CERN CLIC
Machine Protection Studies

Lutz Matthias Hein

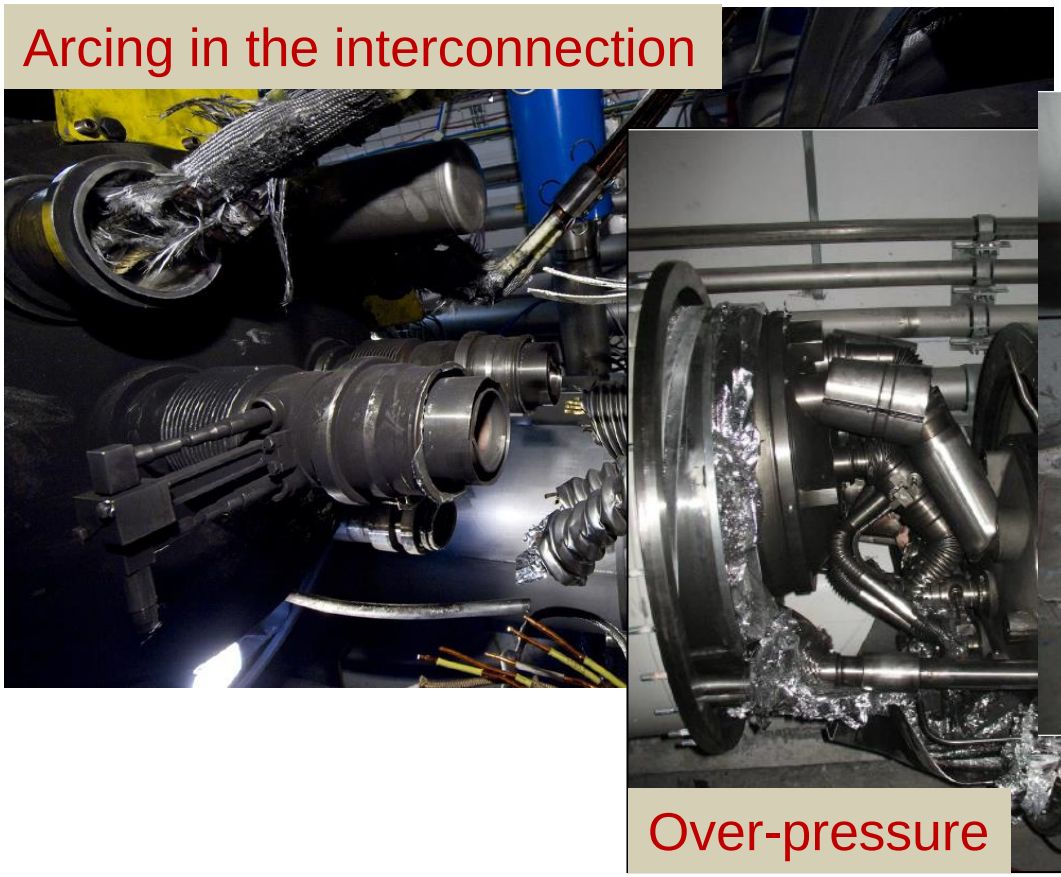
CERN, TE-MPE-PE

Machine Protection

Why ??

Machine Protection

No Beam

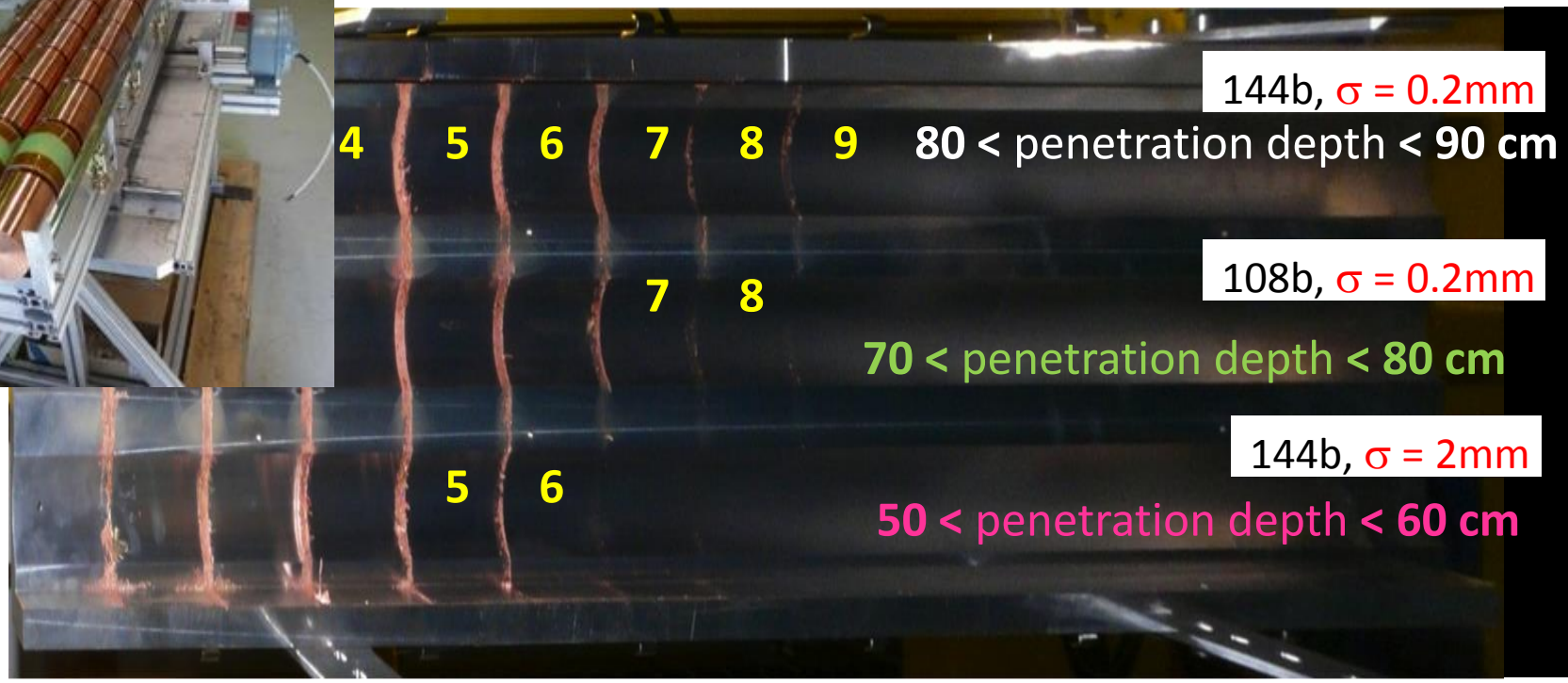


courtesy
Prof. Rüdiger Schmidt (CERN)

