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PARTICLE LOSSES AT COLLIMATORS DURING MAGNET POWERING FAILURES: DISTRIBUTION OF IMPACT PARAMETER



Outline

- Introduction: failure scenario with circulating beam
 - Tracking with MADX
 - Transverse impact distribution
 - Post-impact tracking with sixtrack
 - Estimation of time margin until quench
 - Conclusions
- 

Magnet failure with circulating beam: what happens?

Failures

- Change in the magnet(s) current
- Change in the magnetic field



Time
dependent
change in optics

Evolution of the loss map
(locations in LHC)



Evolution of impact distributions
(transverse at each location)



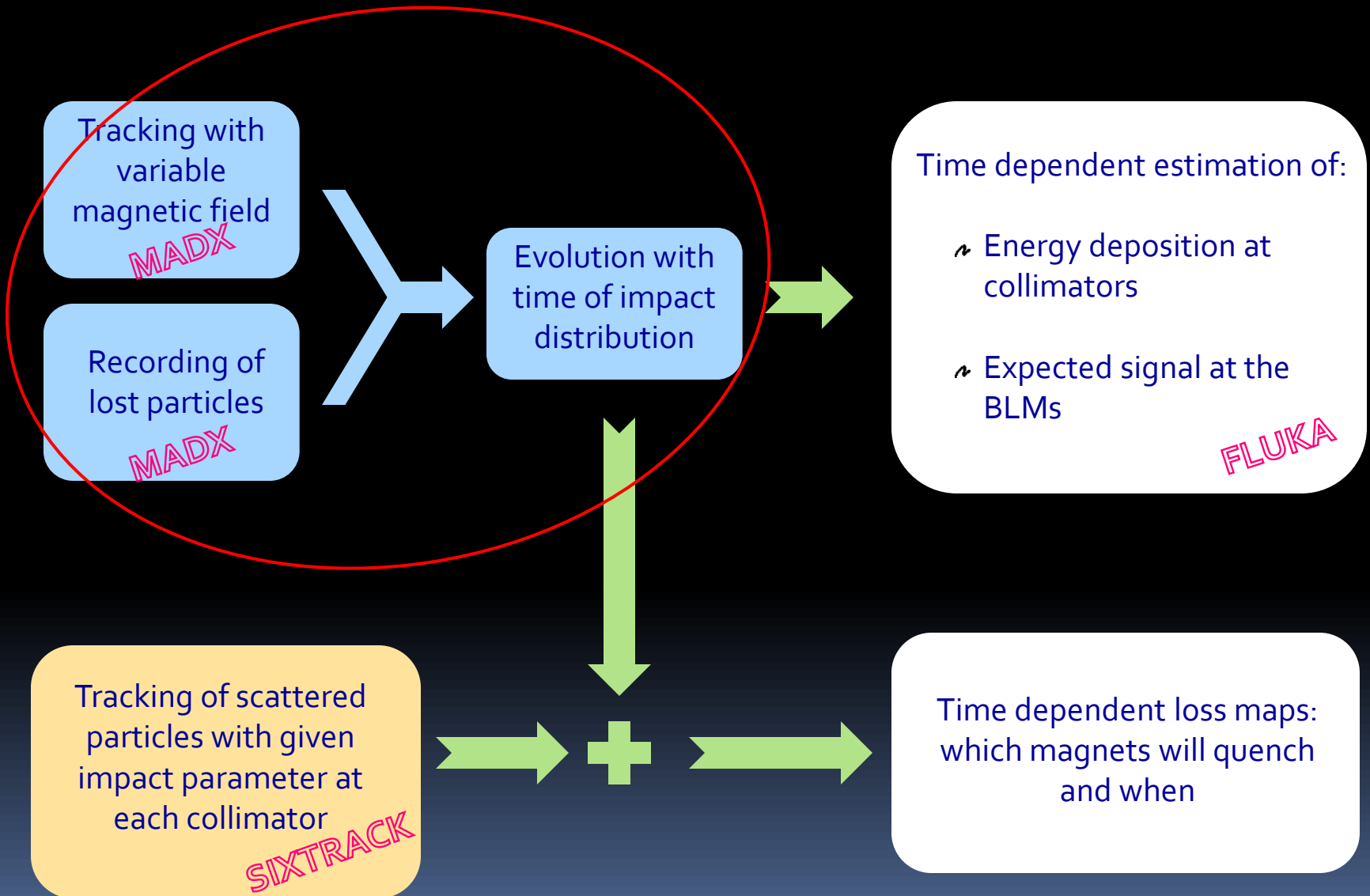
Evolution of
losses with
time



Key questions:

- When is the damage threshold reached in one collimator?
- When shall we expect quenches downstream?
- When will the BLM detection threshold be reached?

