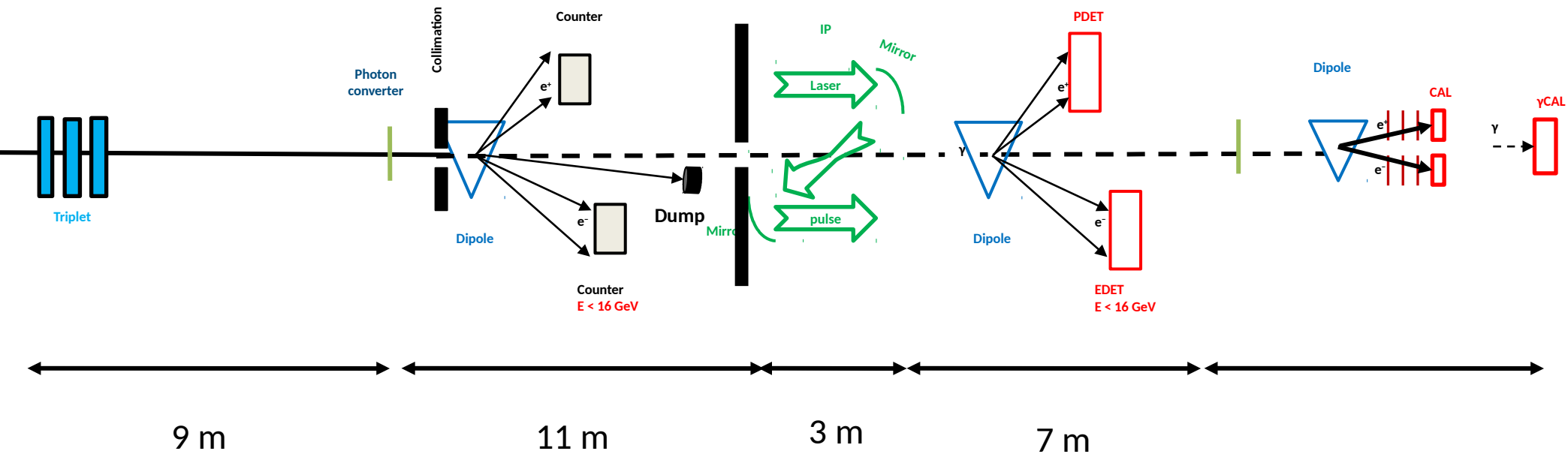


Bremsstrahlung simulation with Geant4

Oleksandr Borysov

LUXE Meeting
February 4, 2019

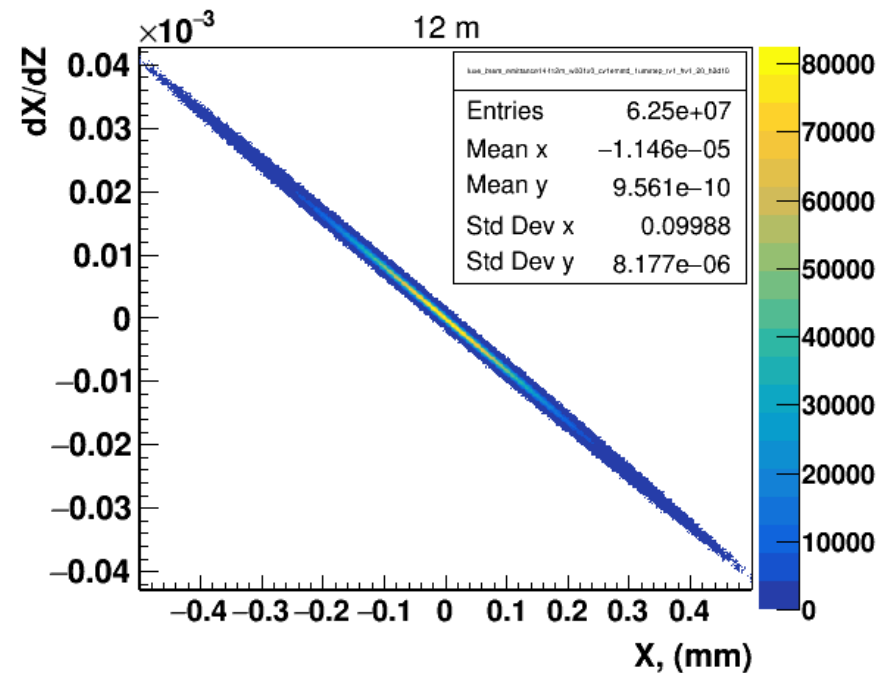
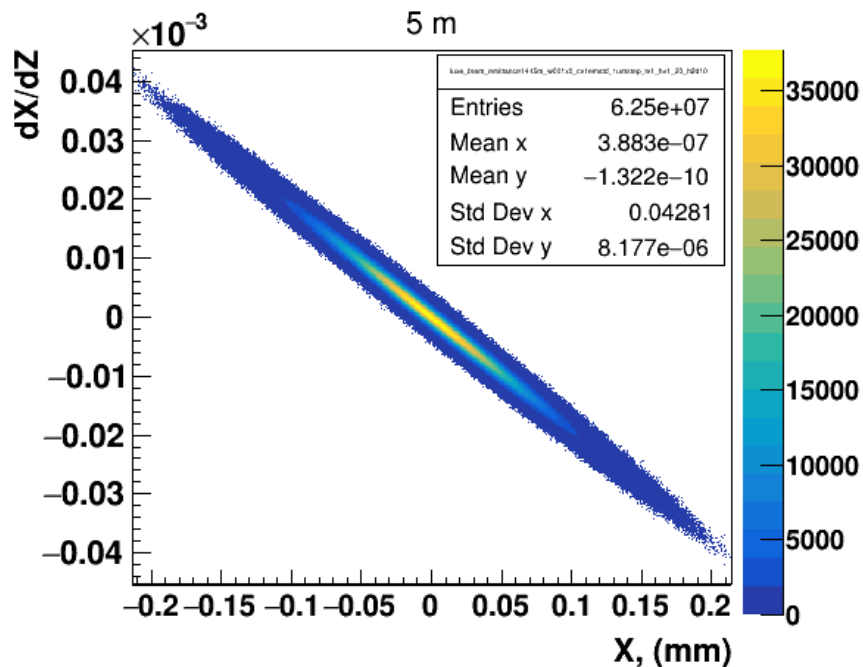
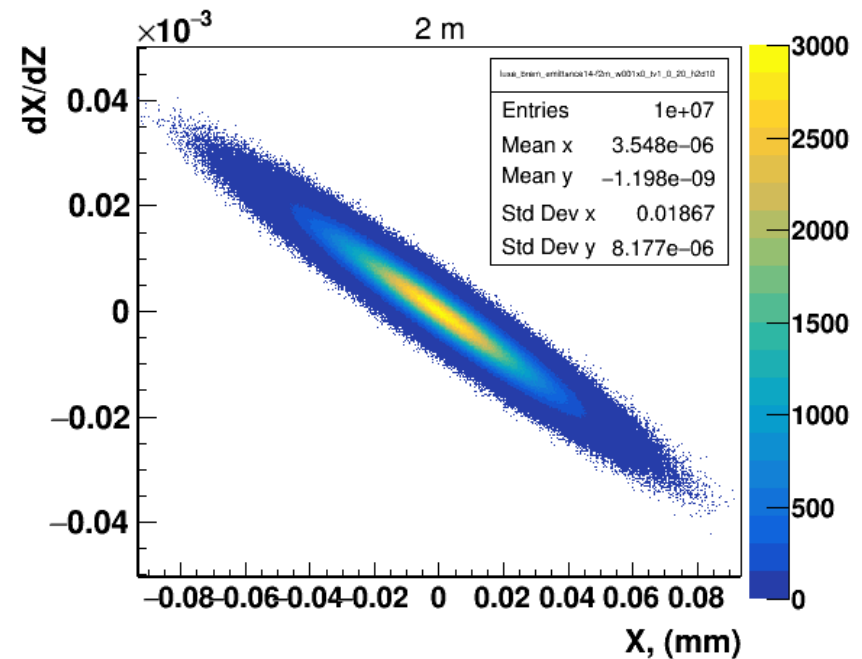
Photon-Photon collisions at LUXE



