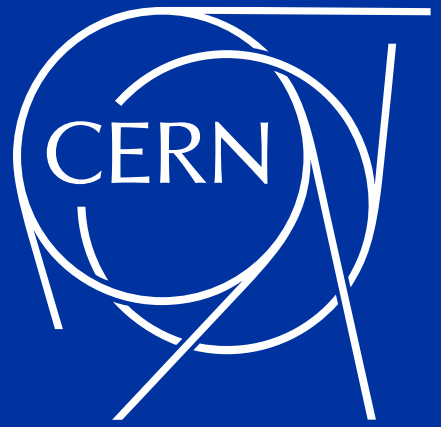


MD with High Current L4 beam in the PSB

S. Albright, F. Asvesta, G. Bellodi, C. Bracco, G.P. Di Giovanni, A. Findlay, E. Gousiou, J.B. Lallement,

A. Lombardi, R. Murillo, F. Roncarolo, E. Sargsyan, P. Skowronski, L. Timeo, A. Topaloudis, R. Wegner

Outline

- **Context for the Machine Development studies**
- **MD planning, short and medium term**
- **Focus on the upcoming test of the 10th May**

A New Source

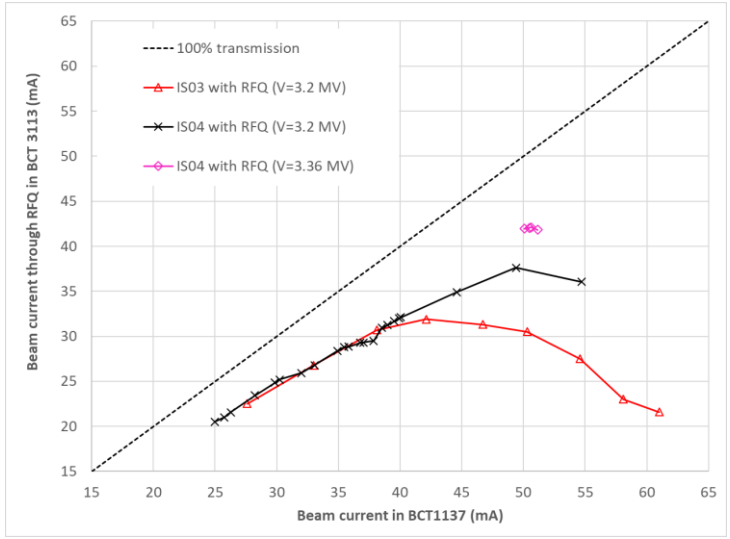
- **A new Linac4 source type - IS04 - is now installed in the Linac4:**
  - **Installation done in YETS22/23 and endorsed by IEFC, see** https://edms.cern.ch/document/2771347/1.0

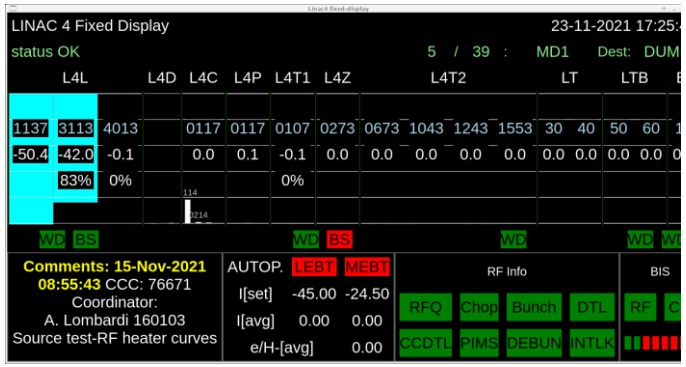
➢ Expected to be at least **as stable and reliable than the previous version:**
  - Reliability test performed at the Linac4 test stand in 2022.

➢ Allows for getting **more current of the RFQ at 3 MeV** as demonstrated late 2021 (see below).

➢ **2 spares** prepared in 2022.

RFQ V=3.2 MV (operational value):
Comparable performance for
beam current <40 mA,
but considerably better above that.





