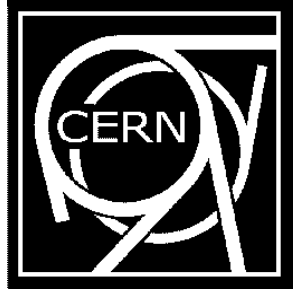


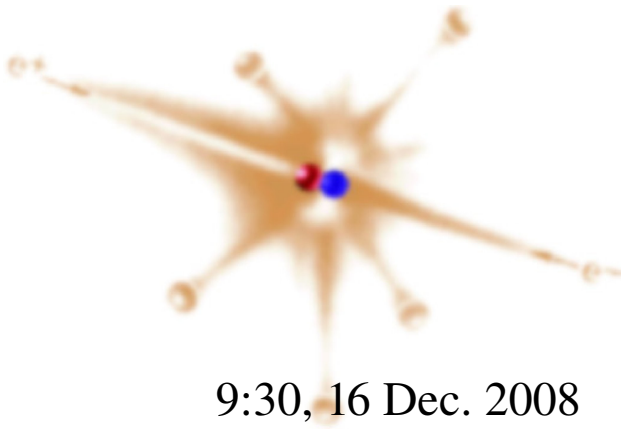
Beam Loss Patterns at LHC Collimators

-

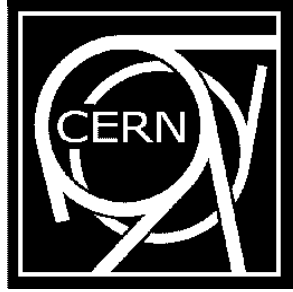
Calibration of BLM Thresholds

Master Thesis

By Till Boehlen & BLM Team



Overview of Study



- 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

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

Prediction of BLM Signals for LHC Collimation Setup

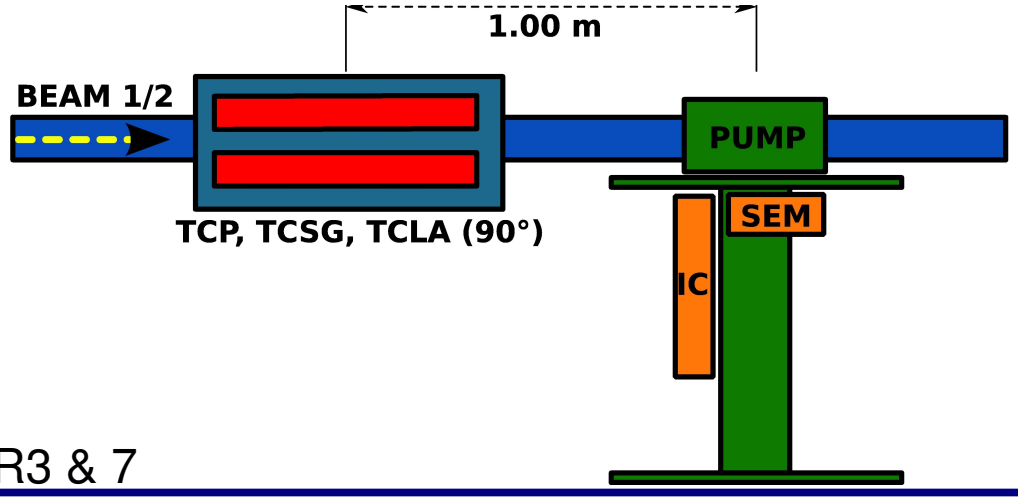
- Implementation: a cell consisting of a (exchangeable) collimator and IC-SEM detector pair
- Prediction:
  - BLM signal per beam proton (=normalized dose)
  - BLM signal per total and peak energy deposition in the collimator
- Focus: variation of BLM signals and energy dep. in collimator due to BLM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

Collimator Types & Locations

Types of Collimators

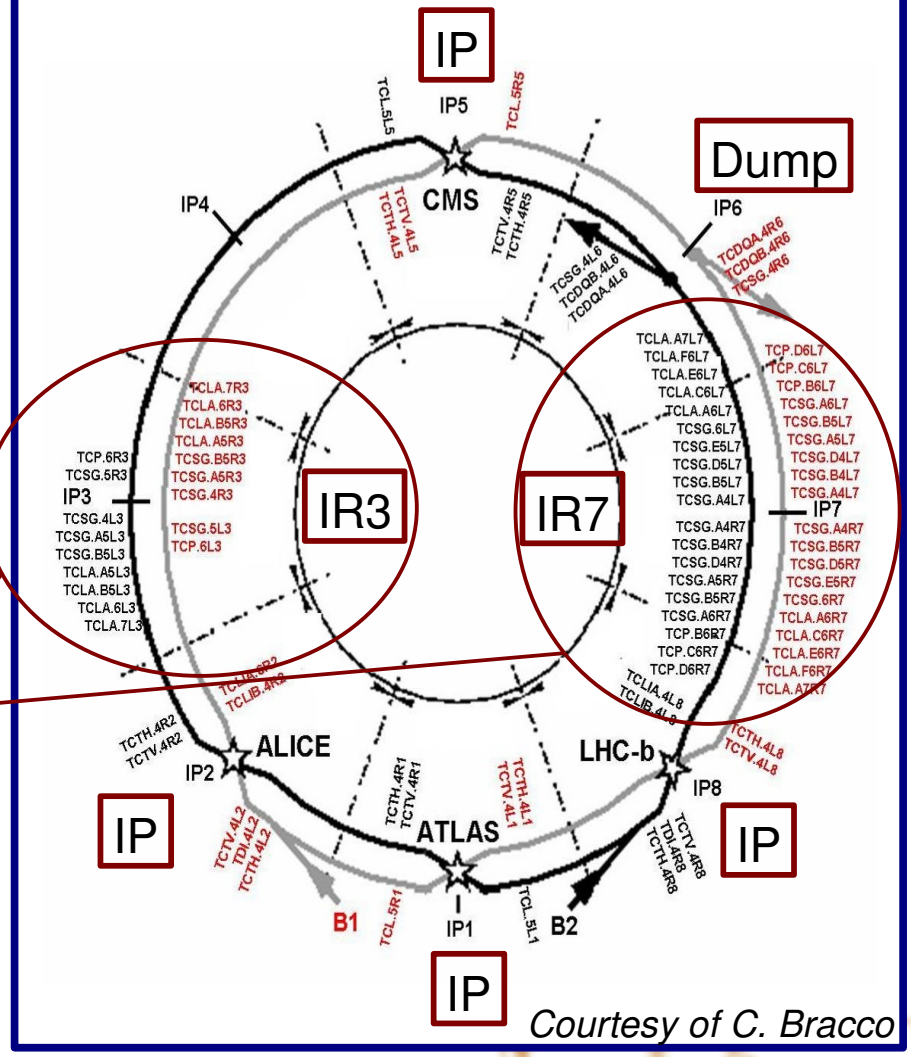
Name	Active Jaw	Material
TCP	60cm	C
TCSG	100m	C
TCLA(TCT)	100m	W in Cu

