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MAMI Experiment - W Target PEDD Results

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Peak Energy Deposition Density (PEDD) per electron calculation with different units:

$$PEDD_{per\ e^-}\ [GeV/cm^3] = \frac{E^{dep}_{max}\ [GeV]}{V_{mesh}[cm^3]} \frac{1}{N^{simulated}_{e^-}}$$

$$PEDD_{per\ e^-}\ [GeV/g] = \frac{E^{dep}_{max}\ [GeV]}{V_{mesh}[cm^3]} \frac{1}{N^{simulated}_{e^-} \rho_W\ [g/cm^3]}$$

$$PEDD_{per\ e^-}\ [J/g] = \frac{E^{dep}_{max}\ [GeV]}{V_{mesh}[cm^3]} \frac{1}{N^{simulated}_{e^-} \rho_W\ [g/cm^3]}\ 1.6 \times 10^{-10}\ [J/GeV]$$

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1. G4 the optimising the optimisation

# of sim. e-	Mesh	Yield	PEDD^{e-} [GeV/cm^3]	PEDD^{e-} [GeV/g]	PEDD^{e-} [J/g]
1000	0.5^3 mm^3	2.017	6.5853	0.3421	5.48×10^{-11}
5000	0.5^3 mm^3	1.954	6.3564	0.3302	5.29×10^{-11}
10000	0.5^3 mm^3	1.950	6.2353	0.3239	5.19×10^{-11}
30000	0.5^3 mm^3	1.969	6.1757	0.3208	5.14×10^{-11}

# of sim. e-	Mesh	Yield	PEDD^{e-} [GeV/cm^3]	PEDD^{e-} [GeV/g]	PEDD^{e-} [J/g]
10000	0.5^3 mm^3	1.950	6.2353	0.3239	5.19×10^{-11}
10000	0.25^3 mm^3	1.954	7.5785	0.3937	6.31×10^{-11}
10000	0.2^3 mm^3	1.968	7.7361	0.4019	6.44×10^{-11}
10000	0.1^3 mm^3	1.989	16.0886	0.8358	1.34×10^{-10}
10000	0.067^3 mm^3	1.99	13.4908	0.7008	1.12×10^{-10}

❖ To determine how many electrons and how small mesh should be used in the Geant4 simulation, we use **W of size 20x20 mm with thickness 16 mm**, where the incident beam size $\sigma_{x,y} = 0.5$ **mm**.

2. Material Thickness optimisation

❖ 10’000 macroparticles can be used for simulation mesh size would be kept at 0.2^3 mm^3 i.e. less than $\sigma_{rms}/2$ as CERN suggests.
PS: Robert recommends order of magnitude smaller mesh than the beam size, to be checked.

Thickness	Yield	$PEDD^{e-}$ [GeV/cm³]	$PEDD^{e-}$ [GeV/g]	$PEDD^{e-}$ [J/g]
2 mm	0.3170	2.9023	0.1508	2.4155×10^{-11}
4 mm	0.9206	5.0913	0.2645	4.2375×10^{-11}
8 mm	2.0014	7.7515	0.4027	6.4516×10^{-11}
12 mm	2.2941	7.4851	0.3888	6.2298×10^{-11}
16 mm	1.9684	7.7361	0.4019	6.4388×10^{-11}
20 mm	1.4880	7.6822	0.3991	6.3939×10^{-11}

3.1. MAMI Beam - FCCee PEDD

Thickness	Yield	PEDD^{e-} [GeV/cm^3]	PEDD^{e-} [GeV/g]	PEDD^{e-} [J/g]
12 mm	2.2941	7.4851	0.3888	6.2298 x 10^{-11}

Beam energy, GeV	
Number of bunches	**2**
e+ bunch charge @200 MeV, e+	4,2E+10
e+ yield	2,3
Bunch charge, e-	**1,8E+10**
Bunch length (rms), mm	1
Bunch transv. size (rms), mm	**0,5**
Bunch separation	tens of ns
Repetition rate (max), Hz	100
Beam power, kW	3,5
Emittance (normalsed max), mm.rad	<1
Energy spread, %	< 1
PEDD (target), J/g	**8,6**
Deposited power (target), kW	**0,6**

