Simulations of TCT beam impacts for different scenarios

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Acknowledgement:

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Outline

- **Scope of this study:**
  - Motivation
  - How to calculate damage limits of TCTs?
- **Dump failure cases:**
  - LHC beam dump system
  - Irregularities in the beam dump
- **New simulations:**
  - Simulation setup
  - Scan over TCT settings and summary of collimator settings
  - Particle statistics
- **Simulation results:**
  - Impact parameter studies on TCT for different scenarios
- **Conclusions**

❖ SCOPE OF THIS STUDY

Motivation

- ✧ This study falls within the framework of LHC collimator material R&D.
- ✧ Estimation of **ROBUSTNESS** and **DAMAGE LIMIT** of **TERTIARY COLLIMATORS**

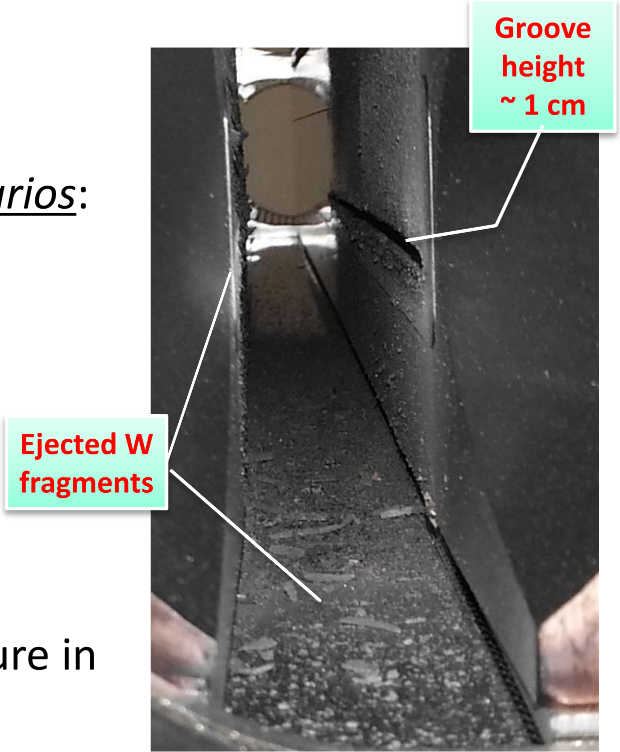
…*in the past*:

→ robustness calculated for *very pessimistic scenarios*:
  - 1 single bunch impact
  - TCT as "isolated" system
  - parallel beam impacting TCT jaw
  - 90° phase advance from dump kicker

…*now*:

→ updated robustness calculation, simulating failure in *more realistic conditions*

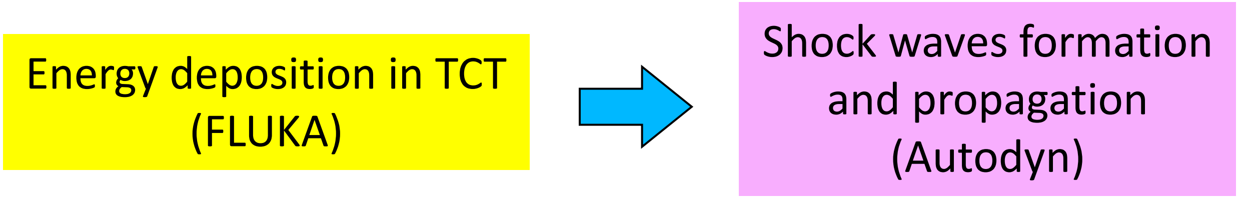
→ generate input for energy deposition and mechanical simulations with *high statistics* for the case of interest


Groove height ~ 1 cm

Ejected W fragments

How to calculate damage limit of TCTs?

So far:



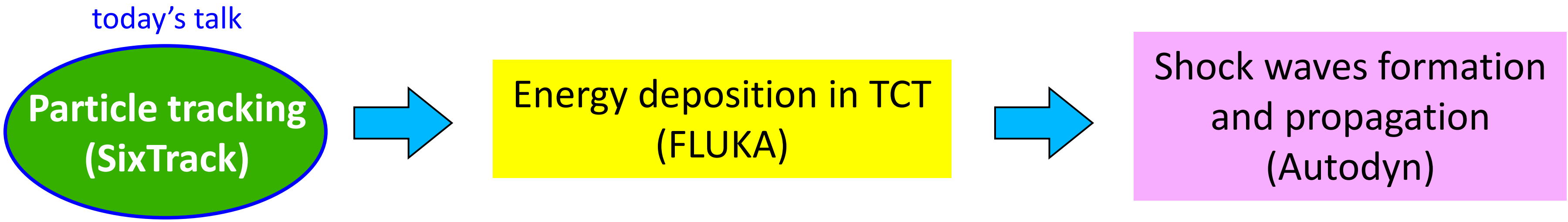
Energy deposition in TCT (FLUKA) → Shock waves formation and propagation (Autodyn)

Present damage estimates:

- **5e9** protons (**Plastic** deformation)
- **2e10** protons (**Fragment** ejection)
- **1e11** protons (**“5th axis”** – catastrophic case)

To more details, see *A. Bertarelli-MPP workshop 2013*

Now…



today’s talk

Particle tracking (SixTrack) → Energy deposition in TCT (FLUKA) → Shock waves formation and propagation (Autodyn)

Which the advantages in adding one more step in the simulation chain?

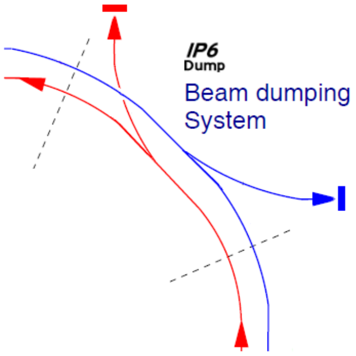
To get **VERY REALISTIC PARTICLE DISTRIBUTION AT TCT!**

