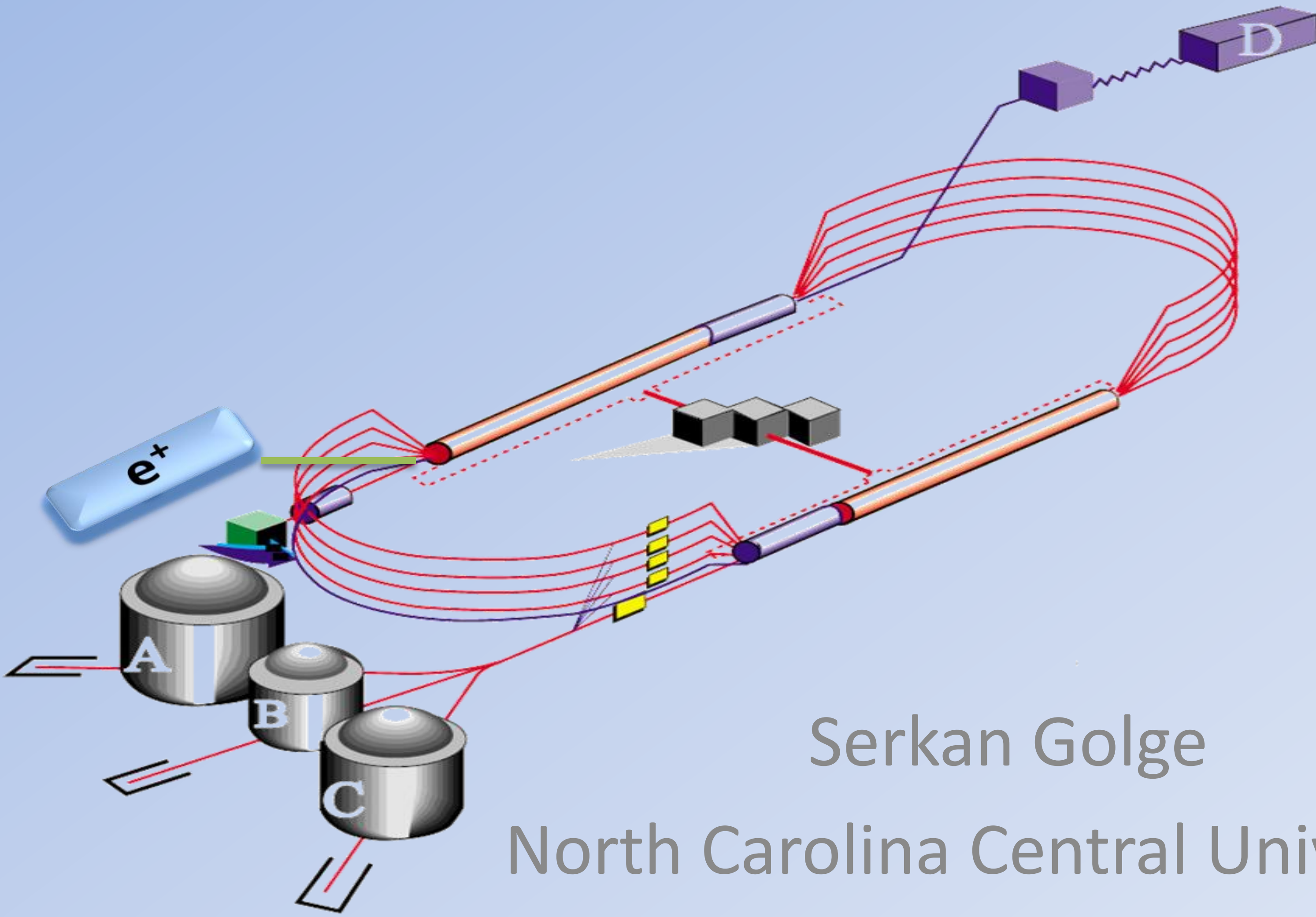
Feasibility and Conceptual Design of a Continuous Wave (C.W.) Positron Source at CEBAF



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North Carolina Central University

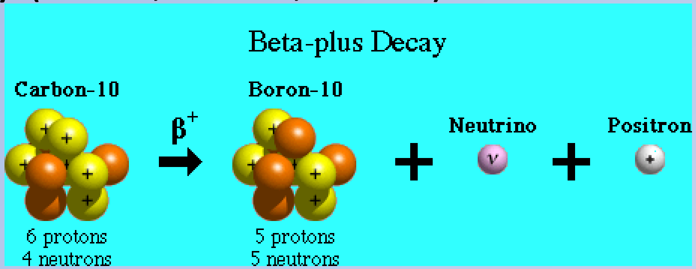
Outline

- Positron Sources
- Positron Design Options
- Target Issues
- Conclusion

How do we get positrons (e^+) ?

Non-Accelerator

Beta Decay (Ca-10, Na-22, Cu-64)



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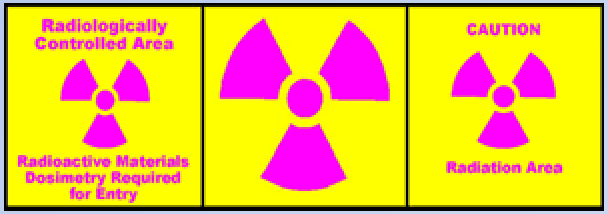
Nuclear Reactor Core (Both β decay and $\gamma \rightarrow e^+ e^-$)



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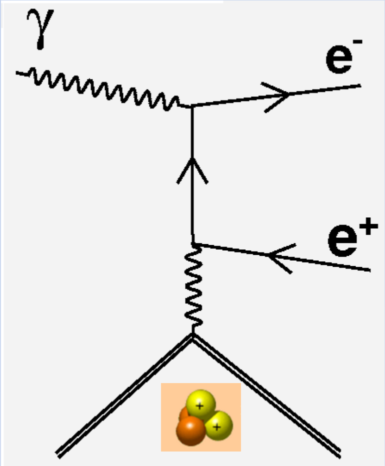
Enhanced by neutron capture on ^{113}Cd or ^{63}Cu

Accelerator

Pair Conversion

$\gamma \rightarrow e^+ e^-$



High-Z

* jlab.org

Comparison

Non-Accelerator

- Small laboratory size (only isotopes needed with a moderator)
- Very limited energy regime
  - (^{22}Na ~ 0.5 MeV e+)
- Random time structure
- Nuclear reactors are not experiment oriented
- Average 10^{6}-10^{8} e^{+}/s

Accelerator

- Requires driving beam (e^{-}, γ)
- Converter target (e.g. Ti, W)
- Timing is set by (e^{-}, γ)
- High energy and high current achievable
  - Up to 10^{12} e^{+}/s

Accelerator e^+ sources

Previous

- SLAC National Accelerator Laboratory (US)
- HERA - Hadron-Electron Ring Accelerator (Germany)
- CESR - Cornell Electron Storage Ring (US)

Present

- BELLE/KEK - National Laboratory for High Energy Physics (Japan)
- VEPP - The Budker Institute of Nuclear Physics (Russia)
- BEPCII – Beijing Electron Positron Collider (China)

