Possible Neutrino Production Beam and Beam Line for the CERN PS

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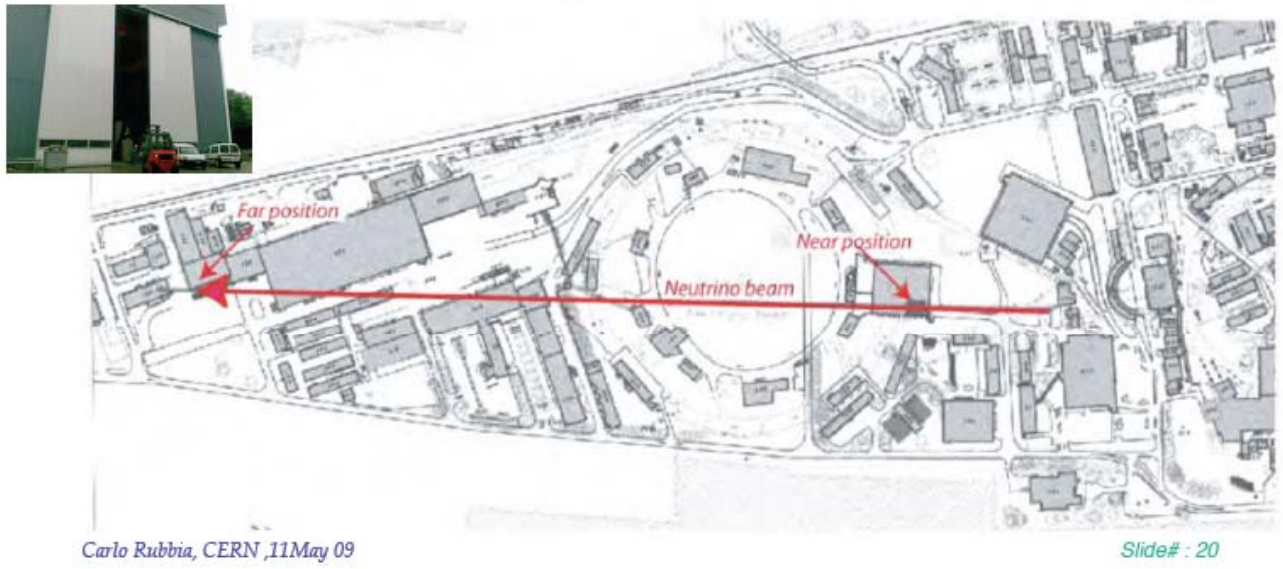
Introduction

- This presentation is based on a request to investigate the feasibility of providing beam to a proposed experiment for the search of $\nu_\mu \rightarrow \nu_e$ oscillations.
- The first proposal for the experiment is documented in the 1999 SPSC report: *CERN-SPSC 99-26*
- A more recent presentation was give by C. Rubbia during the May 2009 workshop: *"New Opportunities in the Physics Landscape at CERN"*
- In the following slides I will look at the feasibility from the PS machine and scheduling side, with a quick glance to the beam line.
- The experimental collaboration would like to use the presented information for future presentations and their letter of intent to the SPSC, end of this year.

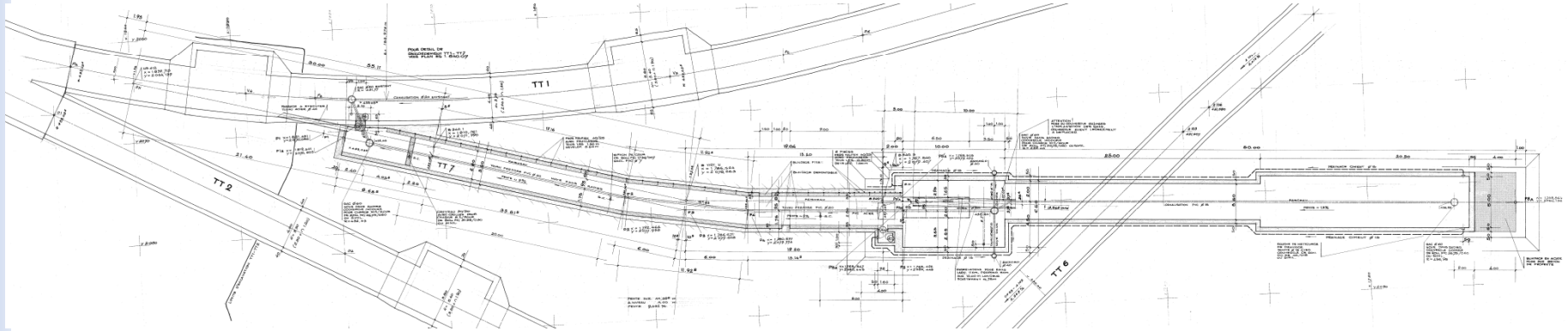
The experiment

- The main ideas are:
  - To have 2 liquid argon detectors (10 t and 500 t) on the CERN Meyrin site
  - To re-use the tunnel, the target and decay tube of the old neutrino oscillation experiment in the TT7 tunnel of the PS
  - To have the PS delivering beam for this experiment.



