Beam Loss Patterns at LHC Collimators

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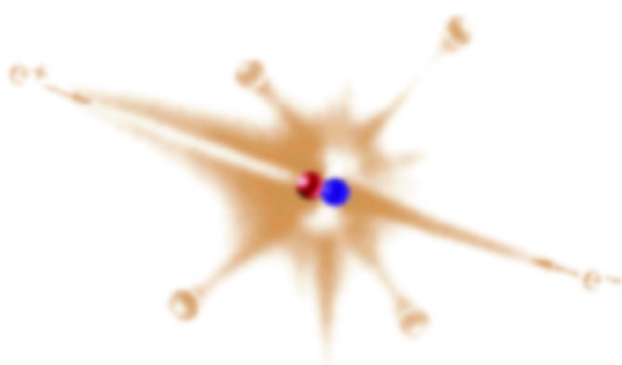
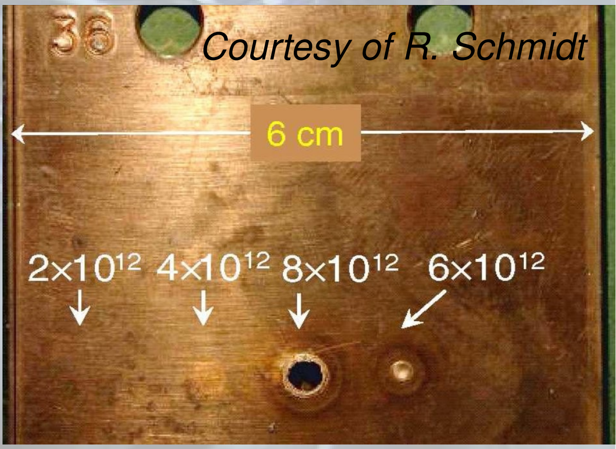
Presentation of Master Thesis by Till Boehlen

Supervised by Prof. Pietralla



Threat of Damage to LHC

- Max. energy: 7 TeV -> 7 times higher than present-day accel.
- Nominal Intensity N: $3*10^{14}$ prot. per beam
  -> 35 times higher than present-day prot. accel.
- Energy stored: 360MJ per beam -> Melts 500kg copper

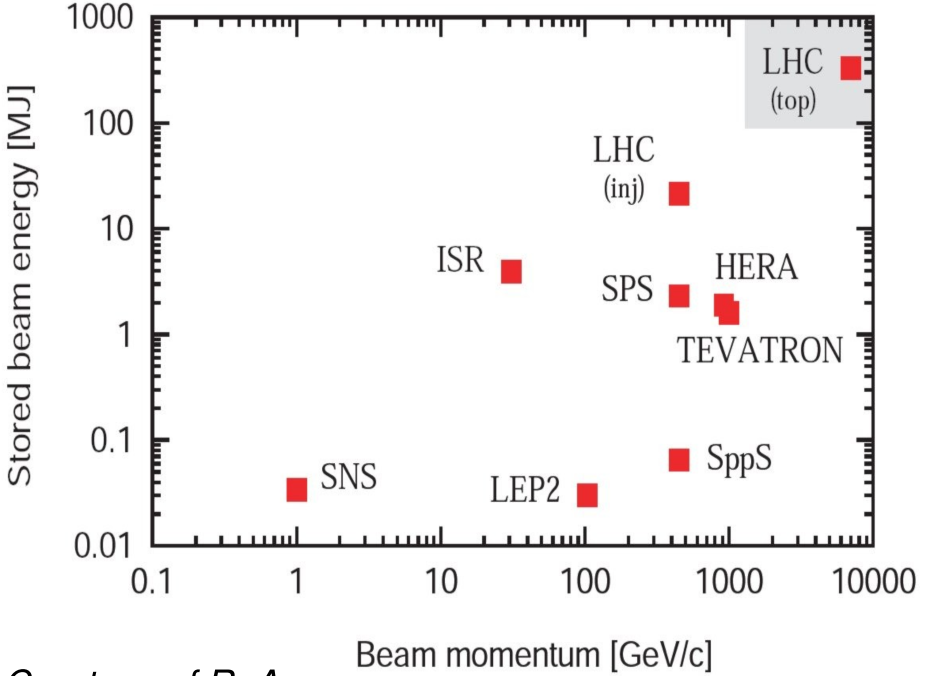


450GeV-protons on copper

Critical beam losses:

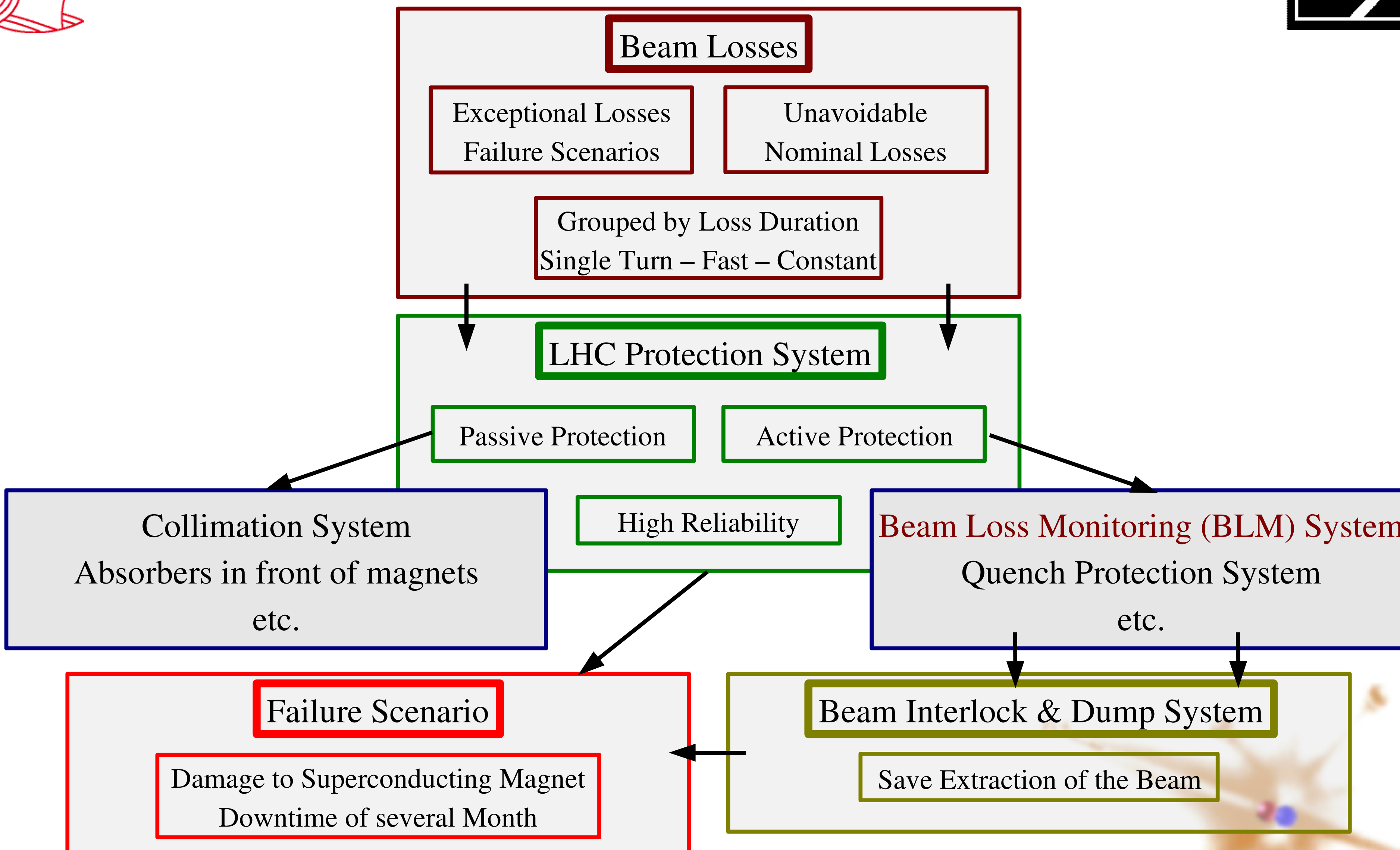
- Damage: $\sim 3*10^{-6}*N$ in one turn
- Quench: $\sim 3*10^{-9}*N$ in one turn

Protection of LHC Components needed!



