*Accelerator Performance Committee meeting*

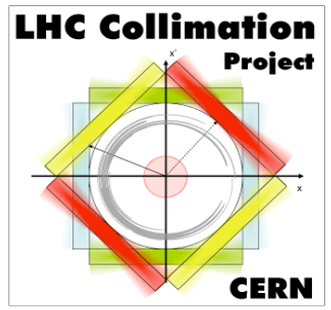
*Geneva, 16 February 2006*

# Beam Loss Patterns at the SPS during the LHC collimator test

**Stefano Redaelli, AB - OP**

*in collaboration with*

*G. Arduini, R. Assmann and G. Robert-Demolaize*

# Motivation for the LHC collimation project

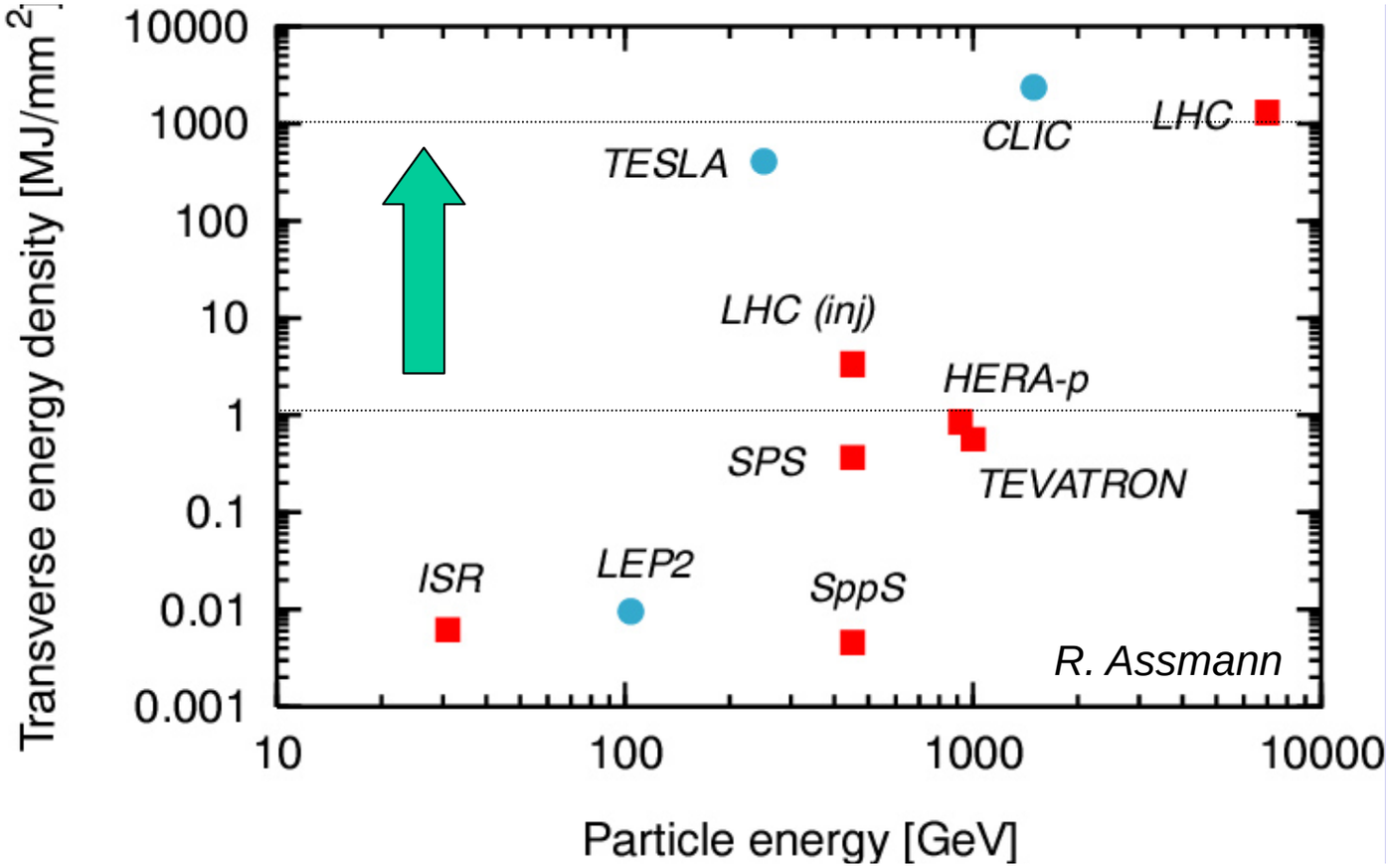
***Understanding beam losses is crucial for the LHC!***

LHC beams, 7 TeV:
2 x 360 MJ stored energy!

→ High damage potential

→ Quench SC magnets

*Local losses in cold magnets*
***< $10^{-7}$-$10^{-9}$*** *of beam intensity!*




Cleaning efficiency:
≈1000 times better
than the state-of-the-art!

We need better simulation tools!

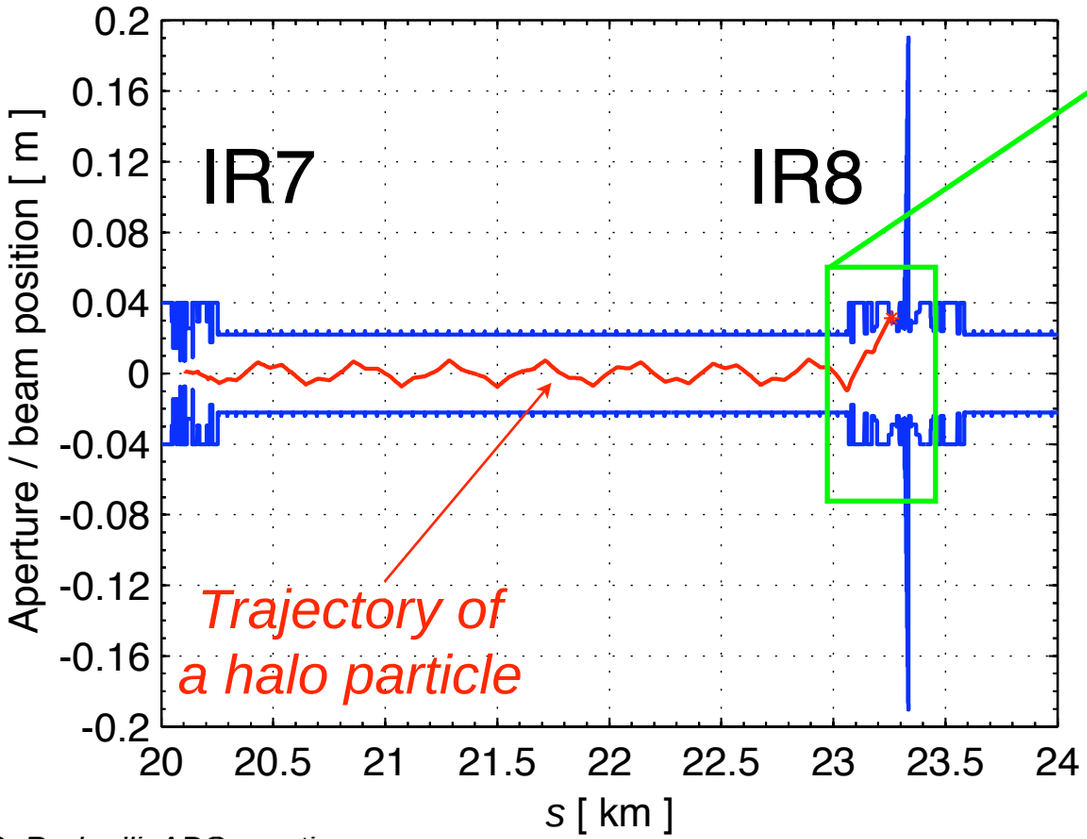
→ ***Benchmark with SPS data!***

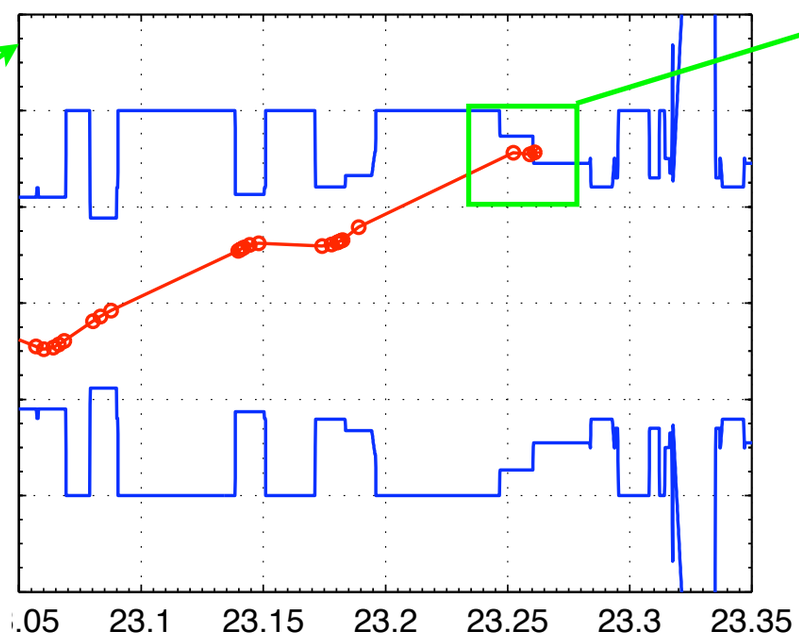
# Overview of my talk

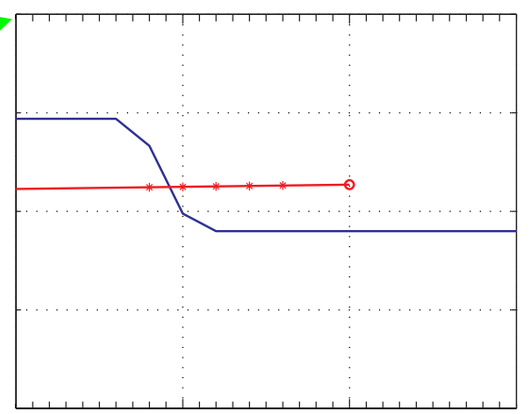
- **Tools for loss map studies**
- **SPS simulations**
- **Measurement of loss maps**
- **Comparison with simulations**
- **Conclusions / outlook**

# LHC loss map simulations

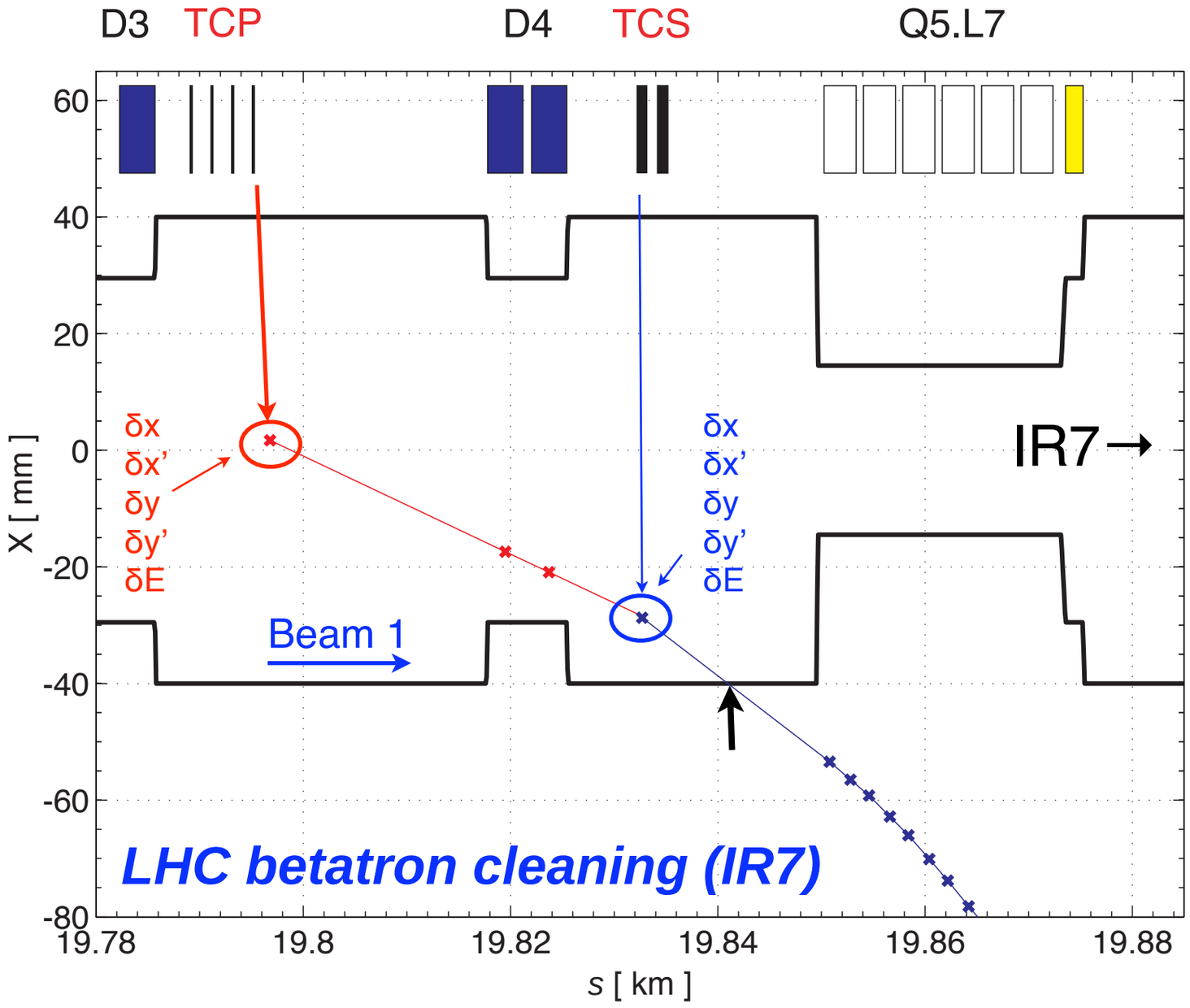
| | |
|---|---|
| **Accurate tracking of halo particles**<br>6D dynamics, chromatic effects, δp/p, high order field errors, ... | **SixTrack** |
| **Scattering routine**<br>Track protons inside collimator materials | **K2** |
| **Detailed collimator geometry**<br>Implement all collimators and protection devices, treat any azimuthal angle, tilt/flatness errors | |
| **Detailed aperture model**<br>Precisely find the locations of losses | **BeamLossPattern** |

