X-RAY FEL's
and
LINEAR COLLIDER's

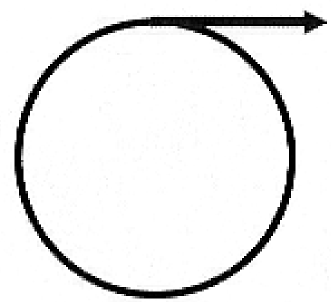
J.M. PATERSON

June 2002

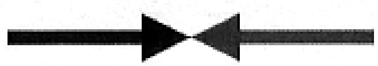
From Storage Rings to Linacs

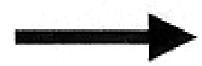
HEP

SR



Storage rings





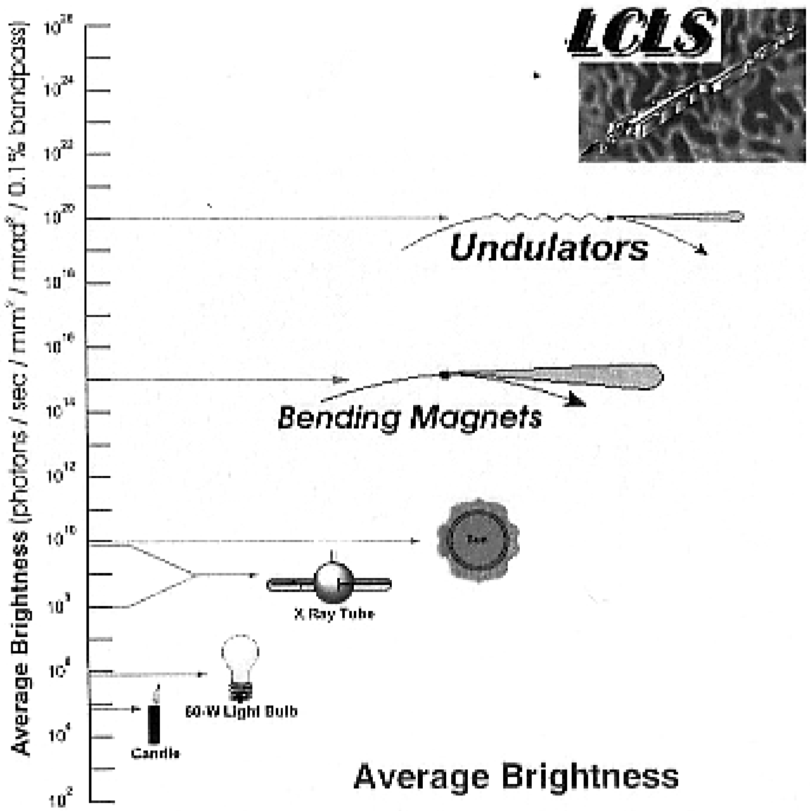
Single pass linear colliders

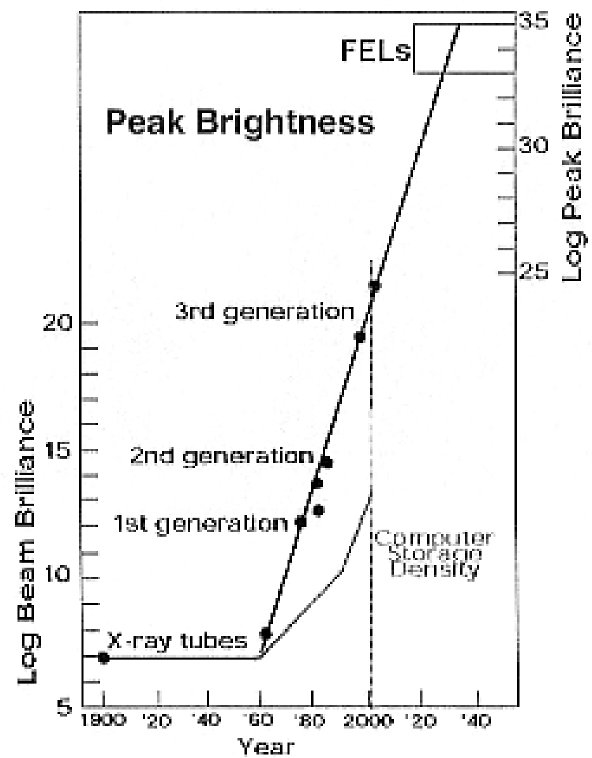
Single pass linacs

Free electron lasers (FELs)
Energy recovery linacs (ERLs)

LCLS Properties Enable Unique New Science

How bright are different light sources ?

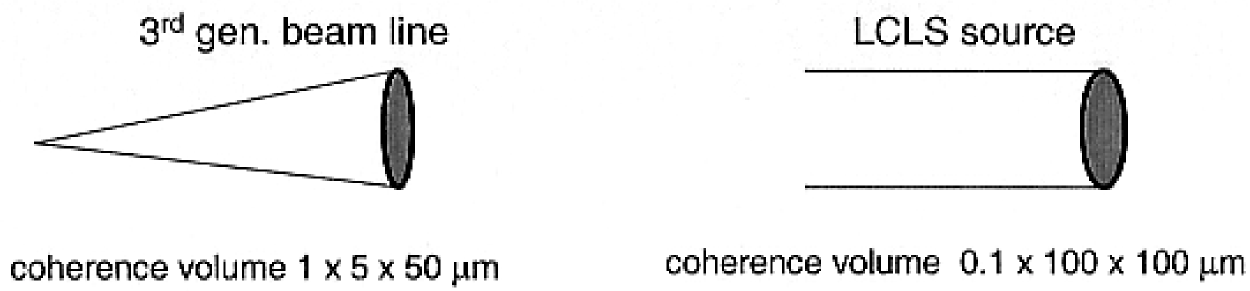




LCLS Properties Enable Unique New Science

- *Peak brightness exceeds existing X-ray sources by $> 10^9$*
- *Time resolution exceeds 3rd gen. synchrotron sources by a factor 10^3*

- *Coherence: degeneracy parameter exceeds present sources $> 10^9$*



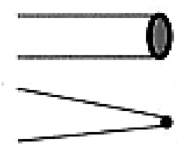
contains 1 photon

contains 10^9 photons

LCLS Properties Enable Unique New Science

LCLS Beam can Probe or Manipulate Matter

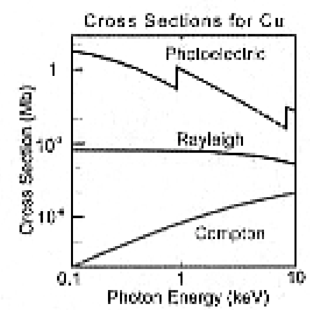
- *Flux density can be varied by focussing: factor 10^6*



