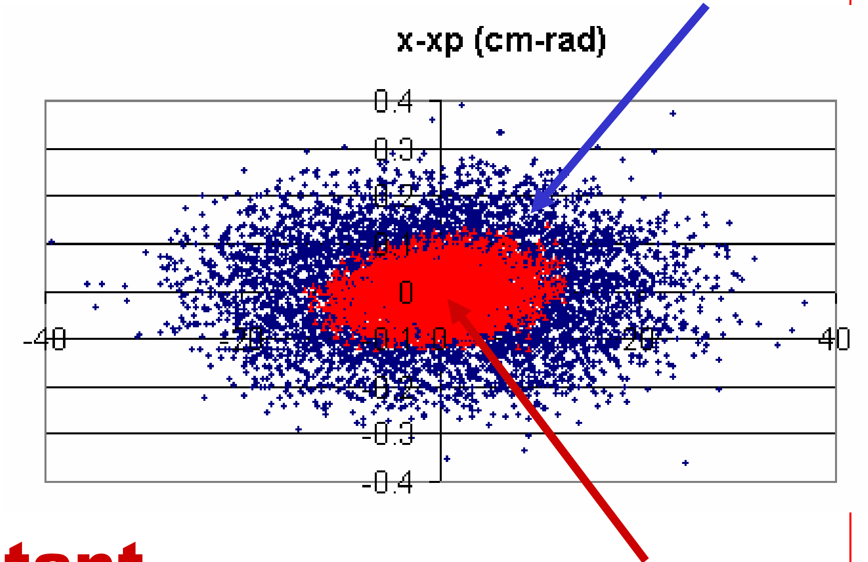
20T → **1.25T**

Ionization cooling

Liquid H_2: dE/dx



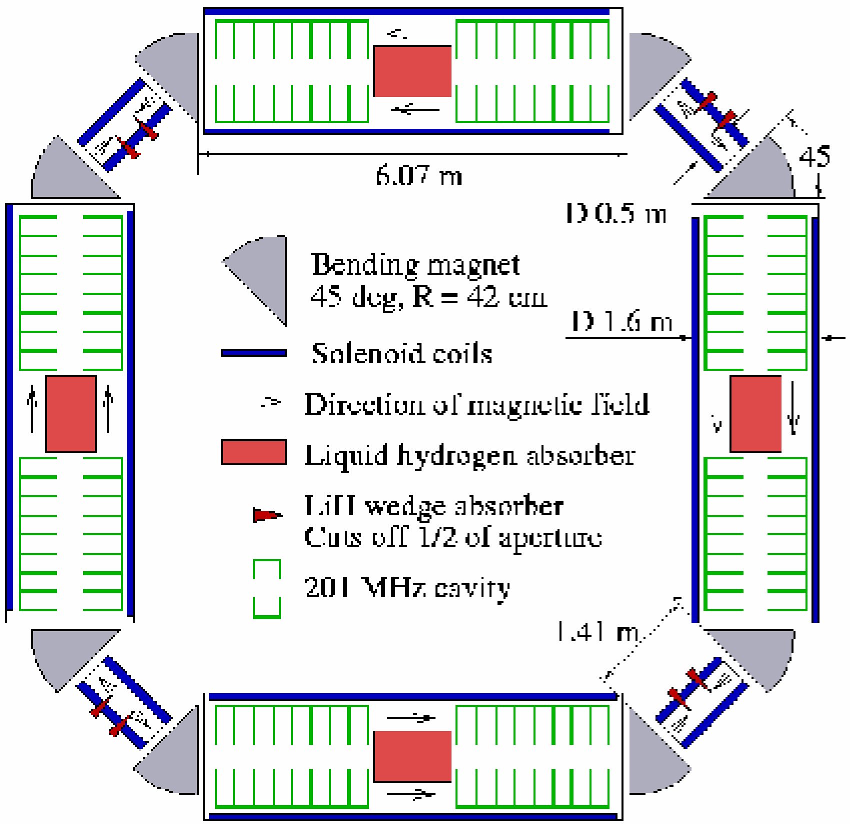
IN



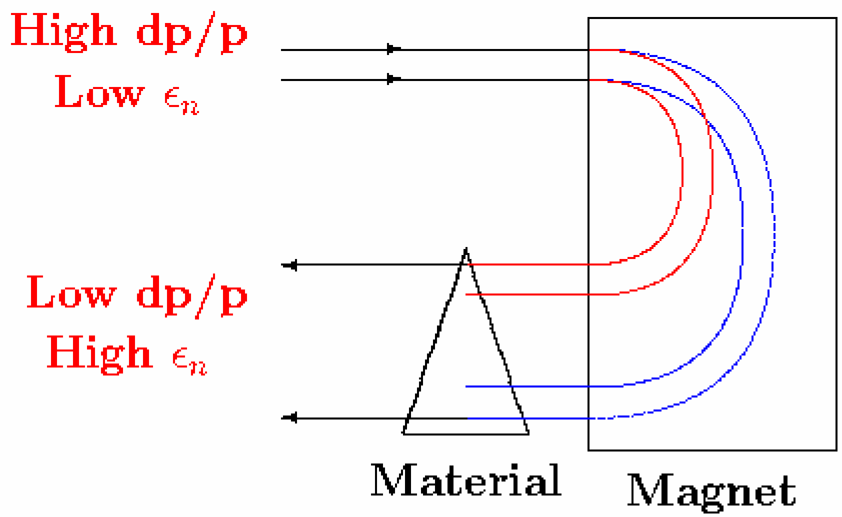
OUT

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

Cooling - rings



Main advantages:
shorter
longitudinal cooling



Balbekov

Palmer

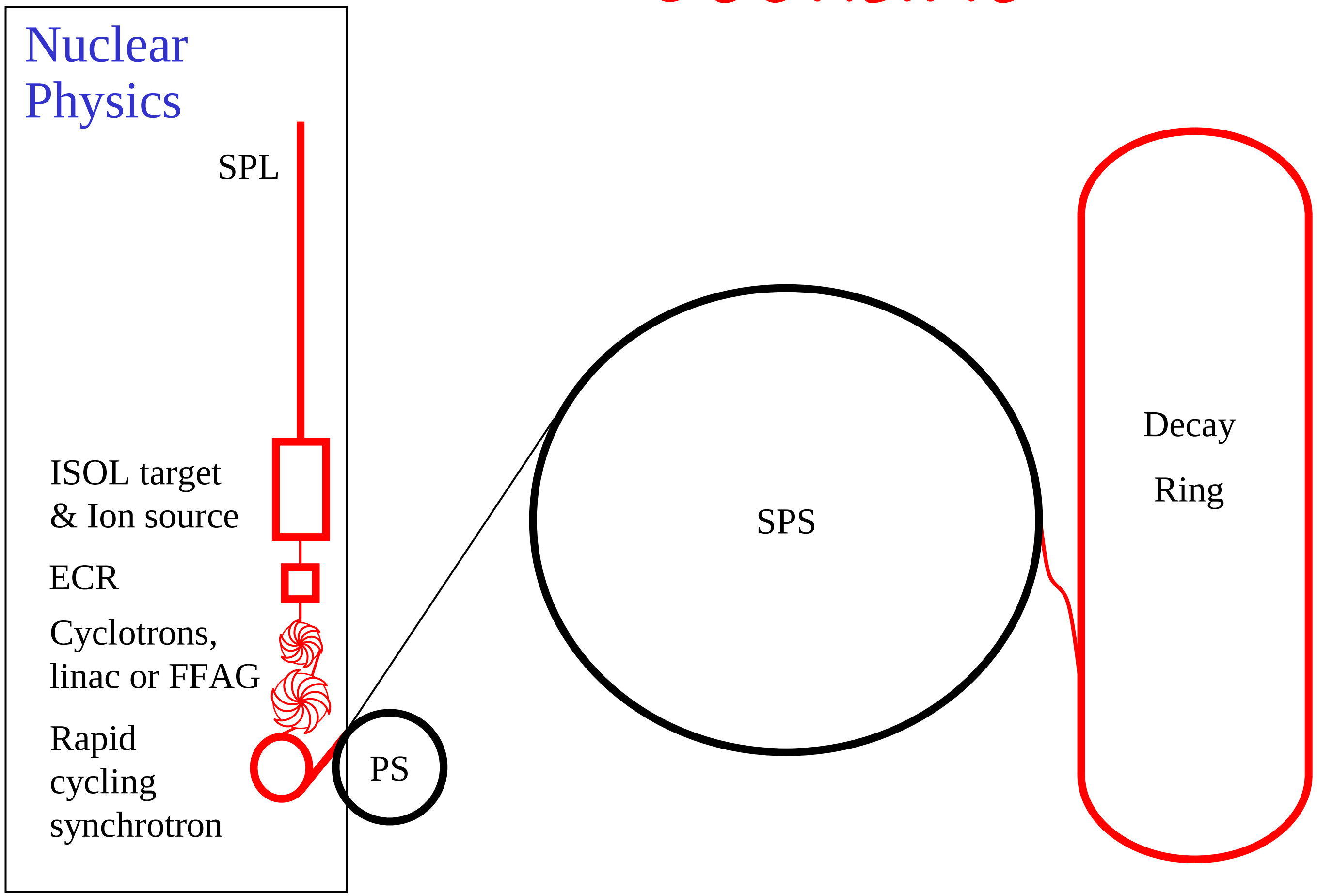
Comparison of General Layout

System	CERN	FNAL (Study I)	BNL (Study II)	Japanese
System rep rate	50 Hz		2.5/5 Hz	
Proton driver type	Linac (SPL)	Synchrotron	Synchrotron (AGS)	Synchrotron
p driver energy	2.2 GeV	16 GeV	24 GeV	50 GeV
Target material	Hg	C	C	
Collection	Horn	Solenoid	Solenoid	
Beam structure	Bunch-to-bucket	Re-bunching	Re-bunching	
Phase rotation	rf	2 induction linacs	3 induction linacs	FFAG
Cooling channel	88 MHz	200 MHz	200 MHz	No cooling
Acceleration	2 RLAs (20/50 GeV)	2 RLAs (20/50 GeV)	1 RLA (20 GeV)	4 FFAGs (1/3/ 10/20-50 GeV)

