AWAKE Status Report
SPSC Meeting
October 21, 2014

AWAKE Collaboration

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AWAKE

AWAKE = Advanced proton-driven plasma WAKEfield acceleration experiment.

Phase I

- Use SPS proton bunch to drive the wake field via the self-modulation instability. 3 10^{11} protons/bunch at 400GeV/particle
- Plasma is laser ionized Rubidium vapor
- Study development of modulation & compare with calculations
- First proton beams in 2016

Phase II

- Inject electrons in proton-driven wake
- Study capture & acceleration process
- Parameter scans & comparison with calculations

Phase III

- Two-cell operation (modulation/acceleration) to demonstrate scalability of acceleration scheme.

Collaboration

John Adams Institute for Accelerator Science,
Budker Institute of Nuclear Physics & Novosibirsk State University
CERN
Cockroft Institute
DESY
Heinrich Heine University, Düsseldorf
Instituto Superior Tecnico
Imperial College
Ludwig Maximilian University
Max Planck Institute for Physics
Max Planck Institute for Plasma Physics
Rutherford Appleton Laboratory
TRIUMF
University College London
University of Oslo
University of Strathclyde

The Collaboration is strong and growing. 16 institutes participating + several requests under consideration.

Revised Organization

Created

a **Physics and Experiment Board**, chaired by **Patric Muggli (MPP)**. Defines physics goals, sets measurement strategy, formulates specifications on beams, plasma cells and related equipment and on the diagnostic devices, and defines the data analysis tools and strategies.

and

a **Technical Board**, chaired by **Edda Gschwendtner (CERN)**. Coordinates design, installation, integration and interfaces of the experiment, resource loaded planning, specifications for technical implementation & monitoring.

Task Groups & Work Packages

Task 1	Metal vapor plasma cell	Erdem Öz	MPP
Task 2	Helicon plasma cell	Olaf Grulke	IPP
Task 3	Pulsed discharge plasma cell	Nelson Lopes	IC/IST
Task 4	Optical sampling diagnostics	Roxana Tarkeshian	MPP
Task 5	Electron spectrometer	Simon Jolly	UCL
Task 6	Simulations	Konstantin Lotov	BINP
Task 7	Electron accelerating structure	Greame Burt	CI
Task 8	Data Acquisition	Peter Sherwood	UCL
Task 9	Laser system	Joshua Moody	MPP
WP	SPS Beam	Elena Shaposhnikova	CERN
WP	Proton and electron beam lines	Chiara Bracco	CERN
WP	Experimental area, integration, installation	Ans Pardons	CERN
WP	Electron injector system	Steffen Doebert	CERN
Sub-WP	Laser beam line and interface	Valentin Fedosseev	CERN
Sub-WP	Synchronisation	Andy Butterworth	CERN
Sub-WP	Radiation Protection	Helmut Vincke	CERN

Proton-Driven Wakefield Acceleration

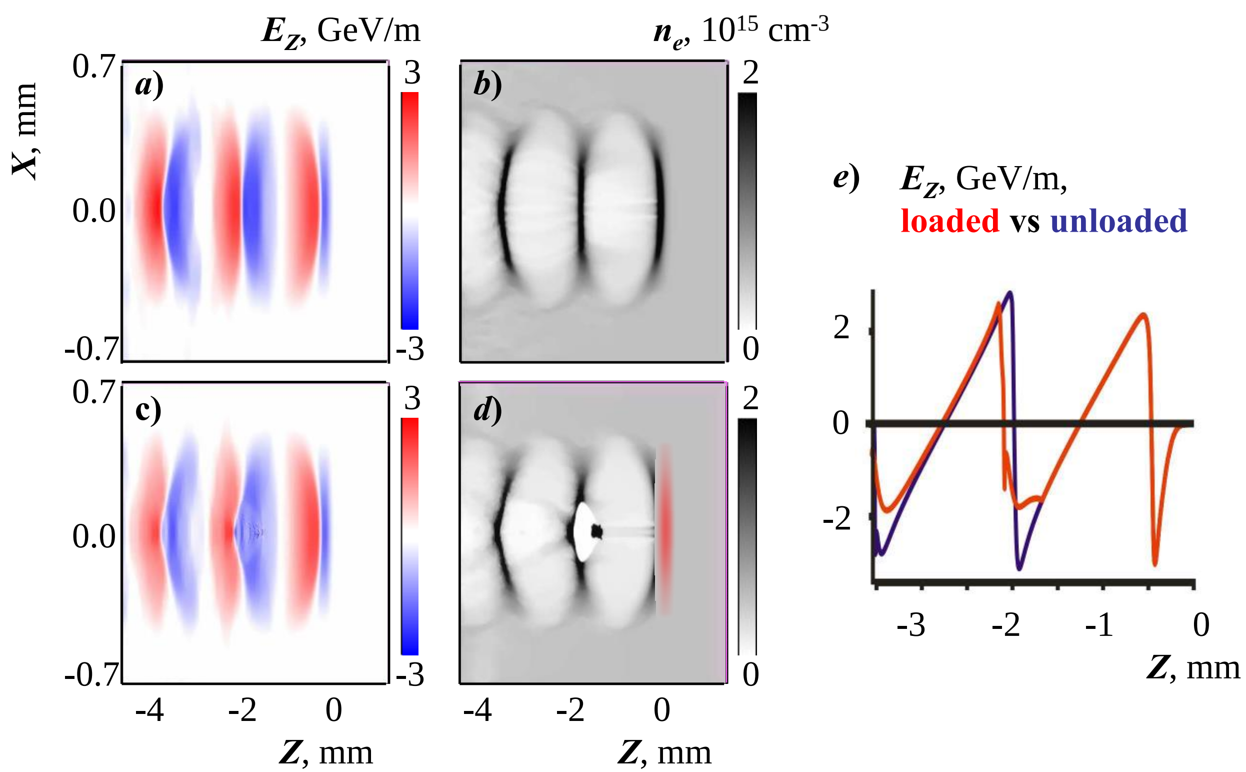
Laser-driven and electron-bunch driven acceleration have made impressive progress. But, will require many stages to reach the TeV scale. Limitation – energy carried by driver.

If we can use protons to drive a wakefield we can have a simpler arrangement - single stage acceleration. Caveat: need very short proton bunches for strong gradients.

Size of accelerator structure set by plasma density

$$\lambda_p \approx 1\ \mathrm{mm}\sqrt{\frac{1\cdot 10^{15}\mathrm{cm}^{-3}}{n_p}}$$

A. Caldwell, K. Lotov, A. Pukhov, F. Simon, *Nature Physics* ***5**, 363 - 367 (2009)*

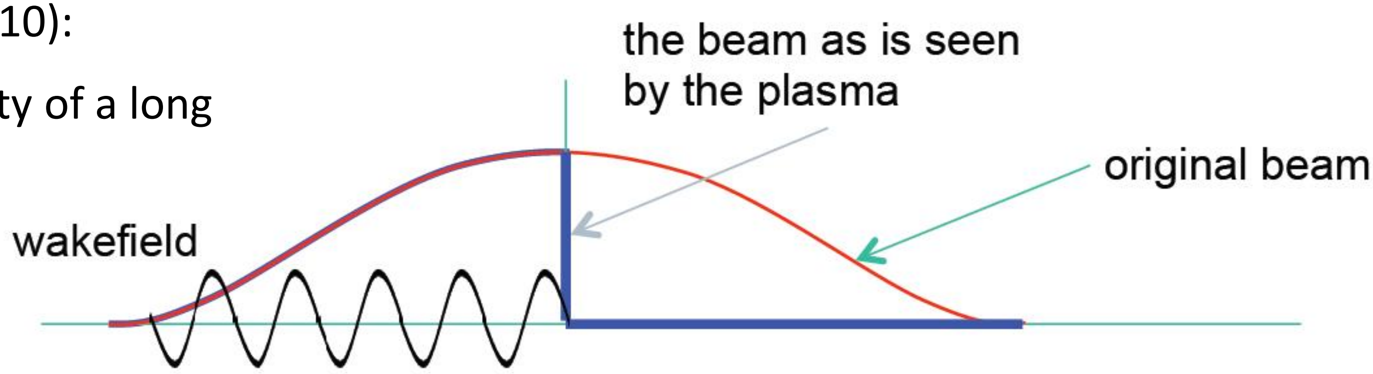


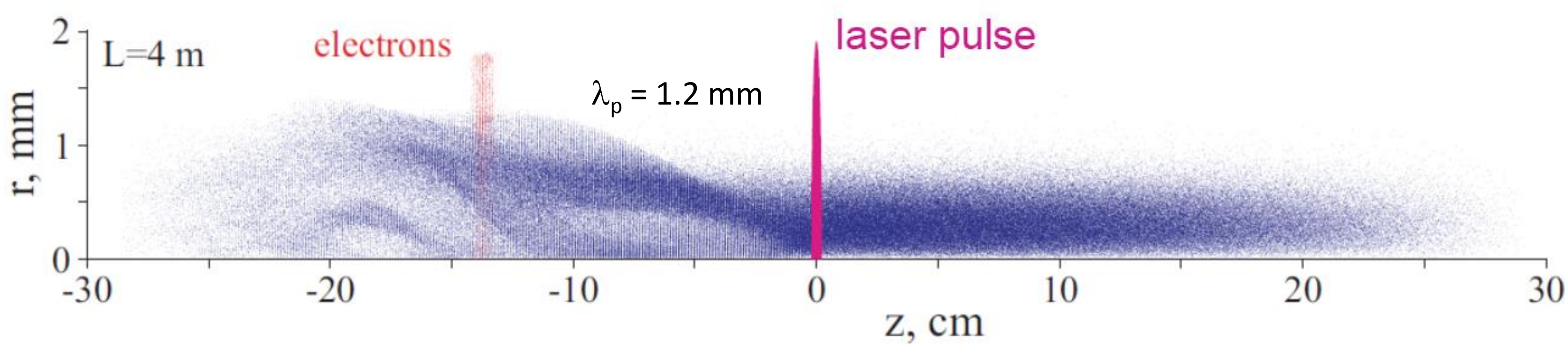
Modulated Proton Bunch

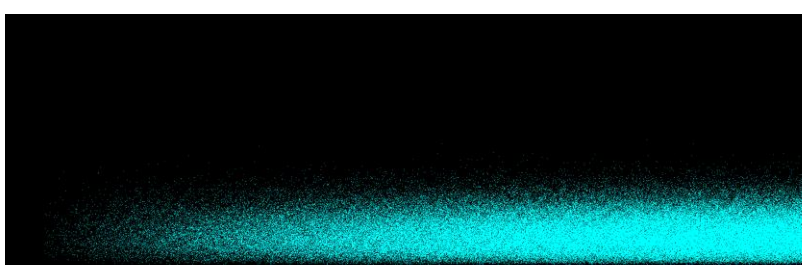
Short bunches ‘created’ by the plasma !

N. Kumar, A. Pukhov, K. Lotov, Phys. Rev. Letters (2010):

Self-modulation instability of a long proton bunch in plasma

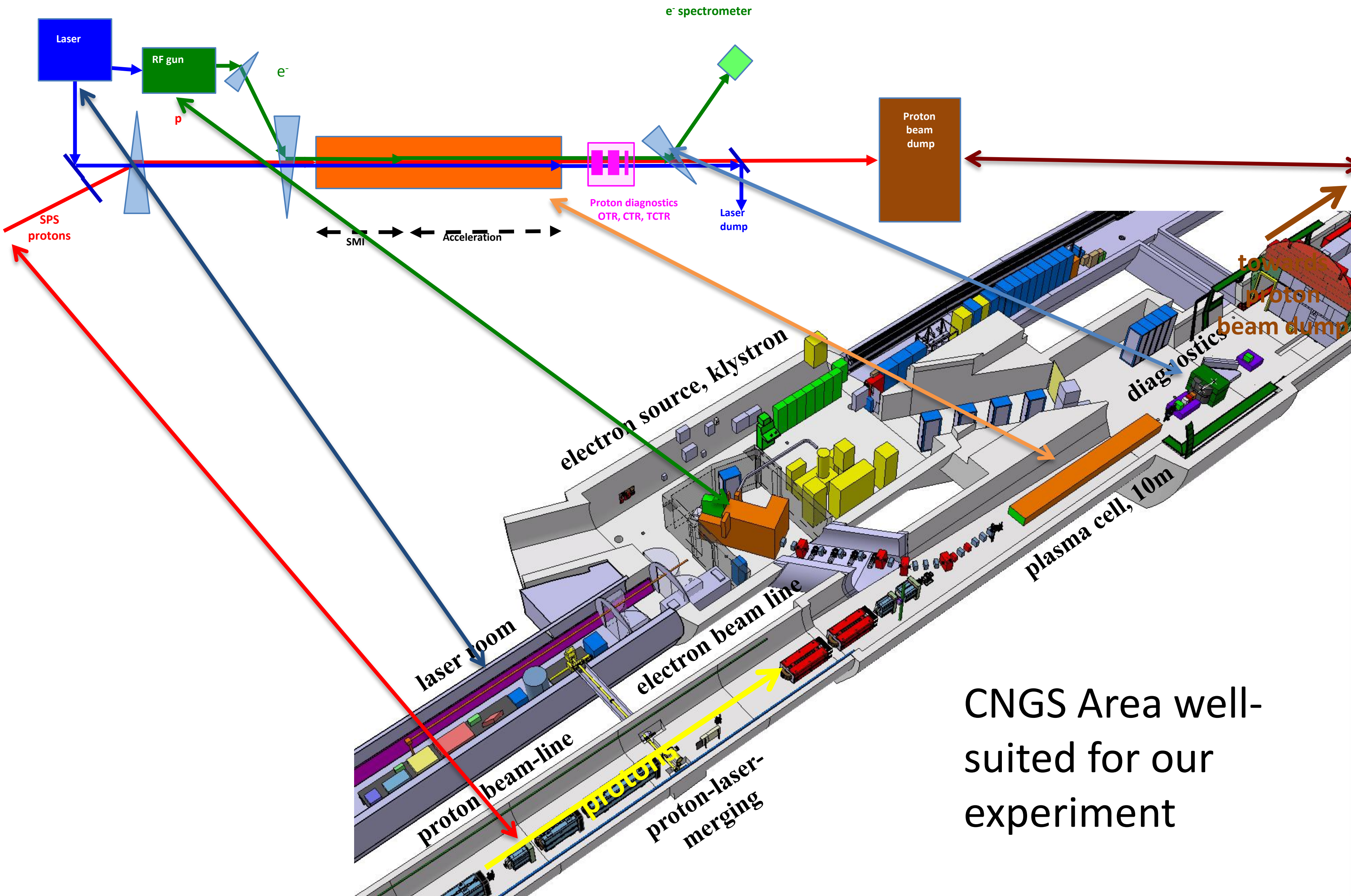






Self-modulated proton bunch resonantly driving plasma wakefields.

