Synchronization, Diagnostics, and Instrumentation
Working Group 4

William Graves, Graeme Hirst, Holger Schlarb

Working Group Conveners

ERL 2005

Working Group Approach

Exceptional diagnostics challenges are created by the need to measure properties of very high quality beams in a (nearly) nondestructive manner.

Workshop activity will focus on sharing of preliminary ideas and brainstorming.

Particular interest in methods delivering more than first or second moments of a distribution, e.g. emittance of short time slices of the bunch, or phase space tomography to find joint time-energy distribution.

Summary of Longitudinal Diagnostics

Non-invasive methods (all demonstrated)

- ✓Electro-optic crystals: ~300 fs profile resolution, 30 fs time jitter
- ✓Synchrotron radiation: couple to streak camera
- ✓Phase and amp modulation of RF: longitudinal transfer functions
- ✓Diagnostic undulators: bunch length, timing, and transverse size
- ✓THz radiation: relative bunchlength monitor, RMS length
- ✓Digital phase measurements: beam arrival time
- ✓Optical replica of electron pulse: 10's of fs resolution

Mildly invasive methods

- ✓Pulse picking with fast deflector into diagnostic beamline

Invasive methods

- ✓Longitudinal phase space tomography
- ✓R56 + R65 for sub-ps time profile

Summary of Transverse Diagnostics

Non-invasive methods

- ✓Optical diffraction radiation for beam size and position(?)
- ✓Synchrotron light interferometer: μm resolution
- ✓HOMs in SRF cavities as BPM: μm resolution, sensitive to angle, too
- ✓Digital BPMs with feedback control: ~μm/μrad stability
- ✓Digital multi-bunch feedback – instability control
- ✓X-ray photon BPM: ~2 μm resolution

Mildly invasive methods

- ✓Pulse picking with fast deflector

Invasive methods

- ✓Slice emittance with RF deflector
- ✓R56 + R65 for sub-ps time profile

Report generated with description of 20 diagnostic devices and methods with group consensus (or lack of) on performance and maturity.

Example Report Entry

Method Name: Synchrotron light interferometer

Quantities Measured: RMS transverse size

Resolution: few microns demonstrated, 1 micron possible in visible assuming Gaussian source

Location (injector, linac, arcs): high energy currently (3-5 GeV), but should work down to ~40 MeV

Strengths: Nondestructive, high resolution

Challenges: Alignment onto slits, different beam sizes require different slit spacing. For best resolution need high fringe visibility.

Comments: Alignment easier if beam split, and horizontal & vertical separately imaged. Resolution depends on fringe visibility requiring high quality detector. X-ray interferograms could give improved resolution. Demonstrated at several labs. Straightforward to use. Sensitive to beam stability.

Summary machine protection

Techniques: All available and can be used from existing machines

Slow system to control beam and operation modes
-> magnets, RF, screens, insertion device, valves
-> full integration of laser system crucial

Fast system to detect beam losses

Detection schemes:

- differential current measurements ~ 10uA and below (long discussion if $\Delta I/I=10^{-5}-10^{-6}$ is possible -> R&D)
- forward power SRF (interlock on re-circulated energy)
- interlock on orbit: likely required to control photon flux
- fast beam loss detection ~ 10nA and below
  - localized: photomultiplier tubes
  - global: coaxial cable, Cherenkov fibre
- online dose measurements (minutes) ~ 100rad level

Summary machine protection

Passive:

- Halo removal in injector
- Collimator section for high energy machines
- Good shield of all critical components
- Careful check of radiation hardness of components

Active:

- Laser control in most cases sufficient
- For high energy machines likely ultra-fast electron beam sweeper (beam circulation) required
  ~ few 100ns activation time

Most challenges:

Overall integration of system which

1) Covers all cases
2) Redundant and fail save
3) And operable!

Summary machine protection

Objectives:

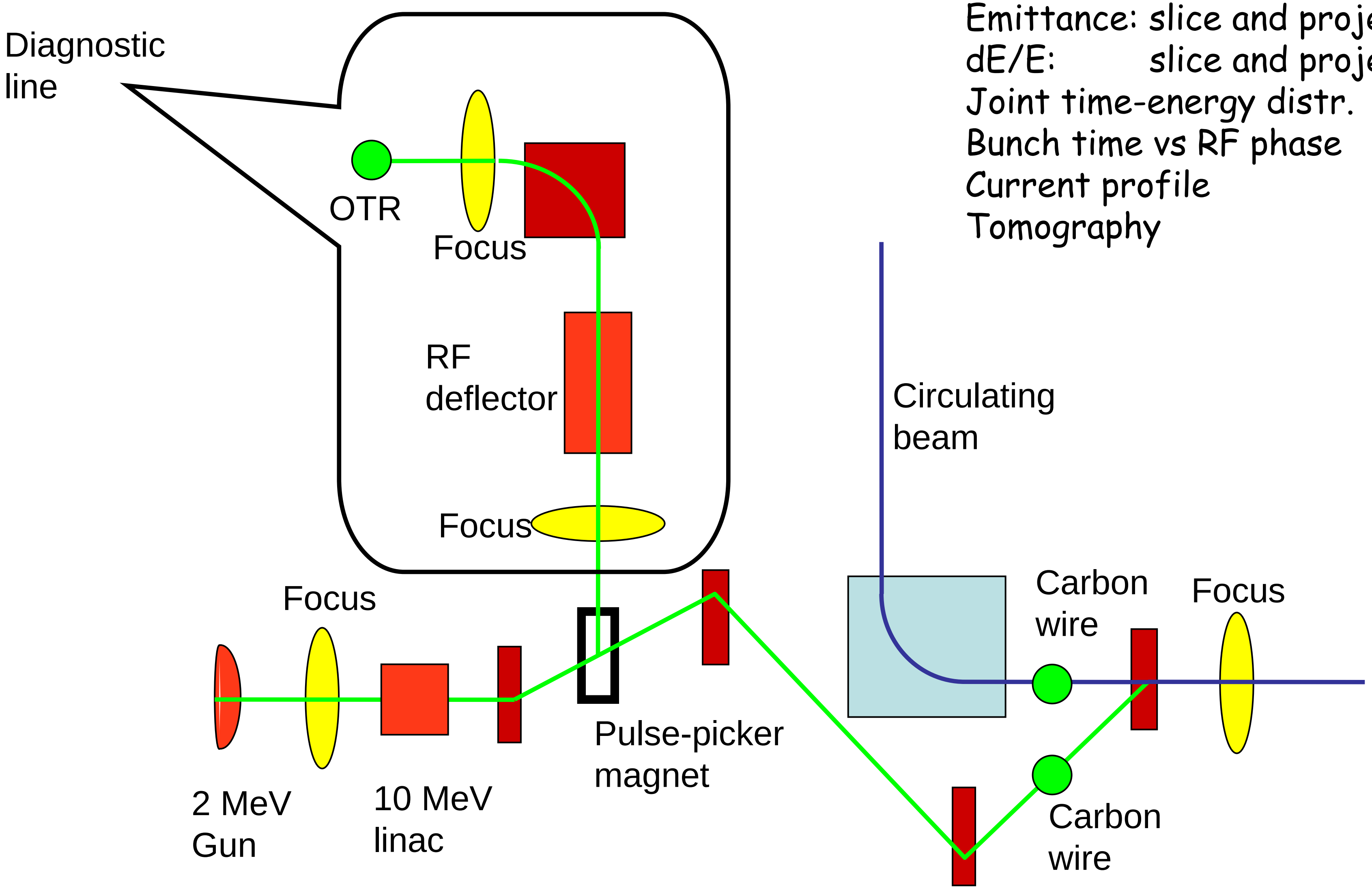
- reduced activation of machine components
- limit damage of electronic and optical devices
- guarantee long life time of insertion devices
- protection of vacuum chamber against
  - rapid or permanent electron beam losses
  - large photon flux (inappropriate orbit)
- technical interlock well be low personal interlock

ERL specific:

- CW mode operation very similar to storage rings, exception: significant larger halo expected
  better control since life time is not effected
- pulsed current with critical beam power is the most challening operation mode
- large variety of different beam modes

