Yield and Polarization

Wei Gai

Wanming Liu

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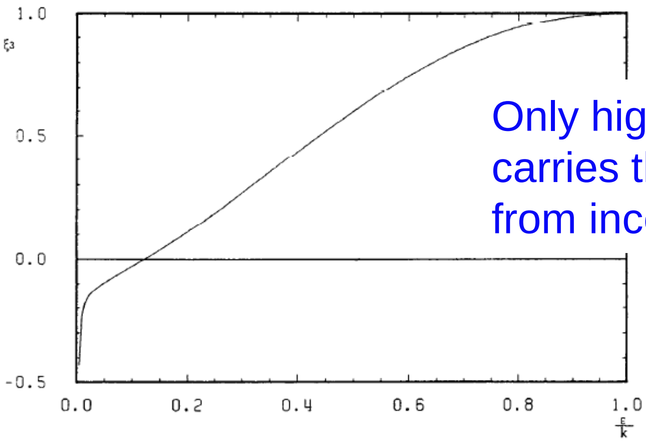
Some facts about pair production



Longitudinal polarization of e+ or e- as function of its fractional energy

Only high energy e+ carries the polarization from incoming photon

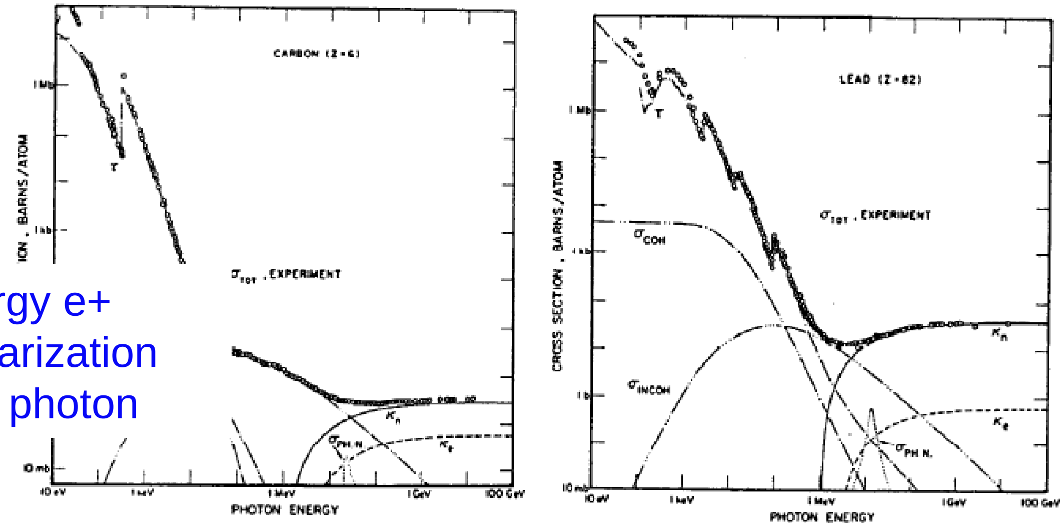
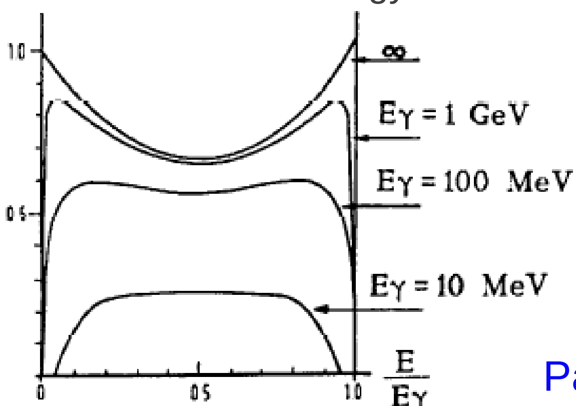


Fig. 1.1 Photon total cross section as a function of energy in Carbon and Lead [ref. 58]

τ = atomic photo-effect
σ_{COH} = coherent scattering (Rayleigh scattering)
σ_{INCOH} = incoherent scattering (Compton scattering)
K_n = pair production, nuclear field
K_e = pair production, electron field
$\sigma_{PH.N.}$ = photonuclear absorption

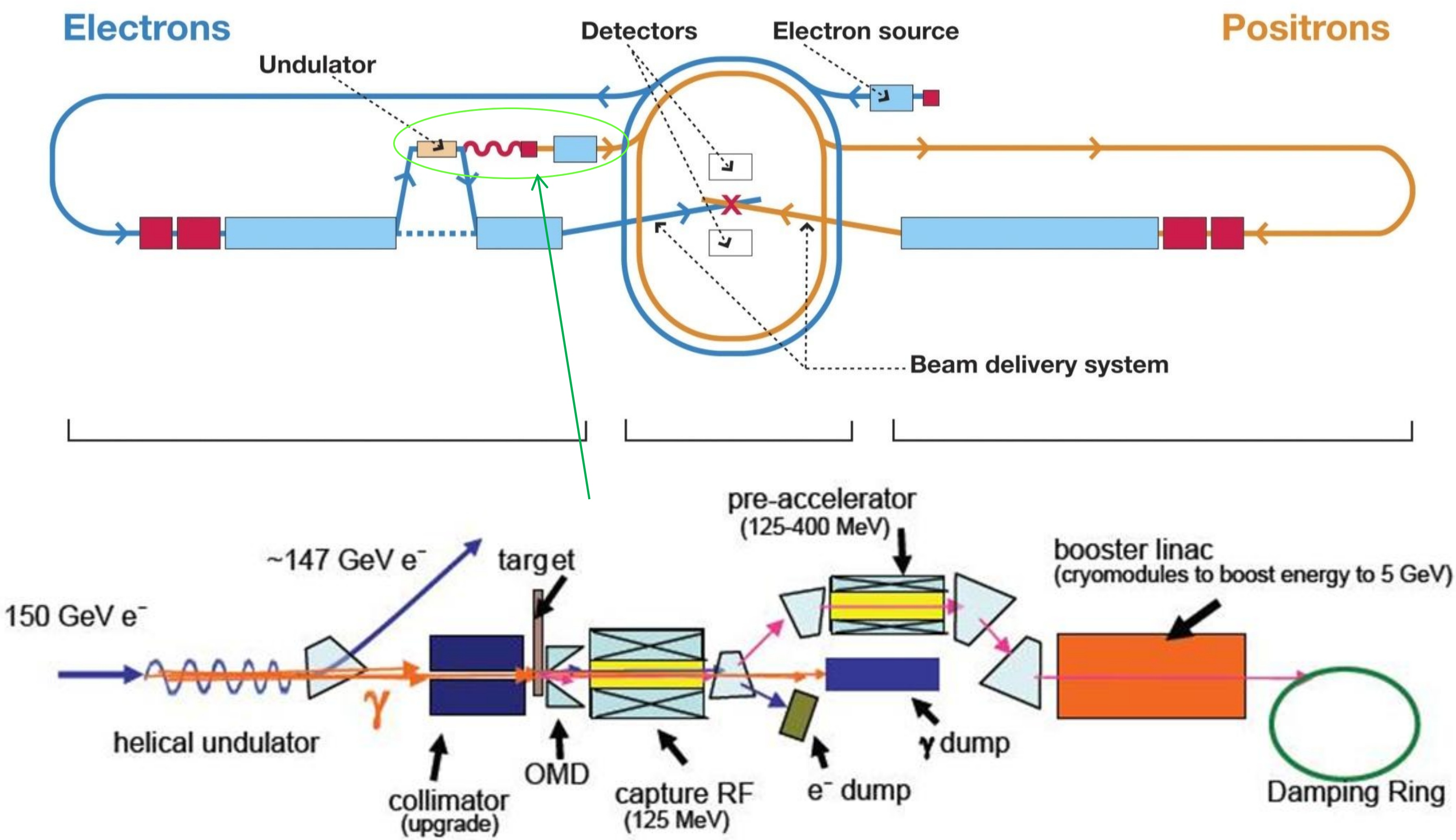
Cross section of pair production is near constant for high energy photons; high Z material tends to have a sharper leading edge for pair production cross section and higher cross section.



Particles are roughly equally distributed except for very high and very low photon energy

Energy distribution of e+/e- pairs as function of fractional energy

ILC RDR baseline schematic



What will have impact on polarization

- Undulator parameters (K, λ)
- Drive beam energy
- Photon collimator
- The capturing optics

Assumptions and conditions

- OMD: flux concentrator : 0.5T at target (z=0), 3.5T at z=2cm decrease adiabatically down to 0.5T at z=14cm.
- Target: 0.4X0 Ti
- Undulator:
  - RDR undulator and high K short period undulators
    - Length is fixed at 231m
    - Drive beam energy varies from 100GeV to 250GeV
  - RDR undulator with lower B field (Lower K)
    - K varies from 0.3 to 0.9
    - Length is fixed to 231m
    - Drive beam energy is 250GeV
- Drift between undulator end and the target: 400m long
- Photon collimator: A numerical mask with an iris at target

Undulator parameters

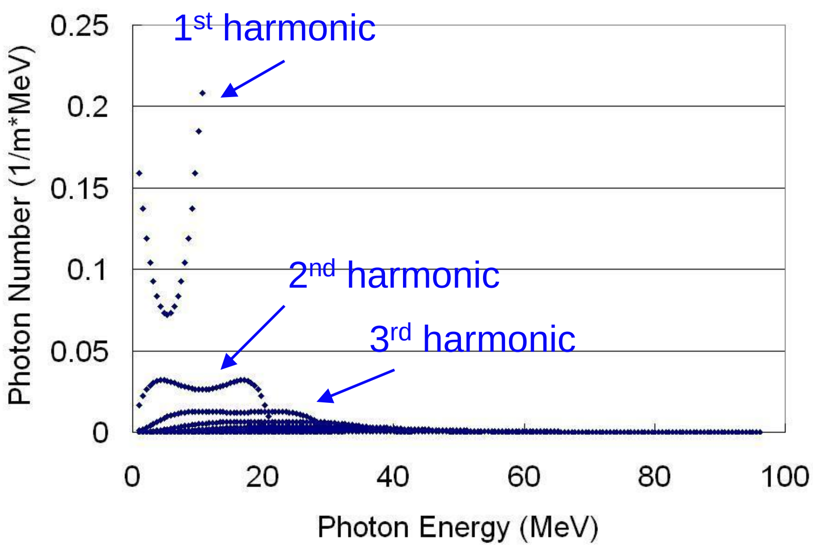
Photon spectrum

$$\frac{dNph}{dE}[\frac{1}{mMeV}] = \frac{10^6 e^2}{4\pi\varepsilon_0 c^2 h^2}\frac{K^2}{\gamma^2}\sum_1^{\infty}(J_n^{'}(x)^2 + [\frac{\alpha_n}{K} - \frac{n}{x}]^2 J_n(x)^2)$$

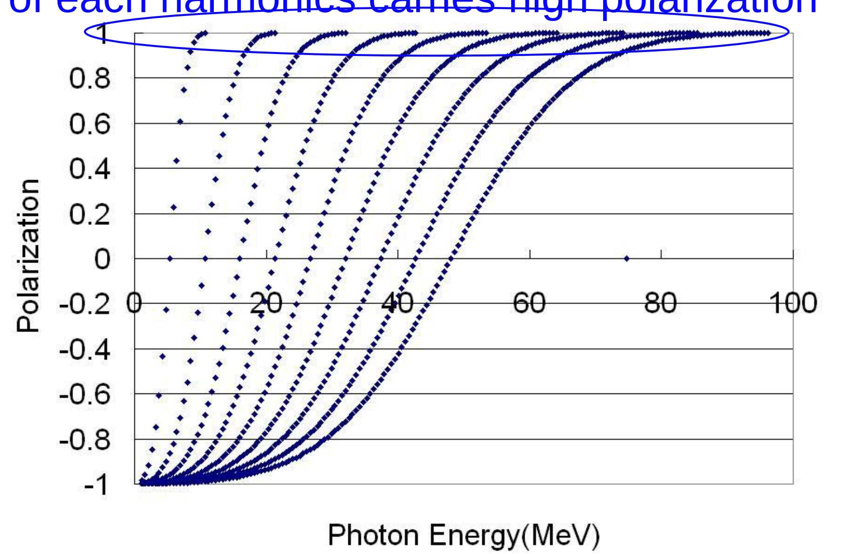
$$K = 0.934 * B[T] * \lambda_u[cm]$$

$$E_1 = \hbar\omega_1 = \hbar\frac{4\pi\gamma^2 c}{(1+K^2)\lambda_u}$$

1st harmonic critical energy

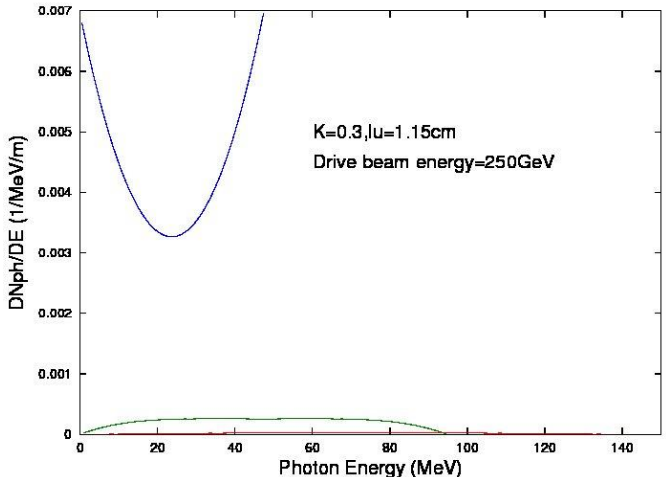


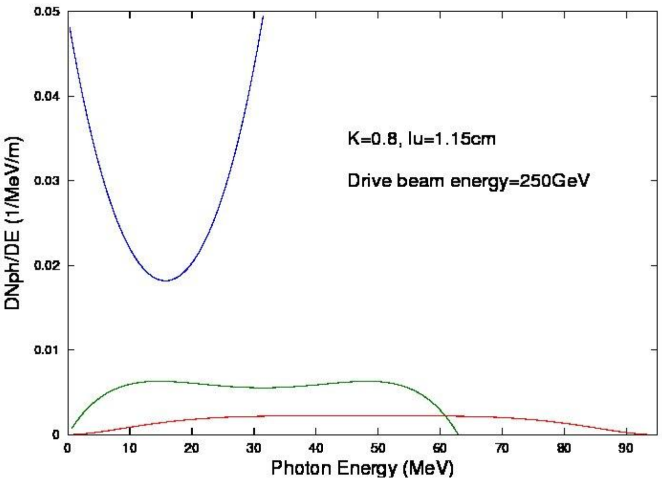
Only photons with energy near critical energy of each harmonics carries high polarization



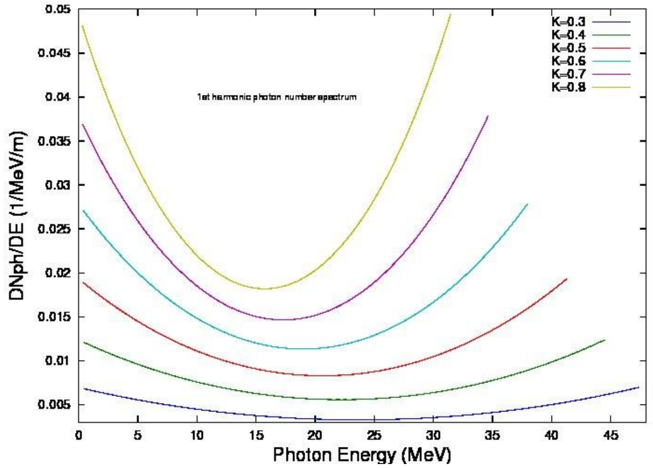
In order to have higher polarization in e+ beam, one would want to have fewer photons from higher order harmonics. 150 GeV and RDR undulator

