THE PHOTON BEAM FOR E159, E160, AND E161

Overview

- Why Coherent Bremsstrahlung
- How Coherent Bremsstrahlung Works
- Flux and Polarization (E159 example)
- Equipment Needed

OVERVIEW OF E159, E160, E161

- A cohesive program of three photoproduction experiments.
- Same coherent bremsstrahlung photon facility needed for all three.
- Same photon beam equipment except for equipment used to measure circular polarization: covered in individual talks.
- E159 and E161 use same polarized target facility.
- E160 and E161 use same large dipole magnet facility.
- Detector, Electronics arrangements very similar, especially E160 and E161.
- Running all three experiments maximizes physics output for investment needed.

WHY COHERENT BREMSSTRAHLUNG

GOAL

High flux of mono-energetic circularly polarized photons.

DRAWBACKS OF ALTERNATIVES

- Incoherent Bremsstrahlung Flux $\Phi \approx dk/k$ gives large rate of low energy photons.
- Bremsstrahlung Difference (changing end-point energy) gives larger statistical and systematic errors than Coherent Bremsstrahlung
- Backscattered laser beam was carefully studied: intensities too low due to emittance growth in A-line.
- Photon tagging rates too low due to 10^{-4} duty cycle.

CONCLUDE:

- Coherent Bremsstrahlung only good solution.
- Has been done previously in E.S.A. and currently used at labs such as Mainz.
- Figure of Merit increases with beam energy: good for 50 GeV electron beam.
- Stable, proven method which will give beam parameters needed by proposals.

OVERVIEW OF COHERENT BREMSSTRAHLUNG

- Momentum transfer q very small. Minimum momentum transfer given by:

  $$\delta = y/2E(1-y)$$

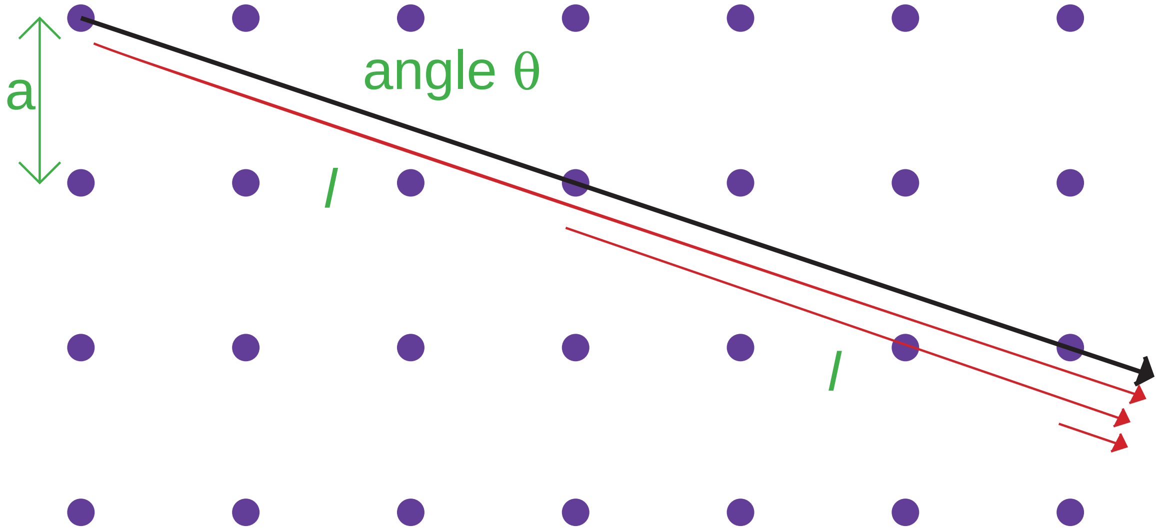
  where $y = k/E$, k is photon energy, E is electron energy (in electron mass units).

- Classical argument based on electron traveling slightly slower than photon. $\Delta l = l(1-\beta)/\beta$, where $l = a/\theta$ is distance between two lattice rows with spacing a and an electron angle θ.

- For coherence, want $\Delta l = n\lambda$, where $\lambda = 2\pi/k$ is wavelength of photon. Combining, we find