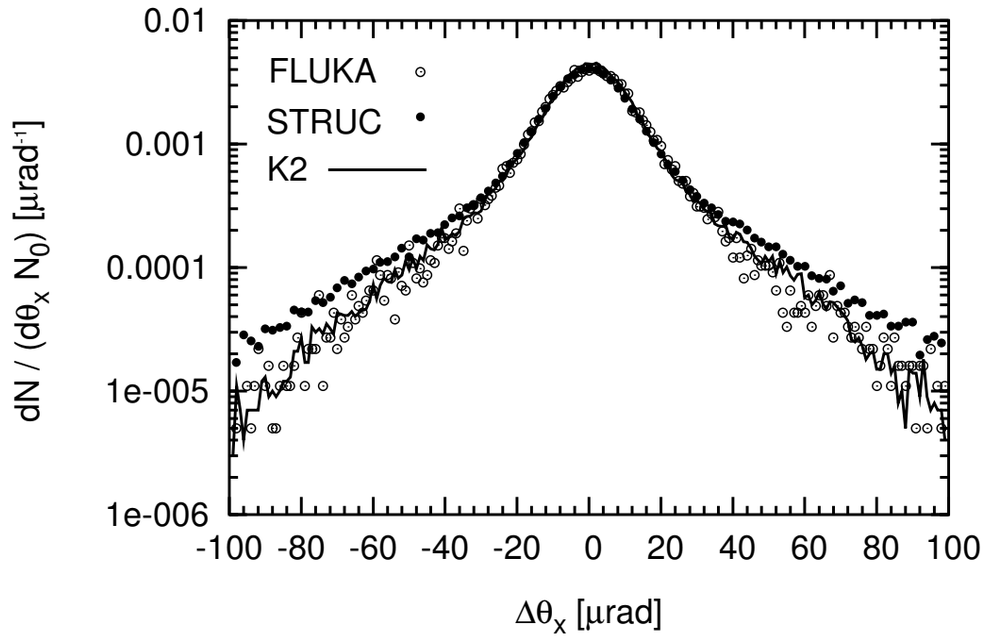


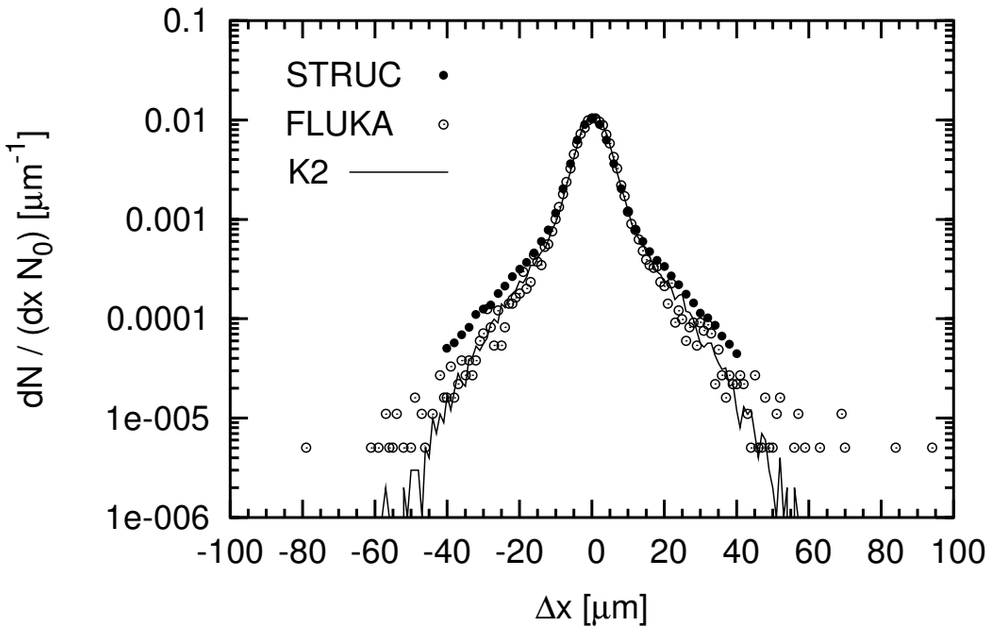



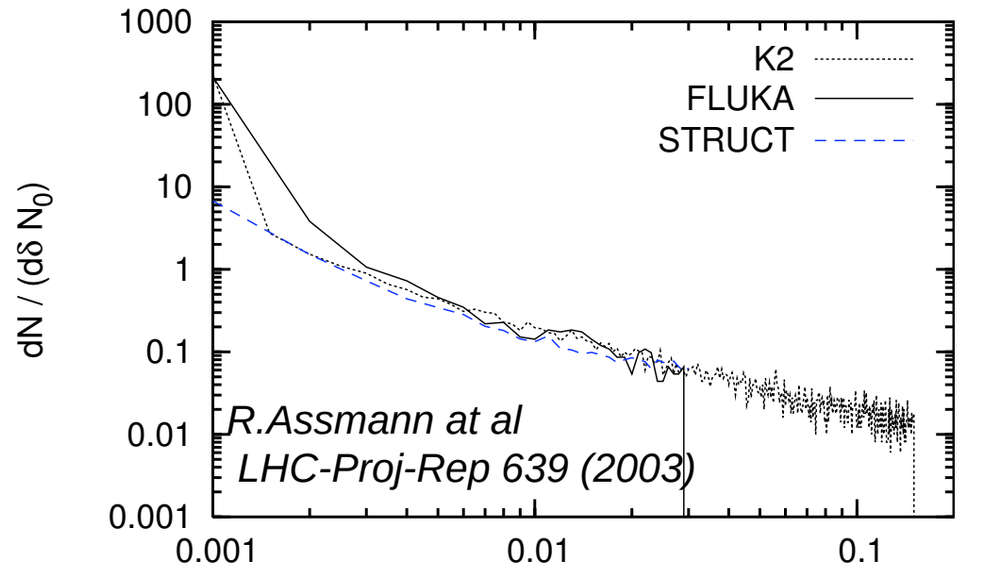



Interpolation: Δs=10cm
(270000 points!)



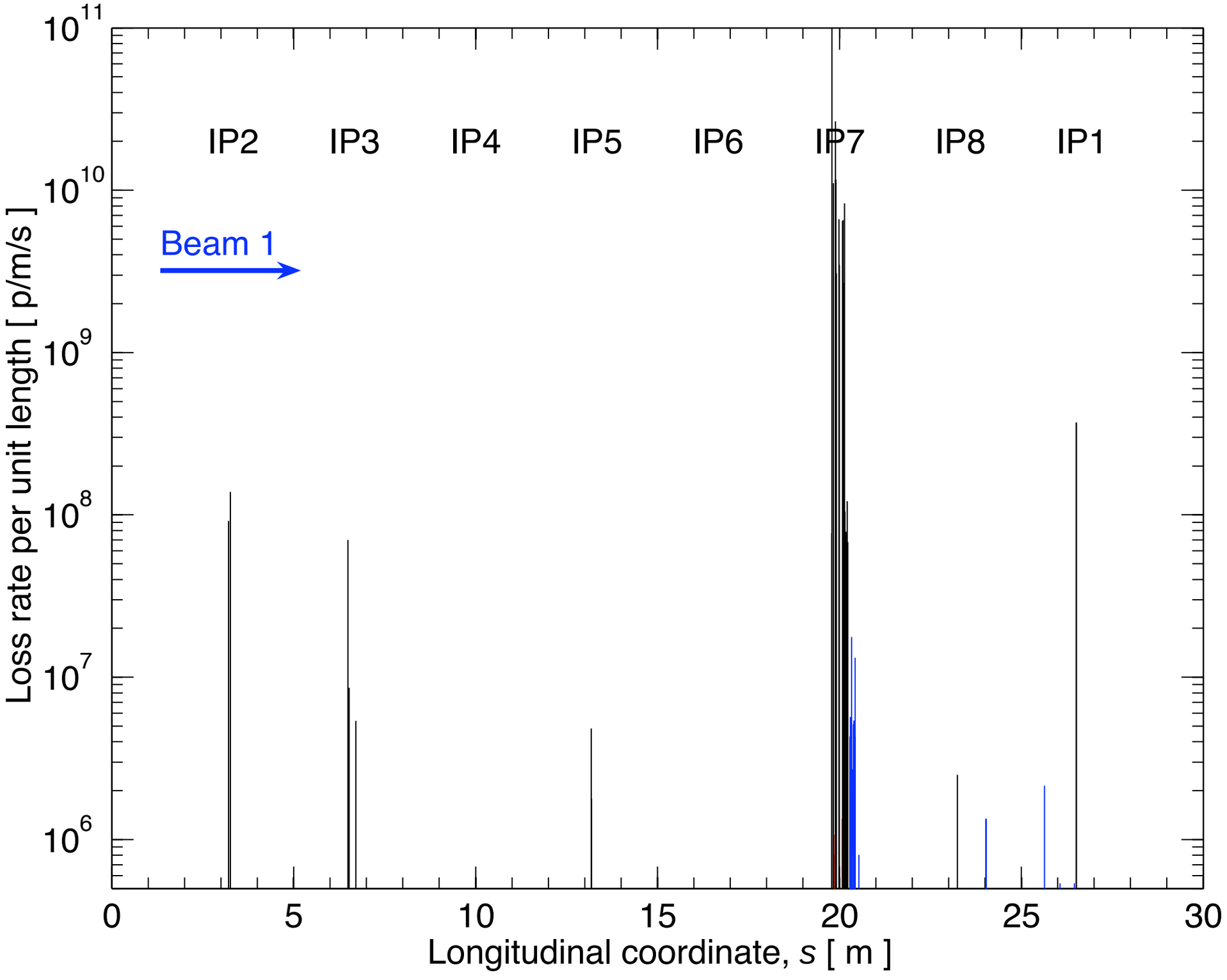



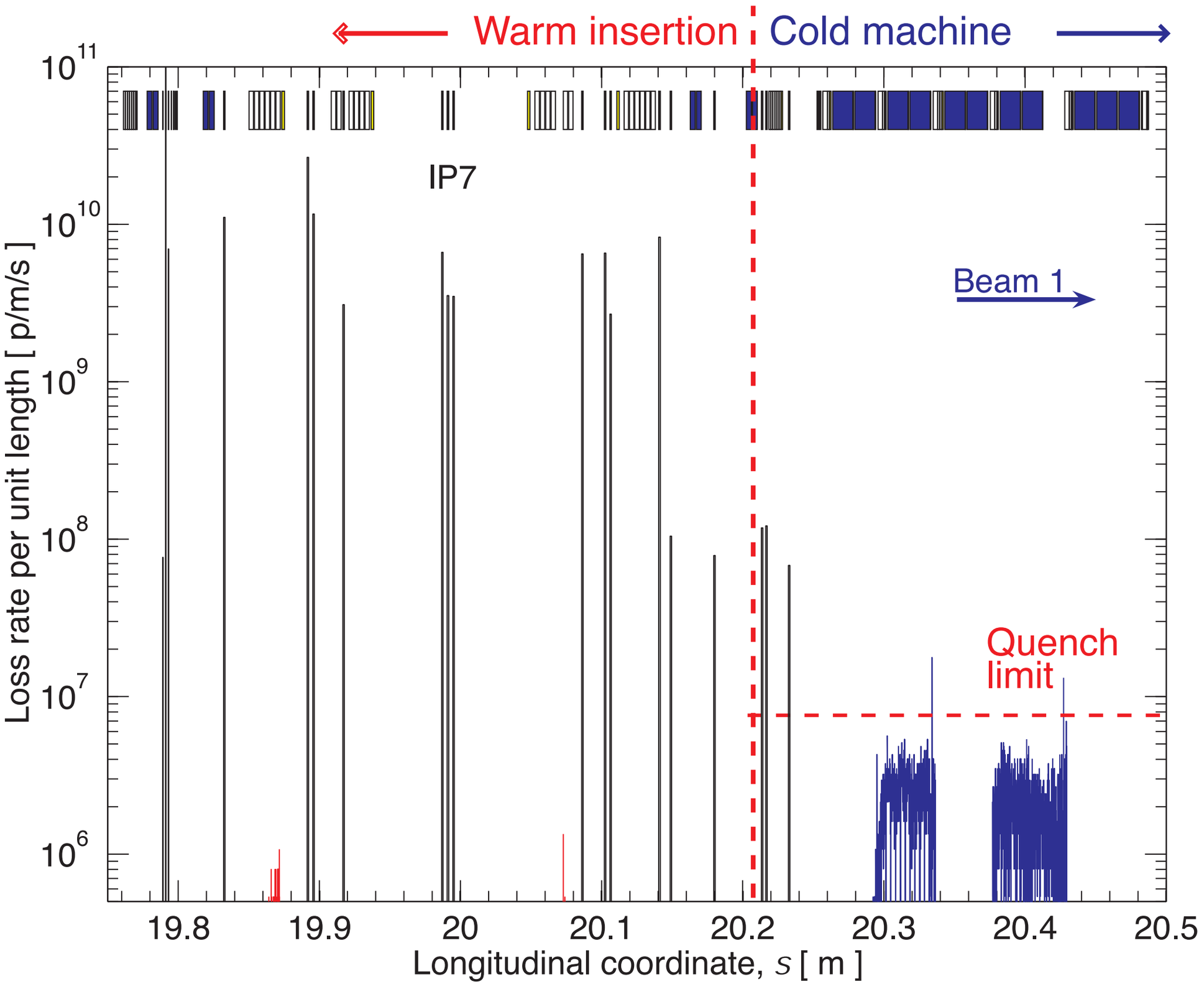

- *Scattering routine called within tracking at each collimator*
- *If particle touches jaw, calculate absorption, offsets, scattering angles and energy error*
- *Trajectories of halo particles saved for off-line aperture analysis (Δs < 10 cm)*

