IMPACT PARAMETERS ON LHC COLLIMATOR FOR DIFFERENT ADT SETTINGS

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many thanks to:

W. Hofle, D. Valuch, R. Bruce, S. Redaelli (CERN)

G. Stancari, A. Valishev (FNAL)

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THE TRANSVERSE FEEDBACK SYSTEM

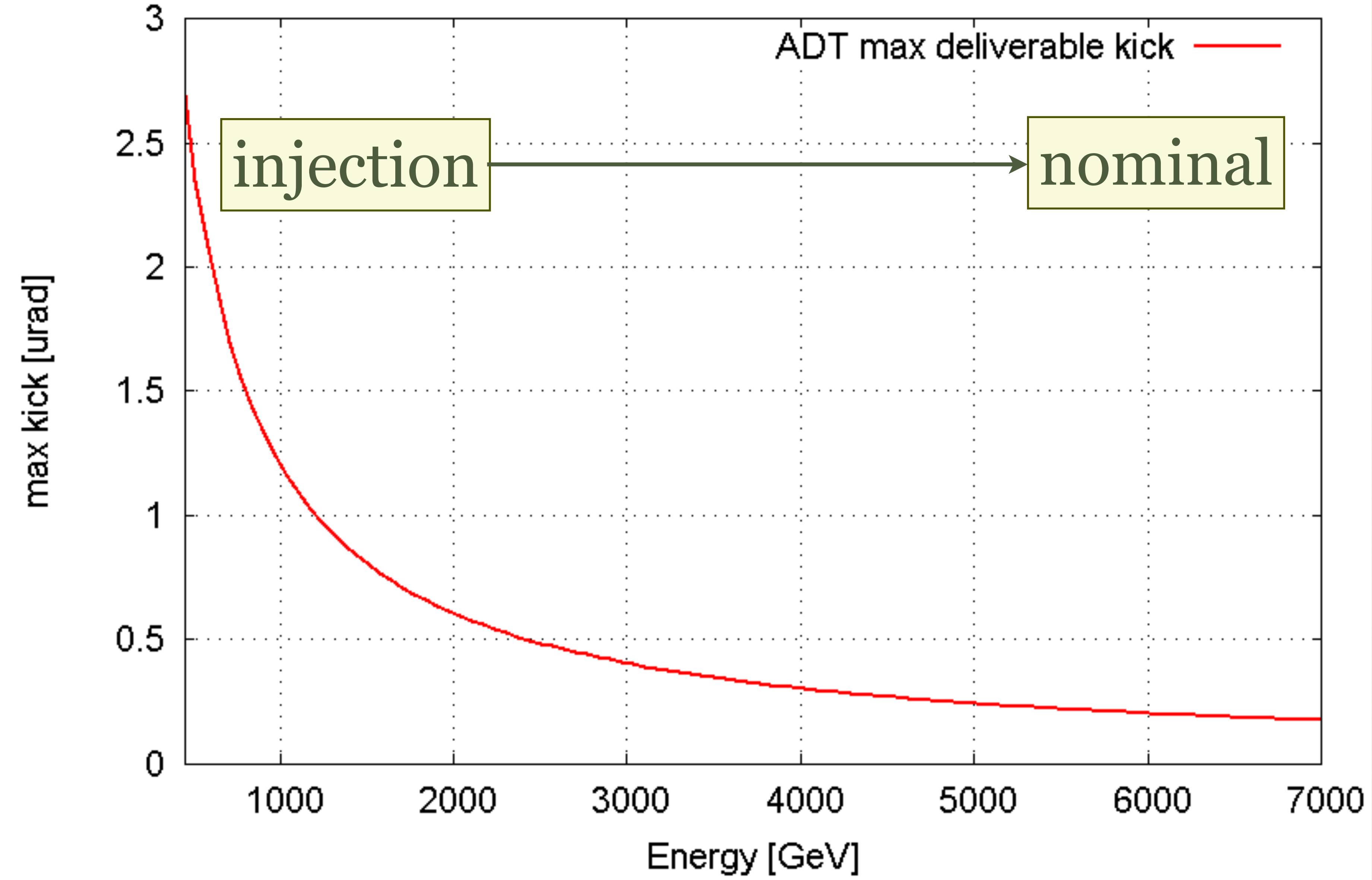
- The transverse feedback system for the LHC comprises a total of four damper systems, one per beam and plane. Each system is equipped with four kickers, whose plates are 1.5 m long with an aperture of d = 52 mm. The maximum voltage difference is V = 10.5 kV . The maximum kick for each kicker can be calculated as:

$$k_M = \frac{V \cdot L}{d} \cdot \frac{1}{E}$$

where L is the plate length and E is the particle energy.

THE TRANSVERSE FEEDBACK SYSTEM

SAME VOLTAGE, DIFFERENT KICKS...

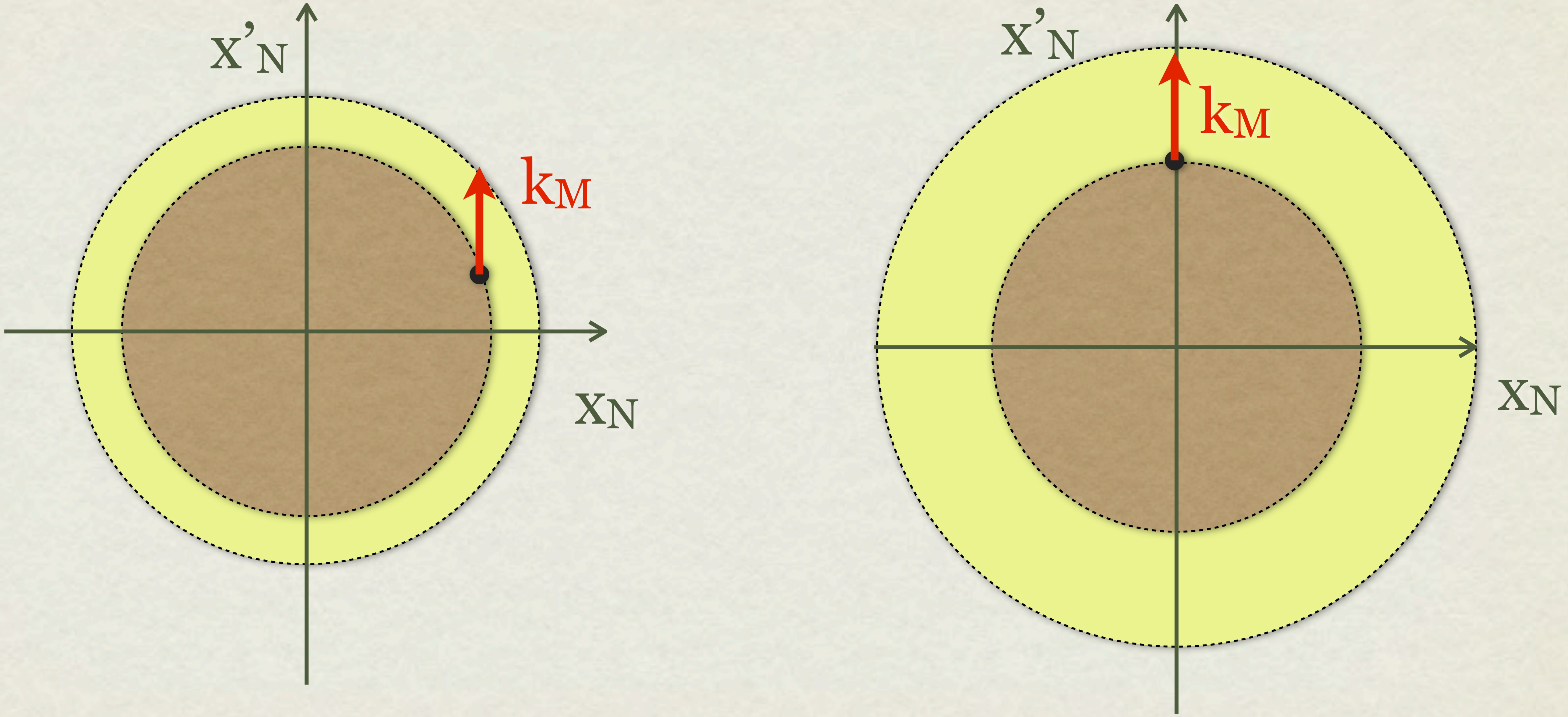


- the maximum kick delivered by the whole system per turn depends on the beam rigidity. It goes from 2.7 μrad at 450 GeV to about 0.2 μrad at the nominal 7 TeV energy.

THE TRANSVERSE FEEDBACK SYSTEM

SAME VOLTAGE, DIFFERENT KICKS...

... SAME KICK, DIFFERENT AMPLITUDE CHANGES...



- The single particle emittance growth depends on the particle position. *Maximum amplitude increase in achieved when φ=90*

THE TRANSVERSE FEEDBACK SYSTEM

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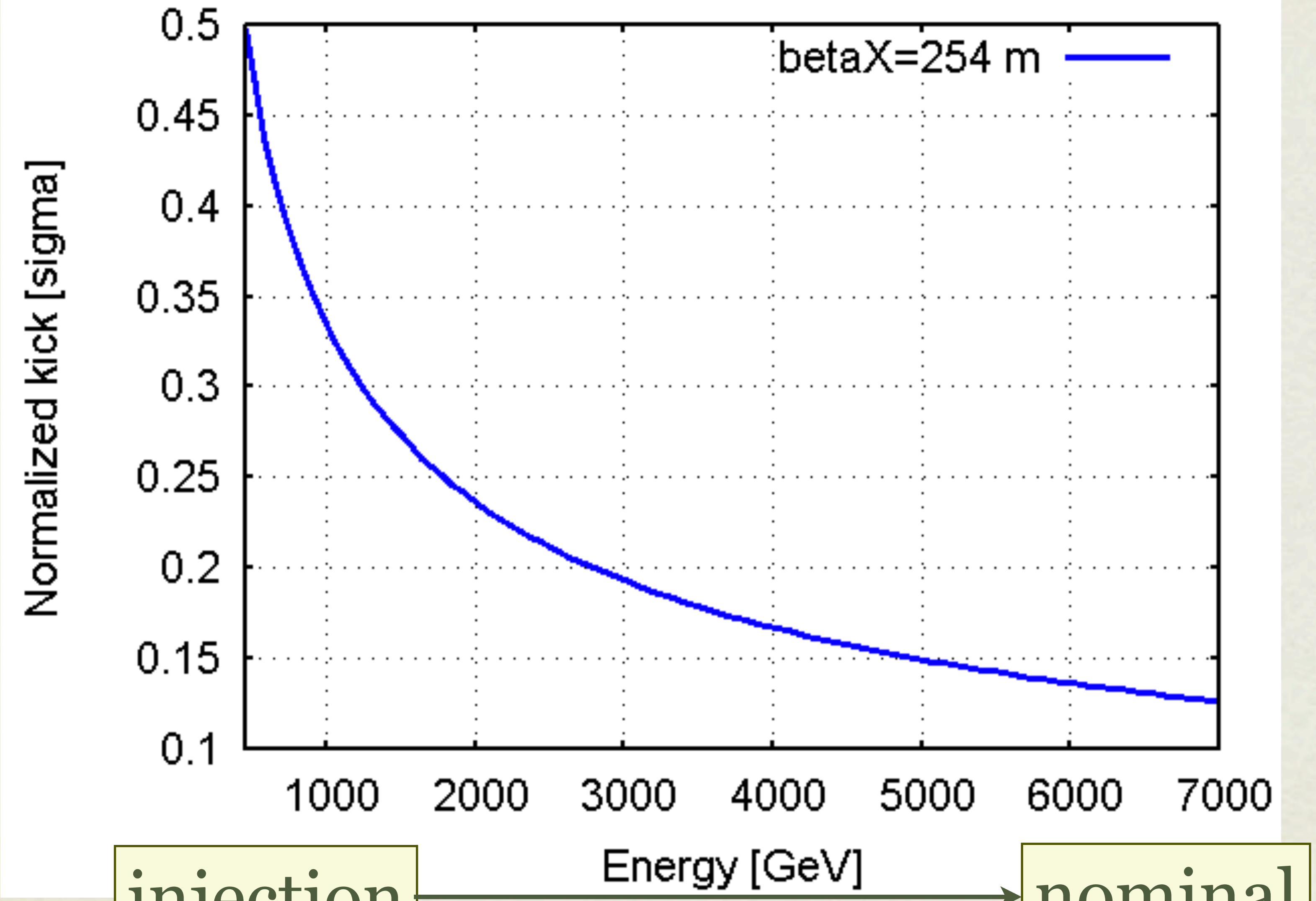
... SAME KICK, DIFFERENT AMPLITUDE CHANGES...