Exemplary Setup



IR3 & 7

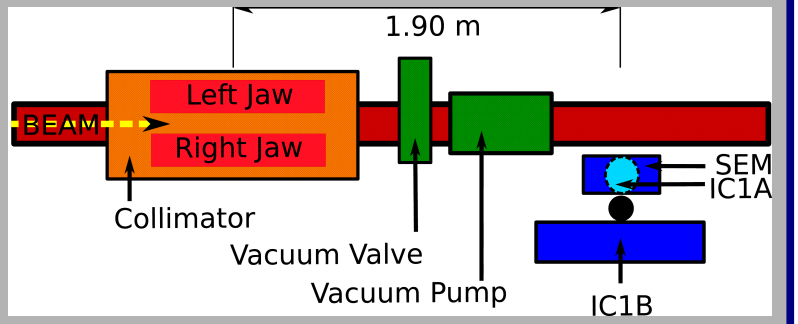
Locations

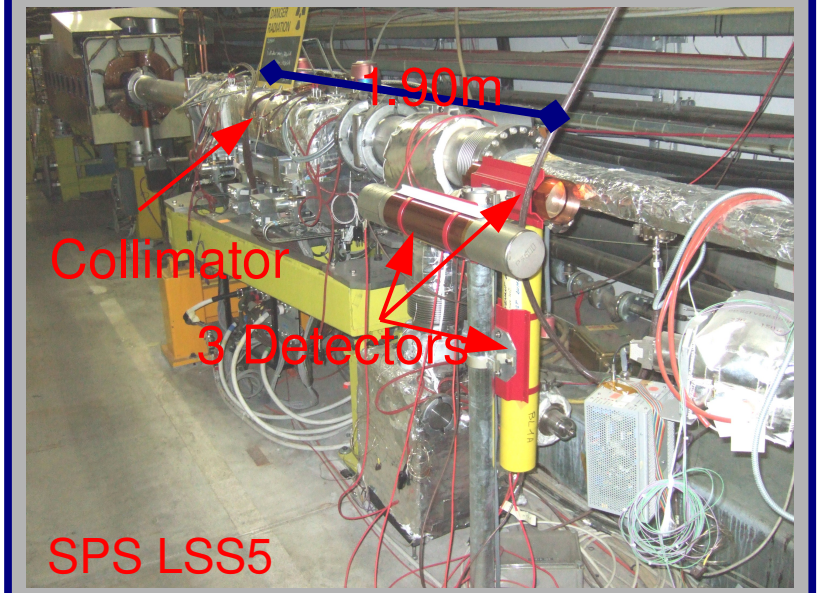


Courtesy of C. Bracco

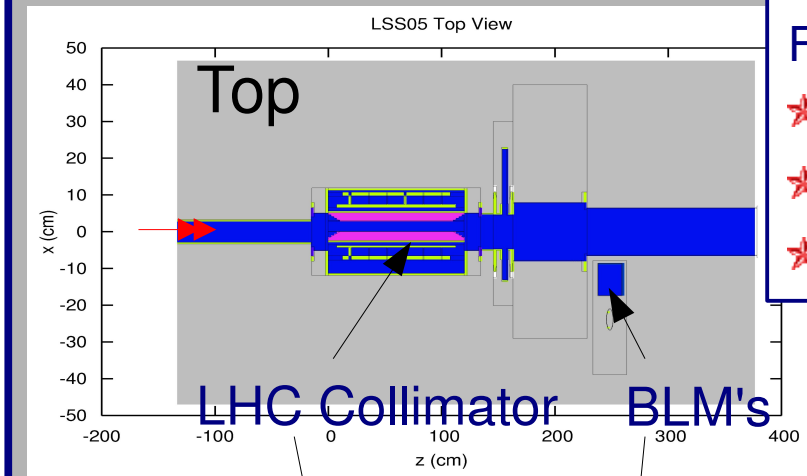
Losses at the LHC collimator in the SPS

Setup Experiment



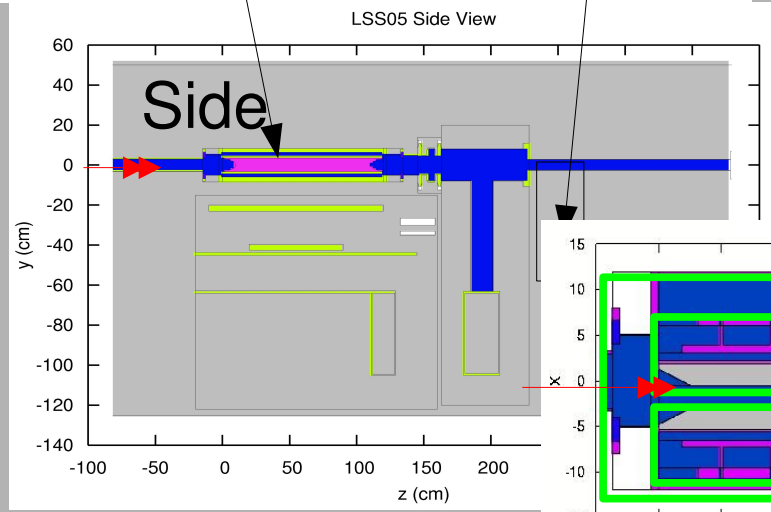


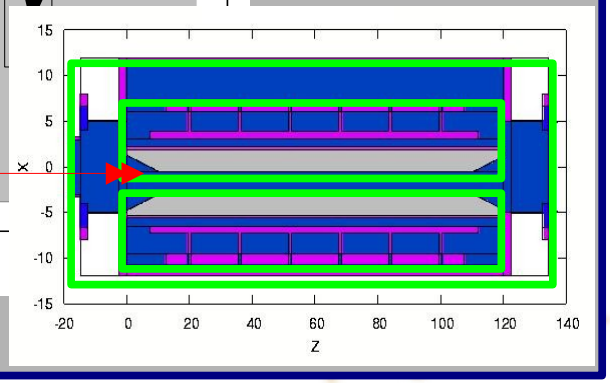
FLUKA Geometry



Focus on:

- Collimator
- BLM detectors
