Betatron radiation as emittance diagnostics for plasma acceleration experiments

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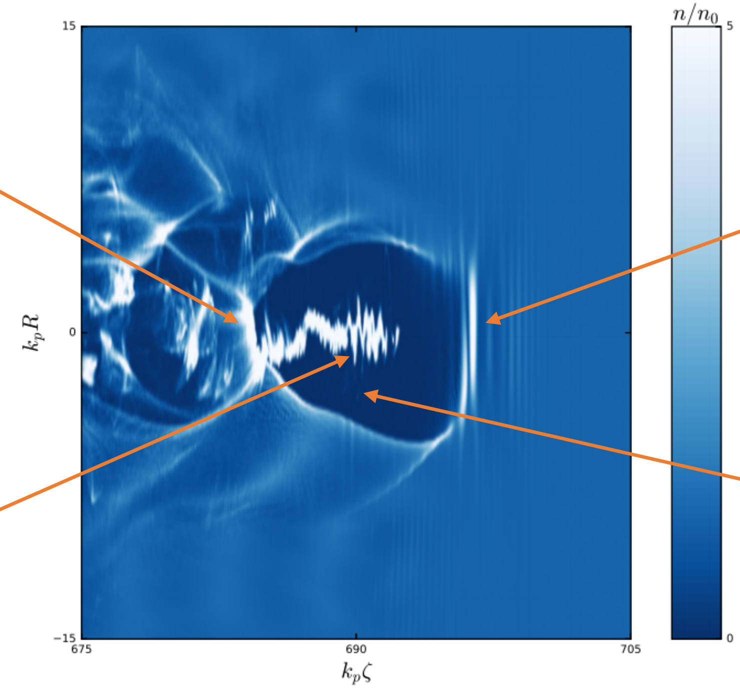
Plasma acceleration and betatron oscillations



Self-injection of electrons from the rear of the bubble

Betatron oscillations of the (self)injected electrons

Laser pulse driving the plasma wave
In the PWFA the plasma wave Is driven by an electron bunch

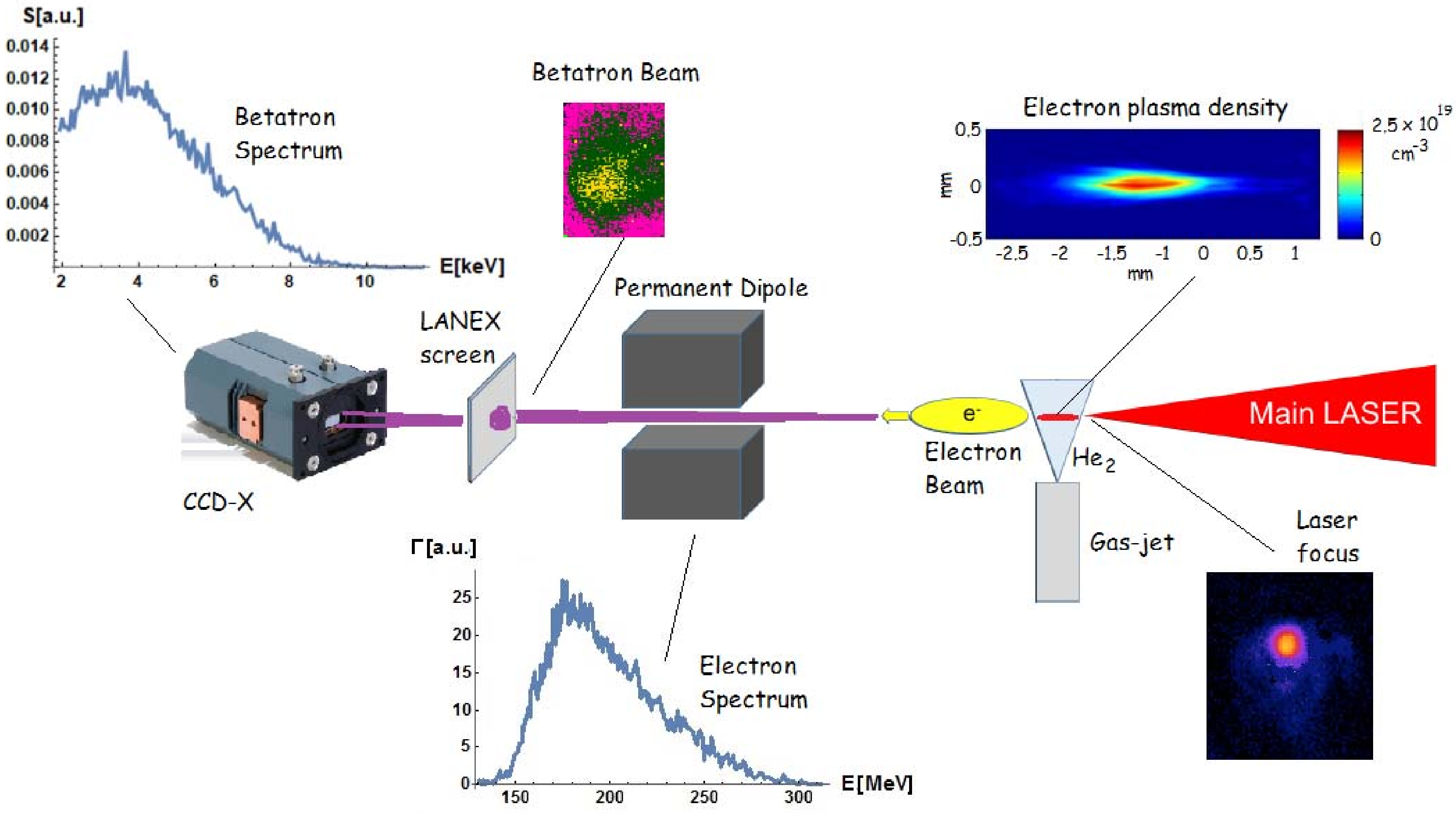
Cavitation region or ion-bubble where the accelerating/focusing fields develop, up to TV/m

