Design of a Compton Back-Scattering X-Ray Source on ERLP

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IoP2006, Warwick

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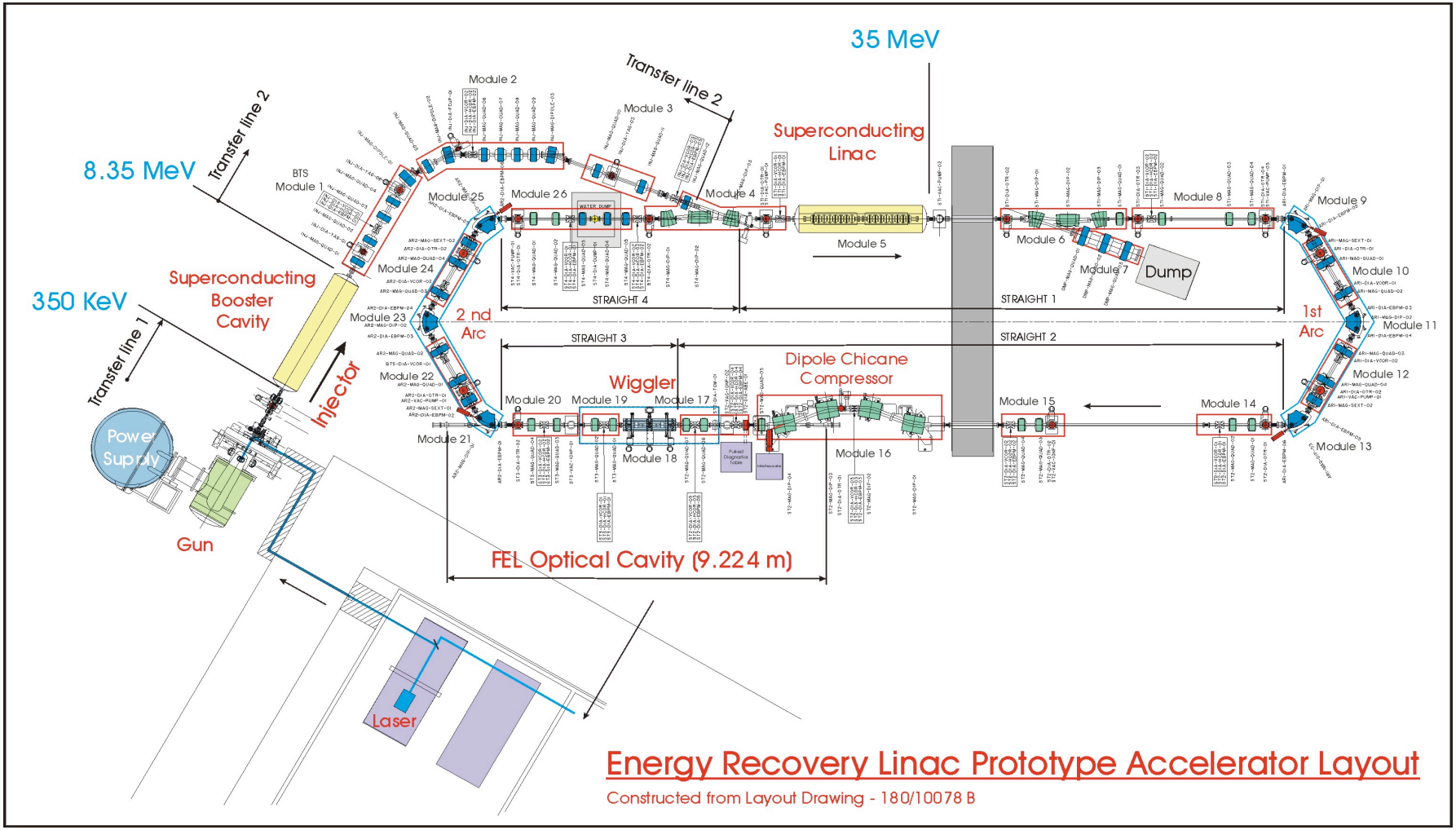
Overview

- ERLP
  - What?
  - Where?
  - Why?
- Inverse Compton Scattering
  - What?
  - Why?
    - Photon energy
    - Scattering angle
    - Particle Physics…
- Electron optics
  - FEL bunch profile
  - CBS bunch profile
- Photon Flux
  - Optimisation
- X-ray distribution
  - Space
  - Energy
- Summary

