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Fielding DIXI - a new x-ray framing camera for the NIF - at JLF

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Summary

- Currently available x-ray framing cameras achieve gate times between 35 – 100 ps

- DIXI (Dilation x-ray imager)
  - is the fastest x-ray framing camera built to date (< 10ps)
  - DIXI achieves a higher temporal resolution by using the time dilation concept
  - scheduled to be installed on NIF at the end of the summer

- Here we present
  - test and calibration measurements of the instrument taken at the COMET laser
  - as well as data from a recent TITAN experiment, where we have taken the first 2D time resolved (~ 7 ps) x-ray images of a target front surface during relativistic laser plasma interactions

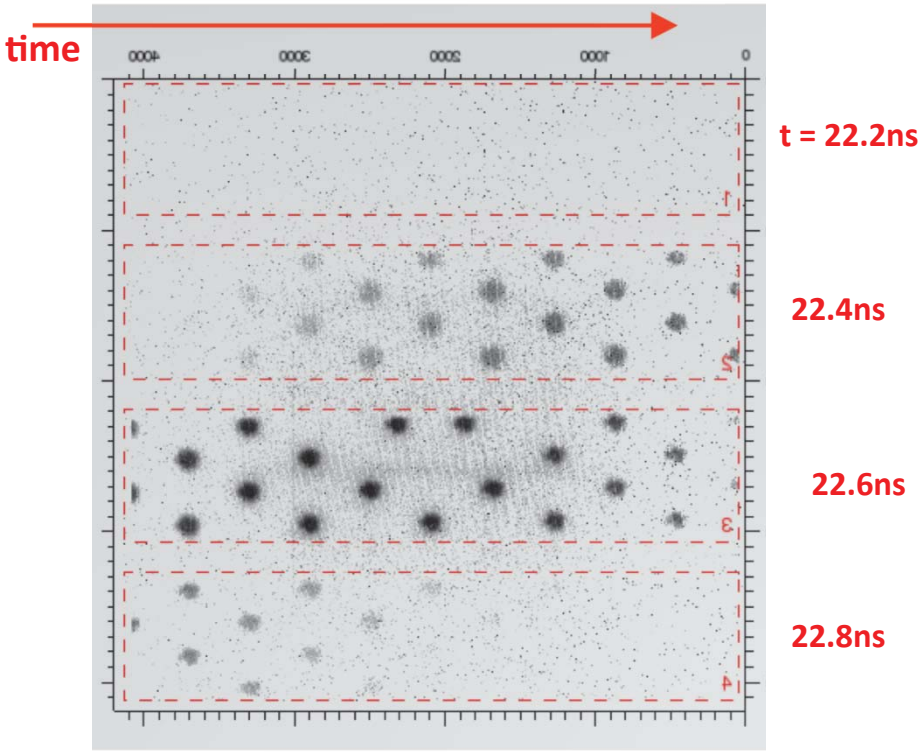
Outline

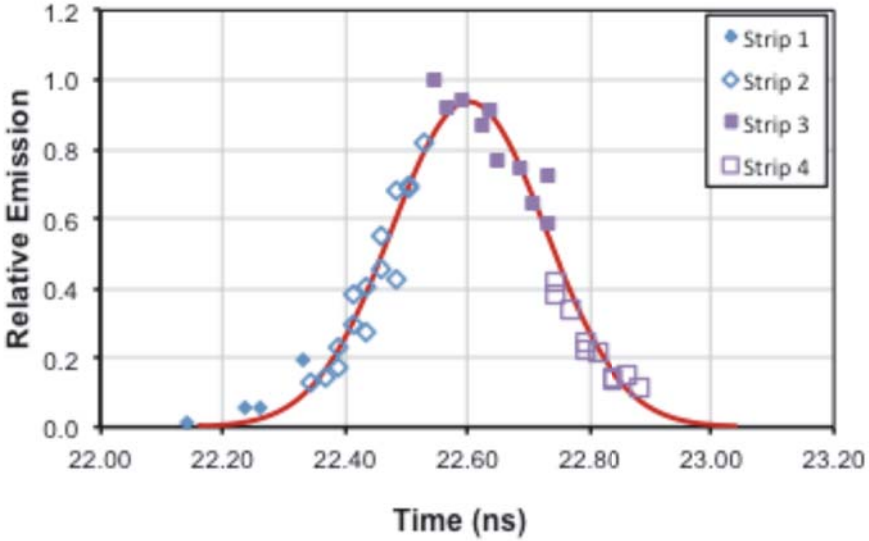
- NIF intended use
- DIXI working principle
- COMET testing
  - Instrument characterization measurements
- TITAN experiment
  - The first 2D time resolved x-ray imaging of a target front surface during relativistic laser plasma interactions
- Summary

- JLF comments – improvement suggestions

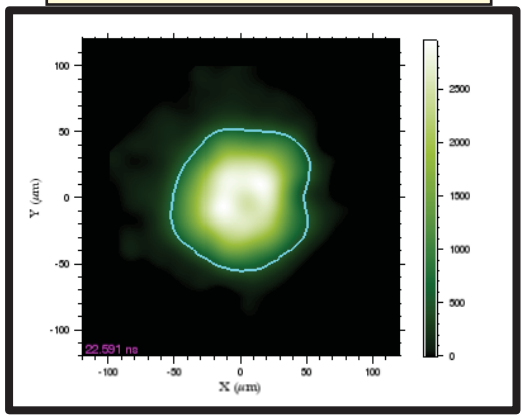
Currently gated imagers are used to show the shape of implosion and measure bang time (peak x-ray emission) on NIF

GXD1 0-0 Corrected Image





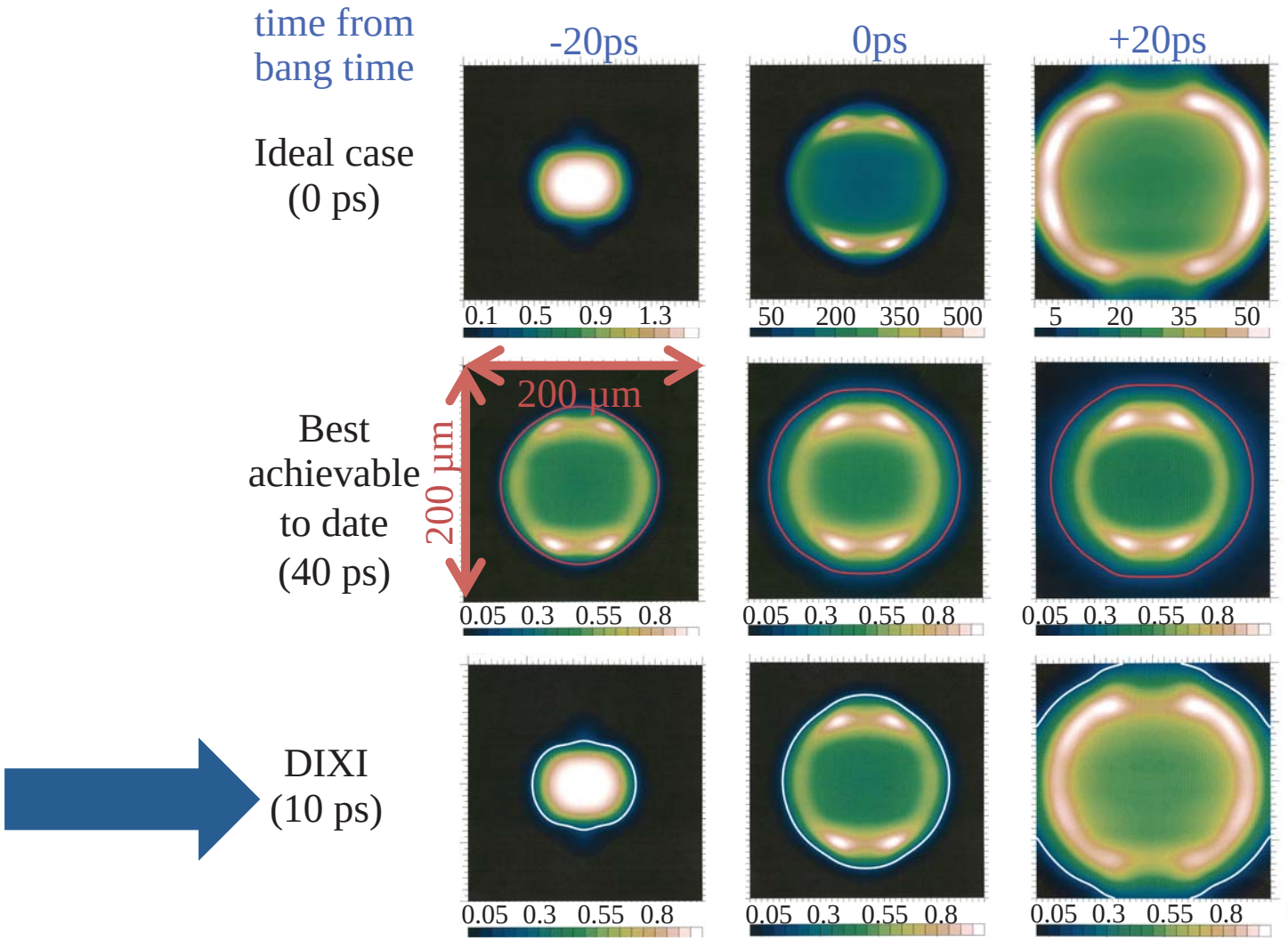
Bang time image



Obviously there are many other applications for framing cameras

N120909-001-999 polar image preliminary analysis courtesy of Robin Benedetti

Model images of an igniting capsule demonstrate need for improved temporal resolution



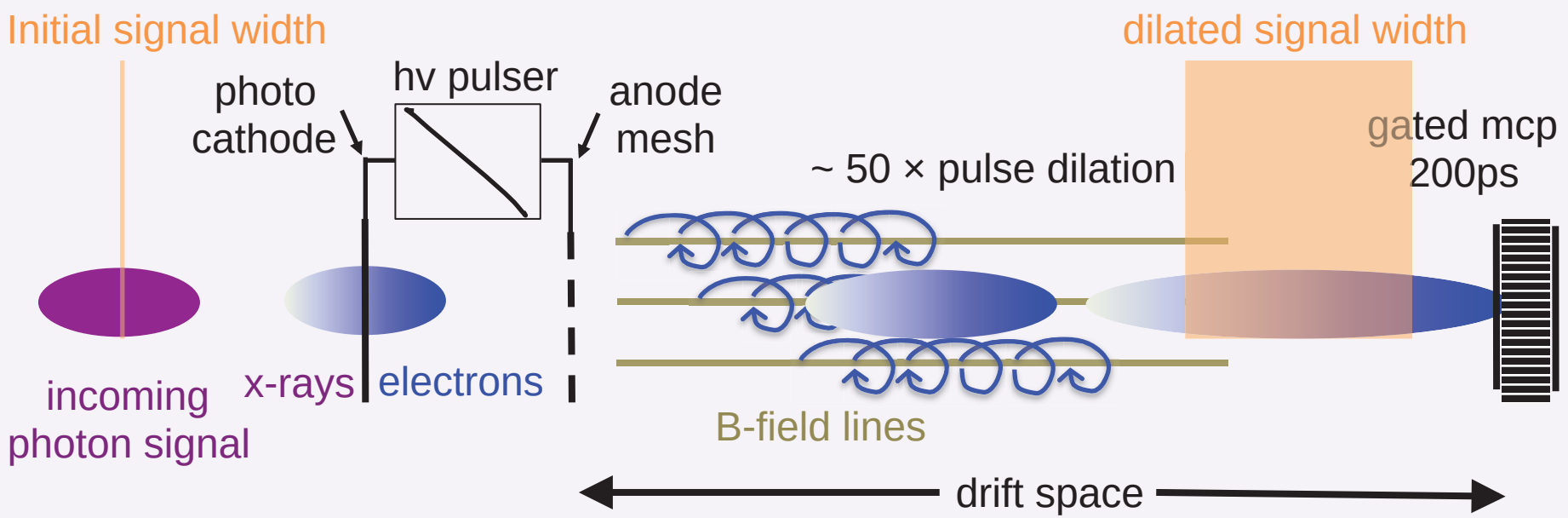
Color scales normalized to peak

Color scales normalized to peak

S. R. Nagel et. al., Rev. of Sci. Instrum., **83**, 10E116 (2012)

Dilation x-ray imager (DIXI) uses pulse-dilation to provide better temporal resolution than currently available

