Loss Map Measurements at 4 TeV and 6.5 TeV

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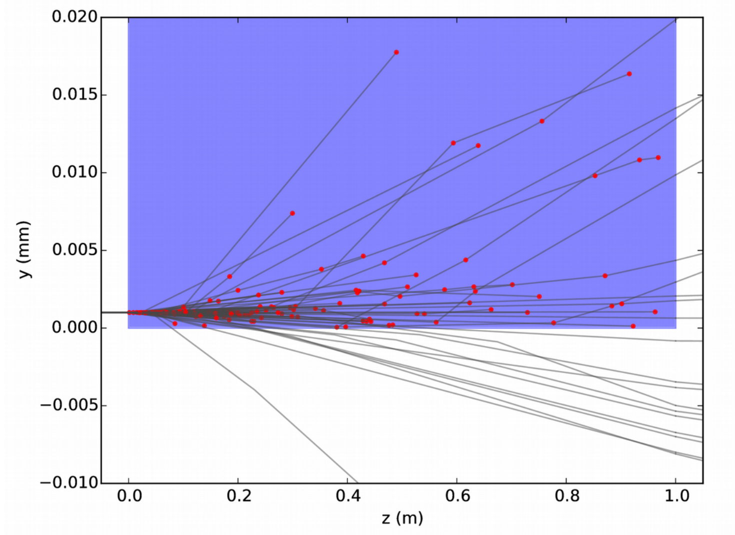
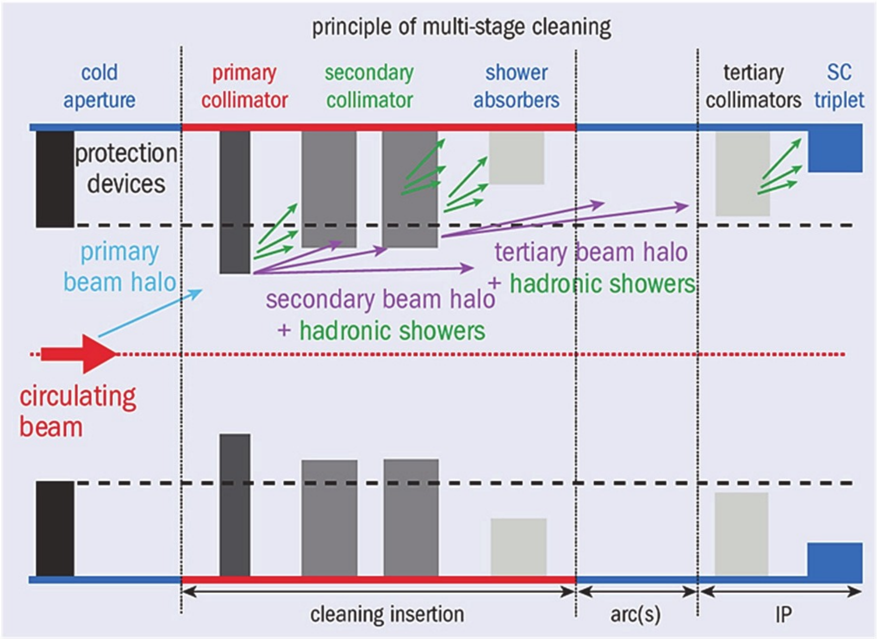
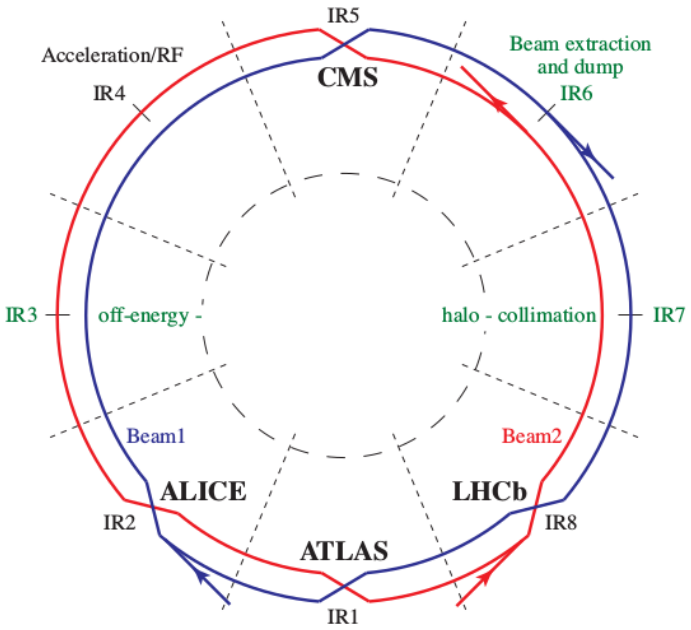
LHC Collimation



