DESY-Test Beam Data on Bremsstrahlung by Positrons in Aluminum

Preliminary Results from Test Beam Experiments @ DESY II (April / May 2024)

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Hamburg, 20.6.2024

HELMHOLTZ

DESY.

Dielectric Suppression in Bremsstrahlung Generation

Introduction

Bethe-Heitler Suppression

- reduction of formation length in presence of matter
- suppression of Bethe-Heitler intensity I for small $\hbar\omega$

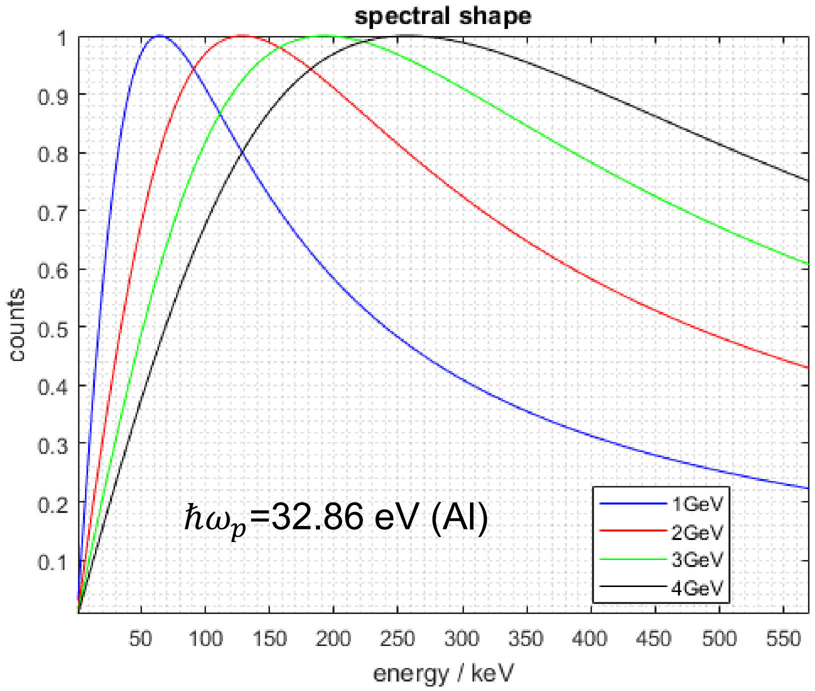
$$\frac{\mathrm{d}^2 I}{\mathrm{d}(\hbar\omega)\mathrm{d}z} \approx \frac{1}{1+\left(\frac{\gamma\cdot\hbar\omega_p}{\hbar\omega}\right)^2}\cdot\frac{\mathrm{d}^2 I_{BH}}{\mathrm{d}(\hbar\omega)\mathrm{d}z}$$

M. Bondarenco, preprint sent by email 12.4.2024, Eq.(14)

- photon counting detector
  - replace intensity by number of photons $I \rightarrow N\cdot\hbar\omega$
  - expected signature measured by detector

$$N \propto \frac{1}{1+\left(\frac{\gamma\cdot\hbar\omega_p}{\hbar\omega}\right)^2}\cdot\frac{1}{\hbar\omega}$$

- expected spectral shape
  - measured by detector



Dielectric Suppression

Dominant Region compared to LPM

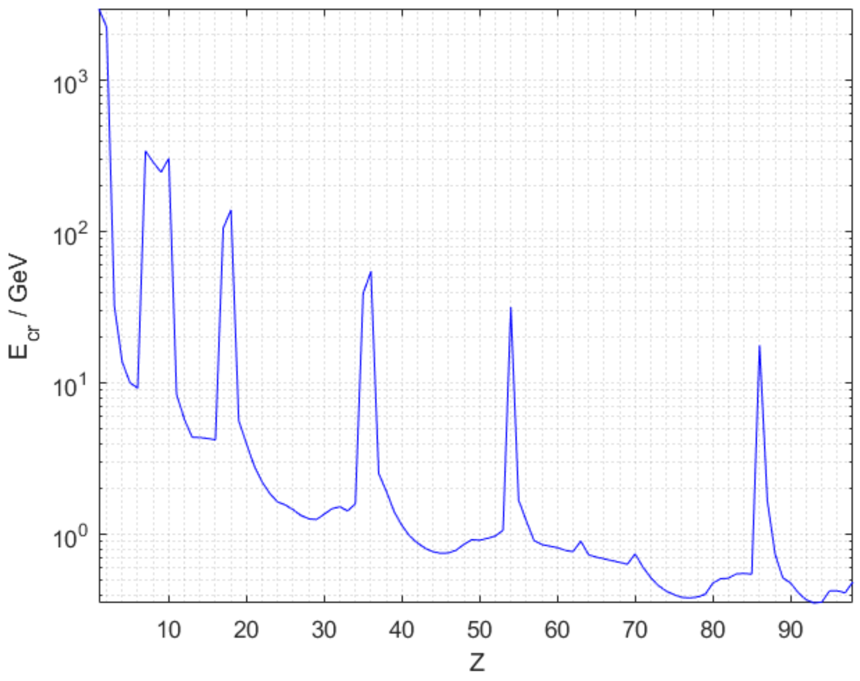
Energy Threshold

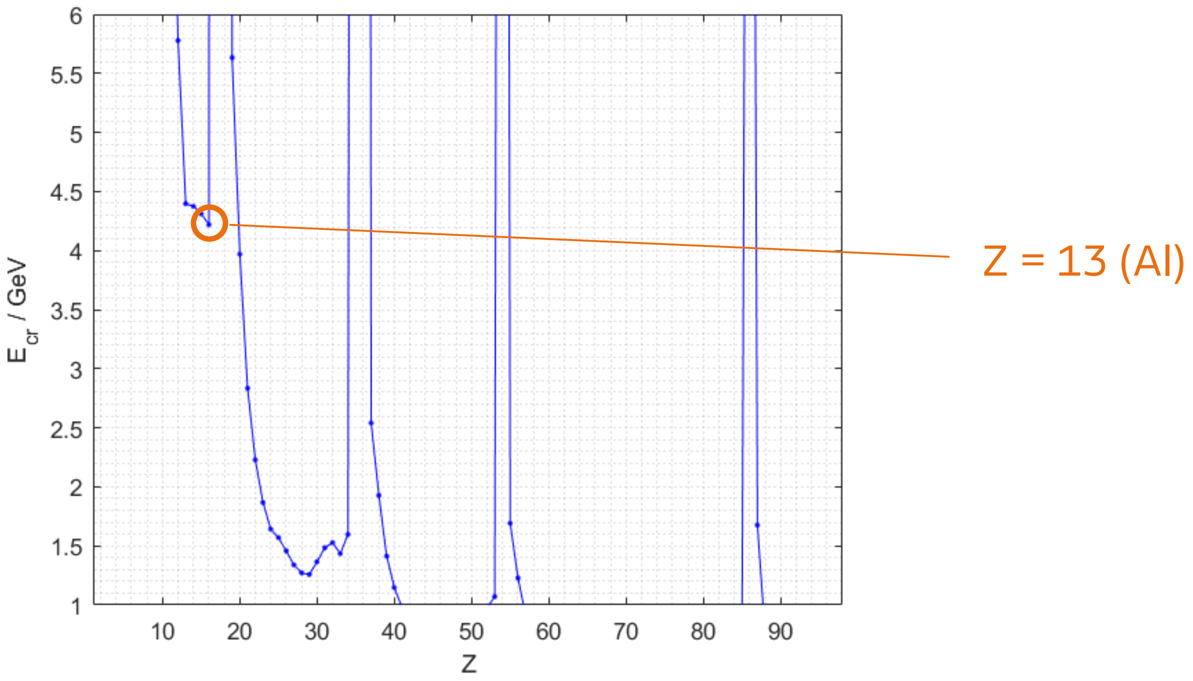
- dielectric suppression overwhelmes LPM suppression for beam energies

$$\boxed{E \leq E_{cr} = \frac{\alpha}{4\pi}\frac{m_0 c^2}{\hbar c}\,\hbar\omega_p X_0}$$

E.L. Feinberg and I. Pomeranchuk, Nuovo Cimento Suppl. A1 series X **III** (1956), 652
S. Klein, Rev. Mod. Phys. **71** (1999) 1501