- Beam tube





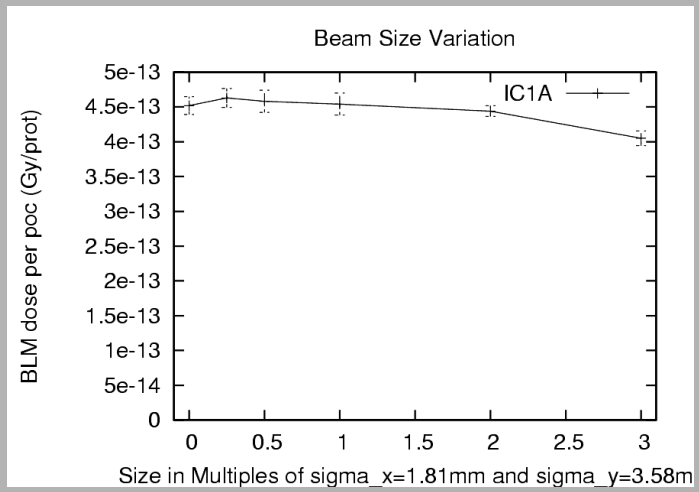
Losses at the LHC collimator in the SPS

Sensitivity studies for BLM signals

- Misalignment
- Geom. simplification
- Production and transport thresholds
- Impact scenarios

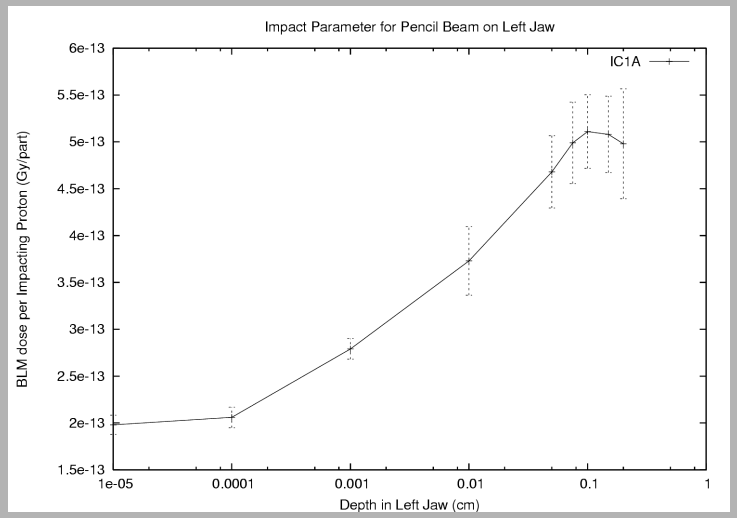
=>Max. change 15%

BLM dose per proton [Gy/part]



Multiples of measured beam size

BLM dose per proton [Gy/part]



