Properties of non pQCD at 7TeV

Wei Li, Massachusetts Institute of Technology

on behalf of ATLAS and CMS collaboration

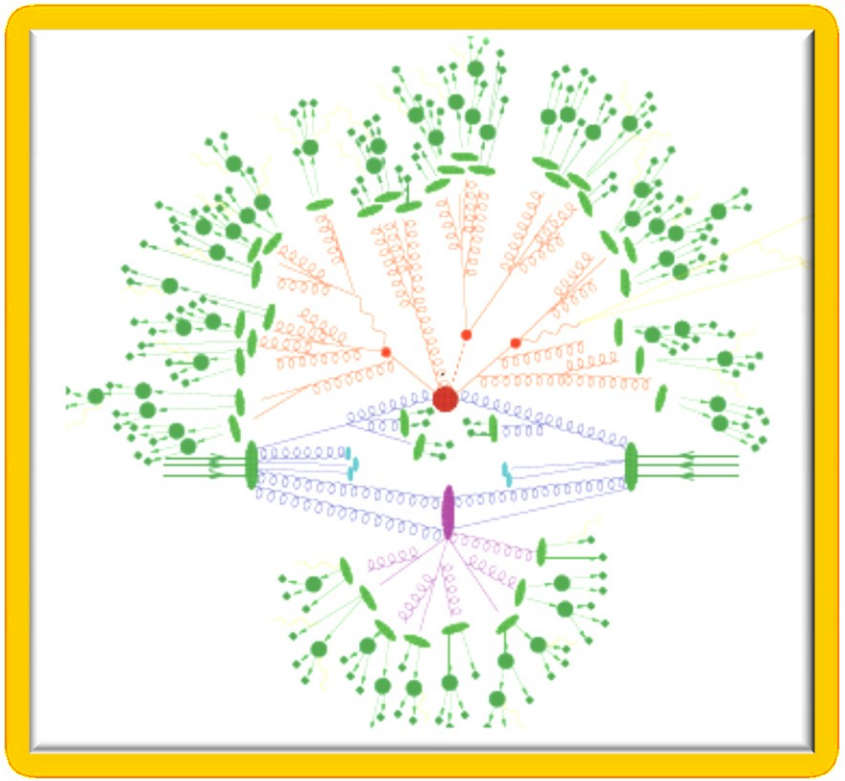
Conference on LHC First Data

Ann Arbor, MI, Dec. 12-14, 2010

LHC Physics requirements

Exploring inch-by-inch the new territory made accessible by LHC

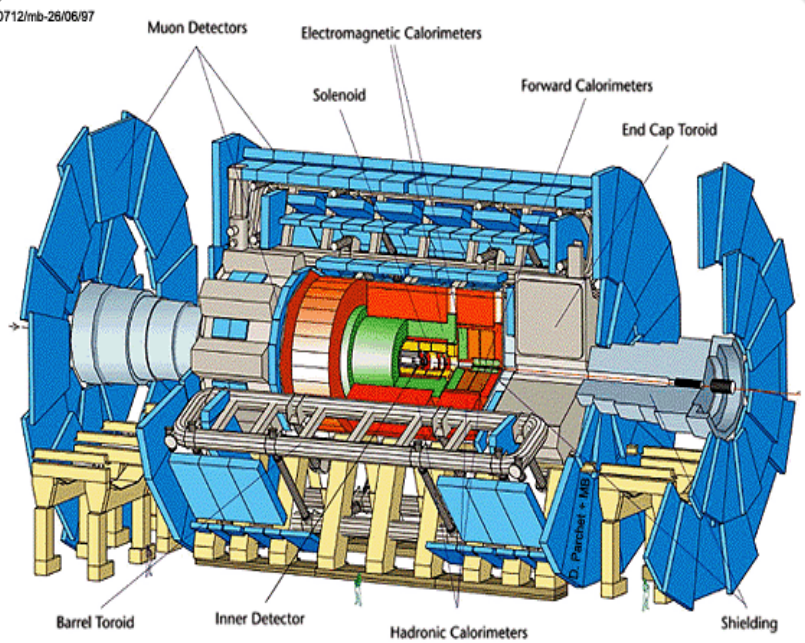
Very complex QCD environment



Soft QCD dominates bulk feature of the particle production in pp

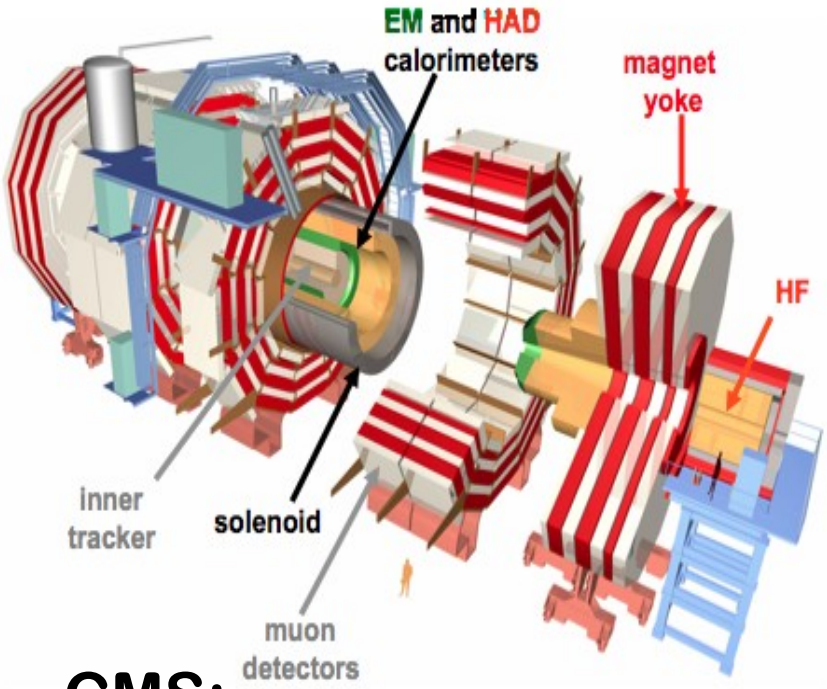
- Still poorly described theoretically
- Critical for tuning MC models and understanding the background for other searches
- New physics!

General purpose detectors: ATLAS vs CMS



ATLAS:

Length : ~45 m
Diameter : ~24 m
Weight : ~7,000 tons
2T solenoid + toroids

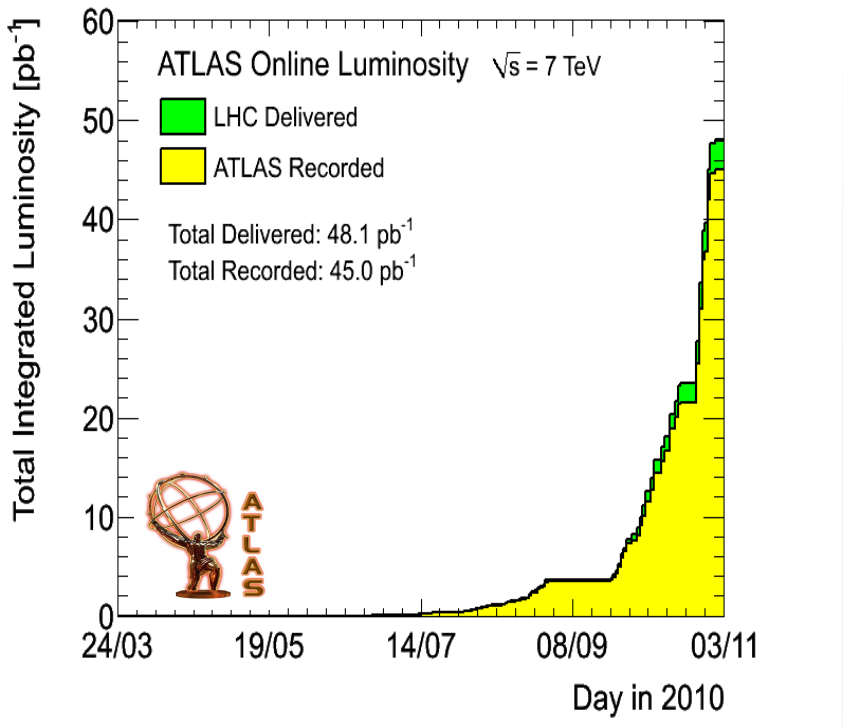


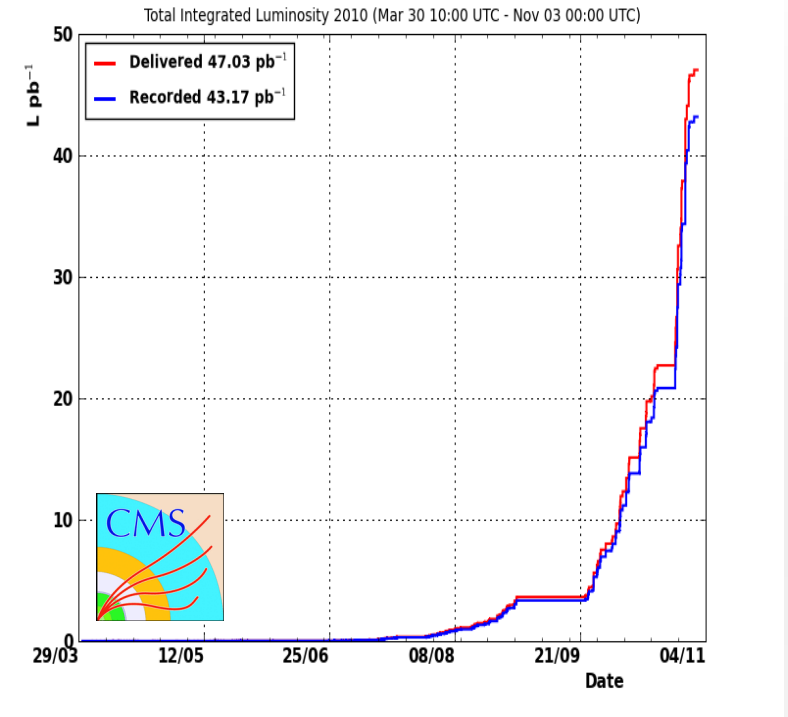
CMS:

Length : ~28.7 m
Diameter : ~15 m
Weight : ~14,000 tons
3.8T solenoid, compact

Excellent performance with first year data!

1st Year Integrated Luminosity





Proton-proton collisions at 7TeV:

- High experimental data-taking efficiency (>90%)
- ~ 45pb^{-1} recorded by each experiment

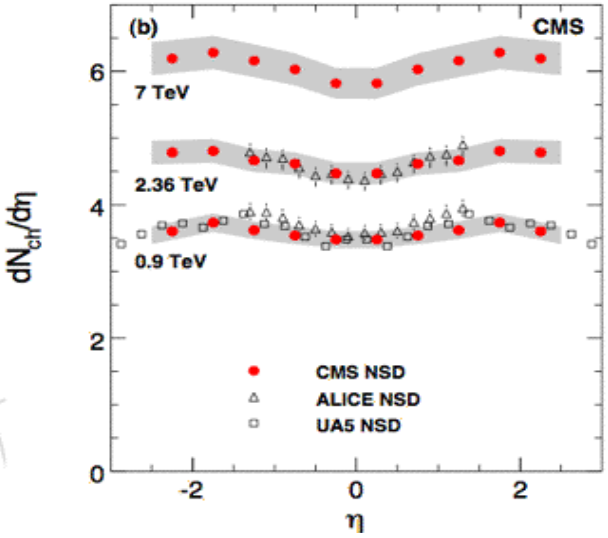
Time to dig for diamonds …

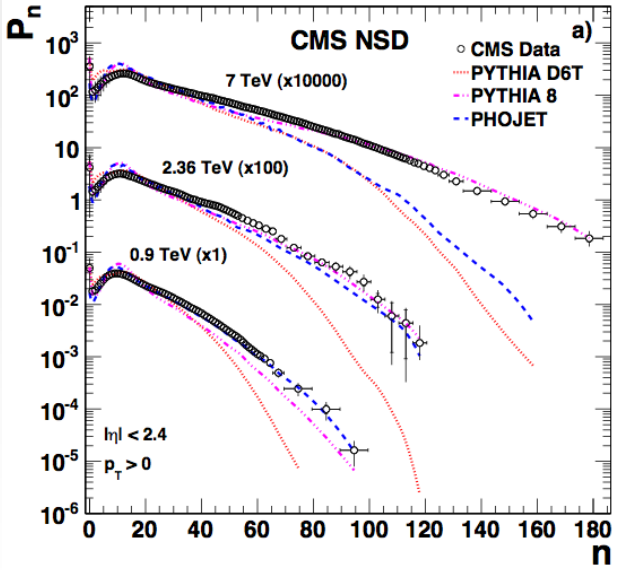
Charged Multiplicity Production

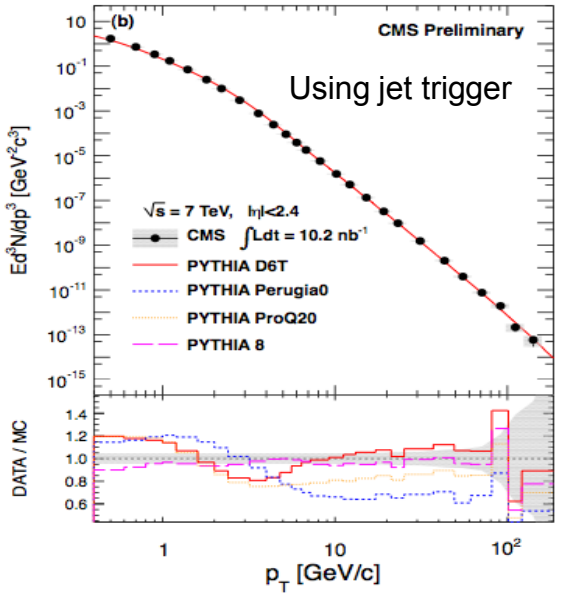
Single Particle Spectra

CMS Results

- Three methods: hit counting, tracklets and tracks for dN/dη
- Extrapolated to $p_T = 0$ (e.g. Tsallis fit below 100MeV/c)
- Corrected to non-single-diffractive (NSD) event (based on PYTHIA)







