Linac4 H^- Ion Source *Work Package*

The numerous contributions of the Linac4 ion source and sLHC teams and international colleagues is gratefully acknowledged

Abstact

Linac 4 IS design parameters: 100* +400 μs, 80 mA H^- pulses at 45 kV,
Repetition rate: 1-2 Hz, Emittance 0.25 πmmmrad

Status of the linac 4 ion source:

An RF driven volume source (copy of the DESY 35 kV, H^- source) is operated at the 3 MeV test stand.

The commissioning at 35 kV has been completed.

July 2010: Electron dump problems encountered during the upgrade to 45 kV.

The source is converted to a 45 kV proton source used for the RFQ and chopper commissioning until April 2012.

August 2010: Crash program initiated to provide a new Linac4 source design.

SLHCPP EU-project: 50Hz, 1.2 ms, 100kW, 2MHz RF plasma Generator designed, produced and tested. *Plasma Generator Test stand* is operational.

(*) pre-pulse of 100 μs to neutralize space charge.

Linac4 WPIS *status*

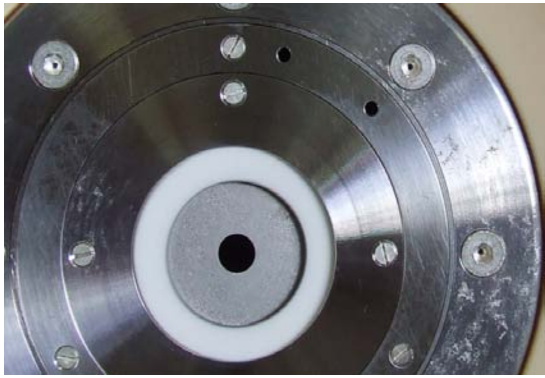
- 2005-July 2010
  - Survey of possible ion source
  - Copy of the DESY drawings
  - 2007, 95 kV and 45 kV design
  - 2008, Production of a Volume source
  - 2009, Commissioning at 35 kV
  - 2010, Commissioning at 45 kV

A radio frequency driven H^- source for Linac4,
Rev. Sci. Instrum. **79, 02A504 2008**

ENGINEERING PARAMETERS FOR DIAGNOSTICS
FOR A SOURCE TEST LINE FOR LINAC 4,
https://edms.cern.ch/document/953231/0.1

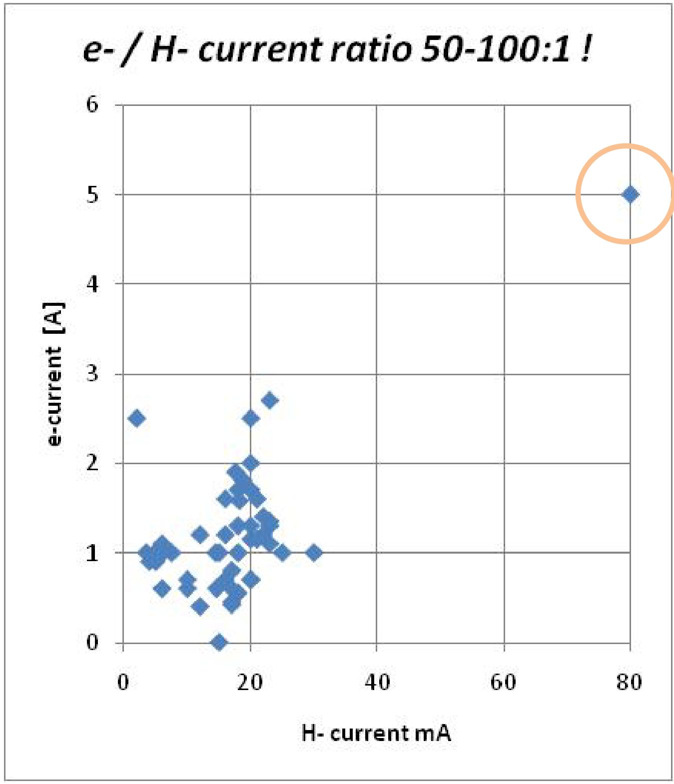
- Aug-2010 –June 2011
  - Analysis of the commissioning findings
  - Proposition of a draft WPIS amendment
  - Decision to produce a H^- ion source test stand and to include Cesiation
  - Review of accelerator H^- ion sources; outcome:
    - Baseline is RF driven H^- ion source
    - Pulsed power supplies
    - Magnetron H^- ion source as backup to be launched asap.
  - March 2011: WPIS vs. shutdown (LS1) schedule
    - Staged approach, 30, 50 , 80 mA
    - 30 mA, 45 kV H^- source on the 3 MeV test stand by mid 2012 !
- Plasma Generator test stand operation:
  - Staff training, vacuum, gas injection
  - RF-Plasma parameters measurement & plasma diagnostics validation

3 MeV test stand: Commissioning findings 7/2010-8/2011



Show stopper

- Electron-dump energy
  - e/H^- from 20 to 100
  - 5 Amps @ 45 kV → 225 J/ms/mm^2
  - *2 orders of magnitude reduction is mandatory*
- High voltage
  - Sparks (2 μF @ 45 kV → 2 kJ)
  - Antenna air ionization
  - Internal capacities (sparks to H_2-line)
- Temperature stability
- Alignment, tuning flexibility
- Spare parts policy (*fast IS-exchange*)
- Emittance is nominal at low current (expected to increase at nominal current)
- Electron to H^- ratio (collar-front plate tuning)
- HT power supply requires upgrade for 2 Hz operations
- 3D beam transport simulation mandatory



After solving e-dump issue, It is worth to complete the 45 kV commissioning of a volume source.

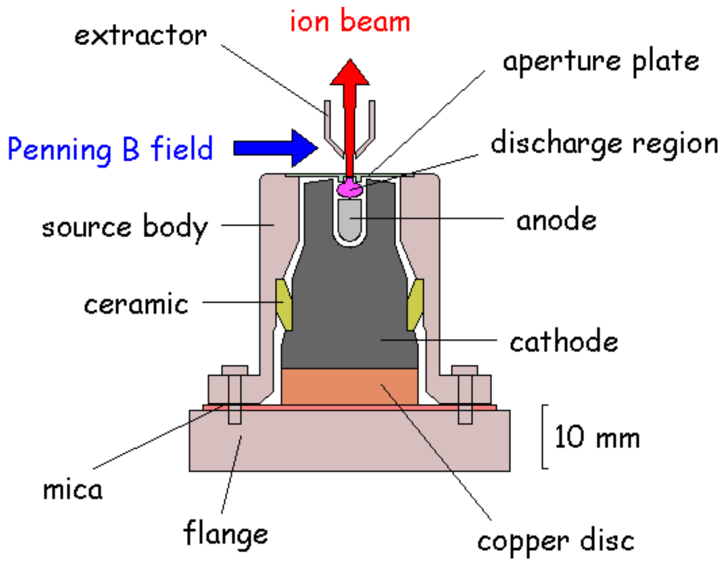
DESY vs. Linac4 ion source parameters

H^- ion source stages		DESY	Linac4 July-2010	*Linac4 Nominal*	L4-nom / DESY
Repetition rate	Hz	6		2	
HT	kV	35	35	45	128%
RF-power	kW	30	30	100	333%
RF-pulse	J	4.5	15	70	15.56
H- current	mA	30	20	60-80	267%
Pulse duration	ms	0.15	0.5	0.7	467%
Emittance	$\pi\mu$m	0.25	0.25	?	
Co-extracted electrons	A		2	5	
e-dump energy	J		35	158	

Strategy for ISWP:

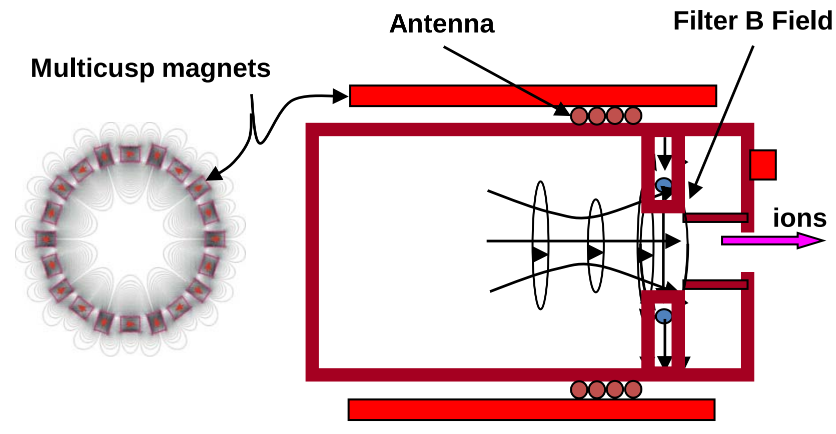
- Systematic analysis of all physical processes is mandatory !
- Simulation will be validated by specific measurements
- Linac4 ISs will have limited life time, they will evolve and needs to be swiftly exchangeable.
- Cesiation must be implemented, learned and integrated (reduction of e/H^- ratio)
- Spare IS and new IS-prototypes will be tested off-line (IS-test stand acceptance procedure),
- Linac4: on-line conditioning &commissioning of ion sources mandatory.

