Early TOTEM Running with the β^*=90m Optics

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on behalf of the

TOTEM Collaboration

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University Park, USA

Brunel University
Uxbridge, UK

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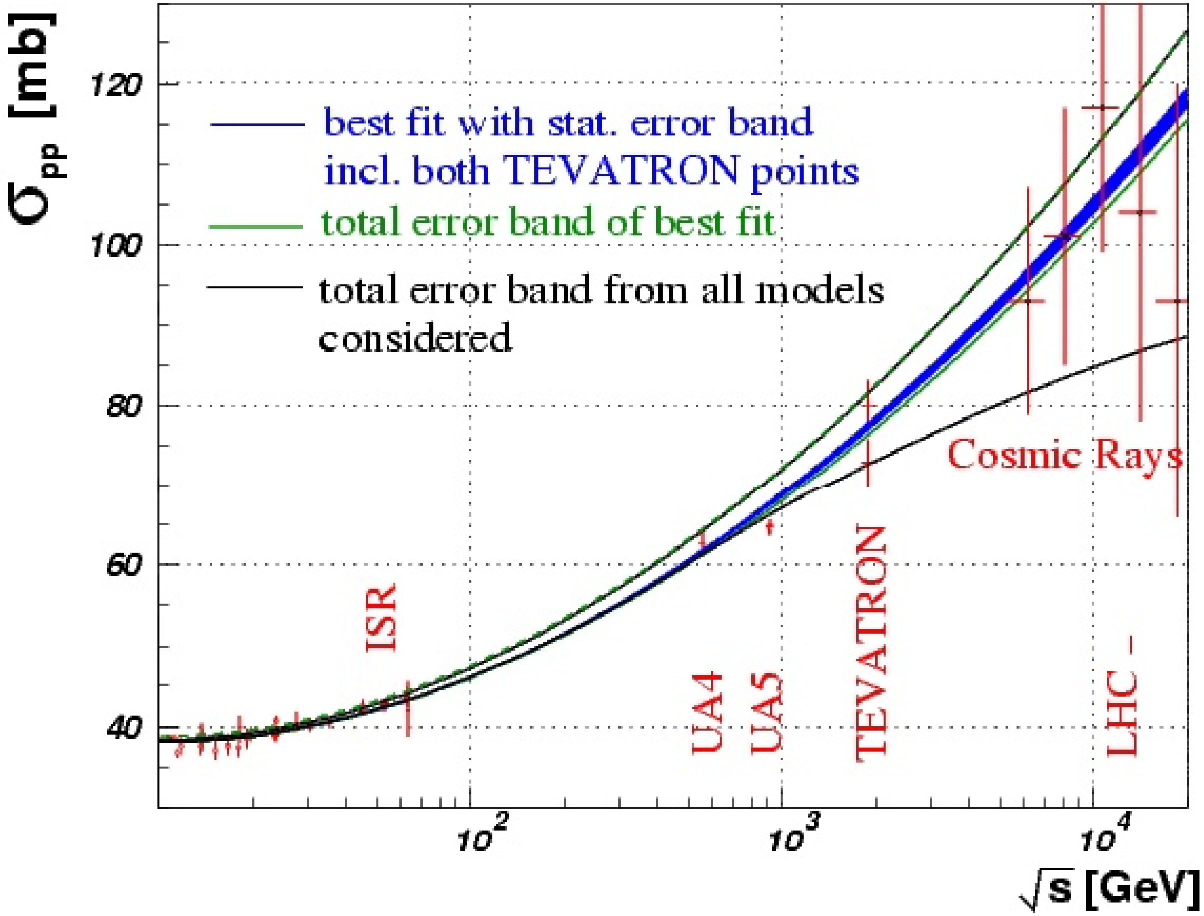
Total p-p Cross-Section



