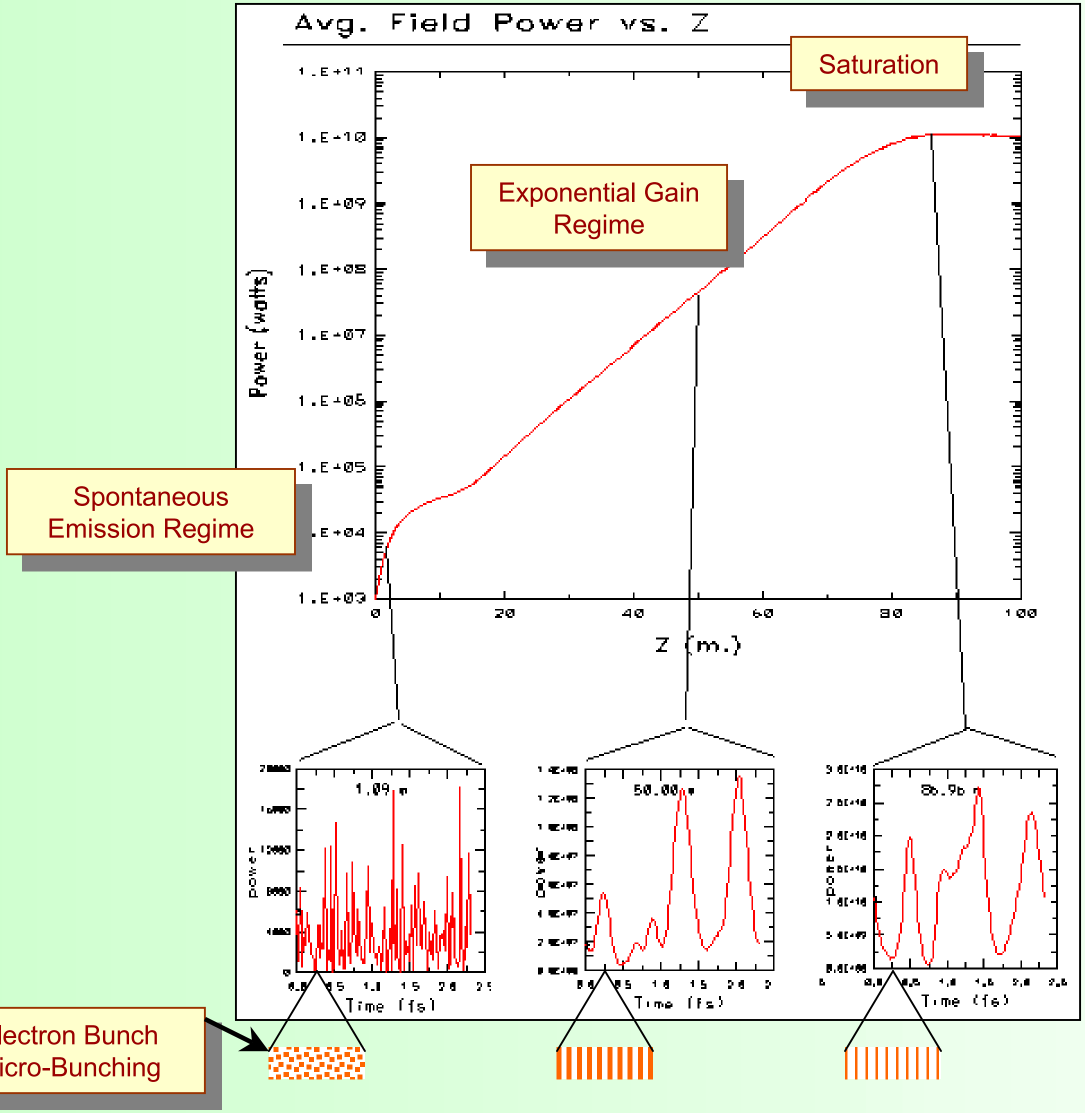
Design Considerations for the LCLS

C.Limborg, SLAC

- Small slice emittance production
- Coherent Synchrotron Radiation
- Undulator
- Resistive wall wakefield

SASE FELs



SASE FEL

- Starts from Noise from spontaneous emission
- Exponential growth of radiated power
- Saturation level

Theory well developed and verified by simulations

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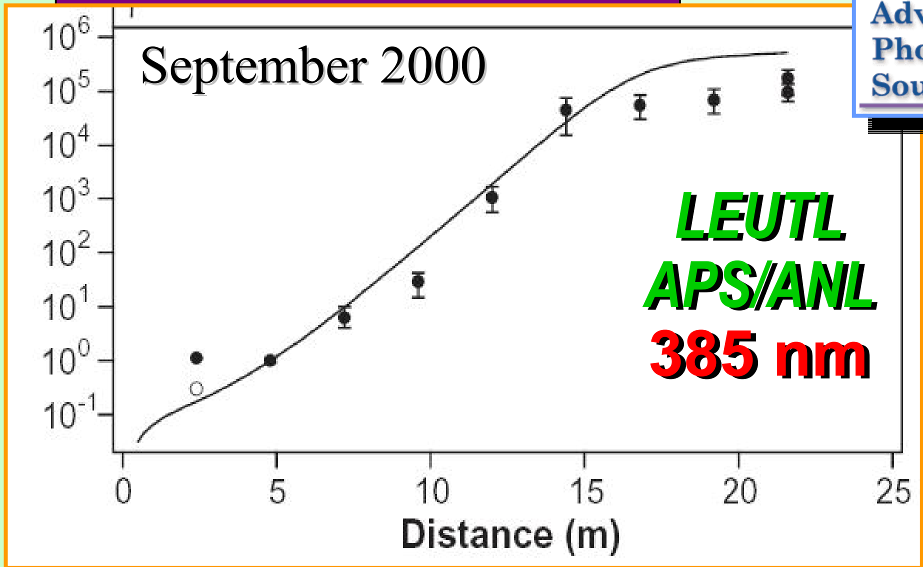
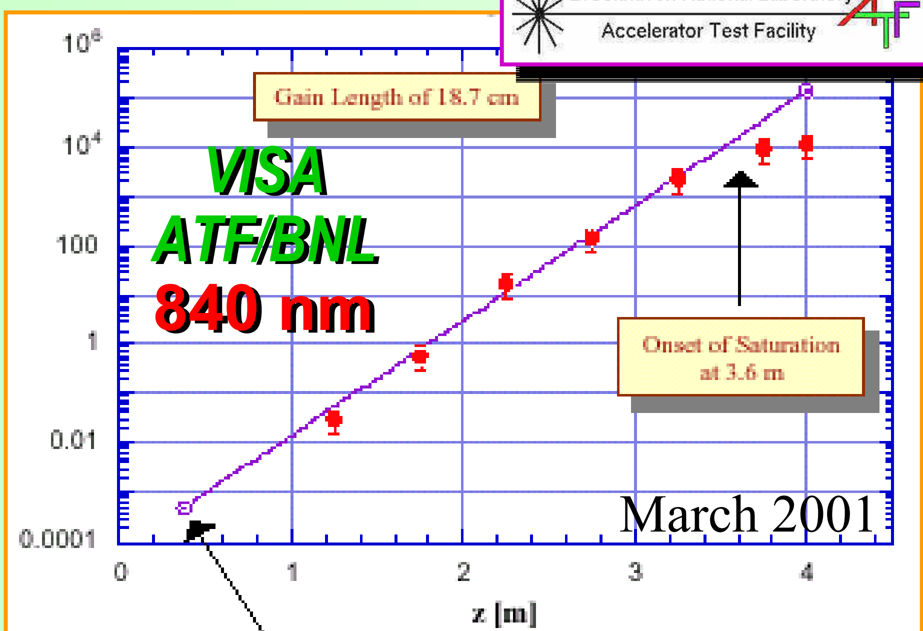
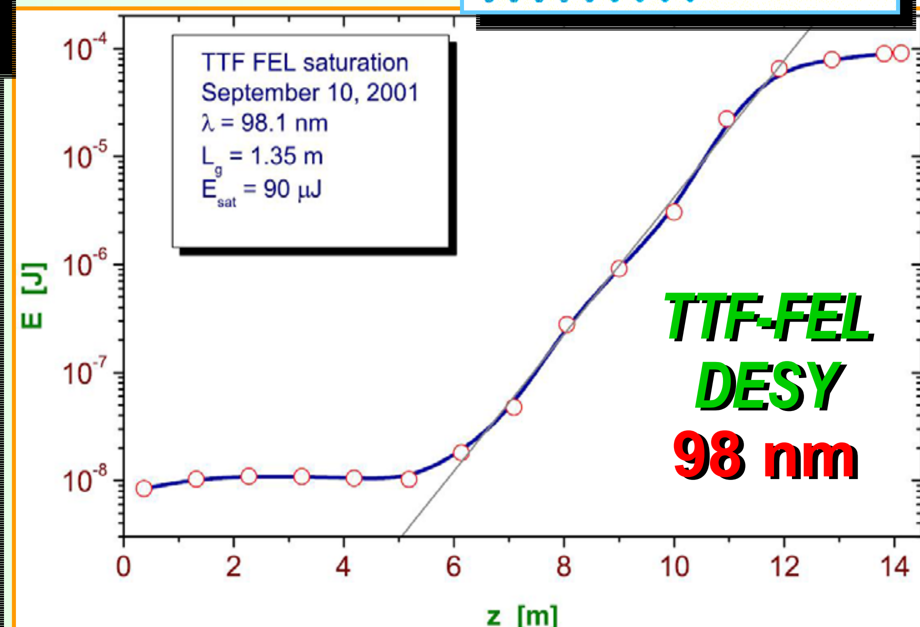
XFEL → 0.1 nm (or 1 Å)