Projected

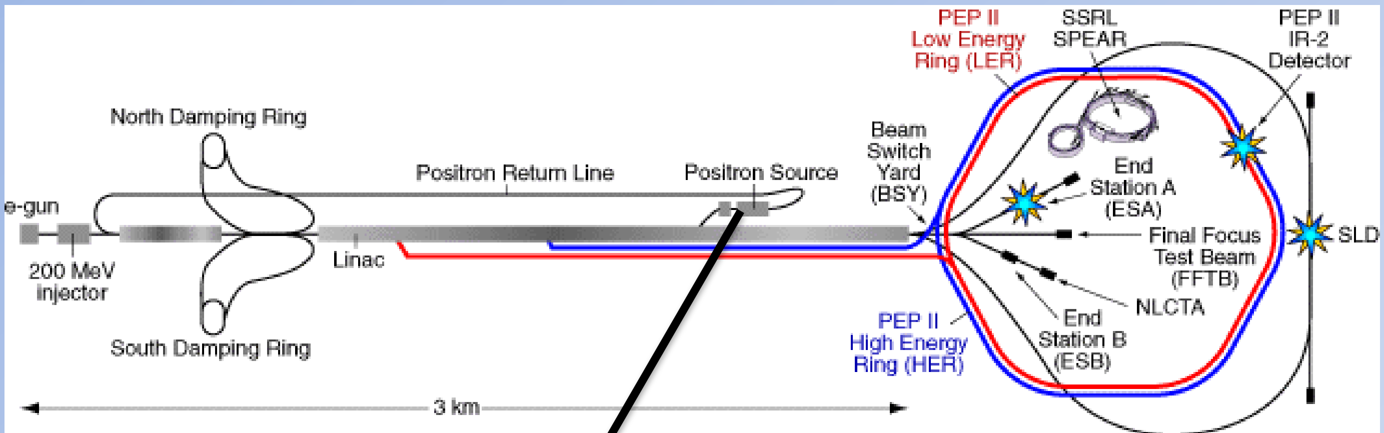
- ILC - International Linear Collider (Undecided)

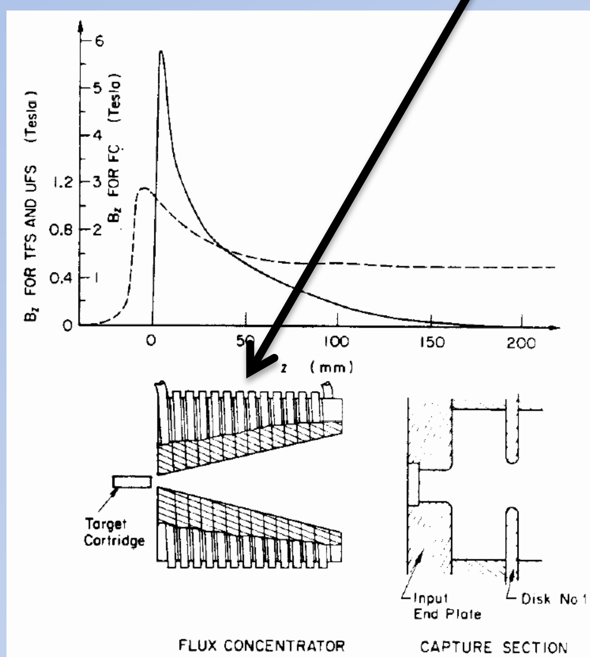
Common features of positron sources

- Pulsed incoming e^- beam
- Flux concentrator solenoids (e^+ capture)
- Damping rings
- Water-cooling target design
- Room temperature RF accelerator at first stage

SLAC

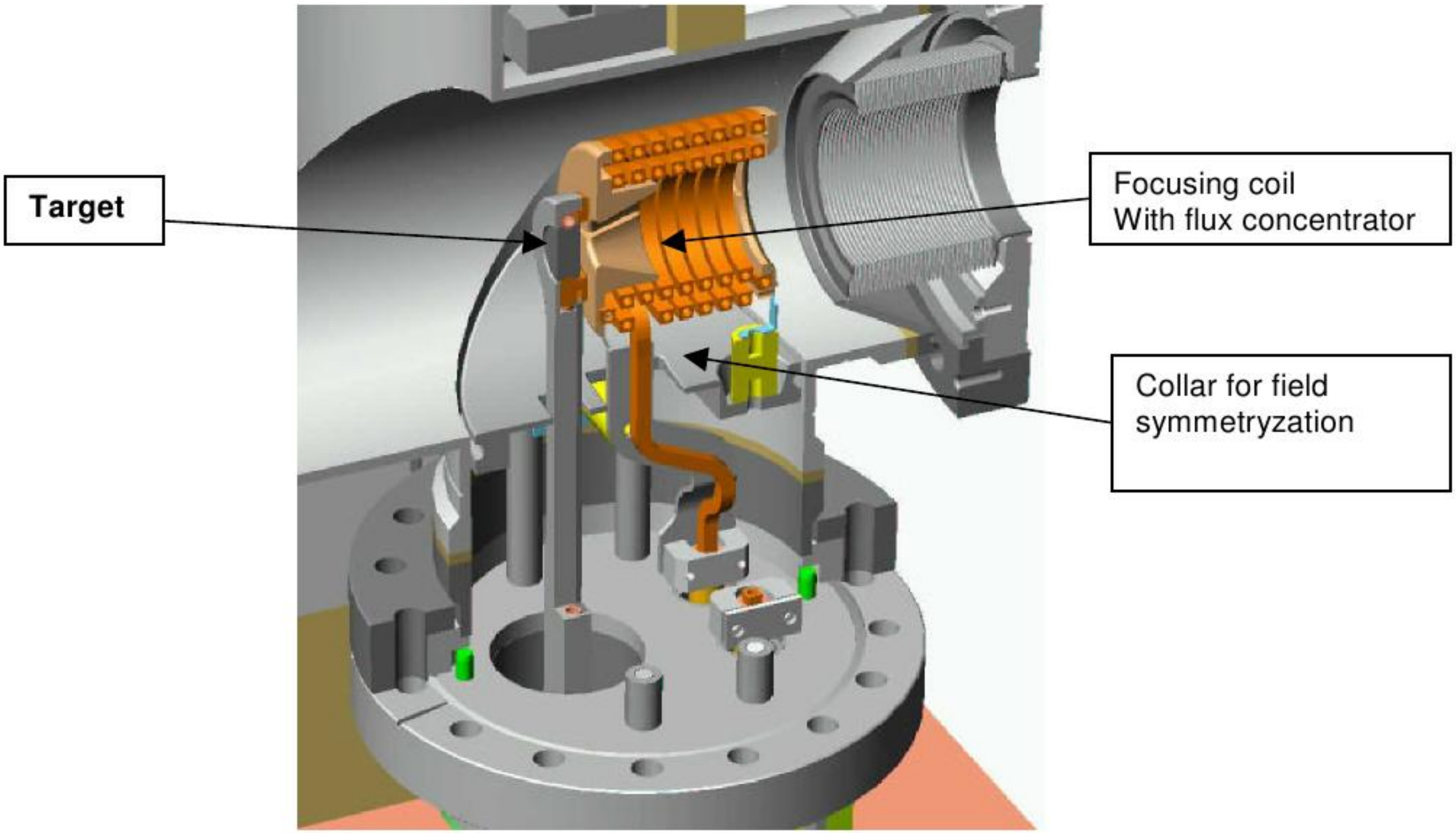
SLAC Layout





Driving electron beam	
Energy (GeV)	33.0
Spot Size 1σ (mm)	0.6
Intensity	5×10^{10} / pulse
Pulse Energy (Joule/pulse)	264.0
Pulse Rate (Hz)	120-180
Beam Power (kW)	47.0
Target	
Material	90% Ta - 10% W and WRe
Length (mm)	20 (or 6 rad. length)
Deposited Energy (Joule/pulse)	53.0
Deposited Power (kW)	9.0
Positron beam	
Capture Energy (MeV)	5 - 20
Spot Size (mm) 1σ	2.0
Normalized Emittance (m·rad)	10^{-2} at 200 MeV
Yield (e^+/e^-)	2.5