- LHC stored energy of 362 MJ per beam (675 MJ for HL-LHC)
- Multi-stage collimation system needed
- Particles scattered by collimators can travel many km along beam pipe
- Carbon primary collimators in IR7 sit closest to the beam
- Secondary collimators (carbon) and absorbers (tungsten) intercept the scattered particles
- Tertiary collimators (tungsten) protect the detectors and the inner triplets

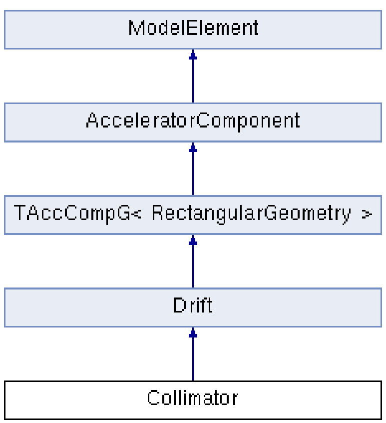


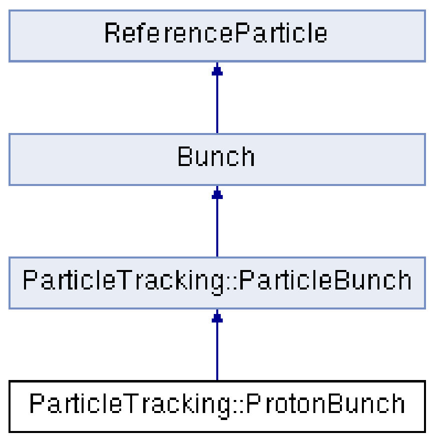


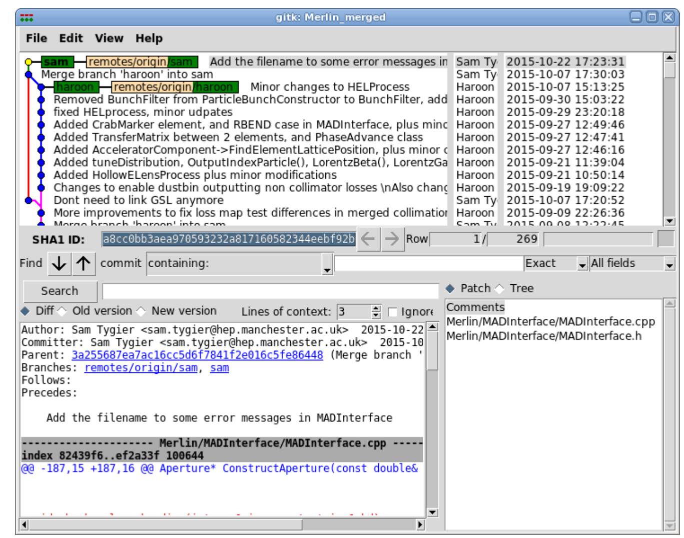
The High Luminosity LHC Book

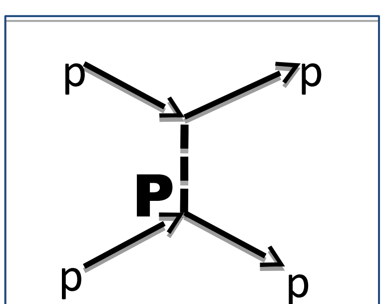
Merlin

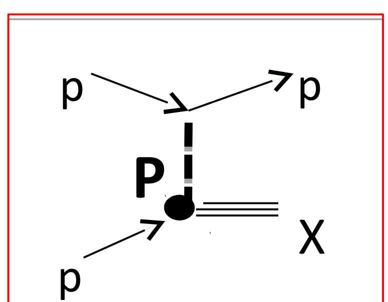
- Accelerator simulation library
- Modular and extensible C++: easy to add new physics, tracking, element types
- 39,000 Lines of code (+4000 of examples)
- Git revision control (github.com/MERLIN-Collaboration)











