Overview of Shower Calculations on the Material Choice

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LTC Meeting Wed 25/6/2003

Accident scenarios

Materials choice:

not driven so much by the standard collimation

but rather by the faulty operations or malfunctions

- Worst Accident scenarios
  - Due to a spontaneous rise of one of the extraction kicker modules during the coast, part of the 7 TeV/c beam is spread across the front of a collimator jaw.
  - Faulty kick by the injection kicker where a full batch of protons hit the front of a collimator jaw at 450 GeV/c
- Very fast absorptions of part of the proton energy
  - Instantaneous temperature rise
  - Thermally induced stresses (overheating/melting)

$\Rightarrow$ Limits material choice which can be used and still be compatible with other machine requirements.

Reference: LHC Project Report 599, LHC Project Note 293

Tools

- FLUKA-2002 (3)

  A.Fasso, A.Ferrari, J.Ranft, P.R.Sala

  Proceedings of the Monte Carlo 2000 Conference, Lisbon,

  Oct. 23-26 2000, Springer-Verlag Berlin, p 955-960 (2001)
- Single scattering treatment
  - MCS can produce artefacts when crossing of an interface and the small "grazing" angle is important compared to a typical scattering angle
  - MCS not suitable for surface roughness
  - Important for the Slowcase
  - ☹ Increases computation time (×500)
- Ions DPMJET-2.53