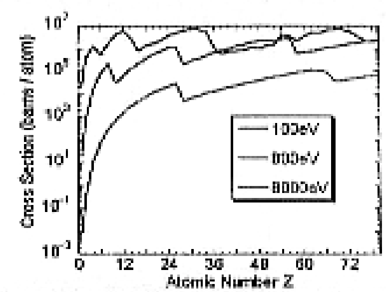
100 x 100 µm

0.1 x 0.1 µm

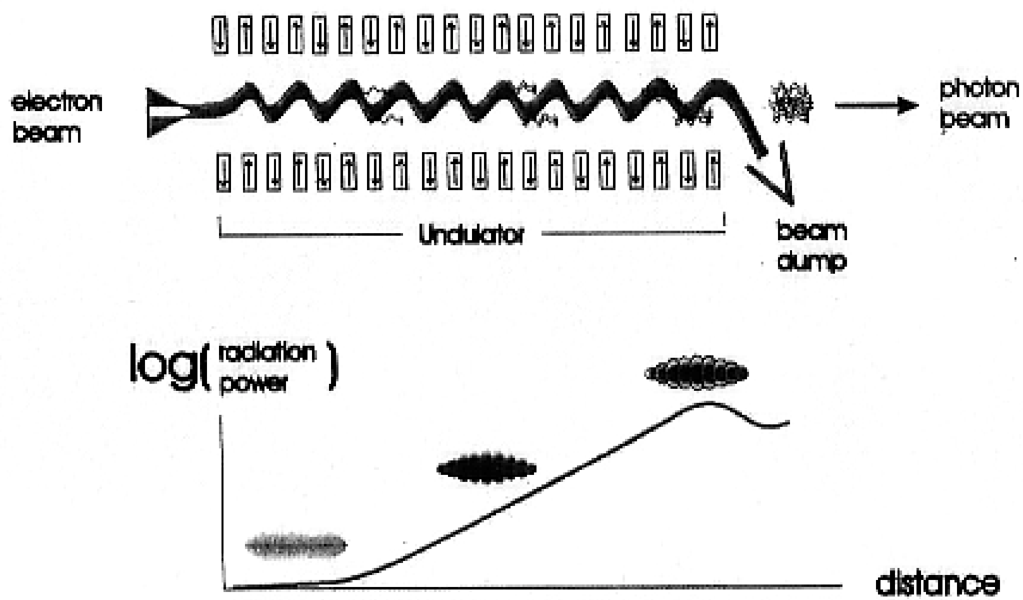
- *X-ray absorption can be varied by tuning energy: factor 10 - 10^2*



- *X-ray absorption depends on atomic number: factor 10^5*

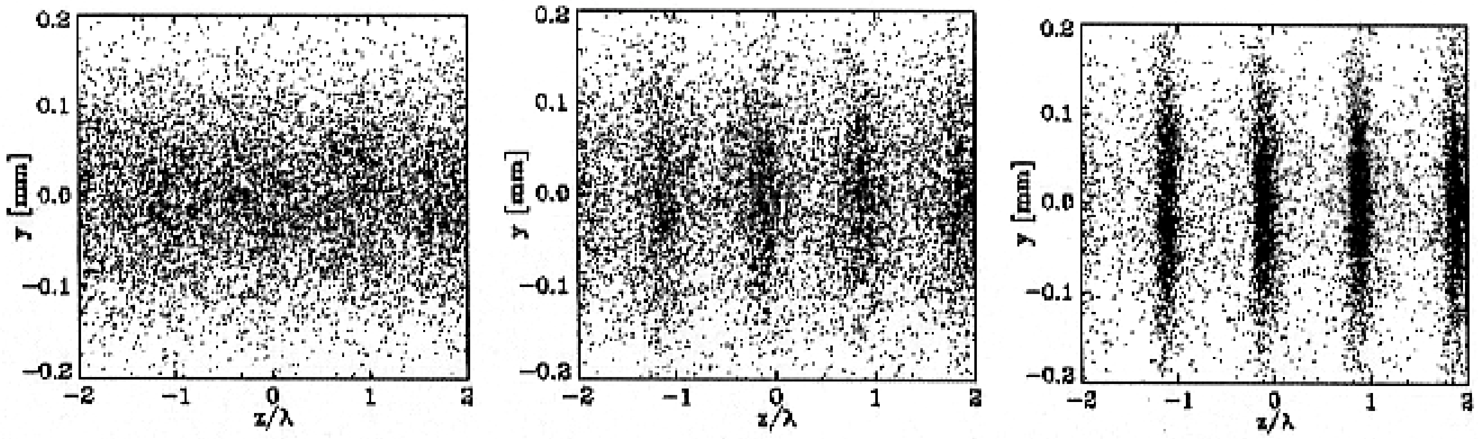


Self-Amplified Spontaneous Emission



Electrons are bunched under the influence of the light that they radiate.
The bunch dimensions are characteristic of the wavelength of the light.

Excerpted from the TESLA Technical Design Report, released March 2001



At entrance to the undulator

Exponential gain regime

Saturation(maximum bunching)

Excerpted from the TESLA Technical Design Report, released March 2001

Why a linear accelerator?

X-ray SASE FEL needs:

energy width $\sigma_E/E \leq 10^{-4}$
and bunch length $\sigma_l \approx 25\ \mu m$ (~100 fs)
$\Rightarrow \sigma_E \times \sigma_l \approx 60$ eV m

storage ring is limited to >1000 eV m

electron emittance $\varepsilon \leq \lambda/4\pi \approx 10^{-11}$ m
LEP (20GeV) (!): $\varepsilon_x > 10^{-10}$ m

several kA peak current
wakefields tolerable for single pass,
BUT not in storage ring

Beam from damping ring NOT suitable

What are the challenges? Electron gun

Electron gun is very critical component:

→ Alternative concepts welcome & under investigation, e.g.

Acceleration by pulsed high voltage +

laser driven photocathode (van der Wiel, Univ. Eindhoven)

or thermionic cathode (Shintake, SPring8)

Understanding has improved a lot

Relevance to Lin. Colliders:

May relax e^- damping ring parameters

Led to flat beam photoinjector (demonstrated @ Fermilab)

ELECTRON GUN'S

FEL's need low emittance

↓

Photocathode RF Guns
with metal cathodes
Accel Voltage >1MV/m

LC's need polarized e^- Gun

↓

Pulsed Photocathode
Semiconductor Cathodes
Polarization > 80%

↘ ↙

Can we get both?

↓

?

