International
MUON Collider
Collaboration

WARWICK

Pion Yield and Energy Deposition Simulations

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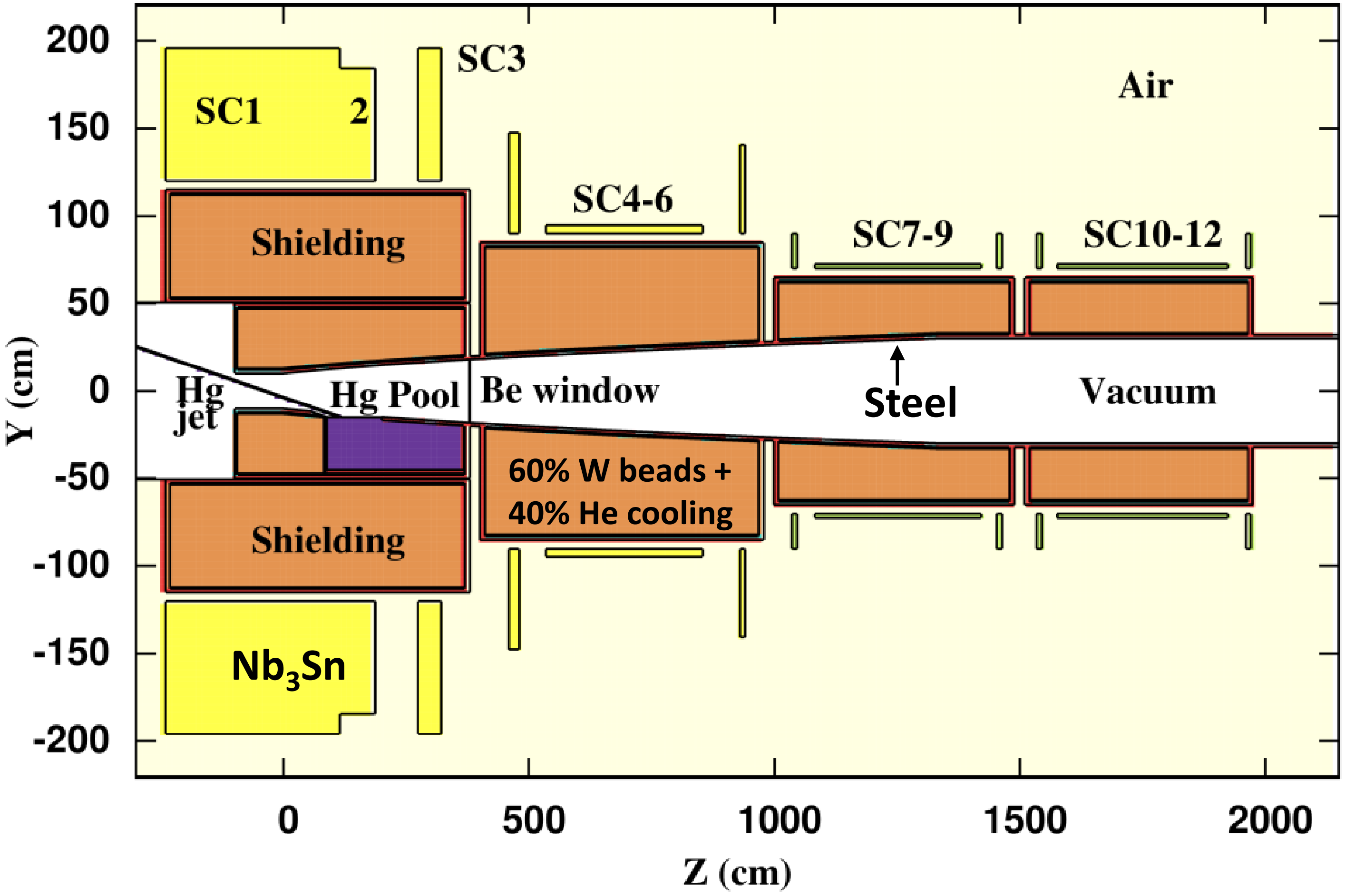
Introduction

- Summary of νFact & μCollider π,μ yields & energy deposition
  - Yields normalised to per proton per GeV (KE)
  - Energy deposition studies: 4MW proton beam
  - Published results from journals & conferences

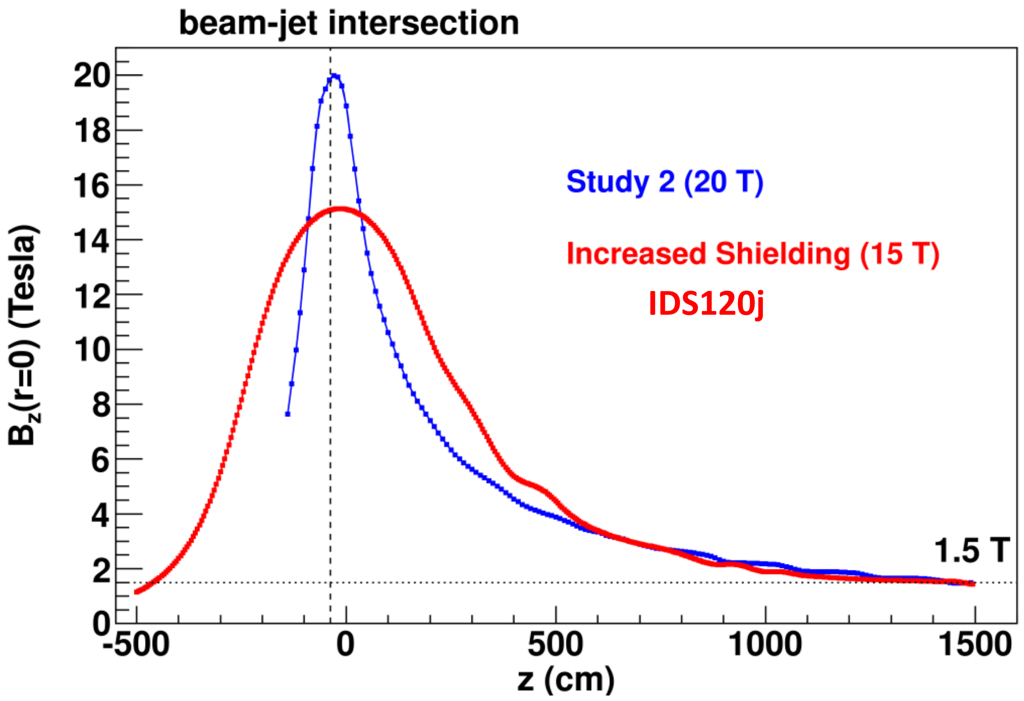
- Target simulation studies:
  - International Design Study, Muon Accelerator Program, EUROnu, …
  - Geometry based on solenoidal focusing
  - MARS, FLUKA & GEANT4 packages (& ICOOL)