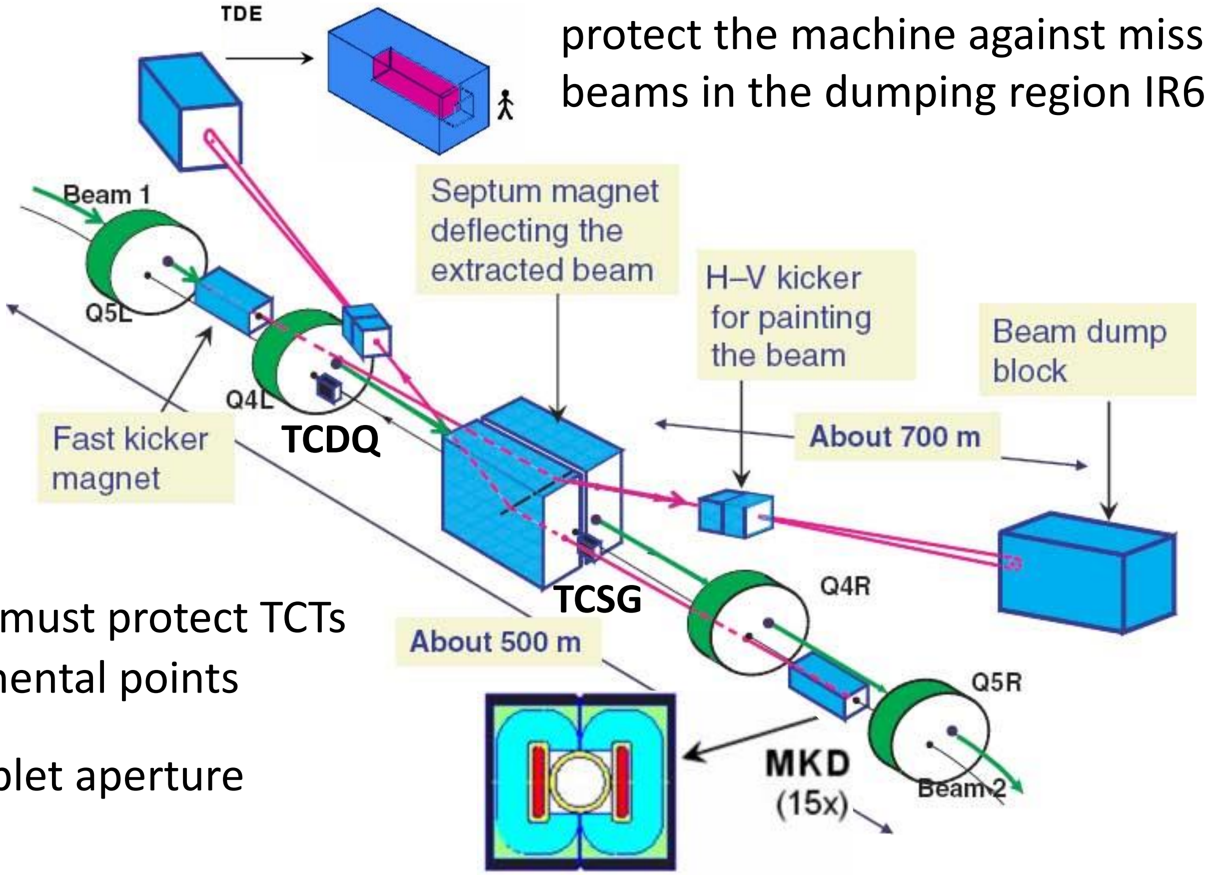
- All LHC ring
- Many bunches
- All collimation system
- 1 dump kicker pre-firing
- Realistic particle tracking

❖ DUMP FAILURE CASES

LHC beam dump system

TCDQ “dump protection” and one TCSG protect the machine against miss-kicked beams in the dumping region IR6.





IR6 dump protection must protect TCTs placed at the experimental points

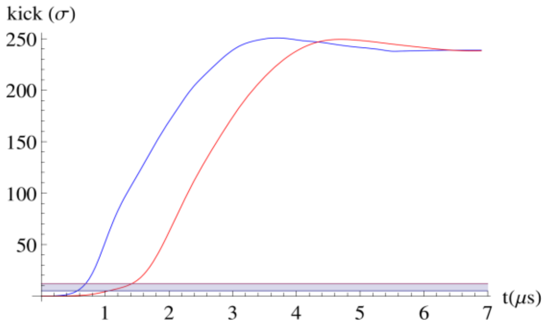
TCTs must protect triplet aperture

Fast abnormal proton losses may be caused by faulty operation of the extraction dump kickers magnets (i.e. MKDs)

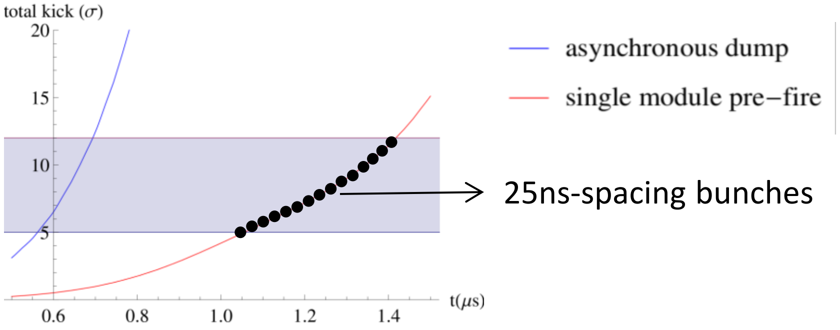
Irregularities of the beam dump

- All MKDs mis-firing (*Asynchronous beam dump*): all the dump kickers are triggered simultaneously but not synchronized with the beam abort gap.

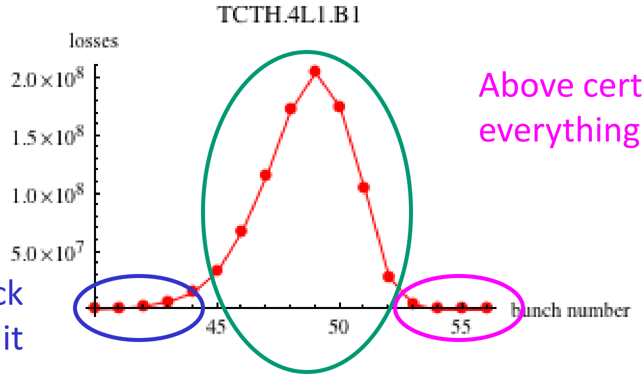
- 1 MKD spontaneously firing (*Single-module pre-fire*): the remaining 14 MKDs are re-triggered.



zoom



25ns-spacing bunches



Above certain kick amplitude, everything caught by TCDQ

Below certain kick amplitude, nothing is hit

→ intermediate kicks to some bunches which are sent directly in TCTs or machine aperture

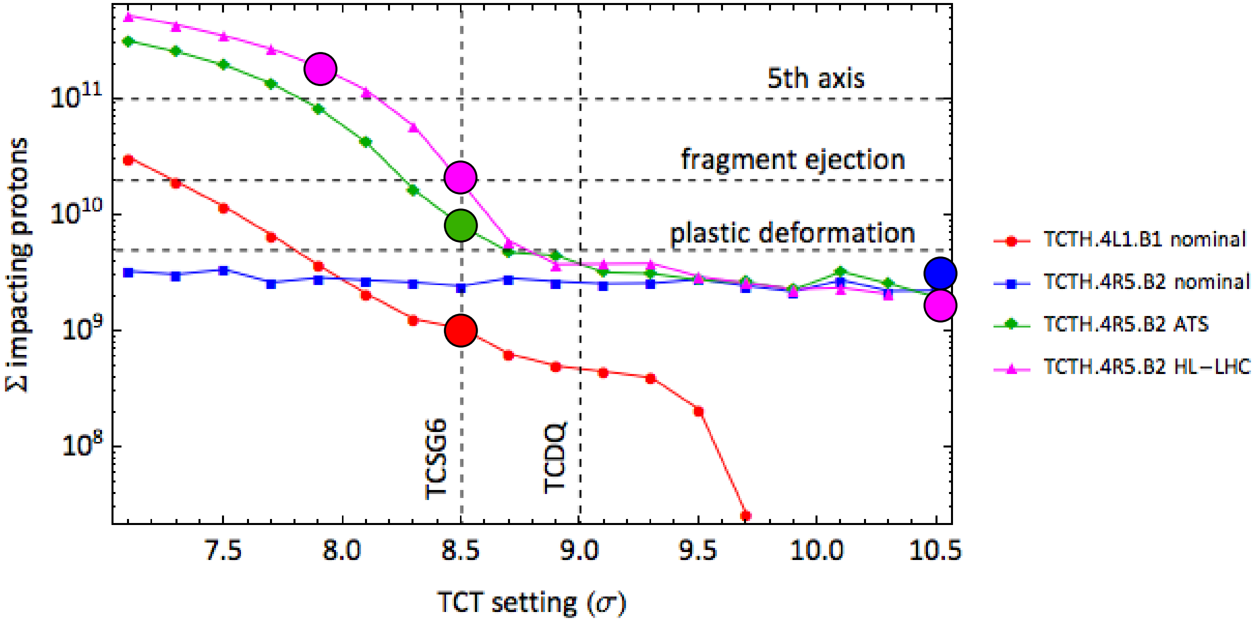
❖ NEW SIMULATIONS

Simulation setup

- Single MKD module pre-fire (MKD.A5R6, the most downstream kicker)
  Time profiles provided by B. Goddard
- Energy: 7 TeV
- Gaussian beam (ε=3.5 μm)
- Separate simulations for each bunch with 25 ns spacing, different kicks.
- Perfect machine (only "error" due to IR1/5 TCTs setting: put further in as they should be to simulate beam losses in these collimators after dump failure)
- Collimator settings: 2 σ retraction
- Optics:
  - Nominal 7 TeV (β*=55cm): B1 and B2
  - HL-LHC (β*=15cm): B2
  - ATS 2015 (β*=55cm): B2

