The Collimation of the LHC Ion Beams

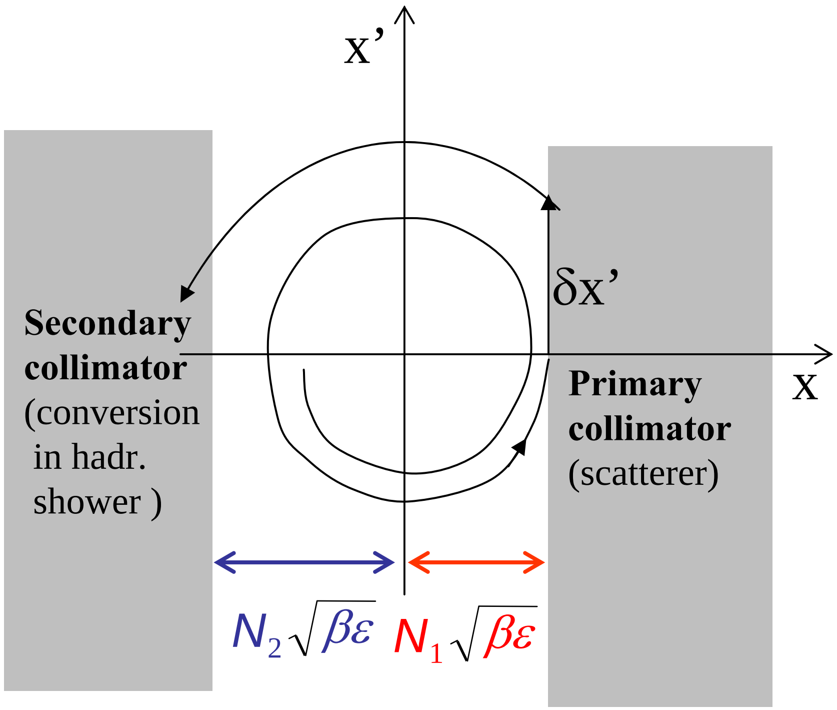
- Issues and non-issues for Ion collimation in LHC
- Ion-matter interactions
- Efficiency of collimation for ions
- Conclusions

Beam power of nominal LHC ion beam 100 times less than protons
So, why is heavy ion collimation in LHC an issue at all ?

Collider	Atomic number	Mass number	Energy / nucleon GeV/u	Circumference m	Number of Bunches	Number part. / Bunch 107	stored energy / beam MJ	instanteneous beam power GW
p-LHC	1	1	7000	26659	2808	11500	362.1	4075
I-LHC	82	208	2760	26659	592	7	3.8	43
I-LHC early scheme	82	208	2760	26659	62	7	0.4	4
p-HERA	1	1	920	6336	180	7000	1.9	88
TEVATRON	1	1	980	6280	36	24000	1.4	65
I-RHIC	79	183	99	3834	60	100	0.2	14
p-RHIC	1	1	230	3834	28	17000	0.2	14

Issues for p-LHC collimation	Issues for I-LHC as well ?
1. cleaning efficiency	✓
2. protection of magnets against 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 / vacuum degradation	**probably not**

Criteria for two stage betatron collimation



Necessary condition :

$$\delta x' > \sqrt{\frac{\left(N_2^{\ 2} - N_1^{\ 2}\right)\varepsilon_N}{\gamma_{REL.}\ \beta_{TWISS}}}$$

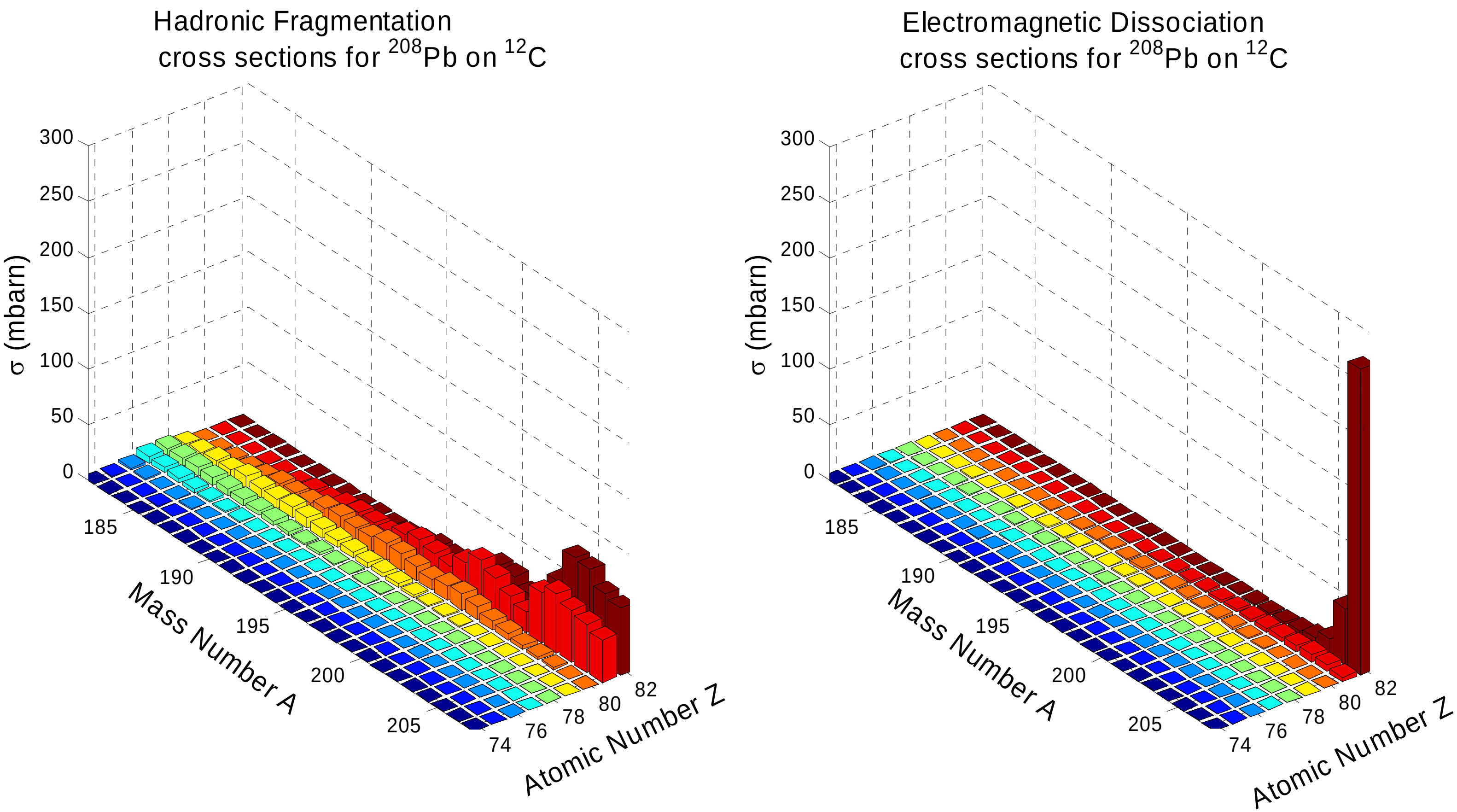
scattering at primary collimator $\delta x'$ is mainly due to multiple Coulomb scattering with

