Measurements of the effect of collisions on transverse beam halo diffusion in the Tevatron and in the LHC

Giulio Stancari

Fermi National Accelerator Laboratory

G. Annala, T. Johnson, V. Previtali, D. Still, A. Valishev (Fermilab), R. Assmann (DESY)
R. Bruce, F. Burkart, S. Redaelli, B. Salvachua, G. Valentino (CERN)

ICFA Workshop on Beam-Beam Effects in Hadron Colliders (BB2013)
CERN, 18-22 March 2013

Halo dynamics and accelerator performance

Halo dynamics influences global accelerator performance

- beam lifetime
- emittance growth
- dynamic aperture
- collimation efficiency

It depends on a multitude of effects, some of which are stochastic in nature

intrabeam scattering

lattice resonances

beam-gas scattering

coupling

ground motion

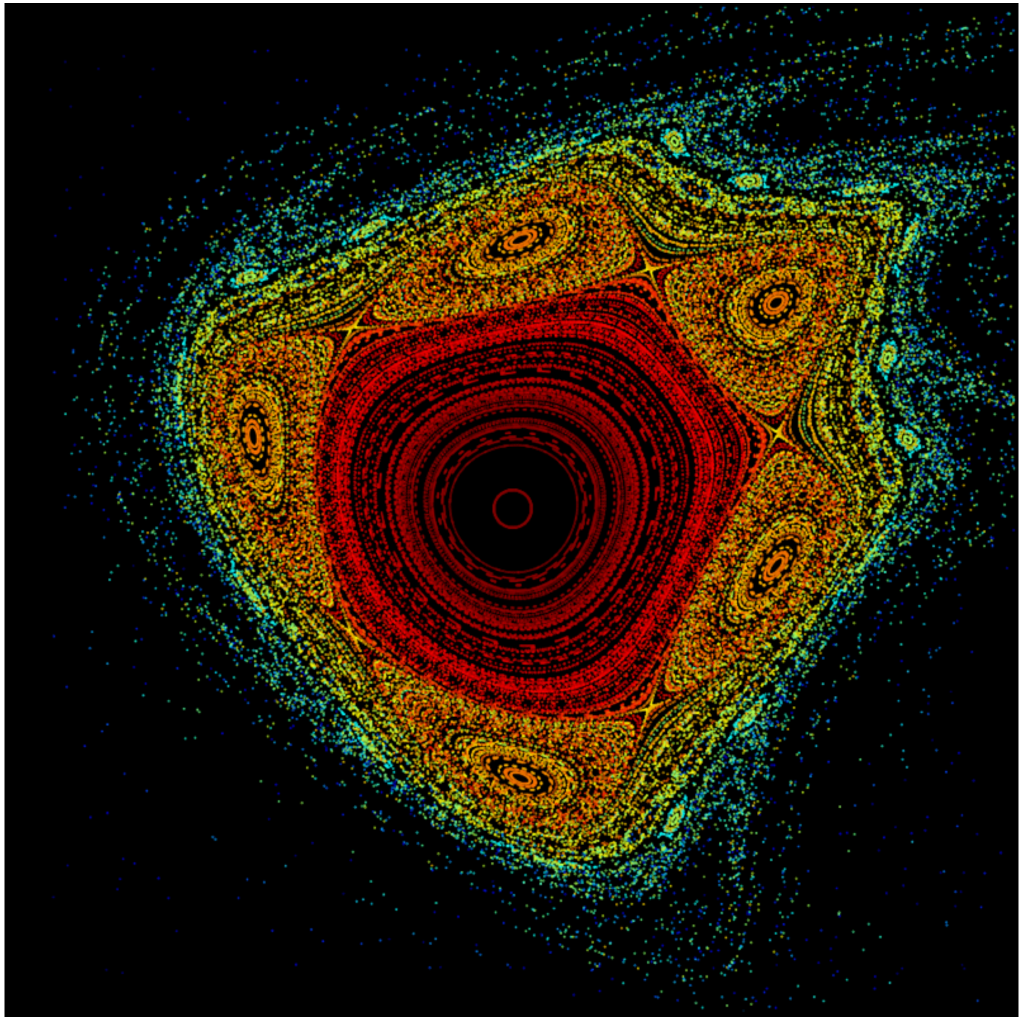
lattice nonlinearities

power-supply ripple

beam-beam forces

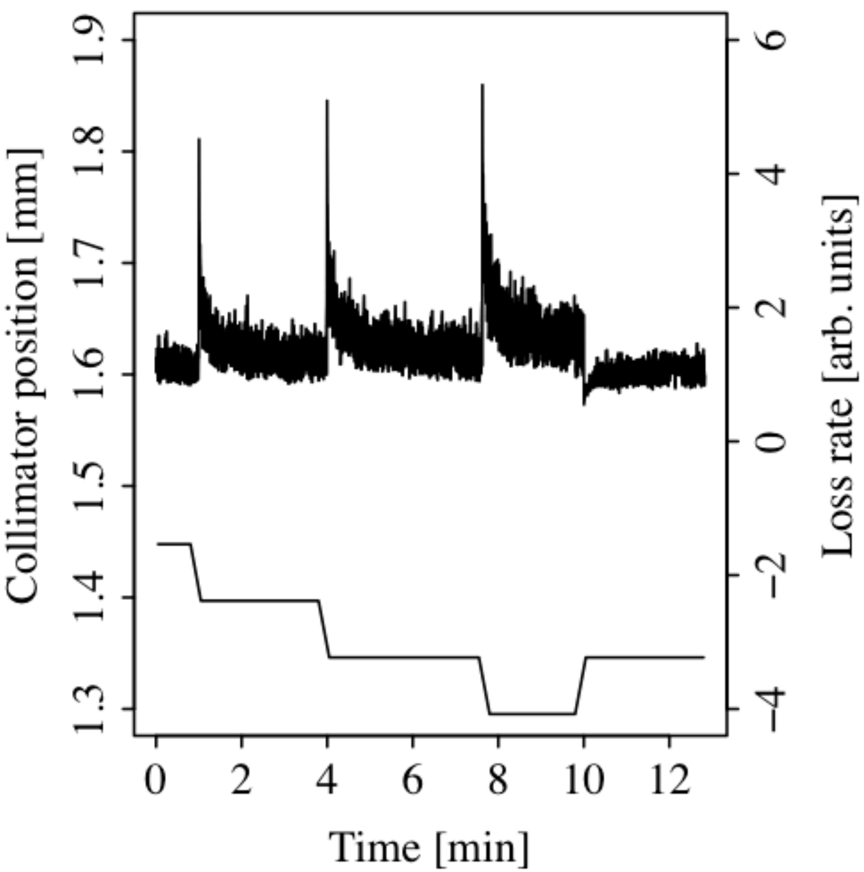
Stochastic character of halo dynamics

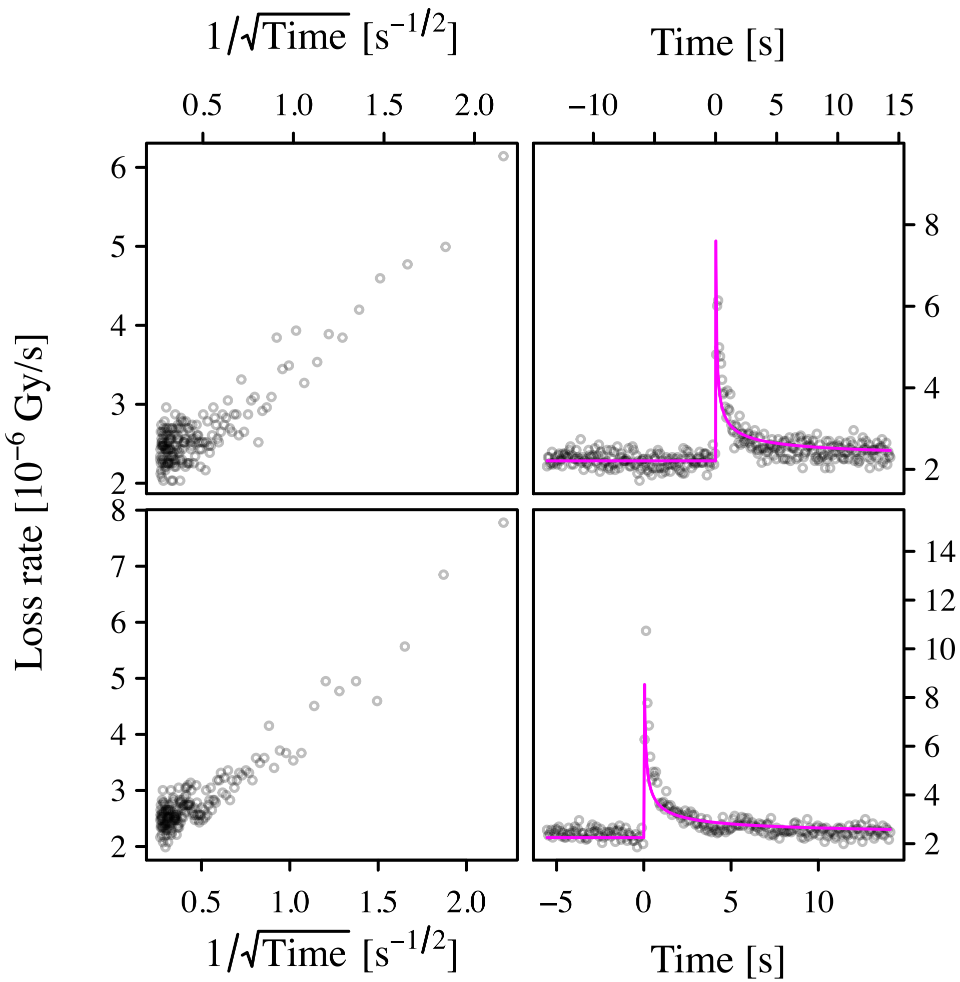
Dynamics is in general very rich: regular and chaotic regions, resonance islands, etc.



Superposition of many effects (some random) can make halo dynamics stochastic

Stochastic nature of halo dynamics often empirically confirmed by relaxation of losses ~ $(\text{time})^{-1/2}$ during collimator setup





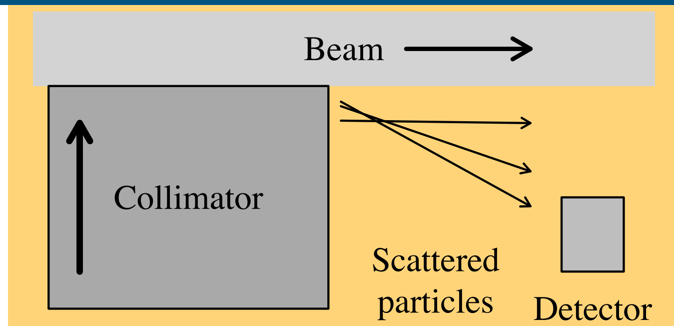
Analytical and numerical studies on collisions and halo dynamics

Just a few examples...

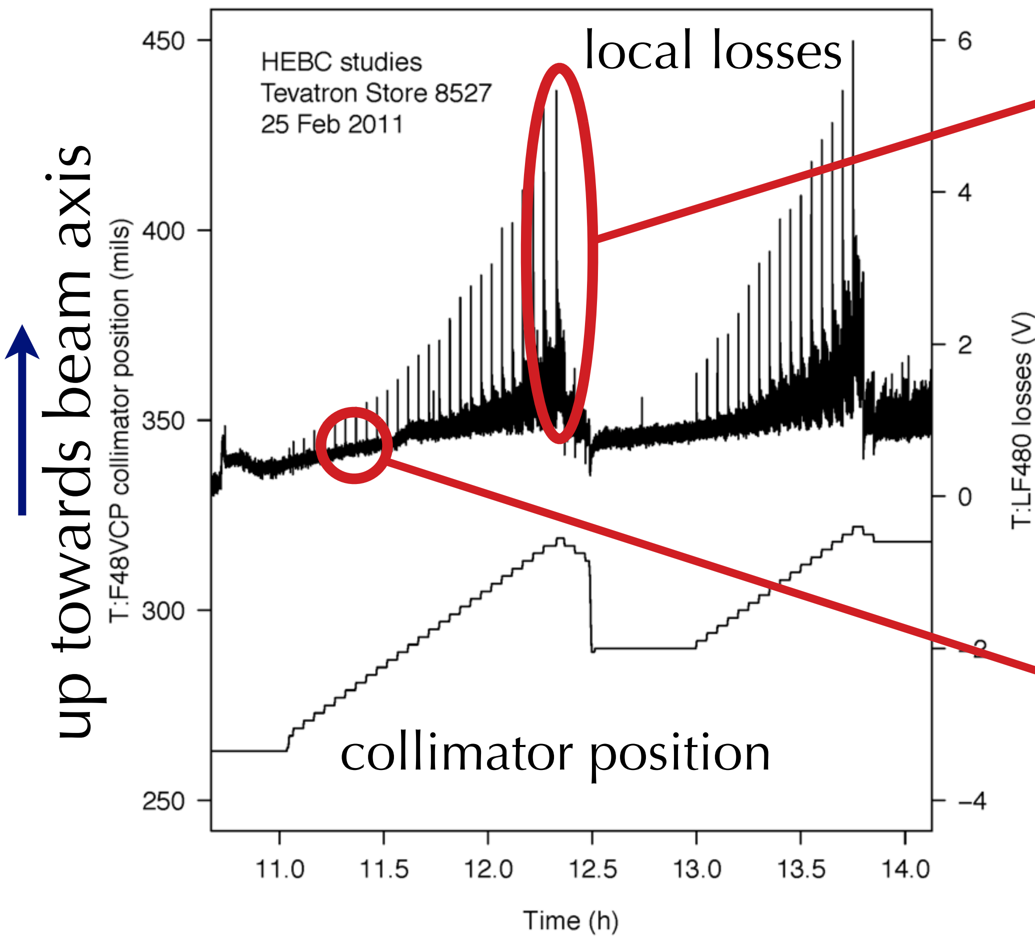
Experiments are challenging and data is scarce

