Electron Beam Diagnostics of the JLab UV FEL

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Outline

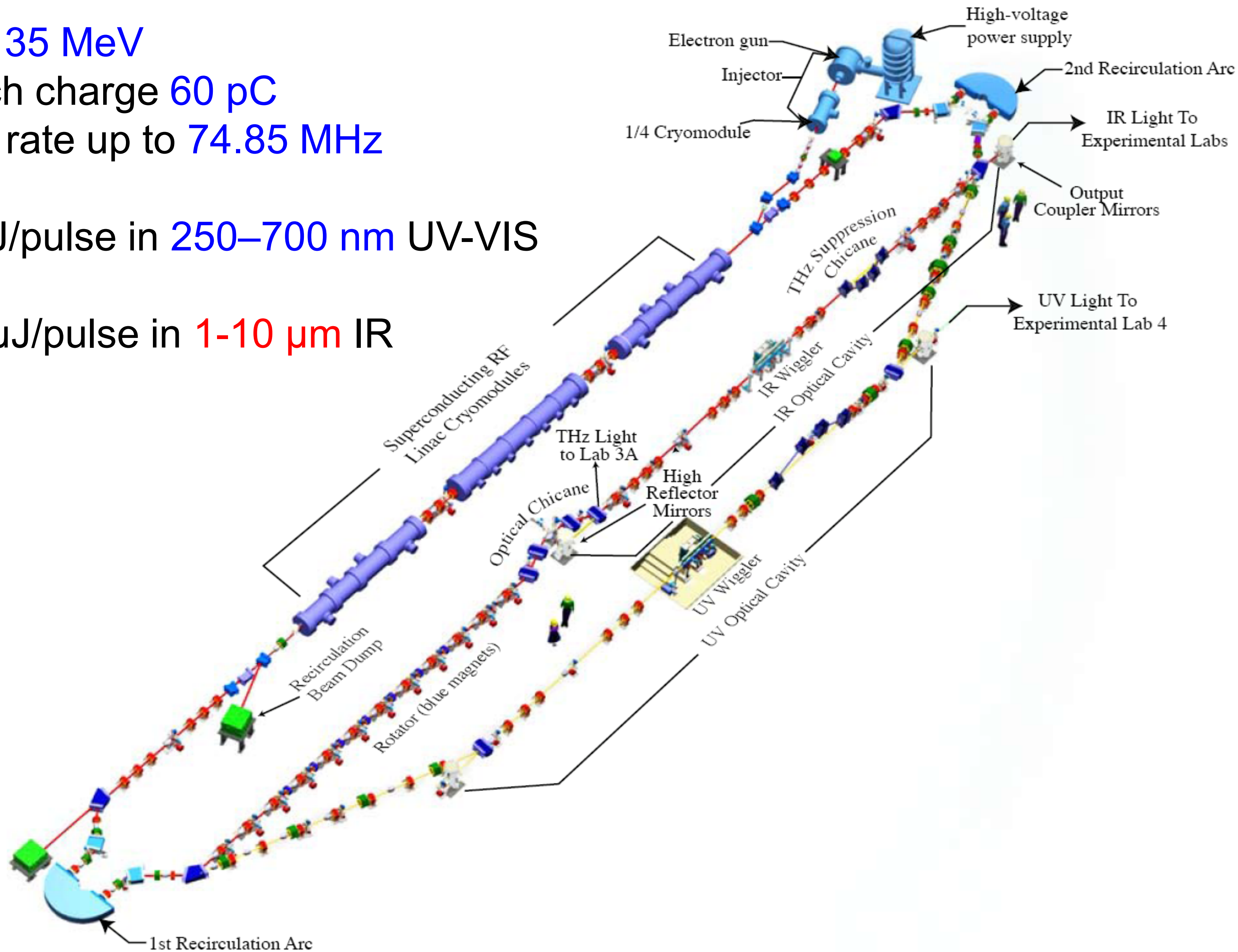
- JLab UV FEL
- Subset of the UV FEL diagnostics is described
  (is evolution of IR FEL diagnostics)
- Transverse beam profile measurements:
  (operation relies very heavily on YAG:Ce, OTR, Phosphor (P46), SR)
- BPM system with new Log-amp based electronics
  (lower cost higher performance compared to previously used)
- Bunch length measurements at the FEL wiggler
  (measured only at full compression ~ 100 fs RMS)
- Longitudinal transfer function (M_{55}) measurements
  (used to ensure proper sextupole settings for RF curvature correction of the LINAC –optimal compression – no harmonics RF)

