

Low energy observables and exclusive production with the ATLAS Detector

EPS-HEP – Venice, Italy. July 6th 2017



Tim Martin

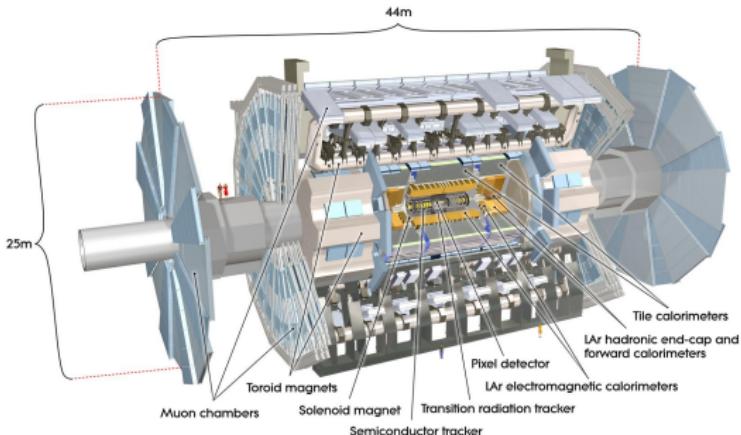
University of Warwick, on behalf of the
ATLAS Collaboration

July 6, 2017

Introduction

Studies of low energy particle production at the LHC help constrain multi parton interactions & hadronisation models: hadron-chains & underlying event.

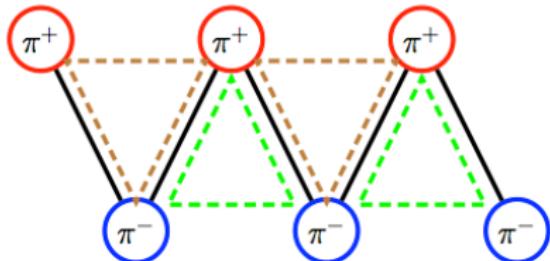
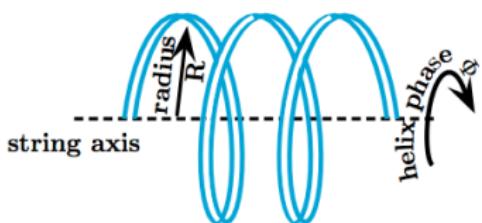
Low mass photo-production of $\mu^+\mu^-$ is another avenue to study high-energy electroweak processes at a hadron collider.



Study of **ordered hadron chains** with the ATLAS detector

Paper in Preparation — ATLAS STDM-2014-08

Helical String Fragmentation

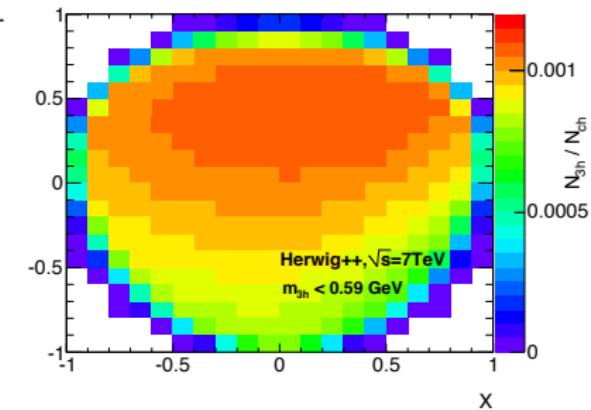
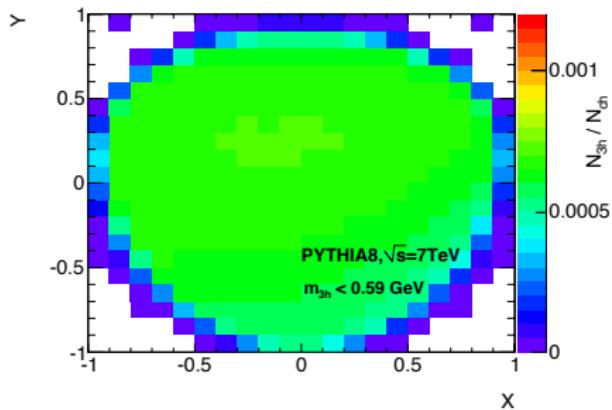


Extension to Lund string hadronisation as found in Pythia to 3D. Go from using quantum tunnelling inspired Gaussian sampling for intrinsic p_T to 2-parameter helix model: kR (string tension, $k \sim 1$ GeV/fm, radius R) and phase $\Delta\Phi$.