S-Band PWT Photoinjector

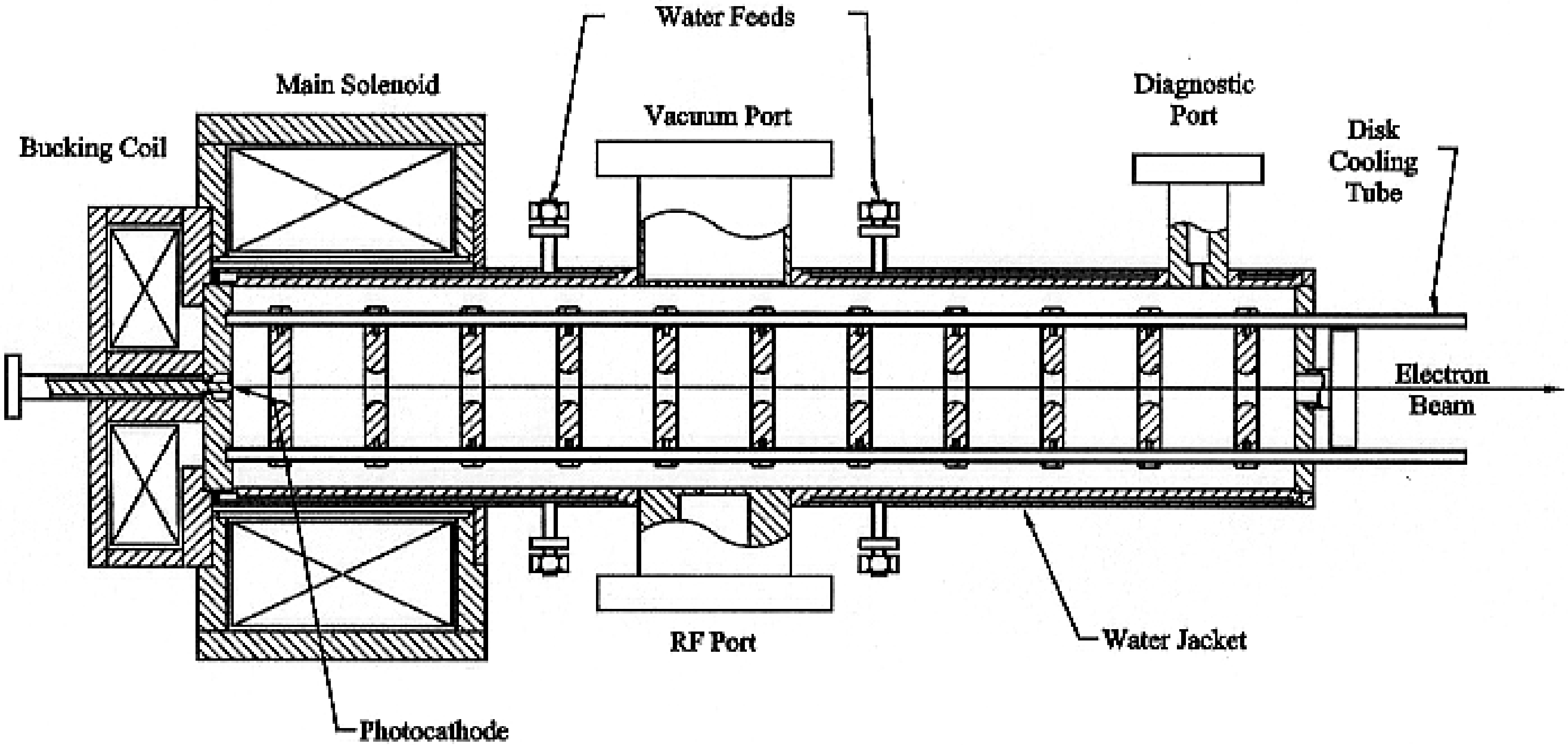
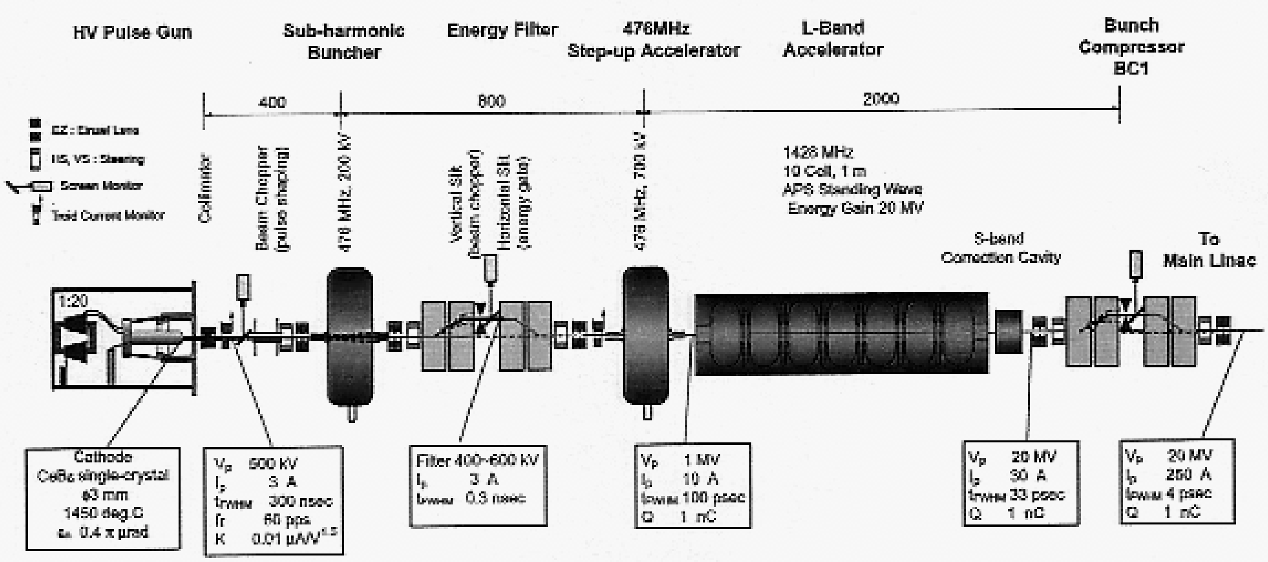
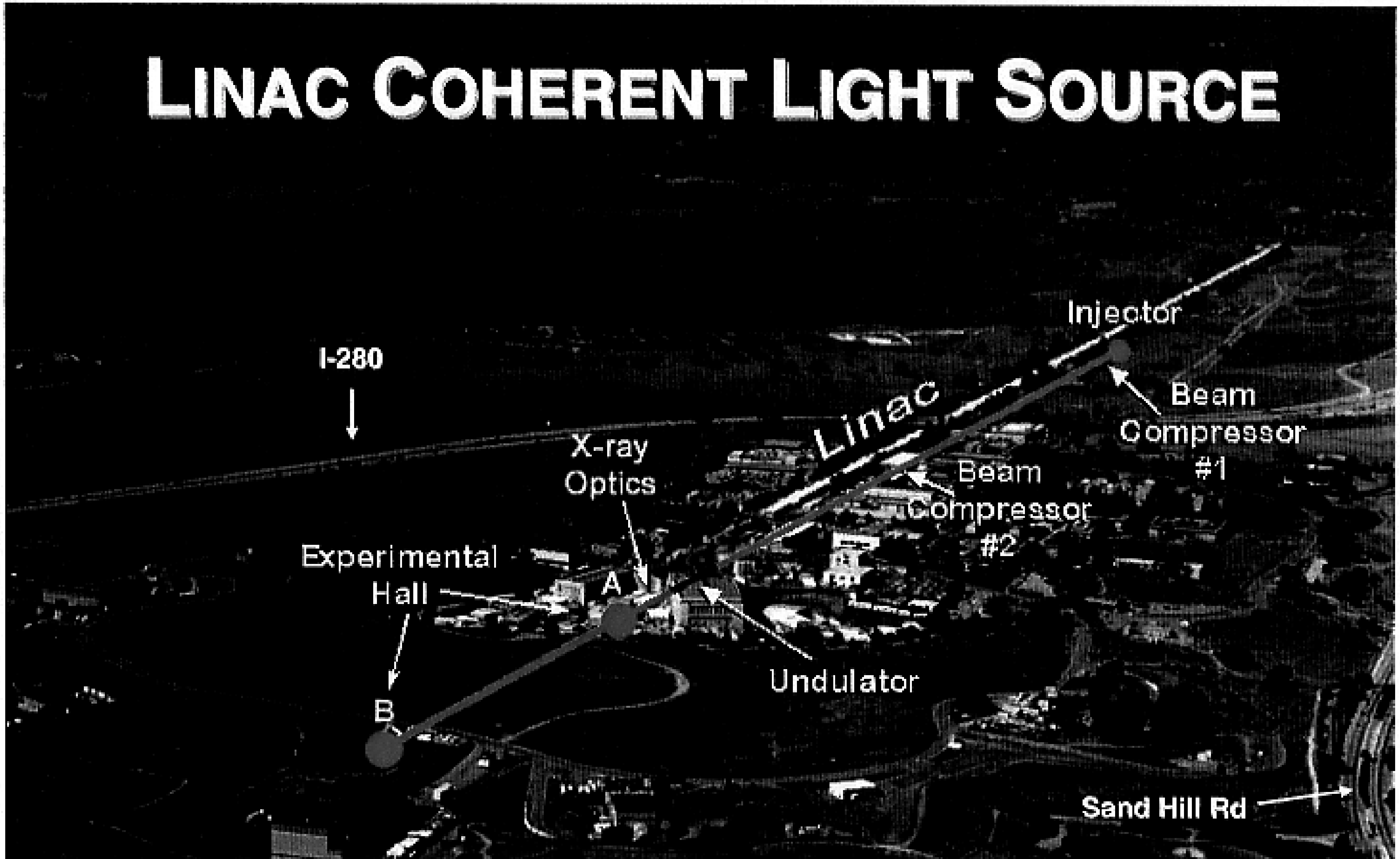


