E200 quad scans at FACET

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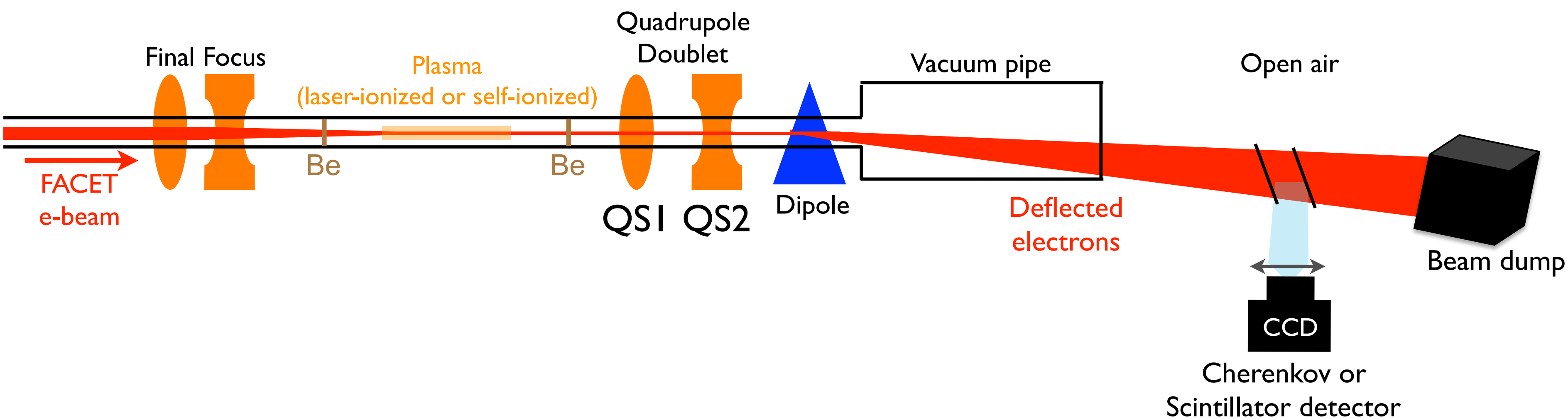
Outline

- Dumpline experimental set-up
- Quad scans for energy spectrum measurements
- Multishot quad scan emittance measurements
- Possible improvements for FACET-II

Dumpline experimental set-up

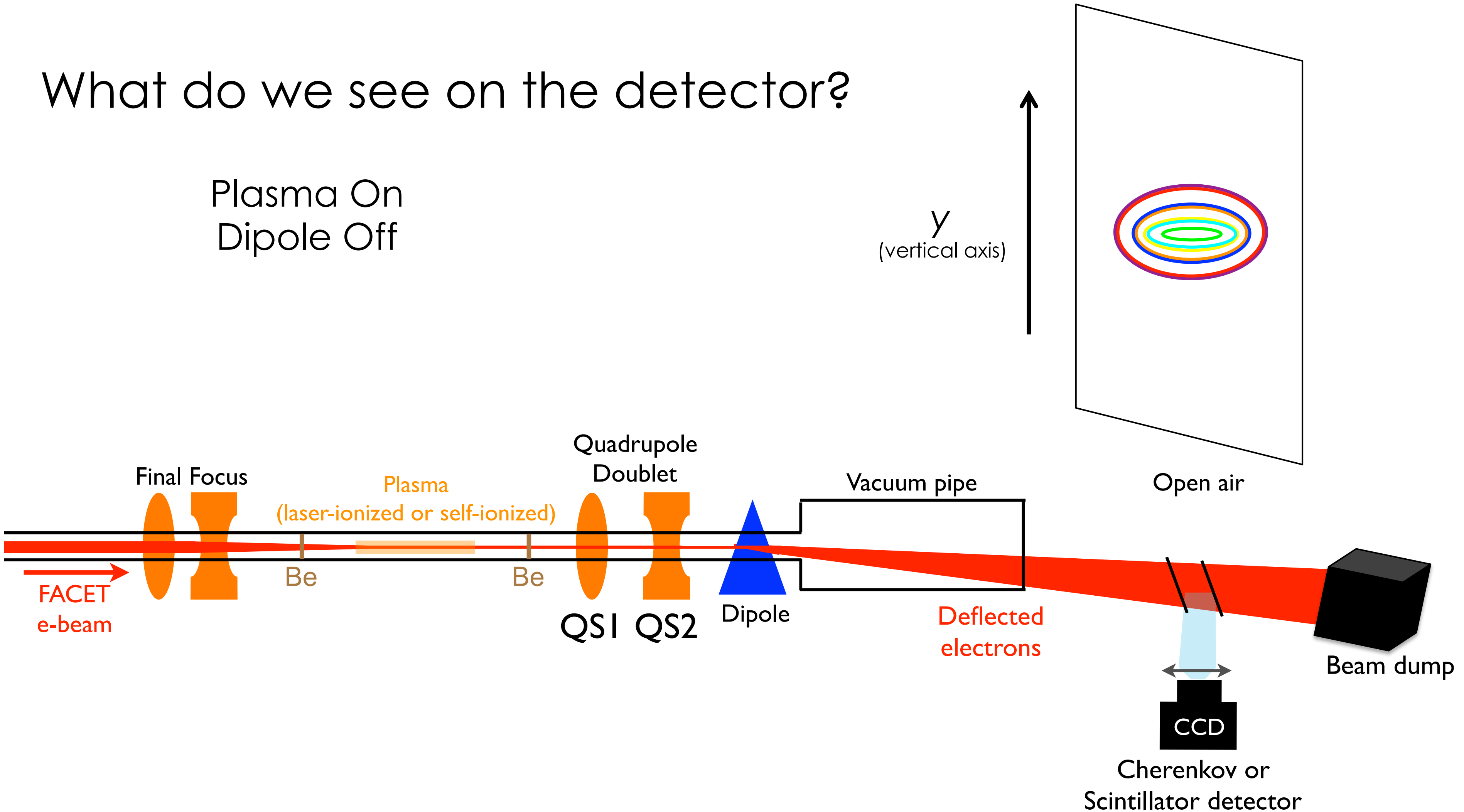
- To properly characterize the beam coming out of the plasma, one needs to re-focus the beam onto the detectors.
- The beam coming out of the plasma has a complex and broad energy spectrum, i.e. is not monoenergetic.
- A quadrupole doublet (QS1 and QS2) and a dipole is used in the dumpline to address these issues.