Just 2 years ago:
SASE saturation not yet demonstrated

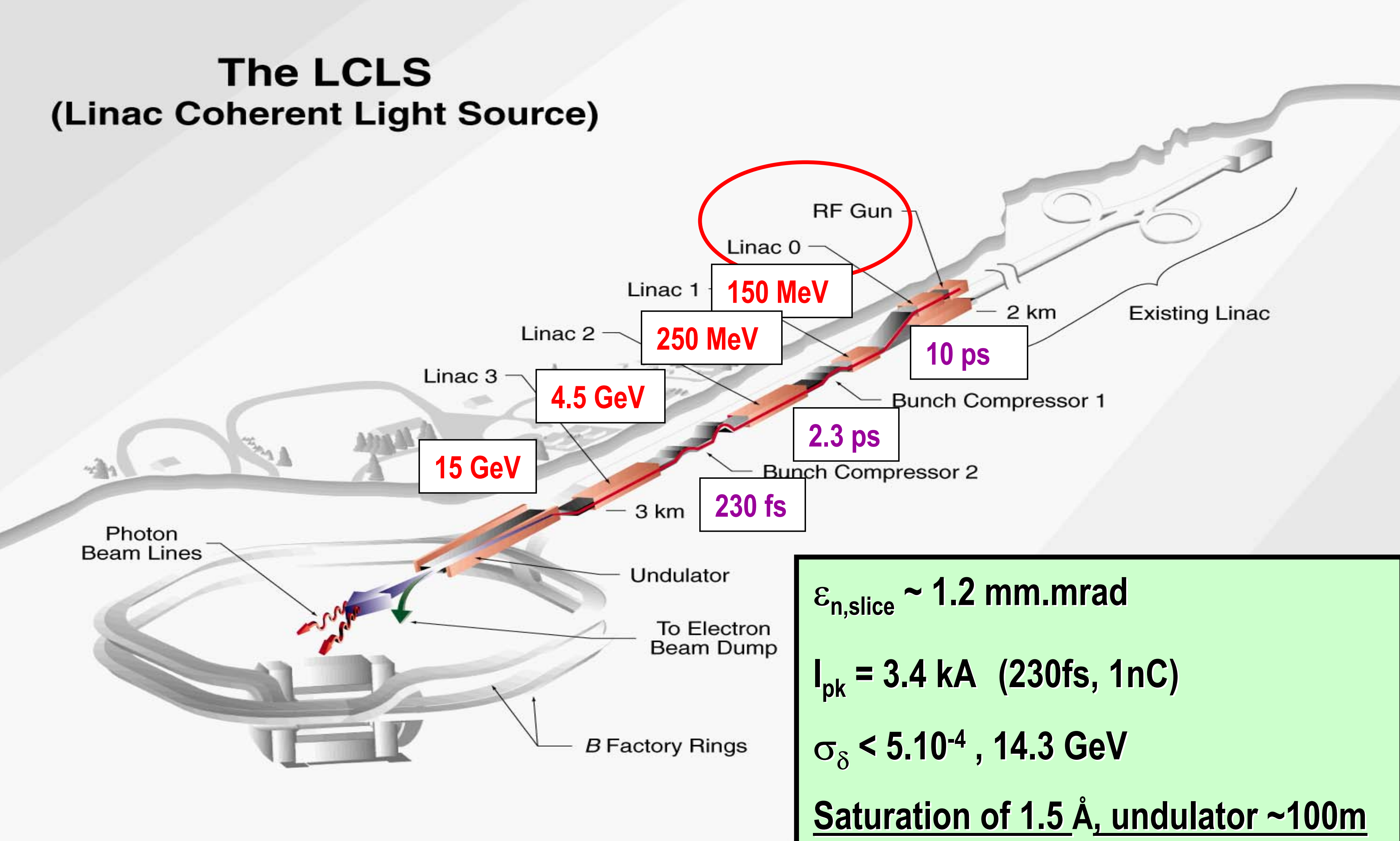
Since September 2000:
3 SASE FEL's demonstrate saturation







X-Ray SASE requirements



$\varepsilon_{n,slice}$ ~ 1.2 mm.mrad

I_{pk} = 3.4 kA (230fs, 1nC)

$\sigma_\delta < 5.10^{-4}$, 14.3 GeV

Saturation of 1.5 Å, undulator ~100m

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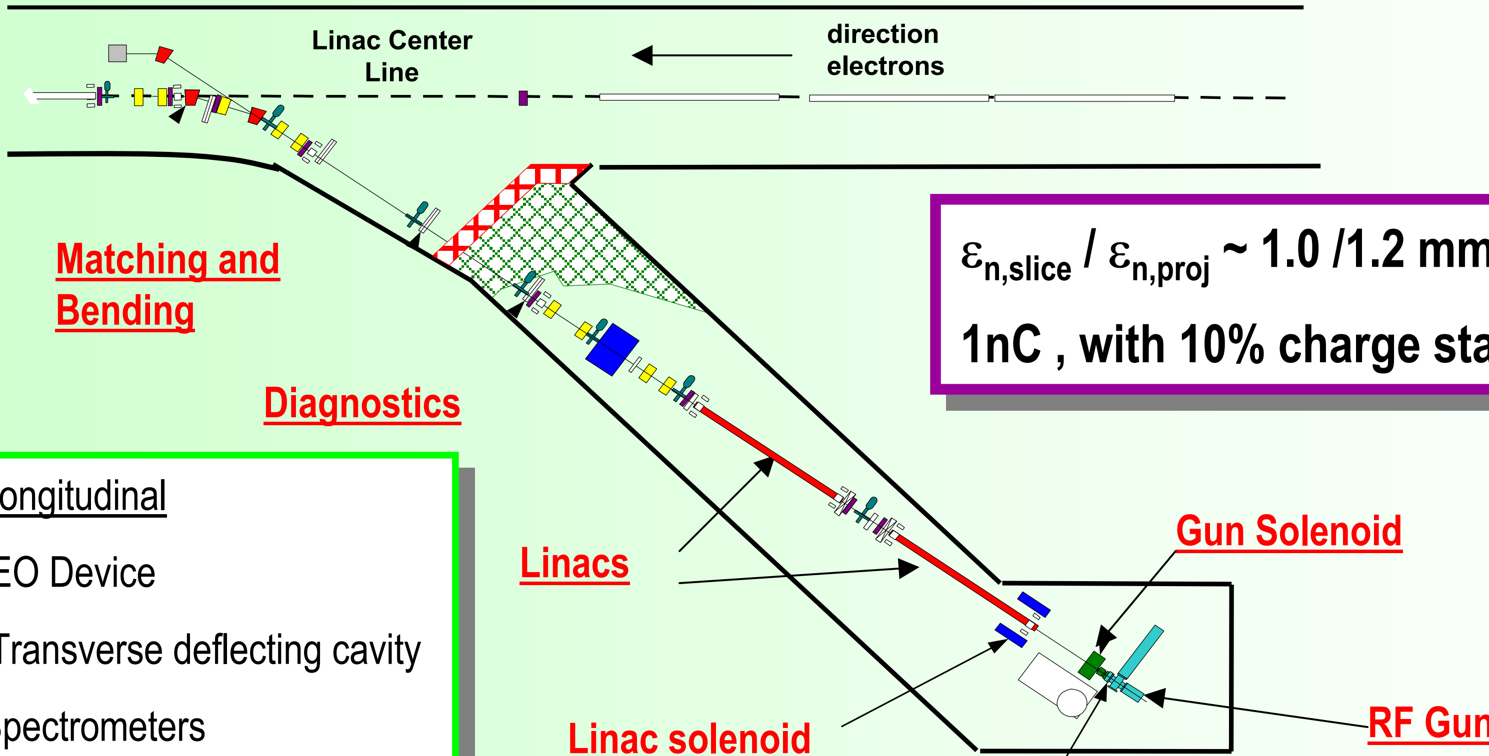
Photo-injector Beamline