Figure 1: Schematic of the DULY S-Band Integrated PWT Photoelectron Linac.

Low Emittance Injector for SASE-FEL

X-ray FEL

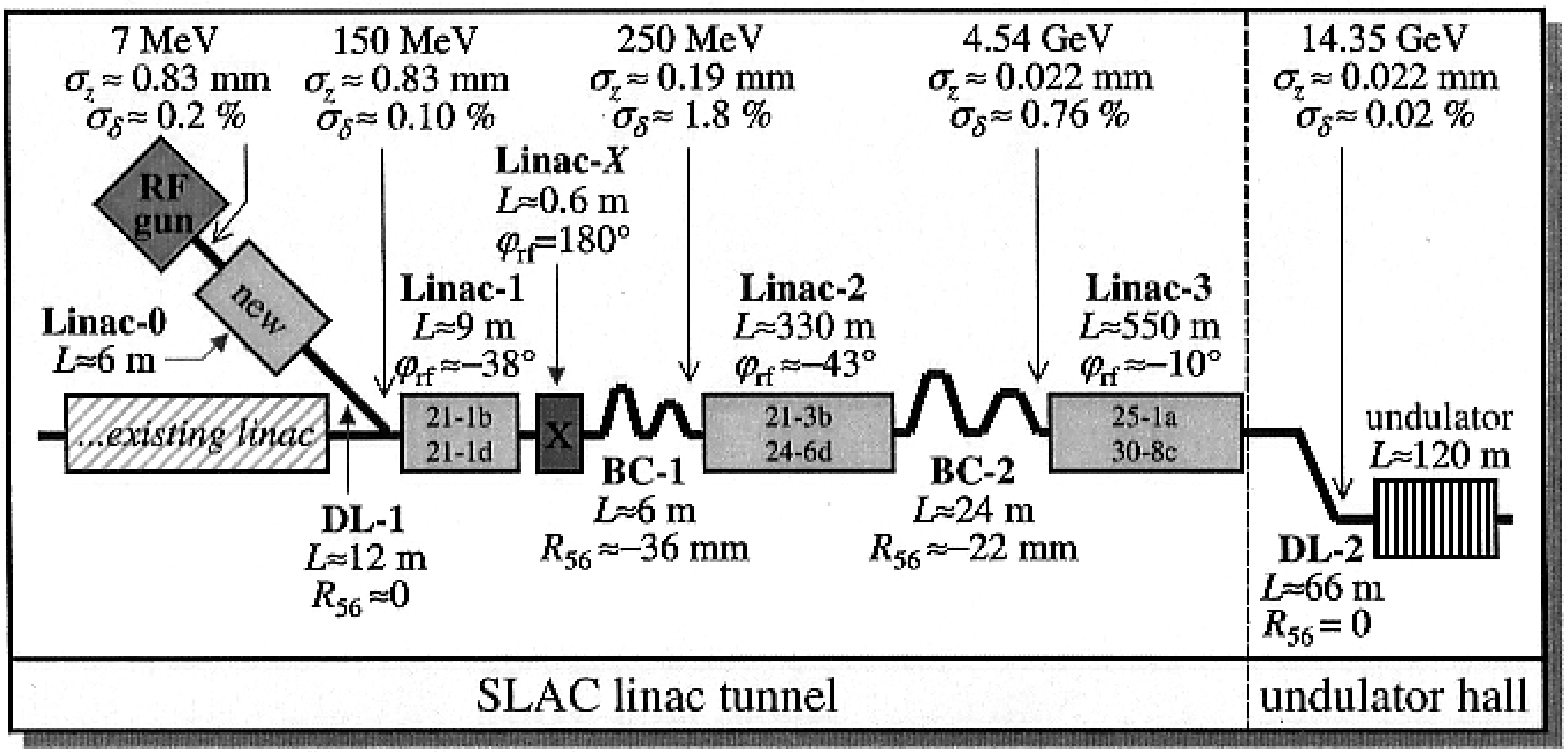



LINAC COHERENT LIGHT SOURCE
Injector
I-280
Linac
Beam
Compressor
#1
X-ray
Optics
Beam
Compressor
#2
Experimental
Hall
A
B
Undulator
Sand Hill Rd

Producing short bunches

At low energy, space charge repulsion degrades the beam properties

Accelerate the bunch, then *compress* it.



