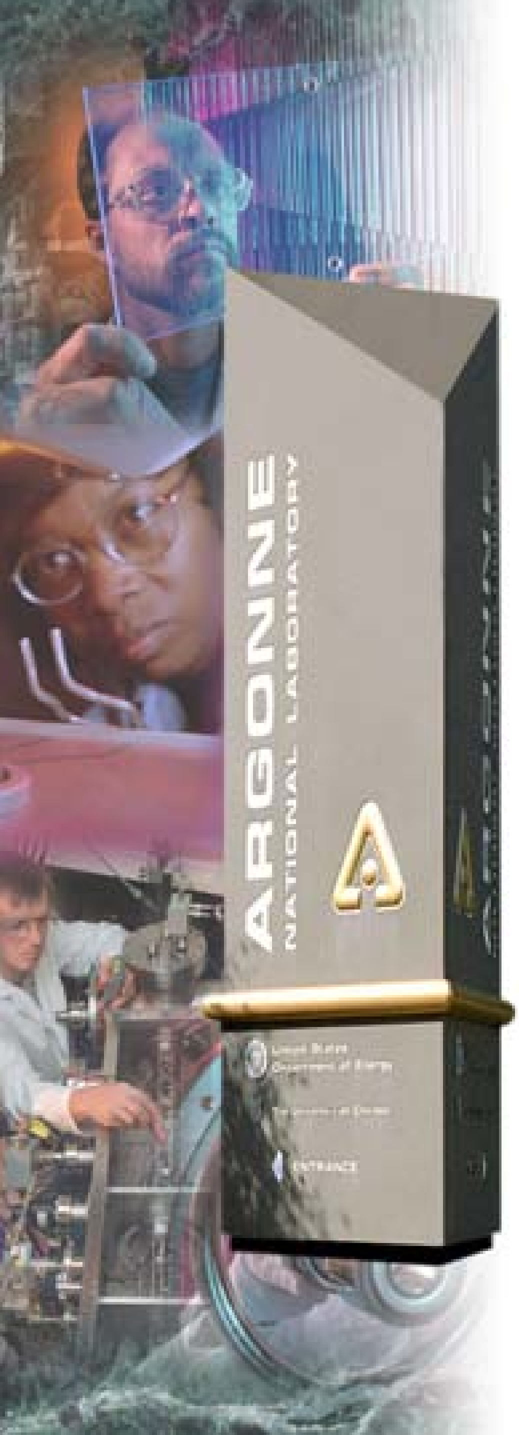

Report on ANL Positron Source Studies:

Simulation and parameter studies of the ILC e+ sources from target to damping ring: undulator based, conventional based and their emulators

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Argonne National Laboratory

Office of Science
U.S. Department of Energy

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Office of Science Laboratory
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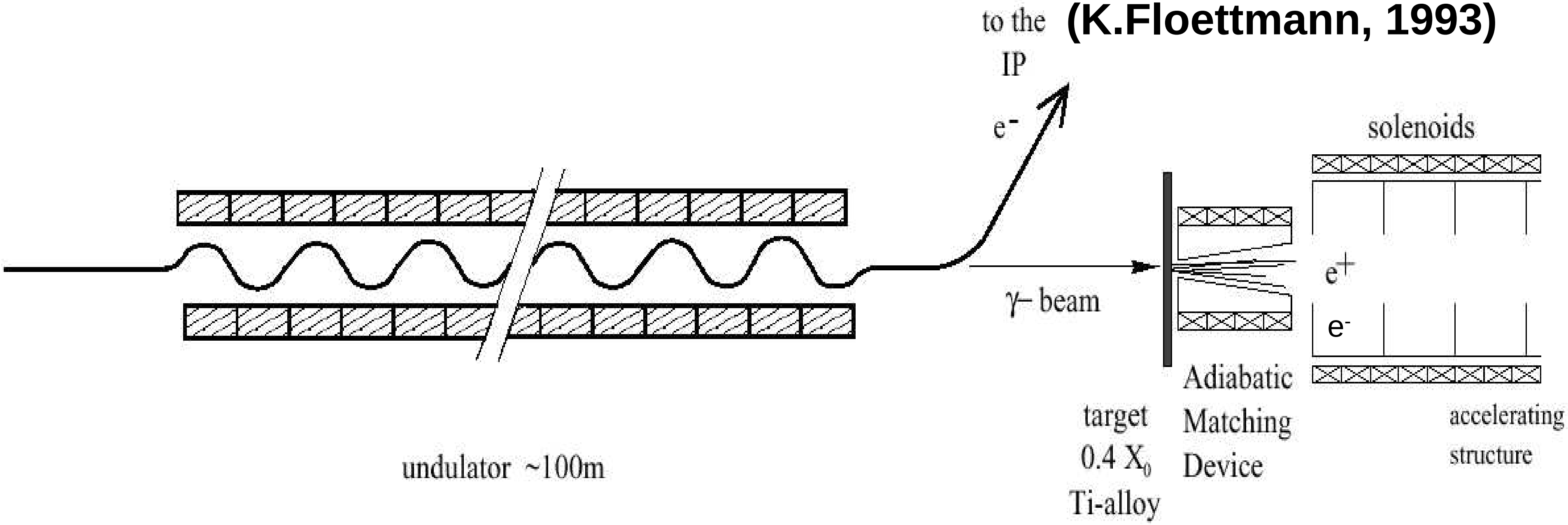
Outline

1. **Undulator based simulation (from target to damping ring)**
2. **Positron source emulator (a faster way to commission the e+ source)**
3. **Conventional e+ source parameter optimizations: Drive energy, target and beam spot sizes.**

1. Undulator-Based ILC Positron Source

(K.Floettmann, 1993)



TESLA TDR DESY 2002

- **Use Gamma rays from the electron beam passing through**
  - an helical undulator→polarized e+ beam
  - planar wiggler →unpolarized e+ beam
- **Both e+ and e- are produced and included in the calculations**

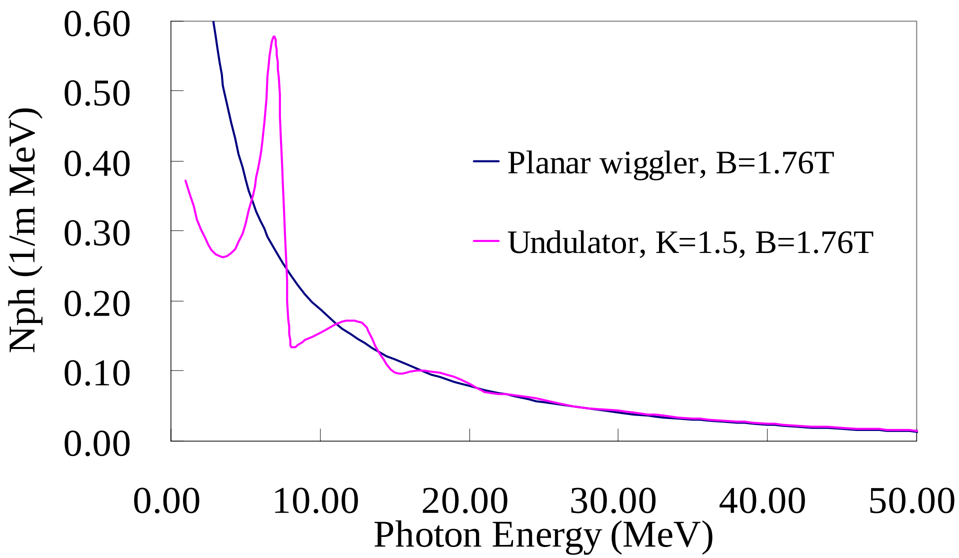
Undulator-Based Positron Source

- **Damping ring requirements:**
  - Charge: 3 – 6 nC
  - Normalized acceptance: $\varepsilon_x+\varepsilon_y < 0.048$ m-rad.
  - Energy spread < ± 1% (peak to peak): 15º of 1.3 GHz acceleration phase.
- **Follow the TESLA TDR design but with lower photon energy (10 MeV generated by 150 GeV e-beam, USSC)**
- **EGS4 for e+/e- production. PARMELA for capturing, transport & acceleration of e+ and e- beams**
- **Normal-conducting linac to 120 MeV and SCRF linac to 5 GeV with ~ 200 TESLA modules.**

Undulator requirements

(for 3nc captured e^+ and 3nC drive electron beam at 150 GeV)

- **L (undulator length) = 22.4 m for $\varepsilon_x + \varepsilon_y$ < 0.024 m-r; L = 18.7 m for <0.048 m-r**
- **Gamma Ray Power**
  - *for $\varepsilon_x+\varepsilon_y$<0.048, 67 kW, and $\varepsilon_x+\varepsilon_y$ < 0.024, 80 kW*
  - *Deposited energy on the target – 7% of gamma beam. ~ 80% of Gamma ray propagates through the target and cause radiation problems down stream*
- **Initial positron and electron beam distributions are produced by EGS4 (# e = 25575, #e+ = 14646, R_{spot} = 2mm)**
- **Positron energy spectrum:**



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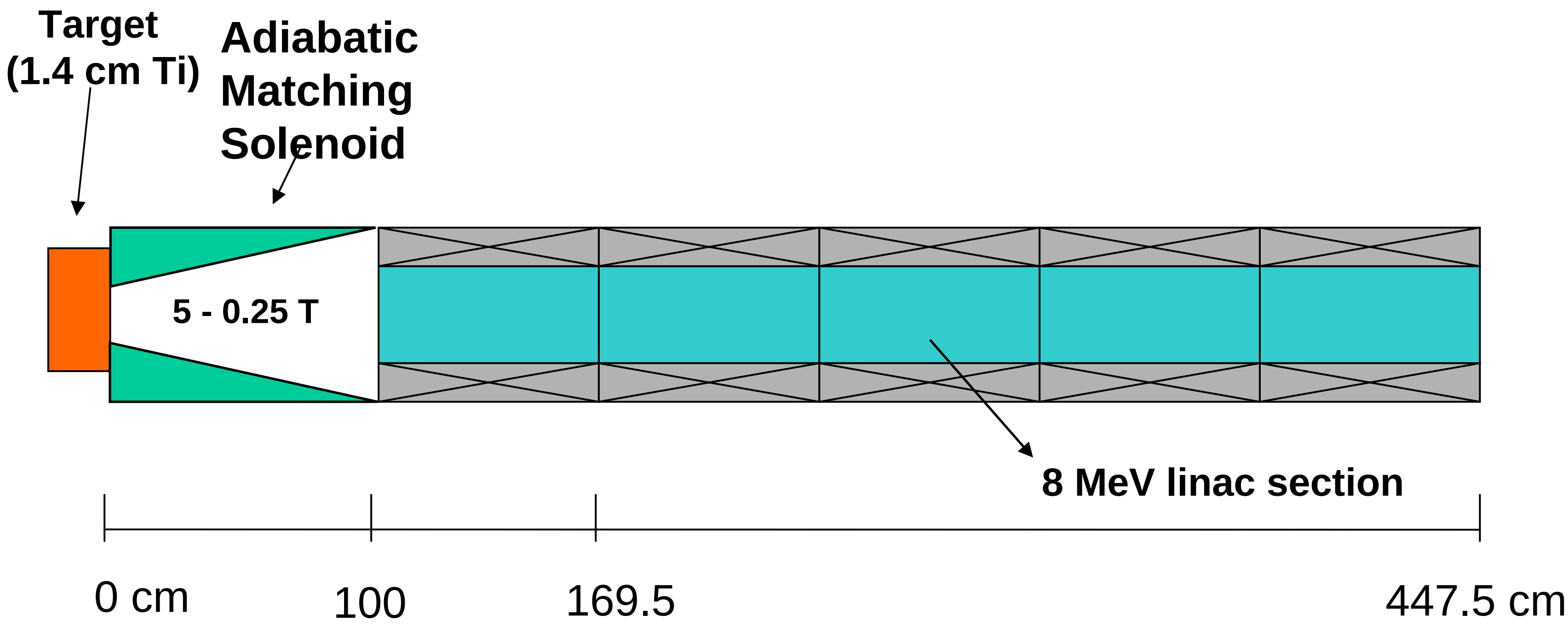
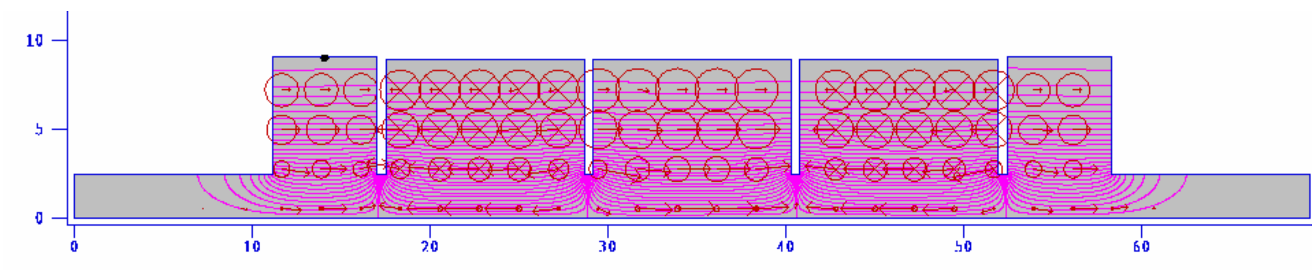
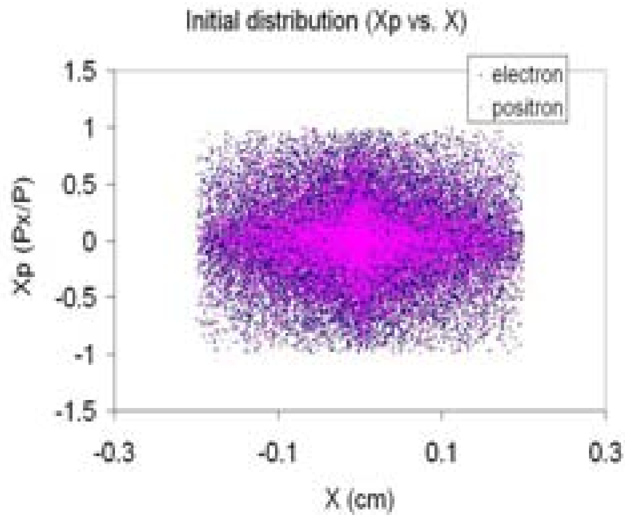
Source, AMD and Pre Accelerator Layout



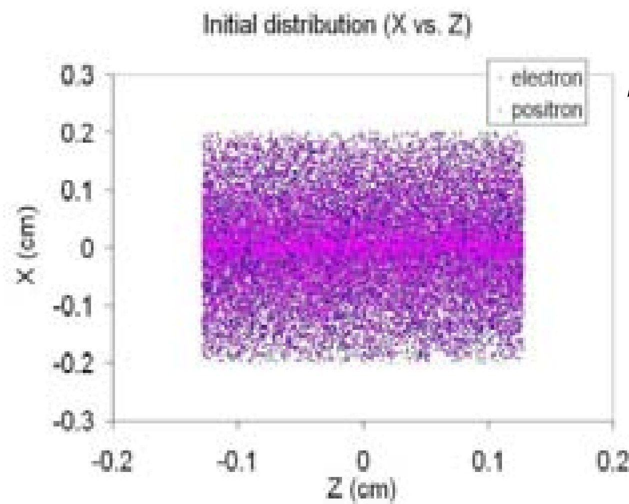


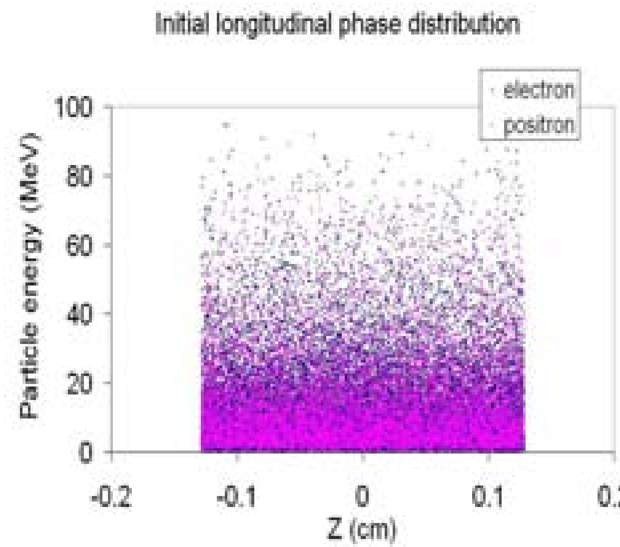
5 cell π mode iris loaded L band linac, the aperture D=5cm, T is about 0.74, E_0T=12MV/m, P=4.4MW. Total energy gain=8.4 MeV, Q=25000, r/Q=613 Ohm

Initial particle distribution at the target exit

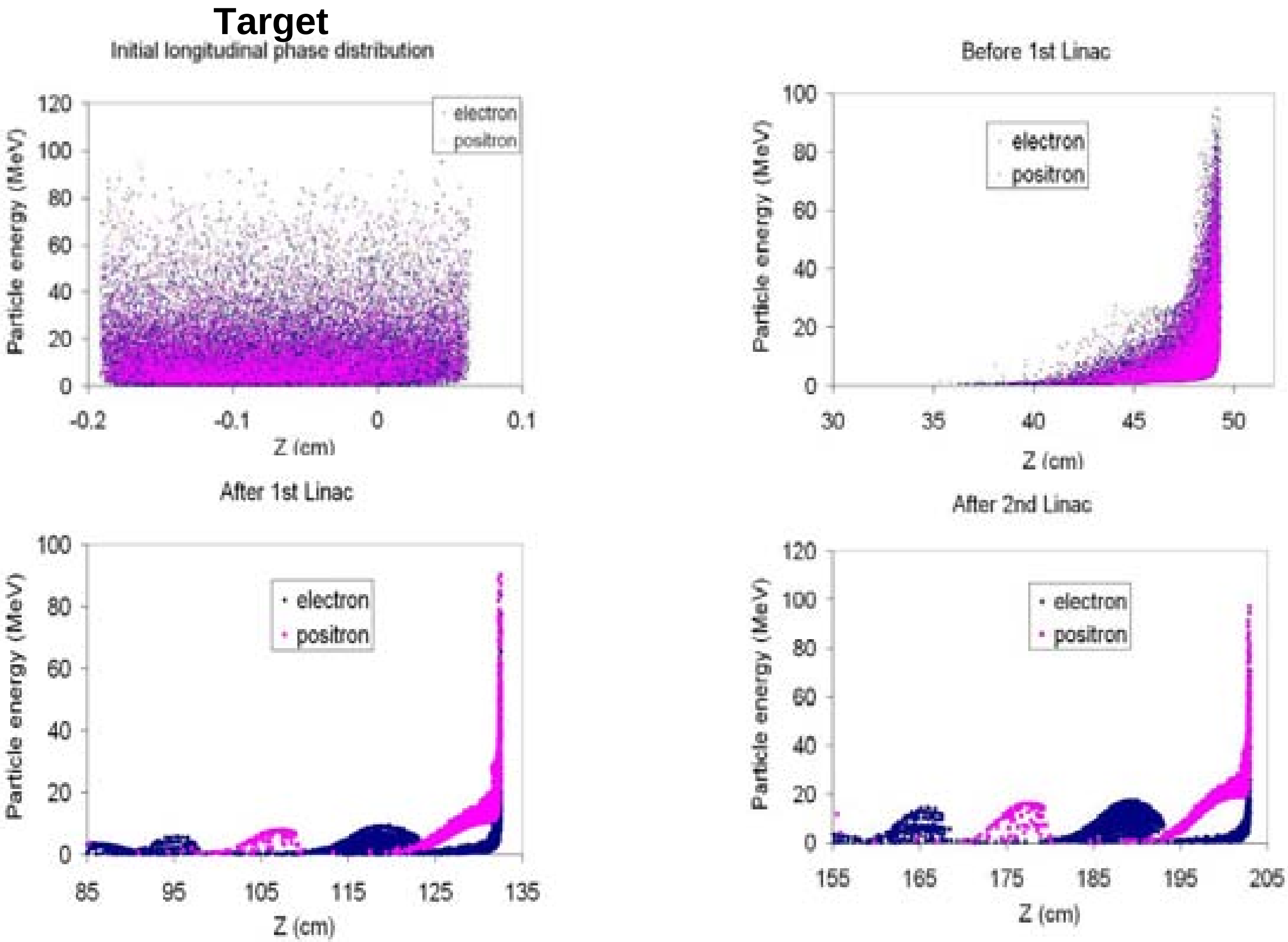


X and Y are symmetric.