# Example of LHC loss patterns



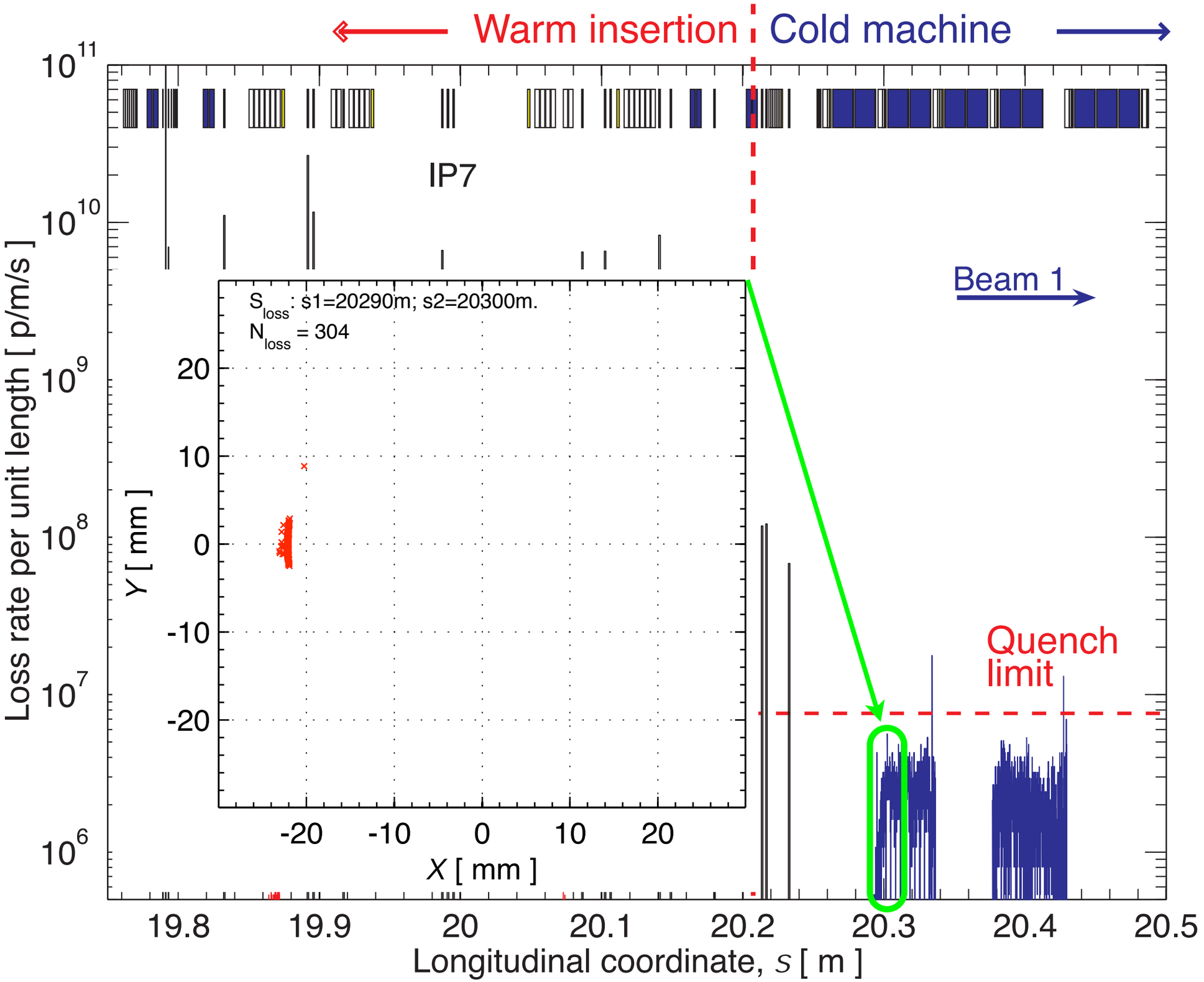

***Cross-check the validity of these results with SPS measurements!***

# Example of LHC loss patterns




***Cross-check the validity of these results with SPS measurements!***

# Example of LHC loss patterns

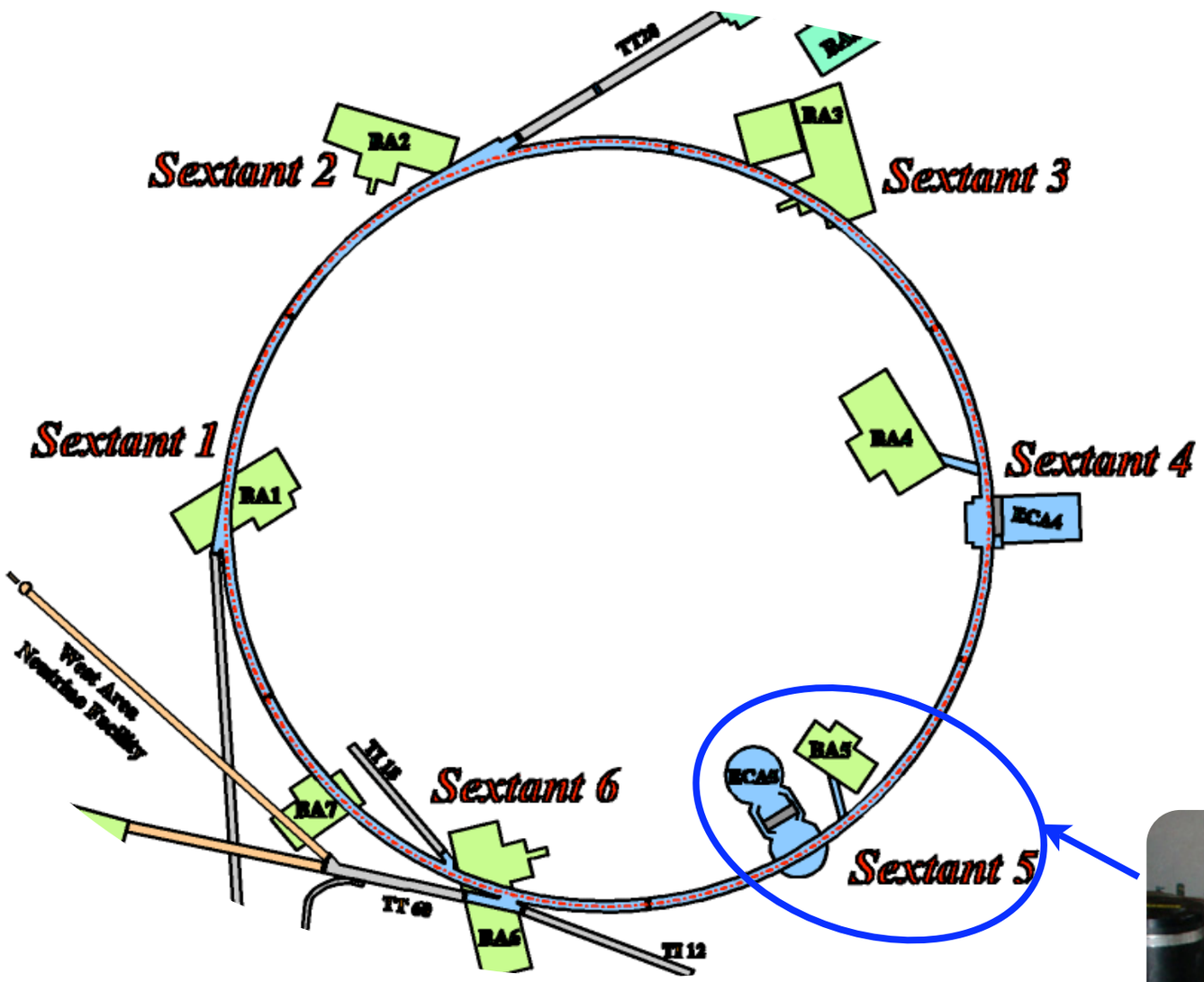


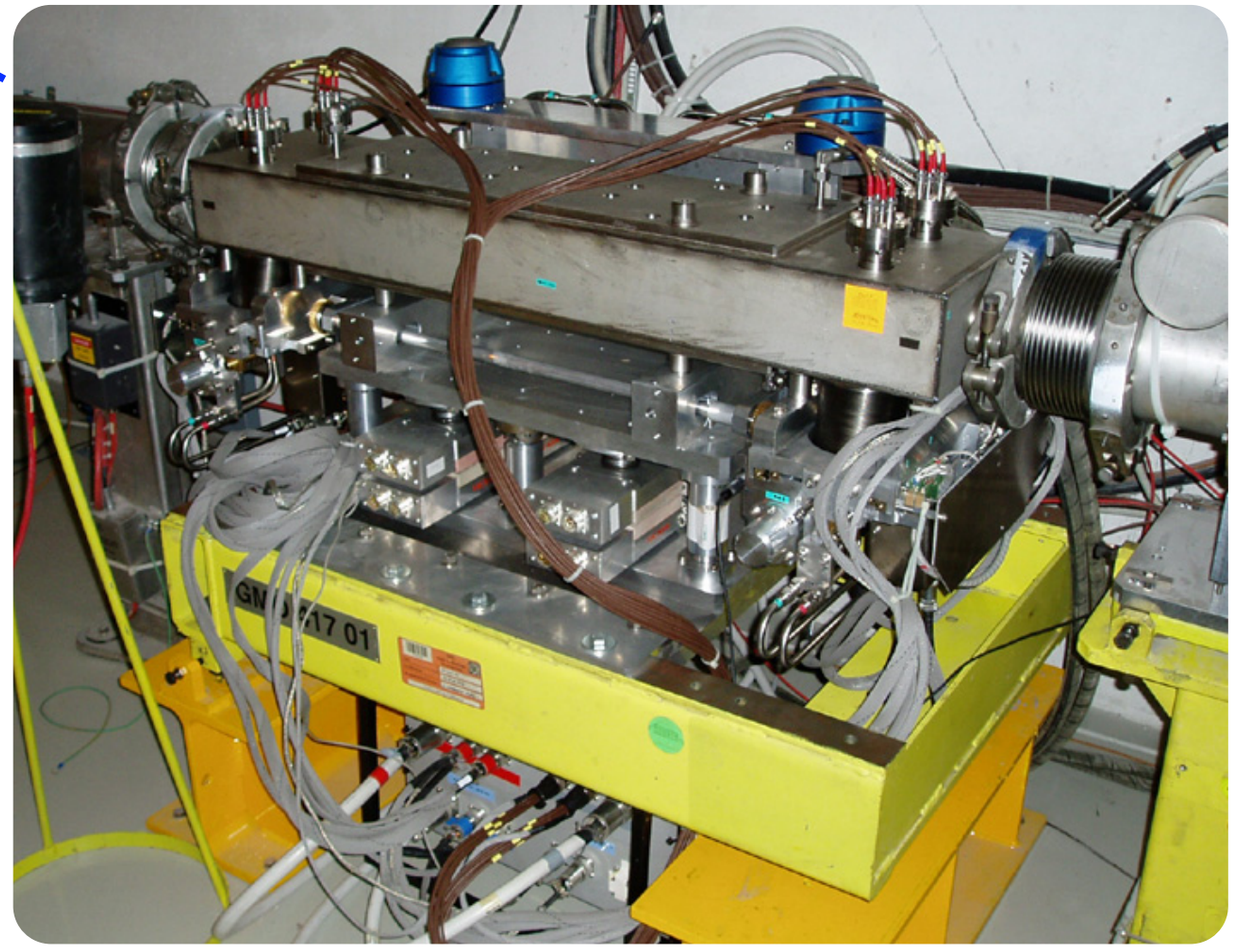

***Cross-check the validity of these results with SPS measurements!***

- Tools for loss map studies
- **SPS simulations**
- Measurement of loss maps
- Comparison with simulations
- Conclusions / outlook

# SPS layout for the 2004 collimator test

to be implemented in simulations



*A horizontal LHC collimator prototype (full mechanical functionalities) installed in SS5 for tests with beam in 2004!*