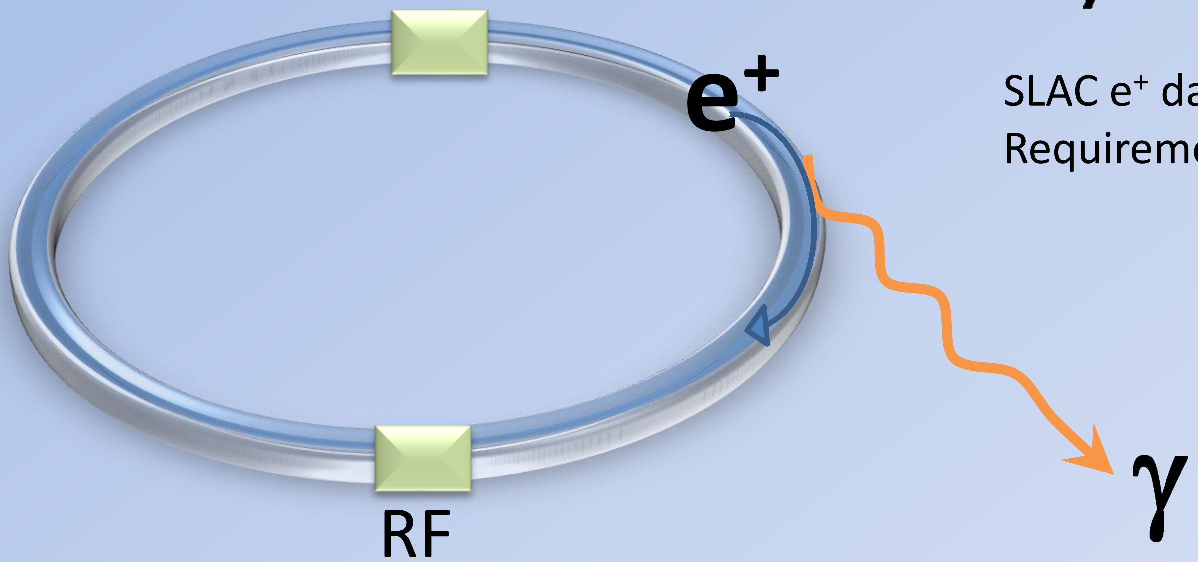
CESR


Target
Focusing coil
With flux concentrator
Collar for field
symmetryzation

Damping ring

$$P \propto \frac{E^4}{\rho^2}$$

P :Radiated power
E: Energy of the particle
ρ : Bending radius

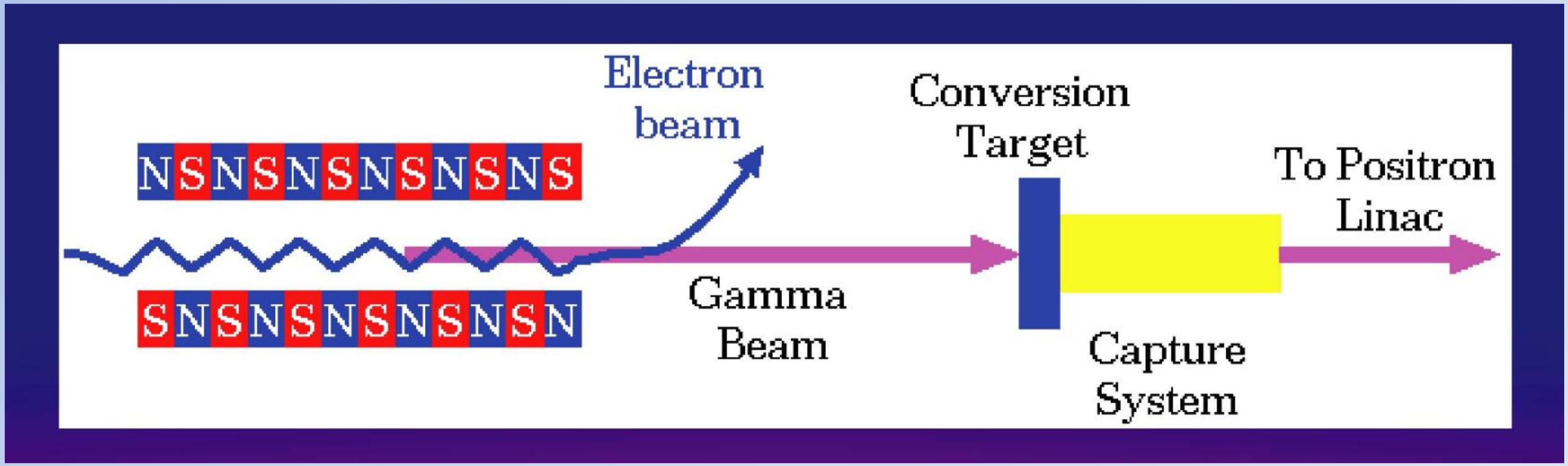


SLAC e^+ damping time ~ 12 ms
Requirement at CEBAF is order of ns.

Damping rings are not suitable for C.W. Beams !

ILC (Projected)

- 150 GeV electron beam in an undulator creates coherent 10 MeV γ-beam
- 14 mm (50% X_0) Ti-Al-V production target
- Adiabatic Matching (Tapered Solenoid) slowly going from 5 T to 0.5 T
- Normal Conducting RF acceleration
- Required current is 10^{14} e^+/s (polarized).



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* ILC School Lectures

What parameters can we use at CEBAF for e^+ creation ?

- Continuous Wave (CW) Positron production

  - 1497 MHz (or sub-harmonic)

- High current & High Power incoming electron beam

  - 126 MeV $\otimes$ 10 mA = 1.2 MW (e^- at 12 GeV upgrade)

