A CW POSITRON SOURCE FOR CEPBAF

BY
Serkan Golge
Old Dominion University
Norfolk,VA

Outline

- Goals and Challenges
- Positron Production at CEBAF Electron Injector Energy
- CEBAF Admittance
- First Order Model of Positron Capture and Injection

Goals and Challenges

- ≥ 100 nA CW positron beam
  - ✓ If beam is transported around first pass, then by 5th pass beam quality is good enough for physics
- Challenges of CW at CEBAF
  - ✓ Pulsed magnets and pulsed RF cavities not feasible
  - ✓ No damping rings
- Minimize cost
- As a trial solution
  - ✓ Produce positrons at Injector
    (12 GeV upgrade P (e-)=120 MeV @ injector)
  - ✓ Capture and inject directly into North Linac

Positron Yield At Target (W) with 120 MeV electrons

In the simulation (g4beamline):

Driving Electron Beam:

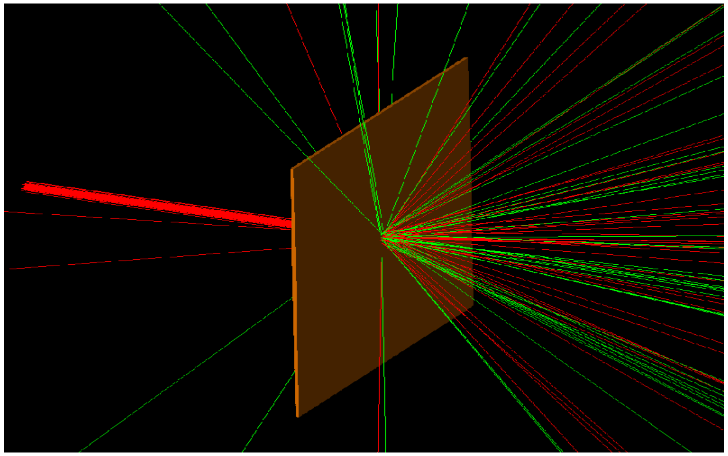
- Geometrical emittance 10^{-8} m•rad @ 120 MeV,
  - ✓ 0.10 mm spot (rms).
- Target thickness: $1X_0$ W (3 mm)
  - ✓ Optimum thickness for maximum e^+ yield per smallest emittance

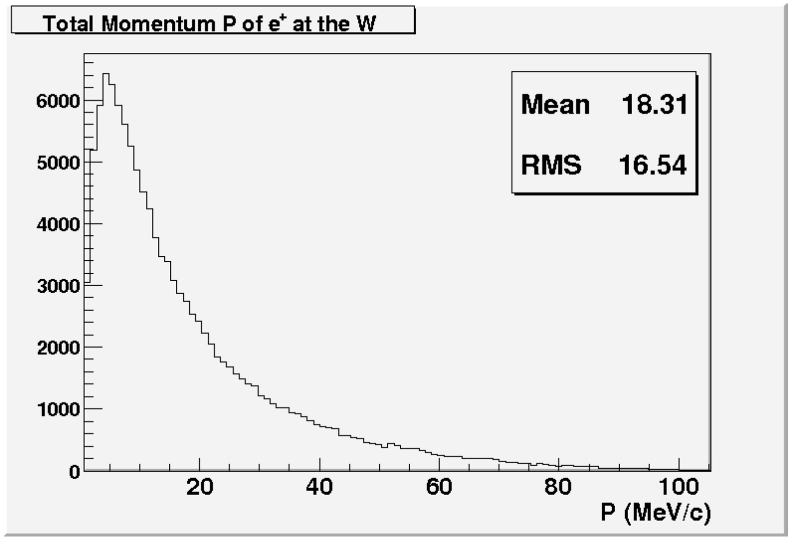
Emerging Positron Beam Spray:

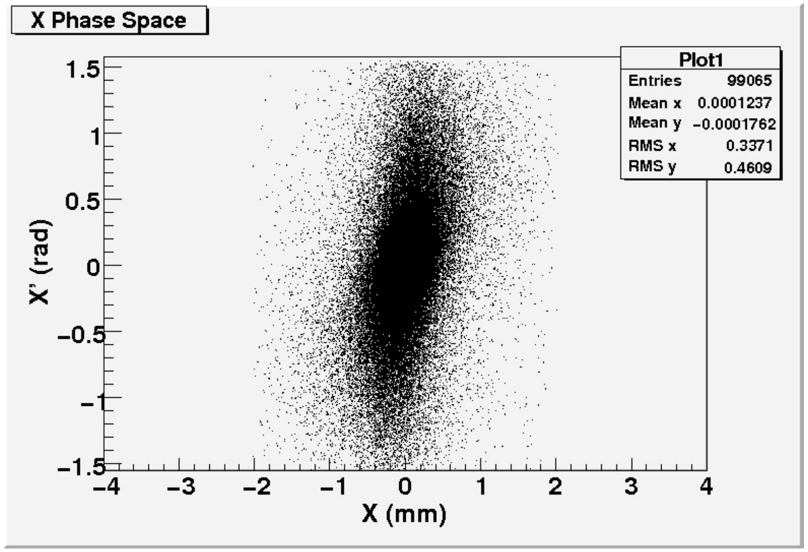
- Yield: 0.12 e^+ per e^- ($0 < P(e^+) < 120$MeV)
- Emittance: $\varepsilon = 0.3$ mm x 450 mrad

During the talk I will always refer geometrical emittance.

Simulation Snapshots







Incident e- Beam Properties on a 3mm W:

Power = 120MeV×10mA = 1.2 MW

$\varepsilon = 10^{-8}$ m•rad

Emerging e+ Properties:

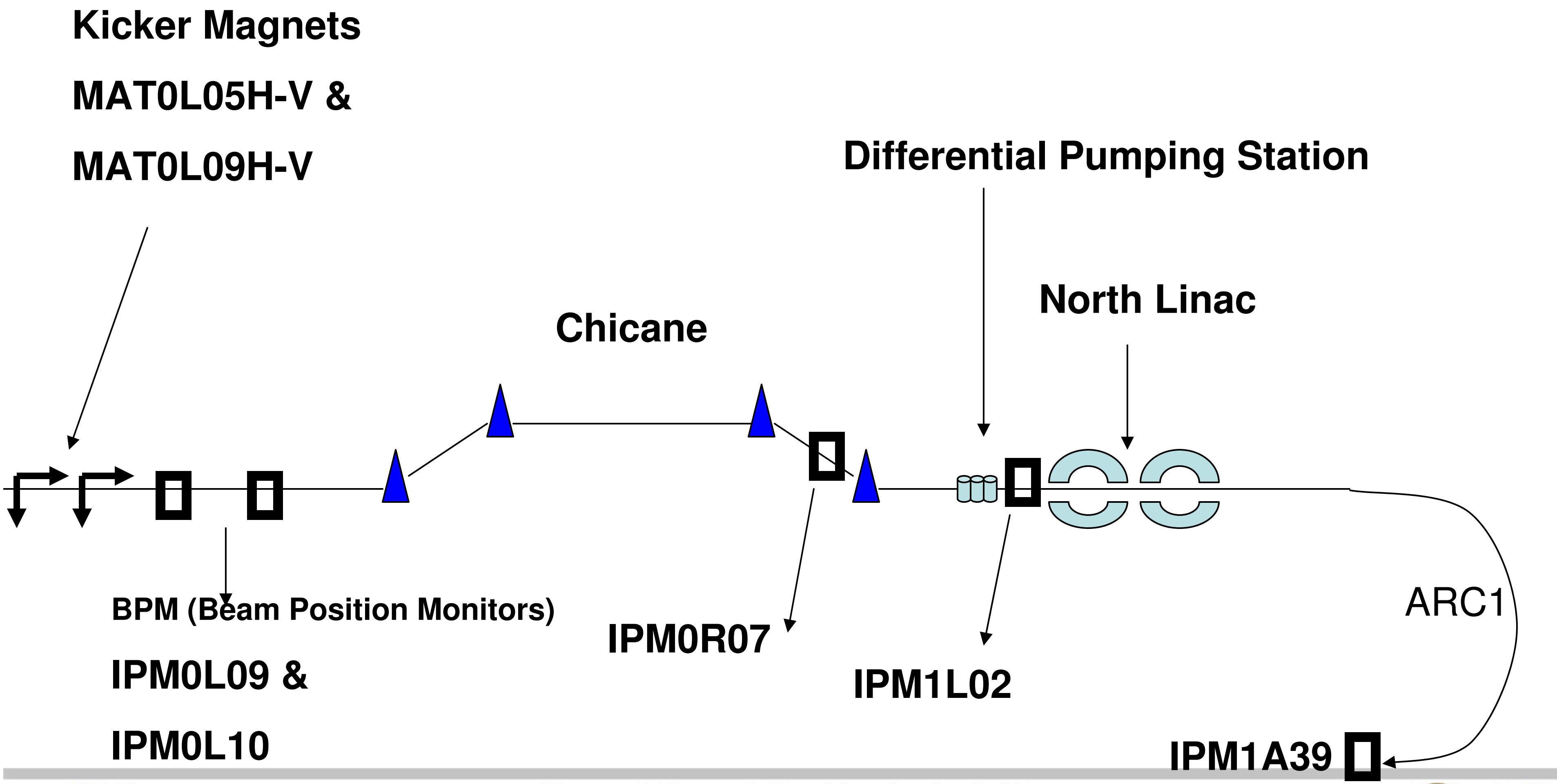
ε = 0.3 mm x 460 mrad ~ 14000×10^{-8} m•rad

Yield : 0.12 e^+ per e^-

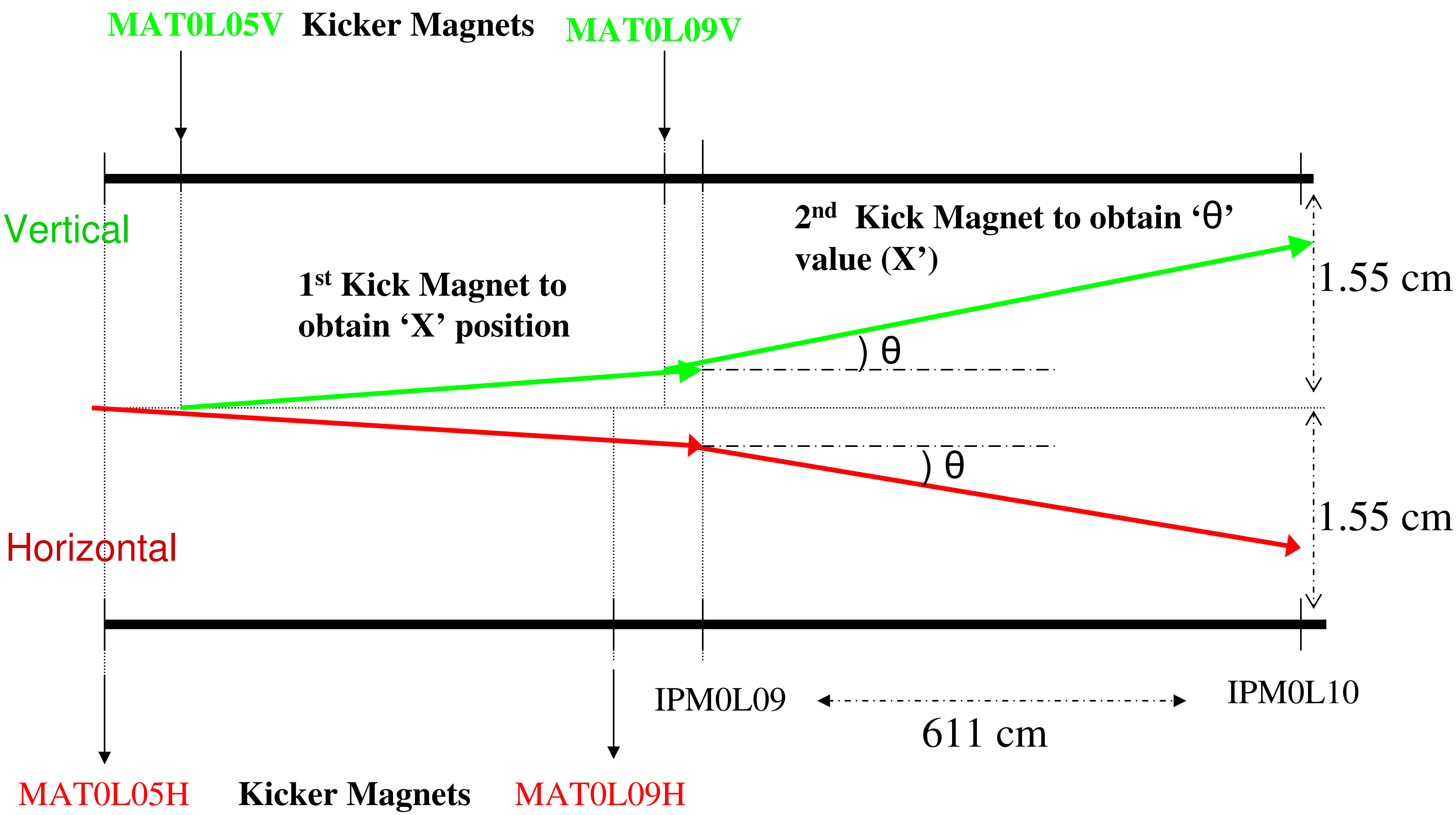
What fraction of these positrons can be transported and usefully injected into CEBAF?

CEBAF Admittance not known!

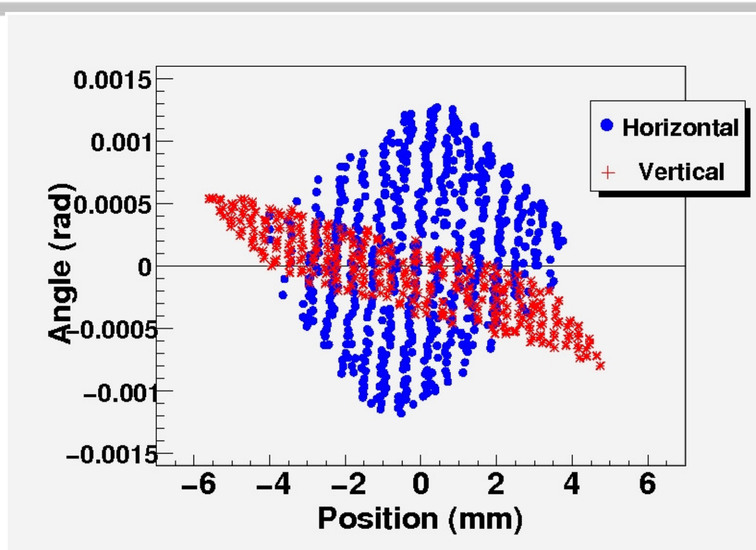
Emittance is too good to know the admittance



