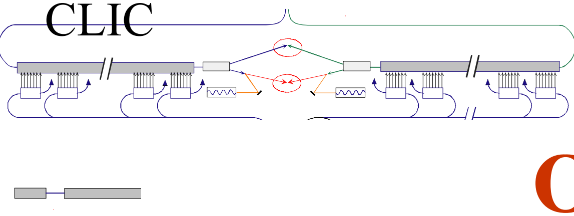
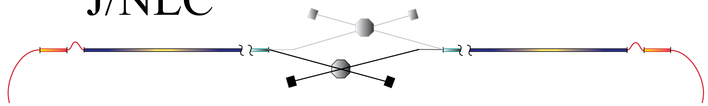
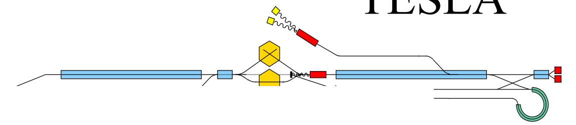
Machine Requirements – IP Beam Instrumentation

Wednesday, June 26, 2002

Marc Ross







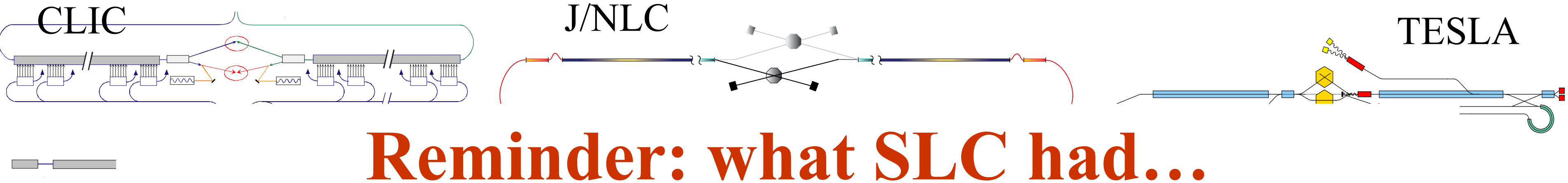
Operational Questions:

Luminosity:

- Short term variation
- Real-time precision
- Correlations (E,P…)
- Frequency of invasive measurements
- Luminosity vs δ
- <u>Luminosity strategies</u>

ET/MW

- Luminosity strategies depend on:
  - *<u>Where the luminosity comes from</u>*
  - *Geometric emittance*
  - *Pinch enhancement*
  - *Many dilutions…*
- IP beam instrumentation should provide this – real time –



Reminder: what SLC had…

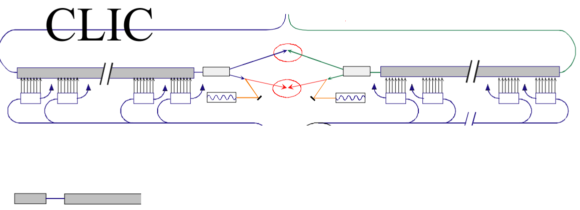
6 channel (spatial) γ BSM

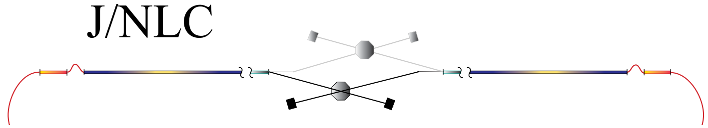
- Always used sum signal
- Ethylene pressure E_cut 0.3 Atm.

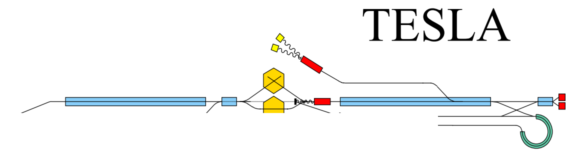
Rad. bha-bha monitor

- Parasitic energy band – $0.85>E/E_b>.65$

Invasive – wire scanners and screen profile monitors





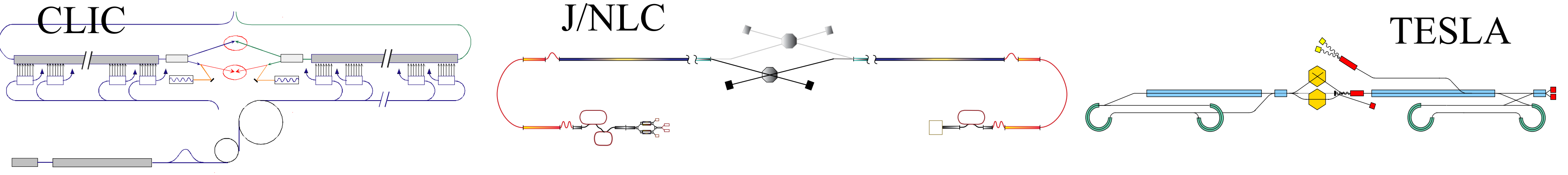


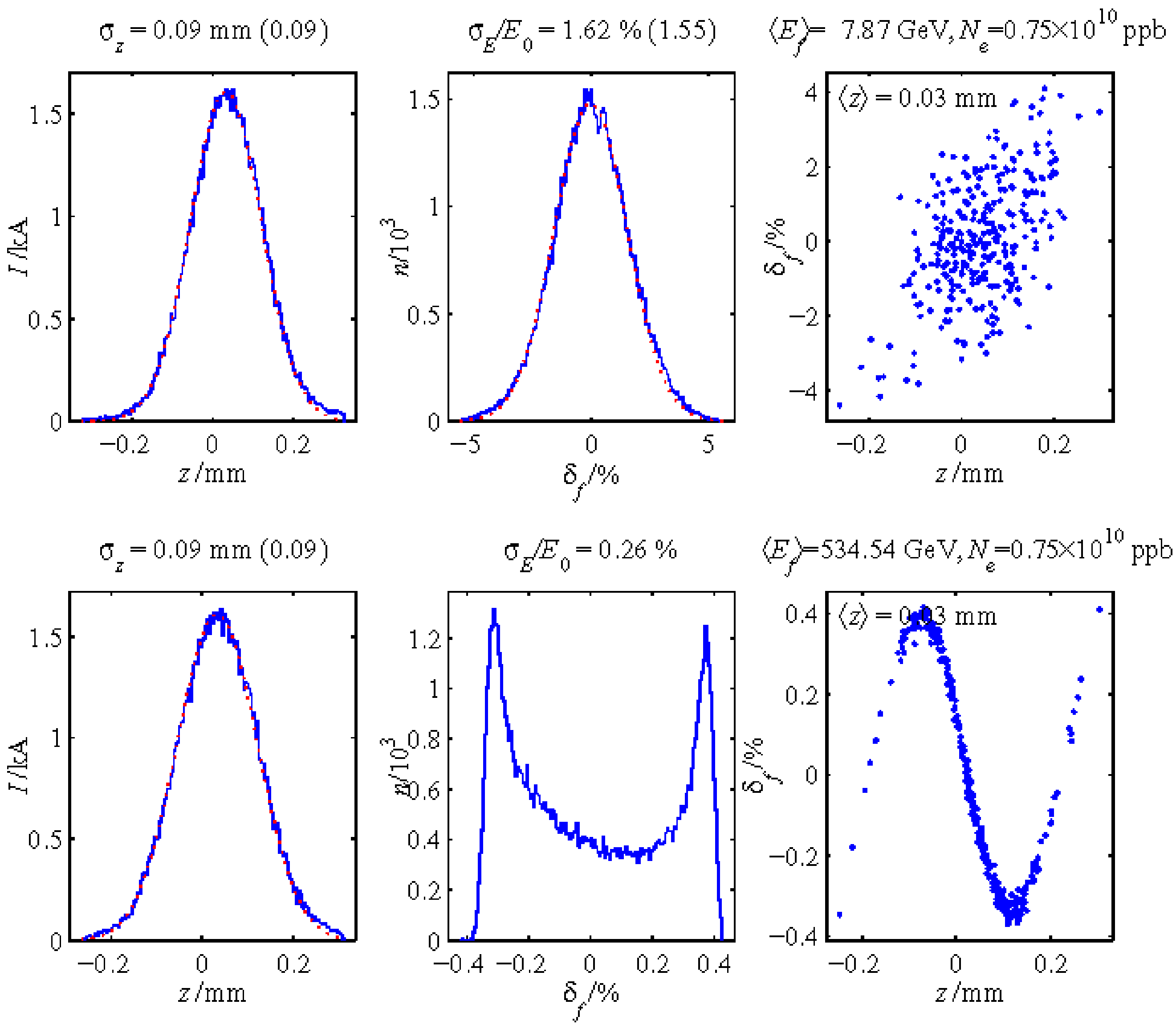
Disruption

- NLC 1.5
- TESLA 1.8
- SLC 1.4 @150 Z’s/hr

Disruption tightens geometric tolerances

- Bunch length
- Longitudinal distribution
- *y z* / *x z* correlations
- Δt
- Crab cavity system





