First measurement of background signals
Campaign at JETi200 (Jena), Aug 2020

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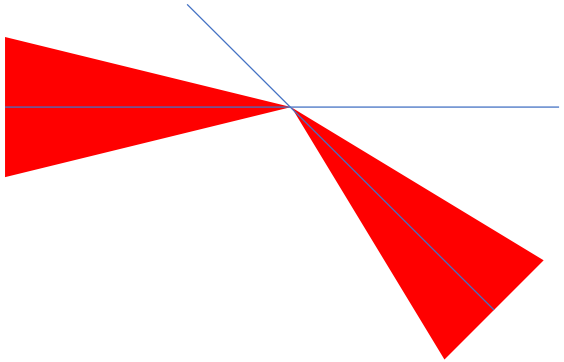
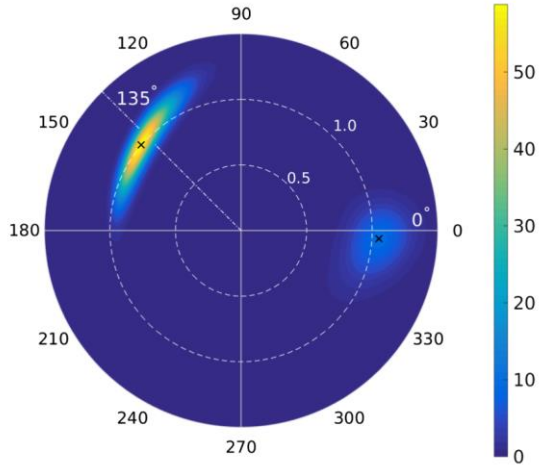
Recap project E2

- Goal: measure photon-photon scattering by colliding 2 (or more) high intensity laser pulses
  - Exact collision parameters: energies, geometry
  - Very low signal, very large background
- Goals project period 1:
  - Quantify background from rest gas and other scatter sources
  - design countermeasures to reduce background signal (fs-gated single photon detector, “vacuum cleaner”, scatter reduction methods)
- Today: results of single beam measurement

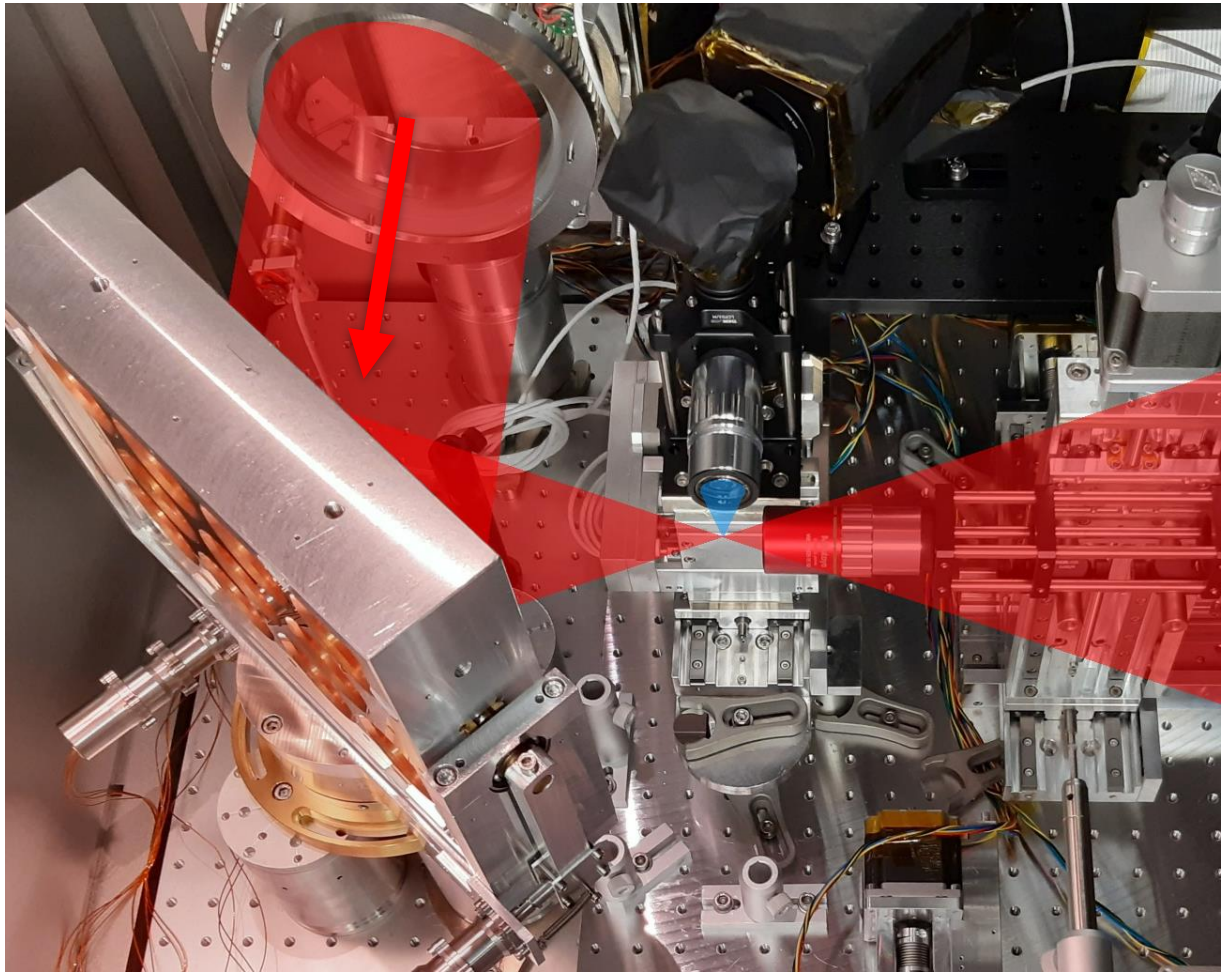




Number of signal photons $\frac{dN_{signal}}{d\omega d\varphi}$

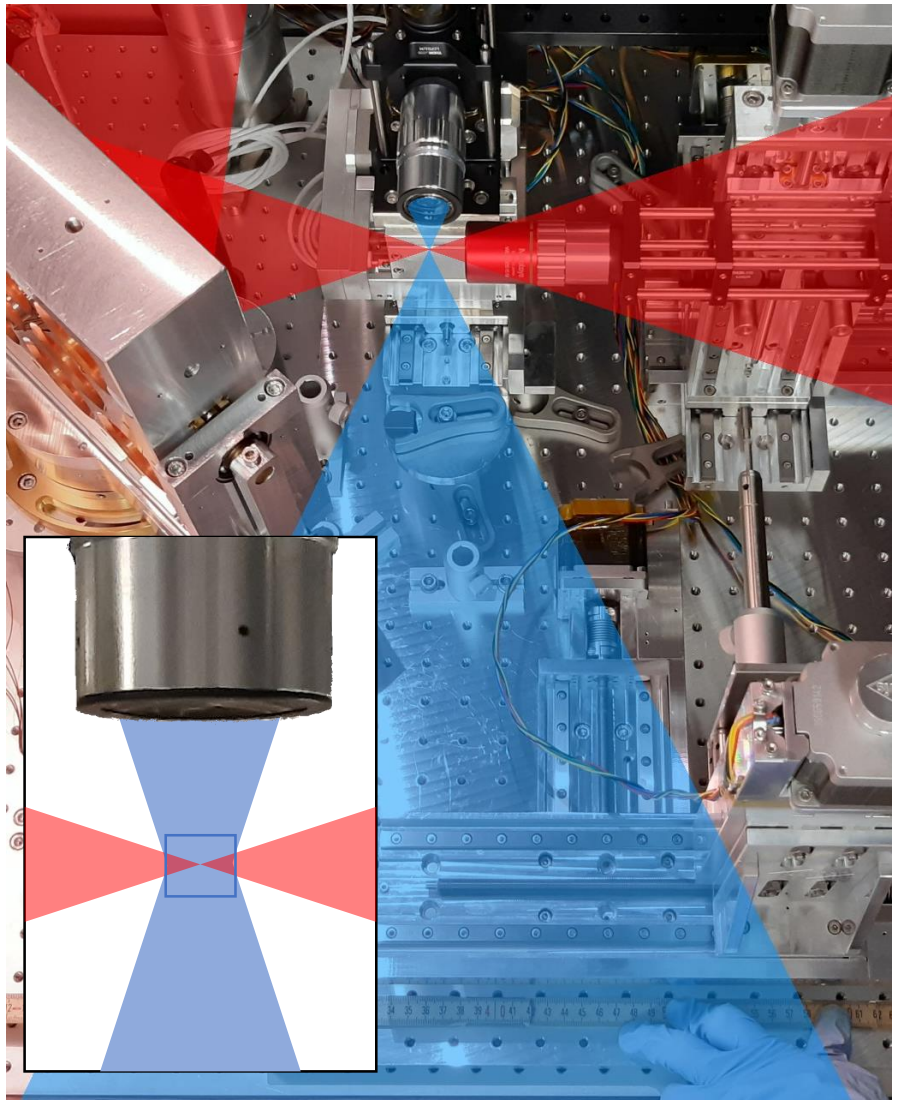
Blinne, A. *et al.* (2019) ‘All-optical signatures of quantum vacuum nonlinearities in generic laser fields’, *Physical Review D*, 99(1). doi: 10.1103/PhysRevD.99.016006.

Setup: Laser

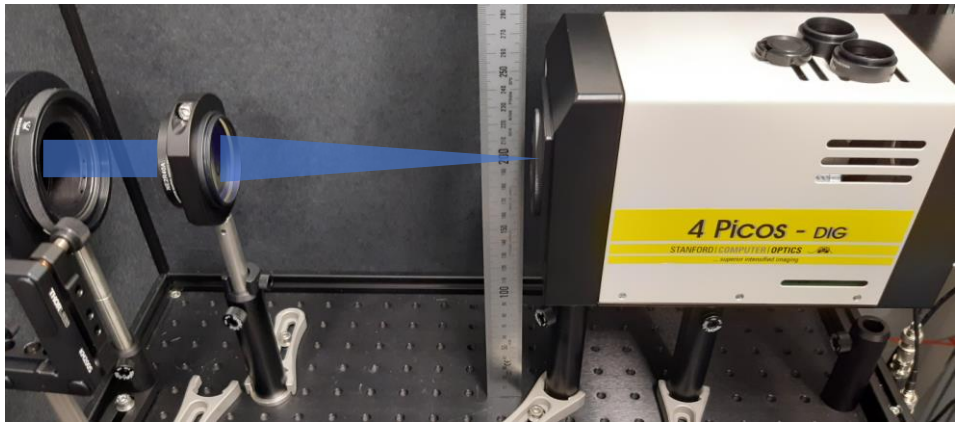


- Single beam laser
- 24fs, 175mJ in focus
- f/1.5 focusing optic (off-axis parabola, OAP)
  - Measured $d_{FWHM} \approx 2.2\mu m$
  - Nominal $z_R \approx 4.3\mu m$
- Focus oberserved from the side
- Polarization H or V
  - Expect large difference in signal from viewing angle

