Collimation of Lead Ions

- Issues and non-issues for Ion collimation in LHC
- Ion-matter interactions
- The ICOSIM program
- Efficiency of collimation for ions
- Conclusions

Issues for p-LHC collimation	Issues for I-LHC as well ?
1. cleaning efficiency	✓
2. protection of magnets against beam induced quenches	✓
3. robustness of collimator against mishaps	✓
4. impedance	- (I_{IONS} ~I_{PROTON}/100)
5. activation and maintainability	- (P_{IONS} ~P_{PROTON}/100)
6. beam induced desorption	✓ (to be studied)

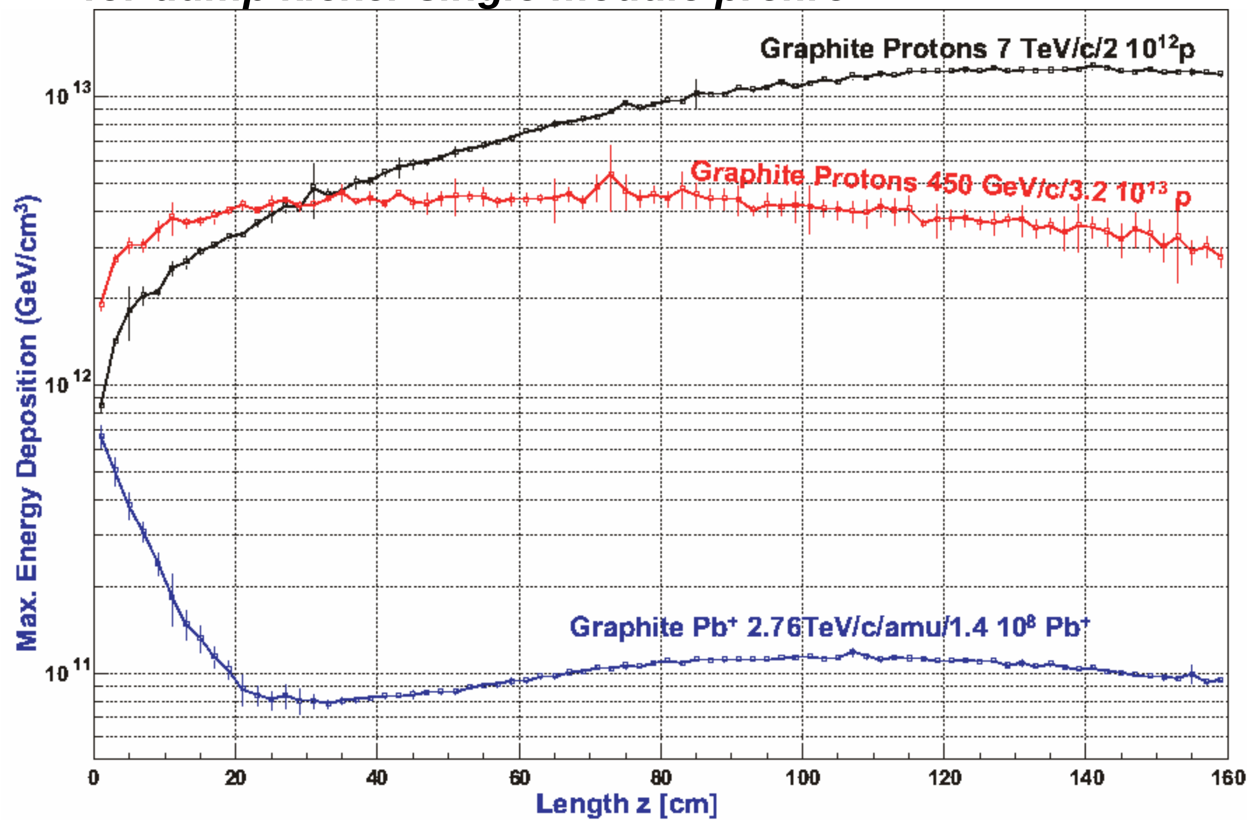
^{208}Pb-ion/matter interactions in comparison with proton/matter interactions.

(values are for particle impact on graphite)

Physics process	p injection	p collision	^{208}Pb injection	^{208}Pb collision
Ionisation energy loss $\frac{dE}{E\,dx}$	0.12 %/m	0.0088 %/m	9.57 %/m	0.73 %/m
Multiple scattering projected r.m.s. angle	$73.5 \mu rad/m^{1/2}$	$4.72 \mu rad/m^{1/2}$	$73.5 \mu rad/m^{1/2}$	$4.72 \mu rad/m^{1/2}$
Electron capture length	-	-	20 cm	312 cm
Electron stripping length	-	-	0.028 cm	0.018 cm
ECPP interaction length	-	-	24.5 cm	0.63 cm
Nuclear interaction length (incl. fragmentation)	38.1 cm	38.1 cm	2.5 cm	2.2 cm
Electromagnetic dissociation length	-	-	33.0 cm	19.0 cm

<u>**Robustness of collimator against mishaps**</u>

FLUKA calculations from Vasilis Vlachoudis
for dump kicker single module prefire



The higher Ionisation loss makes the energy deposition at the impact side almost equal to proton case, despite of 100 times less beam power