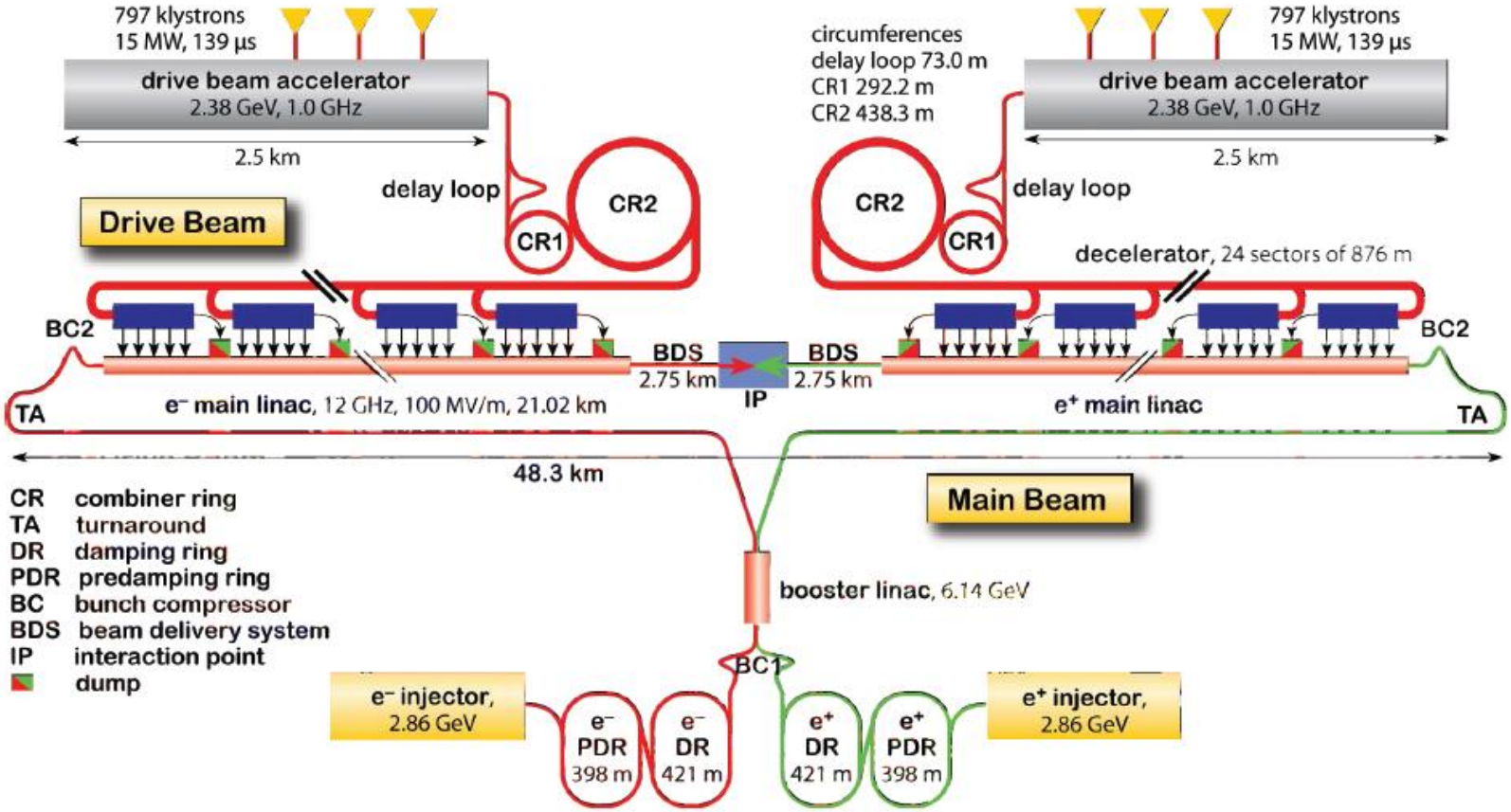
Machine Protection

With Beam

SPS – Beam 450 GeV on Copper
Courtesy: Florian Burkhart (CERN)



Recapitulation



What is the Damage Limit?

Yield Temperatur: – max. instant. Temp.Rise

$$\Delta T = \frac{1}{\varrho c}\left(\frac{dE}{dz}\right)\cdot\sigma(x,y)$$

material density
heat capacity
beam density

Energy Density = BeamCharge × BeamSize^{-1} × dE/dx (ionisation loss)

Destructive capacity: determined by BeamCharge × BeamSize^{-1} **not** Beam Power.

Safe Beam: yield limit in copper **(62 J g^{-1})**

Main Beam : 10000 × 'safe beam'

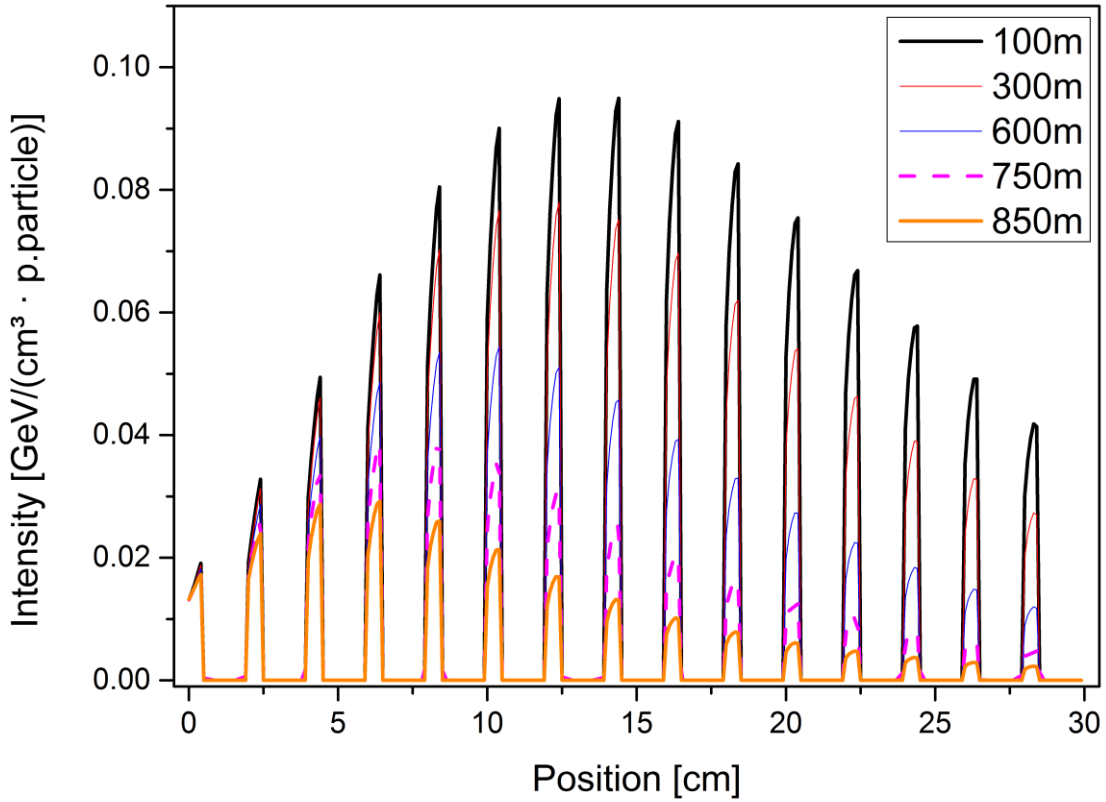
Drive Beam : 100 × 'safe beam'

Charge Density LIMIT
3.94E-04 nC/µm²

Courtesy M.Jonker

What is the Damage Limit?

Charge enhancement by Pair-Production etc.



Fluka Simulation

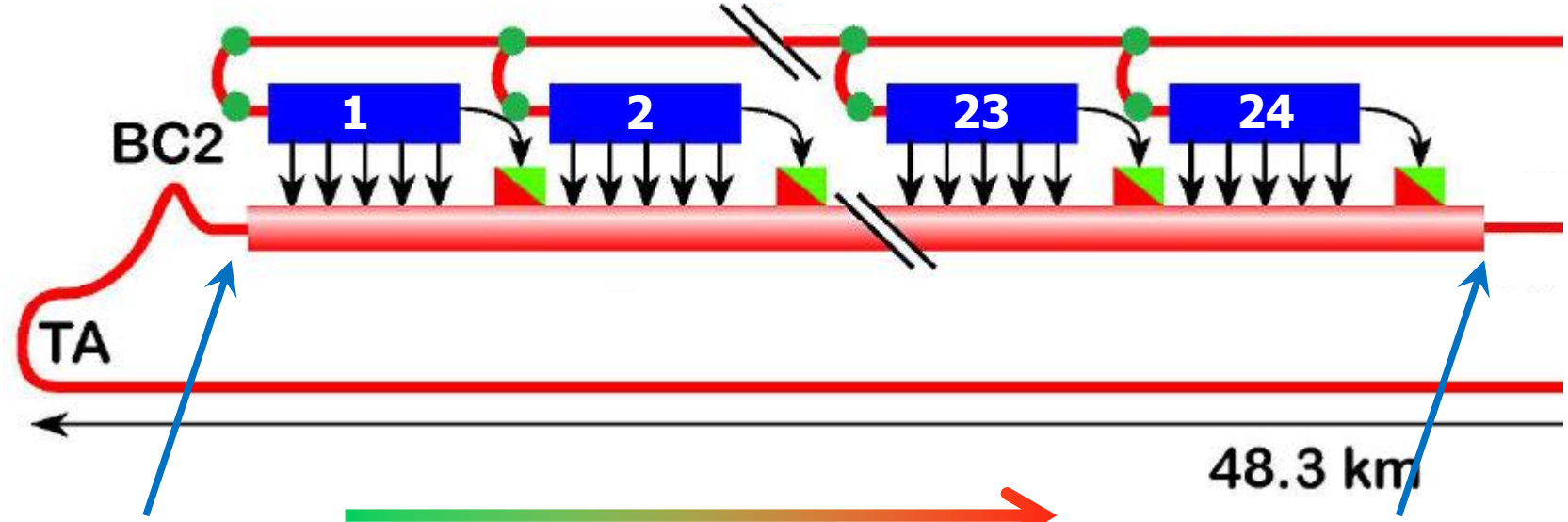
Beam Impact on Copper plates

Charge Density LIMIT

3.94E-04 nC/µm²

÷ 8

24 Types of Decelerator



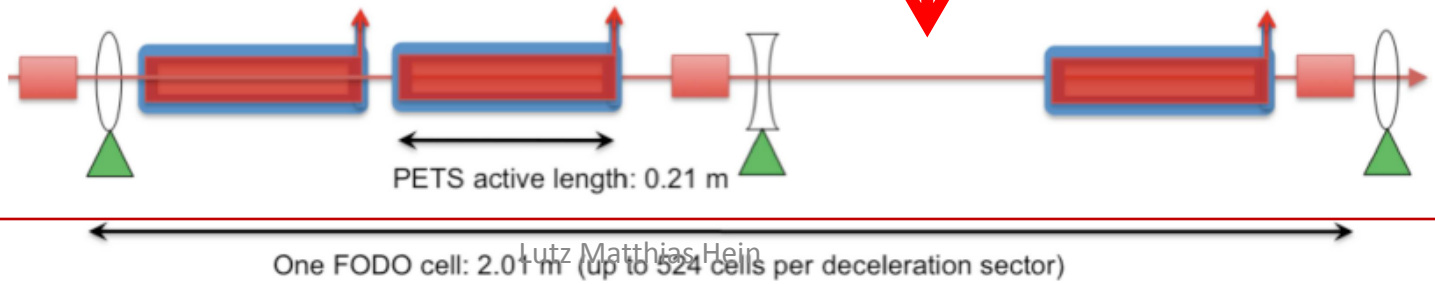
6.14GeV

(830m)