H^- Sources for Linacs



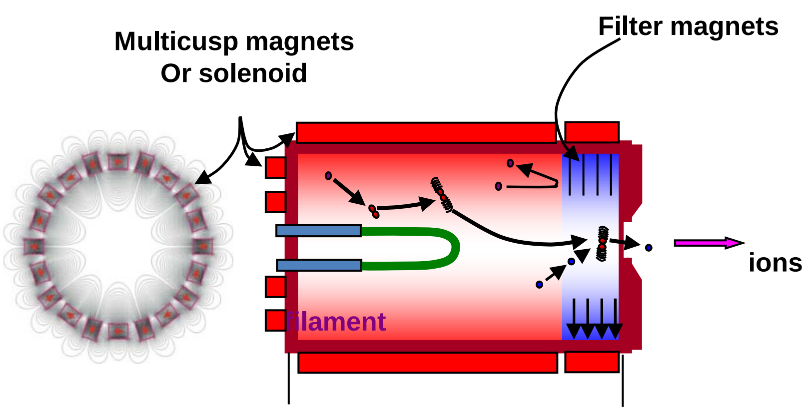
Penning (ISIS)

Linac4 baseline:



RF Antenna → *Volume (DESY)*

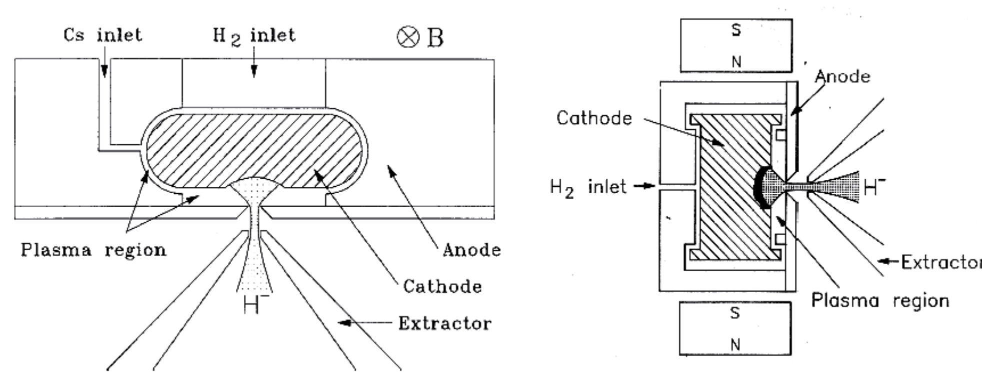
RF Antenna → *+ Cs → Surface (SNS)*



Cathode Discharge (JPARC)

Original drawings, courtesy of Richard Scrivens.

Linac4 high current option:



Arc discharge → *Magnetron (BNL)*

Outcome of accelerators H^- ion sources review Feb. 2011

- Review of world's accelerators H^- ion sources completed (Feb)
  - RAL-ISIS
  - BNL Magnetron + Cs metal
  - JPARC
  - SNS inductive RF internal or external antenna + Cs Chromate
  - DESY inductive RF external antenna
- *No H^- ion sources within specified emittance @ 45kV & nominal beam intensity !*
- Choices for Linac4:
  1) L4-inductive external antenna (volume source) + Cs (surface source)
     - > 1 MCHF already invested
     - Existing know how, intrinsic flexibility
  2) Upgrade of BNL's magnetron to 45 kV as nominal current option and Risk mitigation
     - Simple and reliable for BNL operations @ 35 kV, 6Hz

Summary:

- August 2010 ISWP resource envelope accepted as 0-baseline.
- Pulsed extraction & BNL-IS Mitigation added to the 0-baseline
- Cesiated RF and Magnetron need R&D, learning & demo phase

Cesiated H^- ion sources,

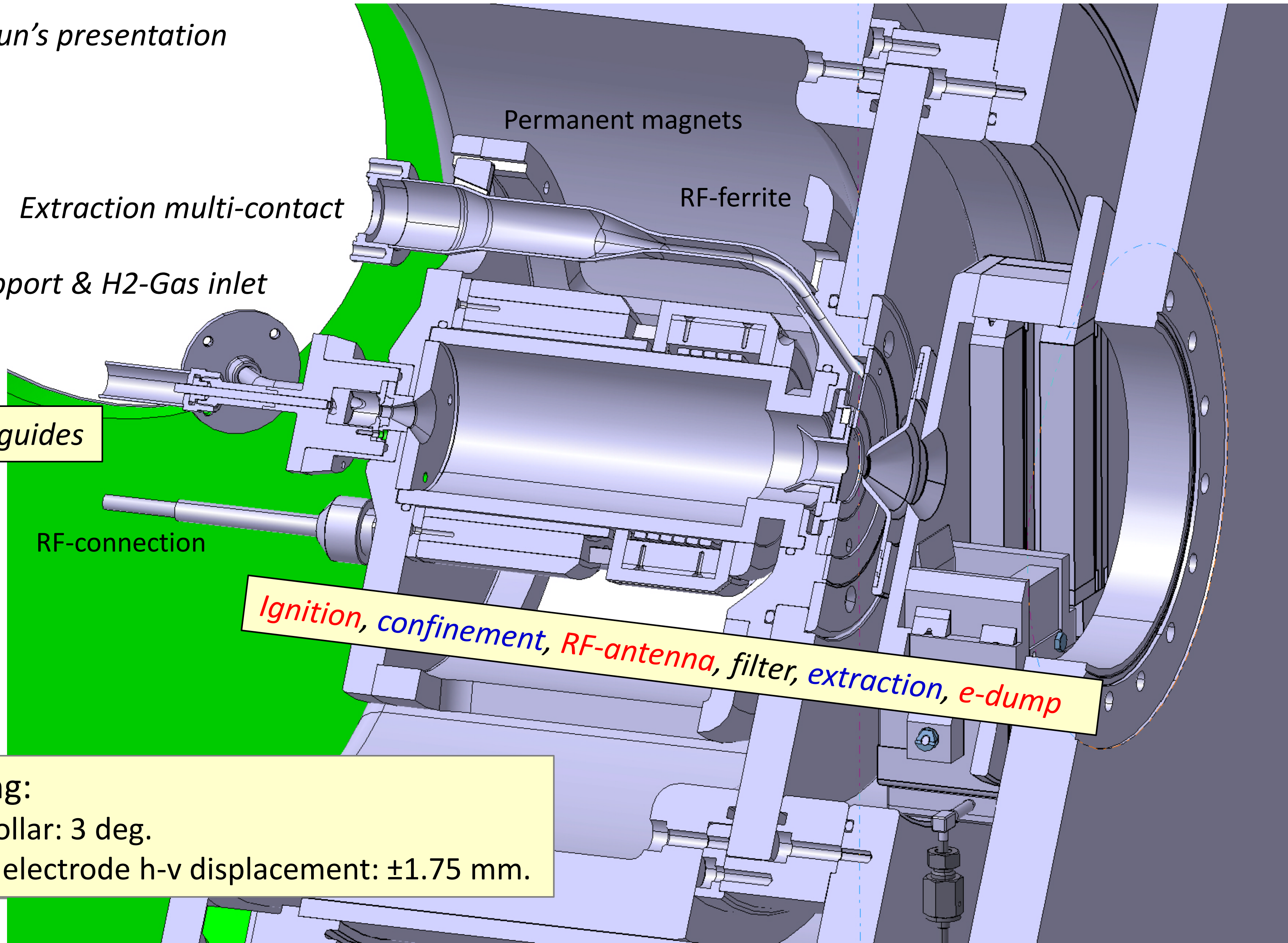
Data extracted for specific operation conditions on: Cs-injection rate, H^- current, emittance, HV, repetition rate and life time

	Cs consumption	*mg/day*	*H^- current, pulse duration, emittance and extraction voltage*	*Rate, Life time*
LANL	20 g / 30 days	600	40 mA, 1000 μs, 0.13 $\pi\mu m$, 80 keV	120 Hz,
DESY		**0**	25 mA, 150 μs, 0.25 $\pi\mu m$, 35 keV	6 Hz, 6 month
J-parc LaB6, W	 tested	0 >0	36 mA, 500 μs, 0.25 $\pi\mu m$, 50 keV 60 mA	25 Hz, 500 h
SNS Goal:	30 mg / 40 days 3 mg	**<0.75** <0.1	56 mA (after RFQ), 1000 μs, 0.2 $\pi\mu m$, 65 keV	60 Hz, 5 weeks
RAL	3 g/month	100	35-80 mA, 800 μs, 0.3 $\pi\mu m$, 65 keV	50 Hz, 1 month
BNL	< 0.5 mg/h	**< 12**	90-100 mA, 700 μs, 0.4 $\pi\mu m$, 35 keV	6 Hz, 3-9 month

Cesiated IS operation must be demonstrated on the test stand prior to on-line operation !
Minimize Cs consumption.

