ELENA Source status and plans

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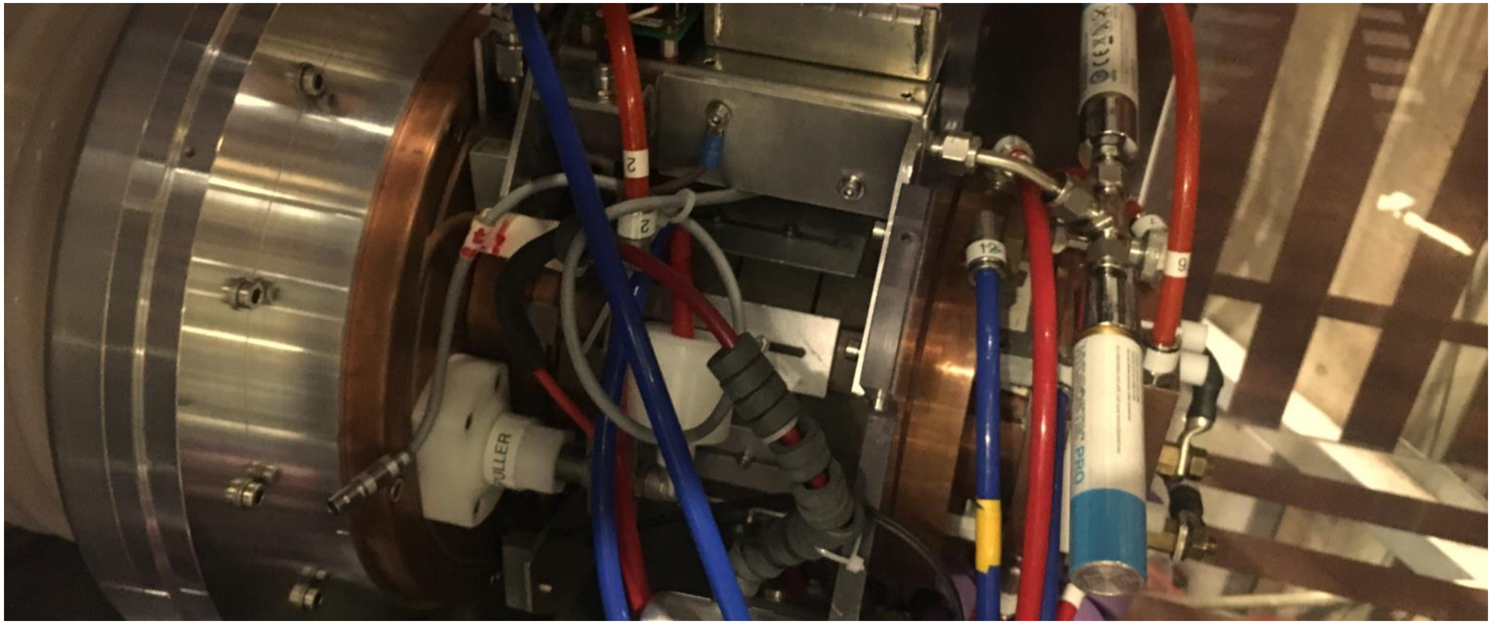
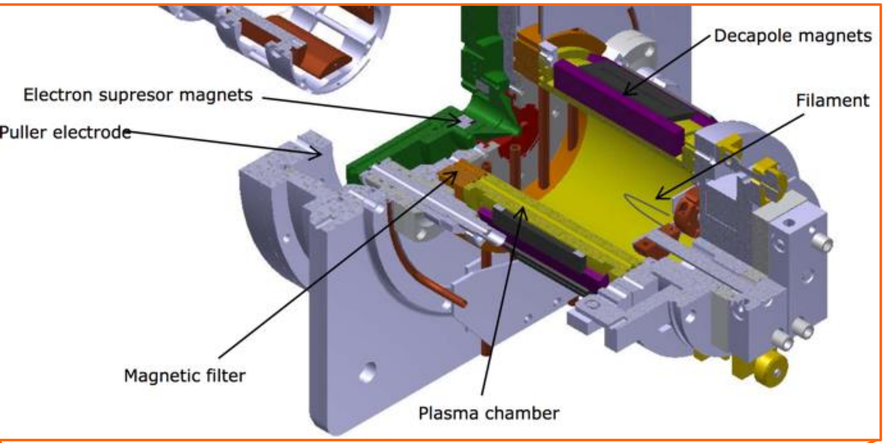
18th of Feb. 2019



- Beam status at the end of 2019
- Plans:
  - Hardware improvement/consolidation
  - Beam stability improvement/study
- Conclusions