Single Particle Spectra

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- Extrapolated to $p_T = 0$ (e.g. Tsallis fit below 100MeV/c)
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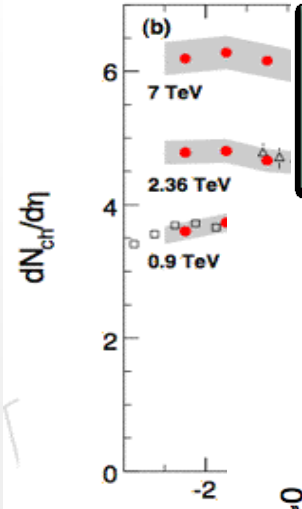
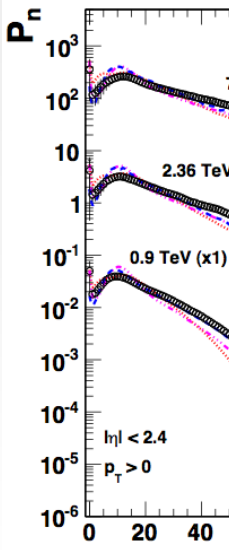
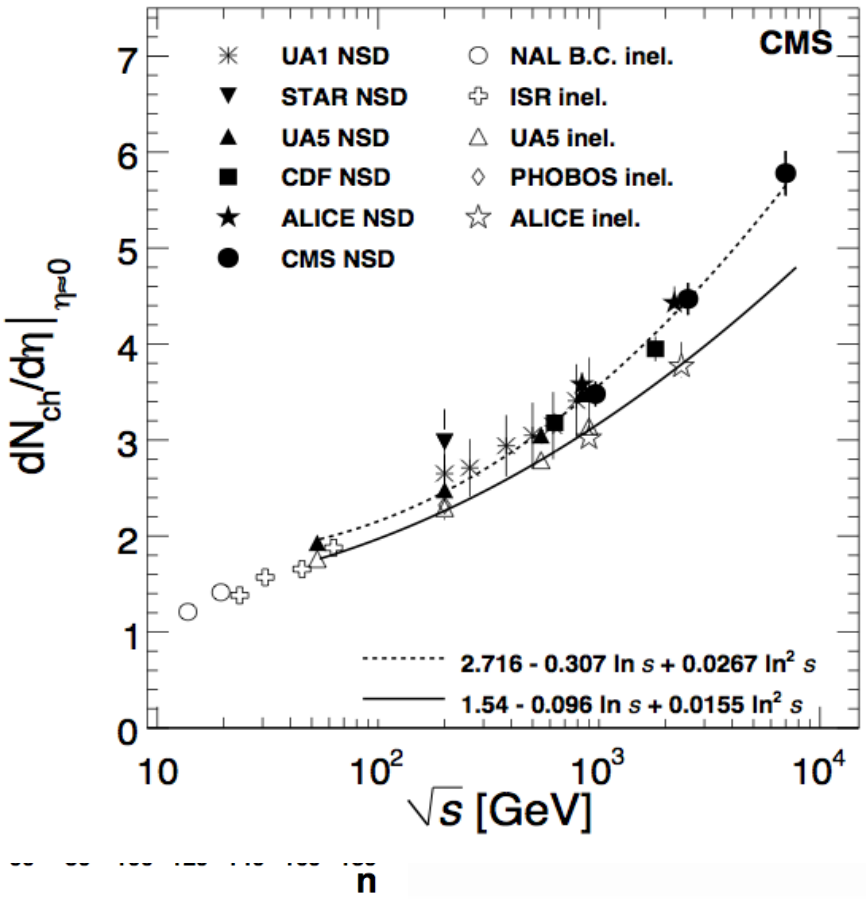
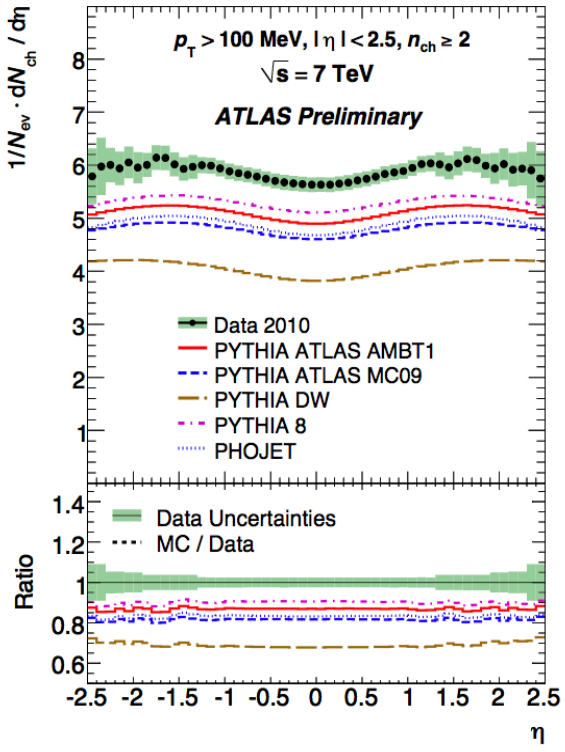
Steeper energy dependence than predicted by most models

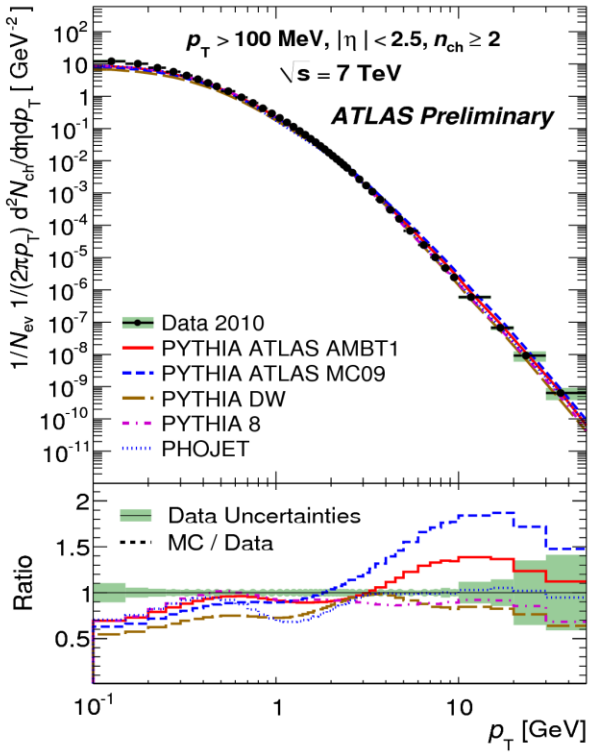


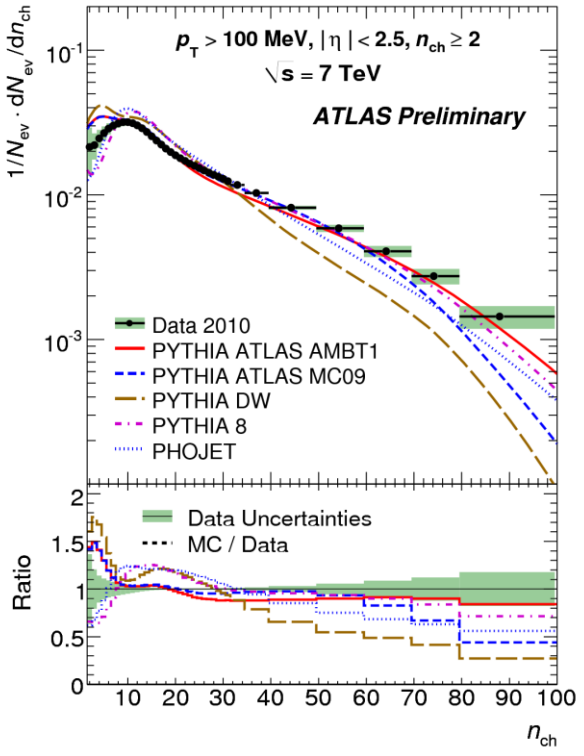




Single Particle Spectra



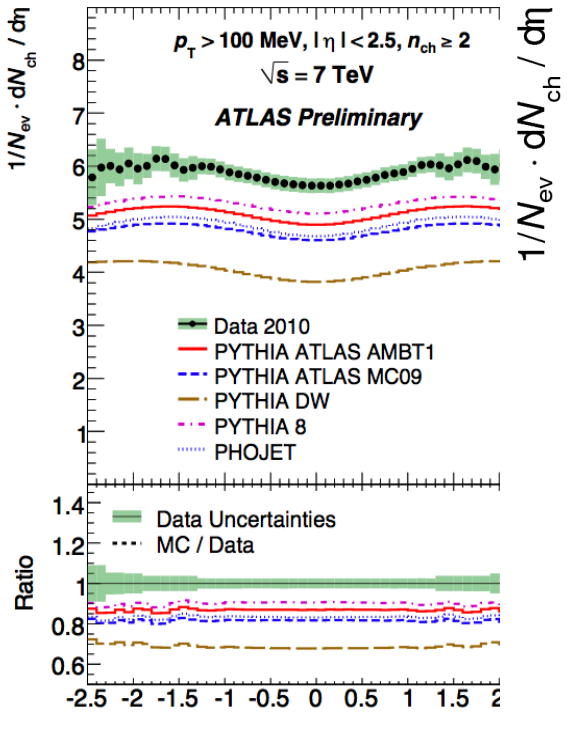


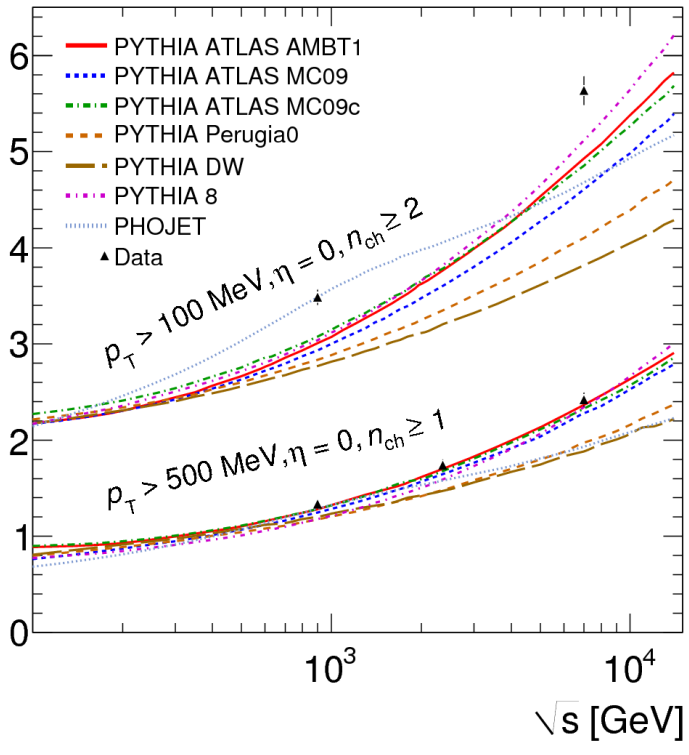


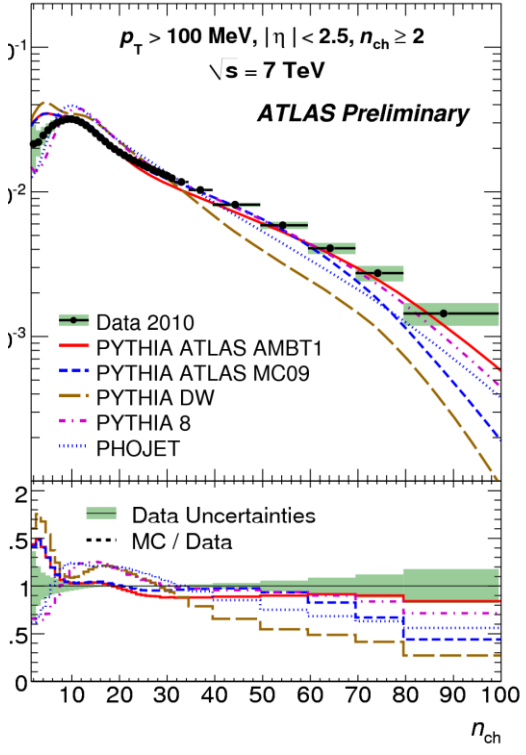
Latest ATLAS Results

- N_{trk}>=2 with p_T>0.1GeV, $|\eta|$<2.5
- No model dependent corrections (i.e. diffractive components)
- Excess of low pT particles not described by MC models:
  AMBT1 tuned in a diffractive-limited phase space (N_{trk}>=6, p_T>0.5GeV/c)

Single Particle Spectra







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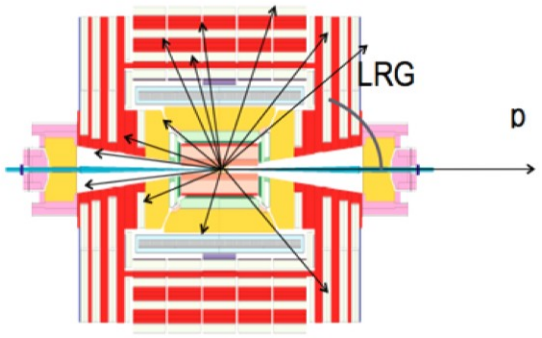
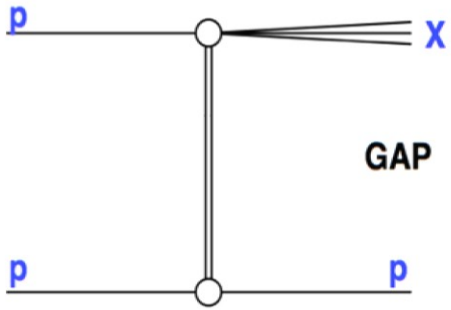
Forward Diffraction

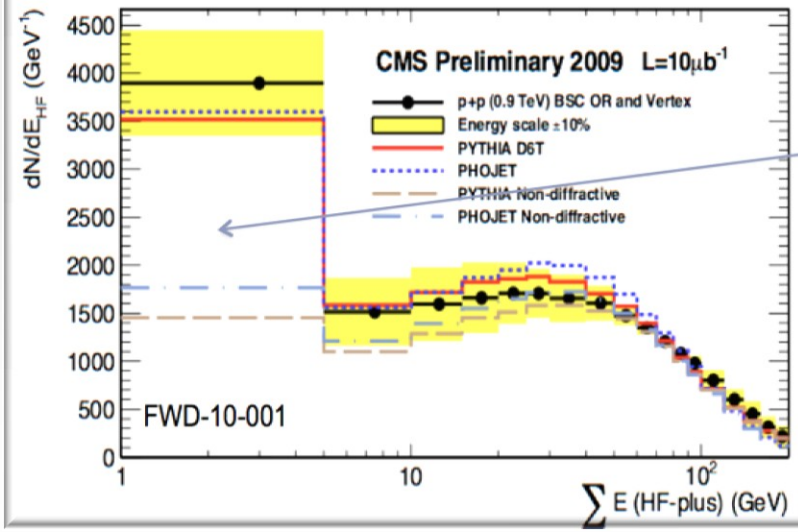
Observation of diffraction in CMS at 0.9TeV

Sketch of single-diffractive event:





Two (groups) final-state hadrons separated in rapidity



Σ E related to the momentum loss of the scattered proton. One expects a (diffractive) peak at low values of this variable ($\sigma \sim 1/\xi$).