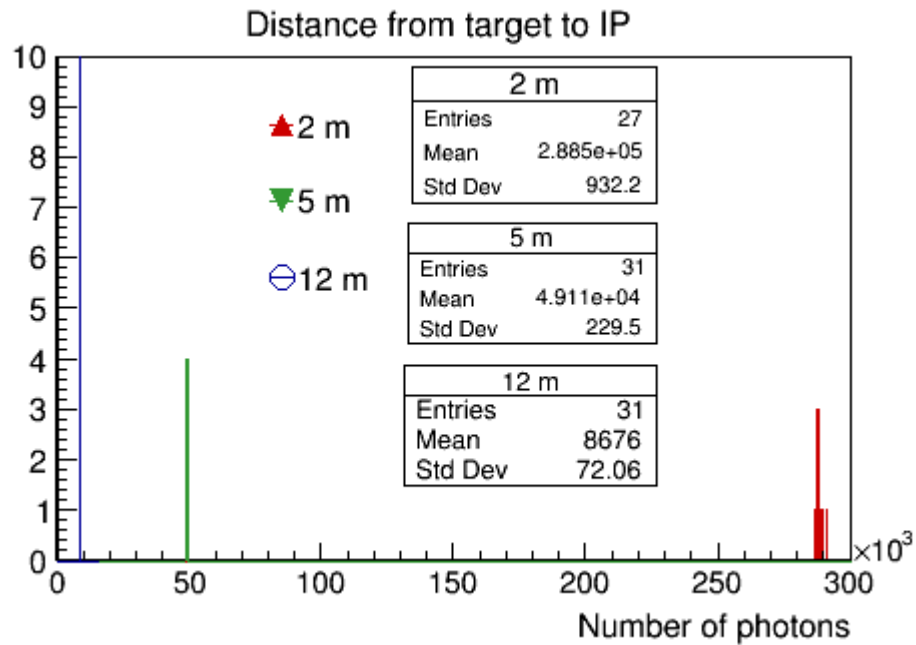
Preliminary estimates!

Target 2 m, 5 m and 12 m upstream of IP

- 2 m: $\sigma_x = 19 \mu\text{m}$;
- 5 m: $\sigma_x = 43 \mu\text{m}$;
- 12 m: $\sigma_x = 100 \mu\text{m}$;



Number of photons



$$N \sim \frac{1}{l^2}$$

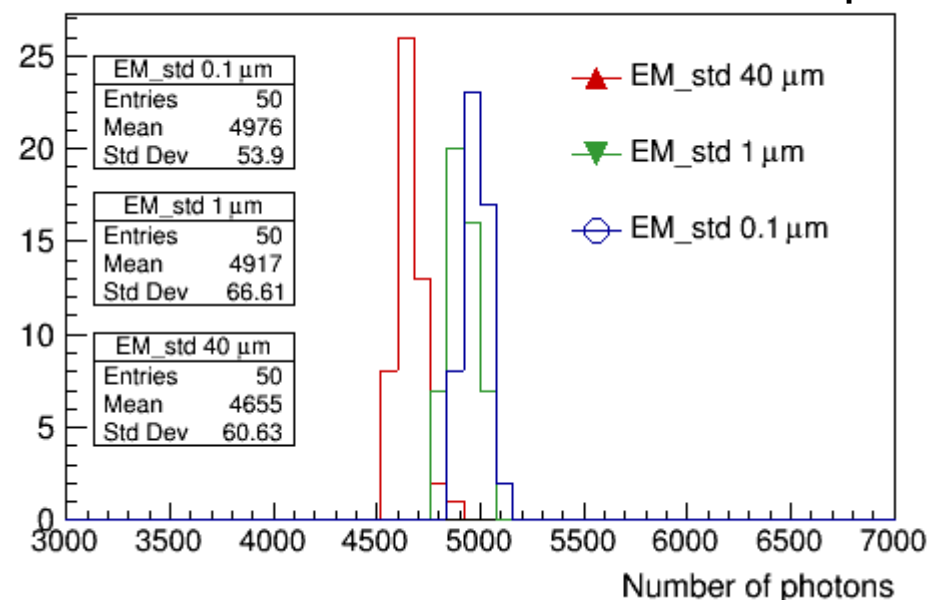
Z, (m)	Z^2	N_Gamma	Z1^2 / Z2^2	N2 / N1		Z1^2 / Z2^2	N2 / N1	
2	4	2.89E+05	6.25E+00	5.8746	0.94	36	33.2565	0.924
5	25	4.91E+04	5.76E+00	5.6611	0.983			
12	144	8675						

Geant4 simulation with different step, different physics lists, different beam

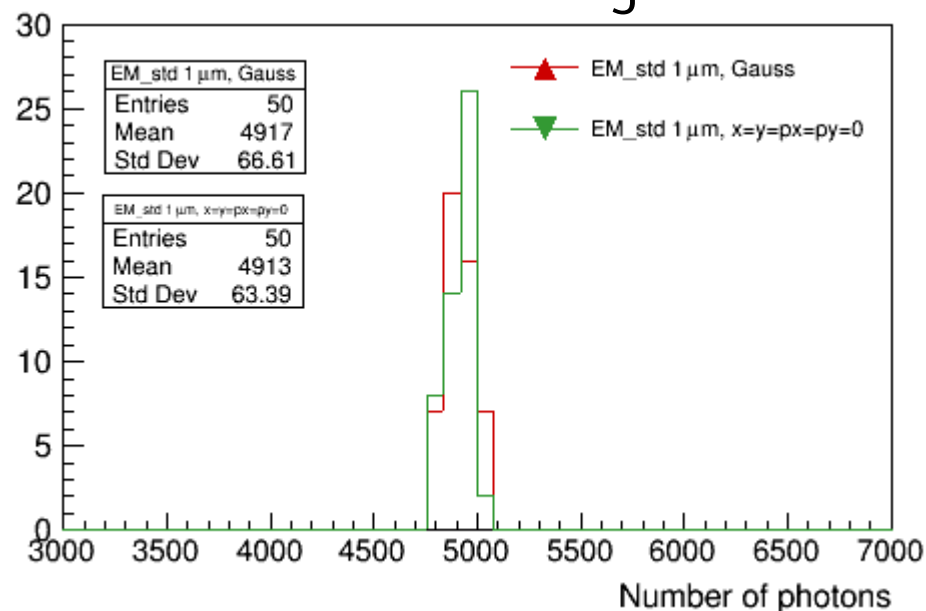
- Gaussian beam, focused on IP;
- Tungsten target 1%X0 (35 μ m) thickness
- 5 m from IP;
- 6.25 M electrons (BX/1000);
- Production cut: 1 μ m.