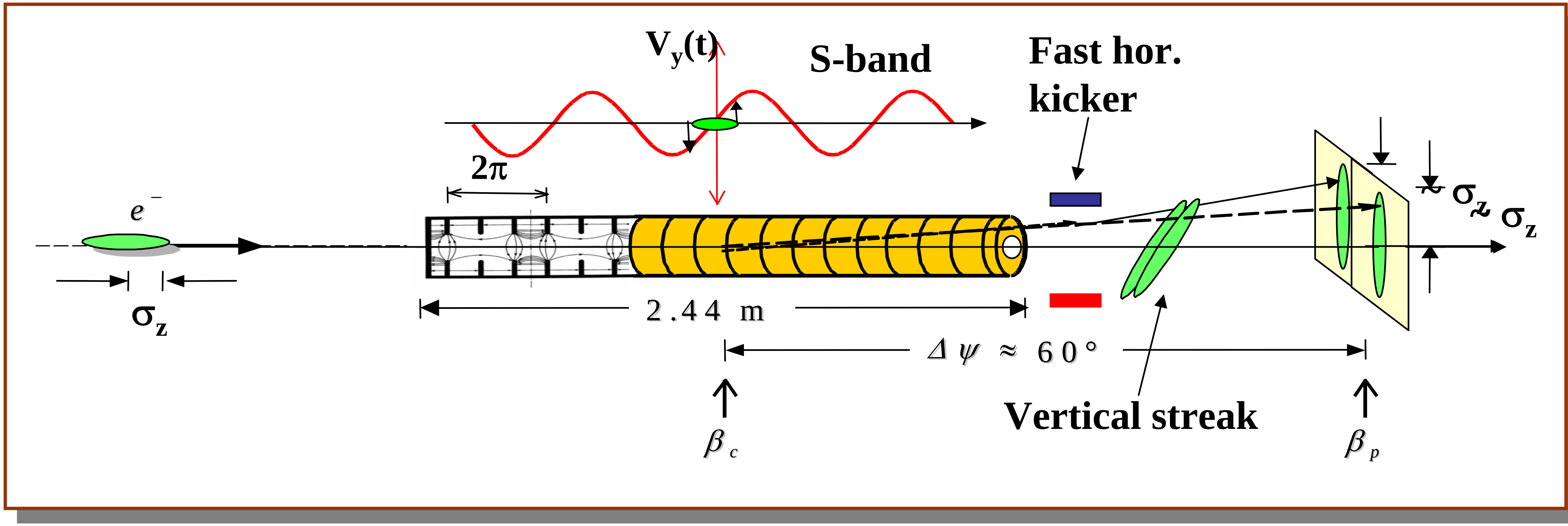
Possible Diagnostic Beamline

Emittance: slice and projected
dE/E: slice and projected
Joint time-energy distr.
Bunch time vs RF phase
Current profile
Tomography



Transverse deflecting structure

- vertical deflecting RF structure (2.856 GHz) operated at zero crossing
- vertical size of beam at imaging screen ⇒ depends on bunch length
- used structures sofar: "LOLA" at exit of SLAC linac, and TTF2 linac
- 25 MW klystron power to "streak" the 28.5 GeV for SPPS, (0.5GeV)
- 'Parasitical' measurement using hor. kicker and off-axis screens
- Resolution: SPPS ~ 60 µm, TTF2 ~ 5 µm (expected)