  $$n(2\pi/a) = \delta/\theta$$

  $$\theta = \frac{y}{2E(1-y)}\frac{a}{n2\pi}$$



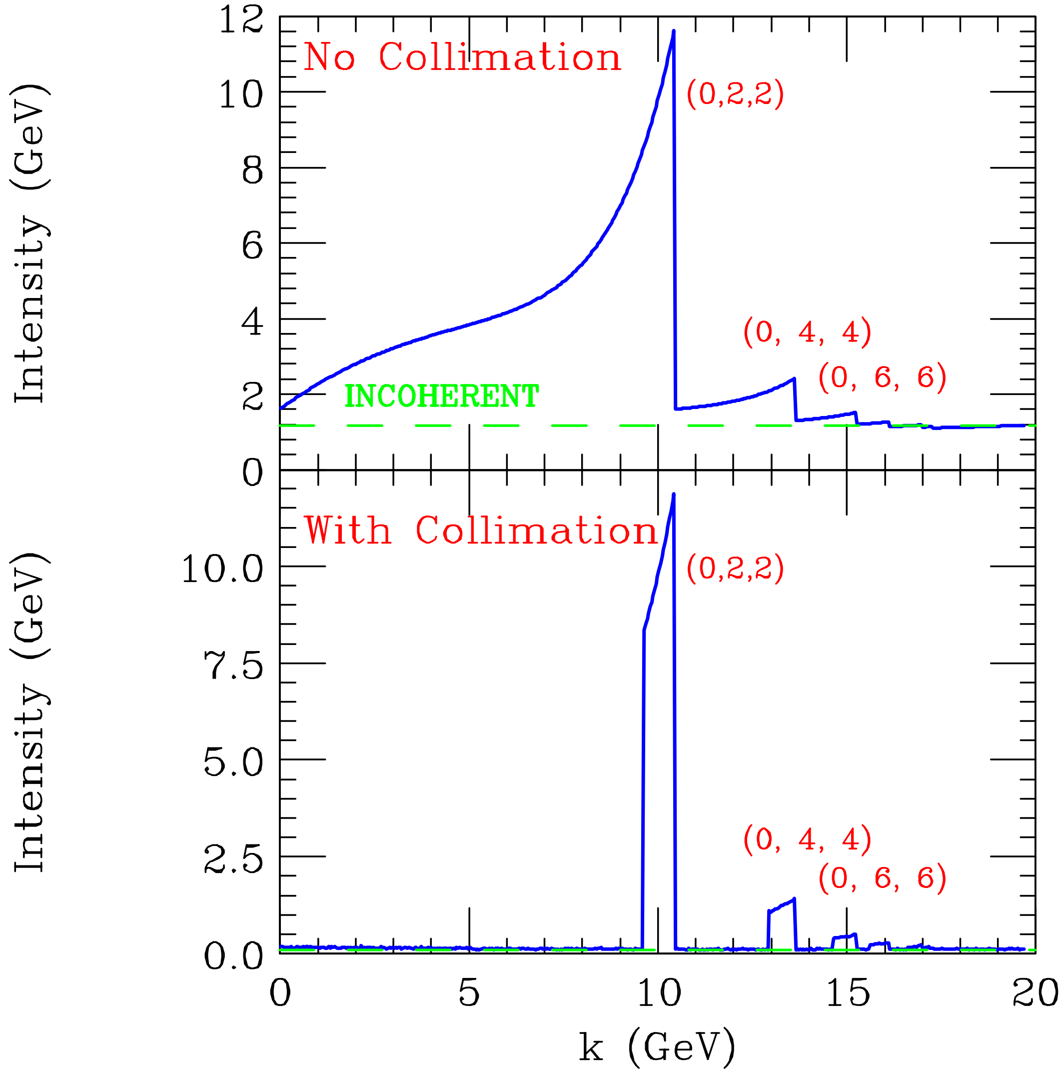
photon waves, velocity=1.
Want to be in phase.

electron, velocity=β.
Lag by one photon wavelength over distance a/θ

OVERVIEW, continued

- Exact quantum mechanical treatment yields same result. Usually crystal described in reciprocal lattice basis $1/a$.
- Ideal crystal: tight lattice (small a), low Z, high Debeye temperature, low mosaic spread. Diamond best choice by far.
- Incoherent bremsstrahlung has continuous angular distribution, independent of k characterized by m_e/E. Coherent radiation very tightly collimated along electron direction at peak intensities; angles grow as photon energy drops below coherence conditions (and intensity drops also).
- Collimation at angle $O(m_e/E)$ enhances coherent/incoherent ratio.

COLLIMATION



Effect of collimation in ideal case (no multiple scattering, mosaic spread, beam emittance).