  J.Rauft, S.Roesler, R.Bugel

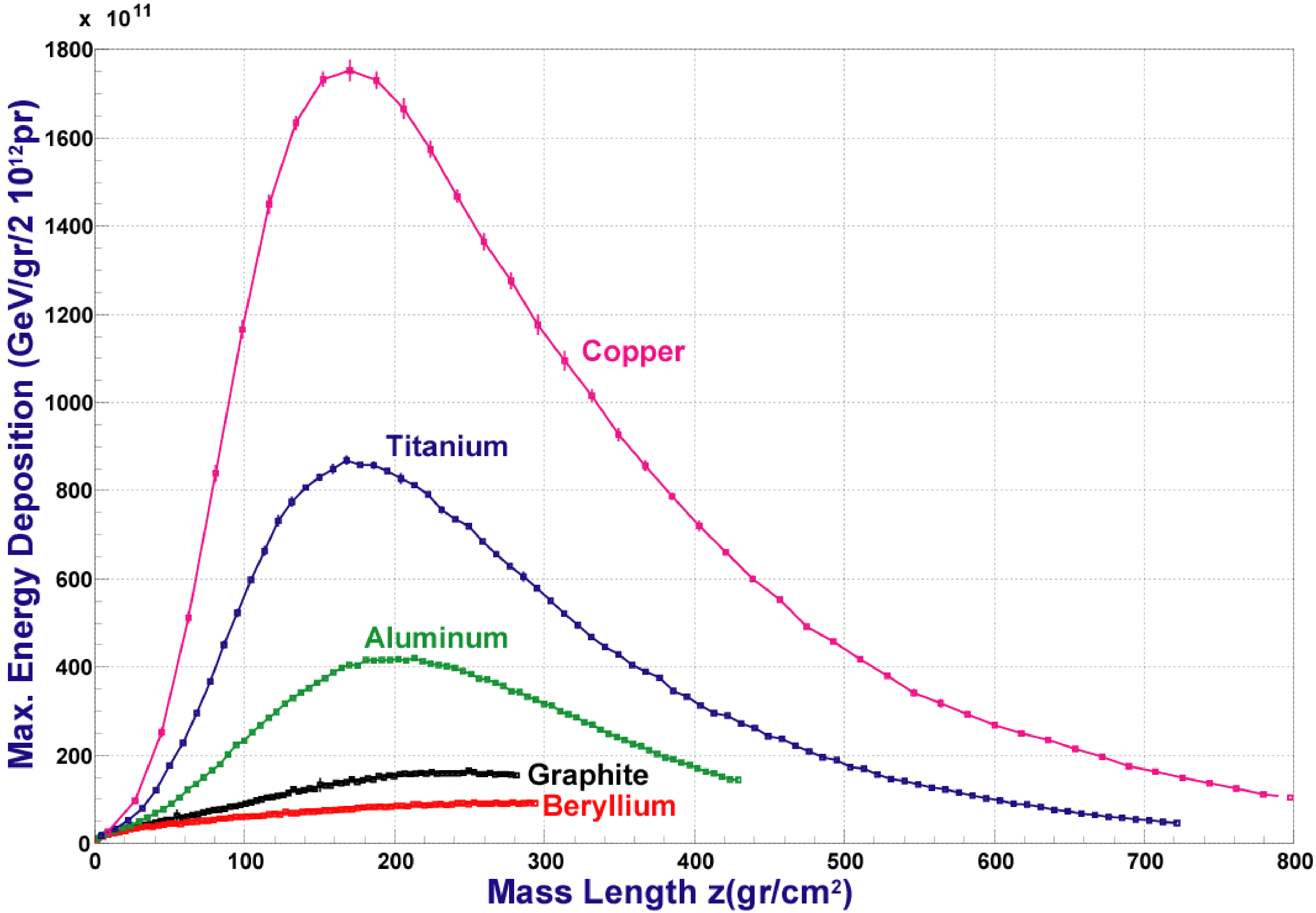
Material Selection

- Low Z material must be used
- Only Graphite and Beryllium can be considered
- Even 100μm Copper coating is not possible!
- Most of the cascade escapes the collimator
- EM contribution very small

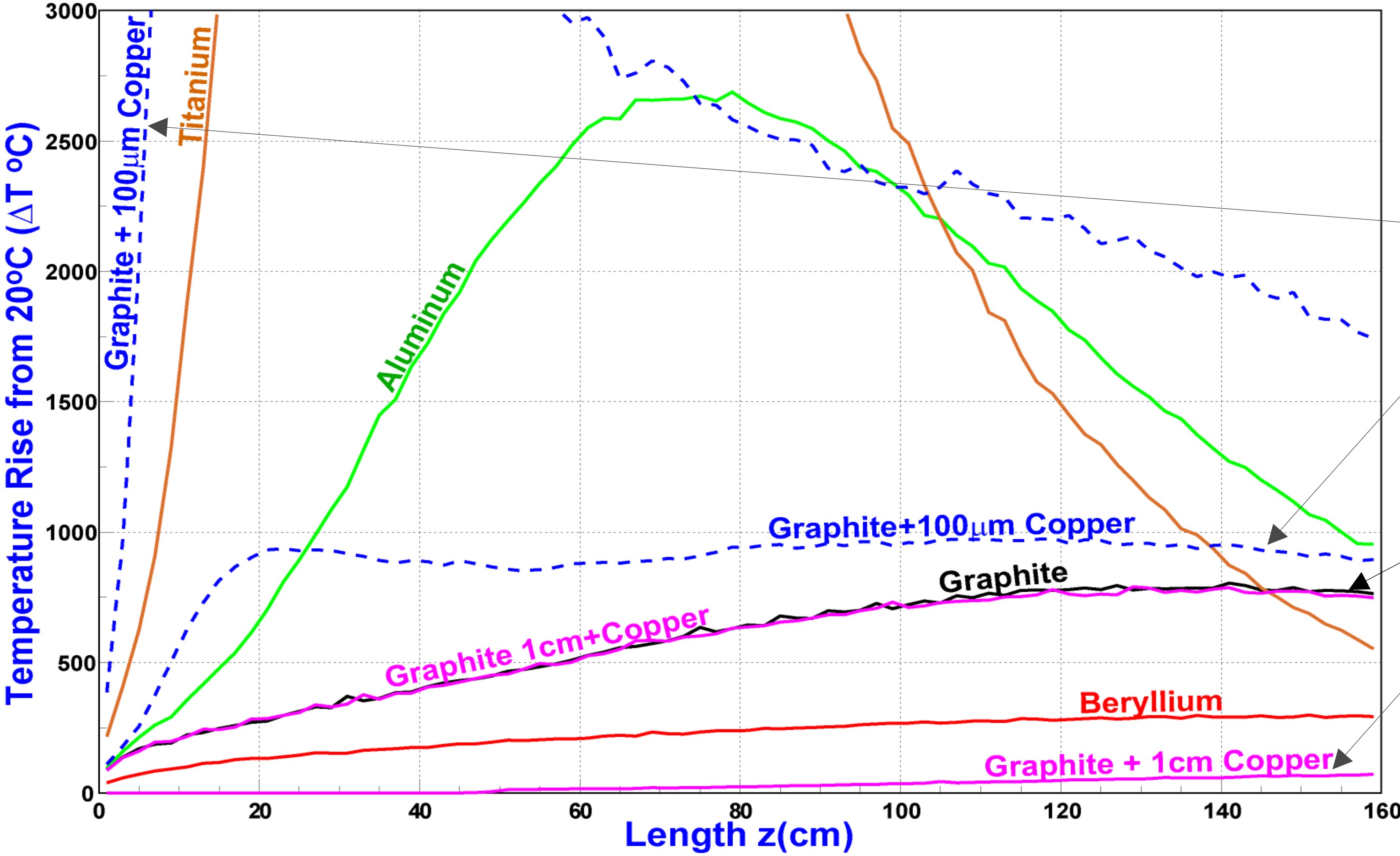
Material	Density g/cm³	Max Energy GeV/cm³	Max Temp °K approx.	Escaping %	EM %
Aluminum	2.7	5.3×10^{13}	~2700	88.8	9
Beryllium	1.848	0.09×10^{14}	310	97	1
Copper	8.96	7×10^{14}	> 5000	34.4	52.4
Graphite	1.77	0.13×10^{14}	800	96.4	1.8
Graphite + Cu 100μm	1.77+8.9	1.6×10^{14} on Cu	800 C, > 5000 Cu	94.1	3.9
1cm Graphite + Copper	1.77+8.9	0.1×10^{14}	800 C, 450 Cu	94.5	3.8
Titanium	4.54	1.7×10^{14}	> 5000	79.5	16.7