Admittance Study



Admittance Data



Oct 2008

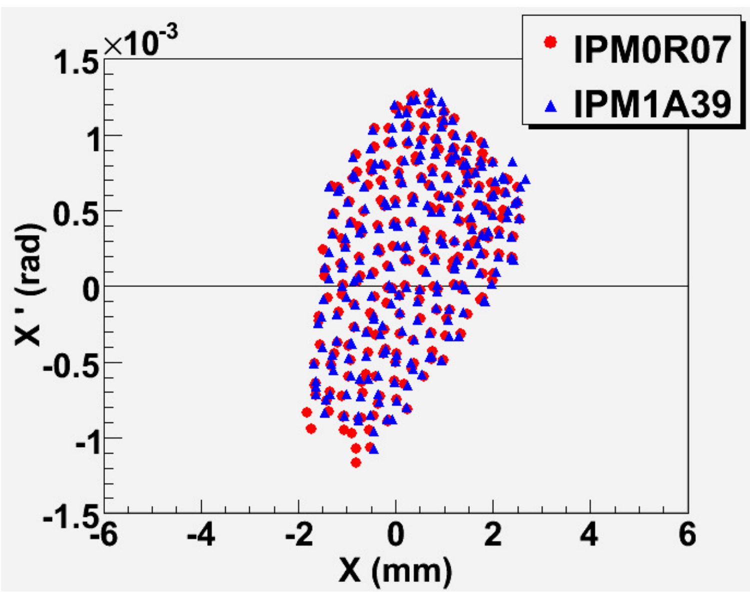
Current @ IPM0R06 > 10 %

<u>Geometrical Admittance</u>

X ~ 10 mm•mrad

Y ~ 4.5 mm•mrad

At the chicane



Jan 2009

Current @ BPM > 10 %

If the beam makes it through the chicane, it makes it through North Linac and around Arc 1

Only a partial sampling of x,y range

Transverse and Longitudinal Acceptance

- **Estimated Transverse Admittance area:**
  - ✓ $(\pi 2 \text{ mm mr})_x \, (\pi 2 \text{ mm mr})_y$

- **Nominal value ΔP/P=±0.001**

  At CEBAF 11 GeV;
  - ✓ Arc 1 (1 GeV) ΔP = ±1 MeV
  - ✓ Possible retune to improve Arc 1 Energy acceptance?

- **Time Acceptance of Linac (on crest)**

  acos(1 - ΔP/P) = 2.56 degrees of 1497 MHZ RF

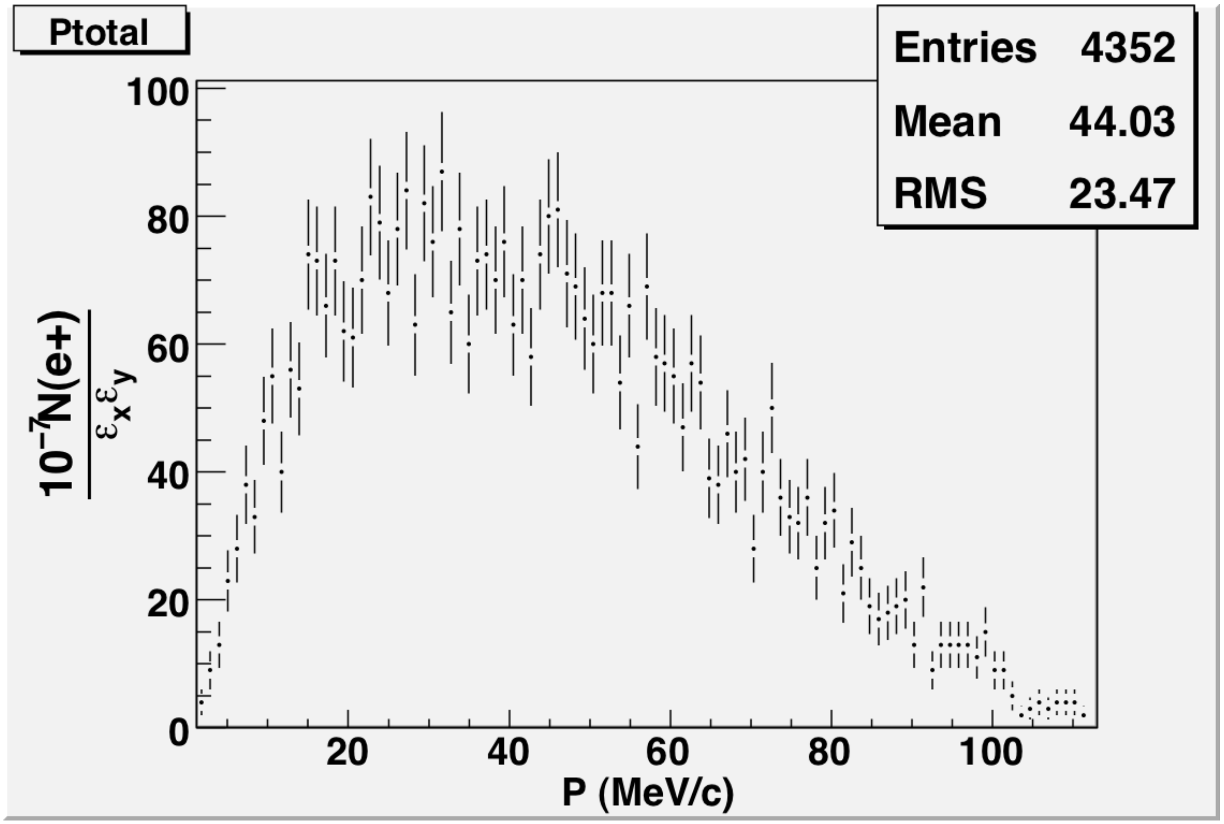
  (1.85 picoseconds = 1 degree of 1497 MHz RF phase)
  - ✓ ΔP/P=0.001 → Δt = 2.56 degrees x 1.85 ps = 4.7 ps

Positron Brightness at Target

Pick an Admittance value:
Ax = π2 ~ 6 mm•mrad
Ay = π2 ~ 6 mm•mrad

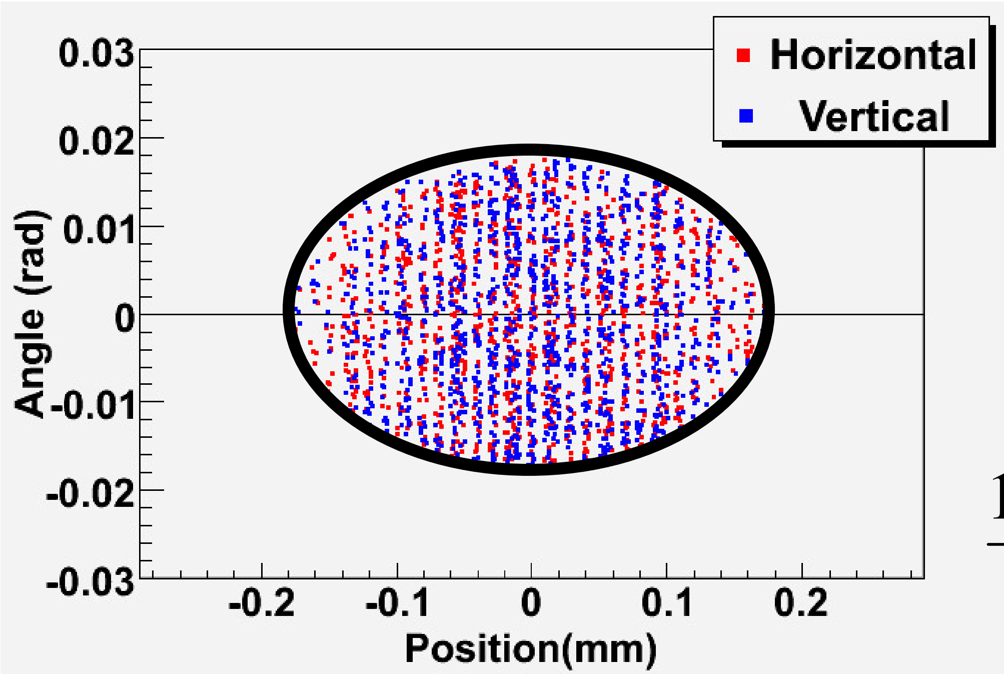
Remember CEBAF INJ
Admittance: 4 to 10 mm.mrad

Brightness



Broad Plateau from 20 to 60 MeV/c positrons

How many e+ is there?