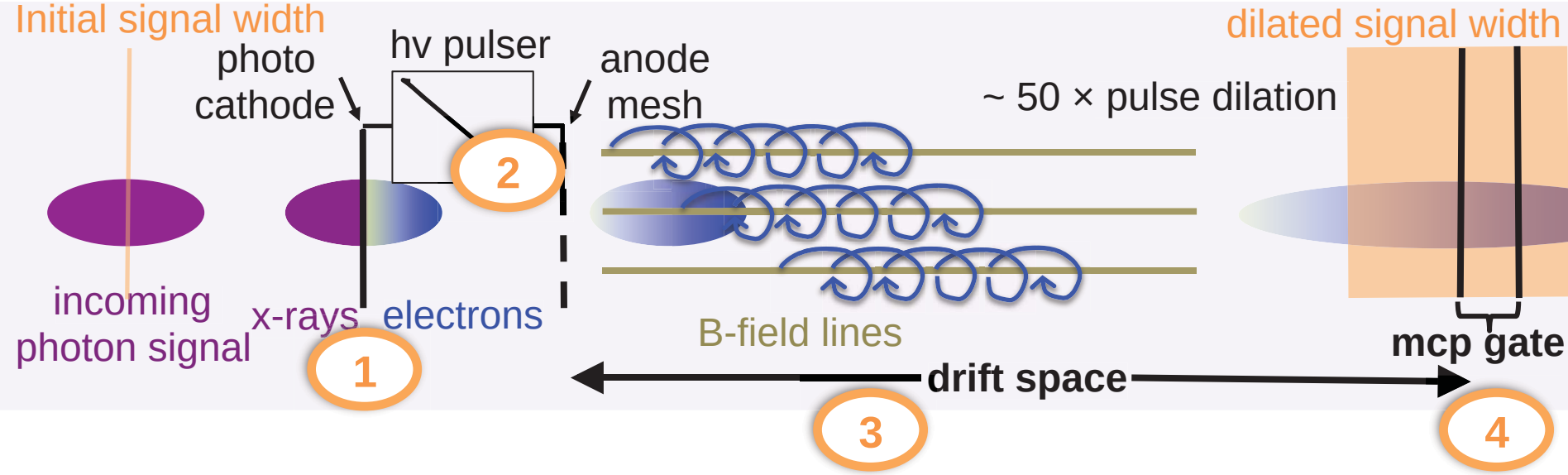
Working principle



Photoelectrons ➔ accelerated by a time varying electric field ➔ energy dispersion ➔ signal stretches as it traverses the drift region ➔ sampled by gated mcp

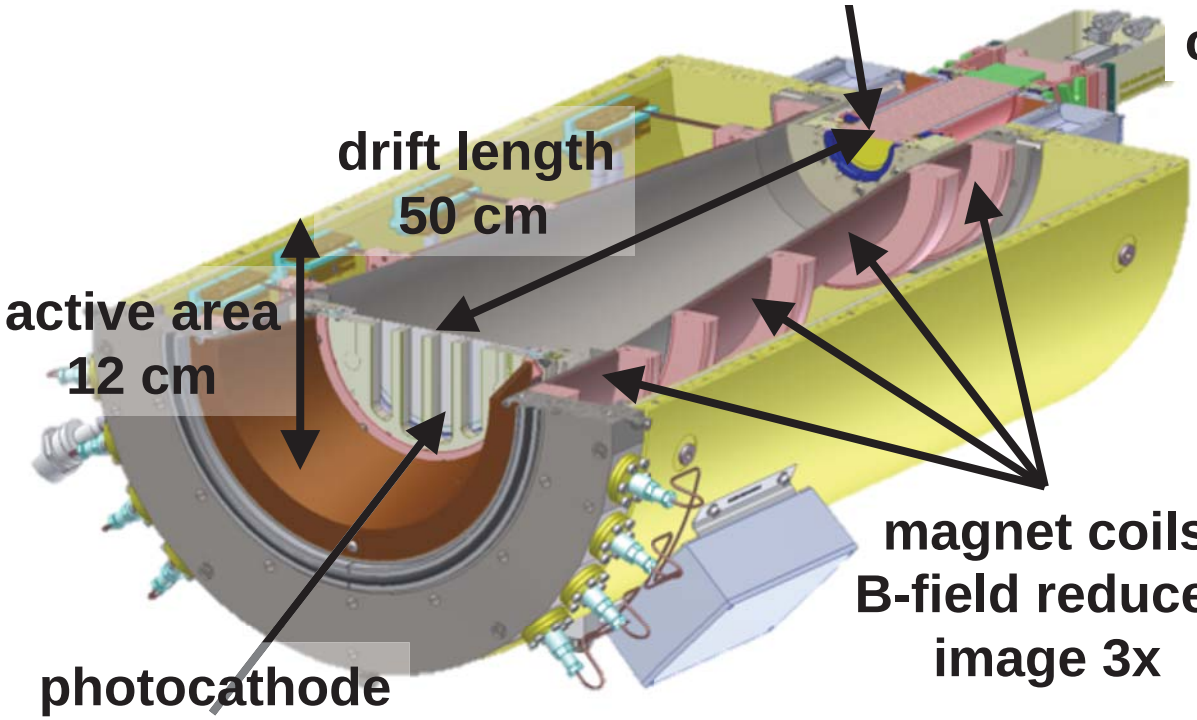
T.J. Hilsabeck *et al.*, Rev. of Sci. Instrum., **81**, 10E317 (2010)
S. R. Nagel *et. al.*, Rev. of Sci. Instrum., **83**, 10E116 (2012)

Four parameters determine the effective shutter speed of DIXI



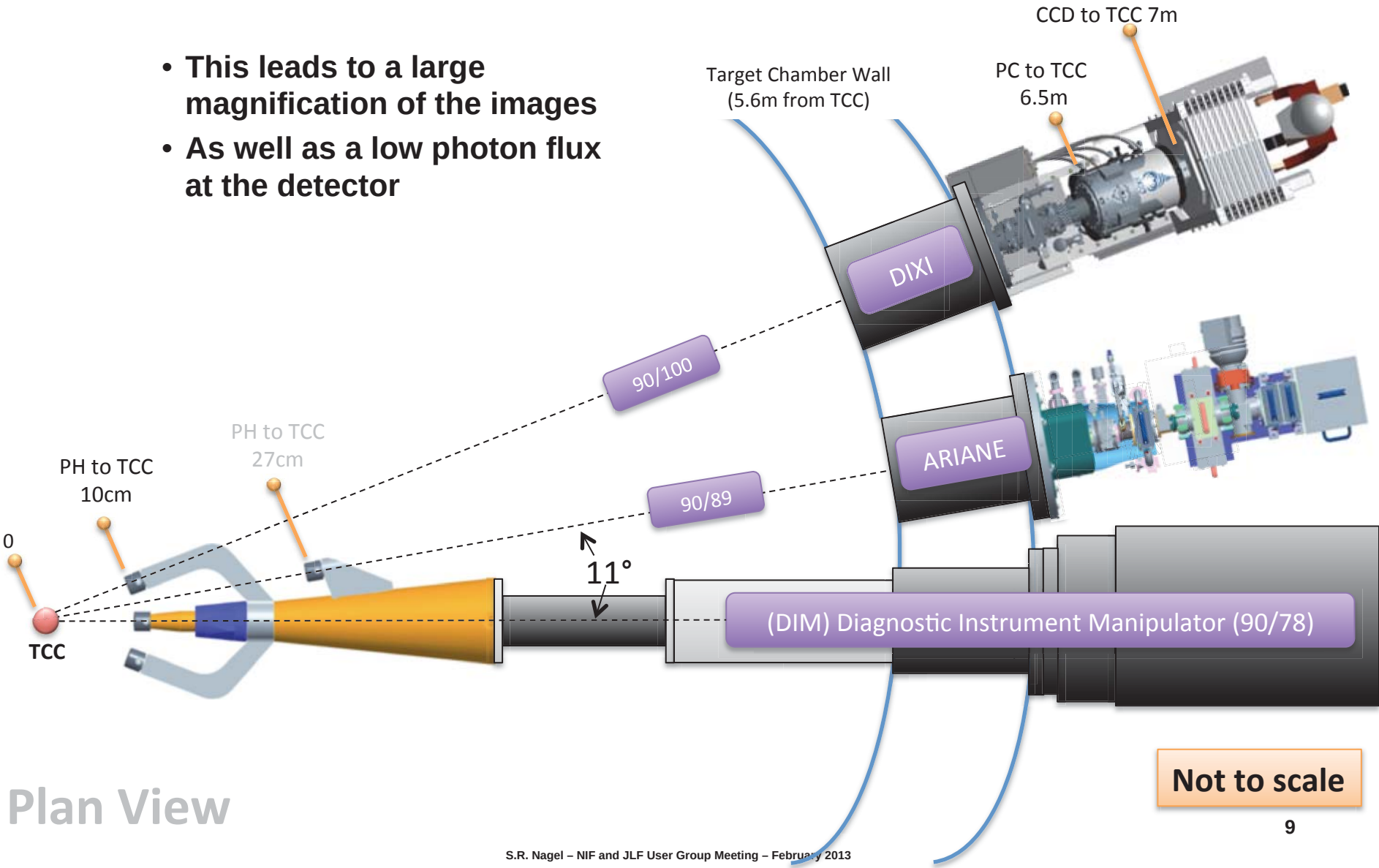
	Parameter	Determines
1.		
2.		
3.		
4.		

DIXI – dilation x-ray imager consists of photocathode, drift space and back end (mcp and phosphor)

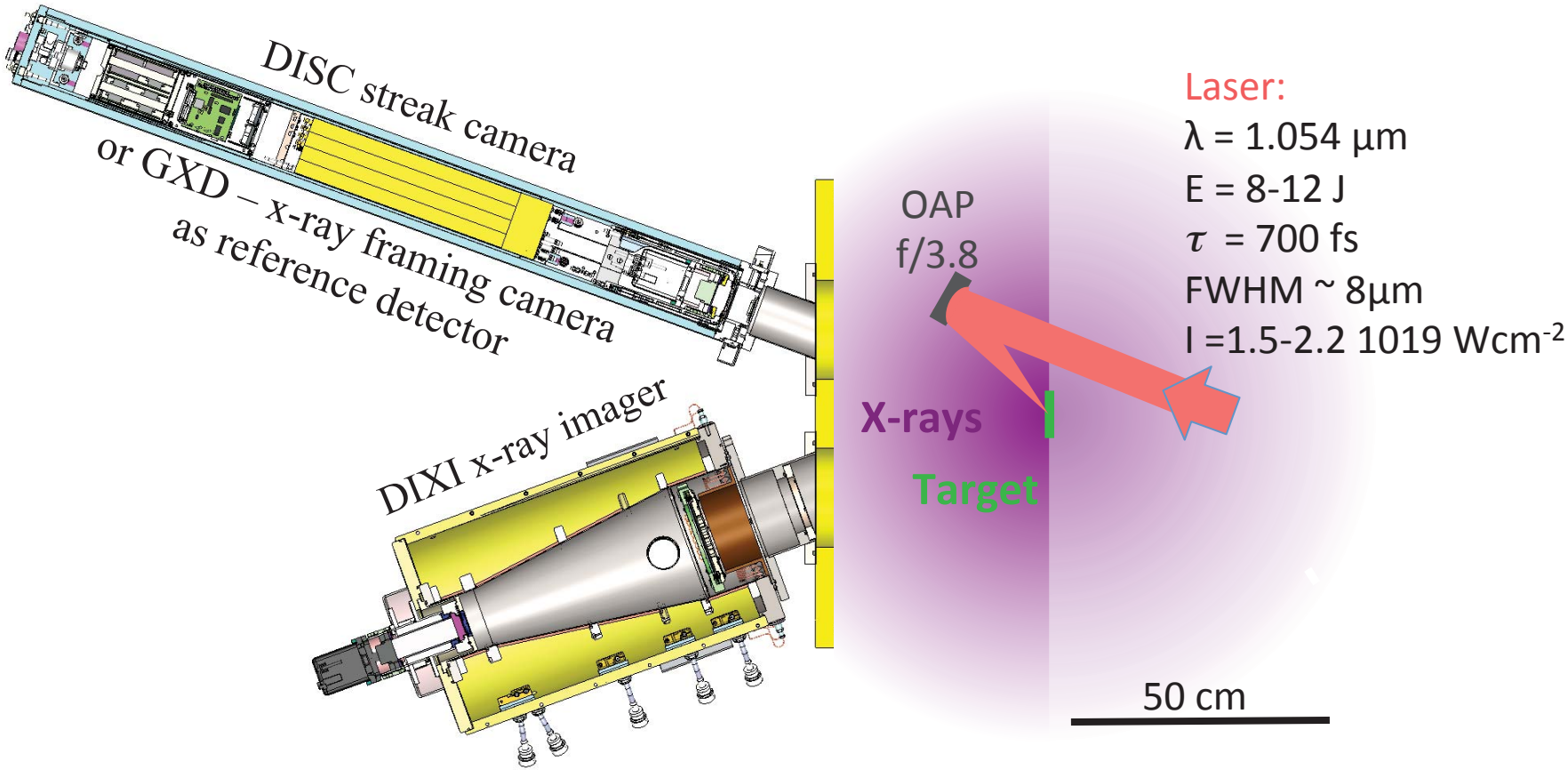


Planned operation on the NIF puts DIXI outside the target chamber

- **This leads to a large magnification of the images**
- **As well as a low photon flux at the detector**