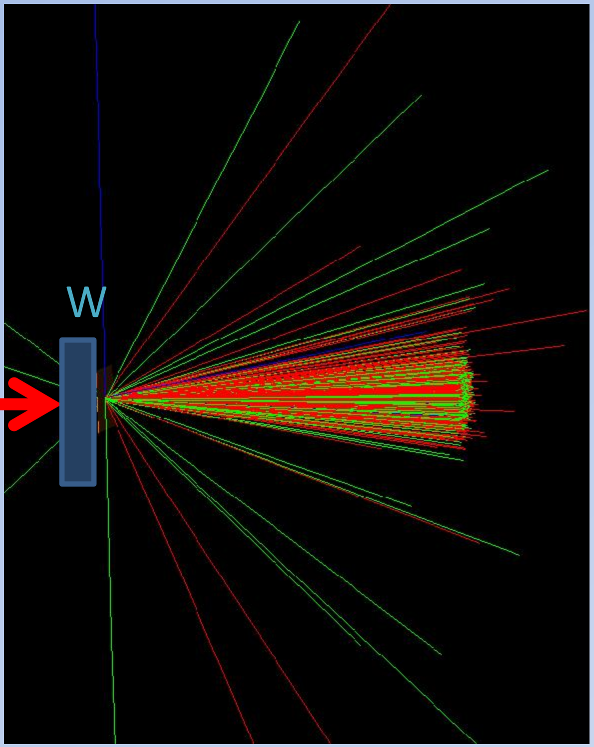
- Rotating Wheel or Liquid Jet Target

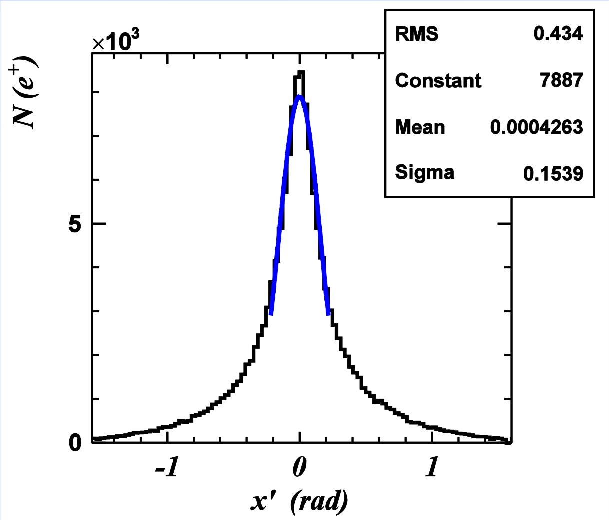
Multiple scattering

$$\theta \approx \frac{13.6MeV}{cp}\sqrt{\frac{x}{X_0}}$$

e$^-$

W





Raw e$^+$
θ ~ 400 mrad
~ 23 °

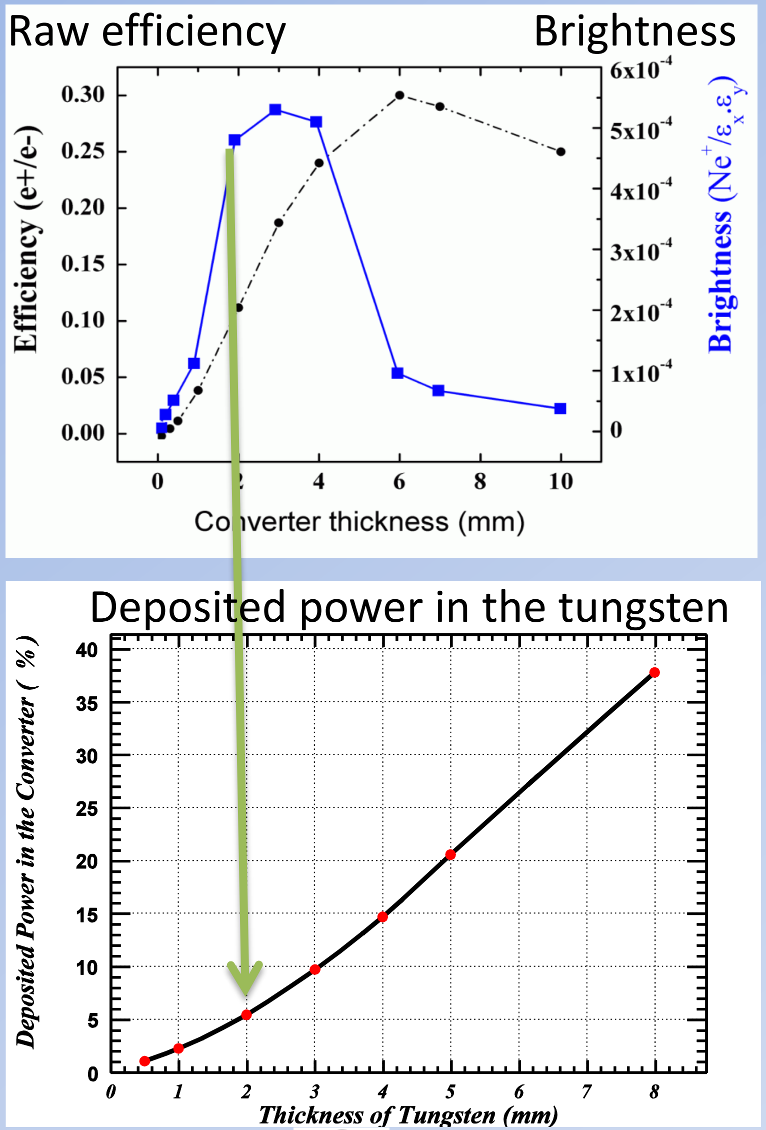
Gaussian fit to 2-σ

x/X_o : Thickness in radiation length
p : Momentum

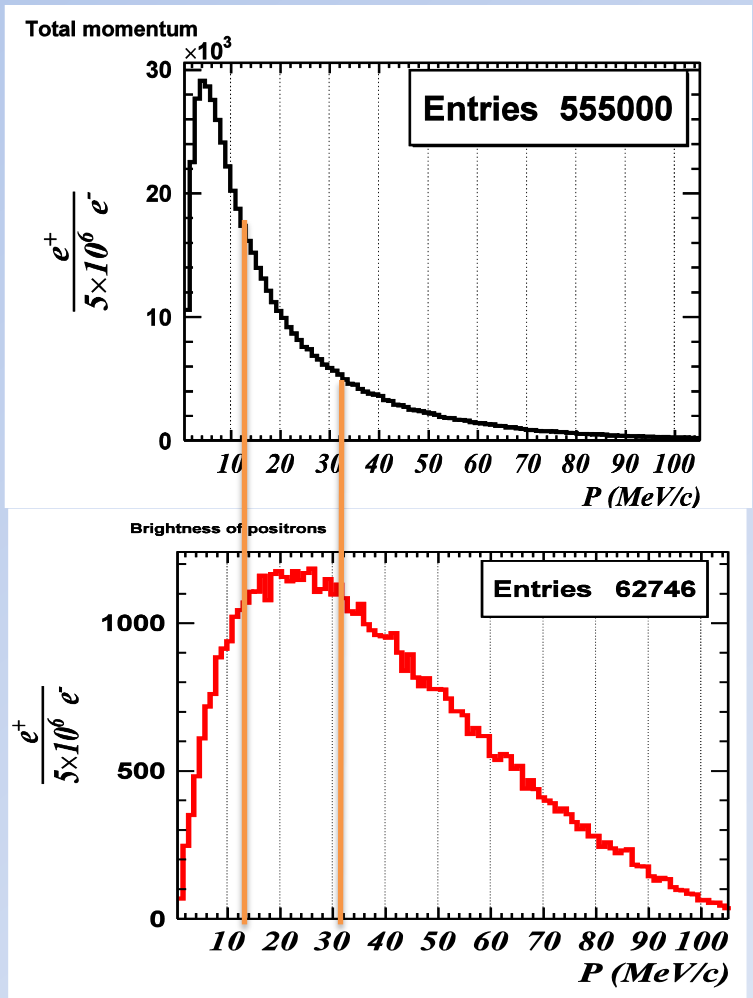
126 MeV e$^-$ on 2 mm W

Brightness of the e+ must be considered !!!!

e+ at the tungsten (W) target



Selected converter thickness is 2 mm (60% X_0)
126 MeV e^- on a 2 mm W



$$|x'(y')| < 100 \text{ mrad}$$

Design objective

- Collect as much as e^+ at source
- Immediately after the e^+ creation, separate e^+ from other secondary particles.
- Accelerate the e^+ beam
- At the North Linac injection point require e^+ beam:
  - (a) Admittance ~ 10-20 mm.mrad (See: S. Golge, et.al., AIP Conf. Proc., **1160**,109)
  - (b) $P(e^+)$ = 126 MeV/c (up to $\Delta p = \pm$ 2 MeV is possible)

How many e^+ can we capture at the target ?

Requirements at the North Linac (NL)

a) P (e^+) = 126 MeV/c

b) Δ t < 4.7 ps and Δp = 2 MeV/c hard cut

c) Admittance

$A(\mathbf{2})_{xy} \sim$ 10 mm.mrad

NL

2

Invariant of motion →

$$\varepsilon^N = \gamma_1 \beta_1 \varepsilon_1 = \gamma_2 \beta_2 \varepsilon_2$$

$\gamma \equiv E / m$

$\beta \equiv v / c \approx 1$

$m = 0.511 MeV$

$$\frac{126}{0.511} 10 = \frac{15}{0.511} A(1)_{xy}$$

$A(\mathbf{1})_{xy}$ = 84 mm.mrad

Collect at Target 15 MeV e^+

1

Design Options

1) Combined Function Magnet (CFM)

