Frontiers of Beam Diagnostics in Plasma Accelerators

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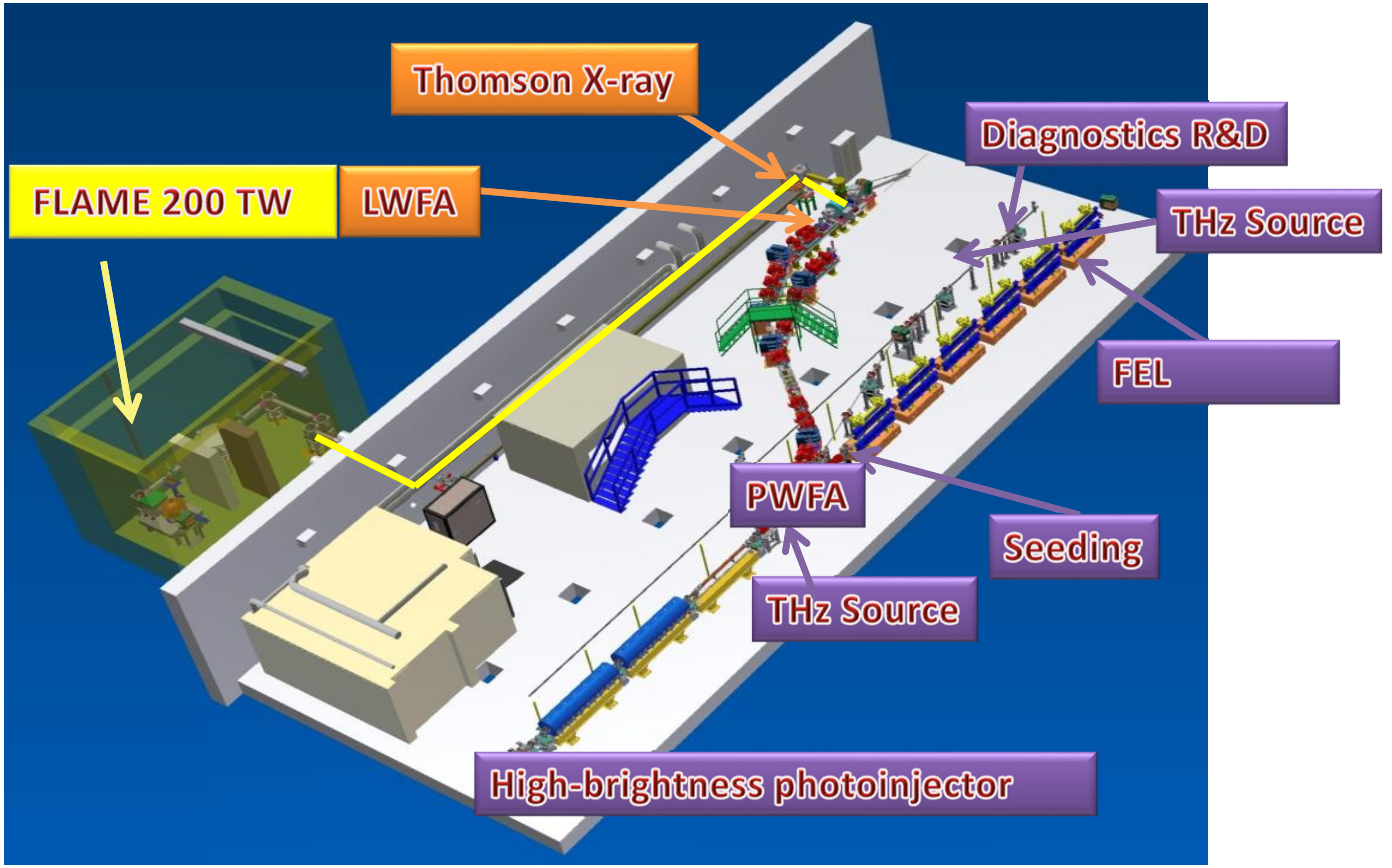
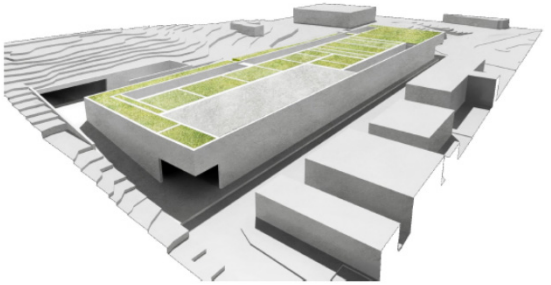
On behalf of SPARC_LAB & Eupraxia collaborations

