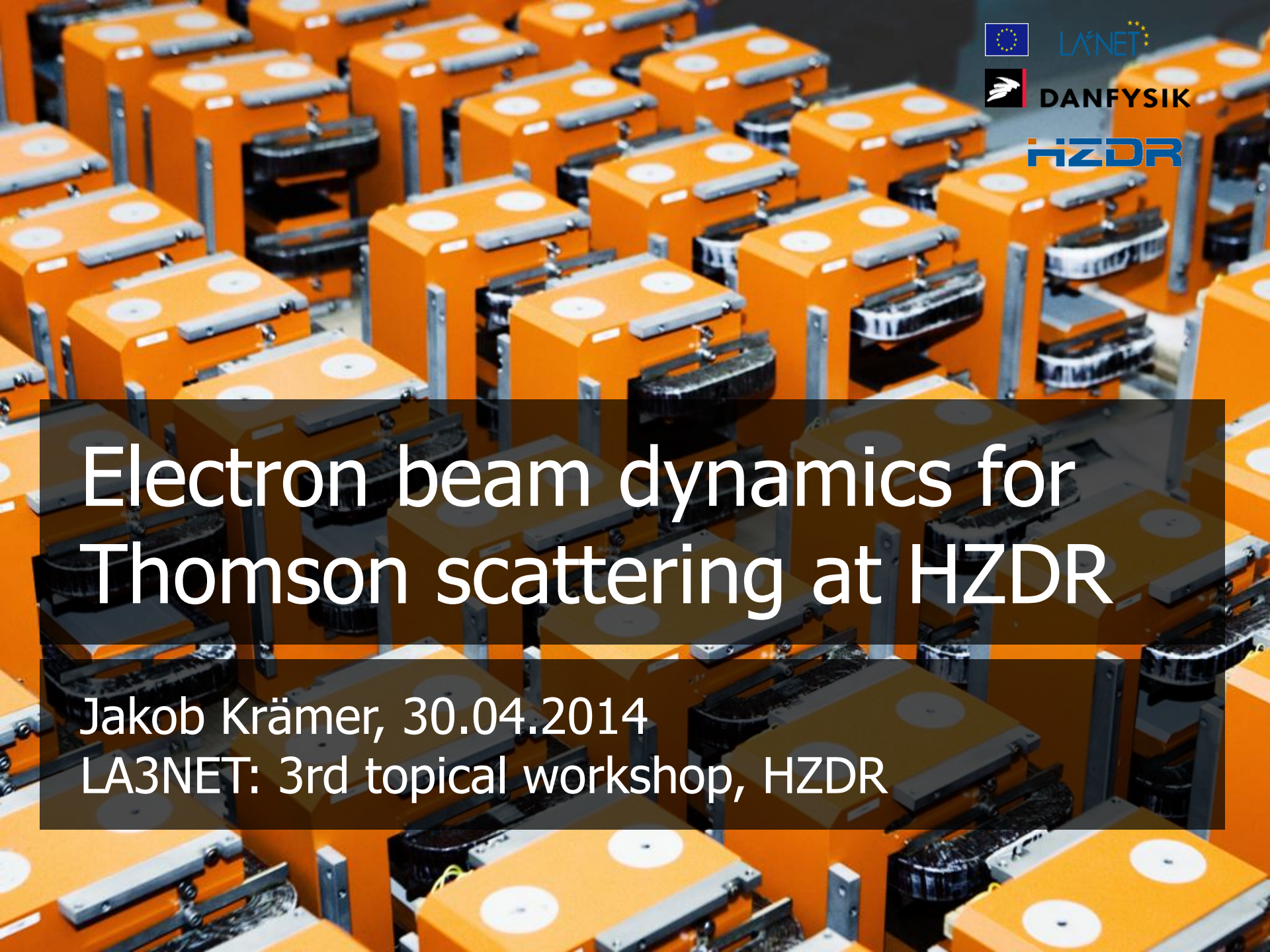
it's all about innovation



Electron beam dynamics for Thomson scattering at HZDR

Jakob Krämer, 30.04.2014

LA3NET: 3rd topical workshop, HZDR

Outline

- Motivation
- Electron beam dynamics at ELBE
  - Bunch compression and longitudinal phase space
  - Space charge
  - Transverse phase space
  - CSR: coherent synchrotron radiation
- Emittance measurements
- Permanent magnet quadrupole design
- Summary

Motivation

- Thomson scattering successfully carried out at HZDR (Axel Jochmann, et al.)