Number of photons inside
 $|x| < 25 \mu\text{m}$ and
 $|y| < 25 \mu\text{m}$;

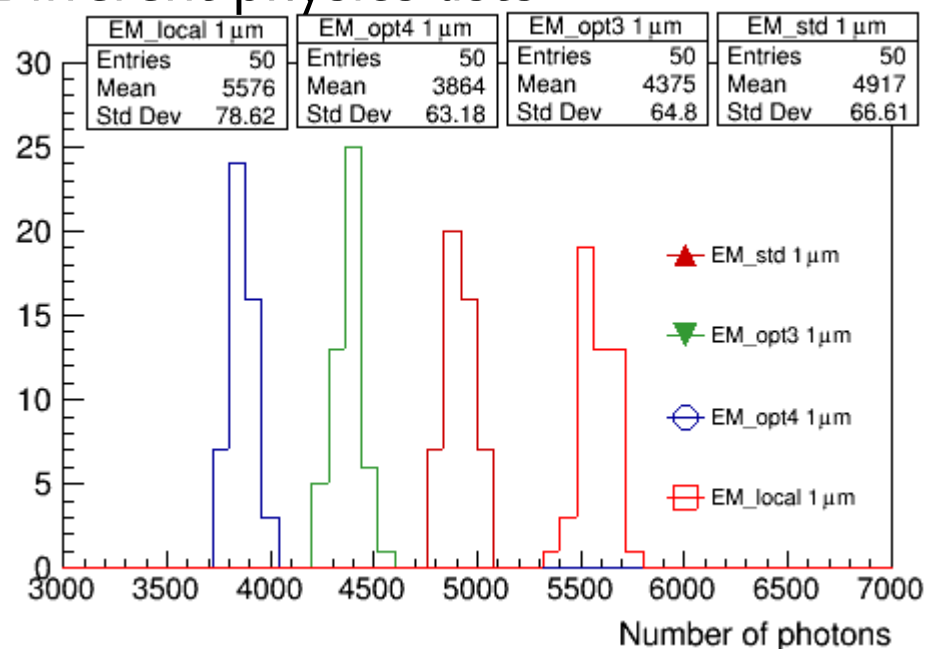
Different step



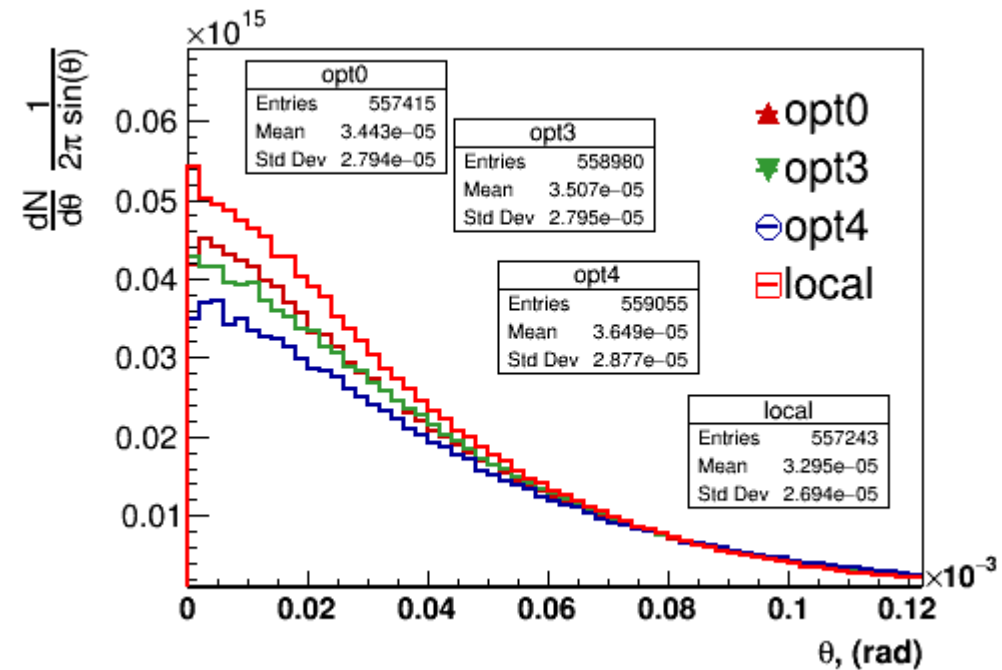
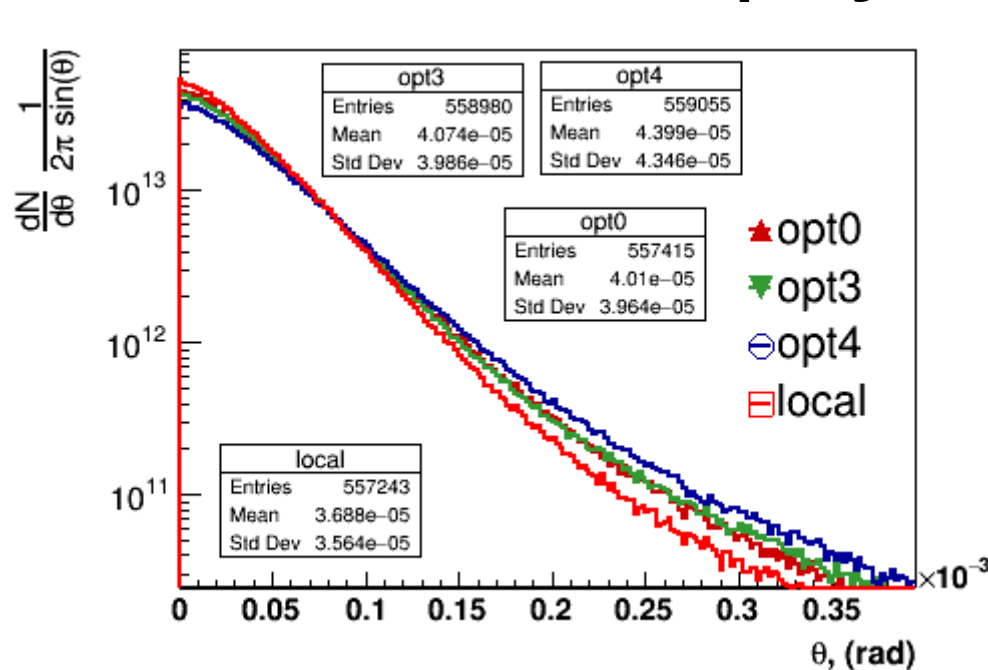
Different beam settings