AWAKE Overview



CNGS Area well-suited for our experiment

AWAKE status report

AWAKE Collaboration

October 2014

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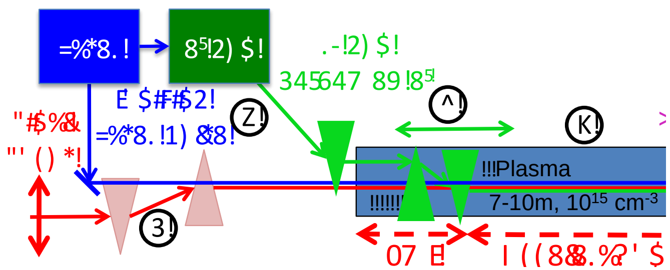
Full status report available on the CERN Document Server.

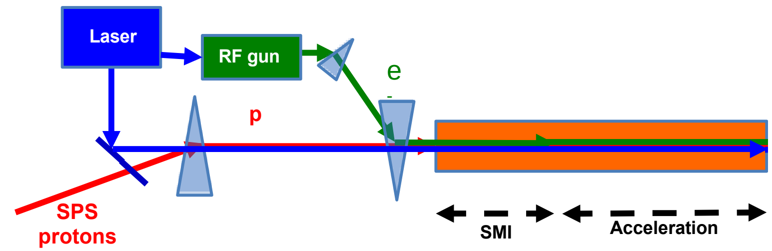
Here we pick out some highlights.

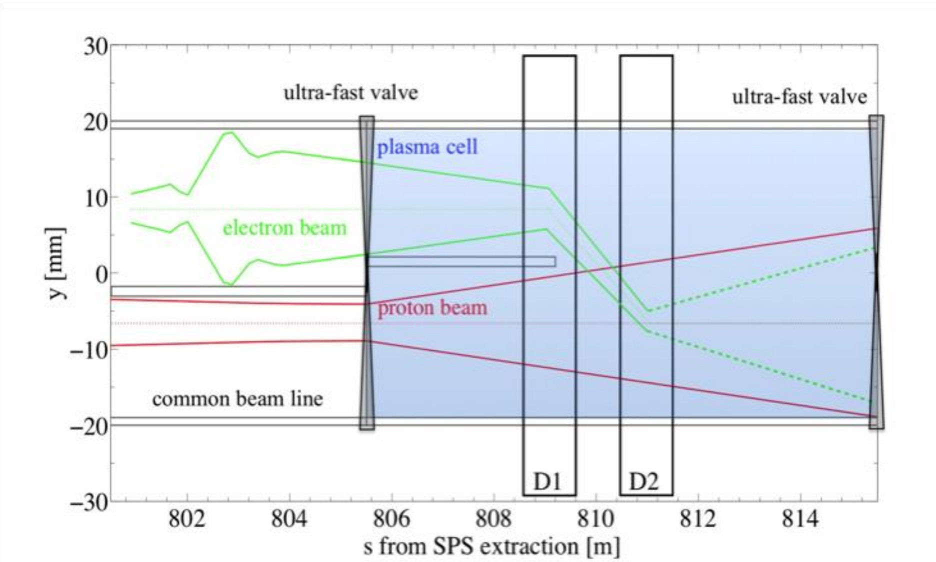
1. New electron injection scheme
2. Plasma cell & Laser system status
3. Electron injector & beamline
4. Diagnostics
5. Experiment layout & radiation safety
6. Simulations
7. Schedule

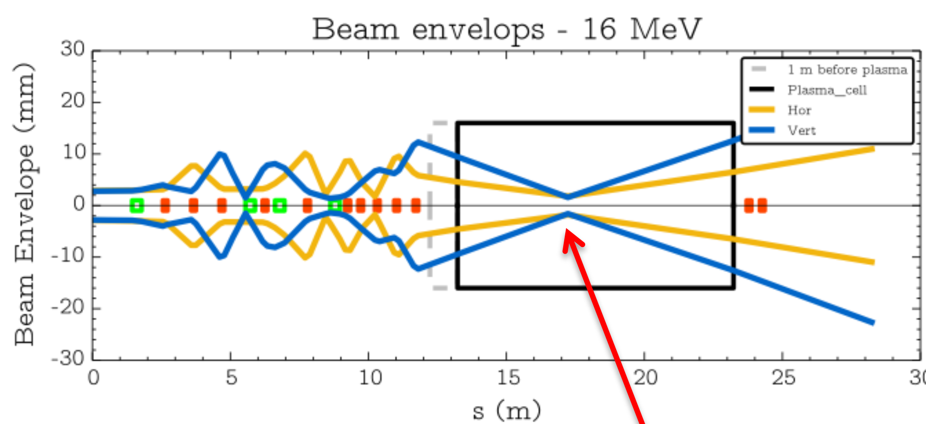
Electron injection scheme

Side Injection of electrons -> on-axis injection









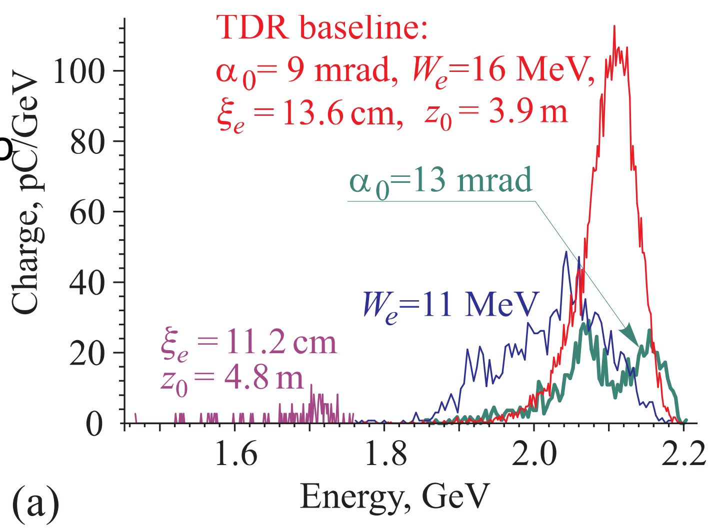
Focus point adjustable

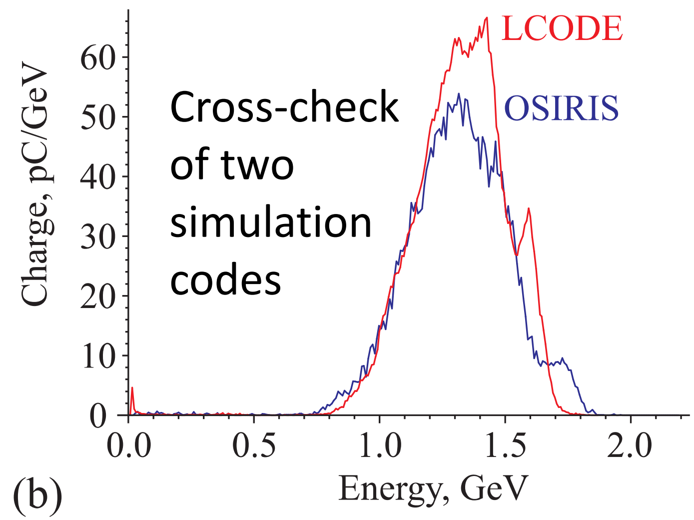
On-axis injection technically easier. Beam dynamics calculation - DESY

Electron injection scheme

Side Injection of electrons -> on-axis injection

Sensitive to parameter settings





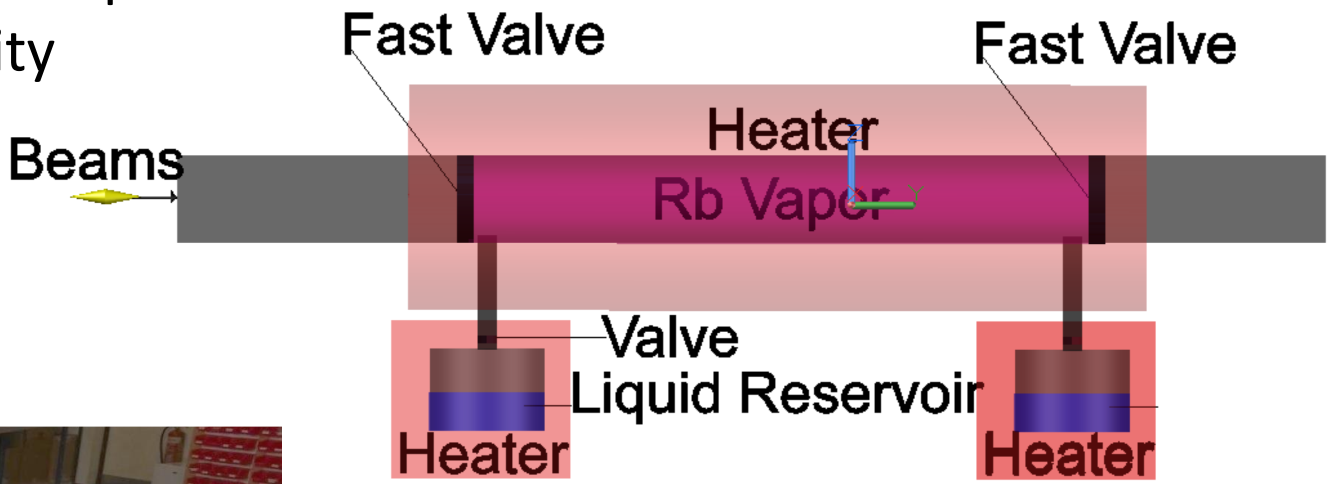
Simulations BINP, IST

On-axis injection has fewer parameters to control

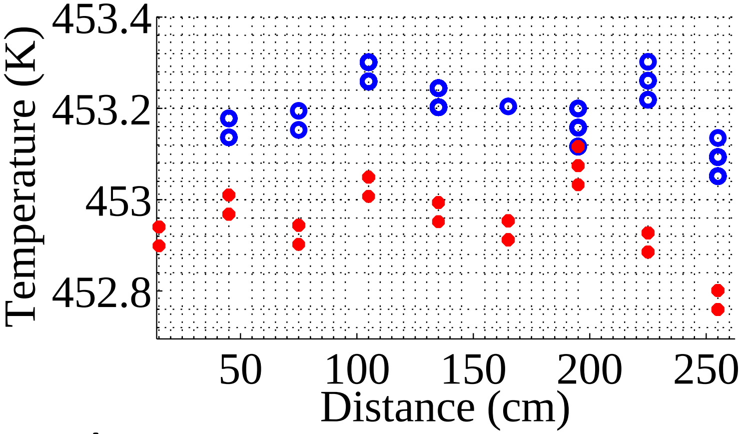
Plasma Sources

1. Rubidium vapor ionized by laser for Phase 1,2. Developed at MPP.

Concept: Oil heated Rb vapor to provide uniform density (requirement: 0.2%)

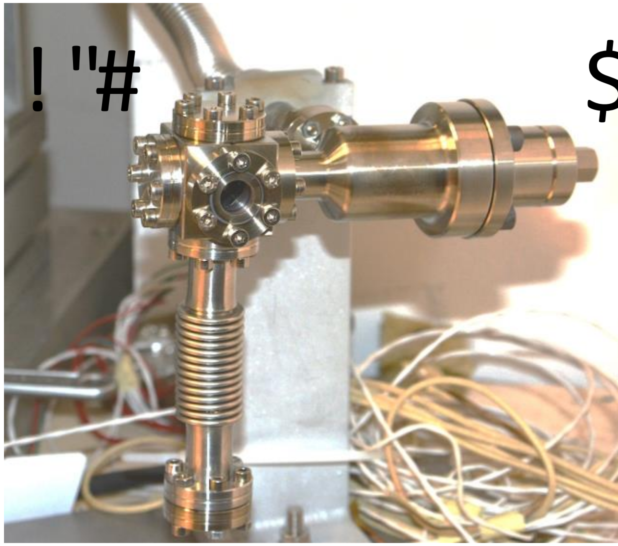


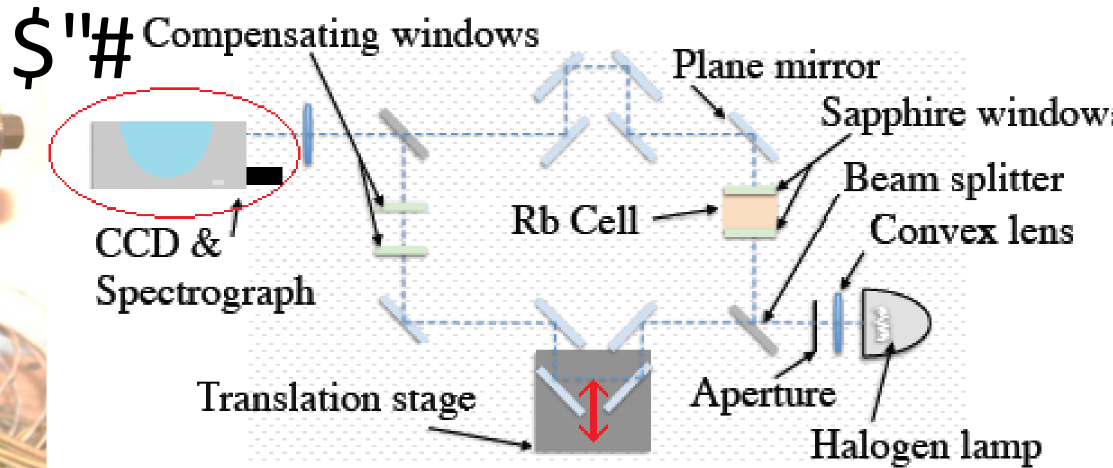
3m Prototype:



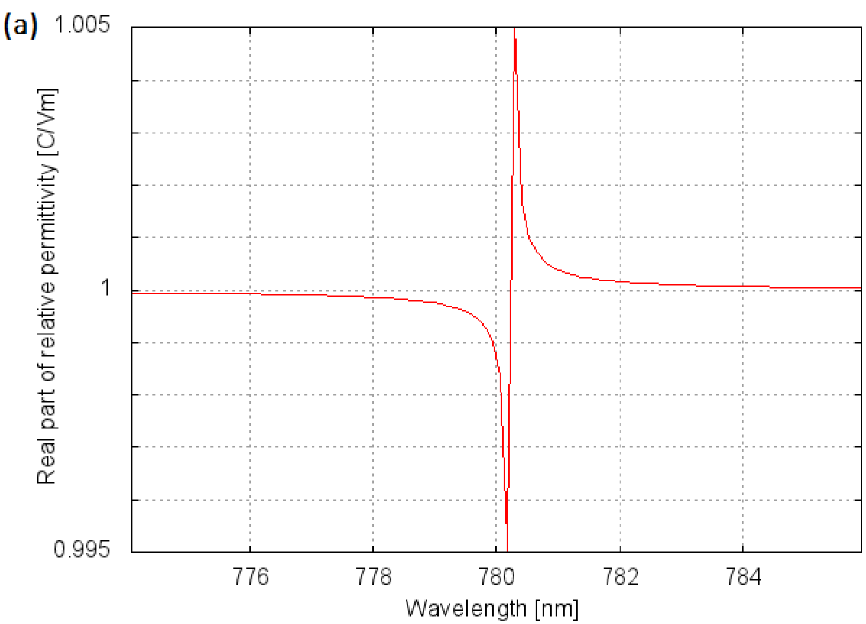
Well within specs. 10m version under design.