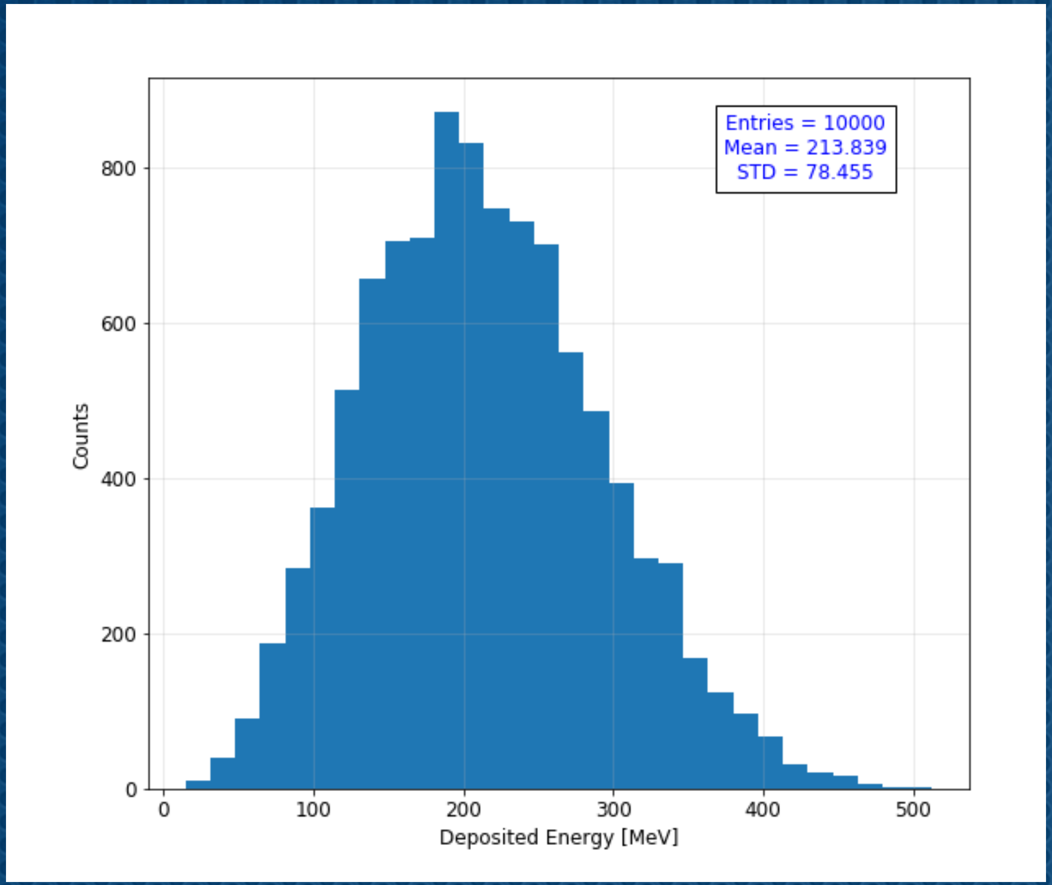
- ❖ Now calculation becomes simple, using PEDD for one electron in J/g, we need 8.6 / 6.23 x 10^{-11} = 1.38 x10^{11} electrons at MAMI to reach FCC-ee PEDD = 8.6 J/g.

- ❖ MAMI bunch charge 1.28×10^5 e- for 2.45 GHz (~0.4 ns), therefore 1.38 x10^{11} / 1.28×10^5 = 1.08 × 10^6 bunches/pulse needed !

- ❖ This would refer to a pulse duration of 0.44 ms!. Allowing 100 or 200 Hz repetition! 0.44 ms pulse with 200 Hz refers to a current of 4.4 uA compared to max 50 uA

3.1. MAMI Beam - FCCee PEDD

Thickness	Yield	PEDD^{e-} [GeV/cm^3]	PEDD^{e-} [GeV/g]	PEDD^{e-} [J/g]
12 mm	2.2941	7.4851	0.3888	6.2298 x 10^{-11}



- We need 1.38 x10^{11} electrons per pulse to reach 8.6 J/g.
- Then the power is
  1.38 x10^{11} x 213.8 MeV = 4.7 W per pulse
- For 200 Hz beam 0.940 kW; whereas FCC is 1.2 kW (@ 200 Hz)
- The maximum power is
  1.38 x10^{11} x 588.81 MeV x 200 = 2.600 kW per pulse

3.2. MAMI Beam - MAX PEDD

Thickness	Yield	$PEDD^{e-}$ [GeV/cm³]	$PEDD^{e-}$ [GeV/g]	$PEDD^{e-}$ [J/g]
12 mm	2.2941	7.4851	0.3888	6.2298×10^{-11}

❖ In order to reach the W-Re alloy PEDD limit 35 J/g we need $35 / 6.23 \times 10^{-11} = 5.62 \times 10^{11}$ electrons at MAMI with the rms beam size 0.5 mm.

❖ MAMI bunch charge 1.28×10^{5} e- for 2.45 GHz (~0.4 ns), therefore $5.62 \times 10^{11} / 1.28 \times 10^{5} = 4.39 \times 10^{6}$ bunches/pulse needed !

❖ This would refer to a pulse duration of 1.79 ms!

❖ Power per pulse $5.62 \times 10^{11} \times$ 213.8 MeV = 19.2 W per pulse, for 200 Hz 3.844 kW

3.2. MAMI Beam - MAX PEDD

Thickness	Yield	E_{dep}^{max}	$PEDD^{e-}$ [GeV/cm^3]	$PEDD^{e-}$ [GeV/g]	$PEDD^{e-}$ [J/g]
12 mm	2.3247	84.348 MeV	67.4784	3.054	5.6162×10^{-10}

$\sigma_{x,y} = 0.1$ mm

❖ In order to reach the W-Re alloy PEDD limit 35 J/g we need $35 / 5.6162 \times 10^{-10} = 6.23 \times 10^{10}$ electrons at MAMI with the rms beam size 0.5 mm.

❖ MAMI bunch charge 1.28×10^5 e- for 2.45 GHz (~0.4 ns), therefore $6.23 \times 10^{10} / 1.28\times10^5 = 4.87 \times 10^5$ bunches/pulse needed !

❖ This would refer to a pulse duration of 0.2 ms!

❖ Power per pulse $5.6162\times10^{10} \times$ 212.4 MeV = 1.90 W per pulse, for 200 Hz 0.380 kW

❖ Maximum Power per pulse $5.6162\times10^{10} \times$ 558.13 MeV = 5.02 W per pulse, for 200 Hz 1.004 kW

3. Target Selection for Beam Test - MAMI Beam Parameters

- Beam energy: 855 MeV (500-855 MeV), E_{min} = 195 MeV
- Beam current: CW e- beam with ~50 μA average beam current
- Repetition rate: kHz- MHz
- Pulse length: 10 μs - > ~ ms
- Bunch charge: 1.28×10^5 e-/bunch
- Bunch spacing: 0.4 ns
- Beam spot size: < 1 mm FWHM => (FWHM = 2.355 σ) => ~0.4 mm RMS (can be smaller ?)