European Organization for Nuclear Research
Organisation Européenne pour la Recherche Nucléaire

CERN INITIATIVES FOR FUTURE ν BEAMS

R. Garoby – 18/11/2008

Swiss Institute of Particle Physics

OUTLINE

1. Context: Plans for future LHC injectors
2. Plans for
   2.1 “Conventional” ν beams:
   - CNGS
   - SPS with the new injectors

   2.2 Neutrino Factory
   2.3 Beta beams
3. Organization of neutrino studies (…):
   - “Euro-ν” Design Study
   - “NEU2012” network inside EUCARD
4. Conclusion

PLANS FOR FUTURE INJECTORS: Motivation

1. Lack of reliability:

   Ageing accelerators (PS is 48 years old !) operating far beyond initial parameters

$\Rightarrow$ need for new accelerators designed for the needs of SLHC

2. Main performance limitation:

Excessive incoherent space charge tune spreads ΔQ_{SC} at injection in the PSB (50 MeV) and PS (1.4 GeV) because of the high required beam brightness N/ε^*.

$$\Delta Q_{SC} \propto \frac{N_b}{\varepsilon_{X,Y}} \cdot \frac{R}{\beta\gamma^2}$$

with N_b : number of protons/bunch

$\varepsilon_{X,Y}$: normalized transverse emittances

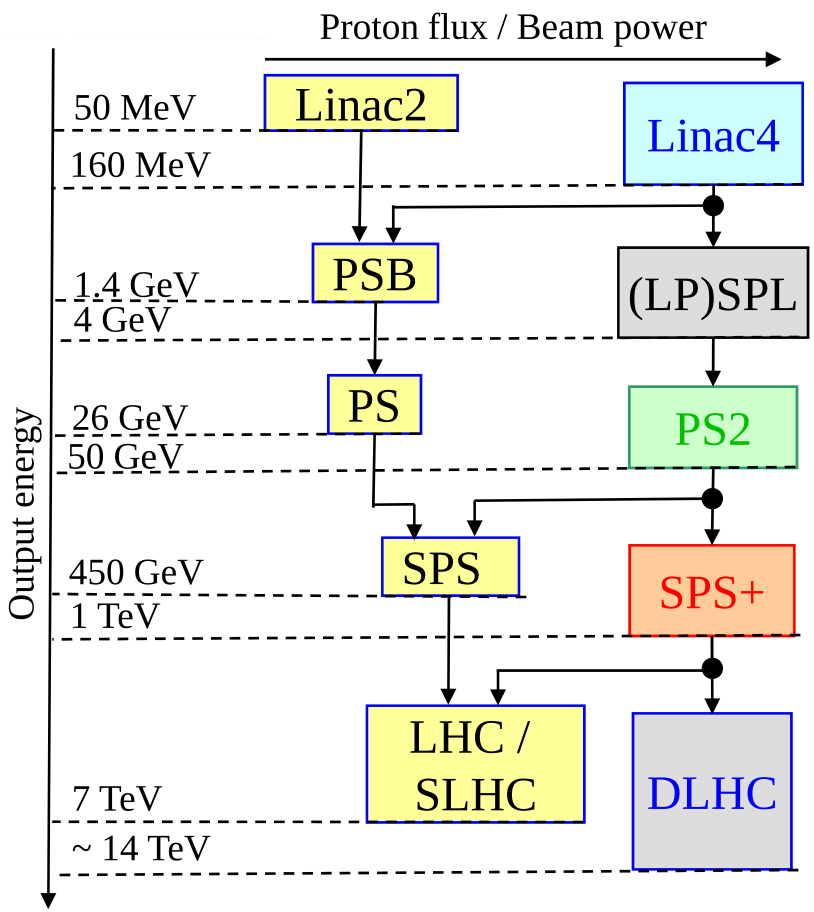
R : mean radius of the accelerator

$\beta\gamma$: classical relativistic parameters

$\Rightarrow$ need to increase the injection energy in the synchrotrons

- Increase injection energy in the PSB from 50 to 160 MeV kinetic
- Increase injection energy in the PSB from 25 to 50 GeV kinetic
- Design the PS successor (PS2) with an acceptable space charge effect for the maximum beam envisaged for SLHC: => injection energy of 4 GeV

PLANS FOR FUTURE INJECTORS: Description



(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)

PLANS FOR FUTURE INJECTORS: PS2 parameters

PS2 goals:

- to provide the beam brightness required by all considered SLHC options
- to improve SPS operation in fixed target mode

Reason	Physical parameter	Value
Space charge PS2	Injection energy (kinetic)	4 GeV
SPS improvement	Ejection energy (kinetic)	50 GeV
LHC	Transverse normalized 1 sigma emittances at ejection for LHC	3 mm.mrad
LHC	Longitudinal emittance/bunch with 25 ns bunch spacing at ejection	0.35 eVs
Twice the ultimate brightness + 10 % margin for beam loss	Nb of protons / bunch with 25 ns bunch spacing at ejection for LHC (total 168 bunches)	3.6×10^{11} (6.05×10^{13})
SPS / PS2 fixed target physics	Nb of protons / bunch with 25 ns bunch spacing (total)	7.5×10^{11} (1.25×10^{14})
Possible bunch spacings in LHC (25, 50 & 75 ns)	Size (ratio PS2/SPS)	15/77
	Circumference	1346.4 m
	h_{RF} for 25 ns (resp. 50 or 75 ns) bunch spacing	180 (resp. 90 or 60)
	Cycling period to 50 GeV without flat porch	2.4 s

PLANS FOR FUTURE INJECTORS: PS2 injector

Requirements of PS2 on its injector:

Reason	Physical parameter	Value
Space charge	Injection energy to PS2 (kinetic)	4 GeV
Twice the ultimate brightness + 20 % margin for beam loss	Nb of protons per PS2 cycle for LHC	6.7×10^{13}
SPS / PS2 fixed target physics	Nb of protons per PS2 cycle for PS2 / SPS fixed target physics	1.4×10^{14}

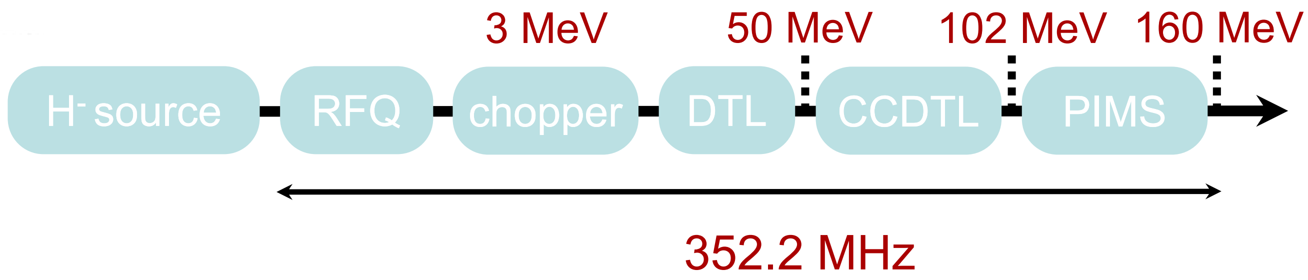
PLANS FOR FUTURE INJECTORS: Why an SPL?

- An H- linac combined with charge exchange injection in the following synchrotron is a proven solution for reliably reaching high beam brightness,
- Superconducting accelerating structures allow for reaching 4 GeV with a single accelerator (minimum beam loss/irradiation + maximum reliability),
- An SPL provides a large potential of extension to adapt to future needs. Among the identified possibilities:
  - Radioactive ion beam facility (4 MW at ~ 2.5 GeV)
  - Proton driver for a neutrino factory (4 MW at 5 GeV) [design available]
  - e+/e- acceleration to ~20 GeV (using recirculation in the β=1 part of the SPL) for LHeC [design
- Large synergy with other projects (ESS, ADS, EURISOL, SNS…) and access to EU support for R & D.

PLANS FOR FUTURE INJECTORS: Stage 1 (1/2)

