

# 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 endpoint 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

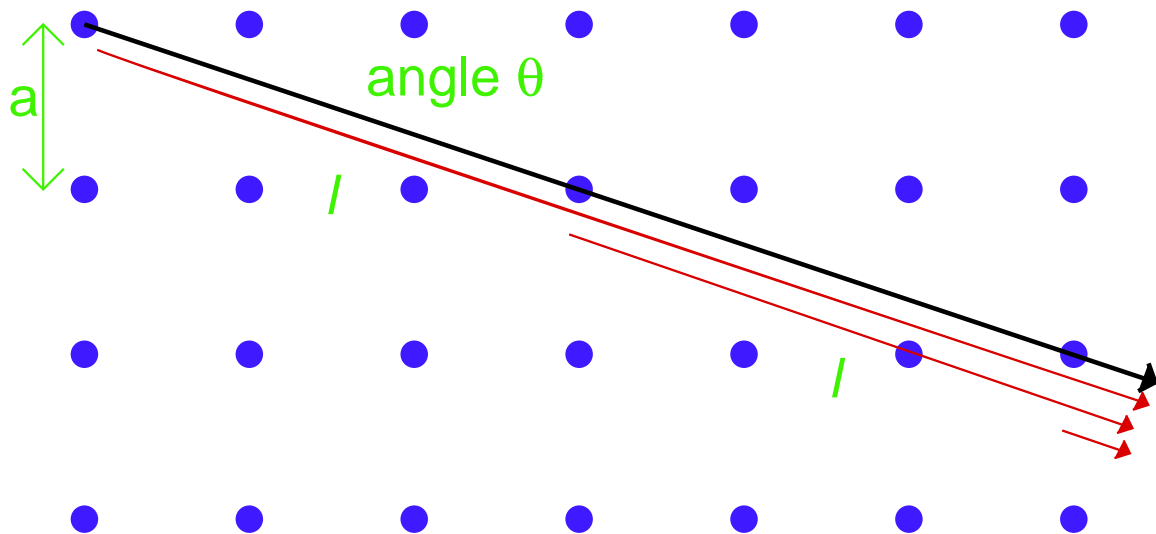
- Momentum transfer  $q$  very small. Minimum momentum transfer given by:

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

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

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



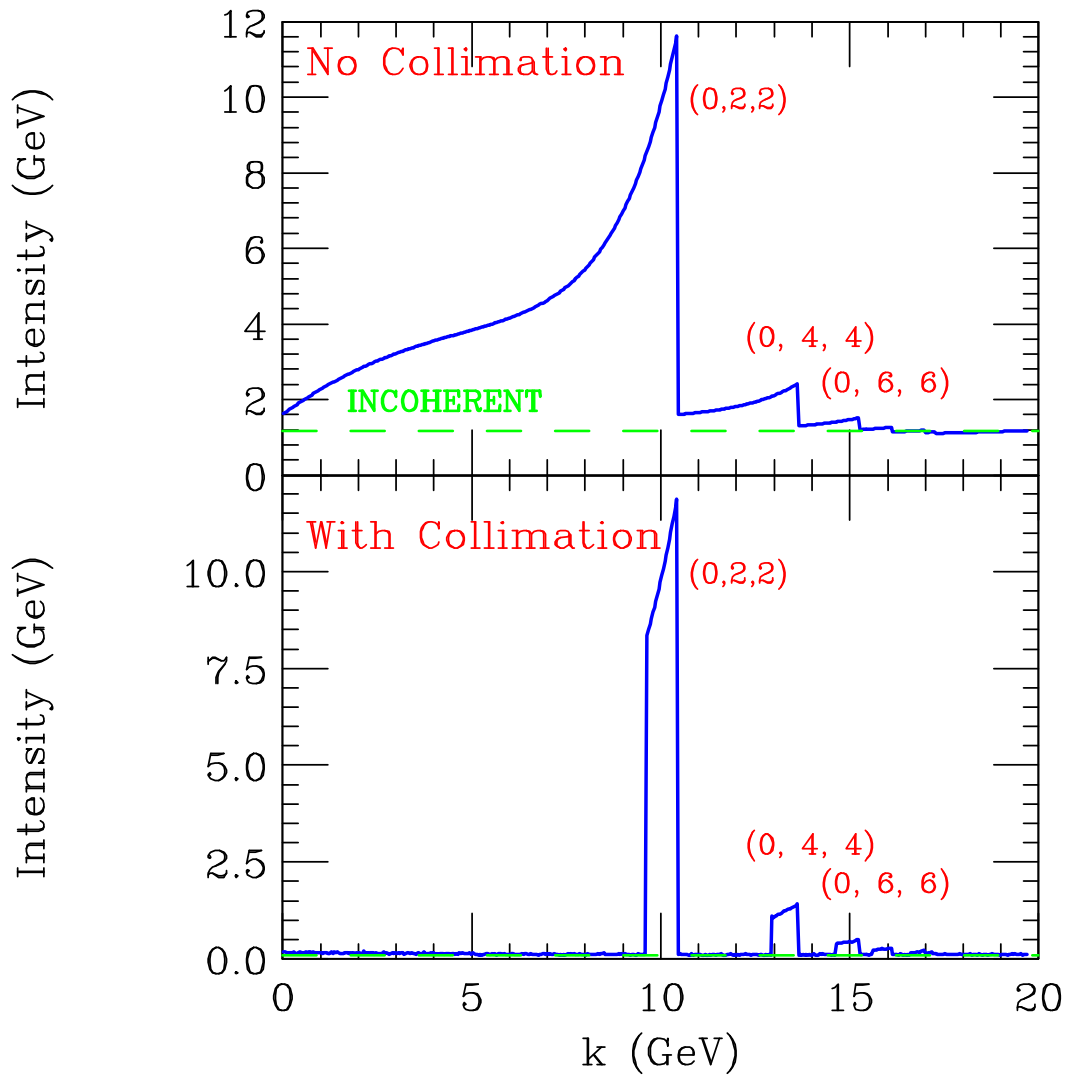
— photon waves, velocity=1.  
Want to be in phase.

— electron, velocity= $\beta$ .  
Lag by one photon wavelength over distance  $a/\theta$

## 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 Debye 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).

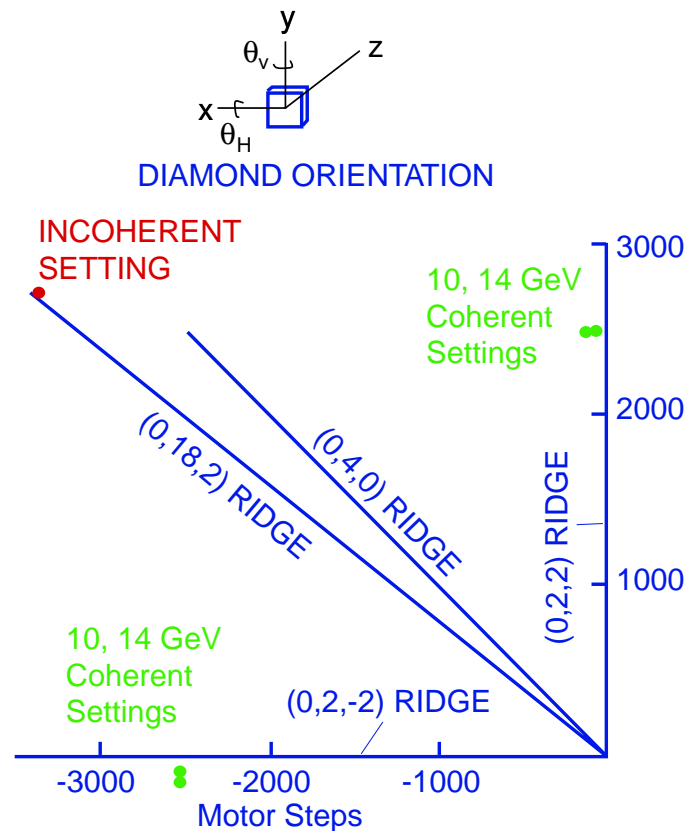
## CALCULATIONS

- 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).