Dumpline experimental set-up

What do we see on the detector?

Plasma On
Dipole Off

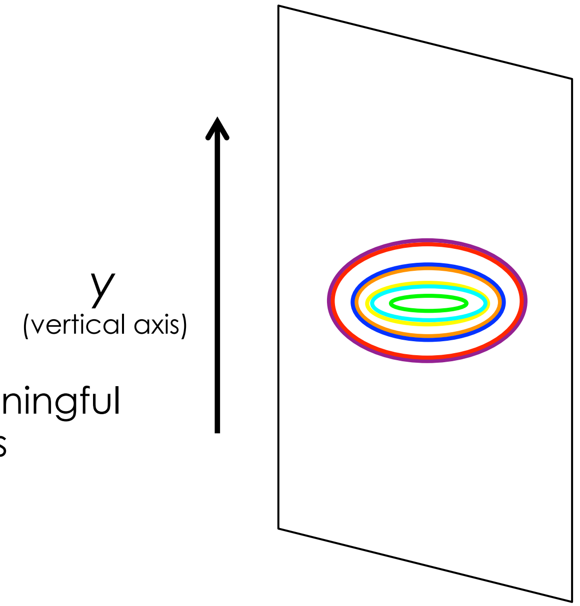


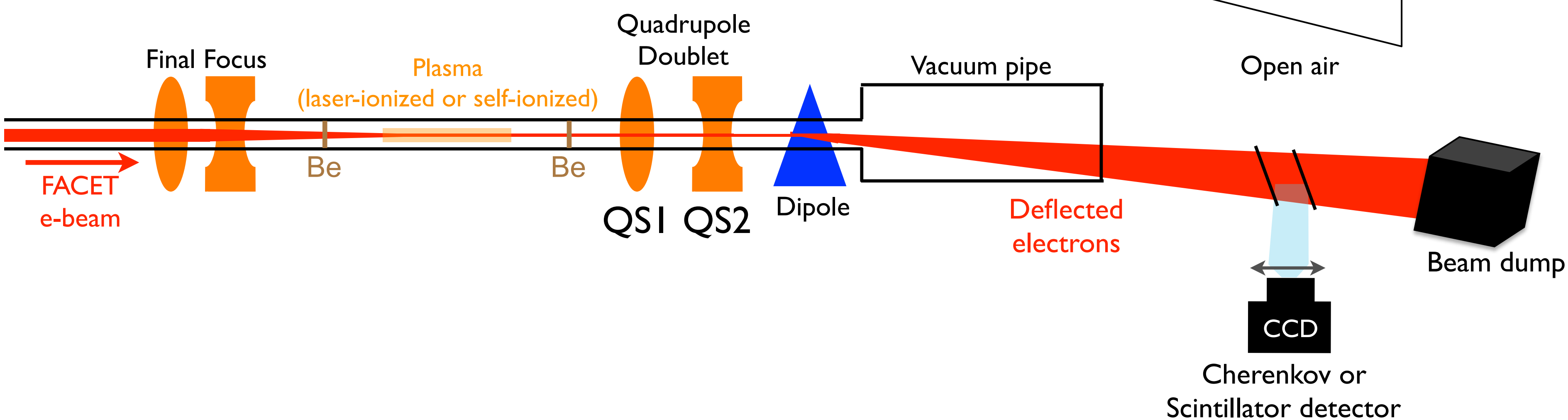
Dumpline experimental set-up

What do we see on the detector?

