IX International Symposium
RREPS-11
RADIATION from RELATIVISTIC ELECTRONS
in PERIODIC STRUCTURES

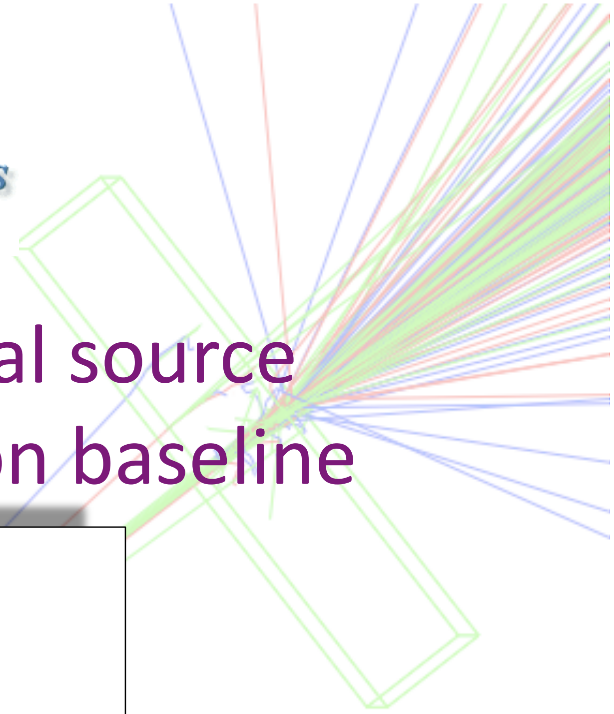
An event generator for crystal source
Application of the CLIC positron baseline

O. Dadoun, LAL Orsay
RRPES-11 RHUL, September 2011
dadoun@lal.in2p3.fr

G. Lemeur, F. Touze, A. Variola& C. Xu (LAL, France)
X. Artru, R. Chehab & M. Chevalier (IPNL, France)
L. Rinolfi & A. Vivoli (CERN)
V. Strakhovenko (BINP)

LABORATOIRE
DE L'ACCÉLÉRATEUR
LINÉAIRE

IX International Symposium
RREPS-11
RADIATION from RELATIVISTIC ELECTRONS
in PERIODIC STRUCTURES



An event generator for crystal source
Application of the CLIC positron baseline

Outline

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Introduction

High intensity e^+ requires at ILC / CLIC

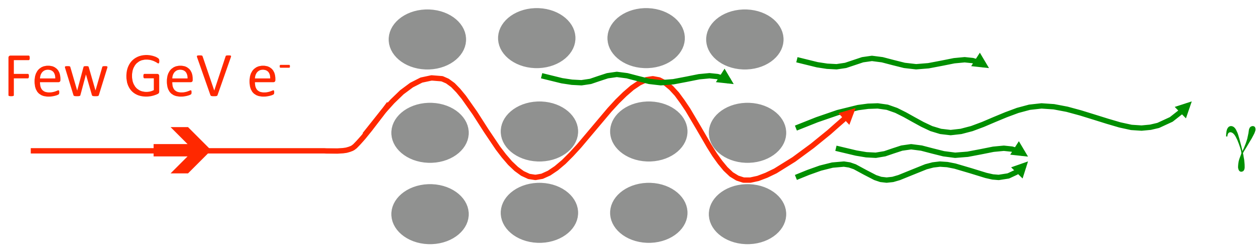
- Radiator : intense source of photons is needed
  - Polarized : undulator & laser-Compton
  - Unpolarized : amorphous & crystal
- Converter : material with a high Z (W)
- Capture section after the converter
  - Optical Matching Device to focus the e^+
  - Pre-injector to accelerate the beam before injection to DR

Introduction

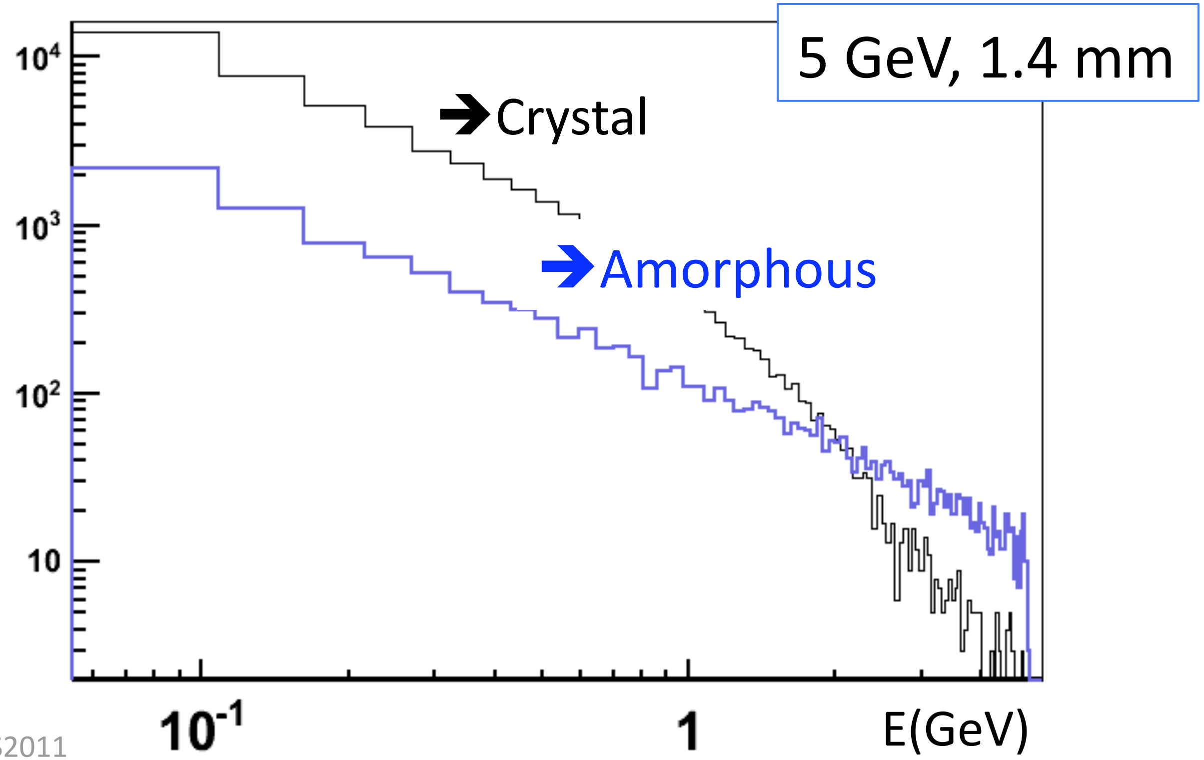
- The conventional scheme using a thick amorphous target presents some difficulties due to high energy deposition
  - Heating ➔ melting target
  - Energy deposition density ➔ target breakdown
    Peak Energy Density Deposition, PEDD < 35 J/g (SLC)
- Decreasing the energy deposition
  - ➔ Reduce the target thickness
  - ➔ Limit the energy in the target
- One solution has been developed since some years using the association of a crystal and an amorphous targets : hybrid source
  - Use a thin crystal radiator to provide an important photon flux

Crystal vs amorphous target

A few GeV electron beam aligned to a <1 1 1> oriented W crystal



Enhancement of γ production w.r.t. to pure Bremsstrahlung process

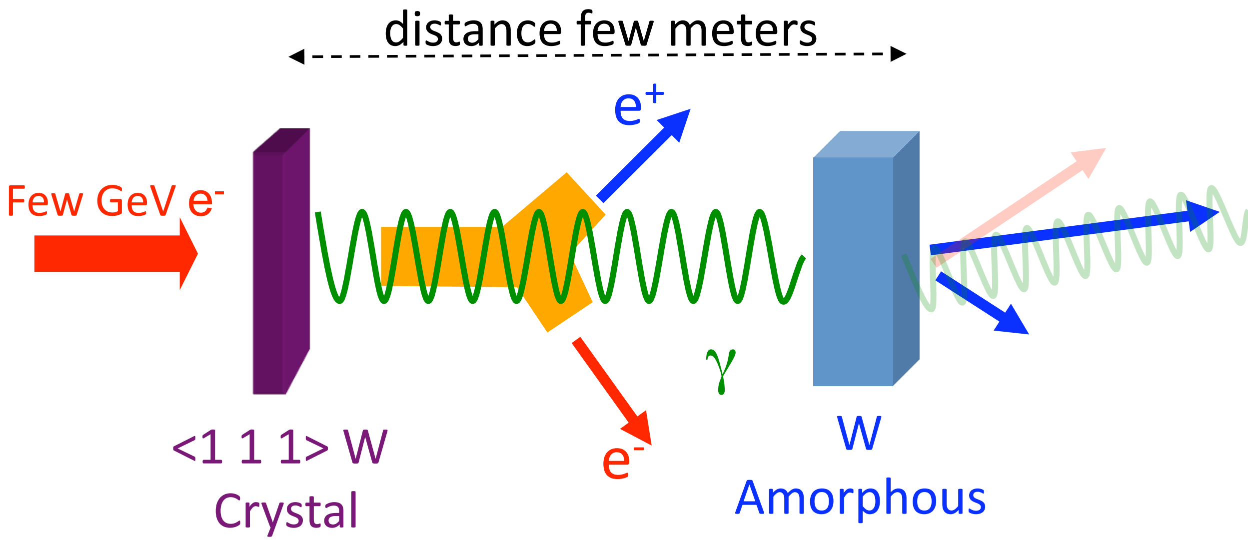


Introduction

- The conventional scheme using a thick amorphous presents some difficulties due to energy deposition
  - Heating : melting target
  - Energy deposition density : breakdown target
    Peak Energy Density Deposition, PEDD < 35 J/g (SLC)
- Decreasing the energy deposition on the convertor
  - Reduce the target thickness
  - Limit the energy on the target
- One solution has been developed using the association of a crystal and an amorphous targets : Hybrid source
  NIMB 266 2008 3868-3875
  - Use a tiny crystal radiator to provide a huge photons flux
  - Spent the charged particle between radiator & converter