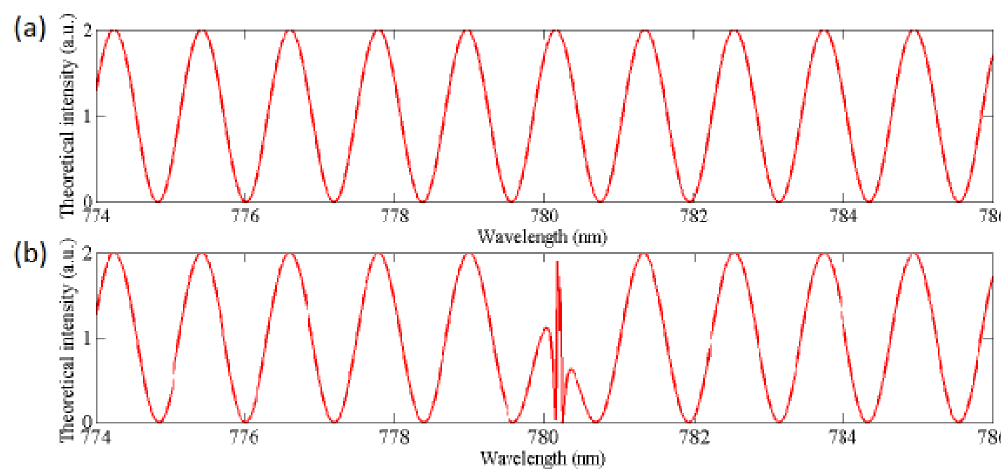
Vapor density measurement developed (interferometer system):





Density 10^{15} cm^{-3} measured as expected



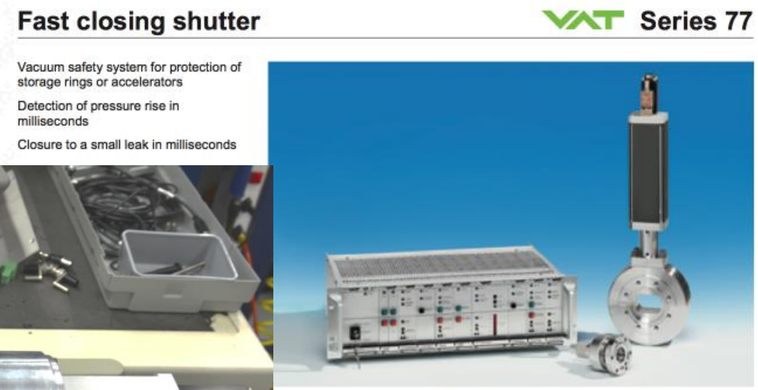


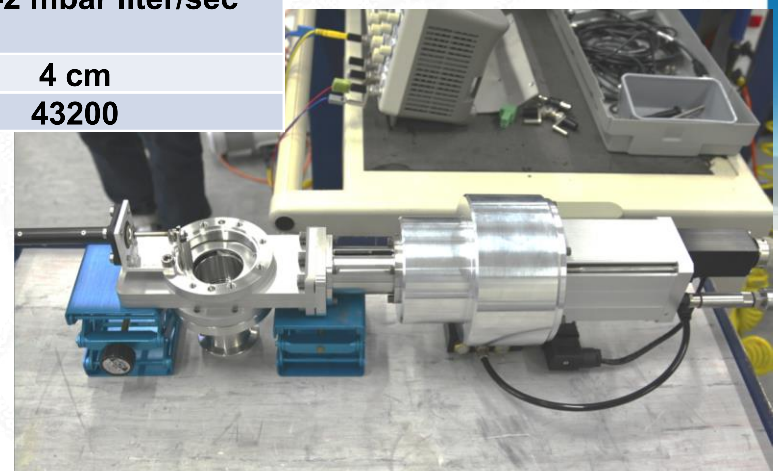
Online Rb density measurement demonstrated

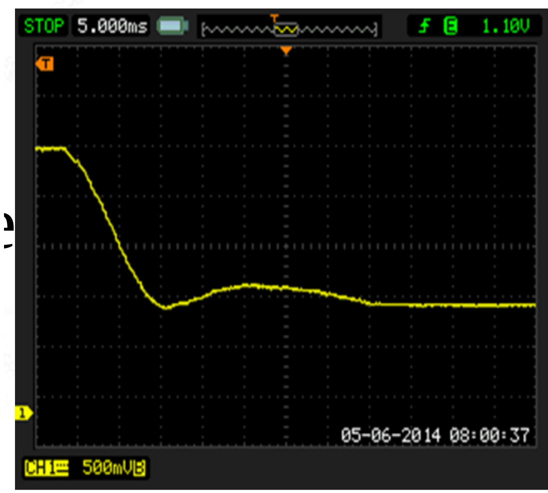
Fast Valves

FAST VALVE DESIGN REQUIREMENTS	
Opening Time	~10 ms
Closing Time	<1 s
Environment	Rubidium, radiation resistant
Temperature	180 - 220 ^oC
Leak Rate	1.75e-2 mbar liter/sec
Aperture Size (D)	4 cm
Number of Cycles	43200

Ultra Fast Custom Valves by VAT







>50k cycles at 230 C; operation with Rb to be demonstrated.

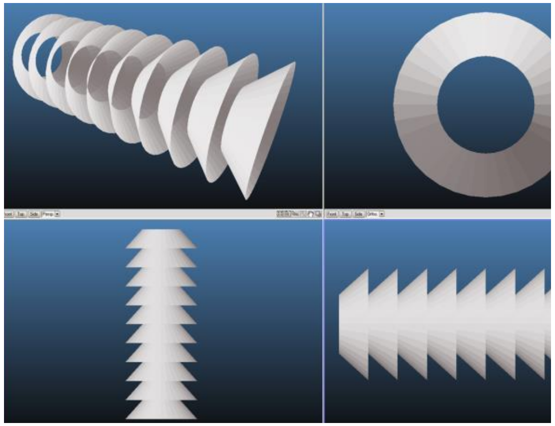
AWAKE CERN SEPT2014, Erdem Oz

Plasma Uniformity

For effective electron capture, need uniform plasma density (recall, plasma wavelength depends directly on plasma density)

Valve opening causes drop in density near ends of plasma cells:

1. Not critical for development of proton modulation
2. Not critical at exit because electrons already at high energy
3. Molecular flow simulations (CERN) indicate drop in density over first meter if no care taken to reduce escape of plasma.
4. Mitigation strategies under study; e.g., baffles
5. Also possible to focus electron bunch to point where plasma uniform.

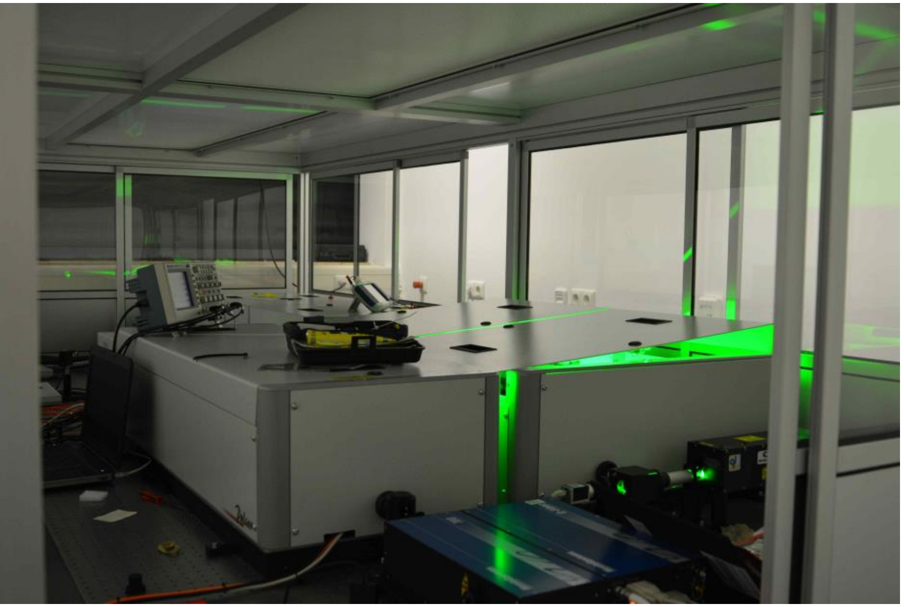


Laser System

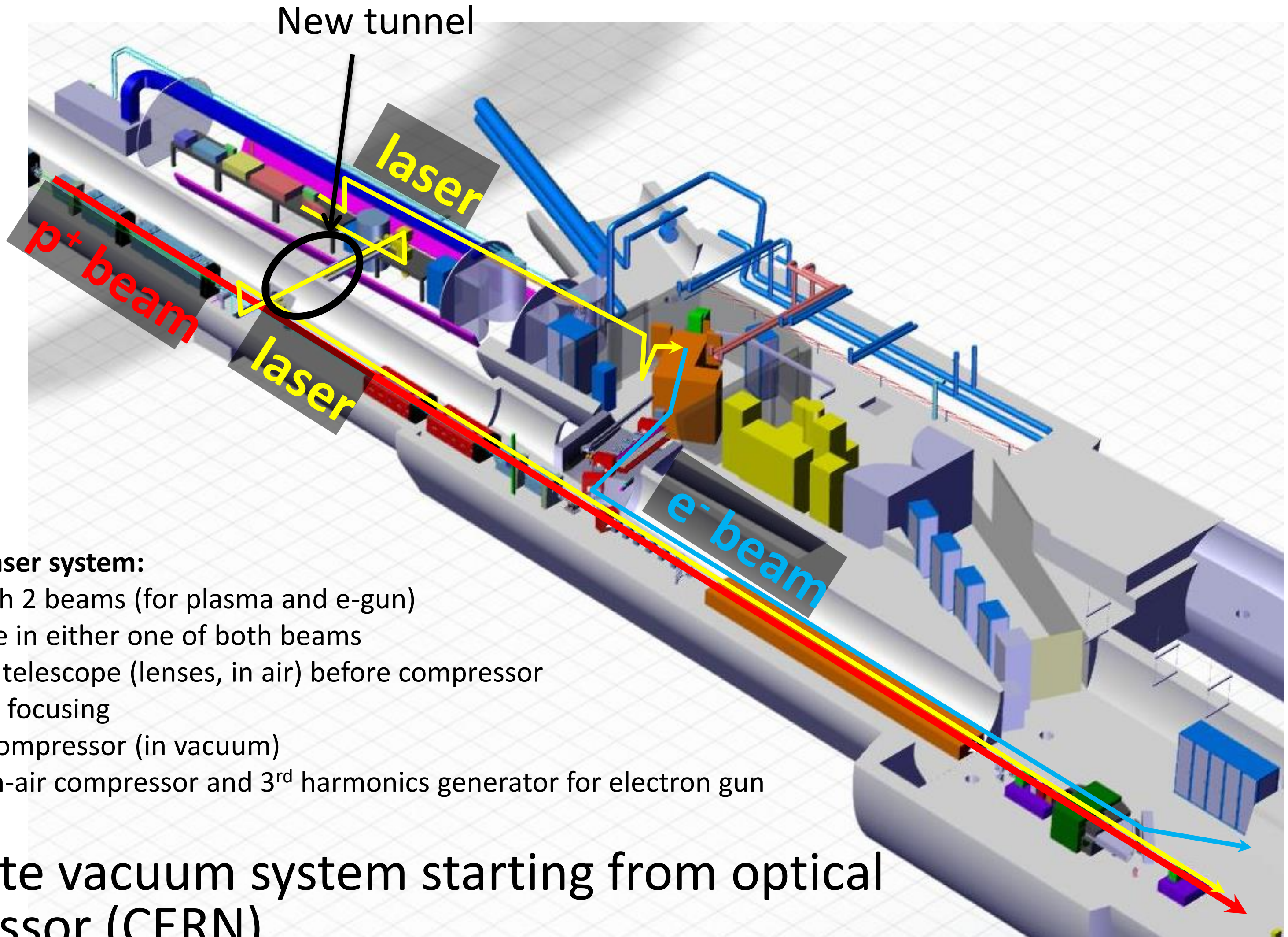
Laser beam to plasma cell	
Laser type	Fibre Ti:Sapphire
Pulse wavelength	$\lambda_0 = 780\,\text{nm}$
Pulse length	100–120 fs
Pulse energy (after compression)	450 mJ
Laser power	4.5 TW
Focused laser size	$\sigma_{x,y} = 1\,\text{mm}$
Energy stability	$\pm 1.5\%$ r.m.s.
Repetition rate	10 Hz
Laser beam to electron source	
Laser type	Ti:Sapphire Centaurus
Pulse wavelength	$\lambda_0 = 260\,\text{nm}$
Pulse length	10 ps
Pulse energy (after compression)	50 μJ
Electron source cathode	Copper
Quantum efficiency	3.00×10^{-5}
Energy stability	$\pm 2.5\%$ r.m.s.

Installation complete at MPP; all specs met or exceeded.