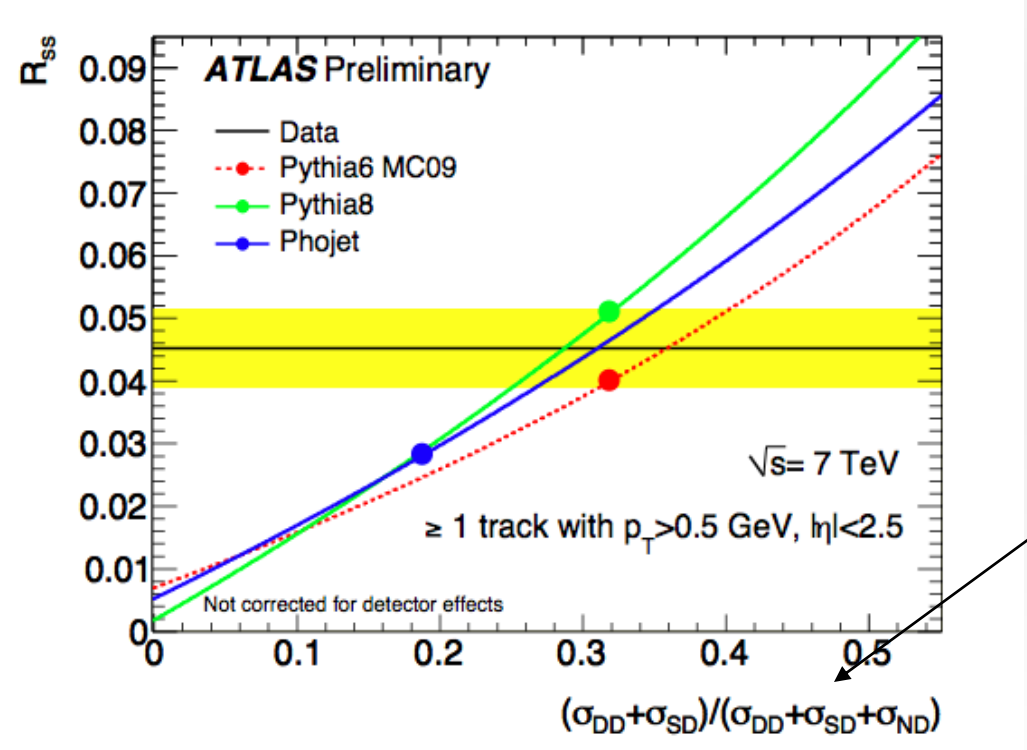
N.B. All plots are uncorrected

Forward Diffraction

Diffraction enhanced sample at ATLAS

Ratio of single-side (MB scintillators) events to any-side events in data:

Rss = 4.52 ± 0.02(stat) ± 0.61(syst) [%] (uncorrected)



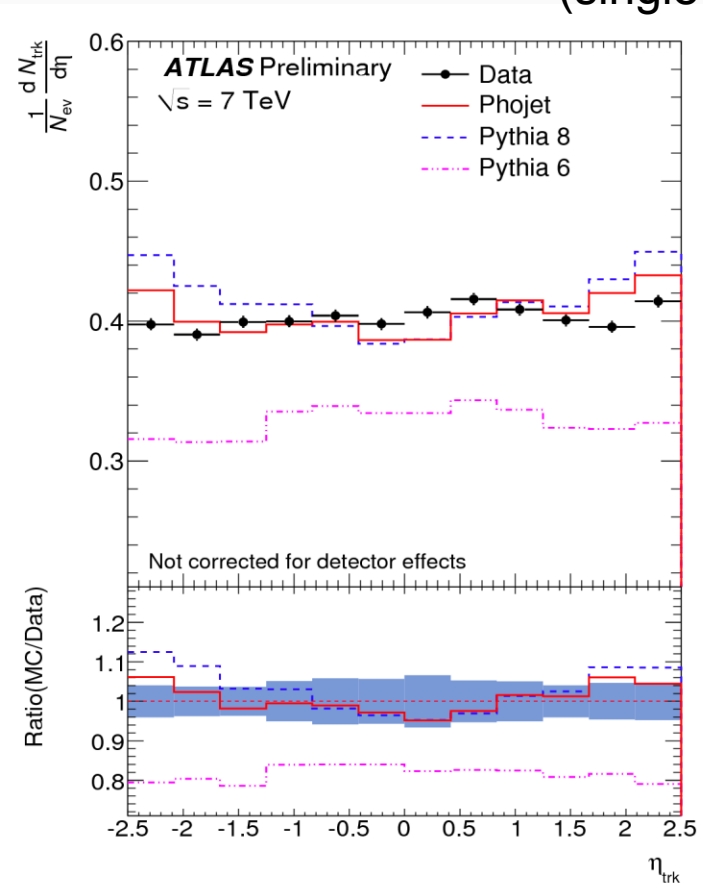
Fraction of diffractive components

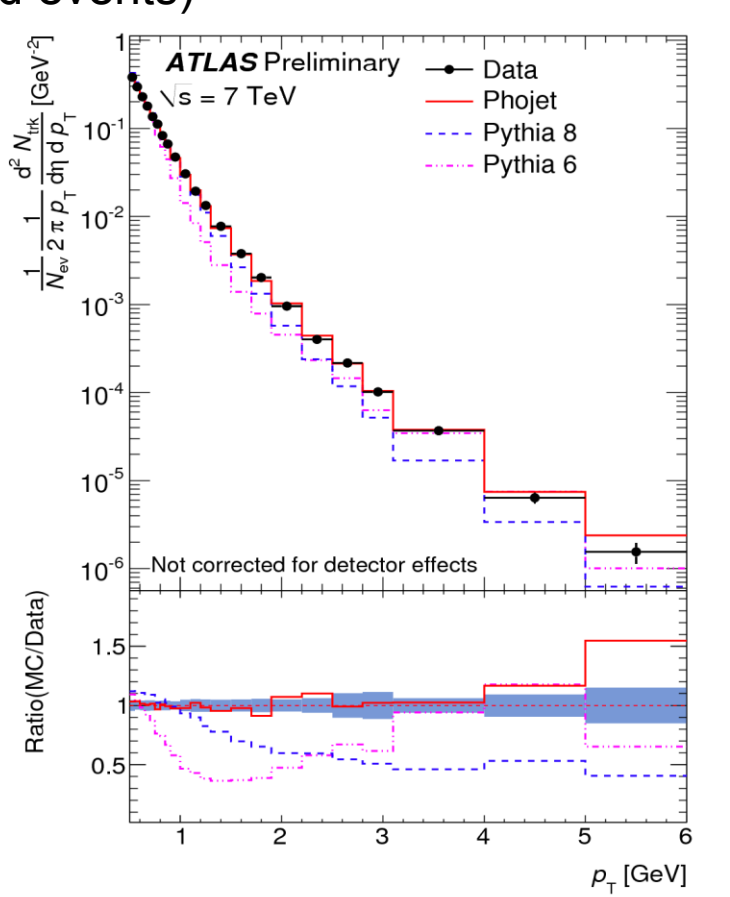
All models favor ~30% diffractive component

Forward Diffraction

Kinematics of diffractive enhanced processes

(single-sided events)



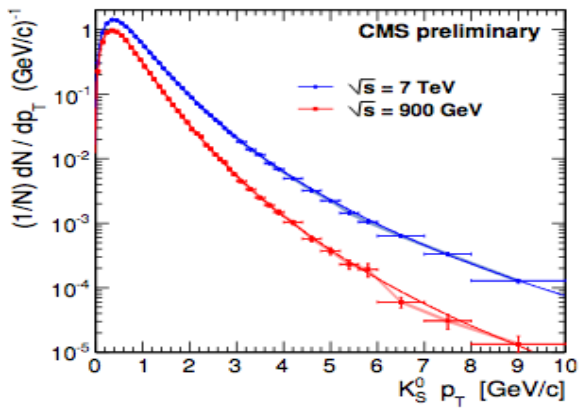


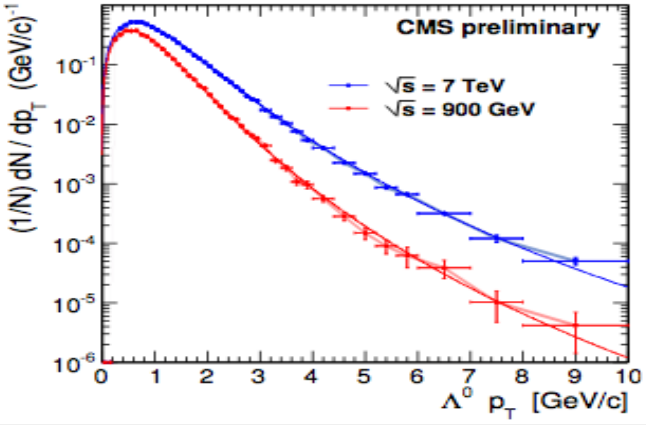
PYTHIA 6 lack of hard diffractive component,
while PHOJET and PYTHIA 8 do a better job

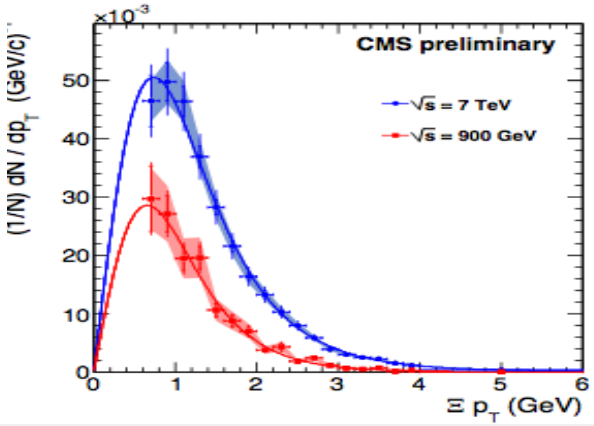
Strange Hadron Production

Mass Peaks : Excellent agreement with PDG!

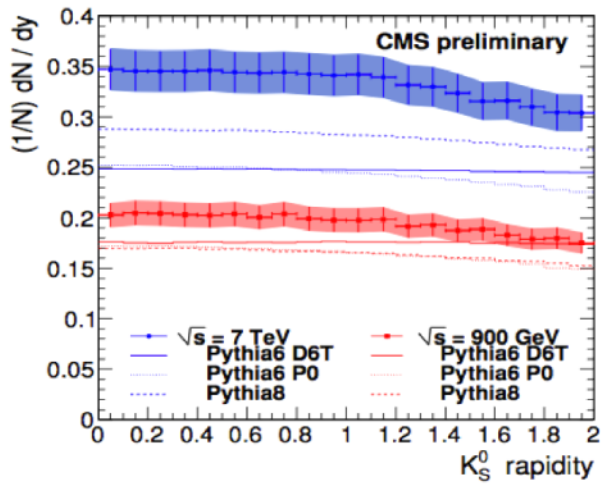
Strange Hadron Production

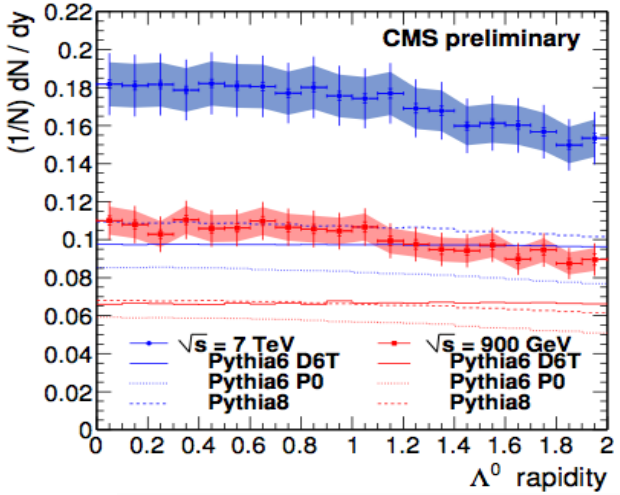


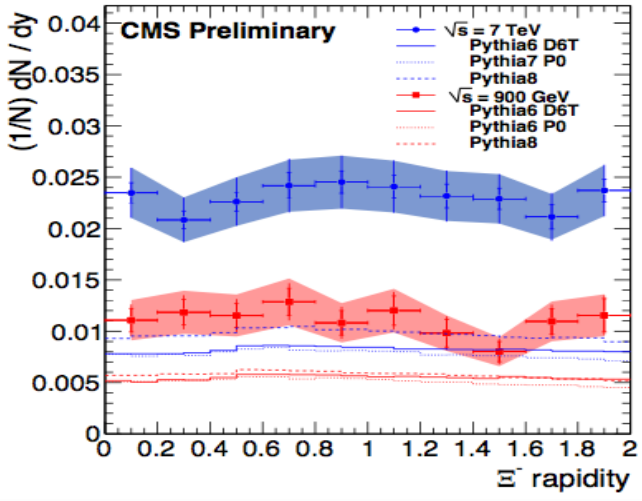




Strange Particle Yield (K_s,Λ,Ξ) underestimated by MC models



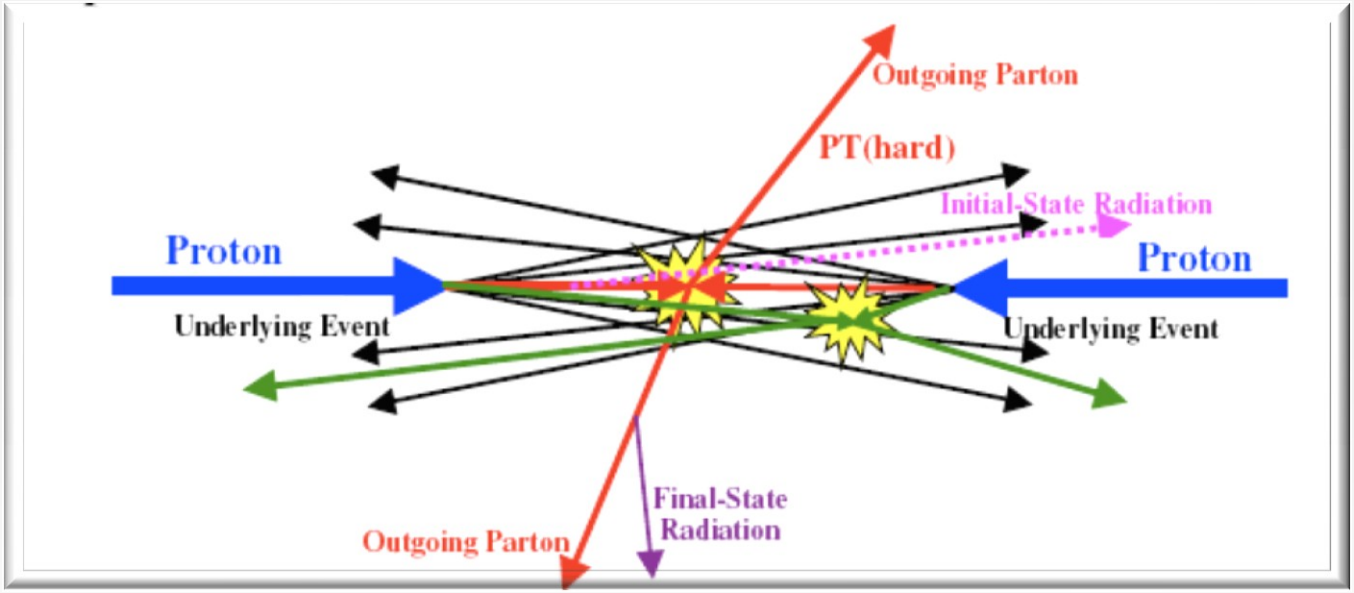




Underlying Event Studies & Particle Correlations

Underlying Event Studies

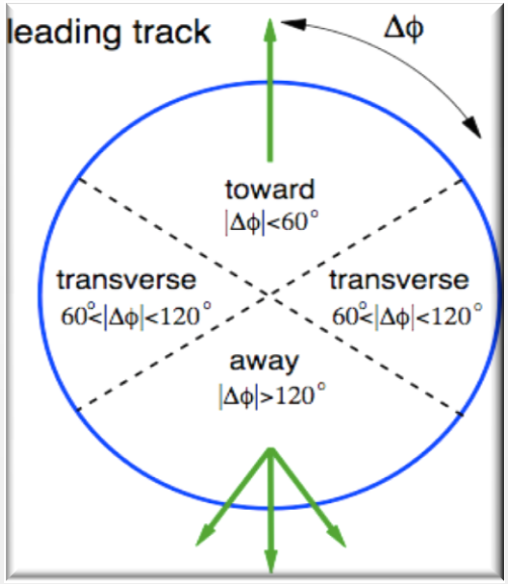
Underlying event (UE): beam-beam remnants, multiple parton interactions, initial and final state radiation, etc. (part that doesn't participate in the hard scattering)



