Linear collider: Electron and positron source Potential R&D items

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3/11/02

Electron Source: Potential R&D Items

- Polarized dc electron gun cathode development
- Polarized rf electron gun
- Flat beam electron gun
- Polarized electron gun laser system development

Electron sources: R&D items

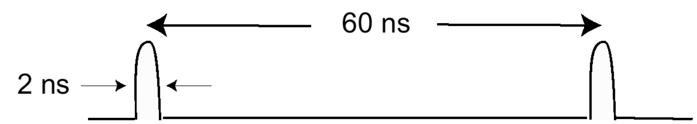
Polarized electron gun cathode development-from LC'02 presentation of T.Maruyama (SLAC)

SLC had 80% polarization. Why more research?

SLC photocathode cannot produce NLC beam with 80% polarization due to the surface charge limit.

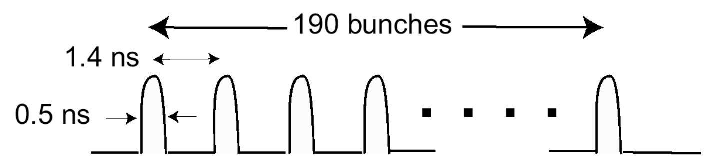
Polarization will be 60 ~ 65%.

SLC beam



1.6×10^{11} e-/bunch achieved

NLC beam



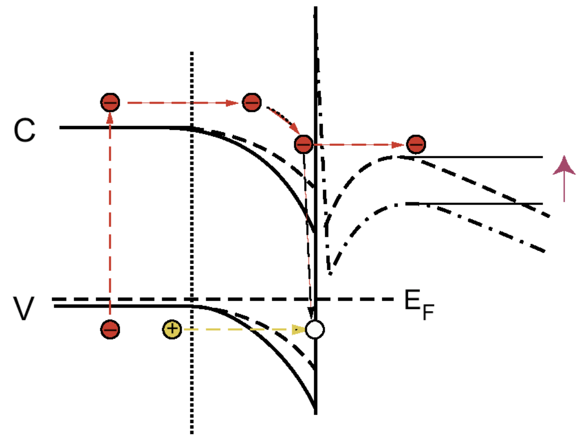
1.4×10^{10} e-/bunch x 190 bunches = 2.7×10^{12}/train

Goals

- Produce NLC beam with 80% polarization
- Higher polarization

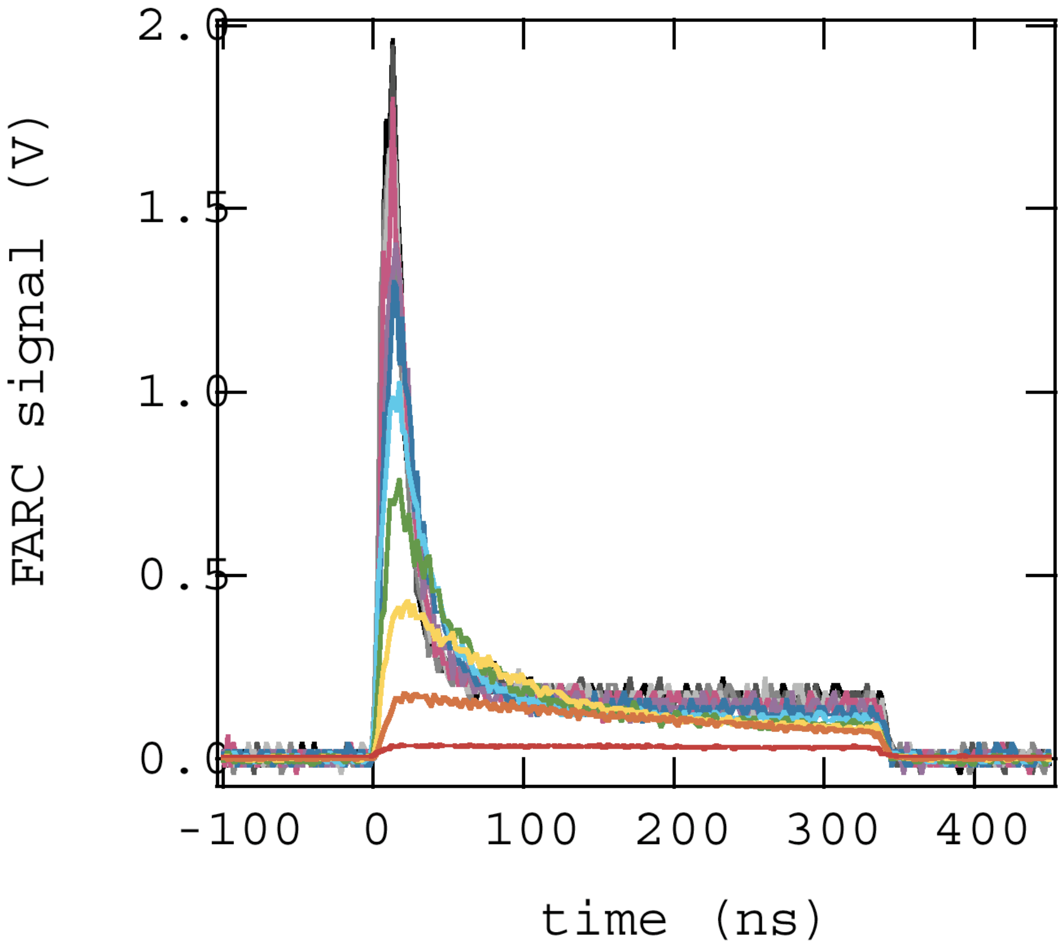
Surface Charge Limit

Charge output is not proportional to light intensity



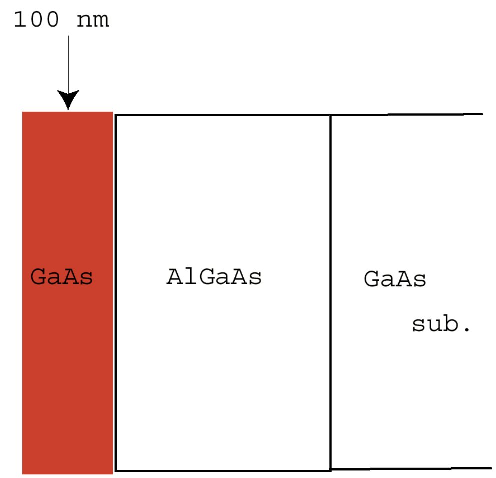
- Photon absorption excites electrons to conduction band
- Electrons can be trapped near the surface
- Electrostatic potential from trapped electrons raises affinity
- Increased affinity decreases emission probability
- Affinity recovers after electron recombination
- Increasing photon flux counterproductive at extremes

Long Pulse Signal



Charge Limit vs. Doping Concentration

Samples: thin unstrained GaAs grown by Quantum Epitaxial Devices



Doping concentration:

$$5 \cdot 10^{18}, \quad 1 \cdot 10^{19}, \quad 2 \cdot 10^{19}, \quad 5 \cdot 10^{19}\ \mathrm{cm}^{-3}$$

