Attempt of a Summary of Lessons from

Beam Loss Generation

D. Schulte for the workshop participants

Talks

Alexander Kaukher: Beam loss mechanisms in FLASH/DESY

Helmut Burkhardt: Halo formation and losses in CLIC

Frank Tecker: Beam loss experience from CTF3

Lauretta Ponce: Beam loss mechanisms : observation from the LHC

Andrea Latina: Overview of Failure Mode Studies for ILC and CLIC

Carlos Omar Maidana Failure studies at CLIC main Linac and Beam Delivery System

Marc Ross: Beam Loss Mechanisms and Mitigation at SLC

Failure Induced Beam Loss

- Dramatic examples
  - Wrong timing/failure of LHC injection kicker
  - Wrong beam phase at ILC main linac injection leads to large loss
  - Failure of a drive beam sector can lead to CLIC beam lost in main linac
- Other potentially important effects
  - Transverse deflection by RF breakdown in CLIC main linac seems no problem
  - Also no major problem in decelerator
  - Magnet failure in decelerator, OK for single failure
  - Octopole failure in LHC, caught by beam loss detection
- Extensive studies are required
  - To identify the sources
  - To mitigate the failure or their impact
  - But residual problem may exist

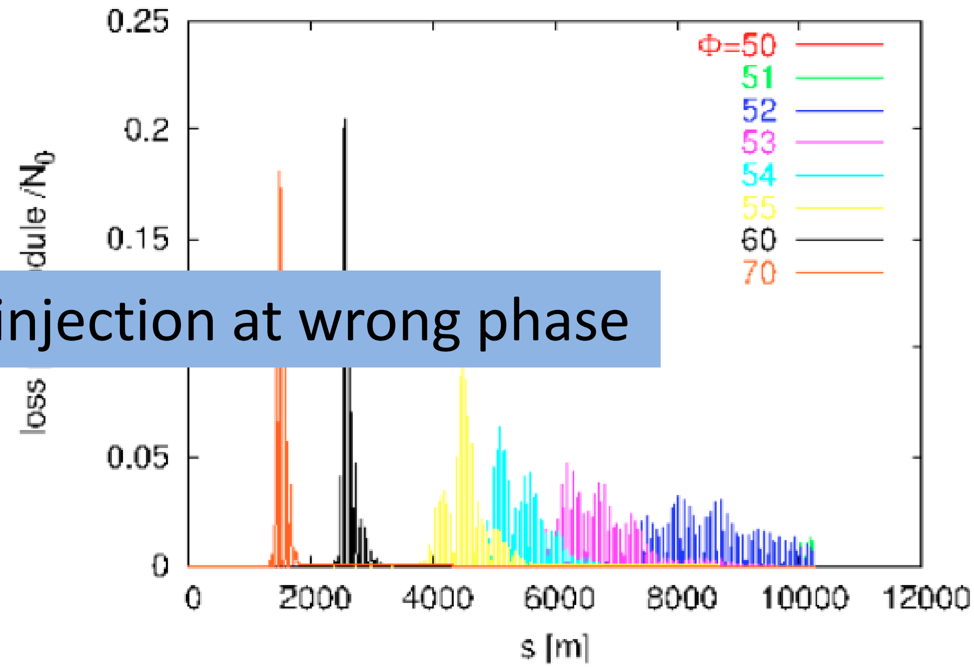
Loss Distribution in the ILC Main Linac

EUROTeV 2006-040

PLACET simulations of losses for different phase errors

- Collaboration DESY / CERN published at EPAC 2006
- Studies of quadrupole failures and errors
- Studies of klystr their impact on t protection