Goal is to collect all positrons within Admittance area of π (2 mm•mrad),

$$\frac{1292\,\mathrm{e}^{+}\ (30 < \mathrm{P} < 50\,\mathrm{MeV/c})}{10^{7}\, e^{-} A_{T}\, 20 MeV/c}$$

Conversion Efficiency within 6 mm•mrad Admittance:

$$\approx \frac{1.3 \cdot 10^{-5}}{2MeV}\left[e^{+}\ \mathrm{per}\ e^{-}\right]$$

Positron Current for Experiment

- 10 mA electron source at 120 MeV
  - ✓ 1.2 MW (!!! HOT !!!)
- Positron yield 10^{-5} into useful admittance
  - ✓ 100 nA positrons within 6 mm•mrad & $\Delta P = \pm$ 1MeV
  - ✓ Luminosity $10^{35}/cm^2/s$ on 4 cm Liquid H_2 target
  - ✓ CLAS12 Luminosity $10^{35}/cm^2/s$.

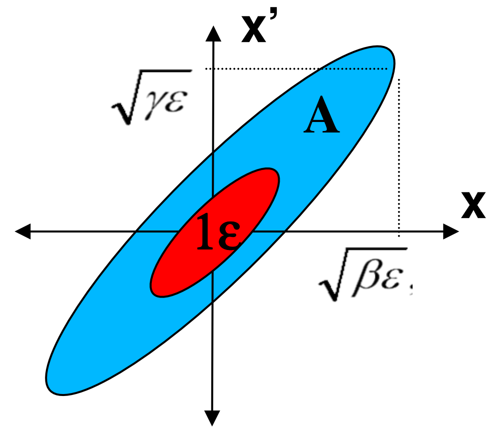
Can We Transport These Positrons?

From Production Target to Linac

- 1st order transport optics study (OPTIM)
  - ✓ Gaussian approximation to Admittance Area

    Use $\pi(3\varepsilon)$ = Admittance

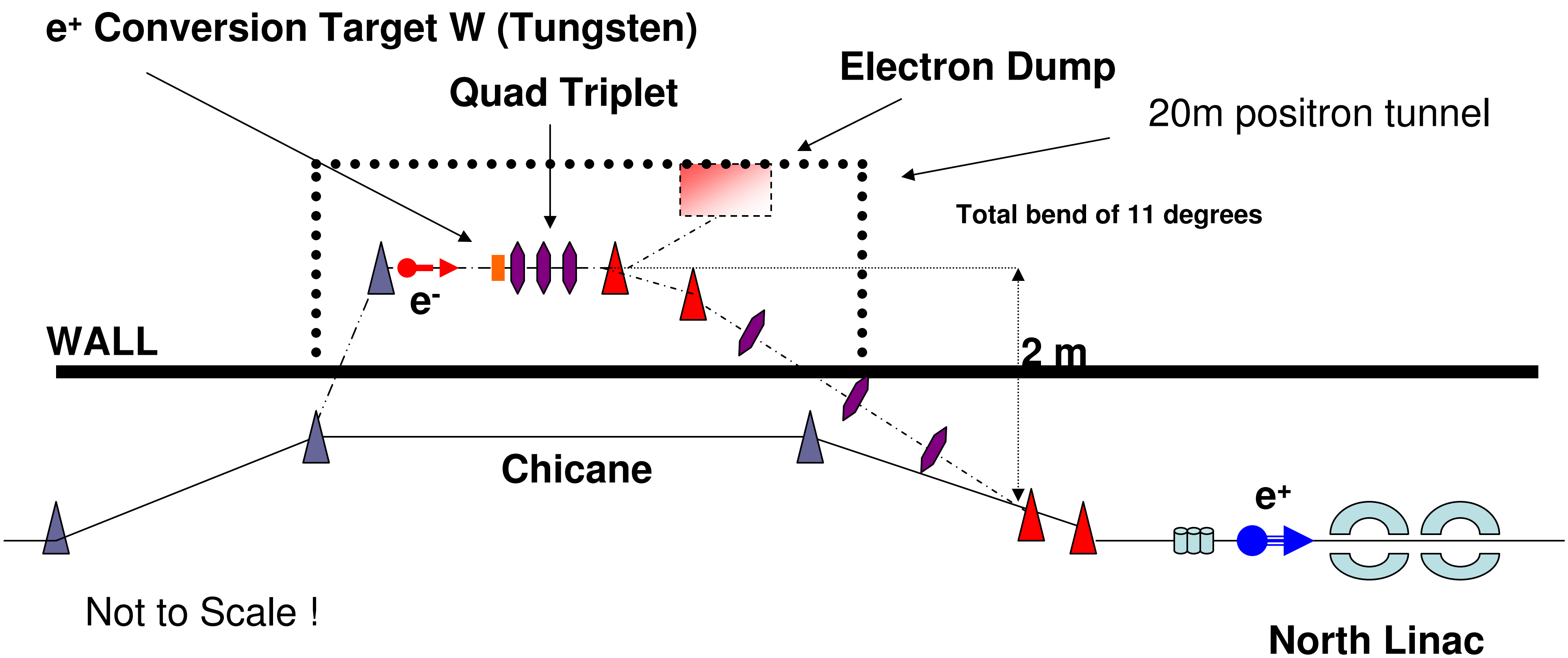
    ε = 0.08 mm x 9 mrad
  - ✓ Δ P = ± 1 MeV
  - ✓ Require Δ t < 5 ps before the LINAC

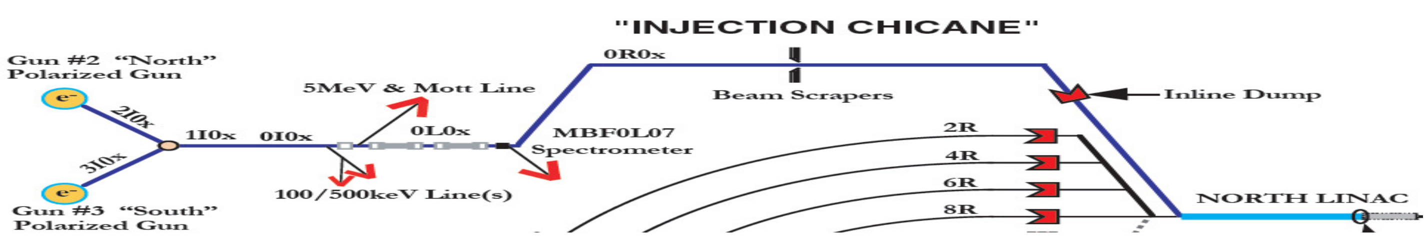


$$\gamma x^2 + \alpha x x' + \beta x'^2 \leq A$$

α, β and γ are twiss parameters.