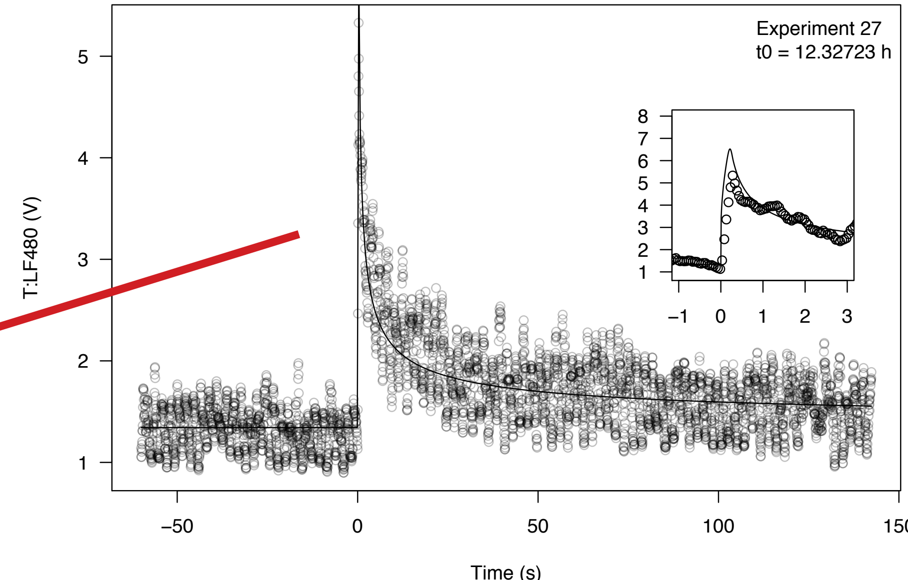
- **SSC**: *long-range, diffusive dynamic aperture*
  - Irwin, SSC-233 (1989)
- **HERA at DESY**: *nonlinearities, tune modulation, fluctuations in orbit offset and beam size*
  - Zimmermann, PhD Thesis (1993)
  - Brüning, PhD Thesis (1994)
  - Seidel, PhD Thesis (1994)
  - Zimmermann, Part. Accel. 49, 67 (1995)
  - Sen and Ellison, PRL 77, 1051 (1996)
- **LHC at CERN**: *head-on, long-range, triplet nonlinearities*
  - Papaphilippou and Zimmermann, PRSTAB 2, 104001 (1999)
  - Papaphilippou and Zimmermann, PRSTAB 5, 074001 (2002)
  - Assmann et al., EPAC (2002)
- **Tevatron at Fermilab**: *beam-beam, nonlinearities, electron lenses*
  - Sen et al., PRSTAB 7, 041001 (2004)
  - Stern et al., PRSTAB 13, 024401 (2010)
  - Previtali et al., IPAC (2012)
- **RHIC at BNL**: *beam-beam, nonlinearities, electron lenses*
  - Abreu et al., BNL-81974-2009-IR, BNL-81975-2009-IR (2009)
- **Beam / electron cloud**:
  - Ohmi and Oide, PRSTAB 10, 014401 (2007)

Measurement of diffusion rate vs. amplitude with collimator scans

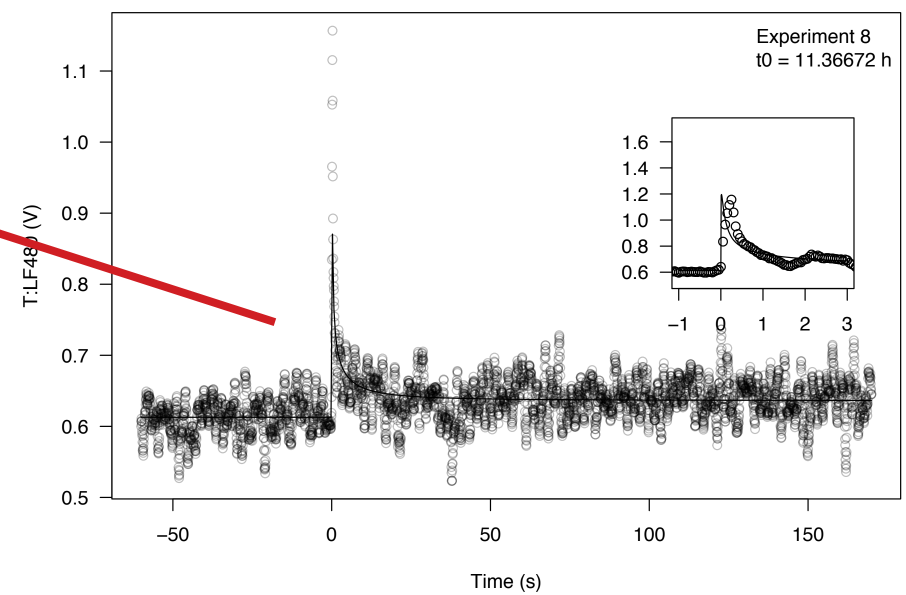


Mess and Seidel, NIMA **351**, 279 (1994)