The beta-beam

- Synergies between several physics communities
  - Neutrino physics
  - Nuclear structure
    - EURISOL
    - Low energy neutrinos (C. Volpe)
  - Astrophysics
- A baseline scenario that could be built today:
  - Use known technology (or reasonable extrapolations of known technology)
  - Use innovations to increase the performance
  - Re-use a maximum of the existing accelerators

CERN: β-beam baseline scenario



Decay ring

Brho = 1500 Tm

B = 5 T

L_{ss} = 2500 m

$^{6}_{2}He \rightarrow ^{6}_{3}Li\, e^{-} \bar{\nu}$

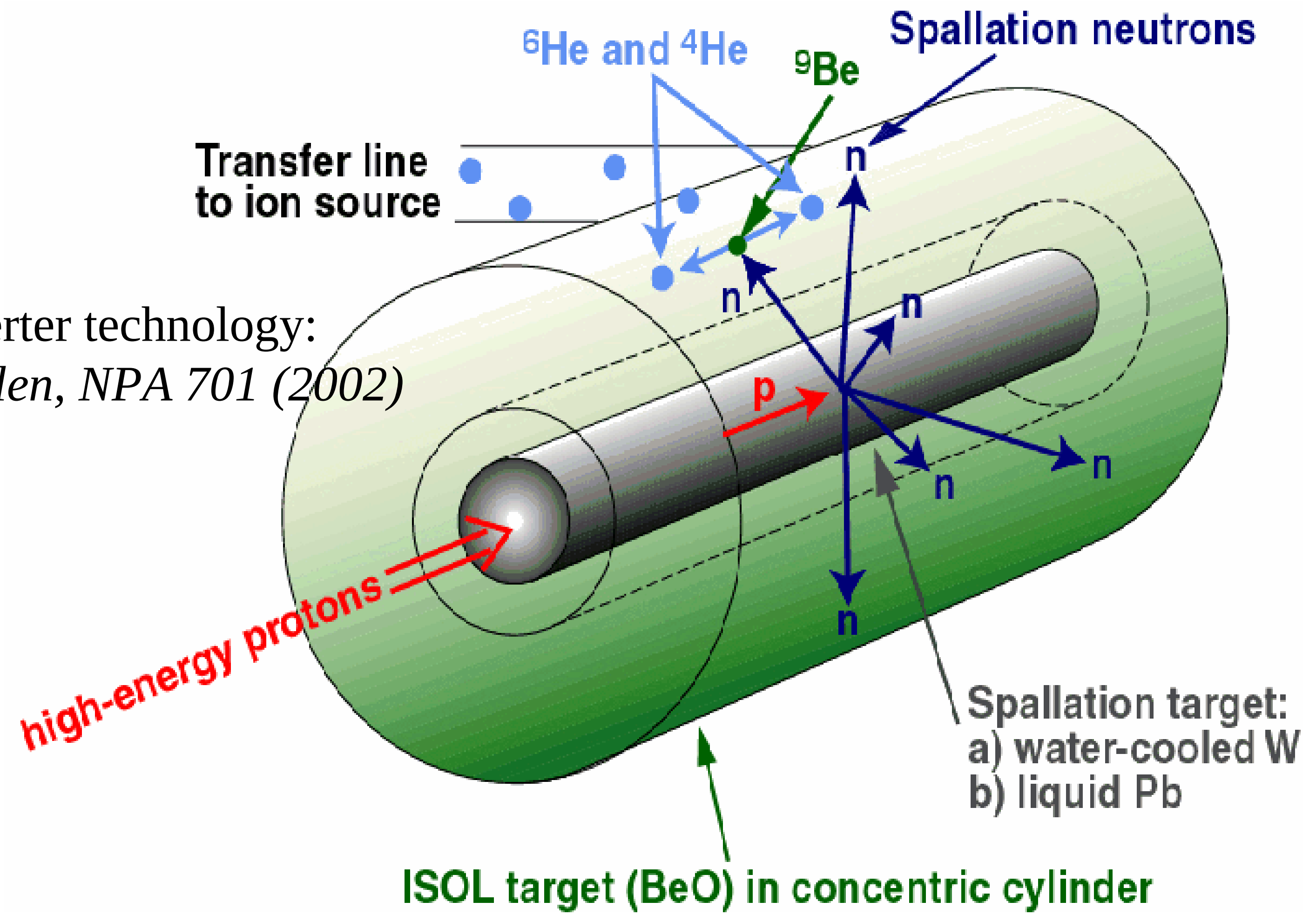
Average E_{cms} = 1.937 MeV

$^{18}_{10}Ne \rightarrow ^{18}_{9}Fe\, e^{+} \nu$

Average E_{cms} = 1.86 MeV

^{6}He production by ^{9}Be(n,a)

Converter technology:
(J. Nolen, NPA 701 (2002) 312c)



Layout very similar to planned EURISOL converter target aiming for 10^{15} fissions per s.