Current models predictions:
90-130 mb

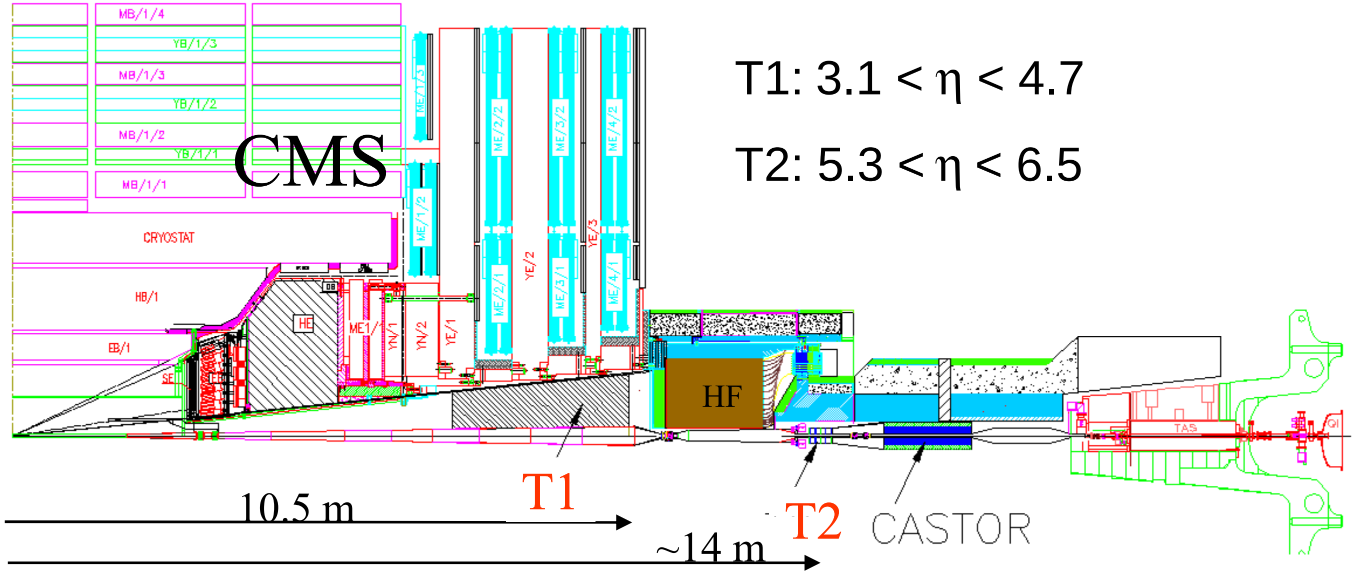
Aim of TOTEM:
~1% accuracy

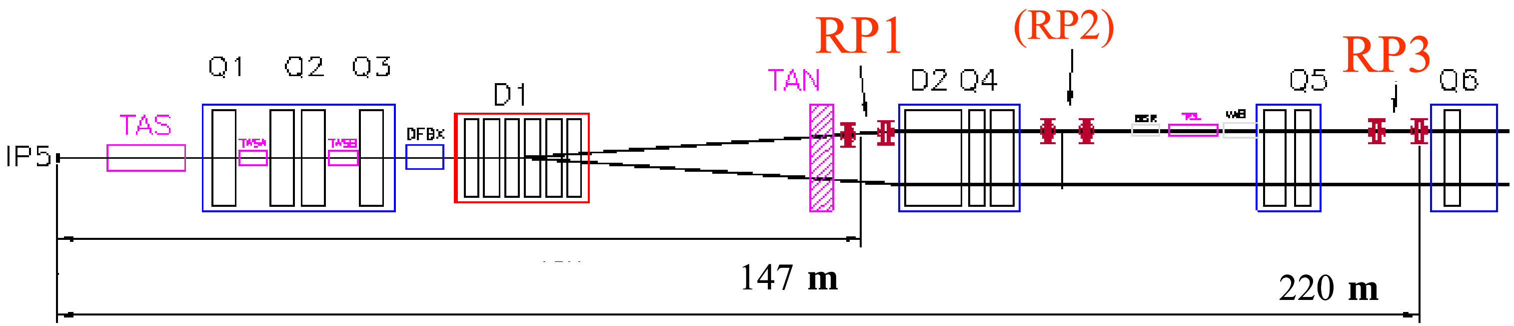
COMPETE Collaboration fits all available hadronic data and predicts:

LHC: $\sigma_{tot} = 111.5 \pm 1.2 \; {}^{+4.1}_{-2.1}$ mb

[PRL 89 201801 (2002)]

TOTEM Detector Configuration





$$\mathcal{L}\,\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2}\left.\frac{dN_{el}}{dt}\right|_{t=0}$$

$$\mathcal{L}\,\sigma_{tot} = N_{el} + N_{inel}$$

$$\Longrightarrow$$

$$\sigma_{tot} = \frac{16\pi}{1+\rho^2}\,\frac{dN_{el}/dt|_{t=0}}{N_{el}+N_{inel}}$$

$$\mathcal{L} = \frac{1+\rho^2}{16\pi}\,\frac{(N_{el}+N_{inel})^2}{dN_{el}/dt|_{t=0}}$$

Comparison of High β^* Optics

Parameters	$\beta^* = 1540$ m (baseline optics)	$\beta^* = 90$ m (early optics)
Crossing angle	0.0	0.0
N of bunches	43	156
N of part./bunch	$3 \cdot 10^{10}$	$4 \cdot 10^{10}$
Emittance ε_n [µm · rad]	1	3.75
RMS beam size at IP [µm]	450	200
RMS beam divergence [µrad]	0.29	2.3
10 σ beam width at RP220 [mm]	0.8	6.25
Peak luminosity [$cm^{-2}\ s^{-1}$]	$1.6 \cdot 10^{28}$	$5 \cdot 10^{29}$
Injection	special	standard
MD commissioning	more difficult	less difficult

$\beta^* = 90$ m

- fits into the 2008 run scenario;
- small integrated luminosity loss in 2008
- ideal for training the RP operation due to wide beams;
- helps beam diagnostics
  - luminosity
  - beam position
  - vertex distribution

Parameter Evolution and Rates

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

$$Eventrate / Cross = \frac{L \sigma_{TOT}}{k_b f}$$

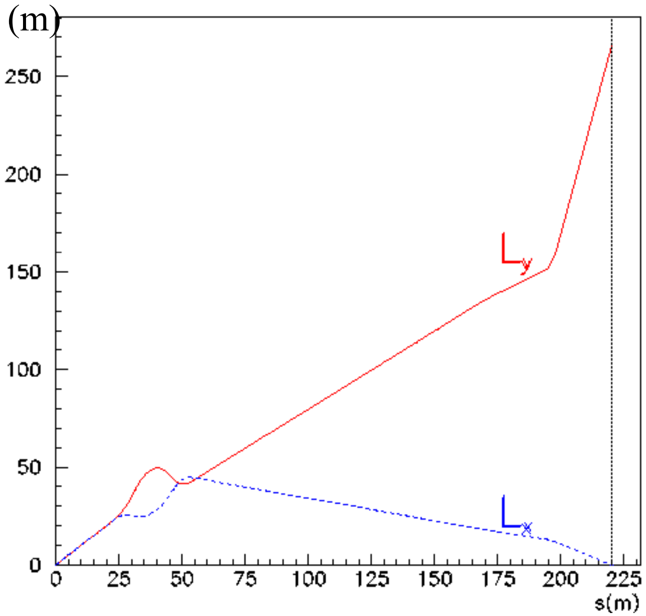
All values for nominal emittance, 7TeV and 10m β* in points 2 and 8

Parameters			Beam levels		Rates in 1 and 5		Rates in 2 (and 8)	
k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
43	$4\ 10^{10}$	11	$1.7\ 10^{12}$	2	$1.1\ 10^{30}$	<< 1	$1.2\ 10^{30}$	0.15
43	$4\ 10^{10}$	2	$1.7\ 10^{12}$	2	$6.1\ 10^{30}$	0.76	$1.2\ 10^{30}$	0.15
156	$4\ 10^{10}$	2	$6.2\ 10^{12}$	7	$2.2\ 10^{31}$	0.76	$4.4\ 10^{30}$	0.15
156	$9\ 10^{10}$	2	$1.4\ 10^{13}$	16	$1.1\ 10^{32}$	3.9	$2.2\ 10^{31}$	0.77
936	$4\ 10^{10}$	11	$3.7\ 10^{13}$	42	$2.4\ 10^{31}$	<< 1	$2.6\ 10^{31}$	0.15
936	$4\ 10^{10}$	2	$3.7\ 10^{13}$	42	$1.3\ 10^{32}$	0.73	$2.6\ 10^{31}$	0.15
936	$6\ 10^{10}$	2	$5.6\ 10^{13}$	63	$2.9\ 10^{32}$	1.6	$6.0\ 10^{31}$	0.34
936	$9\ 10^{10}$	1	$8.4\ 10^{13}$	94	$1.2\ 10^{33}$	7	$1.3\ 10^{32}$	0.76
2808	$4\ 10^{10}$	11	$1.1\ 10^{14}$	126	$7.2\ 10^{31}$	<< 1	$7.9\ 10^{31}$	0.15
2808	$4\ 10^{10}$	2	$1.1\ 10^{14}$	126	$3.8\ 10^{32}$	0.72	$7.9\ 10^{31}$	0.15
2808	$5\ 10^{10}$	1	$1.4\ 10^{14}$	157	$1.1\ 10^{33}$	2.1	$1.2\ 10^{32}$	0.24
2808	$5\ 10^{10}$	0.55	$1.4\ 10^{14}$	157	$1.9\ 10^{33}$	3.6	$1.2\ 10^{32}$	0.24

