Muon Collider & nuSTORM Targets

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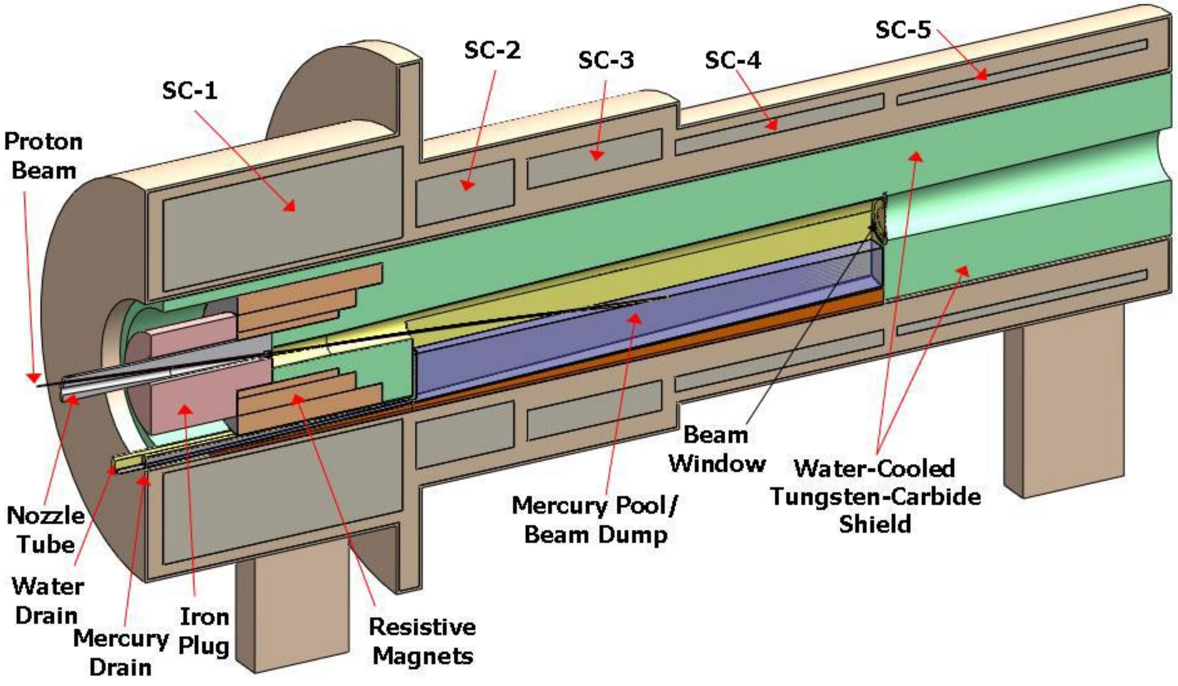
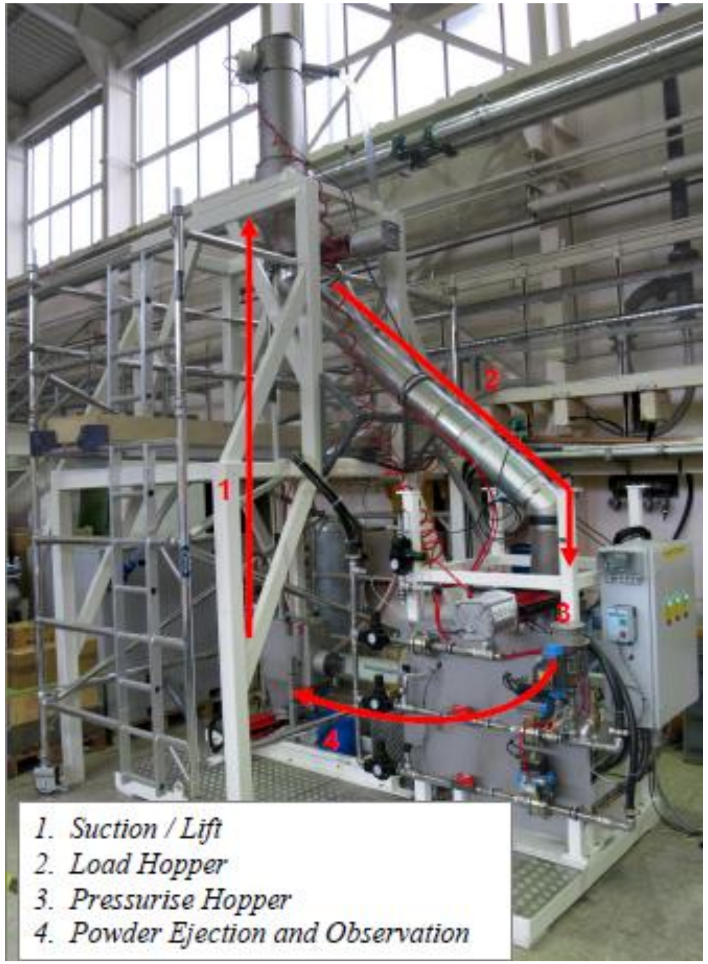
2nd UK Collaboration Meeting, 27 Sept 2021

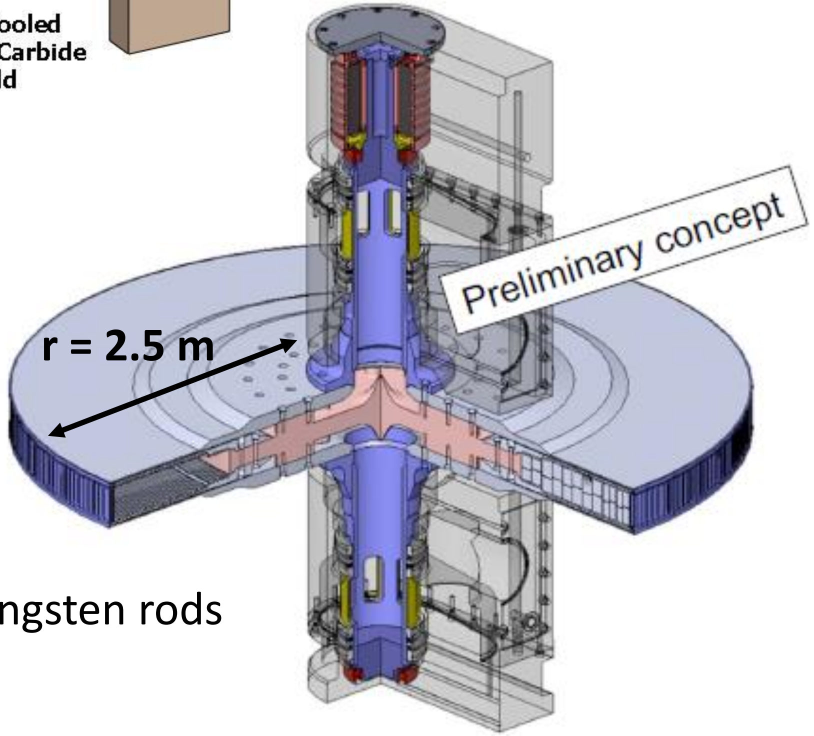
Muon Collider target concepts (4 MW)

Baseline: free Hg jet in 15-20 T tapered solenoidal field



Tungsten powder RAL test rig

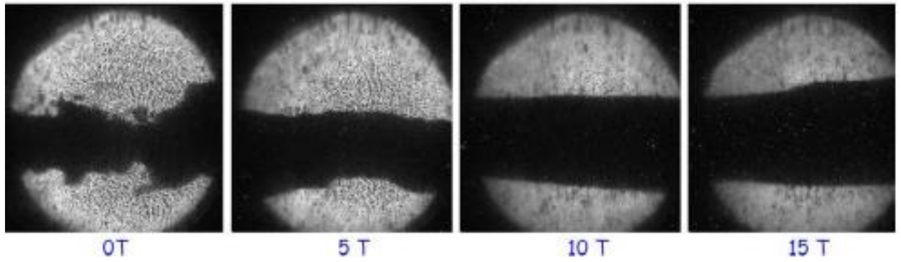




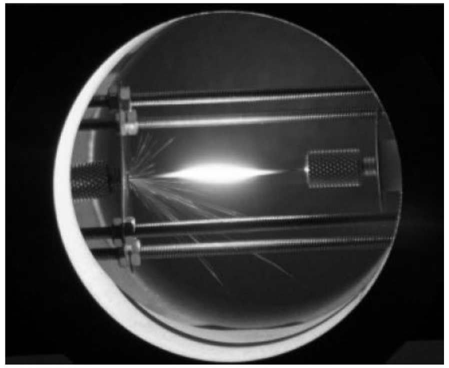
Rotating solid targets e.g. ~100 tungsten rods

Muon Collider target concepts

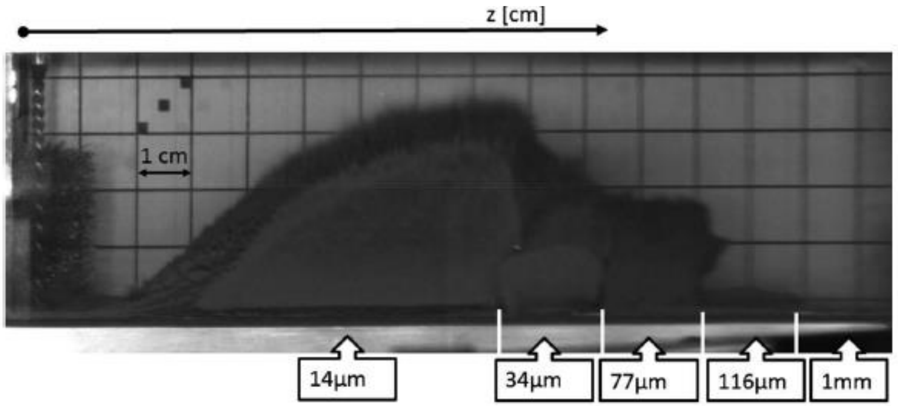
- High-Z liquid: free Hg jet
  - MERIT experiment: p beam interactions in high B field
  - Recirculating between beam pulses
  - Safety risks: future target facilities very unlikely to use Hg jets



- High-Z solids: tungsten rods, 20 cm long in D = 5 m rotating wheel
  - Rods able to withstand thermal shock from 1 pulse (RAL high current wire tests)
  - Radiation cooled before encountering another beam pulse
  - Wheel: Helmholtz coil arrangement for magnets, with shielding gaps