The TT7 tunnel

- The TT7 tunnel was in the past also used for a neutrino oscillation experiment (PS180, early 80's)



- It can be fed with beam from the PS using the TT2 beam line, which needs to be extended with another beam line branching of to TT1 and then to the target in the TT7 tunnel
- At present there is light radio active waste storage in the last part of the TT7 tunnel, which can be removed

The experimental requirements

- There are few, but some challenging, requirements:
  - 2.5 x 10^{20} p.o.t. in 2 years running
  - Primary beam momentum of ~ 19 GeV/c
  - The proton beam hitting the target should be more or less parallel and interact with a target of 6 mm diameter and 80 cm length
  - Running preferably 2012 and 2013

Requirements from A&T sector

- There are 3 points to address:
  - What beam can we provide from the PS ?
  - How can we fulfill the required integrated intensity, taking into account the present and future super cycle requirements ?
  - Beam line design and construction up to the target

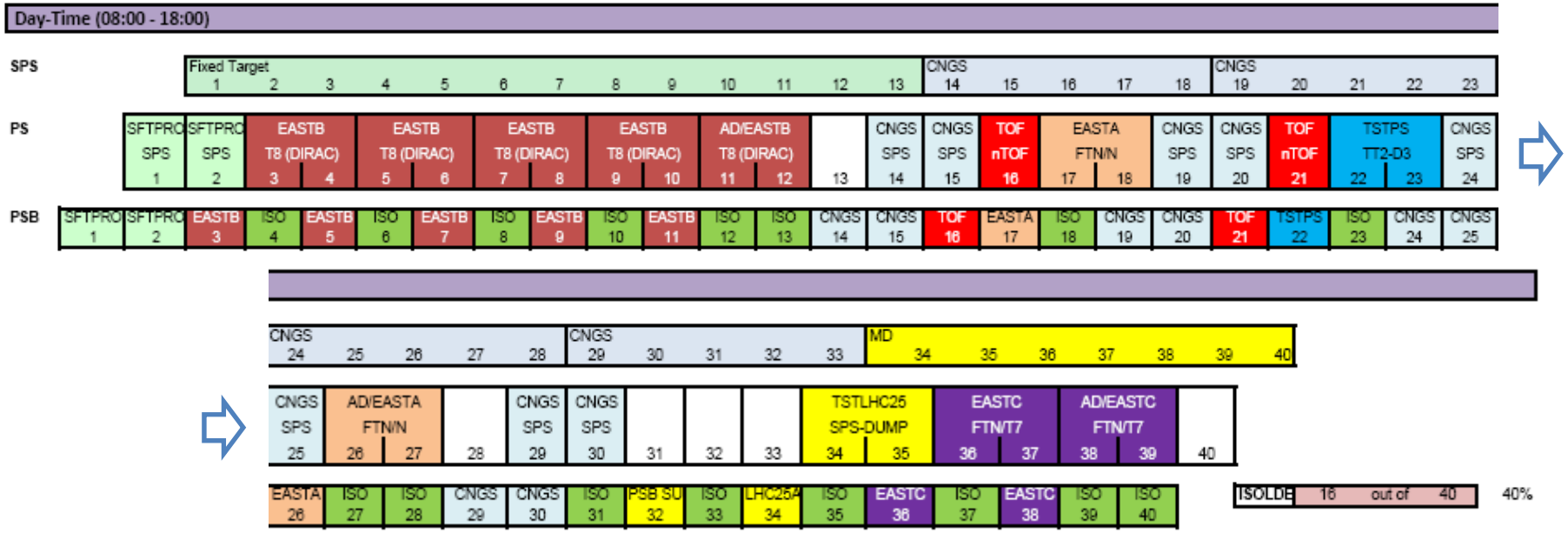
Possible beam from PS

- I propose a cycle similar to nTOF, but with 8 bunches:
  - Momentum: 20 GeV/c
  - Total intensity: 3 x 10^{13} protons per cycle
  - 8 bunches equally spaced with a bunch length of approximately 50 ns each
  - dp/p at (1σ): ~ 0.75x10^{-3}
  - Fast extraction (2.1 micro seconds)
  - Approximate physical transverse emittances at PS extraction (1σ):
    - Horizontal: ~ 11 mm·mrad
    - Vertical: ~ 10 mm·mrad