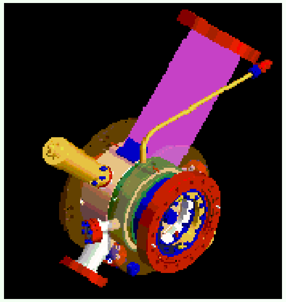


$\varepsilon_{n,slice}$ / $\varepsilon_{n,proj}$ ~ 1.0 /1.2 mm.mrad

1nC , with 10% charge stability

- Longitudinal
  - EO Device
  - Transverse deflecting cavity
  - Spectrometers
- Transverse
  - OTR screens
  - Wirescanner

10 ps with 0.7 ps rise time



1nC

low $\varepsilon_{thermal}$

120MV/m

120Hz

Photo-injector Simulations

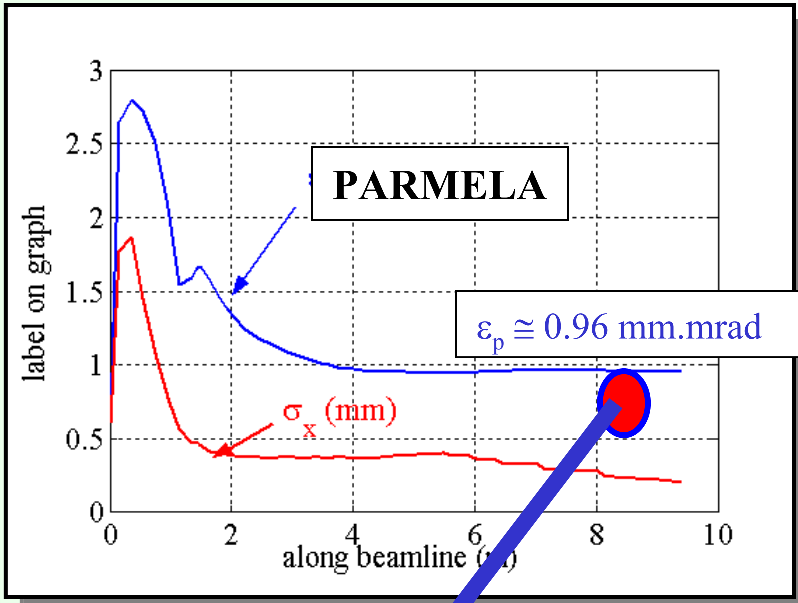
Tuning with **Homdyn** then **PARMELA**

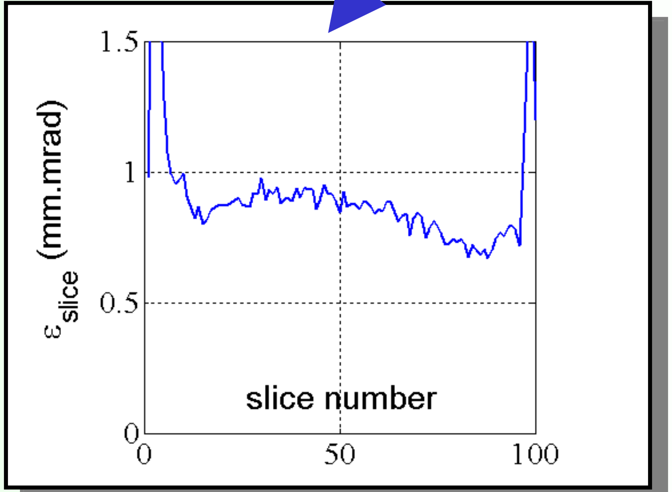
✓ ε_{th} = 0.5 mm.mrad

✓ Pulse 10 ps but 0.7 ps rise time

✓Stability, flexibility of beamline,

PARMELA vs experiment [C.Limborg, WE-P-14]





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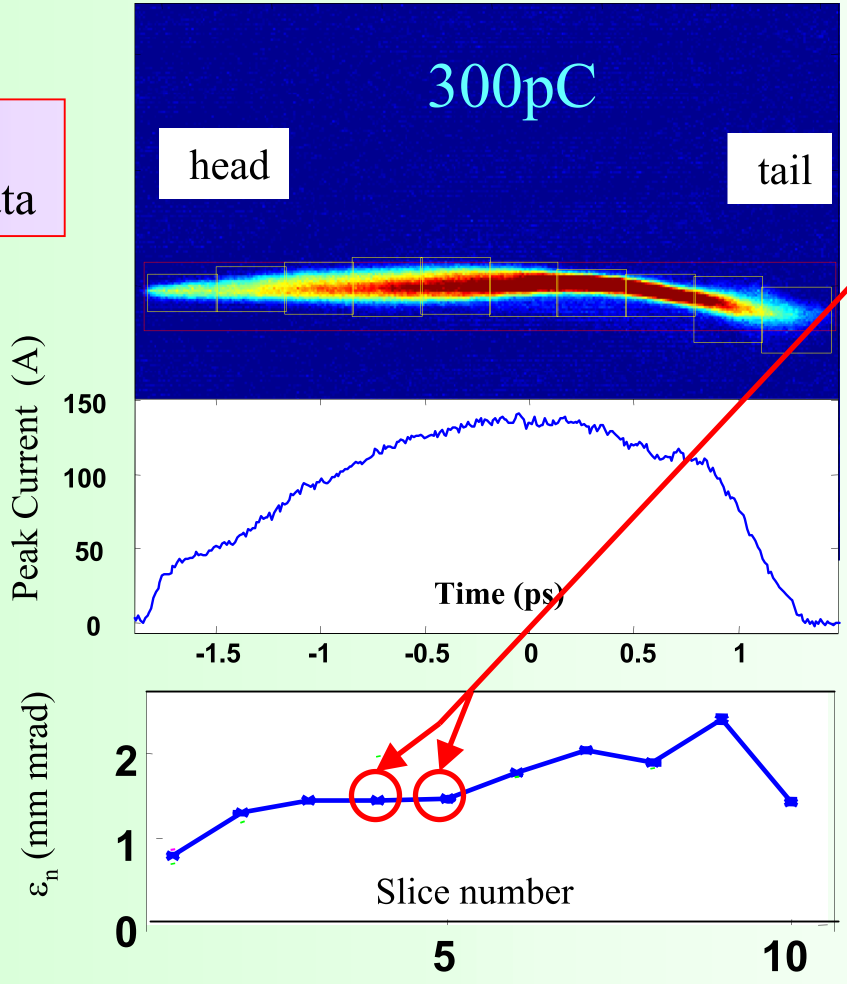
GTF Summer 2002

Spectrometer Image of Slice Quad Scan Data

Instantaneous Peak Current

Slice Emittances



ε_{slice} = 1.3 mm.mrad

for 130 A

~ very close to LCLS requirements

Similar measurements at the DUVFEL facility

(Spring 2002)

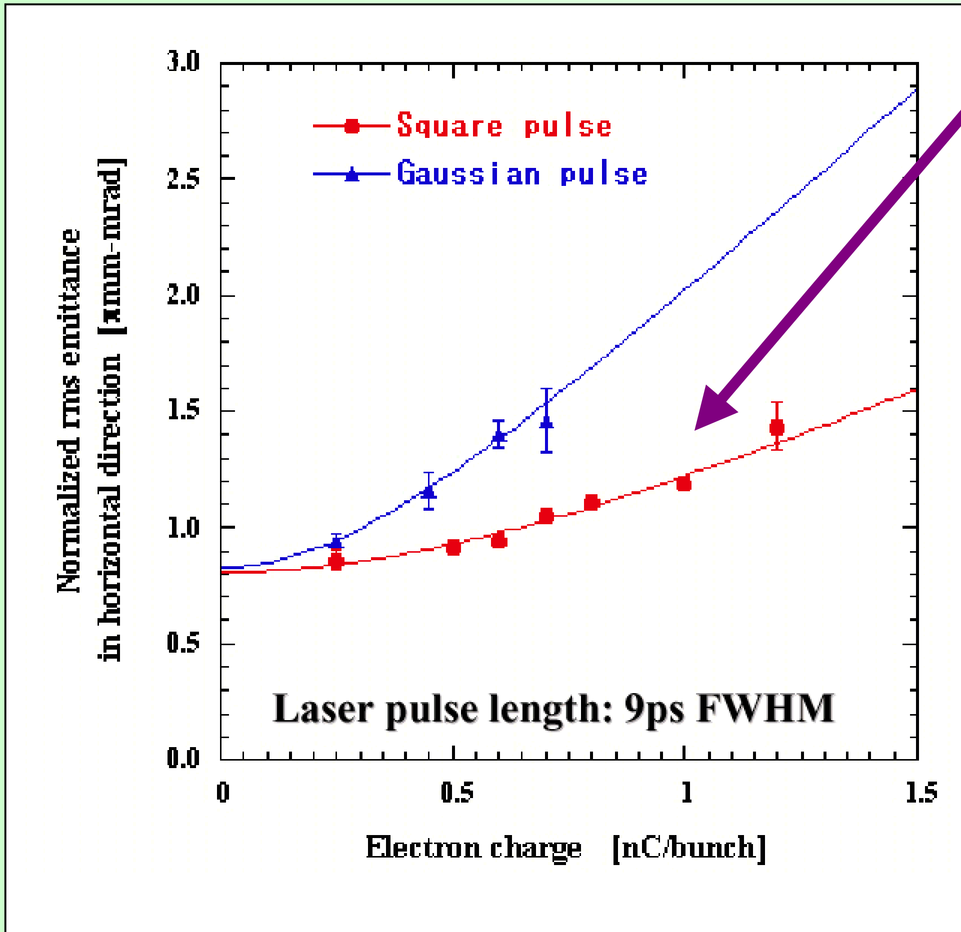
Courtesy D.Dowell [WE-P-07 Dowell et al.]

