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Energy dependence of DPA damage in SC coils and figure of merit for Mu2e @ PIP-II

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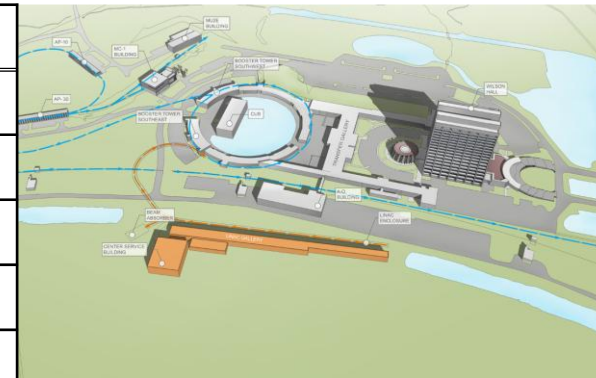
Mu2e@PIP-II upgrade plans

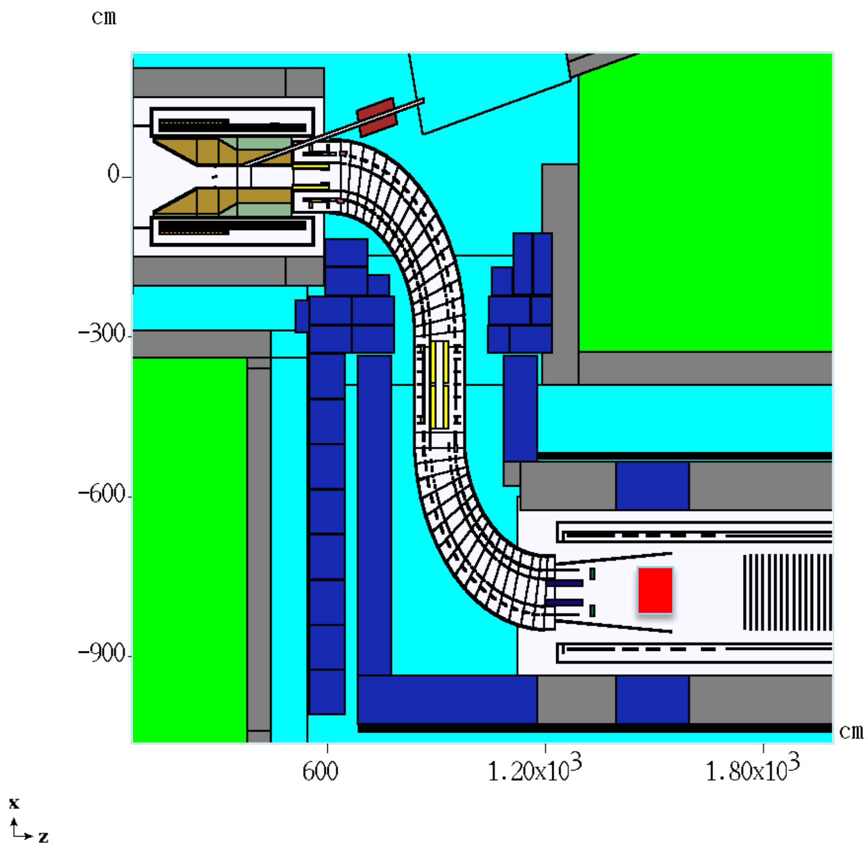
Performance Parameter	PIP	PIP-II	
Linac Beam Energy	400	800	MeV
Linac Beam Current	25	2	mA
Linac Beam Pulse Length	0.03	0.5	msec
Linac Pulse Repetition Rate	15	15	Hz
Linac Beam Power to Booster	4	13	kW
Linac Beam Power Capability (@>10% Duty Factor)	4	~200	kW
Mu2e Upgrade Potential (800 MeV)	NA	>100	kW
Booster Protons per Pulse	4.2×10^{12}	6.4×10^{12}	
Booster Pulse Repetition Rate	15	15	Hz
Booster Beam Power @ 8 GeV	80	120	kW
Beam Power to 8 GeV Program (max)	32	40	kW
Main Injector Cycle Time @ 120 GeV	1.33	1.2	sec
LBNF Beam Power @ 120 GeV*	0.7	1.2	MW
LBNF Upgrade Potential @ 60-120 GeV	NA	>2	MW



- Early next decade
- 250 meter linac
- 800 MeV proton beam (2 mA)
- -> Booster -> 8 GeV (120 kW)
- -> Main Injector/Recycler
- ->120 GeV (1.2 MW)