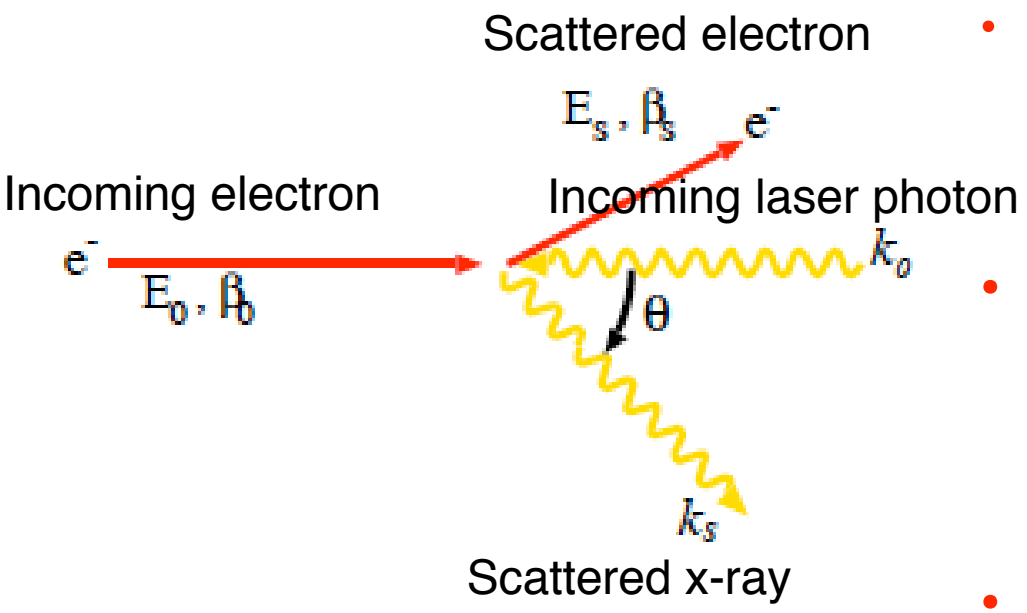
ERLP

- Energy Recovery Linac Prototype
  - Currently under construction at Daresbury Labs
  - Prototype for 4th Generation Light Source
  - Electrons recirculate back into accelerating cavity
  - Arrive π out of phase
  - Energy is dumped back into cavity for reuse accelerating next bunch
- 35 MeV beam, $\varepsilon_n \approx 400$ - 800 nm-rad
- Free Electron Laser (850nm)
- Inverse Compton Scattering…

ERLP


35 MeV
Transfer line 2
Module 2
Module 3
Superconducting Linac
8.35 MeV
Transfer line 2
BTS Module 1
Module 25
Module 26
Module 4
Module 5
Module 6
Module 7
Dump
Module 8
Module 9
Module 10
Module 11
Module 12
Module 13
Module 14
Module 15
Module 16
Module 17
Module 18
Module 19
Module 20
Module 21
Module 22
Module 23
Module 24
Superconducting Booster Cavity
350 KeV
Transfer line 1
Injector
Power Supply
Gun
2 nd Arc
1st Arc
STRAIGHT 1
STRAIGHT 2
STRAIGHT 3
STRAIGHT 4
Wiggler
Dipole Chicane Compressor
FEL Optical Cavity (9.224 m)
Laser
Energy Recovery Linac Prototype Accelerator Layout
Constructed from Layout Drawing - 180/10078 B

Inverse Compton Scattering



- θ is scattering angle of the outgoing photon
- For $E_0 >> k_0$
  $k_{s\,max} \approx 4\gamma^2 k_0$
- For E0 = 35 MeV,
  k0 = 1.54 eV (λ=800nm)
- $k_{s\,max}$ = 28.9 keV (λ = 0.4Å)

