Sources for Linear Colliders

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J. C. Sheppard
SLAC

Acknowledgements (slide theft)

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Outline

Goals for lecture series
Who is J.C. Sheppard
Survey of Requirements
    ILC Electrons
    CLIC Electrons
    ILC Positrons
    CLIC Positrons
    ILC e+ Keep Alive Source
    LCLS Electron Source
Basic Source
    Emittance and Admittance
    Polarization incl. Errors
    Basic electron source
    Basic positron source
    Compare and contrast

Outline, cont'd

- Electron Sources
    - Cathodes
    - Lasers
    - Bunching and Capture
    - Guns
- Positron Sources
    - Pair Production
    - Undulators
    - QE
    - Targets
    - Capture
    - Acceptane and transport
    - Hybrid Target
    - Spin transport
- Polarization
    - Polarimetry

Outline, cont'd

- RF Guns
  - Cu Cathodes
  - Lasers
  - rf Gun
- Review
  - ILC Electron Source
  - ILC Positron Source

Lecture Mechanics

Lecturer talks---you interrupt and ask questions

Talk for about 50 minutes per hour

Take 10 minute break every hour

Homework problems (after lunch at latest…look at penultimate slide for indication of what the homework will be)

Goals for Sources Lectures

What are the main systems in the Sources

What are the principle issues associated with the system components

What are the present R&D topics

Probably not a lot of mathematics in the lectures (lots of math in real life)

Not much discussion on Codes (best to understand the fundamentals at a basic monkey level prior to giving your life over to the packaged programs---write you own)

Who is JCS?

BS EE UCSB 1974 Semiconductor Devices

MS EE MIT 1976 Quantum Electronics/ LiNbO3 Spatial Phase Modulators

Ph.D EE Stanford 1981 Quantum Electronics/VUV Cerenkov Light Source

1980-1981 Post Doc UVa: Linac Pulse Stretcher cw 4 GeV Electron Accelerator (morphed into CEBAF-Jlab)

1981-1987 SLC (a little bit of everything)
1987-1999 Head of SLAC Accelerator Department: SLC, PEP, PEPII, SPEAR, LCLS
2000-Present: NLC, ILC: e+ and e- Sources, E166
Daily Activities: ILC e-Source, FACET, ASTA-LCLS

Survey of Collider Sources

ILC Electrons
ILC Positrons
CLIC Electrons
CLIC Positrons ILC e+ Keep Alive Source
LCLS

Survey of Collider Sources

Sources comprise the systems that generate, capture, and deliver beams of electrons and positrons to the Damping Rings. In the case of ILC and CLIC these are large accelerator complexes.

ILC e- and e+ Sources deliver 200 kW beams at 5 GeV to the Damping Rings. The ILC Positron Source requires 100 kW of multi-MeV (>10 MeV) photons on the target for e+ production

CLIC e- and e+ Sources deliver 29 kW beams at 3 GeV to the Damping Rings. The ILC Positron Source requires 140 kW of 5 GeV electrons on the target for e+ production

The LCLS Injector delivers 18W of 150 MeV electrons to the SLAC linac

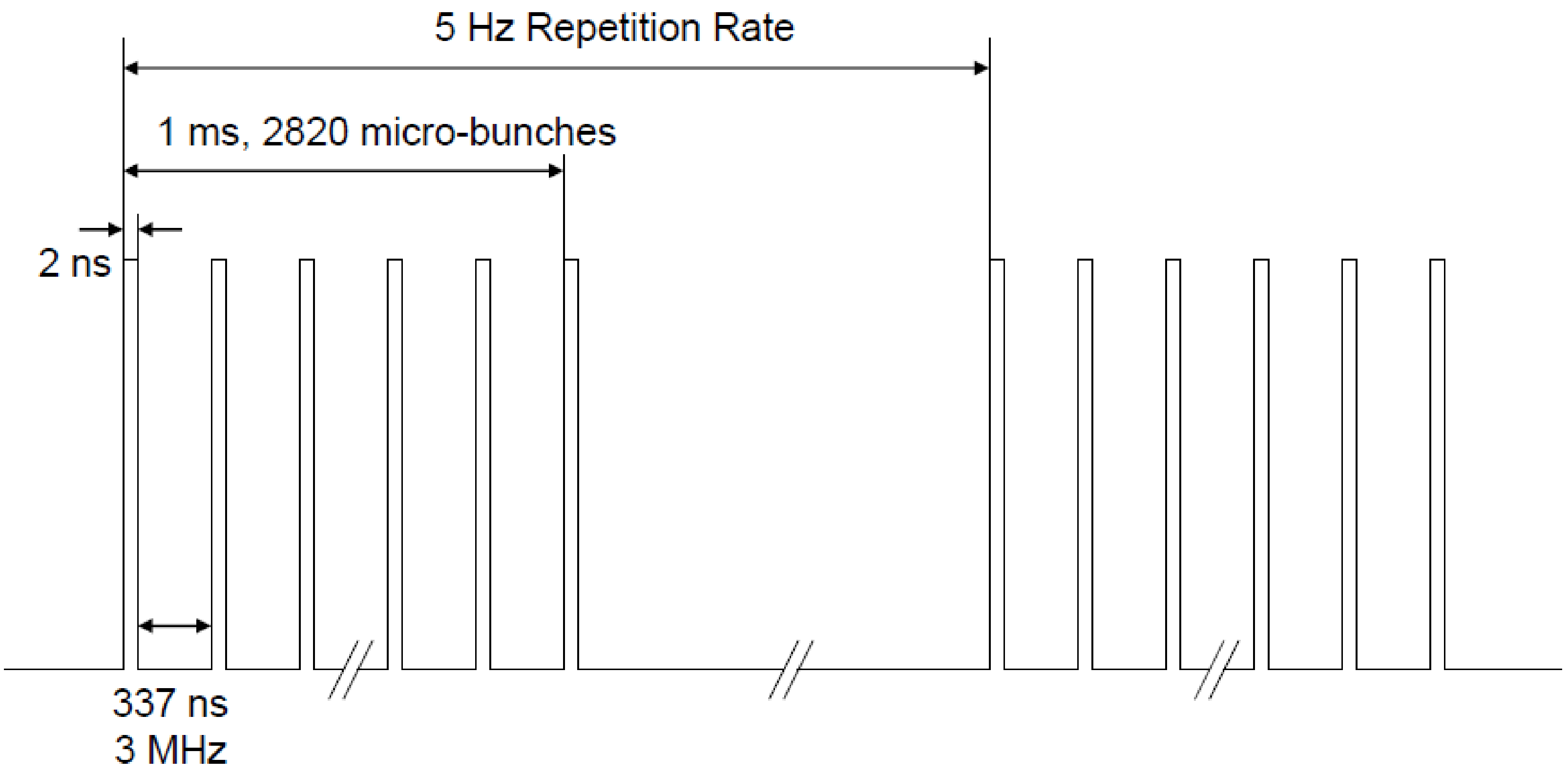
Survey of Collider Sources, 2

The Sources are complete accelerator systems by them selves. The energy range goes from 1eV thru several GeV. The Sources require experts in atomic and material science, thermal hydrodynamics, radiation physics, undulators, magnet technologies, rf acceleration (NCrf and SCrf), lattice design, beam diagnostics,…..

A good foundation in Applied Physics is a good start……

Bunches and Pulses and Pulse Trains

ILC e- Beam Time Structure



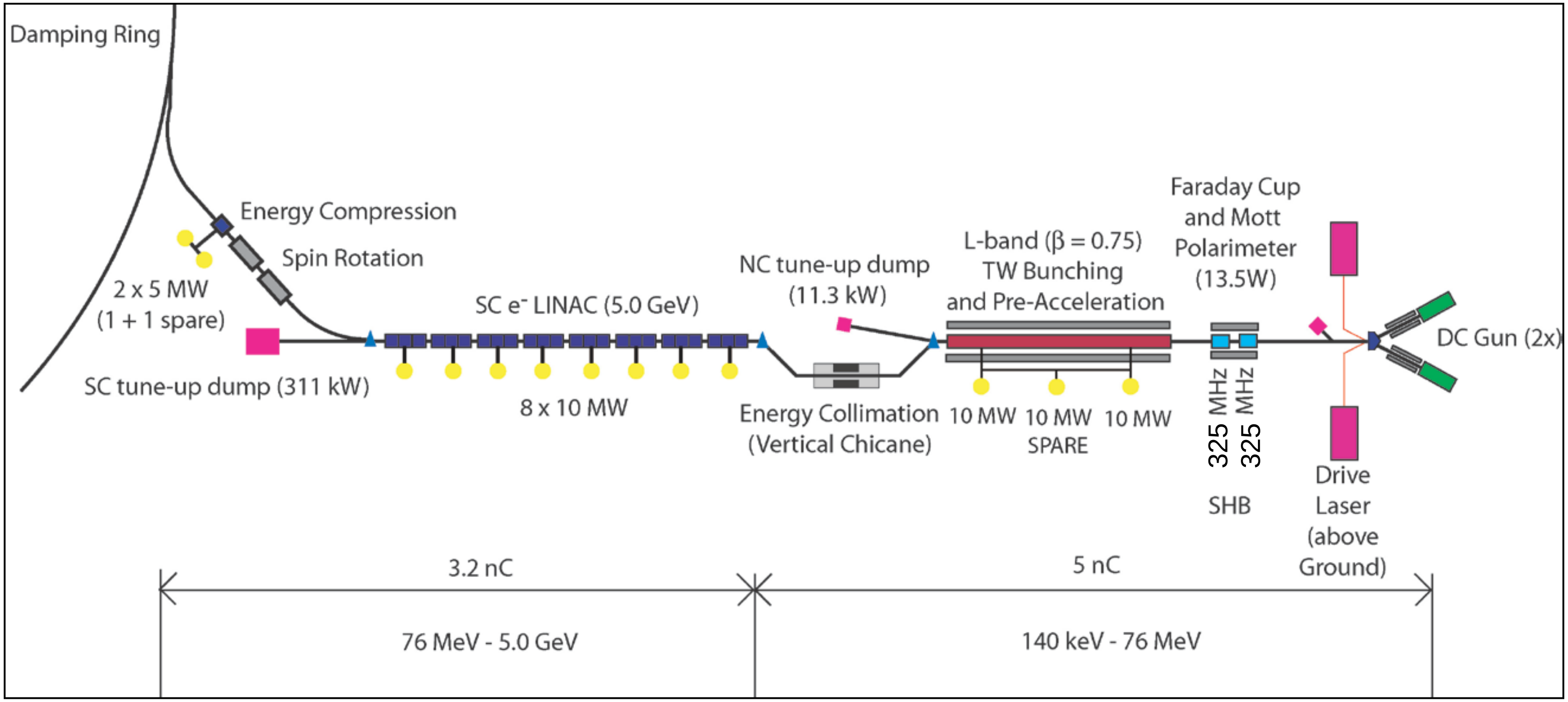
ILC Electron Beams

TABLE 1). Major parameters of the ILC high-current high-polarization electron source.

Parameters	**ILC RDR**	**ILC 500 GeV Ref.**	**ILC TeV Straw**
Particles Per Microbunch	3x10^{10}	3x10^{10}	3x10^{10}
Number Of Microbunch	2625	1312	2280
Width Of Microbunch	1 ns [~ps bunched]	1 ns [~ps bunched]	1 ns [~ps bunched]
Time Between Microbunches	356 ns	670 ns	356 ns
Bunching Frequency	2.8 MHz	1.35 MHz	2.8 MHz
Width Of Macropulse	1 ms	1 ms	1 ms
Macropulse Repetition Rate	5 Hz	5 Hz (10Hz)	5 Hz (10Hz?)
Charge Per Macropulse	8000 nC	4000 nC	7000 nC
Normalized Emittance, source	0.1 m-rad	0.1 m-rad	0.1 m-rad
Normalized Emittance, damped	1x10^{-5} / 4x10^{-8} m-rad	1x10^{-5} / 4x10^{-8} m-rad	1x10^{-5} / 4x10^{-8} m-rad
Polarization, electrons	>80%	>80%	>80%

The Baseline ILC Electron Source

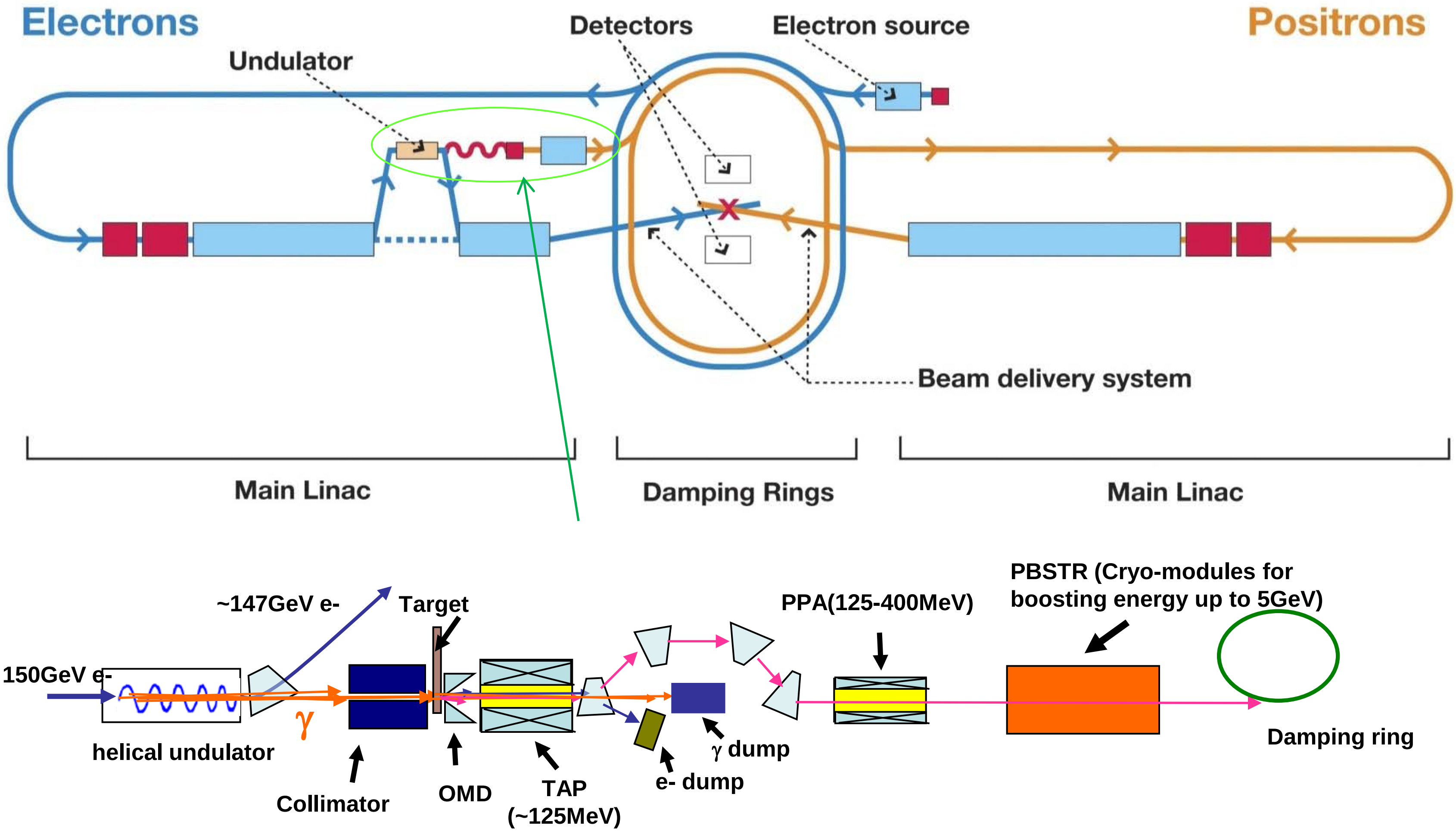
Electron source provides polarized electron beam and consists of all systems from source laser to 5 GeV injection to damping rings. (2011 layout: 325 MHz SHB)



Summary Parameters (Sabine Riemann, 2011)

Parameter	RDR	SB2009	Units
e+ per bunch at IP	2 x 1010	1 to 2 x 1010	
Bunches per pulse	2525	1312	
e+ energy (DR injection)	5	5	GeV
DR transverse acceptance	0.09	0.09	m-rad
DR energy acceptance	±0.5	± 0.5	%
e- drive beam energy	150	125-250	GeV
e- energy loss in undulator	3.01	0.5-4.9	GeV
Undulator period	11.5	11.5	mm
Undulator strength	0.92	0.92	
Active undulator length	147 (210 after pol. Upgrade)	231 max.	m
Field on axis	0.86	0.86	T
Beam aperture	5.85	5.85	mm
Photon energy (1st harm.)	10	1.1 (50 GeV) 28 (250 GeV)	MeV
Photon beam power	131	Max: 102 at 150 GeV	kW
Target material	Ti-6%Al-4%V	Ti-6%Al-4%V	
Target thickness	14	14	mm
Target power adsorption	8	8	%
PEDD in target			
Dist. Undulator center - target	500	500	m
e+ Polarization	34	22	%

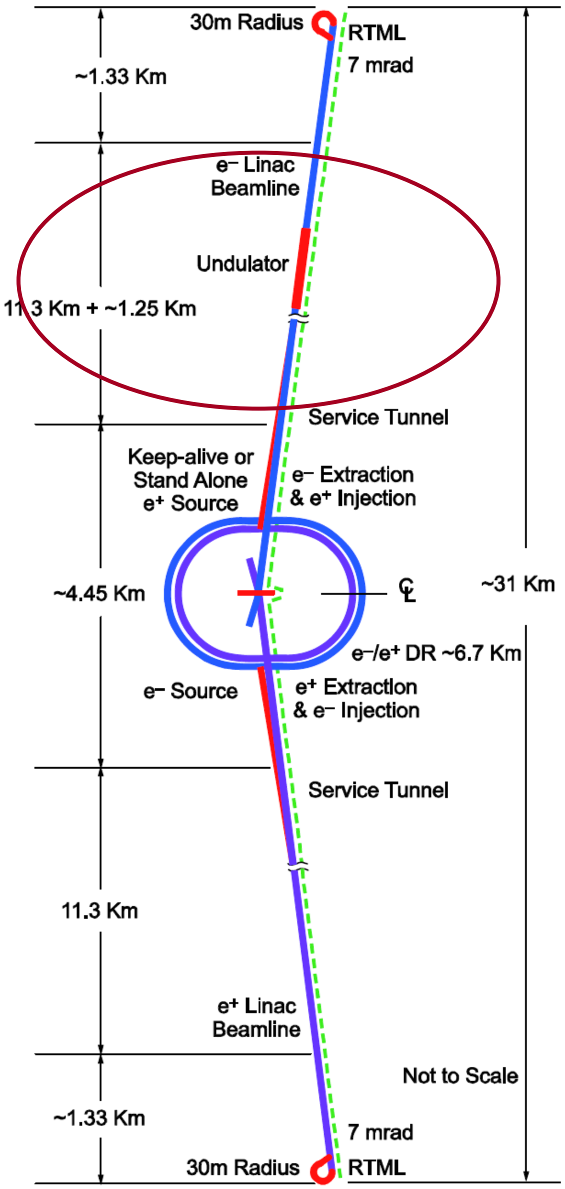
ILC RDR baseline schematic (2007 IHEP meeting)



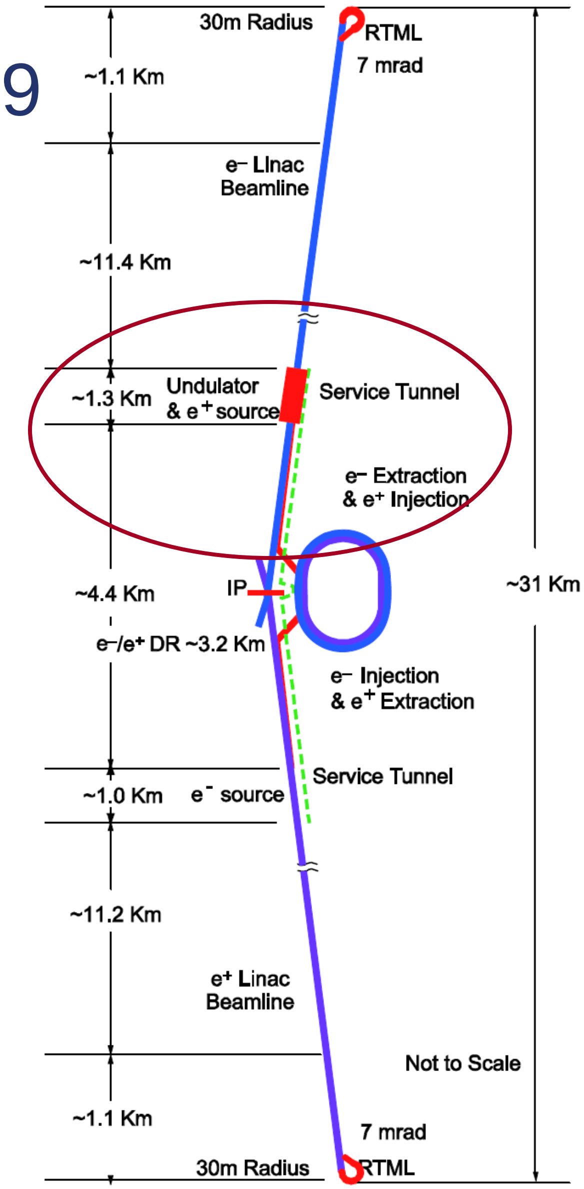
NATIONAL ACCELERATOR LABORATORY

Location of sources at the ILC

RDR
:



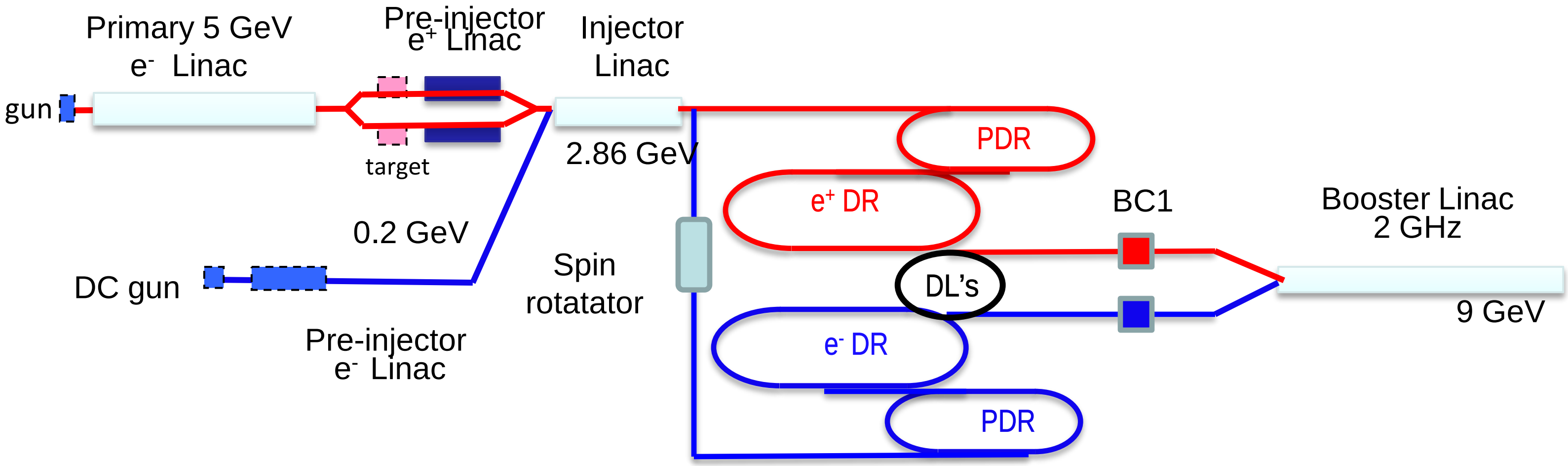
SB2009



CLIC Beam parameters

Parameter	Unit	CLIC polarized electrons	CLIC positrons	CLIC booster
E	GeV	2.86	2.86	9
N	10^9	4.3	4.3	3.75
n_b	-	312	312	312
Δt_b	ns	1	1	0.5
t_{pulse}	ns	312	312	156
$\varepsilon_{x,y}$	µm	< 100	7071, 7577	$600,10 \cdot 10^{-3}$
σ_z	mm	< 4	3.3	$44 \cdot 10^{-3}$
σ_E	%	< 1	1.63	1.7
Charge stability shot-to-shot	%	0.1	0.1	0.1
Charge stability flatness on flat top	%	0.1	0.1	0.1
f_{rep}	Hz	50	50	50
P	kW	29	29	85

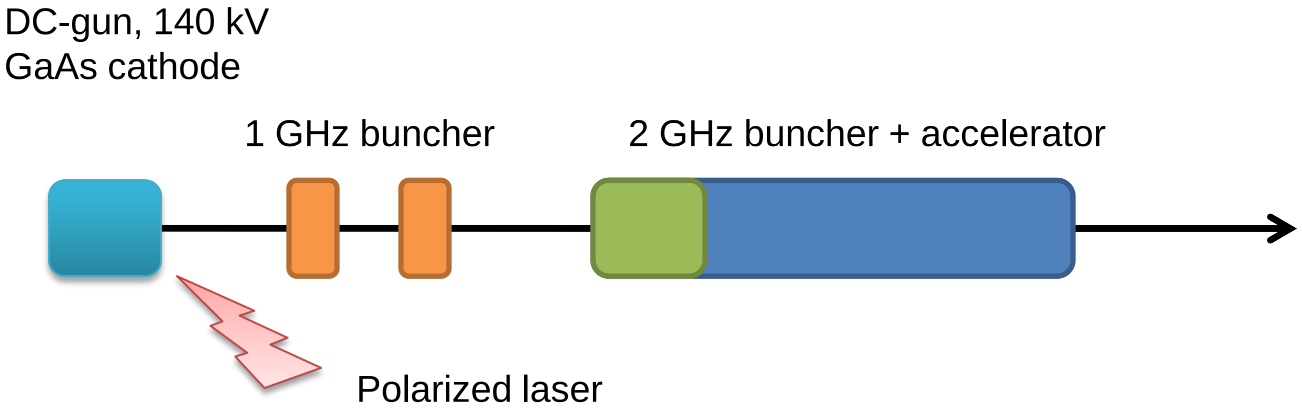
CLIC Layout



- Two hybrid positron sources (only one needed for 3 TeV)
- Common injector linac
- All linac at 2 GHz , bunch spacing 1 GHz before the damping rings

CLIC Polarized electron source

- Classical polarized source wit bunching system
- Charge production demonstrated by SLAC experiment
- Simulations showed 87 % capture efficiency (F. Zou, SLAC)

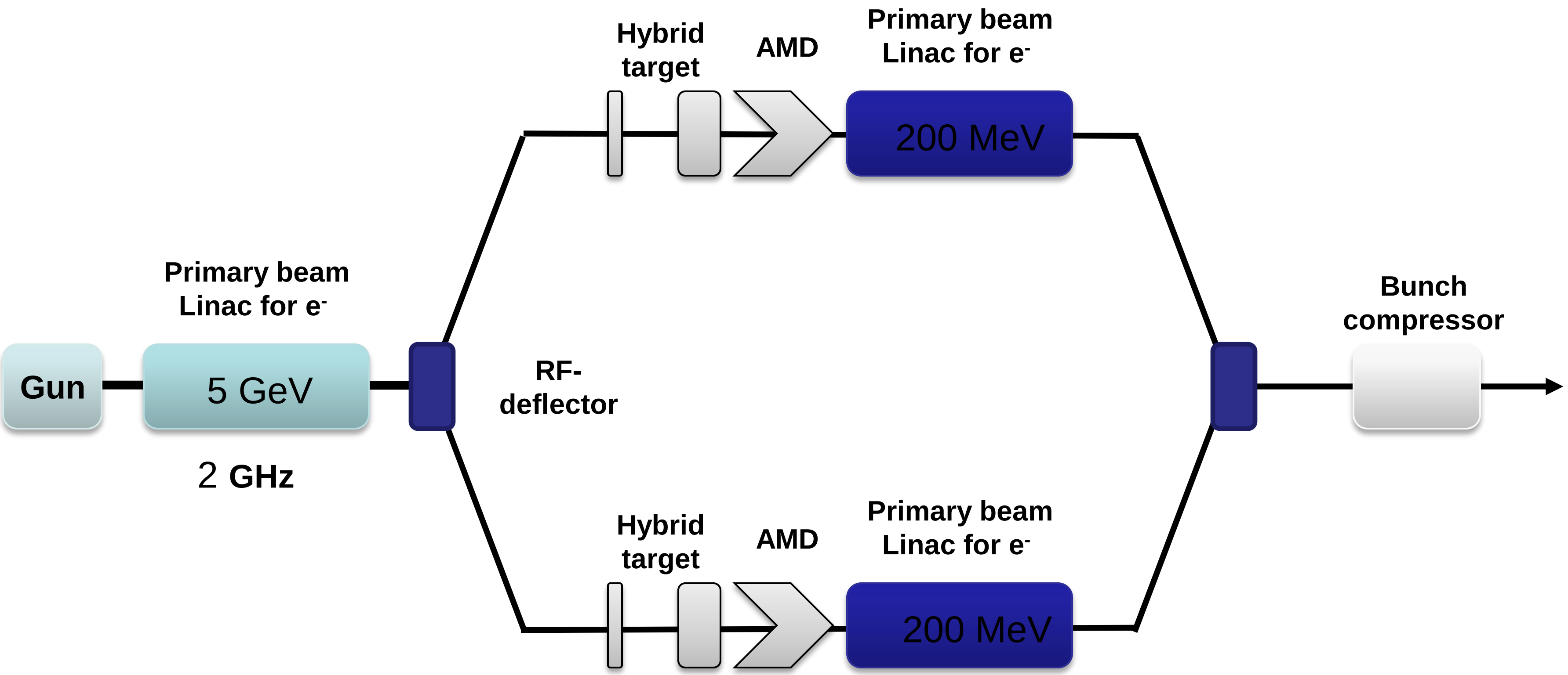

DC-gun, 140 kV
GaAs cathode

1 GHz buncher

2 GHz buncher + accelerator

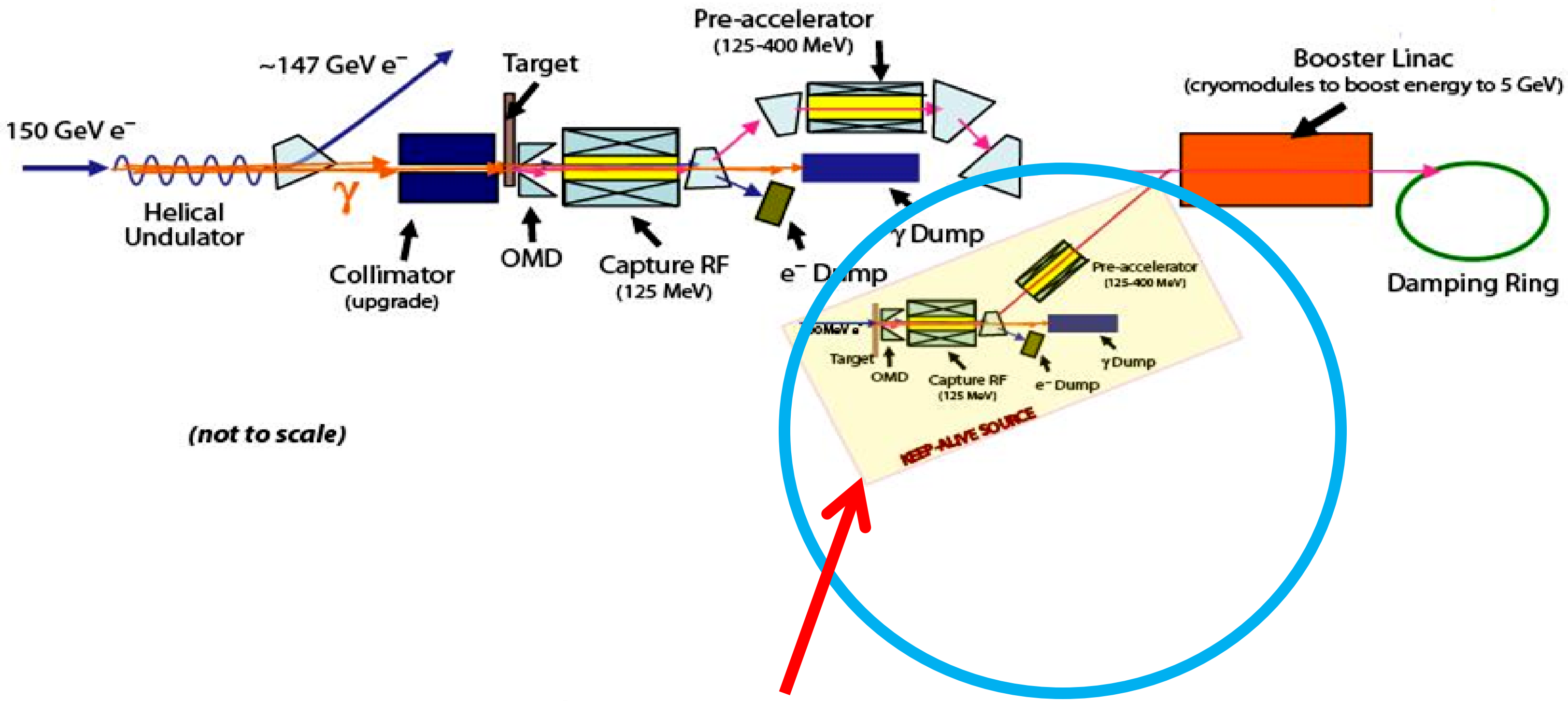
Polarized laser

Positron source conventional ?