Table from S.Holmes, Neutrino Summit, 2014

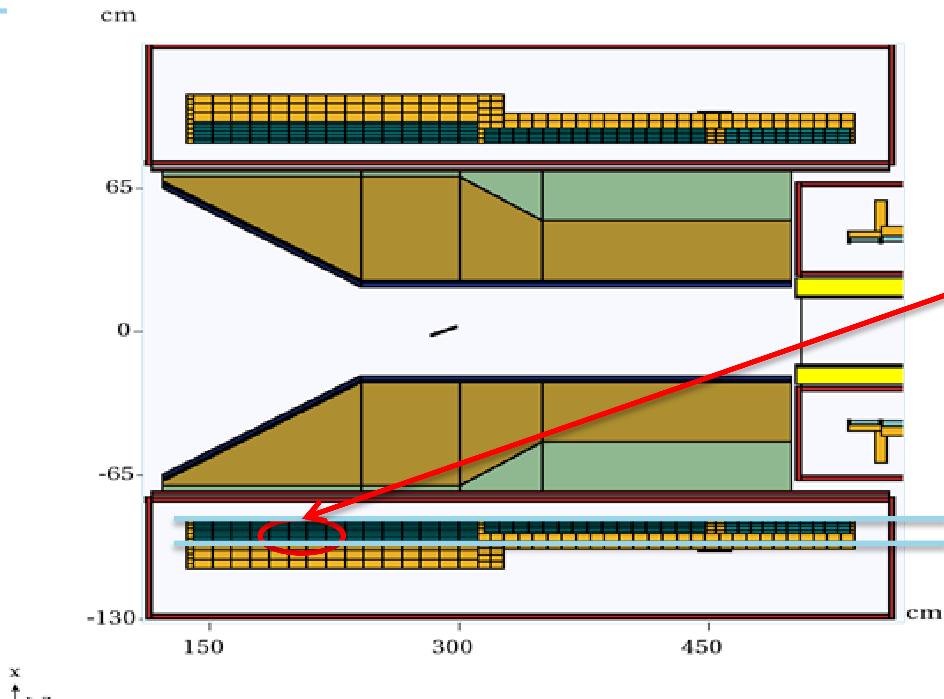
Baseline Mu2e and MARS15 simulations

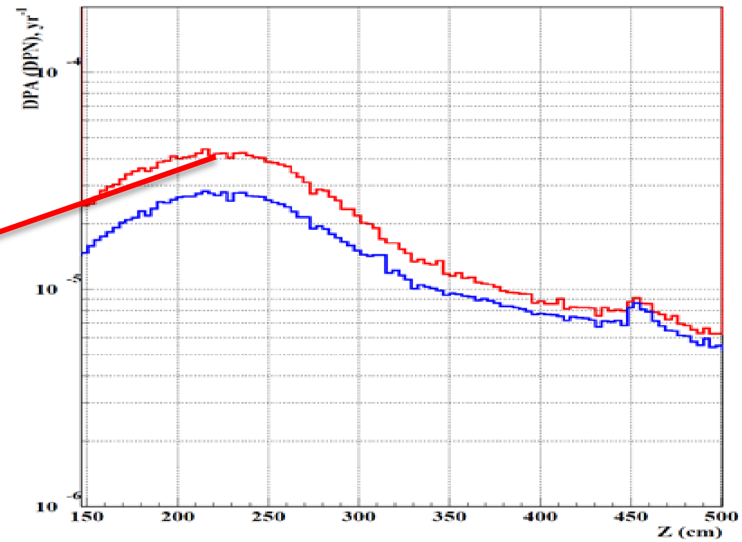


DPA and power density vs beam energy
vs HRS material
Muon yield/stopping rate vs beam energy
Figure of merit (stopping rate per DPA)

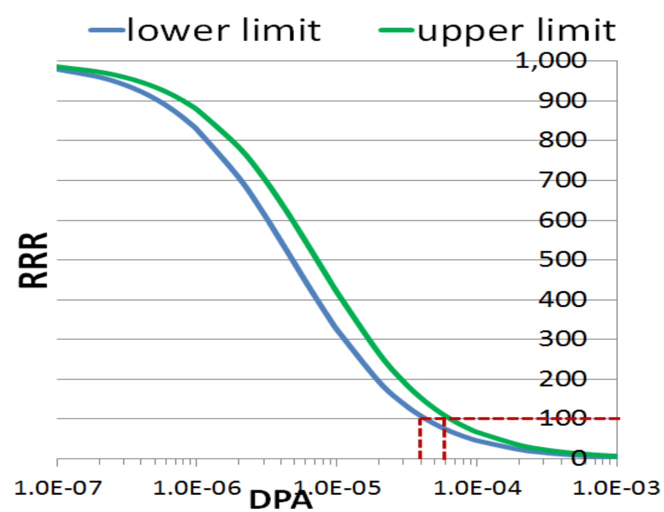
- 8 GeV 8 kW proton beam
- Au target L=16 cm D=0.6 cm (beam σ=0.1 cm)
- Bronze HRS (tungsten considered for upgrade)
- PS, TS, DS (17-foil Al stopping target)
- In MARS15 simulations: LAQGSM, thresholds: 1E-12 GeV for neutrons, 100 keV for charged h., muons, photons