# SPS optics and aperture model

**Main beam parameters**

βx = 24.9m

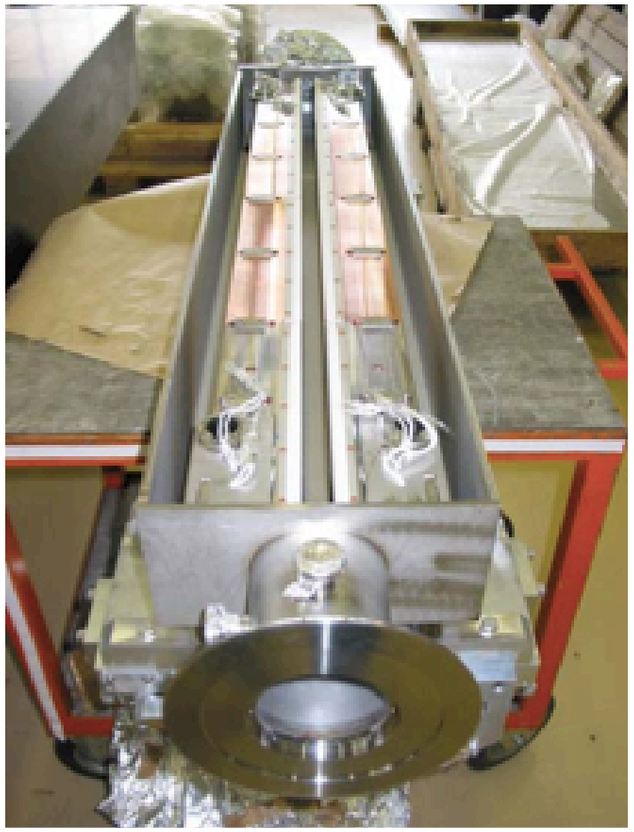
↘ σx ≈ 0.7mm

βy = 89.9m

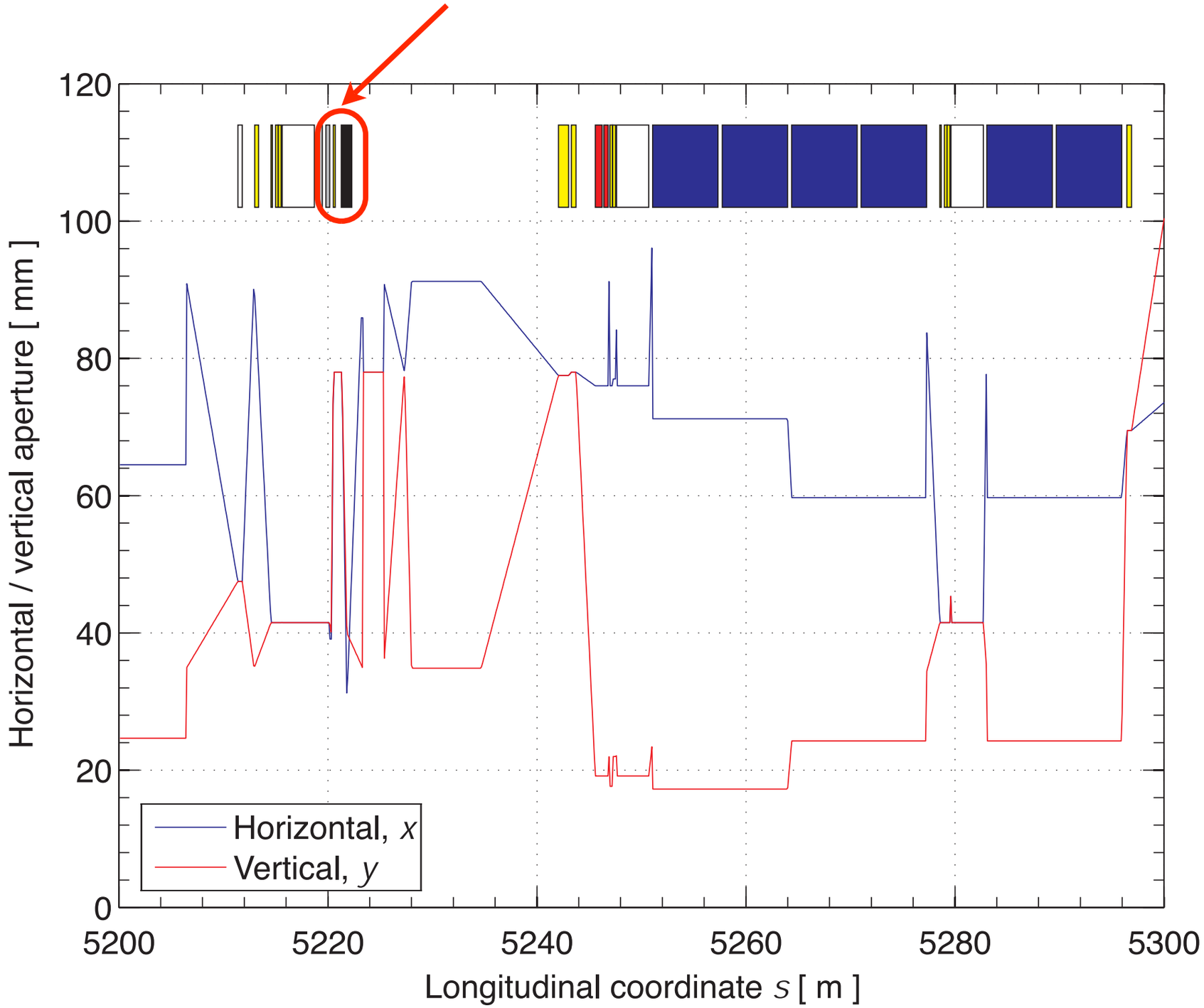
↘ σy ≈ 1.3mm

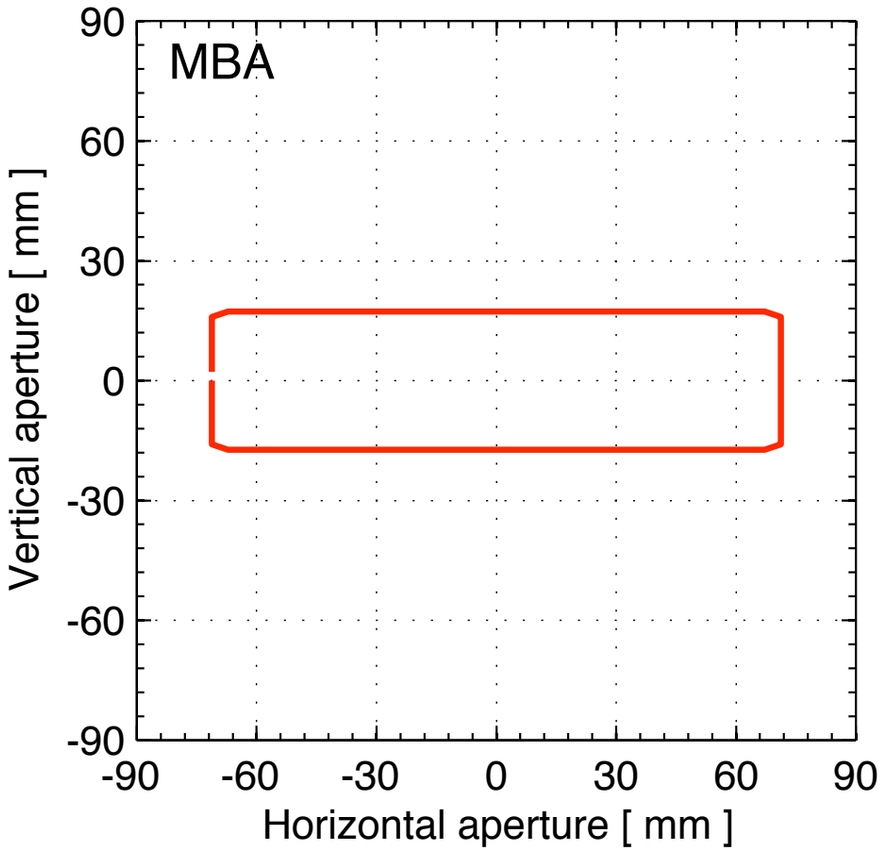
En = 270 GeV / *c*

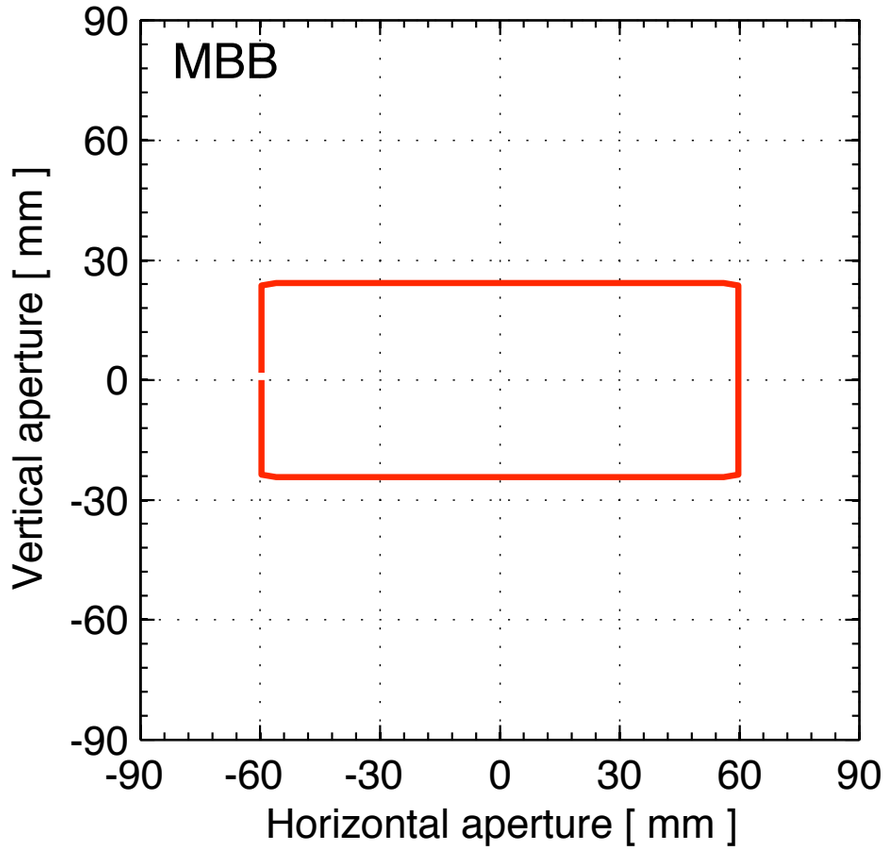
ε ≈ 1-3 *μ*m

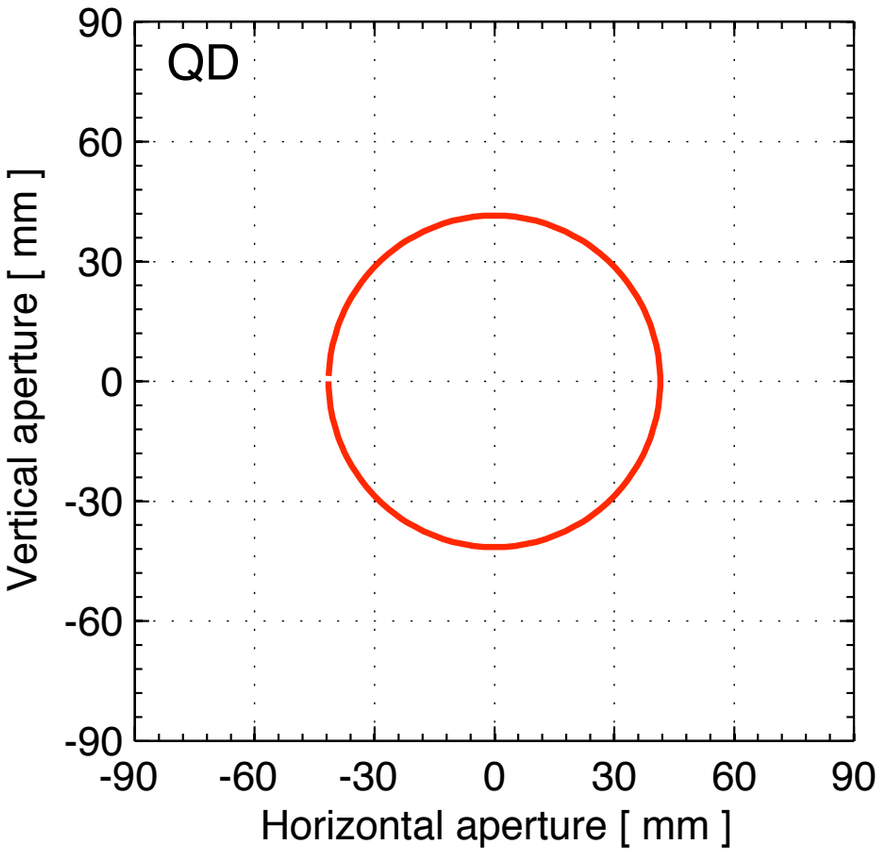


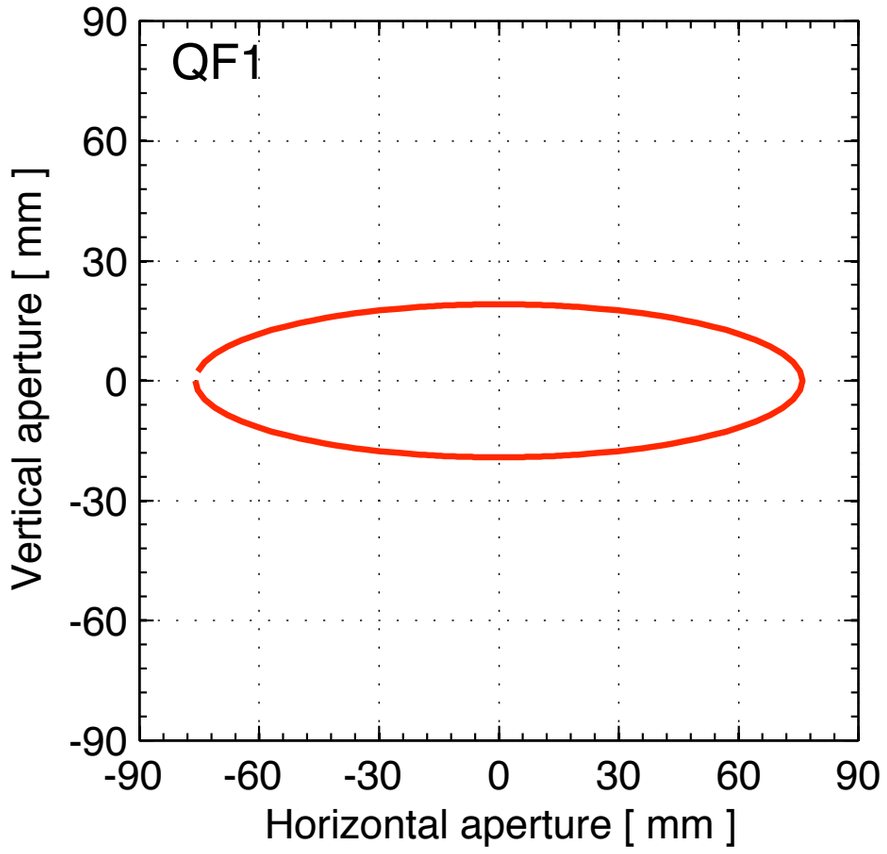
***Prototype LHC collimator***




MBA
Vertical aperture [ mm ]
Horizontal aperture [ mm ]
90
60
30
0
-30
-60
-90


MBB
Vertical aperture [ mm ]
Horizontal aperture [ mm ]
90
60
30
0
-30
-60
-90

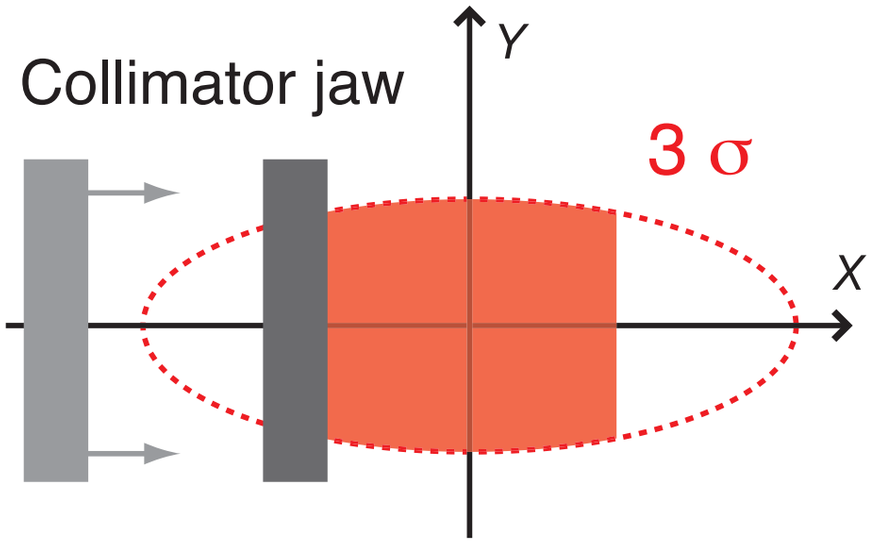

QD
Vertical aperture [ mm ]
Horizontal aperture [ mm ]
90
60
30
0
-30
-60
-90


QF1
Vertical aperture [ mm ]
Horizontal aperture [ mm ]
90
60
30
0
-30
-60
-90

# Example of simulated SPS loss pattern - I

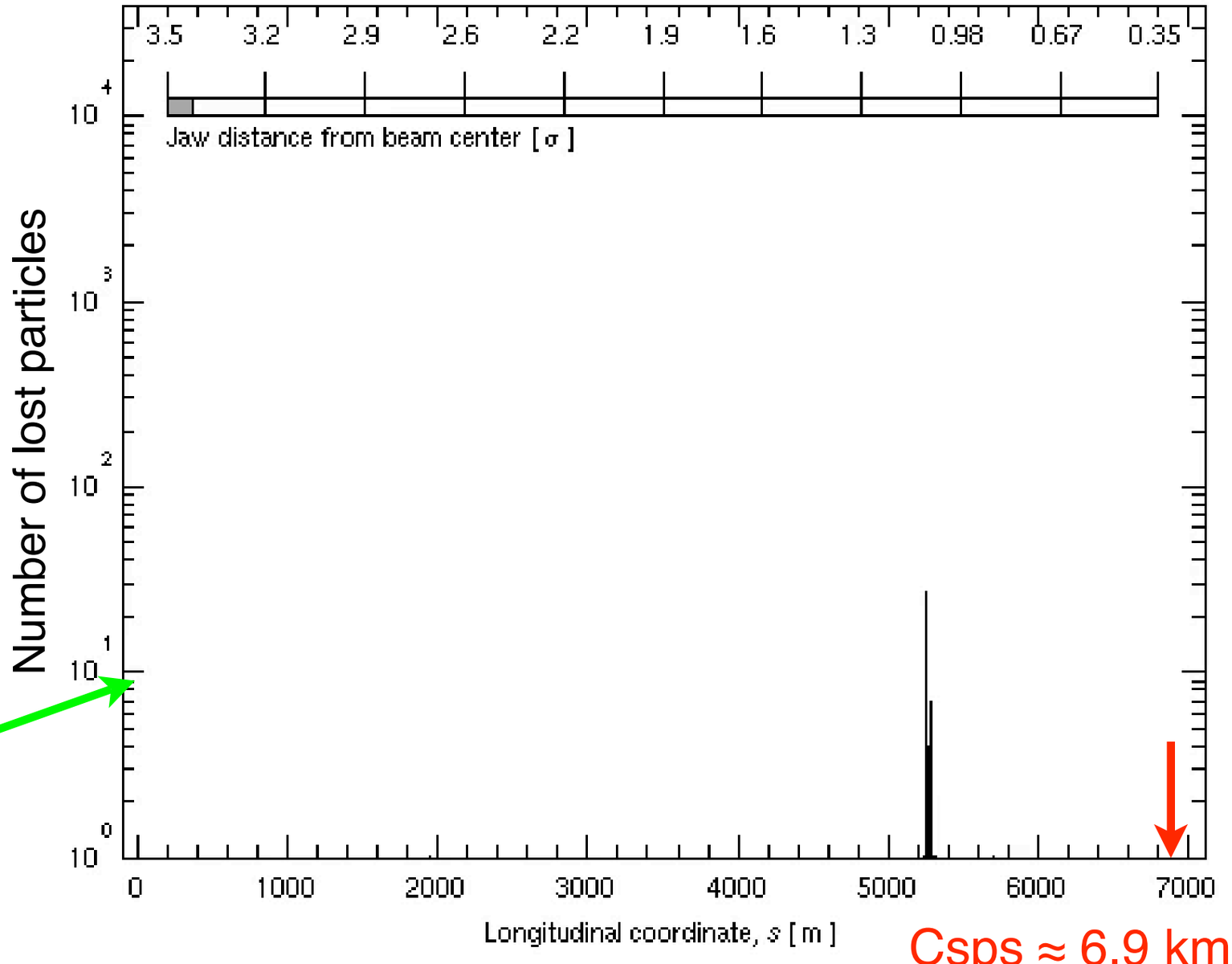
*Simulations include time-dependent jaw movements* (new feature)

- Single or both jaws can be moved at their real speed
- Long tracking runs ~ 20000 turns to simulate the full sweep across the beam



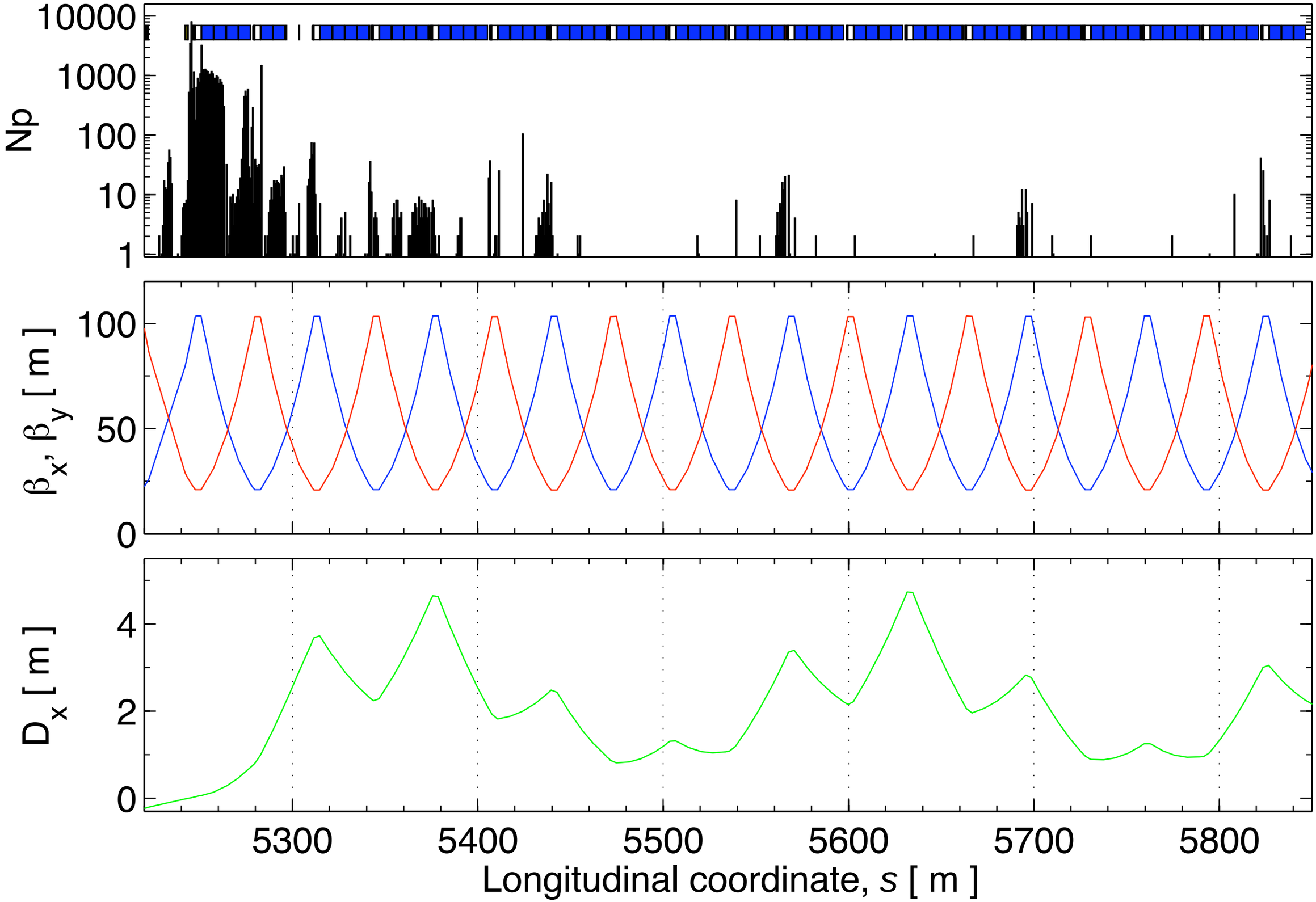

Model accurate to the < 1e-4 level

Can the BLM's measure this wide dynamic range?