AMD: 200 mm long, 20 mm radius, 6T field

ILC Postiron Source



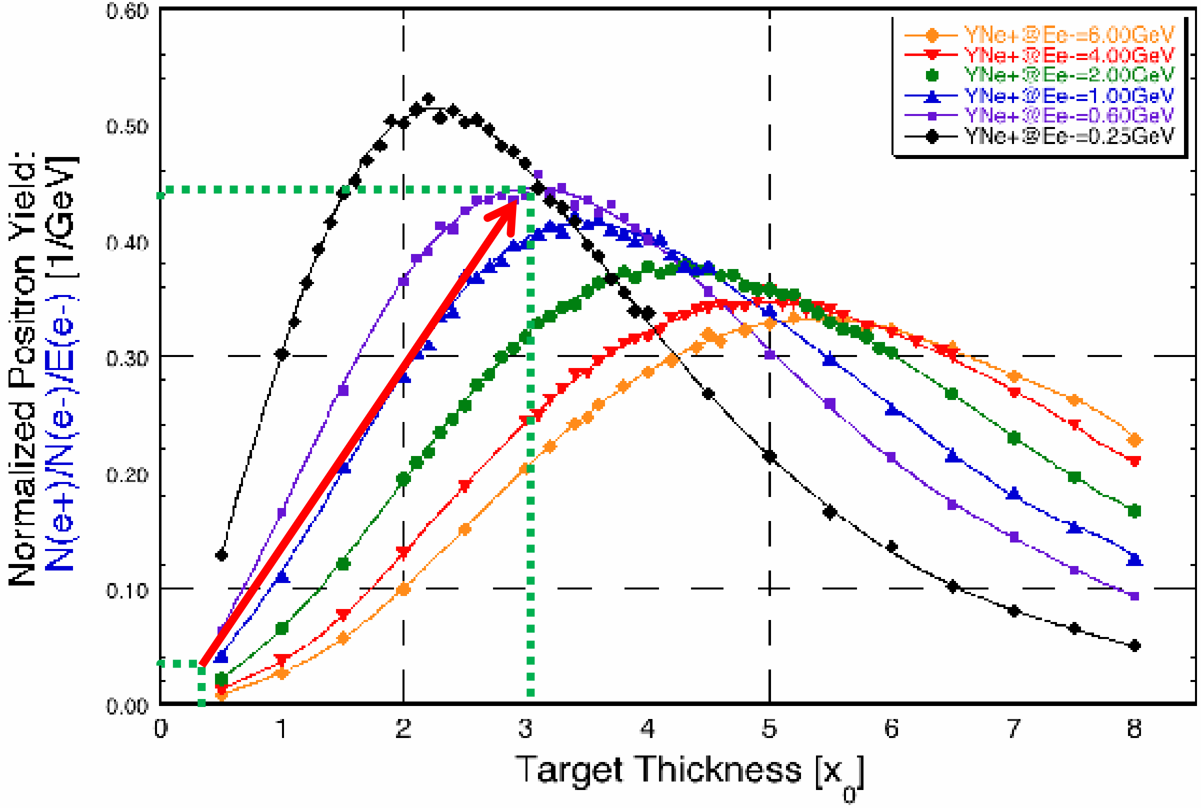
Keep Alive Source

Concept of “Auxiliary“ or “Keep Alive Source

1. RDR Keep Alive source: 10% nominal intensity.
    1. Dedicated 500MeV e- linac
    2. Dedicated e+ target (W or W-Re) and capture section.
2. SB2009 Auxiliary source: 2% intensity
    1. Dedicated 500MeV e- linac
    2. A common e+ target (Ti alloy) and capture with undulator.
    3. Placed in BDS tunnel.
3. Is SB2009 Auxiliary source useful?

KAS/APS yield

- 500 MeV driver with 0.4X$_0$ target makes ~2% intensity.
- The same driver with 3X$_0$ target makes ~20% intensity.
- 0.4X$_0$ Ti alloy and 4X$_0$ W has same thickness .


(EGSnrc simulation)

Two Scenarios

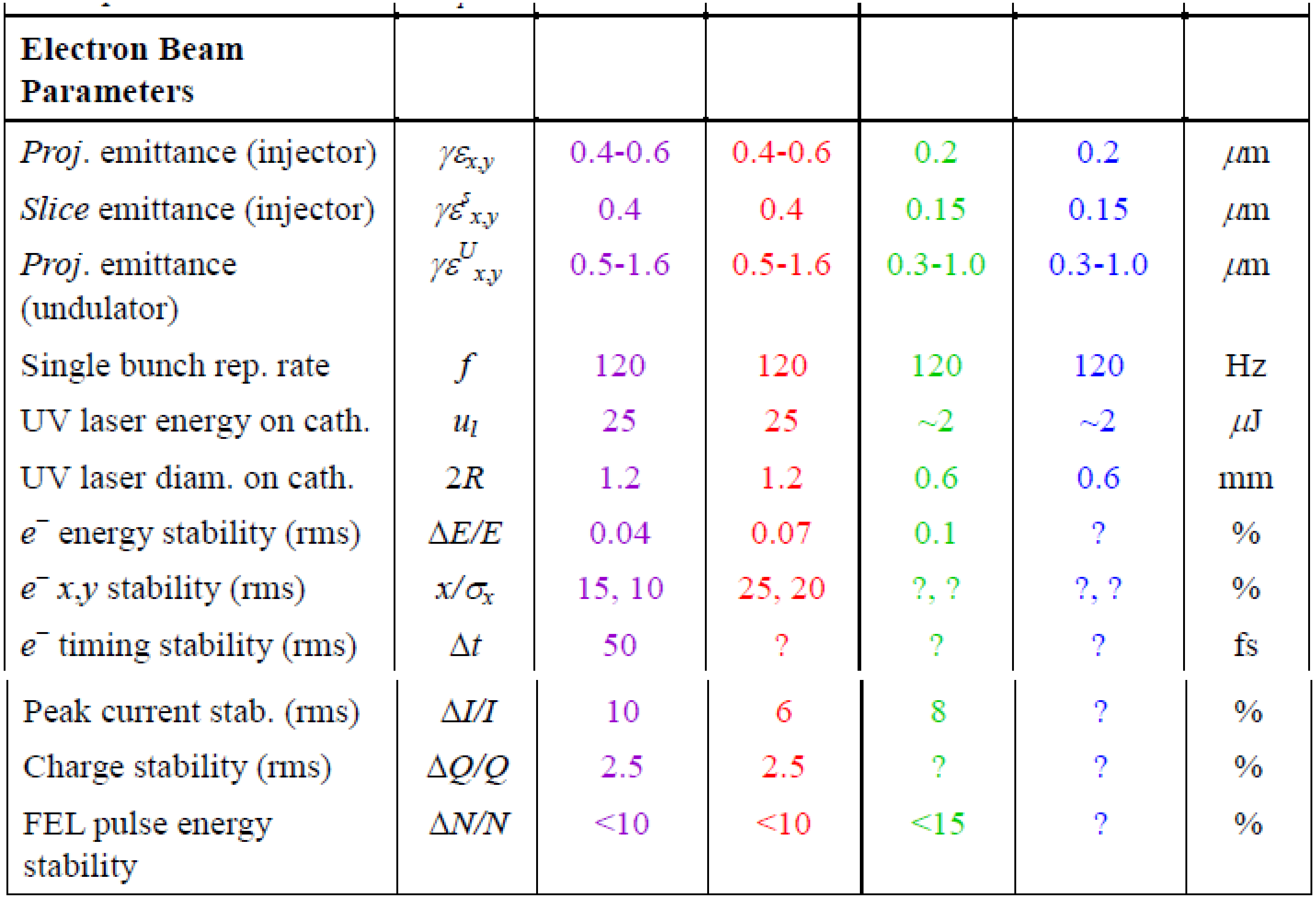
- Start up e+ source is very important in MD phase.
- In the initial phase, $3X_0$ W-Re instead of $0.4X_0$ Ti all

TARGET REPLACE

- 50 0m) can generate 20 % intensity e+ beam.
- The target can be replaced when undulator is ready for the commissioning. KAS becomes a small backup with a few % intensity.
- Could nted in a sam

MOSAIC TARGET

LCLS Parameters



Electron Beam Parameters						
Proj. emittance (injector)	$\gamma\varepsilon_{x,y}$	0.4-0.6	0.4-0.6	0.2	0.2	μm
Slice emittance (injector)	$\gamma\varepsilon^{s}_{x,y}$	0.4	0.4	0.15	0.15	μm
Proj. emittance (undulator)	$\gamma\varepsilon^{U}_{x,y}$	0.5-1.6	0.5-1.6	0.3-1.0	0.3-1.0	μm
Single bunch rep. rate	f	120	120	120	120	Hz
UV laser energy on cath.	u_l	25	25	~2	~2	μJ
UV laser diam. on cath.	$2R$	1.2	1.2	0.6	0.6	mm
e^- energy stability (rms)	$\Delta E/E$	0.04	0.07	0.1	?	%
e^- x,y stability (rms)	x/σ_x	15, 10	25, 20	?, ?	?, ?	%
e^- timing stability (rms)	Δt	50	?	?	?	fs
Peak current stab. (rms)	$\Delta I/I$	10	6	8	?	%
Charge stability (rms)	$\Delta Q/Q$	2.5	2.5	?	?	%
FEL pulse energy stability	$\Delta N/N$	<10	<10	<15	?	%

LCLS Parameters

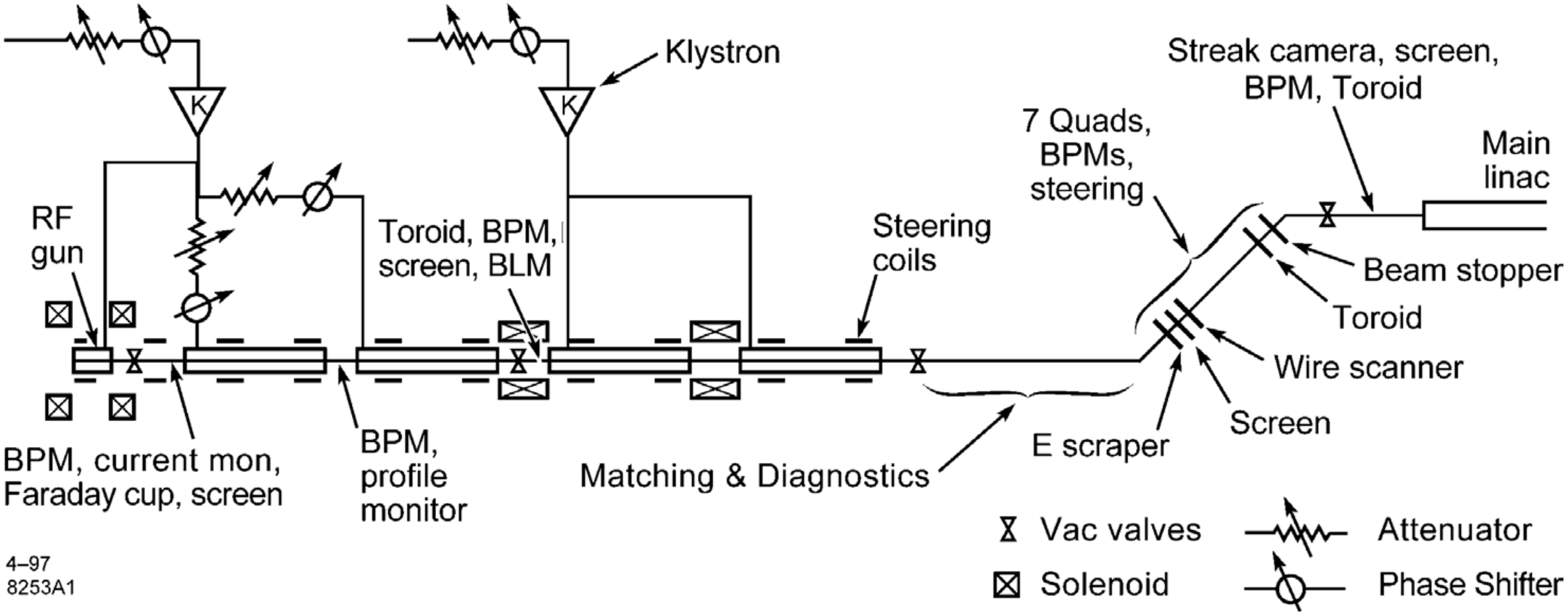


Figure 6.2-1. Overall layout of the LCLS photoinjector showing the rf gun, Linac 0, and the low energy dog leg, with drift sections and diagnostics included

LCLS Parameters

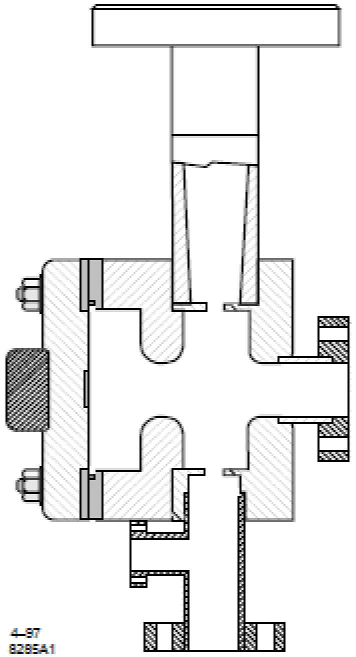


Figure 6.1-1. Cross section of rf gun. The rf coupler is the top coupler shown here. The bottom port is for the adjustable short and vacuum pump. The electron beam exits to the right.

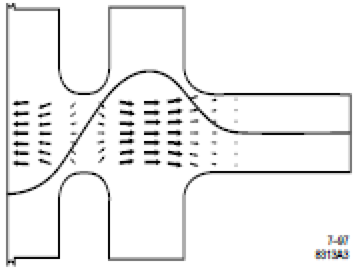


Figure 6.1-2. π-mode field lines for the rf gun obtained with SUPERFISH.

RF Gun delivers 100pC-1 nC, 2 ps long bunches at 6.2 MeV with gradients of ~150MeV on the walls

Basic Source

Space Charge

Emittance

Polarization

Basic Electron Source

Basic Positron Source

Similarities and Differences

Basic Source: Space Charge

$$\frac{d}{dt}\gamma m\vec{v} = q(\vec{E} + \vec{v} \times \vec{B})$$

Radial space charge force goes to zero as v➔c

$$E_r = \frac{Q}{2\pi\varepsilon_o \Delta}\frac{1}{r} \qquad \left(\vec{v} \times \vec{B}\right)_r = -\frac{Q}{2\pi\varepsilon_o \Delta}\frac{1}{r}\frac{v^2}{c^2}$$

$$q(\vec{E} + \vec{v} \times \vec{B})_r \to 0 \; as \; v \to c$$

Line charge density ρ_l = Q/Δ C/m

Basic Source: Space Charge

$$\frac{d}{dt}\gamma m\vec{v} = q(\vec{E} + \vec{v} \times \vec{B})$$

Longitudinal space charge force goes to zero as $\gamma \rightarrow \infty$

$$\ddot{z} = \frac{E_z}{\gamma m} = \frac{qQ}{4\pi\gamma m\varepsilon_o r_o \Delta} = \left(\gamma^2 - 1\right)^{-\frac{1}{2}} \frac{qQ}{4\pi m c\varepsilon_o r_o \Delta_t}$$

$$\ddot{z} \rightarrow 0 \ as \ \gamma \rightarrow \infty, \Delta = \beta c \Delta_t$$

Line charge density $\rho_l = Q/\Delta$ C/m and beam radius r_o

Basic Source: Space Charge

Lesson here: Higher voltage (γ) is better since space charge forces are smaller.

SLC Gun Voltage was 120 kV

NLC and ILC have specified 200 kV

CLIC specifies 140 kV

LCLS operates at 6.2 MV

Question: High voltage seems to be a winner; is high gradient also a good idea? Structures tend to breakdown from gradient rather than voltage.

Why not talk about space charge for the positron production?

Basic Source Emittance and Admittance

Emittance is used to describe the beam. There are several commonly used definitions with and without π. For Colliders, normalized rms emittance is standard. Units are m-rad.

$$\gamma\varepsilon = \gamma\left(\left\langle x^2\right\rangle\left\langle x'^2\right\rangle - \left\langle xx'\right\rangle^2\right)$$

$$\gamma\varepsilon = \gamma\left(\sigma_x^2\sigma_{x'}^2 - \sigma_{xx'}^2\right)$$

Basic Source Emittance and Admittance

How big is the emittances at the cathodes and targets?

$$\sigma_r \approx 5mm\ at\ photocathode$$

$$\sigma_r \approx 2.5mm\ at\ t\mathrm{arg}et\ exit\ face$$

$$\sigma_r' \approx 1mrad\ at\ cathode$$

$$\sigma_r' \approx 1rad\ at\ t\mathrm{arg}et\ exit\ face$$

$$\gamma \approx 1\ at\ cathode$$

$$\gamma \approx 20\ at\ t\mathrm{arg}et\ exit\ face$$

$\gamma\varepsilon_{e-} = 5e{-}6$ m at cathode, 1ns long and $\gamma\varepsilon_{e+} = 5e{-}2$ m at target, 1ps long

Basic Source Emittance and Admittance

$\gamma\varepsilon_{e-} = 5e{-}6$ m at cathode, 1ns long and $\gamma\varepsilon_{e+} = 5e{-}2$ m at target, 1ps long

Small cathode emittances get diluted in bunching and capture process (rf focusing). Large e+ emittances drive design of entire positron system

Basic Source Emittance and Admittance

Longitudinal emittance is not conserved in Bunching or in the Damping Rings. **σ_E** is typically quoted as **σ_E**/E in %. The normalization by γ is sporadic and maybe not too useful.

$$\gamma\varepsilon_z = \gamma\sigma_z\sigma_E$$

Basic Source Emittance and Admittance

Admittance (acceptance) is a property of the lattice and aperture. Is used in comparison with the beam emittance. Aperture and beam stay clear definitions are similar but less general. A has the units of m-rad.

Require $A>\varepsilon$ for transmission, acceptance, capture…..

$$A = a^2/\beta$$

a= beam pipe half aperture

Basic Source Emittance and Admittance

Electron Source Emittances for ILC and CLIC are ~100e-6 m

Electron Source Emittance for the LCLS is ~0.5e-6 m

Positron Source Emittances for ILC and CLIC are ~ 0.05 m

Damping Ring Admittances for ILC and CLIC are ~0.09

Damping Ring Acceptances are set by the dynamic aperture; are driven by the positron beam emittance

Damping Ring Energy Acceptance are ~1%; bunchlength is not really issue due to the low frequency rf in the rings compared to the linacs (sort of)

LCLS is limited by the longitudinal emittance (on a good day)

Basic Source Polarization, incl errors

ILC and CLIC both require electron polarization. The ILC positron beam can be polarized. CLIC does not specify positron polarization

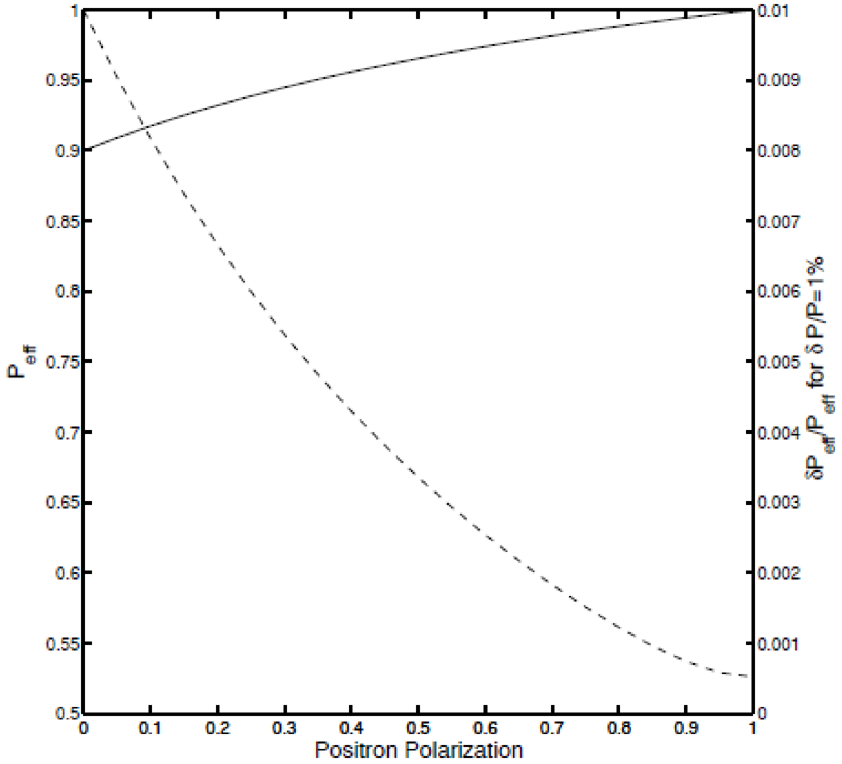
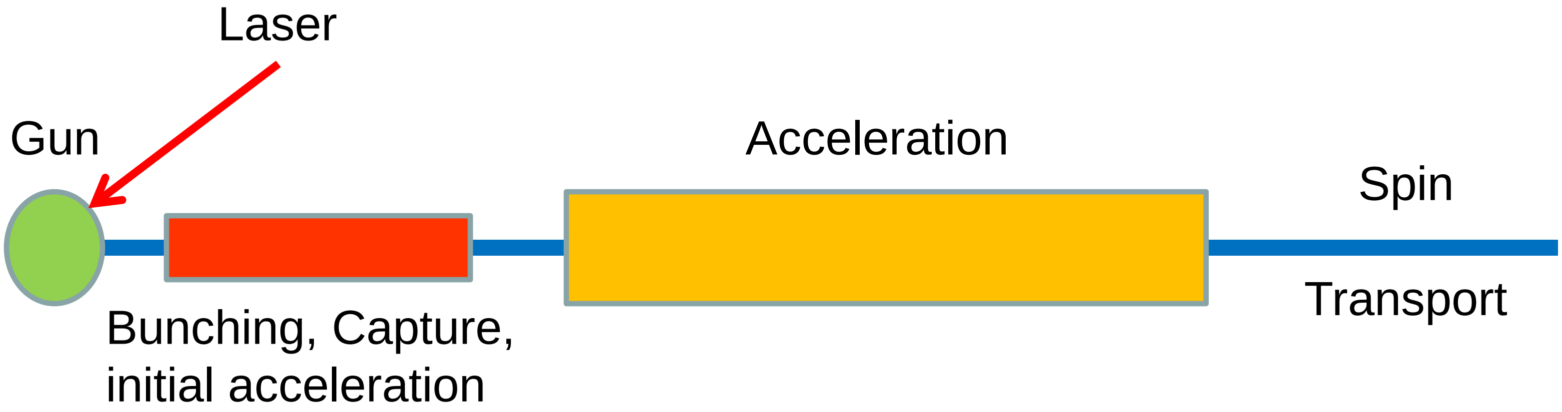


Figure 3: Solid curve: the effective polarization (1) at a Linear Collider as a function of positron polarization, assuming an electron polarization of 90%. Dashed curve: the relative error in the effective polarization. From [11].

Basic Electron Source



Laser

Gun

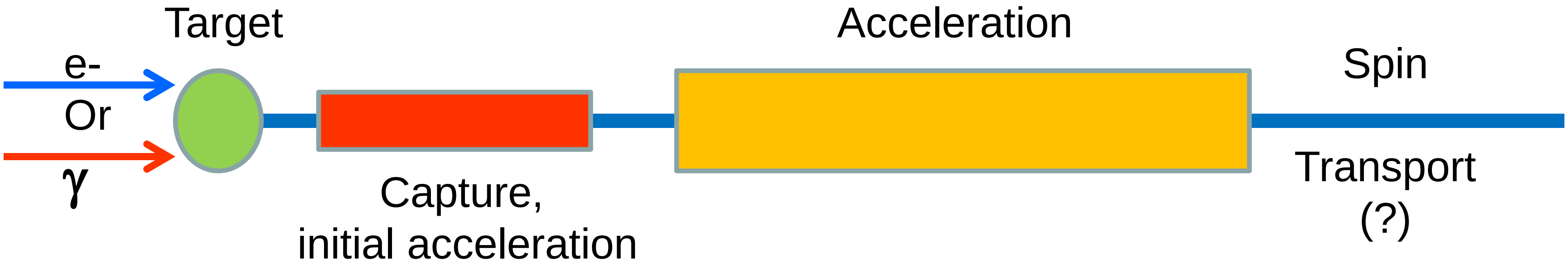
Acceleration

Spin

Transport

Bunching, Capture,
initial acceleration

Basic Positron Source



Basic Source: Compare and Contrast

Electron Source	Positron Source
Polarization/cathode	Target Viability
Bunch Structure/Laser	Transverse Capture
Longitudinal Capture	Energy Compression
	Damping Ring Acceptance

Accelerator component design is driven by large e+ emittance; e- systems general follow alnog with the exception of the cathodes and lasers

Electron Sources

Electron Sources: Cathodes

Require Spin polarized electrons

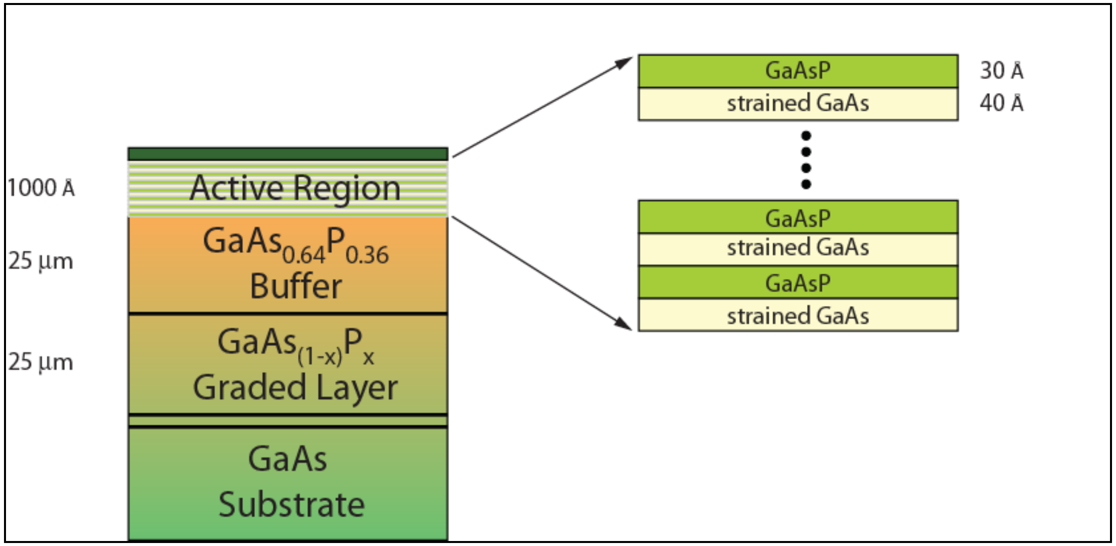
Use GaAs-type NEA cathodes

λ in range of 790 nm➔ Ti:Al_2O_3 lasers

QE in range of 0.5%

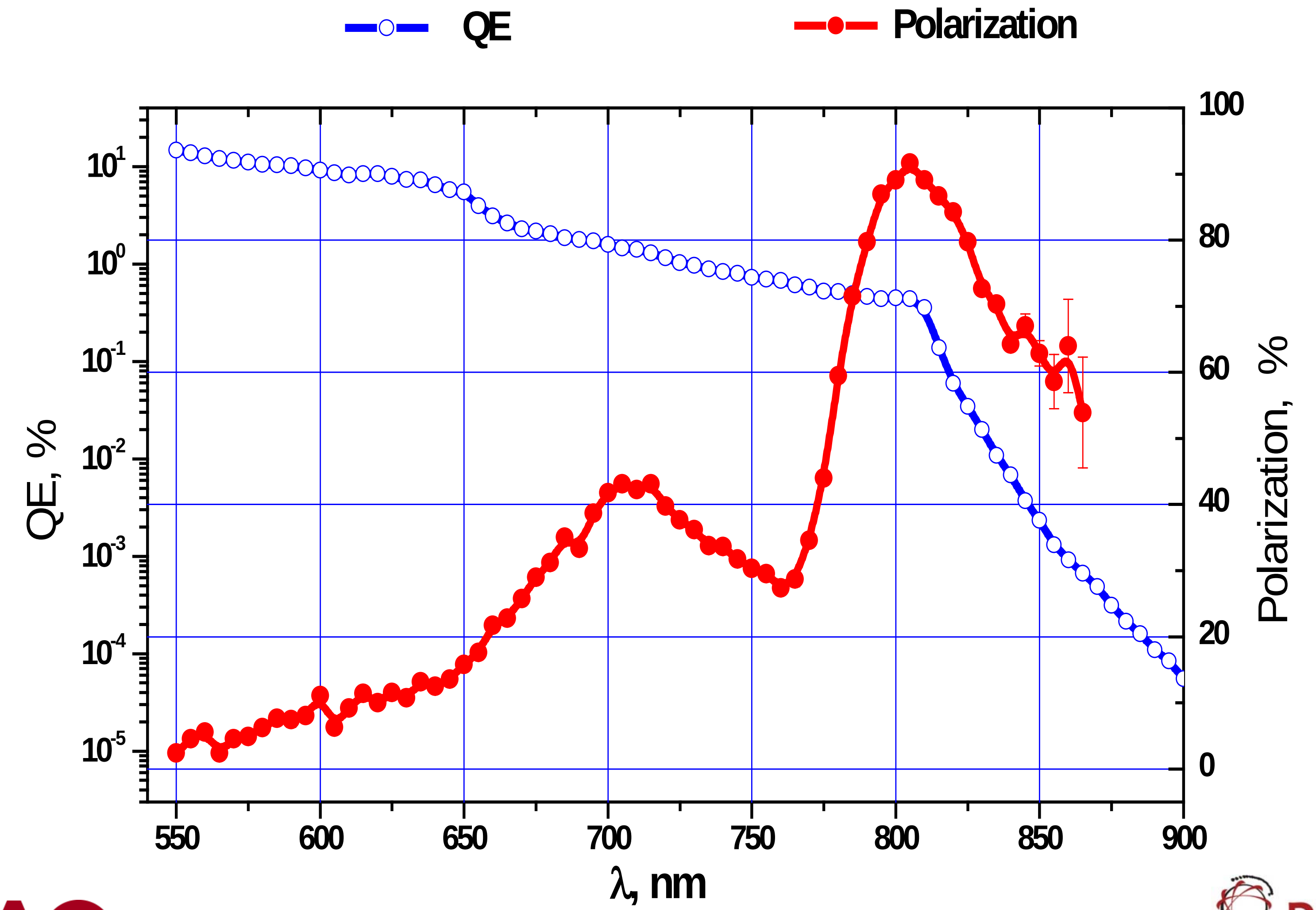
Electron Beams, Cathode Status (RDR)

Baseline design: strained layer superlattice GaAs/GaAsP
Polarization ~ 85 - 90 % ,QE 1% maximum, 0.3-0.5% routinely



High gradient p-doping increases QE and reduces surface charge limit:
5×10^{19} cm^{-3} → 5×10^{17} cm^{-3}

Electron Sources: QE and Polarization



Electron Sources: Cathodes: QE

QE = Quantum Efficiency

= $N_e/N_{h\nu}$

= number of electrons/number of incident photons

QE is a function of wavelength. Is in the range of 0.1%-1% for typical cathodes

Electron Sources: Cathodes: QE

How Much Laser Power (peak and average) was required for the SLC polarized electron source?

$n = 5e10$, $N = 2$, $f = 120$ Hz, $\Delta t = 2$ ns, $R = 0.5$, $QE = 5e\text{-}3$, $\lambda = 790$ nm

$N_{photon} = n/(QE*(1-R)) = 2e13$ per bunch

$\Delta U_{bunch} = 1.24$ eV-micron$/\lambda * N_{photon} = 5\ \mu J$

Peak Power $= \Delta U_{bunch} / \Delta t = 2.5$ kW

Average Power $= \Delta U_{bunch} = 1.2$ mW

Electron Sources: Lasers

Lasers need to produce pulses in the ns-micronsecond range at ~100 Hz (similar problems with Compton polarimeter laser systems

Mode locked systems like to run in the 100 MHz range with 10’s fs pulse width.