Linac4 H^- source; copy of DESY's IS

See O. Midttun's presentation



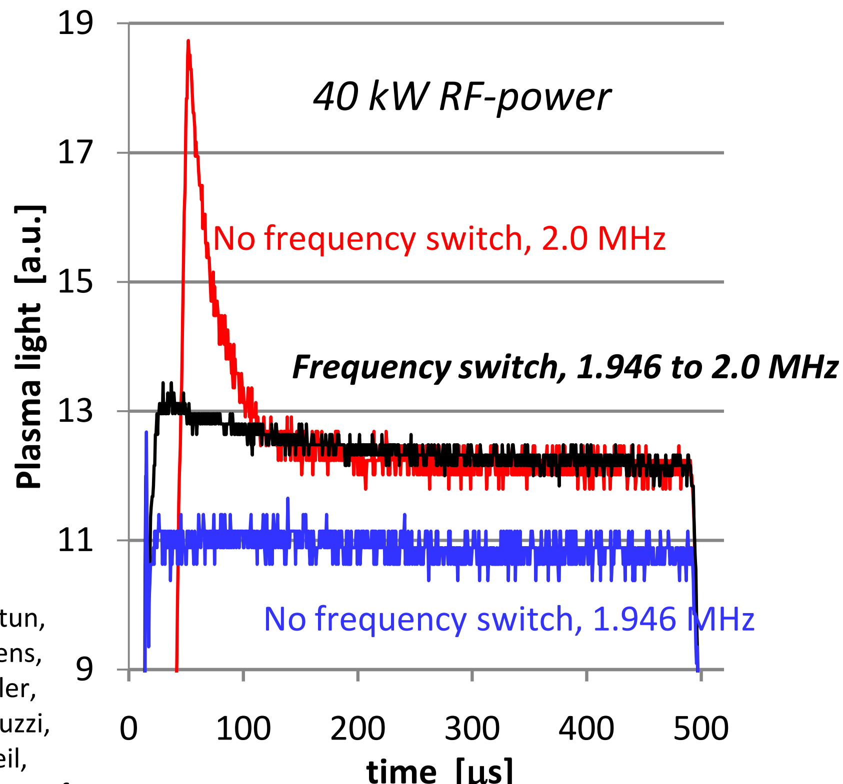
Beam tuning:

- Tilt-able Collar: 3 deg.
- Extraction electrode h-v displacement: ±1.75 mm.

Linac4-IS Volume source:

Plasma light driven RF frequency switch

- Optimum coupling without and with plasma.
- Reduces jittering of ignition time
- Improves current stability



O. Midttun, R. Scrivens, D. Kuchler, M. Paoluzzi, M. O'Neil, C. Mastrostefano

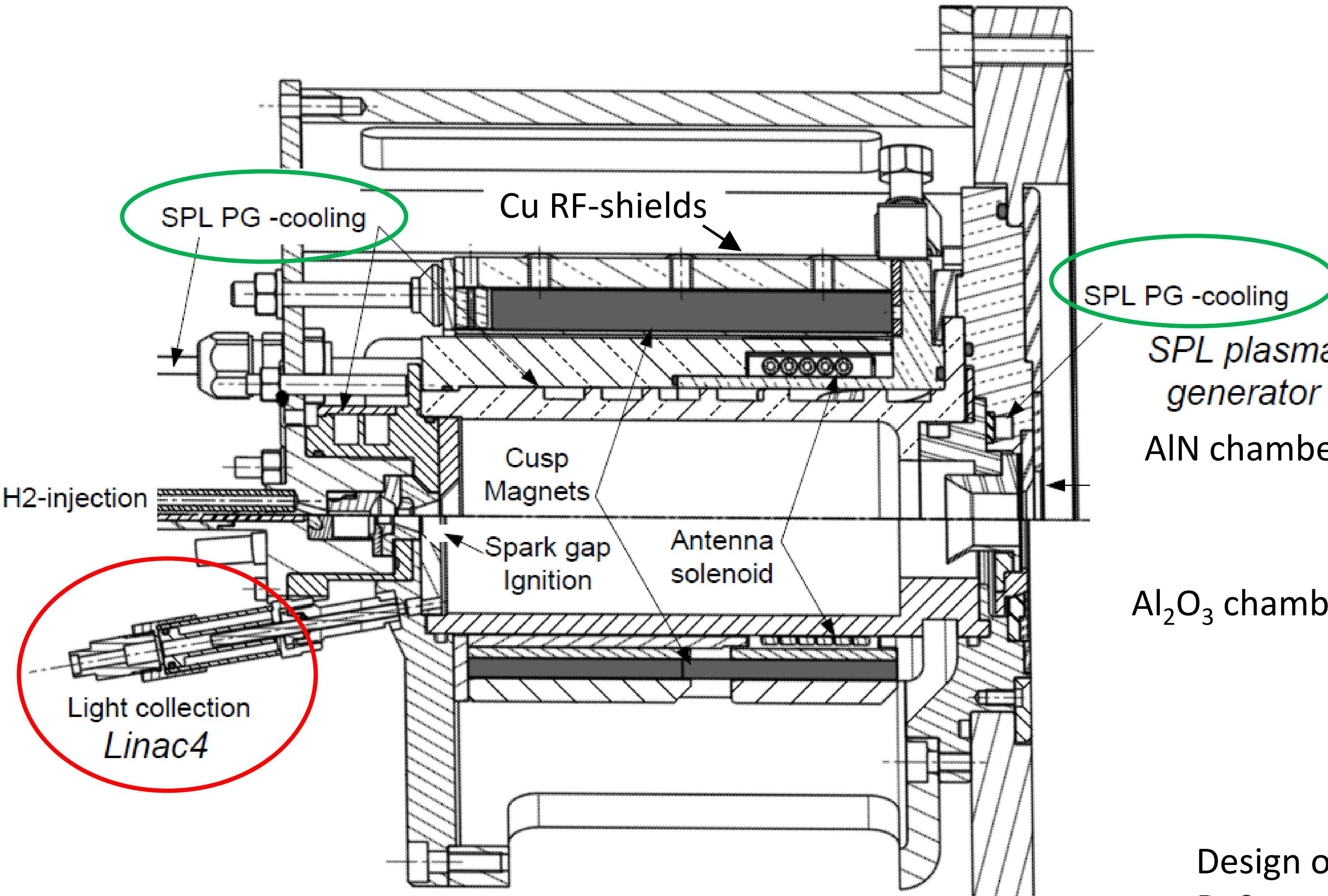
Mandatory parallel tasks:

- IS-R&D + simulation
- 3 MeV tests
- IS Front end design
- IS Test stand production

Making use of existing equipment;
*- **DESY Volume source** kept for 3 MeV commissioning as p-source*
- 20-30 mA H^- volume source provided following upgrades :

1) The e/H^- ratio is kept under control (measurement and modelling)
2) The dump vaporization issue is solved (modelling the electron surface energy flux and secondary electrons and pulse HV-supplies)
3) Modelling the magnetic field, electrode displacement and tilt to understand electron and H^- beam alignment features.
4) Stable ignition (P, RF-switching, discharge)

SPL plasma generator as H^- volume source



SPL plasma generator

AlN chamber

Al_2O_3 chamber

Design office :
D. Steyaert,
E. Chaudet

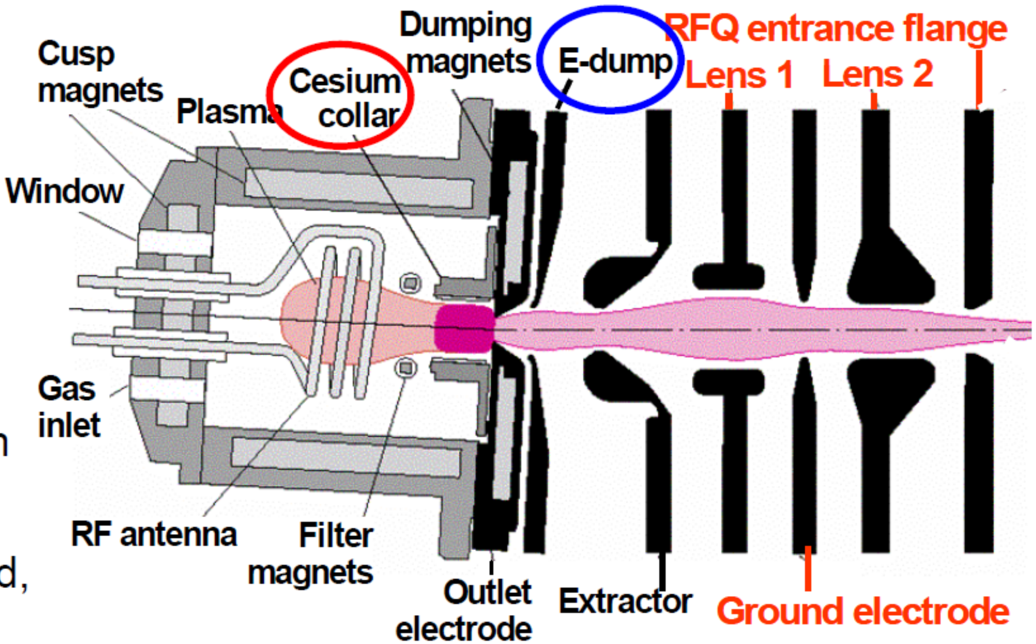
SNS H- ion source, RF internal antenna

Courtesy form: M. P. Stockli,
Presented at NIBS 2010 Takayama

Cs-chromate + Al-Zr getter

The SNS Baseline H- Source

- LBNL developed the SNS H- source, a cesium-enhanced, multicusp ion source.
- Typically 250 W from a 600-W, 13-MHz amplifier generate a continuous low power plasma.
- The high current beam pulses are generated by superimposing 30-70 kW from a pulsed, 80-kW, 2-Mz amplifier.