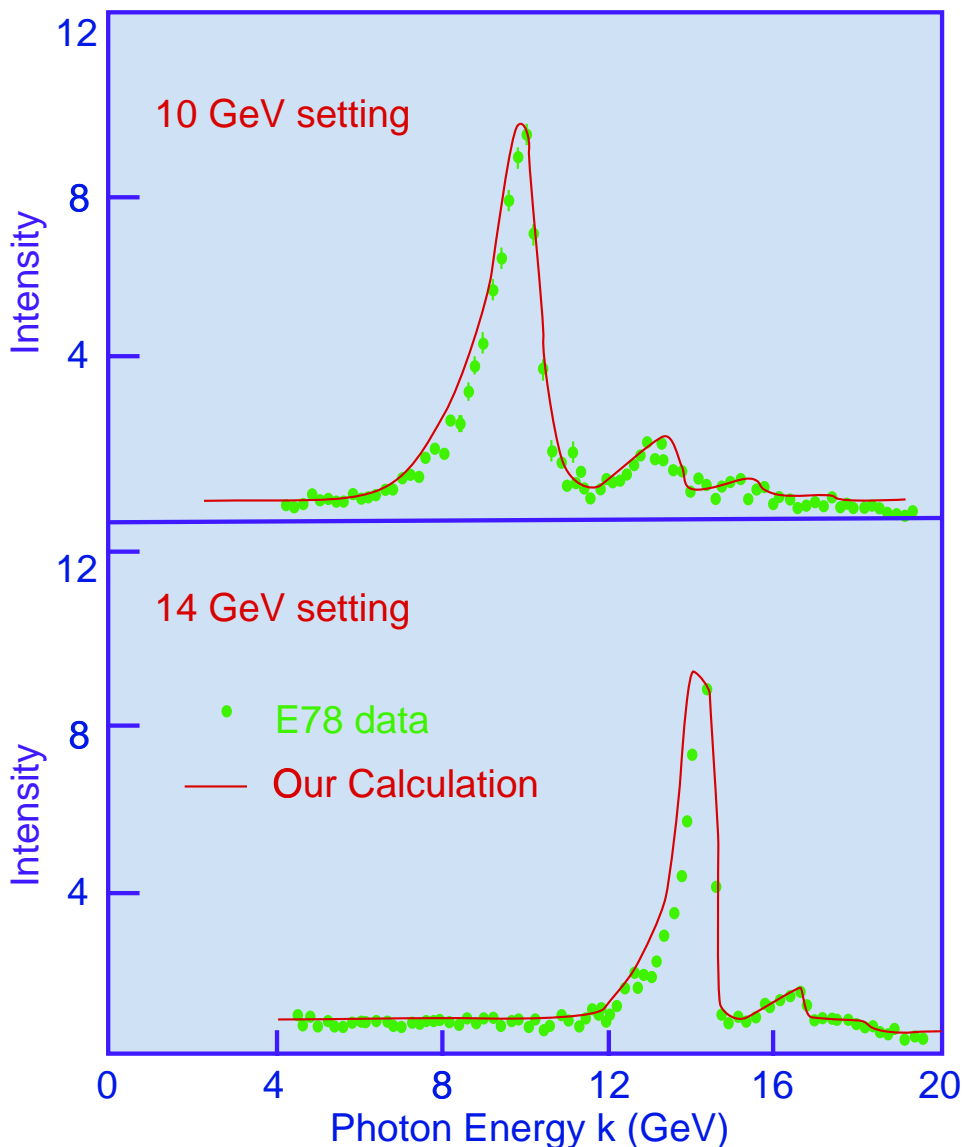
# DIAMOND ORIENTATIONS USED IN E78

- 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.