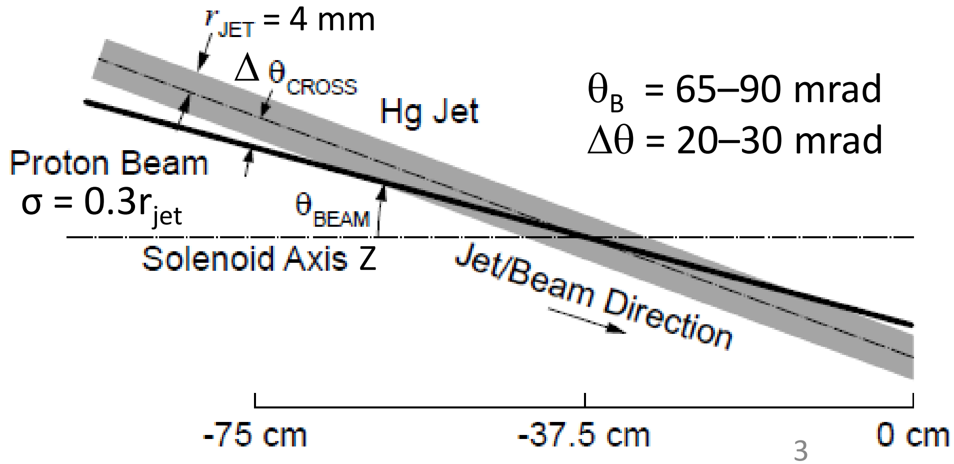
- Target options: Hg or Ga liquid jets, W powder jet, W or C rods