Need Pulse Stretching and amplification, all good fun

No COTS systems available

Electron Sources: Lasers

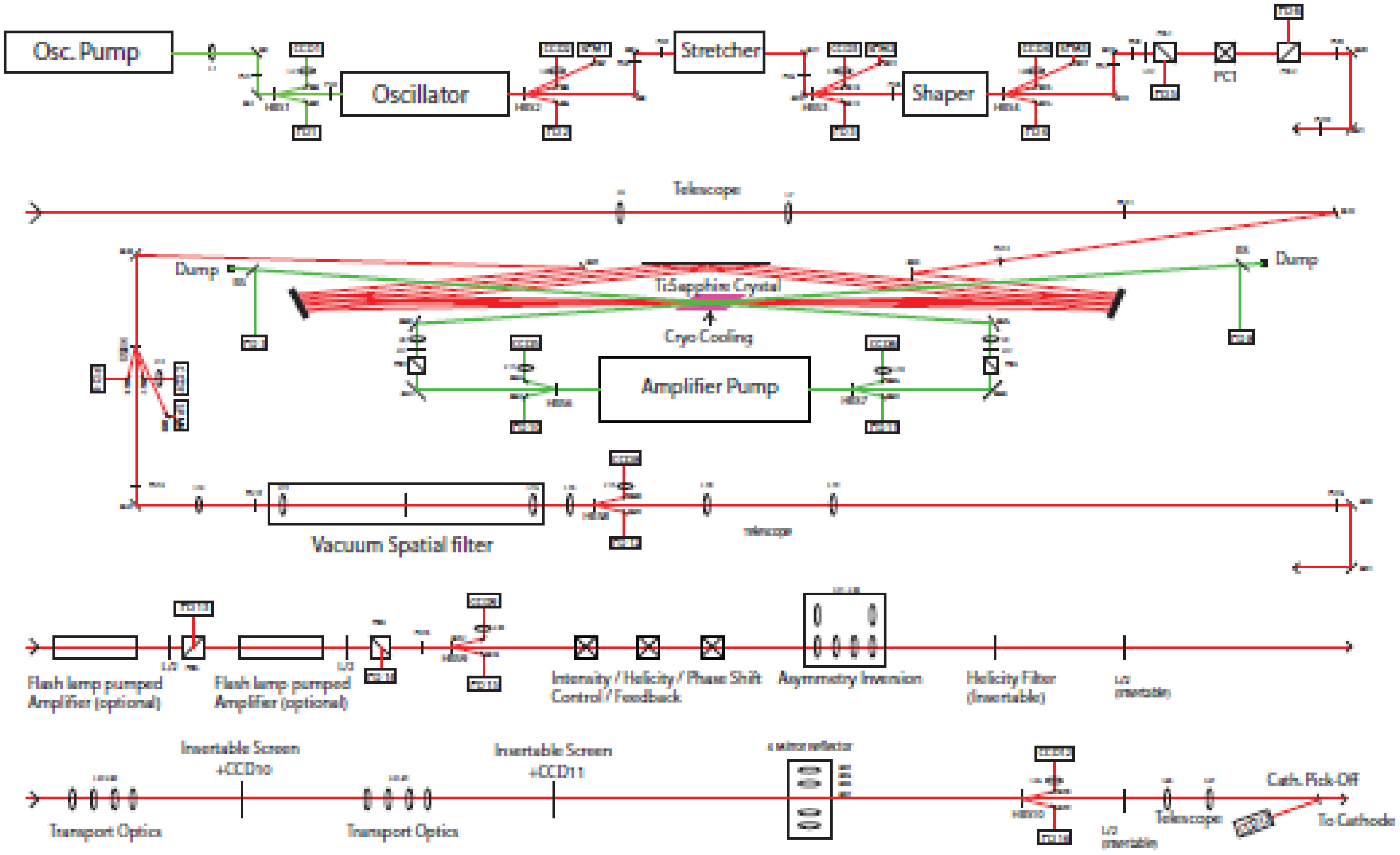
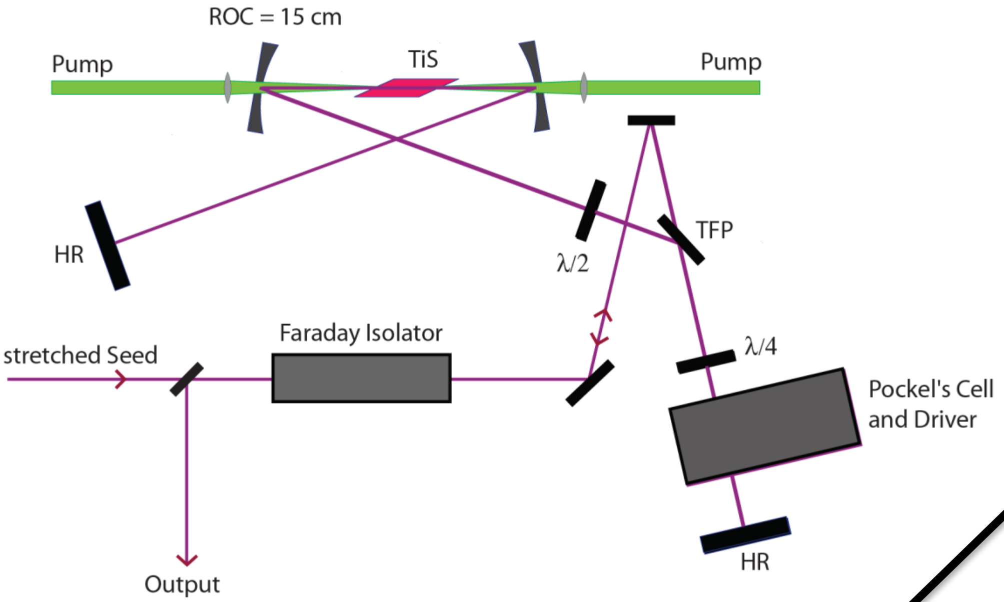
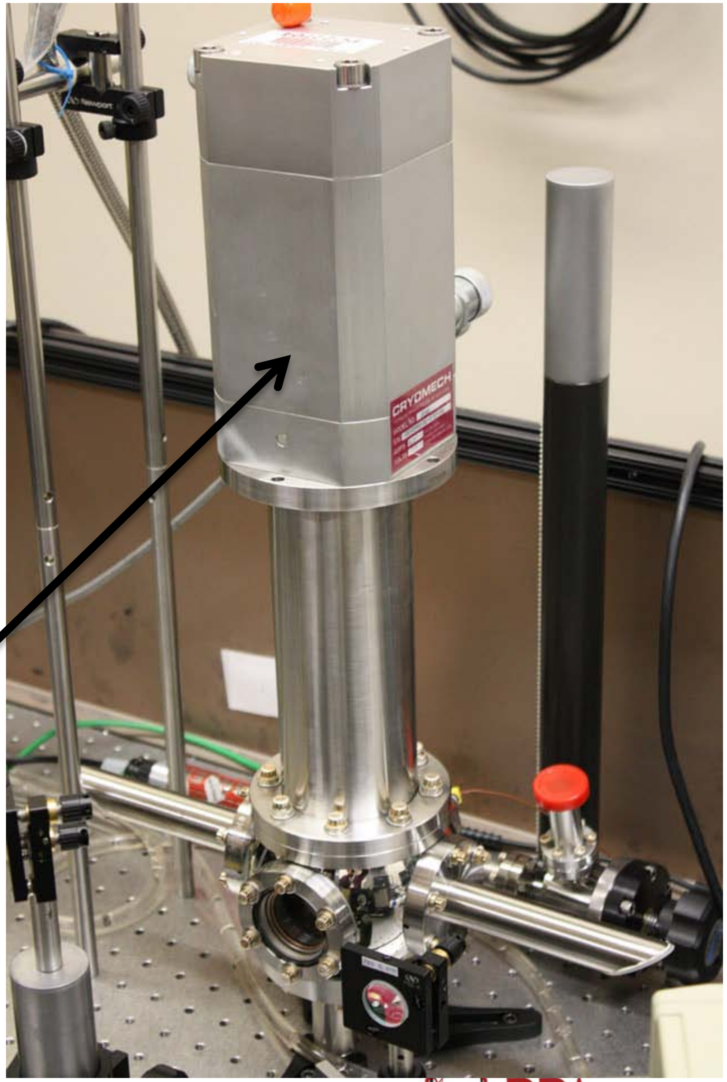


FIGURE 2.2-3. Schematic view of source drive laser system.

ILC Electron Beams, Laser Development

3 MHz Regen Amp





Cryocooled $Ti:Al_2O_3$ gain cell

CLIC Laser Requirements

There are two approaches to the CLIC laser: develop a 2 GHz optical pulse train, chopped and amplified to the proper pulse length and bunch energy or develop a 156 ns cw optical pulse and use an rf system to do all of the electron bunching. The former approach will possibly ease the requirements on the rf bunching system but will not eliminate the need for rf bunching. The CLIC injector linac rf system will run at 2 GHz. This in combination with the damping ring eliminates the concerns of interbunch satellites being generated with the use of a cw optical pulse.

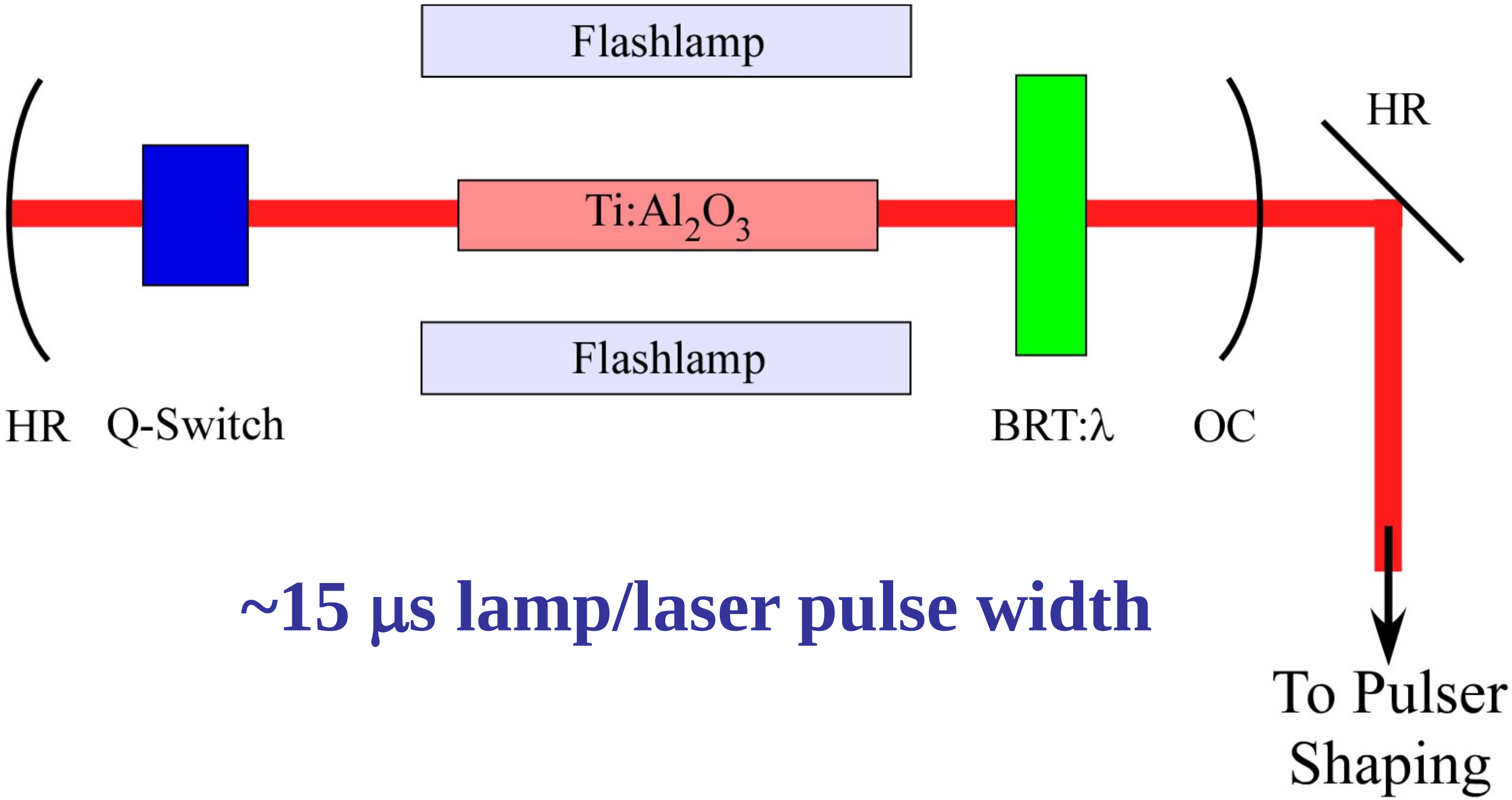
CLIC Electron Beam Demo

Parameter	Symbol	Value	Units	Comments
Electrons per bunch	n_b	6×10^9	#	CLIC spec.
Bunches per pulse	N_b	312	#	CLIC spec.
Pulse length	T_P	156	ns	CLIC spec.
Repetition rate	f_{rep}	50	#	CLIC spec.
Photon energy	$h\nu$	1.6	eV	775 nm
Quantum Efficiency	QE	0.25	%	Optimistic(?)
Capture efficiency	ξ_{rf}	70	%	E158 experience
Overhead factor	f	2	#	Arbitrary

Optical Pulse energy	E_P	548	μJ	
Optical Peak Power	P_P	3.5	kW	
Optical Average Power	P_{avg}	27	mW	

