Collimation for Heavy Ions:

status of studies

- Specific issues of ion collimation
- ICOSIM program: quick description and recap
- ICOSIM: new features and preliminary studies
- Conclusions and to-do-lists

Why ion collimation is an issue

Present LHC collimation system conceived for high intensity proton beams is based on a two-stage concept:

1. short primary collimators (TCPs) where particles undergo multiple scattering over several passages
2. longer secondary collimators (TCSs) where particles with sufficiently large betatron amplitude dissipate their energy in hadronic showers.

Different behaviour of heavy ion beams:

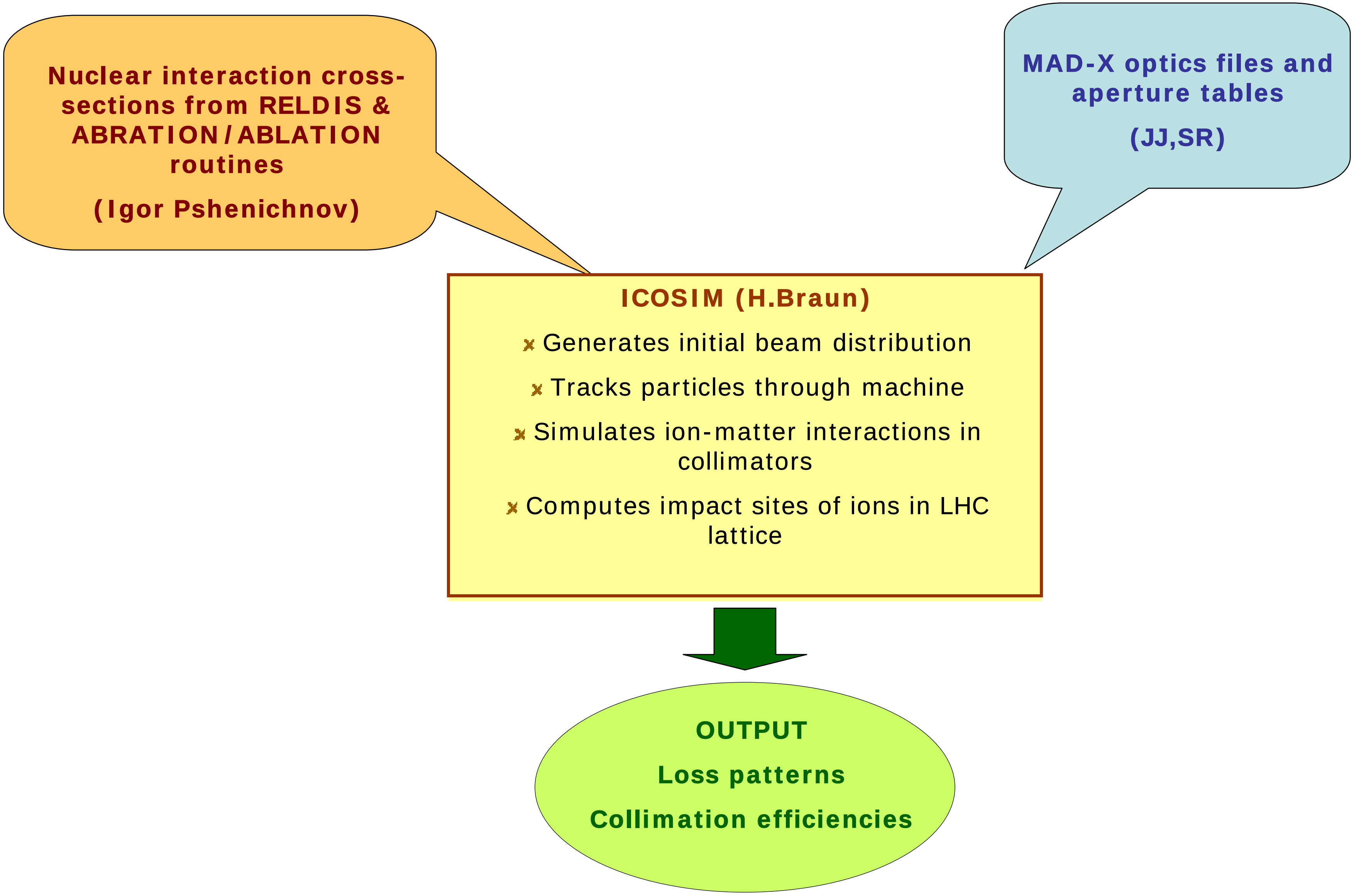
~20 times higher probability of nuclear interactions than protons **+** **Comparable scattering angles**

Very high probabililty to undergo nuclear interactions in TCPs (NF, ED) , with residual ions having different Z/A ratio but similar momentum => not intercepted by the TCSs but lost downstream in the SC magnets of the dispersion suppressor because of different rigidity

Collimation system acts as a **single stage system** for ions

Particle losses in SC magnets exceed permissible values.