FLUKA simulations for the accident case at 7 TeV

Max Energy per mass-length

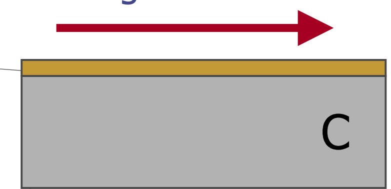


Irregular Beam dump at 7 TeV/c

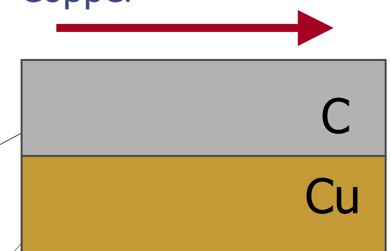


Different Cases

1. Graphite + 100μm Copper coating



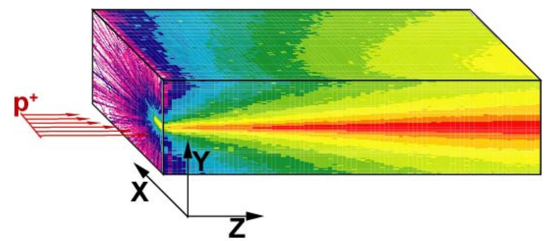
2. 1cm Graphite plate on Copper



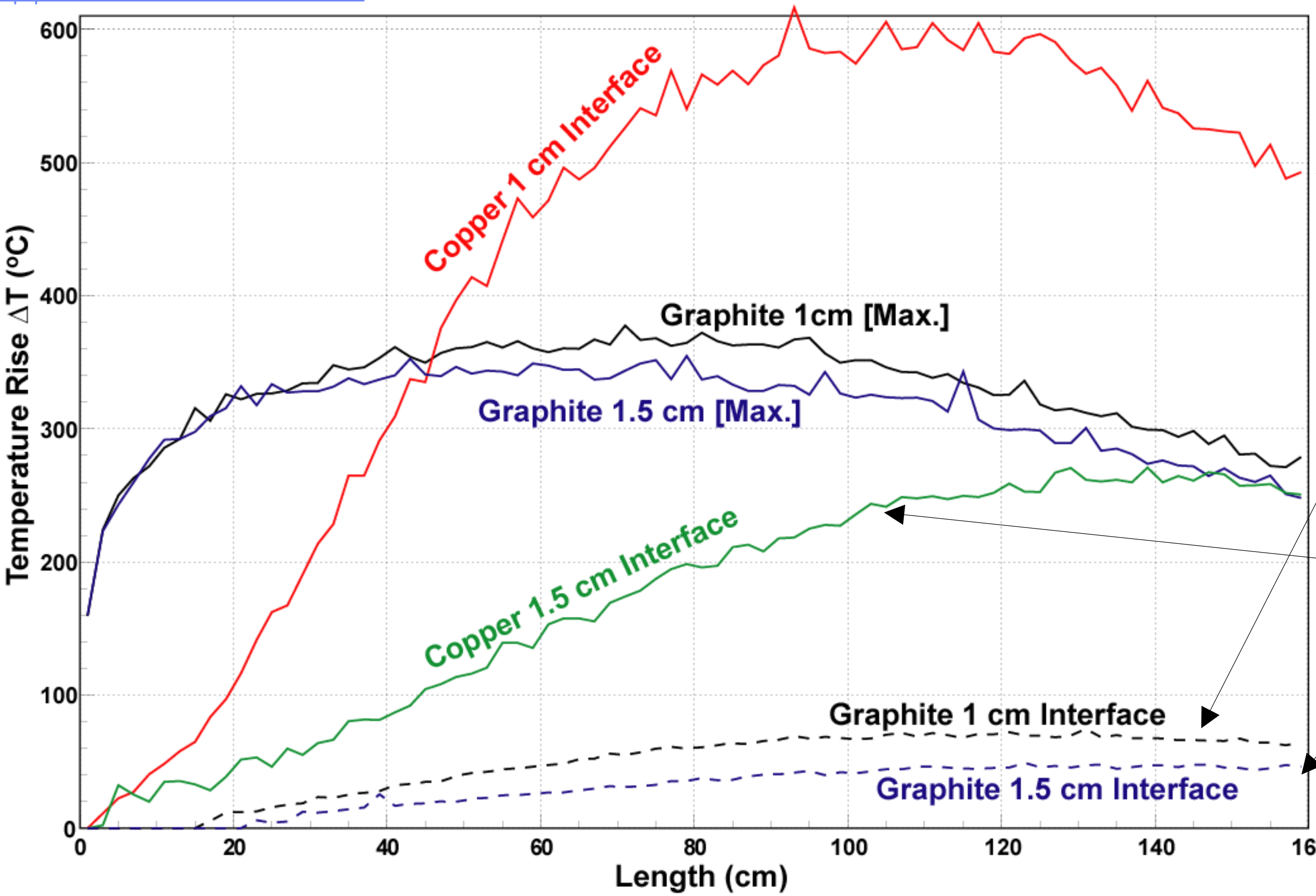
3. Block Materials

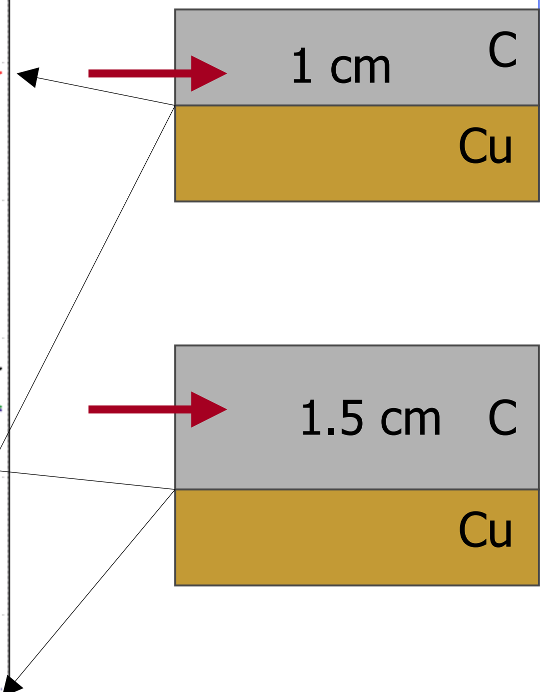
Single module pre-fire with retriggering of 14 after 1.3μs