Need to avoid injection at wrong phase

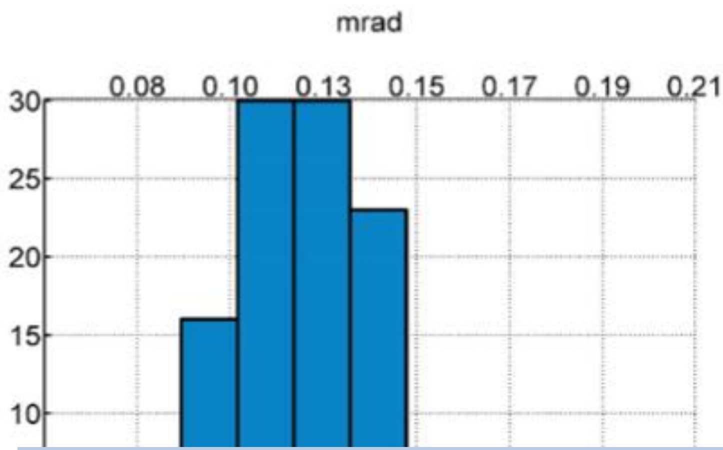


failing quads	% lost particles	failing quads	% lost particles
2	2 %	10	80 %
6	37 %	12	95 %
8	73 %	14	100 %

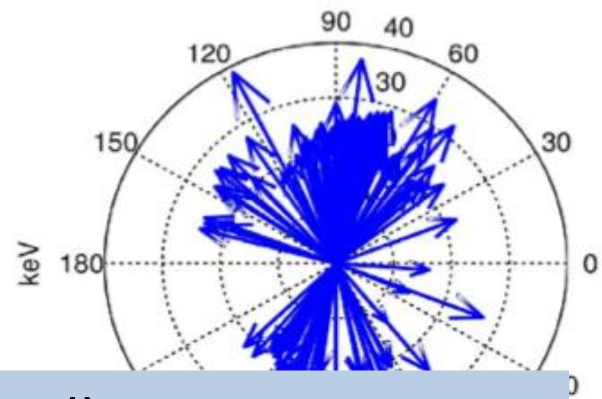
A. Latina

TBTS beam kick measurements

kick magnitude
(typically 0.13 mrad)



transverse electric field
(typically 25 keV)



Worst kick from 40keV is 20% of collimation aperture

But large orbit variation

Wilfrid Farabolini
Andrea Palaia

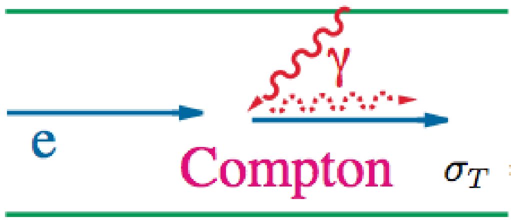
- kicks corresponding to transverse momentum between 10 and 40 keV/c (measurements at NLCTA < 30 keV/c)
- more data with BPMs this year…

Physics Induced Beam Loss

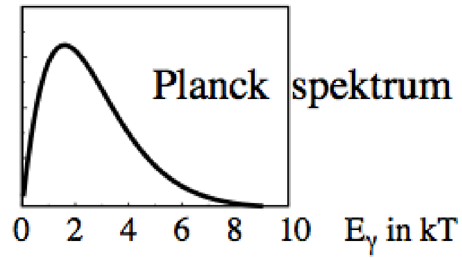
- Beam gas scattering
  - Can be calculated (QED)
  - Implemented in tracking code so can determine losses
- Black body radiation scattering
  - Can be calculated (QED)
  - Should be implemented in code

- Still some surprises
  - Collimation system produces most of the tail that it is supposed to remove
  - But still necessary

Scattering off thermal photons



$\sigma_T = \frac{8\pi}{3} r_e^2 = 0.6652$ barn



mean energies:

initial : $E_\gamma^i =$ 2.7 kT = 0.07 eV

e-rest: $E_\gamma = \gamma E_\gamma^i = 6.2$ keV << m_e

$$\rho_\gamma = 8\pi \left(\frac{kT}{hc}\right)^3 \cdot \underbrace{\int_0^\infty \frac{x^2}{e^x - 1} dx}_{2.404114}$$

$5.32\times10^{14}/m^3$ at room temp.