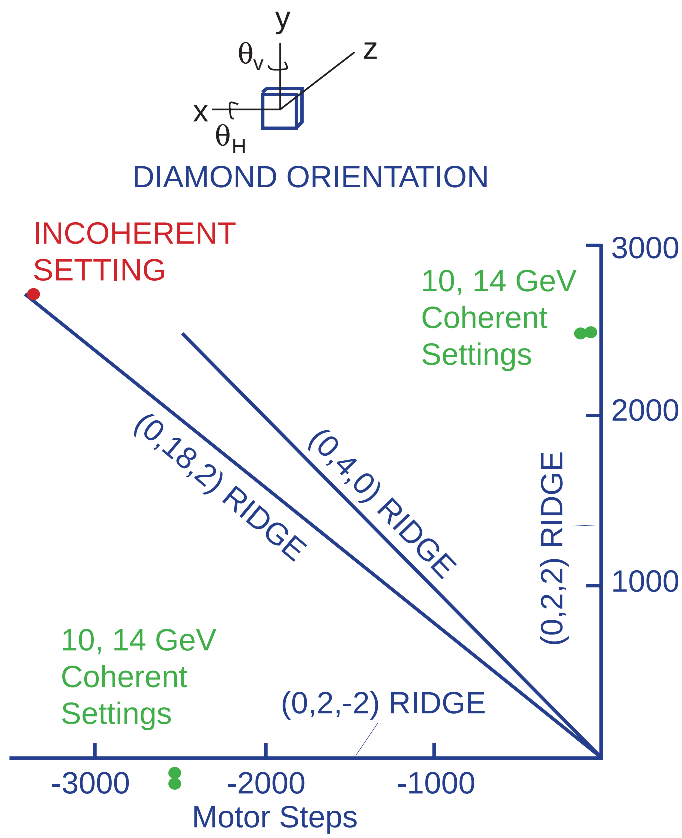
CALCULATIONS

- Use same diamond orientation as SLAC E78 [W. Kaune et al., Phys. Rev. D11, 478 (1975)].: coherent peaks at (0,2,2), (0,4,4), (0,6,6), (0,8,8) etc.
- Rotate crystal with goniometer to angle so primary (0,2,2) peak is at desired photon energy k (0.2 to 0.5 mr typical).
- Simulate electrons with realistic position/angle correlations, assuming beam focused to smallest possible waist at collimator position.
- Effects of multiple scattering in radiator, energy dependence of beam emittance taken into account.

- Include mosaic spread of 0.1 mr typical of good diamond.
- Formulas from review of G. Diambrini Palazzi, Rev. Mod. Phys. 40, 611 (1968).
- Monte Carlo method used to generate large sample of photons. Those hitting collimator are tossed.
- Calculation checked by Yerevan group (experts in this field).

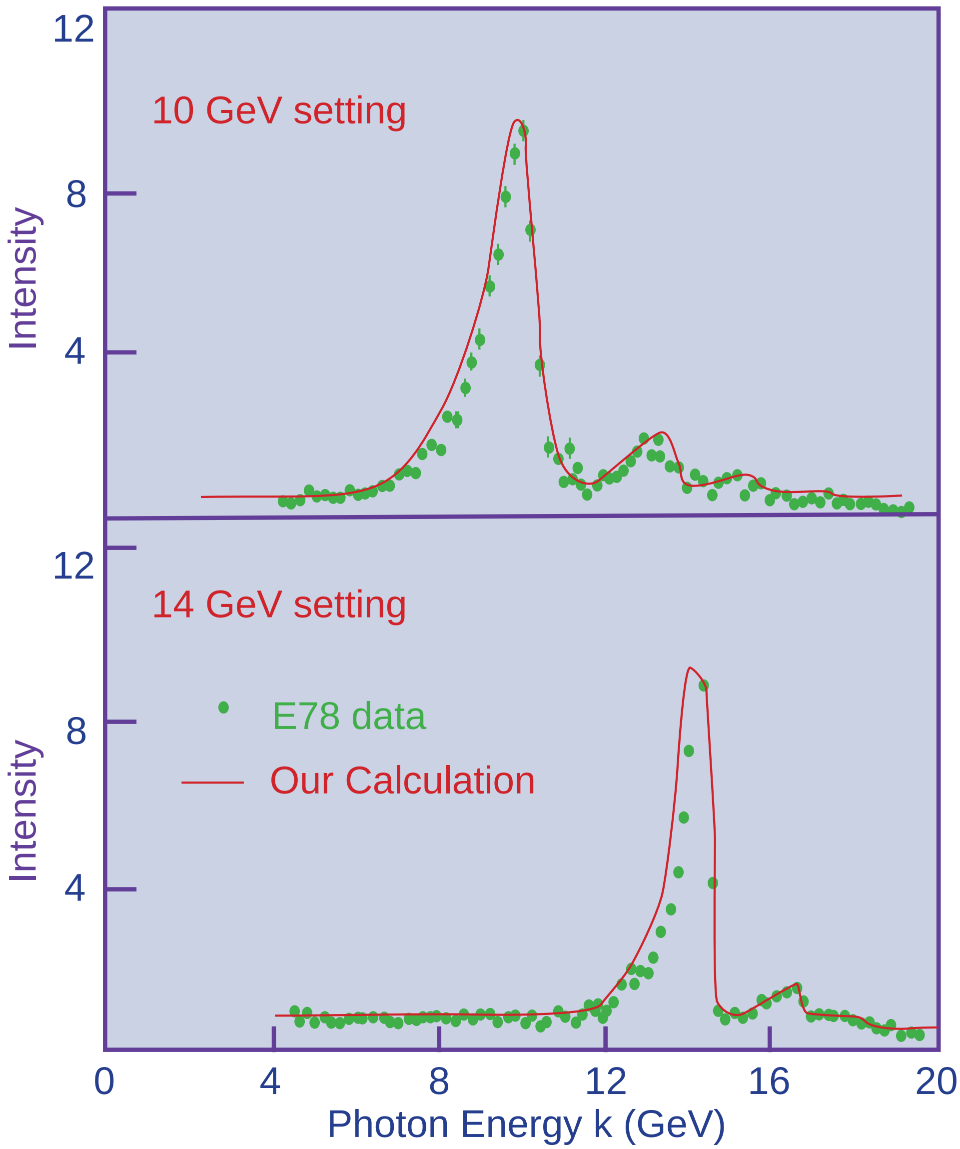
DIAMOND ORIENTATIONS USED IN E78

- Distance from (0,2,2) ridge determines energy of primary spike.
- (0,2,2) and (0,2,-2) ridges used to rotate linear polarization by 90 degrees.
- Incoherent setting had small contamination from (0,18,2) and (0,4,0) ridges.