Undulator parameters





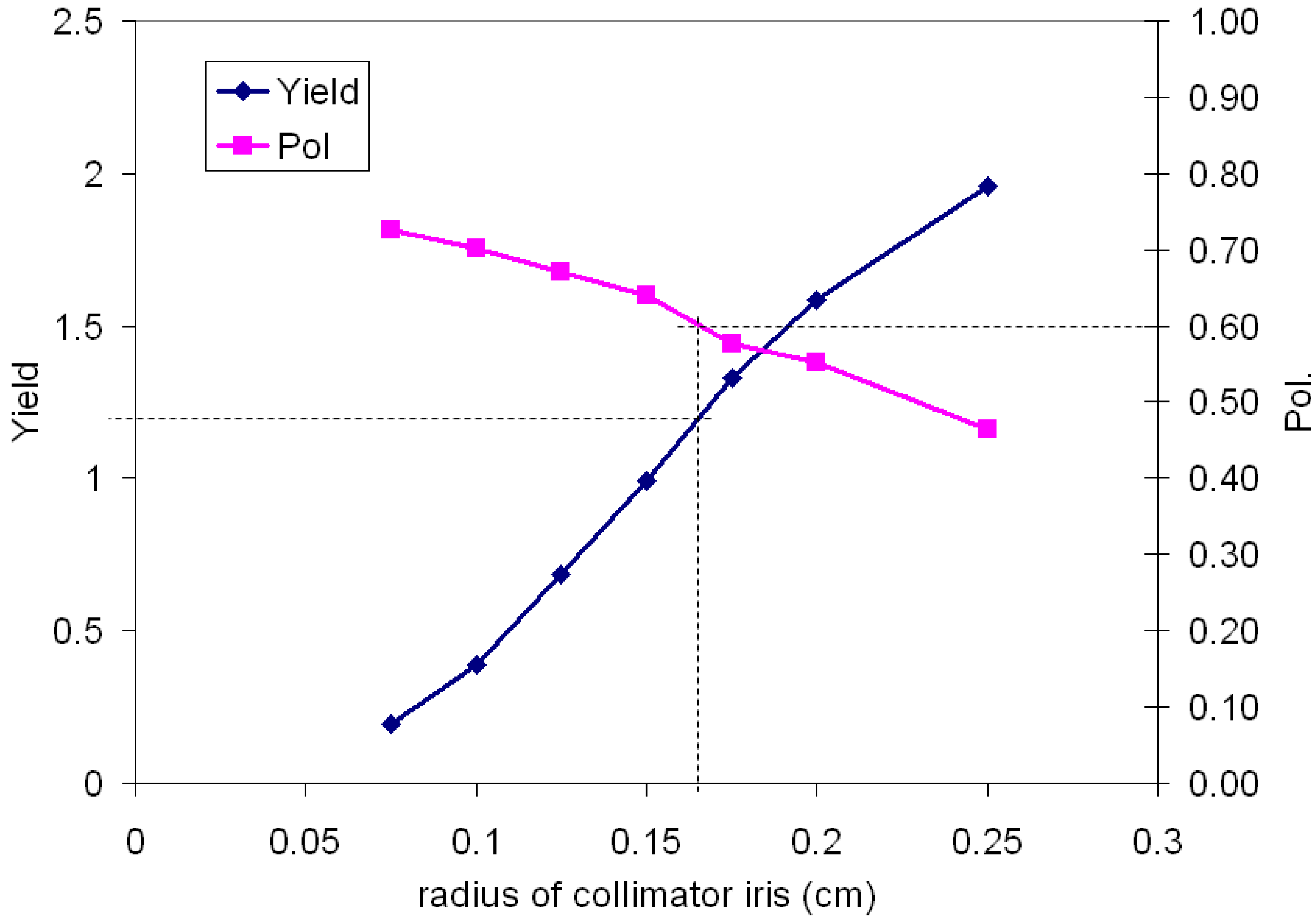
Lower K gives higher 1st harmonic radiation contents in spectrum and also higher critical energies



Lower K radiates less photons for a given length and drive beam

Lowering K can improve the polarization with a price on the e+ beam intensity

150GeV drive beam, RDR undulator (reference)

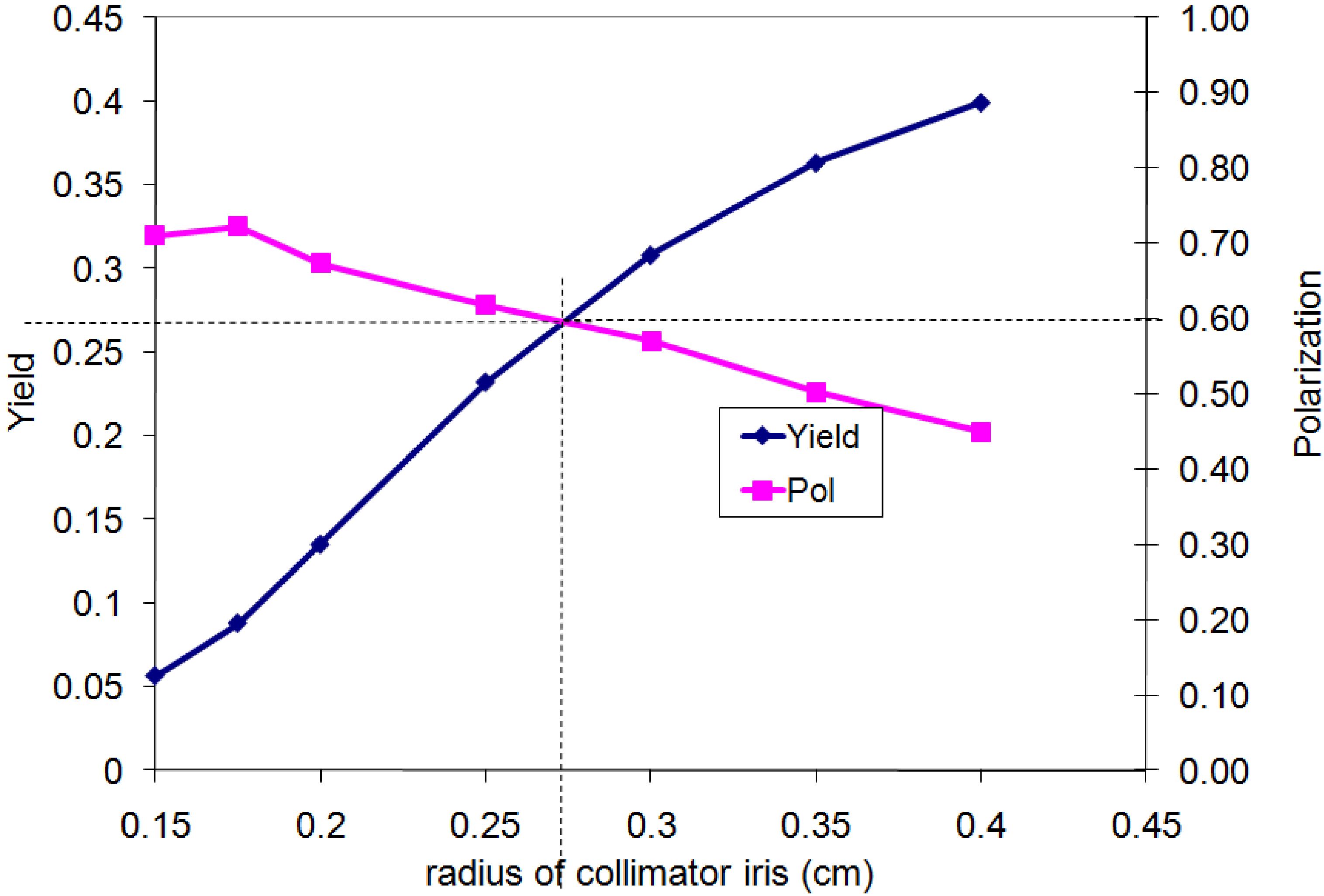


For 150GeV drive beam, 60% polarization required a photon collimator with an iris of ~1.6mm in radius. The corresponding yield is ~1.2 for 231m long RDR undulator

Examples

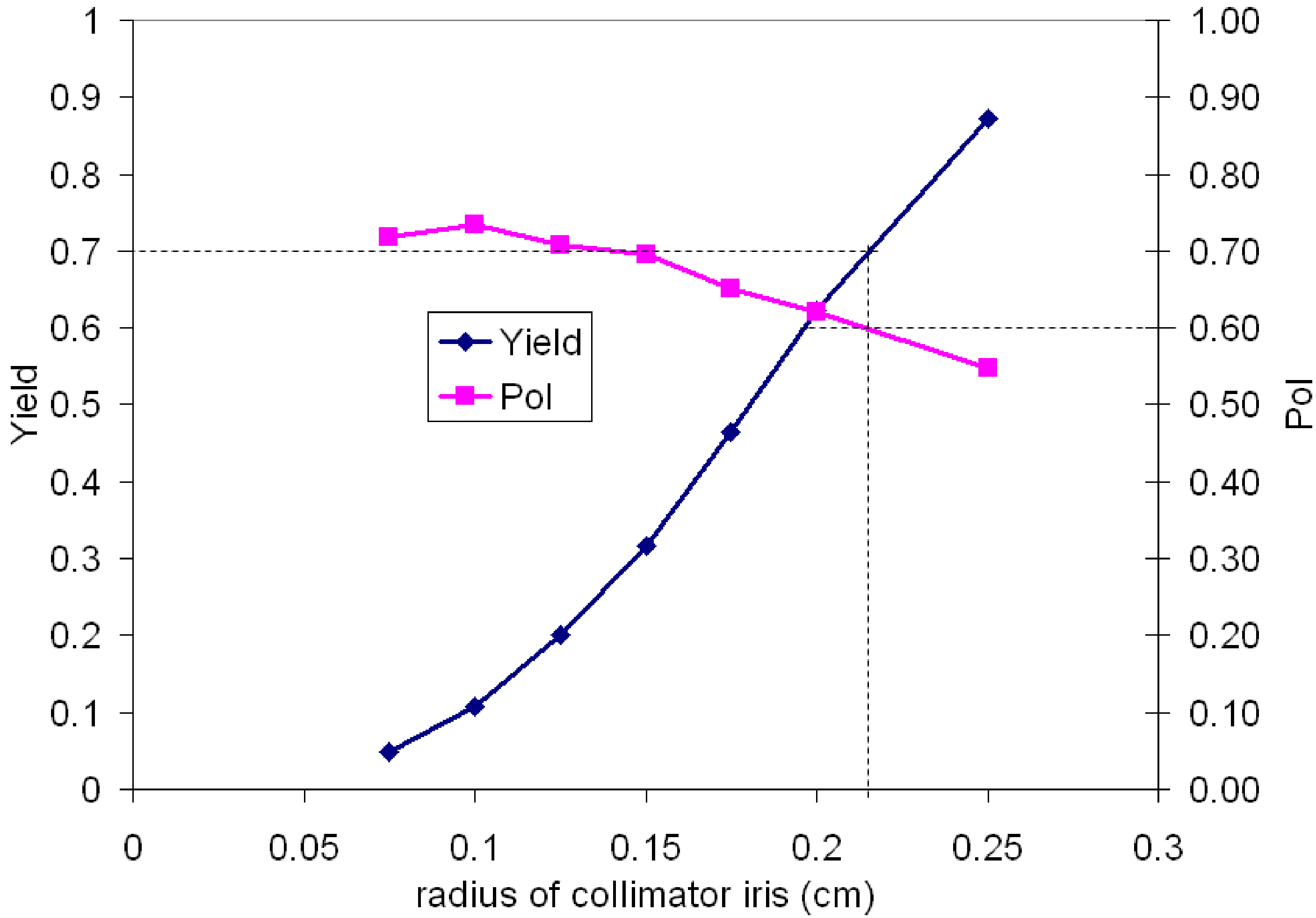
- Varying E (100 -250 GeV),
- K (0.3 – 0.9)
- Lambda (0.9 and 1.15 cm)
- Collimator radius as a variable.

100GeV drive beam, RDR undulator



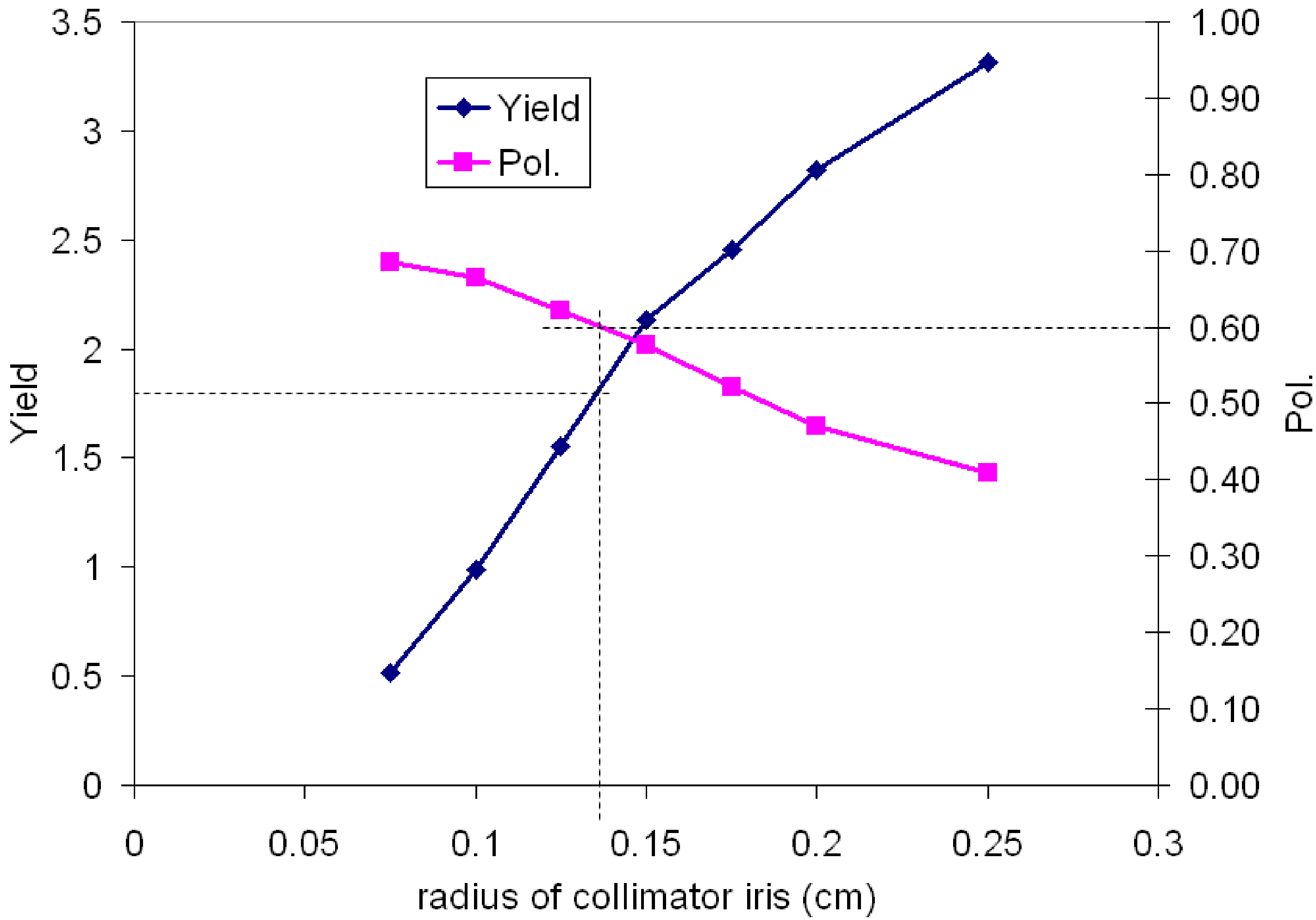
For 100GeV drive beam, 60% polarization required a photon collimator with an iris of ~2.6mm in radius. The corresponding yield is ~0.27 for 231m long RDR undulator