Parameters & Performance

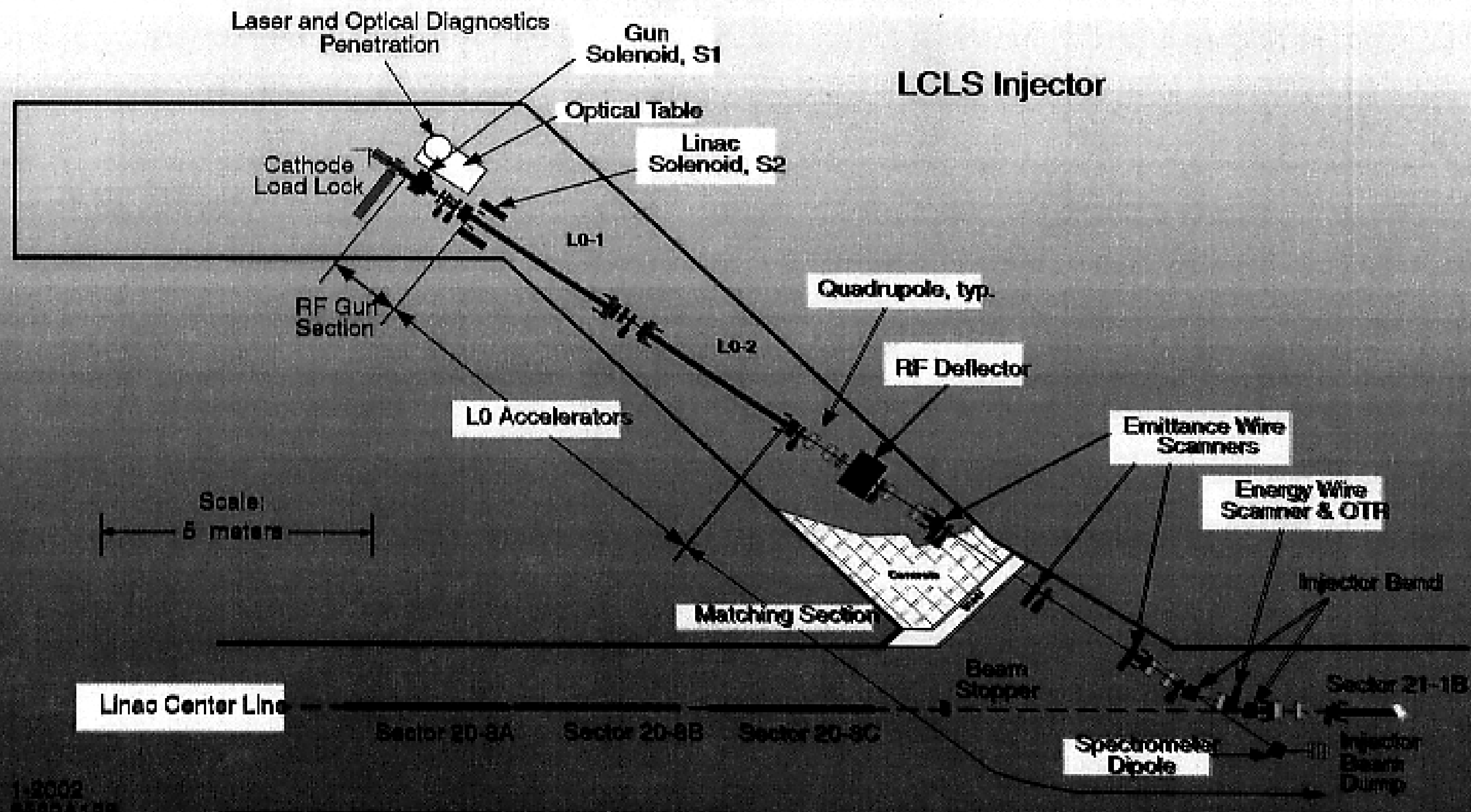
FEL Radiation Wavelength	1.5	0.15	nm
Electron Beam Energy	4.54	14.35	GeV
Repetition Rate (1-bunch)	120	120	Hz
Single Bunch Charge	1	1	nC
Normalized rms Emittance	2.0	1.5	mm-mrad
Peak Current	3.4	3.4	kA
Coherent rms Energy Spread	<2	<1	10^{-3}
Incoherent rms Energy Spread	<0.6	<0.2	10^{-3}
Undulator Length	100	100	m
Peak Coherent Power	11	9.3	GW
Peak Spontaneous Power	8.1	81	GW
Peak Brightness *	1.2	12	10^{32}
Bunch Length	230	230	fsec

