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Recent Soft QCD results from ATLAS

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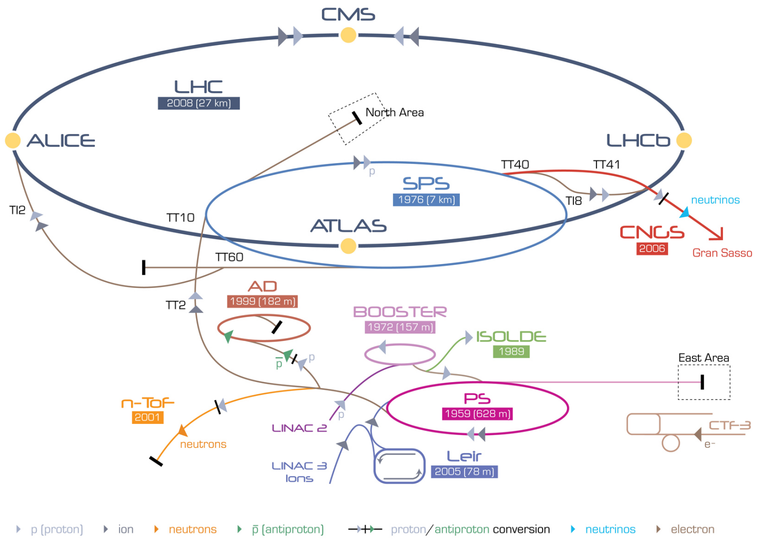
ATLAS and the LHC

The Large Hadron Collider

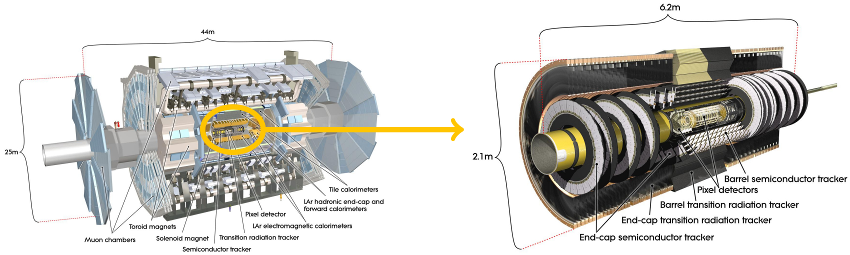
- 27 km circumference proton-proton collider
- Aim to test the Standard Model at energies up to 14 TeV
- Data collected at a variety of $\sqrt{s}$

900 GeV, 2.36 TeV, 2.76 TeV, 7 TeV, 8 TeV

The CERN accelerator complex

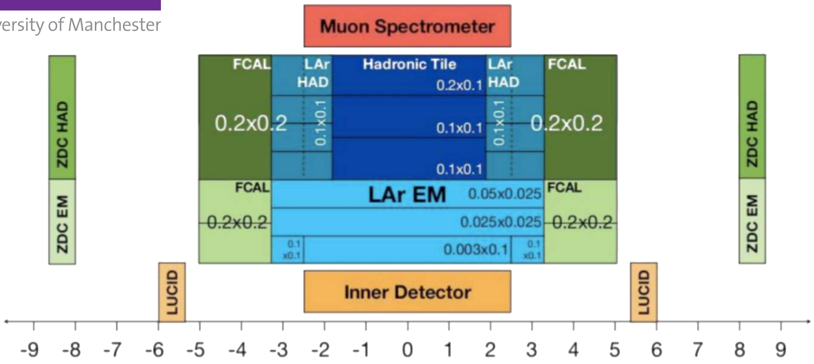


The ATLAS Detector



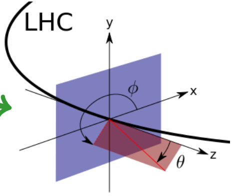
- General purpose experiment consisting of multiple detector regions
- Inner detector reconstructs charged particle tracks in 2 T magnetic field
- Calorimeters measure energies of EM and hadronic particles
- Dedicated spectrometers for muon measurement

The ATLAS Detector



$$\eta = -\ln \tan(\theta/2)$$

- ATLAS uses a right-handed co-ordinate system
- Inner tracking detectors: $|\eta| < 2.5$
- EM and hadronic calorimeters: $|\eta| < 4.9$
- Muon spectrometers: $|\eta| < 2.7$



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Theoretical modelling

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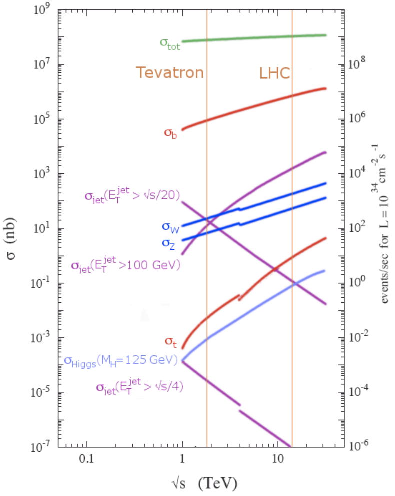
LHC cross sections

Total pp cross section much larger than cross section for "interesting" physics

- bulk of collisions are soft (low p_{T}) QCD processes

LHC has many pp **interactions** per bunch crossing

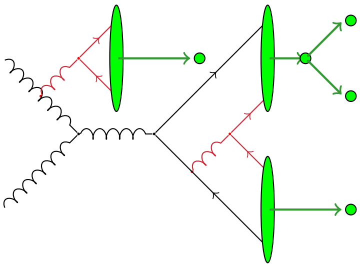
- signal events overlaid with particles from other interactions
- almost every observable influenced by non-perturbative QCD effects
  → PDF effects, multi parton interactions (MPI), and hadronisation
- good modelling of non-perturbative QCD is necessary for precision physics and searches



Proton-(anti)proton cross sections

Monte Carlo Event Structure

- Non-perturbative QCD effects are parametrised using empirical models
- Historically, Monte Carlo generators factorised events into independent pieces



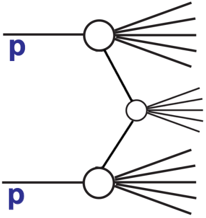
- **Matrix Element**: exact theoretical calculation up to stated accuracy (e.g. LO or NLO).
- Parton Shower: QCD radiation matched to the matrix element (bremsstrahlung).
- Hadronisation: Phenomenological models describing non-perturbative effects.