Beam status

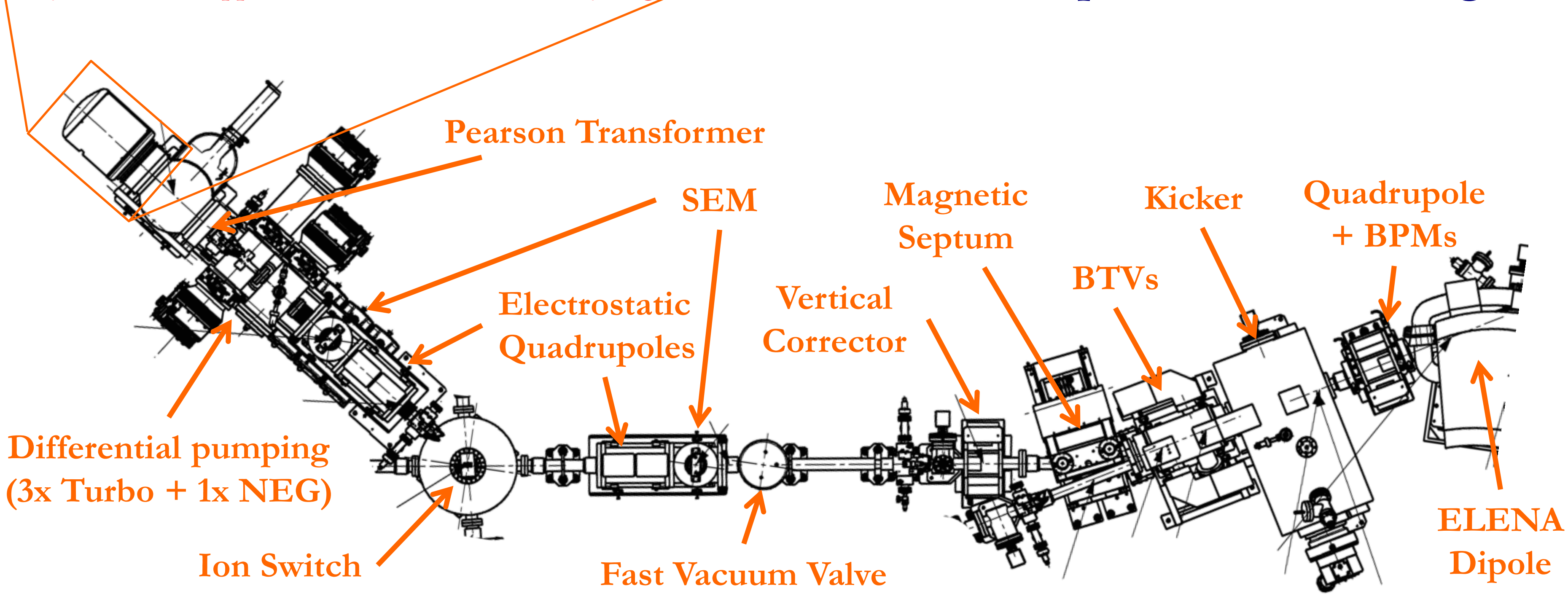
From Source to Ring



Only DC Power Supplies control via PLC in Faraday Cage

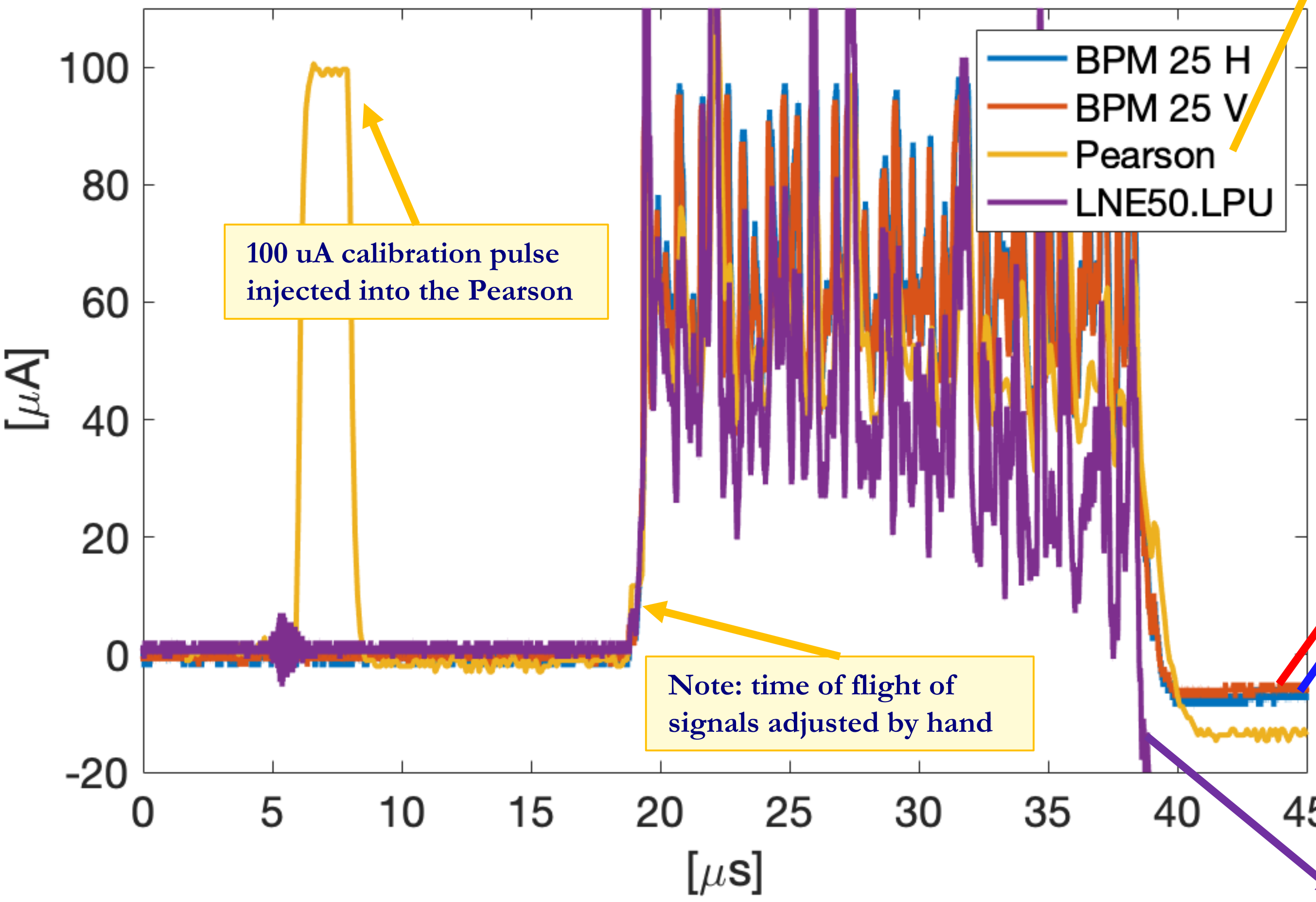
Wish list:

- ~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



Typical acquisition end of 2019

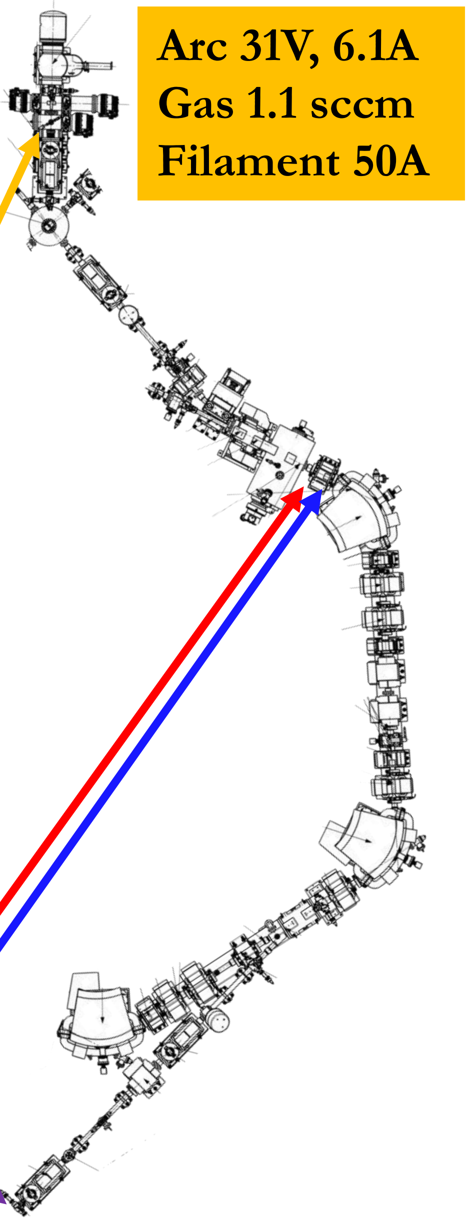
- **100 keV, ~20 us-long** beam magnetically injected in the ring and immediately extracted to GBAR
  - ☐ Intra-pulse, shot-to-shot, strong instability (**>100% intensity fluctuation**)



100 uA calibration pulse injected into the Pearson

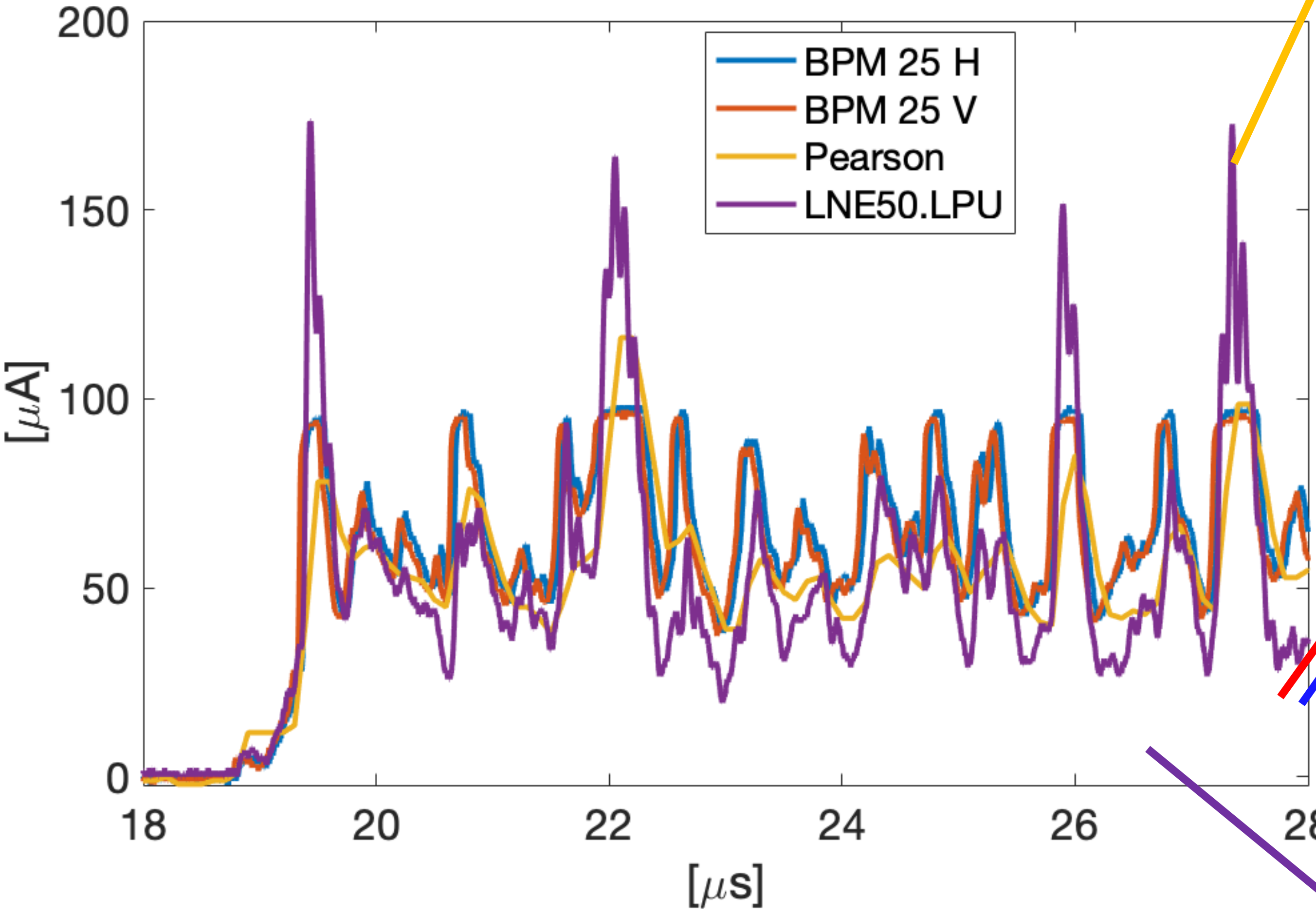
Note: time of flight of signals adjusted by hand