Setup: Scatter diagnostic



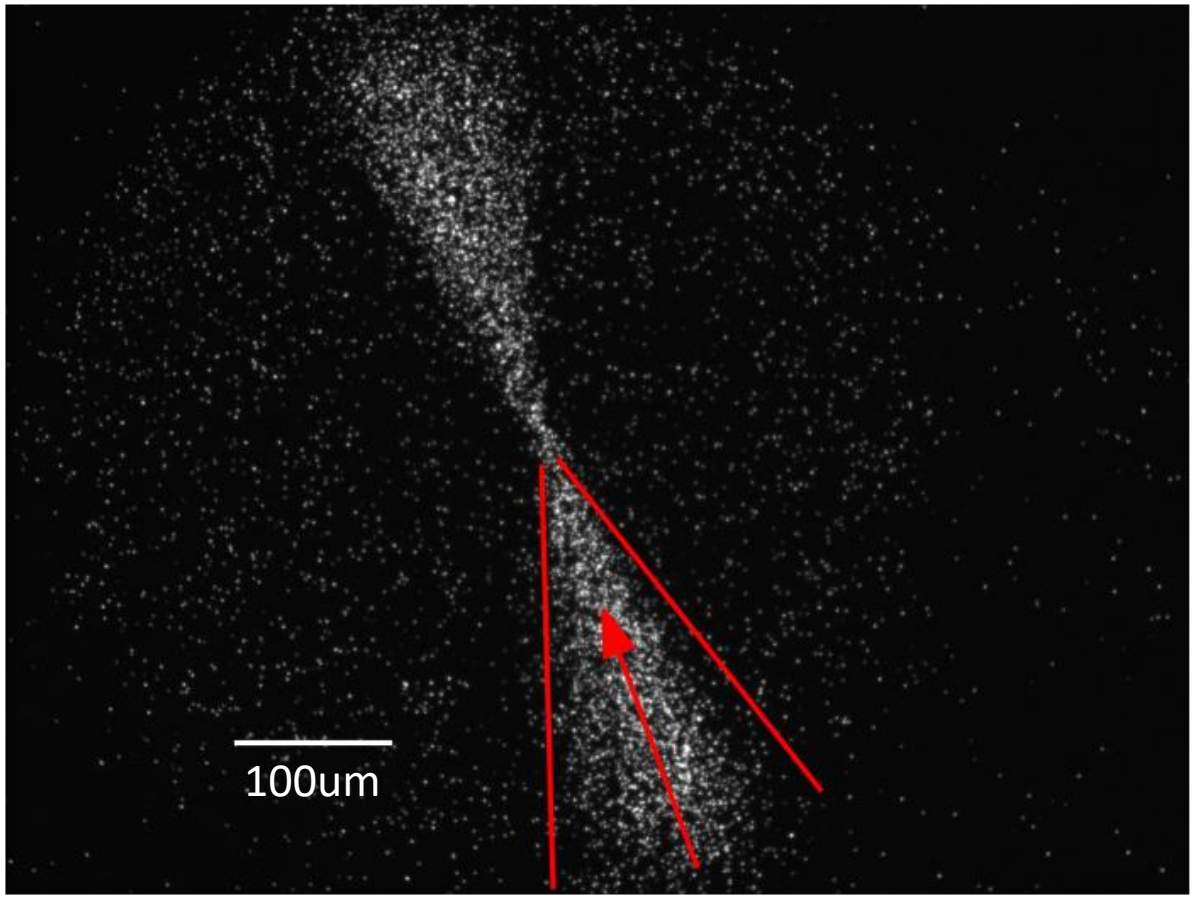
- Outside: 4Picos camera
  - Single photon sensitive
  - Time gated



- absolutely light tight imaging path
- viewing cone free of scatterers

- Vary pressure by adding Helium
- No prepulse, no „vacuum cleaner“

Main diagnostic: Gated single photon camera

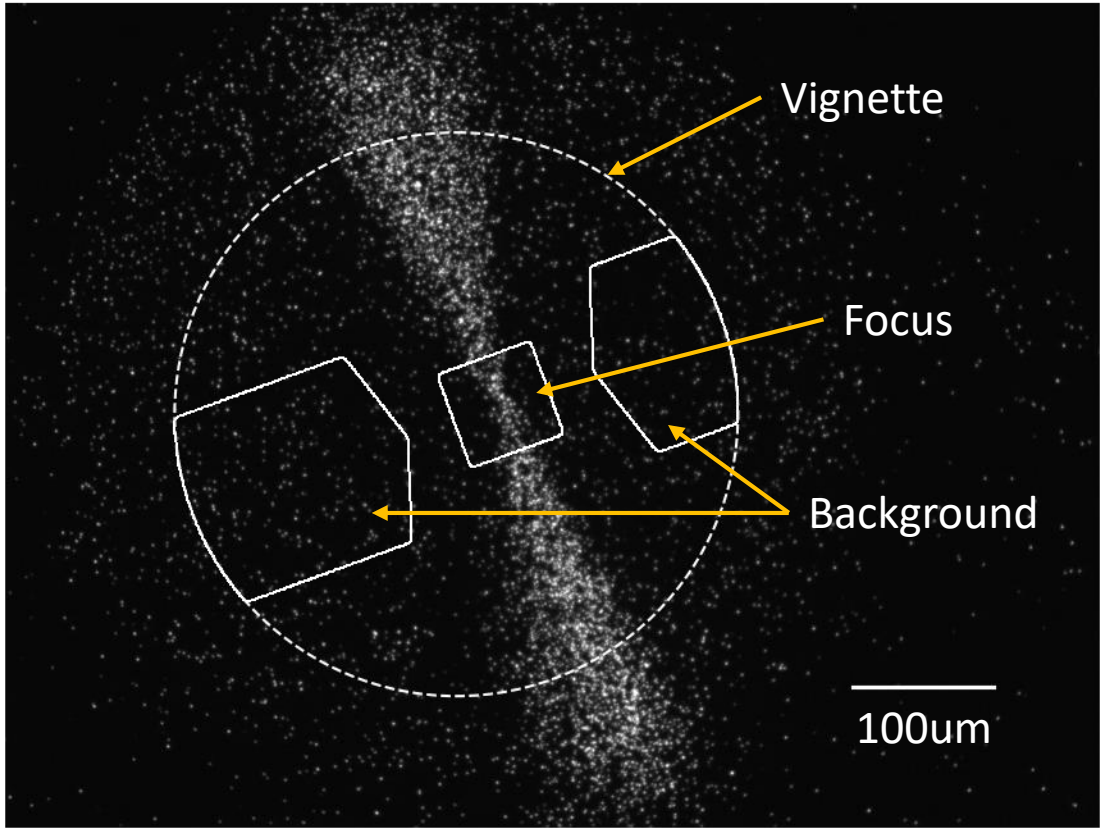


- Image at 70° angle due to setup

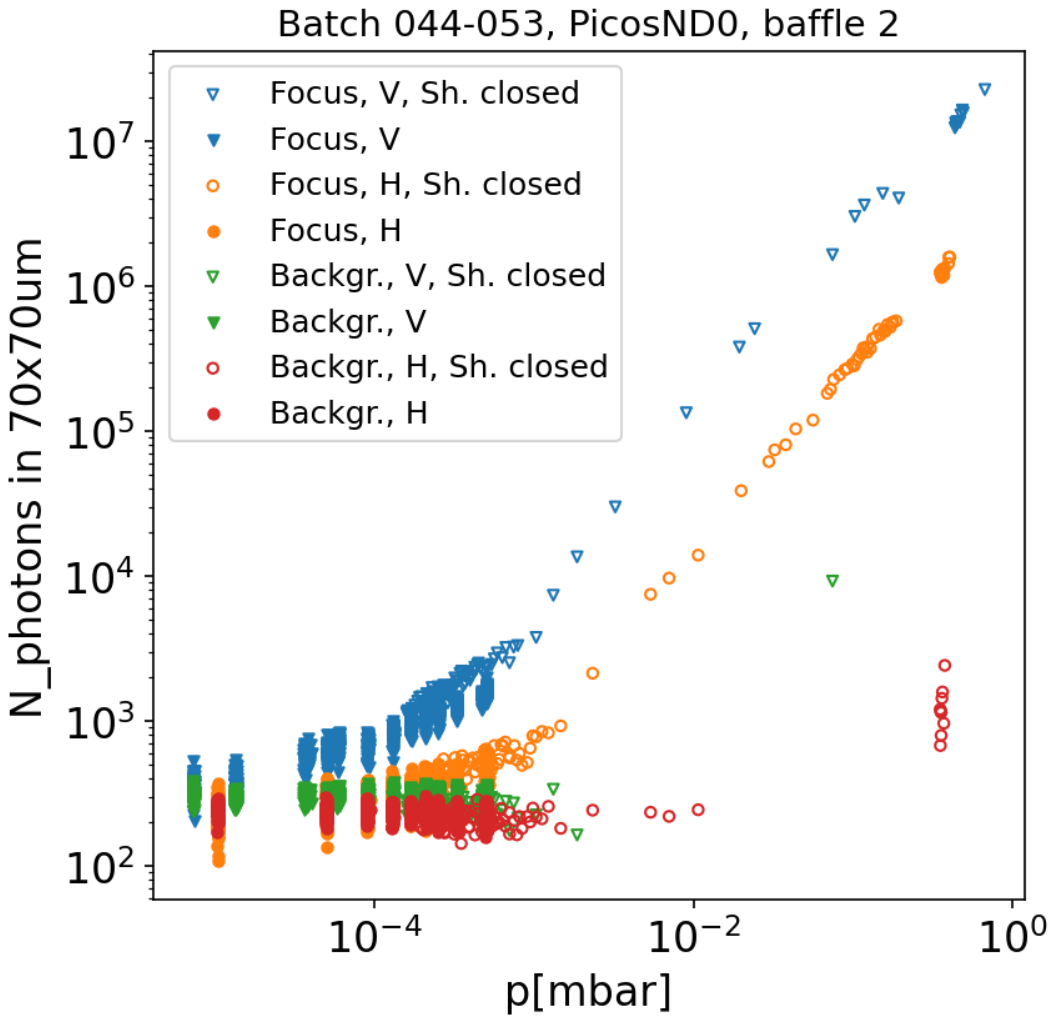
- Laser focus seen as „bow tie“
- Background outside laser cone
- Field of view limited by vignetting

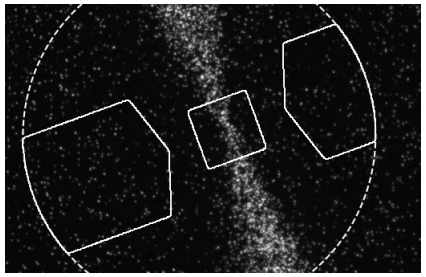
Quantitative evaluation

- Estimate No of photons from pixel counts
- Compensate QE~16.6% at 800nm
- Regions of interest (ROI):
  - Focus 70x70um
  - Background/Out of cone
    - (Photon number scaled to 70x70um)



Pressure scan



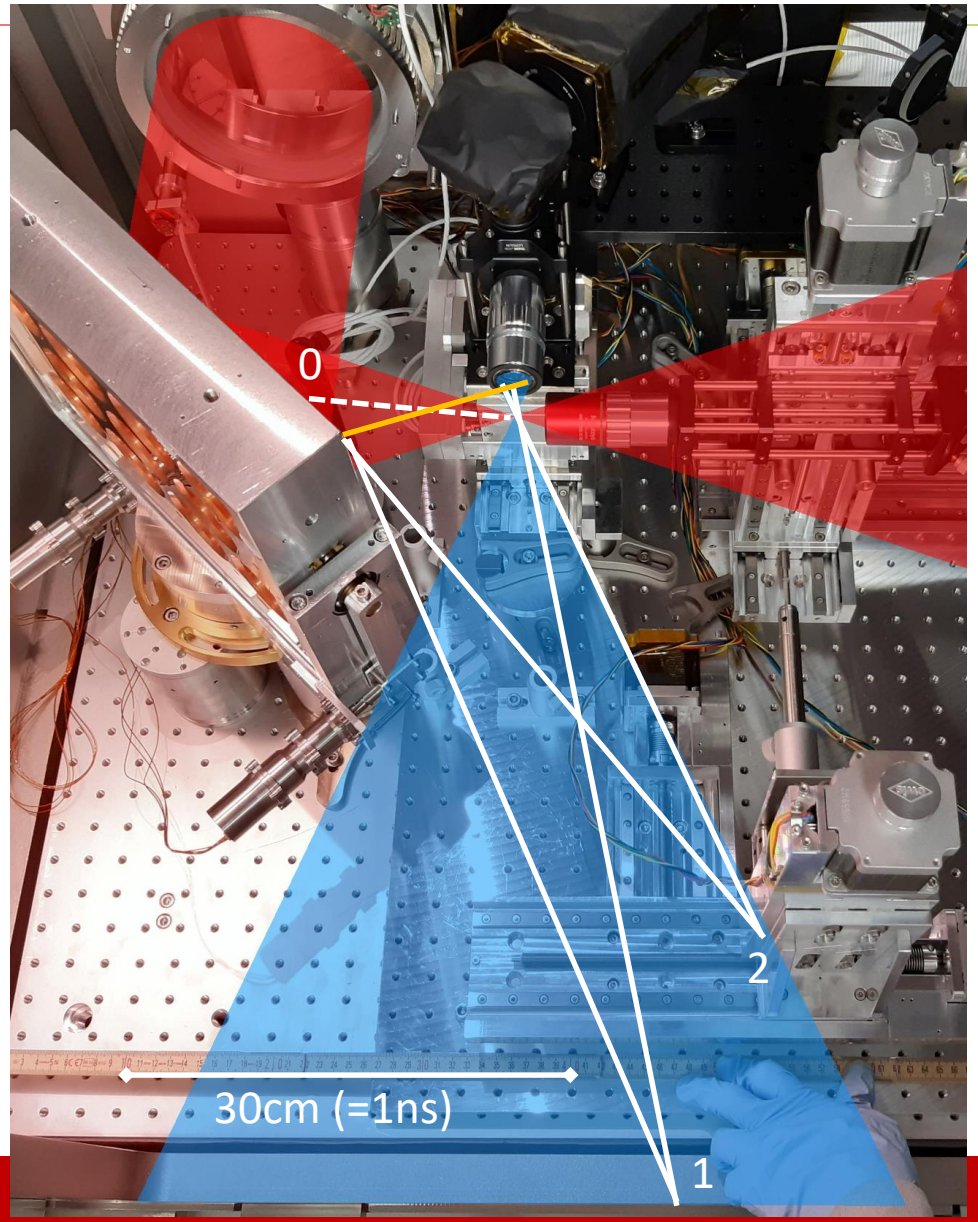


- 70x70um ROI
- Focus signal:
  - Pressure-dependence analysed later
  - constant offset towards lower pressure
  - Similar for both polarizations
  - Similar to background
- Background: **pressure-independent**
  - Mean = 299 for V polarization
  - Mean = 237 for H polarization