General simulation procedure

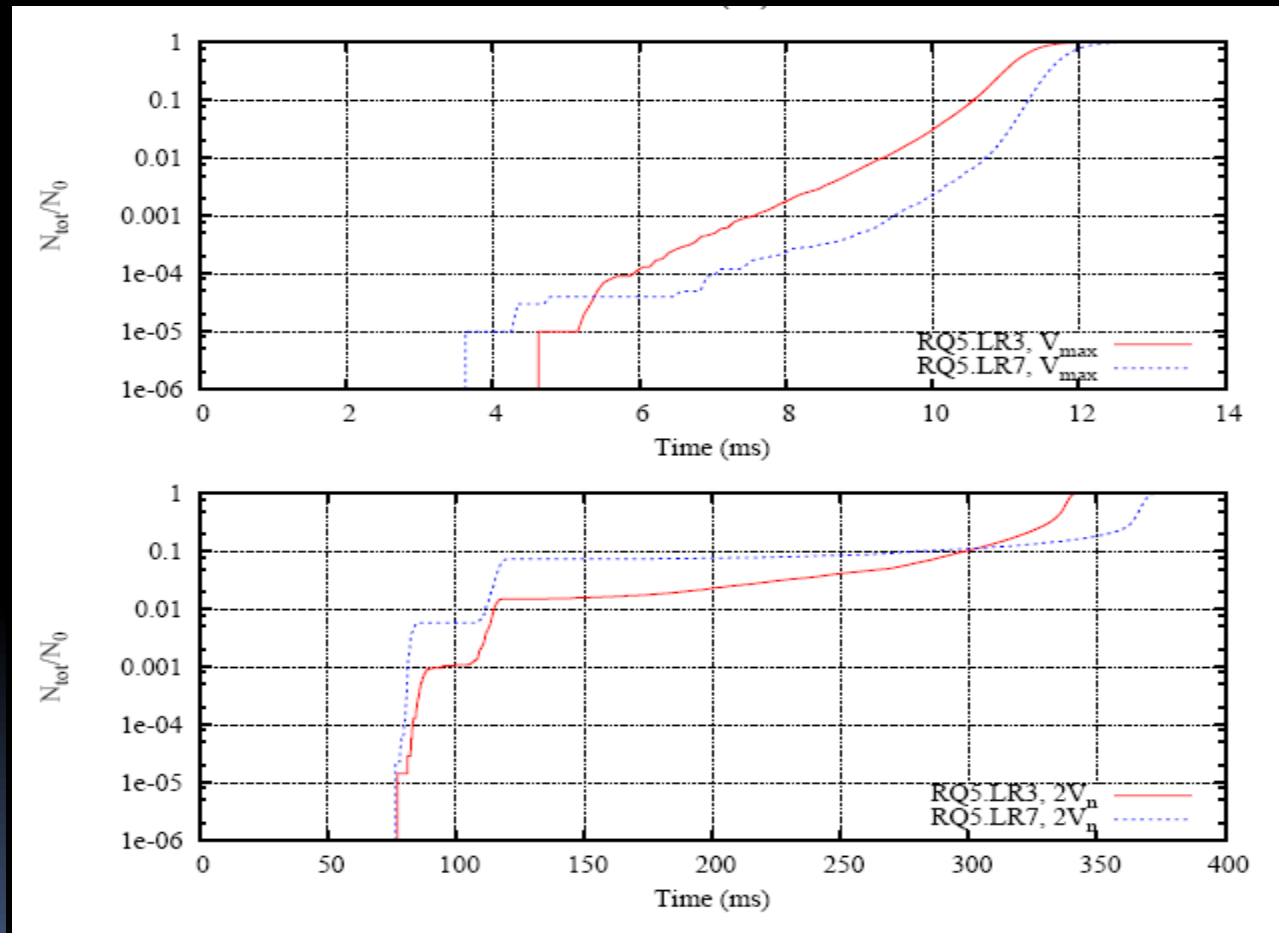


Magnet failure: evolution of the beam

- The transverse evolution of the beam depends on:
 - Type of failing magnet
 - Type of failure
 - Speed of failure
- Dipole failures: easily predictable
 - Change in closed orbit
 - Transverse displacement
- Quadrupole failures: difficult to estimate quantitatively
 - Change in twiss parameters (optics)
 - Defocusing & resonant effects

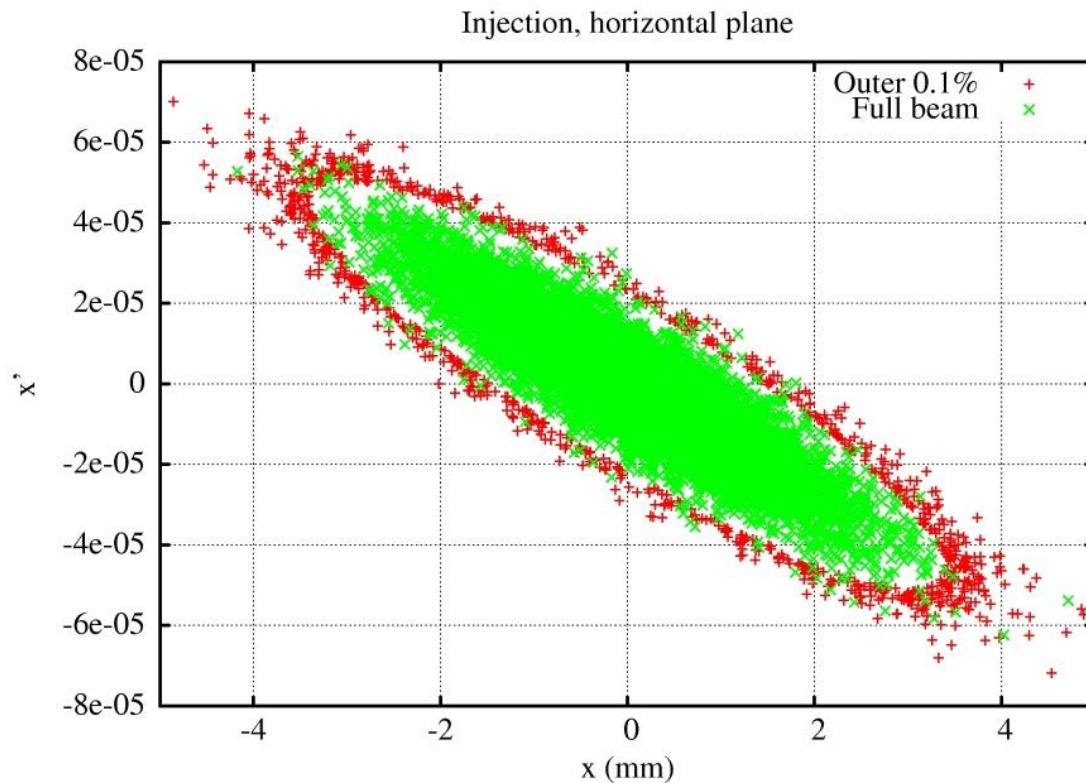
Influence of the speed of failures

Faster failures imply..