$\langle \delta x'^2 \rangle \sim L$

Ions on LHC collimators will be subject to nuclear reaction before sufficient scattering multiple is accumulated !

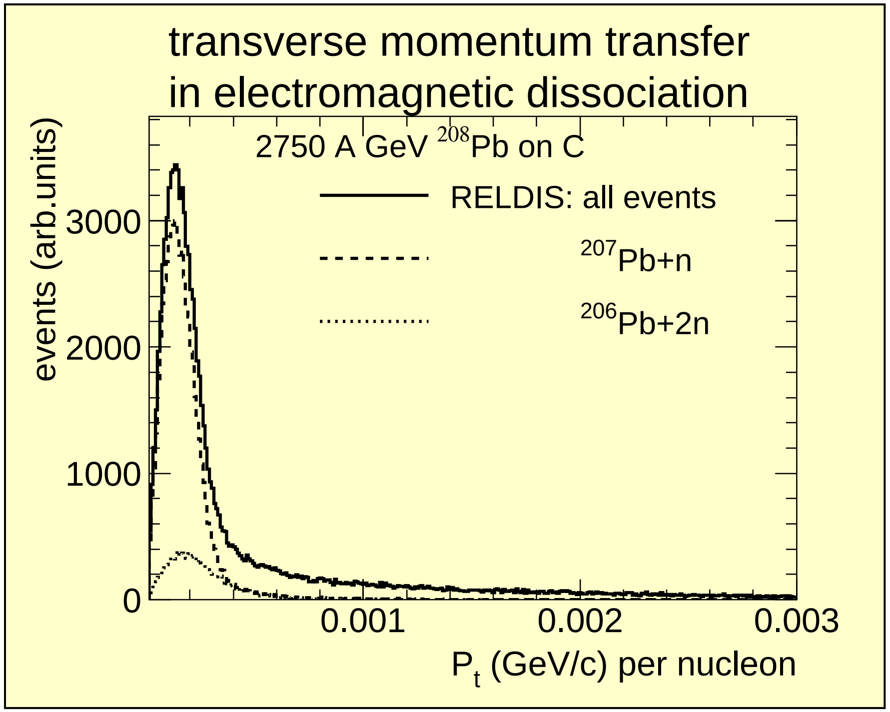
^{208}Pb-ion/matter interactions in comparison with proton/matter interactions.
(values are for particle impact on graphite)

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


Hadronic Fragmentation
cross sections for 208Pb on 12C
σ (mbarn)
300
250
200
150
100
50
0
185
190
195
200
205
Mass Number A
74
76
78
80
82
Atomic Number Z
Electromagnetic Dissociation
cross sections for 208Pb on 12C
σ (mbarn)
300
250
200
150
100
50
0
185
190
195
200
205
Mass Number A
74
76
78
80
82
Atomic Number Z

Nuclear fragmentation leads to a large variety of residual nuclei. Typical transverse momentum transferred order of 1 MeV/c/u, small compared to transverse momentum due to the beam emittance (~ 10 MeV/c/u)

