Time evolution of gas injection calibration data ”gas pumping method”

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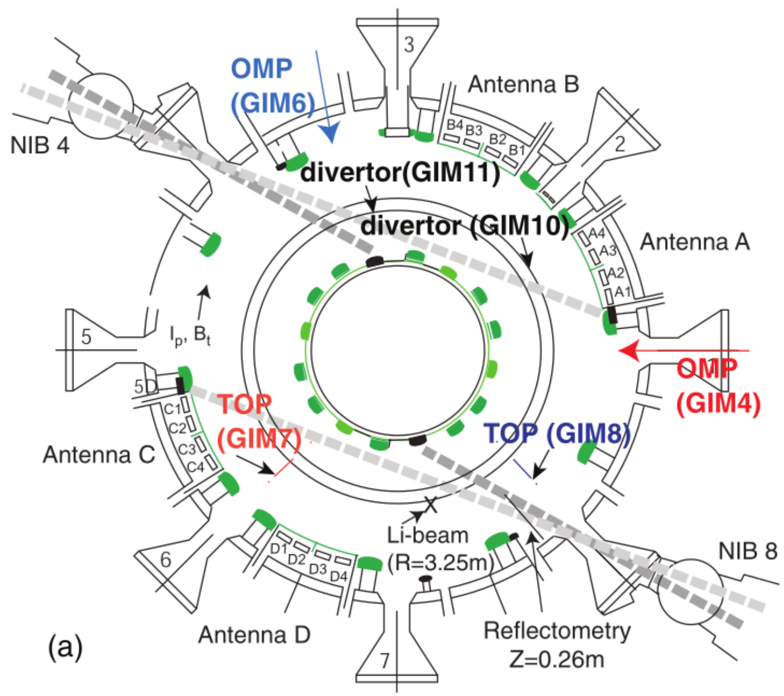
(2023) RGA calibration procedure

During November-December 2023 at the end of the LID-QMS experiments, calibration sessions have been executed. The procedure:

- $\mathrm{D_2}$ gas injections in the JET main chamber from GIM4 volume, for short times ($\Delta t_F < 1\,\mathrm{s}$) at constant pumping speed (as operated during same day LID-QMS experiments);
- acquisition of the drop in pressure in GIM4 (VC offline data);
- acquisition of the RGAs responses (currents) (DF offline data) in scan mode with different mass ranges.



Pulsed calibration Method: "JUMP method"

- The initial pressure inside the JET chamber is constant at the background value P_{bg};
- then the pressure ($\propto \mathrm{I_{RGA}}$) increases due to gas flow (F) inlet from an external calibrated volume (GIM4, $V_{GIM4} = 1.466\,\mathrm{L}$):

$$\Delta P(t) = \frac{\tau F}{V_J}[1 - \exp(-t/\tau)]$$

where $\tau = V_J/S_J$,

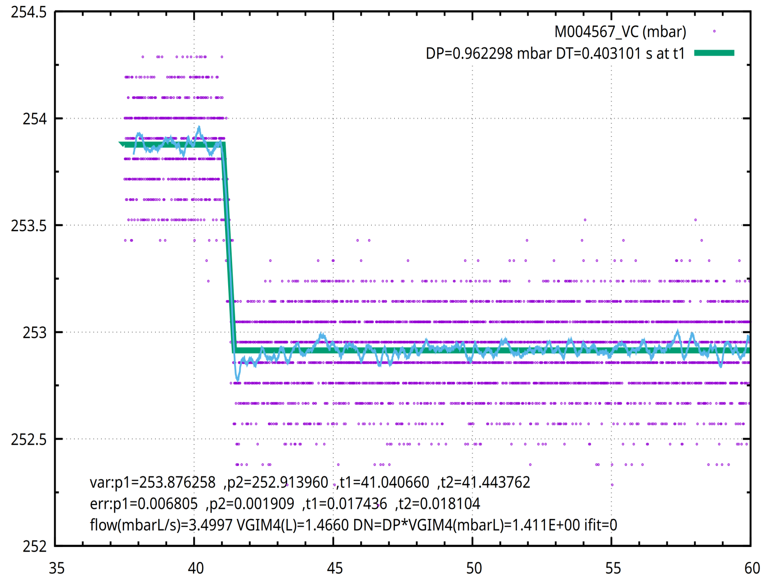
- At the end of flow ($t = t_1$), the pressure decrease rapidlly due to the volume pumping rate but it is "slow down" by gas outgassing:

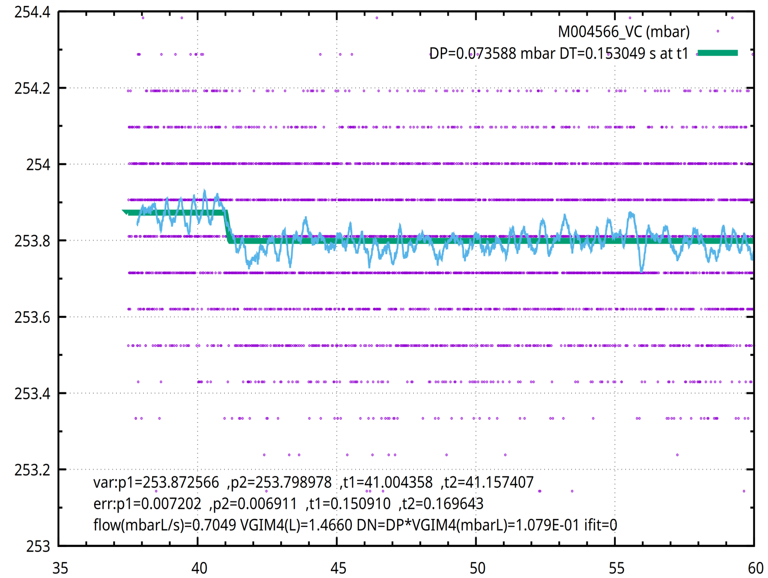
$$\Delta P(t) = \Delta P(t_1)\exp(-(t - t_1)/\tau) + (outgassing)$$