   Solenoid-CFM-Quad. Triplet-2 qt. C50 – C100

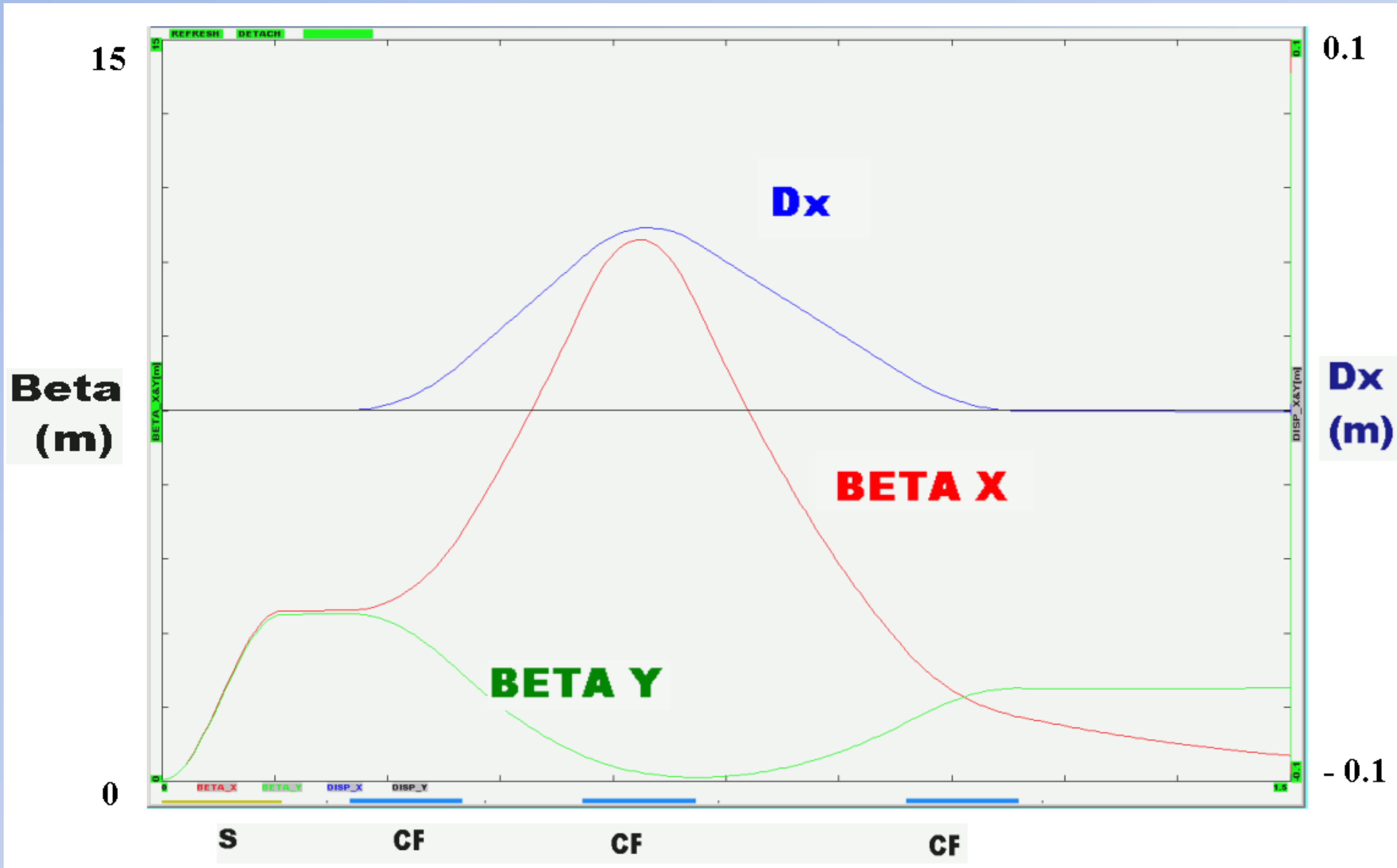
2) Two-Dipole

   Solenoid-Dipoles-Quad. Triplet-2 qt. C50 – C100

3) Microtron Dipole

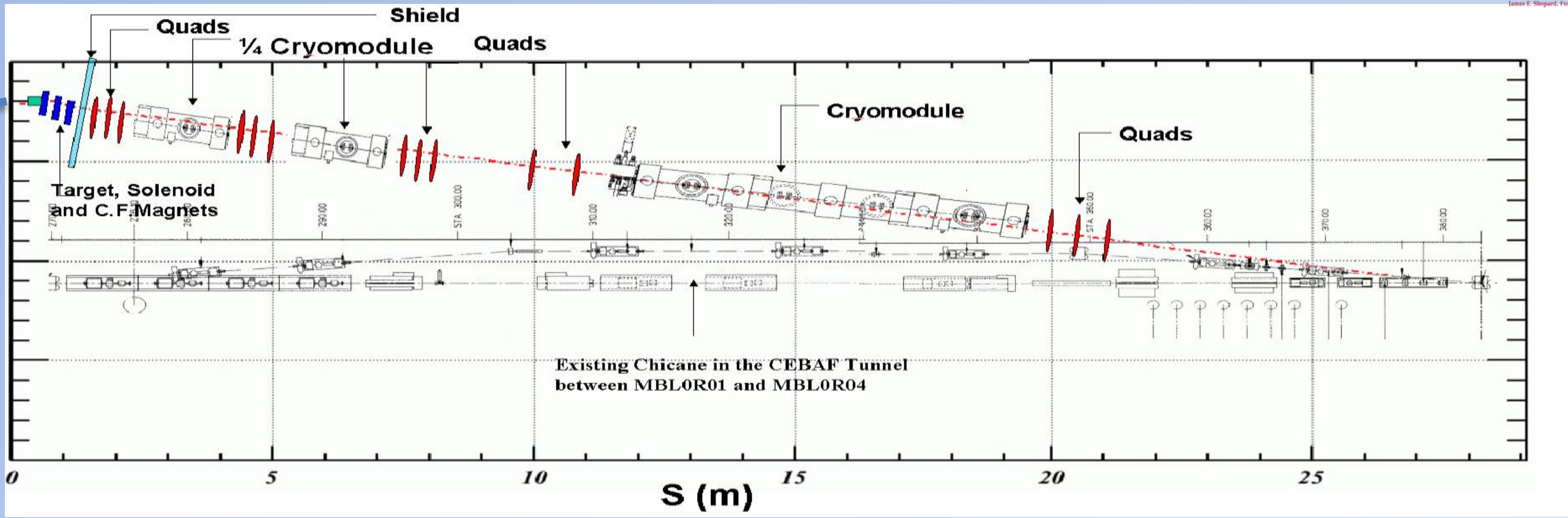
   Solenoid-Microtron-Quad. Triplet-2 qt. C50 – C100