JLab IR/UV ERL Light Source

E = 135 MeV
Bunch charge 60 pC
Rep. rate up to 74.85 MHz

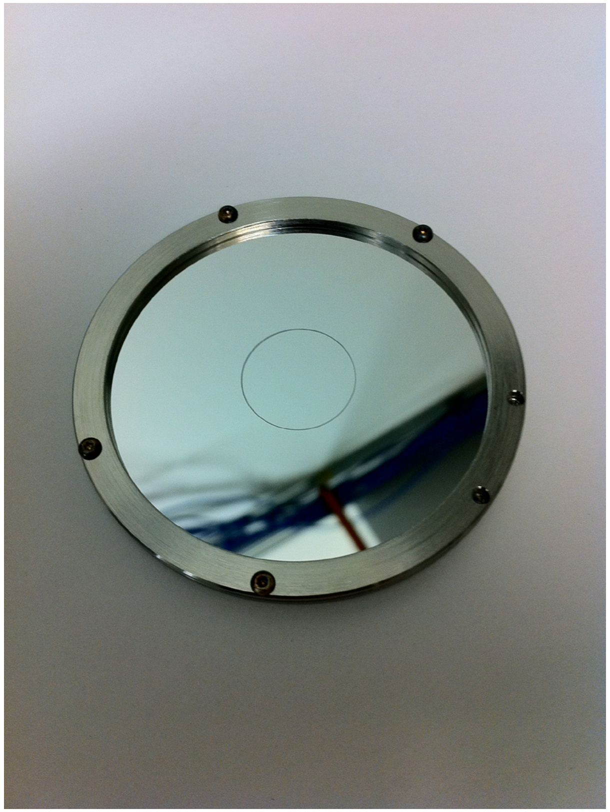
25 μJ/pulse in 250–700 nm UV-VIS

120 μJ/pulse in 1-10 μm IR

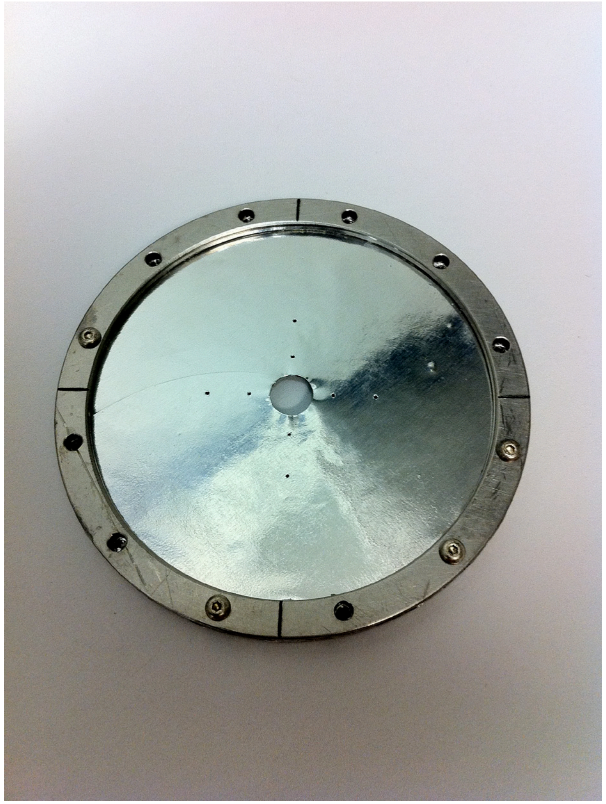


Transverse beam profile YAG:Ce, OTR, SR

Injector (9MeV) YAG:Ce viewer - for injector phasing, emittance, Twiss parameters, δE