125GeV drive beam, RDR undulator



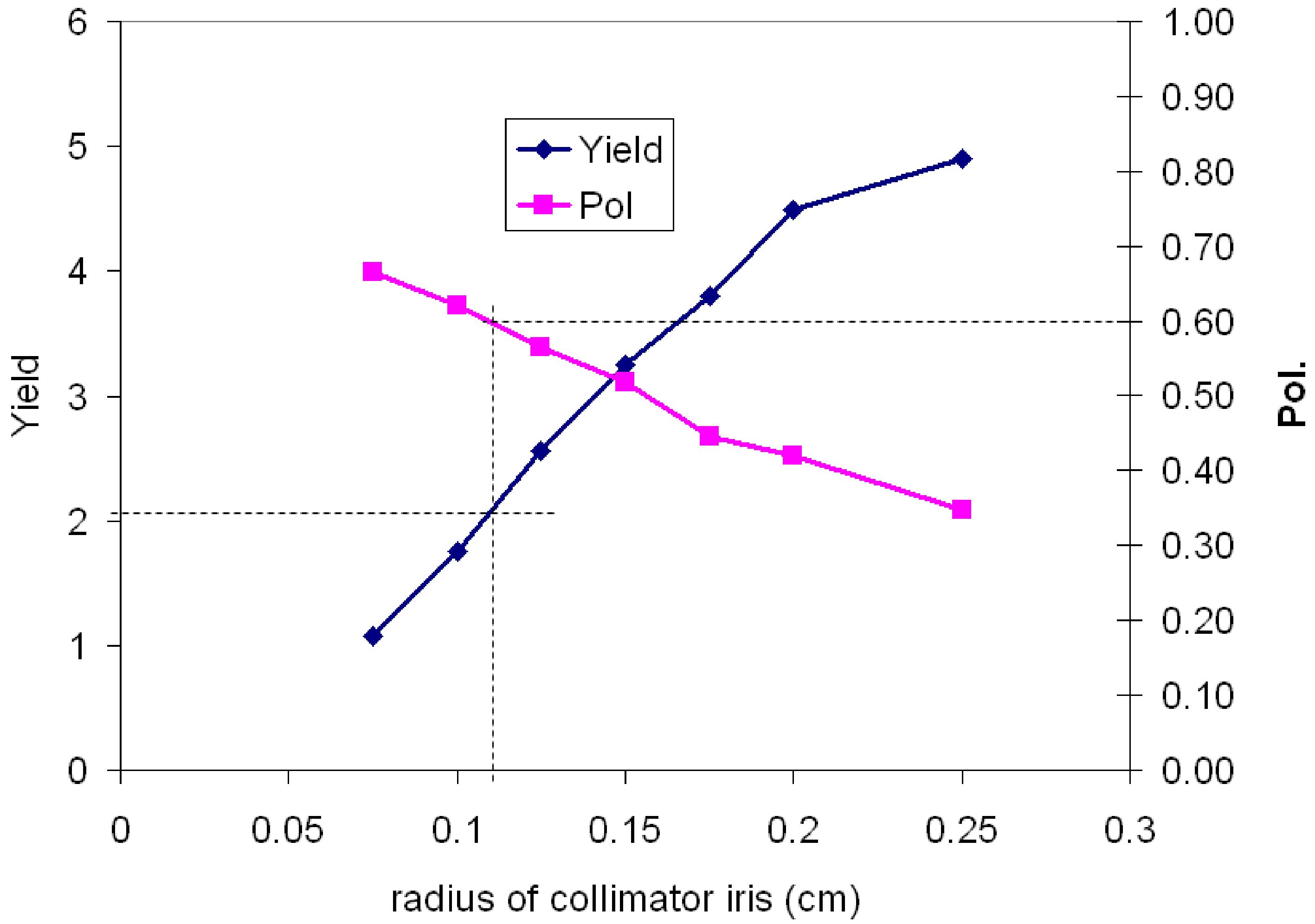
For 125GeV drive beam, 60% polarization required a photon collimator with an iris of ~2.2mm in radius. The corresponding yield is ~0.7 for 231m long RDR undulator

175GeV drive beam, RDR undulator



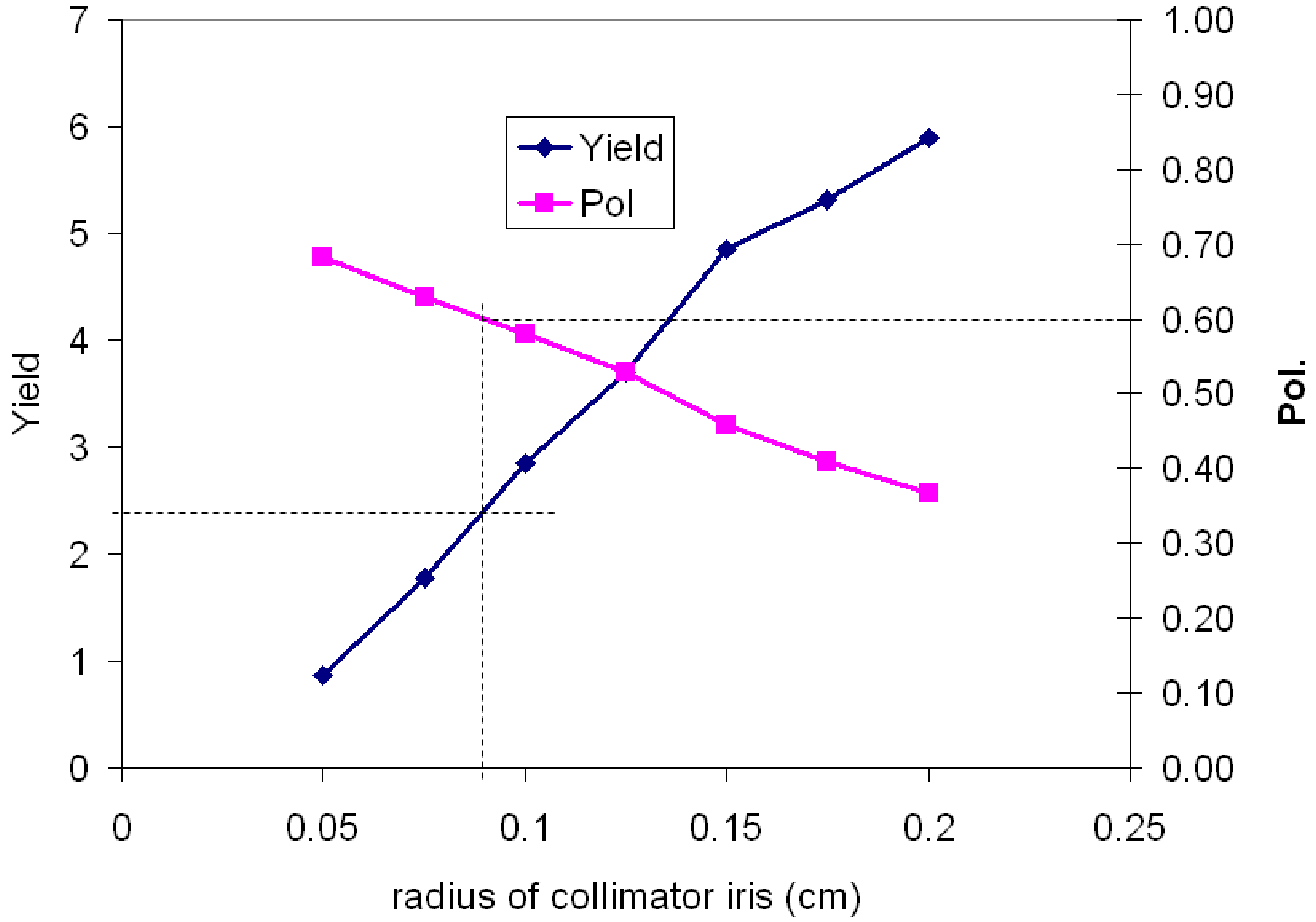
For 175GeV drive beam, 60% polarization required a photon collimator with an iris of ~1.4mm in radius. The corresponding yield is ~1.8 for 231m long RDR undulator

200GeV drive beam, RDR undulator



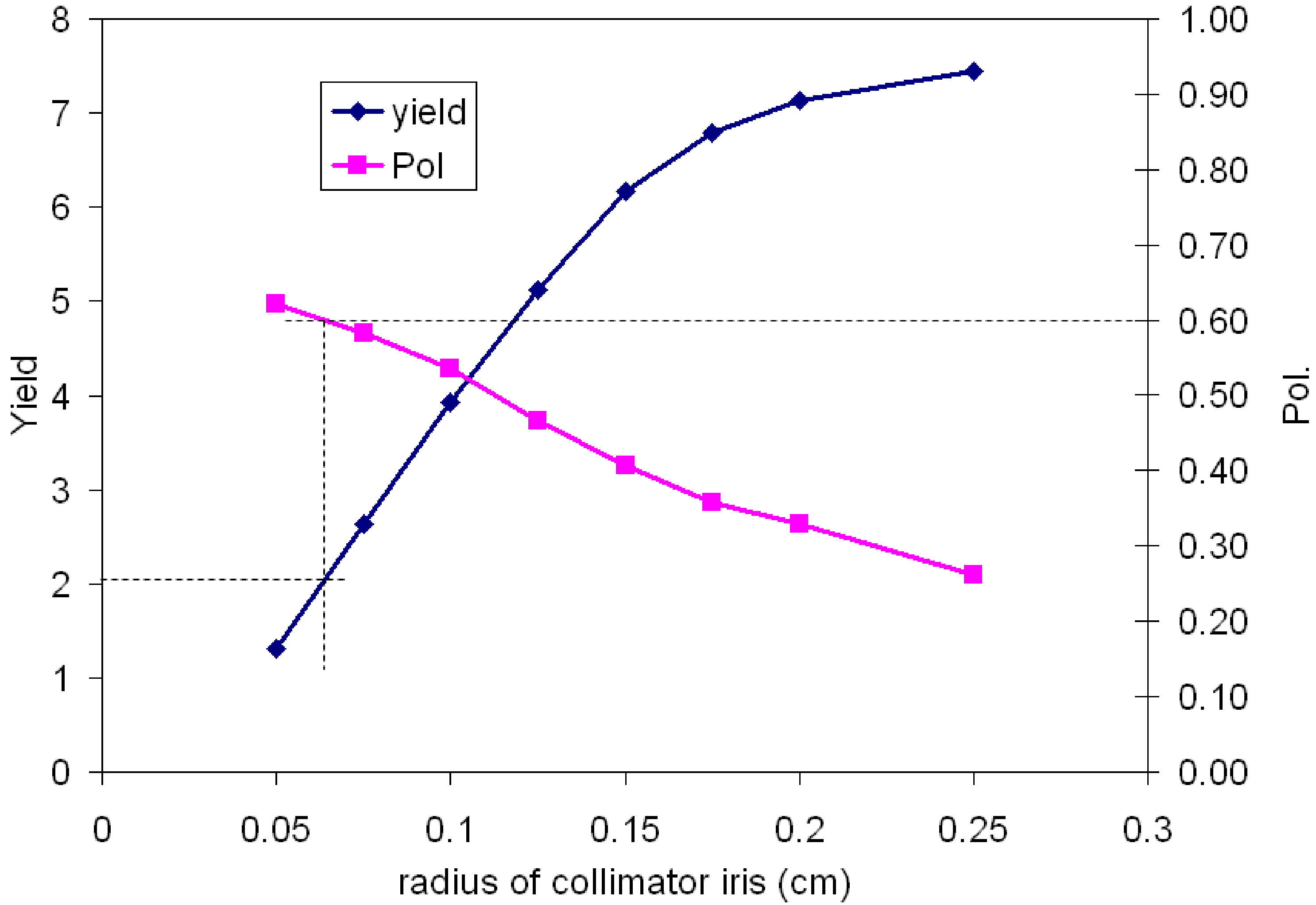
For 200GeV drive beam, 60% polarization required a photon collimator with an iris of ~1.15mm in radius. The corresponding yield is ~2.05 for 231m long RDR undulator

225GeV drive beam, RDR undulator



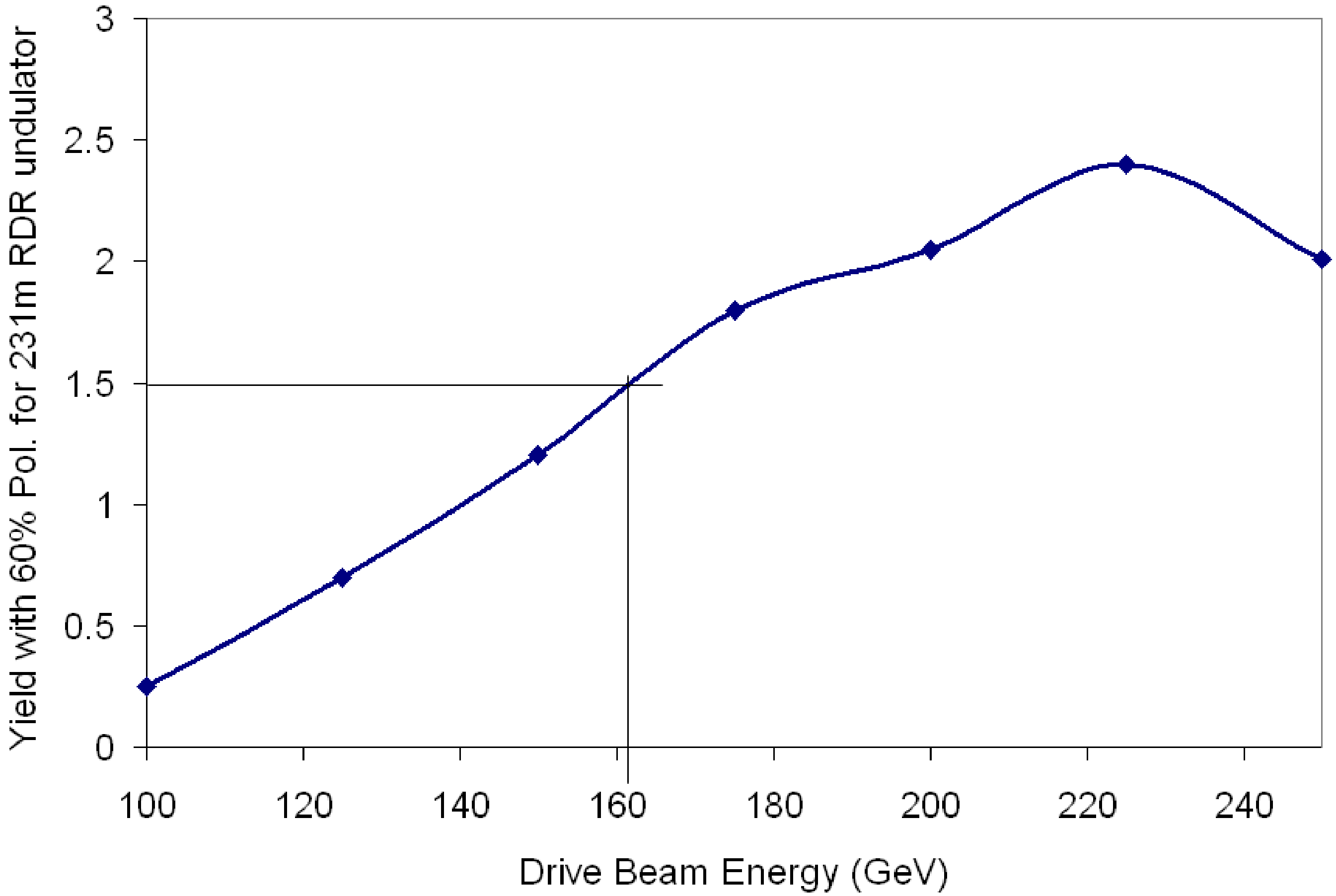
For 225GeV drive beam, 60% polarization required a photon collimator with an iris of ~0.85mm in radius. The corresponding yield is ~2.4 for 231m long RDR undulator