Positron Production Tunnel



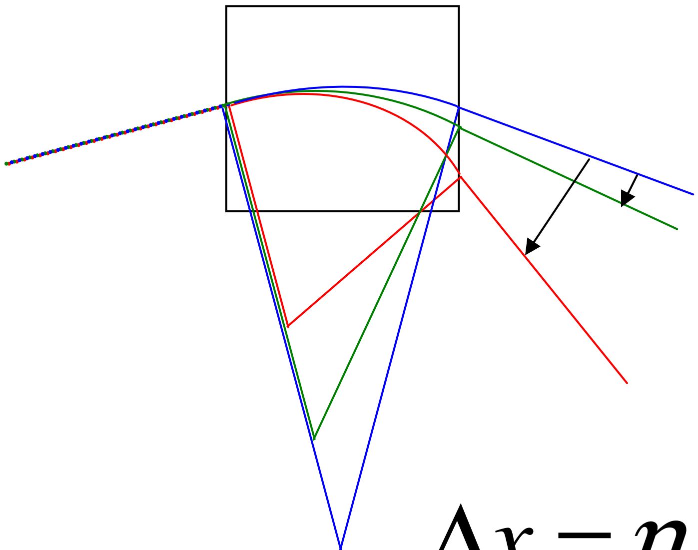


Electron / Positron separation

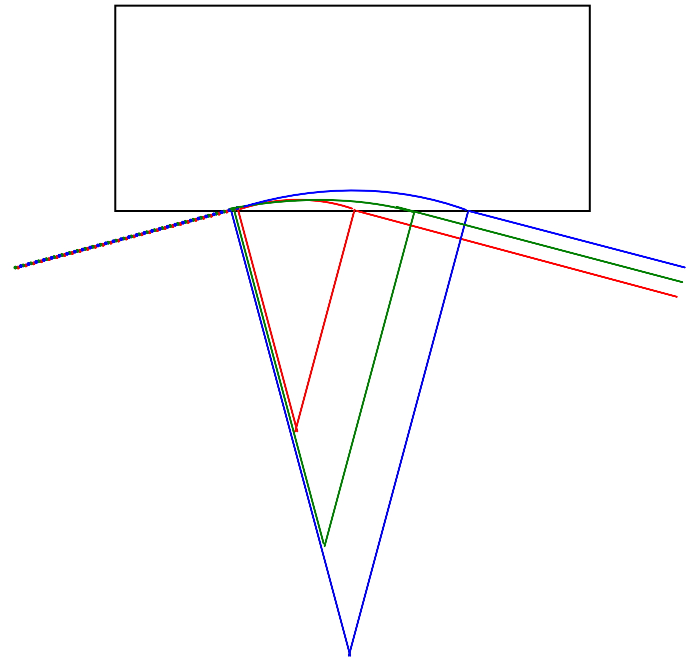
- A dogleg or a chicane is needed in order to transport a clean e^+ separated from e^- and gammas.
- But 1 MeV (2.5% at 40MeV) is a large energy spread.
- What would be the best transport option to avoid path lengthening (growth in time spread) and to have an achromatic design ?

A Nearly Isochronous Arc With Unlimited Momentum Acceptance *

Rectangle Dipole



Microtron Dipole

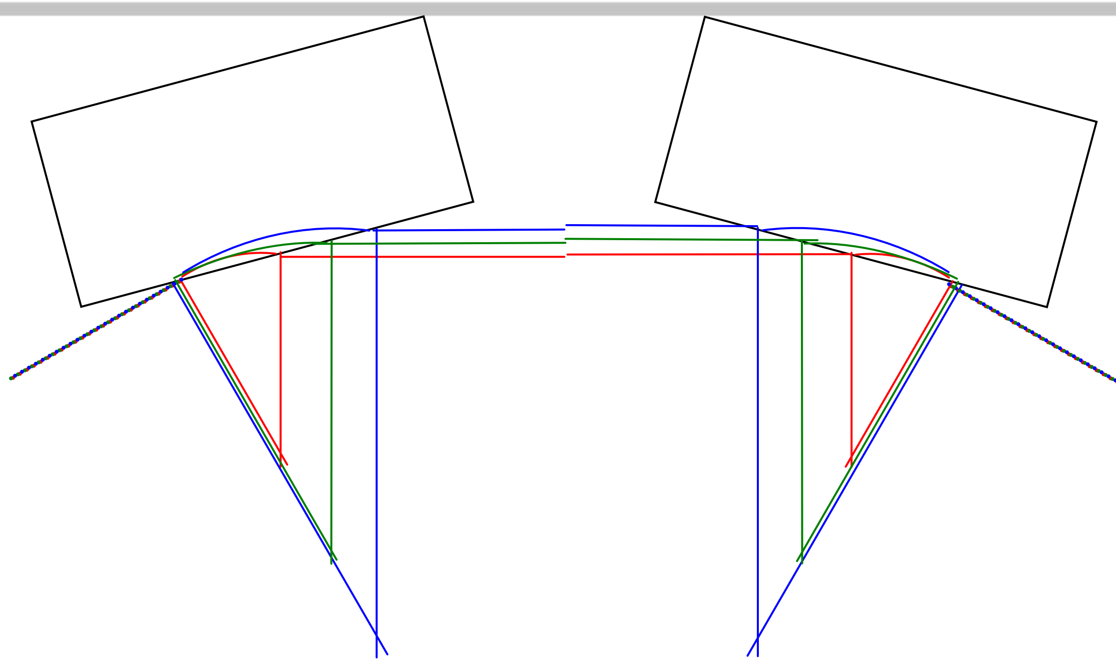


$$\Delta x = \eta \frac{\Delta P}{P}$$

Δx : Deviation from the central orbit in the dispersive plane
η : Dispersion function (a.k.a D)

* JLAB-TN-02-020 by D.Douglas

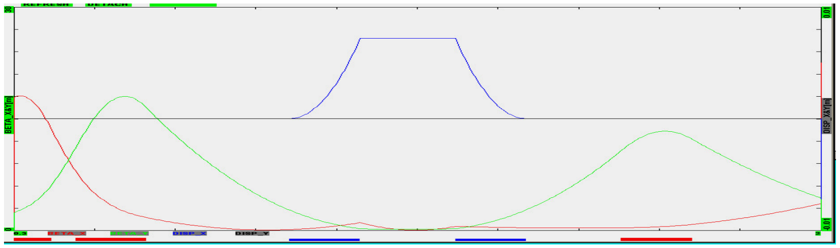
Double Microtron Dipole to form Achromatic Lattice