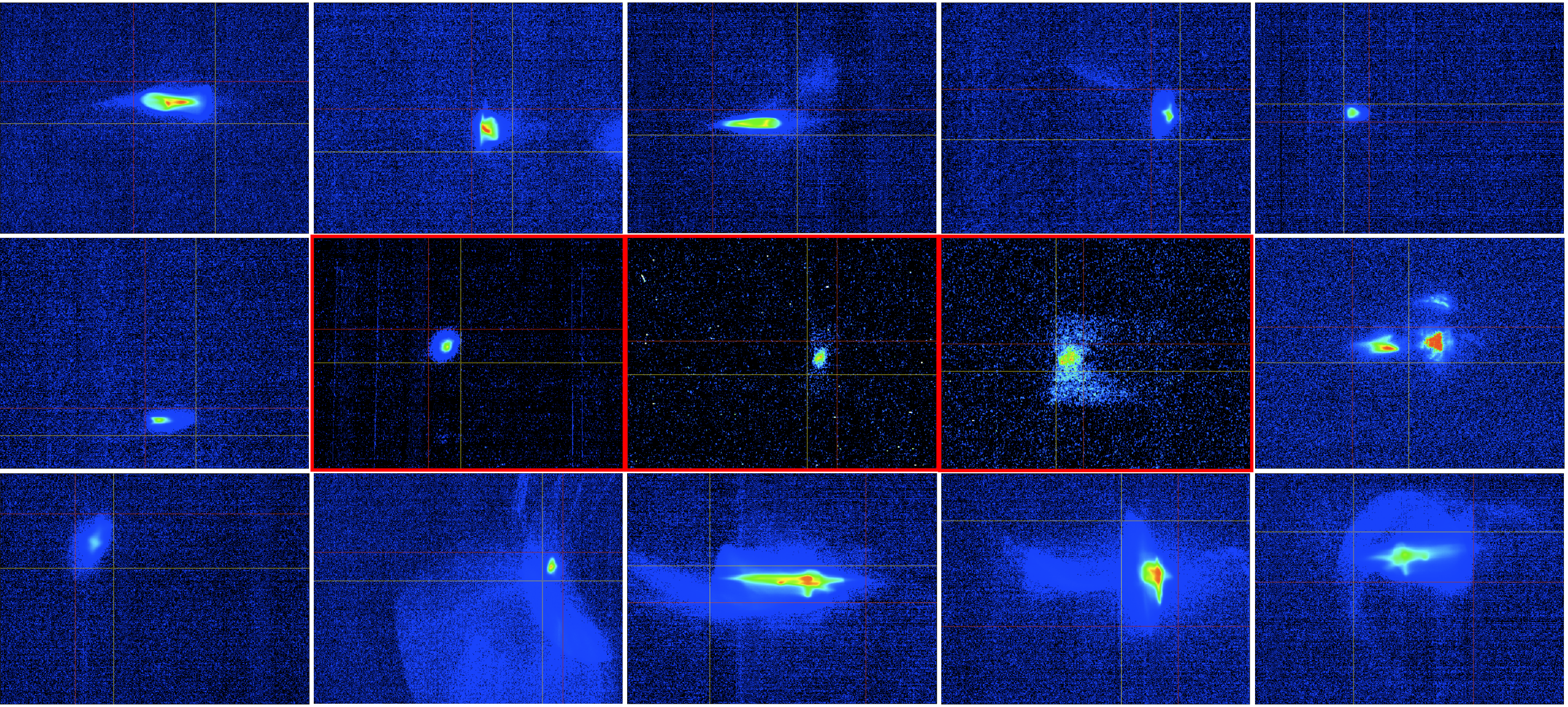


Bunch length via (CTR) and beam size (OTR)
60 um thin Si aluminized



LINAC viewers:
Al foil ~ 10 um thin
5 mm aperture for the accelerating beam

Transport / Transverse match



- ✧ set of transverse beam profiles measured through UV FEL beam line (~1/2 of the accelerator)
- ✧ combination of OTR and phosphor ()P-46 coated viewer is used
- ✧ anything but Gaussian distributions *(live is hard)*
- ✧ with the machine optics model used to understand and adjust the transverse match
- ✧ iterative process between measurements and fitting/adjusting model and beam optics