- dependence on target material
- energy range of DESY II Test Beam

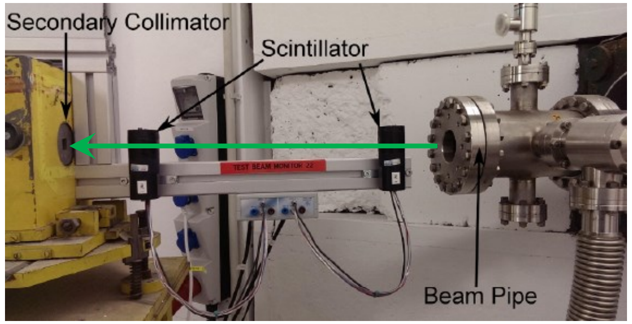


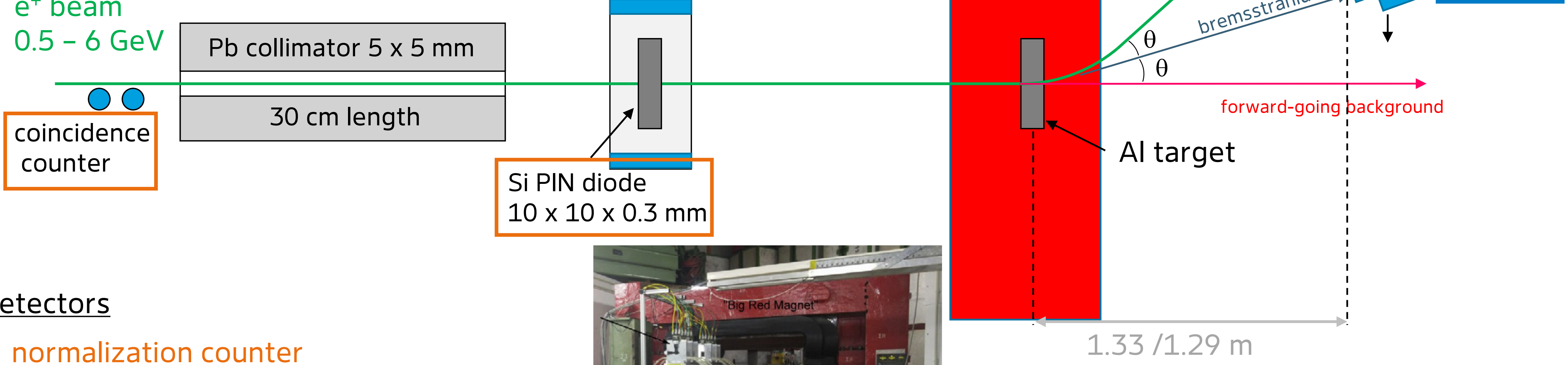


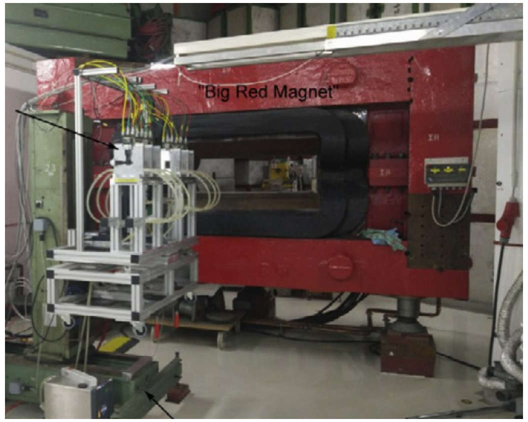
Experiments at DESY II Test Beam Facility

Setup at TB 21

R. Diener et al., NIM **A922** (2019) 265





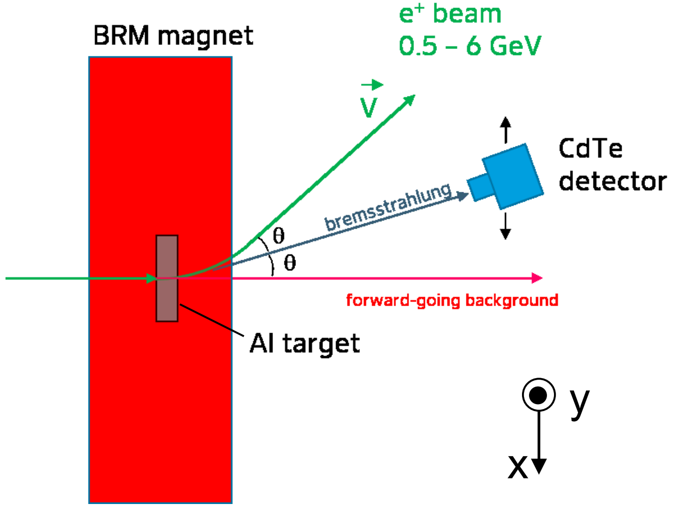


detectors

- normalization counter
  (w.r.t. # incoming particles)
- radiation spectrum

Experiments at DESY II Test Beam Facility

Procedure

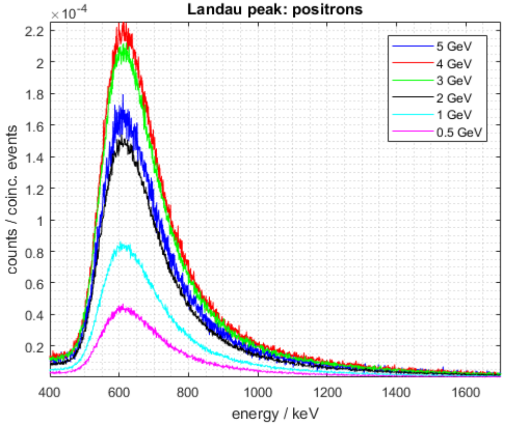


Alignment

- determine detector position along forward going beam axis (x, y direction)
  - intensity of Landau peak as measure
- switch on BRM magnet
  - magnet field B_0 → detector under deflection angle θ

    → align detector position (x) using intensity of Landau peak as measure
  - magnet field $2B_0$ → detector under deflection angle 2θ → det. pos. as before
- insert Al target (t = 10mm)
  - magnet field $2B_0$ → detector under deflection angle θ

    → align detector position (x) using bremsstrahlung intensity as measure



Measurement

- bremsstrahlung
  - $2B_0$, detector pos. Θ, Al target t=10mm
- transition radiation
  - as before, Al foil t≈50µm
- background
  - as before, no target

→ $t_{acq} \approx 12 - 24$h

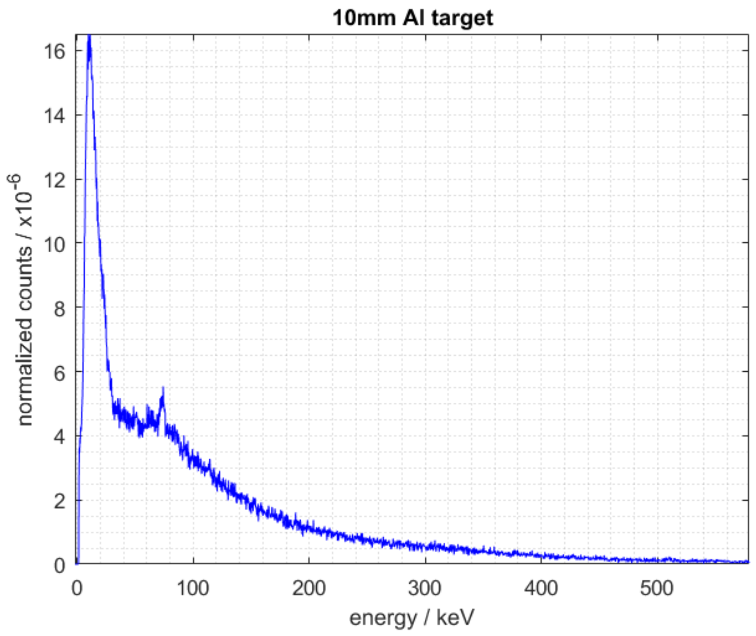
Experiments at DESY II Test Beam Facility