Total:	8 bunches
Range:	$5\sigma - 10\sigma$
Proton/Bunch:	1.05×10^{11} pr
Total:	9×10^{11} pr



Wrong kick at 450 GeV [C-Cu]



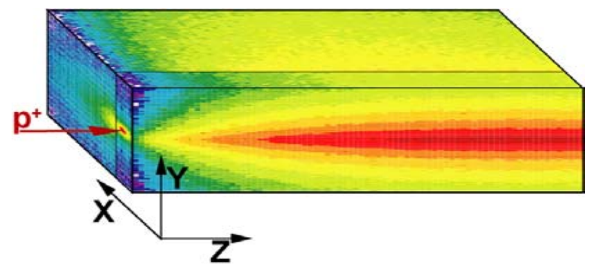


In rare case of injection errors a full batch of

Intensity: 3.2×10^{13} p @ 450 GeV/c

RMS radius: 1.0 mm (round profile)

May hit the front face of the collimator



Normal Collimation at 7 TeV/c

- 2 cases studied: Perfect Alignment, 5 μrad misalignment
- 100cm long graphite "ideal" collimators (no surface roughness)
- Use of single scattering in the sensitive regions of the cascade
- Interacting protons: 4×10^{11} p/s (lifetime 0.2 h) for 10 s
- Impact parameter: 0-200nm (σ_y=0.2 mm)
- Energy: 7 TeV