LINAC4

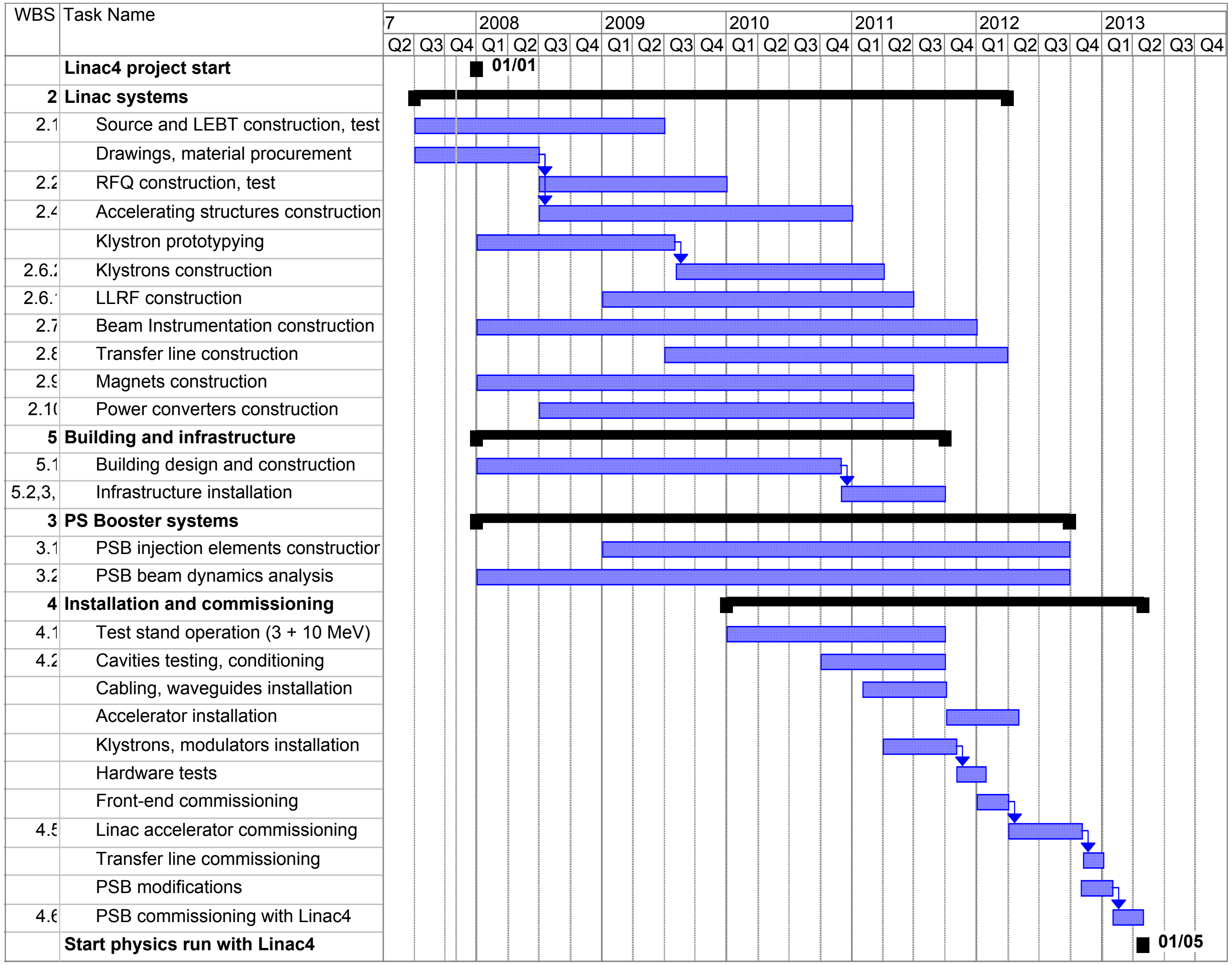
Layout



Beam characteristics

Ion species	**H^-**
Output kinetic energy	**160 MeV**
Bunch frequency	**352.2 MHz**
Max. repetition rate	**1.1 (2) Hz**
Beam pulse duration	**0.4 (1.2) ms**
Chopping factor (beam on)	**62%**
Source current	**80 mA**
RFQ output current	**70 mA**
Linac current	**64 mA**
Average current during beam pulse	**40 mA**
Beam power	**5.1 kW**
Particles / pulse	**$1.0\ 10^{14}$**

PLANS FOR FUTURE INJECTORS: Stage 1 (2/2)



Milestones

- End CE works: December 2010
- Installation: 2011
- Linac commissioning: 2012
- Modifications PSB: shut-down 2012/13 (6 months)
- **Beam from PSB: 1rst of May 2013**

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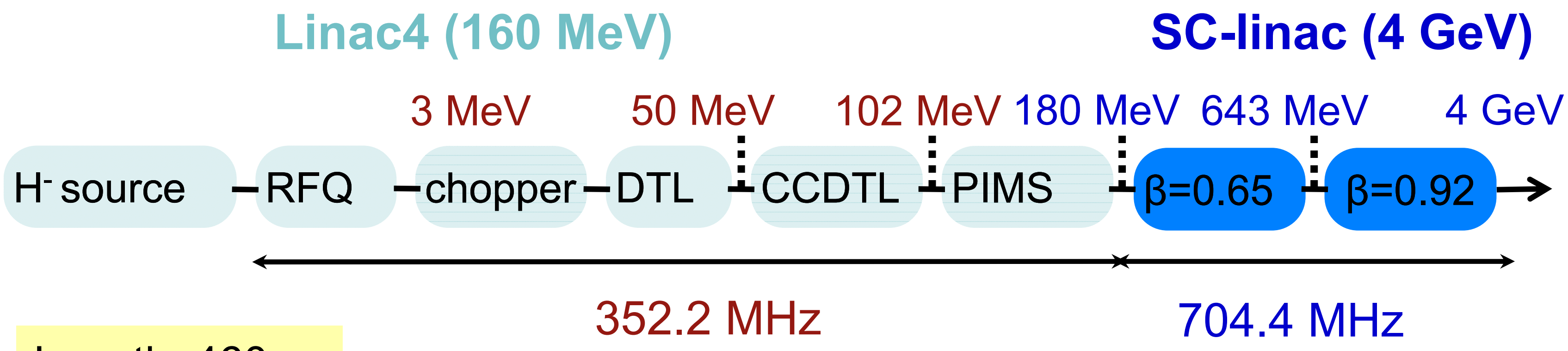
PLANS FOR FUTURE INJECTORS: Stage 2 (1/5)

LP-SPL + PS2



Length: 460 m

LP-SPL beam characteristics

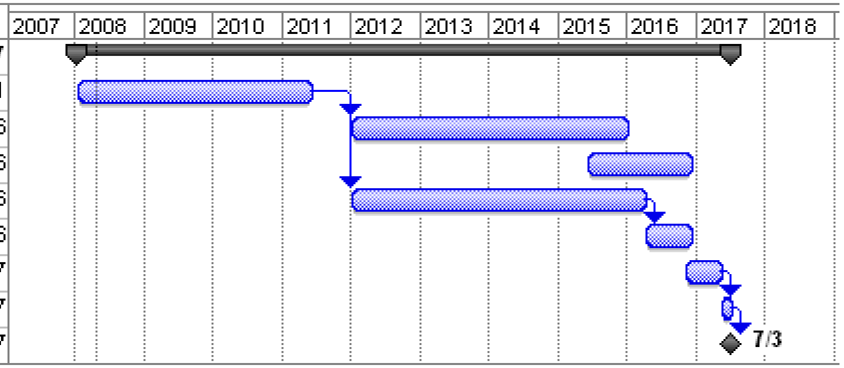
Kinetic energy (GeV)	**4**
Beam power at 4 GeV (MW)	**0.16**
Rep. period (s)	**0.6**
Protons/pulse (x 10^{14})	**1.5**
Average pulse current (mA)	**20**
Pulse duration (ms)	**1.2**

PLANS FOR FUTURE INJECTORS: Stage 2 (2/5)

LP-SPL + PS2

Construction of LP-SPL and PS2 will not interfere with the regular operation of Linac4 + PSB for physics. Similarly, beam commissioning of LP-SPL and PS2 will take place without interference with physics.

ID	Task Name	Start	Finish
1	**SPL + PS2**	**Mon 1/7/08**	**Mon 7/3/17**
2	Design	Mon 1/7/08	Wed 6/1/11
3	SPL Construction	Mon 1/2/12	Fri 1/1/16
4	SPL beam commissioning	Mon 6/1/15	Fri 12/2/16
5	PS2 construction	Mon 1/2/12	Fri 4/1/16
6	PS2 beam commissioning	Mon 4/4/16	Fri 12/2/16
7	SPS modification	Fri 11/4/16	Fri 5/5/17
8	SPS beam commissioning	Mon 5/8/17	Fri 6/30/17
9	Start operation for physics	Mon 7/3/17	Mon 7/3/17