ICOSIM flowchart



Generation of first impact distribution

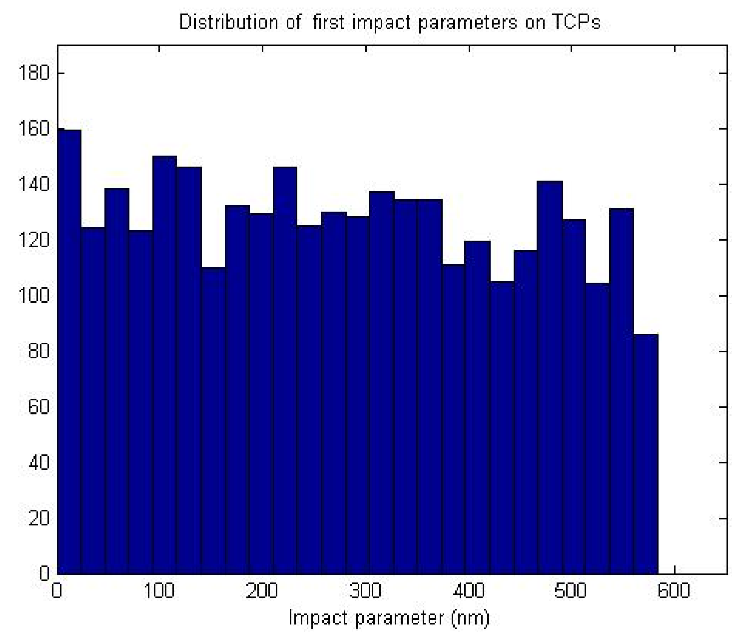
ICOSIM generates randomly populated KV beam distribution in 4D with $\varepsilon=36\mathrm{x}\varepsilon_{nom}$ and 'skin depth' parameter.

Linear tracking from TCP to TCP with slow increase of amplitude dA/dt (every 100 turns) until all particles have hit a TCP

Initial position of hit particles is saved for later tracking

Skin depth parameter and dA/dt (~diffusion velocity) determine the average impact parameter of particles onto primary collimators.

<b>~ 280 nm



Tracking

Typically 10^4-10^5 particles are tracked for ~10^2 turns of the LHC, with particle coordinates transformed element by element.

Linear transfer matrices in ***x, x', y, y', Dp/p***

+

Linear dispersion in bending magnets

Chromaticity in quadrupoles to leading order

Sextupoles in thin element kick approximation

No acceleration (1/Qs <<100)

Check for aperture hits at the end of each element ; in case of hit the exact impact position within the element is found by interpolation.

Aperture cross sections are approximated by ellipses, except for collimators, where full geometry is taken into account.

If hit location is inside a collimator then call is made to fragmentation routines.

Nuclear fragmentation

Uses cross-section tables for NF and ED generated by Igor Pshenichnov's abration/ablation and RELDIS codes.

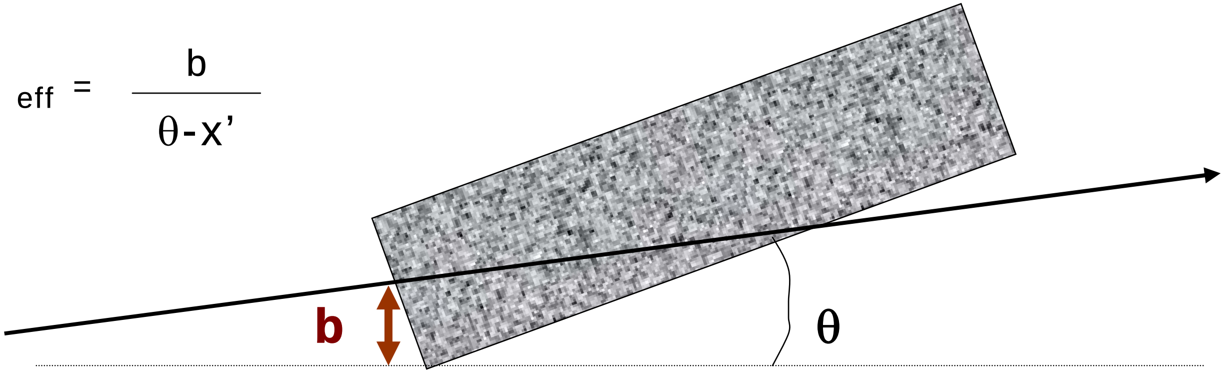
Ionisation energy loss is modelled by the Bethe-Bloch formula for heavy ions with shell and density corrections.

Multiple scattering is described using a Gaussian approximation of the scattering distribution .

The effective particle path is calculated at impact time for each particle.

If the path covered in a collimator is longer than 10 interaction lengths, the particle is assumed to be stopped and absorbed, otherwise the probability for a fragmentation process is randomly computed using the look-up cross-section tables.

$$L_{eff} = \frac{b}{\theta - x'}$$



ICOSIM: new features

✓Recently introduced latest LHC optics (**V6.500**) -> John Jowett

Two cases:

Early Ion Collisions:

	β_x (m)	β_y (m)
IP1	2	2
IP2	1	1
IP5	2	2
IP8	10	10

Nominal Ion Collisions:

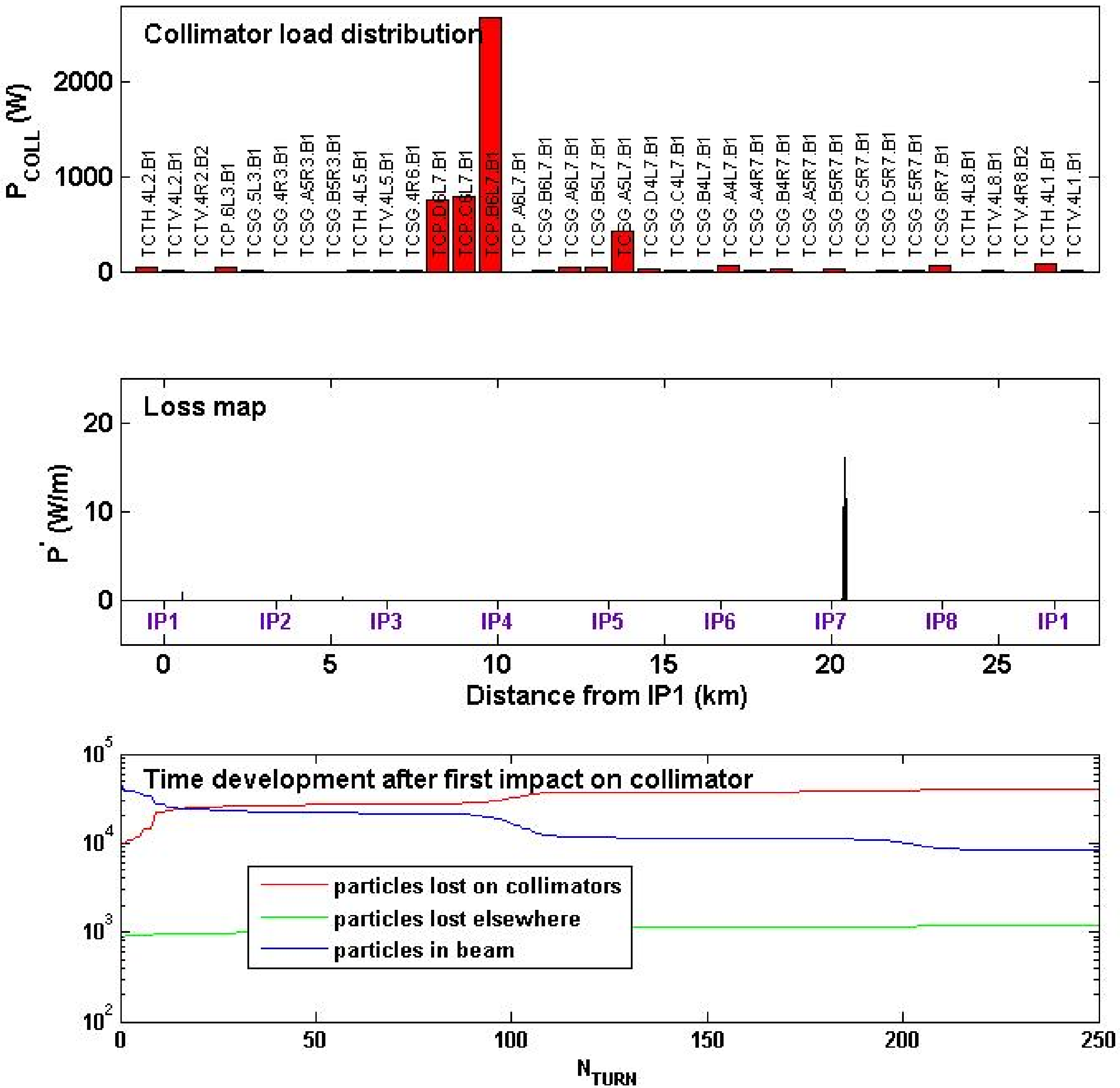
	β_x (m)	β_y (m)
IP1	0.55	0.55
IP2	0.5	0.5
IP5	0.55	0.55
IP8	10	10

✓**New aperture files** provided by Stefano Redaelli, though will need a further update because of a bug in the database that gave wrong specifications for some elements.

✓**List of collimators** updated to include full list of tertiaries (TCTs only, TCLIs and TCLAs not yet included); also changed denominations to be in line with those adopted in the LHC optics database.

✓Changed ρ (**CFC**) **= 2.25** ●⟶ **1.7 g/cm³** (R. Chamizo)