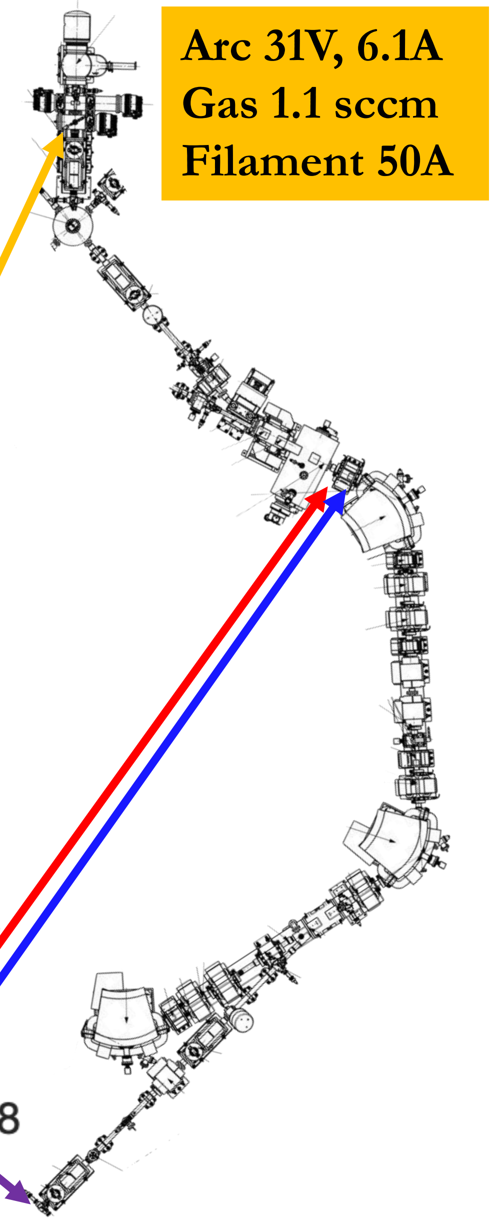
Arc 31V, 6.1A
Gas 1.1 sccm
Filament 50A



Typical acquisition end of 2019 - zoom

- **BPMs saturate** ~100 uA (assuming full transport from source)
- **Pearson bandwidth ~ 3 MHz**
- **LPU has very high bandwidth** (and dynamic range)
  - ☐ (but also higher low-frequency cut-off, so it induces a droop)

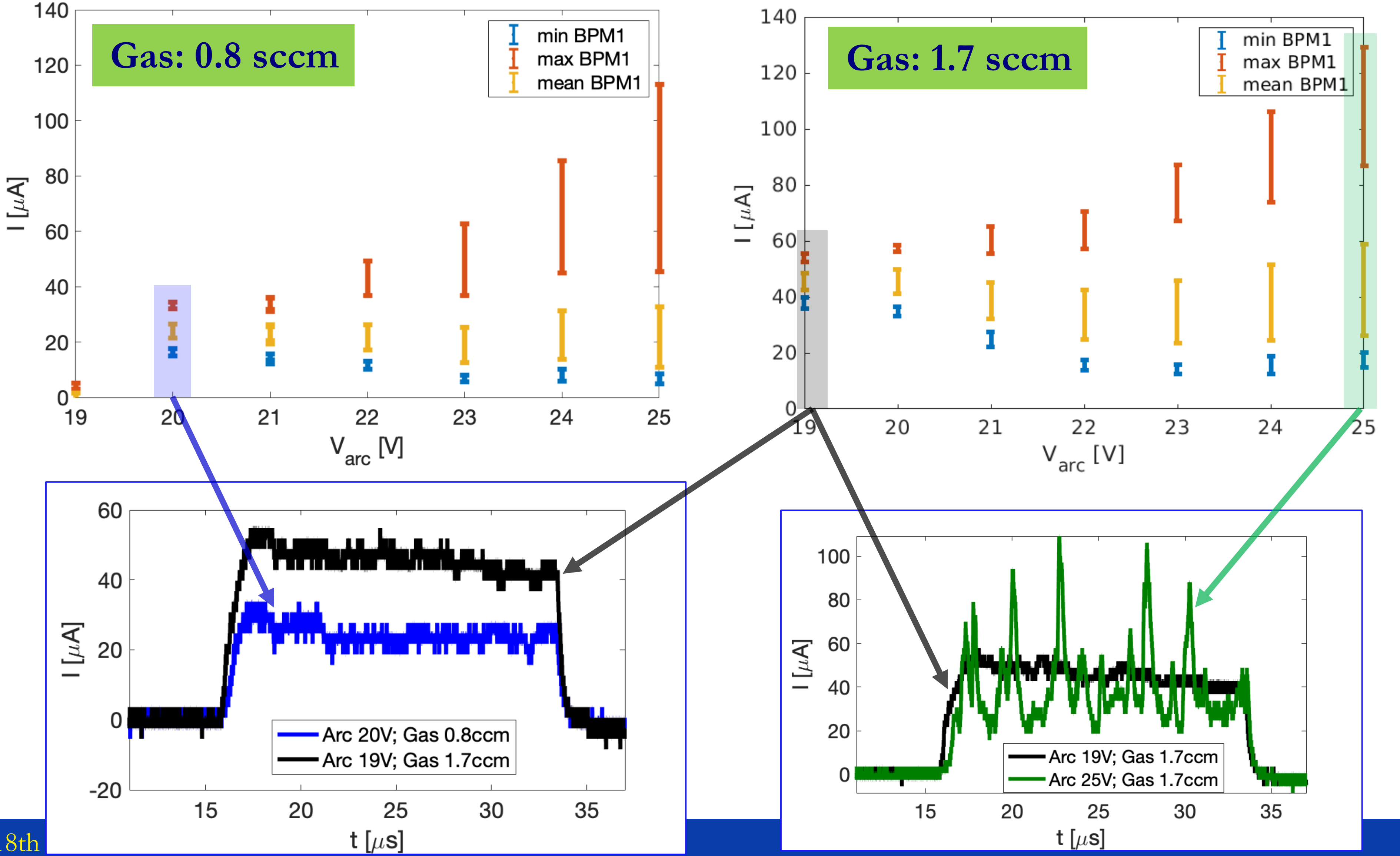




Arc 31V, 6.1A
Gas 1.1 sccm
Filament 50A

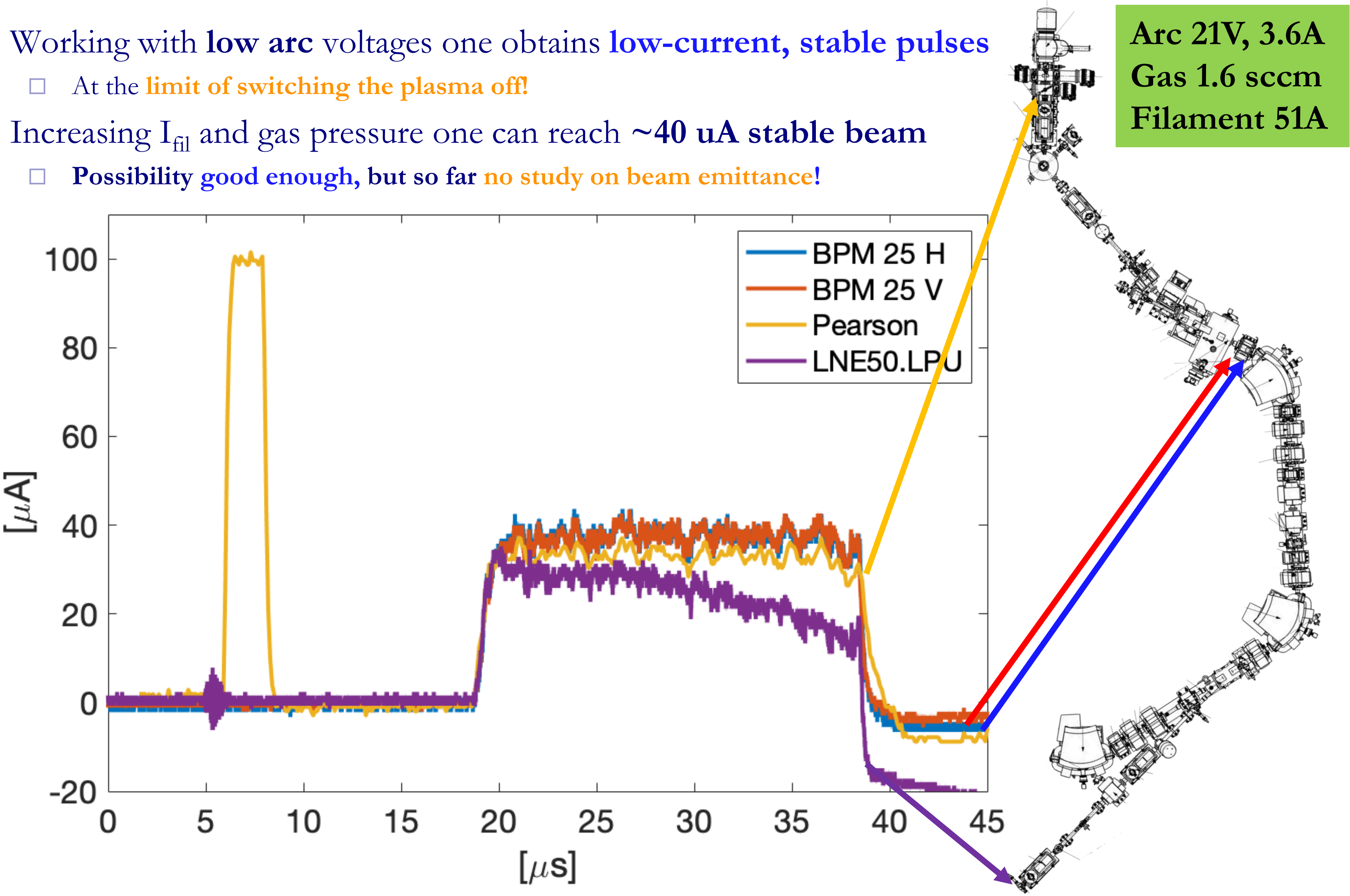
Scan over some parameters

- Basic parameters: 2650 V_{puller}; 6% filament; 70 V_{arc}



Baseline beam – end of 2019

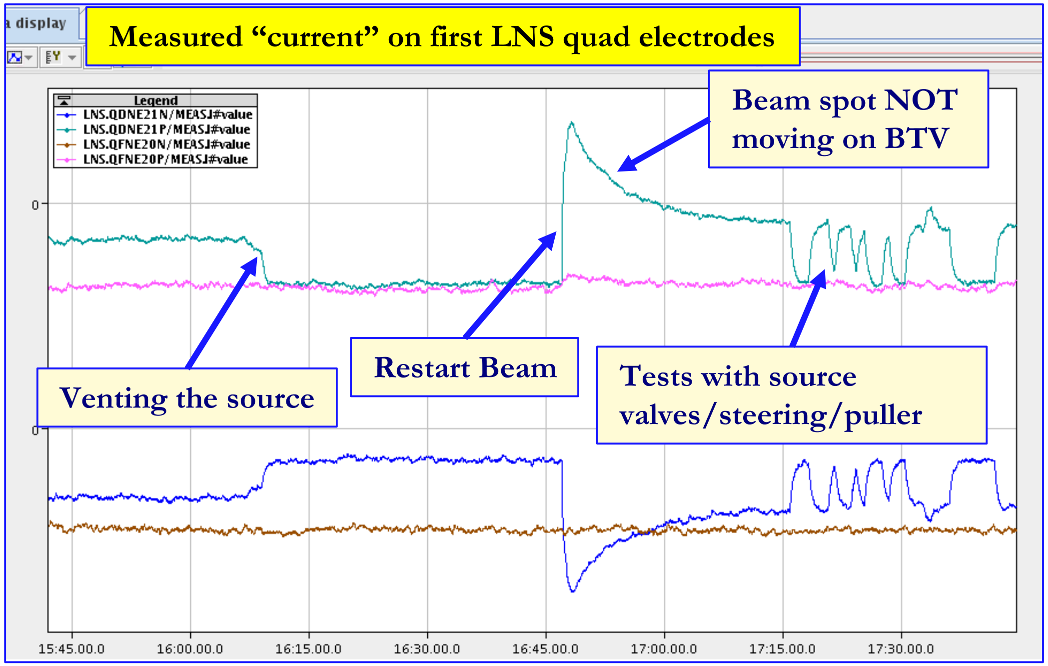
- Working with **low arc** voltages one obtains **low-current, stable pulses**
  - At the **limit of switching the plasma off!**
- Increasing I_{fil} and gas pressure one can reach **~40 uA stable beam**
  - **Possibility good enough, but so far no study on beam emittance!**



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

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.



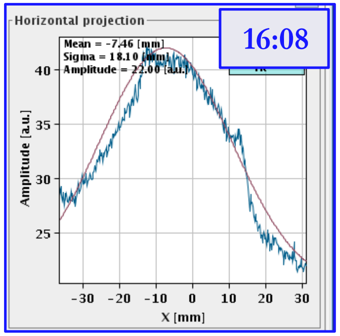
Measured "current" on first LNS quad electrodes

Beam spot NOT moving on BTV

Venting the source

Restart Beam

Tests with source valves/steering/puller



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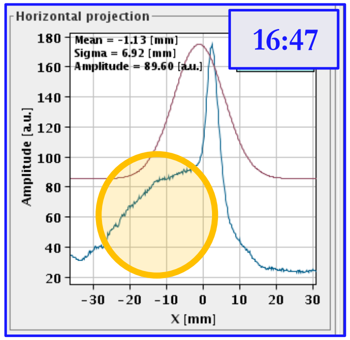

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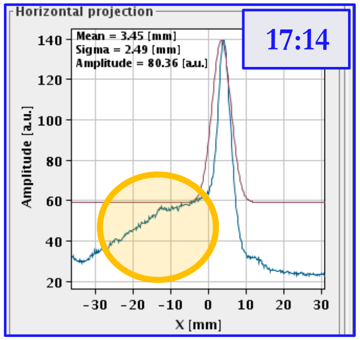

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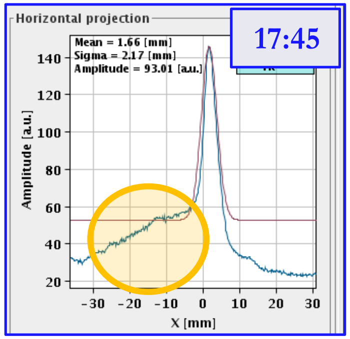


17:45

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

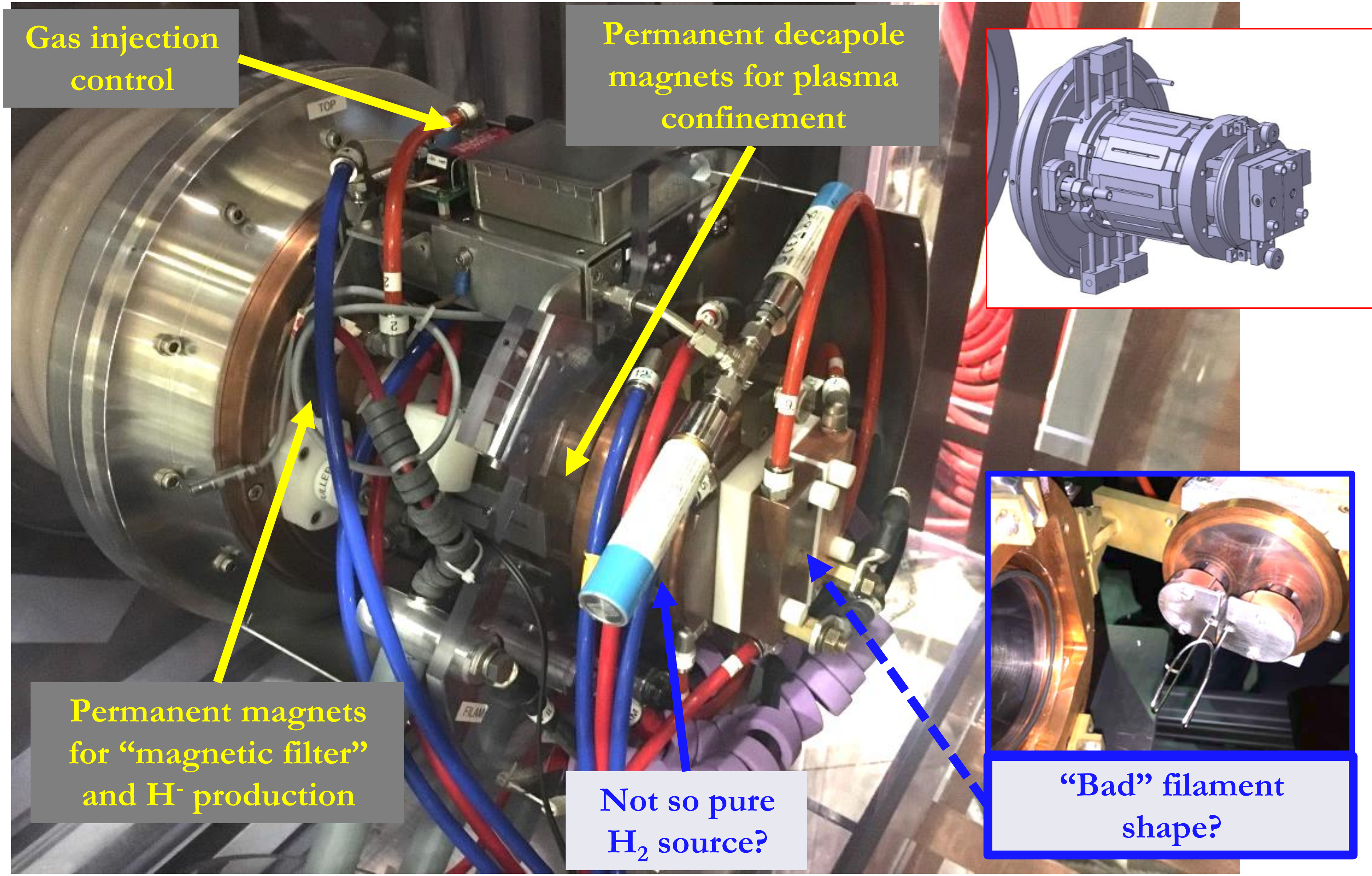
- So far, we have **NO observations** of the **instability on measurable quantities** in the **source** (e.g. arc current)
  - ☐ Instability **could be** in the **H^- production mechanisms**
  - ☐ **To be investigated** with:
    - Measurement of **H^+ beam**
    - Measurement of **e^-** dumped on the puller electrode
  - ☐ Should be affected (**optimized**) by:
    - **Electro-magnetic configuration** of the source
    - **Vacuum**/H_2 purity in the source
    - **H_2 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

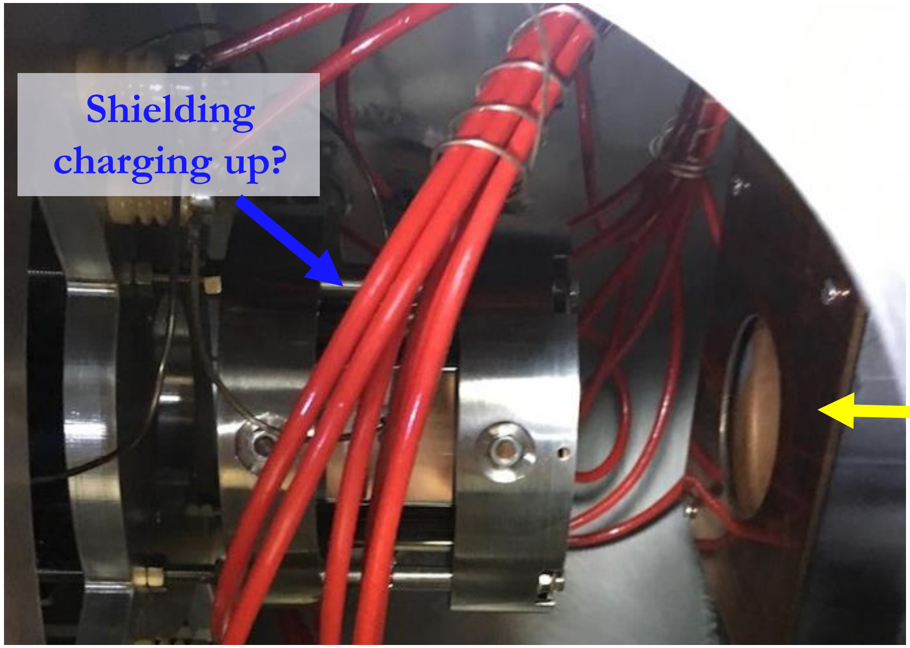
Permanent decapole magnets for plasma confinement

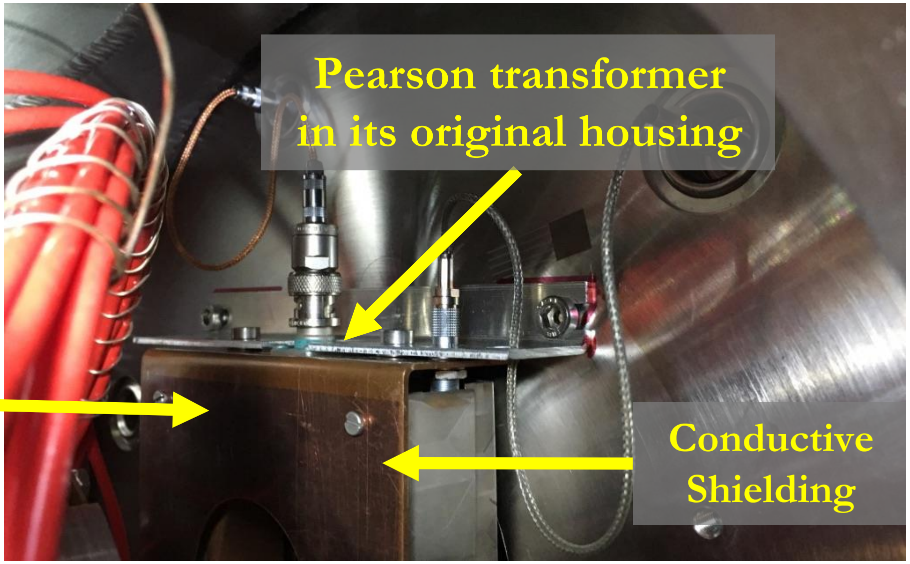
Permanent magnets for “magnetic filter” and H^- production

Not so pure H_2 source?

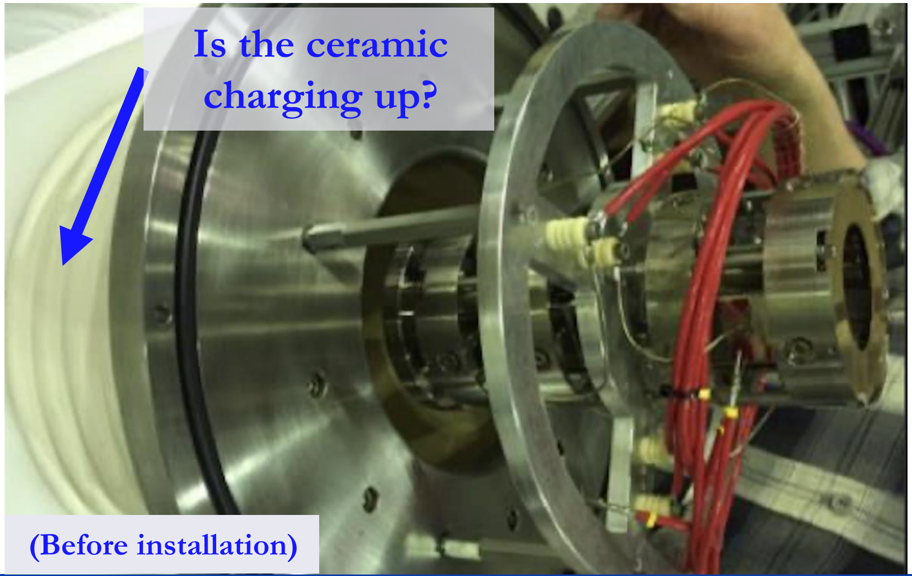
“Bad” filament shape?

Future investigations:
position instability: something charging in front of source?

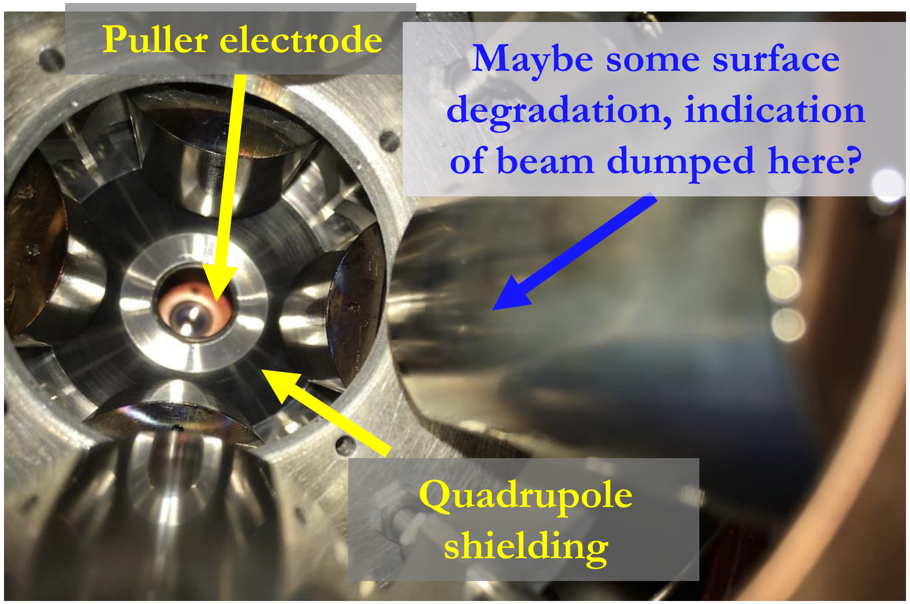

Shielding charging up?


Pearson transformer in its original housing

Conductive Shielding


Is the ceramic charging up?