Target Simulation Geometry



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

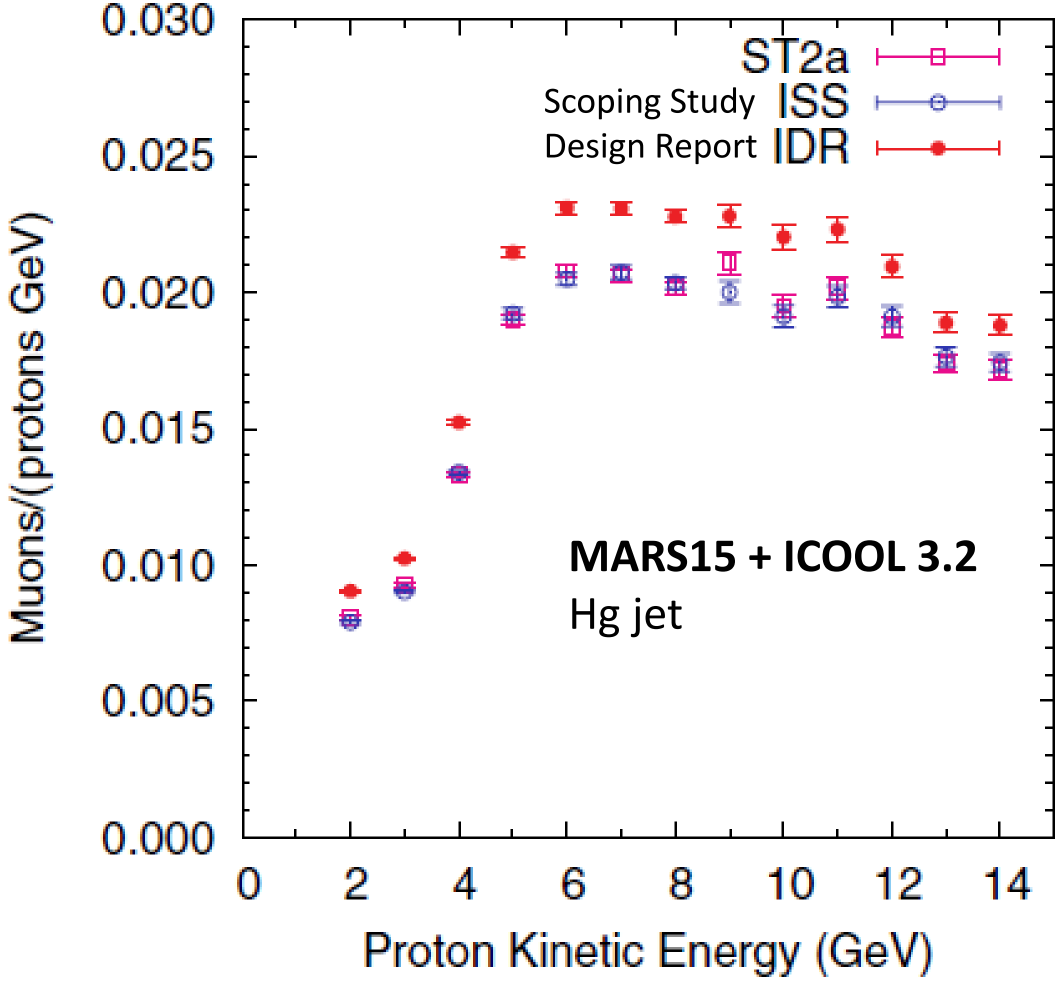




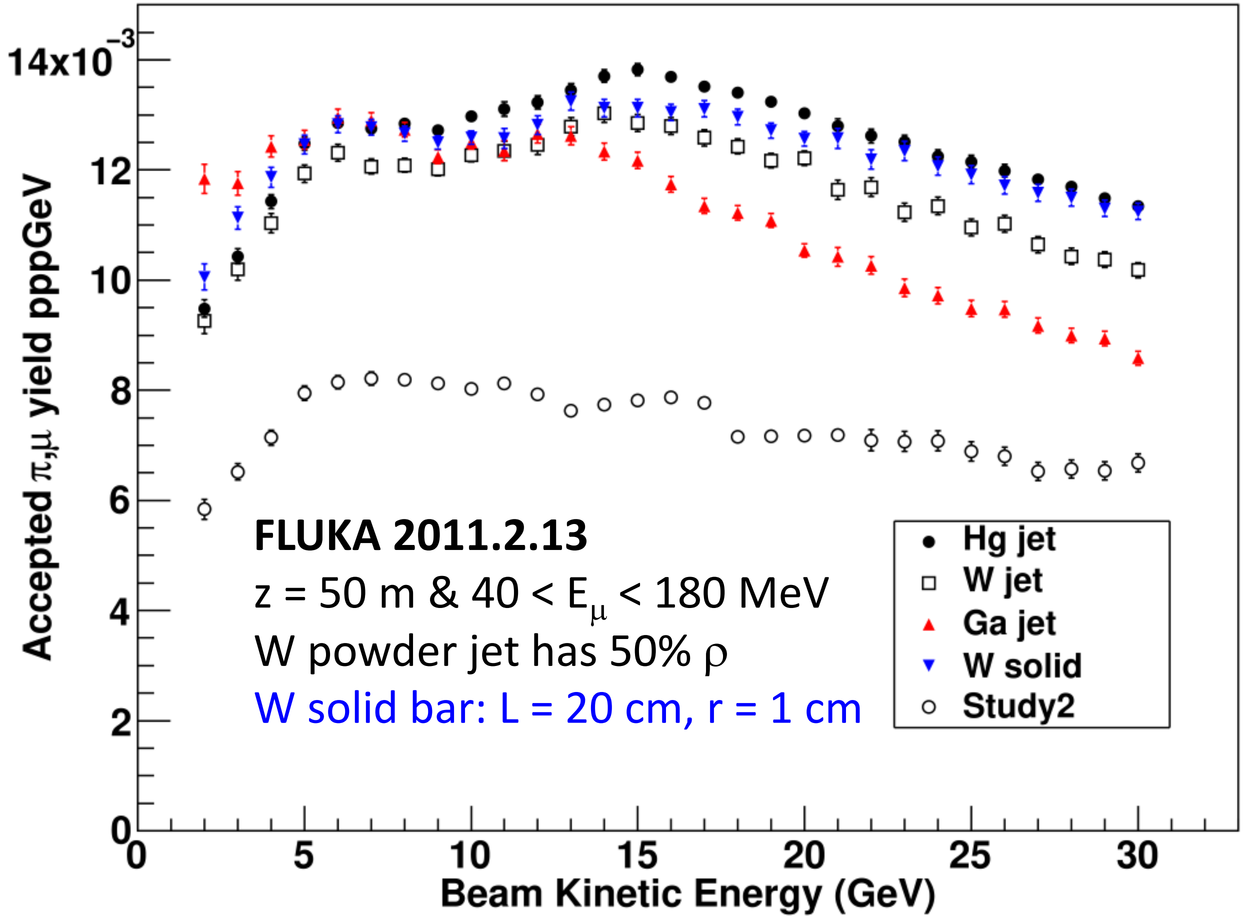
θ_B = 65–90 mrad
$\Delta\theta$ = 20–30 mrad

Accepted (π &) μ yields