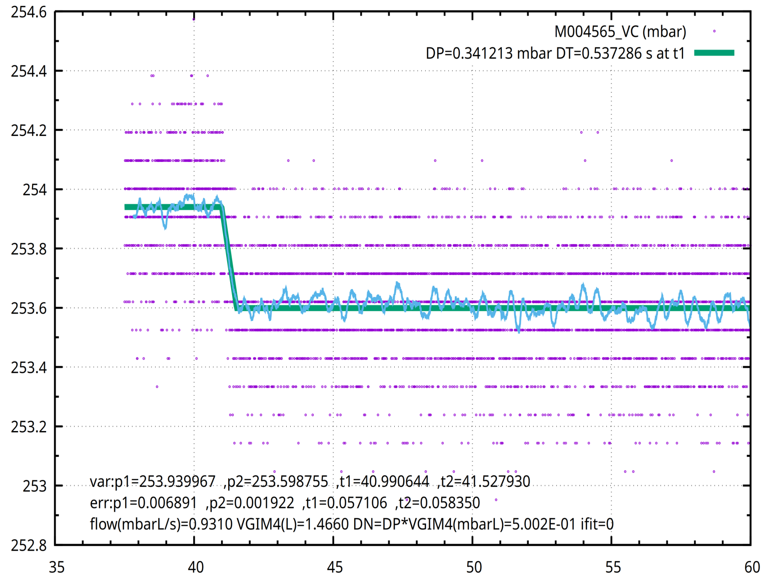
The basic principle of the "jump method": if the gas flow time duration Δt_F is small respect to the JET volume pumping speed characteristic time τ we have a free gas expansion from GIM4 to JET chamber volumes.
For $t = \Delta t_F \ll \tau$:

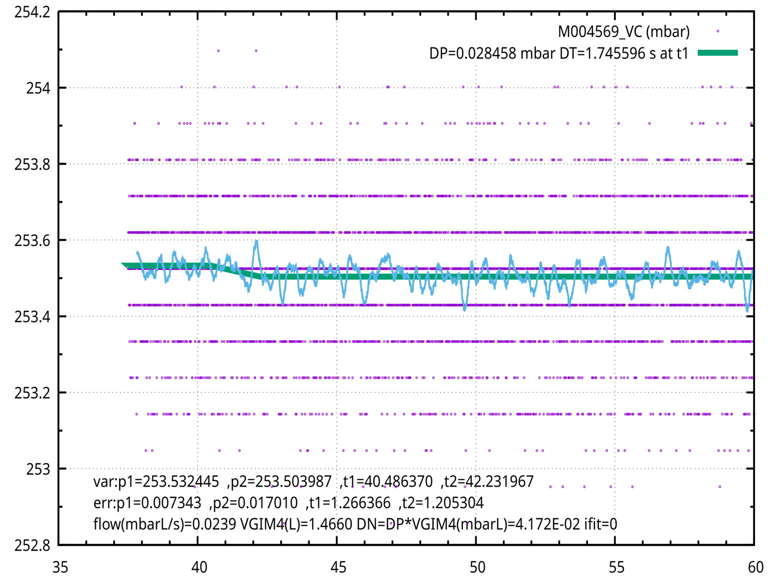
$$\Delta P(t = \Delta t_F) \approx \frac{F}{V_J}\Delta t_F = \Delta P_{GIM4}\frac{V_{GIM4}}{V_J}$$