Interplay between ME and PS complicated at higher orders (eg. CKKW/MLM merging)

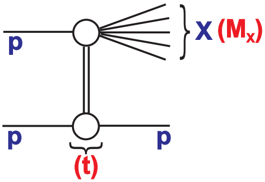
Components of the total cross section

- The majority of events at the LHC are non-diffractive inelastic events
- Another important category is elastic scattering: $pp \to pp$
- The remaining diffractive events are usually divided into
  1. single-diffractive dissociation: $pp \to Xp$
  2. double-diffractive dissocation: $pp \to XY$
  3. central-diffractive: $pp \to pXp$

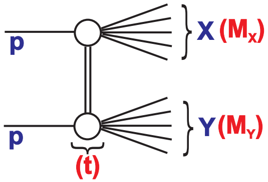
$\to$ Often categorised by the mass of the diffractive system(s), M_X or $\xi_X = M_X^2/s$



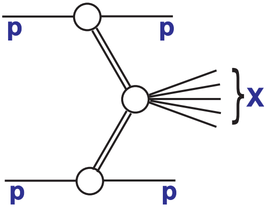
Non-diffractive



Single-diffractive



Double-diffractive



Central-diffractive

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ATLAS Soft QCD results

Soft QCD results

ATLAS has made a lot of measurements in the fields of Soft QCD and Diffraction

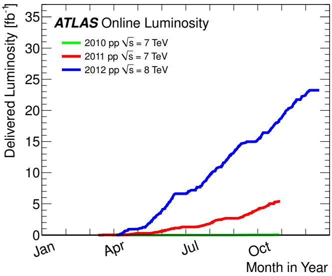
- Charged-particle multiplicities
- Underlying event characteristics
- Inelastic pp cross section
- Hadron production cross sections
- Event-level correlations between particles
- Event shape variables
- Pseudo-rapidity dependence of total transverse energy
- ...many more

Too much to discuss here, so I will just mention some of the most recent results:

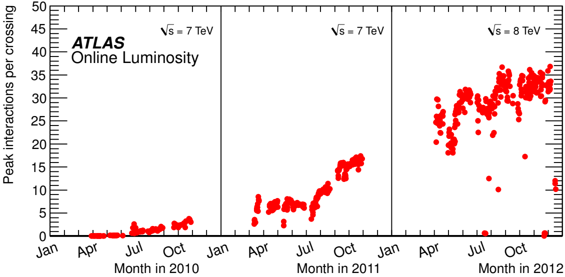
NEW Underlying event in jet events	`EPJC 74 (2014) 2965`
NEW Total elastic pp cross section	`NPB (2014) 486-548`
NEW Underlying event in inclusive Z-boson production	`submitted to EPJC`
NEW Transverse polarisation of Λ and $\bar{\Lambda}$ hyperons	`preliminary`

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults#Soft_QCD

Luminosity and pileup evolution



Luminosity over time



Number of interactions over time

- Increasing luminosity comes from additional interactions (pileup) in each bunch crossing
- Typically, soft QCD measurements want to study events with single interactions
  $\rightarrow$ restricted to special runs with low $\mathcal{L}_{inst}$
- Some analyses use full dataset, applying sophisticated subtraction techniques

Measurement philosophy

1. Measurements should be **corrected** for detector inefficiencies and resolutions (unfolding)
    - determine p_{T} spectrum of charged particles, not of ATLAS tracks

2. Main results cannot be model-dependent **extrapolations** into regions not "seen" by ATLAS (low p_{T} or far-forward particles)
    - we measure what we see, not what the Monte Carlo tells us we should have seen!

3. Event selection theoretically **well defined** and **reproducible**
    - for example, $\geq x$ charged particles with $p_{\mathrm{T}} > y$ and $|\eta| < z$

Underlying event

Challenges in describing data

Underlying event: any hadronic activity not associated with hard scattering process

- Unavoidable background to collision events
- Not well-predicted as non-perturbative effects dominate
- Need to ensure that measurements are not dependent on details of model used

Not possible to unambiguously assign particles to the hard scatter or UE

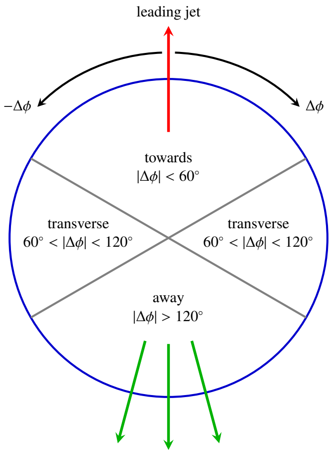
Typically modelled with

- Multiple parton interactions
- Initial/final-state radiation
- Colour reconnection with beam remnants

Overlaid collisions within the same bunch crossing also complicate measurements

Underlying event topology

- Identify a "hard scatter" using a reference object (eg. jet or vector boson)
- Three azimuthal regions defined with respect to the leading object



- Toward and transverse regions are sensitive to the underlying event
- Away region has larger contributions from high p_T recoil, which is modelled by perturbative QCD
- Transverse region is further divided into trans-max and trans-min depending on the amount of activity

Underlying event observables

Interested in properties of soft charged and neutral particles

Densities and averages

- Average p_{T} of charged particles: $\langle p_{\mathrm{T}} \rangle$
- Density of charged particles: $N_{ch}/\delta\eta\delta\phi$
- p_{T} density of charged particles: $\sum p_{\mathrm{T}}/\delta\eta\delta\phi$
- E_{T} density of all particles: $\sum E_{\mathrm{T}}/\delta\eta\delta\phi$

Particle spectra

- Charged particle p_{T} spectrum
- Charged particle multiplicity spectrum

Event selection

Events containing a reference object are selected using the following criteria:

Requirement	jets	Z boson
p_{T}	> 20 GeV	> 20 GeV
rapidity	$|\eta| <$2.8	$|\eta| <$2.4
luminosity	37 pb^{-1}	4.6 fb^{-1}
other	anti-k_t R=0.4	$66 < m_{ll} < 116$

...before event activity is detemined using

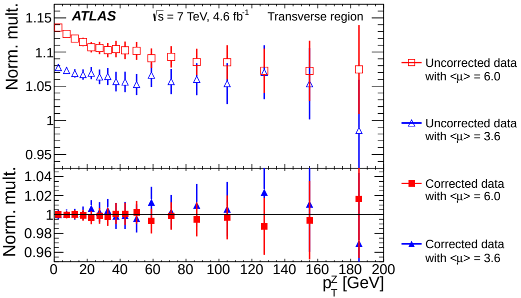
- Charged particles identified by tracks with
  - $p_{\mathrm{T}} > 0.5$ GeV
  - $|\eta| < 2.5$

