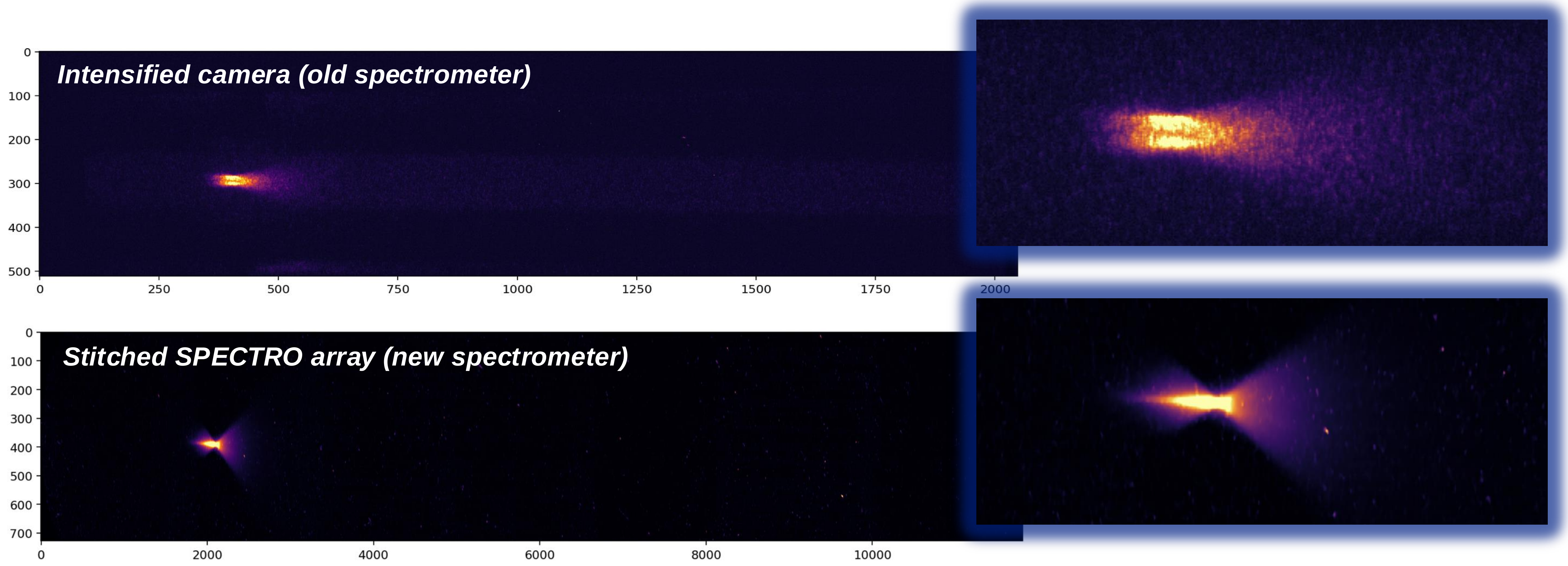
AWAKE Spectrometer Meeting

25.09.24

F. Pannell

Spectrometer stitched image

Technical update



Extensively tested and further developed during the August run

SPECTRO 1 – 7 (entire screen) vignetting, lens distortion, perspective distortion corrected and stitched

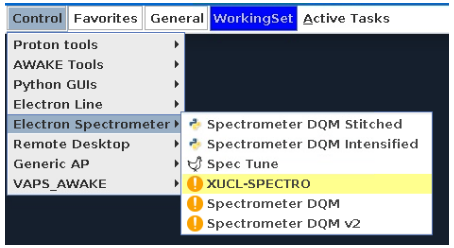
Code on AWAKE gitlab so anyone can use (I am constantly working on it though, so check for latest version…)

Very easy to use, you can import 'SpectroStitch' like you would any other module in python. Let me know if you have any questions :)

Spectrometer DQMs

Technical update

Dave has ‘modernised’ the old spectrometer DQM into a new format, and we have a version for the intensified camera, and the stitched camera array. We also have Spec Tune for simulated beams on the spectrometer.



awakeop login required (magnet subscription)

Plots for:

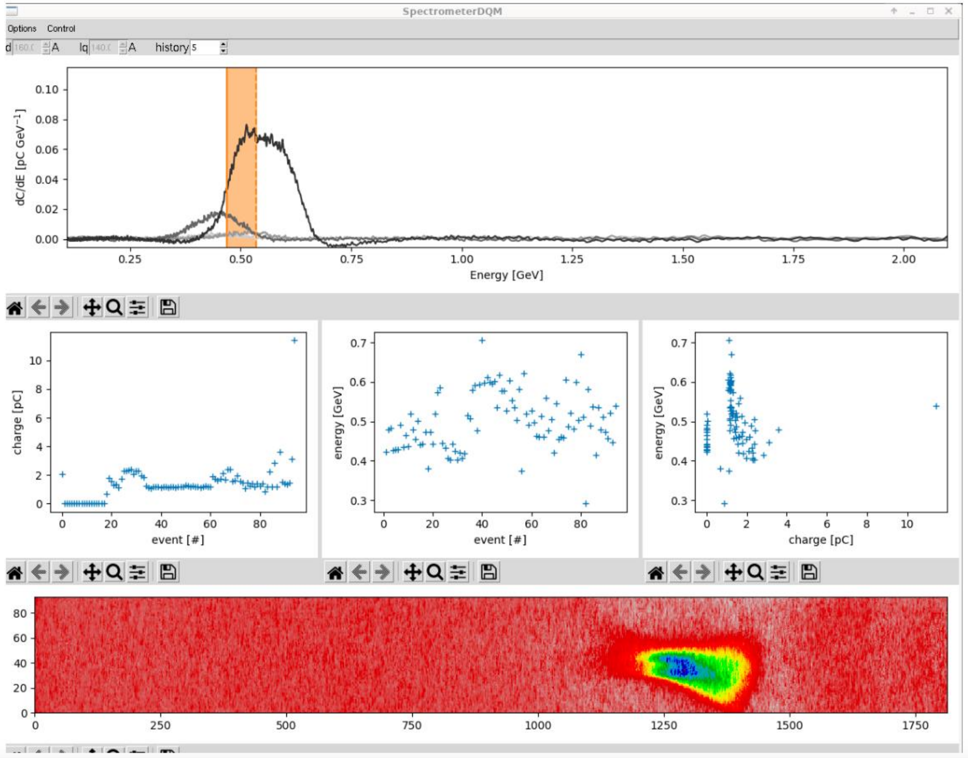
- Charge vs event
- Energy vs event
- Charge vs energy

Charge calculation based off the intensified camera calibration on <u>both</u> DQMs

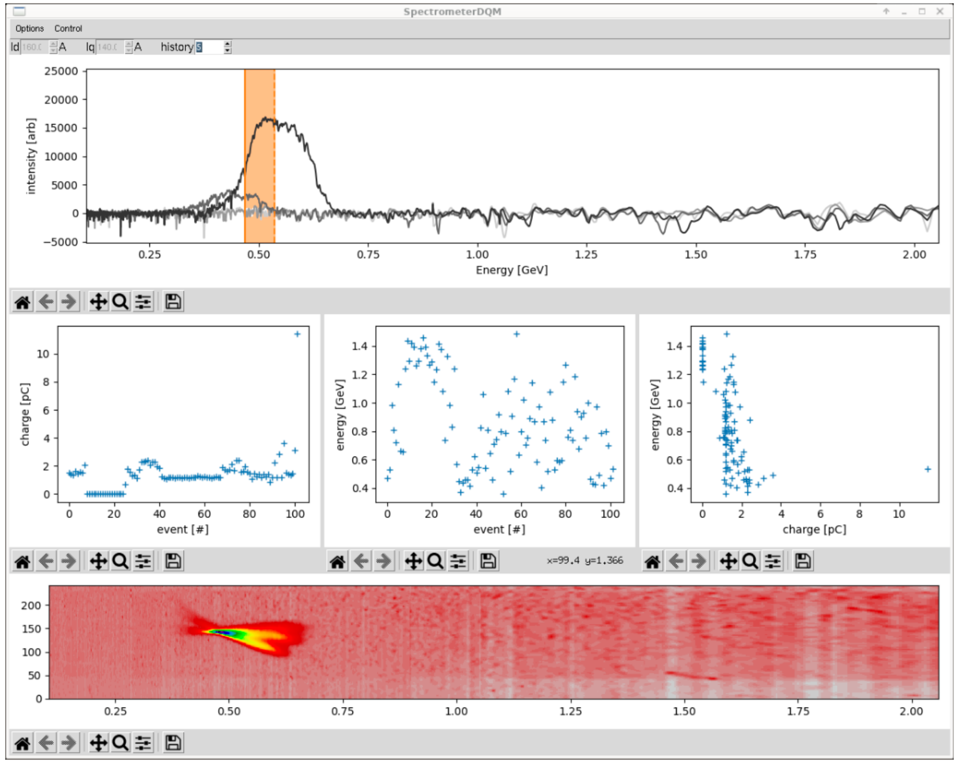
Background subtraction greatly improved from old DQM (and therefore online charge reading)

Stitched image shown in energy

Intensified camera *(same event)*



Stitched SPECTRO array



Experimental update

Emittance

The first measurements of the transverse emittance at AWAKE were performed in November 2022, at the end of Run 2a. This study aimed to demonstrate the possibility of such a measurement and is described in detail in David Cooke's paper (in progress).

The *physics expectations* for the emittance in AWAKE Run 2b are unclear.