RFQ V=3.36 MV: *42 mA out of the RFQ for 50.4 mA input – RECORD.*

Why a New Source

- **All operational beam produced, and performance even exceeded for LHC brightness!**

- ***L4 original design*** was for higher peak currents than the 25 mA (out of RFQ) that is operationally used.
- ***L4 pulse length*** was extended (600 μs from 400 μs) to mitigate the lower (25 mA) current.

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN - AB DEPARTMENT

CERN–AB–2006–084 ABP/RF

Linac4 Technical Design Report

L. Arnaudon, P. Baudrenghien, M. Baylac (LPSC) , G. Bellodi, Y. Body, J. Borburgh, P. Bourquin, J. Bryere, O. Brunner, L. Bruno, C. Carli, F. Caspers, S. Cousineau (ORNL), Y. Cuvet, C. De Almeida Martins, T. Dobers, T. Fowler, R. Garoby, F. Gerigk, B. Goddard, K. Hanke, M. Hori, M. Jones, K. Kahle, W. Kalbreier, T. Kroyer, D. Küchler, A.M. Lombardi, L.A. Lopez-Hernandez, M. Magistris, E. Mahner, M. Martini, S. Maury, T.K. Meinschad, E. Page, M. Paoluzzi, M. Pasini, U. Raich, C. Rossi, J.-P. Royer, E. Sargsyan, J. Serrano, R. Scrivens, M. Silari, M. Timmins, W. Venturini Delsolaro, M. Vretenar, R. Wegner, W. Weterings, T. Zickler

Editors: F. Gerigk, M. Vretenar

11th December 2006
Geneva, Switzerland

Table 1.2: Linac4 beam parameters

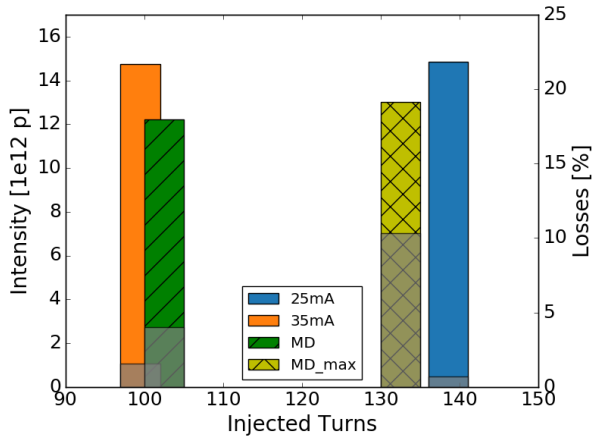
Ion species	H^-
Output energy	160 MeV
Bunch frequency	352.2 MHz
Max. rep.-rate	2 Hz
Beam pulse length	400 μs
Max. beam duty cycle	0.08%
Chopper beam-on factor	62%
Chopping scheme	222/133 full/empty buckets
Source current	80 mA
RFQ output current	70 mA
Linac current	40 mA
Average current	0.032 mA
Beam power	5.1 kW
No. particles per pulse	1.00×10^{14}
No. particles per bunch	1.14×10^{9}
Source transverse emittance	0.2 π mm mrad
Linac transverse emittance	0.4 π mm mrad

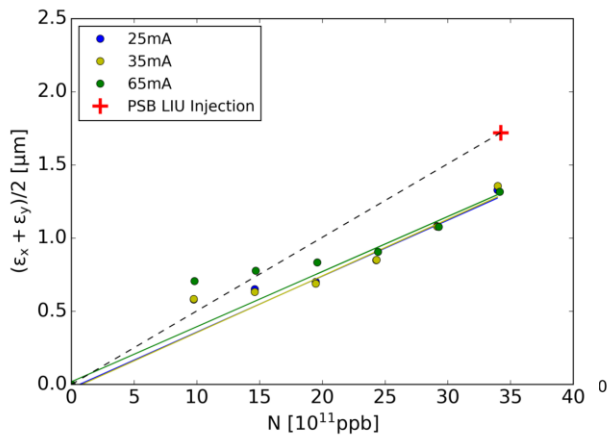
https://cds.cern.ch/record/1004186

Why a New Source

- **ISOLDE (operational & upgrade)** intensities > 4000e10 ppp are very hard to achieve in the PSB.
  - Operational ultimate limit is 6000e10 ppp.
- Study **PSB intensity limitations** in the scope of the **Accelerator Complex Capabilities WG (PBC)**.
- No significant impact on LHC brightness from simulation. To be verified with beam.