- Next steps:
  - Investigation of nonlinear effects
  - Increase photon output -> application as X-ray source

➢ We need to understand the beam dynamics at ELBE better!
  - Know the 6D phase space at the interaction point
  - Find good ELBE settings for Thomson scattering

Our approach

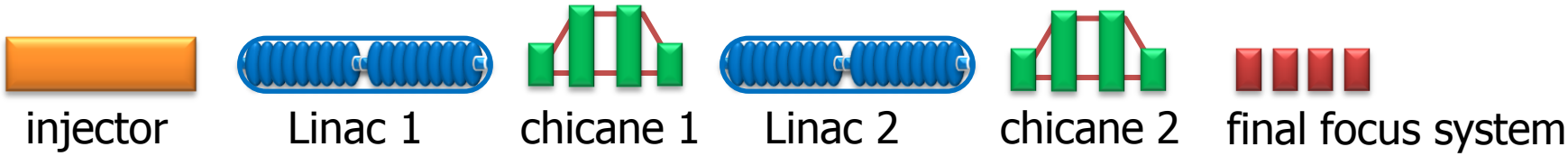
- Plan:
  - Start-2-End simulation of ELBE
  - Match it to measurements
  - Understand physics of ELBE
  - Find good settings to improve beam quality
  - Know 6D phase space @ IP

  ➢ Run next Thomson experiments successfully! ☺

- Start-2-End:
  - Injector: Astra / Parmela
    (thermionic gun: Ulf Lehnert, SRF gun: Pengnan Lu)
  - Switch to ELEGANT at 7-12 MeV
    - Linac 2, chicane(s), transport sections, FFS