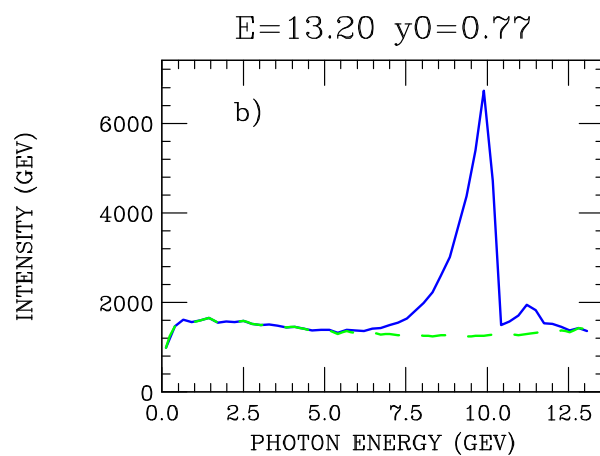
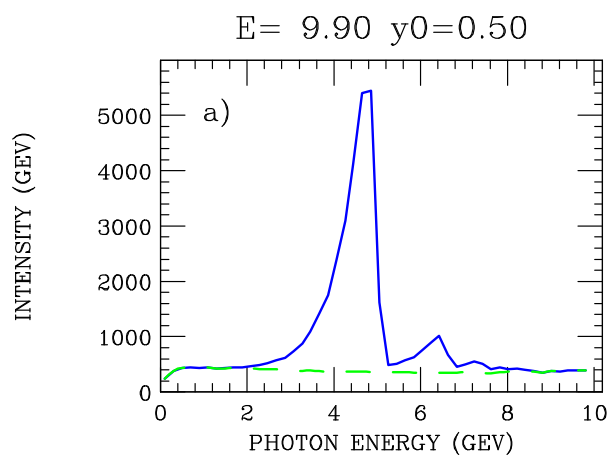
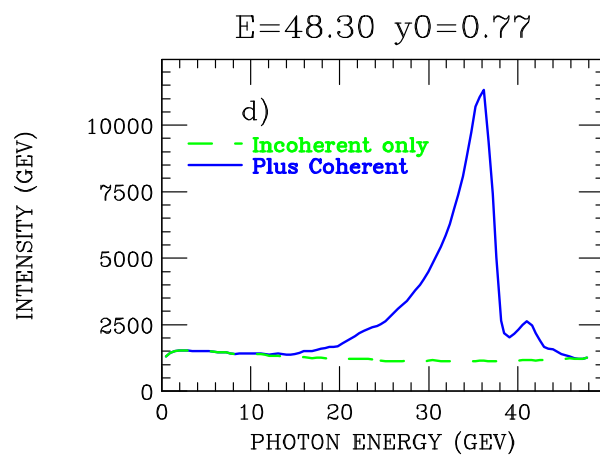
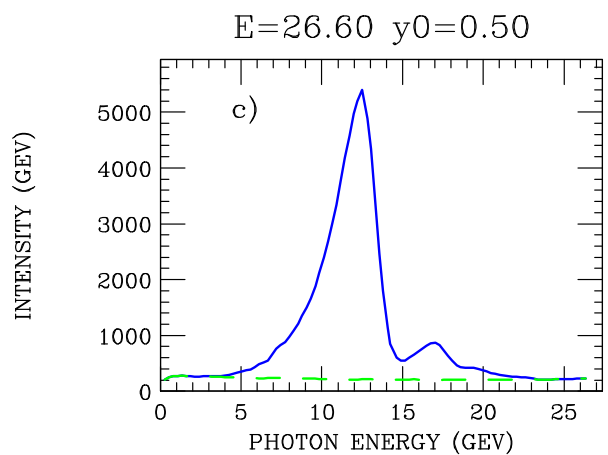