250GeV drive beam, RDR undulator



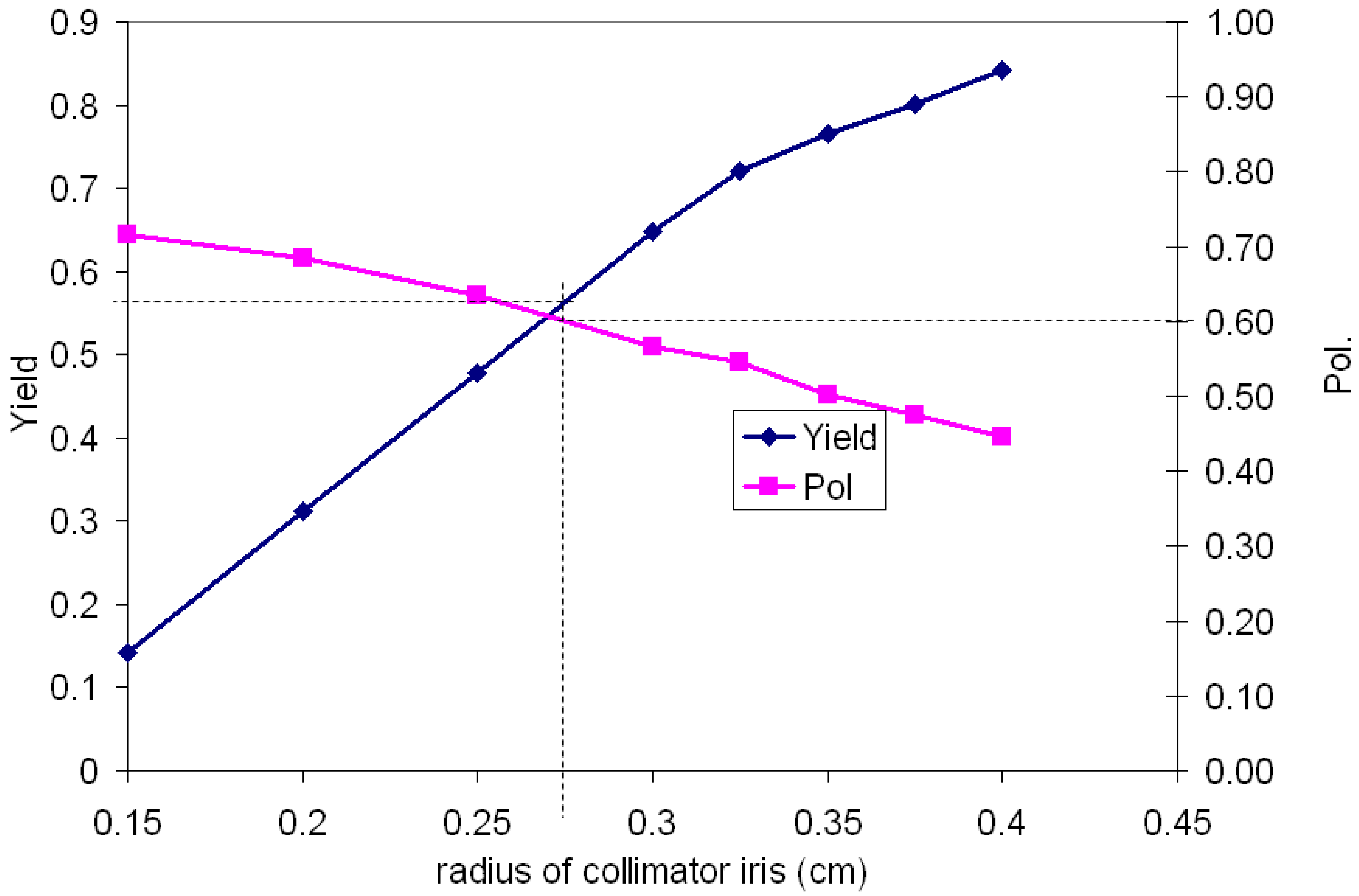
For 250GeV drive beam, 60% polarization required a photon collimator with an iris of ~0.6mm in radius. The corresponding yield is ~2.0 for 231m long RDR undulator

Yield with 60% Pol. As function of drive beam energy. 231m long RDR undulator



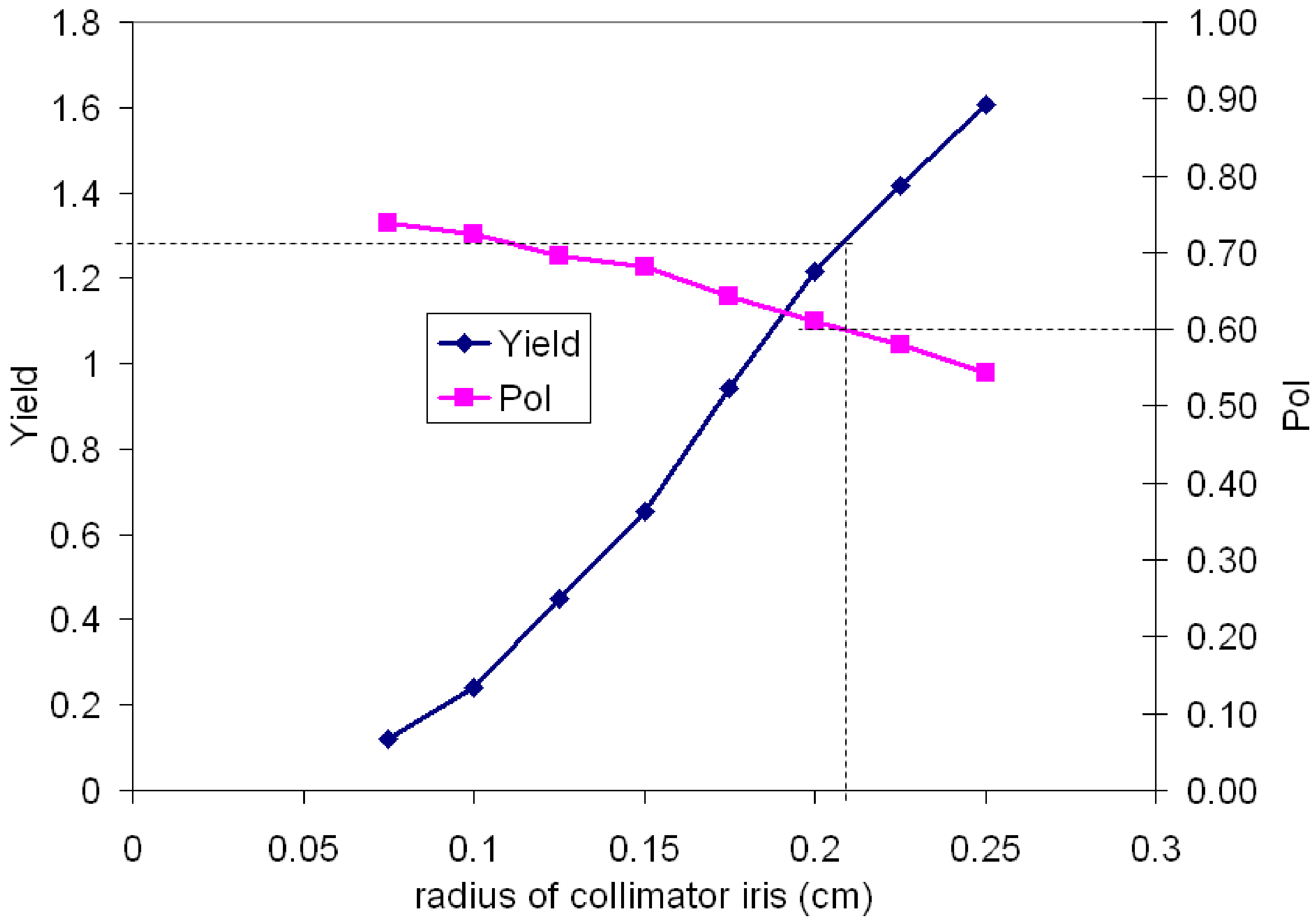
- Yield of 1.5 with 60% yield can be reached with drive beam energy of ~162GeV

Drive beam energy 100GeV, K=0.9,λu=0.9



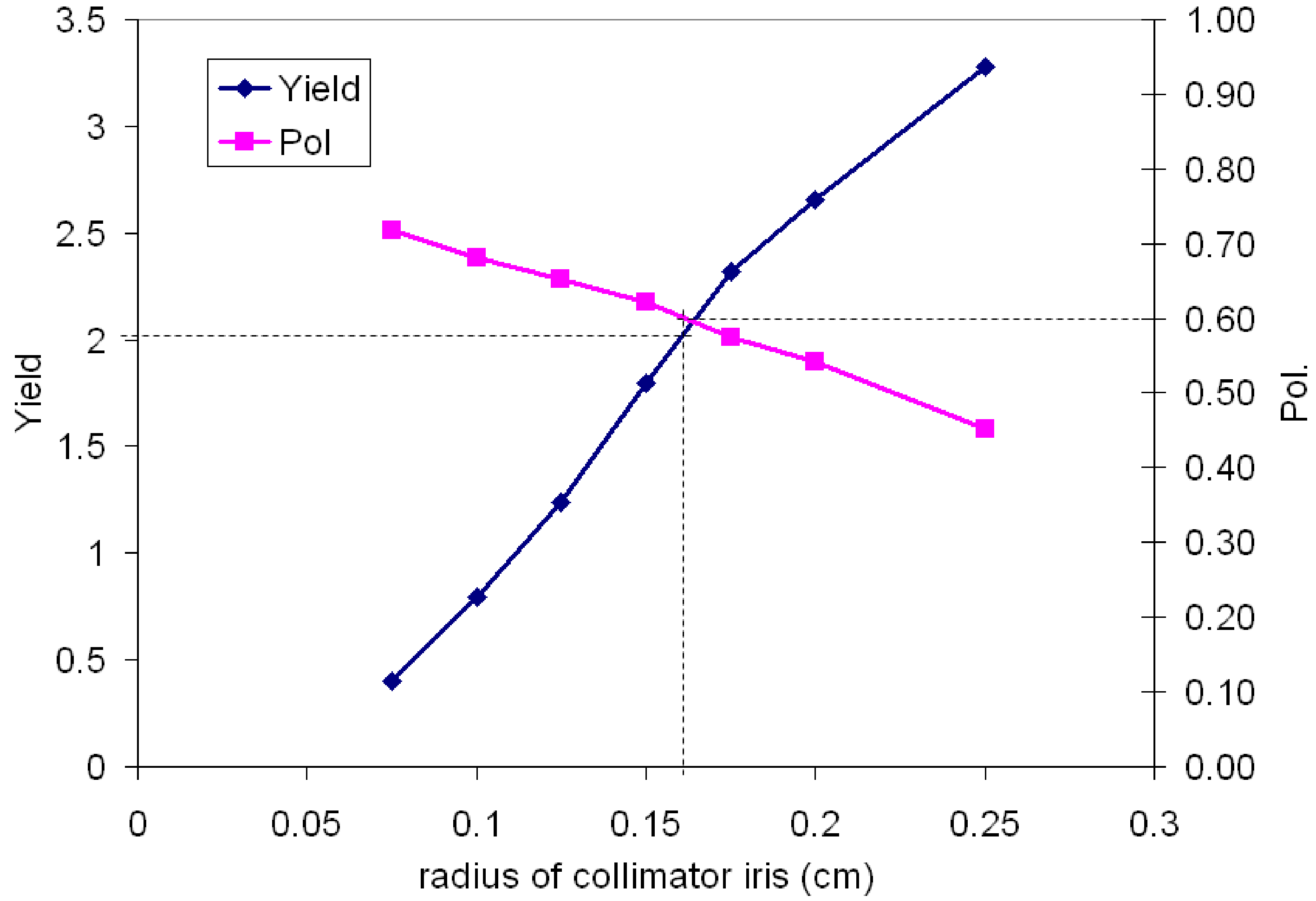
For 60% polarization, an photon collimator with iris of 2.75mm in radius is required and the corresponding yield is only ~0.57 for 231m long undulator.

Drive beam energy 125GeV, K=0.9,λu=0.9



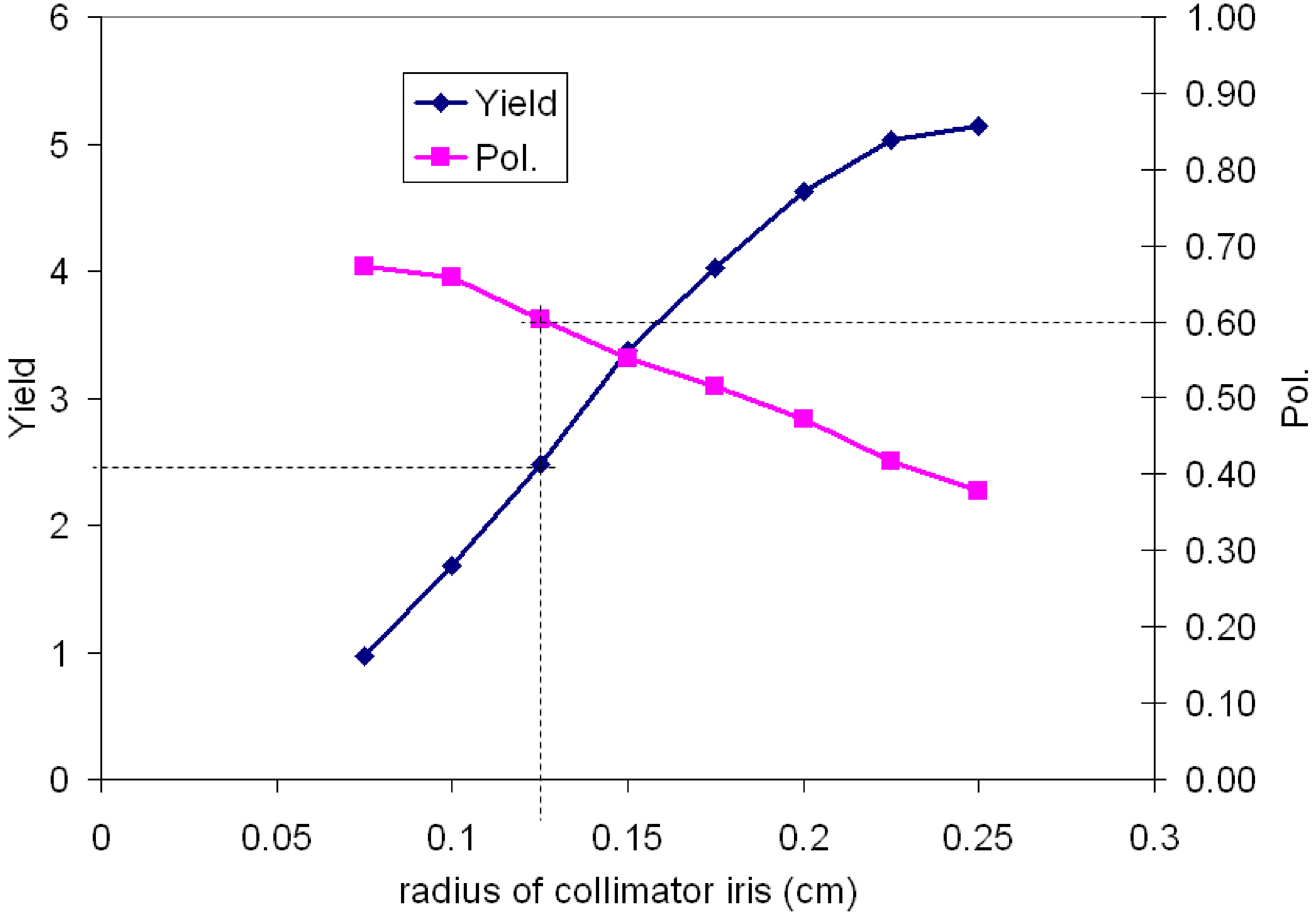
For 125GeV drive beam, the 60% polarization required a photon collimator with an iris of ~2.1mm in radius and the corresponding yield is ~1.28 for 231m long undulator

Drive beam energy 150GeV, K=0.9,λu=0.9



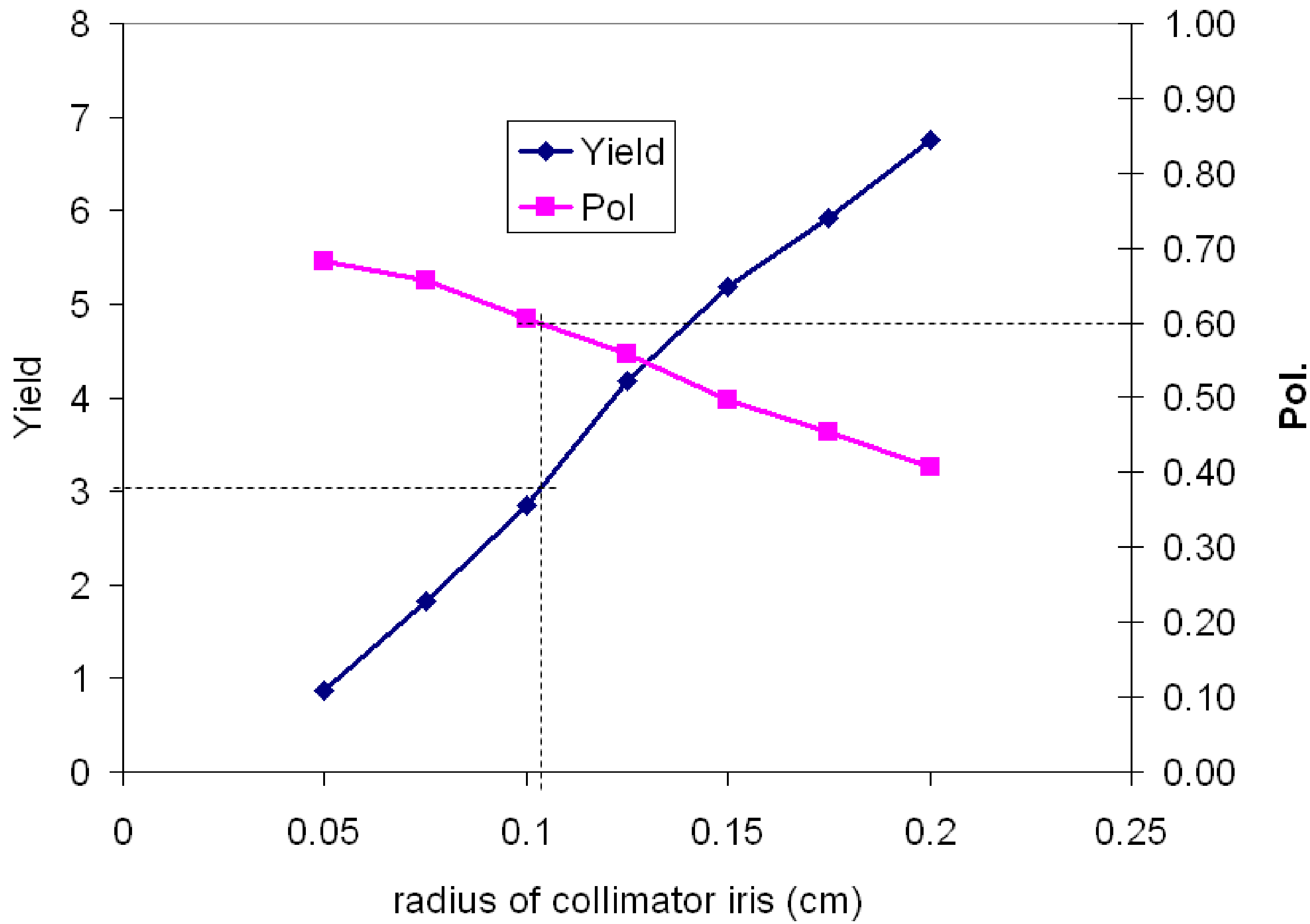
For 150GeV drive beam, 60% polarization required a photon collimator with an iris of ~1.6mm in radius. The corresponding yield is ~2 for 231m long undulator

