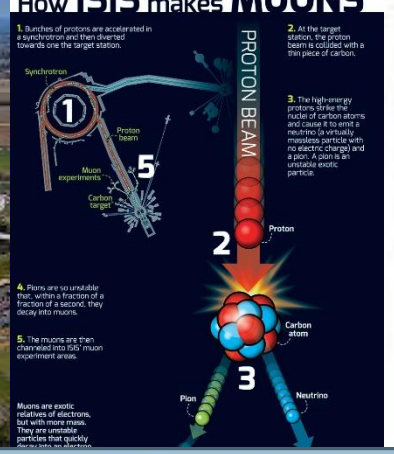
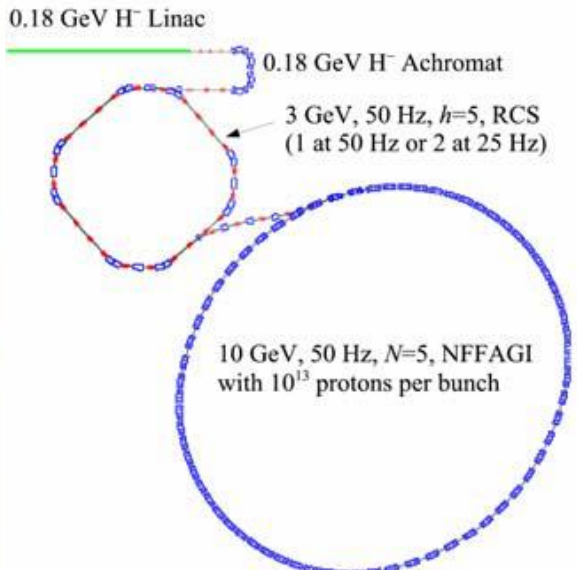
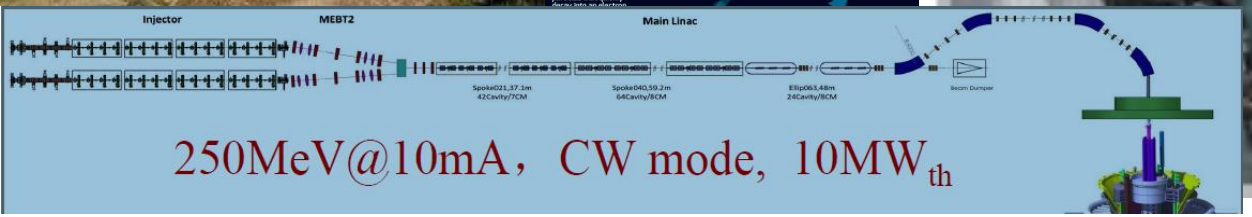
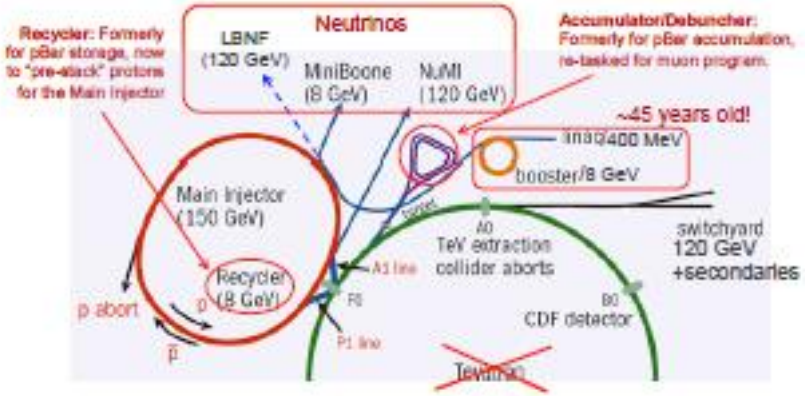