Measure charge output

Measure charge restoration time

Develop photovoltage model

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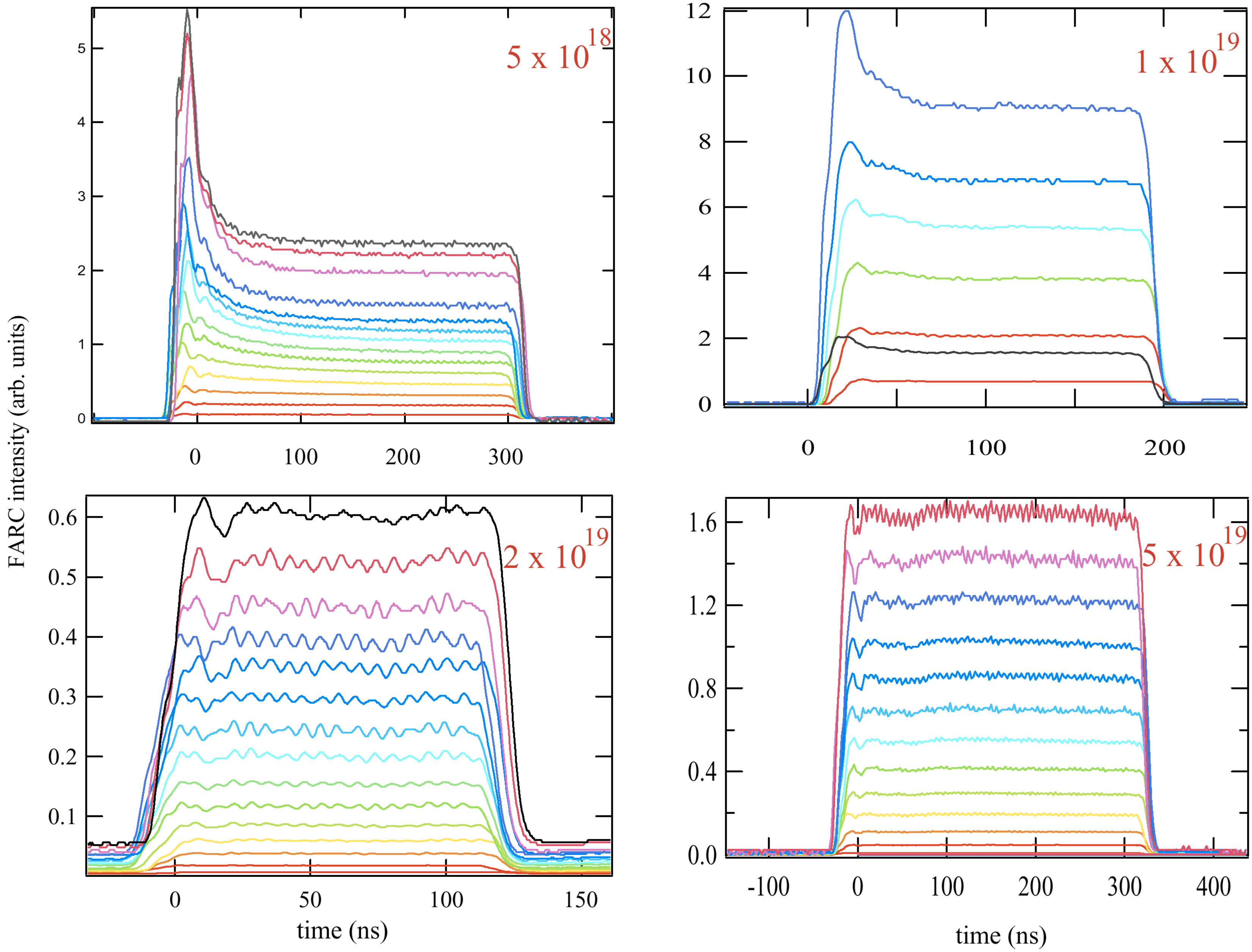
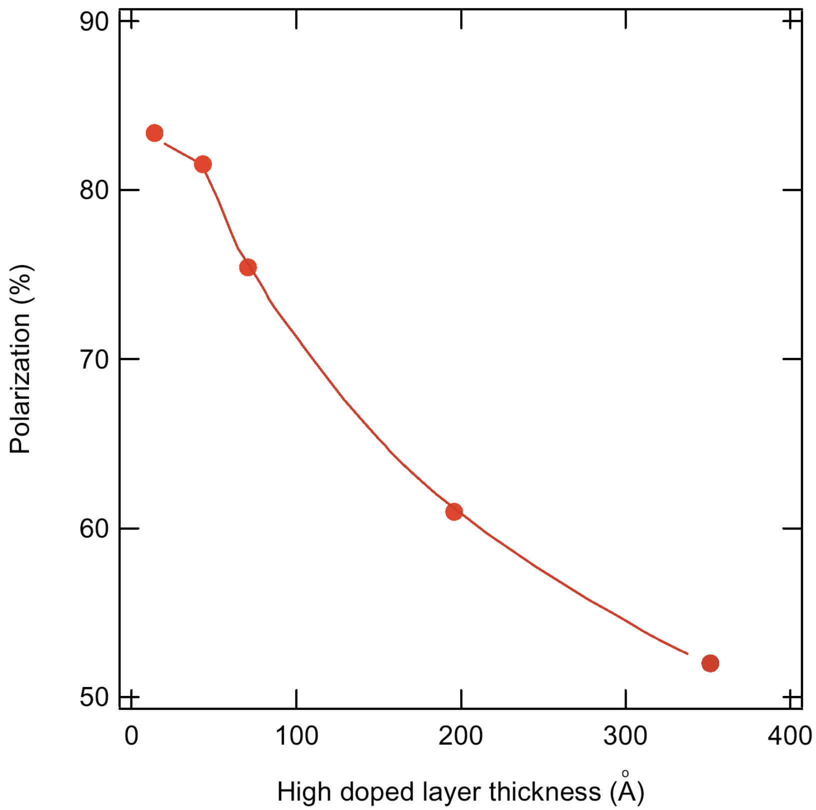
Faraday Cup Signal



Polarization vs High Doped Layer Thickness

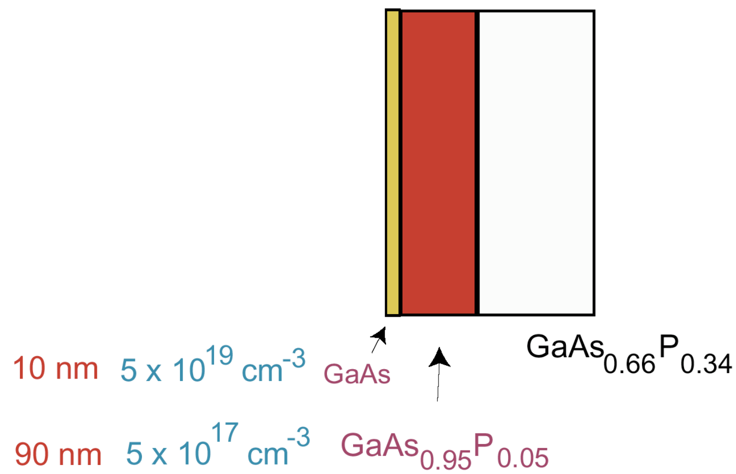


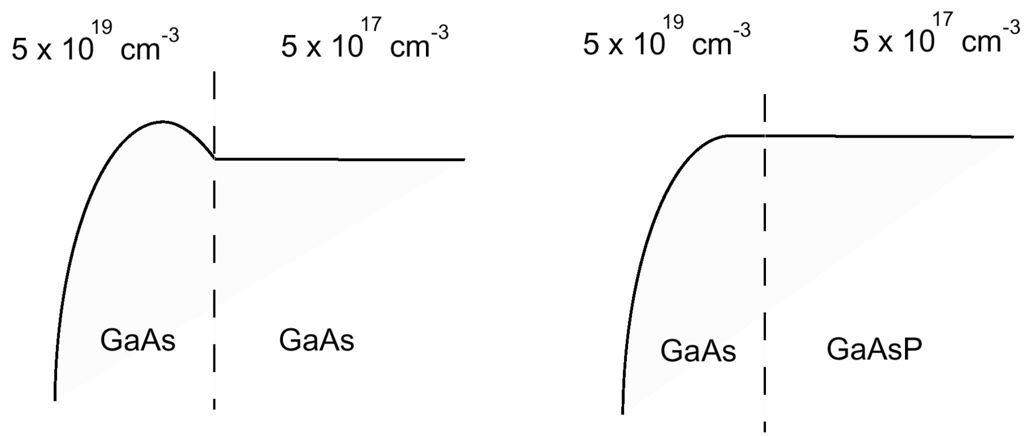
High doping depolarizes spin.

Possible to reach ~80 % polarization with 50 ~ 75 Å of high surface doping.