injection → nominal

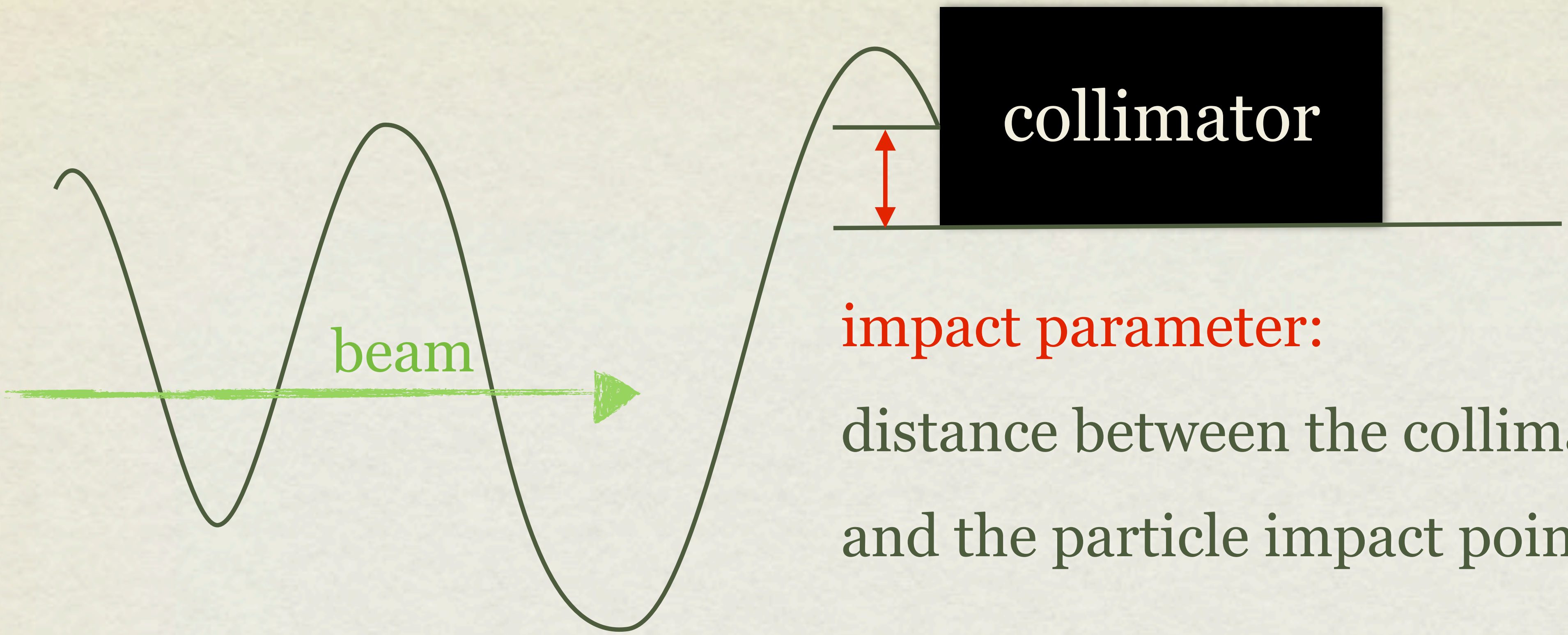
Taking the average β_x at the ADT location (~255 m) and a normalized emittance of 3.5 μ rad, the *maximum* kick provided by the ADT goes from 0.5 σ_x (at injection) to 0.12 σ_x (at nominal 7 TeV)

THE TRANSVERSE ~~FEEDBACK~~ SYSTEM

ADT FOR COLLIMATION STUDIES

- In order to validate the collimation system, loss maps are generated
- It is important for the system validation to study the horizontal and vertical collimation, disentangled
- The kickers are used to selectively blow up the horizontal or the vertical dimension of the halo
- To achieve a reproducible blow-up of the beam a broad- band excitation is used: with this method the output spectrum is sufficiently flat with frequency and represents a white spectrum.

WHY IMPACT PARAMETER?



impact parameter:

distance between the collimator edge

and the particle impact point

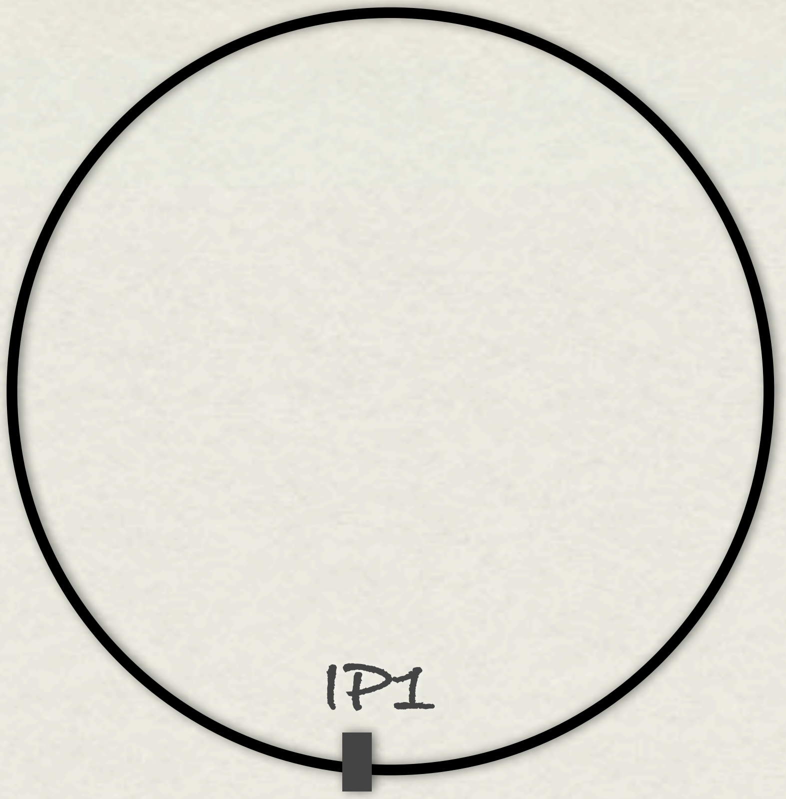
- by blowing the beam up, we increase the impact parameter of particles on collimation. (but we do not know how much)
- it has been questioned if the loss maps measure with enhanced impact parameter are representative of the behavior of the LHC collimation system during operational losses.
- A dedicated code was developed to quantify the impact parameter change, and possibly to use the results as an input for more detailed simulations

“FICO” SIMULATIONS

FICo: First Impact Code

The LHC

very few elements (3) populate this model



In IP1 particles are generated in the normalized space, and, **at each turn, the synchrotron phases are updated** according to a linear oscillation model with appropriate synchrotron frequency.

The code performs a normalized phase space analysis that utilizes the horizontal Twiss functions and phase advances to map the passage of each particle at the four ADT kickers and at the horizontal primary collimator in IP7 (TCP).

“FICO” SIMULATIONS

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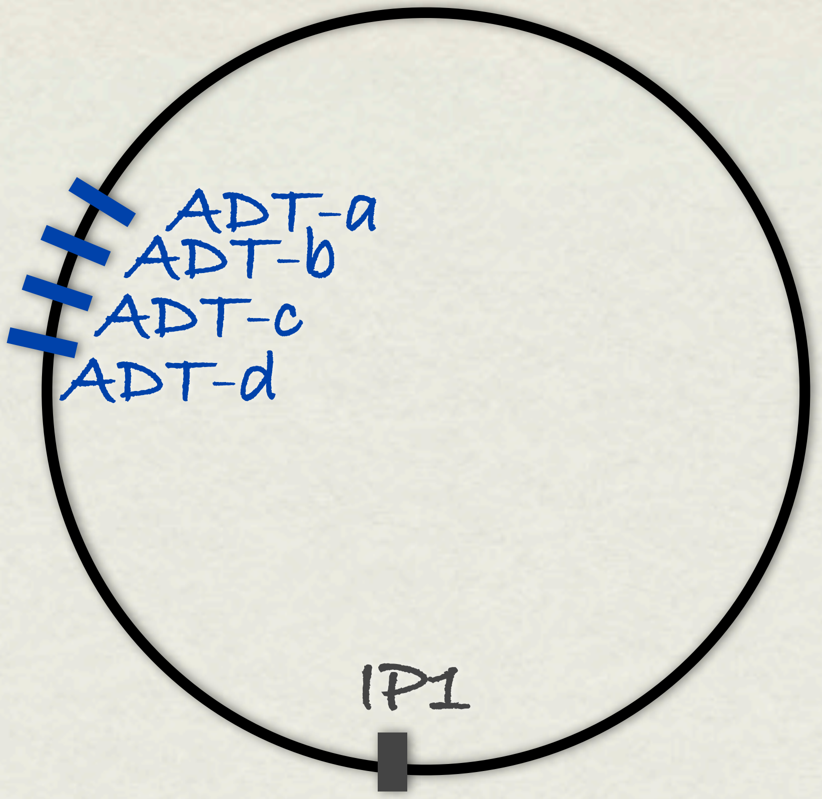
For each passage from the damper kickers, each particle receives a random **normalized kick** in the range $[-g\,kM\sqrt{\beta/\varepsilon}\ :\ g\,kM\sqrt{\beta/\varepsilon}]$ where β is the twiss fnct, ε is the physical emittance, kM is the maximum deliverable kick, and g is the **amplifier gain** which, in our simulations, can be set in the range [0 : 1]