Expectations from simulations





F. Asvesta et al., RFQ3 Review

MD (Original) Planning

Plan:

1. ***Send >30 mA at the end of the L4 (L4Z) & close to PSB injection (LBE):***
   - Measure ***beam characteristics*** (emittances, energy spread etc).
   - Prepare ***optics*** to inject in the PSB.
   - Investigate RF ***power margins.***
2. **Inject high peak current in the PSB:**
   - Investigate impact on high intensity users & high brightness users: ***emittance, profile shape, max. intensity & losses.***
   - Investigate the impact of higher current per turn on ***injection foil*** and ***KSW waveforms.***
   - Investigate the impact of ***double & triple harmonic capture.***

Initial request:

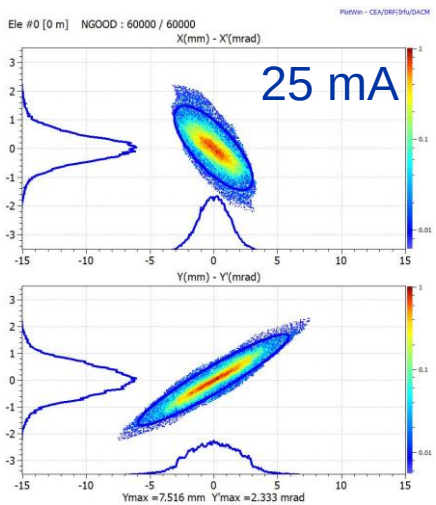
- ***2 Dedicated MD slots for Linac4 setup,*** J.B. Lallement et al.: Injector Performance Panel MD days 2023
  - Source is non-PPM. Switching between configurations 15-30 mins.
- ***2 Dedicated Days (working hours) for PSB at the end of the year, F. Asvesta et al. : IEFC #325***
  - ***Lengthy setup*** *times needed* ***– normal dedicated MD slots might be too short***
  - ***Fully dedicated*** *for the accelerator chain* ***– no beam downstream of the PSB***
  - ***Bottlenecks need to be identified to plan mitigation strategies (LS3) –*** ***time with (and after) MD experience needed***
  - ***Endorsed by the IEFC. Final decision with the ATS***

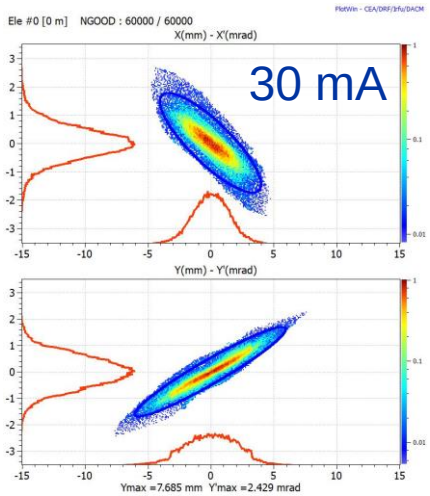
First Test Above 3 MeV: 30 mA Dumped on L4Z