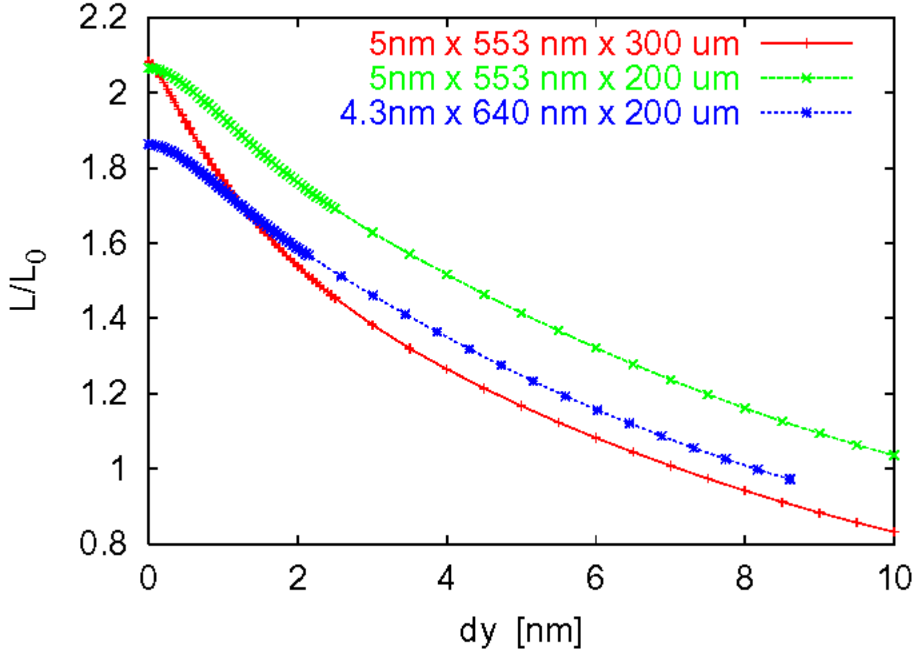
Longitudinal Dynamics

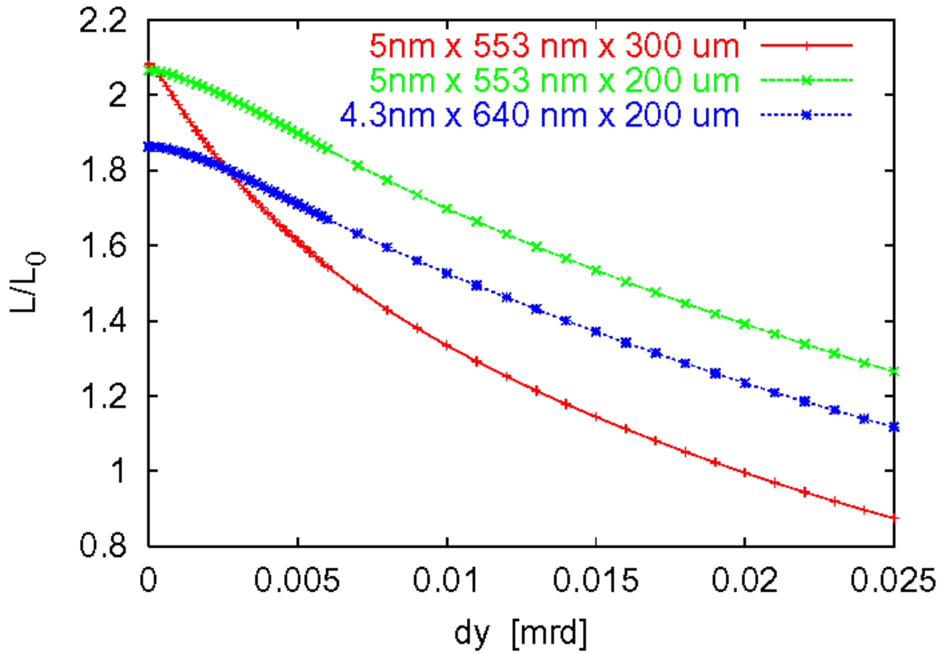
Bunch length,

Energy spread,

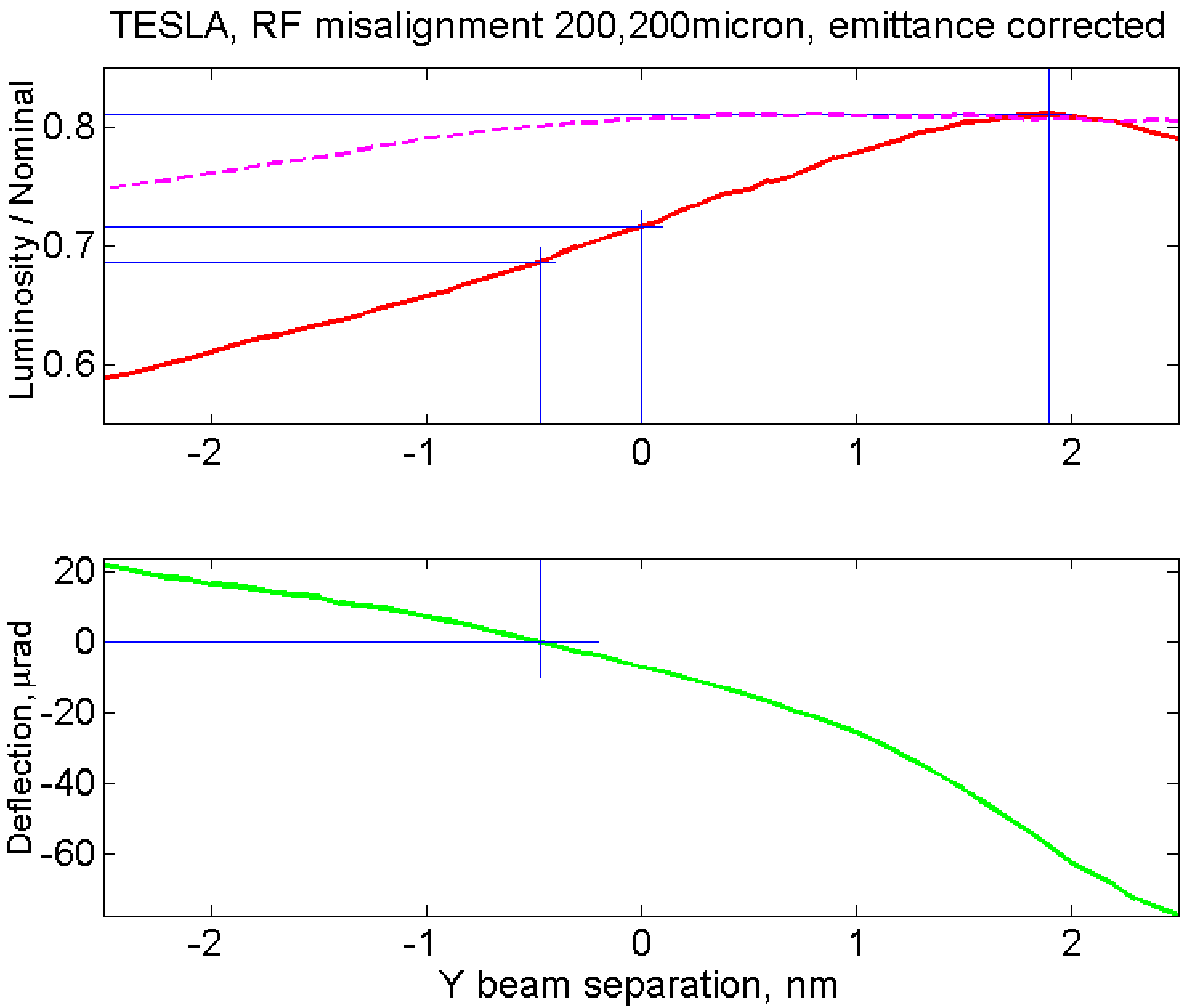
Correlation

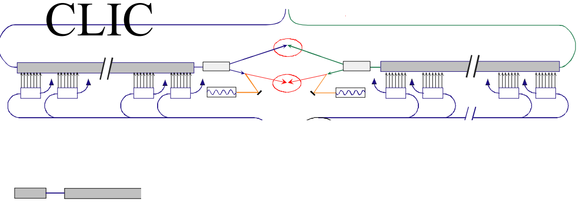
At the beginning and end of the linac

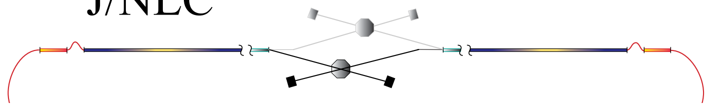


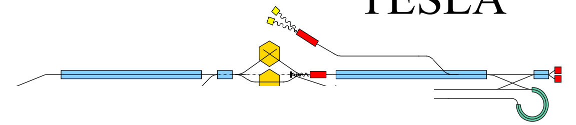


Luminosity (normalized to geometric) as a function of offset (position and angle)


TESLA, RF misalignment 200,200micron, emittance corrected
Luminosity / Nominal
0.8
0.7
0.6
-2
-1
0
1
2
20
0
-20
-40
-60
Deflection, μrad
Y beam separation, nm



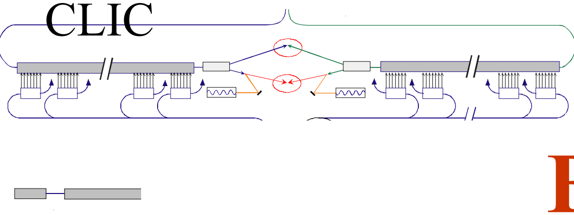


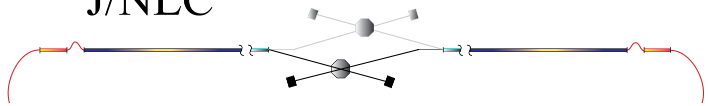


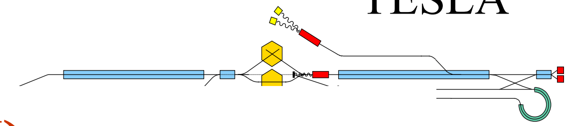
IP instrumentation

- σ_z, $J(z)$
- $x \leftrightarrow z$, $y \leftrightarrow z$, $E \leftrightarrow z$
  - *IP is surrounded by 'crab' cavities*
- $\sigma_{x,y}$
- BSM
  - E, **P**, geometric
- Pair monitor
- Rad bha bha

- Position
- Angle
- Timing
- Feedback



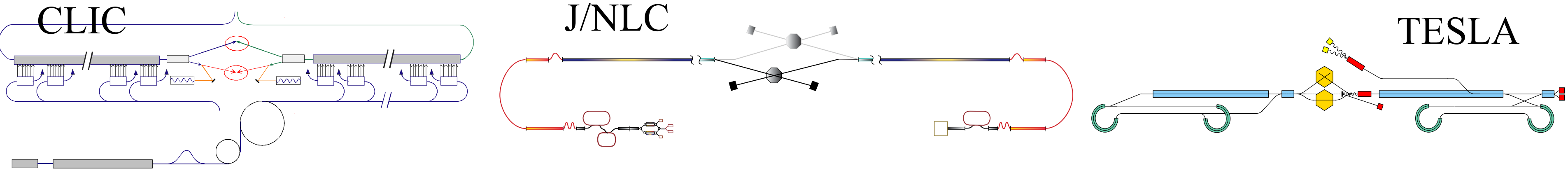


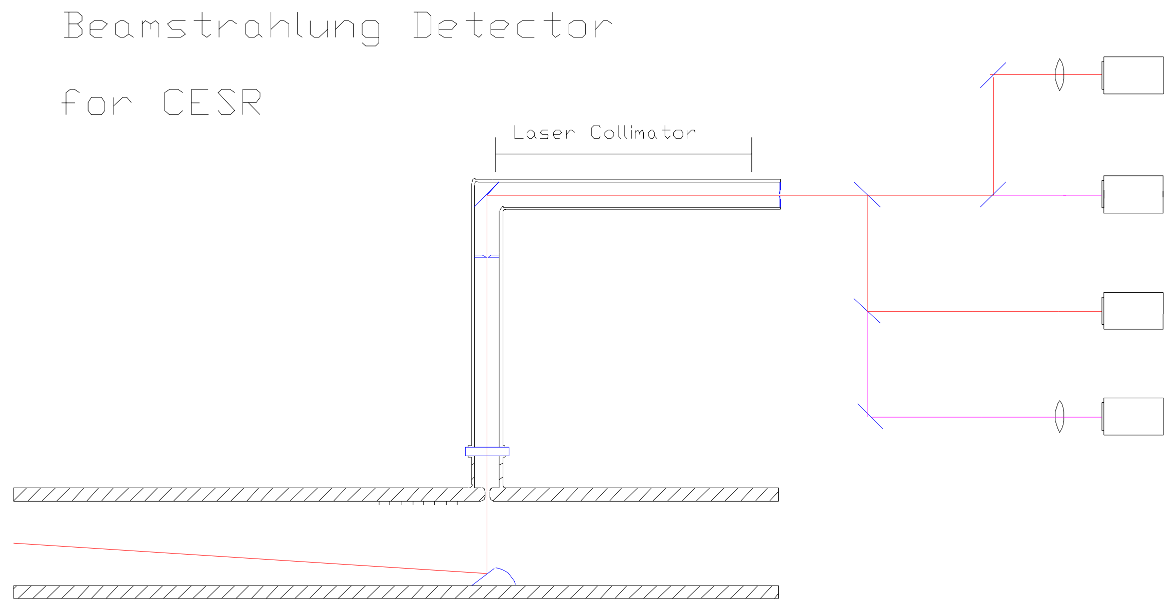


Beamstrahlung (BSM)

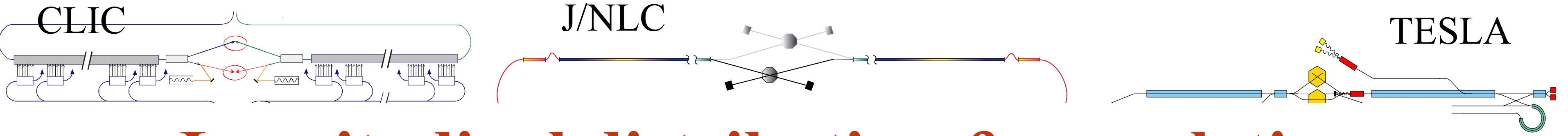
- (Bonvicini et.al. at CESR)

- Power
  - BSM 3-4% of beam power → TESLA 300KW / NLC 400KW
- Divergence
  - 300 μrad rms
- Distribution
  - Non-Gaussian, non-symmetric





This is an ideal RD project – the BSM must be an integral part of the machine

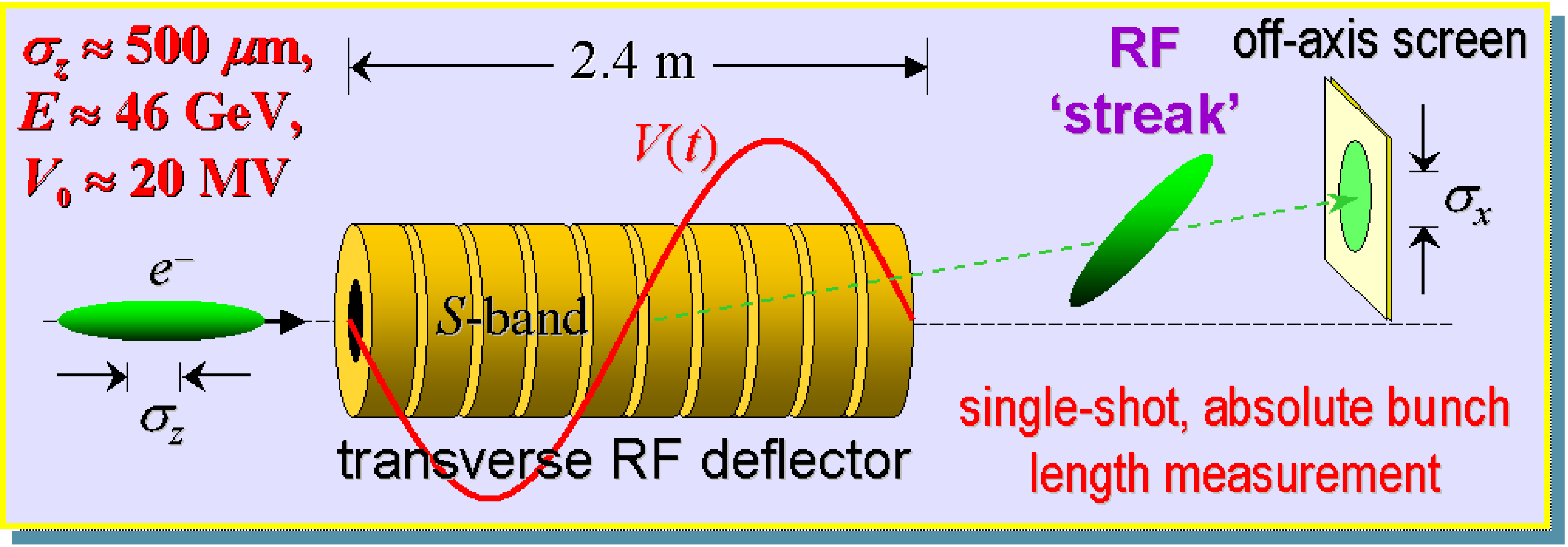


Longitudinal distribution & correlations

- Many dilutions initially appear as linear correlations
  - Linac single bunch wakes foremost
  - Collision sensitivity
- IP is surrounded by ‘crab’ type cavities
  - *x* and *y*
  - Useful for both correction and monitoring
  - How will this work?
- What additional methods can be used to monitor correlations?