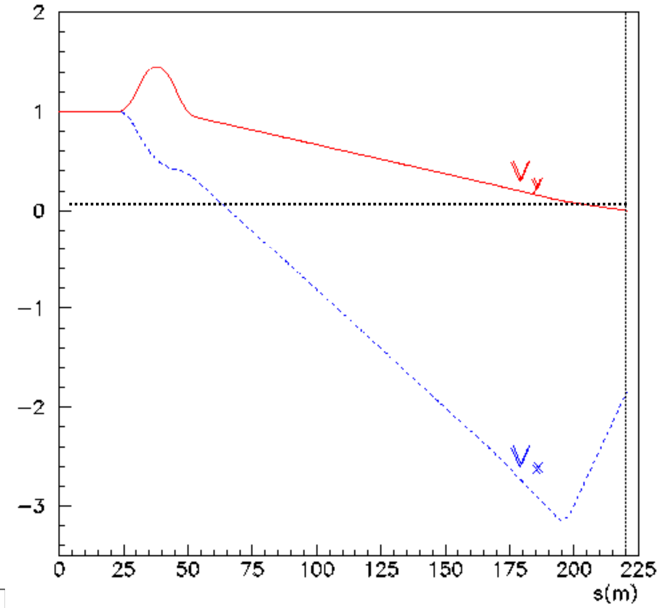
R. Bailey

Optical Functions

$L = (\beta\beta^*)^{1/2} \sin \mu(s)$



$v = (\beta/\beta^*)^{1/2} \cos \mu(s)$



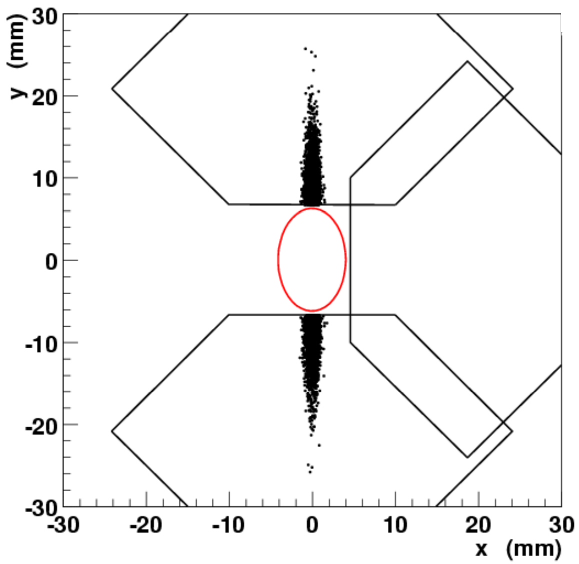
Idea:

L_y large $\quad L_x = 0$

$v_y = 0$

$\mu_y(220) = \pi/2 \quad \mu_x(220) = \pi$

hit distribution (elastic)



$$y = L_y\theta_y^* + \cancel{v_y y^*}$$

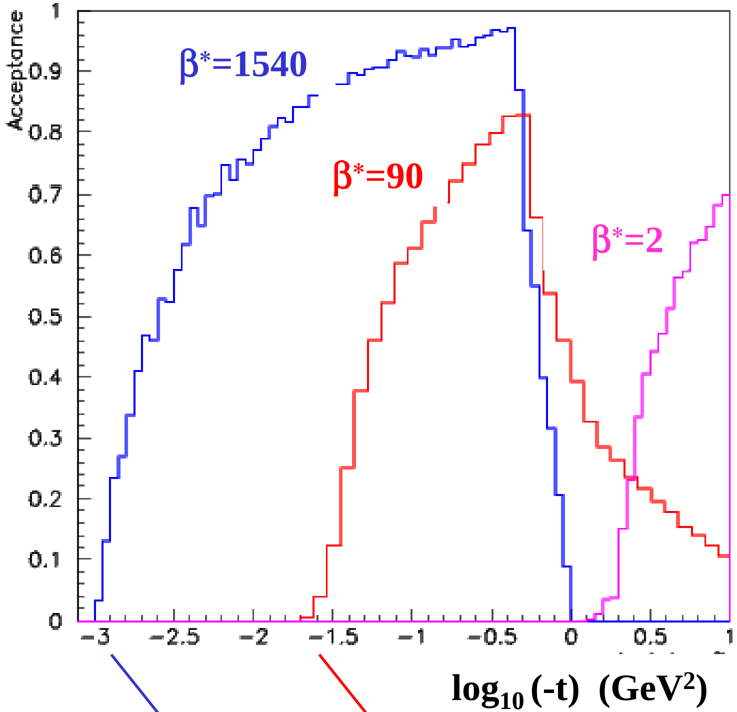
$$x = \cancel{L_x\theta_x^*} + v_x x^* + D\xi$$