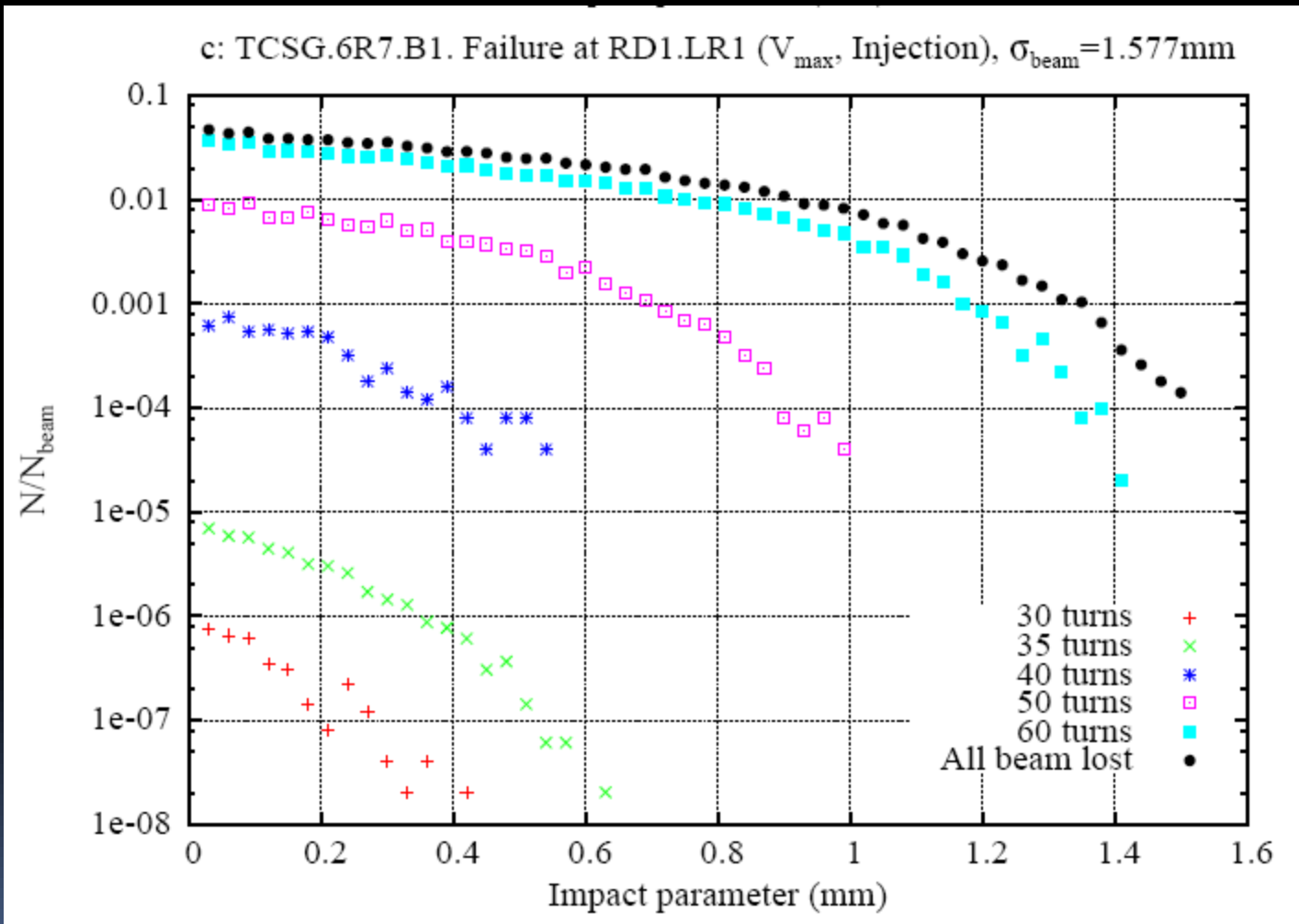


Tracking with variable magnetic field (MADX)

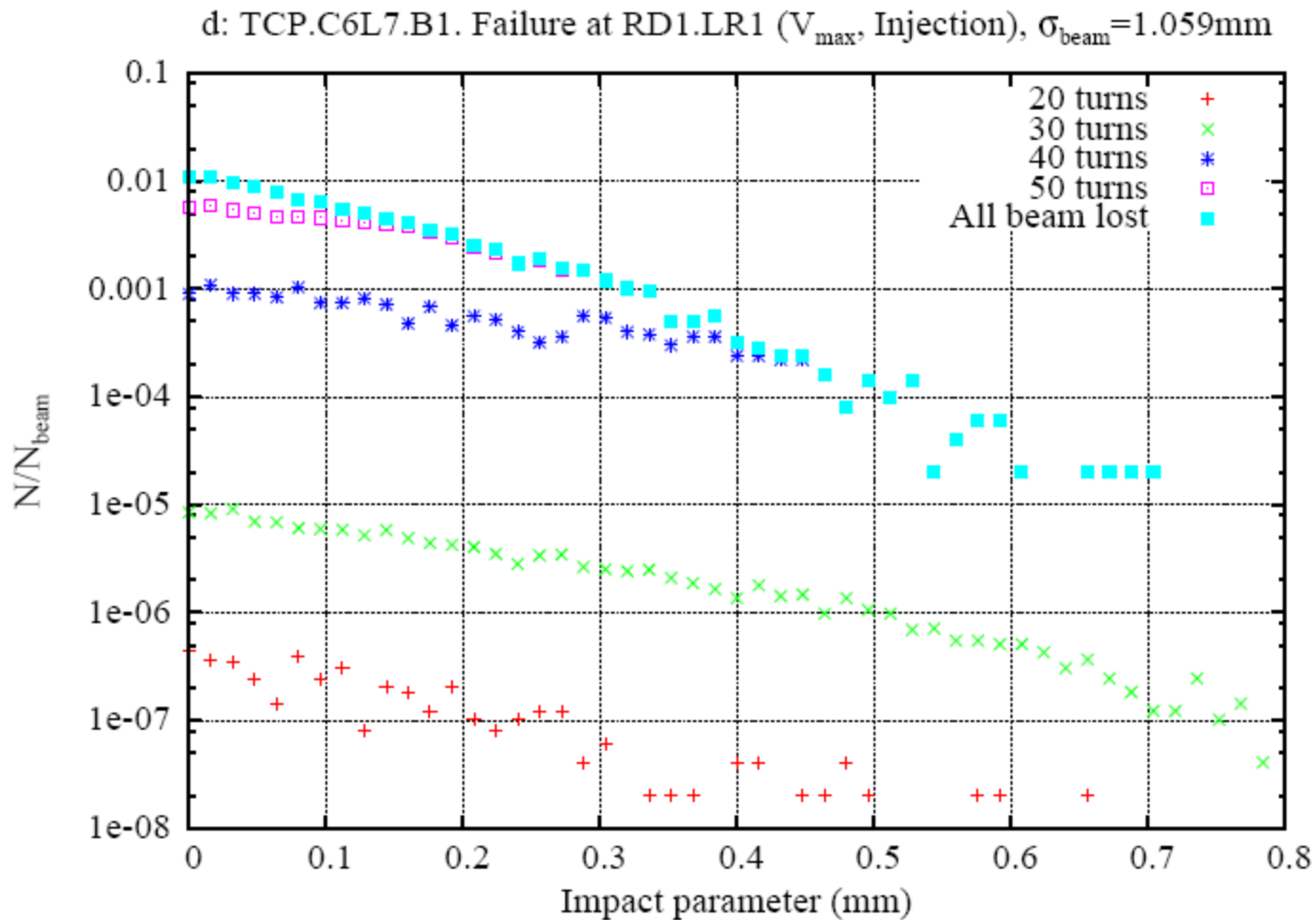
- Two different sets of particles: global view and good resolution
- 5×10^4 particles in each case: “minimum” statistics for 10^{-4} and 10^{-7} of the beam