Required integrated intensity planning

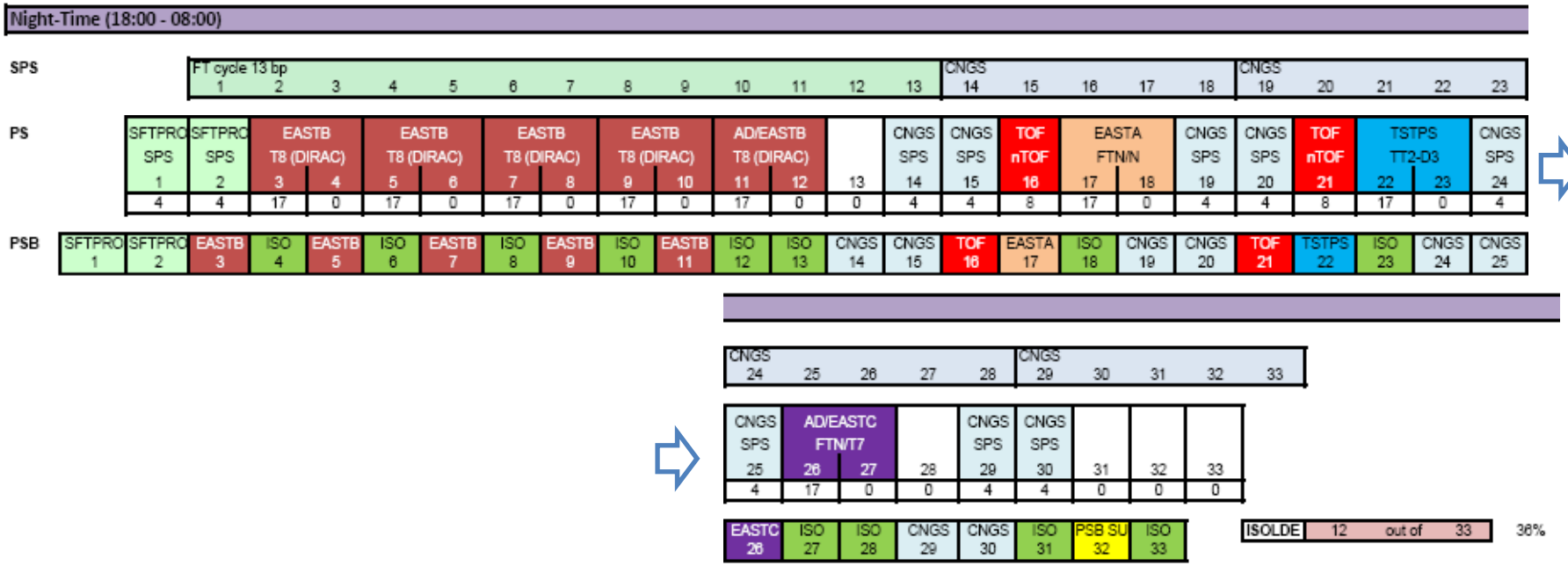
- Experimental requirement 2.5 x 10^{20} p.o.t. in 2 years
- I assume that in 2012 and 2013 the super cycles and users are similar to the present ones.
  - Daytime (10 hrs): 40 bp, 48 seconds (1xFT, 4xCNGS, 1xMD)
  - Night-time (14 hrs): 33 bp, 39.6 seconds (1xFT, 4xCNGS)
- Intensity per cycle: 3 x 10^{13} protons
- Assuming we run 180 days per year, then this would require 12 cycles of 1 bp for an average super cycle length of 36 bp, 43.2 seconds (i.e. 33% duty cycle).
- This place is at present not available in the super cycle.

Typical 2009 Day-time Super Cycle



- Super cycle length of 48 seconds is determined by SPS (FT, CNGS, MD)
- PS East Area:
  - 5 x EASTB for DIRAC
  - 2 x EASTA for North Branch (with parasitic nTOF)
  - 2 x EASTC for T7 Irradiations (with parasitic nTOF)
- nTOF: 2 dedicated cycles + 3 to 4 Parasitic cycles (~ 5.5 x 10^{11} protons/second)
- ISOLDE: ~40% of the PSB cycles (1 PSB SU cycle for setting up)
- TSTPS for setting up and MD in PS

Typical 2009 Night-time Super Cycle



- Super cycle length of 39.6 seconds is determined by SPS (FT, CNGS, MD)
- PS East Area:
  - 5 x EASTB for DIRAC
  - 1 x EASTA for North Branch (with parasitic nTOF)
  - 1 x EASTC for T7 Irradiations (with parasitic nTOF)
- nTOF: 2 dedicated cycles + 2 Parasitic cycles (~ 5.4 x 10^{11} protons/second)
- ISOLDE: ~36% of the PSB cycles (1 PSB SU cycle for setting up)
- TSTPS for setting up and MD in PS