Scan over TCT settings

1. **Scan** over TCT settings for different scenarios
2. **Compare** with previous damage estimates
3. **Select** few relevant cases for further studies with higher statistics, trying to have cases with significantly different number of impacts



- *TCT setting >≈ "dump protection"* → impacts dominated by secondary halo particles (TCT is "shadowed" by TCSG6)
- TCT setting < "dump protection" → impacts dominated by primary halo particles (TCT is not protected by TCSG6, it sees protons coming directly from primary beam)

Summary of collimator settings

		Simulated scenarios (E=7 TeV)					
Collimator half gap		Nominal optics		HL-LHC optics B2			**ATS 2015 B2**
		nom. B1	**nom. B2**	**HL-LHC 1**	**HL-LHC 2**	**HL-LHC 3**	
IR7	TCPs	5.7	5.7	5.7	5.7	5.7	5.7
	TCSGs	7.7	7.7	7.7	7.7	7.7	7.7
	TCLs	10.5	10.5	10.5	10.5	10.5	10.5
IR6	TCSG.4R6	8.5	8.5	8.5	8.5	8.5	8.5
	TCDQAs	9.0	9.0	9.0	9.0	9.0	9.0
IR3	TCPs	15.0	15.0	15.0	15.0	15.0	15.0
	TCSGs	18.0	18.0	18.0	18.0	18.0	18.0
	TCLs	20.0	20.0	20.0	20.0	20.0	20.0
IR1/5	**TCTs**	**8.5**	**10.5**	**10.5**	**8.5**	**7.9**	**8.5**
IR2/8	TCTs	30	30	30	30	30	30

Expected integrated losses on TCT.4L1 (B1)

9e8 “real protons” (1.7e11p per bunch)

Safe!

Expected integrated losses on TCT.4R5 (B2)

3e9 “real protons” (1.7e11p per bunch)

Safe!

A priori, only secondary halo for this case

2e9 “real protons” (2.2e11p per bunch)

Safe!

2e10 “real protons” (2.2e11p per bunch)

fragment ejection!

2e11 “real protons” (2.2e11p per bunch)

> 5th axis limit!!

8e9 “real protons” (1.7e11p per bunch very optimistic!!)

plastic deformation!

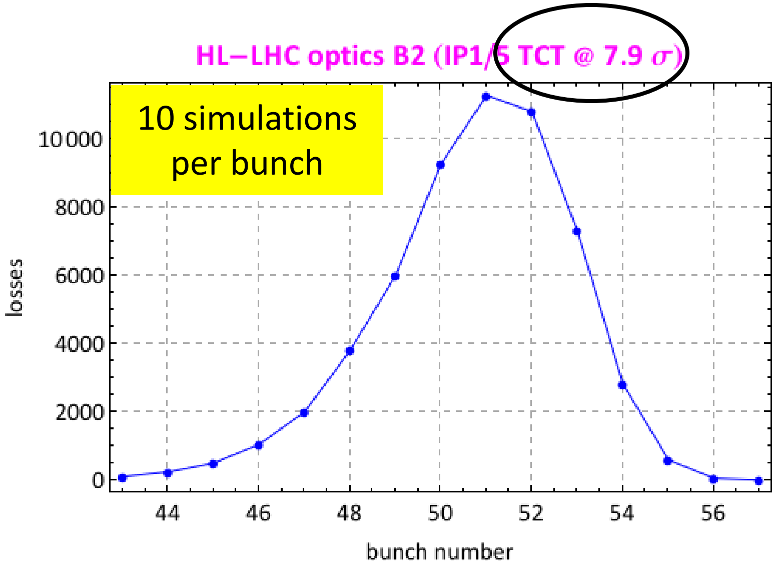
Beam 2 is the most critical one!

Computing time is…a matter of statistics!

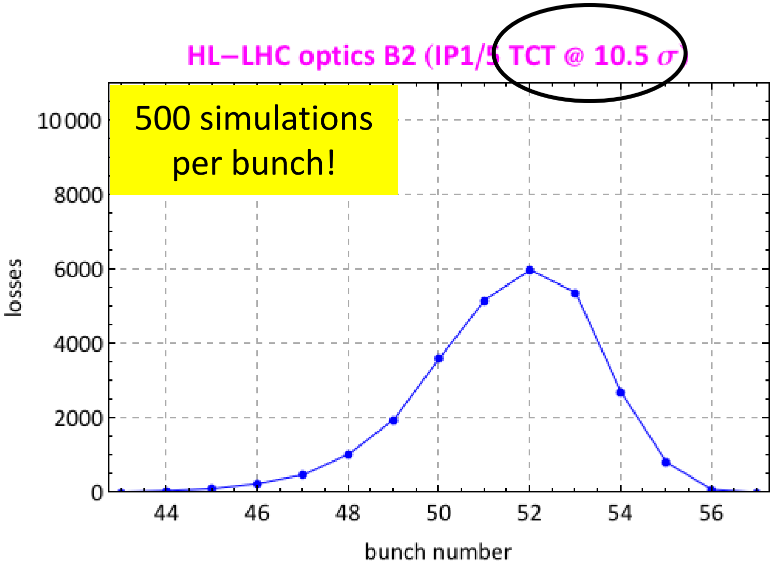
These simulations are very time consuming, but it is necessary to have sufficient losses in TCT (for meaningful FLUKA simulations).

Amount of simulations to run changes depending on the specific scenario.

2 extreme scenarios:


HL–LHC optics B2 (IP1/5 TCT @ 7.9 σ)

10 simulations per bunch


HL–LHC optics B2 (IP1/5 TCT @ 10.5 σ)

500 simulations per bunch!