Total $N(\mu^+) + N(\mu^-)$



Charge-averaged 0.5x$[N(\mu^+) + N(\mu^-)]$



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

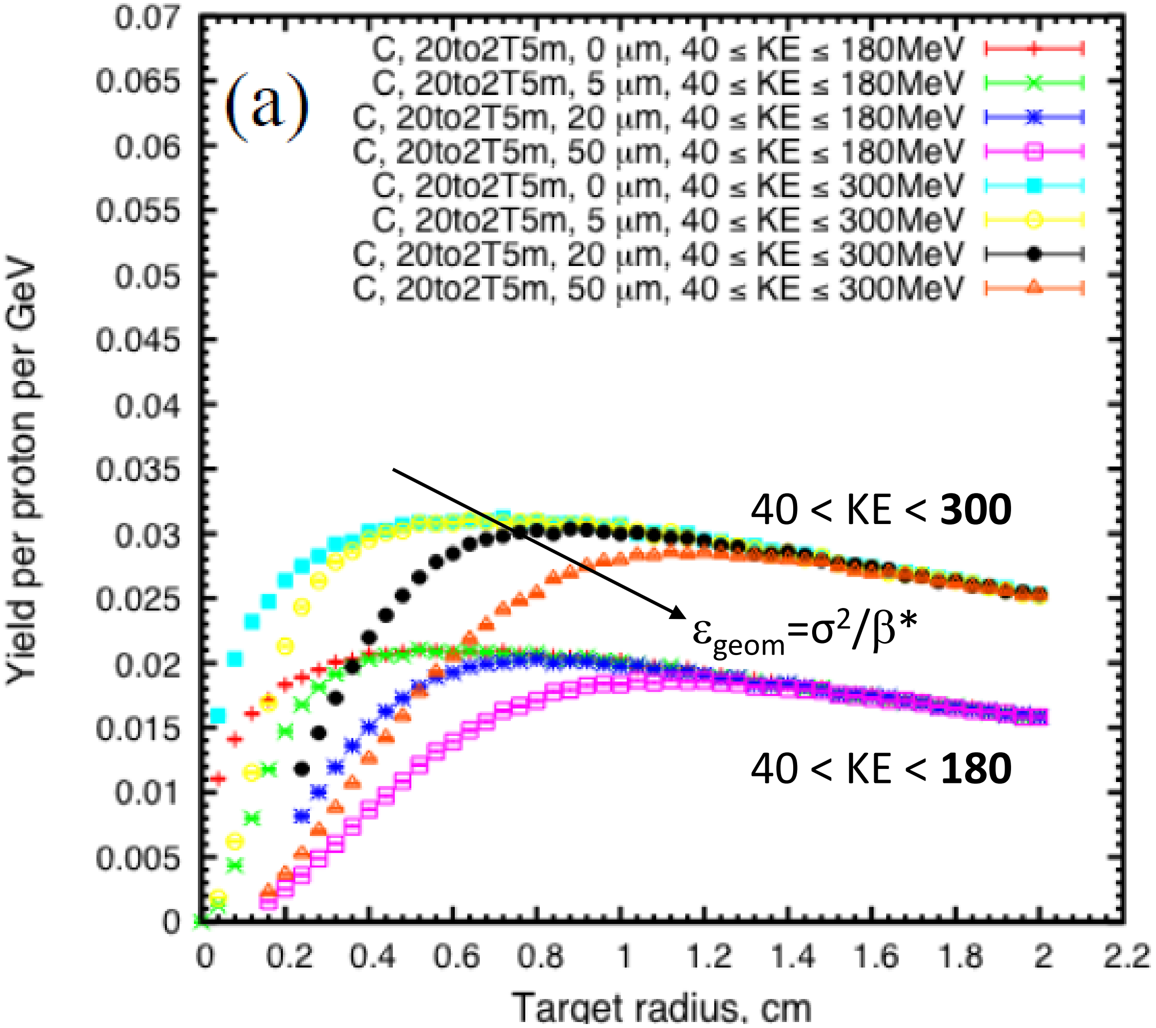
Ga jet study: X. Ding et al., [MOPPC044, IPAC12]