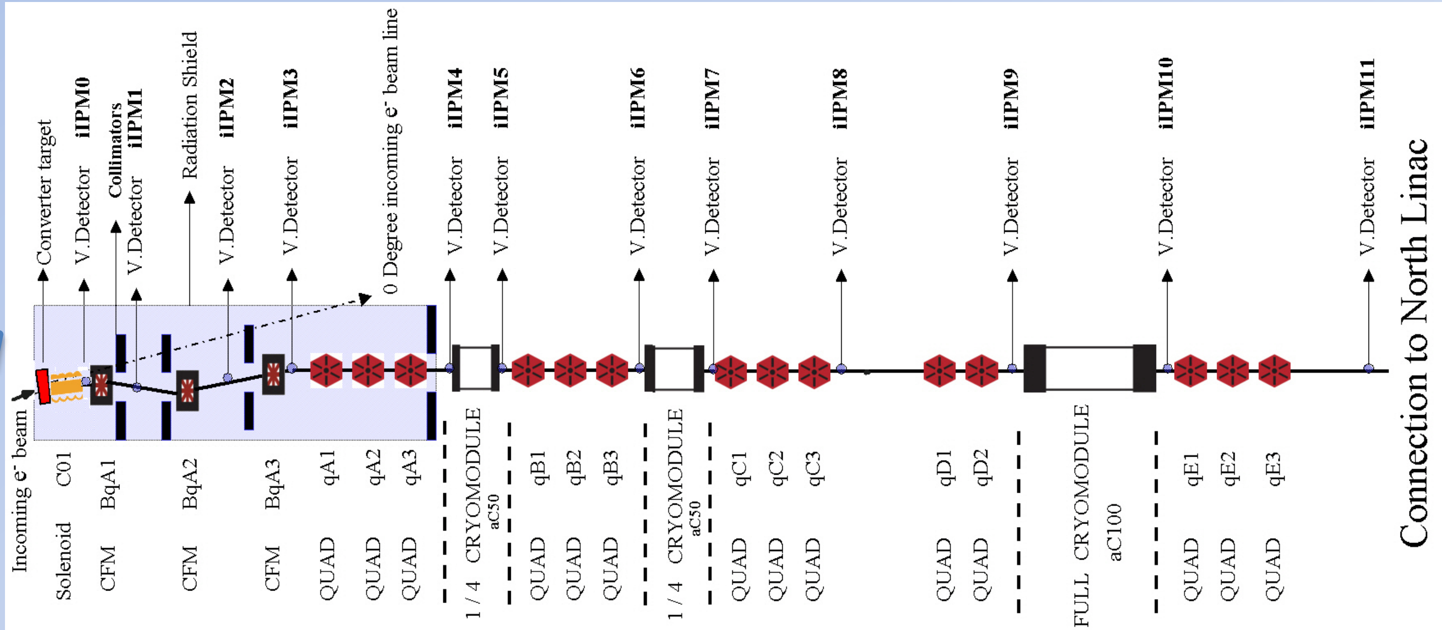
CFM Lattice



15
0
Beta
(m)
0.1
- 0.1
Dx
(m)
Dx
BETA X
BETA Y
REFRESH
DETACH
BETA_X
BETA_Y
DISP_X
DISP_Y
S
CF
CF
CF

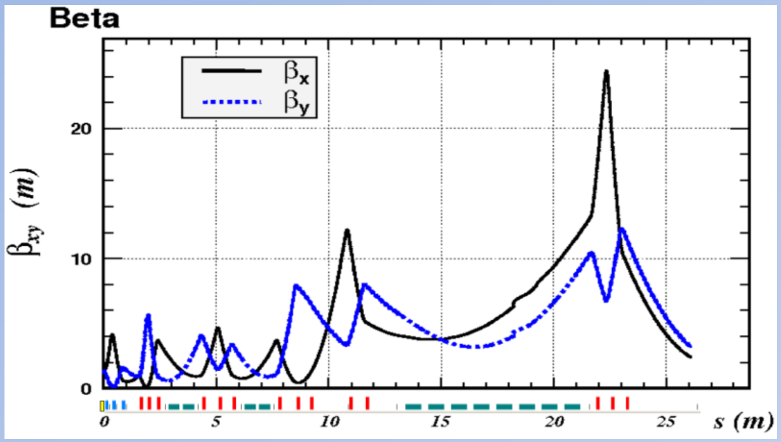
Positron injector schematic

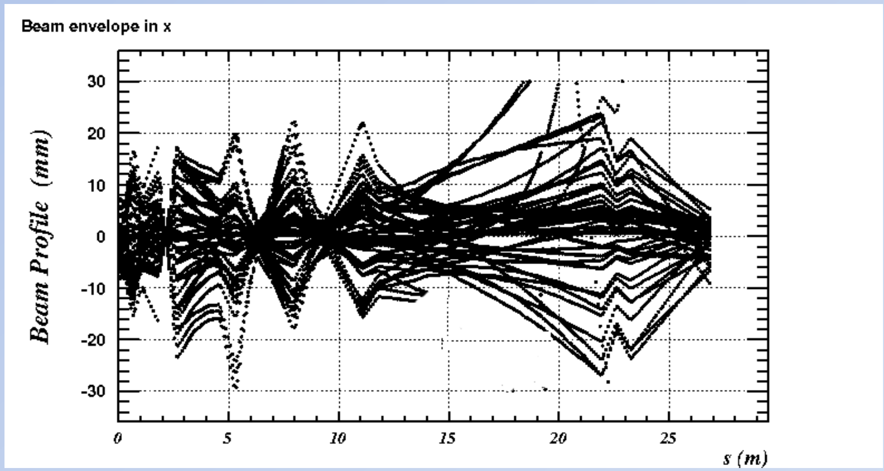


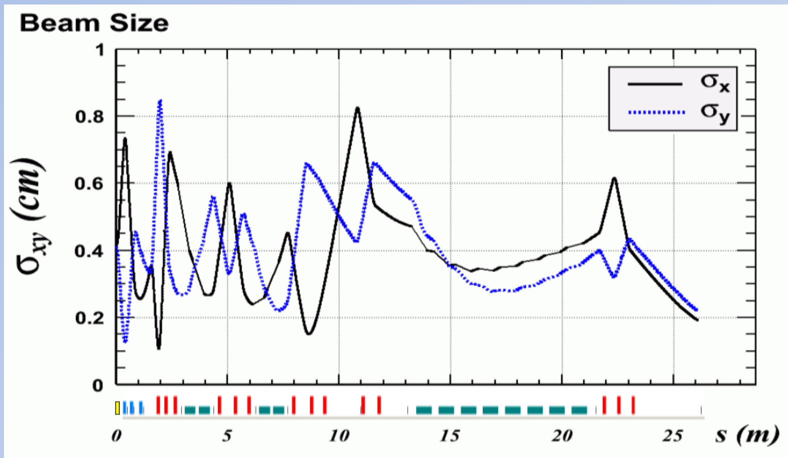


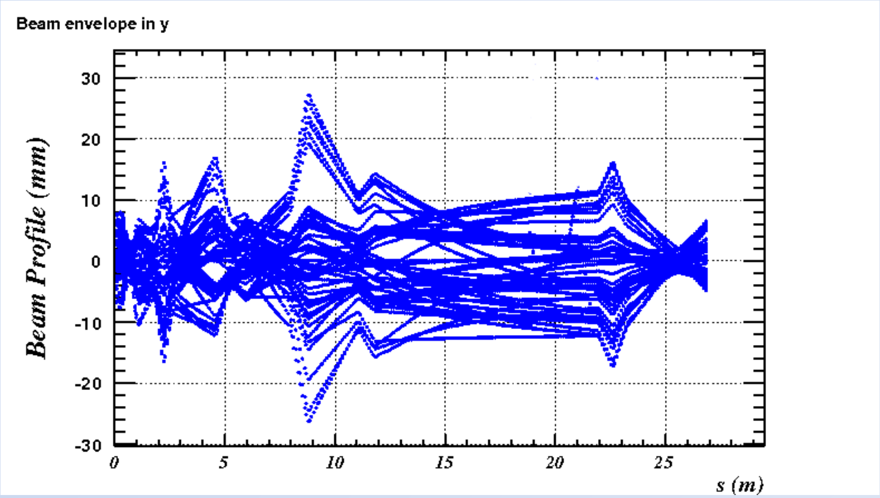
CFM schematic

Positron Beam Profile









Begin

σ_x = 0.1 mm

$\sigma_{x'}$ = 45 mrad

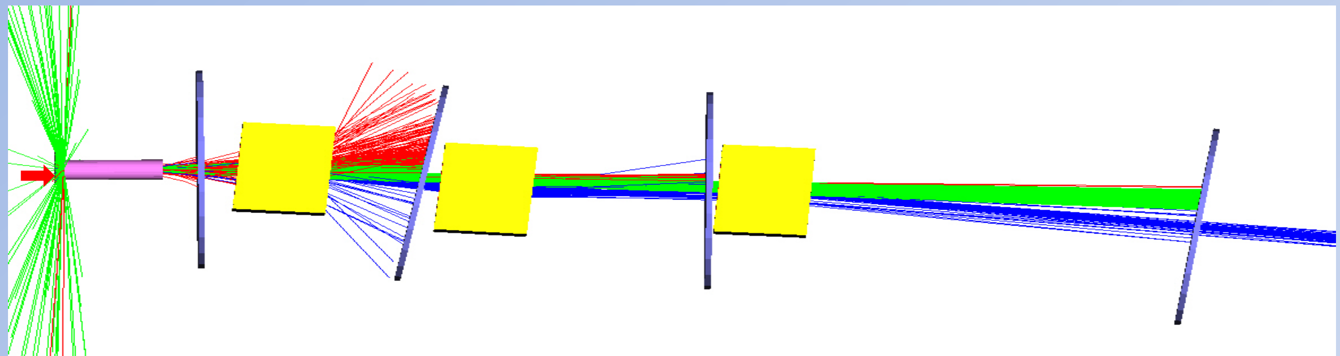
End

σ_x = 1.5 mm