* photons/sec/mm^2/mrad^2/0.1%-BW

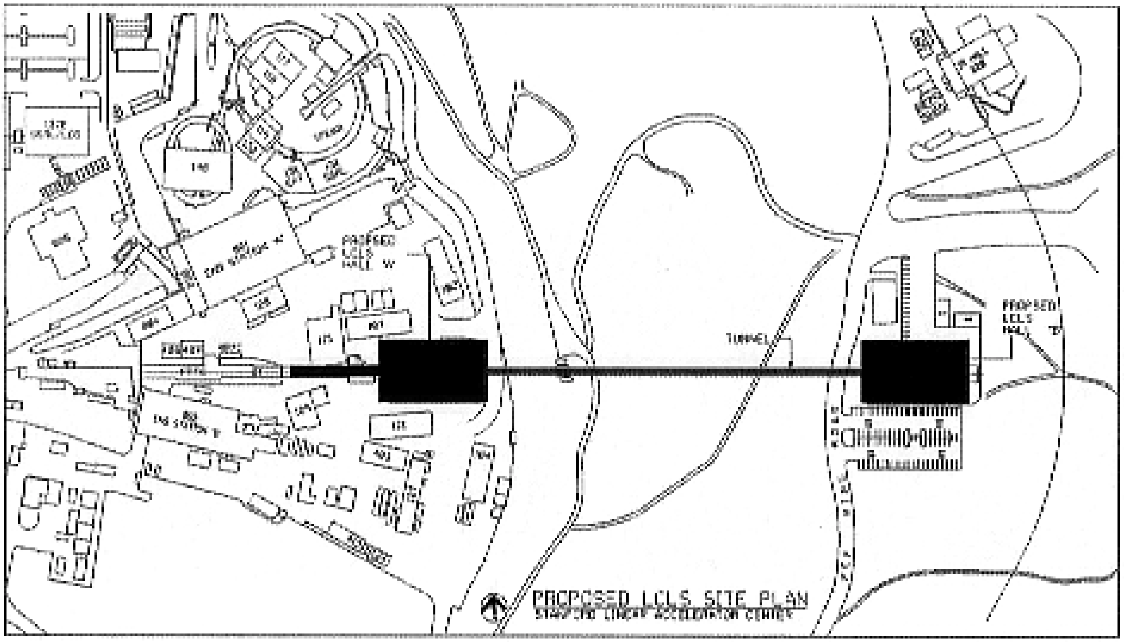
LCLS

Linac Coherent Light Source

Injector at Sector 20



Civil Construction



FFTB Extension

Experimental Hall A

Tunnel

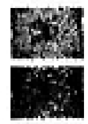
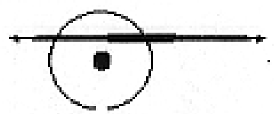
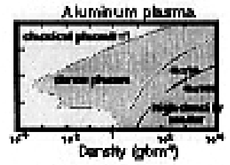
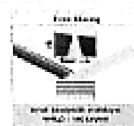
Experimental Hall B

What are the challenges? Undulators

LEUTL undulator

LCLS Science Program – Opportunities for Discovery

Program developed by international team of ~45 scientists working with accelerator and laser physics communities

	***Femtochemistry***	Dan Imre, BNL
	***Nanoscale Dynamics in Condensed matter***	Brian Stephenson, APS
	***Atomic Physics***	Phil Bucksbaum, Univ. of Michigan
	***Plasma and Warm Dense Matter***	Richard Lee, LLNL
	***Structural Studies on Single Particles and Biomolecules***	Janos Hajdu, Uppsala Univ.
	***X-ray Laser Physics***	LCLS Team

Funding Profile

	TEC			OPC	TPC
Fiscal Year	Engineering and Design	Long-Lead Procurement	Construction		
2002				$1,500	$1,500
2003	$6,000				$6,000
2004	$15,000			$4,000	$19,000
2005	$10,000	$29,900		$4,000	$43,900
2006	$2,500		$58,100	$3,500	$64,100
2007			$71,500	$9,700	$81,200
2008			$28,000	$26,000	$54,000
Total	$200,000 to $240,000			$48,700	$245,000 to $295,000

DOE Milestones

June 13, 2001 - Critical Decision 0, Approval of Mission Need

August 2002 - Critical Decision 1, Approval of Preliminary Baseline Range.

February 2003 – Critical Decision 2a, Approval of Long-Lead Procurement

March 2004 - Critical Decision 2, Approval of Performance Baseline

March 2005 – Critical Decision 3, Approval of Start of Construction

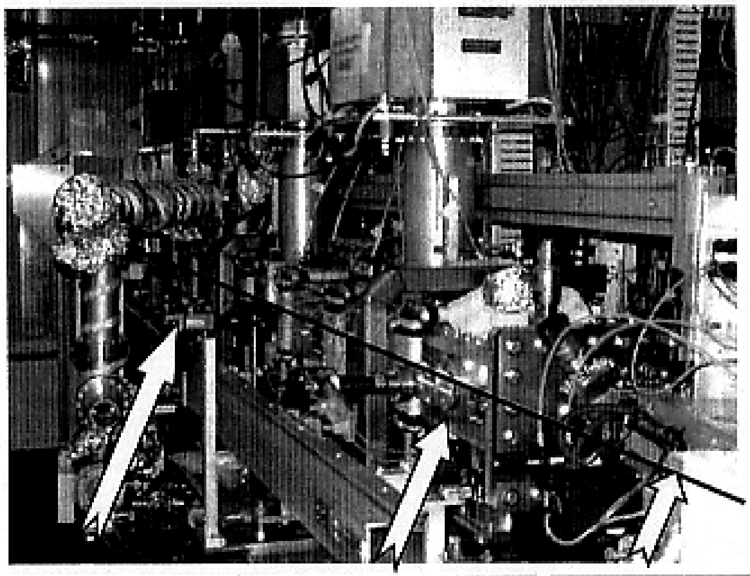
October 2005 – Start of LCLS Construction