- Particles identified with calorimeter clusters (only in the jet measurement)
  - Charged particles: $p > 0.5$ GeV
  - Neutral particles: $p > 0.2$ GeV
  - $|\eta| < 4.8$

Effects of additional pp interactions

- Pileup is important in 4.6 fb^{-1} dataset used in the Z-boson UE measurement
- Impact reduced by requiring tracks to be associated to the primary vertex

$$|d_0| < 1.5 \text{ mm and } |z_0| \sin\theta < 1.5 \text{ mm}$$

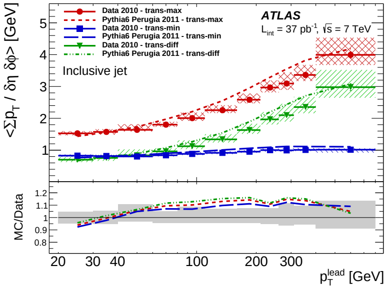


- Residual contribution estimated and subtracted with a data-driven technique
- Tracks associated to points at distance >2 cm from primary vertex used to model pileup contribution
- Pileup correction checked in subsamples with different average number of interactions $\rightarrow$ consistency check

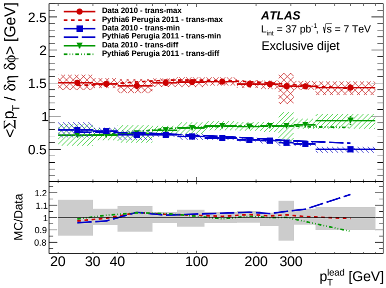
Underlying event in jet events

EPJC 74 (2014) 2965

Inclusive jet selection



Exclusive dijet selection



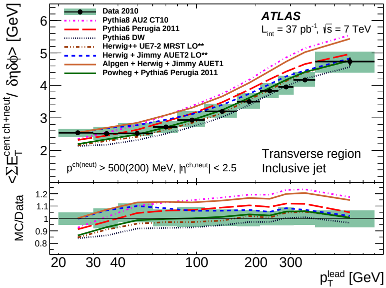
- Trans-min region is flat $\rightarrow$ UE activity can be modelled as constant at hard enough scales
- Trans-max region shows increasing activity with jet p_{T} $\rightarrow$ large contribution from pQCD
- Could indicate colour connection to leading jet

- In exclusive dijet selection both trans-max and trans-min regions are flat
- Veto on additional hard activity gives less sensitivity to perturbative QCD effects

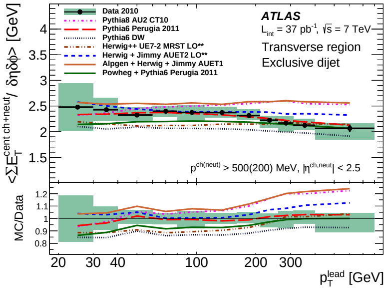
Underlying event in jet events

EPJC 74 (2014) 2965

Inclusive jet selection



Exclusive dijet selection

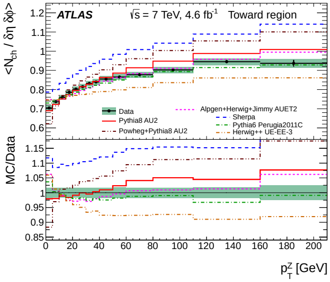


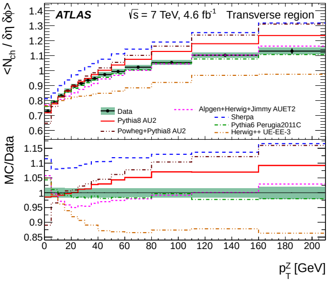
- Similar distributions for $\sum E_T$ measured with calorimeter clusters
- Different Monte Carlo models and tunes compared
- Best agreement given by PYTHIA 6 with Perugia 2011 tune

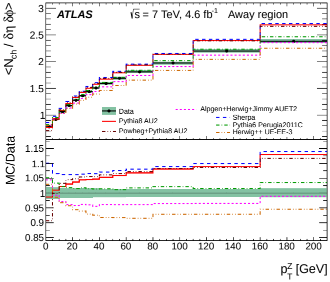
Underlying event in Z events

arXiv:1409.3433

The U



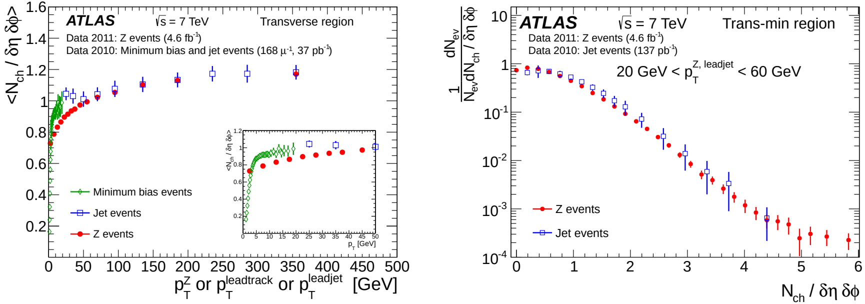




- $Z \to ll$ allows measurement of UE in the toward, transverse and away regions
- Low $p_{\rm T}$ region less sensitive to pQCD $\to$ useful for non-perturbative model tuning
- For high Z $p_{\rm T}$, away region dominated by Z+ 1 jet balance
- Toward and transverse regions are sensitive to higher N_{jets}

Universality of MPI model

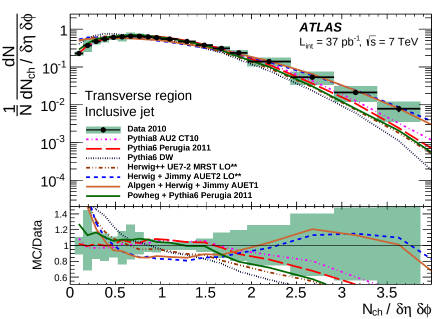
arXiv:1409.3433



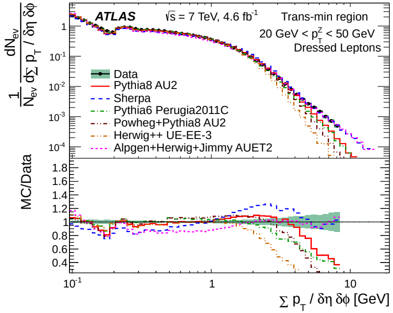
- Underlying event measurements have been made using track, jet and Z-boson references
- Comparison lets us test assumption that multi-parton interactions (MPI) are universal
- Good agreement for jet and Z-boson: especially for trans-min (most sensitive to MPI)
- Reasonable agreement with track measurement
- Qualitative check of universality of MPI model in different hard processes