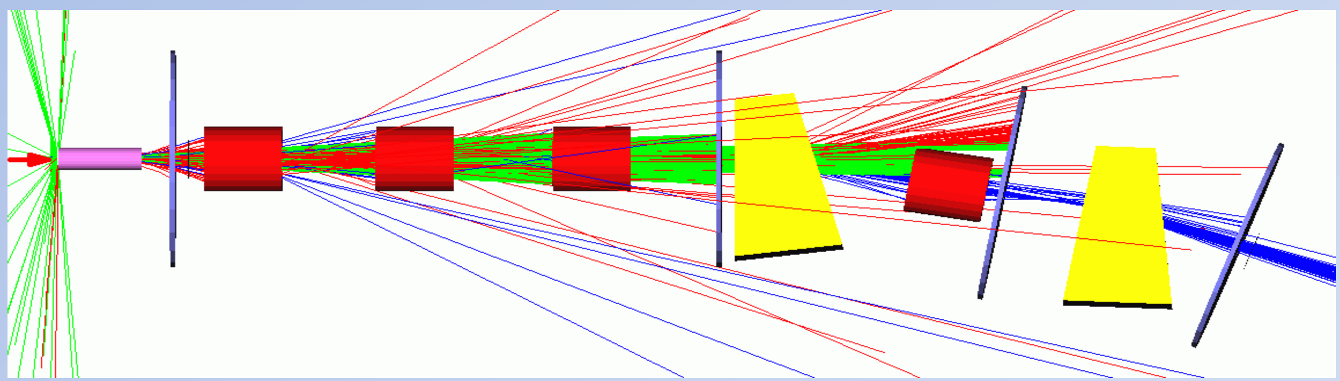
$\sigma_{x'}$ = 1 mrad

Power

1) CFM



2) 2-Dipole

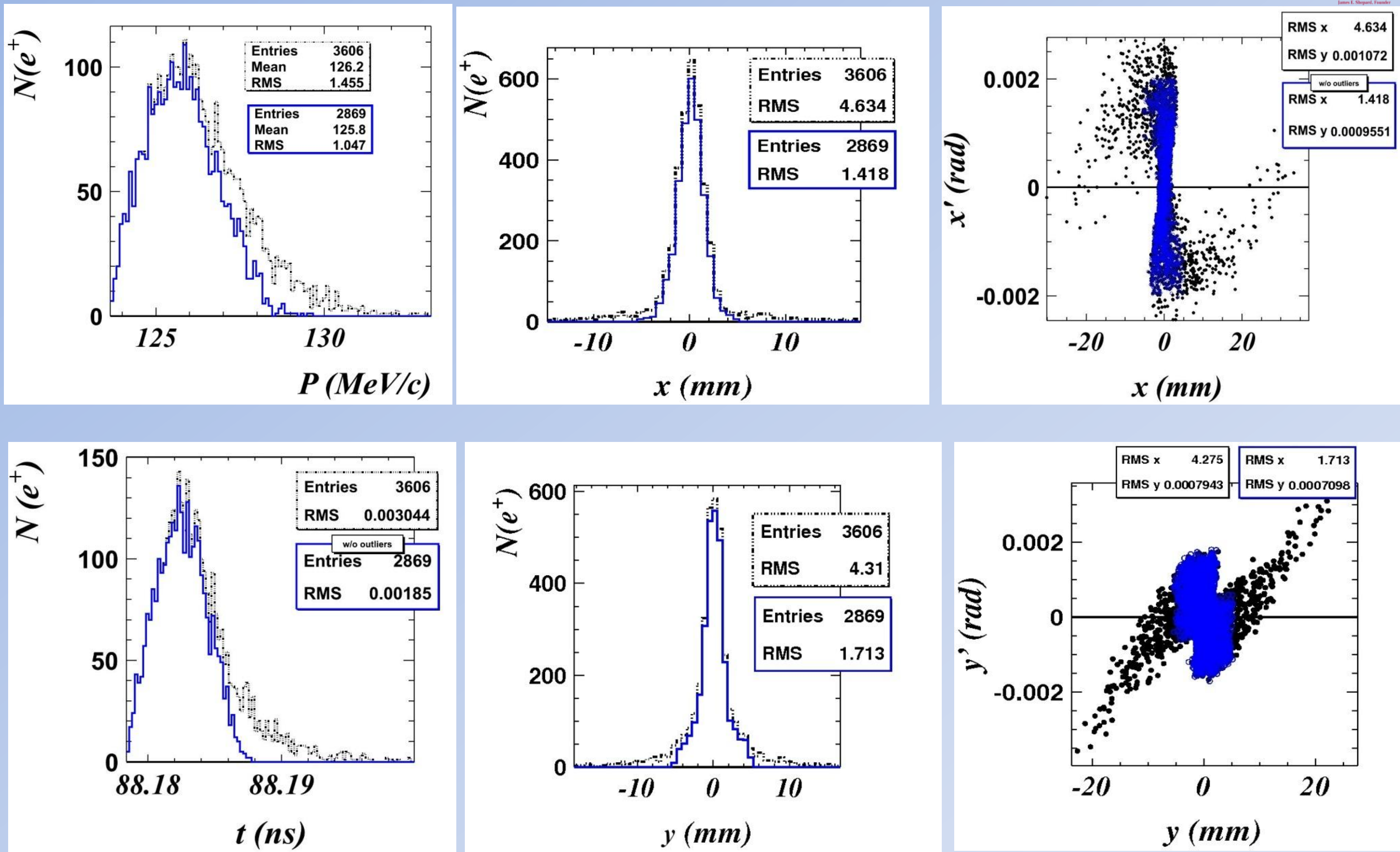


Electrons, Positrons, Gammas

Element	Power Source (e⁻ and γ)	Power Source e^+	Deposited (%)	Power (kW)	Distance m
Target	✓	✓	4.5	55	0.0
Solenoid	✓	✓	21.0	250	0.16
Collimators	✓	✓	10.0	120	2.0
Capture Area Magnets	✓	✓	17.0	200	2.6
1/4 Cryomodule-1		✓	2.0×10^{-3}	0.025	4.0
1/4 Cryomodule-2		✓	9.0×10^{-4}	0.01	7.0
Full Cryomodule		✓	1.2×10^{-3}	0.015	16.0