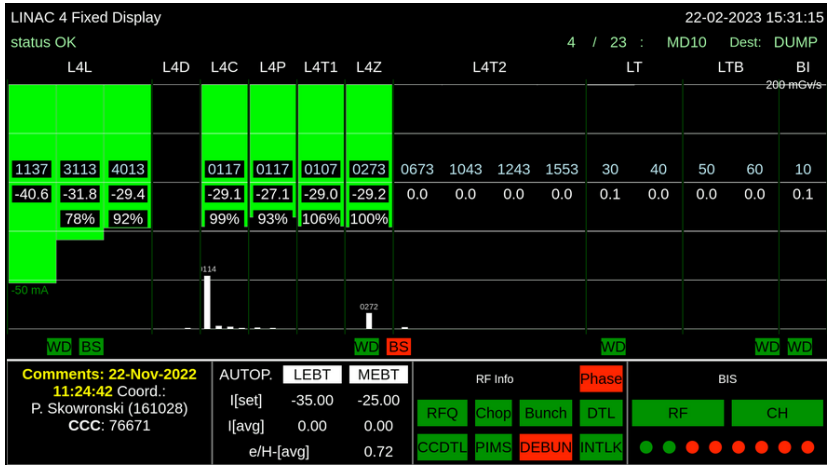
- **Opportunistic approach: Time allocated during the L4 BC to start the tests earlier than planned!**

- On 22/02 the source current increased to 40 mA (35 nominal):
  - Almost **30 mA peak current at 160 MeV from 1 ring with at most 100 μs long pulse.**
  - **RF power and cavities holding the load** @ 30 mA
  - **RFQ voltage slightly increased**.
  - Transverse emittance computed from RMS sizes very similar. Small difference with the tomography.
    - 352 MHz bunch length looked the same.
  - Figured out, trying to push up, that the **solenoids polarity configuration was not optimal** → **polarity switched**