Source For Plasma Accelerators and Radiation Compton with Laser And Beam



EuPRAXIA framework



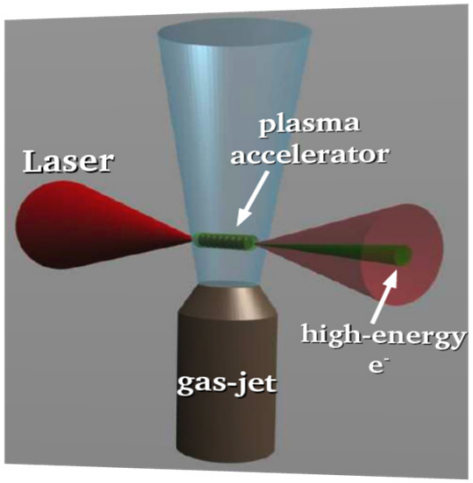
- EuPRAXIA is a design study on a “European plasma research accelerator with excellence in applications
- Eupraxia will produce a conceptual design report for the worldwide first 5 GeV plasma-based accelerator with industrial beam quality and user areas.

- Eupraxia@SPARC_LAB
- Candidate LNF to host EuPRAXIA (1-5 GeV)
- FEL user facility (1 GeV – 3 nm)
- Advanced Accelerator Test facility (LC) + CERN
- 500 MeV by RF Linac + 500 MeV by Plasma (LWFA or PWFA)
- 1 GeV by X-band RF Linac only

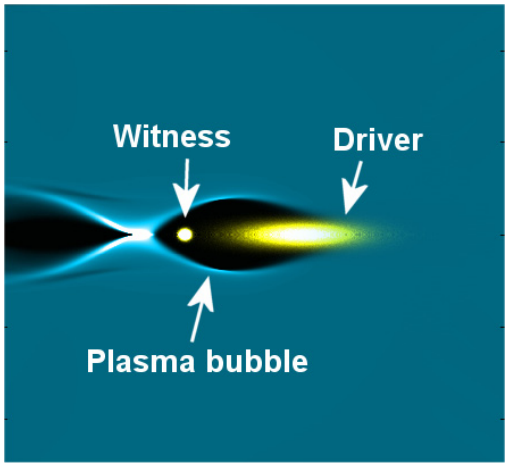
Outline

- This is not an overview, it is more a brain storming from a particular point of view:
- From proof of principle experiments to a real diagnostics
- Diagnostics similarities for LPWA & PWFA
- Problems related to ultra short beams
- Problems related with single shot transverse emittance measurements (and also small values!)
- What we are doing about these problems
- Conclusions

Diagnostics for LWFA & PWFA



- A high intensity laser ionize a gas jet and produce a plasma wave. The field is so strong that the electron are self injected in the bubble



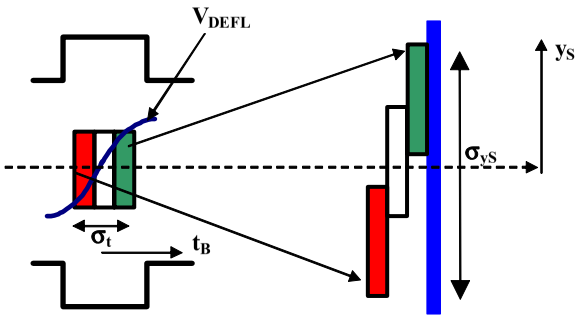
- A high brightness electron beam (or high intensity laser) drives a plasma wave. A witness beam injected on the back of the bubble is then accelerated

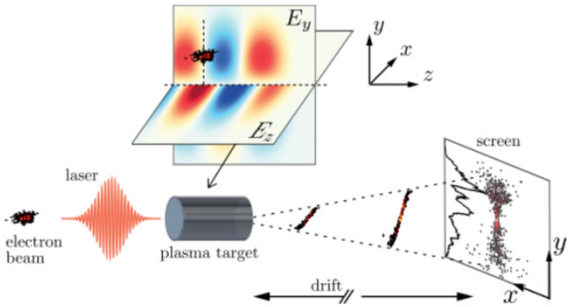
- Similar problems
  - Driver removal
  - Difficulties in capture optics
  - Shot by shot instability

Resolution is not the only constrain

- Resolution for emittance must better than 1 mm-mrad
- Time resolution must be in the fs scale
- The device must work even with shot by shot pointing, energy, time jitter instabilities
- Compactness is a fundamental requirement

Deflecting systems





- Conventional RFD can streak the beam in only one direction
- New design proposed by Grudiev can change the streaking direction
- It paves the way also to multi shot measurements and tomography reconstructions