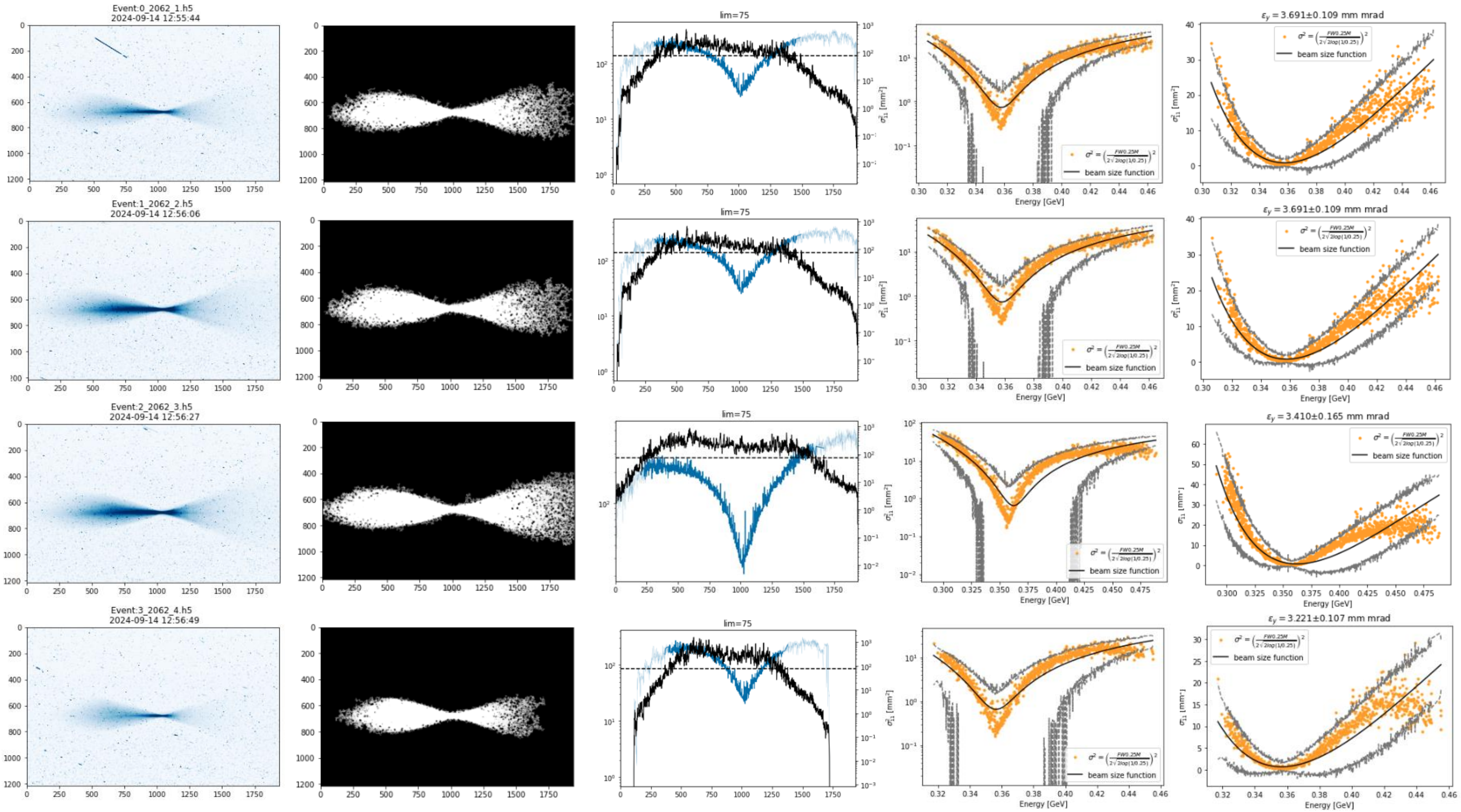
However, an important study remains around the effect of the plasma exit ramp on the emittance of the beam. This is significant ahead of Run 2c, where we hope to control the emittance growth.

The first measurements of the emittance in Run 2b, obtained via the single-shot butterfly technique, and progress towards the exit ramp study are presented here.

First look at Run 2b emittance *2e14 uniform, injection 1.5m 800pC*

Experimental update

Acc. event ***Signal mask*** ***Signal to noise*** ***Beam size function***



correlation coefficient: (0.9084545961768044+0j)
size at quads: 0.00679+/-0.00005
divergence at quads: 0.002134+/-0.000011
position of waist (in y) from first quad: -3.077+/-0.022
size squared at waist: (2.99+/-0.18)e-06
size at waist: 0.00173+/-0.00005
divergence at waist: 0.002134+/-0.000011
emittance 3.69 ± 0.109

correlation coefficient: (0.9084545961768044+0j)
size at quads: 0.00679+/-0.00005
divergence at quads: 0.002134+/-0.000011
position of waist (in y) from first quad: -3.077+/-0.022
size squared at waist: (2.99+/-0.18)e-06
size at waist: 0.00173+/-0.00005
divergence at waist: 0.002134+/-0.000011
emittance 3.69 ± 0.109

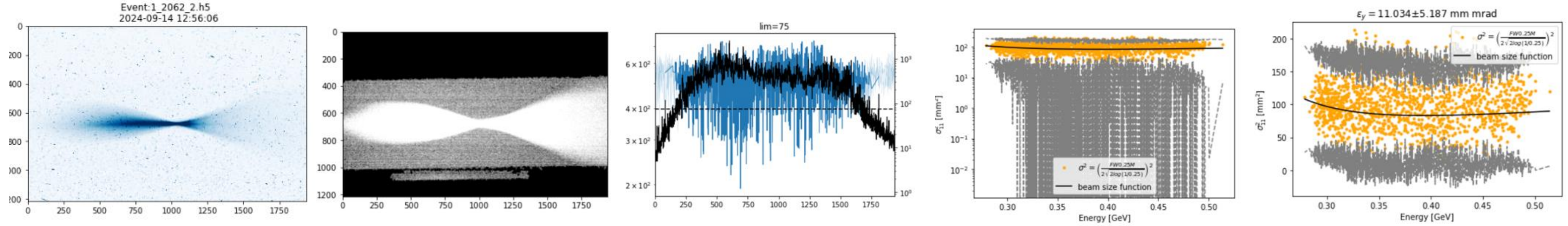
correlation coefficient: (0.8821756181019335+0j)
size at quads: 0.00680+/-0.00004
divergence at quads: 0.001927+/-0.000014
position of waist (in y) from first quad: -3.406+/-0.034
size squared at waist: (3.13+/-0.29)e-06
size at waist: 0.00177+/-0.00008
divergence at waist: 0.001927+/-0.000014
emittance 3.41 ± 0.165

correlation coefficient: (0.8650300940384001+0j)
size at quads: 0.00624+/-0.00007
divergence at quads: 0.002021+/-0.000014
position of waist (in y) from first quad: -2.985+/-0.030
size squared at waist: (2.54+/-0.17)e-06
size at waist: 0.00159+/-0.00005
divergence at waist: 0.002021+/-0.000014
emittance 3.22 ± 0.107

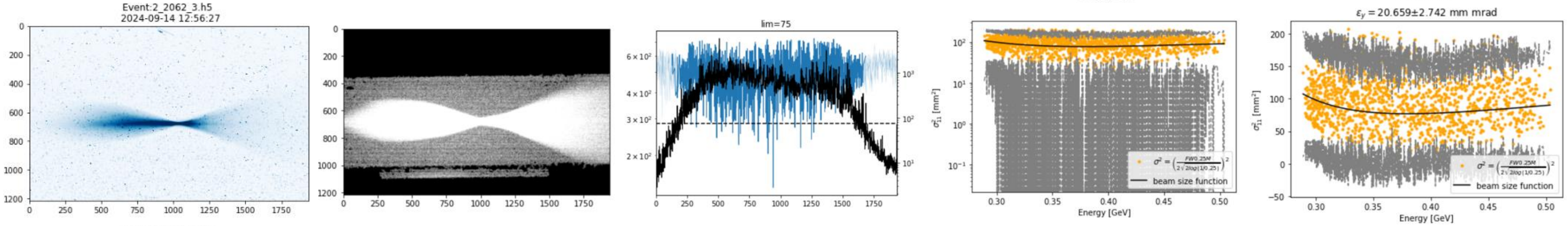
Thresholds and limits are important…

Experimental update

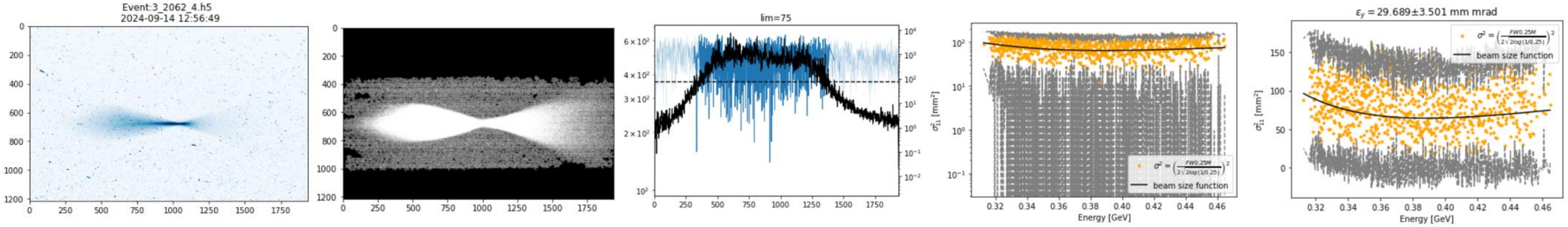
It's somewhat of an optimisation game.
When deciding where the signal ends, a threshold should be set. Too low, you pick up all the background. Too high, we're cutting off parts of the beam and the size measurement is no longer accurate.
Exploring the idea of convergence tests to try and determine the optimal constraints.




```
correlation coefficient:  (0.018883419336790427+0j)
size at quads: 0.0041+/-0.0004
divergence at quads: 0.00474+/-0.00004
position of waist (in y) from first quad: 0.72+/-0.06
size squared at waist: (5+/-5)e-06
size at waist: 0.0023+/-0.0011
divergence at waist: 0.00474+/-0.00004
emittance 11 ± 5.19
```




```
correlation coefficient:  (0.07052187076290715+0j)
size at quads: 0.0052+/-0.0004
divergence at quads: 0.00462+/-0.00004
position of waist (in y) from first quad: 0.57+/-0.07
size squared at waist: (2.0+/-0.5)e-05
size at waist: 0.0045+/-0.0006
divergence at waist: 0.00462+/-0.00004
emittance 20.7 ± 2.74
```

