Comparison with beam data and development plans for SixTrack

R. Bruce on behalf of collimation team, FLUKA team

Outline

- Background on present SixTrack
- Comparison with LHC beam data
- Perspective for future development

SixTrack with collimation: Motivation

- LHC has unprecedented stored beam energy of 362 MJ (design). Max achieved in Run 1: 146.5 MJ. For HL: ~700 MJ!
- A tiny beam loss could quench a superconducting LHC magnets
- Efficient collimation is of fundamental importance to guarantee safe and stable running conditions
- Need to understand in detail at the design stage the expected level of leakage to the cold aperture for different optics/layouts/settings of collimators
- Simulation tool including the multi-turn tracking and the scattering in collimators needed

SixTrack with collimation: history

- SixTrack: 6D thin-lens symplectic element-by-element tracking developed by F. Schmidt for long term tracking in high energy rings.
- Used initially for dynamic aperture studies. Includes multipoles to high order
- SixTrack extended for collimation studies (thesis G. Robert-Demolaize 2003)
  - Including K2 scattering routine (Jeanneret and Trenkler) in collimators
- SixTrack + K2 used to design the present LHC collimation system
- Now LHC is built. how do the simulations compare with actual data?

Setup of benchmarks

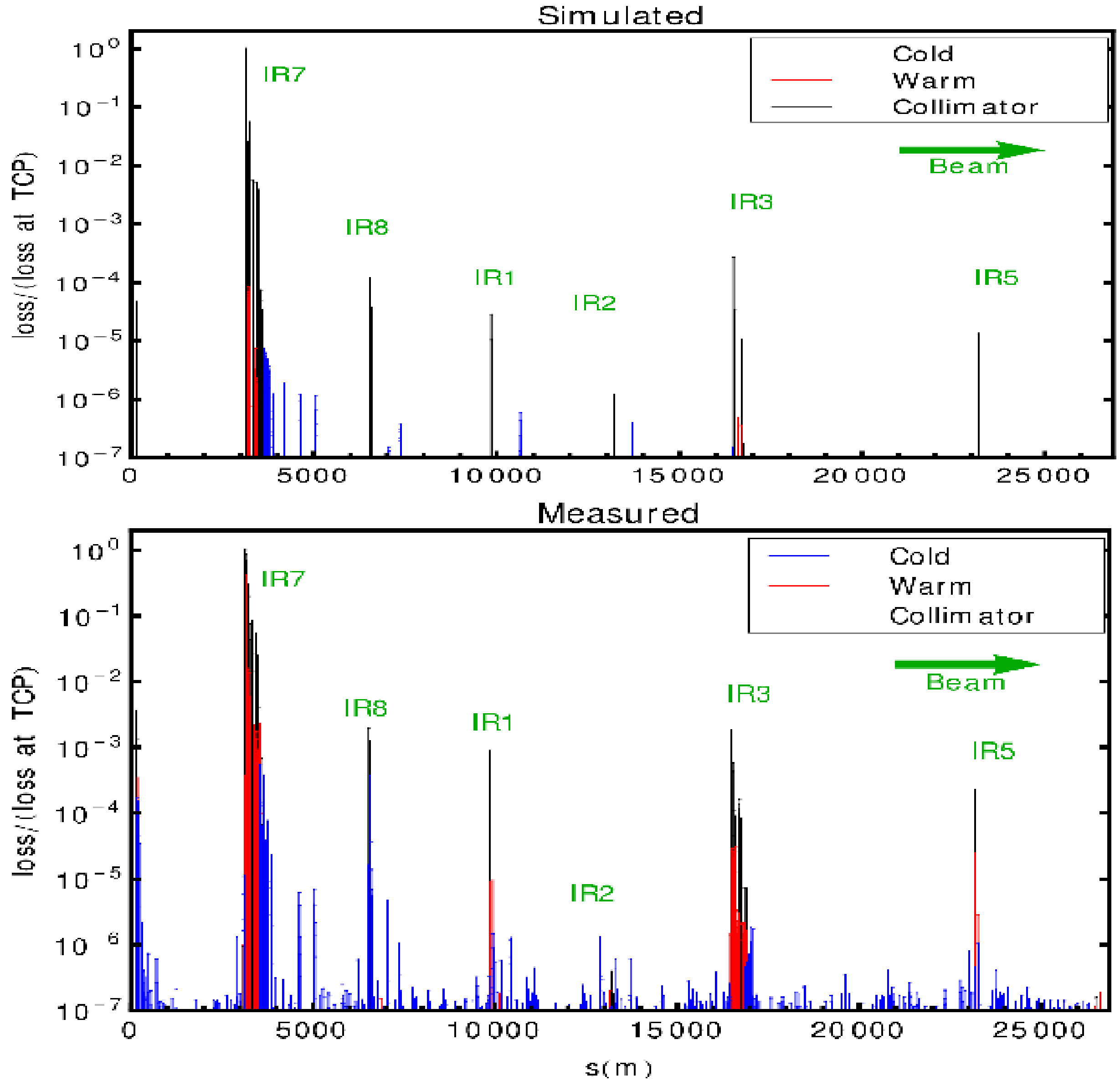
- With LHC beam data, we can cross-check the predictions of SixTrack
  - test case: 2011 machine, 3.5 TeV, β*=1.5m, relaxed collimator settings
- Comparing simulations to LHC BLM data
- Considering qualification loss maps for comparisons of betatron cleaning
  - in physics, loss distribution e.g. at TCTs dominated by collision debris
  - Sharing between momentum and betatron halo (IR3/7) hard to disentangle
- First results presented at IPAC13 – selected for oral presentation