DPA limit and model

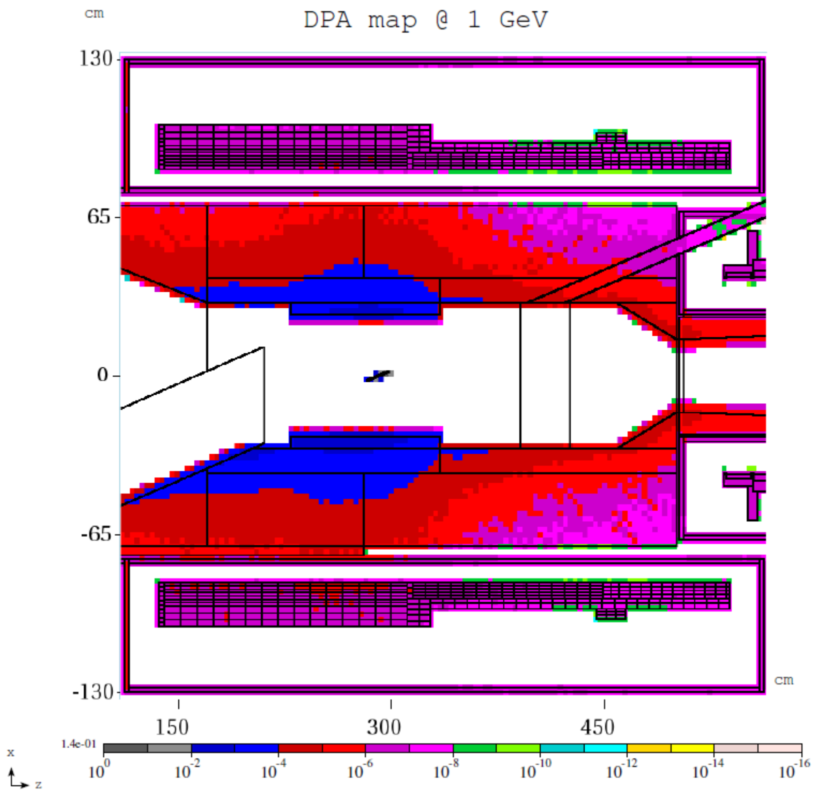


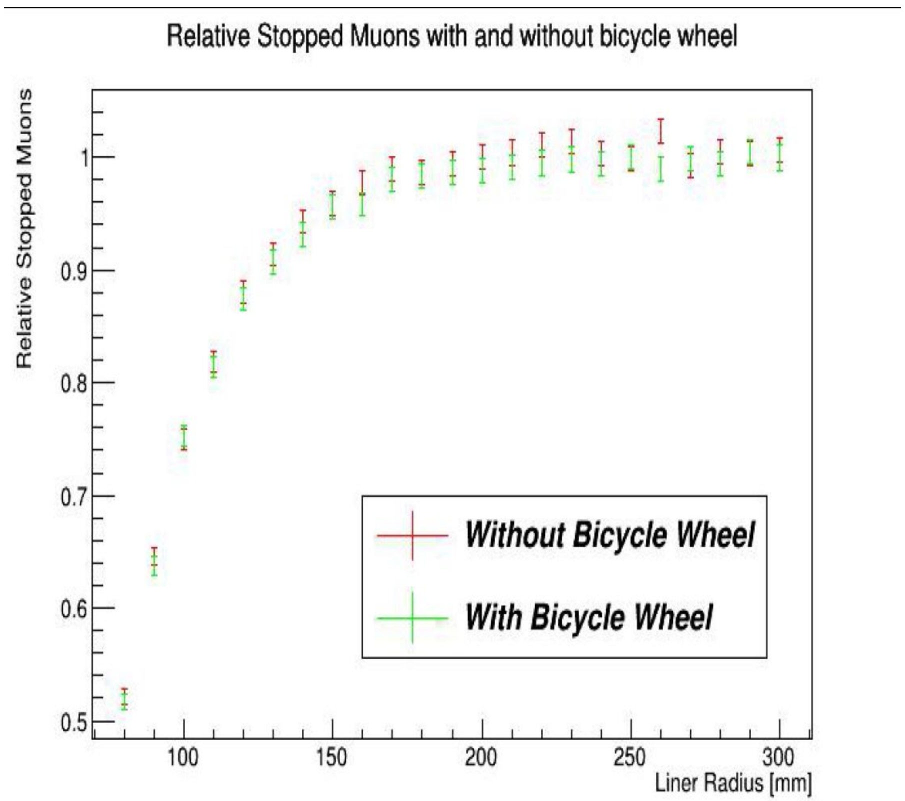


HRS: Bronze, Tungsten, Stainless (?)
DPA model: NRT (below 20 (150) MeV ENDFB-VII/NJOY based cross section library FermiDPA 1.0) is used. NbTi coils
DPA limits incorporate KUR measured data 4-6E-5 DPA