CLIC Electron Beam Demo: Laser

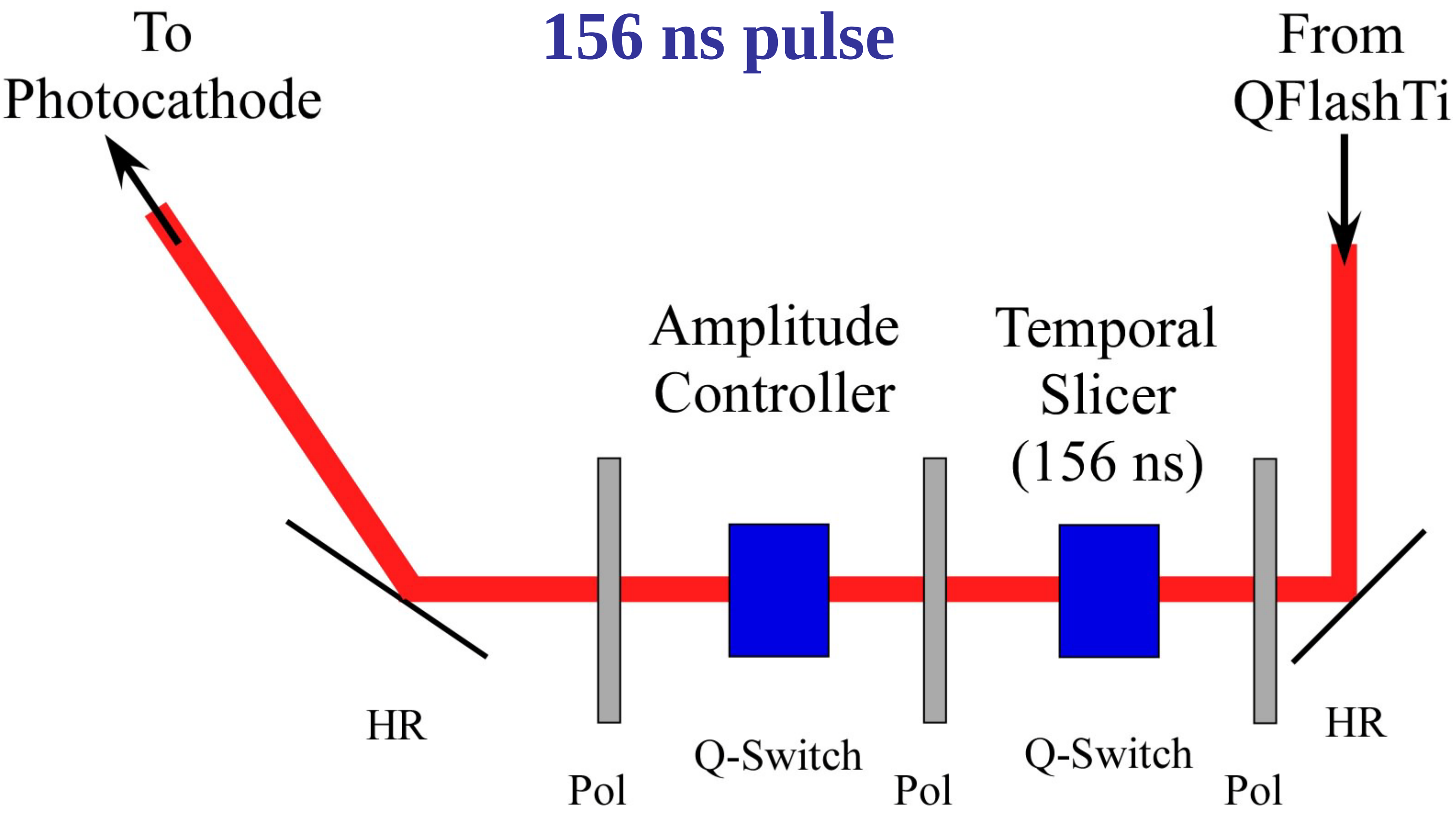
Flash lamped pumped Ti:sapphire laser

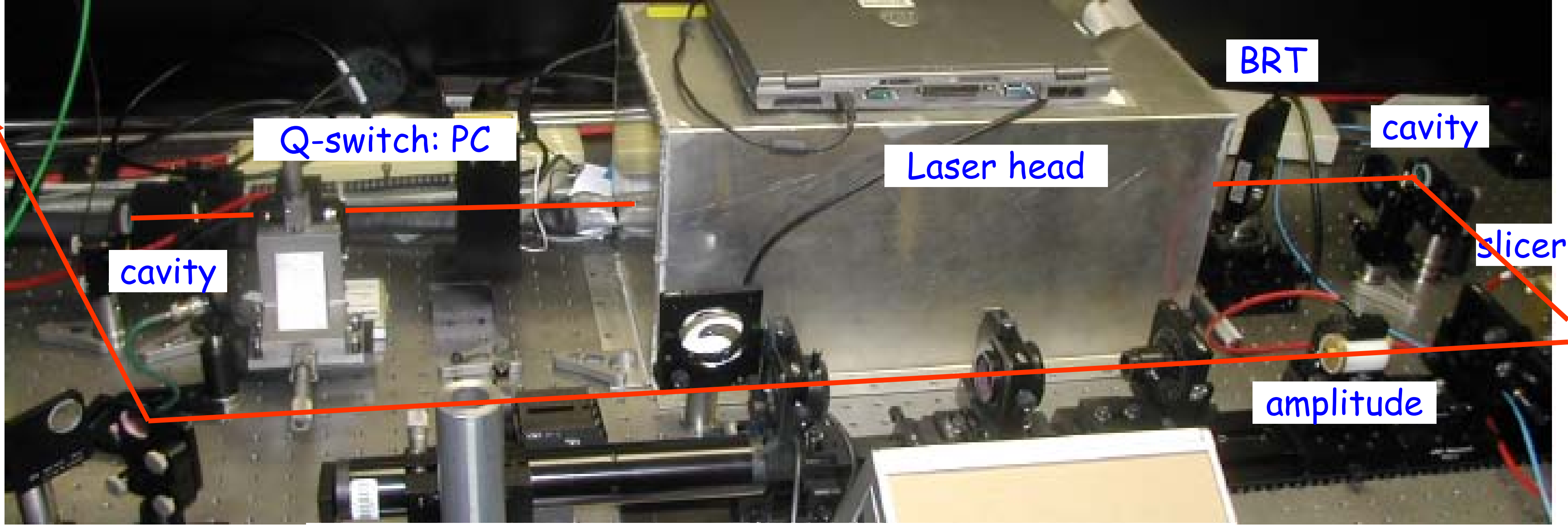


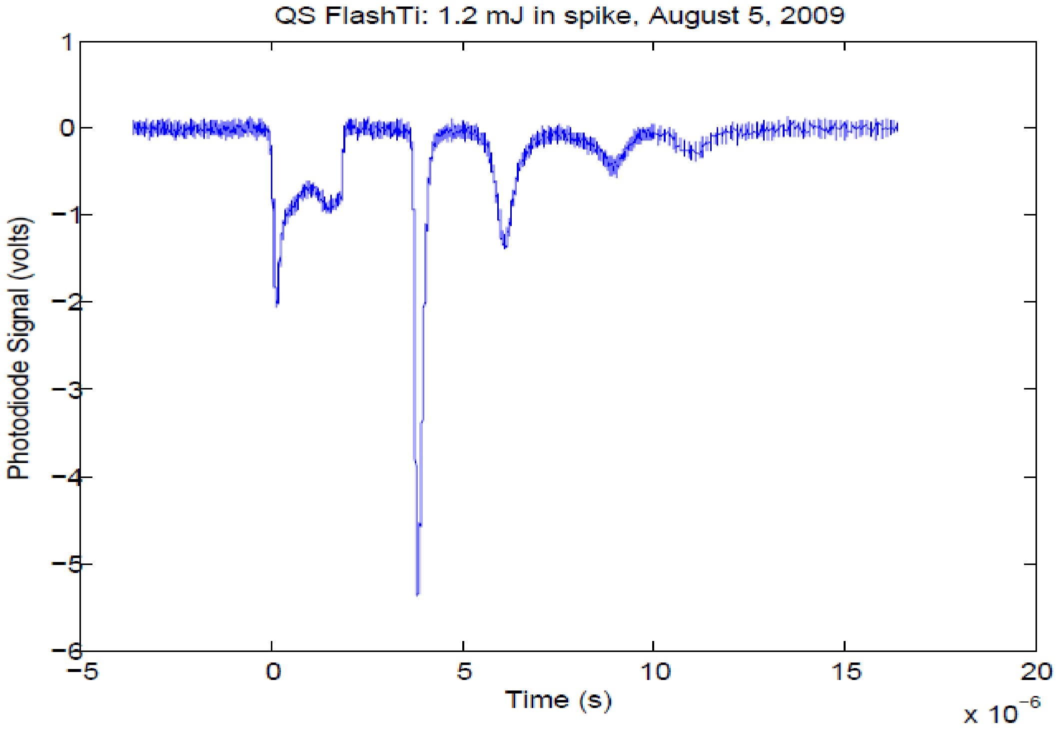
~15 μs lamp/laser pulse width

CLIC Electron Beam Demo: Laser

Pulse Slicing and Amplitude Control

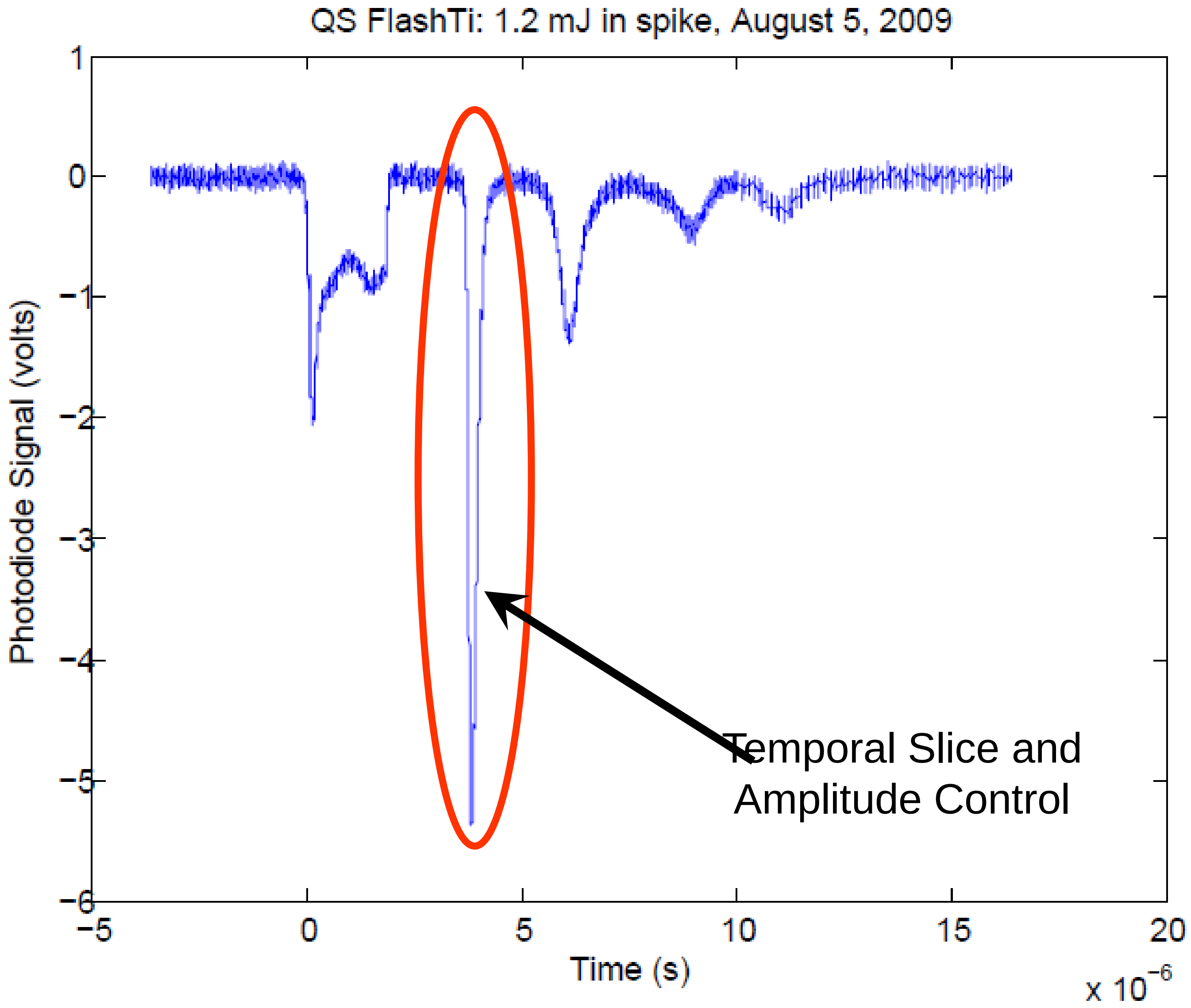





QS FlashTi: 1.2 mJ in spike, August 5, 2009

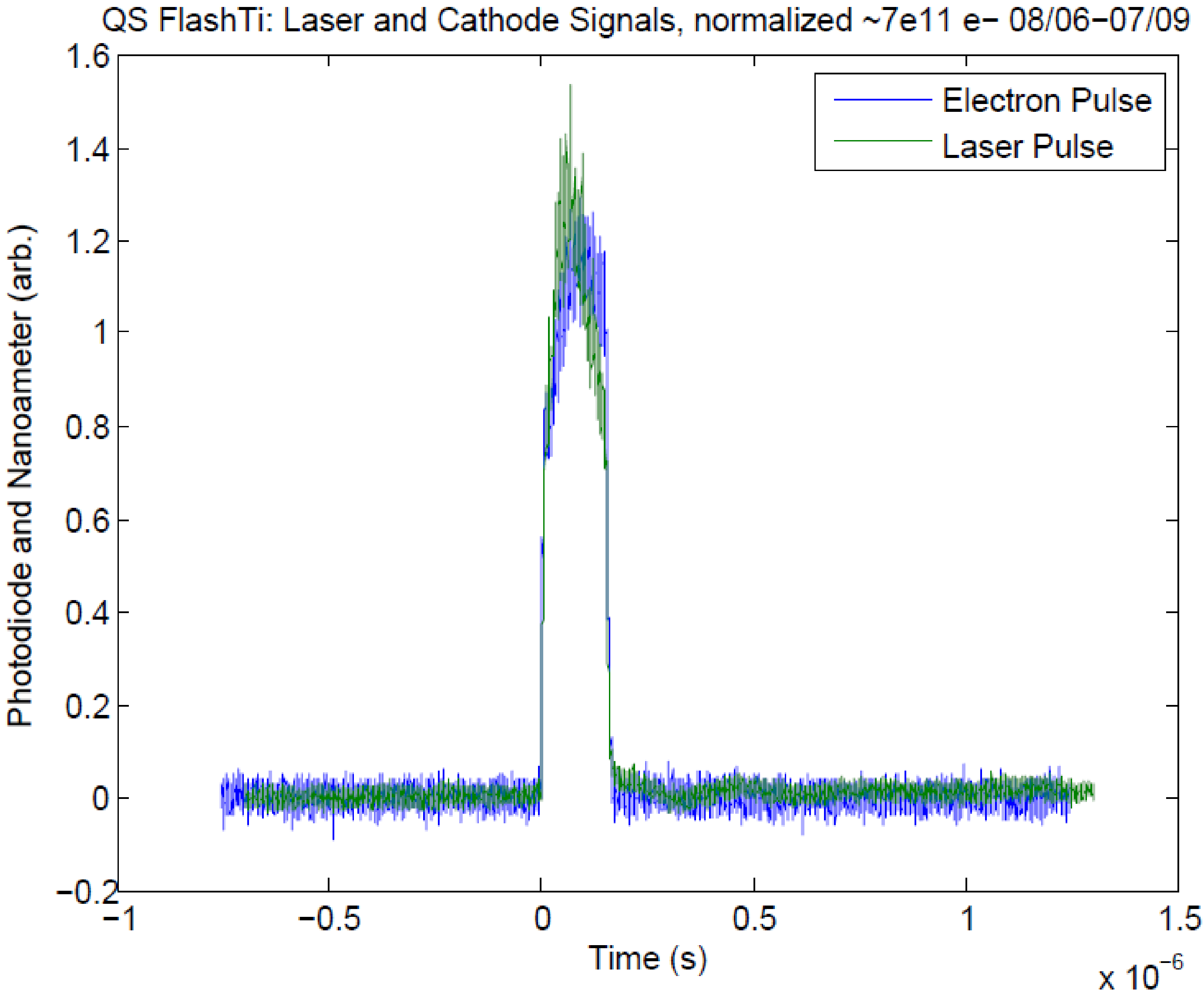
With Brachmann and Sheppard

CLIC Electron Beam Demo: Laser

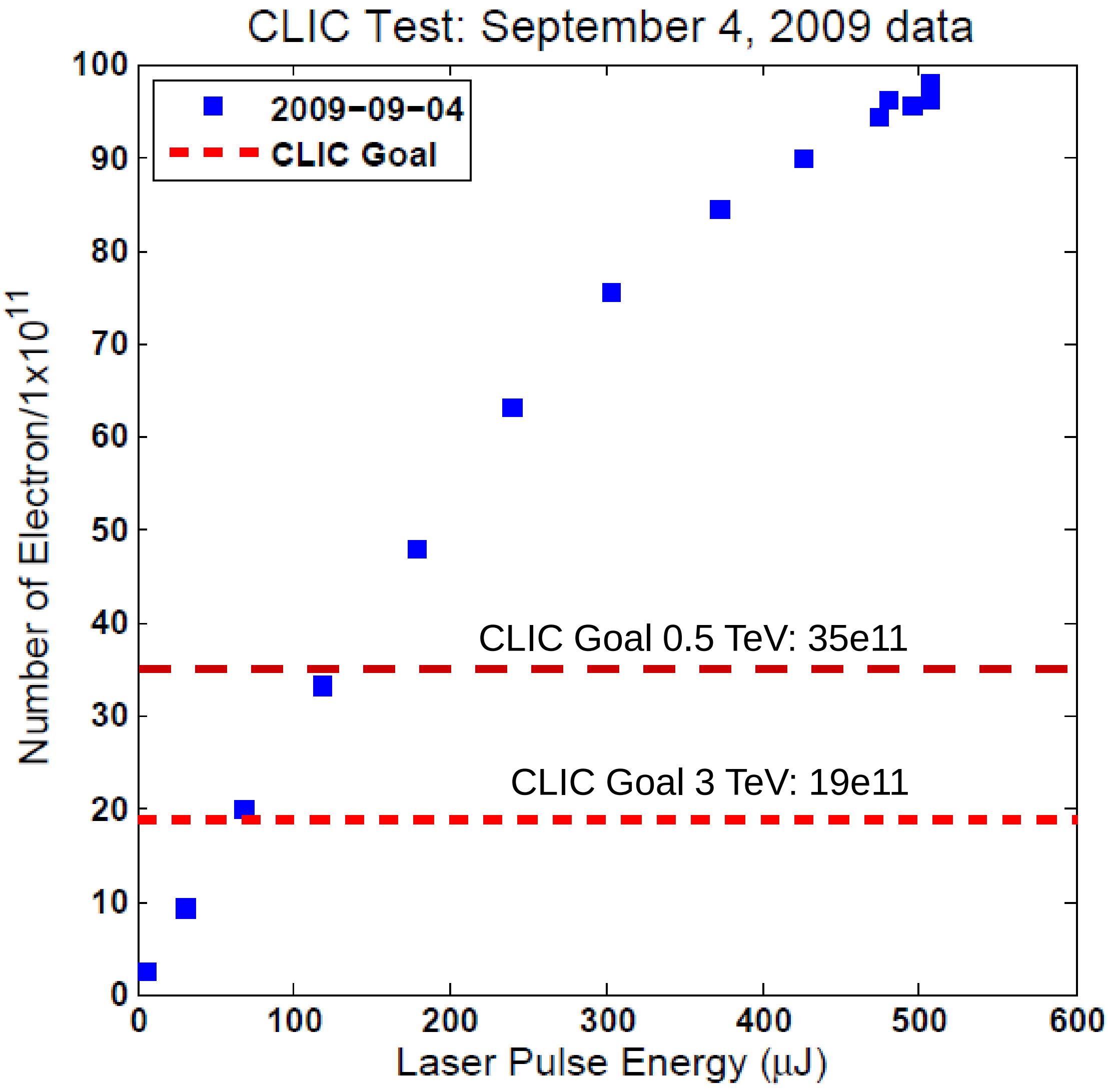


Temporal Slice and Amplitude Control

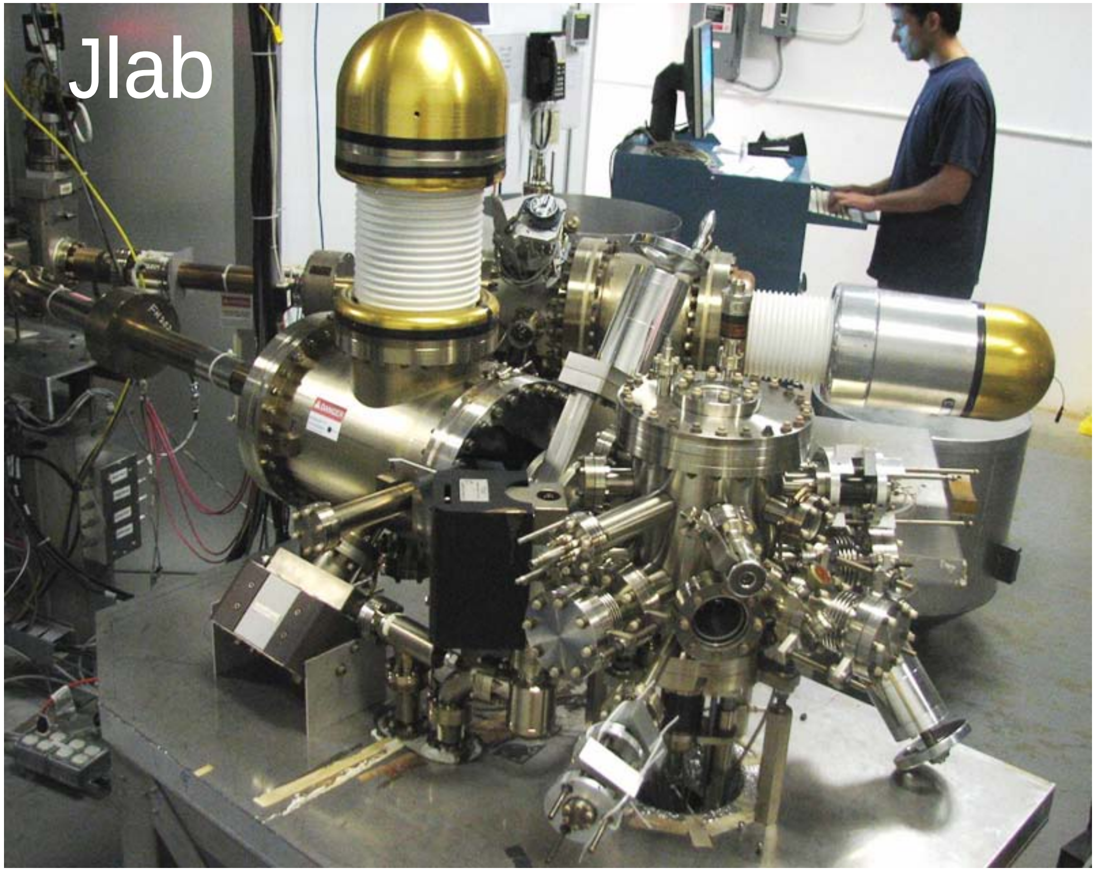
CLIC Electron Beam Demo: Electron Beam



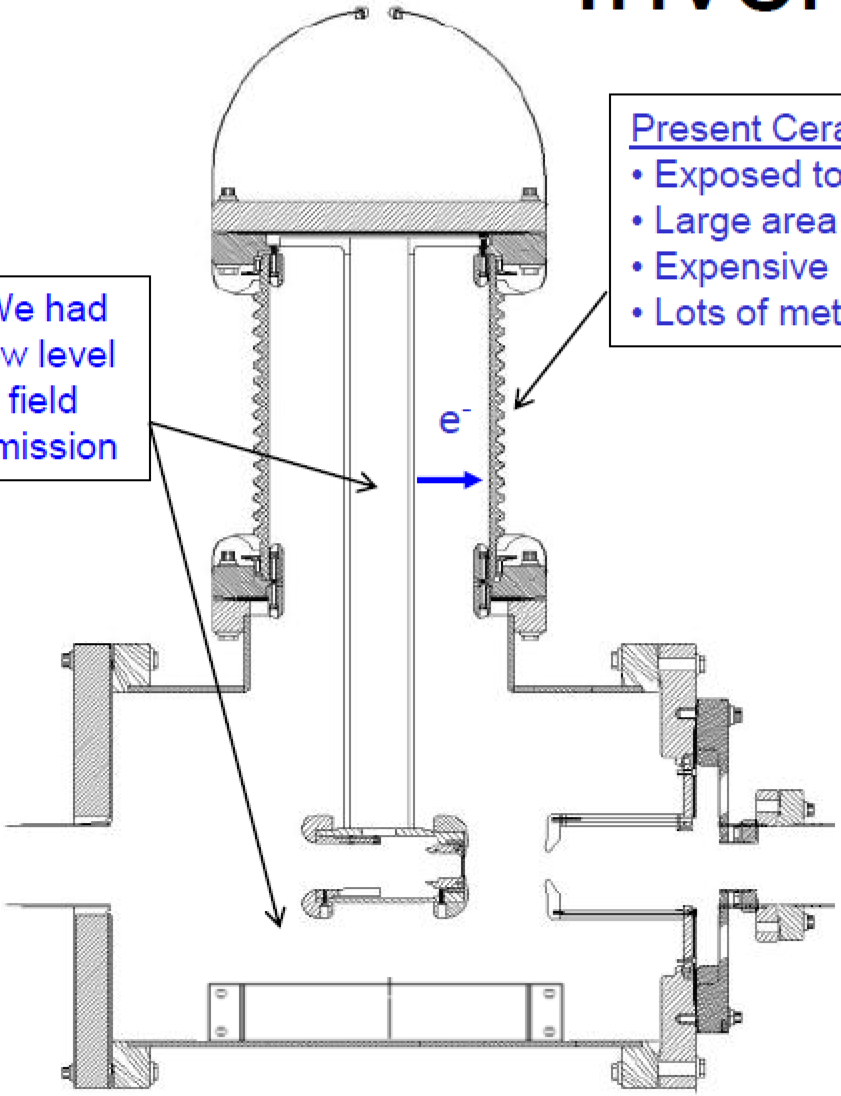
CLIC Electron Beam Demo: Electron Beam



Jefferson Lab Polarized Electron Gun 200 kV (in development)



“Inverted” Gun

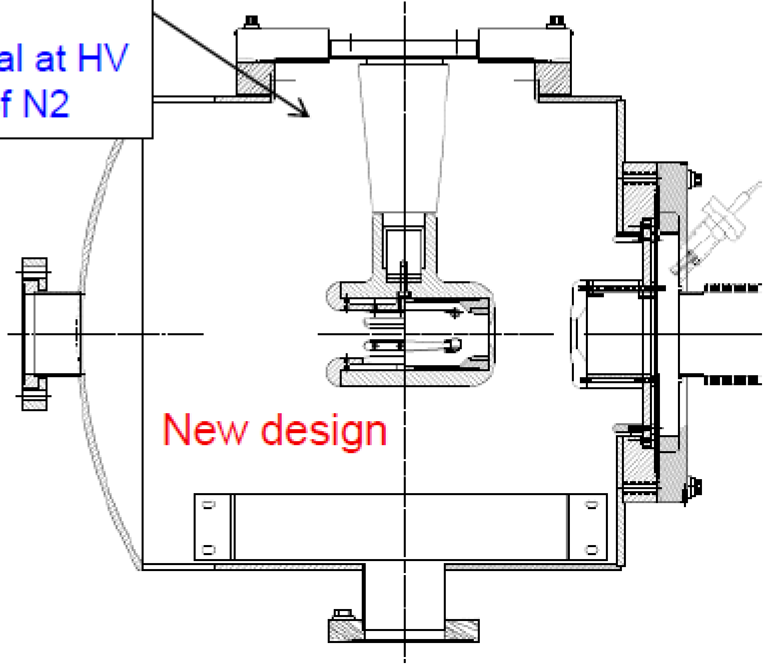


We had low level field emission

Present Ceramic
- Exposed to field emission
- Large area
- Expensive (~$50k)
- Lots of metal at HV

Medical x-ray technology

New Ceramic
- Compact
- ~$5k
- Less metal at HV
- No SF6 of N2

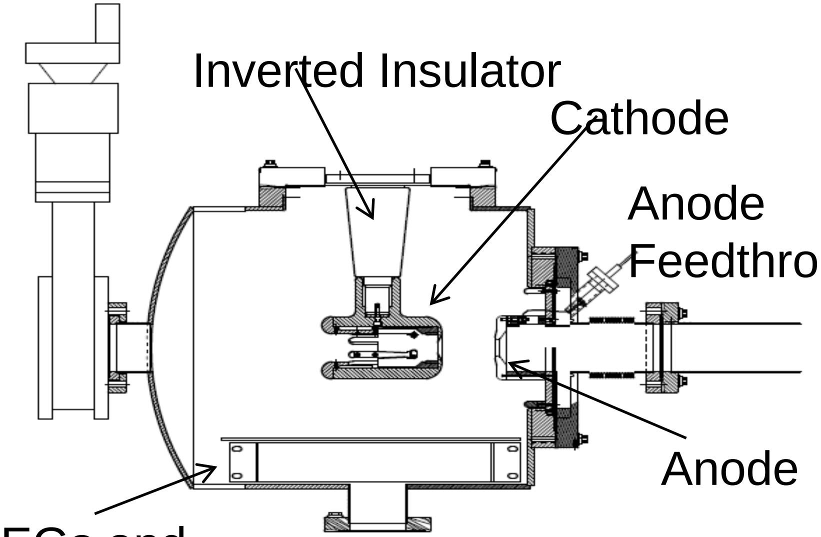


Move away from “conventional” insulator used on most GaAs photoguns today – expensive, months to build, prone to damage from field emission.

High gradient locations not related to beam optics

Gun development at Jlab

Jlab's Inverted gun design



Inverted Insulator

Cathode

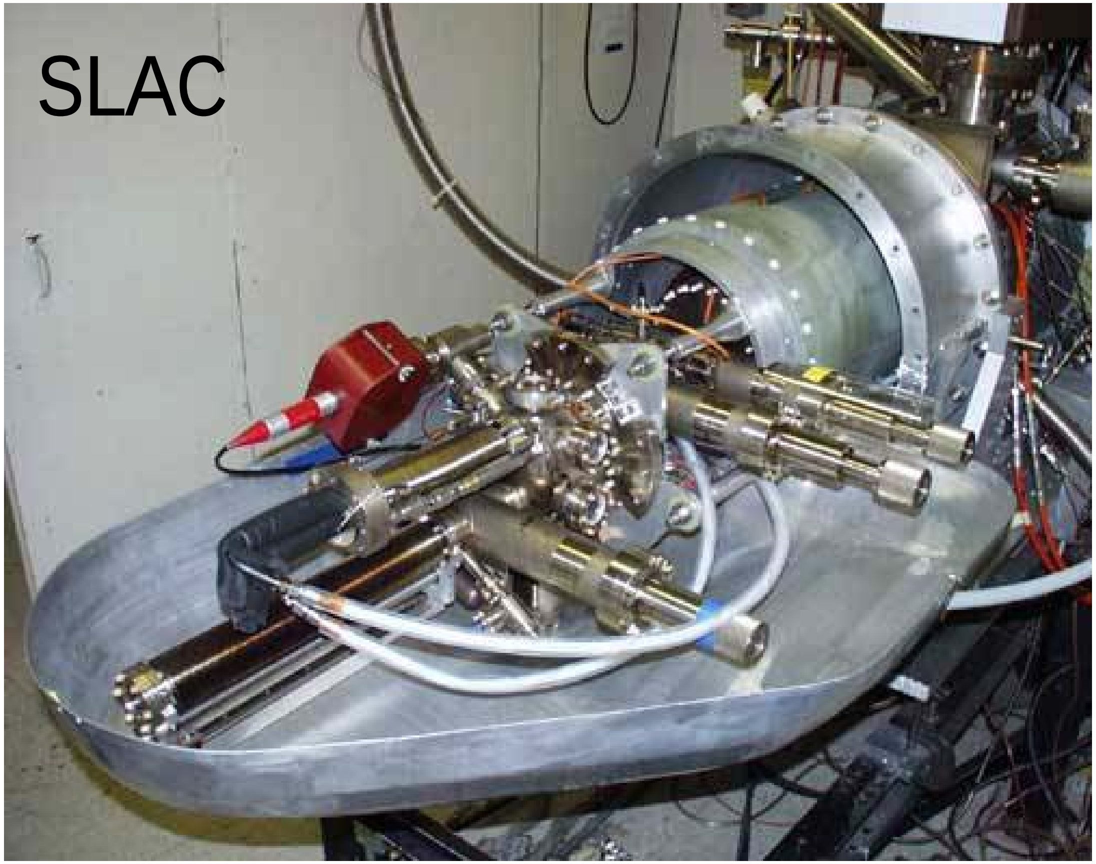
Anode Feedthrough

Anode

NEGs and Ground Screen

conditioned to 150kV without observed field emission

SLAC Polarized Electron Gun, GTL (~1989 back-up)



Electron Sources: Guns

Space Charge Limit

Child's Law (1D): $j_1 = (2.33\times10^{-6})V^{3/2}/d^2$

Child's Law (2D) (PRL **87**, 278301) : $j_2 \cong j_1\left(1+\frac{1}{4}\frac{d}{r}\right)$

Short Pulse (PRL **98**, 164802): $j_{SCL} = j_2\left(2\frac{1-\sqrt{1-3X_{CL}^2/4}}{X_{CL}^3}\right),$

$$X_{CL} = \frac{t_b}{\tau}$$

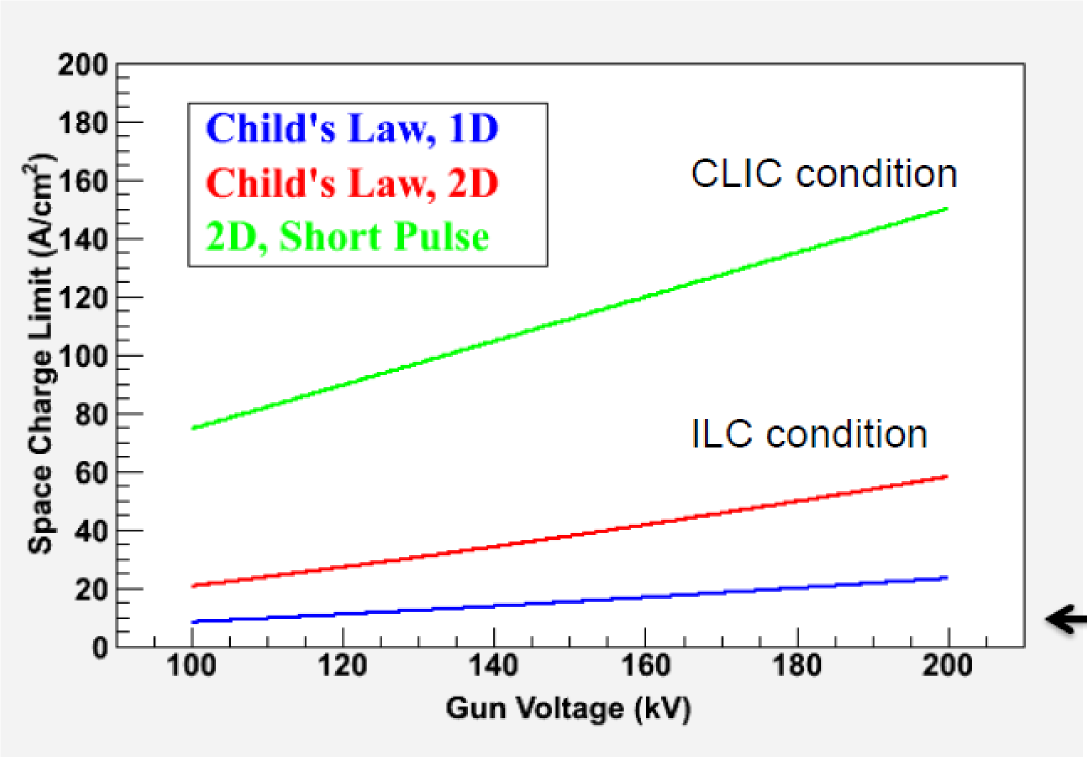
V	Gun voltage
d	Cathode/anode gap (3 cm)
r	Laser spot size (1 cm = 2r)
t_b	microbunch length (100 ps)
τ	Gap transit time (0.48 ns @ 100 kV)

ILC with long microbunch…
won't reap "short pulse" benefit

Electron Sources: Guns

Space Charge Limit – Not an Issue

1D SCL does not apply (i.e. we don't have infinite charge plane)
ILC conditions – with finite beam size 2D - push Child's Current Limit higher…..
CLIC short-bunch condition pushes current limit higher still…..

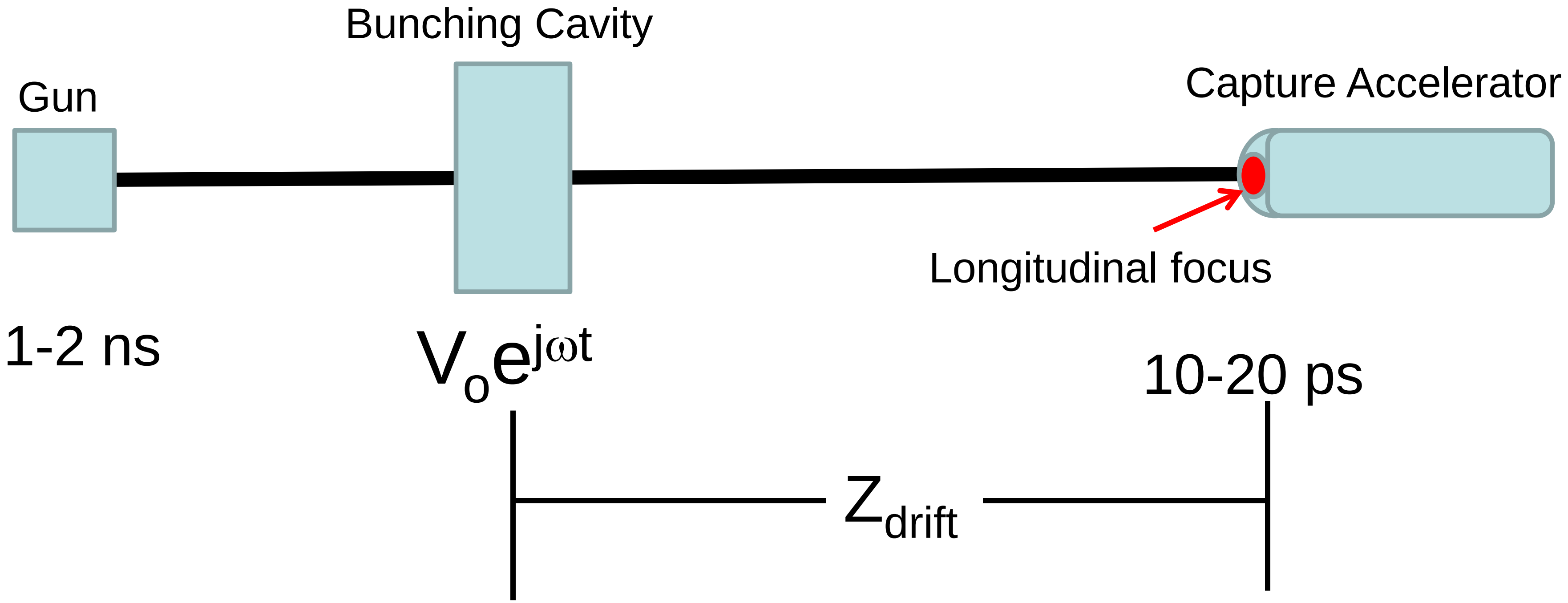


← CLIC/ILC current density

Thanks to Riad Suleiman

Electron Sources: Bunching

Gun Pulses are in 1-2 ns long; need several ps long pulses for acceleration in linac



Bunching Cavity

Gun

Capture Accelerator

Longitudinal focus

1-2 ns

$V_o e^{j\omega t}$

10-20 ps

Z_{drift}

Electron Sources: Bunching

General idea is to modulate the velocity of the electrons in the bunch so that the bunch comes to a minimum at the entrance of the capture accelerating sturcture. Sometimes called longitudinal focusing. Typically use 2 bunchers and a subharmonic frequency of the primary accelerating frequency. Needs to be compatible with the Main Linac rf and Dr rf frequencies

$$\Delta V = \pm V_o e^{j\omega \frac{\Delta}{2v_o}}$$

$$v_o = c\left(1-\gamma^{-2}\right)^{1/2} \qquad \Delta = gun\ pulselength = \beta c \Delta_t$$

$$want\ \Delta v \frac{Z_{drift}}{v_o} = \frac{\Delta}{2}$$

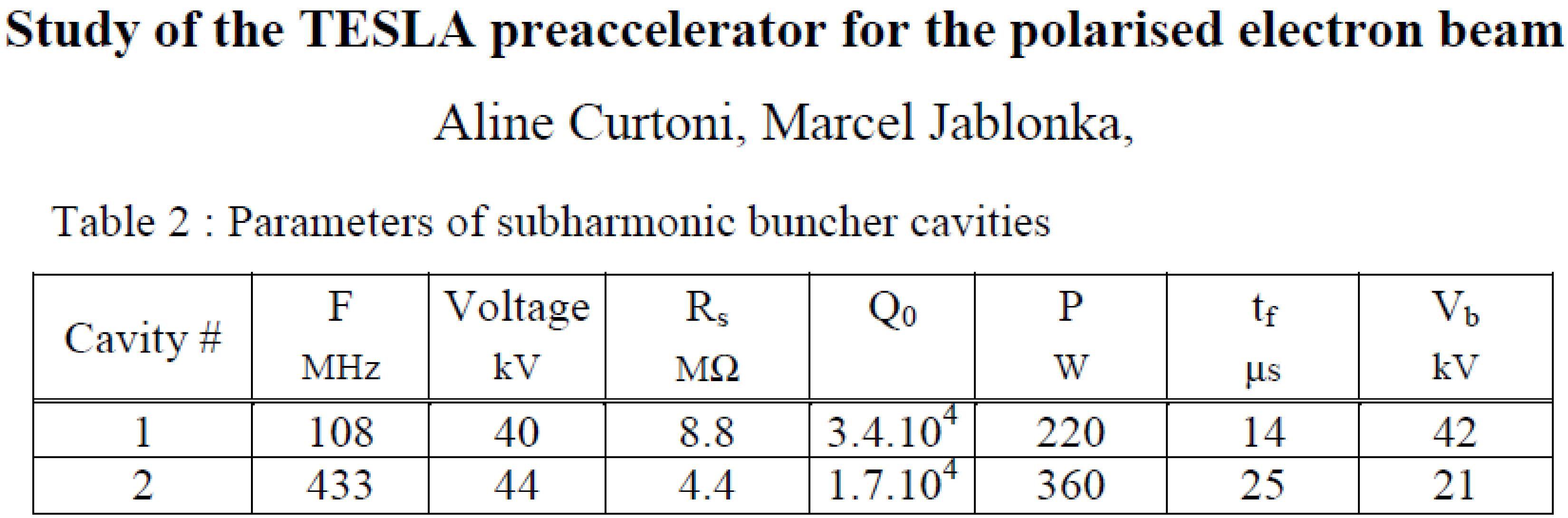
Electron Sources: Bunching

Bunching: Need to think about worrying about longitudinal space charge forces as bunches shrink to the ps scale for non-relativistic beams

ILC Design calls for two 325 MHz bunchers (frequency selected as ½ DR rf freq; helps to ease bunch filling pattern restrictions in the damping rings and in the Main Linacs

325 MHz SHB

Tesla-2001-22-2



Study of the TESLA preaccelerator for the polarised electron beam

Aline Curtoni, Marcel Jablonka,

Table 2 : Parameters of subharmonic buncher cavities

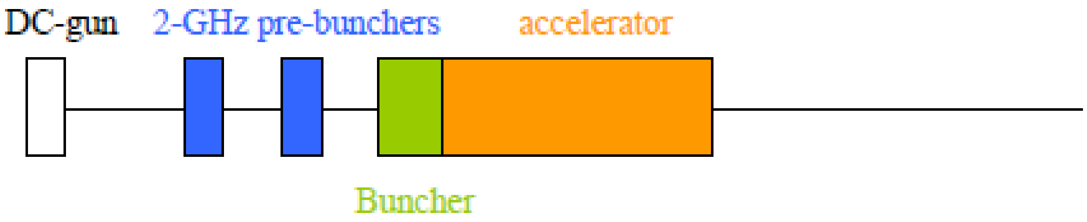
Cavity #	F MHz	Voltage kV	R_s MΩ	Q_0	P W	t_f μs	V_b kV
1	108	40	8.8	$3.4.10^4$	220	14	42
2	433	44	4.4	$1.7.10^4$	360	25	21

$$\omega' V' = \omega_0 V_0$$

Scaled SHB parameters

Cavity #	F MHz	Voltage kV	R_s MΩ	Q_0	P W	t_f μs	V_b kV
1	325	13	5.1	$2.0.10^4$	?	?	?
2	325	59	5.1	$2.0.10^4$	?	?	?

CLIC Electron Beam Demo: Bunching



DC-gun

2-GHz pre-bunchers

accelerator

Buncher

Figure 1: The schematic layout of bunching system for CLIC electron source.

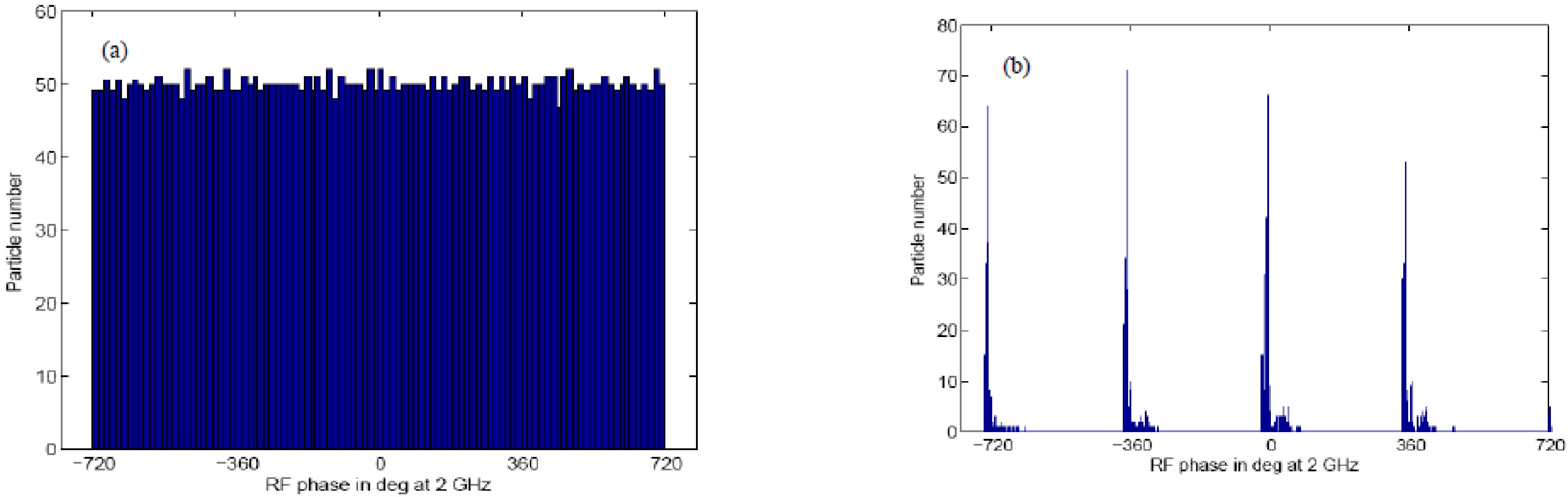
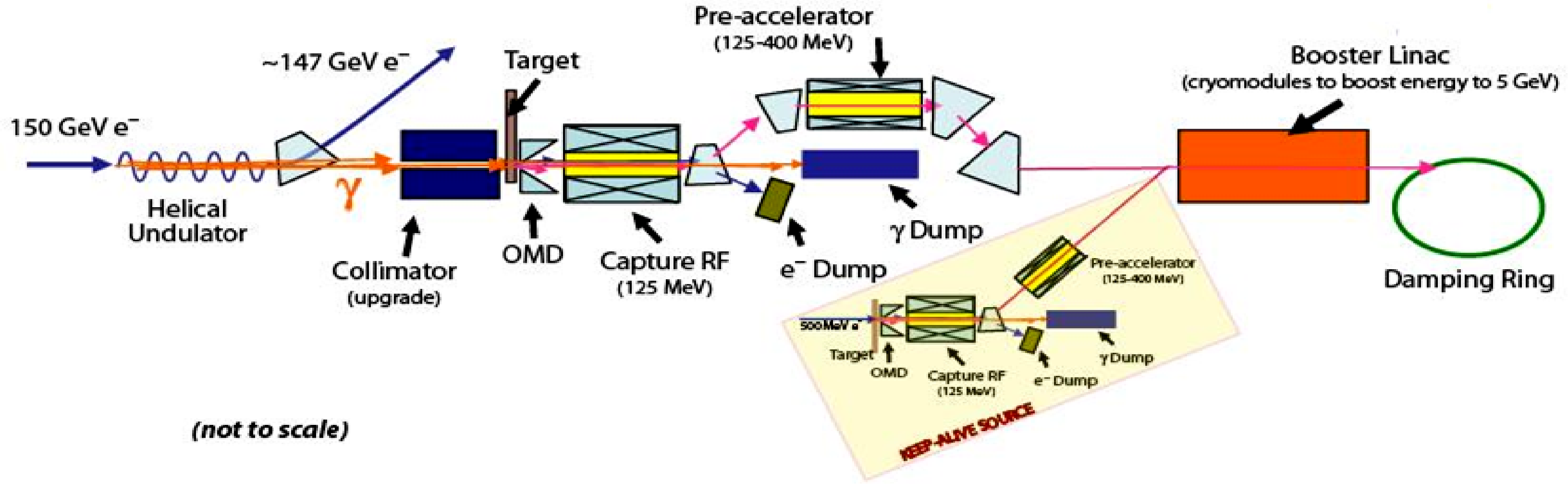


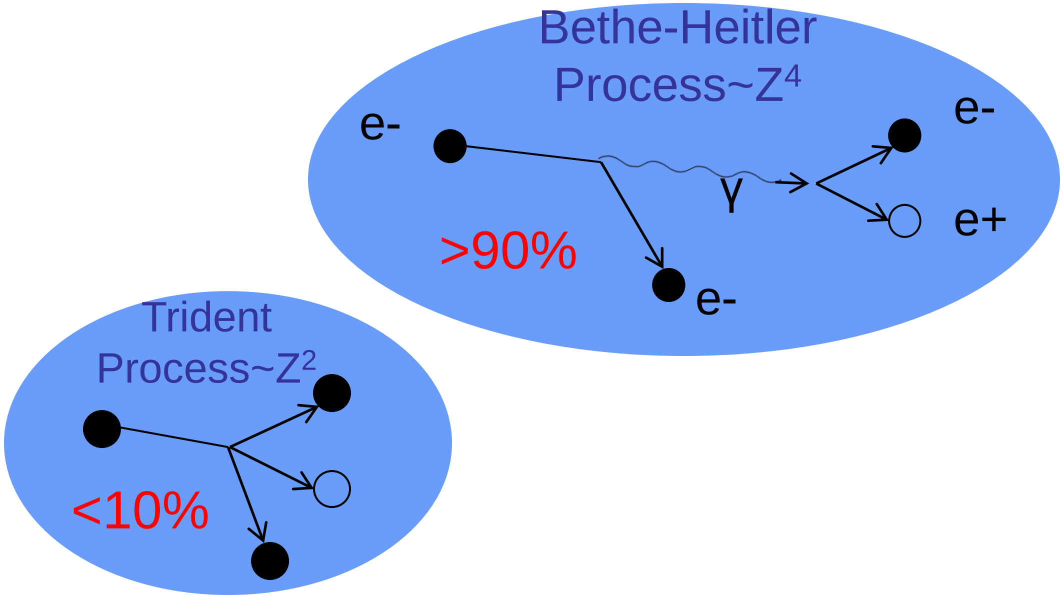
Figure 3: Initial pulse duration (a) on the cathode, and final bunched pulse structure (b) at 19 MeV

Postiron Sources



(not to scale)

Positron Sources: Pair Production



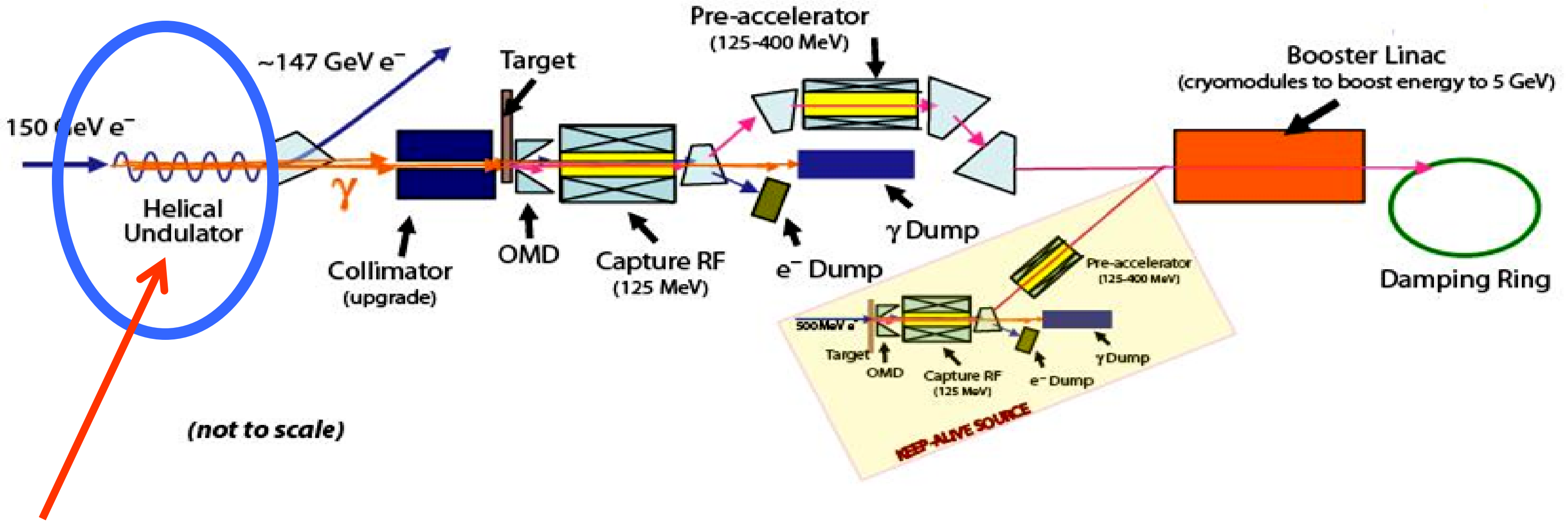
Positrons come from Pair Production in metal targets (W and Ti-alloy); Trident not significant

Positron Sources: Pair Production

In a “conventional” system, high energy electrons generate photons via bremsstrahlung, these photons in turn pair produce. The first n-1/2 radiation lengths of the target create the shower; positrons come from the last ½ radiation length.