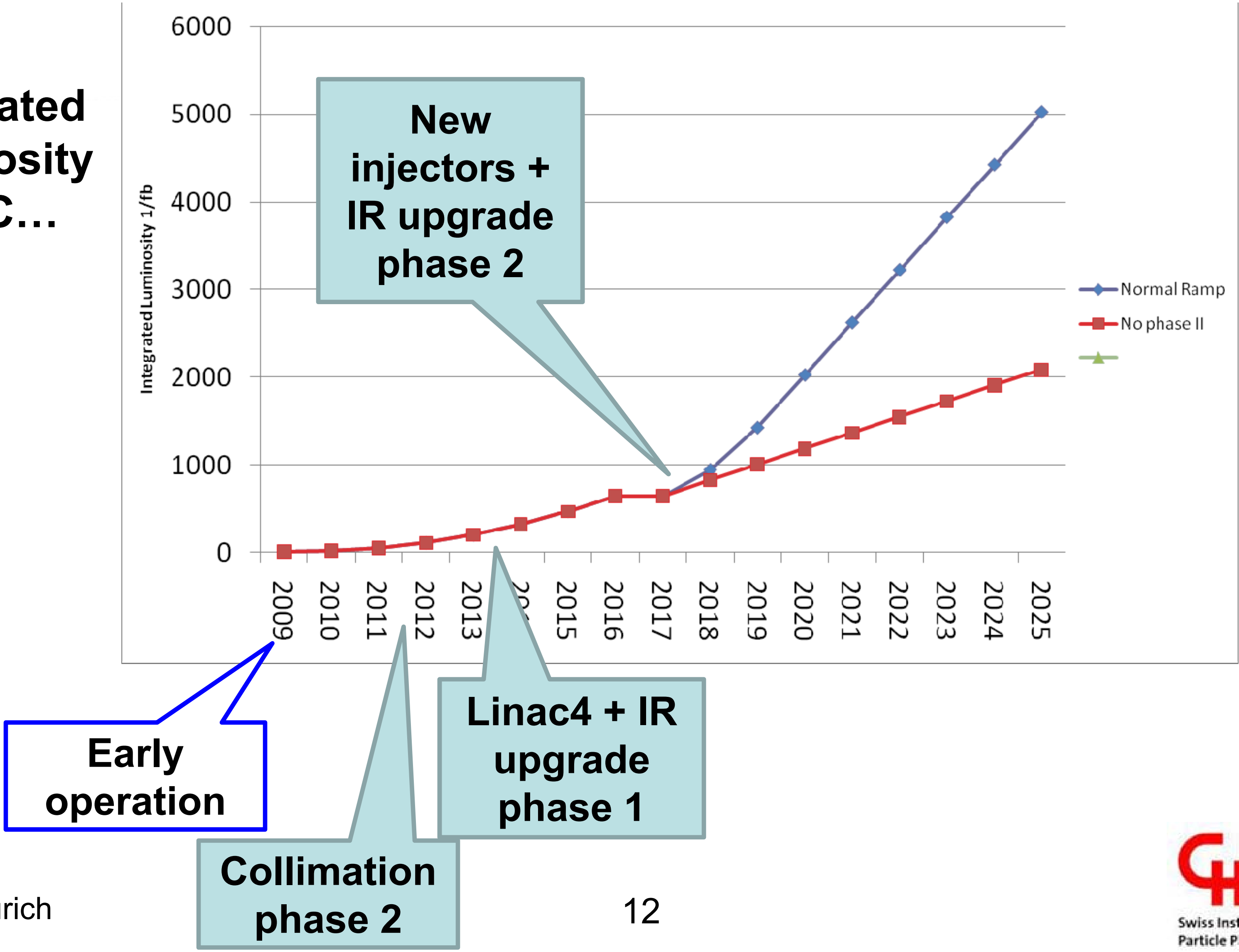


Milestones

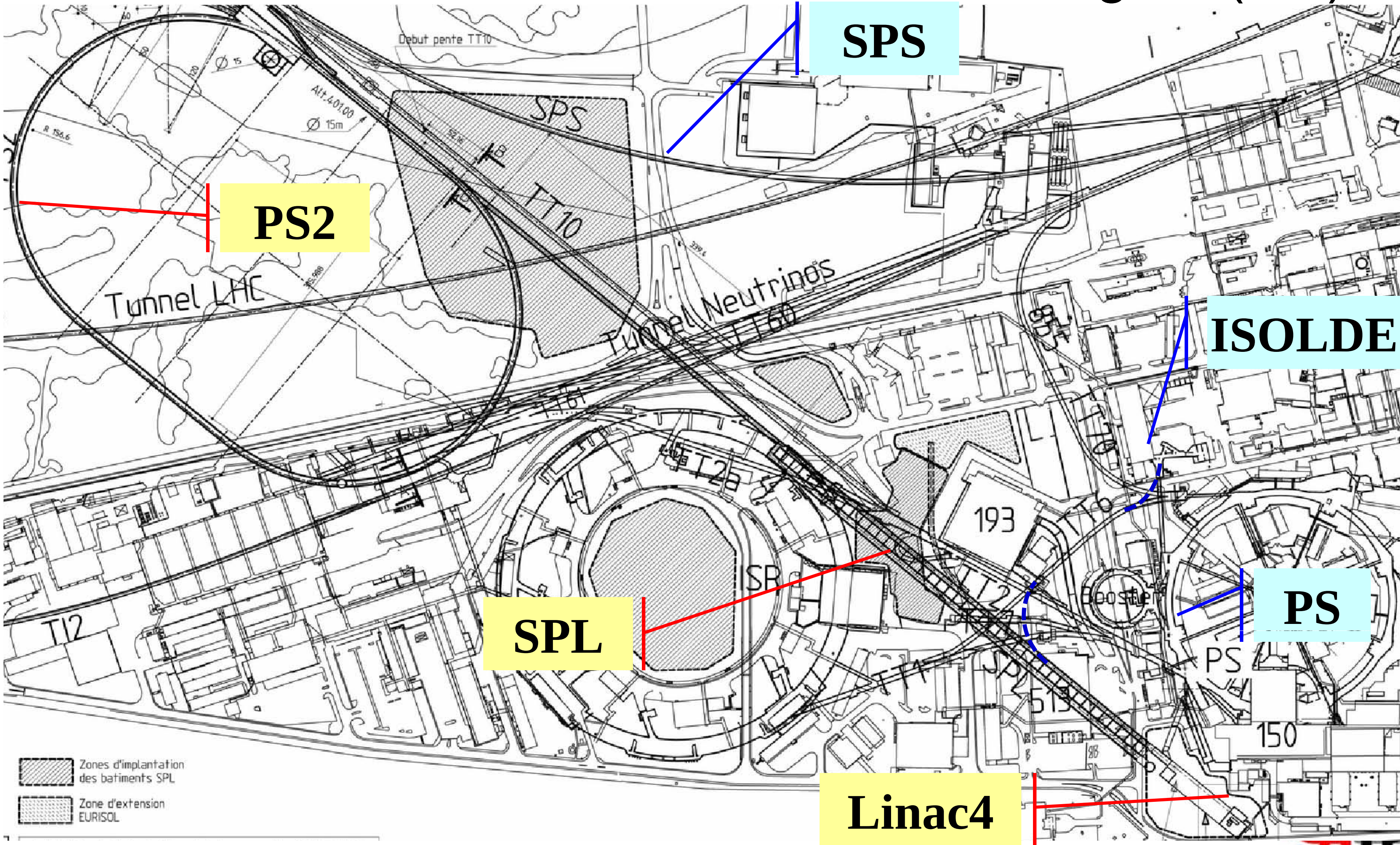
- Project proposal: June 2011
- Project start: January 2012
- LP-SPL commissioning: mid-2015
- PS2 commissioning: mid-2016
- SPS commissioning: May 2017
- **Beam for physics: July 2017**

PLANS FOR FUTURE INJECTORS: Stage 2 (3/5)

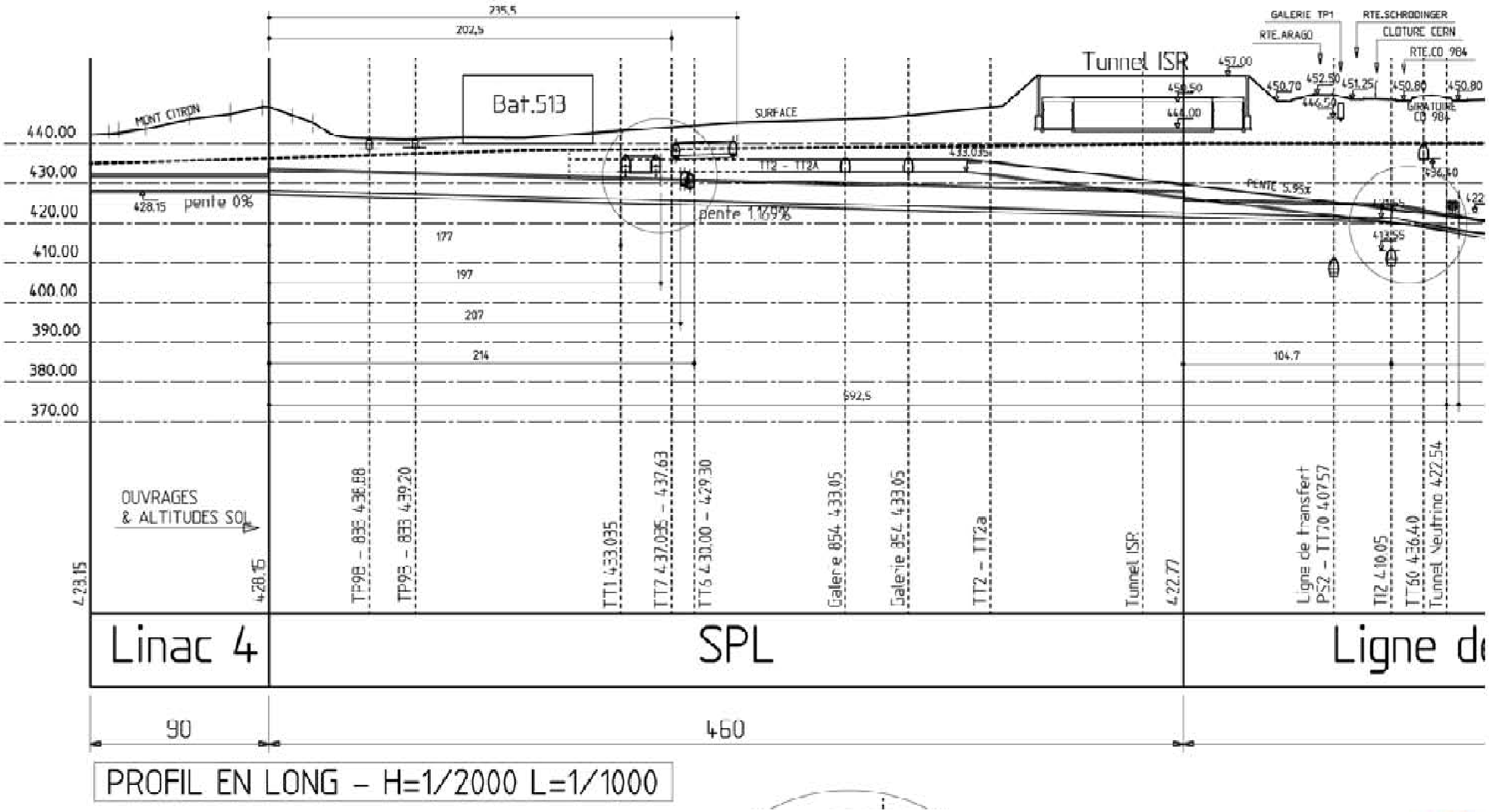
Integrated luminosity in LHC…



PLANS FOR FUTURE INJECTORS: Stage 2 (4/5)