September 2008 – Critical Decision 4, Approve Start of Operations

16 March 2001

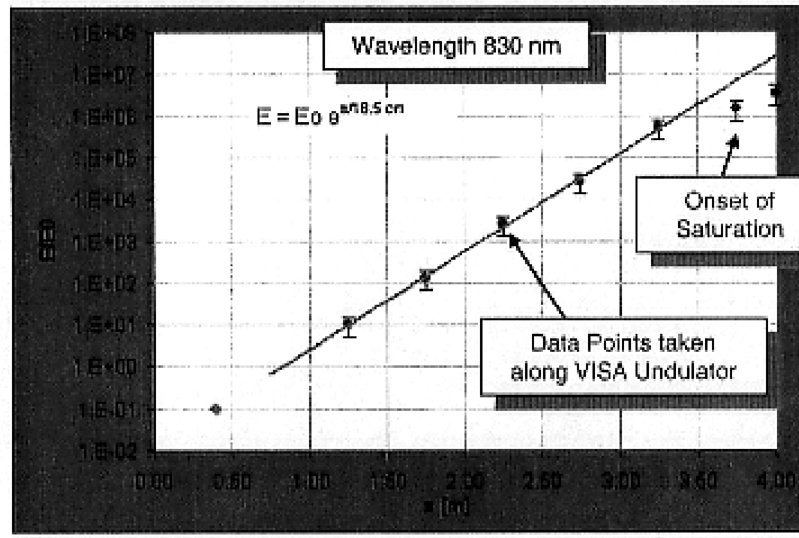
Visible to Infrared SASE Amplifier

BNL-LLNL-SLAC-UCLA

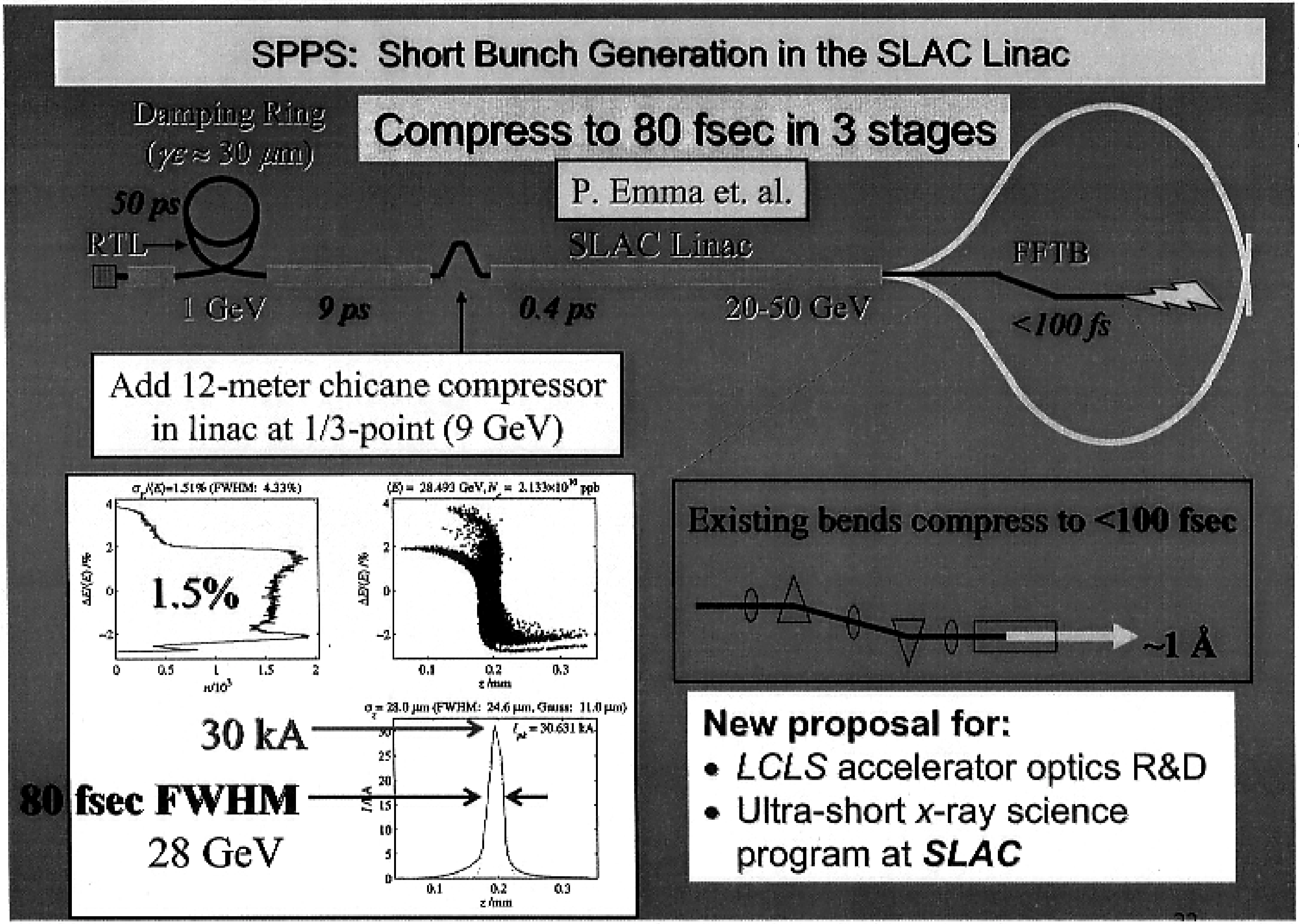


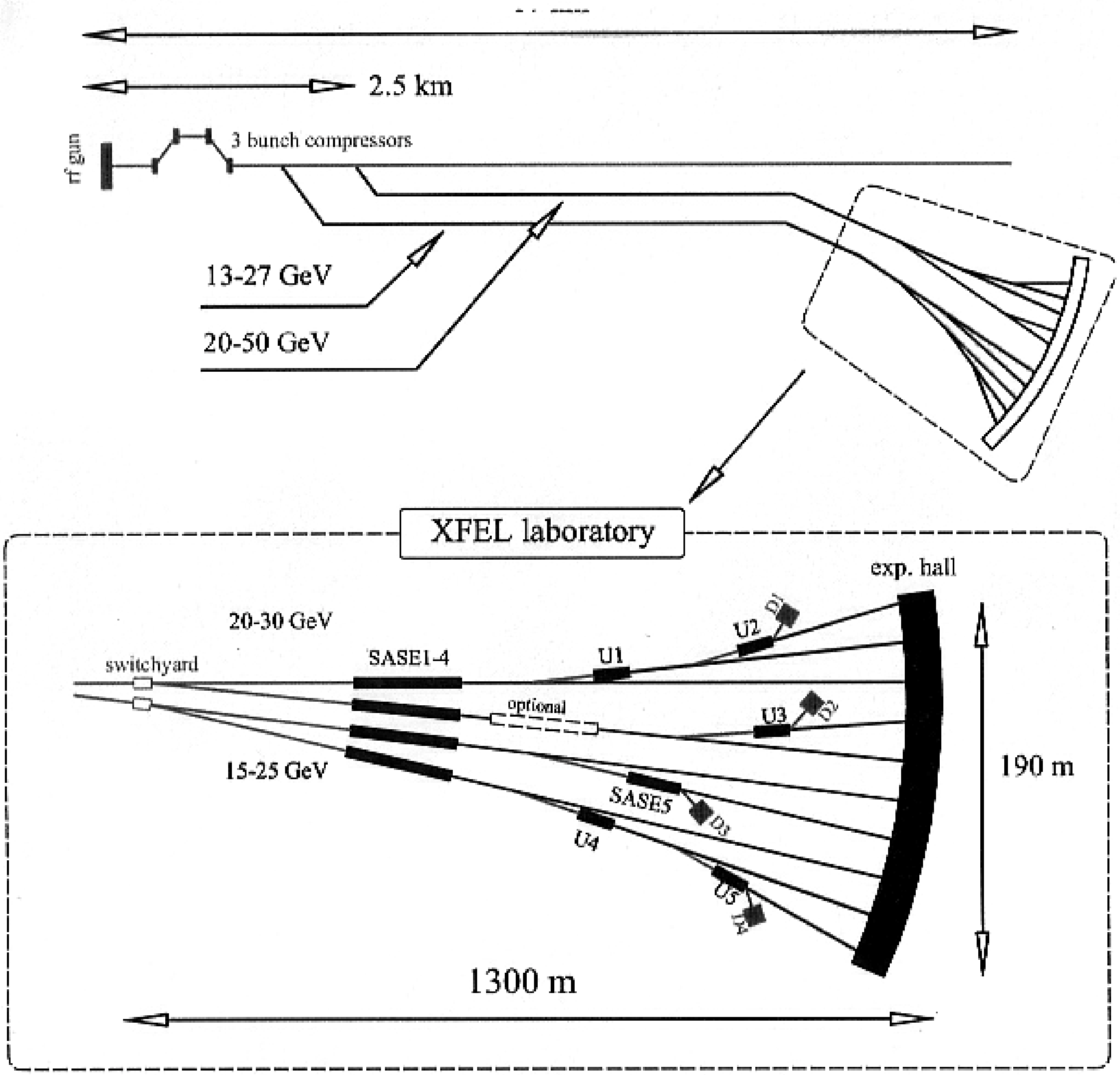
Preliminary recent results (unpublished) from VISA showing large gain (2 10^6) in SASE FEL radiation and evidence of saturation at 830 nm.