In an photon based system, photons are made outside of the target by high energy electrons by using an undulator (ILC and NLC baseline); or for intra-cavity compton sccatters (“alternative source”); from using a hybrid schem (xtal channeling followed by a sweeping magnet) (CLIC baseline).

Postiron Sources



Helical Undulator

Postiron Sources: Yield into DR

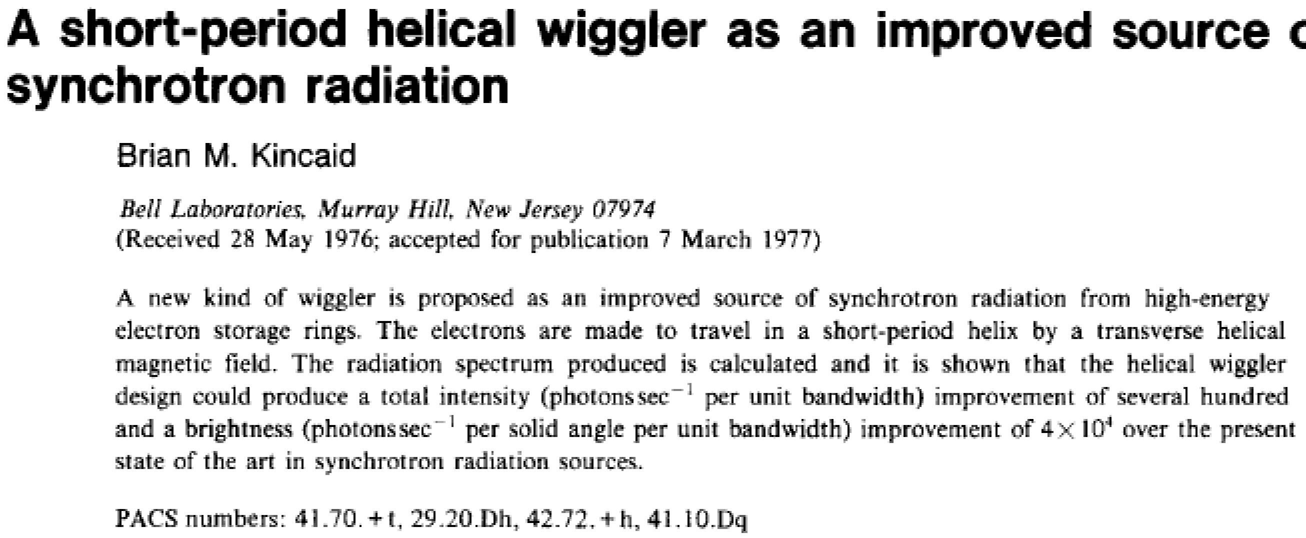
$$N_{e^+} = N_{e^-} Y_u(E_{e^-}, K_u, \lambda_u) \int d\omega S_u(\omega) \frac{dY_{\gamma \to e^+}(Z_t, L_t)}{d\omega} A_c A_{\delta E} A_{\varepsilon dr}$$

The yield of postitrons captured in the DR is a not trivial function of the electron➔photon production rate which depends on the undulator parameters as well as the electron energy; the spectrum of the undulator

photons; the quantum yield of γ➔e+ emitted from the target; the initial capture in the accelerator system; and the energy and phase space acceptance of the damping ring. Whereas the undulator spectrum and photon yield can be modeled straightforwardly (see Kincaid, below) the photon➔e+ yield require simulations (EGS or FLUKA or GEANT4); the accelerator capture lends it self to ray tracing; damping ring acceptance is typically modeled by making cuts on the accelerated simulated positron distributions.

Lots of fun that can keep you busy for a while.

Positron Sources: Undulators



A short-period helical wiggler as an improved source of synchrotron radiation

Brian M. Kincaid

Bell Laboratories, Murray Hill, New Jersey 07974

(Received 28 May 1976; accepted for publication 7 March 1977)

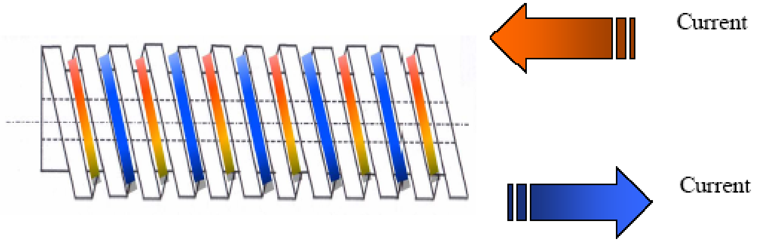
A new kind of wiggler is proposed as an improved source of synchrotron radiation from high-energy electron storage rings. The electrons are made to travel in a short-period helix by a transverse helical magnetic field. The radiation spectrum produced is calculated and it is shown that the helical wiggler design could produce a total intensity (photons sec^{-1} per unit bandwidth) improvement of several hundred and a brightness (photons sec^{-1} per solid angle per unit bandwidth) improvement of 4×10^4 over the present state of the art in synchrotron radiation sources.

PACS numbers: 41.70.+t, 29.20.Dh, 42.72.+h, 41.10.Dq

Polarized Positrons from Helical Undulator

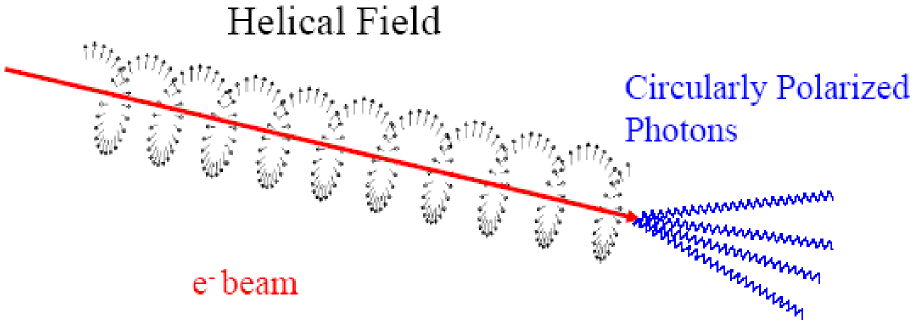
Rotating dipole field in
the transverse planes

- Ribbon-wire wound in a double helix



Electrons follow a helical path

Emission of circularly polarized radiation



Opening angle
of photon beam ~1/γ
(first harmonic)

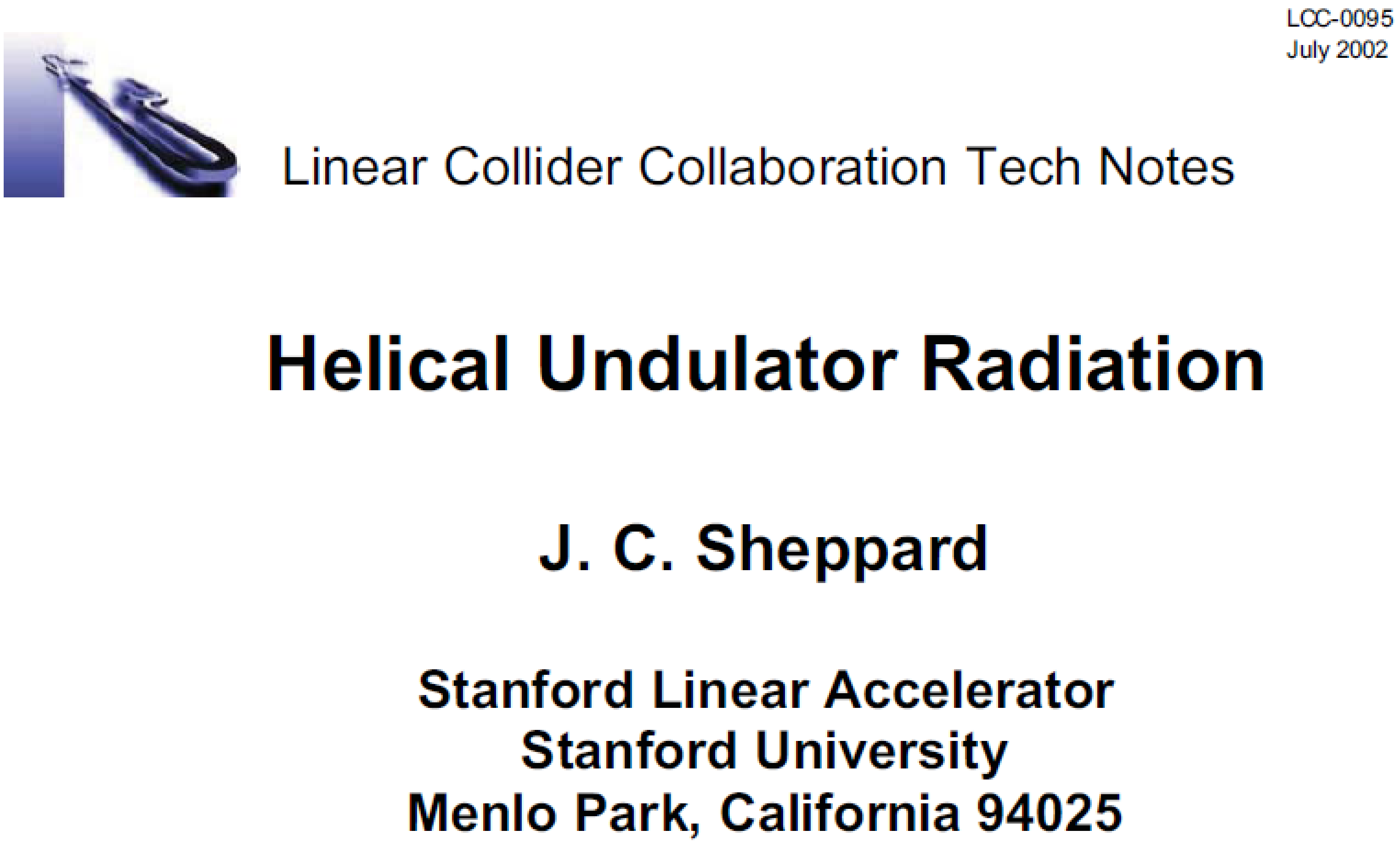
Polarization sign is determined by undulator (direction of the helical field)

photons ~ undulator length

Photon yield in a helical undulator is about 1.5…2 higher than that in a planar undulator (for the parameters of interest)

See also Mikhailichenko, CLNS 04/1894

Positron Sources: Undulators



LCC-0095
July 2002

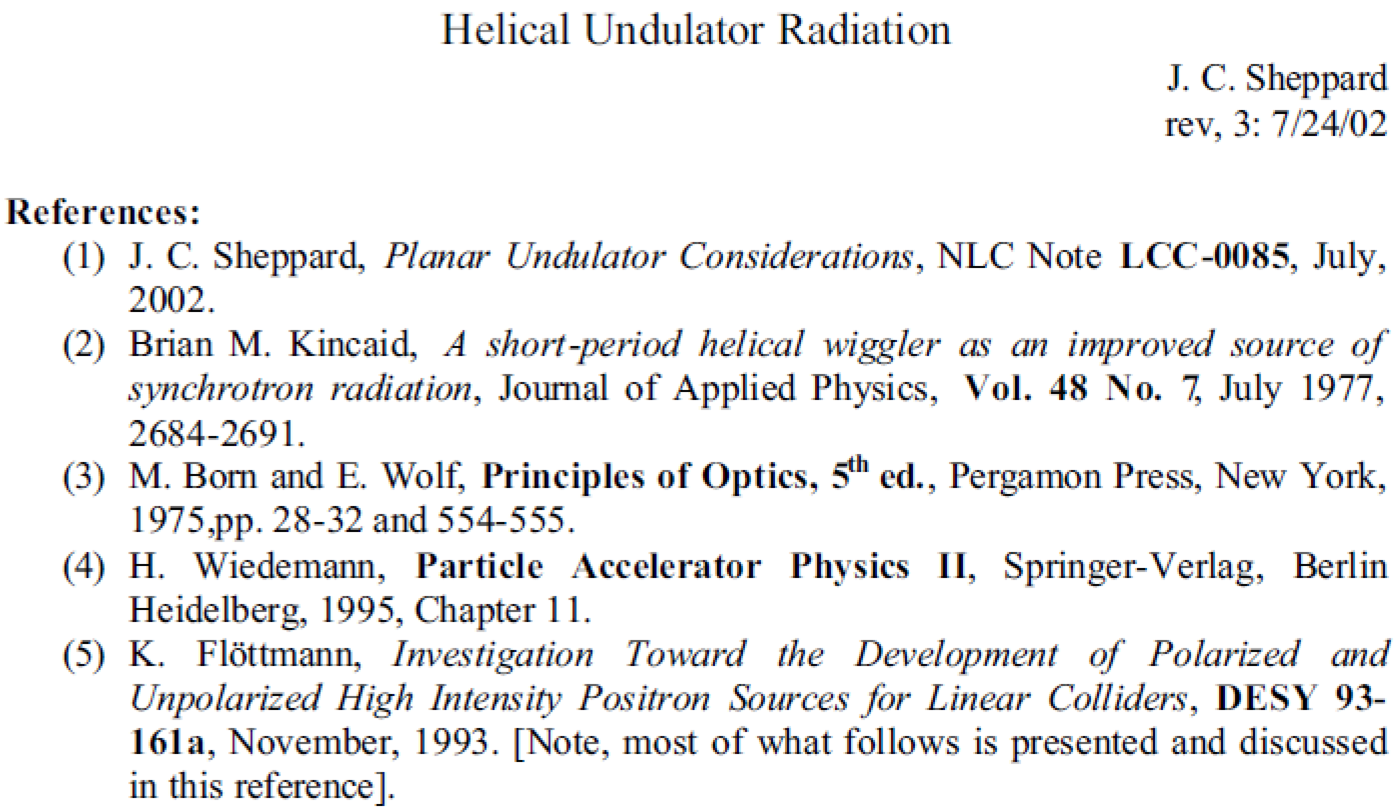
Linear Collider Collaboration Tech Notes

Helical Undulator Radiation

J. C. Sheppard

Stanford Linear Accelerator
Stanford University
Menlo Park, California 94025

Positron Sources: Undulators



Helical Undulator Radiation

J. C. Sheppard
rev, 3: 7/24/02

References:

(1) J. C. Sheppard, *Planar Undulator Considerations*, NLC Note **LCC-0085**, July, 2002.

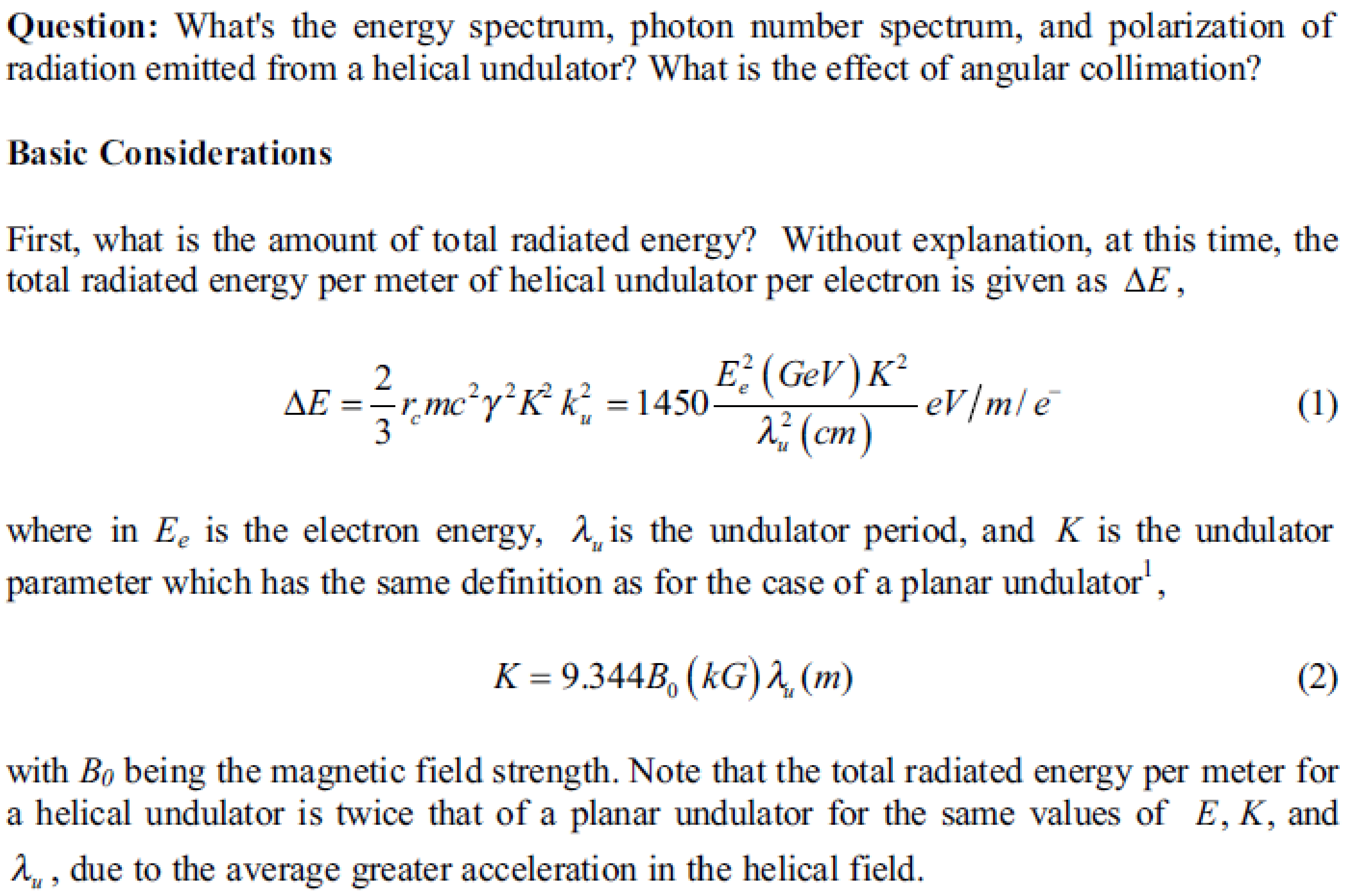
(2) Brian M. Kincaid, *A short-period helical wiggler as an improved source of synchrotron radiation*, Journal of Applied Physics, **Vol. 48 No. 7**, July 1977, 2684-2691.

(3) M. Born and E. Wolf, **Principles of Optics, 5th ed.**, Pergamon Press, New York, 1975,pp. 28-32 and 554-555.

(4) H. Wiedemann, **Particle Accelerator Physics II**, Springer-Verlag, Berlin Heidelberg, 1995, Chapter 11.

(5) K. Flöttmann, *Investigation Toward the Development of Polarized and Unpolarized High Intensity Positron Sources for Linear Colliders*, **DESY 93-161a**, November, 1993. [Note, most of what follows is presented and discussed in this reference].

Positron Sources: Undulators



Question: What's the energy spectrum, photon number spectrum, and polarization of radiation emitted from a helical undulator? What is the effect of angular collimation?

Basic Considerations

First, what is the amount of total radiated energy? Without explanation, at this time, the total radiated energy per meter of helical undulator per electron is given as ΔE,

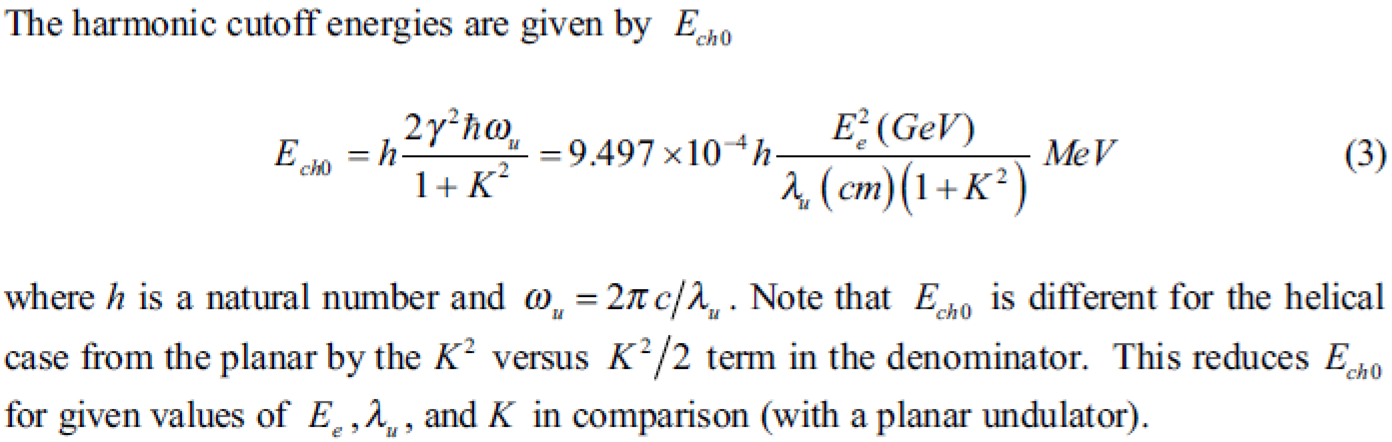
$$\Delta E = \frac{2}{3} r_c mc^2 \gamma^2 K^2 k_u^2 = 1450 \frac{E_e^2 \left(GeV\right) K^2}{\lambda_u^2 \left(cm\right)} eV/m/e^- \qquad (1)$$

where in E_e is the electron energy, λ_u is the undulator period, and K is the undulator parameter which has the same definition as for the case of a planar undulator[1],

$$K = 9.344 B_0 \left(kG\right) \lambda_u \left(m\right) \qquad (2)$$

with B_0 being the magnetic field strength. Note that the total radiated energy per meter for a helical undulator is twice that of a planar undulator for the same values of E, K, and λ_u, due to the average greater acceleration in the helical field.

Positron Sources: Undulators



The harmonic cutoff energies are given by E_{ch0}

$$E_{ch0} = h\frac{2\gamma^2\hbar\omega_u}{1+K^2} = 9.497\times10^{-4}h\frac{E_e^2\,(GeV)}{\lambda_u\,(cm)\left(1+K^2\right)}\ MeV \qquad (3)$$

where h is a natural number and $\omega_u = 2\pi c/\lambda_u$. Note that E_{ch0} is different for the helical case from the planar by the K^2 versus $K^2/2$ term in the denominator. This reduces E_{ch0} for given values of E_e, λ_u, and K in comparison (with a planar undulator).

Positron Sources: Undulators

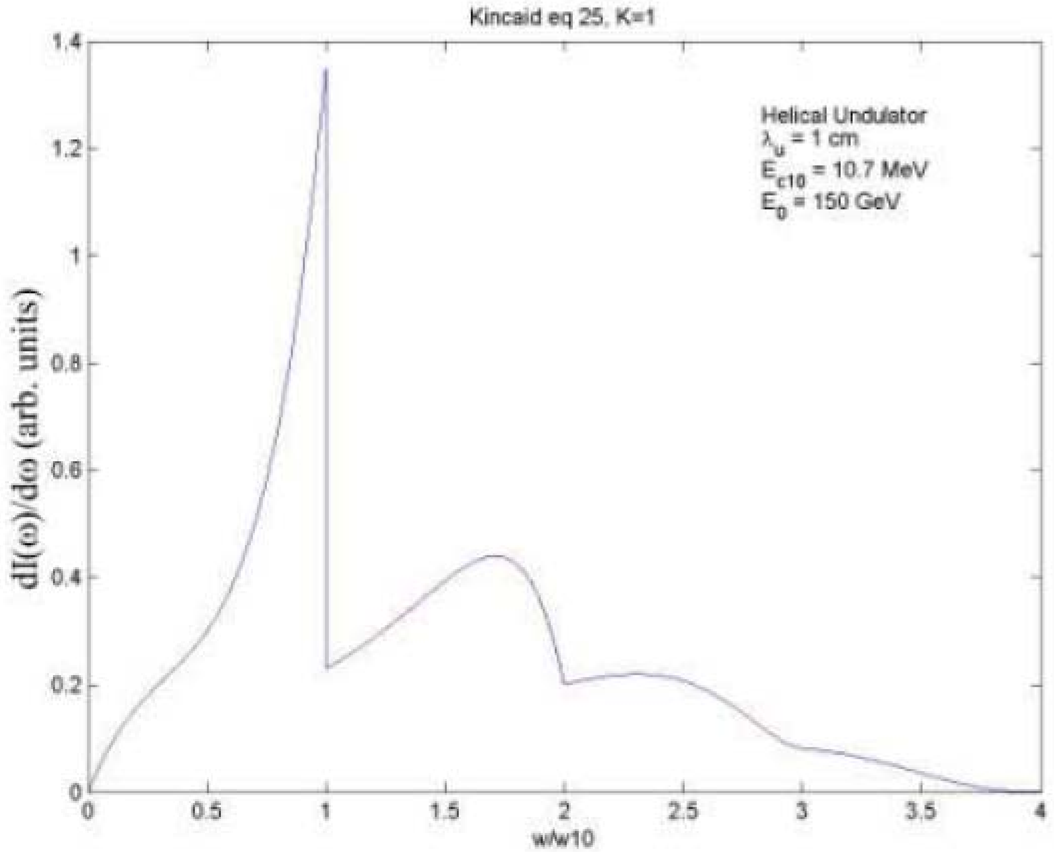


Figure 1: Helical undulator radiation energy spectrum for $K = 1$.

Positron Sources: Undulators

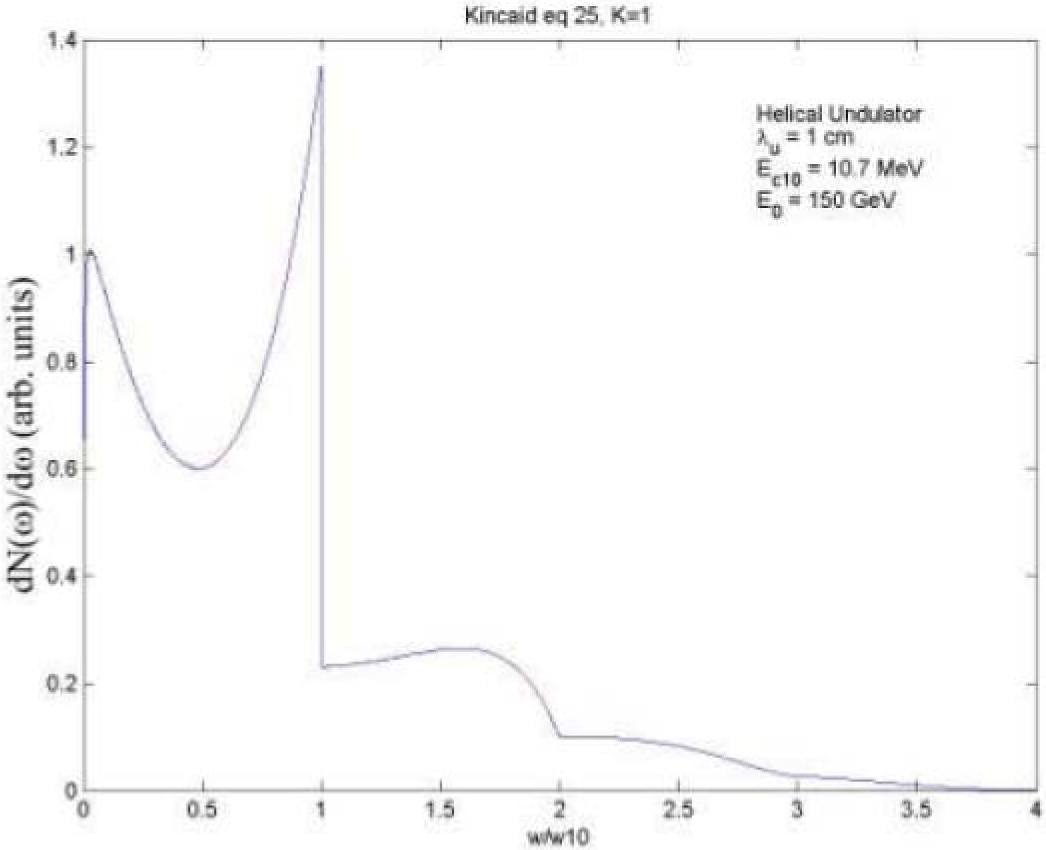


Figure 2: Helical undulator radiation photon number spectrum for $K = 1$.

Positron Sources: QE

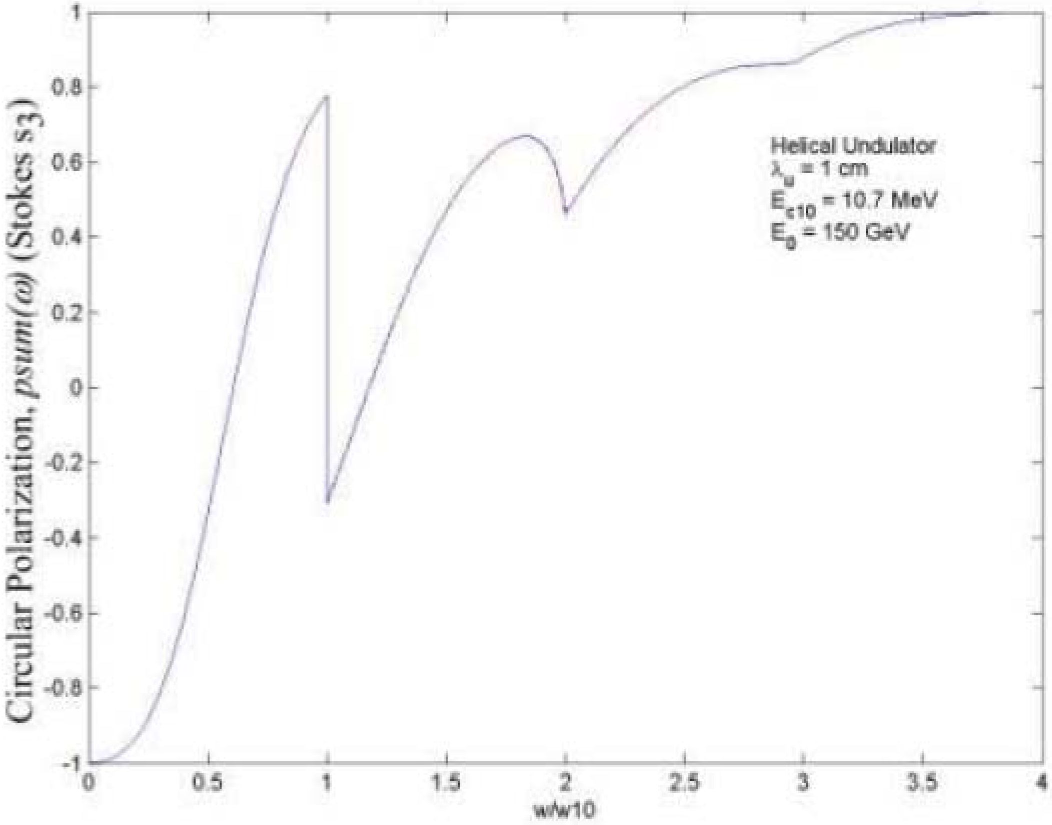
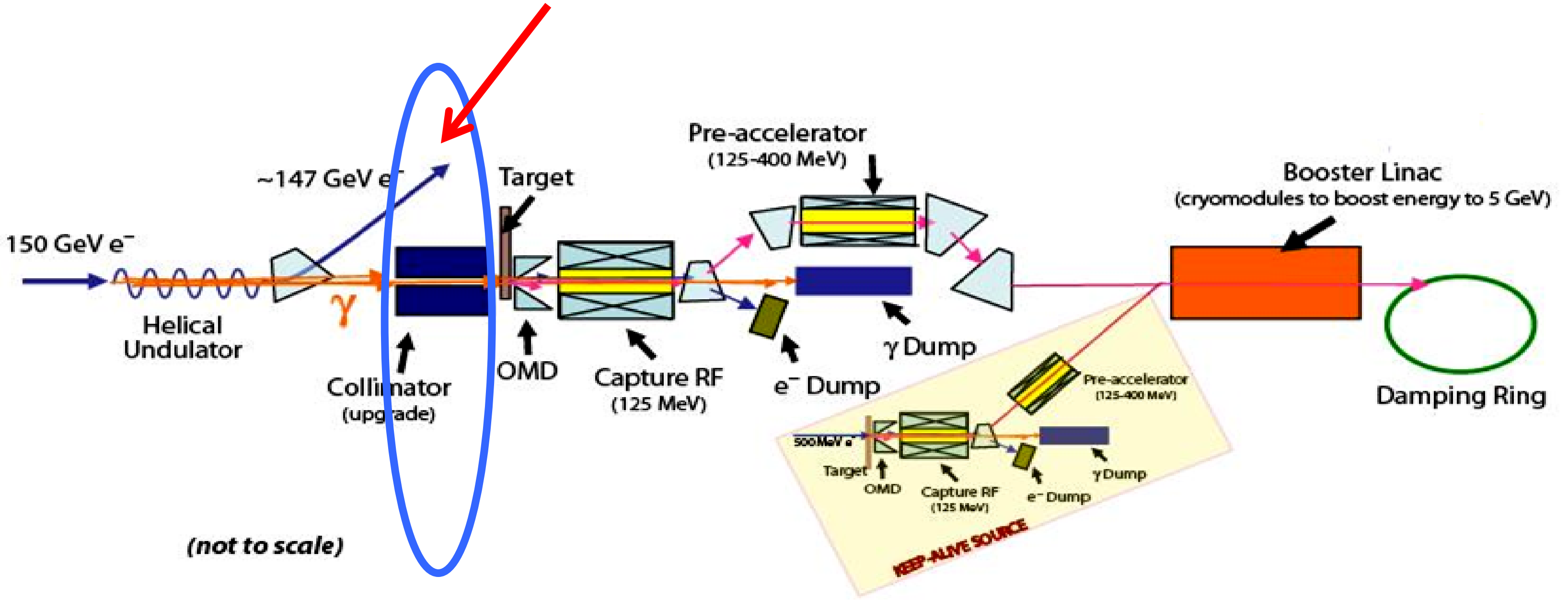


Figure 3: Helical undulator radiation circular polarization for $K=1$. Note, only the first 4 harmonics have been included in the summation.