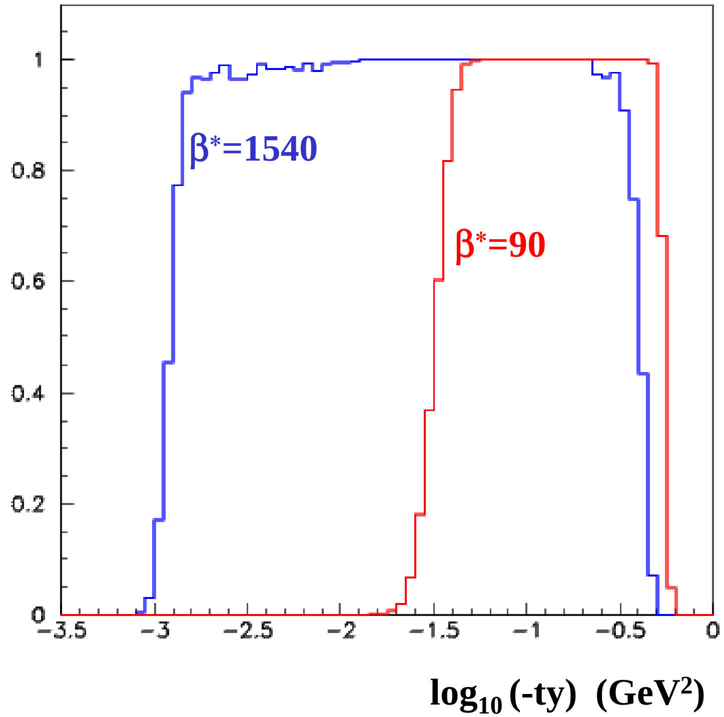
(x^*, y^*): vertex position

(θ_x^*, θ_y^*): emission angle

t-Acceptance at RP220 for Elastic Scattering

$t = t_x + t_y$ $\quad t \sim -(p\,\theta)^2$ $\quad t_y$



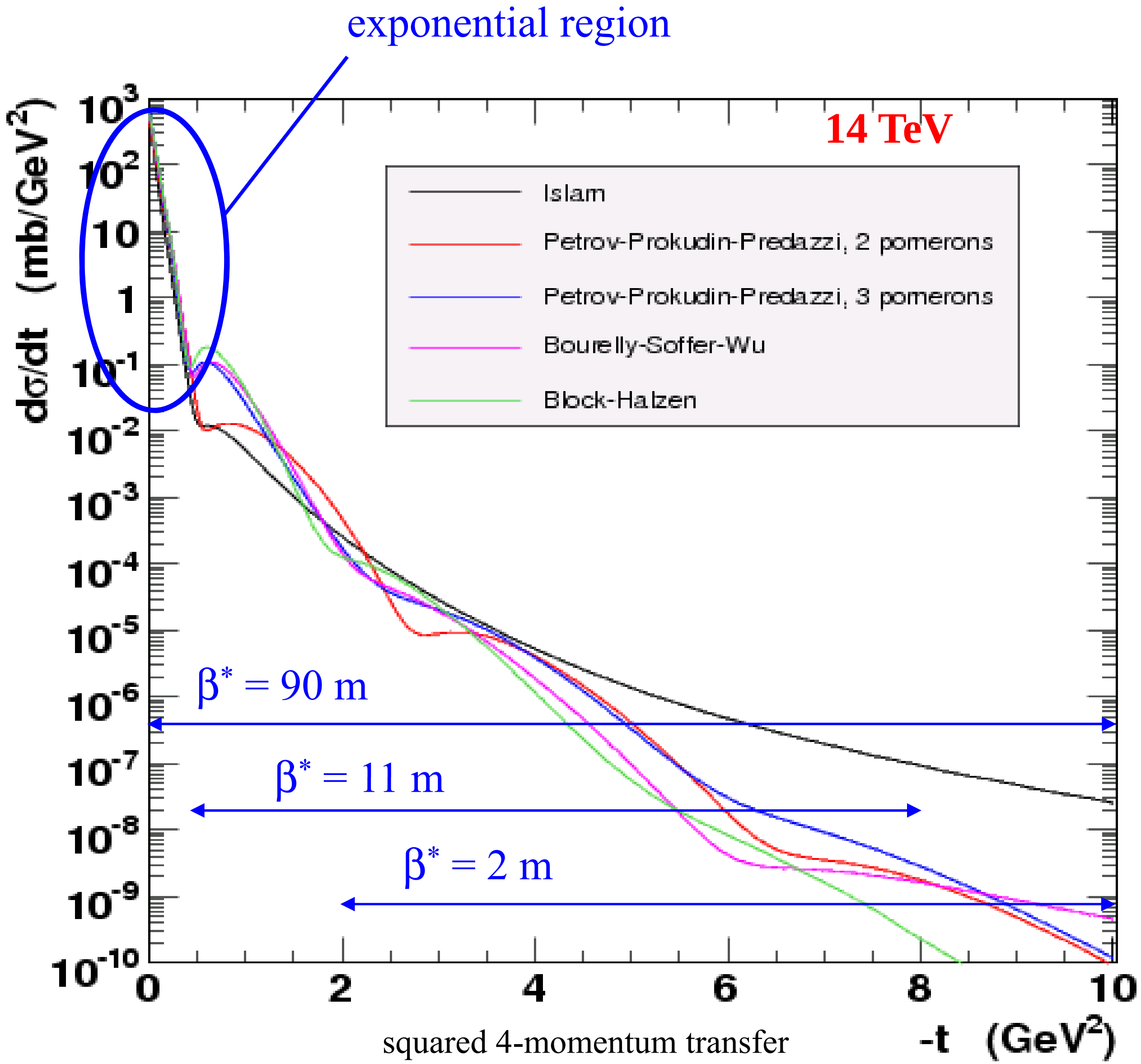


$10\sigma_{beam}$ = 0.8 mm 6.25 mm

+ 0.5 mm detector displacement