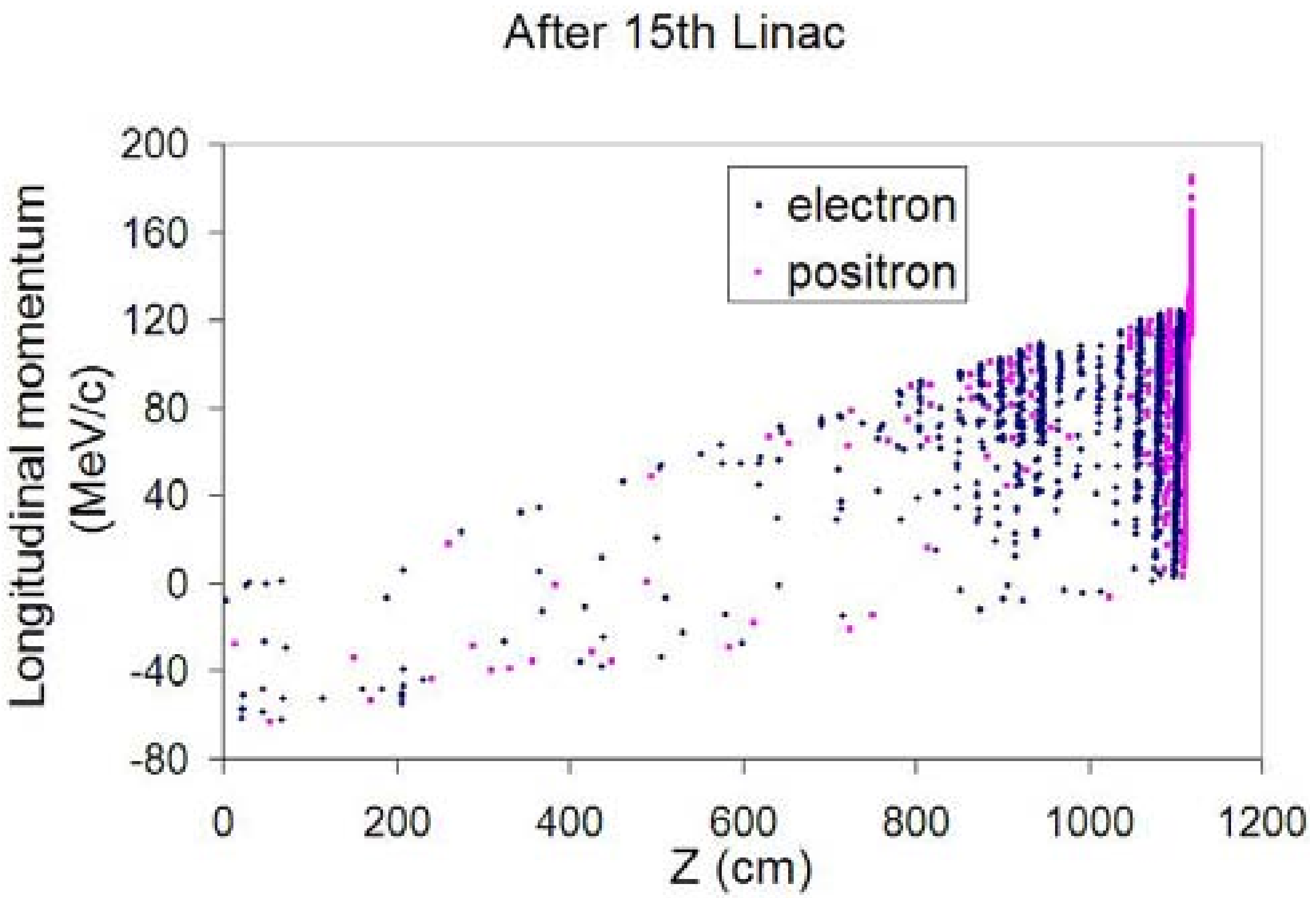




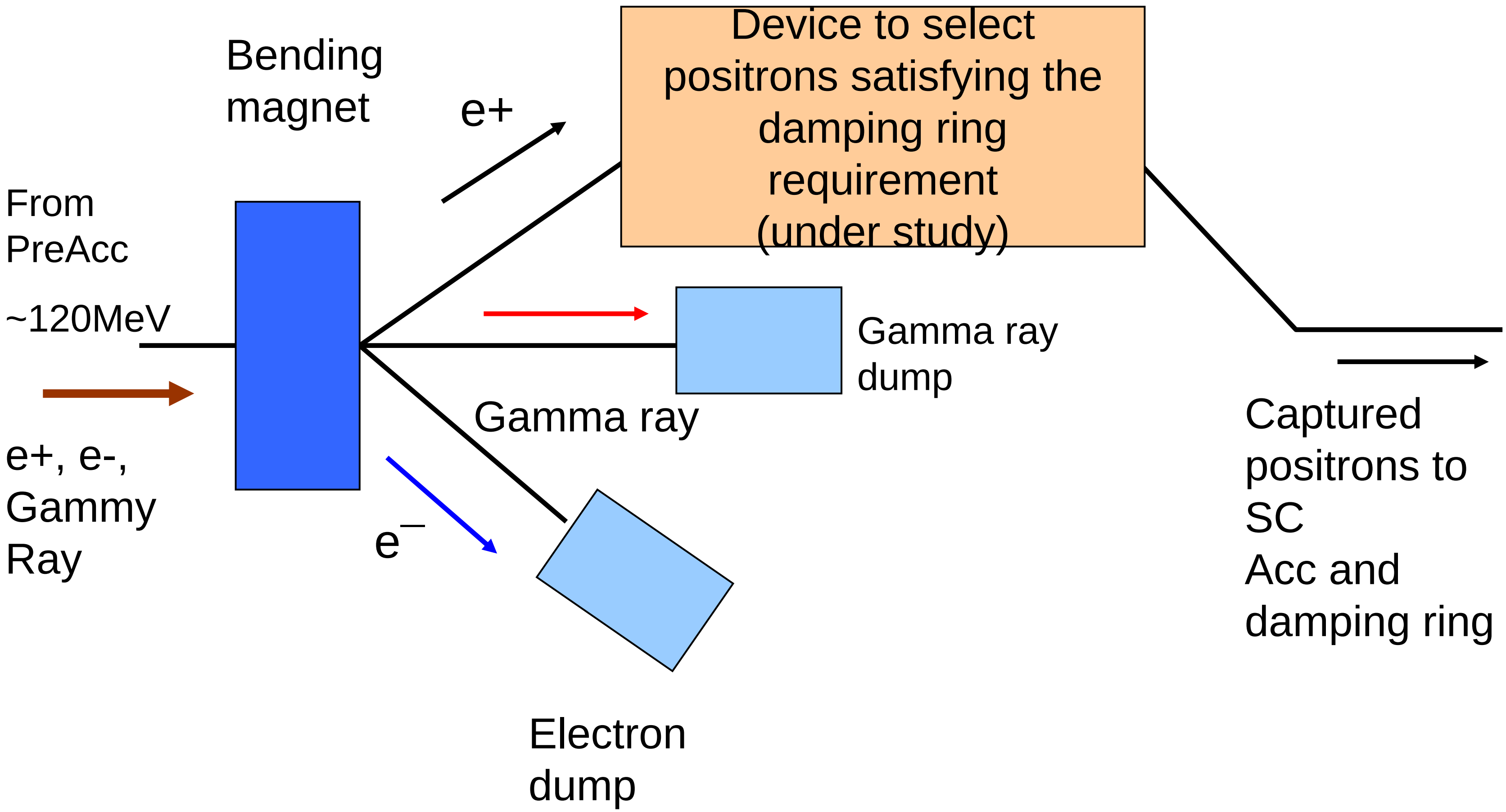
Longitudinal phase-space distribution along Pre-Accelerator



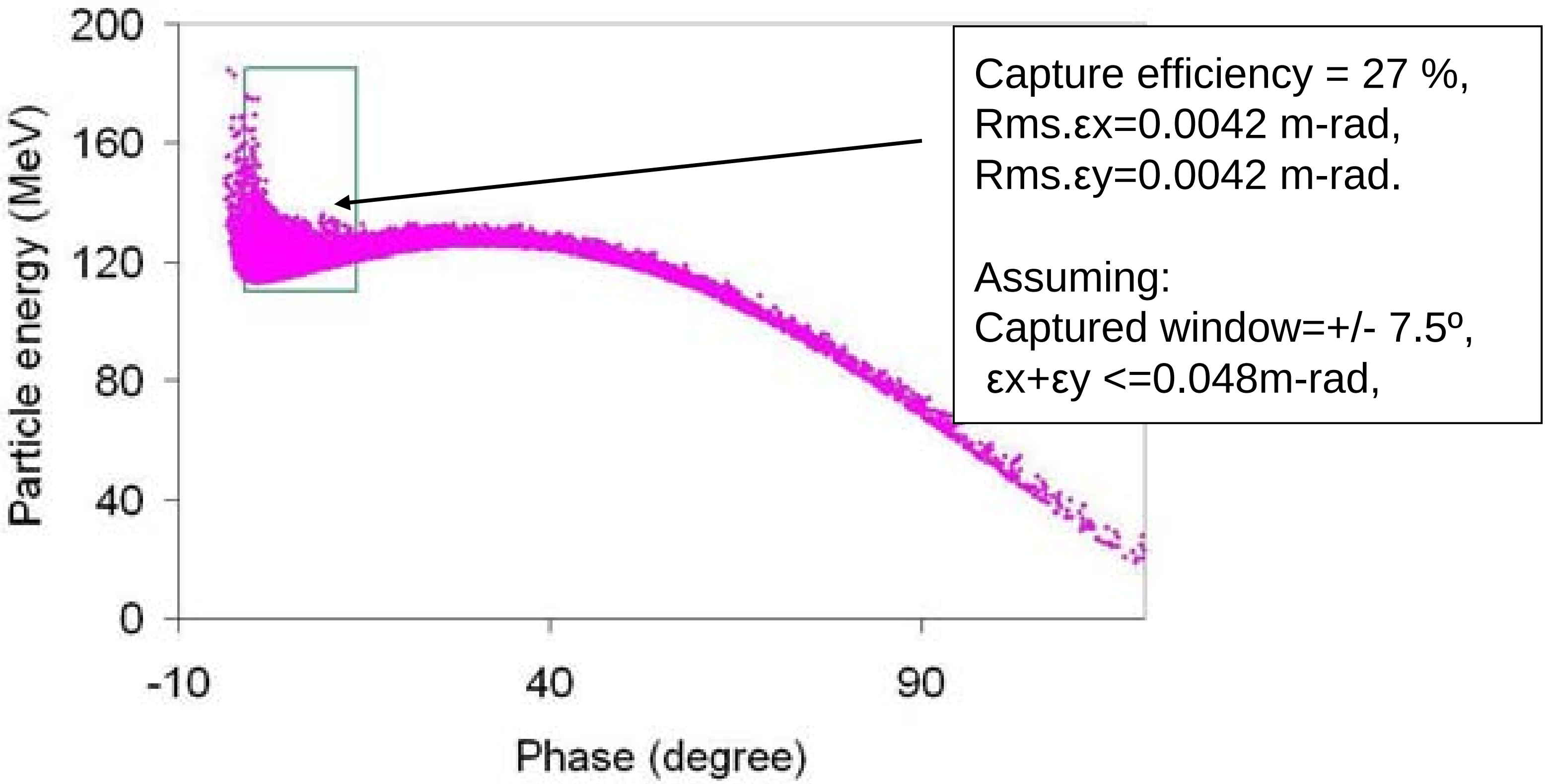
Longitudinal momentum distribution along the pre-accelerator



Positron selection and beam dump schematics.

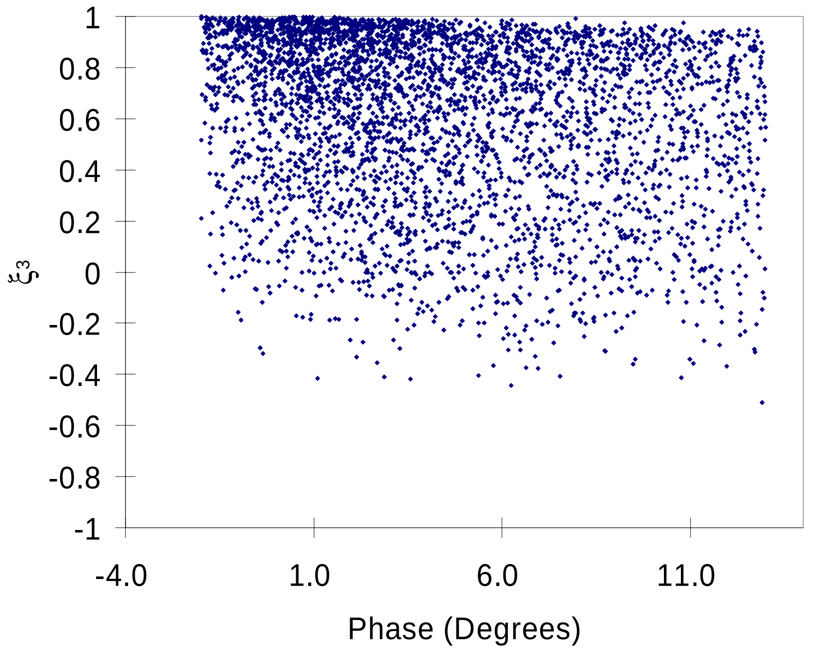


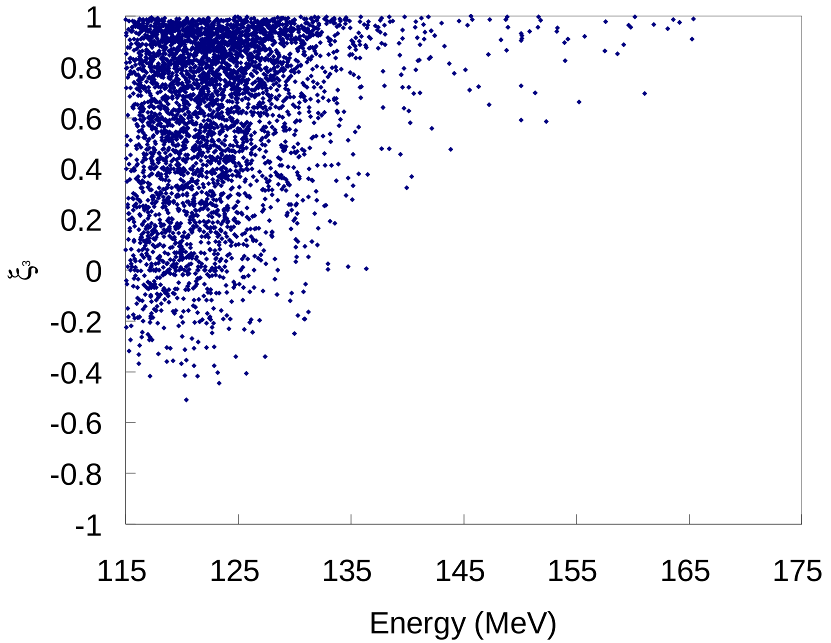
Capture efficiency after 15th Linac (end of pre-acc)



We discovered that the accelerator acted as transverse emittance filter, almost all the particles for selected longitudinal range +- 7.5 degree has εx+εy <=0.048m-rad, therefore there is no need for transverse beam selection, only longitudinal selection is needed.