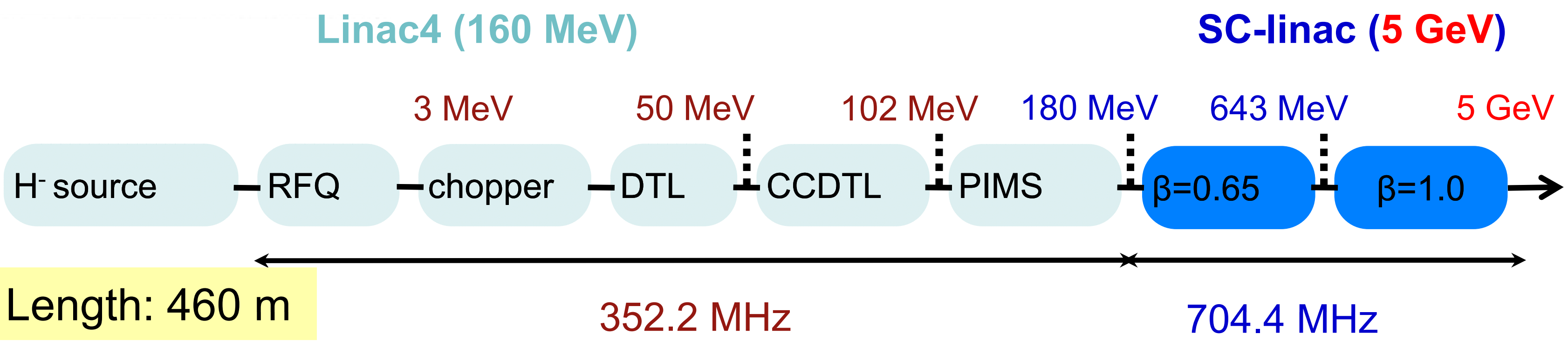


PLANS FOR FUTURE INJECTORS: Stage 2 (5/5)



PLANS FOR FUTURE INJECTORS: Stage 3 (1/4)

HP-SPL



Length: 460 m

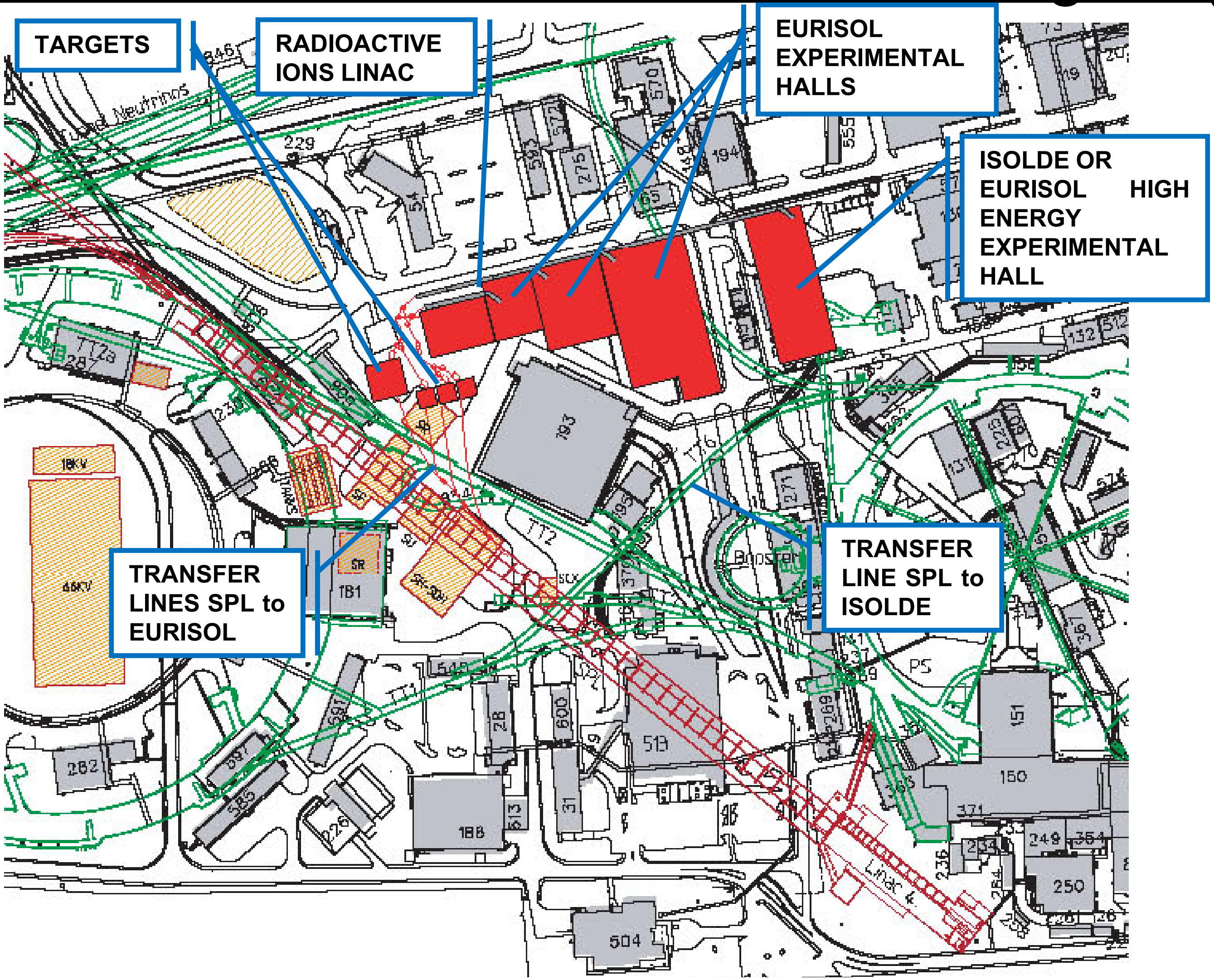
HP-SPL beam characteristics

	Option 1	Option 2
Energy (GeV)	**2.5 or 5**	**2.5 and 5**
Beam power (MW)	**3 MW (2.5 GeV) or 6 MW (5 GeV)**	**4 MW (2.5 GeV) and 4 MW (5 GeV)**
Rep. frequency (Hz)	**50**	**50**
Protons/pulse (x 10^{14})	**1.5**	**2 (2.5 GeV) + 1 (5 GeV)**
Av. Pulse current (mA)	**20**	**40**
Pulse duration (ms)	**1.2**	**0.8 (2.5 GeV) + 0.4 (5 GeV)**

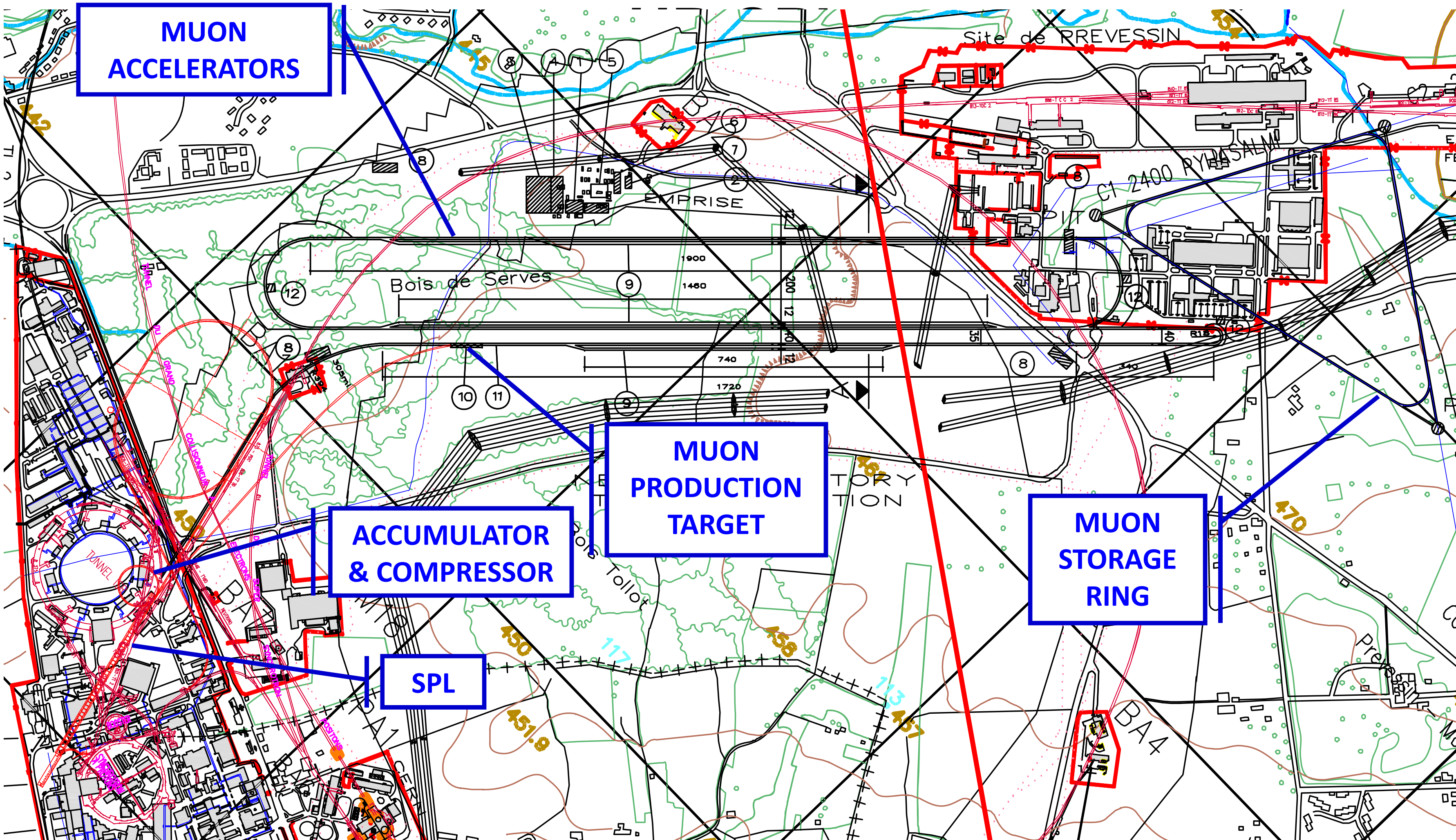
PLANS FOR FUTURE INJECTORS: Stage 3 (2/4)
HP-SPL