Low energy e-dump
Multistage extraction
Einzel lenses
Tilt + Steering

- **After significant modifications, the SNS H- source now routinely produces the 38 mA LINAC beam current required for 1-1.4 MW beams!**
- **The source service cycle has been increased from 2 weeks in 2008, to 3, and to 4 and 5 weeks without seeing old-age signs or failures.**
- **We have demonstrated 56 mA MEBT pulse current and 59 mA MEBT peak current, which is sufficient for 2-3 MW beam power.**

An initial injection of ~3 mg Cs is sufficient for >5 weeks of persistent, ~50 mA H- beams.

BNL's Magnetron surface plasma H^- ion source

- Pulsed H_2 injection
- IS-exchange : 8h
- Life time: 6 month
- Slow buildup of CsOH will gradually block the hydrogen inlet

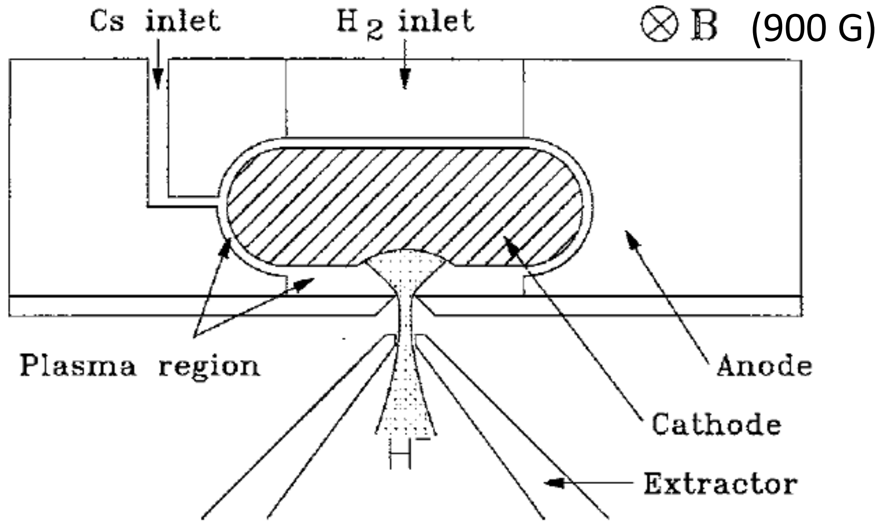
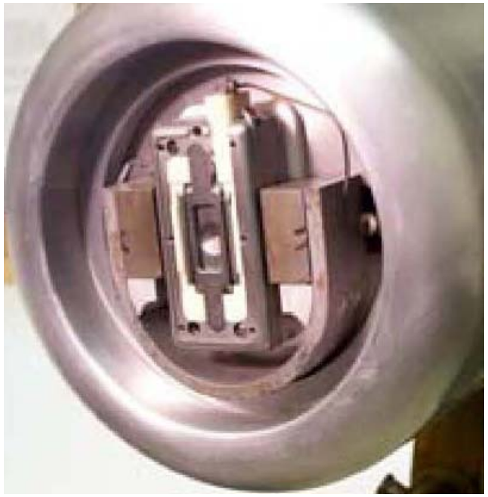


FIGURE 1. Schematic of the magnetron source.

TABLE 1. Typical running parameters	
H- current	90-100 mA
J (H-)	1.5 A/cm^2
Extraction voltage	35 kV
Electron/H-	0.5- 1.0
Arc voltage	140 – 160 V
Arc current	8 – 18 A (see note)
Rep rate	7.5 Hz
Pulse width	700 μs
Duty factor	0.5 %
rms emittance	~ 0.4 π mm mrad
Cs consumption	< 0.5 mg / hr
Gas flow	~ 2 sccm



Ref: **Performance of the Magnetron H- Source on the BNL 200 MeV Linac ,** James G. Alessi, *20th ICFA Advanced Beam Dynamics Workshop on High Intensity and High Brightness Hadron Beams, edited by W. Chou, Y. Mori, D. Neuffer, and I.-F. Ostiguy, 2002*

Mandatory R&D for best Linac4 IS-candidates

function	RF-source	BNL Magnetron
Pulsed gas injection	R&D	R&D
Pulsed HT power supplies	R&D	R&D
Pulsed discharge	Ignition, 20A, 1 kV + R&D on uncorrelated ignitions	Discharge, 400-150 V, 15A, R&D
Cesium injection	Cs-Chromate Single injection	Cs-metal cw flow
H-plasma	Inductive coupling, ignition	Cs-Mo-H plasma & metallurgy
Life time extrapolated to L4	5 weeks, 60 Hz > 3 years	6 month, 6 Hz > 1.5 years
Risks , mitigation	60 to 1-2 Hz, thermal control, commissioning time	6 to 1-2 Hz, heating
Tuning	RF pulse and frequency Gas pressure	Arc power, Gas pressure
Extraction	Multistage 65 kV to 45 kV	Single 35 kV to multi 45 kV, e-dump
Dump & min e/H^-	3D transport	3D & Increased energy

Both system require very similar development at CERN:

- Pulsed power supplies
- Thermal control, Cs-ovens
- 3D Simulation of H^- extraction & e-dump

Test stand & front end design:
Compatible to RF & Magnetron sources and to the SPL PG or DESY-IS

3MeV & L4 milestones vs. ISWP actions

	date	L4-milestone	ISWP action
3MeV	April 2012	3MeV test Protons	Protons
	May-Aug 2012	LEBT June 2012 H^- beam July 2012	New front-end installation and commissioning Installation of proto #1 at the 3MeV test stand
	Sept-Dec	3MeV test H^-	H^- 30 mA
IS-test stand	Oct-Dec 2012		Ion source test stand commissioning
Linac4	Jan 2013		Installation source in L4
	Tbc.		Test IS exchange procedure (proto #1)
	Dec 2013	Decision to connect	
	Feb 2014		Installation of proto #2 in linac4
	April 2014	L4-160 MeV commissioning completed	20 mA required at the end of the linac4 (40 mA at the source)
	… 2015	LSS2 or long MD	Installation of proto #3

WPIS H^- Ion source: staged approach, 2 units each *+ spare*

	#1 Volume source	#2 Surface source	#3 Magnetron
Operational experience H^- current	DESY 30 mA	SNS 50 mA	BNL 80 mA
Plasma Heating process	2 MHz RF Ext. antenna	2 MHz RF Int. & Ext. antenna	Arc discharge
Cesiation		Cs-chromate Single deposition:	Cs metal Constant flow
Cs-Oven test stand		Nov. 2011	Nov. 2011
Electron / H^- ratio	10-100	10	0.5 - 1
357 Plasma test stand (operational)	→ Sept. 2012	2013	2014-2015
3MeV test stand (until Dec-2012) (operational, Bldg. 152)	Jul. 2012- Dec-2012		
IS test stand (Bldg. 357)		2013	2014
Linac4, building 400	Jan 2012	Oct 2013	2015

Challenges being addressed – *Review presentations*

- Design, production
  - Front end — *D.Steyeart, G. Favre*
  - Plasma generators & extraction — *R. Scrivens, T. Zickler, J.-B. Lallement*
  - LEBT, beam diagnostics — *U. Raich*
  - Vaporization of e-dump, Electron to H^- ion ratio — *T. Kalvas, O. Midttun, H. Pereira*
  - Ab initio simulation vs. observables, Emittance
  - Pulsed power supplies — *D. Nisbet, D. Aguglia*
  - Pulsed gas injection, vacuum — *P. Chiggiato*
  - Safety — *M. Kronberger, M. Wilhelmsson*
- Commissioning
  - RF-coupling, Plasma characterization — *M. Paoluzzi, C. Schmitzer*
  - High Voltage sparks
  - Impurities
- Operation
  - Graphical user interface — *I. Kozsar, G. Bellodi, M. O'Neil*
  - Plasma monitoring and diagnostics
  - Stability, Temperature control
  - Beam tuning and alignment
- Identification of Life time limiting processes
  - Antenna ageing
  - Plasma driven abrasion

WP Overview:

L4-Milestones : July 2012 H- tests at 45 keV @3 MeV-TS
January 2013 Move into L4 building

- **Front-end Vacuum Chamber, LEBT & H^- extraction optics**
  - Beam simulation
    Pumping simulation
  - Design: "front end" chamber
  - Production: IS-Test stand
    Modify 3MeV TS
    2 Front ends + LEBTs
    Beam diagnostics
  - *Prototyping ion source*
  - *Commissioning front ends and LEBTs*
    3MeV TS (July-Sept 2012)
    IS-PG-TS (Sept-Dec 2012)