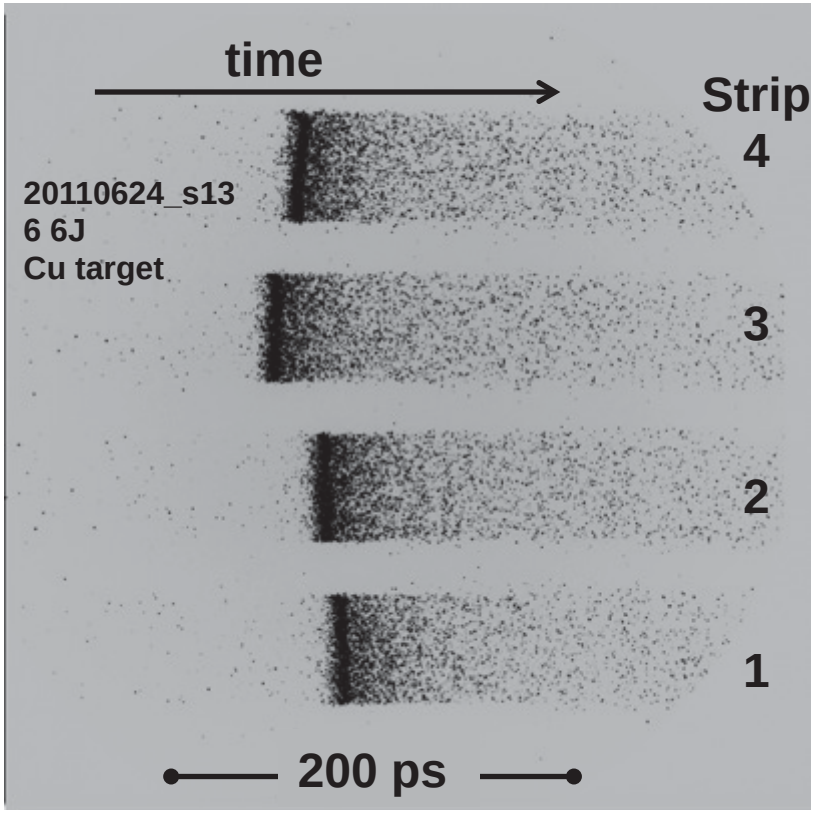


We have tested the DIXI using a short x-ray pulse, which was produced using the COMET laser



- **The x-ray source had an unobstructed path to the instruments.**
- **Strips were co-timed**

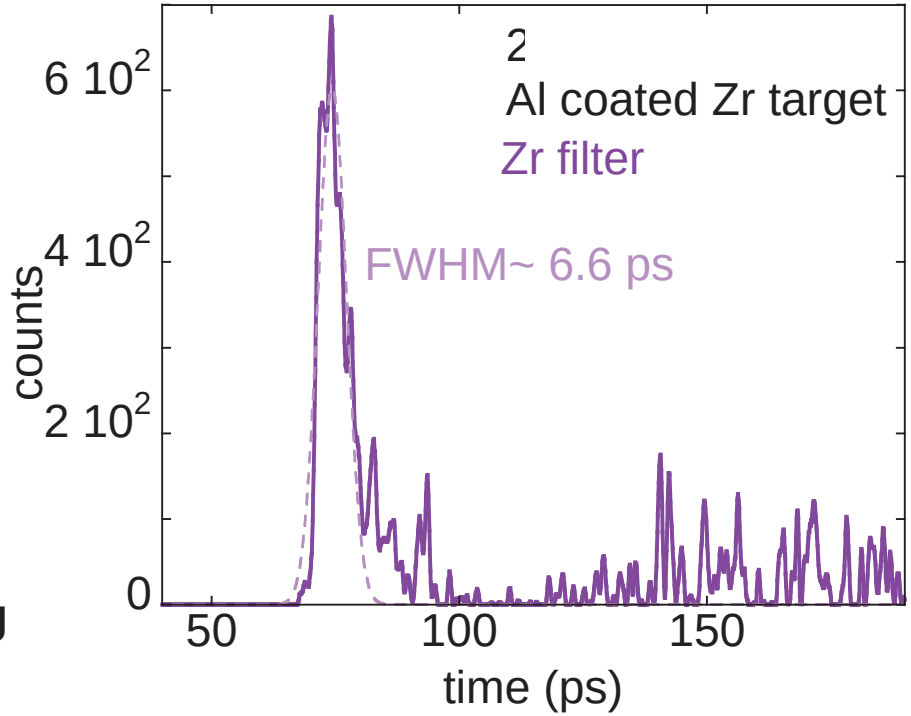
We demonstrated a temporal resolution of <10 ps



Raw data image - no pinhole imaging

Data taken without imaging x-rays

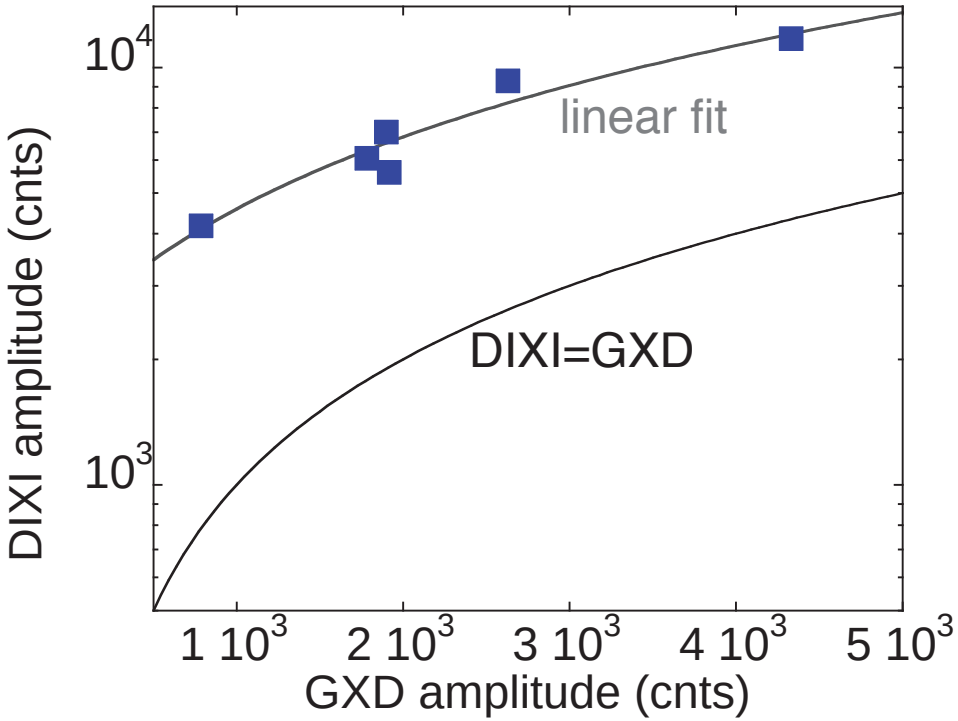
- **allows us to demonstrate temporal resolution**
- **Without imaging, the x-ray impulse looks similar to a streak and**
- **illustrates high voltage pulse along the photo cathode acts like a traveling shutter**



S. R. Nagel et. al., Rev. of Sci. Instrum., **83**, 10E116 (2012)

GXD was used as a reference detector at COMET and the two cameras show a linear correlation

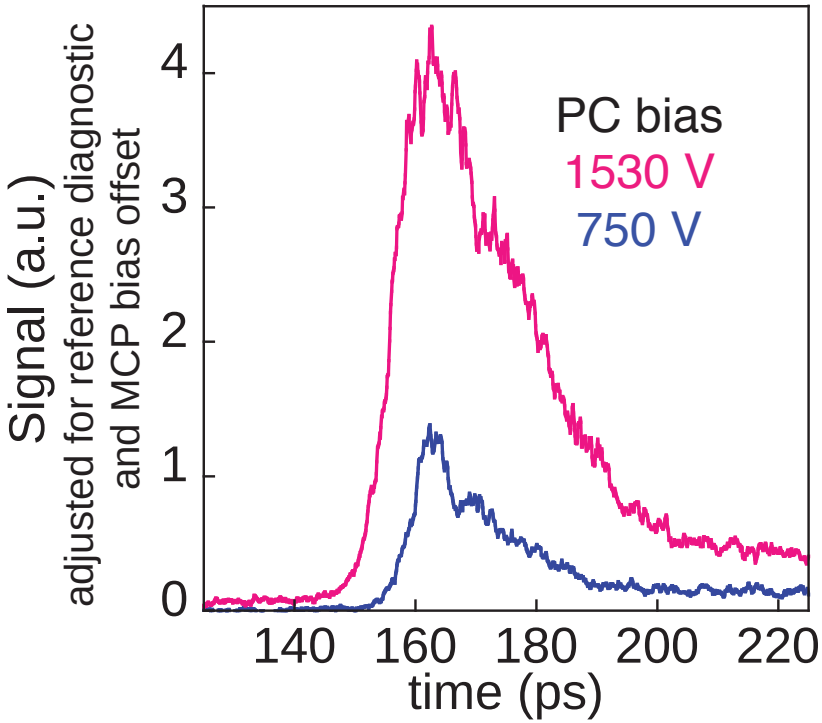
Instrument comparison

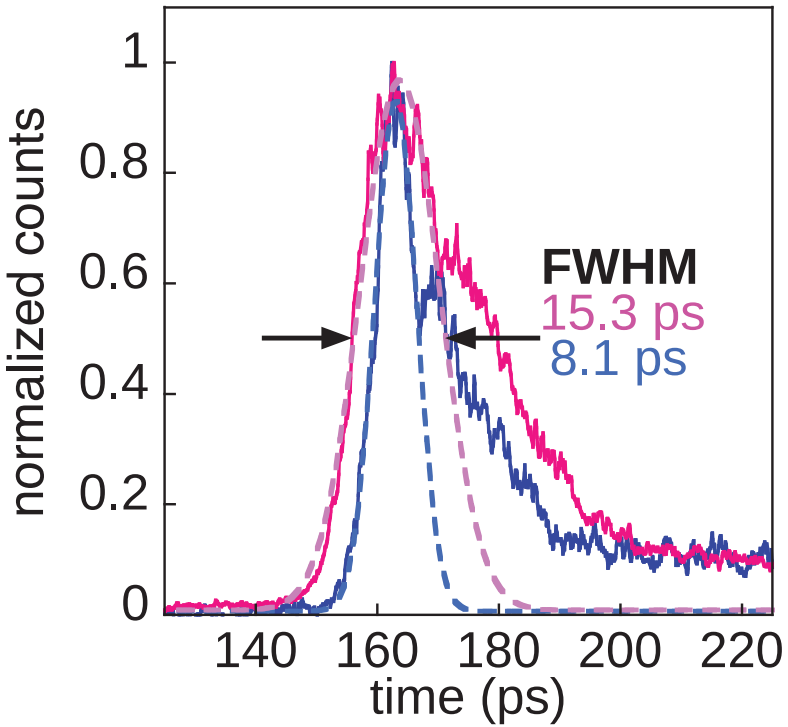


Linear correlation between GXD and DIXI signal with DIXI showing a higher signal level

We can easily adjust the effective gate time of DIXI and optimize the gain if signal starved

