Simulating the Energy Deposited and Temperature Rise in Photon Masks.

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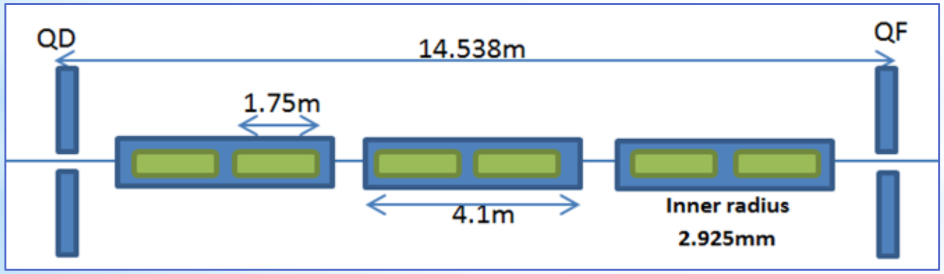
Outlines

- ILC Undulator Structure
- Energy deposited at masks
- Mask design
- FLUKA simulation:
  - Energy density at mask
  - Power leaving the mask
- Conclusion

ILC Undulator structure at ILC250GeV

* Two undulator modules with 1.75m each inserted in one cryomodule with 4.1m.
* 132 modules = 66 cryomodules
* Quadrupoles are located after each three cryomodules in total 23 quads
* Maximum 231m active undulator length,
  319.8 m total undulator length
* Undulator aperture 5.85mm



Parameters	Values
Centre-of-mass energy	**250 GeV**
Bunch population	2.00E+10
Number of bunches	1312
Repetition rate (Hz)	5
Period (m)	**0.0115**
K value	**0.85**
Magnetic field	0.79 T
Undulator Inner radius	**2.925 mm**
Length of undulator module	**1.75 m**
Cryomodule Length	**4.1 m**
Number of Cryomodule	**66**
Total Active magnetic Field Length	**231 m**
Number of Quadrupoles	23
Quadrupole length	1 m
Total lattice length	**319.828 m**

ILC Undulator

* Problem: power deposition on the wall of a long undulator
  * Superconducting undulator
  * Vacuum requirements (e.g. see **O. Malyshev EuroTeV)** https://avs.scitation.org/doi/10.1116/1.2746876.
* **Power deposition on the wall from synchrotron radiation should be ≤1W/m**

  (see also **Duncan Scott, 2008)**

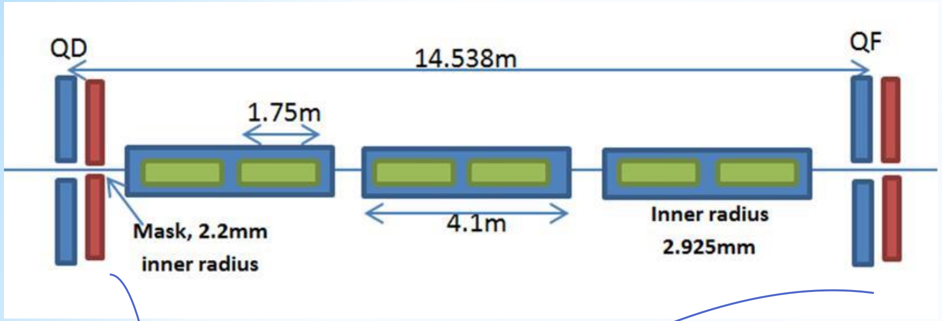
  https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.490620
* For ILC250 (E_{cm} = 250GeV) the full active undulator length is required to generate enough positrons.
  * Although the photon beam is narrow photons hit the wall of the 320m long undulator

Photon opening angle:

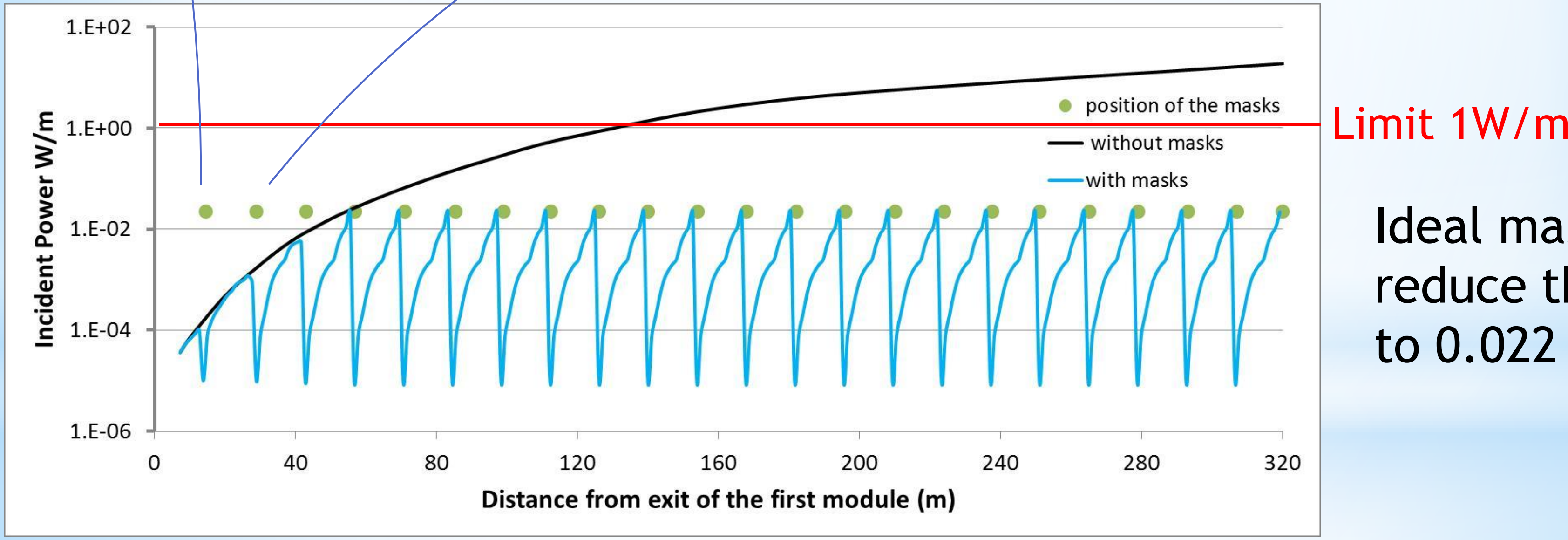
$$\theta = \frac{\left[\left(1+K^2\right)\right]^{1/2}}{\gamma}$$

How can the undulator wall be protected from the synchrotron Radiation ?

Power Deposition without and with Photon Masks

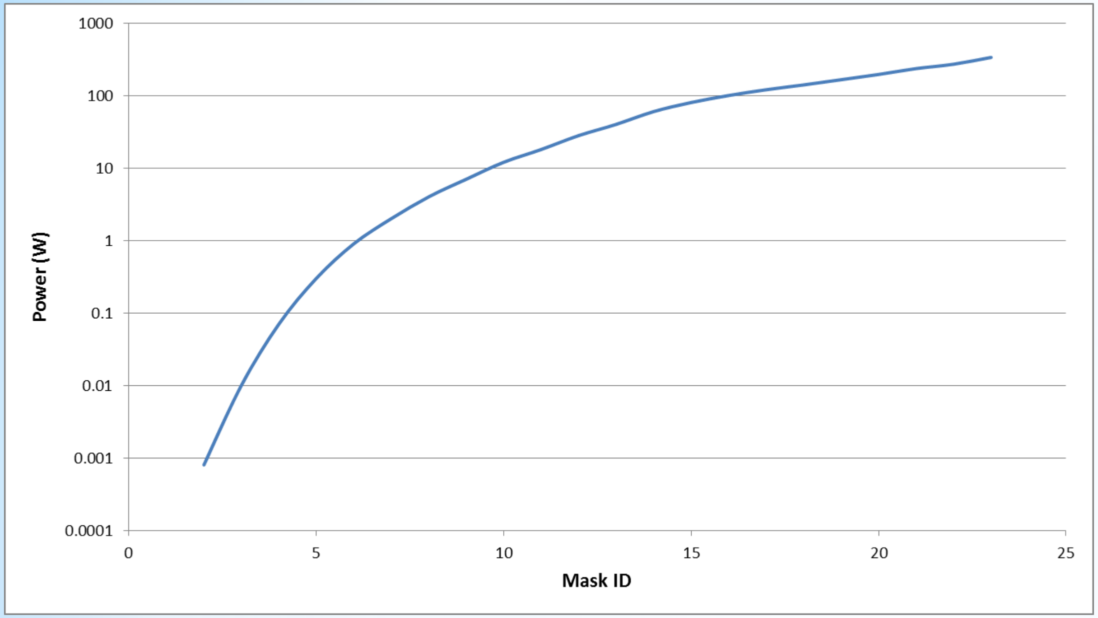


- ILC TDR: mask with 2.2mm radius was chosen.
- Masks placed behind Quadrupoles.



Ideal masks can reduce the peak to 0.022 W/m.