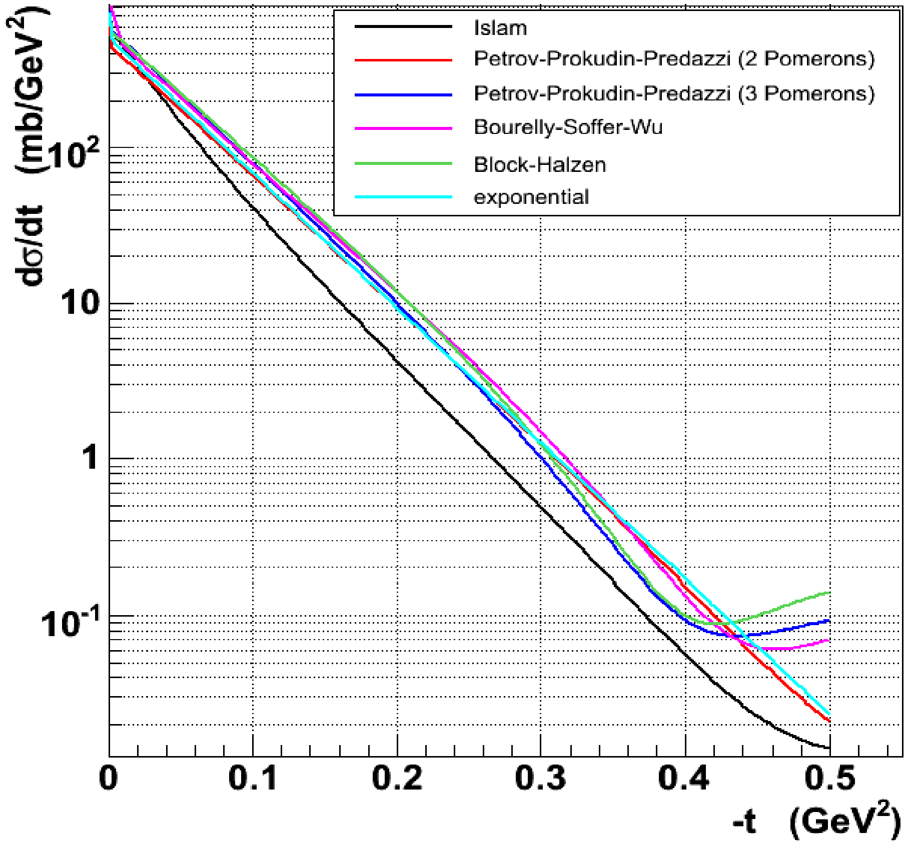
$\sigma(t_y) / t_y \sim 0.02 \text{ GeV} / t_y^{1/2}$

Elastic Scattering

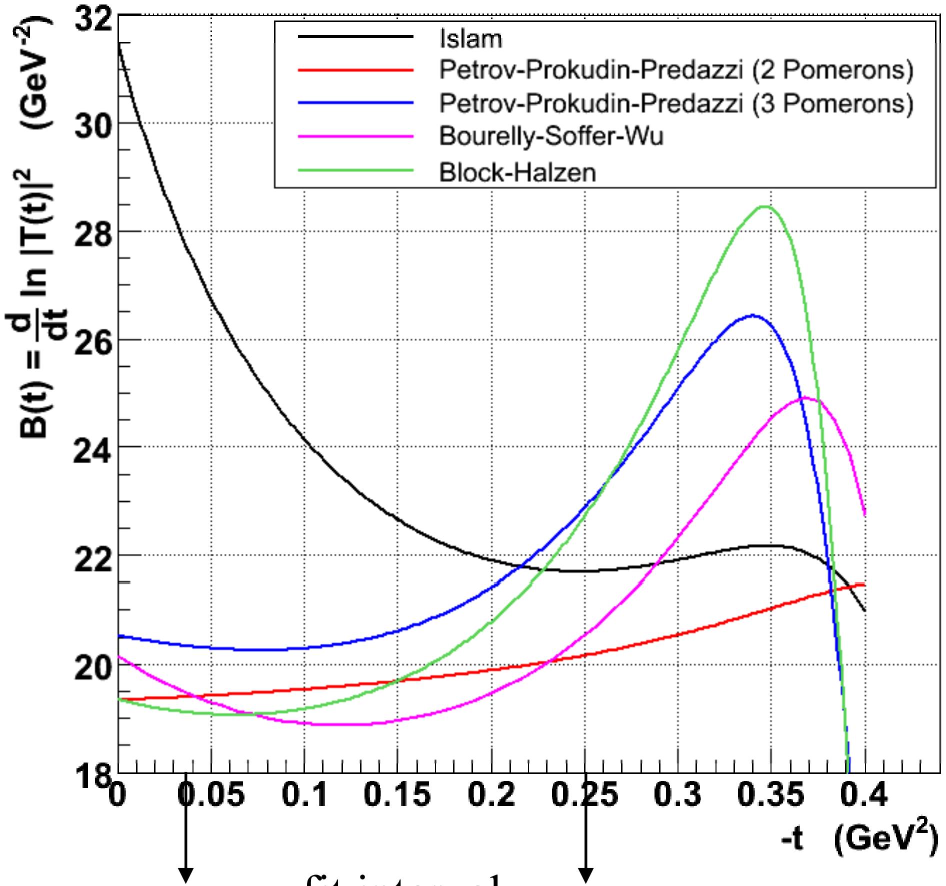


Elastic Scattering at low |t|

$d\sigma/dt = \exp[-B(t)\cdot t]$



Exponential Slope B(t)



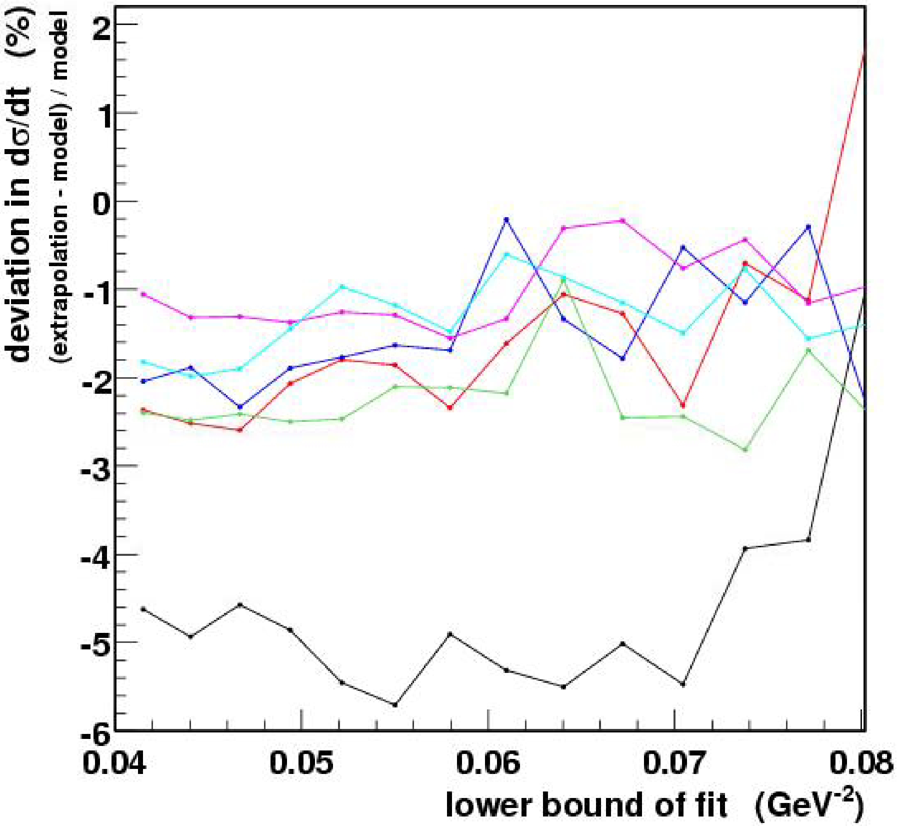
$\beta^* = 1540$ m: $|t|_{min} = 0.002$ GeV^2