Possible Future Super Cycle Changes

- The Dirac experiment (PS212) mentioned in an SPSC presentation to have plans to move to the SPS after 2011.
  - Presentation at SPSC 16 April 2009:
    - http://cdsweb.cern.ch/record/1172364/files/SPSC-SR-045.pdf
  - They occupy 10 bp's in the day and night super cycles
  - However, this would only liberate 5 bp's in the PSB, keeping the ISOLDE duty cycle unchanged
- nTOF requires an increase in number of integrated protons per year and thus number of cycles per super cycle

Assumptions for Possible Scenario

- Assume the following:
  - Similar super cycles than in 2009
  - No EASTB (DIRAC / PS212)
  - Keep the ISOLDE duty cycle unchanged
  - Anticipate request for increase of yearly integrated number protons from nTOF.
  - 180 days of physics run per year
  - Machine availability is not taken into account
  - No limit of number of cycles in PS super cycle (POPS)
- This results in 7 cycles per super cycle day and night to be shared between the nTOF and the TT7 neutrino experiments

nTOF cycle and beam

- The dedicated nTOF cycle produces 1 bunch of $7x10^{12}$ protons on harmonic 8.
- This bunch is shortened from ~ 50 ns to < 25ns and then fast extracted to the nTOF target
- The remaining 7 buckets are empty and unused.
- They could potentially be used for the TT7 neutrino experiment.
- This way 1 cycle is efficiently used to share beam between the nTOF and the TT7 neutrino experiment.

nTOF beam measurements ➡

nTOF & TT7 Cycle Sharing Proposal

- Accelerate $3x10^{13}$ protons in 8 bunches on harmonic 8 up to 20 GeV/c
  - Resulting in $3.75x10^{12}$ protons per bunch
  - $3x10^{13}$ is a good value for stable operation
- TT7 Neutrino's:
  - 7 bunches to the TT7 neutrino target
  - Resulting in $2.63x10^{13}$ p.o.t. per cycle
  - 7 bunches over less than 2 µs
- nTOF:
  - 1 bunch to nTOF target
  - Resulting in $3.75x10^{12}$ p.o.t. per cycle

Possible Yearly Integrate Intensities

- Under the assumed conditions the PS could provide:
  - nTOF only cycles: *Detailed calculation* ➡
    - Resulting in 7 dedicated and 4 parasitic nTOF cycles
    - Total integrated intensity of 2.17×10^{19} p.o.t.
    - This is nearly 200% more than committed in 2009
  - nTOF and TT7 sharing cycles: *Detailed calculation* ➡
    - Resulting in 7 TT7/nTOF sharing cycles and 4 parasitic nTOF cycles
    - nTOF part:
      - Total integrated intensity of 1.34×10^{19} p.o.t.
      - This is 84% more than committed in 2009
    - TT7 neutrino part:
      - 6.69×10^{19} p.o.t. From TT7/nTOF shared cycles
      - This would require 3.74 runs (years) to obtain the required 2.5×10^{20} p.o.t. which is actually requested in 2 years

Possibilities to shorten TT7 run

- To shorten the TT7 run from 3.74 years one could consider the following:
  1. Increase the run duration (assumed at 180 days)
  2. Decrease ISOLDE duty cycle
  3. Produce not all, but some cycles in parallel with nTOF
  4. Push for higher intensities, which is challenging and not guaranteed until proven.
  5. Faster cycling of PSB and PS, requiring substantial amount of time to study and implement and of which the net result is not clear yet.
- The first 3 points are to be defined by the research board, the 4th and 5th would mean beam studies for BE.

Two Beam Sharing Options

- For sharing the nTOF and TT7 beam there are two options:
  1. Single extraction of 8 bunches with Kicker/Septum combination in the TT2 line:
     - (very) Expensive
     - Could work with single extraction from PS
     - All bunches would see bunch rotation (required for nTOF)
  2. Double batch extraction with fast switching magnet in the TT2 line:
     - Cheaper
     - Requires adapting some extraction elements
     - 7 non shortened bunches for TT7 and 1 shortened bunch for nTOF