- → for now, scattering is dominant in relevant pressure region

Potential sources of background

- Light inside collection cone
  - No objects in direct path
  - Light arriving ahead of time? → laser temporal contrast
    - Path 0 ~ 0.5ns
    - Path 1 ~ 4ns
    - Path 2 ~ 3ns
  - Light arriving late, but not fully suppressed by detector
- Light from outside of collection cone
  - Large angle, but scattered into detector
  - Originating from focusing optic
  - Originating from upstream components



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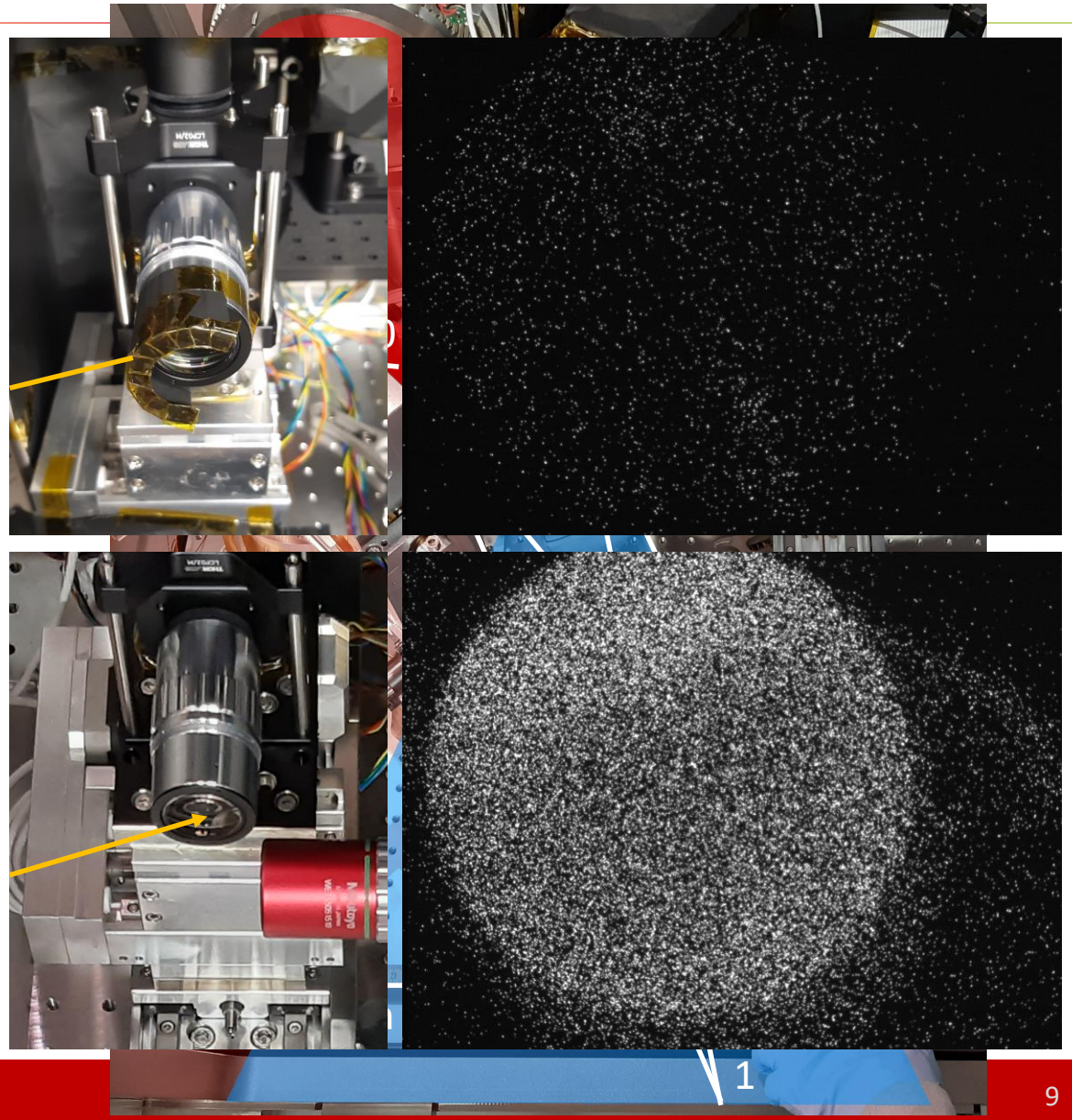
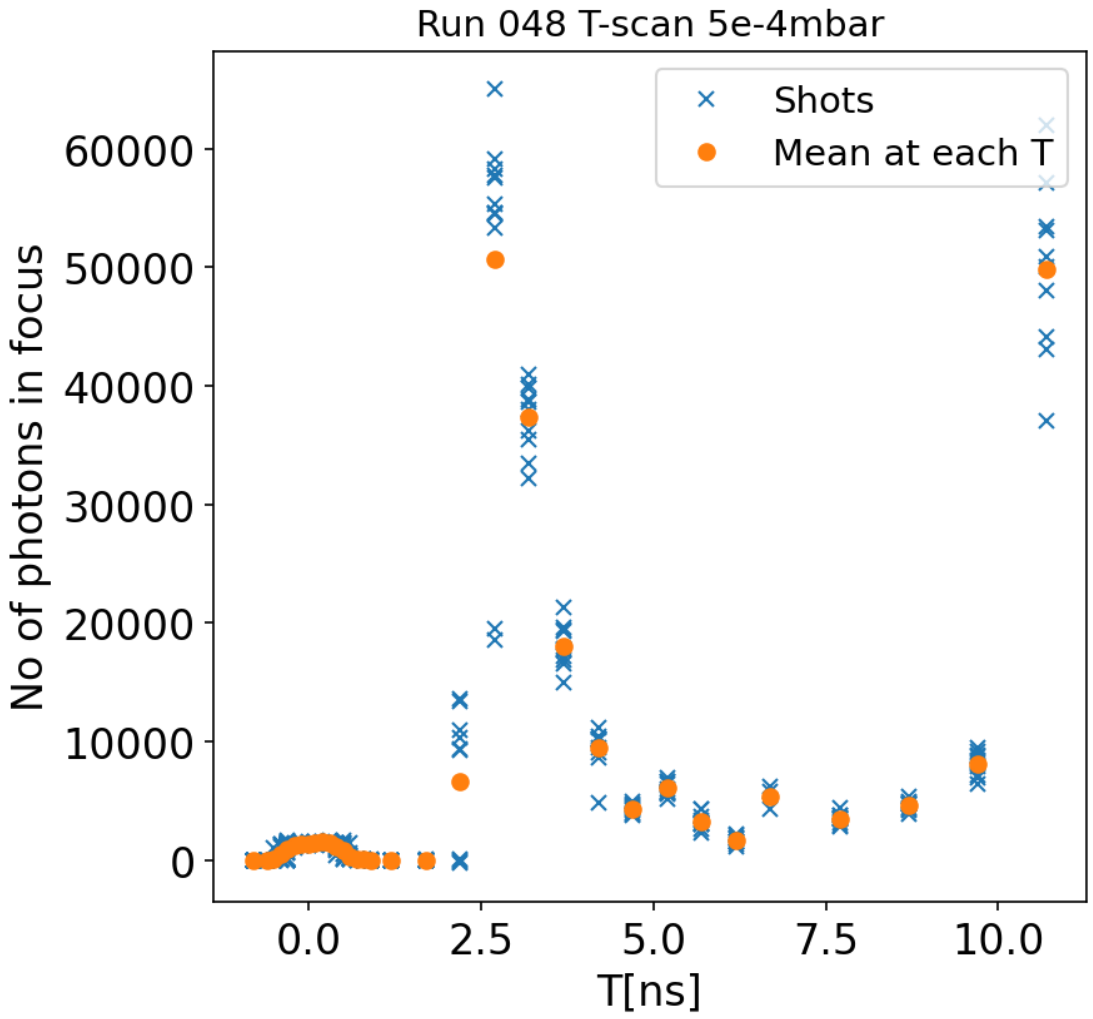
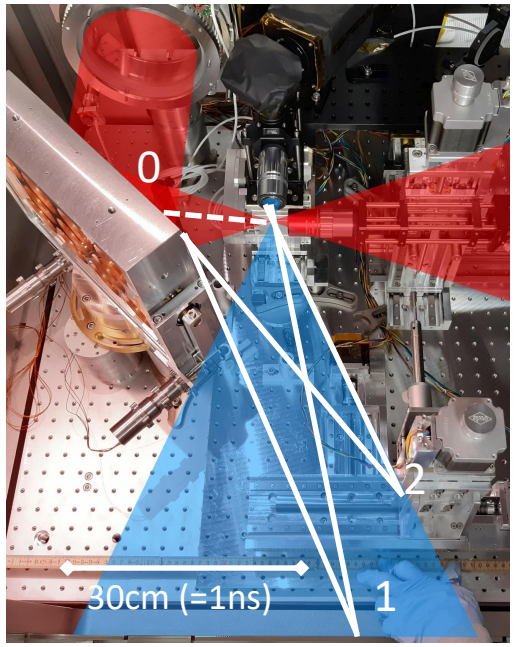
  - Originating from upstream components
  - Lens shade did help!
    - All data shown includes lens shade