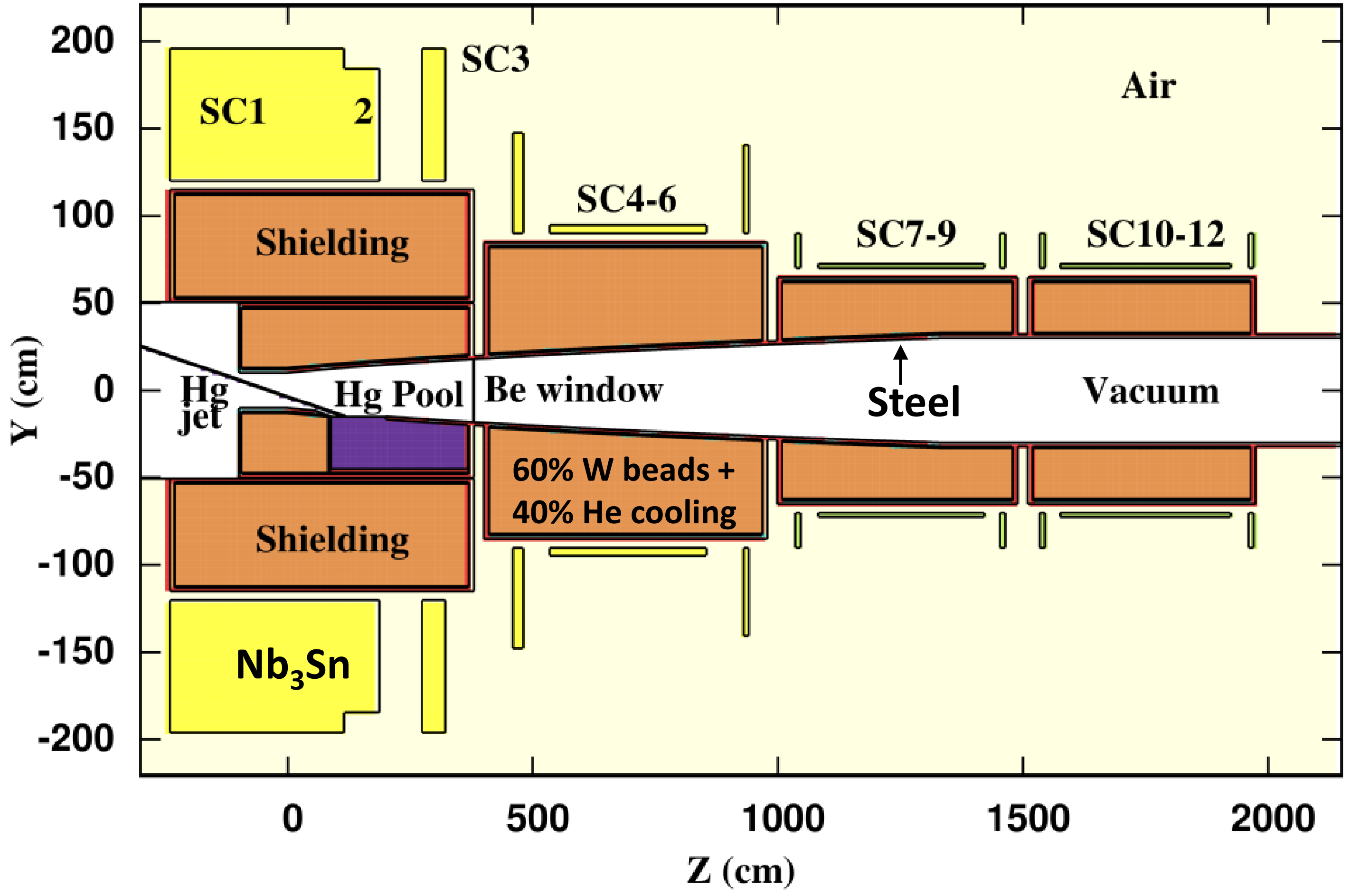


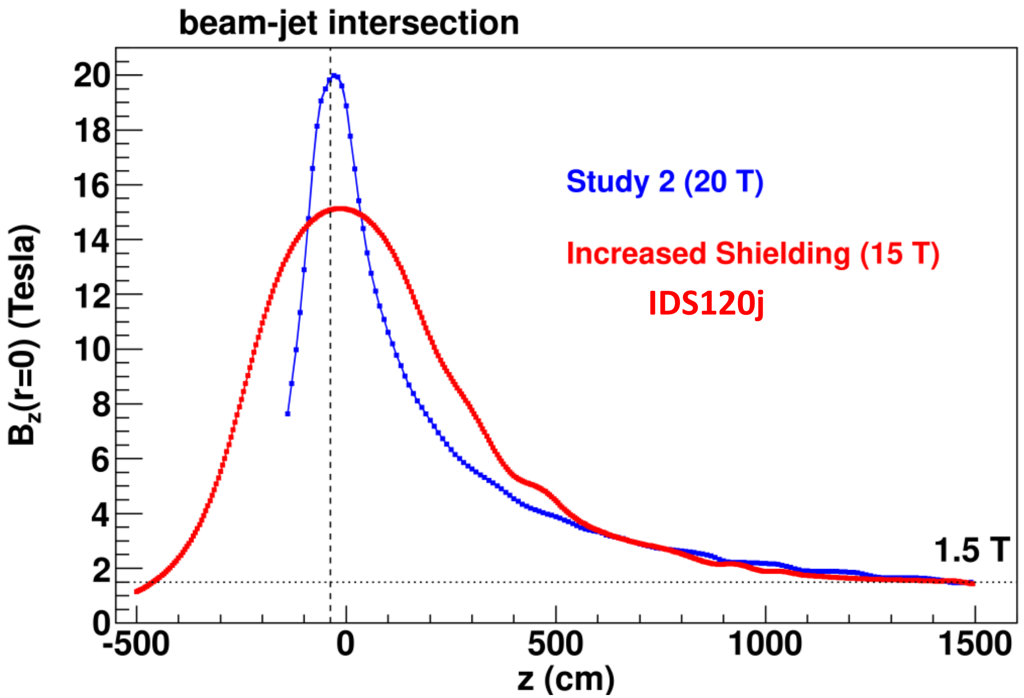
- High-Z powder targets:
  - Quasi-liquid, recirculating between beam pulses
  - RAL test rig & HiRadMat (CERN) in-beam studies
  - R&D: Flow uniformity, erosion, consistent density (~45% solid)

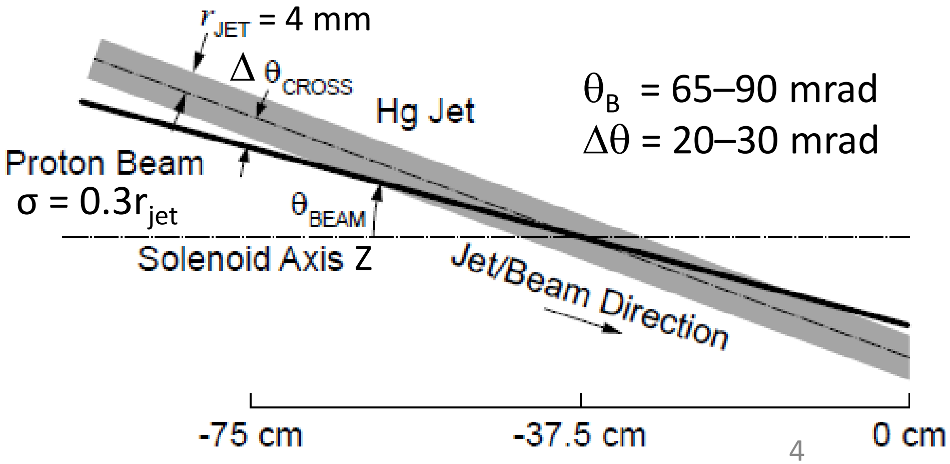


- Low-Z solids: graphite rods
  - Reliable target material, mature technology (T2K, NuMI, …)
  - Not expected to survive 4 MW beam power

Muon Collider target geometry







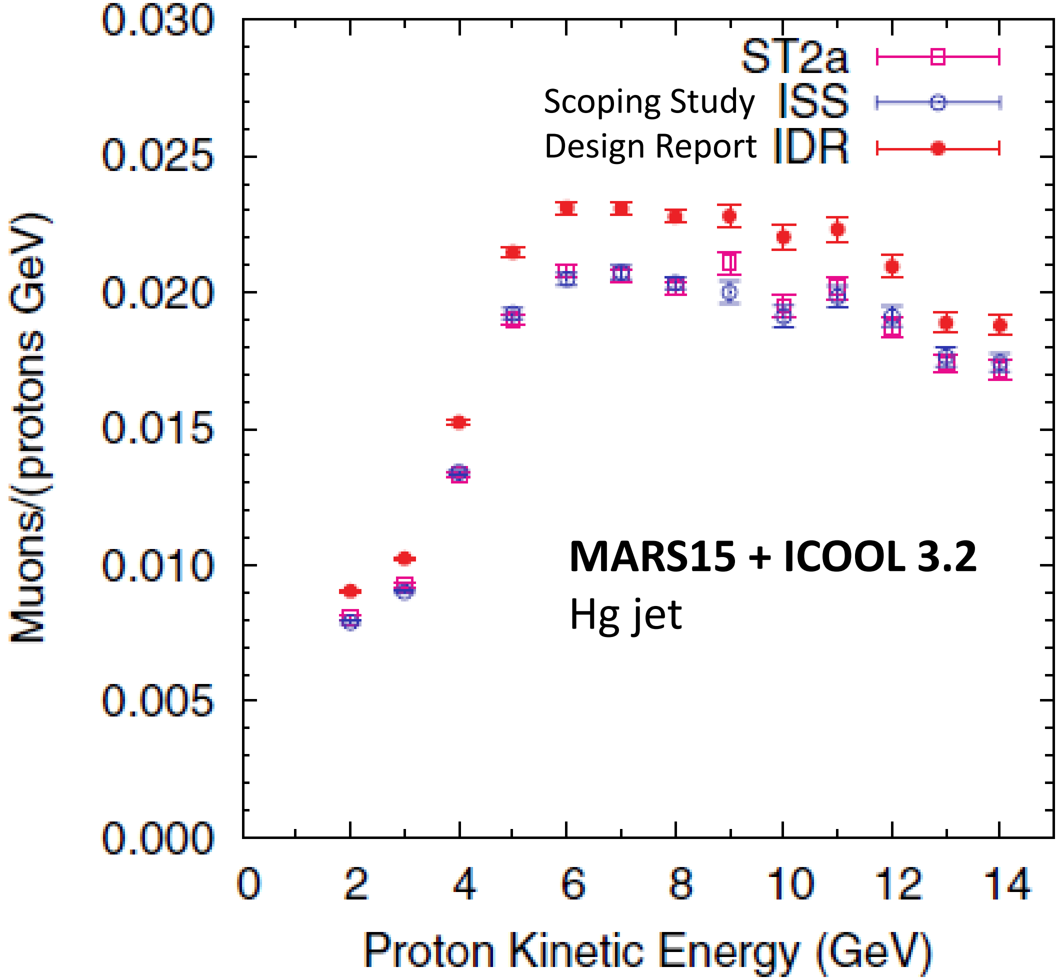
θ_B = 65–90 mrad
$\Delta\theta$ = 20–30 mrad

"**IDS120j**": International Design Study, 120 cm SC inner radius, version j

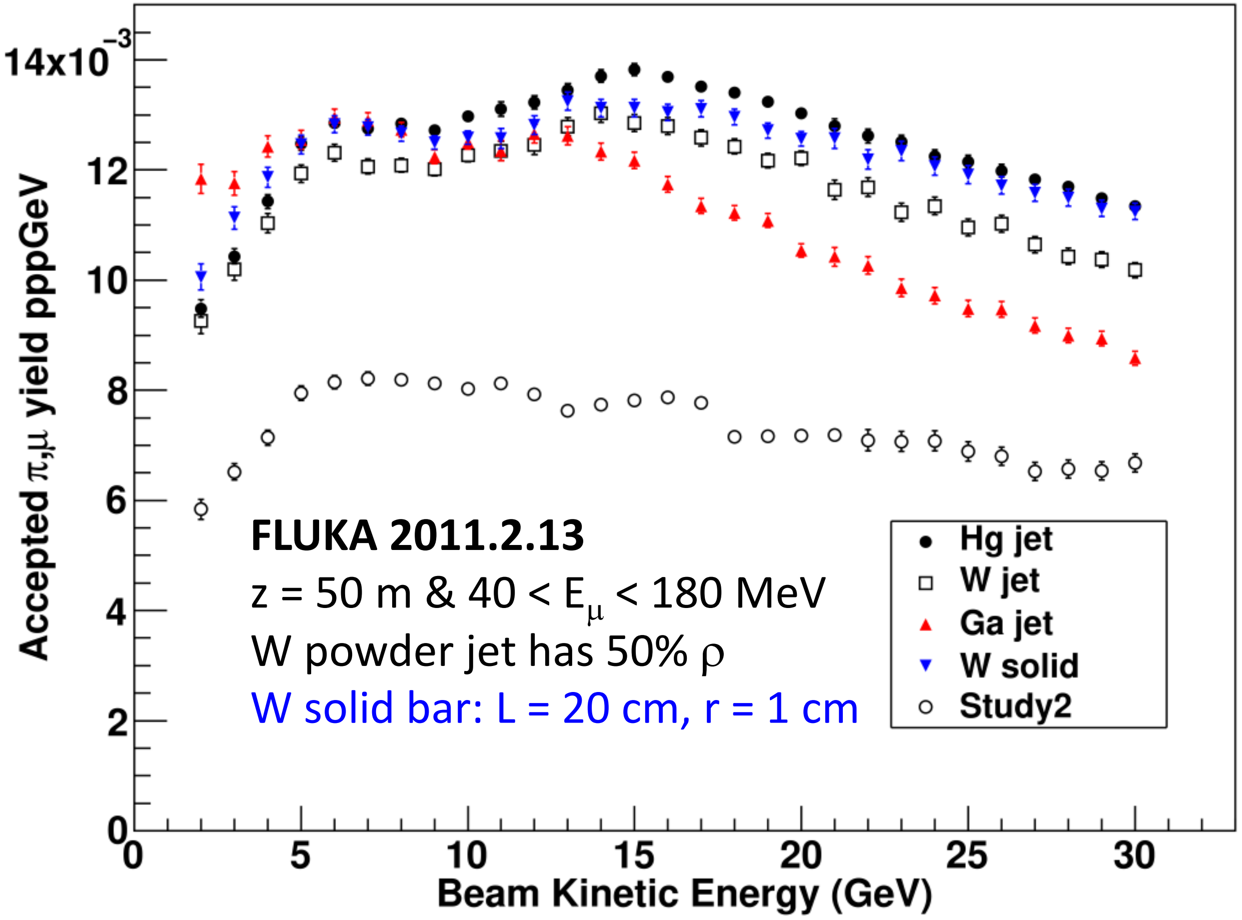
Same magnet arrangement: Hg jet, W solid or powder, graphite