- ✧ fully compressed beam (100 fs RMS) even at 135 MeV can be space charge dominated

Bunch length evolution

- Beam is generated in a HV DC gun (325 kV now) – GaAs photocathode, Drive Laser with almost Gaussian distribution and ~ 13.5 ps RMS pulse length

- compressed down to ~ 5 ps by 1497 MHz buncher cavity before injection in to the booster where it is accelerated to 9MeV

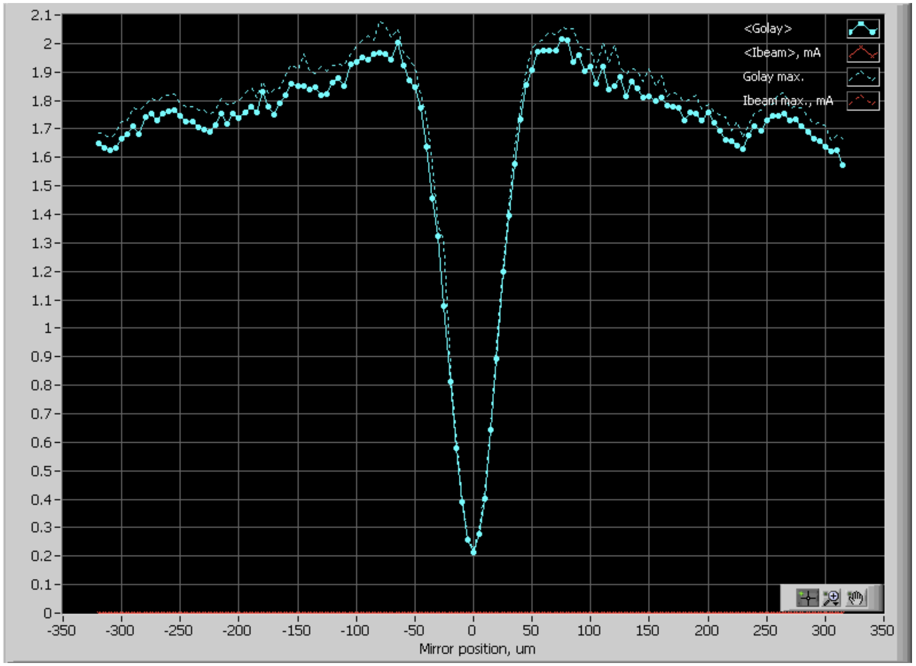
- During acceleration in the booster (2 5-cell SRF cavities) gets compressed to to ~ 2.5 ps - not measured directly but inferred from δE downstream of the LINAC – in good agreement with PARMELA model