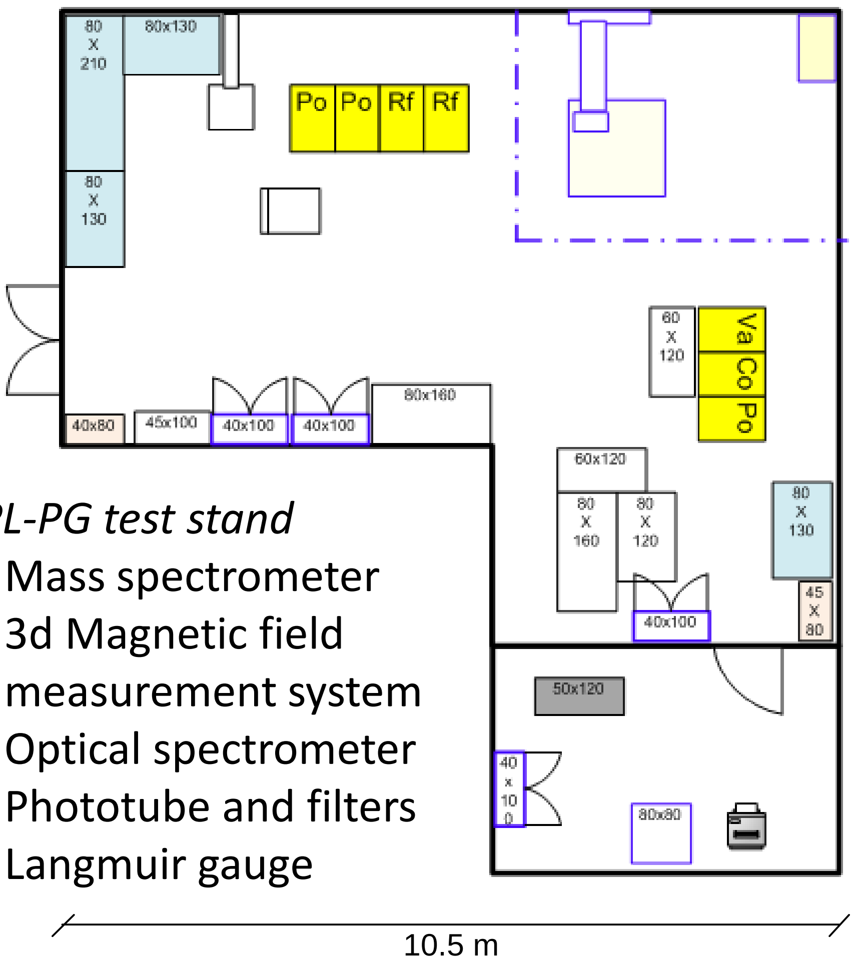
- **Prototypes (6 units)**
  2 units / year
  - Specification
    30, 50, 80 mA
  - Simulation
  - Design: plasma generator
    electron dump
    extraction
  - Production: plasma generator, extraction and RF-matching systems
  - *Testing ion source*
    July 2012
  - Production: Spare Unit

- **Commissioning and testing**
  6 month / IS-unit
  - Matching network
    Test RF-coupling
  - Plasma characterization
    (Optical emission spectroscopy, Langmuir gauge, e/H^- ratio)
  - H^- beam characterization
  - Simulation with tuned e/H^-
    Tilt, Electrode displacement
    & e-dump final settings
  - Stability test (90 days)
  - Analysis of results;
    Ok for On-line operation

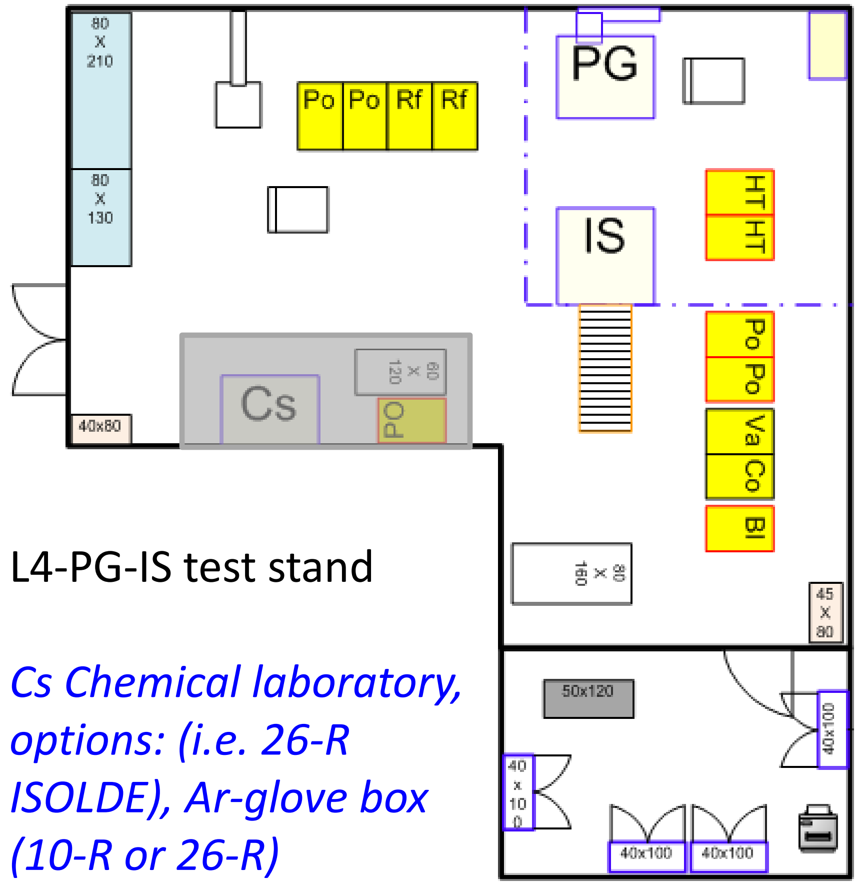
357-R-005; Plasma Generator & Ion source Test stands

Missing space and not suited for Cs-lab
Challenging handling of equipment
Integration study required
+ Cs-transport under inert gas
+ access to CERN's chemical lab

Demineralized Water cooling and SPL RF-generator



SPL-PG test stand
- Mass spectrometer
- 3d Magnetic field measurement system
- Optical spectrometer Phototube and filters
- Langmuir gauge



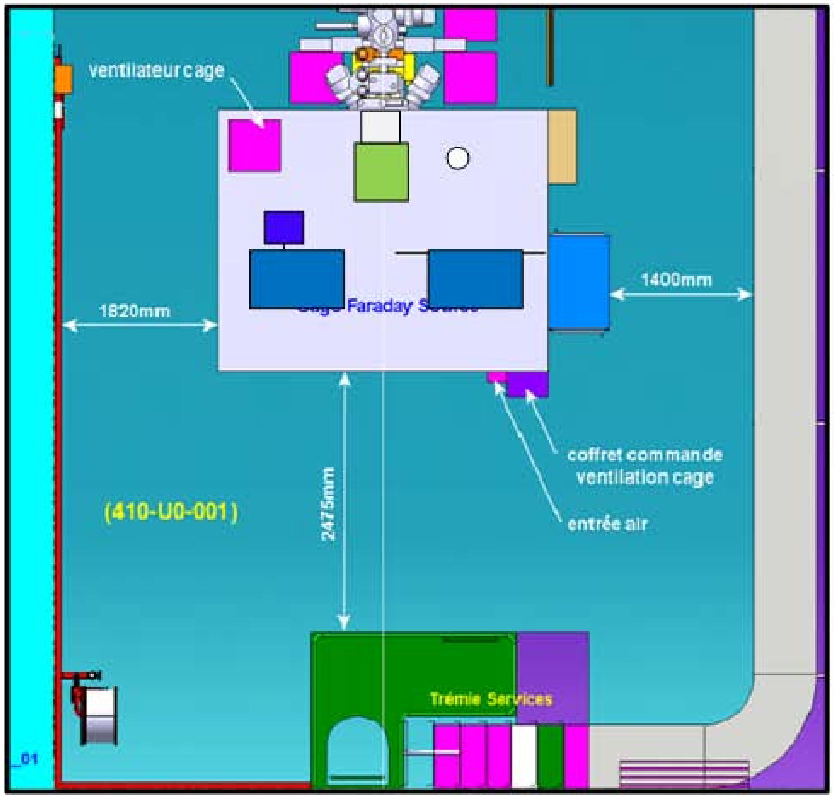
L4-PG-IS test stand

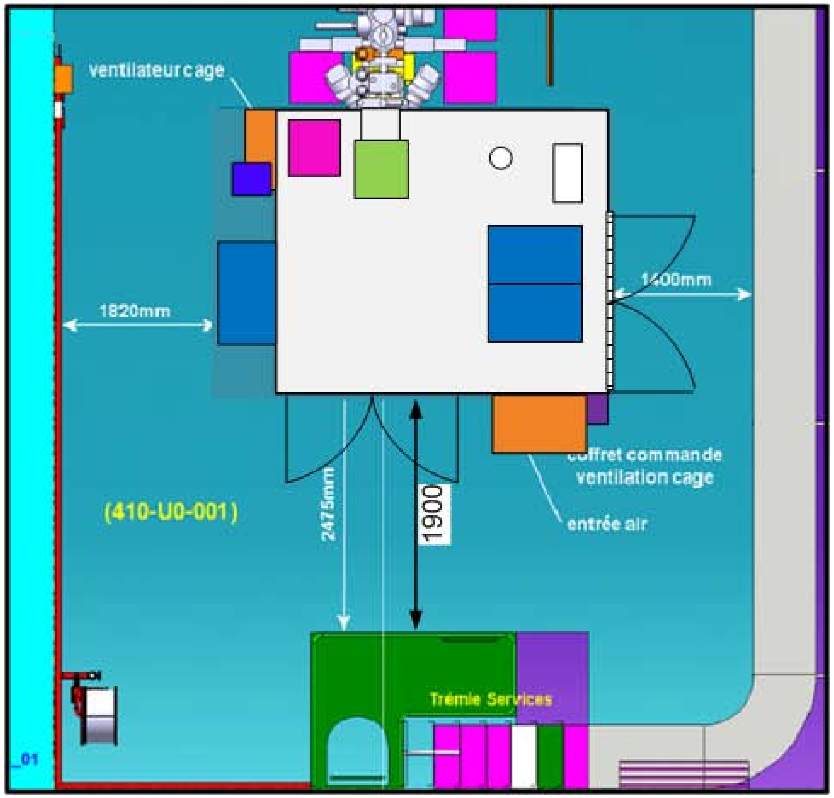
Cs Chemical laboratory, options: (i.e. 26-R ISOLDE), Ar-glove box (10-R or 26-R)