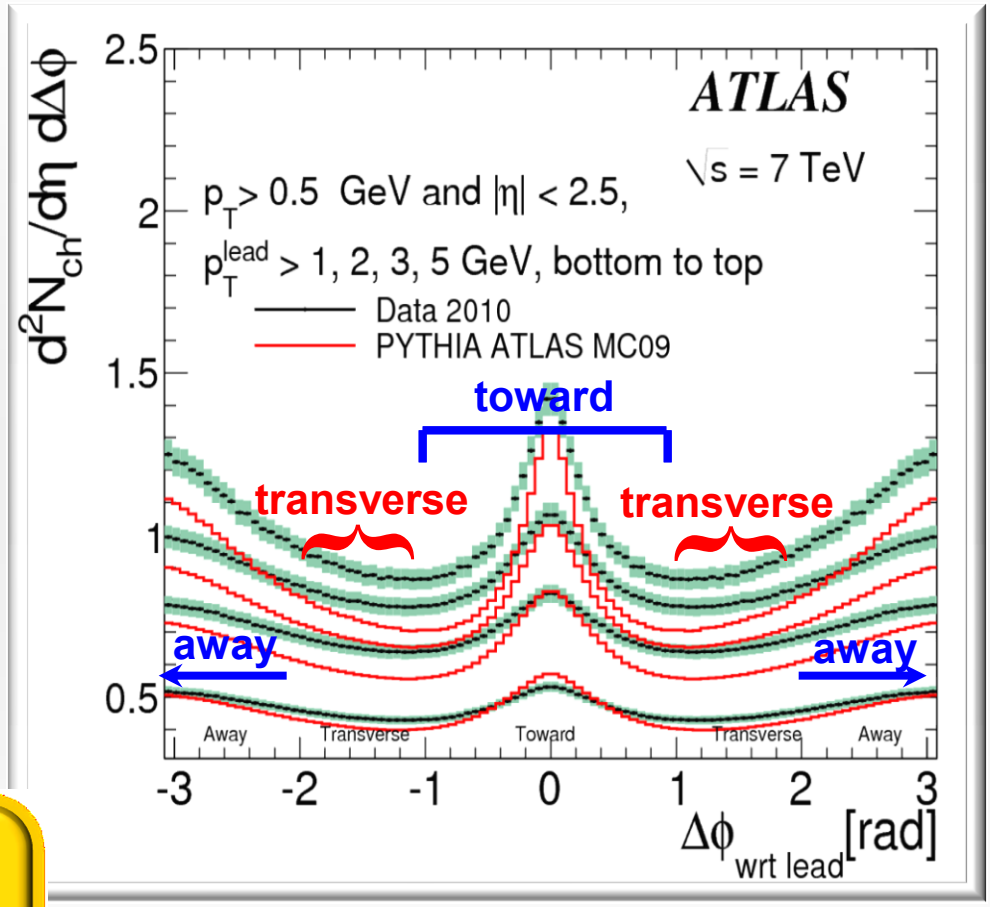
Important and unavoidable QCD background

Crucial for many precise measurements (jets, missing E_T etc.)

Underlying Event Studies



- Leading Track (Jet) define a direction in the ϕ plane
- Track (jet) p_T provide an energy scale

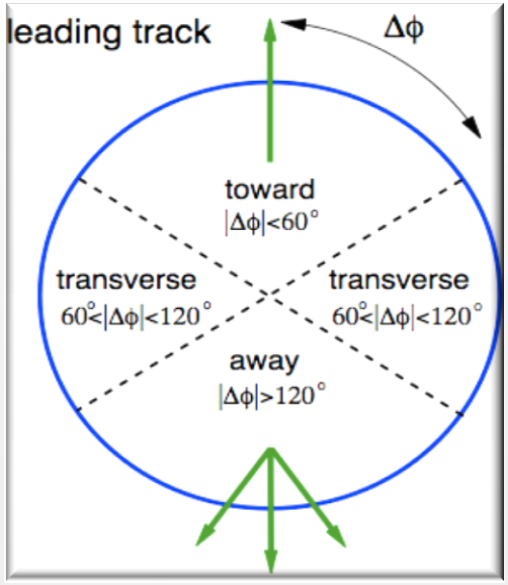


Main observables:

$d^2N_{ch}/d\eta d\phi$ - multiplicity density

$d^2\Sigma p_T/d\eta d\phi$ - energy density

Underlying Event Studies



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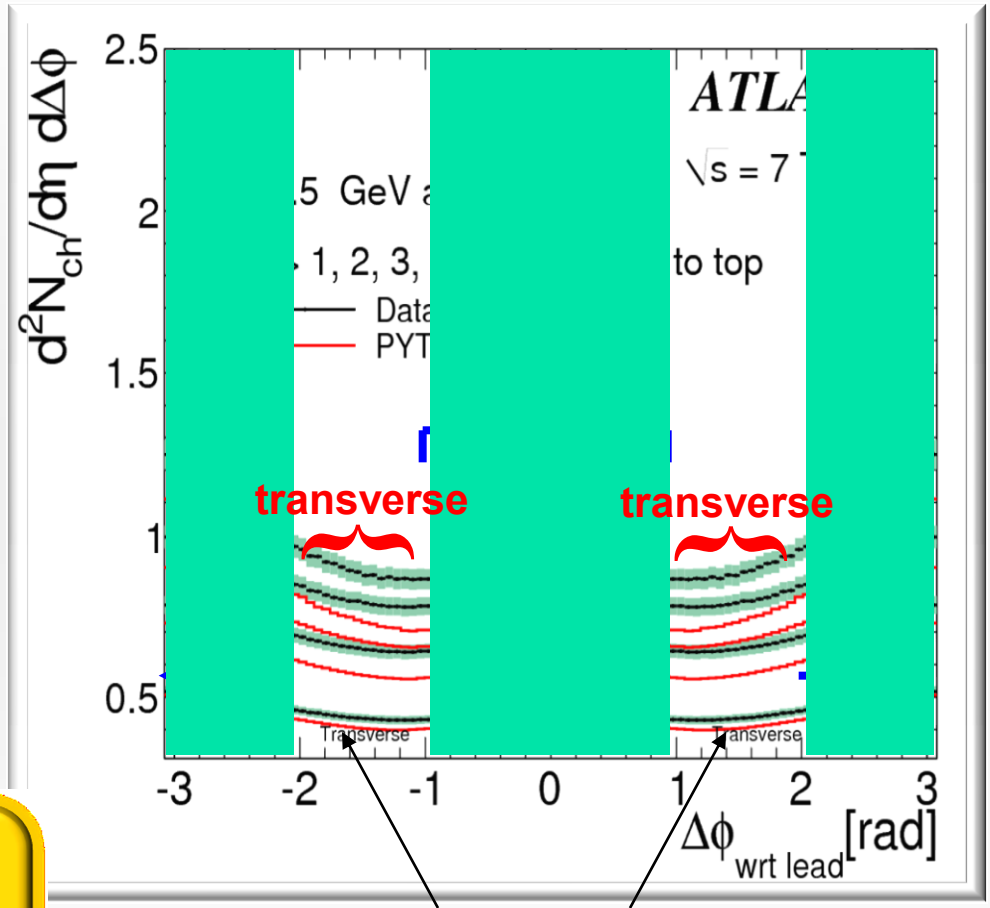


Main observables:

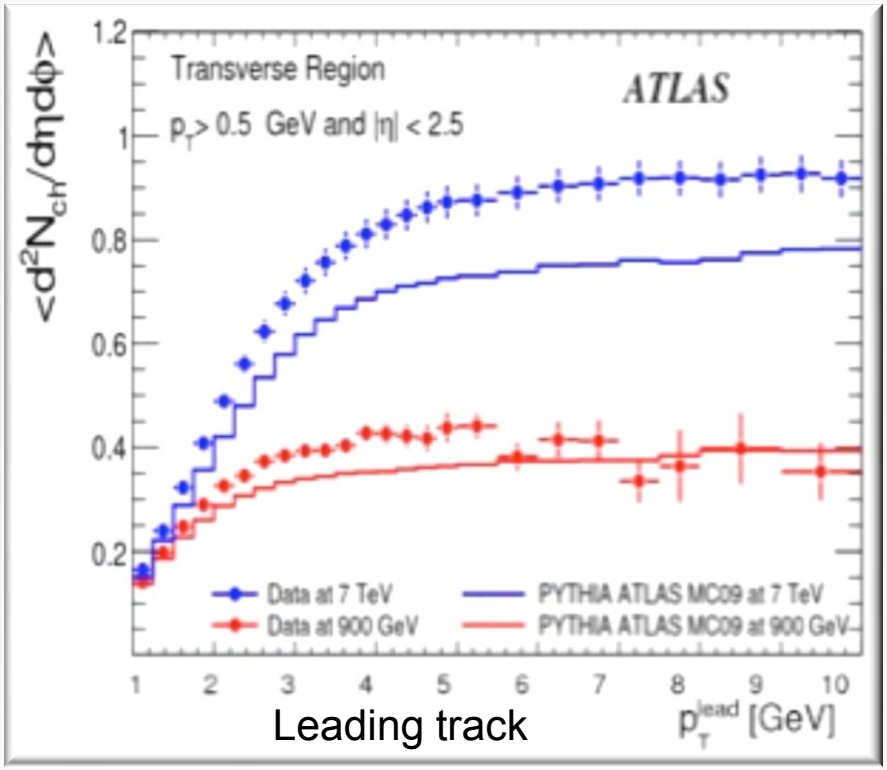
$d^2N_{ch}/d\eta d\phi$ - multiplicity density

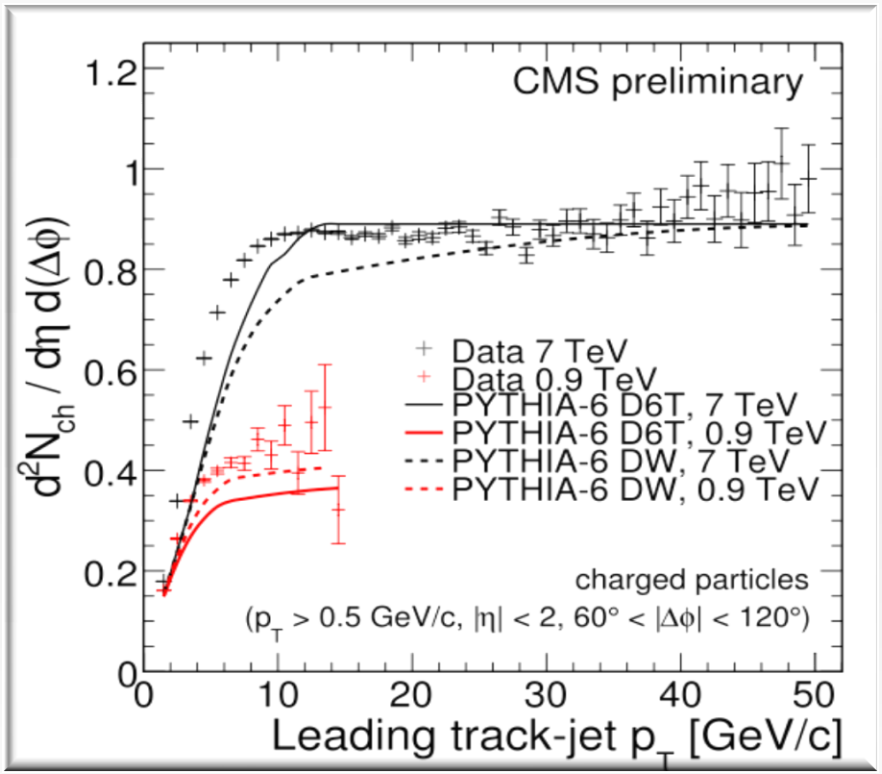
$d^2\Sigma p_T/d\eta d\phi$ - energy density

Transverse region expected to be particularly sensitive to the UE

Underlying Event Studies

Track multiplicity density ($d^2N_{ch}/d\eta d\phi$) in the transverse region





Underlying Event Studies

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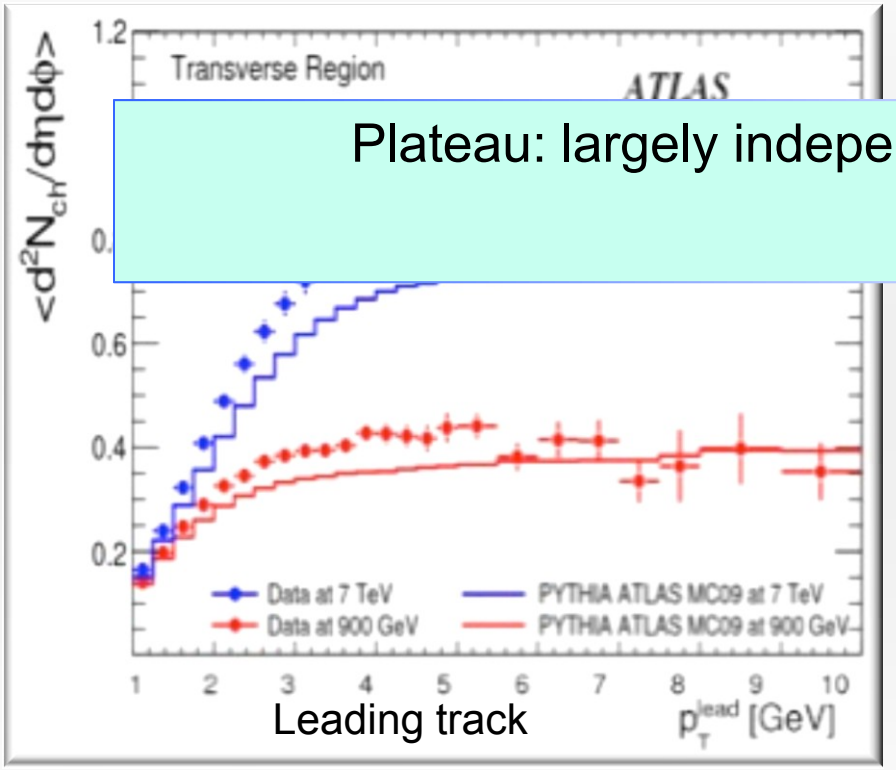
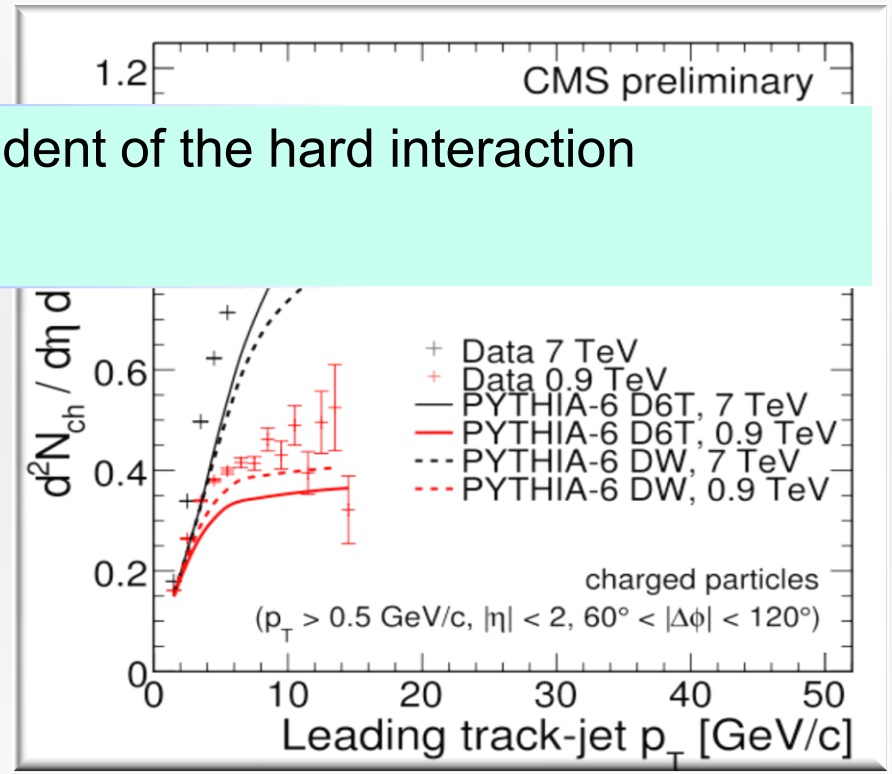