COMPARISON OF OUR CALCULATIONS WITH E78 MEASURED SPECTRA

Actual spectra slightly narrower: mosaic spread and/or beam emittance? Electron beam energy was 19.7 GeV.

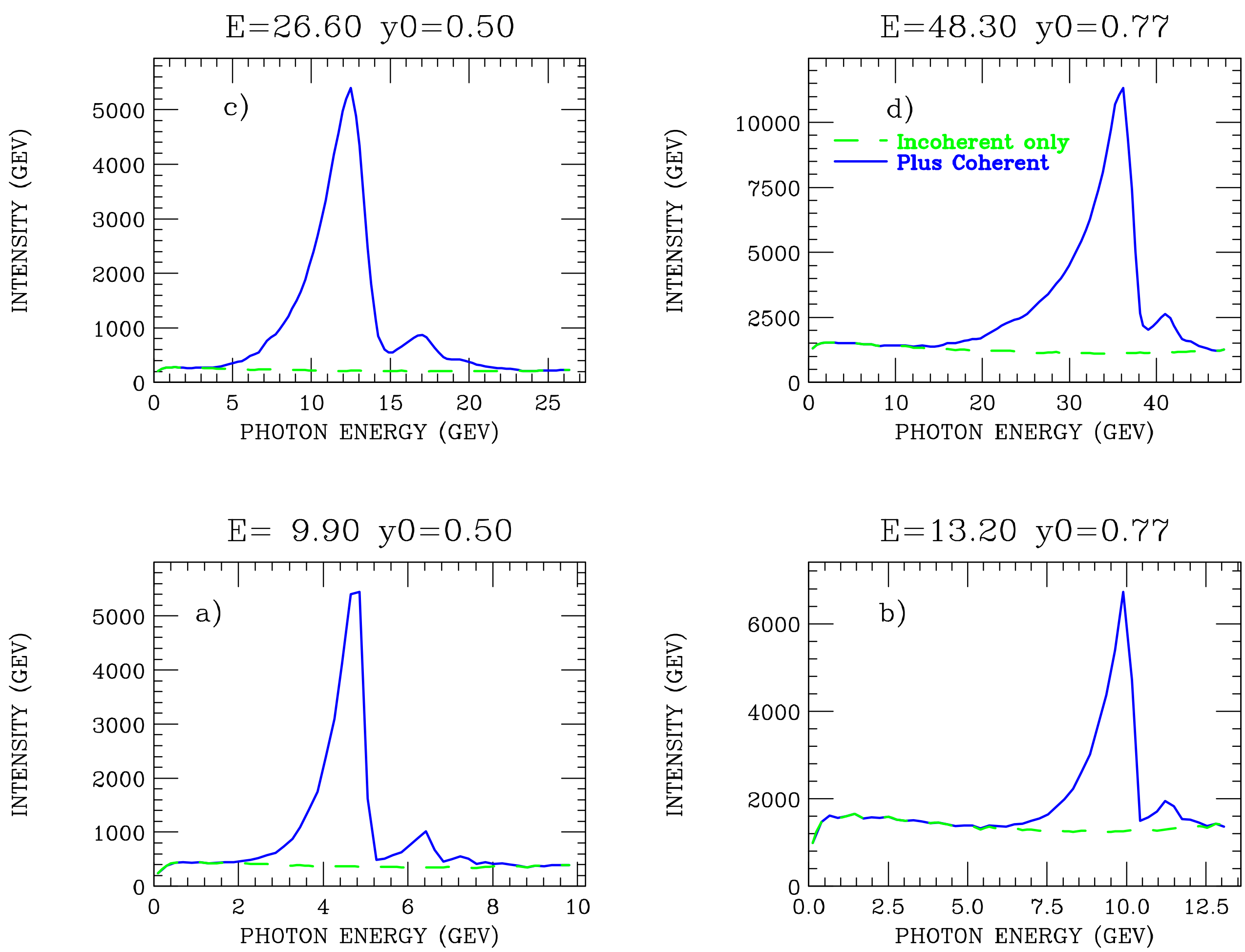


CALCULATED SPECTRA FOR E159, E160, E161

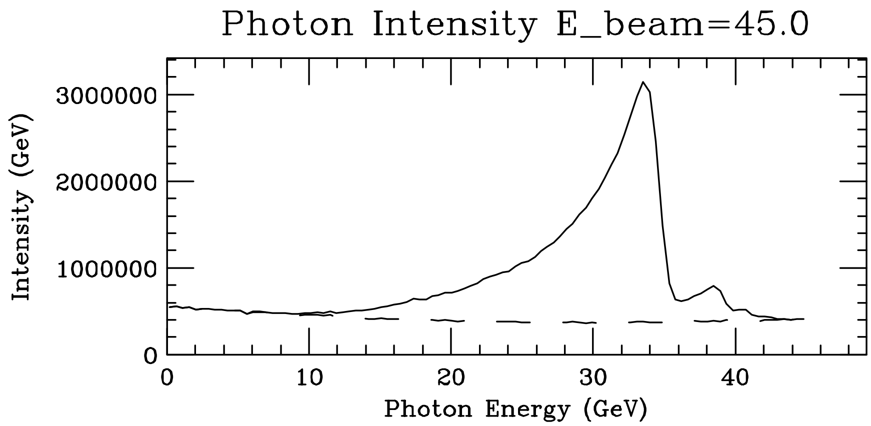
Experiment	Photon Energies	Photons/Spill	Polarization
E159	4 to 40 GeV	10^5 to 10^7	yes
E160	15, 25, 35 GeV	$< 10^7$	no
E161	35, 40, 45 GeV	$< 10^7$	yes