Knobs are only:
Source parameters.
LEBT settings.
RFQ voltage

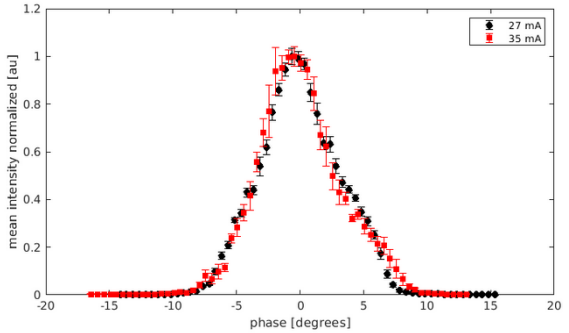


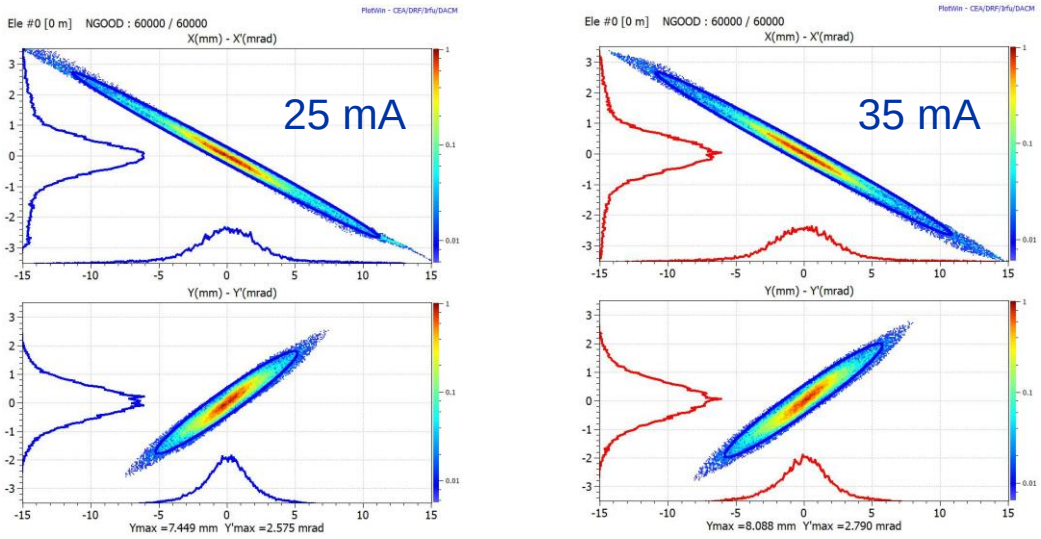


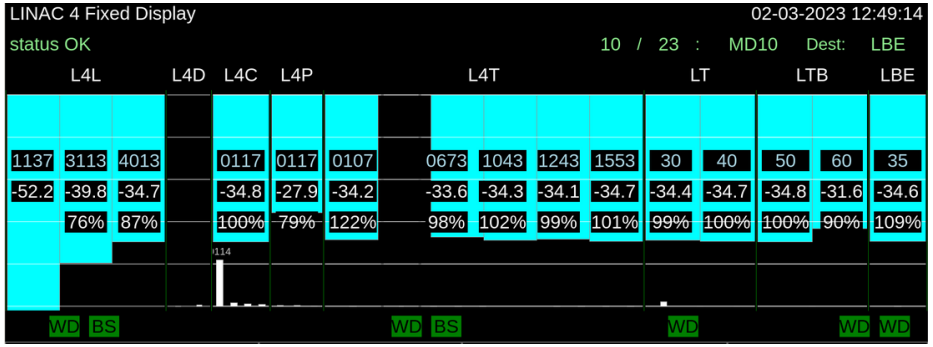


Second Test: 35 mA Dumped on LBE

- **After the solenoids polarities were inverted.**
- On 02/03 source current increased **in steps to 50 mA**:
  - **35 mA at 160 MeV in the L4Z and in the LBE, unchopped.**
  - Longer RF transient observed at this current:
    - Some margin on the RF power available. Most critical lines CCDTL2/7 (LEP Klystrons).
    - In operation we use chopped beam which relaxed the constraints on RF.
  - Small difference on L4Z transverse emittance comparable to what found with 30 mA.
  - Similar 352 MHz bunch length.
  - 35 mA transverse emittance measured at the LBE.







MD Updated Planning

- **Several milestones reached already during BC time!**
- **Current up to 35 mA at 160 MeV and compatible with PSB injection requirements(!):**
  - With the nominal RFQ voltage.
  - Chopping pattern in operation relaxes further the request on the RF power side.
  - **Transverse emittances look well under control, with NO re-matching in the Linac4 above 3 MeV.**
  - **Similar longitudinal phase spread** indicates similar energy spread.

Reason for today's meeting

- **The Linac4 team would like to inject the beam in the PSB during the 1st dedicated MD slot (10th May):**
  - Main reason is feedback on **optics** and **longitudinal characterization** from the PSB.
  - Opportunity for L4 **RFQ test FB** with Kalman and PI and compare results in terms of beam intensity and beam trajectories.

- **The second dedicated MD slot (19th June) should be only Linac4 dedicated:**
  - Explore the peak current reach at the end of the Linac4 in a safe manner, e.g. by increasing the current while reducing the pulse length to control losses at the RFQ:
    - Source and LEBT optimization.
    - Possible check RFQ levels in a safe mode, with experts' agreement.
    - Possible exploration of the MEBT quad settings (delicate procedure from the experts).

- **The request for the 2 dedicated MD days at the end of the year still holds.**

Dedicated MD 10th May 2023 (I)

- **The Linac4 team would like to inject the beam in the PSB during the 1st dedicated MD slot (10th May):**
  - Feedback on **optics** and **longitudinal characterization** from the PSB.
  - Continue L4 **RFQ test FB** with Kalman and PI and compare results in terms of beam intensity and beam trajectories.

- **Set the SC with 1 cycle every 5-10 cycles**
  - **Block the SC composition with I_BCD** to avoid uncontrolled programming of the SC
  - In case a **SC change** is needed, follow the **procedure** below:
    1. Put the beam stopper.
    2. Release the I_BCD external condition, program and load the SC.
    3. After verification, lock back the SC composition with the I_BCD.

- **Set the high current mode in Linac4 (15-30 mins)**

- **Measure energy matching**

Dedicated MD 10th May 2023 (II)

- **The Linac4 team would like to inject the beam in the PSB during the 1st dedicated MD slot (10th May):**
  - Main reason is feedback on **optics** and **longitudinal characterization** from the PSB.
  - Opportunity for L4 **RFQ test FB** with Kalman and PI and compare results in terms of beam intensity and beam trajectories.