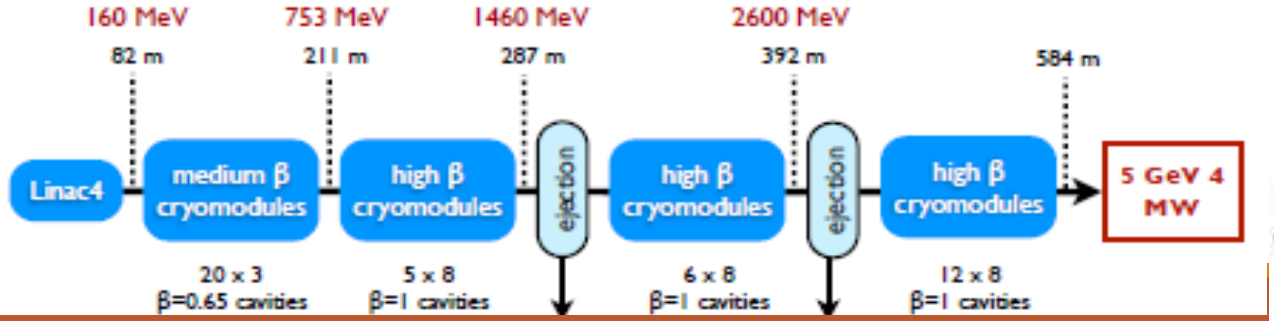


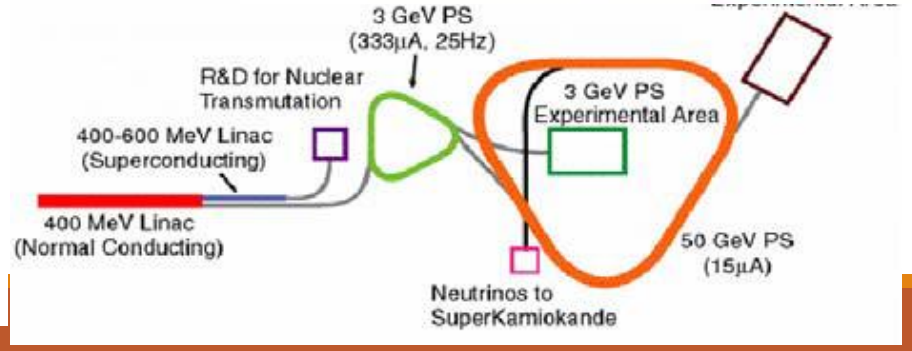


Proton Drivers

ALESSANDRA M LOMBARDI (BE/ABP)







What for ?

neutrinos - FNAL (PIP II), JPARC but also ESS

neutrons – SNS, ESS, ISIS-RAL, PSI.

muons – ISIS-RAL, PSI, TRIUMF, JPARC, FNAL….

Accelerator Driven Systems – ChineseADS, MYRRHA

Radioactive Ion Beams - TRIUMF

Non exhaustive list!!

Just a collection of examples

Muons – what you can do with them

Surface muons (from “stopped” pions in the target, best energy of the impinging protons is around 500 MeV) are low energy high polarisation muons that can be used for

- Mu2e
- Mu2egamma
- Mu2 triple e
- g-2, spin precession experiment

High energy muons (from decay in flight of pions exiting the target, the energy of the impinging protons has to be above 4-5 GeV, production rate is depending on the power) can be further manipulated to obtain muons under controlled conditions of emittance, at high energy (50GeV), energy spread and directionality – not in this talk.

Existing facilities for CLFV with muon decays

Experiment	Beam	Momentum [MeV/c]	Rates [s^{-1}]	BBeamline
MEG ($\mu \to e\gamma$) [25]	μ^+	29.8	$3 \cdot 10^7$	πE5 at PSI
MuLan [24]	μ^+	29.8	$8 \cdot 10^6$	πE3 at PSI
TWIST [26]	μ^+	29.8	$< 5 \cdot 10^3$	TRIUMF
MEG upgrade* ($\mu \to e\gamma$) [27]	μ^+	29.8	$7 \cdot 10^7$	πE5 at PSI
Mu2e* ($\mu^- \to e^-$) [9]	μ^-	~ 40	10^{10}	FNAL
$\mu^+ \to e^+e^-e^+$ (Phase 1)* [29]	μ^+	29.8	$< 1 \cdot 10^8$	πE5 at PSI
$\mu^+ \to e^+e^-e^+$ (Phase 2)* [29]	μ^+	29.8	$2 \cdot 10^9$	HIMB at PSI

Laboratory / Beam Line	Energy / Power	Present Surface μ^+ rate (Hz)	Future estimated μ^+/μ^- rate (Hz)
PSI (CH)	(590 MeV, 1.3 MW, DC)		
LEMS	"	$4 \cdot 10^8$	
πE5	"	$1.6 \cdot 10^8$	
HiMB	(590 MeV, 1 MW, DC)		$4 \cdot 10^{10}(\mu^+)$
J-PARC (JP)	(3 GeV, 1MW, Pulsed) currently 210 KW		
MUSE D-line	"	$3 \cdot 10^7$	
MUSE U-line	"		$2 \cdot 10^8(\mu^+)$(2012)
COMET	(8 GeV, 56 kW, Pulsed)		$10^{11}(\mu^-)$(2019/20)
PRIME/PRISM	(8 GeV, 300 kW, Pulsed)		$10^{11-12}(\mu^-)(> 2020)$
FNAL (USA)			
Mu2e	(8 GeV, 25 kW, Pulsed)		$5 \cdot 10^{10}(\mu^-)$(2019/20)
Project X Mu2e	(3 GeV, 750 kW, DC to pulsed)		$2 \cdot 10^{12}(\mu^-)(> 2022)$

"surface muons, coming from pion decaying in the target ,near the surface. High polarization, very monochromatic

2014

Frederic Teubert

CERN, PH Depart

Proton beams used to produce muons

		energy	power	time structure	
PSI	Cyclotron	590 MeV	1.4MW	DC	
TRIUMF	Cyclotron	500 MeV	0.005	DC	
FNAL-present	Linac + Synchr	400MeV + 8 GeV	0.025MW	Pulsed	
FNAL - upgrade	Different options	8GeV	0.06 to 3.8MW	Pulsed to DC	
JPARC	Linac + Synchr	400MeV + 3 GeV	1MW	Pulsed	
ISIS	Linac + Synchr	800MeV	0.05	Pulsed	Only 5% of protons used to produce muons