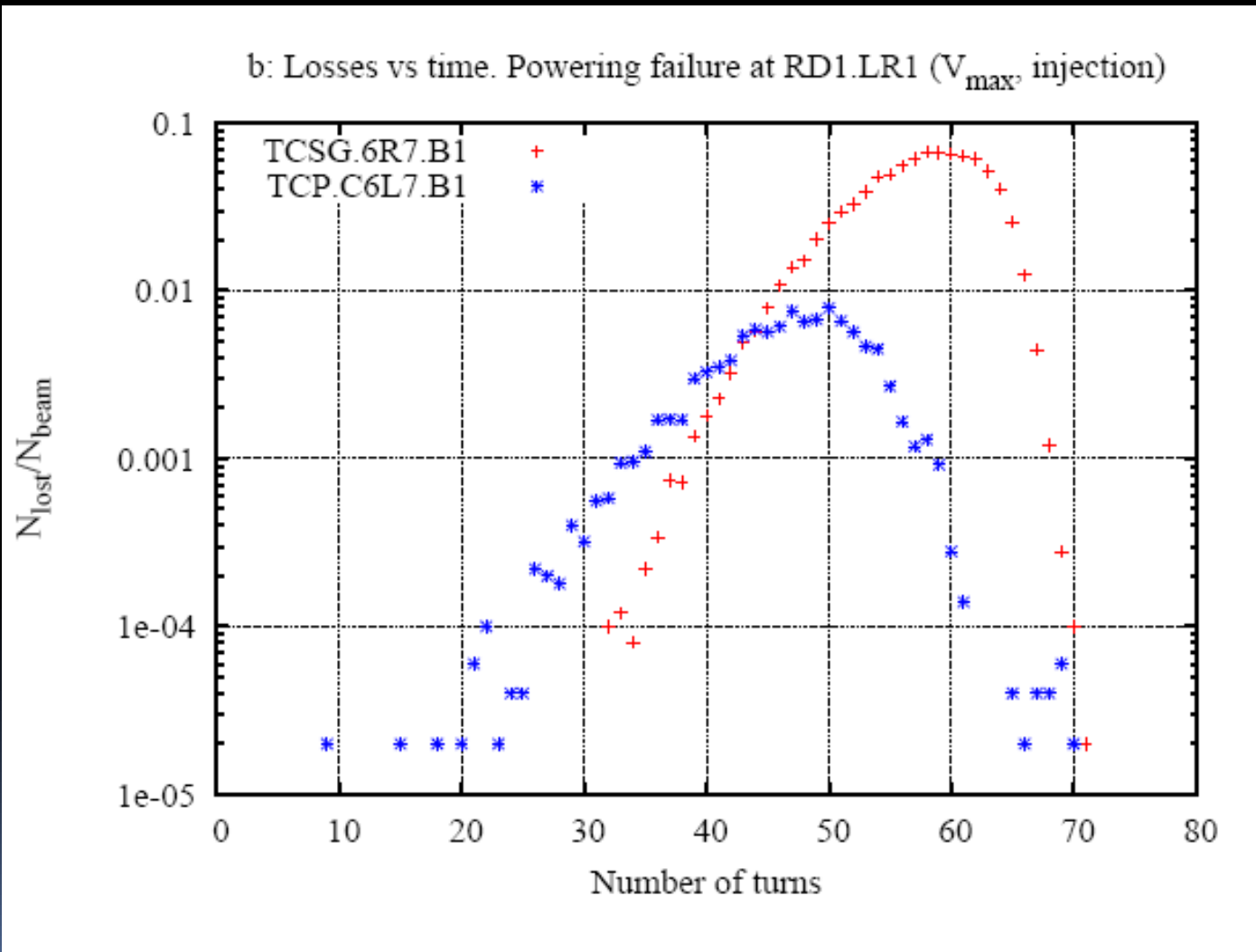
Evolution with time of the impact parameter (dipole)



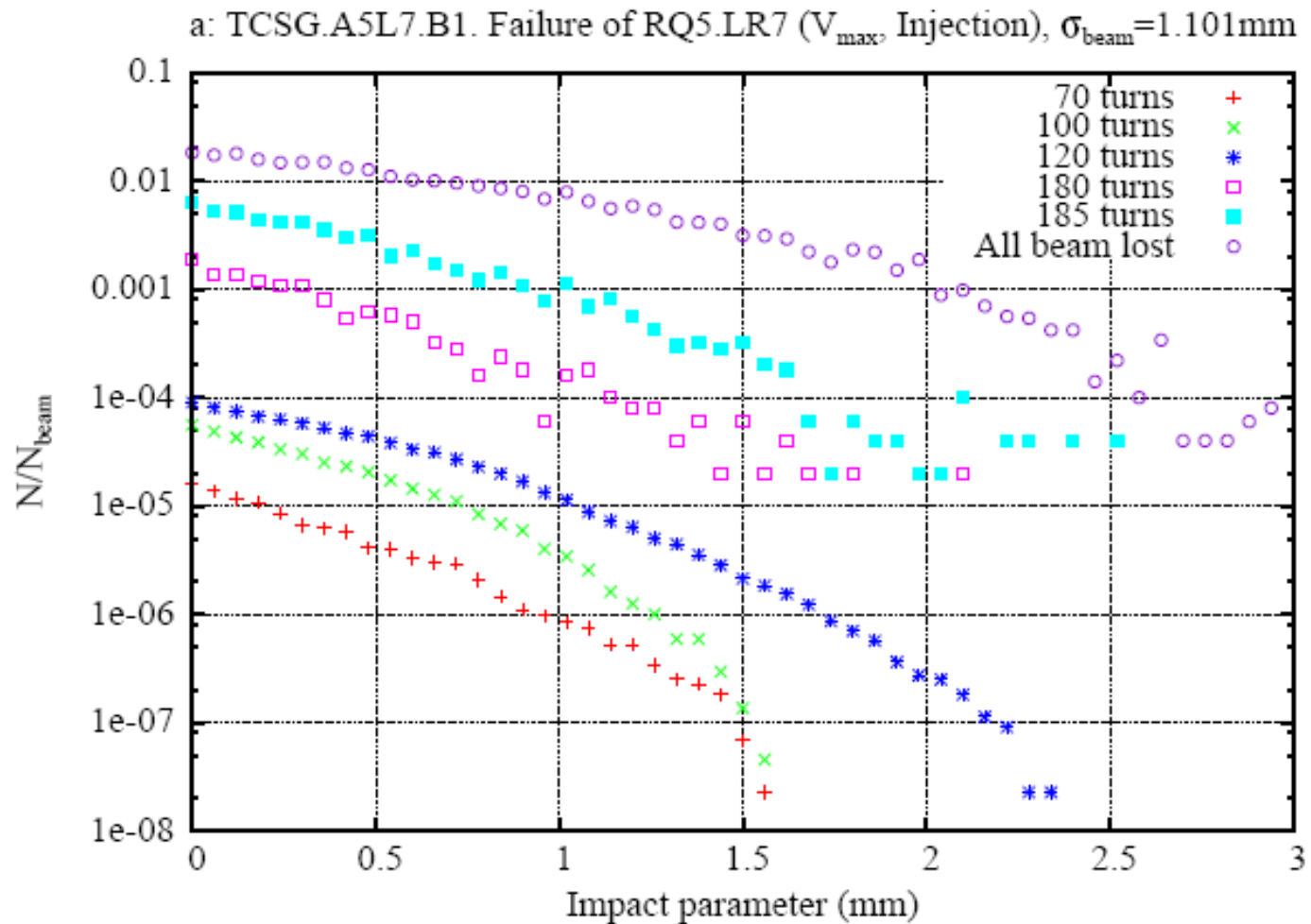
Evolution with time of the impact parameter (dipole)



Lost particles per turn vs time



Evolution with time of the impact parameter (quadrupole)



Fit of the impact distribution

High number of failure cases (about 130 considered so far)

Evolving distribution of the impact parameter



Need of automatic routines and lots of storage space

More elegant and efficient:

1. Find a PDF that fits the distribution of the impact parameter
2. Obtain the parameters of the PDF from the impact parameter of each particle
3. Store these (few) parameters for each failure and turn
4. Reconstruct the distribution when needed

Advantages:

1. Less information is stored
2. The change in the parameters can be interpreted directly
3. Normalized function: independent of number of particles, resolution of the binning, etc.