Hybrid scheme : presentation

DR -IP



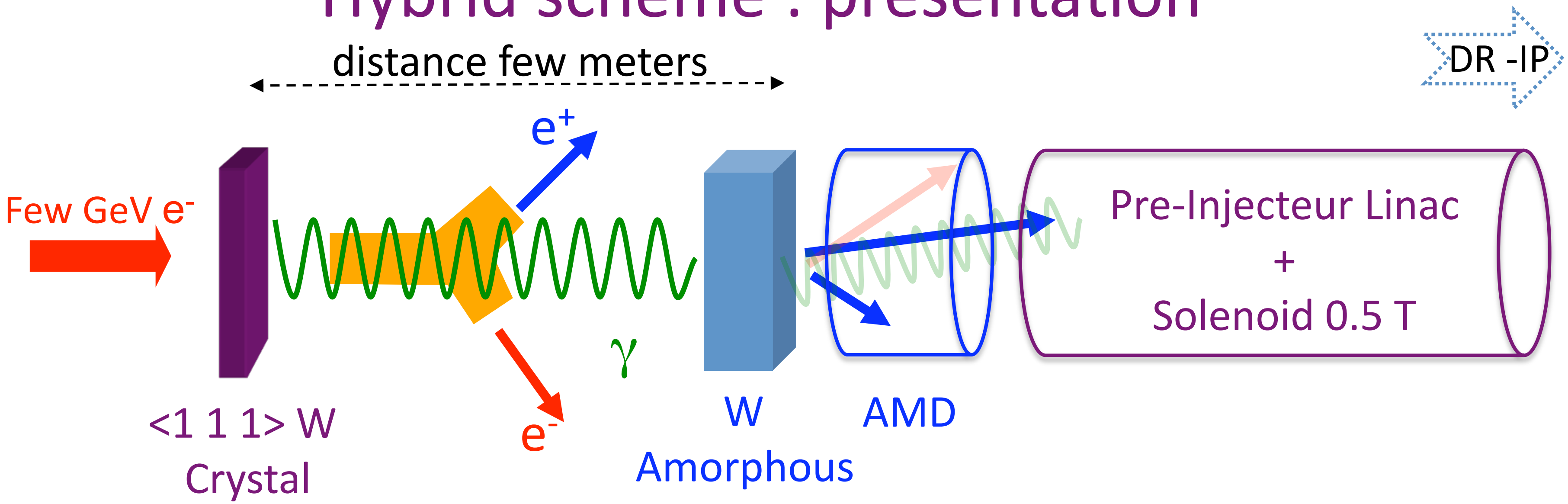
1. Crystal W thickness few mm

2. Amorphous thickness several mm

   How far this converter is located from the radiator ?

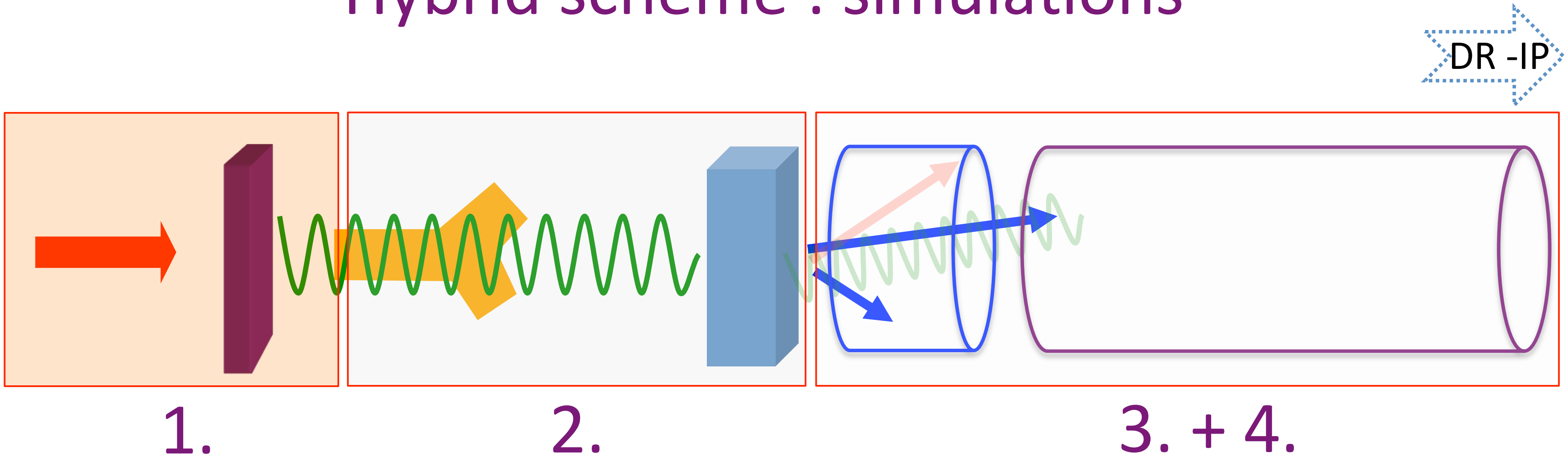
   (sweeping magnet to take off charged particles)

Hybrid scheme : presentation



1. Crystal W thickness few mm
2. Amorphous thickness several mm
3. Optical Matching Device
4. Pre-injector linac encapsulated in 0.5 T axial magnetic field

Hybrid scheme : simulations



1. Crystal W thickness few mm
   - VMS (Prof. V. M. Strakhovenko) & FOT (Prof. X. Artru)
2. Amorphous thickness several mm
   - Geant4, Fluka & EGS ✔
3. Matching lens
   - Geant4 & standard accelerator code such (Parmela, Astra ..) ✔
4. Pre-injector linac encapsulated in 0.5 T axial magnetic field
   - Geant4 & Standard accelerator code such (Parmela, Astra ..) ✔

Hybrid scheme : simulations

- To simulate the hybrid source : at least two different simulations
  1. Crystal simulation
  2. Amorphous + capture section : Geant4
- Why not trying to add the physics processes occurring in a crystal inside Geant4 ?
- Fot simulates
  - Channeling radiation, Coherent and incoherent Bremsstrahlung
  - Pair creation is not taken into account
- Simulate the crystal behaviour in Geant4
  - Add new physics processes such as channeling radiation or coherent bremsstrahlung can be handled but it is difficult
  - Since FOT simulates only the photons use it as an event generator
  - FOT in Fortran should be converted in C^{++} ➔ FOT^{++}

Fot history

NA33 CERN experiment [Belkacem et al.]
150 GeV γ or e- impinging on 185 µm of crystal germanium oriented on its <110> axis

- With γ beam, it confirmed the strong field QED mechanism of pair creation
- With the e- beam radiation was much more intense than expected
- An unexpected peak @ (radiated energy)/(incident energy)=0.8

This peak was explained as an effect of transverse energy loss which accompanies channelling radiation
[V. Tikhomirov, X. Artru, V. Baier, V. Katkov and V. Strakhovenko]

Fot simulation

A simulation code for channeling radiation by ultra relativistic e^- or e^+

X. Artru built a MC Fortran simulation code using the Baier-Katkov formula for synchrotron radiation in non-uniform field
[X. Artru, NIM B48(1990)]

The code has been used to :

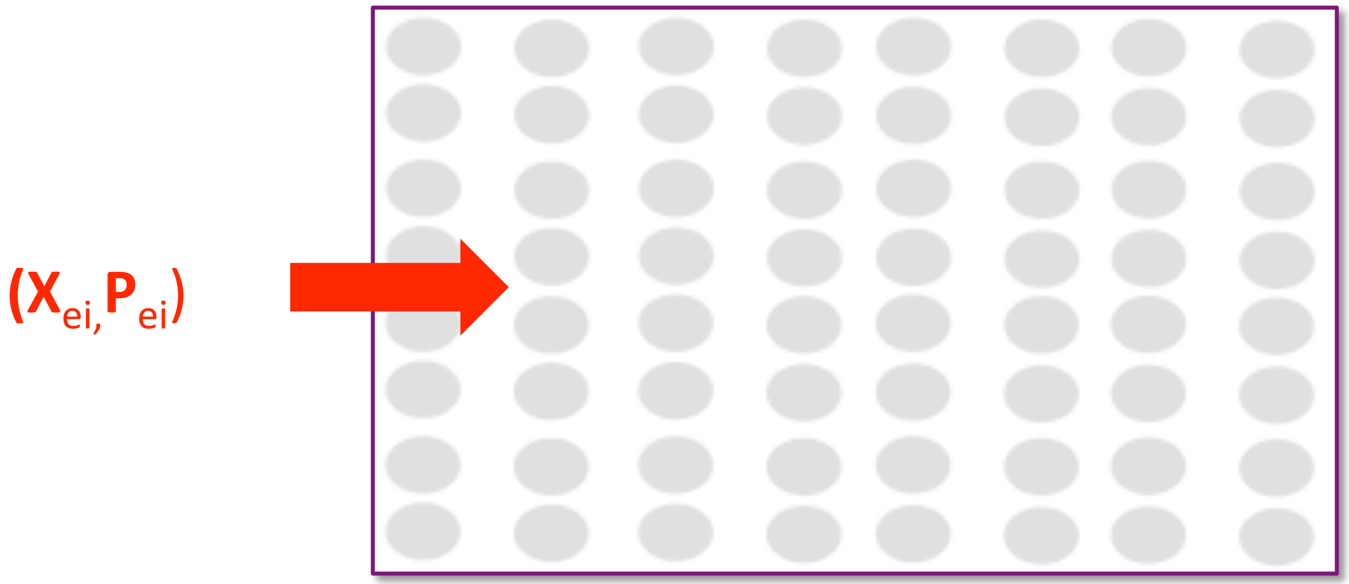
- Present a proposition of positron source using channelling (PAC 1989)
- Simulate the proof of principle experiment at Orsay (1992-93)
- Reproduce the results of a channelling radiation experiment @ 10 GeV [E.N. Tsyganov et al(1989)]
- Interpret another CERN experiment [Phys. Lett. B313 (1993)]