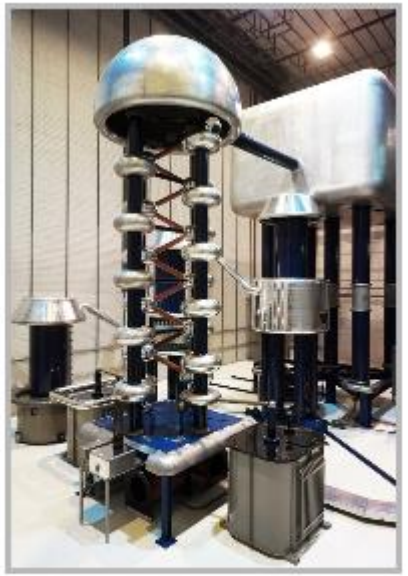
PSI – world's most intense continuous μ source

The carbon target of the SμS muon source

2 carbon targets

6 muon experiments

Possibility of SLOW mu
(decelerated)



The PSI Cockroft-Walton accelerator – the first stage of the proton accelerator facility

The large PSI Ring Cyclotron accelerates protons to about 80% of the speed of light. The magnets are coloured turquoise and the four acceleration cavities dark grey.

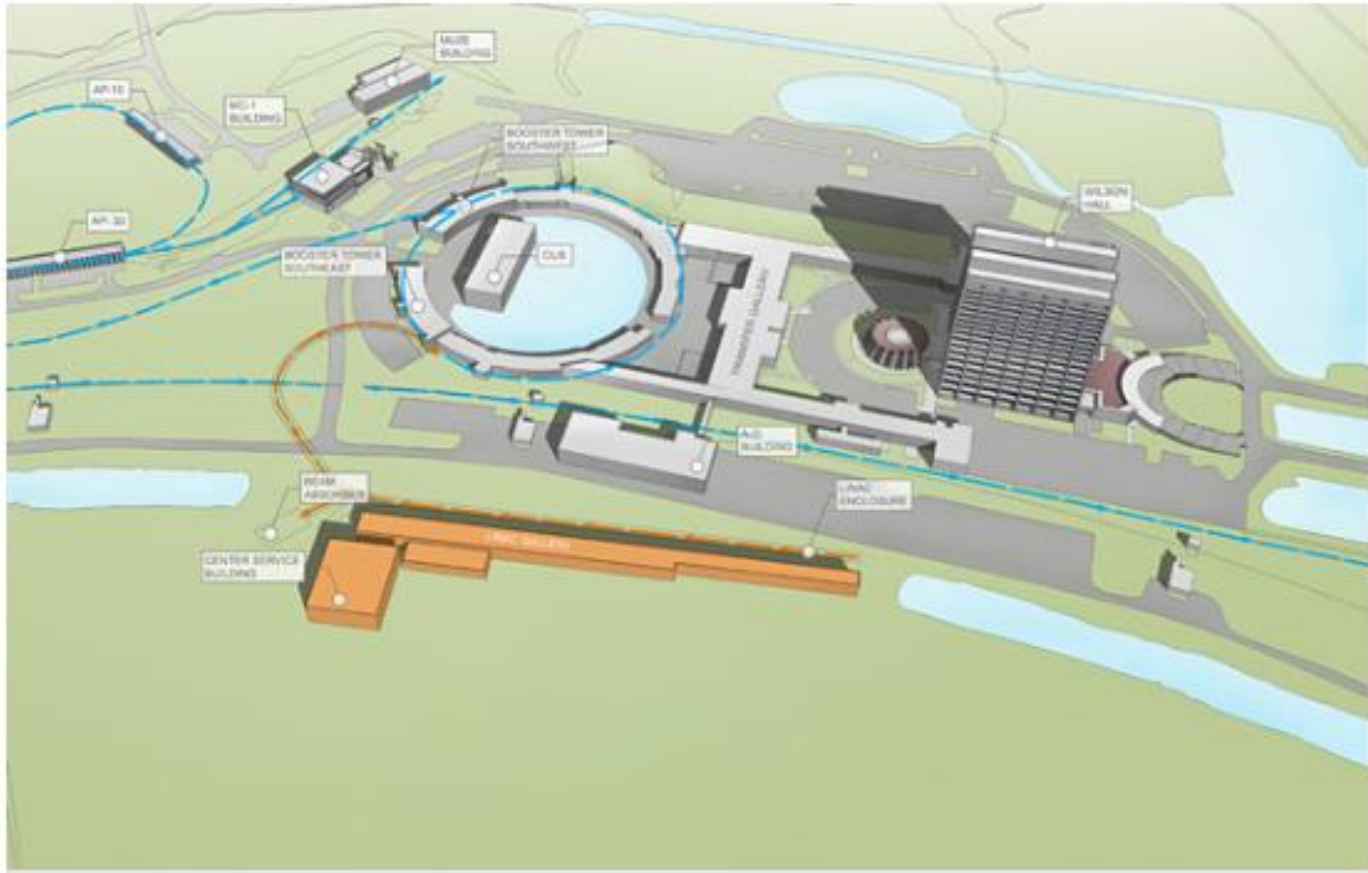
Protons : 2.4 mA at 590 MeV , 1.4 MW

FNAL PIP-II

800 MeV SC linac based on ILC technology

8 GeV Booster

Drawing of Fermilab's planned Muon Campus, future home of the Muon g-2 experiment



The PIP-II linac will be situated on the infield of the (decommissioned) Tevatron accelerator on the Fermilab site.