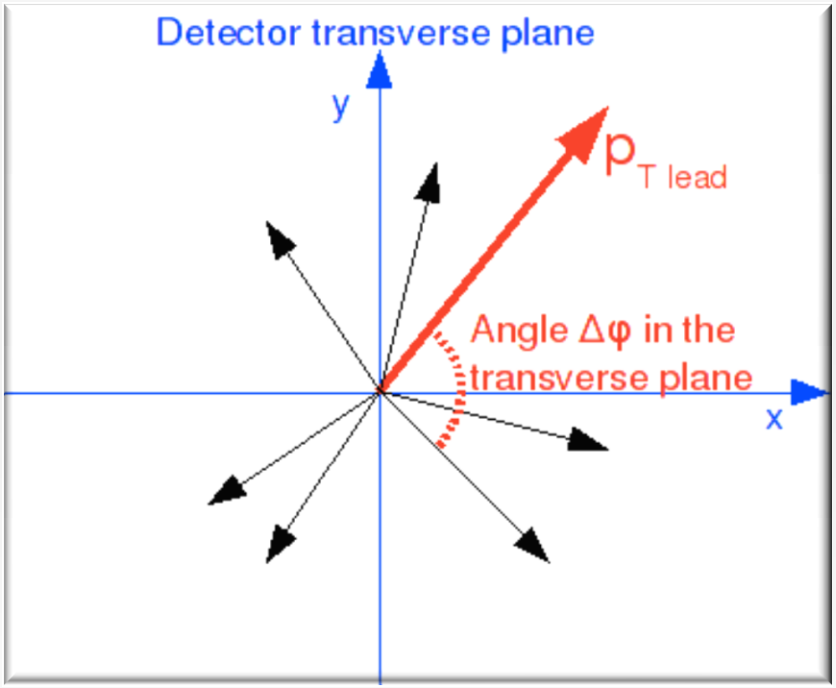
Plateau: largely independent of the hard interaction

Higher density of particles in the transverse region -> **Re-tune MC!**

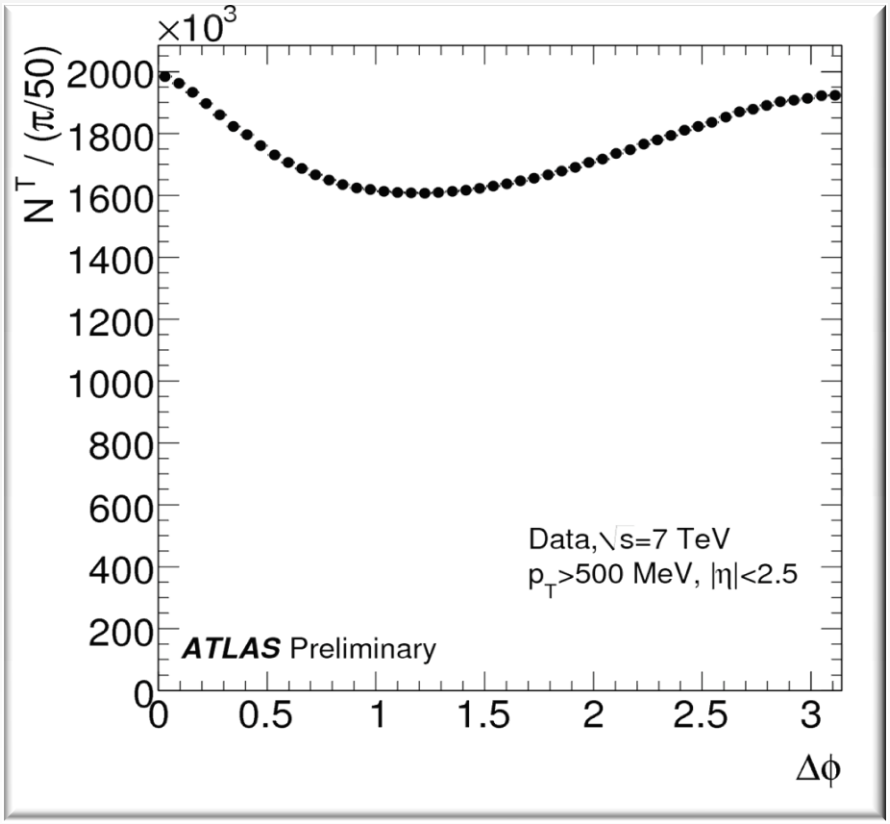
(ATLAS AUET1, CMS Z1)

Di-hadron Angular Correlations

Further investigation on angular structure
for toward and away region



$\Delta\phi = |\phi_{all\ other} - \phi_{lead}|$



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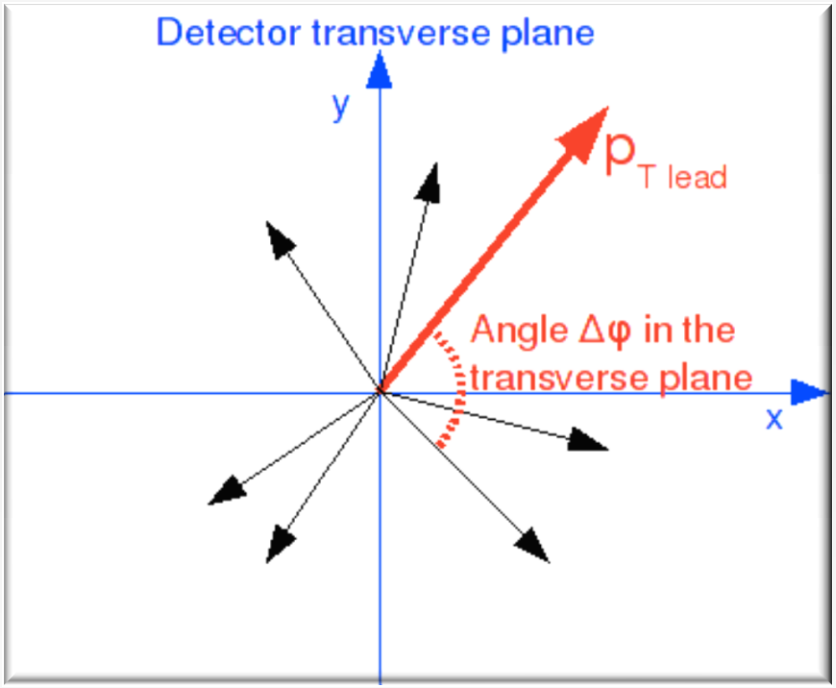

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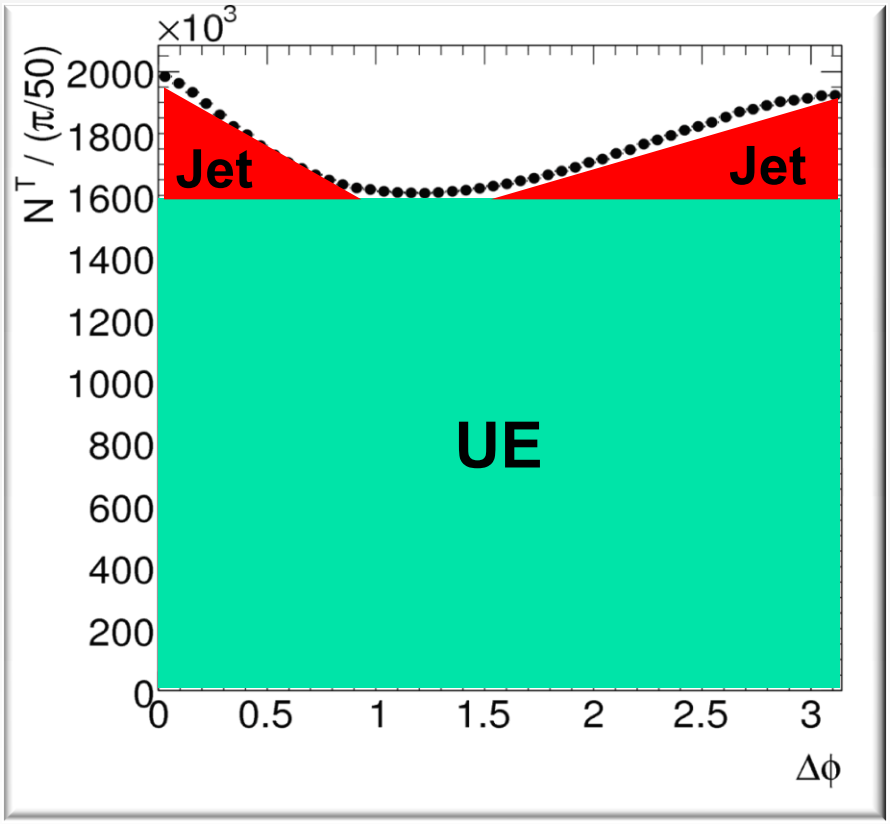

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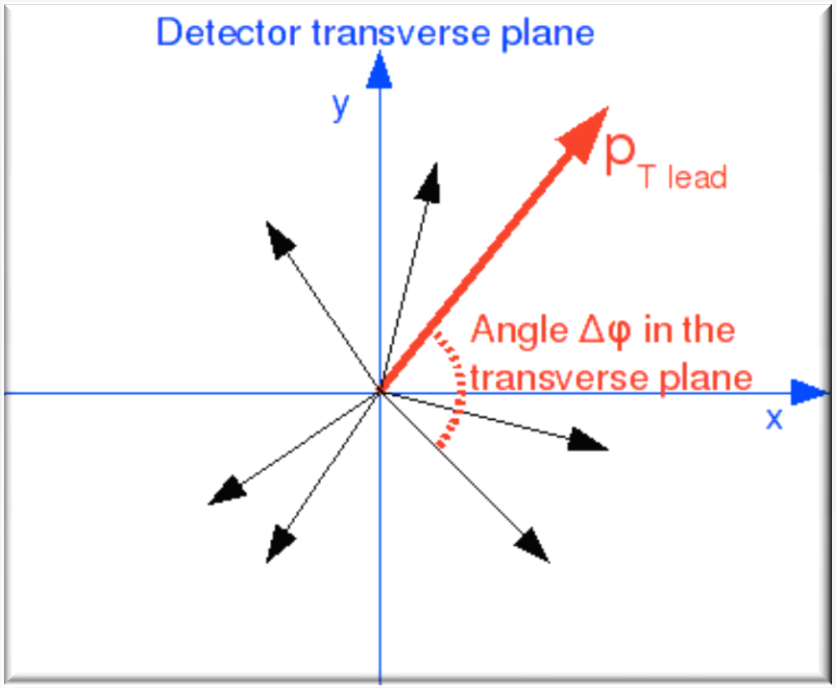

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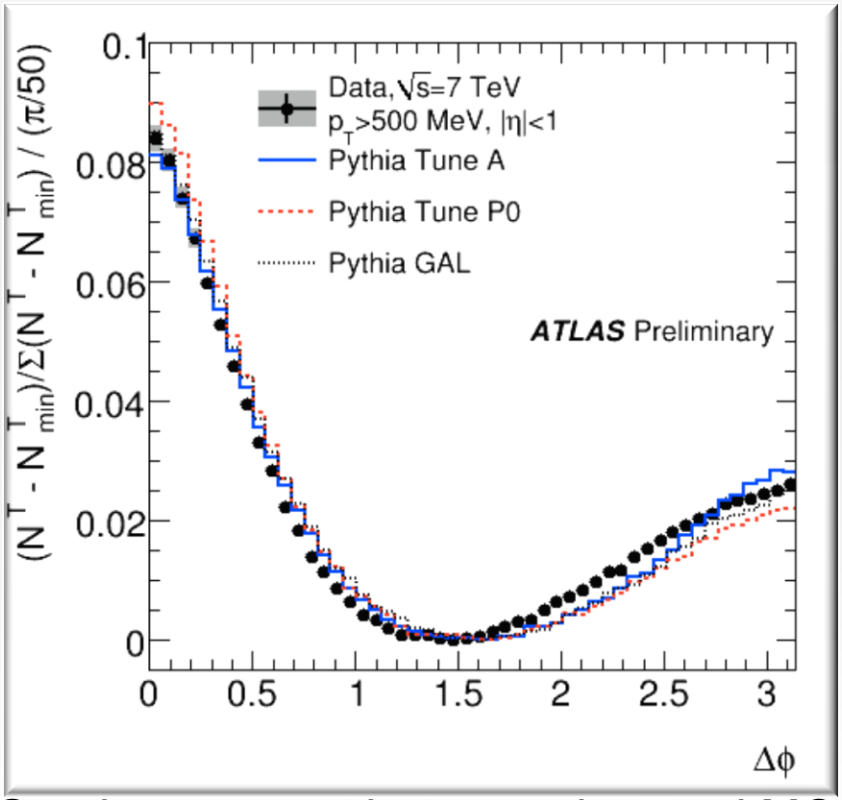
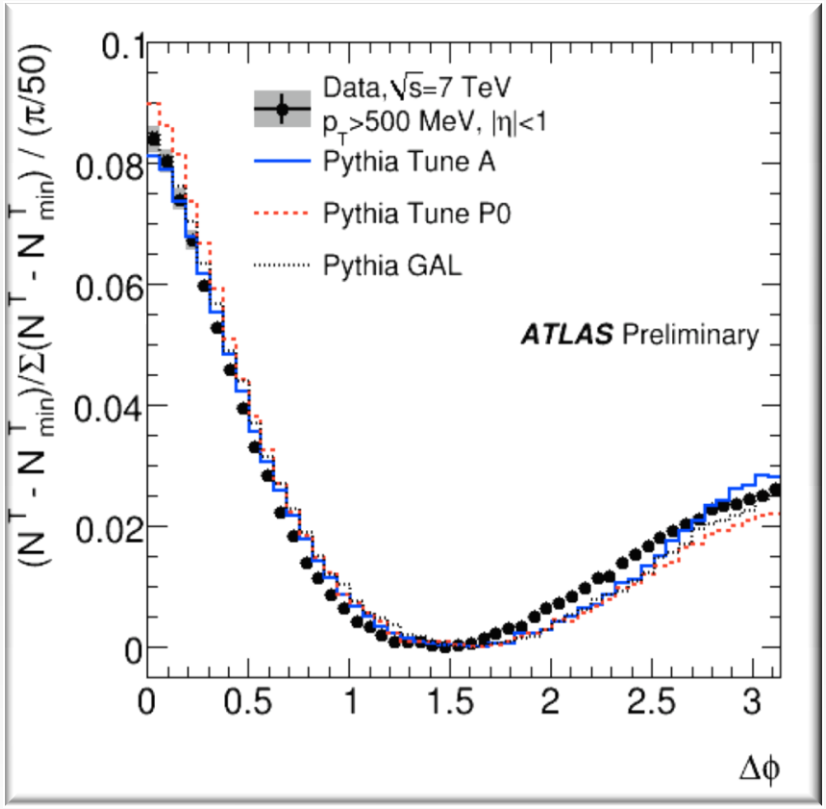
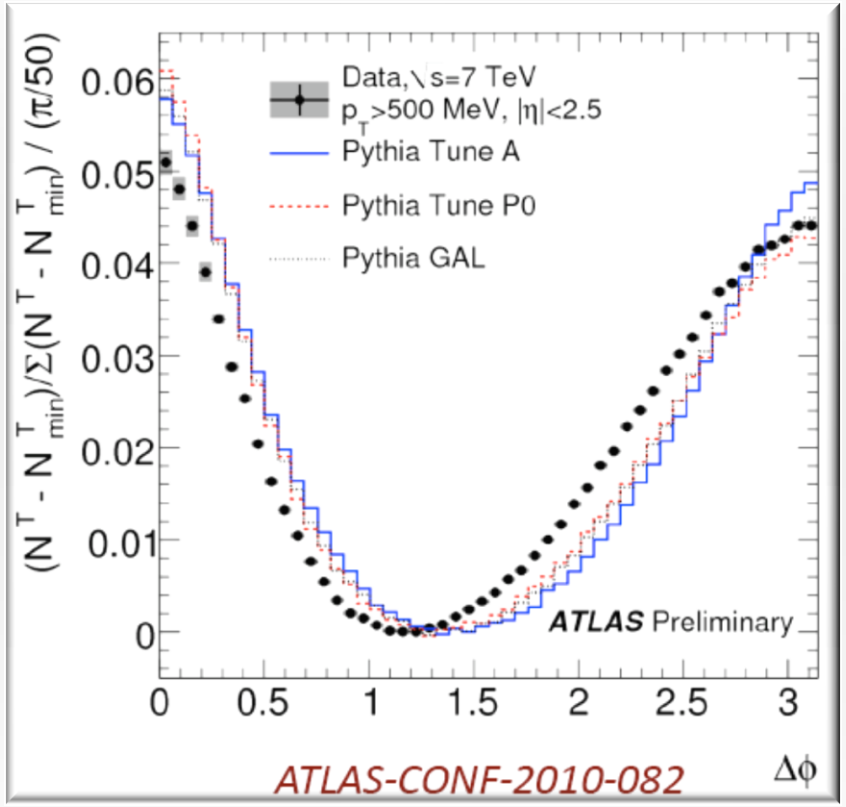