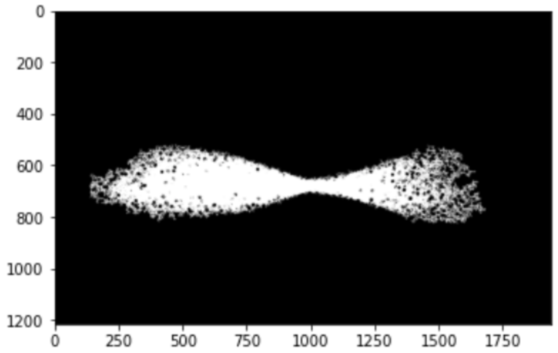


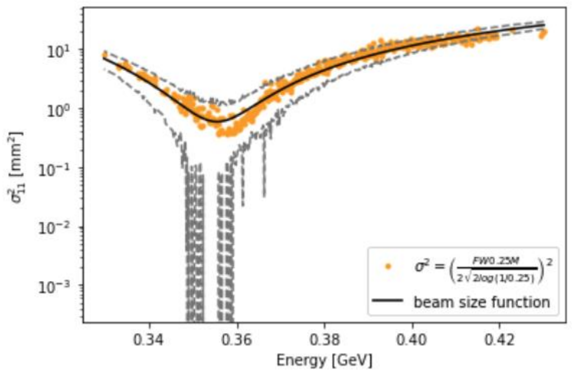

```
correlation coefficient:  (0.14417592459338238+0j)
size at quads: 0.0072+/-0.0006
divergence at quads: 0.00426+/-0.00005
position of waist (in y) from first quad: 0.39+/-0.13
size squared at waist: (4.9+/-1.1)e-05
size at waist: 0.0070+/-0.0008
divergence at waist: 0.00426+/-0.00005
emittance 29.7 ± 3.5
```

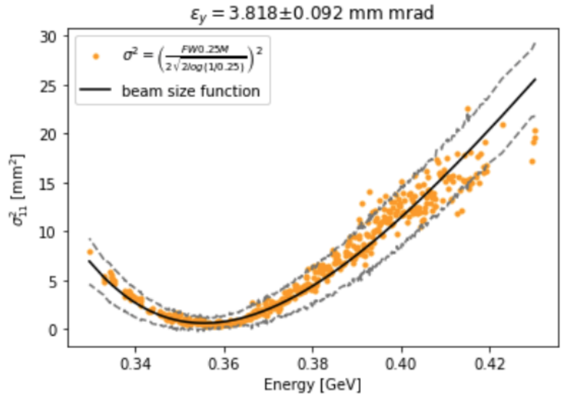
Understanding the resolution

Experimental update

Thanks to the measurement campaign at CLEAR in April 2024 allowing us to obtain a better idea of the scintillator spatial resolution (tungsten knife edge experiment) , we can use a more realistic resolution of the entire system (camera, lens, lanex) on the deconvolution.

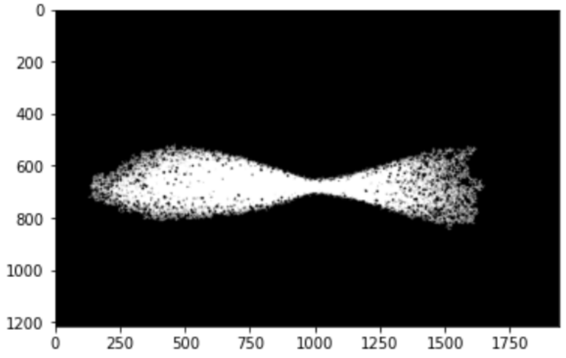


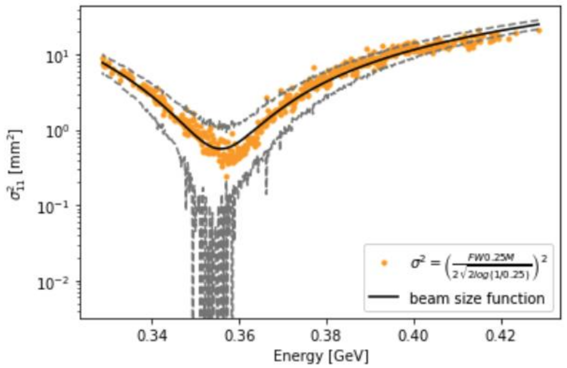


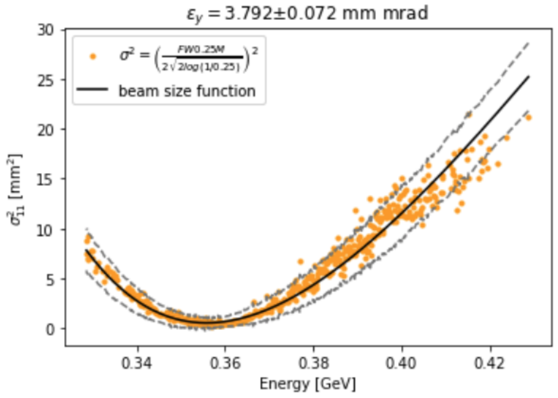


Resolution 210 um

```
correlation coefficient:  (0.9710673742248098+0j)
size at quads: 0.00779+/-0.00006
divergence at quads: 0.002554+/-0.000011
position of waist (in y) from first quad: -2.995+/-0.014
size squared at waist: (2.23+/-0.11)e-06
size at waist: 0.00149+/-0.00004
divergence at waist: 0.002554+/-0.000011
emittance 3.82 ± 0.0916
```





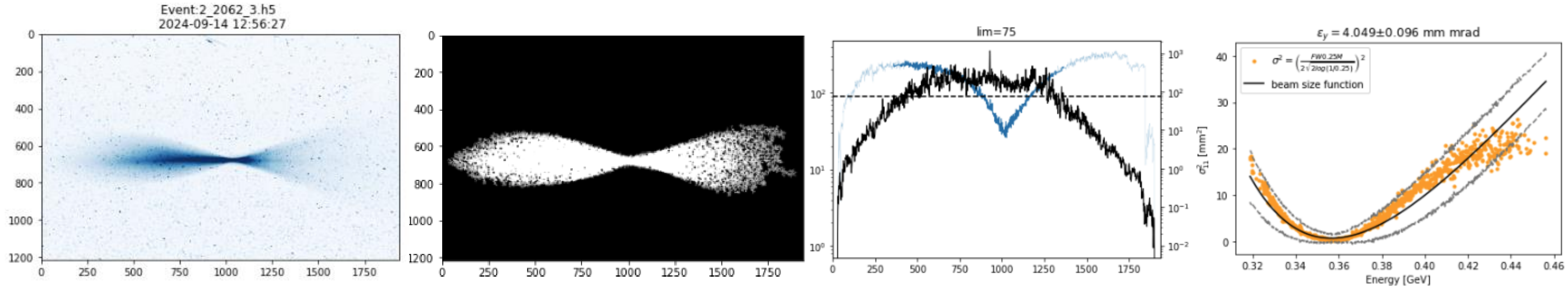


Resolution 150 um

```
correlation coefficient:  (0.9760334501829427+0j)
size at quads: 0.00791+/-0.00004
divergence at quads: 0.002576+/-0.000010
position of waist (in y) from first quad: -3.019+/-0.010
size squared at waist: (2.17+/-0.09)e-06
size at waist: 0.001472+/-0.000029
divergence at waist: 0.002576+/-0.000010
emittance 3.79 ± 0.0724
```

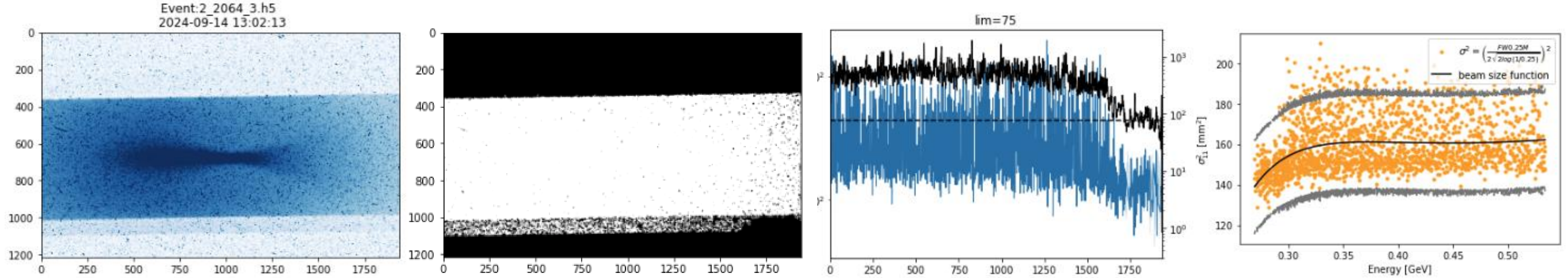
The complexities of high backgrounds…

Experimental update



Standard acceleration (no backgd. subtraction)