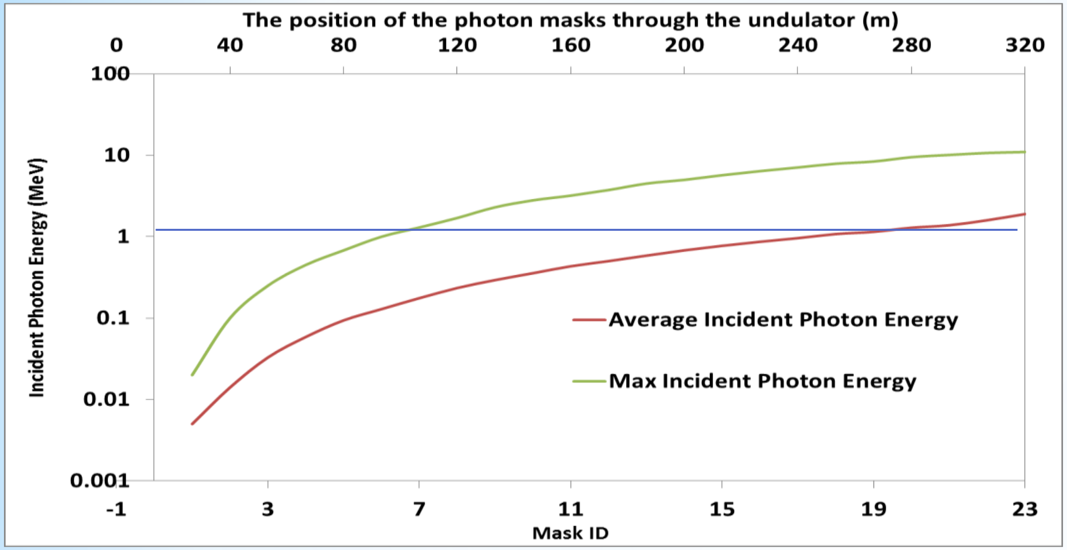
Power Deposited in the masks



- In this study, we assume ideal undulator modules and ideal photon masks.
- First masks:
  - Mask 15 receives 80 W.
- Last mask:
  - Mask 23 receives 335 W.

Mask ID	Average energy [MeV]	Power Deposited [W]
15	0.68	80
16	0.85	100
17	0.97	120
18	1.13	140
19	1.31	165
20	1.46	195
21	1.65	235
22	1.77	270
23	2.01	335

Average energy of photons stopped in the masks



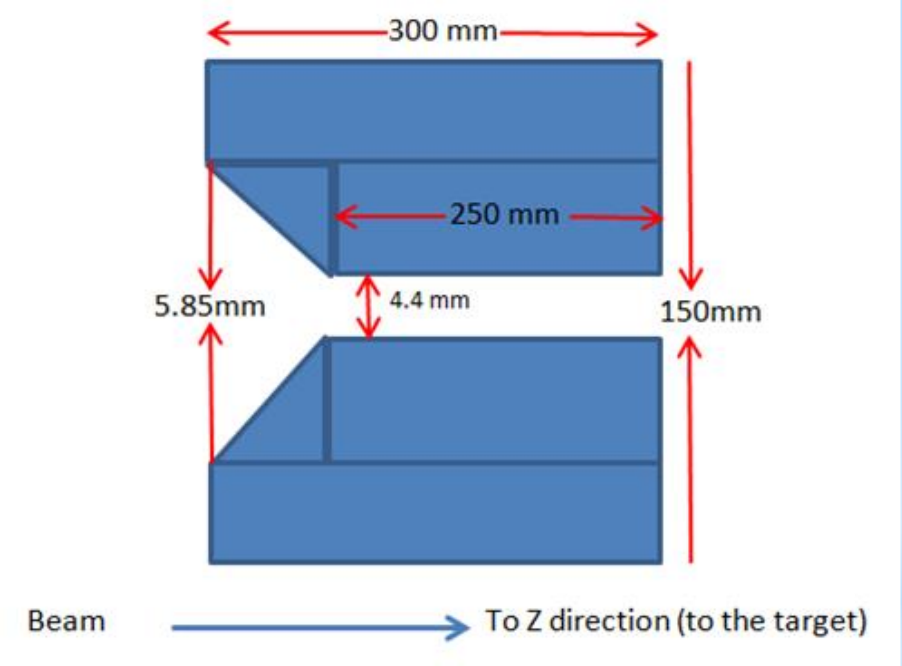
- In this study, we assume ideal undulator modules and ideal photon masks.
- First masks (up to mask17):
  - average photon energy in keV range
- Last masks (from mask 18 to mask 23):
  - max and average photon energy in MeV range.

Mask ID	Average energy [MeV]	Max energy [MeV]
15	0.68	3.49
16	0.85	4.39
17	0.97	5.11
18	1.13	6.16
19	1.31	6.98
20	1.46	7.85
21	1.65	8.97
22	1.77	9.81
23	2.01	10.77

Mask design

The dimension and shape of the mask:

- The energy of the incident photons can reach few MeV.
- The photon mask should stop and protect the undulator wall.
- The length of the masks is 30cm, due to the space reserved for the undulator is limited (319.8m),
- TDR suggests the mask aperture is 4.4mm.
- Outer radius is 15 cm.
- The mask aperture is tapered in the first 5cm (from 0.585cm to 0.44 cm).