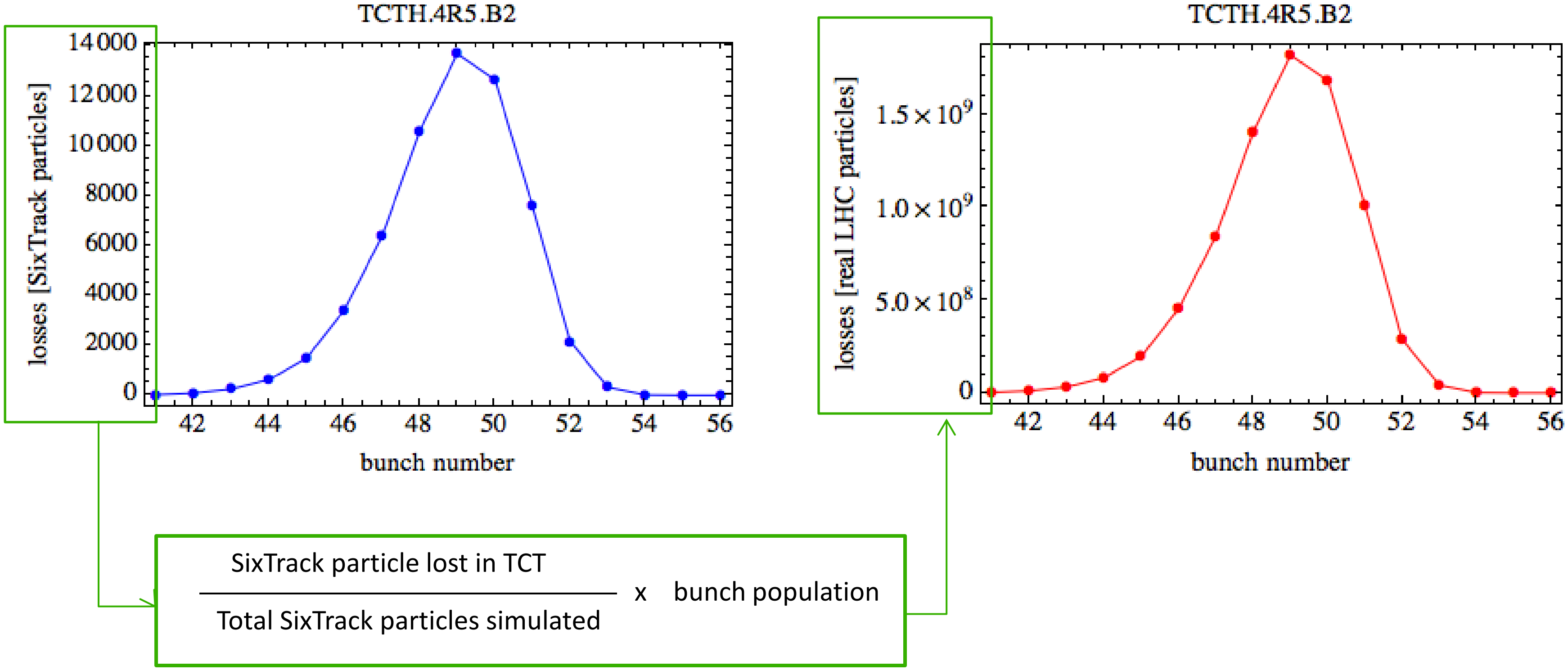
Note: 6400 SixTrack particles for each simulation

Open question: **is the statistics enough for FLUKA simulation?**

“real” LHC protons vs. SixTrack particles

ATS 2015 optics B2

(bunch population=1.7e11 protons)



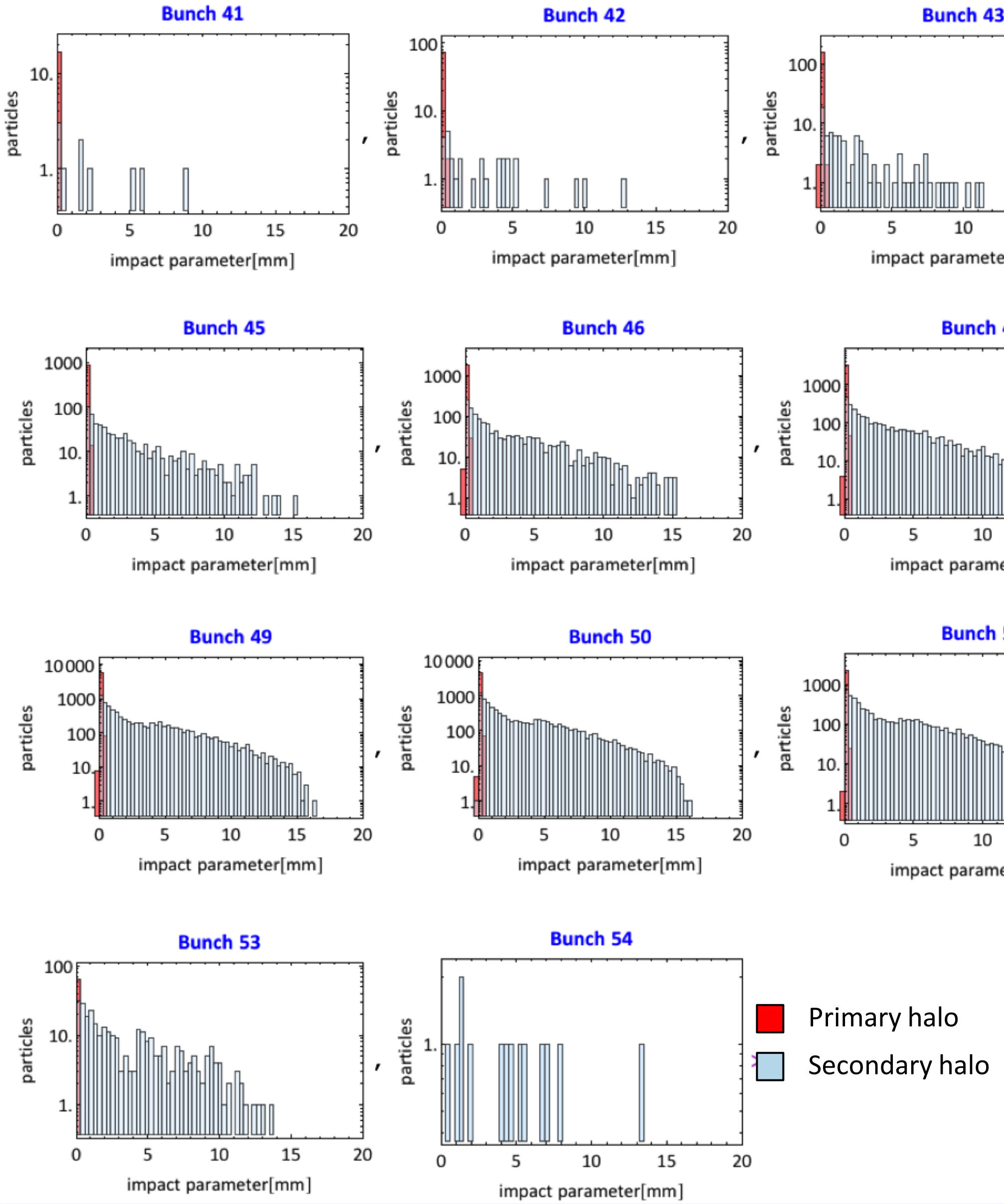
$$\frac{\text{SixTrack particle lost in TCT}}{\text{Total SixTrack particles simulated}} \times \text{bunch population}$$

Important note: in the following slides, ***impact parameter*** refers to the position in x where the particles experience inelastic interaction inside the TCT jaw.

❖ SIMULATION RESULTS

Impact parameter distribution

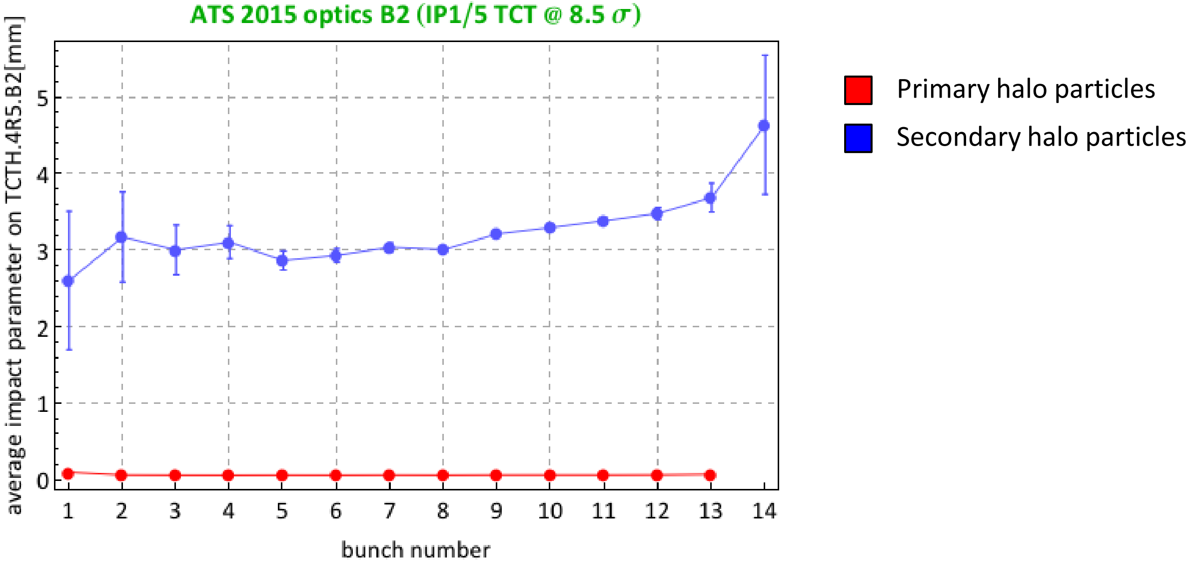
ATS 2015 optics B2 (IR1/5 TCT @ 8.5 σ)