Lab: $E_\gamma' = \gamma E_\gamma^* \cong \gamma^2 E_\gamma^i$ 2.4% at 100 GeV, 5.3% at 250 GeV, 86% at 1.5 TeV

Was important for beam halo in LEP and the dominant single beam lifetime

CLIC 1.5 TeV P = 1.9×10^{-14}/m for 2% energy loss.
integrated over LINAC + BDS still below 10^{-9}
not an issue

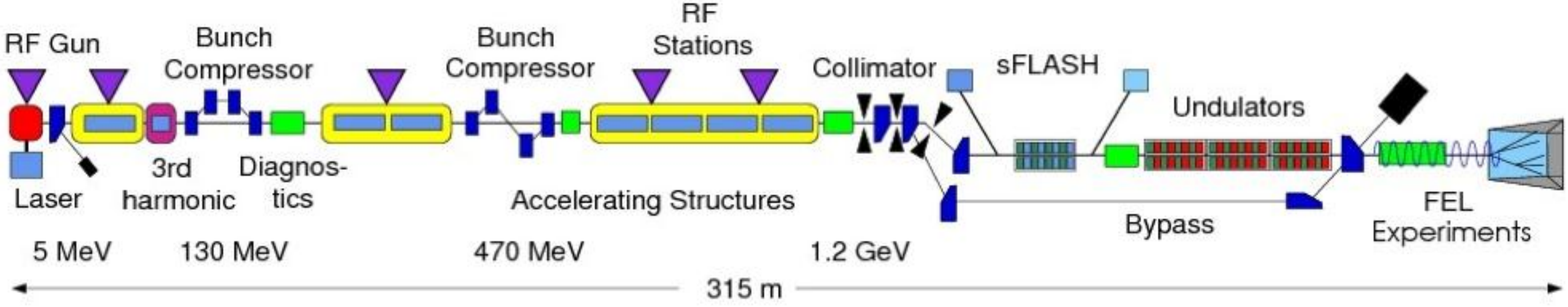
H. Burhardt

MC generator, see SL/Note 93-73 (OP)

Losses of Parasitic Beam

- Examples
  - LHC injection leads to loss of uncaptured beam
  - Dark current in FLASH/linear colliders
  - Satellite bunches in CTF3
- Level of predictability
  - Varies depending on the source
- Mitigation
  - Minimisation of source
  - Collimation, masks
  - Kickers

Free Electron Laser in Hamburg – FLASH



- Linac with superconducting RF cavities, 1.3 GHz
- Short bunches, flexible bunch pattern, low emittance ...

Dark current mainly from gun

Field emission(RF gun gradient ~45 MV/m) → Dark Current → Protection of Undulators

'Predictable sources' of beam losses : screens, wire scanners, LOLA Kicker
Beam losses in collimator are 'pre-programmed'