Lattice

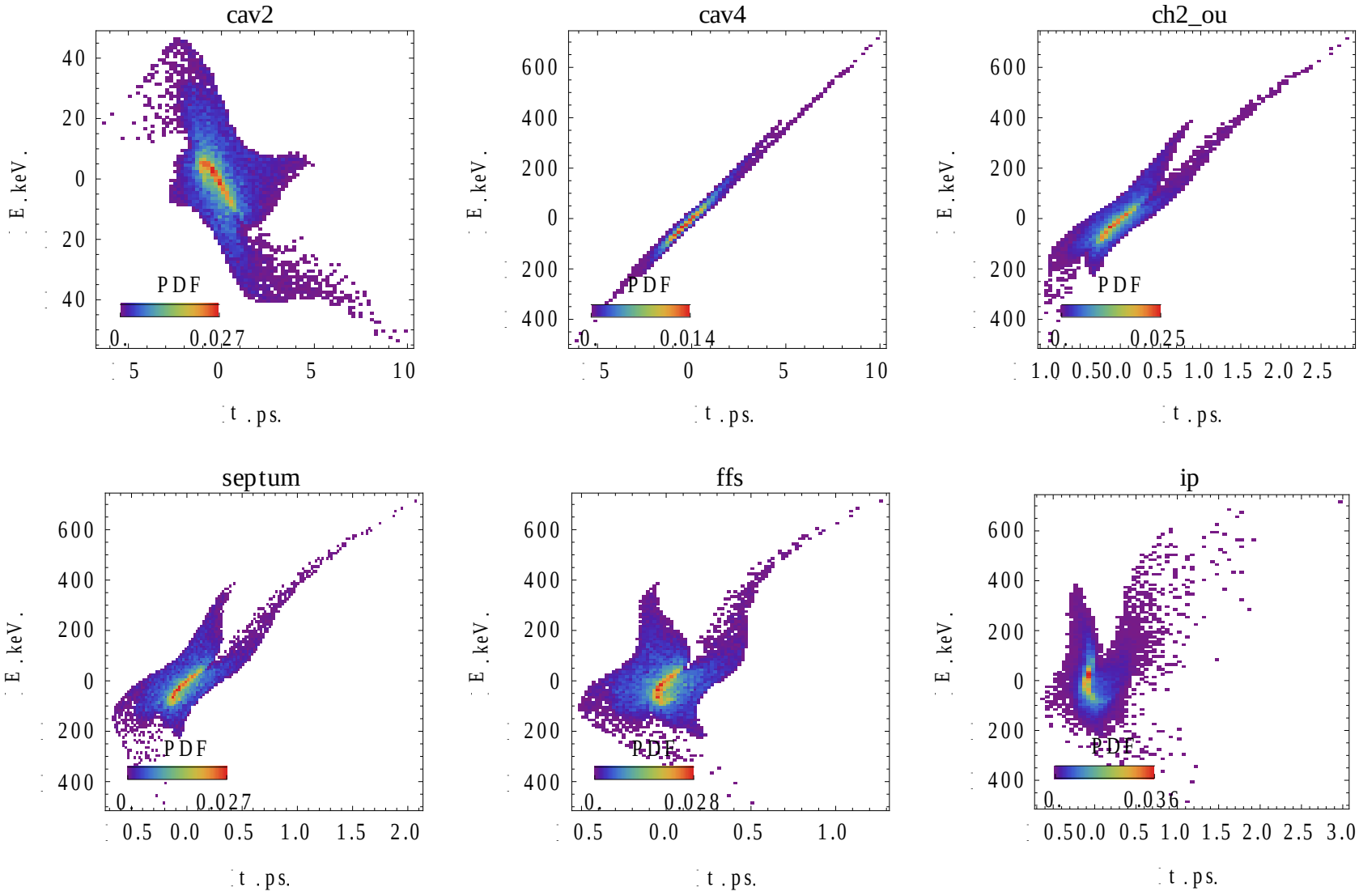
- Injector with thermionic gun
- Accelerate in Linac 1 to 11.2 MeV
- Maybe decompress beam in chicane 1
- Accelerate and chirp beam in Linac 2 to 22.5 MeV, 40-50° off crest
- Compress beam in chicane 2
- Focus beam to IP with laser