Neutrino Facility :LBNF and DUNE

FNAL - upgrades

- Staged increase in proton throughput
- Aimed at long baseline neutrinos
- 8GeV linac is the solution to achieve multi MW beam power

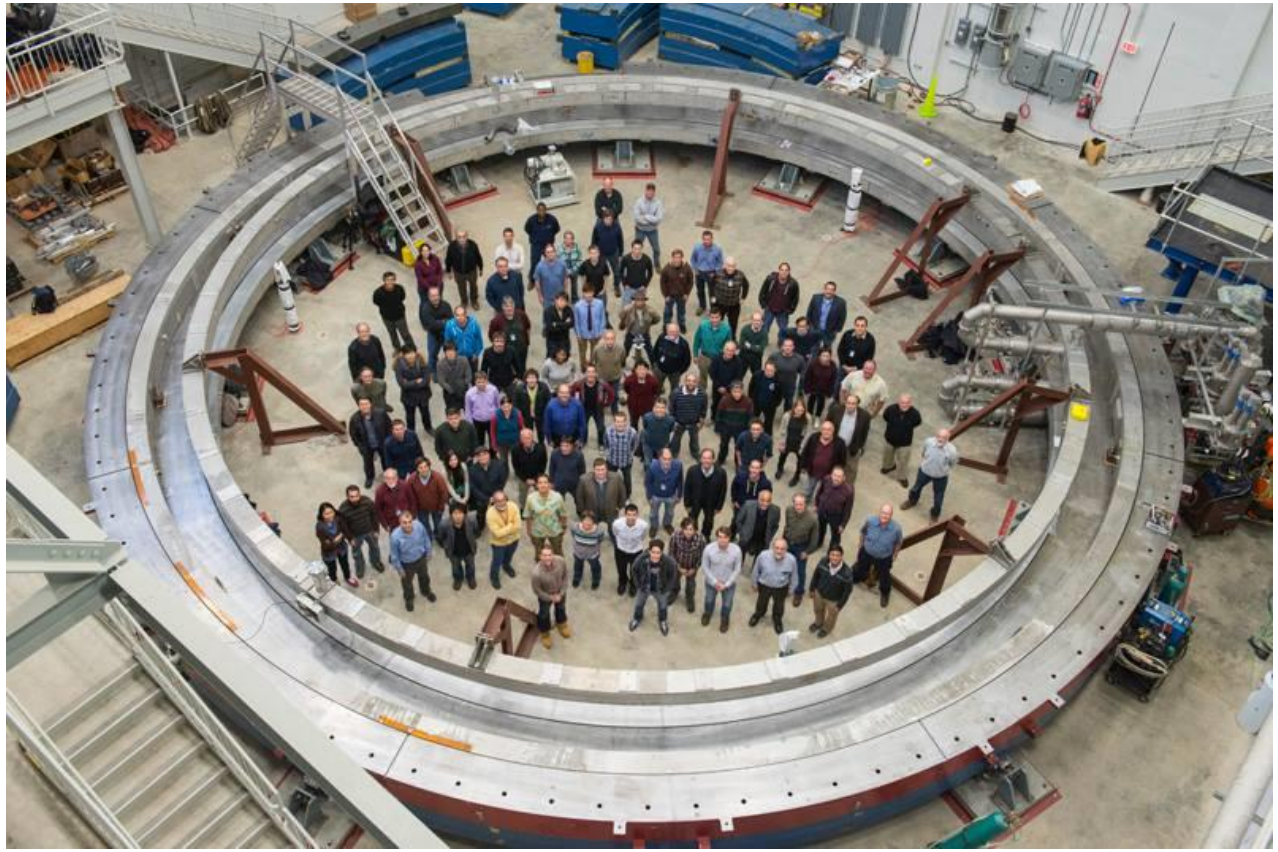
Table 1: Proton Source Parameters for Current Best Performance, the Booster in PIP-II, and for Both the Linac and RCS Options for Future Upgrades. Challenging parameters are highlighted in red.

	Current (best)	PIP-II (Existing Booster)	New 8 GeV Linac	New 8 GeV RCS
MI/Recycler				
Beam Energy [GeV]	120	120	120	120
Cycle Time [s]	.615	1.2	1.2	1.45
Protons per pulse [1e12]	38	75	160	190
Beam Power [MW]	1.2	1.2	2.5	2.5
Proton Source				
Injection Energy [GeV]	0.4	0.8	0.8	0.8-2.0
Extraction Energy [GeV]	8.0	8.0	8.0	8.0
Protons per Pulse [1e12]	3.3	6.4	160	32
Beam Power to Recycler/MI [kW]	38	82	168	168
Maximum Beam Power to 8 GeV Program [kW]	25	82	3872	645

Table 2: Comparison of Rapid Cycling Synchrotrons, including J-PARC. The current tune shift for the Booster is probably an overestimate.