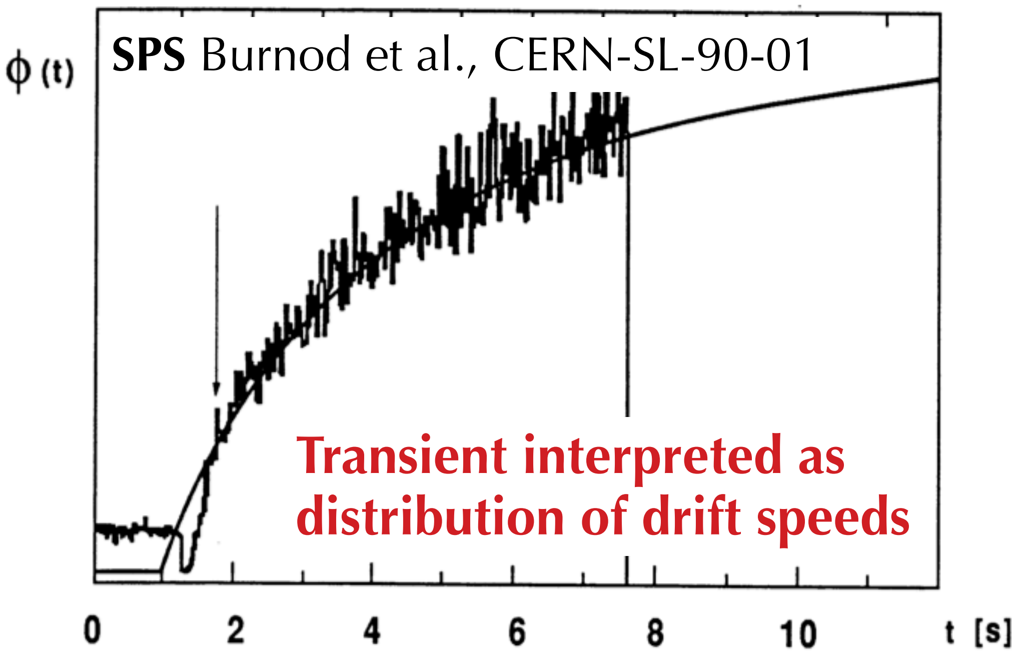


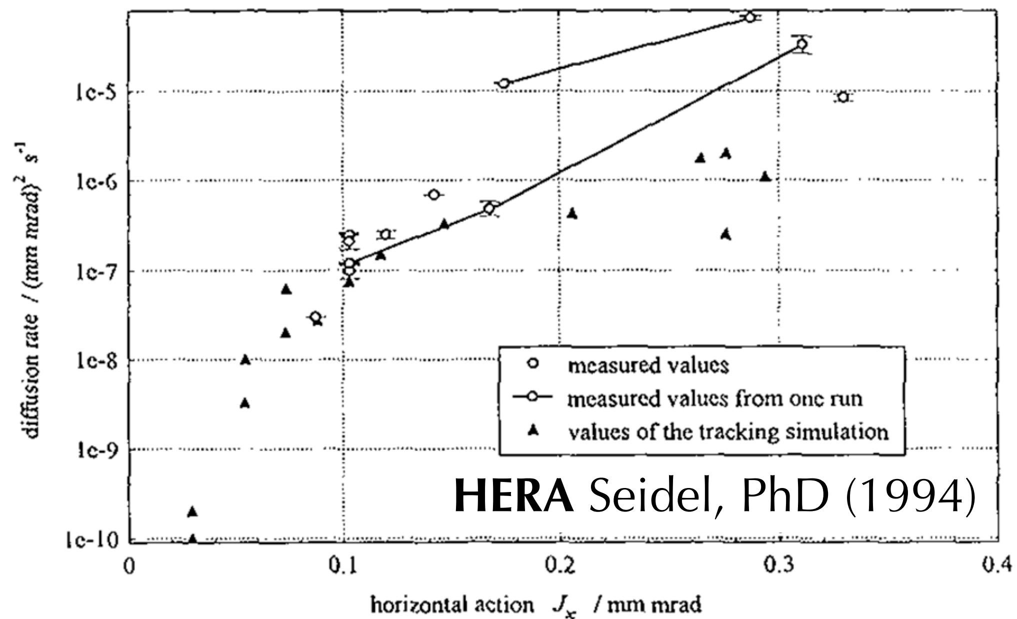


Transient is faster at
large amplitudes (higher diffusion rate)