Nominal lLHC beam 1 at collision



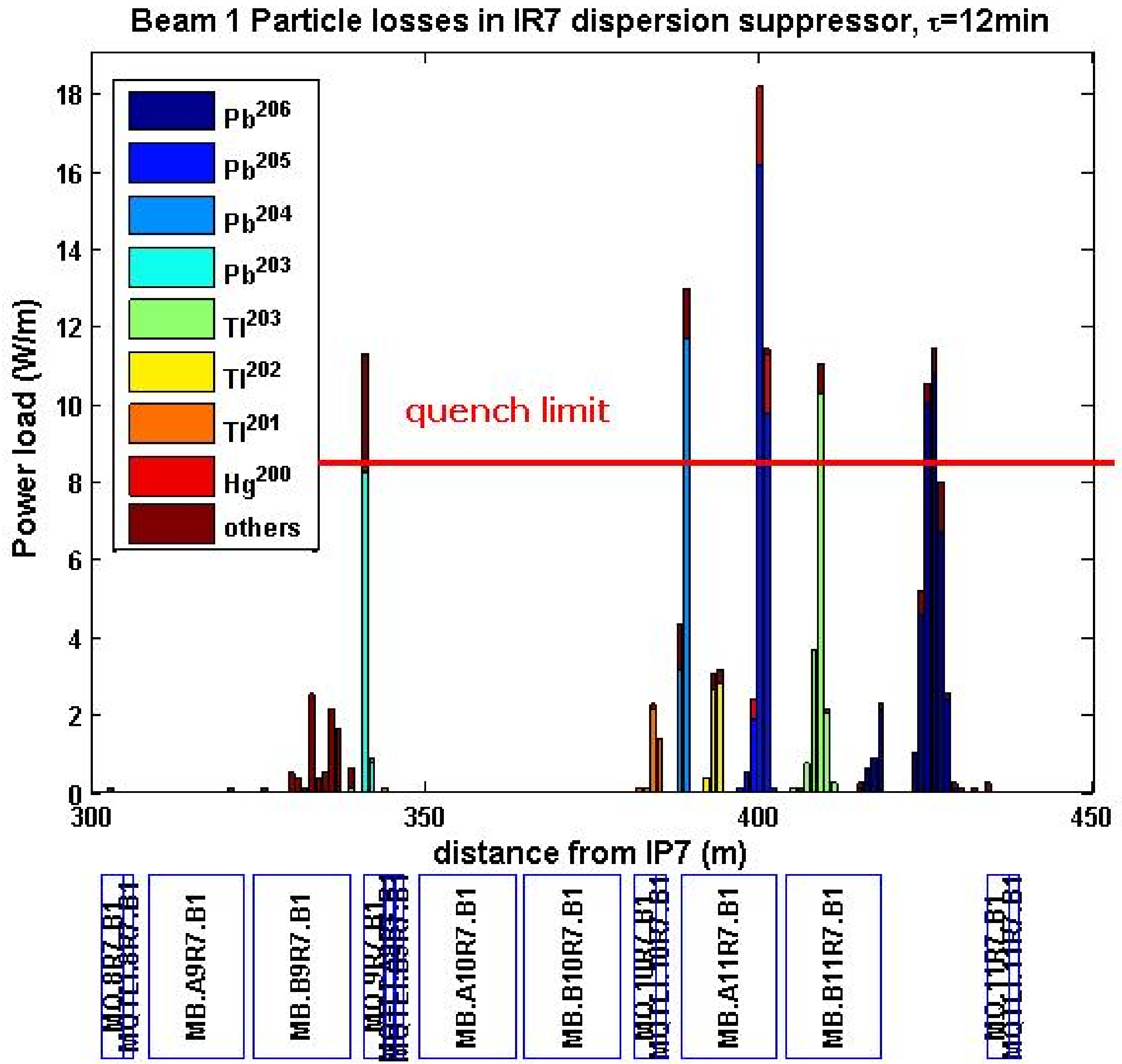
$N_p = 50k$

nrev = 250

<b> = 280 nm

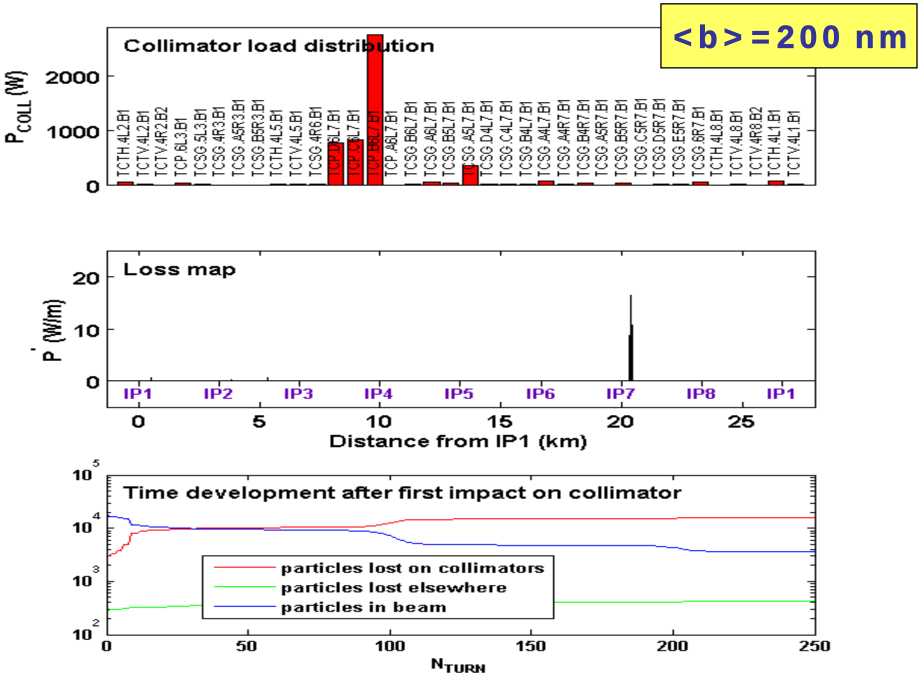
$\rho = 1.7\ g/cm^3$

$\eta = 0.0294$

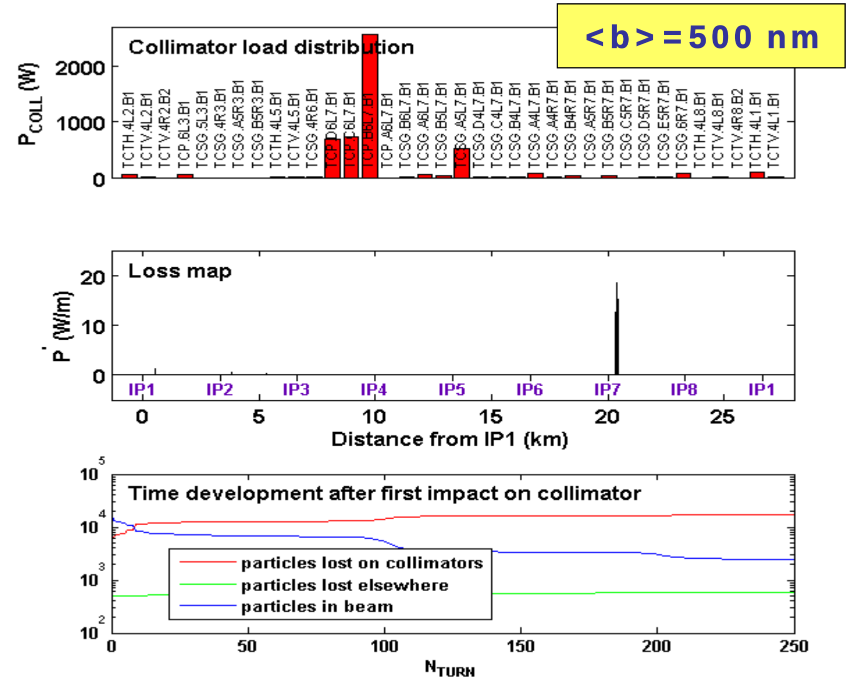


Nominal scheme at collision

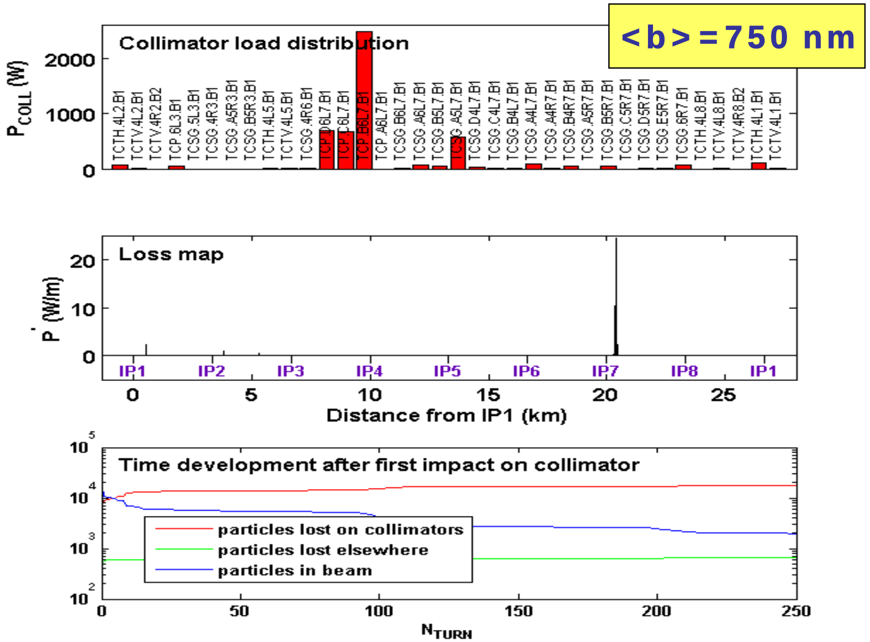
Quench limit= ~8.5 W/m



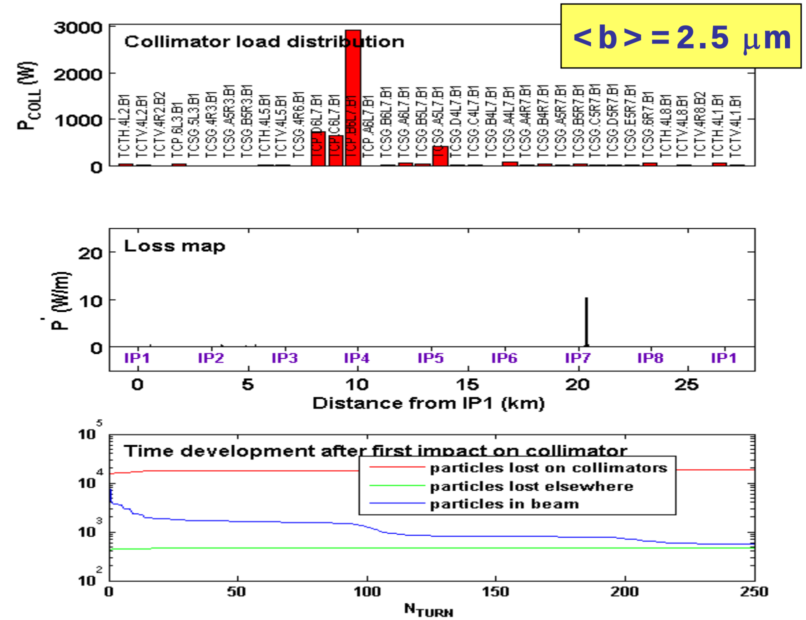
<b>=200 nm
Collimator load distribution
P_{COLL} (W)
Loss map
P' (W/m)
IP1 IP2 IP3 IP4 IP5 IP6 IP7 IP8 IP1
Distance from IP1 (km)
Time development after first impact on collimator
particles lost on collimators
particles lost elsewhere
particles in beam
N_{TURN}



<b>=500 nm
Collimator load distribution
P_{COLL} (W)
Loss map
P' (W/m)
IP1 IP2 IP3 IP4 IP5 IP6 IP7 IP8 IP1
Distance from IP1 (km)
Time development after first impact on collimator
particles lost on collimators
particles lost elsewhere
particles in beam
N_{TURN}