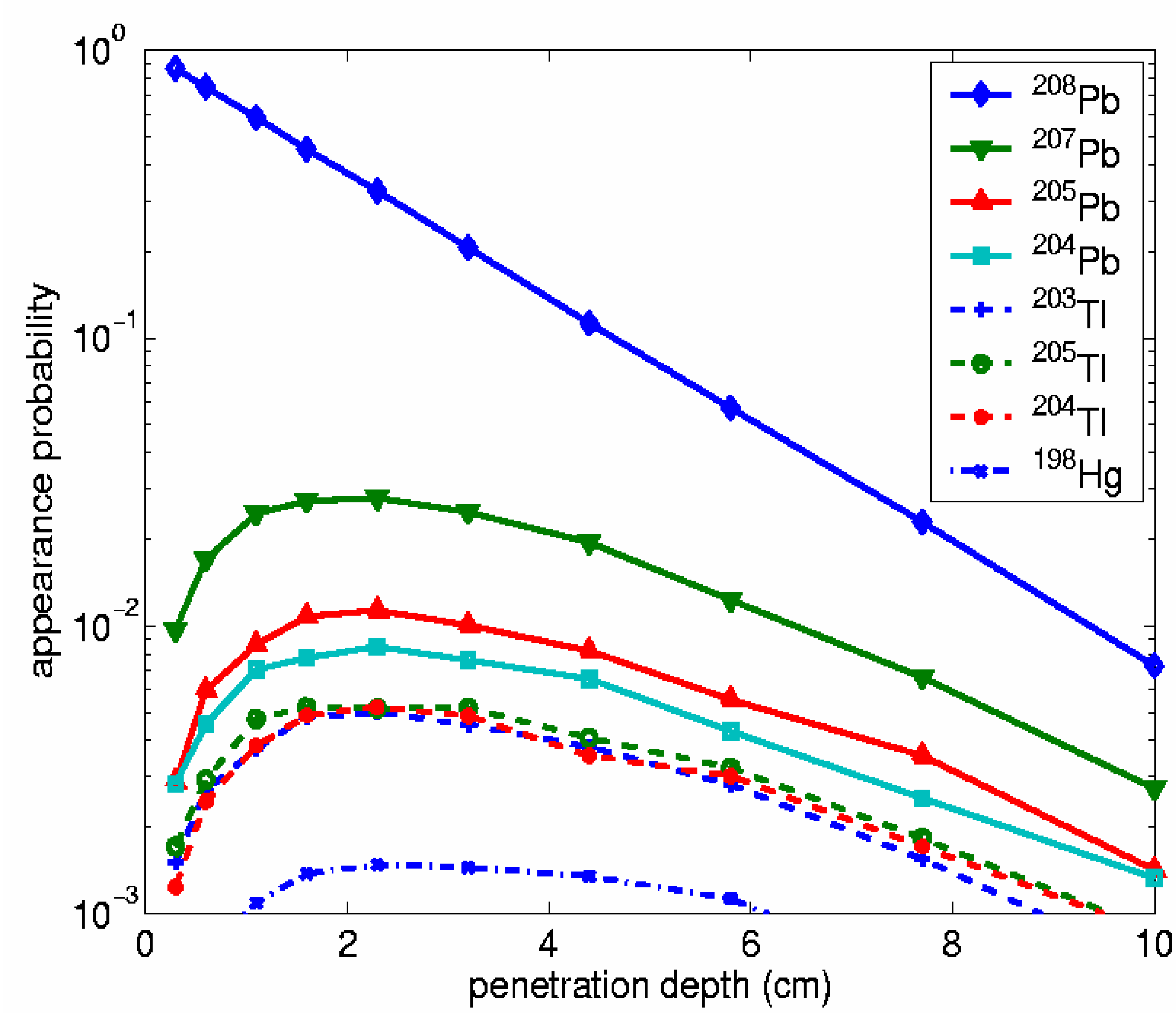
Electromagnetic dissociation leads predominantly to the loss of one neutron or two neutrons.
The transverse momentum transfer in electromagnetic dissociation is even smaller than in nucl. Fragmentation



First impacts of halo ions on primary collimators is usually grazing, small effective length of collimator.

→ high probability of conversion in neighbouring isotopes without change of momentum vector

→ **isotopes miss secondary collimator and are lost in downstream SC magnets because of wrong $B\rho$ value**