- Ti:Sa laser
- λ = 800nm
- 1TW peak power
- 1ps pulse length

Scattered Photon Energy Spread

- Electron
  - Energy spread

$$\frac{\Delta k_s}{k_s} = 2\frac{\Delta\gamma}{\gamma}$$

$\approx 7.5 \cdot 10^{-3}$

  - Beam divergence

$$\frac{\Delta k_s}{k_s} = \frac{\gamma}{2}\sigma_{x'}^2$$

$\approx 5 \cdot 10^{-3}$ for 1 mrad

- Laser
  - Energy spread

$$\frac{\Delta k_s}{k_s} = \frac{\Delta k_0}{k_0}$$

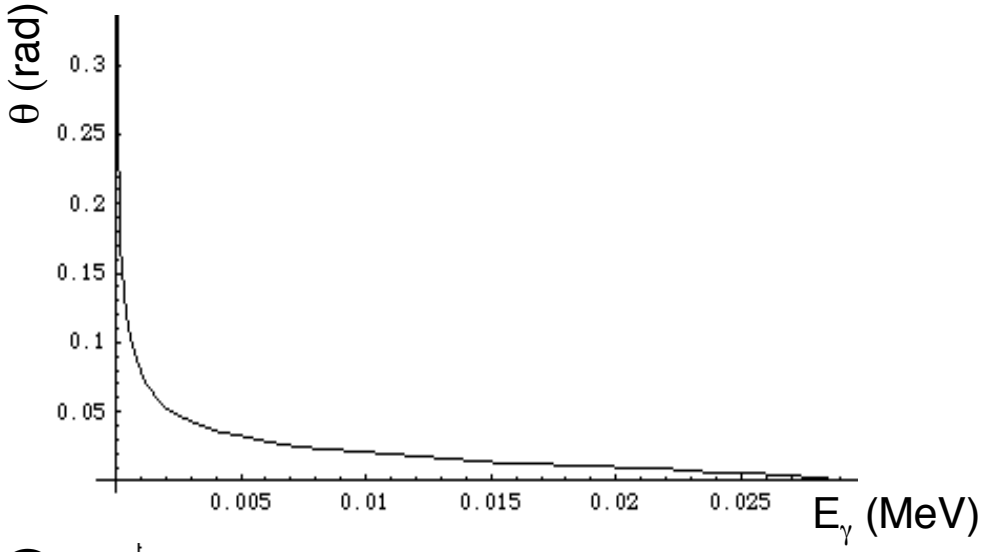
$\approx 3 \cdot 10^{-3}$

  - Beam divergence

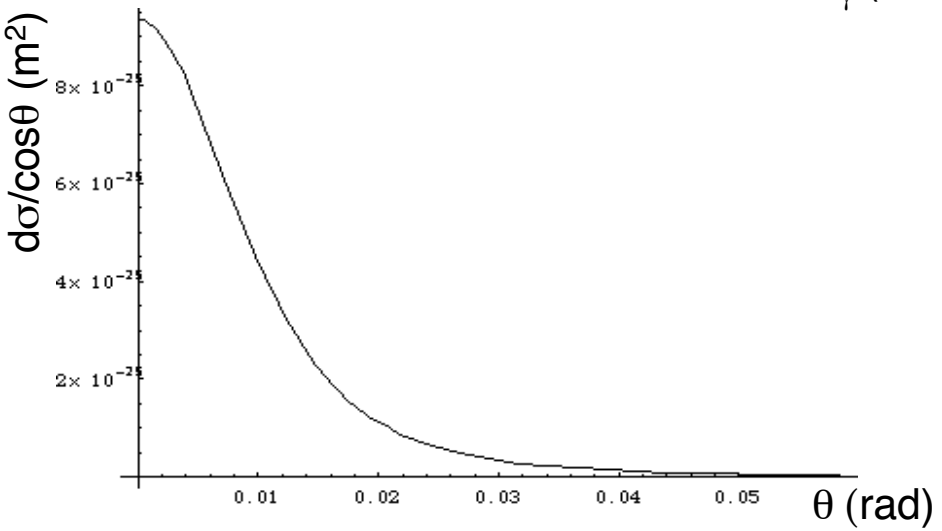
Negligible down to 10μm focal spot size

ICS - Why?

- Energy strongly correlated with angle
  - Energy selection



- Cross-section heavily biased in forward direction
  - High brightness

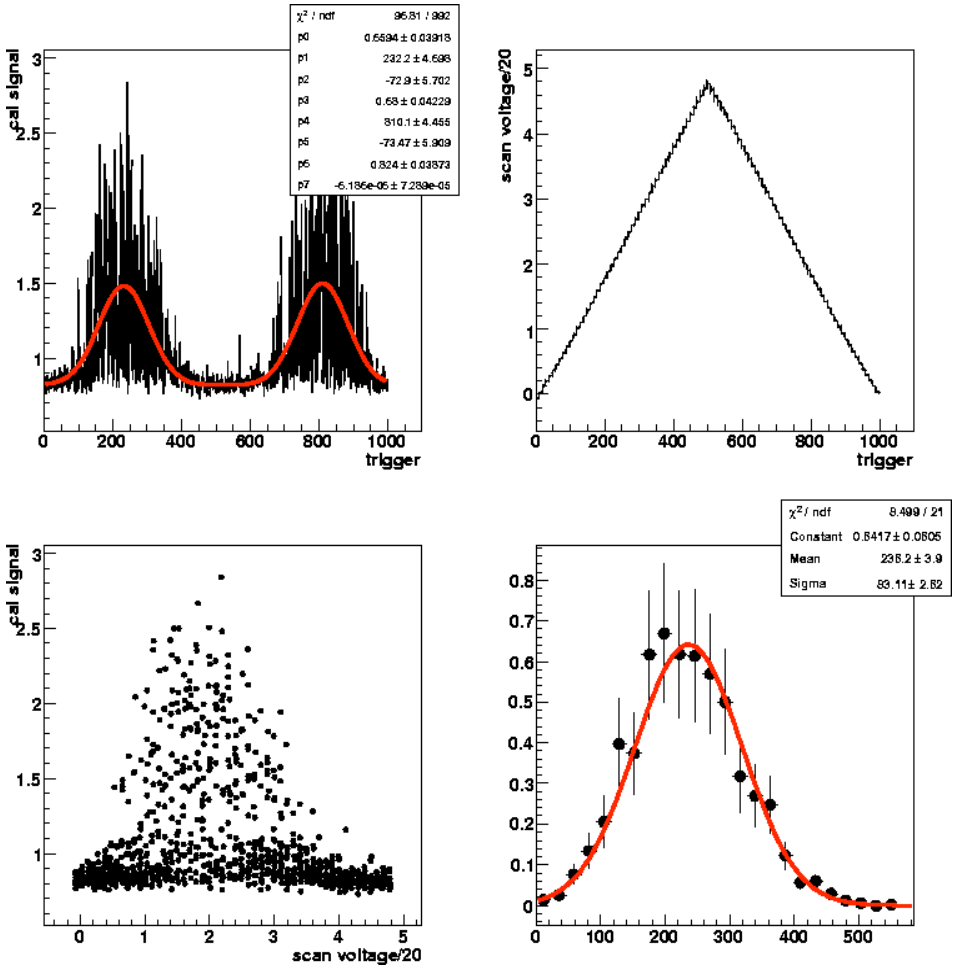


ICS - Why?