Computing tools for ILHC collimation

RELDIS &
ABRATION/ABLATION
(programs of Igor Pshenichnov)
generates cross section tables for fragmentation processes

LHC V6.4 optics files

MAD-X
generates twiss tables

ICOSIM
- **reads MAD-X twiss tables**
- **generates initial impact distribution on collimator**
- **simulates ion/matter interactions in collimator**
- **computes trajectories and impact sites of ions in LHC lattice**

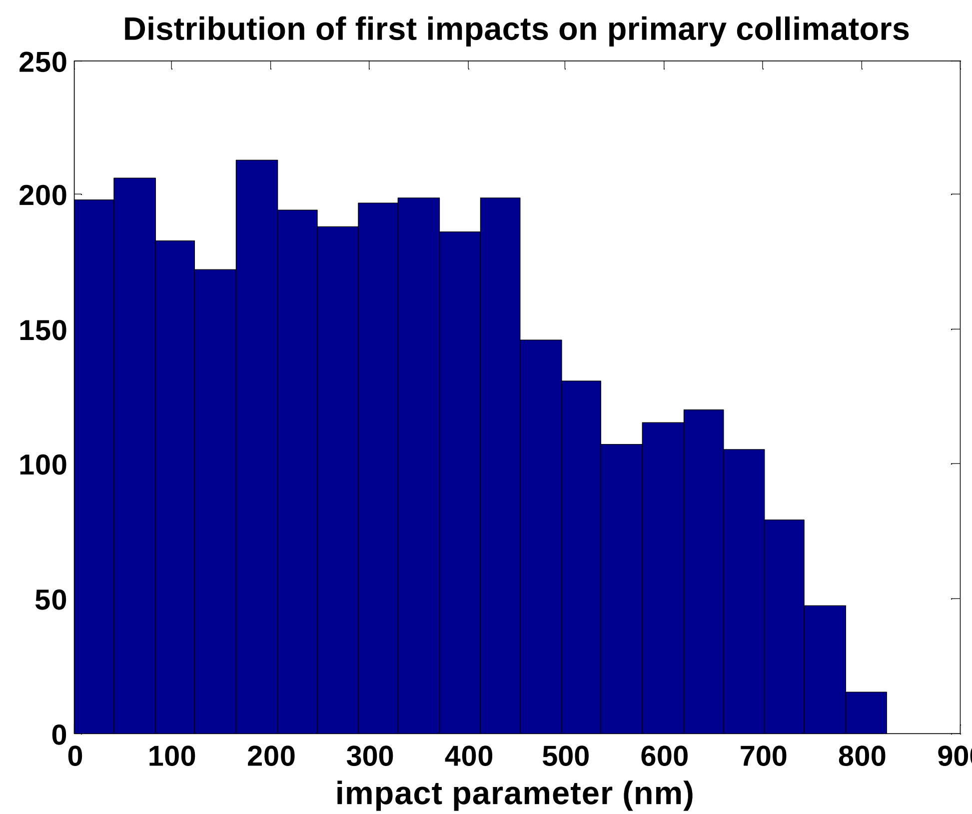
ICOSIM output
- **Loss patterns**
- **Collimation efficiencies**

Generation of first impact distribution in ICOSIM

1. **Randomly populated KV distribution in 4D with ϵ=36·ϵ_{NOM}**

2. **Linear tracking from TCP to TCP and around ring with slow increase of amplitude until all particles have hit a TCP.**

3. **Save first hit position of each particle for later tracking.**

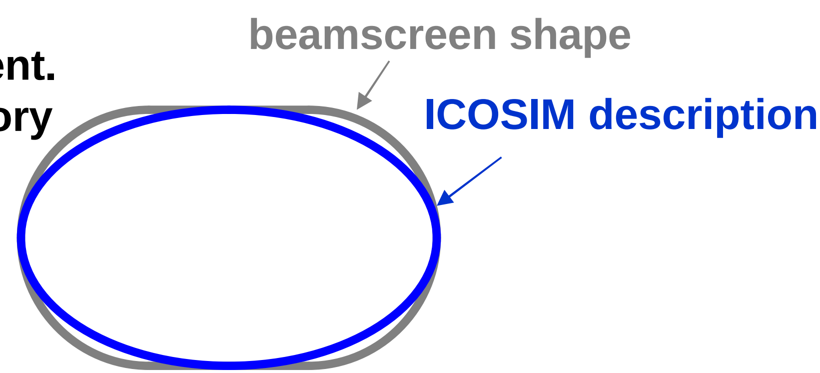


ICOSIM tracking

Problem:
to get decent statistics 10^5 particles have to be tracked for $\sim 10^2$ turns in a lattice with $\sim 10^4$ elements. Since the particle position has to be checked for chamber hits on each element particle coordinates have to be transformed element by element.
$\Rightarrow$ 10^{11} transforms and hit checks have to be computed.

Method:
Linear transfer matrix for X,X',Y,Y',ΔP/P
+
Chromaticity in quadrupoles to leading order.
Sextupoles in thin element kick approximation.
No acceleration (because $1/Q_S$ << 100).