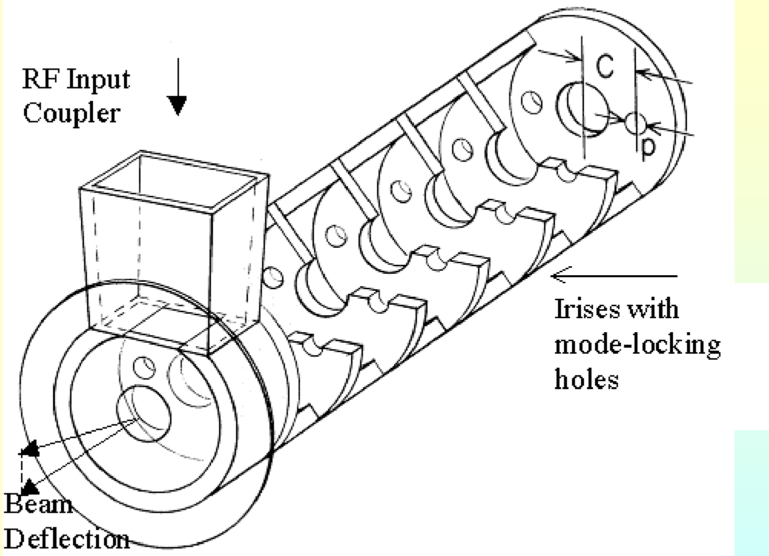
Transverse deflection

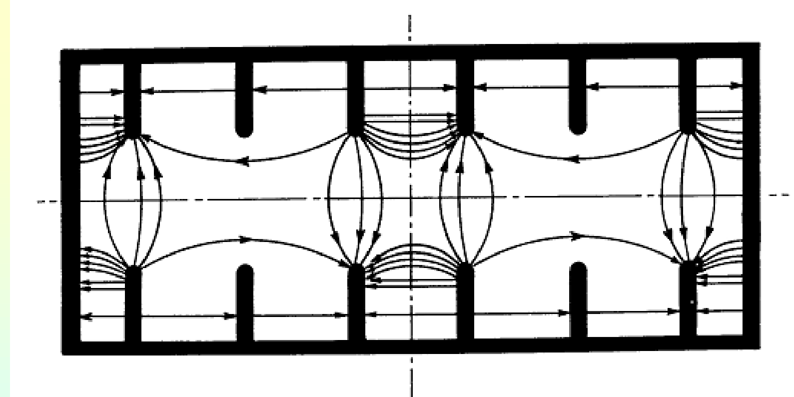
Old idea – 1965 'LOLA IV'
Testing in linac sector 29



Brute force
Calibrated
Expensive
Excellent resolution

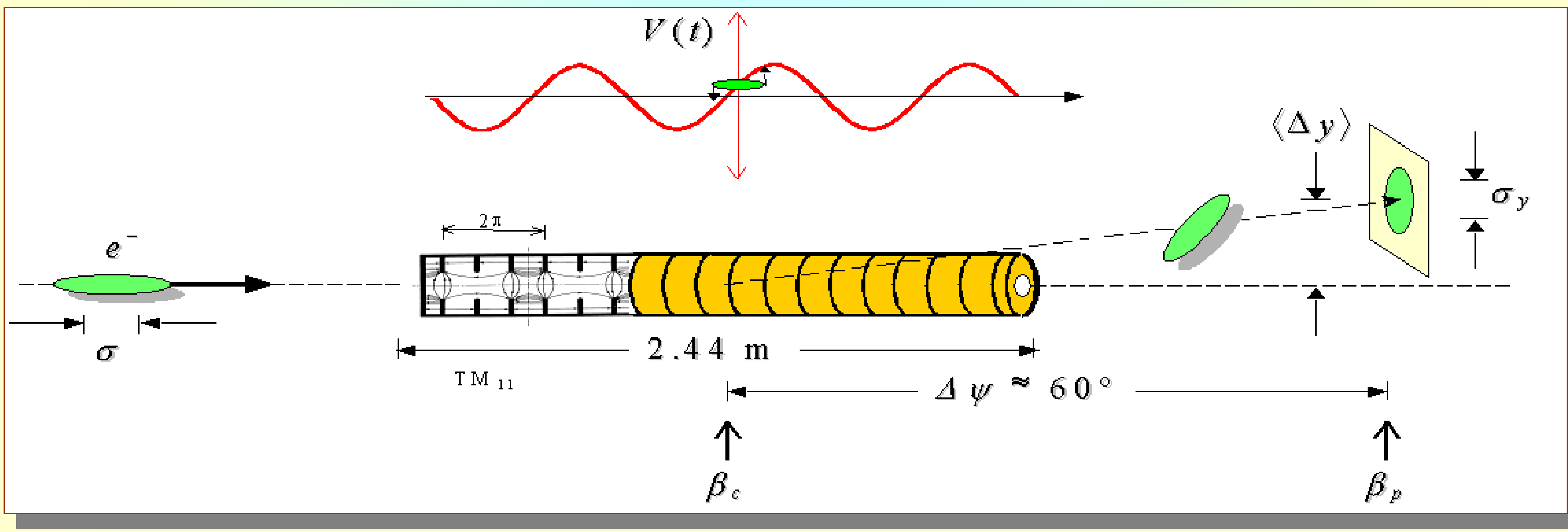
SLAC LCLS – Krejcik/Emma (EPAC 02)
SLAC/DESY TTF2





$$V_0 \approx \left(1.6\ \mathrm{MV/m/MW^{1/2}}\right) L \sqrt{P_0}$$

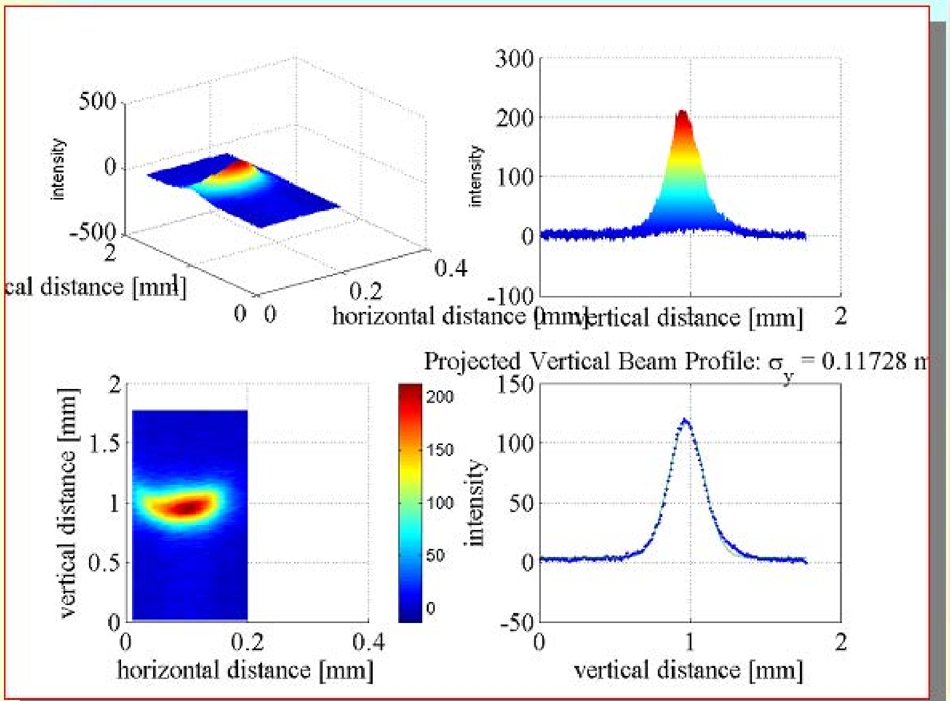
$$bunch\,lenght,\sigma_Z \approx \frac{\lambda_{rf}}{2\pi}\frac{E_S}{\left|eV_0 \sin\Delta\psi\cos\varphi\right|}\sqrt{\frac{\left(\sigma_y^2-\sigma_{y_0}^2\right)}{\beta_d\beta_s}}$$