- With higher peak current along the pulse the ESPREAD might be higher than the configured one.
- **Start with the natural E_{SPREAD} (280 KeV RMS) injection optics and debuncher, ISOLDE-like, configuration.**
- **Measure $_{ESPREAD}$ at injection:**
  - 1-2 turns with PSB RF ON (1.3e11 @ 35 mA for chopping factor = 0.6).
  - Standard measurement during commissioning:
    - A few measurements for quick feedback. Data collection for post-processing.
  - Readapt debuncher and steering to injection, if needed.
    - **Always put back the steering to the operational injection references.**

- **Set 'large' E_{SPREAD} (450 KeV RMS) injection optics and debuncher, LHC-like configuration.**
- **Measure E_{SPREAD} at injection:**
  - 1-2 turns with PSB RF ON (1.3e11 @ 35 mA for chopping factor = 0.6)
  - Readapt debuncher and steering to injection.

Dedicated MD 10th May 2023 (III)

- **The Linac4 team would like to inject the beam in the PSB during the 1st dedicated MD slot (10th May):**
  - Main reason is feedback on **optics** and **longitudinal characterization** from the PSB.
  - Opportunity for L4 **RFQ test FB** with Kalman and PI and compare results in terms of beam intensity and beam trajectories.

- **Scan of E_{SPREAD} as a function of the debuncher voltage**
  - To compare with the operational configuration.

- **Increase intensity on ISOLDE-like cycle:**
  - E_{KIN} at extraction of **1.4 GeV.**
  - **Same KSW waveform** for transverse painting.
  - **Same operational interlocks**
  - Increase the **number of turns in steps**:
    - Measure longitudinal/transverse parameters (performance).
    - **Monitor losses** (**safety**).
  - **Max number of turns allowed per ring is 100:**
    - Special **Cruise Control application** to be prepared for the MD which will **block the number of turns to 100**.
    - More later.

Dedicated MD 10th May 2023 (IV)

- **The Linac4 team would like to inject the beam in the PSB during the 1st dedicated MD slot (10th May):**
  - Main reason is feedback on **optics** and **longitudinal characterization** from the PSB.
  - Opportunity for L4 **RFQ test FB** with Kalman and PI and compare results in terms of beam intensity and beam trajectories.

- **If time allows, LHC brightness on LHC25-like cycle:**
  - E_{KIN} at extraction of **2.0 GeV.**
  - **Same KSW waveform** for transverse painting.
  - **Same operational interlocks**
  - Increase the **number of turns in steps**:
    - Measure longitudinal/transverse parameters (performance).
    - **Monitor losses** (**safety**).

Machine Protection

Possible equipment concerns:

- **New ISO4 source** can provide > 40 mA (out of the RFQ).
- **L4 RF concerns: higher power needed** – ok in the **context of an MD** (i.e. a few hours), problematic for longer times.
  - No major concerns apart from beam losses. RF community interested in approaching power limitations.
  - Equipment **well interlocked**.
- **Debuncher amplifier: limiting any tests on longitudinal painting**
  - Known limitations on LEP klystrons for **future operations** could be further investigated in the scope of the MD.

- **PSB dump**: higher intensity per pulse to be mitigated with lower duty cycle to keep radiation at acceptable levels. In any case the **dump is designed for 1E14 ppp, i.e.2,5e13 ppr for 11m/y for 30 years.**
- **H0H$^-$ dump**: ring pulse length **must be kept ≤ 100 µs** to protect the equipment from **accidental foil ruptures**.
- **RF – BI amplifiers**: monitoring to avoid saturation etc (**already PSB tomoscope in saturation for high intensity**).
- **Foils** have been **designed for > 40 mA.**
- **Loss at high energy on septa or extraction area:**
  - **Monitors and interlocked with BLM or equipment interlocks (vacuum or otherwise).**
  - **No change of interlocks thresholds.**

H0/H- Dump

- Dumps specs at https://edms.cern.ch/document/1293512/1.0
- Another important document is https://edms.cern.ch/document/963395/4.0

Some of the main changes in the current operational setting wrt original specifications

Table 1 – Dump load cases [2].

