"I hear the roar of the big machine…"

X-Band Linear Collider (JLC/NLC): Luminosity Issues

2002 Linear Collider Meeting
Monday Plenary

P. Tenenbaum

The Basics

- JLC/NLC linear collider design uses:
  - 11.424 GHz ("X-Band") RF acceleration…
  - 70 MeV/m unloaded gradient…
  - 0.75×10^{10} e^+/e^- per bunch…
  - 192 bunches per RF pulse with 1.4 nsec spacing (268 nsec total train length)…
  - 120 RF pulses per second…
  - IP spot sizes approx. 250 nm x 2.5 nm…
- To achieve 2.0 – 3.5 x 10^{34} luminosity @ 0.5 – 1.0 TeV CM

Parameter List

	Stage 1		Stage 2	
CMS Energy (GeV)	500		1000	
Site	US	Japan	US	Japan
Luminosity (10^{33})	**20**	**25**	**30**	**25**
Repetition Rate (Hz)	120	150	120	100
Bunch Charge (10^{10})	**0.75**		**0.75**	
Bunches/RF Pulse	192		192	
Bunch Separation (ns)	1.4		1.4	
Eff. Gradient (MV/m)	**48.5**		**48.5**	
Injected $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ (10^{-8})	300 / 2		300 / 2	
$\gamma\varepsilon_x$ at IP (10^{-8} m-rad)	360		360	
$\gamma\varepsilon_y$ at IP (10^{-8} m-rad)	**4**		**4**	
β_x / β_y at IP (mm)	8 / 0.11		13 / 0.11	
σ_x / σ_y at IP (nm)	**243 / 3.0**		**219 / 2.3**	
θ_x / θ_y at IP (nm)	**32 / 28**		**17 / 20**	
σ_z at IP (um)	110		110	
Υ_{ave}	0.14		0.29	
Pinch Enhancement	1.51		1.47	
Beamstrahlung δB (%)	5.4		8.9	
Photons per e+/e-	1.3		1.3	
Two Linac Length (km)	12.6		25.8	

- **Unified JLC/NLC parameter list**
  - **some variation due to different line frequencies!**
  - **Other variations (bunch spacing and charge) conceivable**

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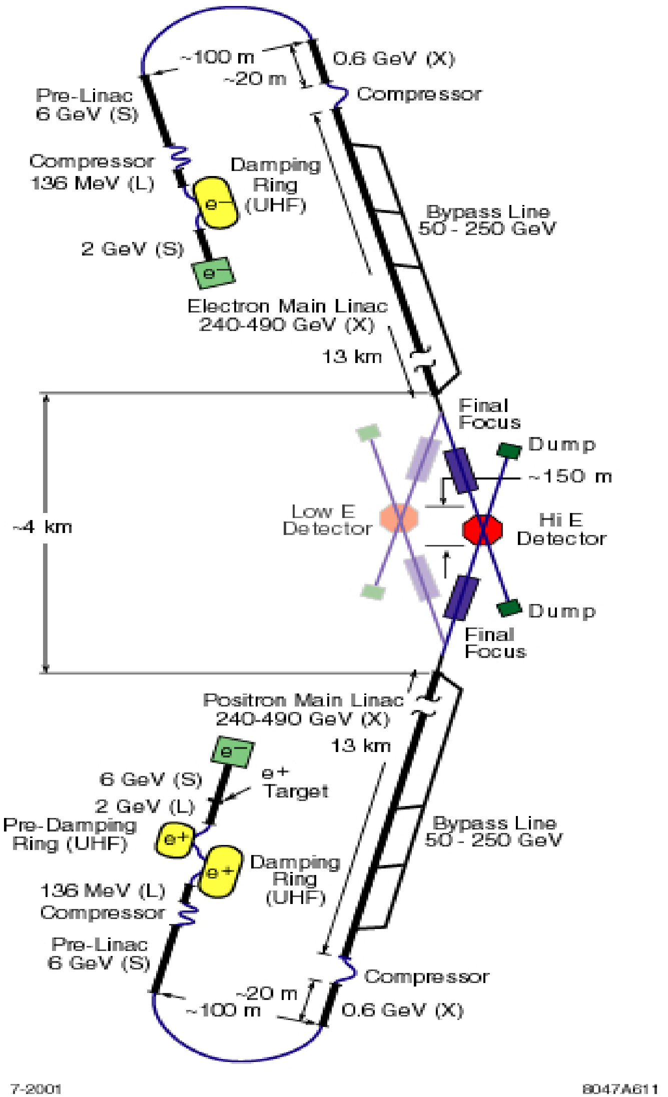
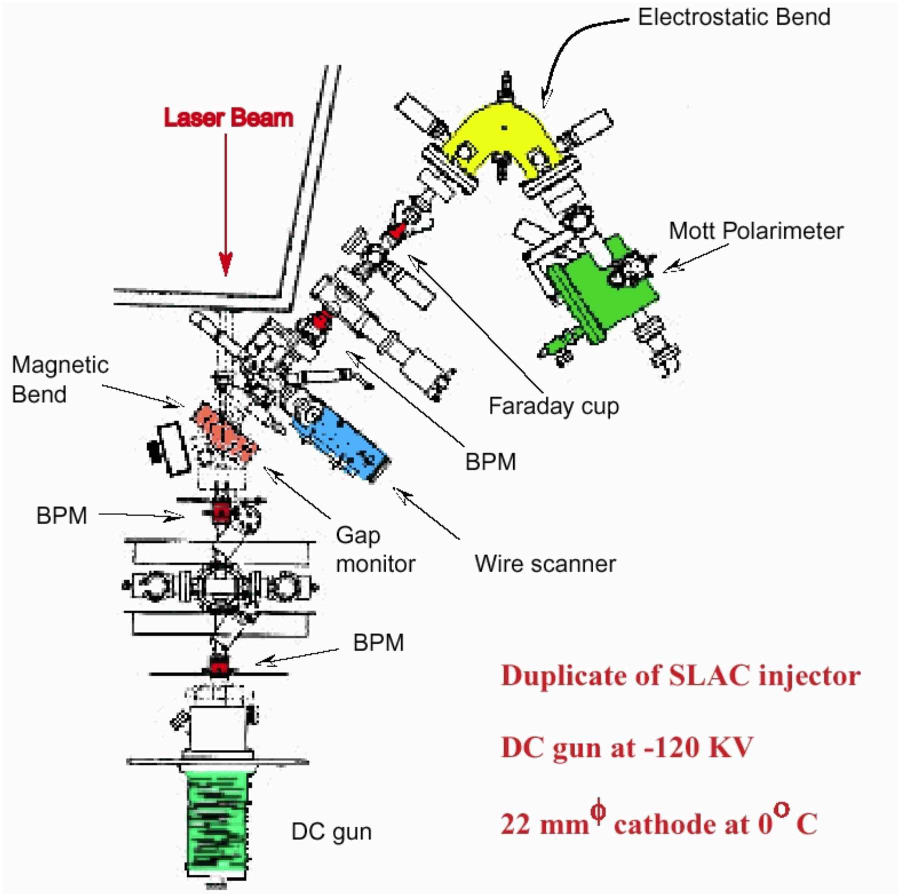
Layout