$\beta^* = 90$ m: $|t|_{min} = 0.04$ GeV^2

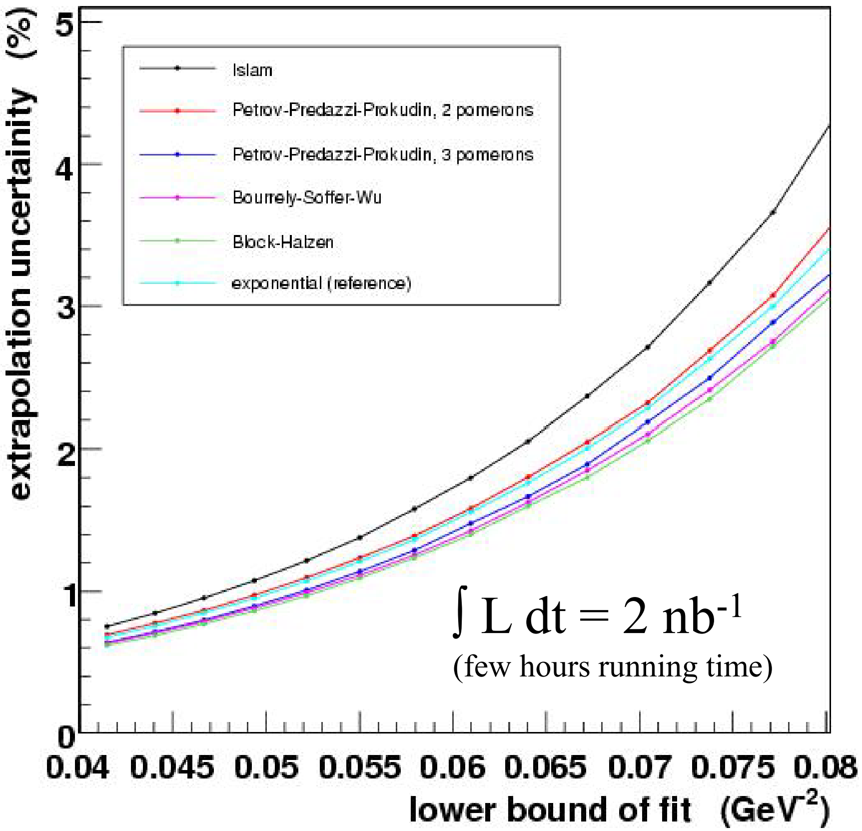
$$B(t) = B_0 + B_1 \cdot t + B_2 \cdot t^2$$

Extrapolation to the Optical Point (t = 0)

(extrapol. - model) / model in $d\sigma/dt\,|_{t=0}$



Extrapolation uncertainty



Common bias due to beam divergence : -2%

Spread of most of the models: ±1%

Systematic error due to uncertainty of optical functions: ± 3%

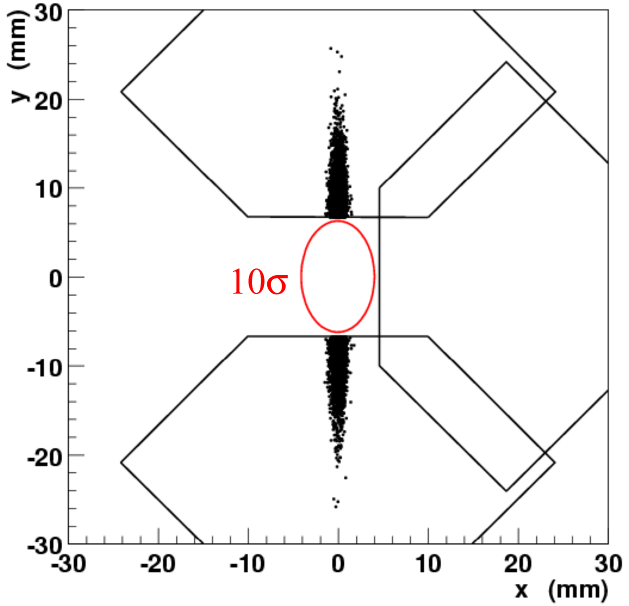
Combined Uncertainty in σ_{tot}

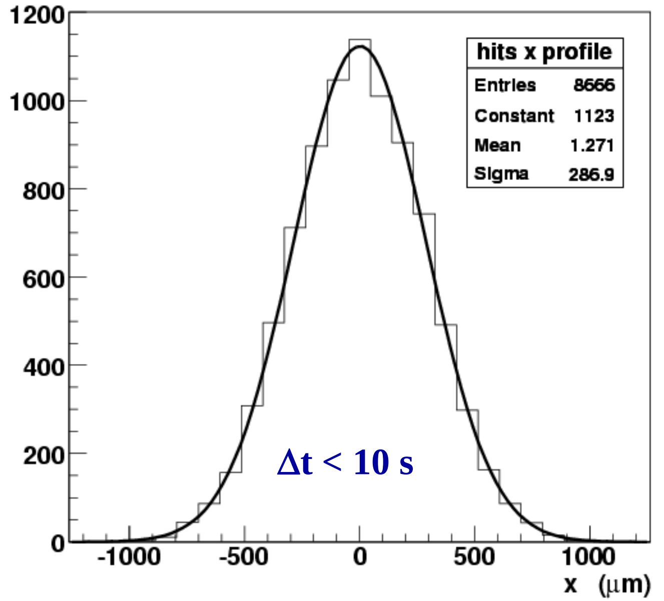
- Extrapolation of elastic cross-section to t = 0: ± 4 %
- Total elastic rate (correlated with extrapolation): ± 2 %
- Total inelastic rate: ± 1 %
  (error dominated by Single Diffractive trigger losses)

==> Total uncertainty including correlations in the error propagation: ± 4 %

Measurement of Beam Parameters

- Luminosity measurement (together with σ_{tot}): ±6%
- Beam profile measurement in x-projection at RP220 (elastic scattering)





==> beam position measurement at RP220 with precision ~ 1μm every minute
to be compared with the machine's BPMs.