Drive beam energy 175GeV, K=0.9,λu=0.9



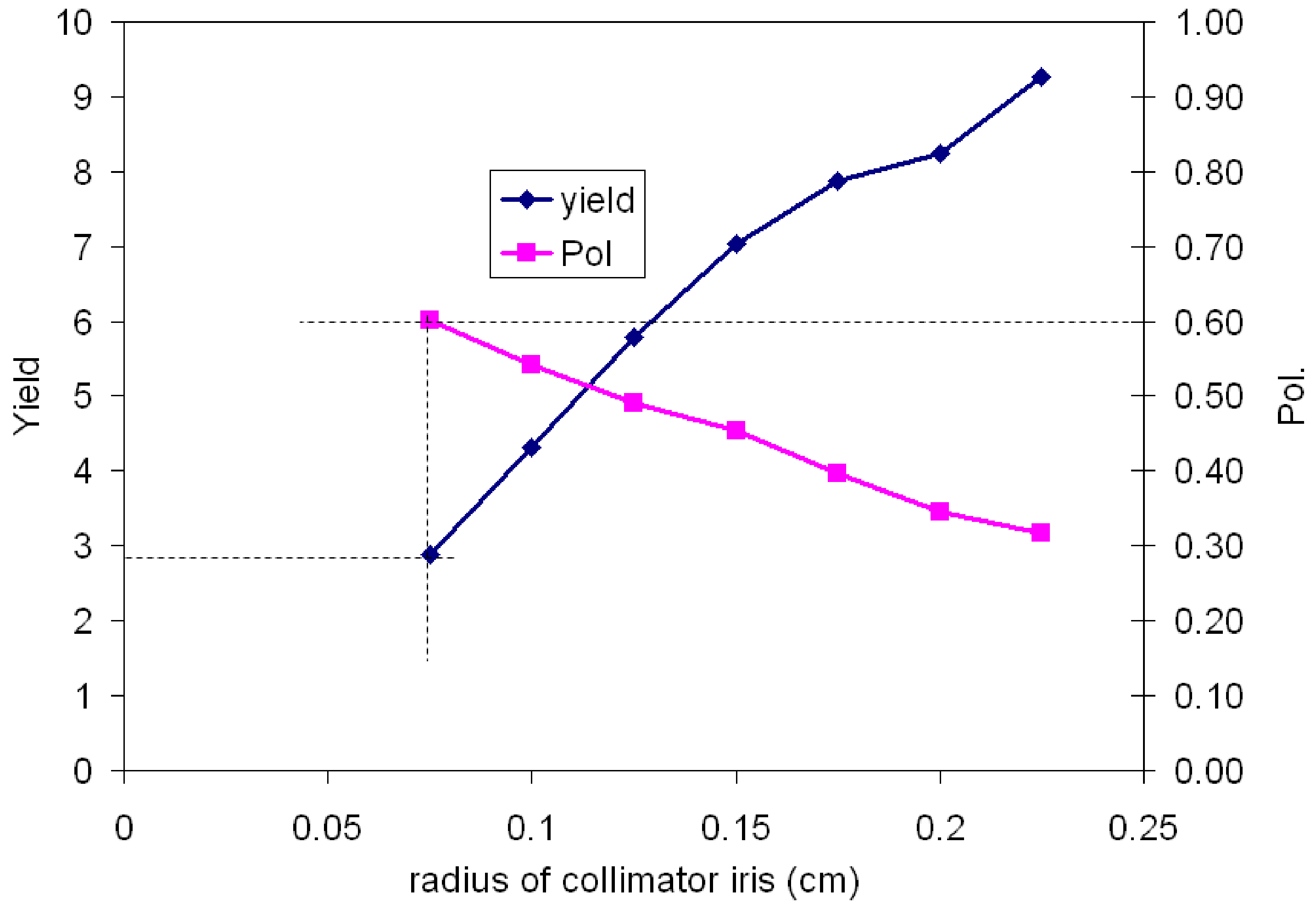
For 175GeV drive beam, 60% polarization required a photon collimator with an iris of ~1.25mm in radius. The corresponding yield is ~2.4 for 231m long undulator

Drive beam energy 200GeV, K=0.9,λu=0.9



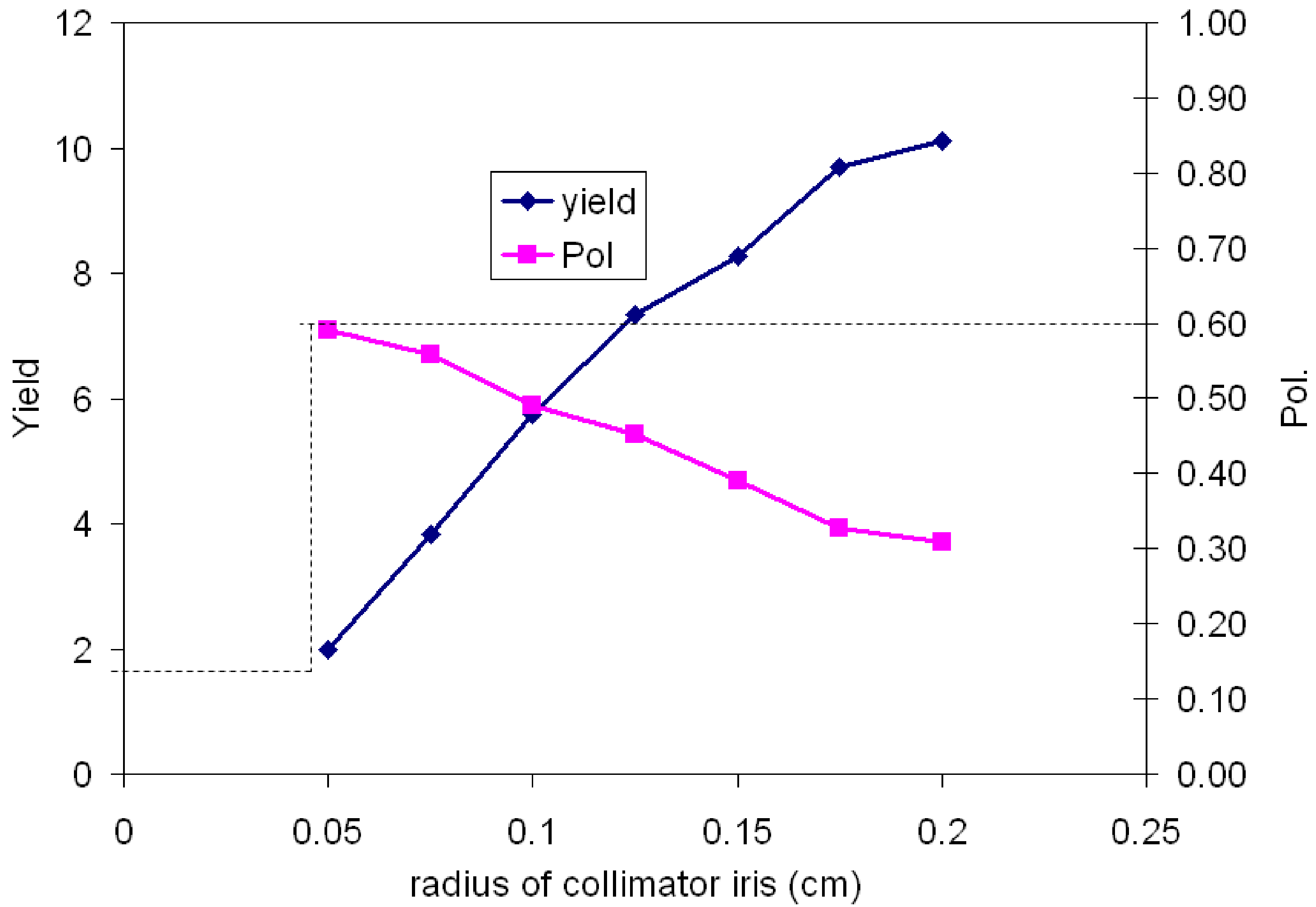
For 200GeV drive beam, 60% polarization required a photon collimator with an iris of ~1.1mm in radius. The corresponding yield is ~3 for 231m long undulator

Drive beam energy 225GeV, K=0.9,λu=0.9



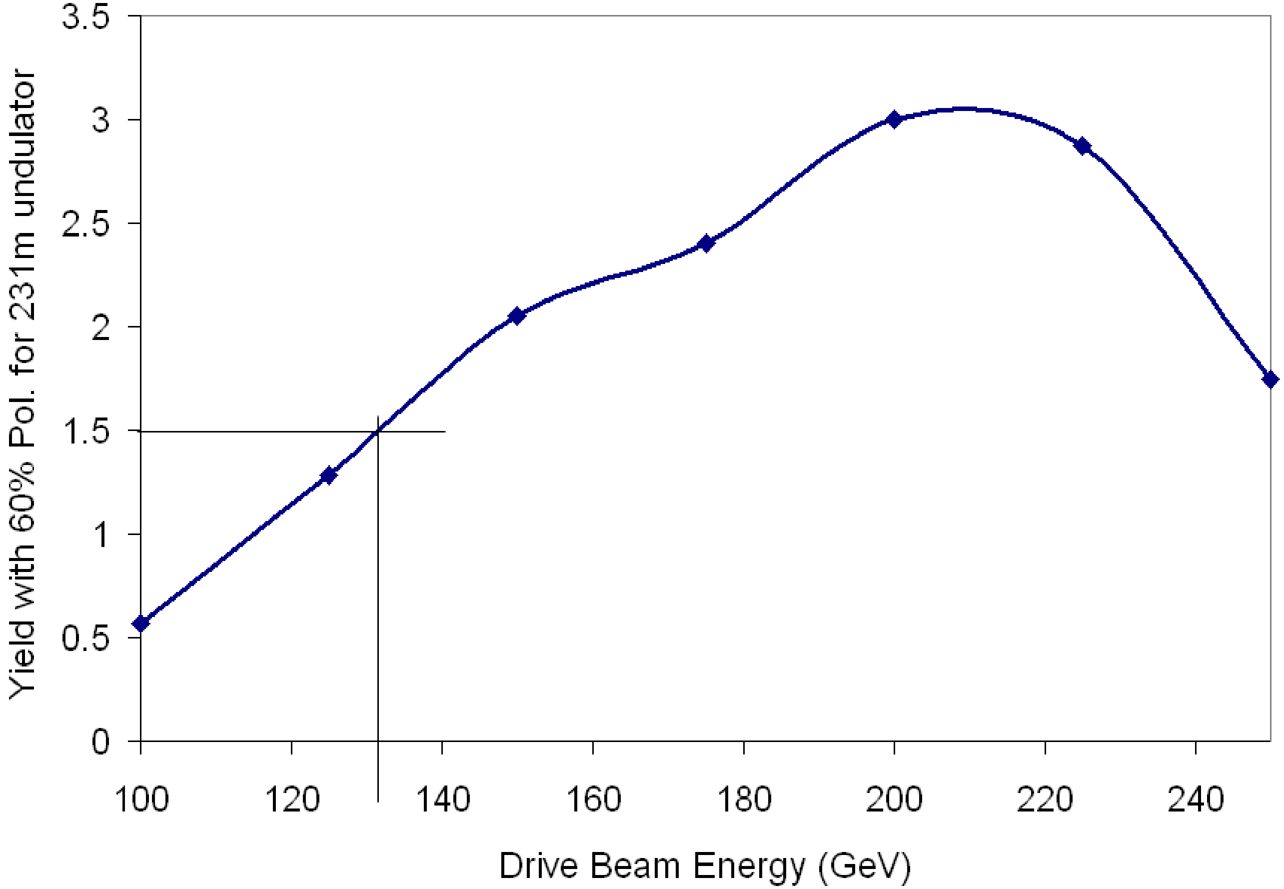
For 200GeV drive beam, 60% polarization required a photon collimator with an iris of ~0.75mm in radius. The corresponding yield is ~2.8 for 231m long undulator

Drive beam energy 250GeV, K=0.9,λu=0.9



For 250GeV drive beam, 60% polarization required a photon collimator with an iris of ~0.45mm in radius. The corresponding yield is ~1.75 for 231m long undulator

Yield with 60% Pol. As function of drive beam energy

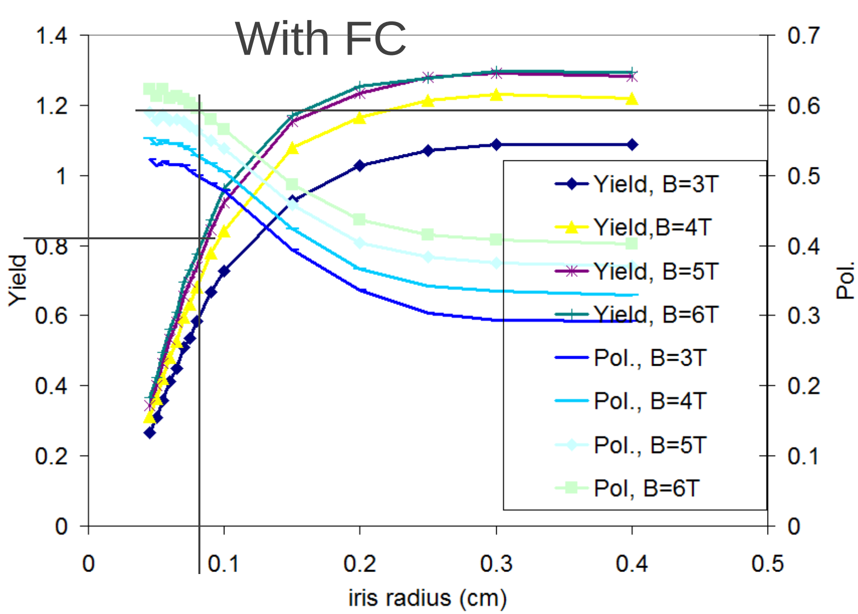


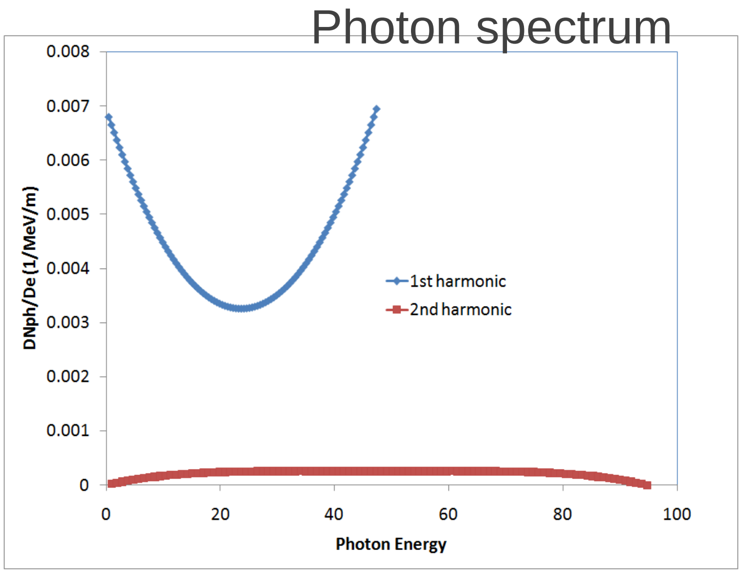
- With 231m long undulator with K=0.9, λu=0.9, 1.5 yield with 60% polarization can be achieved with drive beam energy of about 132GeV

Varying K for RDR undulator at the end of linac.