Single Batch Extraction Scheme

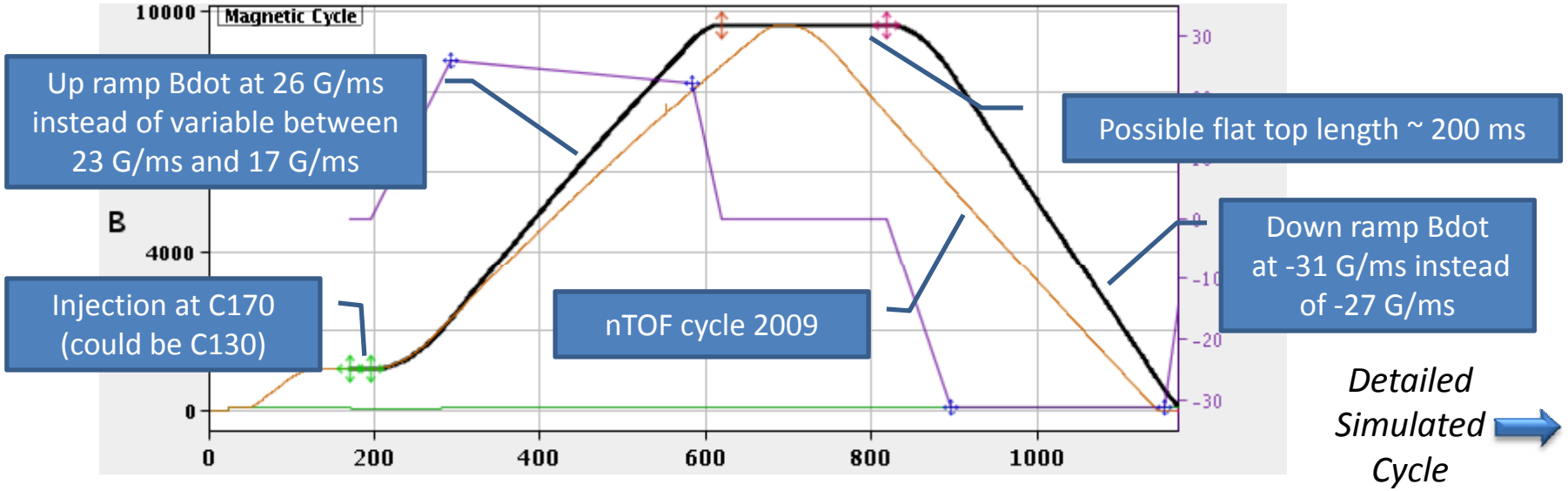
- Present TOF cycle can be used:
  - $3x10^{13}$ on harmonic 8 and single batch fast extraction is fairly standard and clean
  - TT7 will also receive short bunches
- Kicker and (outside vacuum) septum to be developed
- Maximum TT2 line kicker rise time ~ 200 ns
- More complicated implementation in TT2

Double Batch Extraction Scheme

- Flat top on TOF cycle needs to be prolonged, which is only possible when POPS is operational (foreseen for 2011)
- Requires adapting extraction elements to make double batch extraction possible again
- Easier implementation in TT2 line

Cycle Requirements

- At present the nTOF cycle flat top is too short for the proposed 2 extractions.
  - POPS will allow increase of Bdot and to maintain it constant during the ramp
  - New MPS regulation allows earlier injection by ~ 40 ms
- This would result in the following magnetic cycle:



Extraction requirements

- The extraction elements need to be able to pulse twice within ~ 200 ms interval:
  - Extraction bump
    - Requires (most probably adding capacitors, switch and timing)
  - Kick enhancement quadrupoles.
    - Requires (most probably adding capacitors, switch and timing)
  - Extraction septum
    - Requires (most probably adding entire power converter)
    - Additional studies and tests on magnet to be done
  - Extraction kicker
    - The possibility to kick twice on the same flat top with minimum 30 ms interval is already available
- Our TE/EPC colleagues are looking into more details to make it possible to extract twice (incl. rough cost estimate)

nTOF Extraction Settings

TT2/TT7 Transfer Line

- The Transfer line has to be designed and build entirely with either a fast switching magnet or kicker septum combination in the TT2 line
- Some information on the old transfer line is available
- Potential work packages for:
  - Vacuum chambers and pumps
  - Magnets
  - Power converters
  - Beam diagnostics
  - Controls
  - Geometers
  - Cooling and ventilation
  - Access control and safety
  - ...

TT7 Transfer Line Cost Estimate

- A very rough cost estimate for the beam line reconstruction could be obtained in two ways:
  - Taking the FTN beam line price, constructed in 1999/2000, extrapolate to the TT7 length and add an indexation and contingency figure.
  - Or by making a preliminary design (more precise, but requires resources)
- The cost will highly depend on which magnets, power converters, beam pipes etc. can be recuperated
- Since at present there is no manpower available, a preliminary design cannot be made,
- However, a rough estimate based on the FTN line construction price is being made

Conclusions & Outlook (1)

- PS can provide the required beam and integrated intensity under the **assumptions** presented
  - 2.5×10^{20} protons in 3.7 years of 180 days running
  - TOF will receive 85% more than in 2009 committed, but could get nearly 200% more if TT7 would not run
- Sharing the TT7 neutrino and nTOF operation on the same cycle will make more efficient use of the PS and the time available in the super cycle