Parameters & realization at CERN now under discussion. CERN-MPP-Amplitude



Laser System in CNGS



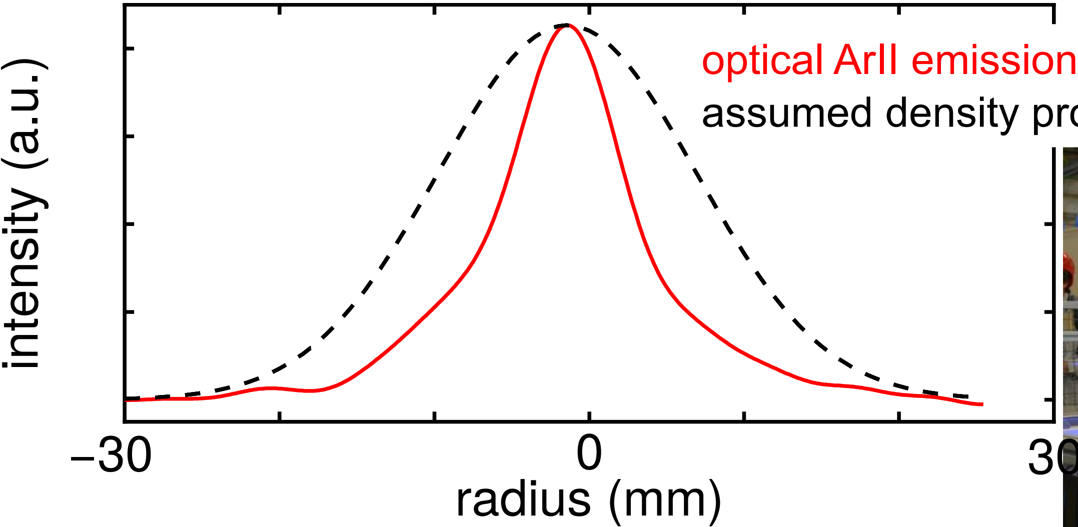
Ti: Sapphire laser system:

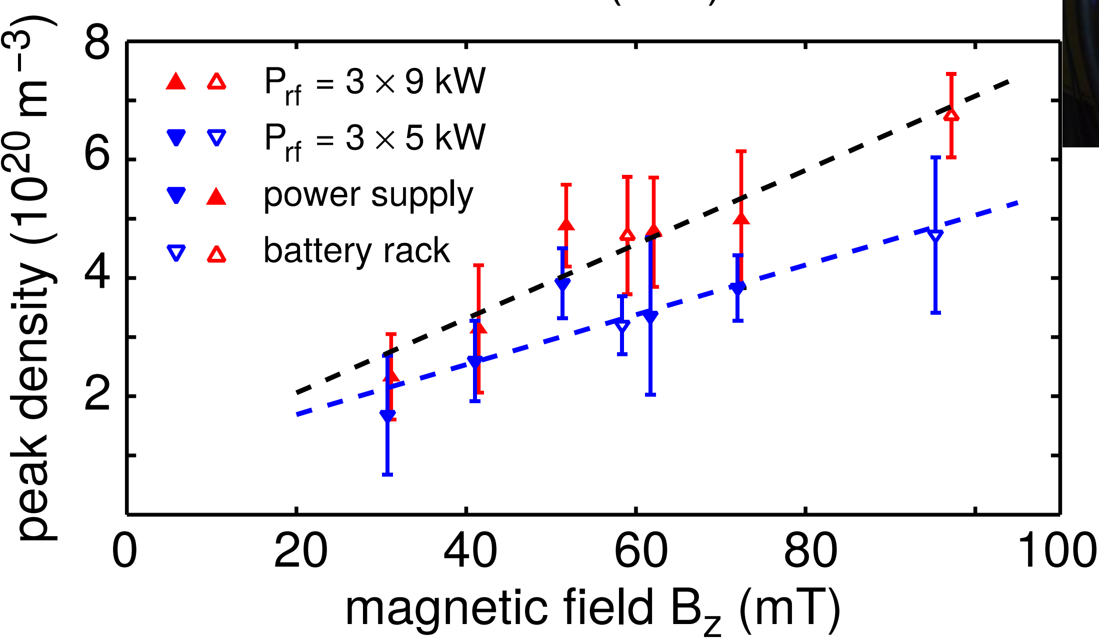
- Laser with 2 beams (for plasma and e-gun)
- Delay line in either one of both beams
- Focusing telescope (lenses, in air) before compressor
- 35 meter focusing
- Optical compressor (in vacuum)
- Optical in-air compressor and 3rd harmonics generator for electron gun

Complete vacuum system starting from optical compressor (CERN).

Helicon cell

1m prototype in regular operation at IPP (Greifswald)

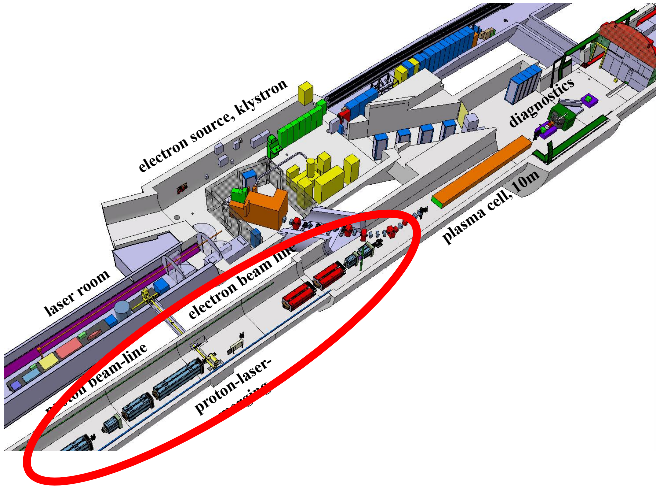




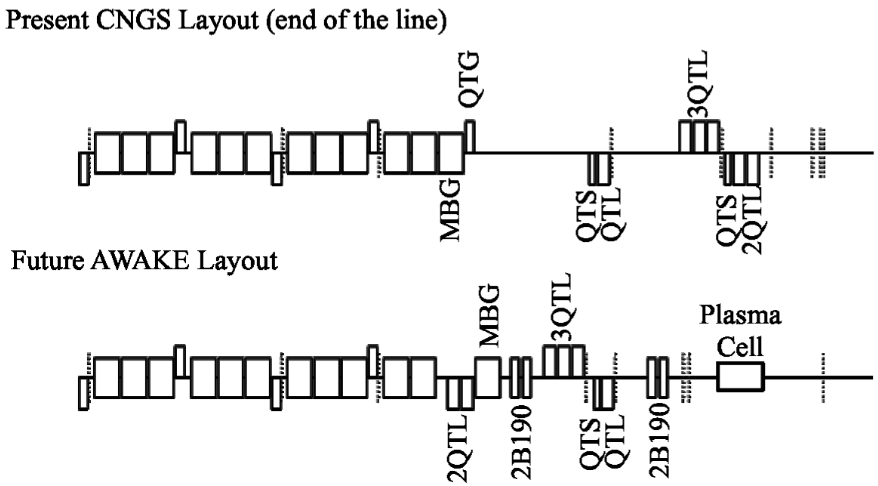
Target density achieved !

Uniformity under study.

Proton Beam Line

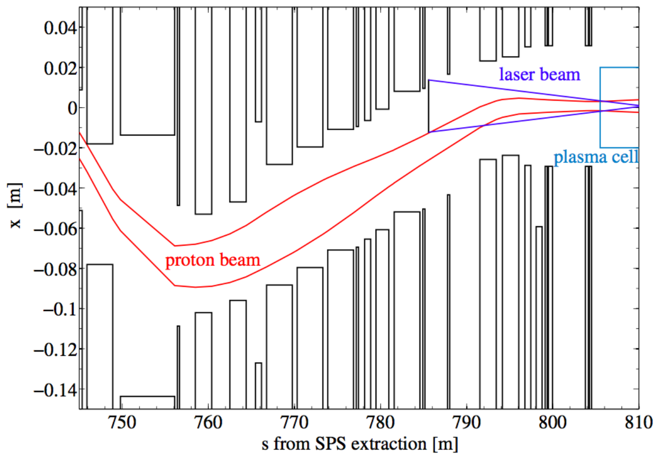


Change of the proton beam line only in the **downstream part (~80m)**



→ **Displace existing magnets** of the final focusing to fulfill optics requirements at plasma cell

→ Move existing dipole and **4 additional dipoles** to create a **chicane for the laser mirror** integration.

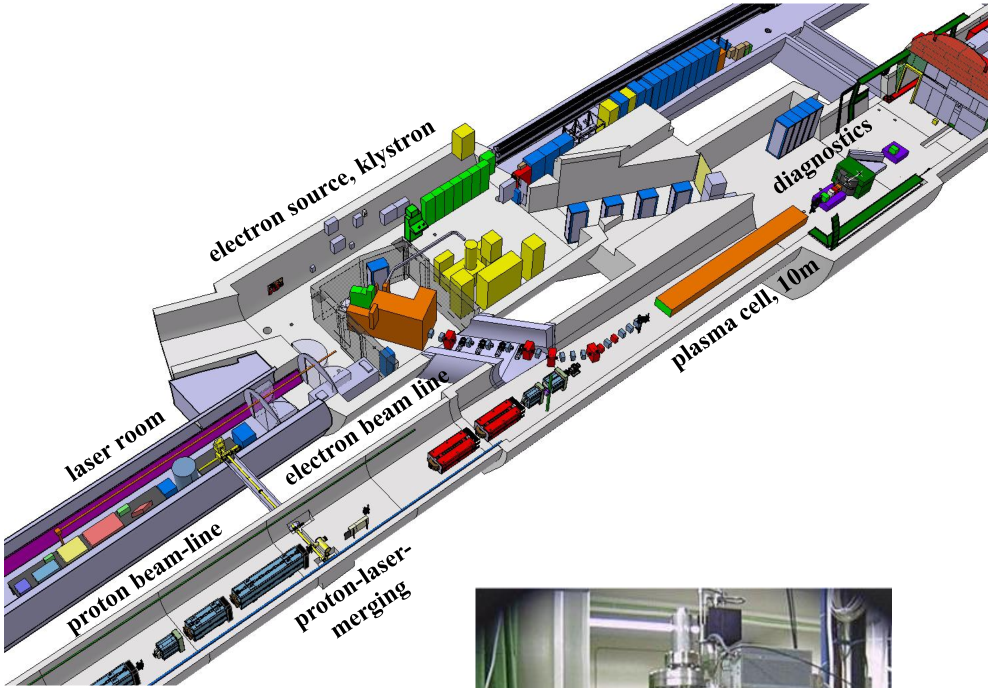


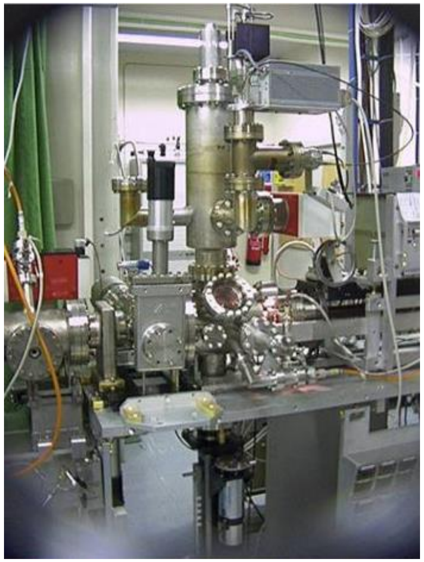
Laser-proton merging 20m upstream the plasma cell

Design complete !

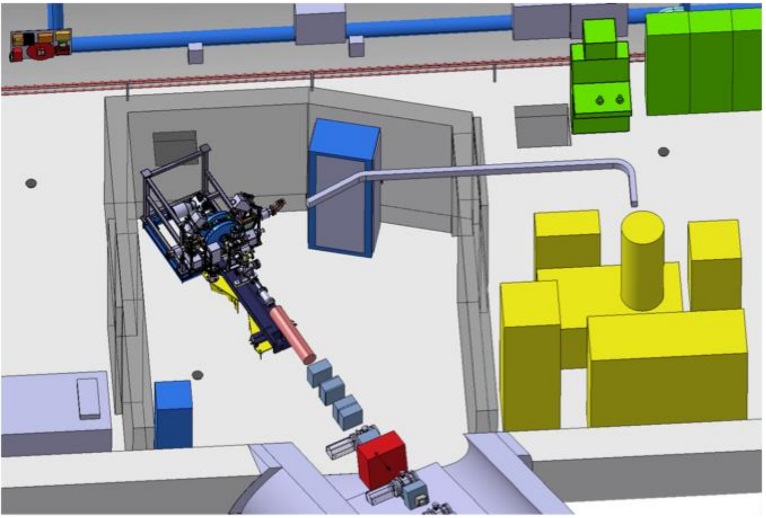
Electron – Source

- In Design Report: new gun, ERC Synergy grant application (not successful)
- New Baseline:
  - Photo injector (**PHIN**) from CTF2 at CERN (5 MeV electrons)
  - Klystron and modulator from CTF3
  - Booster from Cockcroft/Lancaster 5 MeV→ 20 MeV
  - Monitoring/Diagnostics CERN/TRIUMF
  - Beam transport CERN, CI