Primary halo particles not hit any collimator before reaching the TCT, while secondary halo ones are scattered out from dump protection (mainly TCSG).

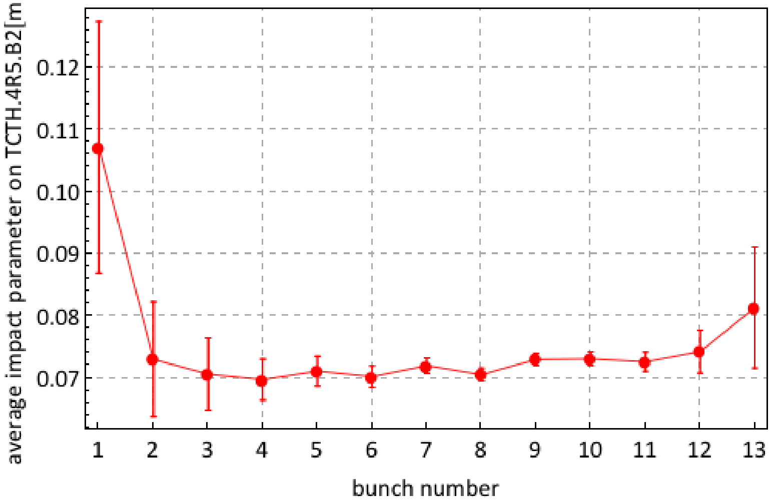
Impact parameter vs. #bunch

ATS 2015 optics B2 (IR1/5 TCT @ 8.5 σ)

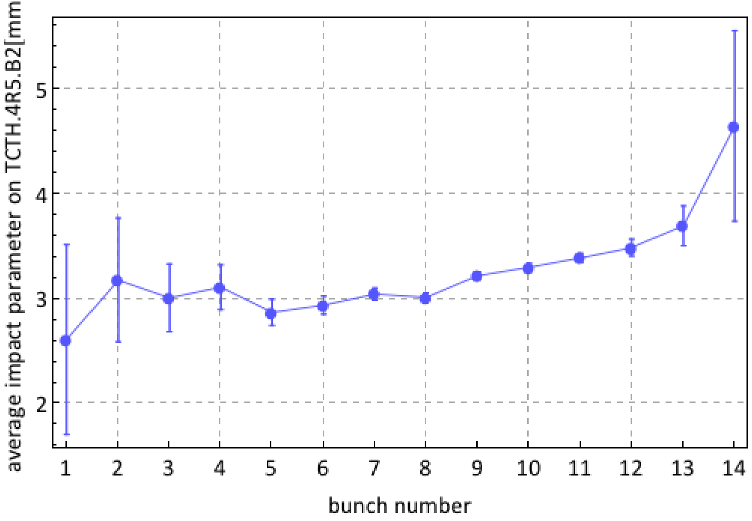


zoom

Primary halo particles

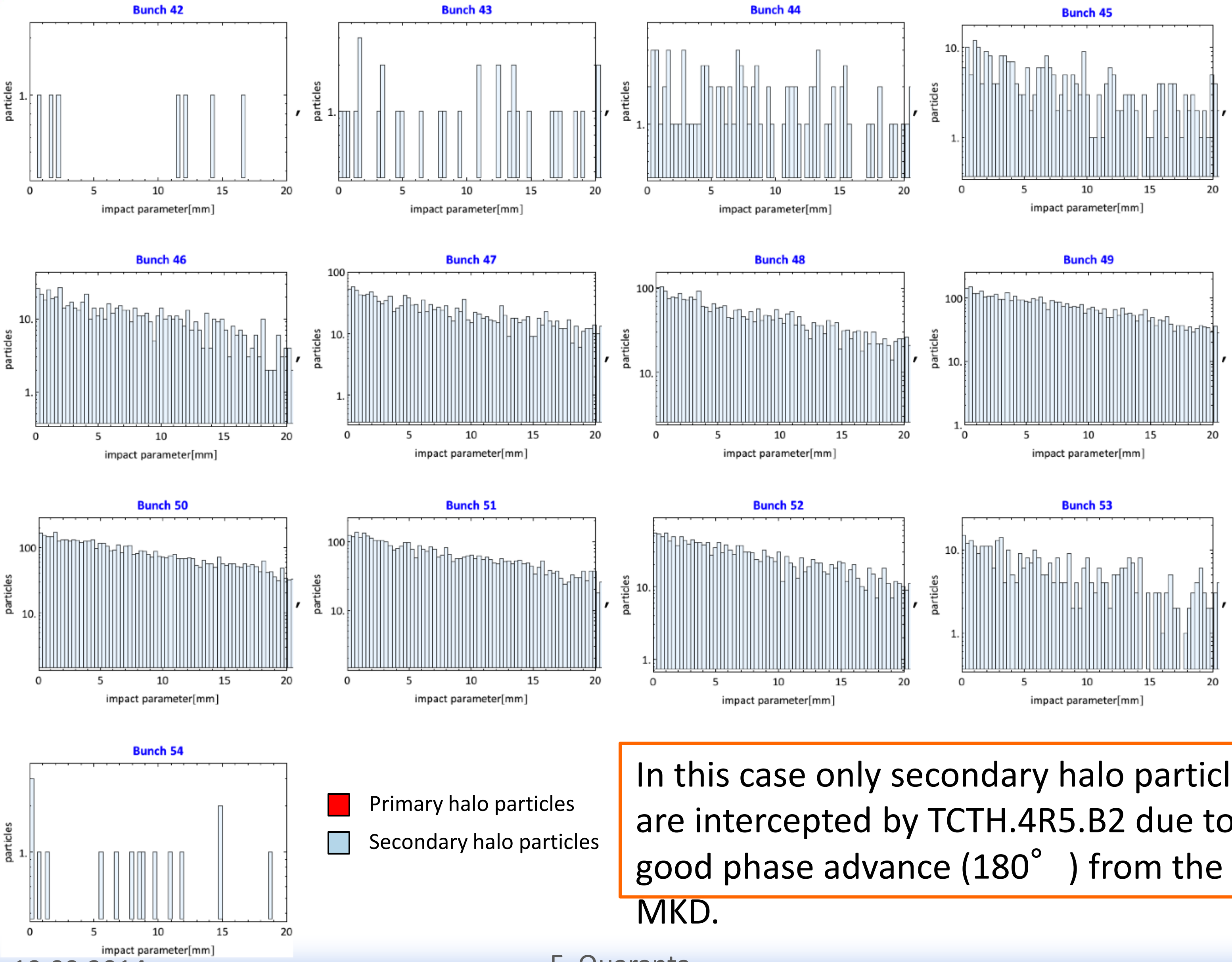


Secondary halo particles



Impact parameter distribution

Nominal 7 TeV optics B2 (IR1/5 TCT @ 10.5 σ)