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

Computing tools for ILHC collimation

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

LHC optics files

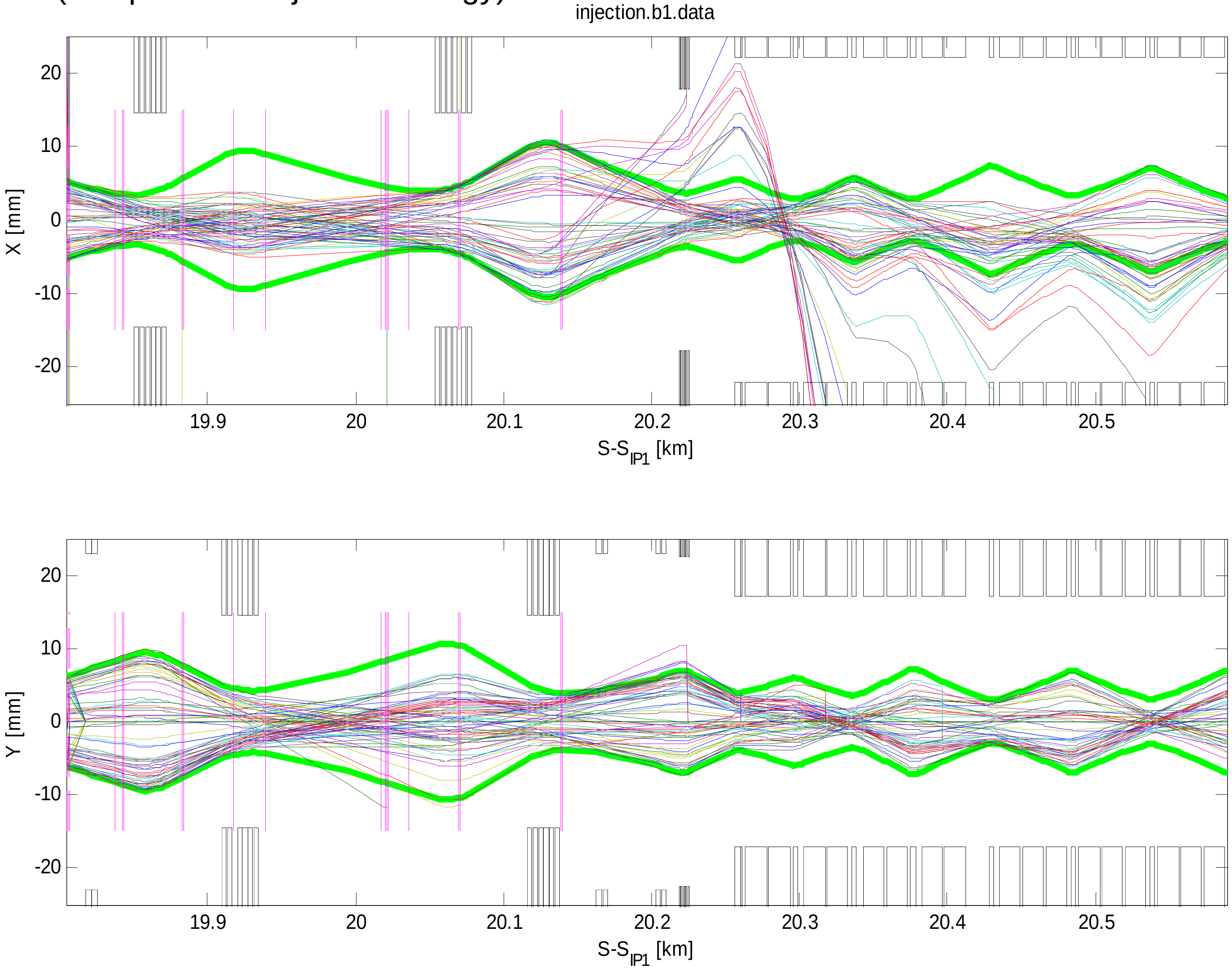
MAD-X
generates twiss function and aperture tables

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

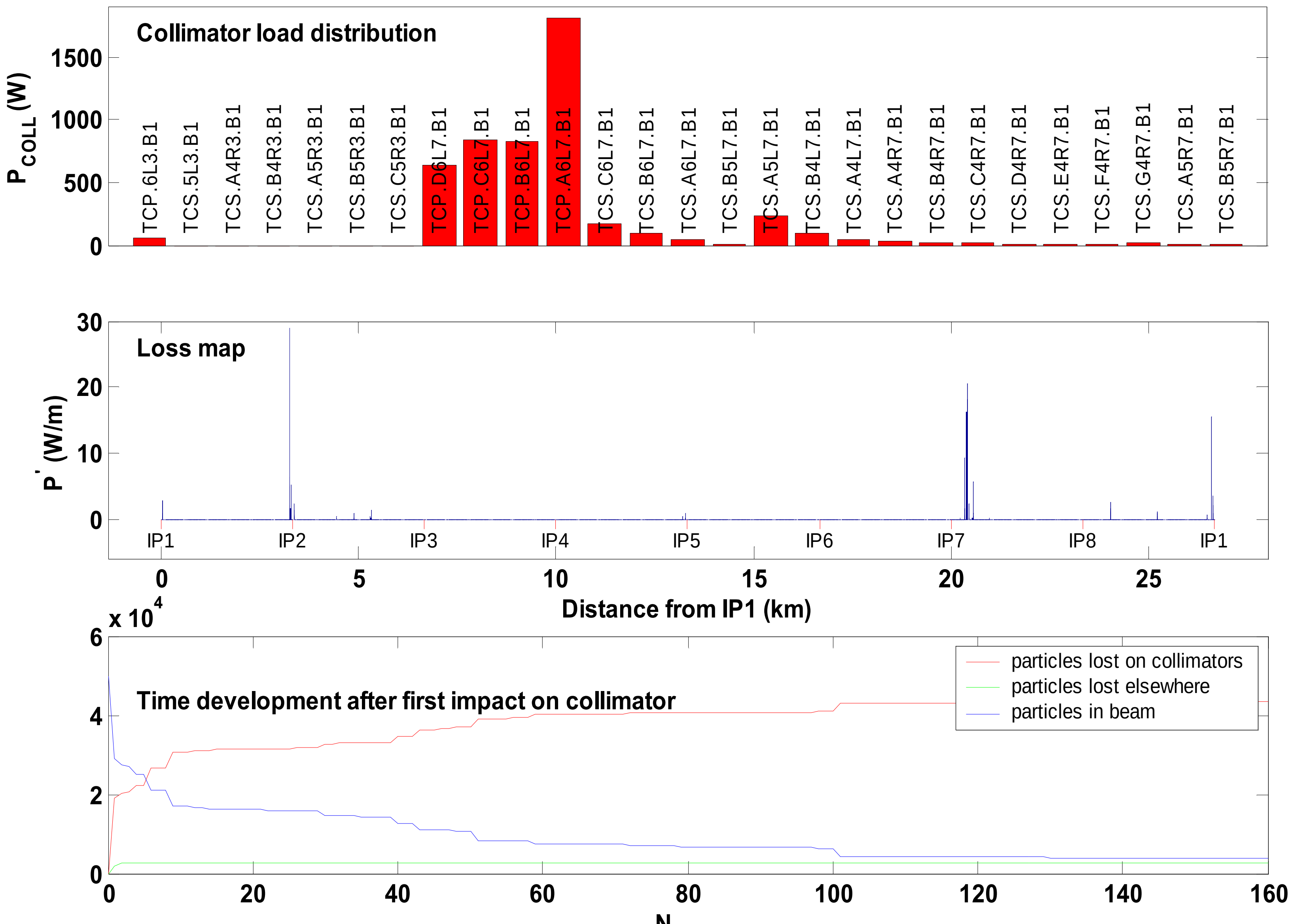
ICOSIM output
- **Loss patterns**
- **Collimation efficiencies**