Beam Time Overview

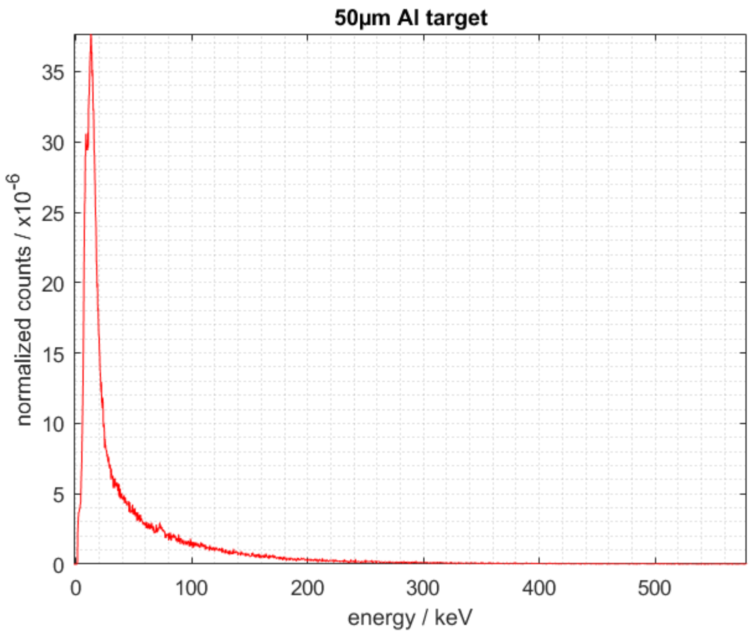
April 2024

- measurement for beam energies 2 GeV & 4 GeV
  - example: 4 GeV

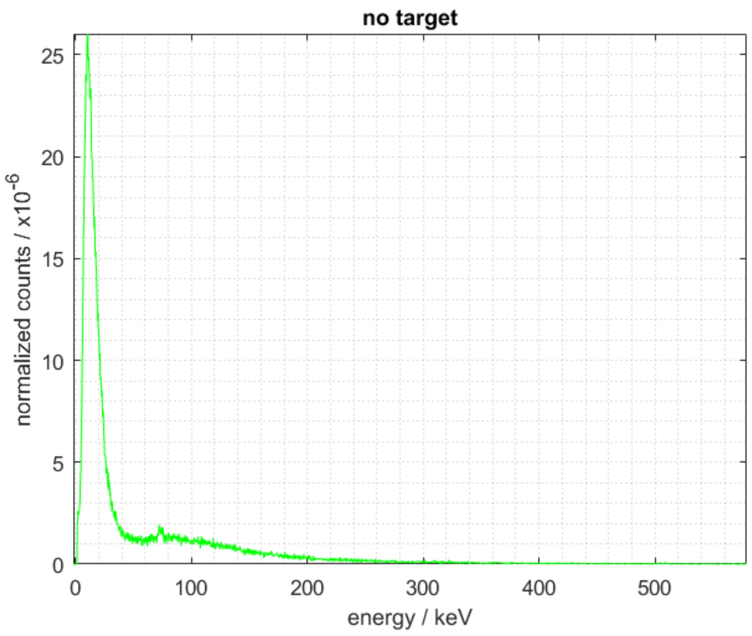
bremsstrahlung



transition radiation



background



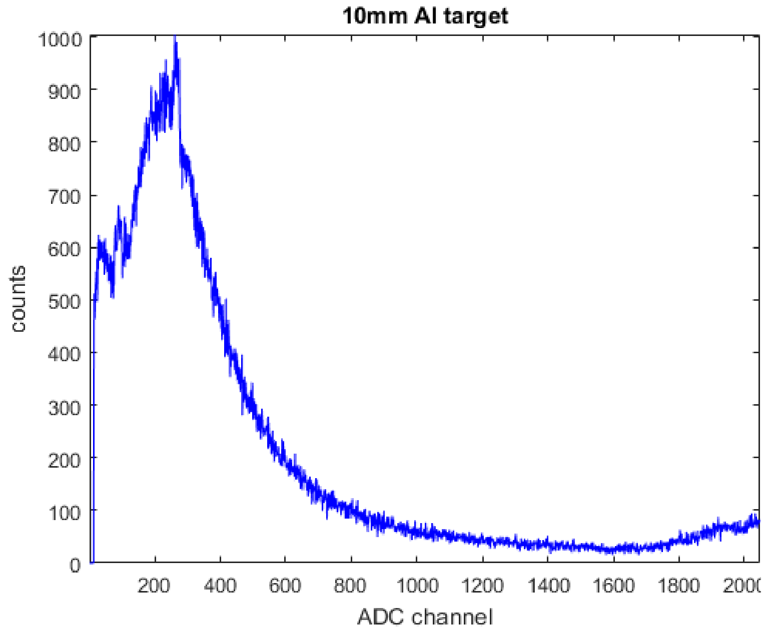
Experiments at DESY II Test Beam Facility

Beam Time Overview

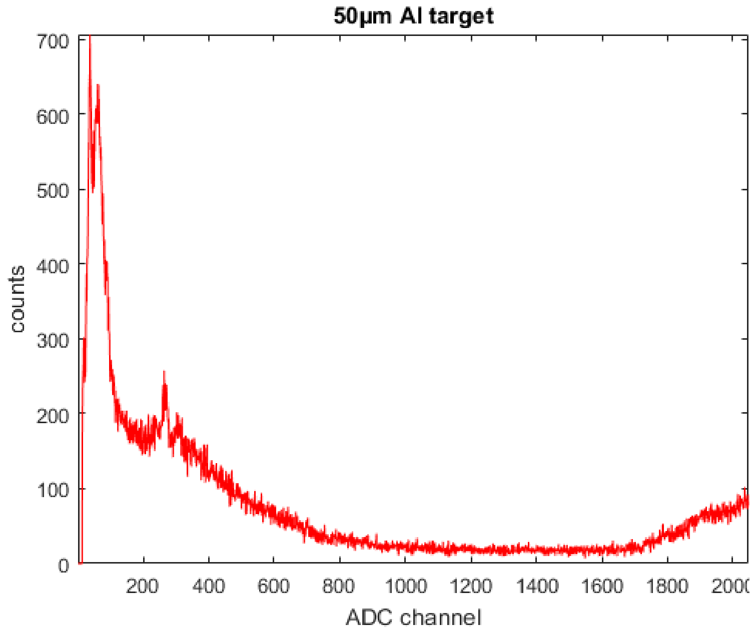
May 2024

- measurement for beam energies 1 GeV & 3 GeV
  - example: 1 GeV

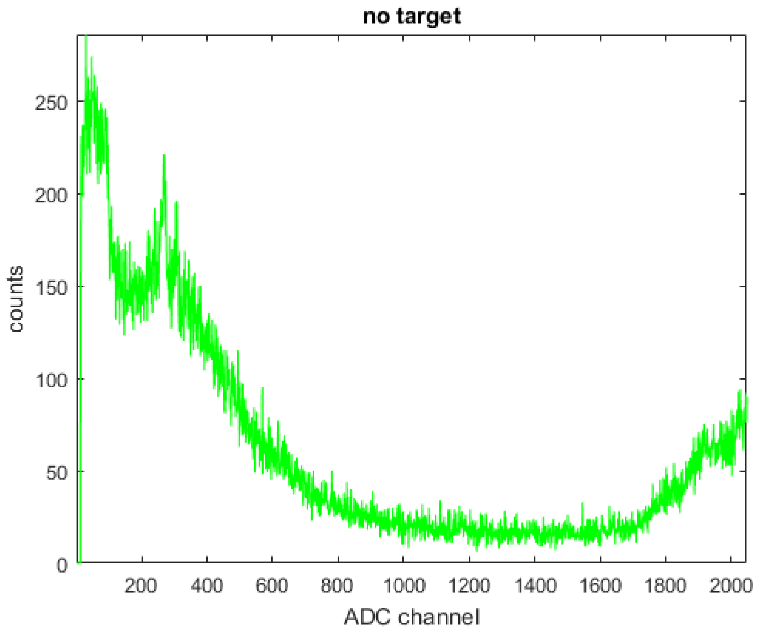
bremsstrahlung



transition radiation



background

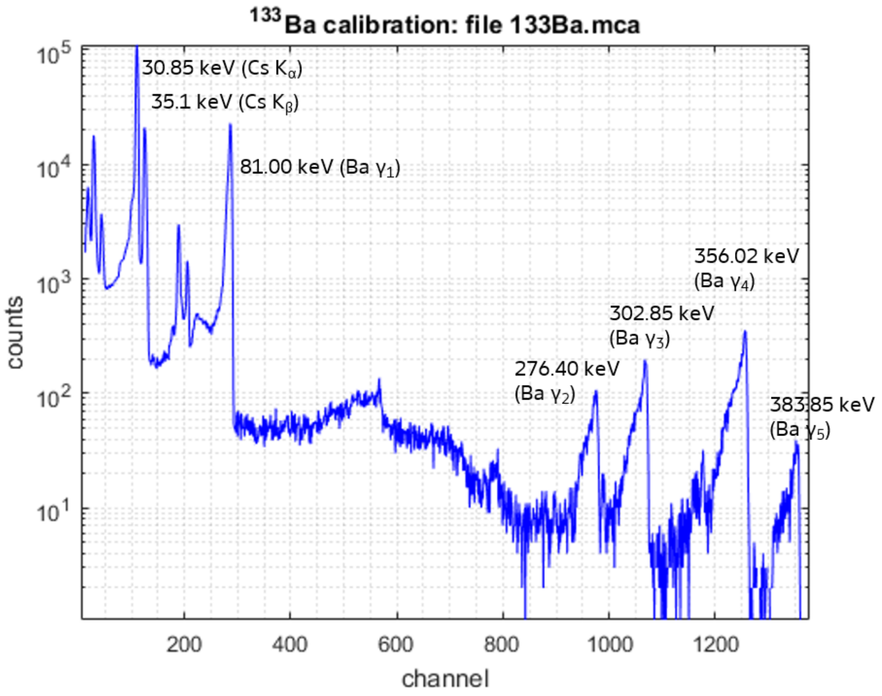


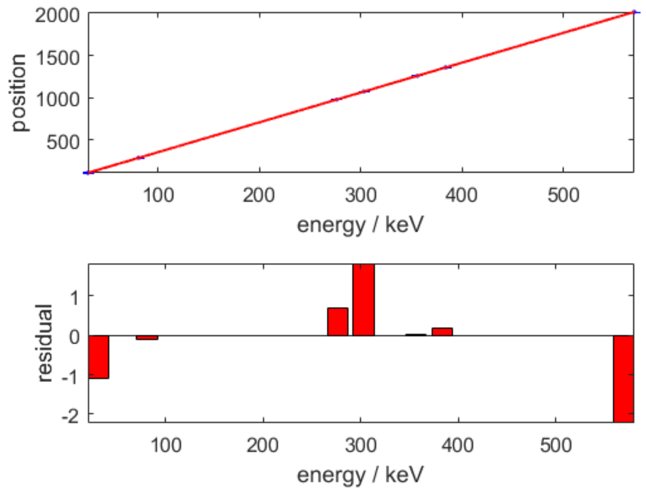
Data Treatment

Preparatory Analysis

Energy Calibration

- calibration sources ^{133}Ba & ^{207}Bi



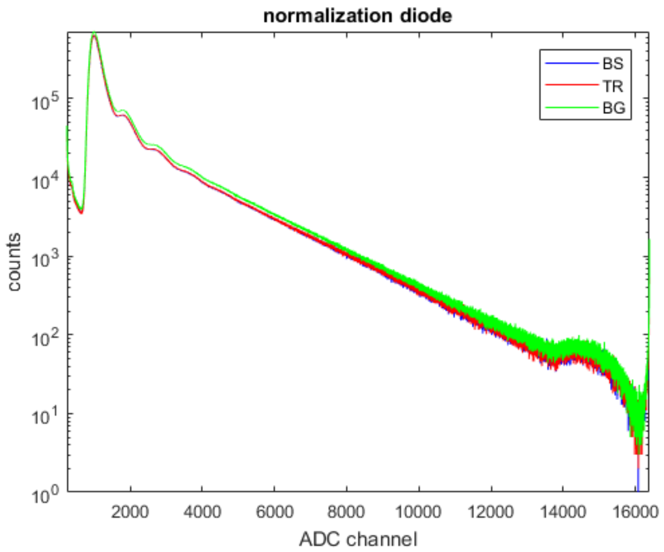


*** Fit Results ***
Chi2 = 10.018 (DoF: 5)
reduced Chi2 = 2.004

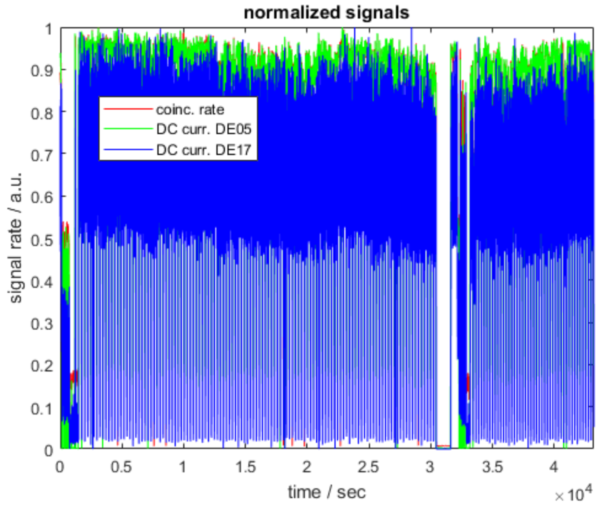
m	0.28323	+/-	4.0995e-05
b	-0.6775	+/-	0.022354