Faraday cage

3MeV test stand Faraday cage
(origin: 95 kV layout)

Linac4 Faraday cage
Gain in accessibility mandatory to host pulsed HV-transformers and for "fast" ion source exchange

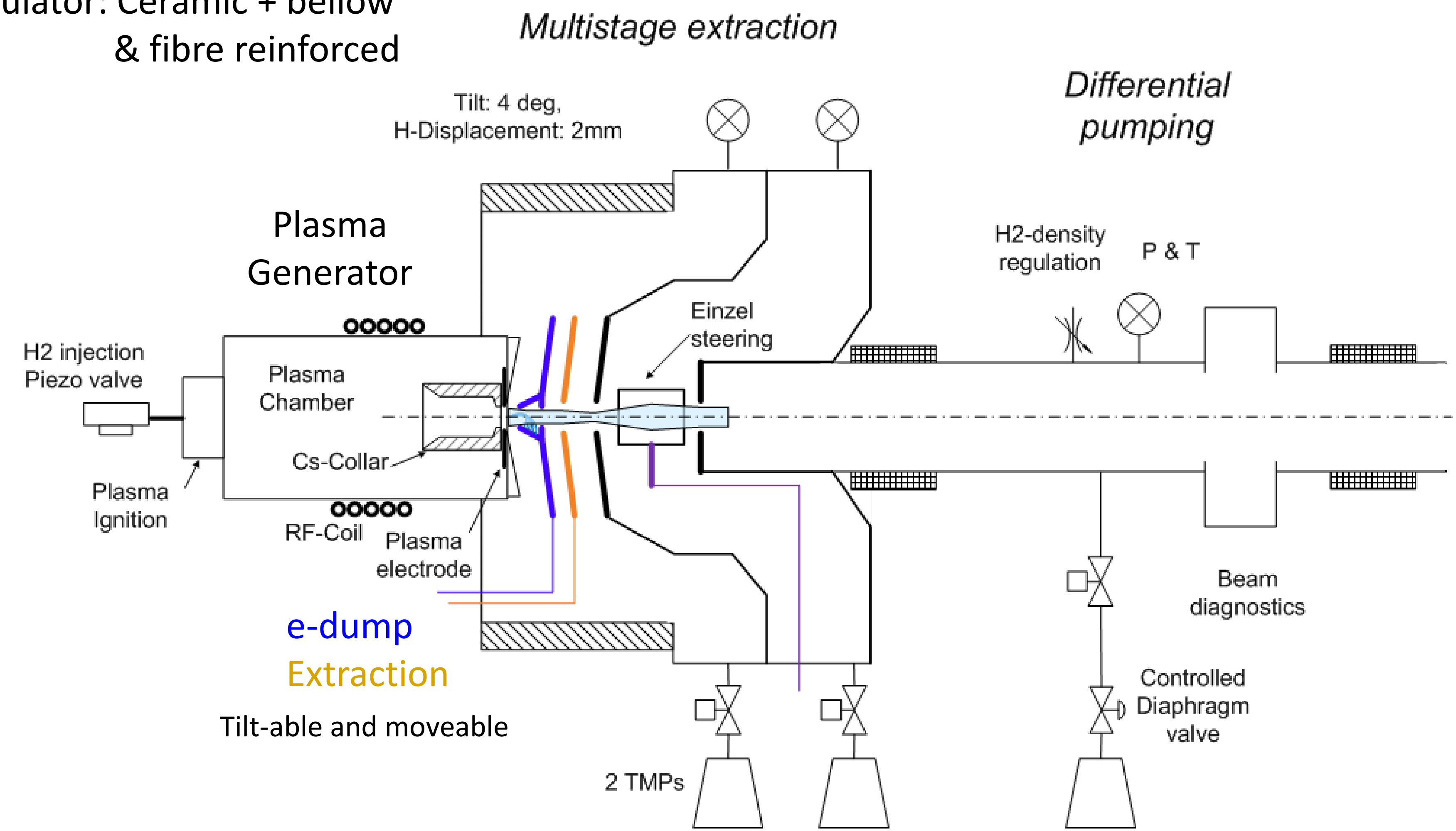




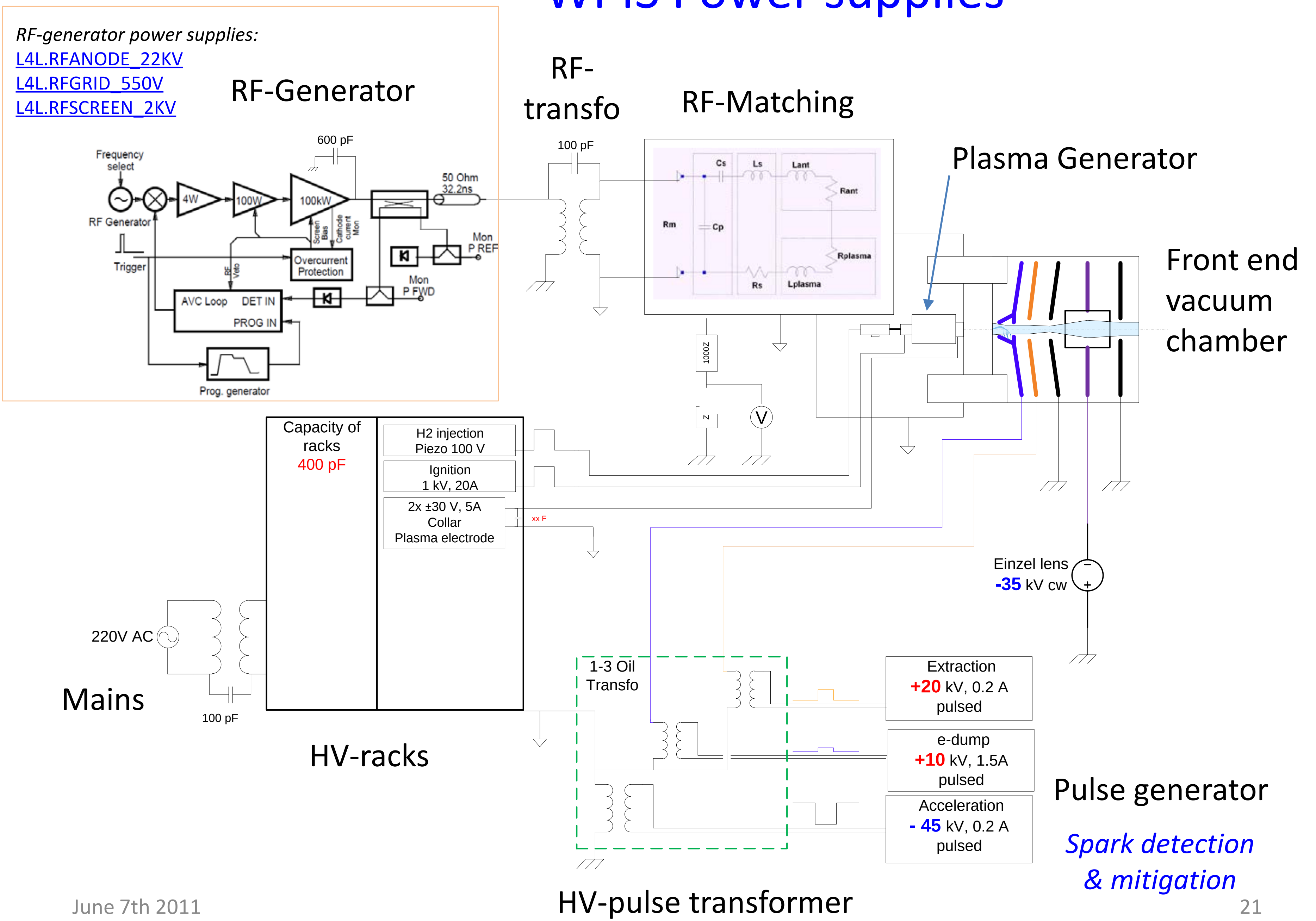
H2 gas system out of HV cage and common to LEBT and IS