Different physics lists

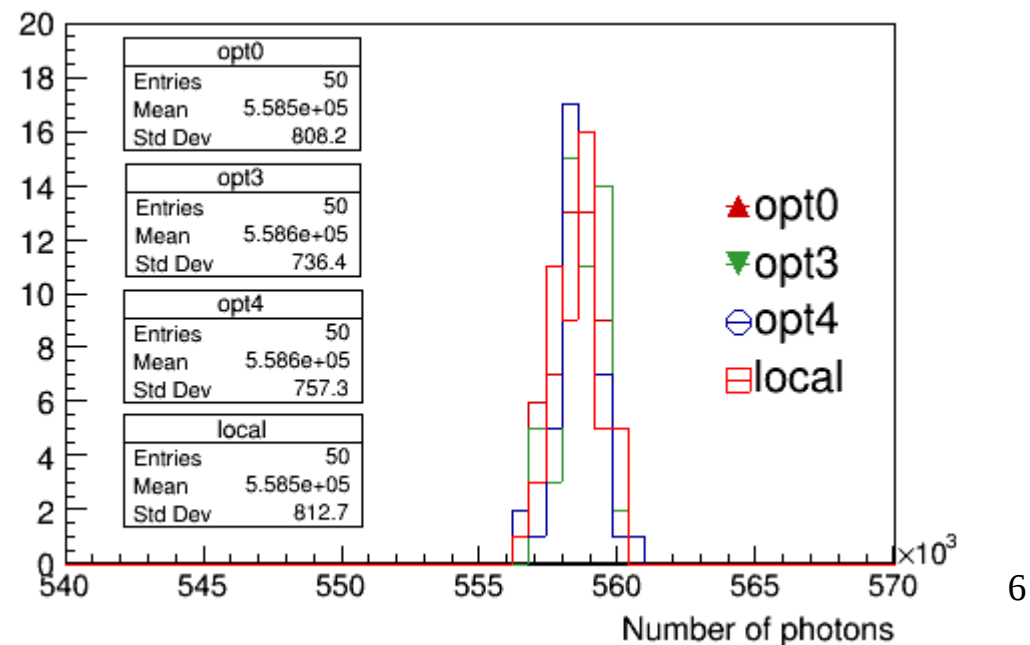


γ angular distribution for different physics lists



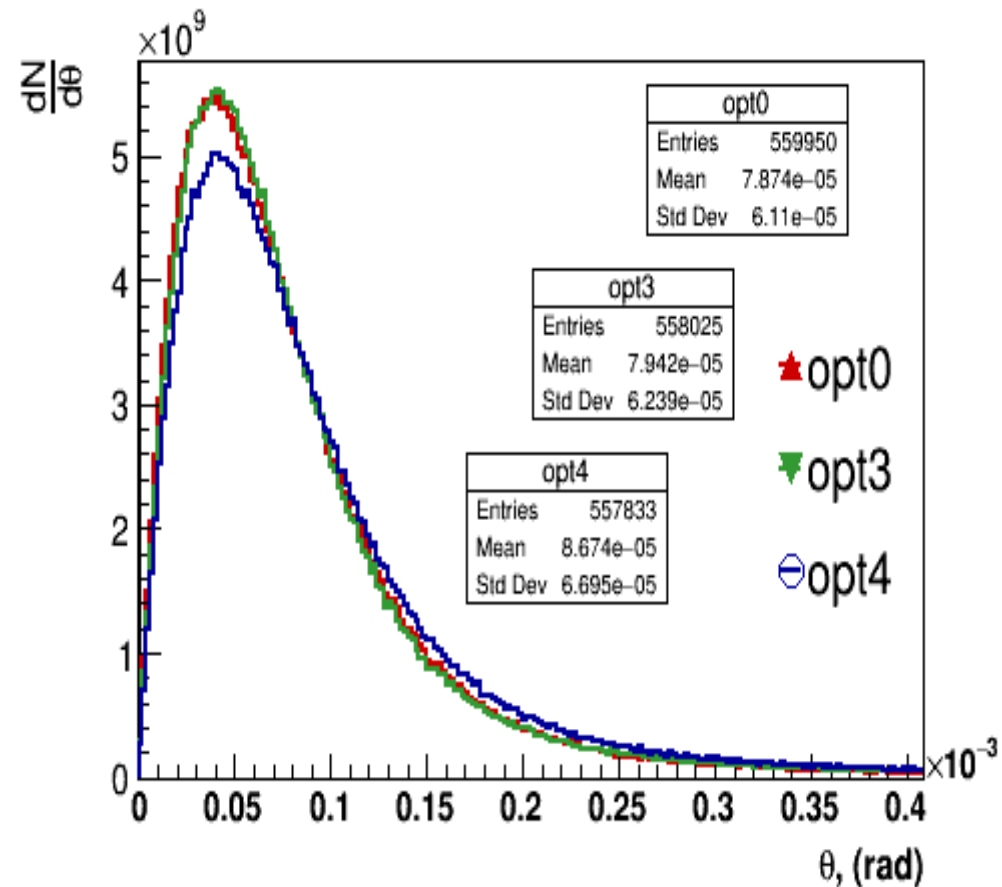
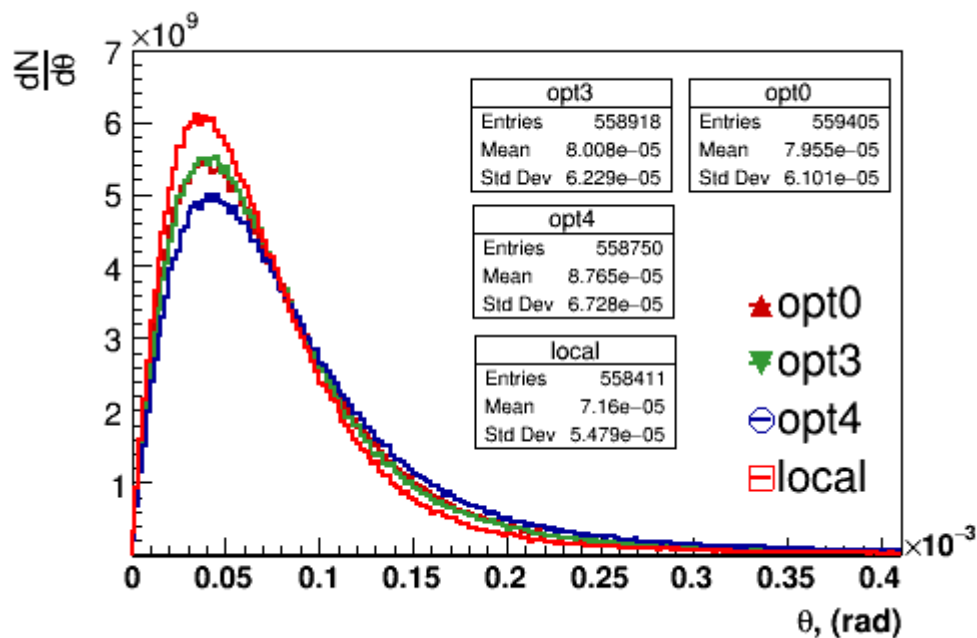
- Angular distribution is the widest for option_4 physics list and the narrowest for the local one.
- Angular distribution explains bottom right plot on previous slide.
- Total number of photons in forward region is identical for all physics lists.