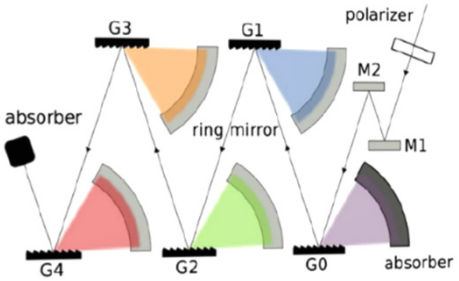
A. Grudiev, CLIC-note-1067 (2016)

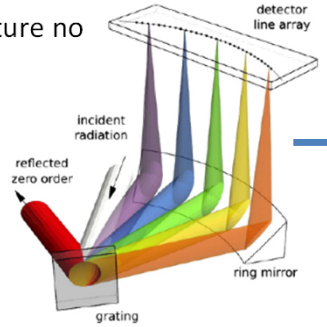
- Plasma deflector
- Attosecond resolution
- Resolution is charge depending
- Need to be tested in an experiment

Dornmair, Irene, et al. "Plasma-driven ultrashort bunch diagnostics." *Physical Review Accelerators and Beams* 19.6 (2016): 062801.

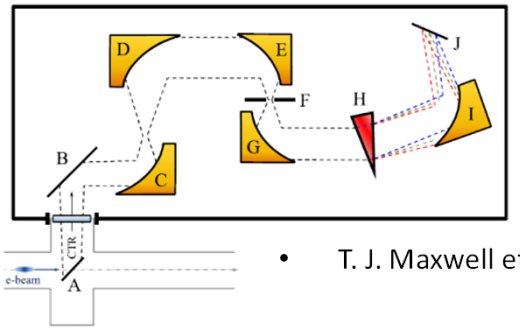
Single shot CTR measurements

Pyro-electric line detector 30 channels @ room temperature no window, works in vacuum fast read out sensitivity



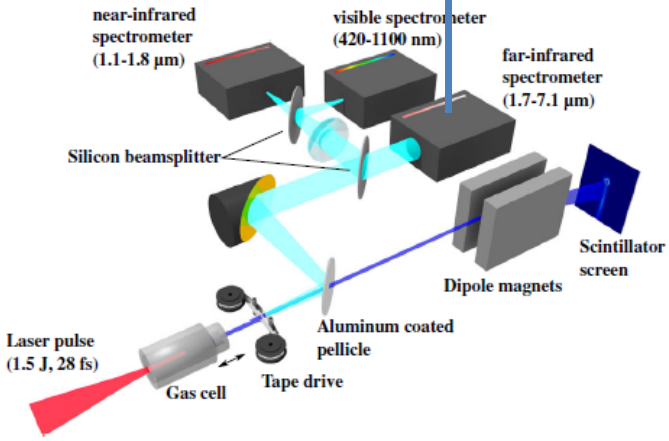


- S. Wesch, B. Schmidt, C. Behrens, H. Delsim-Hashemi, P. Schmuser, Nuclear Instruments and Methods in Physics Research A 665 (2011) 40–47



KRS-5 (thallium bromoiodide) prism based spectrometer developed

- T. J. Maxwell et al. *Physical review letters* 111.18 (2013)



Heigoldt, Matthias, et al. "Temporal evolution of longitudinal bunch profile in a laser wakefield accelerator." *Physical Review Special Topics-Accelerators and Beams* 18.12 (2015): 121302.

Transverse emittance

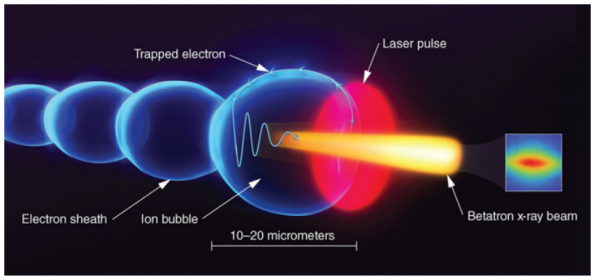
- Where is the space for the diagnostics?
- Remember that rms normalized emittance growths up in a drift…

M. Migliorati et al, Physical Review Special Topics,Accelerators and Beams 16, 011302 (2013)
K. Floettmann, PRSTAB,6, 034202 (2003)