HRS thickness increase possibilities

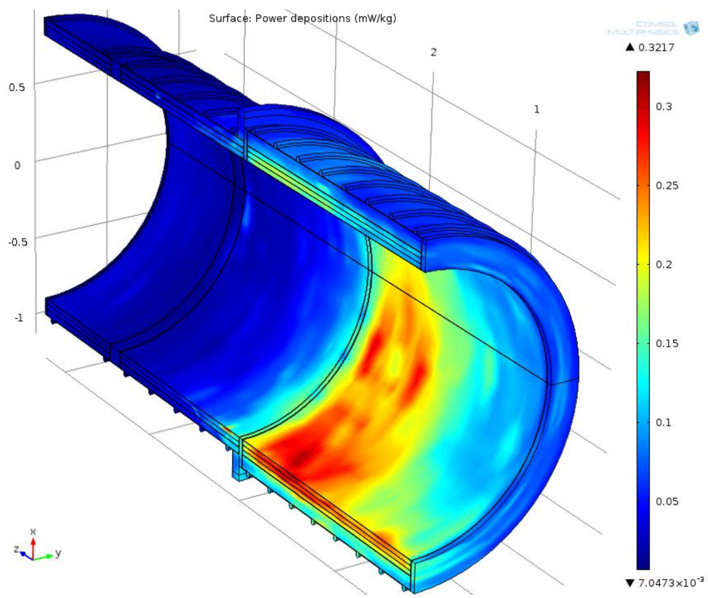




Inner bore radius=20 cm
No yield drop for R>17 cm

K.Lynch and J.Popp
Muon yield change with liner radius

Power density and other limits

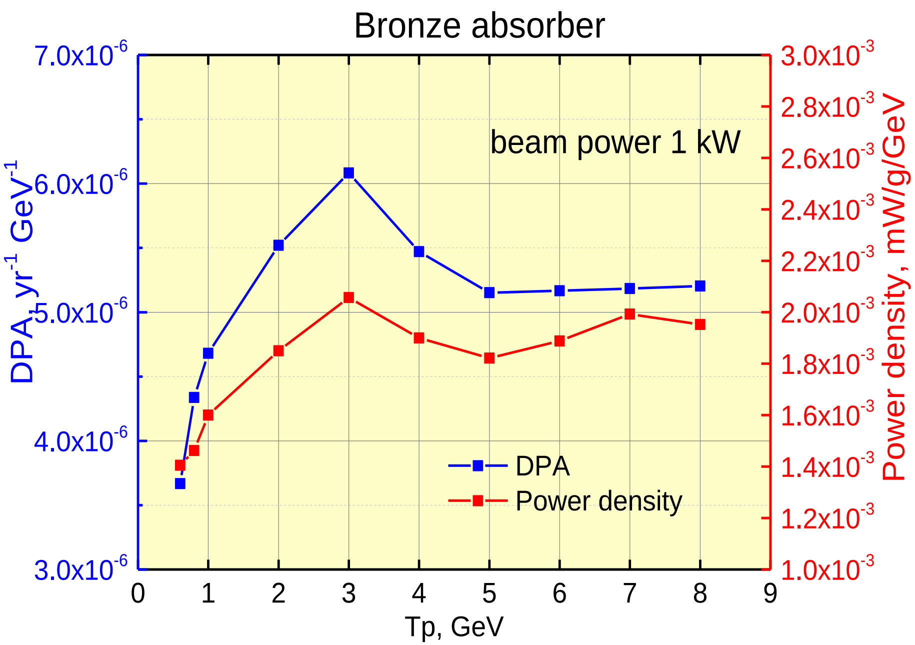


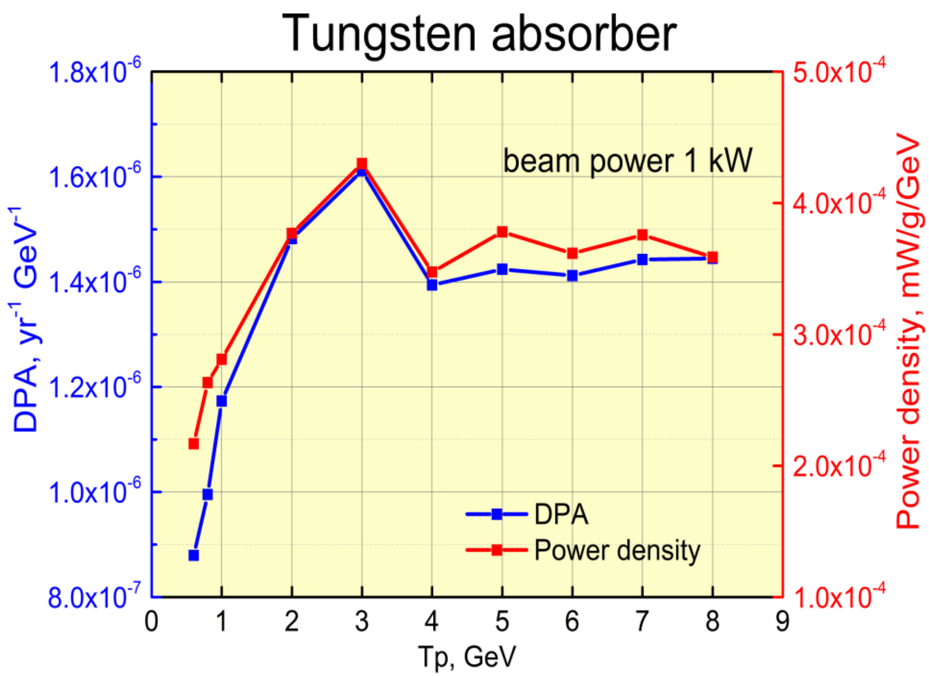
Power density limit:
-depends on the cooling scheme
-involves many other assumptions
Dynamic heat load limit:
-scales with the number of cooling stations
Absorbed dose limit: usually high

Quantity	MARS15, reduced	Limits
Peak Total Neutron flux in coils, n/cm2/s	$8.3*10^9$	
Peak Neutron flux > 100 keV in coils, n/cm2/s	$3.1*10^9$	
Peak Power density, μW/g	17	30
Peak DPA (FermiDPA 1.0)	$4.4*10^{-5}$/yr	$4\text{-}6*10^{-5}$
Peak absorbed dose over the lifetime, MGy	1.7	7
Dynamic heat load, W	42	100