Courtesy of R. Assmann

Protection Systems of the LHC

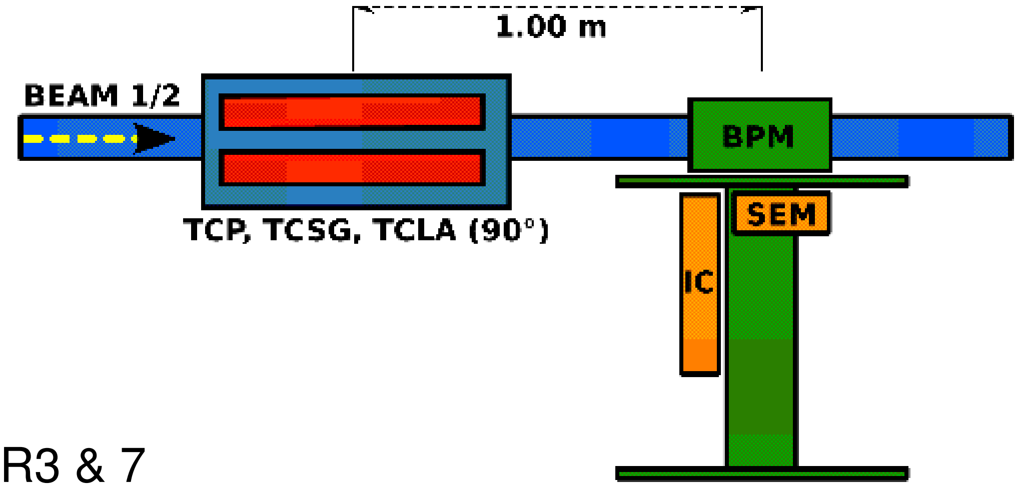


Collimator Types & Locations

Types of Collimators

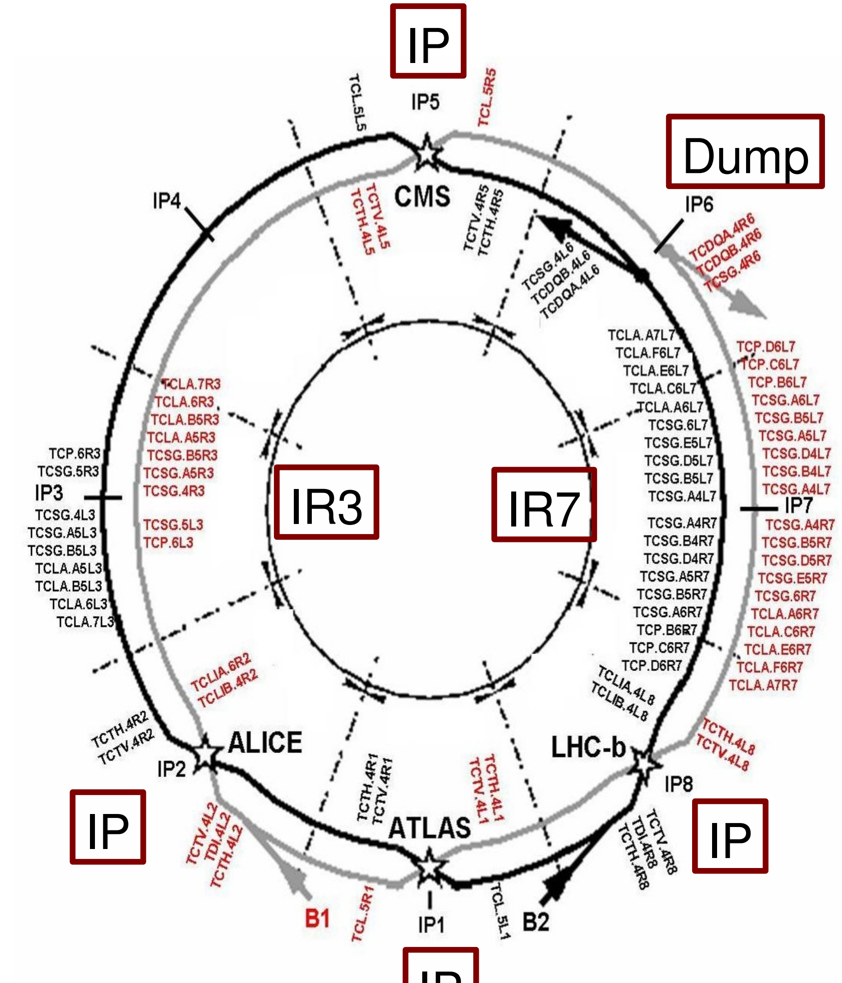
Name	Active Jaw	Material
TCP	60cm	C
TCSG	100m	C
TCLA(TCT)	100m	W in Cu

Exemplary Setup



IR3 & 7

Locations

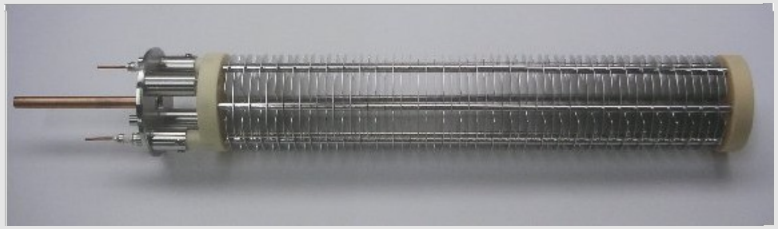


Courtesy of C. Bracco

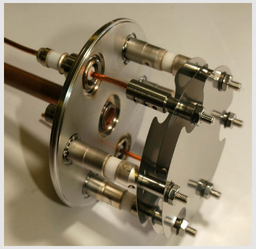
Beam Loss Monitoring System (BLM)

Task
Measure Secondary Particles
from Beam-Induced Showers

Detectors
~3700 Ionization Chamber (IC)



~280 Secondary Emission Monitors (SEM)



Prevent
Beam-Induced Damage & Quenching
of Sensitive Equipment
e.g.: Magnets, Collimators

Damage & Quench Level
transient $\frac{E}{V}$ — steady-state $P = \frac{E}{t}$

μsecs — Loss duration — Several secs

Reaction Time
Detection: one turn (~89μs)
Beam Extraction: 3-4 turns (~350μs)

Detector Threshold
Must be Assessed! Relation of
Energy Deposited in Equipment
to Detector Signal

Contents of Master Thesis

- Part 1: Reproduction of BLM detector measurements by simulation
- Part 2: Prediction of BLM detector signal for the actual LHC setup

Measurement vs. Simulation for LHC-like Setup in SPS

(pre-accelerator of the LHC)