Fot^{++} + Geant4 : G4Fot

Important comments :

- No pair creation generation inside the crystal
- An un-channelled e^- is ejected from FOT simulation even if it is still in the crystal

if its angle (Ψ_t) & transverse energy (E_t) upper than a specified limit

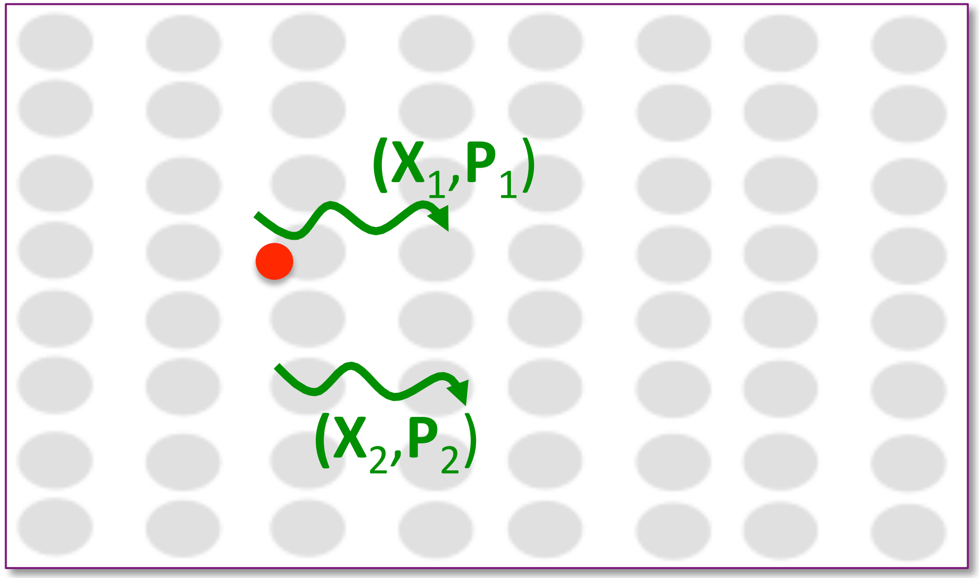


Phase I : Fot^{++} step

During the propagation of the e^- in the crystal

- Channeling radiation $\Psi_t < \Psi_t^{max*}$ & $E_t < E_t^{max*}$
- Coherent Bremsstrahlung $\Psi_t > \Psi_t^{max}$ & $E_t > E_t^{max}$
- Incoherent Bremsstrahlung $\Psi_t >> \Psi_t^{max}$ or $E_t >> E_t^{max}$

Photon phase space is stored …



* $\Psi_t^{max} \approx 10$ mrad , $E_t^{max} \approx 100$keV

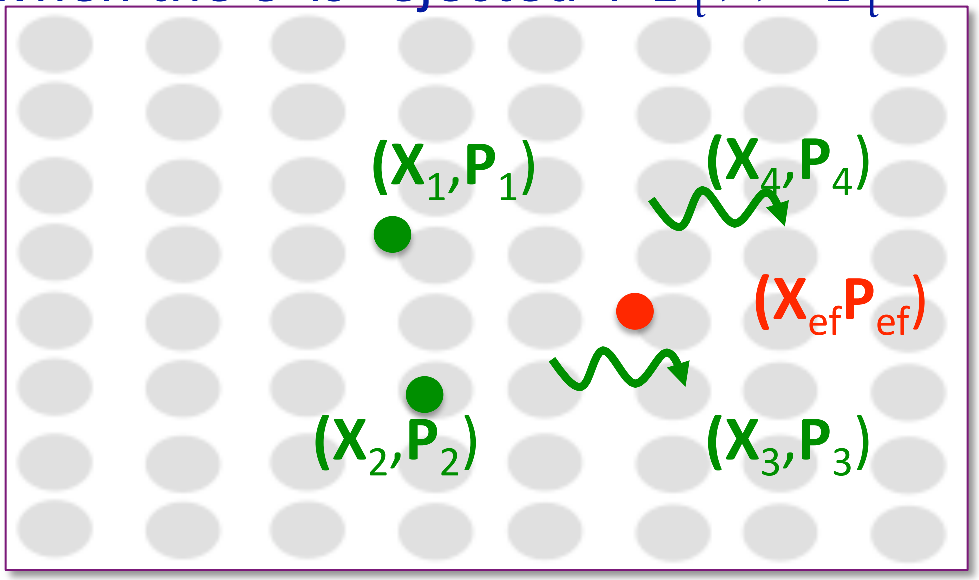
Phase I : Fot^{++} step

During the propagation of the e^- in the crystal

- Channeling radiation $\Psi_t < \Psi_t^{max*}$ & $E_t < E_t^{max*}$
- Coherent Bremsstrahlung $\Psi_t > \Psi_t^{max}$ & $E_t > E_t^{max}$
- Incoherent Bremsstrahlung $\Psi_t >> \Psi_t^{max}$ or $E_t >> E_t^{max}$

Photon phase space is stored … and also for the ejected e^-

Simulation stop when the e^- is "ejected": $\Psi_t >> \Psi_t^{max}$ & $E_t >> E_t^{max}$…



Phase II : Geant4 step

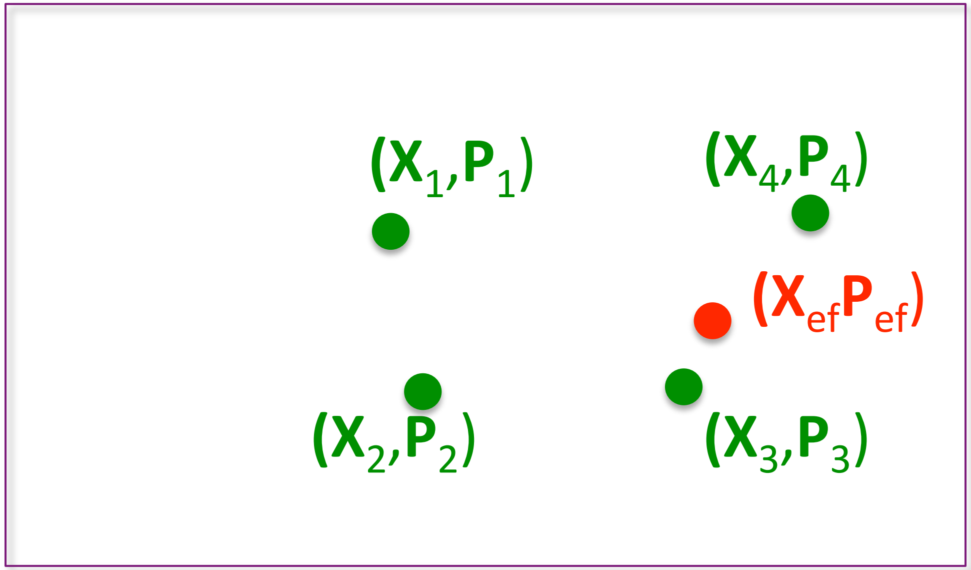
.. then in the program Geant4 takes the γ and e^- control :

the crystal considered as a pure amorphous

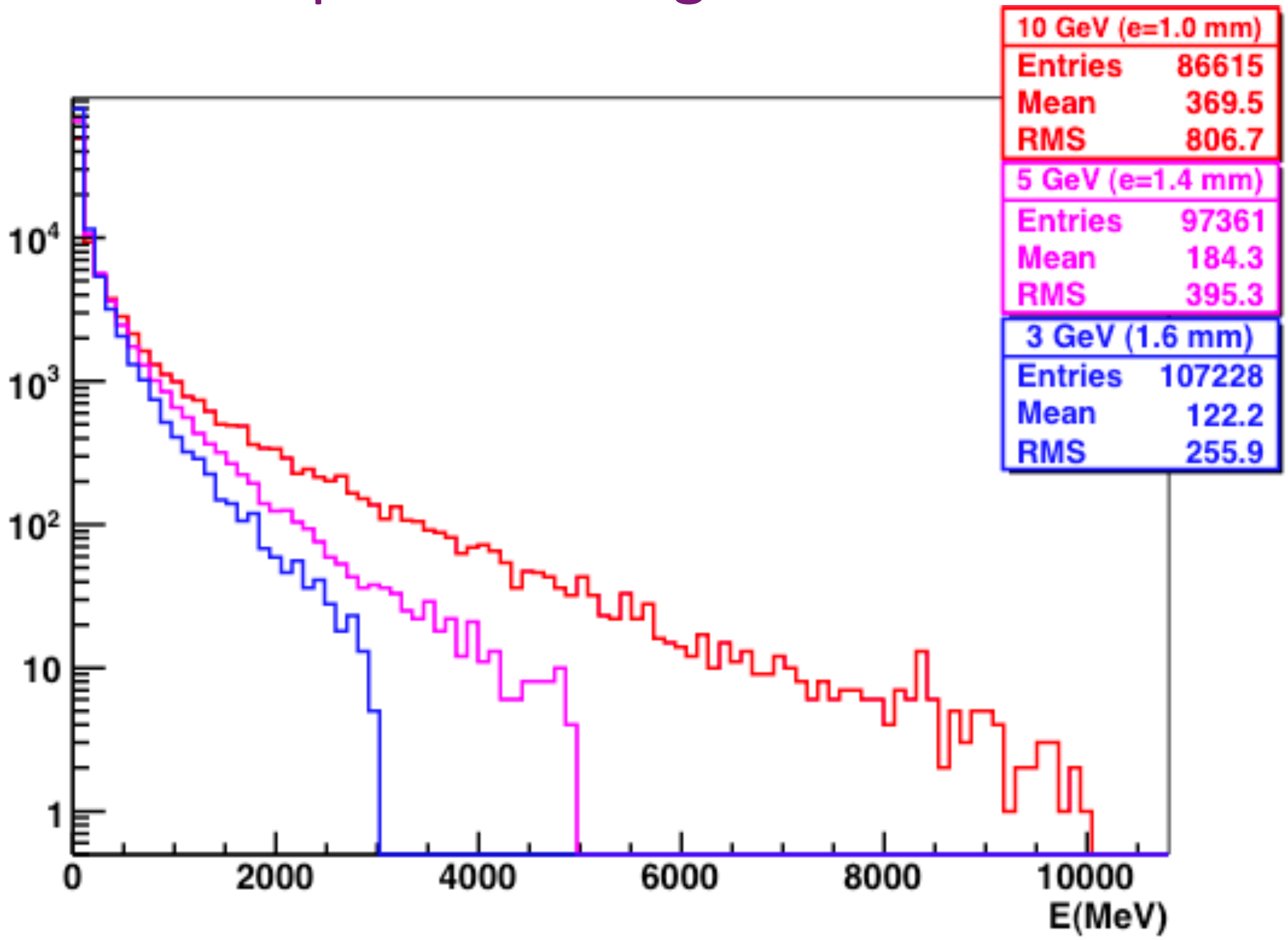
- Propagations
- Physics processes (pair creation …)