Polarization of the captured positrons

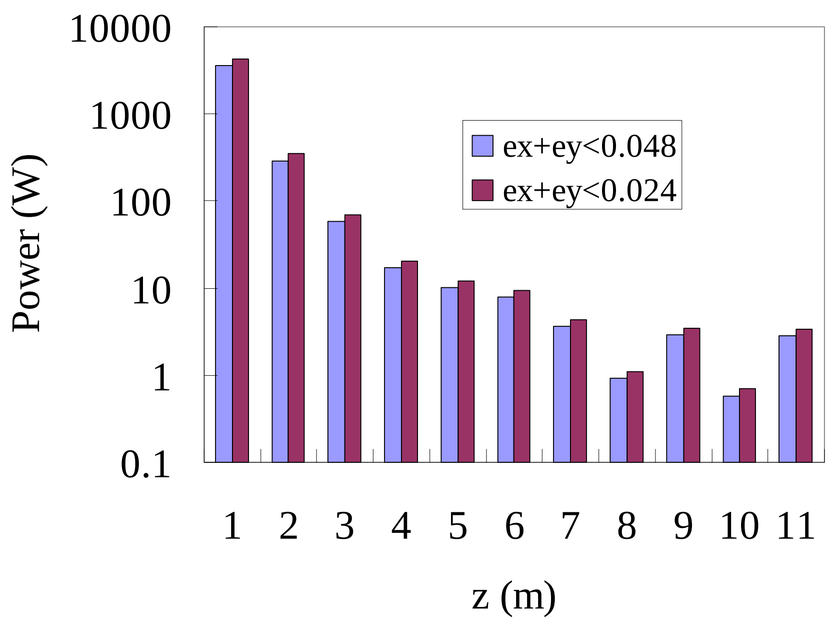




About 50% of captured particle has ξ_3 >0.7. Average polarization is 0.6 or 60%

Power lost along beam line for 3nC captured positron beam

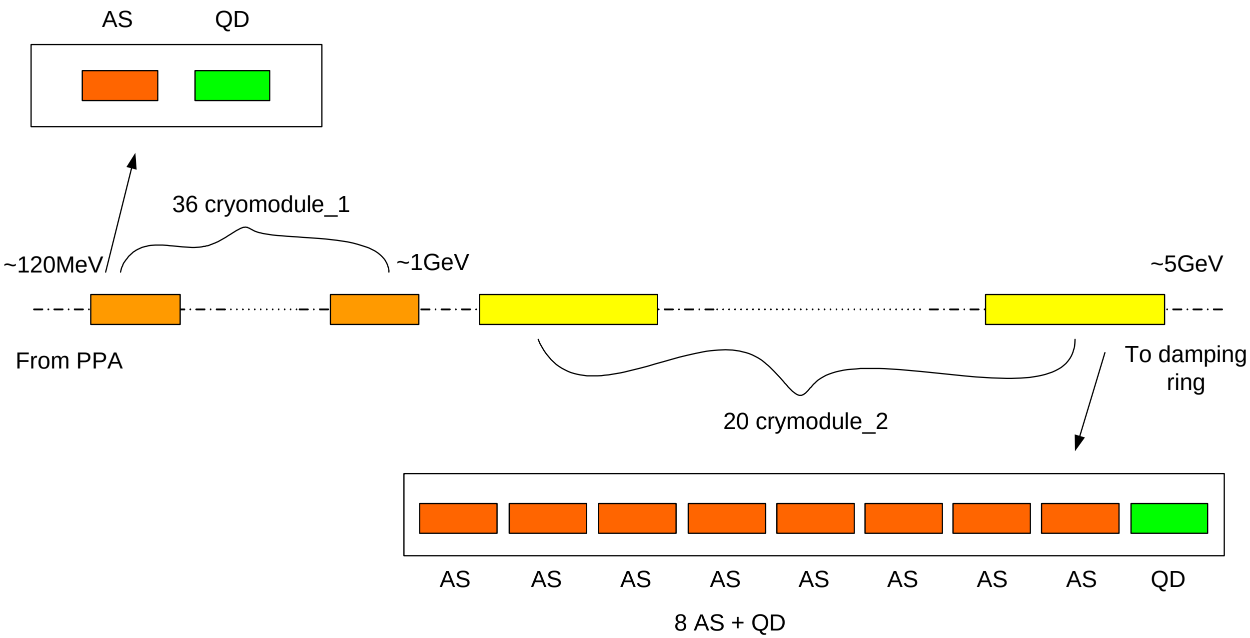
- **For helical undulator:**
  - $\varepsilon_x+\varepsilon_y<0.048$: 16KW
  - $\varepsilon_x+\varepsilon_y<0.024$: 20.19KW



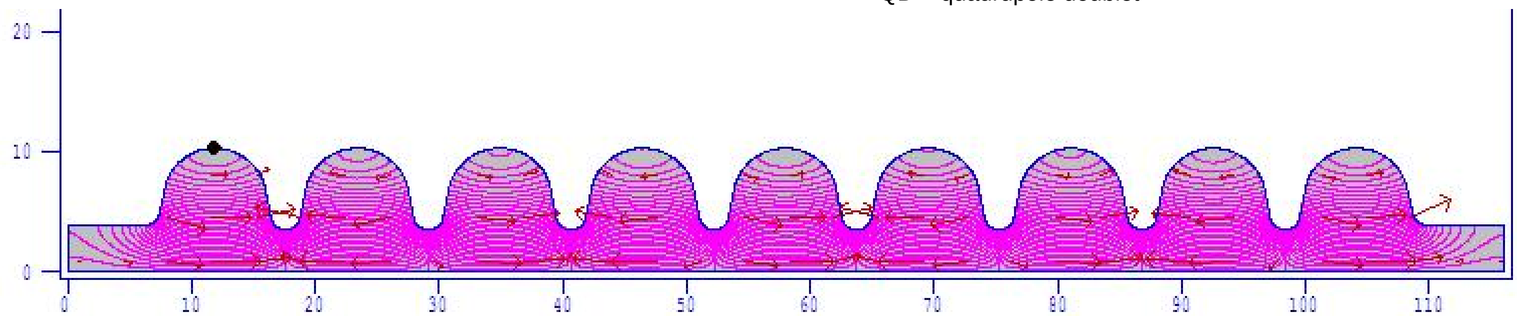
Power deposited in source target by backfired particles:

- **For helical undulator:**
  - ex+ey<0.048: 435.3W
  - ex+ey<0.024: 520.5W

Boosting Energy to 5 GeV to Damping Ring Input

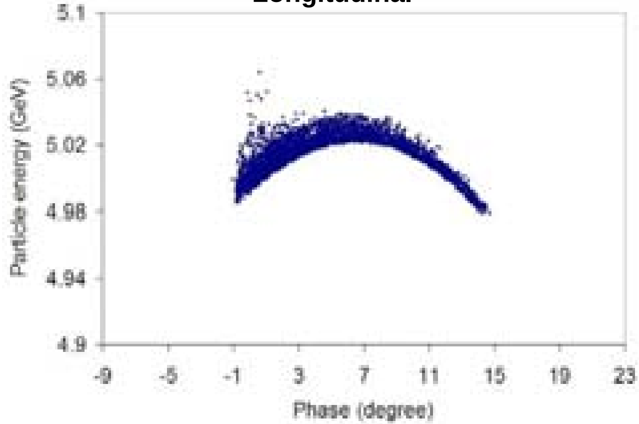


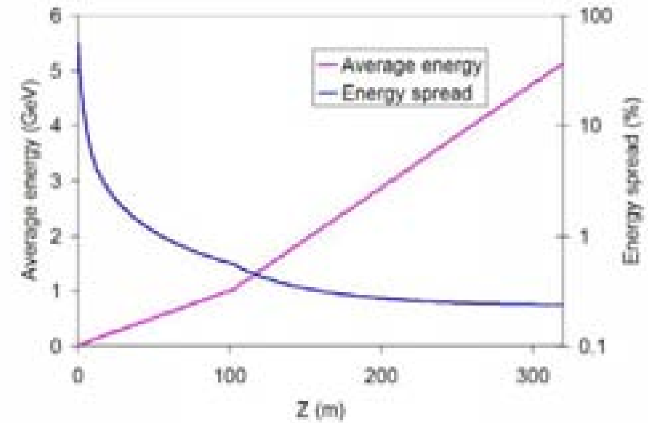
AS = accelerating structure
QD = quadrupole doublet



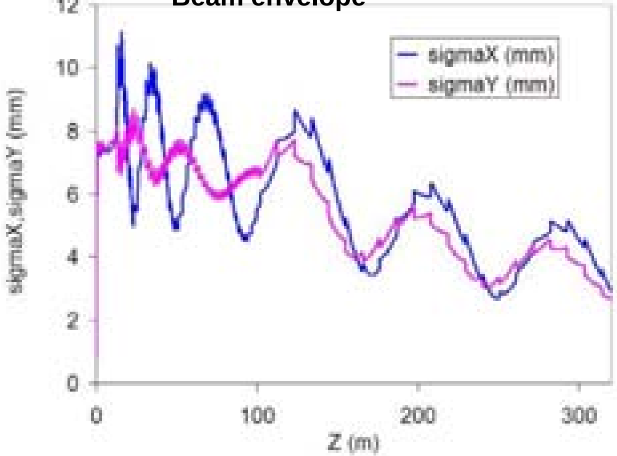
Beam evolution to and longitudinal phase space distribution at 5 GeV

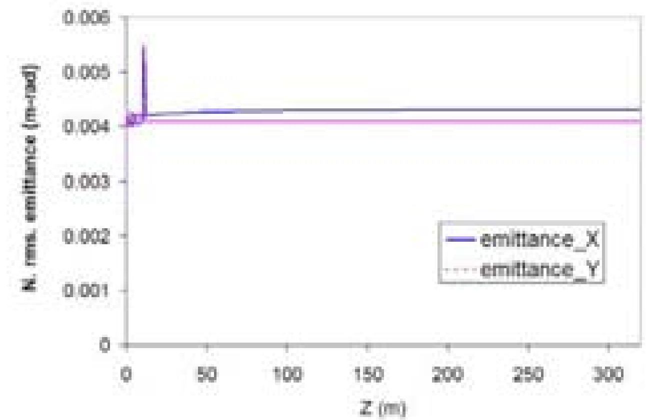
Longitudinal





Beam envelope

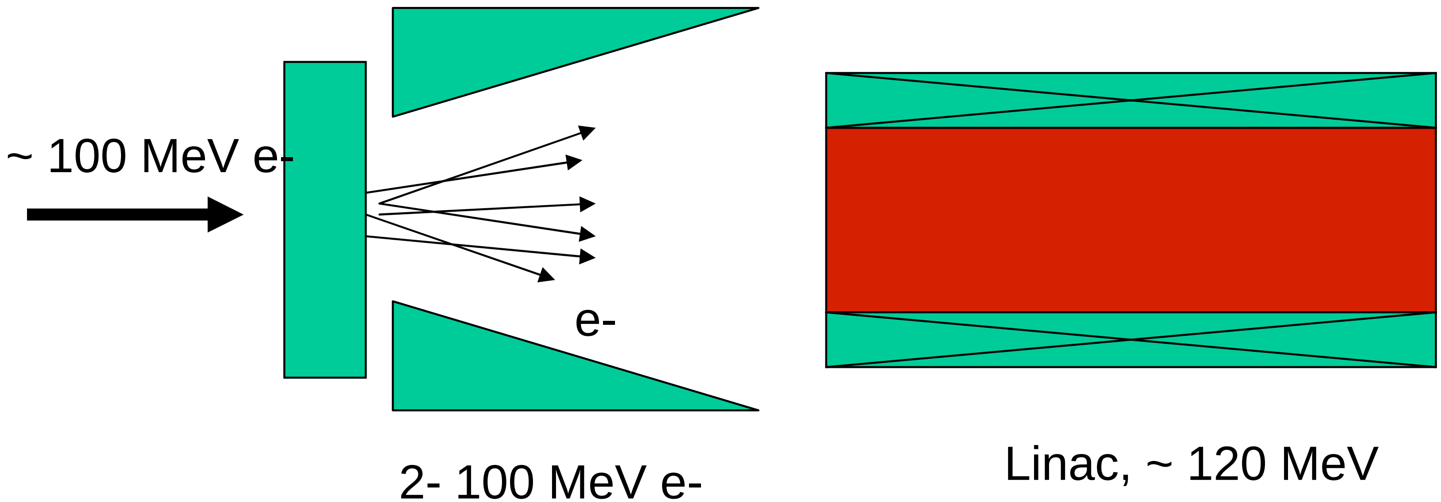




2.Electron Emulator of Positron Source

Motivation: to condition the positron linac and positron damping ring without gamma ray produced positron source or auxiliary positron source. Speed up the commission process.

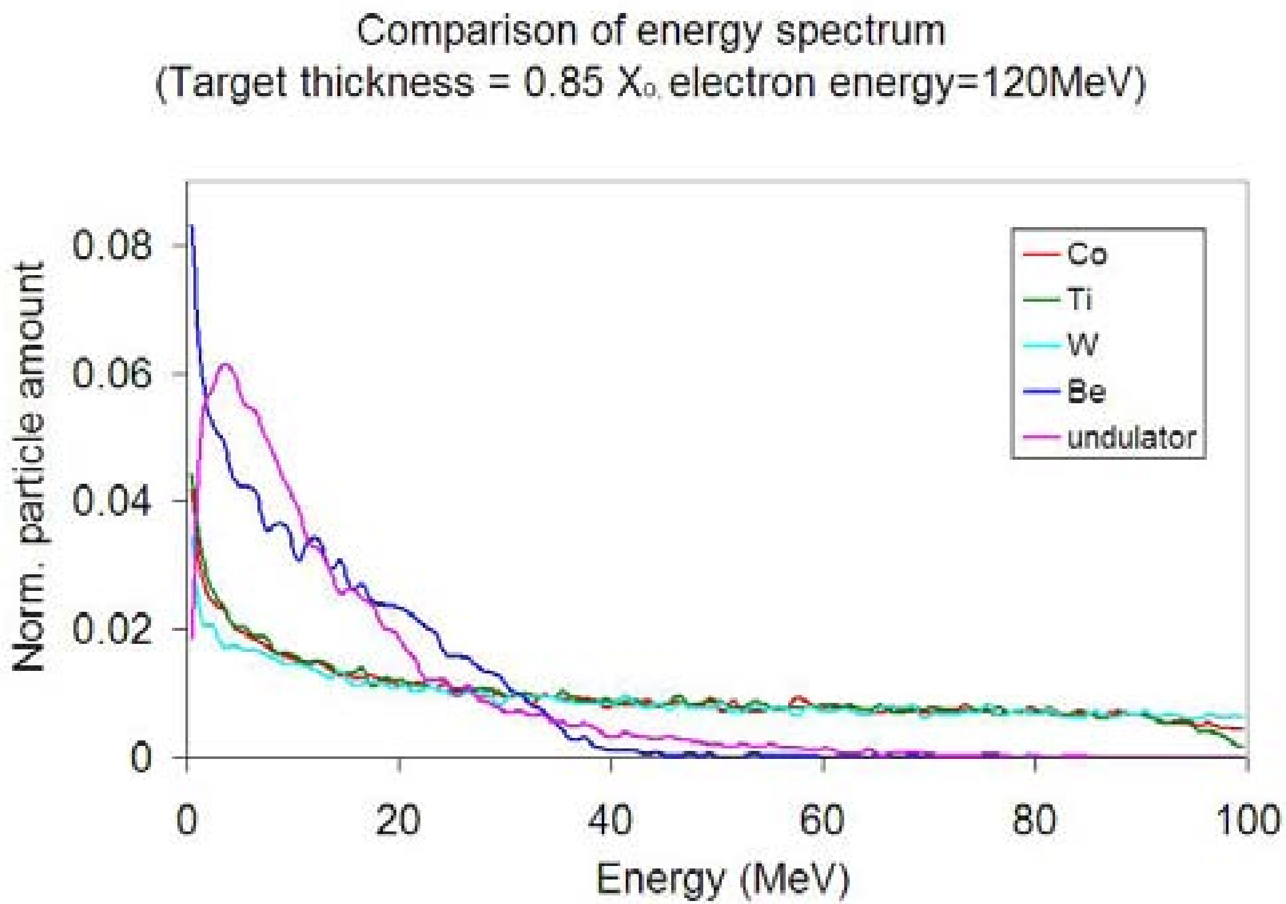
Method: Use electron beam from an L-band RF gun to generate a "simulated" e+ beam.