Higher PC Voltage – longer gate – more signal



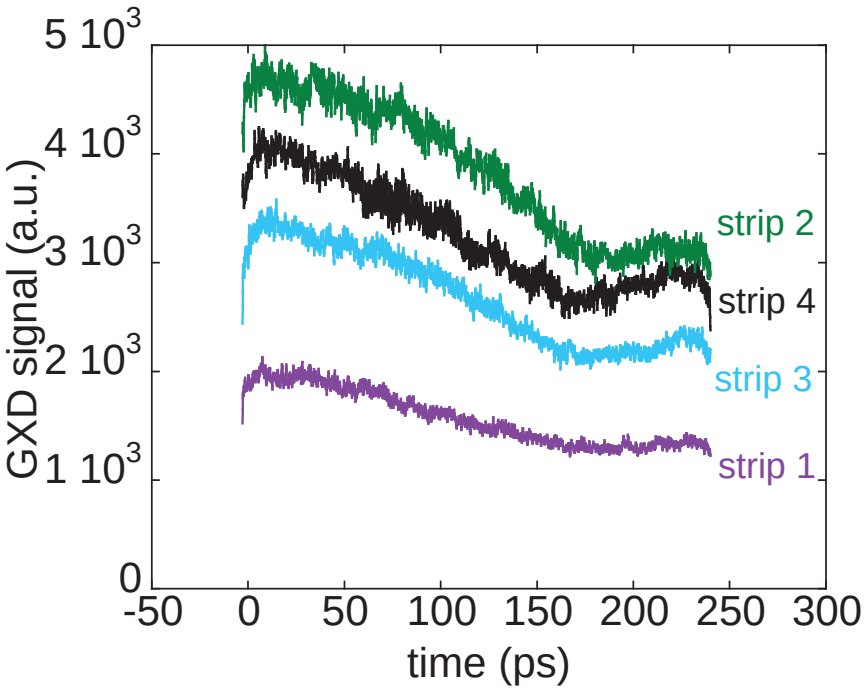


Expected change with increasing PC bias due to effect on dilation:

- **Increase in signal level ~2.8**
- **Broadening of signal**

No observed droop along strips – significant improvement vs. MCP based gated x-ray imagers

GXD – example droop



No droop due to separation into PC and a single strip MCP with wide gate

Spatial resolution of DIXI is a function of the B-field and the spatial resolutions of the PC & MCP

$$\delta_{\mathrm{instr}} = \sqrt{\delta_{\mathrm{PC}}^2 + (\delta_{\mathrm{mcp}} \times \mathrm{Mag}_B)^2}$$

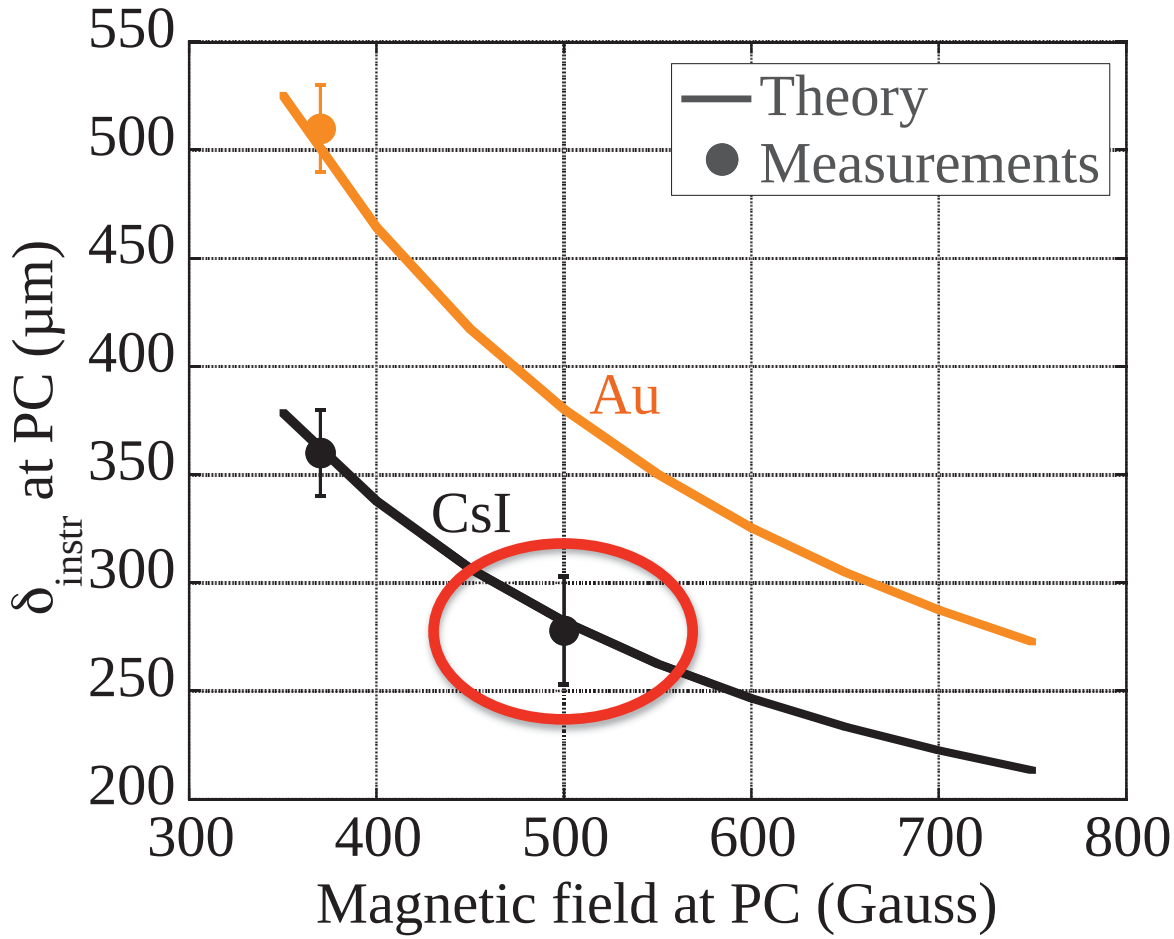
- **δ_{PC} depends on the material of the PC and the magnetic field strength at its position**

$$4r_L[\mu m] = 95000 \frac{\sqrt{T_e[eV]}}{B[\mathrm{Gauss}]}$$

- **Secondary photoelectrons are ejected with a characteristic energy spread depending on the PC material**
- **CsI has a characteristic energy spread of 1.7 eV, compared to Au at 3.5 eV**

T.J. Hilsabeck *et al.,* Rev. of Sci. Instrum., **81**, 10E317 (2010)

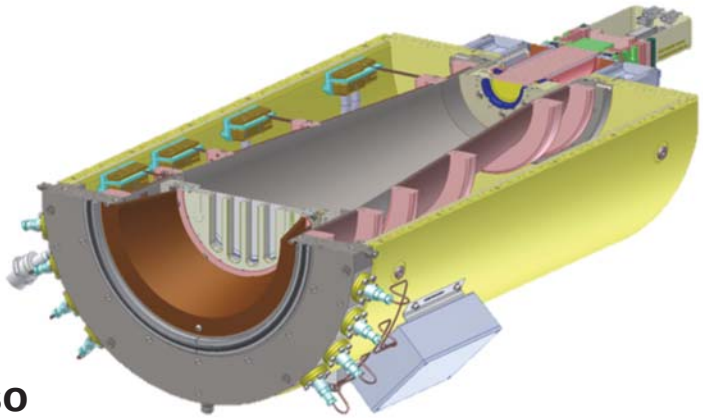
We can meet the spatial resolution requirements for operation on the NIF

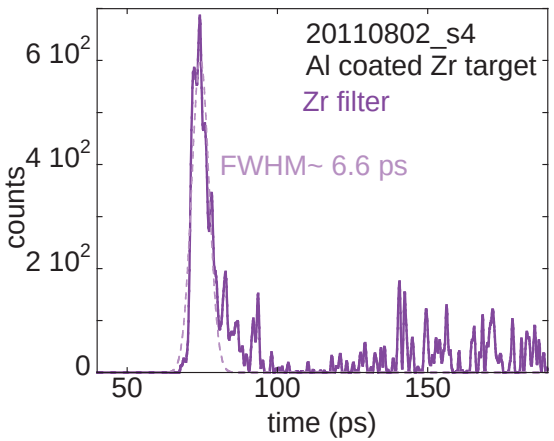


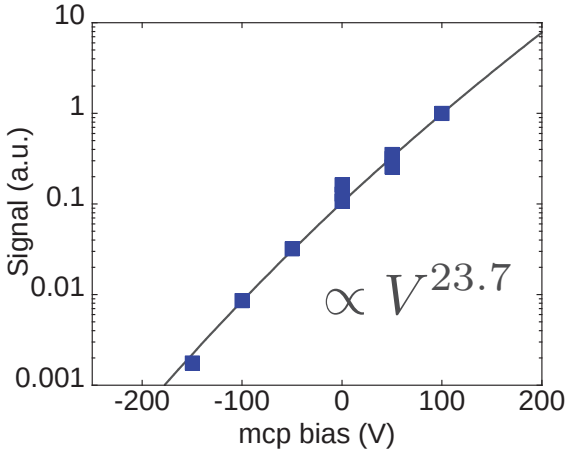
Comparing measured with theoretical δ_{instr} shows good agreement

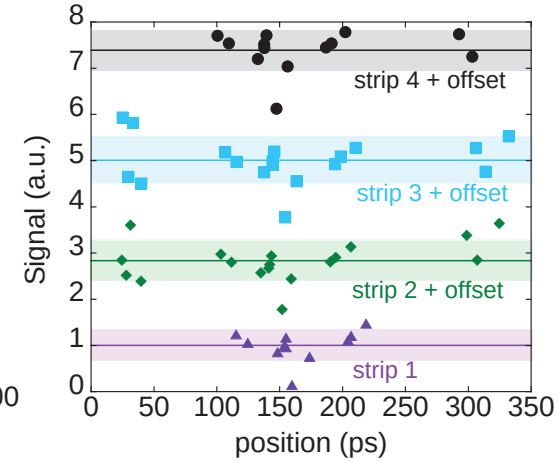
DIXI is fastest x-ray framing camera with improved performance compared to existing diagnostics

- DIXI has a temporal resolution <10 ps
- Control over effective shutter speed and signal amplitude
- Brighter than GXD at same conditions
- Similar mcp gain factor – 3x for 50 V bias change
- No systematic signal droop along PC strips
- Using CsI not only gives a better QE but also results in a better spatial resolution of the instrument





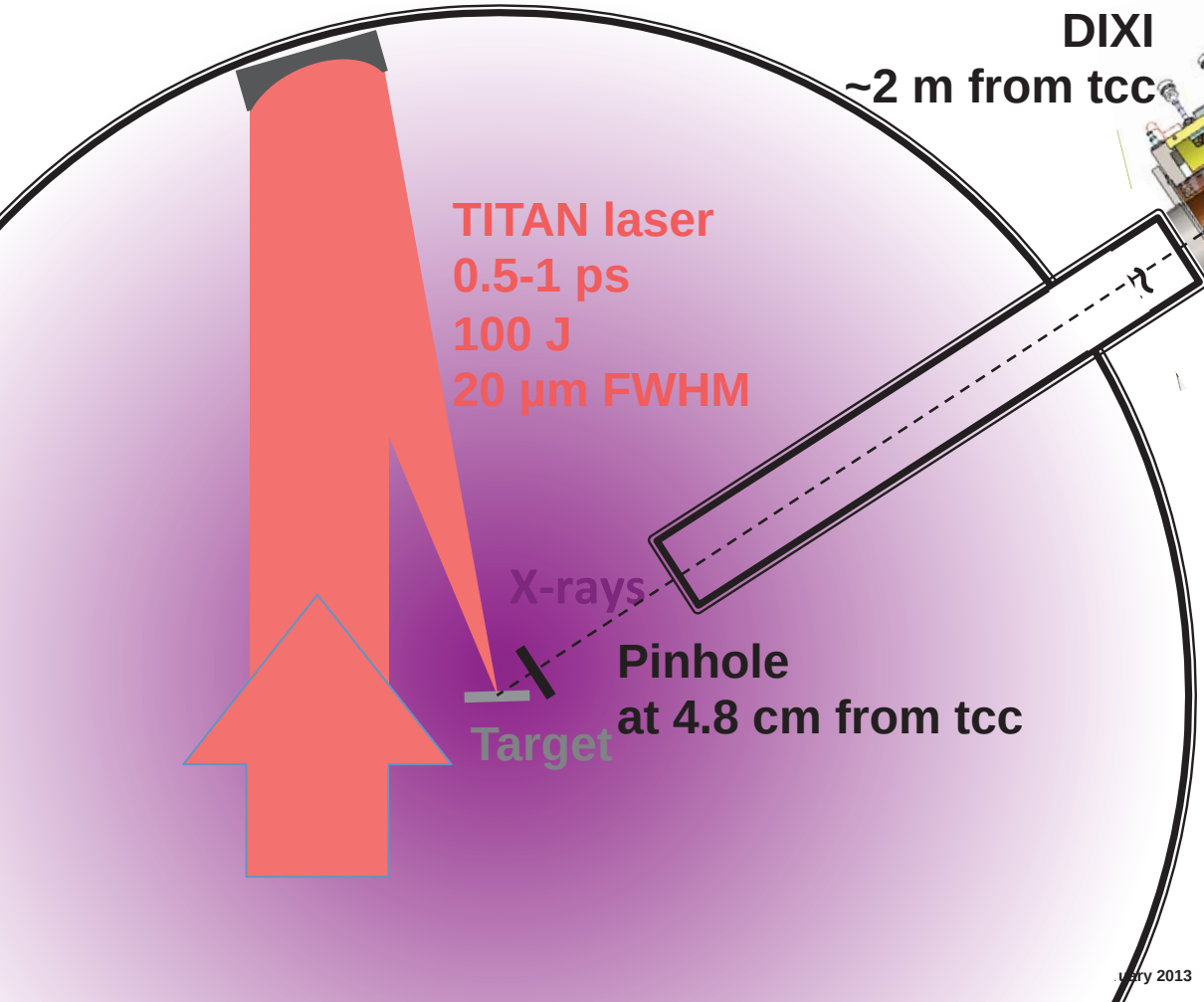


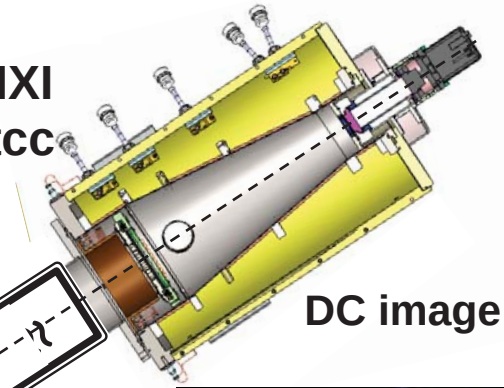


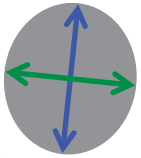
We have now started taking real data on TITAN experiment(s)