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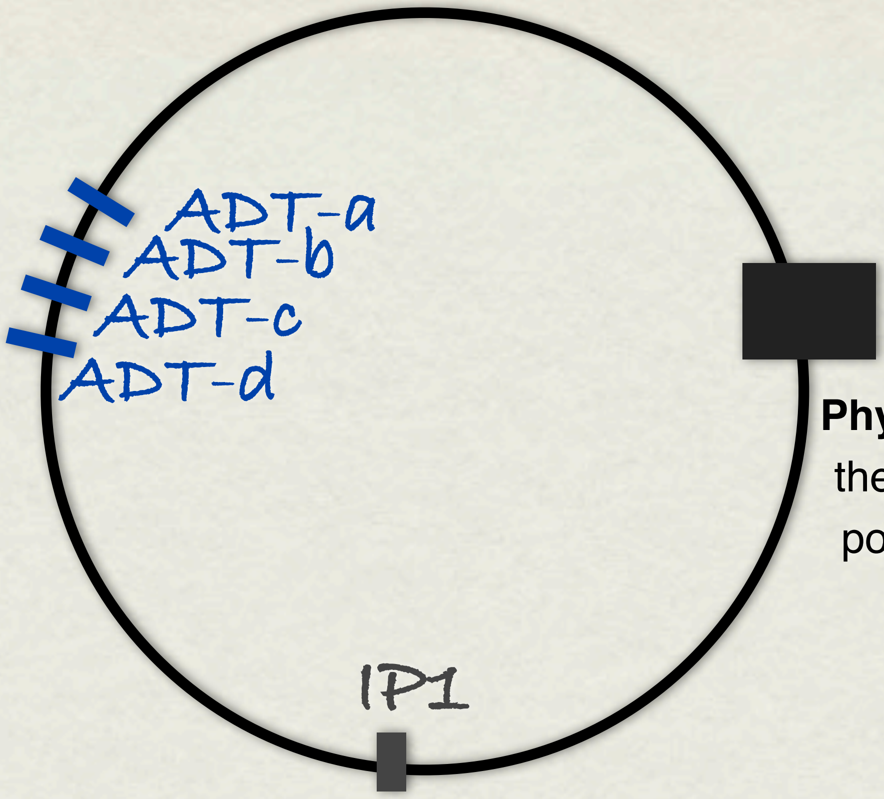

Collimator

Physical coordinates are calculated (through the **optics functions α,β,D**); if the transverse position is larger than the collimator aperture, then particle is removed from simulation. **The TCP is treated as a black absorber.**

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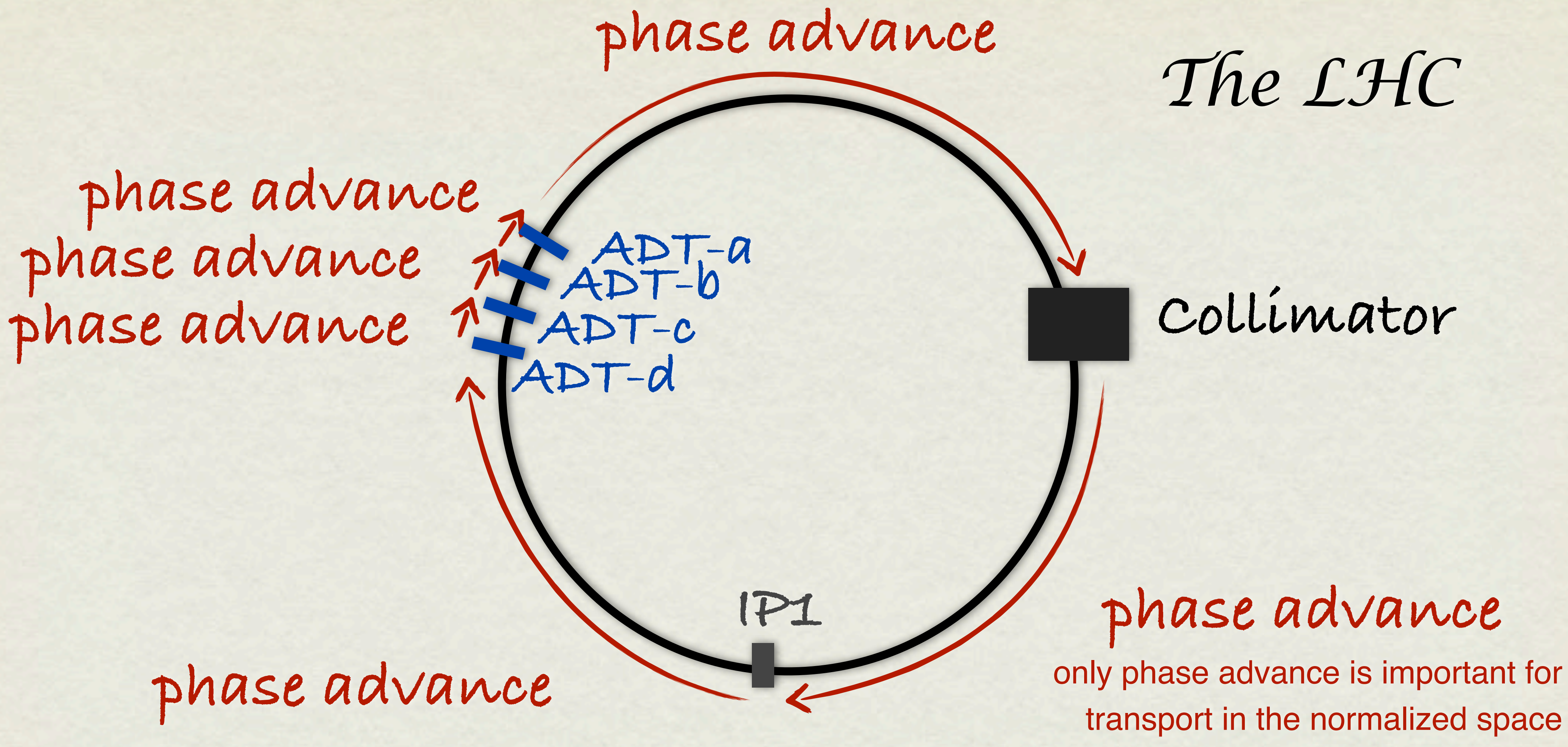


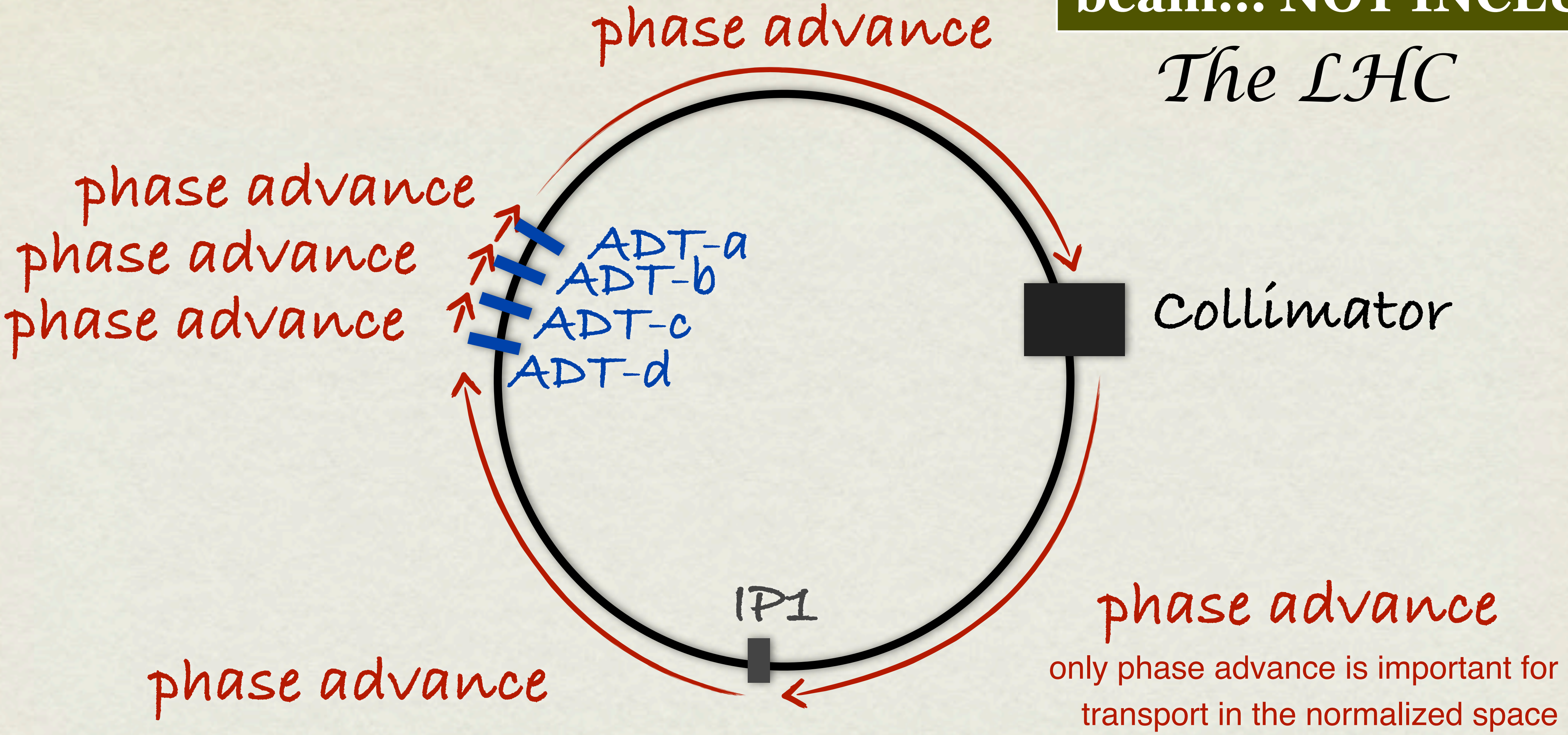
only phase advance is important for transport in the normalized space

The code performs a normalized phase space analysis that utilizes the horizontal Twiss functions and phase advances to map the passage of each particle at the four ADT kickers and at the horizontal primary collimator in IP7 (TCP).