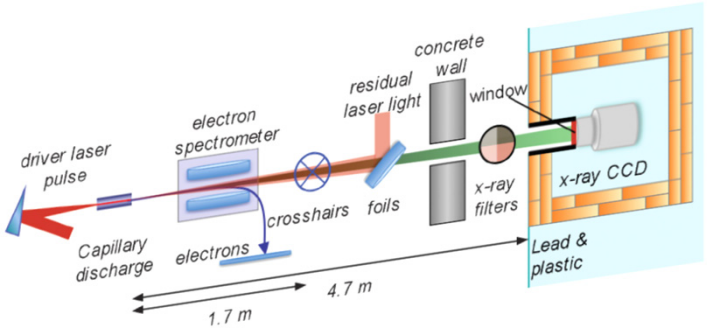
$$\varepsilon_n^2 = \langle\gamma\rangle^2 \sigma_\varepsilon^2 \langle x^2\rangle\langle x'^2\rangle + \\ + \langle\beta\gamma\rangle^2 \left(\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2\right)$$

- Separate the measurements of the source properties from the beam that it is possible to capture and transport
- Use Betatron radiation in the first case
- Develop single shot emittance measure in case of small energy spread after the capture optics

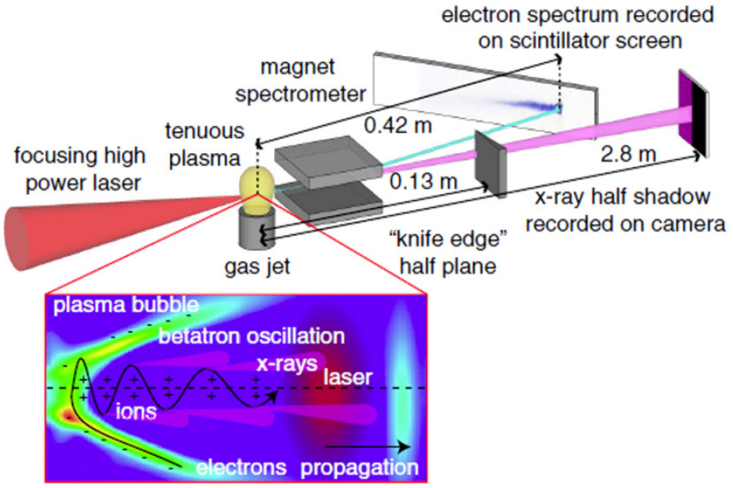
Betatron radiation



Picture from F Albert et al Plasma Phys. Control. Fusion 56 (2014) 084015



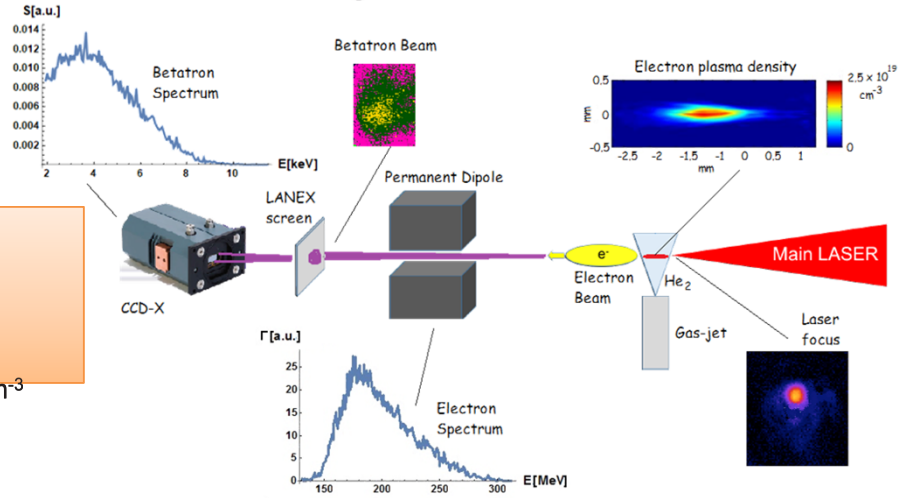
- S. Kneip and al., PRST-AB 15, 021302 (2012)



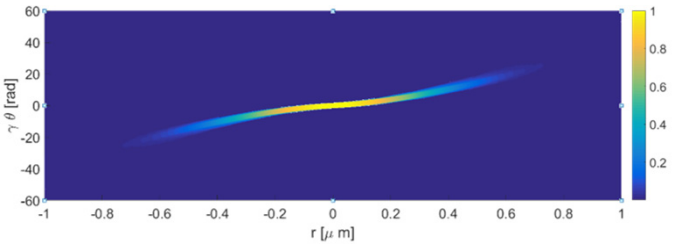
G. R. Plateau and al., Low-Emittance Electron Bunches from a Laser-Plasma Accelerator Measured using Single-Shot X-Ray Spectroscopy, PRL 109, 064802 (2012)

Emittance with the correlation term

- First measurement of the emittance including the correlation term
- The beam profile is retrieved not simply the average dimensions
- An expression is given for the correlation function between the betatron oscillation amplitude and the divergence of the single accelerated electrons, i.e. the angle with respect the acceleration axis, in order to obtain the distribution of the *electron divergences*.