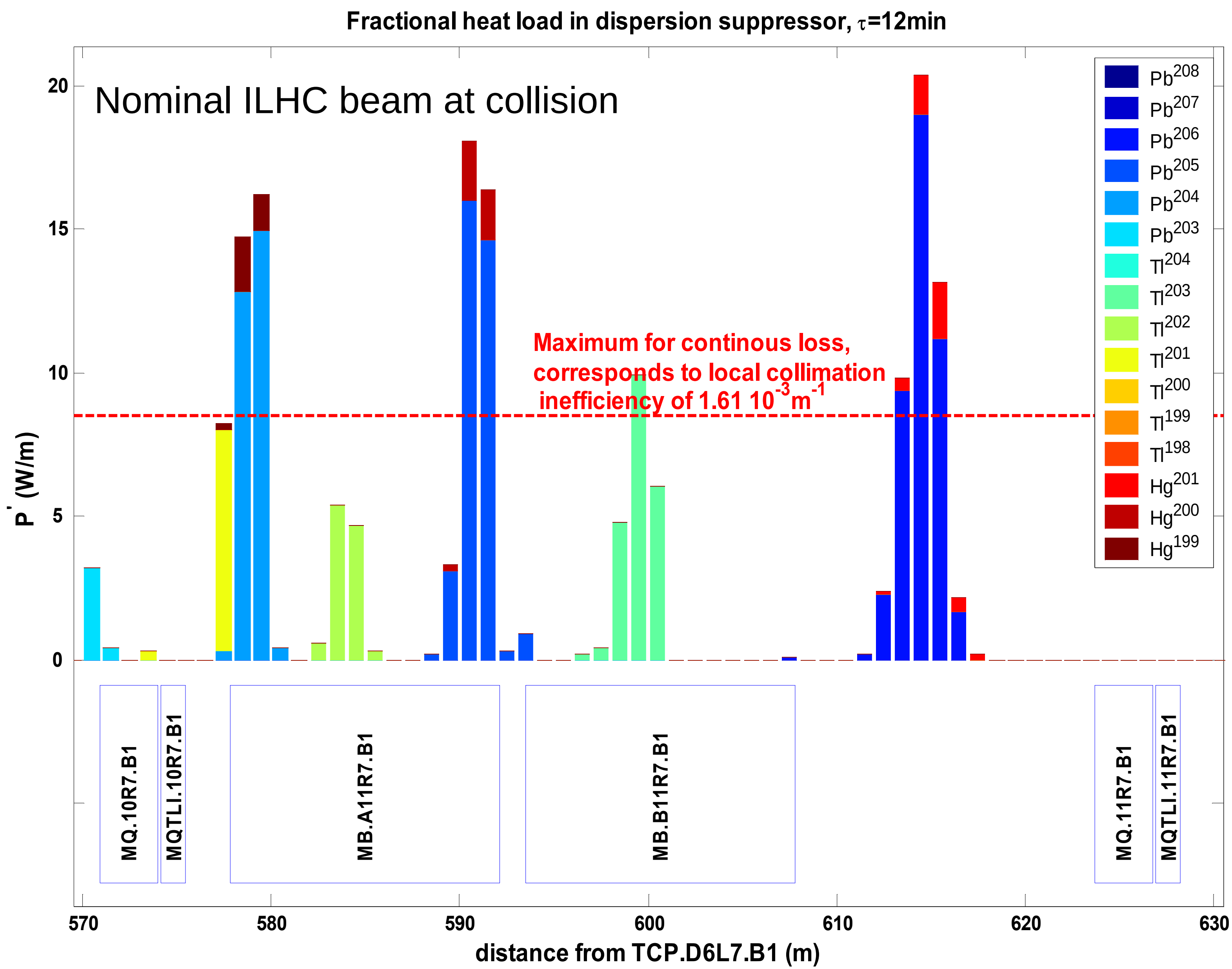
Trajectories around collimation in IR7 as computed by ICOSIM

(computed for injection energy)