# CALCULATED SPECTRA FOR E159, E160, E161

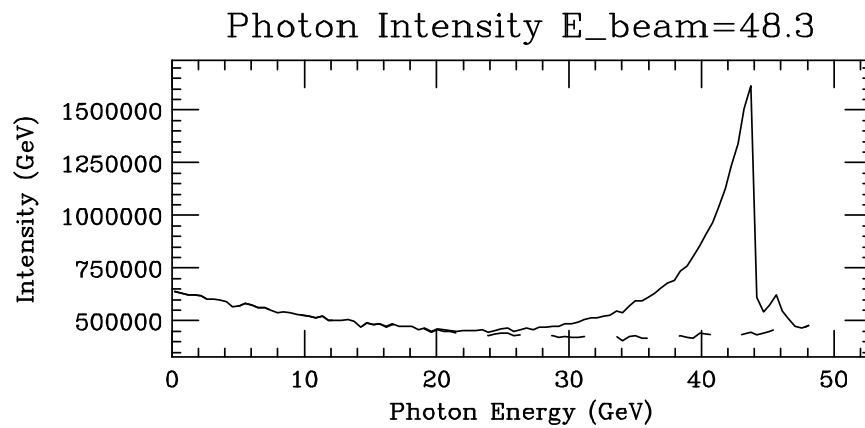
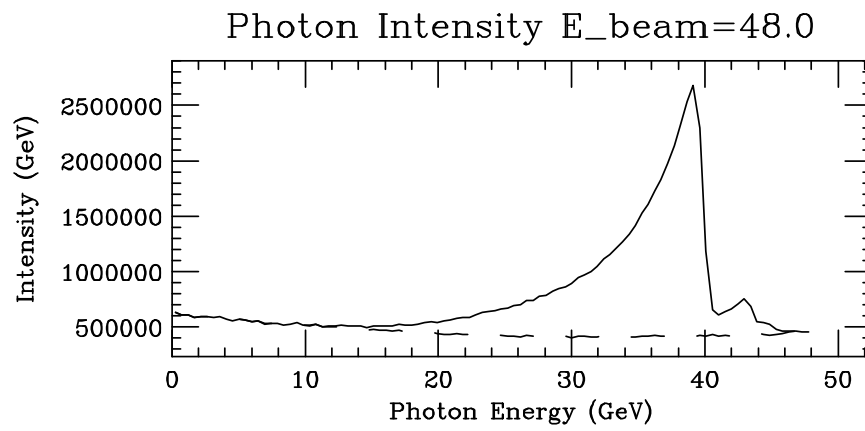
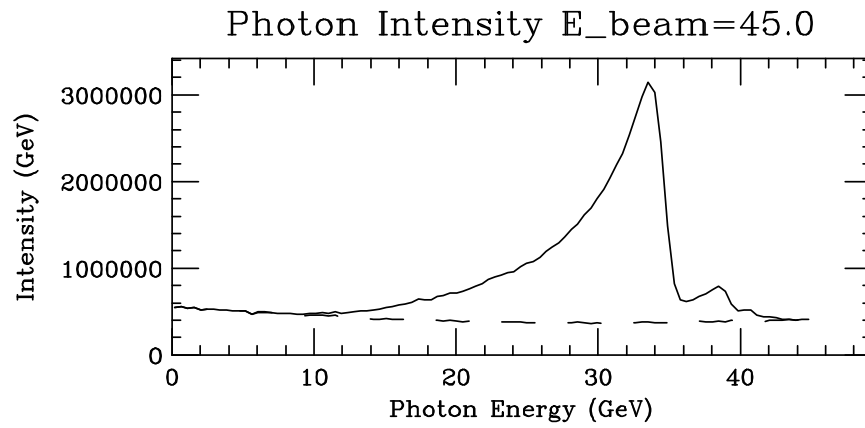
Experiment	Photon Energies	Photons/Spill	Polarization
E159	4 to 40 GeV	$10^5$ to $10^7$	yes
E160	15, 25, 35 GeV	$< 10^7$	no
E161	35, 40, 45 GeV	$< 10^7$	yes

- **Limit current** to about  $3 \times 10^{10}$  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