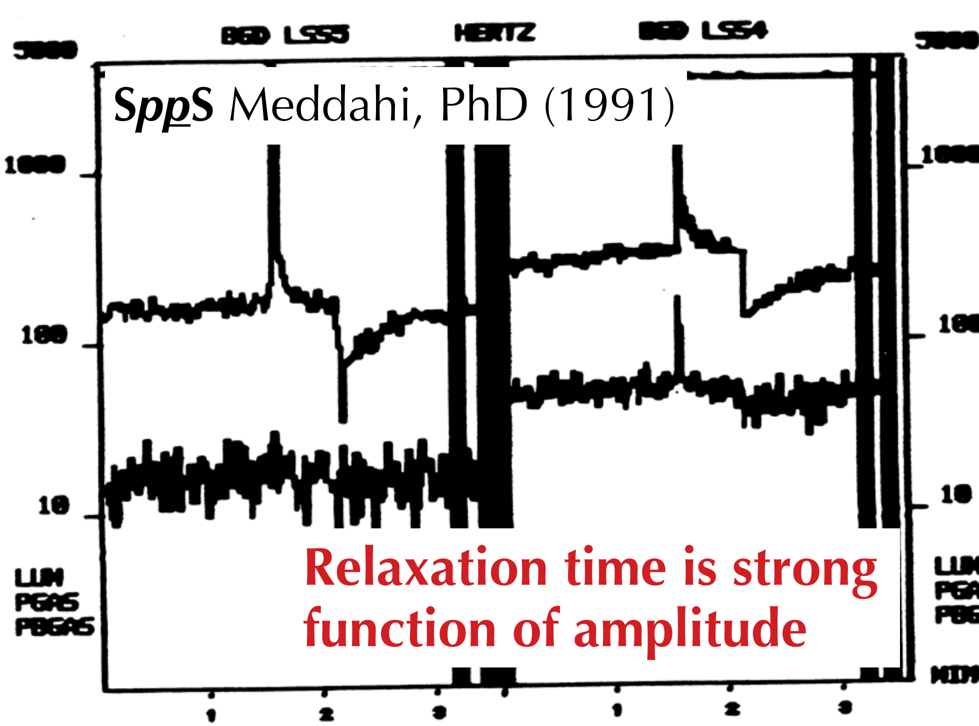


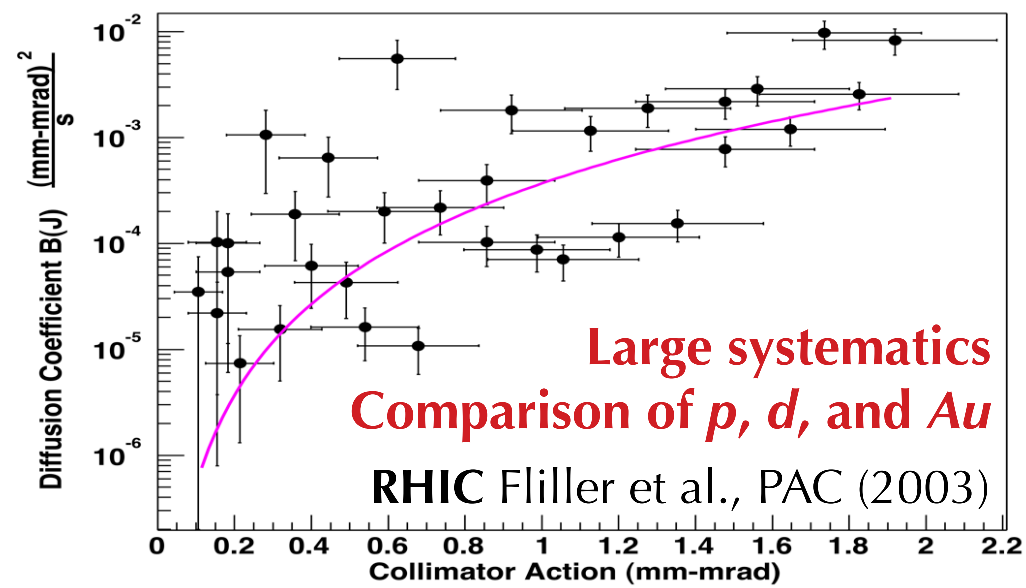
Stancari et al., IPAC11, p. 1882
Stancari, arXiv:1108.5010 [physics.acc-ph]