- The upgrade from LP-SPL to HP-SPL will depend upon the approval of major new physics programmes for Radioactive Ion beams (EURISOL-type facility) and/or for neutrinos (Neutrino factory).
- Staged hardware upgrade during shutdowns
- **Earliest year of operation: 2020**

PLANS FOR FUTURE INJECTORS: Stage 3 (3/4)



PLANS FOR FUTURE INJECTORS: Stage 3 (4/4)



CONVENTIONAL ν BEAMS: CNGS (1/4)

from E. Gschwendtner

732 km baseline
- From CERN to Gran Sasso (Italy) [Elevation of 5.9°]
- Far detectors:
  OPERA (1.21 kt), Icarus (600 t)

Commissioned 2006

Operational since 2007

Proton beam characteristics

- **From SPS: 400 GeV/c**
- **Cycle length: 6 s**
- **Extractions:**
  - **2 separated by 50ms**
- **Pulse length: 10.5μs**
- **Beam intensity:**
  - **2x 2.4 · 10^{13} ppp**
- **σ ~0.5mm**
- **Beam performance:**
  - **4.5· 10^{19} pot/year**

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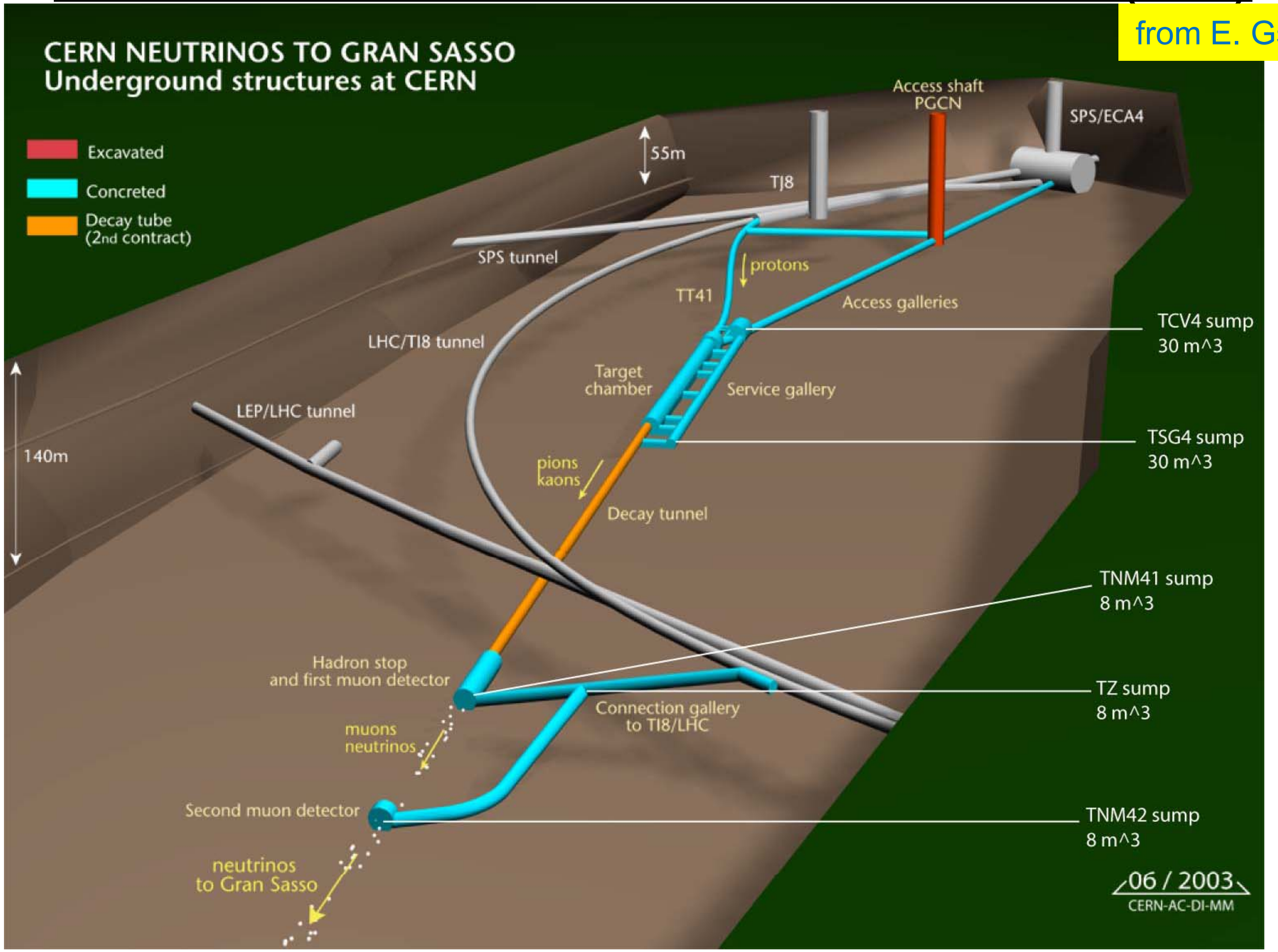
CONVENTIONAL ν BEAMS: CNGS (2/4)

from E. Gschwendtner



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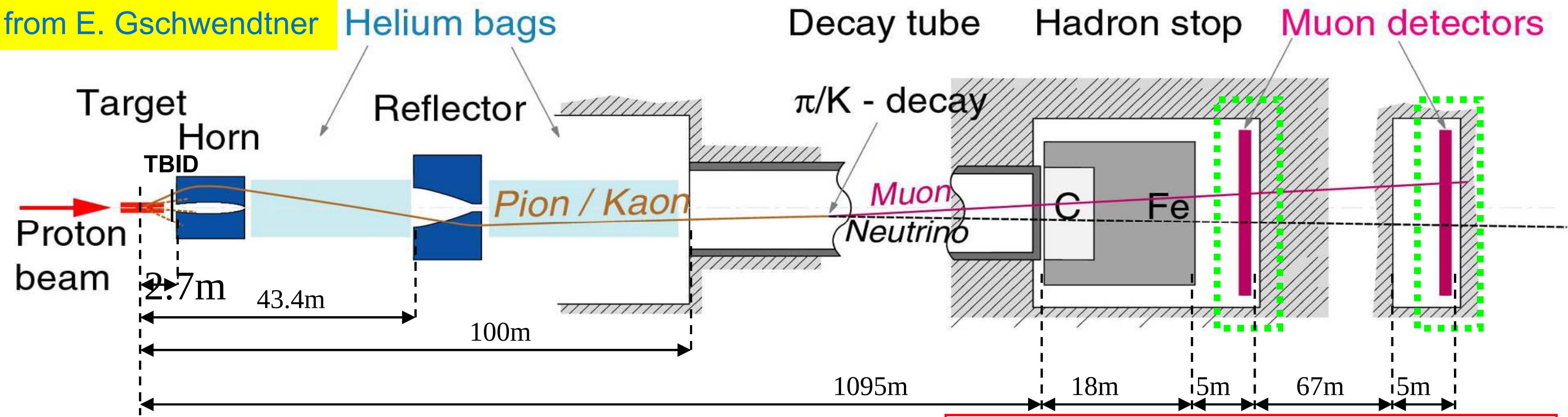
CONVENTIONAL ν BEAMS: CNGS (3/4)

from E. Gschwendtner



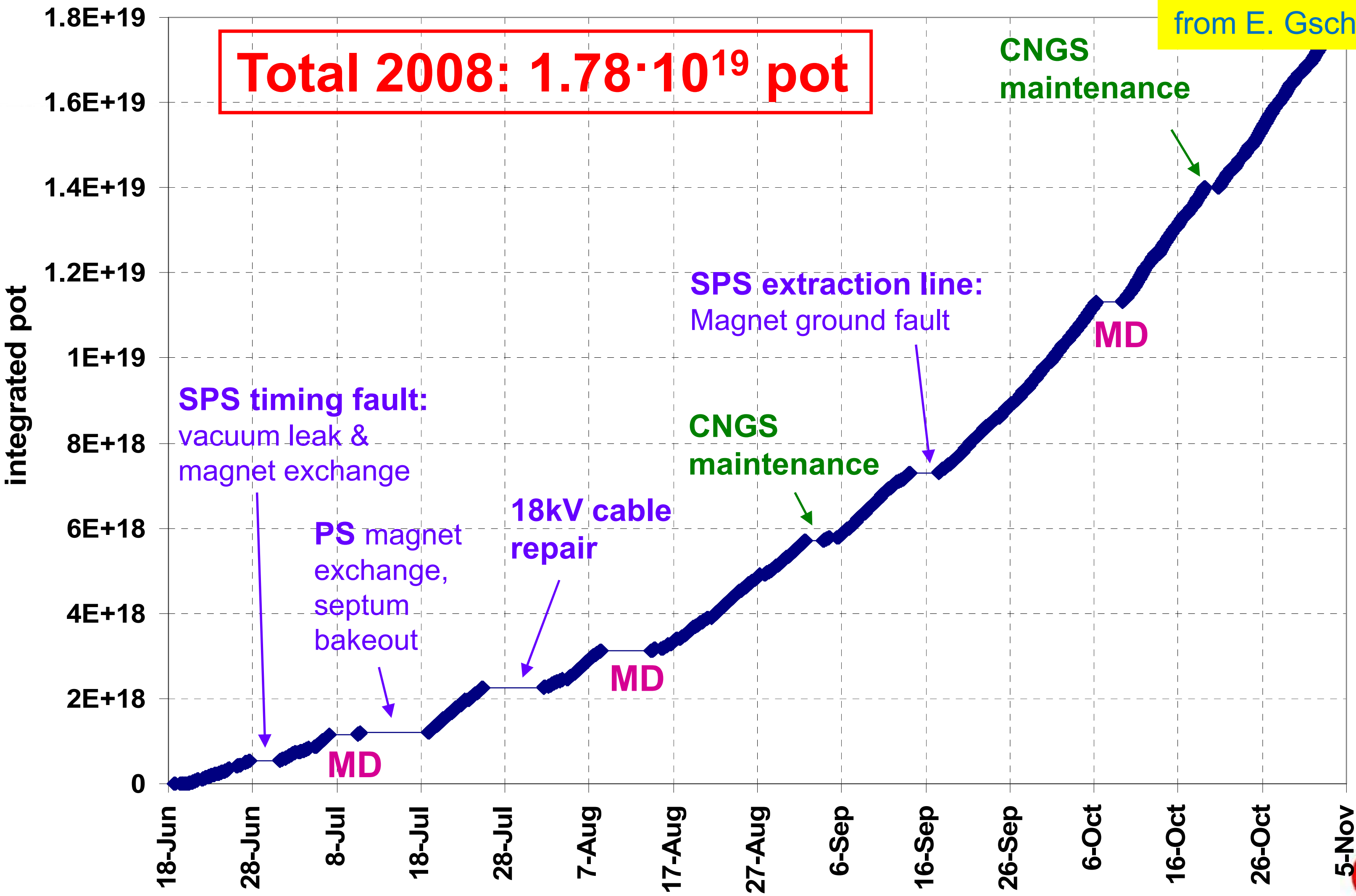
p + C → (interactions) → π^+, K^+
→ (decay in flight) → $\mu^+ + \nu_\mu$