Normalization

- with respect to number of incoming particles



May 2024 normalization with PIN diode



April 2024 normalization with coincidence (partly problems with PIN diode)

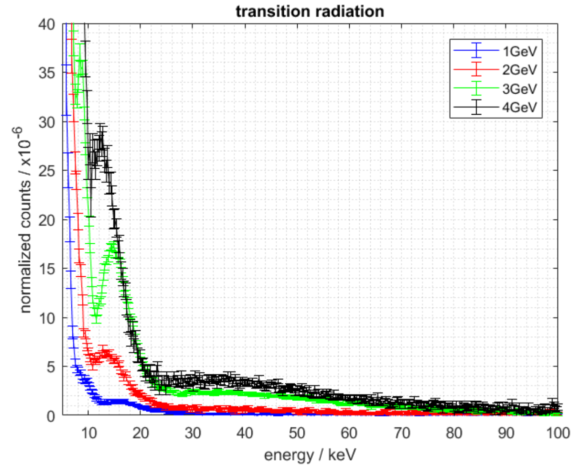
agreement within 5%

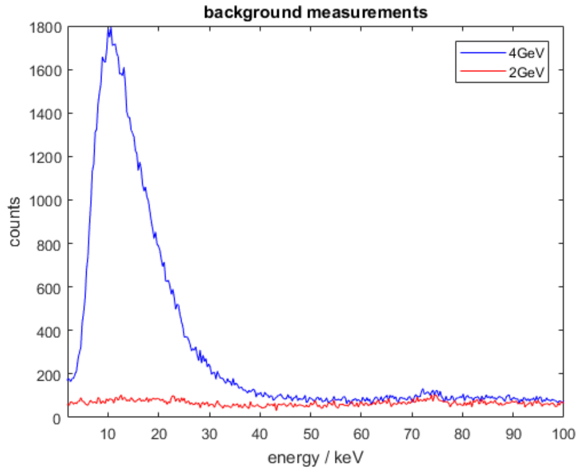
Data Treatment

Background Correction

Assumption

- background is generated in front of target (i.e. transported along beamline)
  - exception transition radiation from target surface → relevant only for $\hbar\omega < 100$ keV
    - → so far not considered in the following
    - → more details: talk A. Potylitsyn
  - exception synchrotron radiation from BRM → relevant @ 4 GeV for $\hbar\omega < 50$ keV
    - → assume that only half of particle path length in BRM contributes to SR background
    - → in energy region up to 50 keV, only half of background is subtracted
    - → detailed simulations, assuming SR near field emission, in process: A. Novokshonov





Background Subtraction

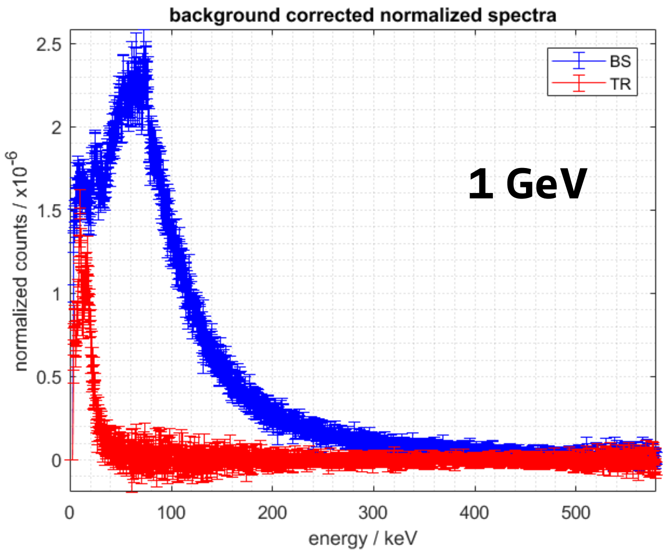
- taking into account transmission through target
  - error in count rate according to error propagation

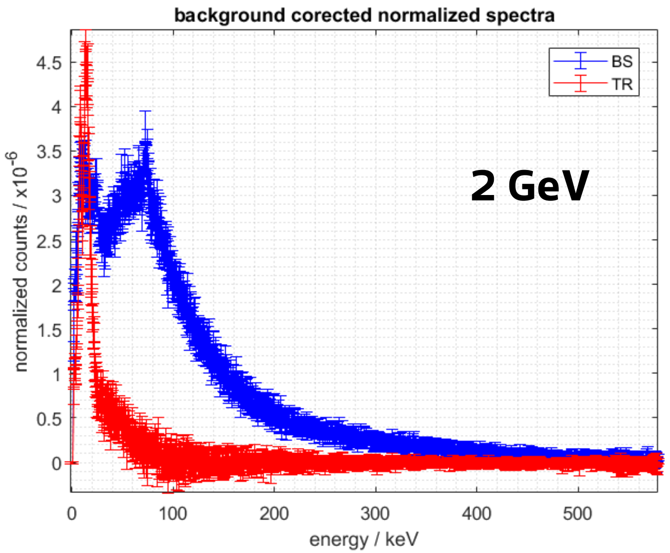
$$\boxed{N_{rad}^{c}(\hbar\omega) = \frac{N_{rad}(\hbar\omega)}{N_{norm,rad}} - T_{target}(\hbar\omega)\,\frac{N_{BG}(\hbar\omega)}{N_{norm,BG}}}$$

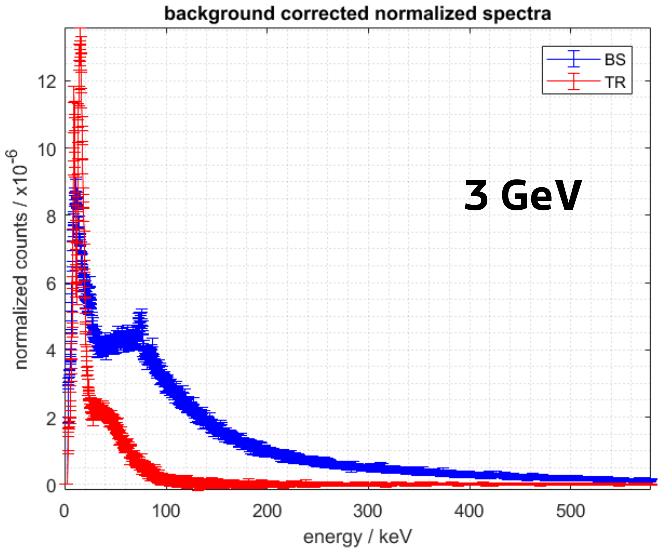
$$rad \rightarrow BS, TR$$

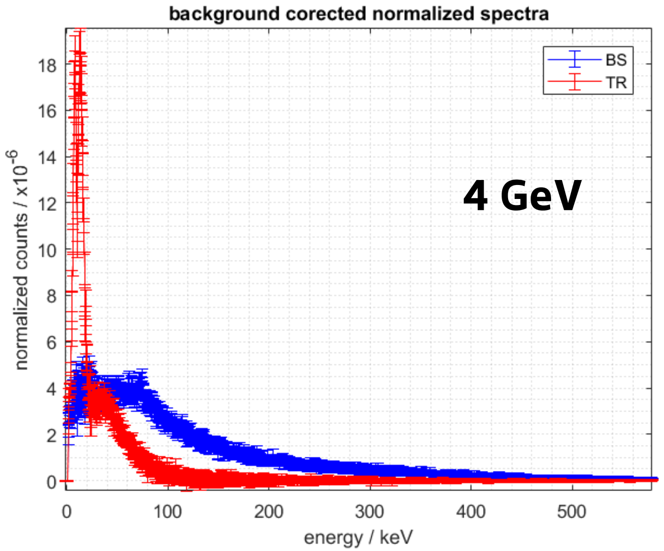
Data Treatment

Background corrected and normalized Spectra









Data Treatment

Detector Efficiency and Transmission through Air

CdTe Detector

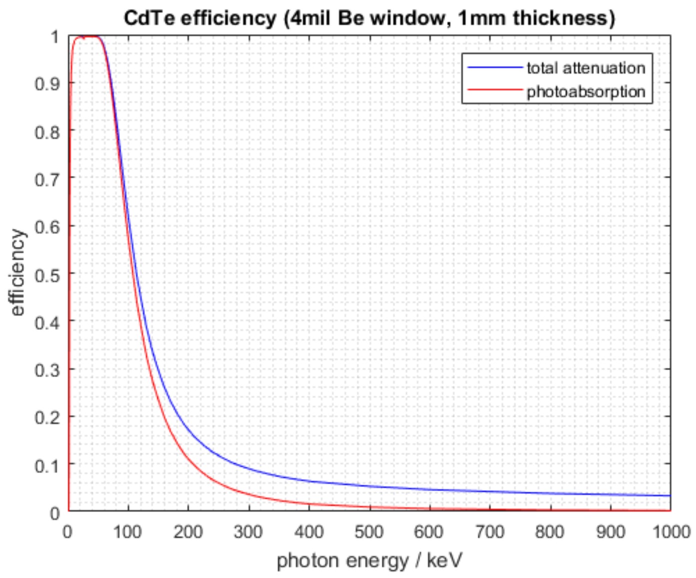
- efficiency correction according to Amptek Efficiency Package

  https://www.amptek.com/internal-products/app-notes/xr-100t-cdte-cadmium-telluride-detector-efficiency-application-note