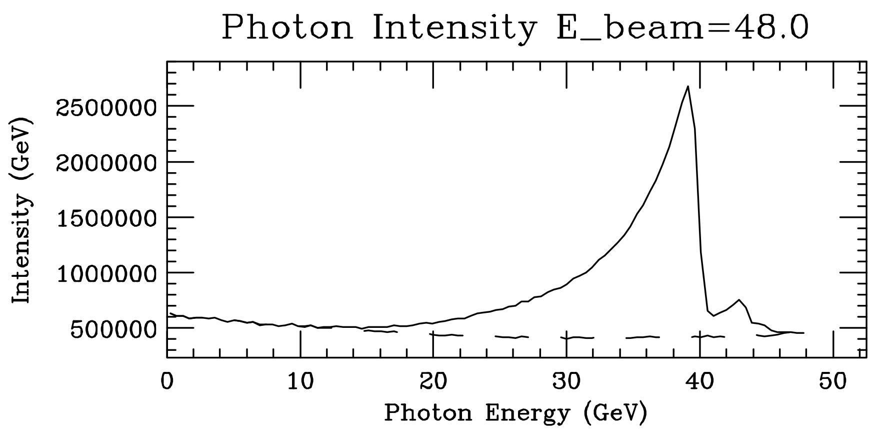
- Limit current to about 3×10^{10} e-/spill to avoid breaking diamonds, limit radiation damage.
- Can use tight collimation, thin diamond when high flux not needed.
- Primary peak position (k/E) tradeoff between maximum beam energy, photon polarization, and flux.
- Lower k/E gives better coherent/incoherent ratio for given k, but polarization is lower.
- Higher k/E reduces effect of higher energy spikes ie. (0,4,4).