Disadvantage:

1. The fit is not 100% accurate, but acceptable

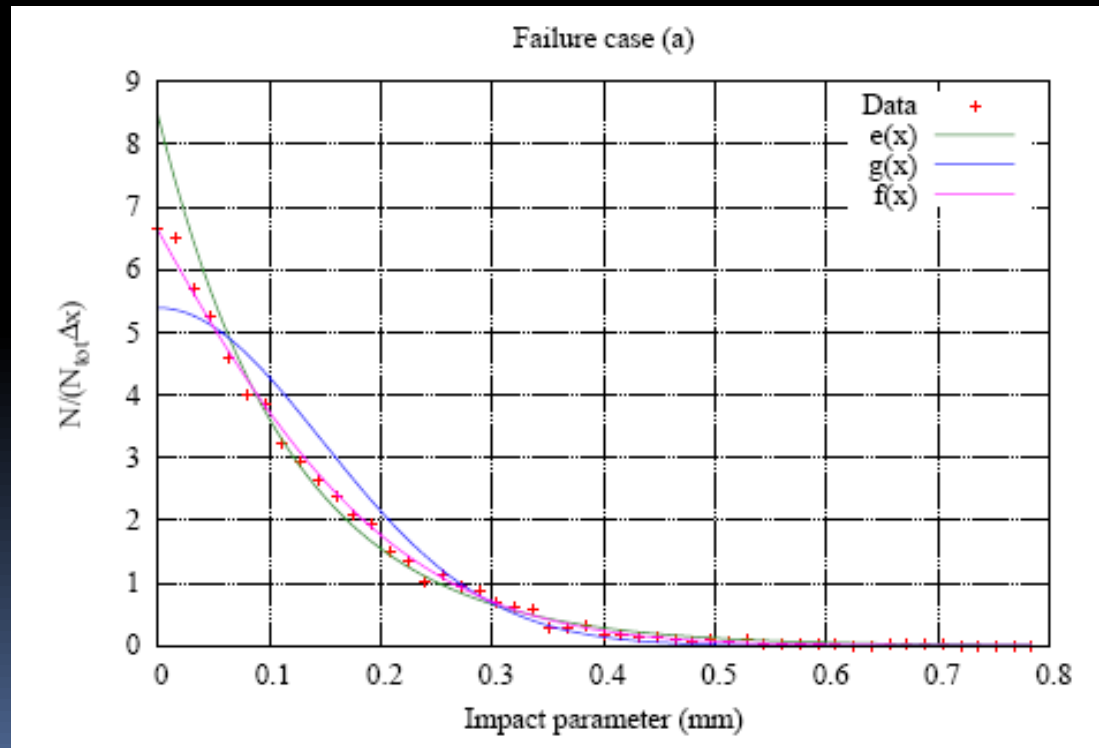
Fit details

Appropriate Probability Density
Function:

$$f(x) = A_f e^{-\frac{x^2}{2\sigma^2} - \frac{x}{\tau}}$$

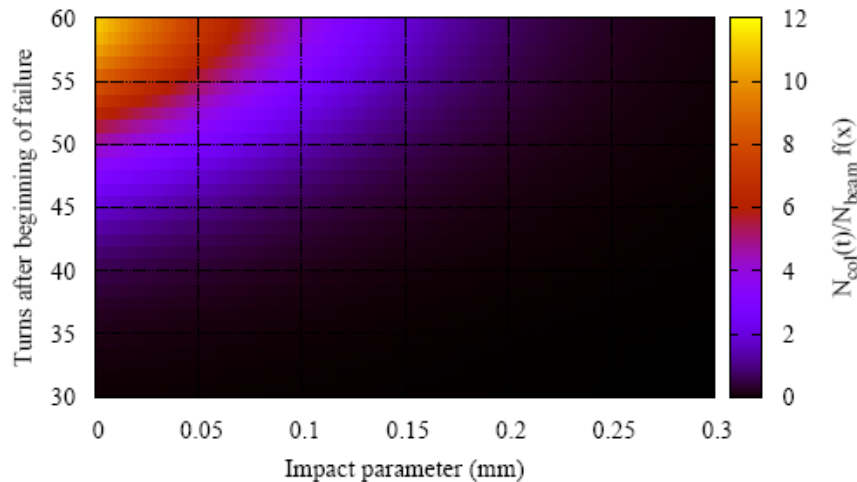
Three parameters to store as a function of time: A_f , σ , τ

Calculated at each turn using the method of the moments

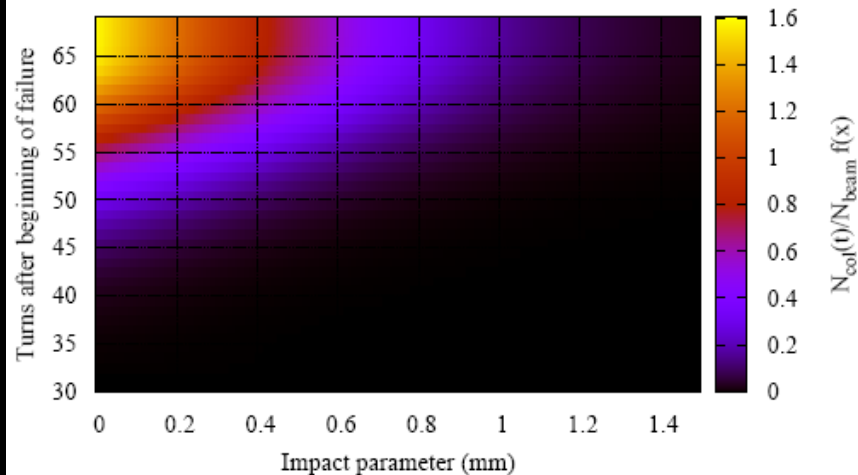


Examples

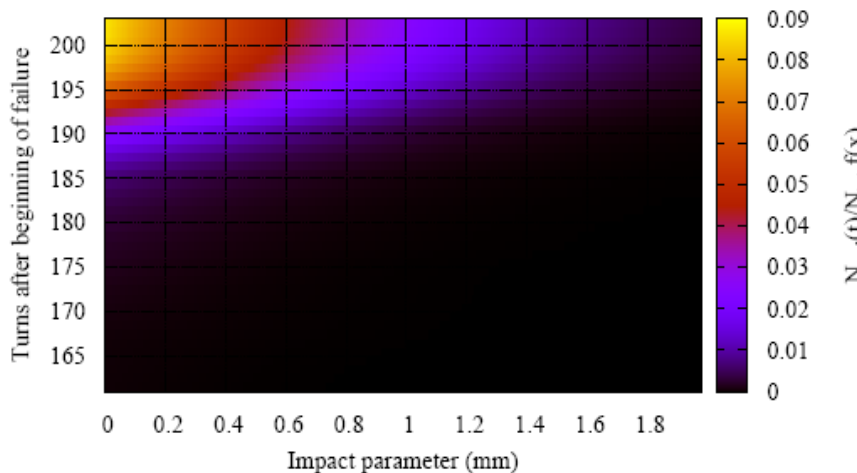
a: TCP.C6L7.B1. Failure at RD1.LR1 (0V, Collision) $\sigma_{\text{beam}}=0.278\text{mm}$