Muon Collider accepted yields

Total N(μ+) + N(μ-)



Charge-averaged 0.5x[N(μ+) + N(μ-)]



X. Ding et al., [Phys. Rev. ST AB 14, 111002 (2011)]

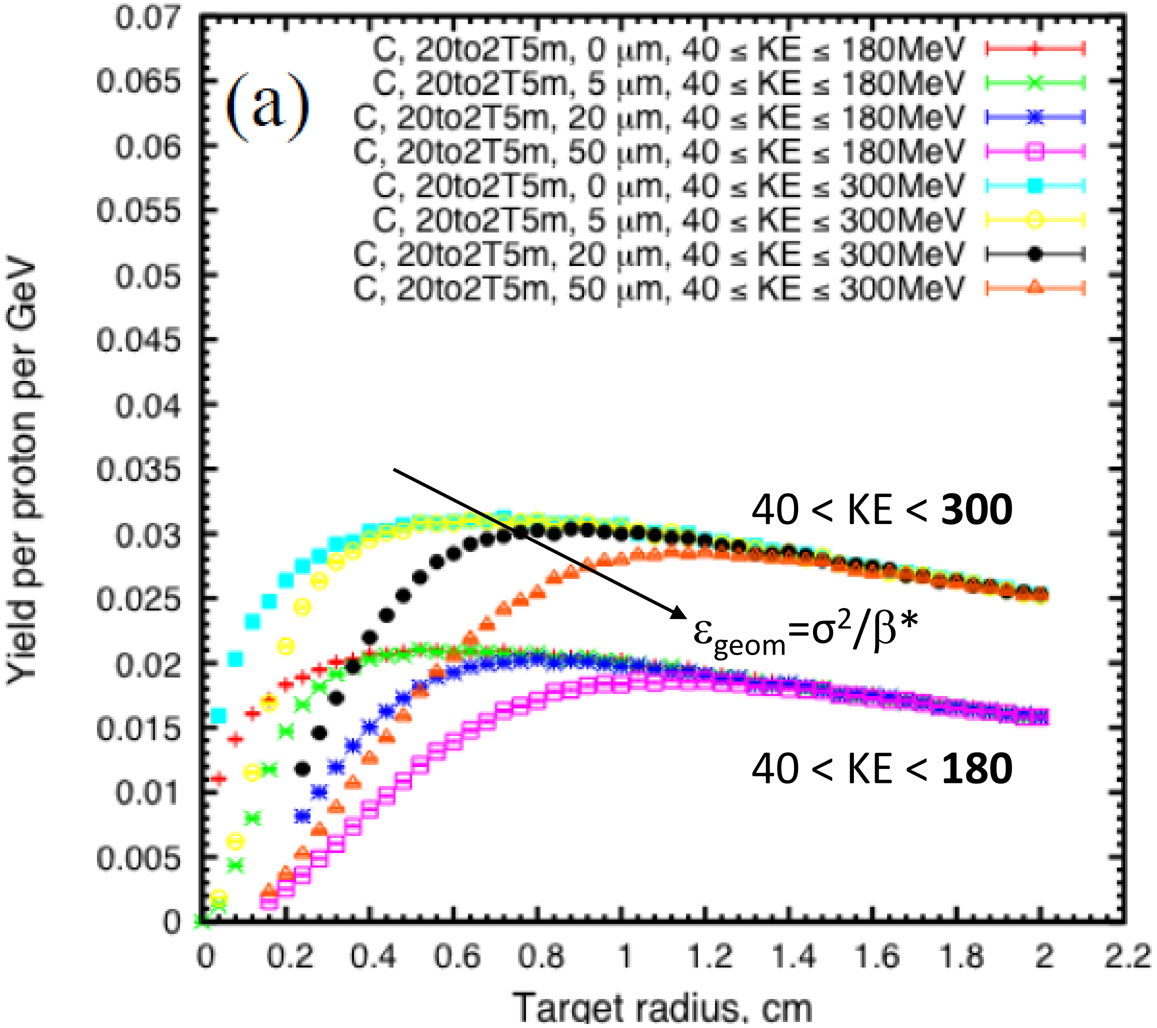
Ga jet study: **X. Ding et al.**, [MOPPC044, IPAC12]

J. Back et al., [Phys. Rev. ST AB 16, 021001 (2013)]

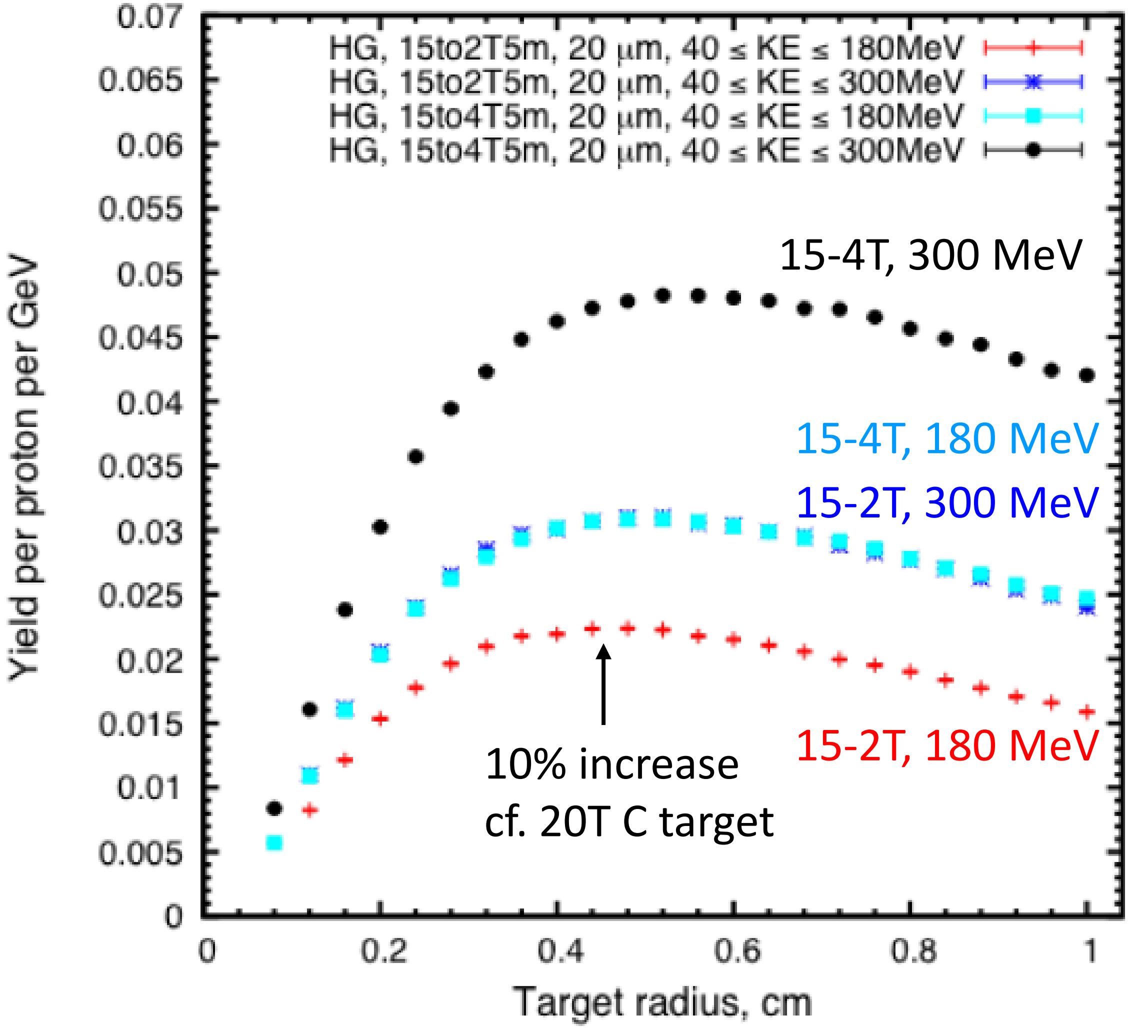
W jet idea: **C. Densham et al.**, [WE1GRC04, PAC09]

Graphite & Hg yields vs target radius (6.75 GeV p beam)

Graphite rod L = 80 cm, B = **20T** – 2T over 5m, **1 MW**



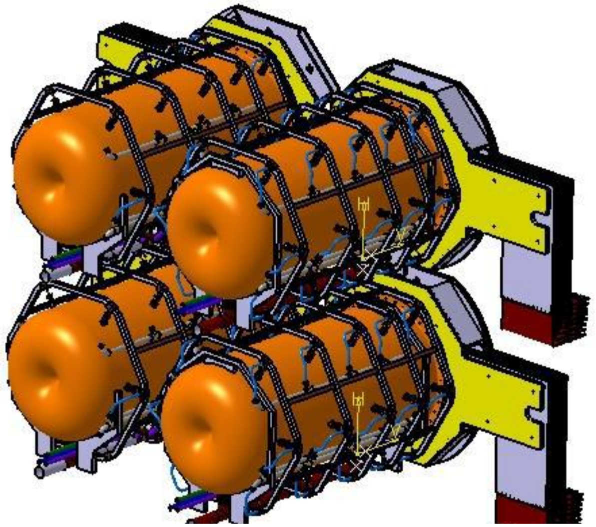
Hg jet, B = **15T** – 2T or 4T over 5m, **4 MW**