Plasma On
Dipole Off

→ Quad scans don't provide meaningful emittance measurements

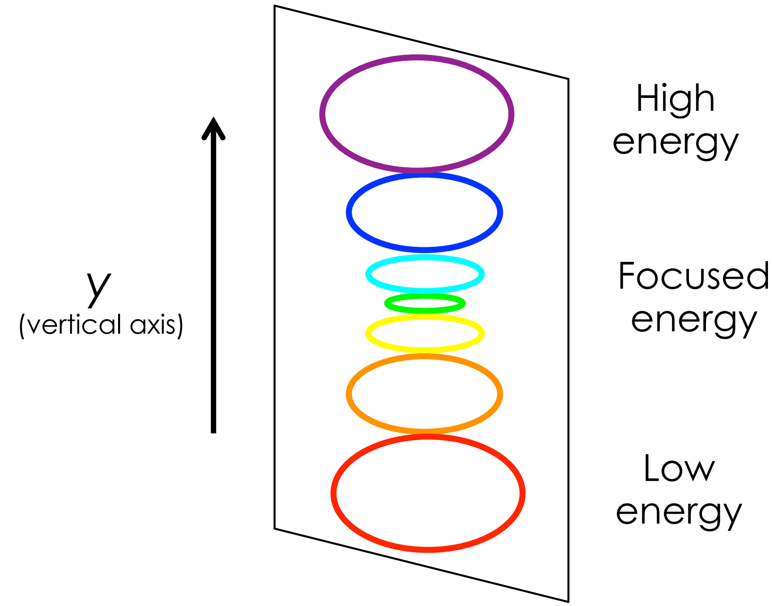


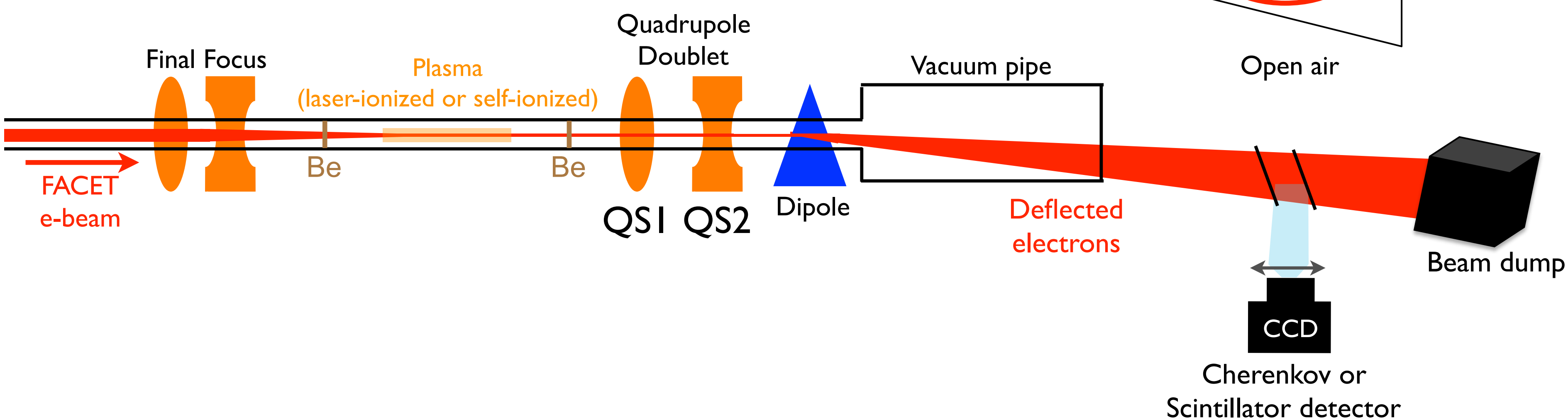


Dumpline experimental set-up

What do we see on the detector?