Diff. Pumping, Insulator, Tilt and Alignment

Insulator: Ceramic + bellow
& fibre reinforced



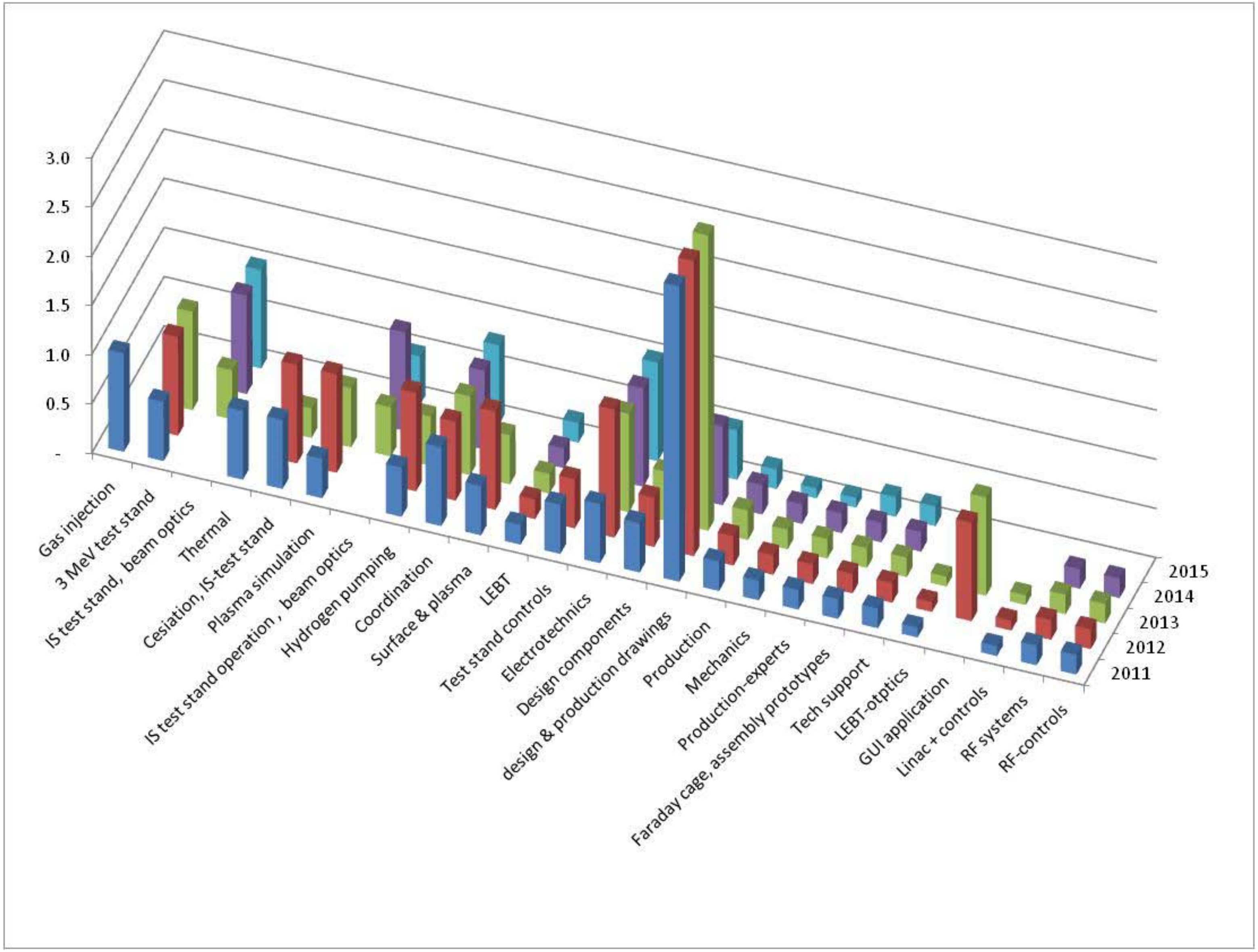
WPIS Power supplies



WP-Linac4 ion sources: Teams involved, additional resources

Group	L4-WP	Staff FTE	Fell. FTE	kCHF	Task description
DGS-SSE	1.3				Safety standard
EN-MME	1.5	8.0		1300	Design, integration, production. (* +BI estimation awaiting confirmation)
BE-ABP	2.1	3.2		900	2nd Low Energy Beam Transport (LEBT) + modifs 1st LEBT
		28.0	14.0	2150	Faraday cage, Ion source &, Beam optics, Specification, Tests, alignment, monitoring and safety systems, GUI, production
EN-MEF		2.7		275	Gas distribution systems (H2, Ar, N2)
TE-ABT		0.5		100	Pre Chopper driver
BE-RF	2.6	1.5		290	Design, operation and maintenance of the RF systems
BE-BI	2.7	1.0		525	Beam Instrumentation, design and production
TE-MSC	2.9			110	Magnets, magnets supports, production
TE-EPC	2.10			1100	Pulsed HV and Magnet Power supplies
TE-VSC	2.11		1.5	300	Design of vacuum & pumping systems, pumping simulation, LEBT density regulation
BE-CO	2.12	1.2		100	Controls, timing, maintenance of GUI
ISWP total :		**47.1**	**15.5**	**7150**	*(some numbers requiring detailed estimation)*

Manpower distribution

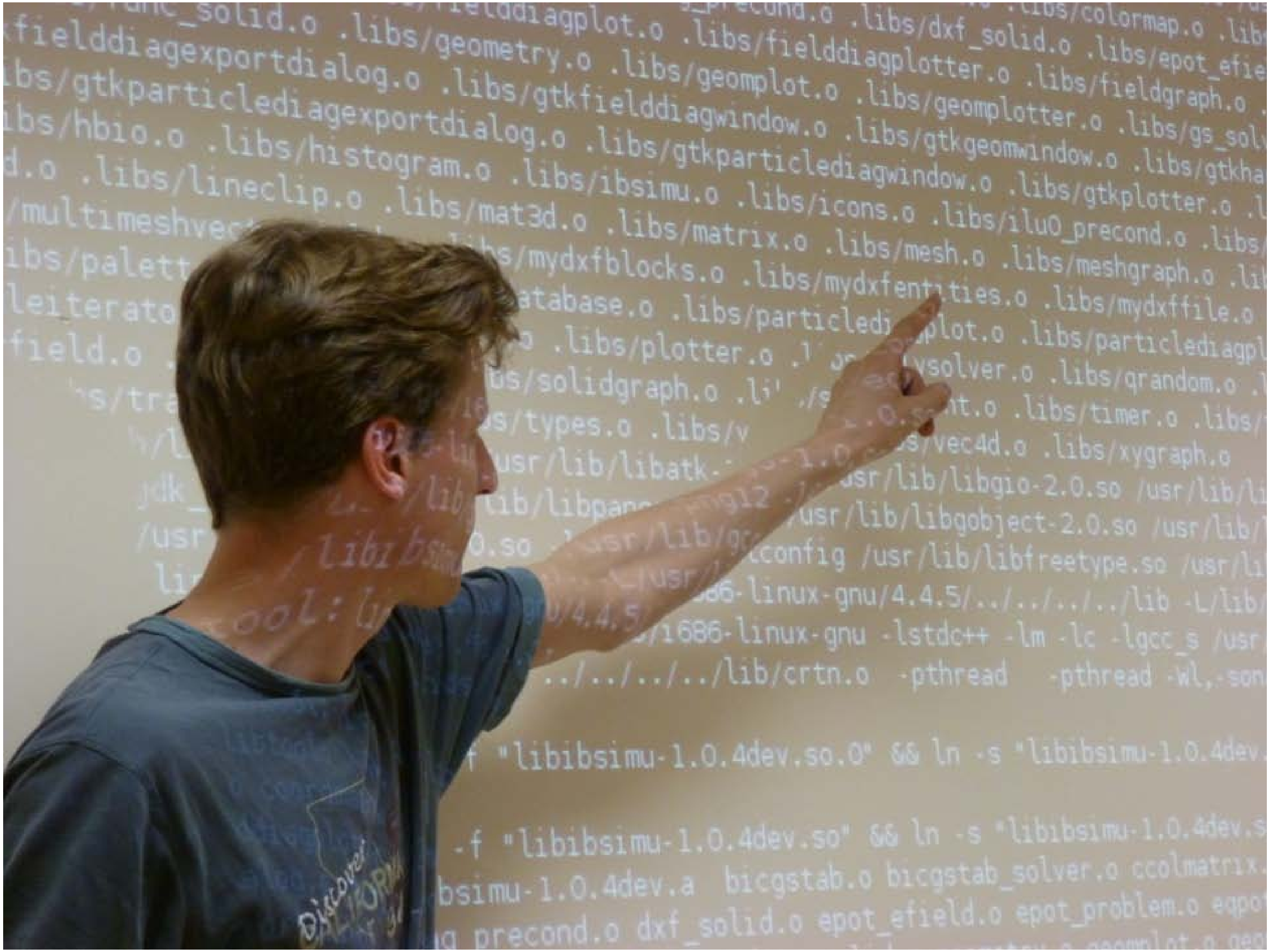


Collaborations, sLHC & linac4 IS

Creative manpower was required to address missing staff and expertise; Fellows, PhDs & Project associates and collaboration to external institutes the list below is our way to address it.