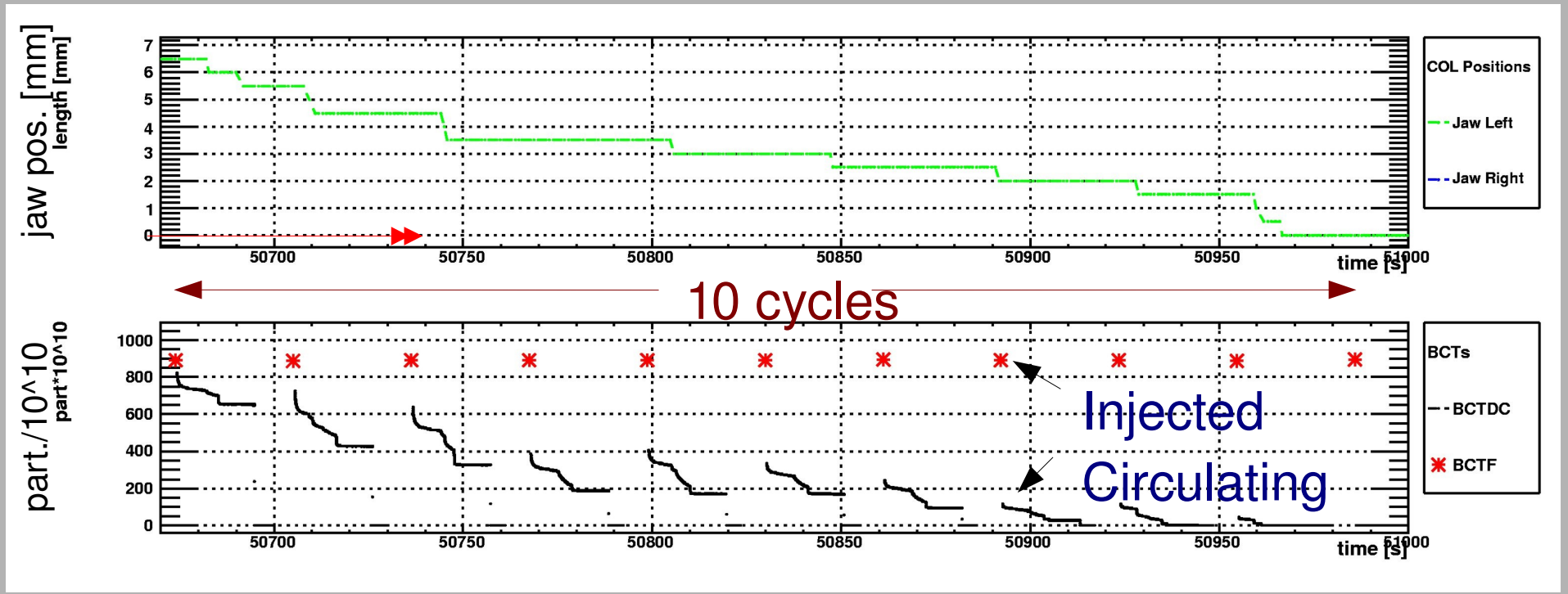
Depth of pencil beam in left jaw [cm]

Measurements in the SPS

Data Acquisition

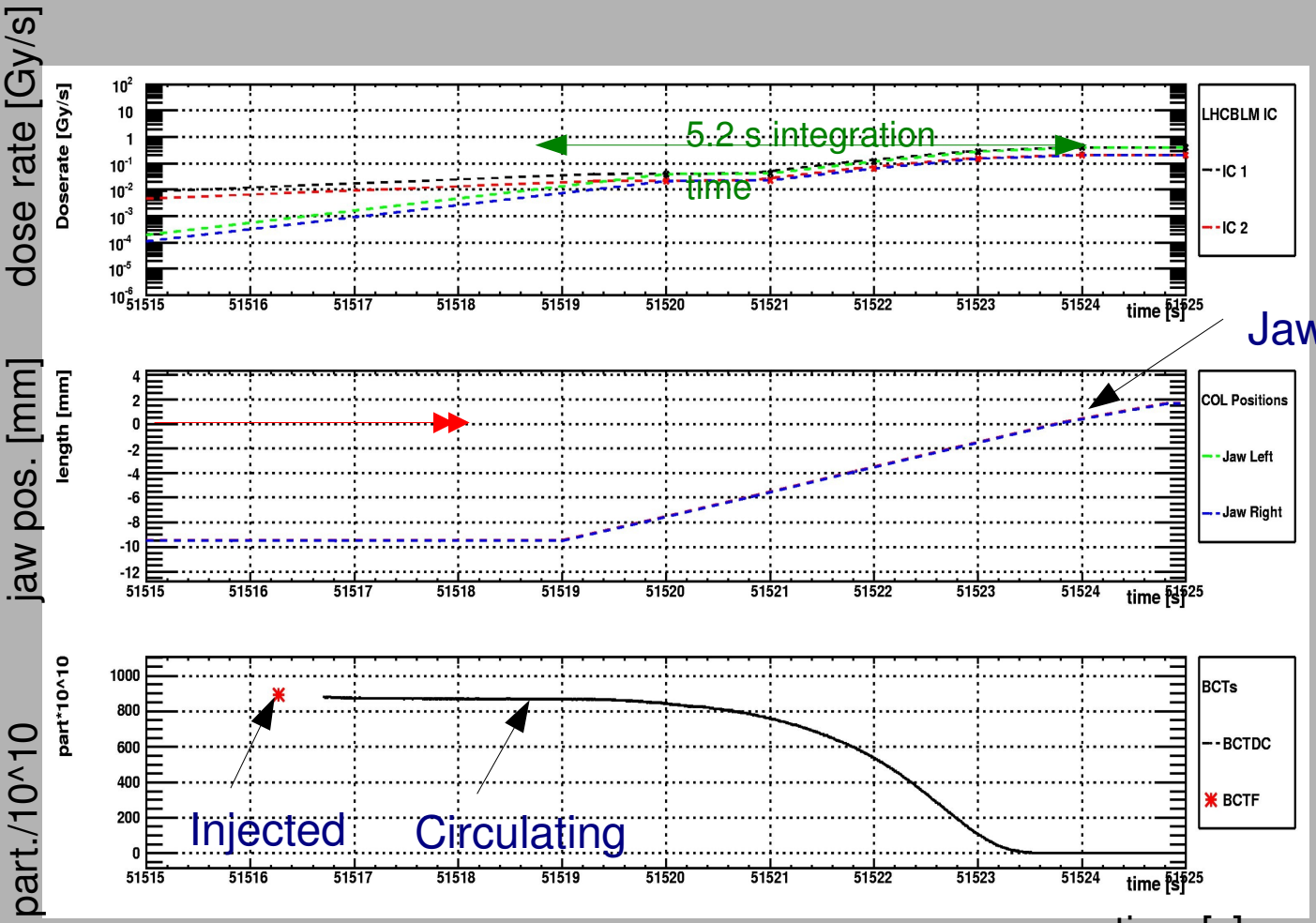
- 3 sessions: circulating mode @ 26 GeV (cycle = 20 sec)
- Injected intensities: 10-90x10^{10}, 900x10^{10}, 1300x10^{10} protons
- Acquisition: beam intensity (beam current transf.), BLM detector signals, collimator jaw positions, wire scanner (transversal beam intensity distribution)