Plasma On
Dipole On

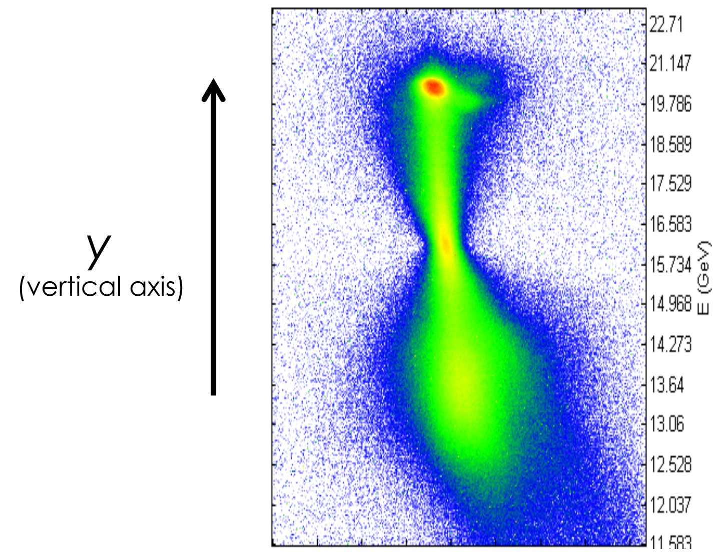


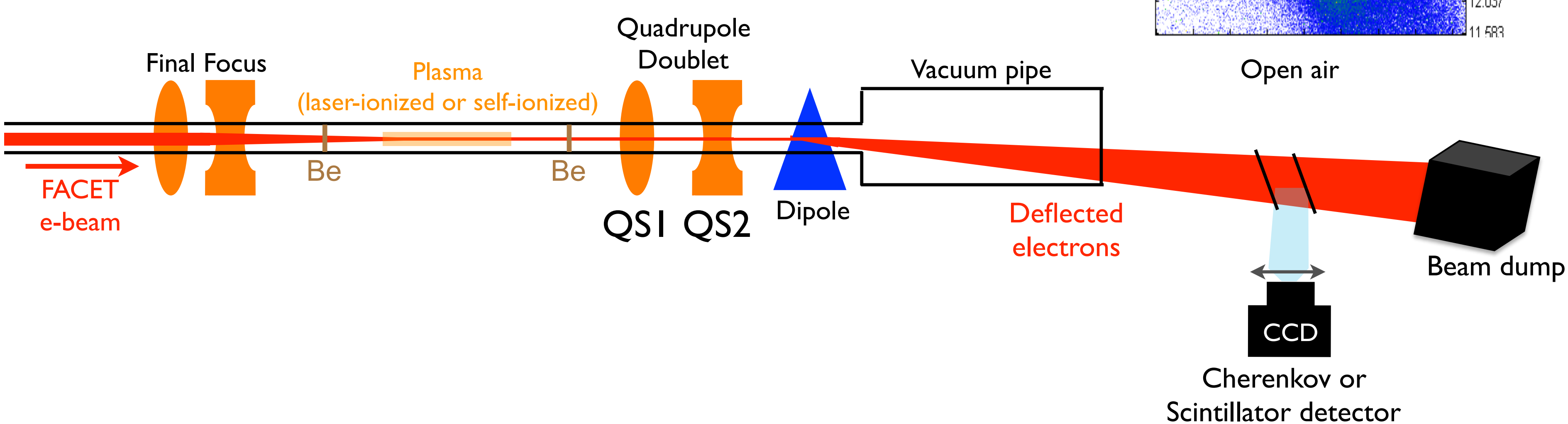


Dumpline experimental set-up

What do we see on the detector?

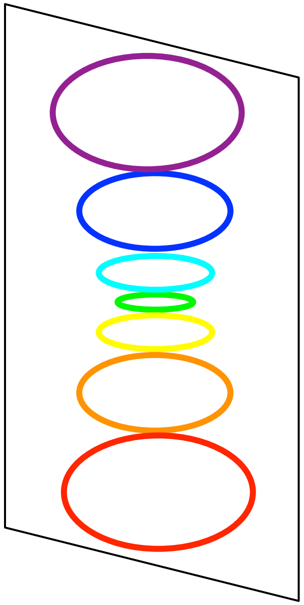
Plasma On
Dipole On





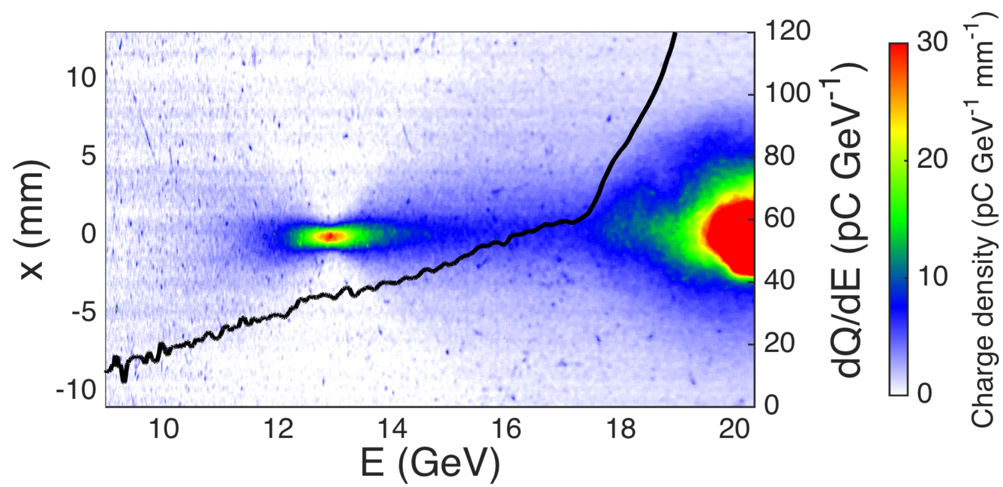
Messages?