Analysis of D_2 injections from GIM4 volume





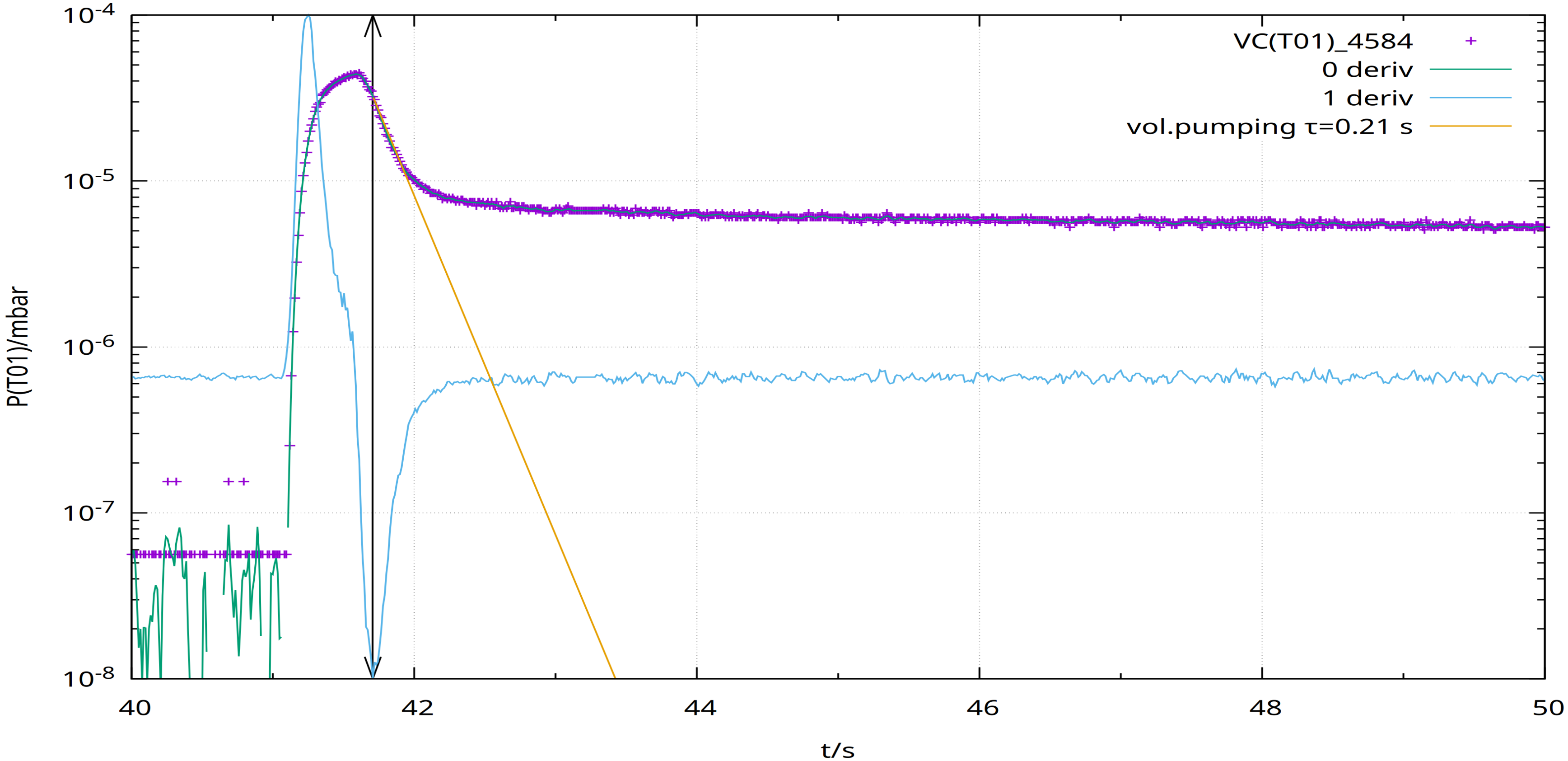




smoothing and fitting according to a piecewise linear function.

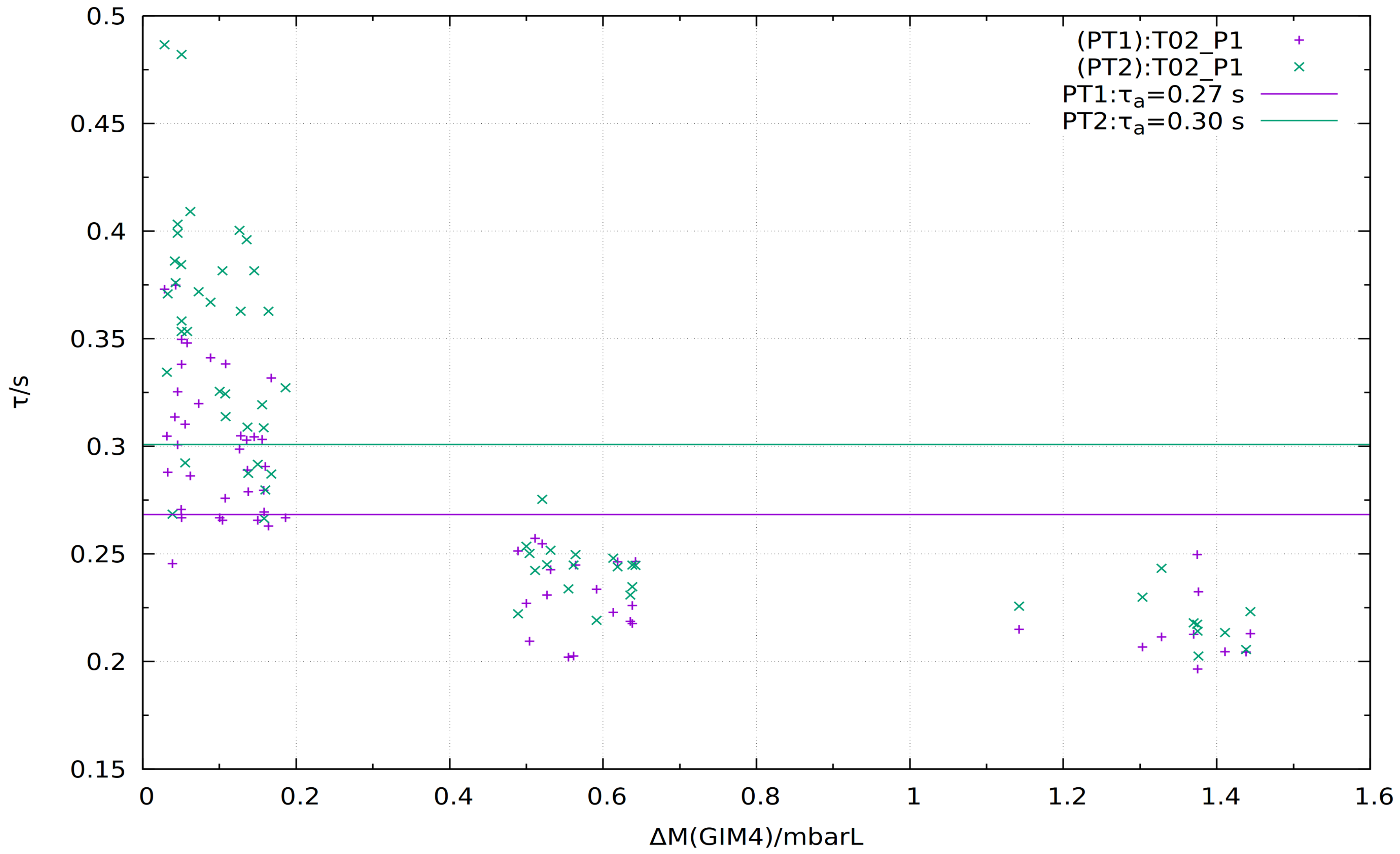
JET chamber pumping speed

In JET chamber before the turbomolecular pumps at OCT1 and OCT5, Penning gauges are housed; the data are stored in the VC subsystem (as VC/T01-P1; VC/T02-P1) and in “mbar” pressure unit.
The sampling rate is high (80 RDGS/s) to resolve the initial transients.