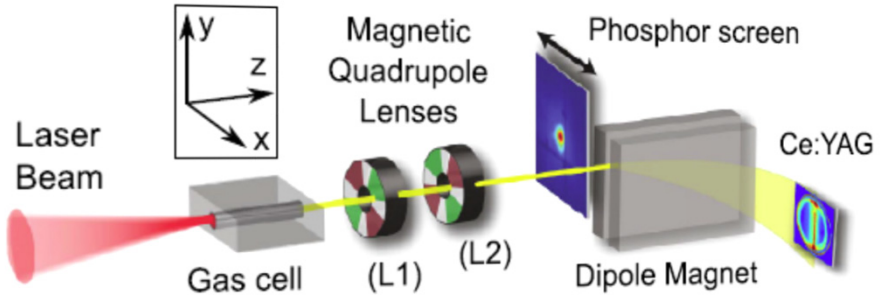


1 J
30 fs (FWHM)
10 μm diameter focus,
a0 ~ 4.4
$n_e=(8\pm1)10^{18}$ cm^{-3}



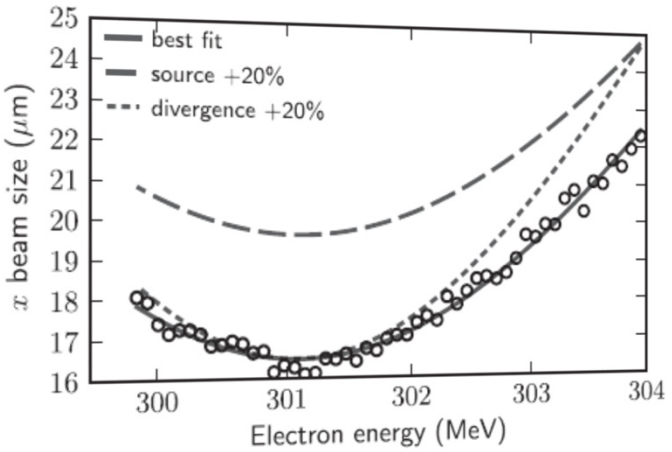
Curcio, A., et al. "Trace-space reconstruction of low-emittance electron beams through betatron radiation in laser-plasma accelerators." *Physical Review Accelerators and Beams* 20.1 (2017): 012801.