High-Gradient-Doped Strained GaAsP

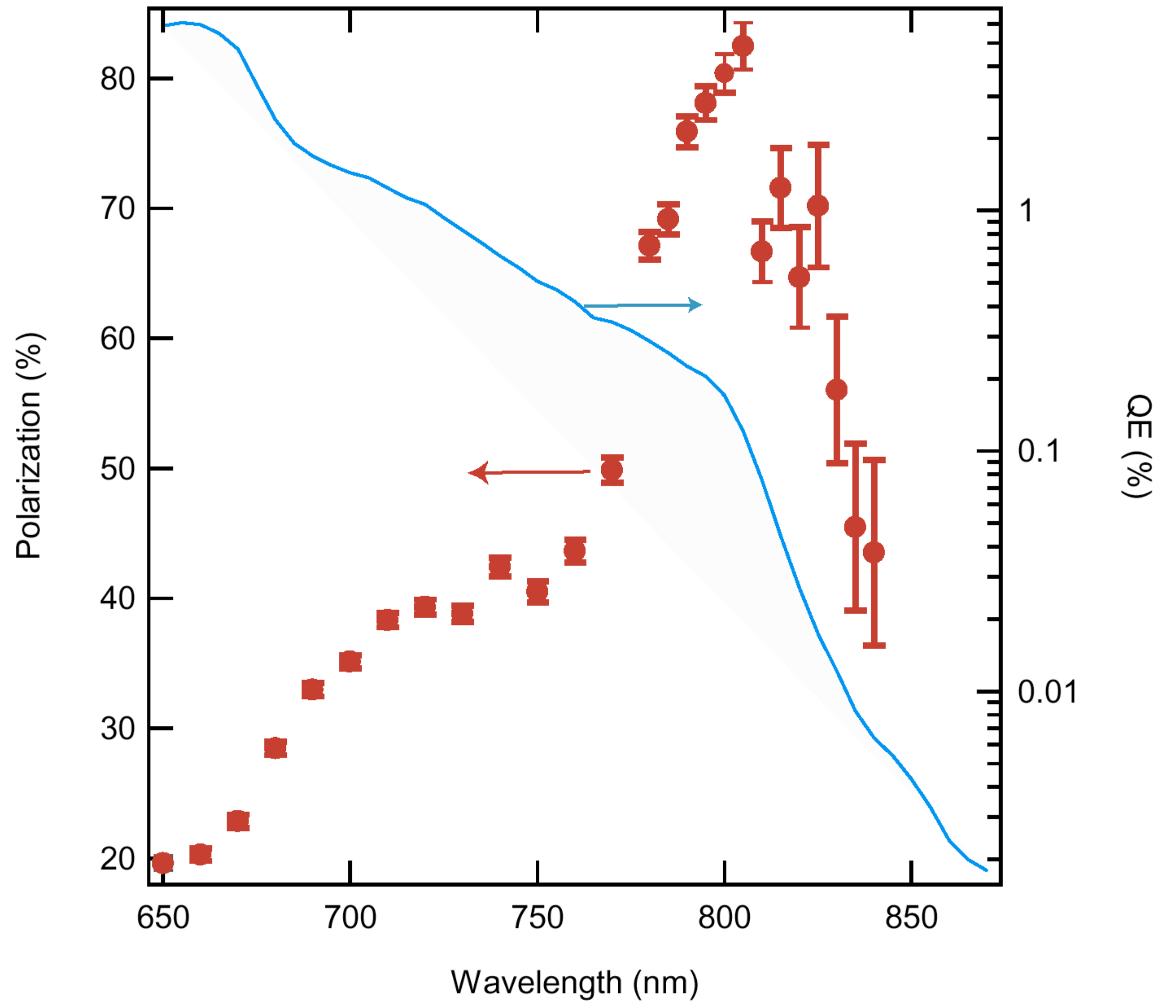
Grown by Bandwidth Semiconductor



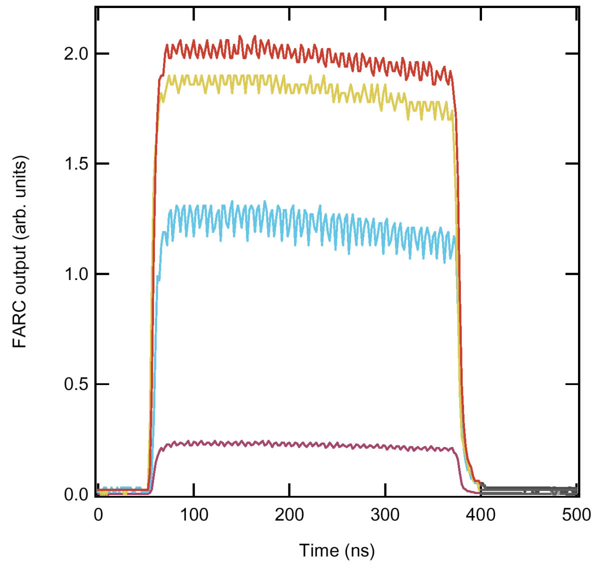


Strained GaAs Strained GaAsP

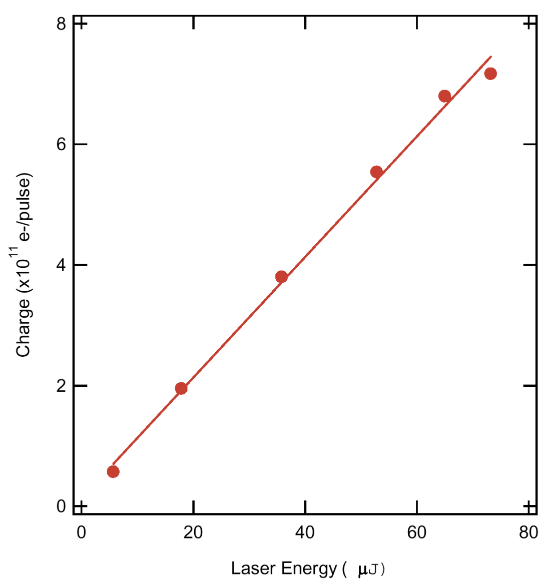
Polarization and QE as a function of wavelength measured in the CTS lab.



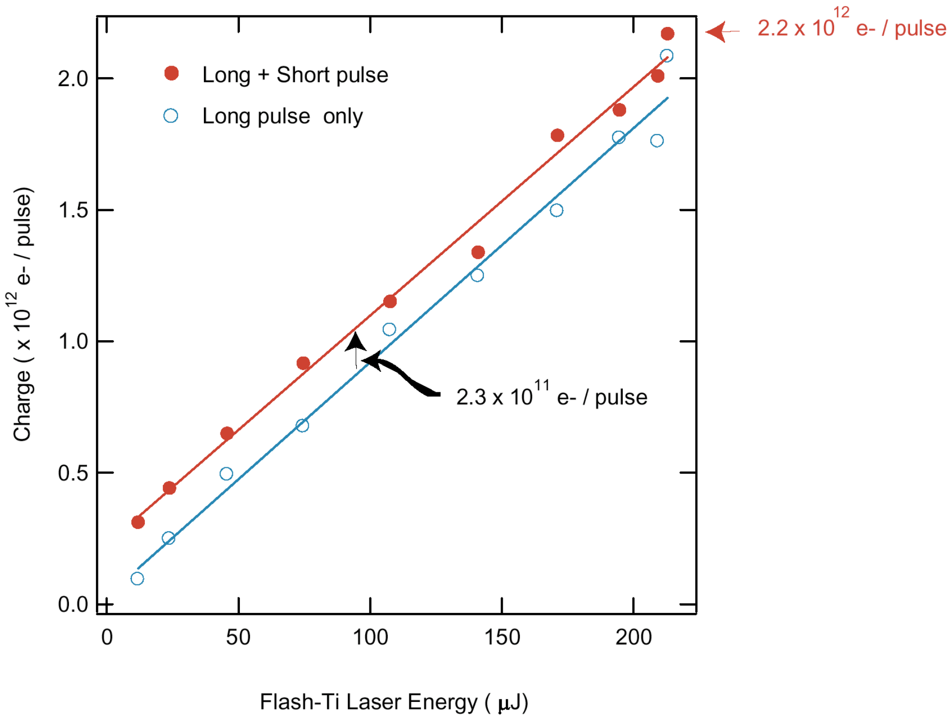
Faraday cup signal measured using varying Flash-Ti laser energies.



Charge output as a function of Flash-Ti laser energy.



Charge Output from 14 mm ϕ Laser Beam



2.2×10^{12} e- → 4.5×10^{12} e- from 20 mmϕ

> NLC train charge 2.7×10^{12} e-

2.3×10^{11} e- in 4 ns → 9.2 A

> NLC peak current 4.5 A

Electron sources: R&D items

Polarized rf electron gun :Issues

- Slow response time of GaAs
- Vacuum requirements
- Cathode Sensitivity to dark current
- Cathode Sensitivity to ion bombardment
- Cathode sensitivity to magnetic field

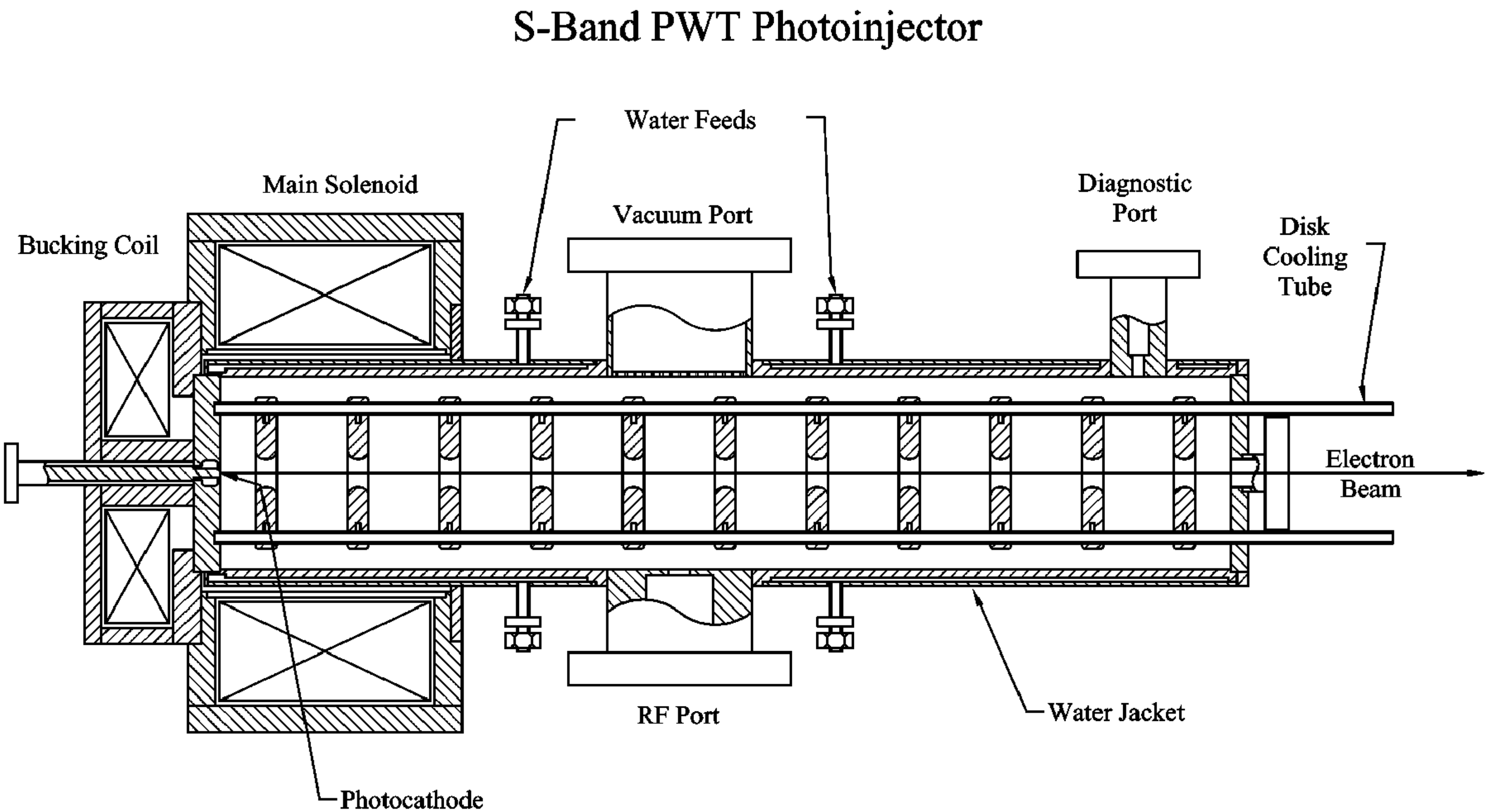


Figure 1: Schematic of the DULY S-Band Integrated PWT Photoelectron Linac.