Number of photons inside
 $|x| < 1.5$ m and
 $|y| < 1.5$ m



Polar angle distribution

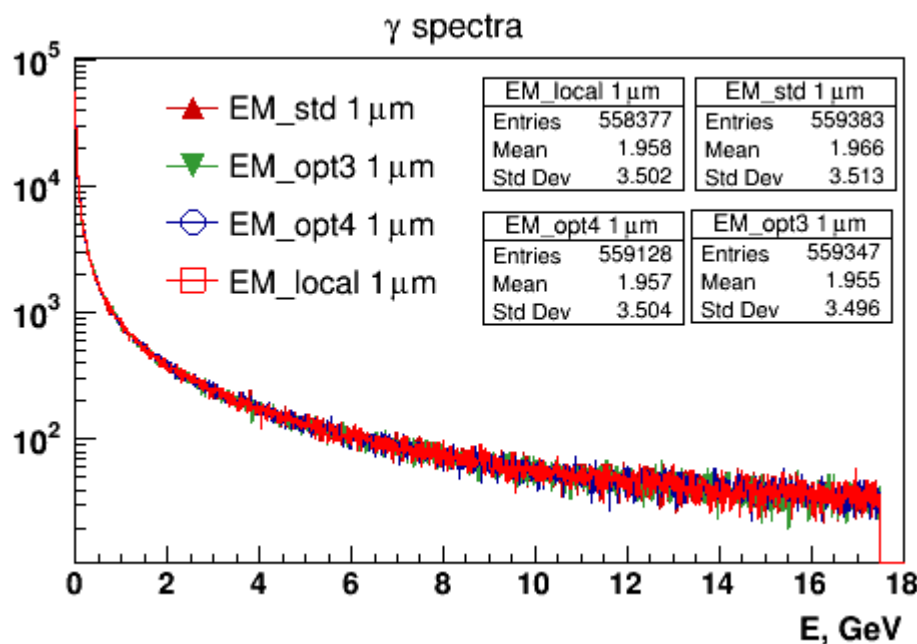
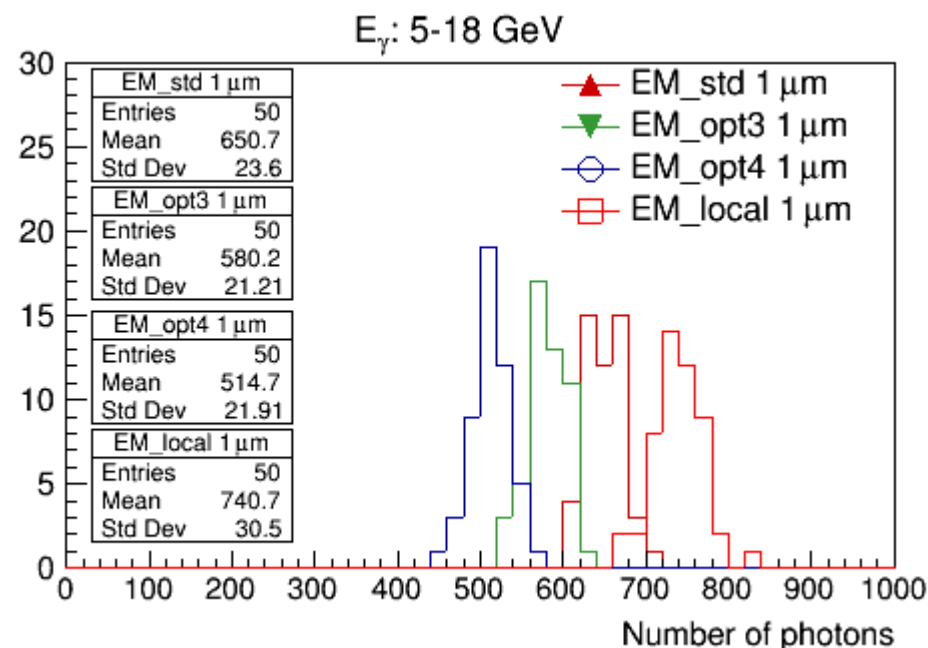
Unidirectional beam:
 $x=y=p_x=p_y=0$



Spectra for different physics lists

- Gaussian beam, focused on IP;
- Tungsten target 1%X0 (35um) thickness
- 5 m from IP;
- 6.25 M electrons (BX/1000);
- Production cut: 1 μm .

Number of photons inside
 $|x| < 25\mu\text{m}$ and
 $|y| < 25\mu\text{m}$ and
 $5\text{GeV} < E_\gamma < 18\text{GeV}$;



```
root [1] 4917.0/3864.0
(double) 1.27252
root [2] 650.0/514.0
(double) 1.26459
```

Geant4 reference physics lists

- EM physics for simulation with high accuracy due to “UseDistanceToBoundary” multiple scattering step limitation and usage of `G4UrbanMscModel` for all charged particles, reduced *finalRange* parameter of stepping function optimized per particle type, alternative model `G4KleinNishinaModel` for Compton scattering, enabled fluorescence, enabled nuclear stopping, `G4Generator2BS` angular generator for bremsstrahlung, `G4IonParameterisedLossModel` for ion ionisation, `G4ePairProduction` for electron/positron, 20 bins energy decade of physics tables, and 10 eV low-energy limit for tables (class name `G4EmStandardPhysics_option3`)
- Combination of EM models for simulation with high accuracy includes multiple scattering with “UseSafetyPlus” type of step limitation by combined `G4WentzelVIModel` and `G4eCoulombScatteringModel` for all particle types, for of e+- below 100 MeV `G4GoudsmitSaundersonMscModel` is used, `RangeFactor = 0.2`, `Scin = 3` (error free stepping near geometry boundaries), reduced *finalRange* parameter of stepping function optimized per particle type, enabled fluorescence, enabled nuclear stopping, enable accurate angular generator for ionisation models, `G4LowEPComptonModel` below 20 MeV, `G4PenelopeGammaConversionModel` below 1 GeV, `G4LivermoreIonisationModel` for electrons and positrons below 100 keV, `G4IonParameterisedLossModel` for ion ionisation, `G4Generator2BS` angular generator for bremsstrahlung, `G4ePairProduction` for electron/positron, and 20 bins per energy decade of physics tables, (class name `G4EmStandardPhysics_option4`)

Physics list comparison

Option 3

```
msc:   for e-   SubType= 10
        RangeFactor= 0.04, stepLimitType: 3, latDisplacement: 1, skin= 1, geomFactor= 2.5
        ===== EM models for the G4Region DefaultRegionForTheWorld =====
        UrbanMsc : Emin=      0 eV   Emax=      10 TeV Table with 220 bins Emin=    100 eV   Emax=      10 TeV
```

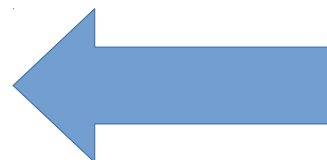
```
eIoni:   for e-   SubType= 2
        dE/dx and range tables from 10 eV to 10 TeV in 240 bins
        Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
        finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 0.01
        ===== EM models for the G4Region DefaultRegionForTheWorld =====
        MollerBhabha : Emin=      0 eV   Emax=      10 TeV
```

Option 4

```
msc:   for e-   SubType= 10
        RangeFactor= 0.02, stepLimitType: 3, latDisplacement: 1, skin= 1, geomFactor= 2.5
        ===== EM models for the G4Region DefaultRegionForTheWorld =====
        UrbanMsc : Emin=      0 eV   Emax=      100 MeV Table with 120 bins Emin=    100 eV   Emax=      100 MeV
        WentzelVIUni : Emin=    100 MeV Emax=      10 TeV Table with 100 bins Emin=    100 MeV Emax=      10 TeV
```

```
eIoni:   for e-   SubType= 2
        dE/dx and range tables from 100 eV to 10 TeV in 220 bins
        Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
        finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 0.01
        ===== EM models for the G4Region DefaultRegionForTheWorld =====
        PenIoni : Emin=      0 eV   Emax=      1 MeV
        MollerBhabha : Emin=      1 MeV Emax=      10 TeV deltaVI
```

```
CoulombScat:   for e-, integral: 1   SubType= 1 BuildTable= 1
        Lambda table from 100 MeV to 10 TeV, 20 bins per decade, spline: 1
        180 < Theta(degree) < 180; pLimit(GeV^1)= 0.139531
        ===== EM models for the G4Region DefaultRegionForTheWorld =====
        eCoulombScattering : Emin=    100 MeV Emax=      10 TeV
```