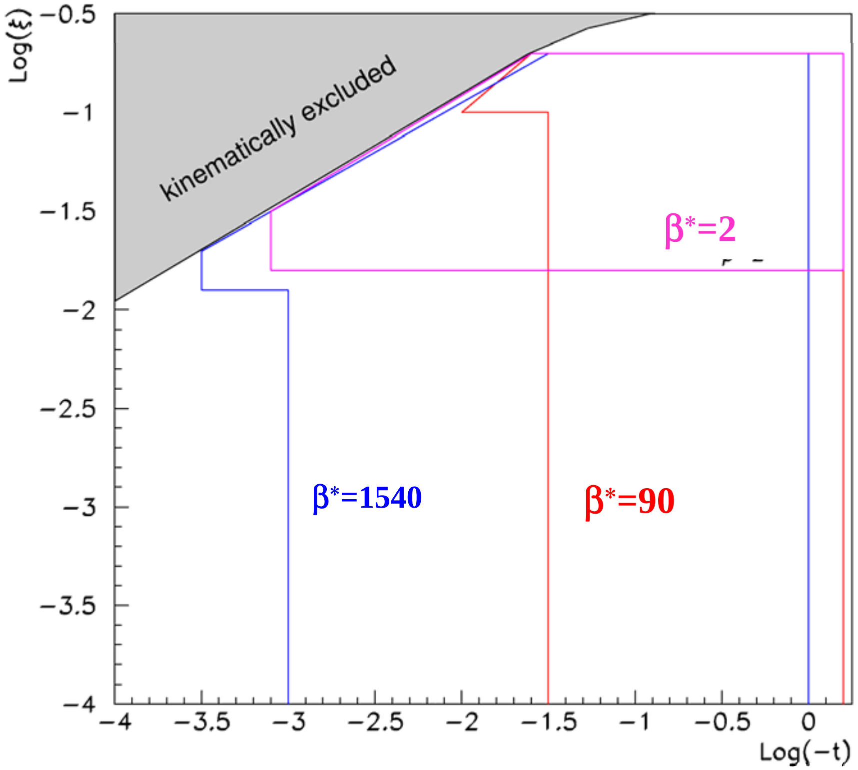
==> horizontal vertex position determination: $x = v_x x^* \quad (v_x \approx -2)$

==> vertex distribution (shape and width)

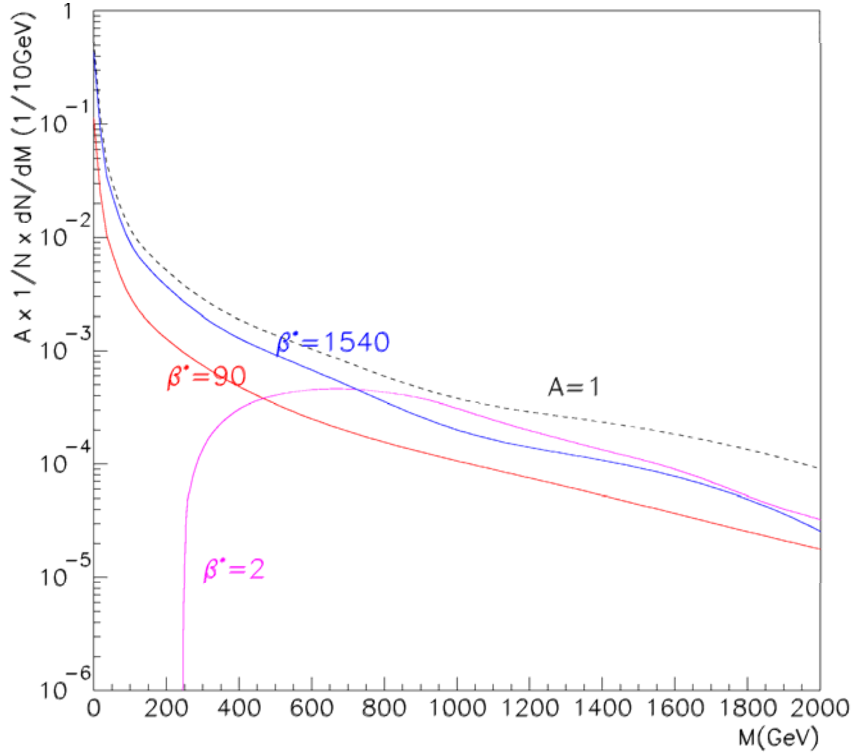
==> assuming round beams: luminosity from beam parameters

Diffractive events

(ξ , t)-acceptance   (ξ = Δp/p)



Mass Distribution for Double Pomeron events



$\beta^* = 90$ m

65% of all diffractive proton are detected, independent of their momentum loss ξ

==> wide range of diffractive studies (Single Diffraction and Double Pomeron Exchange) combined with Rapidity Gap studies in T1/T2