The particles are "inserted" in Geant4 via the Primary Generator Action class

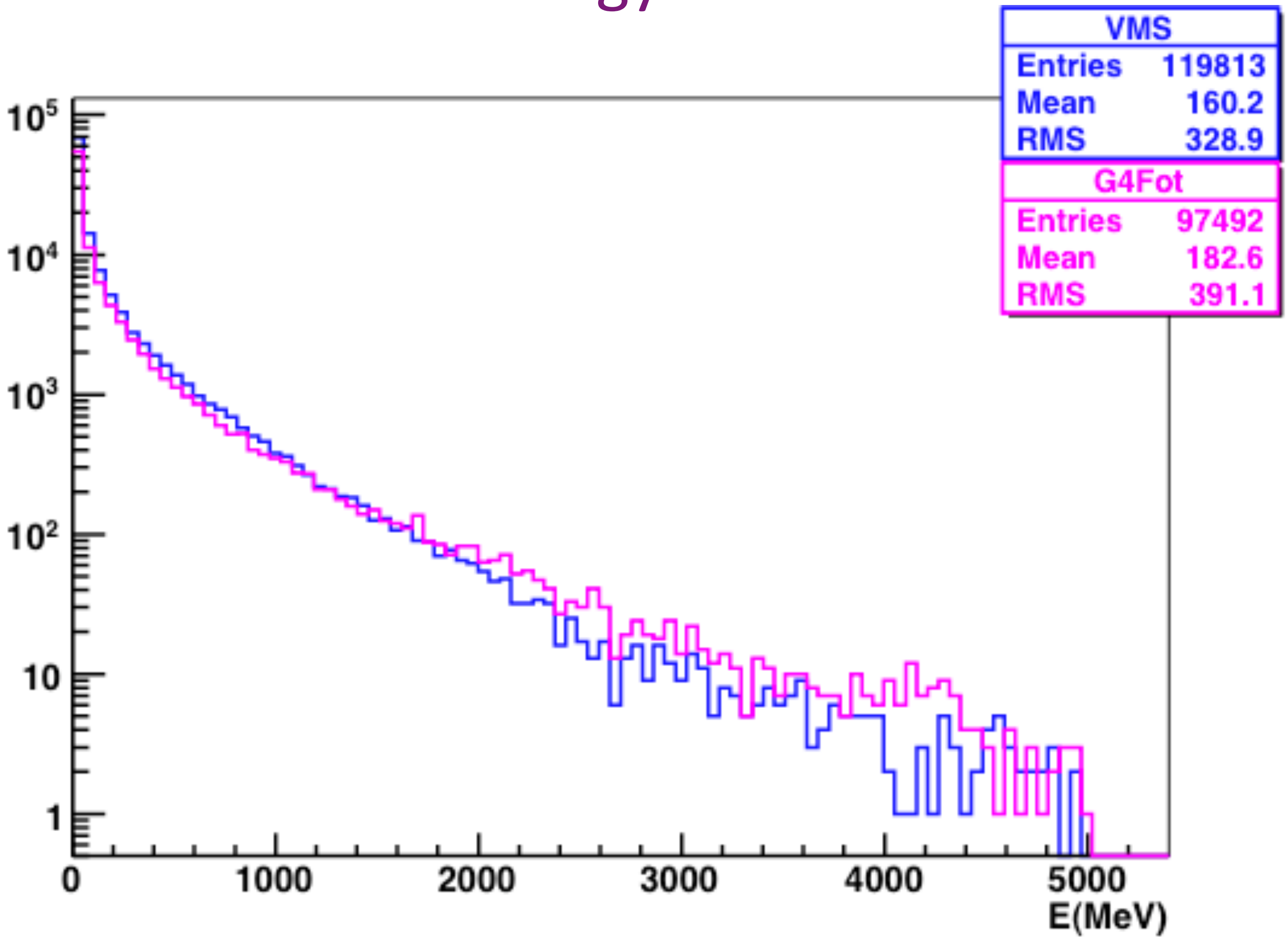
(G4VUserPrimaryGeneratorAction)