How do we check the quality/characteristics of the beams we accelerate?

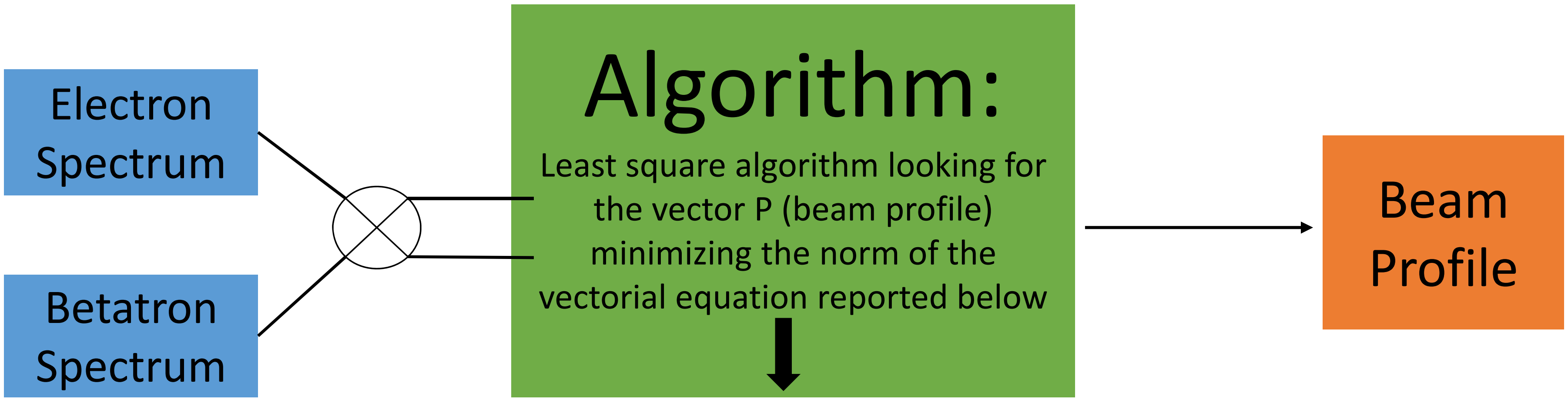
Motivations

- Design/conceivement of a non-intercepting diagnostics for plasma accelerated electron beams
- Infer information about the electrons when they are still inside the plasma accelerating structure
- Measurement of the rms emittance, comprising the correlation term