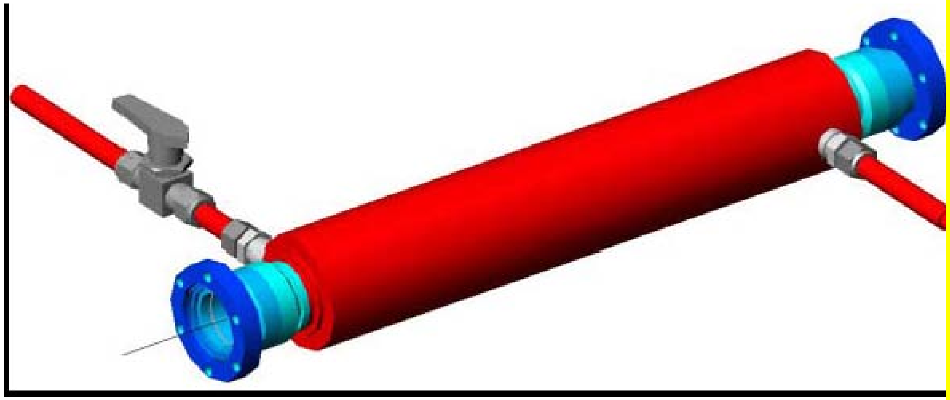
Postiron Sources

Photon Collimator

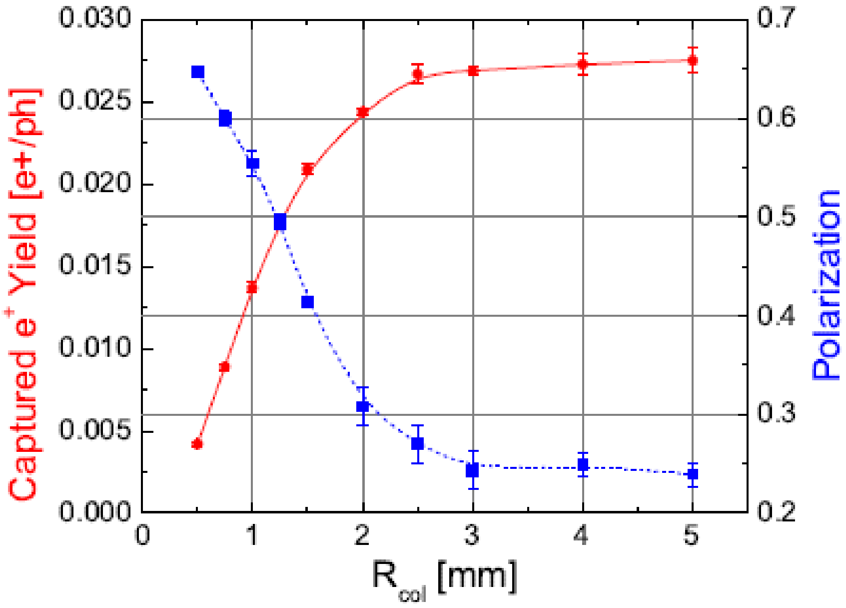


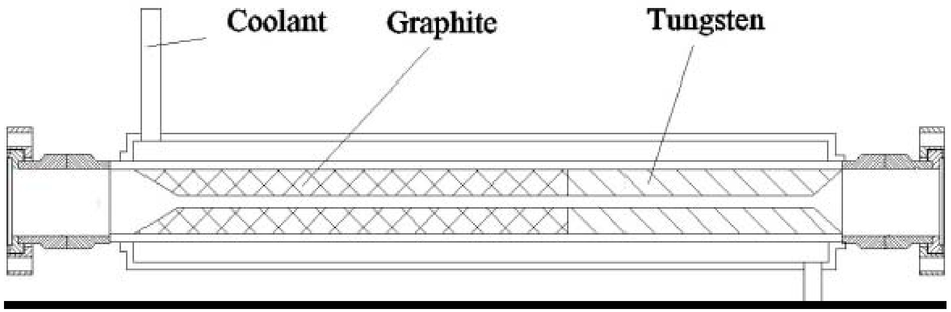
Photon Collimator

Recommendation from ILC positron source meeting in Durham (2009) was to include a tungsten/graphite collimator of radius 2mm.



Yield and Polarization vs Aperture Radius of Photon Collimator





Same specification works for SB2009 (2.5kW in collimator)

A. Ushakov, DESY

https://znwiki3.ifh.de/LCpositrons/CollimatorDesign

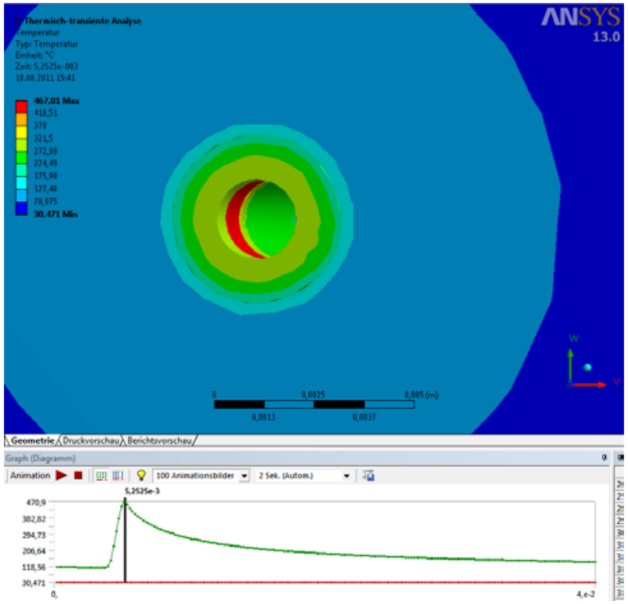
Collimator design studies

- heat loads (temperatures) for different collimator designs are simulated

-> collimator design is improved to withstand the heat load

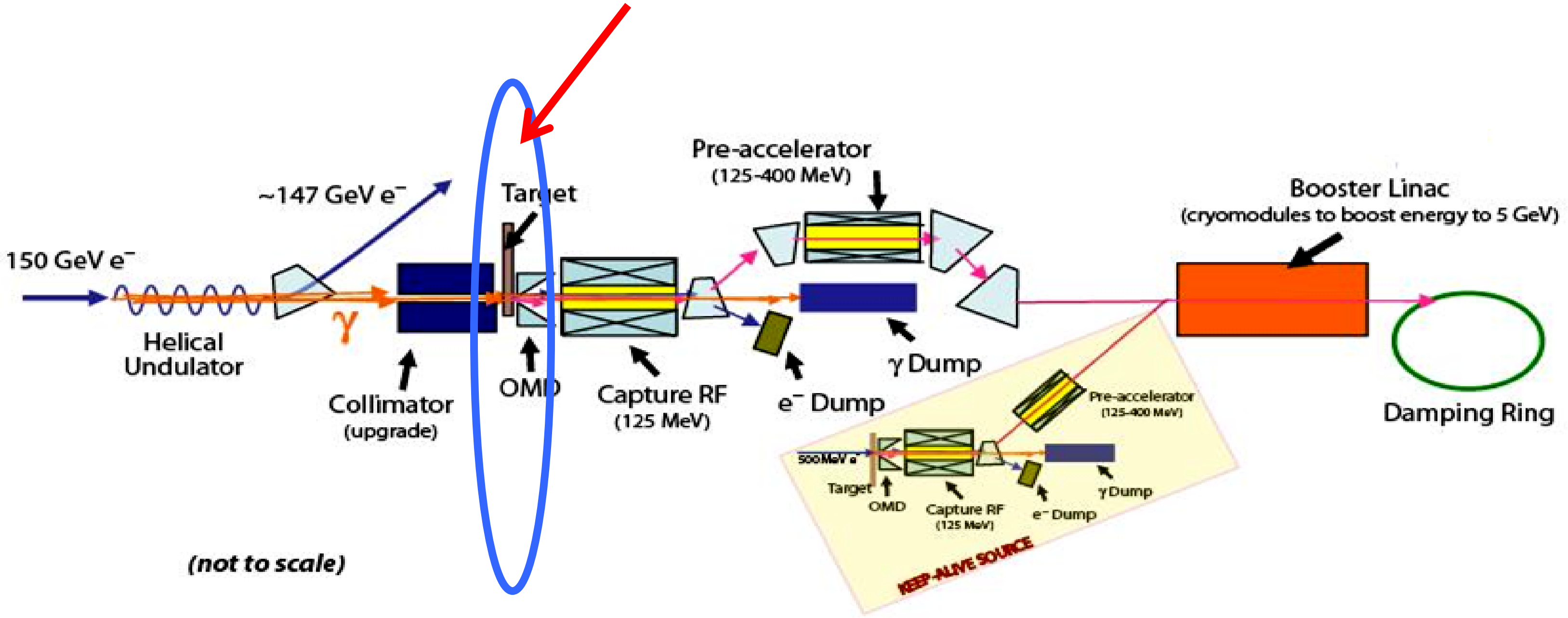
- time dependent heat and structural loads are simulated with ANSYS software

graphite collimator	simulation	theoretical $_{\text{max}}$
temperature	800 K	~ 4000 K
deformation	45 μm	-
stress	10 MPa	20-70 MPa



C: Thermisch-transiente Analyse
Temperatur
Typ: Temperatur
Einheit: °C
Zeit: 5,2525e-003
18.08.2011 15:41

Postiron Sources



Positron Target

(not to scale)

Positron Sources: Targets

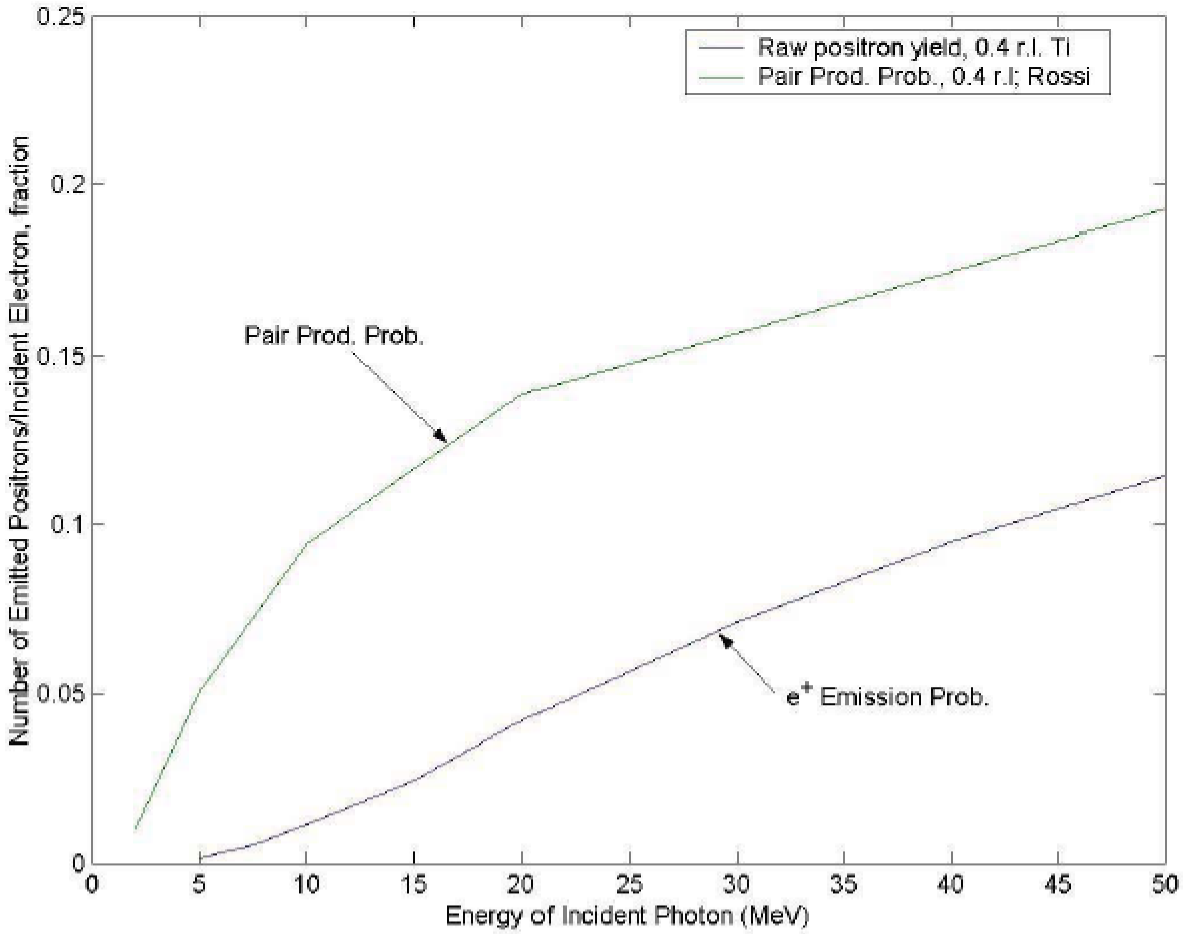


Figure 5.: Pair production probability and positron emission probability for monoenergetic photons incident on 0.4 r.l. of Ti.

Positron Target

Material: Titanium alloy

Thickness: 0.4 X_0 (1.4 cm)

Incident photon spot size on target: $\sigma \sim$ 1.7 mm (rms) (RDR)

~ 1.2 mm (SB2009)

Power deposition in target: 8% → 10.4 kW (RDR); <8 kW (SB2009)

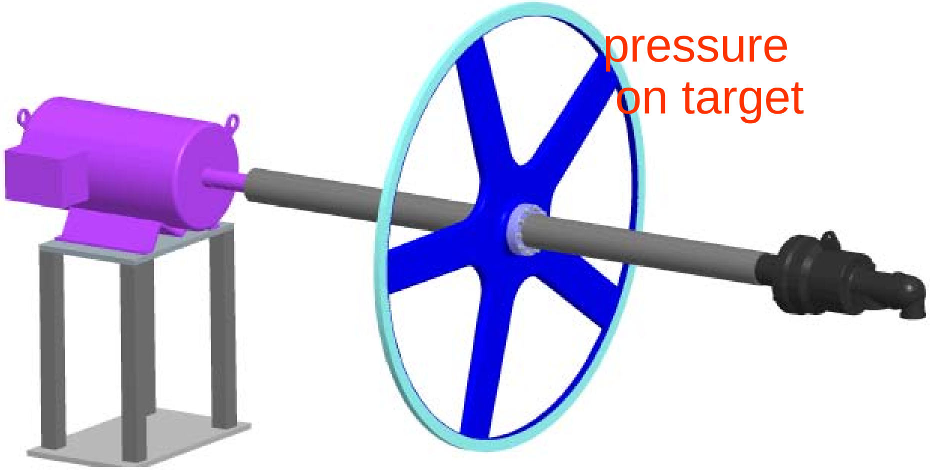
But peak energy deposition density is higher for SB2009 design

Rotate target to reduce local thermal effects and radiation damage → 2m diameter target wheel, 2000 rpm

Issues to be resolved and the solutions validated:

- Stress in target material, shock wave impact lifetime
- rotating vacuum seals to be confirmed suitable

pressure on target



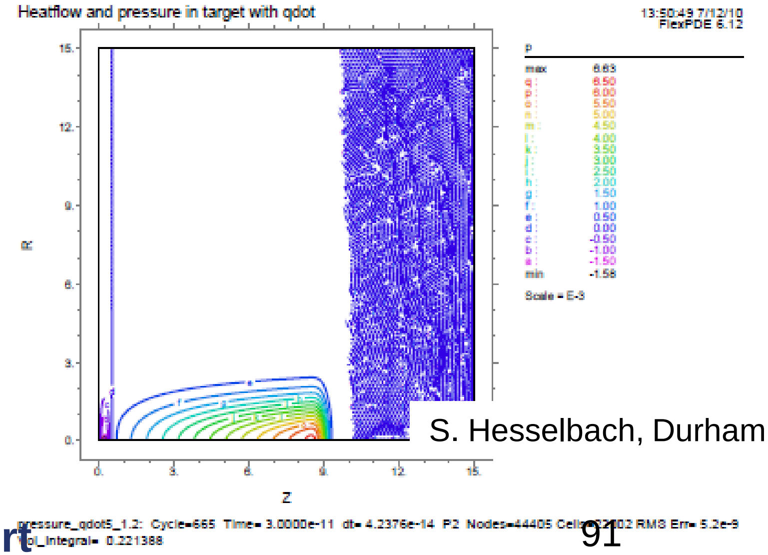
Shockwaves in the target

- Energy deposition causes shockwaves in the material
  - If shock exceeds strain limit of material chunks can spall from the face
- The SLC target showed spall damage after radiation damage had weakened the target material.

- Initial calculations from LLNL had shown no problem in Titanium target
- Two groups are trying to reconfirm result
  - FlexPDE (S. Hesselbach, Durham → DESY)
  - ANSYS (L. Fernandez-Hernando, Daresbury)
  - No definitive results yet
- Investigating possible shockwave experiments
  - FLASH(?)
  - https://znwiki3.ifh.de/LCpositrons/TargetShockWaveStudy

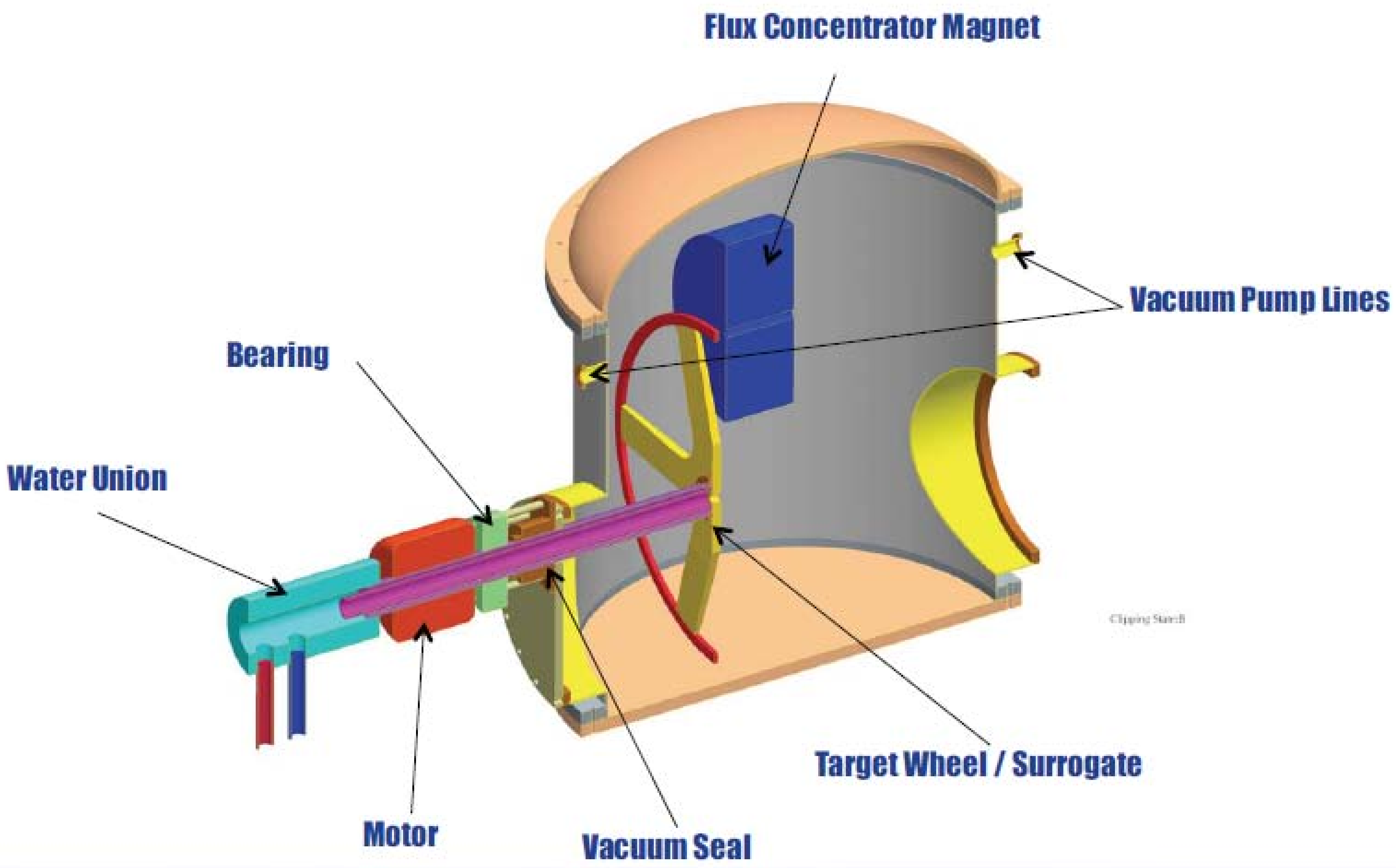
SLC positron target after decommissioning

Contours of P in MPa

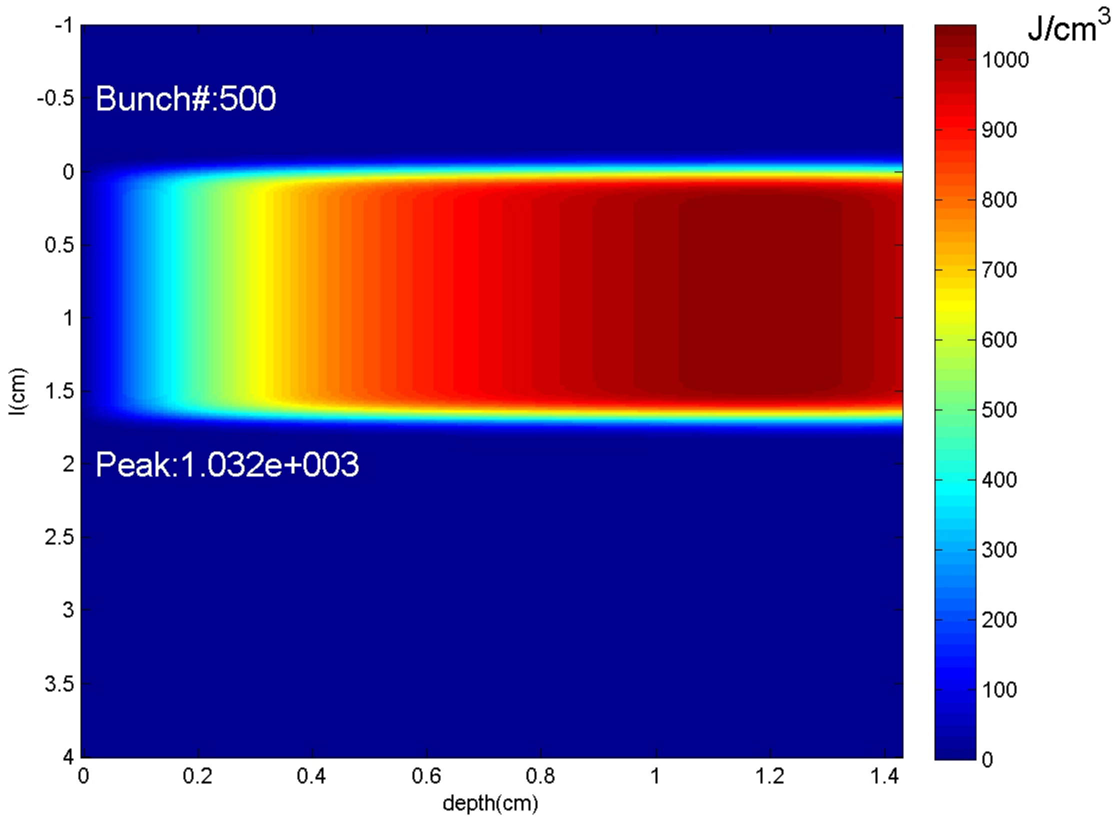


S. Hesselbach, Durham

Positron Sources: Targets

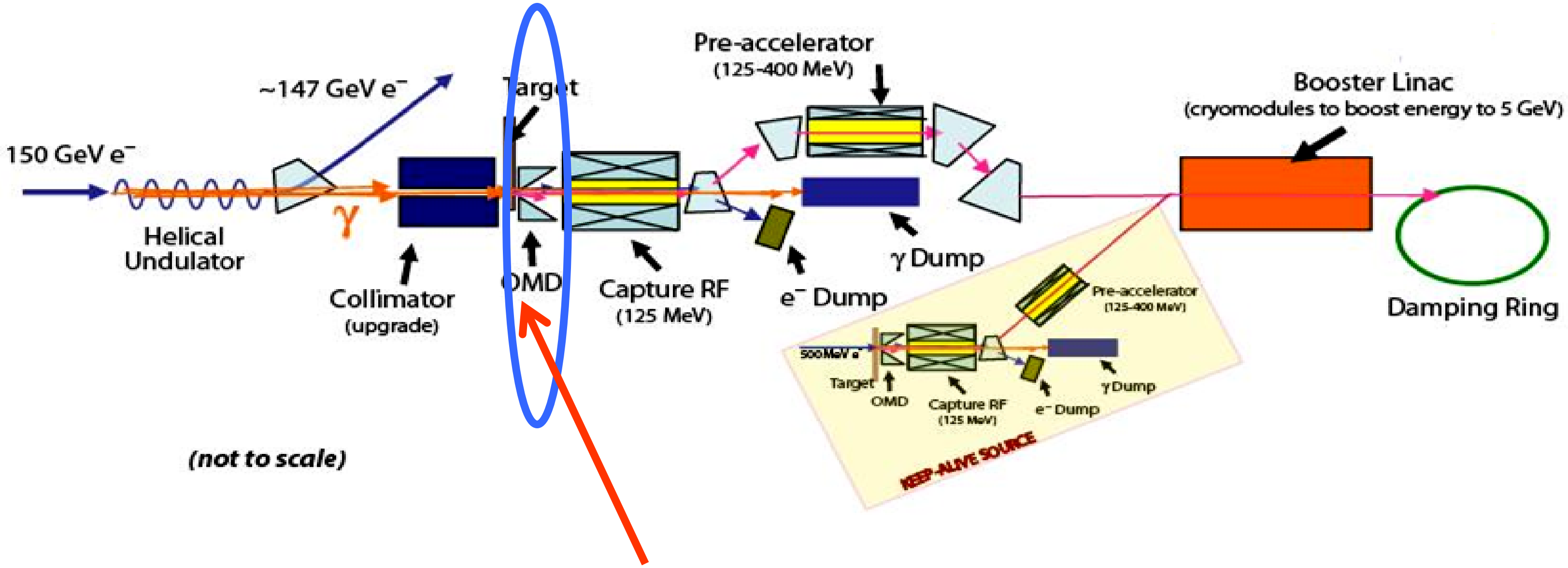


Accumulated effect of energy deposition -bunch separation is 356ns and target is rotating at 900RPM



The accumulated energy deposition in the rotating target (900RPM, 2m diameter) is about 1050 J/cm^3 while the number for RDR is 566J/cm^3. To bring it back to the RDR value, one can consider increase the bunch separation which reduce the number of bunch to 1312 per pulse with 712ns bunch separation or double the drift from undulator end to target

Postiron Sources



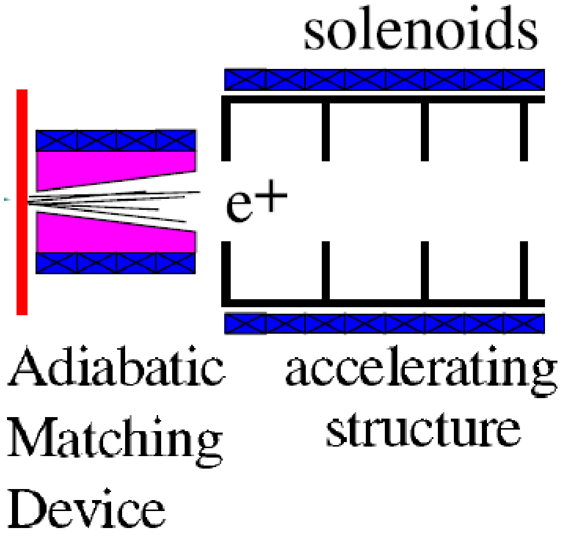
Optical Matching Device

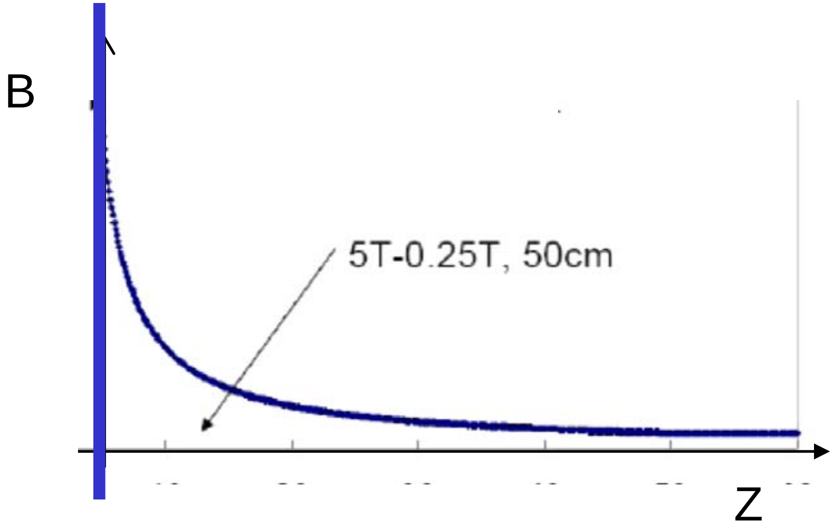
Positron yield ⬄ Optical matching device

OMD: Increases capture efficiency from 10% to as high as 40%

Adiabatic Matching Device (AMD):

Tapered B field from ~5 T at the target to 0.5 T in 50 cm





Target position

Capture efficiency >30%

Rotating target immersed in B field ⬄ eddy currents

Eddy current experiment @ Cockroft Institute

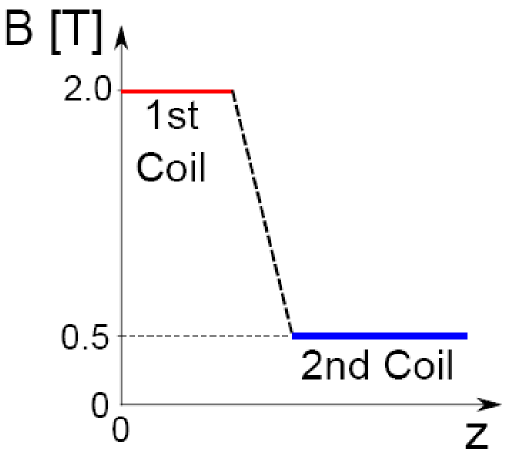
→ expect 8 kW at 2000 rpm

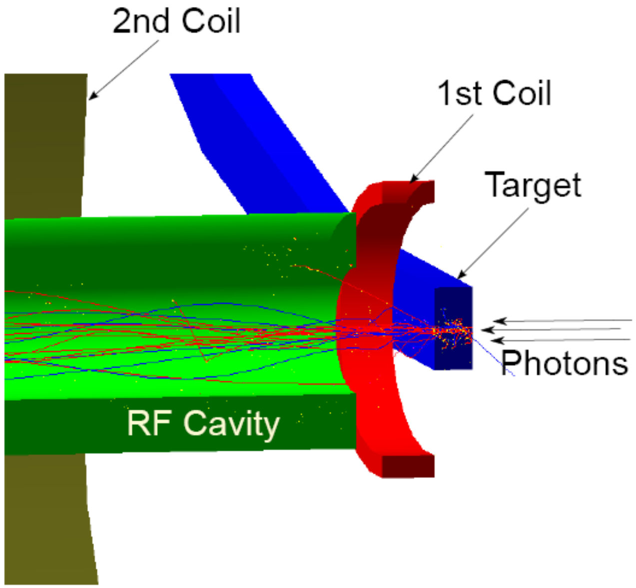
→ heat load on target substantially increased