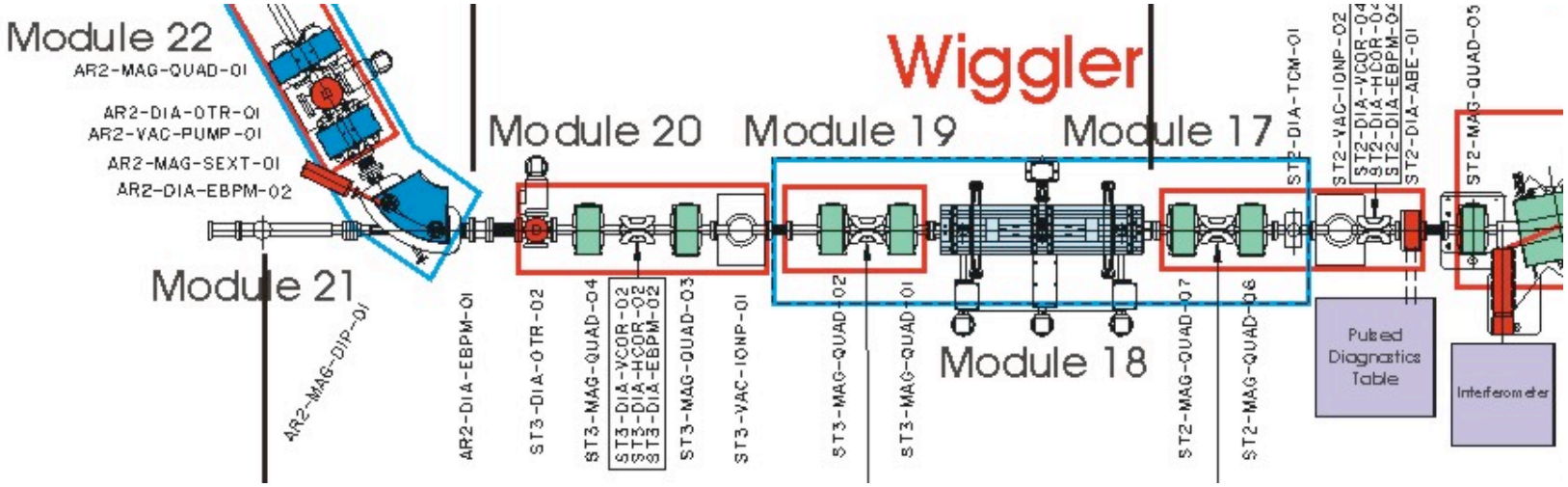
- Coherence enhanced x-ray imaging
  - Imaging of lung tissue
  - Exploration of screening and diagnostic applications of CBS
- Time resolved x-ray diffraction studies
  - Shock compression of matter on sub-picosecond timescales
  - Non-thermal melting

Links to Particle Physics

- Beam diagnostics - Laserwire
  - Photon rate depends on degree of overlap between laser and electron beam
  - Measure beam size
- Expected to be used in ILC…

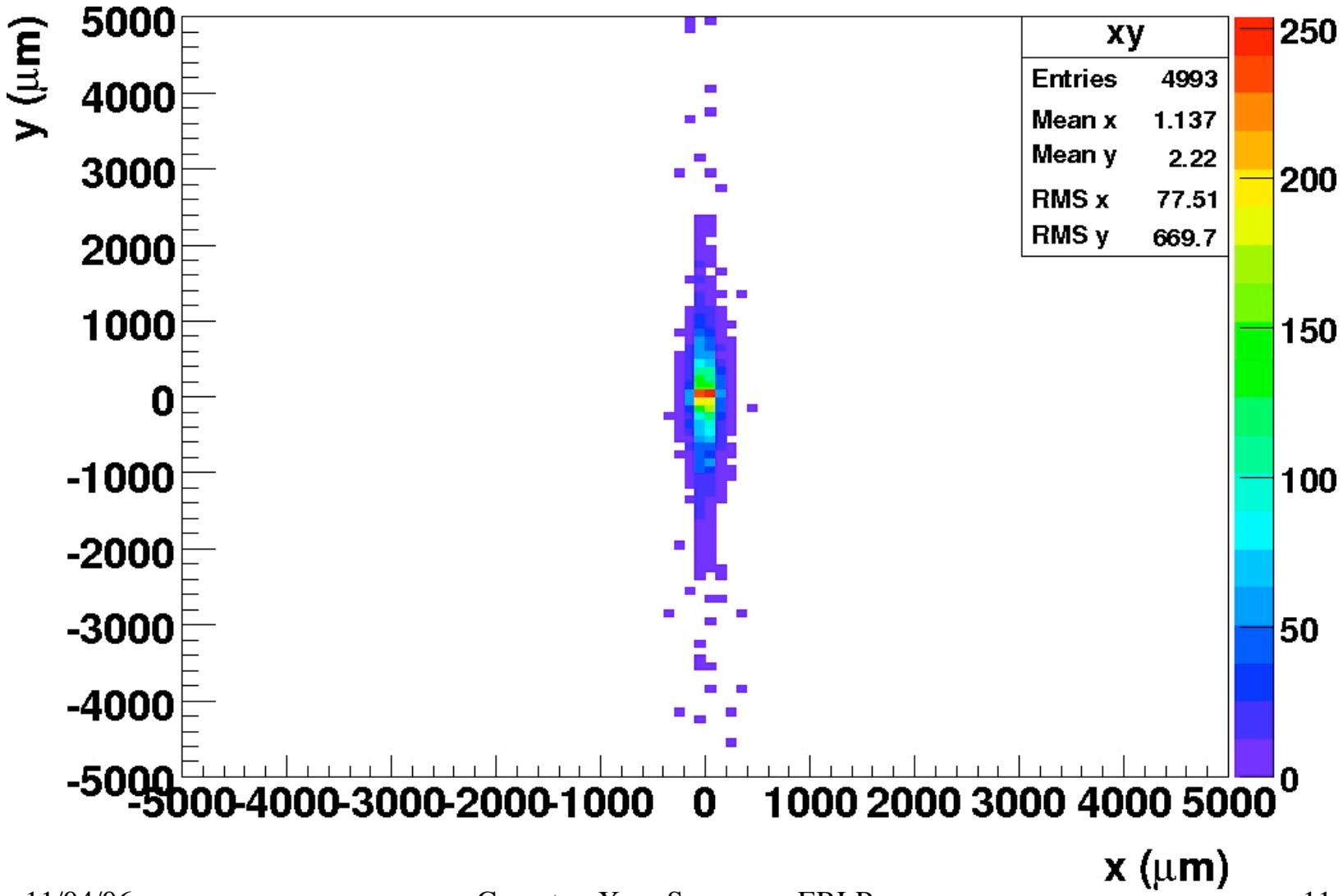


Electron Optics



- Generate smallest focus before beginning of arc
  - Increase luminosity for higher x-ray flux
- Do it without any extra magnets
  - Cost, interference with FEL running…
- Can this be done without losing beam after?
  - Radiation hazard, activated components…