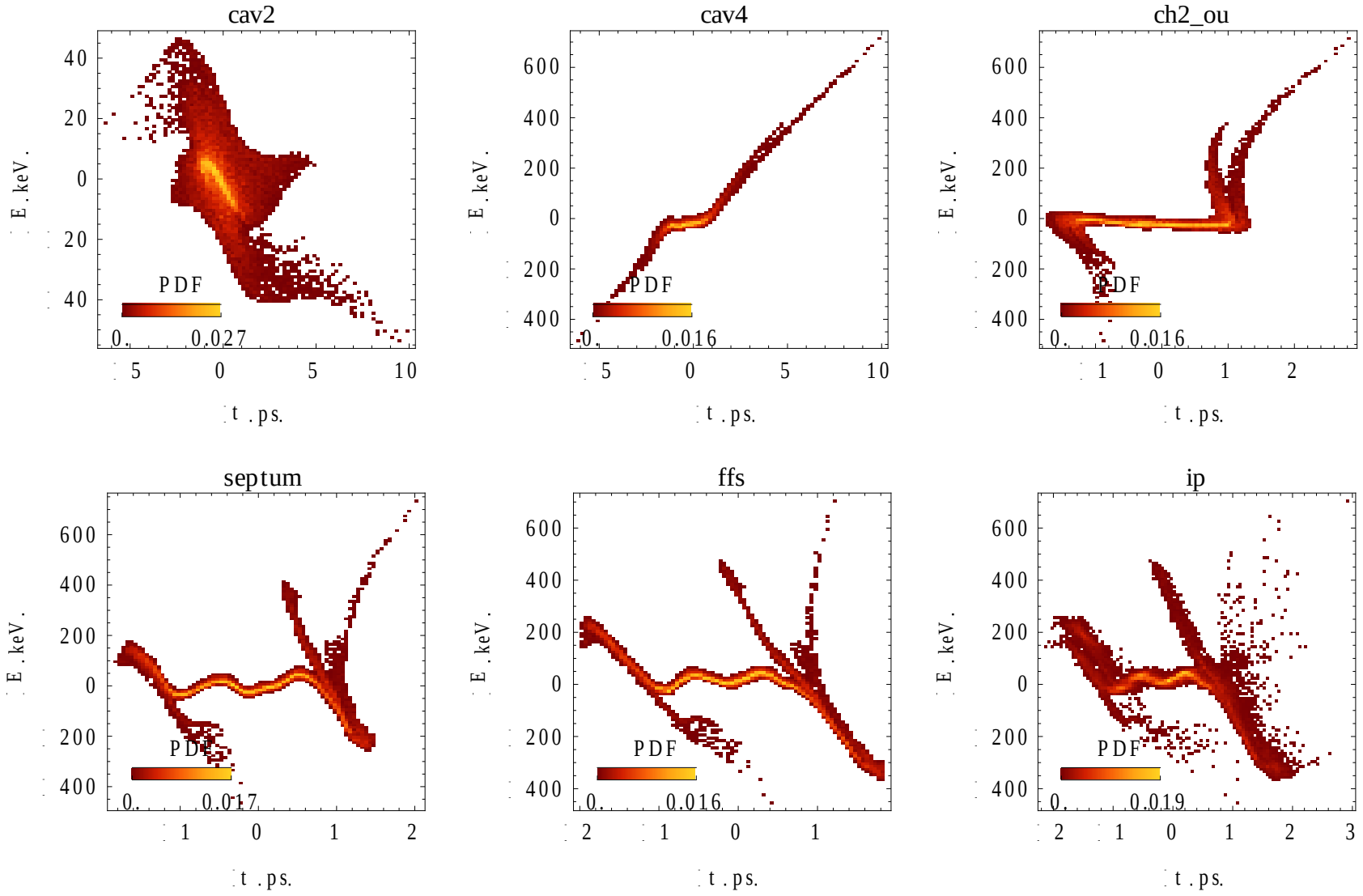
Astra	ELEGANT

- Emittance (norm., horiz.): 11.5 μm
- Emittance (norm., longit.): 15 keV ps

Longitudinal phase space



Longitudinal PS: space charge

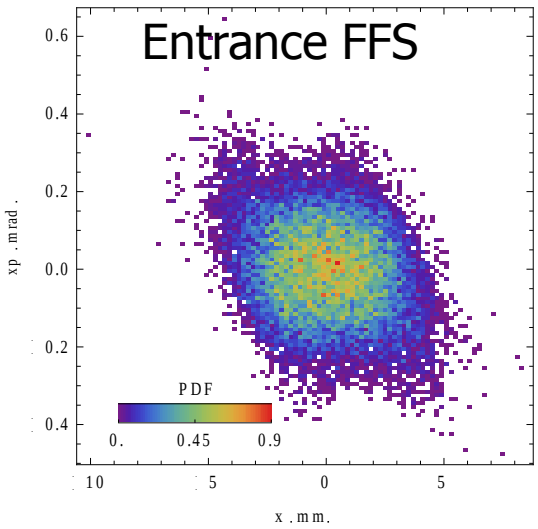


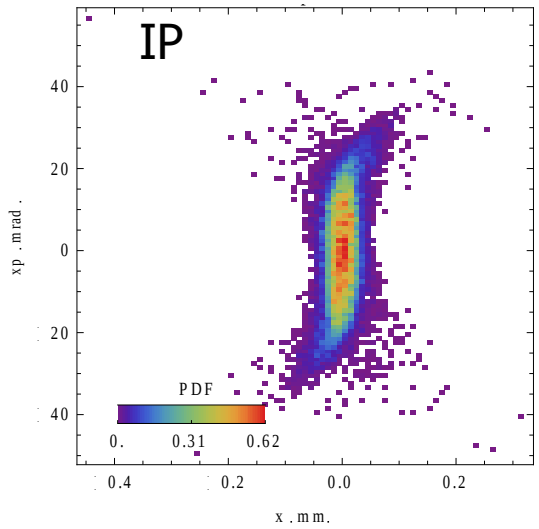
Longitudinal phase space

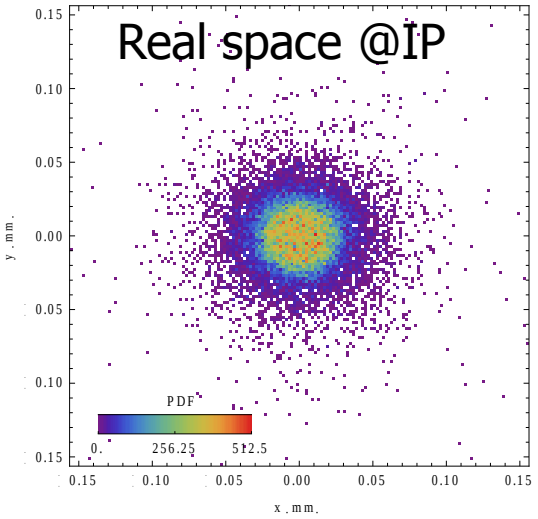
	Long. ε [keV ps]		Bunch length rms [ps]		Energy spread rms [keV]	
		LSC		LSC		LSC
Injector	15.3	15.3	1.3	1.3	14.1	14.1
End chicane	15.4	57.4	0.34	0.88	96	70.3
Entrance FFS	15.1	95.8	0.17	0.96	96	129
IP	17.9	93.3	0.19	0.92	96	129

Transverse phase space

	ε norm. [keV ps]		ε slice [keV ps]		x [mm]		x′ [mrad]	
		CSR		CSR		CSR		CSR
Injector (Astra)	11.6	11.6	11	11	0.94	0.94	0.42	0.42
End chicane	11.6	11.7	10.8	10.8	1.7	1.7	0.16	0.16
Entrance FFS	11.5	11.6	10.6	10.5	2.0	2.1	0.12	0.12
IP	14.9	15.3	13.5	13.8	0.025	0.026	12.8	13.4