LWFA setup at FLAME



First step: beam profile retrievement/1



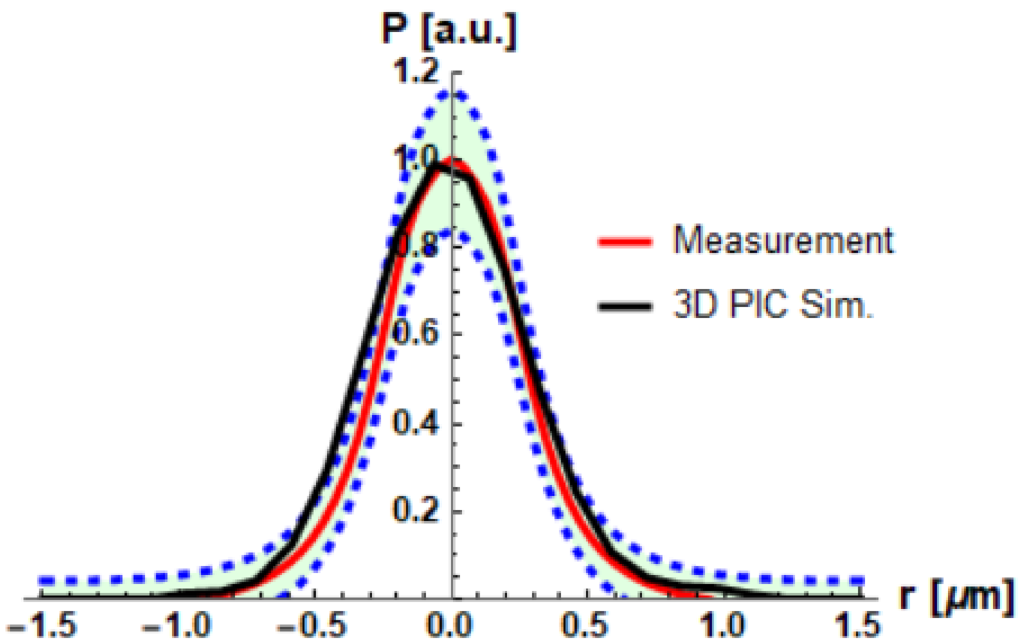
$$r^i P^i S_{ij}^{\star} - \Sigma(E_j) = 0$$

Theoretical spectrum:
Depending on measured plasma density and electron spectrum

Measured betatron spectrum:
To be corrected accounting for X-ray absorption before detection

★ For details on the matrix S, see Ref. Curcio, A., et al. "Trace-space reconstruction of low-emittance electron beams through betatron radiation in laser-plasma accelerators." *Physical Review Accelerators and Beams* 20.1 (2017): 012801.

First step: beam profile retrievement/2

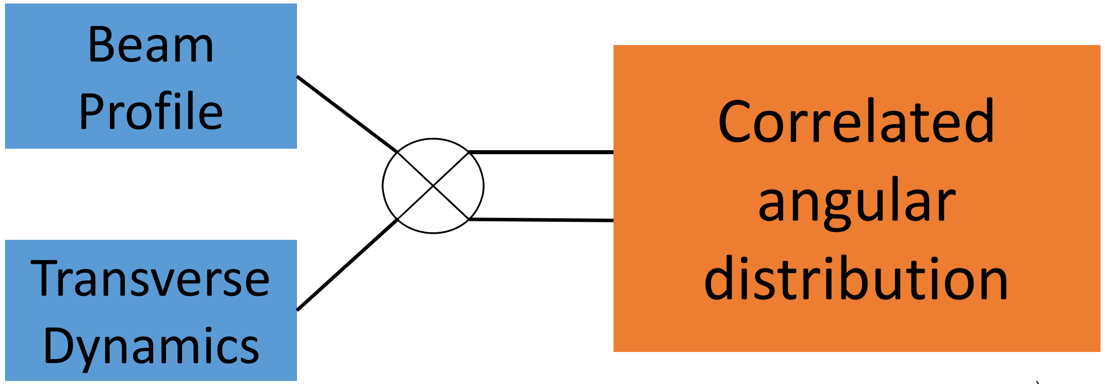


Electron beam radial profile detected (red curve) and simulated (black curve). The blue dashed curves delimit the error region (light green-shadowed).

Beam rms size 0.25±0.04 um

☆ For the generalization to the 2D case , see Ref. Curcio, A., et al. "Single-shot non-intercepting profile monitor of plasma-accelerated electron beams with nanometric resolution." *Applied Physics Letters* 111.13 (2017): 133105.