Parameter	Symbols	*Case 1: foil failure*[1]	*Case 2: operational*[2]	*Case 3: degraded*[3]
Pulse current (mA)	I	~~40~~ **25**	0.8	4
Pulse length (μs)	τ	~~100~~ **150**	100	100
Pulse repetition rate (Hz)	f	~~1.11~~ **0.83**	1.11	1.11
Maximum pulse intensity	Np	2.5E13	5E11	2.5E12
Average beam power (W)	P	710	14.2	71

[1] Case 1: the foil failure implies the dump receives the whole beam instead of only the unstripped part. That is ¼ of the total Linac 4 beam.

[2] Case2: corresponds to 2% stripping inefficiency, i.e. 2% of the incoming beam is not properly stripped.

[3] Case 3: corresponds to a degraded operational case of 10% stripping inefficiency, for a maximum total time of 8 hours, maximum 10 times a year.

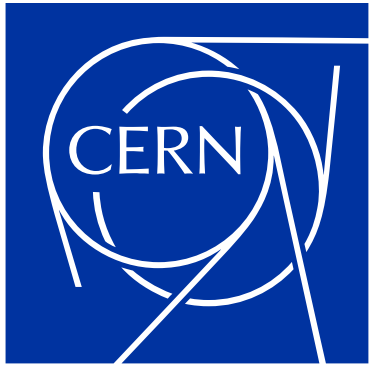
Summary

- **New Linac4 source installed in YETS:**
  - Can provide higher current out of the RFQ at the end of the Linac4.
  - Allocated 2 dedicated MD slots during the year to push L4 performance.

- **Opens the way to study intensity limitations in the PSB, in the scope of PBC:**
  - Additional 2 days of dedicated studies requested for the end of the year.

- **MDs during the Linac4 BC showed that it could reach 35 mA:**
  - Measured beam parameter compatible with PSB injection.
  - **Linac4 needs more feedback from the PSB. First available slot is 10th May.**

- **The Linac4 and PSB were designed for 40 mA out of the RFQ:**
  - **No interlock threshold to be changed.**
  - **No additional risk for the equipment, if designed according to specs.**



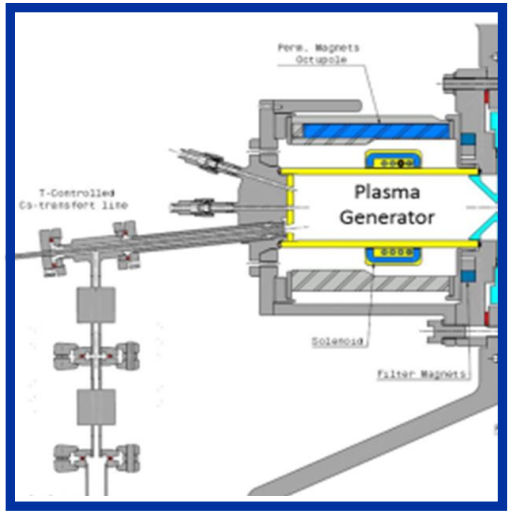
home.cern

What's new : IS03 vs. IS04

IS03 and ISO4 have identical plasma generators:

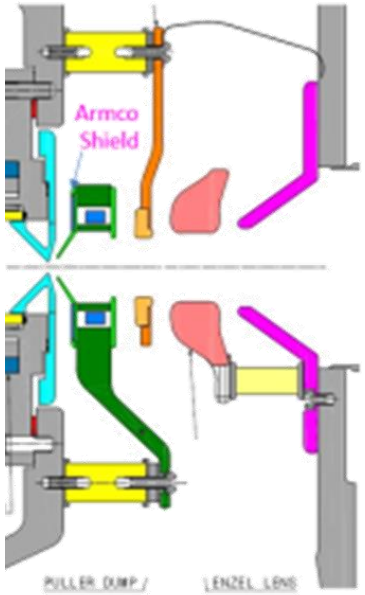
- Plasma chamber.
- RF system (amplifier and antenna).
- Gas injection system.
- Cesiation system.