Ordered hadron chains: identify like-sign pair with minimum $Q^2 = -(p_1 - p_2)^2$, add opposite sign which minimises triplet mass.

Mass of chain of ground state hadrons: $M_{3h} < 575 \pm 20$ MeV

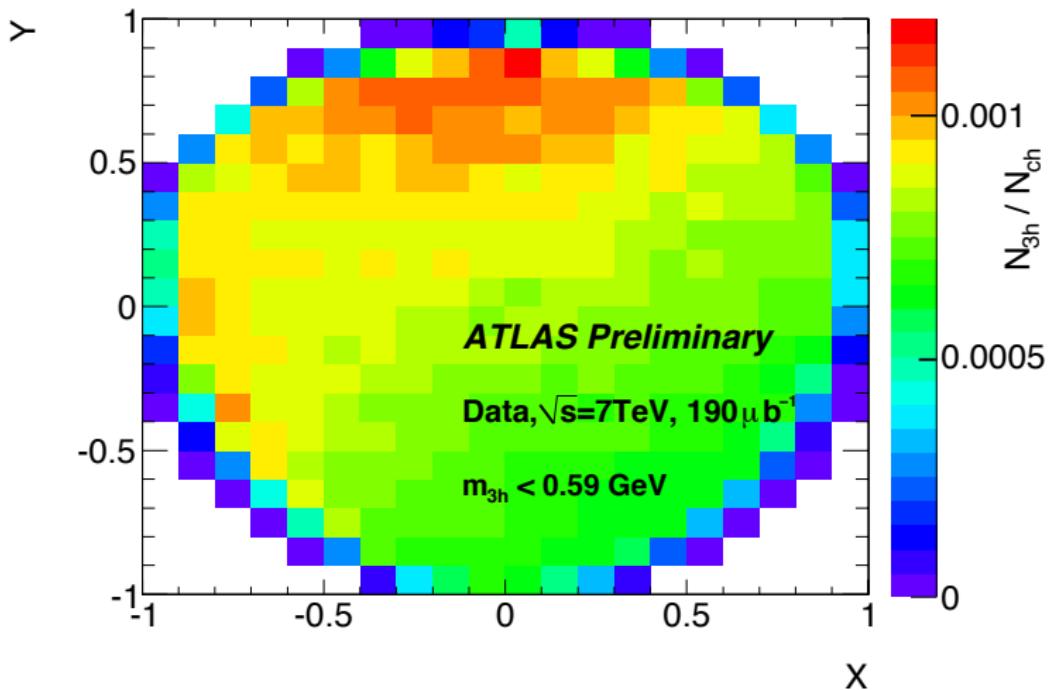
MC 3-body Dalitz Distributions. Pythia & Herwig.



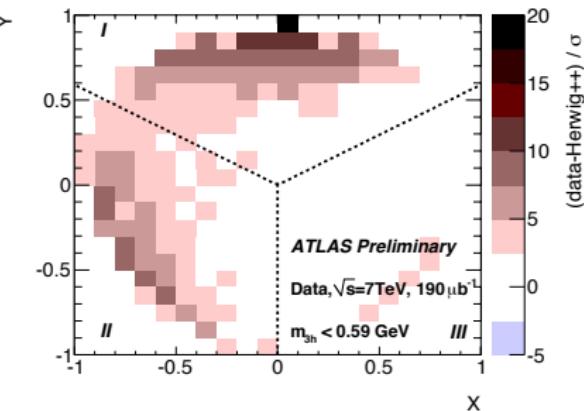
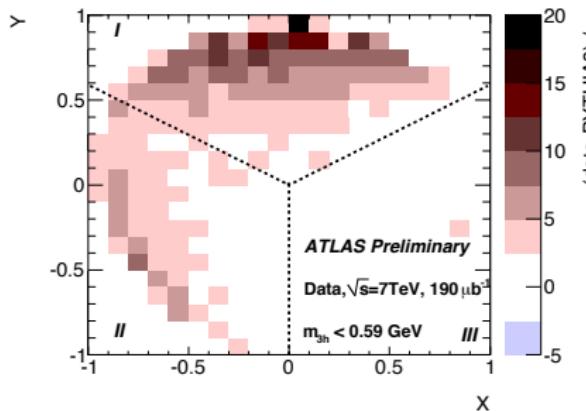
$$X = \sqrt{3} \frac{T_0 - T_2}{\sum T}, Y = \frac{3T_1}{\sum T} - 1$$

$T_i = E_i(m_\pi) - m_\pi$, kinetic energy in the chain's rest frame. $i = 0, 2$ are same-signed, and opposite sign to $i = 1$. Selection: $m_{3h} < 0.59 \text{ GeV}$