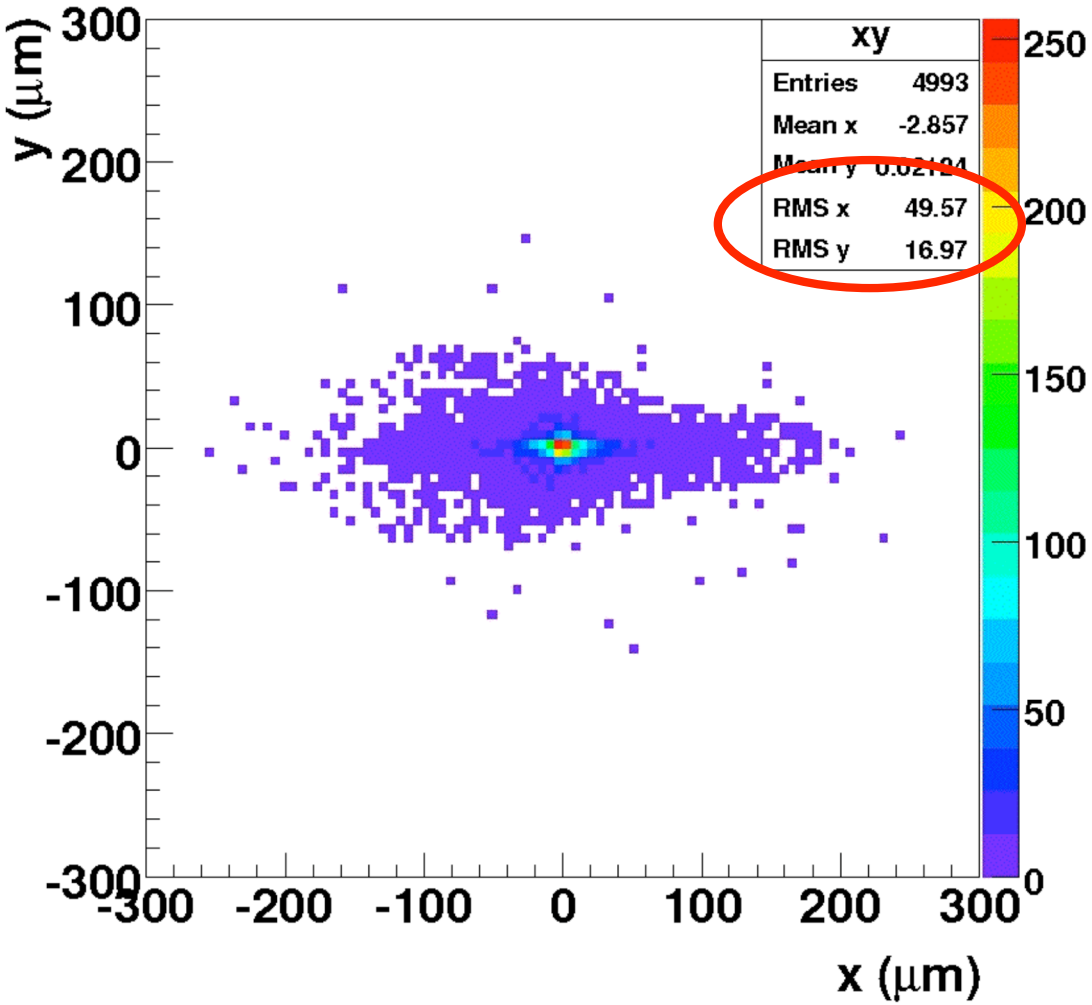
Bunch Profile at CBS (FEL mode)