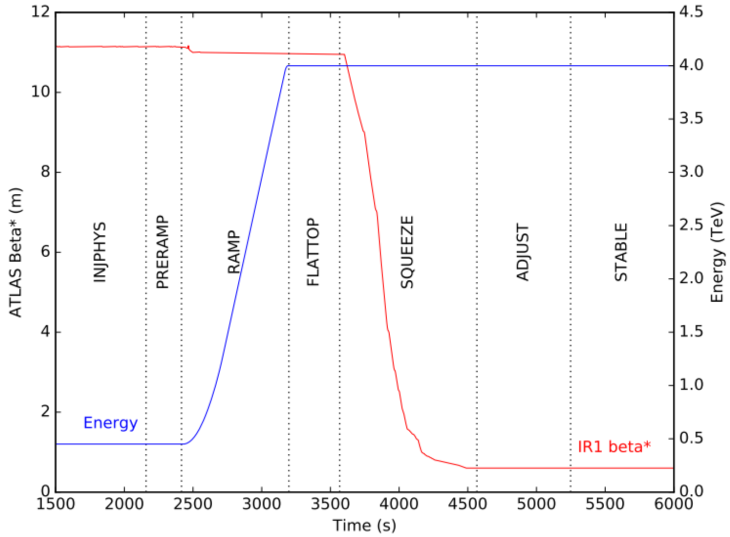
Updated scatting physics for high energy protons on collimator materials:

- Multiple Coulomb scattering
- New Ionization based on Landau theory
- Rutherford scattering
- **New Elastic scattering**
- **New Single Diffraction dissociation**

Simulation vs Data

- Beam Loss Monitors (BLMs)
  - Ionisation chambers placed on outside of elements
  - Record the particle shower
  - Showers can be many meters long
- Merlin simulations
  - Tracks particles through beam pipe vacuum
  - Impacts with collimators use detailed scatting model for leading particle (no secondarys)
  - Impacts in other elements recorded as loss
- Because of this difference we need a way to normalise out the BLM response to the losses

Squeeze



- In each physics fill beam is:
  - Injected, ramped, squeezed
- Squeeze reduces beam size at the interaction point, but increases it in the final focus region
- Simultaneously TCT gaps are reduced
- Good opportunity for simulation/data comparisons
  - Changing optics so can look at relative changes in losses
  - Local inefficiency as a function of beta*
- Since 2016 there is partial squeezing during ramp

Run I - 2012

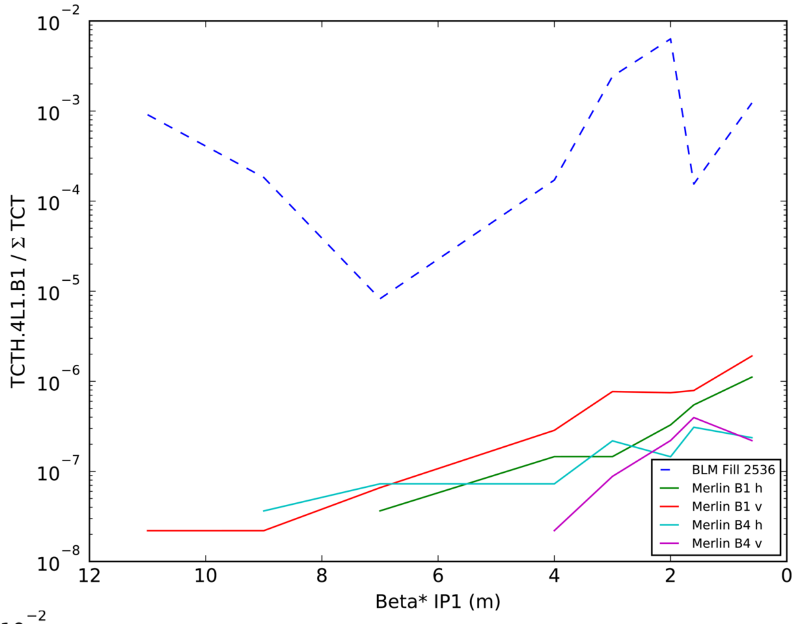
- 4 TeV, beta* 60 cm at IP1/5 (3 m at IP2/8)
- Test case
- Used BLM data recorded during physics fills
- No information about which plane loss happens
- Low signal to background
- Need to use timestamps where losses were high