- Spectral measurement is only accurate over a finite energy bandwidth
- Emittance can be measured in a single shot ("butterfly" method, see next talk)
- Can deduce the exit position of the beam
- Emittance can be measured with a multishot quad scan, if the transport matrix is properly adjusted



Spectral measurements

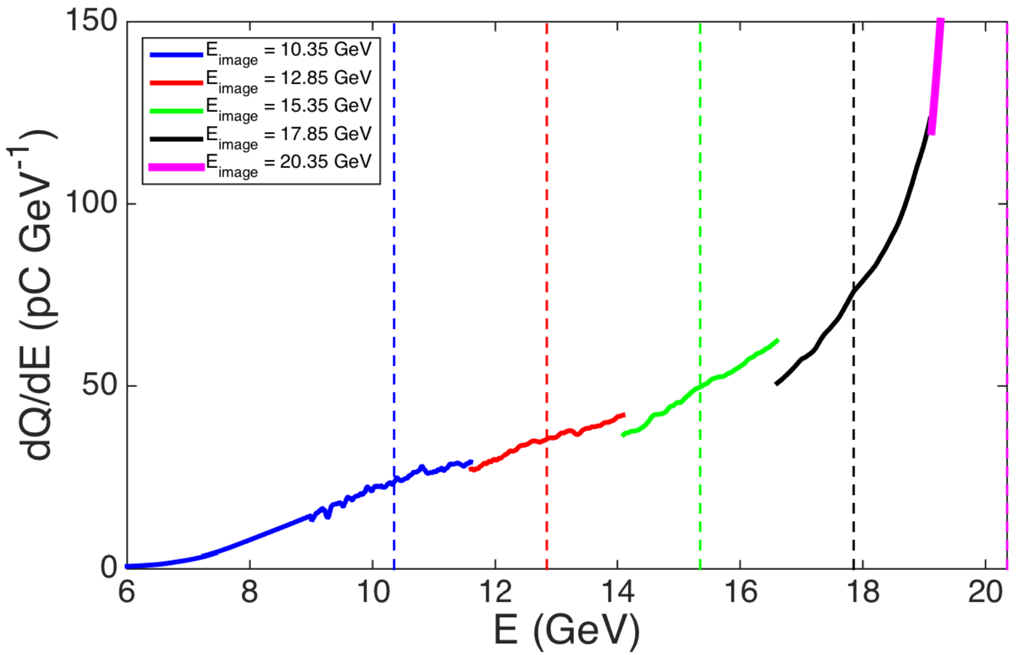
- For large energy loss, it is difficult to measure the decelerated spectrum in a single shot.
- Measured decelerated spectrum is dependent on the quadrupole doublet setting, because particles are defocused away from the focus energy set point and signal goes below noise level.
- How to properly determine the energy transferred to the plasma by the drive beam (energy loss)?



Spectral measurements

- How to properly determine the energy transferred to the plasma by the drive beam (energy loss)?

→ Multishot piecewise spectral measurement



- This was necessary to determine energy loss and energy extraction efficiency (from the plasma wake to the accelerated bunch) in the letter "Multi-gigaelectronvolt acceleration of positrons in a self-loaded plasma wakefield" [Nature 524, 442 (2015)].

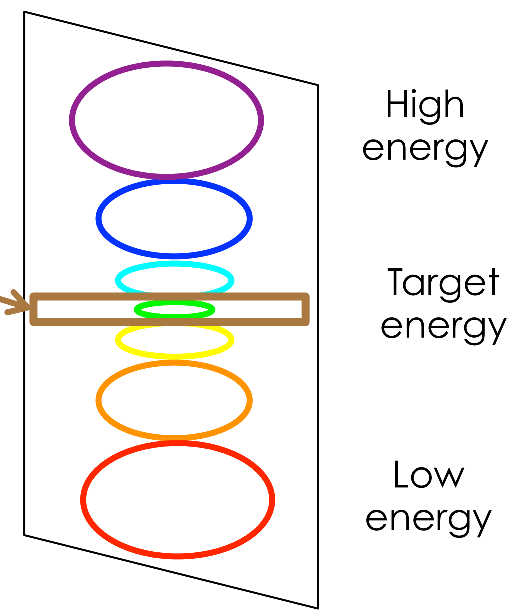
Quad scan emittance measurements

$$\langle x^2\rangle_{\mathrm{im}} = M_{11}^2\langle x^2\rangle_{\mathrm{ob}} + 2M_{11}M_{12}\langle xx'\rangle_{\mathrm{ob}} + M_{12}^2\langle x'^2\rangle_{\mathrm{ob}}$$