The rest of the power is in target vault ~ 500 kW

Positrons at the end of CFM



- Position a collimator, recalculate the r.m.s after trimming the outliers

Dashed: Selected e^+ making to NL, Blue : e^+ without outliers

Positrons at the end of CFM

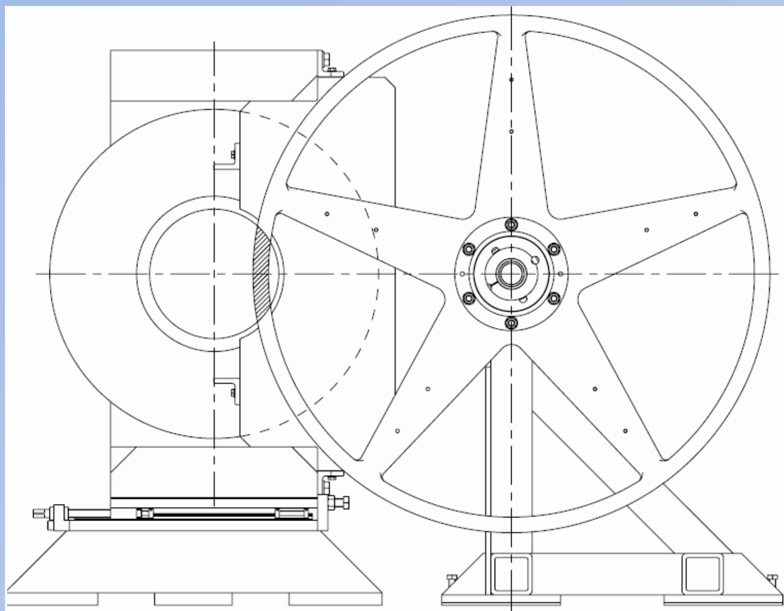
- The efficiency is ~ 2.9×10^{-4}

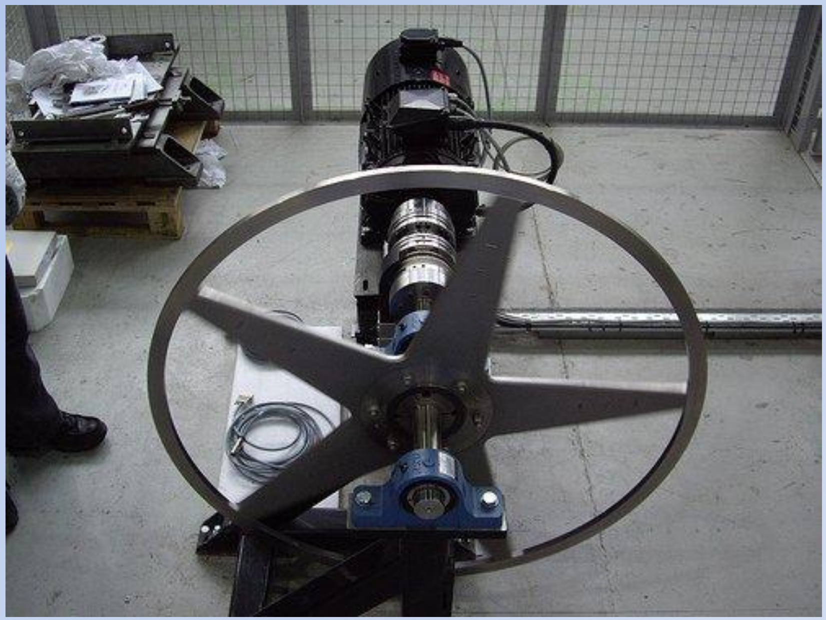
  This is equal to ~ 2.9 μA e^+ current @ 10 mA

  126 MeV/c incoming electron beam.
- P (e^+) = 126 ±1.0 MeV/c
- σ_t = 1.8 ps
- ε_x = 1.6 mm.mrad

  ε_y = 1.7 mm.mrad

Target Option 1



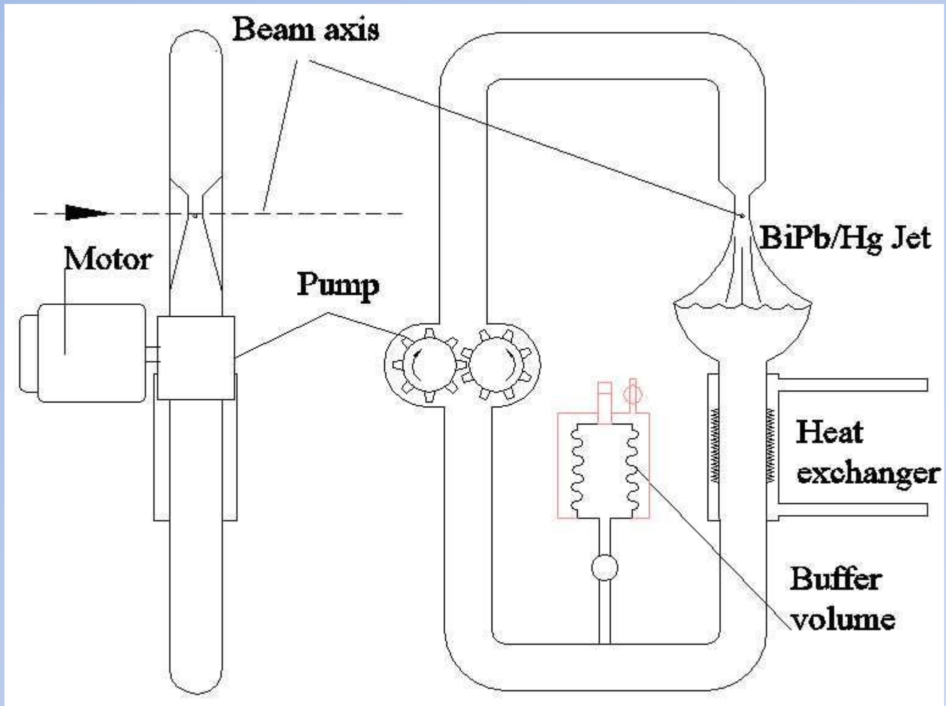


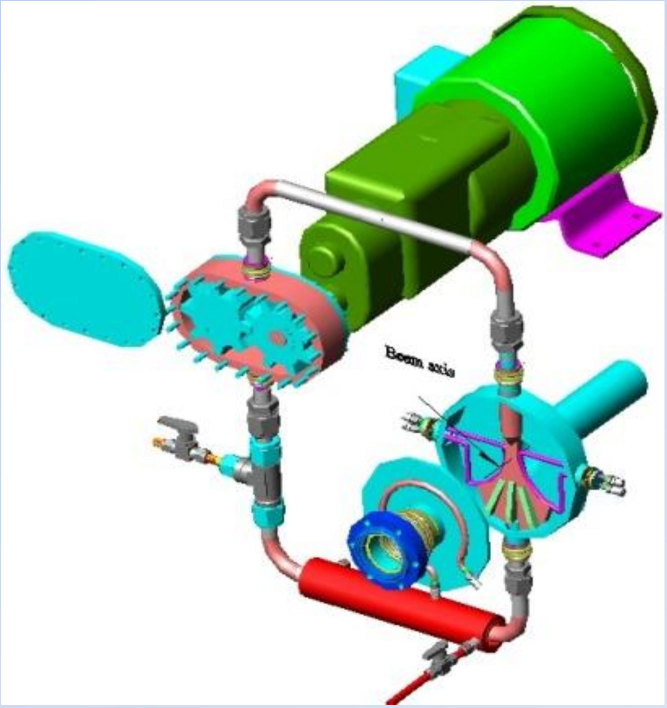
- ILC target design schematic and prototype
- 1 m diameter (2m projected)
- 2000 rpm
- Titanium alloy
- Water-cooled
- 10 kW power deposition @ 130 kW photons

Target Option 2

- High-Z Liquid Target Options
- Mercury (Hg) Jet
- Bizmuth-Lead (Bi-Pb) Jet

- Bi-Pb has melting temperature 154 °C
  Boiling point is 1670° C (*)
- Hg has a boiling point at 356° C





(**)

[* http://academic.brooklyn.cuny.edu/physics/sobel/Nucphys/breed.html](http://academic.brooklyn.cuny.edu/physics/sobel/Nucphys/breed.html)
** JPOS09, A.Mikhailchenko Talk

Summary & Conclusion

- ✓ Optimization process is completed
- ✓ CFM , Two-dipole, Microtron dipole are introduced as design options
- ✓ In all three designs, we can get up to 3μA e^+ from 126 MeV e^- 10 mA hitting on a 2 mm (0.6X_0) tungsten, within all the required CEBAF restrictions
- ✓ Biggest challenge is target design. ~60 kW of power is deposited in tungsten. Various target options are introduced. Currently 10 kW in ILC designs. Need to decrease e^- current if a high power target is not possible.
- ✓ Cost :

Cost Estimation	Price tag
Target	$1M
Magnets	$2M
SRF	$7M
Tunnel	$3M
Installation	$3M
Contingency	$4M

Total : $20M

FEL Positron Source

- ✓ Motivation behind this project is for material science mainly. But positron momentum spectrum is so wide which allows to consider other physics.
- ✓ FEL injector at 10 MeV x 10 mA or 120 MeV x 1 mA are considered.
- ✓ The MeV range positrons are captured and transported, hit a moderator (a tungsten mesh or solid neon moderator) where you get thermalized (eV range) positrons
- ✓ The highest number of slow e+ is in NEPOMUC (Munich, Germany reactor based source) ~10^9 slow e+/s . The goal here at FEL is to achieve ~10^{10} or more slow e+/s.