  - data include

    → absorption in bulk material (100µm)

    → transmission through (a) 4mil Be-window

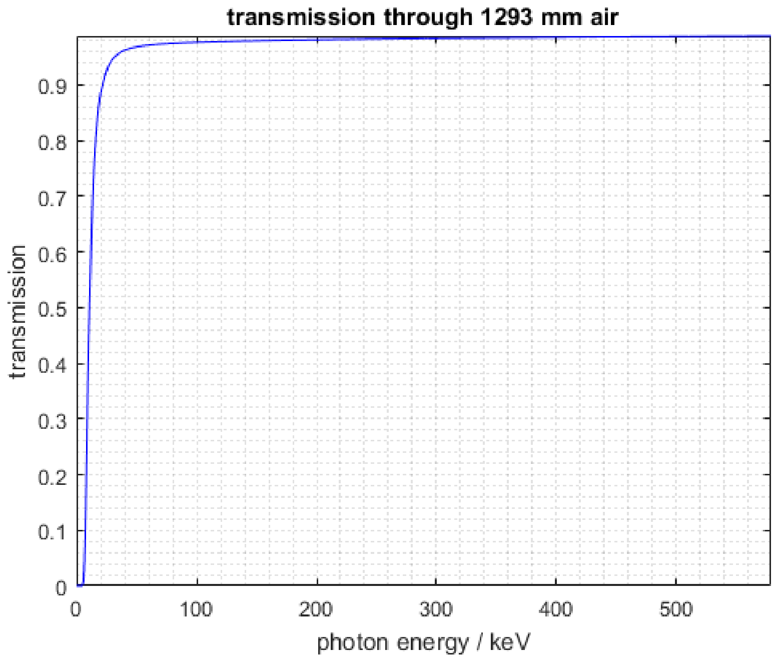


(b) dead layer: 150nm CdTe

(c) contact: 200nm Pt

Air Transmission

- based on NIST data base

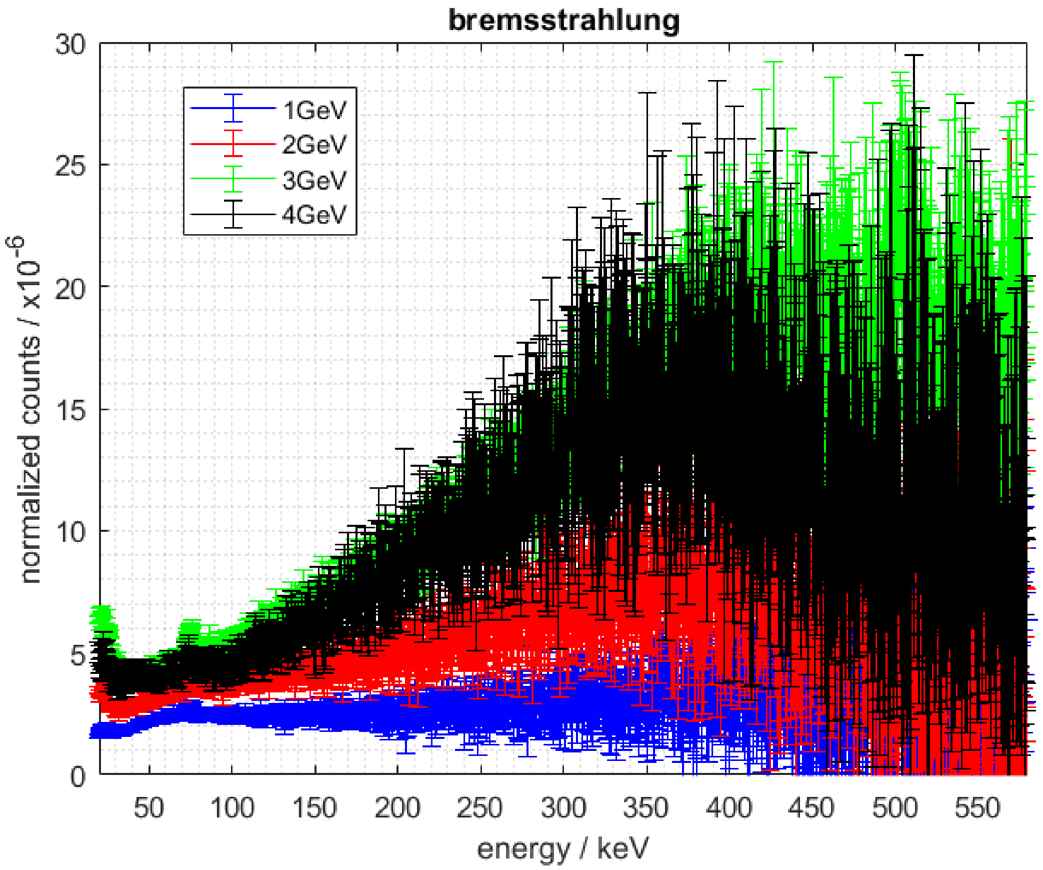


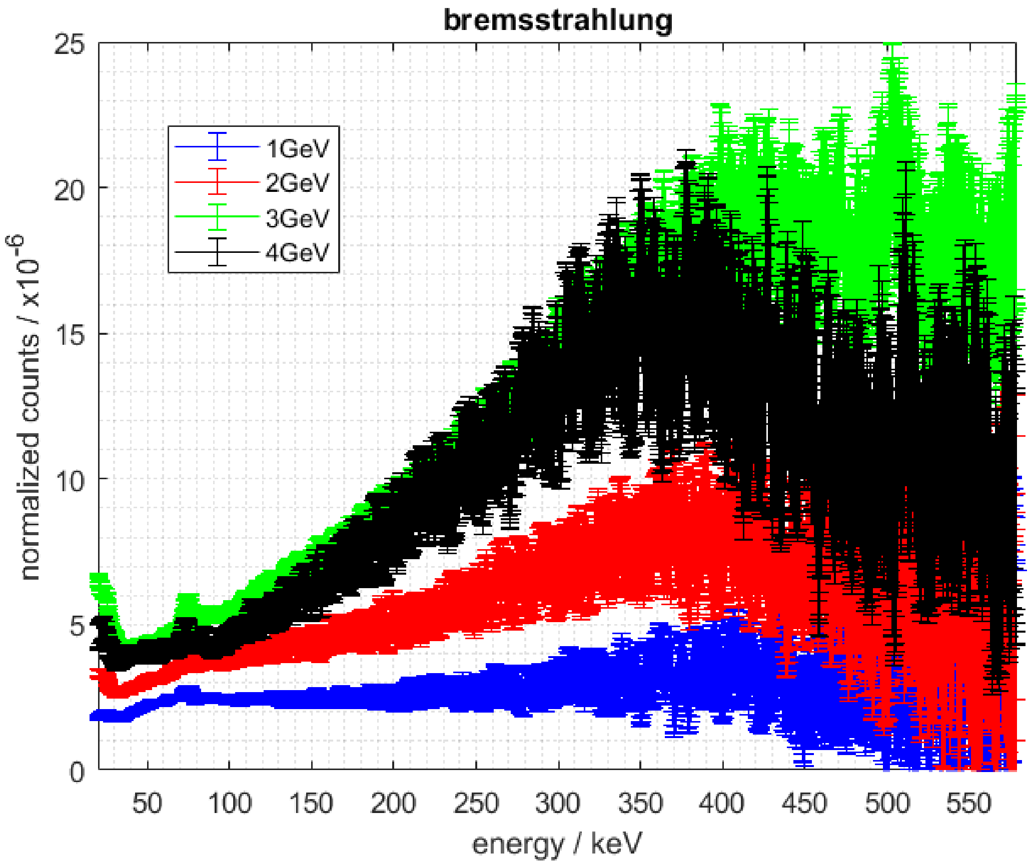
beam time April

1330 mm air

Processed Data