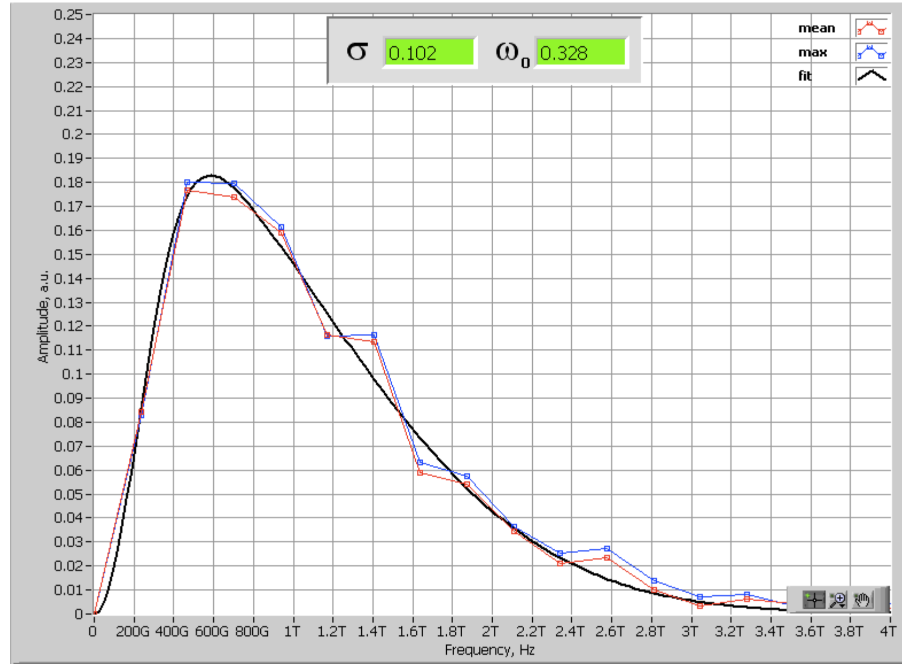
- Compressed in the first 180 deg band and transport line between the band and FEL wiggler; final bunch length 100 – 110 fs

- LINAC RF curvature imprinted on the longitudinal phase space compensated for by sextupoles in the Bates bend (NO harmonic RF used) by introducing second order dependence of the path length on energy – essential for compression