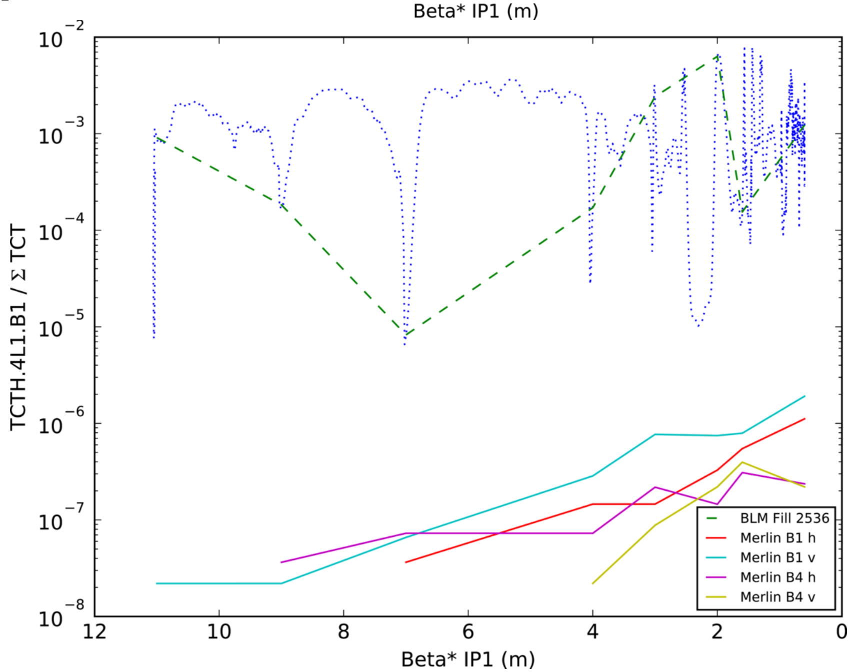
Name	Betx* [m]	Crossing angle [um]
IP1	11.00->0.60	-145.0 V
IP2	10.00->3.00	32.5 V
IP5	11.00->0.60	145.0 H
IP8	10.00->3.00	-456.2 H

Region	Type	Gap [sigma]
IR7	TCP	4.3
	TCS	6.3
IR3	TCP	12.0
	TCS	15.6
IR1	TCT	26.0->9.0
IR5	TCT	26.0->9.0
IR2	TCT	26.0->12.0
IR8	TCT	26.0->12.0

Comparisons

- First method
  - Took a single fill from 2012
  - Take the timestamps at specific values of beta*
  - Extract BLM signal at timestamps
- But found little useful signal, with no clear trend
- Found that the noise on BLM caused poor data around the squeeze points
- Every 2012 fill had similar issues
- Averaging over multiple fills made little difference