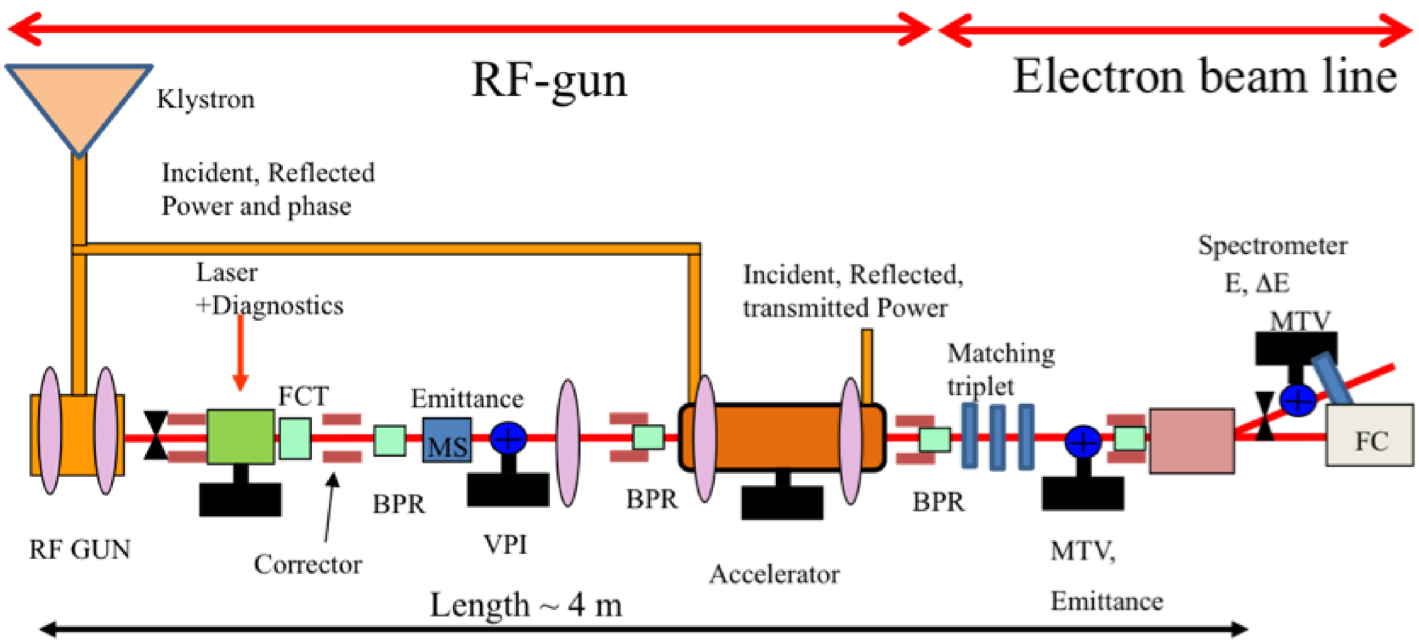




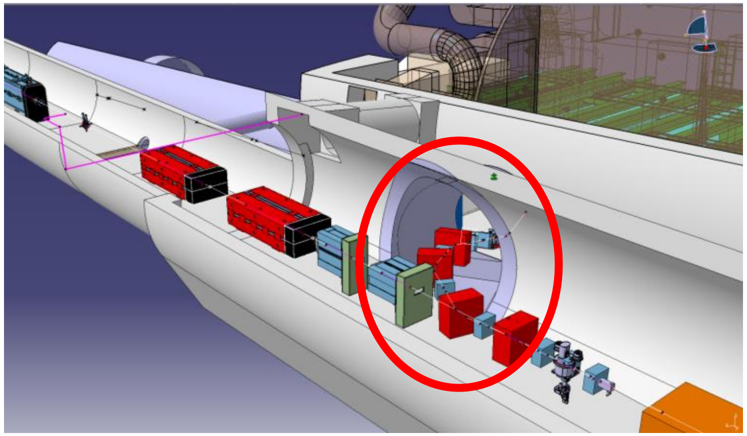
Electron Gun

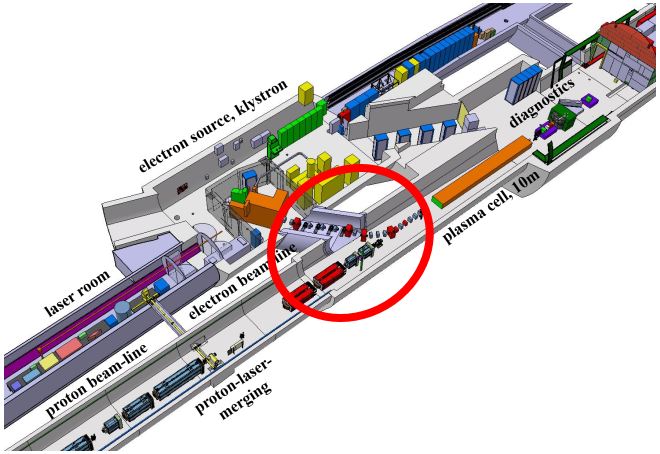


Parameter	Baseline	Range to check
Energy	16 MeV	10–20 MeV
Bunch charge	0.2 nC	0.1–1 nC
Bunch length (σ)	4 ps	0.3–10 ps
Beam focus length (σ)	250 μm	0.25–1 mm
Normalised emittance (r.m.s.)	2 mm mrad	0.5–5 mm mrad
Energy spread (σ)	0.5%	$< 0.5\%$



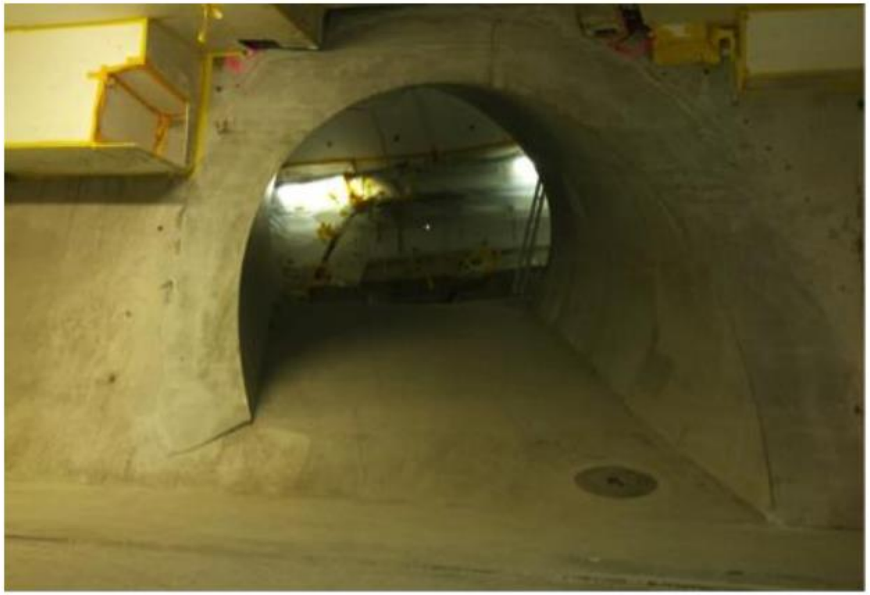
Electron Beam Line





About two months ago:

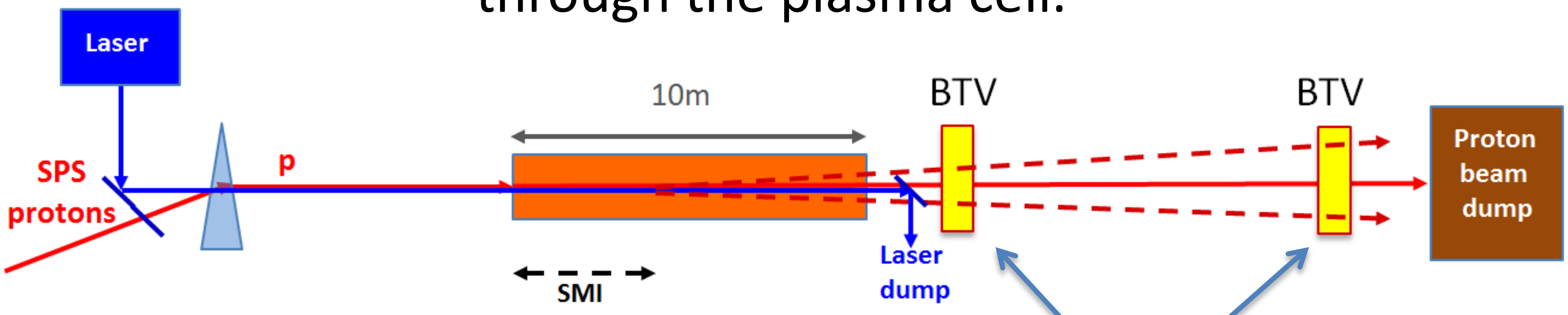
Now:

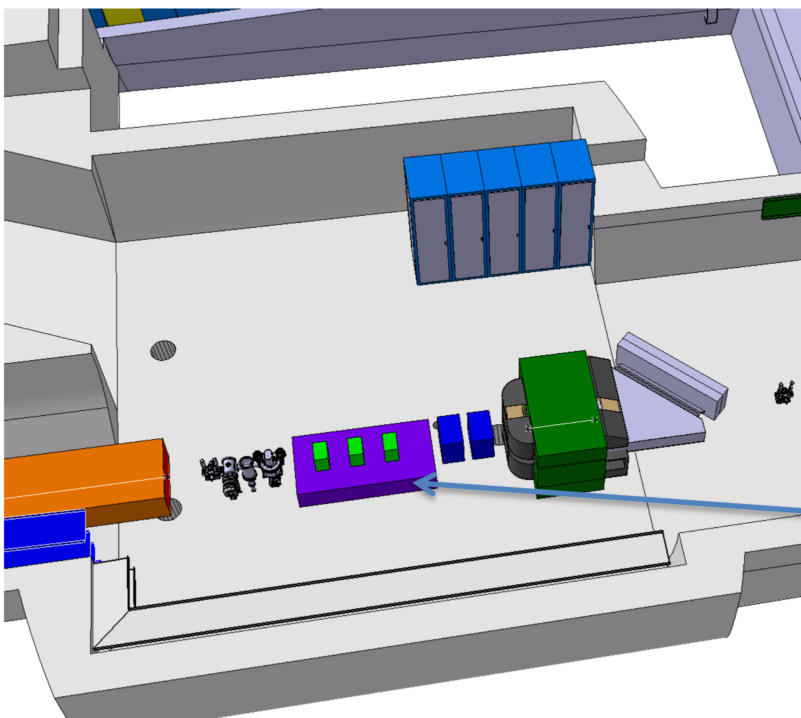


Laser tunnel has been excavated recently also.

Self-Modulation-Instability Diagnostics

Measure the characteristics of the proton beam after propagating through the plasma cell.

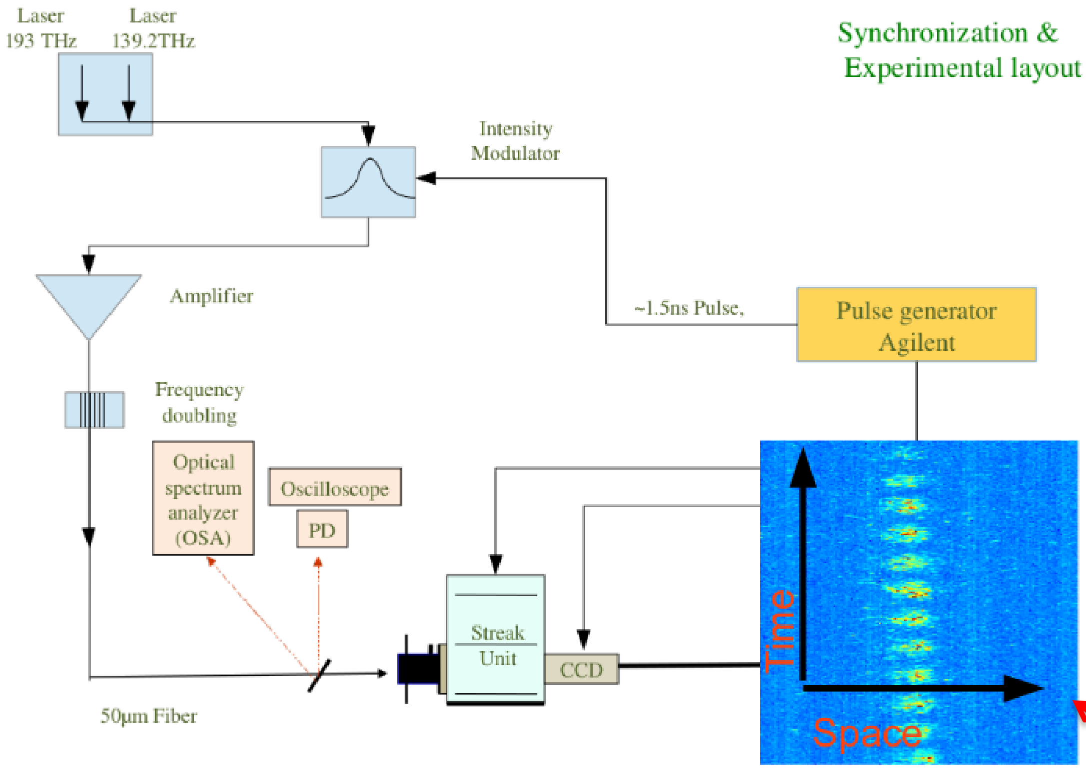


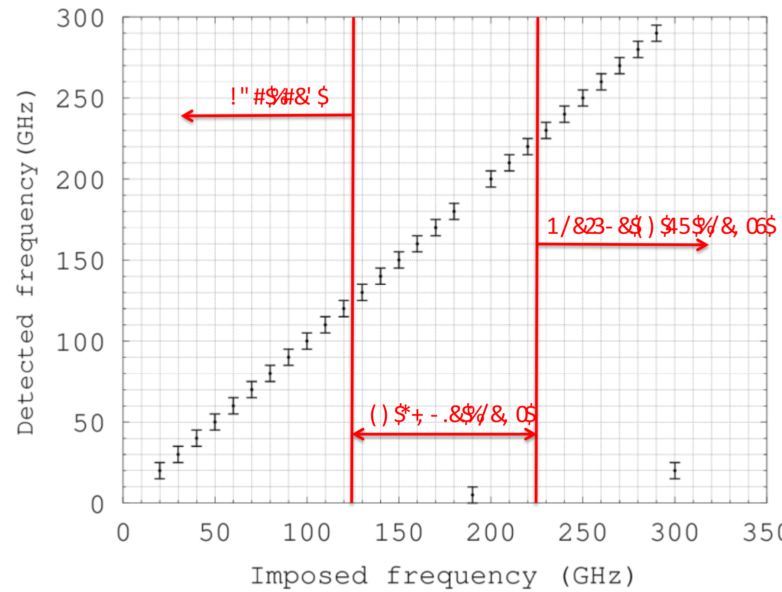


- Transverse size monitoring (first version, CERN)
- Time-resolved (MPP):
  - Optical Transition Radiation
  - Coherent Transition Radiation

Diagnostics ‘table’

Optical Transition Radiation





Test setup at MPP with lasers & streak camera.

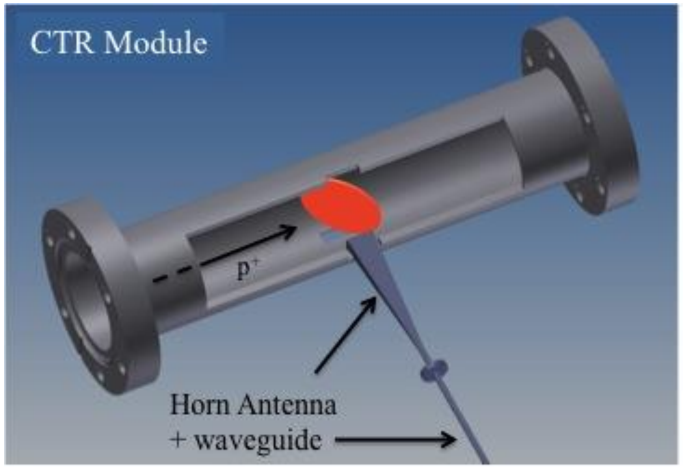
Streak camera image

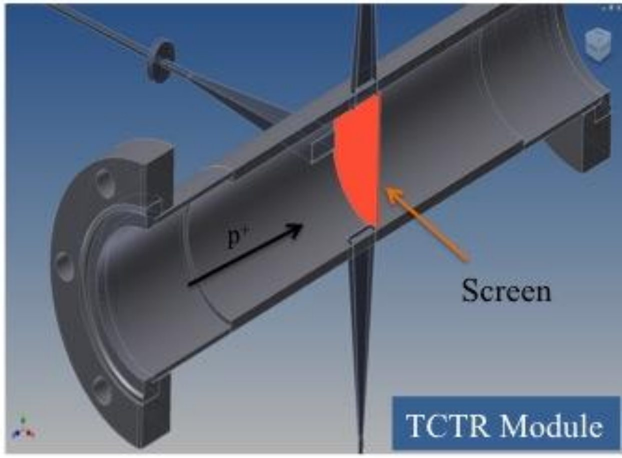
Initial concern – charge buildup in streak camera

Success: can resolve modulated pulse up to 300 GHz

Coherent Transition Radiation

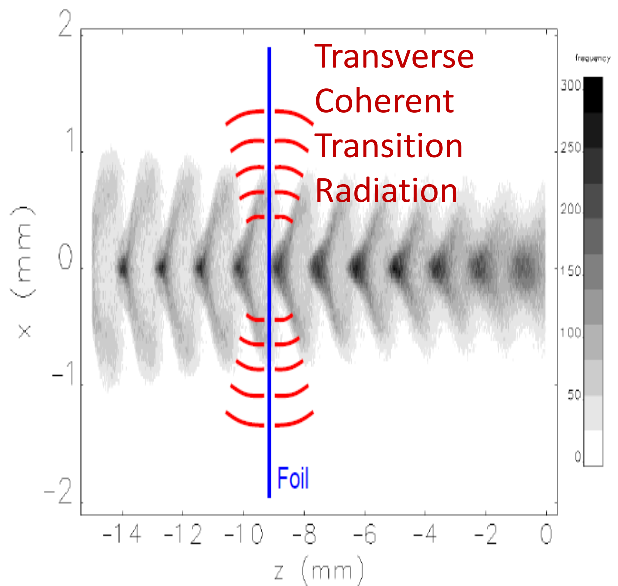
Techniques under development at MPP. Challenge – signal extraction. CST code simulations in progress.