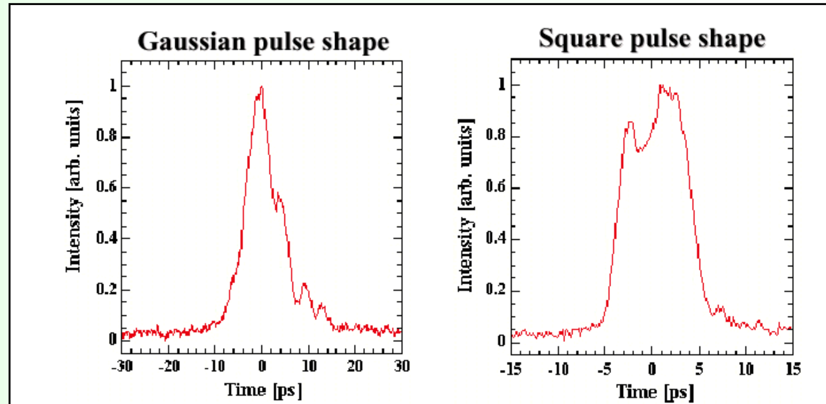
Sumitomo Spring 2002

1nC

ε_p = 1.2 mm.mrad

with "LCLS type" Gun



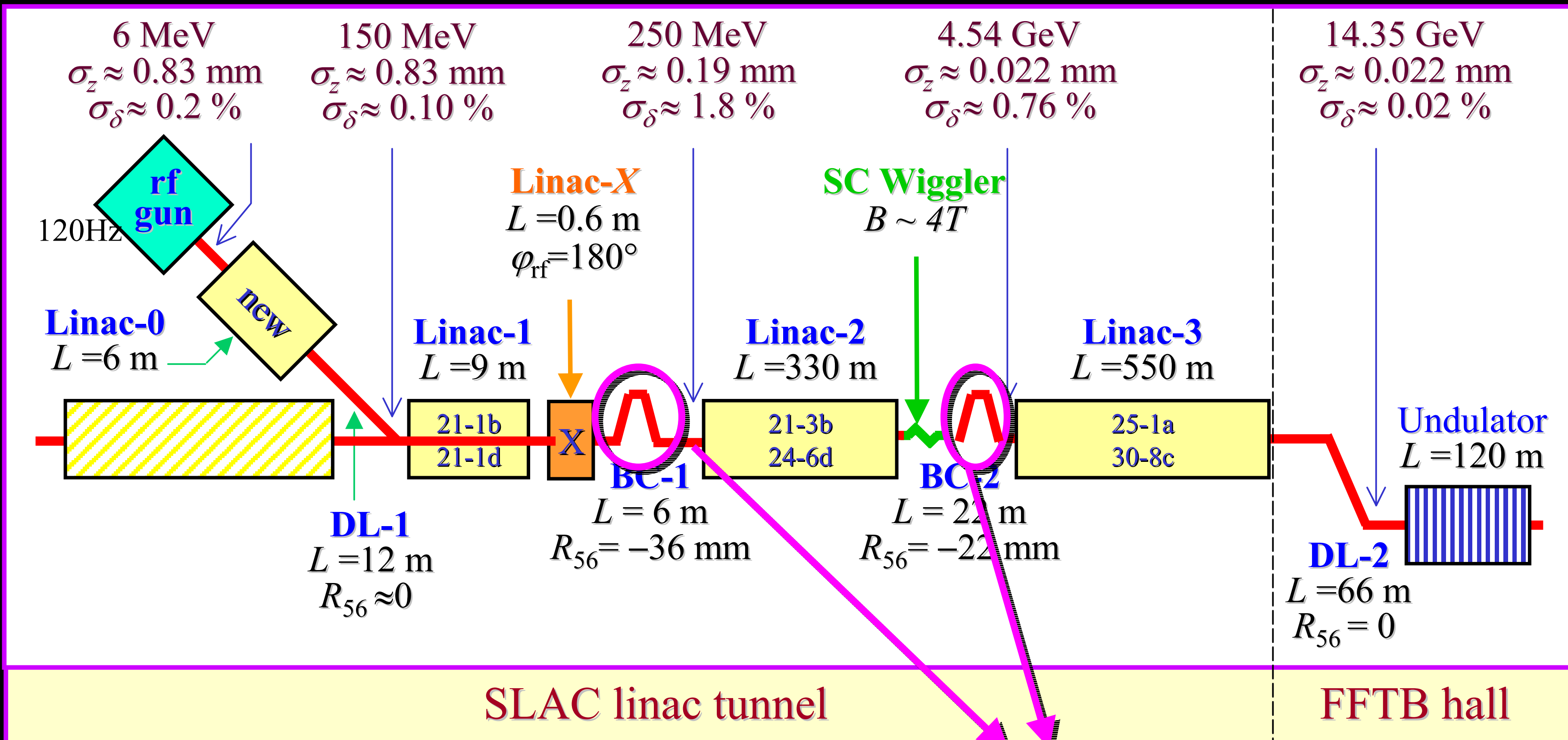


Frequency domain pulse shaping

Courtesy of J.Yang FESTA

Sumitomo Heavy Industries, Ltd.