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

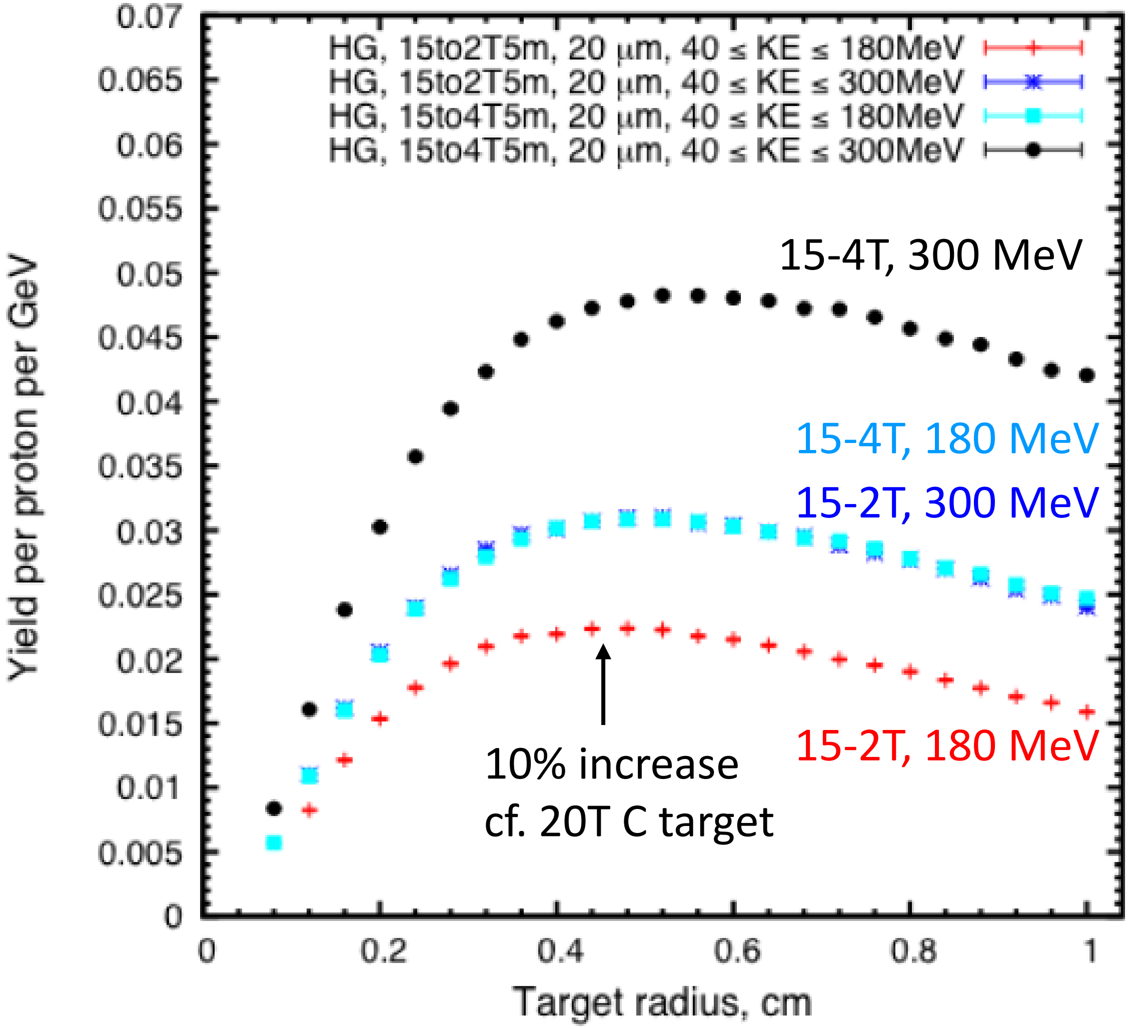


40 < KE < **300**

$\varepsilon_{geom}=\sigma^2/\beta^*$

40 < KE < **180**

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



15-4T, 300 MeV

15-4T, 180 MeV

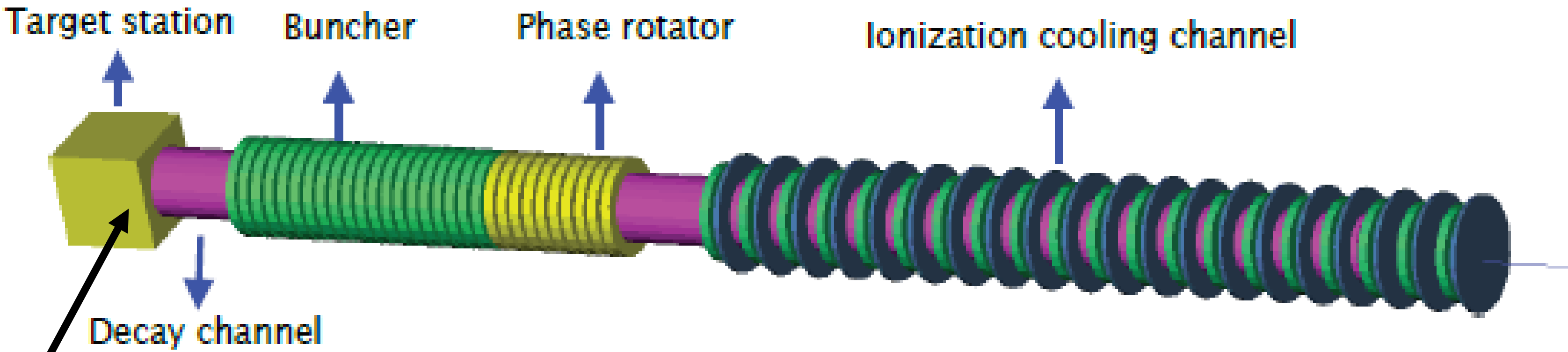
15-2T, 300 MeV

15-2T, 180 MeV

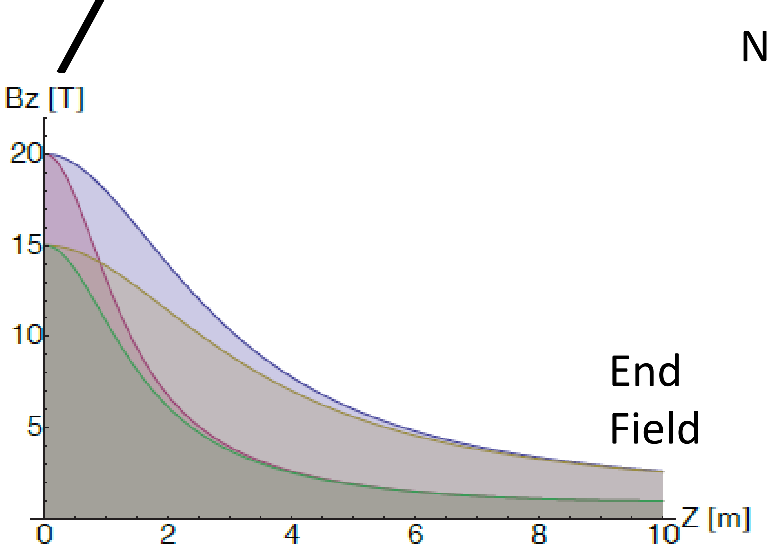
10% increase
cf. 20T C target

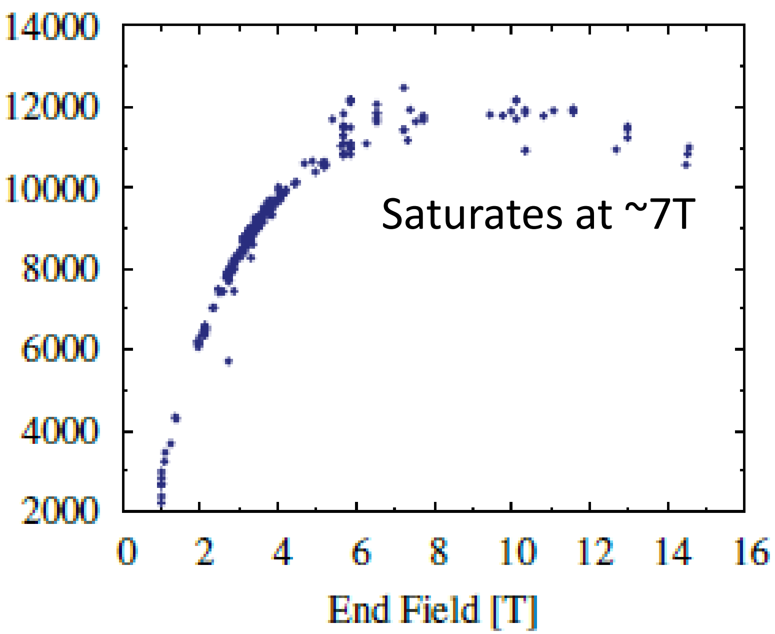
MARS15(2014) study: **X. Ding et al., [TUPMY044, IPAC16]**

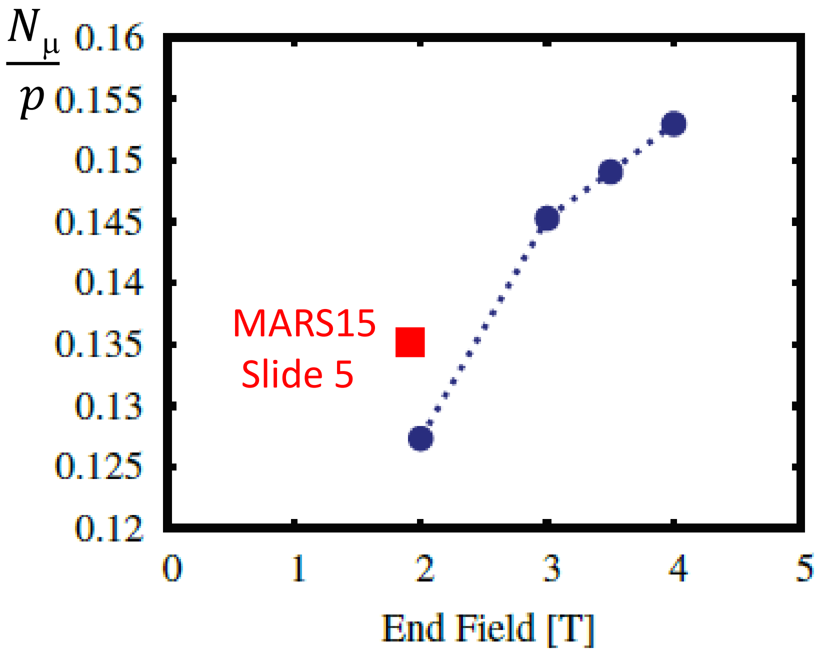
Global Front-End optimisation for graphite target yields



GEANT4 (G4beamline, QGSP model)
Lattice parameters from ICOOL
p beam: E = 6.75 GeV, σ = 2 mm
Graphite rod: L = 80 cm, r = 1 cm
$\theta_{rod} = \theta_{beam}$ = 42 mrad (2.4°) wrt z axis