Bremsstrahlung Spectra

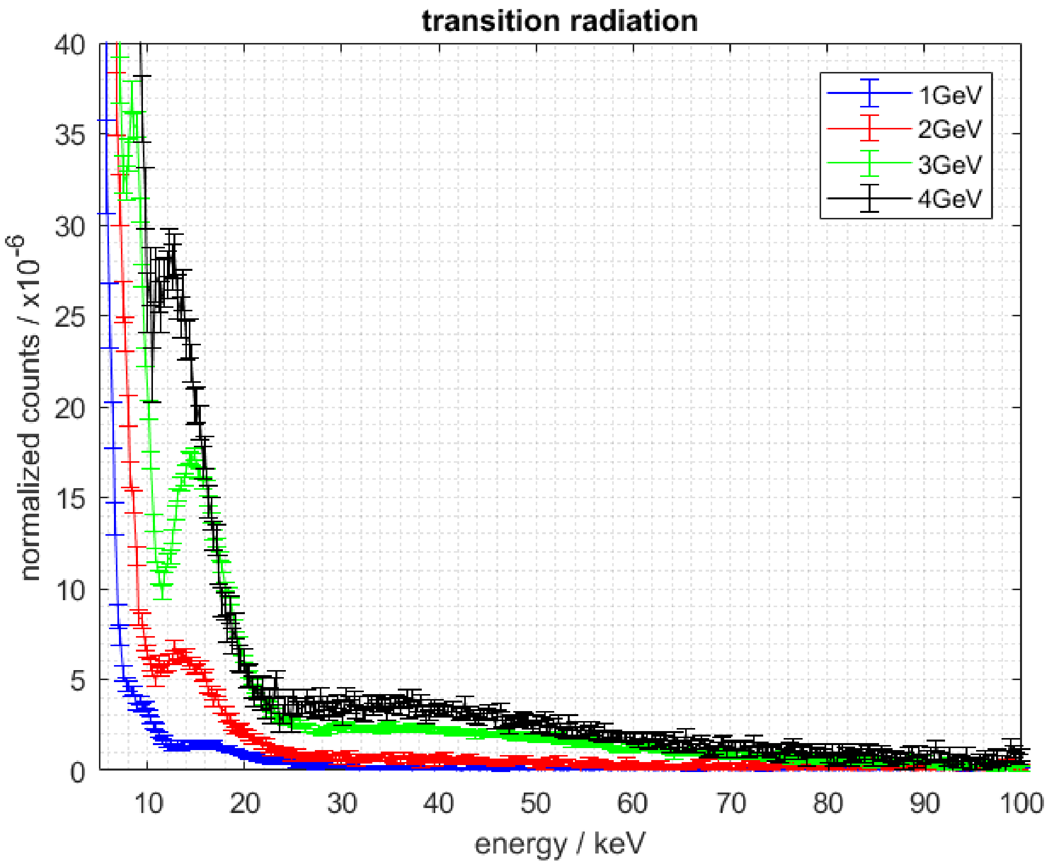


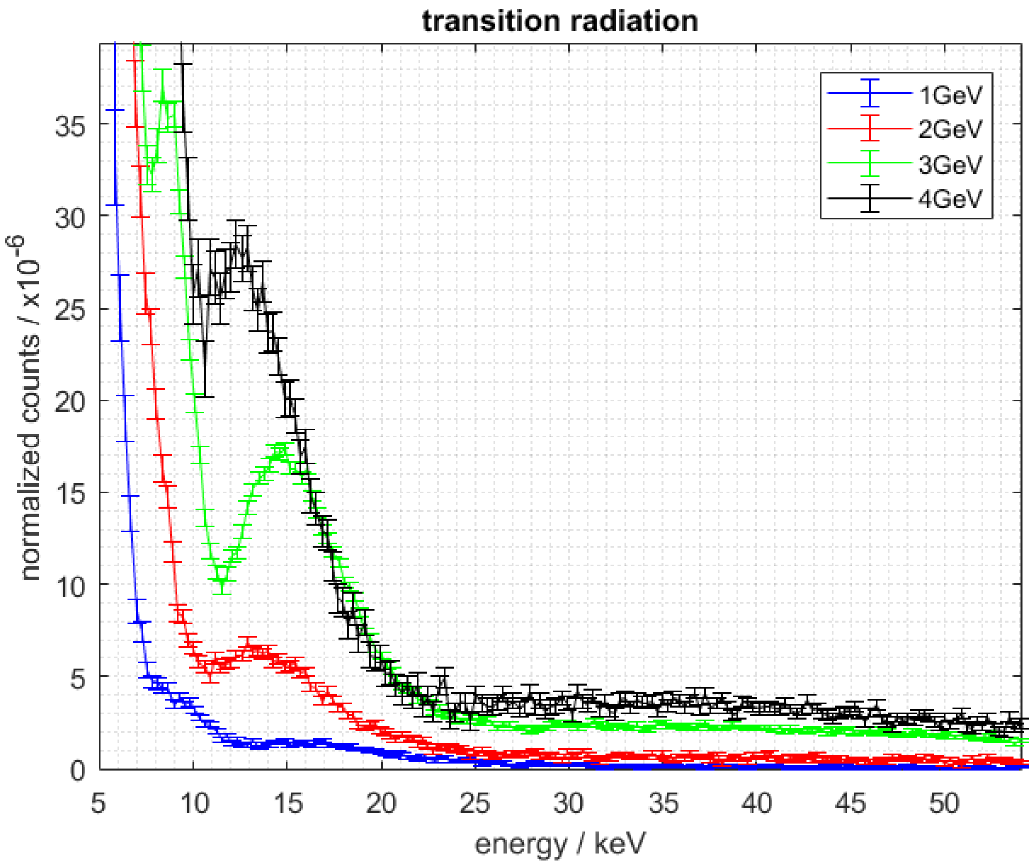


moving average filter: 10 samples

Processed Data

Transition Radiation Spectra



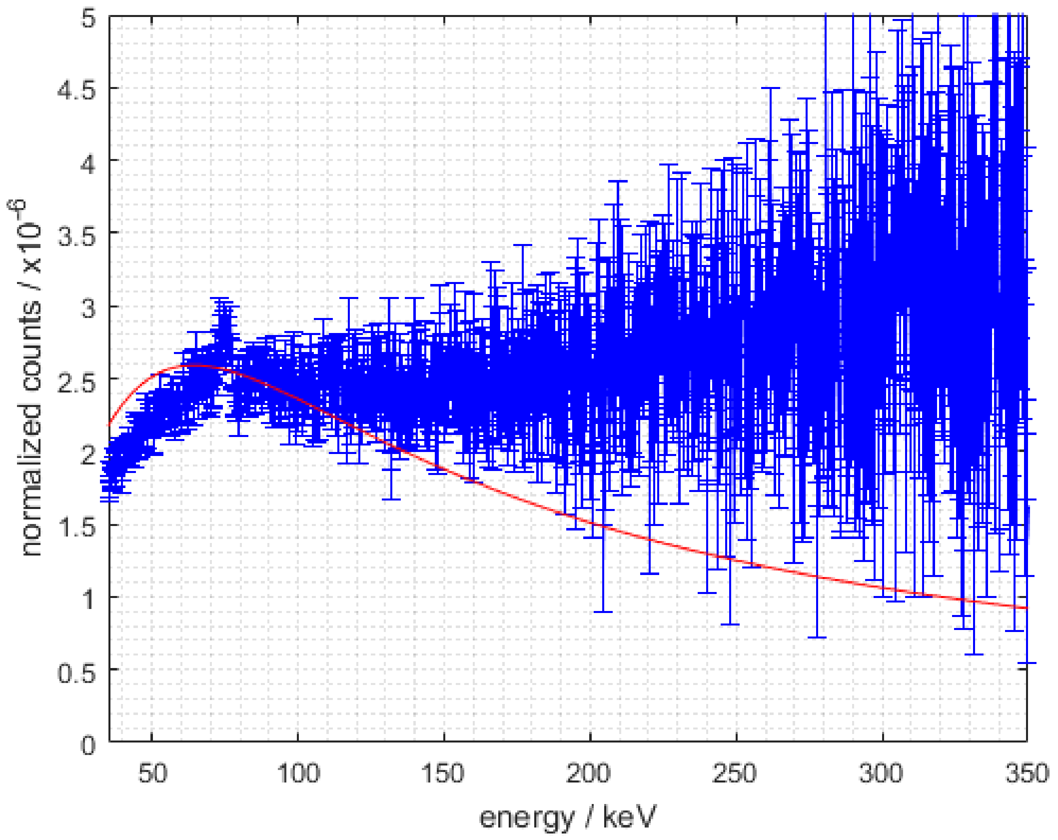


→ see talk A. Potylitsyn

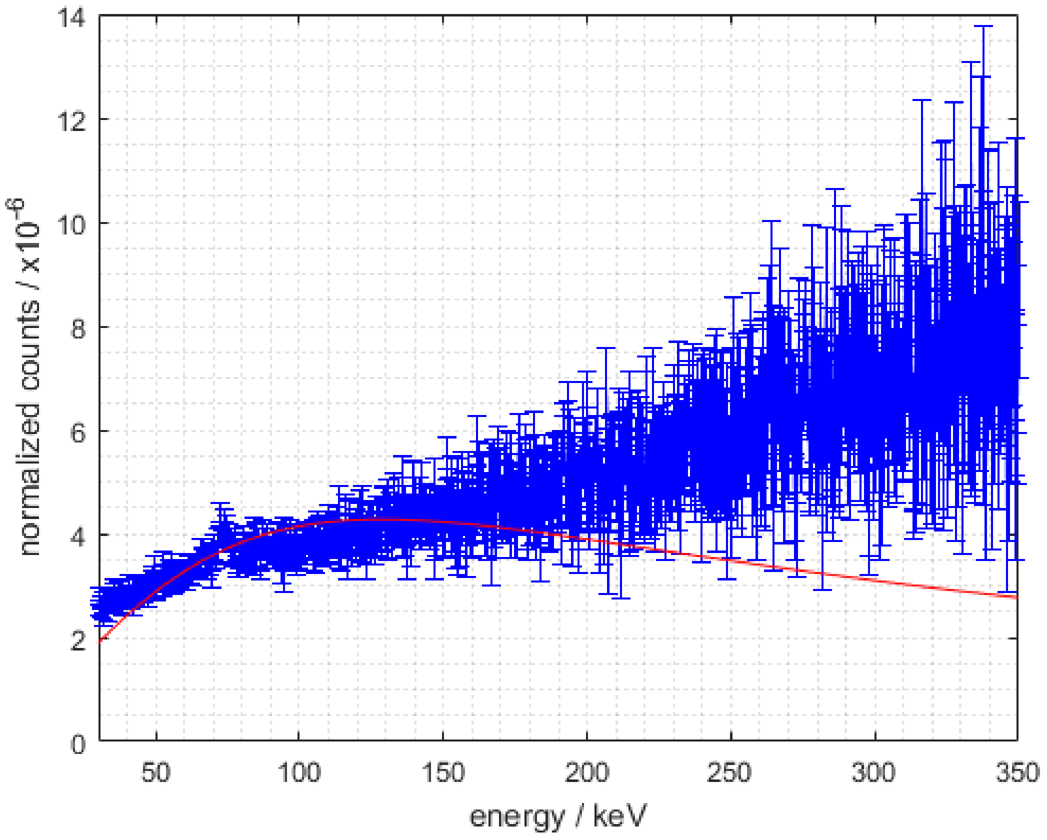
Comparison of spectral Shape

Bremsstrahlung

1 GeV