Mask Material:

- Masks receive high energies in few MeV.
- Material: High Z-materials, large density and small radiation length are needed.
- Three material candidates:
  - Copper
  - Iron
  - Tungsten

Parameter	Copper	Iron	Tungsten
atomic number	29	26	74
Density ($\frac{g}{cm^2}$)	8.96	7.87	19.3
Thermal conductivity (W/m.K)	358	79.5	7.3
heat capacity (J/g/K)	0.385	0.45	0.134
melting point (K)	1357.77	1811	3695
radiation length (cm)	1.436	1.757	0.35

FLUKA Simulation: Copper

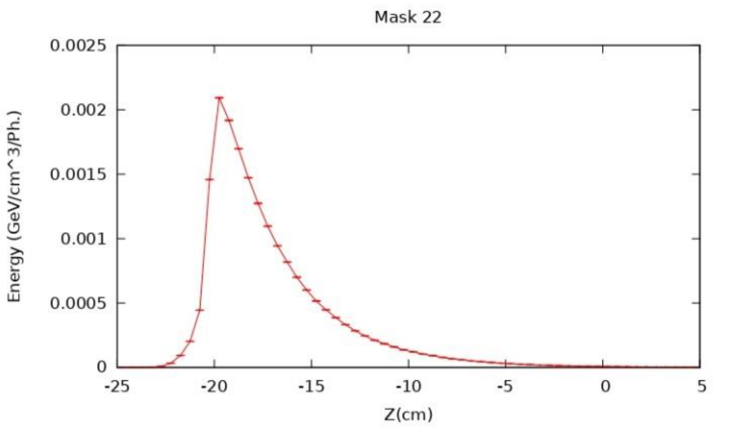
FLUKA: used to calculate the energy density and temperature rise.

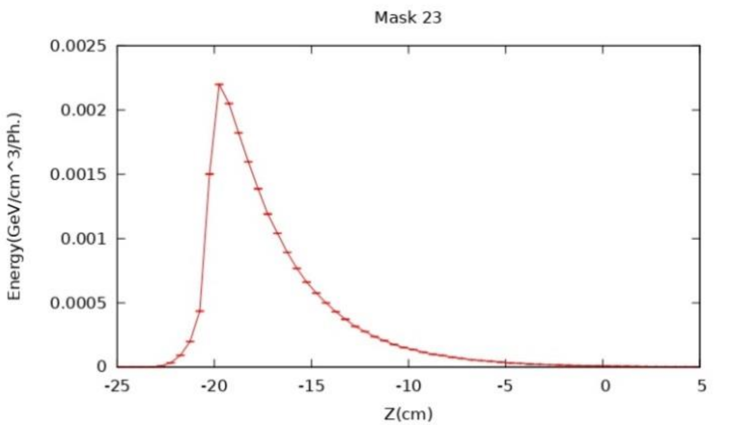
Deposited Energy spectrum at masks (Copper):

Density of Copper = 8.96 g/cm^2

Mask ID	Power Deposited [W]	Average Incident Photon energy [MeV]	Energy Deposited (GeV/cm^3/Ph)	PEDD J/(g*pulse)	Maximum Temperature Rise (K/pulse)	Total Power Stopped by mask
15	80	0.68	0.00123	3.12	8.1	98.1%
16	100	0.85	0.00138	3.63	9.43	98.1%
17	120	0.97	0.00150	4.02	10.44	98.1%
18	140	1.13	0.00163	4.47	11.6	98.2%
19	165	1.31	0.00178	5	12.99	98.3%
20	195	1.46	0.00186	5.55	14.4	98.4%
21	235	1.65	0.00198	6.29	16.35	98.5%
22	270	1.77	0.00210	7.15	18.57	98.5%
23	335	2.01	0.00220	8.18	21.25	98.5%

The profile of the energy deposited along the mask:





FLUKA Simulation: Iron

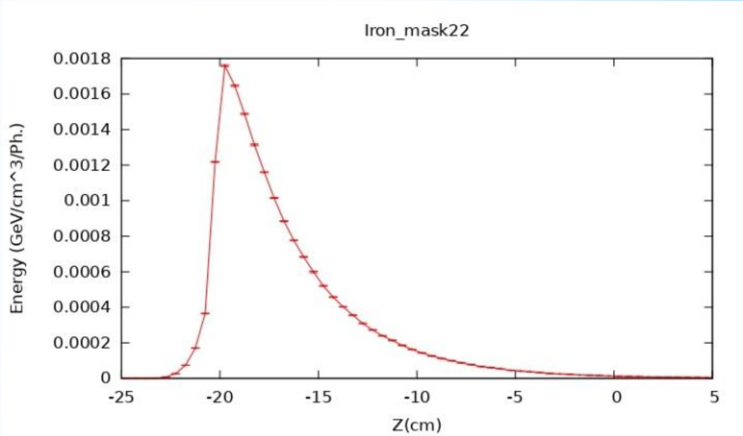
FLUKA: used to calculate the energy density and temperature rise.