1500GeV

(1040m)

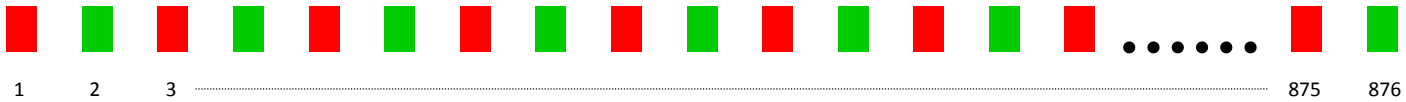
Stronger quadrupoles required
-> Skip cavities for quadrupoles
-> 24 different Decelerator Lattices



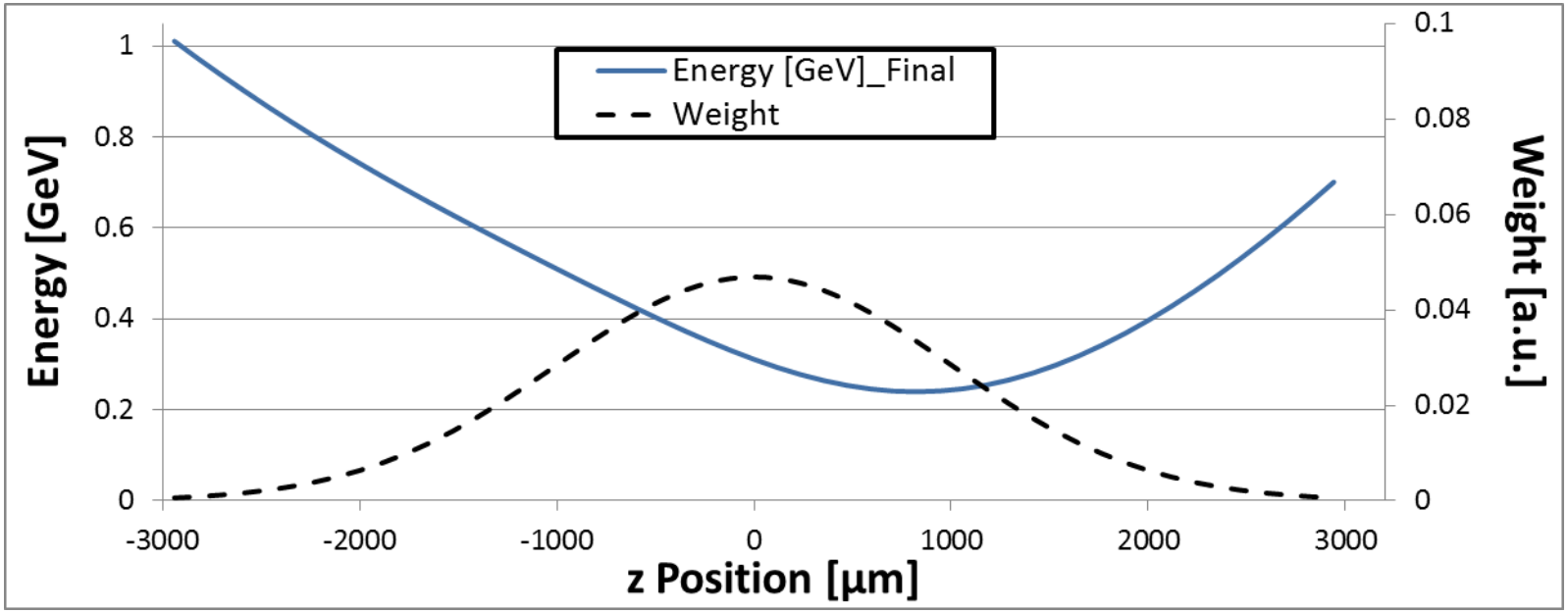
Beam Dynamics

FODO – Lattice:

Phase advance (E_{min}): 90 deg

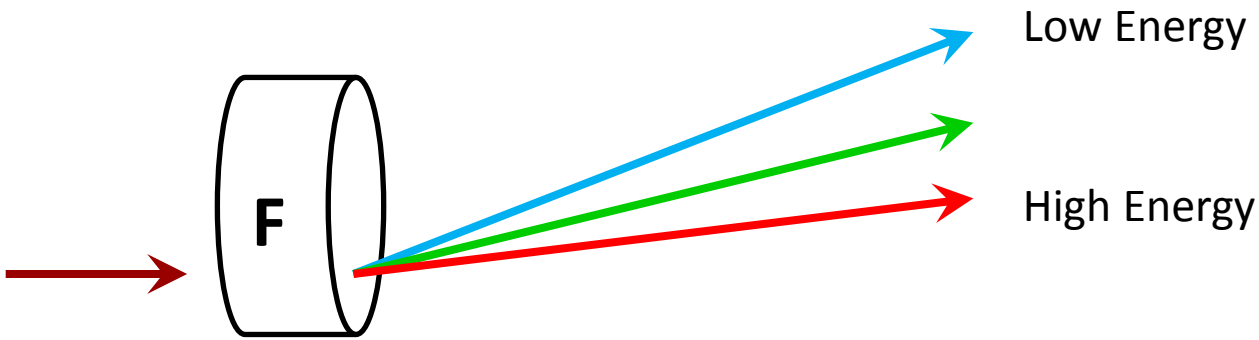


!! Used to decelerate !! 2.4 GeV -> 240MeV

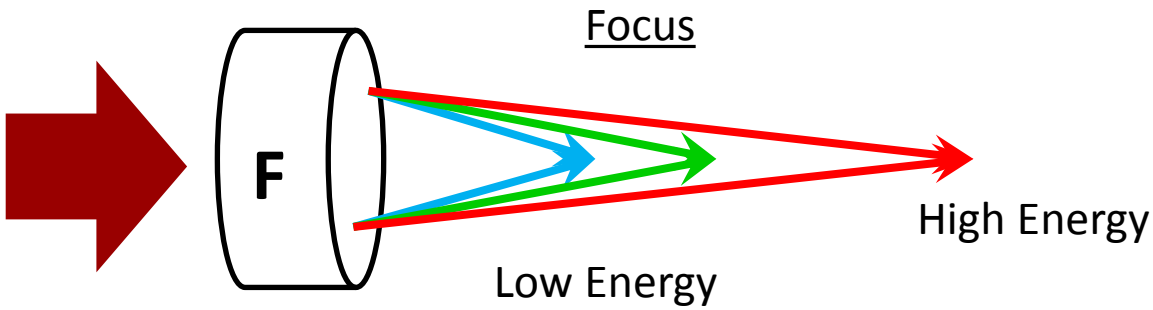


Results of the Energy Spread

I) Kick itself



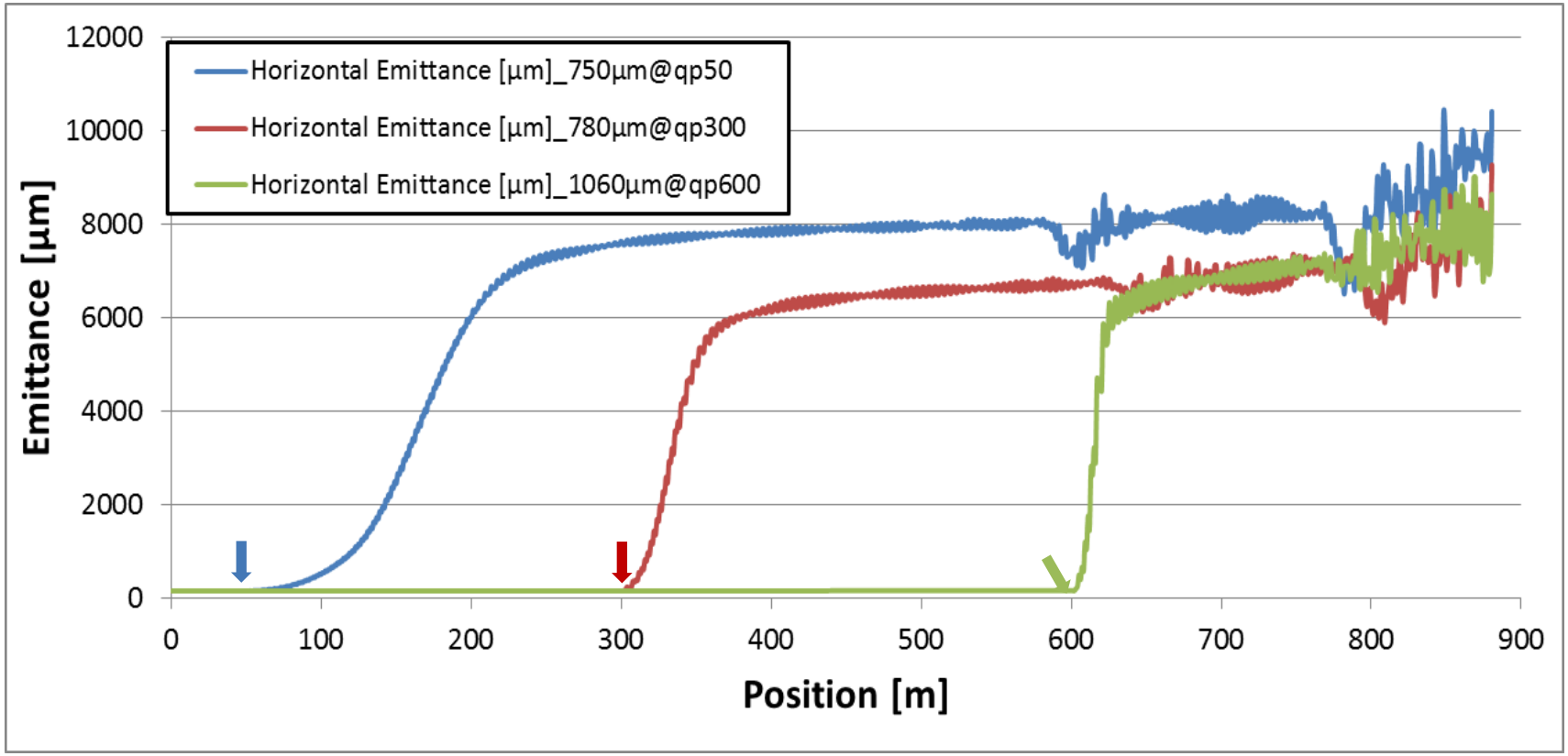
II) Chromaticity



-> Filamentation & Emittance Growth

Filamentation Speed

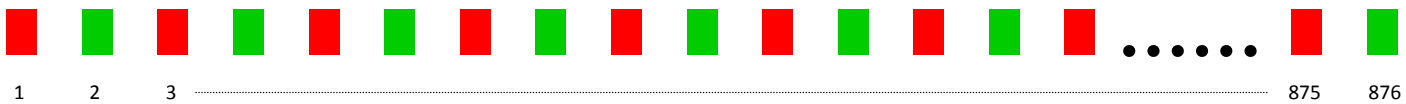
Energy and Phase Advance -> ‘speed‘ of the Filamentation



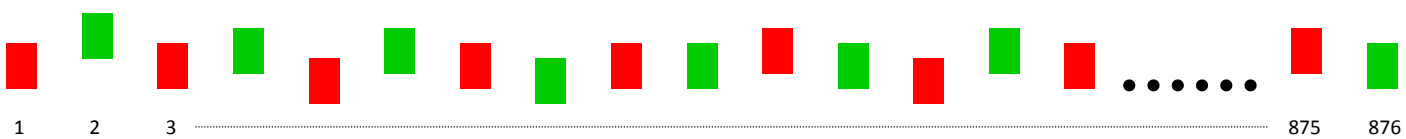
Multiple Kicks

Estimate Limits of Multiple Quadrupole Offsets

Decelerator Nr. 11 (with 876 Quadrupoles):



Misalign of several Quadrupoles etc.:



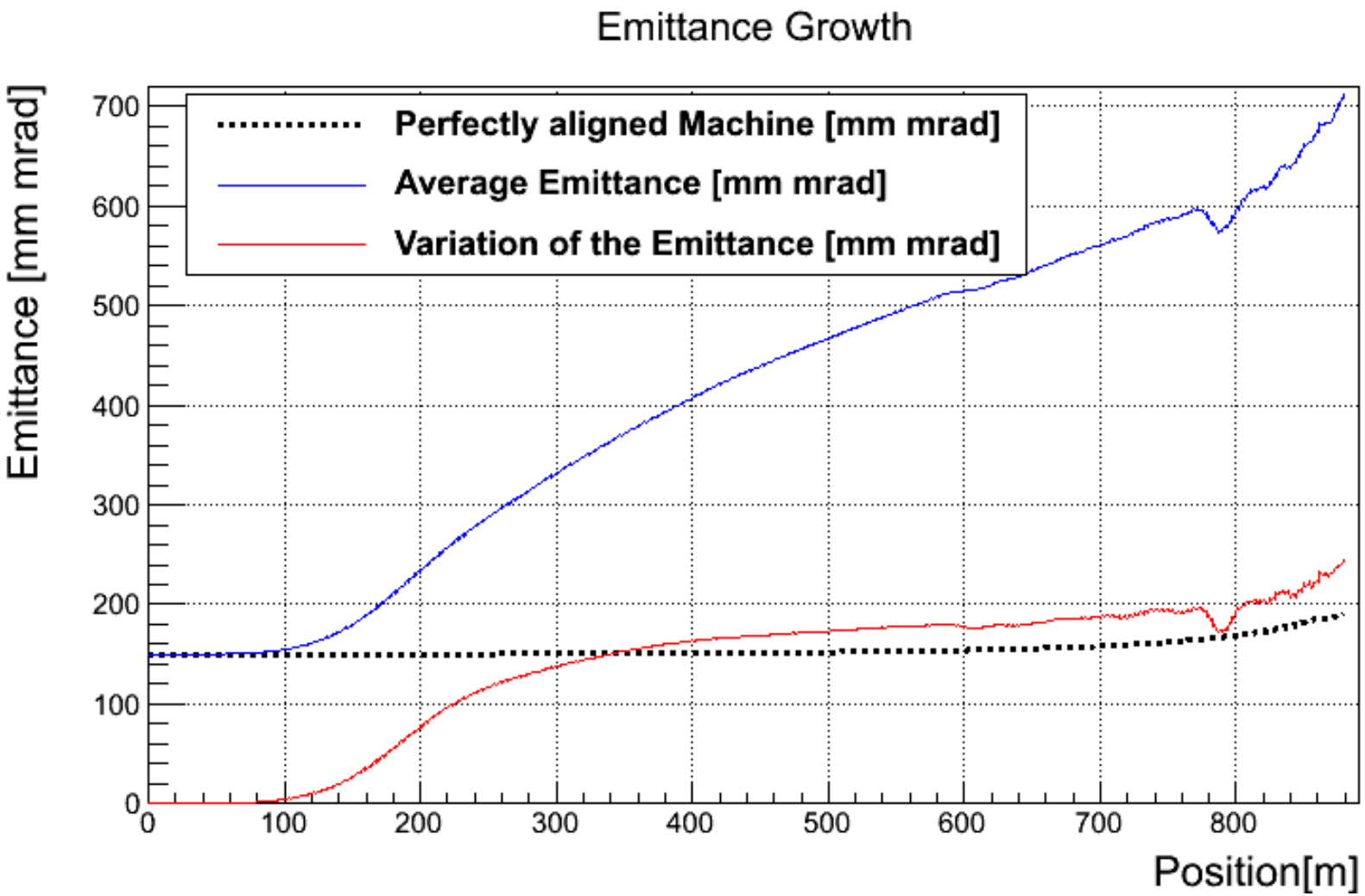
Errors listed in CDR
e.g. Quadrupole

$\sigma_{x,\,y} = 20\mu m$

$\sigma_{x',\,y'} = 1000\mu rad$

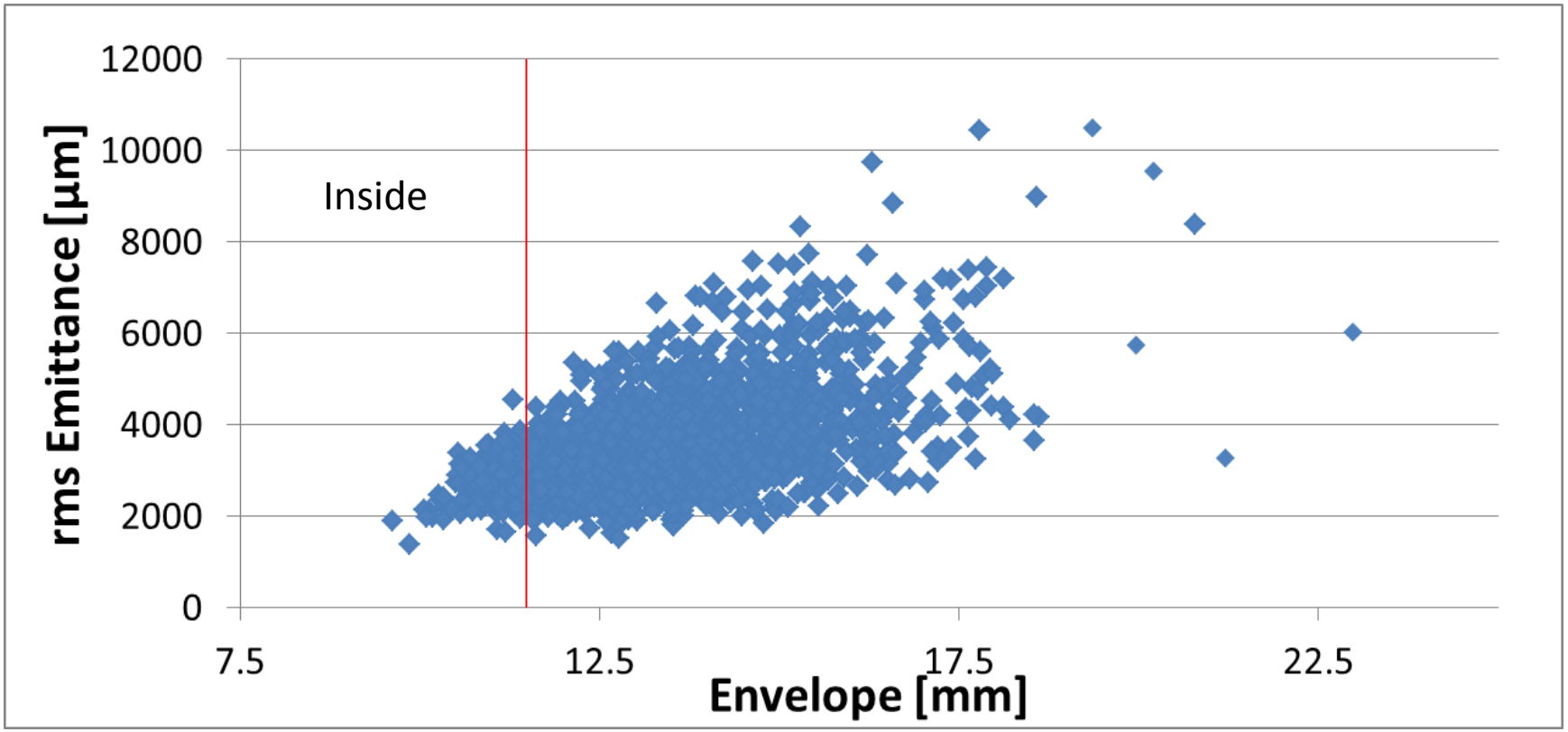
- **Can we simply add qp-kick up into sequences?**
- **Under which circumstances is structural damage espected?**