Check for aperture hit at both ends of each element.
In case of hit condition =TRUE interpolate trajectory to find hit location
No backscattering assumed .
Aperture as described in V6.4 files, but simplified to elliptical shape



If element is of TCP or TCS type collimator transform treated by fragmentation code

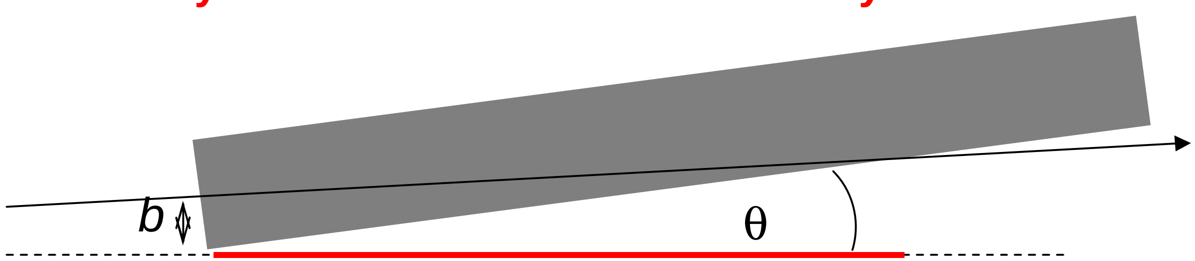
Collimator treatment in ICOSIM

Effects treated:

- **Bethe Bloch energy loss without straggling**
- **Multiple scattering in random gaussian approximation**
- **Fragmentation due to hadronic interaction in peripheral collisions**
- **Fragmentation due to electromagnetic dissociation in ultraperipheral collisions**

Fragmentation happens randomly along the particle path with probabilities computed from Igor Pshenichnov's cross section tables. If Fragment has Z<77 particle is assumed to be stopped in collimator (although in reality debris will go somewhat further). Effective path-length through collimator is determined at impact time.

Accuracy of fractional cross sections only ±50% !



$$L_{EFF} = \frac{b}{q - X'}$$

Rational for this simplification:

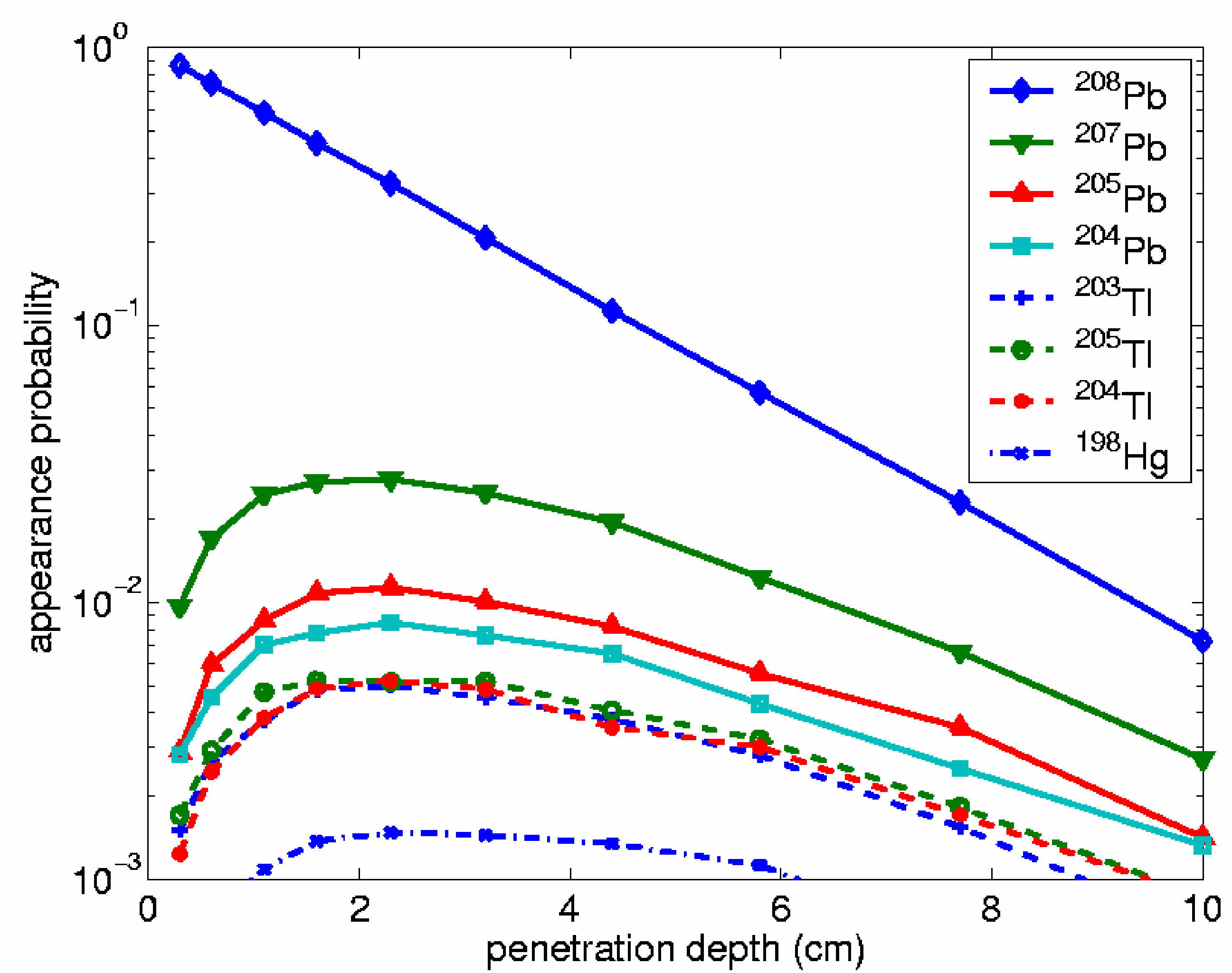
For 2 cm pathlength

θ_{MS} =0.6 μrad

θ_{FRAG}= 0.2 μrad

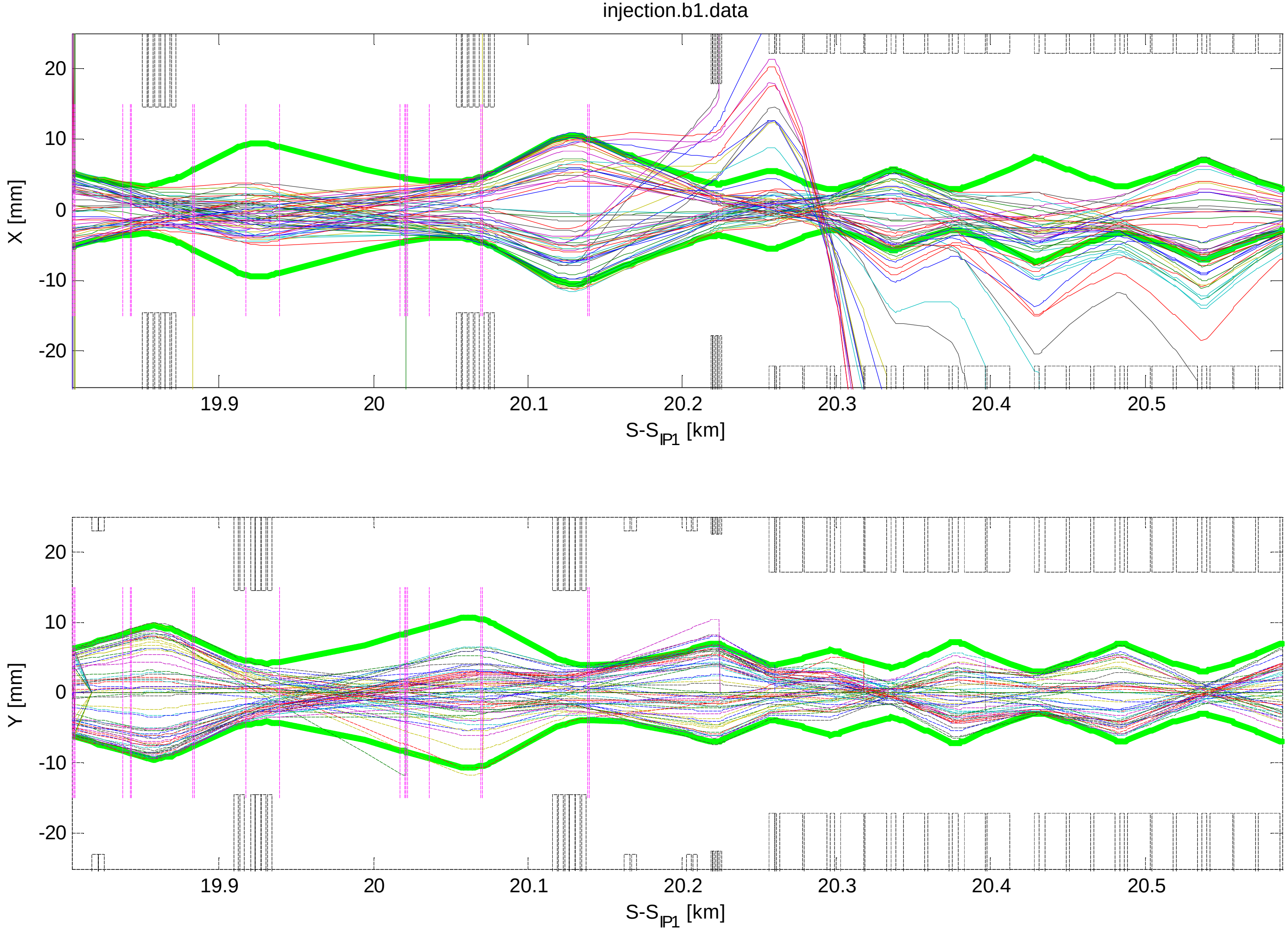