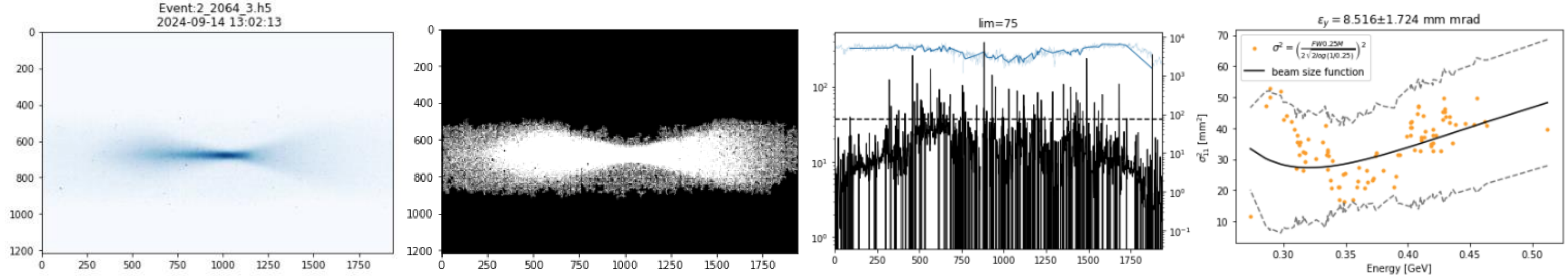
```
correlation coefficient:  (0.9510418309089174+0j)
size at quads: 0.00742+/-0.00004
divergence at quads: 0.002393+/-0.000010
position of waist (in y) from first quad: -3.019+/-0.016
size squared at waist: (2.86+/-0.14)e-06
size at waist: 0.00169+/-0.00004
divergence at waist: 0.002393+/-0.000010
emittance 4.05 ± 0.0963
```



LBDP2 acceleration (no backgd. subtraction)

```
correlation coefficient:  (0.3601342291975343+0j)
size at quads: 0.00111+/-0.00026
divergence at quads: 0.006560+/-0.000007
position of waist (in y) from first quad: 0.823+/-0.007
size squared at waist: (-2.79+/-0.10)e-05

ValueError: math domain error
```

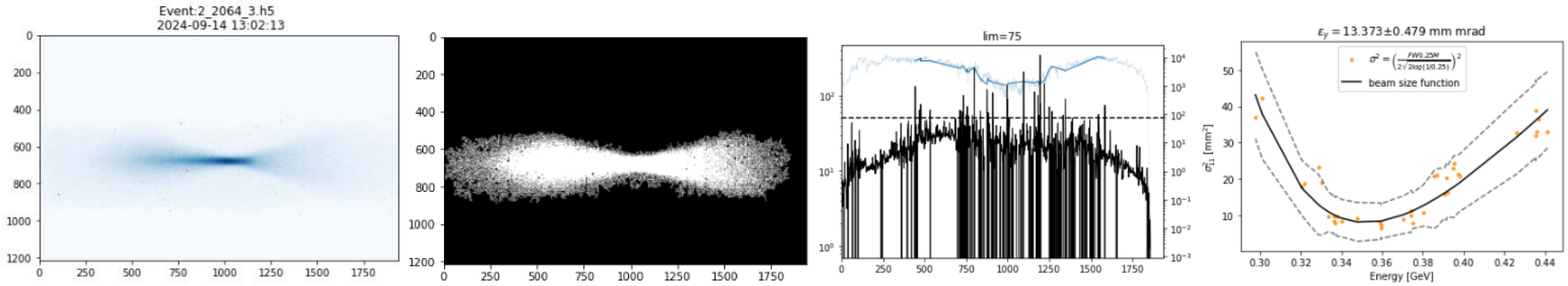


LBDP2 acceleration (backgd subtraction above & below beam & med. filt.)

```
correlation coefficient:  (0.4537014409735805+0j)
size at quads: 0.0027+/-0.0005
divergence at quads: 0.00316+/-0.00006
position of waist (in y) from first quad: 0.17+/-0.12
size squared at waist: (7.2+/-2.8)e-06
size at waist: 0.0027+/-0.0005
divergence at waist: 0.00316+/-0.00006
emittance 8.52 ± 1.72
```

The complexities of high backgrounds…

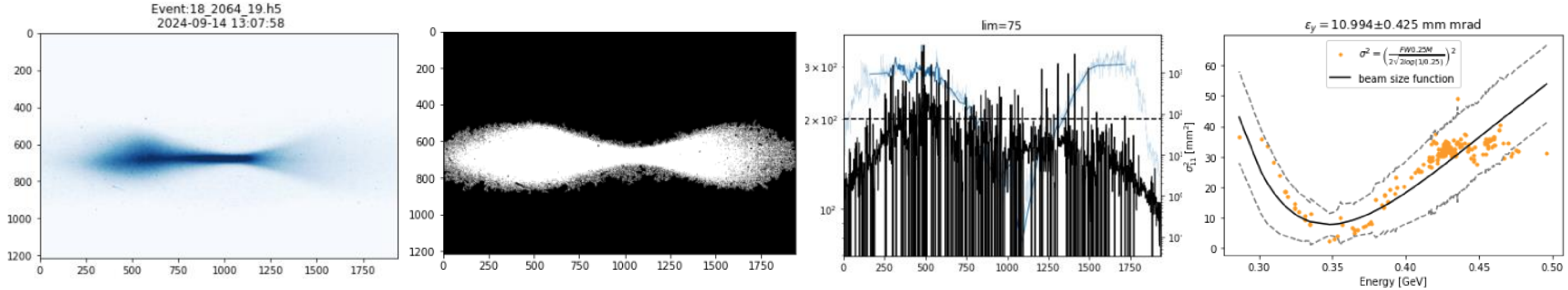
Experimental update



LBDP2 acceleration
(backgd subtraction above & below beam & med. filt. & threshold inc.)

```
correlation coefficient:  (0.9402051010775317+0j)
size at quads: 0.00734+/-0.00027
divergence at quads: 0.00294+/-0.00007
position of waist (in y) from first quad: -1.96+/-0.10
size squared at waist: (2.06+/-0.14)e-05
size at waist: 0.00454+/-0.00015
divergence at waist: 0.00294+/-0.00007
emittance 13.4 ± 0.479
```

If we can find a slightly higher charge event through LBDP2:



LBDP2 acceleration
(backgd subtraction above & below beam & med. filt. & threshold inc.)

```
correlation coefficient:  (0.8367212527830302+0j)
size at quads: 0.00600+/-0.00021
divergence at quads: 0.002736+/-0.000024
position of waist (in y) from first quad: -1.63+/-0.09
size squared at waist: (1.61+/-0.12)e-05
size at waist: 0.00402+/-0.00016
divergence at waist: 0.002736+/-0.000024
emittance 11 ± 0.425
```

We're getting closer to something sensible!! But additional work to remove the background still needs to be done

Currently working on: Checking the emittance (and signal to noise) with the background subtracted stitched image and the high-resolution camera

Experimental update

Plungers

We have multiple plunger gradient scans from the August run; we focused particularly on plungers at low density (2e14, 4e14).
In the control room, from a very rough online analysis, the plunger scan at 2e14, injection 1.5m, RIF +100ps seemed the most successful.
To improve signals and address missing data points, we repeated this same scan at higher injection charge (800pC).
This experiment is presented here.

2e14, uniform, injection **1.5m, 800pC**, RIF +100, eDelay -100
2e14, 4% @ 1.25m, injection **1.5m, 800pC**, RIF +100, eDelay -200

Analysis performed on the distortion and perspective corrected stitched SPECTRO array image

- No concerns over position (to energy) calibration – full screen in view
- Higher resolution than intensified camera image

The experimental approach

Experimental update

Select the configuration (RIF and eDelay) that suits the uniform and density step case

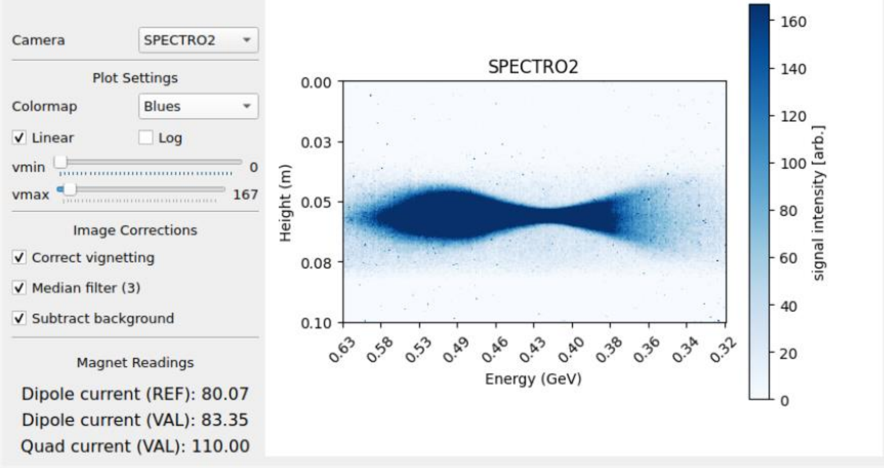
Check stability and reproducibility under standard accelerating conditions (no foils, full 10 meters)