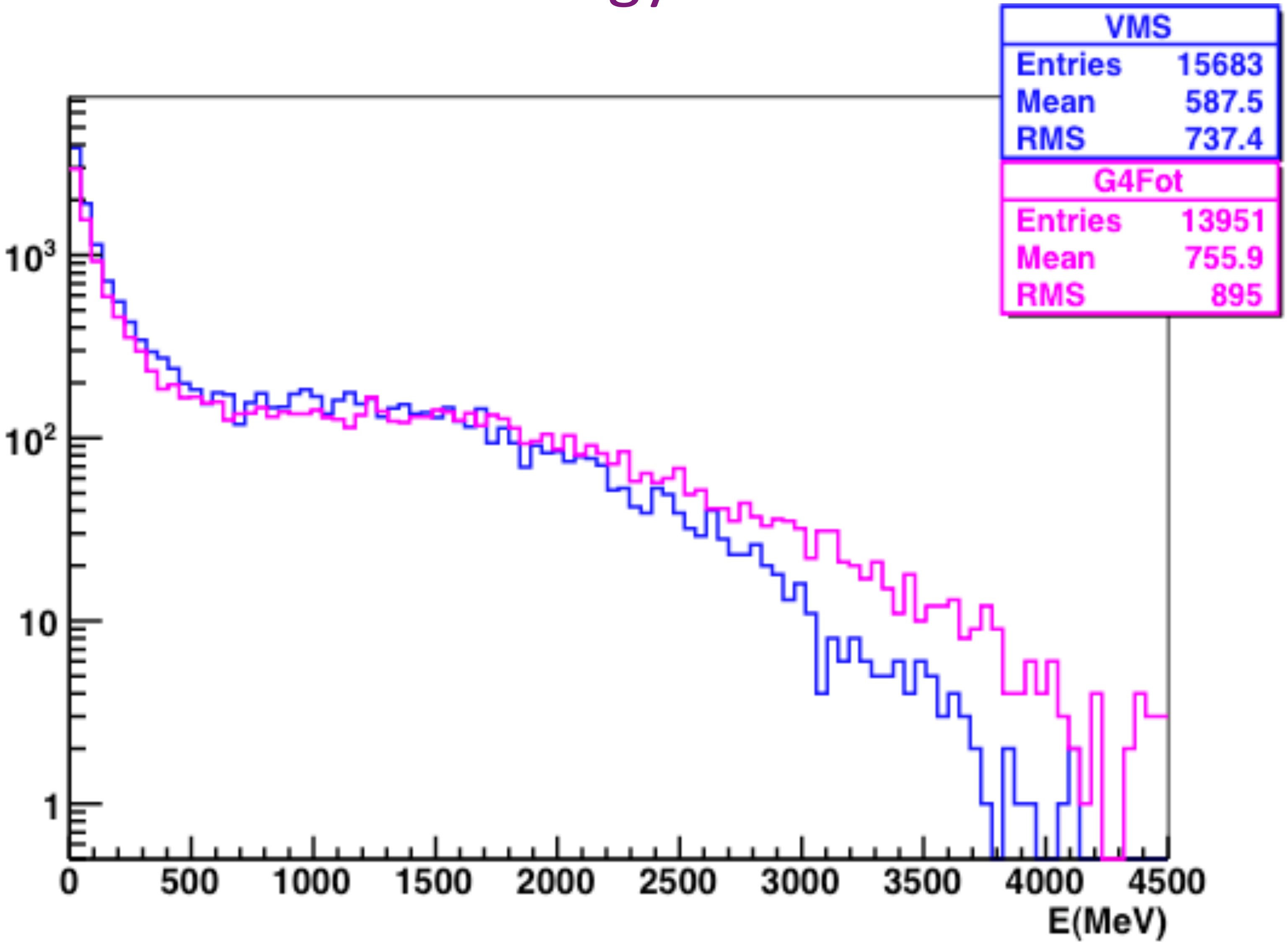
Results: photon energies distributions



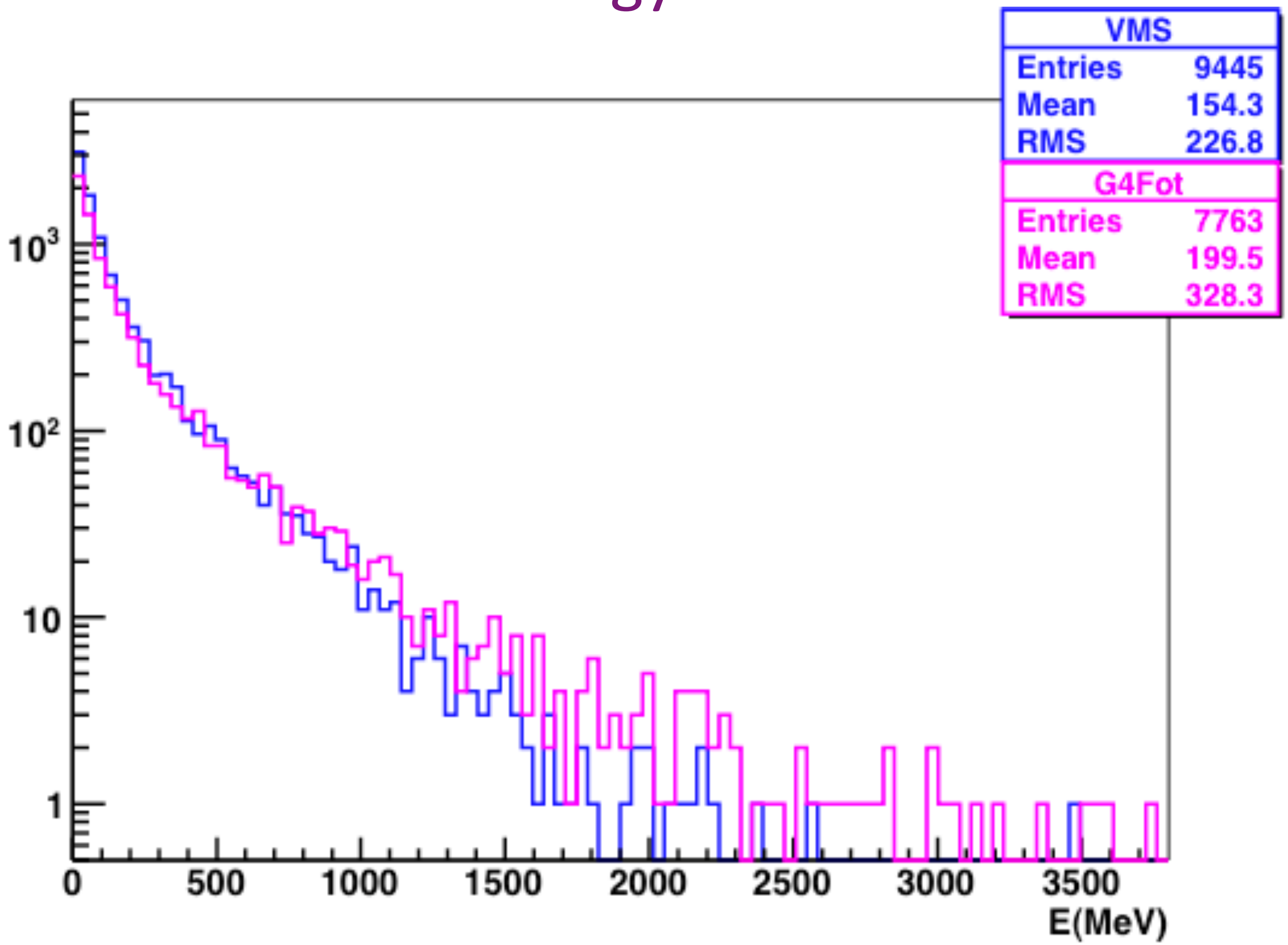
Benchmark: 5 GeV incident e- beam (t=1.4 mm) Photon energy distribution



Benchmark: 5 GeV incident e- beam (t=1.4 mm)
Electron energy distribution



Benchmark: 5 GeV incident e- beam (t=1.4 mm)
Positron energy distribution



G4Fot vs. VMS

- G4Fot seems to give more energetic photons, e- & e+ than VMS
- G4Fot seems to give less particle multiplicity than VMS
- Depending on the incident e^- beam energy

about 15 to 20 % difference is observed between both codes

G4Fot do not consider second generation photon :

e^-e^+ produced by pair creation in the crystal

→ their rechanneling is not considered

The CLIC e+ baseline presented in the following slides is based

on a the CLIC note 808.

At that times only VMS (plus Geant4) simulation were used.

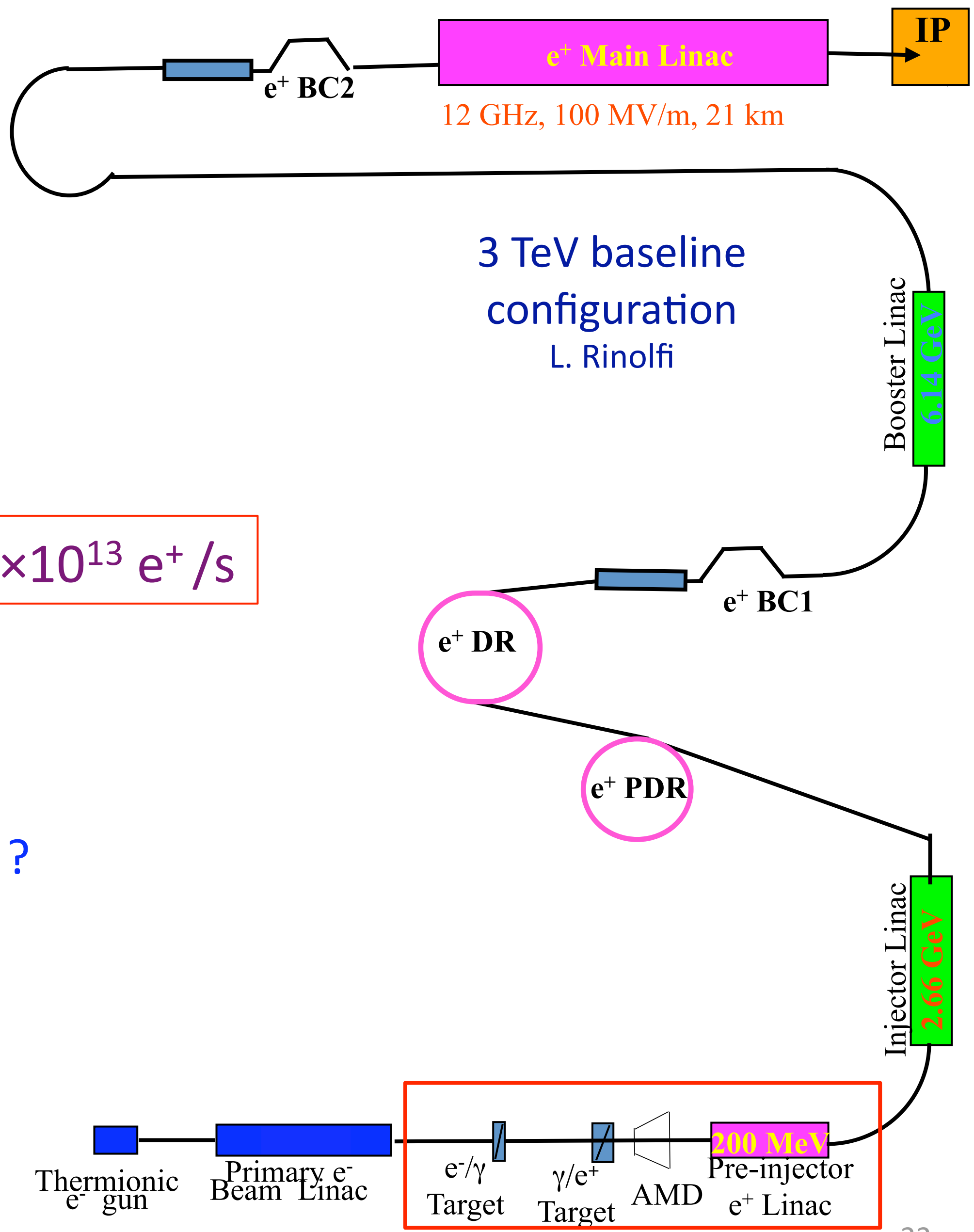
CLIC positron complex

- CLIC : Compact LInear Collider
- Need an intense e^+ source @ IP
  - $\#e^+$/bunch : 3.7×10^9
  - #bunches/train : 312
  - Repetition : 50 Hz

5.8×10^{13} e^+ /s

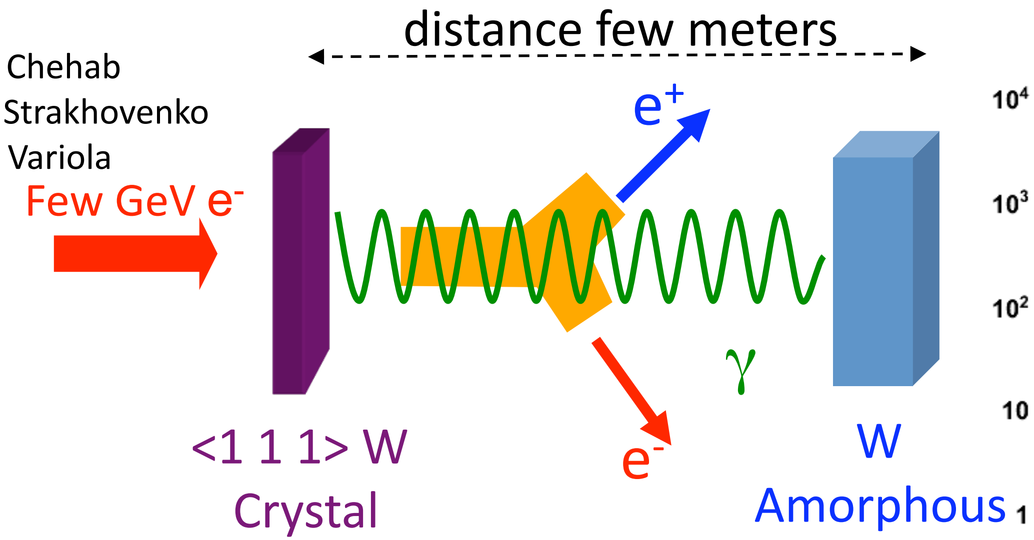
- Hybrid scheme is the e^+ baseline
  - Primary e^- beam energy (<10 GeV) ?