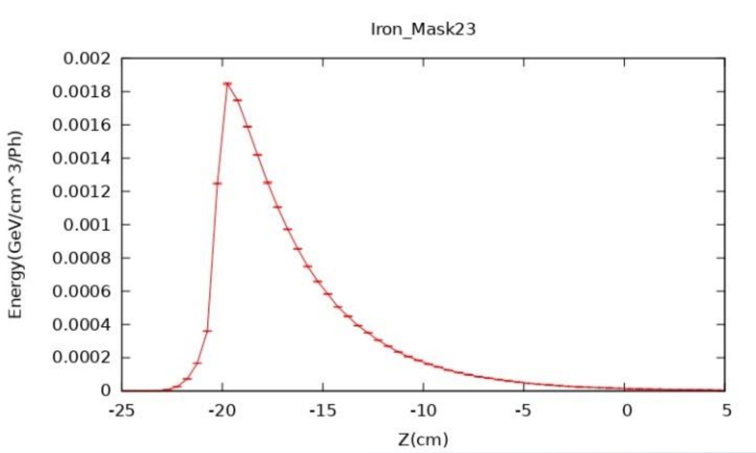
Deposited Energy spectrum at masks (Iron):

Density of Iron = 7.87 g/cm^2

Mask ID	Power Deposited [W]	Average Incident Photon energy [MeV]	PEDD J/(g*pulse)	Maximum Temperature Rise (K/pulse)	Total Power Stopped by mask
15	80	0.68	3.18	7.15	97.3%
22	270	1.77	6.78	15.28	97.5%
23	335	2.01	7.79	17.55	97.5%

The profile of the energy deposited along the mask:





FLUKA Simulation: Tungsten

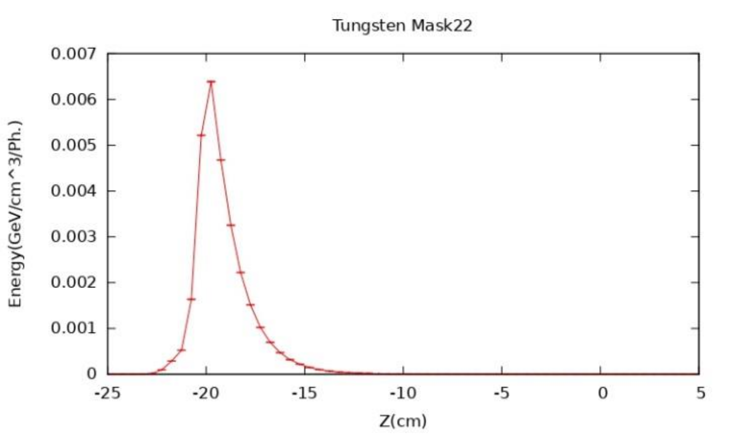
FLUKA: used to calculate the energy density and temperature rise.

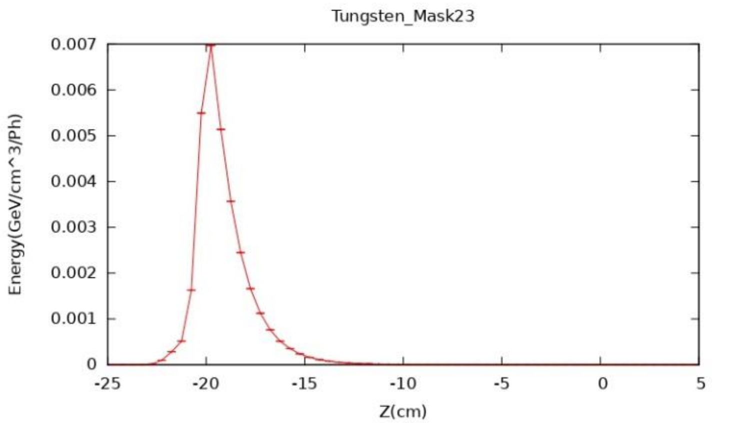
Deposited Energy spectrum at masks (Tungsten):

Density of Tungsten= 19.3 g/cm^2

Mask ID	Power Deposited [W]	Average Incident Photon energy [MeV]	Energy Deposited (GeV/cm^3/Ph)	PEDD J/(g*pulse)	Maximum Temperature Rise (K/pulse)	Total Power Stopped by mask
22	270	1.77	0.0064	10.07	75.14	99.5%
23	335	2.01	0.007	12.09	90.22	99.5%

The profile of the energy deposited along the mask:





Power Leaving the Copper, Iron and Tungsten masks

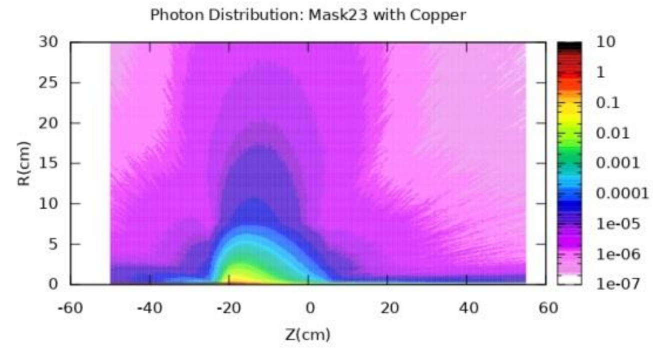
Secondary Particles Distribution around mask

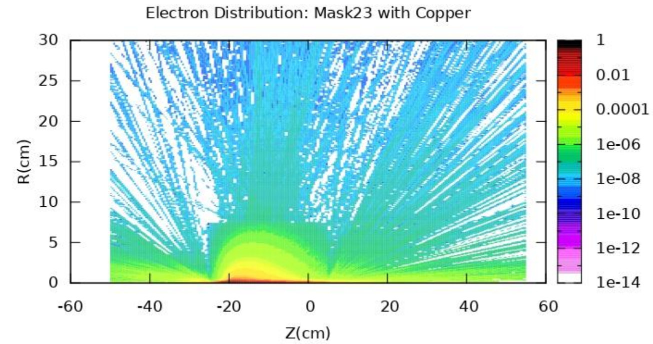
- Secondary Particles Distribution around mask is an important task.
- The secondary particles should not be directed to the undulator wall downstream the mask.

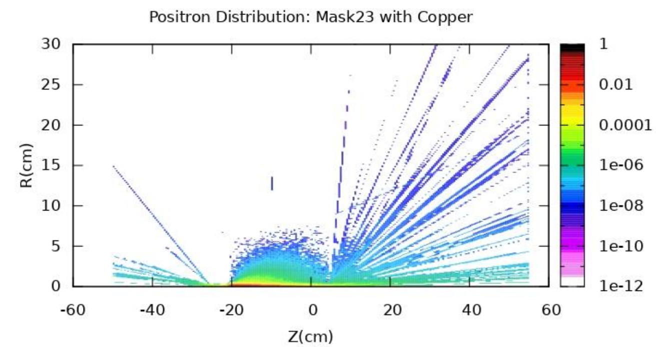
- Mask 23: already downstream the undulator BUT:
  - The worst scenario (highest deposited power) is at mask 23, so it is considered to find a save solution.

Secondary Particles Distribution <u>*(Photon, Electron and Positron are important* for these particular beam parameters*)*</u> around copper mask 23:

- Plots show these secondary particles that leave the mask.
- Most of these are photons.
- Where are these particles going to?