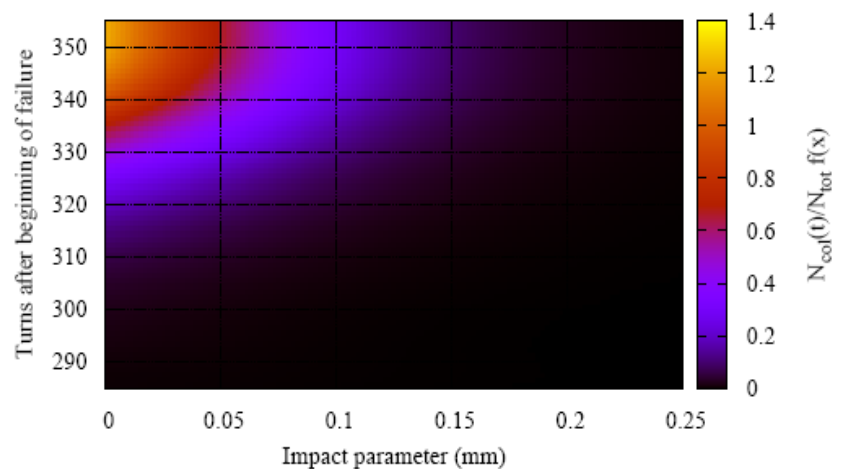
b: TCSG.6R7.B1. Failure at RD1.LR1 (V_{max} , Injection) $\sigma_{\text{beam}}=1.577\text{mm}$



c: TCSG.A5L7. Failure of RQ5.LR7 (V_{max} , Injection), $\sigma_{\text{beam}}=1.101\text{mm}$



d: TCSG.A4R7. Quench at RQX.R1 (Collision), $\sigma_{\text{beam}}=0.262\text{mm}$



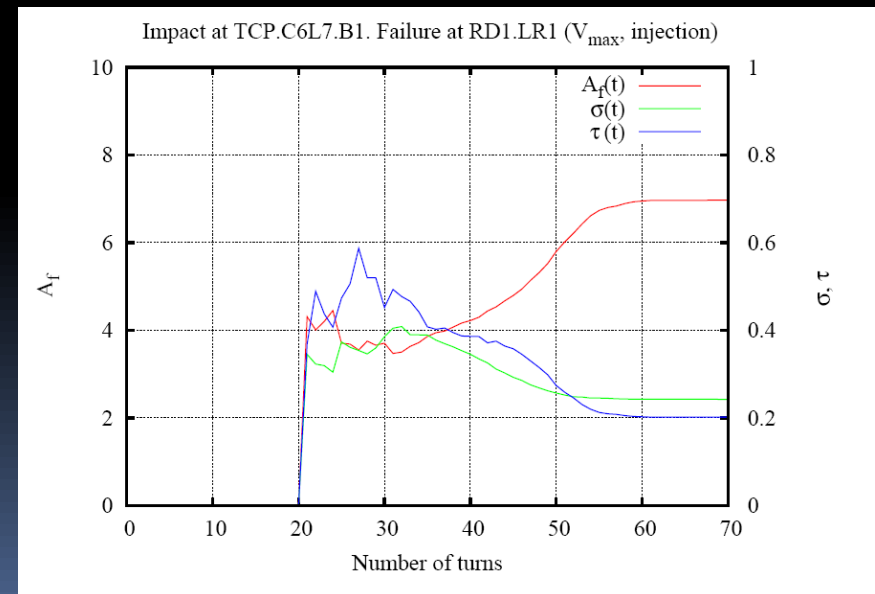
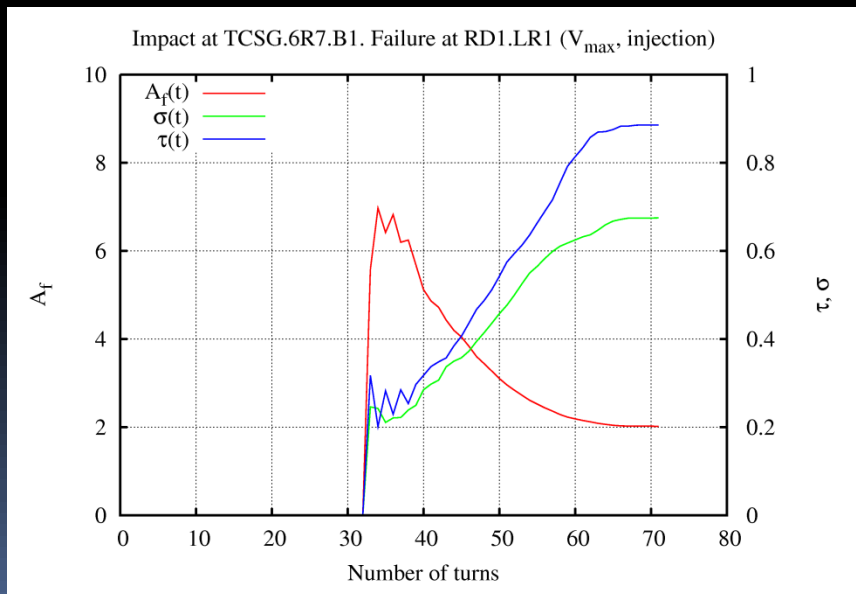
Direct interpretation

A_f , σ , τ plotted vs time contain all the information about the shape of the distribution