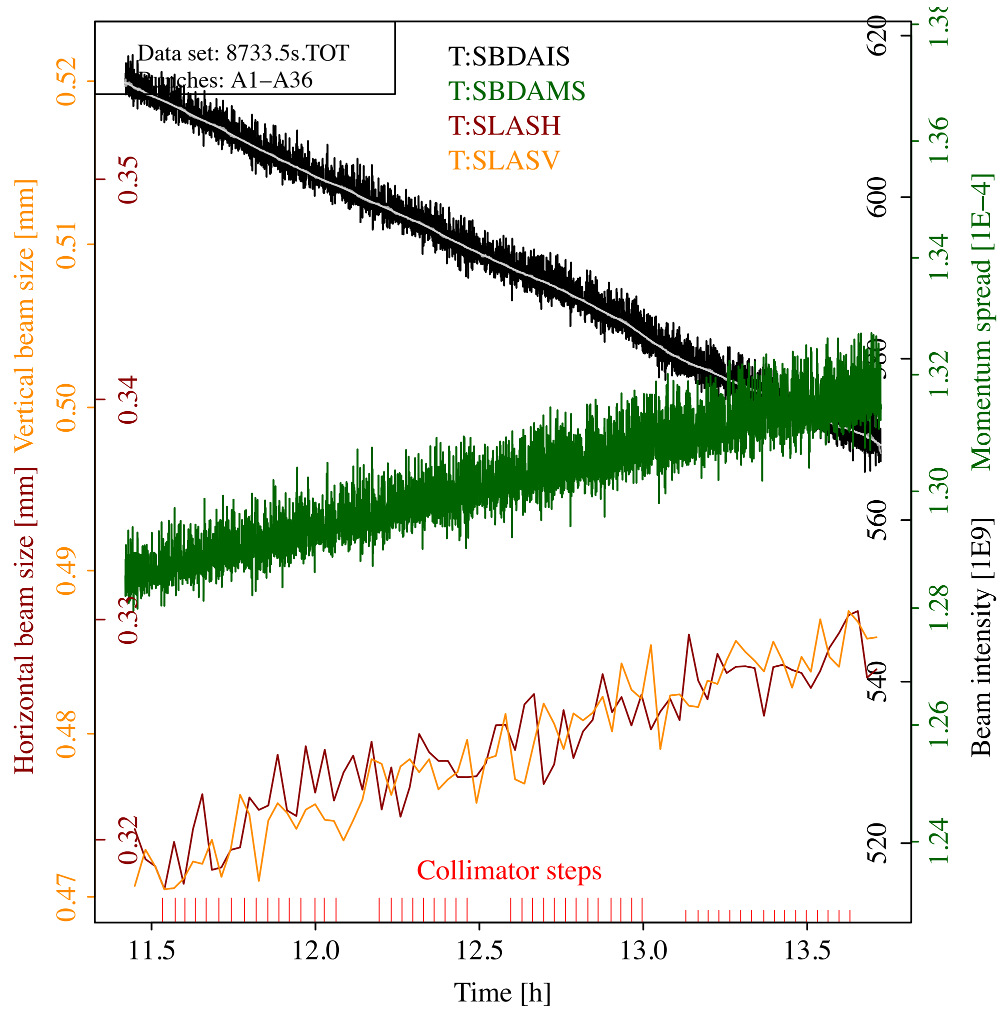


Calculated beam-beam + tune modulation close to measured diffusion rate





Tevatron measurements

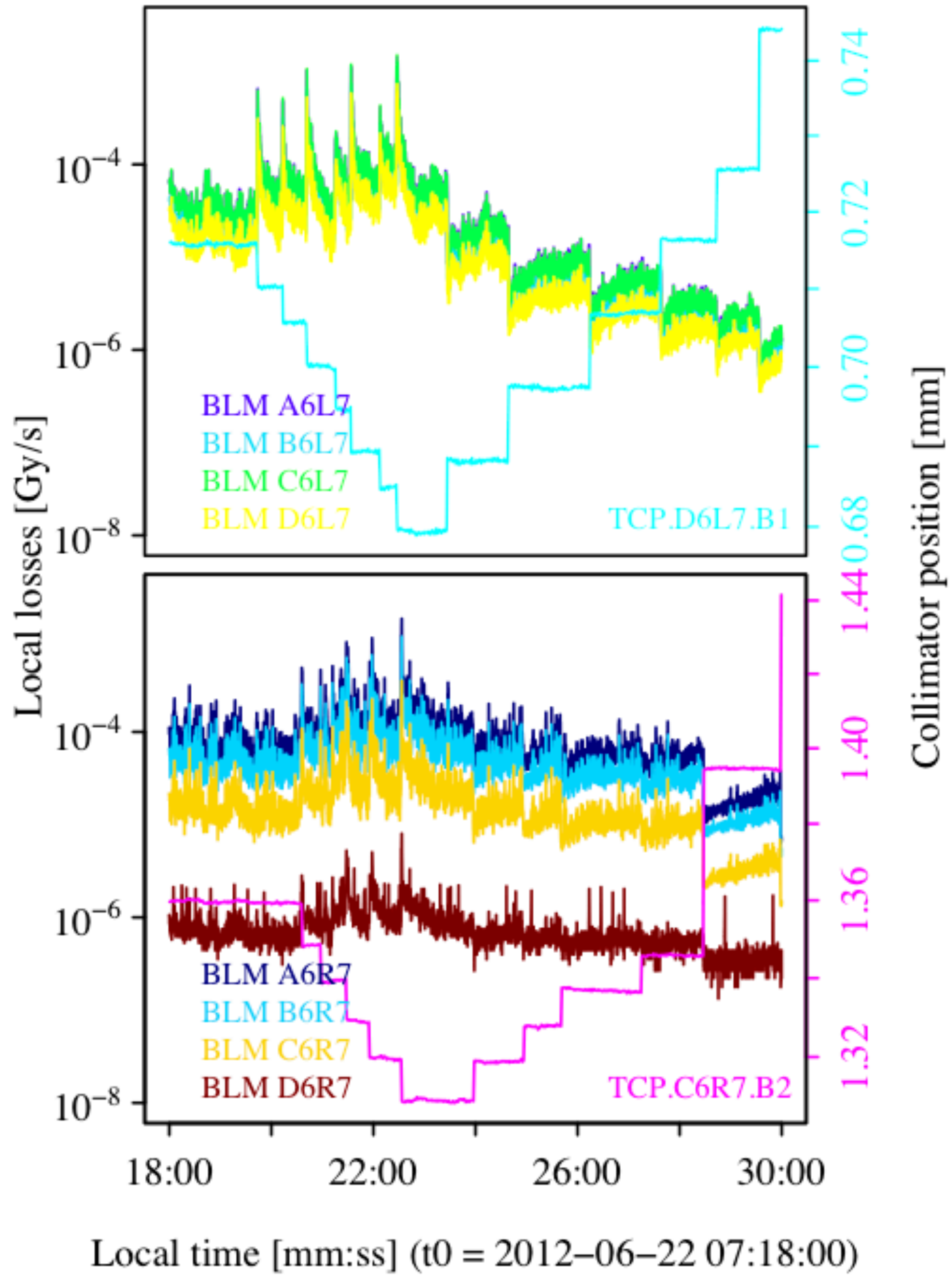


- Beam studies with antiprotons at 0.96 TeV (Feb-May 2011)
- Motivated by hollow electron beam collimator and beam-beam dynamics
- Many experiments at the end of regular collider stores
- One experiment with special antiproton-only store
- Scans using primary vertical collimator on antiprotons
- Minimum step: 25 μm in 20 ms

Stancari et al., IPAC11, p. 1882
Stancari, arXiv:1108.5010 [physics.acc-ph]

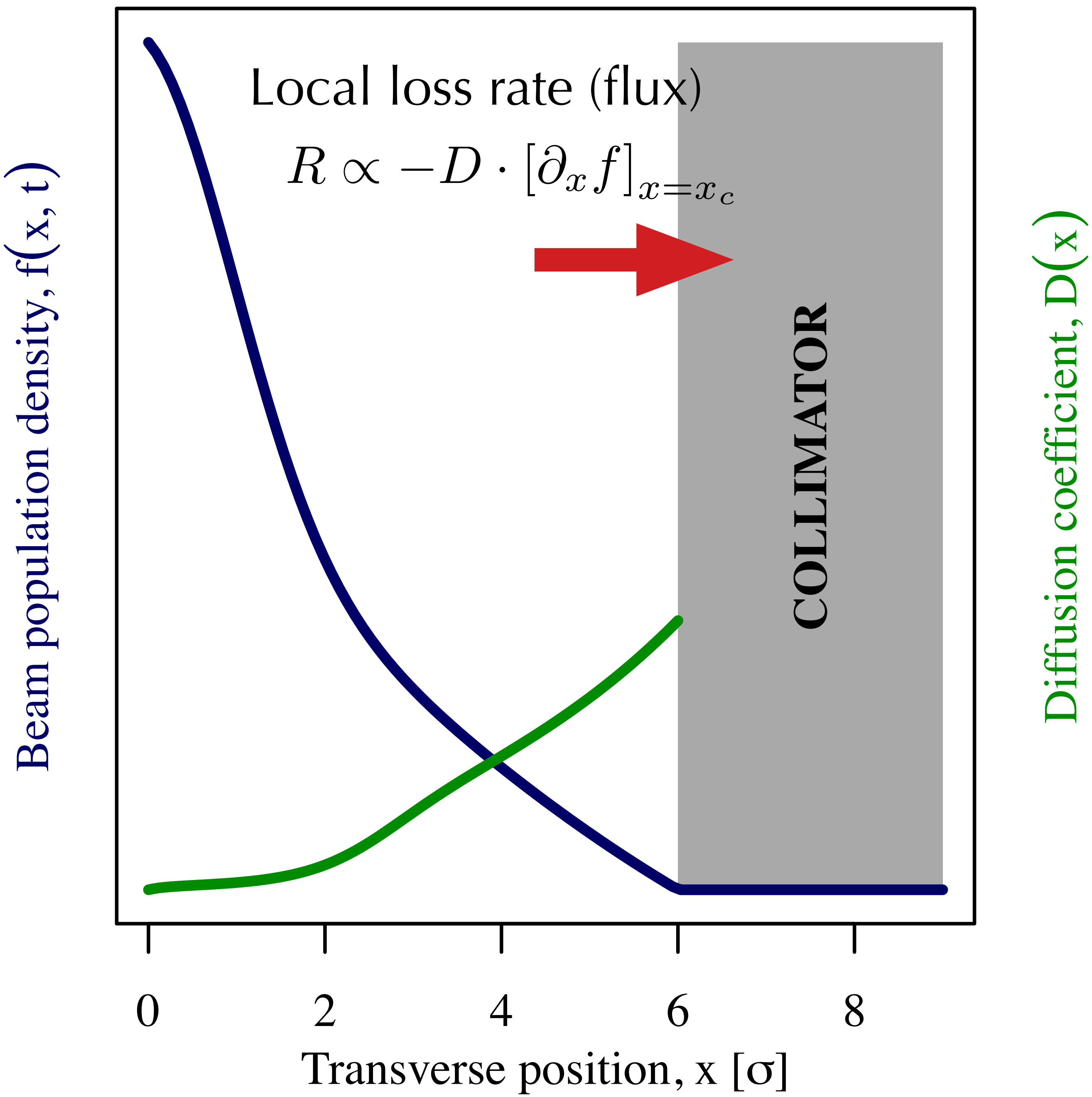
LHC measurements

- Beam studies at 4 TeV (22 June 2012)
- One nominal bunch per beam, 10^{11} *p*/bunch (no long-range)
- Scans using primary collimators: vertical on beam 1, horizontal on beam 2
- 1 scan with separated beams, 1 scan in collision
- Minimum step: 5 μm in 2.5 ms