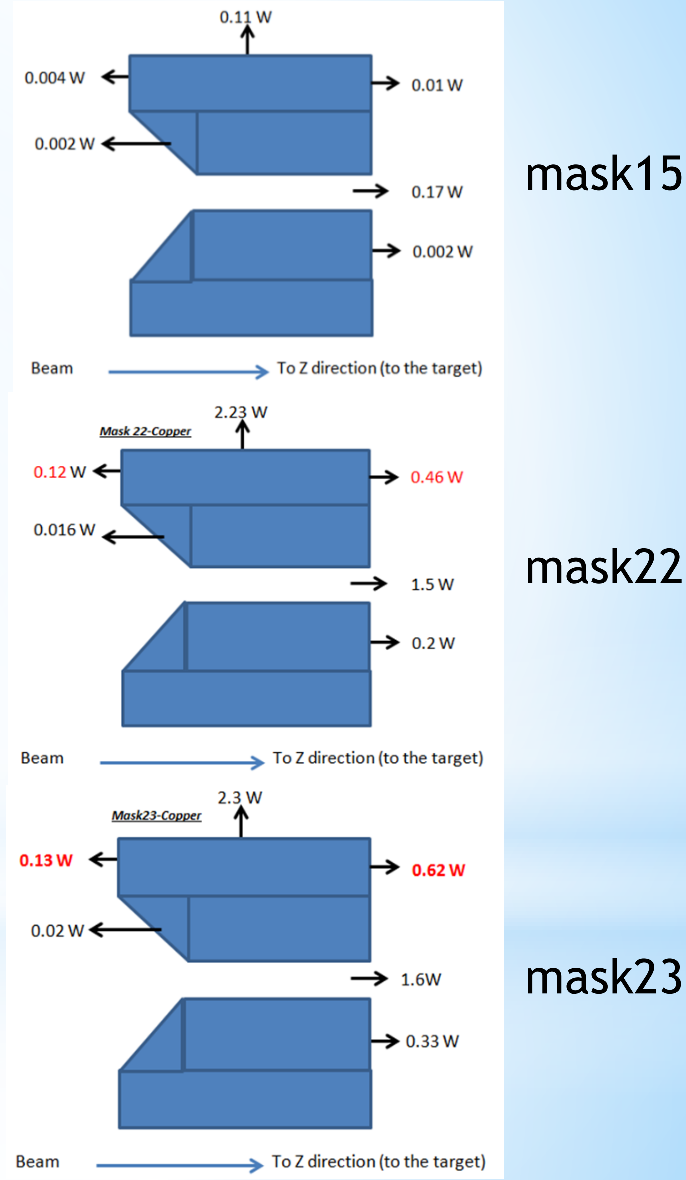




Power leaving the copper mask 15& 22 & 23

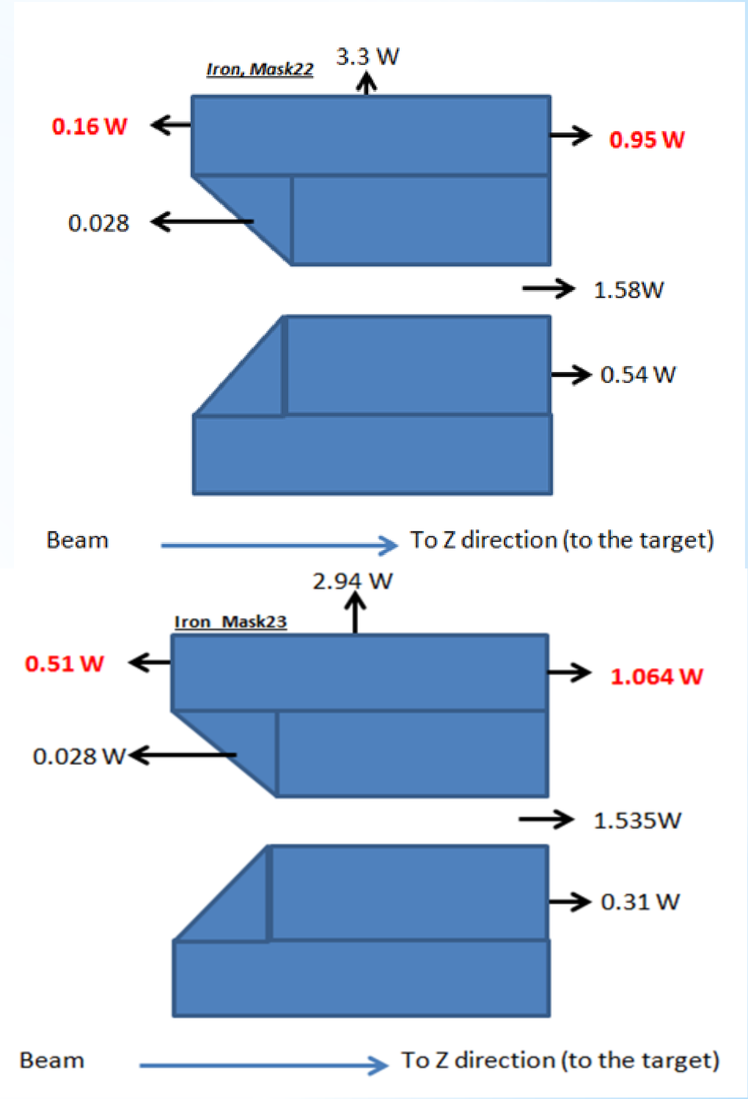
* Copper: can stop ~ 98.5% of the incident power.
* Copper: a good material to be chosen for the 21 masks.
* At mask 22: 0.46 W will be deposited immediately at undulator wall. The radius 0f this power is higher than 5.85mm which is the undulator radius. (The power limit in undulator is 1 W/m).
* At mask 23: 0.62 W will leave the mask but will be out the undulator (mask 23 is located at the exit of the undulator.

Mask ID	Power Deposited [W]	PEDD J/(g*pulse)	Maximum Temperature Rise (K/pulse)	Total Power Stopped by mask
15	80	3.12	8.1	98.1%
22	270	7.15	18.57	98.5%
23	335	8.18	21.25	98.5%



Power leaving the Iron mask 22&23

- Mask 22: 0.95 W will be directed to undulator wall (1W/m is the limit).
- Mask 23: 1.064 W will leave the mask (mask 23 is located at the exit of the undulator)