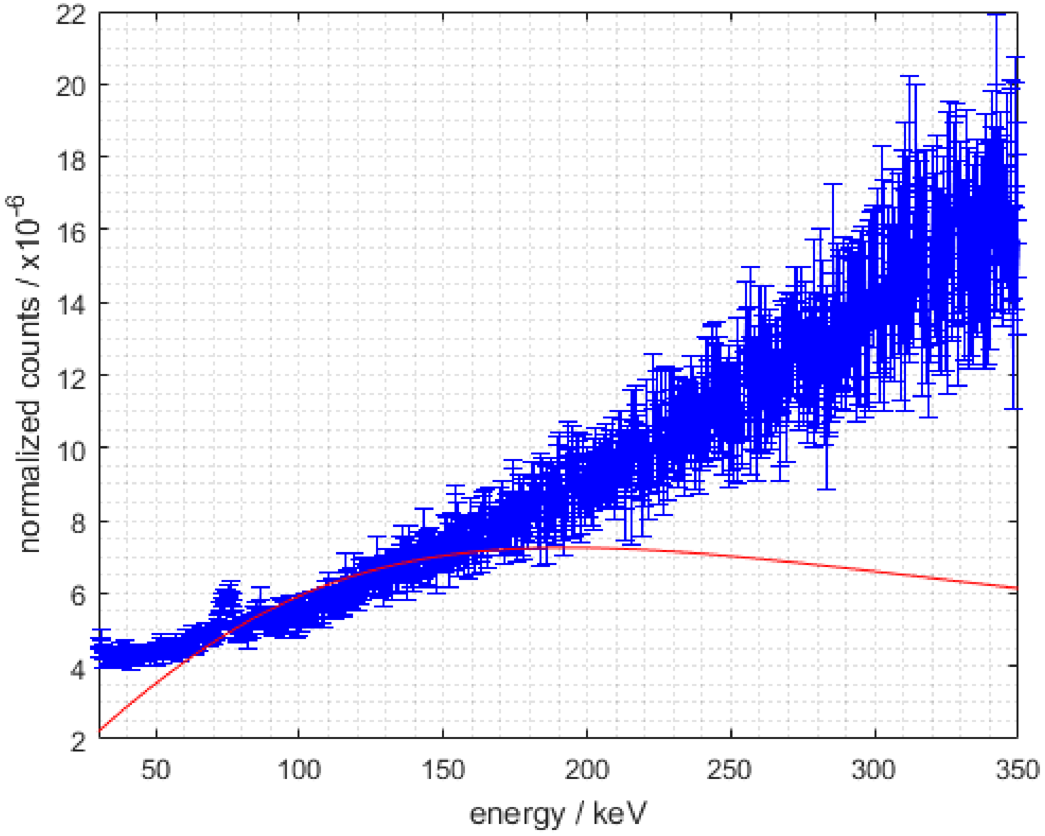
2 GeV



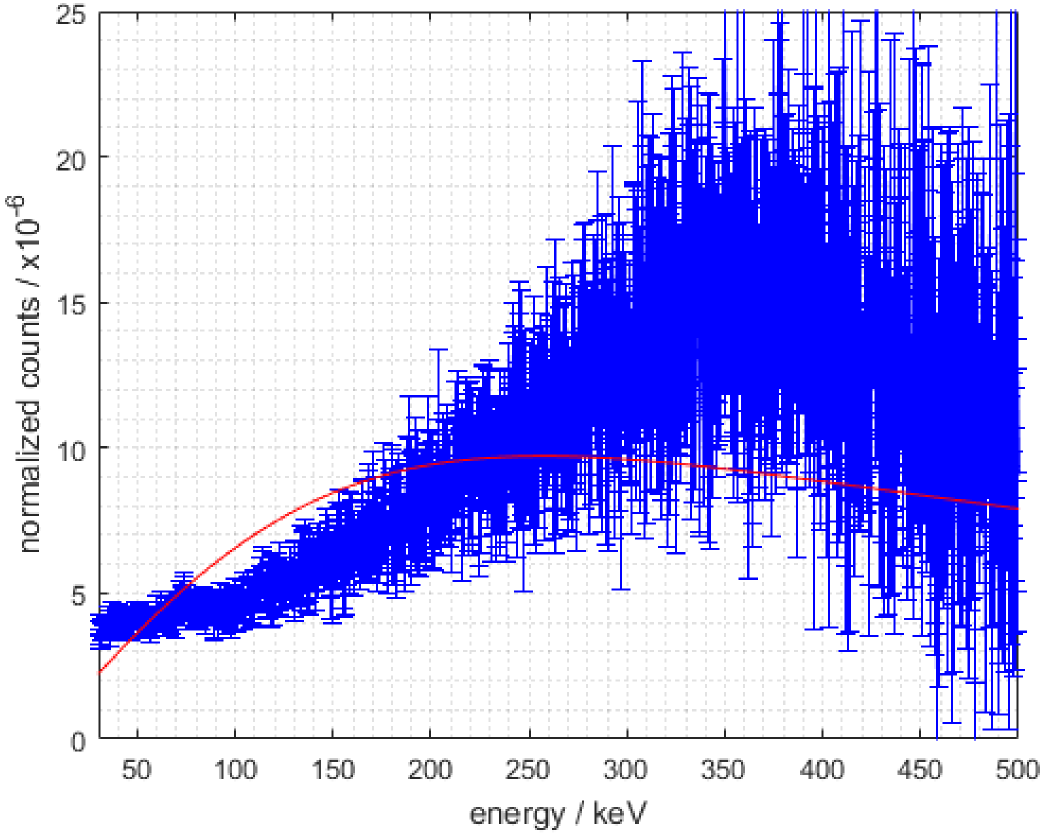
Comparison of spectral Shape

Bremsstrahlung

3 GeV



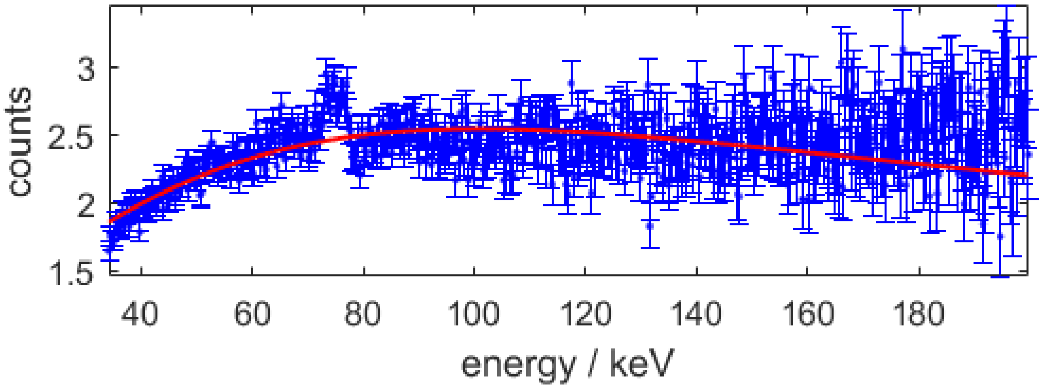
4 GeV

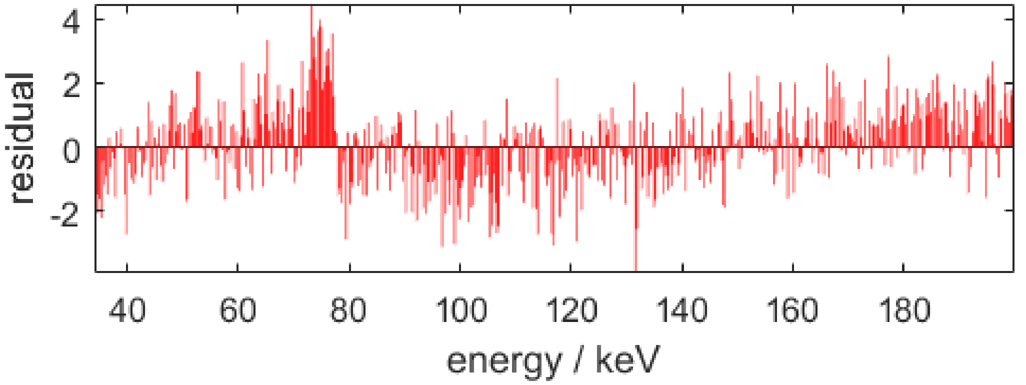


Fit Attempt

Spectral Shape

1 GeV





fit function: $$f(\hbar\omega) = \frac{1}{1 + \frac{GamOmP2}{(\hbar\omega)^2}} \cdot \frac{Amp}{\hbar\omega} + BG$$