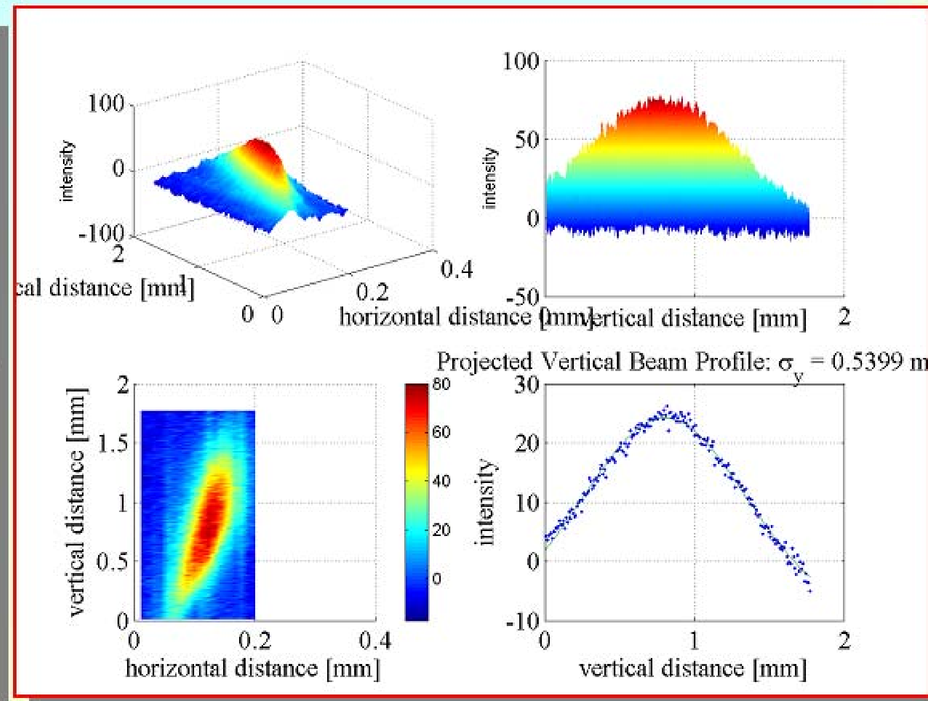
Profile Monitor Images

Damped, scavenger bunch at end of the linac

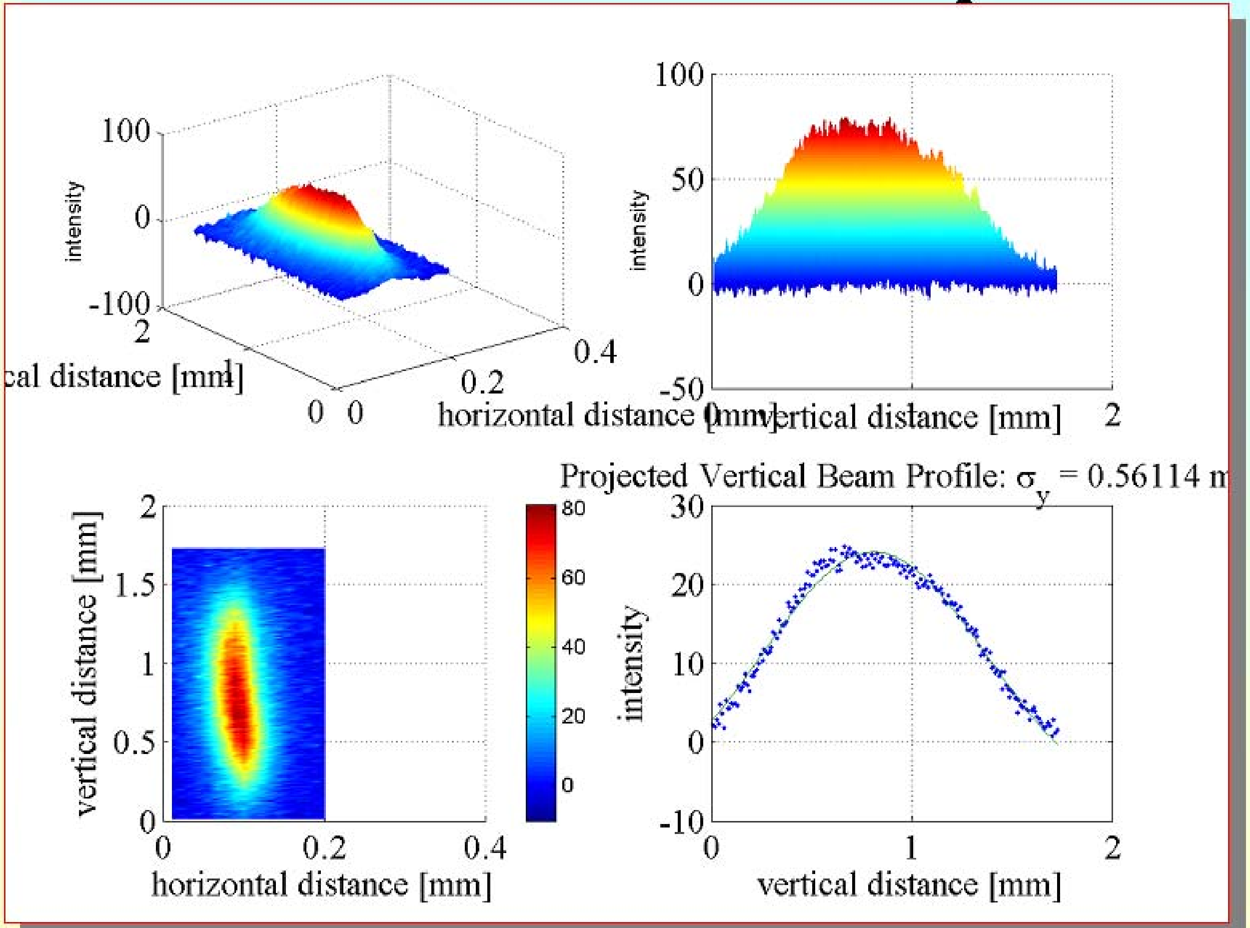
Transverse Cavity OFF



Transverse Cavity ON



Longitudinal Bunch Distribution for an Over-Compressed Beam



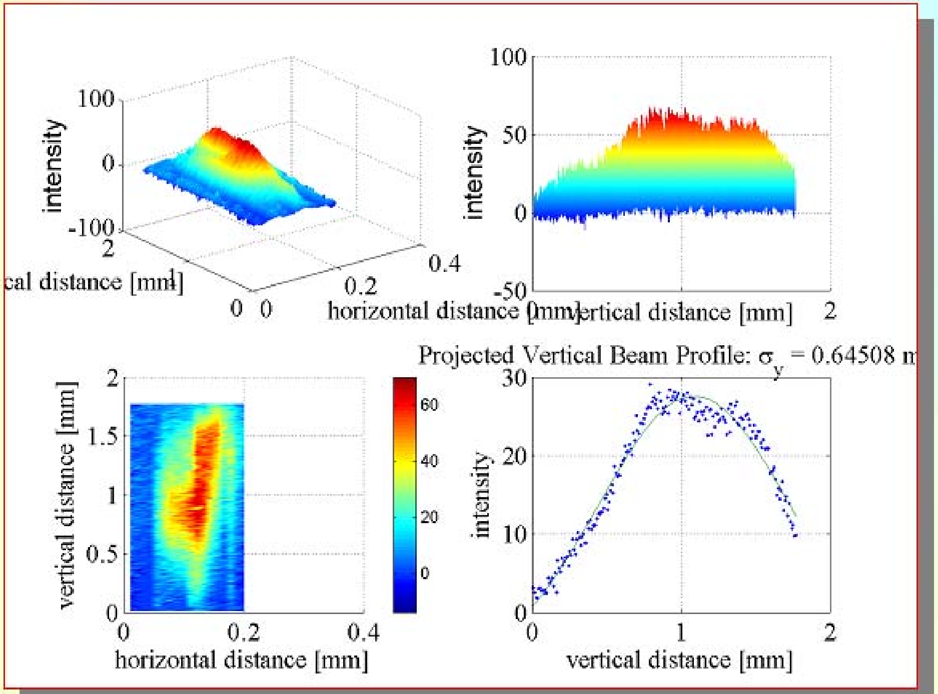
Streaked beam measurement shows characteristic non-Gaussian steep profile of over compression

(RTL Compressor Voltage = 42 MV)

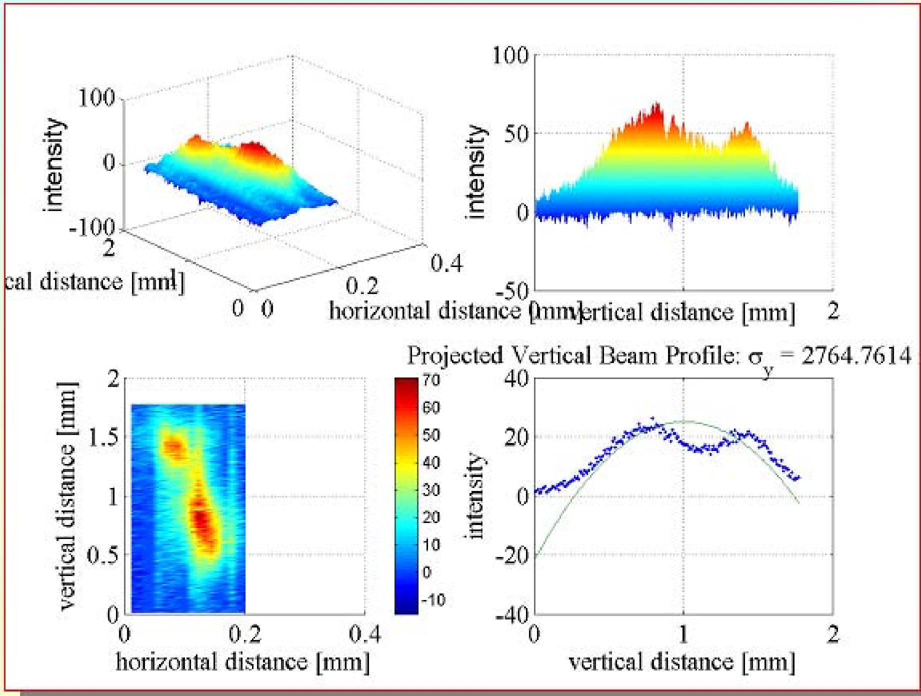
Longitudinal Distribution in Straight-ahead, Undamped Beam From the Gun Can Be Complex

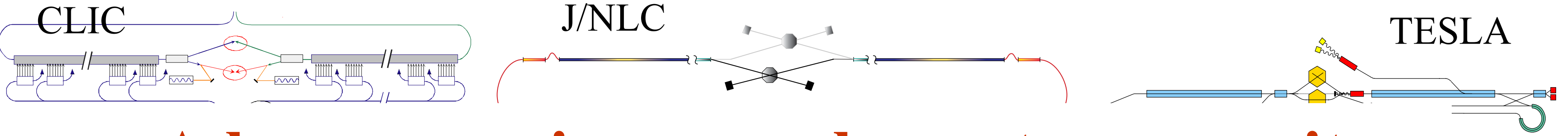
Krejcik / Emma EPAC 2002

Transverse Cavity 0°



Transverse Cavity 180°



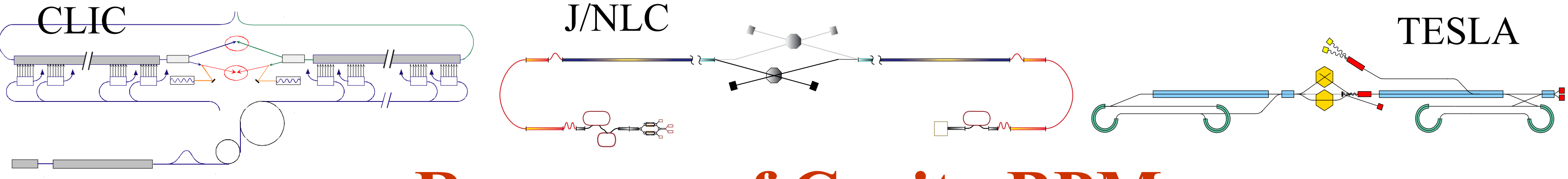


A less expensive, complementary, monitor

- Uses ‘microwave cavity’ BPMs
  - (~not tested)

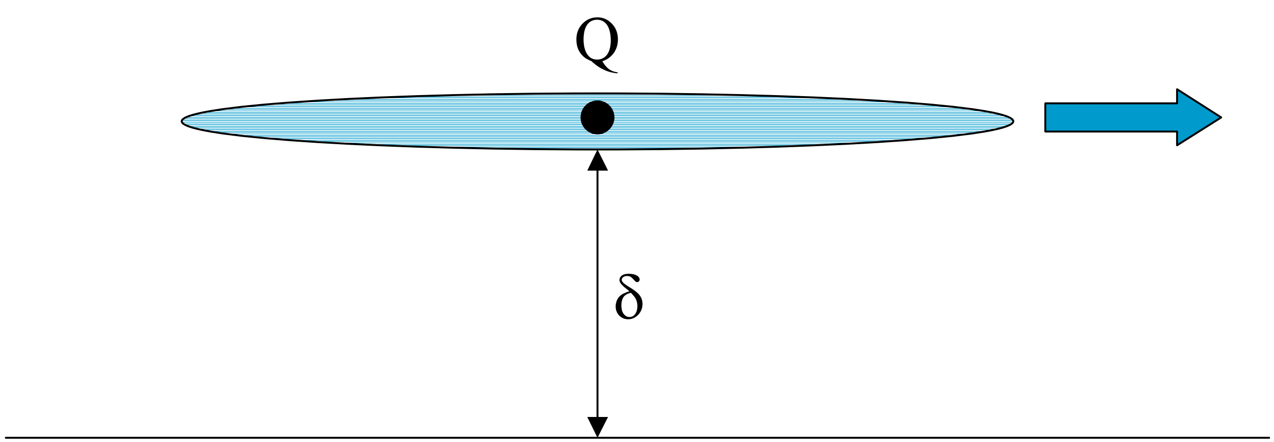
- Single bunch
- Multi-bunch → also effective but different goal/dilution

- <u>TILTMETER</u>



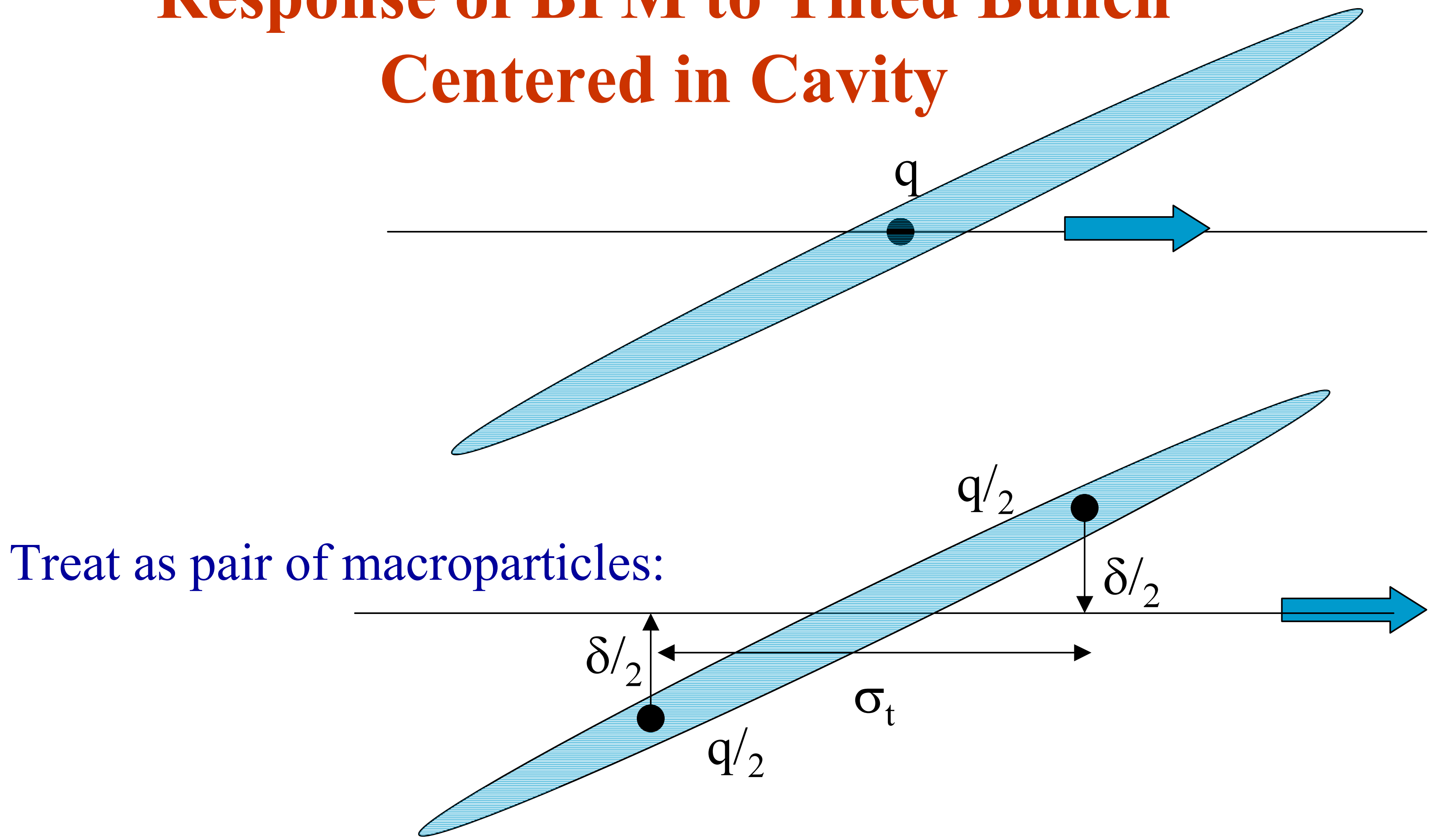
Response of Cavity BPM to Point Charge

S. Smith – Snowmass 2001



$$V(t) = aq\delta \sin(\omega t)$$

Response of BPM to Tilted Bunch Centered in Cavity



$$V(t) = a\frac{q}{2}\frac{\delta}{2}\sin\omega(t-\frac{\sigma_t}{2}) - a\frac{q}{2}\frac{\delta}{2}\sin\omega(t+\frac{\sigma_t}{2}) = \frac{a\delta q}{2}\cos\omega t\sin\frac{\omega\sigma_t}{2}$$