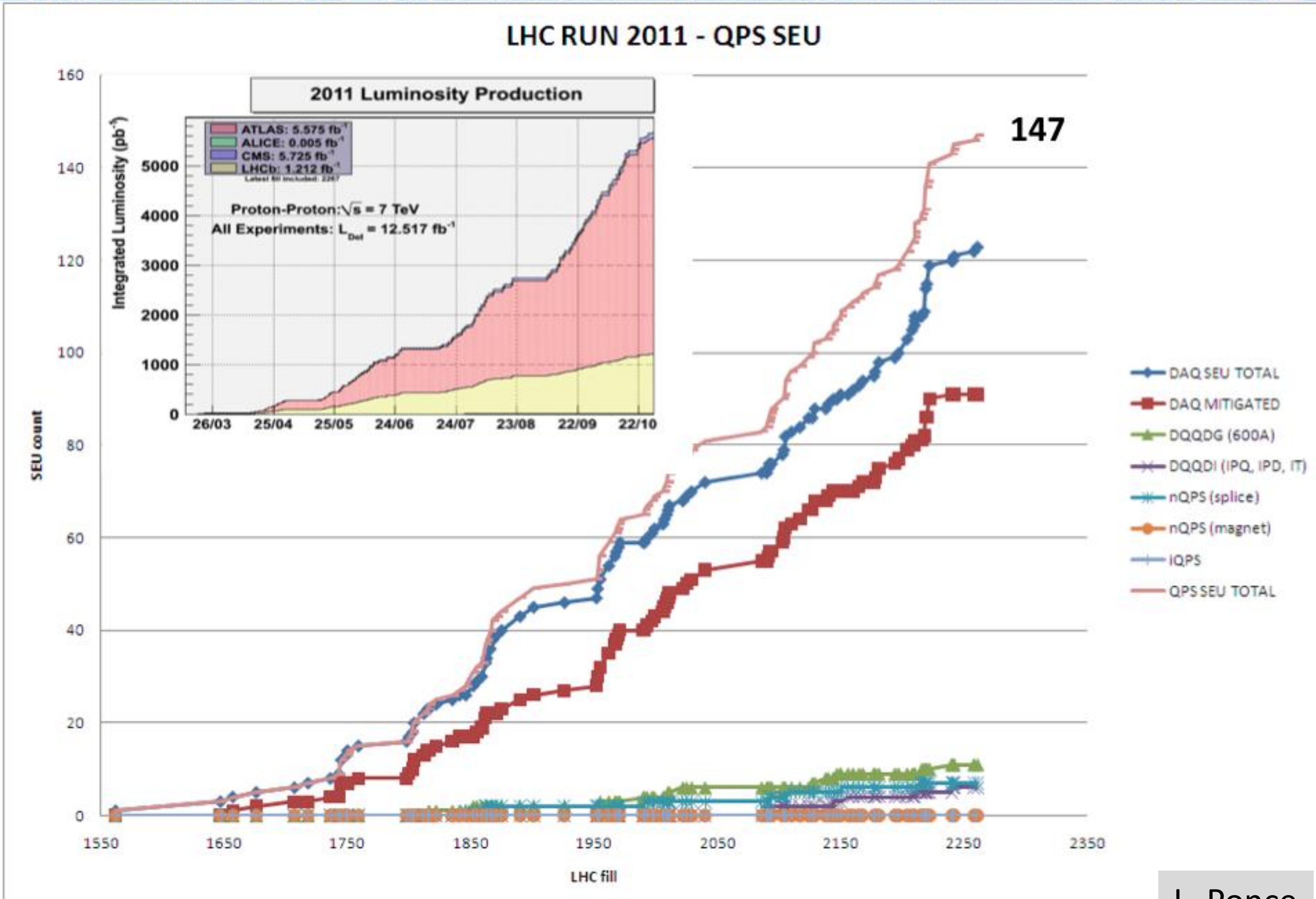
Toroids & Beam Losses Monitors are there to protect the machine from damage

A. Kaukher

Mitigation of Equipment Failure

- E.g. Radiation induced equipment failure
- Try to minimise
  - Failure rate
  - Failure impact
- At LHC can nicely predict failure rate