Second step: angular distribution retrievement/1



$$\theta_d = \sqrt{\frac{\sqrt{1+\frac{1}{2}\gamma_0^2 r_\beta^2 k_{\beta 0}^2}}{4\gamma_0}}\, r_\beta k_p$$

Correlation function between the angle and the position of a single electron of the beam in the bubble

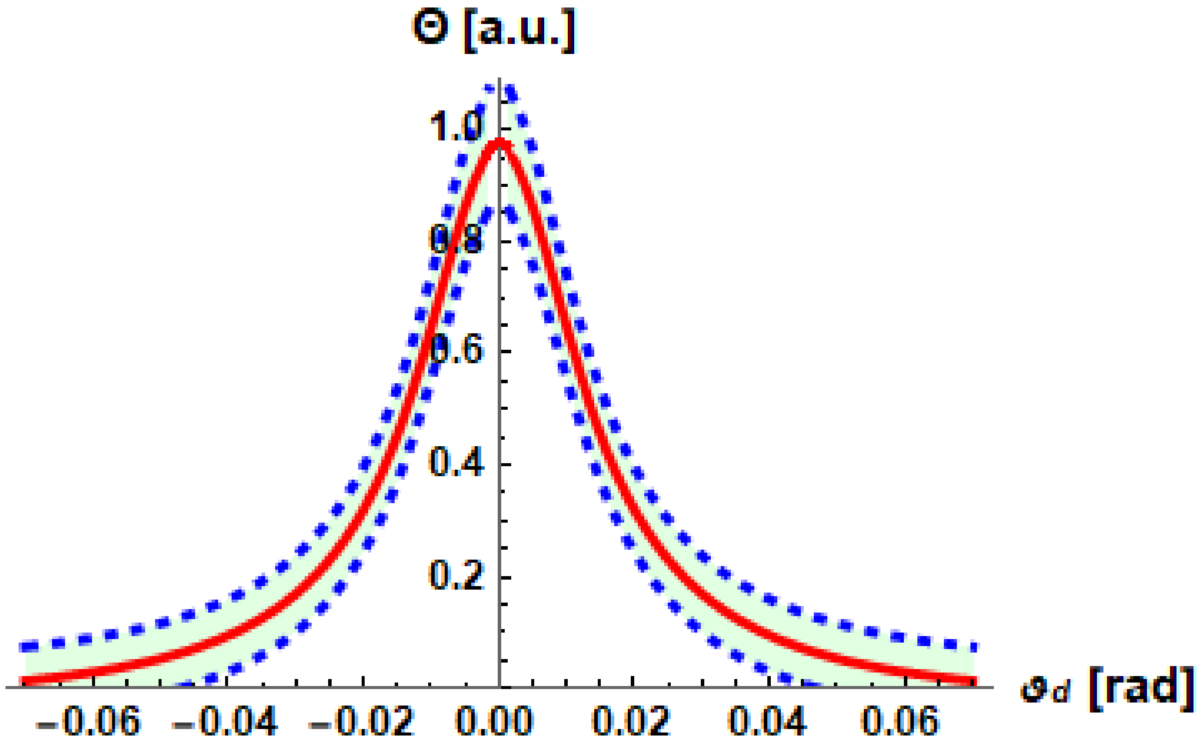
$$\Theta(\theta_d) \propto P[r(\theta_d)]$$

The angular distribution inside the bubble is retrieved starting from the retrieved beam profile !

$$r_\beta = \sqrt{2} r$$

Relation between the betatron radius and the average electron radial position along the acceleration path