Valentino et al.,
PRSTAB **16**, 021003 (2013)

1-dimensional diffusion cartoon of collimation



Diffusion model of loss rate evolution in collimator scans

Distribution function of tails evolves under diffusion with boundary condition at collimator

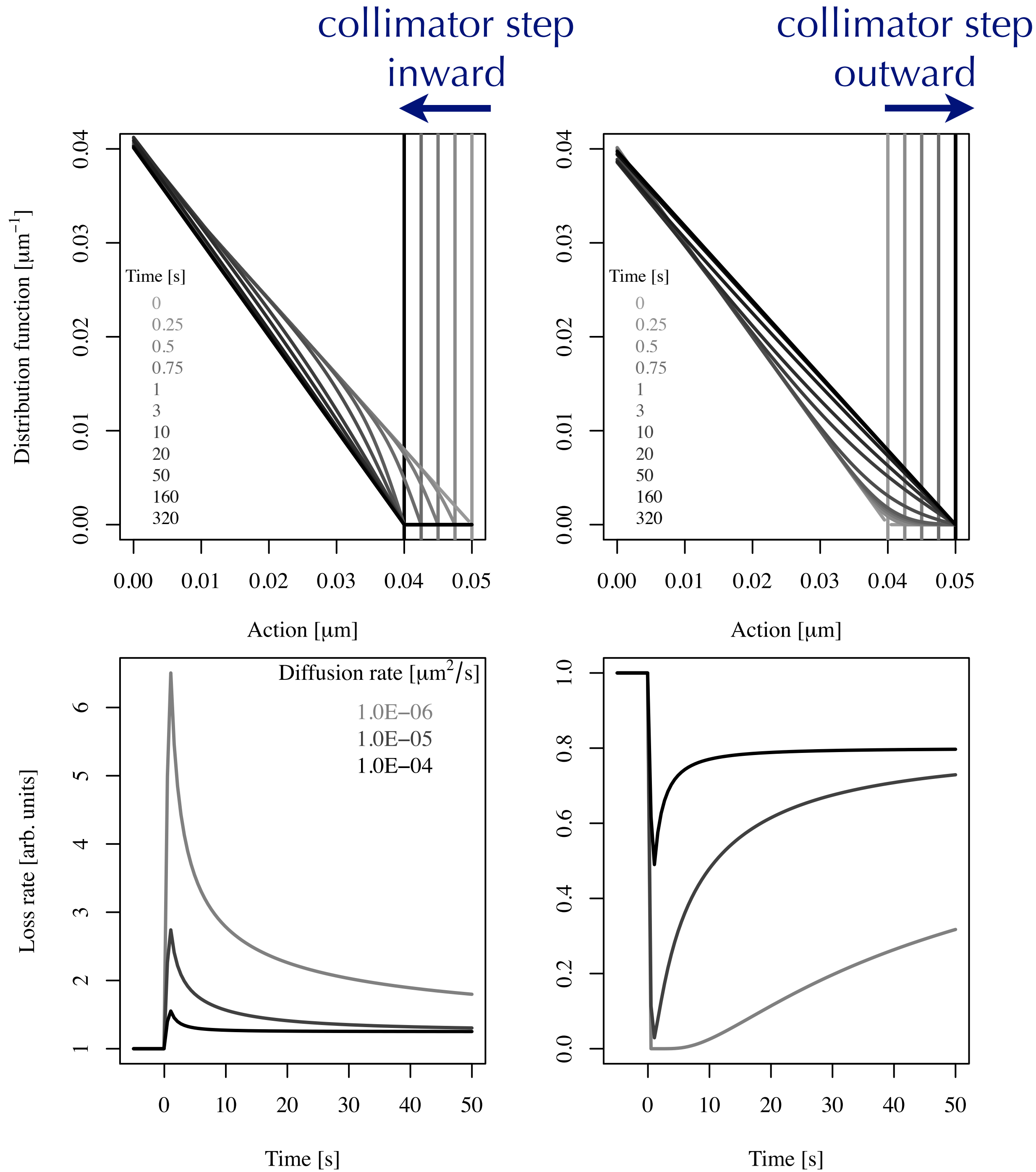
$$\partial_t f = \partial_J \left(D \cdot \partial_J f \right)$$

Instantaneous loss rate is proportional to slope of distribution function

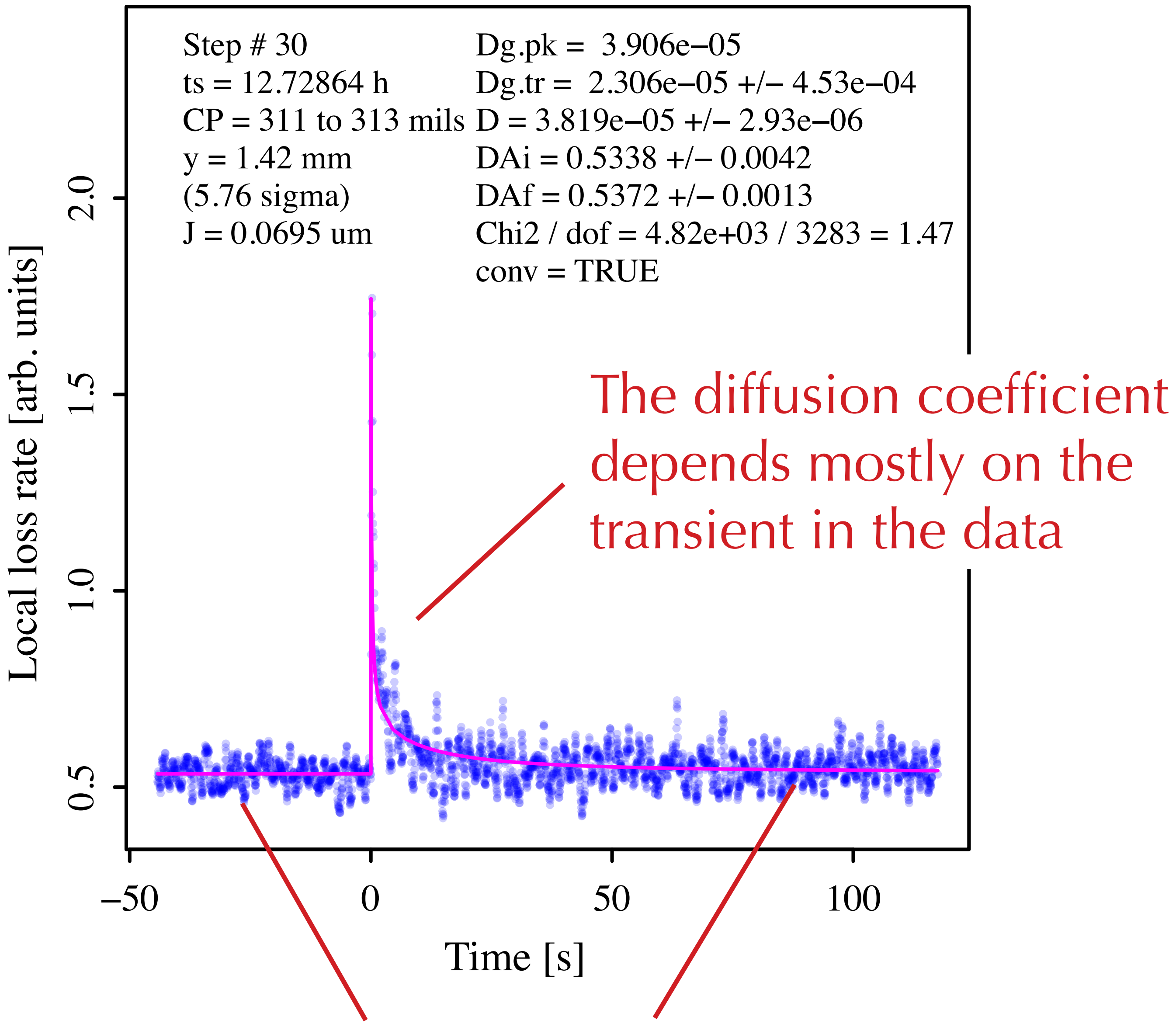
$$R = -k \cdot D \cdot \left[\partial_J f \right]_{J=J_c} + B$$