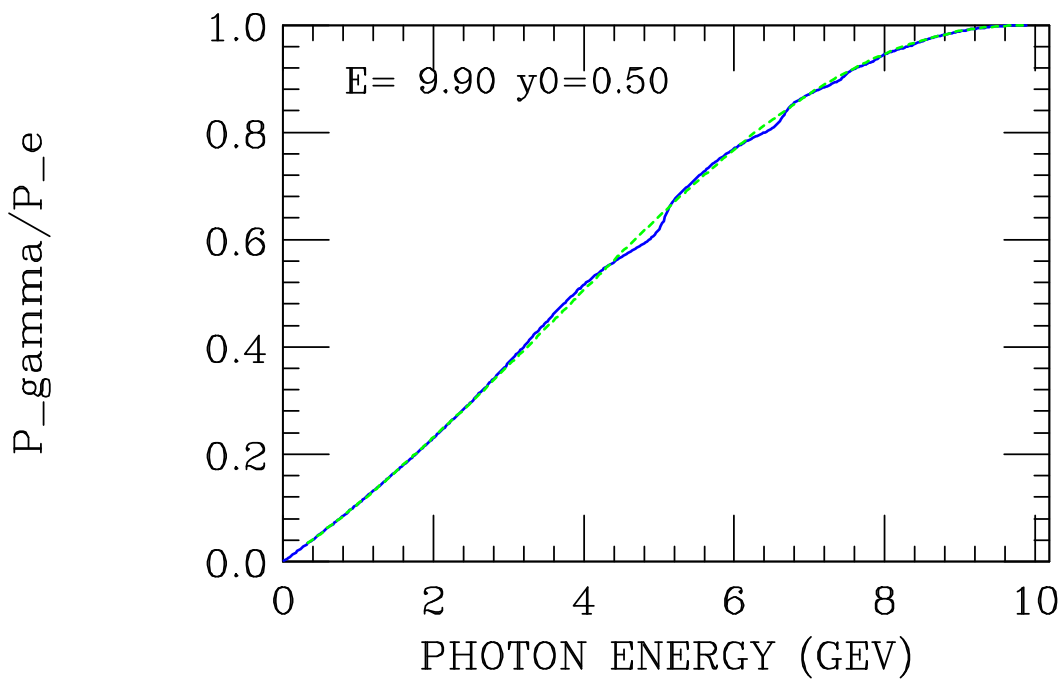
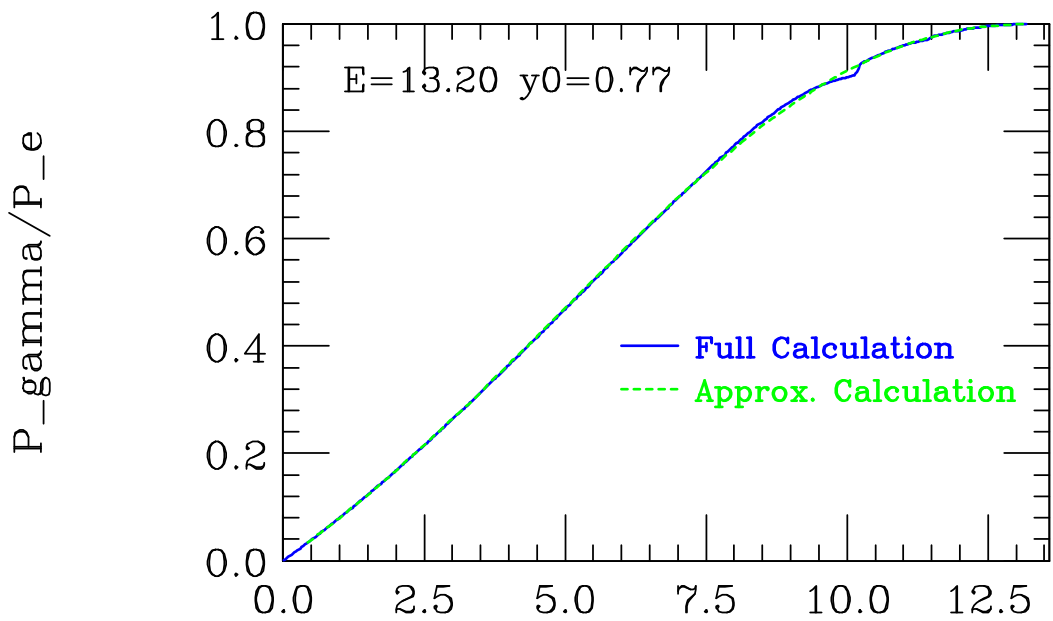
Photon **circular polarization** in crystals calculated I. M. Nadzhafov, Bull. Acad. Sci. USSR, Phys. Ser. Vol. 14, No. 10, p. 2248 (1976).