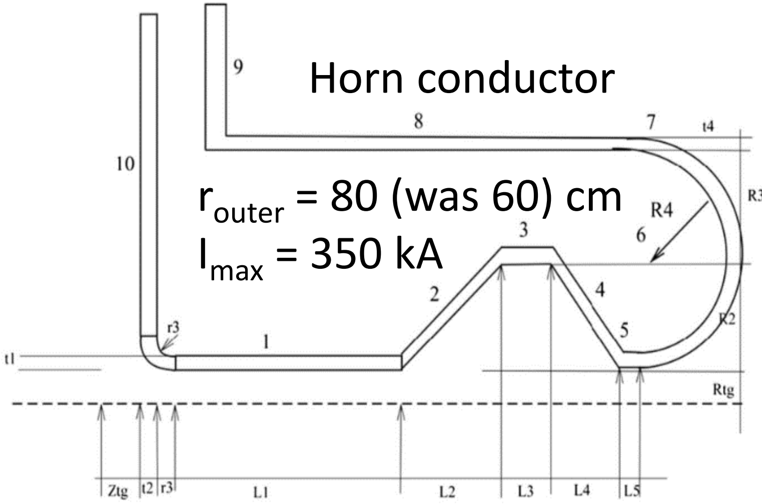


MARS15(2014) study: **X. Ding et al., TUPMY044, IPAC16**

ESSνSB target design

4 x (horn + target)
4 x 1.25 MW = 5 MW

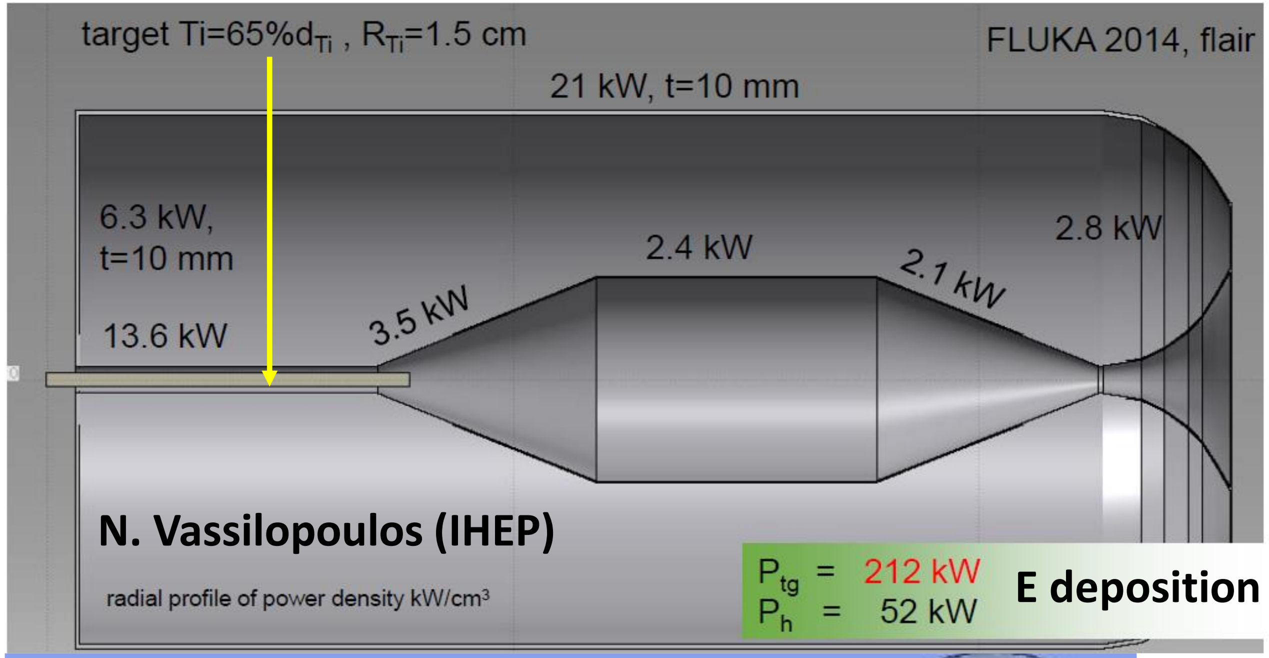




Horn conductor

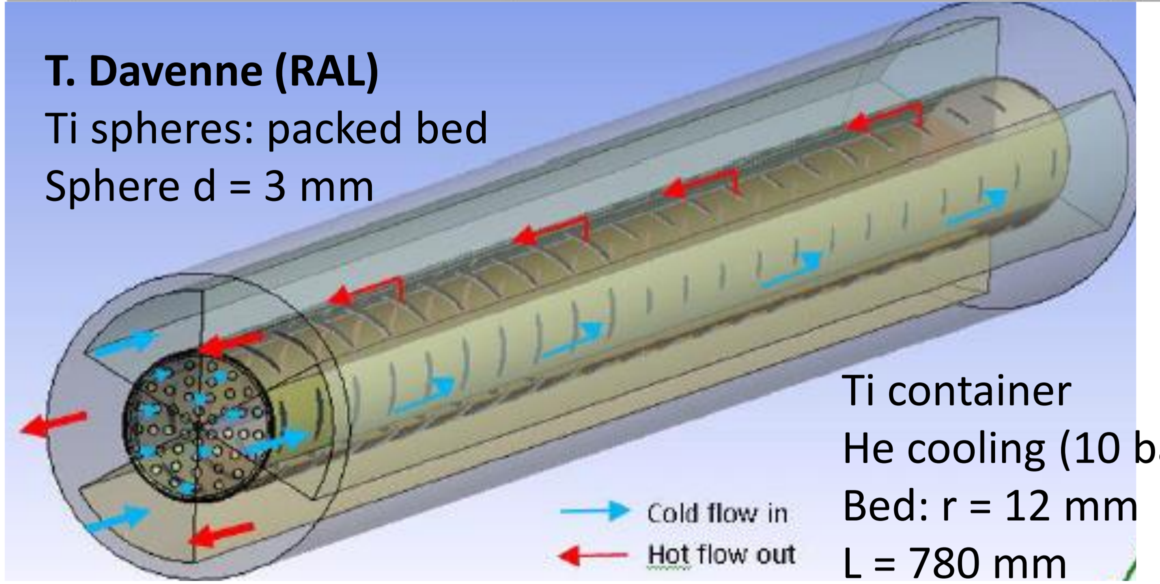
r_{outer} = 80 (was 60) cm
I_{max} = 350 kA

L = 3.0 m (was 2.4 m)



N. Vassilopoulos (IHEP)

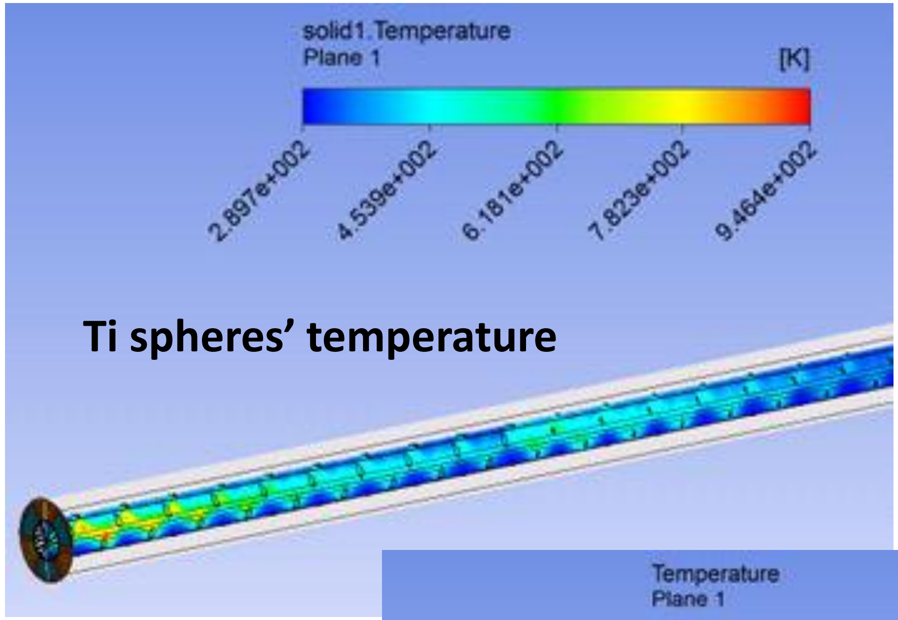
P_{tg} = 212 kW
P_h = 52 kW
E deposition



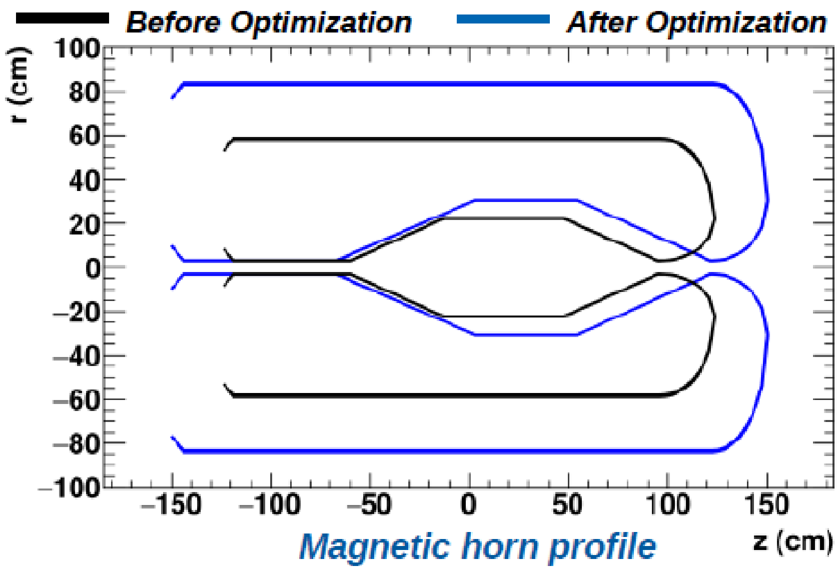
T. Davenne (RAL)
Ti spheres: packed bed
Sphere d = 3 mm

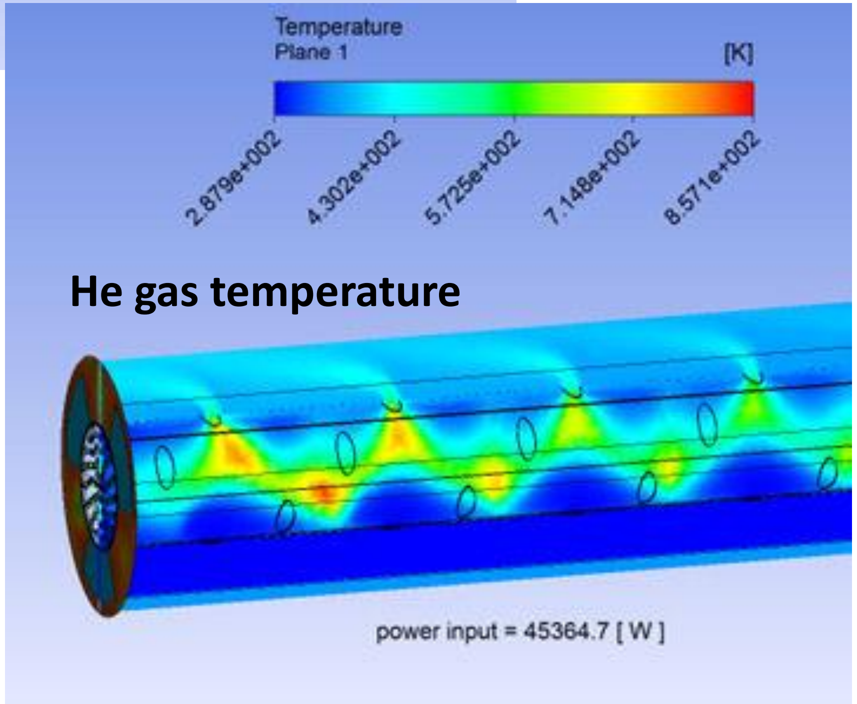
Ti container
He cooling (10 bar)
Bed: r = 12 mm
L = 780 mm

ESSνSB target design

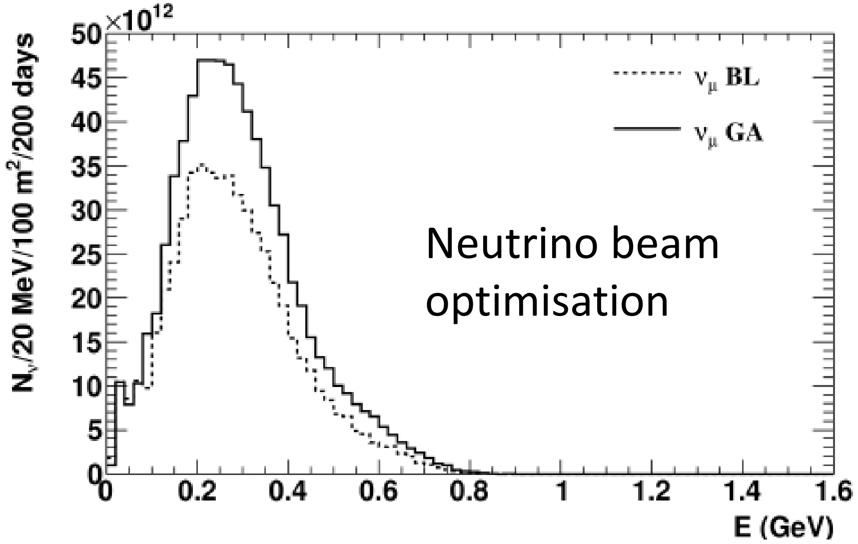


p beam (5 MW):
KE = 2.5 GeV (was 2 GeV)
Freq = 28 Hz (was 14 Hz)
1.5 μs pulse (was 2.9 ms)