loss monitor calibration (k)

background rate (B)

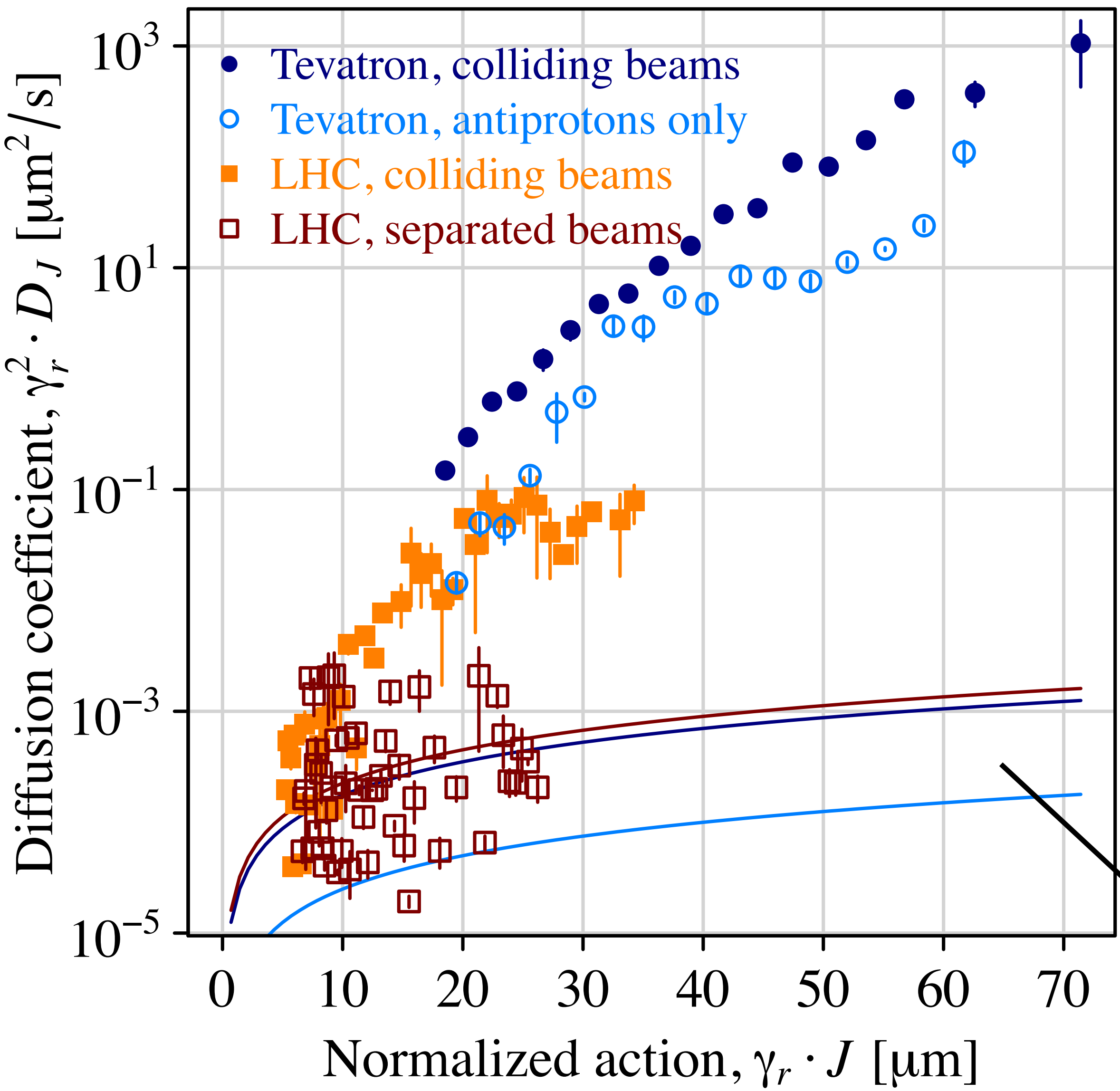


Diffusion model fit to loss rate data



Particle fluxes before and after the step are determined by the steady-state loss levels

Beam halo diffusion rates in the Tevatron and in the LHC



Effect of beam-beam is 1-2 orders of magnitude

Halo diffusion in Tevatron dominated by effects other than beam-beam

Very low noise and nonlinearities in LHC

curves from measured core emittance growth

$$D_J = \dot{\varepsilon} \cdot J$$

Conclusions

- **Halo dynamics** is often **stochastic**, due to the nature and number of effects in real machines
- **Collimator scans** are a sensitive tool for the study of **halo dynamics vs. amplitude**: diffusion coefficients, lifetimes/fluxes, impact parameters, collimation efficiencies, beam populations
- **First measurements of diffusion vs. amplitude** in Tevatron and LHC
- **Tevatron**
  - halo dynamics dominated by effects other than beam-beam
  - collisions enhance diffusion rate by 1 to 2 orders of magnitude
- **LHC**
  - with separated beams, halo diffusion very similar to core: nonlinearities and noise are small
  - in collision (only 1 bunch/beam), diffusion enhancement depends on amplitude, reaching 2 orders of magnitude

Thank you!