3 unknowns, related to the beam parameters:

$\alpha_x, \beta_x, \epsilon_x$

Area of interest, the rest of the image is disregarded

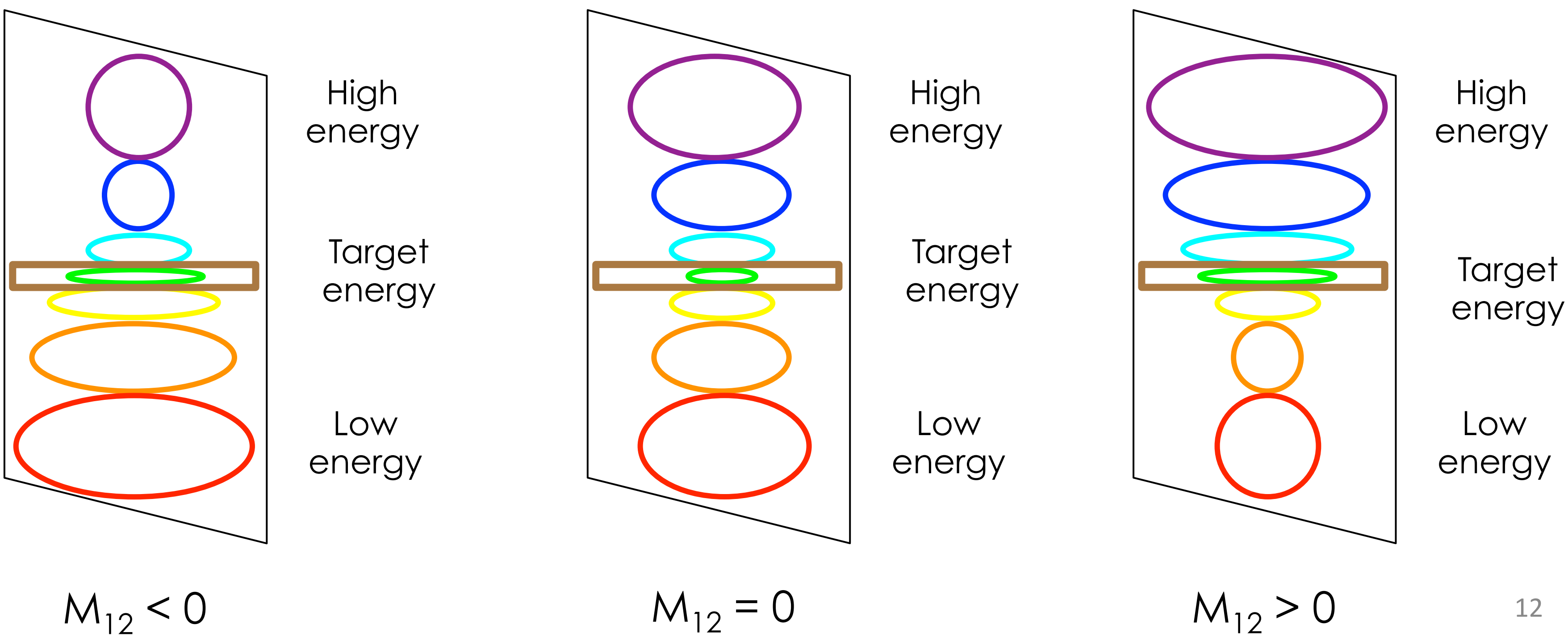


- M_{11} and M_{12} are known.
- M_{11} and M_{12} can be scanned for a target energy.
- The 3 unknowns can then be determined.
- M_{34} = 0 is necessary to minimize chomaticity in the vertical direction, i.e. to minimize the energy bandwidth contributing to the signal in the area of interest.