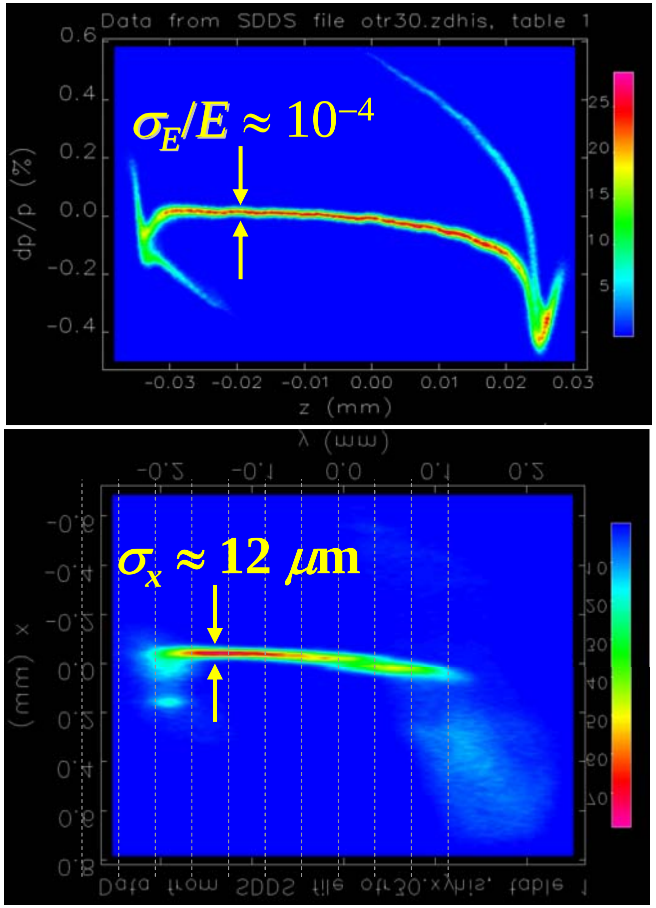


SPPS: P. Krejcik et. al.,TTF2: M. Ross et.al. + MIN DESY

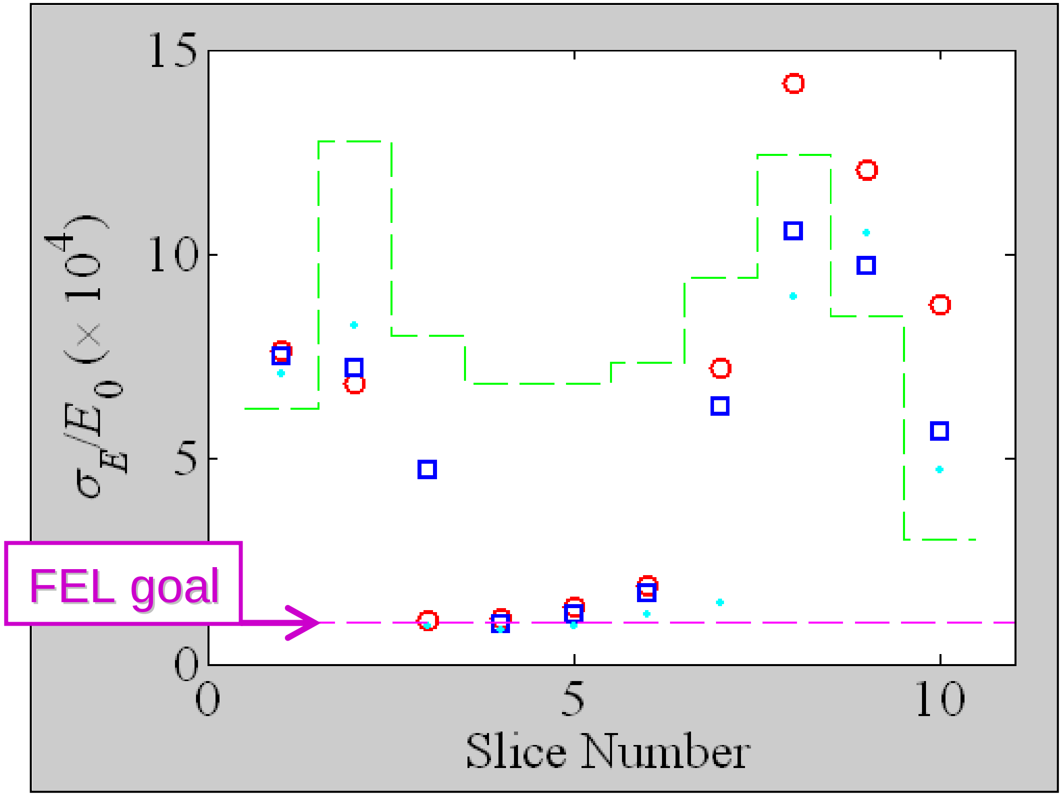
Slice Energy Spread Measurements in the LCLS

elegant **simulation (M. Borland) courtesy P. Emma**

Screen located at dispersive location, η_x=10 cm



LTU at 14 GeV with S-band RF-deflector at 24 MV

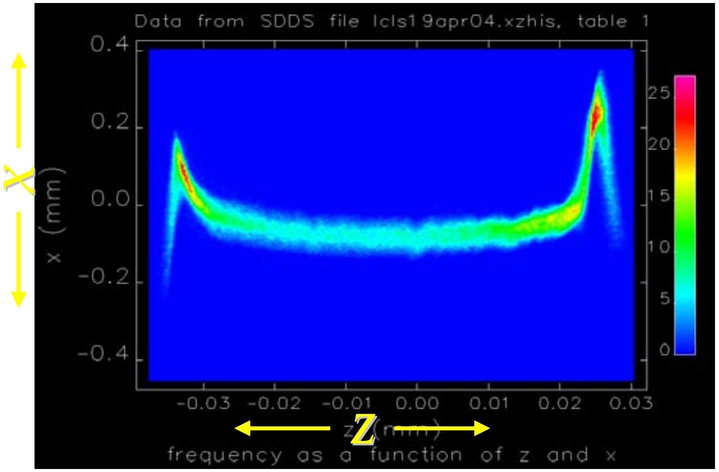


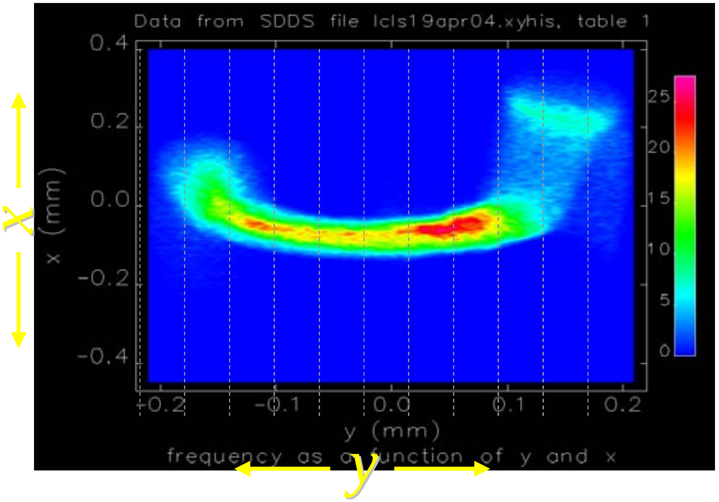
Courtesy of Patrick Krejcik (SLAC)