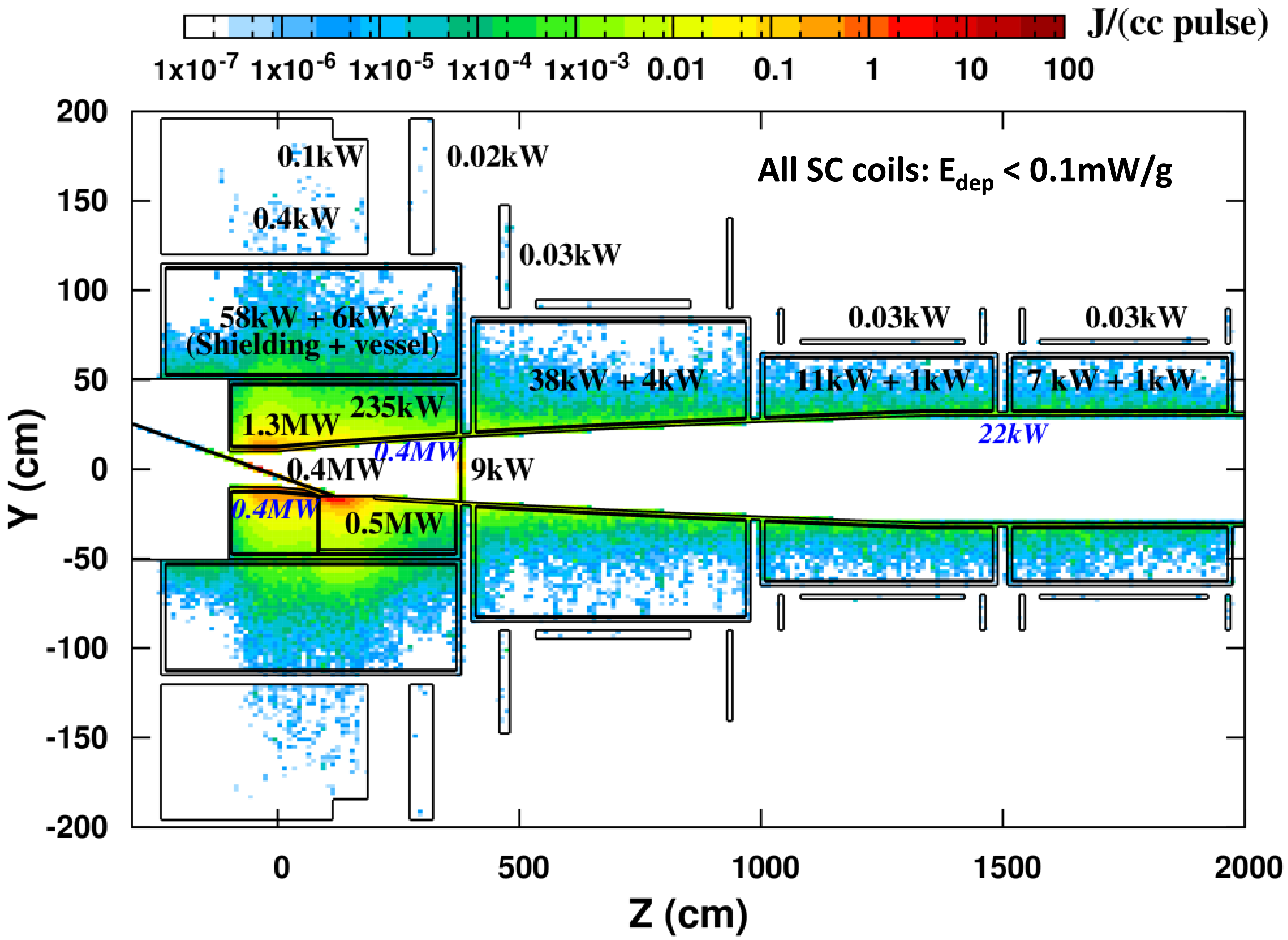






H. Sayed et al., MOPRI007, IPAC14

Energy Deposition (FLUKA 2011.2.13)



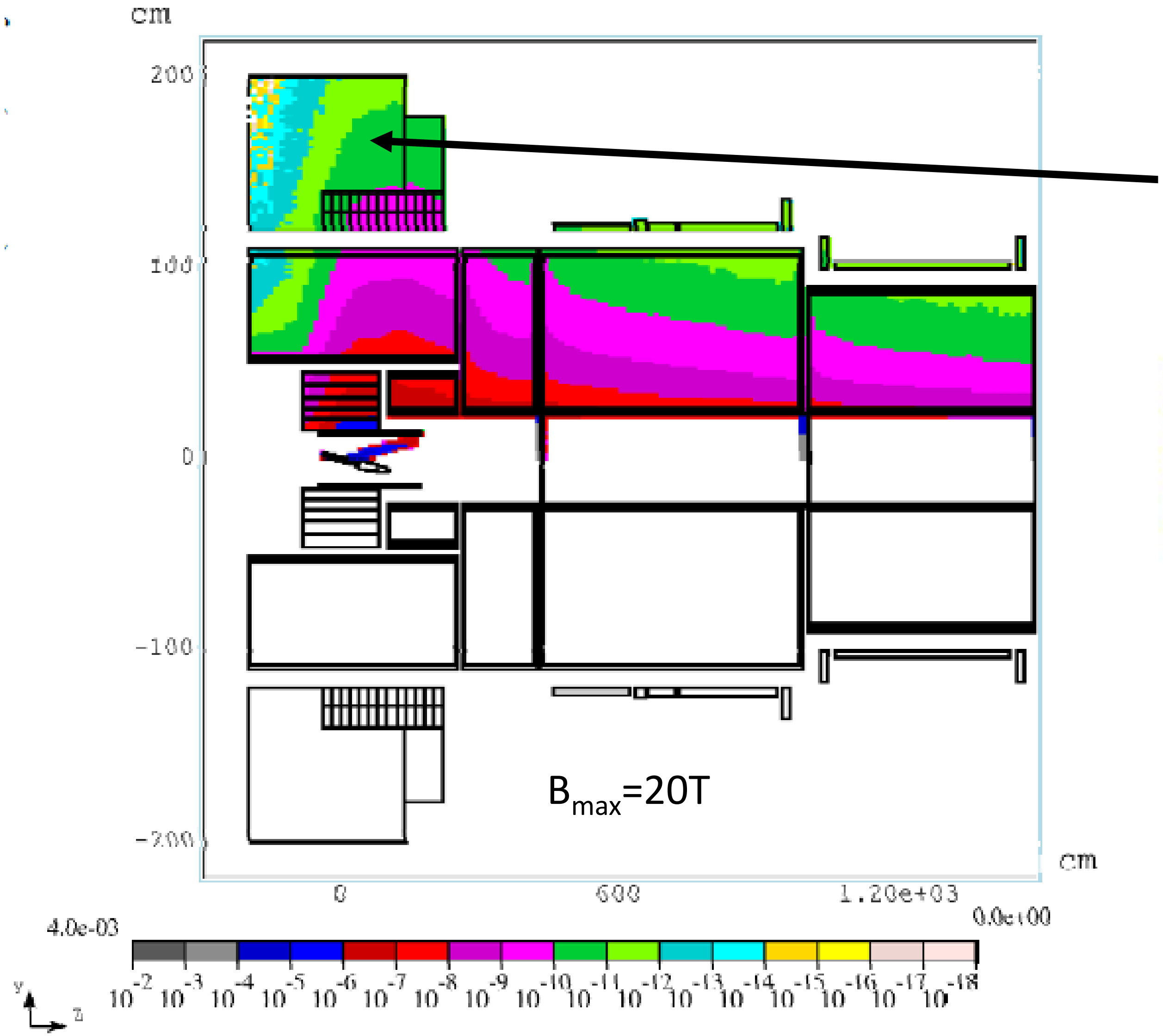
Phys. Rev. ST AB 16, 021001 (2013)