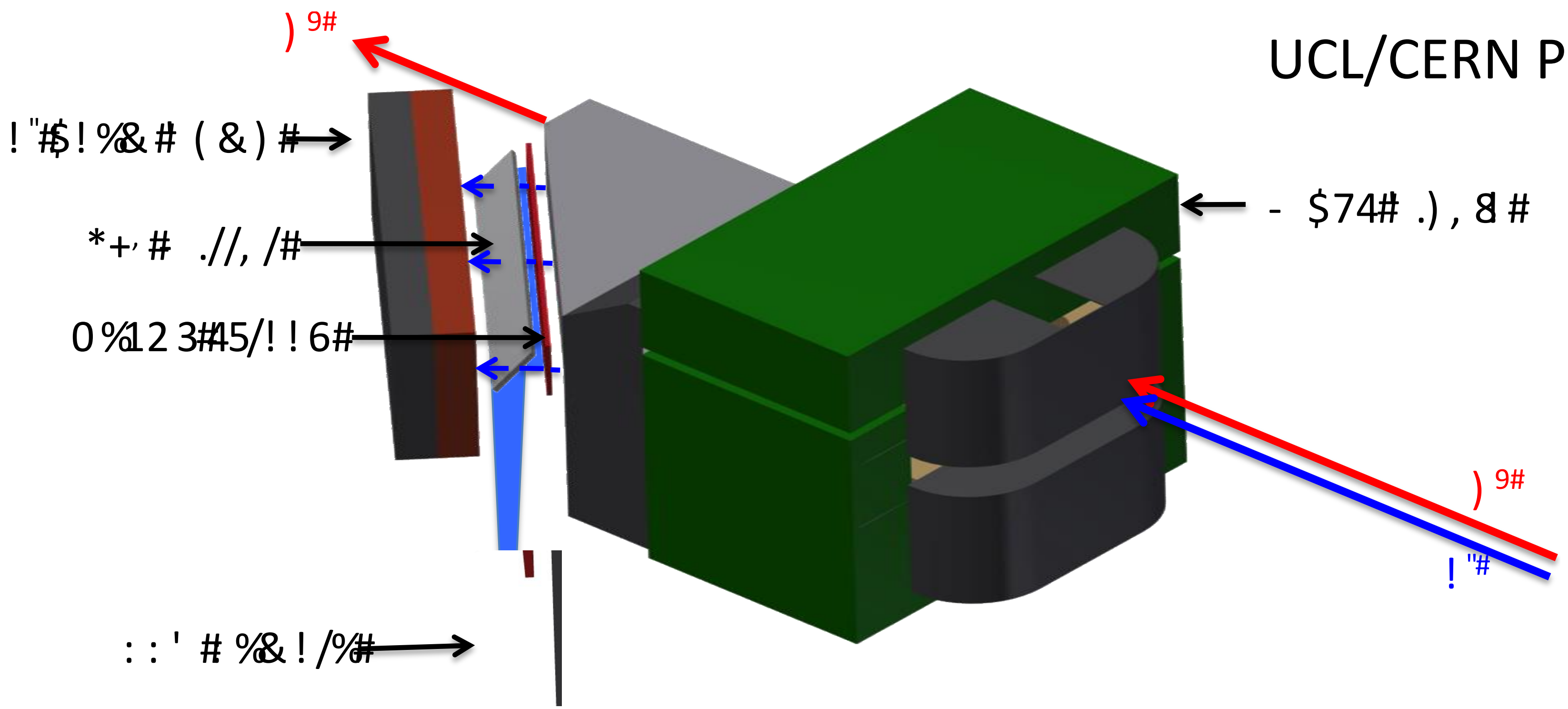
TCTR can distinguish transverse modes (hosing vs SMI)

See A. Pukhov, T. Tueckmantel, Phys. Rev. ST-AB (2012)



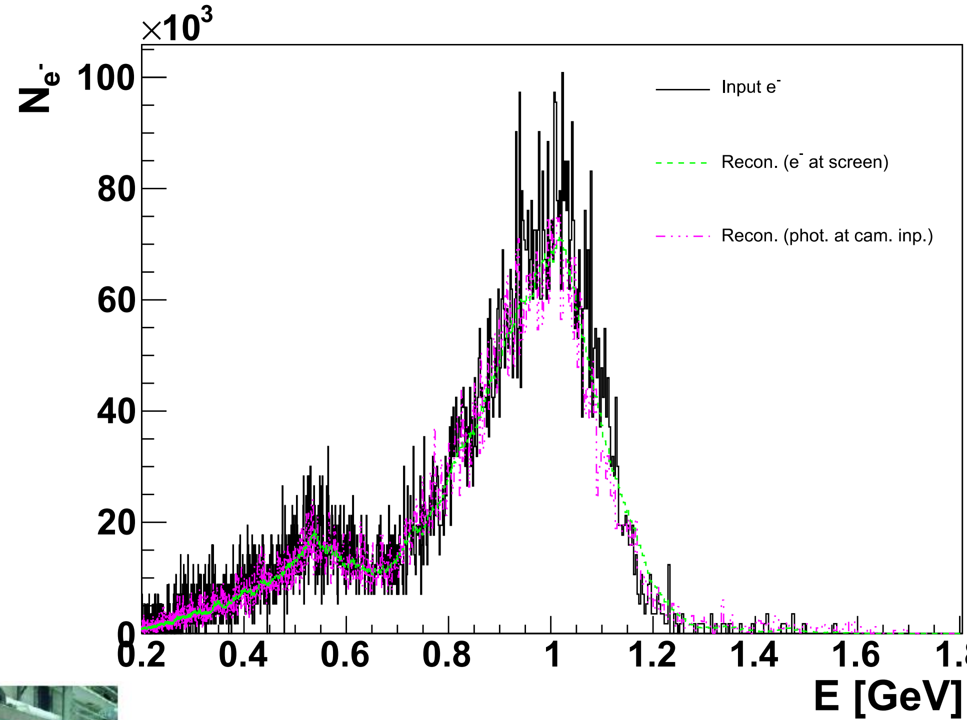
Electron Spectrometer

UCL/CERN Project



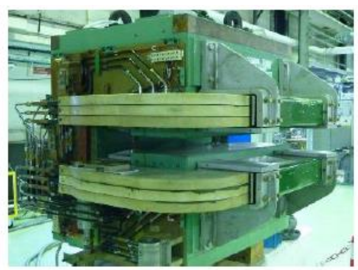
- Measure **peak energy and energy spread** of electrons.
- Measure divergence of electron bunch
- Spectrometer magnet separates electrons from proton beam-line.
- Dispersed electron impact on scintillator screen.
- Resulting light collected with intensified CCD camera.

Performance study (end-to-end simulation). **Energy spectrum fully reproduced.**



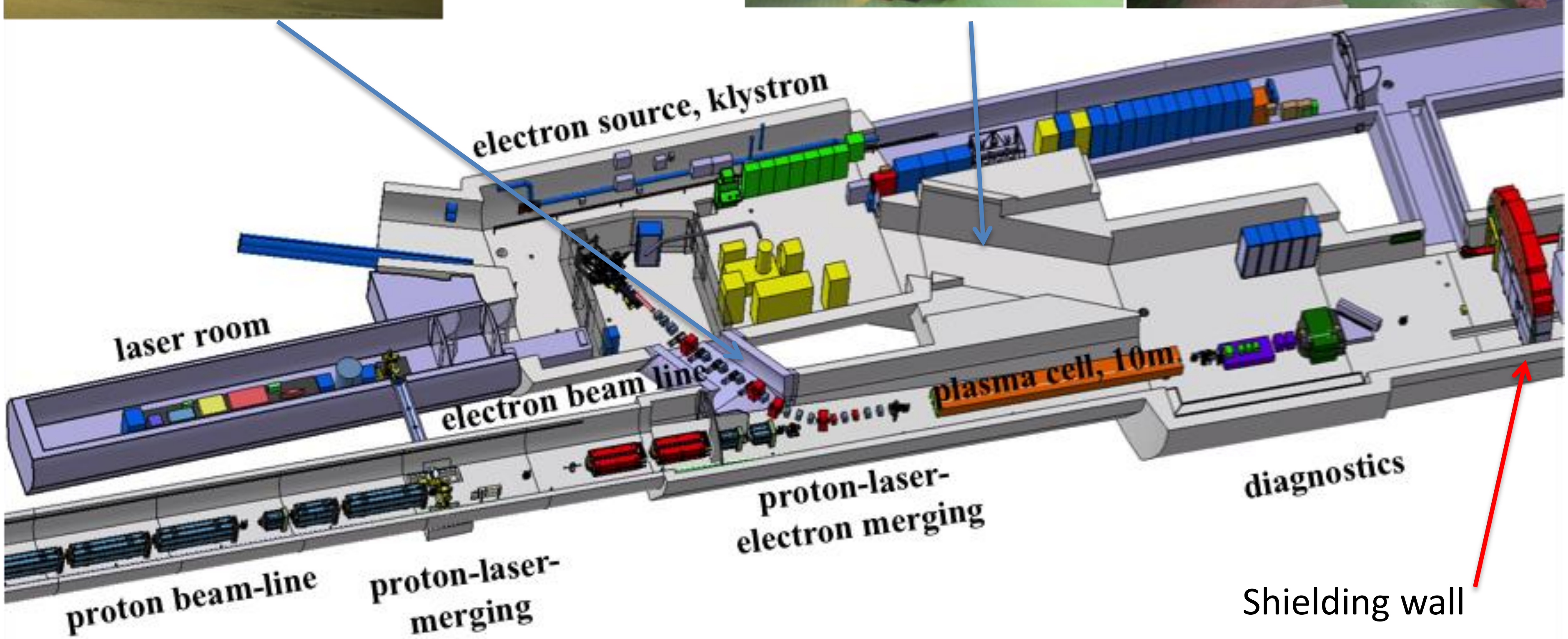
Open issues:

- Smaller magnet?
- Vacuum chamber design
- Location of camera

Photo		
Weight	15 t	8.5 t
Power consumption	60 kW	15 kW rms & 24 kW cycled
Integrated field (B*L)	1.9 T*m	1.3 T*m rms & 1.6 T*m cycled
Max. magnetic field	1.65 T	1.2 T rms & 1.5 T cycled
Horizontal aperture	52 cm	32 cm
Vertical aperture	11 cm	8 cm
Iron length	1 m	1 m
Total length	1.7 m	1.6 m
Total width	1.2 m	1.3 m
Current	545 A	400 A rms & 500 A cycled

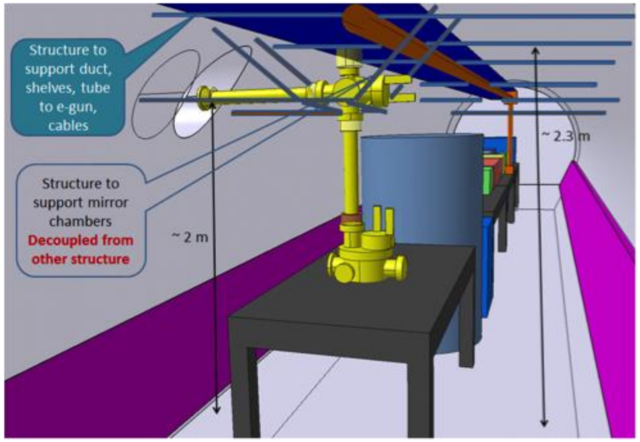
Background from upstream proton interactions under study.