Optical Matching Device (3)

Quarter Wave Transformer (QWT)

QWT is a save solution





but capture efficiency is ~15 %

SB2009 design with QWT

→ Length of helical undulator 231m

upgrade to P(e+) = 60% would make the undulator so long that photon powers become worrying and electron energy loss very high

→ better to use a flux concentrator

Optical Matching Device (2)

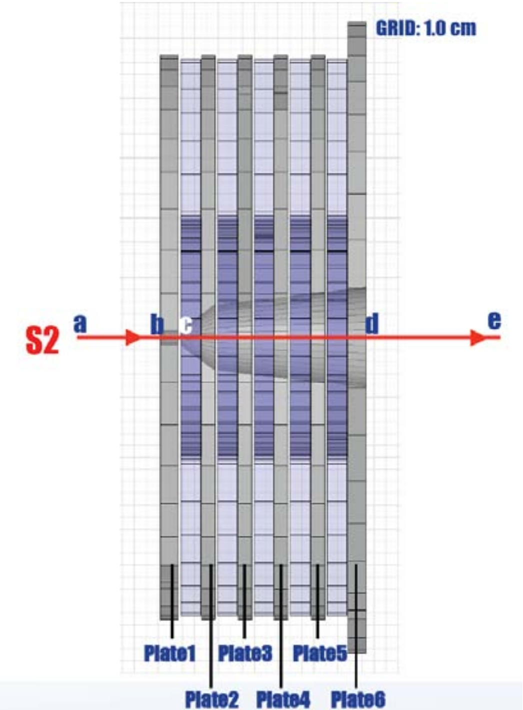
Flux Concentrator (FC)

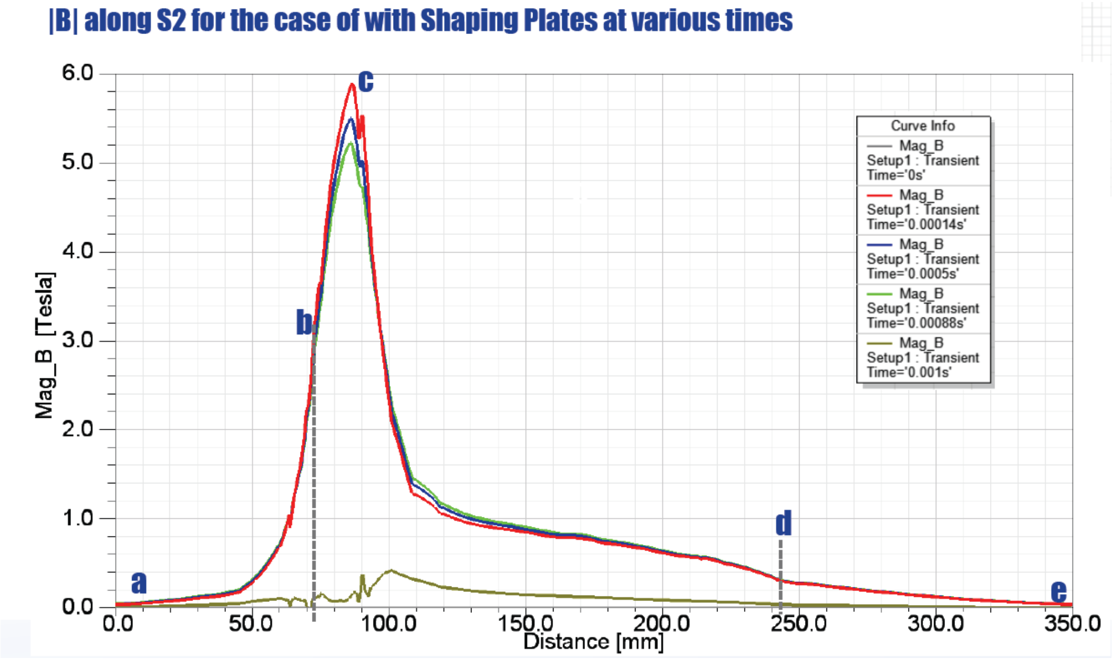
Flux concentrator reduces magnetic field on target but lower capture efficiency ~22%

RDR design with FC

pulsed flux concentrator (used at SLD):

- **ILC** needs ~ 1ms pulse width flat-top
- LLNL: Design and prototype (budget):





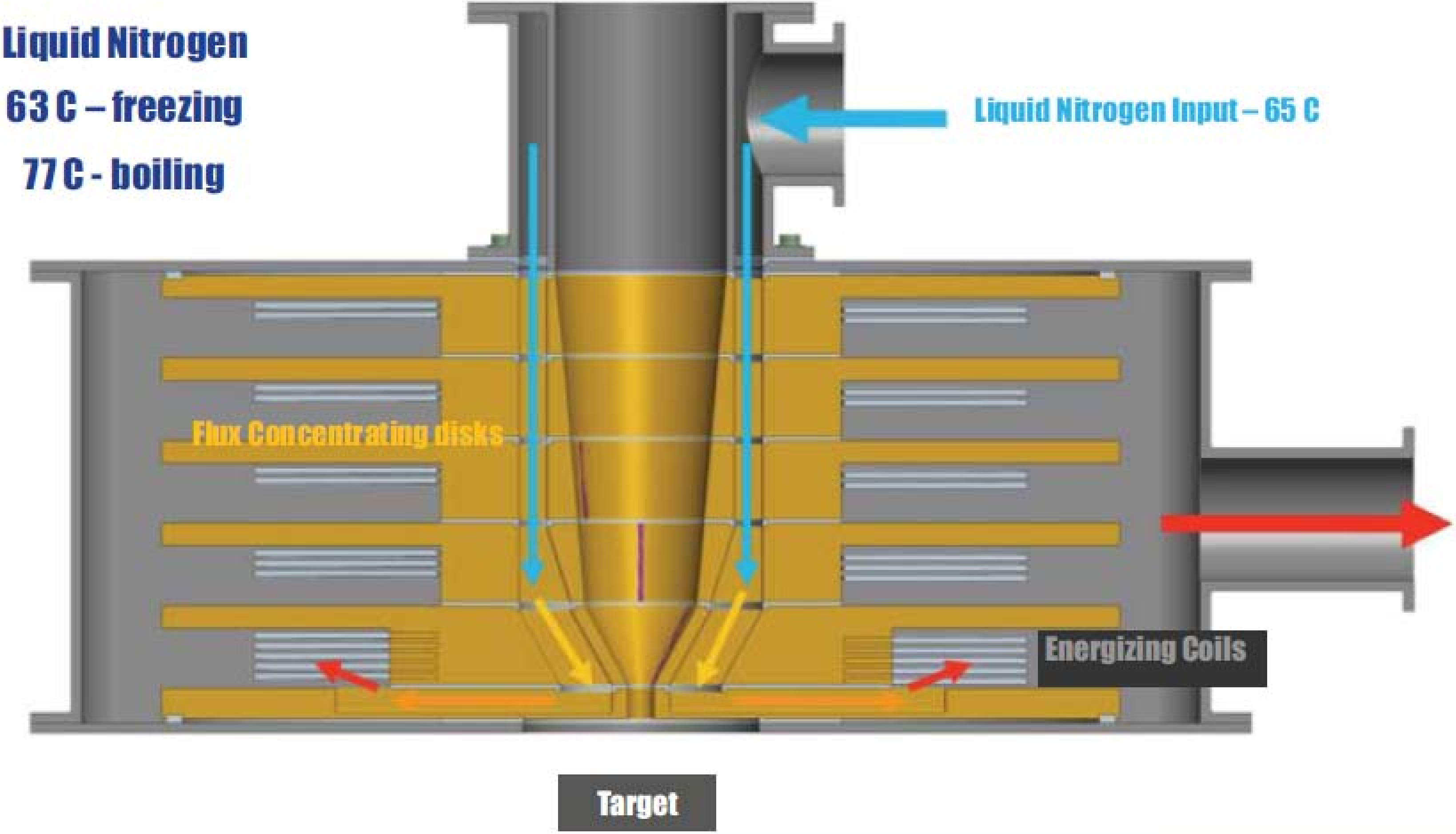
Positron Sources: Targets

The current concept of the device

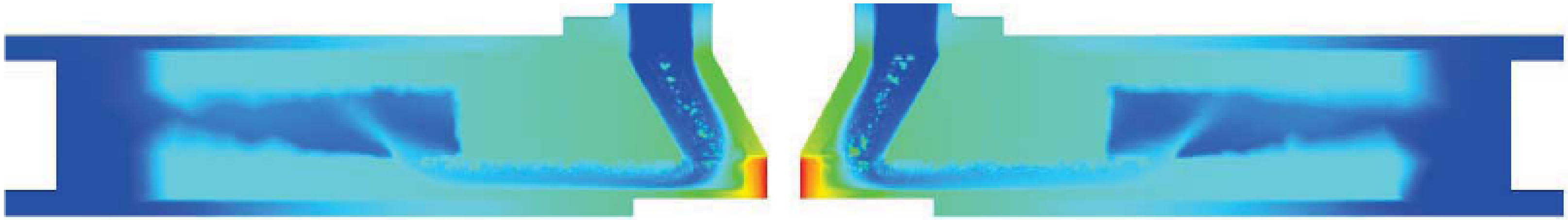
Liquid Nitrogen

63 C – freezing

77 C - boiling



Energy deposition is max at the bore



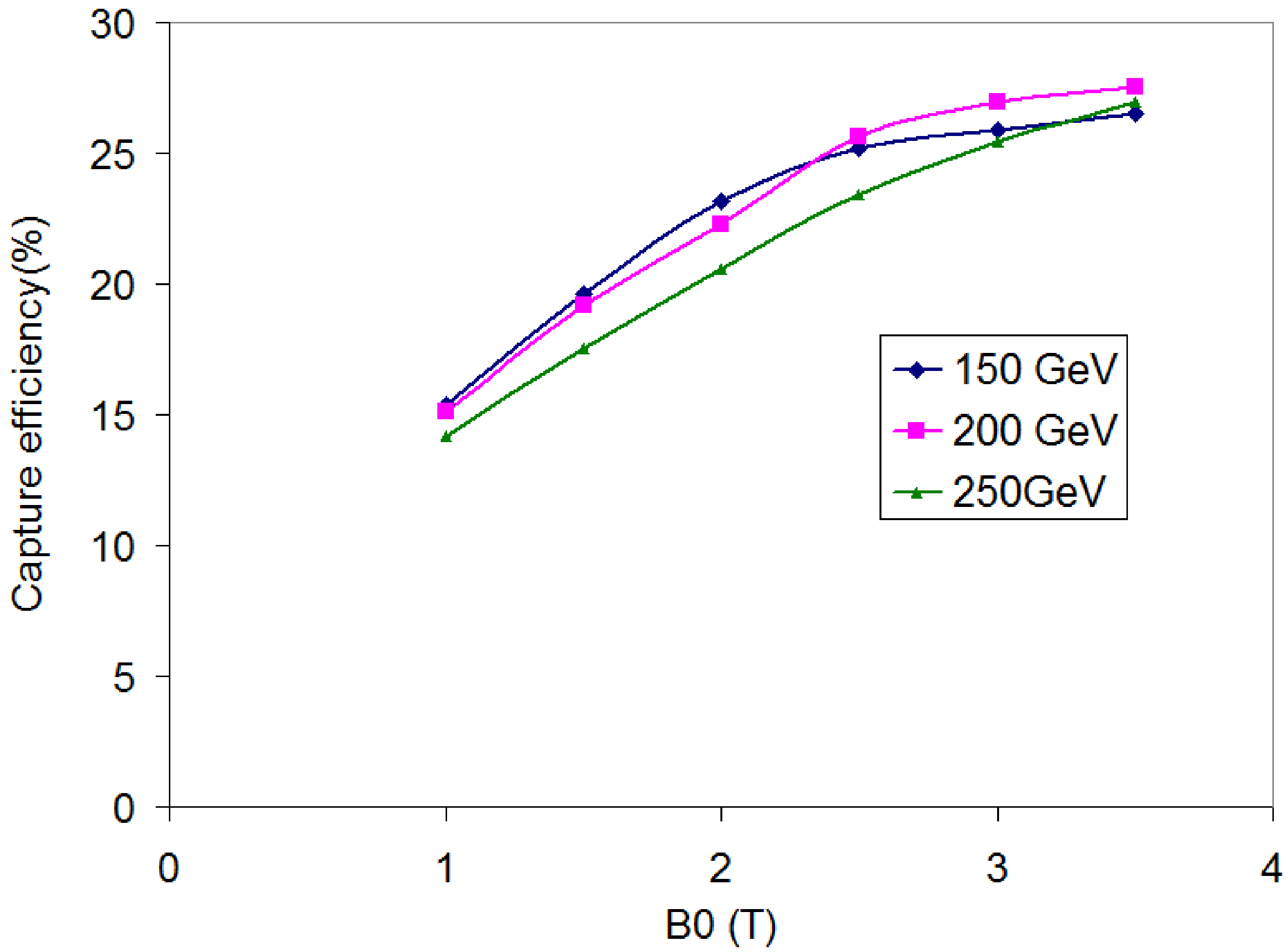
Reduced fea model of heat and coolant flow

65 C

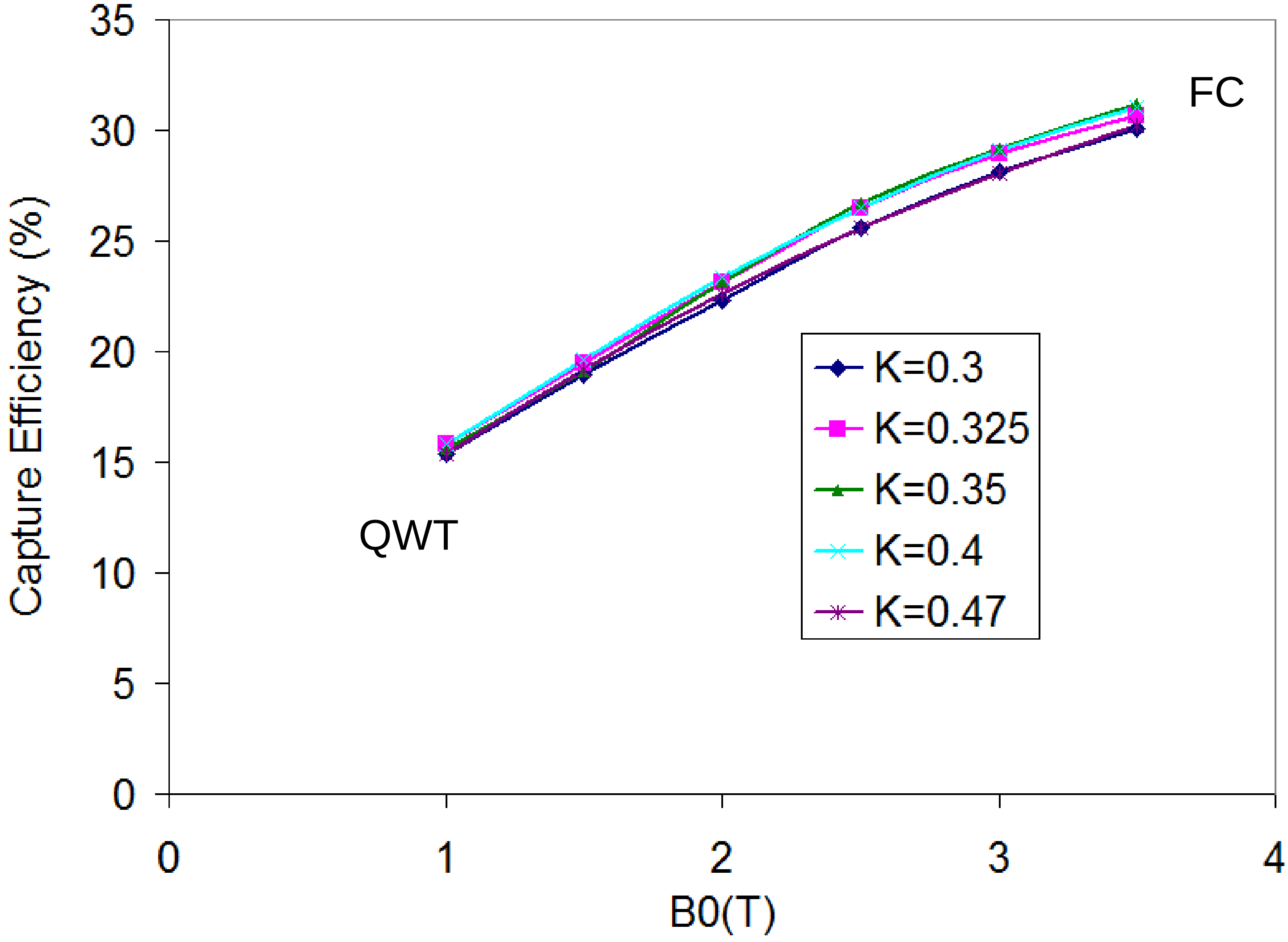
- Average power 800 W
- Desired coolant ΔT of 5 K gives 10 J/gm IN_2 cooling
- Required flow 80 gm/s = 100 cc/s = 6 lpm
- Bore Temp 97 K

- Max radiation is at bore 10^12 Gray/9 months = 8 J/gm/train
- ΔT = 4K from de/dx during the train
- Ok for boiling but prefer reduced depo for repetitive shock

Capture Efficiency for RDR Undulator with Different Drive Beam Energy

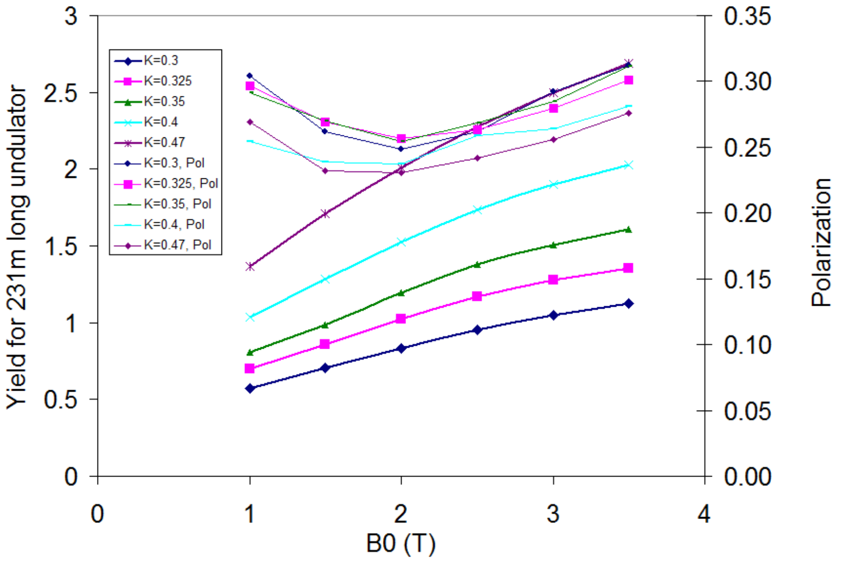


Capture Efficiency for 250 GeV Drive Beam with Different K of Undulators

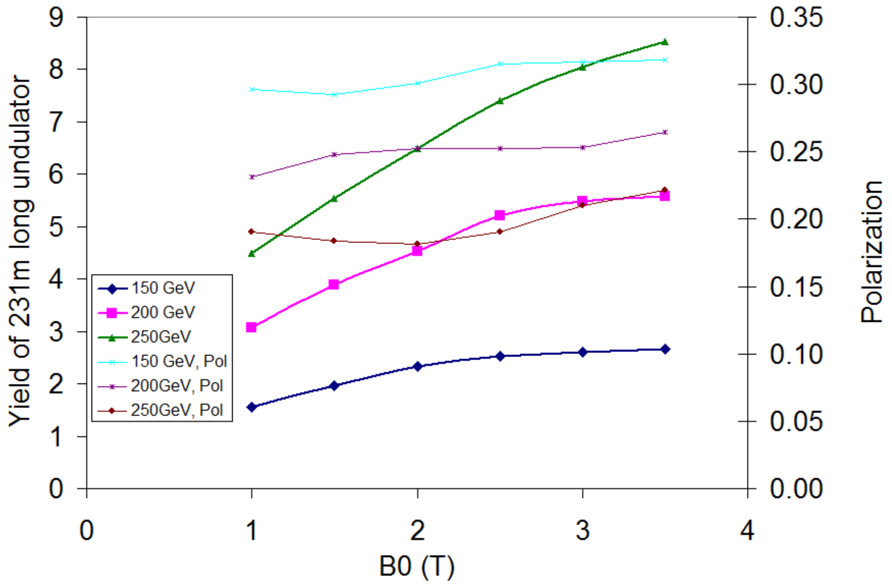


Yield and Pol

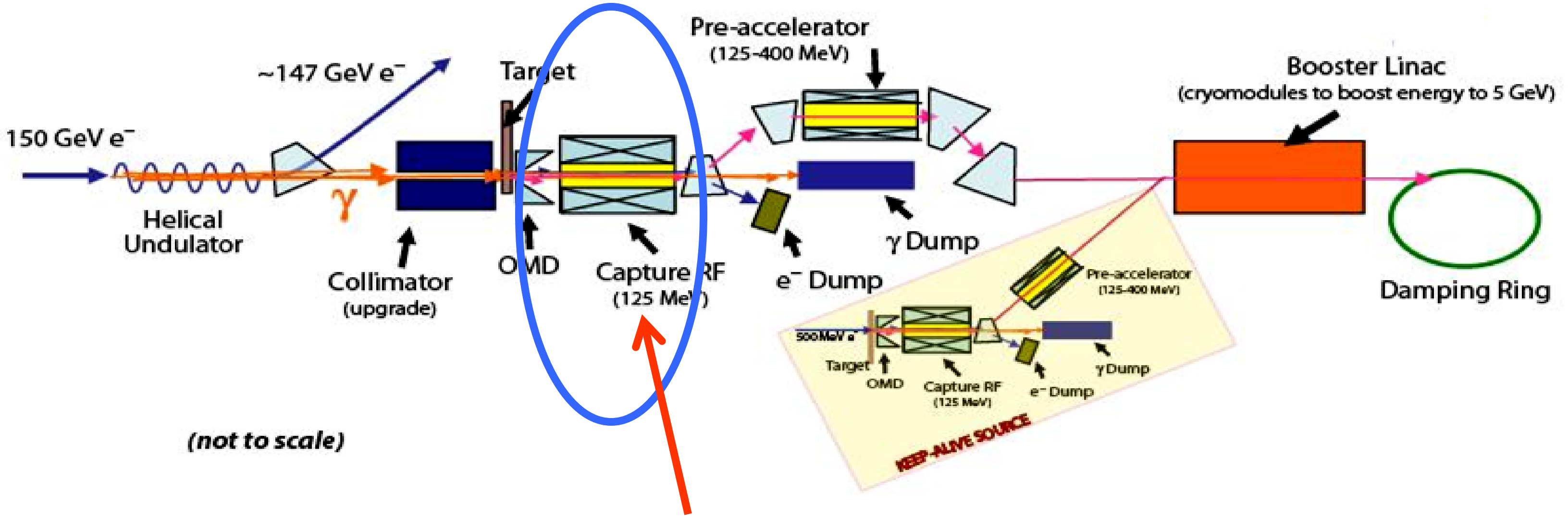
250GeV drive beam



RDR with different drive beam



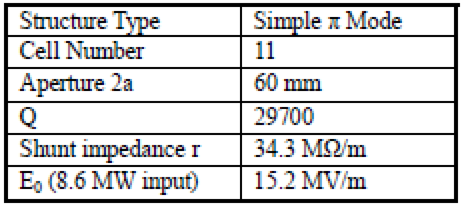
Postiron Sources



Ncrf Capture rf Structures

Positron Sources: Capture

Table 1: Parameters of SW stricture.



Structure Type	Simple π Mode
Cell Number	11
Aperture 2a	60 mm
Q	29700
Shunt impedance r	34.3 MΩ/m
E_0 (8.6 MW input)	15.2 MV/m

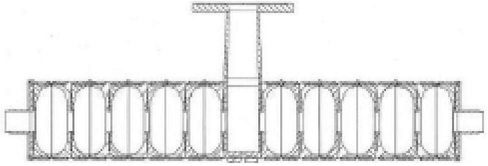


Figure3: 11–cell SW structure.

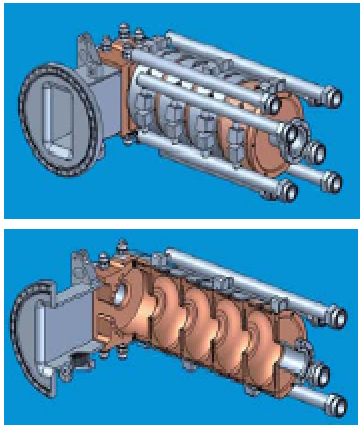
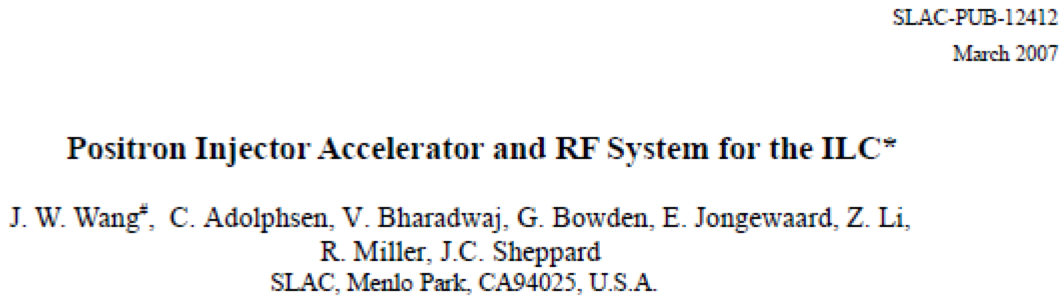


Figure 5. A 5-cell L-Band SW test accelerator section for the positron capturing structure - external view (top) and cut-away view (bottom).



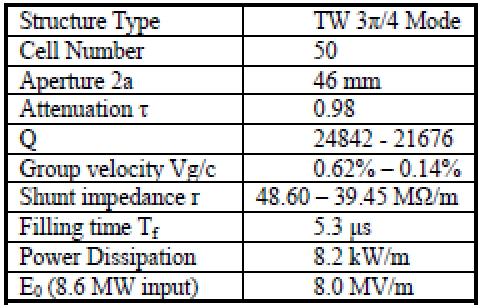
SLAC-PUB-12412

March 2007

Positron Injector Accelerator and RF System for the ILC*

J. W. Wang#, C. Adolphsen, V. Bharadwaj, G. Bowden, E. Jongewaard, Z. Li,
R. Miller, J.C. Sheppard
SLAC, Menlo Park, CA94025, U.S.A.

Table 2. Parameters of TW structure



Structure Type	TW $3\pi/4$ Mode
Cell Number	50
Aperture 2a	46 mm
Attenuation τ	0.98
Q	24842 - 21676
Group velocity Vg/c	0.62% – 0.14%
Shunt impedance r	48.60 – 39.45 MΩ/m
Filling time T_f	5.3 µs
Power Dissipation	8.2 kW/m
E_0 (8.6 MW input)	8.0 MV/m

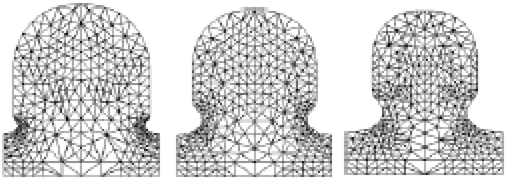


Figure 4. Profiles of the first, middle and last cell for 4.3m $3\pi/4$ Mode TW structures,

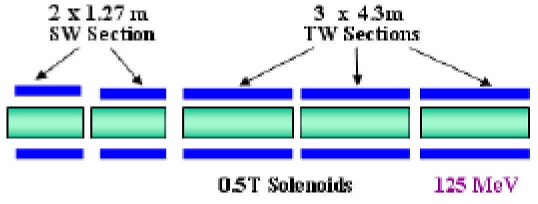


Figure 1. Schematic layout of the capture region.

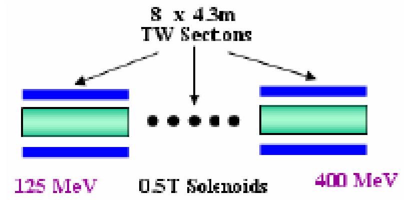
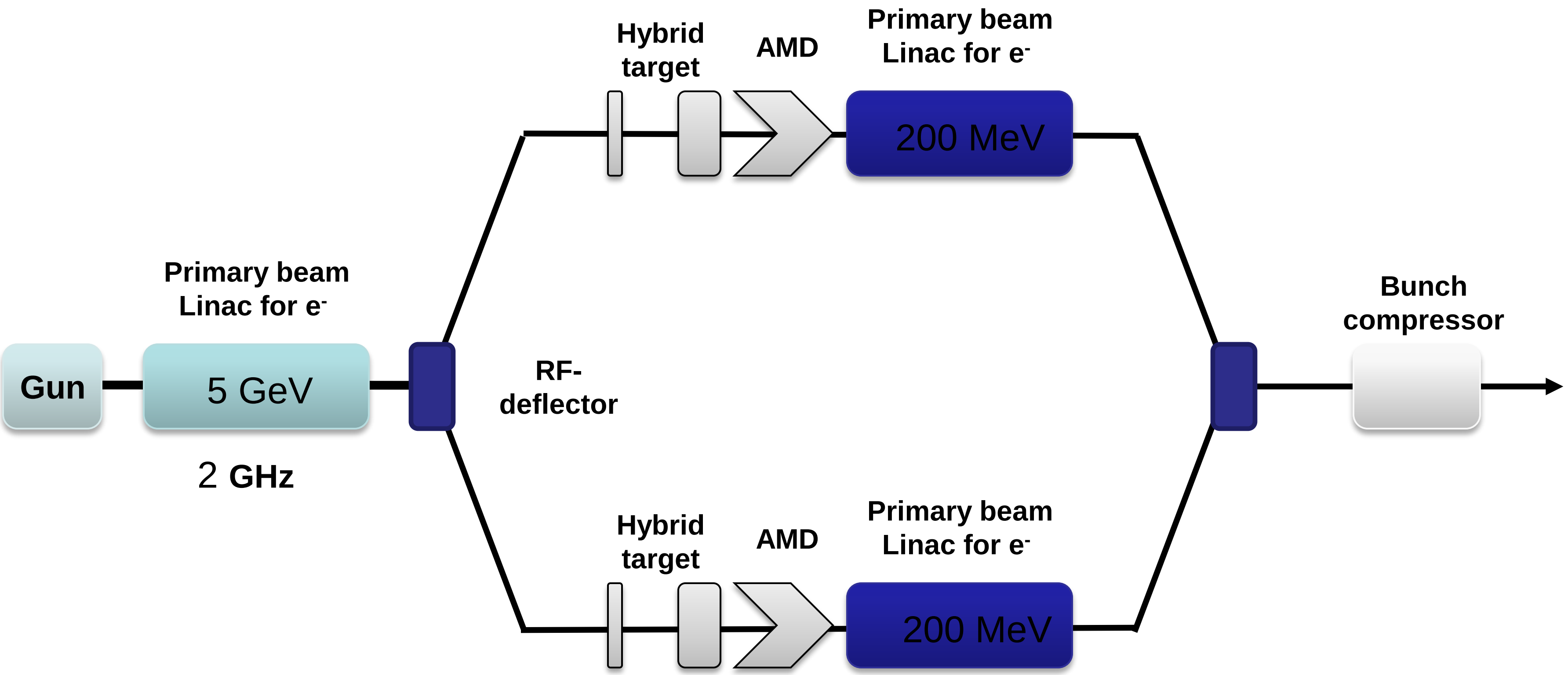


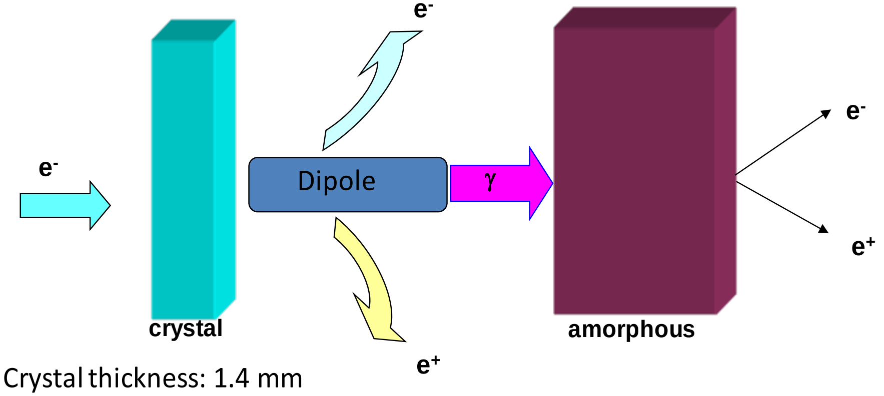
Figure 2. Schematic layout of the pre-accelerator region.