Summary

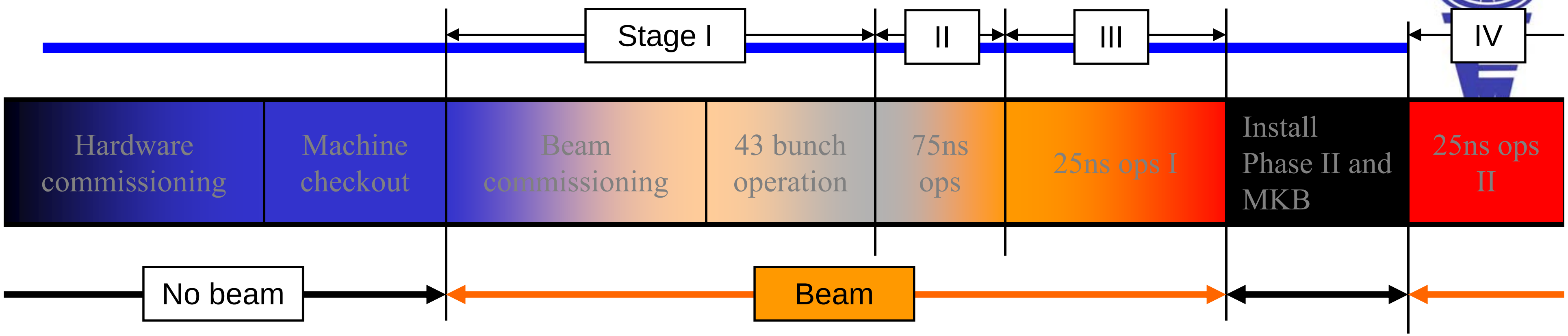
The proposed optics will allow the measurement of:

- Total cross section within ± 4%
- Luminosity within ± 6%
- Horizontal beam position and profile at RP220 within few μm every minute
- Horizontal vertex distribution at IP5
  ==> luminosity determination based on machine parameters
- Diffraction due to the ξ–independent proton acceptance (~ 65%)

The proposed optics can be commissioned at an early LHC stage
(see talk by Helmut Burkhardt)

After gaining experience with this optics, more precise measurements with the baseline optics (1540 m)

Overall commissioning strategy for protons (est^{d}. 2005)



I. Pilot physics run
- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance
- Performance limit 10^{32} cm^{-2} s^{-1} (event pileup)

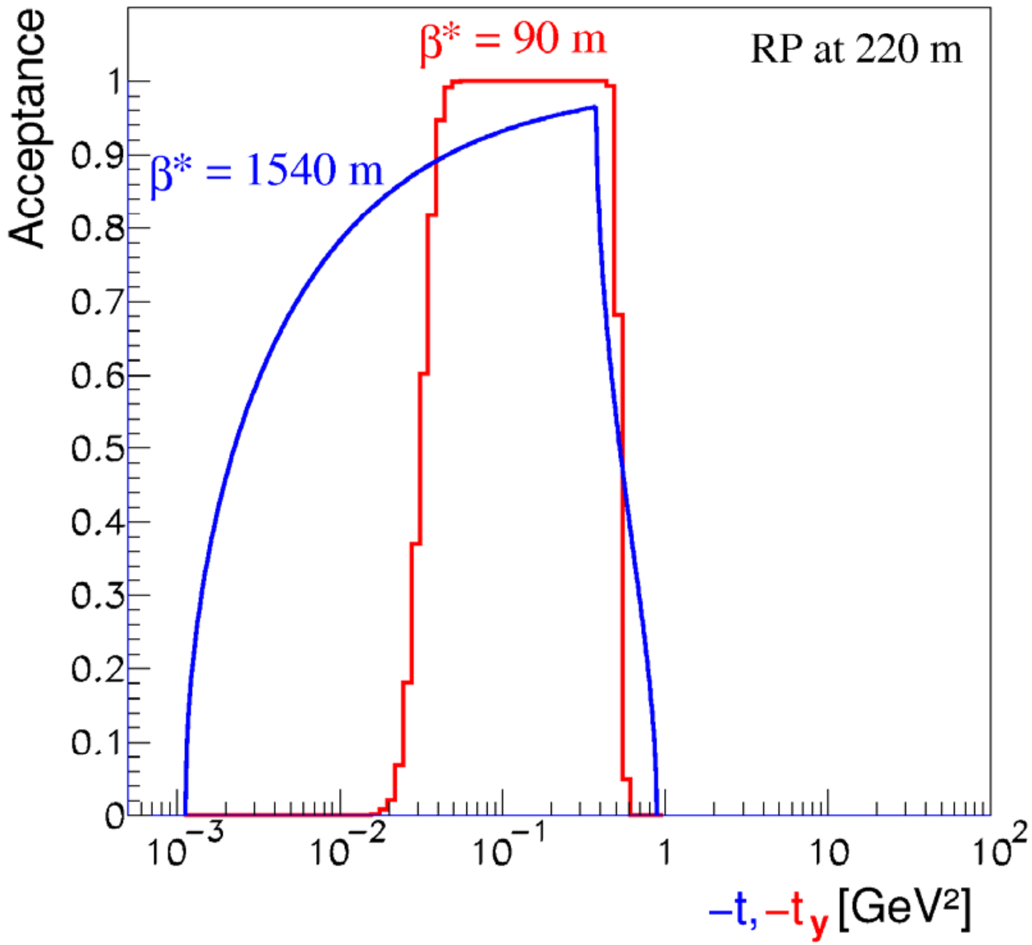
II. 75ns operation
- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle
- Performance limit 10^{33} cm^{-2} s^{-1} (event pileup)

III. 25ns operation I
- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal
- Performance limit 2 10^{33} cm^{-2} s^{-1}

IV. 25ns operation II
- Push towards nominal performance

Minimise
– Complexity
– Beampower
– Losses (β^*)
– Pileup

Optimise
$-N$
$-k_b$
$-\beta^*$



Acceptance
β* = 90 m
RP at 220 m
β* = 1540 m
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
–t, –t_y [GeV²]

Measurement of the Total Rate $N_{el} + N_{inel}$

Trigger Losses

	σ [mb]	T1/T2 double arm trigger loss [mb]	T1/T2 single arm trigger loss [mb]	Systematic error after extrapolation [mb]	
Minimum bias	58	0.3	0.06	0.06	
Single diffractive	14	–	3	0.6	using p @ β* = 1540, 90 m
Double diffractive	7	2.8	0.3	0.1	
Double Pomeron	1	0.2		0.02	using p @ β* = 1540, 90 m
Elastic Scattering	30	–	–	0.2 (2)	@ β* = 1540 (90) m

Total: 0.8 mb ≈ 0.8 % @ β* = 1540 m
2 – 5 mb ≈ 2 – 5 % @ β* = 90 m

Extrapolation of diffractive cross-section to large $1/M^2$ using $d\sigma/dM^2 \sim 1/M^2$.

Loss at low diffractive masses M