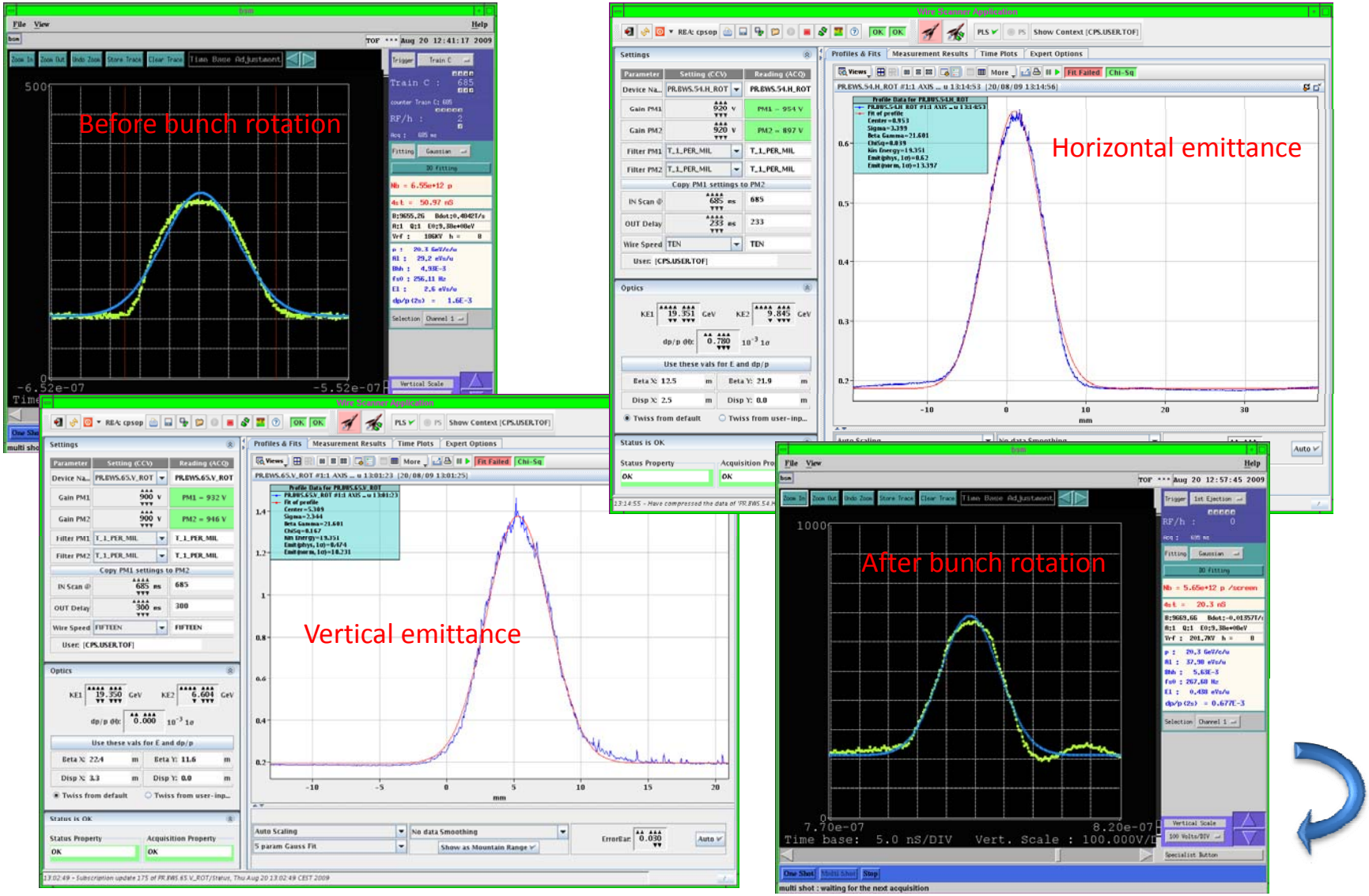
Conclusions & Outlook (2)

- Choice between single batch or double batch extraction needs to be made
  - Slight preference for switching magnet option
  - Rough cost estimate, which is being made, will lead to decision
  - Verification of all rms constraints for double batch extraction case is ongoing
- Rough cost estimate for the TT7 beam line will have to be made on the basis of the FTN construction price as no manpower is available to make preliminary design
- In case the experiment will be approved:
  - Resources will have to be discussed/provided
  - One has to clearly define the responsibilities for all the different parts of the project