Quad scan emittance measurements

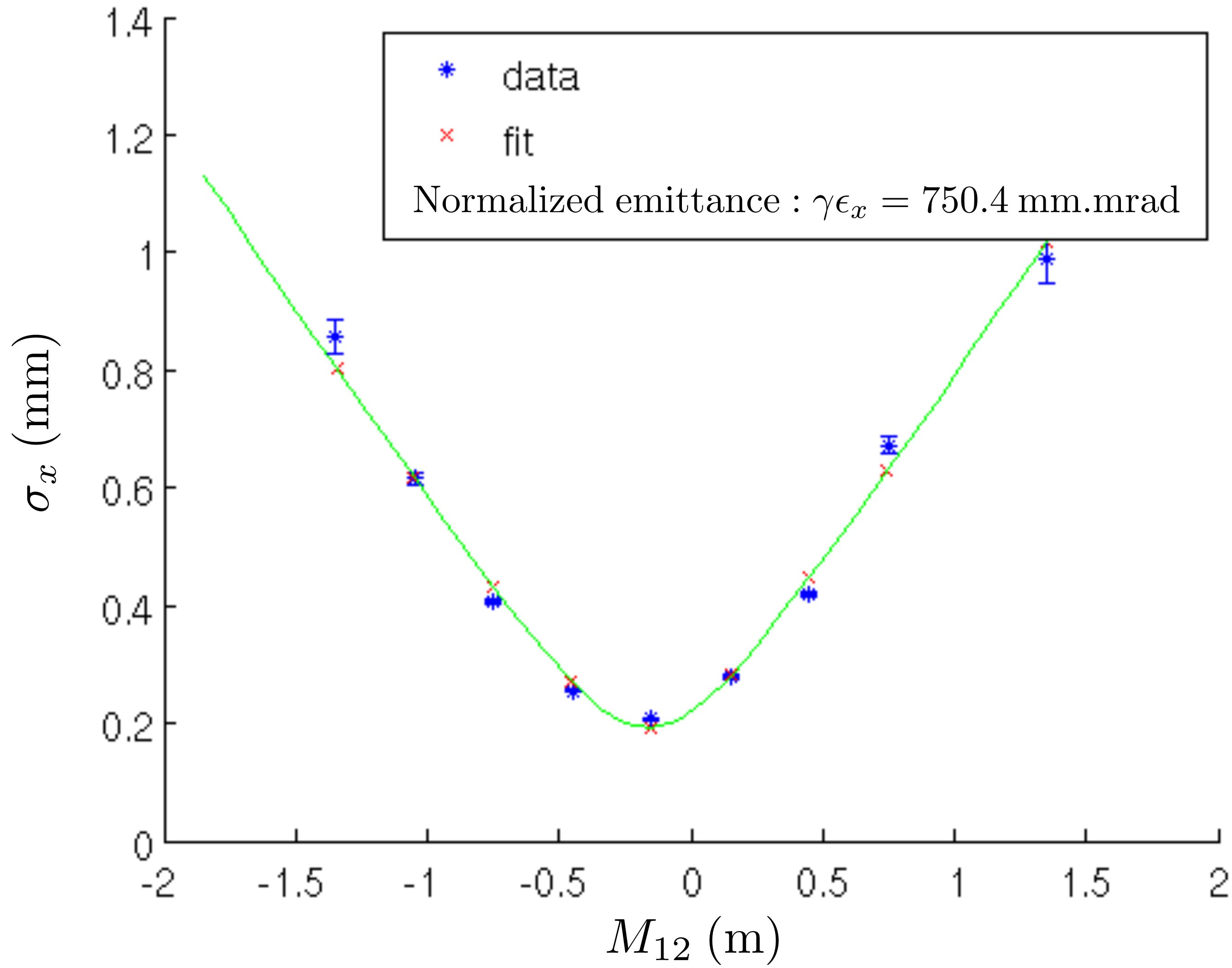
$$\langle x^2\rangle_{\text{im}} = M_{11}^2\langle x^2\rangle_{\text{ob}} + 2M_{11}M_{12}\langle xx'\rangle_{\text{ob}} + M_{12}^2\langle x'^2\rangle_{\text{ob}}$$

- Quad scan: QS1 and QS2 integrated gradient are set to satisfy a required M_{12} value and the additional condition $M_{34}=0$. M_{11} is calculated from the deduced QS1 and QS2 values in order to perform the fit over the experimental data.
- The scanned parameter is therefore M_{12}.