Multiple scattering studies

Nuclear Inst, and Methods in Physics Research B 425 (2018) 18–25

Electron backscattering simulation in Geant4

Paolo Dondero^{a,*}, Alfonso Mantero^a, Vladimir Ivanchenko^{b,c,g}, Simone Lotti^d, Teresa Mineo^e,
Valentina Fioretti^f

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^b CERN, Geneva 23 1211, Switzerland

^c Geant4 Associate International Ltd, 9 Royd Terrace, Hebden Bridge HX7 7BT, United Kingdom

^d INFN/IAPS Roma, Via del Fosso del Cavaliere, 100, 00133 Roma, Italy

^e INFN/IASF Palermo, Via Ugo La Malfa 153, 90146 Palermo, Italy

^f INFN/IASF Bologna, Via P. Gobelli 101, 40129 Bologna, Italy

^g Tomsk State University, Leninsky Pr. 36, 634050 Tomsk, Russia

Tungsten, normal incidence angle

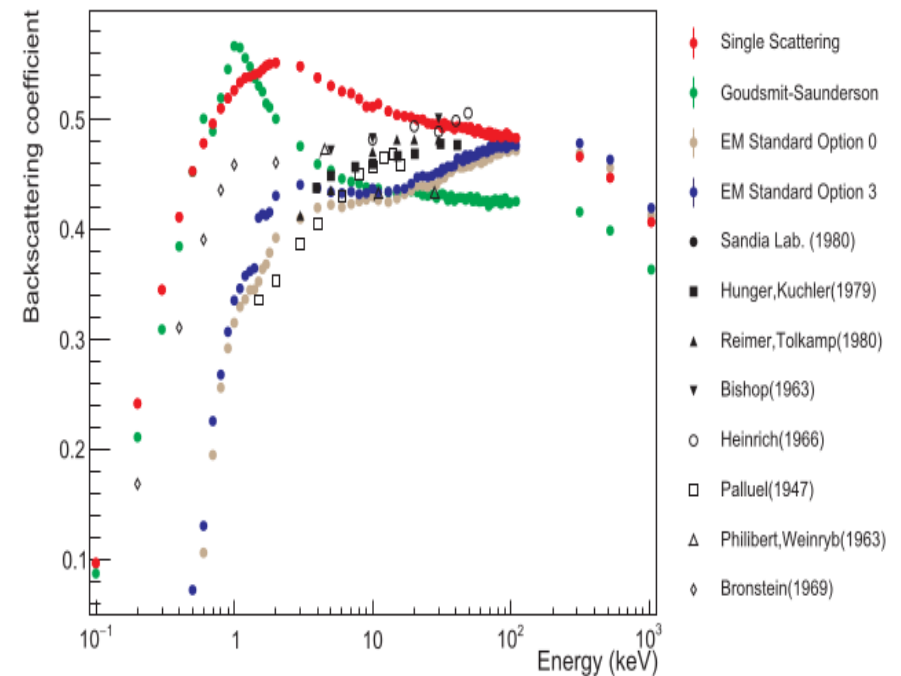
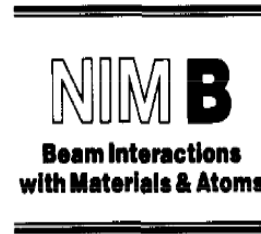


Fig. 8. Geant4 simulations using different standard electromagnetic physics lists are compared with respect to the experimental datasets reported in Table 1 at normal incidence angle using Si (upper figure), and Tungsten (lower figure) as a target. The lowest electron energy was set to 50 eV.

Multiple scattering studies

Nuclear Instruments and Methods in Physics Research B73 (1993) 447–473
North-Holland



On the theory and simulation of multiple elastic scattering of electrons

J.M. Fernández-Varea^a, R. Mayol^a, J. Baró^b and F. Salvat^a

^a *Facultat de Física (ECM), Universitat de Barcelona and Societat Catalana de Física (IEC), Diagonal 647,
08028 Barcelona, Spain*

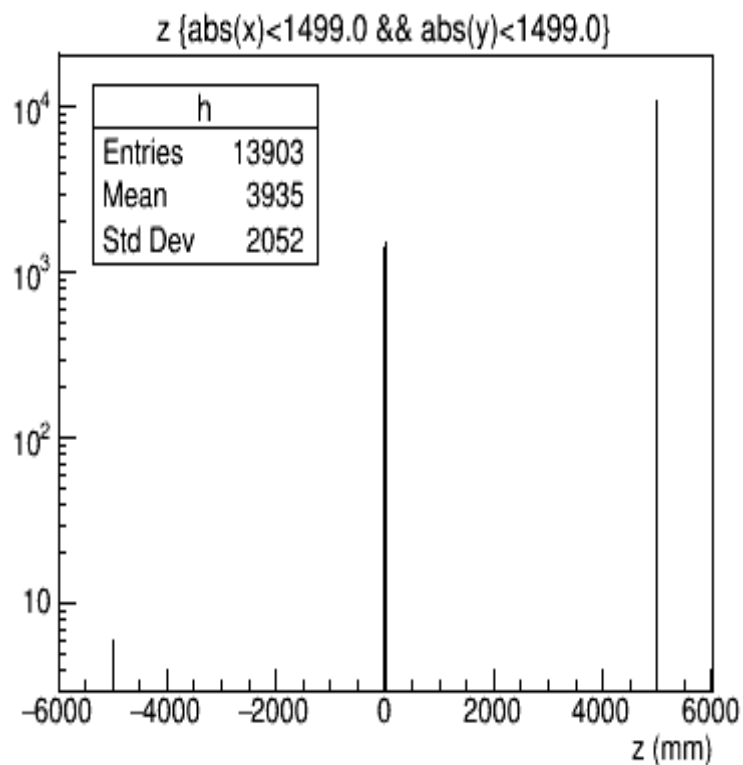
^b *Serveis Científico-Tècnics, Universitat de Barcelona, Martí i Franquès s/n, 08028 Barcelona, Spain*

Received 21 August 1992

We shall consider mixed simulation procedures in which “hard” collisions, with scattering angle χ larger than a given value χ_s , are individually simulated and soft collisions (with $\chi < \chi_s$) are described by means of a multiple scattering approach. It is clear that, by selecting a conveniently large value for the cutoff angle χ_s , the number of hard collisions per electron track can be made small enough to allow their detailed simulation. As the fluctuations in the spatial displacement after a path length s are mainly due to hard collisions, a mixed procedure (with a suitably small value of χ_s) will yield spatial distributions that are considerably more accurate than those from a conventional condensed simulation. Although