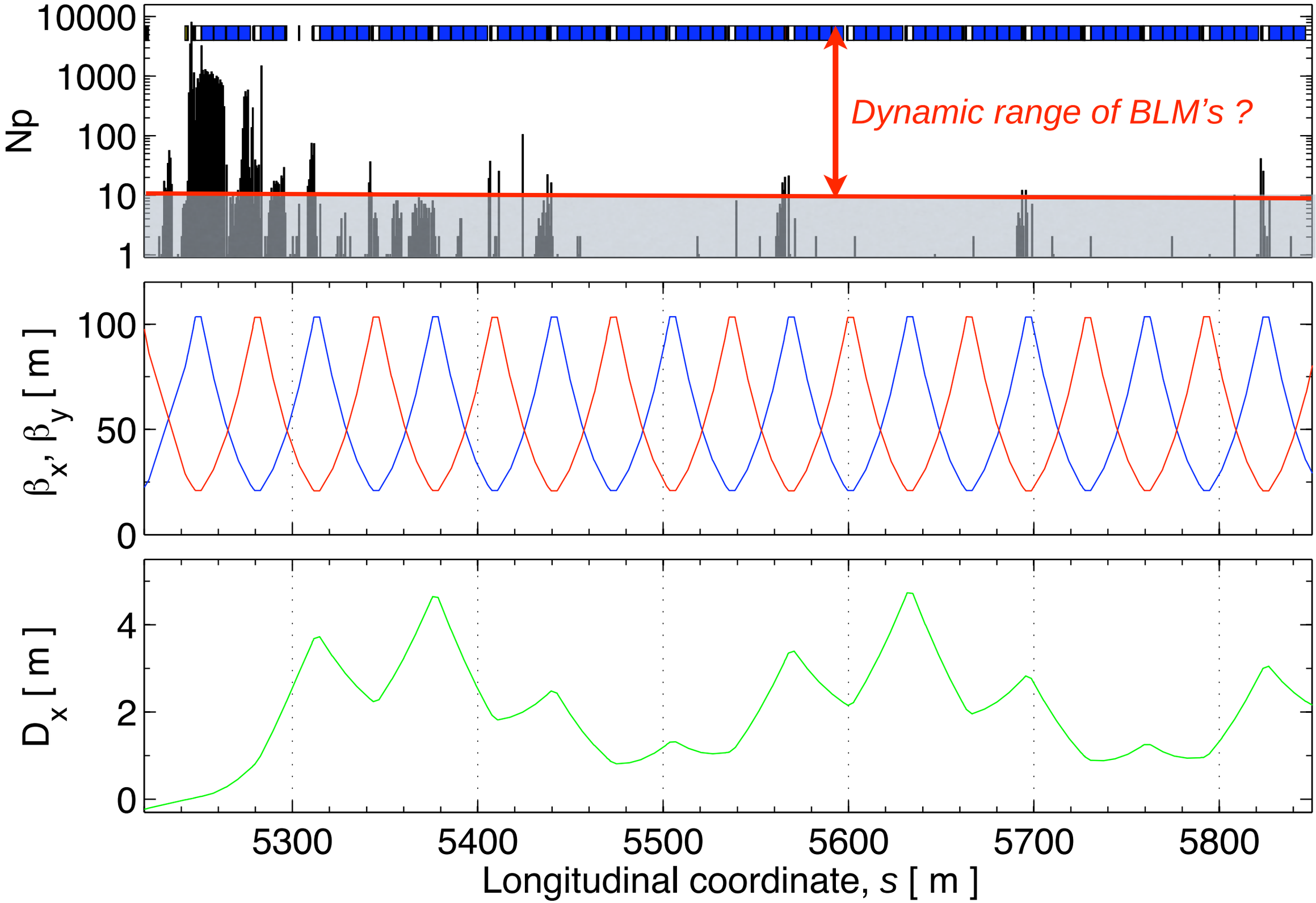



Csps ≈ 6.9 km

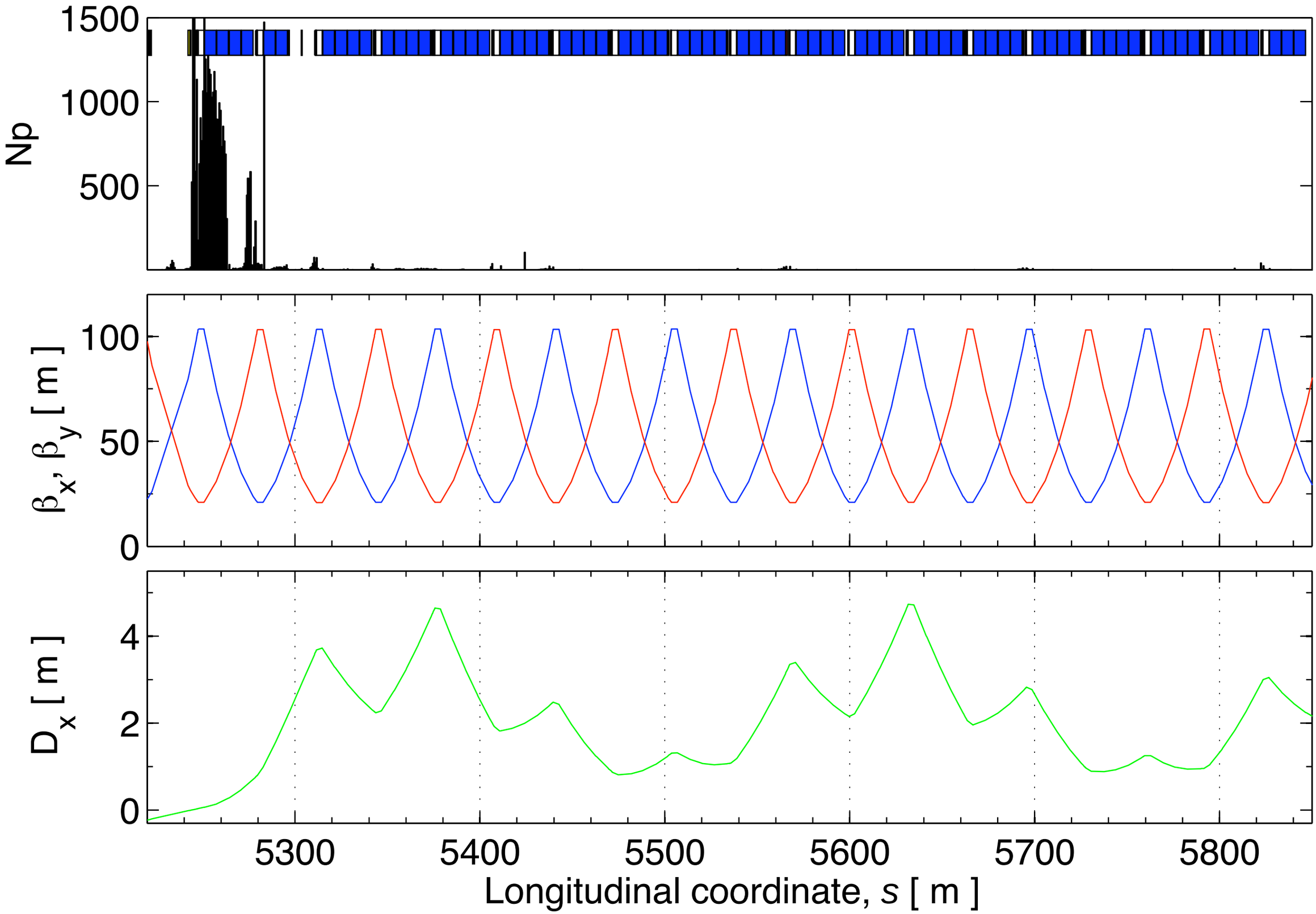
# SPS simulations - example of loss maps - II



# SPS simulations - example of loss maps - II

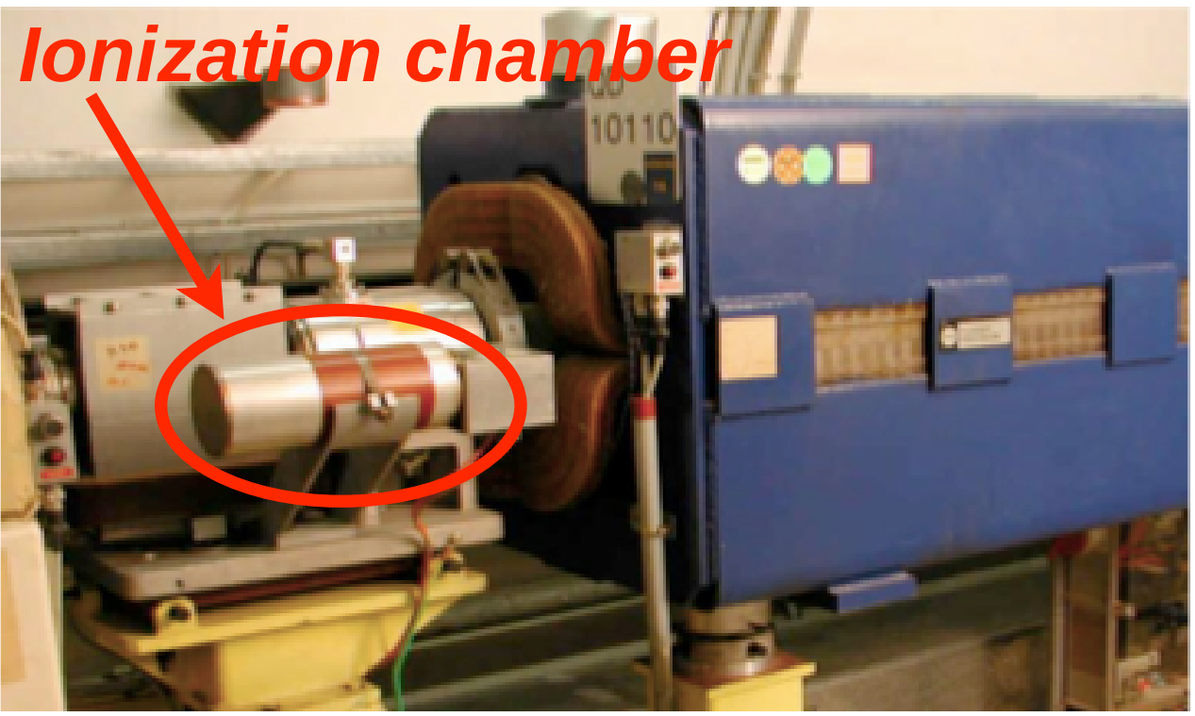


# SPS simulations - example of loss maps - II



- Tools for loss map studies
- SPS simulations
- **Measurement of loss maps**
- Comparison with simulations
- Conclusions / outlook

# SPS loss pattern measurements



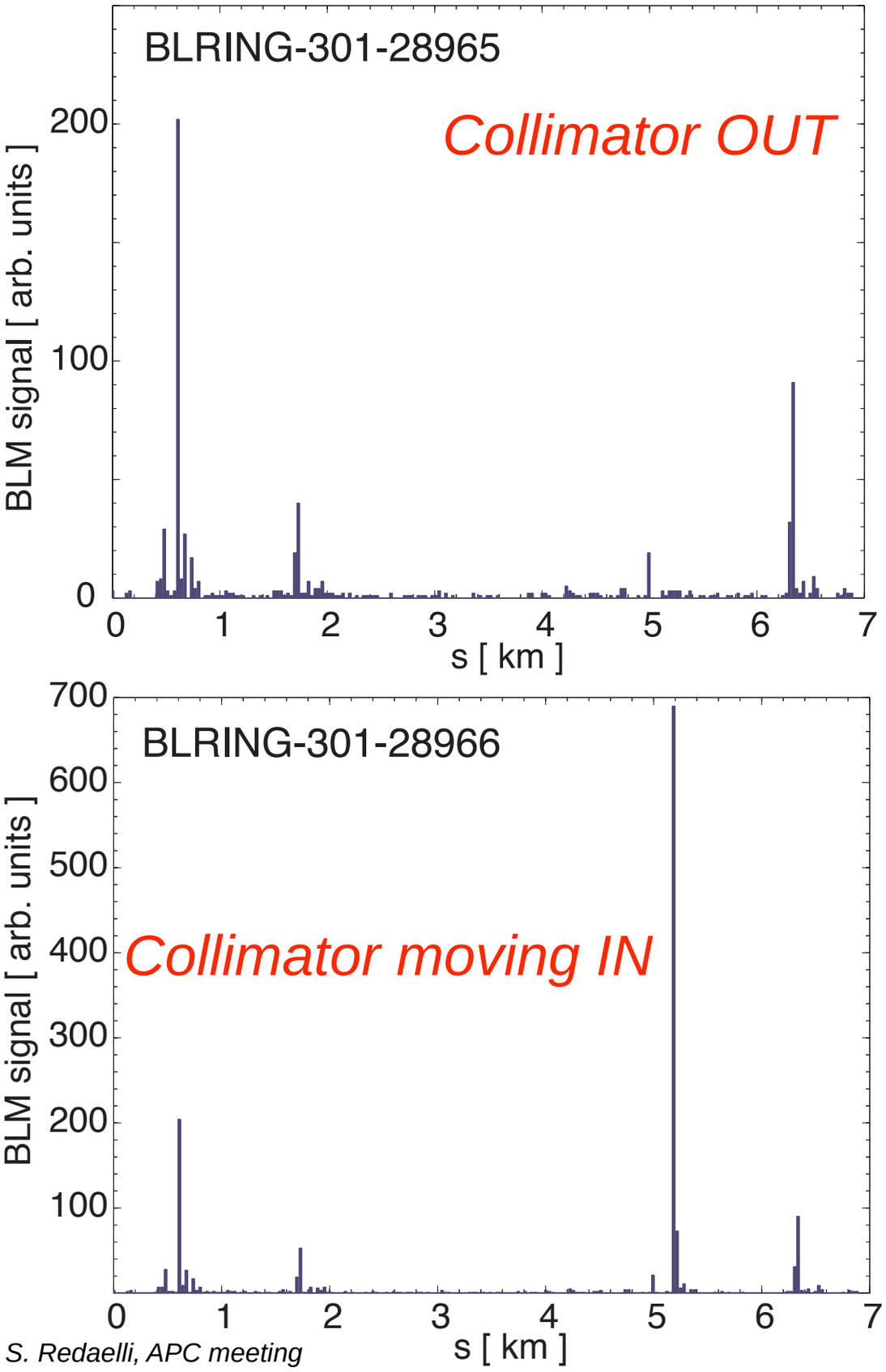

- One ionization chamber per quadrupole
  → Total of 36x6=216 BLM's
- QD (smaller σx) have one horizontal monitor and vice-versa
- Losses integrated over 1 super-cycle:
  1 acquisition every ~ 25 s
  Synchronize data with jaw movements!

## Remarks ☹

- No dedicated measurements on-line: all the analysis is done off-line
- Dig-out the useful information among ~2500-3000 data sets!
- Missing knowledge of energy deposited in the BLM per lost proton

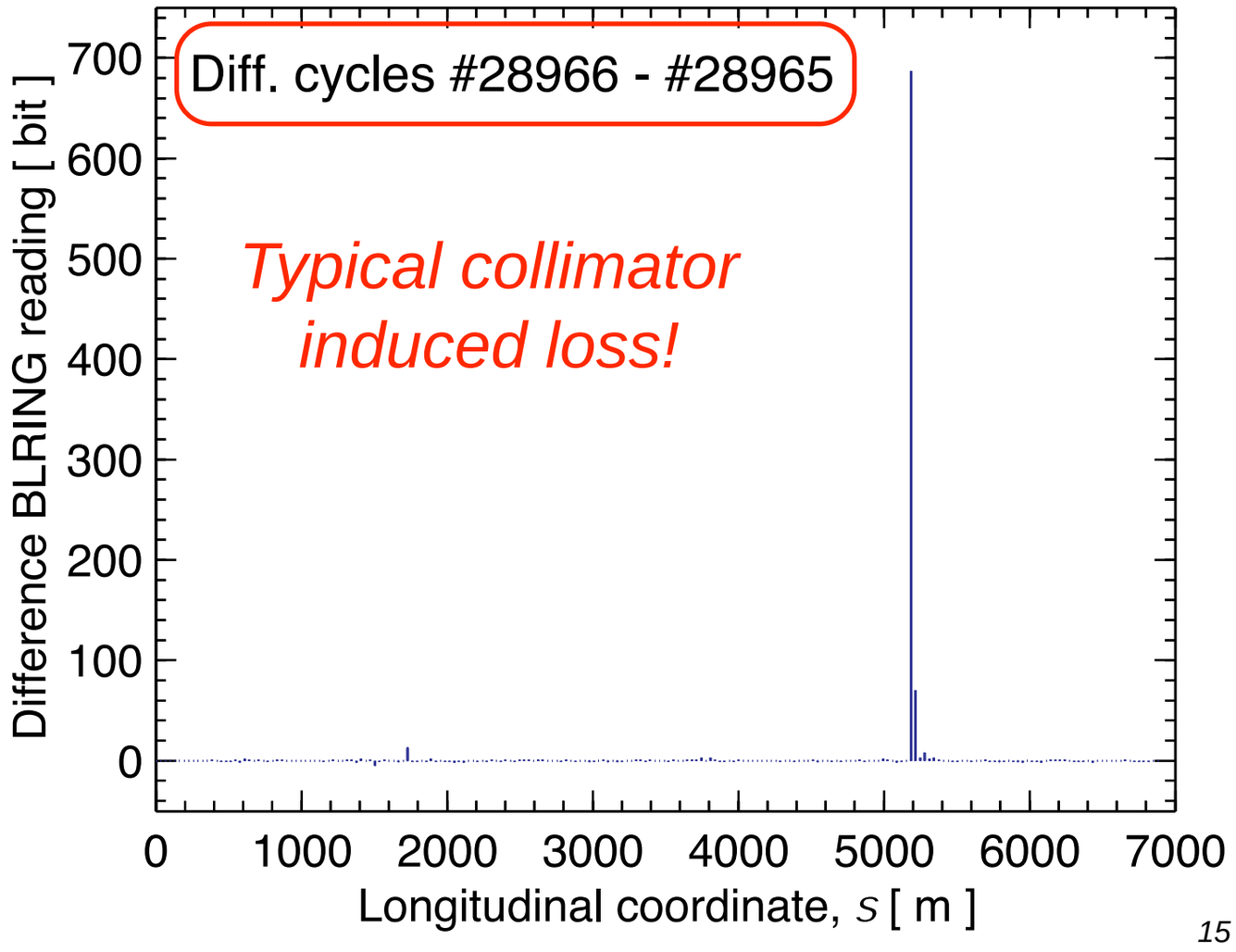
  Predict location of losses but not relative heights of the peaks!

# Data analysis / reduction




Losses induced by the collimator can be seen by taking the **difference** between consecutive super-cycles

Typical loss patterns from collimators are independent of optics, local bottlenecks, etc...