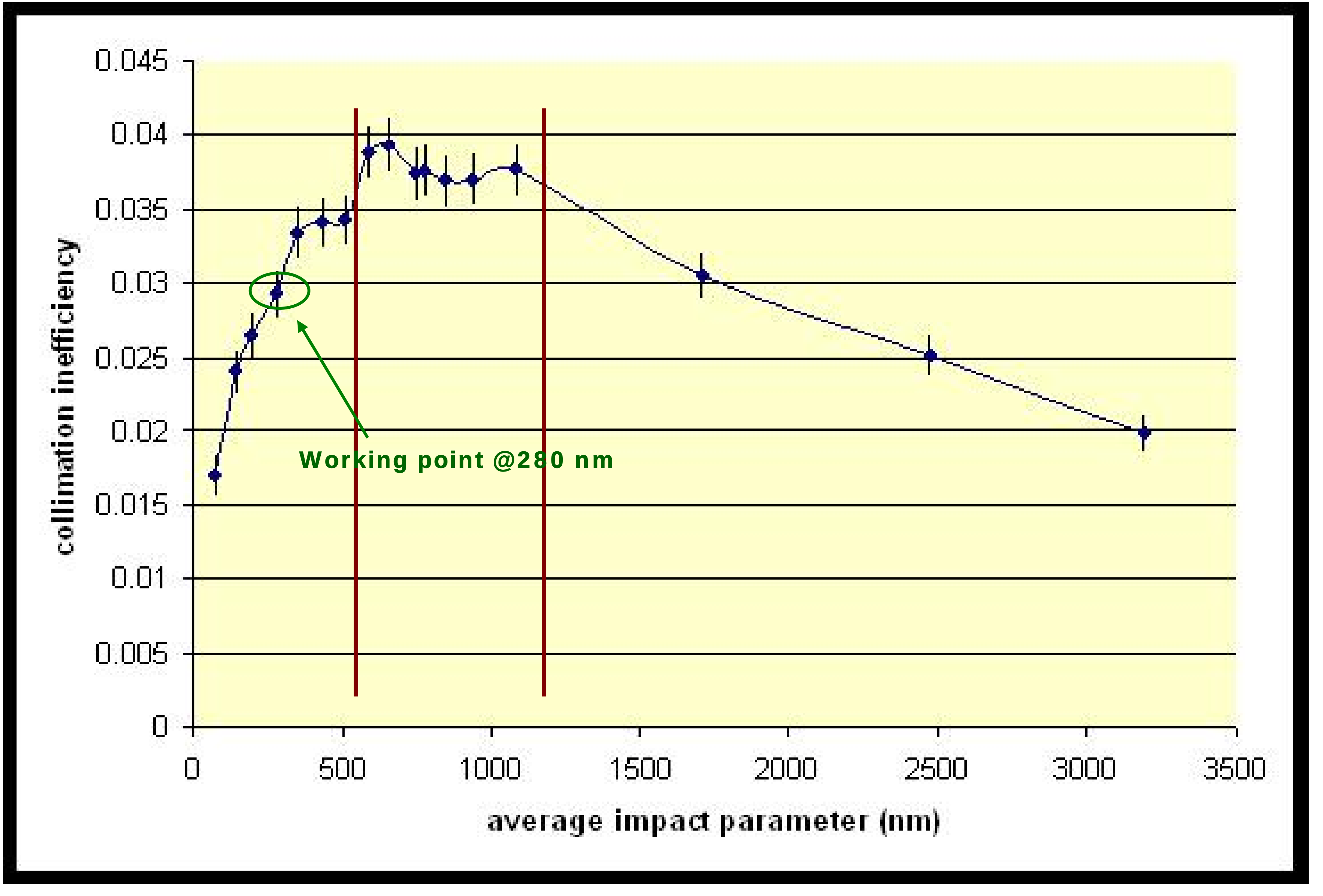


<b>=750 nm
Collimator load distribution
P_{COLL} (W)
Loss map
P' (W/m)
IP1 IP2 IP3 IP4 IP5 IP6 IP7 IP8 IP1
Distance from IP1 (km)
Time development after first impact on collimator
particles lost on collimators
particles lost elsewhere
particles in beam
N_{TURN}



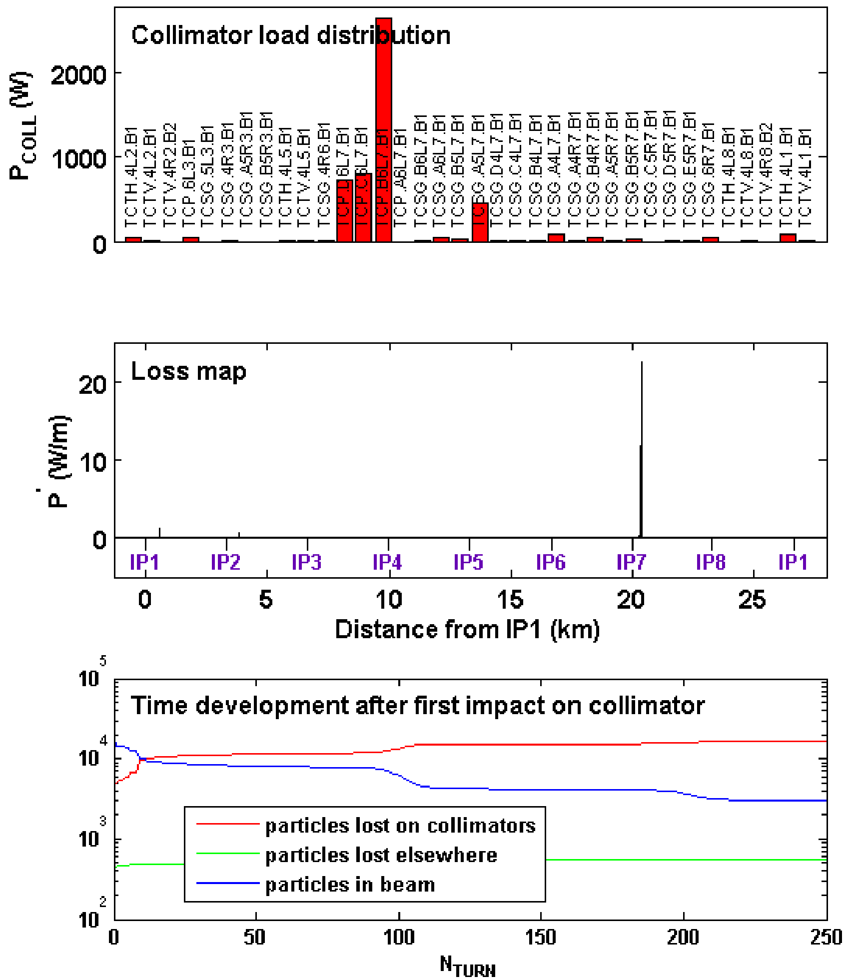
<b>=2.5 μm
Collimator load distribution
P_{COLL} (W)
Loss map
P' (W/m)
IP1 IP2 IP3 IP4 IP5 IP6 IP7 IP8 IP1
Distance from IP1 (km)
Time development after first impact on collimator
particles lost on collimators
particles lost elsewhere
particles in beam
N_{TURN}