-from LC'02 presentation of J.Clendenin (SLAC)

Electron sources: R&D items: Flat beam electron gun:

- An idea of Brinkmann, Derbenev, and Flottmann
- Impose a solenoidal field at the cathode of an rf photocathode gun
- After emerging from the solenoid, the beam has angular momentum
- The angular momentum may be transformed into an emittance asymmetry (flat beam) with a quadrupole channel matched to the solenoid.
- Experiments at the A0 photoinjector at Fermilab have observed a 50:1 transverse emittance ratio in a 17 MeV electron beam

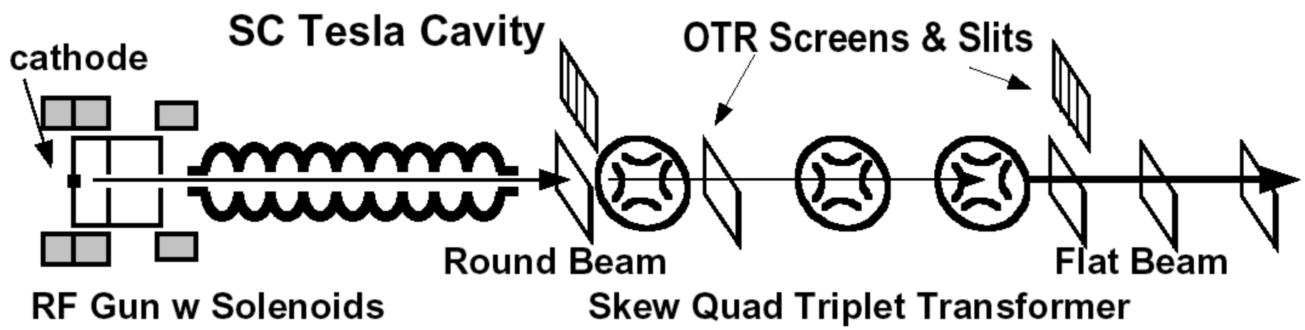


Figure 1: Very schematic rendition of the layout at Fermilab related to this experiment.

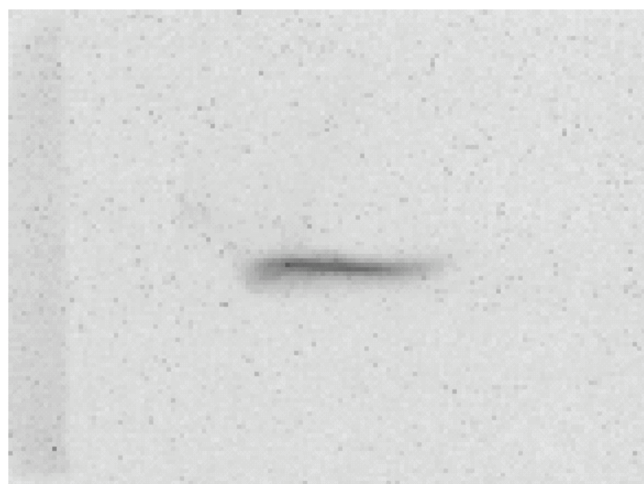


Figure 2: Beam profile on OTR screen 1.2 m downstream of the third skew quadrupole.

Electron sources:
R&D items: Flat beam electron gun

- The actual “flat” emittance in the Fermilab experiment was close to 1 μm, still much larger than a damping ring emittance; but emittance compensation was not correct for the optics used.
- The beam is unpolarized. The technique has not yet been applied to polarized-source photocathodes.

Electron sources:
R&D items

Laser system development-slides from NLC review (SLAC)

Source Laser R+D (Post CDR)

- Use diode laser for source seed
  - Greatly reduced complexity
  - Limited tuning range, electrical bandwidth
- Direct diode pumped lasers: eliminate flash lamps
  - Cr:LiSAF laser crystal: Directly produces the required wavelength
- Diode pumped pump lasers: Eliminate flashlamps
  - Less technically challenging than direct diode pumping final laser
  - Use Nd:YLF (or similar) conventional diode pumped materials
  - Use Yb:YAG newer material - higher efficiency
- Increased optics automation - reduce the need for expert "tweaking" of laser systems
- If new technologies do not perform as required
  - Study performance of conventional systems
  - construct conventional prototype

Positron Sources: Potential R&D Items

- Development of undulator-based (polarized) positron source
- Development of laser-based (polarized) positron source
- Positron yield enhancements using crystal targets

Positron sources:
R&D items

Development of undulator-based (polarized) positron source-slides from R. Pitthan, J. Sheppard (LC'02)

An Immodest Proposal

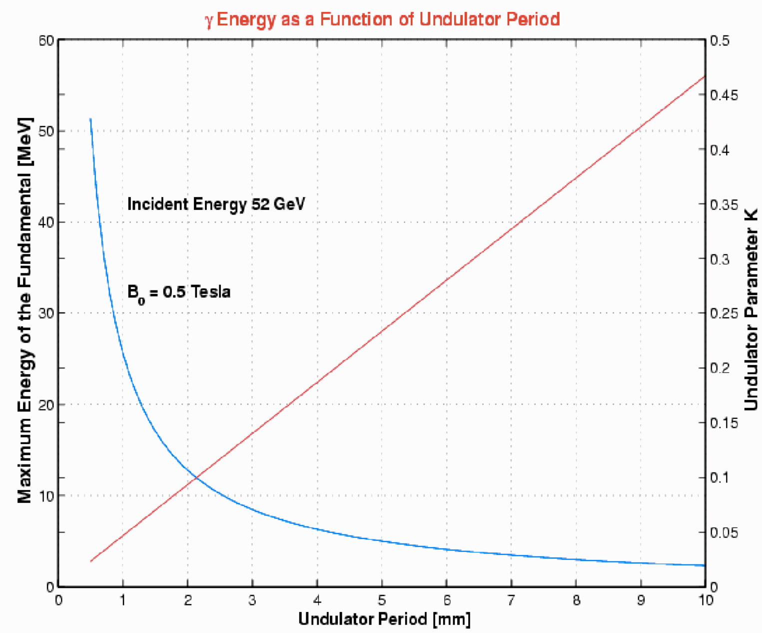
Use the SLAC 50 GeV, low emittance beam in conjunction with a ≈ 1-2 mm period helical undulator to demonstrate undulator based production of polarized positrons for linear colliders

Measure the yield, spectrum, and polarization of both the photons and positrons

Do this in the next 18-30 months in the FFTB enclosure:

- Proof of Principle Demonstration
- Validate Codes
- Develop γ Spin Diagnostics
- Develop e+ Spin Diagnostics

- Maybe Get a Surprise (better not)



SLAC can produce a single bunch electron beam of
N_e = 1x10^{10} e^-/bunch, E_e = 50 GeV, and $\gamma\varepsilon_x = \gamma\varepsilon_y$ = 1.5x10^{-5} m-rad
For a helical undulator $\lambda_u = 0.001\, m \text{ and } B_0 = 0.5\, T,$

$$K_u = 93.44 B_0(T)\lambda_u(m) = 0.0467$$

$$\Delta E(eV) = 1450 \frac{E_e^2(GeV)K_u^2}{\lambda_u^2(cm)} = 7.68\times10^5\ eV/m/e^- = 0.768\ MeV/m/e^-$$

$$E_{c10} = \hbar\omega_{10} = \hbar\frac{4\pi\gamma^2\ c/\lambda_u}{\left(1+K_u^2\right)} = 23.7\ MeV$$

$$_{h\upsilon}E_{avg} = E_{c10}\times\frac{\sum hsum}{\sum hsum./ww10} = 0.51E_{c10} = 12.0\ MeV/photon$$