Data 3-body Dalitz Distributions

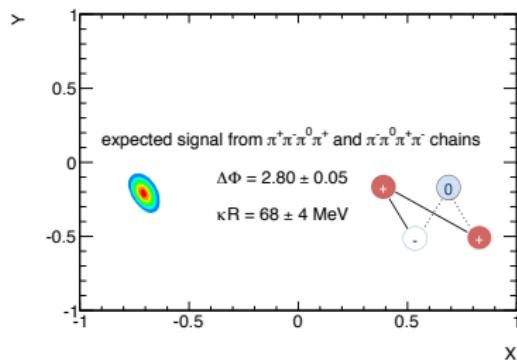
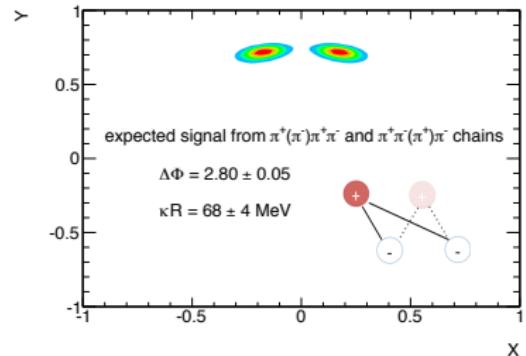
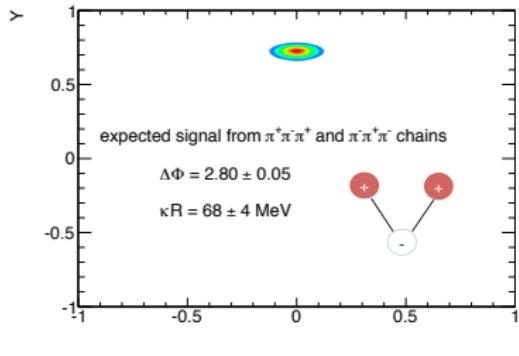


MC 3-body Dalitz Significance

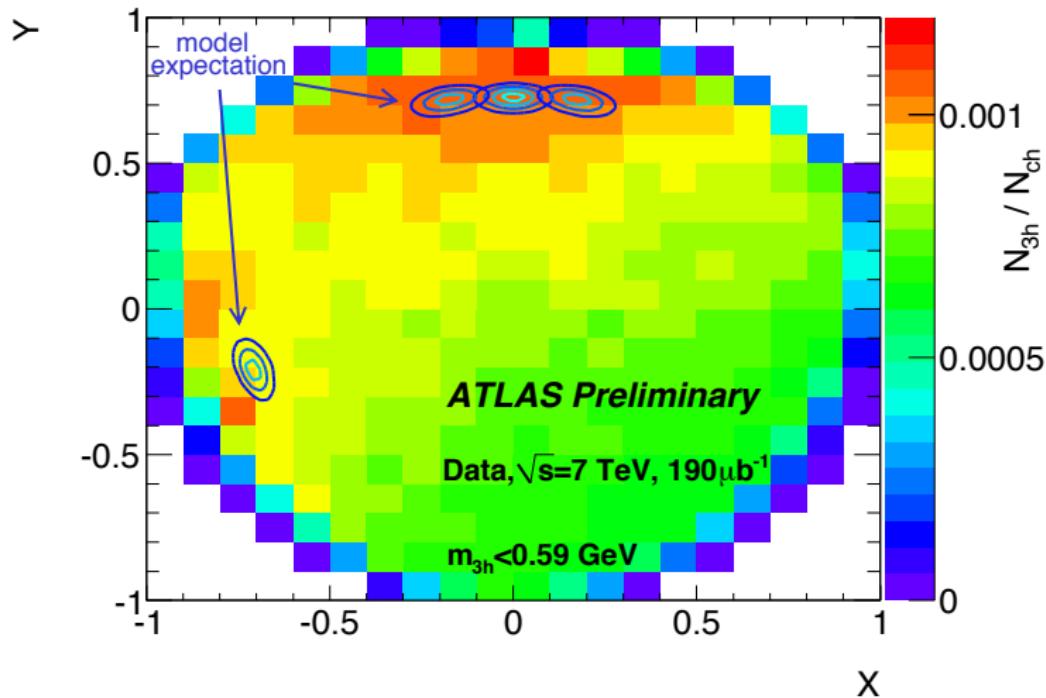


Significance of deviation in data vs Pythia & Herwig.