	Booster (Now)	Booster (PIP-II)	New RCS (800 MeV)	New RCS (2 GeV)	J-PARC RCS
Injection Energy [MeV]	400	800	800	2000	400
Extraction Energy [MeV]	8000	8000	8000	8000	3000
Emittance (normalized) [π-mm-mr]	15	15	20	20	102
Protons/batch [1e12]	4.2	6.6	32	32	84
Tune Shift Parameter	-0.43	-0.11	-0.41	-0.13	-0.28
Frequency [Hz]	15	20	20	20	25
Output power, max [kW]	81	169	819	819	1008

g-2 at FNAL



Back to CERN – year 2007

In its June 2007 session the CERN Council has approved the White Paper "Scientific Activities and Budget Estimates for 2007 and Provisional Projections for the Years 2008-2010 and Perspectives for Long-Term", which includes construction of a 160 MeV H- linear accelerator called LINAC4, and the study of a 5GeV, high beam power, superconducting proton Linac (SPL).

Expectations :

LINAC4

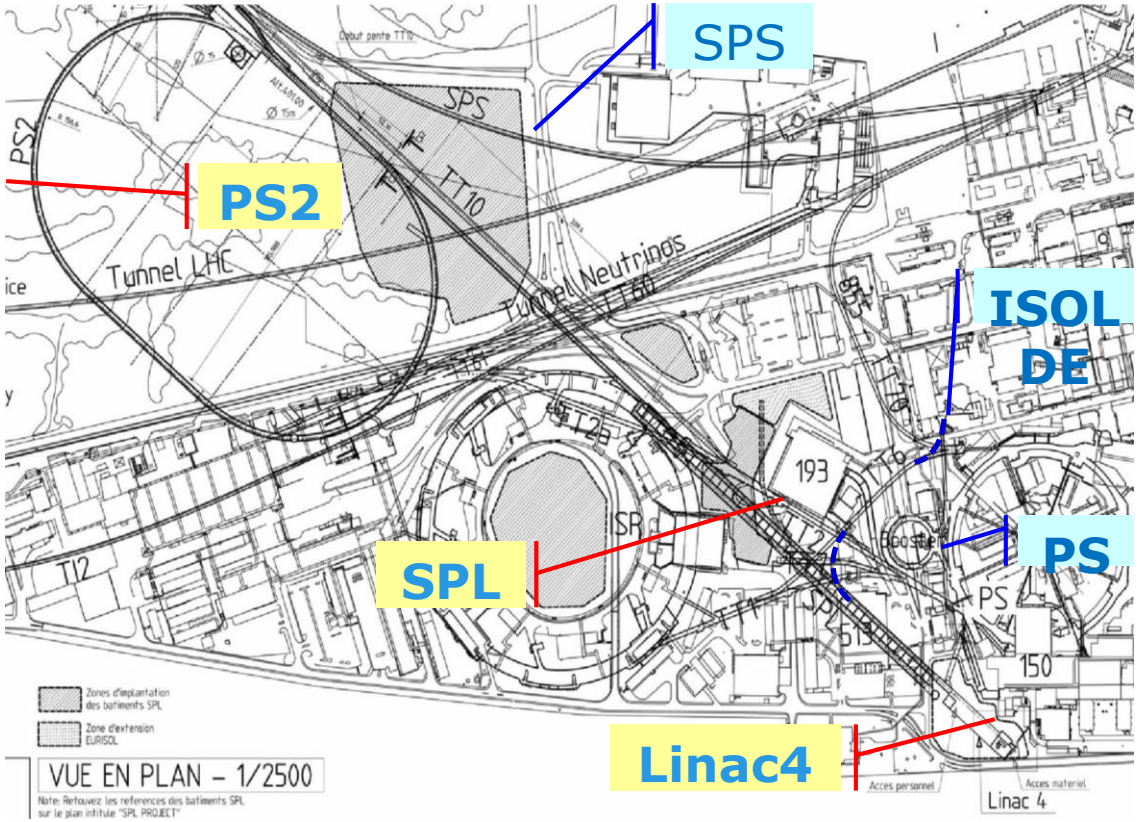
- Rejuvenation of the LINAC (Linac2 dates from 1978)
- Higher performance from the PS Booster (2 X brightness)
  - space charge tune shift decreased by 2;
  - low loss injection process ,
  - Better longitudinal injection (chopping and “energy painting”)

LP-SPL (+PS2)