Particle p_T and multiplicity

EPJC 74 (2014) 2965
arXiv:1409.3433



Jet selection

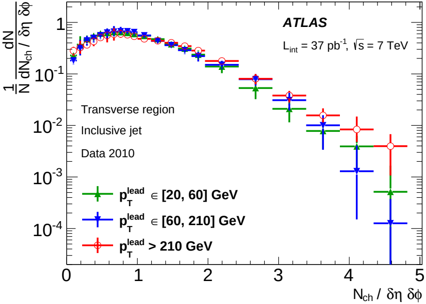


Z-boson selection

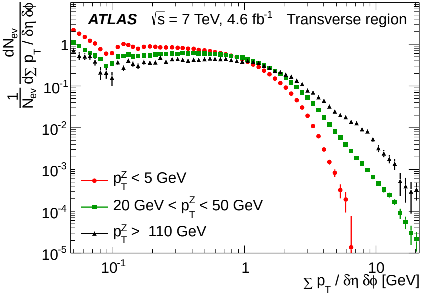
- Double differential charged particle multiplicity and p_T spectra
- Provide further discrimination between Monte Carlo models

Particle p_T and multiplicity

EPJC 74 (2014) 2965
arXiv:1409.3433



Jet selection



Z-boson selection

- Strong dependence on reference object p_T
- Very challenging for current soft QCD models to describe these observables

Underlying event summary

- NEW measurements of underlying event observables in jet and Z-boson events
- Large variety of multiplicity and energy density distributions measured
- Measurements sensitive to non-perturbative QCD parameters and models
  $\rightarrow$ can be used to tune Monte Carlo generators
- Underlying event shown to be sensitive to details of MPI modelling
  $\rightarrow$ parameters related to colour-reconnection, α_s and the IR cut-off
- Underlying event measurements in Run II will provide further test of $\sqrt{s}$ dependence

Total cross section

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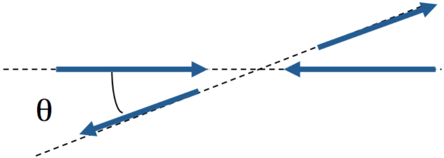
Elastic cross section measurement

NPB (2014) 486-548



- **Total** cross section not calculable in perturbative QCD; can be measured using the optical theorem

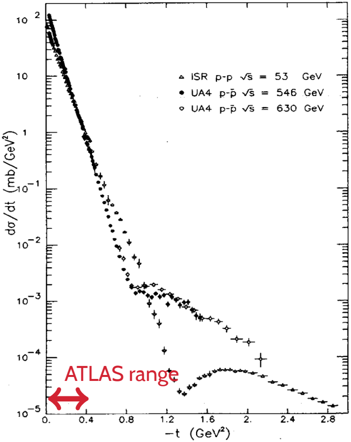
$$\sigma_{tot} = 4\pi \,\mathrm{Im}\left[f_{el}\left(t \to 0\right)\right]$$

where f_{el} is elastic scattering amplitude extrapolated to $t = 0$

- **Elastic** cross section parametrised in terms of momentum transfer

$$t = -2p^2\left(1 - \cos\theta\right) \simeq -p^2\theta^2$$

- Previously done by UA4 Collaboration



UA4, PLB 171 (1986), 142

Experimental setup

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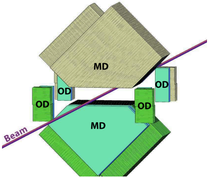
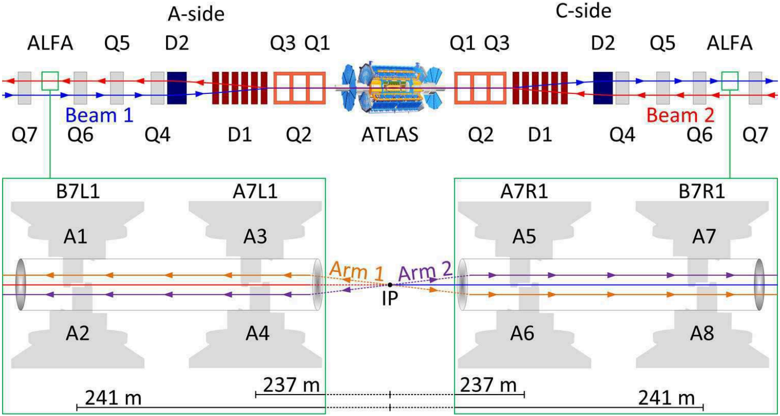
- Use specialised ALFA (Absolute Luminosity For ATLAS) detector
- 4 trackers at 240 m from ATLAS IP (8 "roman pots")
- Can detect very small angle proton scatters





Elastic event selection

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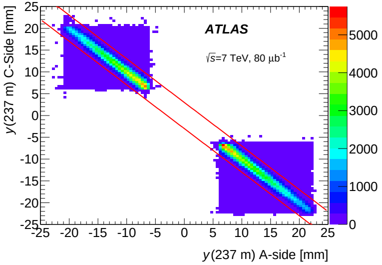
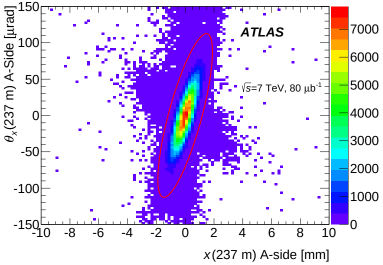
- Dedicated ALFA trigger for elastic events
- Data quality requirements
- Geometrical acceptance cuts
- Back-to-back requirement together with cut on similar background topologies



Correlation between y on A and C sides



Correlation between x and θ_x on A side

- Event distribution after data quality cuts but before acceptance and background cuts
- Elastic events are inside red areas

Detector efficiencies

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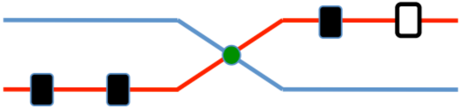
- Main reconstruction problem: one detector may not fire
- Inefficiency mainly due to shower development in the outer detectors



Data-driven correction:

$$\epsilon^{reco} = \frac{N_{4/4}}{N_{4/4} + N_{3/4} + N_{2/4} + N_{1/4} + N_{0/4}}$$

Efficiency: 89.8 ± 0.6% (Arm1) and 88.0 ± 0.9% (Arm2)

- Trigger, DAQ and alignment inefficiencies measured and found to be negligible

Detector acceptance

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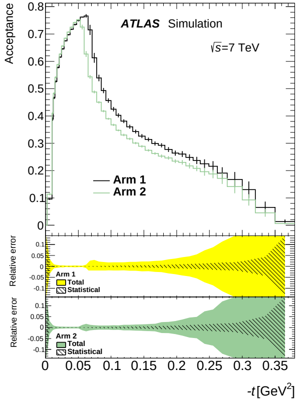
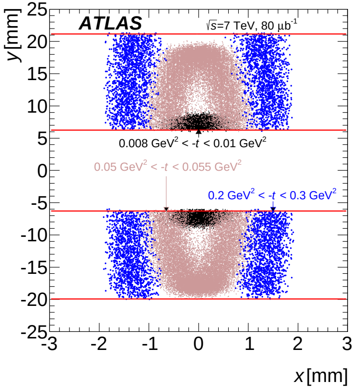
- Accurate beam pipe geometry crucially important in determining vertical cuts



Acceptance spectrum for both arms



Simulated hit pattern on ALFA

- Acceptance determined from Monte Carlo simulation used to correct raw spectra

Non-elastic backgrounds

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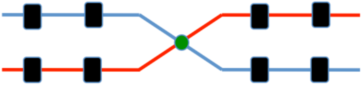
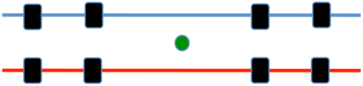
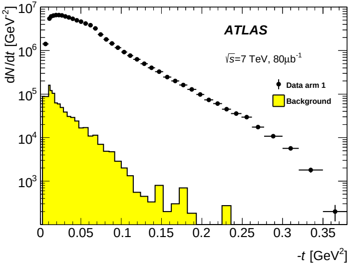


Golden mode



Anti-golden mode

- Irreducible background in the elastic peak from beam halo
- Can be estimated using anti-golden events
  $\rightarrow$ flip the vertical co-ordinate on one side to get a measurement of t
- Background estimated to be $\sim 0.50 \pm 0.25\%$



Correcting measured quantities

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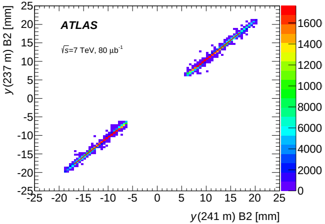
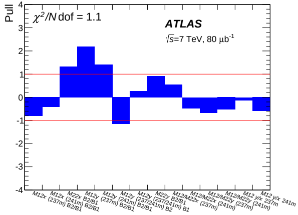
Measured scattering angle θ in detector different from that at interaction point (IP)

$$\begin{pmatrix} x_{det} \\ \theta_{x_{det}} \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \begin{pmatrix} x^*_{IP} \\ \theta^*_{x_{IP}} \end{pmatrix}$$





- Elements of transport matrix calculable from optical function β
- Data used to cross-check matrix elements

$$y = \theta^*_y M_{12} \rightarrow \frac{y_{237m}}{y_{241m}} = \frac{M^{237m}_{12}}{M^{241m}_{12}}$$

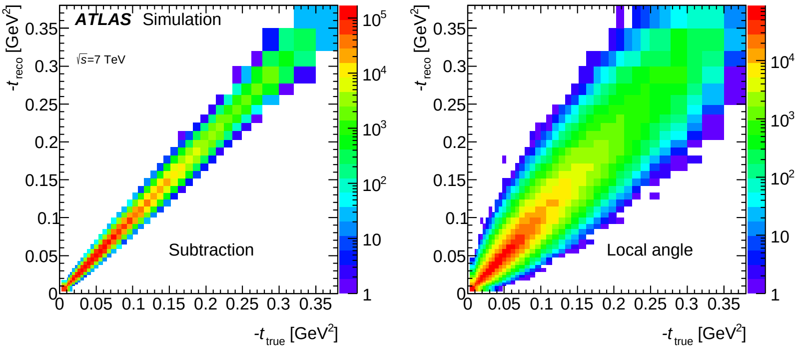
- Reasonable agreement – mostly inside 1σ
- Final result uses both sides (subtraction method):

$$\theta^*_x = \frac{x_A - x_C}{M_{12,A} + M_{12,C}}$$

Unfolding detector effects

NPB (2014) 486-548

- t-spectrum affected by detector resolution and beam smearing effects
  $\rightarrow$ divergence, angular smearing and vertex position
- Reduces 'purity' (fraction of events generated in same bin as reconstructed in) to $\sim$60%
- Detector-induced event migration in t-spectrum corrected using an unfolding procedure



- Clear indication of superiority of subtraction method over local angle

EXTRACTING σ_{tot} AND B

NPB (2014) 486-548

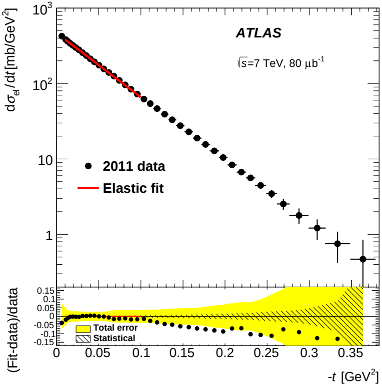
$t = \left[(\theta_x^*)^2 + (\theta_y^*)^2 \right] p^2$ using nominal beam momentum, $p = 3.5$ TeV

- Fit data with all systematic and statistical uncertainties[1]
- Largest uncertainties: luminosity and beam energy.