Source of background: light ahead of time

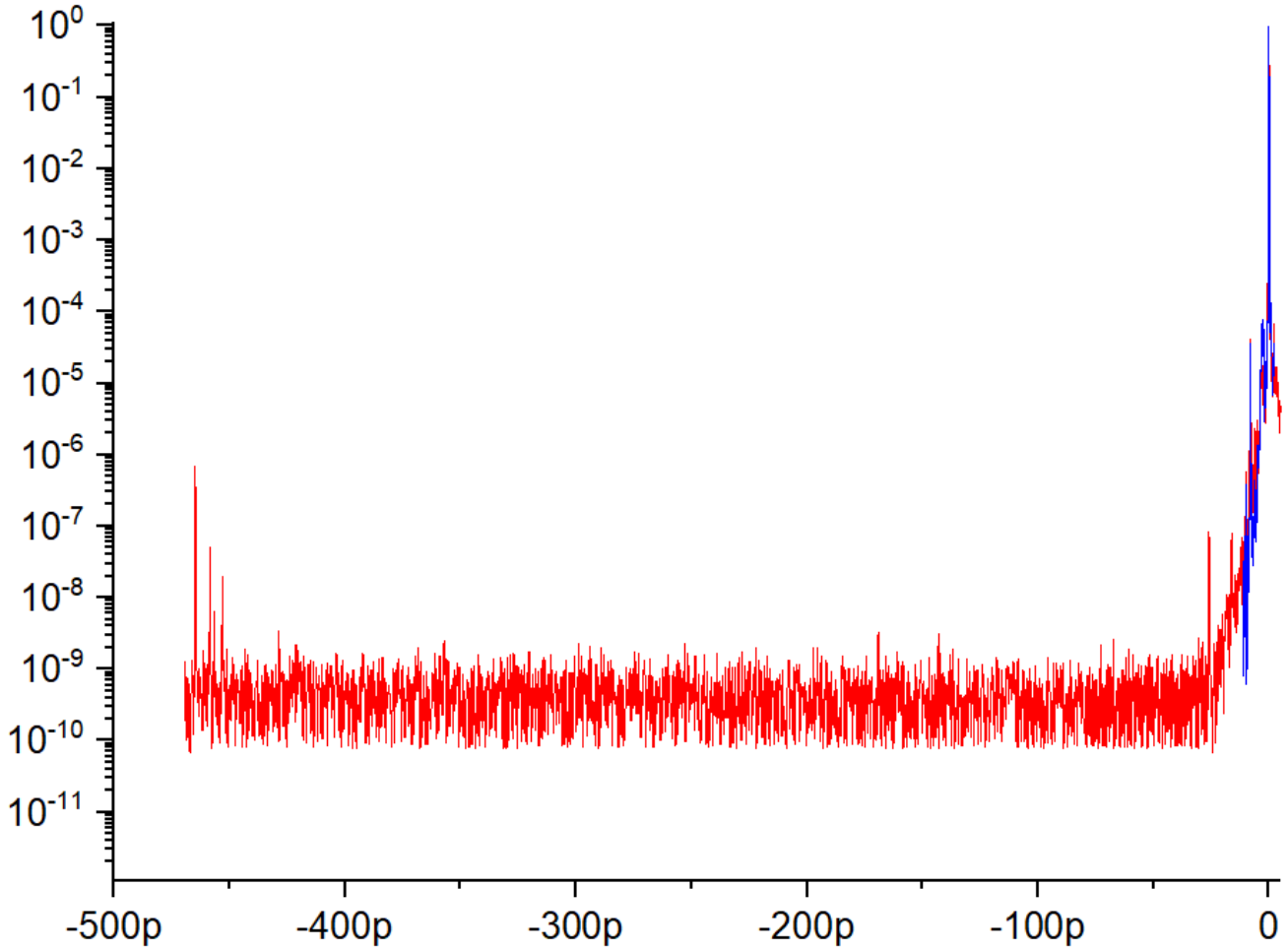




- Light arriving ahead of time?
  - Path 0 ~ 0.5ns
  - Path 1 ~ 4ns
  - Path 2 ~ 3ns
- Estimate collection efficiency
  - $N_{Focus}(2.7ns) = 50669$
  - $N_{Laser} = 7e17$
  - $\eta = \frac{N_{Focus}}{N_{Laser}}$ =7.2e-14

Source of background: light ahead of time

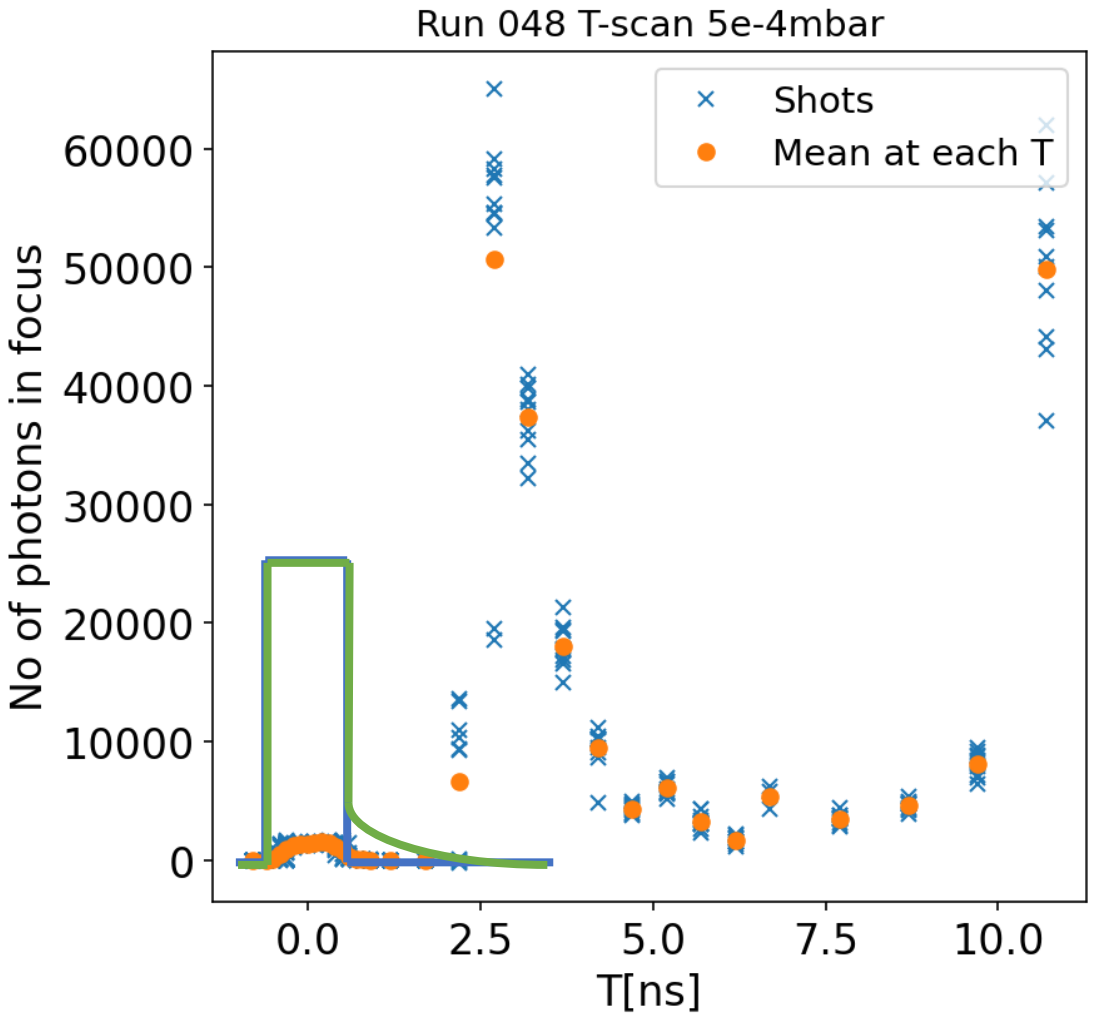
- determine Intensity level at ~3ns earlier
- Amplified spontaneous emission (ASE) on ns scale
- Intensity/Power contrast: 1e-9
  - $P_{peak} = \frac{7e17}{25fs}$
  - $P_{ASE} = \frac{7e8}{25fs} = \frac{2.8e13}{1ns}$
- Collection ratio: 7.2e-14
- → $N_{Focus,ASE} \approx 2$



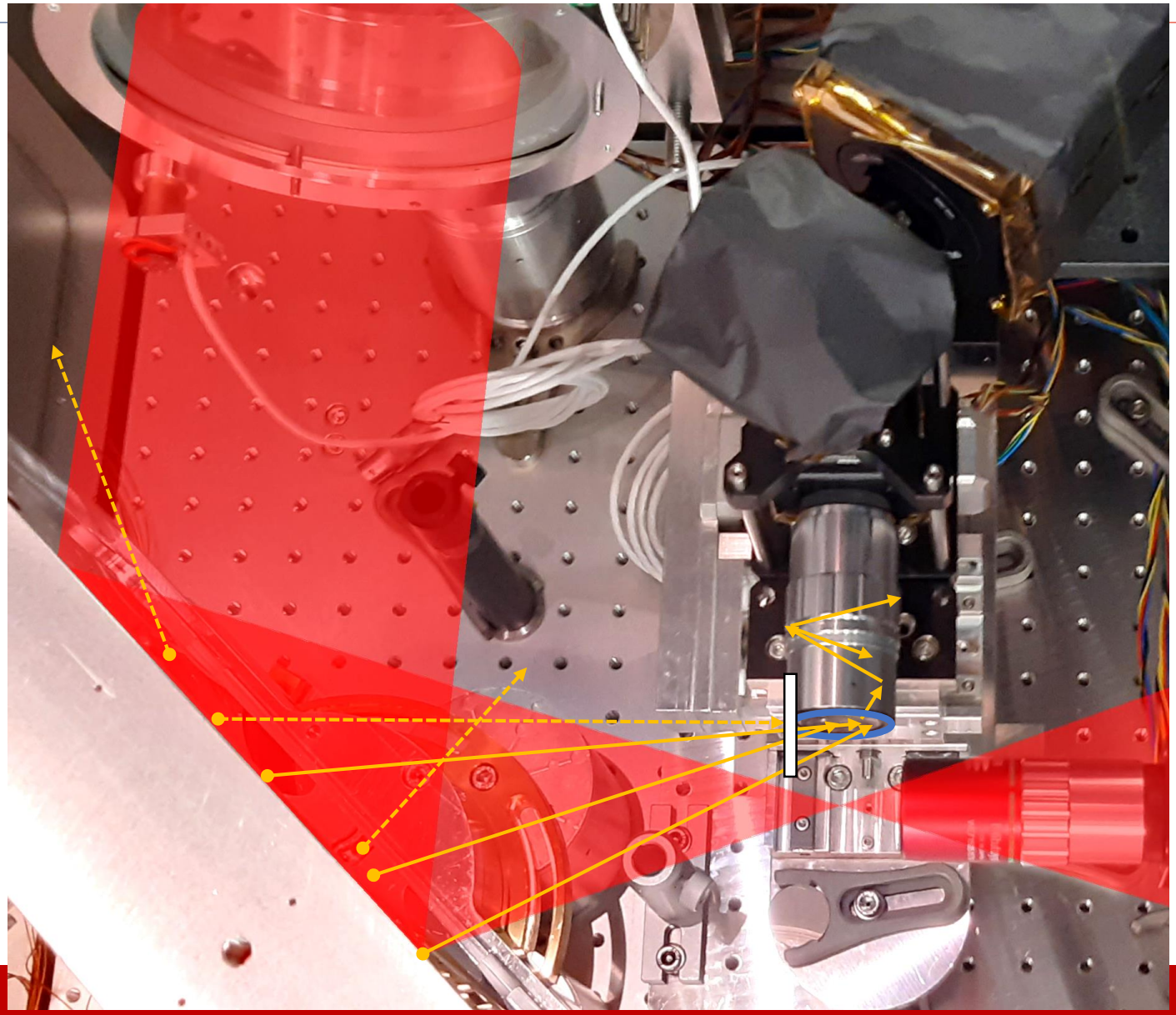
Source of background: time gating limited

- — Ideal gating window
- — finite gating ratio
- $N_{Focus}(2.7ns) = 50669$
- $N_{Focus}(1.2ns) = 7.4$
- $C = \frac{7.4}{50669} = 1.4e-4$

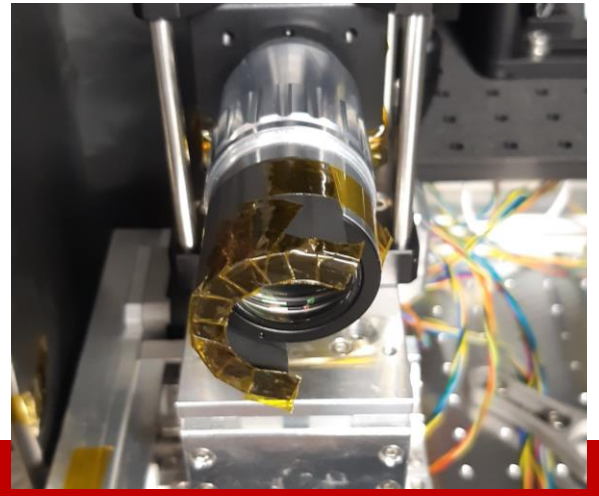
- Worst case:
- → $N_{Focus,GatingLimit} \approx 7$
- (Real gating contrast probably better)