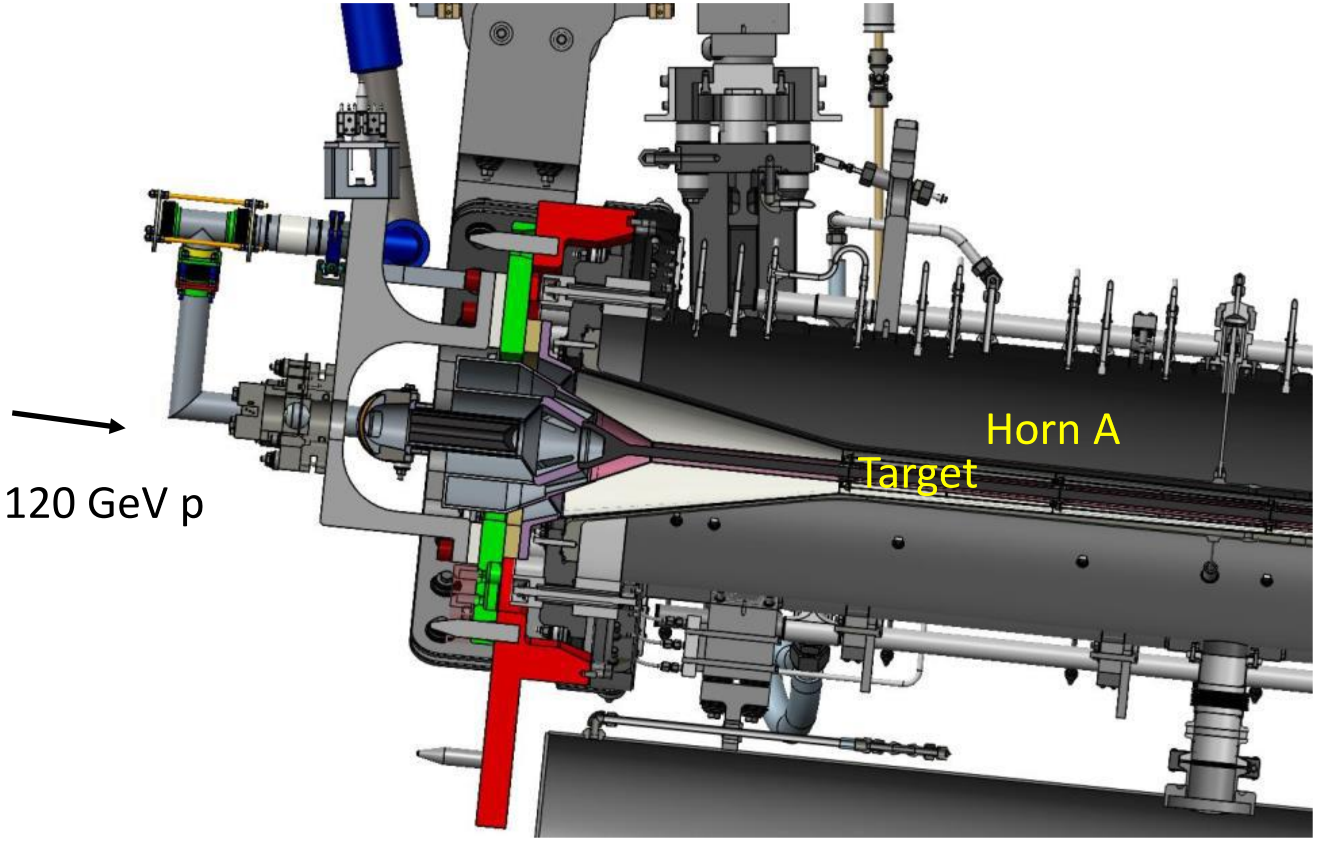


T. Davenne et al. (RAL)
FLUKA & CFX studies

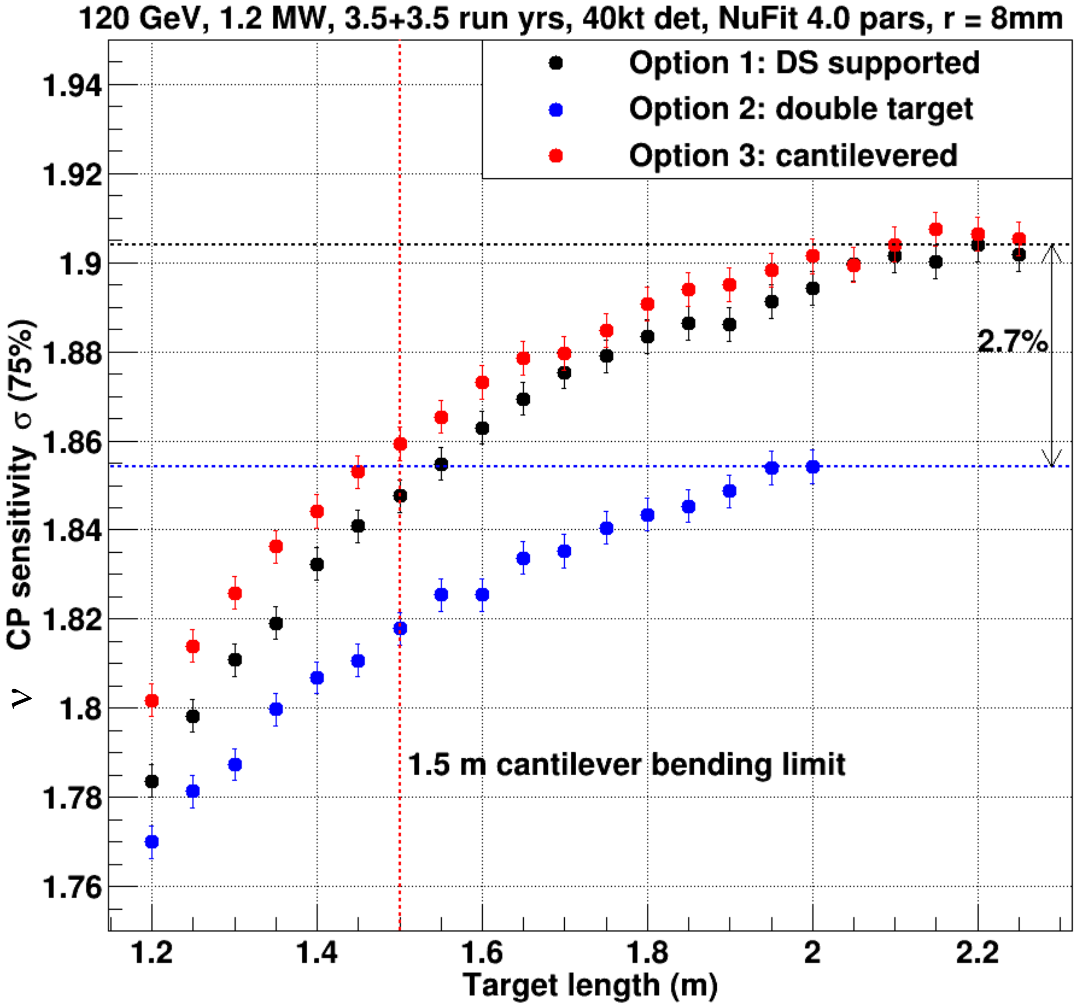


L. D'Alessi et al., EPS-HEP 2021 Conf.

LBNF (for DUNE) target design



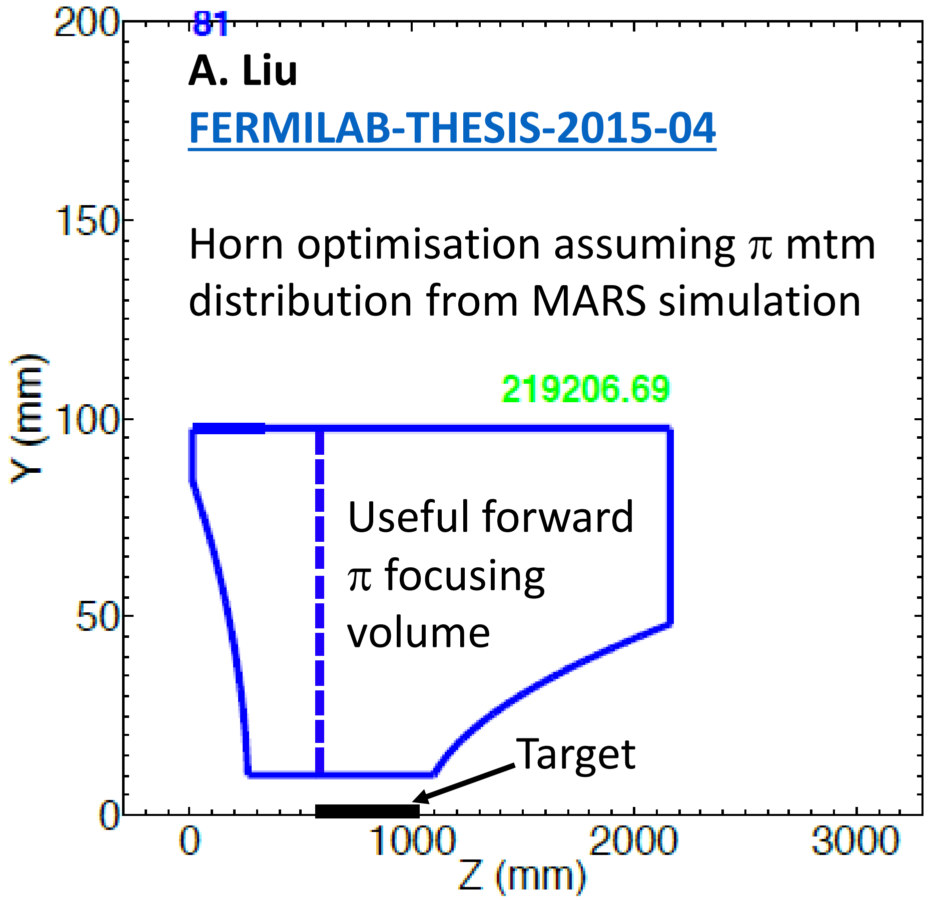
C. Densham et al. (RAL) & J. Back (Warwick)
Graphite cantilevered target inside 1st horn A
Core: L = 1.5 – 1.8 m, r = 8 mm
Upstream Ti support cone; He cooling
Expanding upon T2K target technology