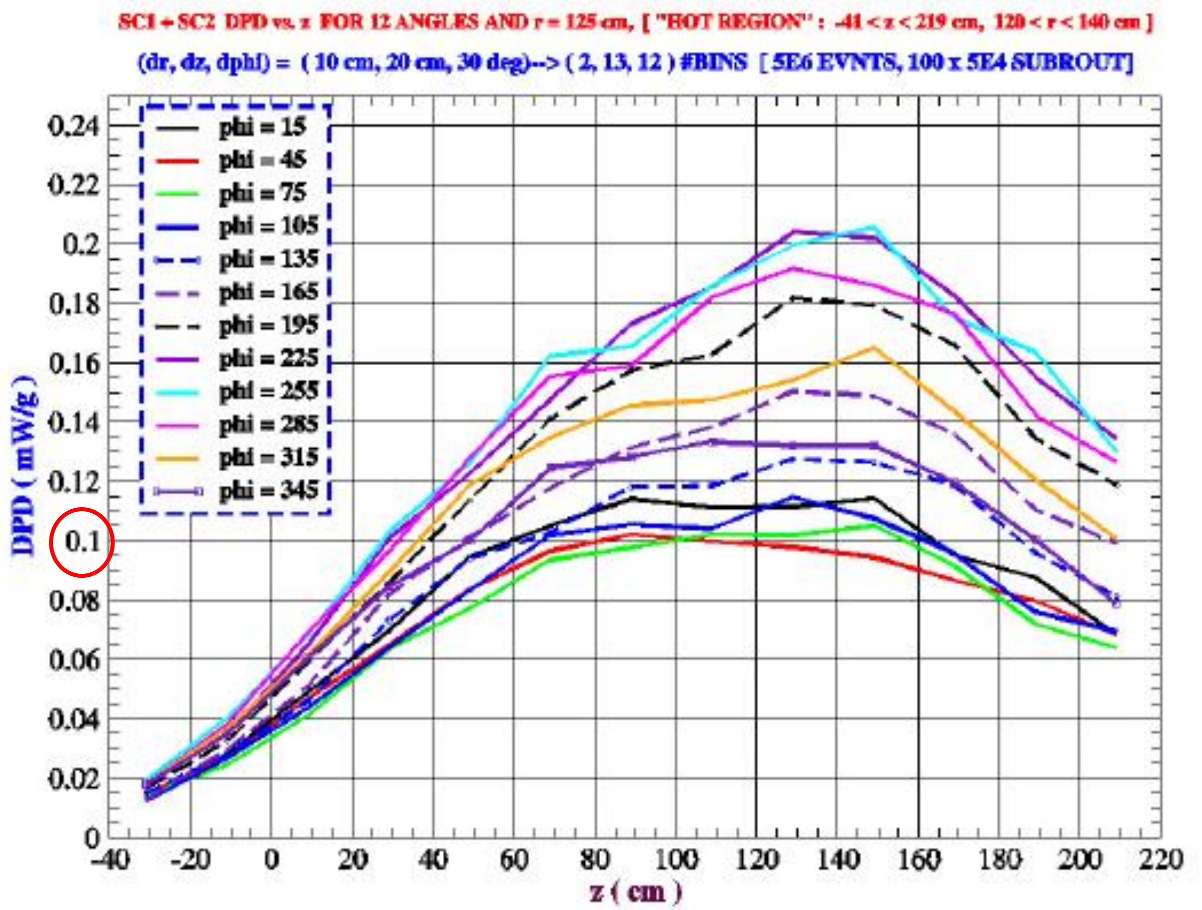
Hg jet target, B_{max} = 15T
IDS120j geometry

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: 4MW & 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

Conclusions

- High atomic Z targets give best yields (p beam KE ~ 10 GeV)
  - Important to also compare target operational lifetime & other safety issues
  - Study of irradiated target materials: **N. Simos et al.,** Phys. Rev. AB 21, 053001 (2018)

- Graphite (He-cooled) "1st stage" 1MW target (L ~ 1m, r ~ 1cm)
  - Normalised yields only 10% less (20T field) than Hg jet (15T field)
  - More shielding needed for SC coils if beam power > 2 MW

- Global optimisation with Front-End is required
  - Solenoid field peak, taper & end-field depend crucially on SC + resistive coil setup
  - Radiation shielding & structural (stored magnetic energy ~3GJ) constraints

- Ideas for further discussion:
  - Refine engineering details (structural supports & services) for a 1st stage graphite target
  - Use hadronic model updates for MARS, GEANT4 & FLUKA
  - Global optimisation with Front-End updates
  - Maintain simulation input/geometry files in a github-like repository