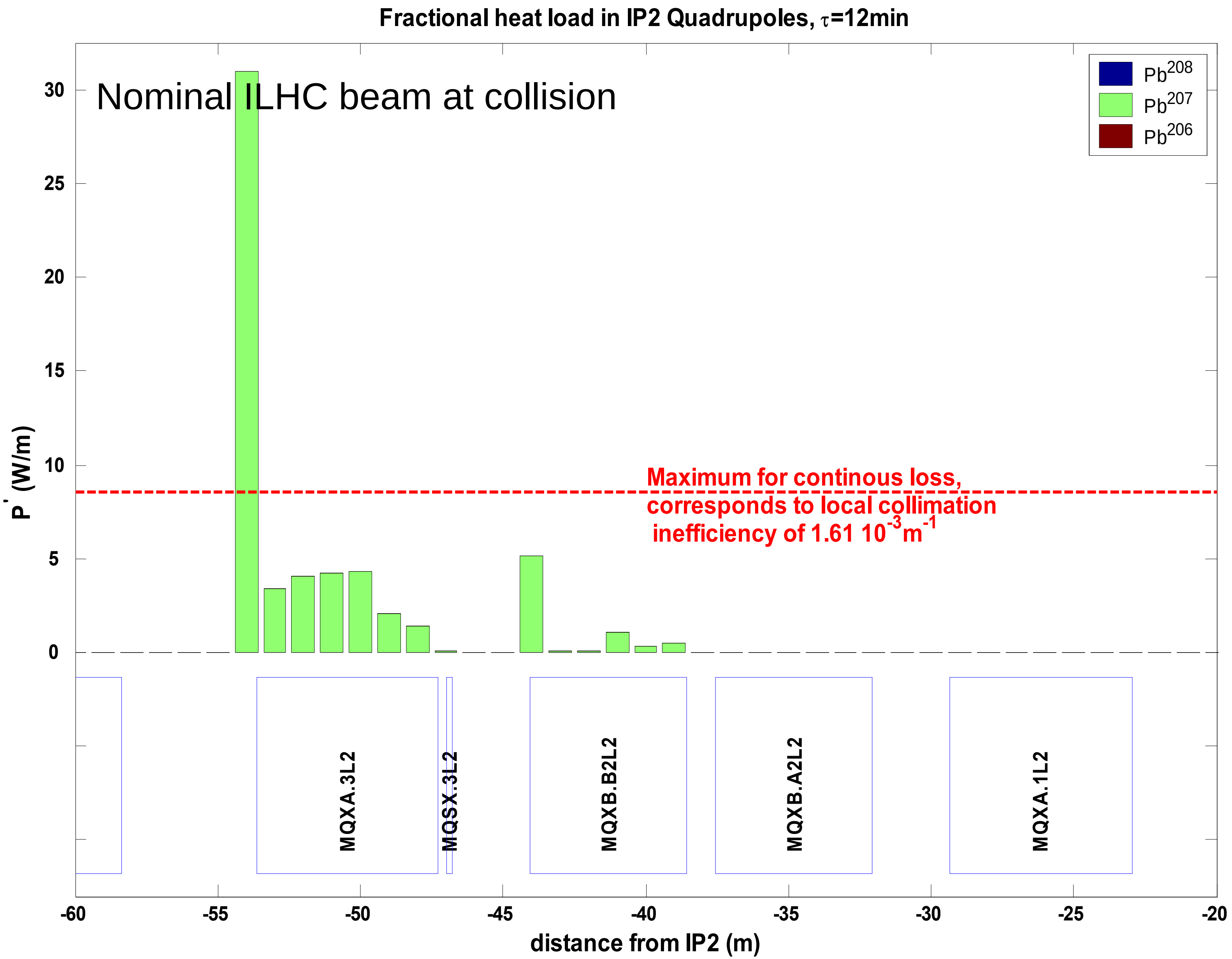


Nominal ILHC beam at collision

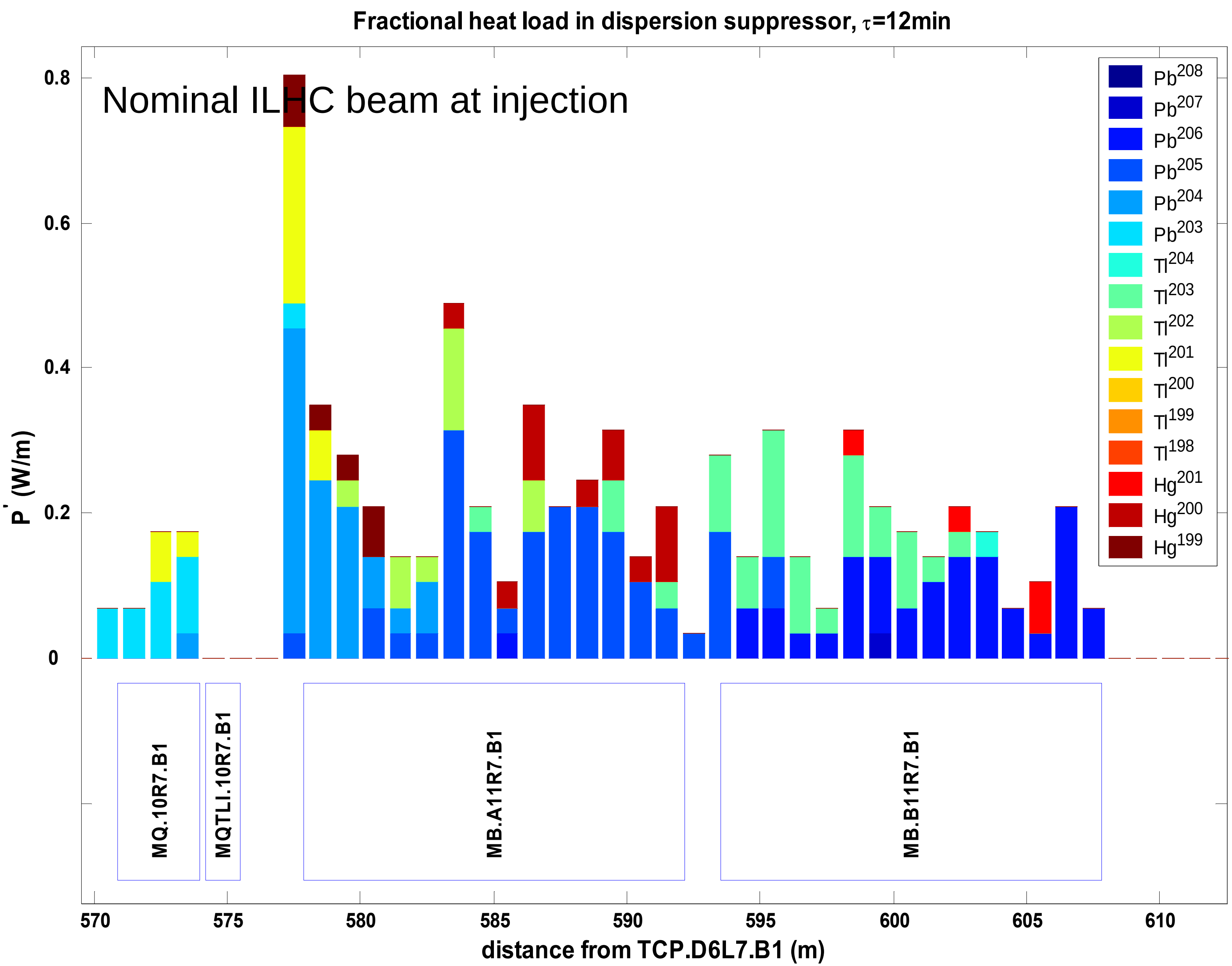


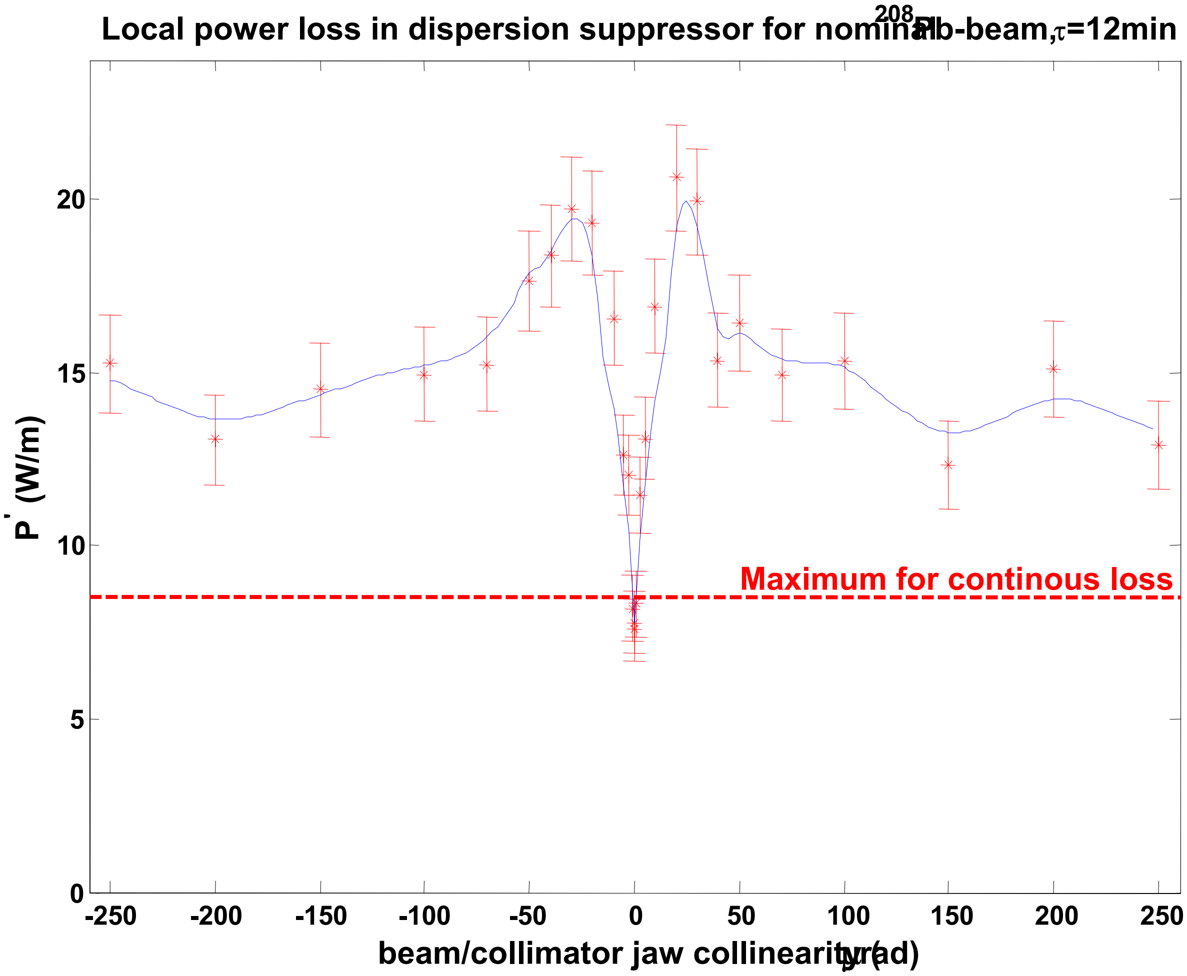


Fractional heat load in dispersion suppressor, τ=12min
Nominal ILHC beam at collision
Maximum for continous loss,
corresponds to local collimation
inefficiency of 1.61 10^-3 m^-1
P' (W/m)
distance from TCP.D6L7.B1 (m)
MQ.10R7.B1
MQTLI.10R7.B1
MB.A11R7.B1
MB.B11R7.B1
MQ.11R7.B1
MQTLI.11R7.B1
Pb208
Pb207
Pb206
Pb205
Pb204
Pb203
Tl204
Tl203
Tl202
Tl201
Tl200
Tl199
Tl198
Hg201
Hg200
Hg199