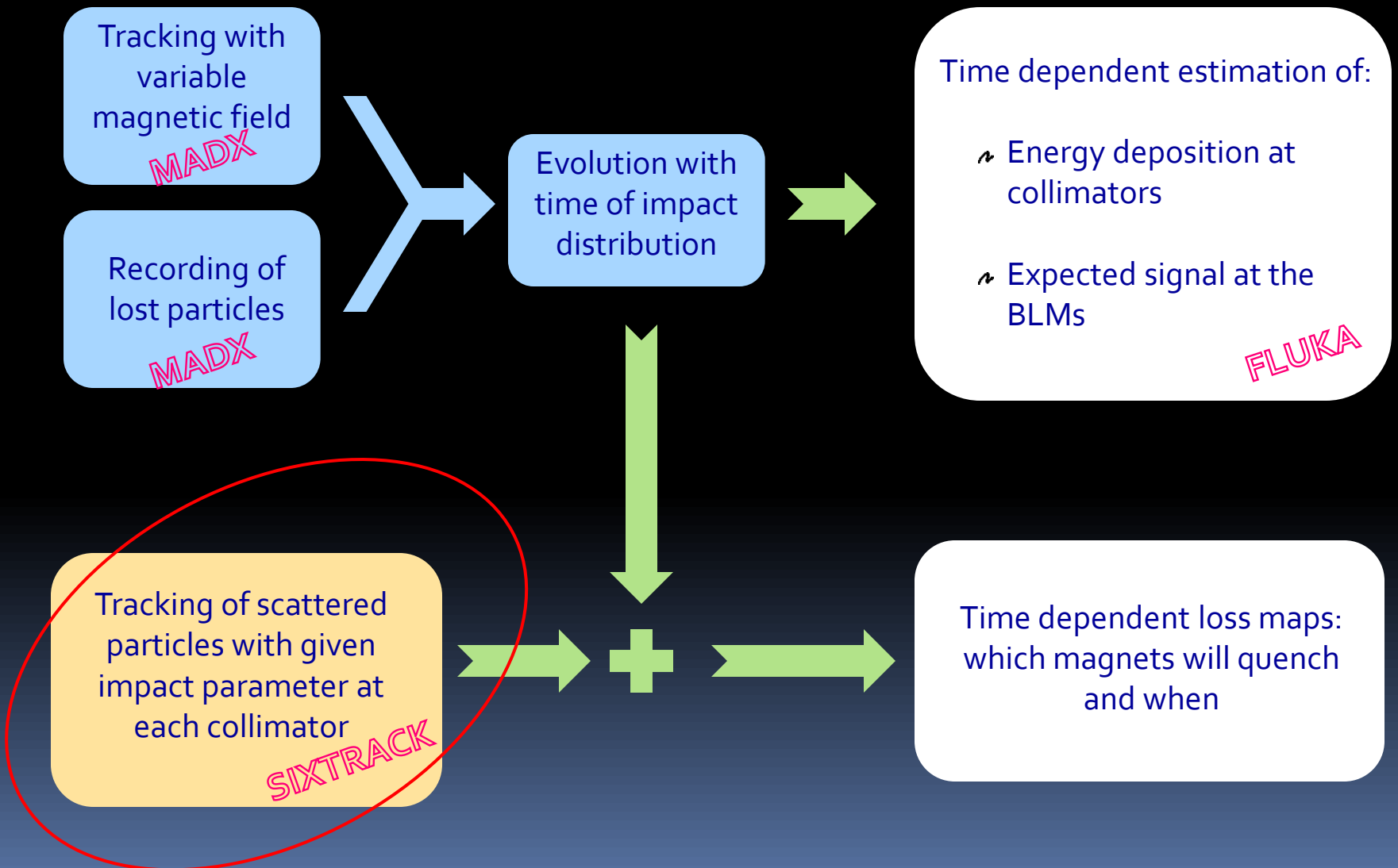
The impact evolution with time is fully defined by this plot and the number of particles lost in the collimator as a function of time

Distribution that gets larger with time

Distribution that gets narrower with time



General simulation procedure

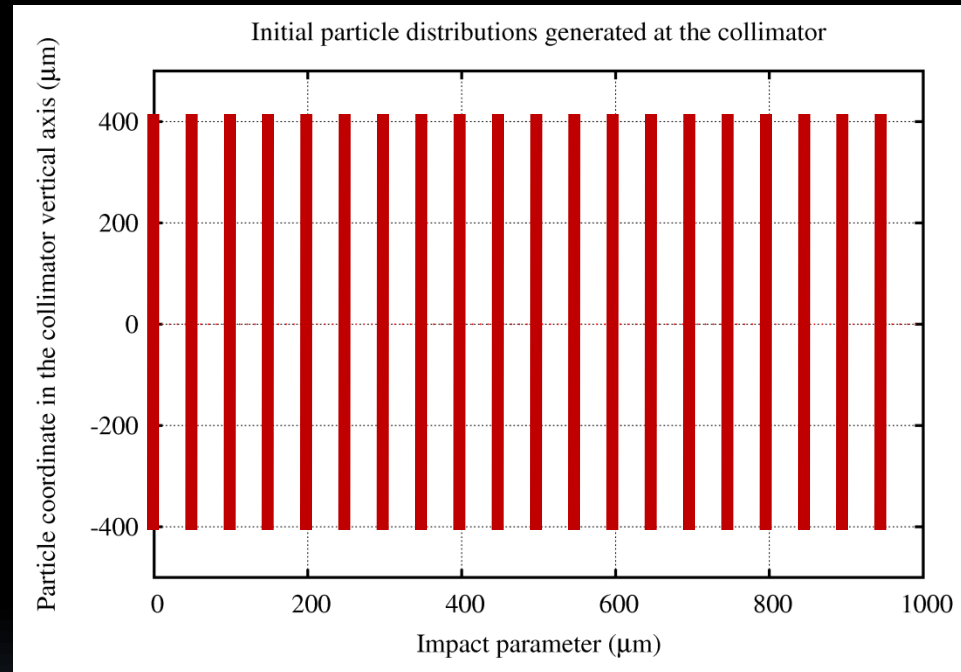


Evolution of scattered particles

- In case of failure, the average impact parameter of collimated particles can reach up to 620 μm (max of $\sim 5 \mu\text{m}$ during normal operation)
- The probability that a particle is scattered after an impact on a collimator depends on its impact parameter.
- Tracking with sixtrack (colltrack) to study this dependence

Procedure

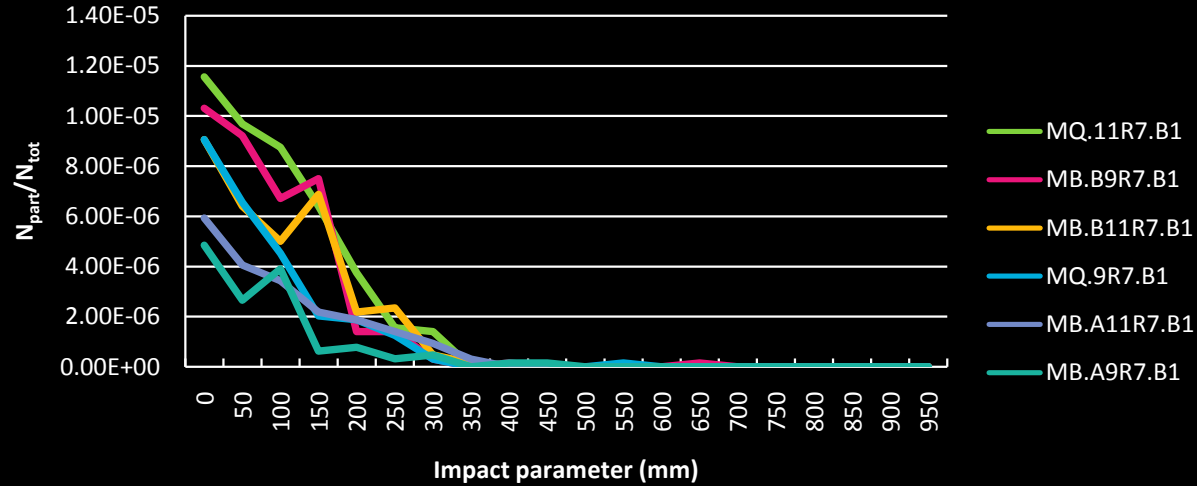
- Sheet beams at different impact parameters are generated (collimator reference frame)