Perfect Alignment

Beam parallel to Z axis

Interacting protons: 0.5934/p

Interaction length: 42.05cm

$$1 - e^{-100/42.05} = 0.907$$

Total Power: 1785 W

5 μrad Misalignment

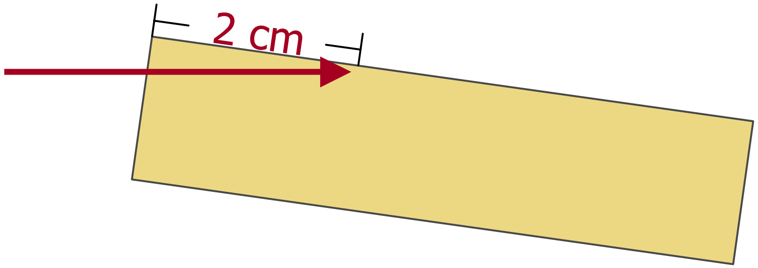
Traversal length: 2cm

Interacting protons: 0.05209/p

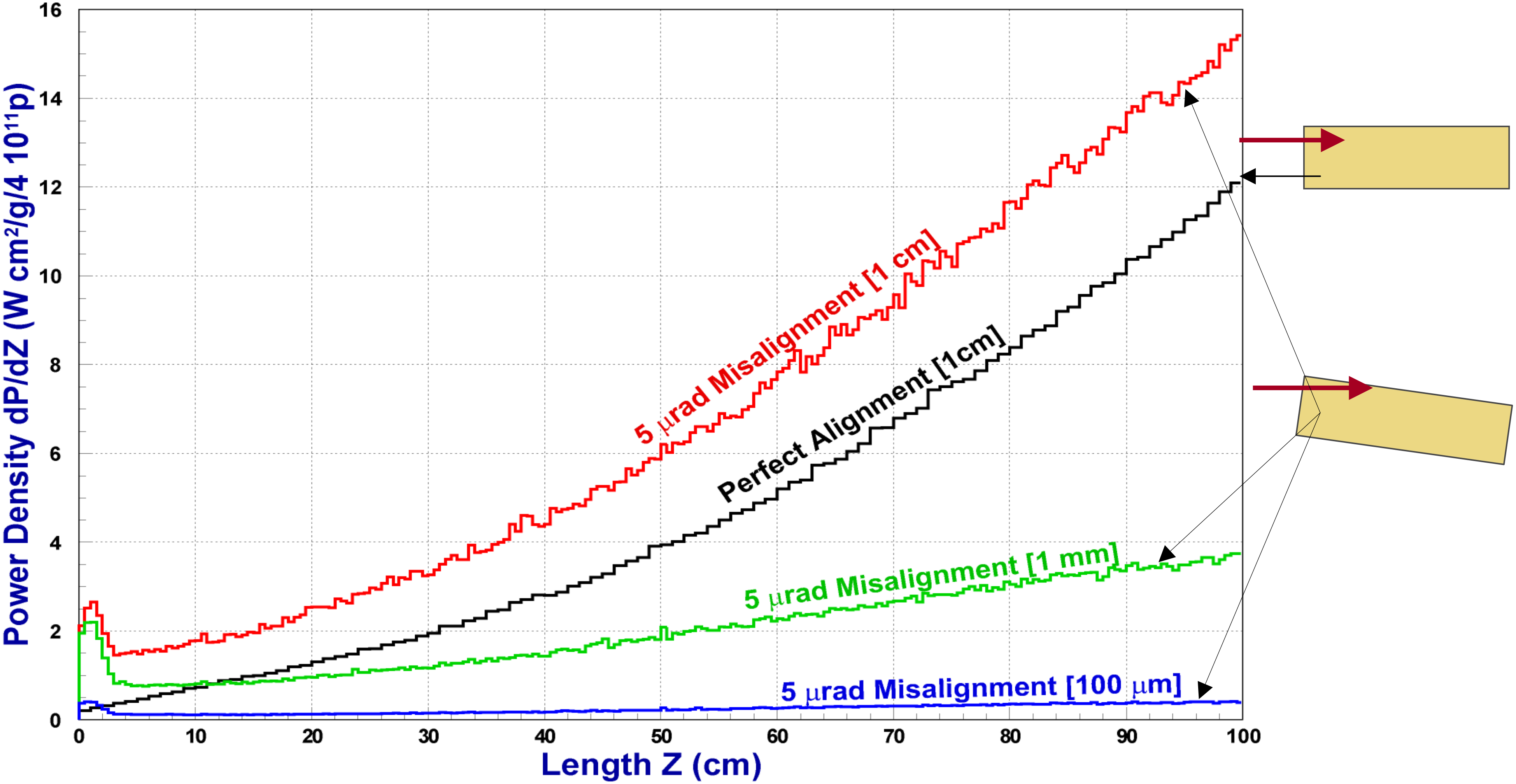
Interaction length: 42.05cm

$$1 - e^{-2/42.05} = 0.04645$$

Total Power: 2960 W



Integrated Power density



Integrated power density over a square area per unit length Z (cm) per gram per 4×10^{11} int. protons [Integration Area: X: 0-1 cm Y: ±50 μm, ±½ mm, ±½ cm]