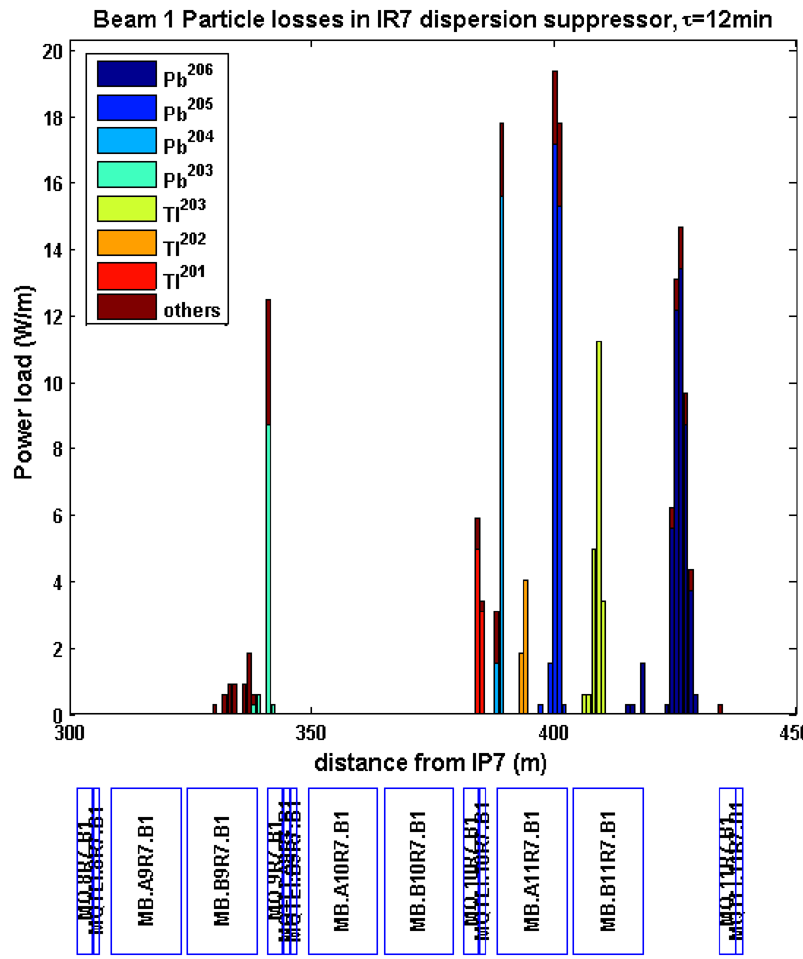
Impact parameter study



Effect of change in ρ

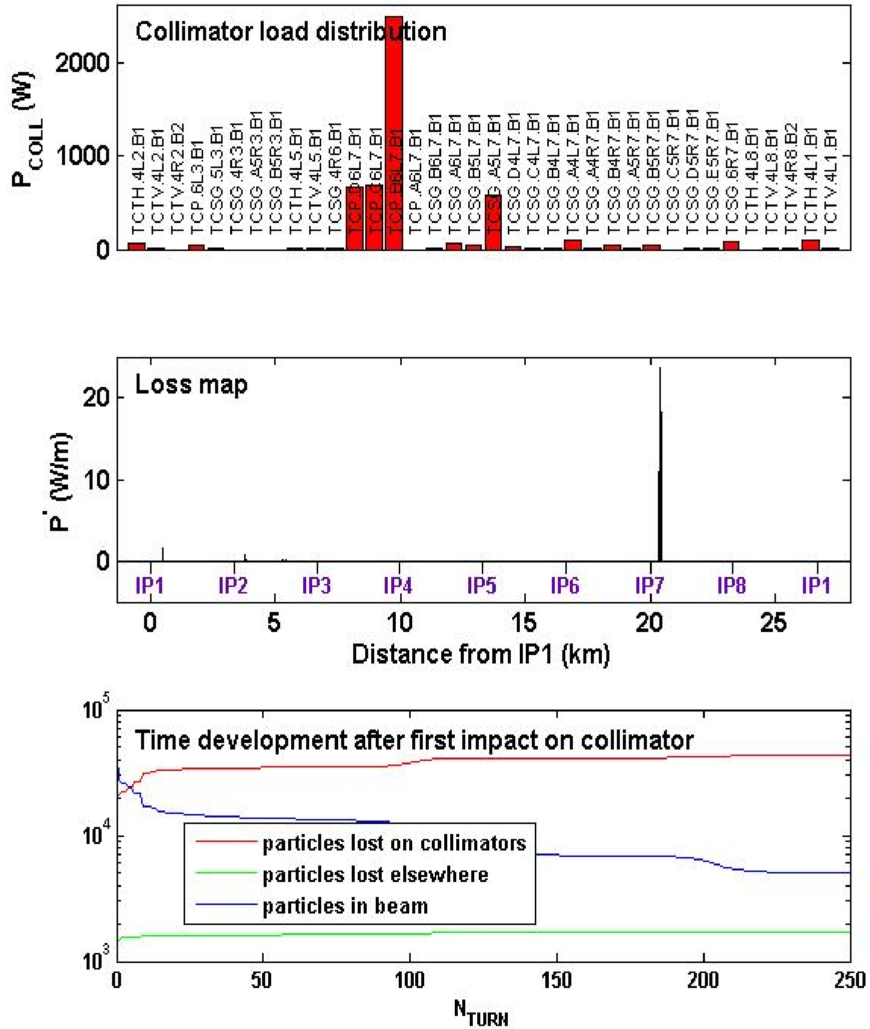
Going back to ρ **= 2.25 g / cm³** for <b>~280 nm ⟹ **η increases to 0.0339**