- **Two interaction regions (sequential, not simultaneous, operation)**
  - **HEIR: minimal bending, 20 mrad crossing angle (set by linac lines)**
    - **up to 3-5 TeV CM (someday!)**
  - **LEIR: more bending, 25-30 mrad crossing angle**
    - **Luminosity okay up to about 1 TeV CM**
- **Bypass lines for running below max energy**
  - **Most flexible for operation and installation**
- **Linac tunnels sized for 1 TeV CM**
  - **stage 1: fill 50%, run thru bypass lines to beam delivery system**
  - **populate 2nd half of each linac over time to reach 1 TeV CM**

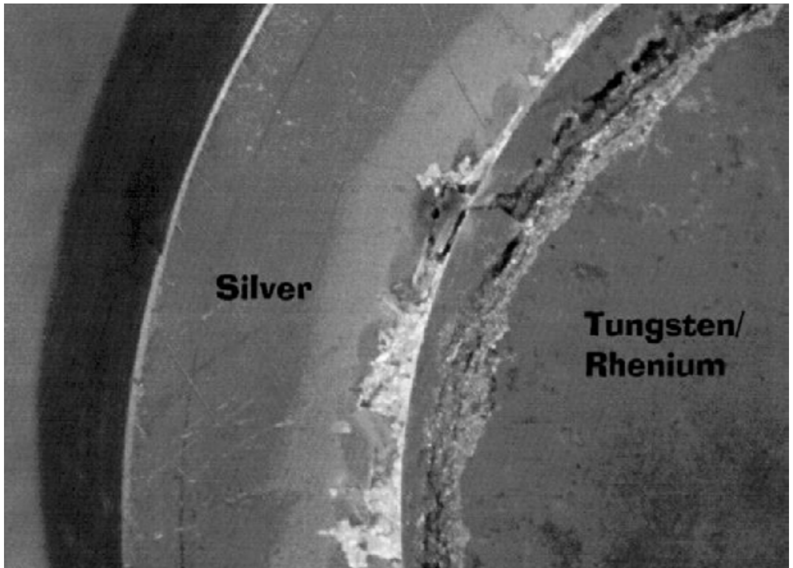
Electron Source

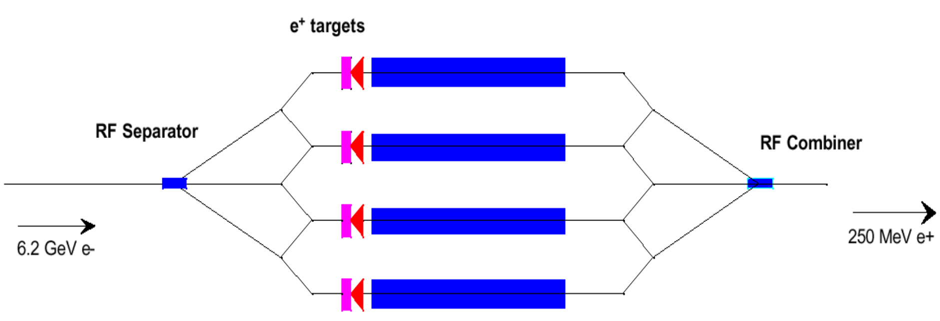


GTL Layout stolen from T. Maruyama…

- **Polarized Photocathode**
- **DC gun (not RF)**
- **Based on the SLAC source used for SLC and E-158**
- **Two sources planned for redundancy**
- **High charge/current, 80% polarization, stability (by bunch and by bunch train)**
- **Excellent recent results by GTL, Nagoya U, SLAC E-158 / Accelerator Dept.**