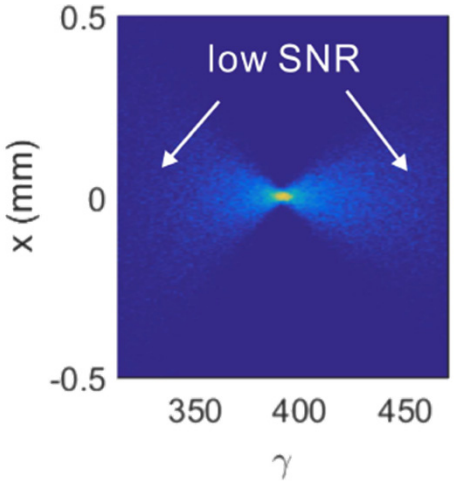
A new kind of Quadscan



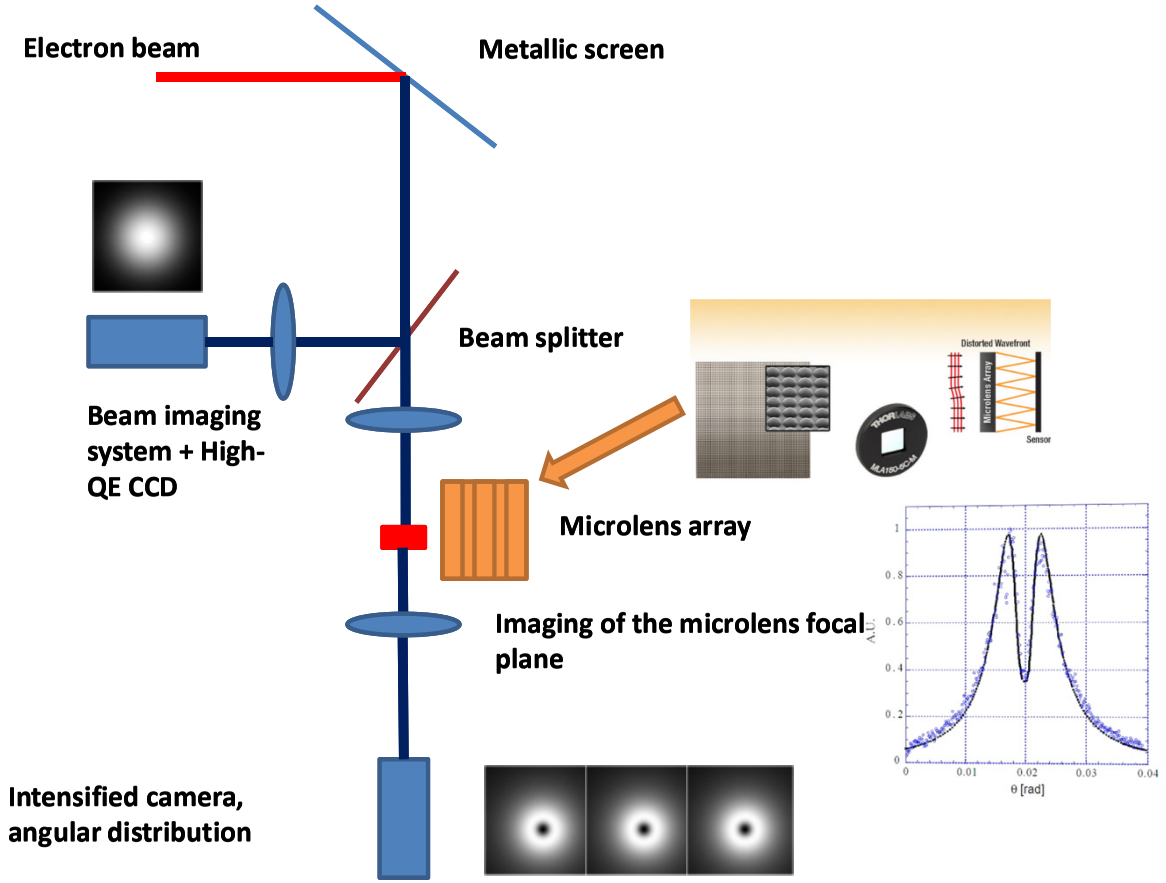
- R. Weingartner and al., PRST-AB 15, 111302 (2012),
- Barber, S. K., et al., Physical Review Letters 119.10 (2017): 104801.
- F Li et al 2018 Plasma Phys. Control. Fusion 60 014029
- F. Li et al, Plasma Physics and Controlled Fusion 60, 044007 (2018)

- Reduction of energy spread (highly desirable) will reduce the resolution of this measurement



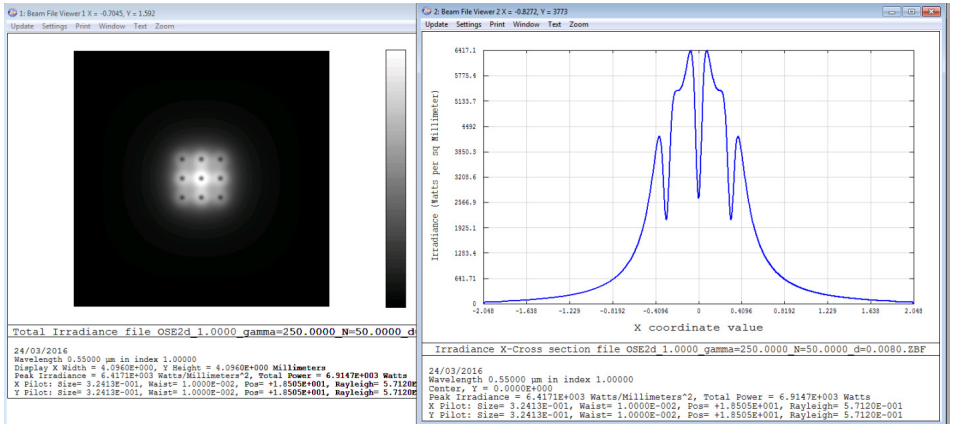


One Shoot Emittance

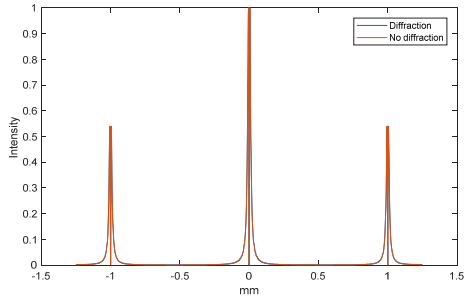


- The sampling is only on the mask and not also on the view screen due to the distance between screen and mask
- There is no problem of scattering, material thickness, cutting of phase space etc.
- Parameter fine tuning can be optical