LCLS Linac Parameters for a 1.5-Å FEL



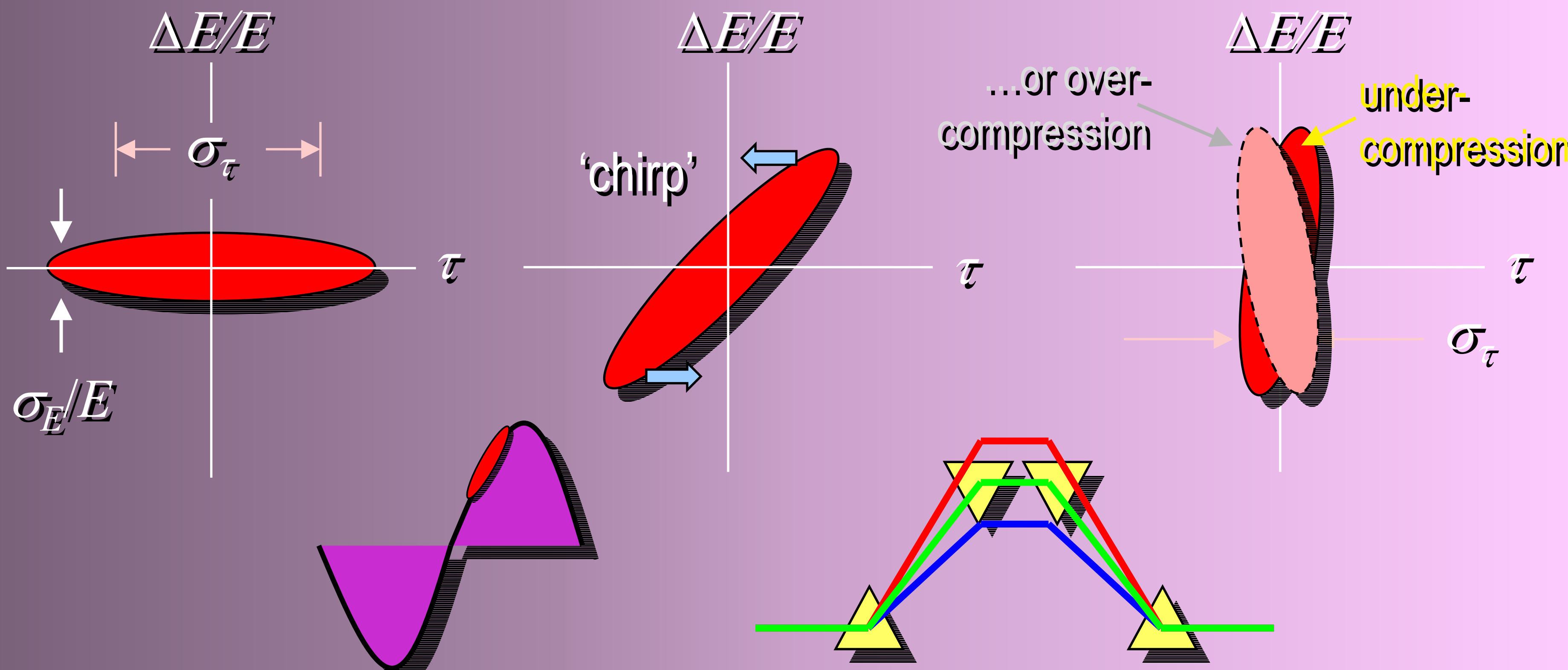
Two stages of bunch compression

1-nC, 10 ps with ε ~ 1.0 mm.mrad ⇒ compressed and accelerated

while preserving slice emittance, providing small energy spread

and stable operation

Magnetic Bunch Compression



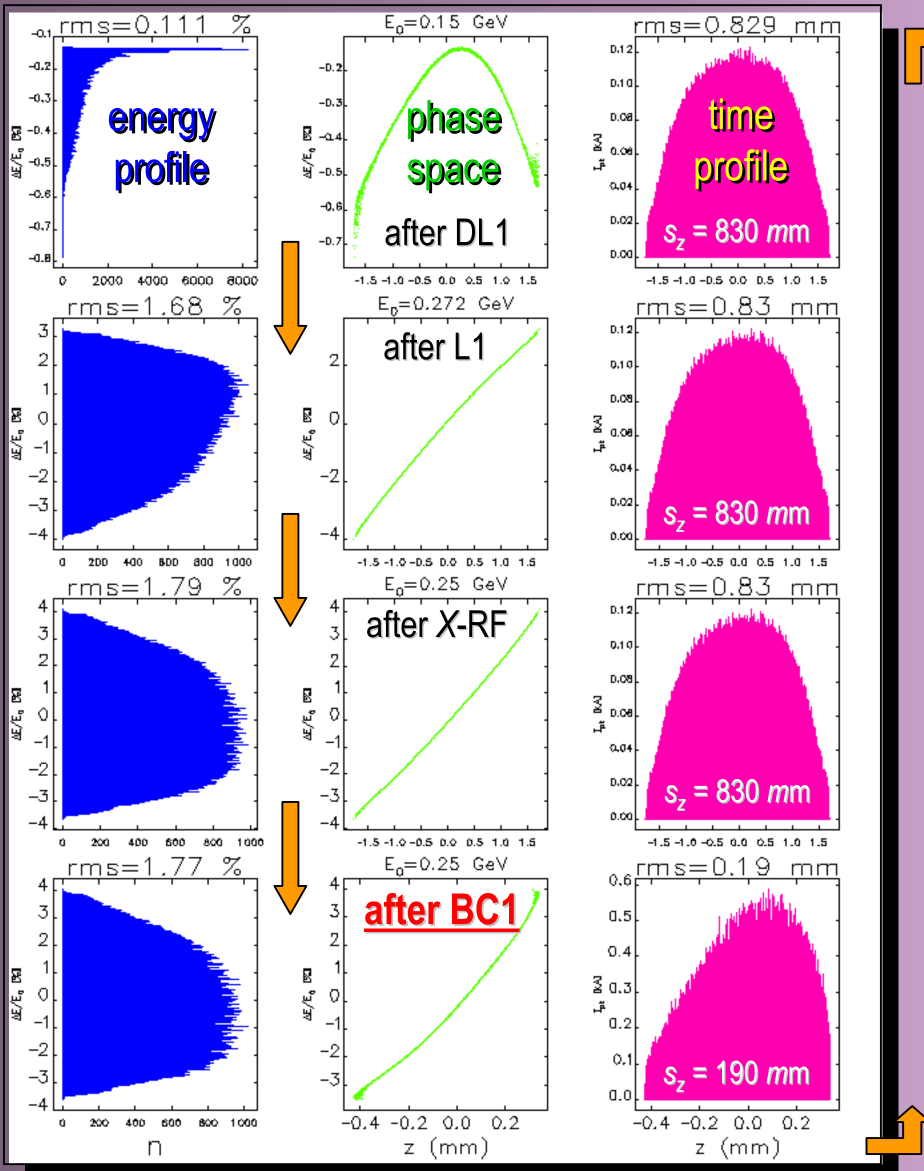
$$V = V_0 \sin(\omega\tau)$$

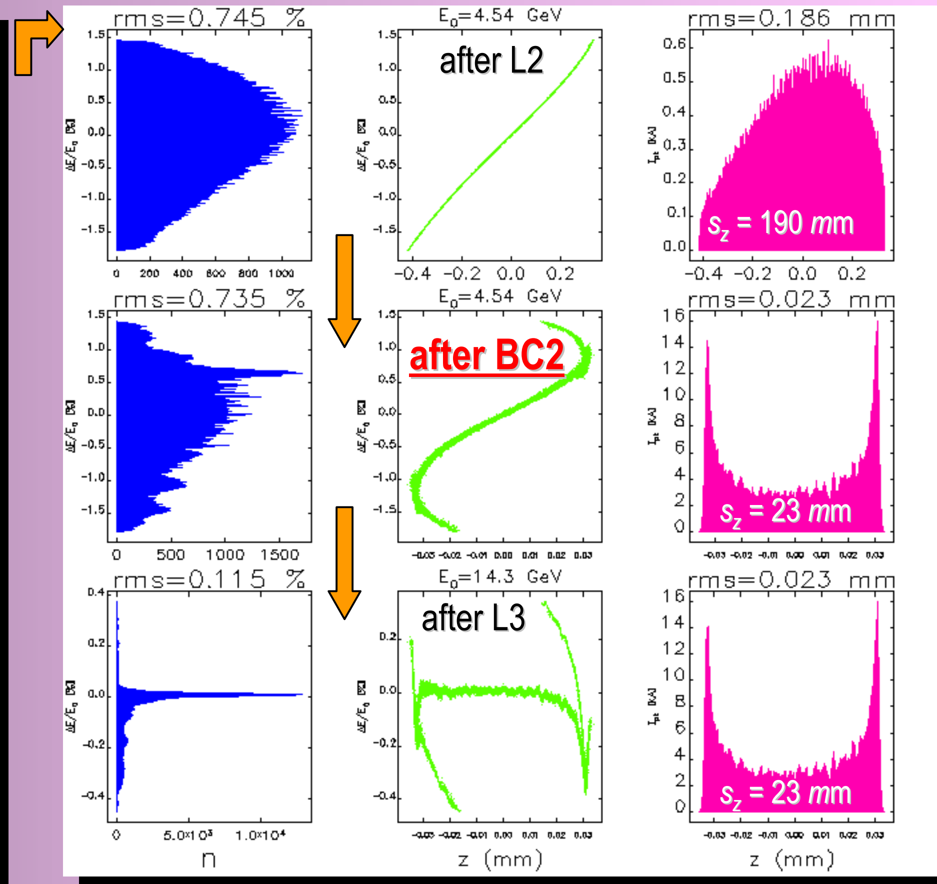
$$\Delta z = R_{56}\,\Delta E/E$$

RF Accelerating Voltage

Path Length-Energy Dependent Beamline

Evolution Longitudinal Phase Space

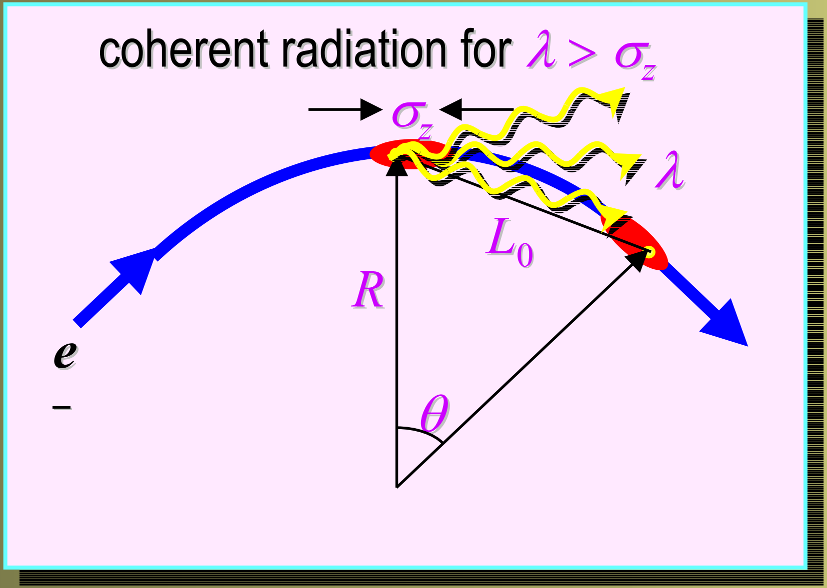


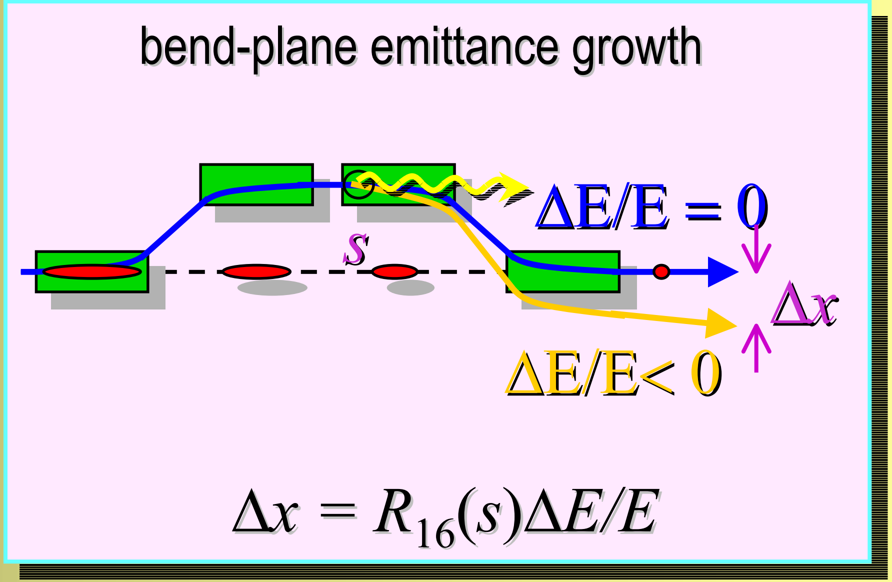


courtesy P.Emma