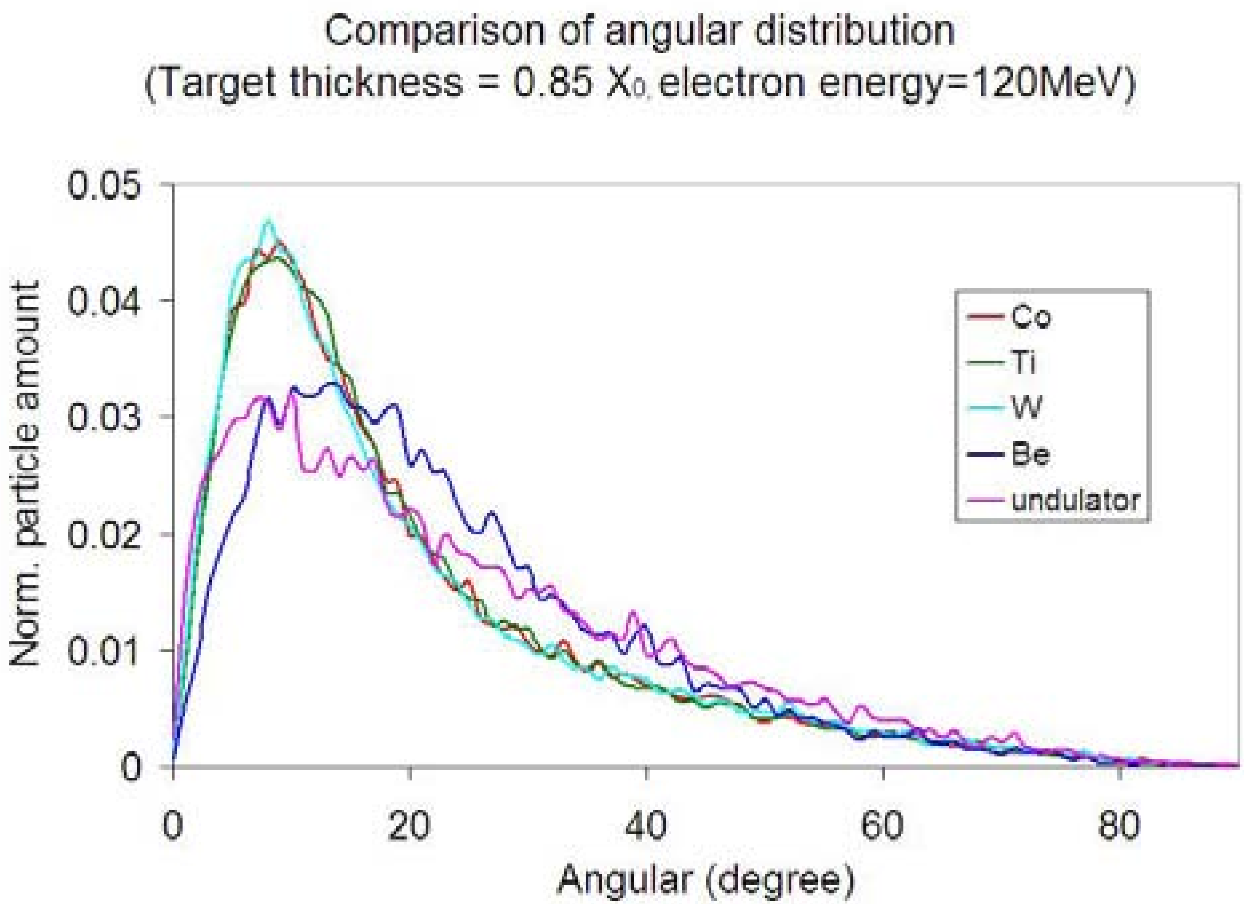
Looking for a few good targets (Using EGS 4):

- Energy, energy spread
- Angular distribution
- Factors under the consideration: **beam energy, target materials, and target thickness**.

Comparison of energy spectrum for different target materials



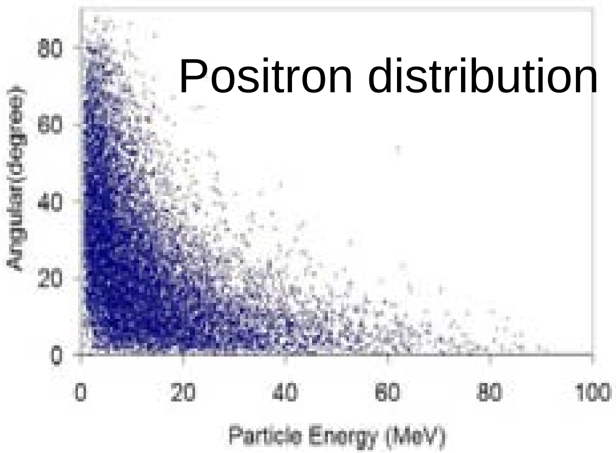
Comparison of angular distribution for different target materials



Be Target Produces a Reasonable Emulator

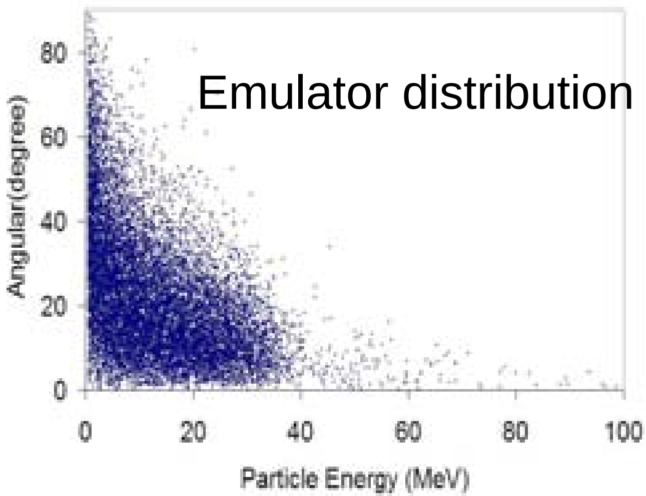
Be target Thickness: 30cm,

Electron energy: 120MeV,

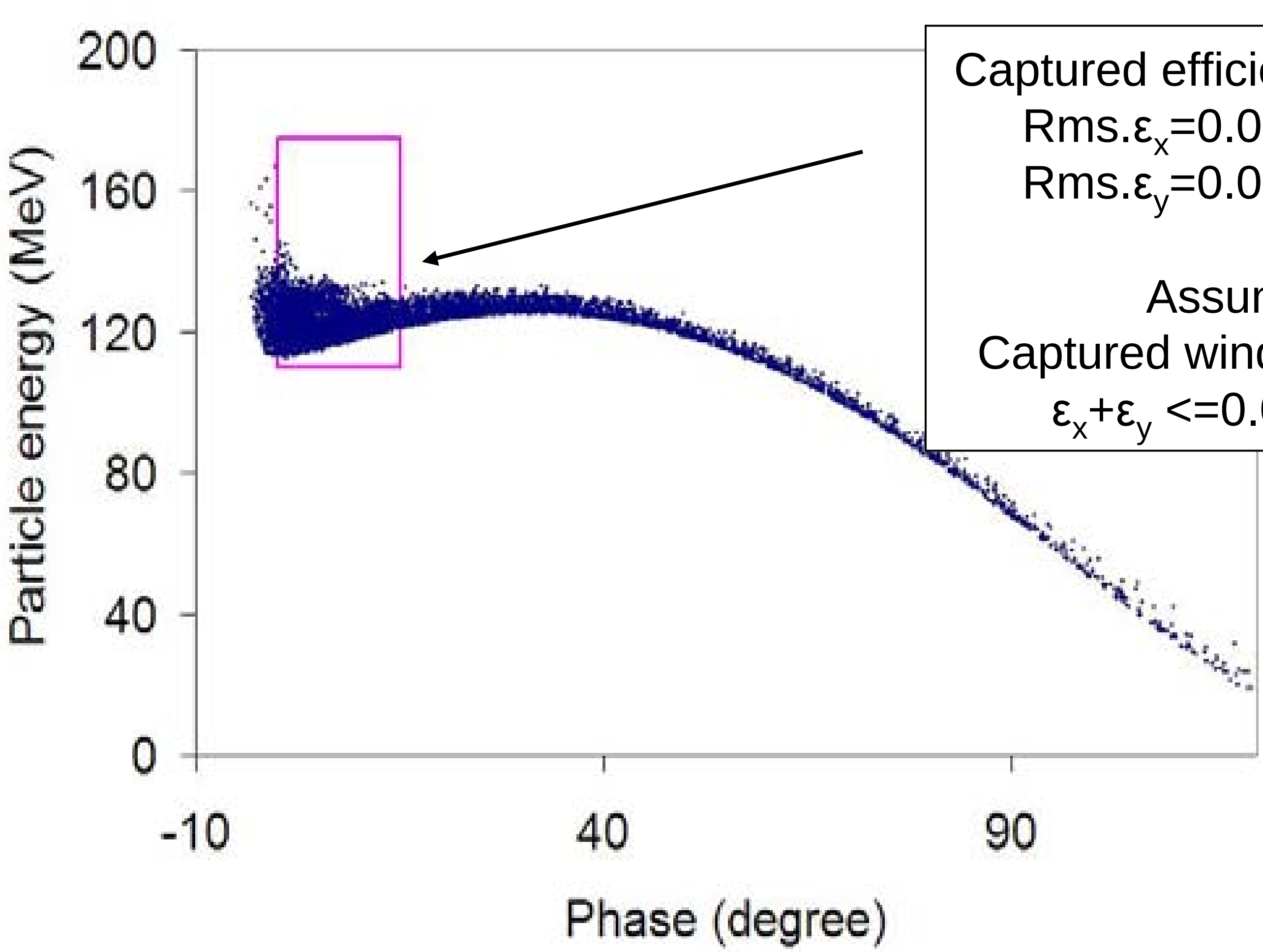


Number of particle bombarding target: 30000

Number of particles yielded from target:13396



Captured electron efficiency after 15th Linac



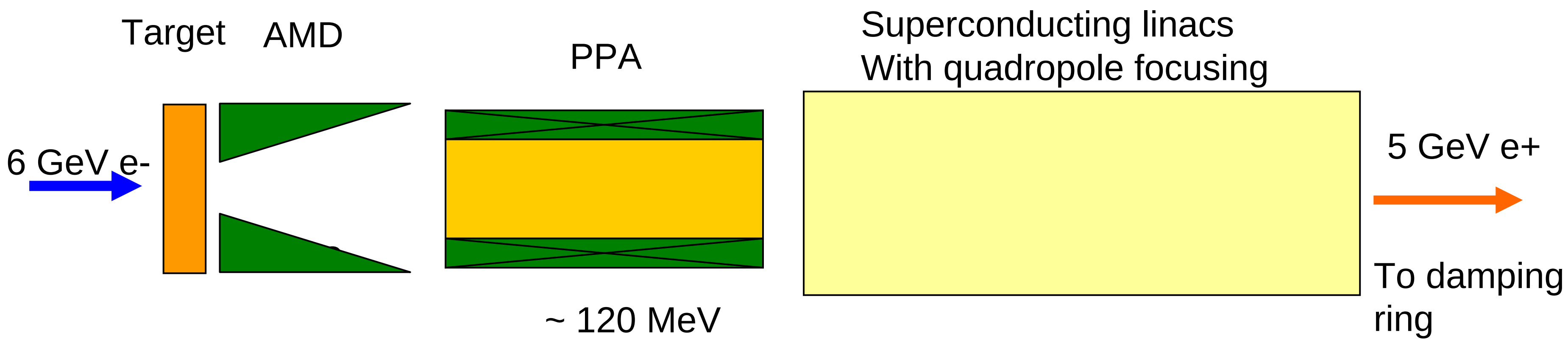
Captured efficiency = 26.4%,
Rms.ε_x=0.0046 m-rad,
Rms.ε_y=0.0046 m-rad.

Assuming:
Captured window=+/- 7.5^o,
$\varepsilon_x+\varepsilon_y$ <=0.048m-rad.

3. Parameter optimization studies of the conventional e+ source (working with SLAC)

- **The influences of target thickness and incident electron energy to positron yield are studied.**
- **We summarized the calculation based on three key parameters:**
  1. Yield based on incoming electron intensity, which is the ratio of number of captured positrons at damping ring entrance (5GeV) to number of incident electrons.
  2. Yield normalized to incident electron energy, which is the number of captured positrons per incident electron energy.
  3. Expected incident energy and deposit energy on target under different condition for a given amount of captured positron,
- **The acceptance criteria for DR is 1% energy spread, $\varepsilon x + \varepsilon y < 0.048\pi m \cdot rad$, and 15 degrees phase window for all the figures unless otherwise specified.**

Schematic of conventional positron source

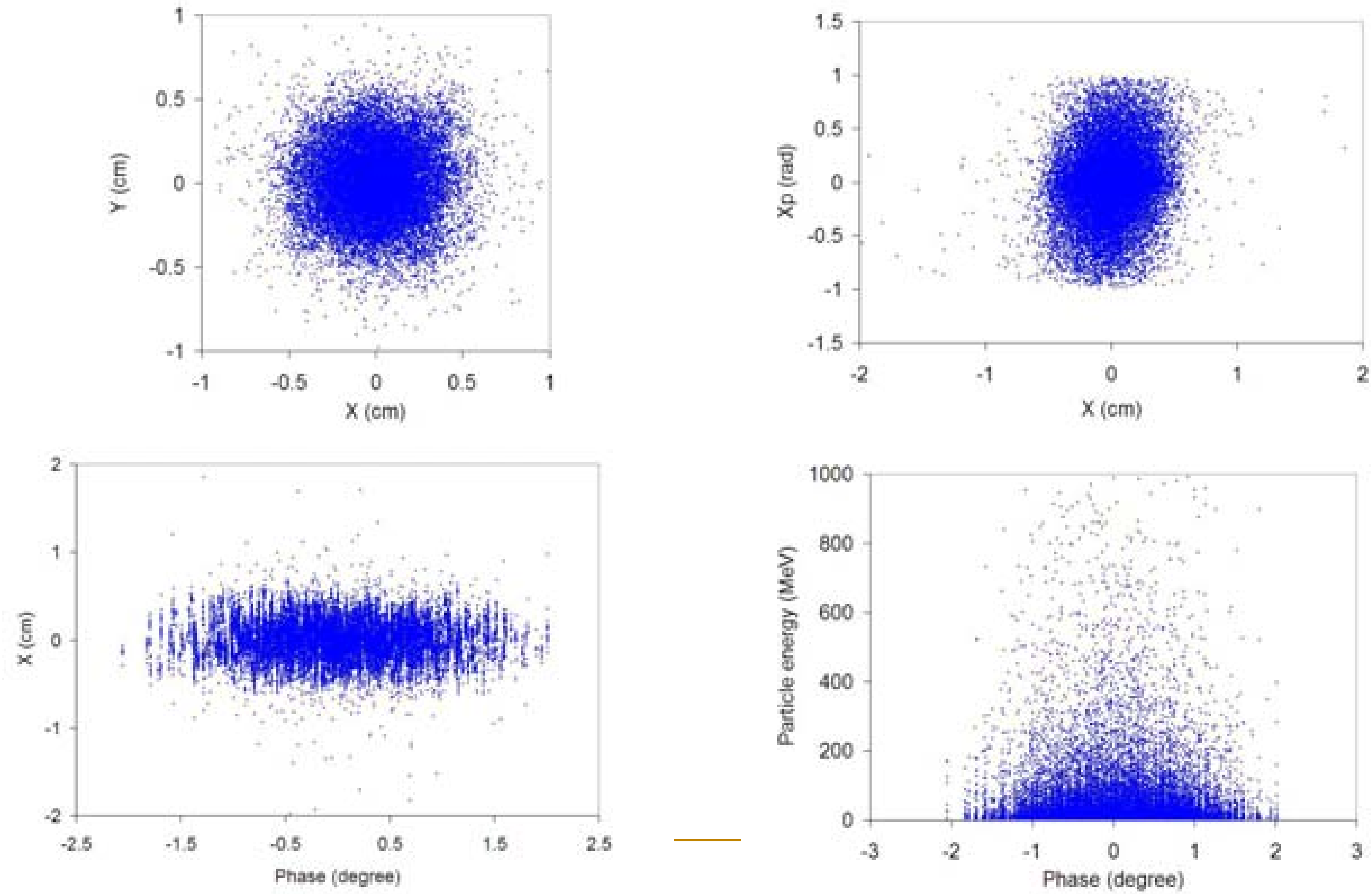


AMD: Adiabatic Matching Device
PPA: Positron Pre-accelerator

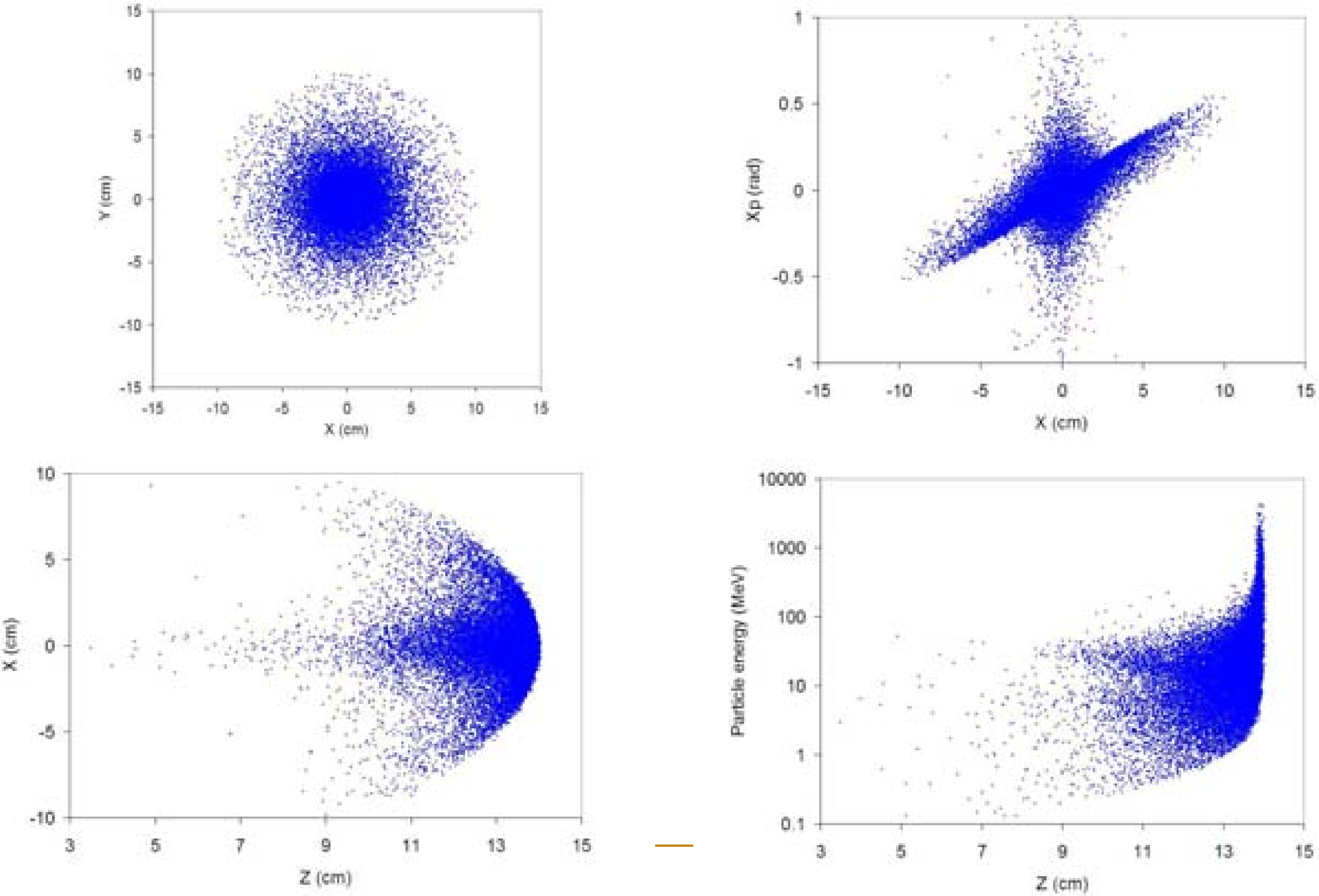
Initial parameters used in simulation for 6 GeV and 4.5 RL case (bench mark)