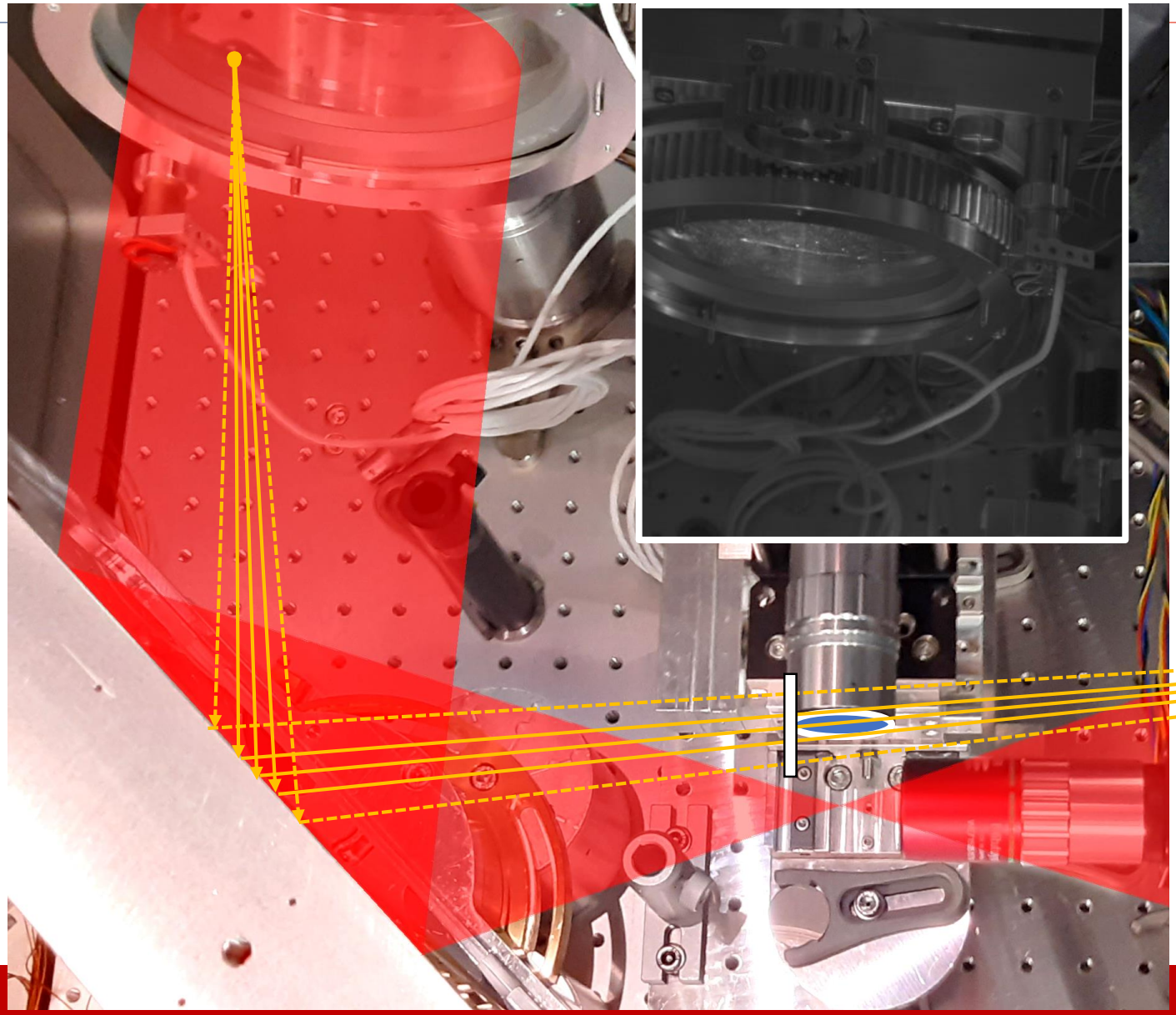
Source of background: scatter from OAP



- Imperfect surface → scattering
- Rays from ~half of OAP can enter microscope objective
- Lens shade can theoretically reduce to 0



Source of background: scatter from upstream optic



- Imperfect surface → scattering
- Real image behind OAP
- Construct rays → some will intersect objective aperture
- Lens shade can theoretically reduce to 0

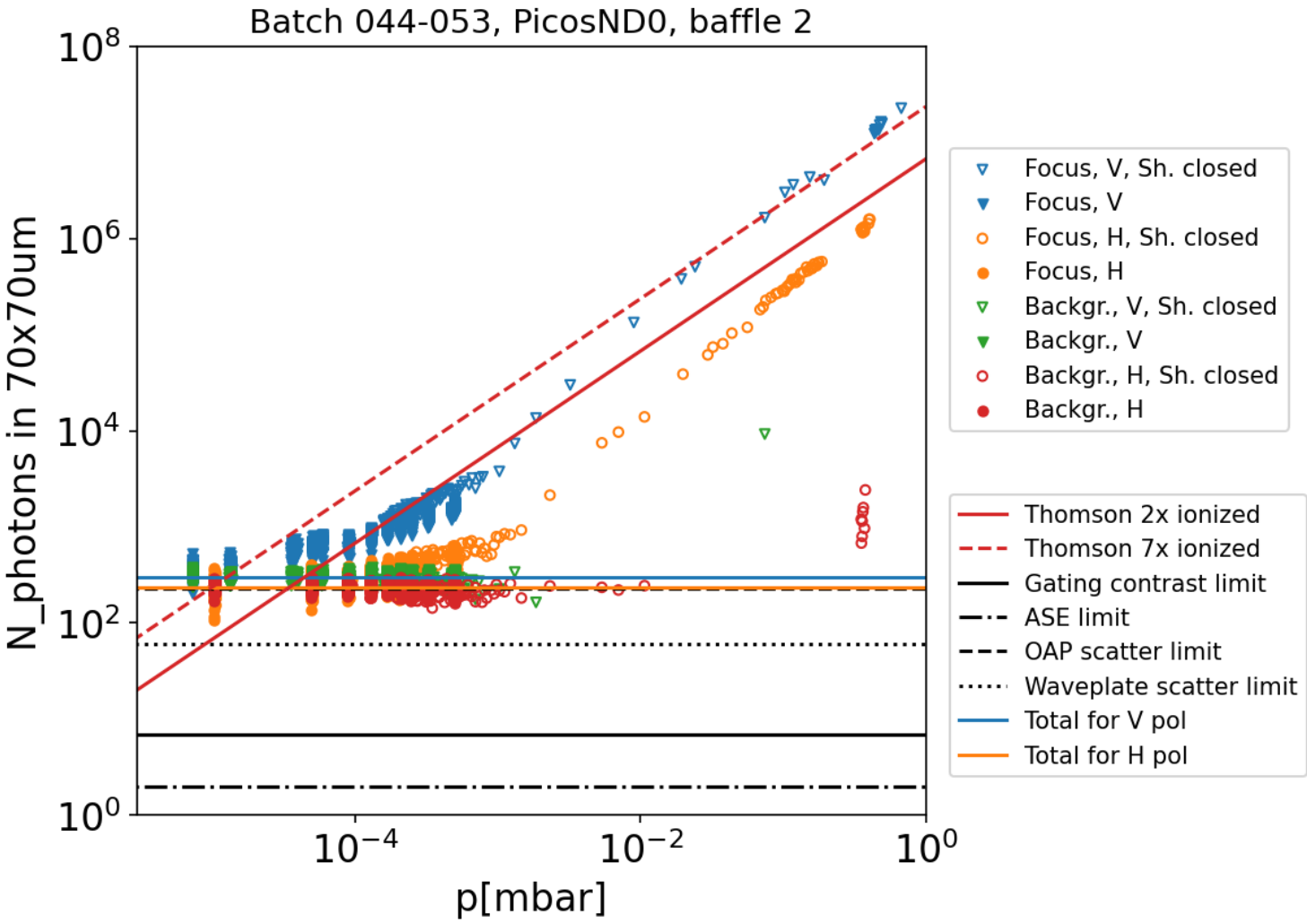
- Final 2 contributions indistinguishible

All background contributions

Contribution	H polarization	V polarization
ASE	2	2
Gating limit	7	7
Waveplate	0	60 (?)
OAP	228	230 (?)
Total	**237**	**299**

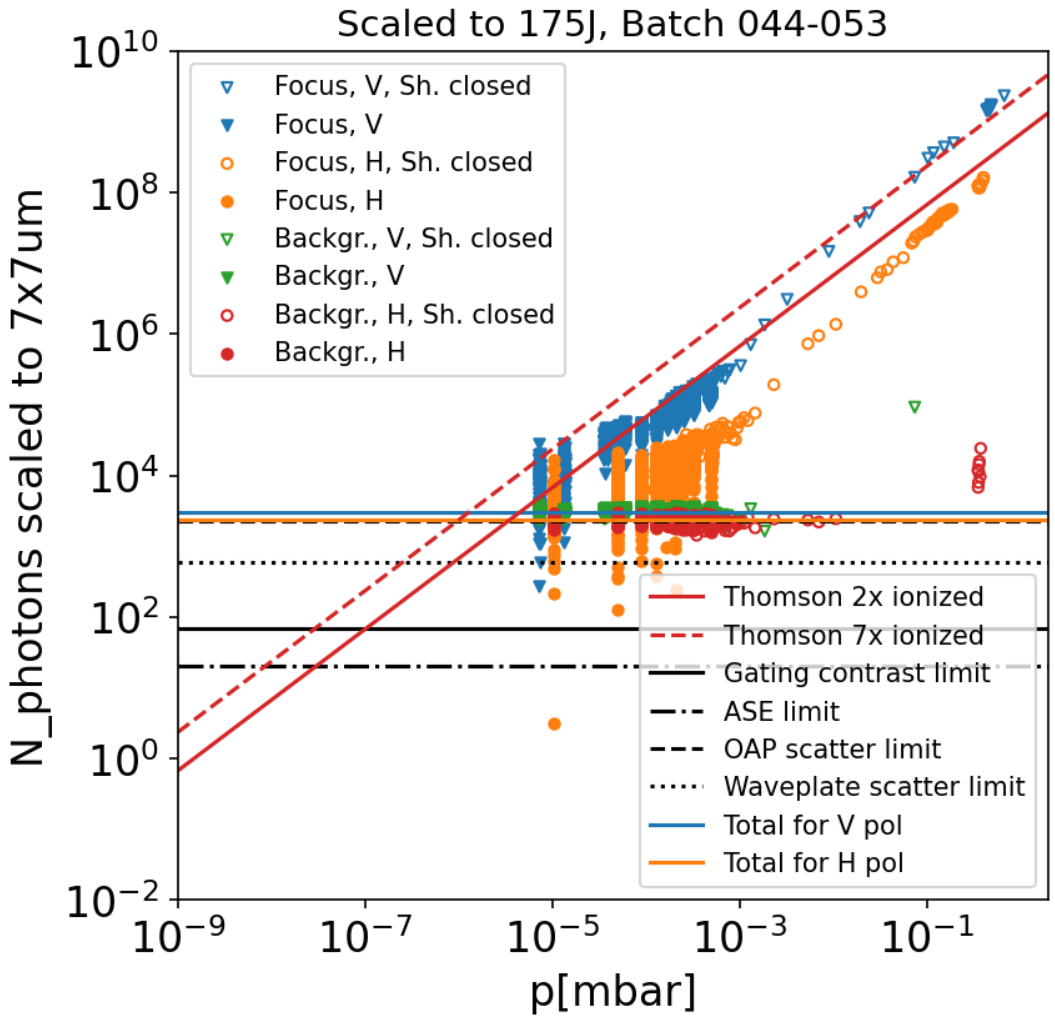
- → for now, most important is OAP + upstream scatter

- Rest gas contribution
  - High pressure (air, N2): fits
  - Low pressure (He): overestimates?
  - Intermediate: to be determined