Tilted bunch

- Point charge offset by δ

$$V_y(t) = aq\delta \sin(\omega t)$$

- Centered, extended bunch tilted at slope δ/σ_t

$$V_t(t) = \frac{a\delta q}{2} \cos \omega t \sin \frac{\omega \sigma_t}{2}$$

- Tilt signal is in *quadrature* to displacement
- The amplitude due to a tilt of δ/σ is down by a factor of:

  with respect to that of a displacement of δ

  (~bunch length / Cavity Period)

$$V_t / V_y = \frac{\omega \sigma_t}{4} = \frac{\pi \sigma_t}{2T}$$

Example

- Bunch length $\sigma_t = 200\ \mu m/c = 0.67$ ps
- Tilt tolerance d = 200 nm
- Cavity Frequency F = 11.424 GHz
- Ratio of tilt to position sensitivity $\frac{1}{2}\pi f\sigma_t = 0.012$
- A bunch tilt of 200 nm / 200 μm (1 mrad) yields as much signal as a beam offset of 0.012 * 200 nm = 2.4nm
- Need BPM resolution of ~ 2 nm to measure this tilt
- Challenging**!**
  - Getting resolution
  - Separating tilt from position
- Use higher cavity frequency?

Need 1 mrad tilt sensitivity for linac tuning

Angled trajectories

- A trajectory that is not parallel to the cavity axis also introduces a quadrature signal (in phase with 'tilt' signal)
- Projected 'dipole' sensitivity is increased by σ_z/cavity length
  - ~ 50

Relative normalized precision
Beam position/beam traj angle

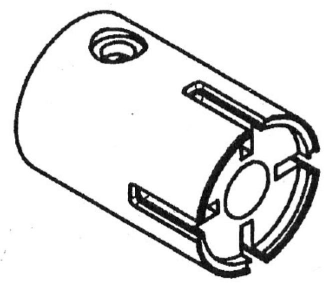
$\sigma_{y\,res}/\sigma_y \sim 5\%$
$\sigma_{y'\,res}/\sigma_{y'} \sim 10x$

Cavity BPM				
	FFTB (Shintake)	ATF ext line (Vogel)	X-band (Naito)	
f	5.712	6.426	11.424	(GHz)
position resolution	20	200	200	(nm)
Vt/Vy (200um sig_z)	0.6%	0.7%	1.2%	(.5 pi sig_t f)
achieved 'projected dipole resolution' (200um sig_z) δ	3.3	29.7	16.7	um
achieved 'tilt' angle resolution	17	149	84	mrad
achieved 'trajectory angle resolution'	3	26	30	urad
cavity 'length'	15	15	8	mm

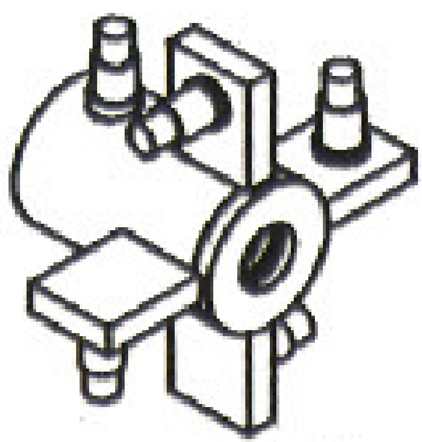
ATF σ_z ~ 8mm gives expected tilt resolution ~ 0.1mrad

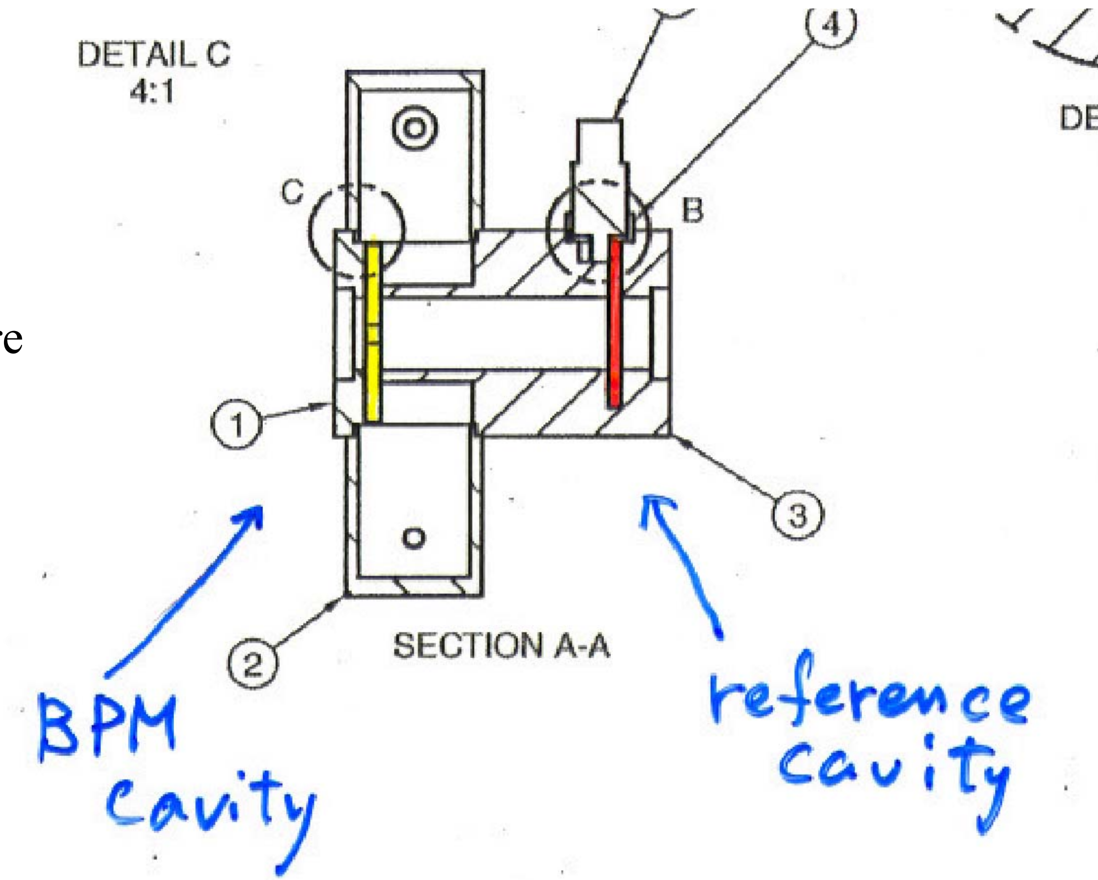
μWave cavity BPM
X-band

Naito/Li



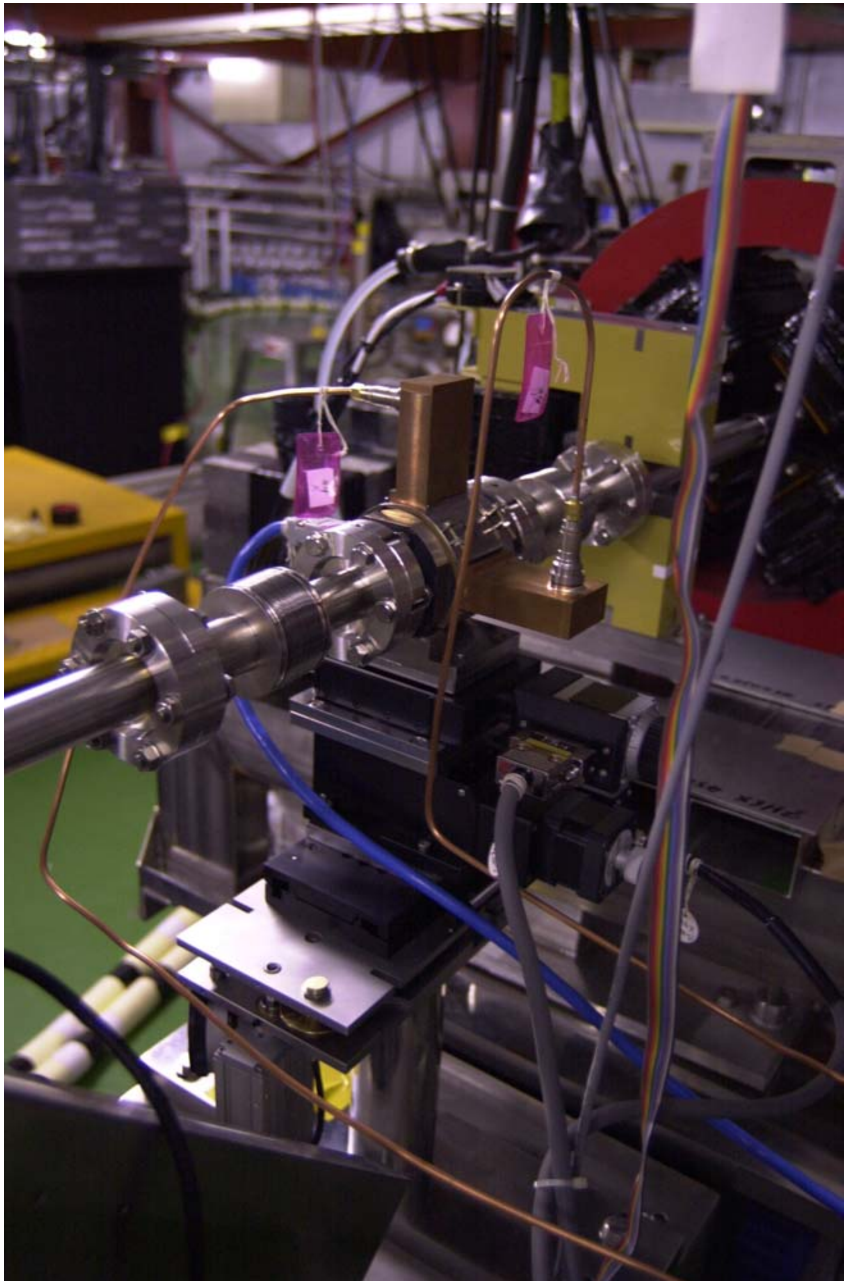
12 mm bore



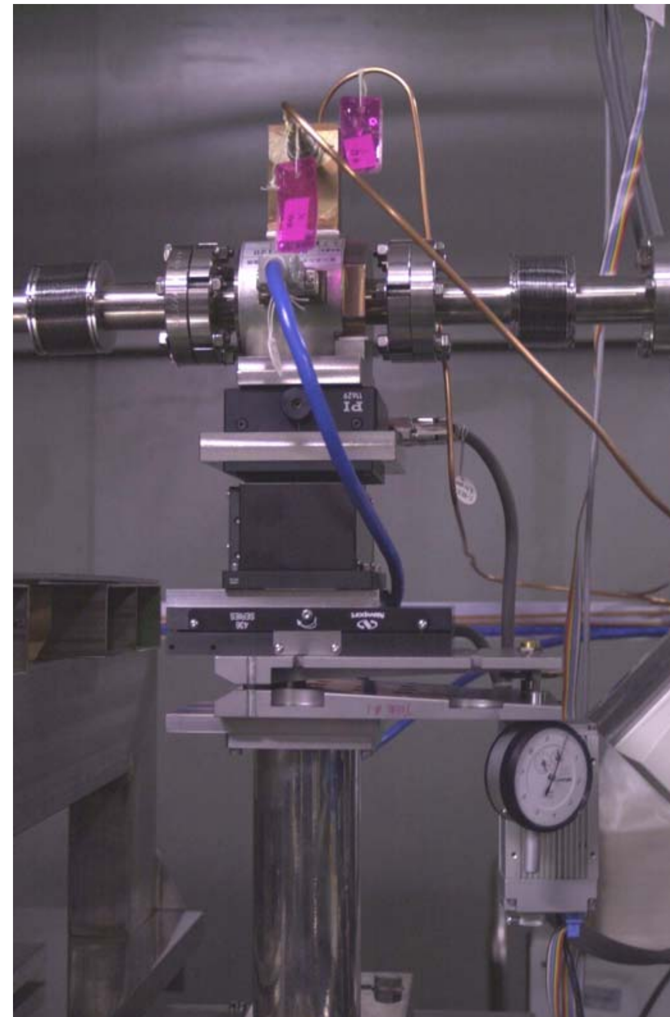


Very good resolution possible – 25 nm achieved in FFTB
few nm possible by <u>limiting spatial dynamic range</u>