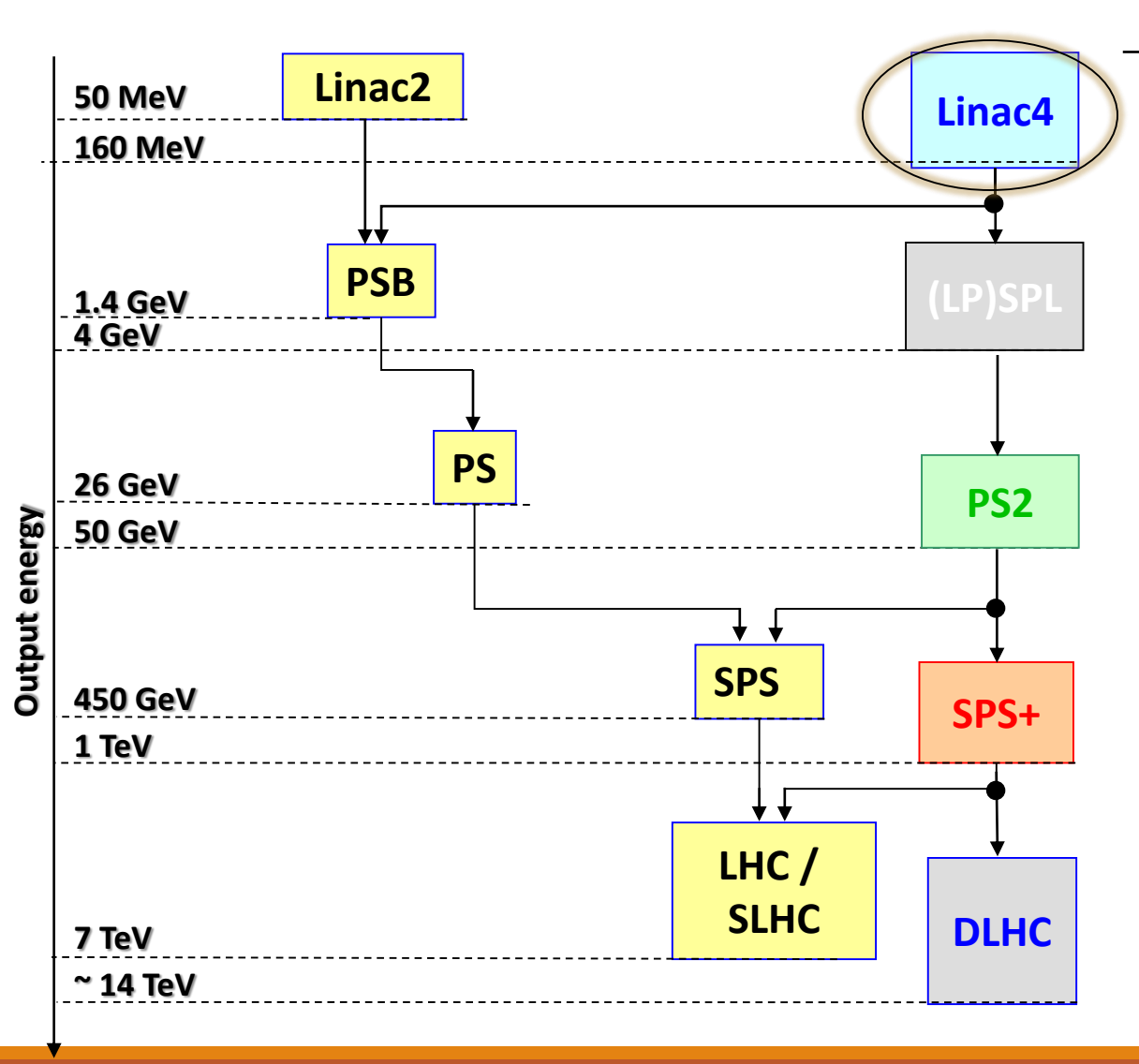
- Rejuvenation of injectors (PBS,PS date from 1972 and 1559)
- Higher performance from SPS and more…
  - SPS could deliver 2.2X the ultimate LHC beam;
  - Potential to increase the intensity per pulse ,
  - 50% of the LP-SPL pulses are available for other physics (ISOLDE/EURISOL, LHeC…)

SPL

- High power (4MW) beam available for neutrino factory,…



Upgrade with a look to the future



2010 :decision to upgrade the existing injectors (LIU project)

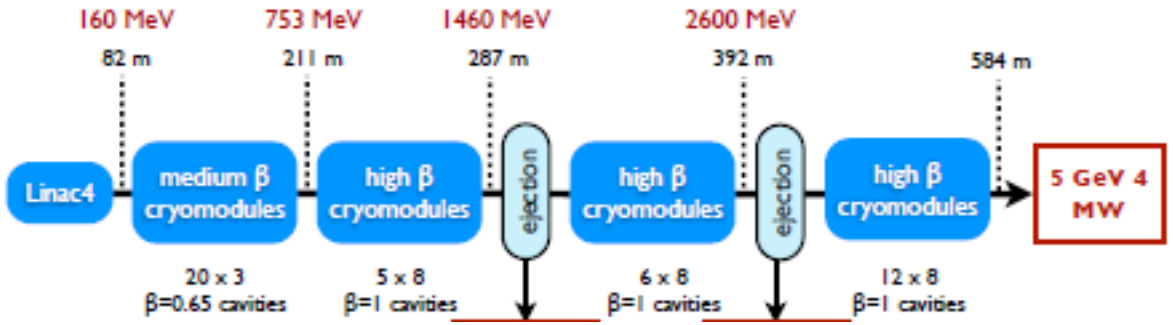
(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)

can we have more than 10^{11} μ/sec , continuously ?

Conceptual Design of the Low-Power and High-Power SPL

CERN–2014–007
5 November 2014

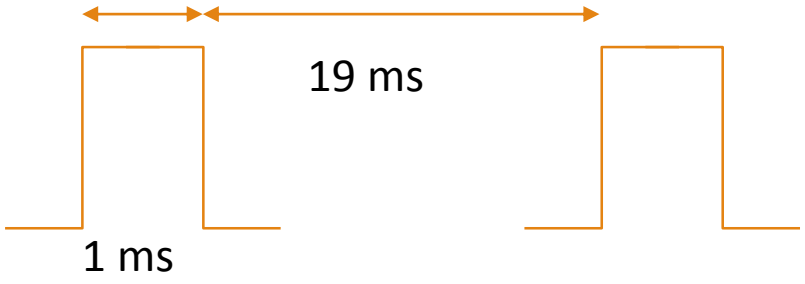
Superconducting H⁻ Linac at CERN



Continuous is not possible at the LINAC4-SPL

Table 2.2: Nominal beam parameters

Parameter	Units	HP-SPL Low-current	HP-SPL High-current	LP-SPL
Energy	GeV	5	5	4
Beam power	MW	4	4	0.144
Repetition rate	Hz	50	50	2
Average pulse current	mA	20	40	20
Peak pulse current	mA	32	64	32
Source current	mA	40	80	40
Chopping ratio	%	62	62	62
Beam pulse length	ms	0.8	0.4	0.9
Protons per pulse	10^{14}	1.0	1.0	1.13