Helical Model Expectations



Model Expectations Overlaid On Data

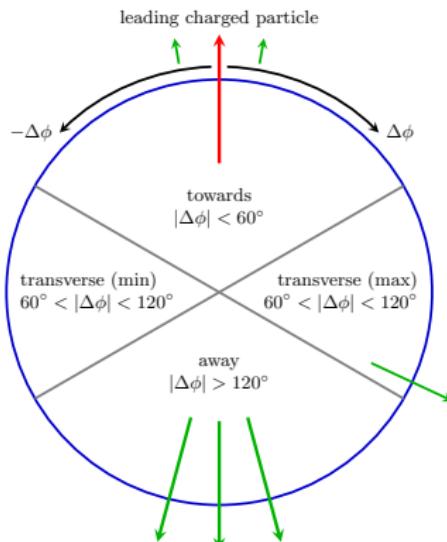


The *Underlying Event* with tracks at $\sqrt{s} = 13$ TeV with ATLAS

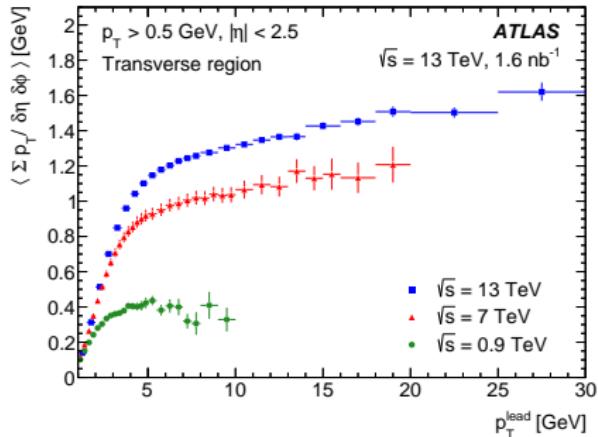
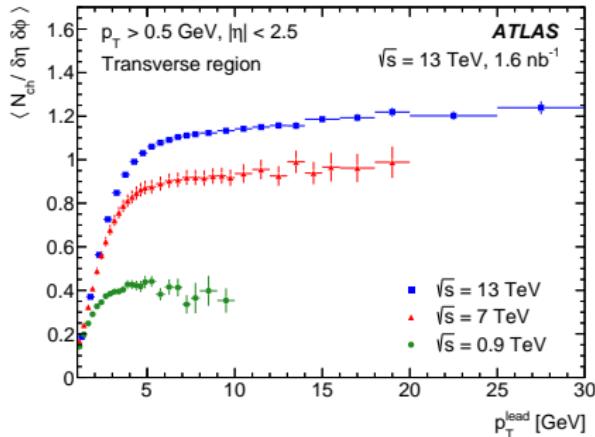
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The ‘Underlying Event’ (or: everything *but* the hard scatter)

Investigate the $\Delta\phi$ correlations of the final state radiation pattern with respect to the **leading** track. Generated by multiple partonic interactions within the pp interaction and their colour connections.



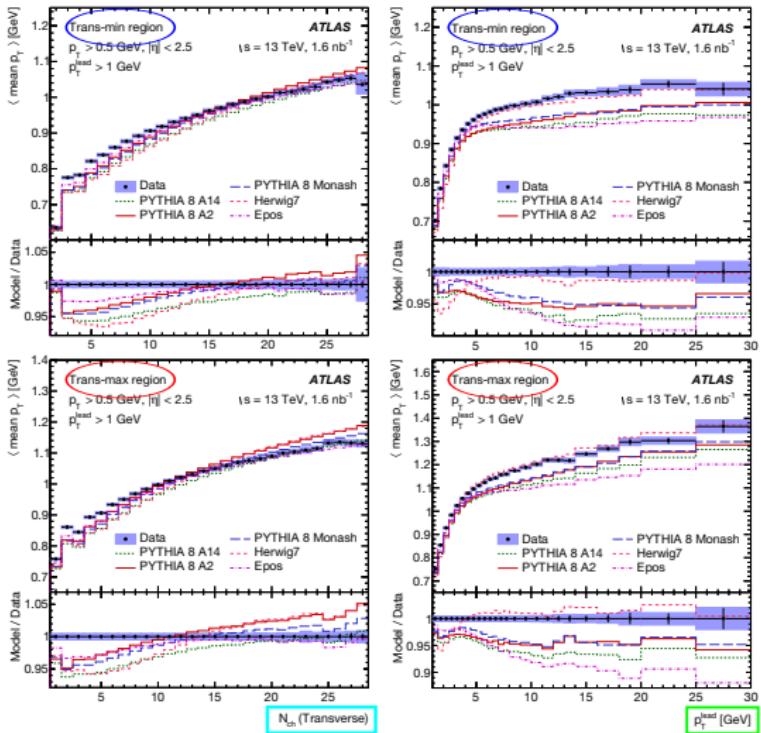
Flattening Of $\langle p_T \rangle$ & $\langle N_{ch} \rangle$



By $p_T^{\text{lead}} > 5 \text{ GeV}$, the pp impact parameter ~ 0 .