SIMULATIONS AND MEASUREMENTS OF CLEANING WITH 100 MJ BEAMS IN THE LHC

R. Bruce*, R.W. Assmann, V. Boccone, C. Bracco, M. Cauchi, F. Cerutti, D. Deboy, A. Ferrari, L. Lari, A. Marsili, A. Mereghetti, E. Quaranta, S. Redaelli, G. Robert-Demolaize, A. Rossi, B. Salvachua, E. Skordis, G. Valentino, T. Weiler, V. Vlachoudis, D. Wollmann, CERN, Geneva, Switzerland

Qualitative comparison

- Excellent qualitative agreement
- Simulation predicts all important cold loss location
- Quantitatively, significant differences → shower and BLM response not accounted for
- Machine imperfections not included



Machine imperfections

- Details on SixTrack imperfection models given in talk A. Marsili
- New study since IPAC (work in progress): Updated machine imperfections
- Considering several types of random imperfections at collimators
  - Errors on collimator surface curvature
  - Errors on collimator tilt
  - Errors on collimator centering
  - Errors on collimator gap

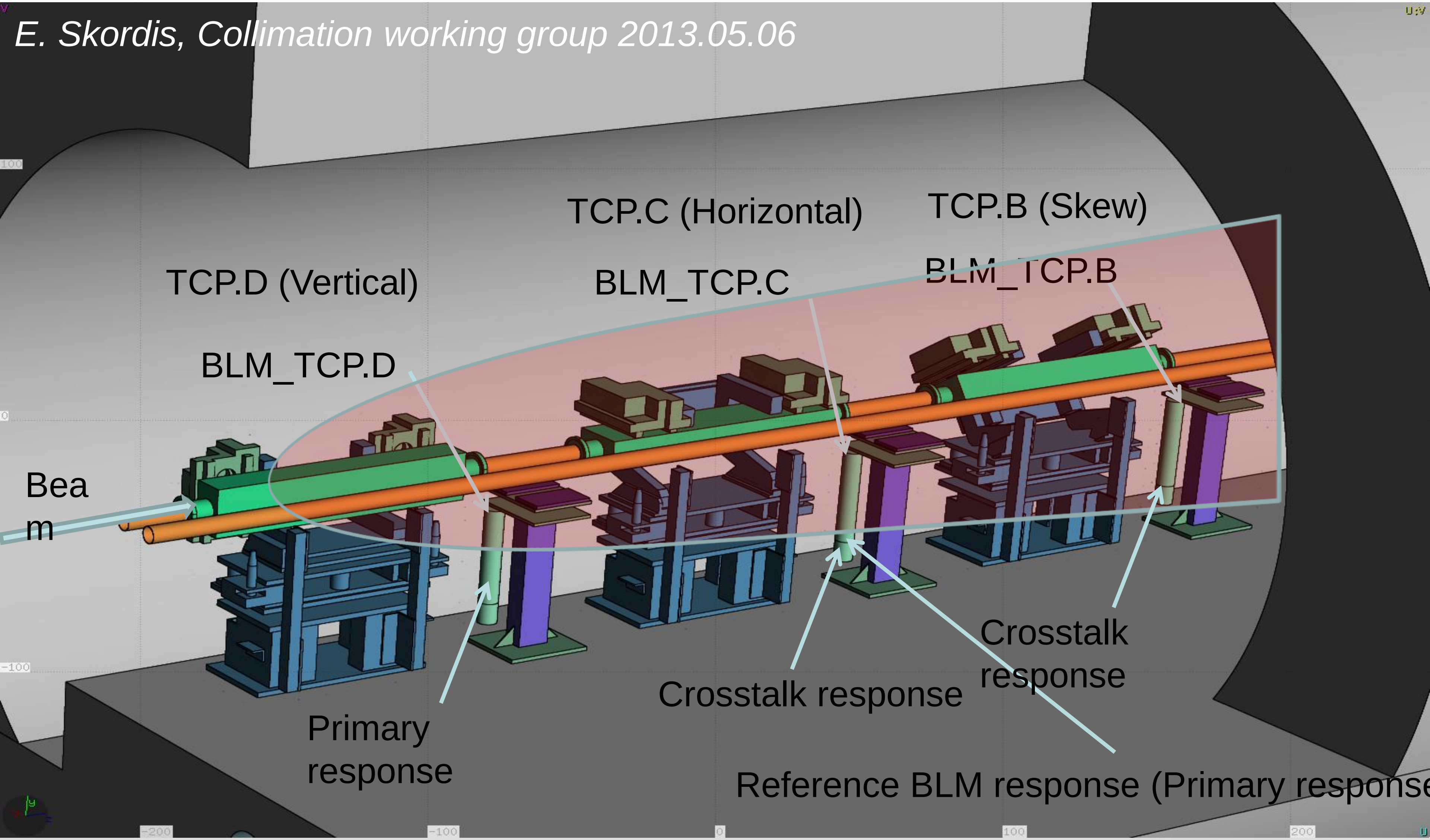
  Parameters as in thesis C. Bracco (surface curvature, tilt)