1) All momentum components are dispersed along parallel orbits

2) The dispersion function η_x is linear

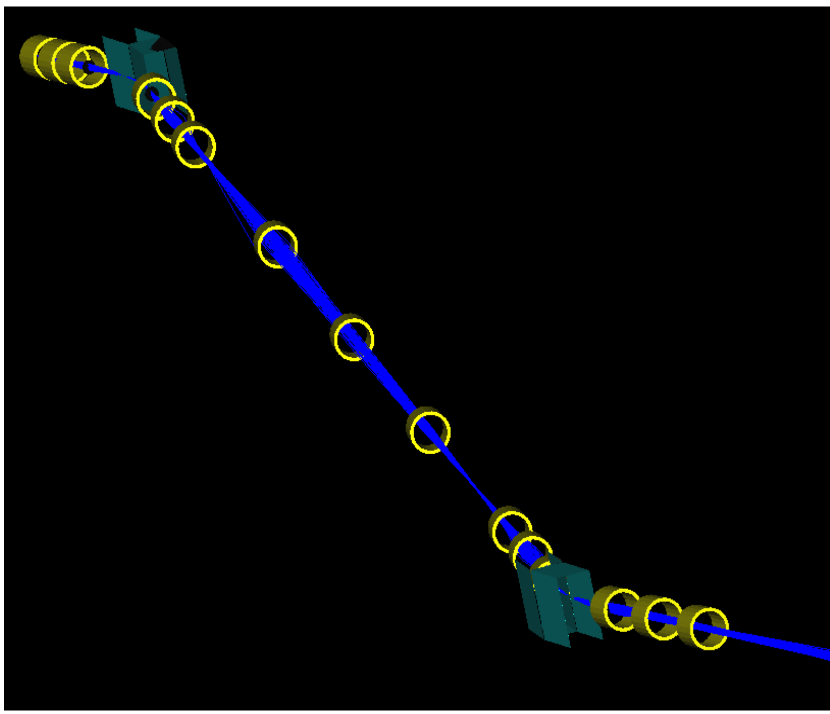
$\eta'_x = 0$

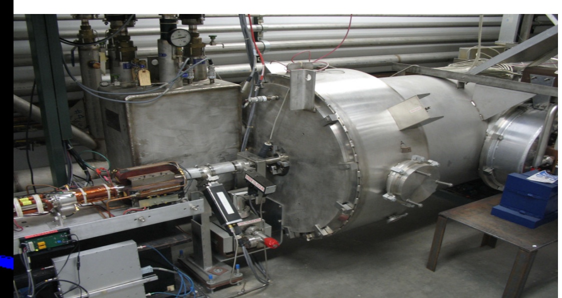


Optim Beta Functions and Beam Size at P(e+) = 40MeV (ε = 0.7 mm•mrad)

G4beamline

- Initial Study with gaussian beam
- 95% transmission of initial admittance
  - Need to optimize/match beta functions
- 5 ps time spread





Conclusions

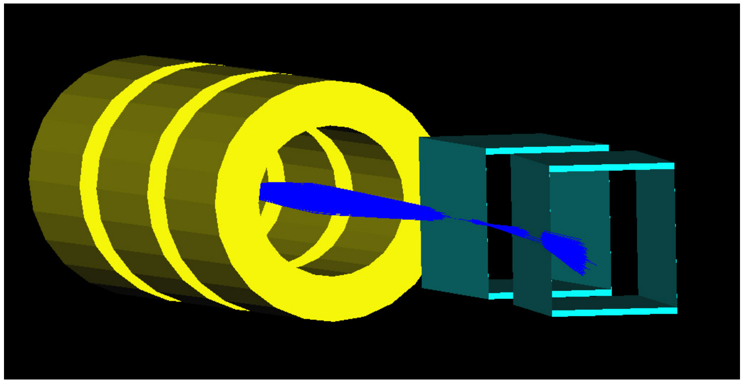
- A positron source in a new 20 m service tunnel(area) is presented
  - ✓ Service tunnel shields injector and linac from MW power deposition in production area.
- One of the biggest challenges is the power deposition in the W target without melting it (20% of incoming 1.2 MW power is deposited in W), the rest of the electrons and photons are sprayed throughout in production region.
  - ✓ Spinning target, liquid jet target etc. may be necessary.
- Simulations show that 100 nA positron beam can be transported into North Linac.
- G4Beamline studies in process.
- ...

Conjectures for Improved Yield

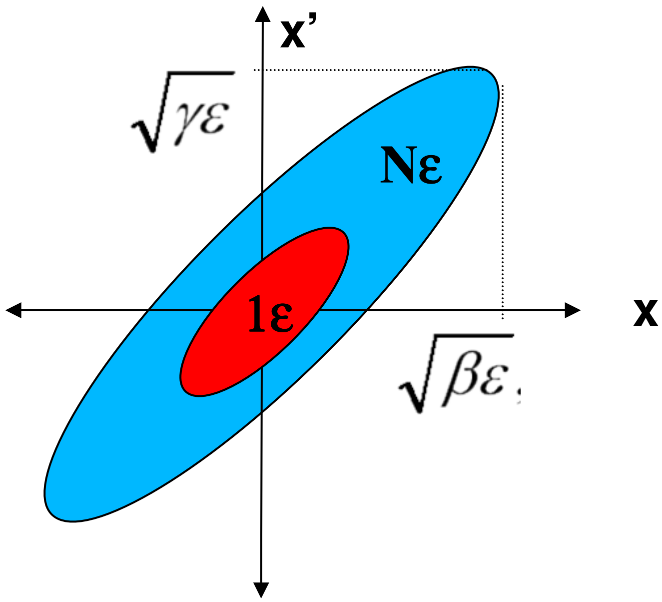
- Nominal arc acceptance 10^{-3}
  - ✓ ±1 MeV can go up to ± 2 MeV at Arc 1
- Physics program possibly can tolerate full 10^{-3} spread at 11 GeV
  - ✓ Factor of 5 increase in positron current
- FEL has operated with 15% energy spread
  - ✓ Operate Linac off crest, 1st and 2nd pass
  - ✓ Momentum compaction in RF
  - ✓ Time:Energy correlated transport in arcs ($M_{56}\neq0$)
- Improve positron yield by factor of 10-to-100

Backup Slides

g4



Selection of Positrons



Accept e⁺ if;

$$\gamma x^2 + \alpha x x' + \beta x'^2 \leq N\varepsilon$$

α, β and γ are twiss parameters.

Where area of an ellipse:

Area = Admittance = πNε

(N× 1–sigma value)

1) Goal & Challenges

- 25 nA CW positron beam
- Challenges of CW
  - Pulsed magnets / accel not feasible
  - No damping rings
- CEBAF Admittance
  - π2 mm mr at 60 MeV NL injection and
- $\delta p/p = \pm 1.e\text{-}3$. at arc (±1 MeV @ 1GeV)

2) Production at injector

a) Yield for different thickness of tungsten at different energies, Emittance

b) Power Deposition at target

c) yield within e=2 mm.mrad at 120 MeV e- and yield at 10 MeV e- larger emittance maybe

d) Alpha study at the target

2) Admittance Study

3) Quad Triplet + dogleg study at 10 MeV (3 MeV e+)

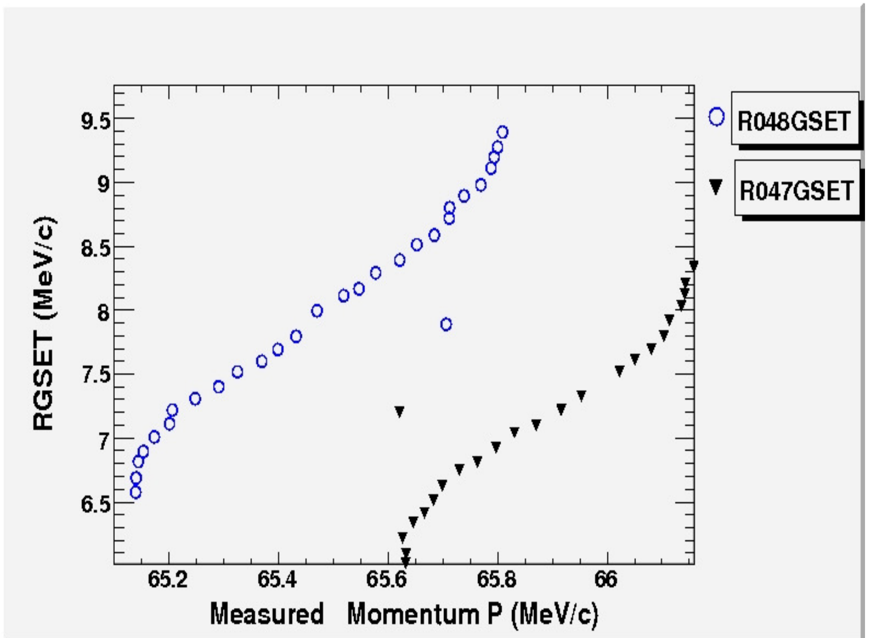
X and 120 MeV (40 -60 MeV e+)