Test of tracks end points

Distribution of track
end points



Transverse beam dynamics

These are known as Hill's (homogeneous) Equations of Motion, more succinctly written as:

$$\begin{aligned} x'' + K_x(s)x &= 0 \\ y'' + K_y(s)y &= 0 \end{aligned}$$

Phase advance is related to Beta function, $\beta(s)$

$$\varphi = \int_0^s \frac{1}{\beta(s)} ds$$

Beta function, $\beta(s)$, is determined exclusively by magnetic lattice, $K(s)$

$$\frac{1}{2} \beta \beta'' - \frac{1}{4} \beta'^2 + \beta^2 K = 1$$

We can also define useful quantities related to the Beta function:

$$\begin{aligned} \alpha &= -\frac{1}{2} \beta' \\ \gamma &= \frac{1 + \alpha^2}{\beta} \end{aligned}$$

$$u = \sqrt{\varepsilon \beta(s)} \cos(\varphi(s) - \phi)$$

If $K=0$ (no field) $\beta(z) = \beta^* + \frac{z^2}{\beta^*}$

with $z=0$ at IP

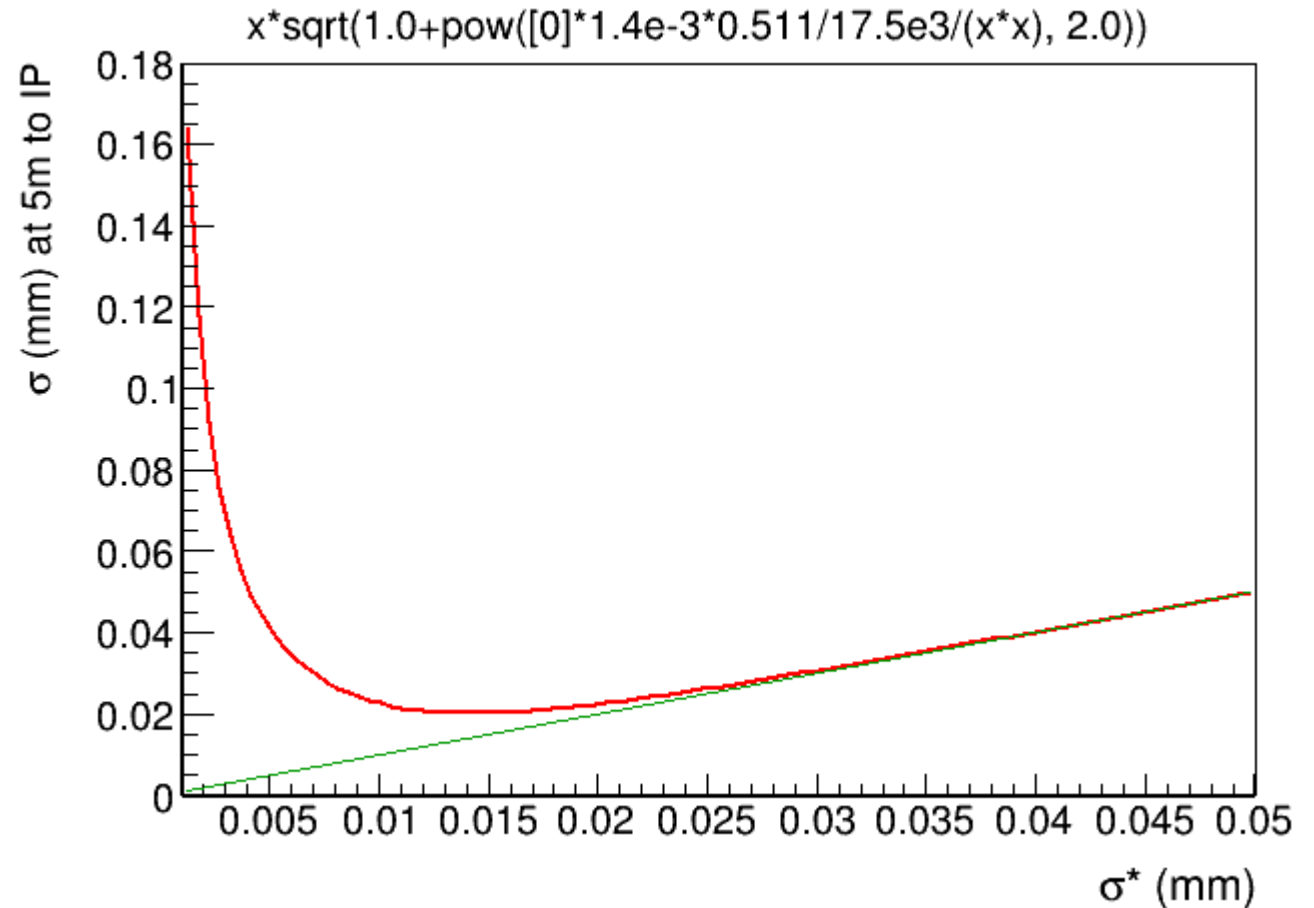
$$\beta^* = \frac{\sigma^{*2}}{\varepsilon}$$

Dependence between $\sigma(z)$ and σ^*

$$\sigma(z) = \sigma^* \sqrt{1 + \left(\frac{z \varepsilon}{\sigma^{*2}} \right)^2}$$

↓

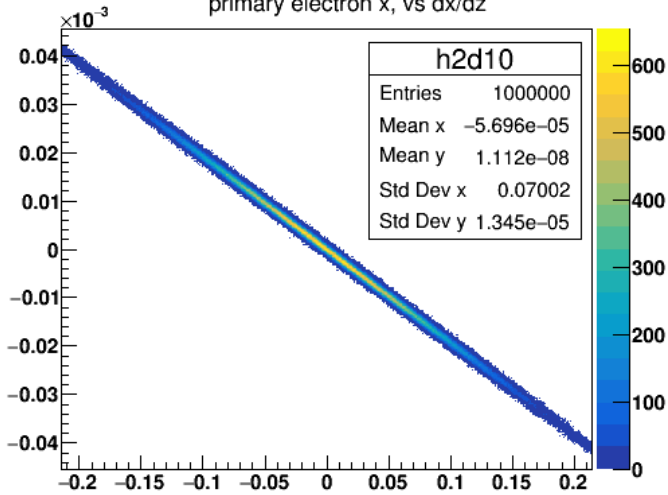
$$\frac{\sqrt{\langle p_{x,y}^2 \rangle}}{p_z} \frac{z}{\sigma_{x,y}^*}$$