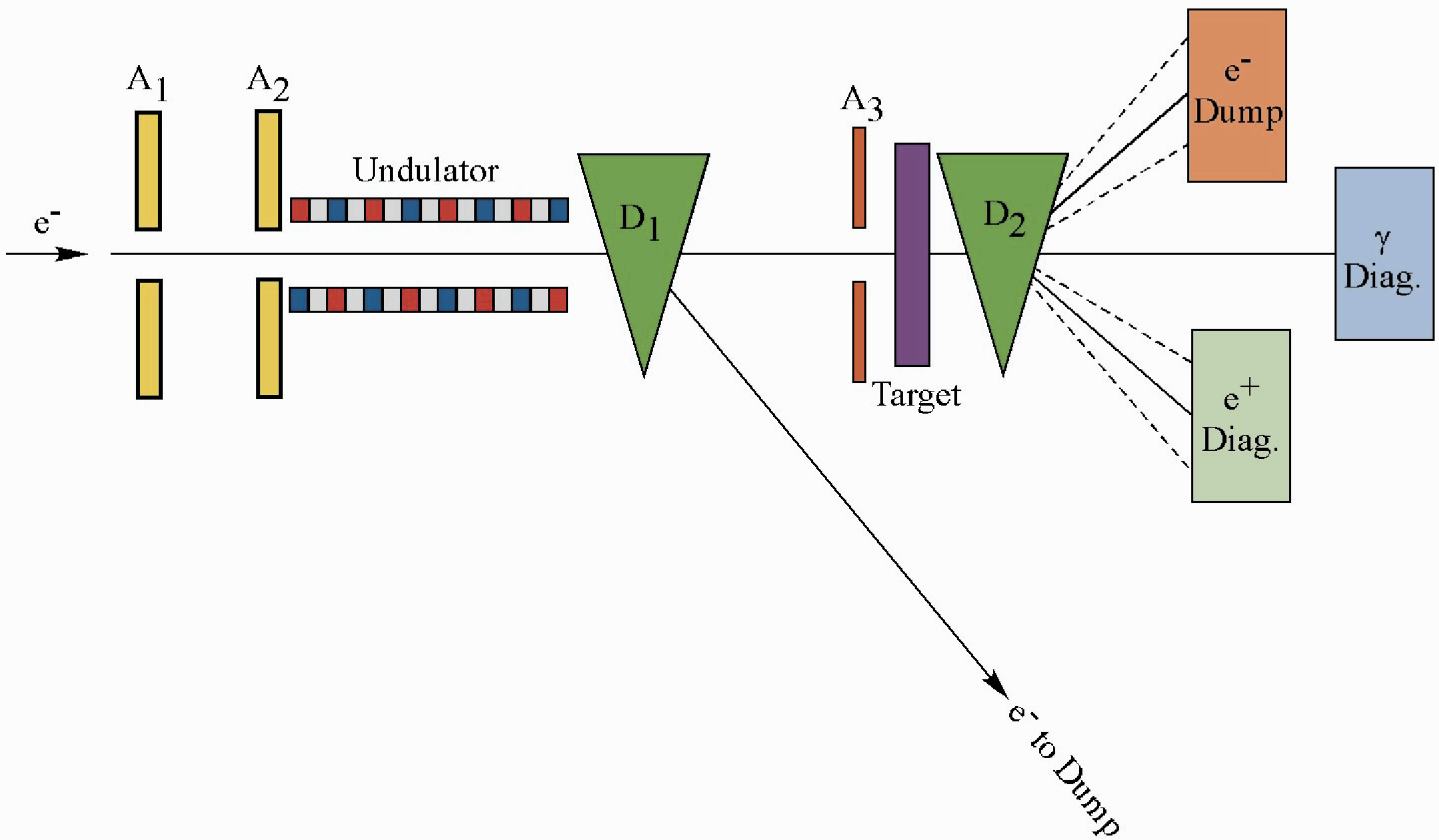
$$N_{h\upsilon} = \frac{\Delta E}{_{h\upsilon}E_{avg}} = \frac{0.768\ MeV/m/e^-}{12.0\ MeV/photons} = 0.064\ photons/m/e^-$$

In this energy region, $_{h\upsilon}Y_p$, the yield of positrons from gammas incident on 0.4 r.l. of Ti, is about 5%.

For N_- = 1x10^{10} e^- per bunch, the expected yield of e^+ is then

$$N_+ = N_-\times N_{h\upsilon}\times{}_{h\upsilon}Y_p = 1\times10^{10}\times0.064\times0.05 = 3\times10^7\ e^+/m/bunch$$

What Does the Hardware Look Like?



Built and Tested (Rossmanith)!

- Much R&D exist on short period undulators. Gap:Period typically ≈ 1:4
- Example for planar configuration with a double superconducting solenoid from ANKA (Karlsruhe).
- Period λ_u = 3.8 mm
- Design field B_0 (solenoid center) = 0.5 Tesla, field in gap is 3 times higher

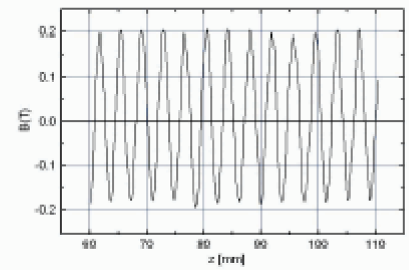
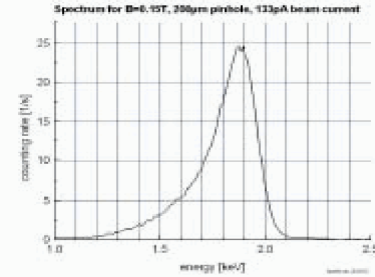


Fig. 3 Field of one undulator coil measured with a miniature Hall probe at a distance of 0.5 mm. The current was 600 A.



- Experiment done at Mainz at 885 MeV: achieved were 1.8 keV X-rays
- Scaled to 52 GeV @ 0.5 Tesla: 6.2 MeV
- Scaled to 52 GeV @ 1.0 Tesla: 12.4 MeV
- Scaled to 52 GeV @ 1.9 mm and 1 Tesla: ≈25 MeV

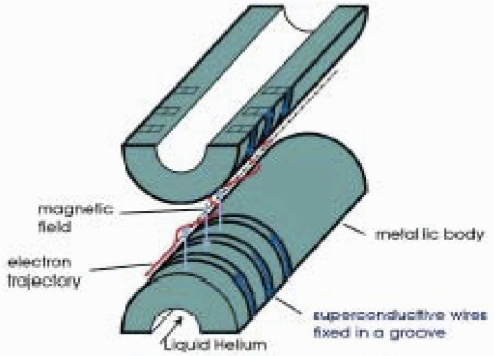
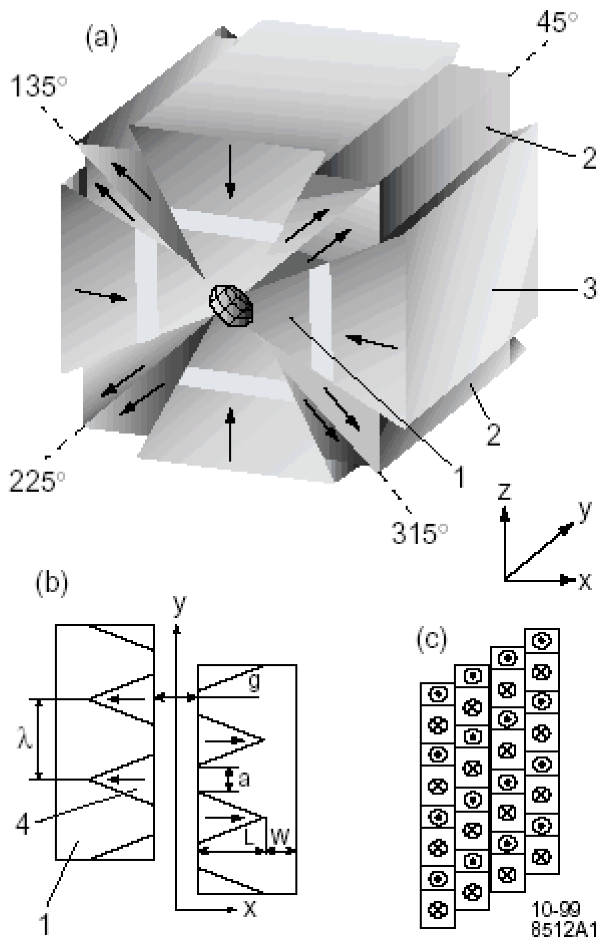


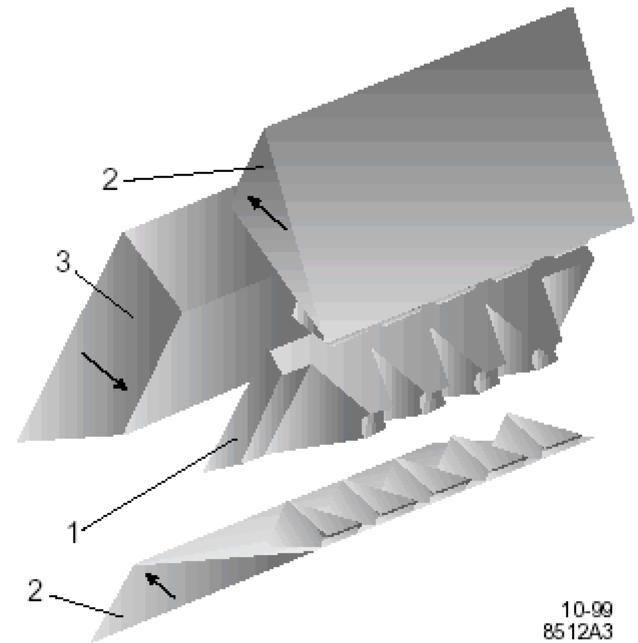
Fig. 1 Layout of the undulator. The field is generated by superconductive wires with alternating current directions. Two identical coils, indirectly cooled by LHe, are placed above and below the electron beam.

Designed: Permanent Magnet Helical Design

- At SSRL: hybrid/PM development

SLAC-PUB-8347

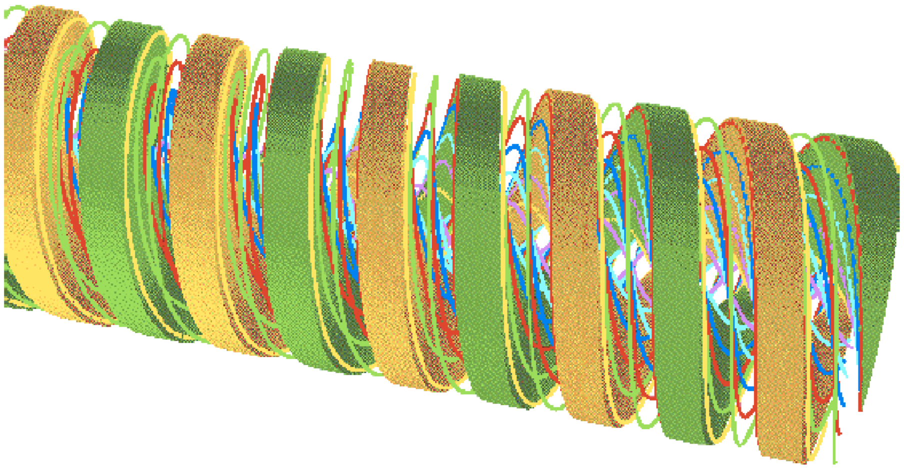


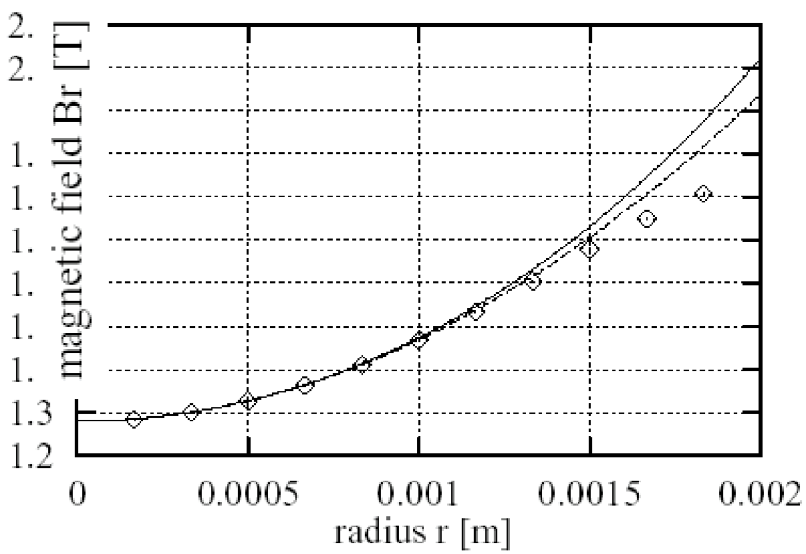


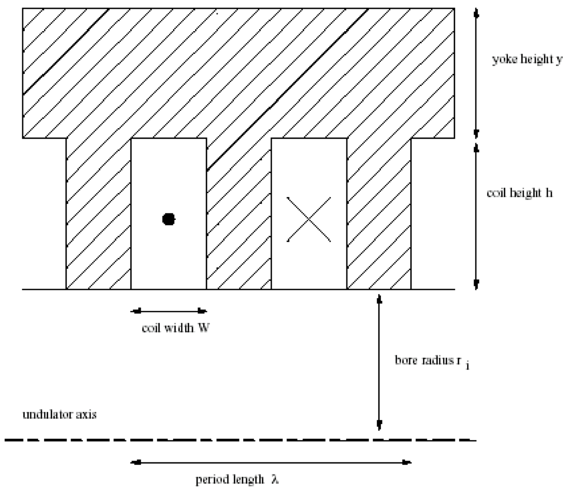
Period structure machined into the steel mono block

Designed: Superconduction with Iron

- DESY double helix design (Flöttmann, Wipf)
- Designed for λ_u = 12 mm, but can reach smaller values





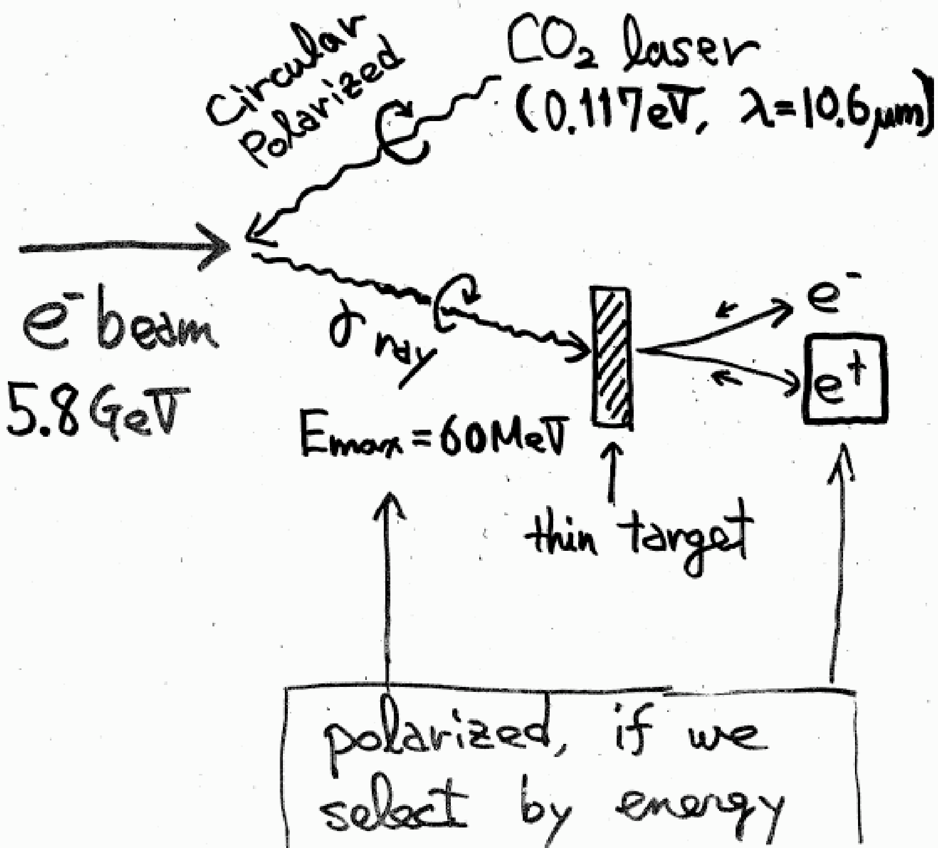


Positron sources: R&D items

Development of laser-Compton based (polarized) positron source-slides from Tsunehiko Omori (KEK) (LC'02)