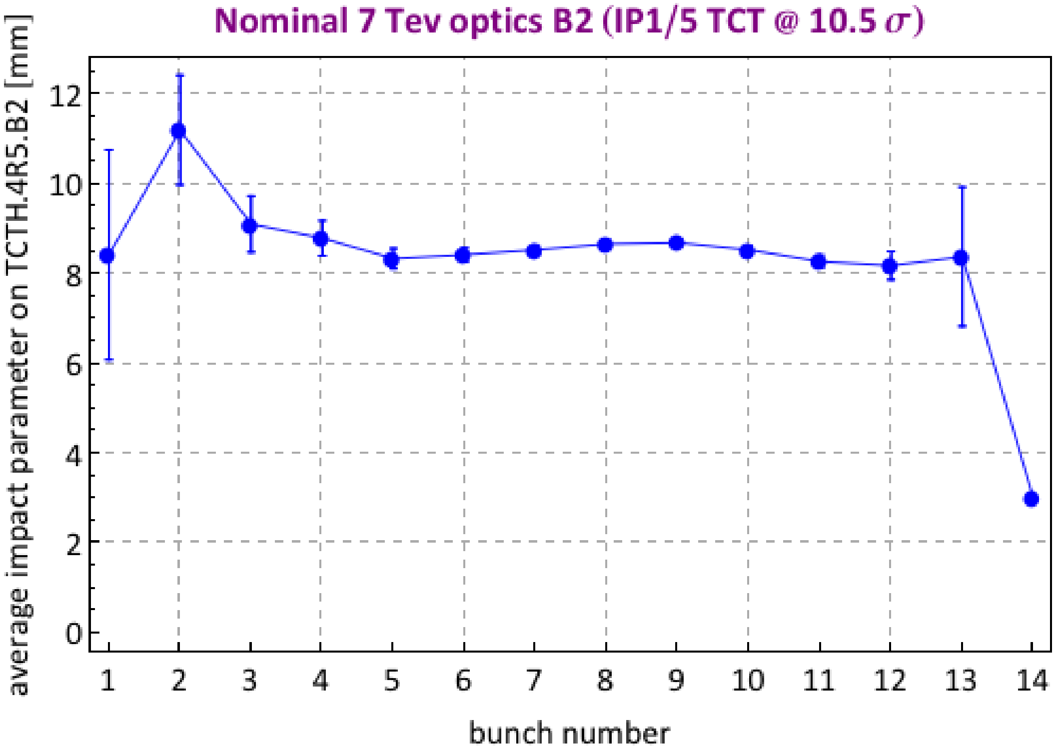
In this case only secondary halo particles are intercepted by TCTH.4R5.B2 due to good phase advance (180°) from the MKD.

Impact parameter vs. #bunch

Nominal 7 TeV optics B2 (IR1/5 TCT @ 10.5 σ)

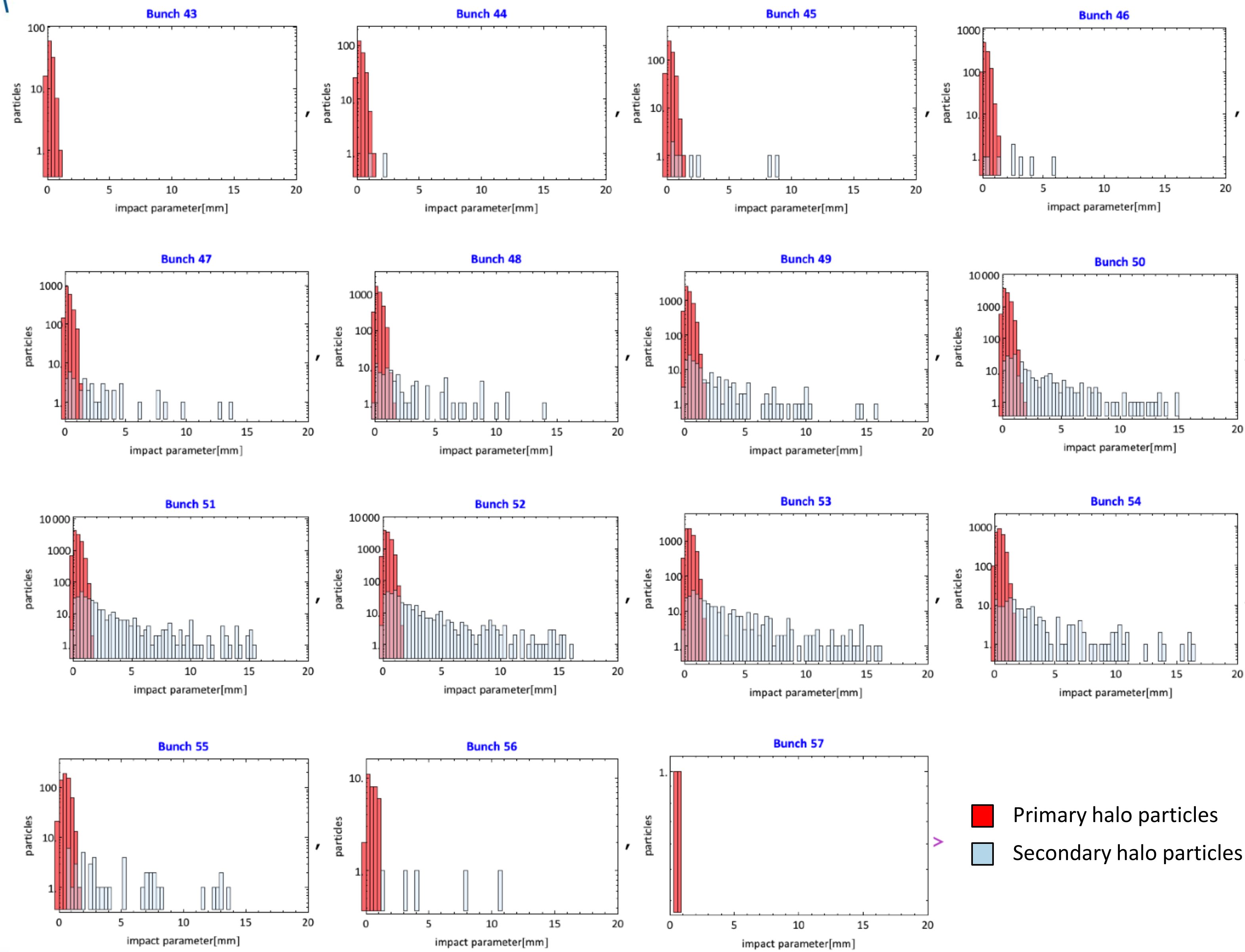
🟥 Primary halo particles

🟦 Secondary halo particles



Impact parameter distribution

HL-LHC optics B2 (IR1/5 TCT @ 7.9 σ)