Coherent Synchrotron Radiation (CSR)

- Powerful radiation generates energy spread in bends
- Projected emittance growth (short bunch worse)





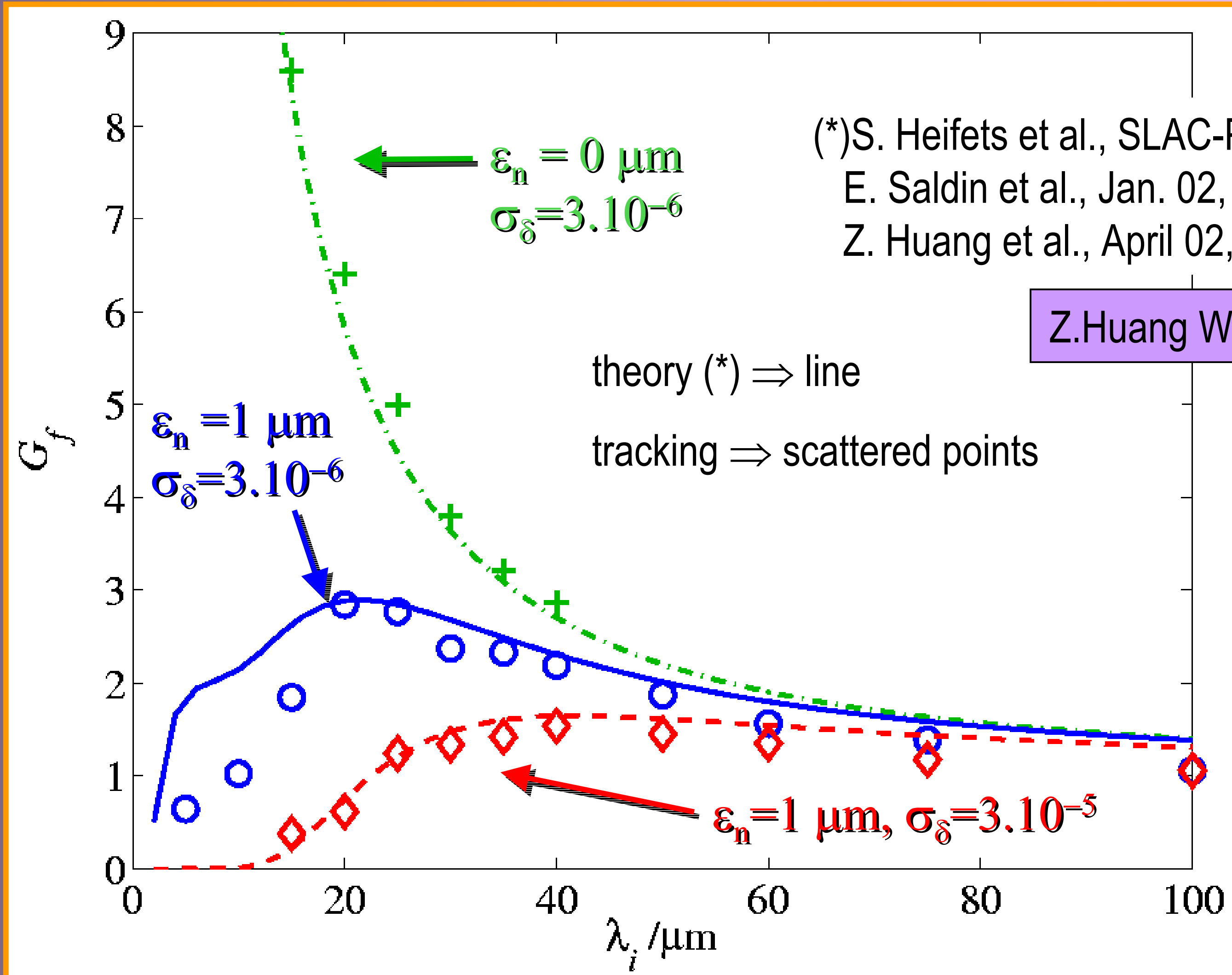
- Micro-bunching Instability: deteriorates ε_{slice} and $\sigma_{\delta,slice}$

Amplification of strongest line/energy density components

First observed by M.Borland in simulations

CSR Microbunching: theory / tracking

Microbunching Gain



(*)S. Heifets et al., SLAC-PUB-9165,03-2002
E. Saldin et al., Jan. 02, NIM, A483,2002
Z. Huang et al., April 02,PRST-AB, 07-2002

Z.Huang WE-O-04

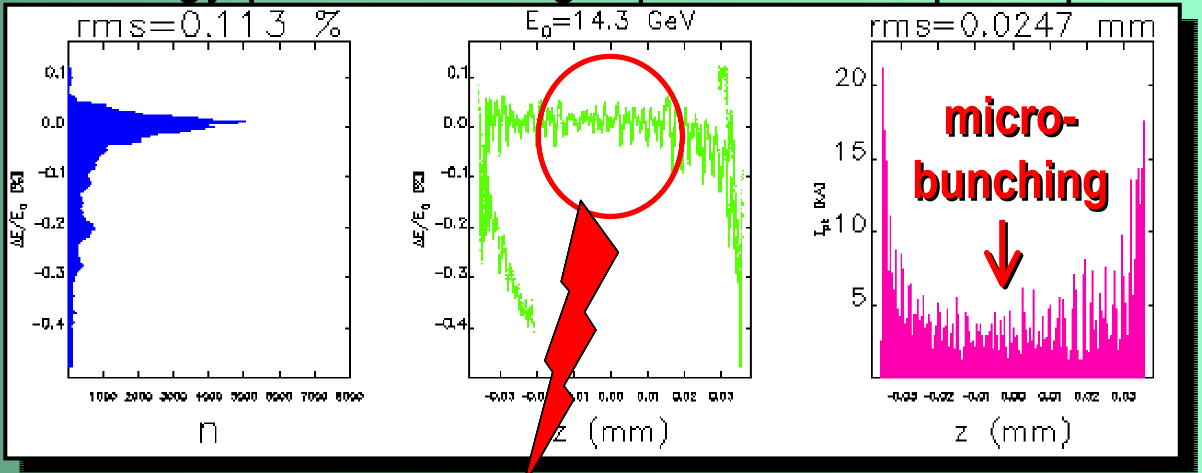
Initial modulation wavelength prior to compressor