CLIC Positron source conventional ?



AMD: 200 mm long, 20 mm radius, 6T field

CLIC Hybrid target



Crystal thickness: 1.4 mm
Oriented along the <111> axis

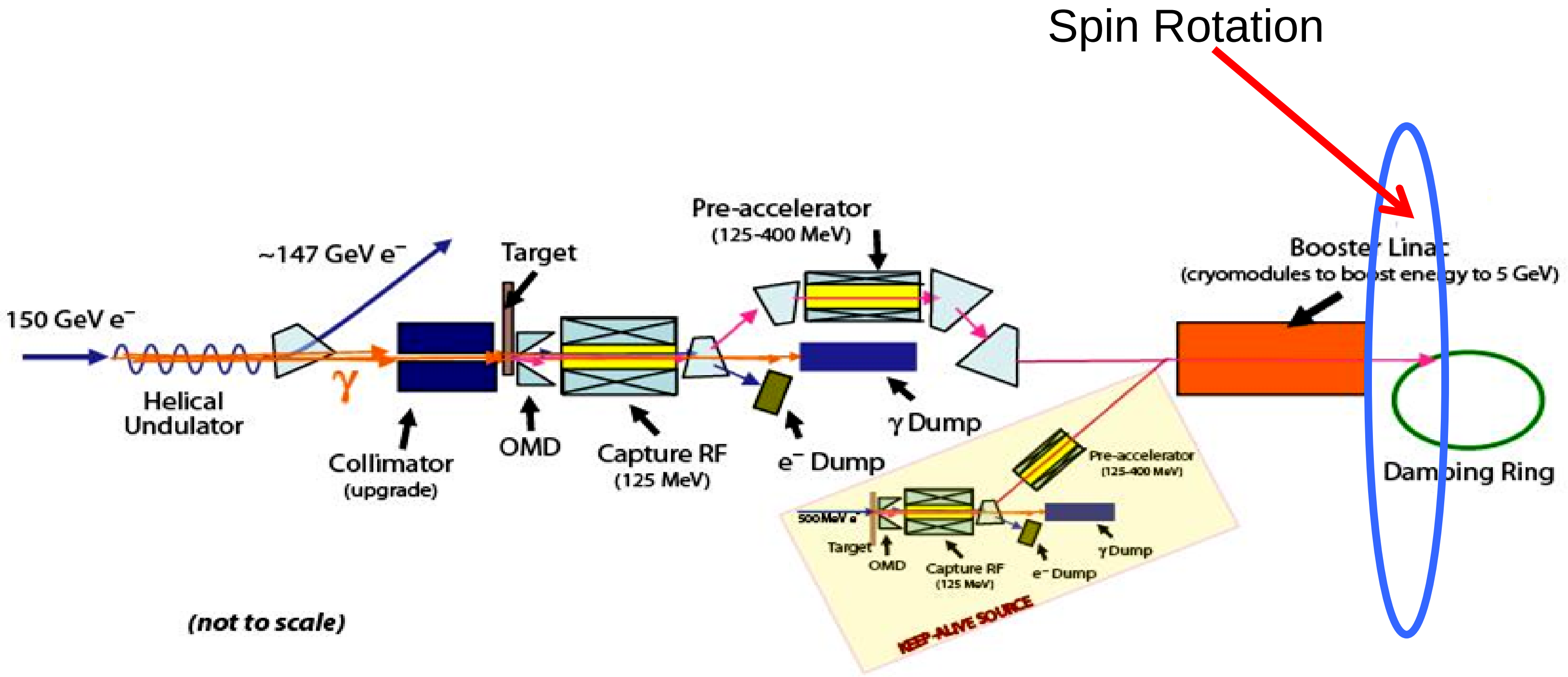
Distance (crystal-amorphous) d = 2 m

Amorphous thickness e =10 mm

Target Parameters Crystal		
Material	Tungsten	W
Thickness (radiation length)	0.4	χ_0
Thickness (length)	1.40	mm
Energy deposited	~1	kW

Target Parameters Amorphous		
Material	Tungsten	W
Thickness (Radiation length)	3	χ_0
Thickness (length)	10	mm
PEDD	30	J/g
Distance to the crystal	2	m

Postiron Sources



Spin Rotation

(not to scale)

Spin rotator location

- Spin precedes around the magnetic field

) Longitudinal Polarization should be perpendicular before DR injection

) Polarization control after DR

Spin depolarization

- In the damping rings, if the spin direction is not perpendicular to the horizontal plane, spin precedes during the storage

- Because the precession frequency depends on the beam energy, the precession phase is randomized by energy spread

- This randomization causes a significant depolarization. The spin direction has to be perpendicular to the horizontal plane to avoid this depolarization effect by the precession

Essential spin dynamics

Bryan W. Montague, Phys. Rep., **113**, No. 1, 8-13 (1984)

- Spin Precession

$$\phi_s = G\,\gamma_0\,\alpha$$

- Mean polarization:

$$< P_z >= P_0 e^{\frac{-(G\gamma_0\alpha\sigma_\delta)^2}{2}}$$

- Relative depolarization:

$$1 - \frac{< P_z >}{P_0}$$

- Where

Symbol	Value	Description
G	0.00115965219	anomalous momentum of the electron
α	-	arc bending angle
γ_0	-	relativistic factor
σ_δ	-	energy spread

March 7, 2001
jcs
rev. 1: 6/12/02
rev. 2: 6/18/02

Spin Rotation Equations

Two questions: how much does the spin precess when an electron bends in a magnetic field? and how much does the transverse component of the spin rotate in a longitudinal, solenoidal field? And what is the precession due to bending in an electric field? The short answers are given below in engineering units. For BL in units of kG-m, and E in GeV:

$$\theta_{Bend} = \frac{B(kG)L(m)}{33.359E(GeV)}\ rad \qquad (14')$$

$$\theta_{prec} = \frac{E(GeV)}{0.44065}\theta_{Bend} \qquad (15')$$

$$\phi_{rot} = \frac{B(kG)L(m)}{33.359E(GeV)} \qquad (16')$$

$$\theta_{prec\_\mathcal{E}} = \left[\left(\frac{\gamma^2-1}{\gamma}\right)\left(\frac{g}{2}\right)-\gamma\right]\theta_{Bend\_\mathcal{E}} \qquad (22)$$

Derivations of these expressions follow for the curious. This note is as much for my benefit as for anyone else who might read it. My chosen reference is J. D. Jackson, **Classical Electrodynamics**, 2nd Ed., John Wiley & Sons, Inc., 1975. Also, one might have a look at T. Roser, "Thomas-BMT Equation," **Handbook of Accelerator Physics and Engineering**, A. W. Chao and M. Tigner, ed., World Scientific, 1999, p. 148.

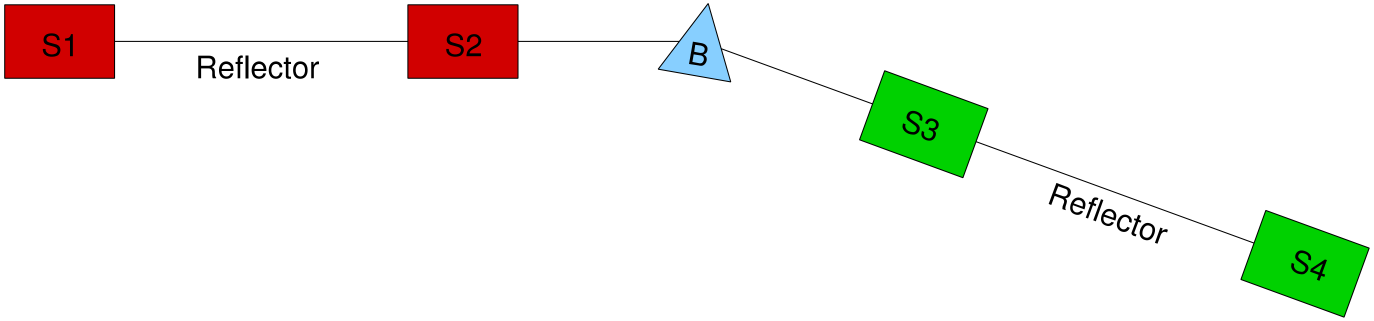
Solenoid based spin rotator

) First designed by Paul Emma for NLC

- Spin Rotation is achieved by two solenoids with a bending magnet in between
- Each solenoid is split in two parts separated by a *reflector* $\begin{pmatrix} I_2 & 0 \\ 0 & -I_2 \end{pmatrix}$ to correct for couplings) there are four solenoids in total
- The central bending section must rotate the spin by 90 degrees
- This configuration allows arbitrary spin orientation

) Sketch

Spin rotator lattice



egrees phase advance in Y

- Bend section : mini arc composed by three FODO cells with 90 degrees phase advance in X and Y (can be shortened)

The spin rotator at the entrance of the pre-damping rings starts from the bends

Solenoid strength

- ~~Each of the four solenoids must be capable of providing a maximum of ± 45~~ degrees spin rotation

$$\psi_{\text{spin}} = \pi/4, \qquad \text{with} \qquad \psi_{\text{beam}} = \psi_{\text{spin}}/2$$

\- Solenoid strength

$$k = \frac{\psi_{\text{spin}}}{2L} = \frac{B_z}{2(B_0\rho)}$$

Assuming 2.6 meters long solenoids (like ILC)

$$k = \frac{\pi/4}{2} \frac{1}{(L = 2.6 \text{ m})} = 0.15104 \text{ m}^{-1}$$

⇒ The maximum longitudinal field is:

$$B_{z,max} \ = \ 2 \cdot k \cdot (B_0\rho) \ = \ 2 \cdot k \cdot \frac{E_0}{ec} = \ 2 \cdot 0.15104 \text{ m}^{-1} \cdot \frac{E_0}{ec}$$

required magnetic field at 2.86 or 9 GeV is:

$$B_{z,max} \text{ @ } 2.86 \text{ GeV} = \mathbf{2.9} \text{ T}$$

$$B_{z,max} \text{ @ } 9 \text{ GeV} = \mathbf{9.1} \text{ T}$$

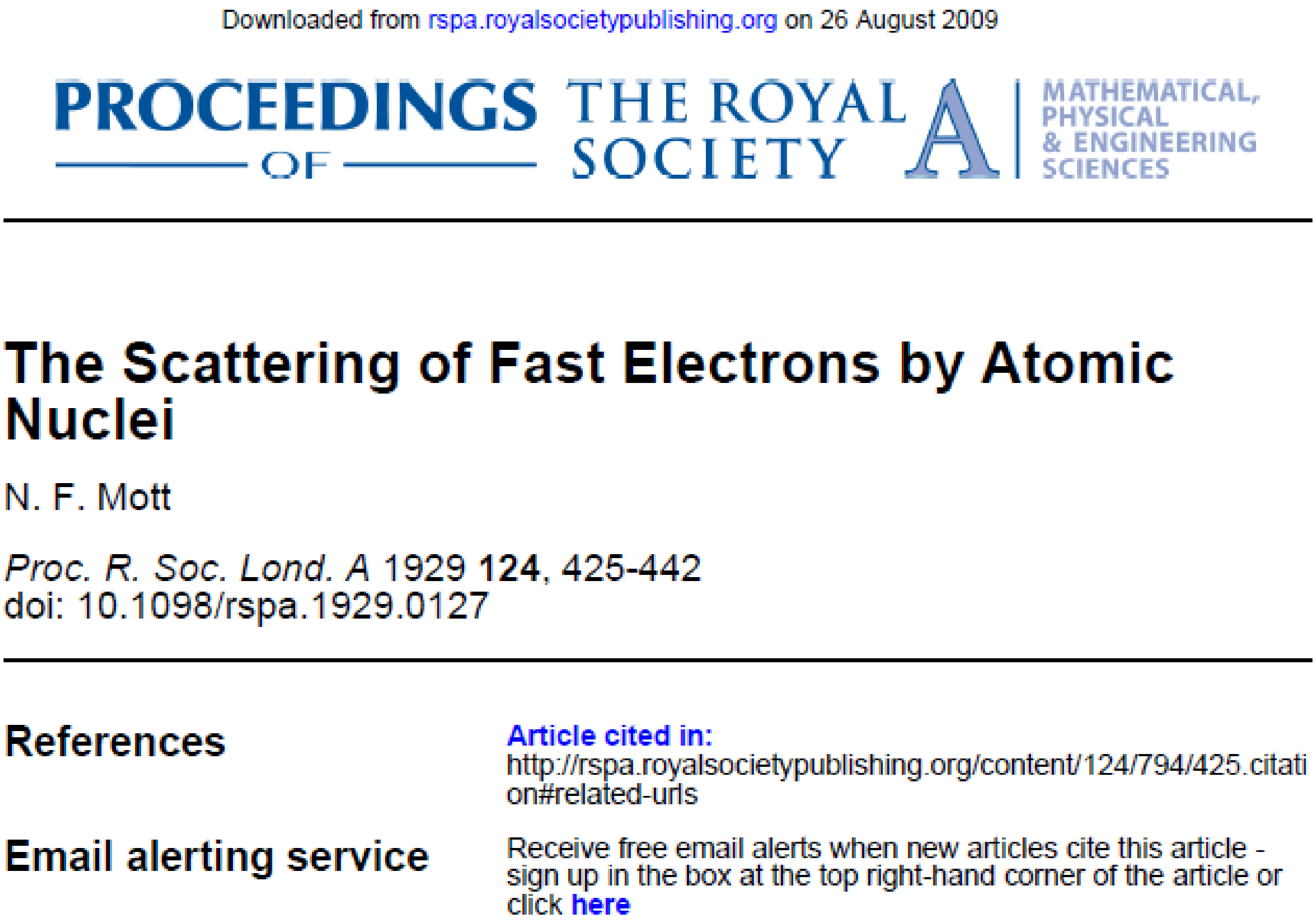
Positron Sources: Polarimetery

Polarimetery

- Not going to say too much
- Relies on finding a process that depends on the spin orientation
- The processes are all based on scattering

Low energy---(non-relativistic….gun energies) Mott Scattering—charged paricles
Low energy---(several MeV……) Compton Transmission—polarized photons off of polarized electrons
High Energy---(>100's MeV) Moeller Scattering---e-/e+ scattering off polarized e- in a magnetized foil [Bhabha in case of e+]
High Energy---(GeV) Compton Scattering—laser photons off e-/e+

CLIC Electron Beam Demo: Polarimetry



PROCEEDINGS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

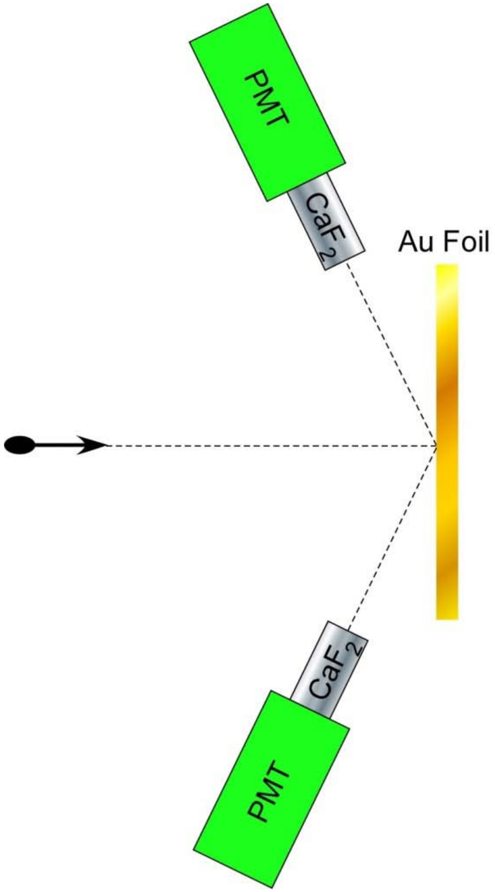
The Scattering of Fast Electrons by Atomic Nuclei

N. F. Mott

Proc. R. Soc. Lond. A 1929 **124**, 425-442
doi: 10.1098/rspa.1929.0127

References	**Article cited in:** http://rspa.royalsocietypublishing.org/content/124/794/425.citation#related-urls
Email alerting service	Receive free email alerts when new articles cite this article - sign up in the box at the top right-hand corner of the article or click **here**

CLIC Electron Beam Demo: Polarimetry



Mott Polarimetry:

Scatter electrons off a gold foil and measure up-down asymmetry

RF Guns

Required for XFELs due to low longitudinal emittnace

Not used for LC primary elctrons due to polarization requirement

Used for CLIC Drive beam generation

Cathode Heating for Operations and Cleaning

J. C. Sheppard, et al.
Rev. 1: November 4, 2011

What are the pulse temperature changes during normal LCLS operations and during laser cleaning? I am coming up with $\Delta T_{ops} = 51^{\circ}K$ and $\Delta T_{clean} = 2835^{\circ}K$.

$\Delta T_{ops} = 51^{\circ}K$ seems reasonable whereas $\Delta T_{clean} = 2835^{\circ}K$ seems interesting.

Table 1 lists a variety of copper properties

Property	Symbol	Value	Units
Atomic weight	A_r	63.5	-
Density	ρ	8940	kG/m^3
Heat capacity	C_V	0.385	kJ/kg/°K
Heat of fusion	ΔH_{fus}	13.36	kJ/mol
Heat of vaporization	ΔH_V	300.4	kJ/mol
Melting Point	Tm	1358	°K
Boiling Point	Tv	2835	°K
Index of refraction	ñ	1.47+1.78i	@5.00 eV
Optical reflection coefficient	R	0.366	@5.00 eV
Optical attenuation length	λ_{opt}	23	nm @5.00 eV

Table 2 lists typical laser parameters for 100 pC operations and for laser cleaning

Property	Symbol	Value	Units
Spot Size	D	1.00×10^{-3}	m (spot diameter)
Pulse Energy	U_{ops}	10×10^{-6}	J (100pC@QE=5e-5)
Spot Size	σ_r	30×10^{-6}	m (rms spot size)
Pulse Energy	U_{clean}	$17\text{-}20 \times 10^{-6}$	J

RF Guns: Cu Cathode

The basic formula for temperature rise is:

$$\Delta T = \frac{R \times \varepsilon \Delta E}{C_v \rho \Delta V}$$

Wherein R = the optical reflection coefficient; ε = the fractional amount of energy absorbed in the depth λ_{opt} , ΔE = incident energy; C_v = heat capacity; ρ = material density; and ΔV = the volume into which RεΔE is absorbed.

For standard operations, the temperature rise is small compared to the melting temperature so the ΔE is simply: $\Delta E = U_{ops}$. Thus

$$\Delta T_{ops} = \frac{R \times \varepsilon U_{ops}}{C_v \rho \Delta V_{ops}}$$

RF Guns: Cu Cathode

The reflection coefficient, R, is given by:

$$R=\left(\frac{\tilde{n}-1}{\tilde{n}+1}\right)\left(\frac{\tilde{n}-1}{\tilde{n}+1}\right)^{\dagger}=0.366$$

The fractional amount of energy absorbed in one attenuation depth, λ_{opt} , is:

$$\varepsilon(z=\lambda_{opt})=(1-e^{-2z/\lambda_{opt}})=(1-e^{-2})=0.86\,.$$

Underestimates volume because thermal diffusion has been neglected

Note: $\lambda_{opt}=\frac{\lambda}{2\pi\,\mathrm{Im}(\tilde{n})}=\frac{\lambda}{2\pi\kappa}=23\,nm$.

The volume into which the energy is deposited is take for the case of normal operations to be:

$$\Delta V_{ops}=\pi\frac{D^2}{4}\lambda_{opt}=1.8\times10^{-14}\,m^3\,.$$

For the case of laser cleaning, the energy is deposited in the volume:

$$\Delta V_{clean}=2\pi\sigma_r^2\lambda_{opt}=1.6\times10^{-16}\,m^3\,.$$

RF Guns: Cu Cathode

The energy density in the case of laser cleaning raises the temperature to the melting temperature (but not to boiling). So at 1358°K the deposited energy available to increase the temperature is reduced by the heat of fusion, ΔE_m:

$$\Delta E_{fus} = \rho \Delta V_{clean} \Delta H_{fus} = 0.24 \times 10^{-6}\, J$$

And for completeness

$$\Delta E_{v} = \rho \Delta V_{clean} \Delta H_{v} = 5.5 \times 10^{-6}\, J\,.$$

The temperature rise during laser cleaning is thus given as

$$\Delta T_{clean} = \frac{R \times \varepsilon U_{clean}}{C_v \rho \Delta V_{clean}} \quad \text{for } T<1358^\circ K$$

and

$$\Delta T_{clean} = \frac{(R \times \varepsilon U_{clean} - \Delta E_{fus})}{C_v \rho \Delta V_{clean}} \quad \text{for } T>1358^\circ K$$

Calculation needs to be corrected……to include thermal diffusion over the 2 ps laser pulse in comparison to a 23 nm absorption depth

RF Guns: Laser

LCLS Laser is a tripled Ti:Sapphire system running at 252 nm.

10 µJ per pulse for 100 pC

20 µJ per pulse in 30 mm rms spot for laser cleaning

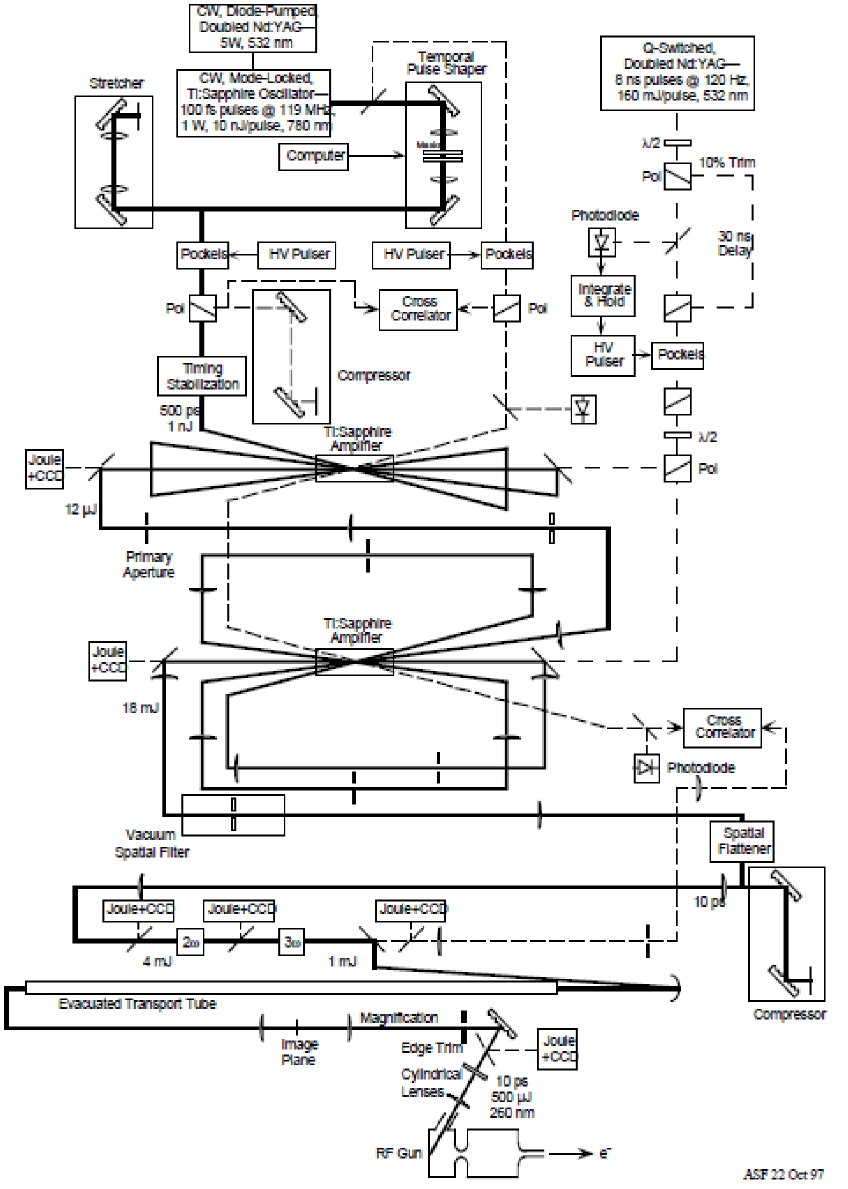


Figure 6.1-5. The drive laser for the rf photocathode electron gun for the LCLS. The thick lines show the main beam path, the closely spaced, dashed lines indicate diagnostic beams, and the widely spaced, dashed lines are pump beams.

LCLS Parameters

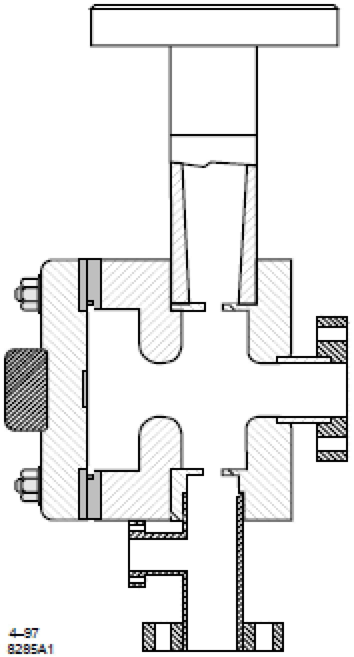


Figure 6. 1-1. Cross section of rf gun. The rf coupler is the top coupler shown here. The bottom port is for the adjustable short and vacuum pump. The electron beam exits to the right.

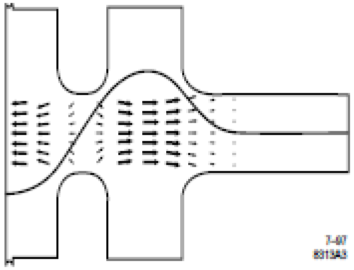


Figure 6. 1-2. π-mode field lines for the rf gun obtained with SUPERFISH.

RF Gun delivers 100pC-1 nC, 2 ps long bunches at 6.2 MeV with gradients of ~150MeV on the walls

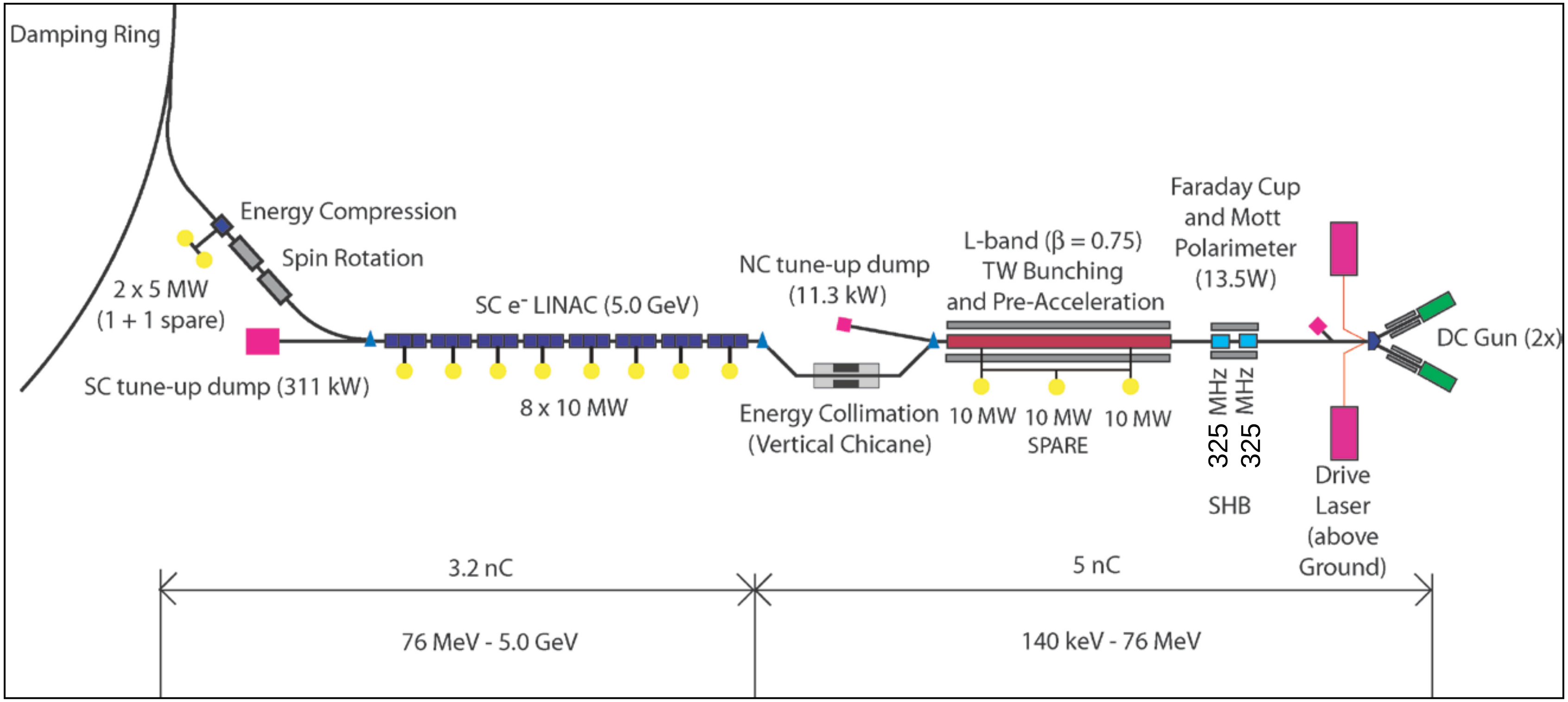
Review

ILC Electron Source

ILC Positron Source

Review: ILC Electron Source

Electron source provides polarized electron beam and consists of all systems from source laser to 5 GeV injection to damping rings. (2011 layout: 325 MHz SHB)



200 kW Electron Beam

200 kV Guns: under development

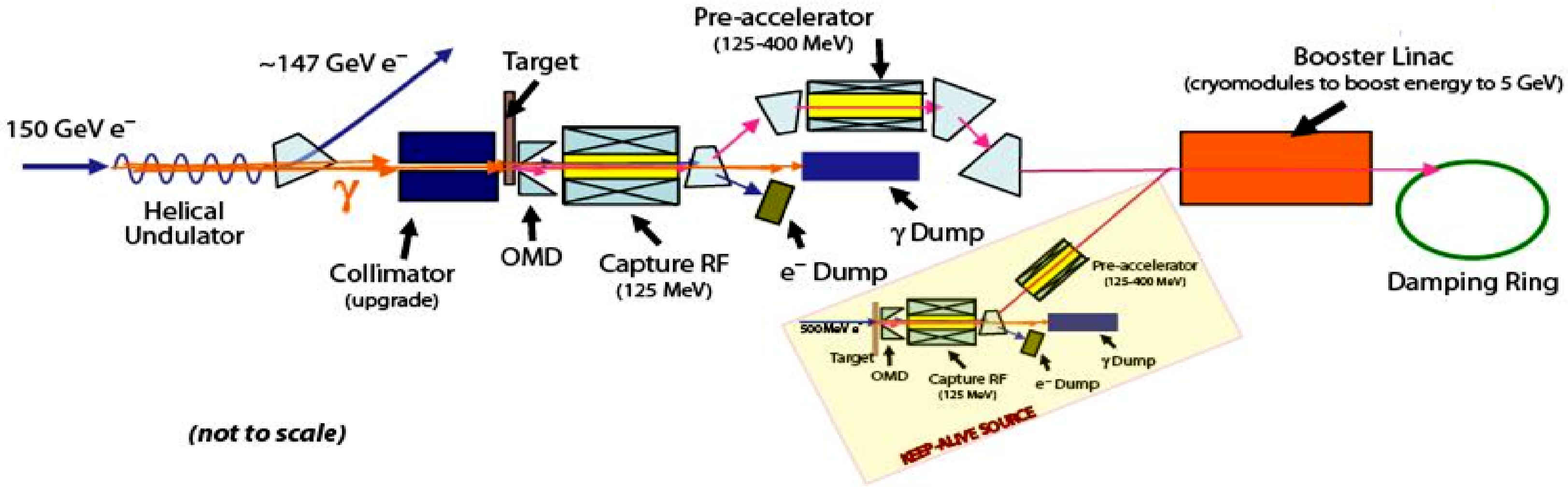
1.5 MHz Lasers: under development

325 MHz Bunching System (October, 2011): needs development

NC RF 1 ms Accelerator Structures: needs development

10 Hz SCrf Accelerator Structures: need attention, Main Linac people

Review: ILC Positron Source



(not to scale)

200 kW Positron Beam

Helical Undulator λ= 1 cm, K =1: Needs development

100 kW Photon Collimator: Needs development

Rotating Ti-target: Needs development

1 ms Flux Concentrator: Needs development

NCrf SW Capture Section: Needs development

200 kW Positron Beam

NC rf TW Accelerator Sections: Needs development

Low energy Lattice: Needs development

Positron Spin Flip Transport: Needs development

Keep Alive System: Needs development

Review: Homework

Space charge derivation
Laser power requirements
Drive beam/undulator lengths
Spin Rotation equation derivations

Extra credit: 1-d thermal diffusion

Review: Final Exam Questions

Question 1

Question 2

Question 3

Answer any 2