Data from all three centre of mass energies of recent use in tuning colour reconnection: **ATL-PHYS-PUB-2017-008**

Putting Them Together: $\langle \text{mean } p_T \rangle$

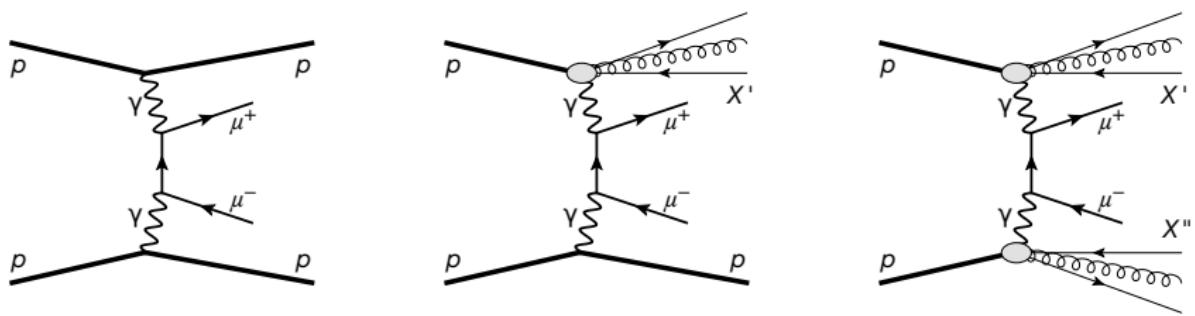


NEW!

The *exclusive* $\gamma\gamma \rightarrow \mu^+\mu^-$ process at
 $\sqrt{s} = 13$ TeV with ATLAS

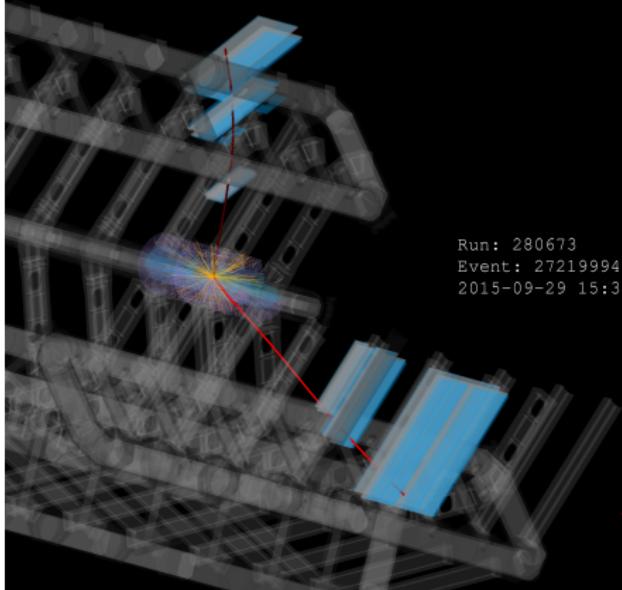
Paper in Preparation — ATLAS STDM-2016-13

Exclusive & Dissociative Interactions - the EPA

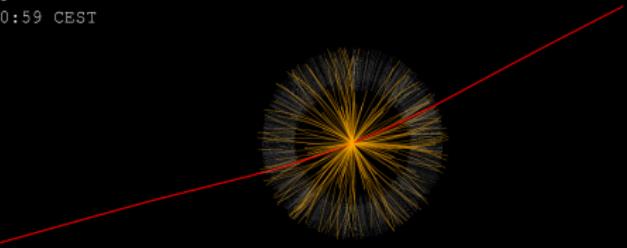
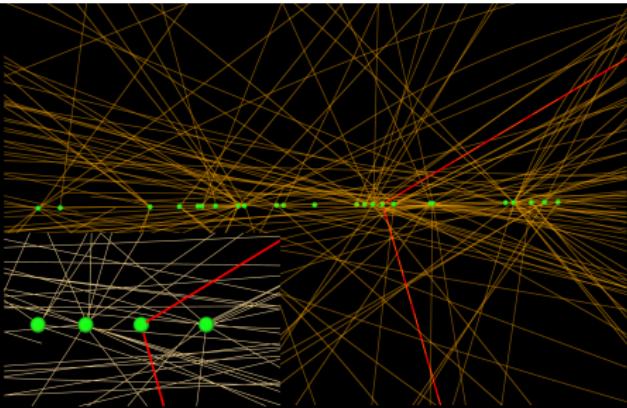


Turn the LHC into a $\gamma\gamma$ collider: modelled as a flux of quasi-real ($Q^2 < 0.01 \text{ GeV}^2$) photons under the Equivalent Photon Approximation (EPA), the Fourier transform of the proton's EM form-factor.