  Updated parameters based on Run 1 OP data (centering, gap)
- Considering other machine imperfections
  - Random magnetic errors create realistic errors on beta function, dispersion and betatron phase
  - Random misalignments/kicks create residual closed orbit and changes dispersion
  - Using orbit correctors to (partially) correct residual orbit with Mikado

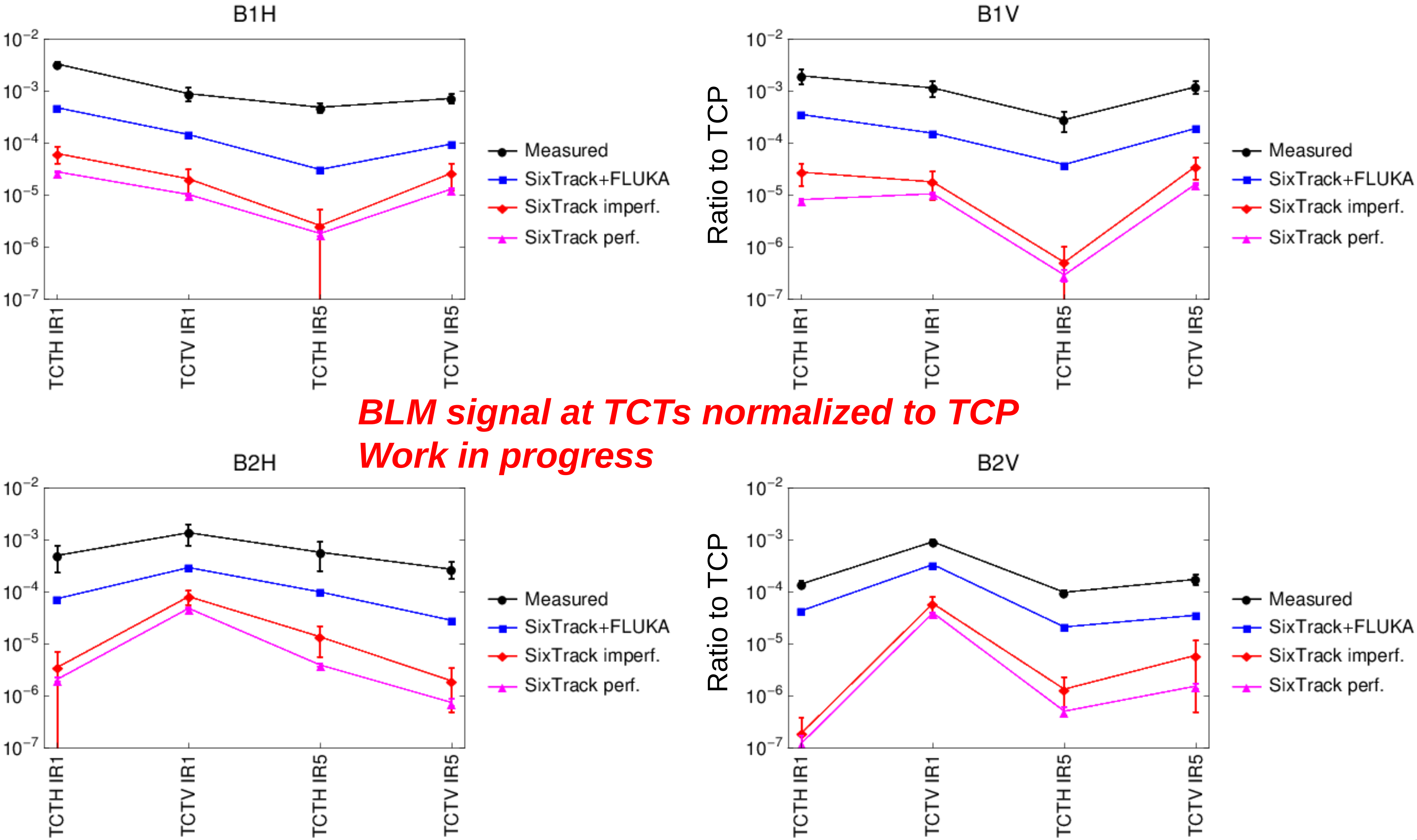
FLUKA shower simulations

- Previous plot: Comparing distribution of lost primary protons from simulation with measured BLM signals
- For a quantitative comparison, need to simulate shower development between primary loss and the BLM
- FLUKA simulations performed for some selected locations to obtain BLM response, i.e. BLM signal per lost nearby proton at selected locations:
  - TCTs (E. Skordis et al., talk in collimation working group 2013.05.06)
  - IR7 (F. Cerutti, E. Skordis et al., talks in 2011 and 2013 Collimation reviews)
- For comparison with measurements:
  - FLUKA result for perfect machine scaled up by increase factor from SixTrack of nearby losses when imperfections are introduced
  - Measurements averaged over all relevant 2011 loss maps (considering the order in which the resonance was crossed in the two planes)