*** Fit Results ***
Chi2 = 912.084 (DoF: 583)
reduced Chi2 = 1.564

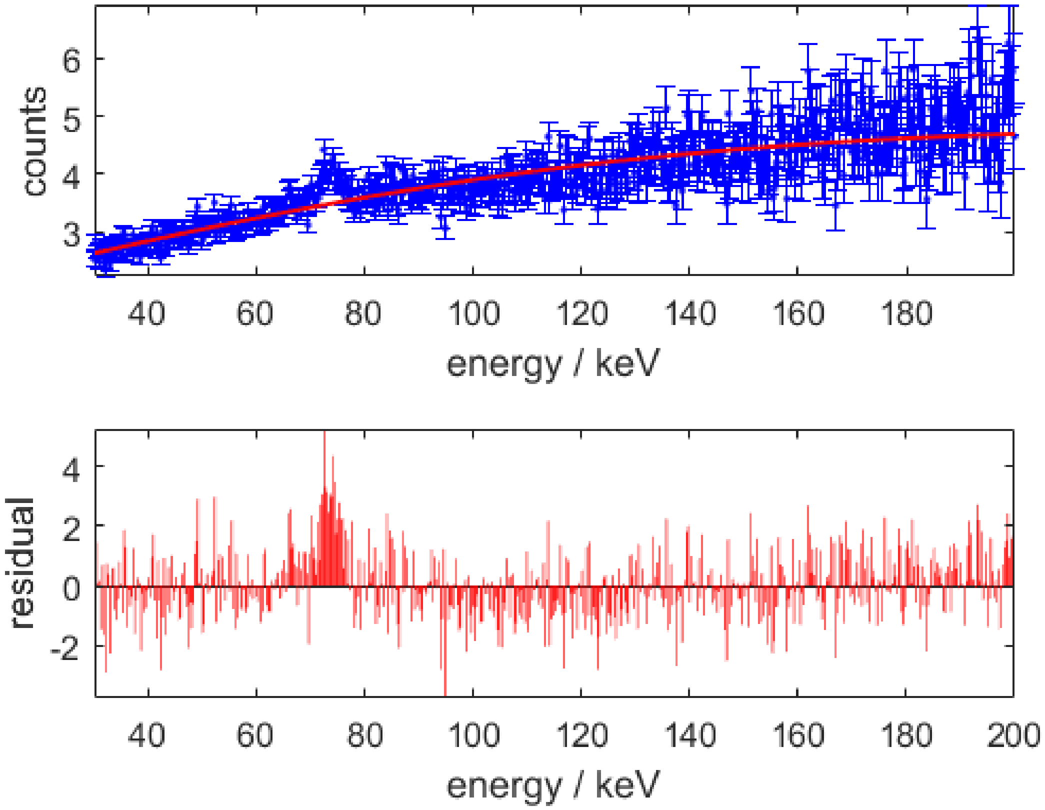
Amp	352.62	+/-	11.8773
GamOmP2	10163.9304	+/-	318.7648
BG	0.79605	+/-	0.066023

plasma frequency: (51.52 +/- 0.46) eV

Fit Attempt

Spectral Shape

2 GeV



fit function: $$f(\hbar\omega) = \frac{1}{1 + \frac{GamOmP2}{(\hbar\omega)^2}} \cdot \frac{Amp}{\hbar\omega} + BG$$

*** Fit Results ***
Chi2 = 838.339 (DoF: 596)
reduced Chi2 = 1.407

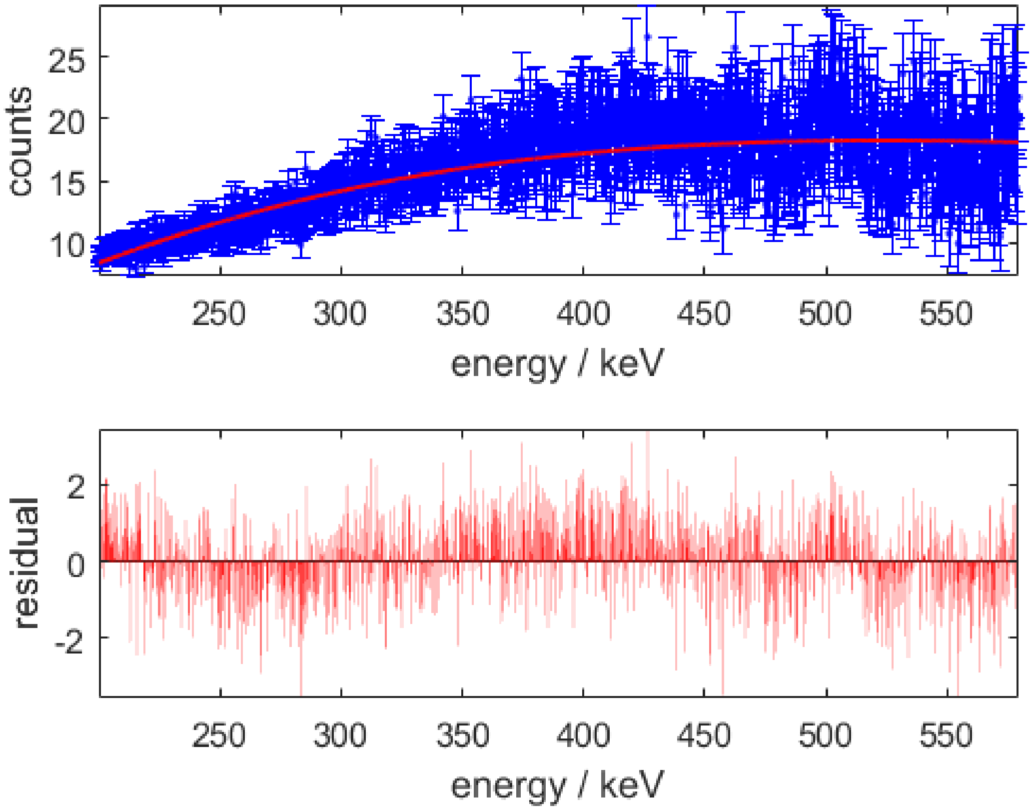
Amp	1387.9776	+/-	103.5016
GamOmP2	61733.0833	+/-	6980.5519
BG	1.9657	+/-	0.048186

plasma frequency: (126.96 +/- 0.72) eV

Fit Attempt

Spectral Shape

3 GeV



fit function: $$f(\hbar\omega) = \frac{1}{1 + \frac{GamOmP2}{(\hbar\omega)^2}} \cdot \frac{Amp}{\hbar\omega} + BG$$

*** Fit Results ***
Chi2 = 1578.924 (DoF: 1337)
reduced Chi2 = 1.181

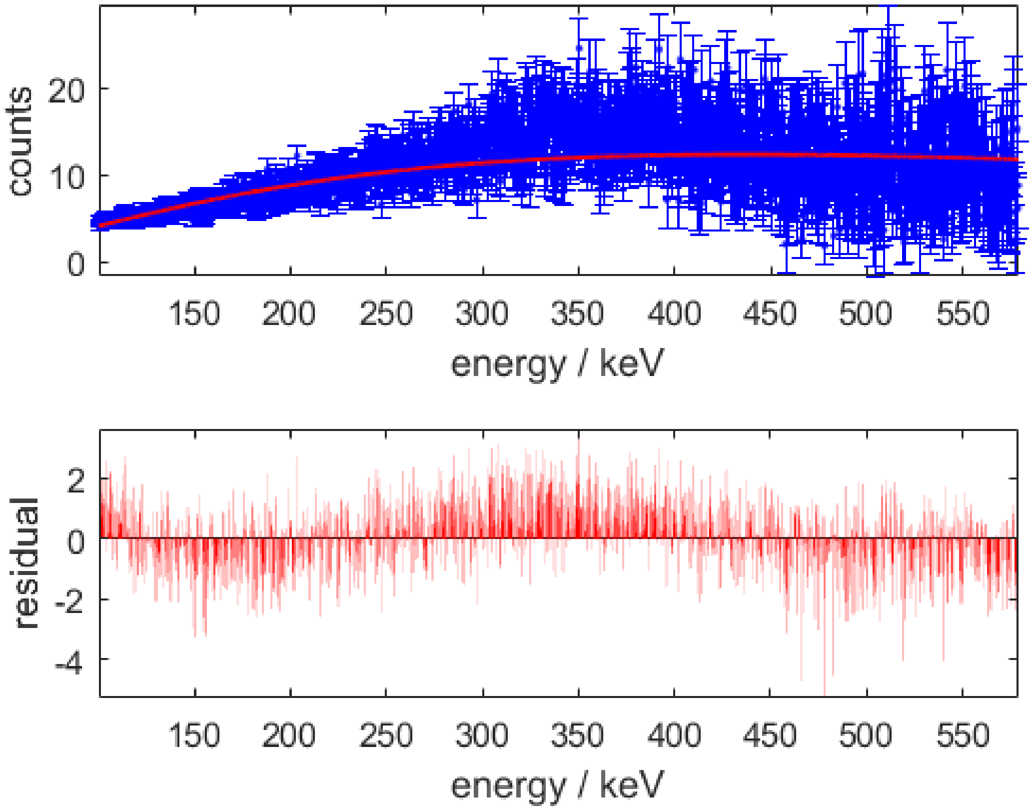
Amp	31000.7296	+/-	405.3317
GamOmP2	274413.9047	+/-	10059.8579
BG	-11.3192	+/-	0.78397

plasma frequency: (89.23 +/- 0.00) eV

Fit Attempt

Spectral Shape

4 GeV



fit function: $$f(\hbar\omega) = \frac{1}{1 + \frac{GamOmP2}{(\hbar\omega)^2}} \cdot \frac{Amp}{\hbar\omega} + BG$$

*** Fit Results ***
Chi2 = 2334.584 (DoF: 1685)
reduced Chi2 = 1.386

Amp	12739.4752	+/-	265.7728
GamOmP2	191472.1327	+/-	8459.7103
BG	-2.249	+/-	0.23905

plasma frequency: (223.60 +/- 0.00) eV

Summary & Conclusion

- investigation of bremsstrahlung emission from 10 mm Al target
  - two beamtimes: April & May 2024
- target position in center of magnet allows to suppress background level
  - measurement of spectra with reasonable accuracy possible
- measurements performed with CdTe detector
  - positron energies of E = 1, 2, 3, 4 GeV
- spectra show suppression at low beam energies
  - shapes do not correspond to expected ones
- improved background correction necessary
  - TR from single boundary
  - SR emission in BRM magnet
- experimental improvement:
  - detector with higher efficiency for high photon energies would help…

Contact

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