Production of β⁺ emitters

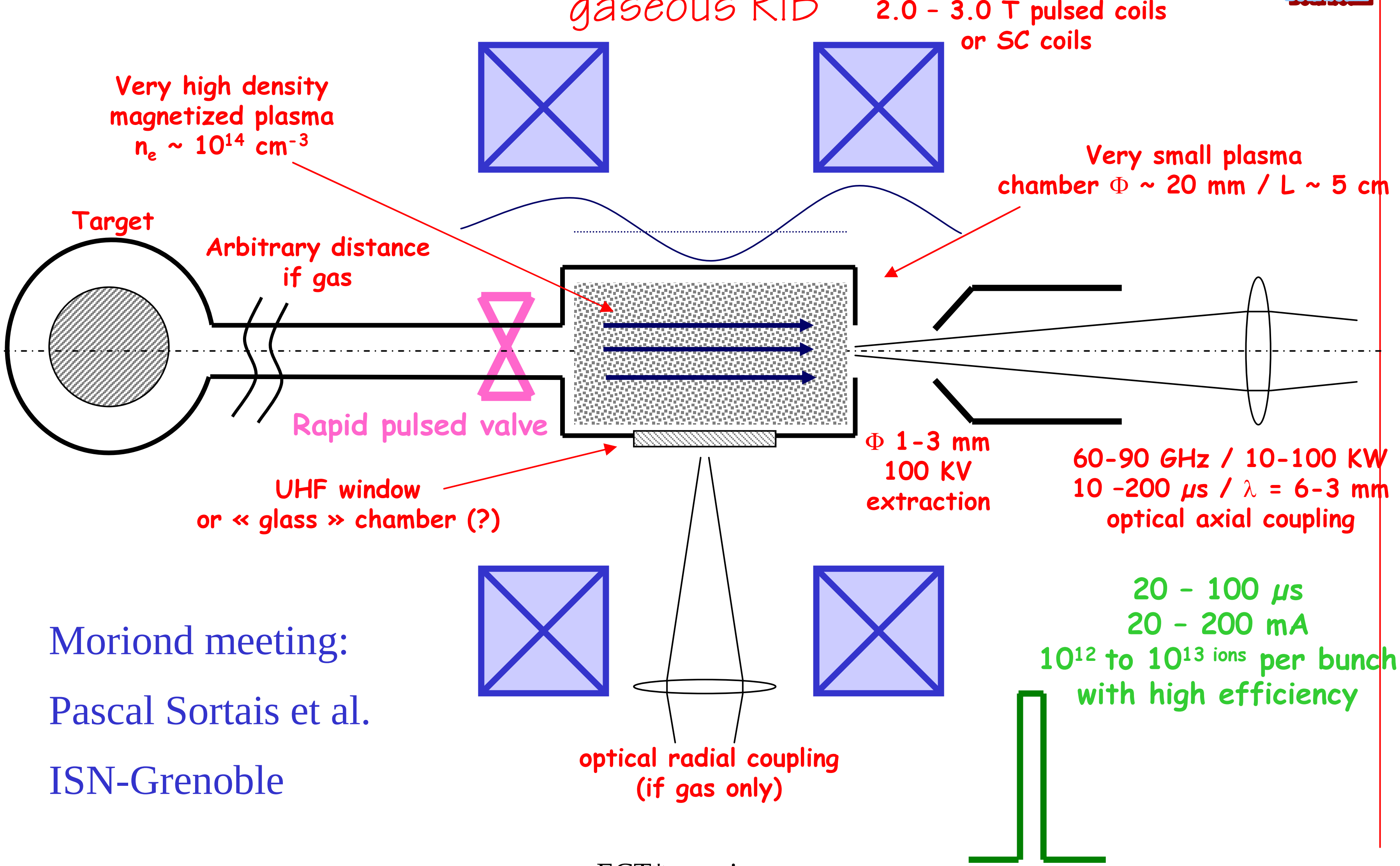
Scenario 1

- **Spallation of close-by target nuclides:**
  $^{18,19}Ne$ from MgO and $^{34,35}Ar$ in CaO
  - **Production rate for ^{18}Ne is $1x10^{12}$ s^{-1} (with 2.2 GeV 100 μA proton beam, cross-sections of some mb and a 1 m long oxide target of 10% theoretical density)**
  - **^{19}Ne can be produced with one order of magnitude higher intensity but the half life is 17 seconds!**

Scenario 2

- **alternatively use (α,n) and (^{3}He,n) reactions:**
  $^{12}C(^{3,4}He,n)^{14,15}O$, $^{16}O(^{3,4}He,n)^{18,19}Ne$, $^{32}S(^{3,4}He,n)^{34,35}Ar$
  - **Intense $^{3,4}He$ beams of 10-100 mA 50 MeV are required**