Challenge: Dissociative backgrounds, somewhat irreducible at ATLAS.

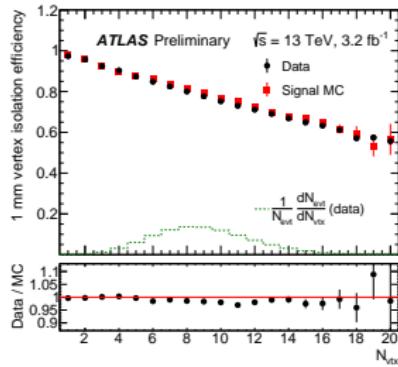


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Event: 272199949
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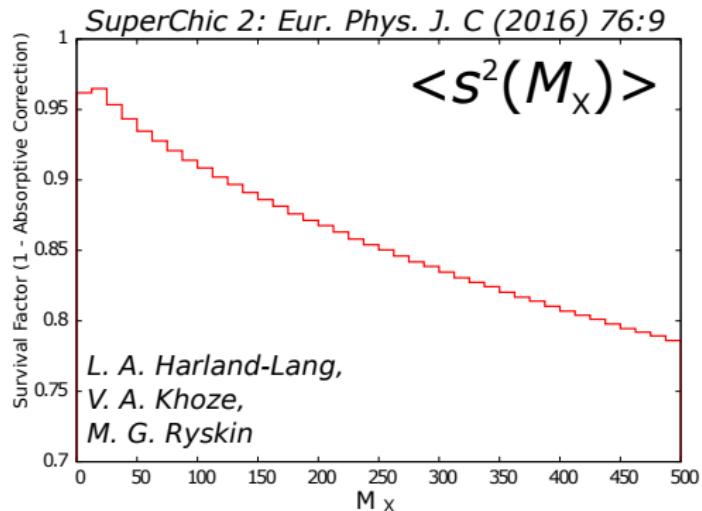
Pileup & Absorptive Corrections in Finite Size Model

Challenge: Ascertaining exclusivity in the presence of pile up vertices with $\mu \sim 13$. Require zero additional tracks within 1mm of $\mu^+ \mu^-$ vertex.



Challenge: pp Absorptive effects (typically additional gluon interactions) suppress the exclusive cross-section. Modelled by finite-size parametrisation based on E_γ , impact parameter & proton opacity. Requires γ at radii $r > 0.64 \text{ fm}$

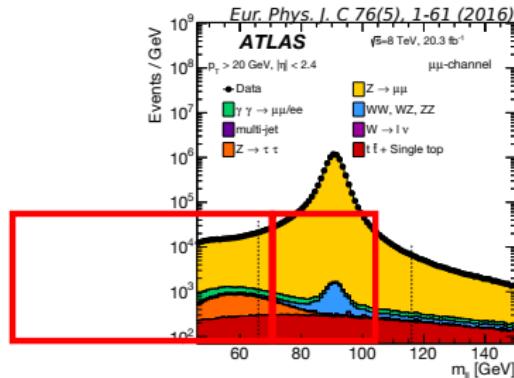
Absorptive Corrections in SuperChic2



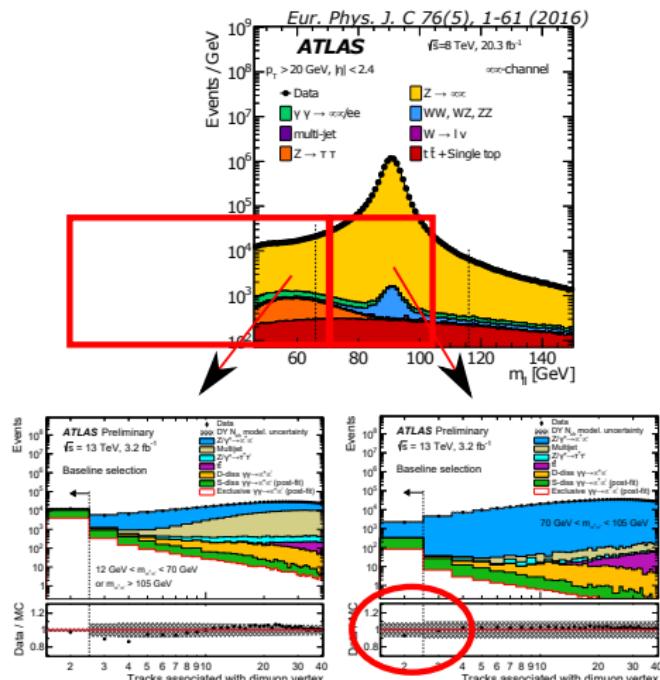
'Survival Factor' as a function of central system mass, M_X (GeV), for two-photon mediated processes.