Example: FLUKA model of IR7 TCPs



2011 results including FLUKA BLM response: TCTs

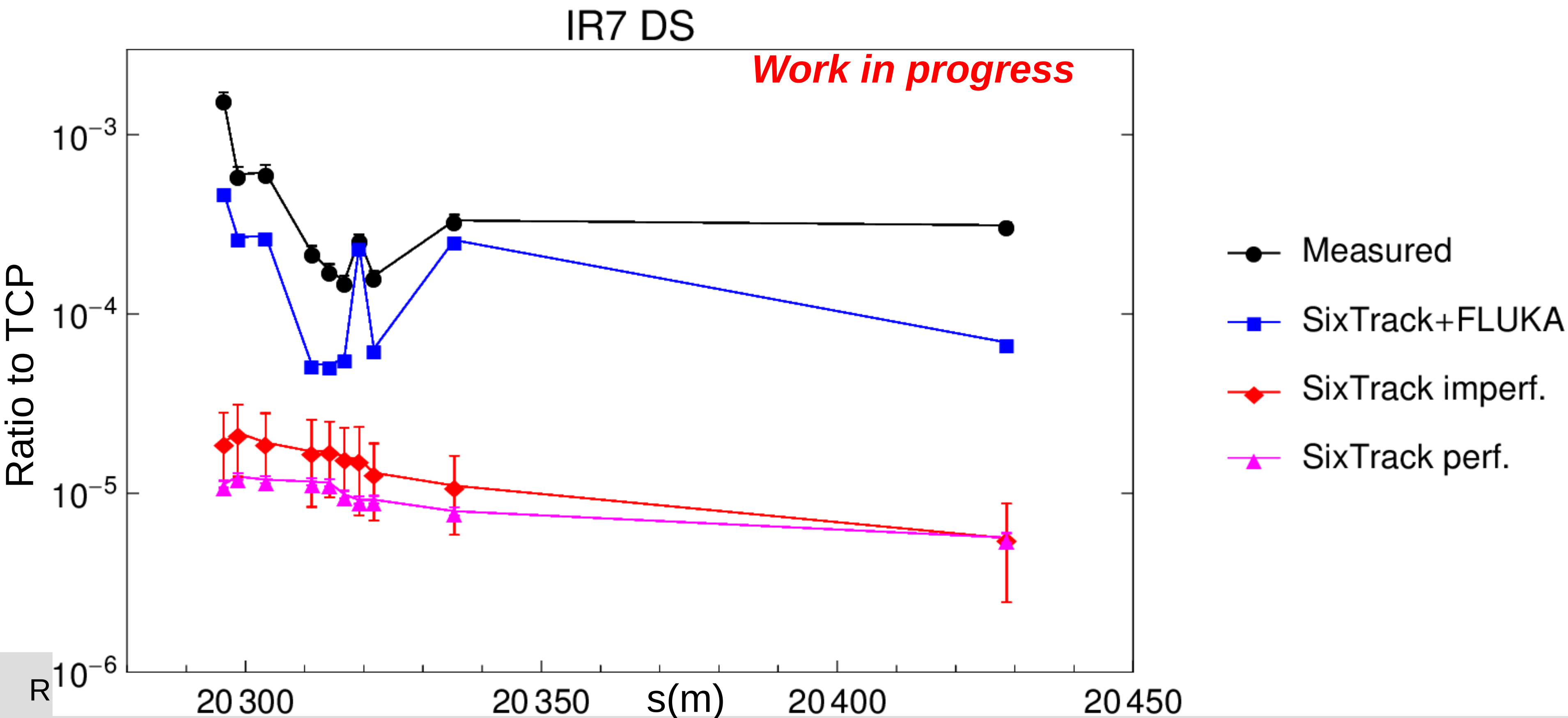