Target	
Material	W23Re
Length	4.5 RL
Electron Beam	
Energy	6 GeV
Transverse size, $\sigma x = \sigma y$	2 mm
Longitudinal size, σt	1.5 ps
Adiabatic Matching Device	
Field profile	$Bz = Bmax/(1 + gz)$
Field at the target, Bmax	6 Tesla
Field coefficient, g	0.78 cm-1
Length of AMD	14.1 cm
Pre-accelerator	
Wavelength	23 cm
Energy	0…...120 MeV
Length	10.5 m
Focusing field	0.5 Tesla
Accelerating gradient	12 MV/m
Accelerator	
Wavelength	23 cm
Energy	120 MeV ….5 GeV
Length	303 m
Accelerating gradient	25 MV/m

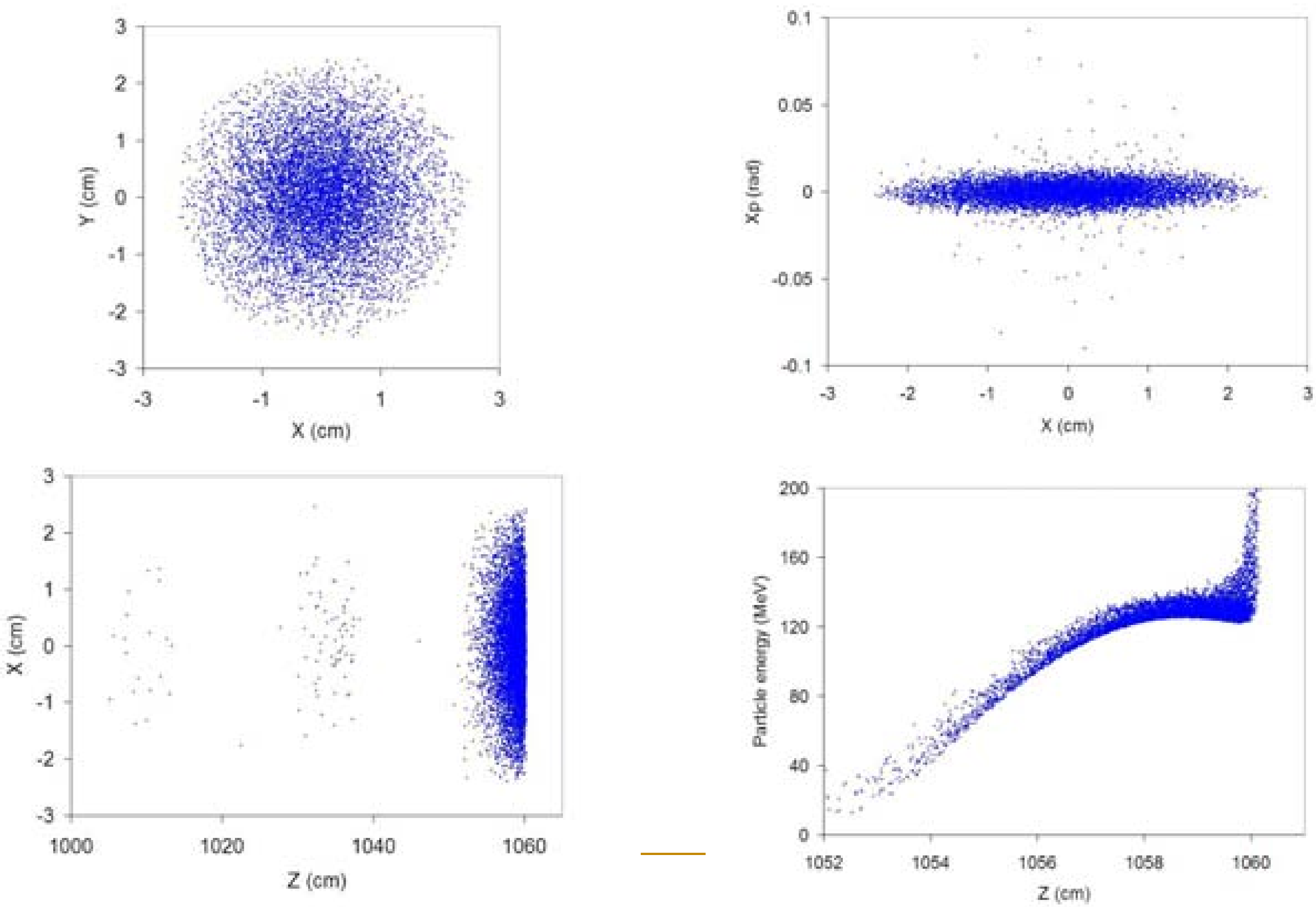
Initial positron distribution



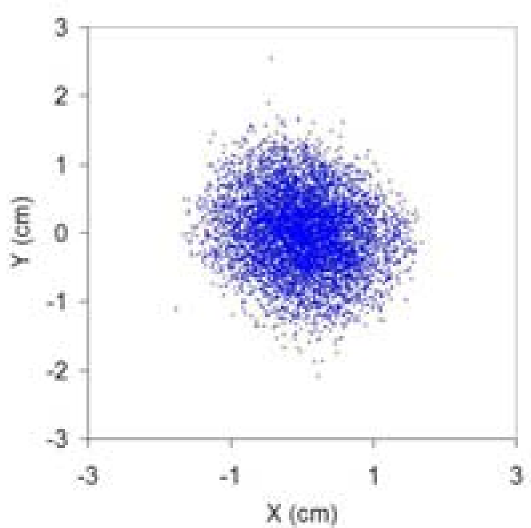
Phase distribution at AMD exit

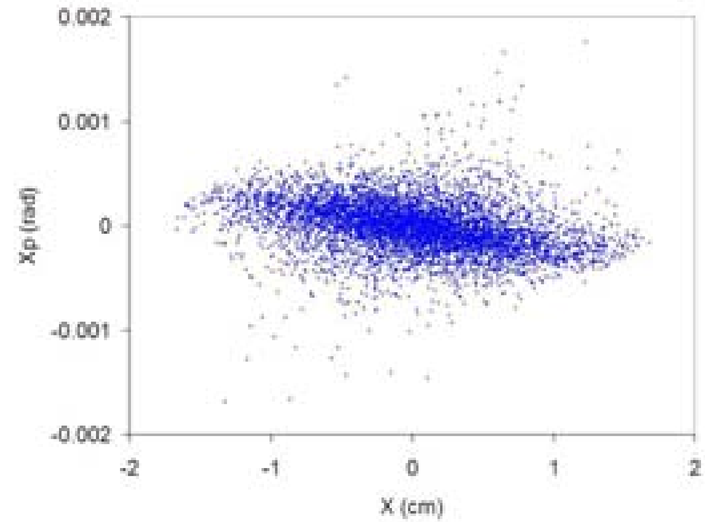


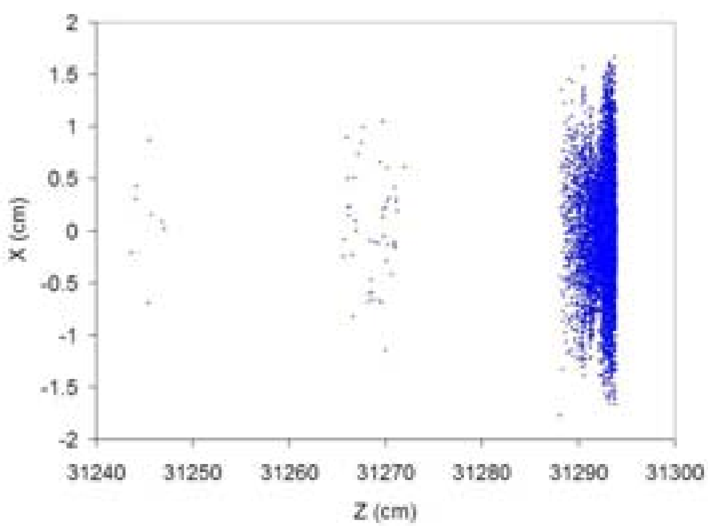
Phase distribution at pre-accelerator exit (120MeV)

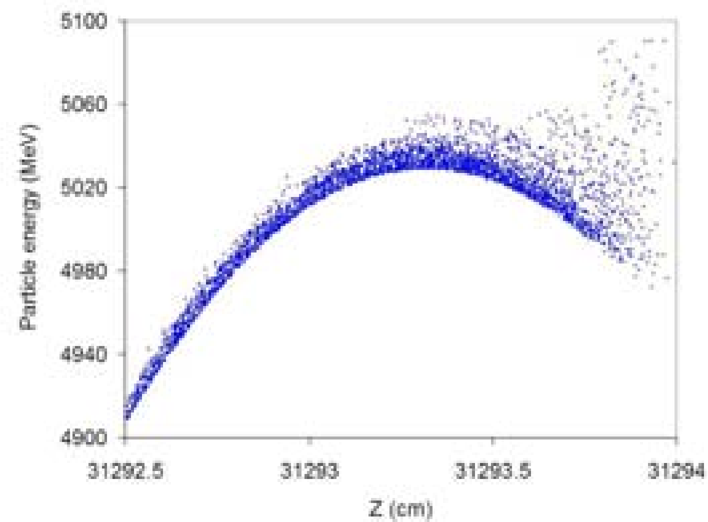


Phase distribution before entrance of damping ring (5GeV)

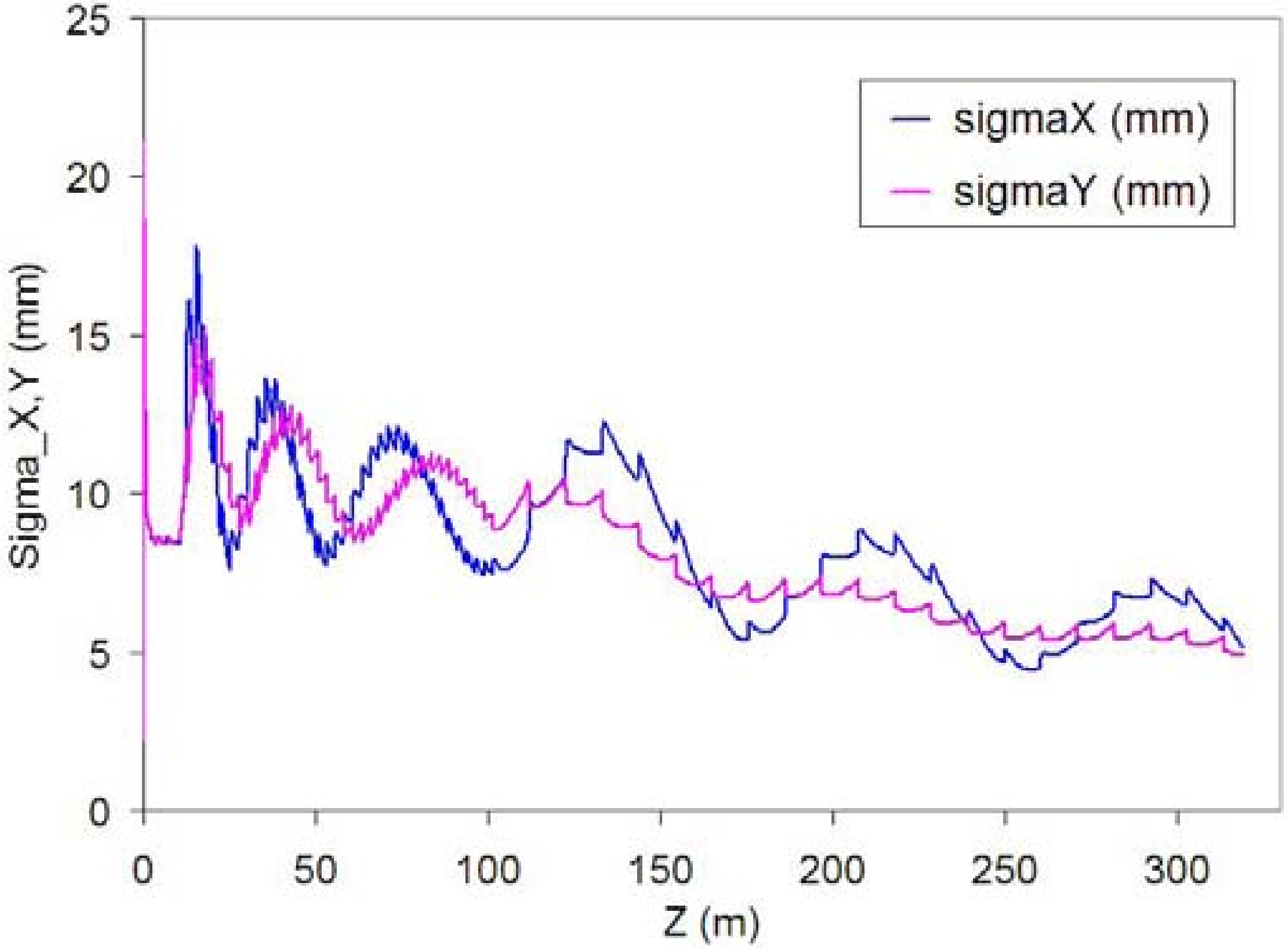






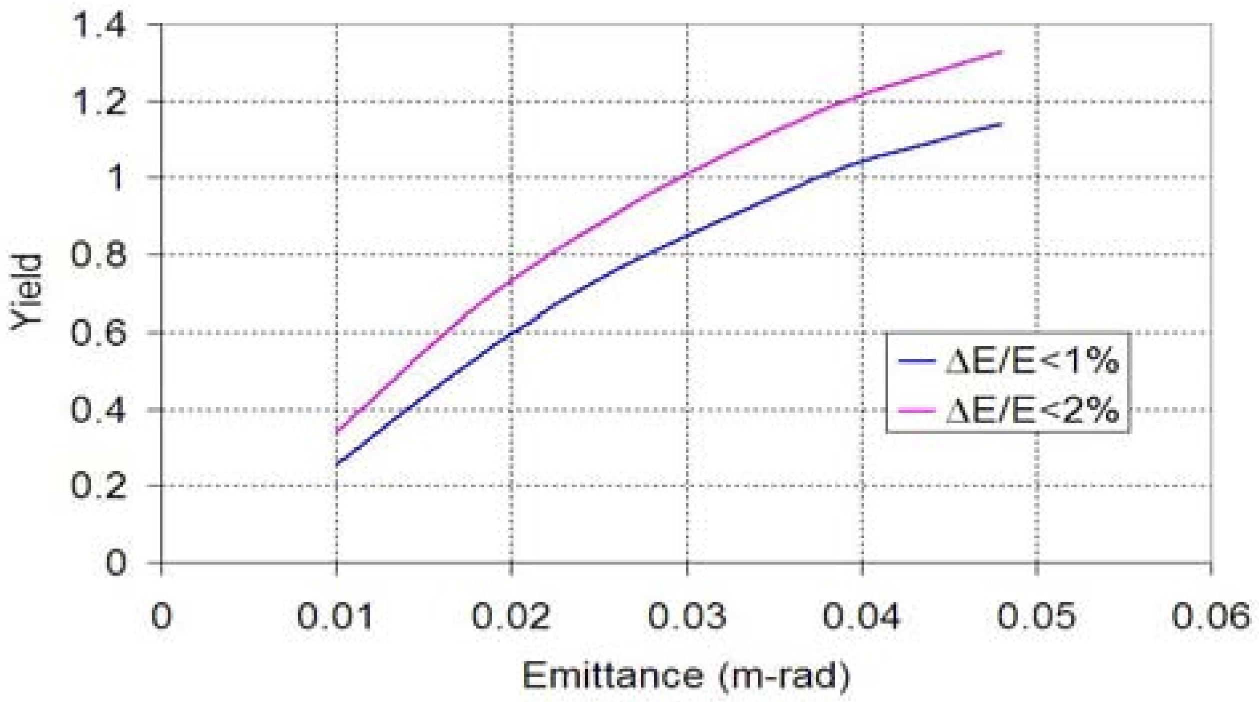


Rms. positron beam envelop



Yield vs. damping ring aperture

Positron yield is defined as the ratio of the number of captured positrons to that of incoming electrons striking the conversion target.