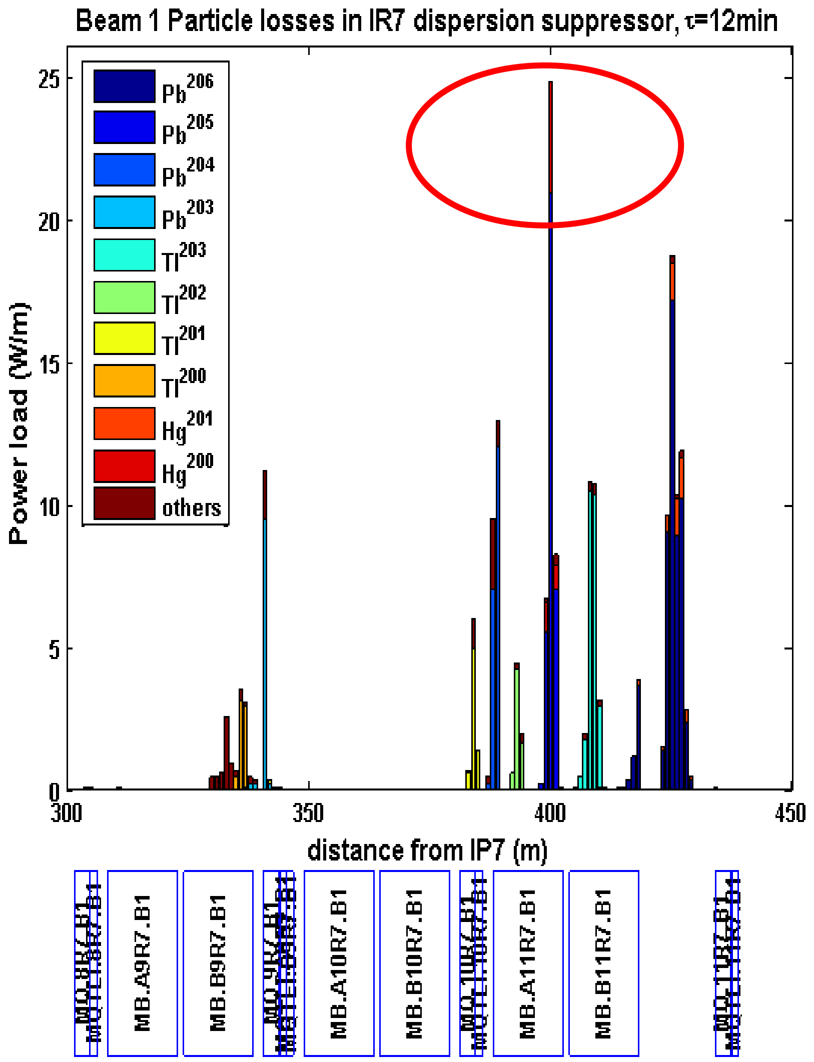




Now taking ρ=**1.7 g/cm³** and **<b>~ 750 nm** (plateau region):

$\eta = 0.04$





Conclusions and to-do list

So far..:

- Re-run code for new LHC optics and aperture description.
- Changed value of collimators' density and studied effect on losses.
- Investigated dependence of simulation results on the average impact parameter on TCPs (as results from the choice of values for intial beam distribution 'skin depth' and 'diffusion velocity' of the particles dA/dt). Behaviour at large b is as expected, but the very small collimation inefficiencies at small b need further delving into.
- Working point might need moving back onto plateau region, but power loads get worse.

From here on..:

- Insert latest **aperture description** (once database bugs have been fixed) and follow-up AT quench level predictions
- Study loss distribution for losses concentrated on a **single collimator jaw** and compare with the pattern obtained for losses distributed uniformly on all collimators.
- Include **separation bumps** at IPs
- Study sensitivity to **orbit oscillations** (still to figure out how to implement it exactly in the code)

- Follow-up **FLUKA upgrade** for heavy ion physics modelling.
- **Benchmarking** of ICOSIM results with SPS data.