Minimizing Microbunching

energy profile | long. space | temporal profile

Without Super-Conducting Wiggler

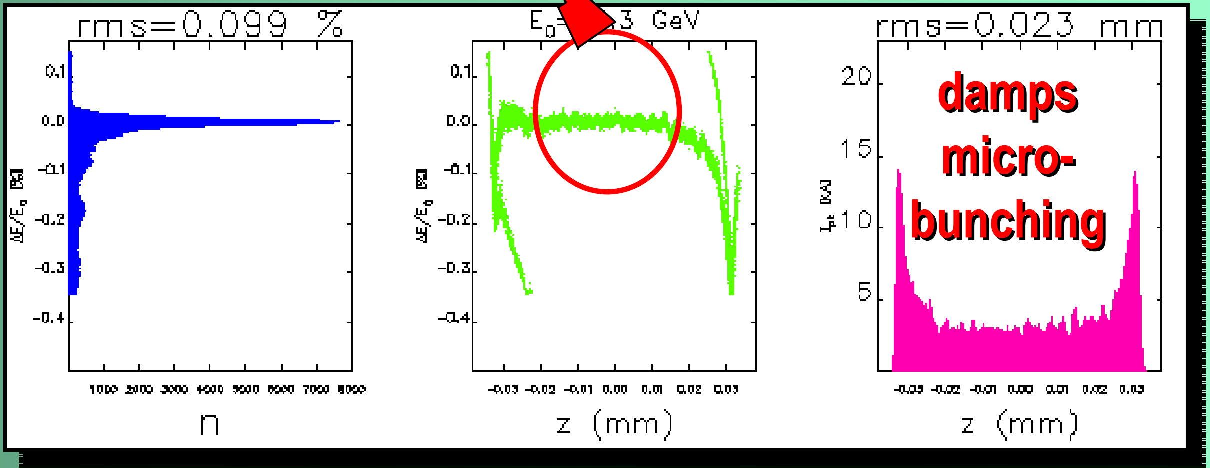
σ_δ = 3.10^{-6} before BC2



Entrance of undulator

With Super-Conducting Wiggler

σ_δ = 3.10^{-5} before BC2

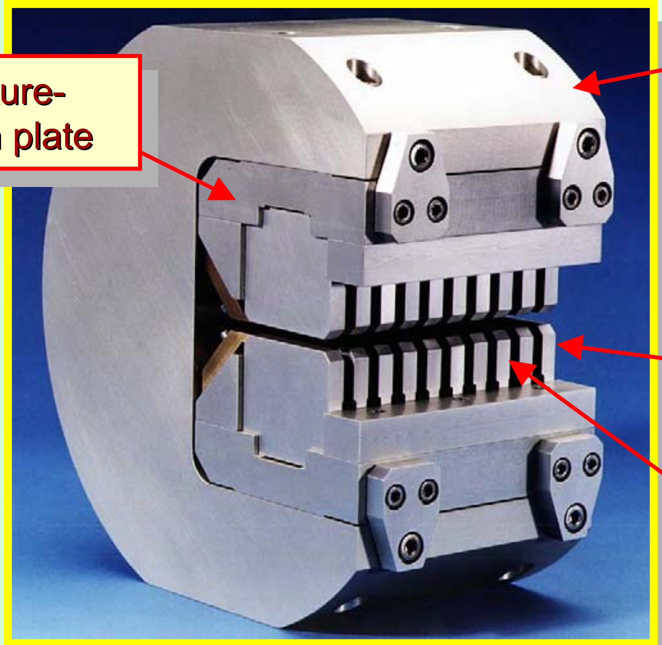


tracking with *Elegant* code, written by M. Borland, ANL

Undulator

- 120 m undulator channel
  - ✓ 33 segments of 3.4 m, λ_u = 3 cm, K = 3.71
  - ✓ space for future enhancements (seeding, slicing, harmonics)
- 3.4-m section already built at ANL and is being measured

Al temperature-compensation plate



Titanium strong-back

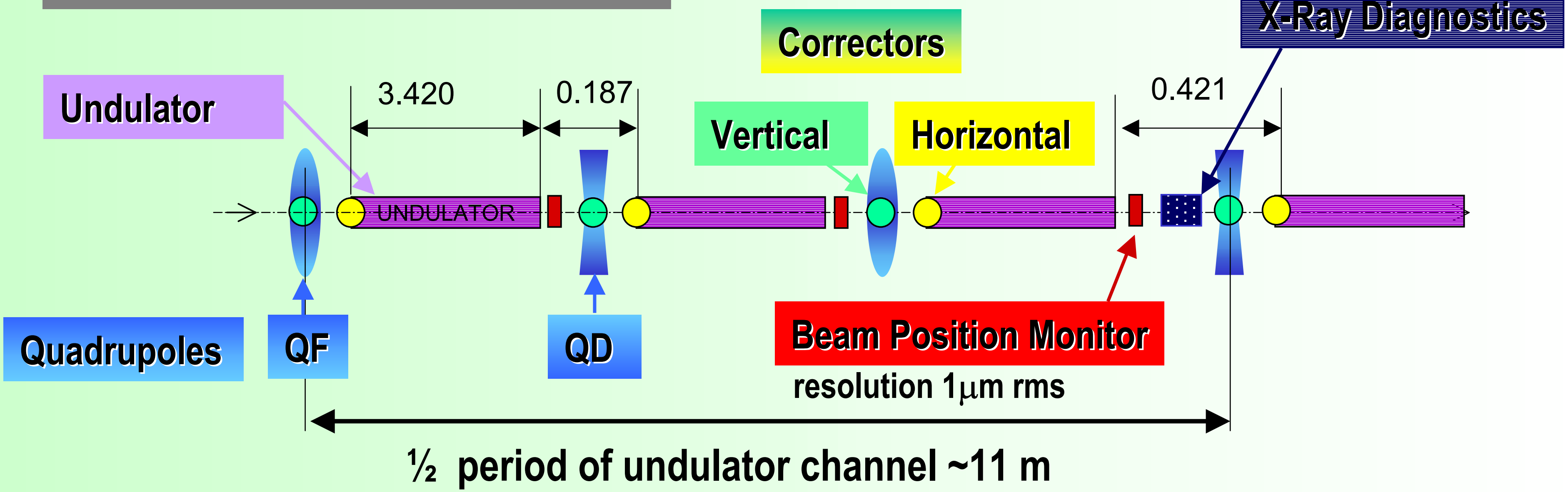
Va permendur poles

Nd-Fe-B magnets

Advanced Photon Source

Courtesy E. Gluskin,L.Moog, *ANL*

Undulator Systems



- Trajectory straight $\Rightarrow \sigma_{x,y} < 5\ \mu m$ over gain length

Beam-based Alignment

- ✓ Measure Energy dependent trajectory
- ✓ Move Quadrupoles and undulators,
- ✓ Correct BPM offsets