- The above slides are a reference case for 6 GeV drive beam, 4.5 RL

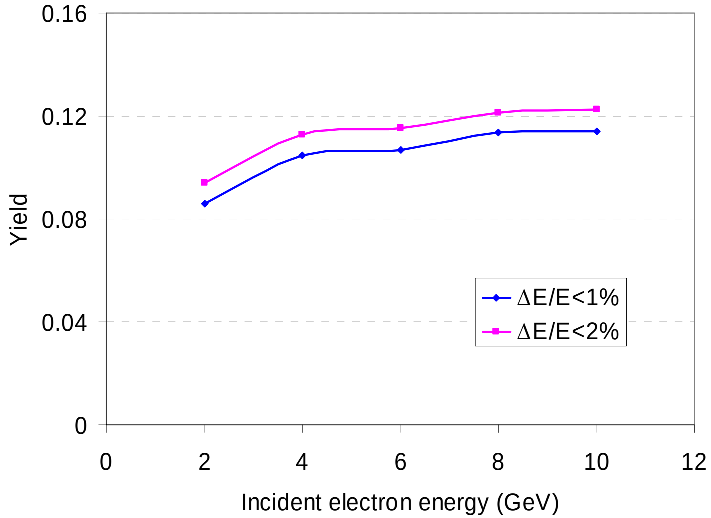
- The results are in agreement with Yuri's results (from Yuri's note on the web).

Wide parameters sweeping covered in the simulations (40 cases)

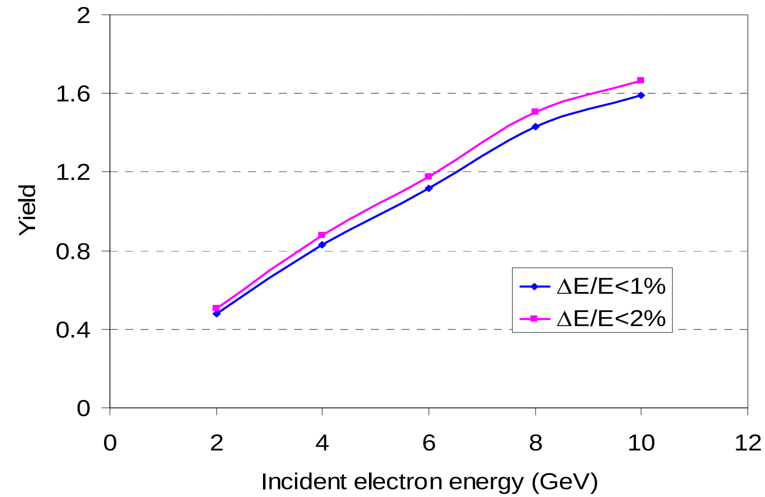
Target	
Material	W23Re
Length	1,2,3,4,5,6,7,8 RL
Electron Beam	
Energy	2,4,6,8,10 GeV
Transverse size, σx = σy	2 mm
Longitudinal size, σt	1.5 ps
Adiabatic Matching Device	
Field profile	Bz = Bmax/(1 + gz)
Field at the target, Bmax	6 Tesla
Field coefficient, g	0.78 cm-1
Length of AMD	14.1 cm
Pre-accelerator	
Wavelength	23 cm
Energy	0…...120 MeV
Length	10.5 m
Focusing field	0.5 Tesla
Accelerating gradient	12 MV/m
Accelerator	
Wavelength	23 cm
Energy	120 MeV ….5 GeV
Length	303 m
Accelerating gradient	25 MV/m

Typical results of yield vs energy at given target thickness

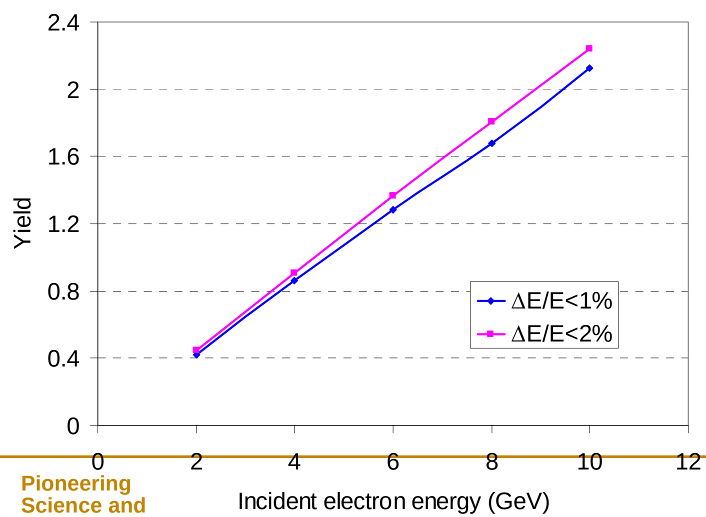
Yield vs. energy at 1 radiation length



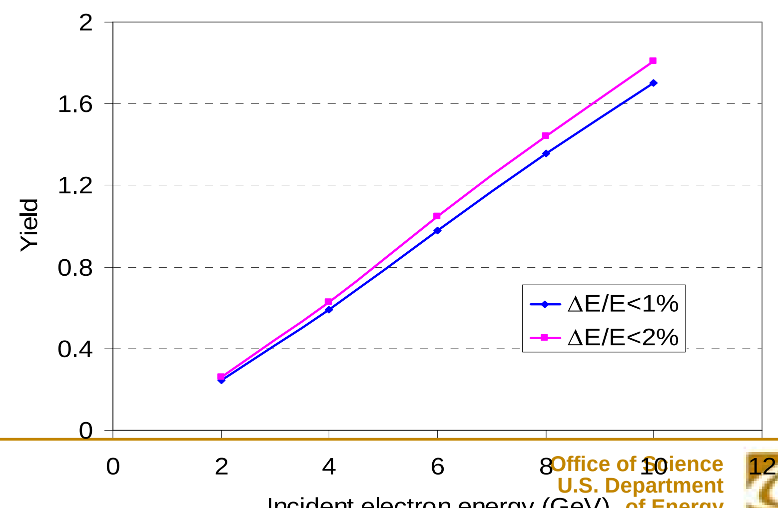
Yield vs. energy at 4 radiation length



Yield vs. energy at 6 radiation length

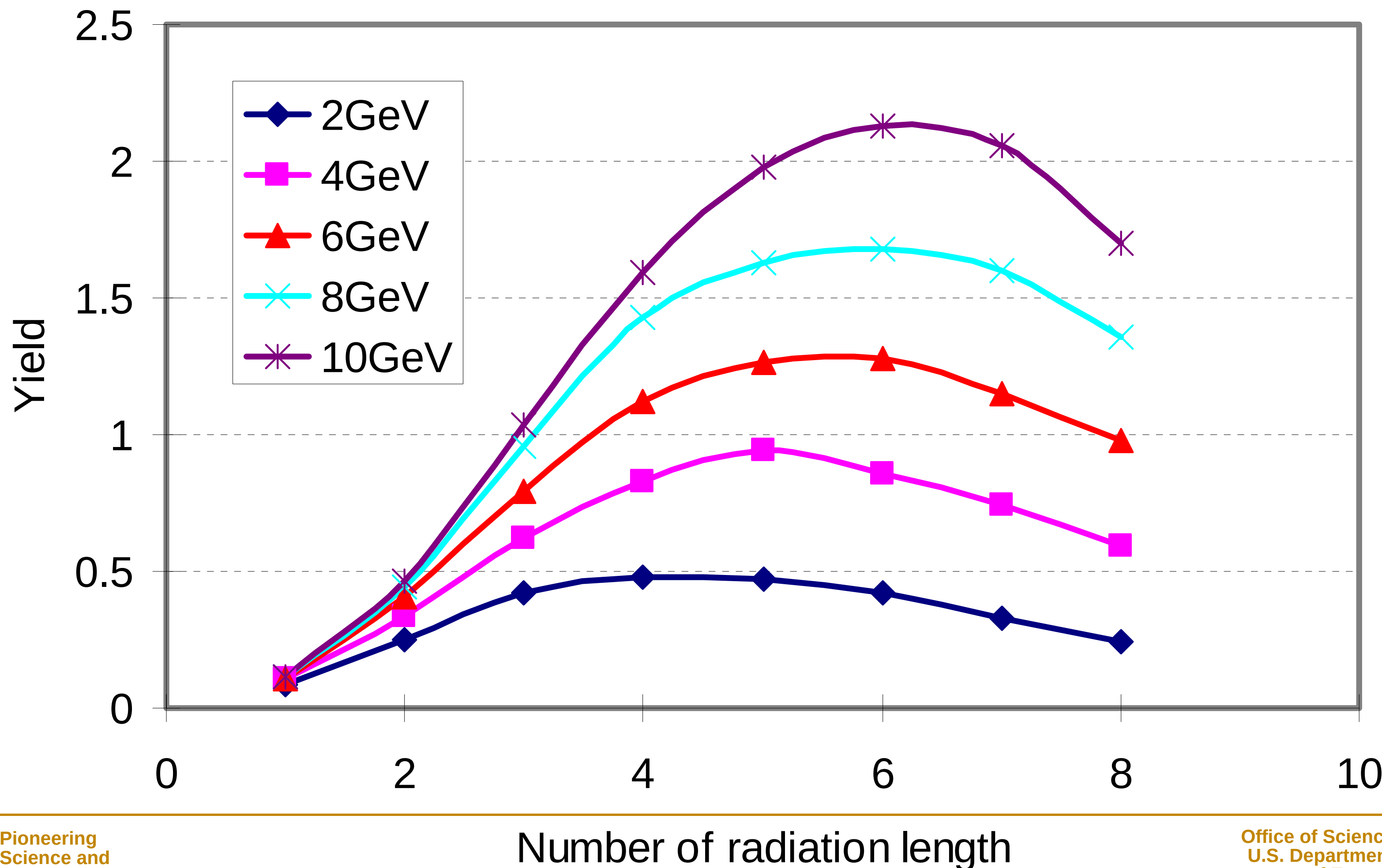


Yield vs. energy at 8 radiation length

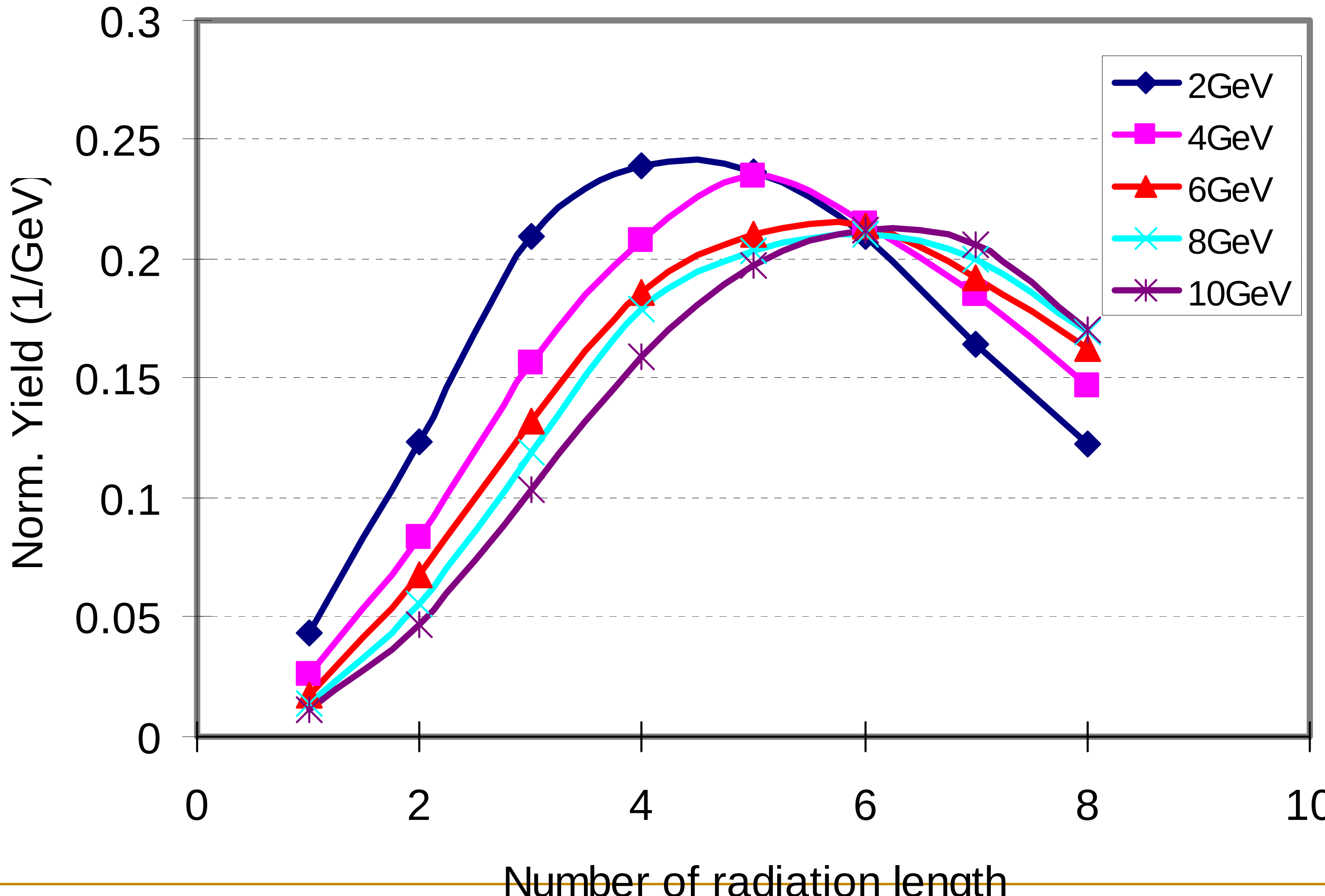


Yield vs. radiation length at given incident energy (all 1% energy spread)

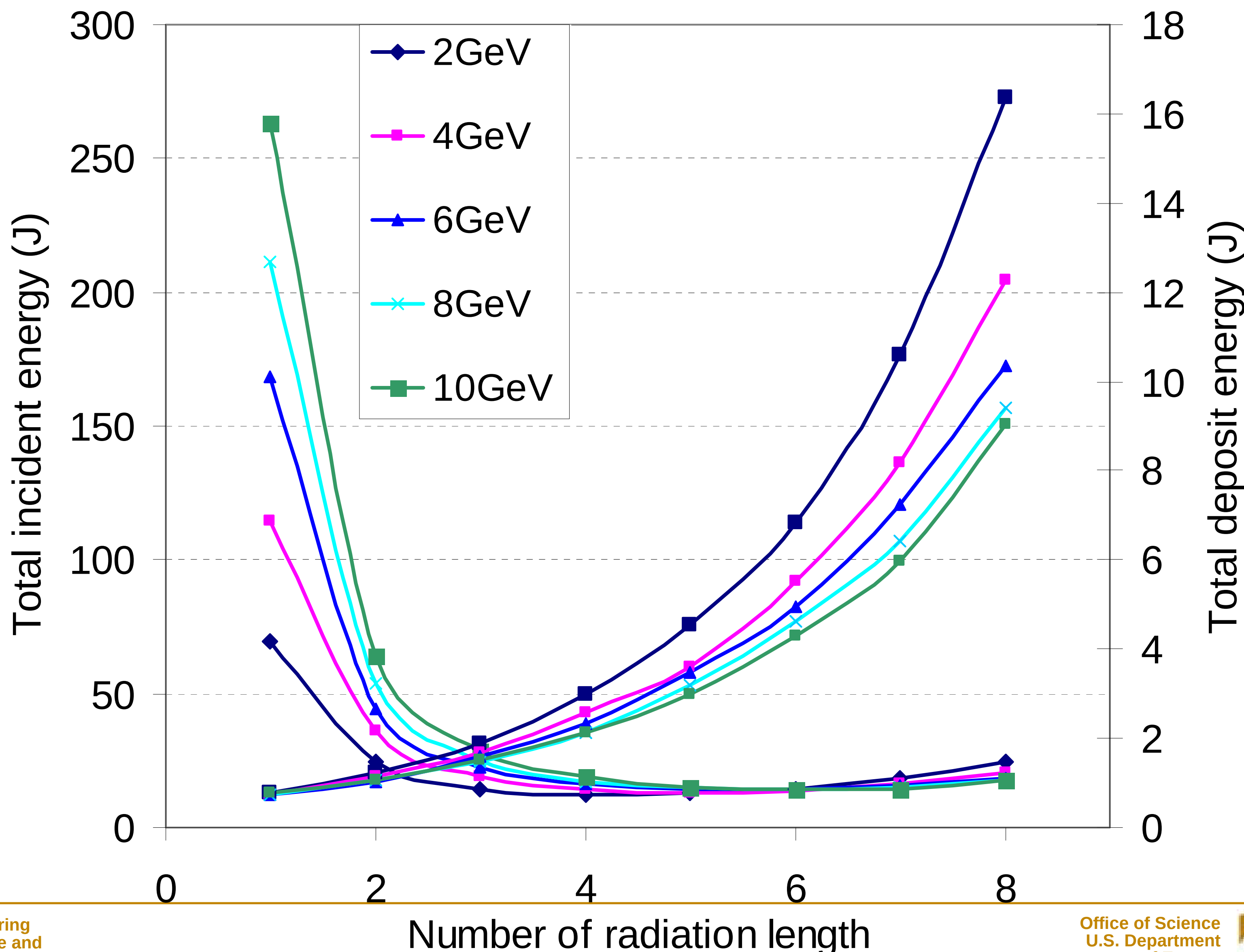
(Yield is defined as the ratio of number of captured positrons to number of incident electrons.)



Normalized Yield vs. radiation length at given incident electron beam energy.