“FICO” SIMULATIONS

non linearities such as sextupoles, octupoles, multiple errors, beam beam... NOT INCLUDED

FICo: First Impact Code



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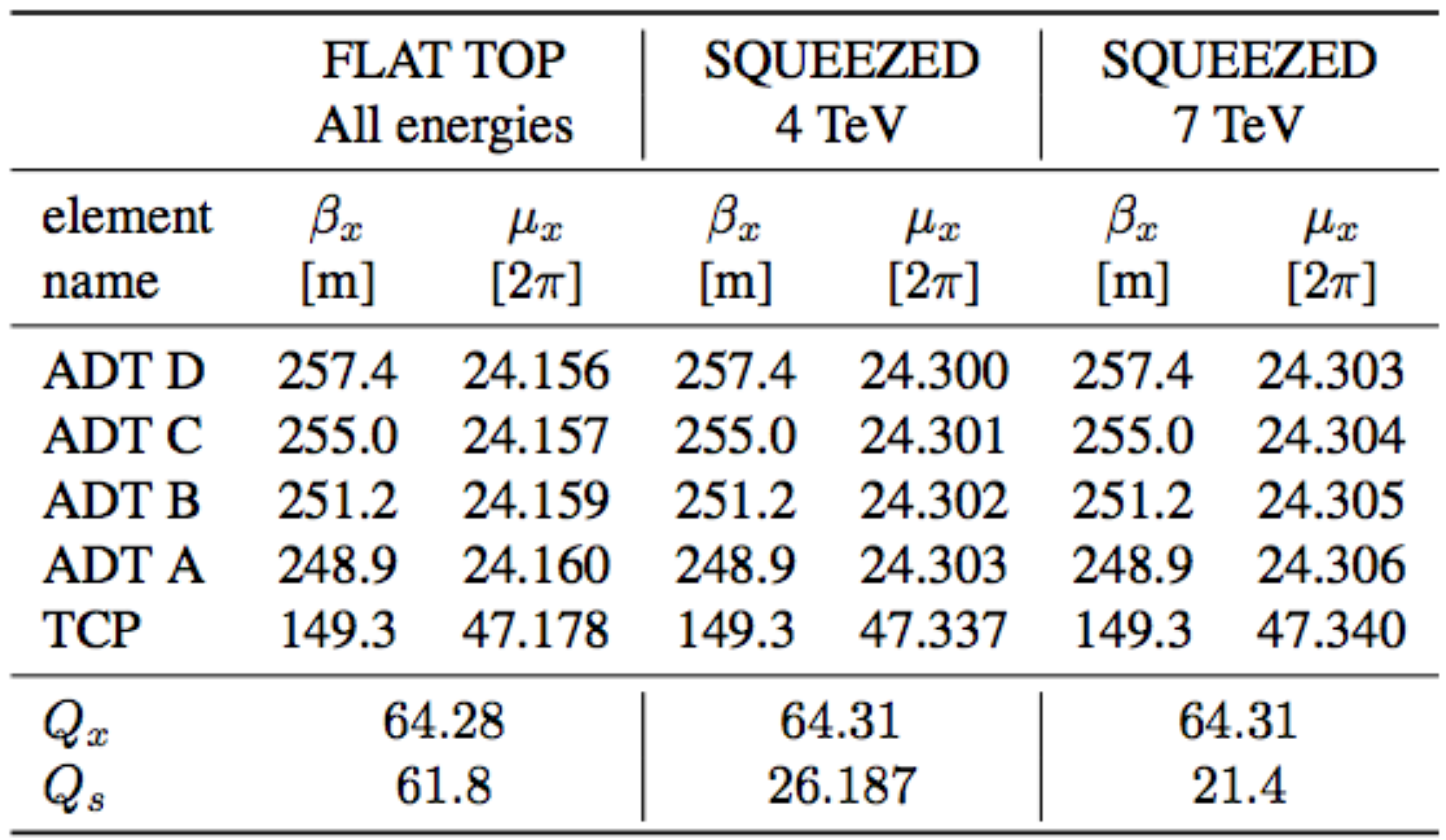
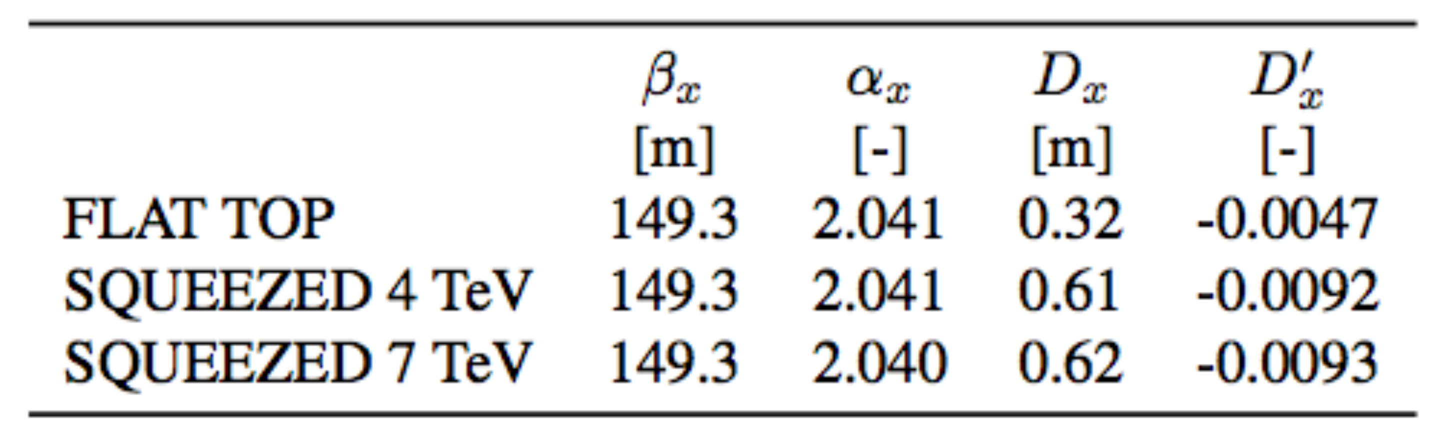
SIMULATIONS PARAMETERS



	FLAT TOP All energies		SQUEEZED 4 TeV		SQUEEZED 7 TeV	
element name	β_x [m]	μ_x [2π]	β_x [m]	μ_x [2π]	β_x [m]	μ_x [2π]
ADT D	257.4	24.156	257.4	24.300	257.4	24.303
ADT C	255.0	24.157	255.0	24.301	255.0	24.304
ADT B	251.2	24.159	251.2	24.302	251.2	24.305
ADT A	248.9	24.160	248.9	24.303	248.9	24.306
TCP	149.3	47.178	149.3	47.337	149.3	47.340
Q_x	64.28		64.31		64.31	
Q_s	61.8		26.187		21.4	



	β_x [m]	α_x [-]	D_x [m]	D'_x [-]
FLAT TOP	149.3	2.041	0.32	-0.0047
SQUEEZED 4 TeV	149.3	2.041	0.61	-0.0092
SQUEEZED 7 TeV	149.3	2.040	0.62	-0.0093

5 cases:

1. ***Flat top 450 GeV***
2. ***Flat top 4 TeV***
3. ***Flat top 7 TeV***
4. ***Squeezed optics 4 TeV***
5. ***Squeezed optics 7 TeV***

for each case, 10 different ADT gains (0.1,0.2 ... 1.0)

for each gain, 10^5 particles and up to 10^7 turns

main difference between FlatTop and SQueezed is the tune (little change in the optics functions)

HALO GENERATION

- The initial particle distribution is assumed to be a *double gaussian both in the normalized betatron and in the normalized synchrotron space.*

What happens in the normalized space?

	Physical space	**Normalized space**
Variables	*x, x'*	*ξ, ξ'* $\xi = x/\sqrt{\varepsilon\beta}$ $\xi' = \dfrac{\alpha x + \beta x'}{\varepsilon\beta}$
Distribution	*double Gaussian* *in x, x'*	*double Gaussian* *in ξ, ξ'*

... true both for betatron (x, xp) and synchrotron (s, dp/p) space

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What happens in the normalized space?

	Physical space	Normalized space	
Variables	x, x'	ξ, ξ' $\xi = x/\sqrt{\varepsilon\beta}$ $\xi' = \dfrac{\alpha x + \beta x'}{\varepsilon\beta}$	A_β, φ $A_\beta = \sqrt{\xi^2 + \xi'^2}$ $\varphi = \arctan \xi'/\xi$
Distribution	*double Gaussian* *in* x, x'	*double Gaussian* *in* ξ, ξ'	*Rayleigh in* A_β $\propto A_\beta e^{-A_\beta^2}$ *uniform in* φ $0 < \varphi < 2\pi$