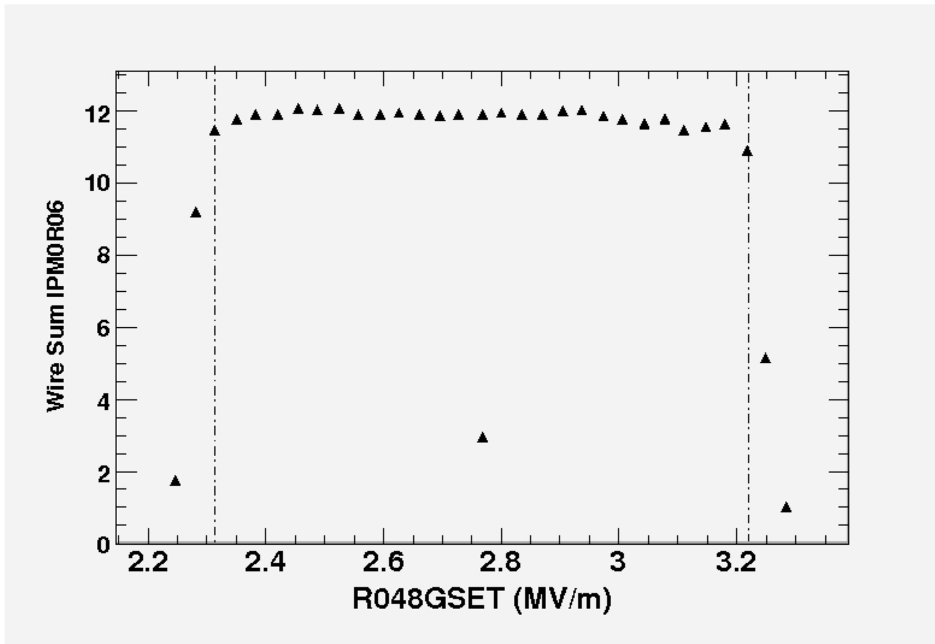
4) Quad Triplet + grazing dipole study at 120 MeV (40 MeV e+)

5) Quad Triplet + dogleg + ¼ cryo unit study (at 10 and 120 MeV)

6) Heat deposition and dump of electrons photons

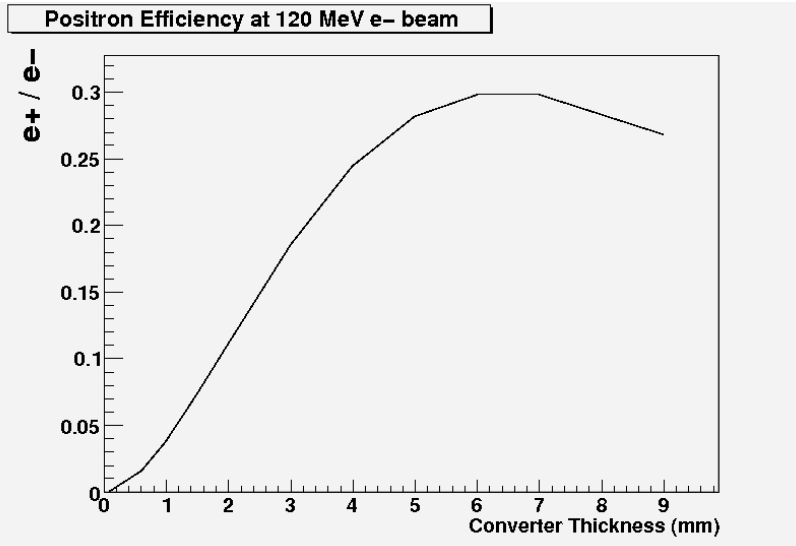
Energy Acceptance





The *energy* acceptance is;
0.9 MeV at the chicane

Efficiency



W Thick	Beta	Alpha x	Alpha y	Emit	P	e+ (10^7e-)
(mm)	(m)	-	-	(mm.mrad)	MeV/c	#/MeV
2	0.0043	-0.006	-0.0221	2.3	5	371
2	0.00437	-0.11	-0.214	2.11	20	987
2	0.0041	-0.0436	-0.075	2.15	40	986
2	0.0043	-0.135	-0.236	2	60	672
3	0.0044	-0.012	-0.034	2.3	5	417
3	0.0046	-0.08	-0.15	2.3	20	1059
3	0.0046	-0.095	-0.17	2.2	40	984
3	0.0046	-0.147	-0.346	2.2	60	625
4	0.0046	-0.044	-0.133	2.4	20	780
4	0.0047	-0.123	-0.336	2.2	60	515