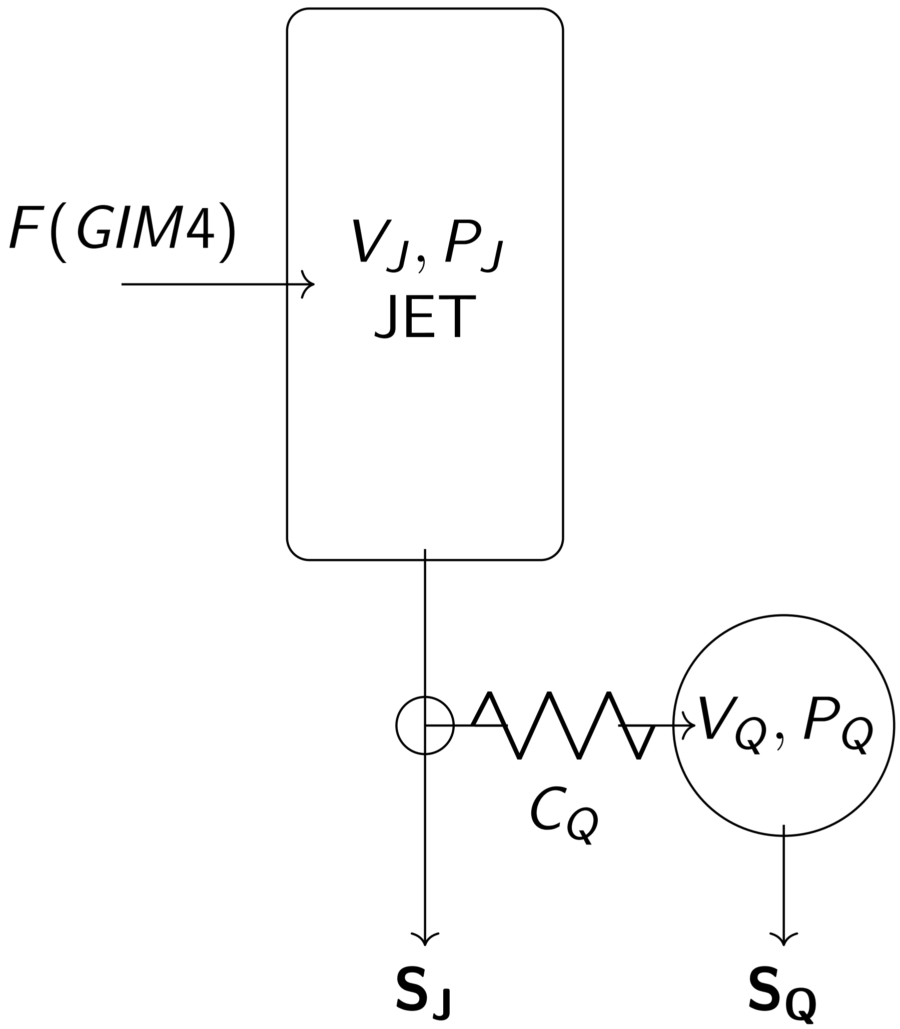
for $V_J(JET) \approx 180\,\mathrm{m}^3$: $S(T1) = V_J/\tau \approx 850\,\mathrm{m}^3/\mathrm{s}$.

T01-T02 pump (1/e) chracteristic time τ



for $V_J(JET) \approx 180\,\mathrm{m}^3$: $S(T1) \approx 660\,\mathrm{m}^3/\mathrm{s}$; $S(T2) \approx 600\,\mathrm{m}^3/\mathrm{s}$.

Gas dynamics in RGA calibration



The time responses in the discharge (JET torus), (P_J, V_J), and RGA (P_Q, V_Q) volumes $(\tau_J = V_J/S_J)$:

$$V_J \frac{dP_J}{dt} = F - S_J P_J - G + H_J$$

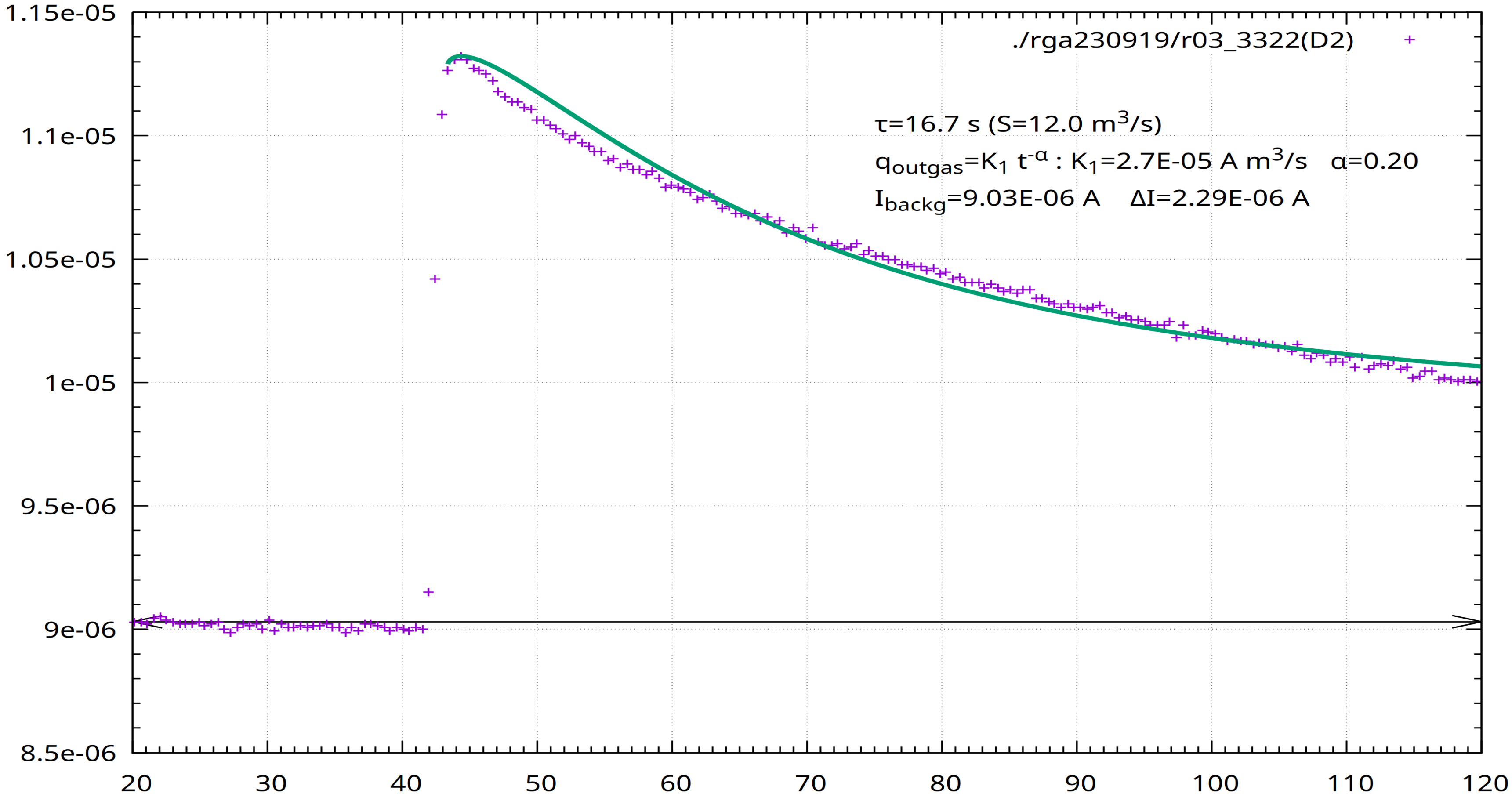
$$V_Q \frac{dP_Q}{dt} = G - S_Q P_Q + H_Q$$