Radiation induced fault statistics 2011



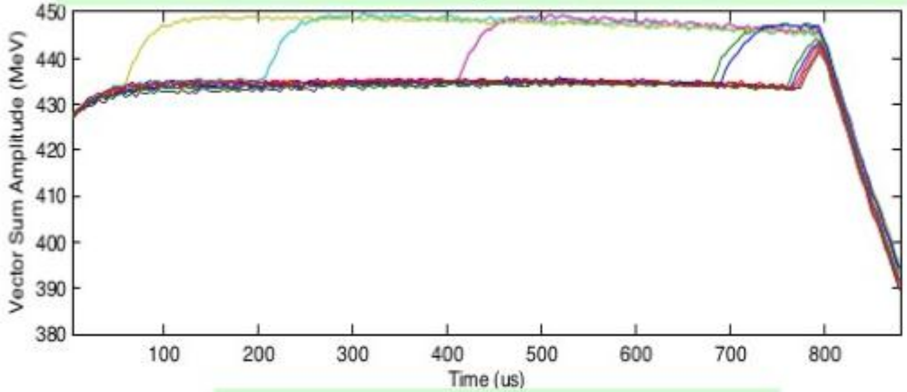
L. Ponce

Transient Effects

- Changes of transfer lines in LHC pose a problem
- FLASH pulse shortening can lead to loss of dark current
- Transients pose a problem to recover from trips in FLASH
- Safe beam to avoid transients as much as possible
  - But not fully possible
  - E.g. main linac with multi-bunch beam loading
- Lessons try to minimise transient effects
  - Minimise difference between operation with different beams
  - Important for ramp-up
  - Safe beam/pilot beam
  - Slow changes of the machine
  - Anticipation of secondary changes

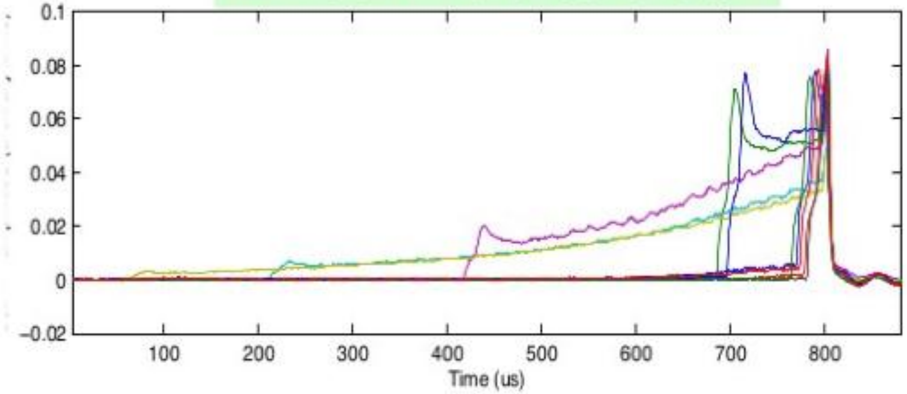
'Phantom' trips due to dark current

ACC1 Vector Sum Amplitude over bunch train



Cavity voltage jumps due to loss of beam loading

BLM 36BYP over bunch train



Total gradient vector sum increases, dark current hits wall, BLM signal rises

A. Kaukher

Courtesy J. Carwardine

Linac Collimation:

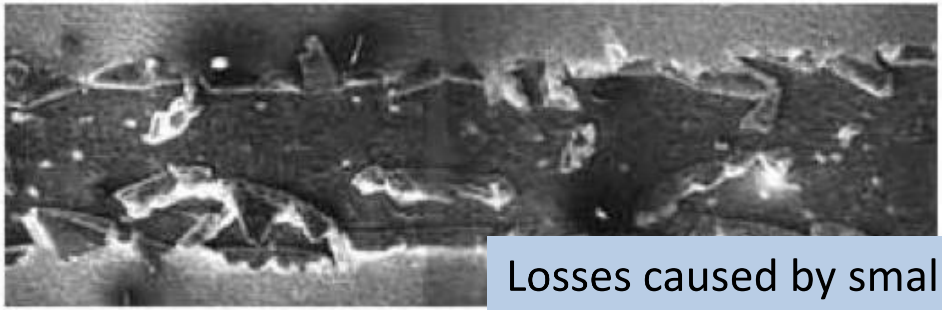
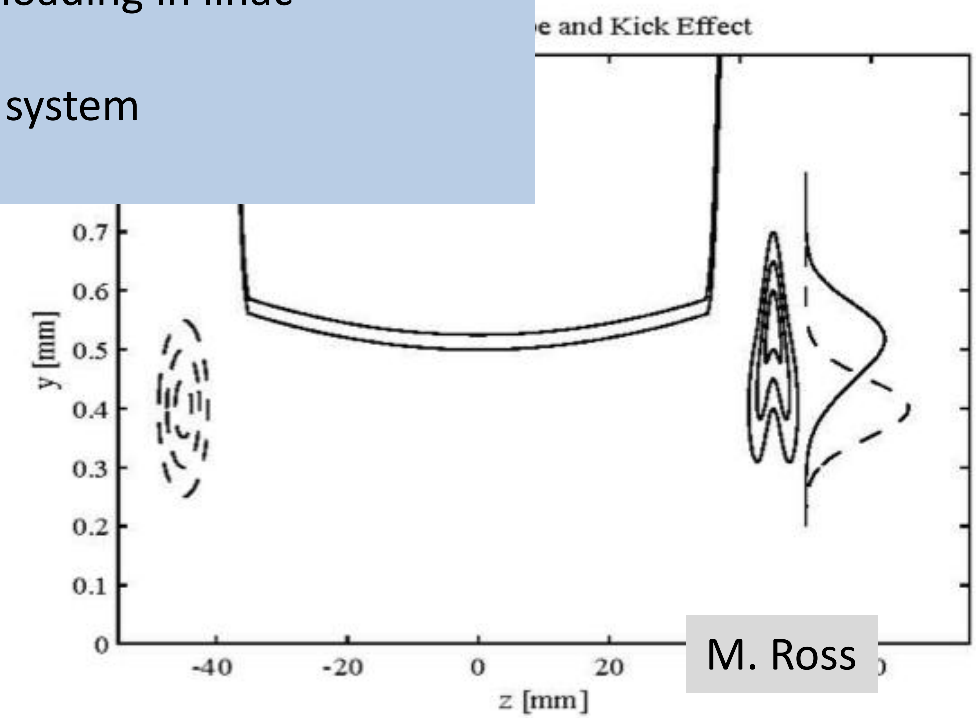


Fig. 1: Damaged collimator su
The beam enters at the left, creat

- 47 GeV (max) collimation system
- ... <1mm

Losses caused by small damping ring instability
-> deformed phase space
-> losses in bunch compressor
-> variation of beam loading in linac
-> change of orbit
-> loss in collimation system
-> MPS stops beam

- Collimator damage
- de-lamination
- (Au coated to reduce resistive wake)



M. Ross

SLC

- The SLAC Linear Collider (SLC) was intended in part to demonstrate that linear colliders could work.
- Even though it did not meet luminosity goals, physics goals were met and remain comparable to LEP results.
- **Stabiliz** … **nd transiti** … **ne protect** … **instabi** …
- **MPS fa** … **of relative** … **longitudinal instabilities in a kind of chain reaction that involved the ring, bunch compressor, normal-conducting linac and collimation systems.**