First Method: "Direct Dumping"



Measurements in the SPS

Second Method: “Continuous Scraping”



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: Sim1: -30% Sim2: -40%

Session	No. 1		No. 2		No. 3	
Jaw Pos. [mm]	Left 0.0	Left 5.5	Left 0.0	Left 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"

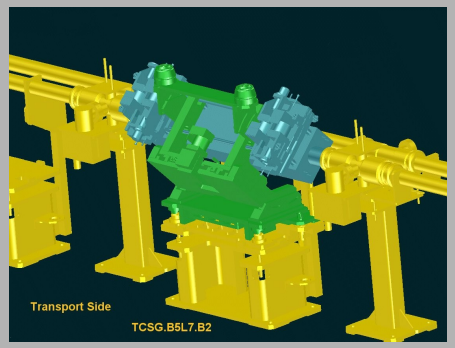
- Intensities are integrated over ~3sec
- Bigger uncertainties of BLM signals due to:
  - Returning protons
  - Impact distribution/beam-jaw angle
- Similar to LHC nominal scenario

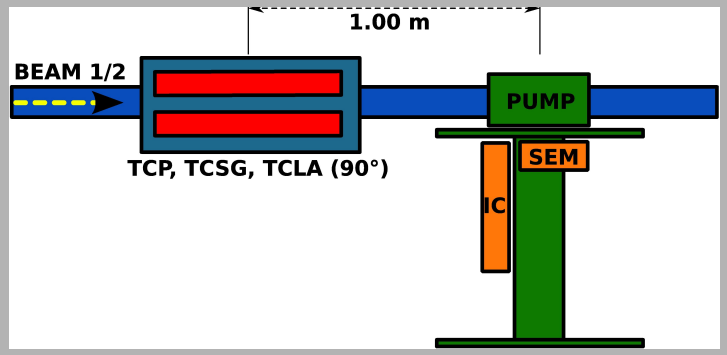
Max. deviation (Meas./Sim.):
IC: +/-21%
SEM: Sim1: +73% Sim2: +/-40%

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

Approach: Implementation of single “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

Previous SPS simulation:

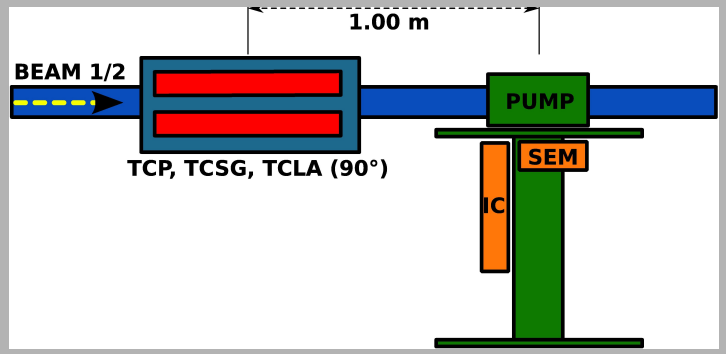
- Particle fluxes through BLM detectors are comparable

Implementation by FLUKA team:

- BLM signals agree within 5%

LHC Setup: Cell Geometry

Geometry



Signal of the BLM's influenced by:

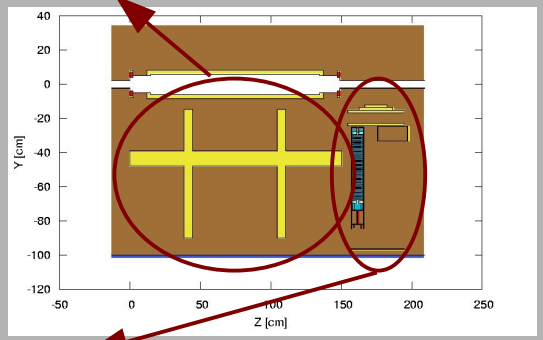
- Simplification of the Geometry

All collimator-detector cells are similar, but:

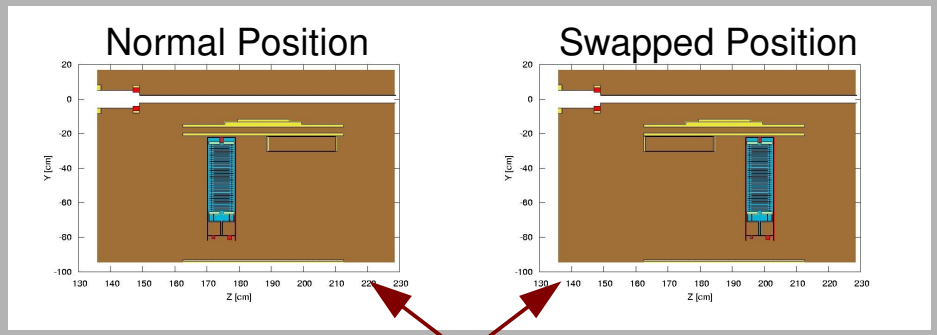
- Misalignment of BLM's
- BLM detector position may vary
- Rotational position of the collimator varies

Influence on BLM Signal

- Simplified support (max. change 16%)



- Displacing BLM support (max. change 22%)