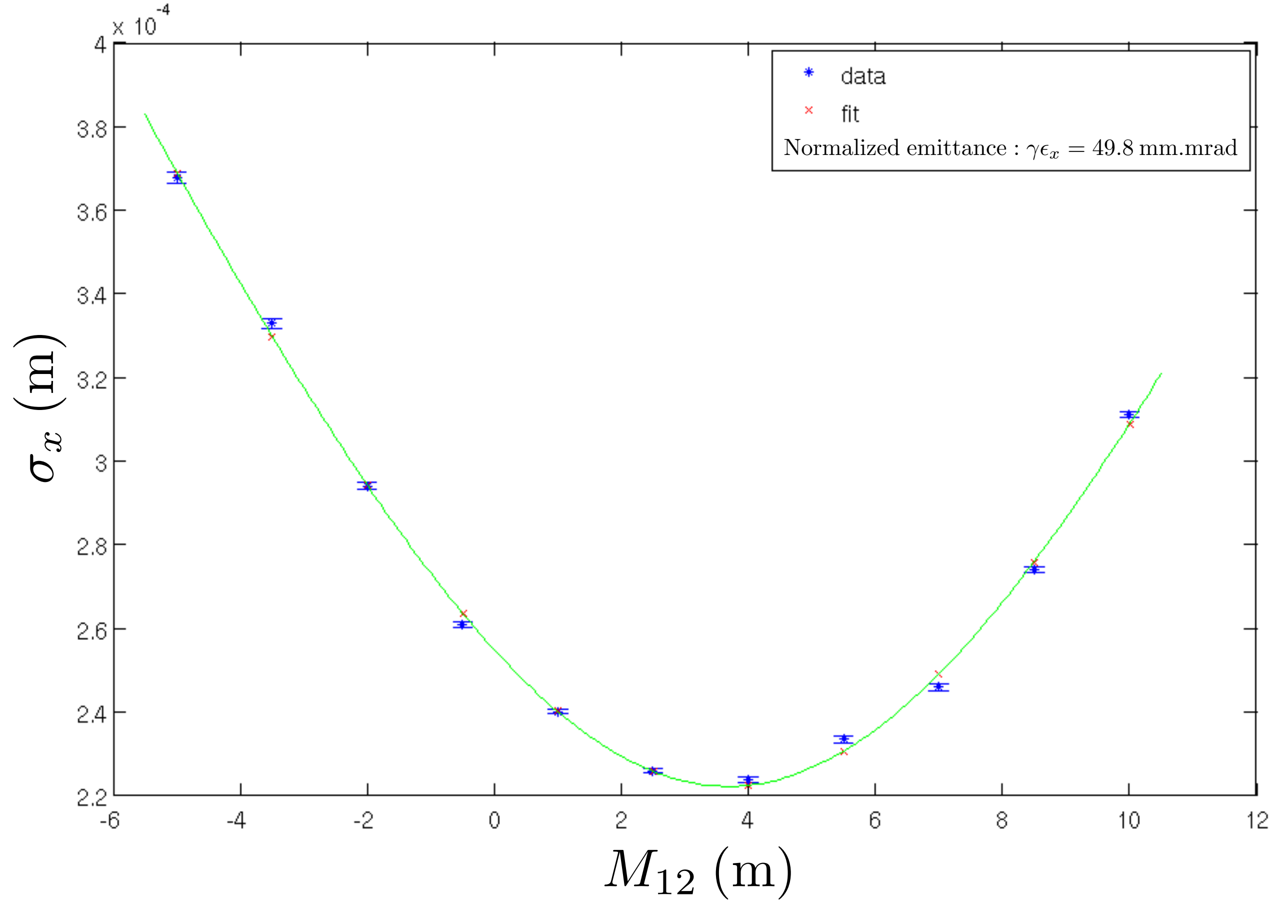
Quad scan emittance measurements

- Data from April 2016
- Two-bunch positron acceleration in uniform plasma
- Quad scan to characterize witness bunch emittance at an energy gain of +1.25 GeV



Quad scan emittance measurements

- Data from April 2016
- Witness bunch characterized in the absence of plasma



Quad scan emittance measurements

Pros:

- Precise measurement, no assumption on energy dependence of beam parameters.
- Can resolve very low divergence beams because the transport matrix can be scanned over a very wide range (typically M_{12} from -20 m to +20 m). Same beam size resolution than “butterfly” method, limited by the scintillator resolution and M_{11}.
- Can be used to validate “butterfly” method, which is a single shot measurement.

Cons:

- It is a multishot measurement. Cannot detect rare shots with extremely small emittance. Needs relatively stable outcoming beams.
- Works for the x dimension, not for the *y* dimension. Shouldn’t be a problem with more symmetric input beams.

Possible improvements for FACET-II

- Remove windows downstream of the plasma (Be window).
- Increase M_{11} as much as possible, to increase beam size resolution in the object plane.
- Improve beam size resolution in the image plane.
- If more quadrupoles are considered in the dumpline, optimization can be performed to reduce chromaticity in the *y* dimension over a wider energy bandwidth.

Conclusion

- Quad scans are usually necessary to properly characterize decelerated energy spectrum and energy transferred to the plasma by the drive beam

- Emittance measurement is possible with a quad scan in a dispersed region
  - ➢ Was demonstrated at FACET.
  - ➢ Can be very promising for FACET-II emittance preservation studies with normalized emittance down to a few micrometers.
  - ➢ An excellent complement to "butterfly" measurements.

- Several improvements possible:
  - ➢ Remove Be window.
  - ➢ Increase M_{11}.
  - ➢ Improve scintillator/profile monitor resolution.