Check charge capture through LBDP2, to assess how likely signal will be seen through a plunger

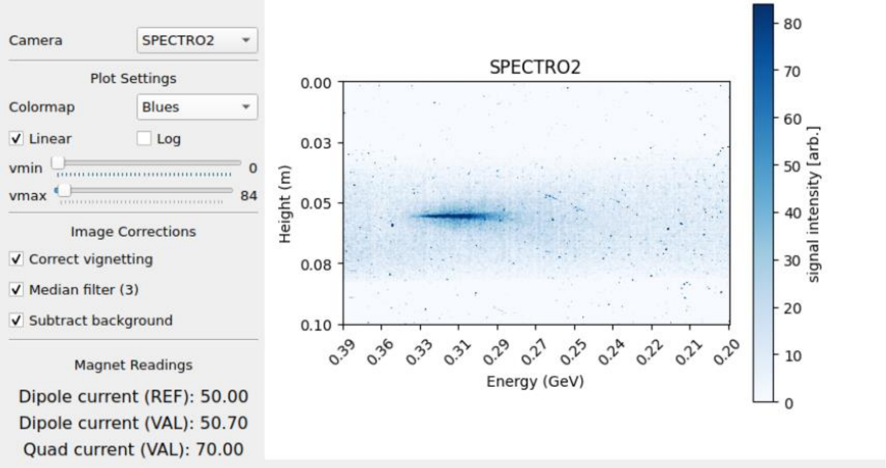
10 laser shots delivered on each plunger, until no hint of a signal remains. For each plunger:

- The spectrometer quadrupoles are shifted in accordance with the altered spectrometer geometry and predicted energy gain.
- The spectrometer dipole is moved to place the signal, regardless of energy, on SPECTRO2. This is to minimise over-dispersing weaker signals, as well as avoiding the highest radiation camera.

LBDP2 (10 meters acceleration)



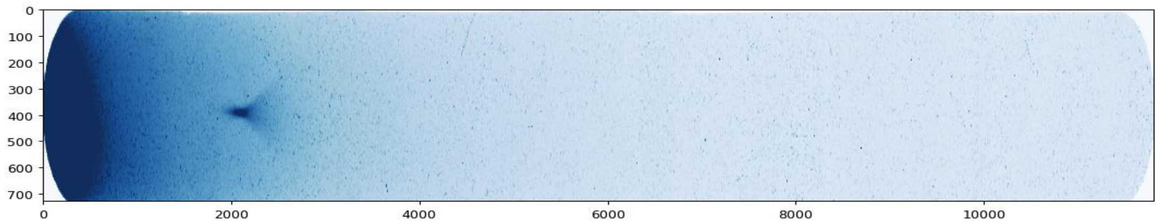
Plunger 7 (6.5 meters acceleration)



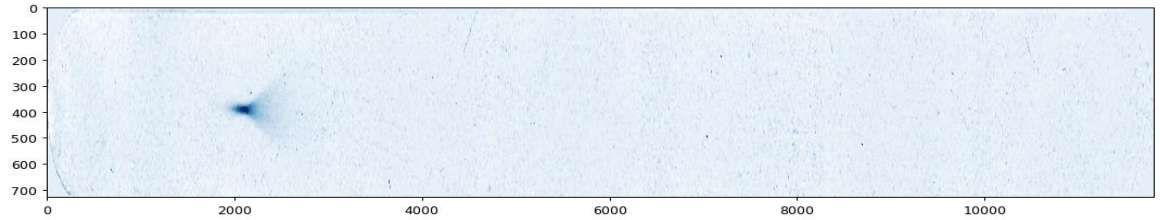
The analysis approach

Experimental update

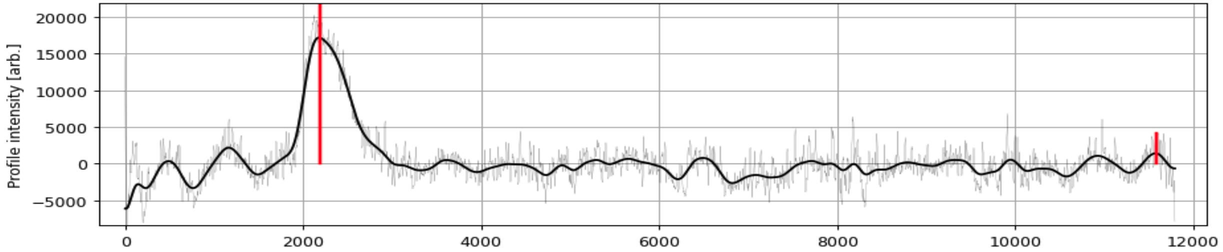
Obtain the 7-camera, corrected and stitched image of the acceleration event



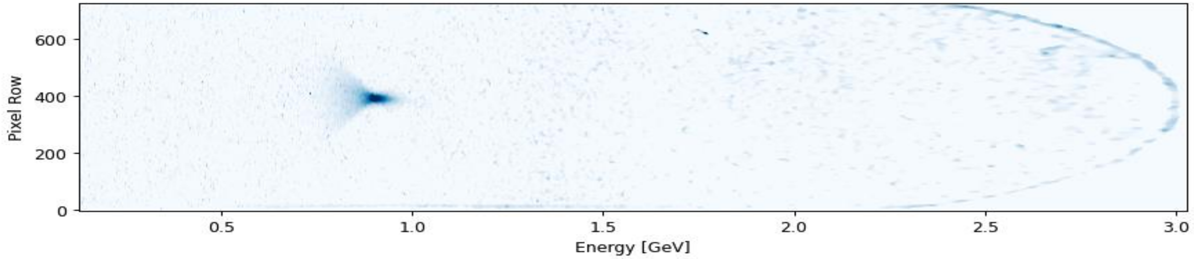
Apply a background subtraction to enhance the signal. Used here: strong background subtraction based off fits to various AWAKE proton conditions



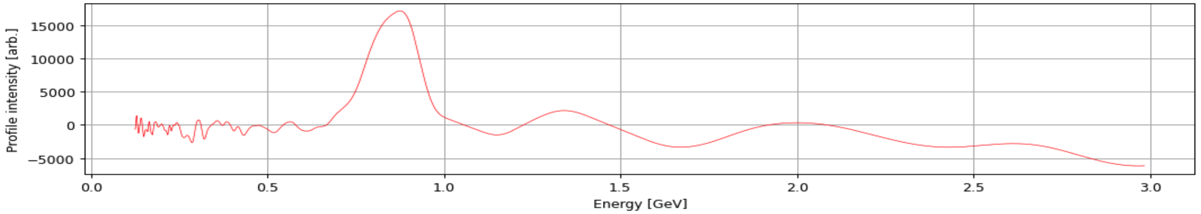
Identify location of peak in the image. Done here by sampling random intervals, optimising and binning.



Convert the image from pixels to energy via the spectrometer position to energy conversion model



Convert the 1D pixel array of the event into energy via the spectrometer position to energy conversion model