Positron Source



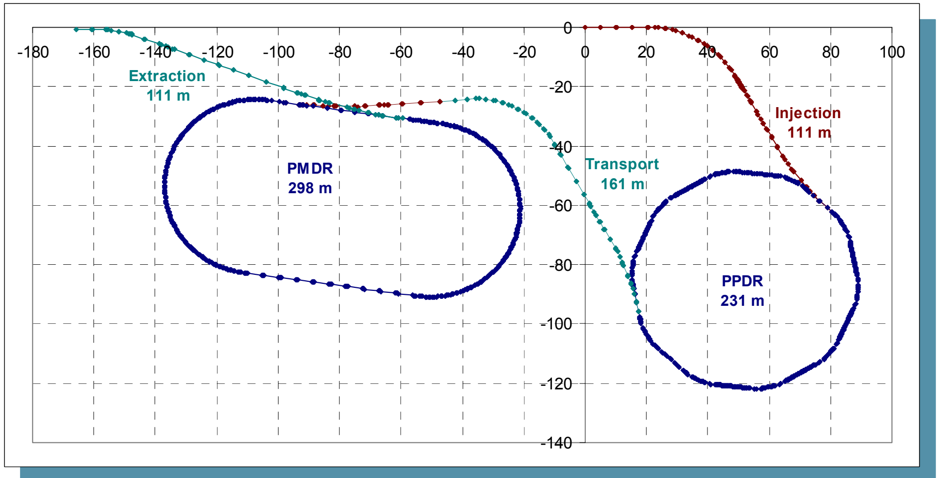


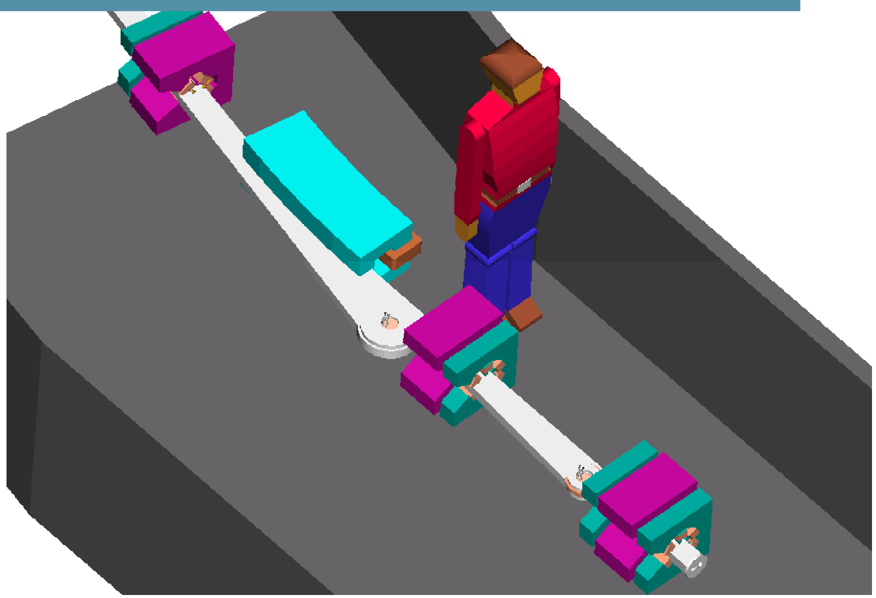
3 out of 4 target system schematic

Images stolen from D. Schultz and J. Sheppard

- "Conventional" (6 GeV e^- on 4 R.L. W-Re target)
- Based on improved SLAC design
  - L-band capture (larger acceptance)
  - multiplexed targets (reduce peak shock load)
  - Bigger targets (reduce avg heat/shock/radiation damage)
- Also considering TESLA-style source (undulator in main e^- beam and thin target)

Damping Rings



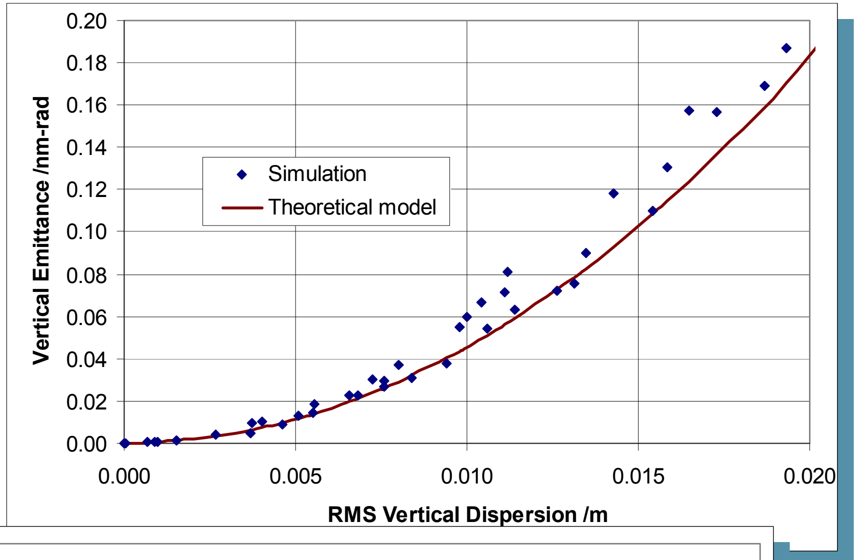


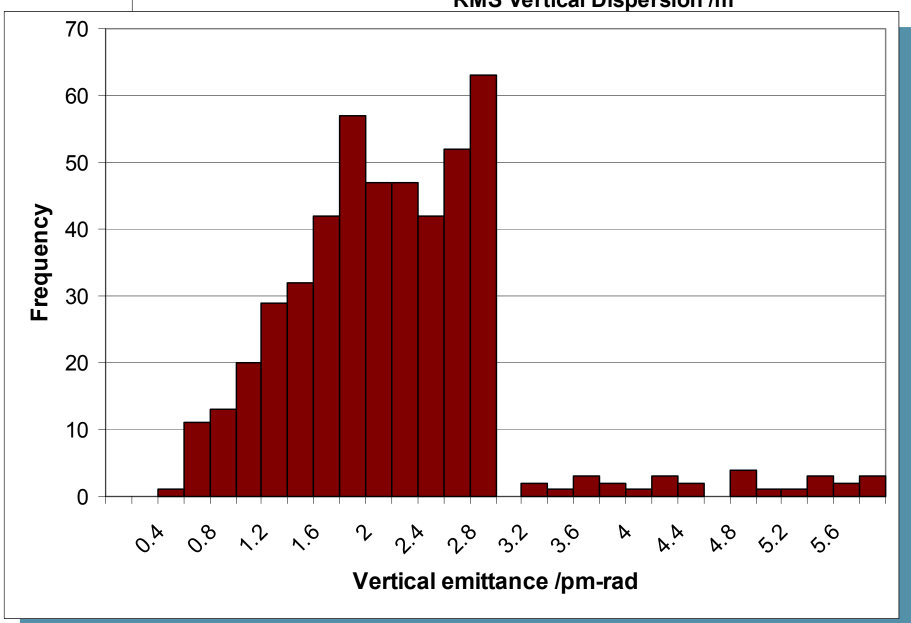
- **Main damping rings:**
  - **similar to 3rd generation light sources**
    - **energy (1.98 GeV)**
    - **emittance ($\gamma\varepsilon$ = 3 x 0.02 mm.mrad)**
  - **Single-turn injection and extraction of bunch trains (challenging!)**