Air cooled graphite target magazine
- 4 in situ spares
- 2.7 interaction lengths
- Target table movable horizontally/vertically for alignment

- **TBID multiplicity detector**
- **2 horns (horn and reflector)**
  - Water cooled, pulsed with 10ms half-sine wave pulse of up to 150/180kA, 0.3Hz, remote polarity change possible
- **Decay pipe:**
  - 1000m, diameter 2.45m, 1mbar vacuum
- **Hadron absorber:**
  - Absorbs 100kW of protons and other hadrons
- **2 muon monitor stations: muon fluxes and profiles**

CONVENTIONAL ν BEAMS: CNGS (4/4)

from E. Gschwendtner



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CONVENTIONAL ν BEAMS: SPS with new injectors (1/4)

from M. Meddahi

Analysis of the maximum potential proton flux to CNGS

M. Meddahi and E. Shaposhnikova
CERN AB-2007-013 (PAF)

1. Hypothesis : scenario, SPS beam sharing, CNGS cycle length, SPS maximum intensity
2. CNGS design values and limitations
3. SPS limitations
4. Estimated proton flux

CONVENTIONAL ν BEAMS: SPS with new injectors (2/4)

from M. Meddahi

Intensity limitation from the design values of the CNGS facility

Equipment	Protons per extraction	Protons per cycle	POT per year
Radiation Protection calculation and optimisation			Soil/concrete activation: **4.5 E19** Residual dose for intervention: **1.38 E20** Air/water activation: **7.6 E19**
Target	**3.5 E13** from dynamic stresses and assuming increased time between 2 extractions	**1.4 E14** from target cooling	**2 E20** from radiation damage
Horns	**3.5 E13** from powering system: maximum of 2 extractions	**7 E13** from water cooling system	**1.38 E20** from air cooling system and mechanical fatigue lifetime (2 E7 pulses)
Shielding, Decay Tube, Hadron stop design			**1.38 E20** from air/water cooling systems
Kicker system	**3.5 E13** from ferrite heating, with MKE equipped with shielding stripes (TBC) from powering system: maximum of 2 extractions	**1 E14** marginal, pending 2007 SPS beam measurements	
Instrumentation	**3.5 E13** from dynamic range – Electronics system		

CONVENTIONAL ν BEAMS: SPS with new injectors (3/4)

from M. Meddahi

To be noted:

•After 5 years of nominal operation:
some equipments will have reached their design lifetime.

• Space for any more equipments: target chamber, service gallery or surface buildings -e.g. horn capacitor banks, cooling units, extraction kicker resonant charging power supplies.

• CNGS needs to run at nominal intensity for sometime to benchmark the validity of the design and the models, assess if margins exist, the reliability and performance of equipment, the beam line operation efficiency…

• Activation of the equipment and tunnels – RP calculations/ studies required. Measured values during operation can be first scaled up to the new requested intensity for first estimate.

CONVENTIONAL ν BEAMS: SPS with new injectors (4/4)

POT/year [10^{19}] for 200 days of operation with 80% machine efficiency

from M. Meddahi

	SPS cycle length	6 s		4.8 s	
	Injection Energy	14 GeV		26 GeV	
	Beam sharing / Max SPS intensity @ 400GeV [$\times 10^{13}$]	0.45	0.85	0.45	0.85
Present injectors + machines' improvement	4.8	5	9.4		
	5.7	5.9	11.1		
Future injectors (>2016) + SPS RF upgrade	7			9	17.1
Future injectors + new SPS RF system + CNGS new equipment design	10			12.9	24.5

ν FACTORY: SPL-based proton driver (1/5)

from M. Aiba

✓ An HP-SPL based 5 GeV – 4 MW proton driver has been designed (HP-SPL + 2 fixed energy rings (accumulator & compressor)

CERN-AB-2008-060 BI

Feasibility Study of Accumulator and Compressor for the 6-bunches SPL based Proton Driver

M. Aiba

Table 1: Requirements for the neutrino factory proton driver.
Taken from the summary of 3rd ISS [4].
* Maximum bunch spacing ~50/(Nb-1) for the number of bunches Nb >2.

Parameters	Values (basic/range)	Unit
Kinetic energy	10 / 5-15	GeV
Burst repetition rate	50 / -	Hz
Number of bunches per burst	4 / 1-6	
Bunch spacing	16 / 0.6-16 *	μs
Total duration of the burst	~50 / 40-60	μs
Bunch length	2 / 1-3	ns

ν FACTORY: SPL-based proton driver (2/5)