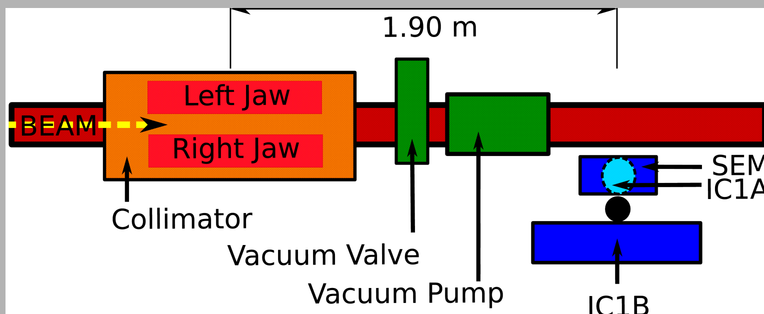
- Setup: LHC collimator, 2 IC's, and
  1 SEM detector
- Simulation tool: Monte Carlo particle code FLUKA
- Goal: determine accuracy of predicting BLM signals by simulations for an LHC collimation scenario

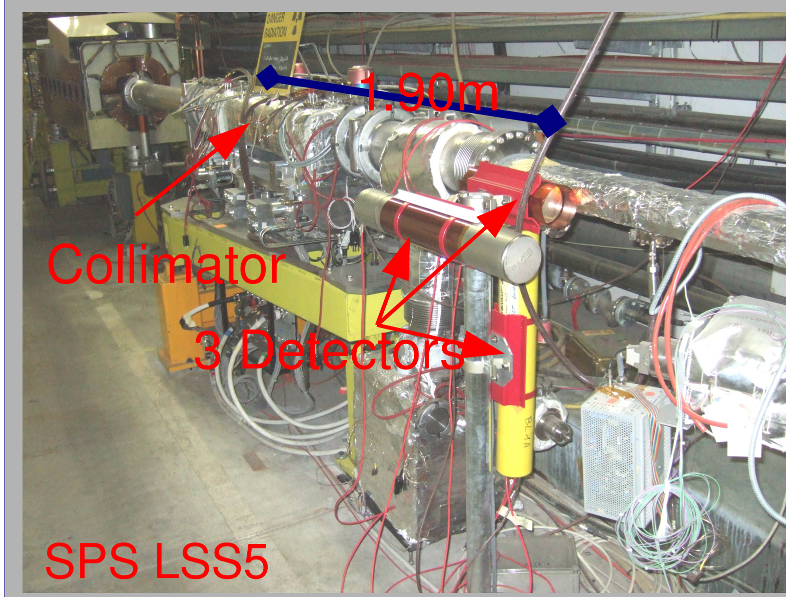
Prediction of BLM Signals for LHC Collimation Setup

- Implementation: a cell consisting of a (exchangeable) collimator and IC-SEM detector pair
- Prediction:
  - BLM signal per beam proton (=normalized dose)
  - BLM signal per total and peak energy deposition in the collimator
- Focus: variation of BLM signals and energy dep. in collimator due to BLM misalignment & beam impact scenario

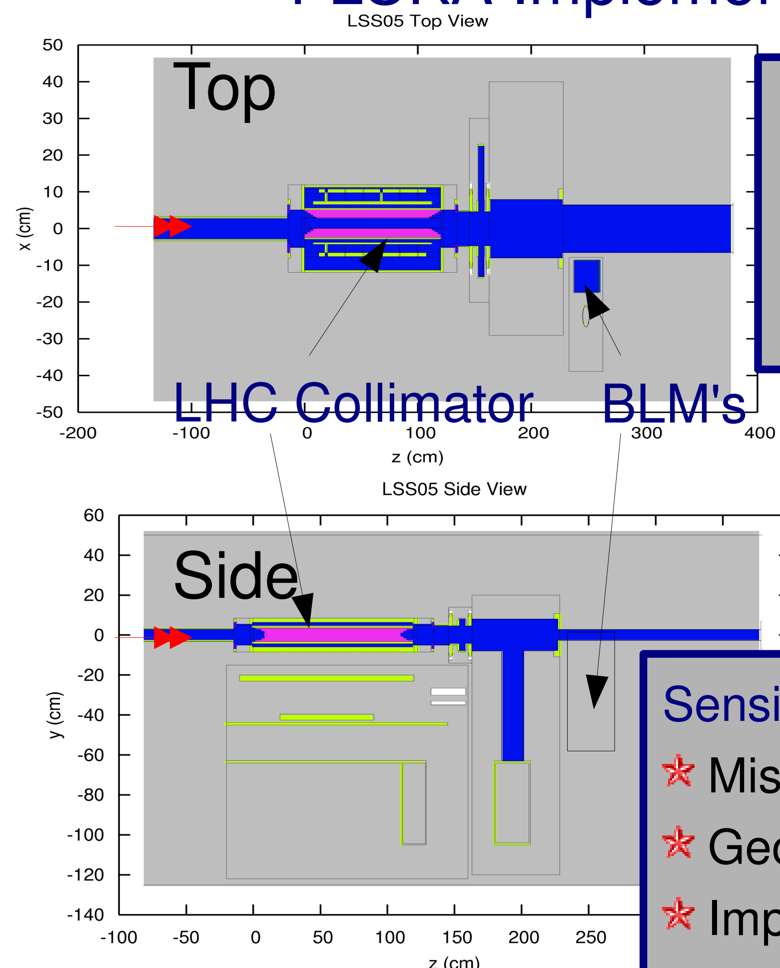
Losses at the LHC collimator in the SPS

Setup Experiment





FLUKA Implementation



Focus on:

- Collimator
- BLM Detectors
- Beam Tube

Sensitivity study:

- Misalignment
- Geom. Simplification
- Impact scenarios

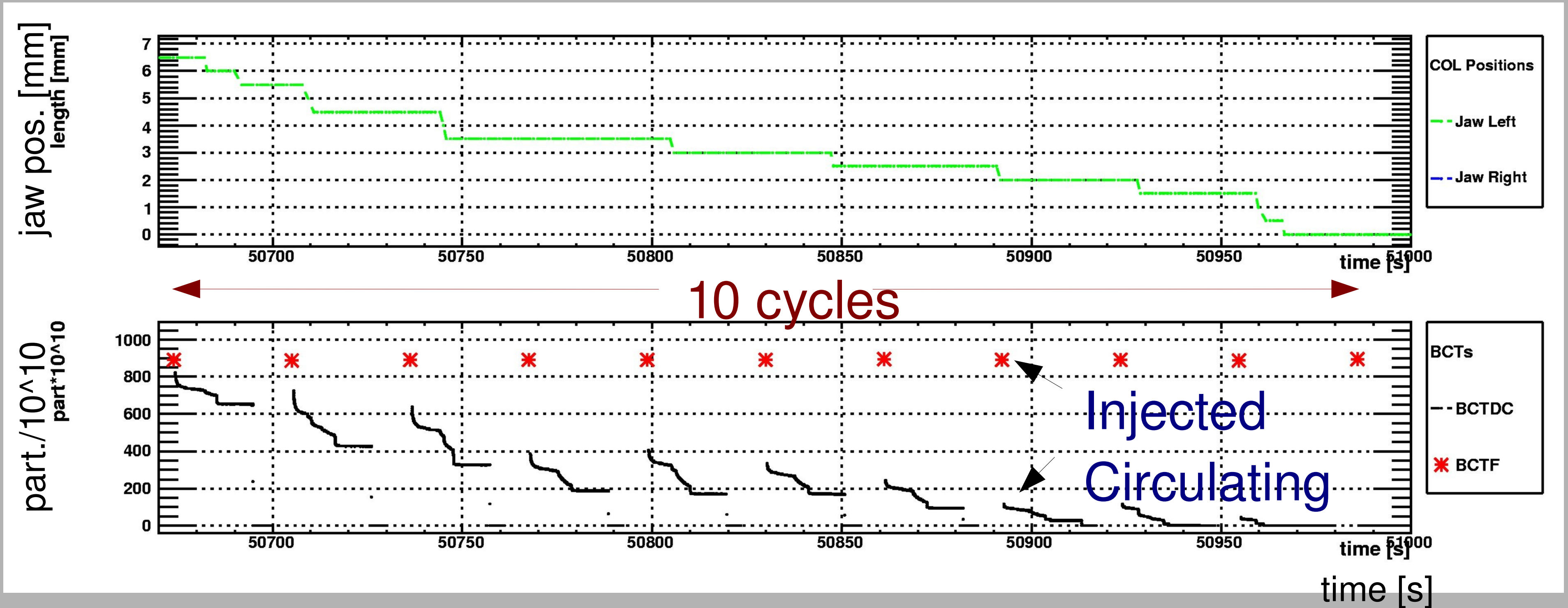
=>Max. change 15%

Measurements in the SPS

Data Acquisition

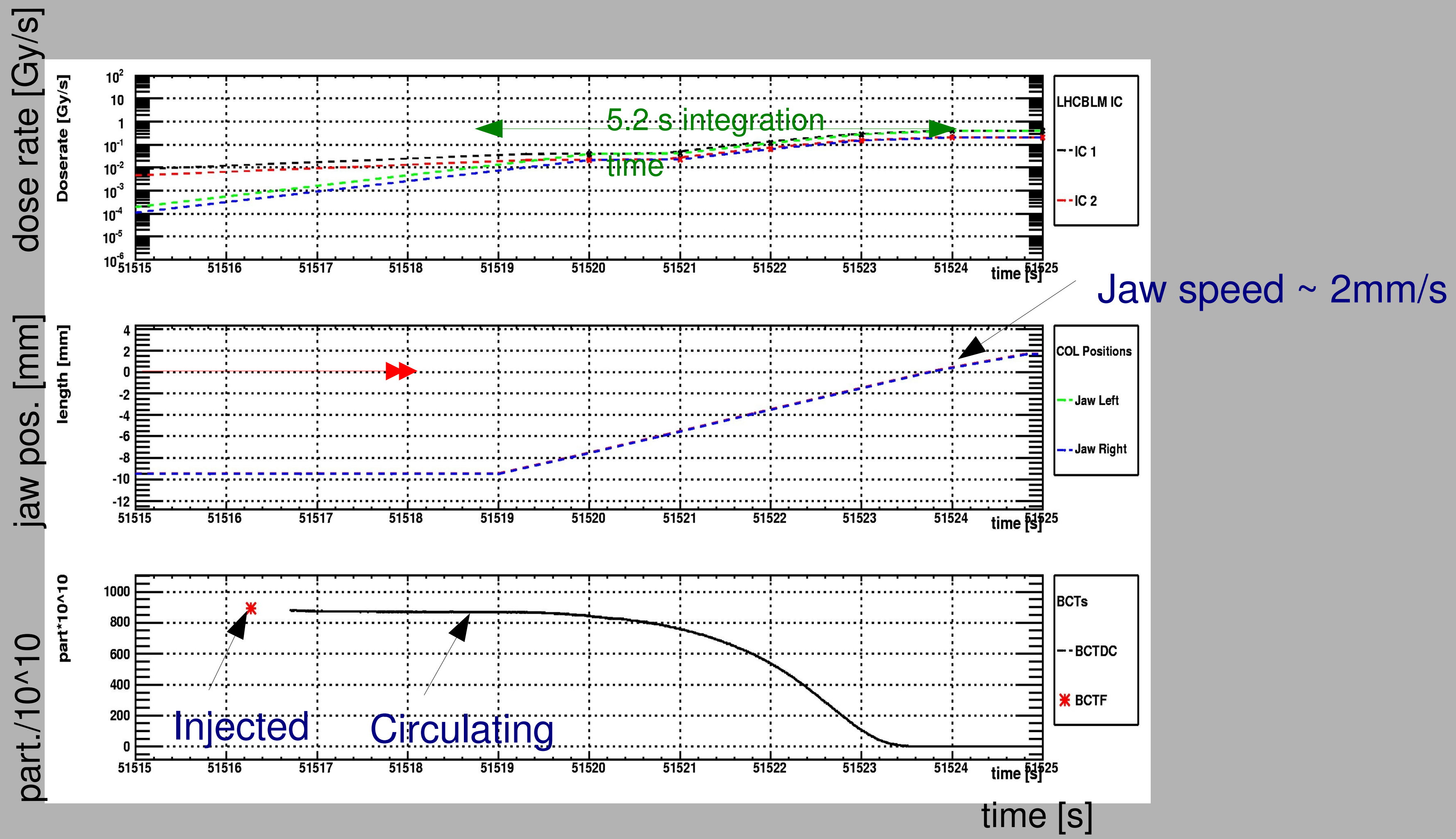
- 3 sessions: circulating mode @ 26 GeV (cycle = 20 sec)
- Injected intensities: 10-90x10^{10}, 900x10^{10}, 1300x10^{10} protons
- Acquisition: beam intensity (beam current converters), BLM detector signals, collimator jaw positions wire scanner (transversal beam intensity distribution)

First Method: "Direct Dumping"



Measurements in the SPS

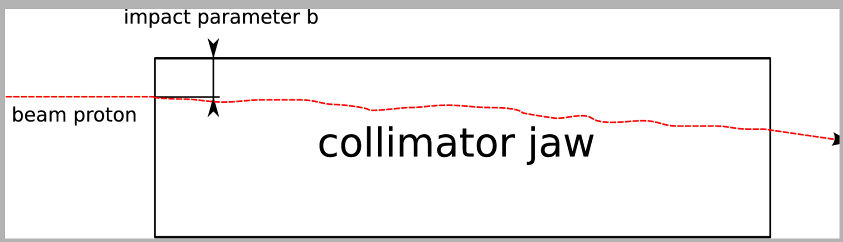
Second Method: “Continuous Scraping”



Measurements in the SPS

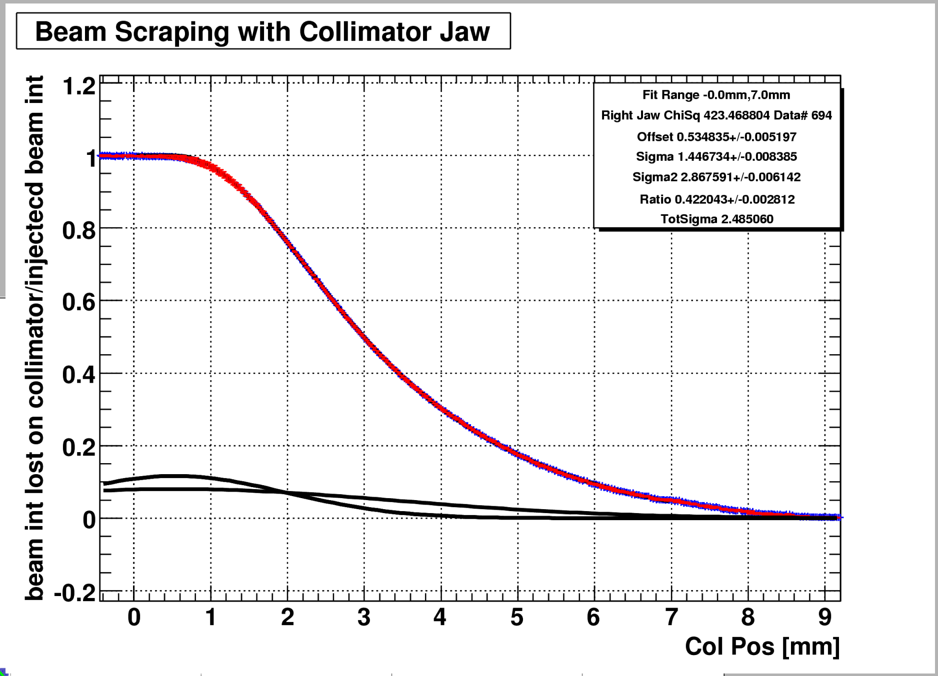
Determination of the Impact Distributions on the Collimator