VISA Pulse Energy vs. Position



Wavelength	**830nm**
RMS Bunch Length:	**900 fs**
Average Charge:	**170 pC**
Peak Current:	**~200 A**
Measured Projected Emittance:	**1.7 mm mrad**
Energy Spread:	**7×10^{-4}**
Gain Length	**18.5 cm**
Equivalent Spontaneous Energy:	**5 pJ**
Peak SASE Energy:	**10 μJ**
Total Gain:	**2×10^{6}**


SPPS: Short Bunch Generation in the SLAC Linac
Compress to 80 fsec in 3 stages
P. Emma et. al.
Damping Ring
($\gamma\varepsilon \approx 30\ \mu m$)
50 ps
RTL
1 GeV
9 ps
0.4 ps
SLAC Linac
20-50 GeV
FFTB
<100 fs
Add 12-meter chicane compressor
in linac at 1/3-point (9 GeV)
1.5%
30 kA
80 fsec FWHM
28 GeV
Existing bends compress to <100 fsec
~1 Å
New proposal for:
• *LCLS* accelerator optics R&D
• Ultra-short *x*-ray science program at ***SLAC***



2.5 km
rf gun
3 bunch compressors
13-27 GeV
20-50 GeV
XFEL laboratory
exp. hall
20-30 GeV
switchyard
SASE1-4
U1
U2
D1
optional
U3
D2
15-25 GeV
SASE5
D3
U4
U5
D4
190 m
1300 m

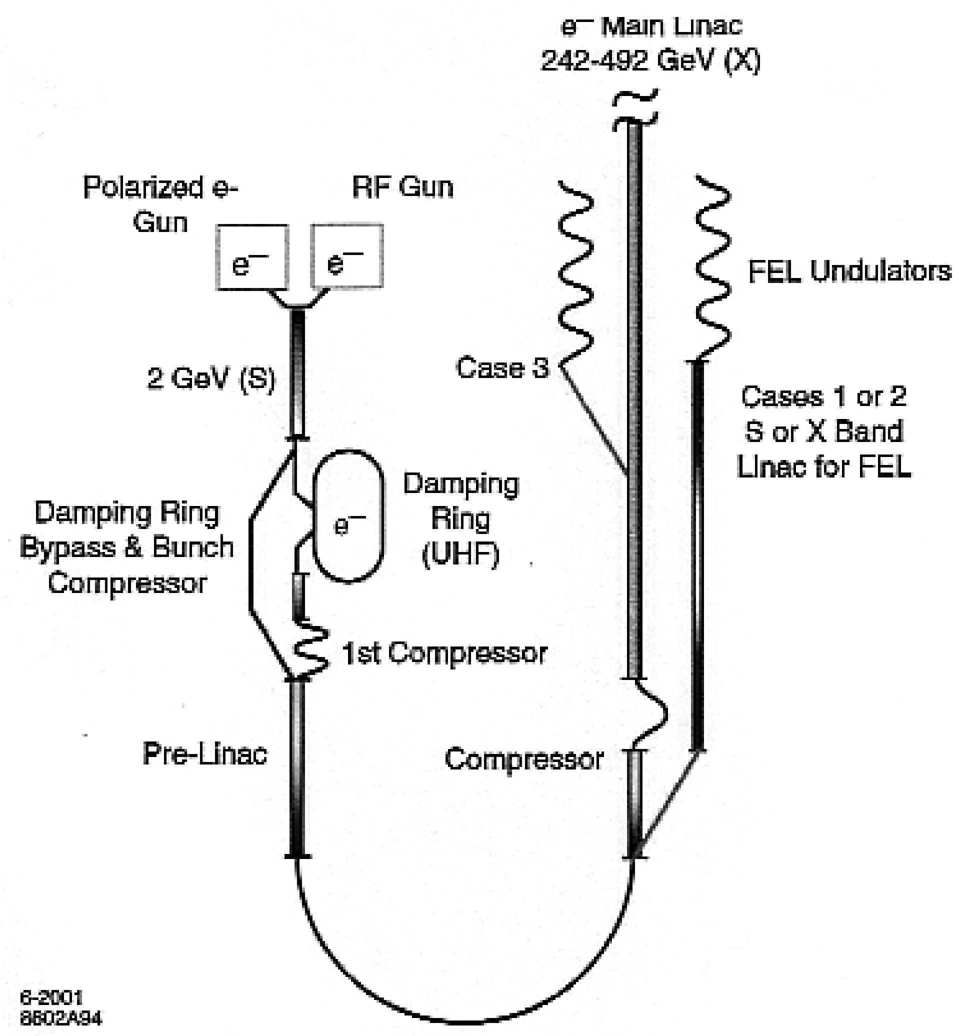


Figure 2.2: Schematic showing the layout of the FEL accelerator sections for three different scenarios.

Conclusions on FEL's and Linear Colliders

Q. Should a new Linear Collider have an X-ray FEL Facility?

A. YES & NO ? My Opinion, June 2002!

- We should share R&D on Technology, Engineering,
  Accelerator Physics and Site Development.
  Today this is lop sided, by at least 10:1 ratio.

- We should get the HEP and Other Science Communities to work together in support of Common Interest but NOT A ONE OFF SINGLE PROPOSAL

- A Single Proposal is hazardous to everyone's health!
  A Team Effort, graded and staged approach is healthy!
  Keep an open mind and a flexible approach, showing that the programs are coupled for efficiency, cross fertilization of ideas and common underlying technology.

- Footnote for High Energy Physicists about Small Science
  The Advanced Photon Source with Experiments ~ \$1B
  The Spallation Neutron Source with Experiments ~ \$1.5B