Accumulation — Duration = 400 μs

Compression

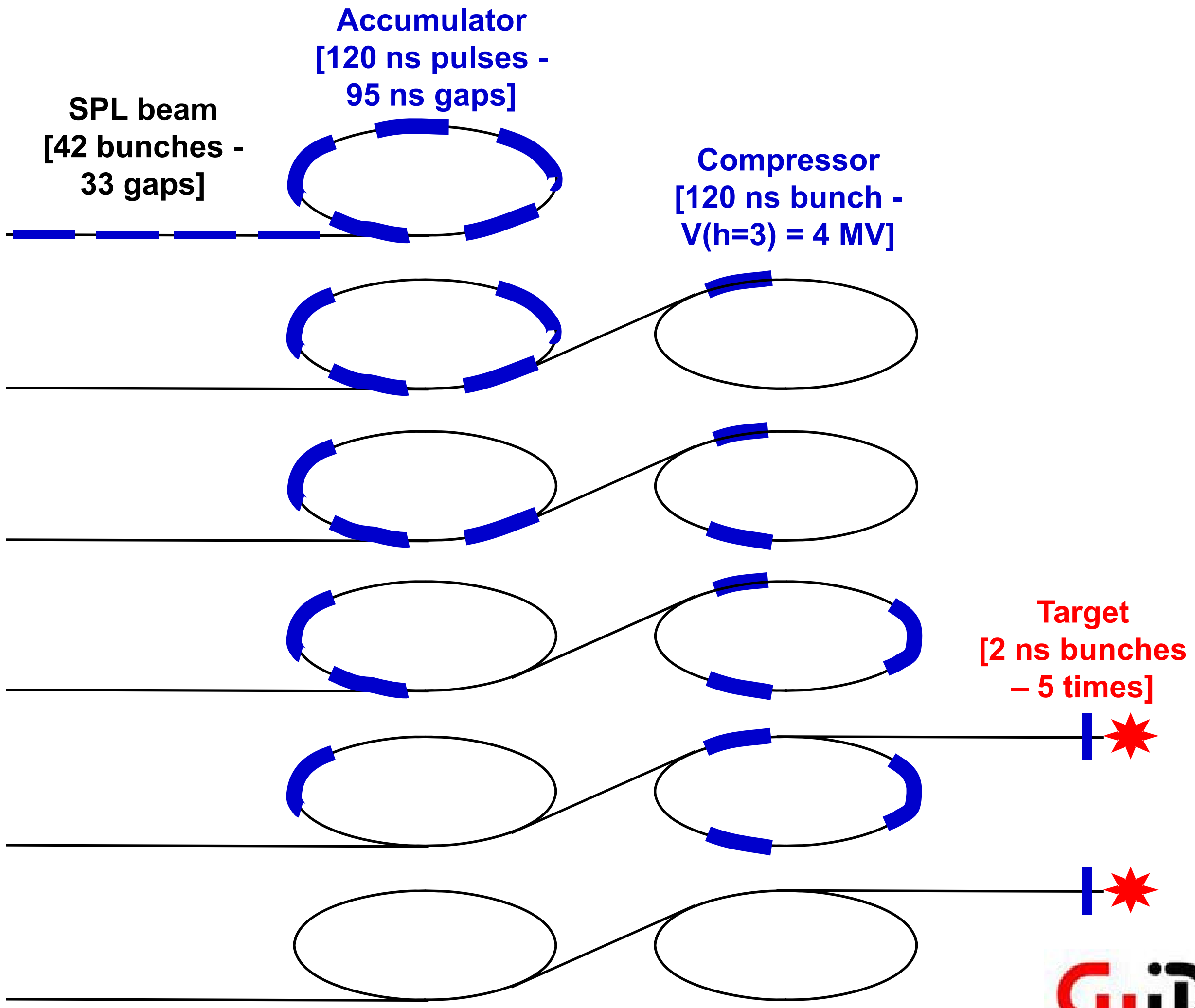
t = 0 μs

t = 12 μs

t = 24 μs

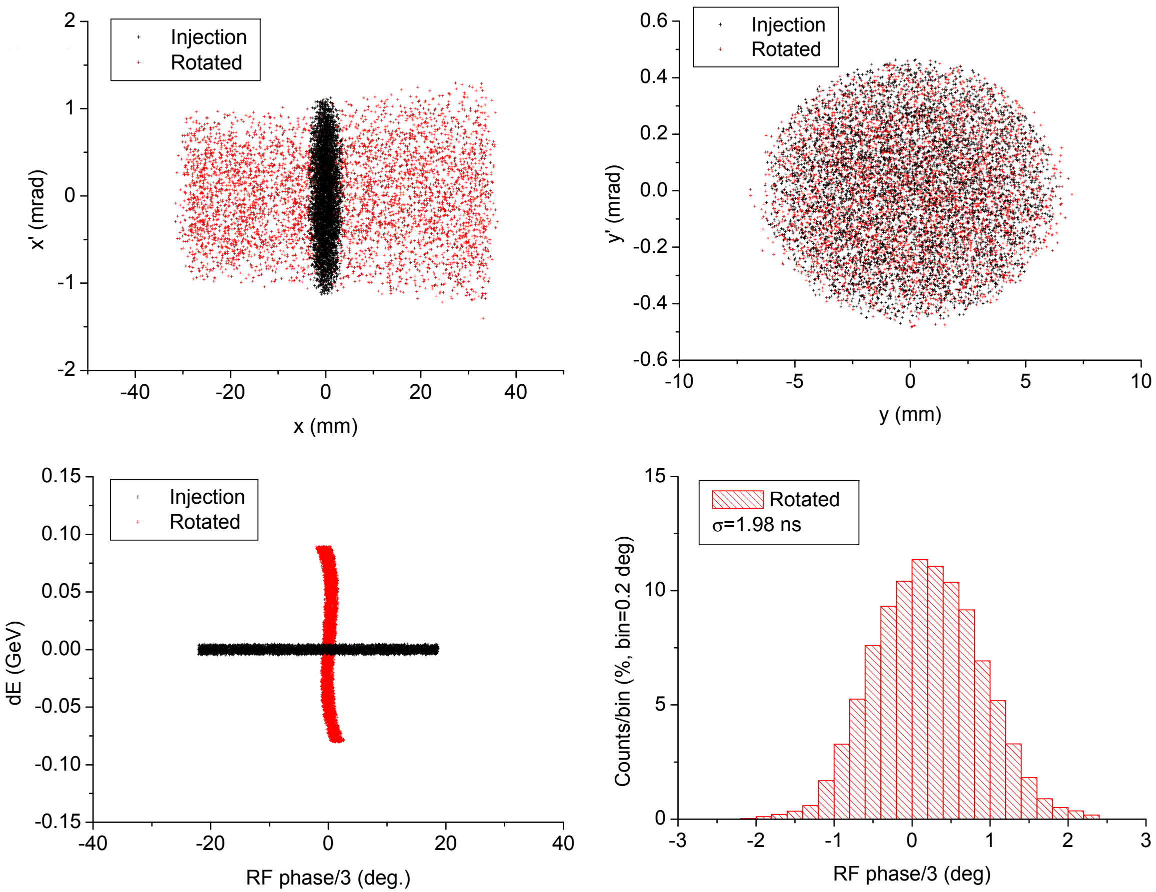
t = 36 μs

etc. until t = 84 μs



ν FACTORY: SPL-based proton driver (3/5)

from M. Aiba



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ν FACTORY: SPL-based proton driver (4/5)

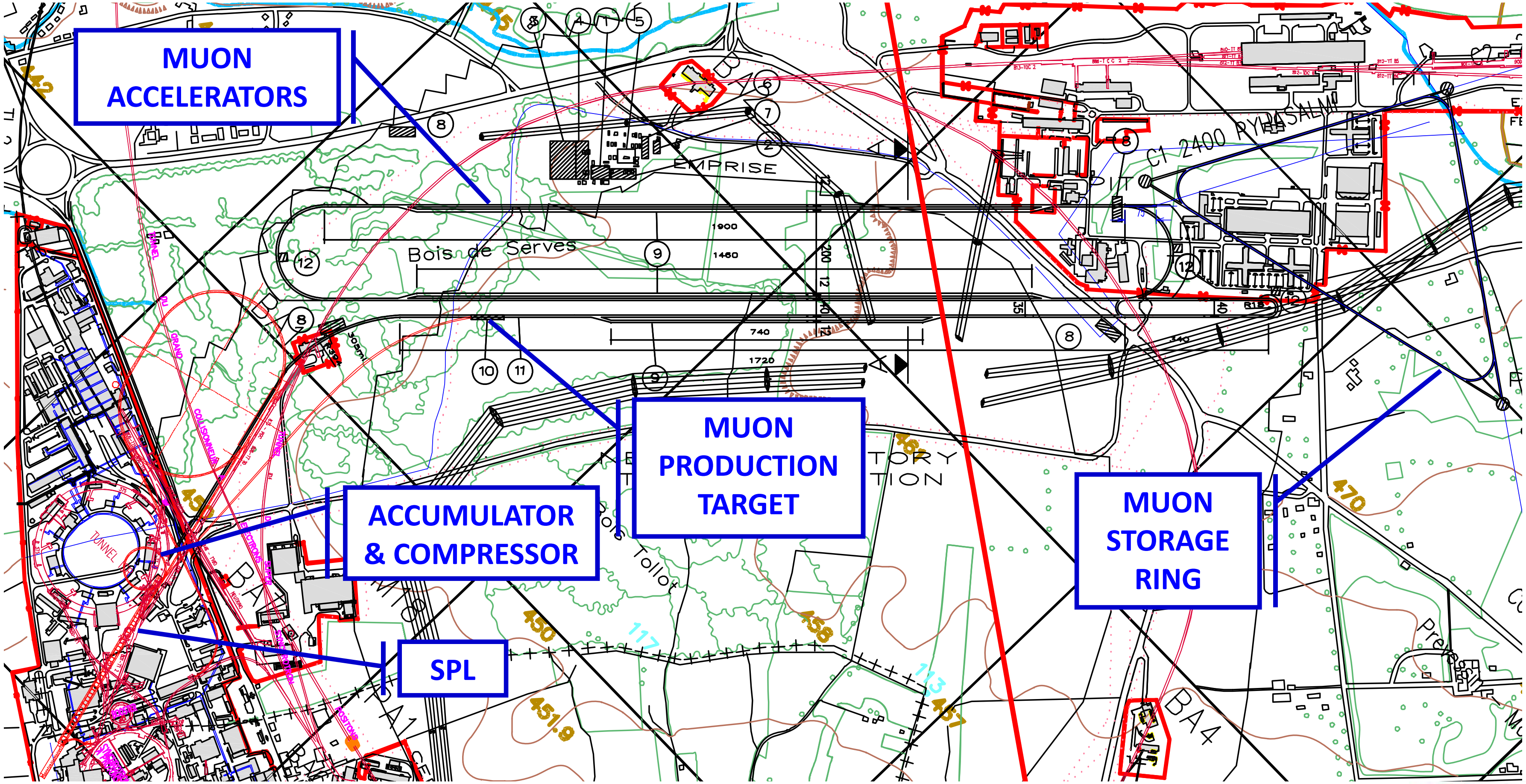
from M. Aiba

SPL for proton driver		**Output beam**	
Parameters	Values	Parameters	Values
Kinetic beam energy	5 GeV	Kinetic beam energy	5 GeV
Repetition rate	50 Hz	Repetition rate	50 Hz
Average current during the burst	40 mA	No. of bunches per cycle	6
Beam power	4 MW	Bunch length (r.m.s.)	~2 ns
		Bunch spacing	~12 μs
		Transverse emittance (r.m.s., physical)	3 πmm-mrad

Accumulator		**Compressor**	
Parameters	Values	Parameters	Values
Circumference	318.5 m	Circumference	314.2 m
Transition gamma	6.33	Transition gamma	2.3
RF voltage	-	RF voltage	4 MV
Harmonics number	-	Harmonic number	3
No. of arc cells	24	No. of arc cells	6
Super periodicity	2	Super periodicity	2
Nominal transverse tune	7.77/ 7.67	Nominal transverse tune	10.79/5.77
No. of turns for accum.	400	No. of turns for comp.	36
Maximum no. of bunches	6	Maximum no. of bunches	3
Main quadrupole		Main quadrupole	
Bore radius	56 mm	Bore radius	148 mm
Field gradient	5.5 T/m	Field gradient	7.1 T/m
Magnetic length	1.2 m	Magnetic length	1.9 m
Main bending		Main bending	
Full gap	103 mm	Full gap	125 mm
Full width	162 mm	Full width	379 mm
Field stength	1.7 T	Field strength	5.1 T
Magnetic length	1.5 m	Magnetic length	3 m

ν FACTORY (5/5)

- ✓ The layout of the future injectors is compatible with a ν Factory at CERN.