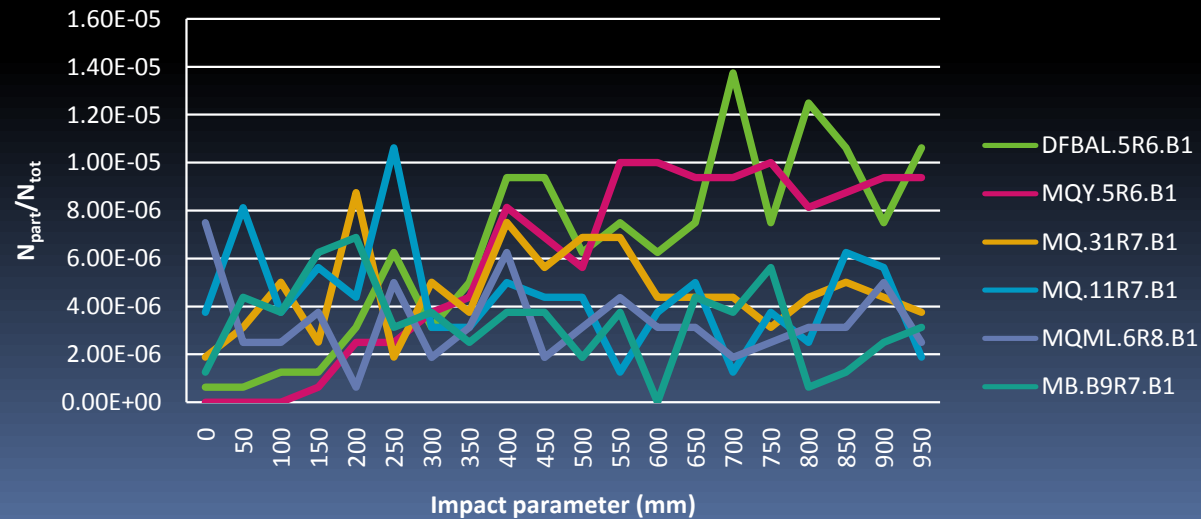
- Each sheet beam carries $1.6 \cdot 10^6$ particles, they are spaced by $50 \mu\text{m}$
- The scattered particles are tracked and losses are recorded for each initial impact parameter

Scattered protons hitting the cold aperture

Initial impact at TCP.C6L7.B1, collision optics

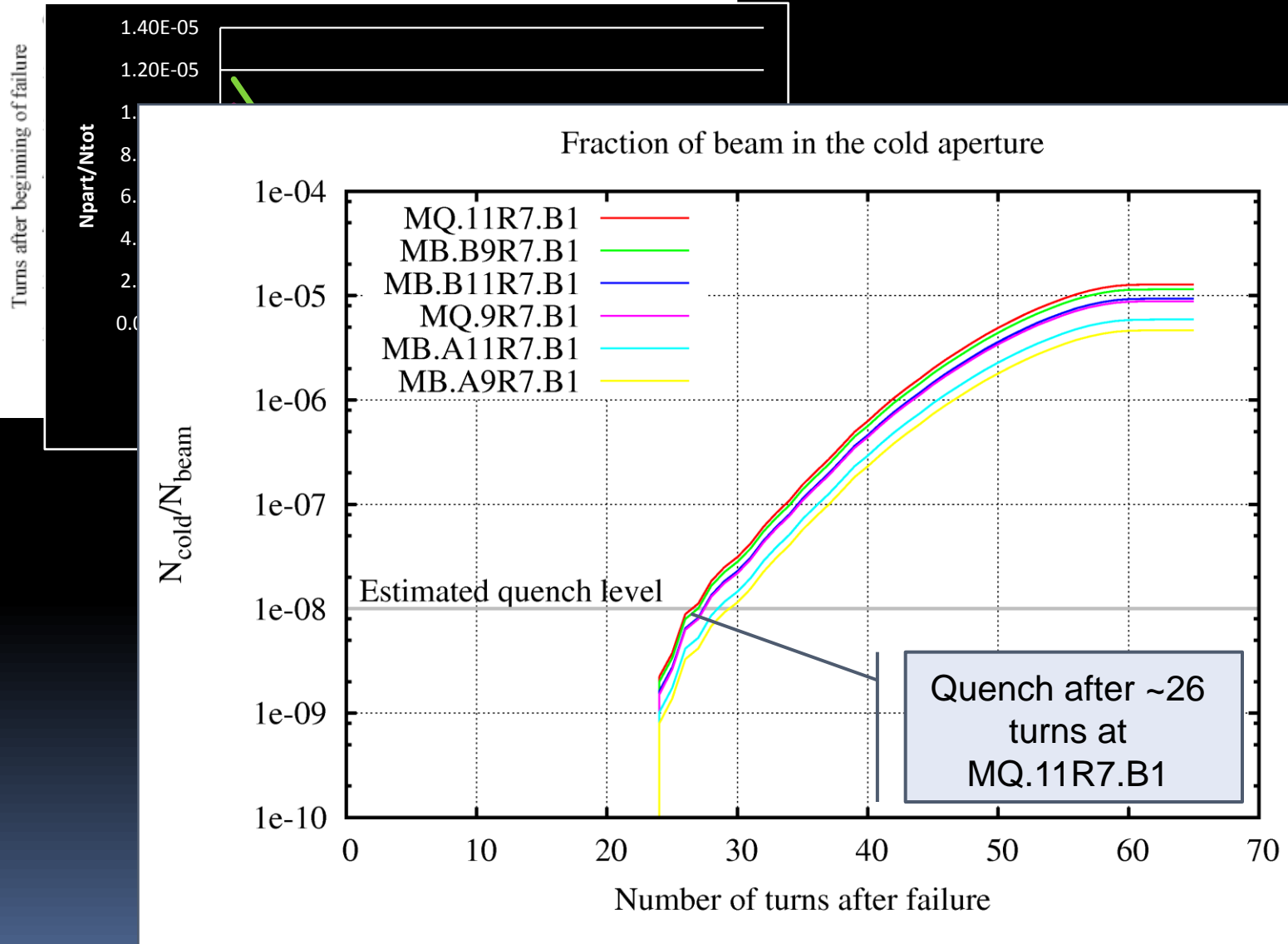


Initial impact at TCP.C6L7.B1, injection optics



Combination of the results


a: TCP.C6L7.B1. Failure at RD1.LR1 (0V, Collision) $\sigma_{\text{beam}}=0.278\text{mm}$



Summary, conclusions & outlook

- The **evolution of the impact distribution** has been successfully estimated for a number of relevant failures
- An exponential PDF allows an **analytical reconstruction** of the distribution with little stored data (**3 parameters only**)
- A sampled simulation using sixtrack has been done to estimate the **influence of the impact parameter** at the collimator **on the losses downstream**
- Combination of the time-dependent impact distribution and the data from the sixtrack simulations allows estimating the **quench time constant** for each failure scenario

- Challenge: **automatic treatment** of output data for all the failure scenarios
- **Time constants** for **damage** at collimators and **BLM detection** to be obtained from the impact distributions using FLUKA



Thank you for your attention
(and questions)

Quadrupole failures. Some observed effects