Good agreement between data and MC
Additional constraints to the models

Di-hadron Angular Correlations

$|\eta|<1$ ⟶ $|\eta|<2.5$





Discrepancy bigger between data and MC at wider η range

Need to understand long range behavior in η better

Di-hadron Angular Correlations

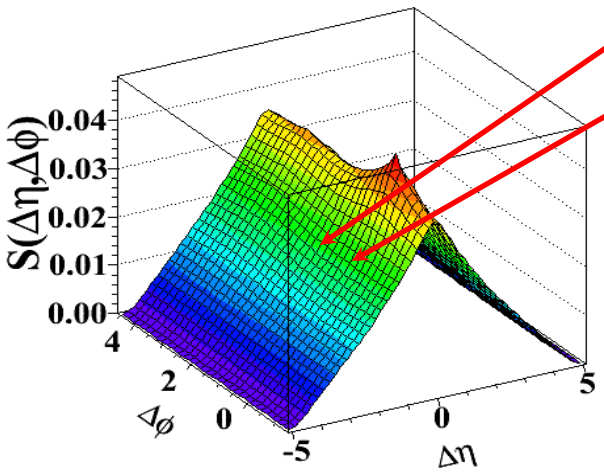
Moving on to **2-D ($\Delta\eta$,$\Delta\phi$)** correlations

$$\Delta\eta = \eta_1 - \eta_2$$
$$\Delta\varphi = \varphi_1 - \varphi_2$$

CMS pp 7TeV

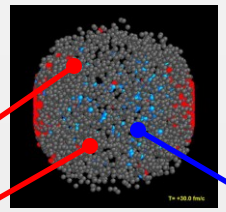
Signal distribution:

$$S_N(\Delta\eta,\Delta\varphi) = \frac{1}{N(N-1)}\frac{d^2N^{signal}}{d\Delta\eta d\Delta\varphi}$$

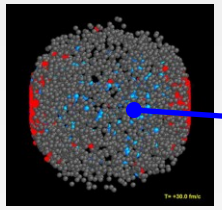


same event pairs

Event 1

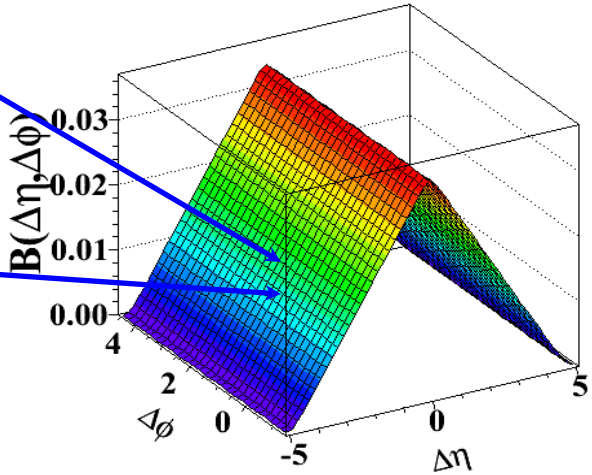


Event 2



Background distribution:

$$B_N(\Delta\eta,\Delta\varphi) = \frac{1}{N^2}\frac{d^2N^{bkg}}{d\Delta\eta d\Delta\varphi}$$

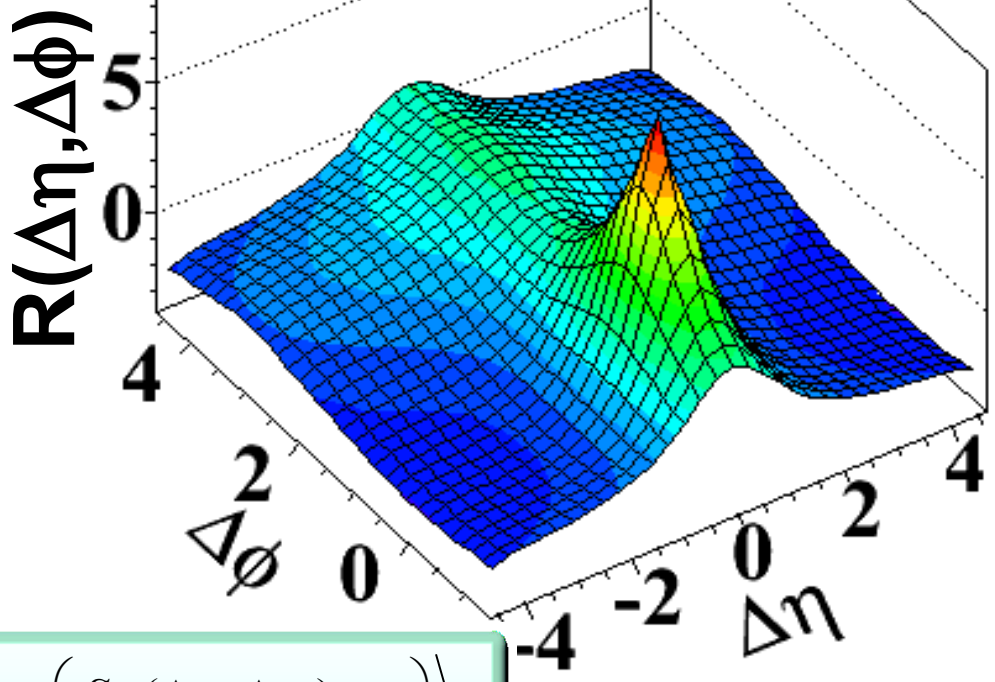


mixed event pairs

Track cuts:
p_T>0.1GeV/c
|η|<2.4

Di-hadron Angular Correlations

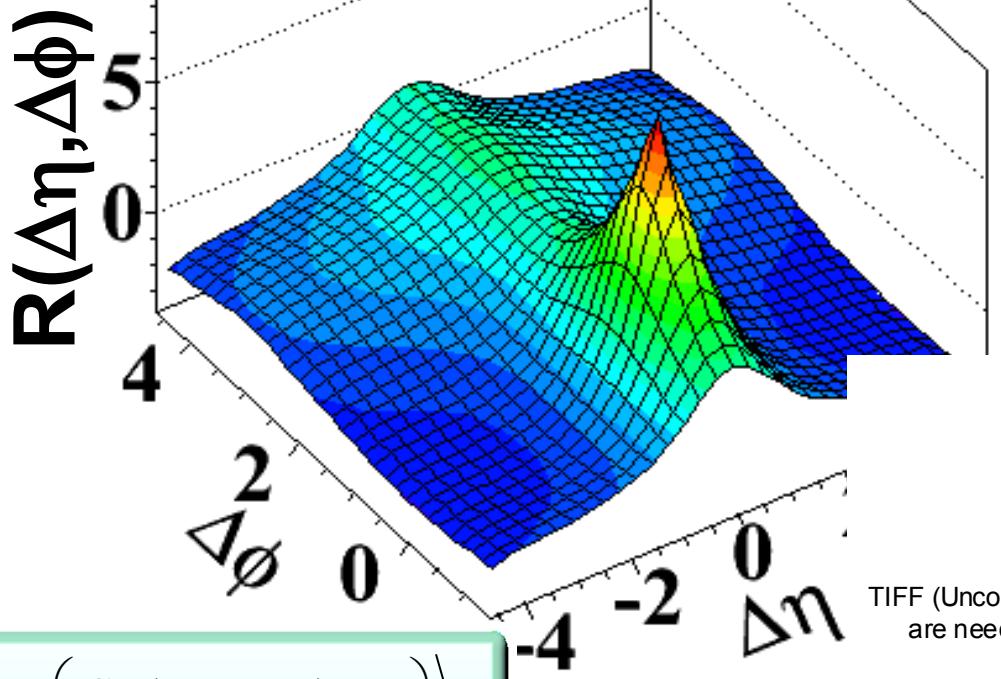
Track cuts:
p_T>0.1GeV/c
|η|<2.4



$$R(\Delta\eta,\Delta\varphi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)} - 1\right)\right\rangle_N$$

Di-hadron Angular Correlations

Track cuts:
p_T>0.1GeV/c
|η|<2.4

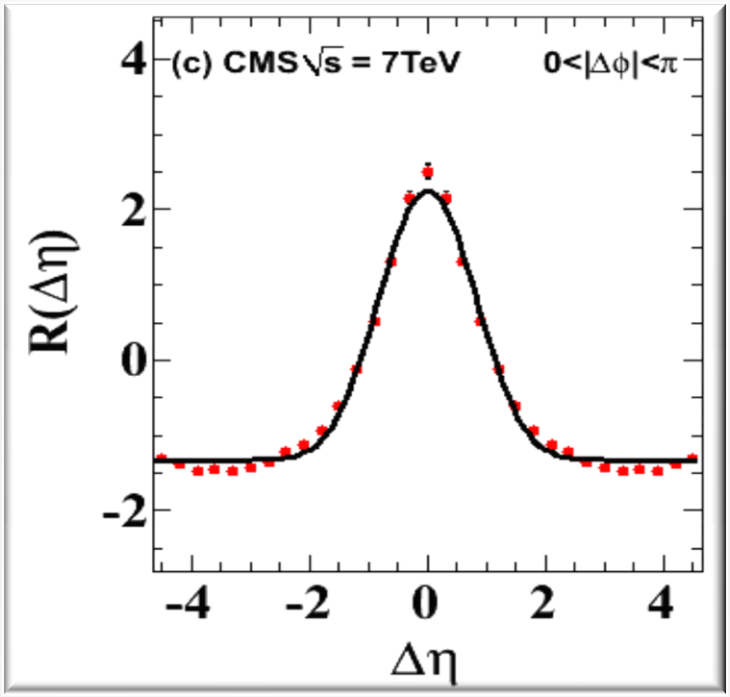


QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

$$R(\Delta\eta,\Delta\varphi)=\left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)}-1\right)\right\rangle_N$$