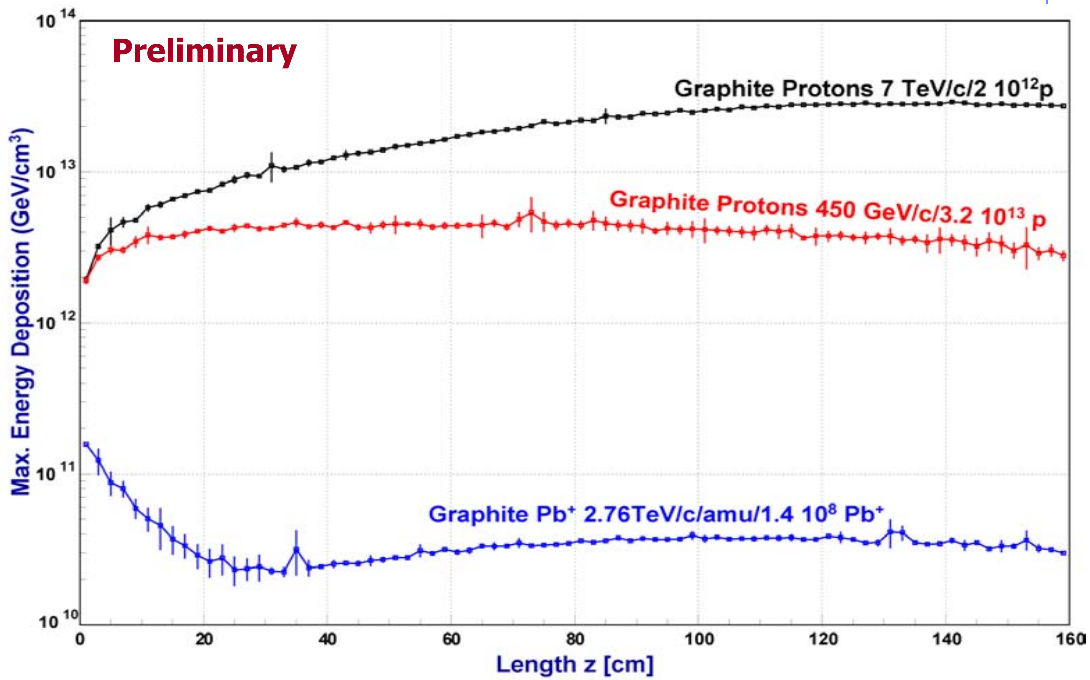
Heating is higher on the badly aligned compared with the perfect one!

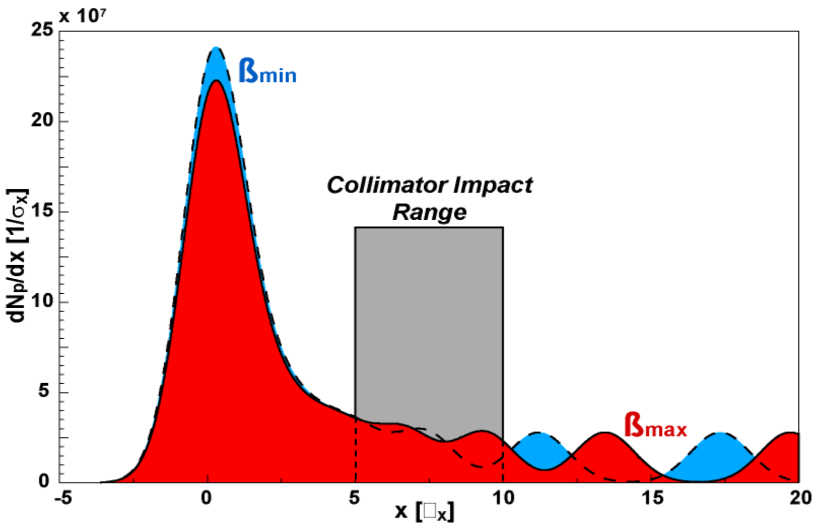
Ions Irregular Beam Dump

Accident Case

Single module pre-fire

Total:	2 bunches over 5σ
Range:	5 σ – 10 σ
Ions/Bunch:	$7{\times}10^7$ Pb^+
Total:	$1.4{\times}10^8$ Pb^+
Ion Energy:	574 TeV/Pb^+
	= 2.76 TeV/amu
	(= 7 TeV 82/208)





Escaping:	97 %
EM Cascade:	2.3 %

Ions 2-3 Orders of magnitude smaller energy deposition!