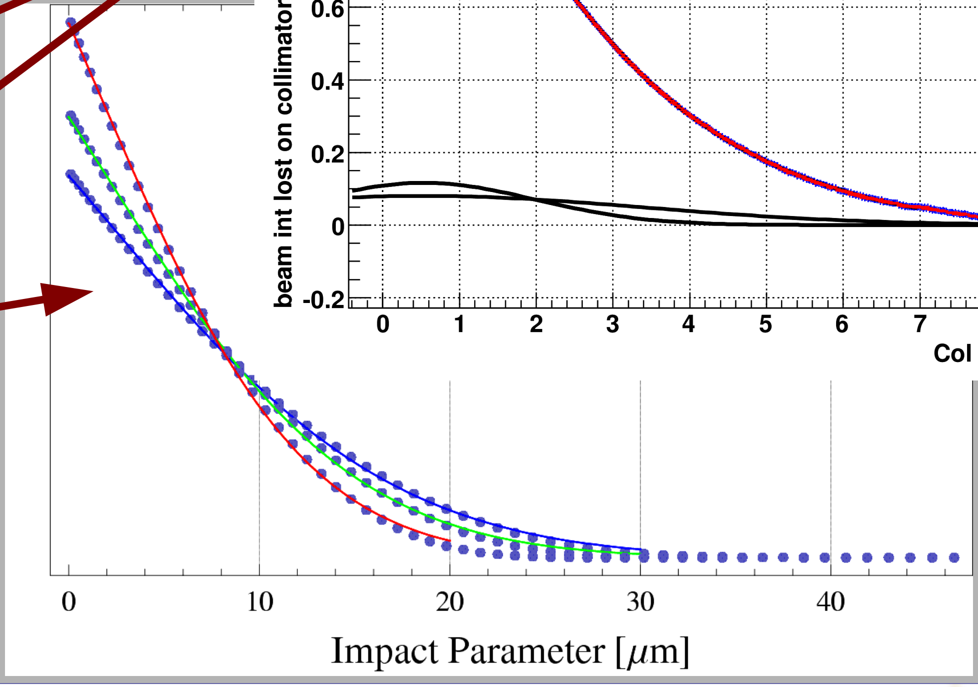
Definition of impact parameter:



- Beam center position w.r.t. the collimator jaws
- Beam size at the collimator
- Beam impact distribution for continuous scrapings

Input for reproduction of measurements by simulations





Comparison: Measurement vs. Simulation

First Method: "Direct Dumping"

- High intensities in short time
- IC detectors: space-charge effects
- Similar to LHC failure scenario

Max. deviation (Meas./Sim.):

IC: +9%

SEM: -30% (FLUKA+Geant4: -40%)

Session	No. 1		No. 2		No. 3	
Jaw Pos. [mm]	Left 0.0	 5.5	Left 0.0	 5.5	Left 3.25	Right 1.75
Meas.	Normalized dose/10^{-13} [Gy/proton lost on collimator]					
IC1B	saturated		saturated		2.70 ± 0.10	2.50 ± 0.07
SEM	7.60 ± 0.12	7.32 ± 0.12	3.11 ± 0.02	2.98 ± 0.02	5.73 ± 0.17	4.27 ± 0.05
Sim.	Normalized dose/10^{-13} [Gy/proton lost on collimator]					
IC1B	-	-	-	-	2.49 ± 0.07	2.30 ± 0.13
SEM	10.2 ± 0.4	10.4 ± 0.3	10.2 ± 0.4	10.4 ± 0.3	7.13 ± 0.19	5.95 ± 0.24
Ratio	Measurement/Simulation					
IC1B	-	-	~~-~~	~~-~~	1.08	1.09
SEM	0.75	0.70	~~0.31~~	~~0.29~~	0.80	0.72

Second Method: "Continuous Scraping"

- Intensities are integrated over ~3sec
- Bigger uncertainties of BLM signals due to:
  - Returning protons
  - Impact distribution/beam-jaw angle
- Similar to LHC nominal scenario

Max. deviation (Meas./Sim.):

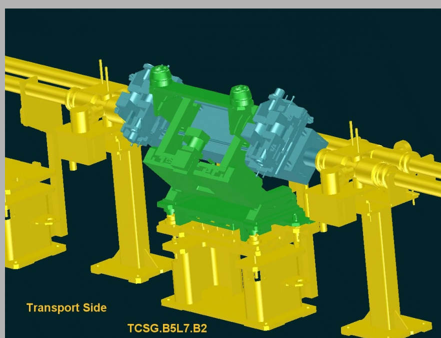
IC: +/-20%

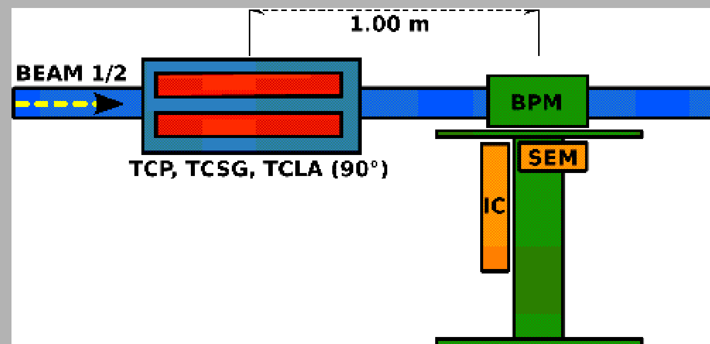
SEM: +73% (FLUKA+Geant4: +/-40%)