60-90 GHz « ECR Duoplasmatron » for gaseous RIB

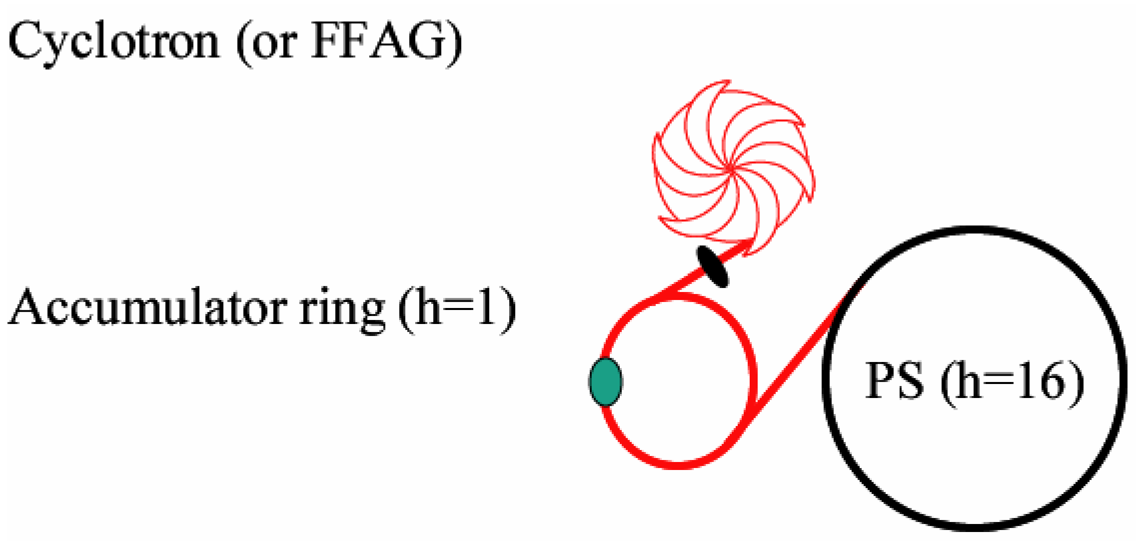


Moriond meeting:

Pascal Sortais et al.