At TITAN we are imaging the x-ray emission from the front side of short pulse laser plasma interactions

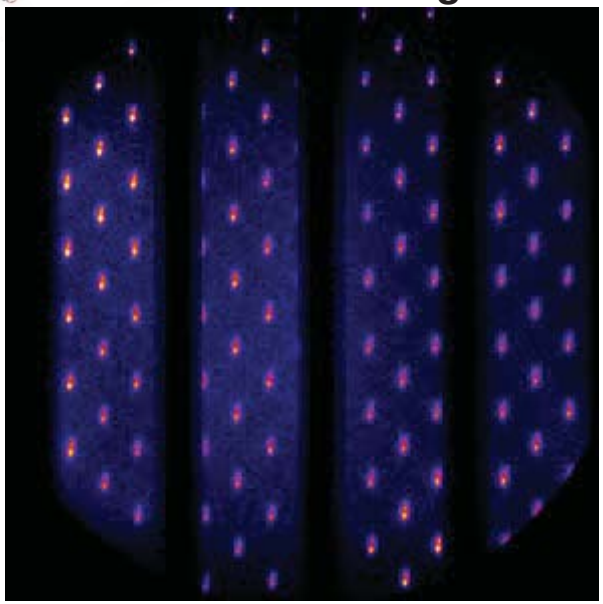
pinhole imaging with
- magnification of ~ 40 x and
- temporal gate width of 7ps



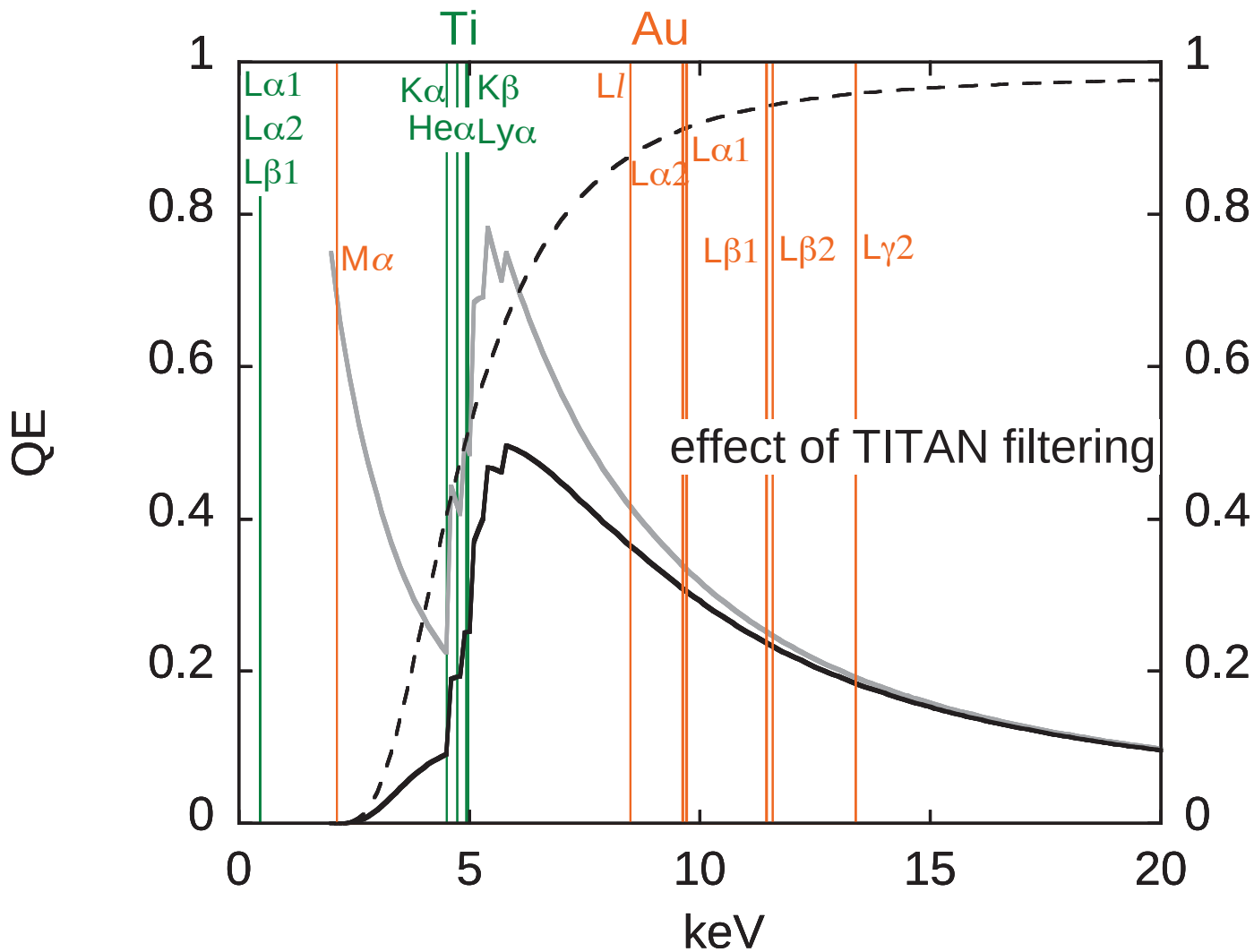




DC image of PH array
Mag ~40x



Our filtering picks out different features for different target materials



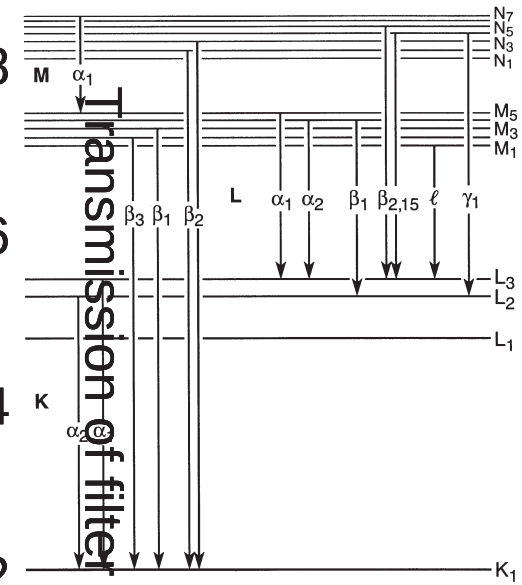
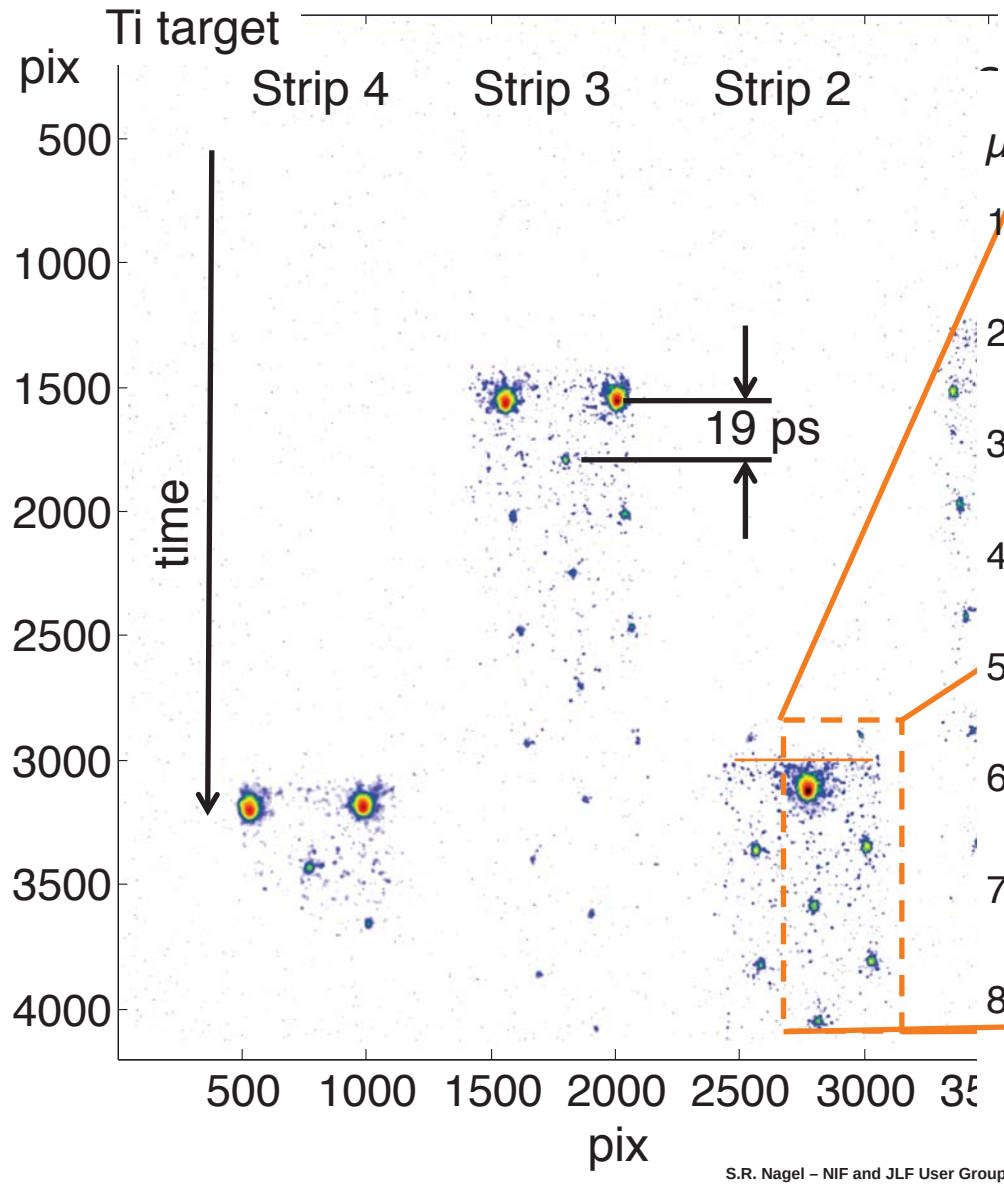
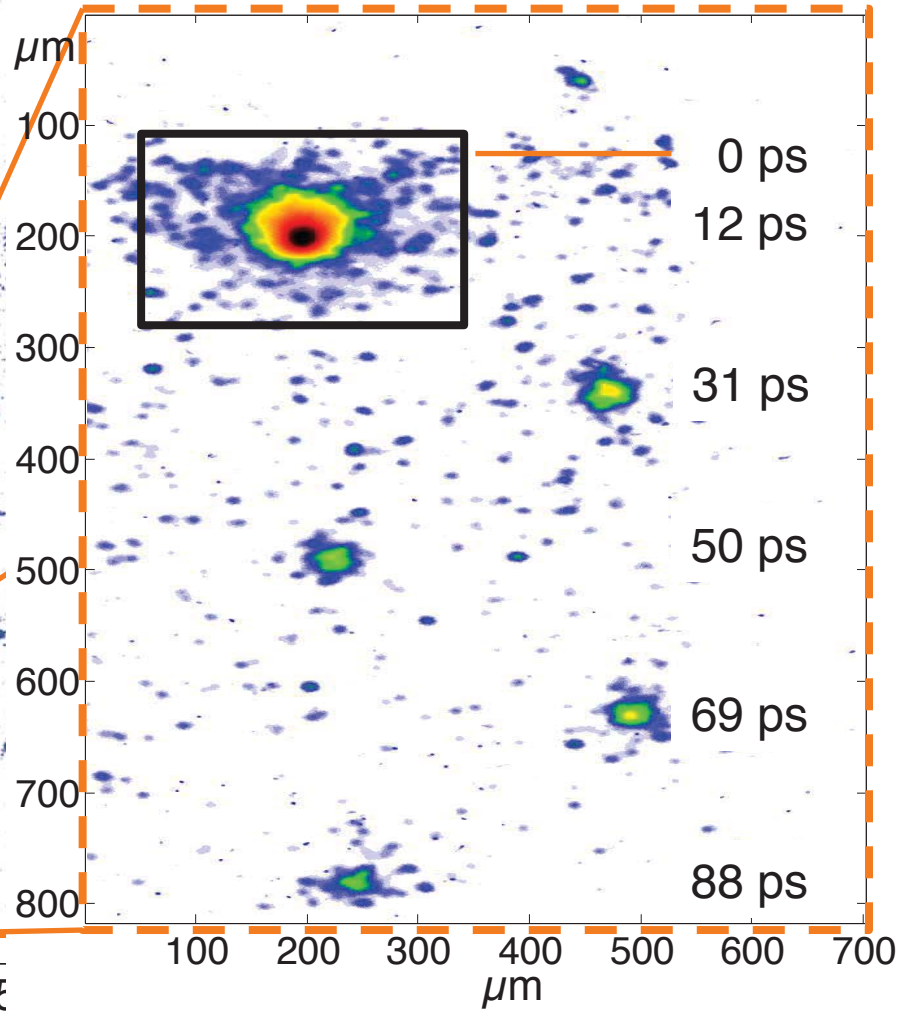


Fig. 1-1. Transitions that give rise to the emission lines in Table 1-3.