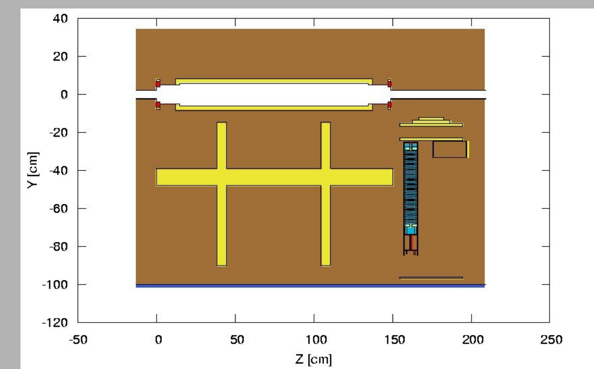
Session	No. 1		No. 3		Ratio 1	Ratio 3
Jaw	Left	Right	Left	Right	Left/Right	
Meas.	Normalized dose/10^{-13} [Gy/proton lost on collimator]					
IC1A	3.08 ± 0.02	2.26 ± 0.12	2.64 ± 0.04	2.41 ± 0.02	1.36	1.09
IC1B	-	-	1.92 ± 0.03	1.95 ± 0.01	-	0.98
SEM	9.84 ± 0.30	8.35 ± 0.30	8.57 ± 0.43	7.65 ± 0.42	1.18	1.12
Sim.	Normalized dose/10^{-13} [Gy/proton lost on collimator]					
IC1A	3.19 ± 0.45	2.14 ± 0.30	3.33 ± 0.43	2.57 ± 0.38	1.49	1.30
IC1B	2.20 ± 0.31	1.57 ± 0.22	2.41 ± 0.35	1.62 ± 0.21	1.40	1.48
SEM	8.18 ± 1.22	5.10 ± 0.81	8.56 ± 1.19	4.40 ± 0.61	1.60	1.95
Ratio	Measurement/Simulation					
IC1A	0.97	1.06	0.79	0.94		
IC1B	-	-	0.80	1.20		
SEM	1.20	1.64	1.00	1.73		

Simulations for LHC Setup

Implementation of “Collimator-Detector Cell”







Aim:

Predicting ratios of BLM signal to total and peak energy deposition (ED) in collimators

Focus:

Dependency of these ratios on different parameters:

- detector misalignment
- impact parameter
- beam-jaw angle
- higher order particle halos from upstream

Cross-checks

SPS simulation:

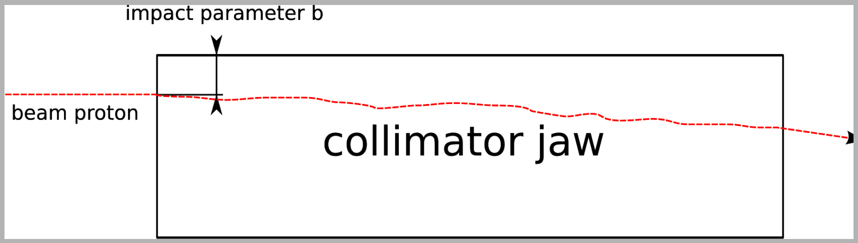
- Particle fluxes through BLM detectors are comparable

Implementation by FLUKA team:

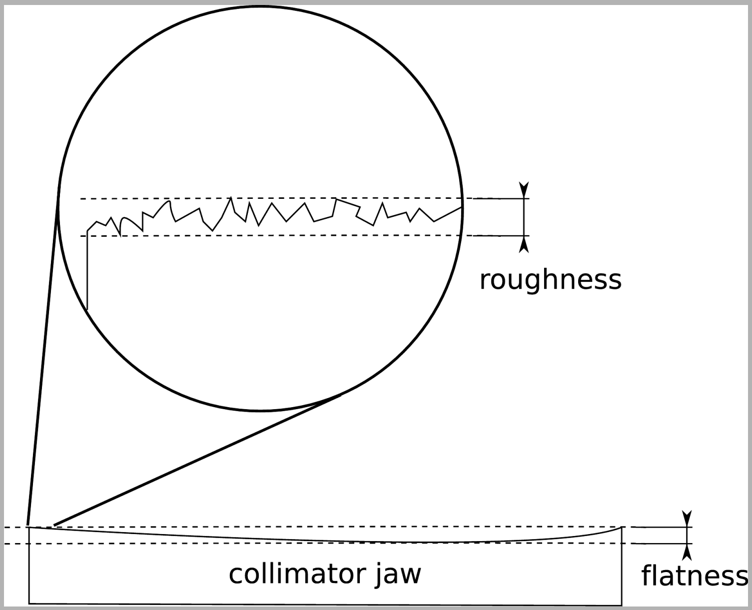
- BLM signals agree within 5%

Simulations for LHC Setup

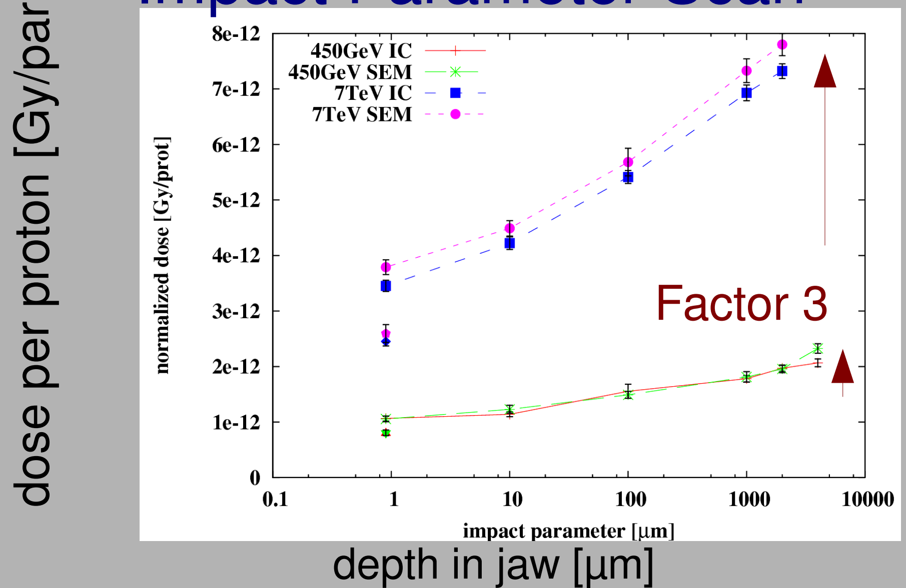
Definition Impact Parameter

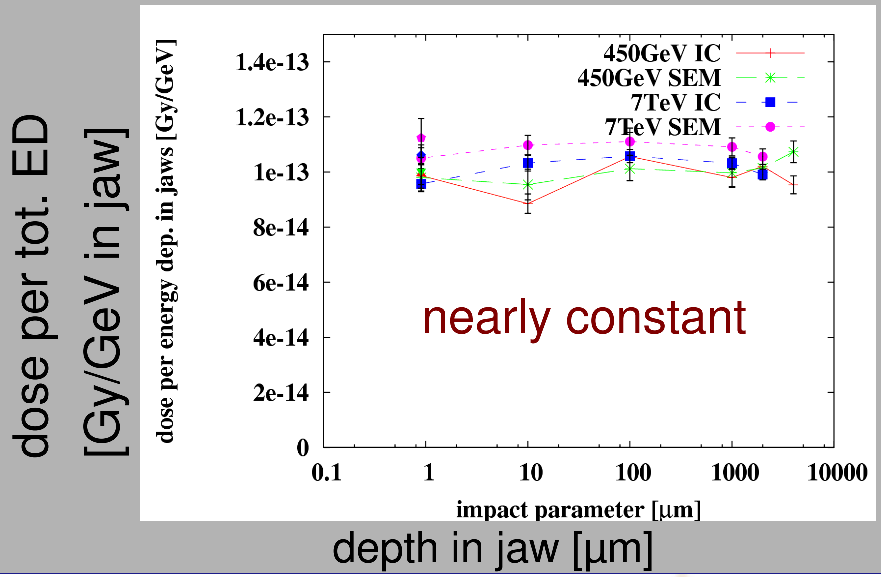


Jaw Roughness & Flatness



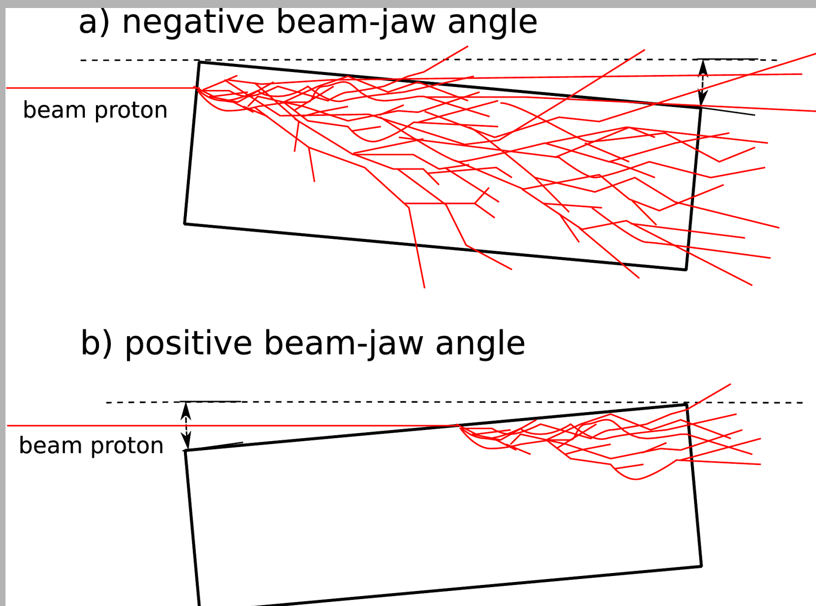
Impact Parameter Scan





Simulations for LHC Setup

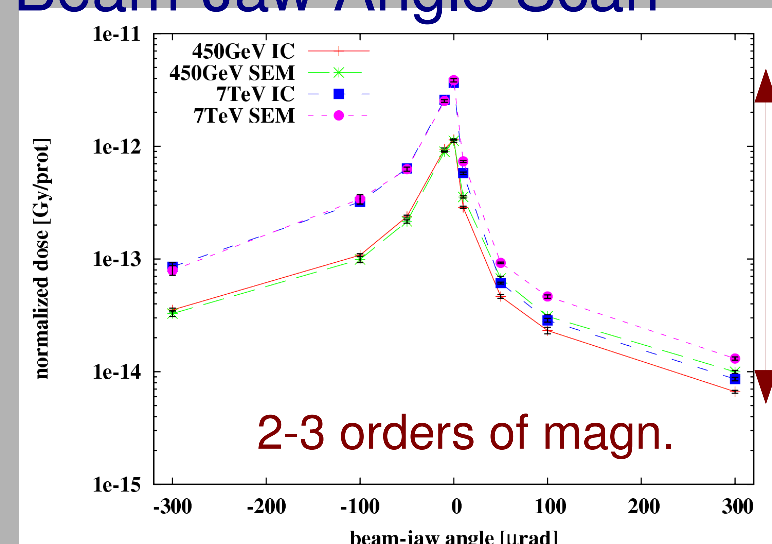
Illustration: Beam-Jaw Angle



Save estimation for protons when setting to lowest signal-to-energy deposition ratio.

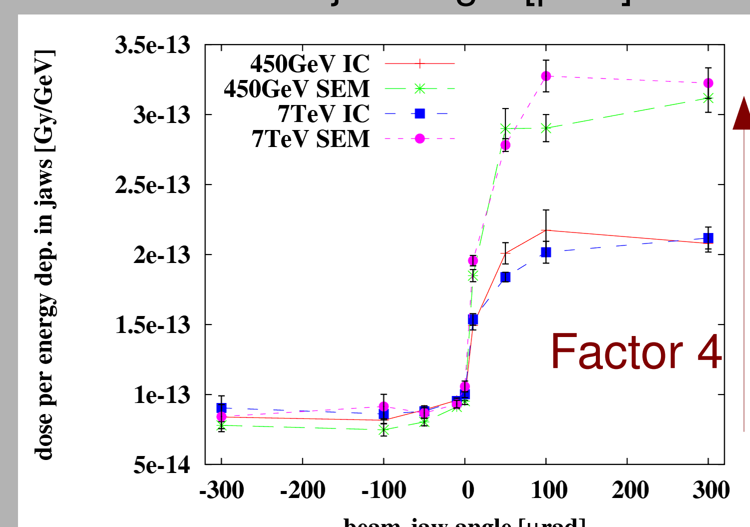
Beam-Jaw Angle Scan

dose per proton [Gy/part]



beam-jaw angle [µrad]

dose per tot. ED in jaw [Gy/GeV]



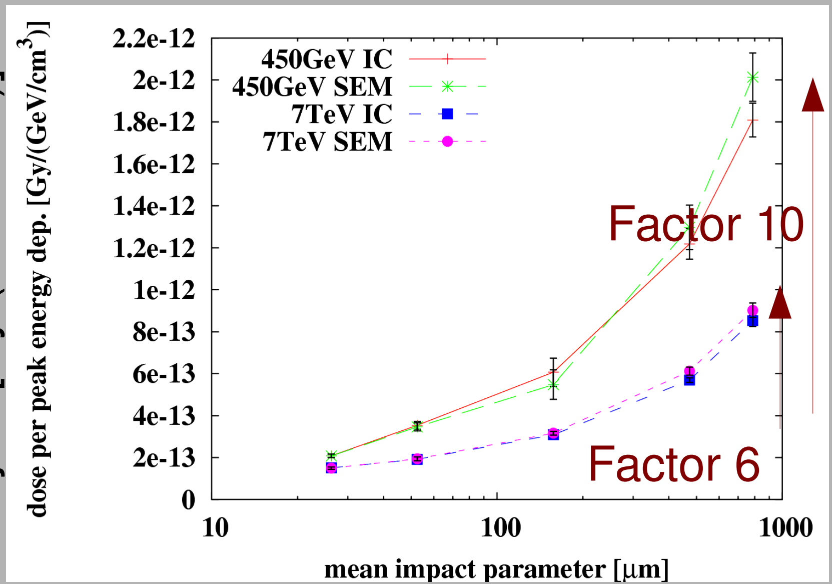
beam-jaw angle [µrad]

Simulations for LHC Setup

Peak Energy deposition

Assumes Gaussian tails as particle distributions on collimator (typical distributions for failure scenarios calculated by A. Gómez Alonso)

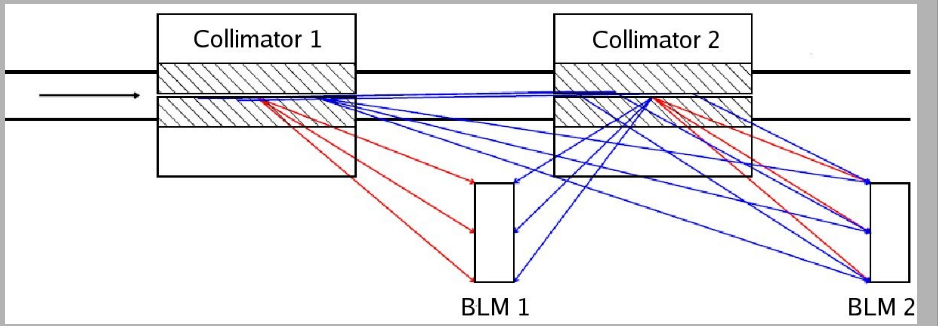
dose per peak ED in jaw [Gy/(GeV/cm^3)]



mean impact parameter [µm]

Higher Particle Order Halos

Mixed particle spectra hitting downstream collimators



Simulations for 3 "collimator-detector cells"

- Beam protons impacting on Cell 1
- Particles exiting through beam pipe propagated through Cell 2 and Cell 3

Results:

- Ratio of BLM signal to total energy dep. in jaw for Cell 3 is 25% of Cell 1!