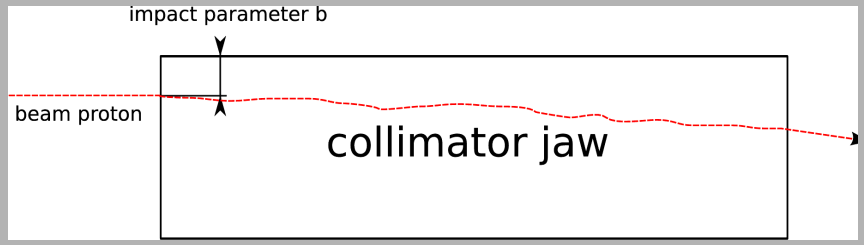


- Change between two positions (max. change 137%)
- Rotational position (max. change 36%)

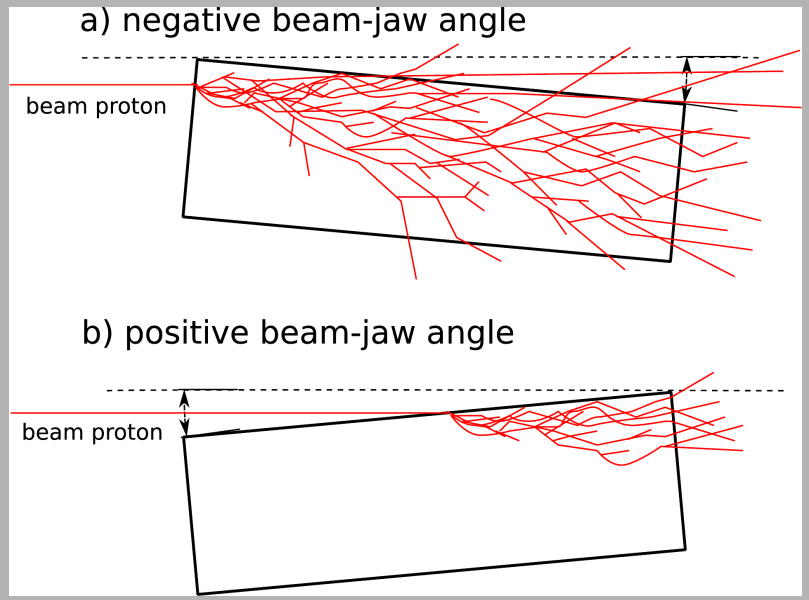
LHC Setup: Collimator Jaws

Situation

- Beam protons on jaw with small impact parameters (µm to mm)

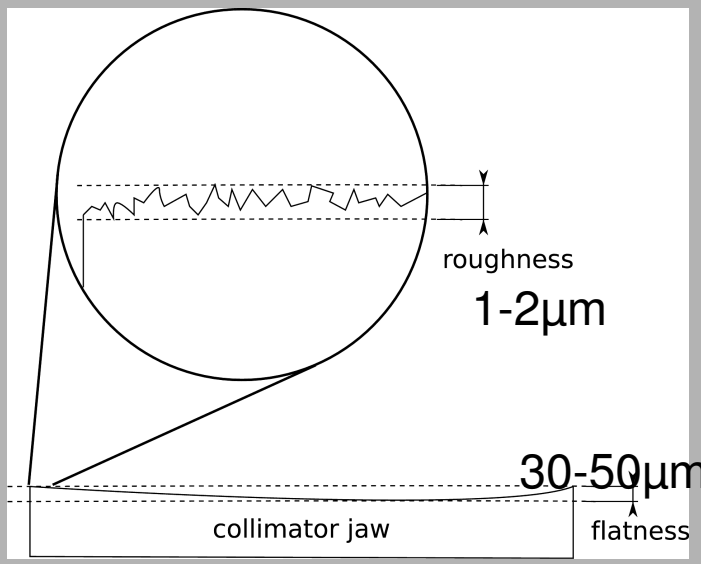


- Beam-jaw angle may vary for operational scenario (~10µm)



Additionally

- Surface structure of collimator



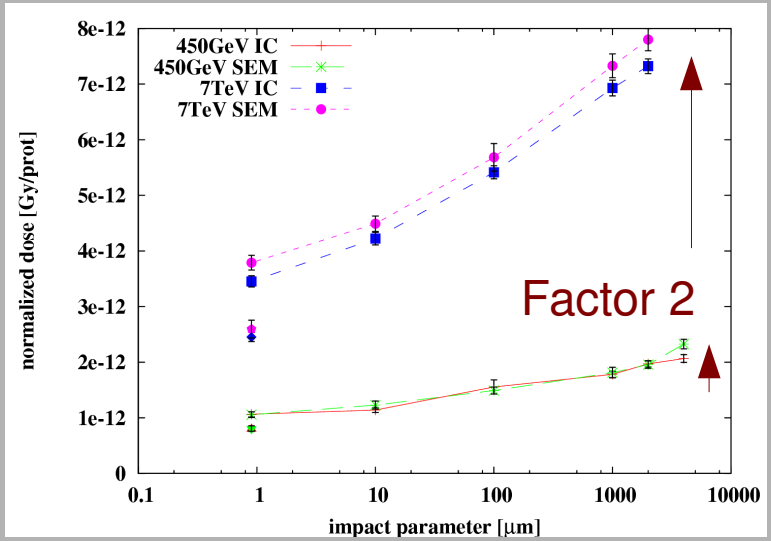
- Roughness: reduced density of surface layer
- Flatness: similar effect (reduced effective length) as beam-jaw angle
- FLUKA MCS formalism: step size too big for impact par. ~ 1µm? => change 3-9%