Different σ^* , $z = 5\text{m}$

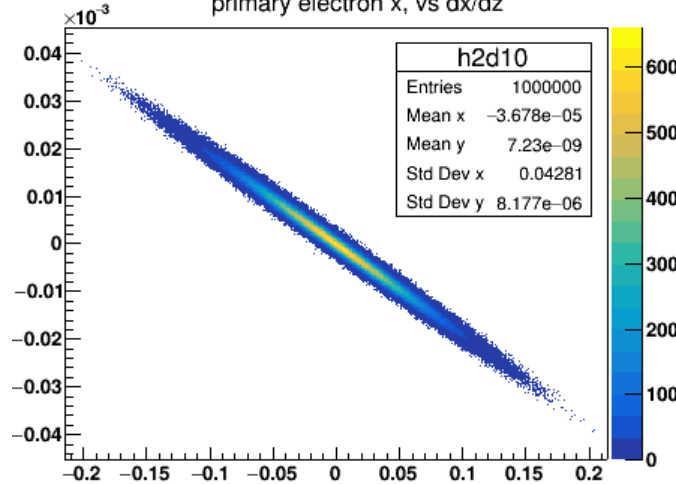
$\sigma^* = 3\ \mu\text{m}$

primary electron x, vs dx/dz



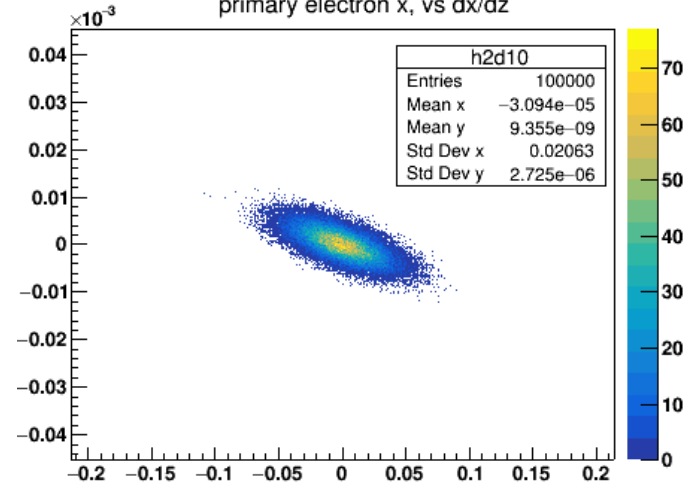
$\sigma^* = 5\ \mu\text{m}$

primary electron x, vs dx/dz

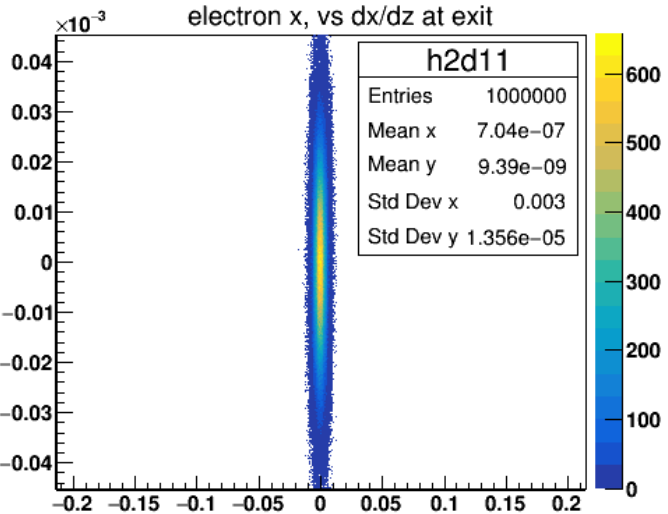


$\sigma^* = 15\ \mu\text{m}$

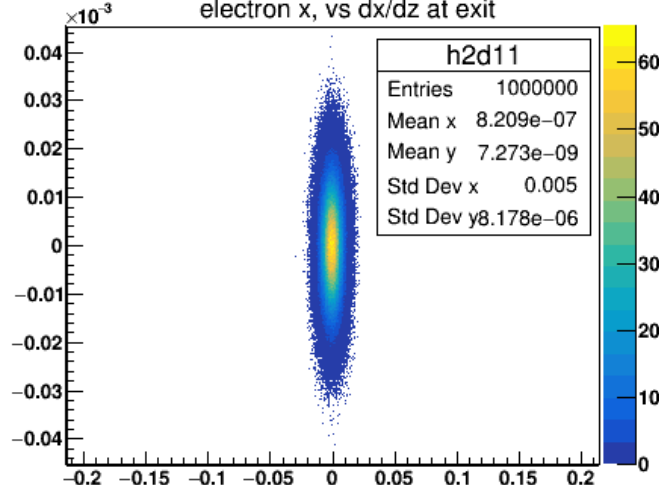
primary electron x, vs dx/dz



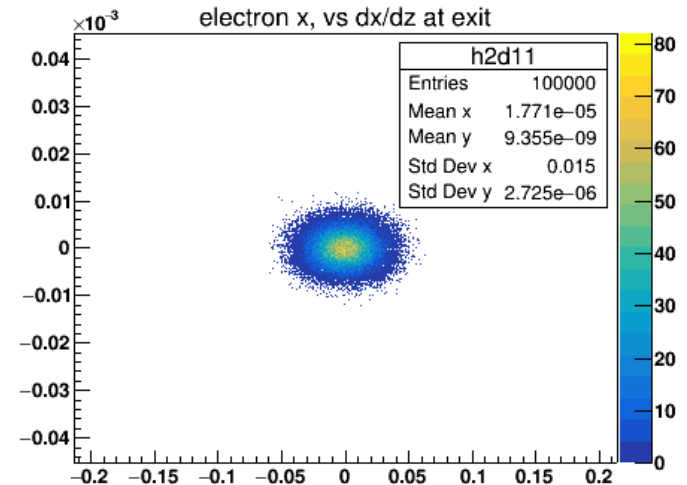
electron x, vs dx/dz at exit



electron x, vs dx/dz at exit

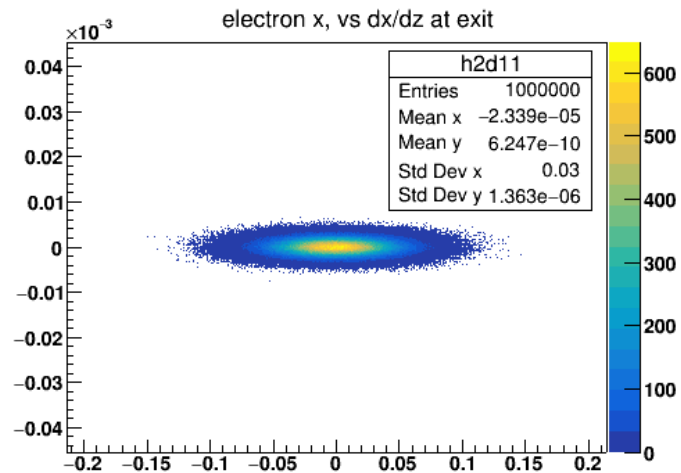
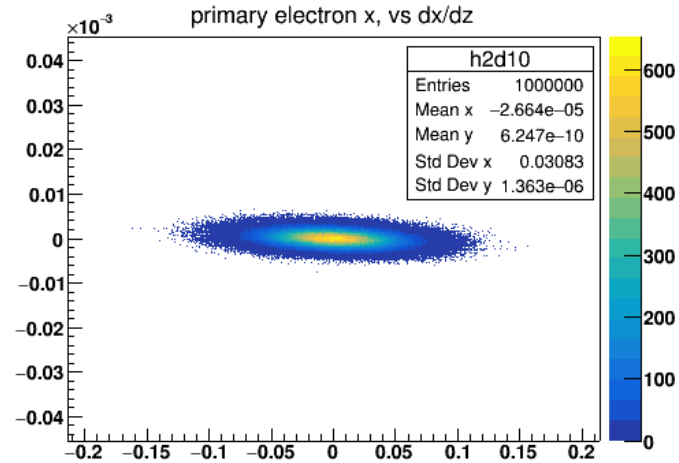


electron x, vs dx/dz at exit



Different σ^* , $z = 5\text{m}$

$\sigma^* = 30\ \mu\text{m}$





RMS Quantities

We can relate our Twiss Parameters for the beam to RMS quantities, as well:

$$\beta = \frac{u_{\text{RMS}}^2}{\epsilon_{\text{RMS}}}$$

$$\gamma = \frac{u'^2_{\text{RMS}}}{\epsilon_{\text{RMS}}}$$

$$\alpha = \frac{-(uu')_{\text{RMS}}}{\epsilon_{\text{RMS}}}$$

Beam Ellipse in Phase Space:

