Results on Total and Elastic Cross Sections in p+p collisions at √s = 200 GeV with the STAR Detector at RHIC

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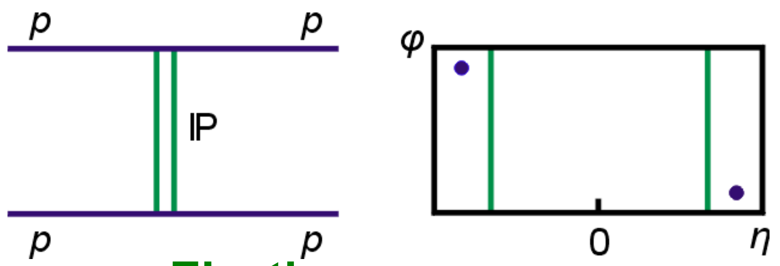
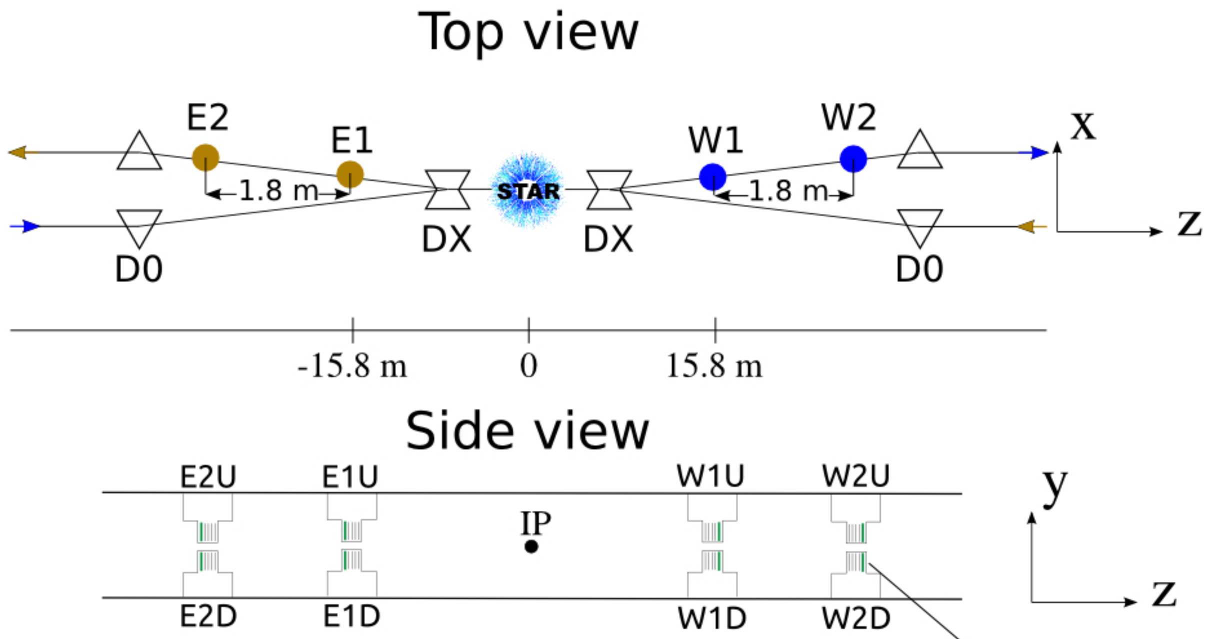
For the STAR Collaboration

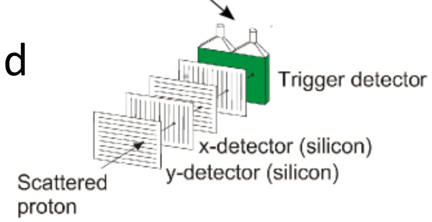


Elastic: p + p → p + p

1. Experimental setup at STAR
2. Data set
3. Analysis
4. Distributions of physics variables (-t, ϕ)
5. Simulations and efficiency, acceptance corrections
6. Results: dσ/dt, B-slope, σ_{tot}, σ_{el}

Experimental Setup

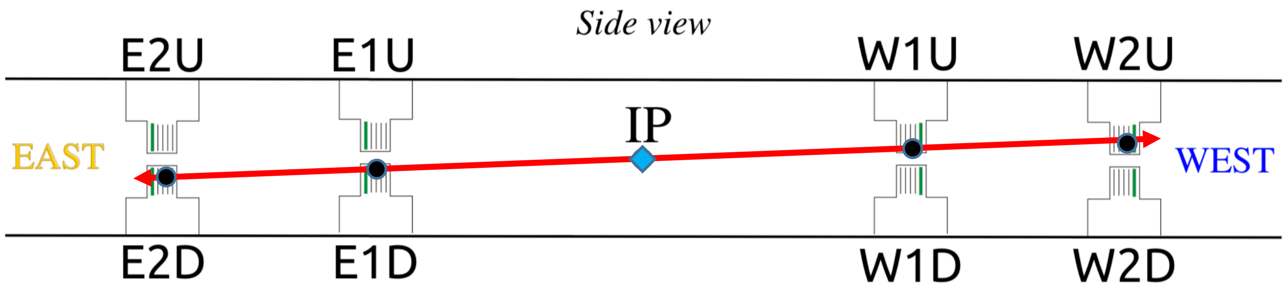




There is only one dipole magnet (DX) between the collision point and the Roman Pots (RPs). Bending is only in the (x,z) plane.

In this configuration, the RP program at STAR was able to acquire large data samples without special running conditions – mostly for CEP, SDD and CP analyses.

Data Analysis



- Trigger was very inclusive: it required only a signal in at least one RP on each side.

$$\mathbf{RP\_ET} = (\mathbf{E1U} \vee \mathbf{E2U} \vee \mathbf{E1D} \vee \mathbf{E2D}) \wedge (\mathbf{W1U} \vee \mathbf{W2U} \vee \mathbf{W1D} \vee \mathbf{W2D})$$

- Need to minimize background and maximize efficiency.
- To reduce background need angle reconstruction => two RPs on each side in up – down combination.

$$\mathbf{EU} = (\mathbf{E1U} \wedge \mathbf{E2U})\ ;\ \mathbf{ED} = (\mathbf{E1D} \wedge \mathbf{E2D})$$
$$\mathbf{WU} = (\mathbf{W1U} \wedge \mathbf{W2U})\ ;\ \mathbf{WD} = (\mathbf{W1D} \wedge \mathbf{W2D})$$
$$\mathbf{ET1} = (\mathbf{EU} \wedge \mathbf{WD})$$
$$\mathbf{ET2} = (\mathbf{ED} \wedge \mathbf{WU})$$

- Use events with four track points (two on each side of IP) – one track point per Roman Pot.
- Finally, choose fiducial region away from the apertures of DX magnet and beam pipe in front of the RPs.

Collinearity

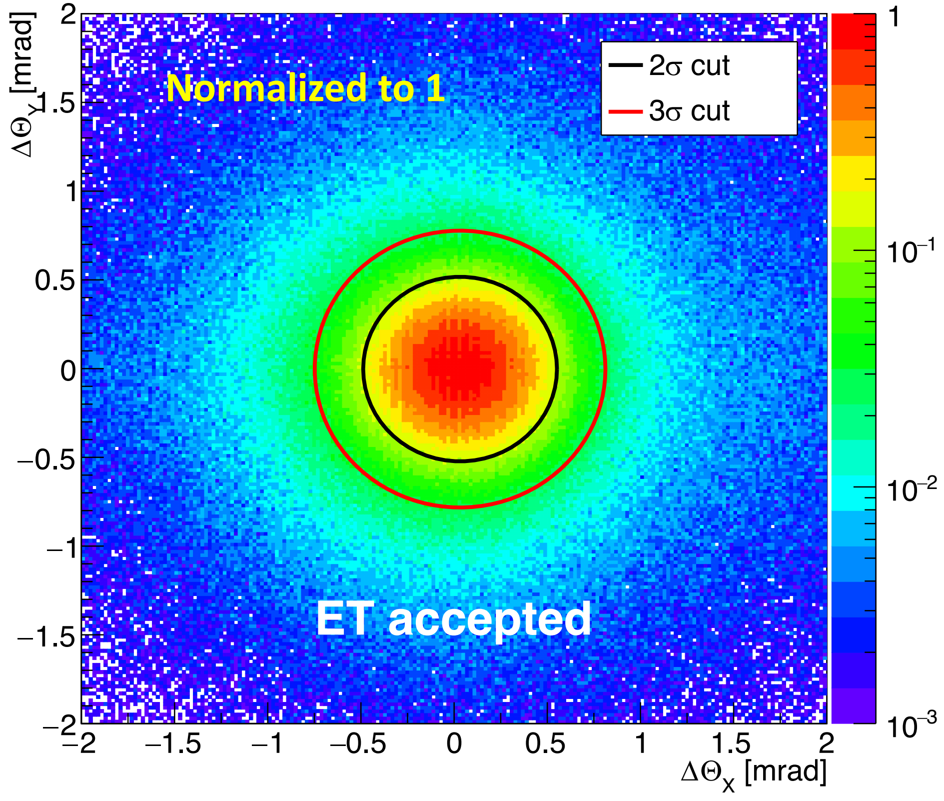
$$\vec{p_1} = -\vec{p_2} \Rightarrow (\Theta_{x1}, \Theta_{y1}) = (-\Theta_{x2}, -\Theta_{y2})$$

Since the elastic events must satisfy collinearity condition collinearity within $2\sigma_\theta$ is required.

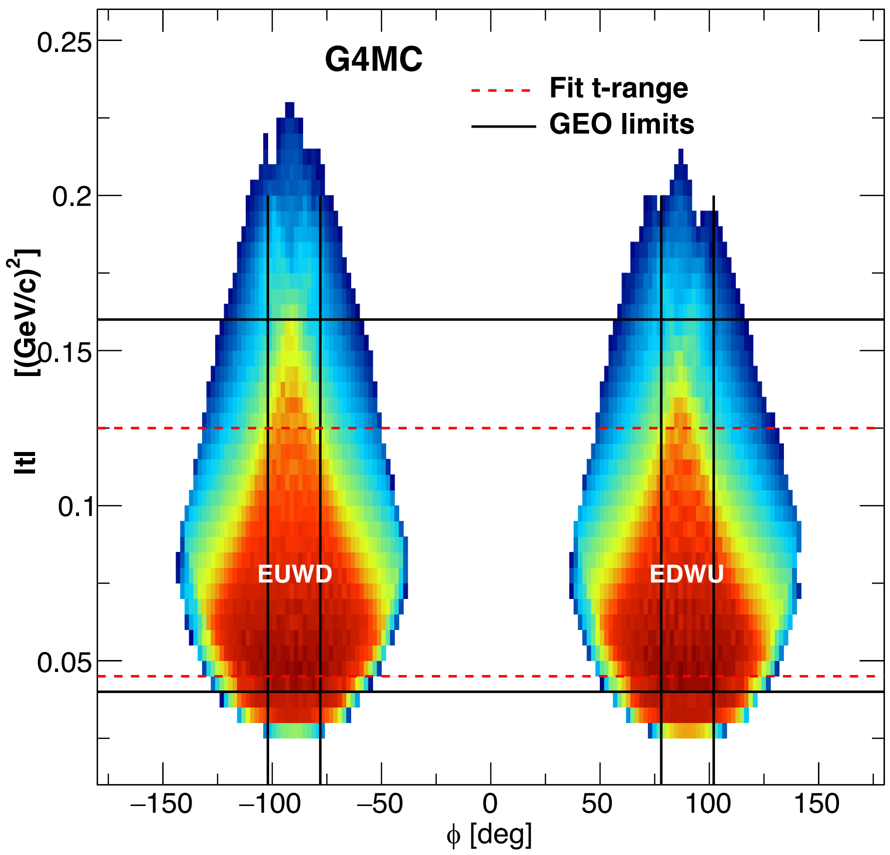
Namely $|\theta_{West} + \theta_{East}| < 2\sigma_\theta$,

where $\sigma_\theta = 255$ µrad is mostly due to beam angular divergence.

Events are well centered within 2σ and 3σ contours.



Geometrical Acceptance GEANT4 MC: I



Choice of geometrical acceptance in (t,ϕ) plane, -t = $p^2\Theta^2$

$$0.04 \leq |t| \leq 0.16[(GeV/c)^2]$$

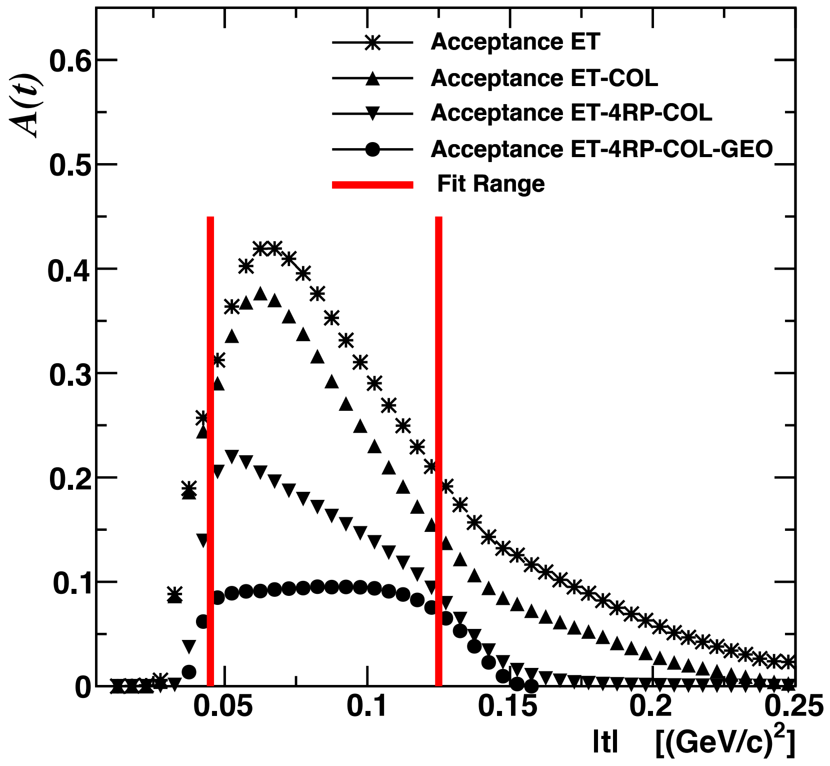
$$79.5 \leq |\phi| \leq 101.5[deg]$$

$$2.00 \leq \theta \leq 4.00[mrad]$$

Choose region away from steep variation due to edges of acceptance:

1. At low |t| away from the beam envelope.
2. At "large" |t| away from the apertures.

Geometrical Acceptance and Event Yields



In the fit range the acceptance is basically flat.

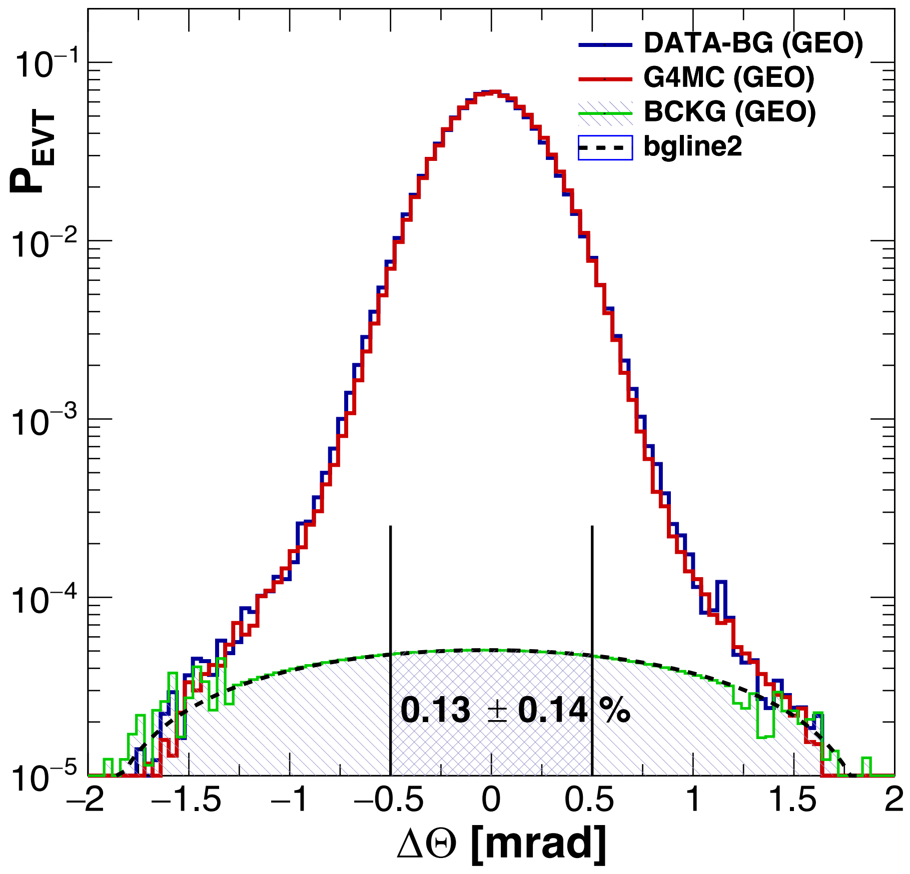
Condition	# events
ET triggered	6.607M
ET accepted	3.974M
Collinear	2.696M
4 PT Collinear	1.100M
4 PT Collinear Geom.	0.667M

667K events were used for the final analysis

Integrated luminosity ~1.83 pb^{-1}

GEANT4 MC: Background Study

1. Each distribution is normalized to 1, independently
2. Normalization MC to Data done by normalizing peaks
3. Background mostly due to the re-scattered protons in the the beam pipe and the DX magnet
4. Background is small − 0.13%, after 2ΔΘ cut and after geometrical acceptance cut



Results: Corrected dσ/dt and Fits

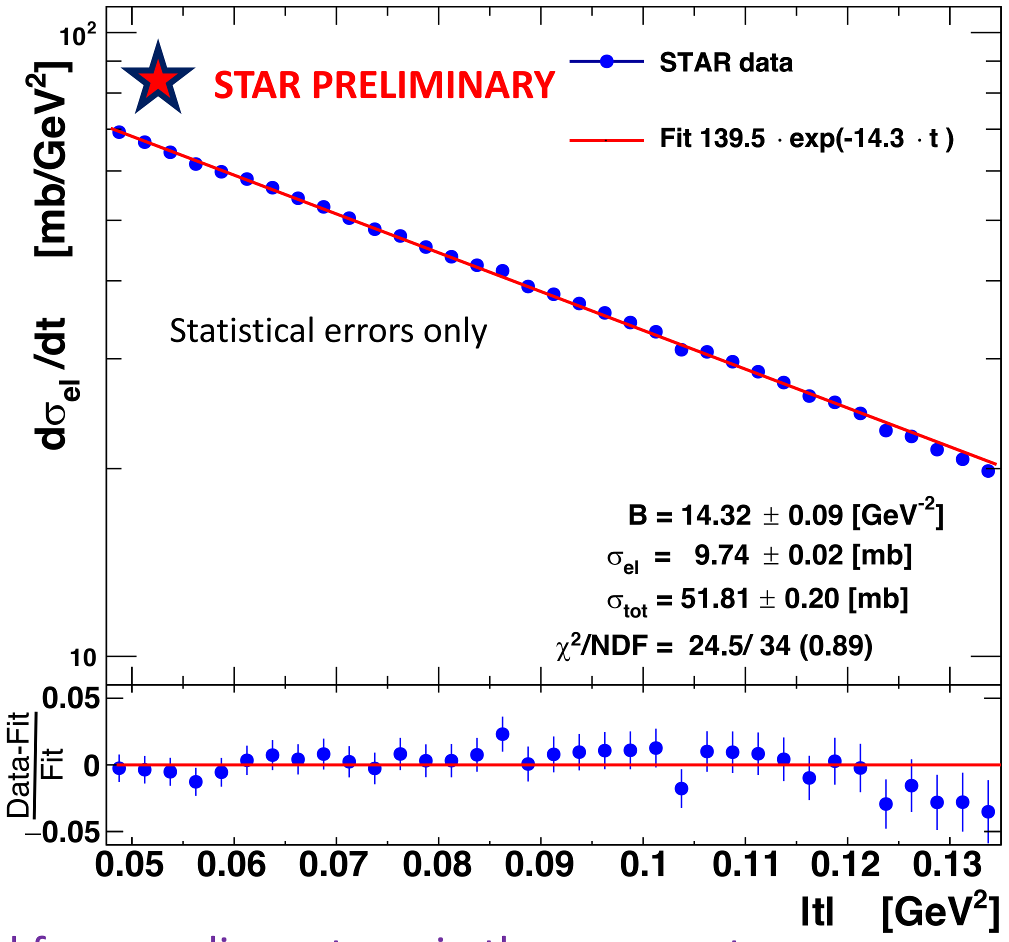
$$\frac{d\sigma_{el}}{dt} = \frac{1+\rho^2}{16\pi(\hbar c)^2} \cdot \sigma_{tot}^2 \cdot e^{-B\,|t|}$$

Optical theorem $$\sigma_{tot}^2 = \left(\frac{16\pi(\hbar c)^2}{1+\rho^2}\right) \frac{d\sigma_{el}}{dt}\bigg|_{t=0}$$

Extrapolated to full t-range $$\sigma_{el} = \int \frac{d\sigma_{el}}{dt} dt$$

The value of ρ = 0.128 from COMPETE model was used*.

* Phys. Rev. Lett. 89 (2002) 201801



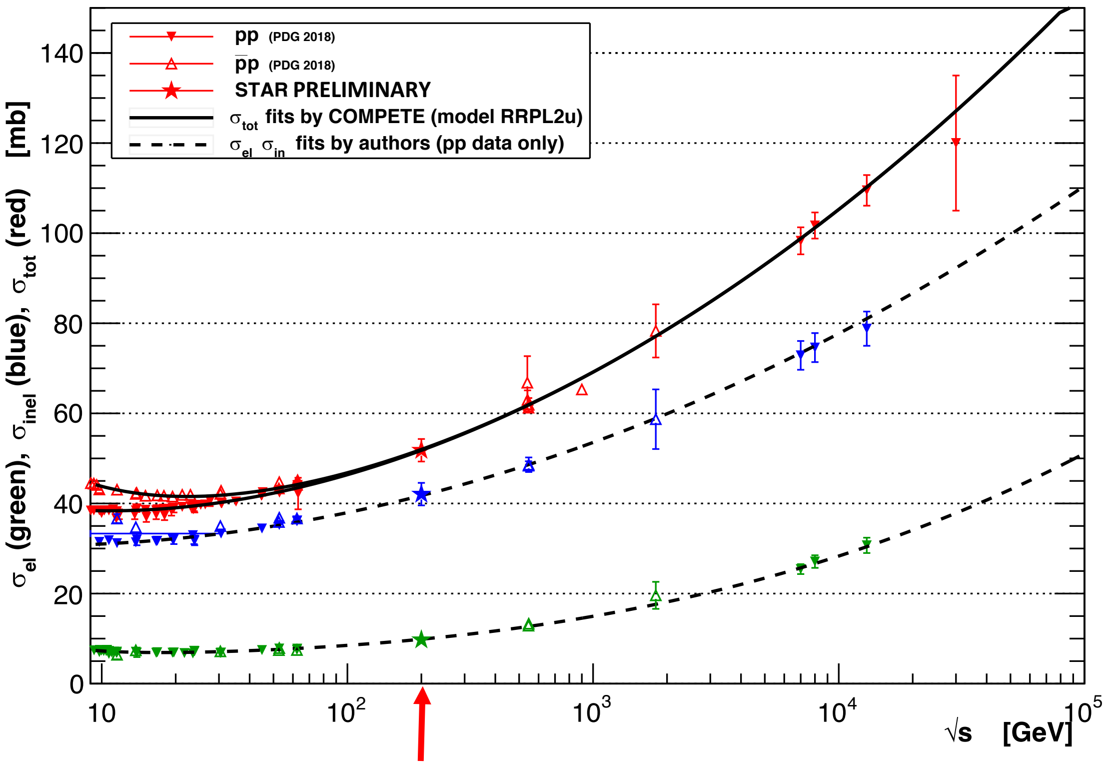
We don't see a need for a nonlinear term in the exponent

STAR Preliminary Results at √s = 200 GeV

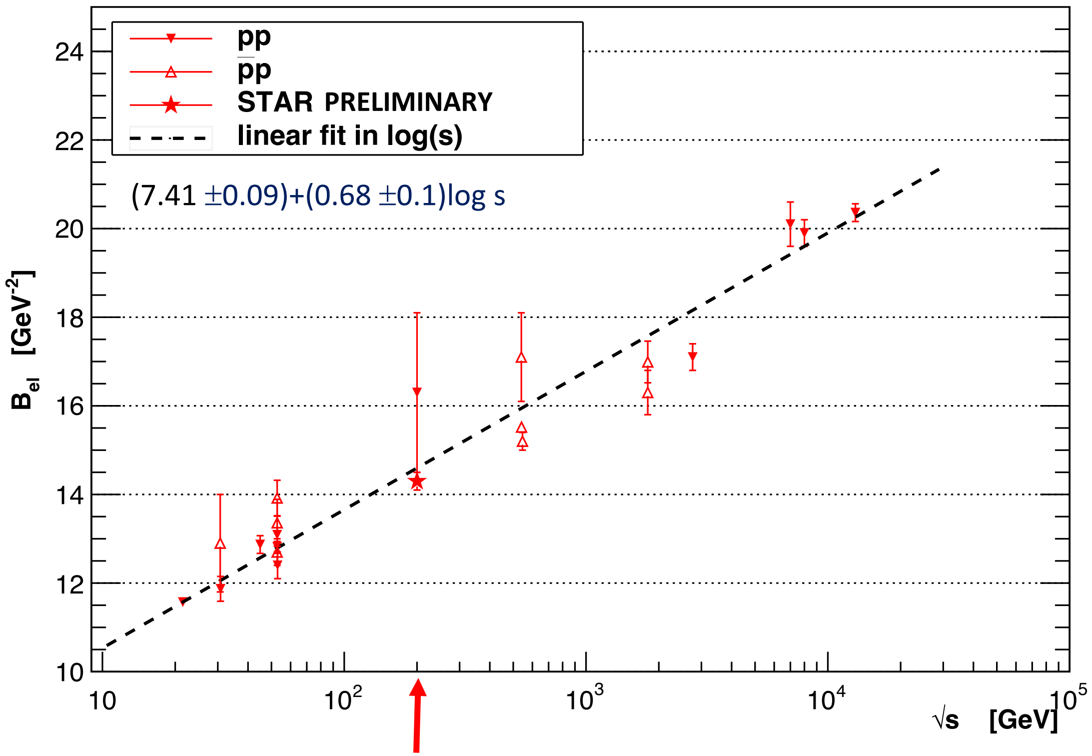
Quantity			Statistical	Systematic uncertainties			
name	units	Value	uncertainty	beam-tilt	lumi	ρ	full
$d\sigma_{el}/dt\vert_{t=0}$	[mb/GeV^2]	139.53	±1.06	$^{+1.07}_{-0.83}$	$^{+10.50}_{-10.07}$	n/a	$^{+10.55}_{-10.10}$
B	[GeV^{-2}]	14.32	±0.09	$^{+0.18}_{-0.32}$	n/a	n/a	$^{+0.18}_{-0.32}$
σ_{el}	[mb]	9.74	±0.02	$^{+0.06}_{-0.04}$	$^{+0.74}_{-0.59}$	n/a	$^{+0.74}_{-0.59}$
σ_{el}^{det}	[mb]	3.63	±0.01	$^{+0.02}_{-0.01}$	$^{+0.28}_{-0.23}$	n/a	$^{+0.28}_{-0.23}$
σ_{tot}	[mb]	51.81	±0.20	$^{+0.19}_{-0.61}$	$^{+1.91}_{-1.90}$	$^{+0.19}_{-0.41}$	$^{+1.93}_{-2.04}$
σ_{inel}	[mb]	42.07	±0.20	$^{+0.20}_{-0.61}$	$^{+2.05}_{-1.99}$	$^{+0.20}_{-0.40}$	$^{+2.07}_{-2.12}$