- **Pre-damping ring**
  - **positrons only**
  - **reduces huge emittance from target to level acceptable to MDR ($\gamma\varepsilon$ ~ 150 mm.mrad)**

Images stolen from T. Raubenheimer and A. Wolski

Damping Rings (2)

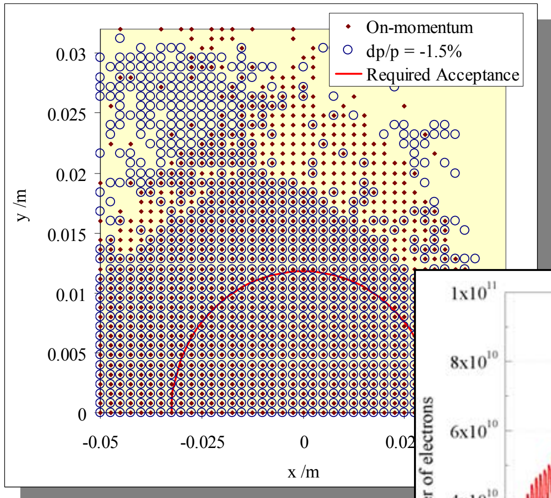


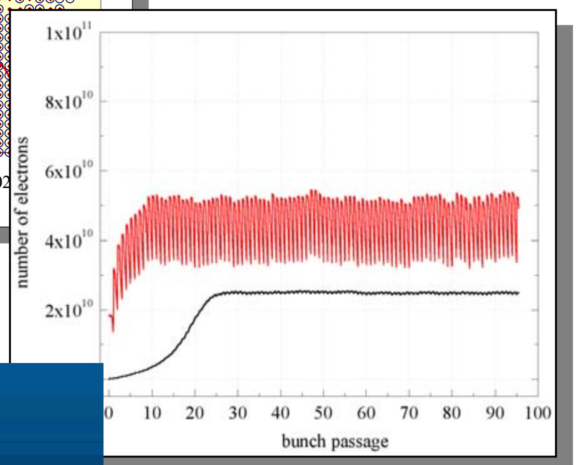


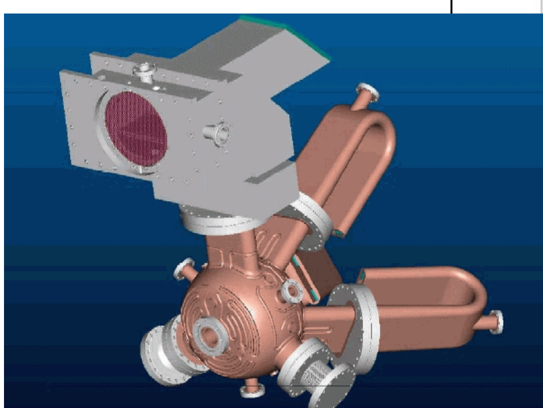
- **Need low emittance and short damping times**
  - **lots of wigglers – 46 m in MDRs, 50 m in PPDR)**
  - **Still need to store trains for multiple machine cycles (1 cycle ~ 8 msec)**
    - **3 trains stored in MDR**
    - **2 trains stored in PPDR**
    - **gaps for kickers**
- **Alignment of DR elements crucial for low emittance**
  - **Achievable with hi-res BPMs, magnet movers, skewquad trims on sextupoles**

Images stolen from A. Wolski

Damping Rings (3)





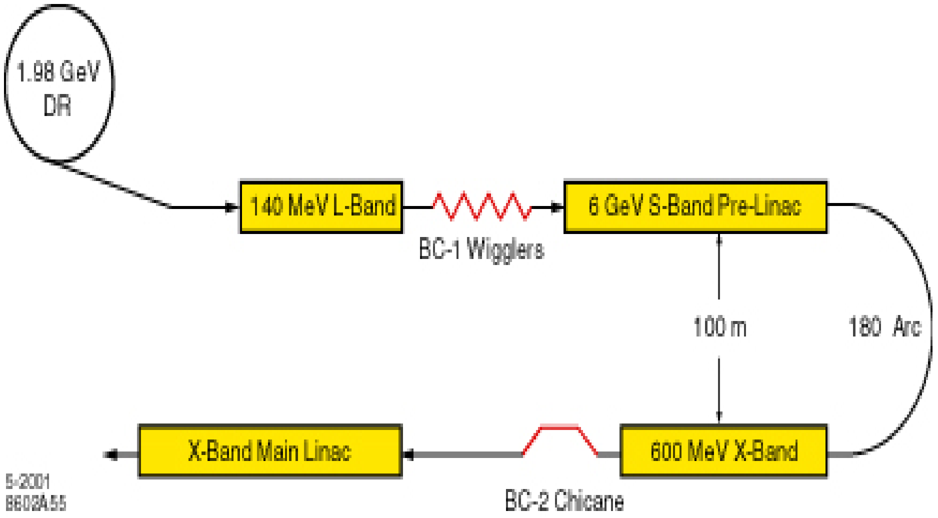


- Lots of fun storage ring issues
  - Ions
  - electron clouds
  - HOM instabilities
  - Path length control
  - Dynamic aperture (esp. with wigglers)
  - Intra-beam Scattering
  - Non-invasive beam size diagnostics
  - etc etc etc