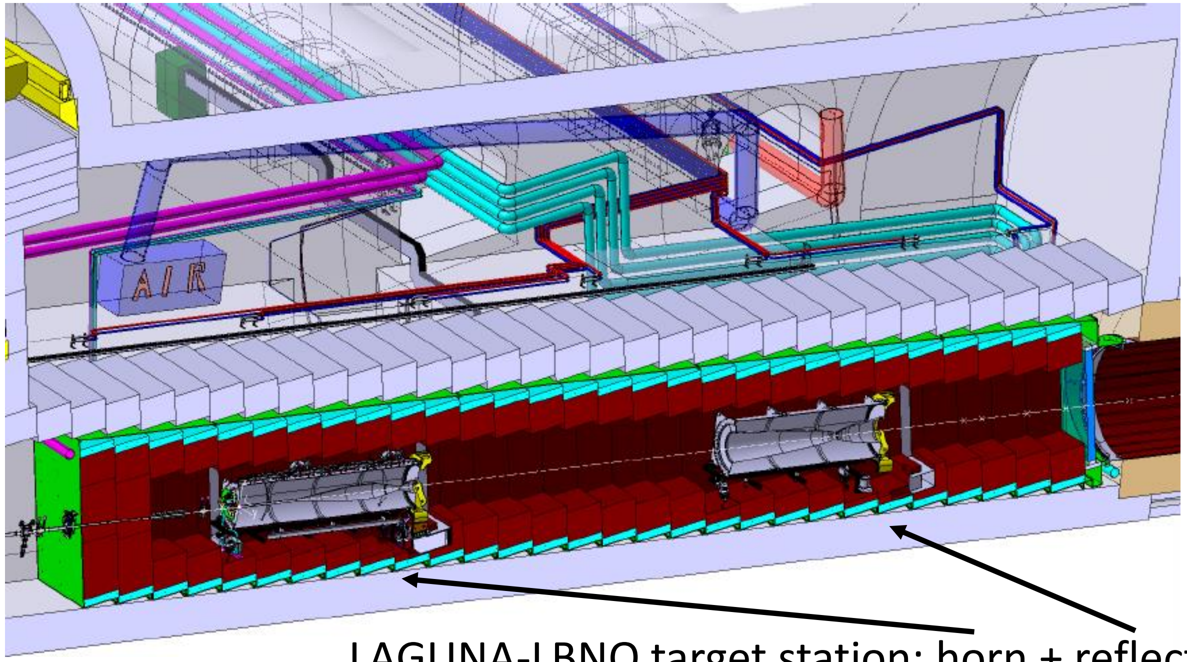
1.5 m cantilever = 2 x 1 m targets

IPAC’21 physics paper: WEPAB212

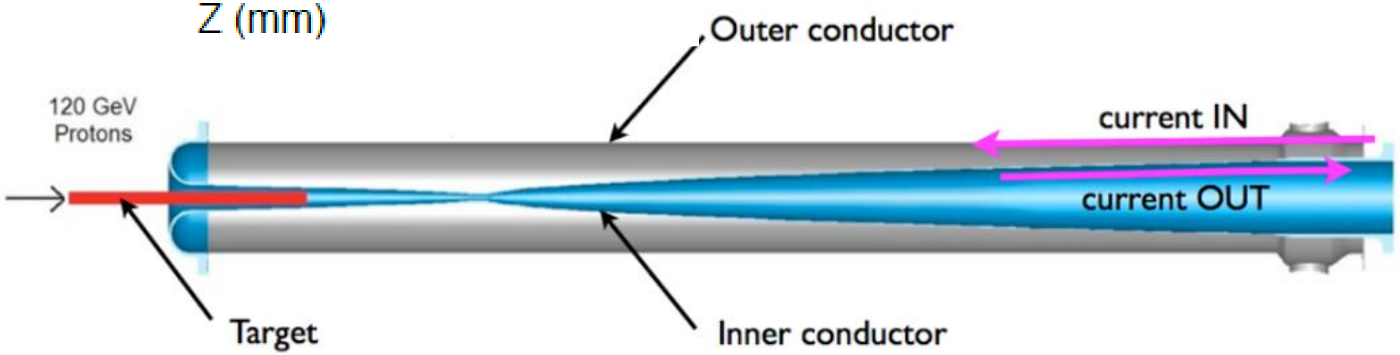
nuSTORM target concepts



nuSTORM @ CERN report

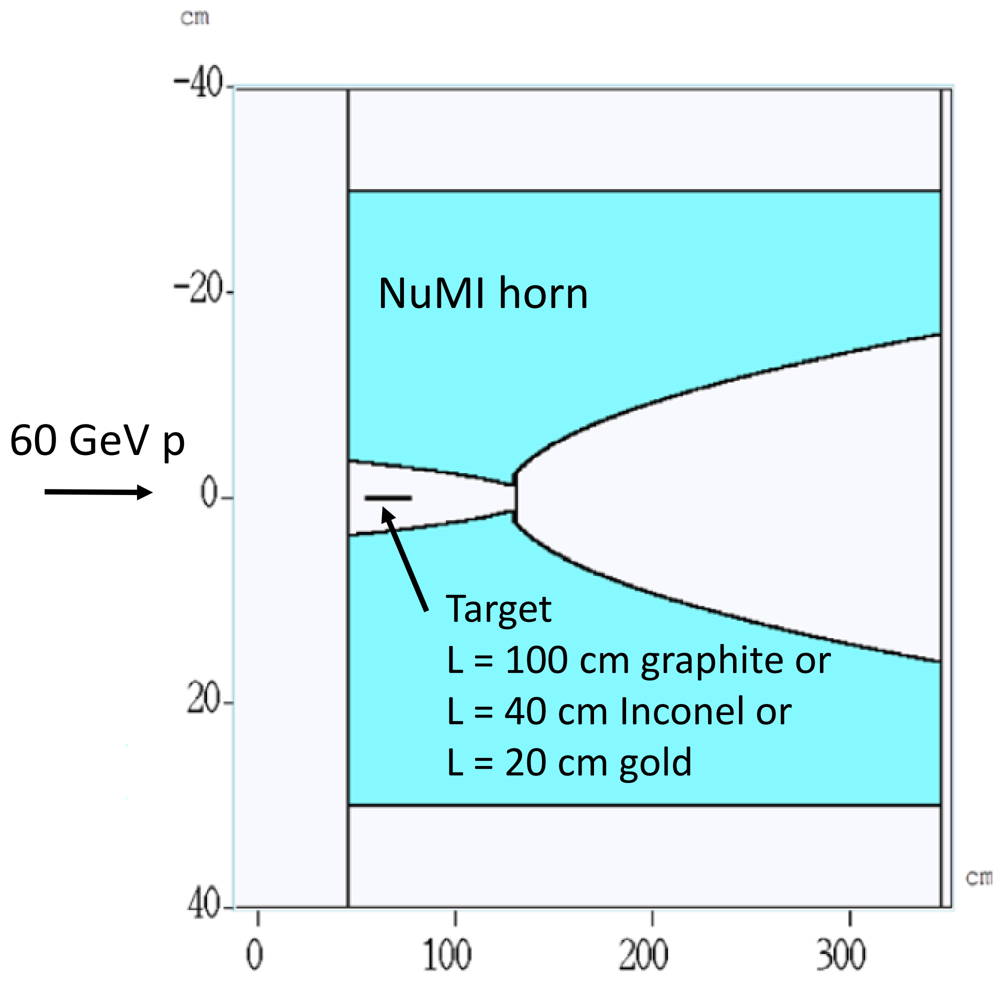


LAGUNA-LBNO target station: horn + reflector
26 GeV PS proton beam, graphite target