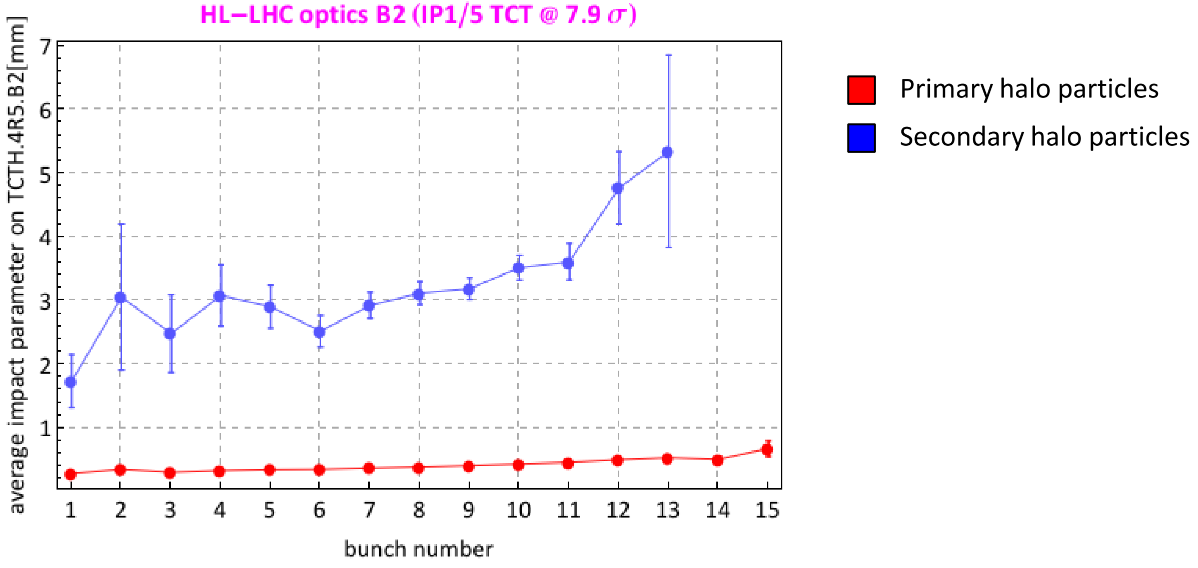


🟥 Primary halo particles

🟦 Secondary halo particles

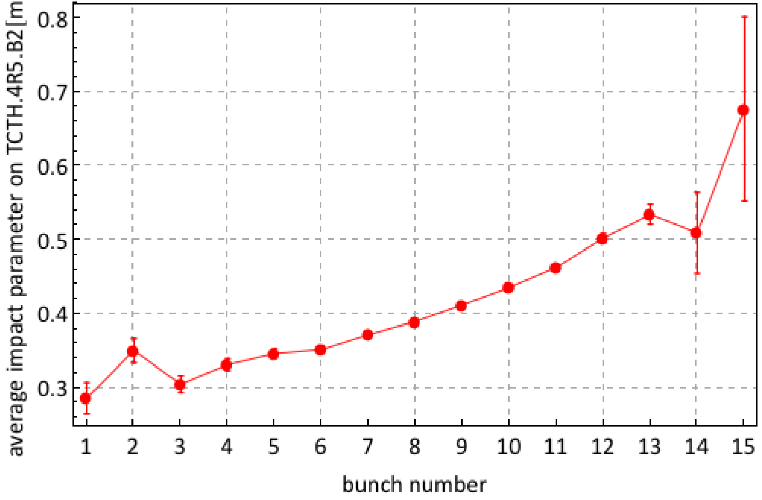
Impact parameter vs. #bunch

HL-LHC optics B2 (IR1/5 TCT @ 7.9 σ)