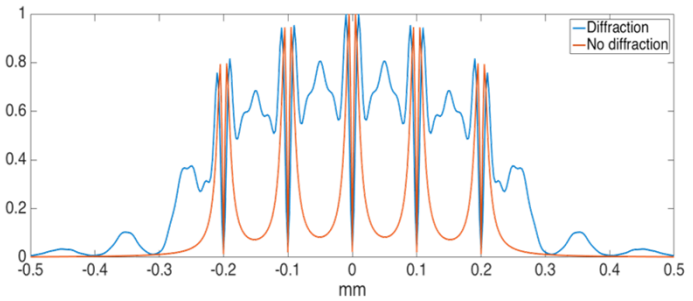
Zemax simulations



Bisesto, F. G., et al. "Zemax simulations describing collective effects in transition and diffraction radiation." Optics express 26.4 (2018): 5075-5082.

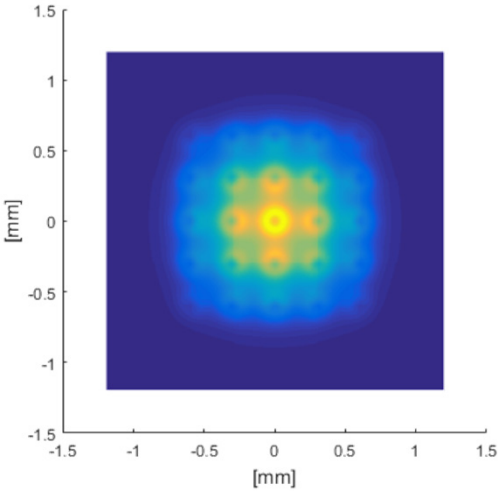


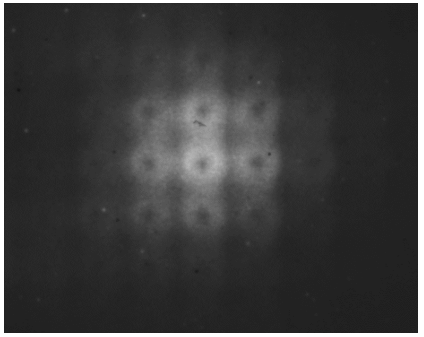
- f=10 mm D=1mm Energy=1 GeV

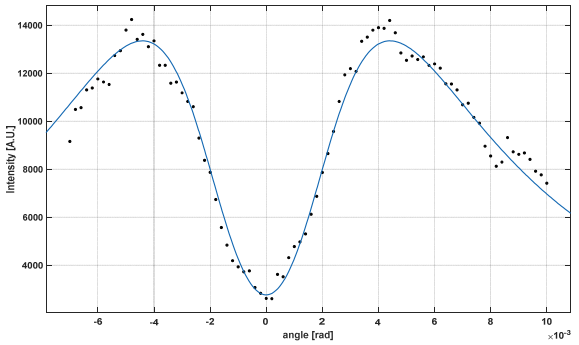


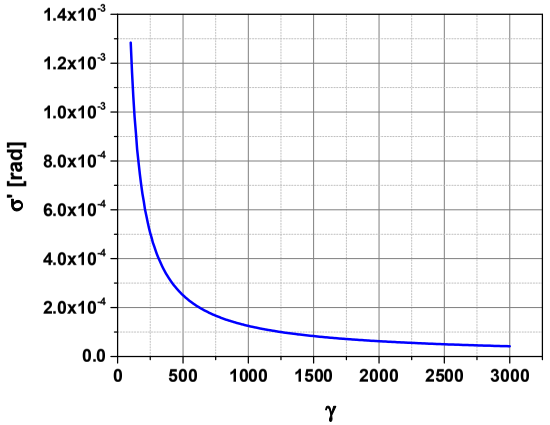
- f=10 mm D=0.1 mm Energy=1 GeV

2D


1.5
1
0.5
0
-0.5
-1
-1.5
[mm]
-1.5
-1
-0.5
0
0.5
1
1.5
[mm]