Total incident energy and deposit energy vs. target thickness (assuming 3nC e+ are captured)



Studying the effect of target thickness and incident beam spot size on yield

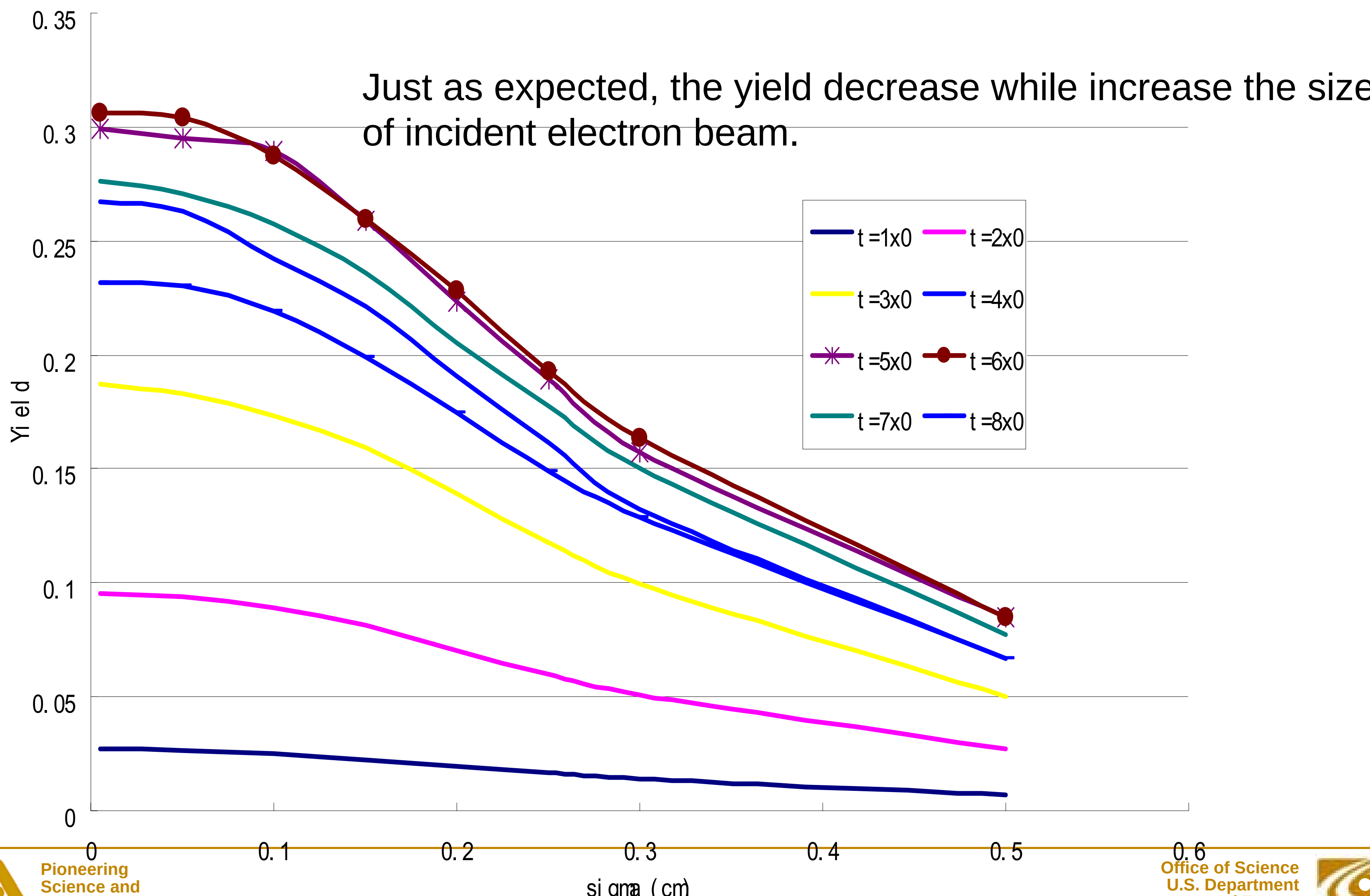
Target thickness (t): 1,2,3,4,5,6,7,8 r.l.
Electron beam spot size (sigmax): 0.05, 0.5, 1, 1.5, 2, 2.5, 3, 5mm

Incident electron beam energy: 6GeV, 2 GeV

In all the following figures, Yield is normalized to incident electron energy and is defined as:

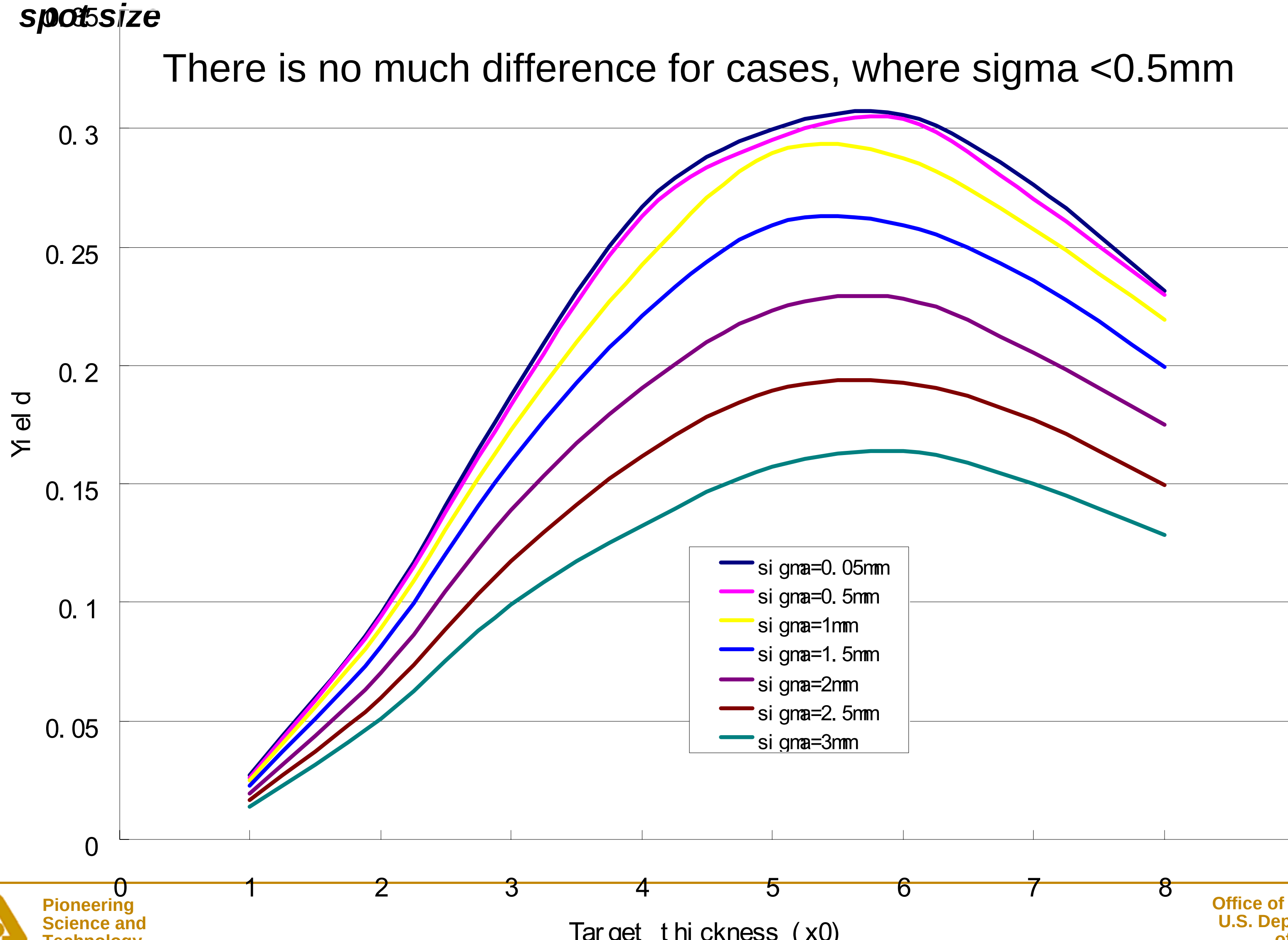
$$\frac{Number\ of\ Captured\ Positron}{Number\ of\ Incident\ Electron * Electron\ Energy\ in\ GeV}$$

Yield vs spot size

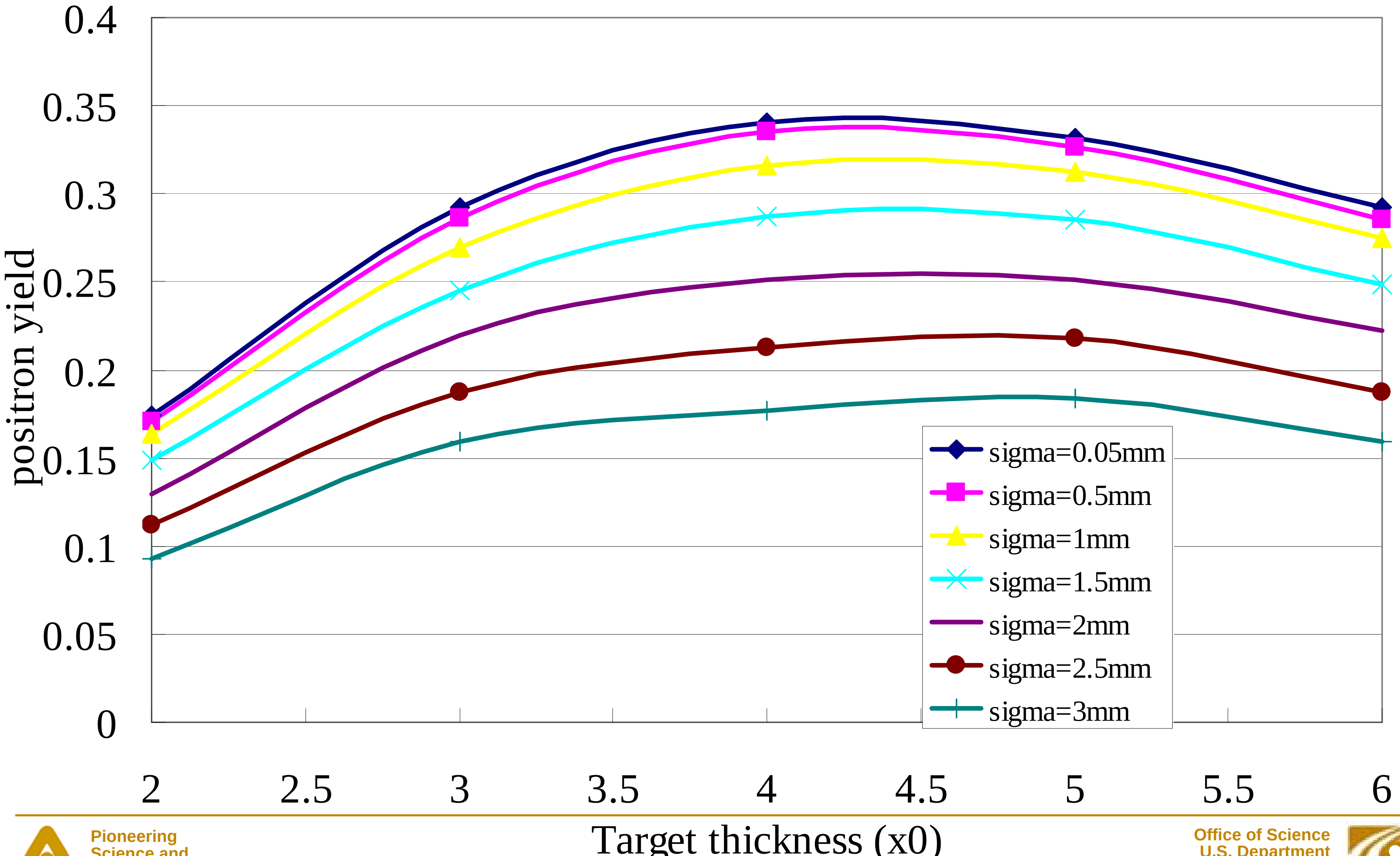


Yield vs target thickness for e- beam with energy of 6GeV and different incident beam spot size

There is no much difference for cases, where sigma <0.5mm



Yield vs target thickness for e- beam of energy at 2GeV and different spot size



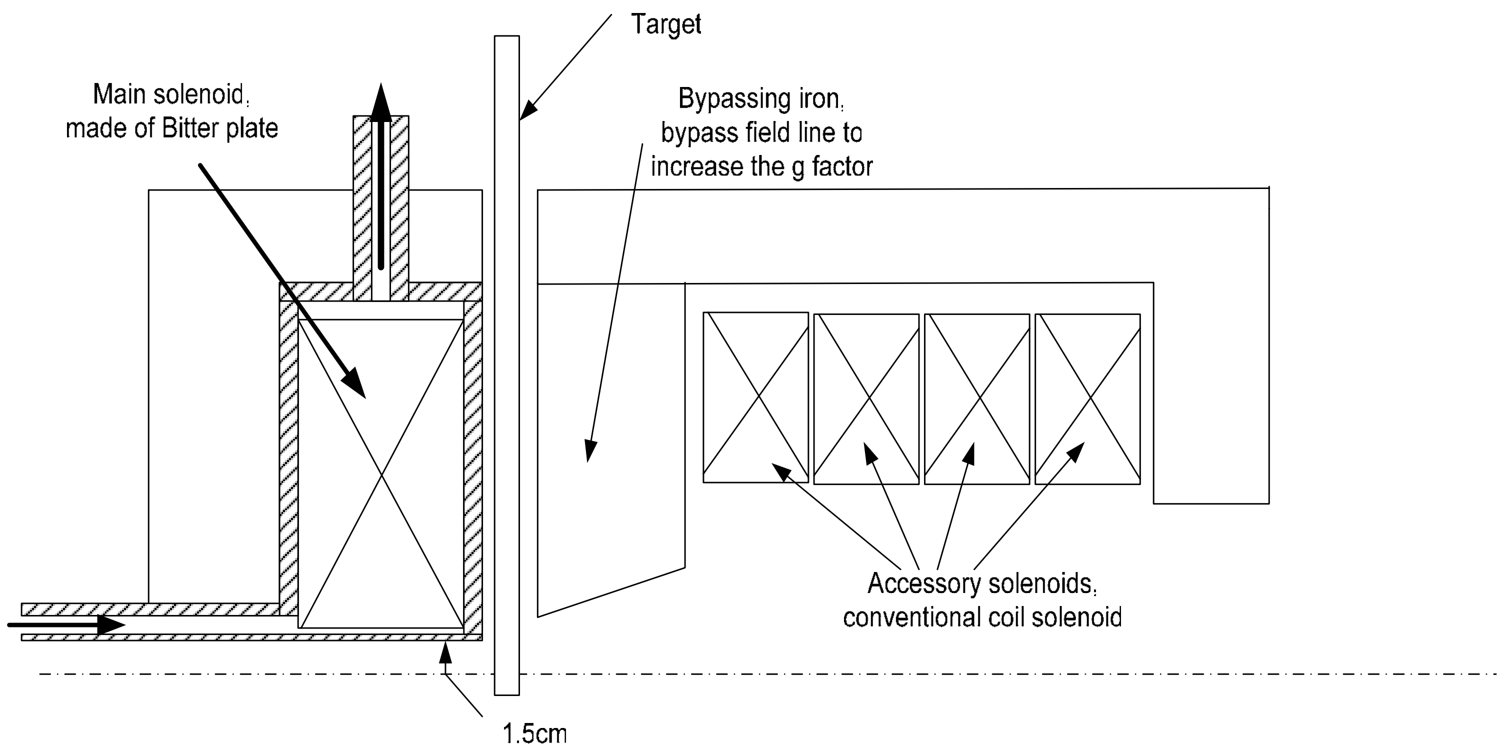
observation

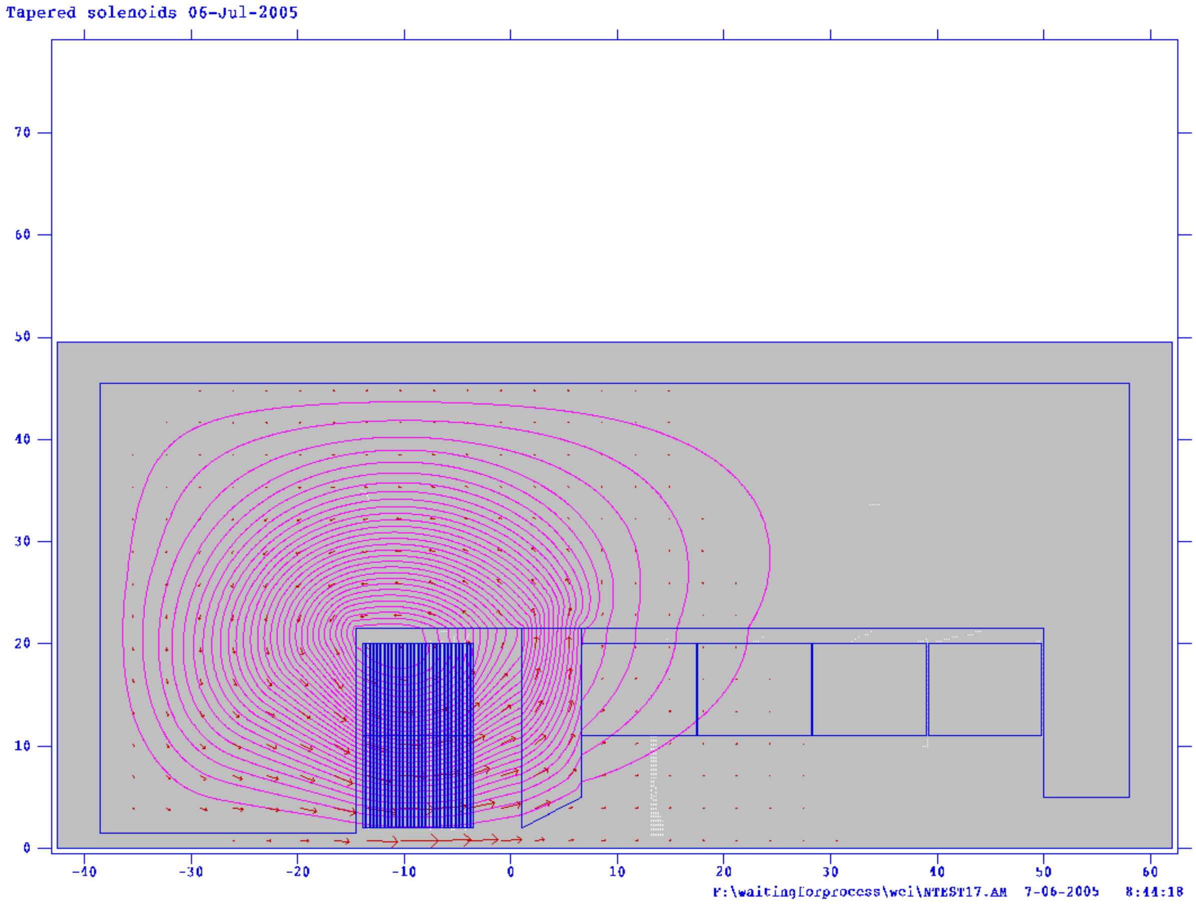
- **Without detailed optimizing, we observe:**
  - RL < 6 in all cases.
  - Best case seems to be at 2-4 GeV, ~ 4 RL.
  - Energy deposited and total energy incident show that the radiation length would be at ~ 4 RL.
  - Beam spot size should be as small as possible (~1.5 mm)