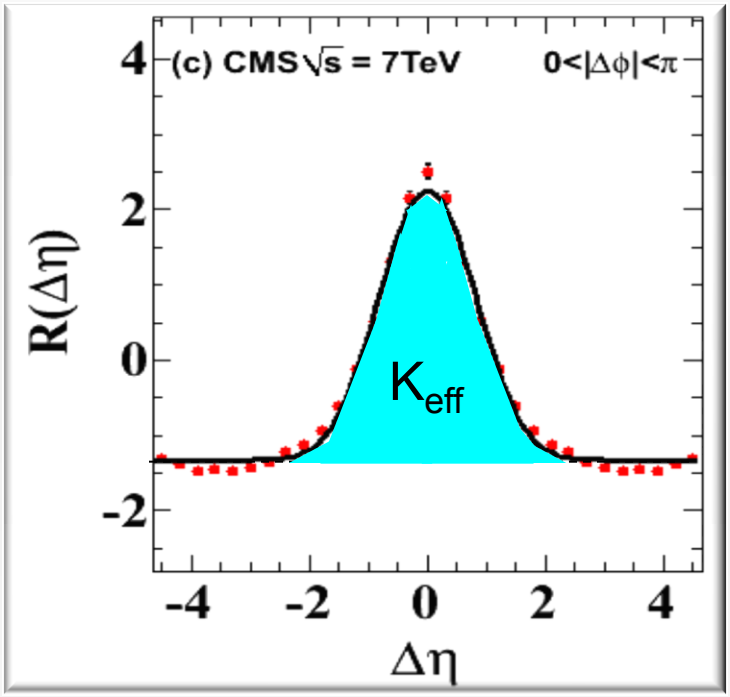
Di-hadron Angular Correlations

1-D “projection” to $\Delta\eta$ axis

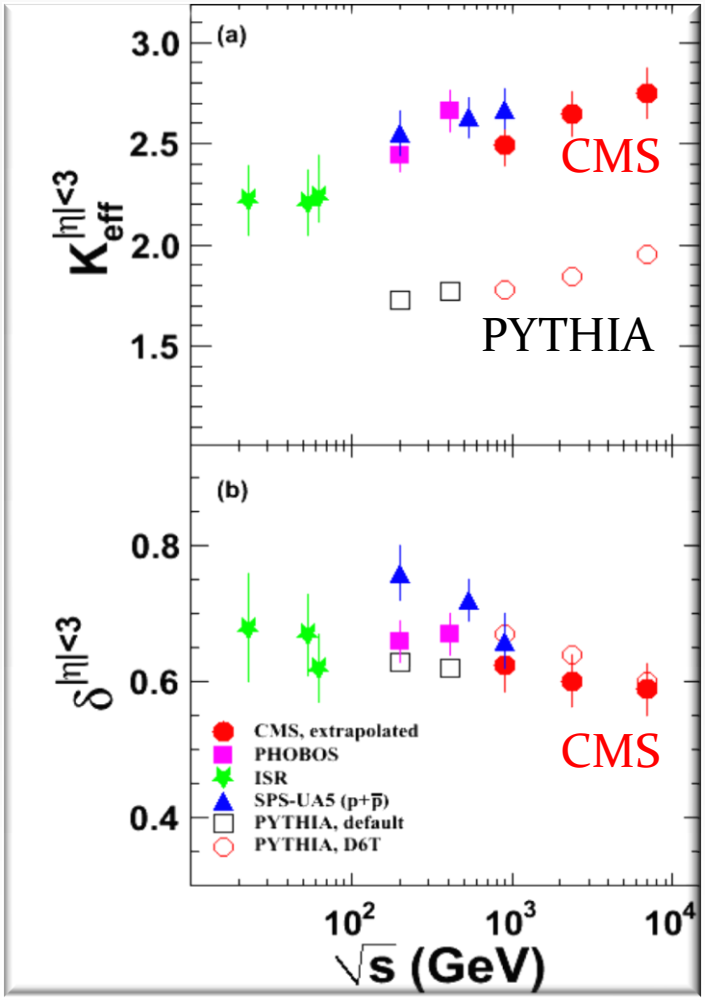


Di-hadron Angular Correlations

1-D "projection" to $\Delta\eta$ axis

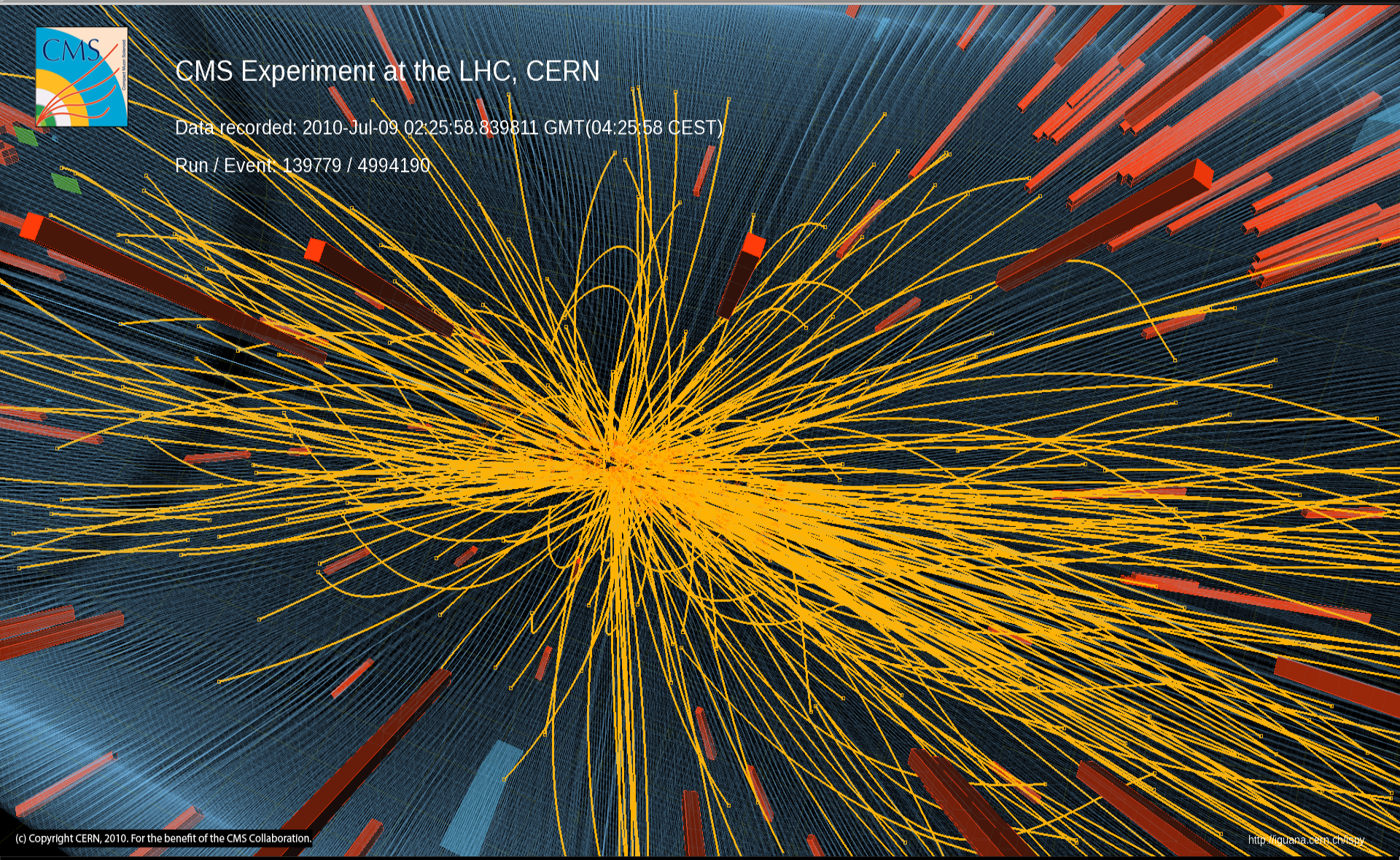


K_{eff}: Number of correlated particles
δ: extent of correlation in η



- PYTHIA describes the energy dependence
- Matches width (δ) of correlations in η
- Underestimates the strength of correlations

High Multiplicity pp collisions



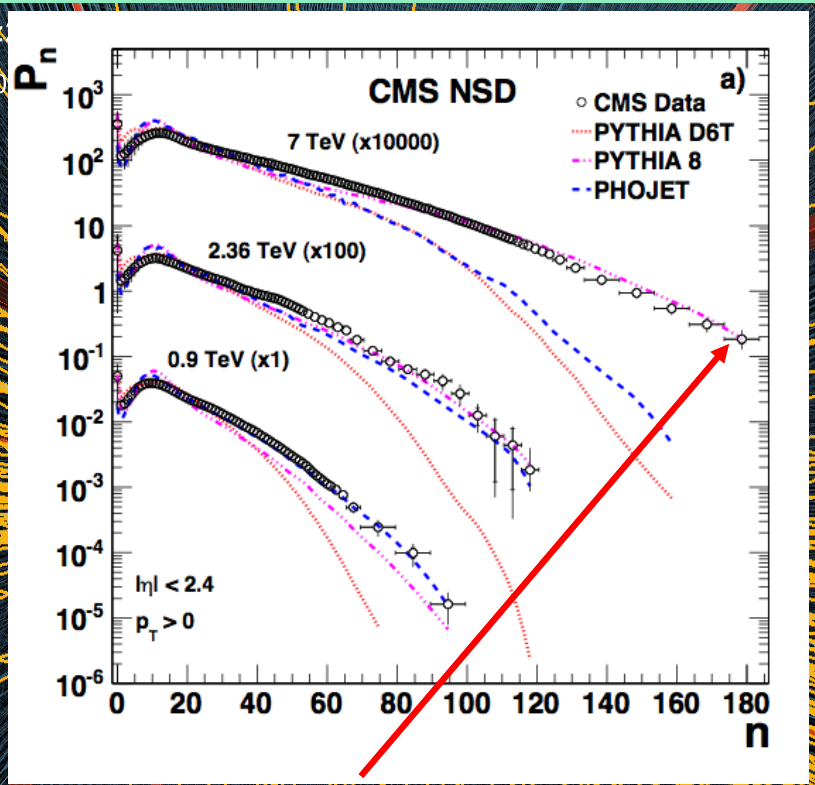
High Multiplicity pp collisions

CMS Expe

Data recorded: 2010-Jul-09 02:

Run / Event: 139779 / 4994190

High Multiplicity events are rare in nature

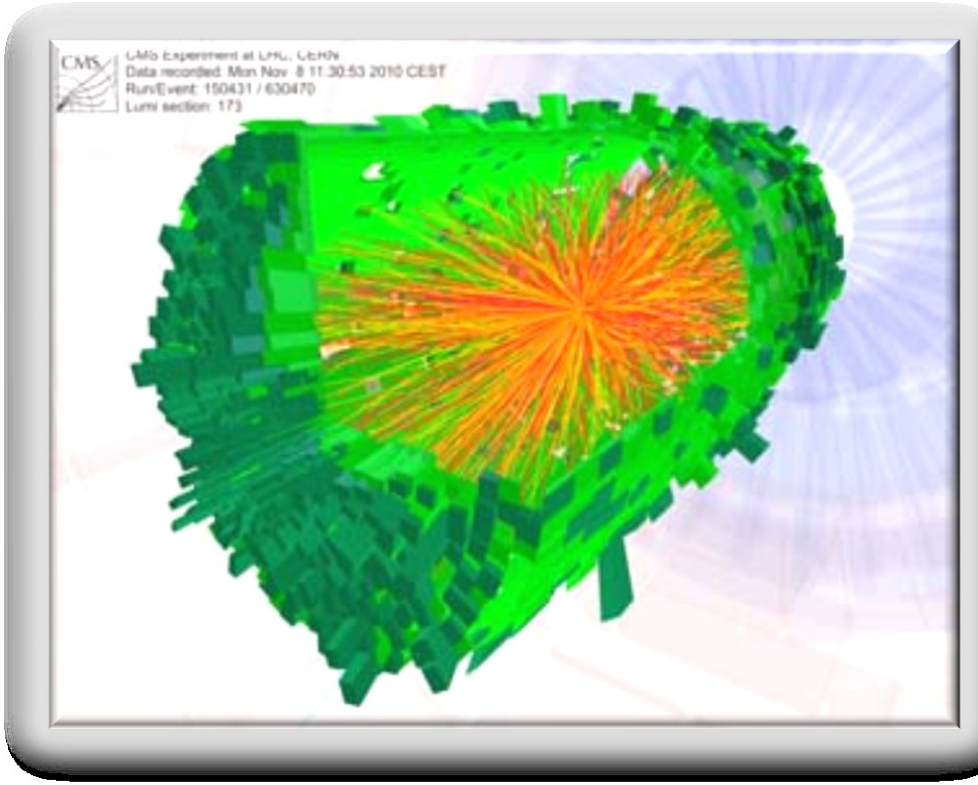


Very high particle density regime

➔*Is there anything peculiar happening there?*

(c) Copyright CERN, 2010. For the benefit of the CMS Collaboration.

High Multiplicity pp collisions



Very high particle density regime

➔*Is there anything peculiar happening there?*

➔***Potential connection to heavy ion physics***

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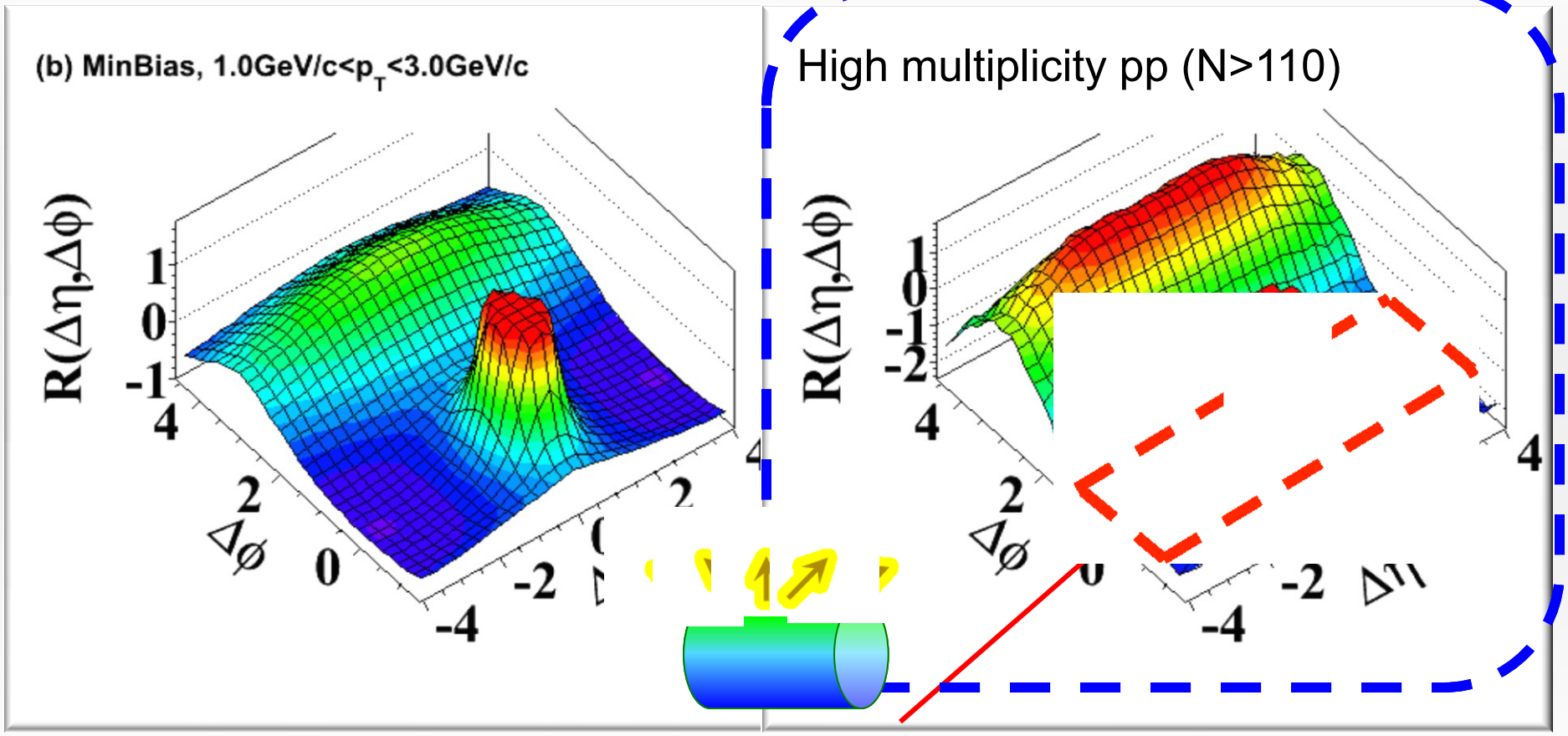
http://iguana.cern.ch/isby

Correlations in High Multiplicity pp

Higher p_T: 1-3 GeV/c

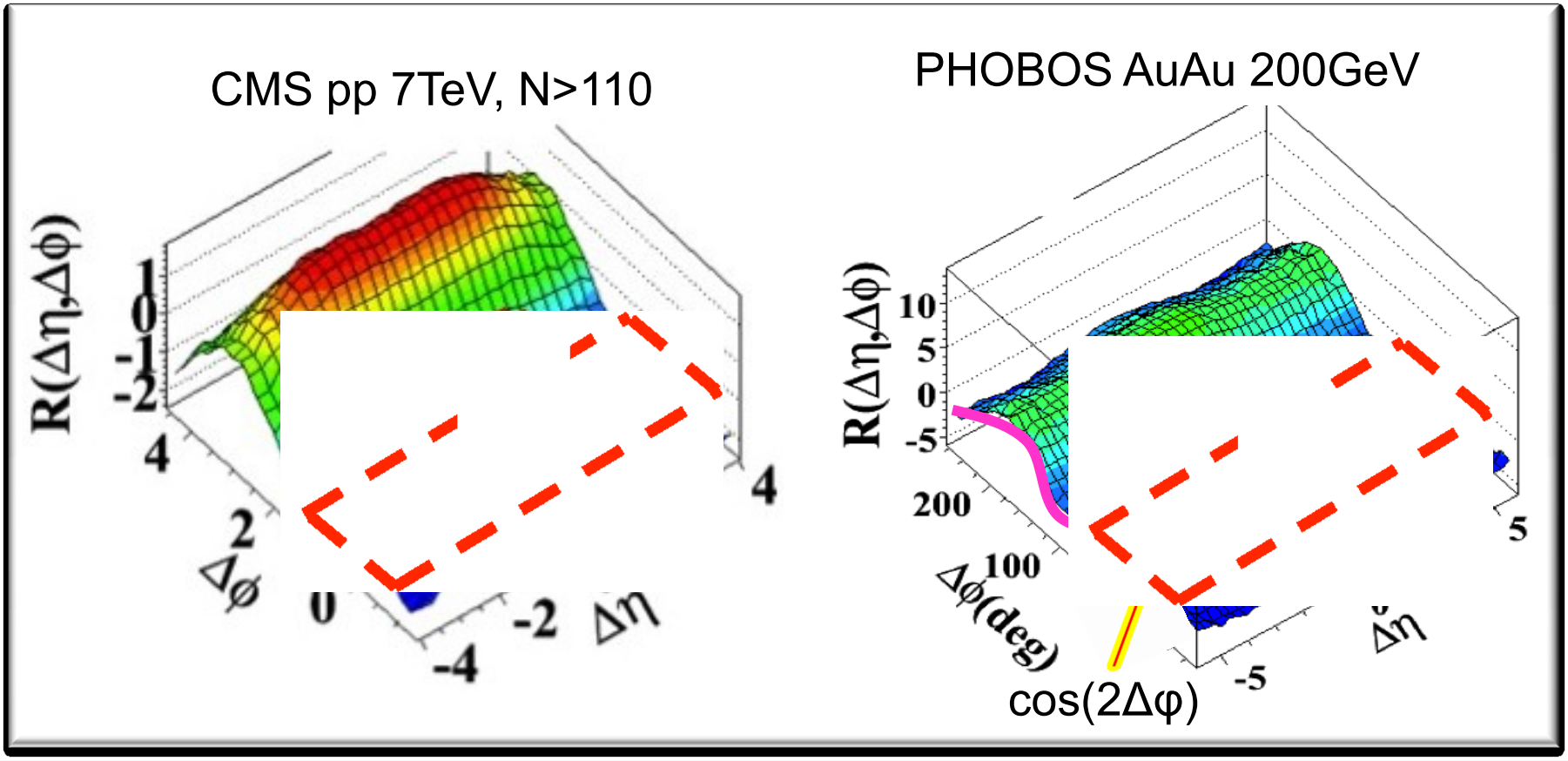
"Discovery"



Striking "**ridge-like**" structure extending over $\Delta\eta$ at $\Delta\phi \sim 0$

Not existing in any pp MC models

“Ridge” in pp and Heavy Ion



Similar “ridge” in high multiplicity pp and Heavy Ion!