- Compression ration from the cathode to the wiggler ~ 125 – 135

Bunch length at full compression



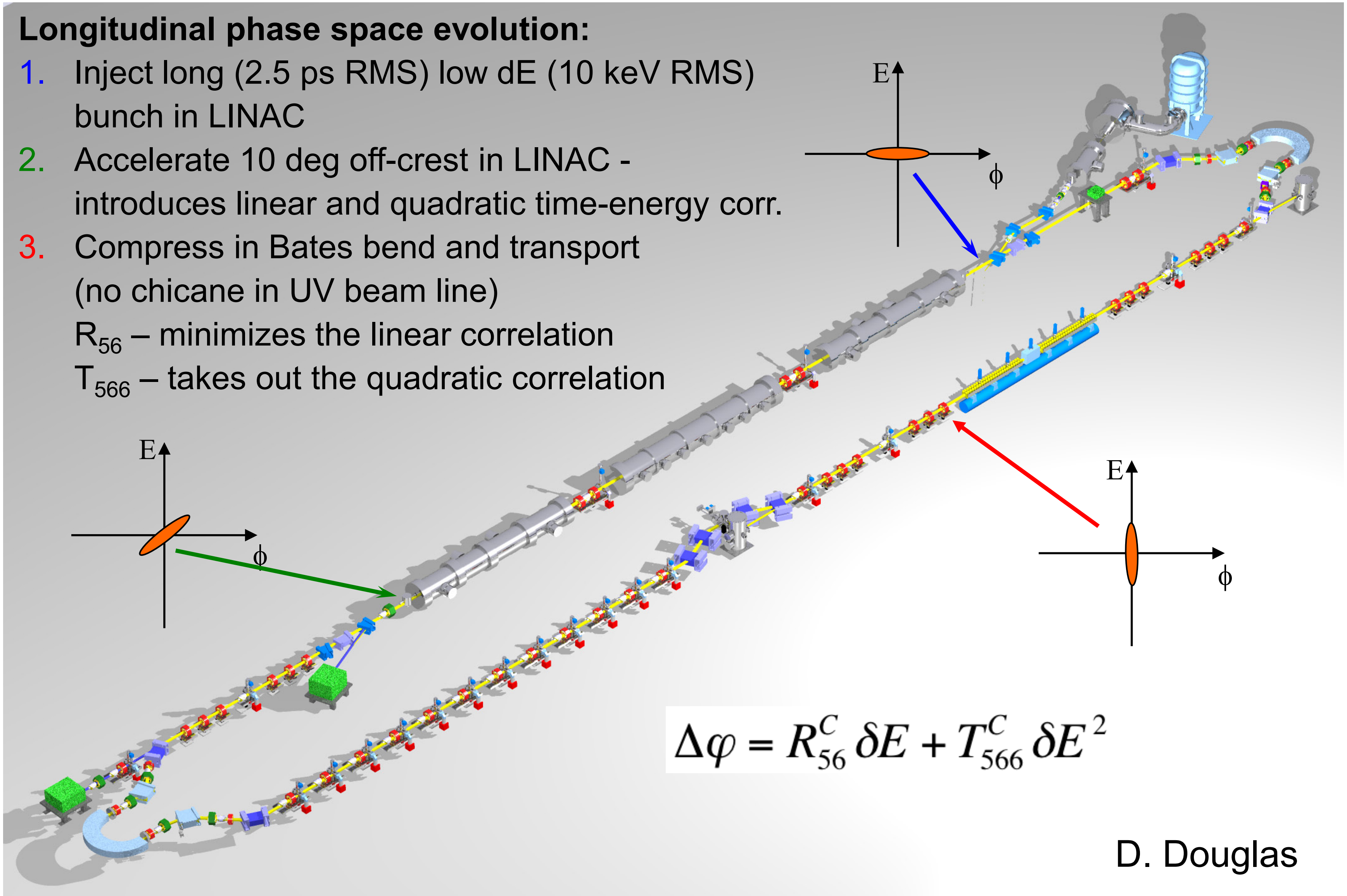


- modified Martin-Puplett interferometer with single detector (Golay cell)
- measures autocorrelation function of CTR or CSR (phase information lost)
- data evaluation in frequency domain assuming Gaussian distribution
- Gaussian power spectrum × HPF fitted to measured spectrum
- blackbody spectral measurements used to estimate limit of the setup (~ 50 fs)

Nonlinear compression strategy (M_{55})

Longitudinal phase space evolution:

1. Inject long (2.5 ps RMS) low dE (10 keV RMS) bunch in LINAC
2. Accelerate 10 deg off-crest in LINAC - introduces linear and quadratic time-energy corr.
3. Compress in Bates bend and transport (no chicane in UV beam line)
   R_{56} – minimizes the linear correlation
   T_{566} – takes out the quadratic correlation



$$\Delta\varphi = R_{56}^{C}\,\delta E + T_{566}^{C}\,\delta E^{2}$$

D. Douglas

Connecting R_{56} & T_{566} to M_{55}

$$\varphi_W = \left(1 + R_{56}^C \cdot R_{65}^L\right)\varphi_0 + \left[R_{56}^C \cdot T_{655}^L + \left(R_{65}^L\right)^2 \cdot T_{566}^C\right]\varphi_0^2$$