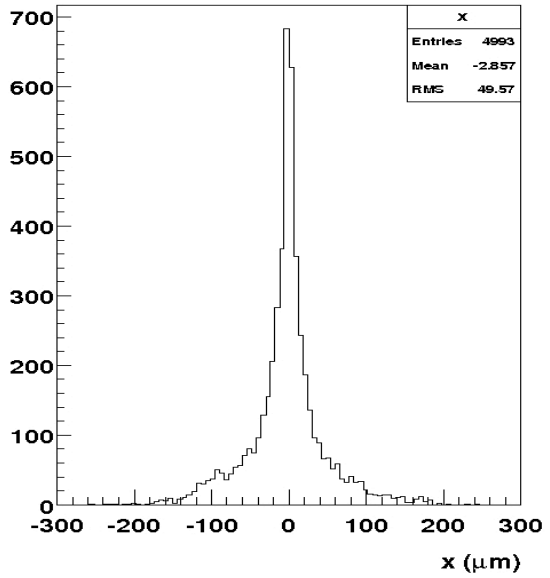


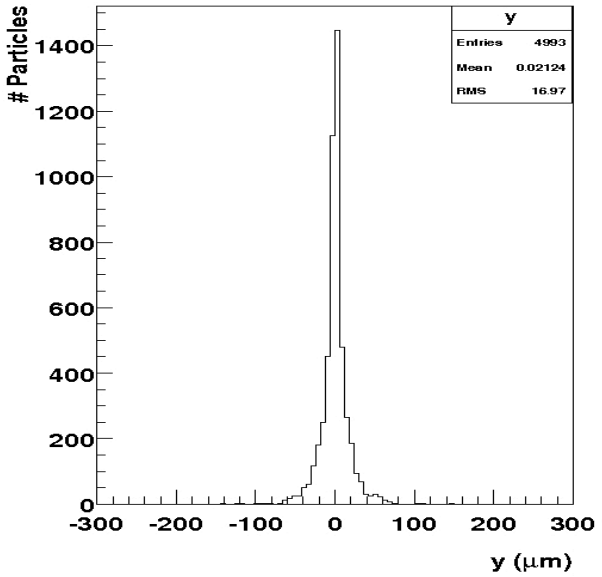
Modifications

- Remove wiggler and FEL cavity mirrors
- Vary all quads between bunch compressor and CBS
- Forget about everything downstream…
- 