θ_{COLL}˜ 20 μrad

X'˜ 16 μrad

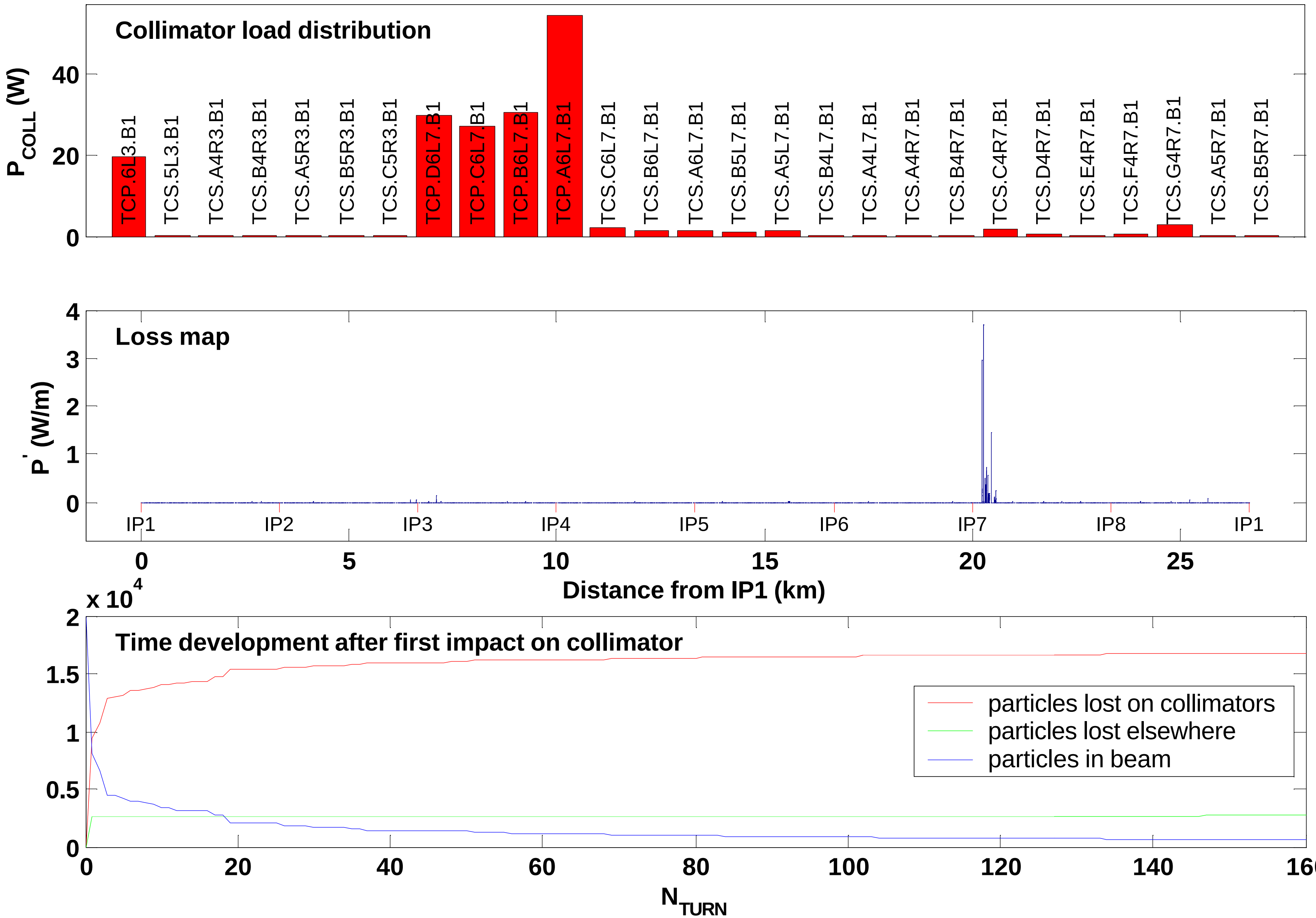


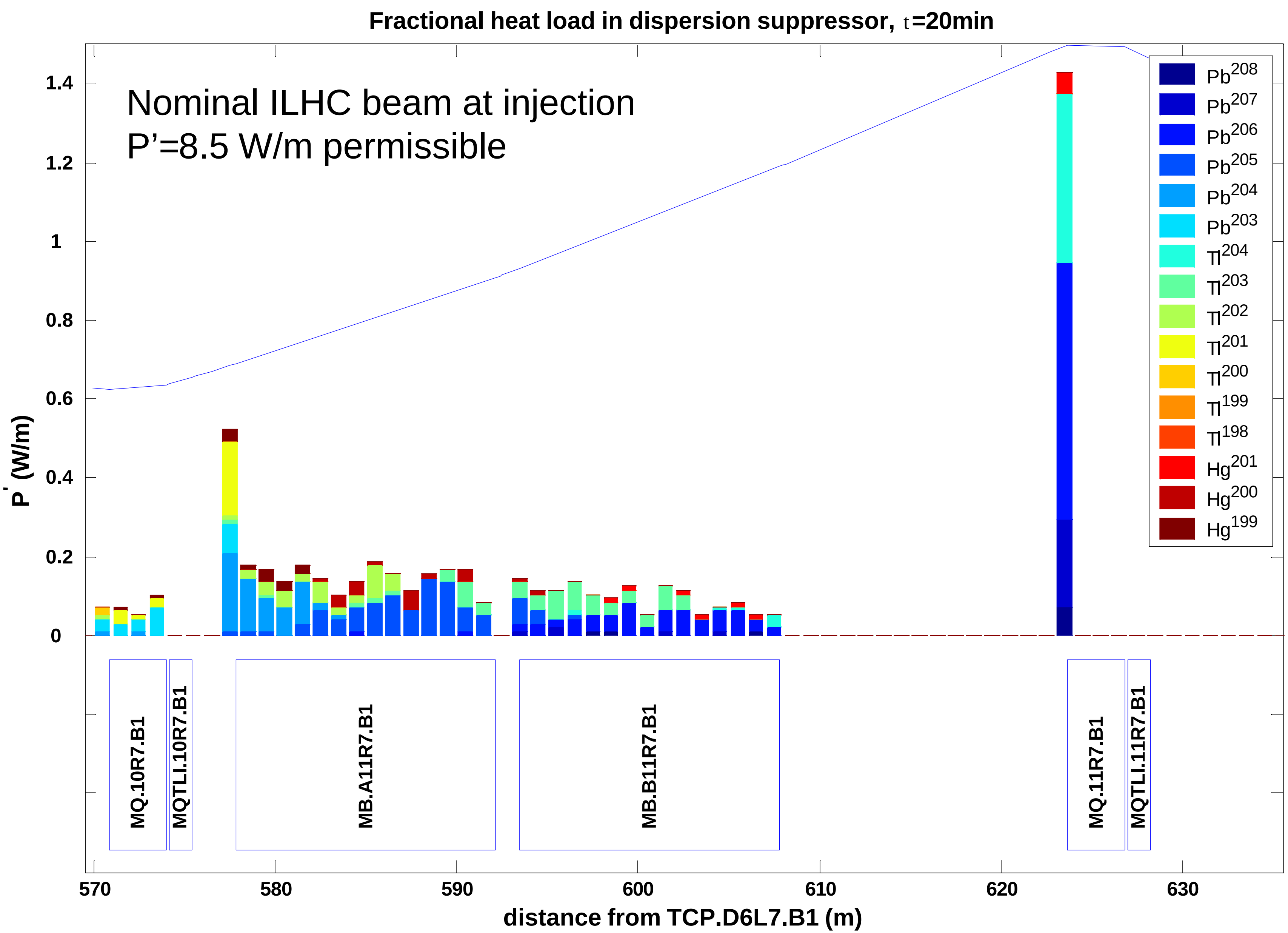
The probability to convert a ^{208}Pb nucleus into a neighboring nucleus.
The calculation is performed for ion impact on graphite at LHC collision energy