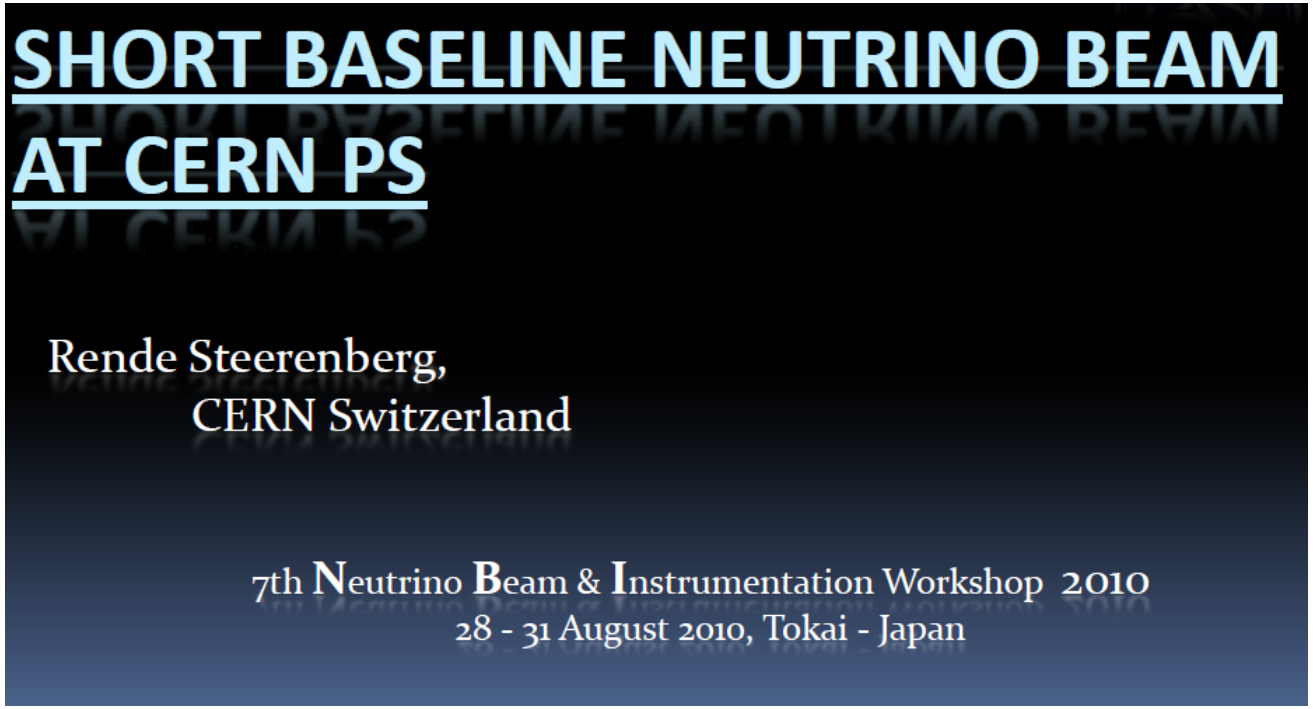


If we wanted a continuous beam

- the design approach for CW linac is different than the one we used for LINAC4/SPL
- we should redesign the SC part of the HP-SPL with lower gradient (from 25MV/m to 17MV/m)
- in the same foot print of the SPL (600m) we could achieve 2 or 2.5 GeV , 2MW
- we can capitalise on R&D done for SPL / synergy with ESS linac