Talk at NuFact'12, July 23-28, 2012, Williamsburg

DPA as a function of beam energy



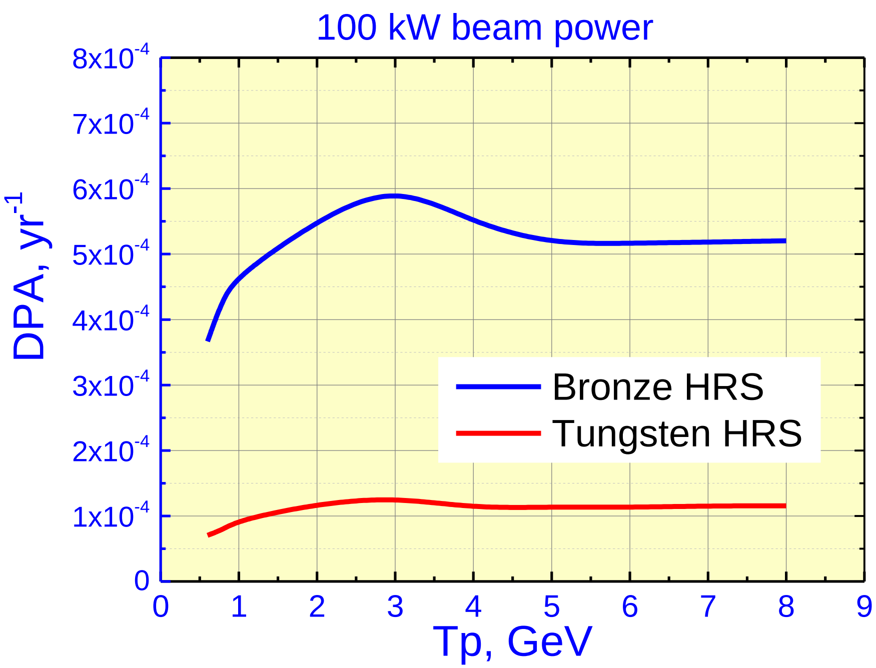


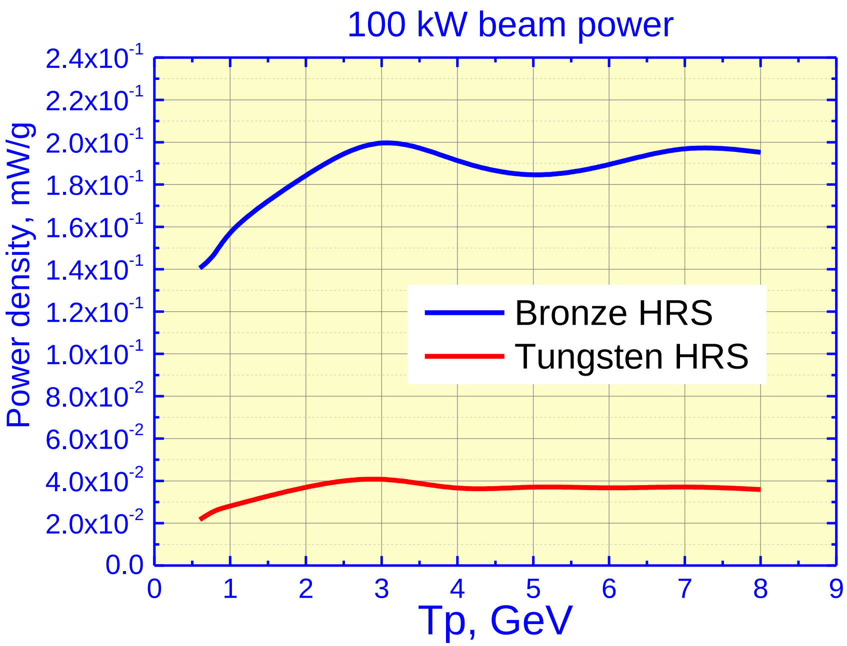
DPA damage and peak power density are:

Largest at ~3 GeV and drops with energy below that energy

Larger for bronze than for tungsten by a factor of ~3-4

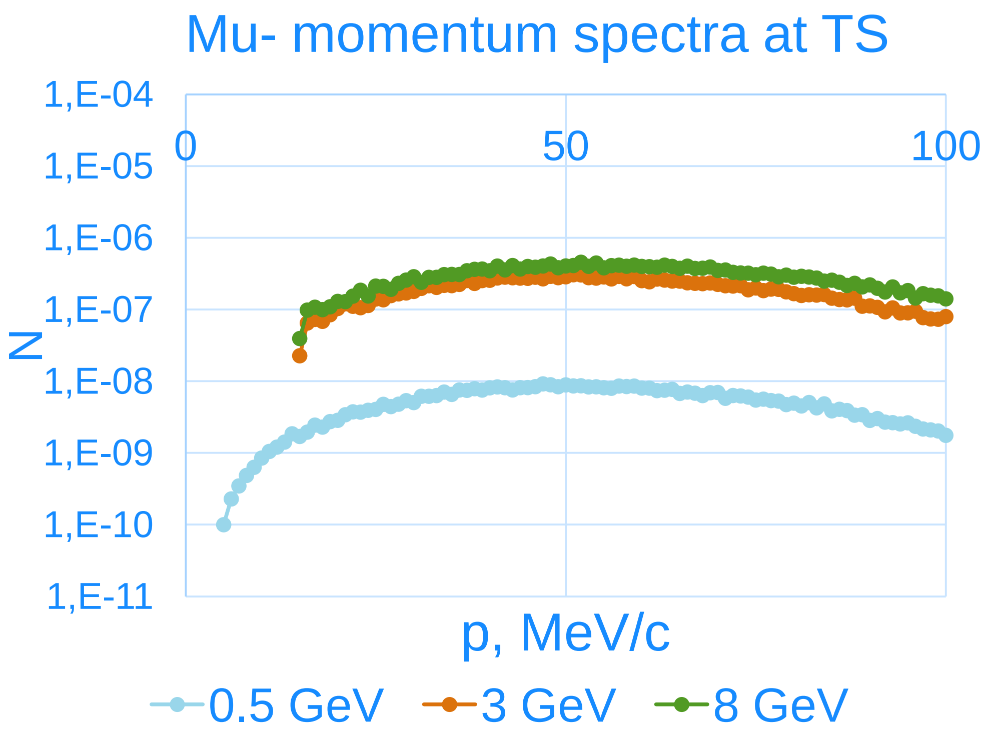
DPA and power density @ 100 kW

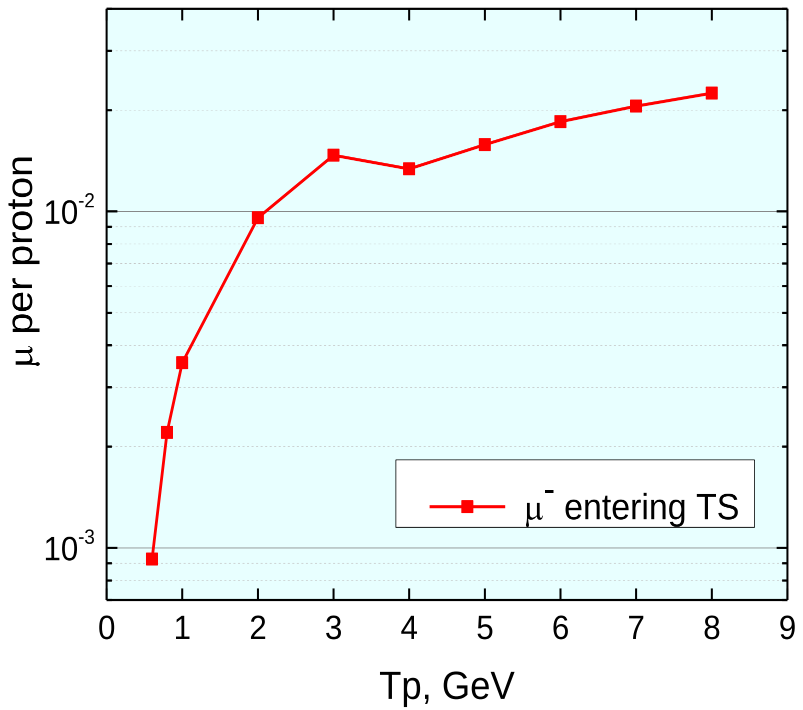




- DPA: Current coil design can tolerate 100 kW at proton energies < 1 GeV.
- Power density: different cooling scheme may be required.
- Above 1 GeV (DPA) or 2 GeV almost flat with energy.