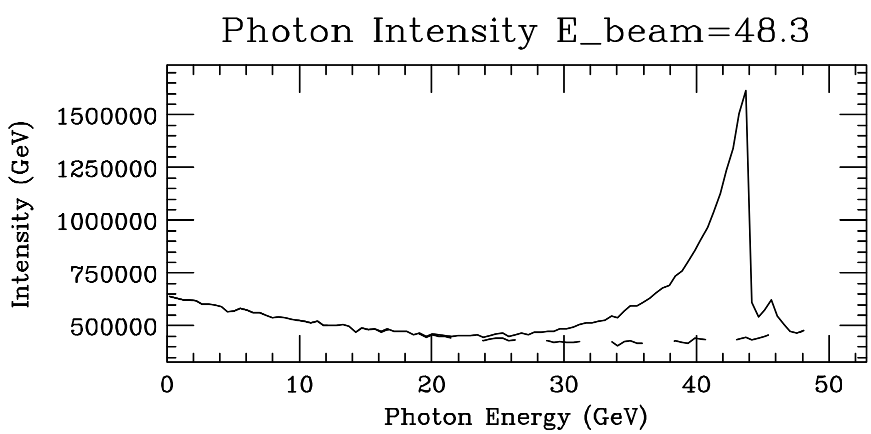
REPRESENTATIVE SPECTRA FOR E159



INTENSITY SPECTRA FOR E161







PHOTON POLARIZATION

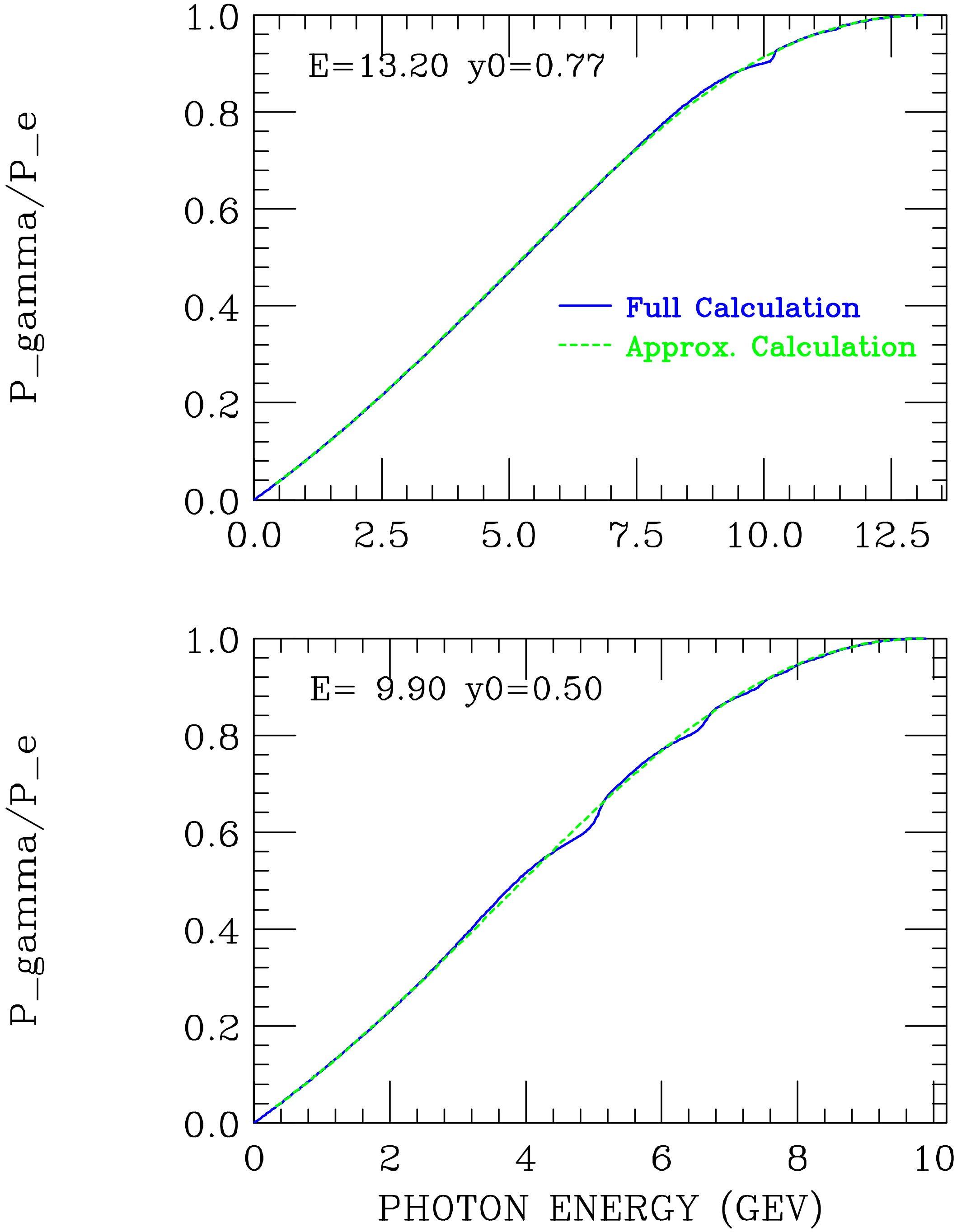
Photon circular polarization in crystals calculated I. M. Nadzhafov, Bull. Acad. Sci. USSR, Phys. Ser. Vol. 14, No. 10, p. 2248 (1976).

- For large k, almost same for coherent and incoherent:

$$P_\gamma = P_e \frac{1-(1-y)^2 - \frac{2}{3}y(1-y)}{1+(1-y)^2 - \frac{2}{3}(1-y)}$$