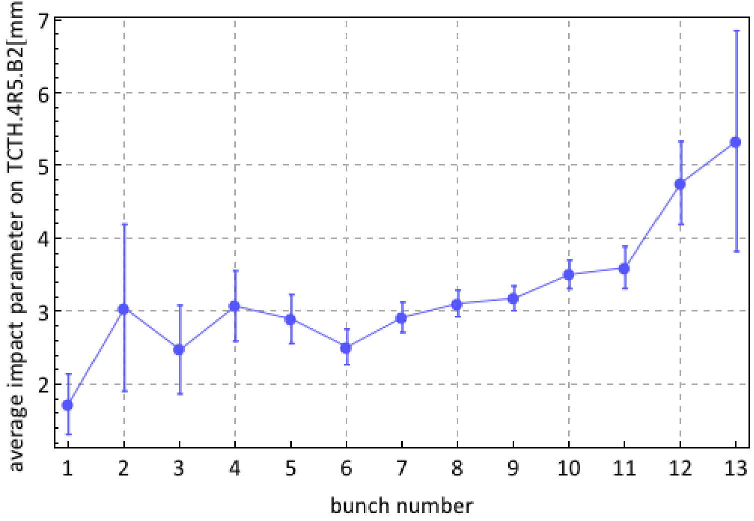


zoom

Primary halo particles

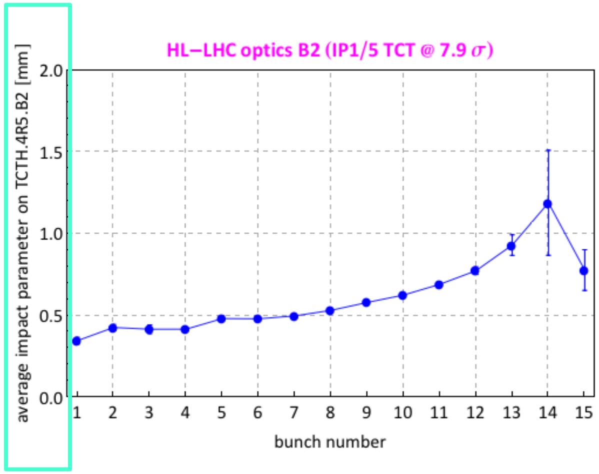


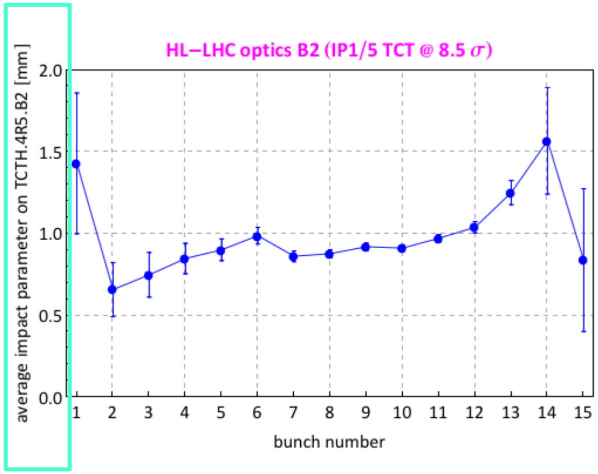
Secondary halo particles

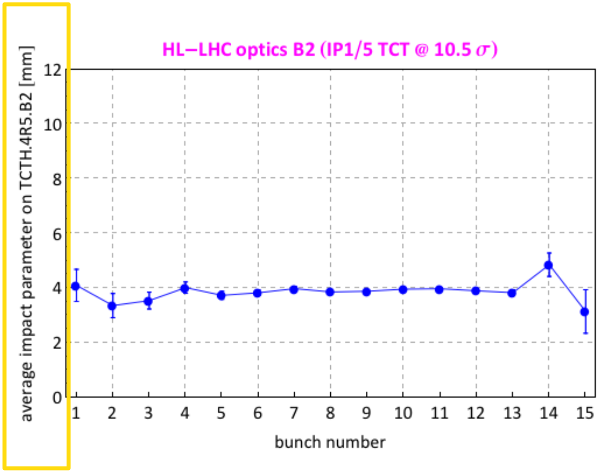


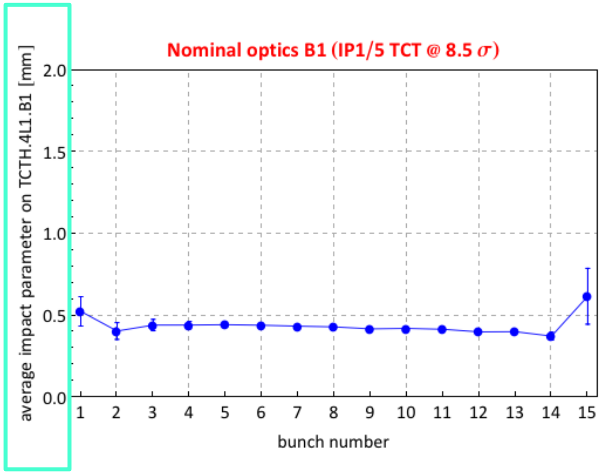
Summary of impact parameters

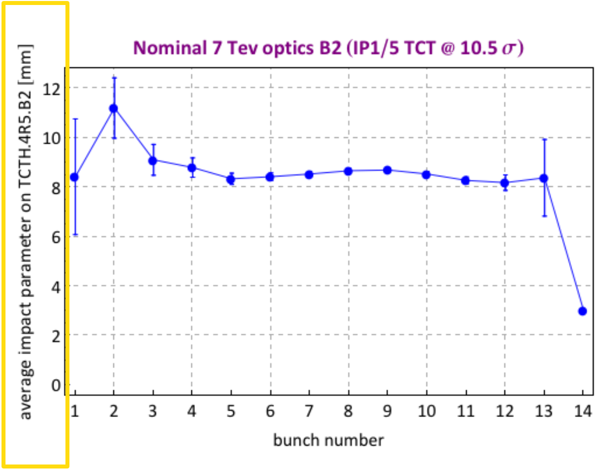
Average impact parameter from primary and secondary halo in the all the cases simulated.

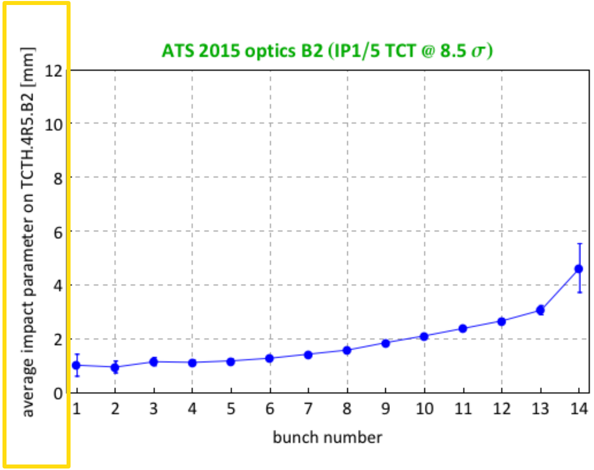

HL–LHC optics B2 (IP1/5 TCT @ 7.9 σ)


HL–LHC optics B2 (IP1/5 TCT @ 8.5 σ)


HL–LHC optics B2 (IP1/5 TCT @ 10.5 σ)

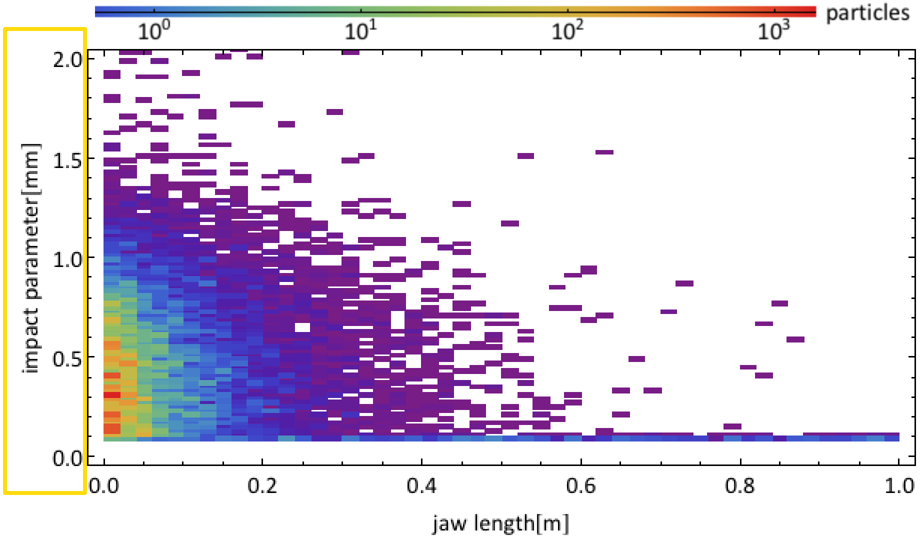

Nominal optics B1 (IP1/5 TCT @ 8.5 σ)


Nominal 7 Tev optics B2 (IP1/5 TCT @ 10.5 σ)


ATS 2015 optics B2 (IP1/5 TCT @ 8.5 σ)

Please pay attention to the different scale!!

Distribution of particles absorbed in TCTH.4R5.B2

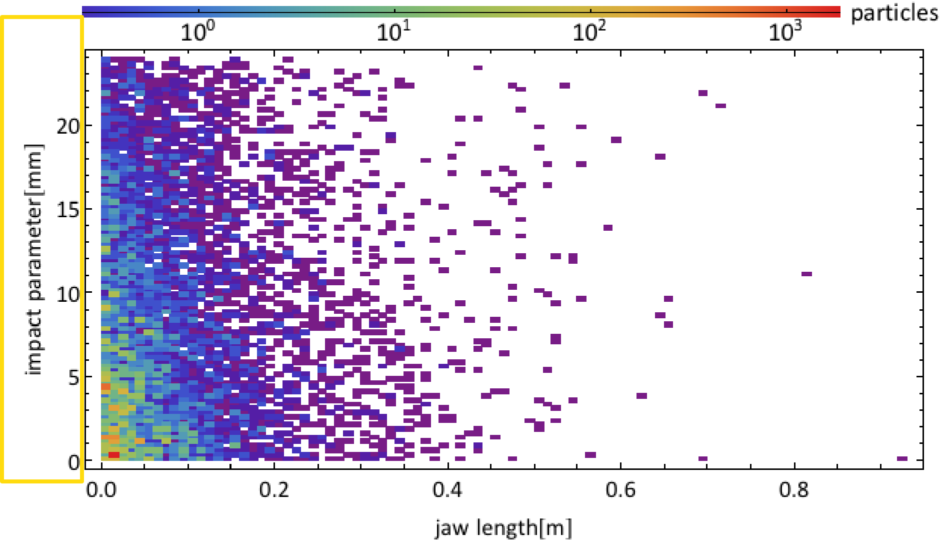


ATS 2015 optics B2

(TCT=8.5 σ)

Nominal 7 TeV optics B2

(TCT=10.5 σ)



Note: different scale!

❖ CONCLUSIONS

Summary and Outlook

- **6 scenarios studied** to have selection of cases with:
  - different amount of total particles hitting the TCT
  - different impact distribution
  - different amount of primary and secondary halo particles

- **Coordinates of inelastic interaction** available **bunch by bunch** for all the cases shown for further FLUKA simulations

Open discussion:

which of the cases will be simulated with FLUKA + AUTODYN??

Comments after the meeting

- Slide 14: for further simulations, make sure to be consistent with “real” values (1.7e11 p/b maybe will not be realistic in immediate post LS1)

- Slide 23: now TCT parallel to the beam, for the future add tilt angle and see if impact distribution changes

- Slide 24: check first plot (it must be primary halo, maybe something wrong in the script to generate the plots. CHECK!) → fixed!

- FLUKA simulation will be time-consuming, they have to run simulation for each bunch for the cases which will be selected between the ones presented

- Cases to simulate:
    1. Nominal post LS1
    2. One case where we are dominated by primary halo (maybe nom.B1 or HL-LHC 8.5 or 7.9-very pessimistic)
    3. One case where we are dominated by secondary halo (nom.B2)

- Discuss with MME people