- Undulator: λu=1.15cm, K=0.3 – 0.9
- OMD:
  - FC, 0.5T ramp up to over B in 2cm and then adiabatically fall back to 0.5T at z=14cm, where B varied from 3T to 6T.
- Length of undulator 231m
- Target: 0.4X0 Ti target
- Drift from Undulator end to target: 400m
- Varying photon collimator iris.

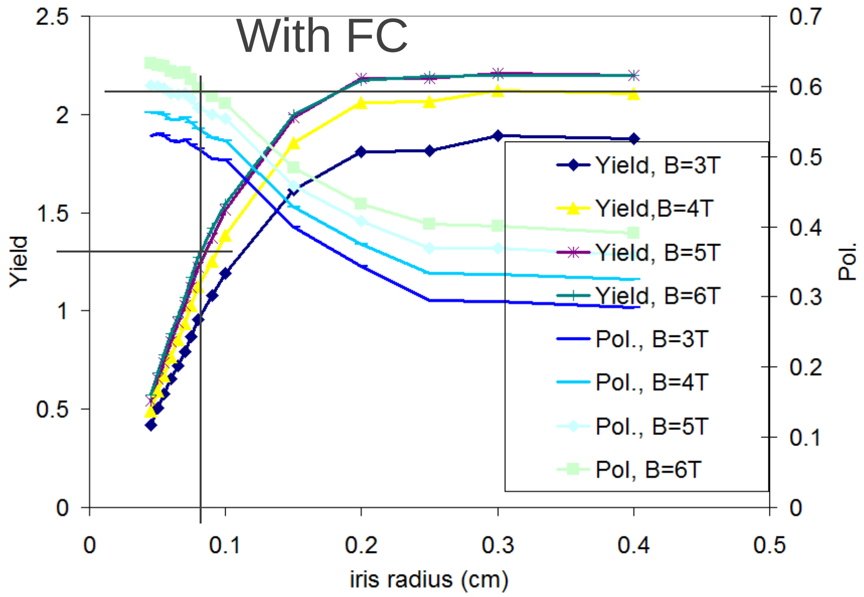
K=0.3, Drive beam energy 250GeV

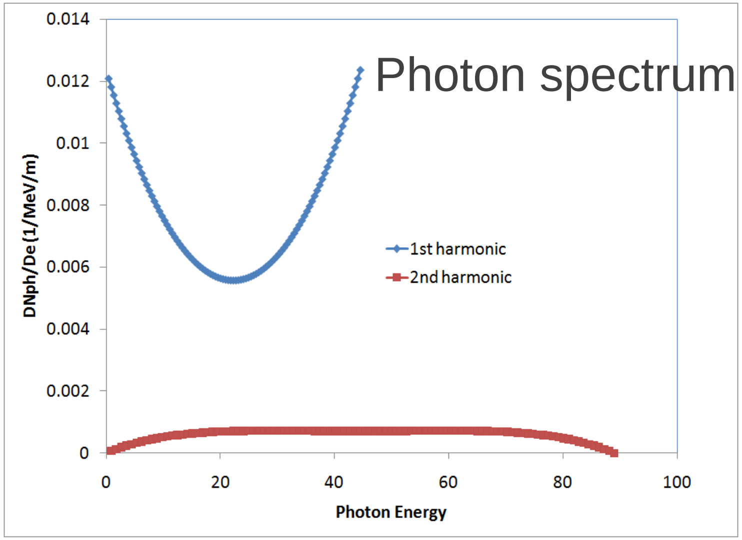




When K is 0.3, the total number of photon is small and also the photon from 2nd harmonic is very small comparing with 1st harmonic radiation. For 60% polarization, the positron yield is about 0.8.