$$G = C_Q(P_J - P_Q)$$

$$I_Q = K_{sQ} P_Q \ (always\ valid)$$

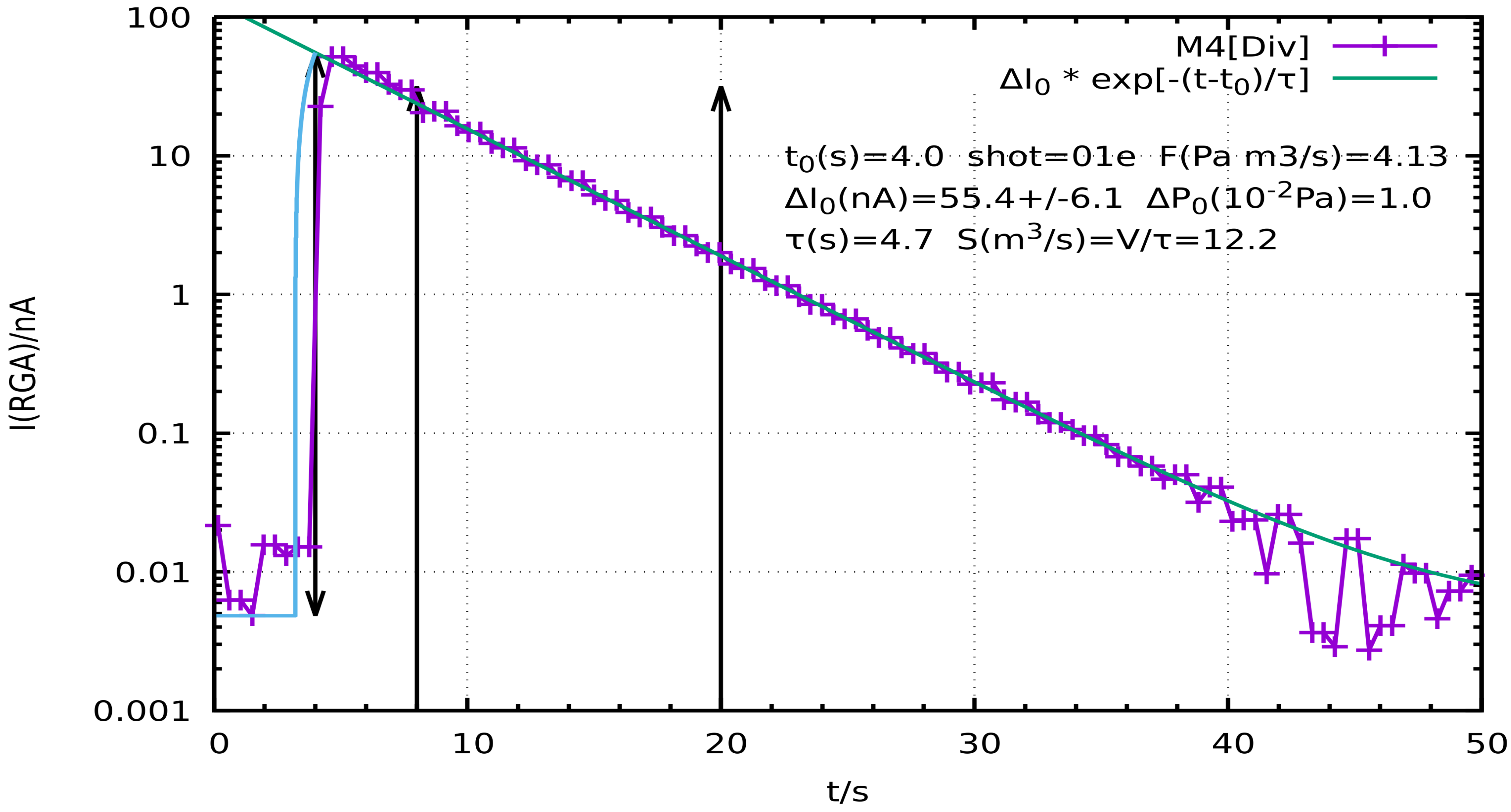
$$I_Q = K_{sJ} P_J \ (equilibrium\ approximation)$$

JET: RGA3 data analysis from D_2 injection (25/11/2023)



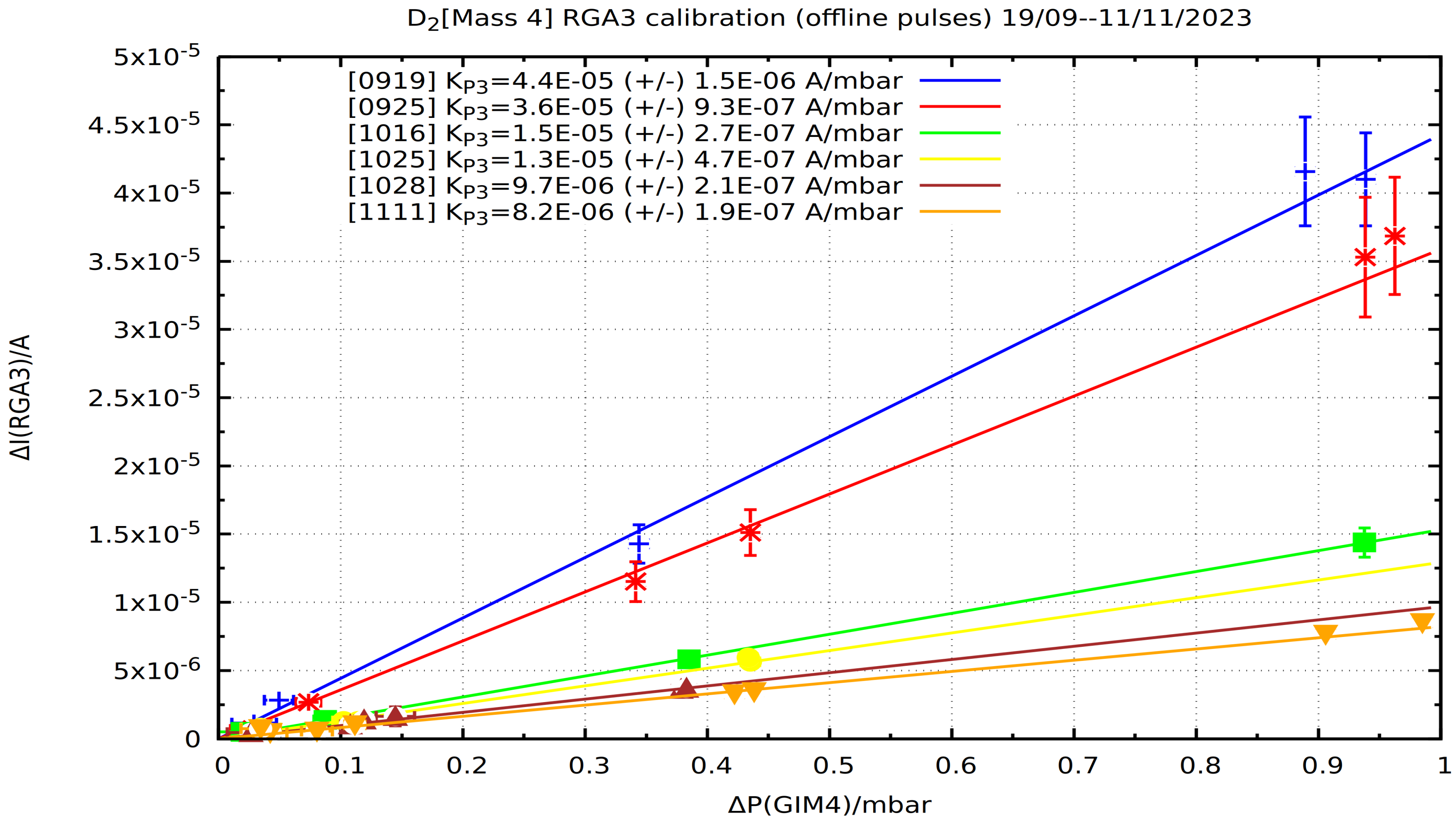
$\tau(RGA) \approx V_Q/S_Q \gg \tau_J(JET)$; outgassing high ($\propto 1/t^\alpha$ with $\alpha < 0.5$). Small sampling rate 2 RDGS/s (it is very difficult to resolve the initial transient).

WEST: (calibration D_2, shot 59330) RGA divertor



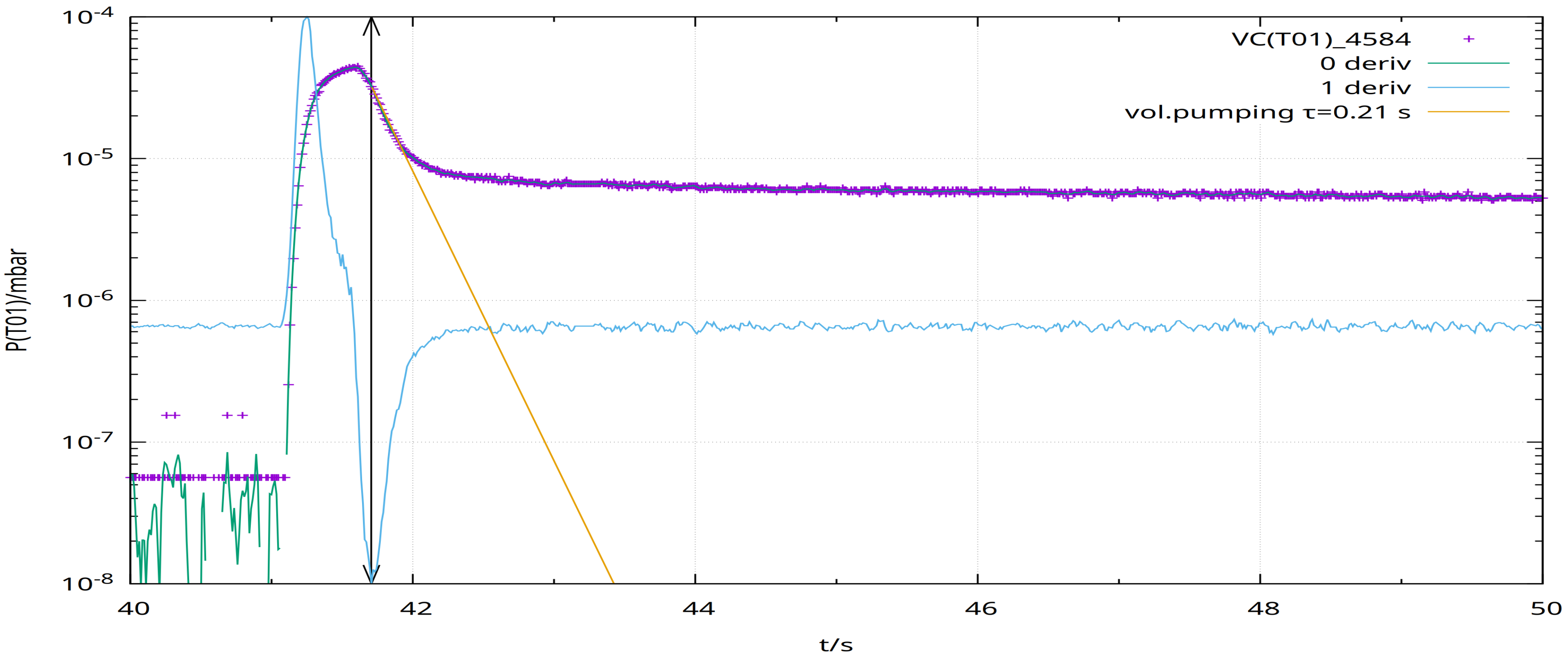
$\Delta t_F = 120\,\mathrm{ms}$, $\tau = 4.7$ s, $S = 58\mathrm{m}^3/\tau = 12.2$ m3/s.

RGA3 calibration factors $\Delta I(MAX) = K_P \Delta P$



pumping conditions: torus sealed with T1 turbo pump, LN2 conditions, RGAs in SEM mode.

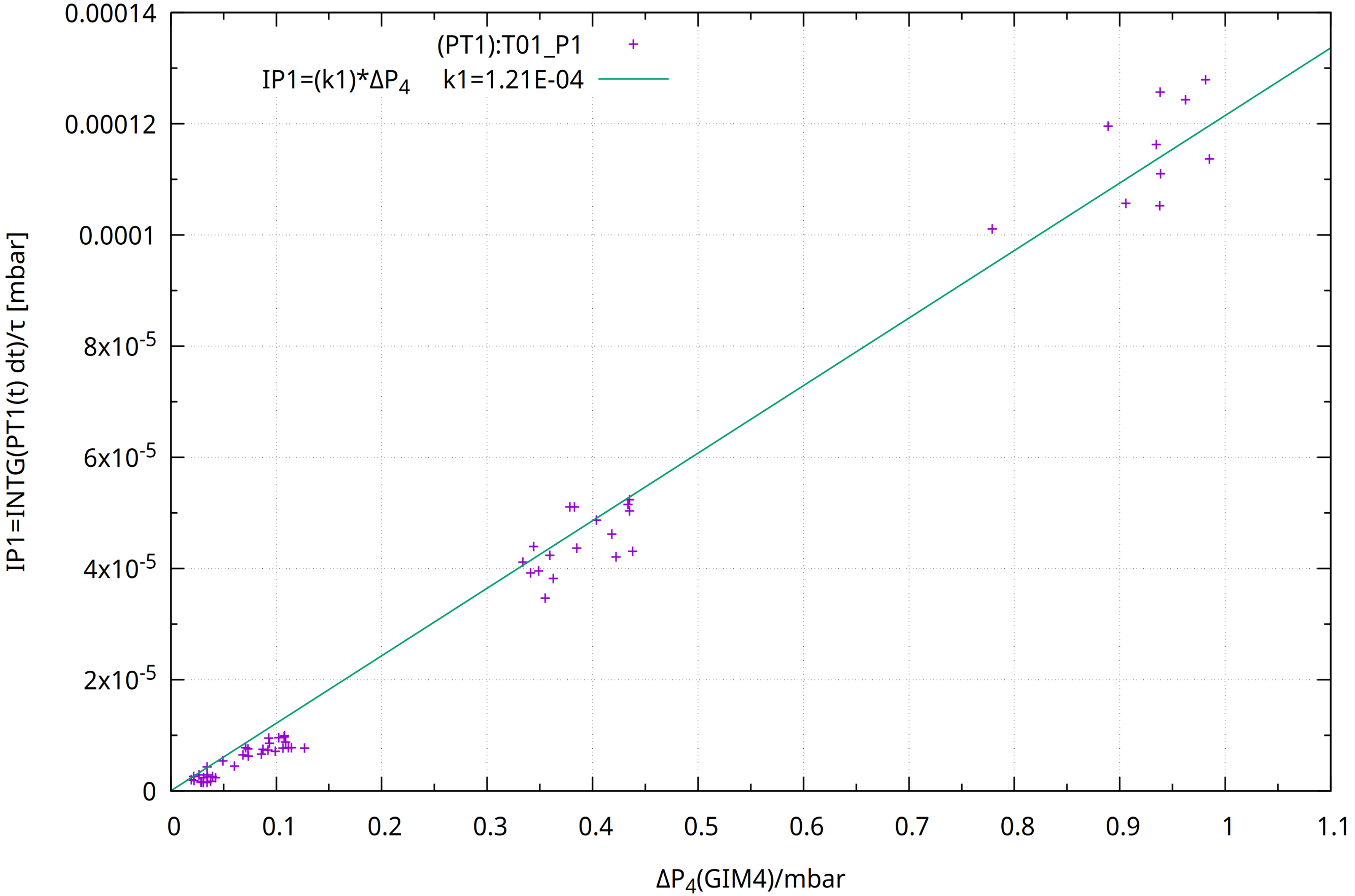
Penning gauge calibration: integral method