ATF Cavity BPM – V. Vogel / H. Hayano

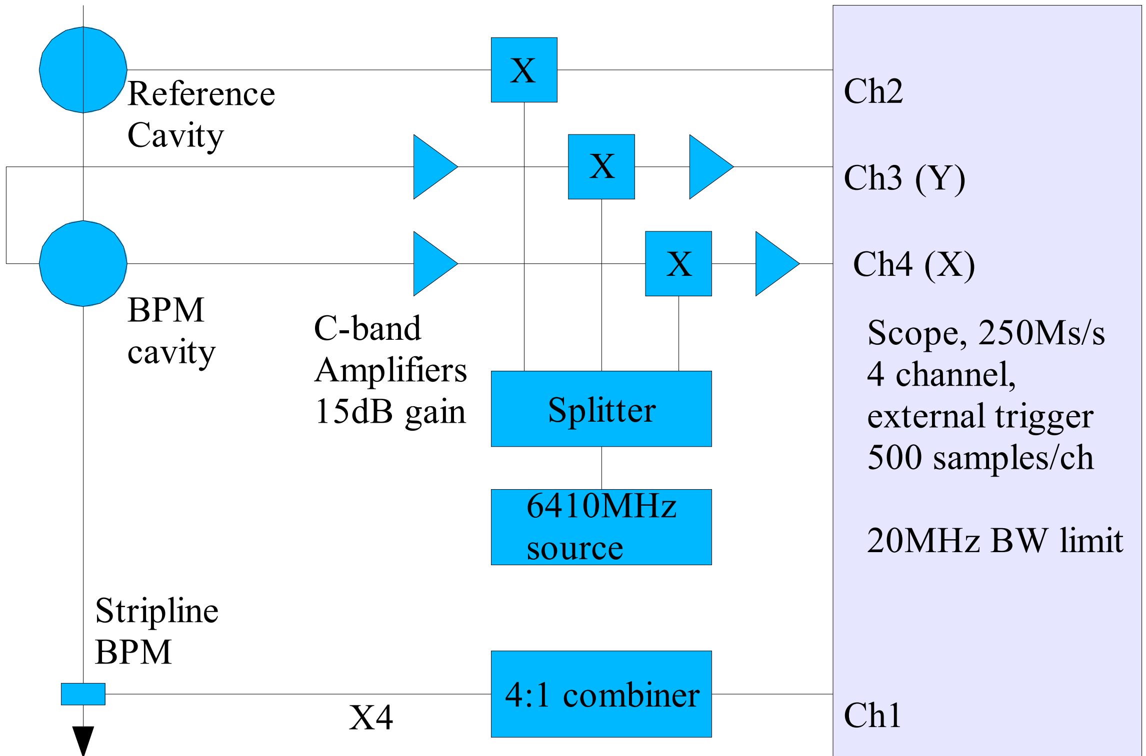


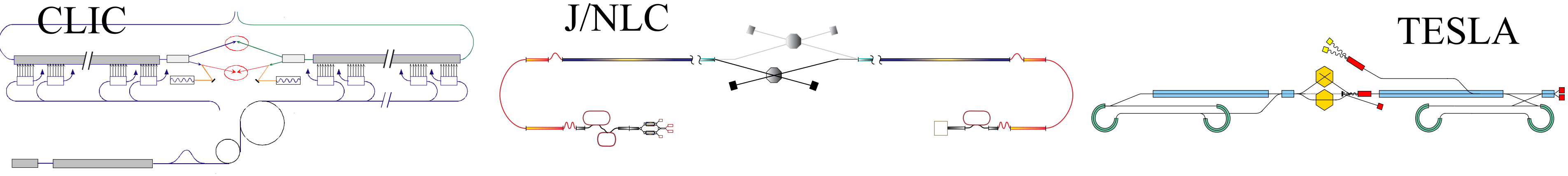
ATF extraction line
C-band cavity
L = 12mm, Radius = 26mm, f = 6426MHz, λ=46.6mm
Movers – x, y, pitch (*y*-*z*)



Tilt monitor electronics

J. Frisch

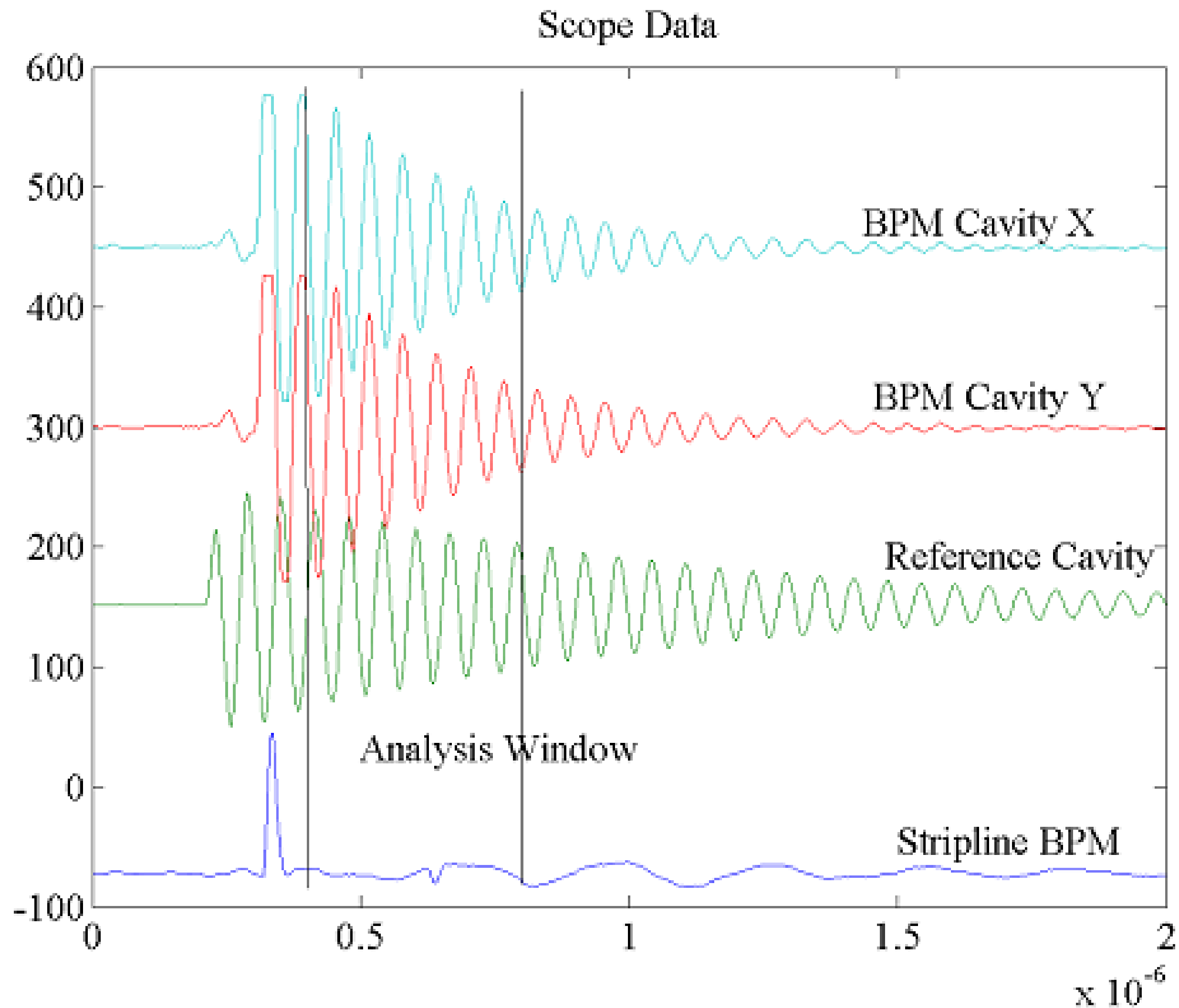


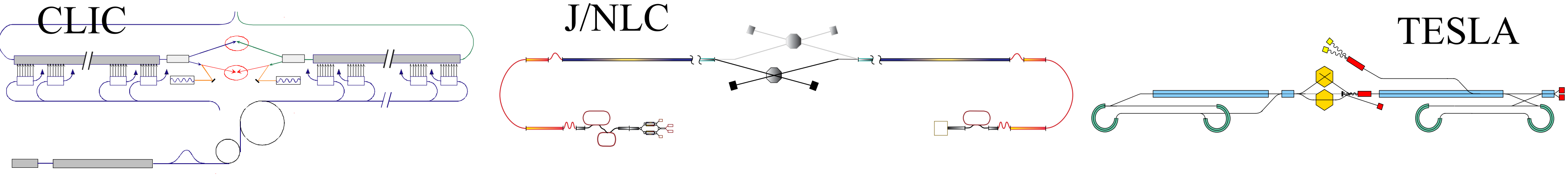


Raw 'mixed – down' scope data from cavity BPM

Phase and amplitude wrt ref are extracted

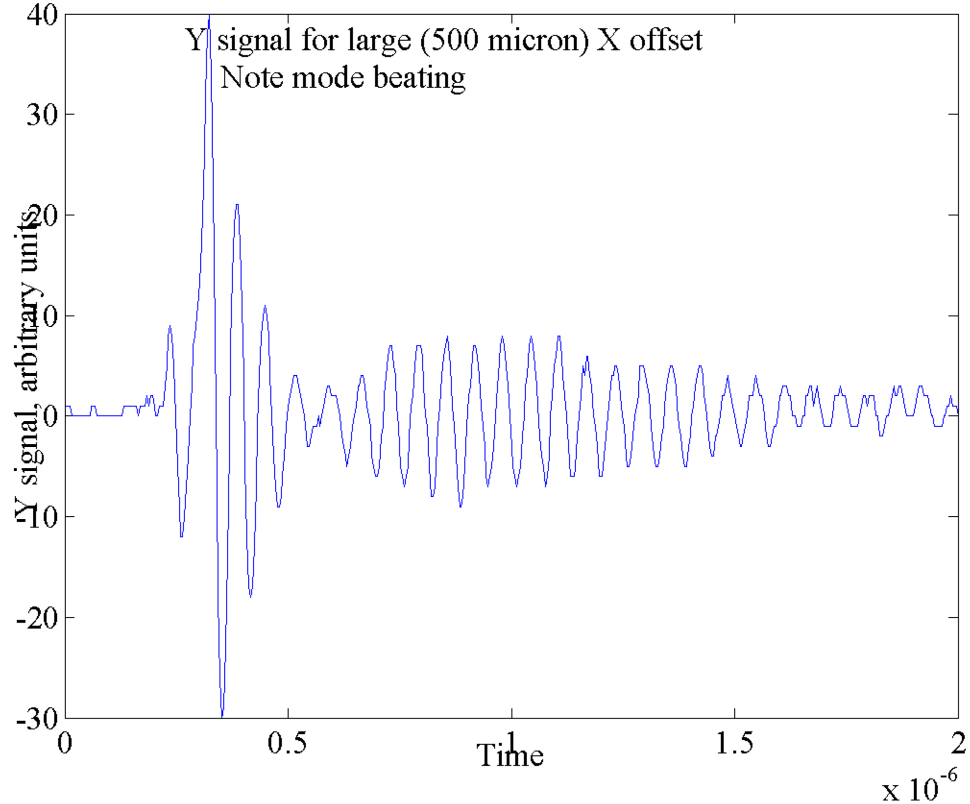
(I and Q)

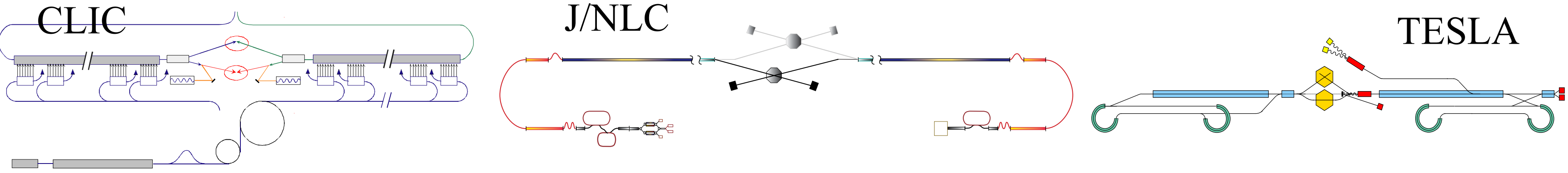




If there is a large offset in one plane, and little in the other, we see beating between modes

(nominally cylindrically symmetric cavity)