- Tools for loss map studies
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- Measurement of loss maps
- **Comparison with simulations**
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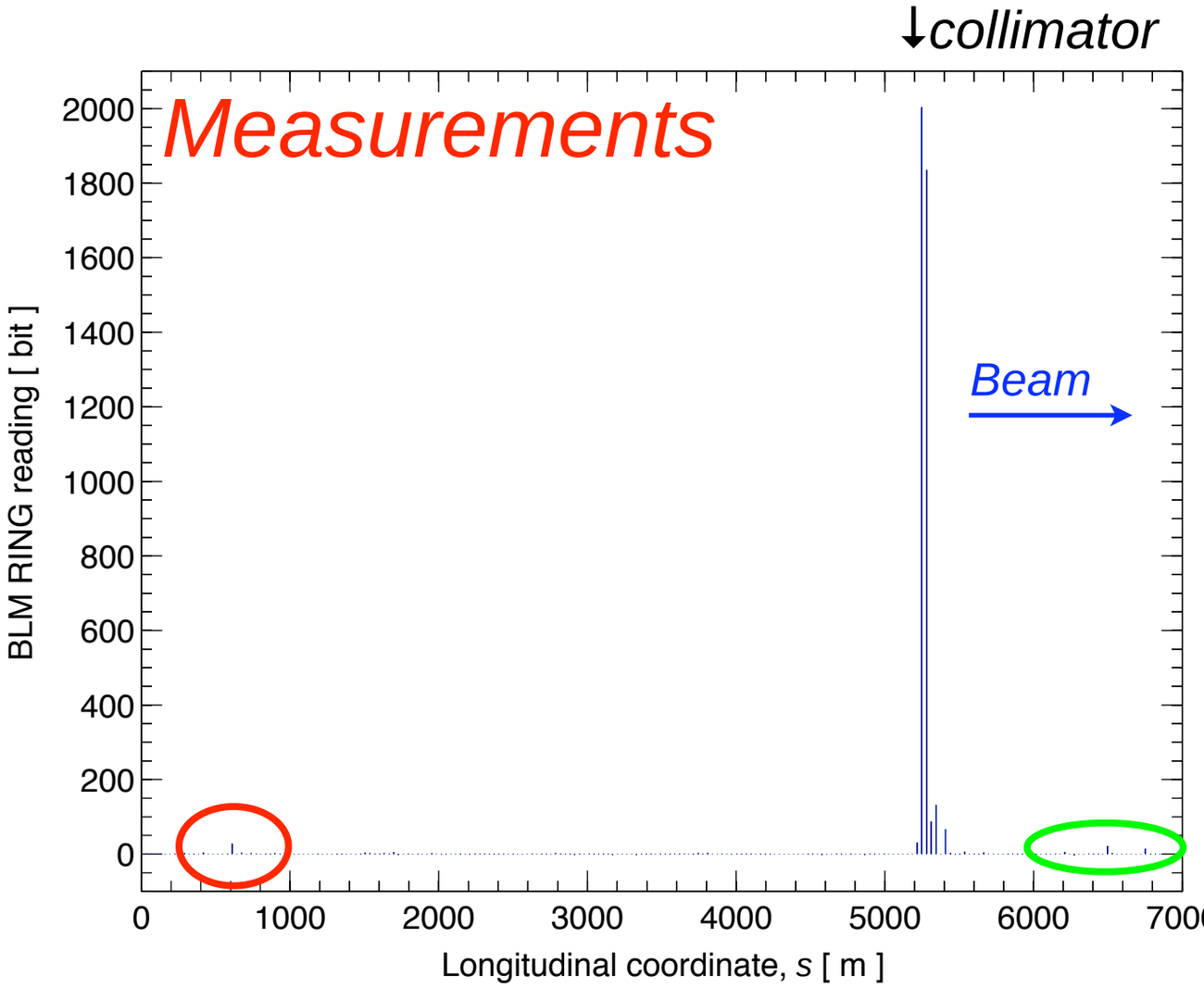
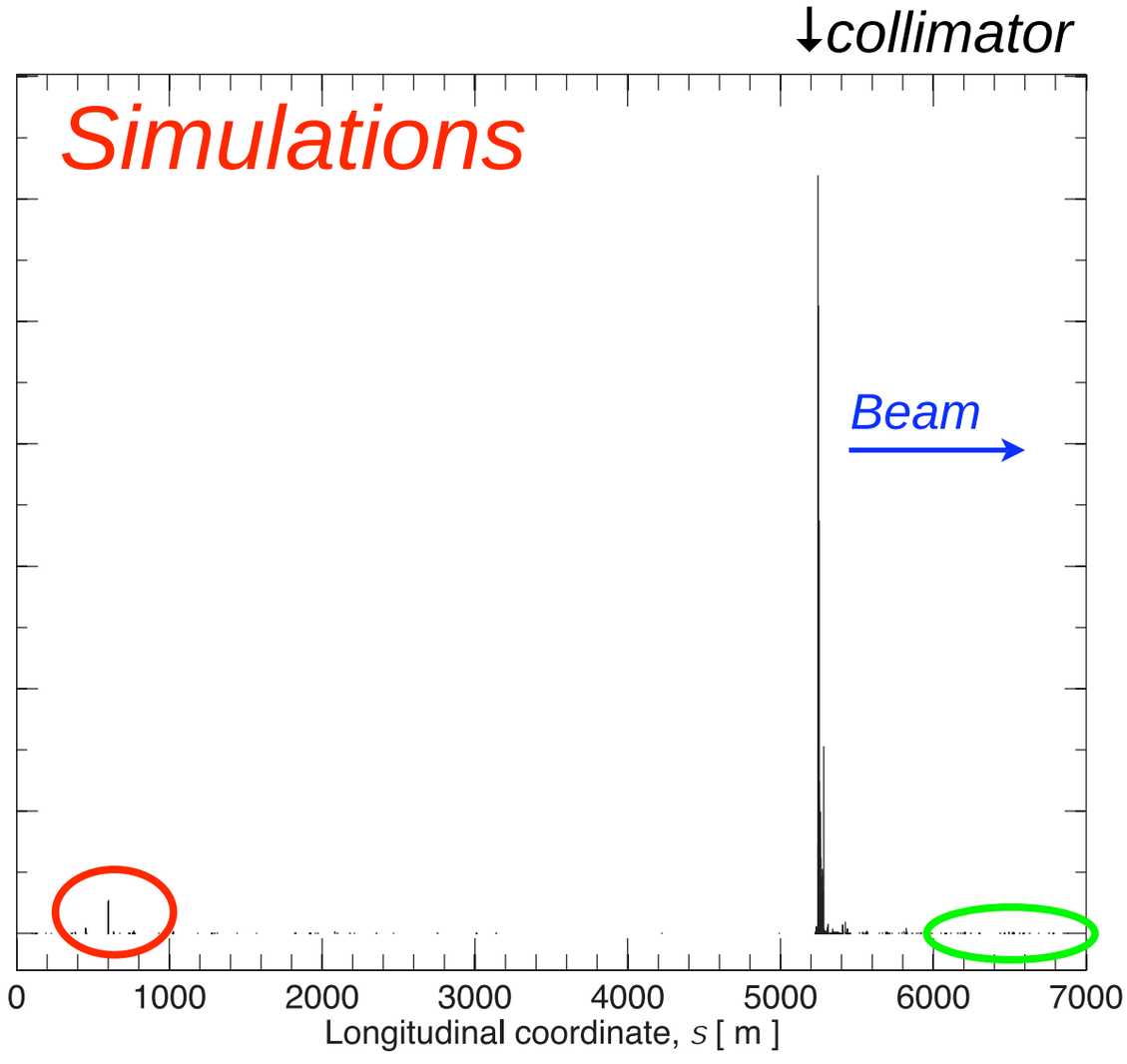
# Comparison - overall loss pattern

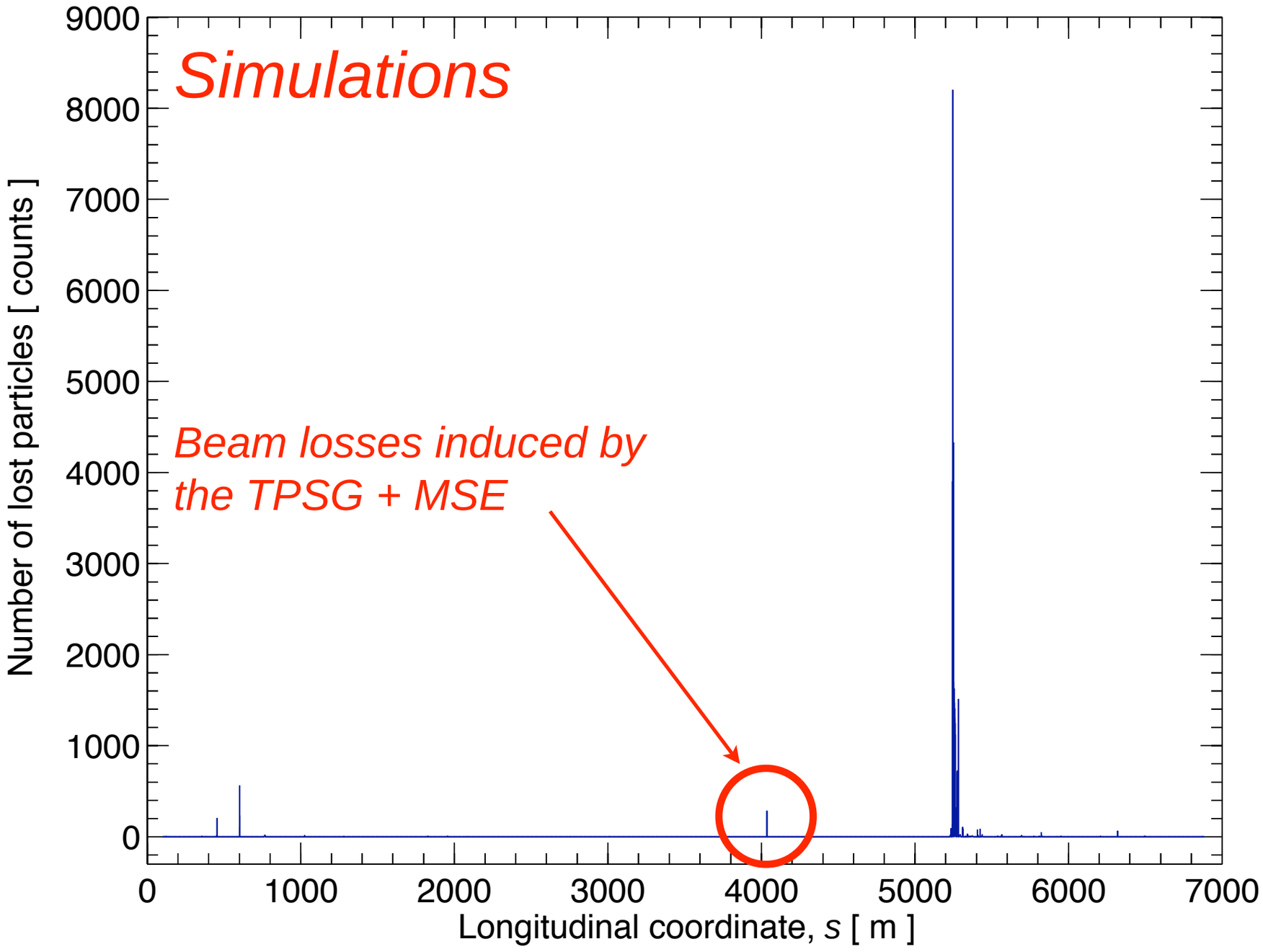



**Overall loss pattern along the full ring is correctly predicted!**

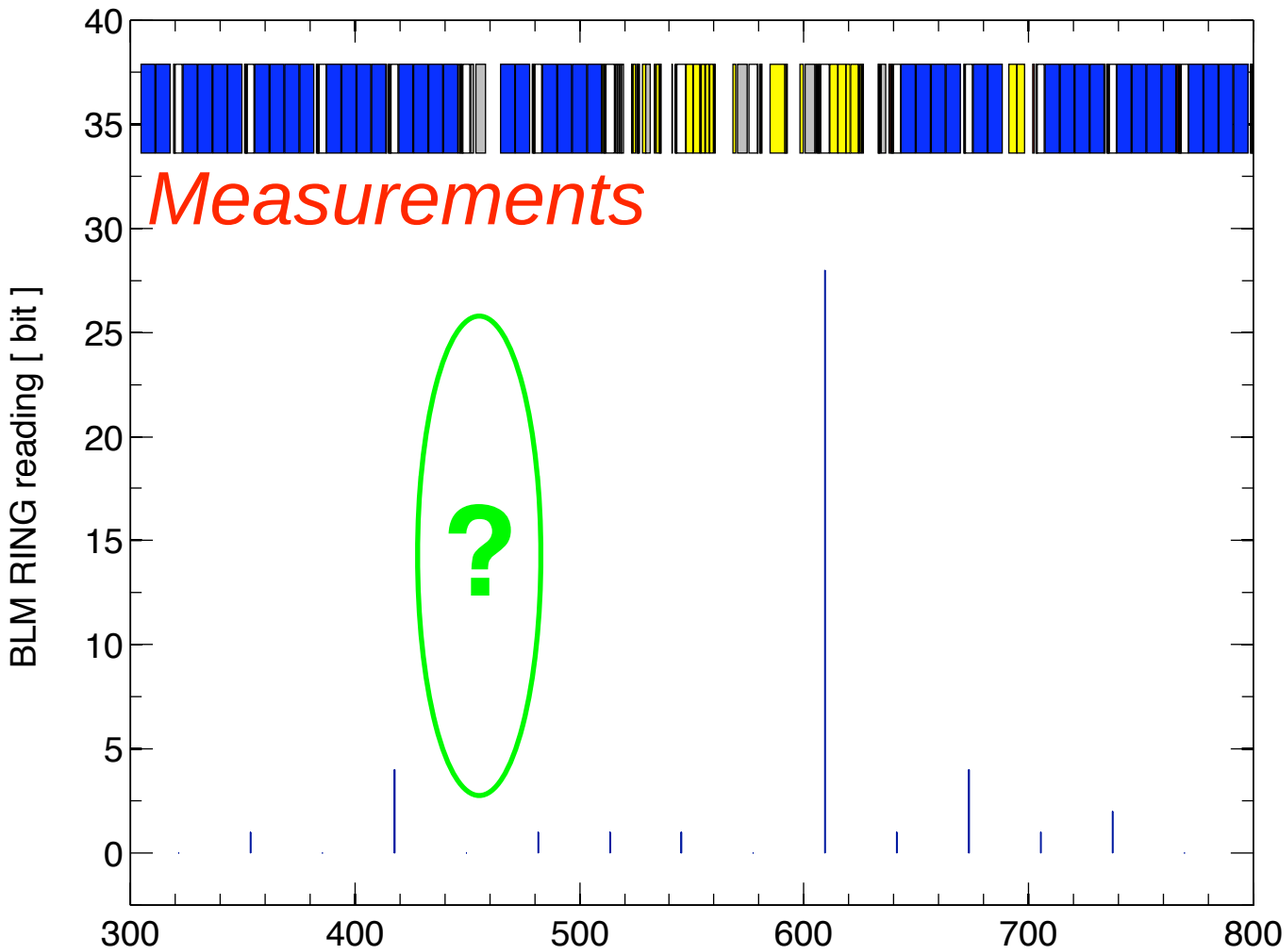
- ↘ Main losses immediately downstream of the collimator
- ↘ Next significant peak at an SPS collimator, >2.5km downstream!

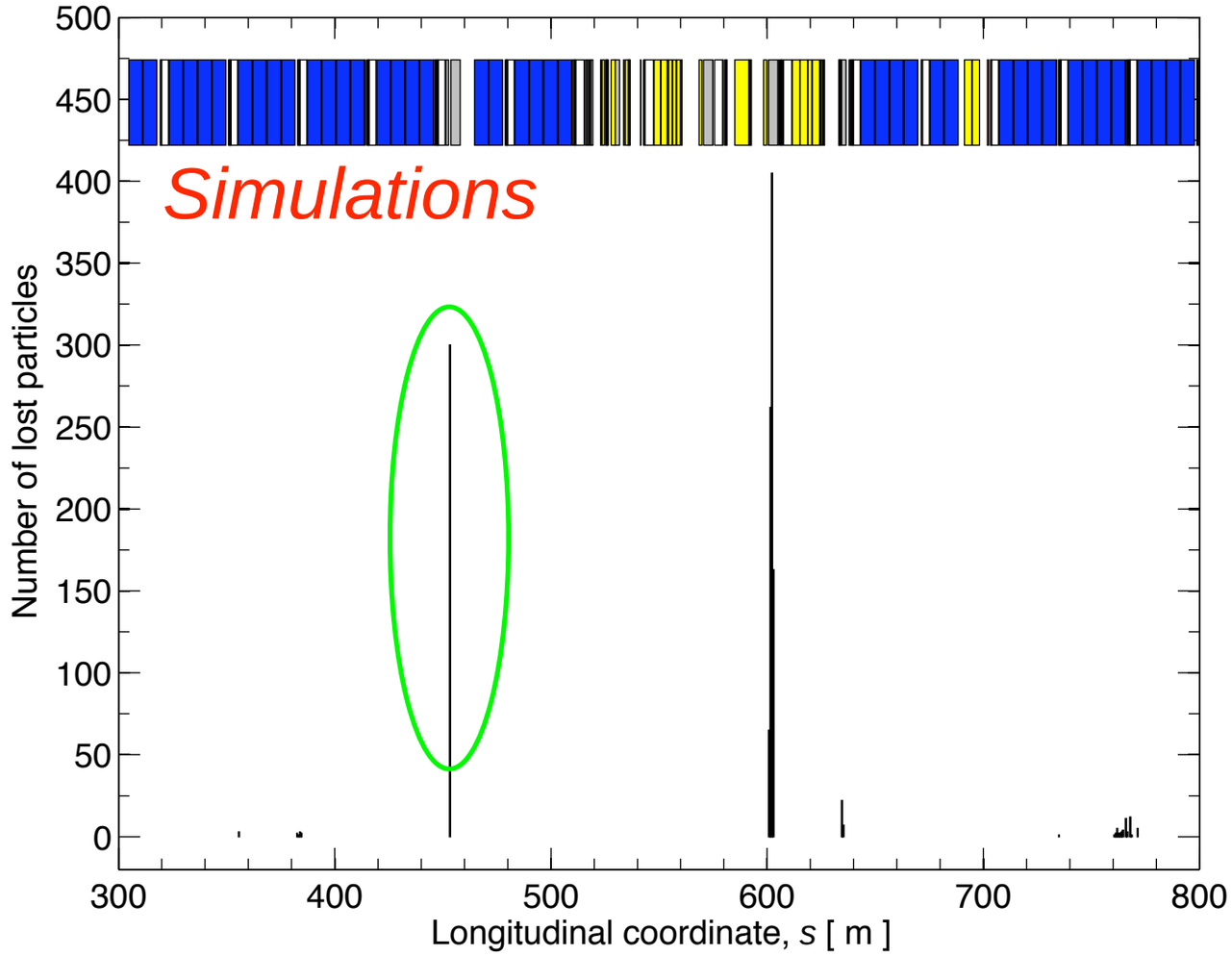
# The comparison showed that the correct settings of TPSG+MSE were **missing** in first simulation runs!