BLM signal at TCTs normalized to TCP

Work in progress

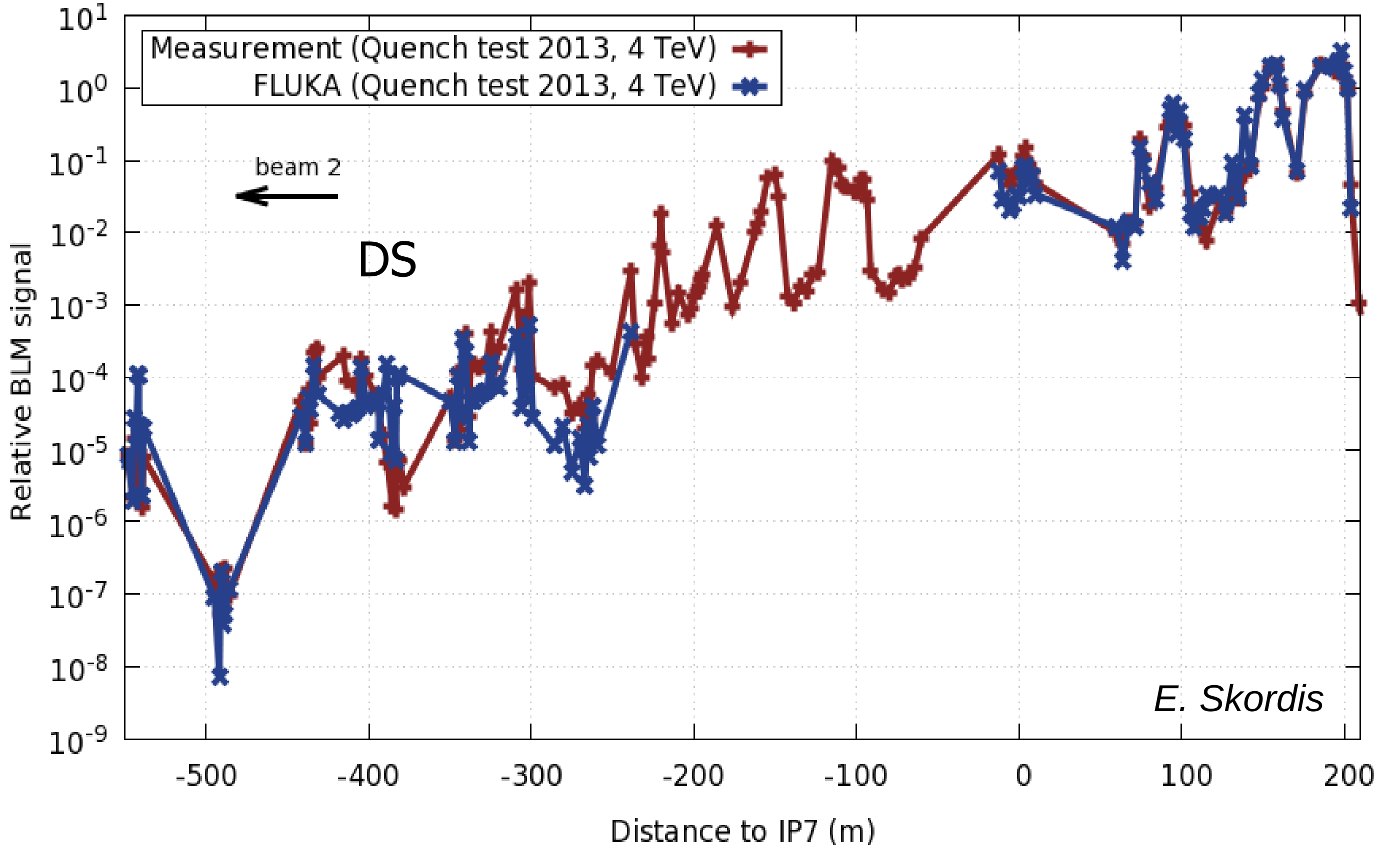
2011 results including FLUKA BLM response: IR7 DS