New Bunch Profile at CBS

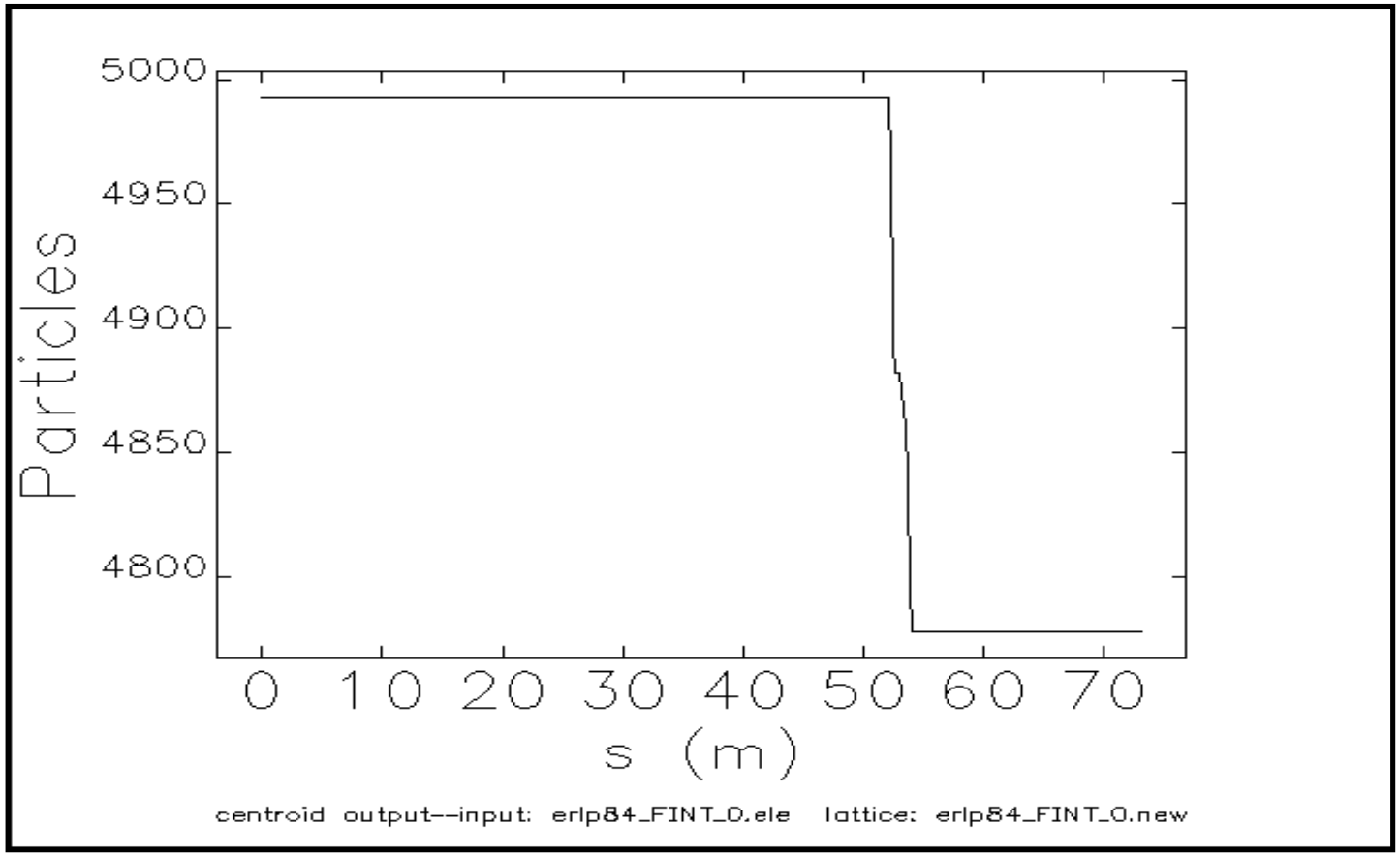




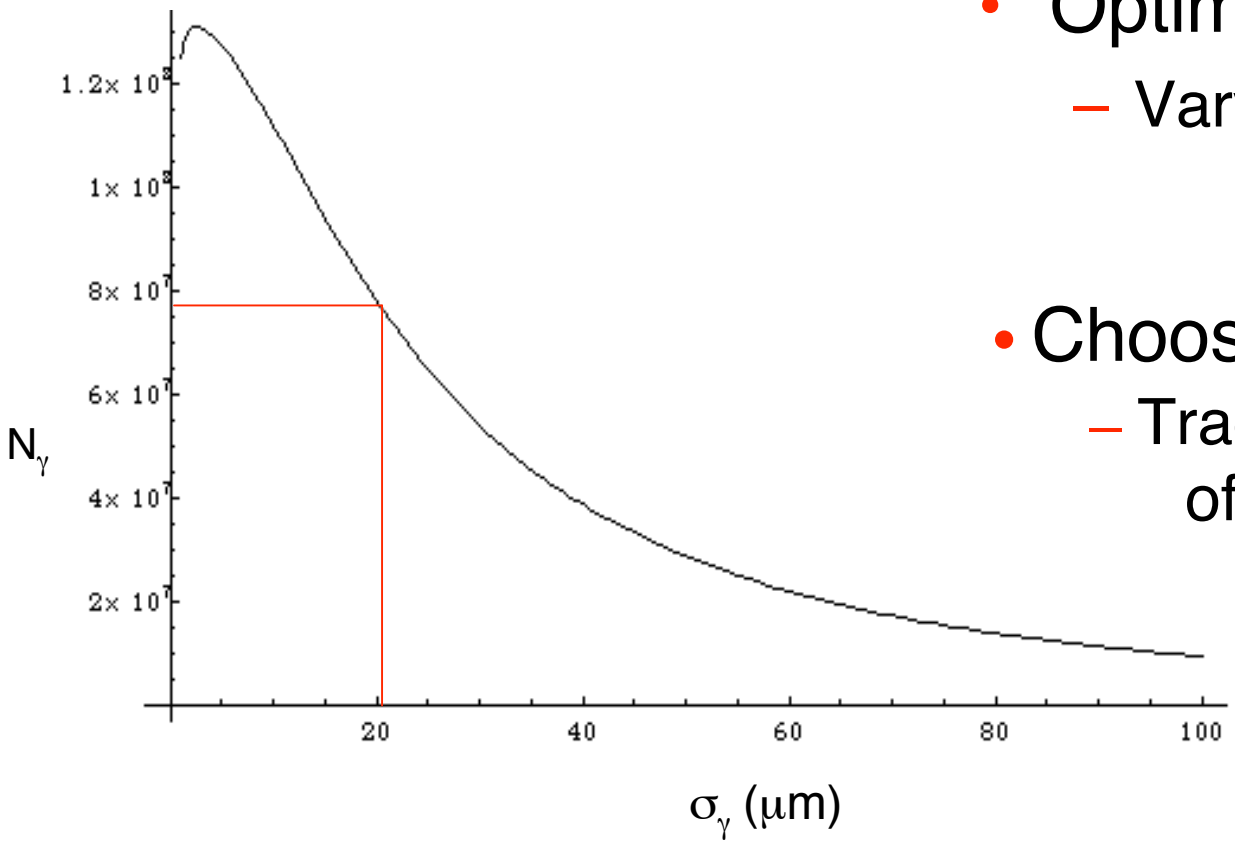


Beam Losses

- Beam losses ~4.3%



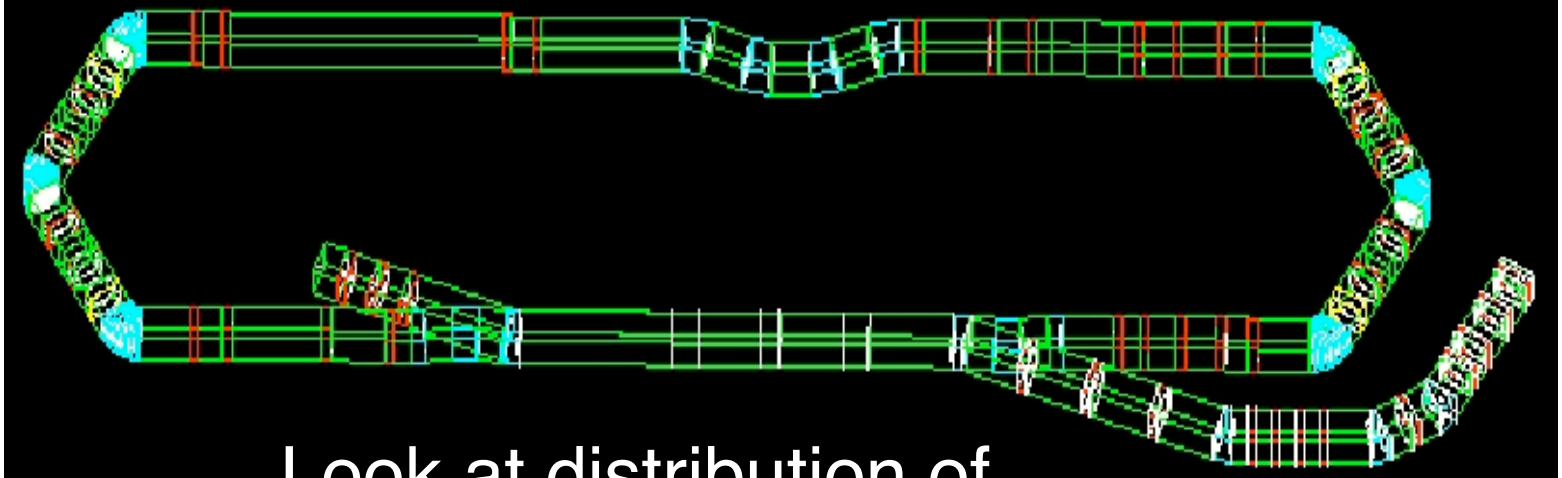
Beam Matching



- Optimise luminosity
  - Vary laser focus size
- Choose 20μm spot size
  - Trade high flux for ease of alignment