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

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

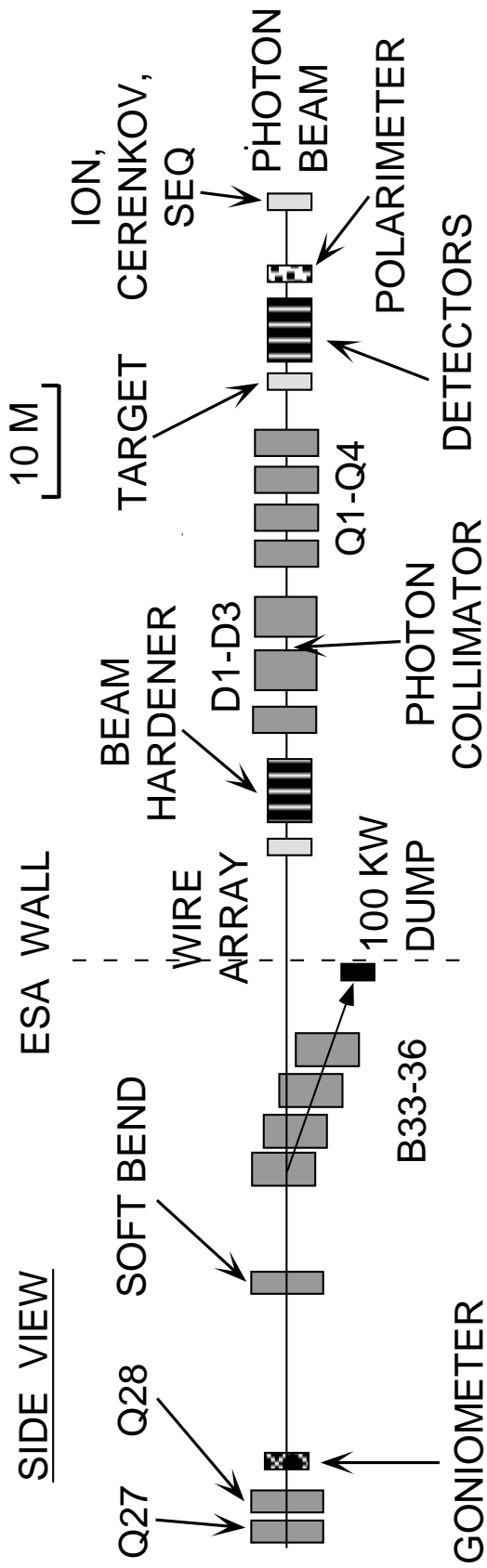
- where  $y = k/E$
- **Full calculation** shows small dips at coherent peaks due to linear polarization component (final polarization is elliptical).
- Typical **linear polarization** is 0.1 to 0.4, given very approximately by  $(1 - y)$ . Effect **cancels** due to azimuthal symmetry of detectors in 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