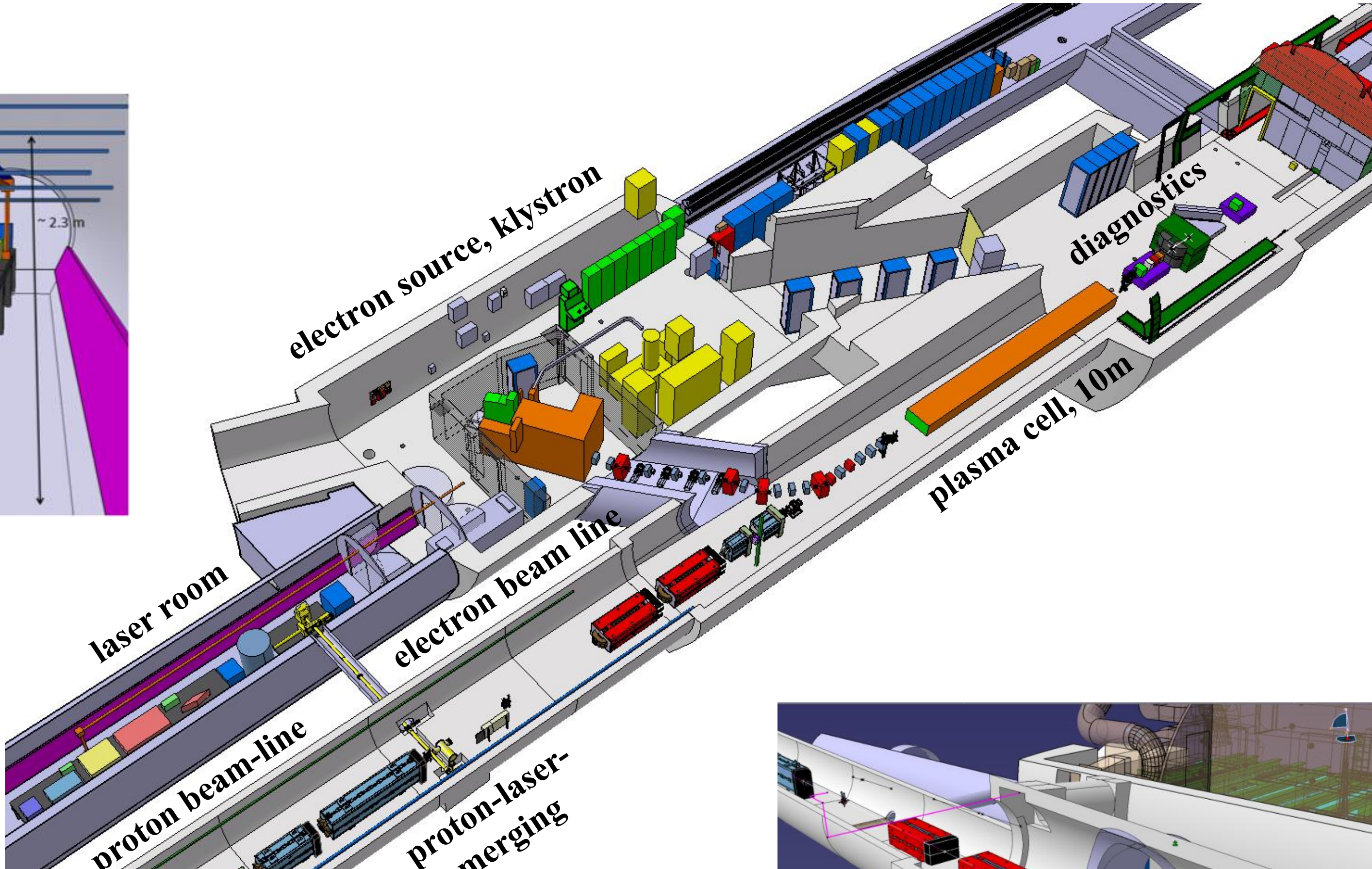
Preparation of Experimental Area



Layout & design

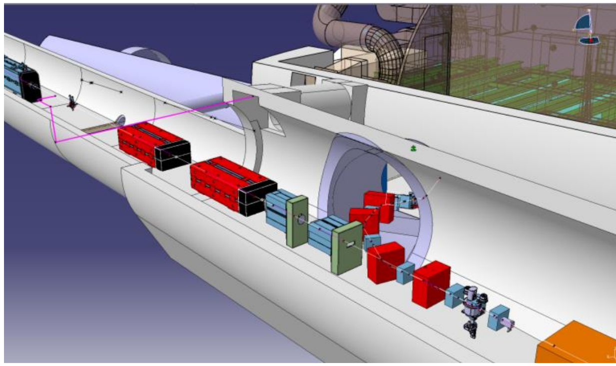
Laser lab layout





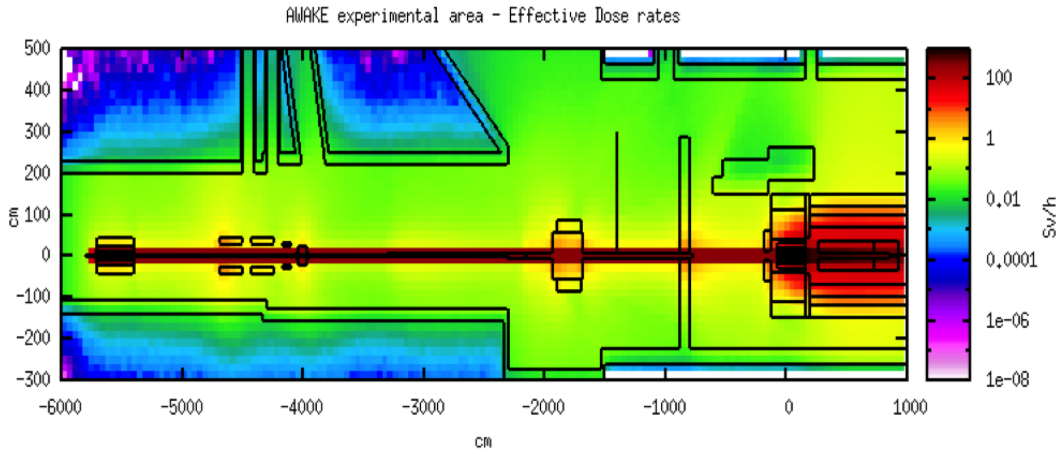
Currently working on:
Placement of electronics, power supplies, cabling, etc.

Vacuum design (specs, pumping, etc.) specifications under study.



Radiation Studies

Task	Impact on	Status
Gas activation in decay tunnel	Choice of gas Access to AWAKE area	Finished
Airborne radioactivity in AWAKE area	Access to AWAKE area Ventilation system Air release to environment	Ongoing Air release preliminary
Prompt dose rates	Access to AWAKE during electron beam operation	Ongoing. Preliminary dose maps available
Material activation and residual dose rates	Access to AWAKE Safety shutter of decay tube	Ongoing. Preliminary dose maps available
Activation of cooling water	Cooling of hadron stopper	Pending
Activation of ground water and soil	Environment	Pending. Comparing with CNGS operation

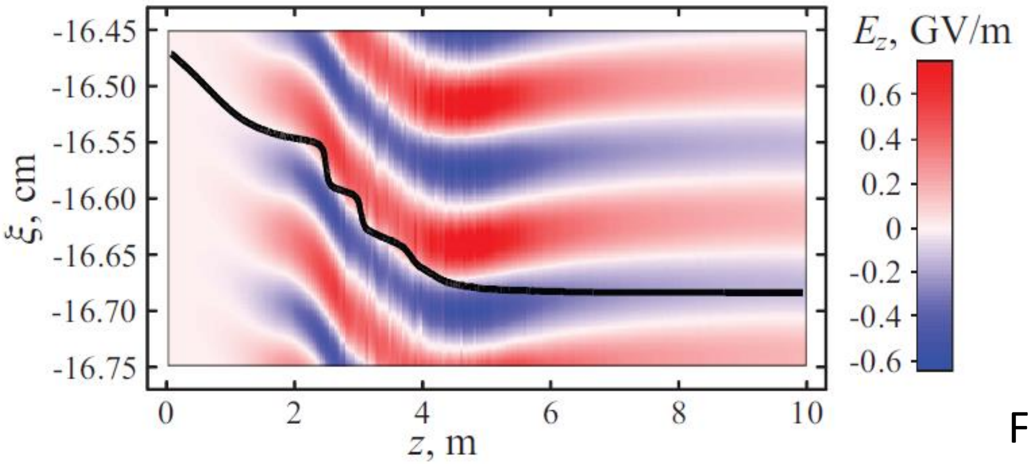


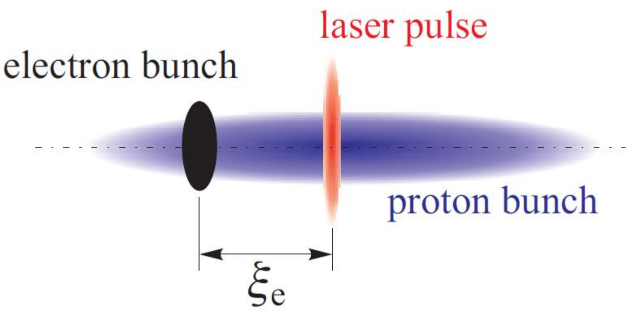
Extensive set of radiation studies carried out with conservative settings.

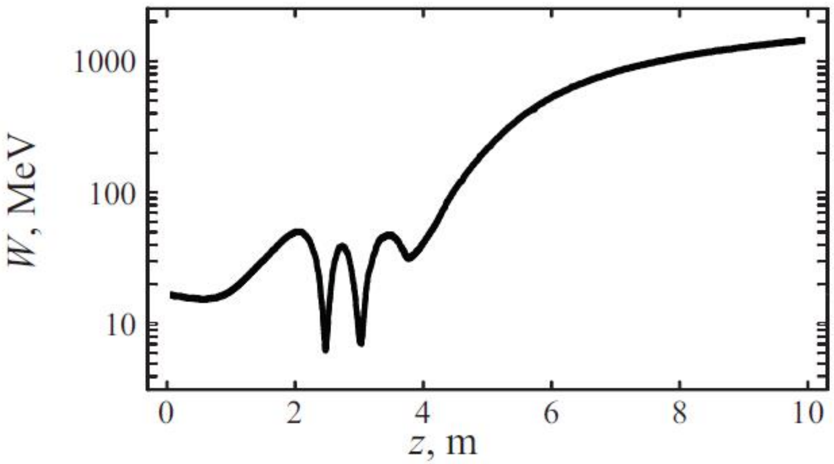
Important issue: vacuum separation window SPS beamline & AWAKE area. Impact on placement of sensitive electronics in experimental area. Further studies ongoing.

Simulations

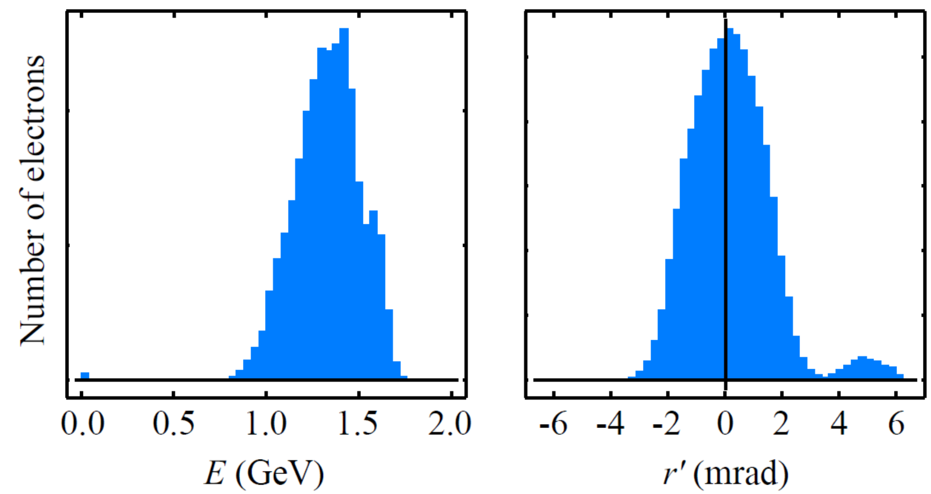
Typical trajectory of accelerated electron:







Final energy & angle distributions in e-beam:

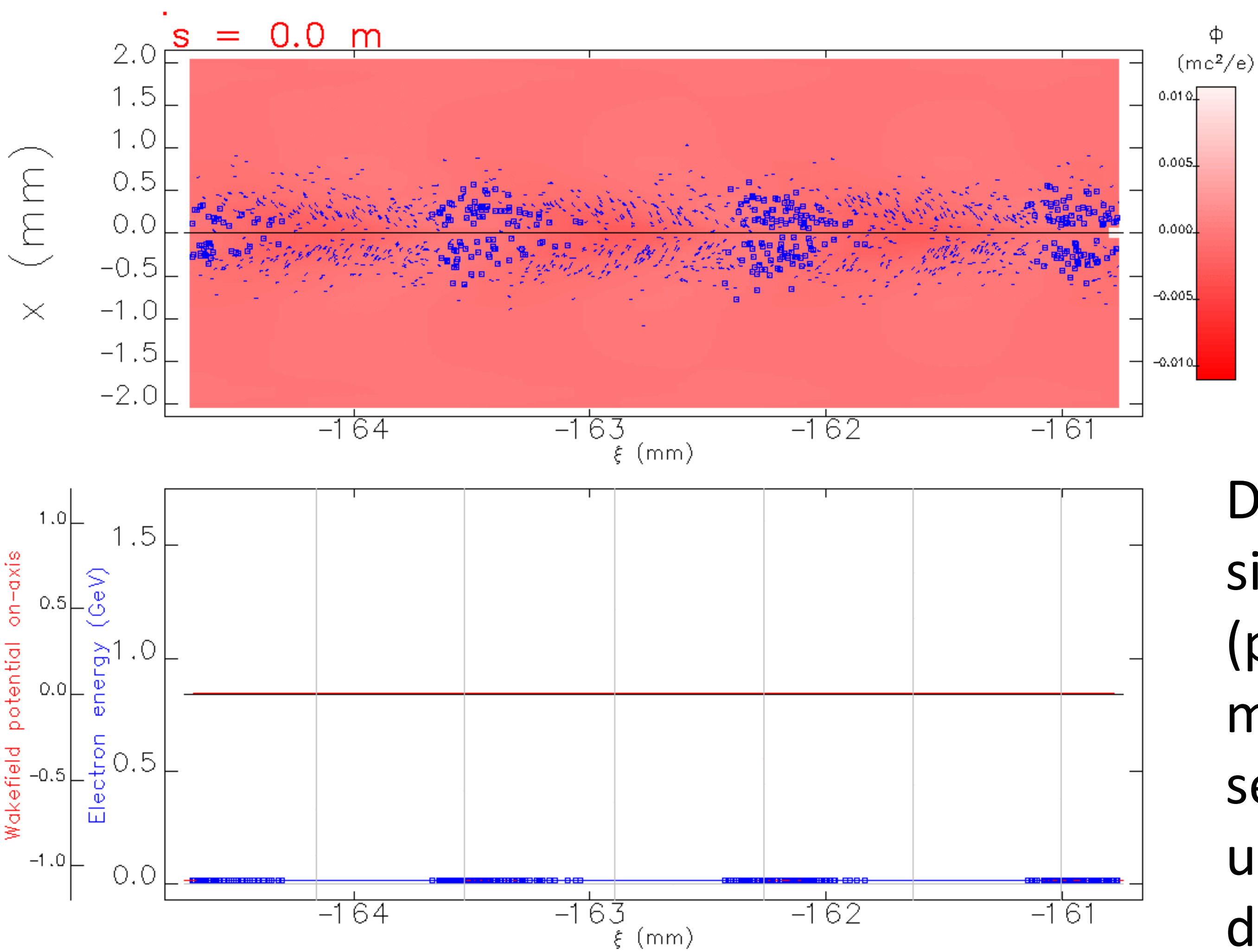


Simulation team: BINP, Düsseldorf, IST, Oslo, UCL

Simulations

On-axis injection: animation of electron trapping and acceleration

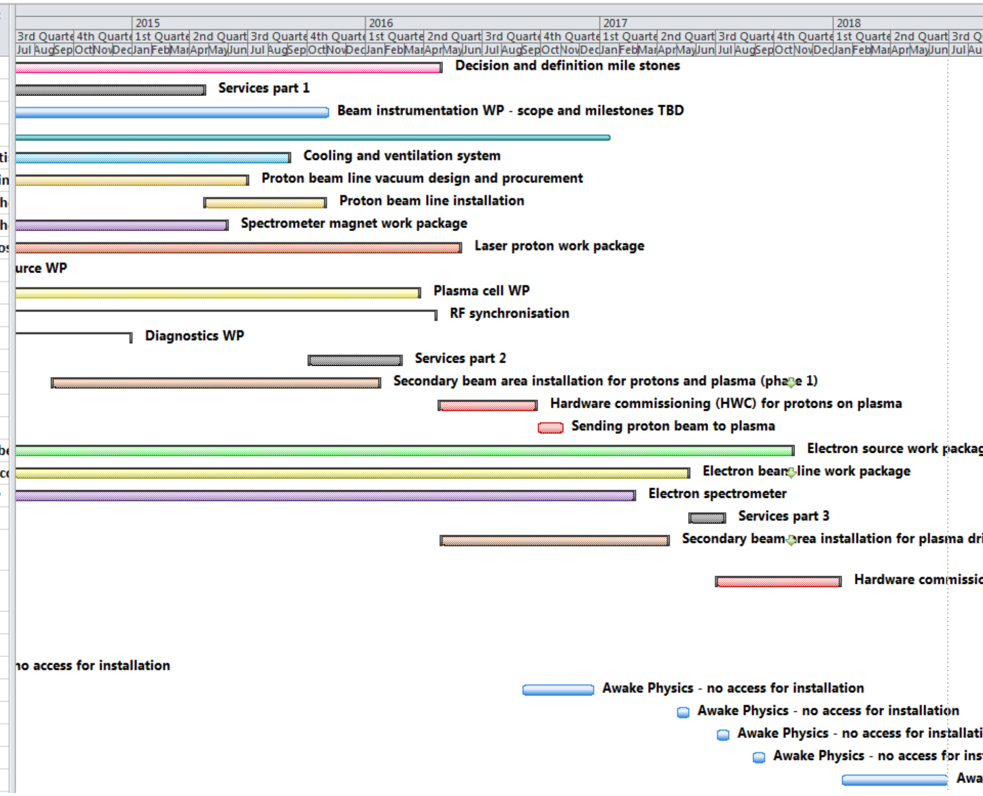
(Wakefield potential)