- Good fit ($\chi^2/N_{dof} = 7.4/16$) over range
- 0.01: as close to 0 as possible while keeping acceptance > 10%
- 0.1: limit fit to region where exponential description is valid

$\sigma_{tot} = 95.4 \pm 1.4$ mb

$B = 19.7 \pm 0.3$ GeV^{-2}



Fit of σ_{tot} and B

[1] Fit: $\frac{d\sigma_{el}}{dt} = \frac{4\pi\alpha^2(\hbar c)^2}{|t|^2} G^4(t) - \sigma_{tot} \frac{\alpha G^2(t)}{|t|} \left[\sin(\alpha\phi(t)) + \rho\cos(\alpha\phi(t))\right] e^{-B|t|/2} + \sigma_{tot}^2 \frac{1+\rho^2}{16\pi(\hbar c)^2} e^{-B|t|}$

Derived results

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Elastic cross section from the integrated fit function:

$$\sigma_{el} = \frac{\sigma_{tot}}{B}\frac{1+\rho^2}{16\pi(\hbar c)^2} \quad \rightarrow \quad \boldsymbol{\sigma_{el} = 24.0 \pm 0.6} \textbf{ mb}$$

Optical point:

$$\left.\frac{d\sigma}{dt}\right|_{t\rightarrow 0} = 474 \pm 13 \text{ mb GeV}^{-2}$$

Inelastic cross section:

$$\sigma_{in} = \sigma_{tot} - \sigma_{el} \quad \rightarrow \quad \boldsymbol{\sigma_{in} = 71.3 \pm 0.9} \textbf{ mb}$$

Comparison with other results

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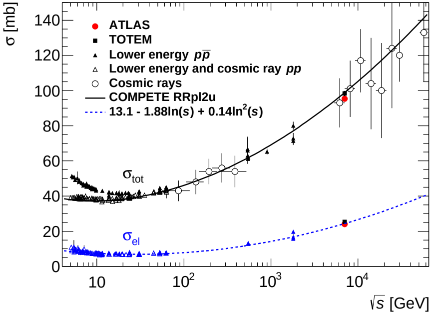
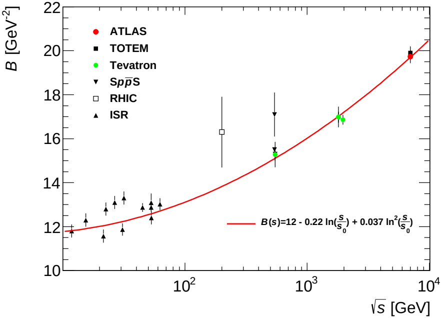


Total cross section: σ_{tot}

- ATLAS: 95.4 ± 1.4 mb
- TOTEM: 98.6 ± 2.2 mb

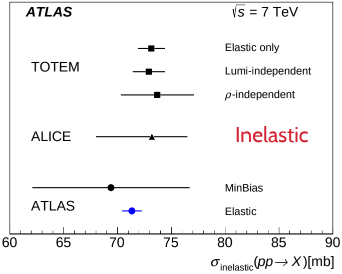
Nuclear slope: B

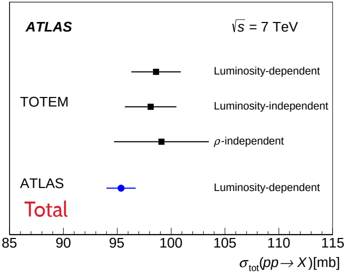
- ATLAS: 19.7 ± 0.3 GeV^{-2}
- TOTEM: 19.9 ± 0.3 GeV^{-2}

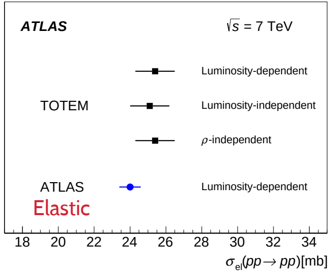


Comparison with other results

NPB (2014) 486-548







- More precise than previous direct ATLAS measurement
- Due to large theoretical uncertainties in extrapolation to full phase-space

Summary

NPB (2014) 486-548

- NEW ATLAS measurements of pp cross sections and nuclear slope at $\sqrt{s} = 7$ TeV
- Measurements of σ_{tot}, σ_{el} and σ_{in}
- Extracted from elastic scattering measurements
- More precise than previous direct measurement by ATLAS
- In good agreement with previous LHC results from TOTEM (and ALICE)

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Transverse polarization of Λ and $\bar{\Lambda}$ hyperons

Polarisation

- Λ hyperon: spin ½ particle
- Polarisation, P, defined as:

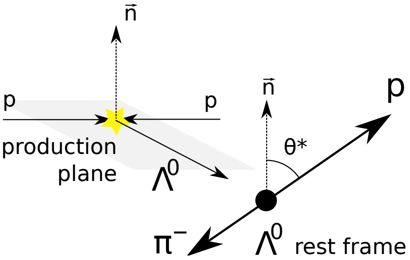
$$P = \frac{N_{+1/2} - N_{-1/2}}{N_{+1/2} + N_{-1/2}}$$

$\Lambda \to p\pi^-$ and $\bar{\Lambda} \to \bar{p}\pi^+$ decays

- Angular distribution given by:

$$w(\cos\theta^*) = \frac{1}{2}(1 + \alpha P \cos\theta^*)$$

where $\alpha = 0.642 \pm 0.013$ is the known parity-violating decay asymmetry (world average)



- polarization measured in direction normal to production plane: $\vec{n} = \hat{p}_{beam} \times \vec{p}$
- as function of p_T and $x_F = p_z/p_{beam}$
- measured for $x_F < 0.0025$

No theoretically motivated model exists to date!

Selection and measurement strategy

- Data from the beginning of 2010: $\mathcal{L}_{int} = 760\ \mu b^{-1}$
- Trigger selection: at least one hit in MBTS (at least one reconstructed collision vertex)
- Fiducial volume: $0.8 < p_{\rm T} < 15$ GeV, $|\eta| < 2.5$, and $5 \times 10^{-5} < x_F < 0.01$
- Accept all long-lived two-prong decay candidates

Background suppression

- Decay vertex fit probability > 0.05
- Transverse decay distance significance: $L_{xy}/\sigma_{L_{xy}} > 15$
- Combinatorial background: requirements on impact parameter and decay angle
- Physics background: invariant mass veto for $K^0_S \to \pi^+\pi^-$ and $\gamma \to e^+e^-$
- Mass window: 1100 – 1135 MeV

Accepted ~ 420000 $\Lambda \to p\pi^-$ and ~ 380000 $\bar{\Lambda} \to \bar{p}\pi^+$ candidates