- 2011 simulations (F. Cerutti et al). Re-tracking single diffractive events
- Shower from the straight section not accounted for
- 2011 FLUKA geometry - recent updates includes more details



Simulated/measured BLM signals in 2013 quench test

- 2013 quench test (collimators more open than during standard operation) simulated with SixTrack + FLUKA. Perfect machine simulated
  - Imperfections expected to improve agreement in DS
- Energy deposition results shown in 2013 collimation review (E. Skordis et al.) and in Daresbury (F. Cerutti et al.)
- With updated geometry and accounting for shower from LSS



Status of comparisons with measurements

- Excellent quantitative agreement in LSS7. Agreement of about a factor 2-3 at highest BLMs in IR7 DS and a factor 5 at the TCTs
  - Good result considering all uncertainties and that the measurements vary over 7 orders of magnitude.
    - Significant impact of unknown imperfections.
    - Uncertainty in primary loss distribution
    - Intrinsic uncertainties in simulations – e.g. scattering physics and tracking
  - FLUKA simulations of other losses with very well-defined primary loss (e.g. wire scanner) have shown better agreement
  - Some effects still to be quantified, e.g. effect on optics and impact parameter from crossing 3rd order resonance (change in loss map expected to be small)
- In spite of several uncertainties, present SixTrack works rather well.
  - Used to design the present collimation which has performed extremely well
  - Found uncertainties should be kept in mind when simulating HL
- Still, there is room for improvement!

Development areas

- SixTrack workshop held in June – a lot of ongoing work!
  https://indico.cern.ch/conferenceDisplay.py?confId=260066
- Main categories:
  - Functionality to simulate new physics cases
  - Physics models
    - Scattering
    - Tracking
  - Usability, outputs, bug fixes

New physics scenarios

- Asynchronous dumps (L. Lari – talk later!)
- Heavy ion collimation (P. Hermes – just started)
- Crystals (D. Mirarchi, V. Previtali)
- Momentum collimation (E. Quaranta)
- Electron lens (V. Previtali)
- Tune modulation element (V. Previtali)
- Crab cavities (J. Barranco, B. Rendon, F. Bouly)

Physics models

- Scattering in collimators
  - Updates of present K2 (C. Tambasco, B. Salvachua)
  - FLUKA – ongoing work in EN-STI on FLUKA-SixTrack coupling (see talk by A. Lechner)
  - Scattering models in other codes
    - Merlin (see talk J. Molson). Could be “easily” ported to SixTrack?
    - BDSIM + Geant 4 (see talk L. Nevay)
  - With many parallel studies ongoing: important to perform inter-code comparisons.
  - For more details on scattering routines, see talk later by J. Molson
- Tracking
  - Use of exact drift Hamiltonian and other projects (R. De Maria, M. Fjellstrom)

Summary

- SixTrack with collimation used to design present LHC collimation system
  - Collimation worked extremely well in Run 1
- The running machine allows comparison with measurements
  - All important measured loss locations are found in SixTrack loss maps – excellent qualitative agreement
  - For a quantitative comparison, need to simulate shower to BLMs – done with FLUKA for some selected BLM locations
  - Excellent quantitative agreement in IR7 LSS. Factor 2-3 agreement in IR7 DS and factor 5 at TCTs (much further away from primary loss)
  - Quantitative agreement is acceptable considering all uncertainties and the 7 orders of magnitude found in measurements
- Development of SixTrack ongoing in several areas
  - New physics cases
  - Physics modeling
  - Bug fixes / output, usability