$\sigma_{x,y} < 3\ \mu m$ achievable along undulator

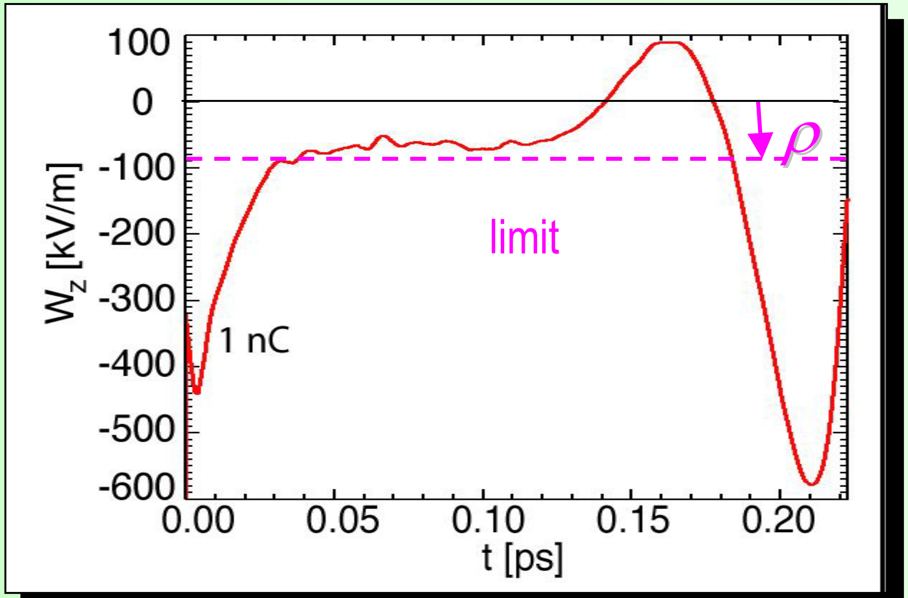
P.Emma Simulations

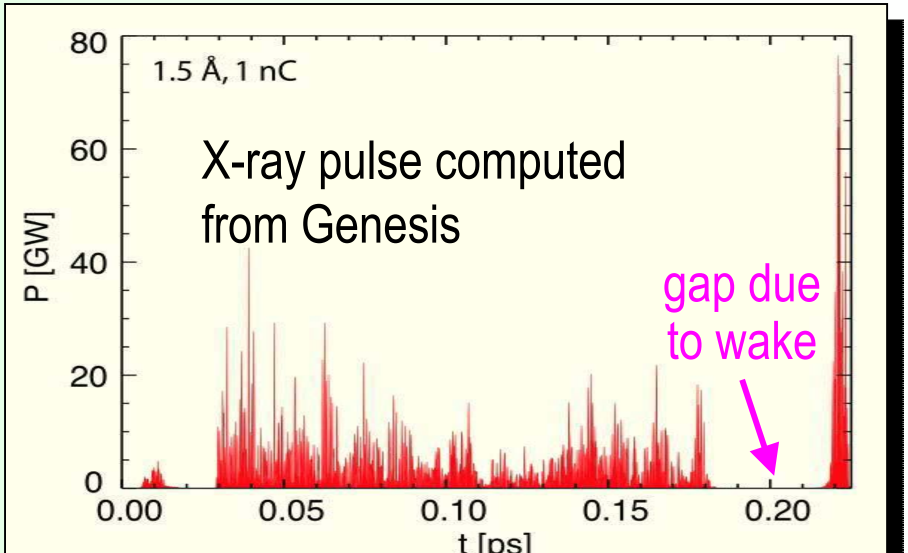
Undulator Chamber Wakefields

- Resistive wall dominant over roughness and geometric wakefields
- $h_{1/2,chamber}$ = 2.5 mm for high undulator fields

$$\left(\frac{\sigma_E}{E}\right)_{RW} \approx (0.22)\frac{e^2 cNL_u}{\pi^2 rE\sigma_z^{3/2}}\sqrt{\frac{Z_0}{\sigma}}$$

Wake changes 'slice' energy during exponential gain regime



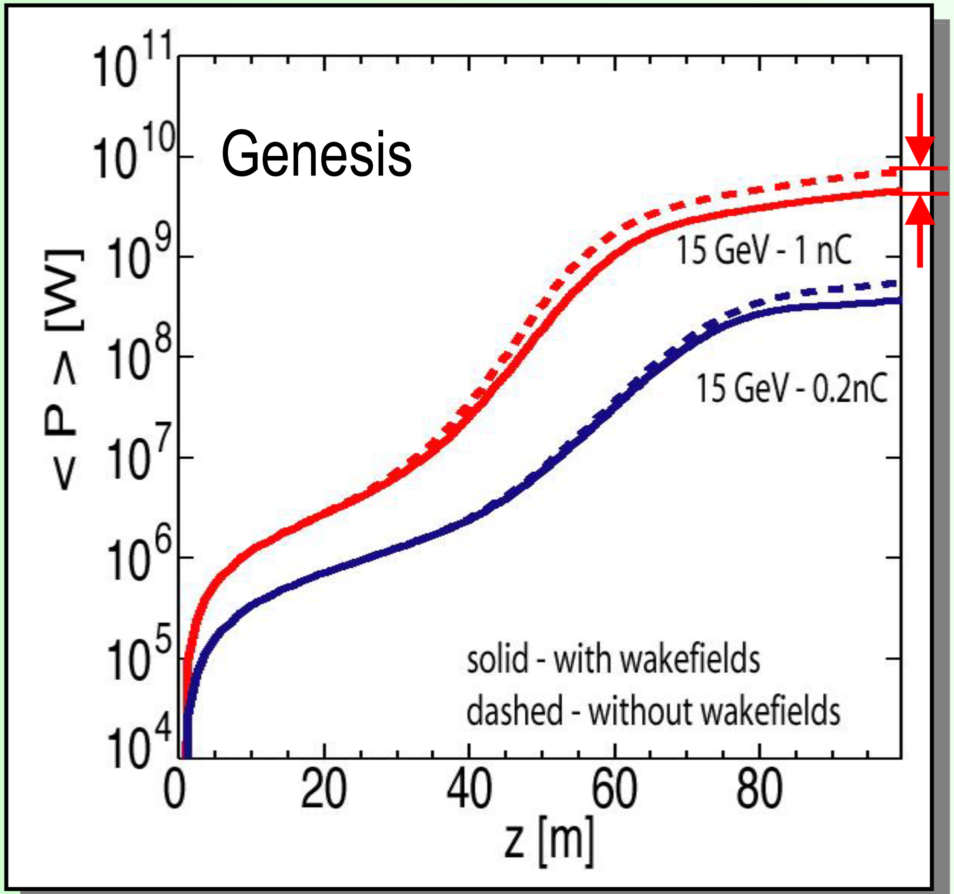


Courtesy S.Reiche

S. Reiche, [WE-P-49] Active pulse length control down to 10 fs by wakefields

Peak Power along Undulator

Start-to-End Simulations: PARMELA ⇒ Elegant ⇒ Genesis



~40% power loss due to wakefield

Courtesy S.Reiche

Project Schedule

2003 – Project Engineering Design Begins

Spring 2004 – Complete Preliminary Design

October 2004 – Start long-lead procurements

October 2005 - Start of civil construction

Winter 2007 – Begin FEL commissioning

October 2008 – Project Complete

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Conclusion

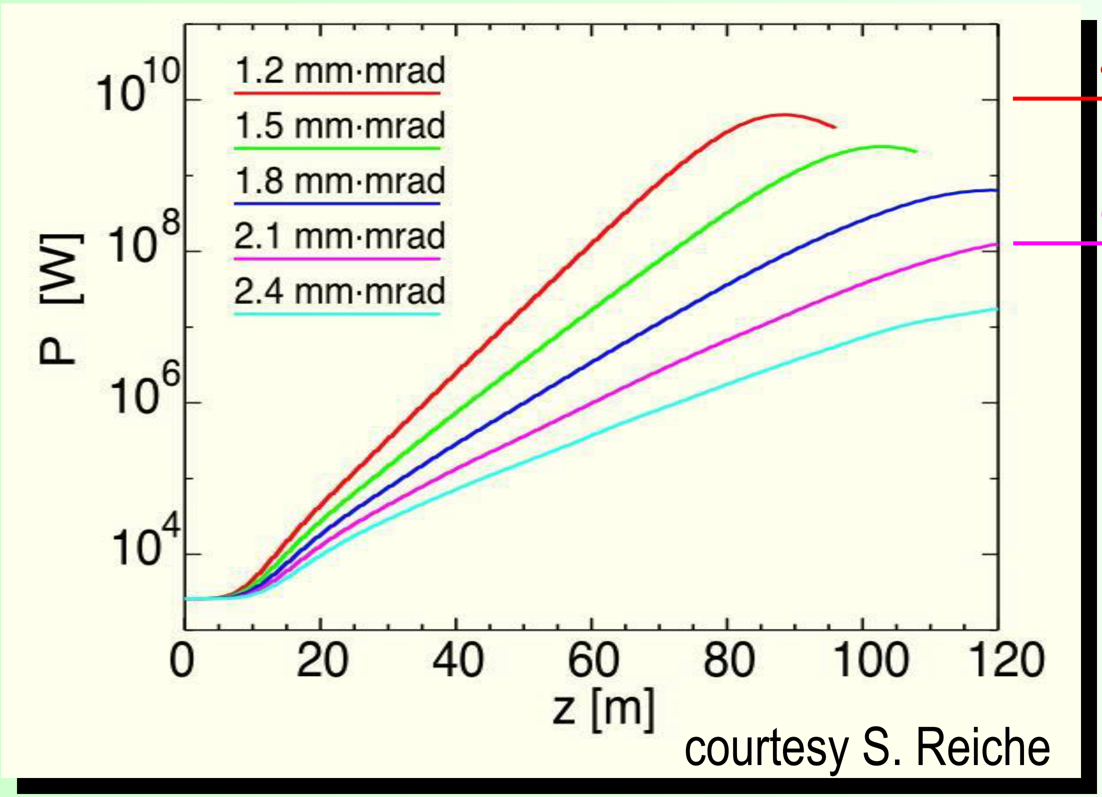
Many challenges

- ❖ Very promising photo-injector results
- ❖ CSR : good understanding
- ❖ Resistive wall wakefields in undulator

http://www-ssrl.slac.stanford.edu/lcls/CDR/

X-Ray optics	R.Bionta WS-P-09
Short Electron bunches	P.Krejcik TU-O-08
Short X-Ray Pulses	J.Hastings WS-O-11

Back-Up



$\varepsilon_N = 1.2\ \mu\text{m}$ → $P = P_0$

$\varepsilon_N = 2.0\ \mu\text{m}$ → $P = P_0/100$