Example image showing evolution of x-ray emission with 7 ps temporal resolution

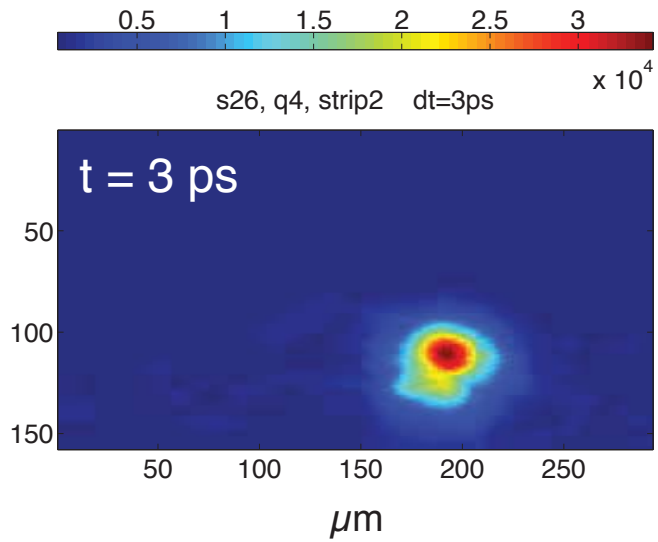


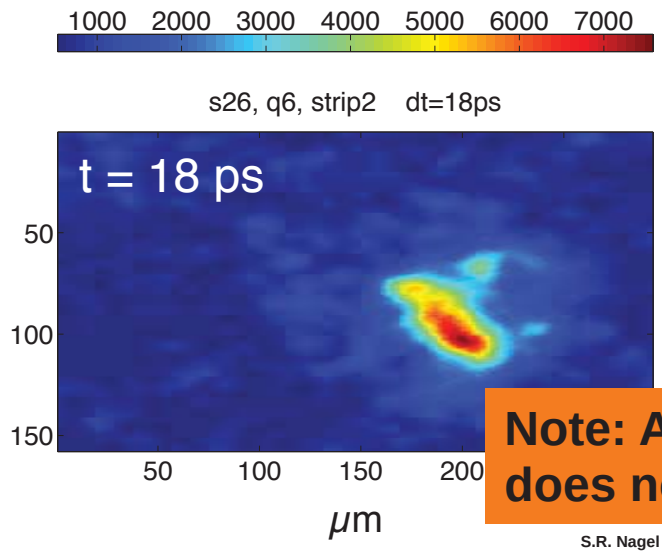
Cropped image and parallax taken out



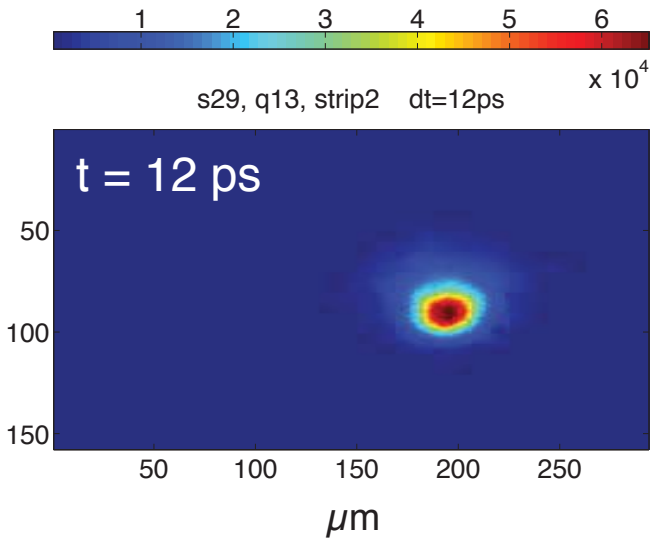
At the start the Au emission is similar in shape and size, compared to Ti, but later emission is larger and non-symmetric

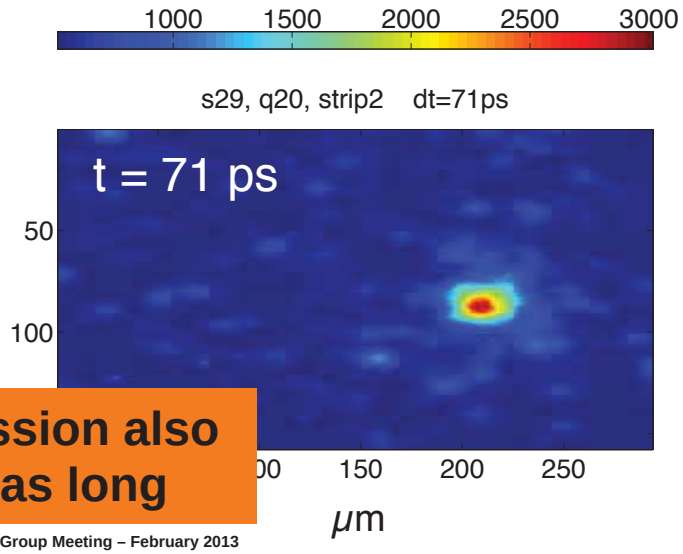
Au – no injection





Ti – no injection

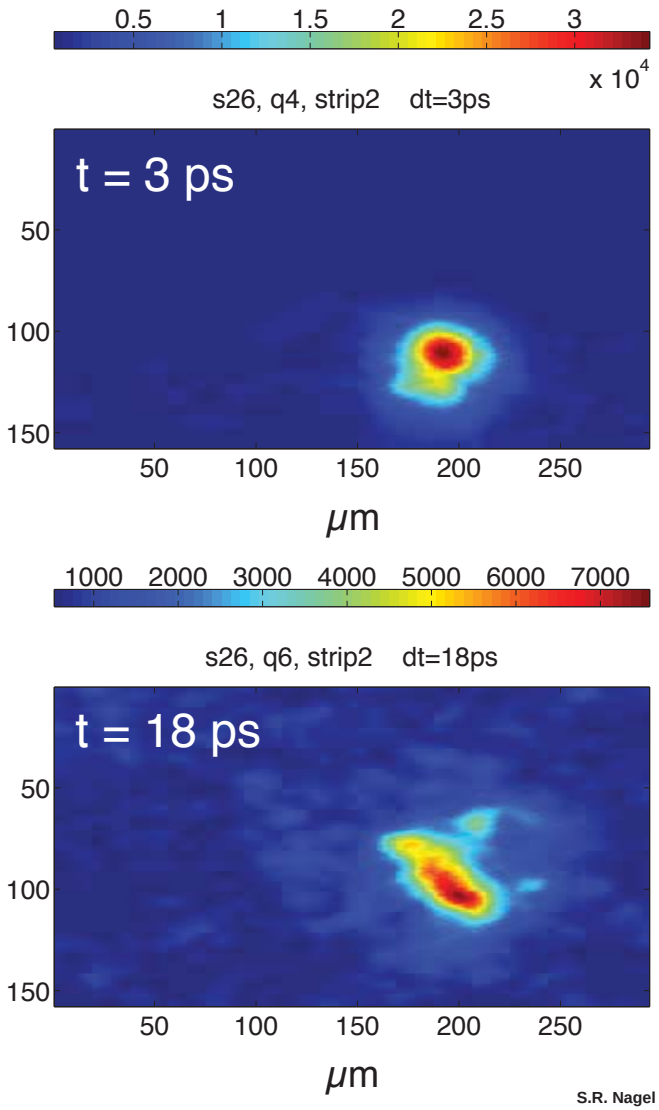




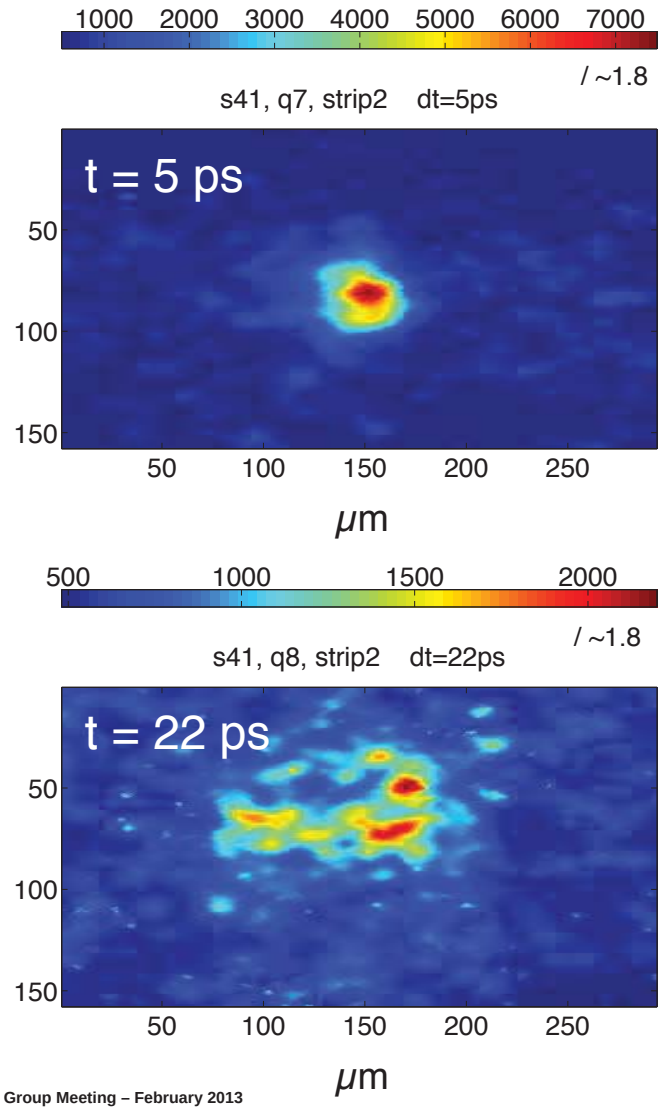
Note: Au emission also does not last as long

Injection of 3 ns pre-pulse changed x-ray emission characteristics – shown here for Au target