LHC Setup: Scans

Impact Parameter Scan

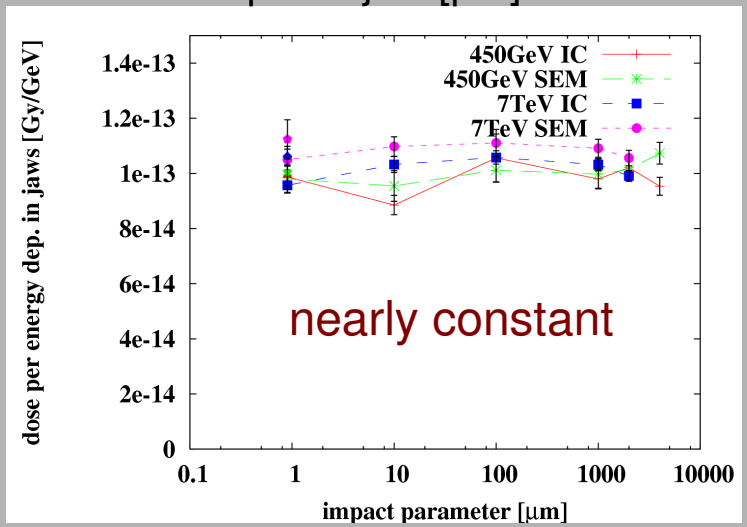
with pencil beam

BLM dose per proton [Gy/part]



depth in jaw [µm]

BLM dose per tot. ED in jaws [Gy/GeV]

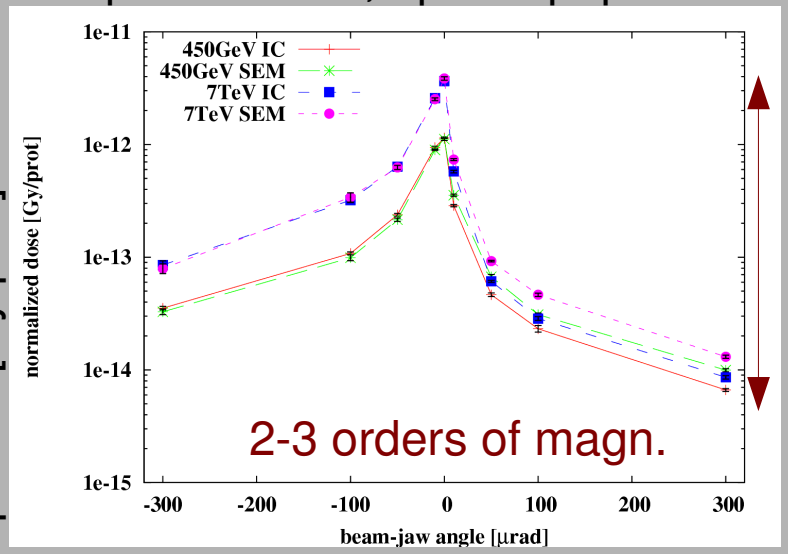


depth in jaw [µm]

Beam-Jaw Angle Scan

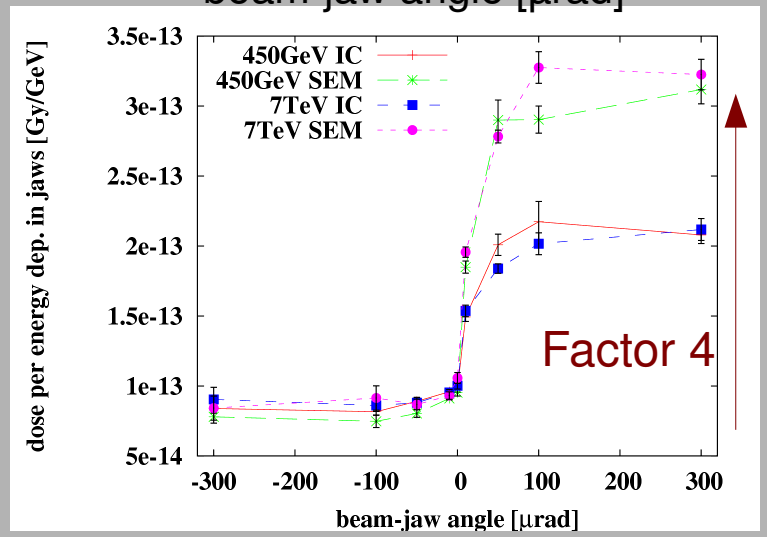
with pencil beam, 2µm imp. par.!

BLM dose per proton [Gy/part]



beam-jaw angle [µrad]

BLM dose per tot. ED in jaws [Gy/GeV]

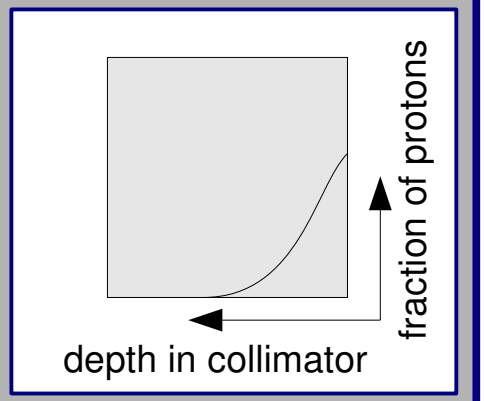


beam-jaw angle [µrad]