Multiple Kicks



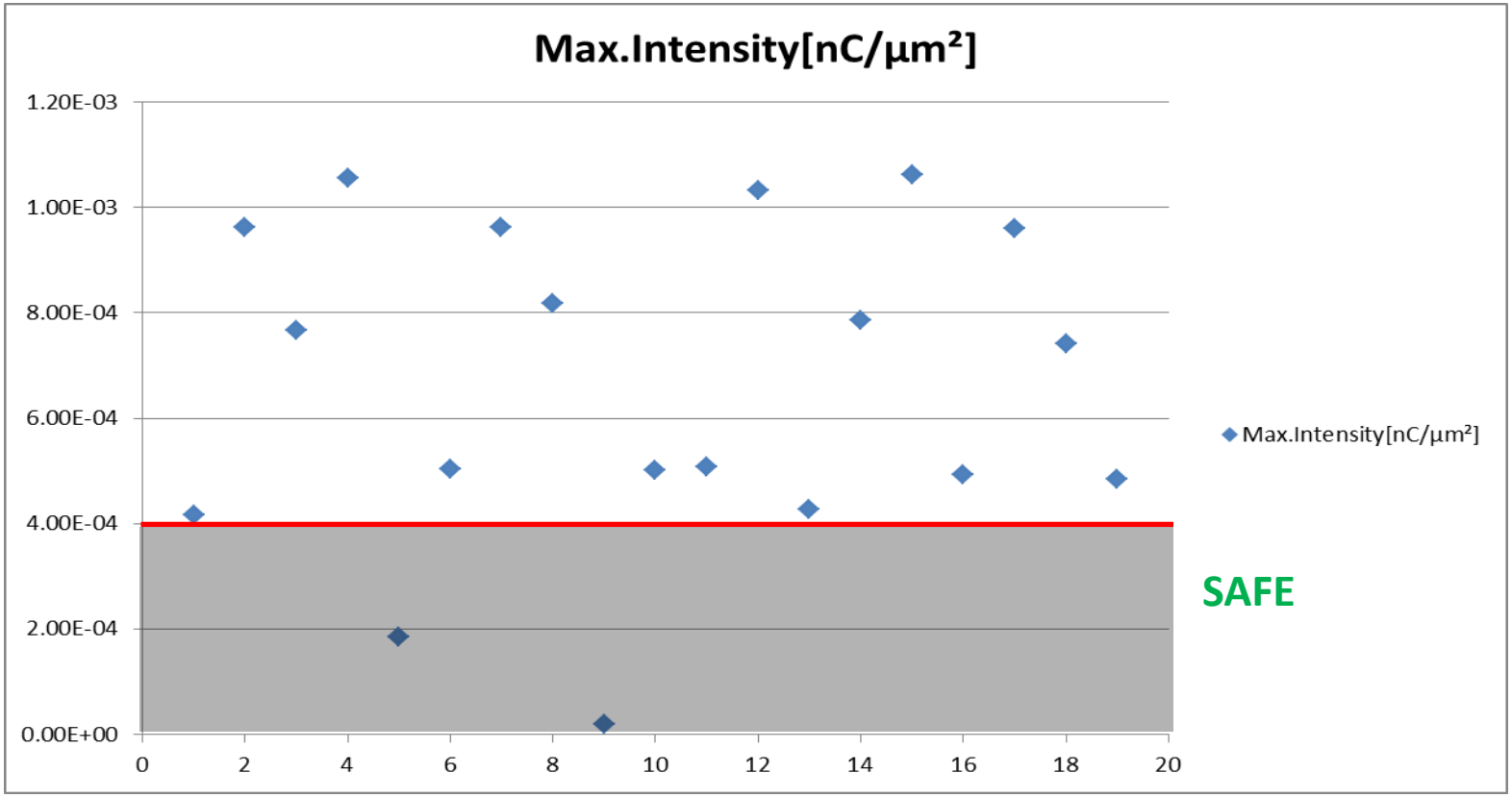
Multiple Kicks

Random Seeded Quadrupole Alignment Errors



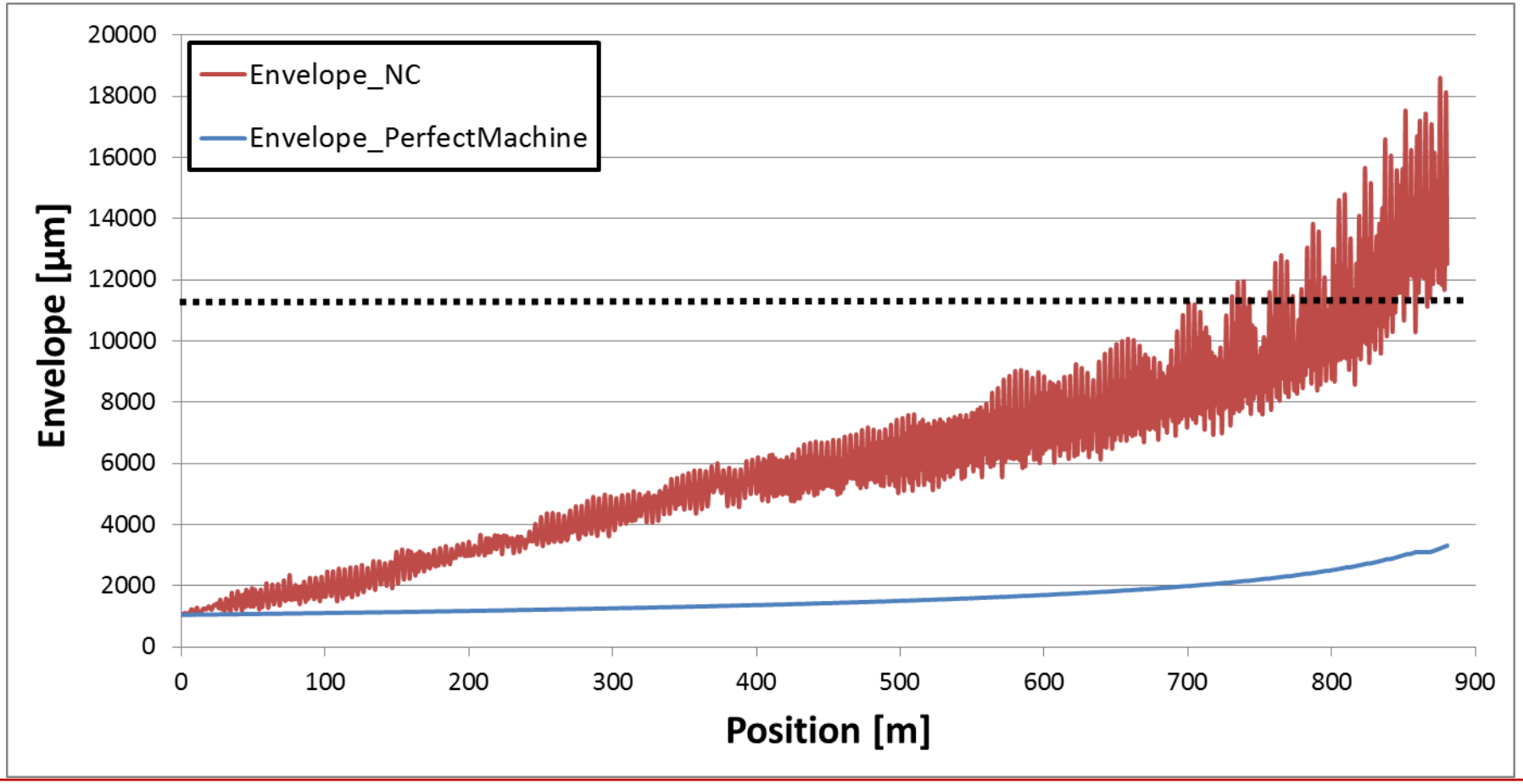
Multiple Kicks

Random Seeded Quadrupole Alignment Errors

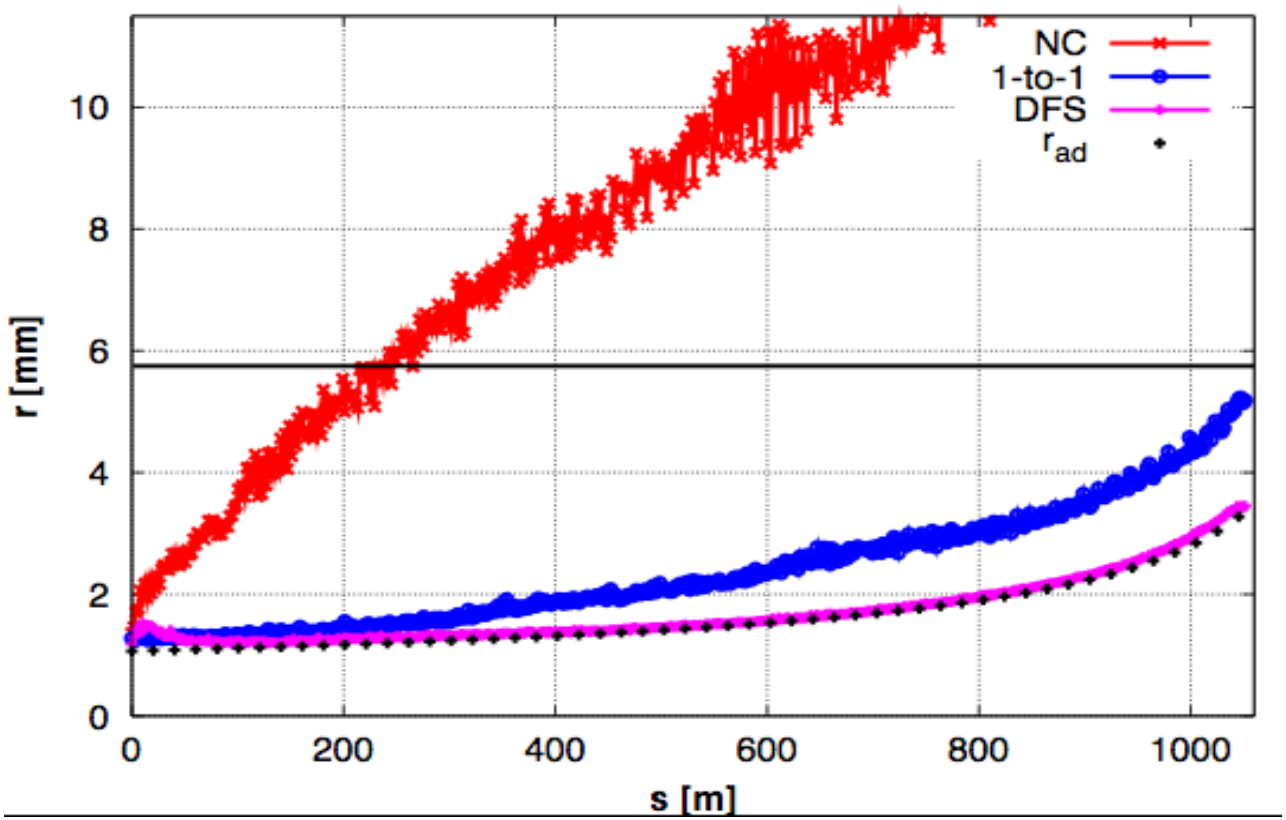


Multiple Kicks

Envelope **Intensity: 10.6 · 10^{-4} nC/µm² -> 0.0**



Dispersion-free correction



Additional Informations

CERN-THESIS-2010-024

Talk: A. Latina
Results of BBA
tests at FACET and Fermi
(starting in ~5 min, **here**)

Dispersion-free correction takes out dispersion and drives the whole beam very close to the BPM centres

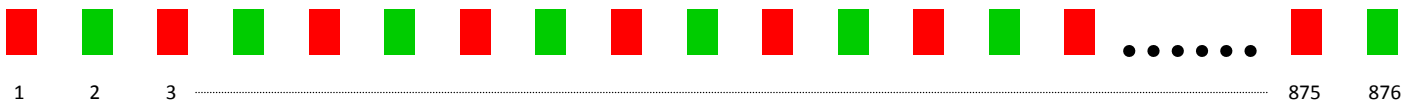
NB: correction strategy is to first perform 1-to1 then DFS

Courtesy – E.Adli

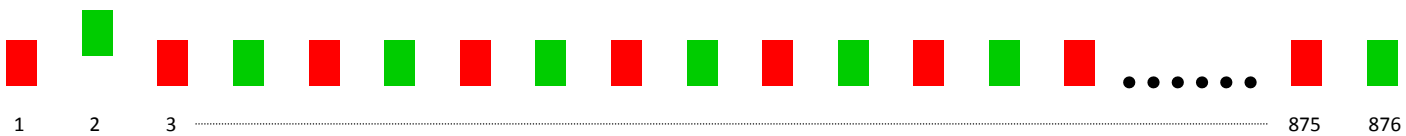
Single Kicks

<u>Estimate Limits of Single Quadrupole Offsets</u>

Decelerator Nr. 11 (with 876 Quadrupoles):



Misalign single Quadrupole:



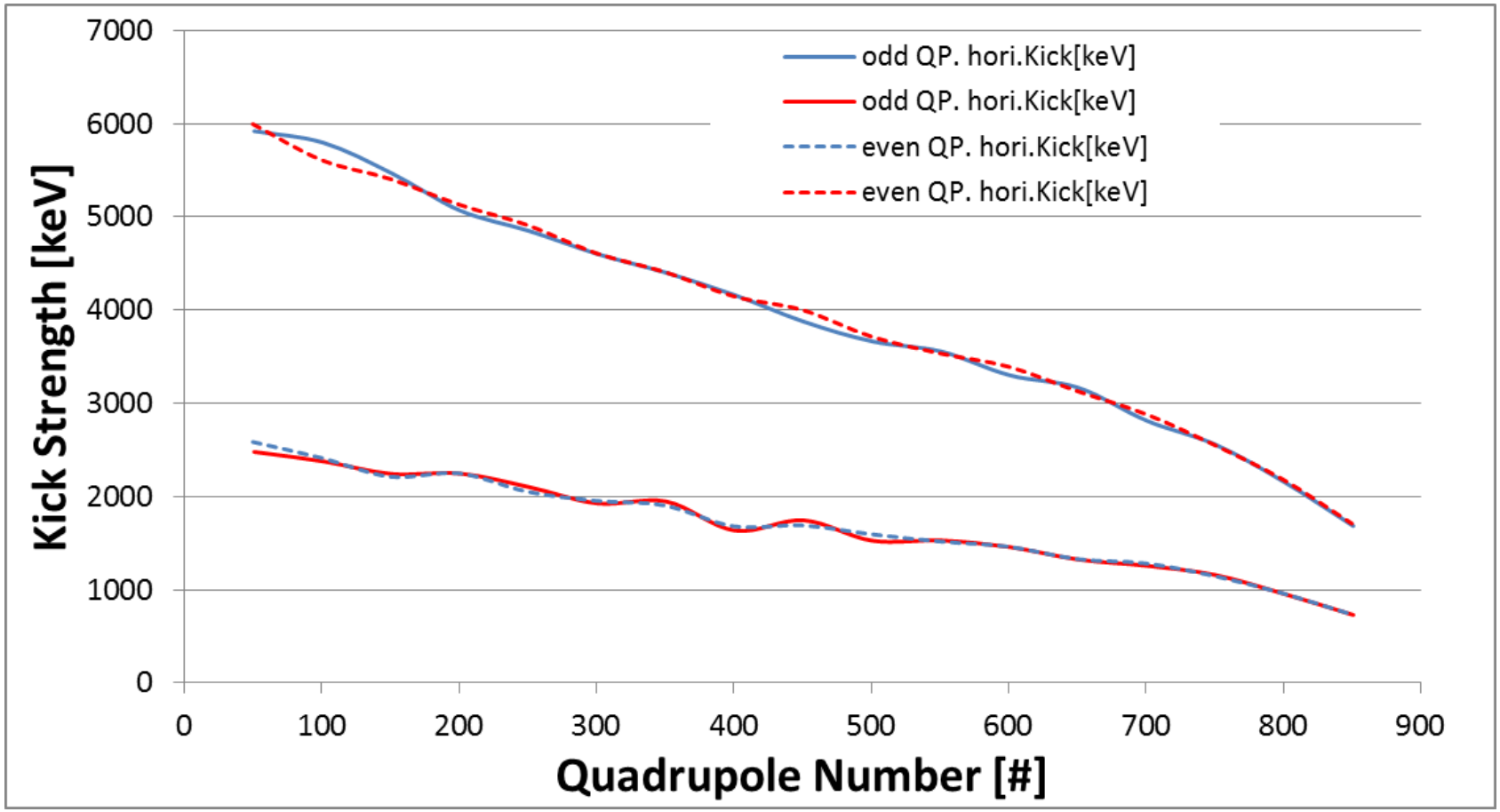
!! There are differences between focusing and defocusing Quadrupoles !!