taking second order transport matrix elements

directly measured

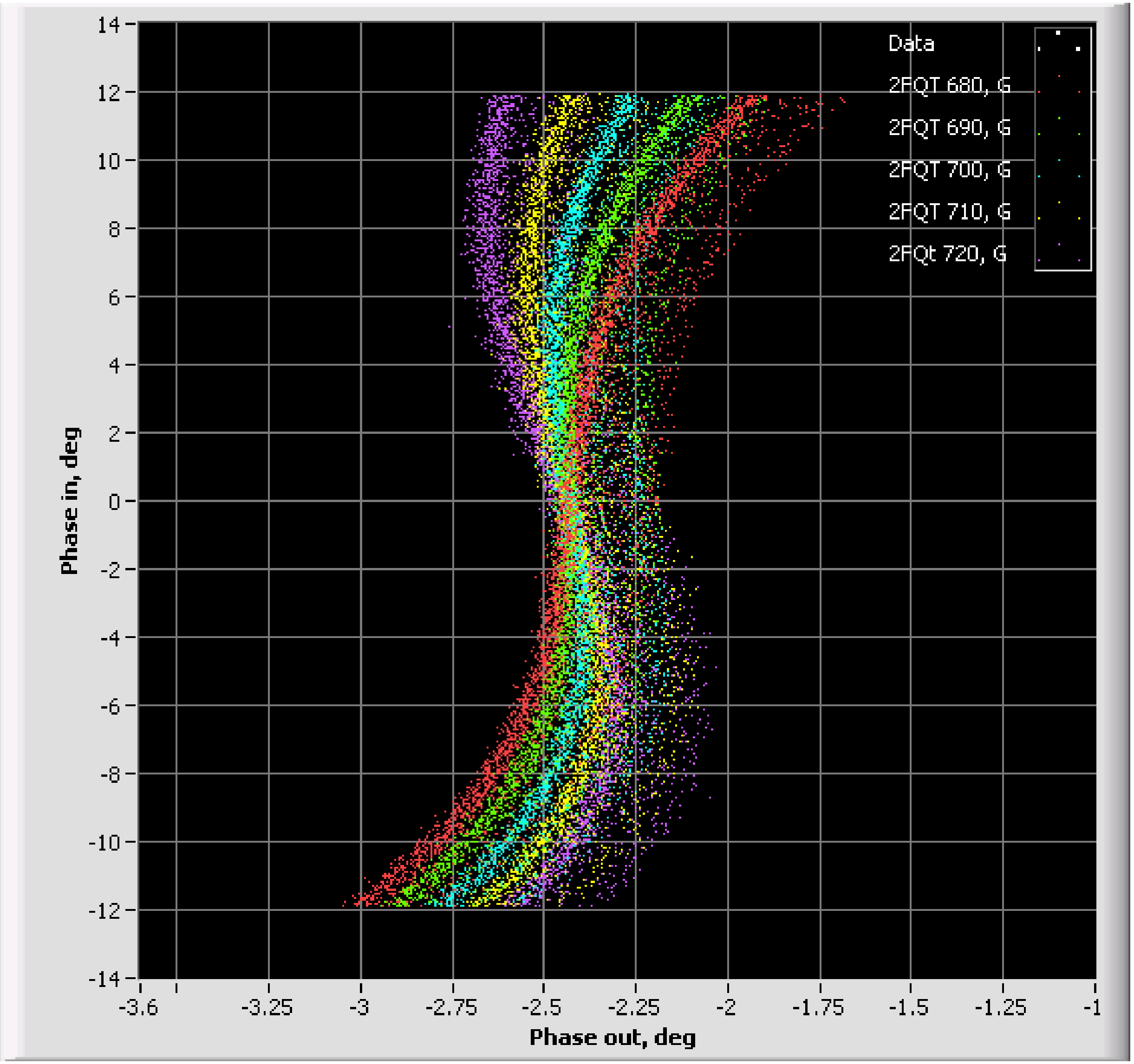
$$R_{55}^{inj \to w} = 1 + R_{56}^C \cdot R_{65}^L$$

$$T_{555}^{inj \to w} = R_{56}^C \cdot T_{655}^L + \left(R_{65}^L\right)^2 \cdot T_{566}^C$$

are adjusted in compressor

- R_{56} and T_{566} are validated via longitudinal transfer function measurements.
- Arrival phase is measured with a pillbox cavity + heterodyne receiver.
- Phase of the injector is modulated relative to the LINAC phase
- Essential ~ 15 % energy acceptance and ~ 30 % phase acceptance

M55 measurements (quads)