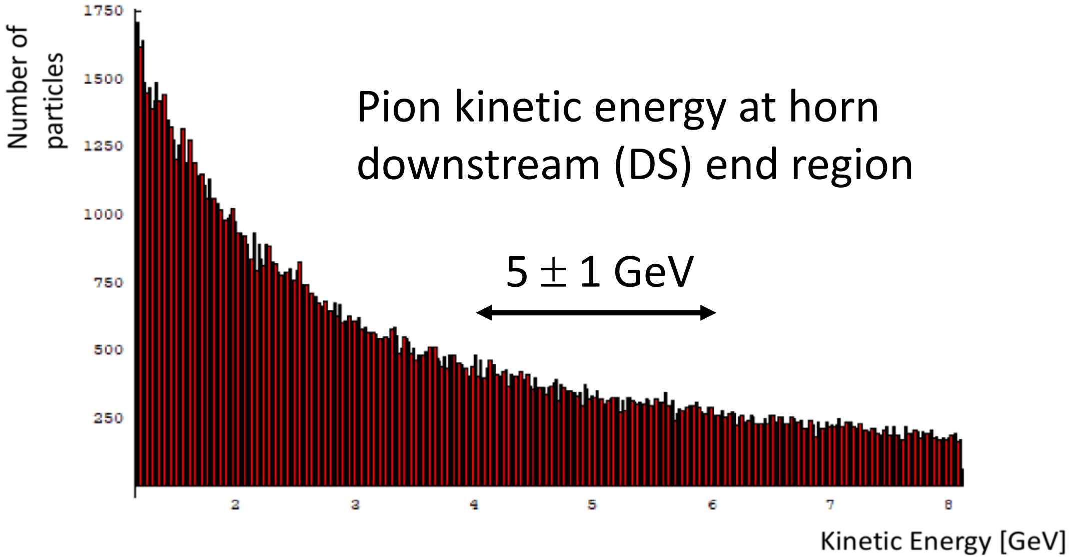


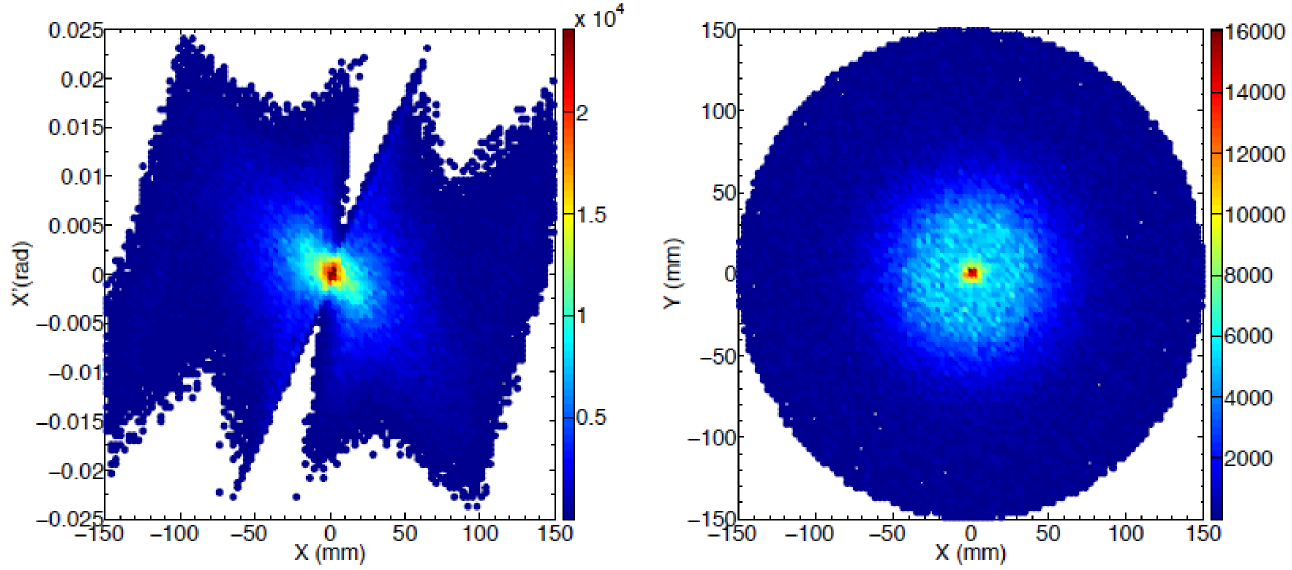
Inconel or graphite

nuSTORM target simulations: MARS



[MARS geometry (2012)]
S. Striganov





Phase space for 5 ± 1 GeV/c pions at horn DS end

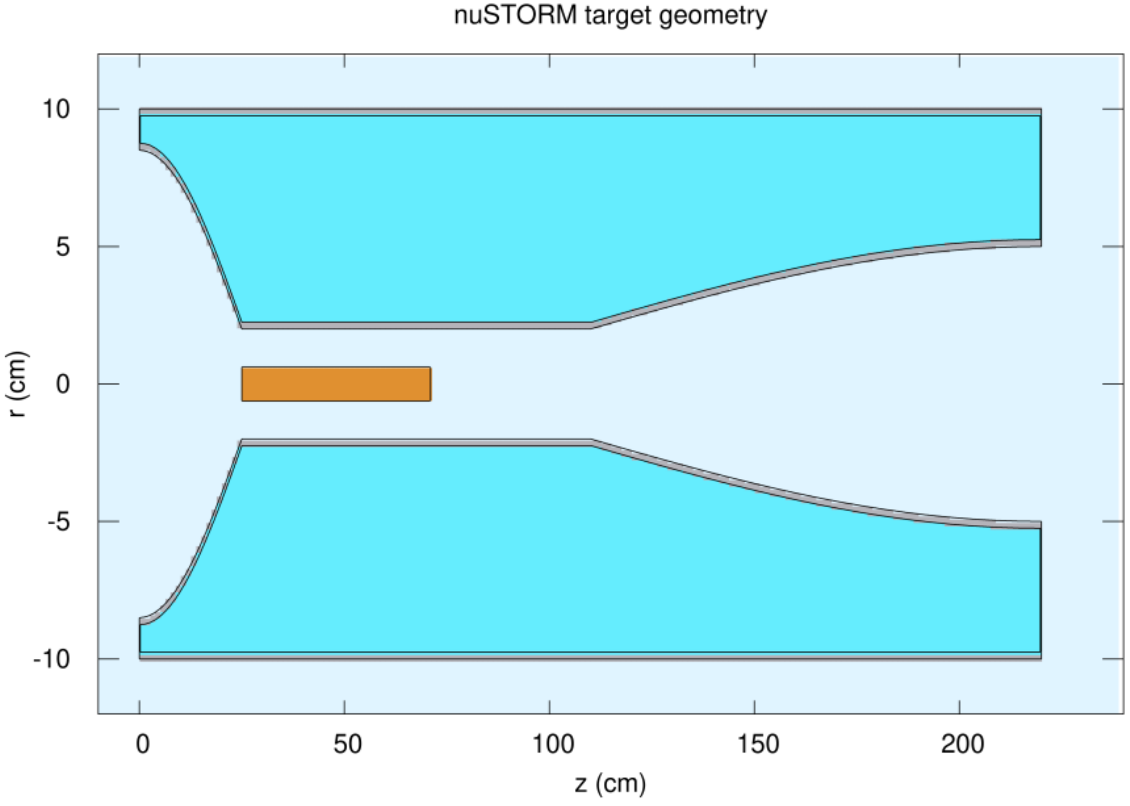
nuSTORM target pyg4ometry

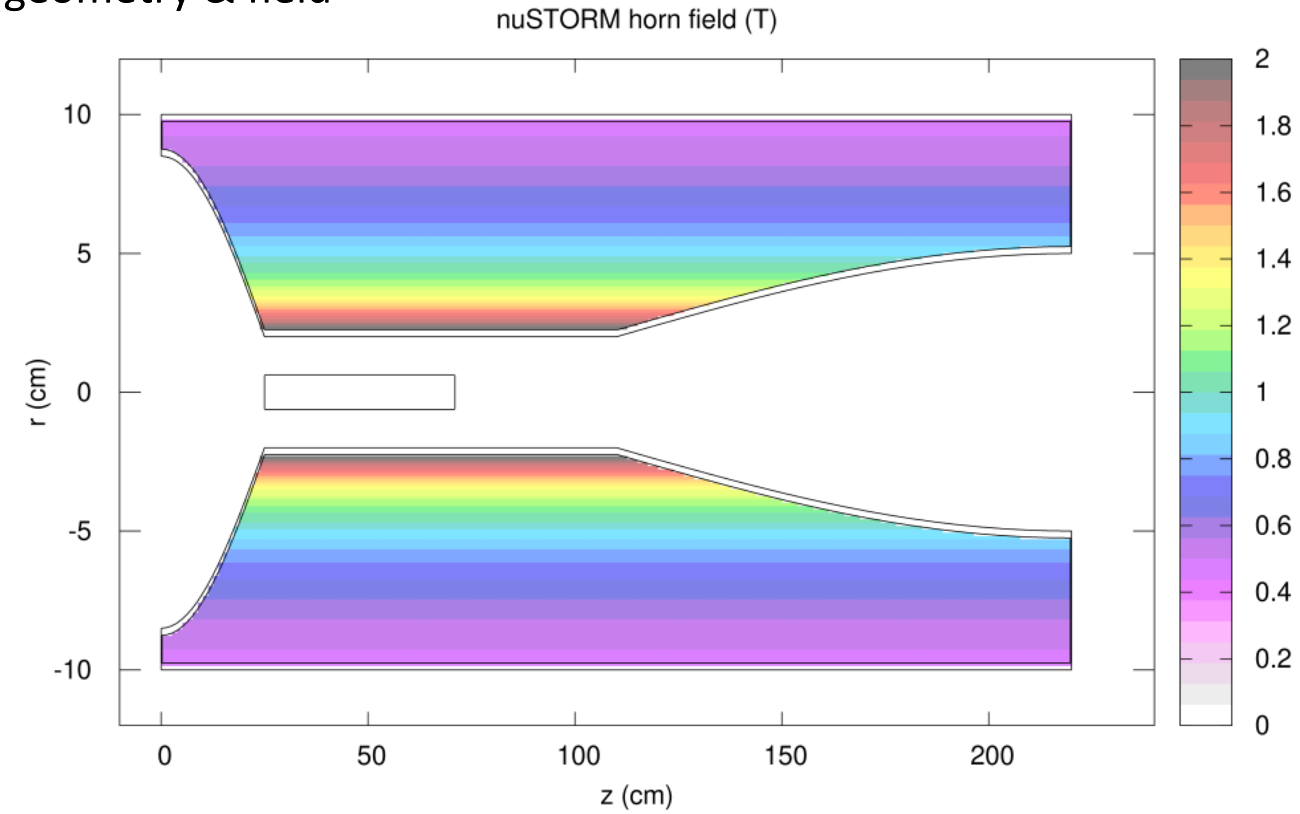
Using **pyg4ometry**:

single python script to define geometry shapes & materials

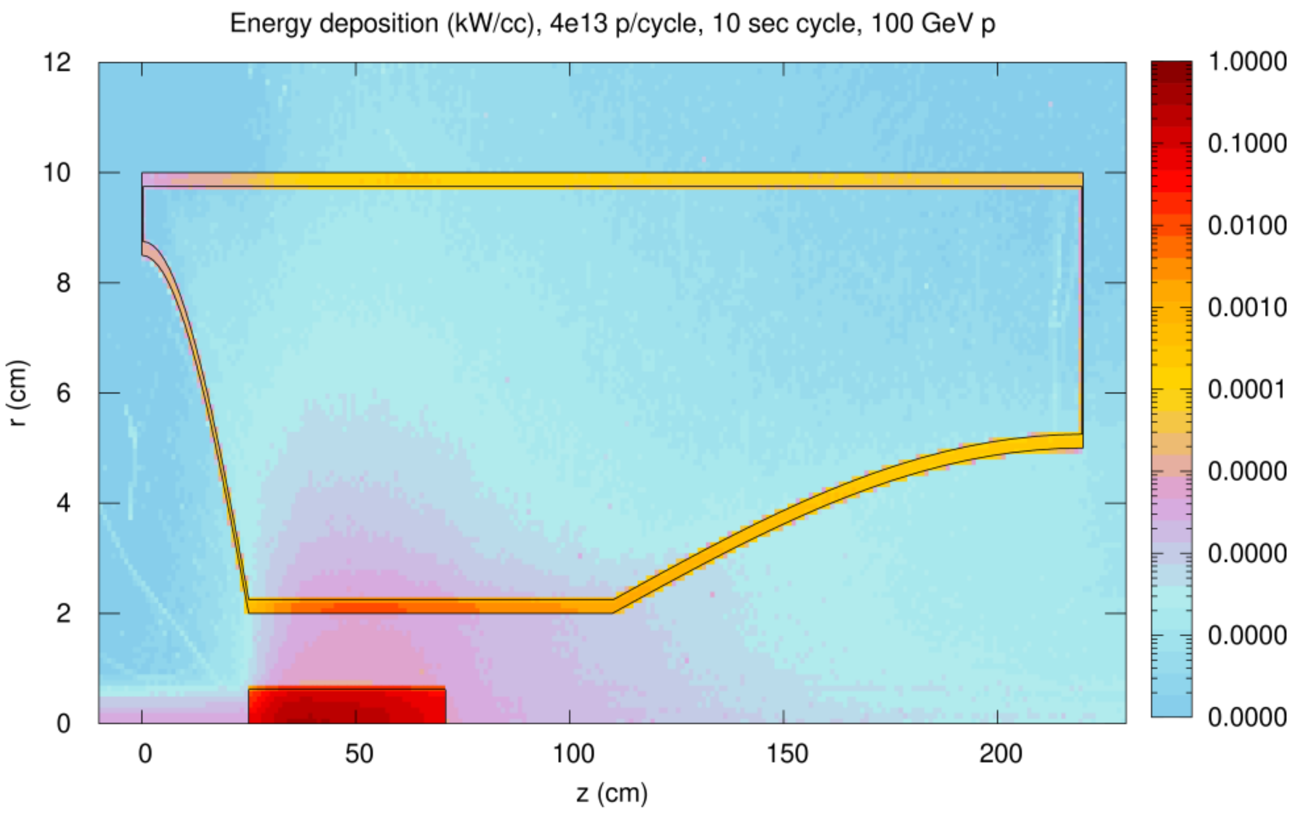
automatically writes **GDML** (BDSIM, Geant4) & **FLUKA** formats

FLUKA geometry & field

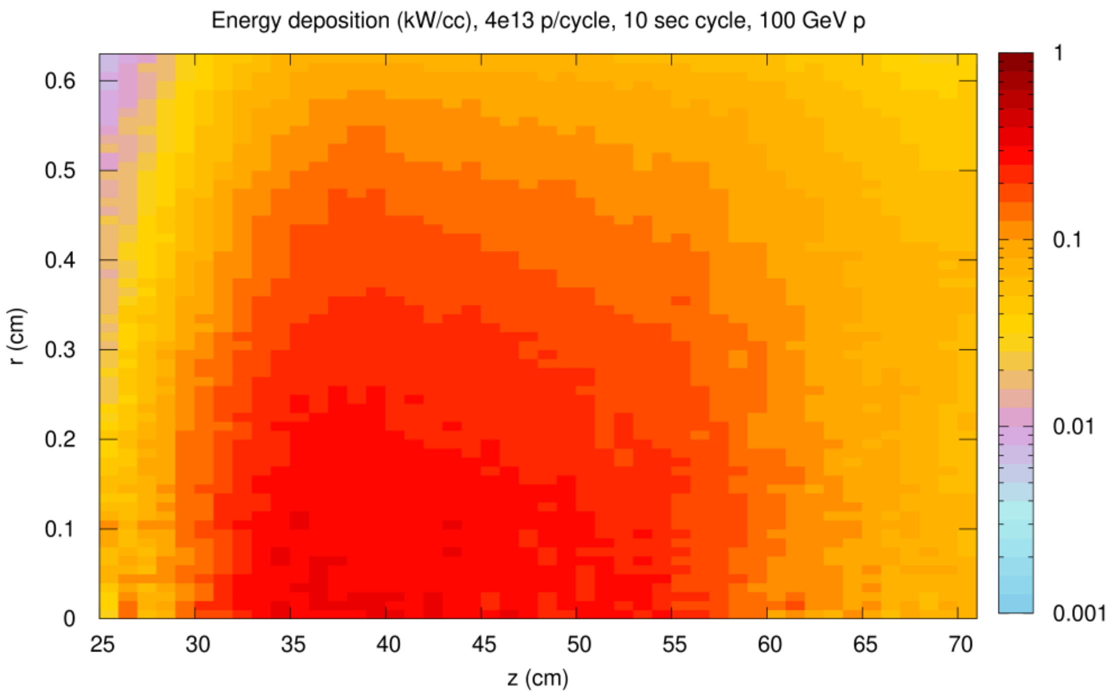




nuSTORM target: FLUKA energy deposition test



Inconel target: r = 6.3 mm, L = 46 cm; σ_{beam} = 2.67 mm



Summary

- Muon Collider targets (4 MW, 5 – 10 GeV p beam):
  - R&D for **high-Z** targets: Hg jet, tungsten powder & solid bars
  - Tapered solenoidal focusing: SC magnet forces, shielding & structural supports
  - Graphite option also studied: 1 MW
  - Significant challenges remain: target lifetime & operational safety
  - RaDIATE collaboration: study of irradiated material properties

- Ideas from other projects:
  - ESSνSB 4 x (target + horn) for 5 MW (2.5 GeV)

    Packed bed of titanium spheres with He cooling
  - LBNF cantilevered graphite target + 3 focusing horns (1.2 – 2.4 MW, 120 GeV p beam)