($\sigma_{pq} \approx 20\mu m$)

Single Kicks

Step2 – Damage:

When do we „hit“ the aperture?



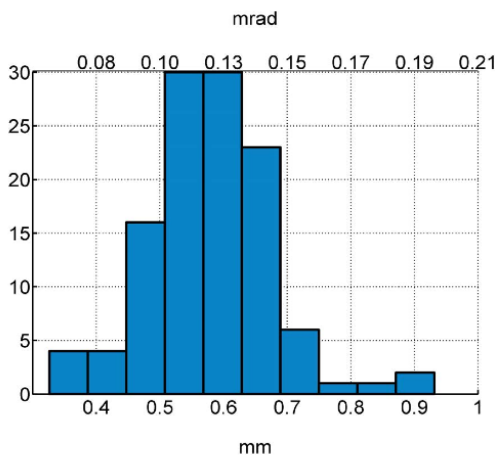
Single Kicks

Step2 – Damage: **Kick Limits: 1000keV .. 6000keV**

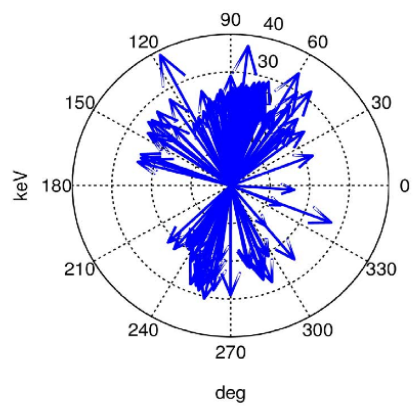
QP-Movements: 10 µm Offsets = 36.3keV .. 3.63 keV

RF-Kicks:

kick magnitude
(typically 0.13 mrad)

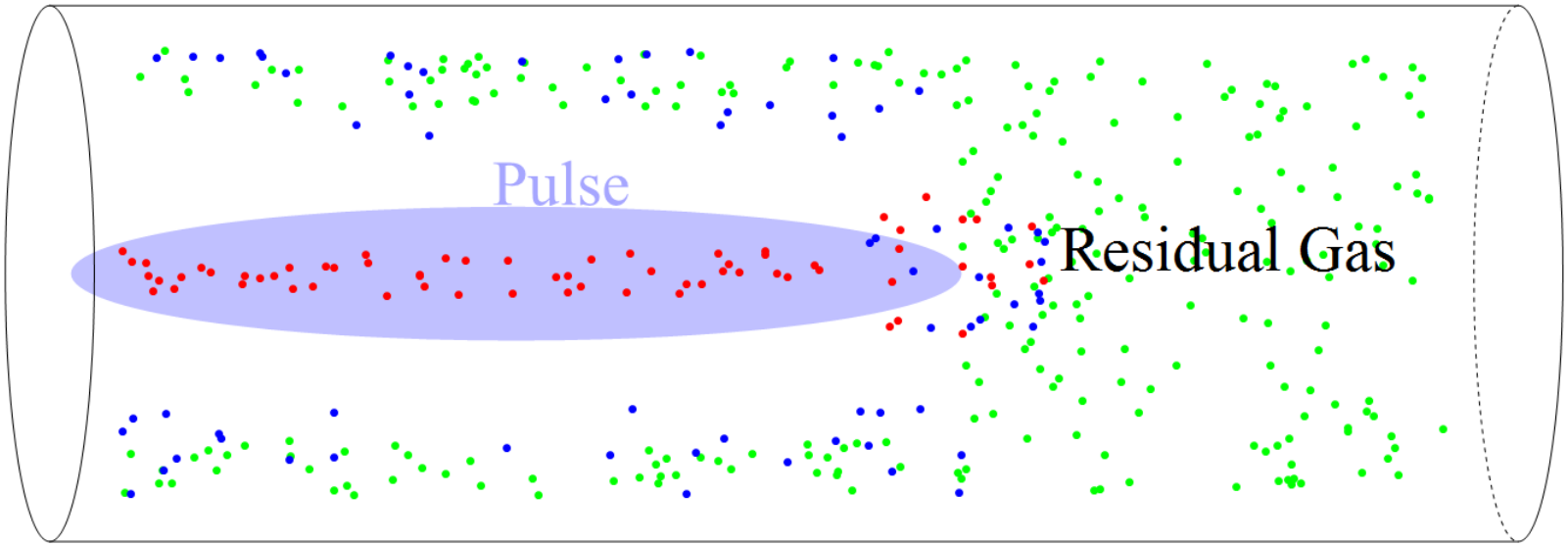


transverse electric field
(typically 25 keV)



Wilfrid Farabolini
Andrea Palaia
IPAC-2012-MOEPPB001

Residual Gas Scattering

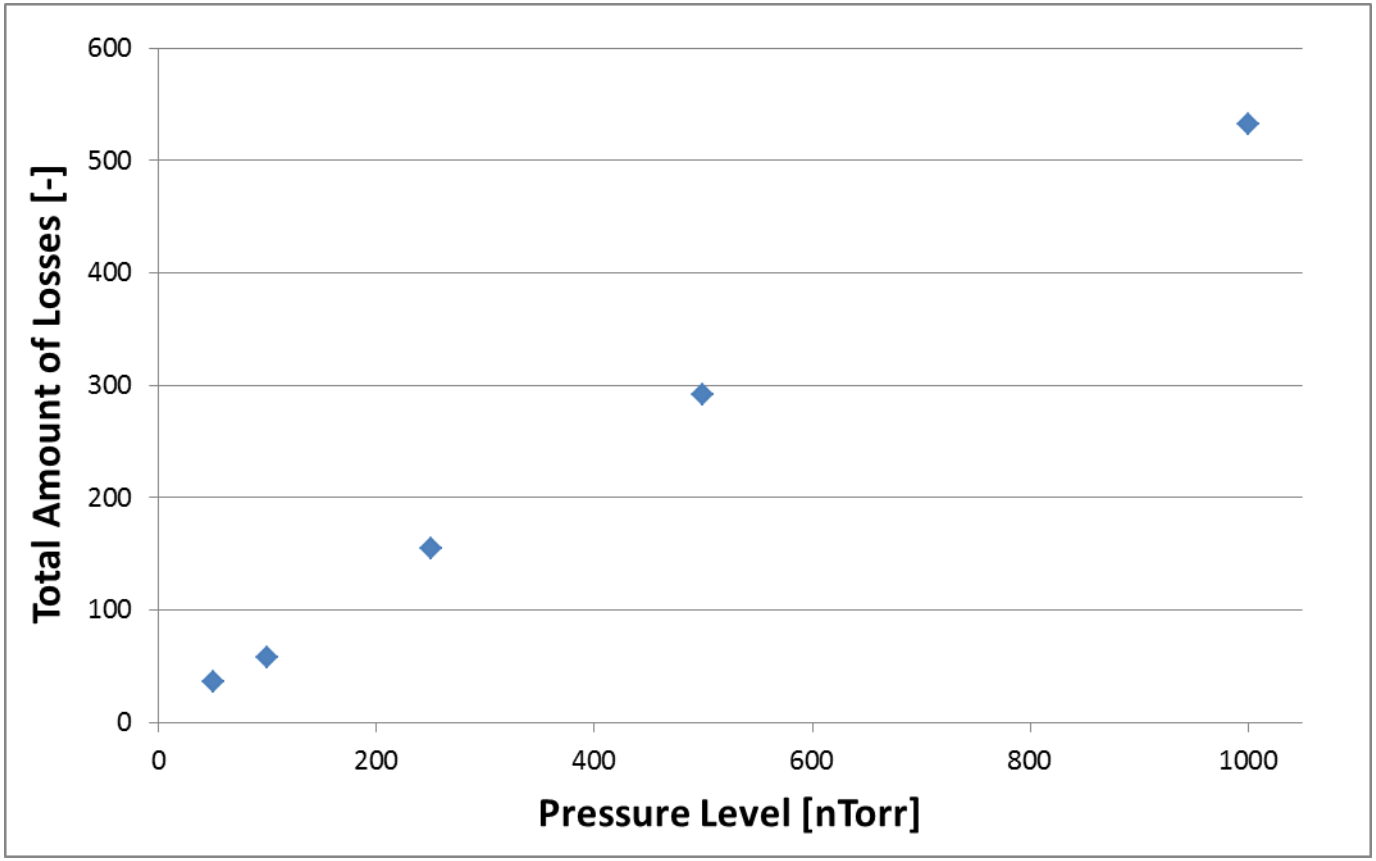


Halo and Tail generator HTGEN, H. Burkhardt
Placet, A.Latina, D. Schulte et. al.