The 4D information in (x,x',E,t) is summarized in the (A_β, A_s) space

… true both for betatron (x, xp) and synchrotron (s, dp/p) space

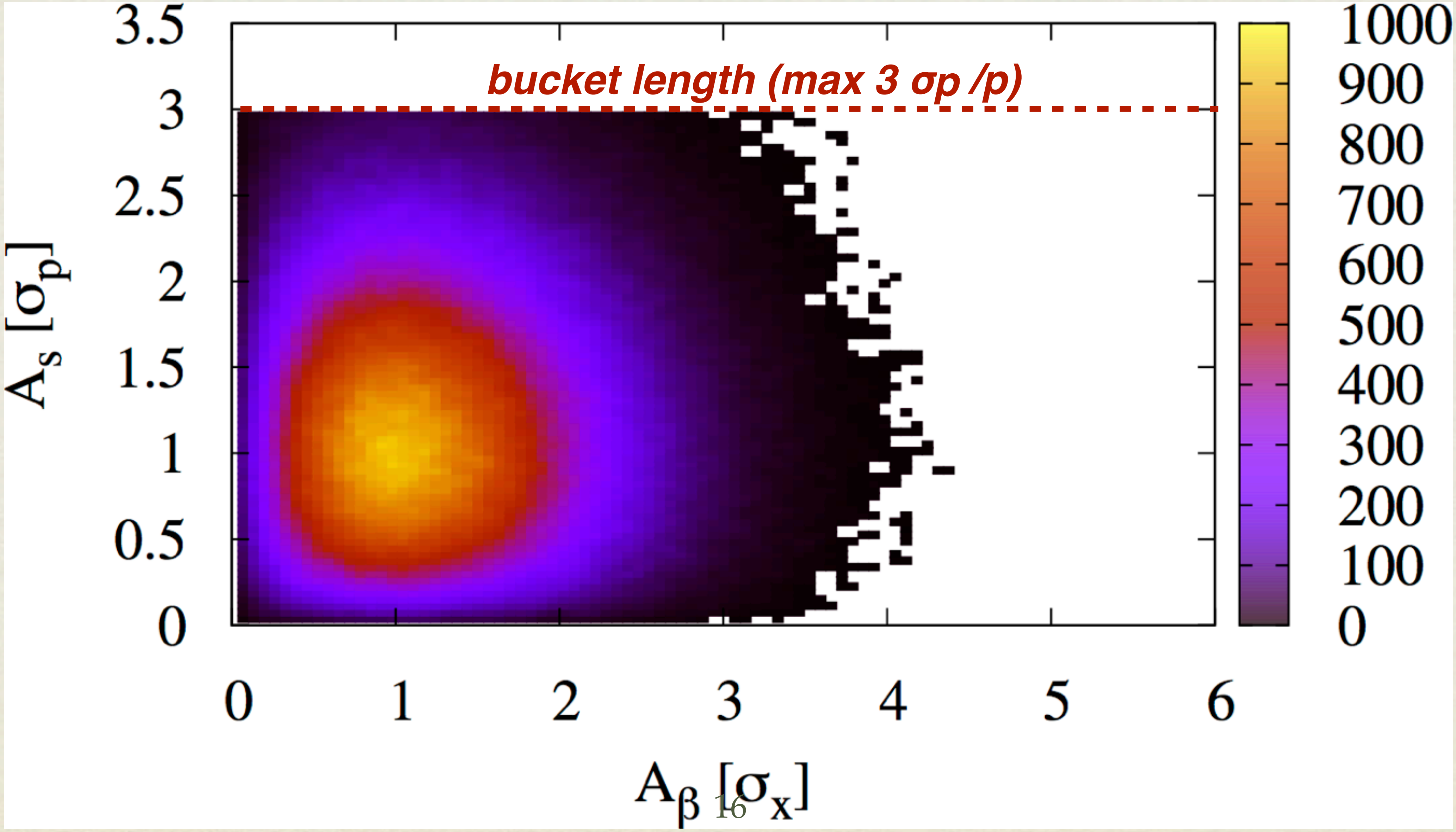
HALO GENERATION

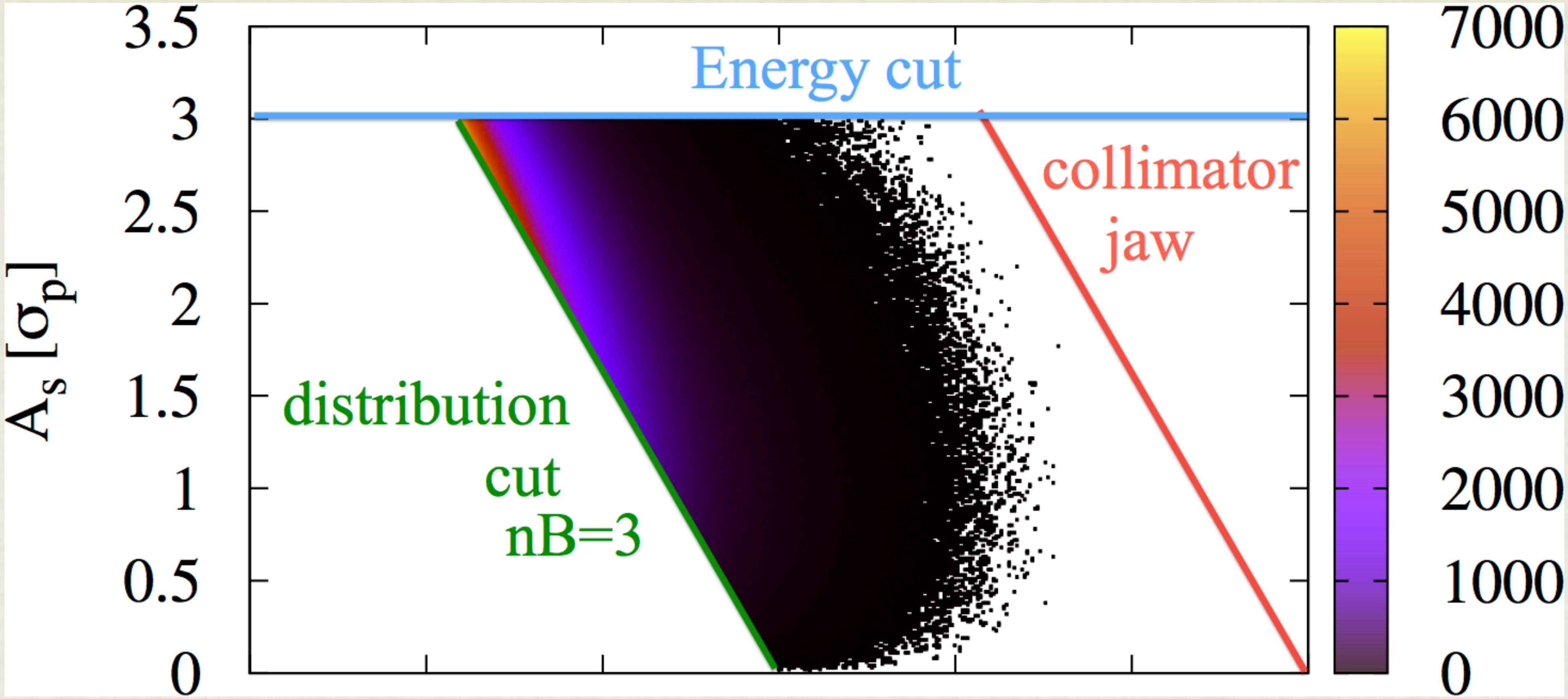
(A_β, A_s) space

- The initial particle distribution is assumed to be a *double gaussian both in the normalized betatron and in the normalized synchrotron space.*

to be checked

A normalized transverse emittance of 3.5 µm rad and a typical $\sigma p / p = 3.6 \; 10^{-4}$ are assumed.



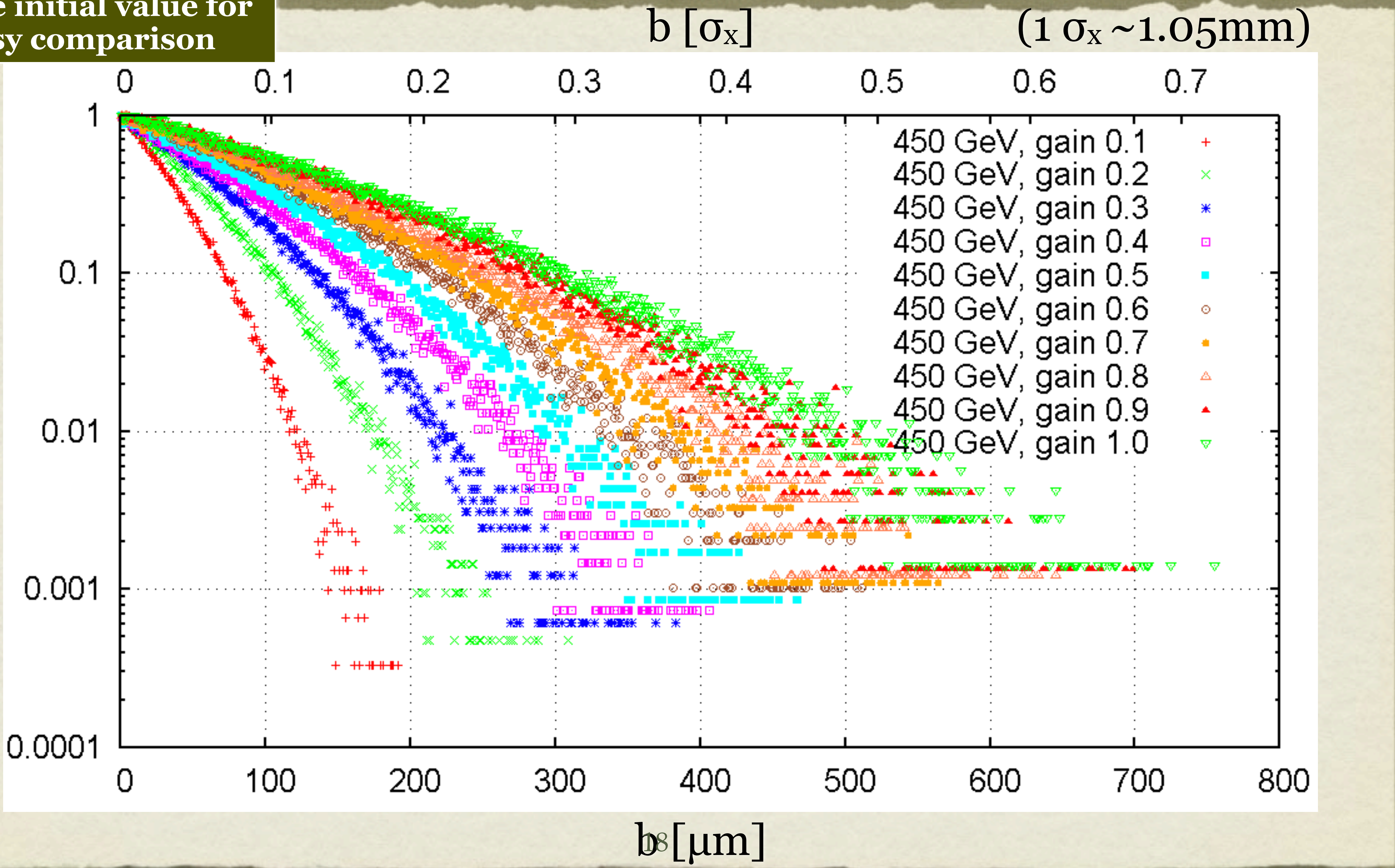


Three cuts can be applied to the initial particle distribution:

- **Energy cut:** a maximum momentum acceptance of $3\sigma_p/p$ is considered.
- **Collimator cut:** since non-linearities are not included in the code, the primary collimator jaws describe a line in the same space: no particles over the collimator aperture are generated.
- **Beam core cut:** for some cases, it might be useful to disregard the beam core and study only halo particle; a cut can be applied so that only the region adjacent to the collimator edge in the space A_β , A_s is generated. In the example shown in Fig. 1 (top), a distribution cut has been applied such that no on-momentum particles over betatron amplitude n_β = $3\sigma_x$ are generated