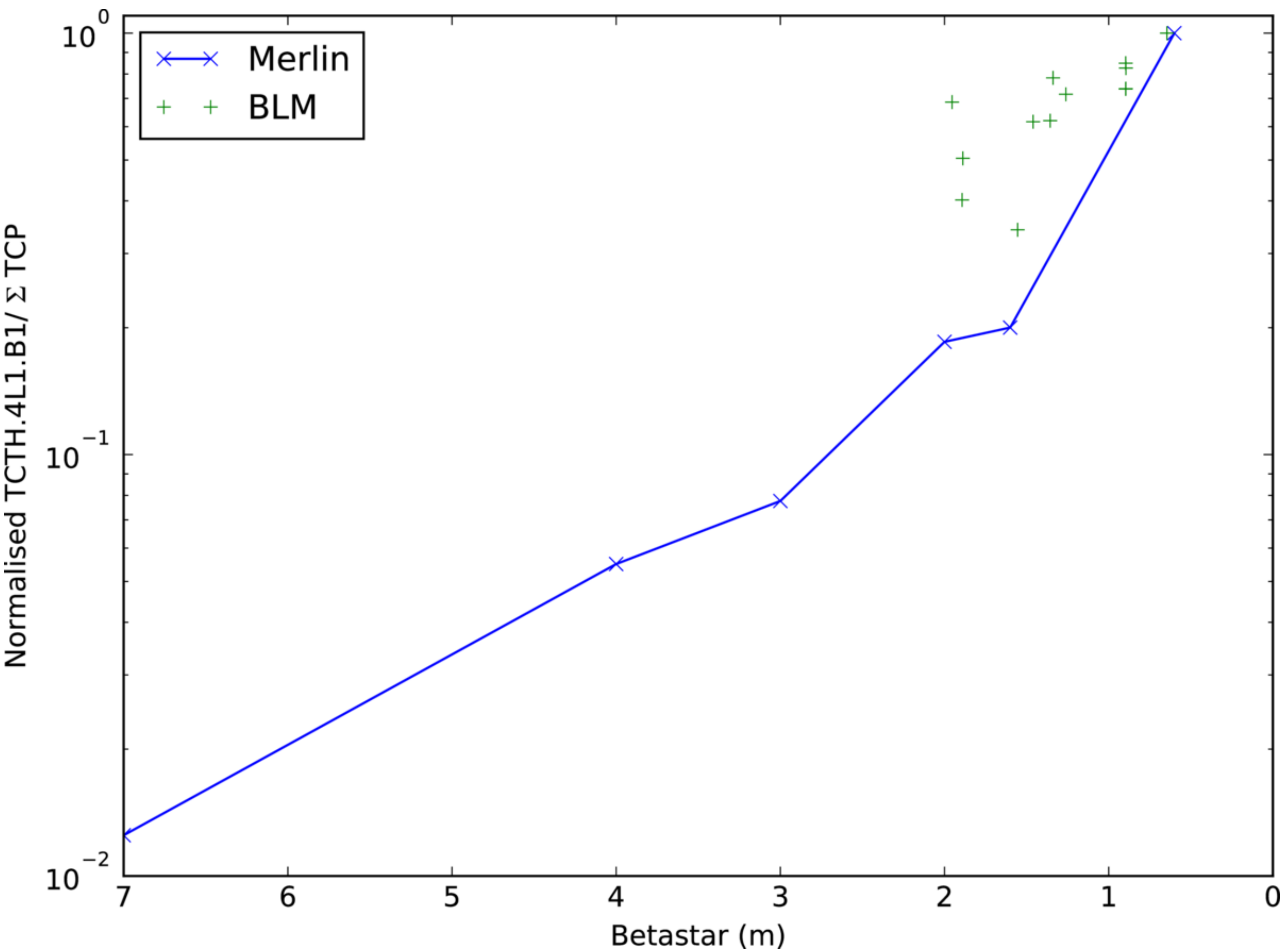


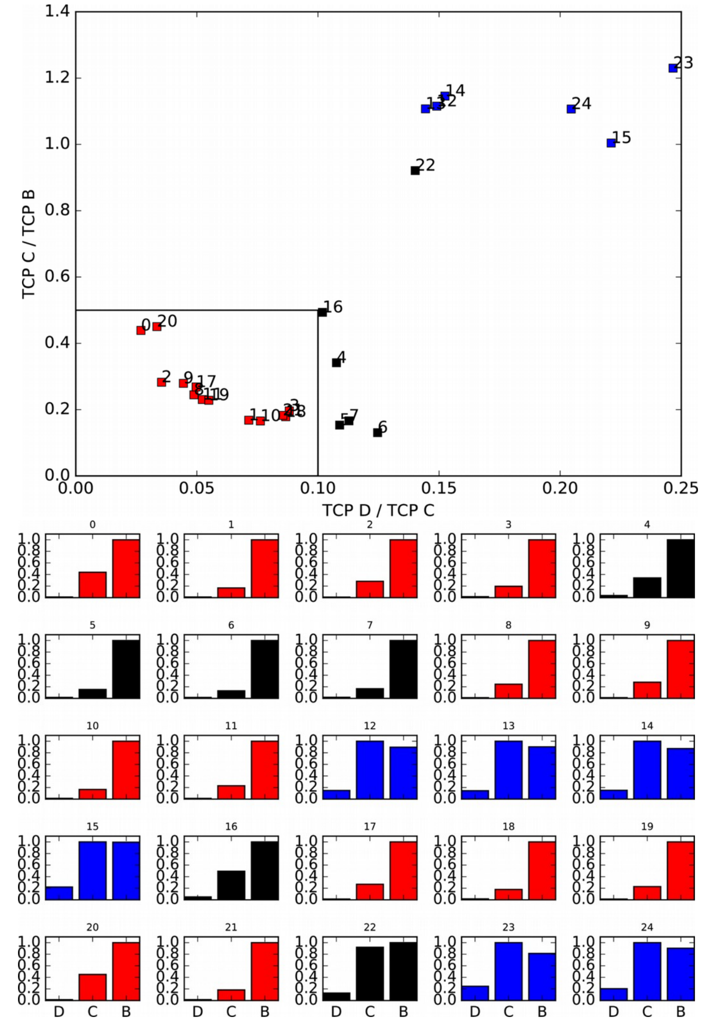
Filtering

- The best BLM data happens when the loss rate is high
  - Take every 2012 physics fill that reached stable beams
  - Take time windows during the squeeze
  - Look for peaks on given TCT
  - Check if simultaneous peak on TCP