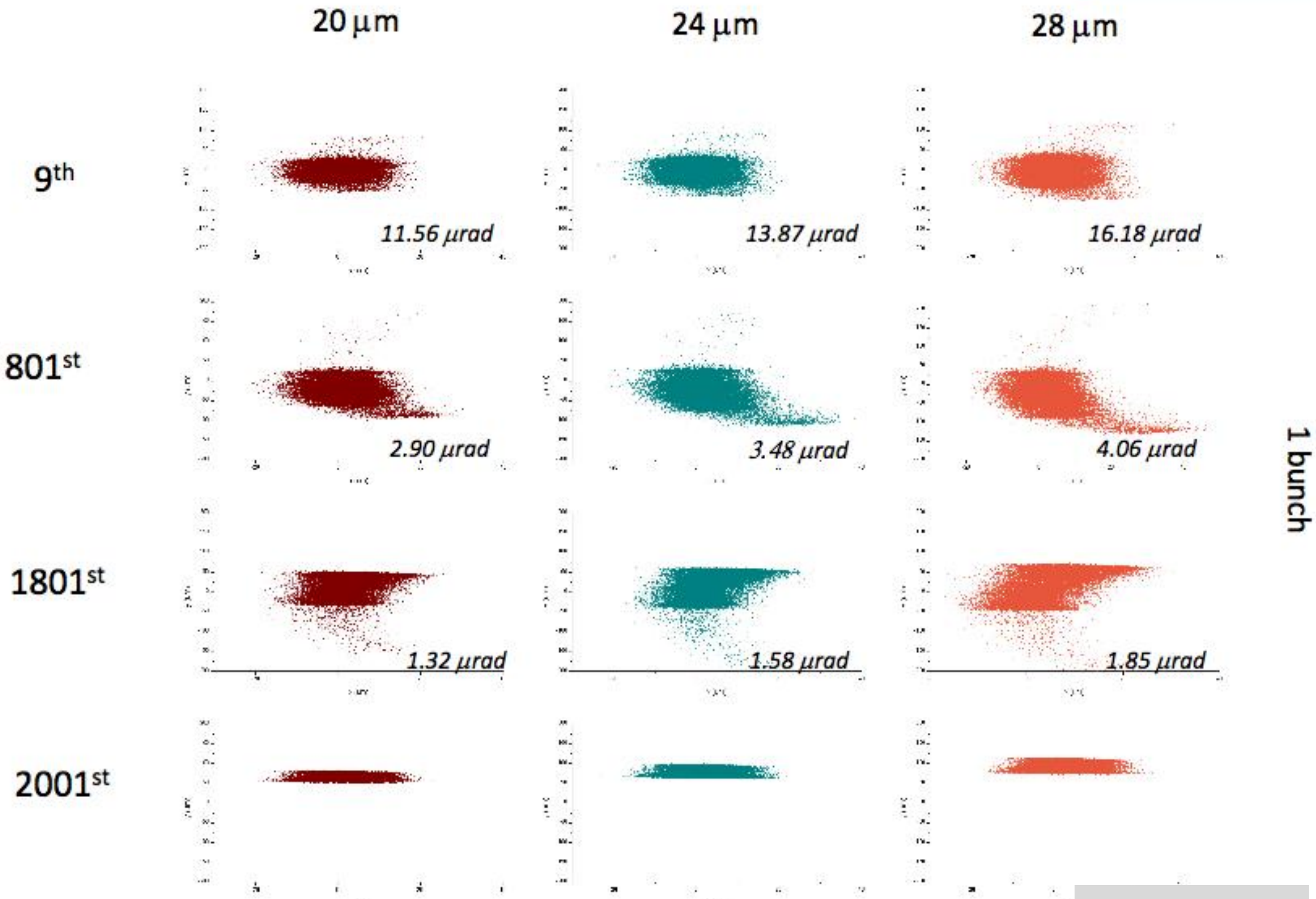
Integrated studies are essential
-> inclusion of relevant phenomena
-> correct modeling of different phenomena

Obviously more easily said then done

Tracking Tools

- Modeling of the machines is essential
  - Combined effect of different parts of the machine, e.g. damping ring, bunch compressor and linac
- Codes are available
  - Benchmarked with other codes for the tracking part
- Some loss generation is included
- Main challenge is to have correct models for different components
  - E.g. Wakefields
  - Imperfections
  - Vacuum level
  - Surface effects (electron cloud, …)
  - …
- Large efforts have been made to verify models
  - But not always possible