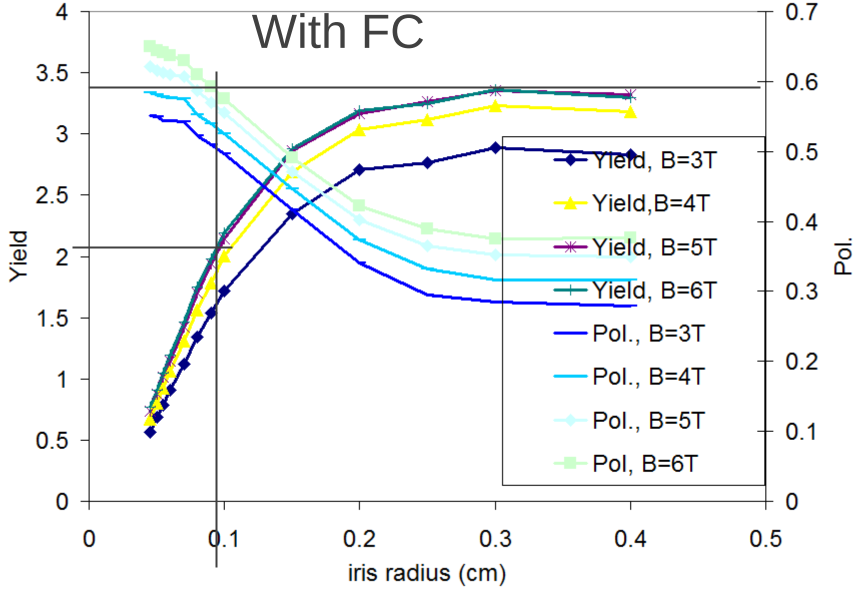
K=0.4, Drive beam energy 250GeV

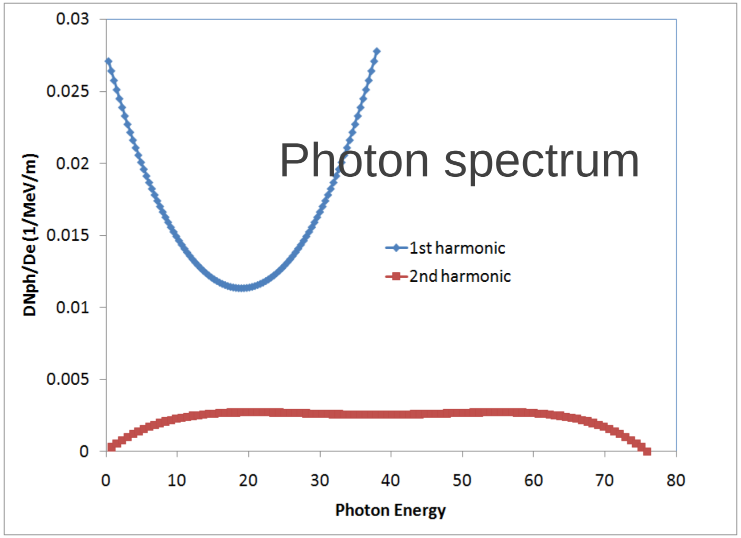




For 60% polarization, the positron yield is about 1.3

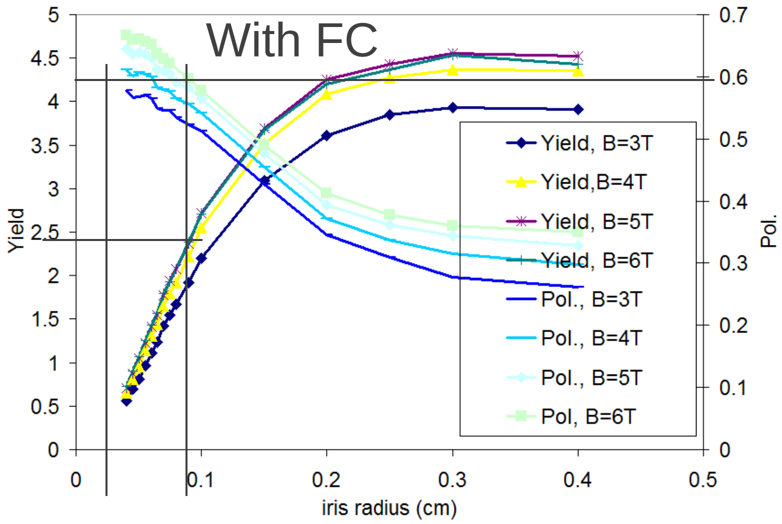
K=0.5, Drive beam energy 250GeV

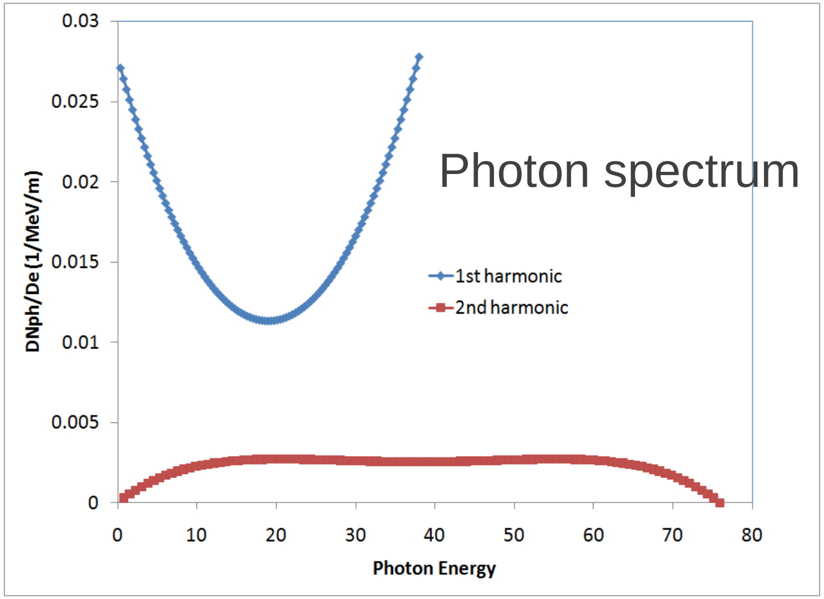




For 60% polarization, the positron yield is about 2.0

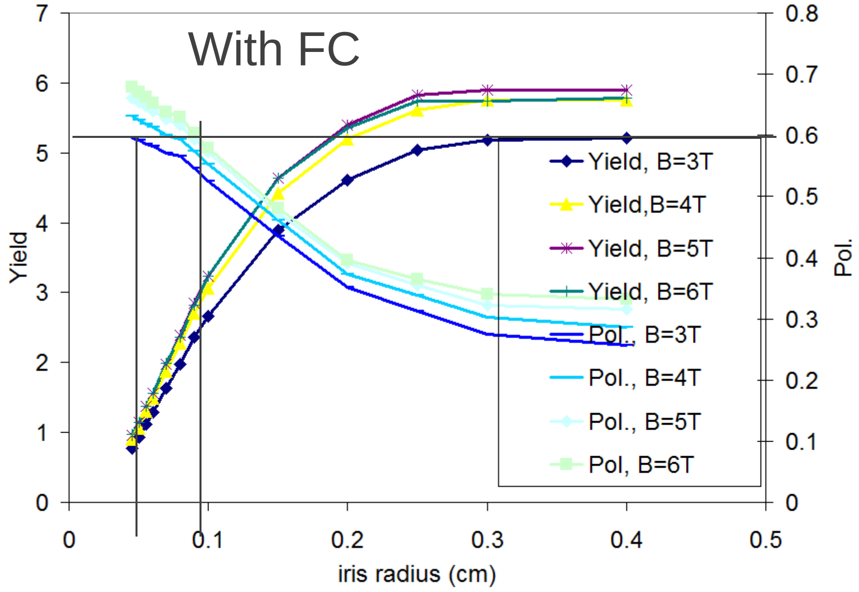
K=0.6, Drive beam energy 250GeV

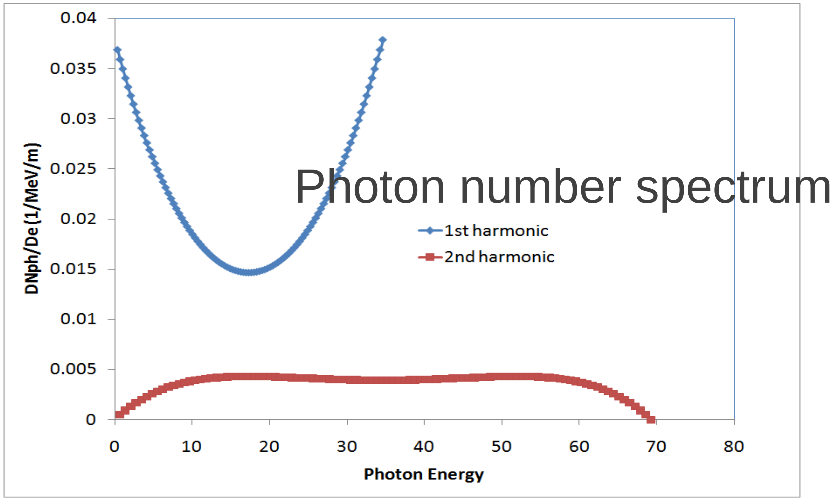




For 60% polarization, the positron yield is about 2.4

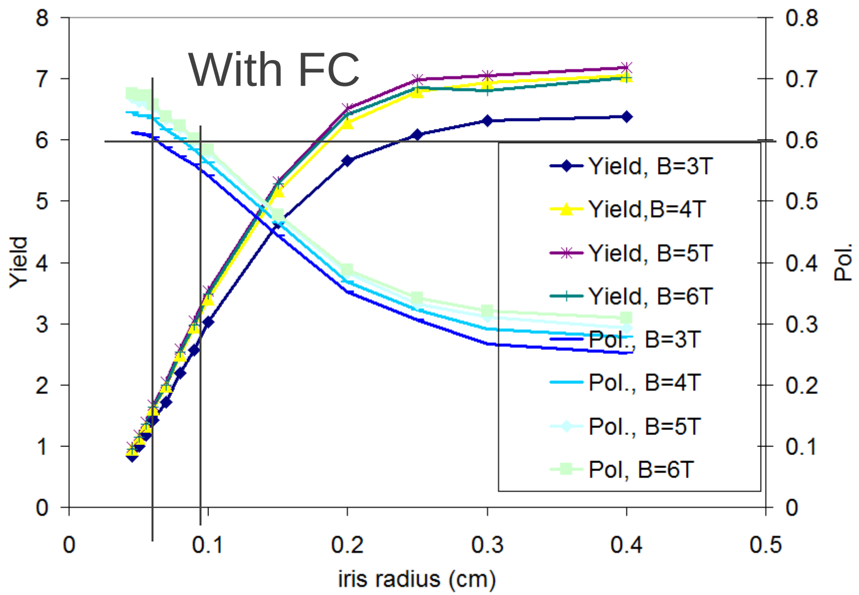
K=0.7, Drive beam energy 250GeV

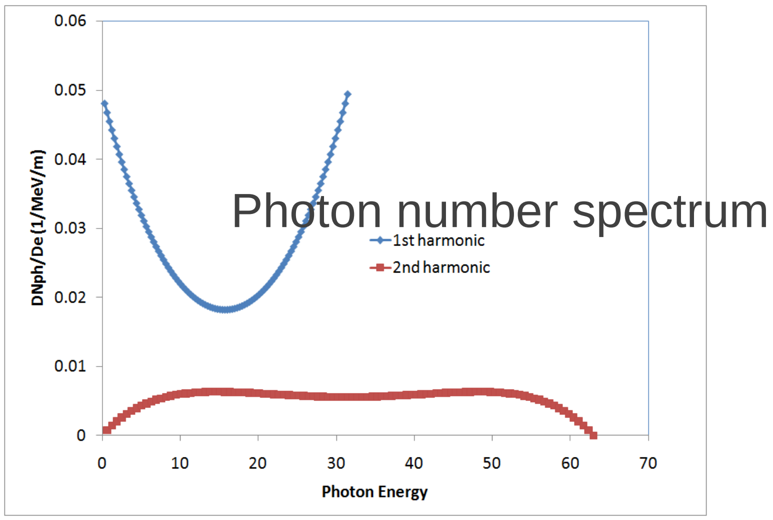




For 60% polarization, the positron yield is about 3.0 when strong FC is applied

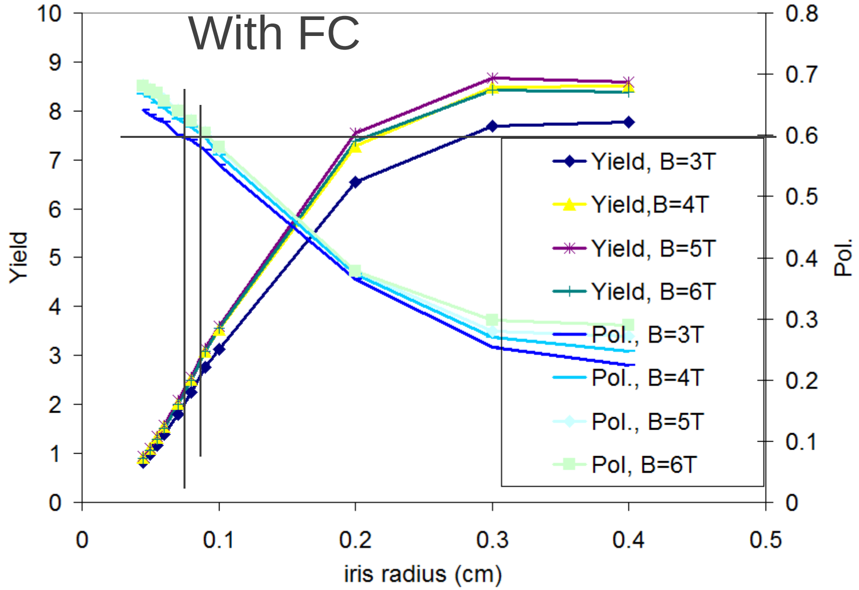
K=0.8, Drive beam energy 250GeV

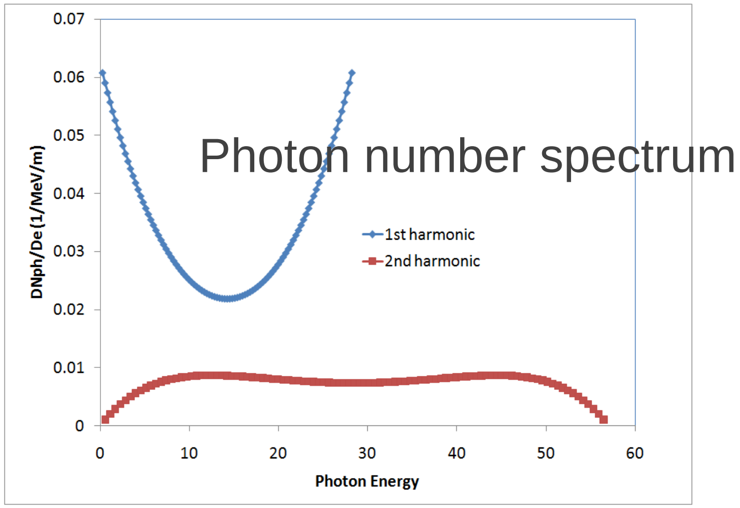




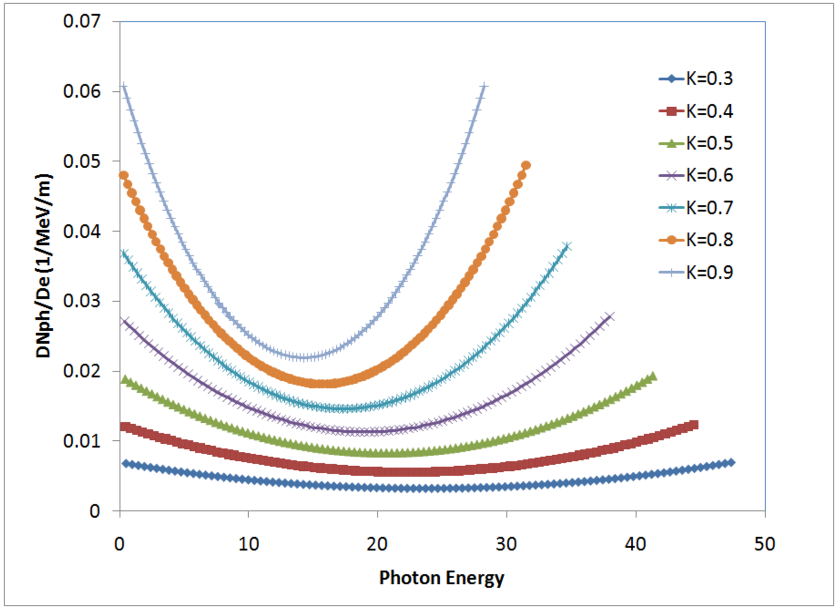
For 60% polarization, the positron yield is about 3.2 when strong FC is applied

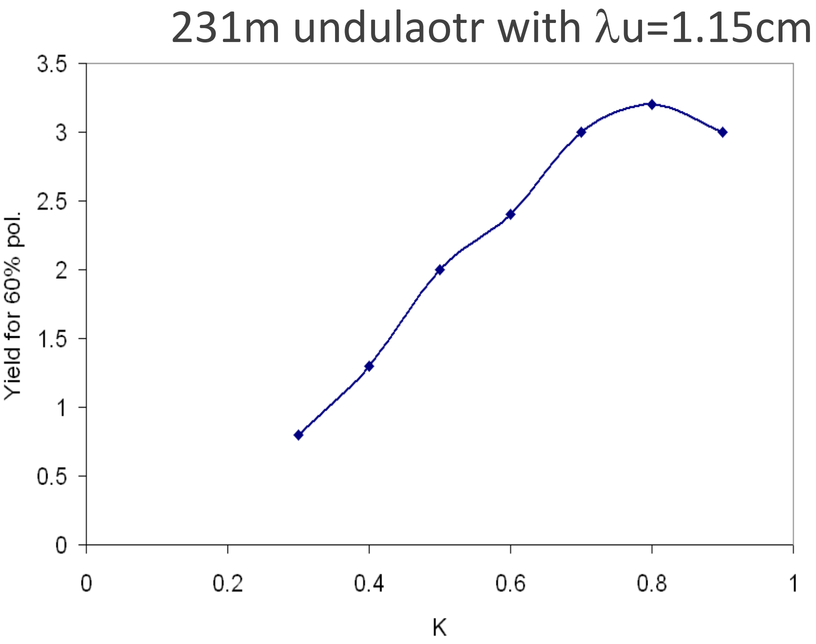
K=0.9, Drive beam energy 250GeV





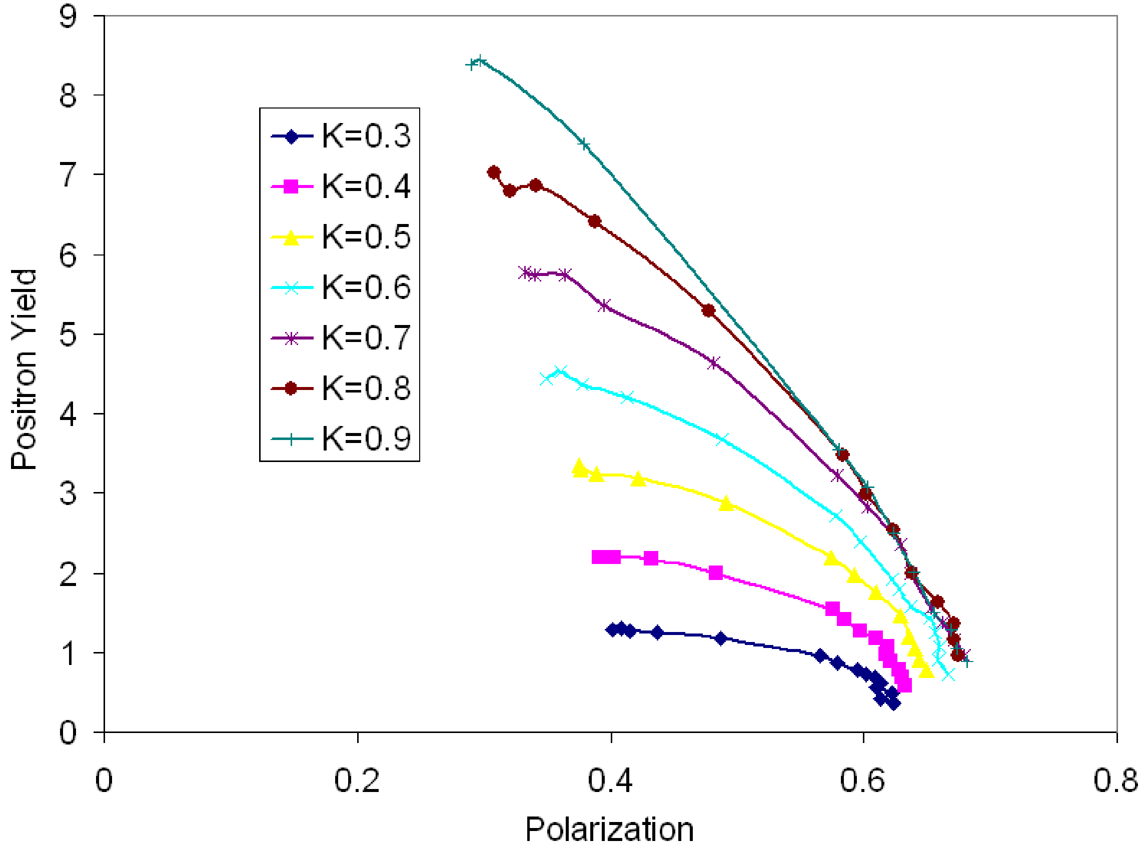
For 60% polarization, the positron yield is about 3 when a strong FC (peak over 6T) is applied. When a softer FC (peak about 3T) is applied, the 60% polarization has corresponding yield of about 2.0





- Disadvantage of Low K: increase the critical energy of photon of helical undlator radiations and lower the number of photon produced for a given length of undulator.
- Advantage of low K: lower high order harmonic radiation
- 1.5 yield with 60% polarization can be achieved by lowering K down to ~0.42 with strong FC

Yield vs Pol for fixed 250GeV drive beam
K varies, λu=1.15cm



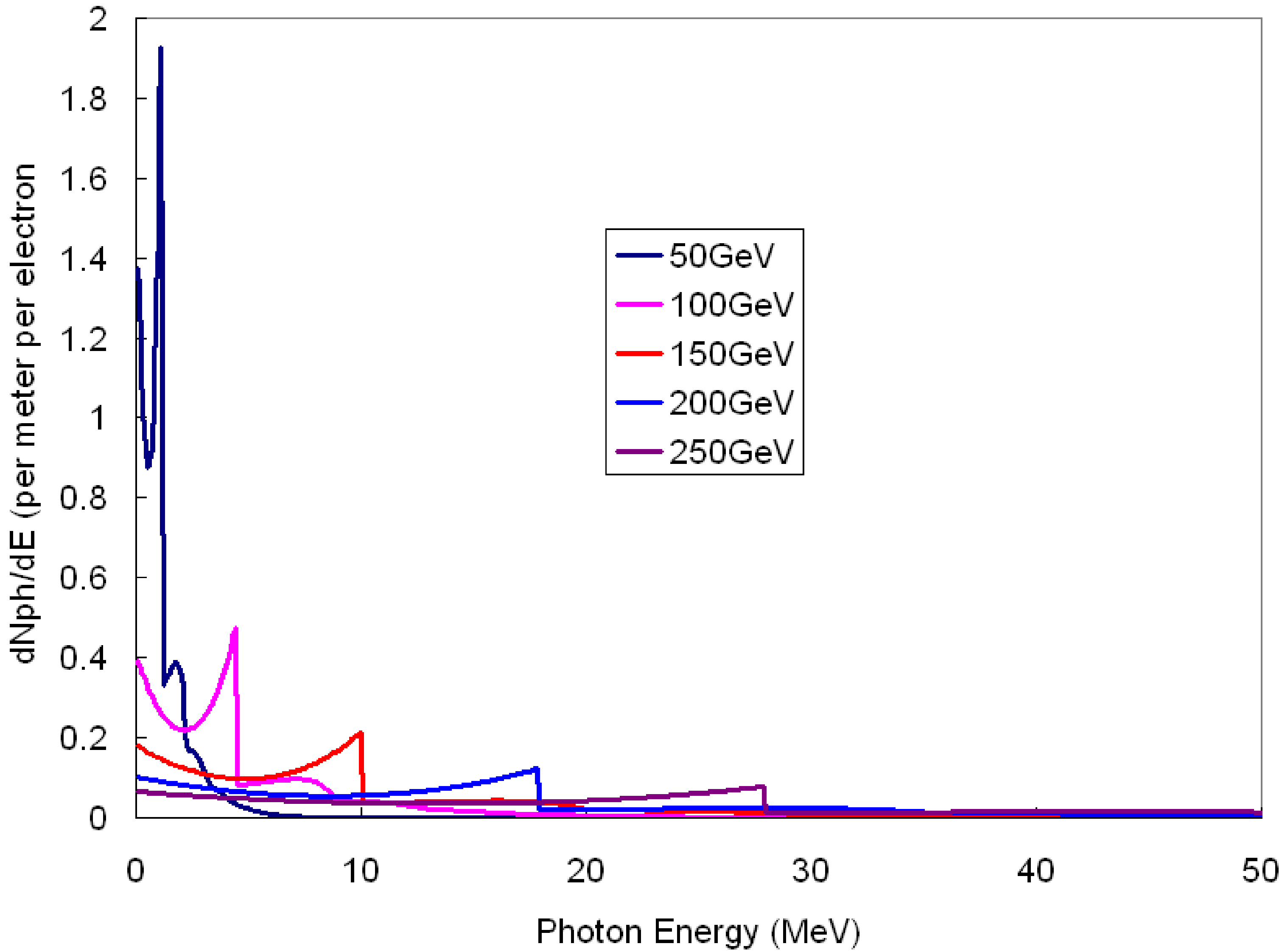
- For a fixed drive beam energy, and given requirement on polarization, higher K gives higher yield. Higher K also gives a higher achievable polarization.

RDR undulator, Quarter Wave Capturing

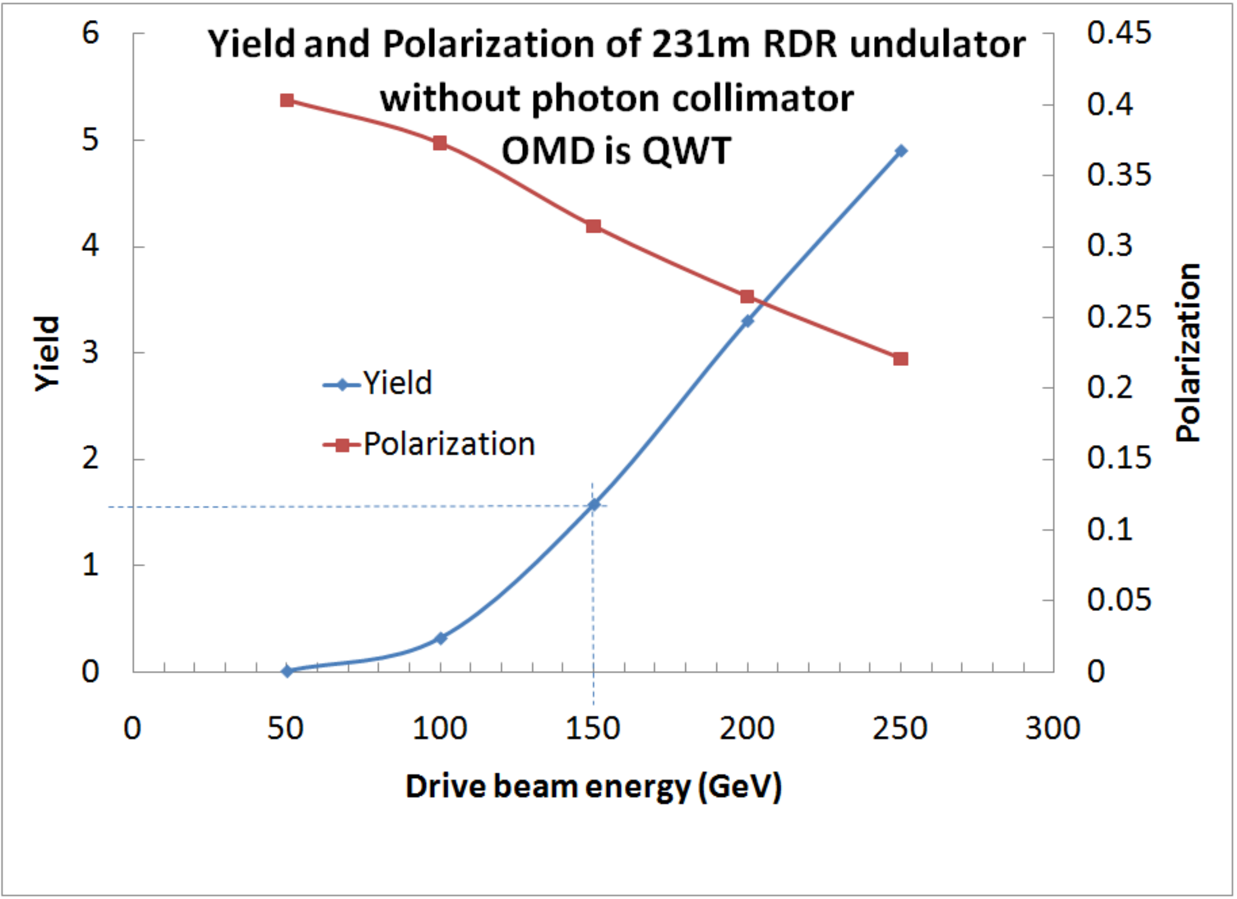
- Undulator: RDR undulator, K=0.92, λu=1.15cm
- Length of undulator: 231m
- Target to end of undulator:400m
- Target: 0.4X0, Ti
- Drive beam energies: 50GeV to 250GeV

- Mainly studied for different drive beam energies.