The main sources of systematic uncertainty are:
luminosity measurement and beam tilt angle in the RP coordinate system .

Comparison with the World Data



σ_{inel} is calculated



STAR results compare well with the world data and the COMPETE predictions: Phys. Rev. Lett. 89 (2002) 201801

Plots form the TOTEM Collaboration https://arxiv.org/pdf/1712.06153v2.pdf with STAR preliminary results added

Summary

1. The STAR experiment at RHIC measured elastic differential cross sections in the |t|-range [0.045, 0.135] $(GeV/c)^2$ in p+p collisions at $\sqrt{s}$ = 200 GeV.

2. The resulting values of B-slope, σ_{tot}, σ_{el} and σ_{el}^{det} are:

   - Slope parameter B = 14.32 $\pm$ 0.09 (stat) $[^{+0.18}_{-0.32}]$ (syst)$(GeV/c)^{-2}$
   - The total cross section σ_{tot}= 51.81 $\pm$ 0.2 (stat) $[^{+1.93}_{-2.04}]$ (syst) (mb)
     COMPETE Predictor, Phys. Rev. Lett. 89 (2002) 201801 σ_{tot}= 51.76 $\pm$ 0.12 (stat) $^{+0.4}_{-0.2}$ (syst) mb
   - The elastic cross section σ_{el} = 9.74 $\pm$ 0.02 (stat) $[^{+0.74}_{-0.59}]$ (syst) mb
   - Elastic cross section within acceptance σ_{el}^{det} = 3.63 $\pm$ 0.01 $[^{+0.28}_{-0.23}]$ (syst) mb
   - We see no need for a quadratic term in the exponent of the elastic cross section

We also have data at $\sqrt{s}$ = 510 GeV at higher t-range, where there is change in slope

At this point, the largest syst. uncertainties are: 1% due to the beam tilt angle and 7% due to the luminosity. We expect the luminosity uncertainty to be about 3% after the careful calibration.