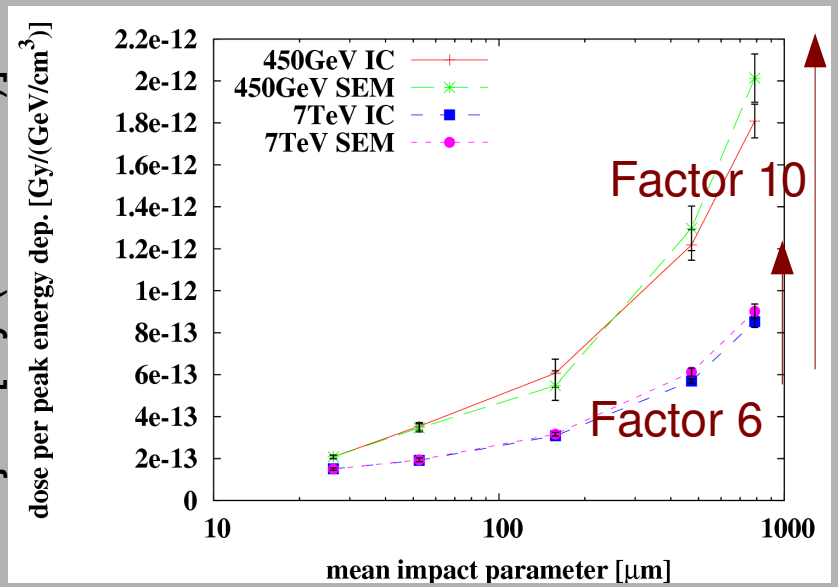
LHC Setup: Peak ED & Cross-talks

Peak Energy deposition

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



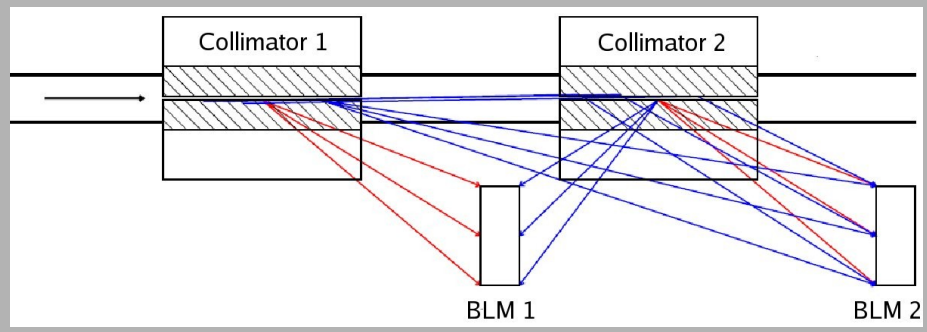
Typical mean impact par.: 25-800µm



mean impact parameter [µm]

Higher Order Particle Halos

Mixed particle spectra hitting downstream collimators



Simulations: 3 "TCP 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 (with IR3+7 implementation by FLUKA Team)

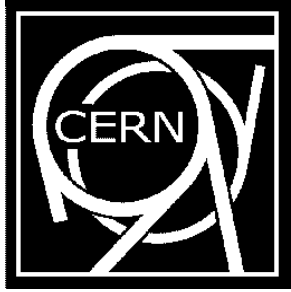
Summary & Conclusions

Part 1: Comparison Meas.-Sim.: Experimental Setup in the SPS

- Max. deviation Meas./Sim. for IC detectors: ±21%
- Max. deviation Meas./Sim. for SEM detectors: ±40% (Sim2), +73%/-30% (Sim1)
- Determined discrepancy between meas.-sim. interpreted as systematic uncertainty for assessment of BLM detector thresholds by simulations.

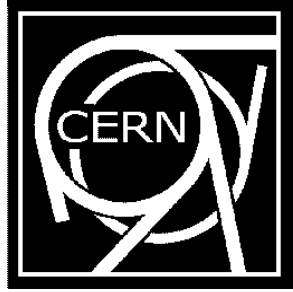
- Proposed additional error: IC: 21% SEM: 40%

Summary & Conclusions



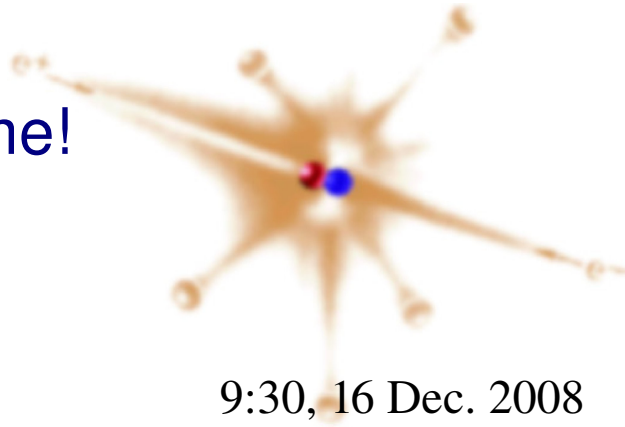
Part 2: Simulation Studies for the LHC Collimation Scenario

- Investigating ratios of BLM signal to (total and peak) energy deposition (ED) in collimator jaws
- Signal-to-total ED ratio (steady-state losses):
  - about constant for different impact parameters (TCP, TCSG),
  - only increasing for different beam-jaw angles,
  - but: decreasing for mixed particle spectra from upstream=> systematic calculation needed!
  - preliminary suggestion: security margin of factor 10 from lowest calculated ratios
- Signal-to-peak ED ratio (transient losses):
  - for typical failure cases ratio decreases by a factor of 10 for smaller mean impact par.
  - set to lowest ratios (no mixed particle spectra considered!)



Thanks for attentive ...

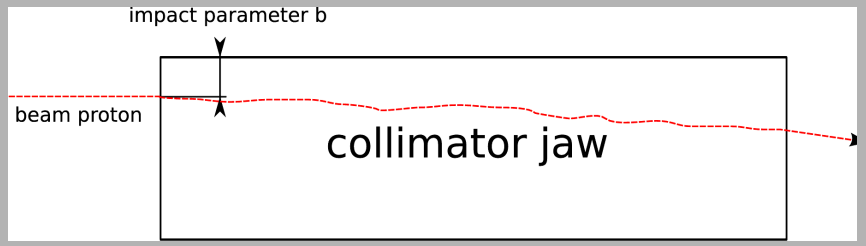
Comments and questions welcome!



Measurements in the SPS(Add.)

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