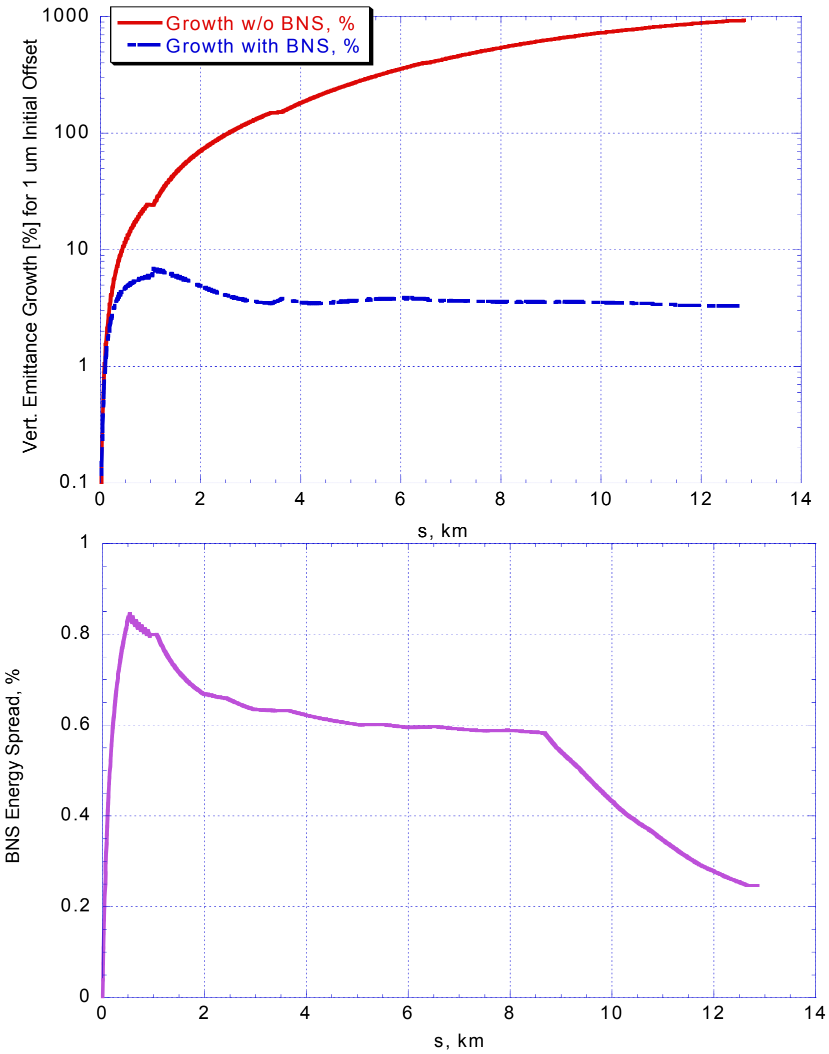
Images stolen from A. Wolski

Bunch Compressors

- Reduce σ_z from ~ 5 mm (DR) to 110 µm (linac)
- 2-stage design
  - stage 1: 5 mm → 600 µm @ 1.98 GeV
  - Stage 2: 600 µm →110 µm @ 8 GeV
- Prevents DR phase errors from becoming IP Energy errors
- Be careful of coherent synchrotron radiation!