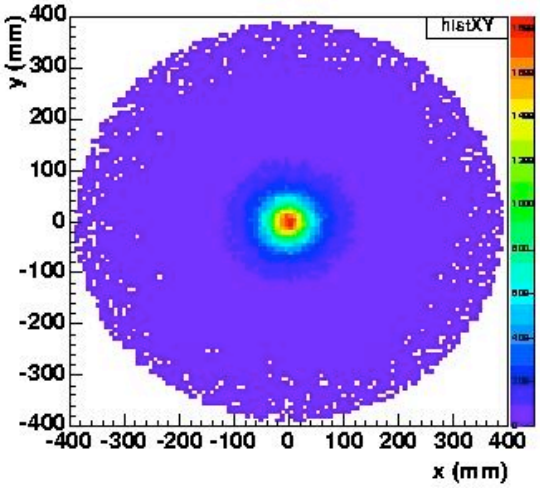
Photon Distribution

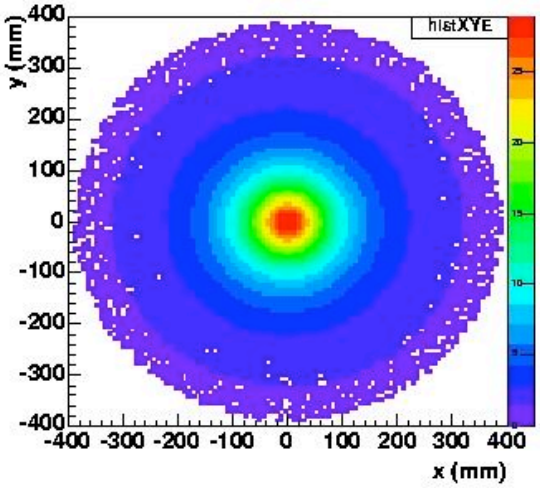
Model interaction point in BDSIM

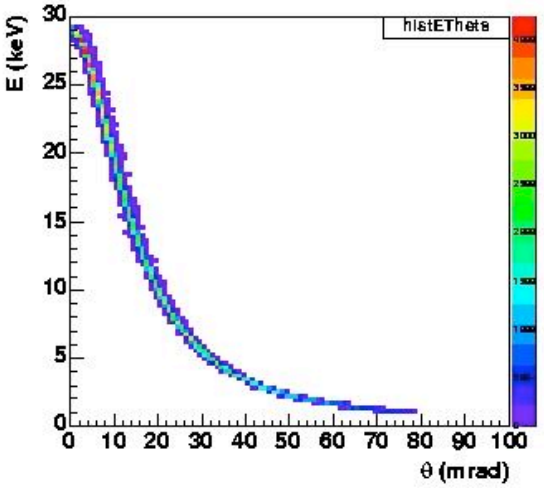


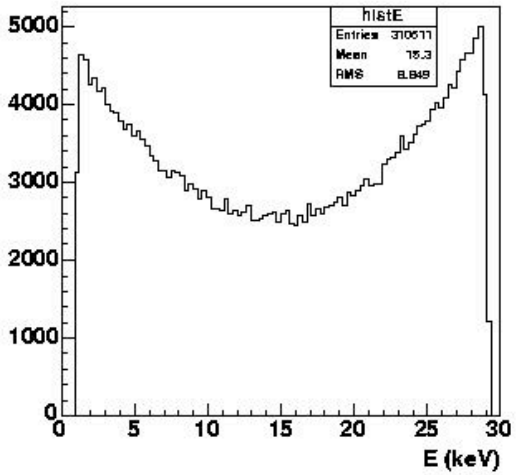
Look at distribution of photons in space/angle and energy

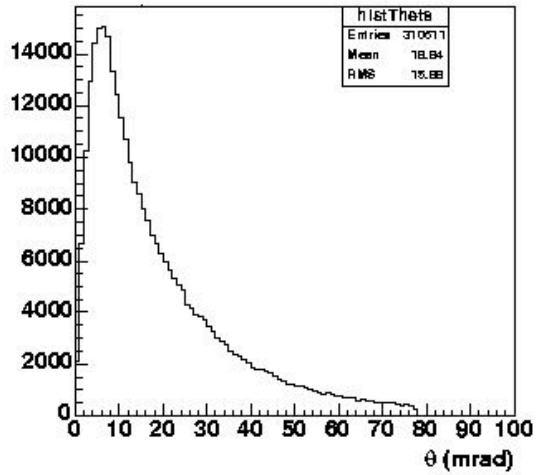
Photon Distribution (2)











- Ignored photons with energy <1keV

Summary

- Work so far
  - Inverse Compton source can provide γ's in the 10-30 keV range
  - Highly collimated beam
    - $\theta \sim \pm 80$ mrad (200% bandpass)
    - $\theta \sim \pm 10$ mrad (~14% bandpass)
  - Interaction region beam sizes ~20-50μm achievable
    - ~10^7-10^8 γ's per bunch crossing
  - Majority of beam isn't lost after CBS

- Work in progress
  - Determine effect of beam losses. Radiation levels too high?
  - Beam diagnostics: Initial beams and x-rays
  - How do we bring the beams into alignment? Laser delivery system…