RDR undulator photon number spectrum



Drive beam energy dependents (no collimation)

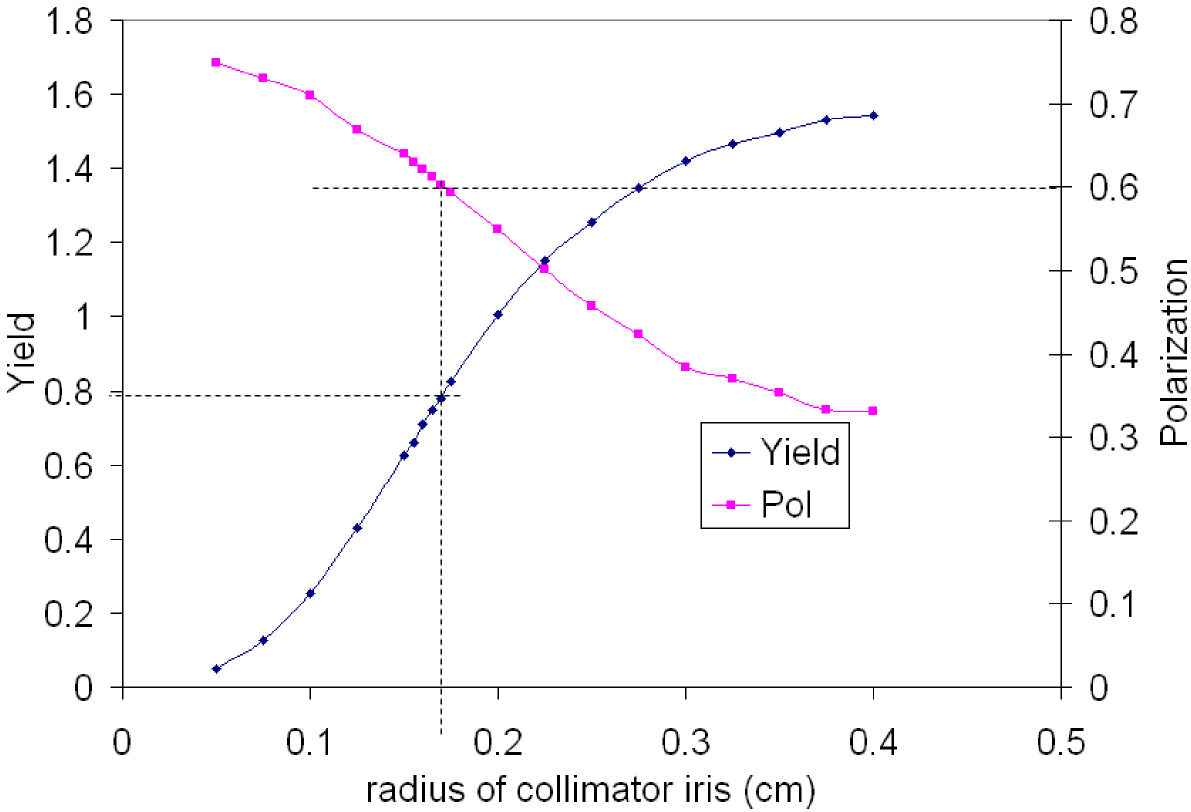


Drive beam energy	Energy lost per 100m	Energy lost for 1.5 yield
50GeV	~225MeV	N/A
100GeV	~900MeV	~9.9GeV
150GeV	~2GeV	~4.6GeV
200GeV	~3.6GeV	~3.7GeV
250GeV	~5.6GeV	~3.96GeV

Drive beam energy	Yield	Polarization
50GeV	0.0041	0.403
100GeV	0.3138	0.373
150GeV	1.572	0.314
200GeV	3.298	0.265
250GeV	4.898	0.221

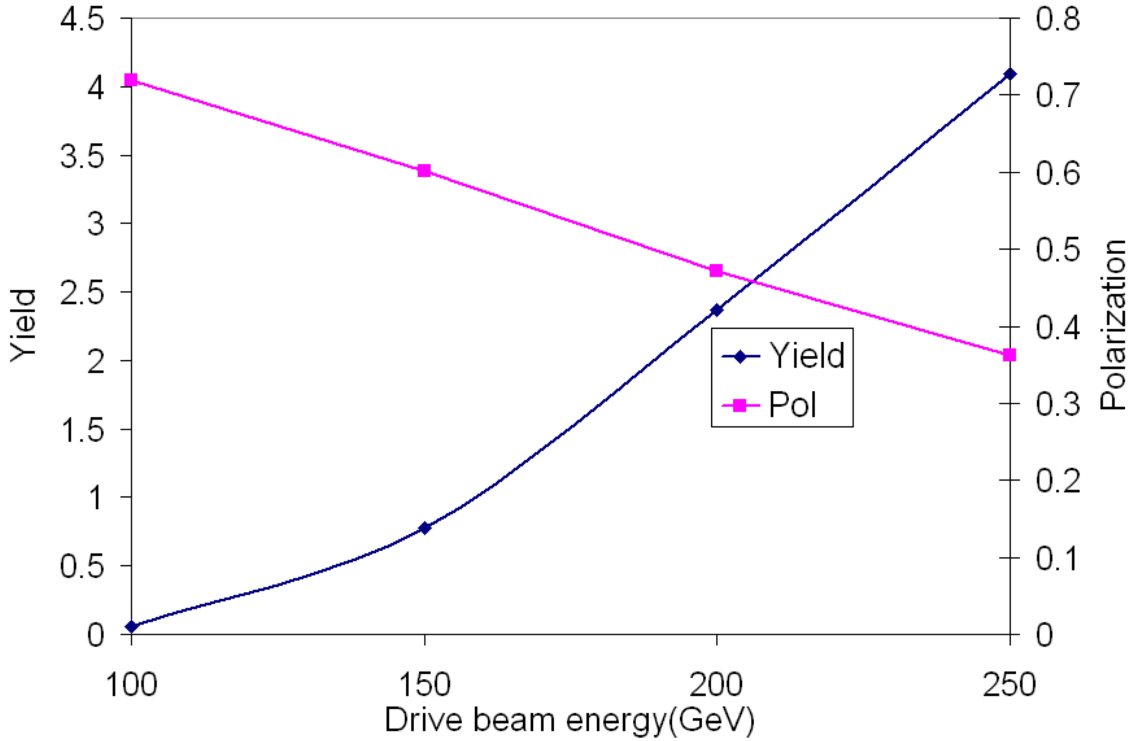
Collimator effects

231m RDR undulator, 150GeV drive beam, ¼ wave transformer



Drive beam energy	Energy lost per 100m	Energy lost for 1.5 yield and 60% polarization
150GeV	~2GeV	~8.8GeV

Drive beam energy dependent for a fixed collimator.



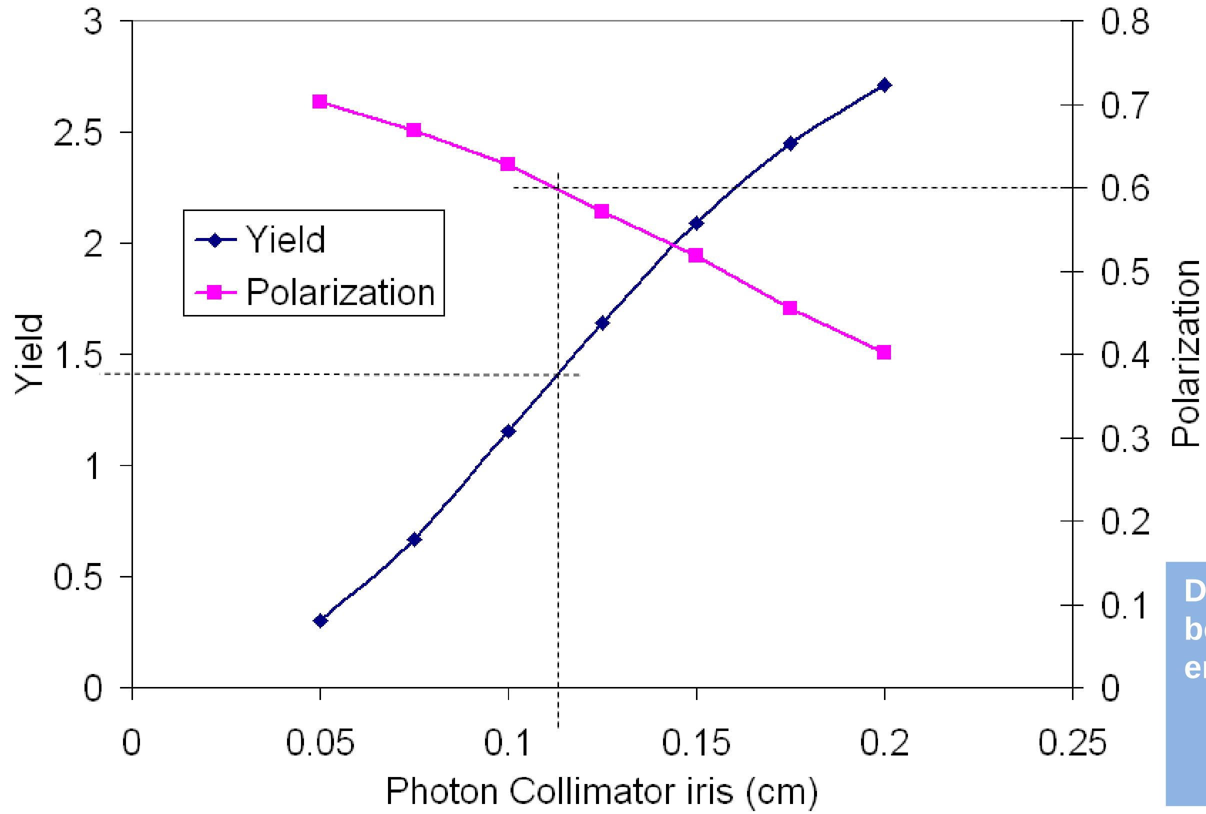
231m RDR undulator,
¼ wave transformer,
radius of collimator: 0.17cm

Drive beam energy	Energy lost per 100m	Energy lost for 1.5 yield
100GeV	~900MeV	N/A
150GeV	~2GeV	~8.9GeV
200GeV	~3.6GeV	~5.26GeV
250GeV	~5.6GeV	~4.7GeV

Drive beam energy	Yield	Polarization
100GeV	0.054	0.72
150GeV	0.78	0.60
200GeV	2.37	0.47
250GeV	4.09	0.36

Polarization dependents on Collimator for 200GeV drive beam energy

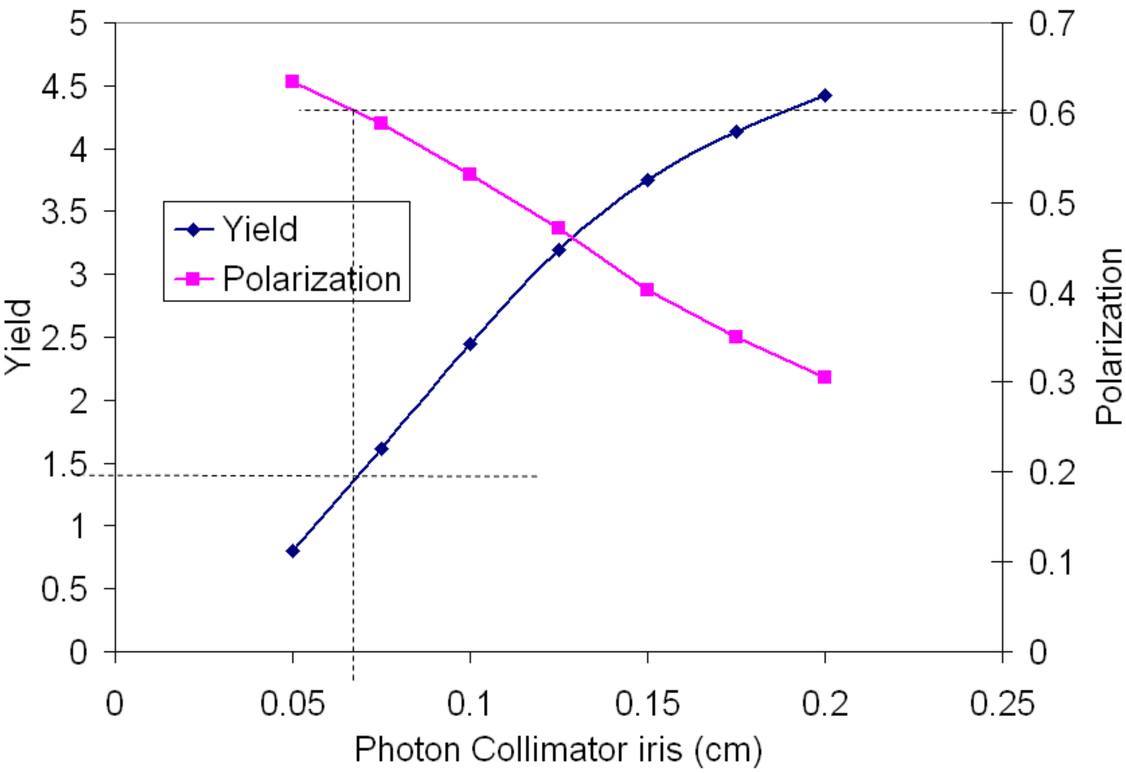
231 RDR undulator driving with 200GeV beam
OMD is QWT. Target is 0.4X0 Ti



Drive beam energy	Energy lost per 100m	Energy lost for 1.5 yield and 60% polarization
200GeV	~3.6GeV	~9.24GeV

Polarization dependents on Collimator for 250GeV drive beam energy

231 RDR undulator driving with 250GeV beam
OMD is QWT. Target is 0.4X0 Ti



Drive beam energy	Energy lost per 100m	Energy lost for 1.5 yield and 60% polarizatio n
250GeV	~5.6GeV	~13.8GeV

Summary

- For undulator with K=0.9 and λu=0.9cm, 60% polarization and 1.5 yield, can be achieved with 125GeV drive beam, a photon collimator of ~2.1mm and ~270m long of such undulator.
- For RDR undulator, yield of 1.5 with 60% polarization can be achieved with 150GeV, a photon collimator of ~1.6mm and ~300m long RDR undulator.
- For end of linac operation, 60% polarization for all scenario will require changing of photon collimator iris.
- For a fixed drive beam energy, and given requirement on polarization, higher K gives higher yield. Higher K also gives a higher achievable polarization because it makes the photon collimation easier.
- For a given undulator parameter, and a given required polarization, the yield increase with drive beam energy with the penalty of more challenge to the photon collimator design. As a result, higher drive beam energy will have a lower achievable polarization.
- One may ague that lower K will have a smaller contents of high order harmonics and would thus helps on the polarization. But it is not the case. Lower K leads to a sharper cone of radiation and will increase the difficulty in photon collimation. Lower K will also leads to a smaller number of photon radiation for a given length of undulator and thus requires a much long undulator.