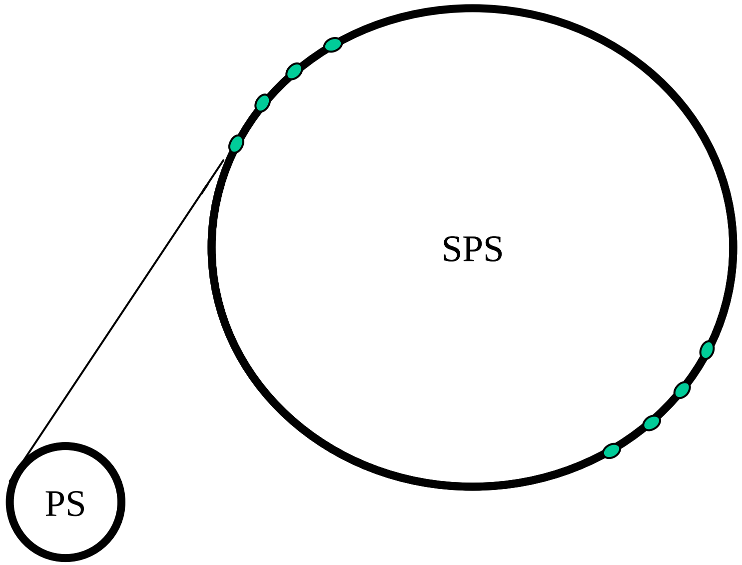
ISN-Grenoble

Overview: Accumulation



- Sequential filling of 16 buckets in the PS from the storage ring

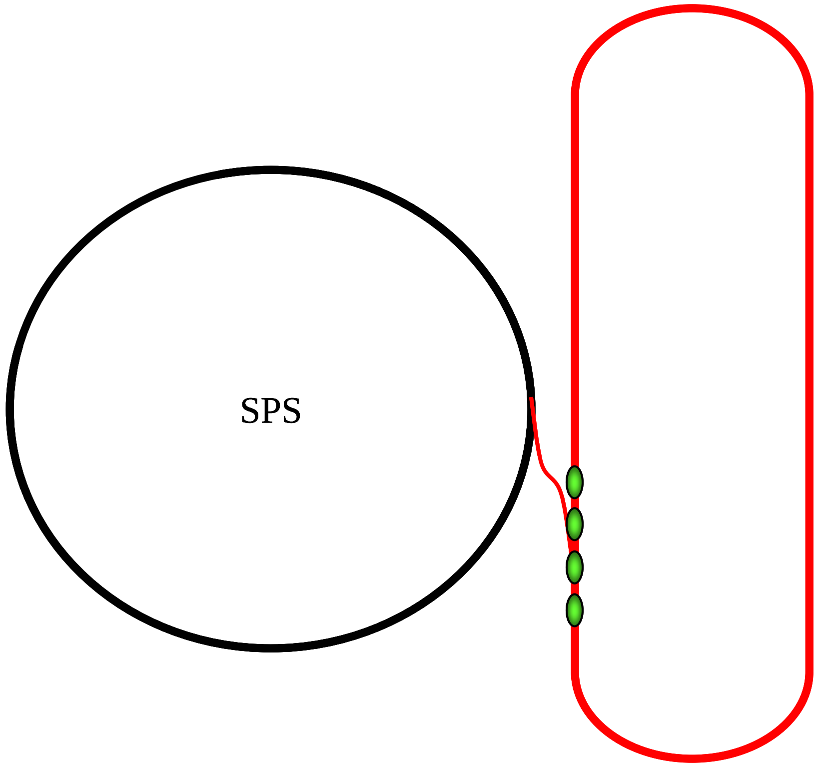
Overview: PS to SPS



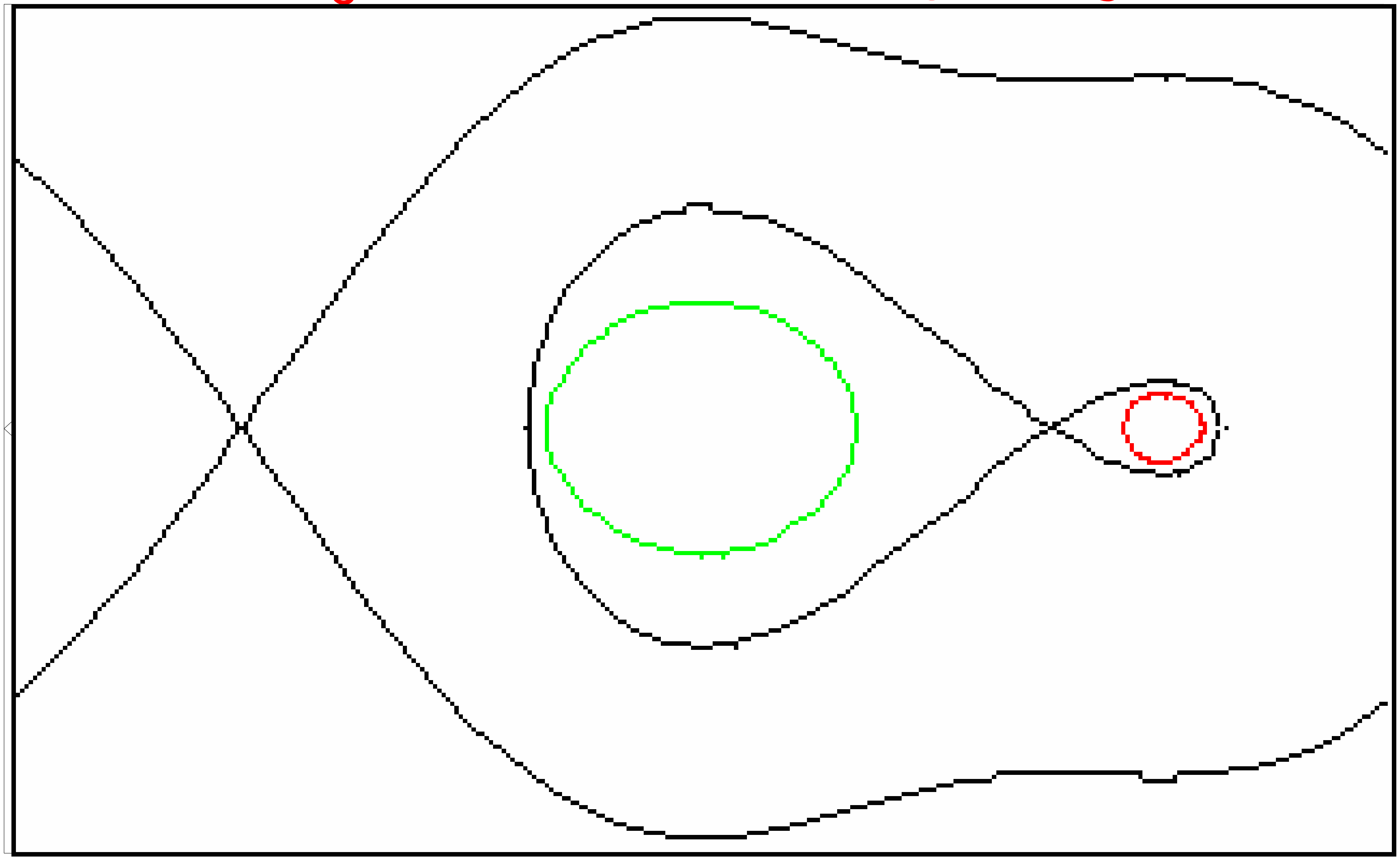
- Merging in PS to 8 buckets
- Blow-up before transfer to manage space charge limit in SPS