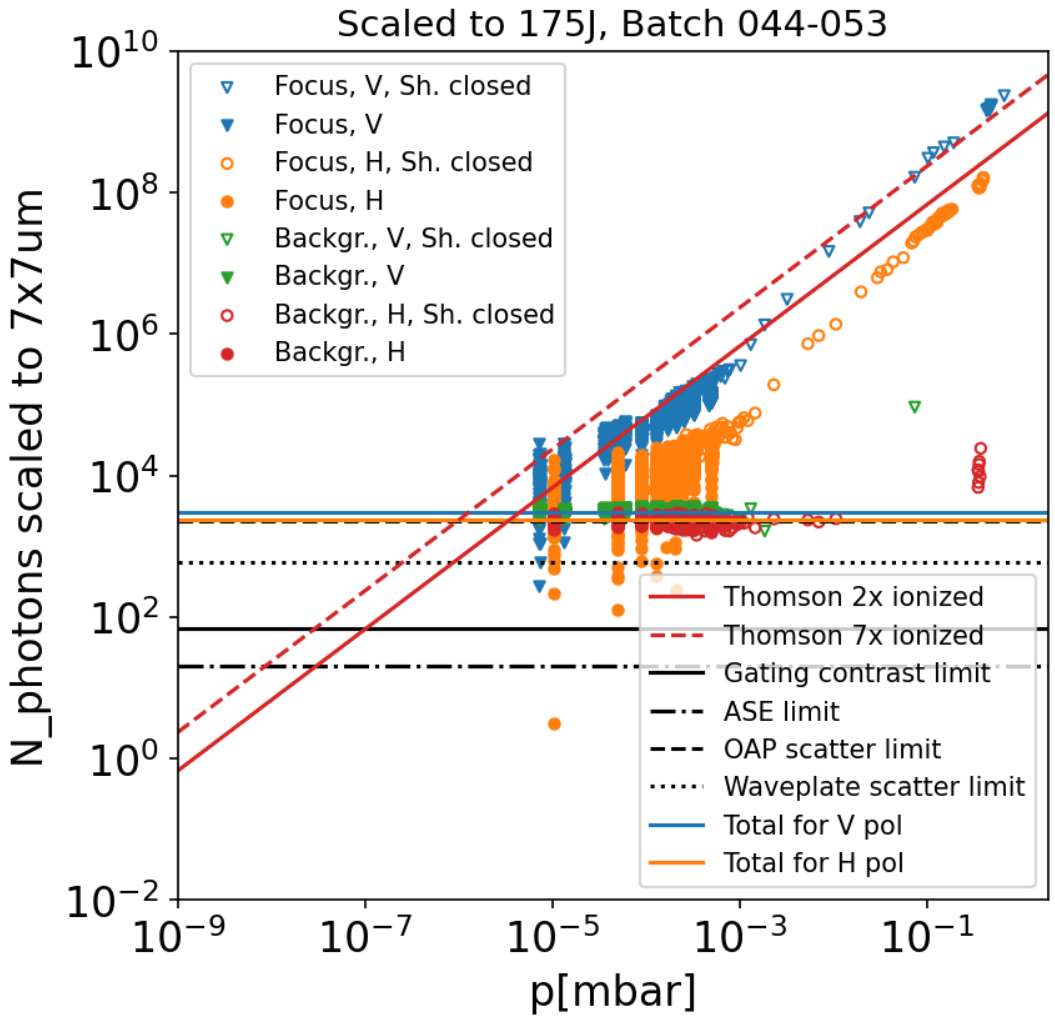
Towards multi-beam Petawatt experiments

- For realistic numbers:
- Scale from 175mJ to 175J
- Reduce 70x70um box to 7x7um
  - Background drops 100x
  - Rest gas in focus needs correction factor, drops 10x
- → scattering 3 orders of magnitude too high
- → rest gas needs to be < 1e-9mbar (at least locally at focus)



Open physical questions

- Ratio between H and V polarization
  - Theory 88x
  - Measurement ~8x
- Accumulated image
  - Focus not brightest spot
- How will shorter gating affect scatter background?



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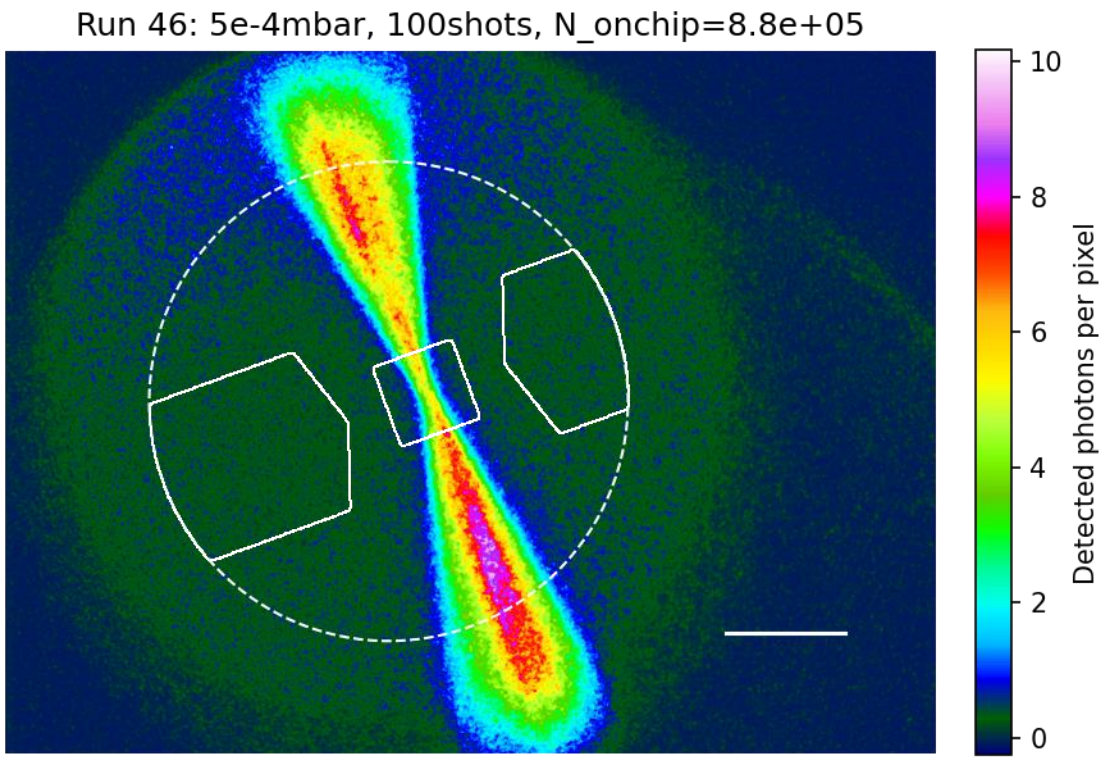


Conclusion

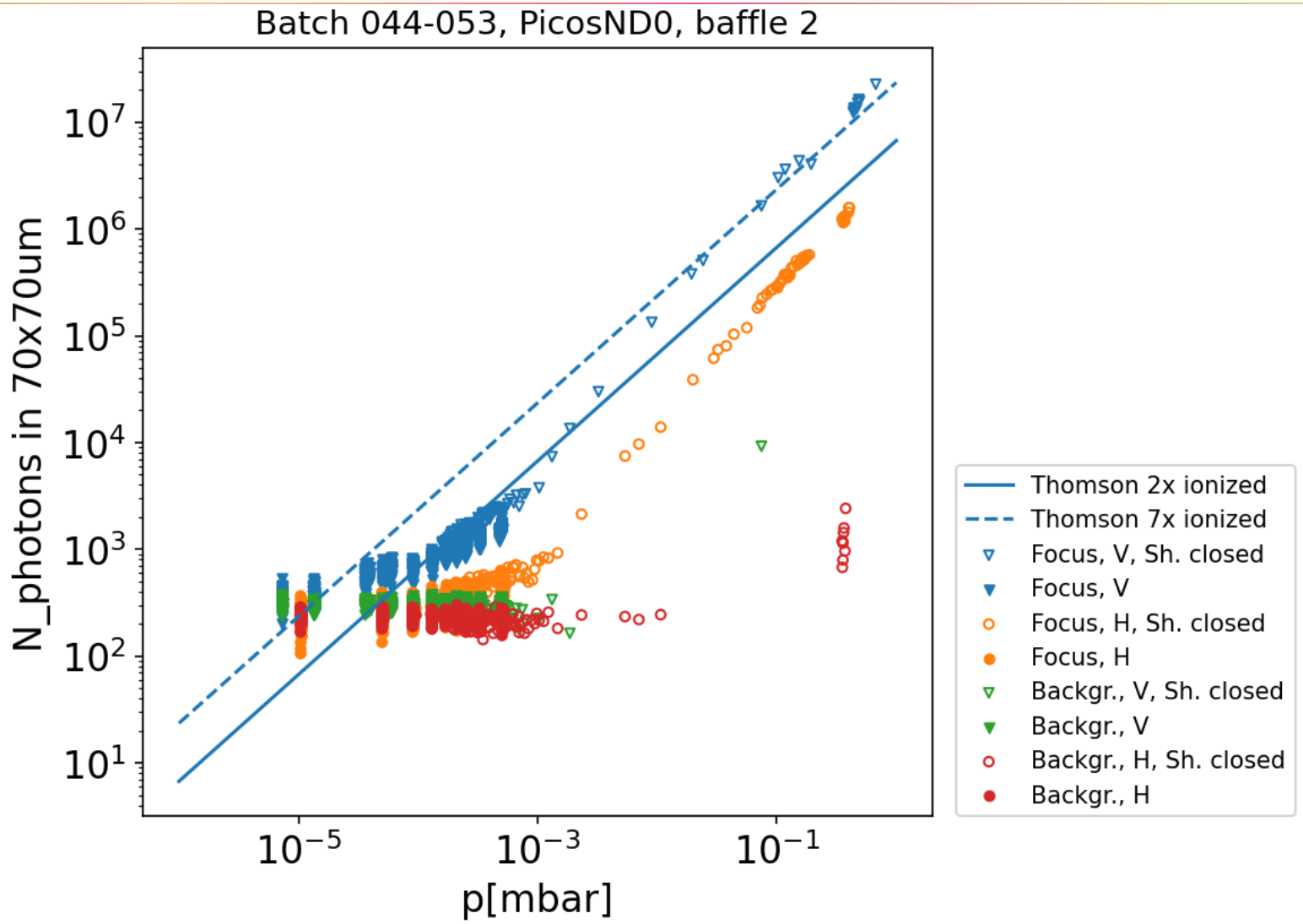
- First measurements of (almost) vacuum laser focus
- Dominant background contribution by geometric scattering into collection optic
  - Estimated 3 orders of magnitude away from feasible photon-photon experiment
- Next steps/ next beamtime
  - Higher power
  - Improve collection optic
  - Change observation angle
  - Higher quality focusing optic

Backup

Thomson model for measured data at 70x70um

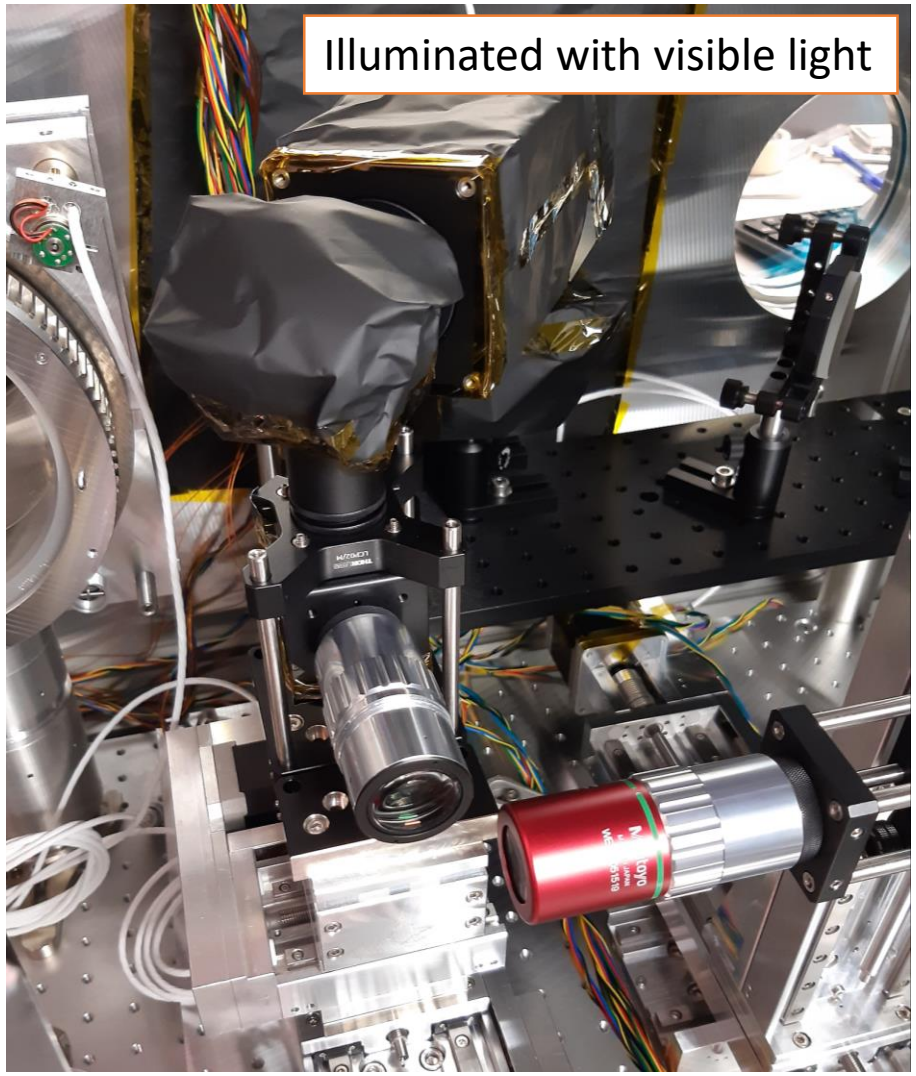
- Assume unpolarized
- Emission in 4pi
- Solid angle of collection given by NA of microscope
- Low pressure: He dominant
- High pressure: N2 dominant