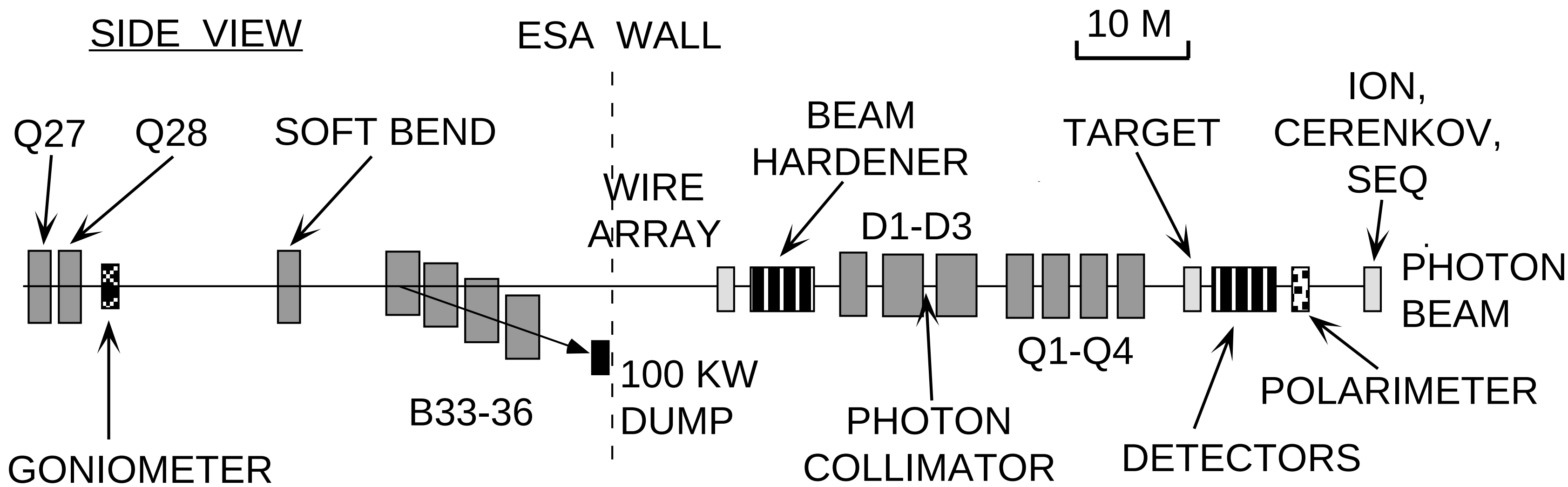
- where $y = k/E$
- Full calculation shows small dips at coherent peaks due to linear polarization component (final polarization is elliptical).
- Typical linear polarization is 0.1 to 0.4, given very approximately by $(1-y)$. Effect cancels due to azimuthal symmetry of detectors in all experiments. Cancels again in spin asymmetries due to random helicity flip of longitudinally polarized electron beam.

PHOTON CIRCULAR POLARIZATION



BEAM LINE OVERVIEW

- Goniometer
- Sweeping magnets to dump electron beam
- Beam dump
- Hardener
- Collimator and position monitors
- Polarimeter (see E159 presentation)
- Flux and intensity measuring devices

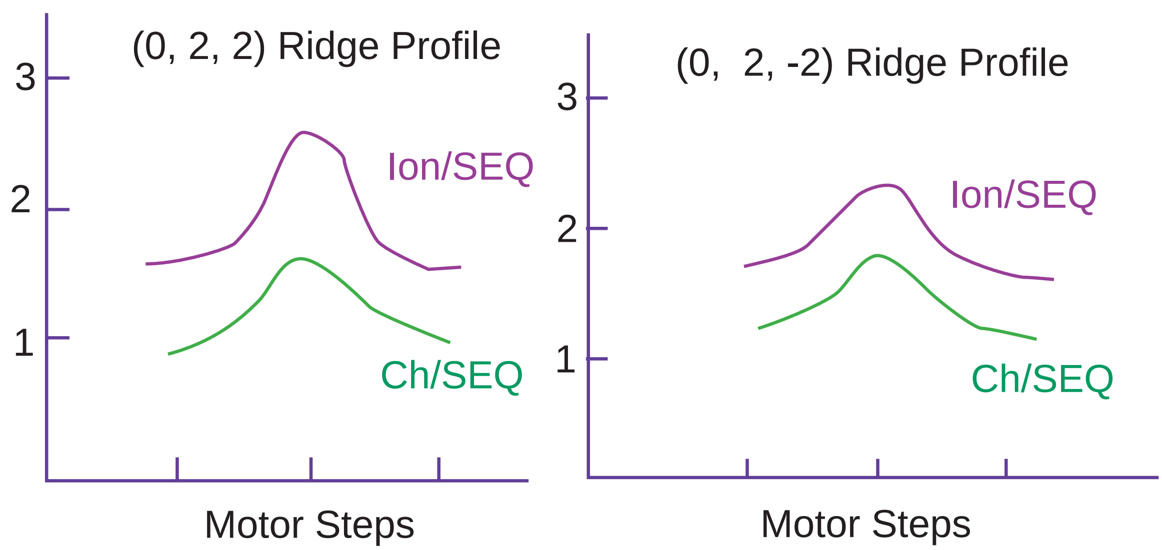

SIDE VIEW
ESA WALL
10 M
Q27
Q28
SOFT BEND
WIRE ARRAY
BEAM HARDENER
D1-D3
TARGET
ION, CERENKOV, SEQ
PHOTON BEAM
GONIOMETER
B33-36
100 KW DUMP
PHOTON COLLIMATOR
Q1-Q4
DETECTORS
POLARIMETER

GONIOMETER

- Device to accurately position diamonds. Angles fixed in 25 μr steps.
- Commissioned by Roy Schwitters, SLAC-TN-70-32 (1970).
- Still available for use. Can hold two crystals.
- To be re-installed downstream Q27/Q28 quad pair as in SLAC E78.
- Have checked desired optics can be obtained without Q30 and Q38.
- Diamonds from E78 still available? Yerevan group can provide more.
- Will obtain supply of very thin diamonds with lowest possible mosaic spread.

CALIBRATION OF GONIOMETER

- Was done by scanning across the (0,2,2) [or (0,2,-2)] ridge profile.
- Ratio of flux (Ion chamber or Cherenkov) to Intensity (SEQ) is maximum when energy of main spike passes through zero.