    Studied cases : 3, 4, 5 & 10 GeV
  - Targets thicknesses ?
  - Distance radiator convertor ?

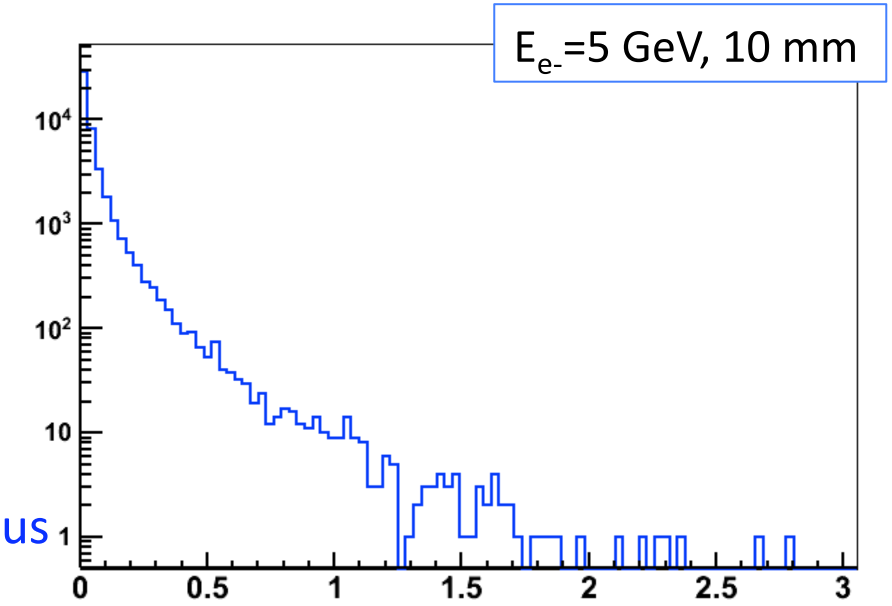


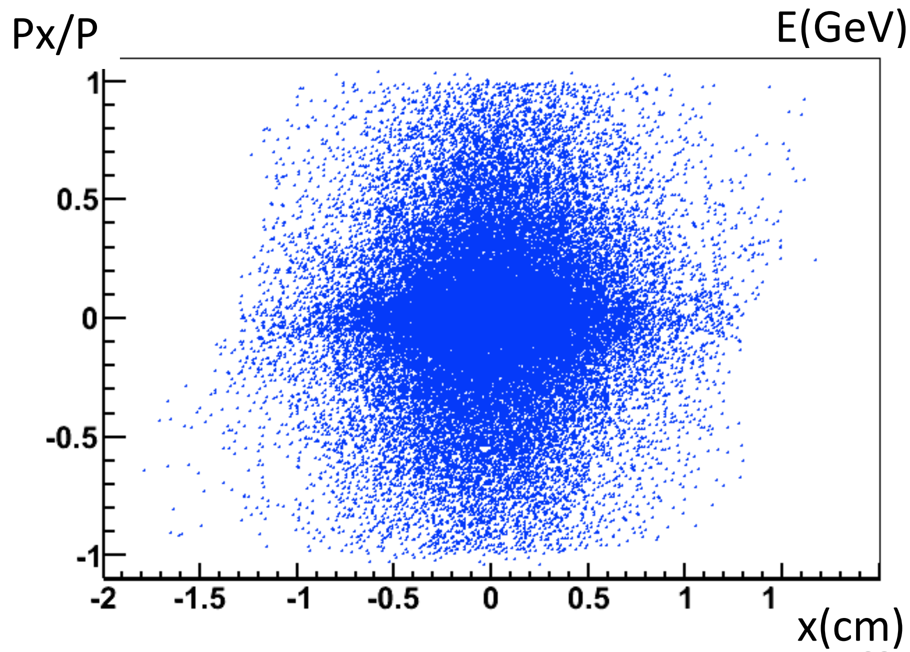
Hybrid source : CLIC positrons baseline

R. Chehab
V. Strakhovenko
A. Variola

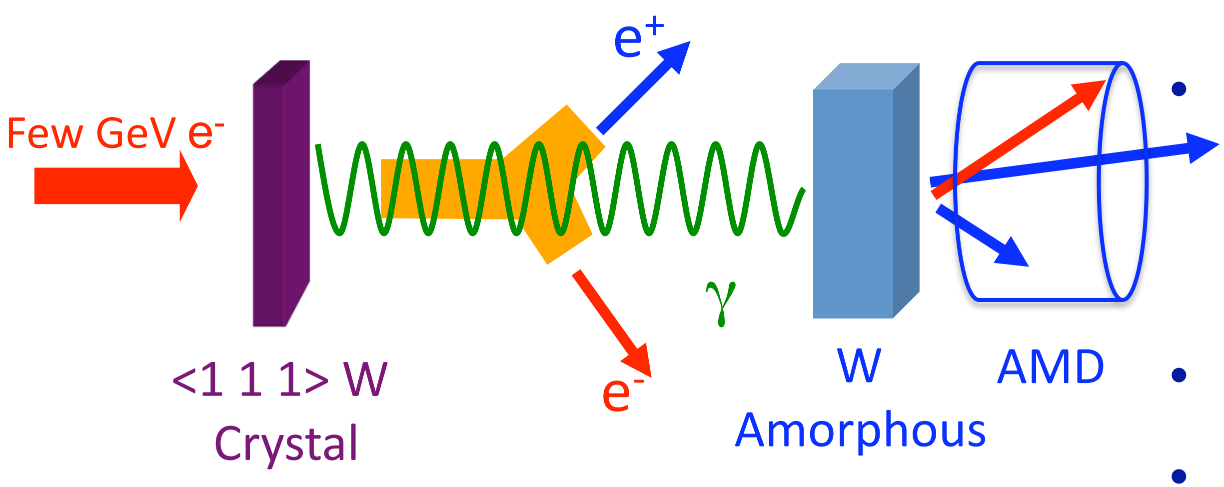


- Crystal thickness few mm
- Amorphous thickness several mm
- e^+ yield (Ne^+/Ne^-) : 5 to 15
- $<E_{e+}>$: 40 to 70 MeV
- After the amorphous
  - Large angles & small dimension
- Matching lens
  - Adiabatic Matching Device (AMD)

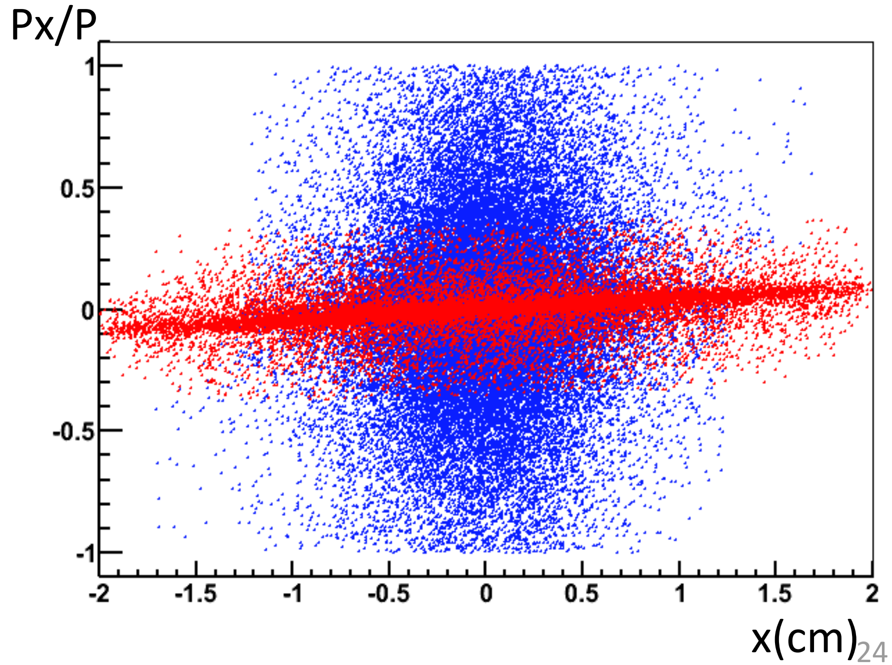




AMD effect on the positron beam



- $B(z)=B_0/(1+\alpha z)$
  - B_{max} = 6 T, B_0 =0.5 T
  - L=0.2 cm
- e^+ yield (Ne^+/Ne^-) 1 to 4
- $<E_{e+}>$: 50 to 110 MeV