Fractional heat load in IP2 Quadrupoles, τ=12min
Nominal ILHC beam at collision
Pb208
Pb207
Pb206
Maximum for continous loss,
corresponds to local collimation
inefficiency of 1.61 10-3m-1
P' (W/m)
0
5
10
15
20
25
30
MQXA.3L2
MQSX.3L2
MQXB.B2L2
MQXB.A2L2
MQXA.1L2
-60
-55
-50
-45
-40
-35
-30
-25
-20
distance from IP2 (m)

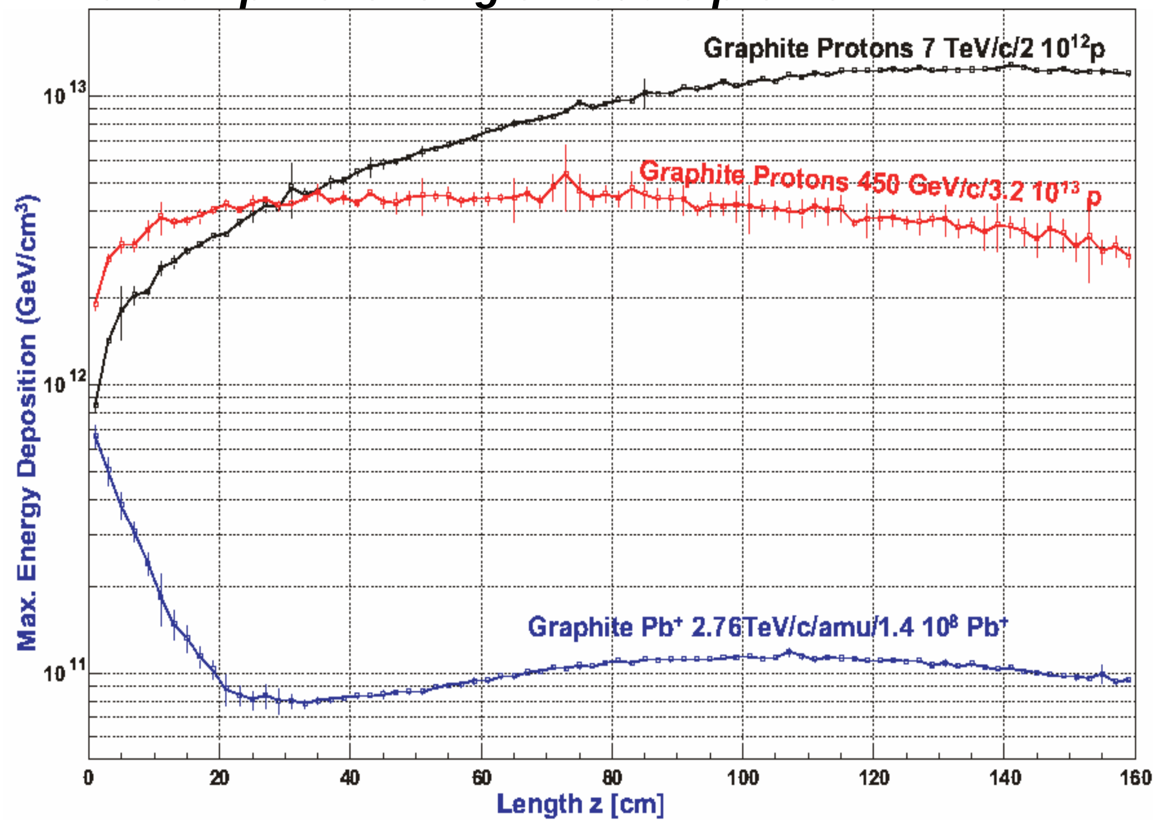

Fractional heat load in dispersion suppressor, τ=12min
Nominal ILHC beam at injection
P' (W/m)
0.8
0.6
0.4
0.2
0
Pb208
Pb207
Pb206
Pb205
Pb204
Pb203
Tl204
Tl203
Tl202
Tl201
Tl200
Tl199
Tl198
Hg201
Hg200
Hg199
MQ.10R7.B1
MQTLI.10R7.B1
MB.A11R7.B1
MB.B11R7.B1
570
575
580
585
590
595
600
605
610
distance from TCP.D6L7.B1 (m)



Local power loss in dispersion suppressor for nominal 208Pb-beam, τ=12min
P' (W/m)
20
15
10
5
0
-250
-200
-150
-100
-50
0
50
100
150
200
250
beam/collimator jaw collinearity (μrad)
Maximum for continous loss

Robustness of collimator against mishaps

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

Conclusions

- **Present 2 stage collimation of LHC gives insufficient protection of s.c. magnets against heavy ion fragments.**
  Collimation system acts almost like a single stage system.
  ⇒ particle losses in SC magnets exceeds permissible values by a factor ~2 for nominal ion beams

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

- **Injection seems to be ok**

- **Although 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.**

- **Error bars on loss map simulations are large because of uncertainties in dA/dt and fractional cross sections are considerable**

- **Presently the use of thin, high Z spoilers is under study, as potential improvement path. But no conclusive results by now.**

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