ELECTRON DEFLECTION TO DUMP

- Deflection by 12 degrees into 2 MW dump not practical with 50 GeV beam (was designed for 20 GeV), and dump in poor condition in any case.
- Will deflect beam by about 6 degrees instead.
- Existing magnets B33-B36 will be refurbished and extra coils added (as per original design) to increase bending power by about 40%.
- Some spare coils exist; some new ones must be wound.

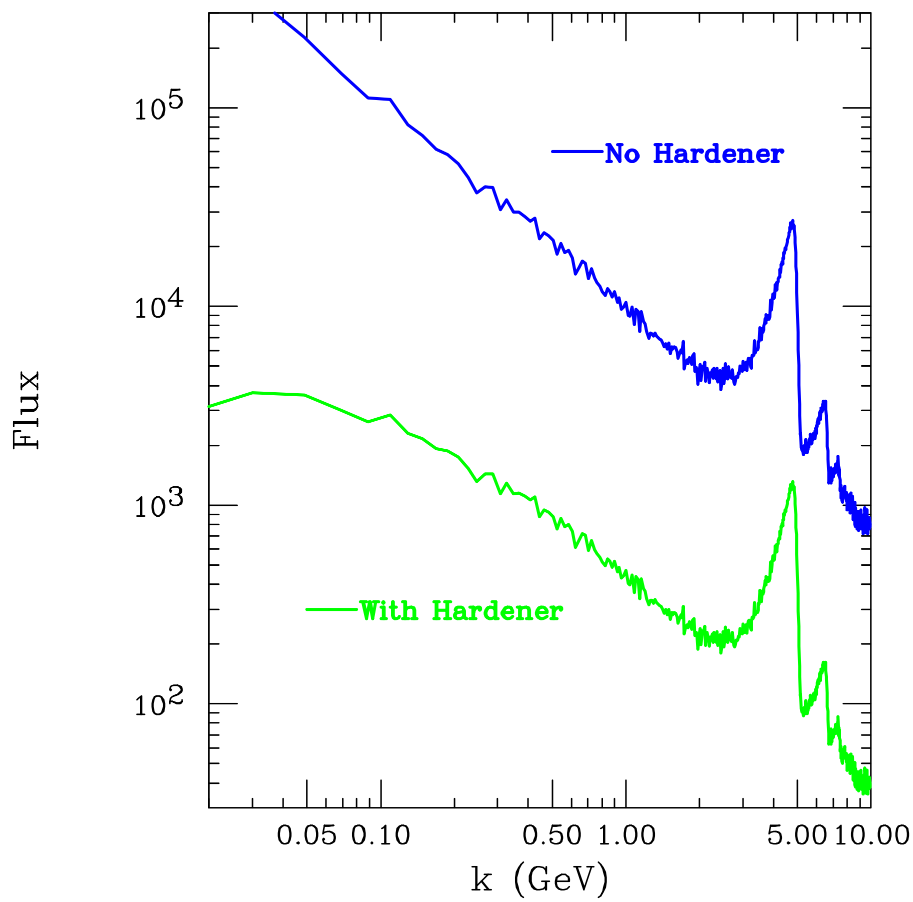
- Estimate 2 weeks to remove magnets from beamline, about 6 weeks to re-install (with goniometer).
- Work on vacuum chamber will be needed.
- Use old A-bend power supplies with extensive refurbishing (under discussion).
- Will add very weak magnet in front of B33 to reduce synchrotron flux going in to E.S.A.

ELECTRON BEAM DUMP

- Probably use aluminum dump of SLC Final Focus design (100 KW).
- Will need new stands.
- 100 kW more than adequate. Most running will be 20 kW or less to avoid cracking the diamond radiators.

BEAM HADENDER

- May be used in E159 if works well.
  Not essential.
- Ideally, removes low energy photons because total cross section (Compton plus Pair) larger than for higher energy photons.



COLLIMATOR

- Need thick (70 r.l.) tungsten collimators about 90 m from radiators.
- Will have two for E159 and E161: 1 mm radius and 3 mm radius.
- Steering will be done as in E78 with 4-quadrant SEM system. One will already be in place for E158 with larger opening.
- E158 magnet D3 will be on to deflect charged particles not absorbed in collimator.
- Extra lead will be added between Q1 and Q4 to range out high energy muons (minimum deflection angle 30 mr).

BEAM MONITORS

- Very similar to E78 setup: standard devices.
- Ion chamber (thin window to convert fraction of photons) measures photon flux.
- Gas Cherenkov counter also measure flux.
- Faraday cup S.E.Q. is a total photon absorber: measures total intensity.

SUMMARY

- Well-established technique. Has been (and is being) used at many labs.
- Reliable and stable system: not very sensitive to electron beam parameters.
- Moderate cost.
- Provides by far the highest rate of quasi-monochromatic circularly polarized photons available anywhere for $k > 5$ GeV.