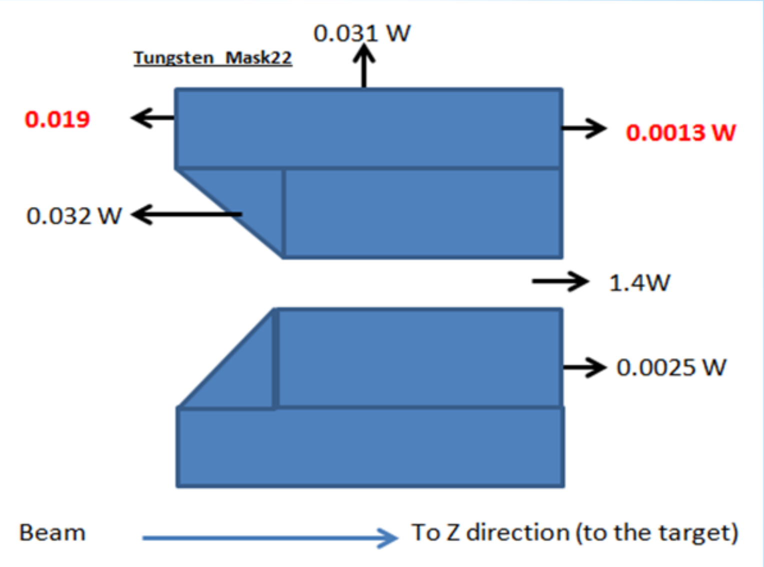
Mask ID	Power Deposited [W]	PEDD J/(g*pulse)	Maximum Temperature Rise (K/pulse)	Total Power Stopped by mask
22	270	6.78	15.28	97.5%
23	335	7.79	17.55	97.5%

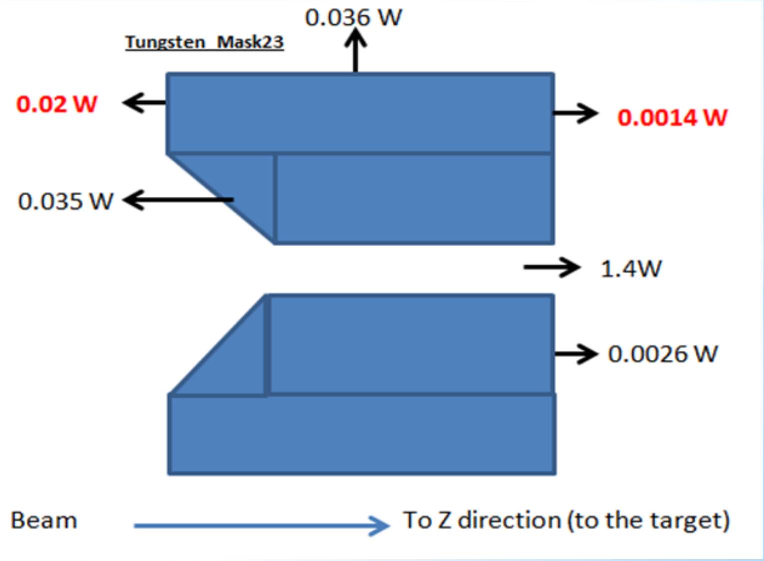
Power leaving the Tungsten mask 22&23

Tungsten stops ~ 99.5%

Decreases the power that leave the mask into undulator wall direction to 0.0013 W .

Mask ID	Power Deposited [W]	PEDD J/(g*pulse)	Maximum Temperature Rise (K/pulse)	Total Power Stopped by mask
22	270	10.07	75.14	99.5%
23	335	12.09	90.22	99.5%





Conclusion

- A possible photon mask geometry with a high photon absorption efficiency has been modelled for three different materials.
- The length of the W mask is $85X_0$ and iron and copper only $17X_0$ and $20.89X_0$, respectively, i.e. a W mask could be substantially shorter.
- Iron mask stops the lowest amount of power (97.5%) compared to the other candidates (Cu and W).
- Copper mask absorbs ~98.5%.
- Tungsten can stop ~ 99.5%.
- To reduce directed power to the undulator wall the last masks (22 and 23) can be made of Tungsten or Copper + Tungsten.
- 2.55 W are leaving the last copper mask (23) in the forward direction and 0.15 W in the backward direction.
- Estimations of power coming from masks to undulator wall is a subject of further studies.
- Energy deposition and temperature increase studies proved that for these particular beam parameters, the masks are safe. For example, the PEDD at copper mask 23 is 8.18 J/(g*pulse), and maximum temperature rise is 21.25 K/pulse.
- The final mask geometry will depend on the non-ideal undulator which is in work.

THANK YOU

Mask 23	Energy Deposited (GeV/cm^3/Ph)	PEDD J/(g*pulse)	Material Density (g/cm^3)	Maximum Temperature Rise (K/pulse)	Total Power Stopped by mask
Iron	0.00178	7.79	7.87	17.55	97.5%
Copper	0.00220	8.18	8.96	21.25	98.5%
Tungsten	0.018	12.09	19.3	232	99.7%