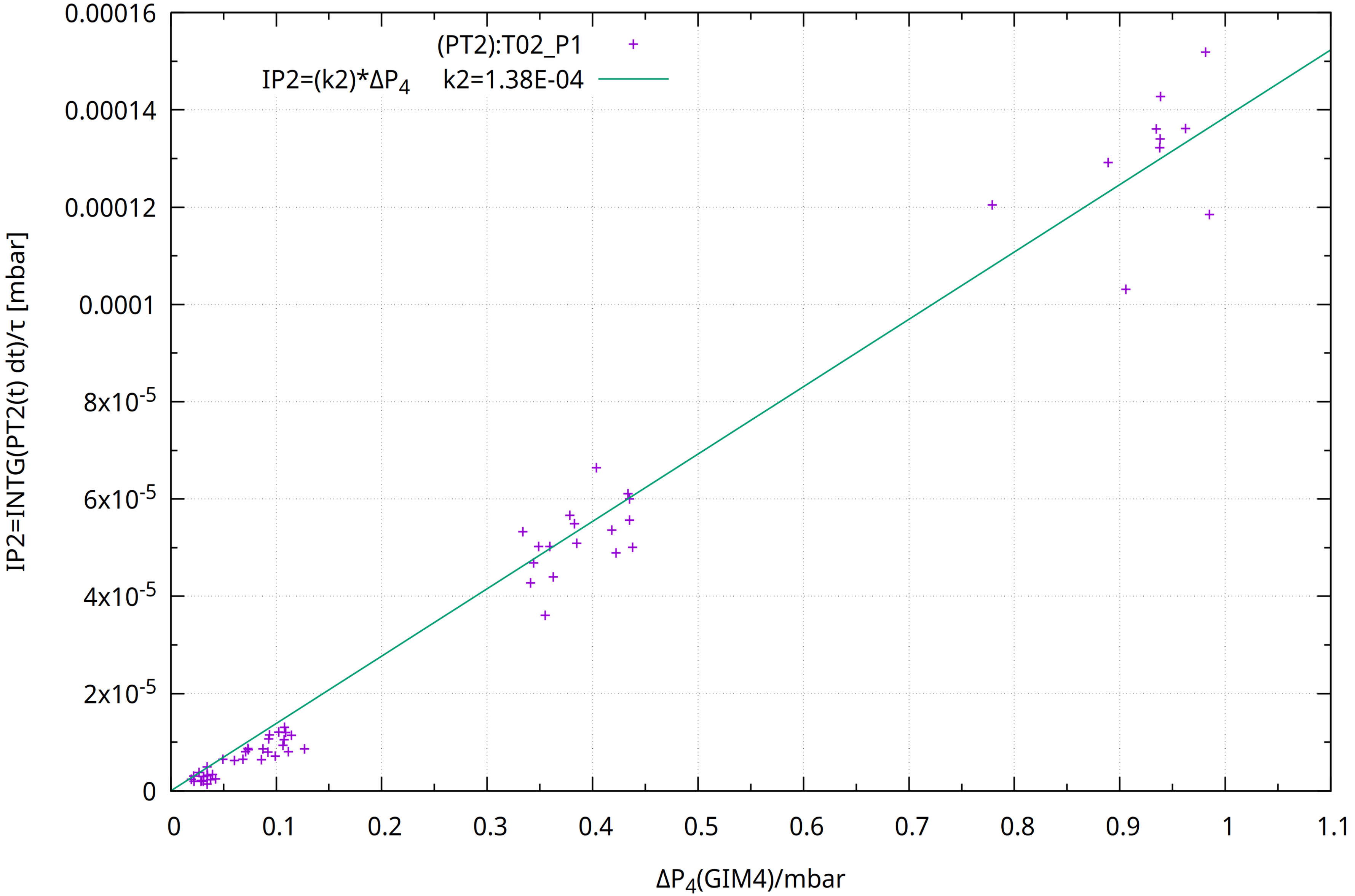
$$\tau_V \approx -\frac{\mathrm{P}(t)}{\dot{\mathrm{P}}(t)} \ (@t = t_1, \min[\dot{\mathrm{P}}(t)] < 0) \qquad \Delta Q(P(t)) = \int_{t_0}^{\infty} \mathrm{P}(t)dt \approx \int_{t_0}^{t_1} \mathrm{P}(t)dt + P(t_1)\tau_V$$

$$\frac{\Delta Q}{\tau_V} = K_P \Delta P(GIM4) \qquad t_0(@\, bkg.); [\Delta Q(P(t))] = \mathrm{mbar\,s}$$

T01 Penning gauge calibration factor (OCT1 valve open)



T02 Penning gauge calibration factor (OCT1 valve closed)



Conclusions and Proposals

The calibration of hydrogen isotopes with mass spectrometry (RGA) has revealed some critical issues:

- the time constant in RGA systems is much longer than the pumping times in the main chamber (RGAs are not suitable for real time analysis);
- high outgassing rate (difficult to differentiate from pumping speed);
- the data sampling is low (not suitable for resolving the initial transient).

under these conditions it is worth investigating the use of pressure gauges (penning) for calibration and analysis:

- smaller time constant (in agreement with pumping speed values), higher sample rate to resolve the experiment transients;
- outgassing (same problems as RGA) but can be easily separated from the volume pumping rate;

In view of this, RGAs can be used primarily for vacuum analysis and for determining the primary gas(es) in the system (qualitative analysis), while the quantitative analysis will be performed by pressure gauges.