Amplitude level calculation differential in the kinematics of the outgoing pp .

Combatting Drell-Yan & Other Backgrounds

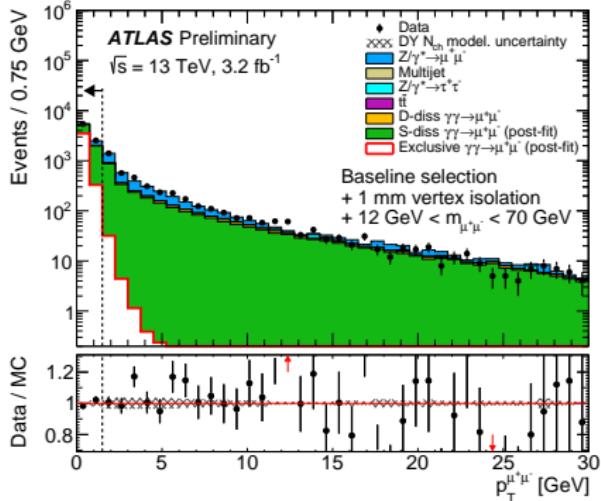
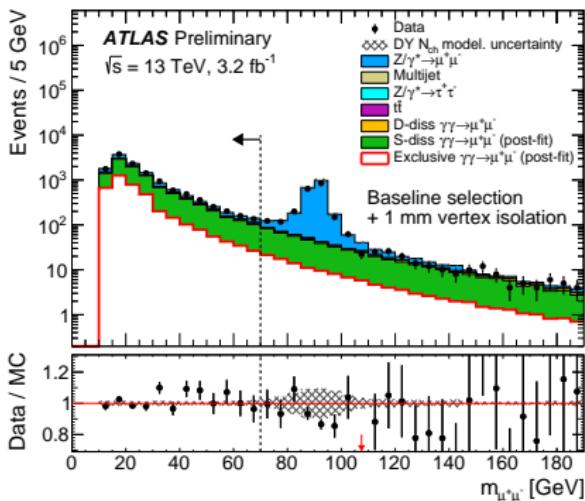


Combatting Drell-Yan & Other Backgrounds



Two-track-on vertex bin with Z selection indicates MC modelling to 10%

1mm Vertex Exclusivity, Z cut, $p_T^{\mu^+\mu^-} < 1.5$ GeV cut



Data with typical pileup $\mu \sim 13$. Data-driven $78 \pm 1\%$ veto efficiency.

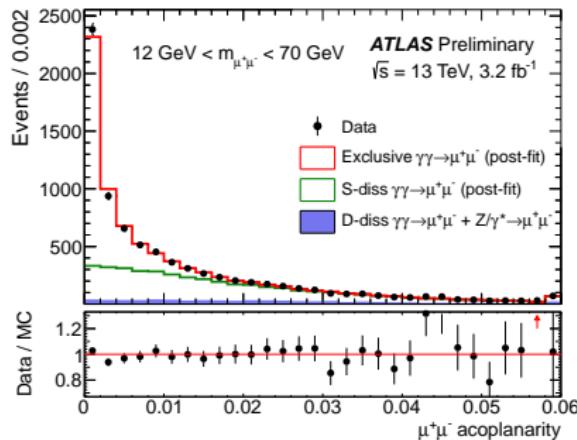
p_T cut - further single dissociative suppression.