  - If TCT and TCP above threshold, keep point
  - Rank by product of TCT and TCP, keep highest
  - Use TCP H/V/Skew ratios to identify loss plane
  - Left with small number of points

Results

- Can see TCT BLM increase as beta* is squeezed
- But not very strong demonstration





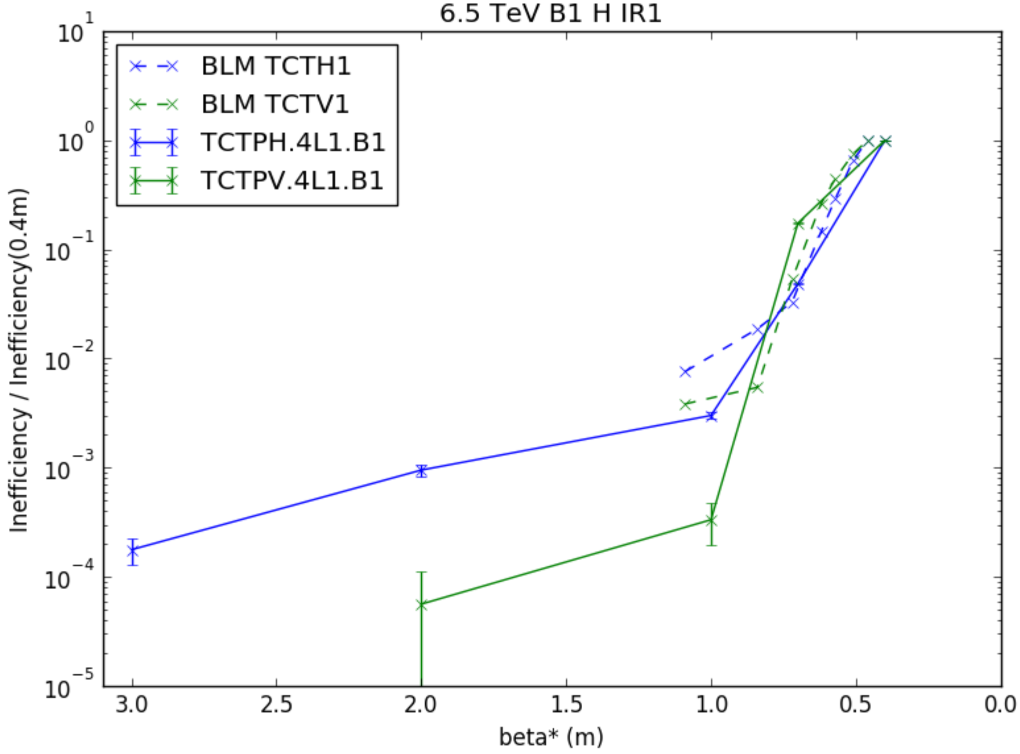
Run II (2016)