Trajectories around collimation in IR7 as computed by ICOSIM



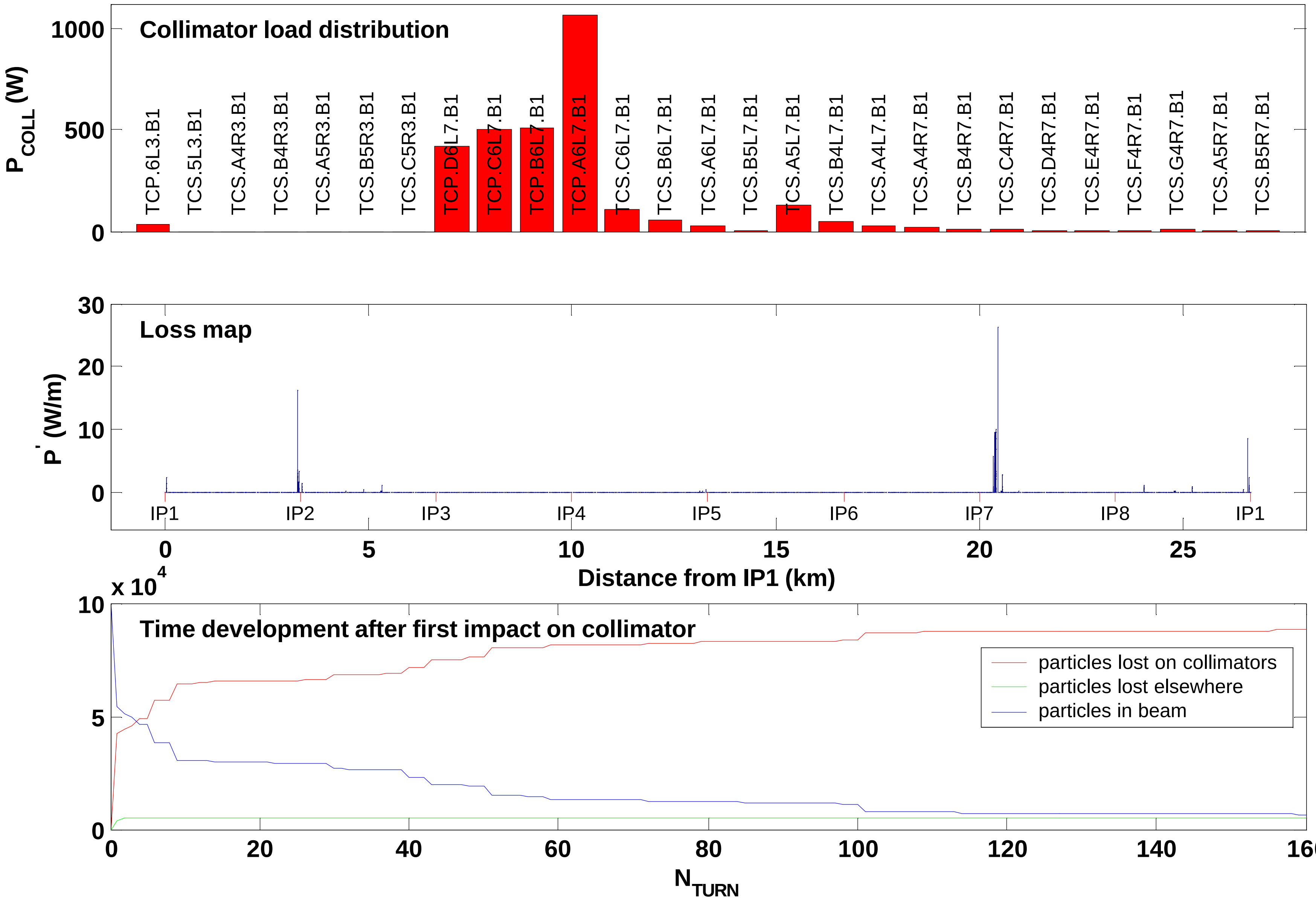
Nominal ILHC beam at injection



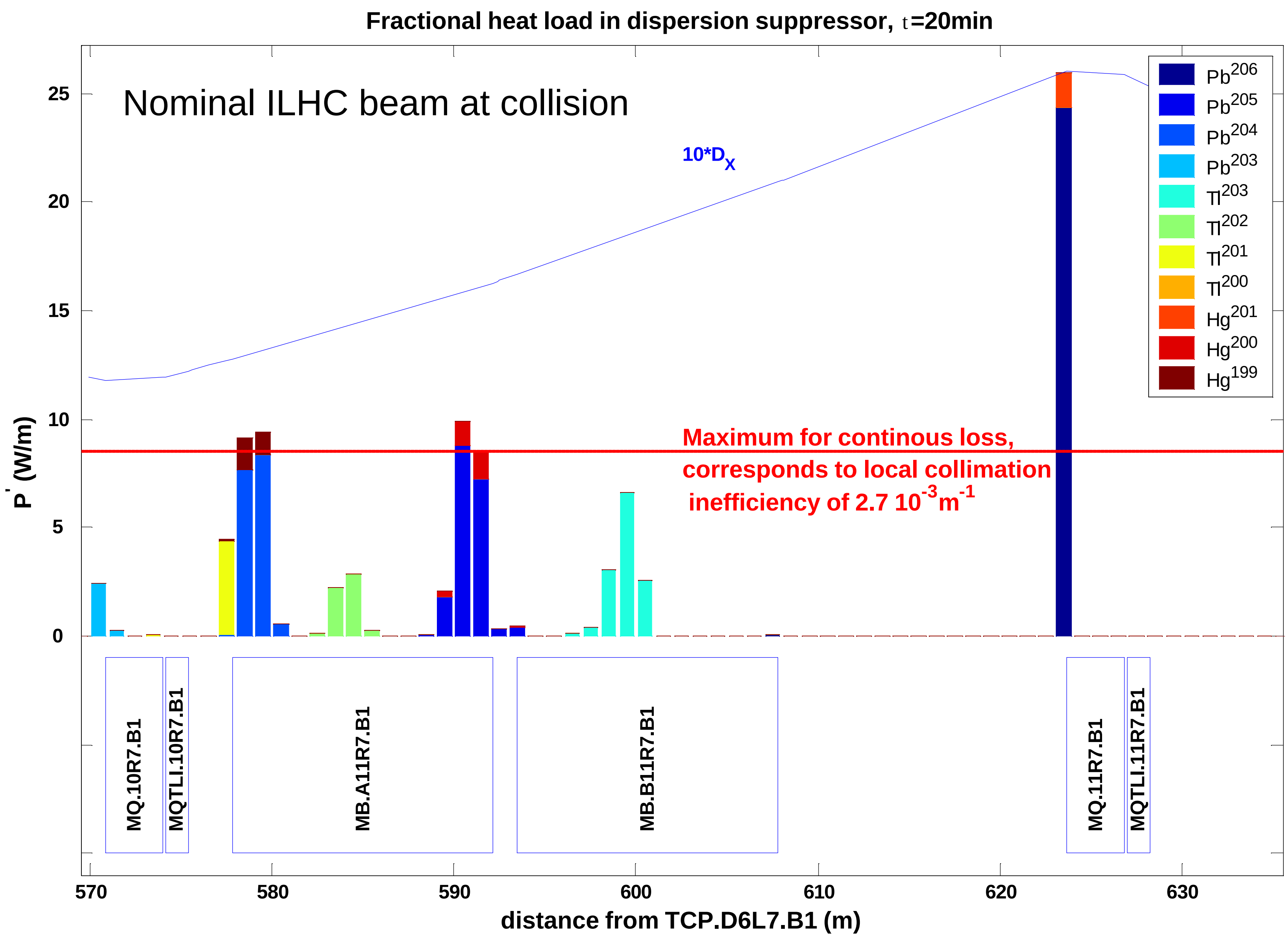


LHC collimation wg, 28 November 2003

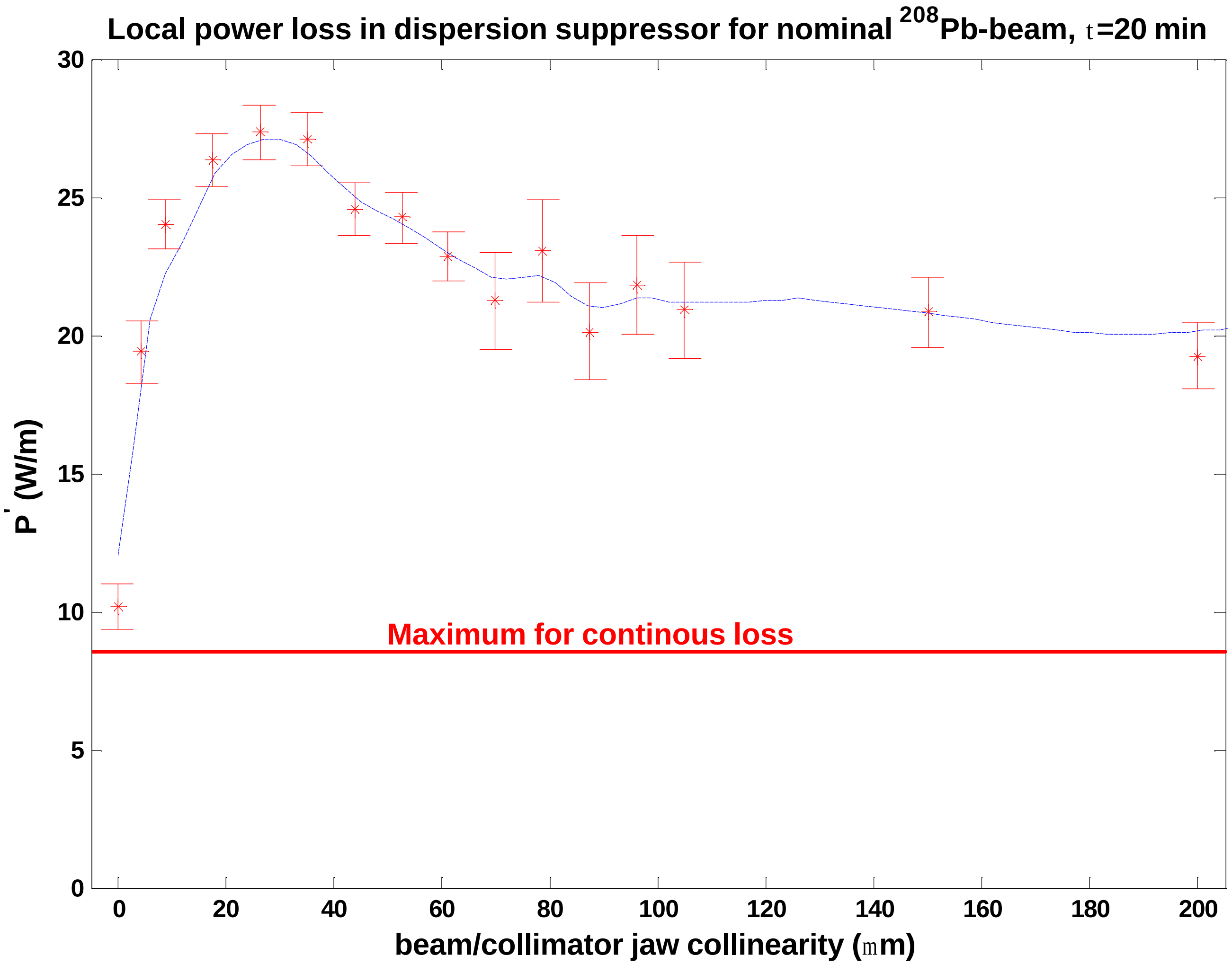
Nominal ILHC beam at collision



LHC collimation wg, 28 November 2003



LHC collimation wg, 28 November 2003


Local power loss in dispersion suppressor for nominal 208Pb-beam, t=20 min
30
25
20
15
10
5
0
P' (W/m)
Maximum for continous loss
0
20
40
60
80
100
120
140
160
180
200
beam/collimator jaw collinearity (mm)

Conclusions

- **Although beam power P_{Ions} ˜ 1/100 $P_{Protons}$ the damage potential on the impact face of the collimator is comparable for both beams, because relative energy loss due to ionisation is ˜ 100 times larger for ions.**

- **Principle of 2 stage collimation doesn’t work for ions in LHC**
  Collimation system acts almost like a single stage system.
  Þ **Poor collimation efficiency and significant particle losses in dispersion compressor.**
  As a consequence either lifetime* for nominal Ion parameters in collision has to be kept higher than the 20 min specified for protons or beam current has to be reduced.

- **Early Ion scheme seems to be ok**

- **Injection seems to be ok**

- **No obvious improvement path found so far.**

* lifetime due to non IP beam loss mechanism (IBS, resid. gas, orbit errors, ß beat…)

Potential further studies

- Redo simulations for new IR7 layout
- Improve physics model collimator (i.e. Gauss mult. scattering Þ Molière scattering)
- Improve aperture model in ICOSIM
- Try spoiler and/or very short TCP
- Different materials for TCP (however, almost excluded by damage potential see above)
- dA/dt of betatron motion due to residual gas scattering and IBS should be studied in more detail to get better estimates of collimator impact parameter distribution
- Layout with dispersion generating elements (but seems excluded for technical reasons)
- Momentum cleaning in IP3
- ?

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