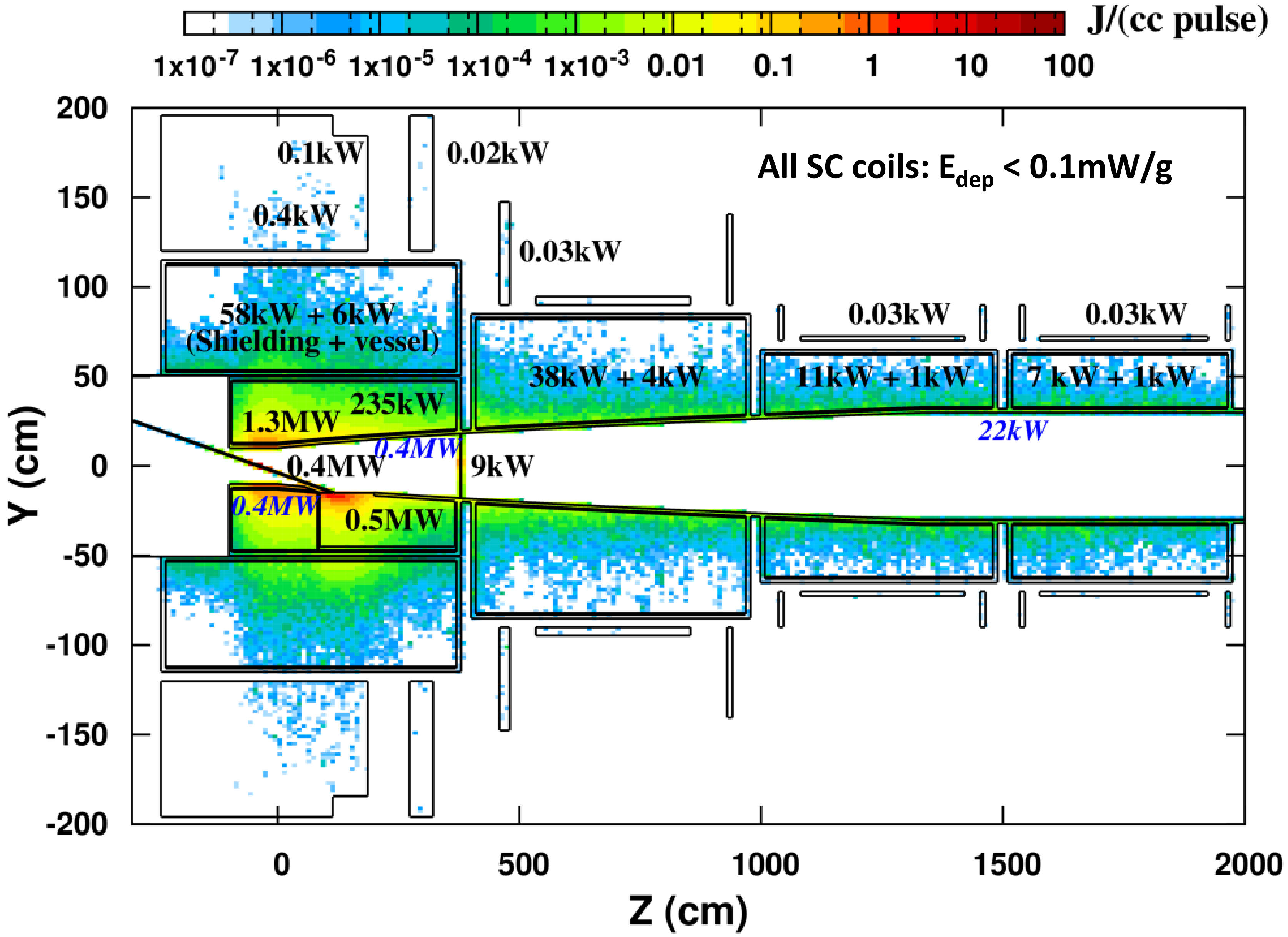
    Expanding upon T2K target technology

- nuSTORM target:
  - Basic concept, needs much more (engineering) detail

    e.g. target container & support; relative position of horn & target (for target support)
  - Pyg4ometry initial template: for BDSIM/Geant4 & FLUKA
  - Consider CERN PS (26 GeV) or SPS (100 GeV)

    Need π beam acceptance criteria for relative performance

Muon Collider energy deposition (FLUKA 2011.2.13)



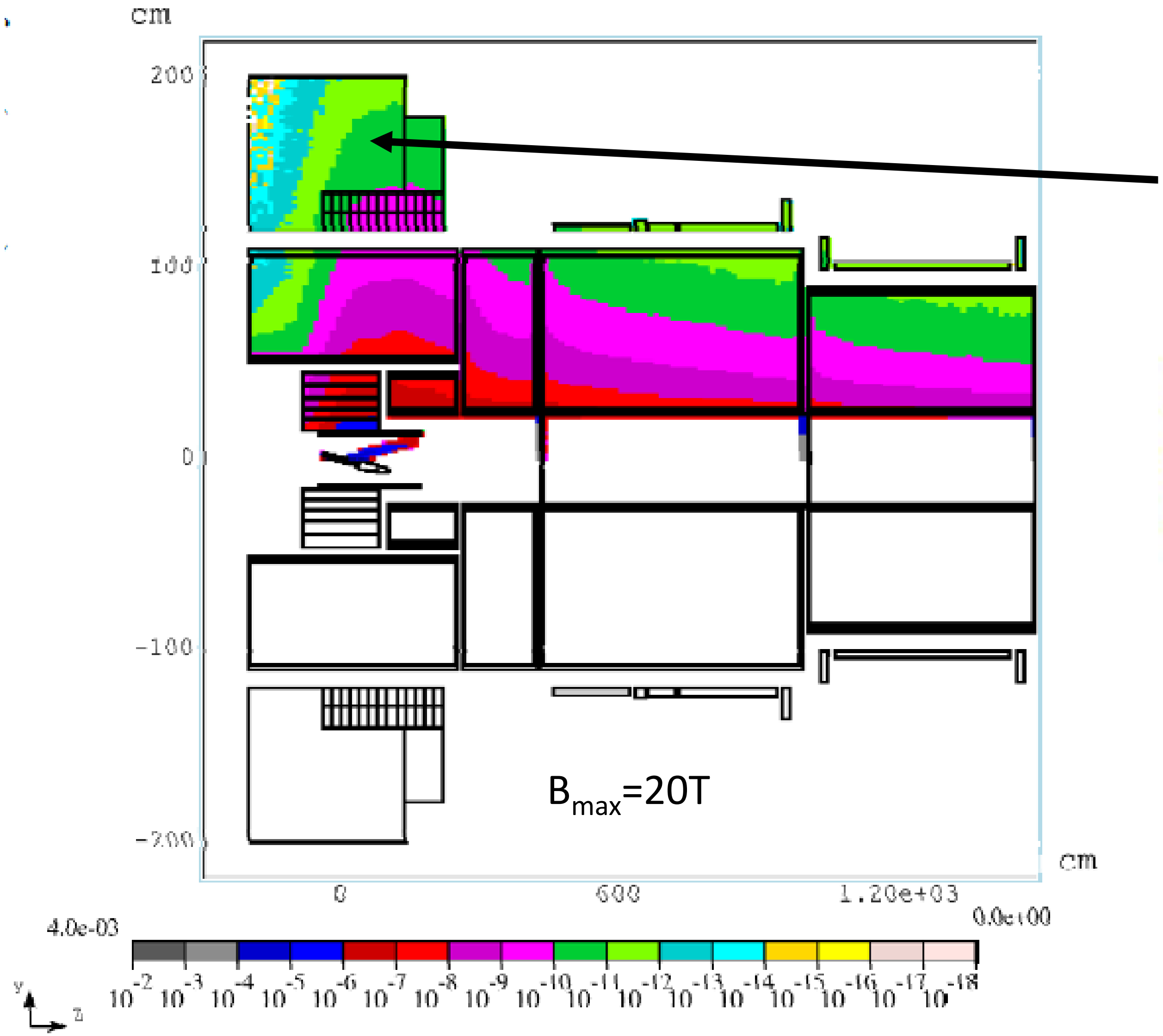
[Phys. Rev. ST AB 16, 021001 (2013)]

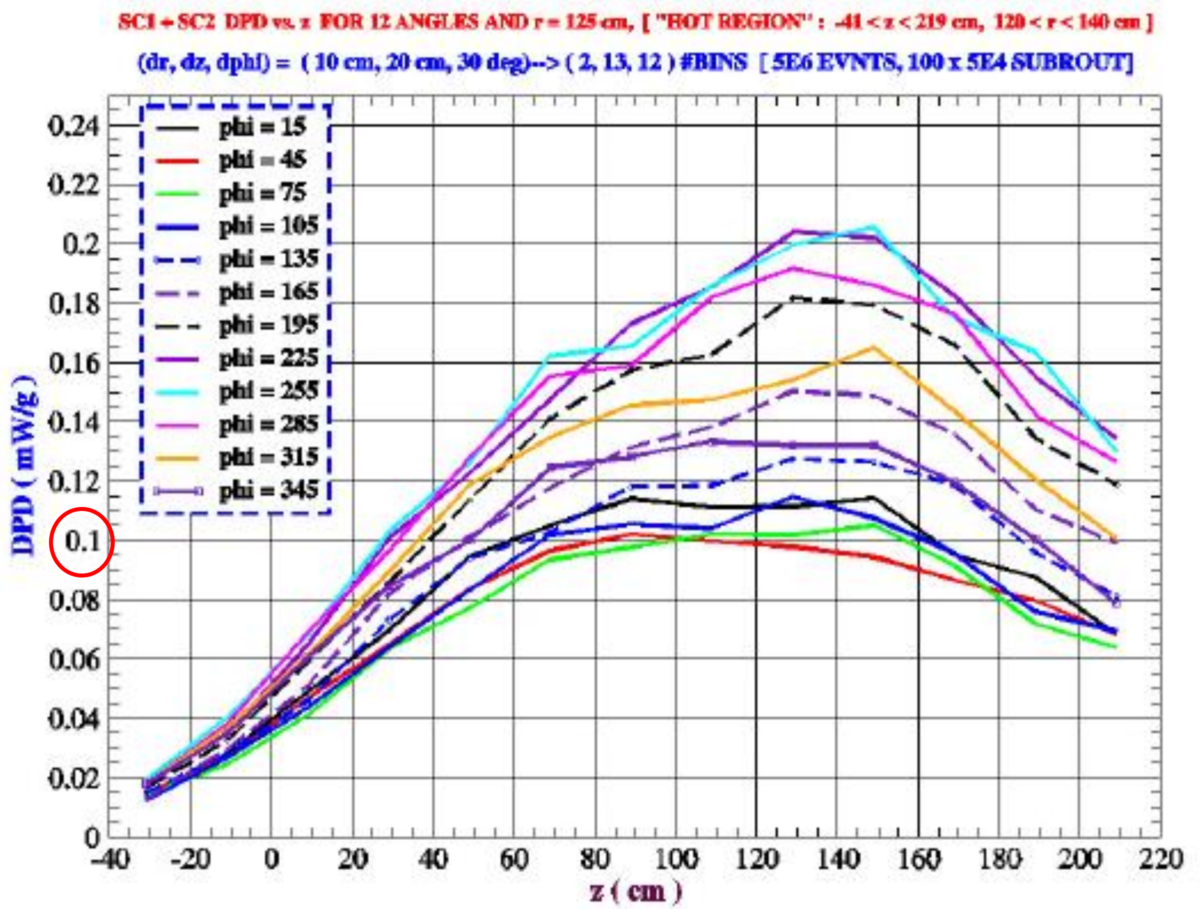
Hg jet target, B_{max} = 15T
IDS120j geometry

p beam:
8 GeV, 4MW, 50Hz,
3.125 x 10^{15} s^{-1}

Agrees with MARS15 (~10%)
N. Souchlas et al., [WEPPD036, IPAC12]

Graphite target energy deposition: 4 MW & MARS15(2014)





Power density in SC coils 1+2 vs z axis for different ϕ

Solenoidal helices: target π production peaks at ϕ = 235°

For 4MW, max E_{dep} = 0.2 mW/g = 2 x safe limit

K. McDonald et al., THPRI088, IPAC14