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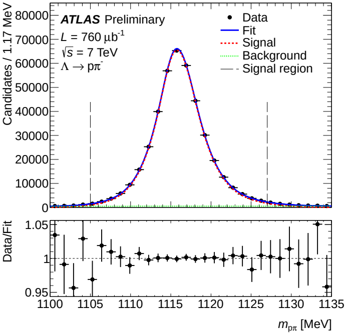
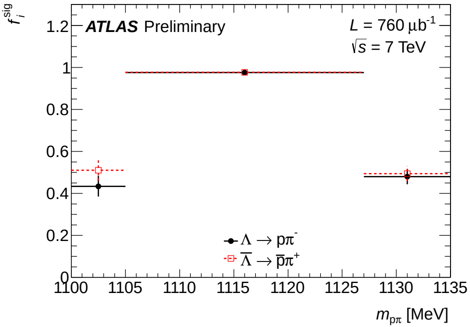
Signal extraction





- Divide invariant mass range into signal region and sidebands
- Complicated multi-parameter fit to Λ candidate distribution
- Allows extraction of signal fractions, f_i^{sig}
- Performed separately in signal region and sidebands

Reconstructed decay angle distribution

$$w(t) \propto \epsilon(t)\,[(1+\alpha P t)] \otimes R(t', t)$$

where t' and t are true and reconstructed decay angles ($\cos\theta^*$), $\epsilon(t)$ is the efficiency function and $R(t', t)$ the resolution function

Method of moments

- The expectation value (first moment) of $w(t)$ is linear in P:

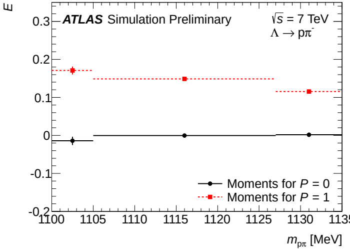
$$E(w|P=p) \equiv E(p) = C_0 + C_1 p = E(0) + [E(1) - E(0)]p$$

- $E(0)$ and $E(1)$ estimated from Monte Carlo samples with polarisation set to 0 and 1

Polarisation of background contribution

However, background events have their own polarisation, so:

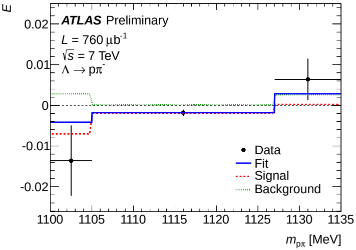
$$E_i^{exp}\,(P, E_{bkg}) = f_i^{sig}\left[E_i^{MC}(0) + \left[E_i^{MC}(1) - E_i^{MC}(0)\right]\,P\right] + (1 - f_i^{sig})\,E_{bkg}$$



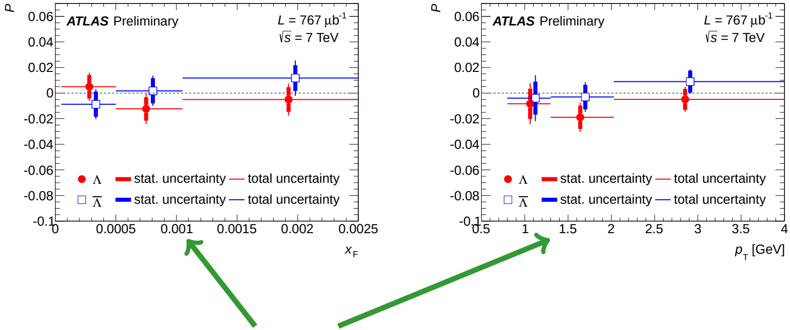
- Moments calculated separately in the signal region and sidebands
- Assume E_{bkg} is independent of mass
- Signal fractions are already determined so...

- Simultaneous fit in signal and sideband regions allows extraction of P and E_{bkg}

$$\chi^2(P, E_{bkg}) = \sum_{i=1}^{3} \frac{\left[E_i - E_i^{exp}\,(P, E_{bkg})\right]^2}{\sigma_{E_i}^2}$$



Results

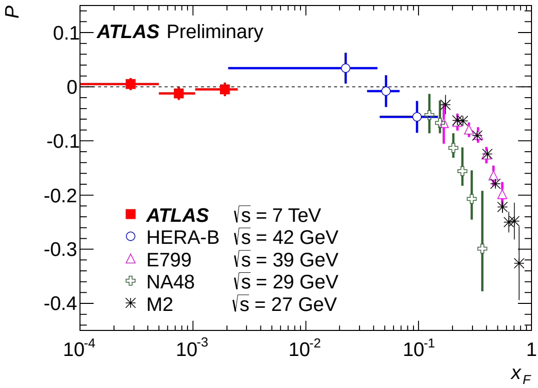


- Measurement in bins of x_F and p_{T}
- Polarization $< 2\%$ in all bins
- Polarization in fiducial phase space consistent with zero in all bins

$$P(\Lambda) = -0.010 \pm 0.005(stat) \pm 0.004(syst)$$

$$P(\bar{\Lambda}) = 0.002 \pm 0.006(stat) \pm 0.004(syst)$$

Comparison to previous results



- ATLAS covers different kinematic phase space than previous experiments $\rightarrow$ direct comparison of results non-trivial
- No theoretically motivated prediction, only empirical models

- **ATLAS**: $\langle p_{\mathrm{T}} \rangle \sim$ 1.8 – 2.1 GeV and $\sqrt{s} = 7$ TeV
- **HERA-B** and **E799**: $\langle p_{\mathrm{T}} \rangle \sim$ 0.67 – 2.2 GeV and $\sqrt{s} \sim 40$ GeV
- Some energy dependence could be introduced
  $\rightarrow$ about half the Λ produced in ATLAS come from decays
- Dilutes polarisation $\rightarrow$ expect measurement to be same or smaller than extrapolation
  $\rightarrow$ satisfied here

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Summary

- NEW ATLAS measurement of Λ hyperon polarisations
- Previous (mostly fixed-target) experiments measured polarisations up to $P \sim 30\%$
- Theoretical expectation:
  - Expected that P_Λ increases with p_T (up to saturation point $\sim$ 1 GeV)
  - Expected that P_Λ decreases with x_F
- All previous measurements showed $P_{\bar{\Lambda}}$ consistent with zero
  $\rightarrow$ In agreement with measurement here

Conclusions

Conclusions

Underlying event

- Important test of non-perturbative QCD modelling
- Useful for further Monte Carlo tuning
- Demonstration of universality of MPI
- Run II measurements will help test $\sqrt{s}$ dependence

pp cross sections

- Inelastic, elastic and total pp cross sections measured
- First measurement to use ALFA detector
- More precise than previous direct inelastic cross section measurement