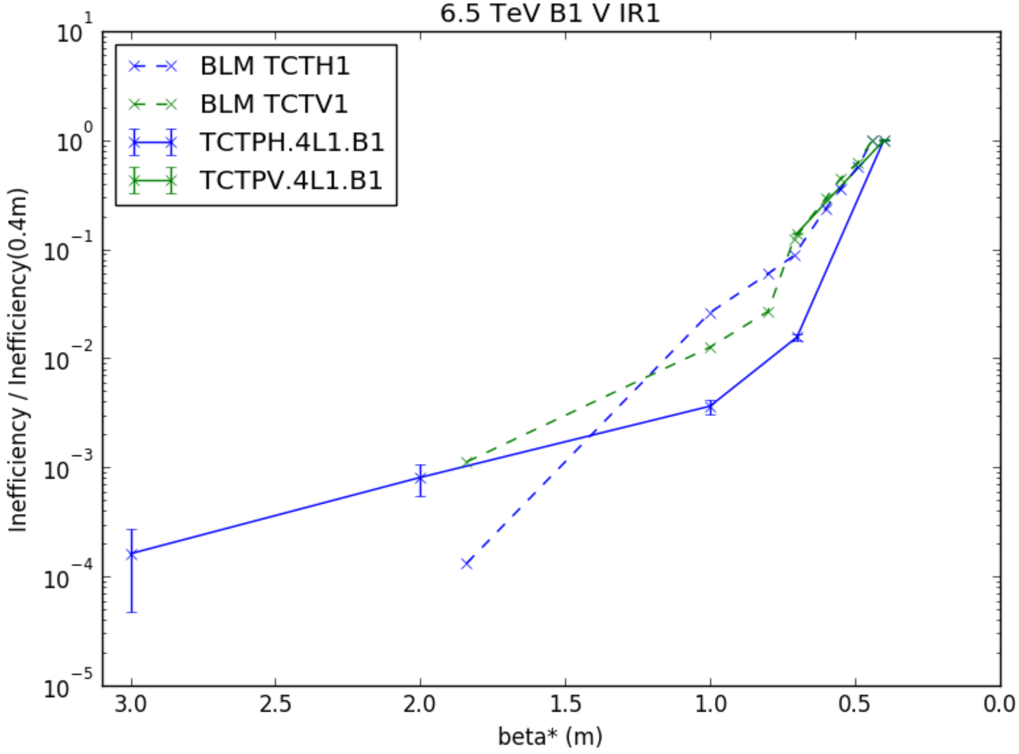
- 6.5 TeV – beta* 40 cm at IP1/5
- Combined ramp and squeeze, so only used final 3m → 40 cm
- Loss maps made during MD sessions
  - Separate loss maps in each plane and beam
- Beam excited with transverse dampers

Region	Type	Gap [sigma]
IR7	TCP	5.5
	TCS	7.5
IR3	TCP	15.0
	TCS	18.0
IR1	TCT	23.0->9.0
IR5	TCT	23.0->9.0
IR2	TCT	37.0
IR8	TCT	23.0->15.0

Name	Betx* [m]	Crossing angle [um]
IP1	3.00->0.40	-185.0 V
IP2	10.00->10.00	200.0 V
IP5	3.00->0.40	185.0 H
IP8	6.00->3.00	-250.0 H