No injected pre-pulse – only ASE

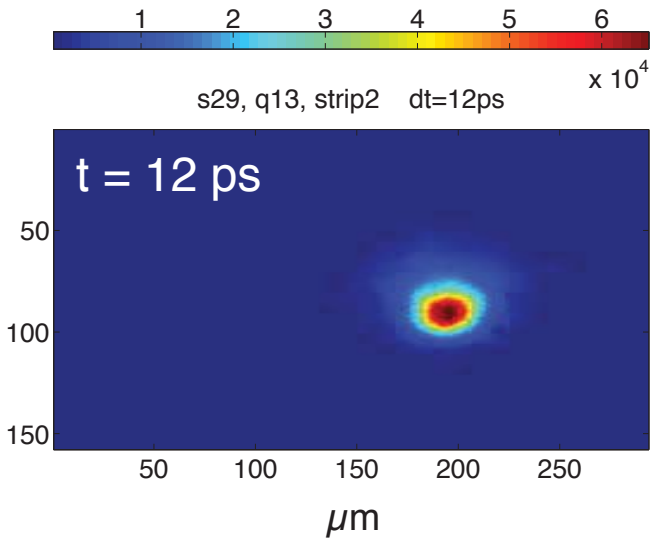


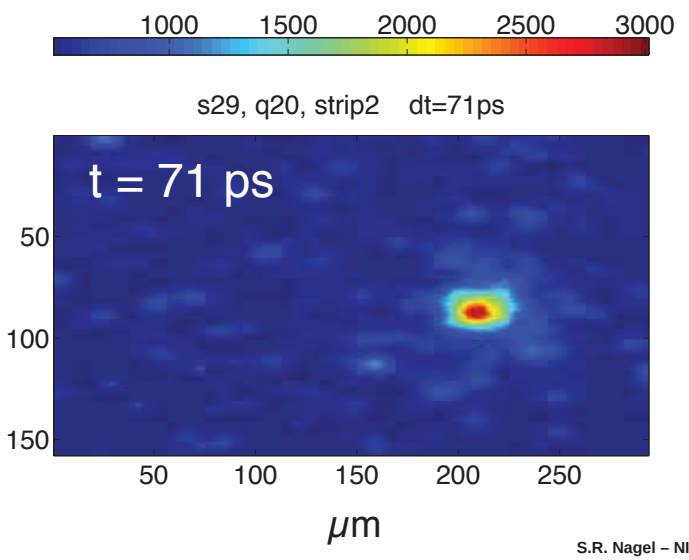
50 mJ, 3 ns pre-pulse injected



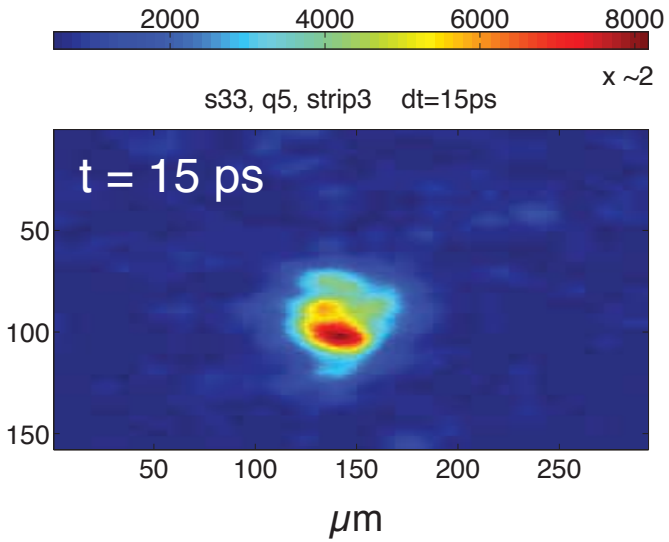
Injection of 3 ns pre-pulse also changed x-ray emission characteristics – for Titanium target

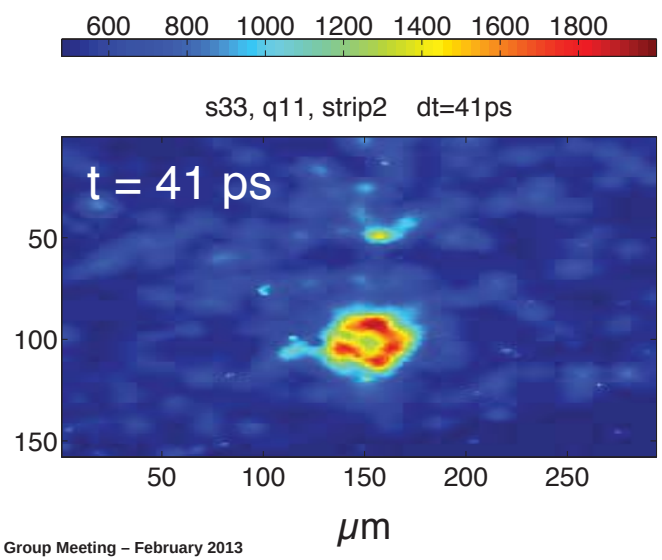
No injected pre-pulse – only ASE



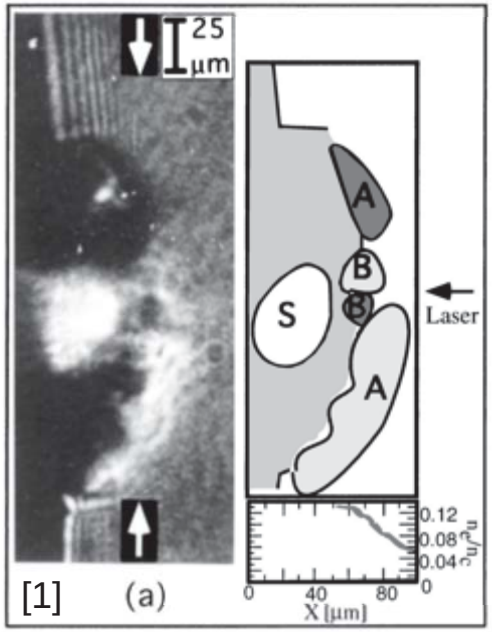


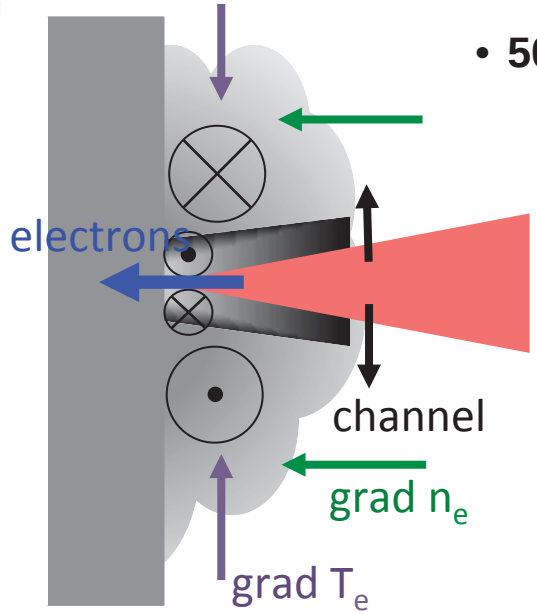
50 mJ, 3 ns pre-pulse injected



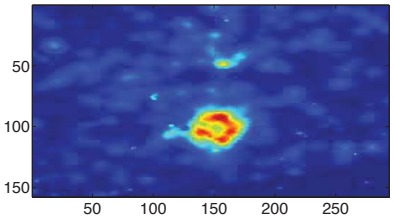


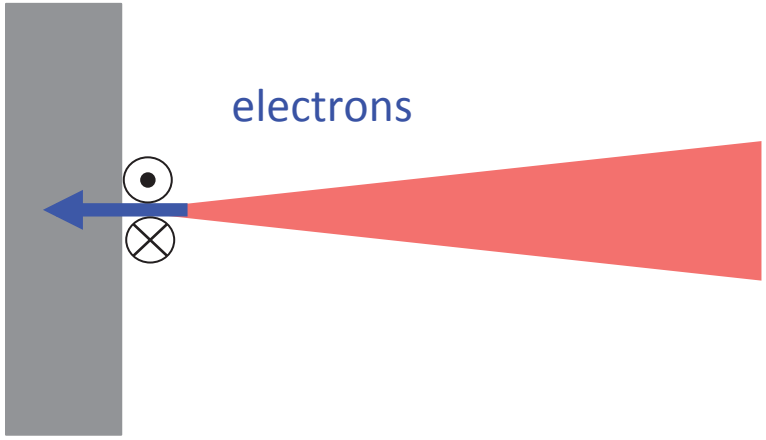
Magnetic fields are under investigation as a possible cause for the observed change in x-ray emission shape



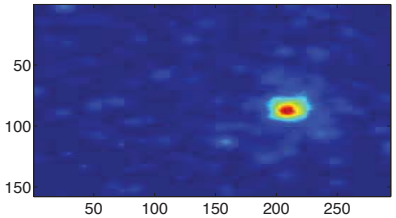


- 50 mJ 3ns injected pulse
  - Channel formation in pre-plasma
  - Magnetic field inside channel from electrons moving with laser
  - Magnetic field outside the channel due to grad T_e x grad n_e
  - Channel expansion after laser turn off