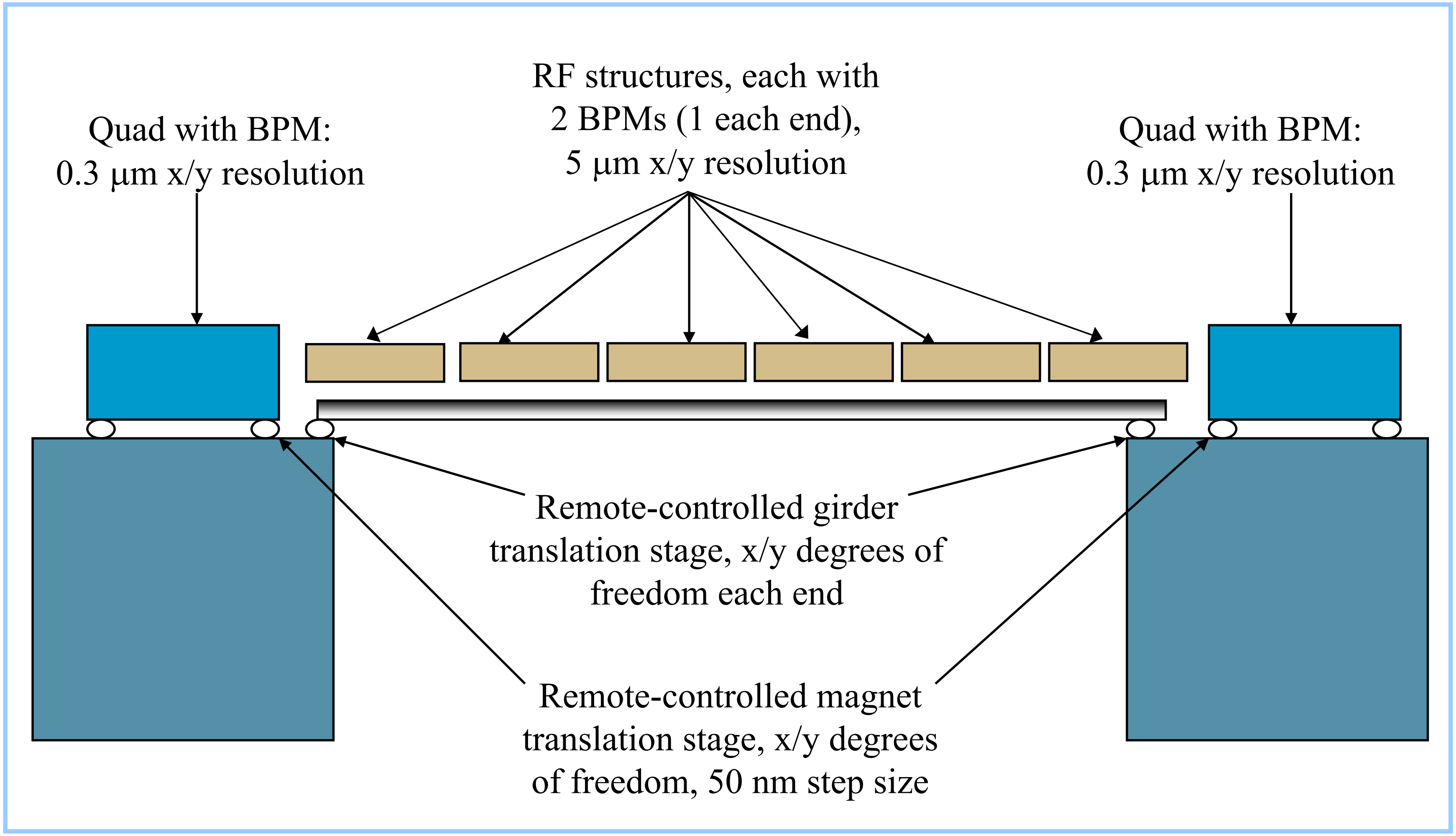


Main Linacs

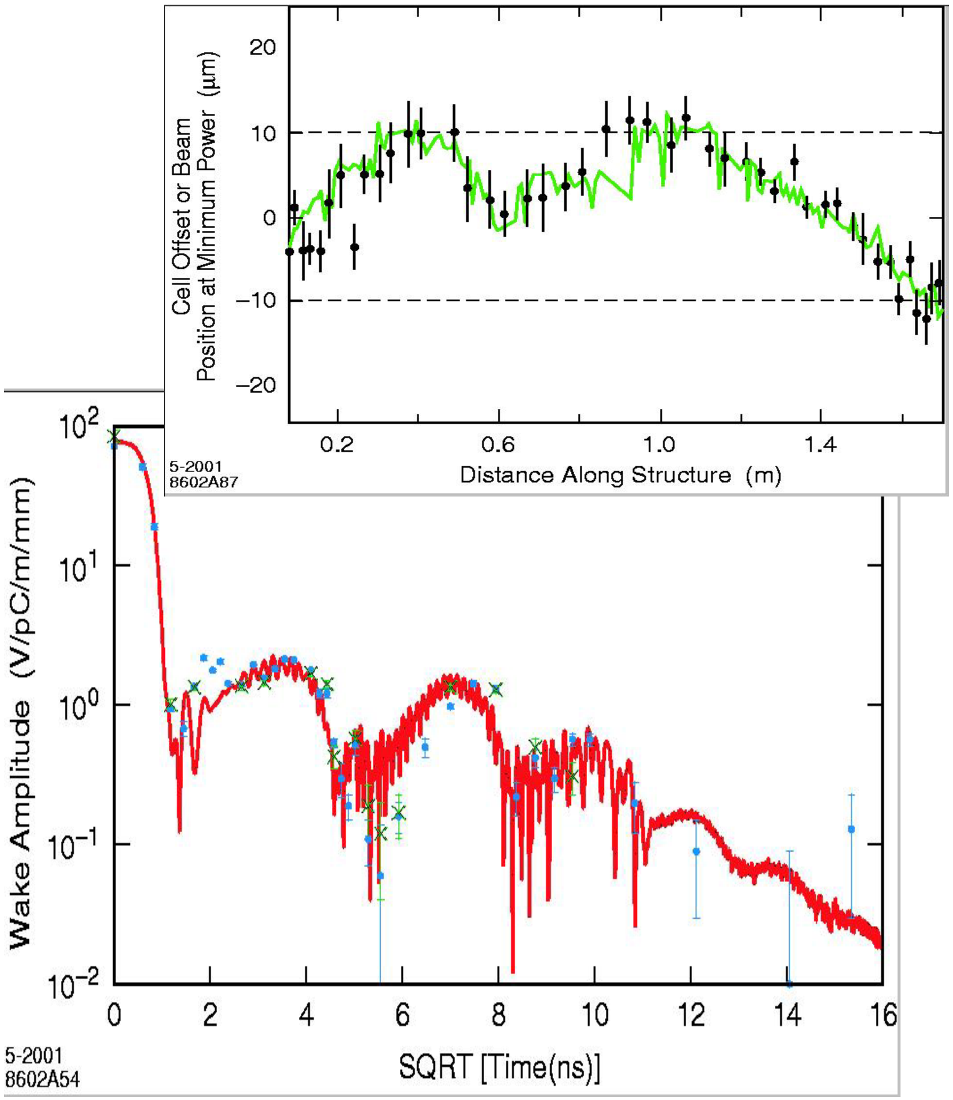


- About 12 km long each
- Use 0.6 m or 0.9 m X-band RF structures
- Strong wakefields drive ML design
- Short-range: cause beam break-up
  - cure with energy spread along bunch (“BNS Damping”)
  - Leads to tight quad alignment tolerances

Main Linac Module



Main Linac: Long Range Wakefields



- **Address by detuning (different HOM freqs in different cells) and direct damping**
  - **Implies tolerance on HOM freqs, structure straightness**
- **Short strucs: need to interleave 2-3 structure types on a girder**
  - **implies tolerance on alignment of structures on girder**
- **Additional reduction via sub-train feedback**
  - **relies on deflections within train being constant from train to train**

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Main Linac Emittance Budget

Effect	Tolerance	$\Delta\gamma\epsilon_y$, mm.mrad
Beam-to-Quad Offsets	2.0 μm	0.005
Quad Strength Errors	0.1%	0.0001
Struc-to-Girder Misalignments	30 μm	0.0014 (single-bunch) 0.0002 (multi-bunch)*
Struc-to-Girder Tilts	30 μrad	0.0008
Struc BPM Resolution	5 μm	0.0006
Quad Rotations	200 μrad	0.0008
Mover Steering Interval	30 minutes	0.0004
Structure Bow	50 μm	0.0002*
Cell-to-Cell Errors	3.5 μm	0.0002*
HOM Freq Errors	1 MHz	0.0002*
Total		0.0099 (50%)