Next steps for the ILC e+ source works at ANL

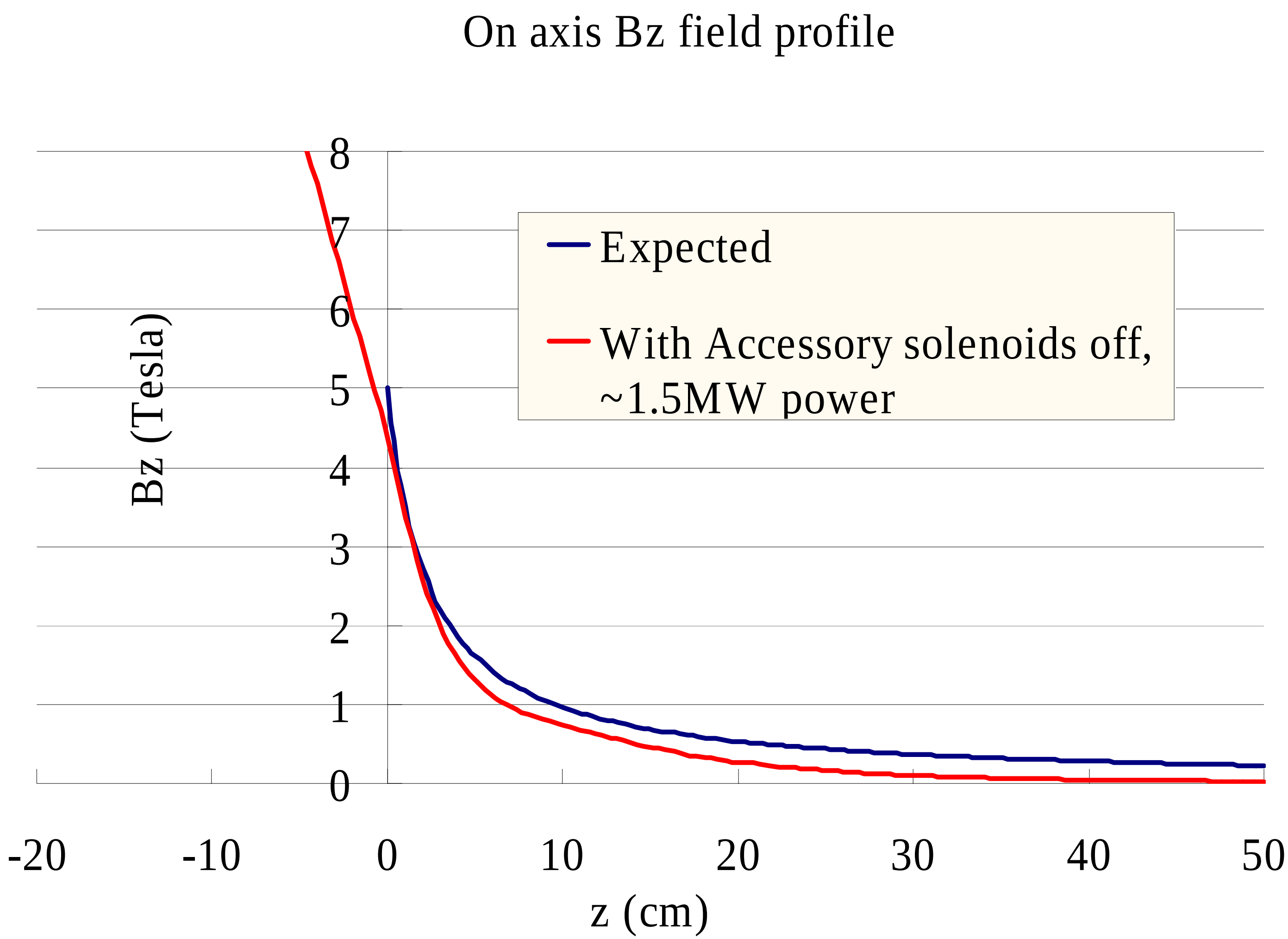
- **Planning to do more detailed optimization including sweeping AMD parameters and RF phases**
- **Look into the AMD design, and see if it is possible to use conventional pulsed solenoid (bitter solenoid, preliminary exploration shows possible).**
- **Continue to optimize the source parameters for different wiggler design options. Examine the radiation background in details**
- **Optimize the design of positron emulator parameters, such as target material, thickness, energy selection and so on. Study ways to experimentally demonstrate e+ emulator**
- **Others as needed.**

Exploration of the AMD design using normal conducting coils



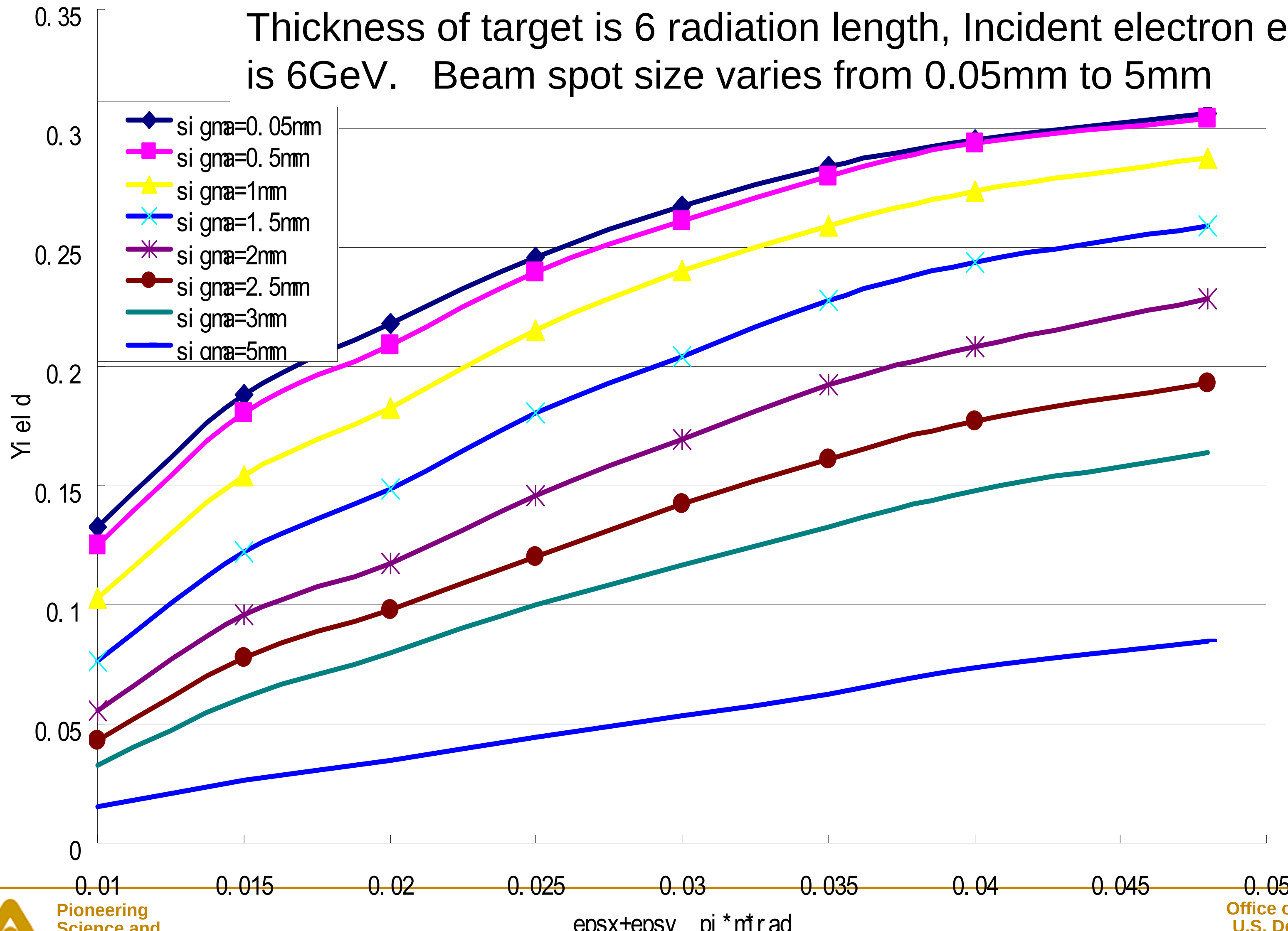


Tapered solenoids 06-Jul-2005
70
60
50
40
30
20
10
0
-40
-30
-20
-10
0
10
20
30
40
50
60
F:\waitingforprocess\wei\NTEST17.AM 7-06-2005 8:44:18

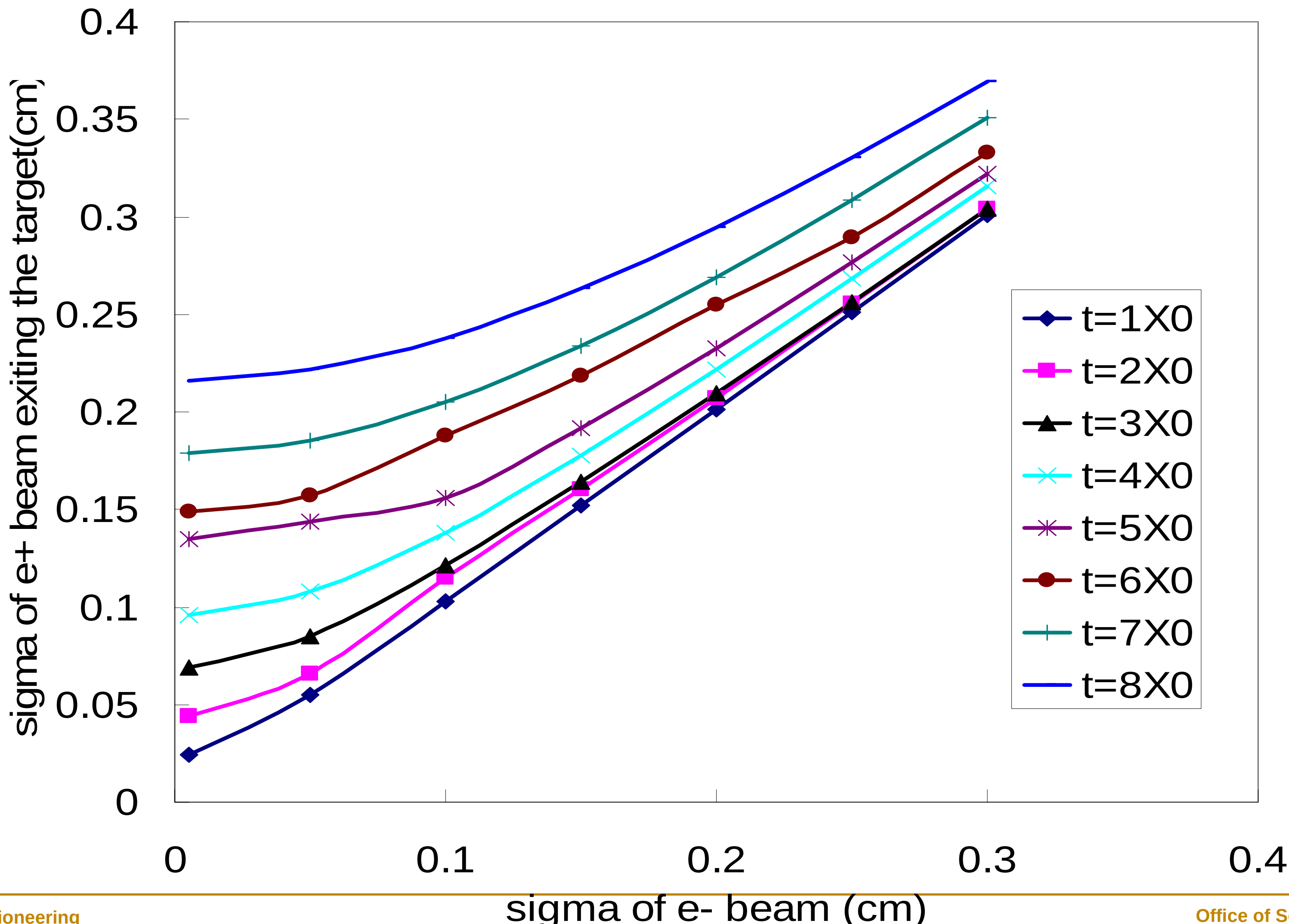

On axis Bz field profile
Expected
With Accessory solenoids off, ~1.5MW power
Bz (Tesla)
8
7
6
5
4
3
2
1
0
-20
-10
0
10
20
30
40
50
z (cm)

Yield vs DR aperture

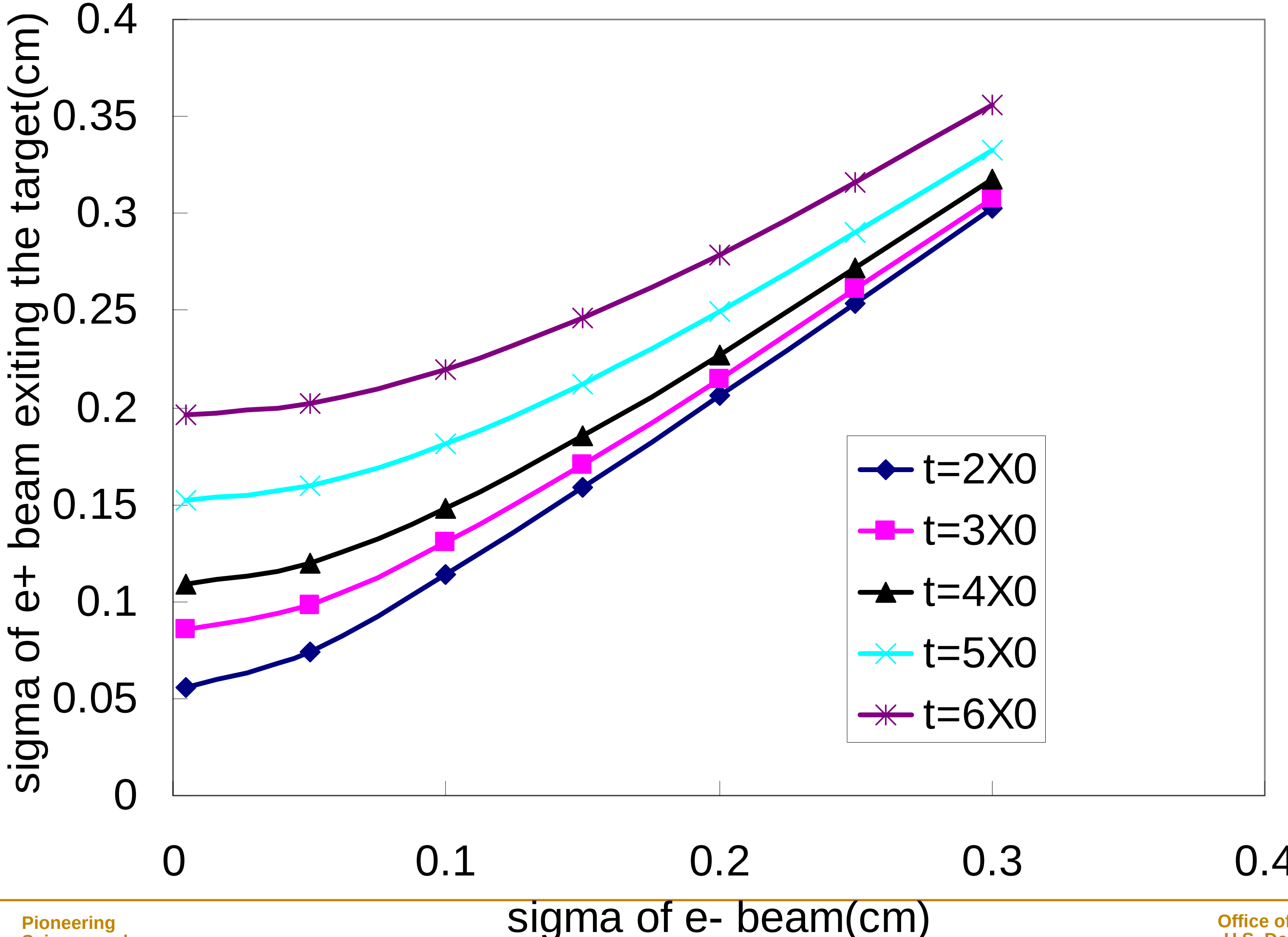
Thickness of target is 6 radiation length, Incident electron energy is 6GeV.   Beam spot size varies from 0.05mm to 5mm



Relation between sigma of e+ beam exiting target and the incident e- beam.
Energy of incident e- beam is 6GeV.



Relation between sigma of e+ beam exiting target and the incident e- beam. Energy of incident e- beam is 2GeV.



Among the cases where incident e- beam energy is 6GeV, t=5~6 r.l. and sigmax = 0.05 mm has the best yield rate.

Among those cases where incident e- beam energy is 2GeV, t= 4~5 r.l. and sigmax = 0.05 mm has the best yield rate.

Comparing 6GeV with 2GeV cases, 2GeV has a better optimized yield than 6GeV.

All these cases showing that using smaller spot size will increase the yield rate but it will also increase the density of deposited power on the target at a higher rate. When spot size lower to bellow 0.5mm, no more significant increase on the yield rate observed.