Emittance at Target

- Trans Admittance = π•ε

$3\varepsilon = \sqrt{3}\sigma_x * \sqrt{3}\sigma_{x'}$

$\sigma_x = 0.08$ mm

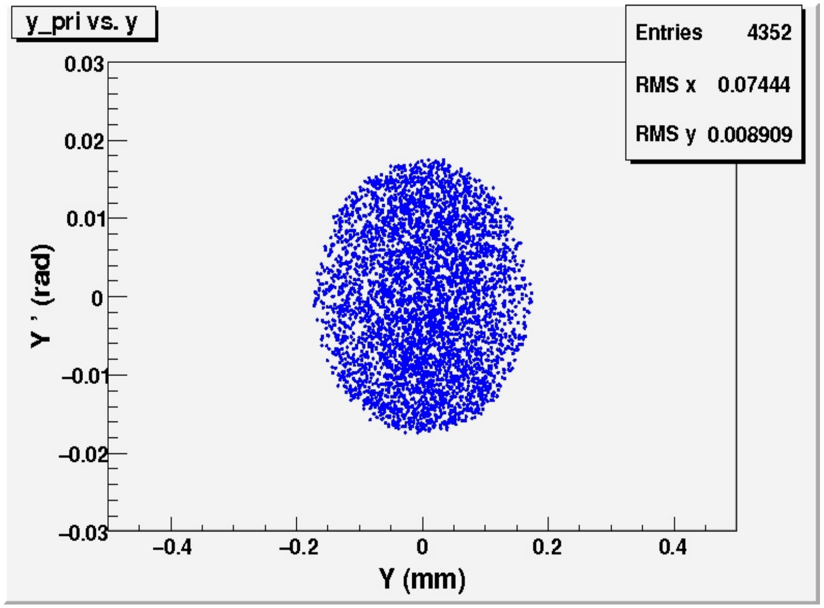
$\sigma_{x'} = 9$ mrad

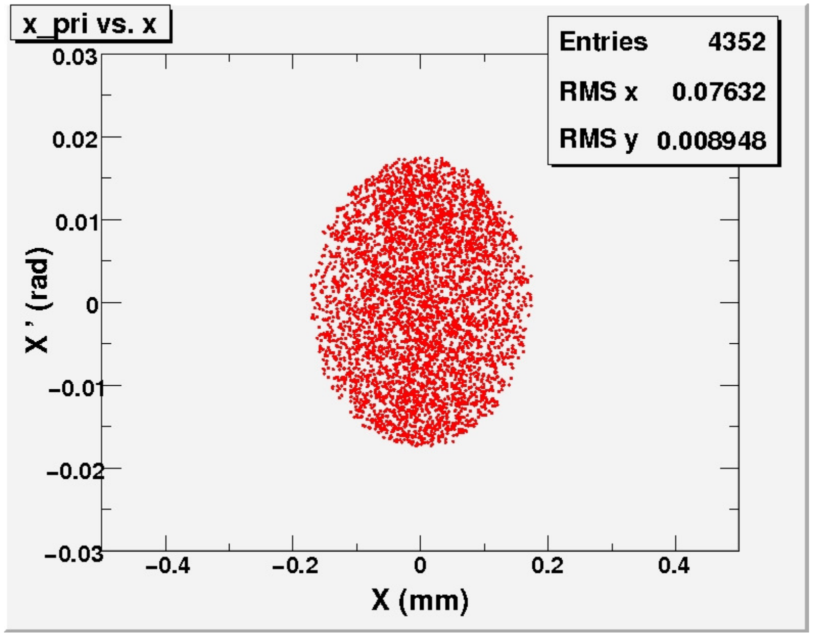
$3\varepsilon = 2$ **mm.mrad** $= 2$ μ**m**

F: Fraction of the beam

$$\pi\varepsilon = -\frac{2\pi\sigma^2}{\beta}\ln(1 - \mathrm{F})$$

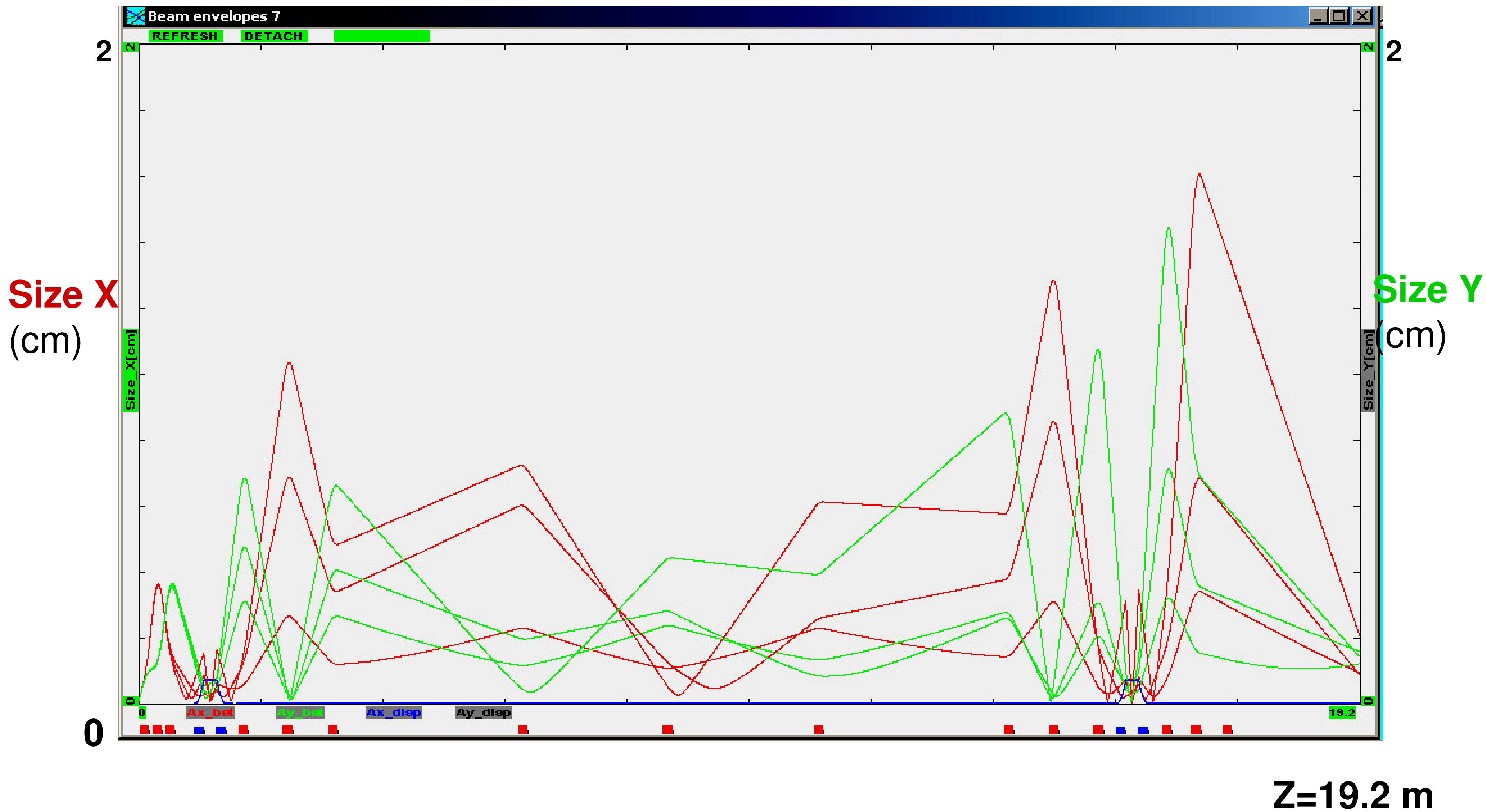
Emittance at Target
π3ε Admittance cut





Conversion Efficiency: 4352 e+/10^7e- at full P spectrum @ π2 mm.mrad

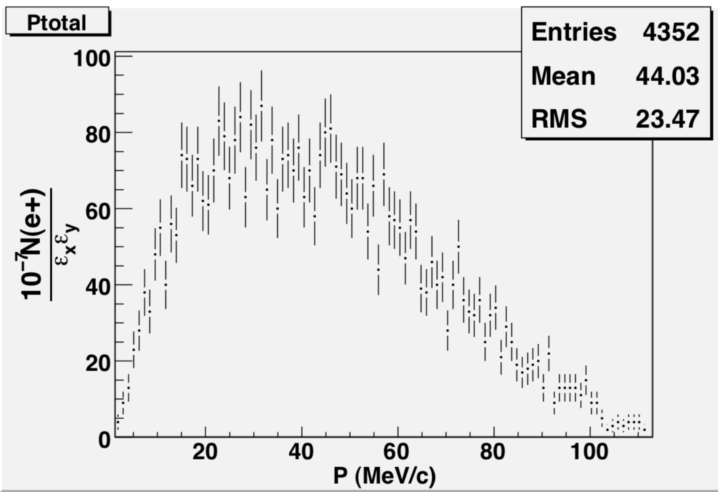
Beam Size P(e+) = 40 ± 1 MeV/c



Positron Brightness at Target

Brightness Bins

120 MeV electrons on a 3 mm W



$$\frac{N(e^+)}{\varepsilon_x \varepsilon_y MeV}$$

Broad Plateau from 20 to 60 MeV/c positrons

Pick an Admittance value:

Ax = π2 mm•mrad ~ 6

Ay = π2 mm•mrad ~ 6

Remember CEBAF INJ Admittance: 4 to 10 mm.mrad

Optim Beta Functions P(e+) = 40 ± 1 MeV/c