Overview: Decay ring

- Ejection to matched dispersion trajectory
- Asymmetric bunch merging

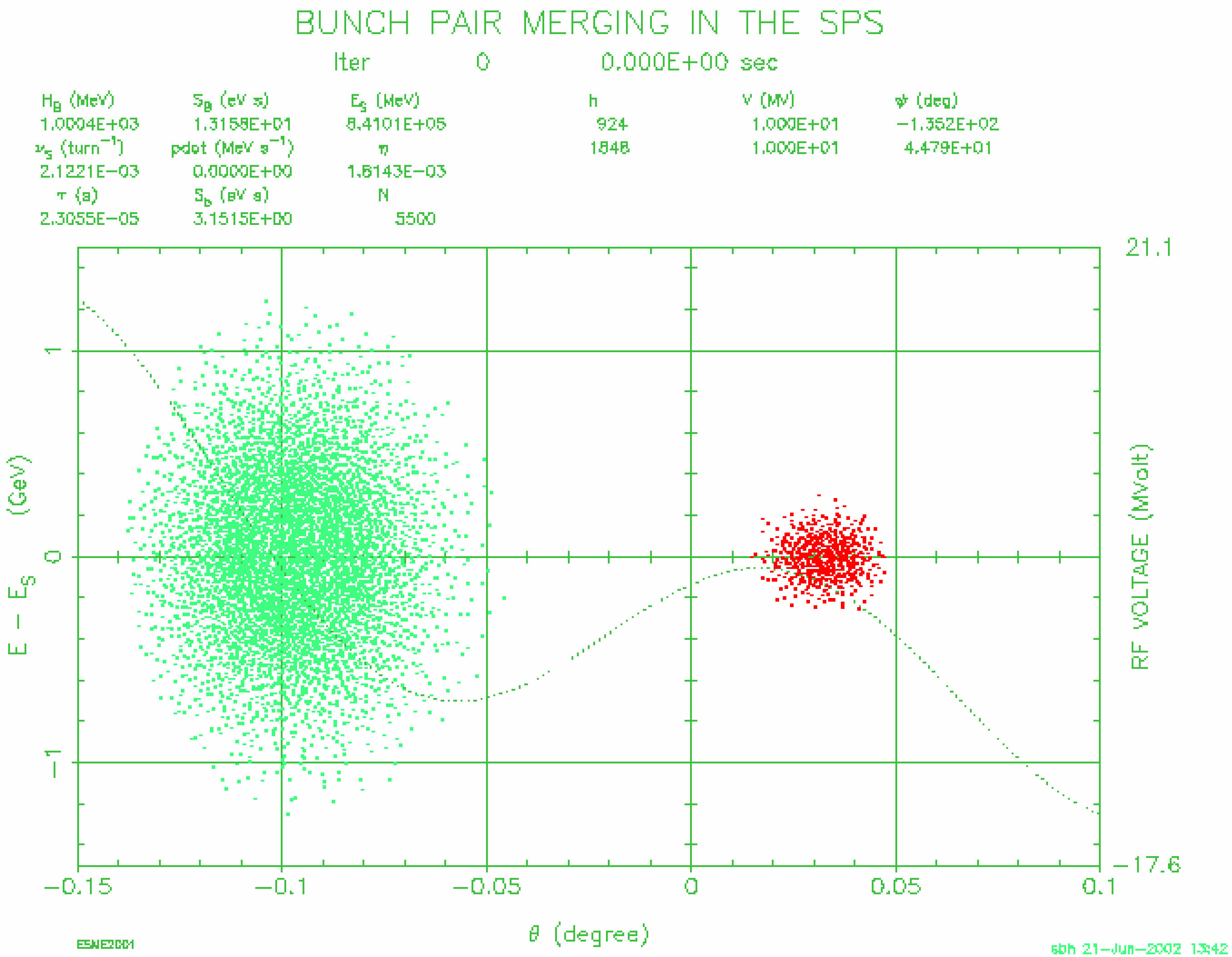


Injection to decay ring



M. Benedikt

Asymmetric bunch merging



ECT* meeting

S. Hancock

Decay losses

- Acceleration losses:

	^{6}He ($T_{1/2}$=0.8 s)	^{18}Ne ($T_{1/2}$=1.67 s)
Accumulation	<47 mW/m	<2.9 mW/m
PS	1.2 W/m	90 mW/m
SPS	0.41 W/m	32 mW/m
Decay ring	8.9 W/m	0.6 W/m

A. Jansson

Intensities:

- ^{6}He:
  - Decay ring: 2.0×10^{14} ions in four 10 ns long bunch
- ^{18}Ne (single target)
  - Decay ring: 9.1×10^{12} ions in four 10 ns long bunch
  - Only β-decay losses accounted for, efficiency <50%