IMPACT PARAMETER RESULTS

curves are normalized to the initial value for easy comparison



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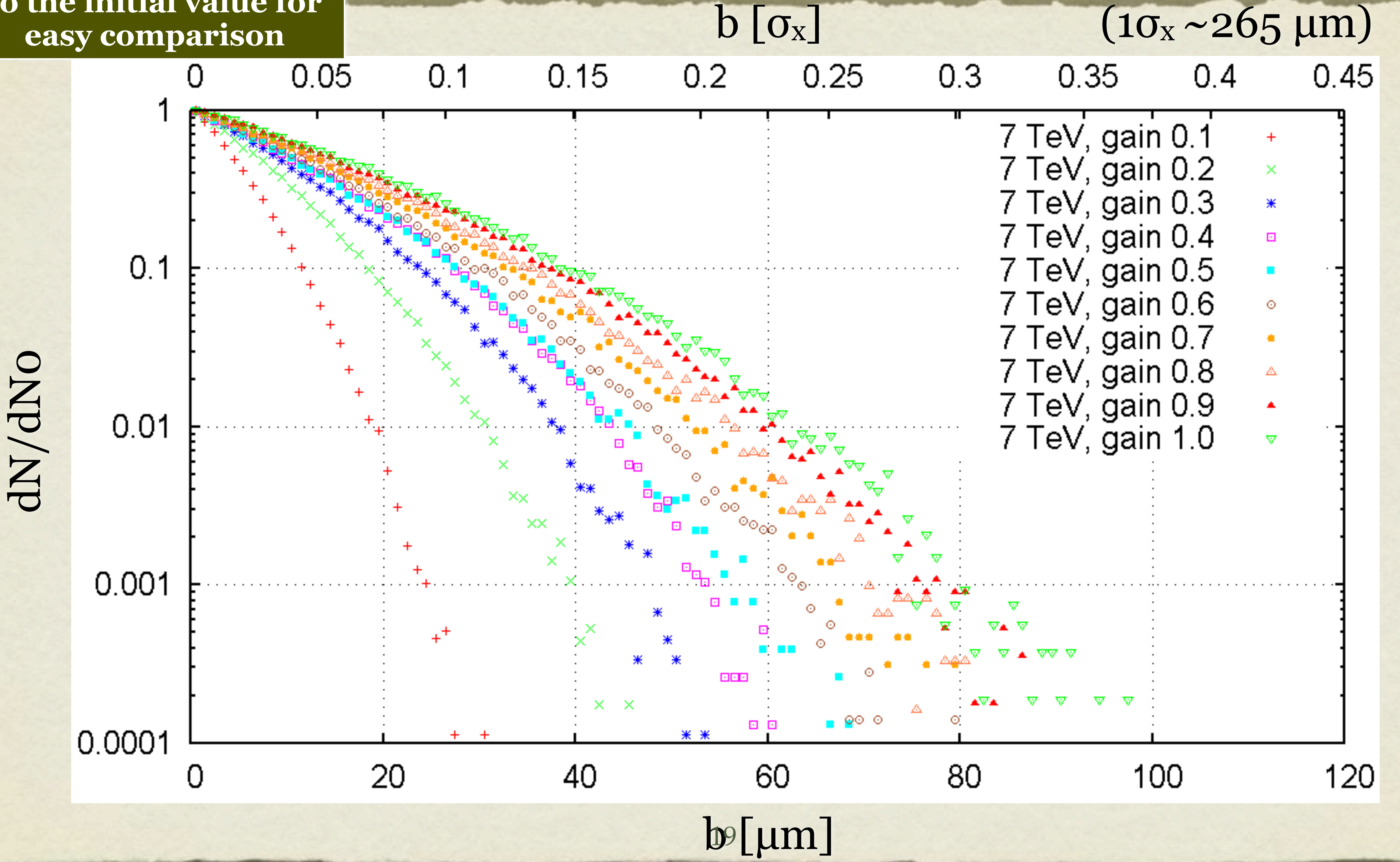
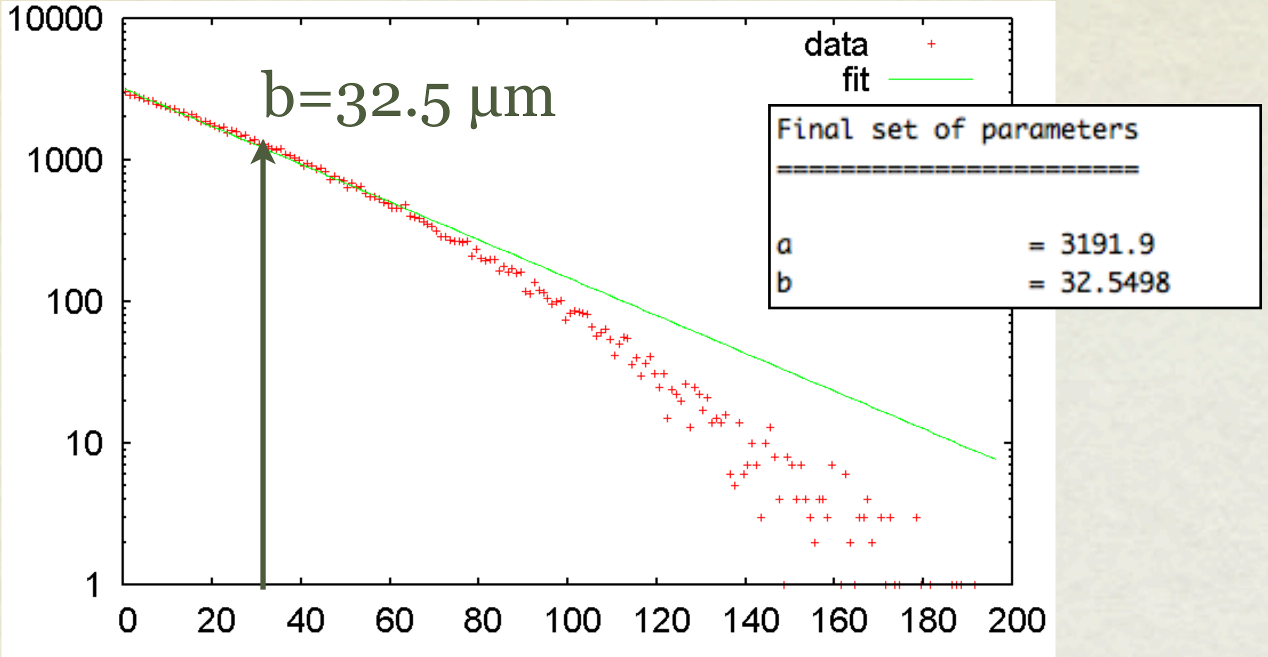


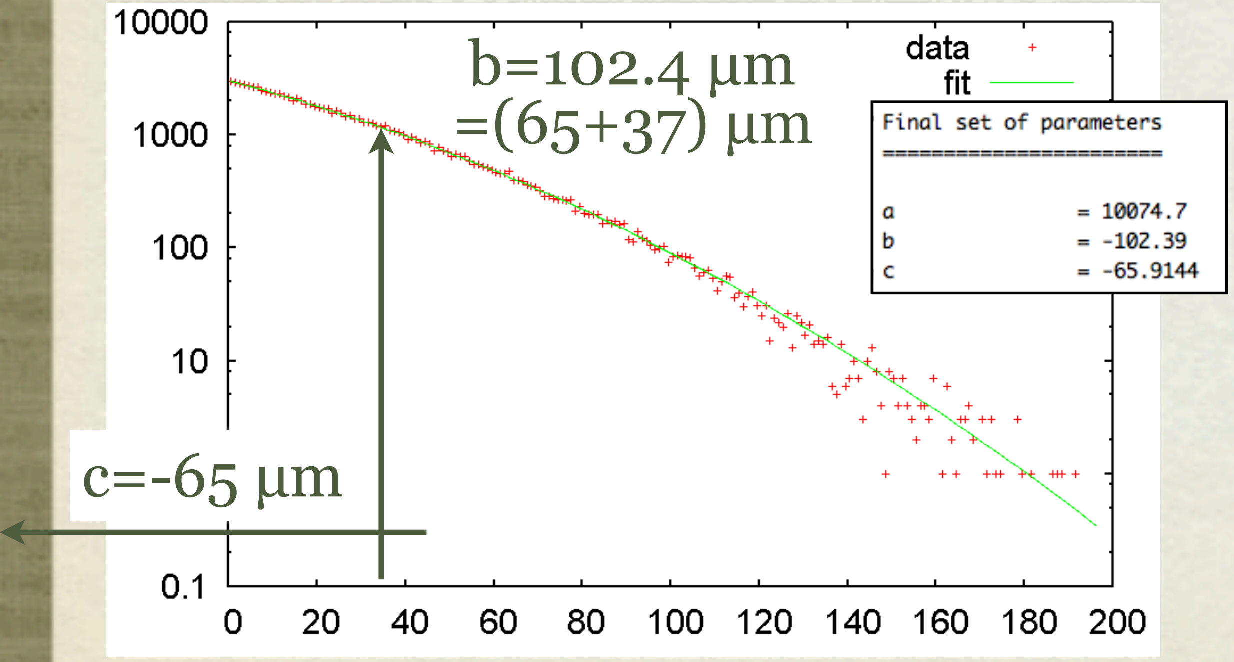
IMPACT PARAMETER - DATA ANALYSIS



b=32.5 μm

```
Final set of parameters
=======================

a               = 3191.9
b               = 32.5498
```



b=102.4 μm
=(65+37) μm

c=-65 μm

```
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a               = 10074.7
b               = -102.39
c               = -65.9144
```

to characterize the curves with a single parameter, different fits have been tried:

1. Exponential fit: $a\, e^{\frac{-x}{b}}$

does not describes well the tails

2. off-centered Gaussian fit: $a\, e^{\frac{-(x-c)^2}{2b^2}}$

describes the curve, but does not provide a single parameter to qualify the curves

3. numerical calculation of r.m.s $b = \sqrt{\frac{\sum x_i^2}{n}}$

```
r.m.s. of the distribution:      18.8758
```

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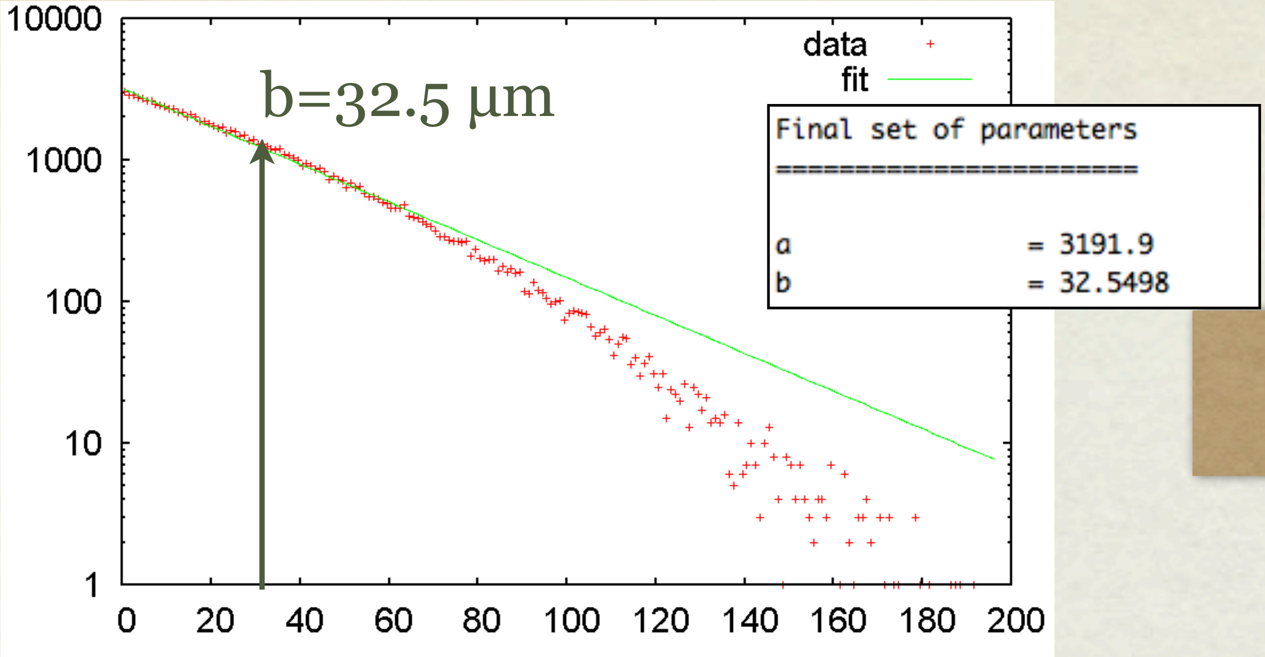