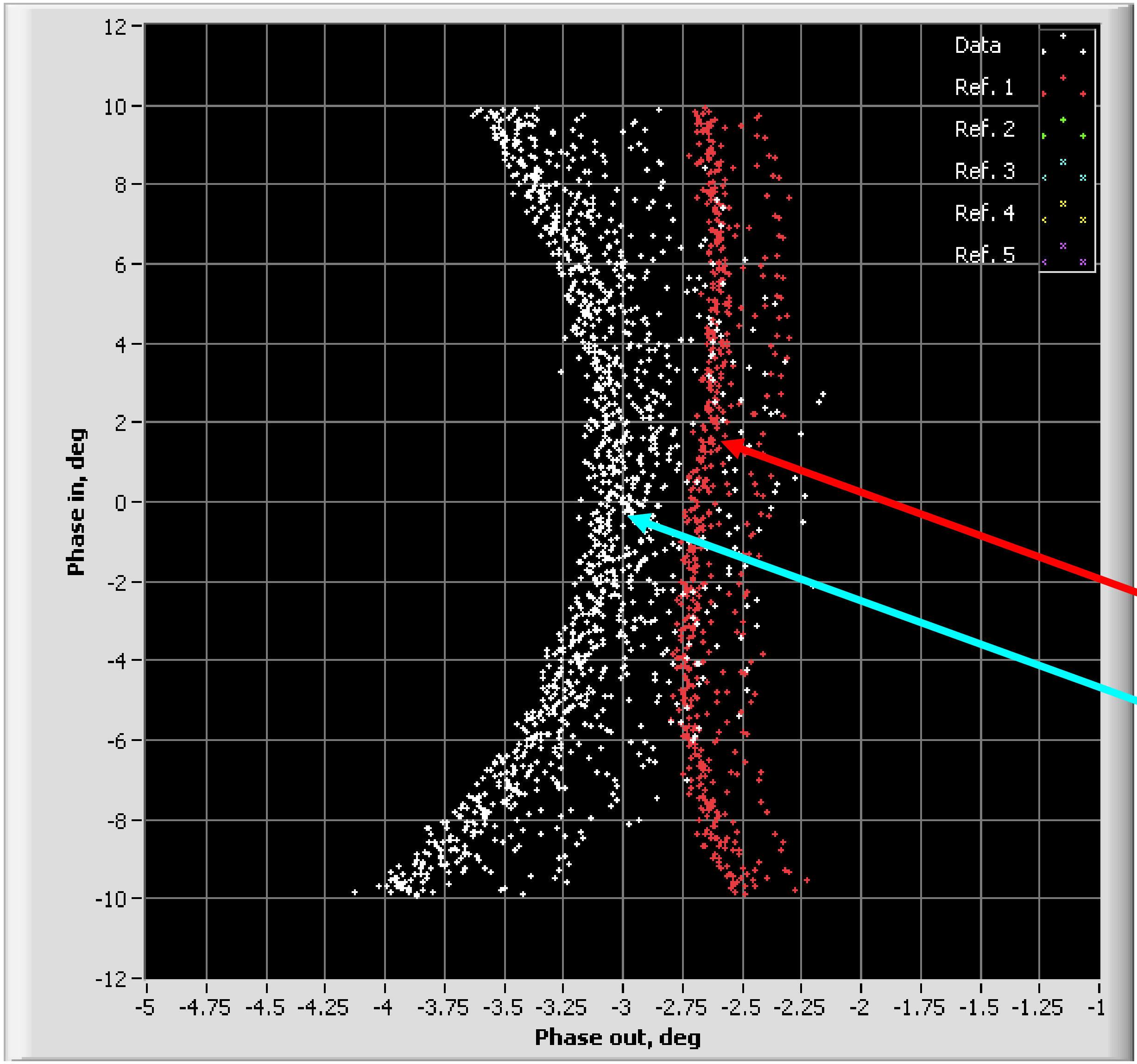


R_{56} of the compressor is adjusted by quadrupoles in dispersive locations in ARC1

measure is the linear correlation between φ_{in} and φ_{out}

the goal is to min the correlation

M55 measurements (sextupoles)



T_{566} of the compressor is adjusted by sextupoles in dispersive locations in ARC1

measure is the quadratic correlation between φ_{in} and φ_{out}

- near optimal setup

- sextupoles not adjusted