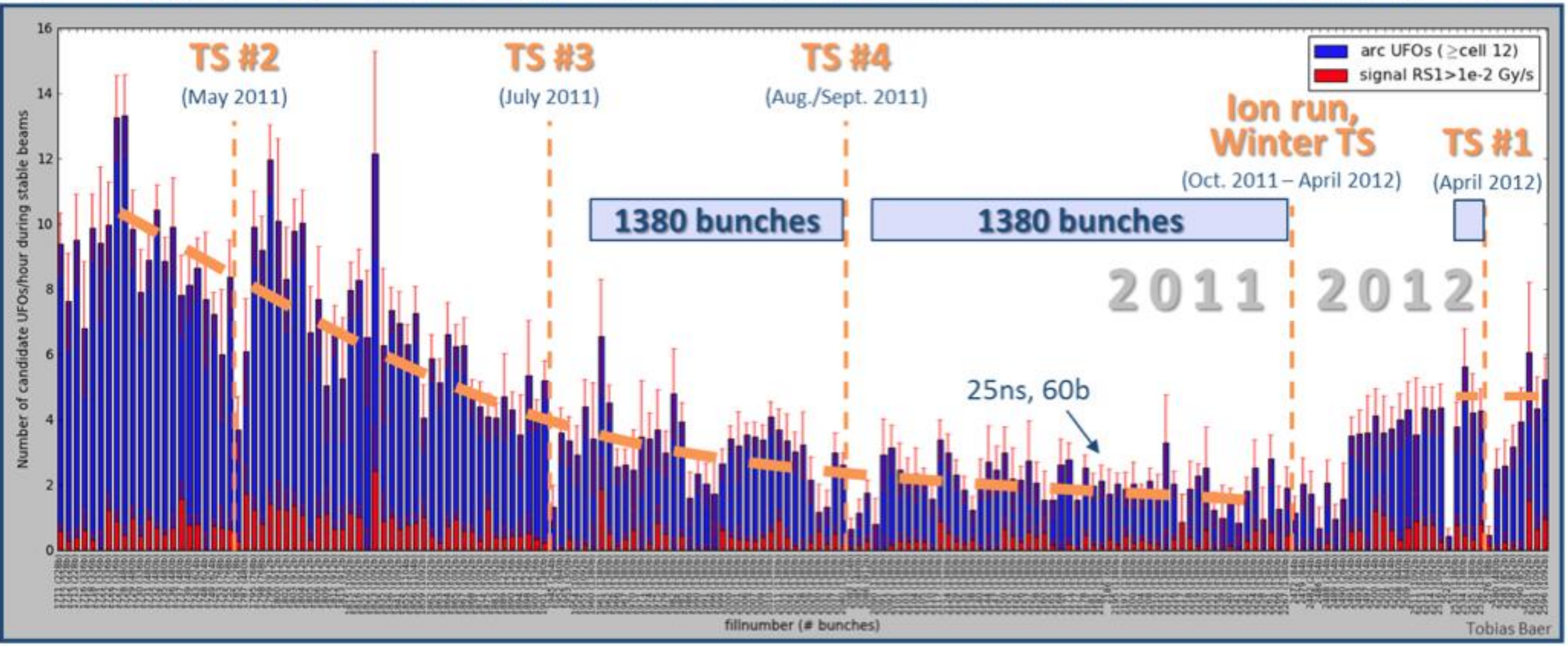
Material damage caused by the BDS beam & beam dynamics at the collimators



Betatron collimator entrance

C. Maidana

UFO Rate



2011: Decrease of UFO rate from ≈10 UFOs/hour to ≈2 UFOs/hour.

2012: About 2-3 times higher UFO rate compared to October 2011.

But still something unexpected may happen

L. Ponce

Conclusion

- Many effects are fundamentally similar
  - Often understand effects
  - But not all
- Lessons learned are often similar
  - Transients are critical
  - Integrated studies are essential
  - Rates of failures
  - Sources of losses
  - …
- Need modeling tools
  - Main issue is the proper model for the reality
- Expect the unexpected

- Very useful workshop
  - Should have some follow-up