Database with simulation output (particle position, momentum, time) set up & being used for diagnostic studies.

Detailed Schedule

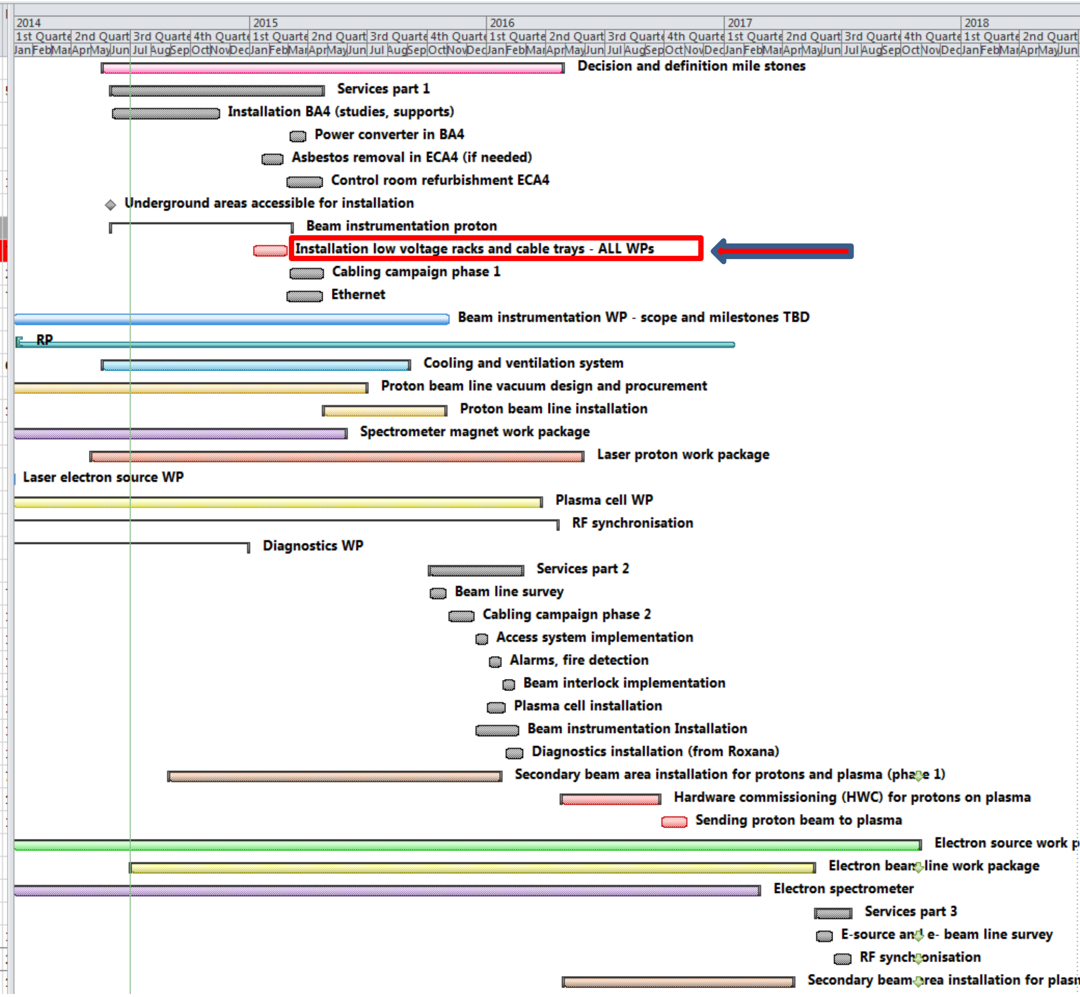
Task Name	Duration	Start	Finish	Predec	Contact
Decision and definition mile stones	**509 days**	**19/05/2014**	**29/04/2016**		**Edda**
Services part 1	**235 days**	**30/05/2014**	**24/04/2015**	**5**	
Beam instrumentation WP - scope and milestones TBD	24 mons	01/01/2014	03/11/2015		
Radiation protection tasks		**06/01/2014**			
Cooling and ventilation system	**340 days**	**19/05/2014**	**04/09/2015**	**6**	**M. Batti**
Proton beam line vacuum design and procurement	**392 days**	**27/12/2013**	**29/06/2015**		**N. Critin**
Proton beam line installation	**135 days**	**24/04/2015**	**30/10/2015**	**14**	**J. Bauch**
Spectrometer magnet work package	**367 days**	**01/01/2014**	**28/05/2015**		**J. Bauch**
Laser proton work package	**542 days?**	**01/05/2014**	**27/05/2016**		**V. Fedos**
Laser electron source WP	1 day?	01/01/2014	01/01/2014		
Plasma cell WP	**583 days?**	**01/01/2014**	**25/03/2016**		
RF synchronisation	**600 days**	**01/01/2014**	**19/04/2016**		
Diagnostics WP	**260 days?**	**01/01/2014**	**31/12/2014**		
Services part 2	**104 days**	**05/10/2015**	**25/02/2016**		
Secondary beam area installation for protons and plasma (phase 1)	**366 days?**	**29/08/2014**	**22/01/2016**	**7**	
Hardware commissioning (HWC) for protons on plasma	**110 days**	**25/04/2016**	**23/09/2016**	**14,38,50,**	
Sending proton beam to plasma	6 wks	26/09/2016	04/11/2016	165	
Electron source work package	**999 days**	**01/01/2014**	**30/10/2017**		**S. Doebe**
Electron beam line work package	**755 days**	**30/06/2014**	**19/05/2017**		**C. Bracco**
Electron spectrometer	**823 days**	**01/01/2014**	**24/02/2017**		**S. Jolly**
Services part 3	**40 days**	**22/05/2017**	**14/07/2017**		
Secondary beam area installation for plasma driven electron acceleration (phase 2)	**252 days?**	**29/04/2016**	**17/04/2017**	**11**	
Hardware commissioning (HWC) for plasma driven electron acceleration	**140 days**	**03/07/2017**	**12/01/2018**		
Awake Physics - no access for installation	1 day?	01/01/2014	01/01/2014		
Awake Physics - no access for installation	4 mons	01/09/2016	21/12/2016		
Awake Physics - no access for installation	3 wks	01/05/2017	19/05/2017		
Awake Physics - no access for installation	3 wks	03/07/2017	21/07/2017		
Awake Physics - no access for installation	3 wks	28/08/2017	15/09/2017		
Awake Electron Physics	24 wks	15/01/2018	29/06/2018	216	



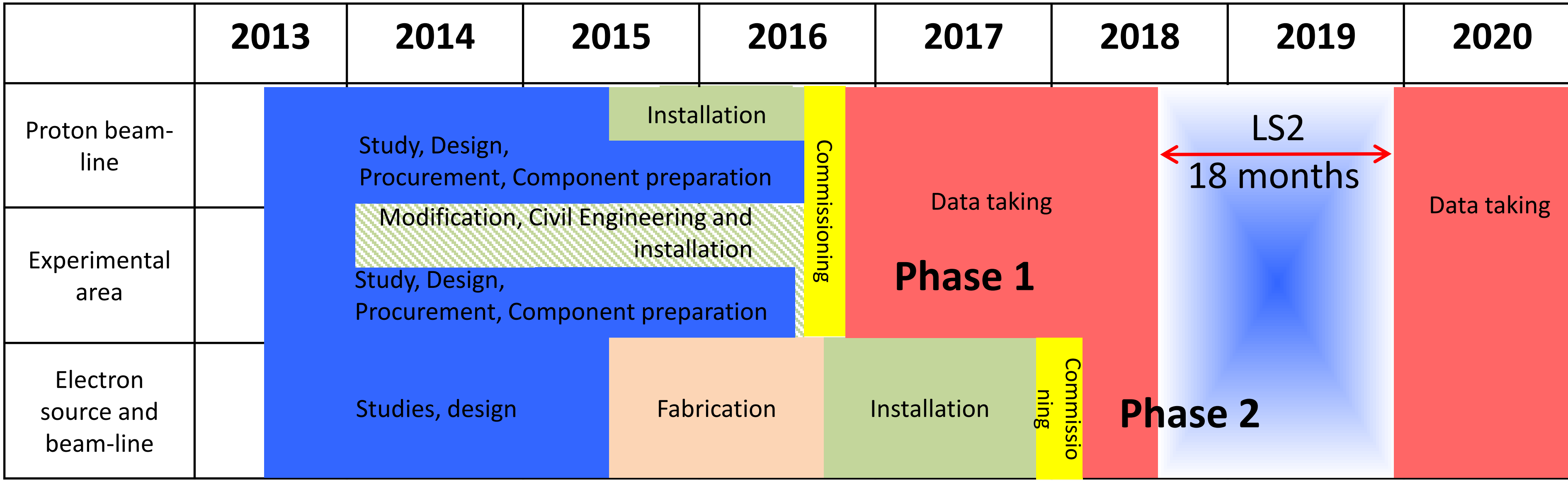
CERN Project Managers keeping everyone on schedule !

An Example …

Task Name	Duration	Start	Finish
Decision and definition mile stones	**509 days**	**19/05/2014**	**29/04/2016**
Services part 1	**235 days**	**30/05/2014**	**24/04/2015**
Installation BA4 (studies, supports)	6 mons	02/06/2014	14/11/2014
Power converter in BA4	4 wks	02/03/2015	27/03/2015
Asbestos removal in ECA4 (if needed)	5 wks	19/01/2015	20/02/2015
Control room refurbishment ECA4	8 wks	26/02/2015	22/04/2015
Underground areas accessible for installation	0 days	30/05/2014	30/05/2014
Beam instrumentation proton	**200 days**	**30/05/2014**	**06/03/2015**
Installation low voltage racks and cable trays - ALL WPs	8 wks	05/01/2015	27/02/2015
Cabling campaign phase 1	8 wks	02/03/2015	24/04/2015
Ethernet	8 wks	26/02/2015	22/04/2015
Beam instrumentation WP - scope and milestones TBD	24 mons	01/01/2014	03/11/2015
Radiation protection tasks		**06/01/2014**	
Cooling and ventilation system	**340 days**	**19/05/2014**	**04/09/2015**
Proton beam line vacuum design and procurement	**392 days**	**27/12/2013**	**29/06/2015**
Proton beam line installation	**135 days**	**24/04/2015**	**30/10/2015**
Spectrometer magnet work package	**367 days**	**01/01/2014**	**28/05/2015**
Laser proton work package	**542 days?**	**01/05/2014**	**27/05/2016**
Laser electron source WP	1 day?	01/01/2014	01/01/2014
Plasma cell WP	**583 days?**	**01/01/2014**	**25/03/2016**
RF synchronisation	**600 days**	**01/01/2014**	**19/04/2016**
Diagnostics WP	**260 days?**	**01/01/2014**	**31/12/2014**
Services part 2	**104 days**	**05/10/2015**	**25/02/2016**
Beam line survey	4 wks	05/10/2015	30/10/2015
Cabling campaign phase 2	6 wks	02/11/2015	11/12/2015
Access system implementation	3 wks	14/12/2015	01/01/2016
Alarms, fire detection	3 wks	04/01/2016	22/01/2016
Beam interlock implementation	3 wks	25/01/2016	12/02/2016
Plasma cell installation	4 wks	01/01/2016	28/01/2016
Beam instrumentation Installation	10 wks	14/12/2015	19/02/2016
Diagnostics installation (from Roxana)	1 mon	29/01/2016	25/02/2016
Secondary beam area installation for protons and plasma (phase 1)	**366 days?**	**29/08/2014**	**22/01/2016**
Hardware commissioning (HWC) for protons on plasma	**110 days**	**25/04/2016**	**23/09/2016**
Sending proton beam to plasma	6 wks	26/09/2016	04/11/2016
Electron source work package	**999 days**	**01/01/2014**	**30/10/2017**
Electron beam line work package	**755 days**	**30/06/2014**	**19/05/2017**
Electron spectrometer	**823 days**	**01/01/2014**	**24/02/2017**
Services part 3	**40 days**	**22/05/2017**	**14/07/2017**
E-source and e- beam line survey	4 wks	22/05/2017	16/06/2017
RF synchronisation	4 wks	19/06/2017	14/07/2017
Secondary beam area installation for plasma driven electron	**252 days?**	**29/04/2016**	**17/04/2017**



Schedule



Science Program:

1. Benchmark experiments – first ever proton-driven plasma wakefields
2. Detailed comparison of experimental measurements with simulations
3. Demonstration of high-gradient acceleration of electrons
4. Develop long, scalable & uniform plasma cells; test in AWAKE experiment

Goal: Design high quality & high energy electron accelerator based on acquired knowledge.