Thanks For Your Attention

Additional Slides for Details Below

nTOF beam measurements



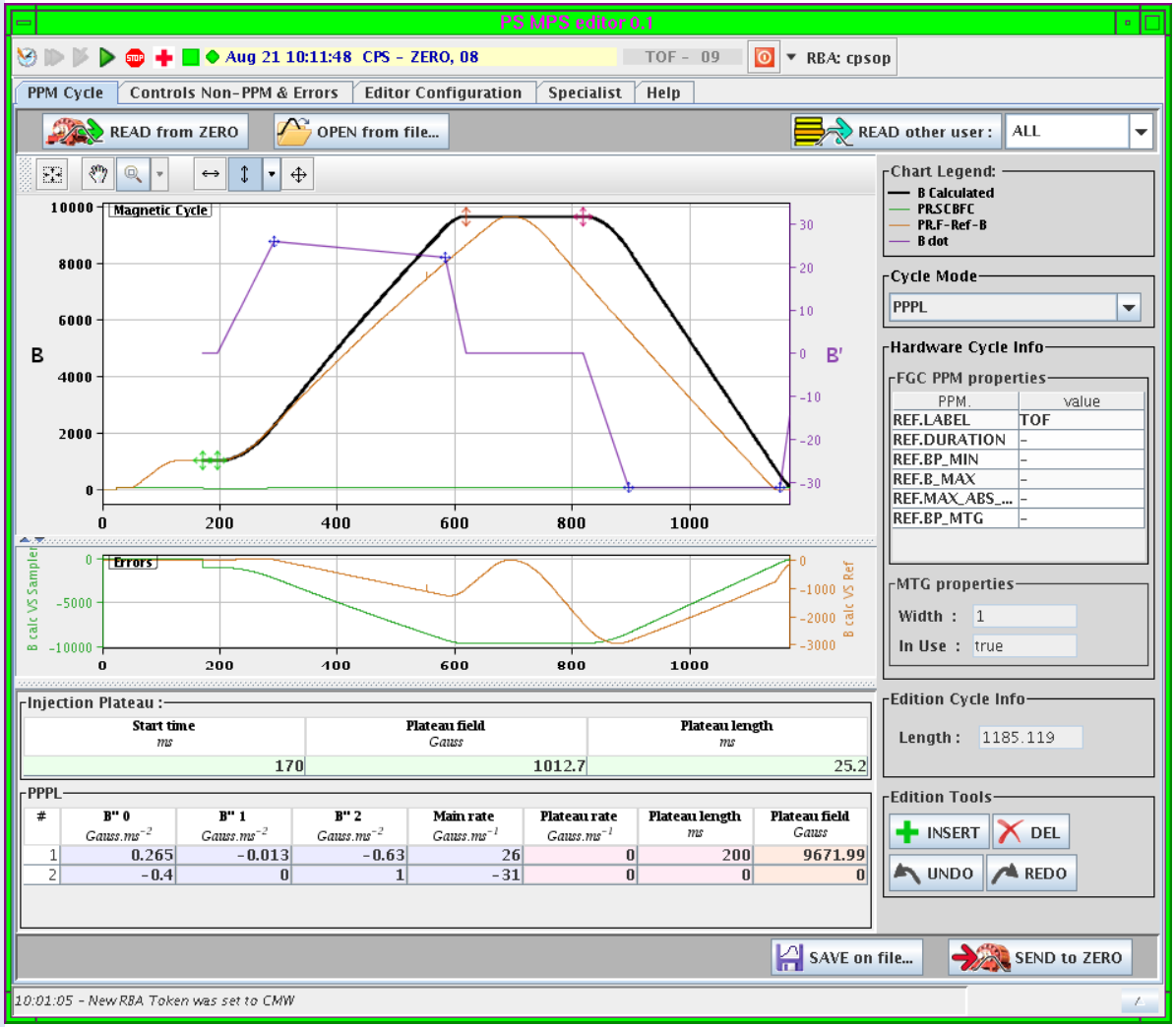
nTOF Only Integrated Intensity Calculation