IS03 and ISO4 have different extractions and electron dumping schemes

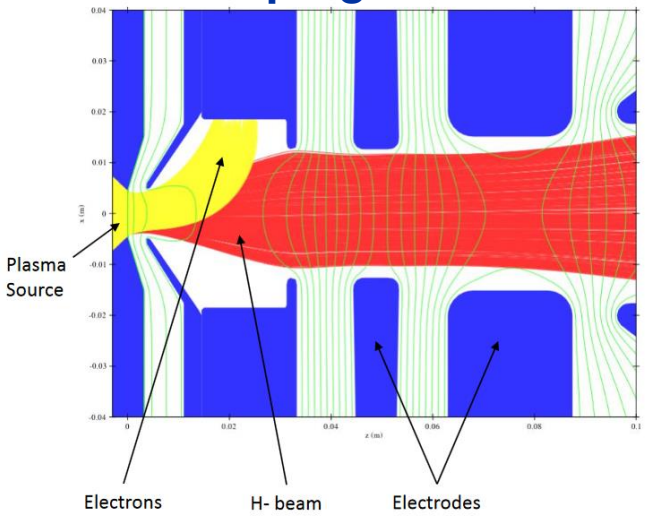


ISO4 vs. IS03

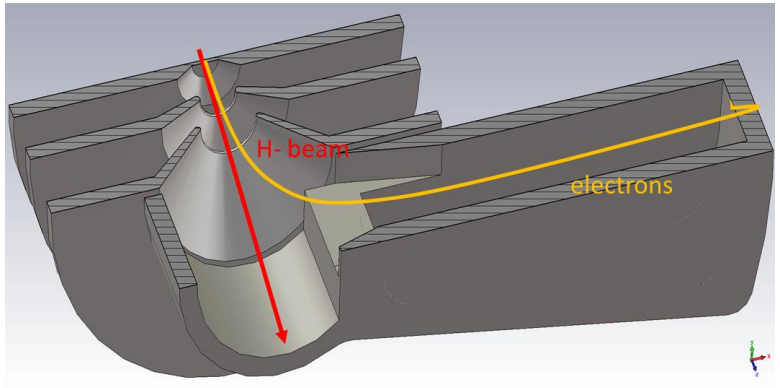
- ✓ Simplified design with only plasma, puller and ground electrodes :Eliminated puller-dump and Einzel lens causing emittance growth
- ✓ 6 cm shorter
- ✓ Co-extracted 45 keV e^- onto a dedicated dump

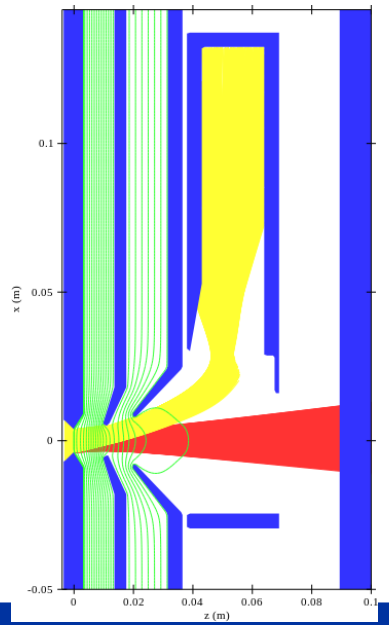


IS03 – Dumping 10 keV e^-



IS04 – Dumping 45 keV e^-





Prospects from the IS04 Source

- RFQ voltage scans with IS03 source show lower transmission compared to the IS04 source, even for the operational voltage of 3.2 MV
- Better RFQ transmission with IS04 beam is consistent with the smaller emittance measured at the test stand
- Due to lack of time, IS04 and LEBT were not optimized for lower beam currents