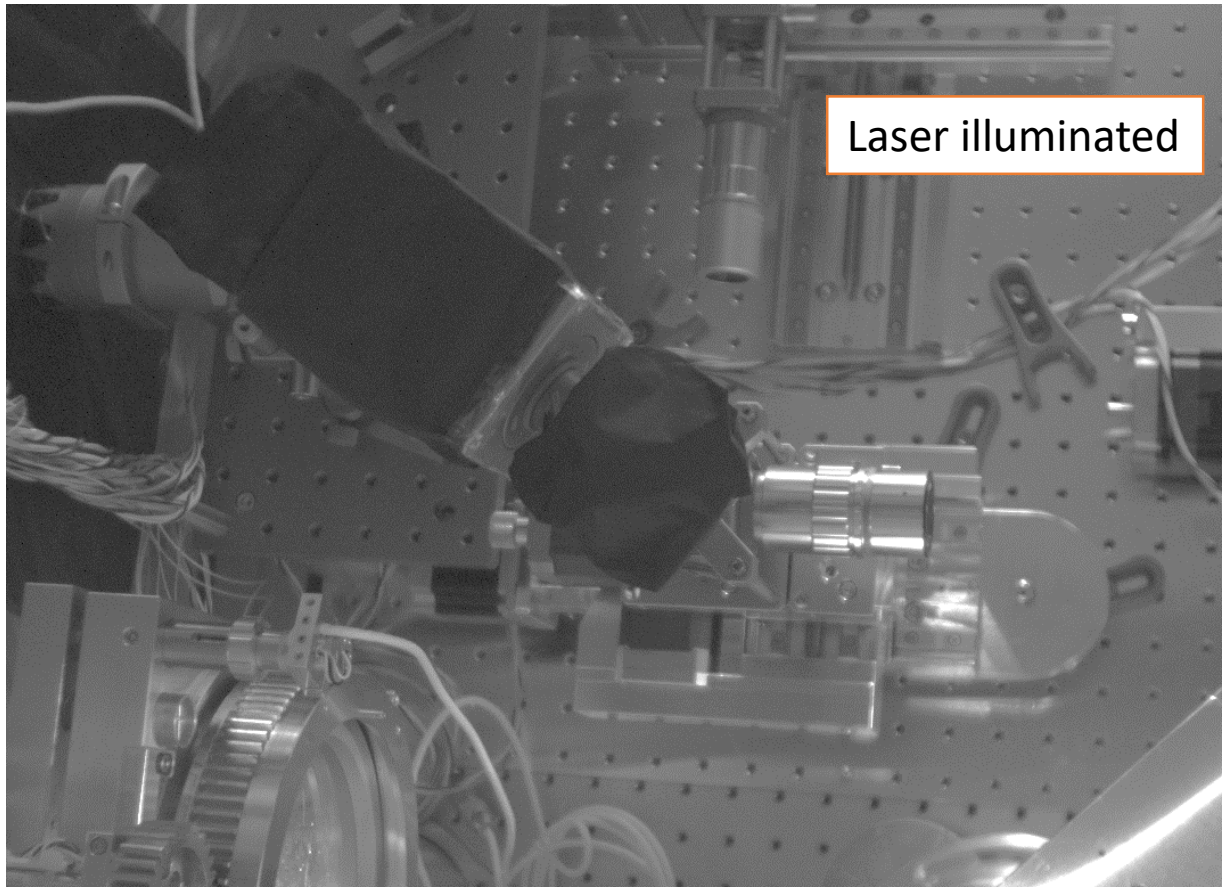
Atom	Level	IP (eV)	I ($\frac{W}{cm^3}$)	a_0
H	1	13.6	$2.2 \cdot 10^{14}$	0.01
He	1	24.6	$1.7 \cdot 10^{15}$	0.03
	2	54.4	$1.0 \cdot 10^{16}$	0.07
N	1	14.5	$2.8 \cdot 10^{14}$	0.01
	2	29.6	$1.2 \cdot 10^{15}$	0.02
	3	47.5	$3.3 \cdot 10^{15}$	0.04
	4	77.5	$1.2 \cdot 10^{16}$	0.08
	5	97.9	$2.0 \cdot 10^{16}$	0.1
	6	552	$1.8 \cdot 10^{18}$	1.8
	7	667	$2.3 \cdot 10^{18}$	2.3



[S. Kuschel Dissertation, p32]
https://www.db-thueringen.de/servlets/MCRFileNodeServlet/dbt_derivate_00040537/Dissertation_Kuschel.pdf

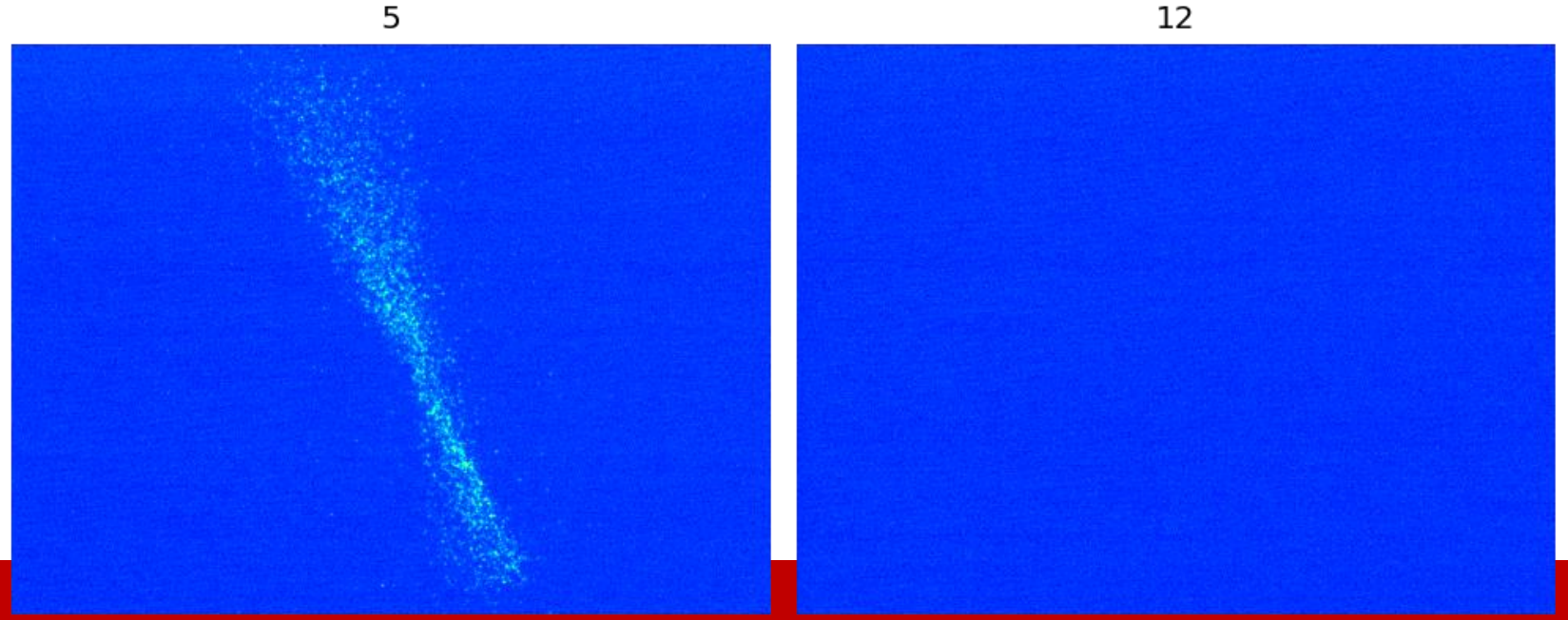
Lesson learnt: Shiny is the new black





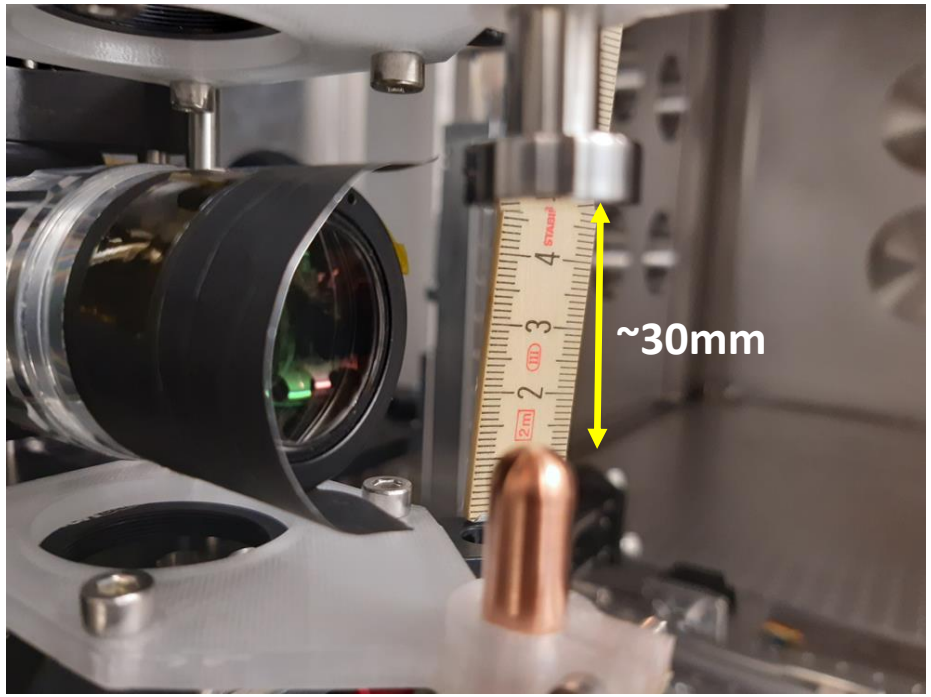
Thorlabs black aluminium foil is black for 800nm light
Thorlabs black tubes etc. are shiny for 800nm light!