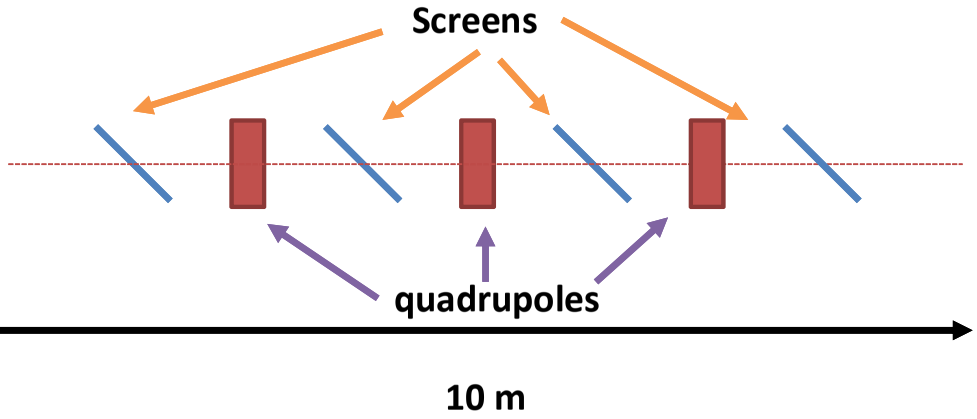


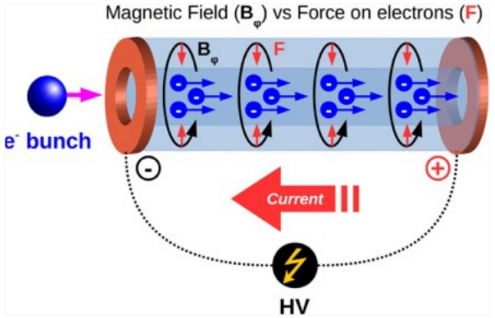

Intensity [A.U.]
angle [rad]
×10⁻³


σ' [rad]
γ

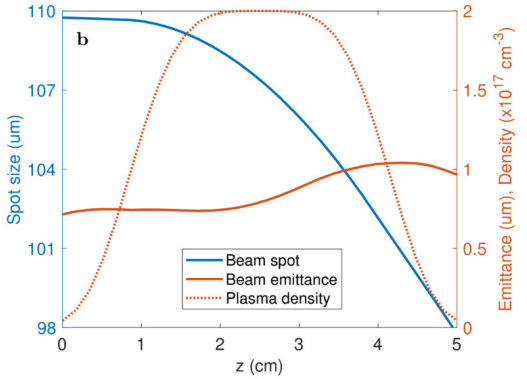
Multiple OTR monitors with plasma lens?

- C. Thomas, N. Delerue and R. Bartolini "Single shot transverse emittance measurement from OTR screens in a drift transport section", 2011 JINST 6 P07004





- A plasma lens can focus in both planes with kT/m gradient



J. van Tilborg et al. PRL 115, 184802 (2015)
Pompili, R., et al. *Applied Physics Letters* 110.10 (2017): 104101.
Marocchino, A., et al." *Applied Physics Letters* 111.18 (2017): 184101.

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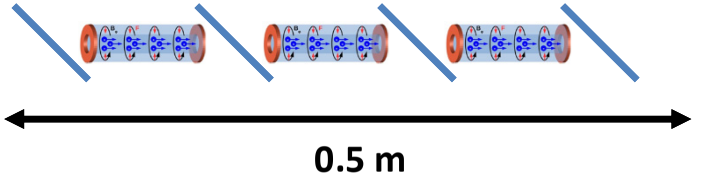

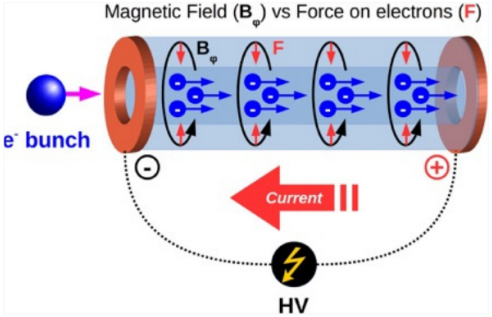

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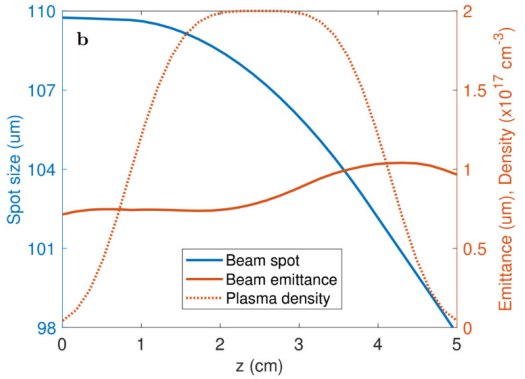

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Marocchino, A., et al." *Applied Physics Letters* 111.18 (2017): 184101.

Conclusions

- Plasma acceleration sets a completely new class of problems.
- Longitudinal single shot diagnostics with resolution in the fs range seems to be feasible, even if it is not easy to handle
- Emittance measurement is a more complicated task
- Our strategy is to use Betatron radiation for source optimization and some single shot new methods for the beam after capture, filtering, energy spread reduction etc.

Finally it's over

Thank you for your attention