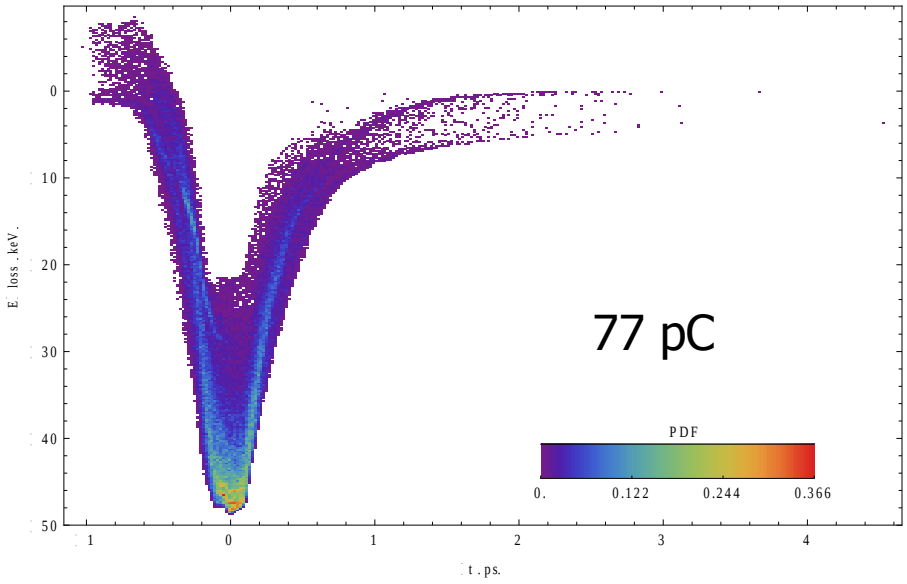


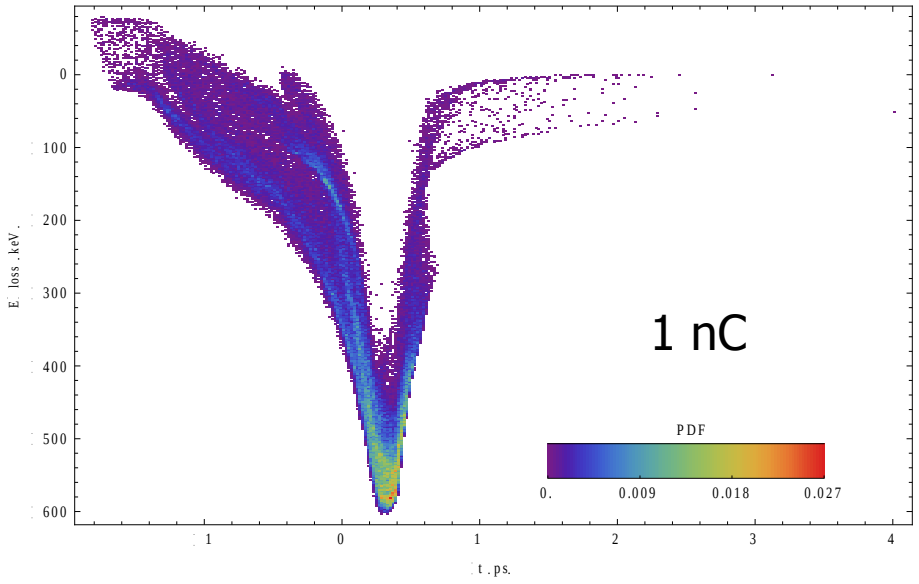




CSR: 77 pC vs 1 nC

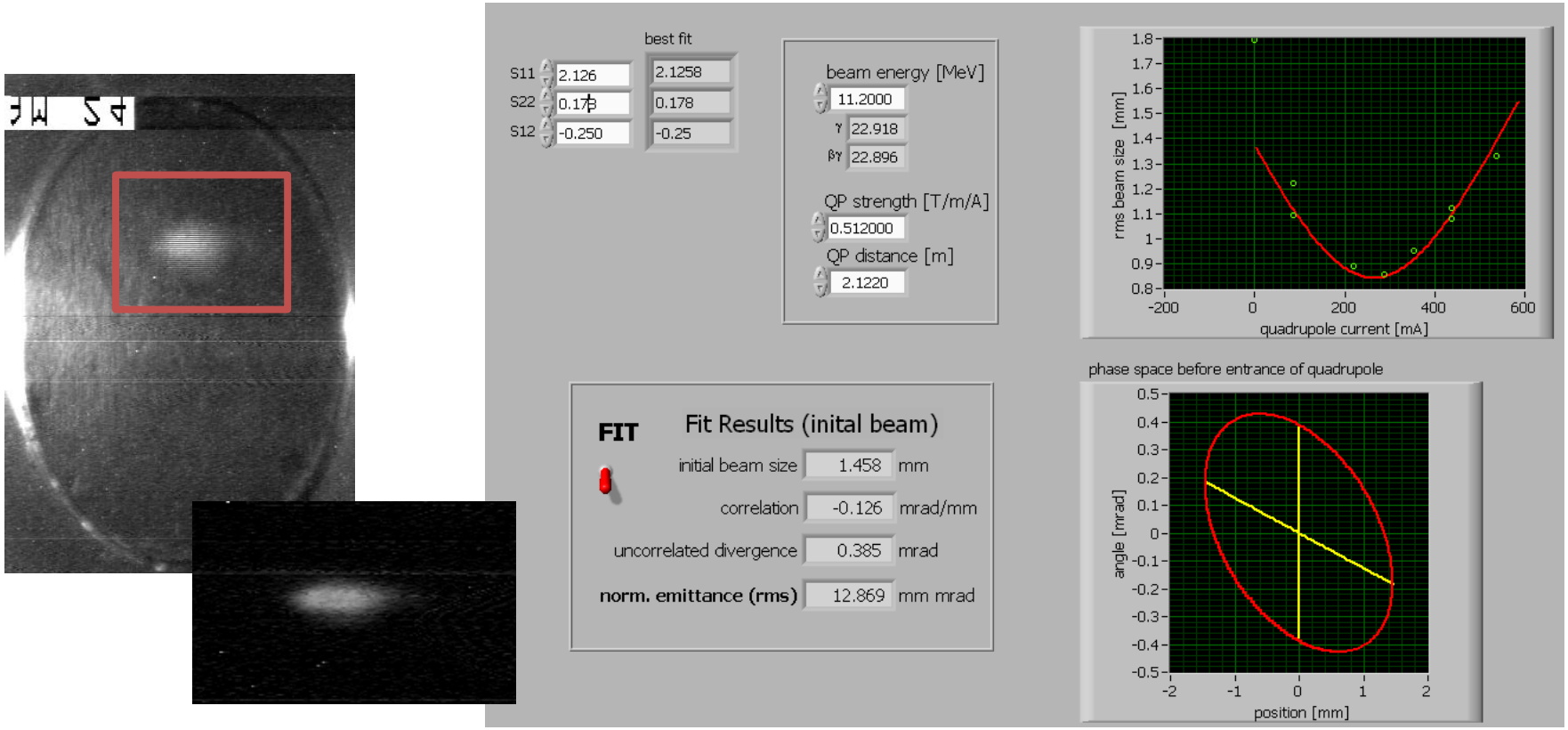
- Strong CSR effects for a 1 nC bunch expected:
  - norm emittance increases from 11.3 to 27.5 µm for same beam distribution
  - Electrons loose up to 600 keV due to radiation





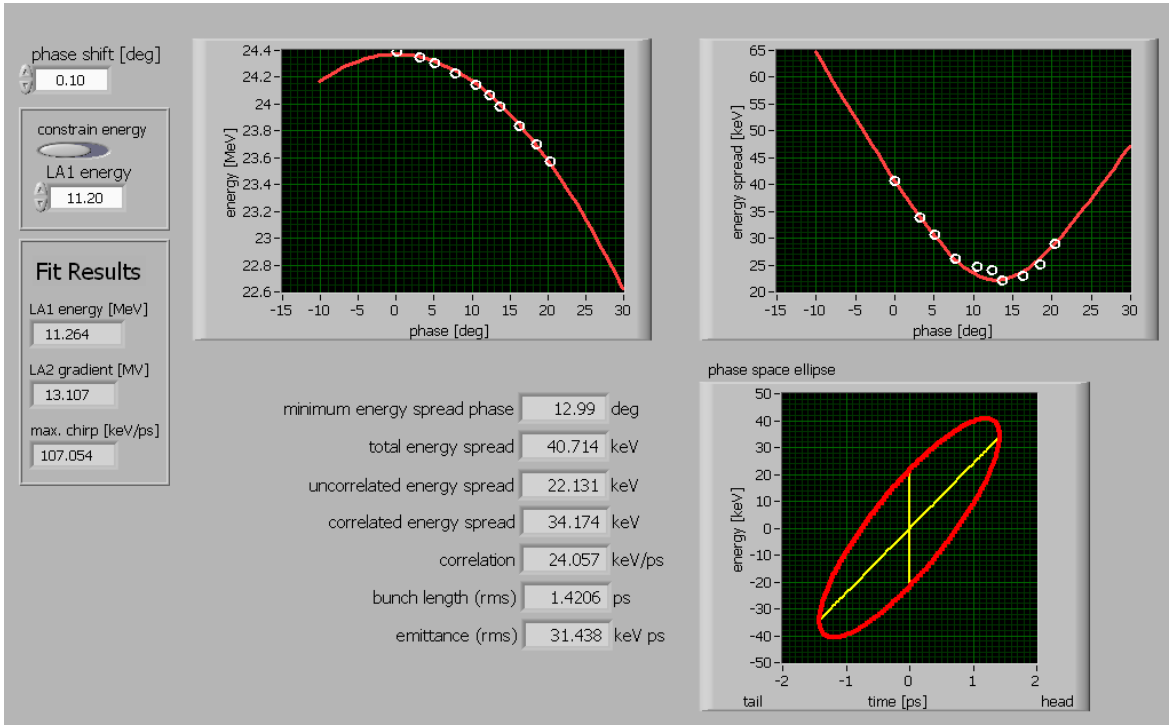
Measurement of transverse emittance - Quadrupole scan