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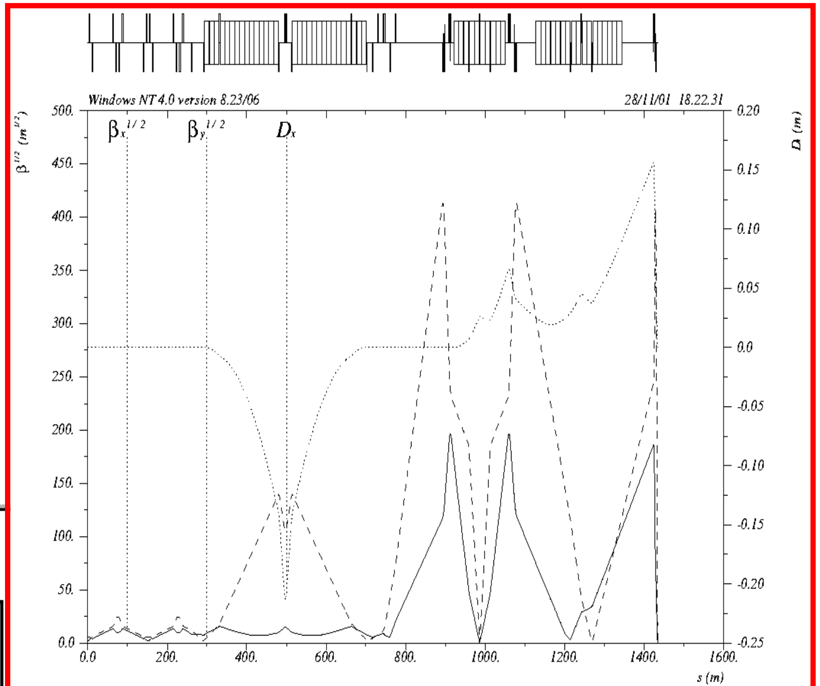
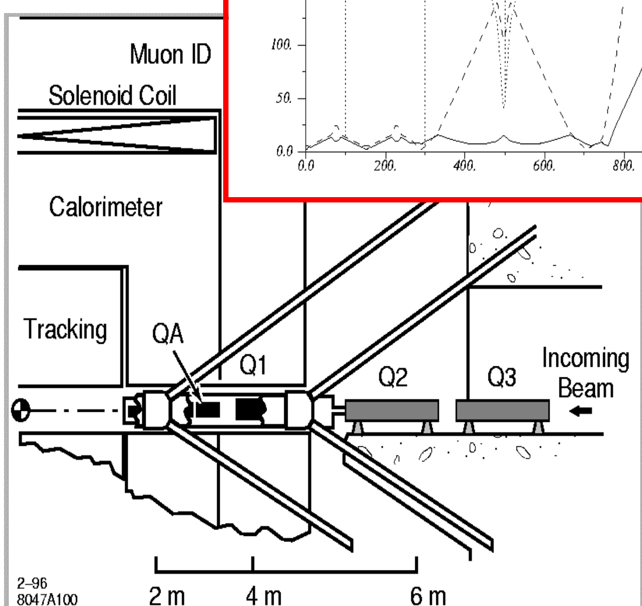
Beam Delivery System





- **Both IRs use short "Raimondi/Seryi" design with integrated collimation**
  - **Cancel coll aberrations in FF**
- **Principal challenges:**
  - **delicate cancellation of aberrations**
  - **Stability – both position and strength – of magnets, esp. final doublet**
  - **Collimation – wakefields, protection of BDS, protection of collimators**

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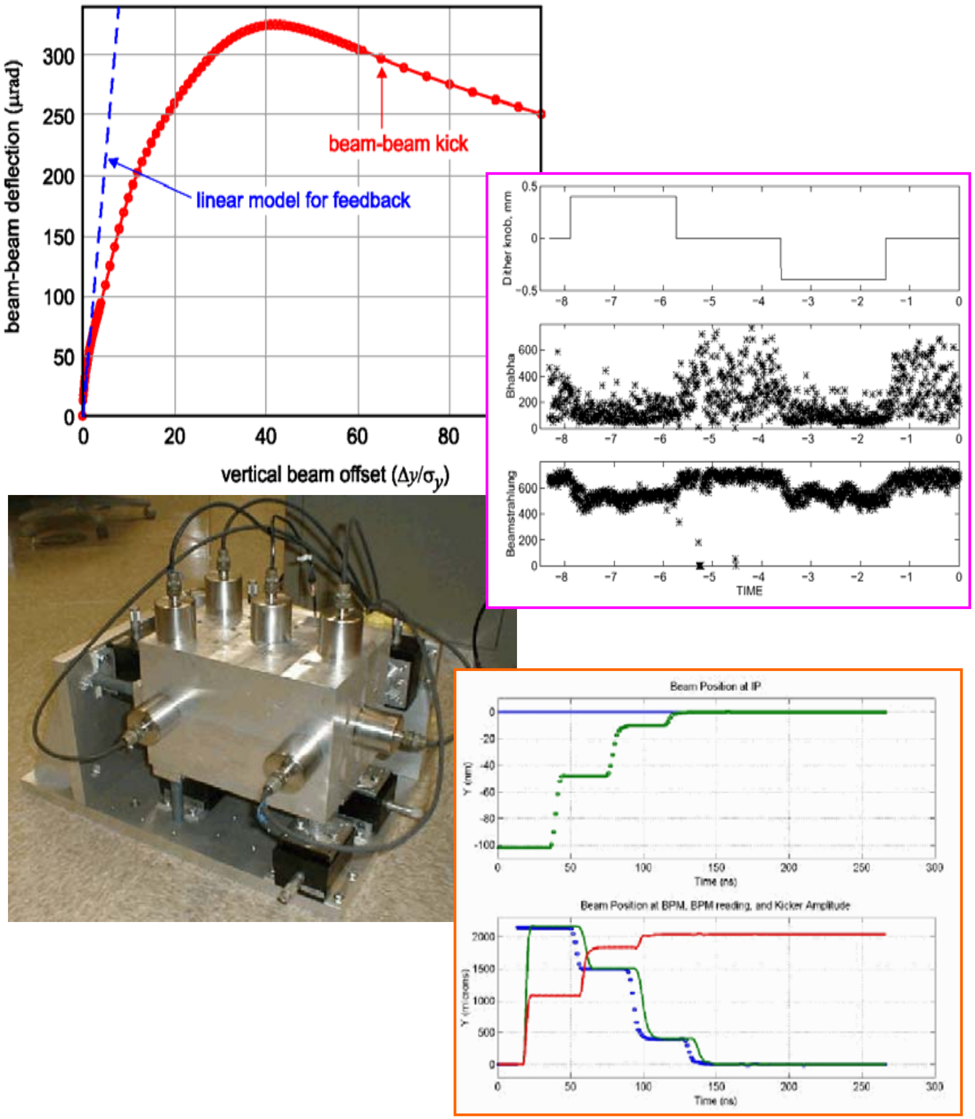
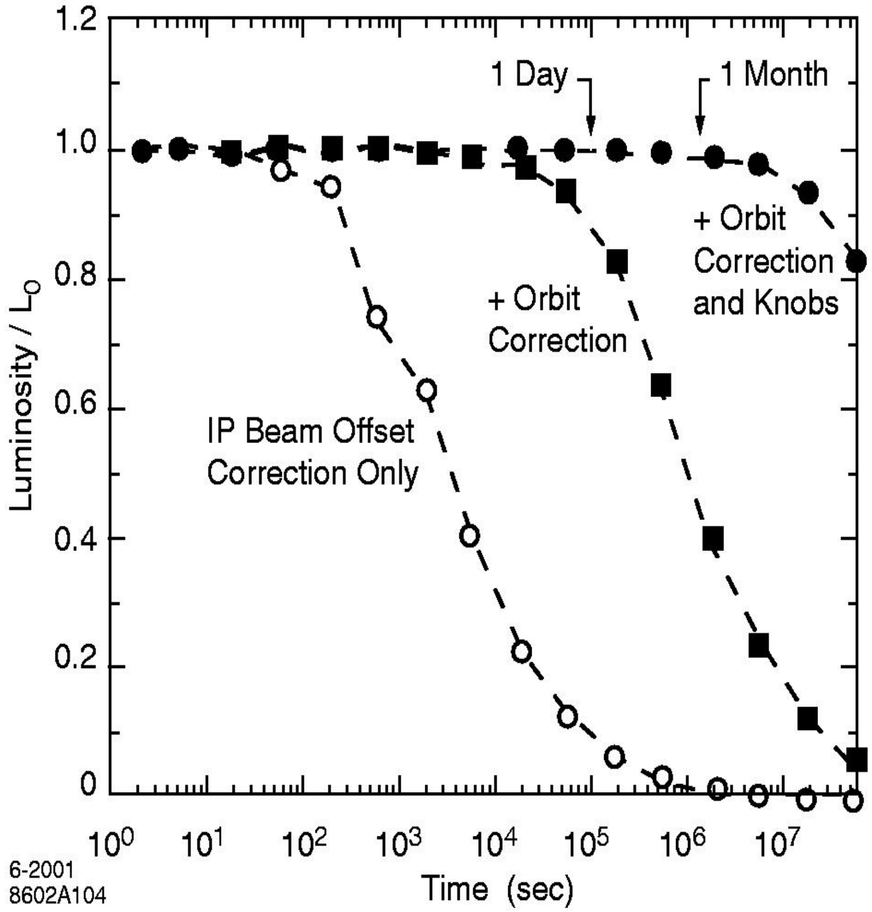
Stabilization of BDS