Residual Gas Scattering

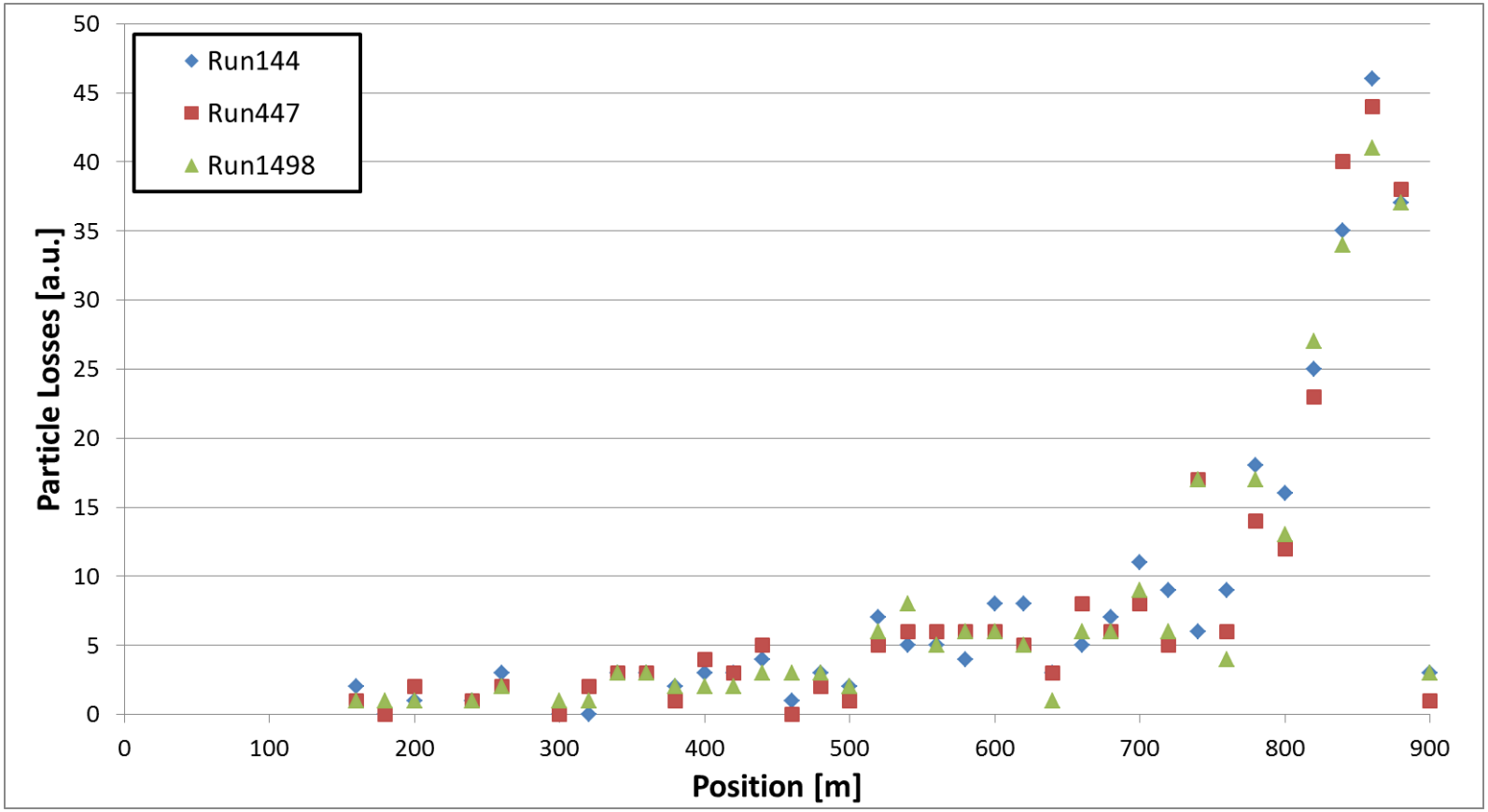
Scaling: Pressure Vs. Losses

Residual Gas
Z=7, N=14
nitrogen



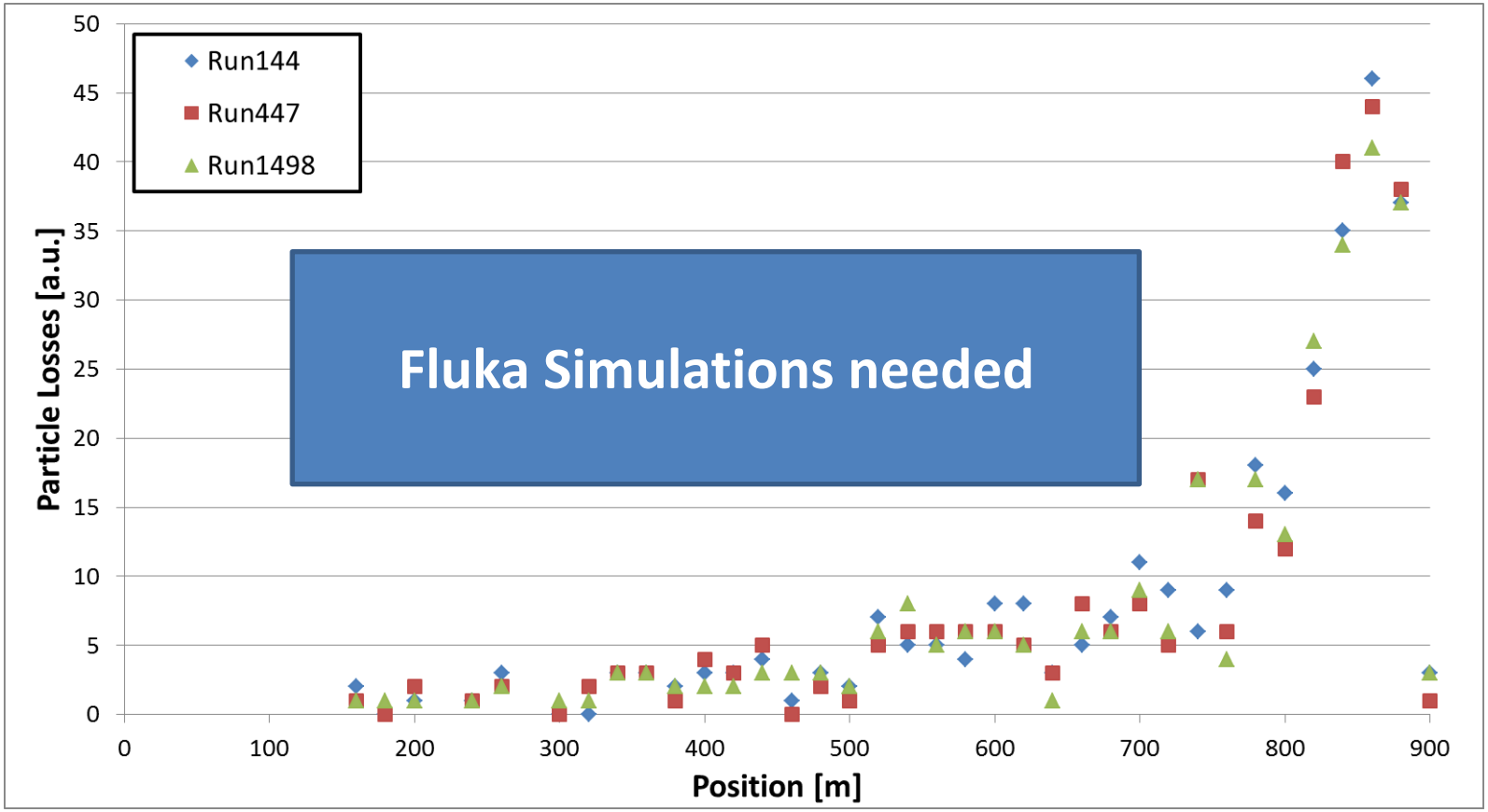
Residual Gas Scattering

Locations of Losses



Residual Gas Scattering

Locations of Losses



Conclusion

- Damage Limits strongly dependent on Particle Energy
- Uncorrected Machines
  - Particle Losses are very likely
  - Damage Threshold likely exceeded
- Corrected Machine
  - Losses by residual gas scattering (further studies ongoing)
- Threshold for isolated disturbances ≈ 100 x keV