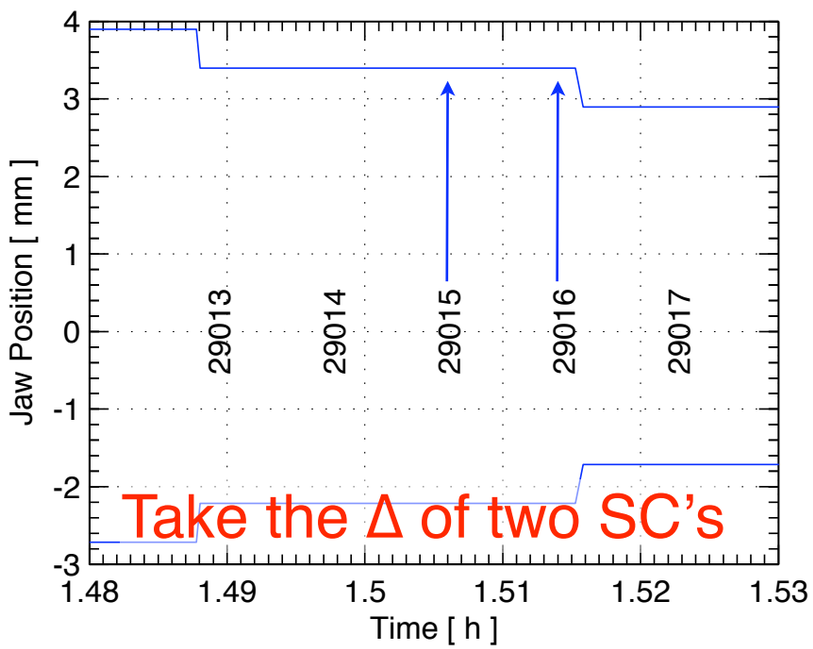



***Prediction power***: We found that the TPSG was OUT and not IN!

# Peaks at the TIDP / TIDV

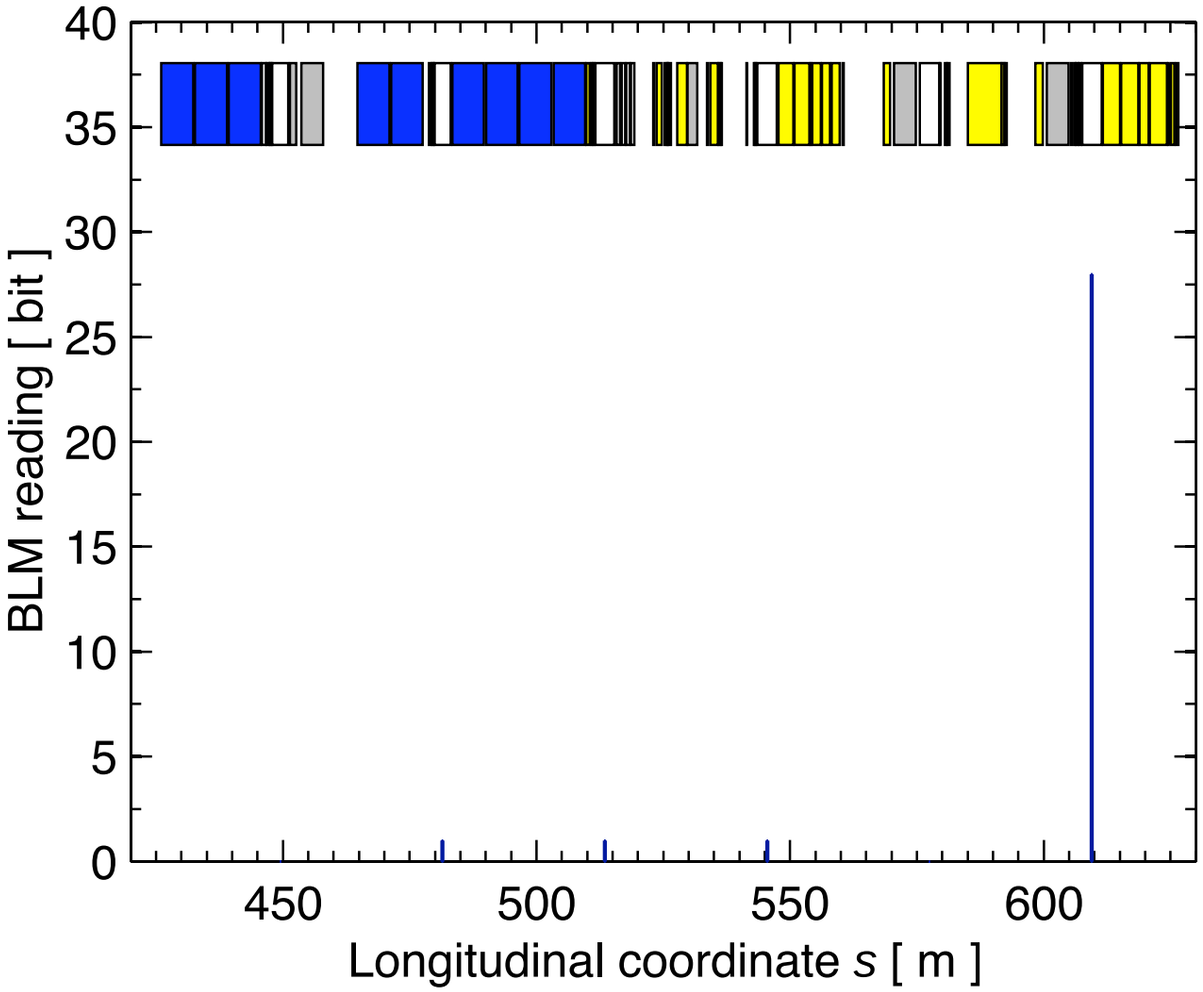



*Simulations predict precisely the loss locations several km downstream of the collimator!*

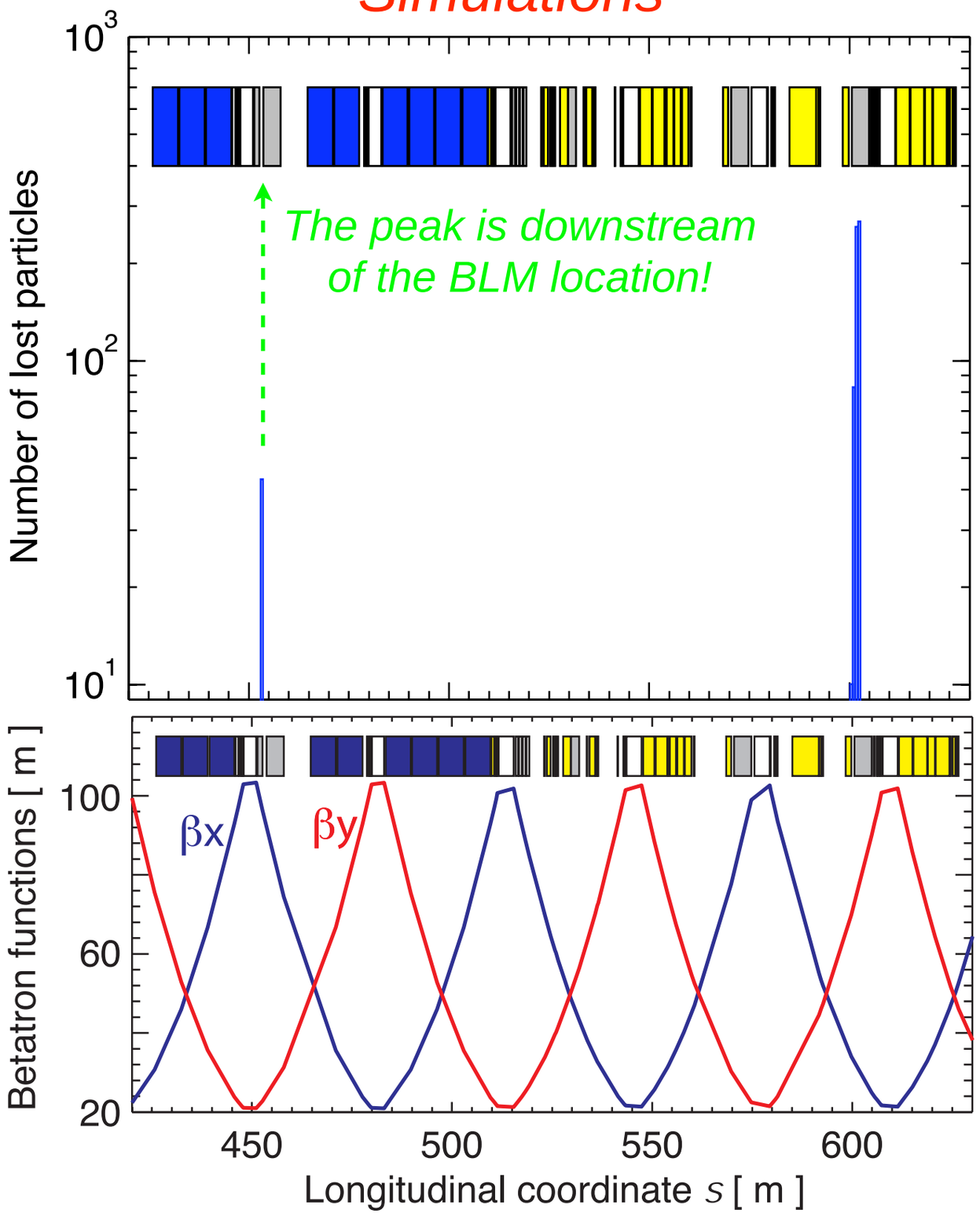
## Measurements




*Difference understood if details of BLM mounting are taken into account!*

*We can nicely simulate losses but, of course, cannot measure without BLM's!*

## Simulations



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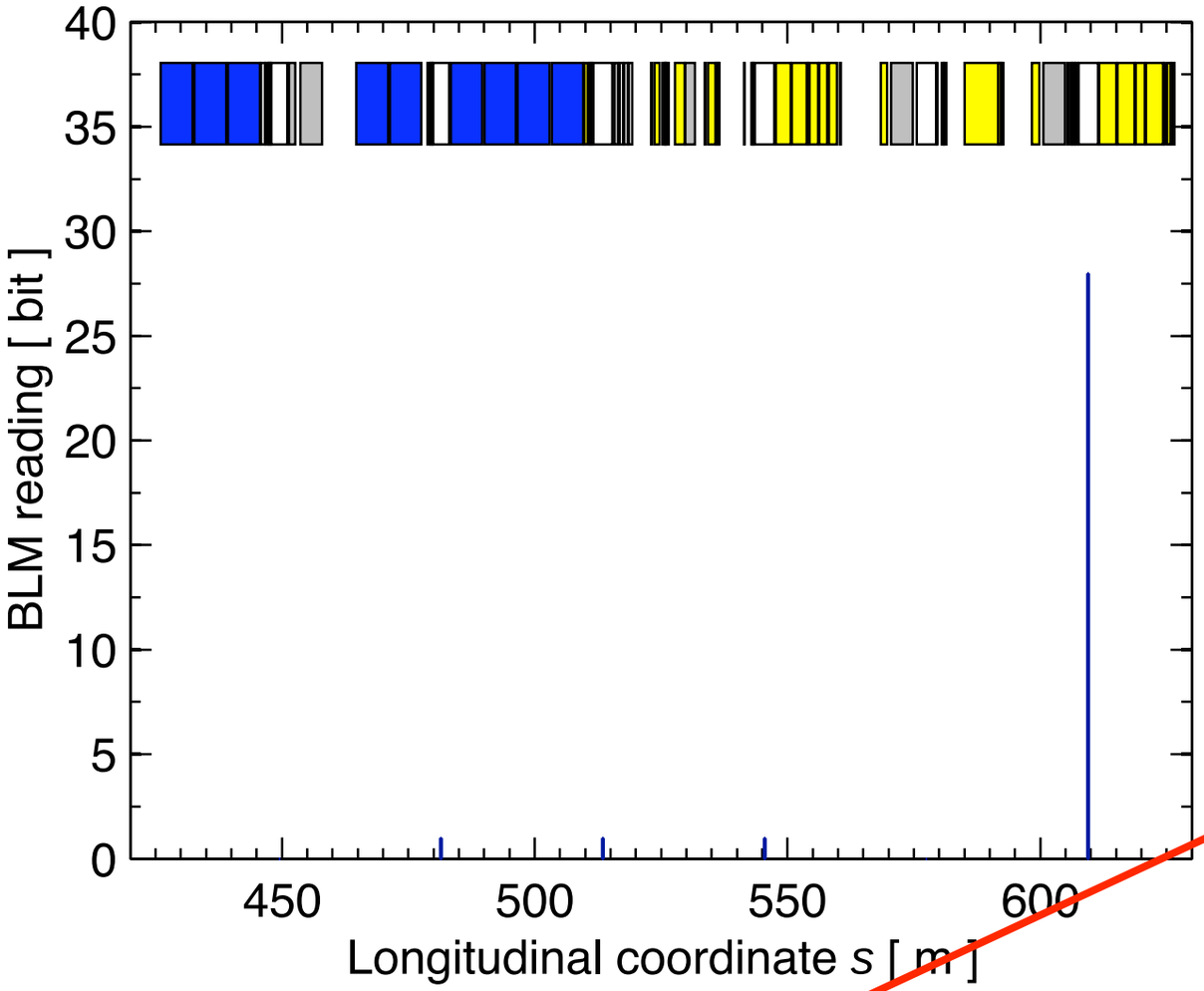


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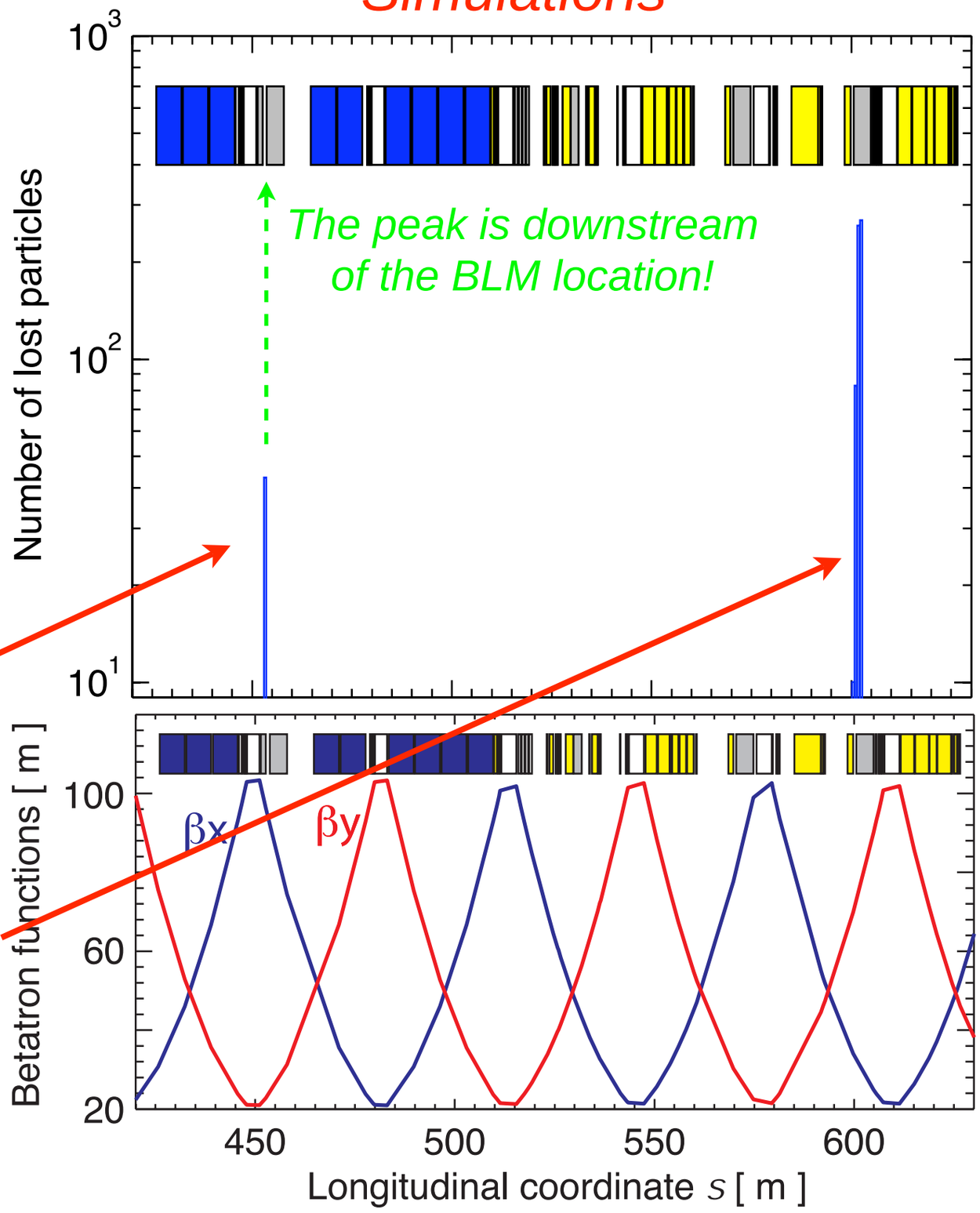
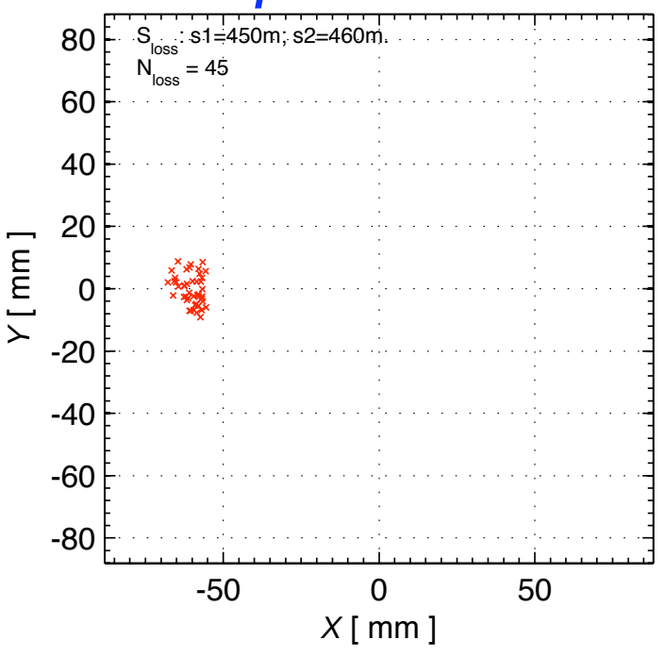
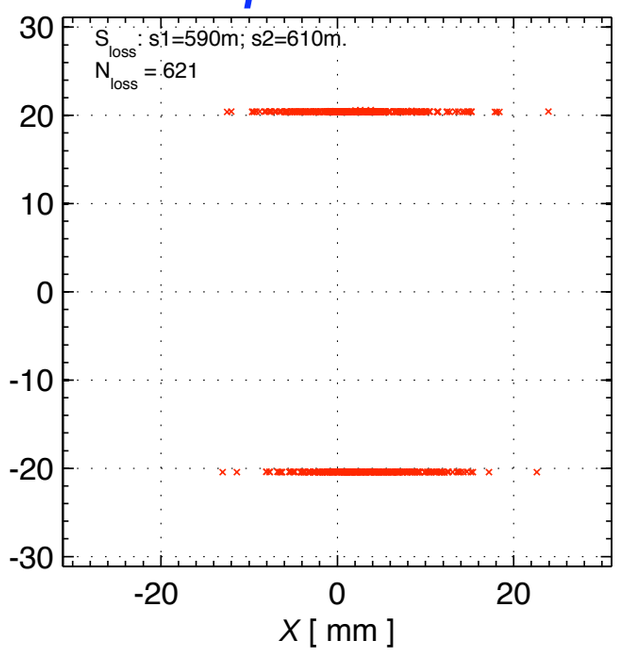