(Before installation)


Puller electrode

Maybe some surface degradation, indication of beam dumped here?

Quadrupole shielding

On the side: crowded HV cabinet

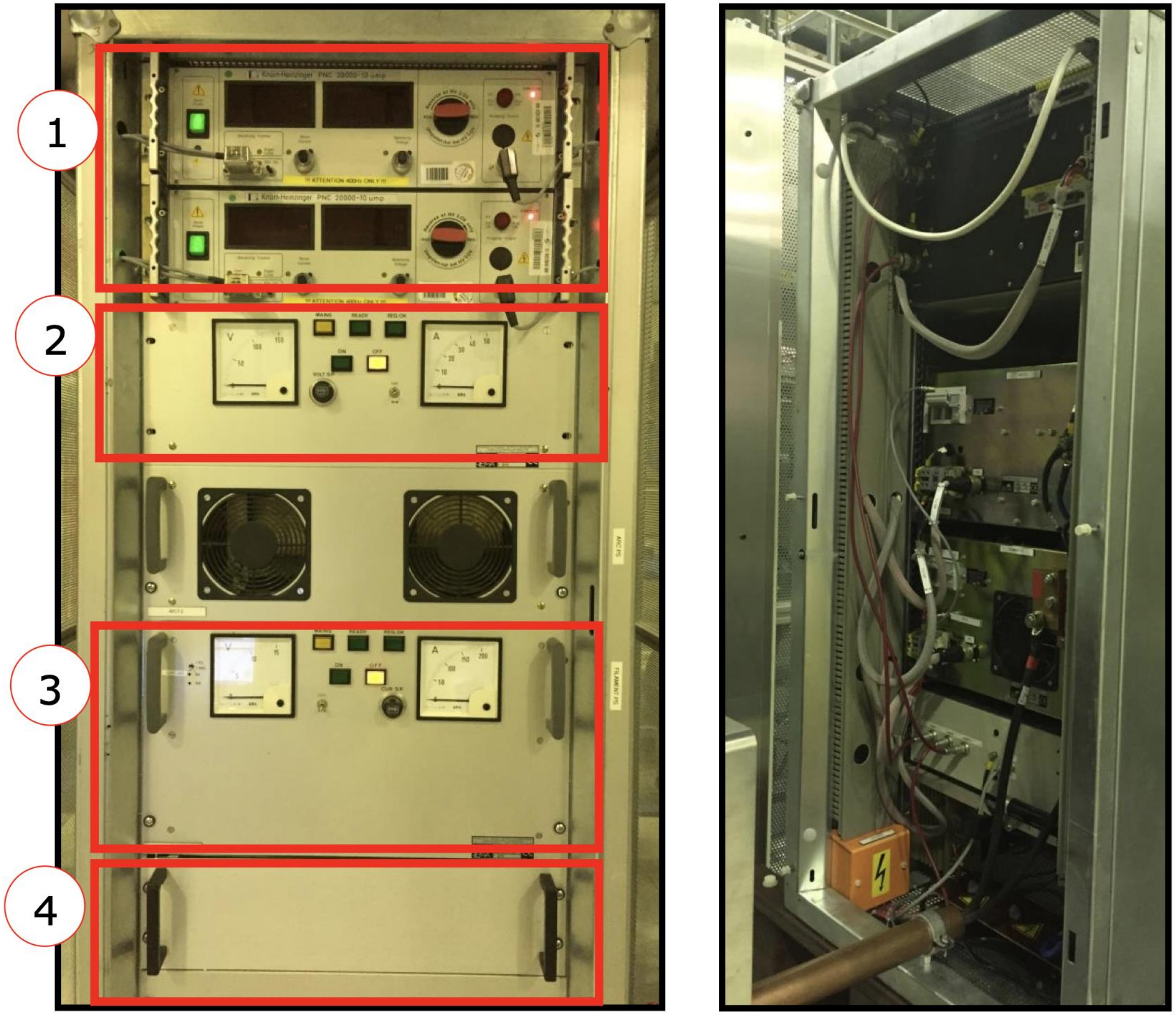


Figure 11: Front and rear view of the HV cabinet.

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 **H_2 cartridge** purity
  - Improve **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(?)

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**

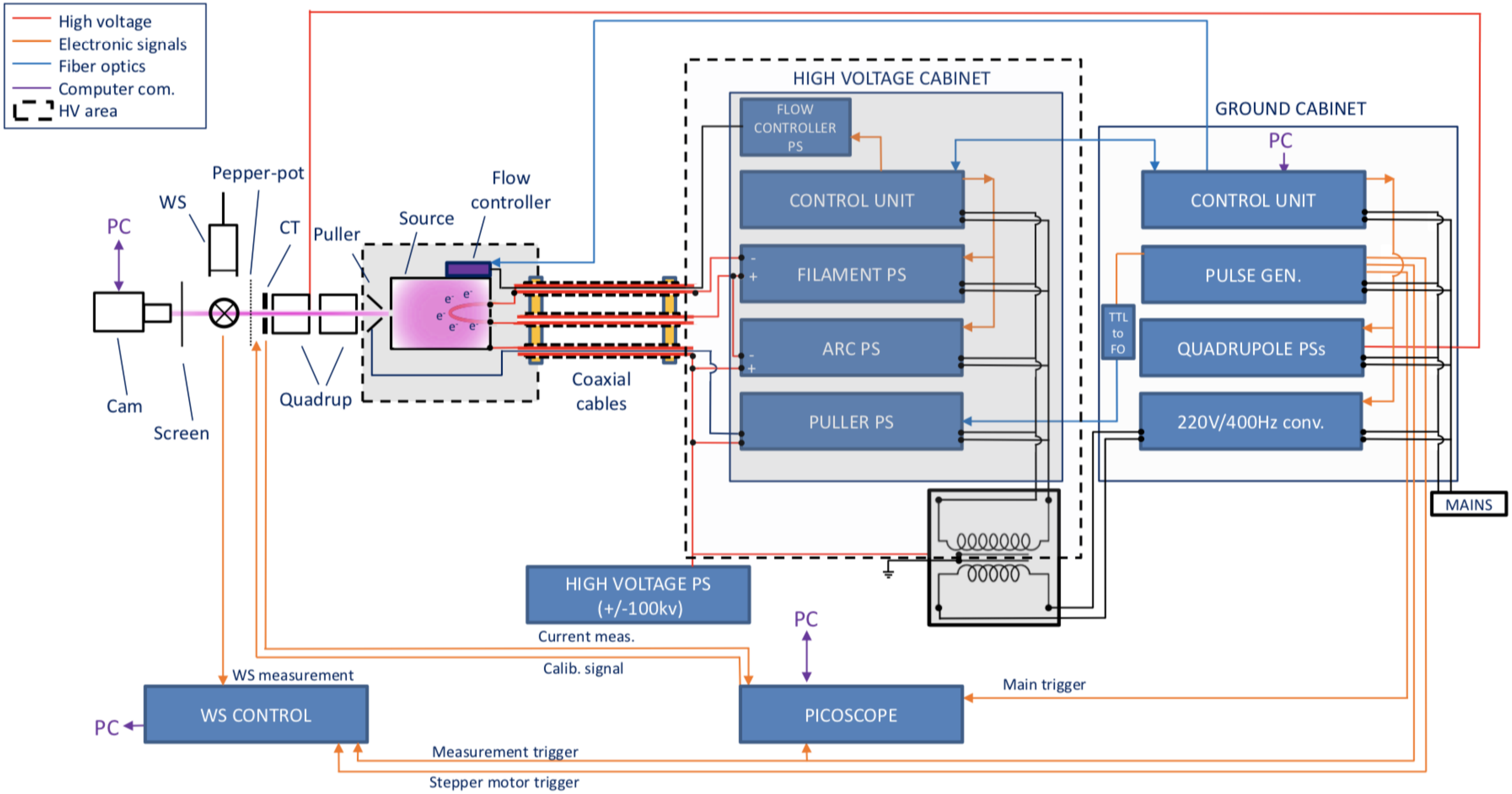
- **Two main threats** for the full exploitation of the source:
  - **Intra-pulse instability**
  - **Long-term drift of beam position**

- **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!