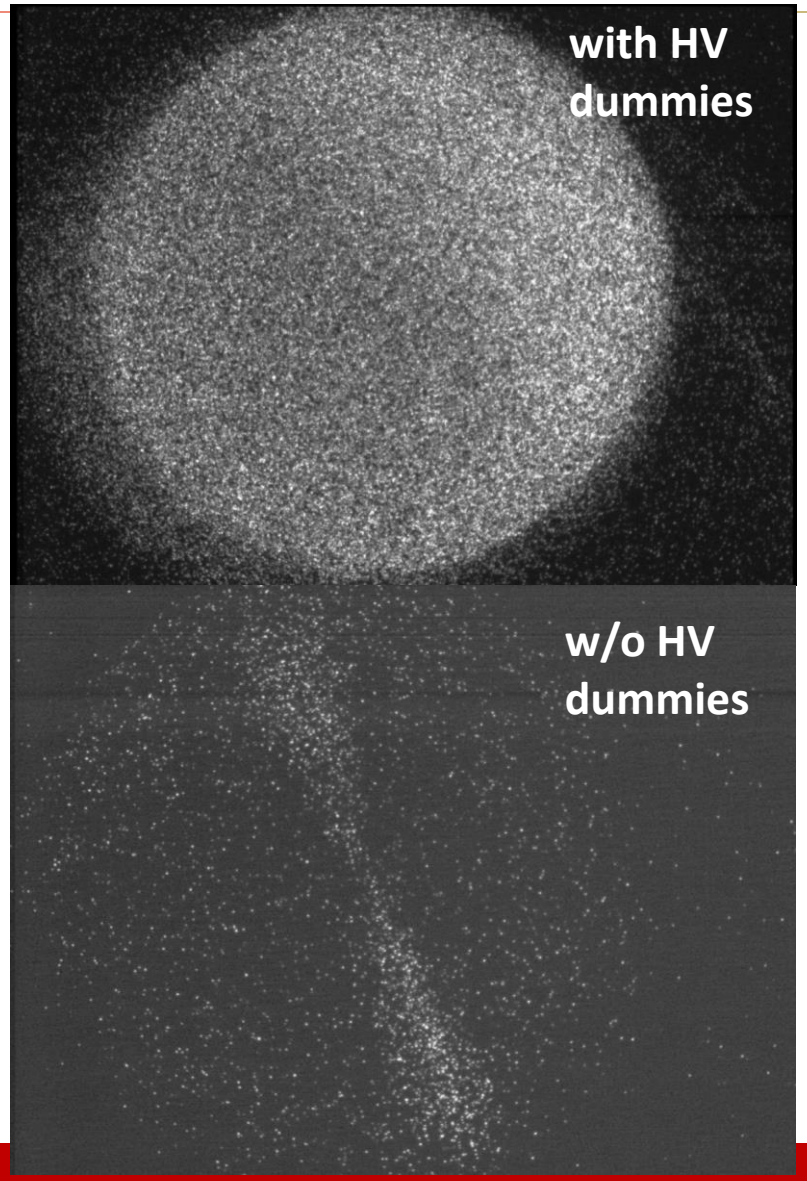
- 25.08.20 – Run 27 (first bowtie)
- High power, ExpShutter closed, 1.14mbar
- ND4 on Picos accidentally
- Shot 5 = 1420V Gain, 1ns, T=157.0ns ==T0
- Shot 12 = identical, + HR mirror before Picos → suppresses 800nm light
- → no second harmonic or other wavelengths detectable



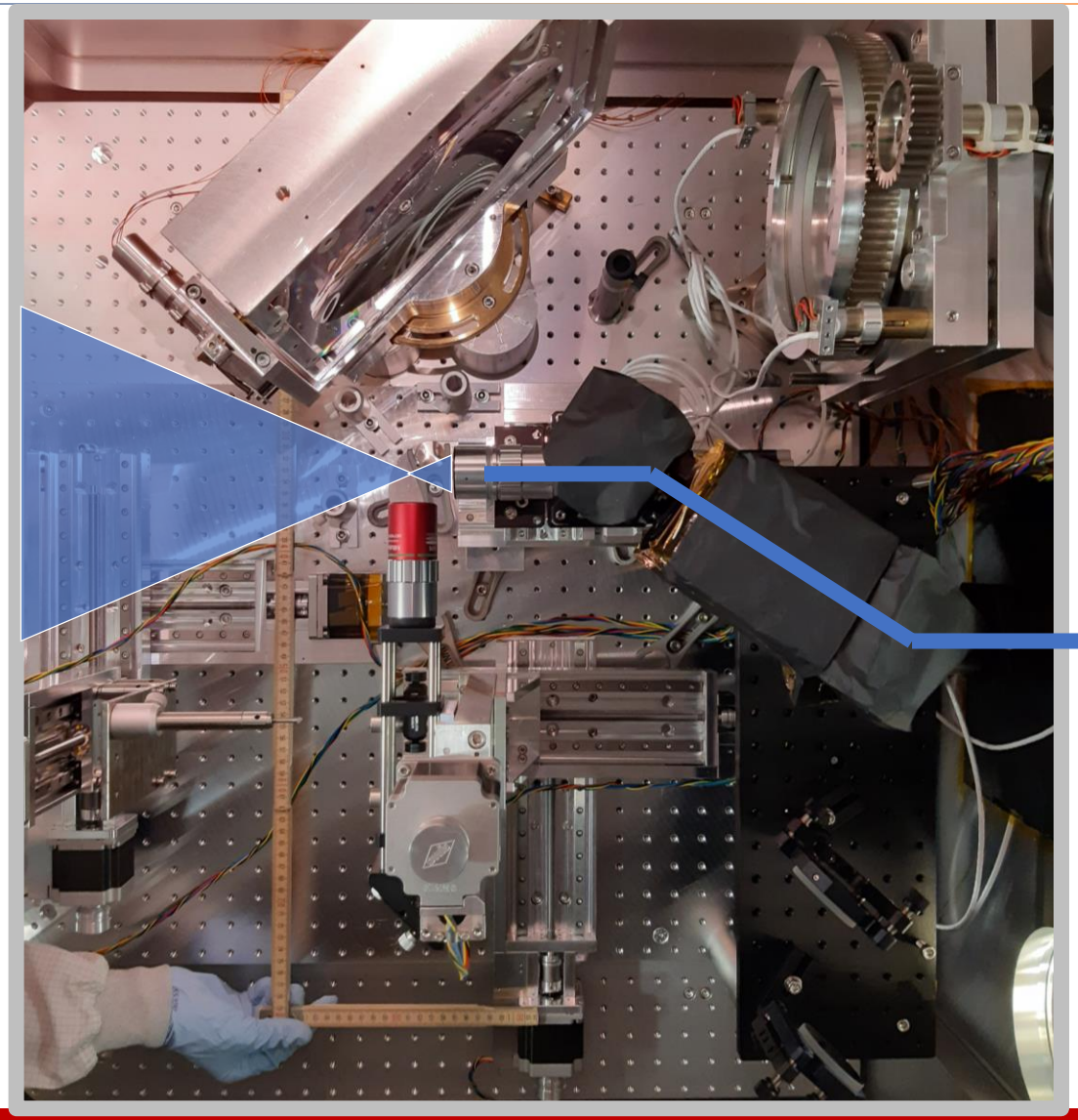
HV dummy – not feasible in this design

„vacuum cleaner“ electrode dummies:
Produce too much scattering, must be moved
Further away

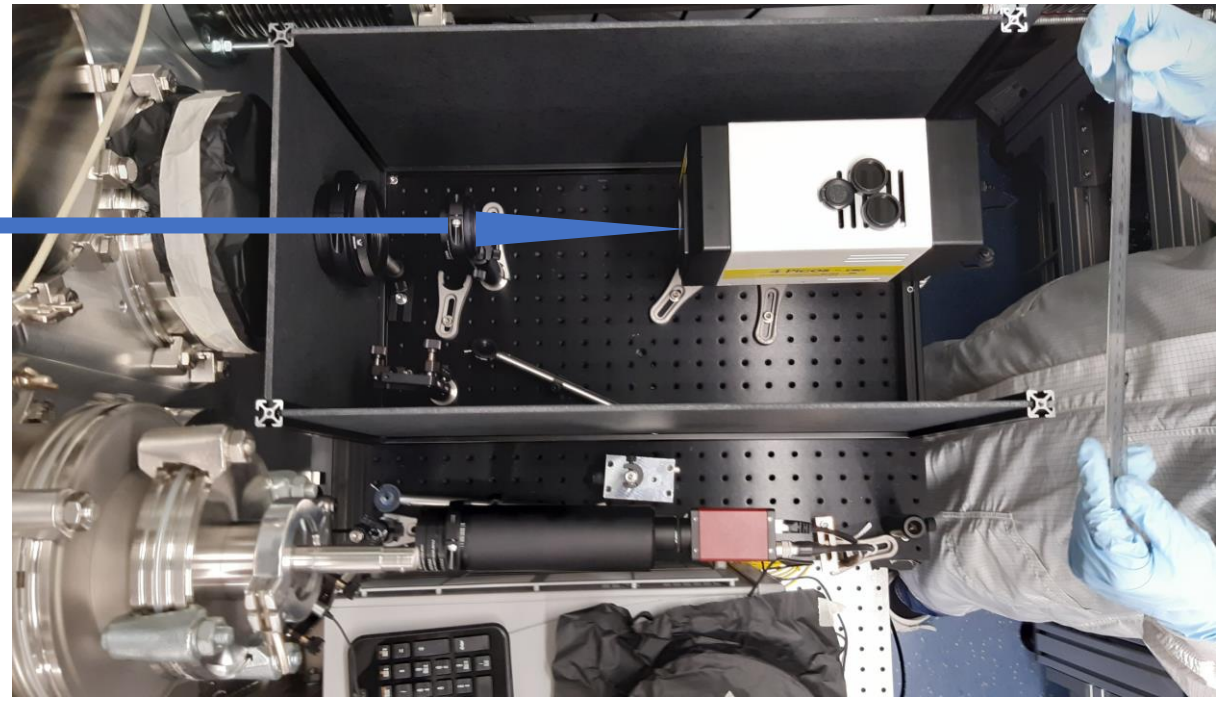




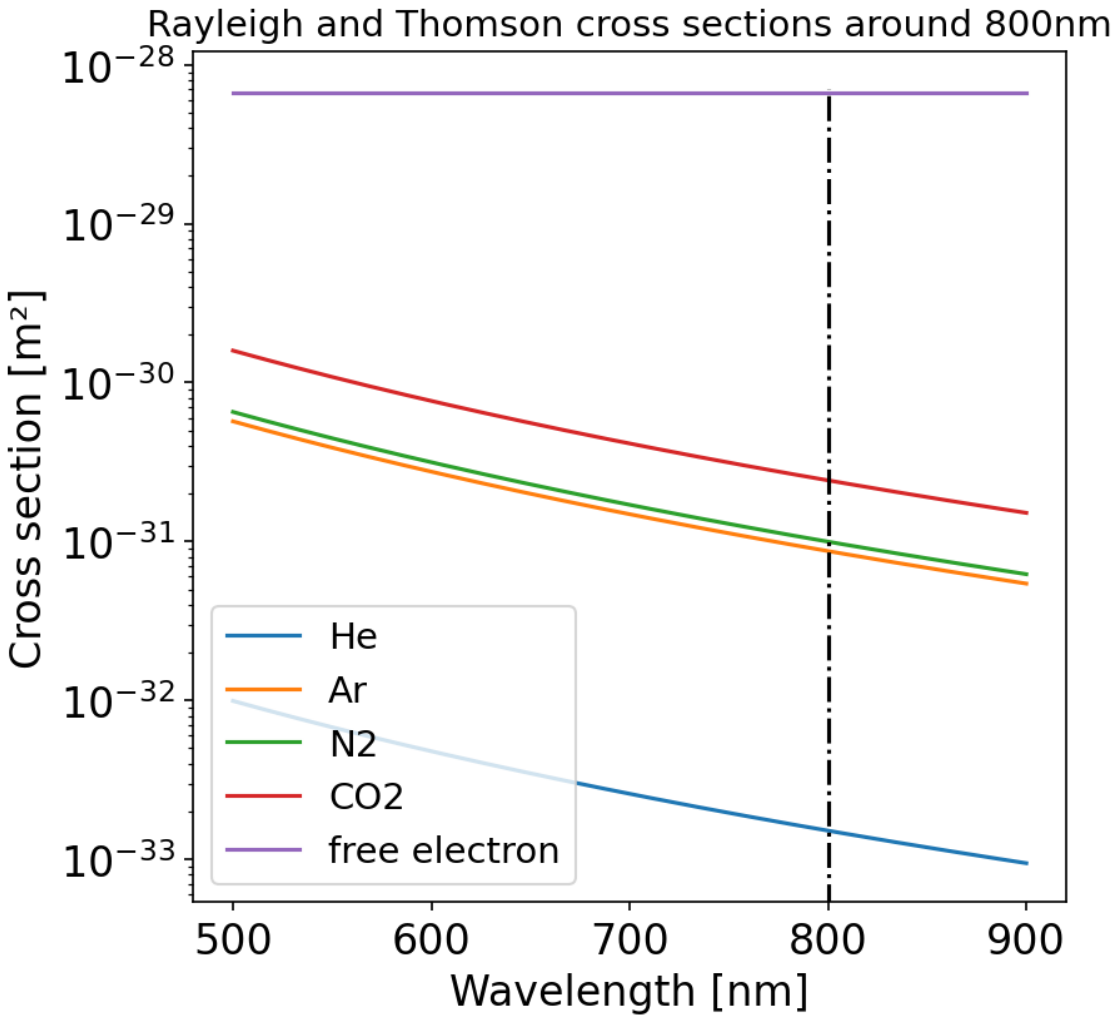
Imaging system



- Light tight imaging path
- 20x magnification
- 4Picos gated camera



Rayleigh and Thomson cross sections around 800nm



- Dipole radiation:
  - Objective NA=0.40
  - H = 1/88 of V signal