Ions Normal operation

Normal Collimation

Bunches: 592

Interacting: 5.8 10^7 Pb^+/s

Bunch spacing: 100 ns

5 μrad Misalignment

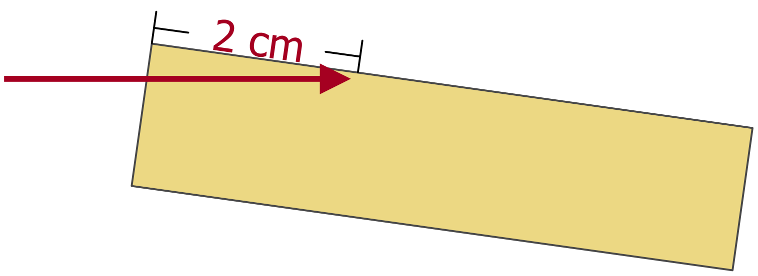
Traversal length: 2cm

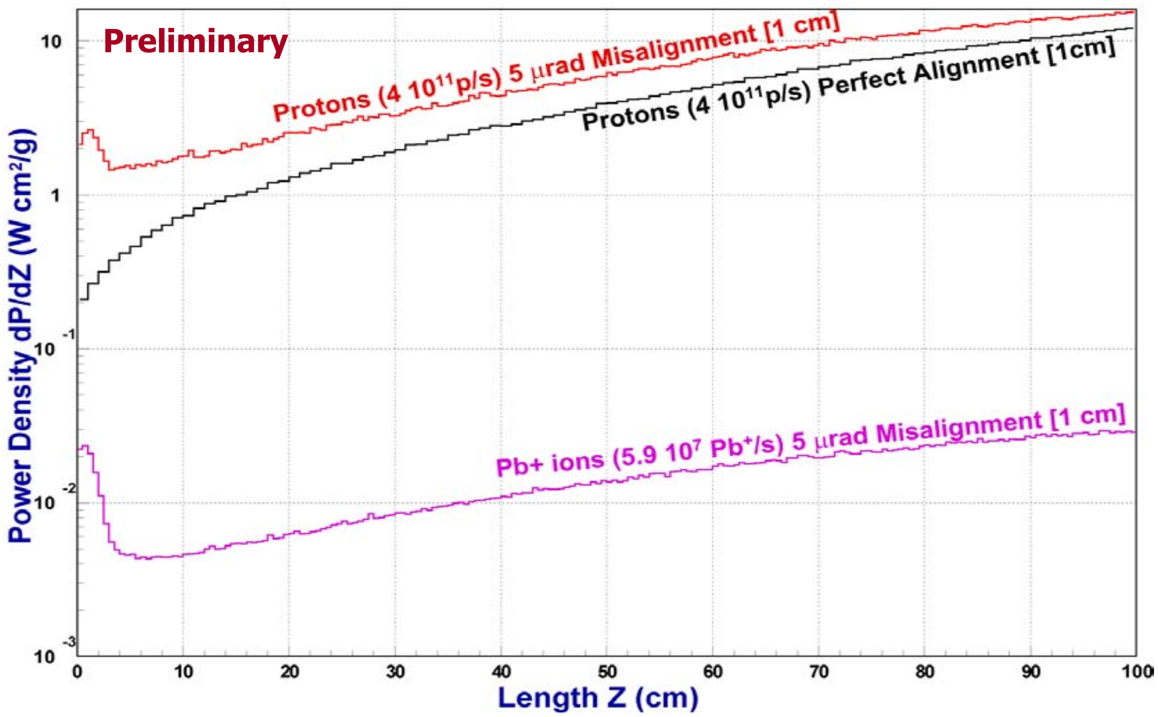
Interacting Ions: 0.44/Pb^+

Interaction length: 3.46cm

$$1 - e^{-2/3.46} = 0.439$$

Total Power: 7 W





Ions 2-3 Orders of magnitude smaller energy deposition!

A fraction of Ions loses a few nucleons and enters back to the beam line

Summary

- Low Z material must be used
- Only Graphite and Beryllium can be considered
- Even 100μm Copper coating is not possible!
- Sensitive to alignment, surface roughness
- Energy deposition from Ions is very small!

- Safety factor in calculations
  - Accident case: 30%
  - Slow case: factor $\times$2-3