Λ polarisation

- Λ polarisation found to be consistent with zero
  $\rightarrow$ expected in x_F range under consideration
- $\bar{\Lambda}$ polarisation also found to be consistent with zero
  $\rightarrow$ in agreement with $previous measurements$

BACKUP

Underlying event in jet events systematics

- Jet reconstruction
- Track reconsttruction efficiency
- Calorimeter reconstruction
- Background
- Unfolding

Quantity	Inclusive jets			Exclusive dijets		
	Pile-up and merged vertices			Pile-up and merged vertices		
All observables	1–3%			1–5%		
Charged tracks	Unfolding	Efficiency		Unfolding	Efficiency	
$\sum p_T$	3%	1–7%		3–13%	2–7%	
N_{ch}	1–2%	3–4%		3–22%	3–7%	
mean p_T	1%	0–4%		1–9%	1%	
Calo clusters	Unfolding	Efficiency		Unfolding	Efficiency	
$\sum E_T, \lvert\eta\rvert < 4.8$	2–3%	4–6%		5–21%	4–9%	
$\sum E_T, \lvert\eta\rvert < 2.5$	3–5%	4–6%		1–21%	4–7%	
Jets	Energy resolution	JES	Efficiency	Energy resolution	JES	Efficiency
p_T^{lead}	0.3–1%	0.3–4%	0.1–2%	0.4–3%	1–3%	0.3–3%

Underlying event in Z-boson events
Systematics

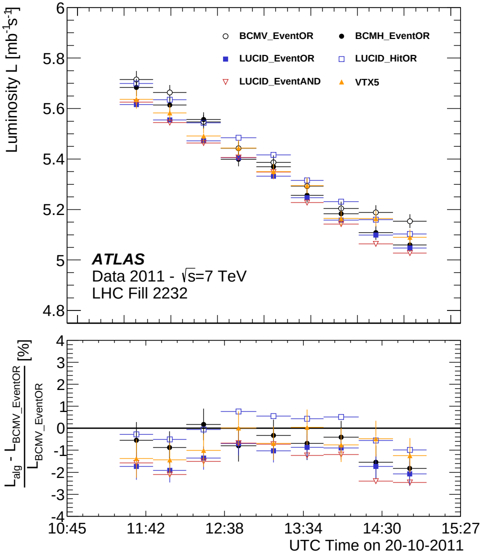
- Lepton identication and scale
- Track reconsttruction efficiency
- Pile-up
- Background
- Unfolding

Observable	Correlation	N_{ch} vs p_T^Z	$\sum p_T$ vs p_T^Z	Mean p_T vs p_T^Z	Mean p_T vs N_{ch}
Lepton selection	No	$0.5-1.0$	$0.1-1.0$	<0.5	$0.1-2.5$
Track reconstruction	Yes	$1.0-2.0$	$0.5-2.0$	<0.5	<0.5
Impact parameter requirement	Yes	$0.5-1.0$	$1.0-2.0$	$0.1-2.0$	<0.5
Pile-up removal	Yes	$0.5-2.0$	$0.5-2.0$	<0.2	$0.2-0.5$
Background correction	No	$0.5-2.0$	$0.5-2.0$	<0.5	<0.5
Unfolding	No	$0.5-3.0$	$0.5-3.0$	<0.5	$0.2-2.0$
Electron isolation	No	$0.1-1.0$	$0.5-2.0$	$0.1-1.5$	<1.0
Combined systematic uncertainty		$1.0-3.0$	$1.0-4.0$	<1.0	$1.0-3.5$

ALFA RUN SETUP

- High β^* runs for ATLAS, in parallel with TOTEM around CMS
- In October 2011, ATLAS/ALFA had dedicated beam time:
  - Intermediate optics with β^* = 90 m
  - Phase advance of β_y = 90° (parallel-to-point focusing in vertical)
  - Phase advance of $\beta_x \simeq 180^\circ$
  - Small emittance (2-3 µm.mrad)
  - Small divergence ($\sim$ 3 µrad)
  - One pair of colliding bunches with low intensity ($\simeq 7^{10}$ protons)
  - $\mathcal{L} \simeq 10^{27}$cm^{-2} s^{-1}($\mu \simeq 0.035$)
- 800k good elastic events used for the analysis of σ_{tot} and the nuclear slope, B

ALFA LUMINOSITY



- Luminosity estimated by ATLAS: $\mathcal{L} = 78.7 \pm 1.9$ µb
- Calibration transfer uncertainty from spread of measurements
- Uncertainty on the absolute luminosity scale is 1.53%
- Beam backgrounds 0.2%

Λ polarisation systematics

- Individual contributions added in quadrature (before rounding)
- Total systematic uncertainty smaller than statistical one

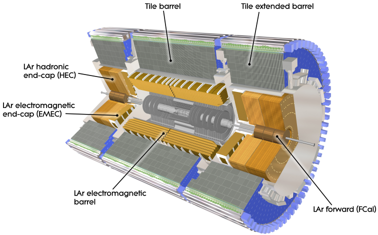
Systematic uncertainty	Λ	$\bar{\Lambda}$
MC statistics	0.003	0.003
Mass range	0.003	0.003
Background	0.001	0.001
Kinematic weighting	0.001	0.001
Other contributions	$< 5 \times 10^{-4}$	$< 5 \times 10^{-4}$
Total	0.004	0.004

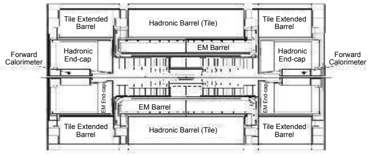
Λ polarisation parametrisation

- Many possible parametrisations
- One popular one is that presented by B. Lundberg in PRD 40 (1989) 3557
- Assumes energy independence and neglects detector effects

$$P = \left(-0.268x_F - 0.338x_F^3\right) \times \left(1 - e^{-4.5p_T^2}\right)$$

The ATLAS Detector: Calorimeters





- **EM calorimeters**
  - Barrel $|\eta| < 1.475$
  - End-cap $1.375 \leq |\eta| < 3.2$
- **Hadronic calorimeters**
  - Barrel $|\eta| < 1.0$
  - Extended barrel $0.8 \leq |\eta| < 1.7$
  - End-cap $1.5 \leq |\eta| < 3.2$
- **Forward calorimeters**
  - LAr $3.2 \leq |\eta| < 4.9$