=> Systematic studies needed

Summary & Conclusions

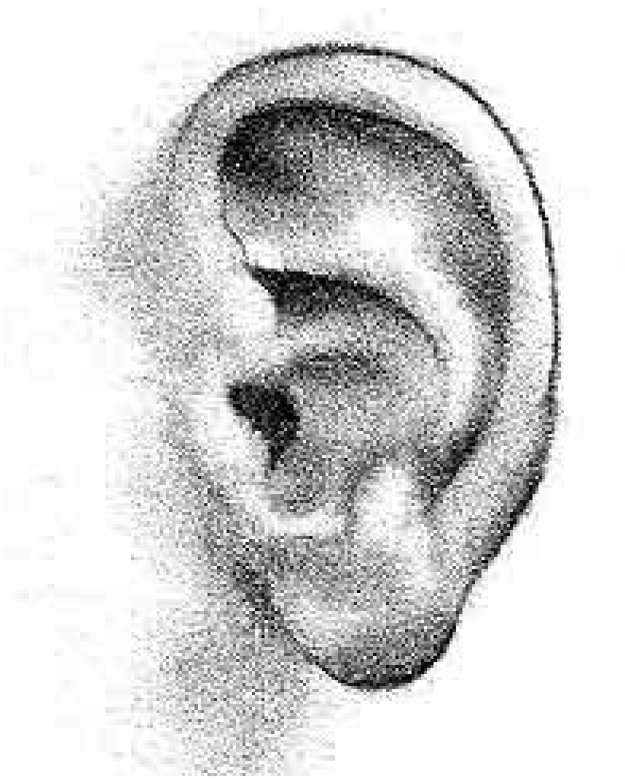
Part 1: Comparison Measurement-Simulation: Experimental Setup in the SPS

- Max. deviation Meas./Sim. for IC detectors: ±21%
- Max. deviation Meas./Sim. for SEM detectors: ±40%(FLUKA+Geant4), 73%(FLUKA)
- Final determined discrepancy between meas.-sim. Interpreted as systematic uncertainty for assessment of BLM detector thresholds by simulations

Part 2: Simulation Studies for the LHC Collimation Scenario

- Investigating ratios of BLM signal to (total and peak) energy deposition (ED) in collimator jaws
- Signal-to-total ED ratio:
  - about constant for different impact parameter,
  - only increasing for different beam-jaw angles,
  - decreasing for mixed particle spectra from upstream=> systematic calculation needed!
- Signal-to-peak ED ratio:
  -

Thanks for attentive ...



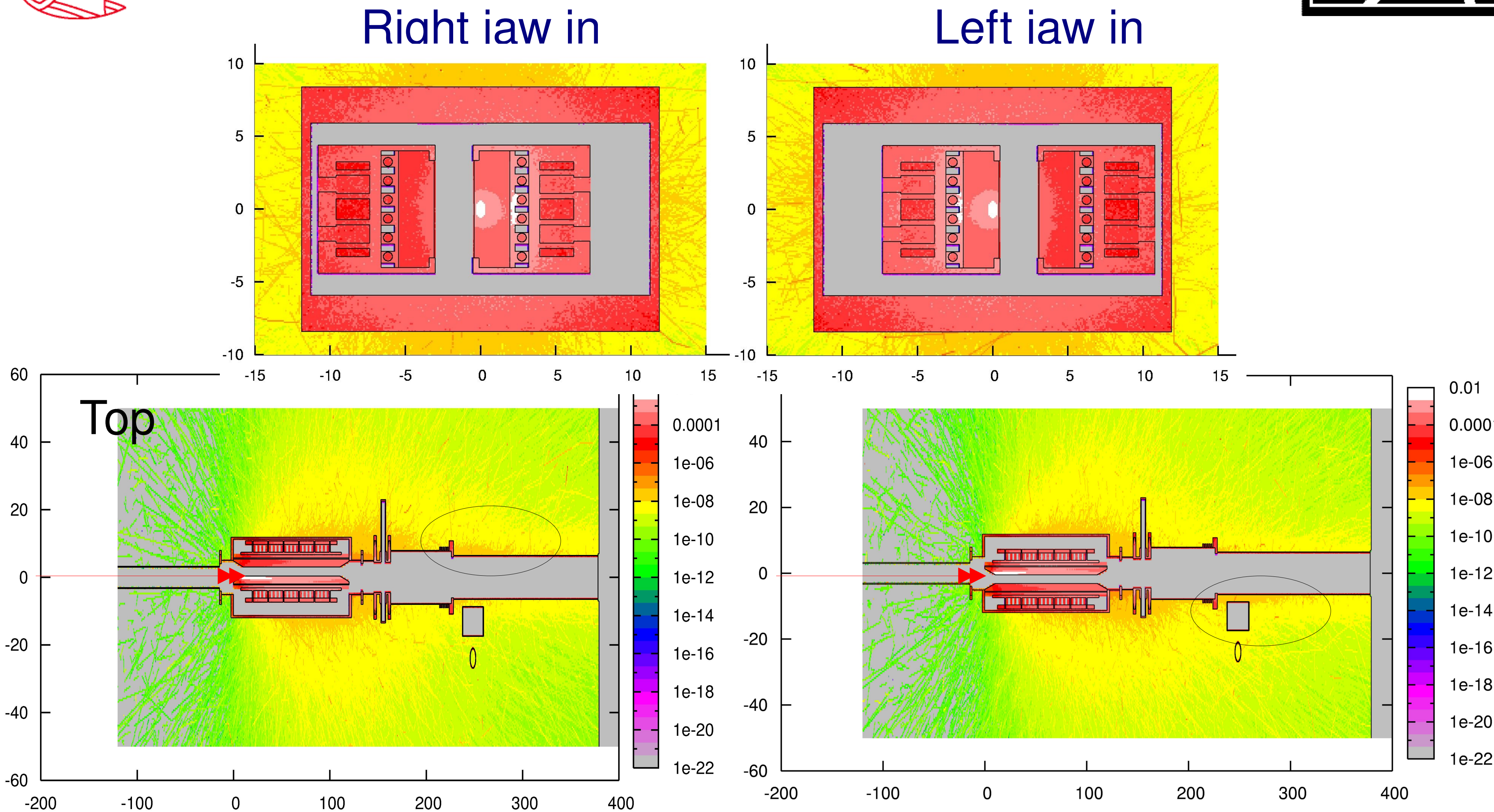
Comments and questions welcome!

OLD:Summary & Outlook

- Implementation of experimental setup in FLUKA
- Several scans of model parameters => max. systematic error of 15%
- Measurements: few data usable: space-charge effects, missing logging data (software)
- First comparisons between meas. and sim. => agreement within 5% (but low statistics!)
  - Agreement of other meas.-model comparisons 10-50%

- Final determined discrepancy of meas.-model as systematic uncertainty for assessment of LHC BLM detector thresholds by simulations
- Impact parameter studies will be continued at LHC energies
  - Further systematic error for determining thresholds
- Inclusion of determination of peak energy and total energy deposition in collimator
- More measurements in May 2008 – optimizing conditions
  - Lower intensities (no saturations), improved calibration of impact parameter

Preliminary Results (Add.)



- IC signal ratio Right/Left Sim: 0.73±0.05 Exp: 0.71±0.09