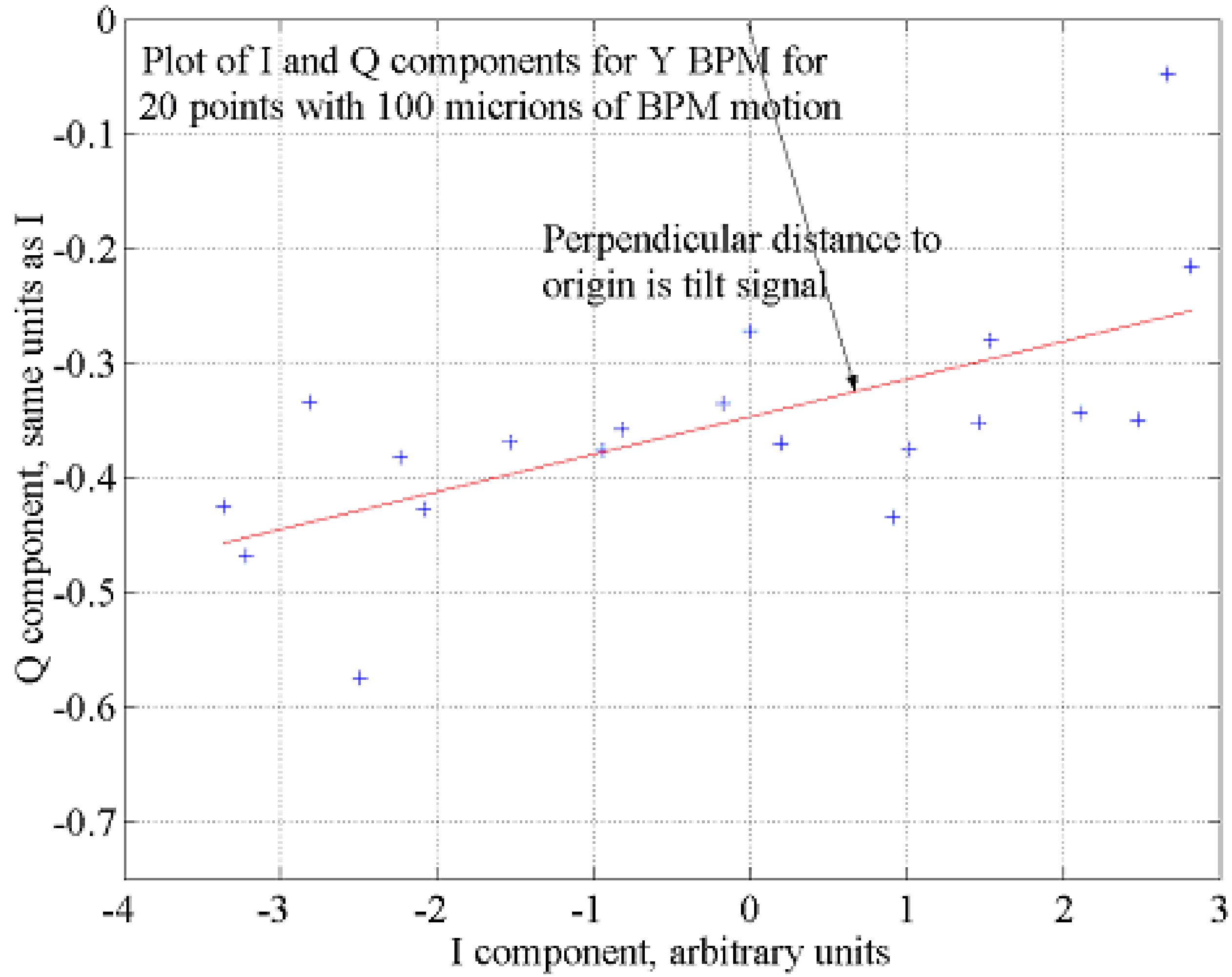


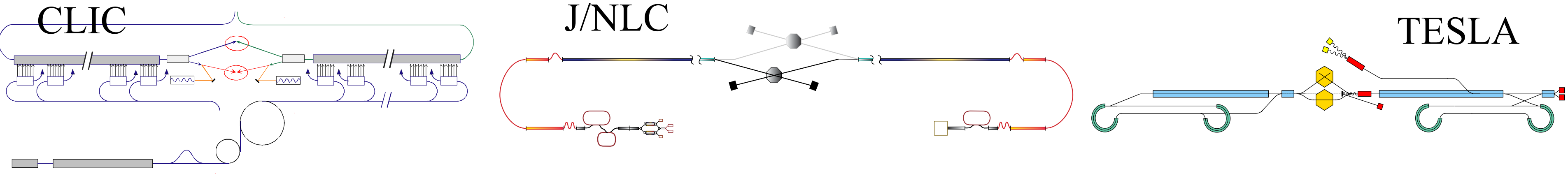


I Q response as the cavity is moved vertically using mover

The angle is arbitrary (phase offset between ref and BPM cavity)

A 'monopole' beam with an axial trajectory should give a (0,0) response at some point

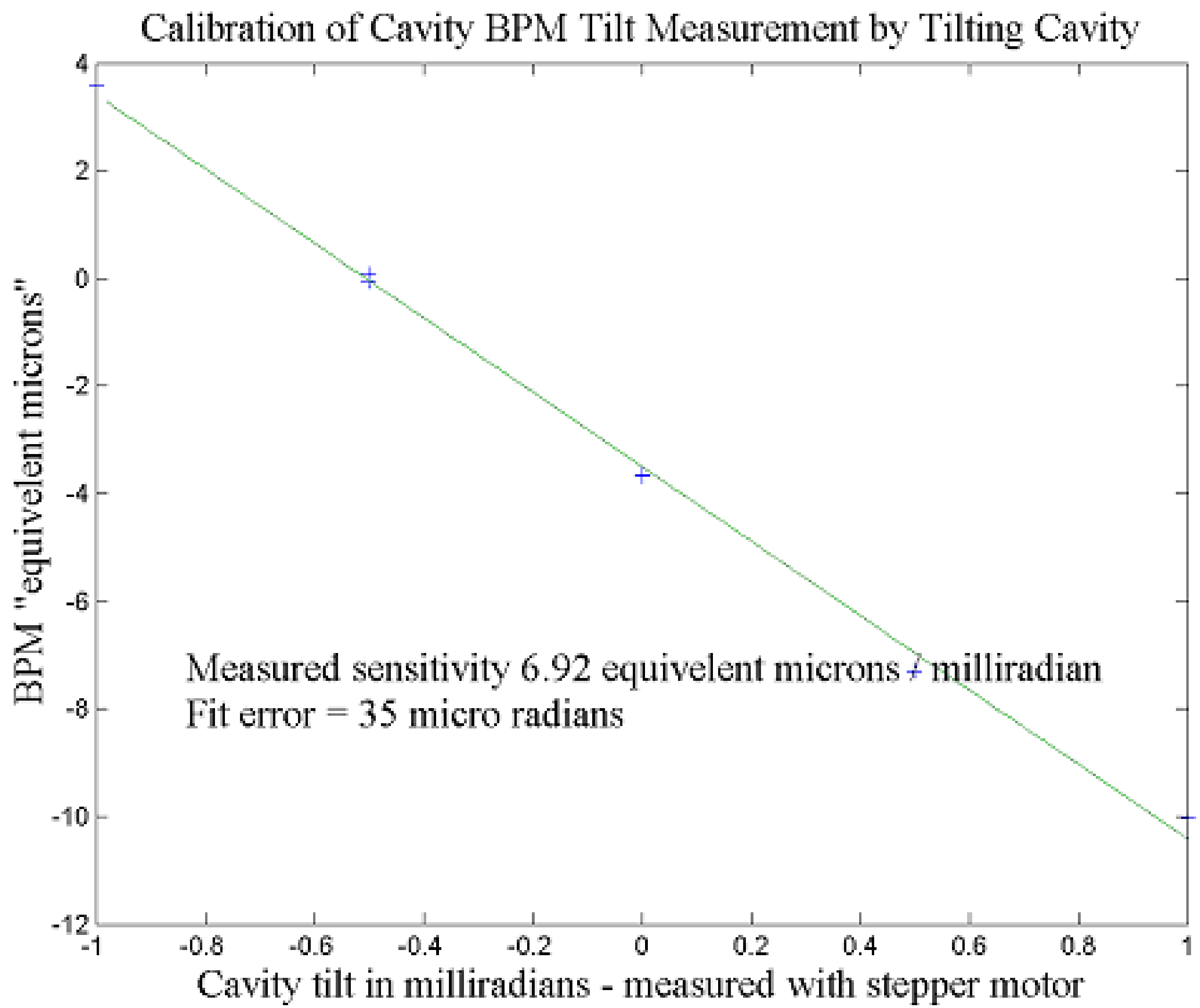


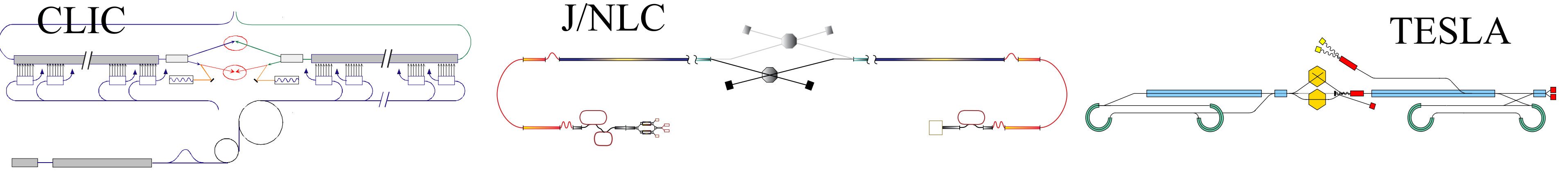


Use the cavity ‘tilter’ to observe response to tilted trajectories

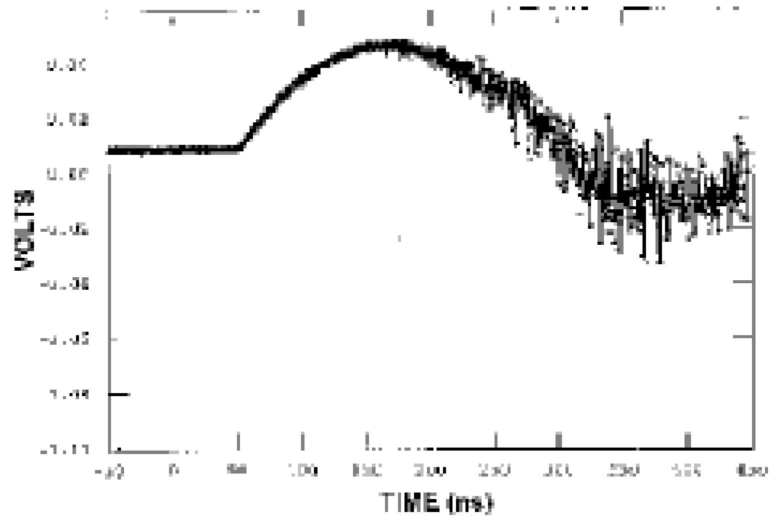
(Beam ‘tilter’ was not ready during this test – May 2002)

Compare 35 urad with 26 in table estimate



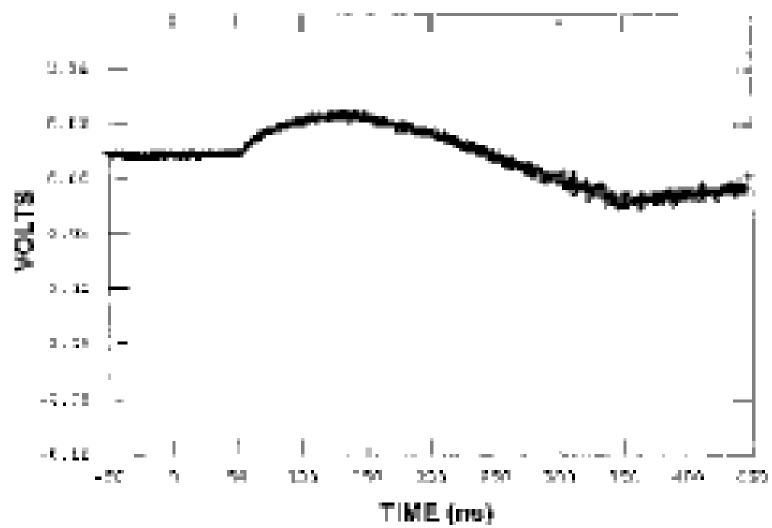


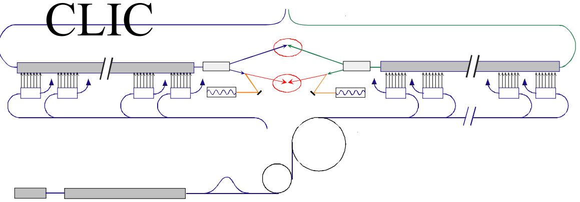
The tiltmeter can also be used to measure the 'tilt' of the full bunch train.