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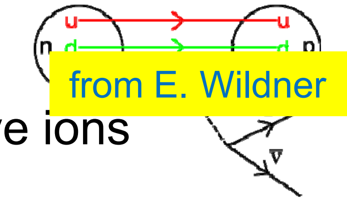
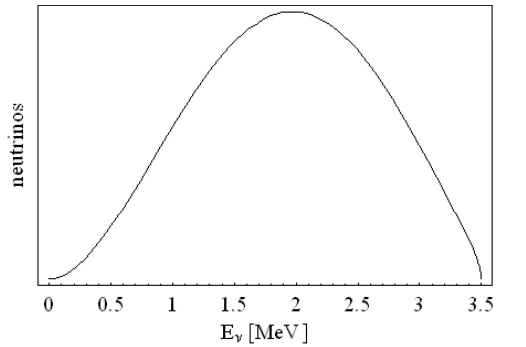
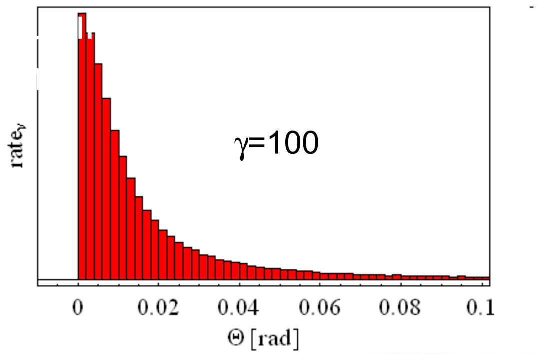
β BEAM FACILITY: Principle



from E. Wildner

- ✓ Aim: production of (anti-)ν beams from the β decay of radio-active ions circulating in a storage ring
  - Similar concept to the ν factory, but parent particle is a β-active isotope instead of a μ.
- ✓ Beta-decay at rest
  - ν–spectrum well known from electron spectrum
  - Reaction energy Q typically of a few MeV
- ✓ Accelerate parent ion to relativistic γ_{max}
  - Boosted ν energy spectrum: $E_\nu \leq 2\gamma Q$
  - Forward focusing of ν: $\theta \leq 1/\gamma$
- ✓ Pure electron (anti-)ν beam!
  - Depending on β^+- or β^-- decay we get a ν or anti-ν
  - Two different parent ions for ν and anti-ν beams
- ✓ Physics applications of a beta-beam
  - Primarily ν oscillation physics and CP-violation
  - Cross-sections of ν-nucleus interaction





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β BEAM FACILITY: EURISOL scenario

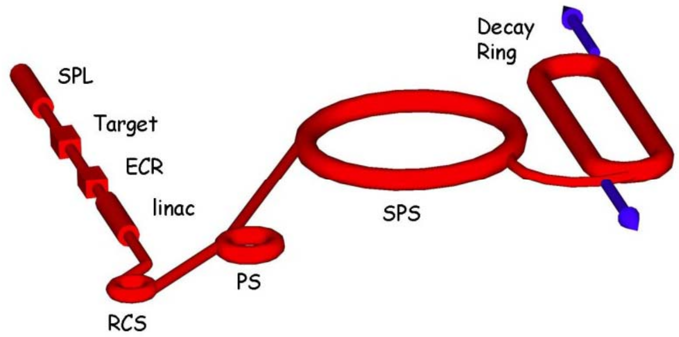
from E. Wildner

Based on CERN boundaries

Ion choice: ^{6}He and ^{18}Ne

Based on existing technology and machines

- Ion production through ISOL technique
- Bunching and first acceleration: ECR, linac
- Rapid cycling synchrotron
- Use of existing machines: PS and SPS



Relativistic gamma=100 for both ions

- SPS allows maximum of 150 (^{6}He) or 250 (^{18}Ne)
- Gamma choice optimized for physics reach

Opportunity to share a Mton Water Cherenkov detector with a CERN super-beam, proton decay studies and a neutrino observatory

Achieve an annual neutrino rate of

- 2.9×10^{18} anti-neutrinos from ^{6}He
- $1.1\ 10^{18}$ neutrinos from ^{18}Ne

top-down approach

The EURISOL scenario will serve as reference for further studies and developments: Within Euroν we will study ^{8}Li and ^{8}B

β BEAM FACILITY: Ions production schemes (1/N)

from E. Wildner

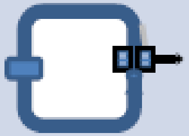
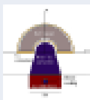
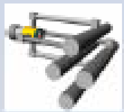
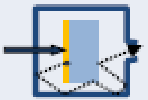
- ✓ ISOL method at 1-2 GeV (200 kW)
  - > 1 10^{13} ^{6}He per second
  - < 8 10^{11} ^{18}Ne per second
  - Studied within EURISOL
- ✓ Direct production
  - > 1 10^{13} (?) ^{6}He per second
  - 1 10^{13} ^{18}Ne per second
  - Studied at LLN, Soreq, WI and GANIL
- ✓ Production ring
  - 10^{14} (?) ^{8}Li
  - > 10^{13} (?) ^{8}B
  - Will be studied within EURO-ν

Aim:
He 2.9 10^{18} (2.0 10^{13}/s)
Ne 1.1 10^{18} (2.0 10^{13}/s)

Courtesy M. Lindroos

β BEAM FACILITY: Ions production schemes (2/N)

from E. Wildner

Illustration	METHOD	Advantage	Drawback
	Production ring	-"Re-use" of driver beam thanks to cooling -Huge cross sections for compound nucleus	-Challenging gas target design -Collection device efficiency
	Converter target, with low and high energy driver	Can accept very high intensity driver beam (>1 MW)	Limited to neutron produced isotopes such as ^{6}He and ^{8}Li
	ISOL with >1 GeV protons	Universal, any non-refractory isotope can be produced at high intensity with good beam quality	Can only accepted up to some 100 kW of driver beam
	Direct production	-Low energy and high intensity driver -Huge cross sections for compound nucleus	-Challenging very high intensity driver design -Extraction efficiency

Courtesy M. Lindroos

β BEAM FACILITY: EURO-ν DS (1/2)

from E. Wildner

- The study will focus on production issues for ^{8}Li and ^{8}B
  - ^{8}B is highly reactive and has never been produced as an ISOL beam
  - Production ring: enhanced direct production
    - Ring lattice design
    - Cooling
    - Collection of the produced ions (UCL, INFN, ANL), release efficiencies and cross sections for the reactions
    - Sources ECR (LPSC, GHMFL)
    - Supersonic Gas injector (PPPL)
- Parallel studies
  - Multiple Charge State Linacs (P Ostroumov, ANL)
  - Intensity limitations

β BEAM FACILITY: EURO-ν DS (2/2)

from E. Wildner

✓ Optimization of the Decay Ring (CERN, CEA,TRIUMF)
- Lattice design for new ions
- Open midplane superconducting magnets
- R&D superconductors, higher field magnets
- Field quality, beam dynamics
- Injection process revised (merging, collimation)
- Duty cycle revised
- Collimation design

✓ A new PS?
- Magnet protection system
- Intensity limitations?

✓ Overall radiation & radioprotection studies

β BEAM FACILITY: PLANS

from E. Wildner

- ✓ The EURISOL β-beam conceptual design report will be presented in the second half of 2009
  - First coherent study of a β-beam facility
- ✓ A beta-beam facility using ^{8}Li and ^{8}B
  - Experience from EURISOL
  - First results will come from Euro-ν DS WP (starting fall 2008).

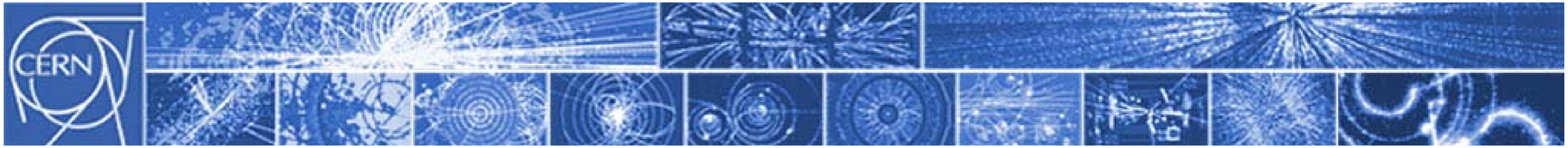
ORGANIZATION OF ν STUDIES: Generalities

with help from
M. Meddahi

✓ Supported by the EU inside:

- FP6 (EURISOL Design Study and BENE Network in CARE)
- FP7 (EURO-ν Design Study and NEU2012 Network in EUCARD

✓ Contributing to the International Design Study for a Neutrino Factory (NF-IDS)



ORGANIZATION OF ν STUDIES: EURO-ν

with help from M. Meddahi

✓ Generalities:

- 4 years contract (Sept. 2009 – August 2012)
- Goal: comparison between the 3 types of ν facilities (SB, βB, νF)
- CERN commitments in 4 work packages:
  - Management (M. Lindroos) (Total ~ 1 man.year)
    β-beam (E. Wildner etc.) (Total ~ 4 man.years)
    ν-factory (M. Martini etc.) (Total ~ 3.2 man.years)
  - Physics (I. Ephtymyopoulos ?) (Total ~ 0.1 man/year)

✓ Status:

✓ Late start

✓ **CERN participation to ν-factory is not secure (retirement of M. Martini)**

ORGANIZATION OF ν STUDIES: NEU2012

with help from
M. Meddahi

- ✓ Generalities:
  - 4 years contract (April 2009 – March 2013)
  - Goal: link the ν community and propose in 2012 (2013 ?) a roadmap to the next accelerator-based ν facility
  - CERN commitments in the 3 tasks:
    - Coordination and communication (fellow supervised by ?)
    - Getting the most of existing facilities (CNGS for CERN) (E. Gschwendtner)
    - After analysis of options, make recommendations for the next facility (?)

- ✓ Status:
  - ✓ Late start
  - ✓ **No CERN staff in charge**

ORGANIZATION OF ν STUDIES: NF-IDS

with help from
M. Meddahi

✓ Generalities:

- Born from the International Scoping Study
- Deliverables:
  - Interim Design Report in 2010
  - Reference Design Report (engineering design of most components) in 2012
- CERN commitment:
  - **None after the move of M. Meddahi to another activity**

CONCLUSION

- ✓ Support for future ν facilities at CERN is weak, especially for ν-factory and it will vanish in a couple of years (retirement of M. Martini).
- ✓ There is still some output, thanks to inertia…
- ✓ It is impossible to get decisions on resources:
  - as long as the new management structure is not in place (January 2009)
  - before the new DG has stated his scientific strategy (Council meeting in March 2009).

⇒ It is still time to inform the new DG…