BACKUP

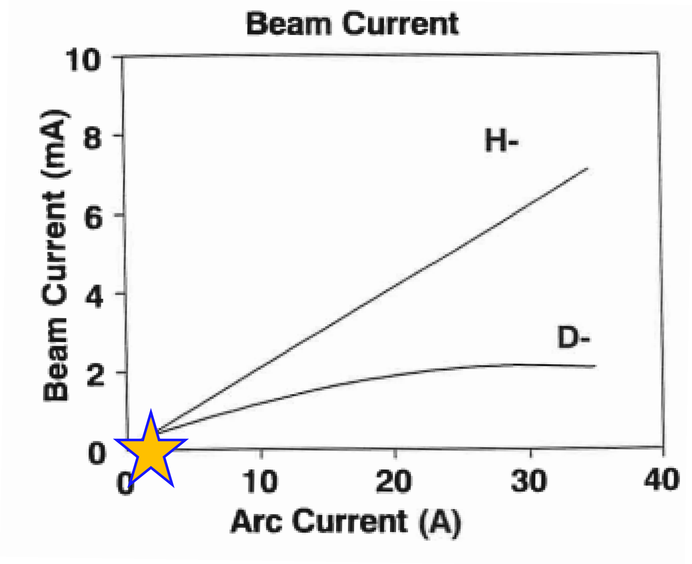
Source cabling (partially outdated)



from Ana Megía-Macías - link

Source operation point

(with respect to source user manual graphs)

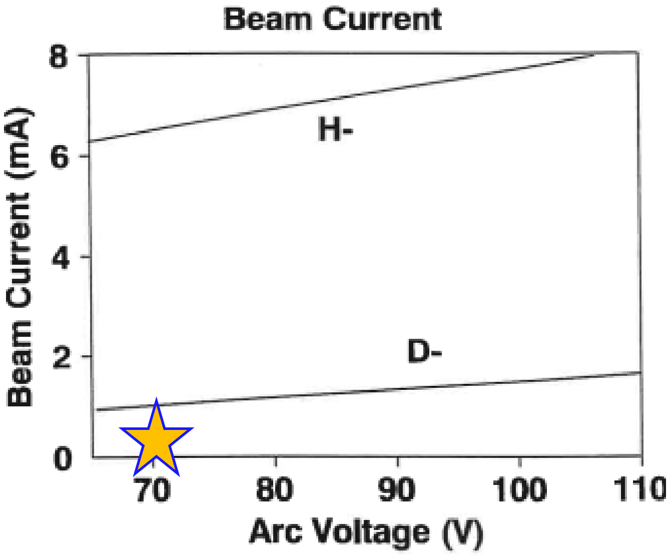


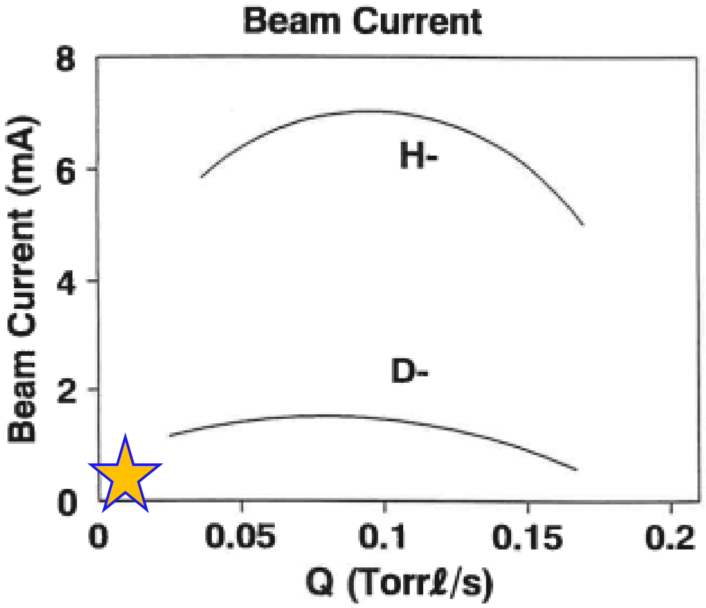
ELENA source

Iarc=1-2 A

Uarc=70 V

Q=0.006-0.018 Torr*l/s

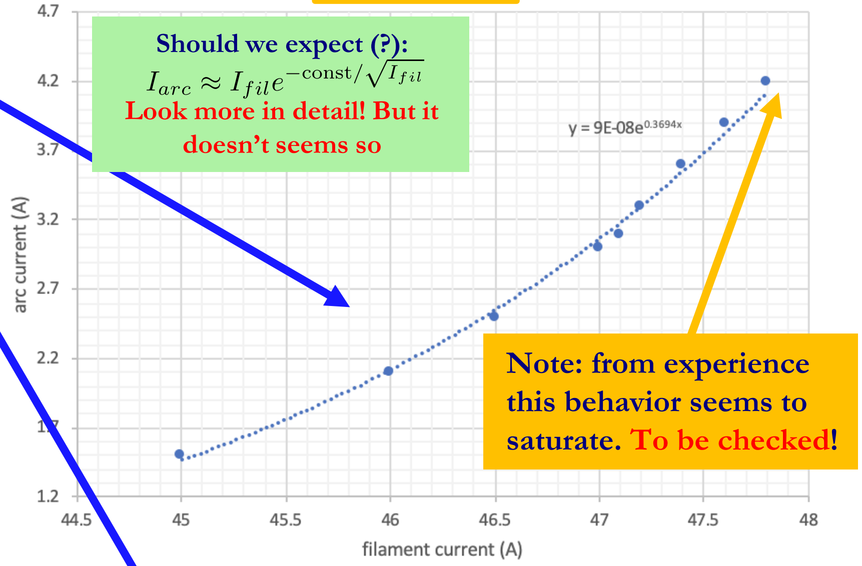




General behavior of source parameters

- 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=0.7sccm

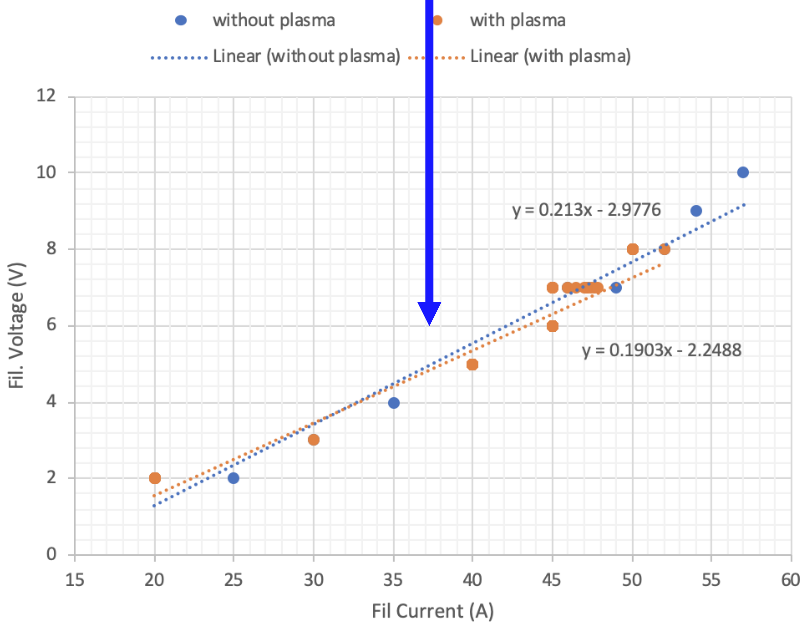


Should we expect (?):

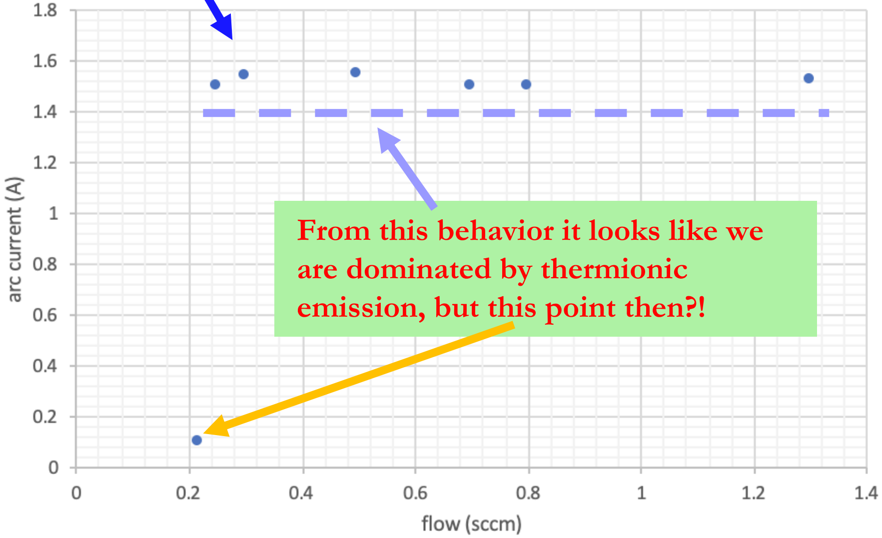
$$I_{arc} \approx I_{fil} e^{-\text{const}/\sqrt{I_{fil}}}$$