2e14: Example signals across the scans

Experimental update

2e14, uniform

LBDP2

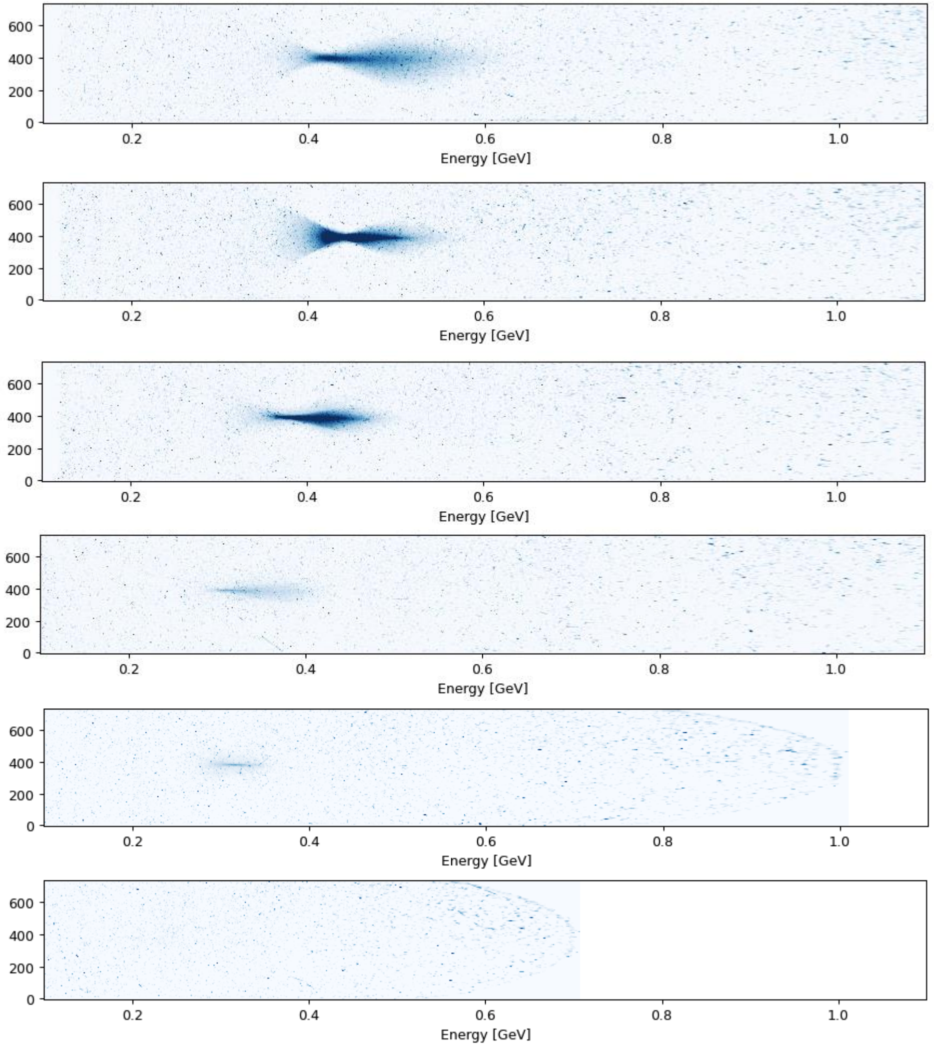
Plunger 10

Plunger 9

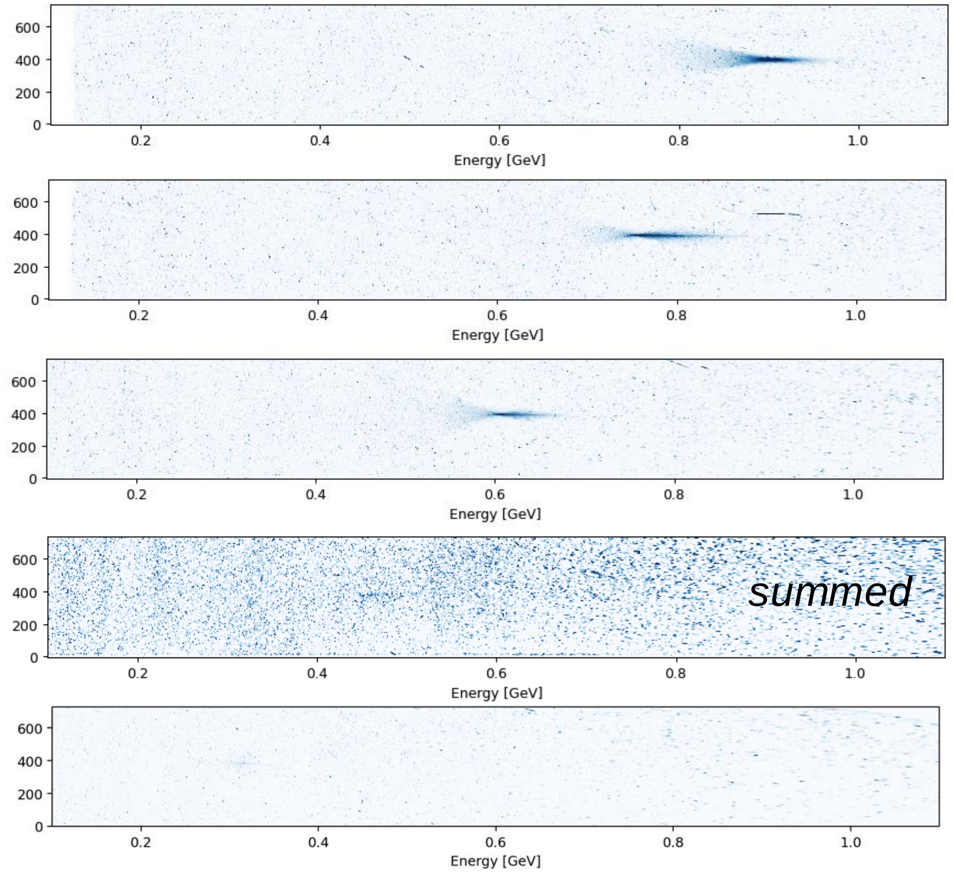
Plunger 8

Plunger 7

Plunger 6



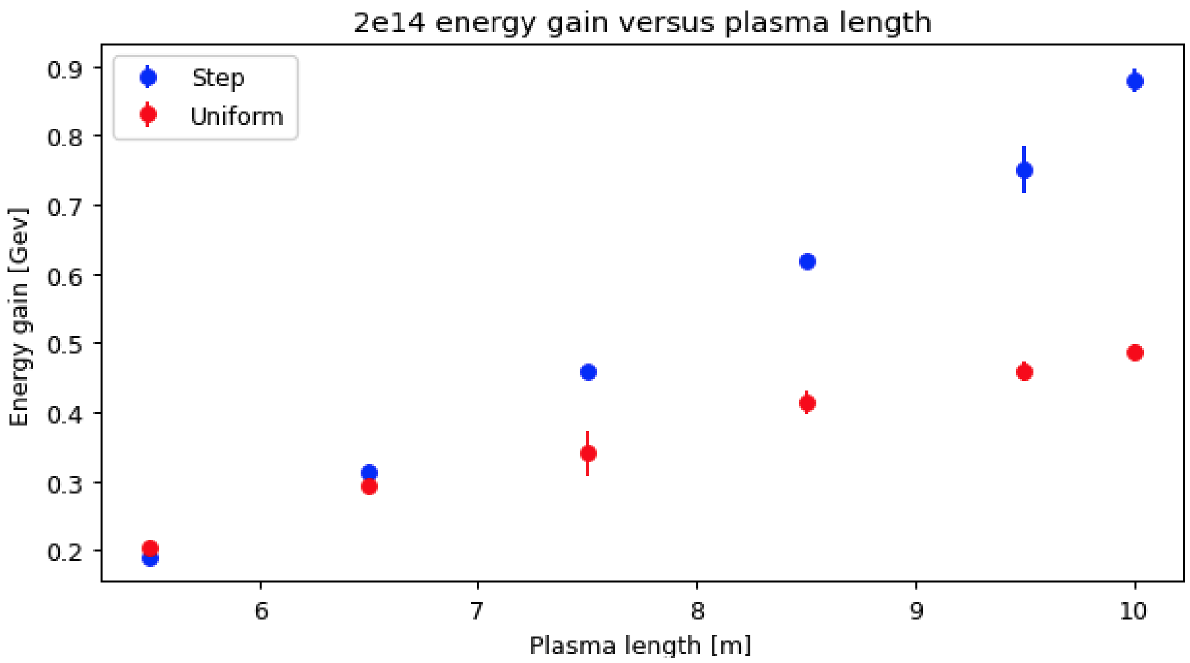
2e14, 4% @ 1.25m



(SPECTRO GUI)

Experimental update

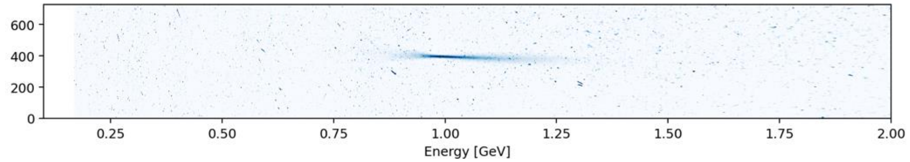
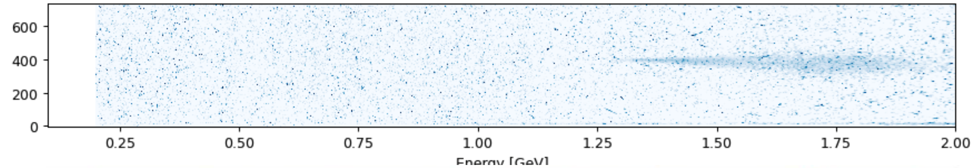
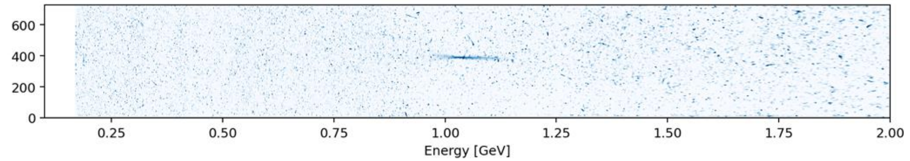
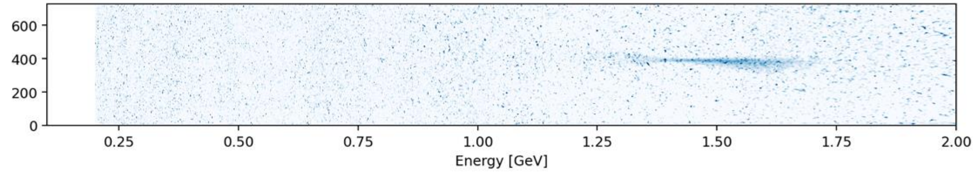
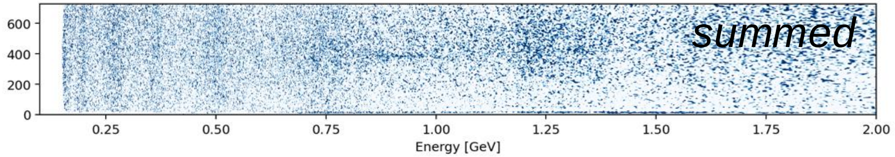
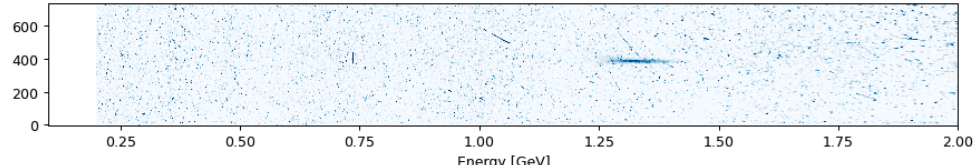
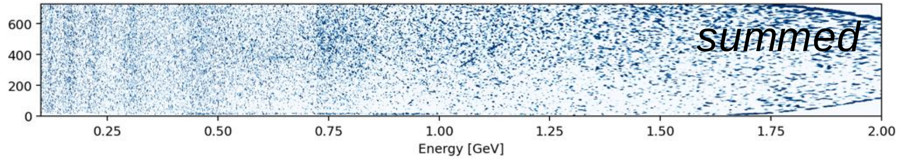
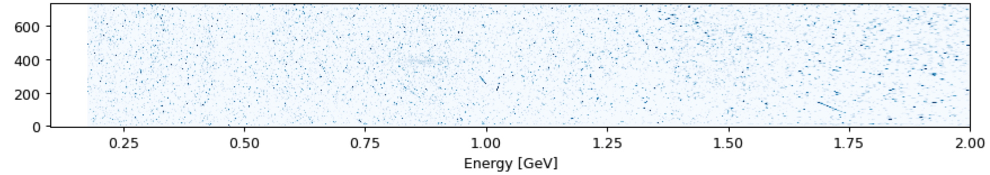
2e14 gradient measurement