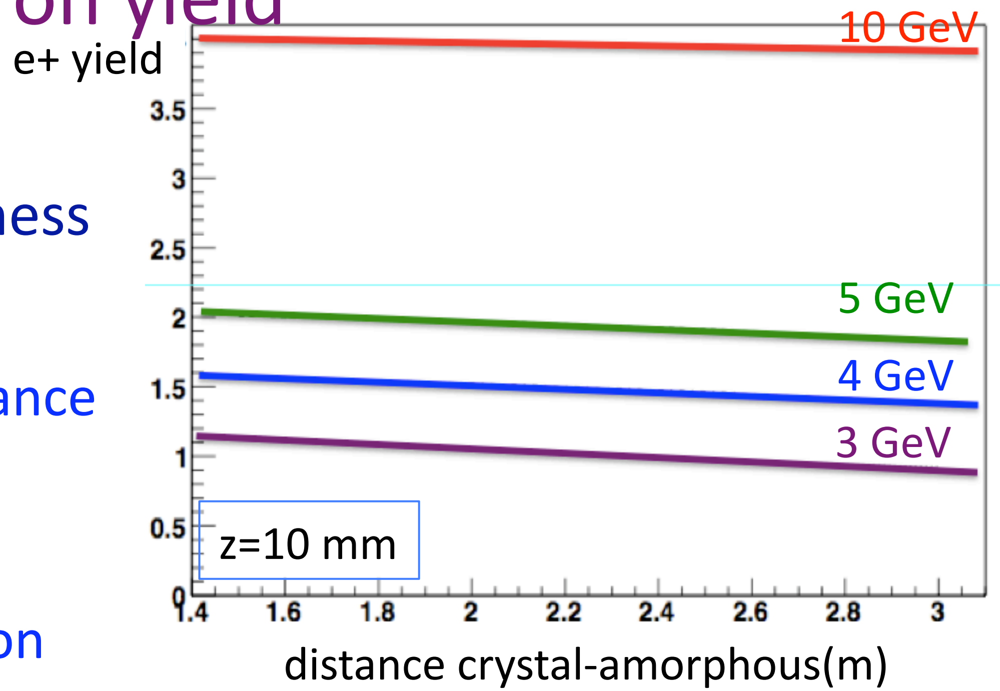


- After the AMD

  Small angles & large dimensions

  easier to transport
- Distance crystal – amorphous studies

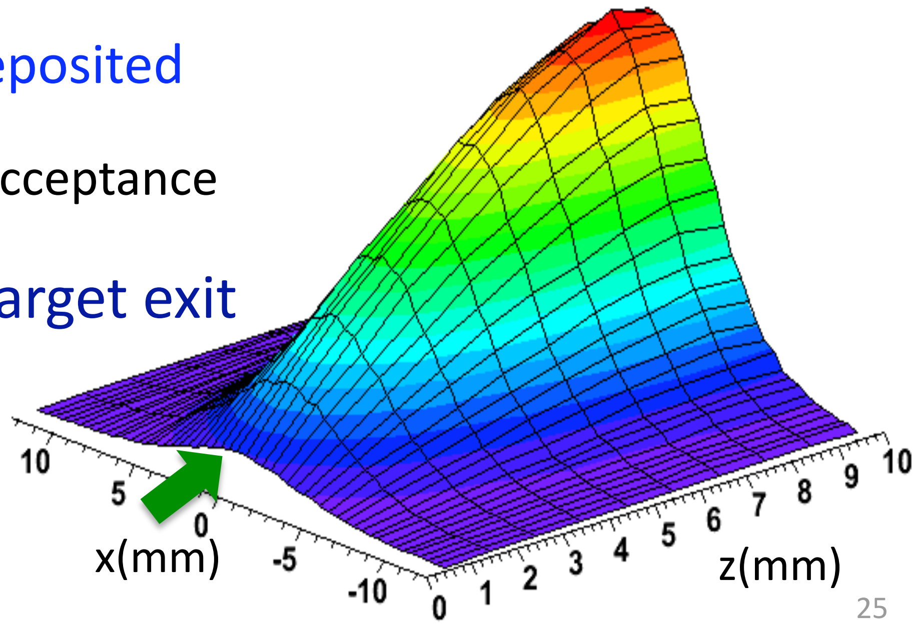
Positron yield



- For fix amorphous target thickness the e^+ yield varies slightly
  - AMD large geometrical acceptance
- High distance is preferable
  - Space for dipole implementation
  - ↗ γ spot size ↘ energy density deposited

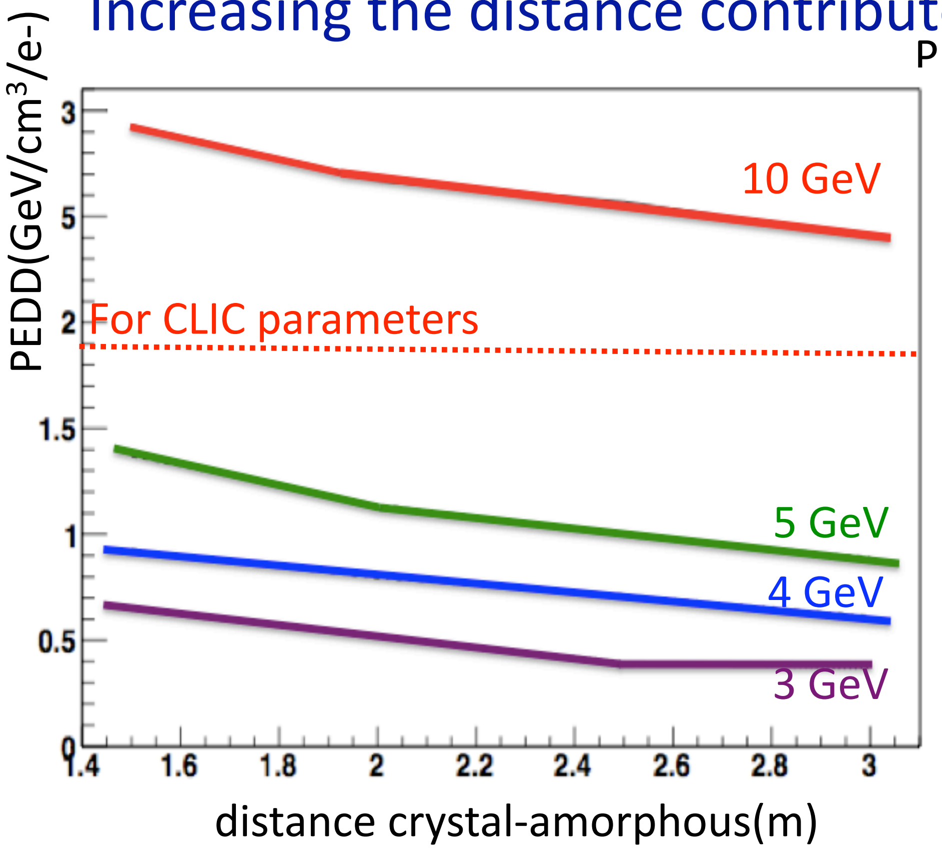
Up to the limit of the AMD geometrical acceptance

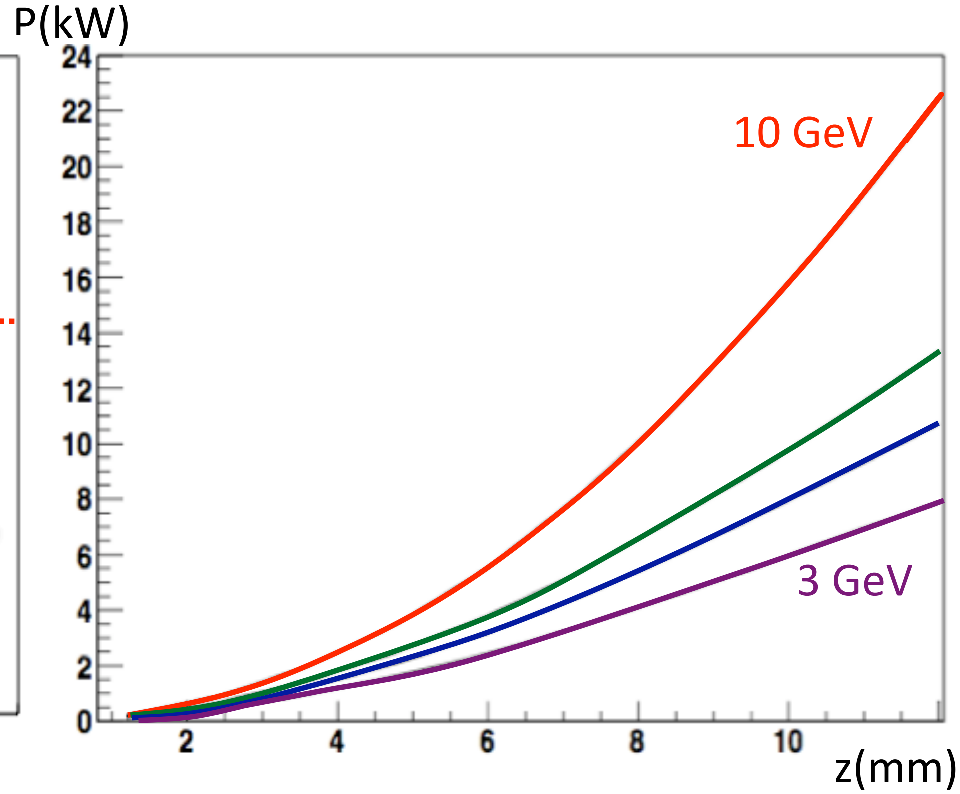
- The energy density is max. at the target exit
- PEDD [W] < 35 J/g