- **Steering feedbacks**
- **IP optimization fbcks**
  - **"dither" waist, eta, coupling and tune on luminosity signal**
- **IP Collision steering feedback**
  - **tune beam-beam offset on deflection signal**
- **Sub-train IP Collision feedback?**
- **Fast active final doublet position control**

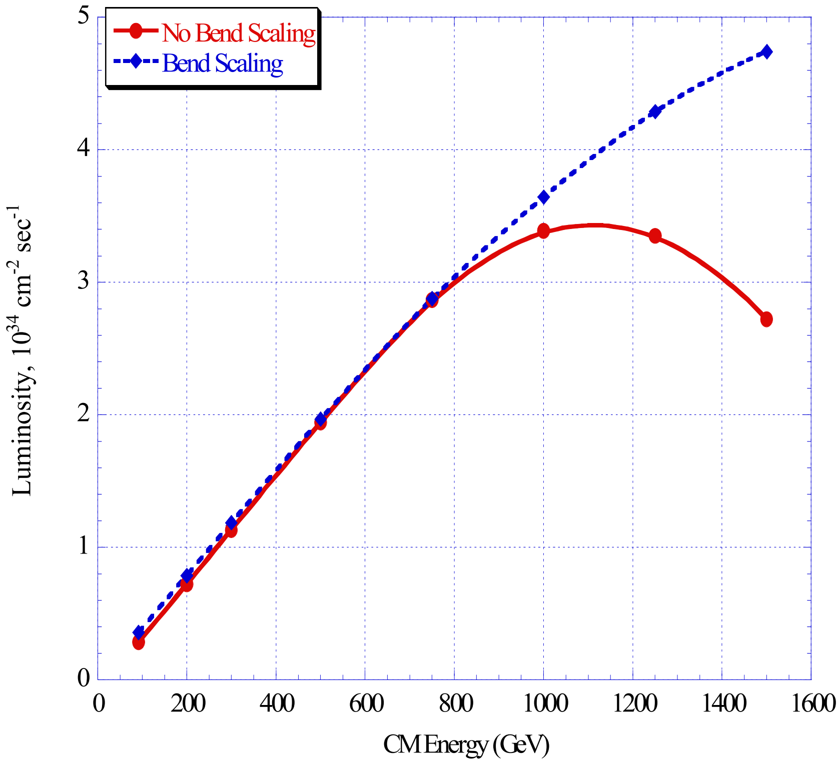
Images stolen from L. Hendrickson, T. Himel, S. Smith, TESLA-TDR

Stabilization of BDS (2)



- Longer term: driven by diffusive ground motion
- Tools to preserve luminosity
  - IP collide feedback
  - steering feedback through sextupoles
  - Adjust aberrations via dither feedbacks
- Only 1 overall realign needed per year

BDS Energy Scaling



Plot data courtesy Y. Nosochkov

- **Lower energy – aberrations get worse**
- **Higher energy – SR dilutions get worse**
- **Can be addressed by scaling BDS bends**
  - **changes geometry**
- **In practice, little improvement seen at lower energies**

Conclusion and Provocation

- JLC/NLC pushes X-band technology to the state of the art (and maybe a bit past)
  - gradient issues – see next talk!
  - wakefields make linac more challenging, requires more/better diagnostic and control
- JLC/NLC damping rings are not too far from existing light sources
- JLC/NLC BDS is reasonable extrapolation from SLC and FFTB
  - not too different from CLIC, TESLA BDS for similar energies
- It's been an exciting and productive couple of years since LC99!