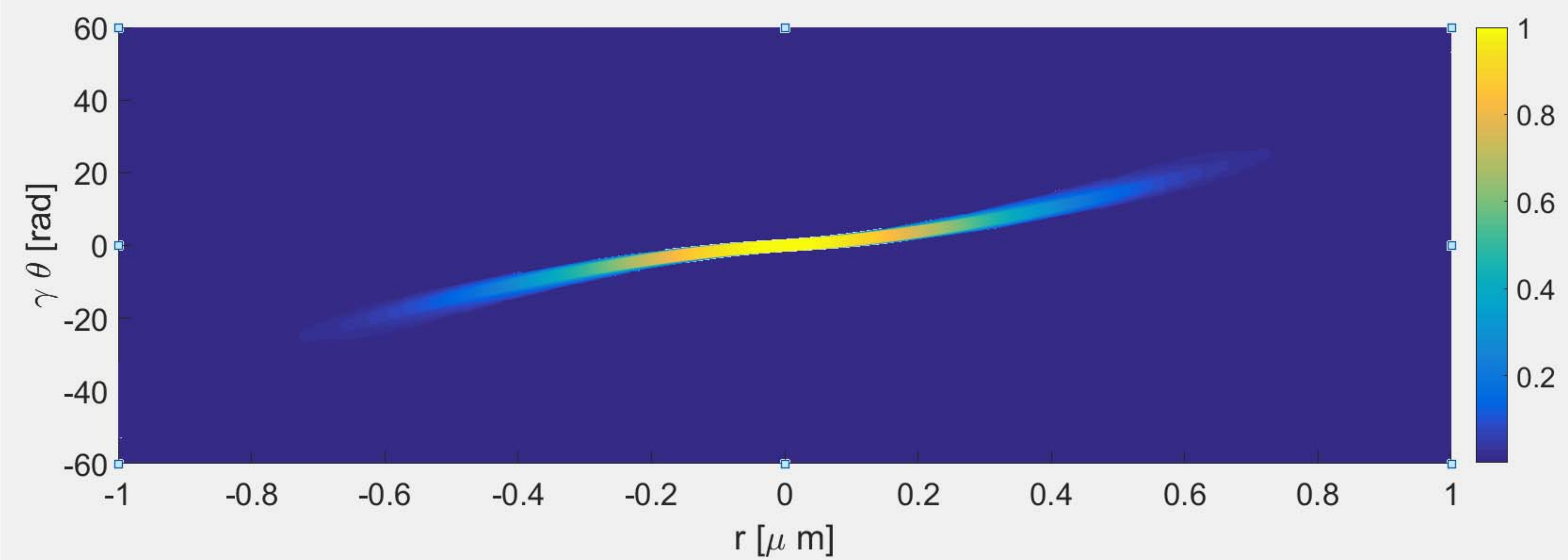
Second step: angular distribution retrievement/2



Angular distribution of the electron beam detected inside the bubble (red curve) .
The blue dashed curves delimit the error region (light green-shadowed).

Beam rms divergence 13±2 mrad.

Final step: Phase space recontruction



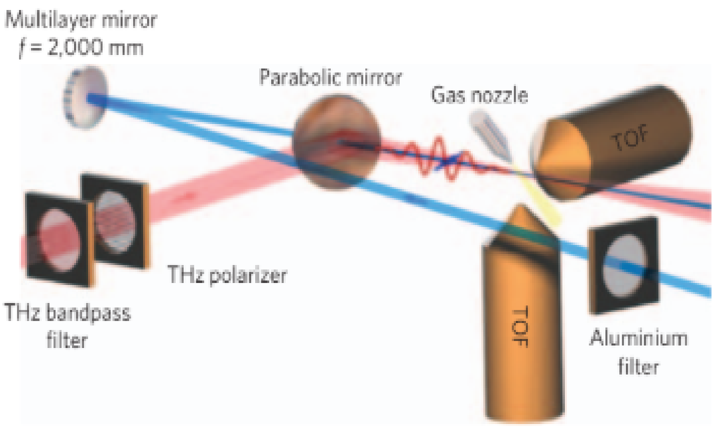
$$\epsilon_{r_\beta N} = \gamma_0 \sqrt{(\sigma_\gamma/\gamma_0)^2 \sigma_r^2 \sigma_\theta^2 + \epsilon_{r_\beta}^2}$$

Normalized rms emittance (correlated): 0.6 mm mrad

Normalized rms emittance (non correlated, upper limit): 1.6 mm mrad

What about the longitudinal phase space??

One idea is that to use a THz streak camera, using betatron radiation to generate photoelectrons, then watching at the energy modulation



THz Streak-Camera

Horizontally polarized soft X-ray (blue beam) and vertically polarized terahertz (red beam) pulses are focused and collinearly superimposed in a krypton gas target. Photoelectrons are detected with two time-of-flight (TOF) spectrometers, one parallel and one perpendicular to the terahertz polarization. A terahertz bandpass filter is used to narrow and smooth the terahertz spectrum. An aluminium filter is used to reduce the soft X-ray intensity.

For THz Streak-Camera, see Ref. : Frühling, U., Wieland, M., Gensch, M., Gebert, T., Schütte, B., Krikunova, M., ... & Plönjes, E. (2009). Single-shot terahertz-field-driven X-ray streak camera. *Nature Photonics*, *3*(9), 523.

Retrieval of the longitudinal phase space?

Another approach would be analogous to the one used for the retrieval of the transverse emittance, MUTATIS MUTANDIS!

Which is now the matrix to invert?

First if all, is it possible to find an expression for it?

How does the betatron power/spectrum depends on the longitudinal position of the single electrons within the bunch?

Work in progress, we are trying to find answer to the questions above…

AC1

Thanks
for your attention

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Diapositiva 12

AC1 Alex Curcio; 14/09/2018