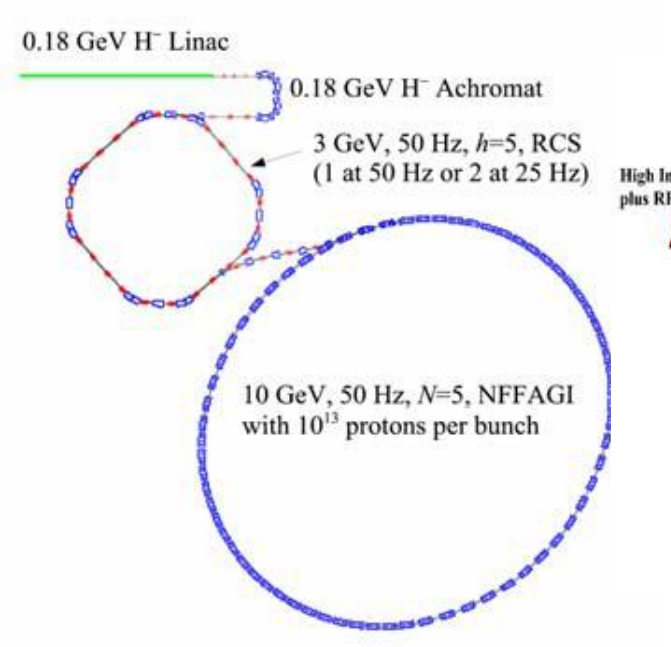
Use what we have , e.g. PS

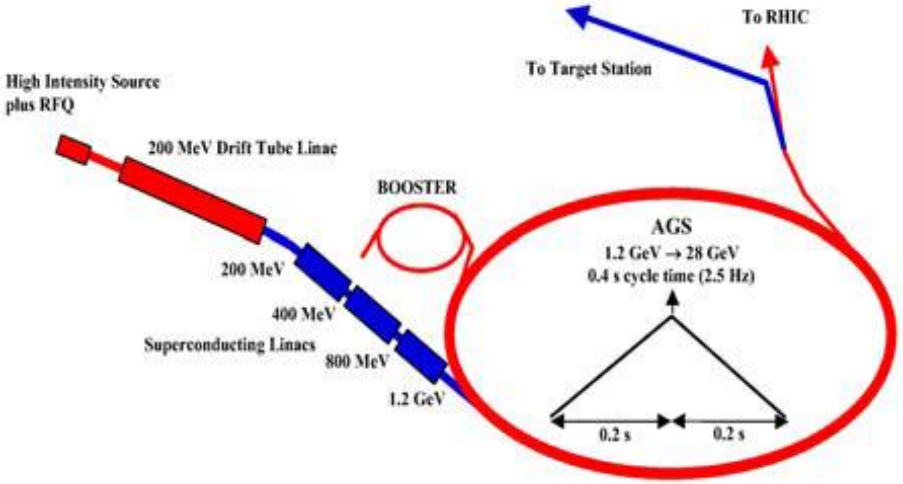
- To re-use the tunnel, the target and decay tube of the old neutrino oscillation experiment in the TT7 tunnel of the PS
- PS can provide 2-3x10^{13} protons per pulse (1.2sec) of 20GeV/c
- Already proposed for a short baseline neutrino experiment, could be used for muons.
- We need to look into the details…..

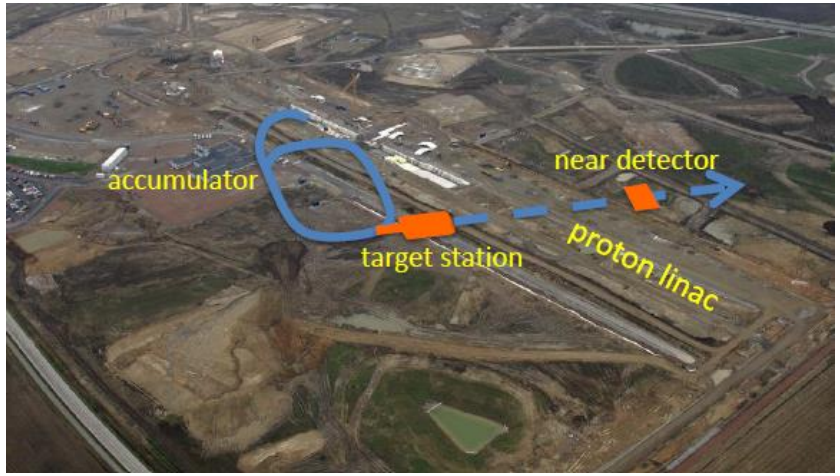


Protons drivers followed by nu-factories

GeV Multi Megawatt Pulsed







Forget proton drivers!

Positron beam (45 GeV) interacting on a plasma target

Could produce Muons with E around 20 GeV (γ=200; lifetime about 500µsec)

And very small emittance

	positron source	proton source
μ rate[Hz]	$9 \cdot 10^{10}$	$2 \cdot 10^{13}$
μ/bunch	$4.5 \cdot 10^{7}$	$2 \cdot 10^{12}$
normalised ϵ [μm-mrad]	40	25000

TUPMY001 Proceedings of IPAC2016, Busan, Korea

VERY LOW EMITTANCE MUON BEAM USING POSITRON BEAM ON TARGET

M. Antonelli, M. Biagini, M. Boscolo, A. Variola INFN/LNF, Frascati, Italy
P. Raimondi, ESRF Grenoble, France
G. Cavoto INFN Roma, Italy E. Bagli INFN Ferrara, Italy

....and also

M.W. Krasny

muon production using gammas

Tomorrow at 14:20

Discussion of the scientific potential of muon beams

18 November 2015
CERN
Europe/Zurich timezone

HIGS as a source of high intensity secondary beams

- *High Intensity highly polarised electron and positron beams (~10^{17} 1/s)*
- *Polarized muon and neutrino beams (~10^{12} 1/s and 4x10^{19} 1/year)**
- *High intensity monochromatic neutron beams (GDR in heavy nuclei as s a source of neutron beam: $\gamma + A \rightarrow A-1 + n$) (~10^{15} 1/s)*

Conclusions

There is a lot of very advanced activity on muons outside CERN

In this talk I presented first ideas/options not in the baseline

- SPL like LINAC
- Using PS and TT7

This is not the end….. Listen to Ken Long’s talk on Nu – STORM