Energy deposition studies

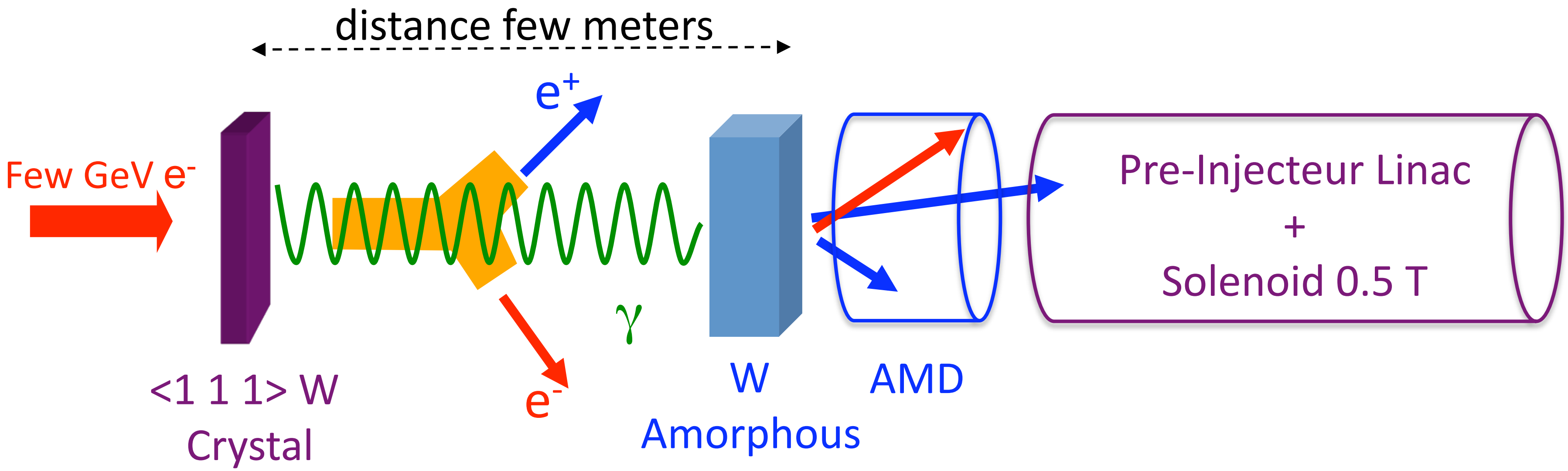
Increasing the distance contributes to lower the PEDD



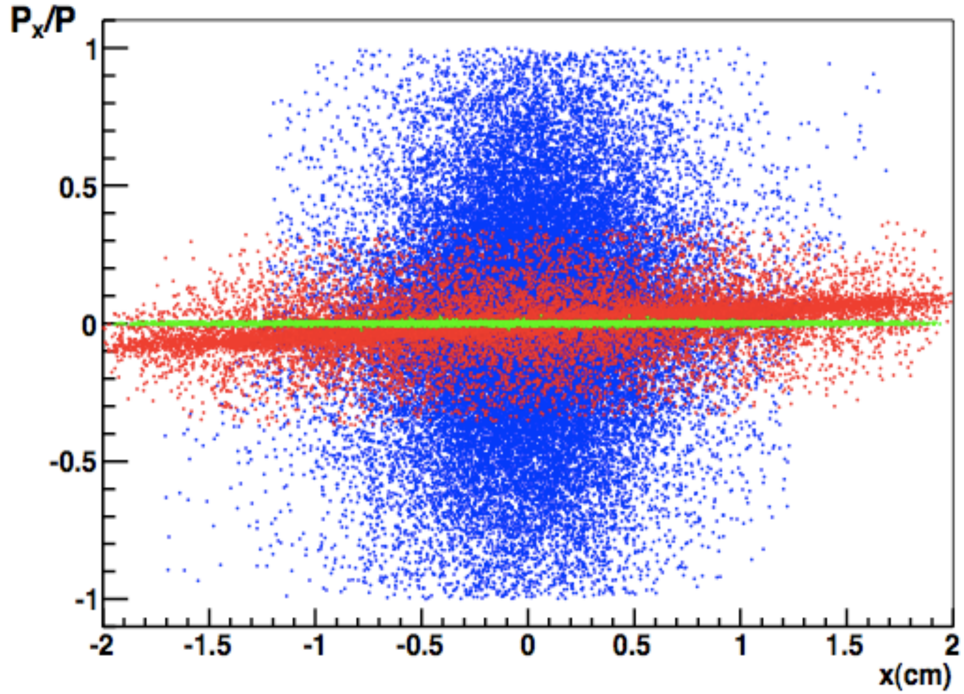


- Total power consideration
- Selected parameters ➔ 5 GeV, z=10 mm & d=2m
  - Average power ≈ 10 kW
  - PEDD ≈ 22 J/g (60% of margin before breakdown)

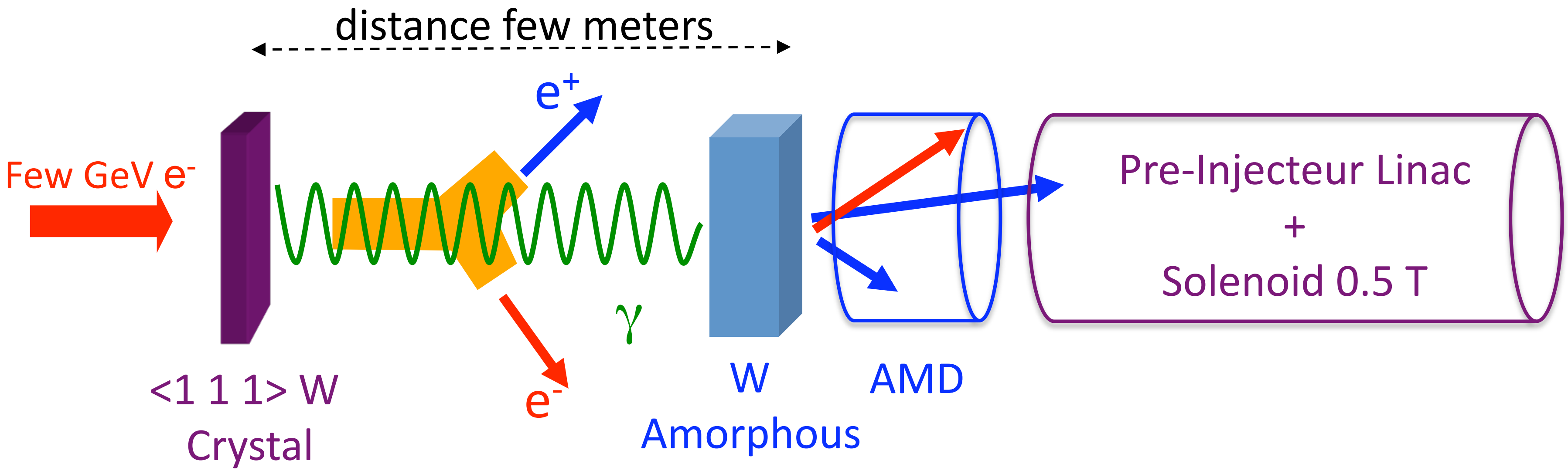
Pre-Injector linac



- Downstream the AMD Pre-injector linac
  - 2 GHz cavities
  - E=10 MV/m
- After 40 m
  - ε_{norm}(rms) ≈ 7.4×10^{-3} m×rad
  - 200 MeV
  - e^+ yield (Ne^+/Ne^-) ≈ 0.8



Pre-Injector linac



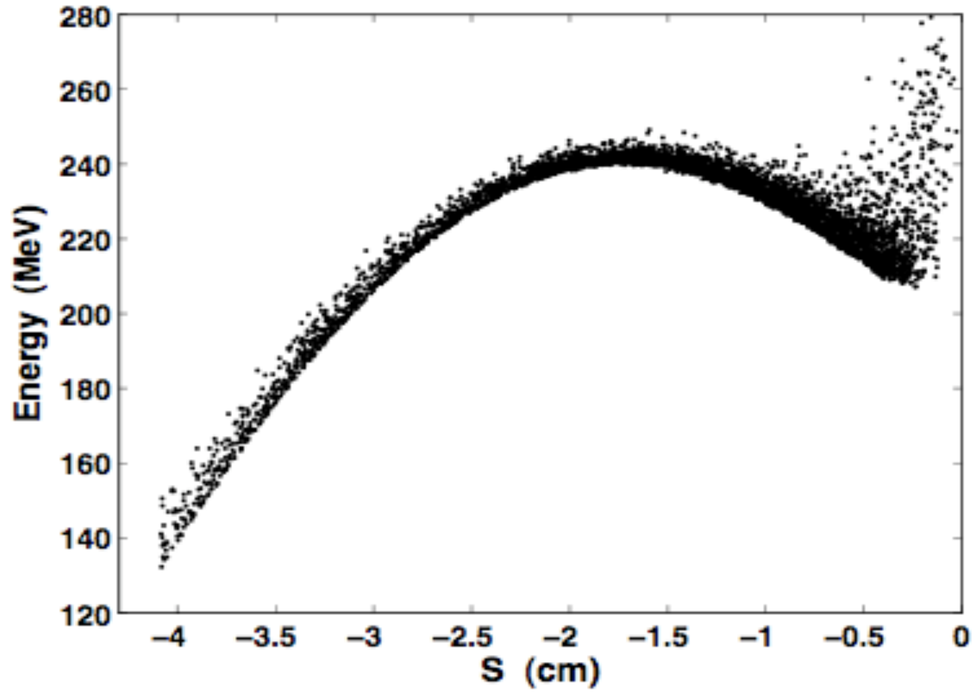
e^+ yield (Ne^+/Ne^-) ≈ 0.8

Is this yield is enough ?

➔ Increase by 25%-35%

➔ Average power : 12.5-13.5 kW

➔ PEDD : 28-30 J/g



Conclusions & prospects

- Without any modification inside your Geant4 code you can use FOT^{++}
  - Can be used as generator for Fluka or EGS
- G4Fot vs. VMS
  - G4Fot seems to give more energetic photons, e- , e+ than VMS
  - G4Fot seems to give less particle multiplicity than VMS
  - Need to understand those differences
  - Compare G4Fot with an other simulation
- Code modification
  - Full STL : trigonometry, random generator …
  - Add energy deposition calculation
- Hybrid scheme proposition for ILC under investigation R. Chehab, C. Xu & P. Sievers
- Some simulation for KEKb experiment
  - Have been already done using VMS
  - Do the same with G4Fot