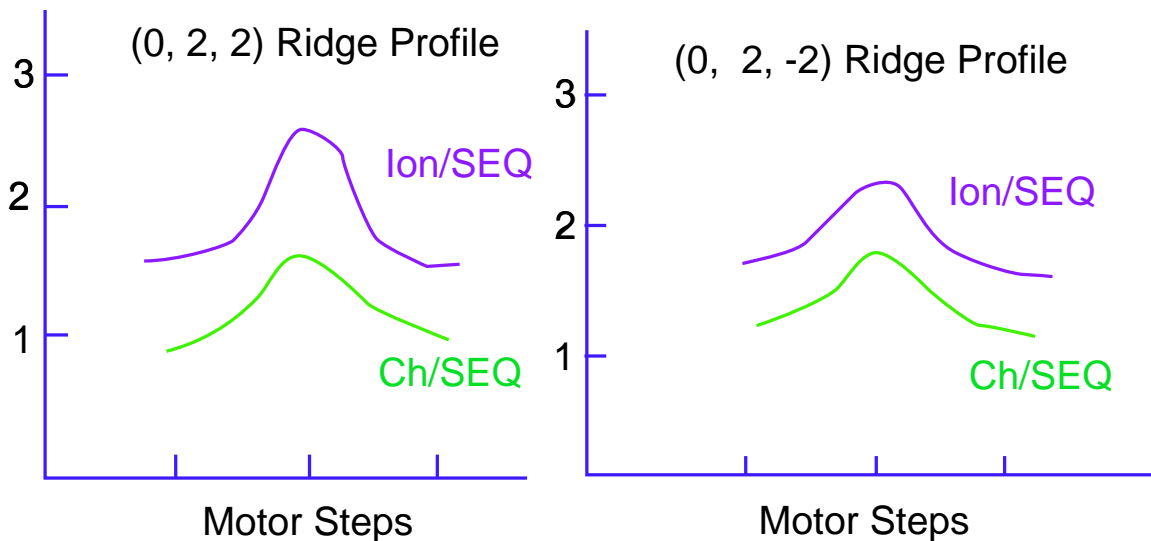


# GONIOMETER

- Device to accurately [position diamonds](#).  
Angles fixed in  $25 \mu r$  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.

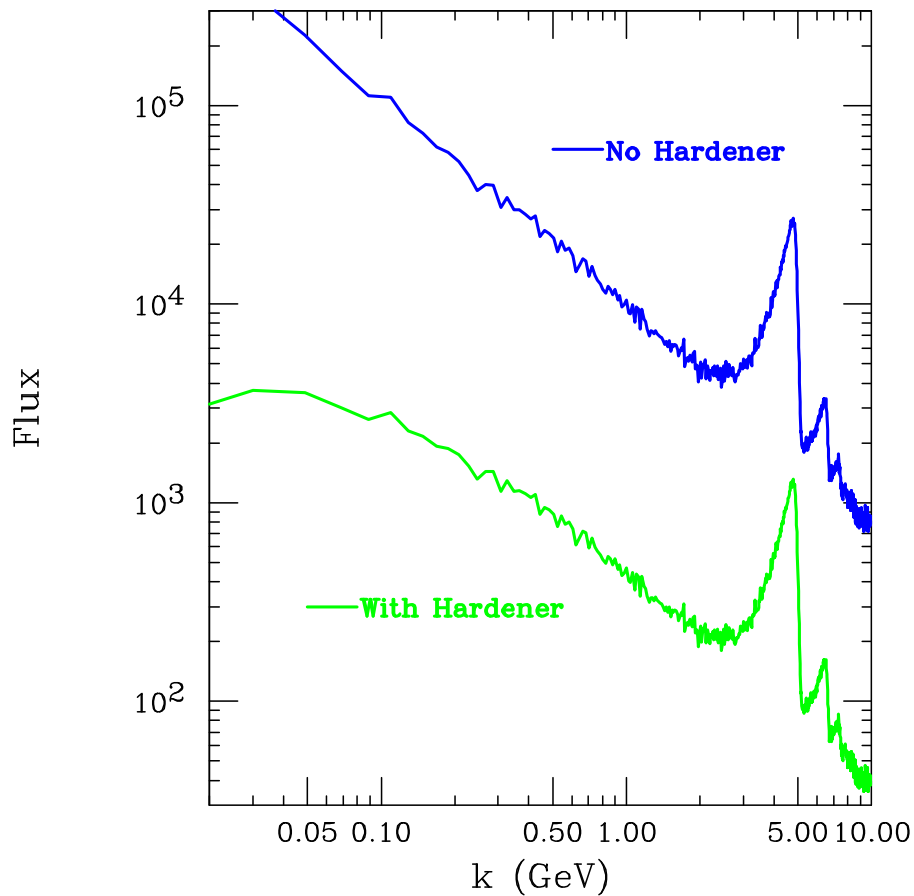
- Estimate **2 weeks** to remove magnets from beamline, about **6 weeks** to re-install (with goniometer).
- Work on **vacuum chamber** will be needed.
- Use old A-bend **power supplies** with extensive refurbishing (under discussion).
- Will add very weak magnet in front of B33 to reduce **synchrotron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

- 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.