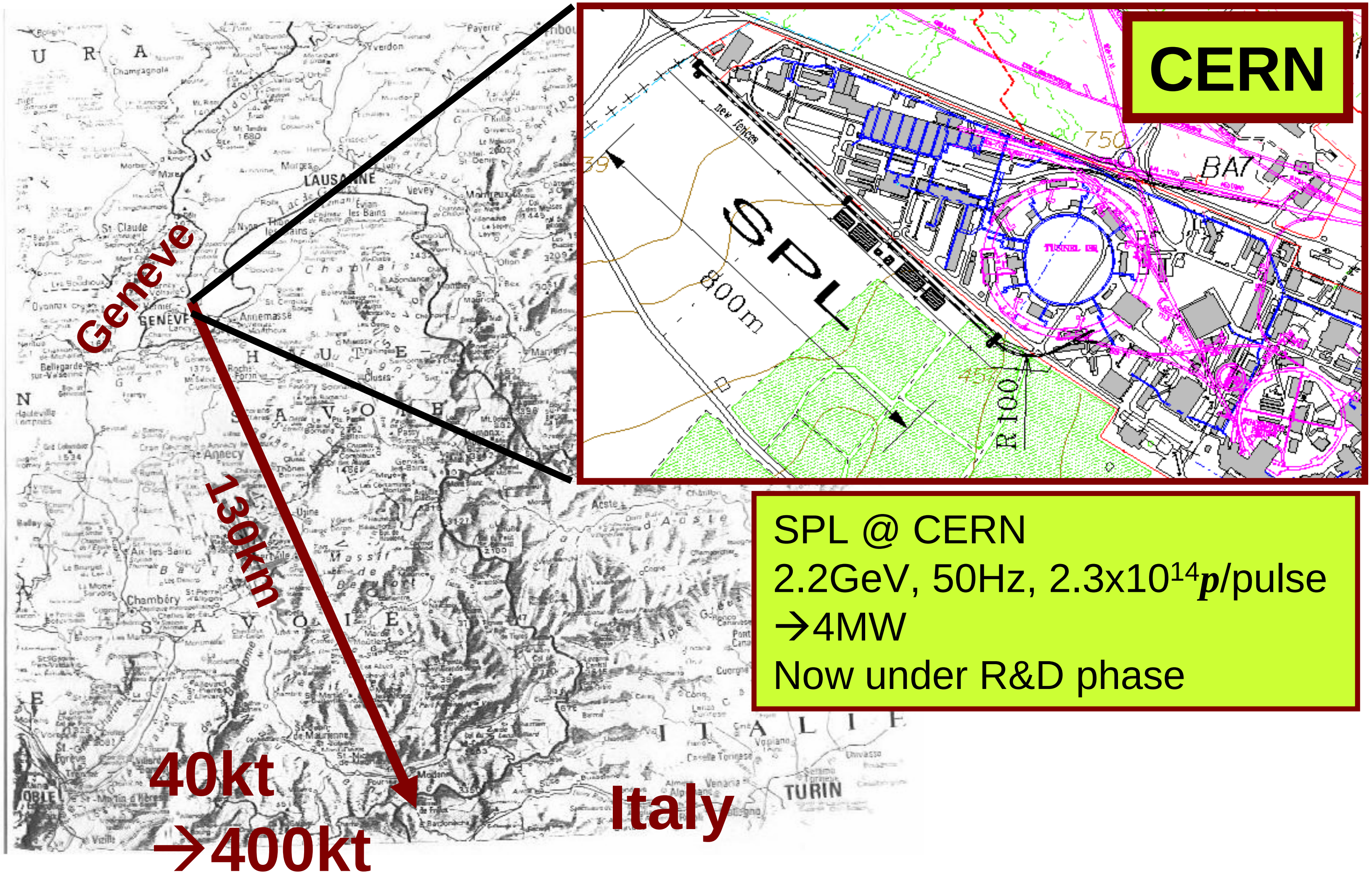
Moriond meeting

- Annual electro week meeting in Les Arcs
- Workshop on Radioactive beams for Nuclear and Neutrino Physics
  - Organizer: Jacques Bouchez, CEA, Saclay
- Many new ideas, among them:
  - Multiple targets for Ne production
  - ECR bunching (P. Sortais)
  - Ne and He in the decay ring simultaneously
  - Low energy beta facility (C. Volpe)
    - GSI, GANIL and CERN (in close detector)

Ne and He in decay ring simultaneously

- Enormous "gain" in counting time
  - Years!
- Requiring γ=150 for He will at equal rigidity result in a γ=250 for Ne
  - Physics?
  - Detector simulation should give "best" compromise
- Requiring equal revolution time will result in a ΔR of 20 mm (R_0=1090 m)
  - Manageable?

CERN to FREJUS



SPL @ CERN
2.2GeV, 50Hz, 2.3x10^{14} p/pulse
→4MW
Now under R&D phase

Neutron beams?

- As for a neutrino beam and neutron beam can be created if a beta-delayed neutron emitter is stored in the decay ring
  - High energy
    - Physics case?
  - Low energy
    - Medical use – neutron therapy
    - Waste transmutation at neutron resonances
      - Intensity?

Comments

- The super beam can be available soon (when the necessary high power drivers are completed)
- The beta-beam is largely based on existing technology but requires costly civil engineering for the decay ring
  - Moderate extrapolations on target technology
  - Strong synergies with projects in nuclear physics
    - EURISOL
    - GSI upgrade
    - SPIRAL-2
    - SPES in Legnaro
    - Ion programme in LHC and low energy ion (accelerator and) storage rings in Europe
  - Low energy beta-beam facility (C. Volpe)
- The R&D for a full scale muon based neutrino factory is fascinating but very challenging
  - Target issues still requires major R&D
  - Ionization cooling has to be experimentally tested