Mu- spectra and yields at TS

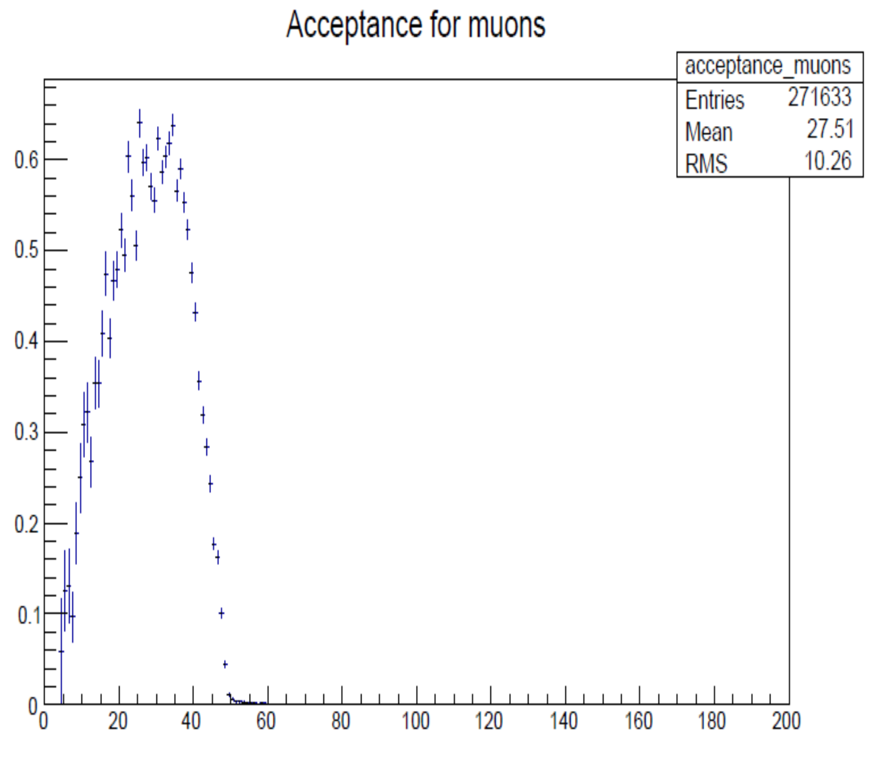


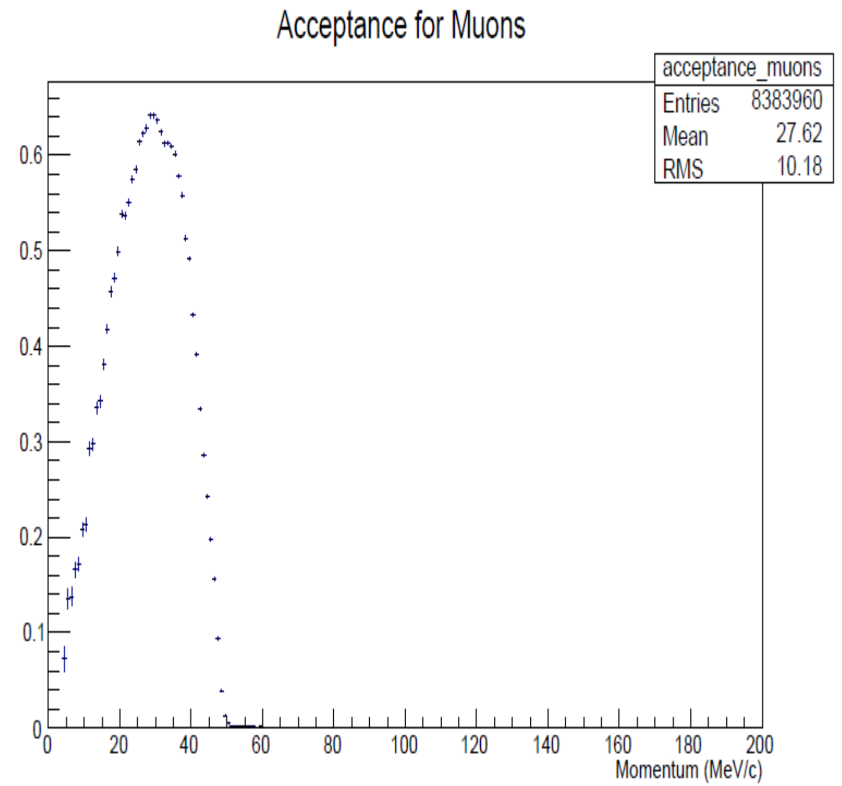


Constant beam intensity (not power) = $6 \cdot 10^{12}$ p/s

Steepest rise in μ^- yields is between 0.5 and 2 GeV.

Acceptance

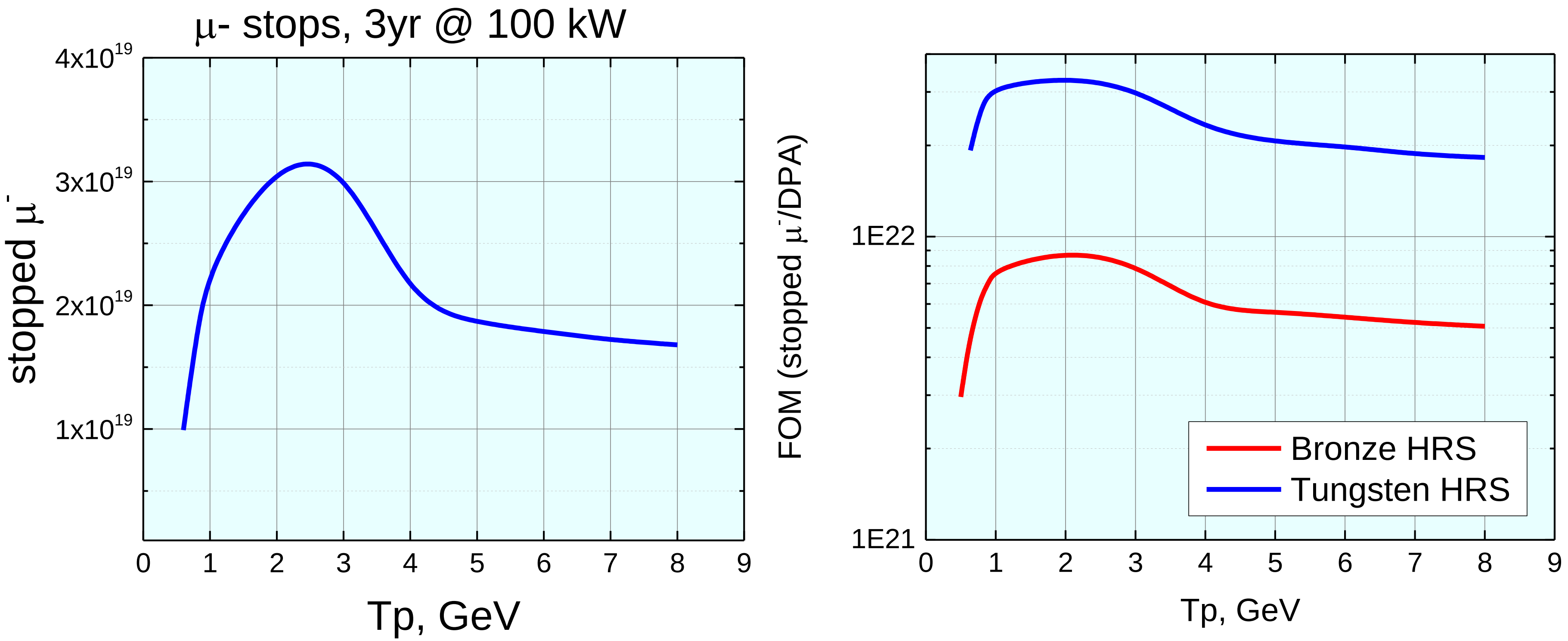




At 0.8 GeV Average 1-8 GeV

Calculated using G4beamline, used with MARS15 calculated muon spectra at TS

Mu- stopping rates and Figure of Merit



- 3 years = 3.6E20 protons on target
- If only stopped muons are taken into account: 2-3 GeV
- If also DPA is accounted for: 1-3 GeV is optimal
- FOM : 0.8 GeV is at least as good as 8 GeV

Conclusions

- Energy dependence of DPA damage, power density, muon yield and muon stopping rate is studied.
- Figure of Merit (stopped muon to DPA ratio) is proposed.
- Current coil/ tungsten HRS design can tolerate 100 kW @ energies < 1 GeV.
- FOM is largest in the 1-3 GeV range.
- FOM for 0.8 GeV is slightly better than for 8 GeV.