2e14, uniform, injection **1.5m, 800pC**, RIF +100, eDelay -100
2e14, 4% @ 1.25m, injection **1.5m, 800pC**, RIF +100, eDelay -200

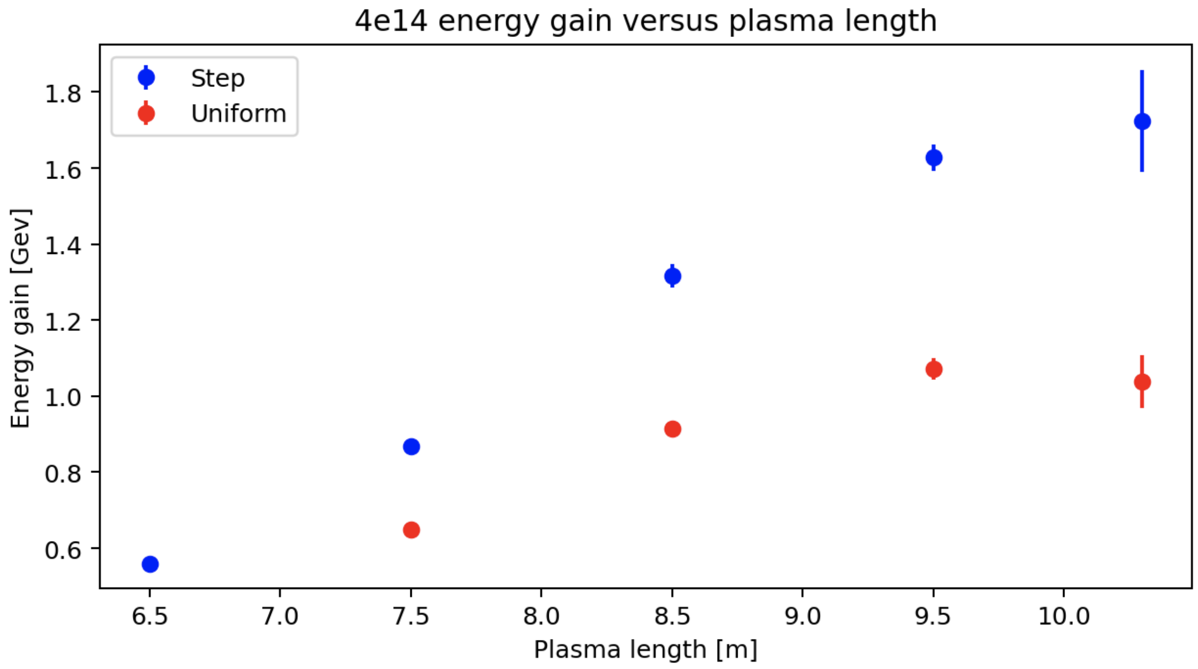
4e14: Example signals across the scans

Experimental update

	4e14, uniform	**4e14, 2% @ 1.25m**
LBDP2		
Plunger 10		
Plunger 9		
Plunger 8		
Plunger 7	*No signal*	*(SPECTRO GUI)*
Plunger 6	*No signal*	*No signal*

Experimental update

4e14 gradient measurement

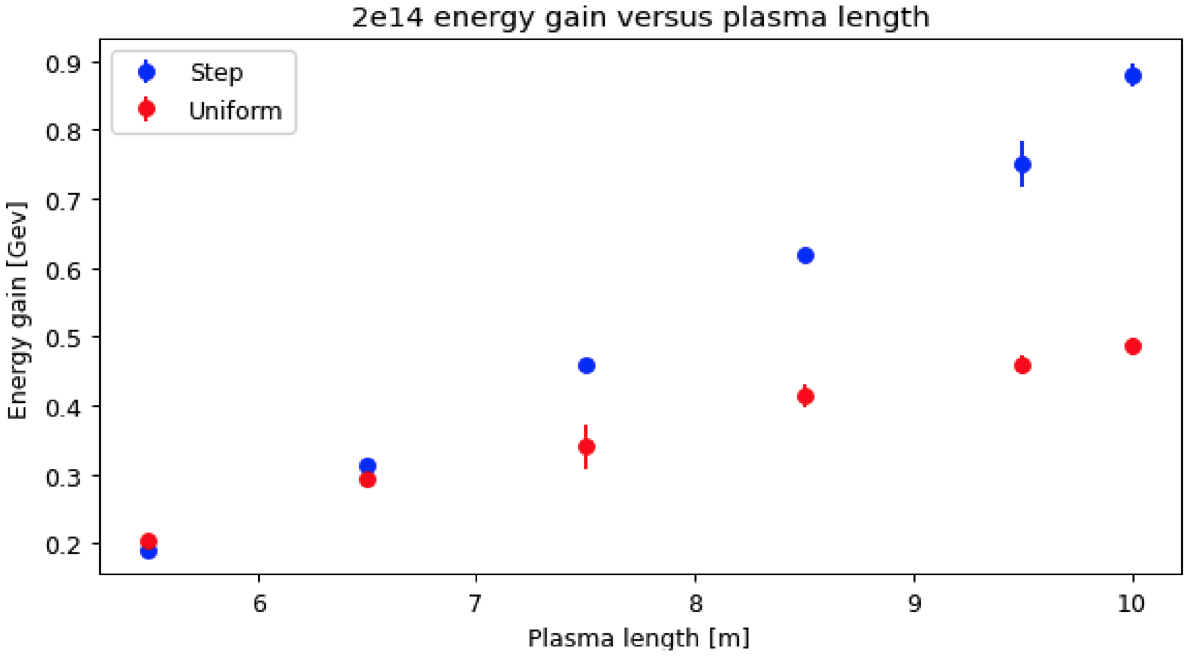


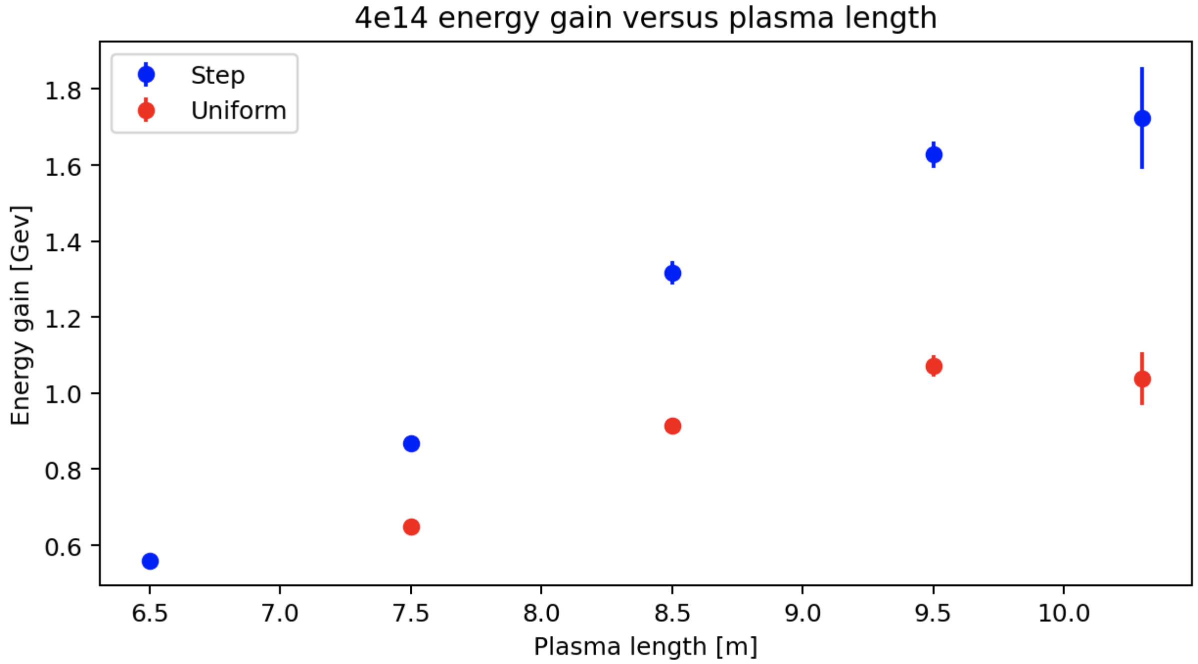
We were very up against the (LHC) clock with this measurement… repeat!