Slice-Emittance Measurements in LCLS

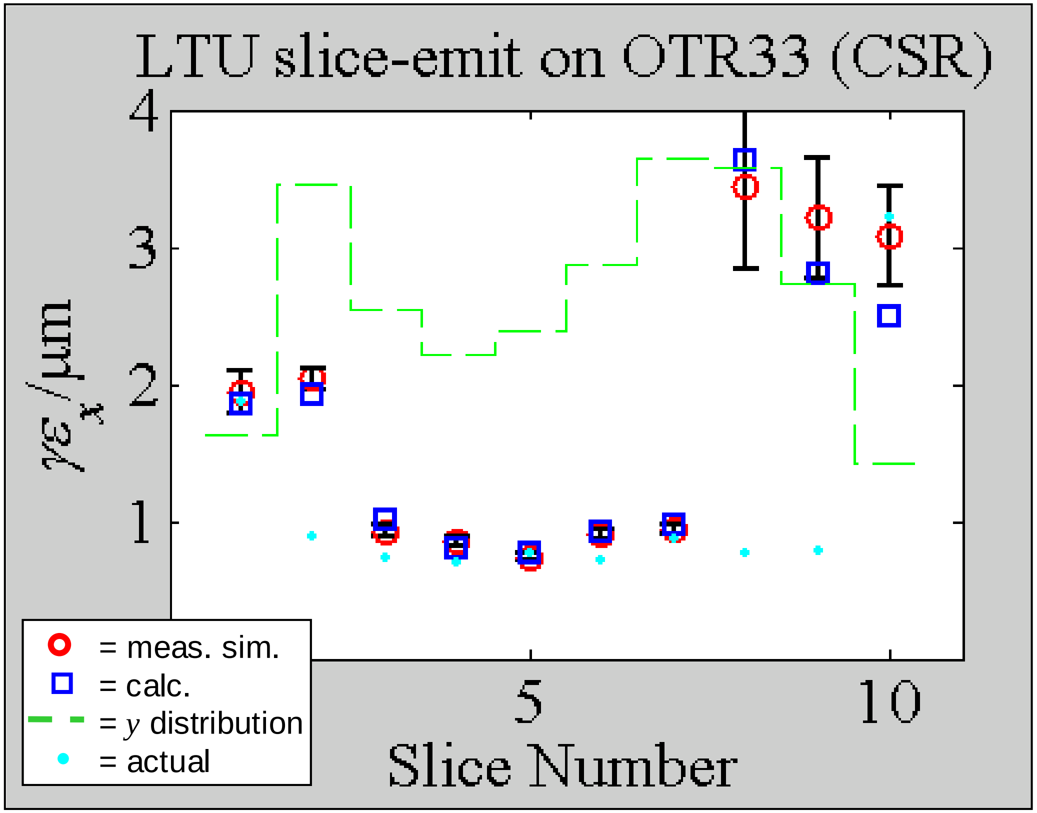
elegant simulation (M. Borland) courtesy P. Emma

3-screen method





LTU at 14 GeV with S-band RF-deflector at 24 MV

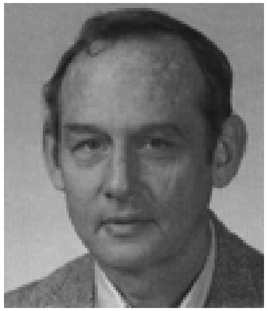


Courtesy of Patrick Krejcik (SLAC)

Growing Confidence

Performance anxiety prior to workshop

Current level is improving



Success looks achievable

Conclusions

Good progress on diagnostics concepts. Many interesting ideas. Productive & provocative group discussions.

Some systems are mature and can meet the ERL requirements with present performance.

Pulse-picker with dedicated diagnostic line could be implemented to allow use of high resolution 6D diagnostics using destructive methods.

Following initial description of diagnostics, need to develop detailed studies, and integrate measurements with electron optics.

Report generated!