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

$$C_{or,mol,H_2}[\mathrm{l/s}] = 43.8 \cdot A \quad \text{@20deg for H}_2$$

$$A := \text{cross section } [\mathrm{cm}^2]$$

$$P_c \cdot S = Q = C_{or}(P_s - P_c)$$

$$P_c\left(\frac{S}{C_{or}}+1\right) = P_s = (2200/5.5+1)P_c = 400P_c$$

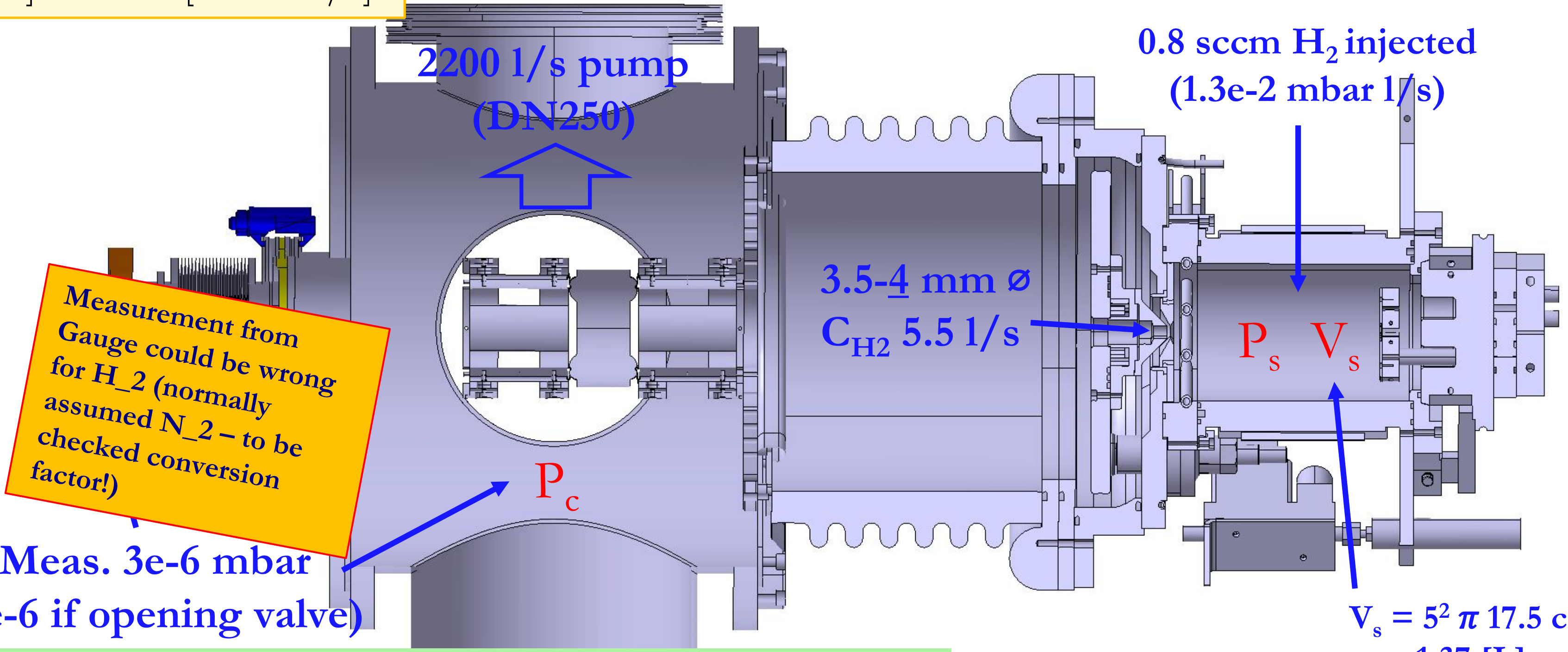
$$1[\mathrm{sccm}] = 0.016[\mathrm{mbar}\cdot\mathrm{l/s}]$$

Estimate of gas density:

$$n_{H_2} = N_A\frac{P_s}{RT}$$

$$n_{H_2} = 2.47\times10^{22}[\mathrm{m}^{-3}\cdot\mathrm{mbar}^{-1}]\cdot P_s[\mathrm{mbar}]$$

$$P_s = 1.2\times10^{-3}[\mathrm{mbar}];\ n_{H_2} = 3\times10^{19}[\mathrm{m}^{-3}]$$



2200 l/s pump (DN250)

0.8 sccm H_2 injected (1.3e-2 mbar l/s)

3.5-4 mm ø

C_{H2} 5.5 l/s

P_s V_s

P_c

Measurement from Gauge could be wrong for H_2 (normally assumed N_2 – to be checked conversion factor!)

Meas. 3e-6 mbar (2e-6 if opening valve)

$V_s = 5^2 \pi\, 17.5$ cm^3 = 1.37 [L]

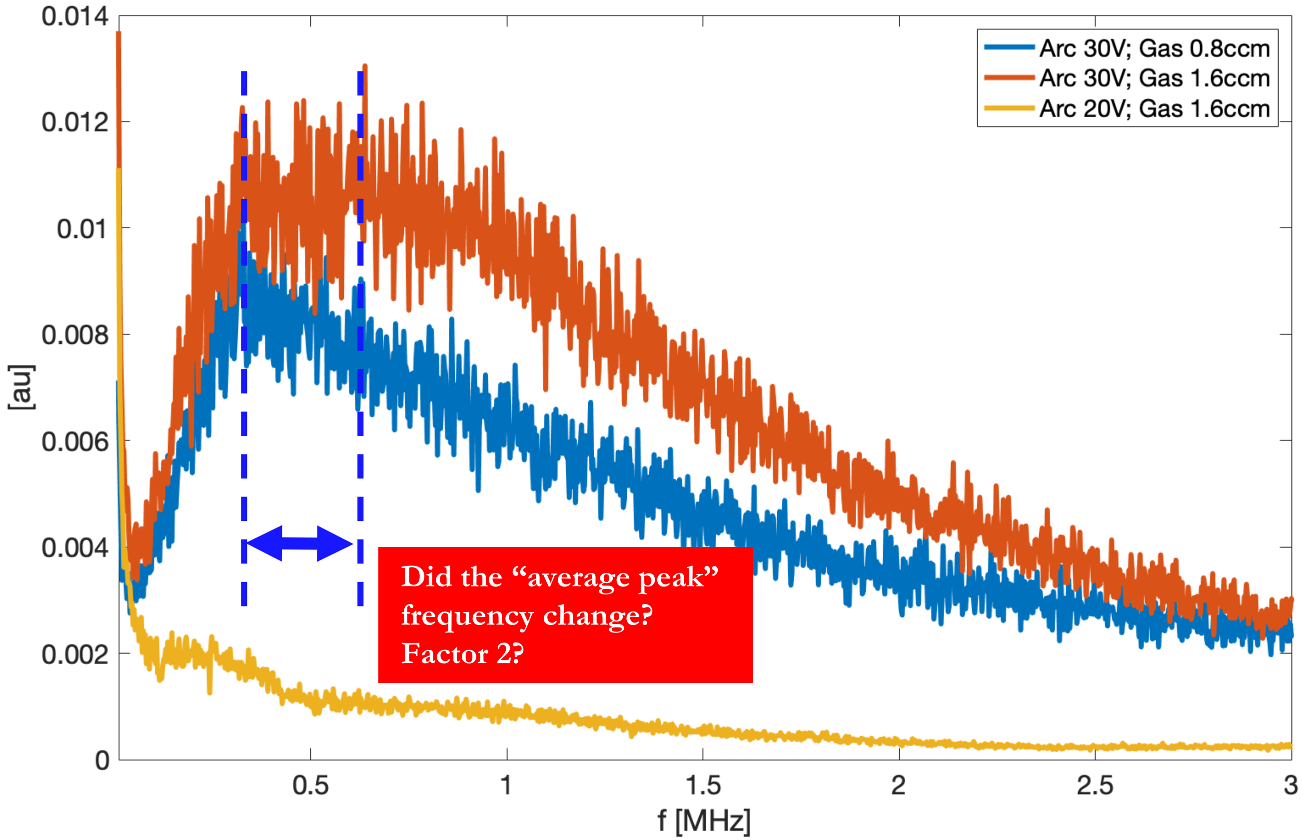
$$P_c = \frac{Q}{S} = \frac{1.3\times10^{-2}}{2200} = 6\times10^{-6}[\mathrm{mbar}]$$

Crosscheck of expected vacuum pressure : we are wrong only of factor 2 somewhere

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.)**



Did the "average peak" frequency change?
Factor 2?

Plasma frequency

$$\omega_p^2 = \frac{n_e e^2}{m_e \epsilon_0} \Rightarrow f = \frac{1}{2\pi}\frac{e}{\sqrt{m_e \epsilon_0}}\sqrt{n_e} = \boxed{8.979\sqrt{n_e}}$$

$$\epsilon_0 = 8.854187817 \cdot 10^{-12}\ [\mathrm{F/m}]$$
$$e = -1.602176634 \cdot 10^{-19}\ [\mathrm{C}]$$
$$m_e = 9.10938188 \cdot 10^{-31}\ [\mathrm{kg}]$$

- 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]