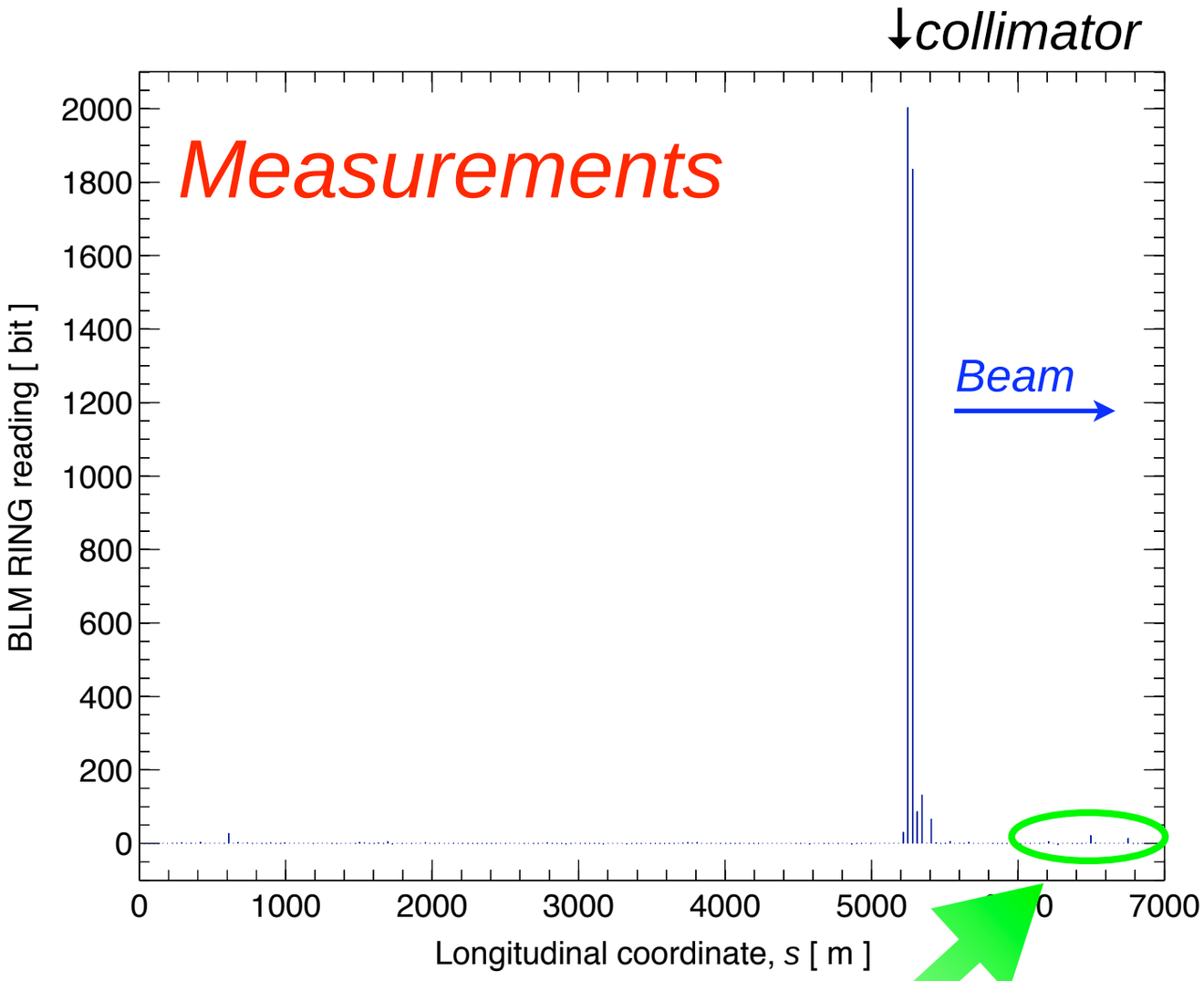

## 1st peak:TIDP

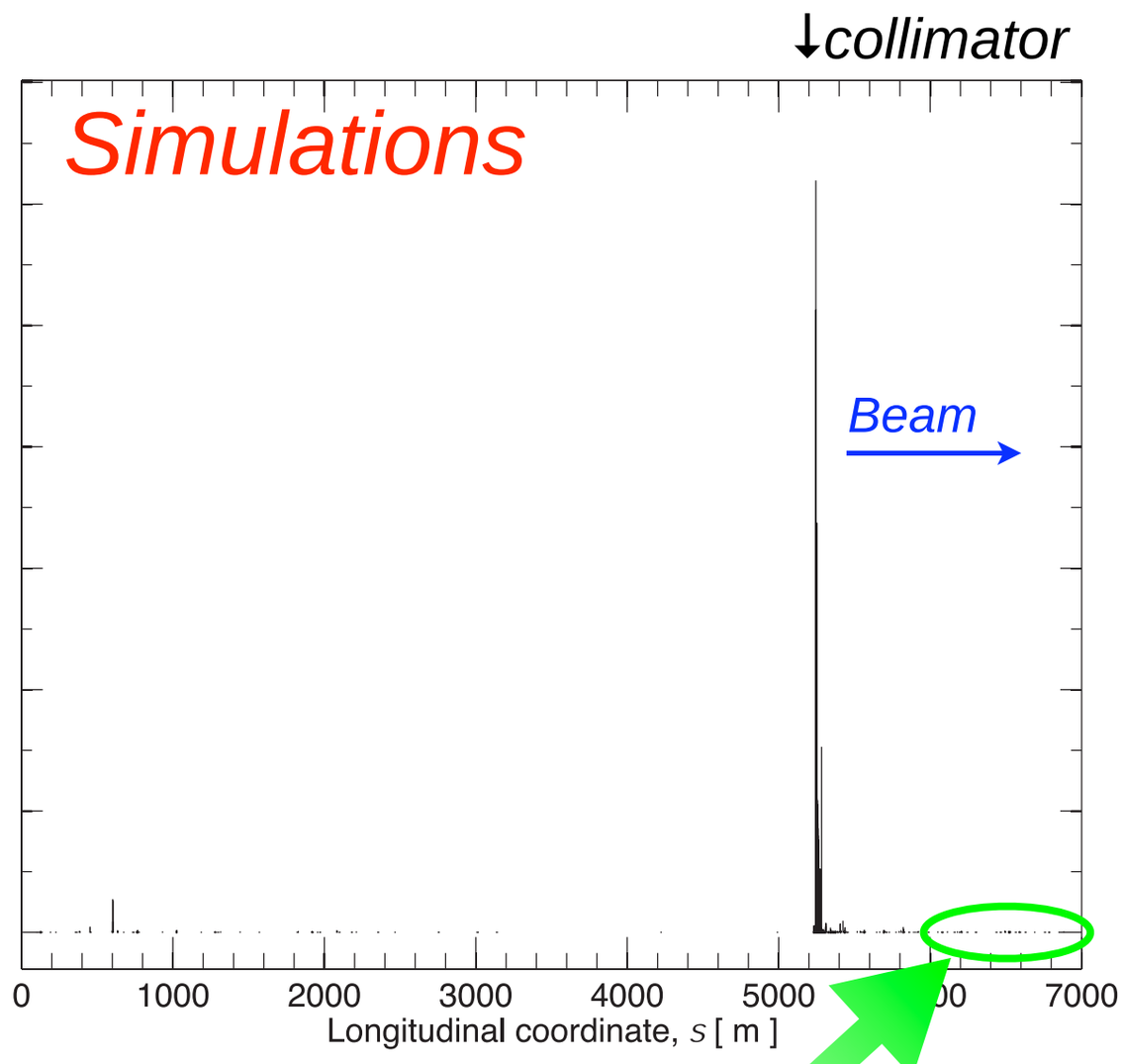



## 2nd peak:TIDV



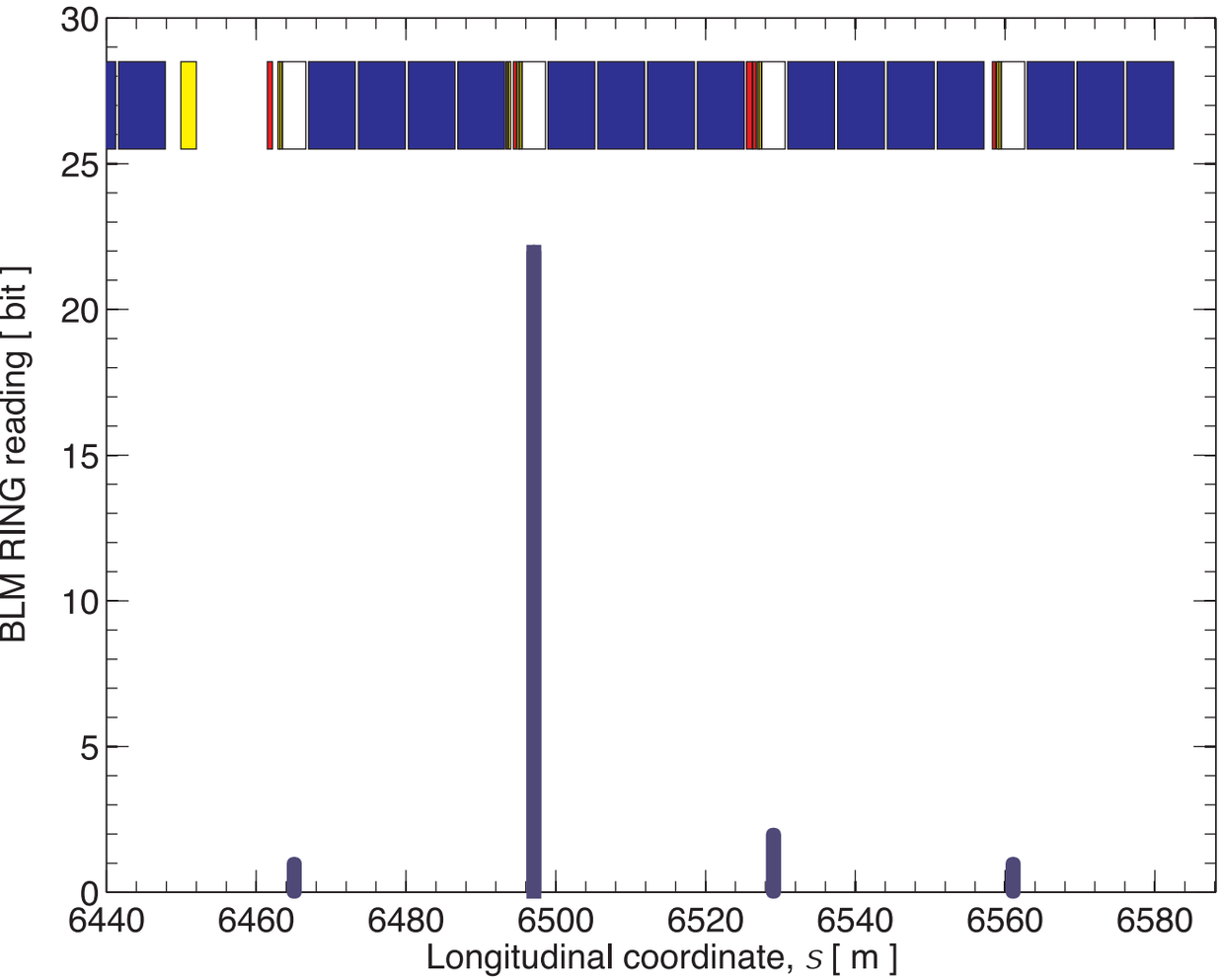
# Details of another loss location: peaks 1 km downstream of the collimator



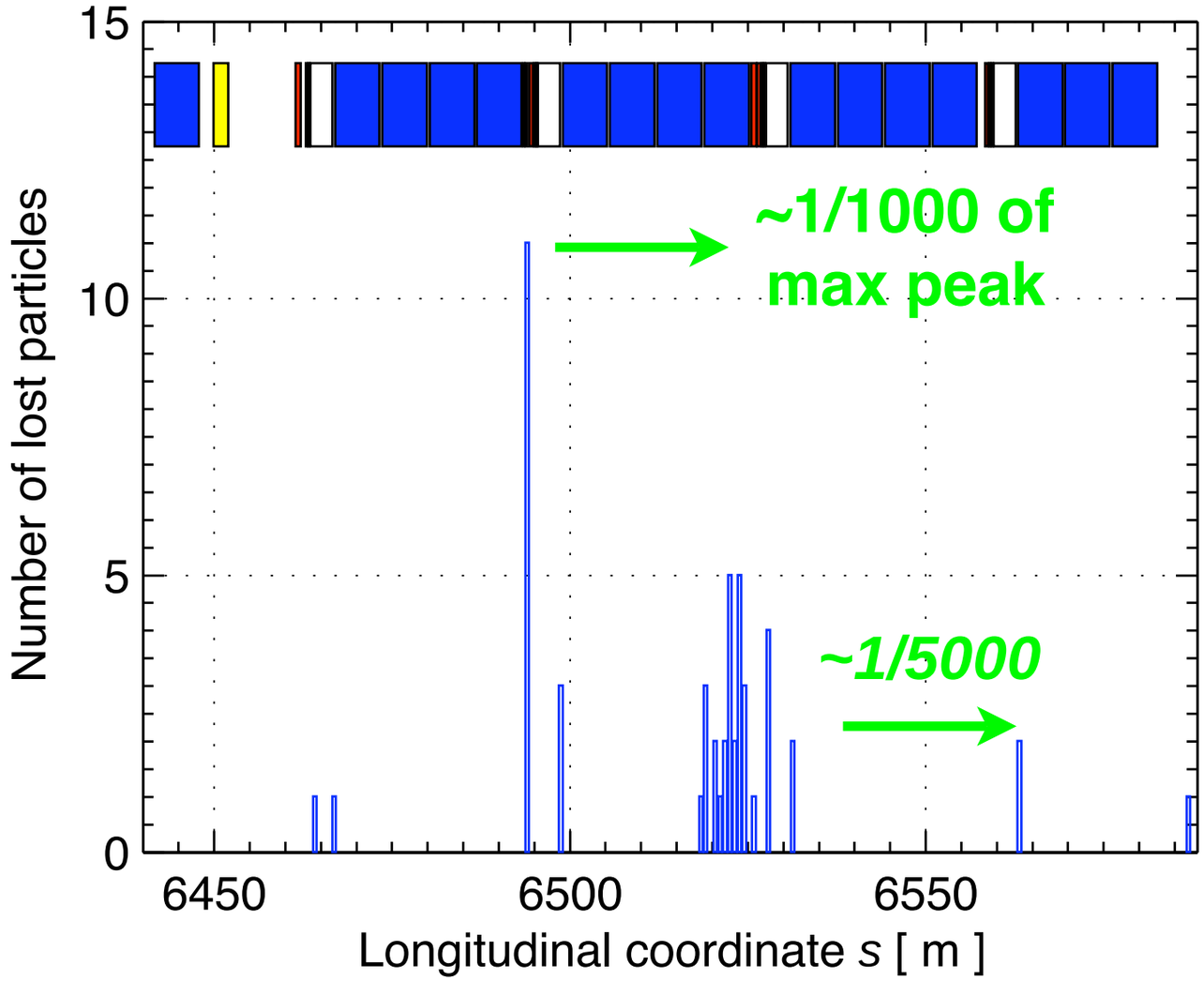



# *We look at small loss peaks in regions with no collimators:*

## *Measurements*




## *Simulations*




***Simulations agree qualitatively with measurements also at locations without collimators!***

# Conclusions

- Beam loss simulations set-up to predict measured SPS loss patterns

  *Results from 2004 collimator test with beam are used*

- Simulation benchmark was challenging but successful at the end!

  *No dedicated measurement sets*

  *Missing information of deposited energy on BLM*

- The results of this work confirm the power of simulations!

  *Good agreement for the prediction of loss locations*

  *Could identify from simulations minor setting errors of the model*

  *Small differences were understood: BLM location vs loss location*

**We are can trust our simulation package for the LHC studies!**

# Outlook

A collimator test with beam at the SPS is foreseen for 2006.

What could we improve?

- Dedicated data taking session during the test.
- Faster BLM acquisition would help carrying out detailed studies

  ➞ *Can we have turn-by-turn measurements?*

- Measurements / simulations with additional scrapers?

  ➞ *Understanding of hardware is required*

- More advanced ideas: Use strong non-linear elements?

  ➞ *Further cross-check of tracking for the LHC*

- Setup non-linear bumps (with R. Tomas)

  ➞ *Use the extraction sextupoles? Are there other available?*