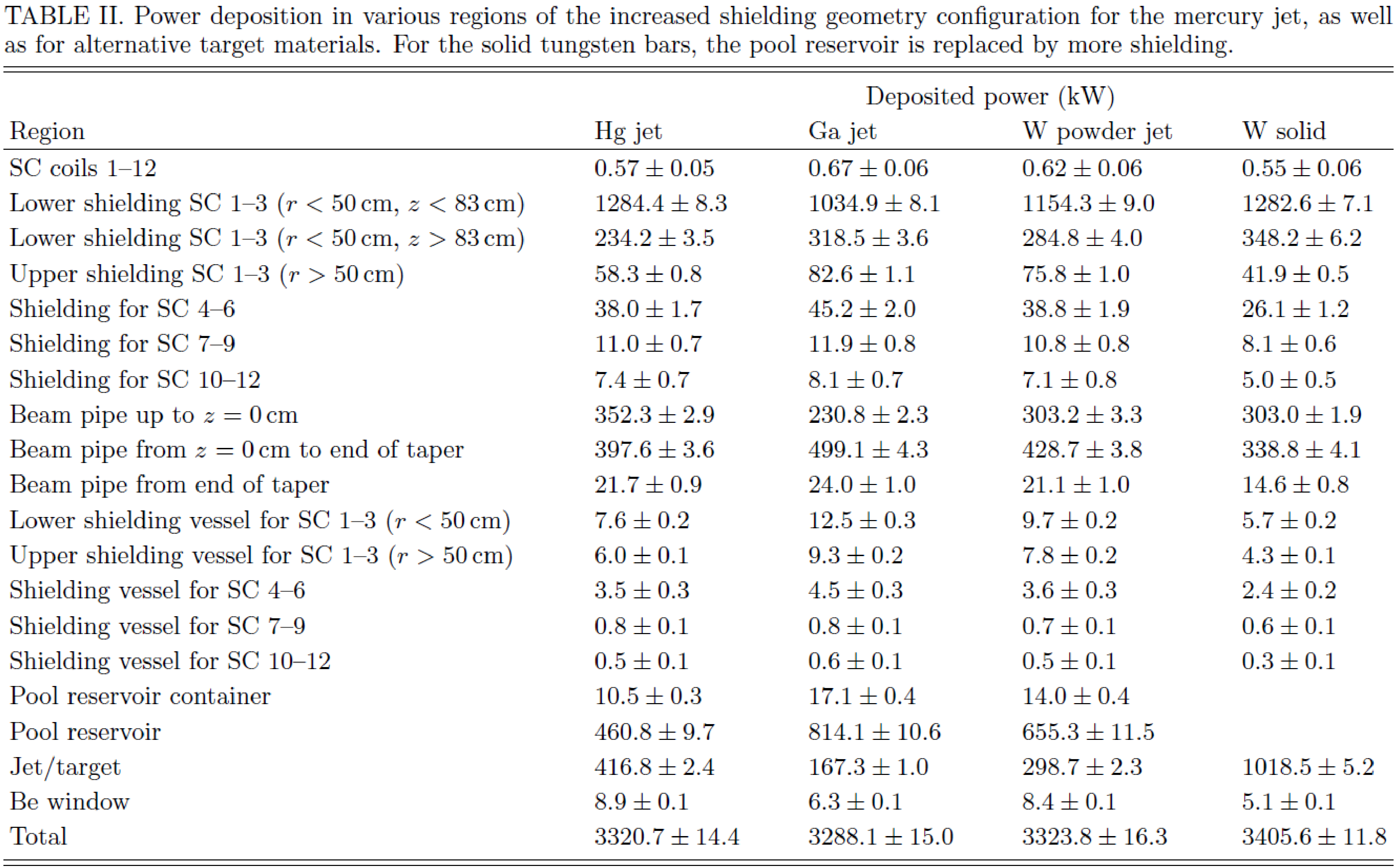


TABLE II. Power deposition in various regions of the increased shielding geometry configuration for the mercury jet, as well as for alternative target materials. For the solid tungsten bars, the pool reservoir is replaced by more shielding.

	Deposited power (kW)			
Region	Hg jet	Ga jet	W powder jet	W solid
SC coils 1–12	0.57 ± 0.05	0.67 ± 0.06	0.62 ± 0.06	0.55 ± 0.06
Lower shielding SC 1–3 ($r < 50\,\mathrm{cm}$, $z < 83\,\mathrm{cm}$)	1284.4 ± 8.3	1034.9 ± 8.1	1154.3 ± 9.0	1282.6 ± 7.1
Lower shielding SC 1–3 ($r < 50\,\mathrm{cm}$, $z > 83\,\mathrm{cm}$)	234.2 ± 3.5	318.5 ± 3.6	284.8 ± 4.0	348.2 ± 6.2
Upper shielding SC 1–3 ($r > 50\,\mathrm{cm}$)	58.3 ± 0.8	82.6 ± 1.1	75.8 ± 1.0	41.9 ± 0.5
Shielding for SC 4–6	38.0 ± 1.7	45.2 ± 2.0	38.8 ± 1.9	26.1 ± 1.2
Shielding for SC 7–9	11.0 ± 0.7	11.9 ± 0.8	10.8 ± 0.8	8.1 ± 0.6
Shielding for SC 10–12	7.4 ± 0.7	8.1 ± 0.7	7.1 ± 0.8	5.0 ± 0.5
Beam pipe up to $z = 0\,\mathrm{cm}$	352.3 ± 2.9	230.8 ± 2.3	303.2 ± 3.3	303.0 ± 1.9
Beam pipe from $z = 0\,\mathrm{cm}$ to end of taper	397.6 ± 3.6	499.1 ± 4.3	428.7 ± 3.8	338.8 ± 4.1
Beam pipe from end of taper	21.7 ± 0.9	24.0 ± 1.0	21.1 ± 1.0	14.6 ± 0.8
Lower shielding vessel for SC 1–3 ($r < 50\,\mathrm{cm}$)	7.6 ± 0.2	12.5 ± 0.3	9.7 ± 0.2	5.7 ± 0.2
Upper shielding vessel for SC 1–3 ($r > 50\,\mathrm{cm}$)	6.0 ± 0.1	9.3 ± 0.2	7.8 ± 0.2	4.3 ± 0.1
Shielding vessel for SC 4–6	3.5 ± 0.3	4.5 ± 0.3	3.6 ± 0.3	2.4 ± 0.2
Shielding vessel for SC 7–9	0.8 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.6 ± 0.1
Shielding vessel for SC 10–12	0.5 ± 0.1	0.6 ± 0.1	0.5 ± 0.1	0.3 ± 0.1
Pool reservoir container	10.5 ± 0.3	17.1 ± 0.4	14.0 ± 0.4	
Pool reservoir	460.8 ± 9.7	814.1 ± 10.6	655.3 ± 11.5	
Jet/target	416.8 ± 2.4	167.3 ± 1.0	298.7 ± 2.3	1018.5 ± 5.2
Be window	8.9 ± 0.1	6.3 ± 0.1	8.4 ± 0.1	5.1 ± 0.1
Total	3320.7 ± 14.4	3288.1 ± 15.0	3323.8 ± 16.3	3405.6 ± 11.8

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