Beam status at the end of 2019

Plans:
- Hardware improvement/consolidation
- Beam stability improvement/study

Conclusions
Beam status
Wish list:

- ~100 uA; ~1 us; ~square pulses
  - Only 650 ns-long pulses injectable by kicker
- Good Stability/Repeatability
  - order ~1% for intensity and beam shape
  - order ~0.1% better for energy
- Transverse optics matched to ring

Only DC Power Supplies control via PLC in Faraday Cage
Typical acquisition end of 2019

- **100 keV, ~20 us-long** beam magnetically injected in the ring and immediately extracted to GBAR
  - Intra-pulse, shot-to-shot, strong instability (>100% intensity fluctuation)

100 uA calibration pulse injected into the Pearson

Note: time of flight of signals adjusted by hand

Arc 31V, 6.1A
Gas 1.1 sccm
Filament 50A

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Typical acquisition end of 2019 - zoom

- **BPMs saturate** $\sim 100$ uA (assuming full transport from source)
- **Pearson bandwidth** $\sim 3$ MHz
- **LPU has very high bandwidth** (and dynamic range)

  (but also higher low-frequency cut-off, so it induces a droop)

![Graph](image_url)

Arc 31V, 6.1A
Gas 1.1 sccm
Filament 50A
Scan over some parameters

- Basic parameters: $2650 \text{ V}_{\text{puller}}$; 6% filament; $70 \text{ V}_{\text{arc}}$

- Gas: 0.8 sccm

- Gas: 1.7 sccm
Baseline beam – end of 2019

- Working with **low arc** voltages one obtains **low-current, stable pulses**
  - At the **limit of switching the plasma off!**

- Increasing $I_{fil}$ and gas pressure one can reach $\sim 40 \text{ uA}$ **stable beam**
  - Possibility **good enough**, but so far **no study on beam emittance!**

Arc 21V, 3.6A
Gas 1.6 sccm
Filament 51A

![Graph showing beam current over time](image)
Beam disappearing after some time

- Well known issue in 2018, it “disappeared” in 2019 when running the source in pulsed mode. It came back at end of 2019 when running in DC mode.

- Example of 16/12/2020 (elogbook)
  - Beam lost ⇒ Changed H$_2$ cartridge ⇒ beam came back “slowly” by itself in the center of BTV, but afterwards it moved again.
  - Trying to vent the source ⇒ the beam seemed to be stable, at least for a few hours.
  - Trying to mess-up with source steering, closing/opening valves.
    - Several attempts in ~30 minutes, but beam came back all the time the same.

Measured “current” on first LNS quad electrodes

Beam spot NOT moving on BTV

Venting the source

Restart Beam

Tests with source valves/steering/puller

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Ongoing investigations and plans
Present working hypothesis

- **We have a working (stable) low-current beam**
  - we could access a much **high intensity** beam, but which is **unstable**
  - when source running with DC HV, **long-term position drift** observed

- So far, we have **NO observations** of the **instability on measurable quantities in the source** (e.g. arc current)
  - Instability **could be** in the **H⁻ production mechanisms**
  - **To be investigated** with:
    - Measurement of **H⁺ beam**
    - Measurement of **e⁻** dumped on the puller electrode
  - Should be affected (**optimized** by):
    - **Electro-magnetic configuration** of the source
    - **Vacuum/H₂ purity in the source**
    - **H₂ ionization process** stability

- Confident that **orbit instability** is due to **charging up** in the source
  - Need to further investigate and **probably optimize e⁻ dump**

- **Backup:** run the HV in pulsed mode at “low” intensity.
Future investigations:

intra-pulse instability: some wrong configuration?

Gas injection control

Permanent magnets for "magnetic filter" and H⁺ production

Permaneent decapole magnets for plasma confinement

Not so pure H₂ source?

“Bad” filament shape?
Future investigations:

**Position instability:** something charging in front of source?

- Shielding charging up?
- Pearson transformer in its original housing
- Conductive Shielding
- Puller electrode
- Maybe some surface degradation, indication of beam dumped here?
- Quadrupole shielding

(Is the ceramic charging up?)

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On the side: crowded HV cabinet

1. **Puller** power supplies
   - Begin replaced by smaller form-factor ones (Fug?)

2. **Arc** power supply

3. **Filament** power supply

4. **Puller** fast switch unit
   - Modified to have slightly longer switching time (order of 1 us), but no impact on beam stability.

- Idea to profit of smaller puller power supplies to ease interventions/measurements in the HV cabinet

*(Outdated) pictures from EDMS 1720664*
Present Action Plan

- As soon as possible [ongoing]:
  - Measure \( \text{H}_2 \text{ cartridge} \) purity
  - Improve \( \text{HV cabinet} \) spacing
  - Prepare new Pearson housing with additional Fraday-cup-like plate
    - Be also ready to improve in-vacuum cabling of the doublet in front of the source

- When source accessible [March]:
  - Leak detection and RGA analysis of the source vacuum
  - Prepare (HV) tooling for measurement of voltages/currents next to the source.
  - Eventually replace Pearson housing and in-vacuum HV cables

- When possible to start the source [March-April]:
  - (Re-)measure all voltages/currents next to the source
    - Important to measure electrons being correctly dumped on the puller plate
  - Try pulsing the source in proton mode and measure instability with Pearson
  - Eventually try to modify magnetic configuration, filament shape, etc..