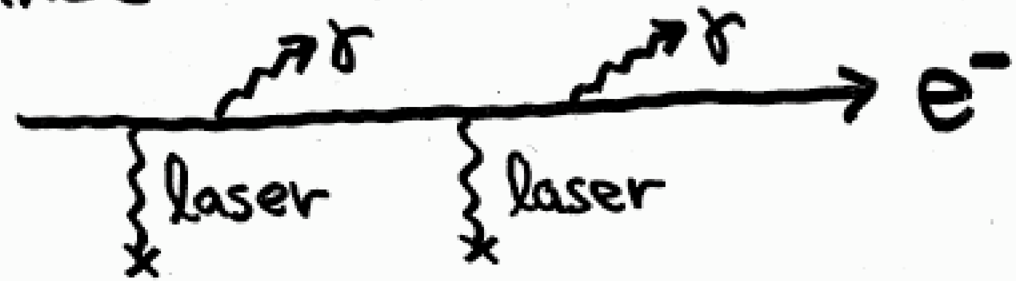
Our Choice

Backward Laser-Compton Scattering



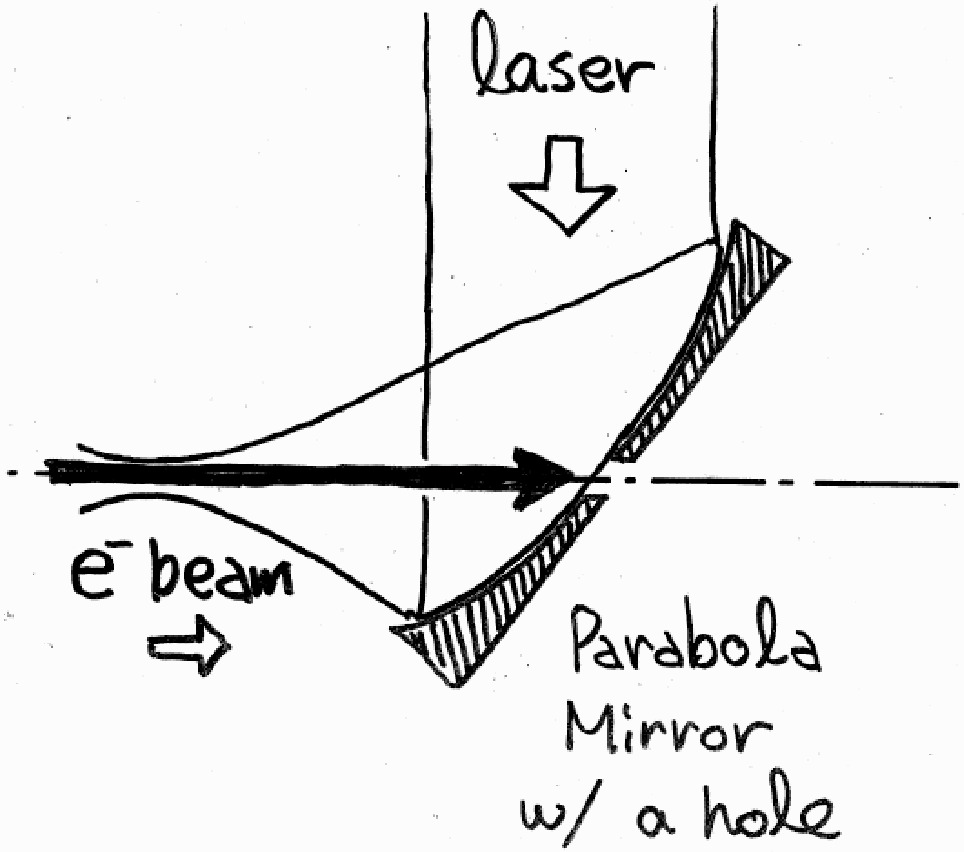
σ_{pair}(tungsten: W, Z=74) = 25000 mb

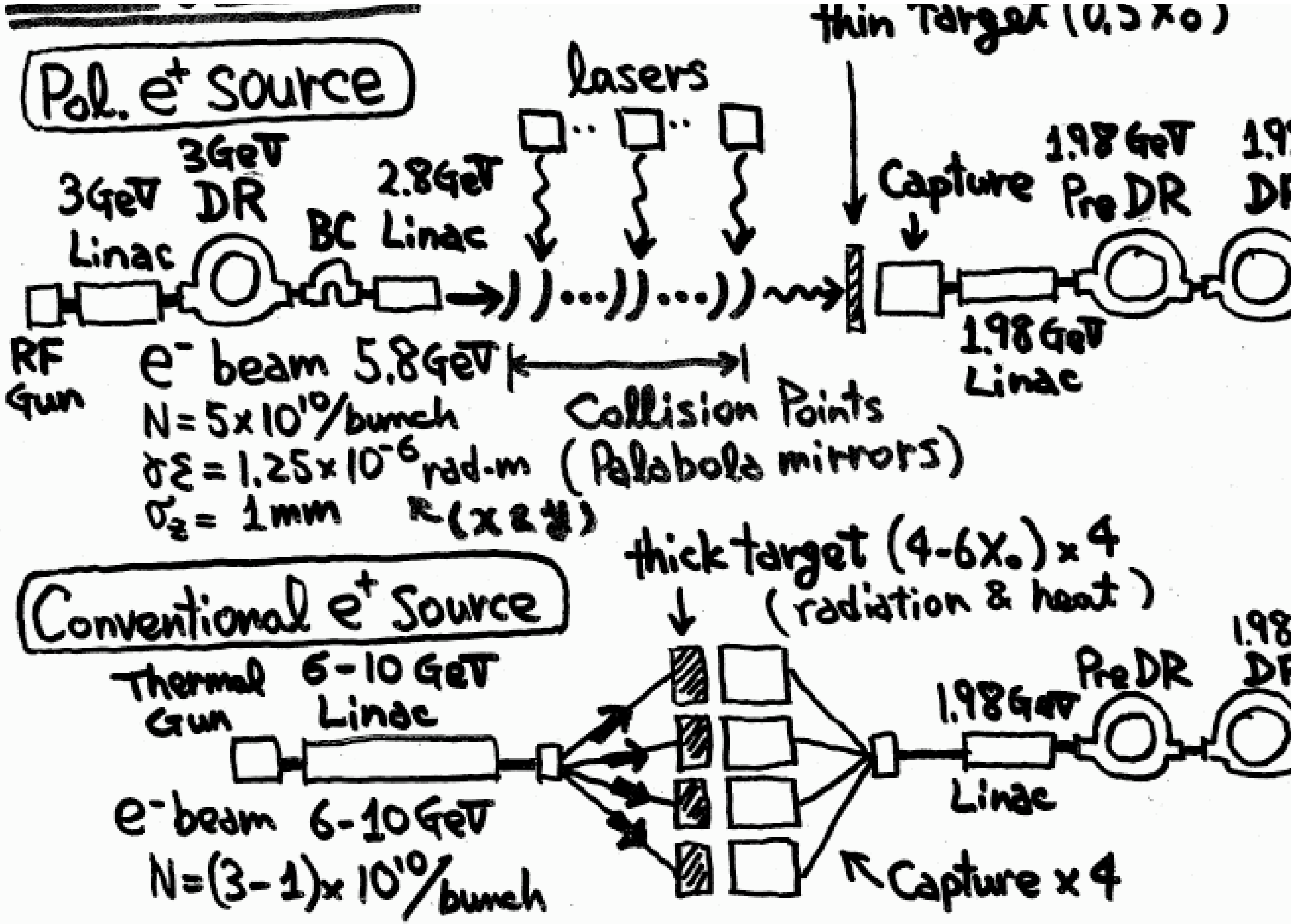
(3) Since 60 MeV ≪ 5.8 GeV

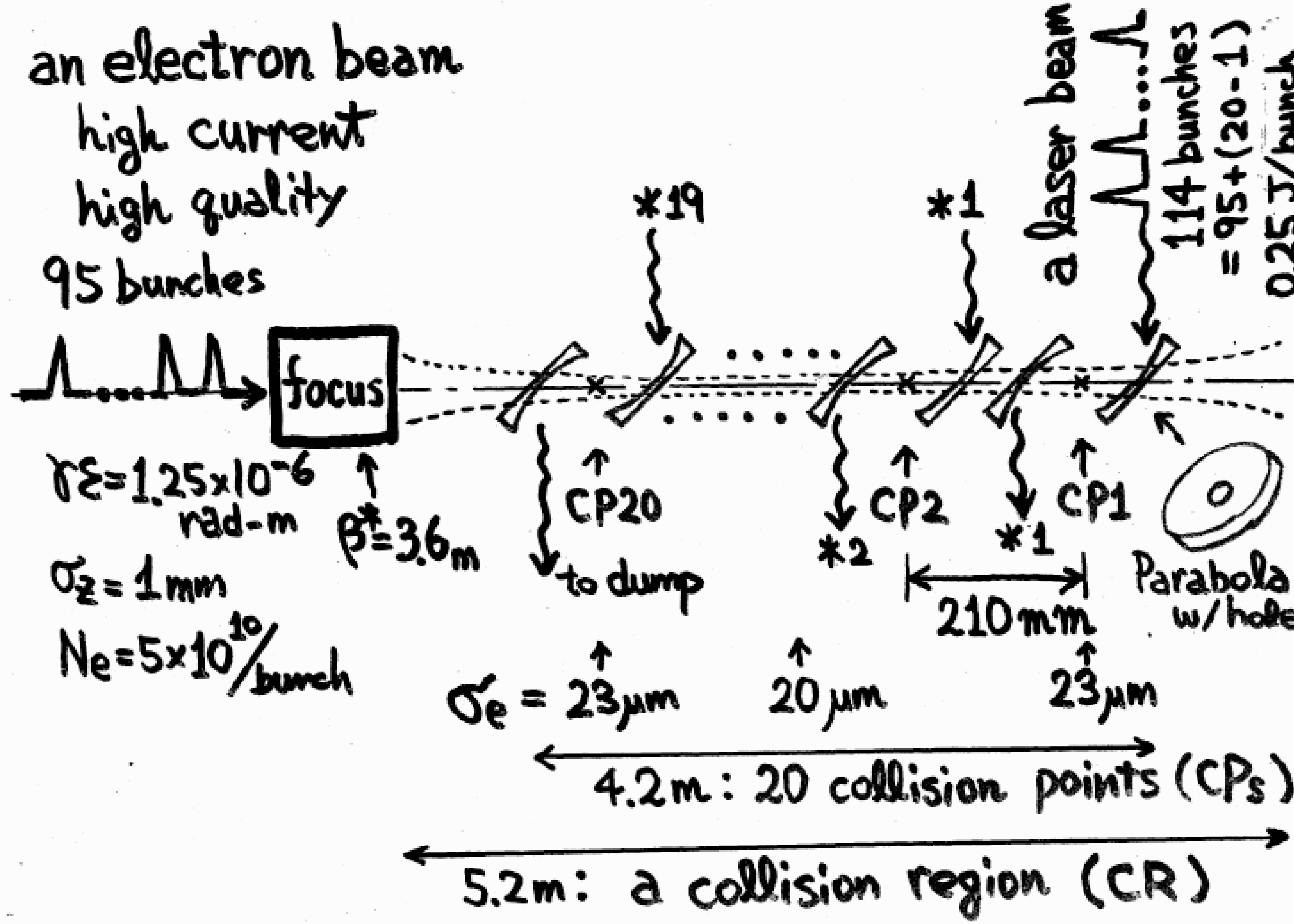


Head-on Collision

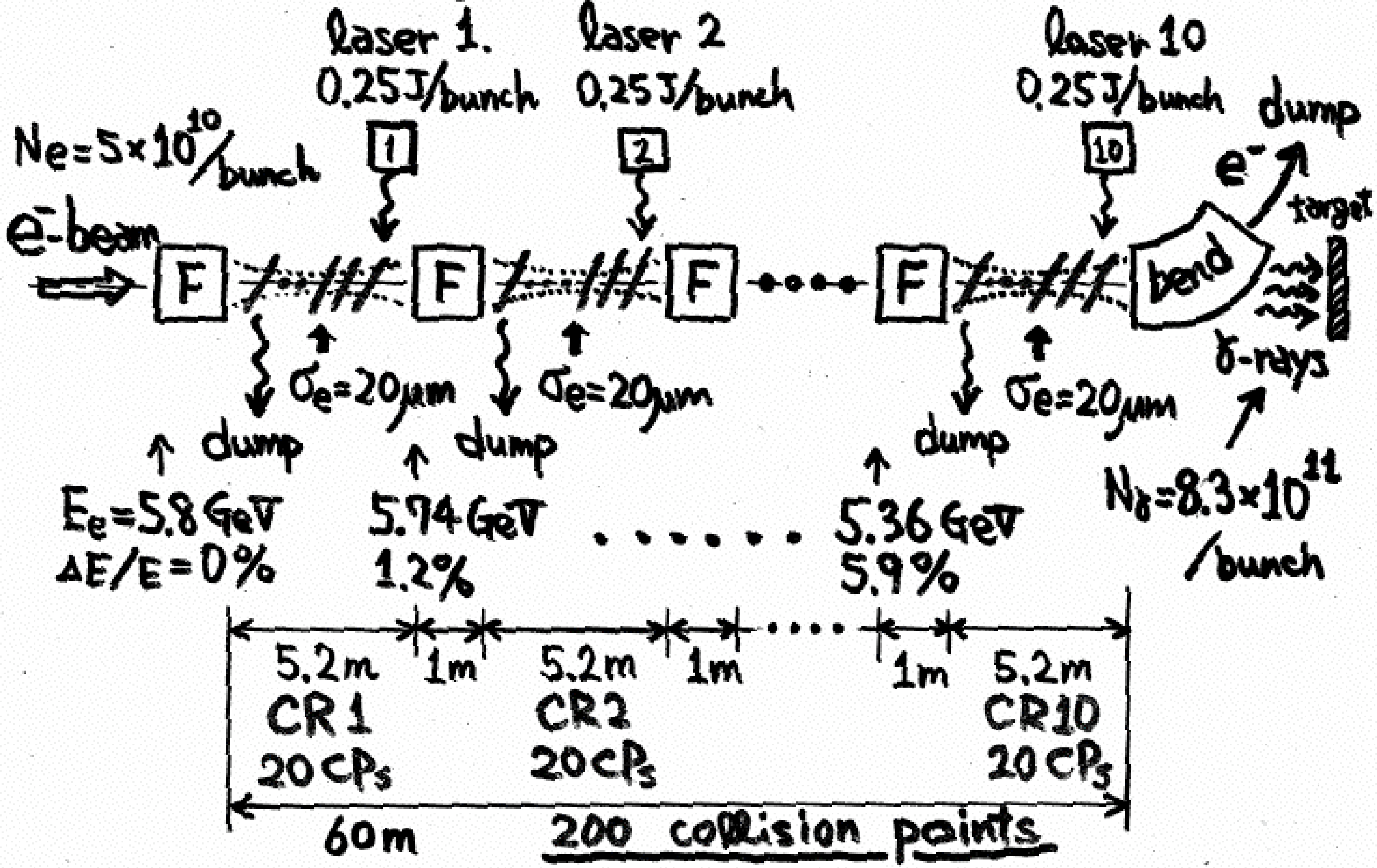
e⁻ beam → ← laser beam




thin Target (0.5 X0)
Pol. e+ source
lasers
3GeV
3GeV
DR
2.8GeV
BC
Linac
Linac
Capture
1.98 GeV
Pre DR
RF
Gun
e- beam 5.8GeV
N=5x10^10/bunch
γε=1.25x10^-6 rad-m
σz= 1mm
(x & y)
Collision Points
(Palabola mirrors)
1.98 GeV
Linac
thick target (4-6X0) x 4
(radiation & heat)
Conventional e+ Source
Thermal
Gun
6-10 GeV
Linac
e- beam 6-10 GeV
N=(3-1)x 10^10/bunch
1.98 GeV
Pre DR
Linac
Capture x 4


an electron beam
high current
high quality
95 bunches
focus
γε=1.25x10^-6 rad-m
β*=3.6m
σz = 1mm
Ne=5x10^10/bunch
*19
*1
a laser beam
114 bunches
=95+(20-1)
0.25 J/bunch
to dump
CP20
*2
CP2
*1
CP1
Parabola w/hole
210mm
σe = 23μm
20μm
23μm
4.2m: 20 collision points (CPs)
5.2m: a collision region (CR)

10 collision regions /w e⁻-beam refocusing



- We have pre-conceptual design
  - CO_2 laser ×10
    - 0.25 J/bunch, 114 bunches/train
  - 5.8 GeV high current linac ×1
  - + Damping Ring