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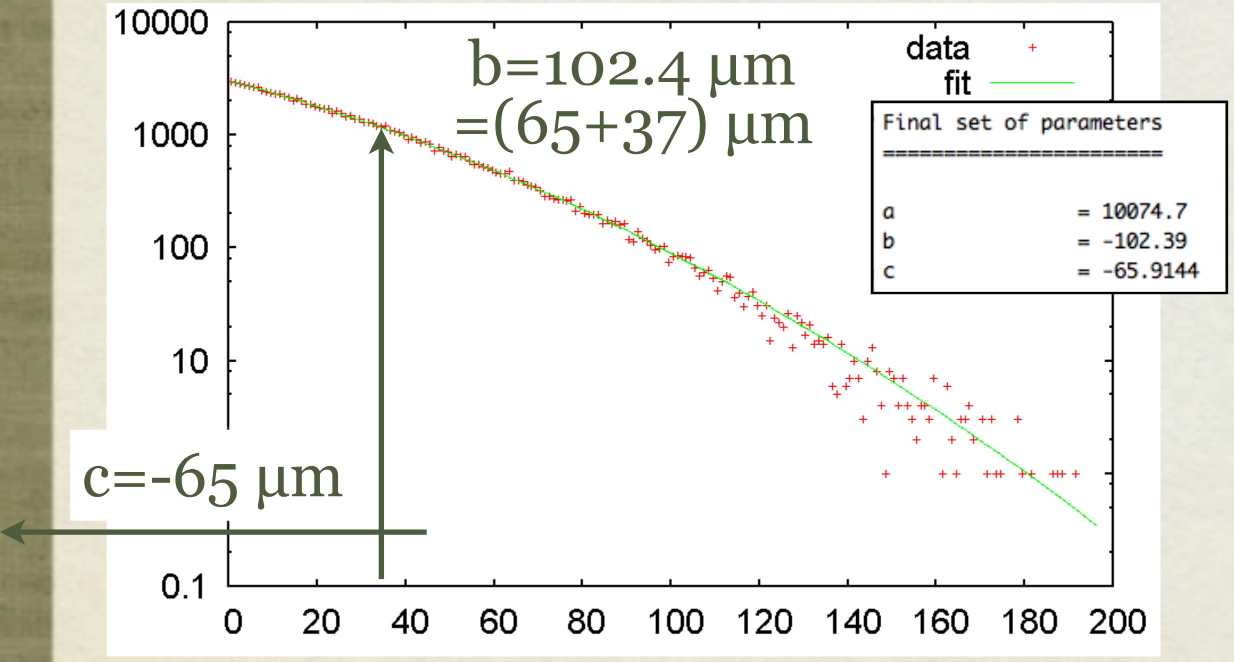

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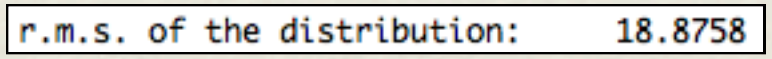

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The 3 methods can be used to qualify the curve. For sake of simplicity we selected the exponential fit.

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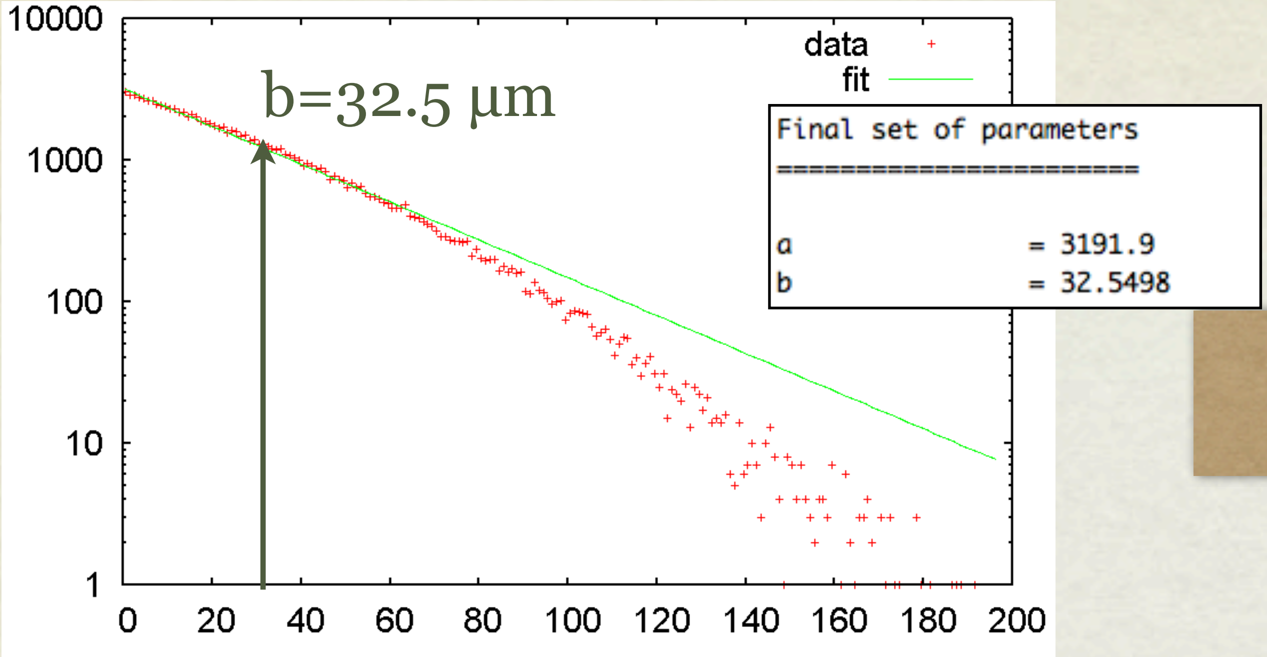

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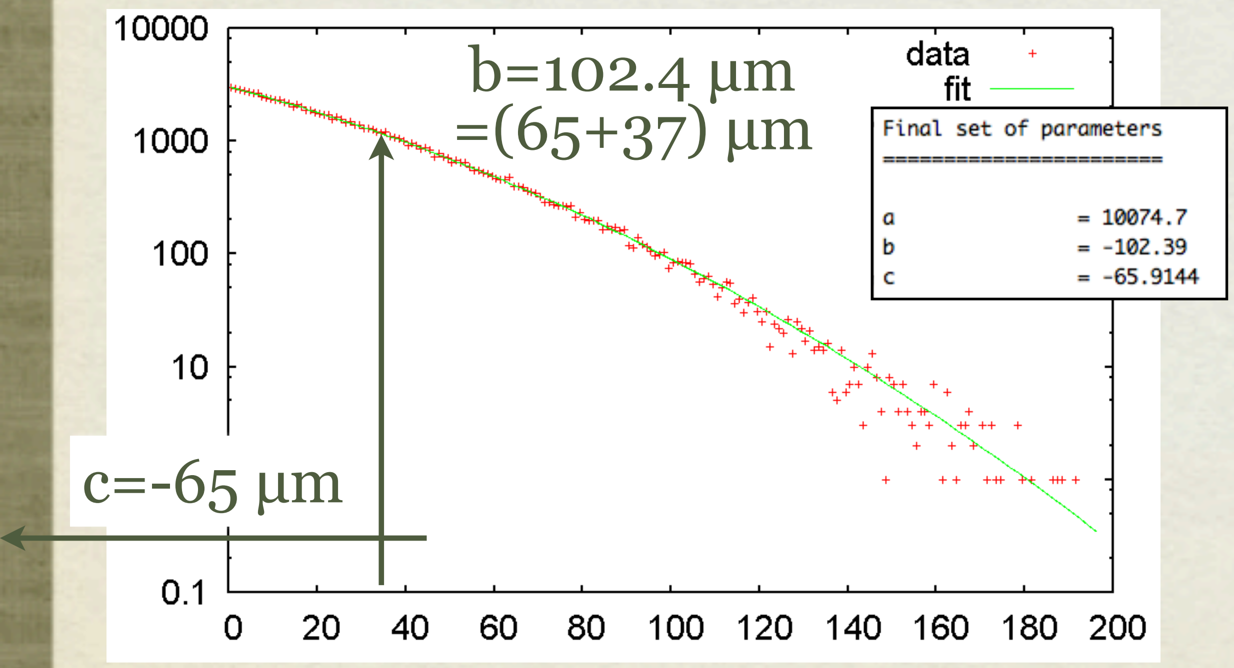

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to characterize the curves with a single parameter, different fits have been tried:

1. Exponential fit: $a\,e^{\frac{-x}{b}}$ typical impact parameter

does not describes well the tails

2. off-centered Gaussian fit: $a\,e^{\frac{-(x-c)^2}{2b^2}}$

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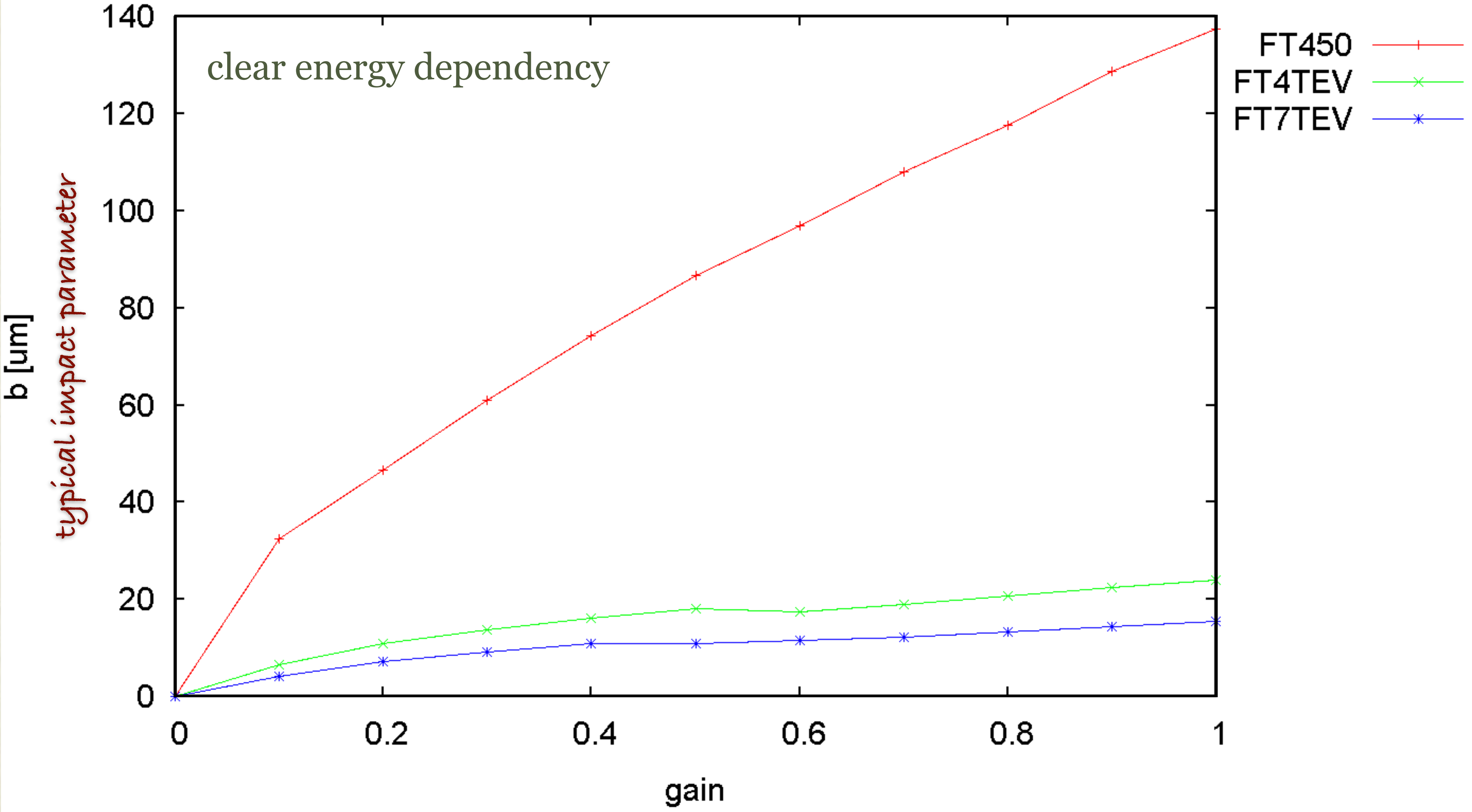
RESULTS SUMMARY

typical impact parameter
at 450 GeV:up to more than 100 μm
at 4 TeV and 7 TeV: up to 10-20 μm



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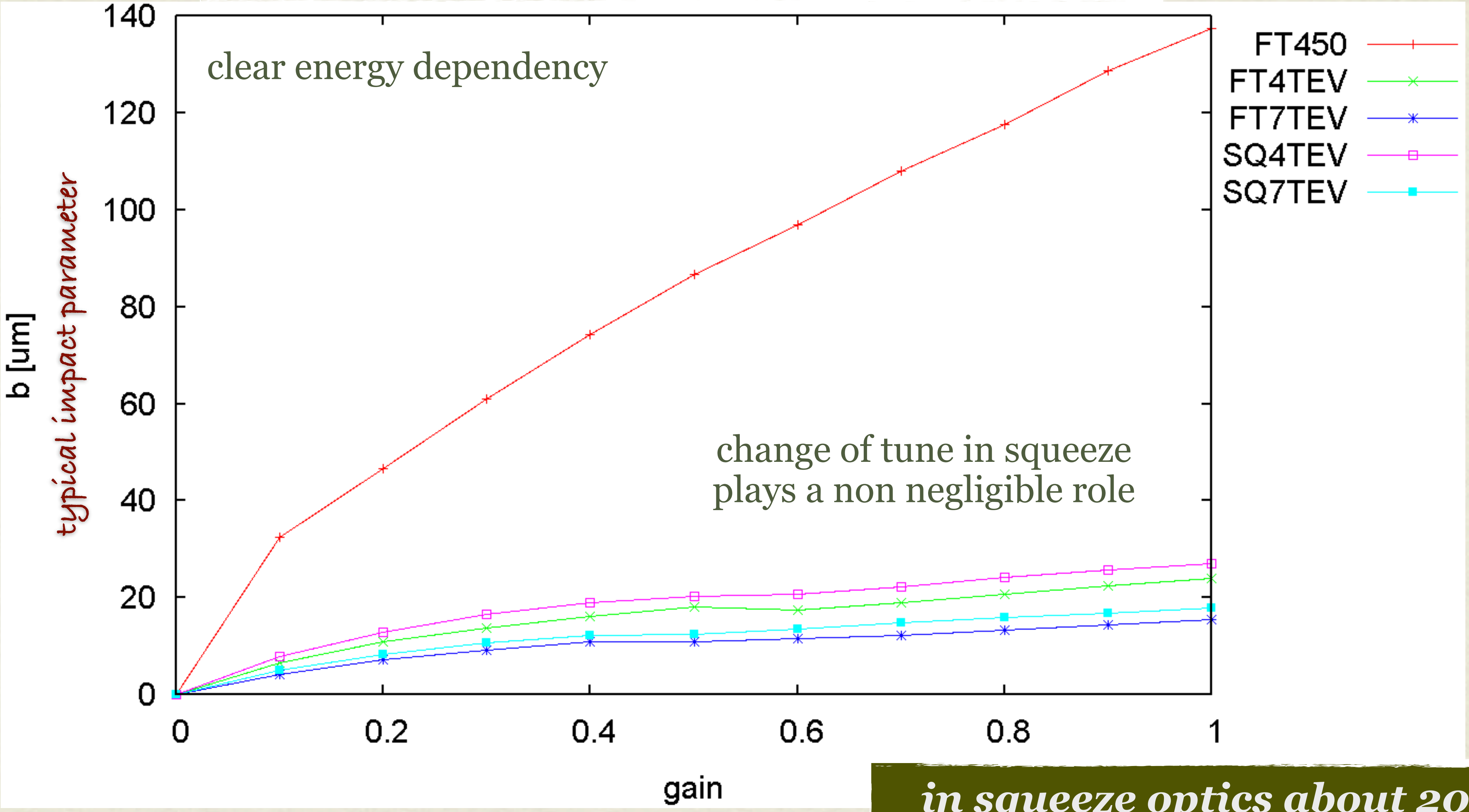


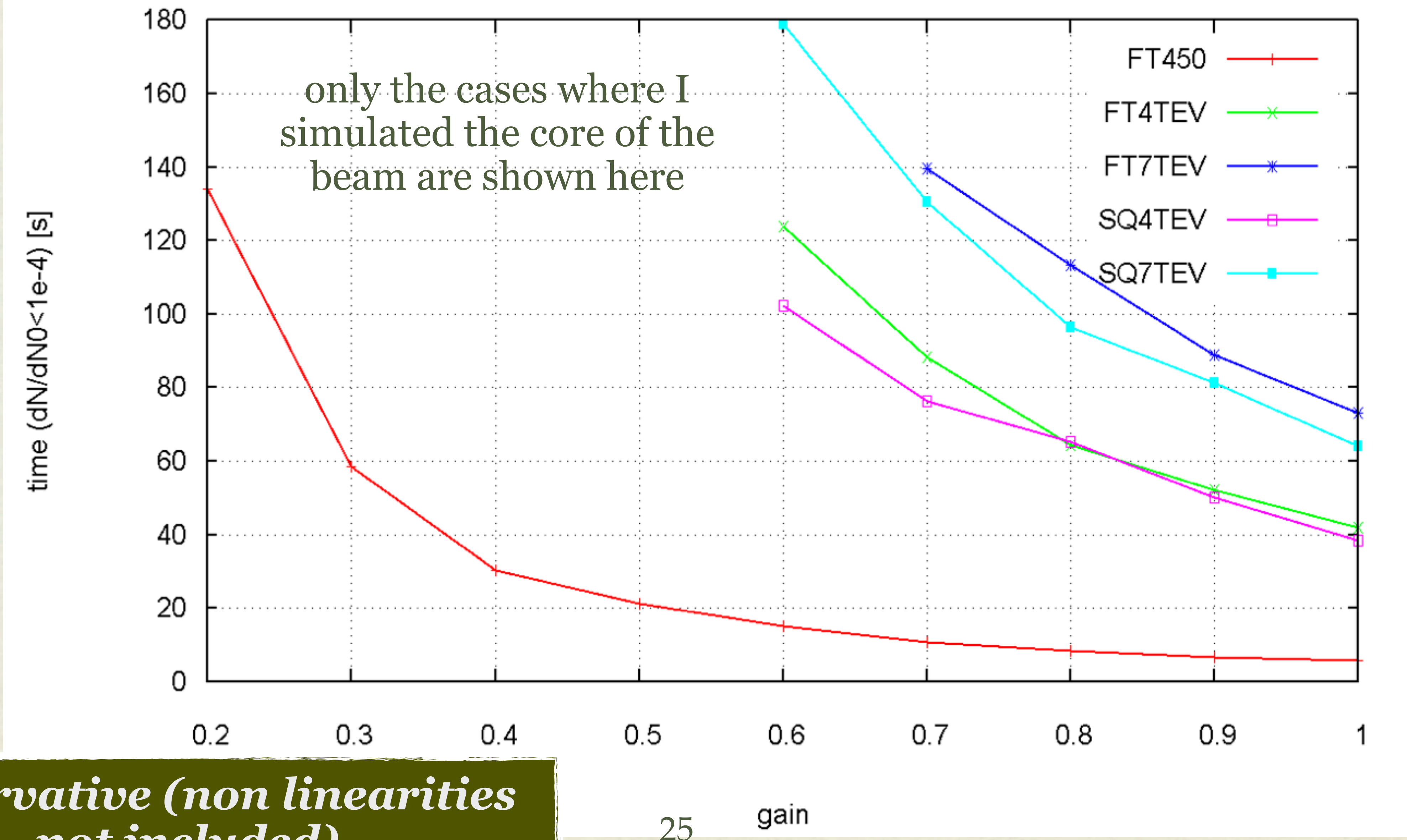
clear energy dependency

change of tune in squeeze plays a non negligible role

in squeeze optics about 20% larger impact parameter

HOW FAST ARE WE KILLING THE BEAM?

ADT is obviously avery powerful device. When used at full power, it can quickly dump the whole beam.
FICO gives us an estimation of the time needed to dump the whole beam.
Here we plot the time needed to reduce the initial distribution to less that 10^{-4} of the initial population



only the cases where I simulated the core of the beam are shown here

conservative (non linearities not included)

SUMMARY

- a new linear code - FICO (First Impact Code) - has been developed to quickly estimate the change in impact parameter on primary collimator when using ADT for heating the beam
- the dependency of impact parameter of ADT gain has been calculated for different machine configurations
- typical impact parameter
  at 450 GeV:up to more than 100 μm
  at 4 TeV and 7 TeV: up to 10-20 μm
- At its maximum power, the ADT can dump the whole beam in:
  at 450 GeV: less than 5 seconds
  at 4 TeV: about 40 seconds
  at 7 TeV: about 1 minute
- Next steps:
  - correlate linear gain with operational parameters and compare with the used settings
  - understand limits in the model (improve? use more some other code (SixTrack?)
  - correlate with Sixtrack simulations - variation of cleaning efficiency with impact parameters

THANKS!