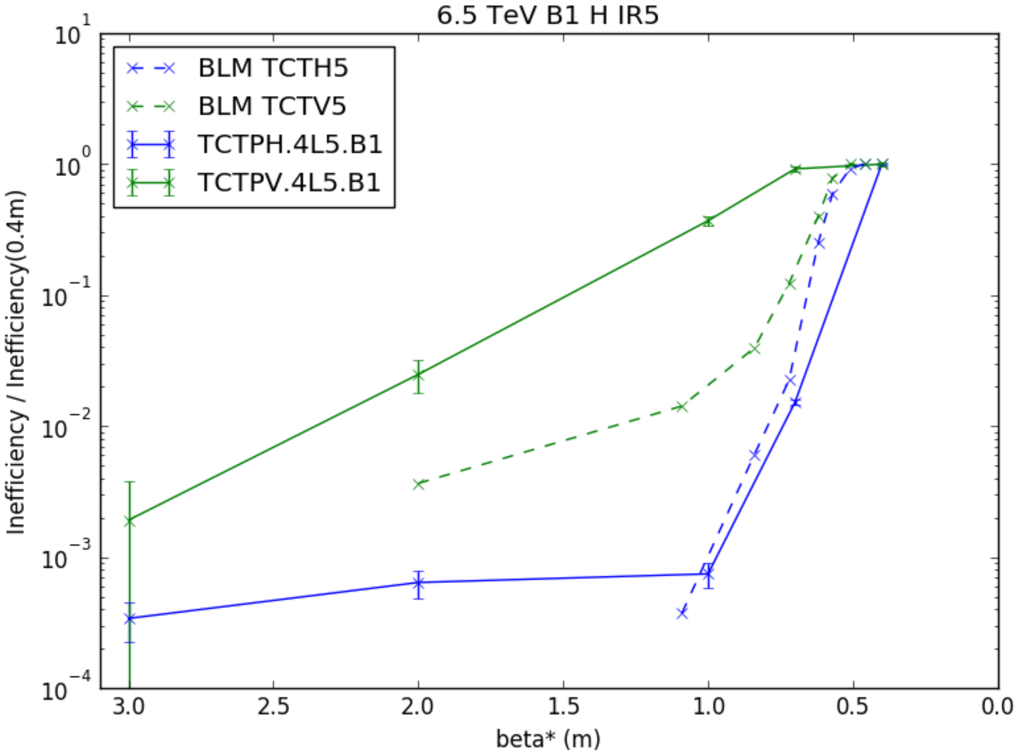
Results - IR1

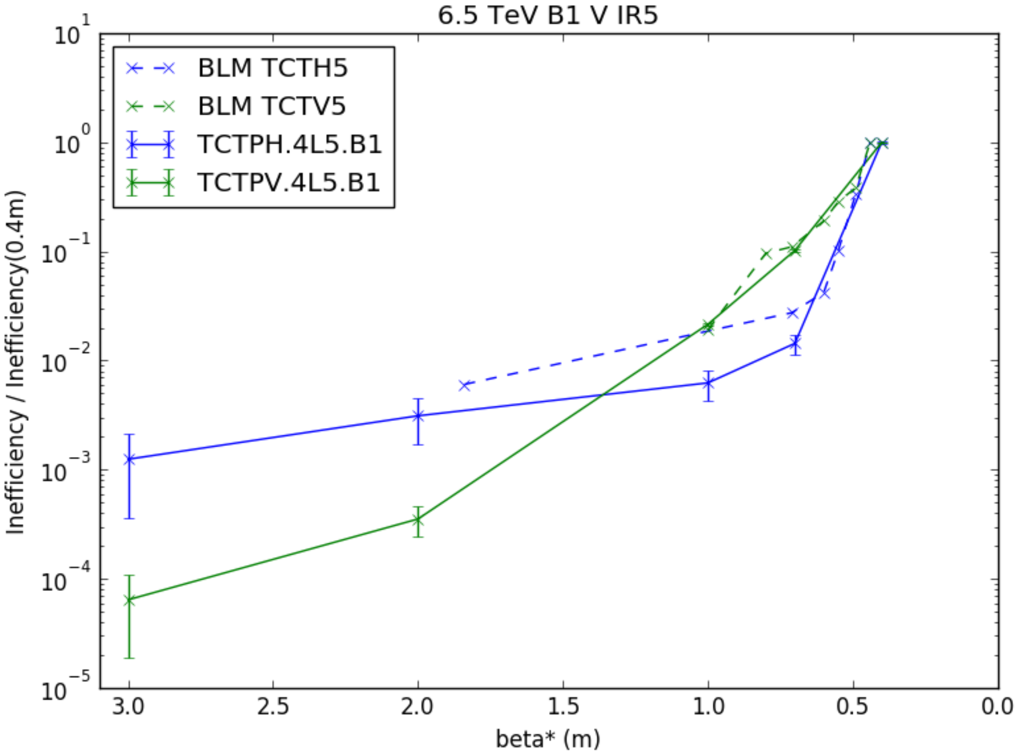




- Good agreement with H excitation
- With V excitation TCTPV drop off is too sudden
  - Currently investigating

Results IR5





- Good agreement and shapes
- IR8 also good
- IR2 has too low signal

IR1 vertical

- Losses on TCTPV.4L1.B1 only at 40 and 70 cm
- Keep track of last scatter of each particle, record when lost
- For particles lost at TCTPV.4L1.B1, where did they last scatter

	40 cm	70 cm
TCSG.D4L7.B1	1280	133
TCSG.B5R7.B1	892	147
TCSG.D5R7.B1	772	96
TCSG.A4R7.B1	674	131
TCSG.A4L7.B1	443	75
TCSG.E5R7.B1	99	21
TCSG.6R7.B1	6	1
TCLA.C6R7.B1	3	2

Vertical phase advance to TCTPV4L1 (deg)

	40 cm	70 cm	100 cm	200 cm	300 cm
TCSG.D4L7	198.8	177.2	170.6	152.0	143.2
TCSG.B5R7	120.2	98.6	92.1	73.5	64.6

- Need to do individual particle tracking to see how the optics changes are effecting loss locations

Conclusion

- Merlin is showing good agreement to the BLM data
- 2012 analysis is limited by the BLM data
- 2016 have specific measurements
- Still analysing smaller differences