- SNS M.P. Stockli: Visit J. Lettry to SNS (April), Operation and GUI, IS-conditionning, ion source exchange of external, internal antenna plasma Generators (SNS linac and test stand)
- IPP Garching (*sLHC*): Seminar U. Fantz at CERN,
  - Visit J. Lettry, M. Kronberger (February):
    - Visit Cs-laboratory and ITER ion source
    - Emission spectroscopy and Cs-density diagnostics
    - Interpretation of emission spectroscopy via CR models
- Rutherford Appleton Laboratory, ISIS ion source
  - Visit D. Faircloth December (eddy current shielding), february-March high power operation of SPL plasma Generator
  - Visit J. Lettry to RAL (January), ion source operation and exchange, new test stand.
  - Arc discharge plasma simulation (John Adams Institute)
- Prof. Akiyoshi Hatayama, (KEIO university, Japan)
  - Simulation of e-heating in Hydrogen plasma, undefined schedule, upgrade from arc discharge to external antenna.
- S. Mochalskyy (Orsay & Cadarache), 3D-simulation of the plasma in the CERN linac4 ion source (Plasma parameter measurement pending).
- O. Tarvainen &T. Kalvas(University of Jyvaskyla) *sLHC & Linac4*
  - UV-VUV Lyman lines emission spectroscopy on sLHC plasma. 2 weeks plasma (*completed*).
  - T. Kalvas code for simulation of multistage extraction with co-extracted electrons (6 weeks lecture)
- BNL, James Alessi, visit R. Scrivens, F. Wenander and J. Lettry (Feb. Apr. 2011)
  - Operation, drawings

Ibsimu/libs/lecture/Taneli Kalvas.uni.jyvaskyla



Sputtering and Mo-deposition under H2-vapours

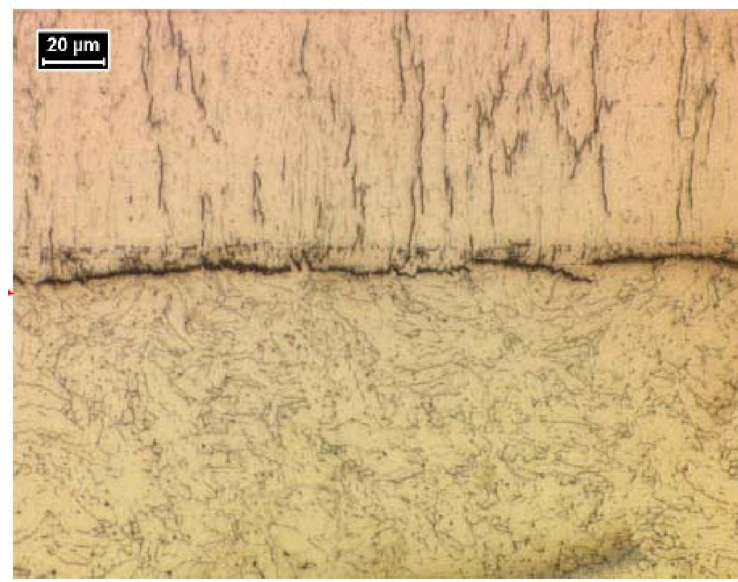
RAL-penning cathode by Courtesy of D. Faircloth

EN Engineering Department

SEM observations:

Cathode tip: sample 2 section analysis

Cs Sputtering of Mo
epitaxial Mo-growth under H_2 atm.
Generation of brittle Mo-flakes



MME Mechanical & Materials Engineering

I. Kozsar
BE-OP

WPIS Controls, Operation, Monitoring

Controls: Settings and readout of effective value

- Power supplies: All currents and voltages (+ timing)
- RF Amplifier:
  - Power setting (time), frequency shift
  - Injected, reflected power
  - Current and voltage phase, Power deposited into the plasma
- Plasma generator: OES-intensities: Hα, Hβ, Hγ (time)
- Gas injection, settings pulse (time), H2-Pressure
- Vacuum: Pressure of differential pumping tanks (time)
  - H2 Density of LEBT

Graphical user interface software supervision *by CO-OP team*

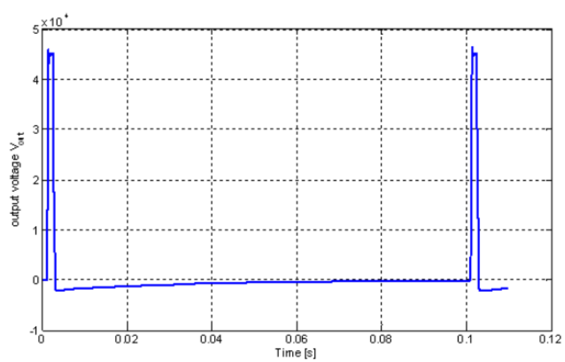
FESA: Front End Software Architecture

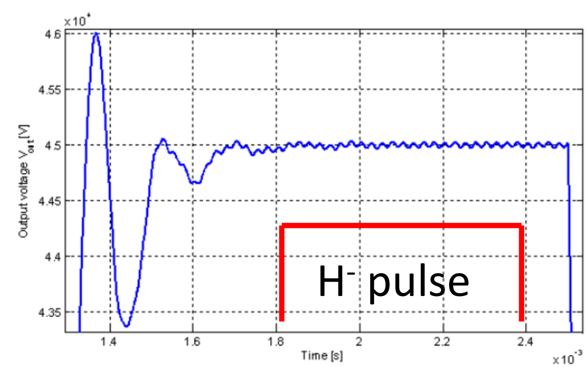
OASIS: Open Analogue Signal Information System

D. Nisbet
D. Aguglia

WPIS Power supplies

Name, location		Responsible Group	type	Voltage, polarity	Load	load duration	Pulse duration	Rep. rate	357 test facility's test			3 MeV Linac4	Spares	Status		
					[A]	[ms]	[ms]	[Hz]	PG	Cs	IS			total	avail.	need
Acceleration, HT racks	Gnd + transfo	TE/EPC	R&D	-45 kV	0.2	0.7	2-5	2			1	1	1	3		3
Extraction	Gnd + transfo	TE/EPC	R&D	20 kV	0.2	0.7	2-5	2			1	1	1	3		3
Electron dump	Gnd + transfo	TE/EPC	R&D	4 kV	2	0.7	2-5	2			1	1	1	3		3
Insulation transformer	Gnd	*	commercial								1	1	1	3	1	2
Einzel lens	Gnd	TE/EPC	commercial	-40 kV	0.2	0.7	cw				1	1	1	3		3
Collar	HT-racks	*BE/ABP*	CERN	+/- 30 V			cw		1			1	1	3	2	1
Plasma electrode	HT-racks	*BE/ABP*	CERN	+/- 30 V			cw		1			1	1	3	2	1
Ignition	HT-racks	*BE/ABP*	R&D	+ 1 kV	20	0.1	0.1	2	1			1	1	3	2	1
Arc discharge	Gnd + transfo		R&D	400 / 150 V	20	1					1			1		1
Cs-Cromate Oven	HT-racks		R&D							1		1		2		2
Cs-metal Oven	HT-racks		R&D							1				1		1
LEBT solenoid	Gnd	TE/EPC	commercial		350		cw				2	2	1	5		5
LEBT steerers	Gnd	TE/EPC	commercial		10		cw				4	4	1	9		9
LEBT pre chopper	Gnd		R&D			0.1					1	1	1	3		3
HT- for RF amplifier	Gnd	TE/EPC	CERN	20 kV	2		cw				1	1	1	3	2	1
HT- for commissionning	Gnd		CERN	-50 kV	0.05		cw				1	1		2	1	1





Summary

- WPIS review:
  - Resources presented by tasks representatives
  - LEBT completion realistic
  - IS-test stand completion + commissioning is challenging.
  - Extraction simulation well under way, mandatory measurements will be available end of 2012.
  - Draft differential pumping design in progress, teething front end vacuum chamber and insulator (specification may have to be down graded).
- Risk:
  - Delay; design and production under high load (2011-13)
  - Technical: installing the pulsed power-front end in the 3MeV test stand will be challenging integration review as soon as all volumes are available (sept. 2011)
  - Cs-lab: Chemical laboratory identified for Ar-glove box Option for Cs-Lab at ISOLDE end 2011.
- Installing a new extraction system, new power supplies and a new source mid 2012 is challenging but leaves 5 month for debugging and commissioning of the prototypes *This is our baseline*.
- Resource estimate : 47 FTE, 7.2 MCHF (16 FTE fellows + PJAS + Phds). Revision of cost attribution within L4-WPs needed.

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Action plan August 2010, (No HV-Pulsing, No Magnetron)

draft Schedule & draft Resources: *34 FTE, 4.5 MCHF*

Date	L4-IS 3 MeV test stand	L4-IS -tunnel Bldg. 400	L4-IS upgrades	sLHC Plasma Generator test stand	H- IS test stand	Cs Laboratory
2010			Minimal dump, protons	RF and plasma diagnostics		Design
2011	protons, ~~*mini H- pulse*~~		**Rev. world's IS** **Rev. WPIS June**	Gas Dynamics, Upgrade to HT	Design, production	
2012			Multistage and e- dump		Test and commissioning	
2013	Move to L4-building 400	Commissioning in L4 building	New HT-supply & extraction		Operation	Surface source Proto.
2014		Operation, Upgrade, control	Spare parts		Operation	Test of prototype
2015					Move test stand to 152	

	mY	*fraction*	*kCHF*	*hours*
total Manpower	33.9			
staff	20.3	60%		
Fellows	*13.6*	40%, 36%	1632	
FSU+MME		18%	791	15500
hardware		46%	2064	
total cost			4487	

Resources' profile		*2011*	*2012*	*2013*	*2014*	*2015*
Hardware 2.1 MCHF Design office 0.8 MCHF	kCHF	1062	1637	958	494	336
fellows 1.6 MCHF		24%	36%	21%	11%	7%
Staff 20.3 FTE	FTE	7.9	11.1	7.4	4.7	2.8
fellows 13.6 FTE		23%	33%	22%	14%	8%