4e14, uniform, injection **1.5m, 800pC**, RIF +200, eDelay -400
4e14, 2% @ 1.25m, injection **1.5m, 800pC**, RIF +200, eDelay -400

Experimental update

Gradient measurement





2e14, uniform, injection **1.5m, 800pC**, RIF +100, eDelay -100
2e14, 4% @ 1.25m, injection **1.5m, 800pC**, RIF +100, eDelay -200

4e14, uniform, injection **1.5m, 800pC**, RIF +200, eDelay -400
4e14, 2% @ 1.25m, injection **1.5m, 800pC**, RIF +200, eDelay -400

Stitched image work largely complete. Ongoing updates as room for improvement/bugs are spotted.

Spectrometer DQMs upgraded, much better background subtraction (and therefore online charge measurements). Stitched image implemented, plotted in energy.

Emittance measurements underway. First look at results with standard acceleration show higher geometric emittances than the Run 2a study. Previous issue with extracting emittance from weak signals in standard acceleration setup has been resolved. Background subtraction when a foil is in the line remains challenging, but progress is being made.

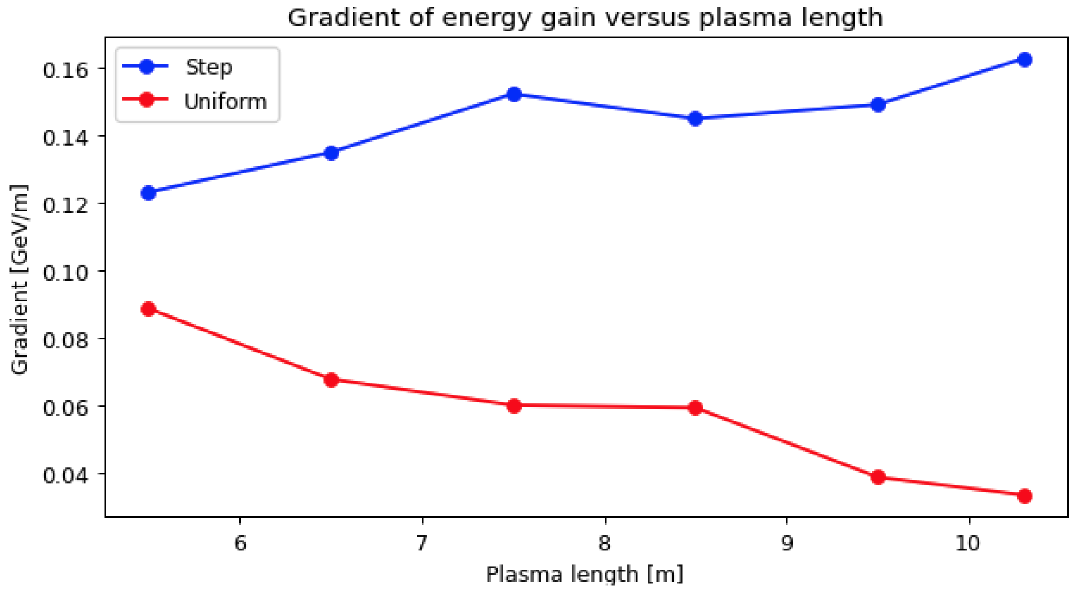
Plunger scan analysis continues. The 2e14 800pC scan appeared to be the ‘cleanest’ result in the control room. Offline analysis supports this. Remaining plunger gradient plots to be added to the summary book before the next run starts.

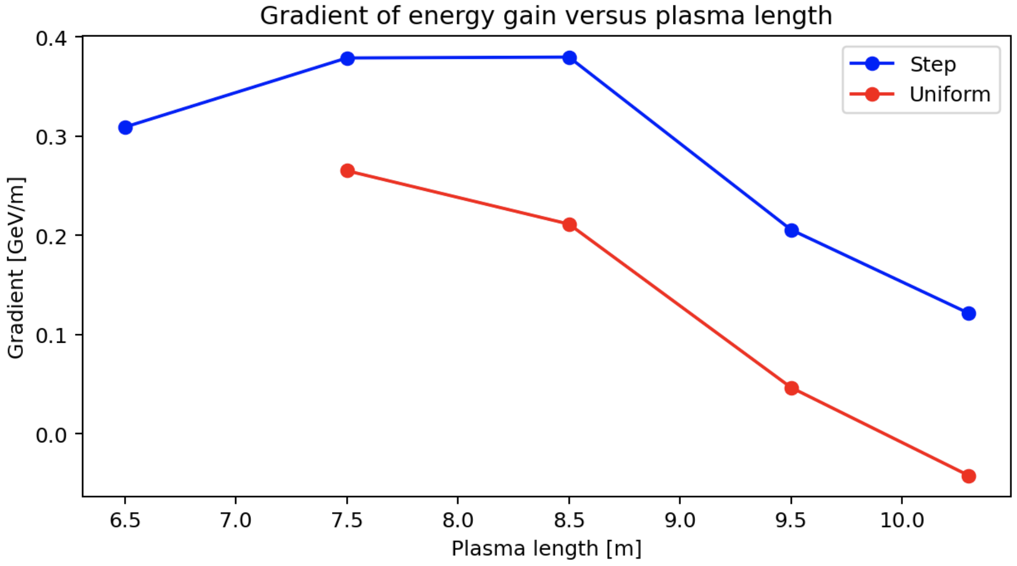
Thank you!!

Back up

Experimental update

Gradient measurement



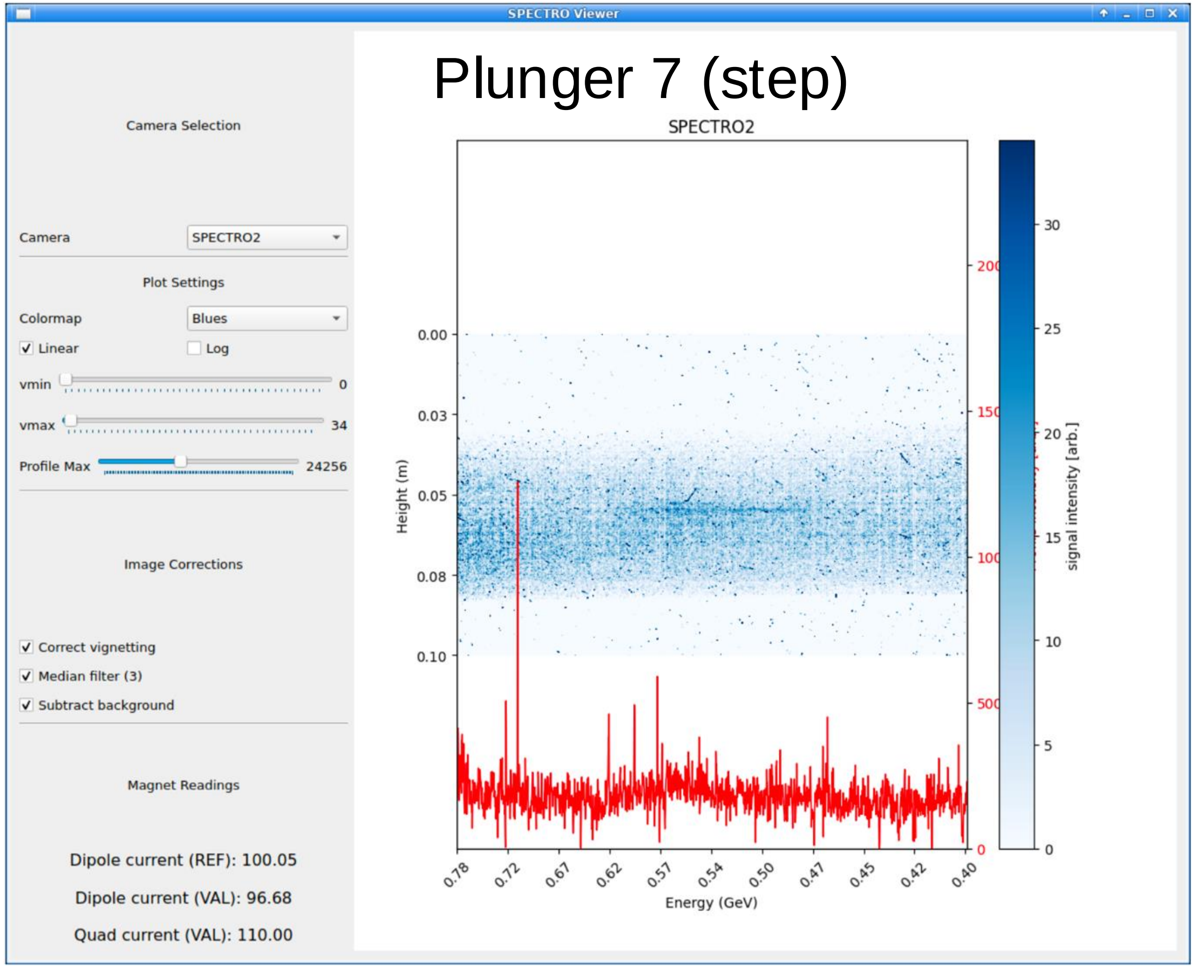


2e14, uniform, injection **1.5m, 800pC**, RIF +100, eDelay -100
2e14, 4% @ 1.25m, injection **1.5m, 800pC**, RIF +100, eDelay -200

4e14, uniform, injection **1.5m, 800pC**, RIF +200, eDelay -400
4e14, 2% @ 1.25m, injection **1.5m, 800pC**, RIF +200, eDelay -400

SPECTRO GUI

Experimental update



SPECTRO GUI

Experimental update