Calculation for sharing beam on the dedicated TOF cycle:								
Total extracted intensity	7.00E+12	protons						
number of bunches to TOF	1	bunch	resulting in	7.00E+12	p.o.t./cycle			
Daytime duration	10	hours	Daytime TOF flux	1.02E+12	prot./sec.	Integrated intensity TOF daytime	3.68E+16	protons
Daytime super cycle length	40	bp						
Daytime super cycle length	48	seconds						
Number of cycles in daytime S.C.	7							
Nighttime duration	14	hours	Nighttime TOF flux	1.24E+12	prot./sec.	Integrated intensity TOF nighttime	6.24E+16	protons
Nighttime super cycle length	33	bp						
Nighttime super cycle length	39.6	seconds						
Number of cycles in nighttime S.C.	7							
Number of days running	180	days	Average 24 hours TOF flux	1.15E+12	prot./sec.	Integrated intensity TOF 24 hours	9.91E+16	protons
						Integrated intensity TOF per run	**1.78E+19**	**protons**
Calculation for parasitic TOF beam on EAST:								
Parasitic bunch intenisty	3.50E+12	protons						
Number of parasitic cycles daytime	4		resulting in a daytime flux	2.92E+11	prot./sec.	Integrated intensity TOF parasitic day	1.05E+16	protons
Number of parasitic cycles nighttime	3		resulting in a nighttime flux	2.19E+11	prot./sec.	Integrated intensity TOF parasitic night	1.10E+16	protons
						Integrated intensity TOF parasitic 24 hours	2.15E+16	protons
Intensity committed to TOF 2009	7.30E+18							
Intensity required by TT7	2.50E+20	p.o.t./2 years				**Integrated intensity TOF parasitic per run**	**3.87E+18**	**protons**
Intensity required by TT7	1.25E+20	p.o.t./year						
Final results for TOF:								
Total integrated TOF per run	**2.17E+19**	**protons**		**197%**	**Increase w.r.t. 2009**			

nTOF/TT7 Sharing Intensity Calculations

Calculation for sharing beam on the dedicated TOF cycle:								
Total extracted intensity	3.00E+13	protons						
harmonic number	8							
number of bunches to TOF	1	bunch	resulting in	3.75E+12	p.o.t./cycle			
number of bunches to TT7	7	bunches	resulting in	2.63E+13	p.o.t. /cycle			
Daytime duration	10	hours	Daytime TOF flux	5.47E+11	prot./sec.	Integrated intensity TOF daytime	1.97E+16	protons
Daytime super cycle length	40	bp	Daytime TT7 flux	3.83E+12	prot./sec.	Integrated intensity TT7 daytime	1.38E+17	protons
Daytime super cycle length	48	seconds						
Number of cycles in daytime S.C.	7							
Nighttime duration	14	hours	Nighttime TOF flux	6.63E+11	prot./sec.	Integrated intensity TOF nighttime	3.34E+16	protons
Nighttime super cycle length	33	bp	Nightime TT7 flux	4.64E+12	prot./sec.	Integrated intensity TT7 nighttime	2.34E+17	protons
Nighttime super cycle length	39.6	seconds						
Number of cycles in nighttime S.C.	7							
Number of days running	180	days	Average 24 hours TOF flux	6.15E+11	prot./sec.	Integrated intensity TOF 24 hours	5.31E+16	protons
			Average 24 hours TT7 flux	1.28E+13	prot./sec.	Integrated intensity TT7 24 hours	3.72E+17	protons
						Integrated intensity TOF per run	**9.56E+18**	**protons**
						Integrated intensity TT7 per run	**6.69E+19**	**protons**
Calculation for parasitic TOF beam on EAST:								
Parasitic bunch intenisty	3.50E+12	protons						
Number of parasitic cycles daytime	4		resulting in a daytime flux	2.92E+11	prot./sec.	Integrated intensity TOF parasitic day	1.05E+16	protons
Number of parasitic cycles nighttime	3		resulting in a nighttime flux	2.19E+11	prot./sec.	Integrated intensity TOF parasitic night	1.10E+16	protons
						Integrated intensity TOF parasitic 24 hours	2.15E+16	protons
Intensity committed to TOF 2009	7.30E+18							
Intensity required by TT7	2.50E+20	p.o.t./2 years				**Integrated intensity TOF parasitic per run**	**3.87E+18**	**protons**
Intensity required by TT7	1.25E+20	p.o.t./year						
Final results for TOF and TT7:								
Total integrated TOF per run	**1.34E+19**	**protons**		**84%**	**Increase w.r.t. 2009**			
Total integrated TT7 per run	**6.69E+19**	**protons**		**54%**	**of the required yearly intensity**			
Number of TT7 runs required	**3.74**	**years**						

Simulation of Possible Magnetic Cycle



- Precondition:
  POPS is operational

- Bdot up = 26 G/ms
- Bdot down = -31 G/ms
- Injection = 170 ms
- Flat top length = 200 ms
- Extraction 1 = ~ 640 ms
- Extraction 2 = ~ 820 ms

- Possibility to lengthen the FT by another 40 ms by injecting at C130 instead of C170

Extraction Elements Values

- Extraction element settings for nTOF:

Extraction Element	Control Value	Unit
PE.SMH16	21300	A
PE.BSW16-12	360	A
PE.BSW16-14	360	A
PE.BSW16-20	360	A
PE.BSW16-22	360	A
PE.QKE16	1426	A
PE.KFA71	690	KV