- Scan quadrupole field – watch the beam size at a screen
- Fit according to 1st order matrix transport
- Transverse emittance from fitting parameters tell



Measurement of longitudinal emittance - Linac phase scan

- Scan phase of 2nd Linac – watch beam size after an energy spectrometer
- Fit parabola to data
- Get uncorrelated energy spread and bunch length as well as the longitudinal emittance as fitting parameters



Measurement results

- Good longitudinal emittance: 30 keV ps
- Good transverse emittance: 13 mm mrad
- ➢ In good agreement with simulation

- We expected a strong transverse emittance increase in x due to CSR from a set of measurements, where we had turned on/off the chicane and beam chirp:

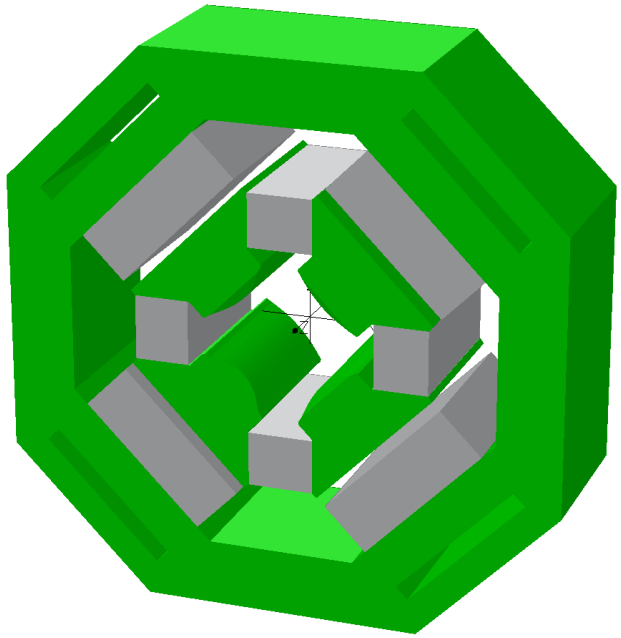
chirp \ chicane	**On**	**Off**
On	20.5 μm	15.0 μm
Off	14.4 μm	13.8 μm

- ➢ Not in agreement with simulation
- ➢ Technical issue, like jitter, space charge or just different = bad machine settings?

Design of the permanent magnet based quadrupoles

- 4 quadrupole with increasing gradient used as a telescope focusing system to minimize chromatic aberrations
- Hybrid design: poles made of iron
- Sm2Co17 blocks behind poles can be shimmed to correct for errors of magnetization
- Additional block between the poles to obtain higher gradients

- All 4 quad will be mounted on a motorized stage to adjust the focusing properties to different beam energies between 20 and 30 MeV.



Summary & outlook

- We started running Start-2-End simulations combining Astra & ELEGANT
- Space charge limits the bunch compression
  - Machine setting can be optimized taking space charge into account
- CSR is less important for 77 pC bunch charge than expected
  - BUT: strong CSR effects expected for the 1 nC upgrade!

Thank you for your attention!

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