    - 5×10^{10} e^-/bunch, 95 bunches/train
    - $\gamma\varepsilon = 1.25\times10^{-6}$ rad-m (x and y)
  - 200 collision points
    - reuse laser beams
    - refocus an e^--beam
  - → **positrons**
    - 1.2×10^{10} e^+/bunch
    - 95 bunches/train
    - (Safty Factor ≃ 1.1)
    - **pol. = 56 %**

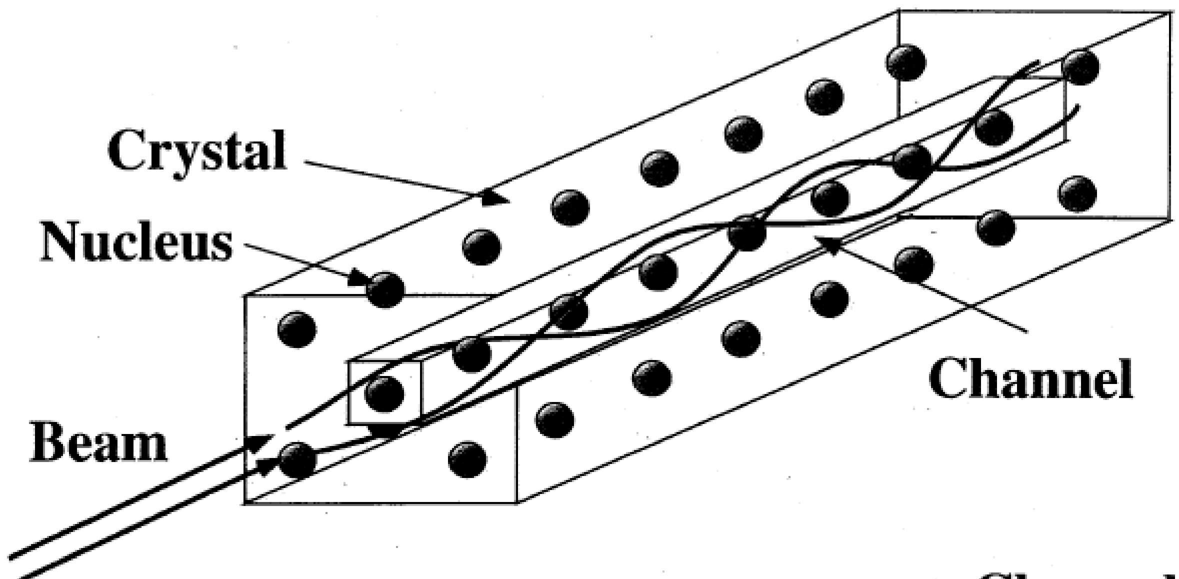
Wall Plug Power ≃ 9.4 MW

Heat/Thermal problem of target
- Heat load ≃ 1.5 kW (continuous)
- Stress 510 MPa (instantaneous)
- → No Problem!

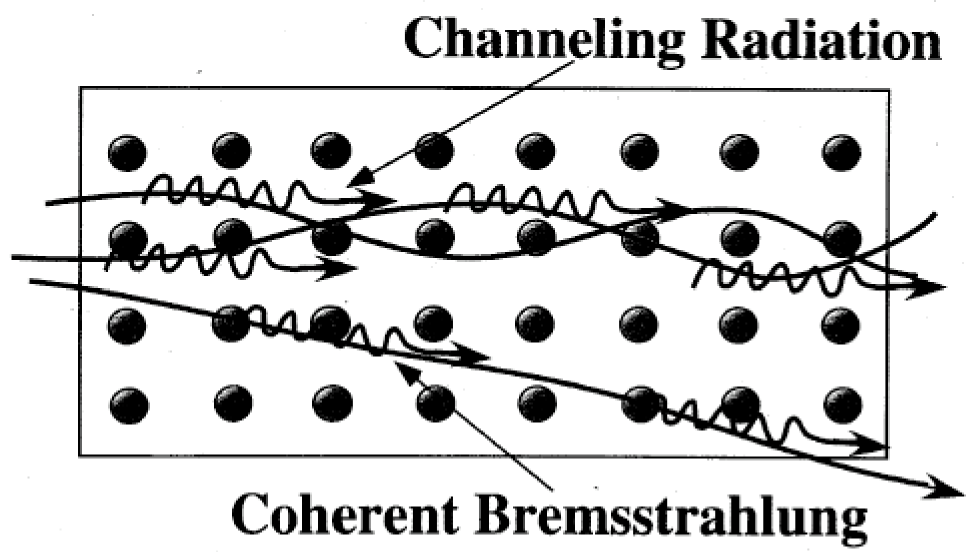
Positron sources:
R&D items

Positron yield enhancement from crystal targets-
slides from Kazura Furukawa (KEK) (LC’02)

Channeling and Coherent Bremsstrahlung



◆ In single crystal these two phenomena enhance e.m. shower (photon) and positron yields



Summary

- Positron Production Enhancement with W Crystal was Measured

  Dependencies on

  Incident Energy (4, 8 GeV),

  Target Thickness (2.2, 5.3, 9, etc mm)

  Out-going Positron Energy (5,10,15,20 MeV)

  → Refine Simulation Codes

- With Thin (2.2 mm) Crystal 5-Times Enhancement was Observed (5~6)
- Yield from 9mm Crystal was Larger than 15-28mm Amorphous
- Diamond Compound (Thick Diamond+Tungsten) Target May be promising
- Need Heating Simulation