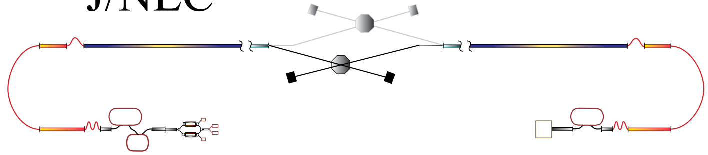


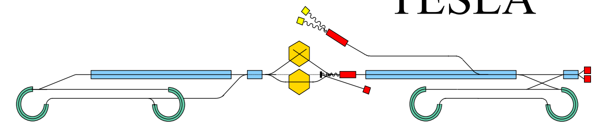
Signal from uwave cavity BPM for 300 ns <u>E158 SLAC</u> long pulse beam

Offset(t) * Intensity (t) vs time

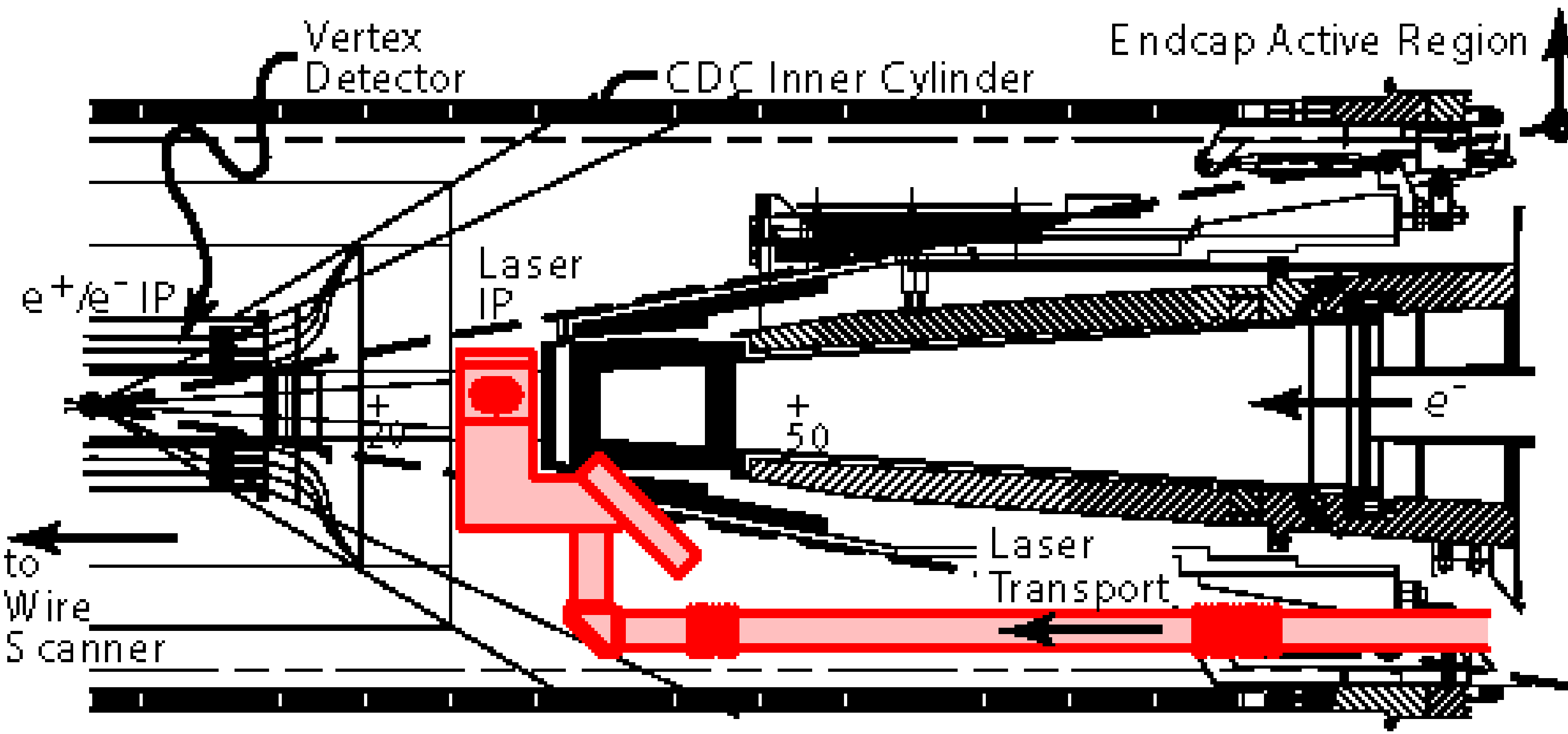


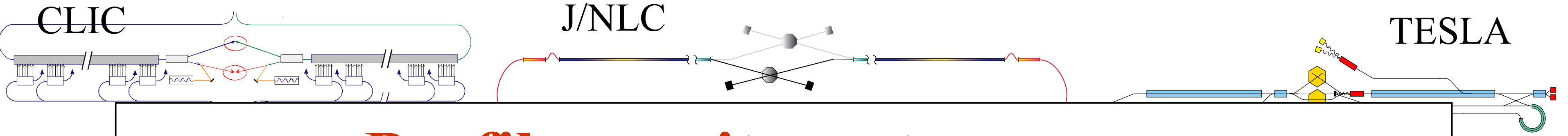






SLD at SLC – the innermost vacuum chamber is a crude cavity BPM

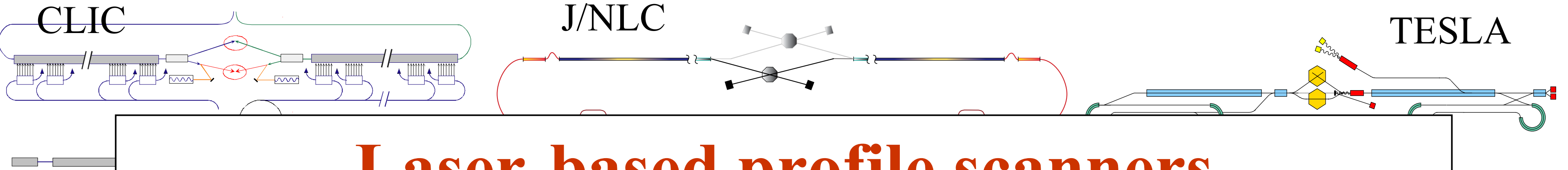




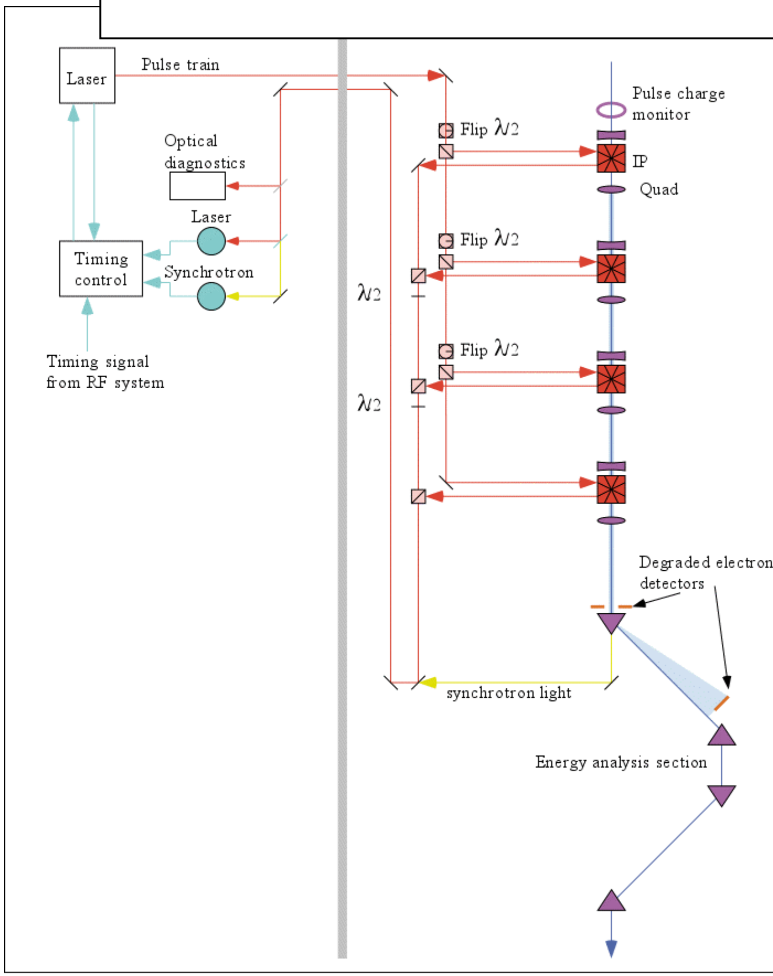
Profile monitor – transverse

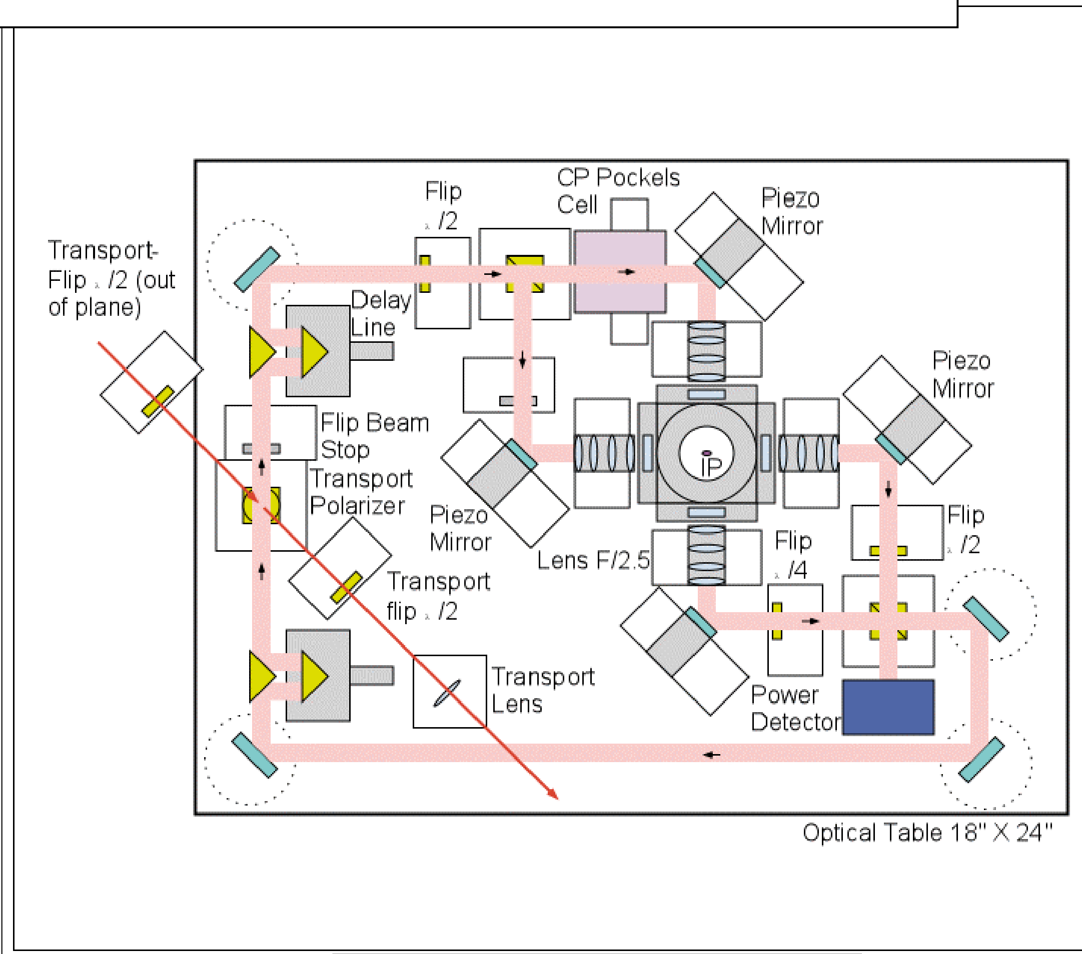
- Scanners
  - wire — Limited at LC due to wire damage; maybe ok for FEL
  - laser — ubiquitous at LC

- Imager
  - OTR — unlimited resolution; problems with target damage
    - DTR — under study at Tesla Test F/ KEK ATF
  - SR

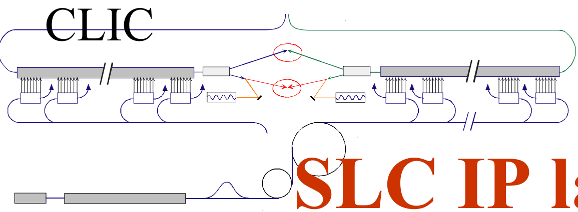


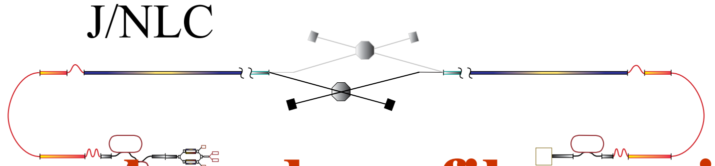
Laser-based profile scanners

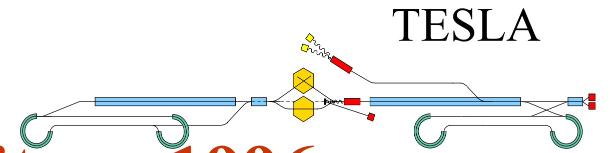




NLC design layout







SLC IP laser based profile monitor - 1996