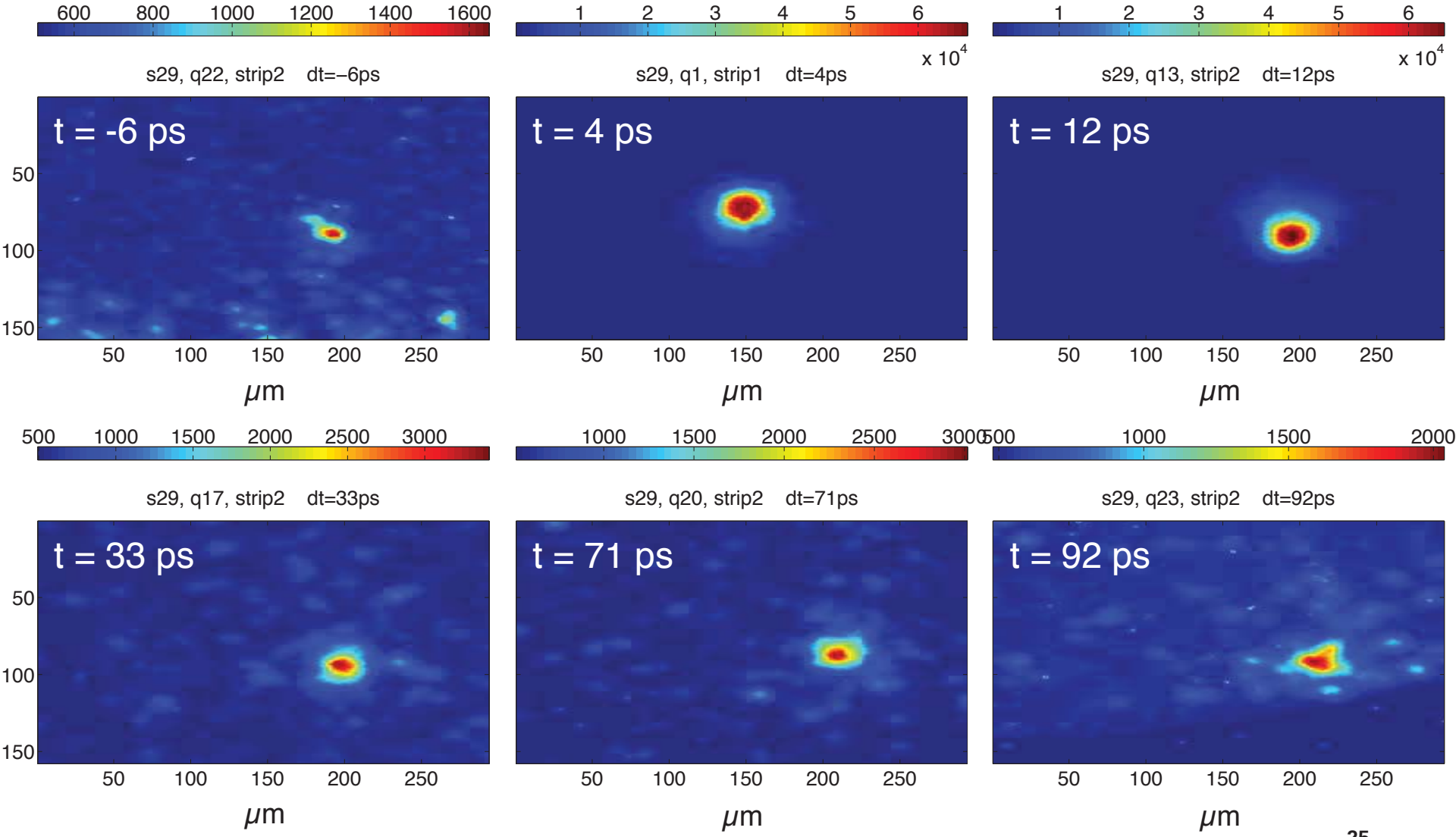


- No injection
  - no significant channel formation and expansion

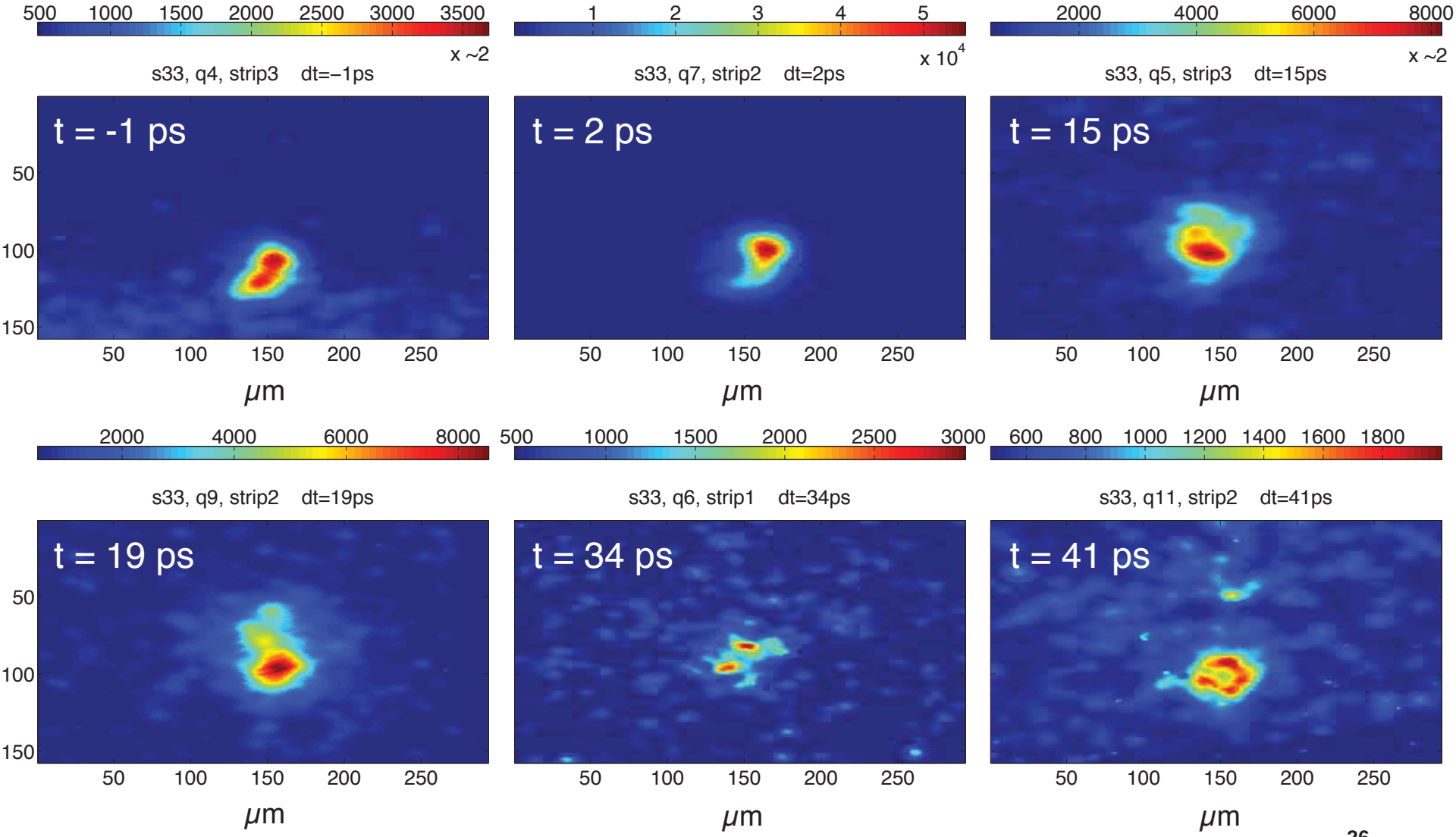


[1] Borghesi et al., PRL, 80, 5137 (1998), Figure 1

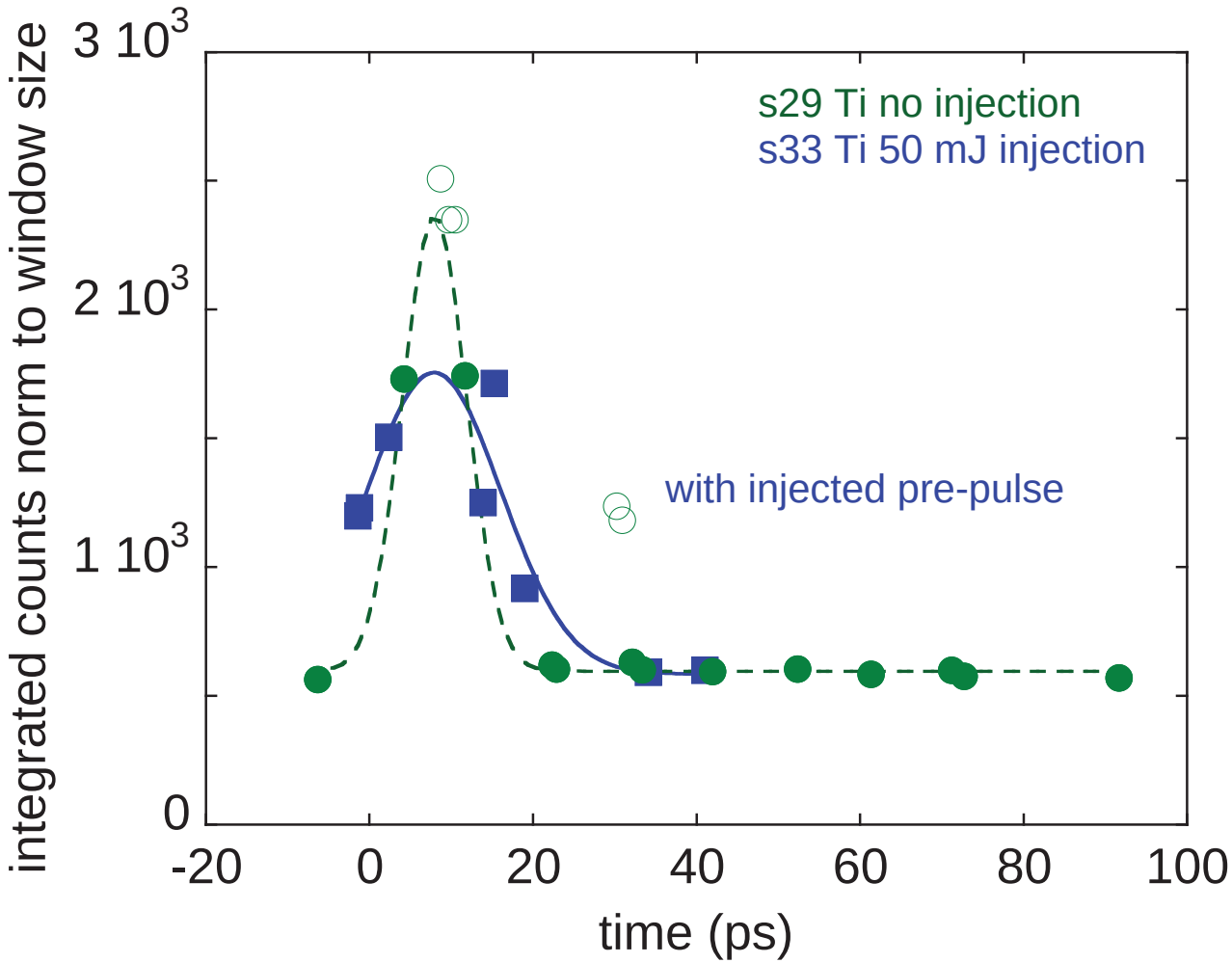
No injection emission for Titanium target is very long and stays very round and confined



50 mJ 3 ns injected pre-pulse shot shows shows larger, less defined spot and less emission



Injected pre-pulse does not affect the time of integrated peak emission per frame



Preliminary analysis suggests:

- **Emission peaks at the same time**
- **With injection the peak emission is not as bright but longer**
- **However, extended measurable emission for "clean" case (may be due to long lived He-alpha emission)**

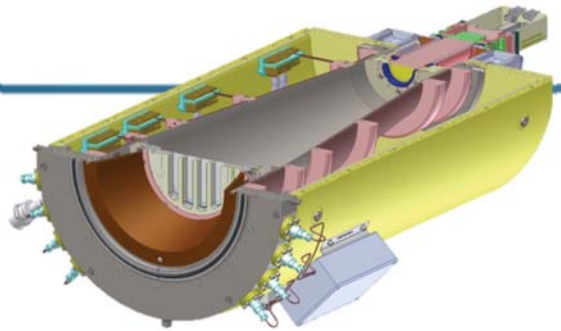
- **Could be due to magnetic field effects and electron dynamics changing due to pre-plasma effects**

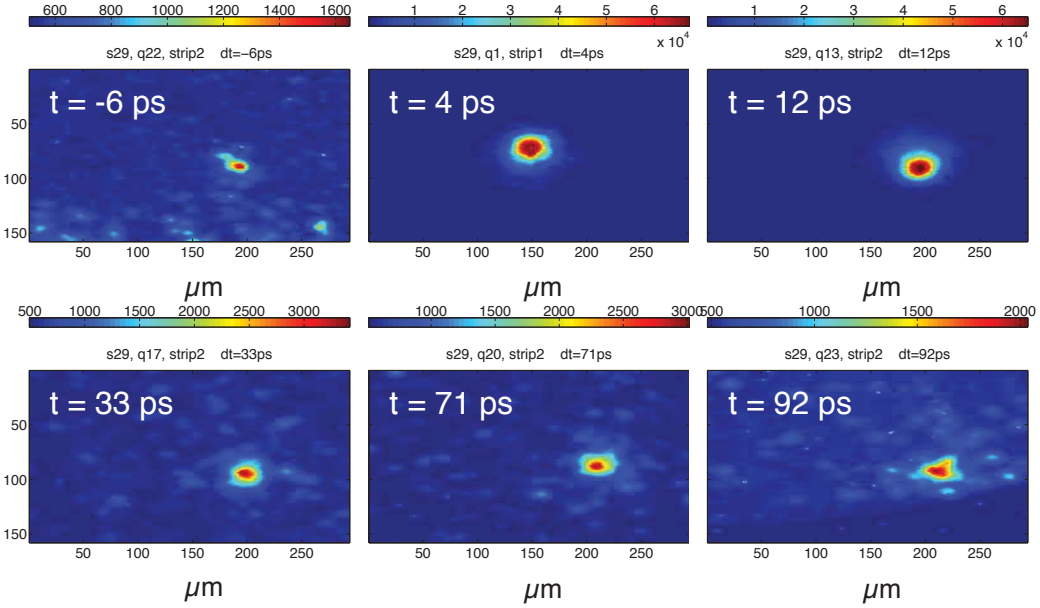
Next experiment, we will use a tighter spaced pinhole set to obtain more frames with less temporal separation and gather more insight.

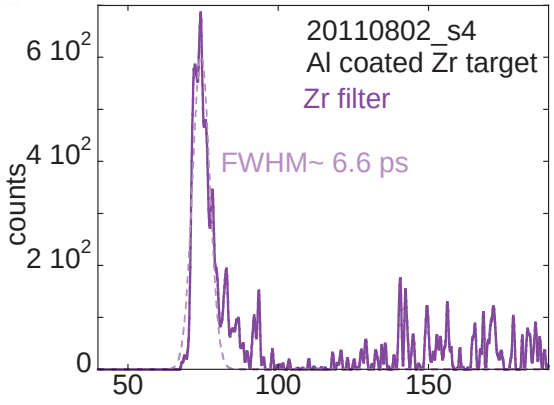
Summary

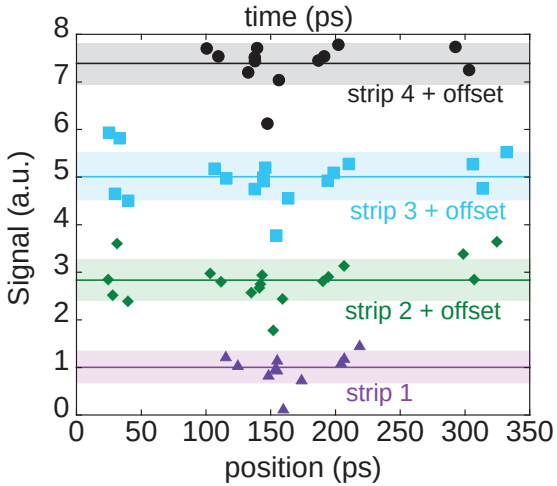
- **DIXI is fastest (<10 ps) x-ray framing camera with improved performance compared to existing diagnostics**

- **X-ray emission time resolved images allow for a detailed study of the electrons dynamics during and shortly after the laser plasma interaction**









Improvement suggestions for JLF

- Pre-pulse improvement esp. for TITAN
- Laser diagnostics installation and maintenance as standard in all TA.
  - Monitoring pulse duration, near and far field, pre-pulse, energy
- 2nd near PW short pulse beam capability for TITAN

- Everyone is working really hard for the users, and we are aware that the facility is understaffed! Ideally more staff would be available to for example support during maintenance periods, or to prepare equipment for maintenance periods.

NIF