- When possible to send beam to the ring [April-]:
  - Confirm charging up occurs in the source sector (before differential pumping)
  - Try adding magnets to better dump electrons(?)

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Conclusions

- **We know more and more our source**
- **We demonstrated to have a working H⁻ beam**
  - probably good enough for most purposes
  - Transfer line commissioning
    - SEM debug
  - Ring setup/optimization

- **Two main threats** for the full exploitation of the source:
  - Intra-pulse instability
  - Long-term drift of beam position

- **Not yet (extensively) investigated** are the transverse beam properties and matching with the ring optics
  - If emittance reduction by scraping needed, having more intensity from the source will be desired, i.e. we need to continue our activities

Thank you for your attention and questions!
Source cabling (partially outdated)

from Ana Megía-Macías - link
ELENA source
I_{arc}=1-2 \, \text{A}
U_{arc}=70 \, \text{V}
Q=0.006-0.018 \, \text{Torr*}l/\text{s}
General behavior of source parameters

- Arc current depends (exponentially?!) on the filament current (for a given gas flow)
- Arc current (for a given Arc voltage and Filament current) does not depend on gas pressure (until the plasma stops)
- Filament voltage only depends on filament current, independently of the plasma

Flow=0.7 sccm

Should we expect (?): 
$I_{arc} \approx I_{file} e^{-\frac{const}{\sqrt{I_{fil}}}}$
Look more in detail! But it doesn’t seems so

Note: from experience this behavior seems to saturate. To be checked!

Fil=45 A; Arc=70 V

From this behavior it looks like we are dominated by thermionic emission, but this point then?!
Estimated pressure in the source

\[ C_{or,mol,H_2}[l/s] = 43.8 \cdot A \quad @20\text{deg for H}_2 \]
\[ A := \text{cross section [cm}^2\text{]} \]

\[ P_c \cdot S = Q = C_{or}(P_s - P_c) \]
\[ P_c \left( \frac{S}{C_{or}} + 1 \right) = P_s = \left( \frac{2200}{5.5} + 1 \right)P_c = 400P_c \]

1[sccm] = 0.016[mbar \cdot l/s]

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Measurements:

- Meas. 3e-6 mbar (2e-6 if opening valve)
- Crosscheck of expected vacuum pressure: we are wrong only of factor 2 somewhere

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Estimated gas density:

\[ n_{H_2} = N_A \frac{P_s}{RT} \]
\[ n_{H_2} = 2.47 \times 10^{22}[m^{-3} \cdot \text{mbar}^{-1}] \cdot P_s[\text{mbar}] \]
\[ P_s = 1.2 \times 10^{-3}[\text{mbar}]; \quad n_{H_2} = 3 \times 10^{19}[m^{-3}] \]

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Diagram:

- 2200 l/s pump (DN250)
- 0.8 sccm H\(_2\) injected (1.3e-2 mbar l/s)
- 3.5-4 mm \(\phi\)
- \(C_{H_2}\ 5.5\ l/s\)
- \(\frac{P_s}{V_s} = 5^2 \pi \ 17.5\ \text{cm}^3 = 1.37\ \text{[L]}\)

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Mean FFT over 3 configurations

No specific frequency pops out, maybe tendency to move peak to higher frequencies for higher gas pressures?! Could it be compatible with plasma frequency?

• (Tried to looked at other data with shorter pulses, fewer shots, different conditions… difficult to conclude anything: to be repeated with longer pulses, scanning over arc voltage.)
Plasma frequency

\[ \omega_p^2 = \frac{n_e e^2}{m_e \epsilon_0} \quad \Rightarrow \quad f = \frac{1}{2\pi} \frac{e}{\sqrt{m_e \epsilon_0}} \sqrt{n_e} = 8.979\sqrt{n_e} \]

- If \( f_e = 1 \) MHz, then plasma electron density of the order of \( 1e10 \) \([m^{-3}]\).
  - Is this plausible? It seems way too small!
- If we double the gas injection, we should double the plasma density.
  - If so, we should expect \( \sqrt{2} \) higher plasma frequency.
- The same applies for the “ion” density. In our case we talk about protons, i.e.:
  \[ f_i = f_e \sqrt{\frac{m_e}{m_i}} \approx f_e \sqrt{\frac{0.511}{938}} \approx 0.023 \times f_e \approx 0.21\sqrt{n_i} \]
  - for \( f_i = 1 \) MHz we should then expect a plasma proton density of \( 2e13 \) \([m^{-3}]\).

All values way too far from estimated gas density in the source: \( 3e19 \) \([m^{-3}]\)