Fit The Acoplanarity: $1 - |\Delta\phi_{\mu^+\mu^-}|/\pi$

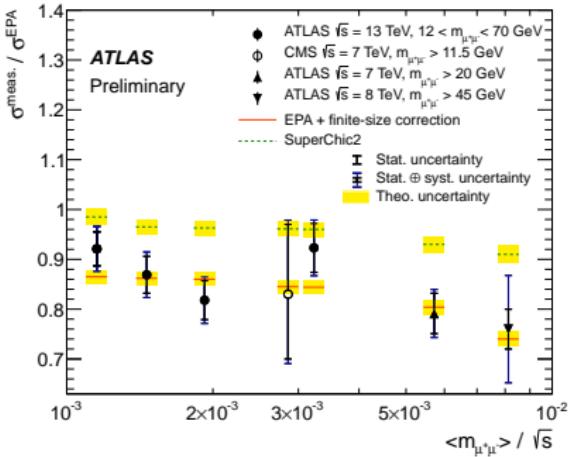
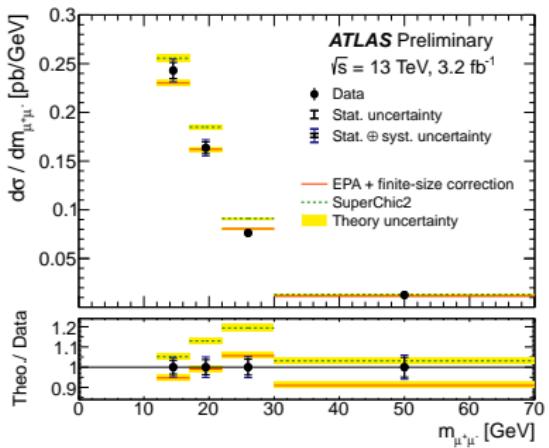
Fiducial cross section for $p_T^\mu > 6 \text{ GeV}$ ($12 < m_{\mu^+\mu^-} < 30 \text{ GeV}$), $p_T^\mu > 10 \text{ GeV}$ ($30 < m_{\mu^+\mu^-} < 70 \text{ GeV}$) & corrected for detector inefficiency.

Extracted via binned maximum likelihood fit of $N_{\text{exc.}}$, $N_{\text{s-diss.}}$.

$$\sigma_{\gamma\gamma \rightarrow \mu^+\mu^-}^{\text{exc.fid.}} = 3.12 \pm 0.07(\text{stat}) \pm 0.10(\text{sys.}) \text{ pb}$$



Cross Section Binned in $m_{\mu^+\mu^-}$ & $\langle x \rangle \approx \langle m_{\mu^+\mu^-} \rangle / \sqrt{s}$



Look for **absorptive effects** as fn. of energy fraction of quasi-real γ .

Insufficient suppression in SuperChic2 (10-15%). Possibly originating from the photon flux at small impact parameter.

Conclusions

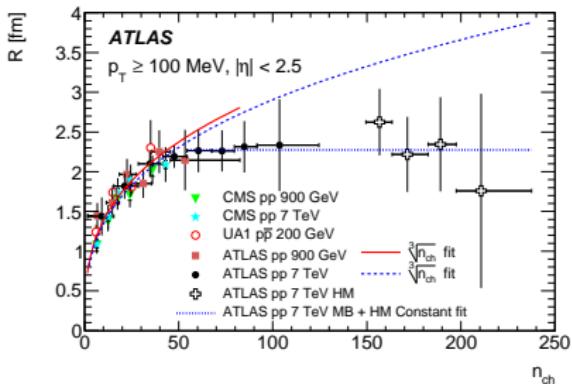
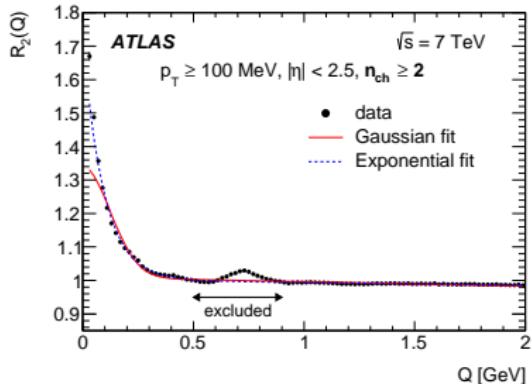
First measurement of the exclusive $pp \rightarrow \mu\mu$ photo-production process at $\sqrt{s} = 13$ TeV, with $12 < m_{\mu^+\mu^-} < 70$ GeV.

Absorptivity corrections are studies as a function of the energy fraction the γ takes from the p .

Evidence of structure in the three-body kinematics of inclusive particle production in pp interactions. Can be interpreted in the context of a helical gluon packing within a Lund string model.

'Underlying Event' studies exhibit sensitivity to soft & hard radiation modelling in pp interactions. Data of great use in Monte Carlo tuning.

Bose Einstein Condensate Eur. Phys. J. C75 (2015) 466



Enhancement in production of nearby identical bosons. R is a double ratio of a particle correlator with like-sign over opposite-sign, and data over MC (with no BEC).

Study multi-particle production & size of region emitting correlated particles.