(even p_T dependence)

Possible indication of “heavy ion”-like collective effects in pp?

Summary

Excellent performance of ATLAS and CMS detectors for studying QCD physics at LHC

Comprehensive results on single particle spectra, underlying event and particle correlations

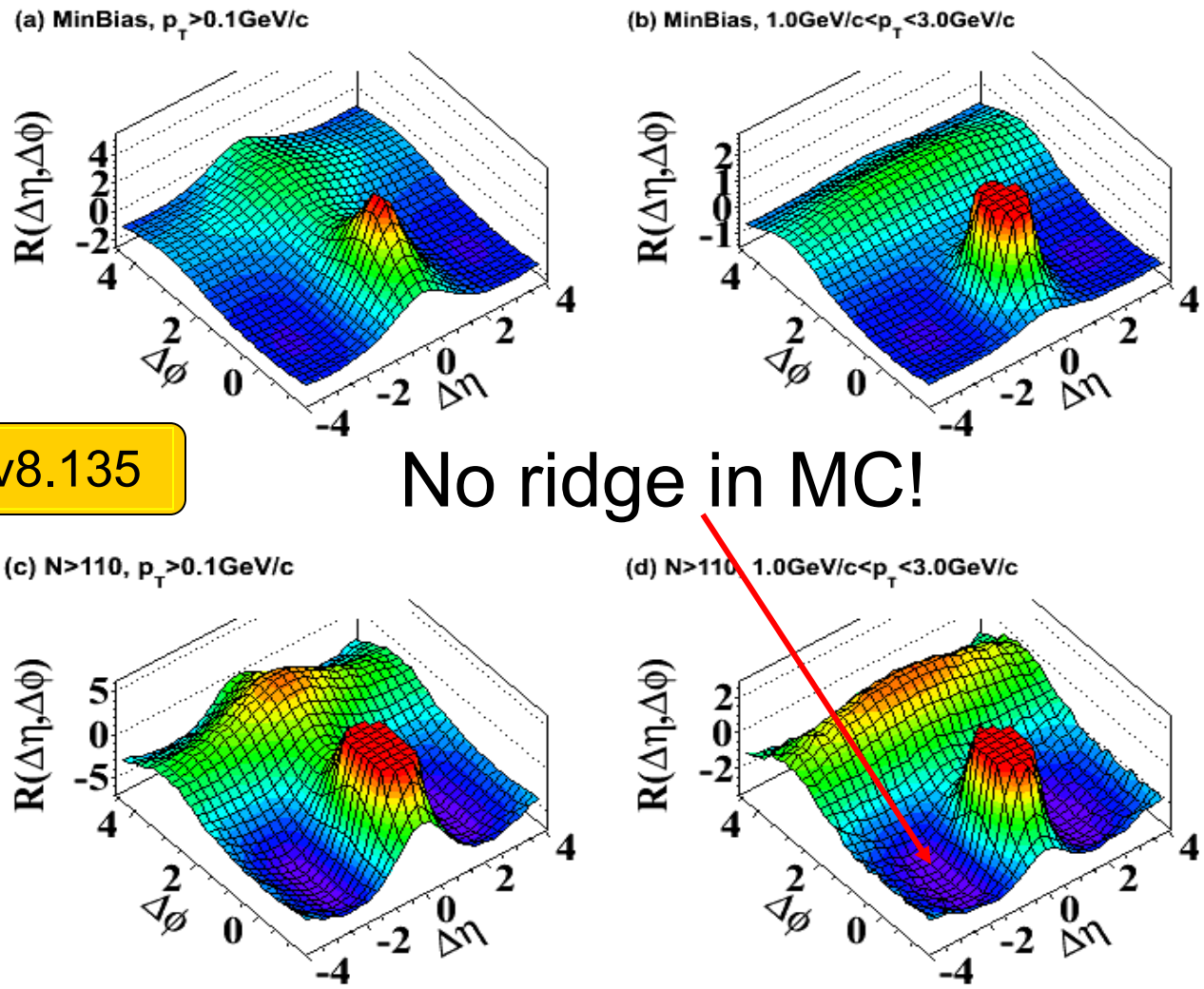
All data on soft QCD pose challenges for MC models

First new, unexpected observation at LHC and potential connection to heavy ion physics:
Long-range, near-side correlations in high multiplicity events
($|\Delta\eta|>2$) ($\Delta\phi\sim0$)

QCD physics entering a new testing ground!
More surprises to come!

Backups

Comparing to MC model

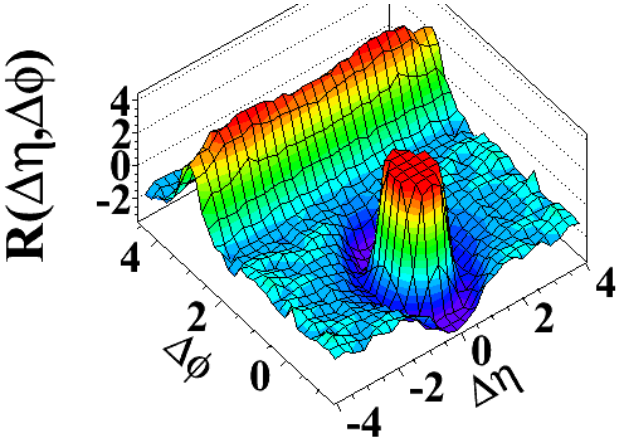


PYTHIA8, v8.135

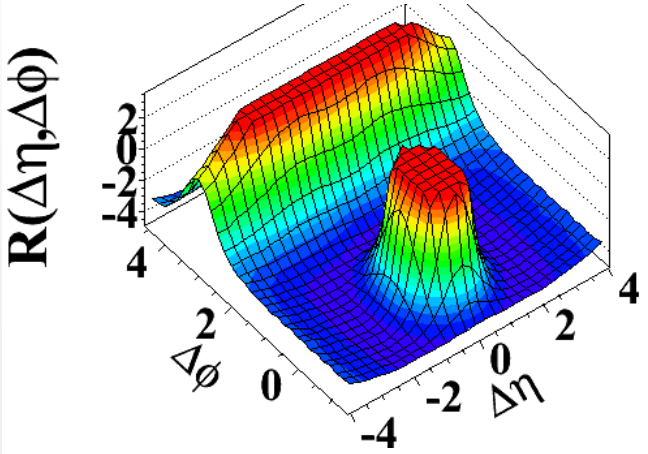
No ridge in MC!

More MC models …

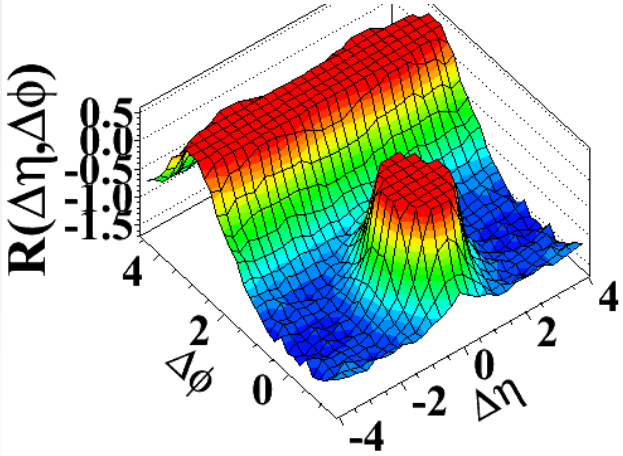
PYTHIA D6T MinBias, N>70



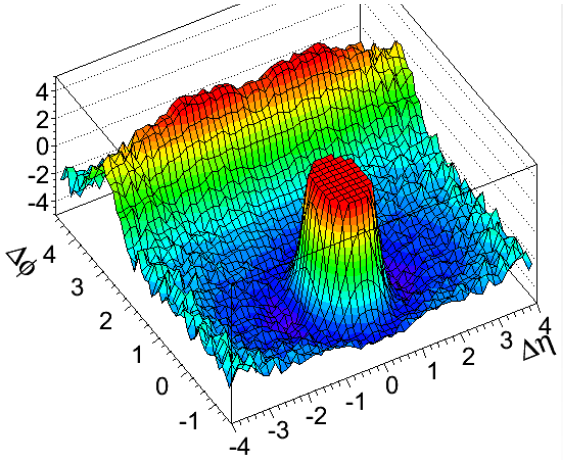
PYTHIA D6T, Dijet 80-120GeV



HERWIG++, N>110

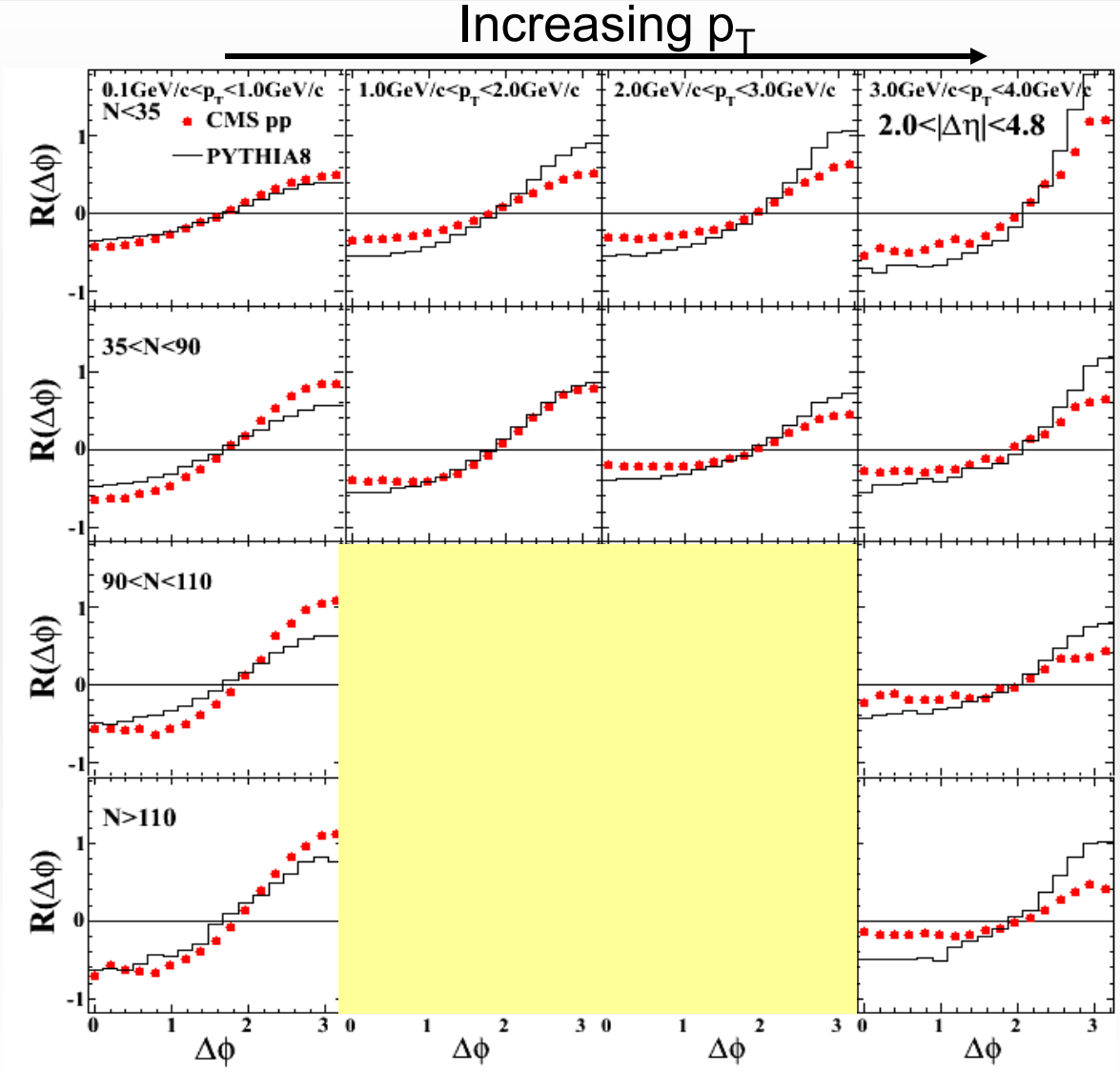


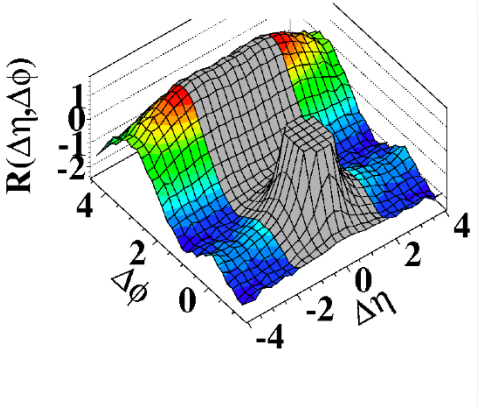
Madgraph, Dijet 100-250GeV, N>90



No **PRE**-diction of the effect in existing theoretical pp models!

1-D projected R(Δϕ) at large Δη

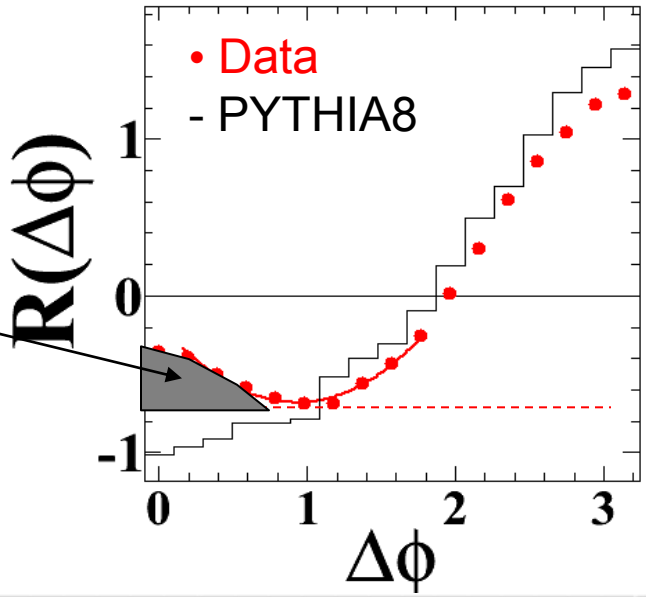




Quantify the Ridge

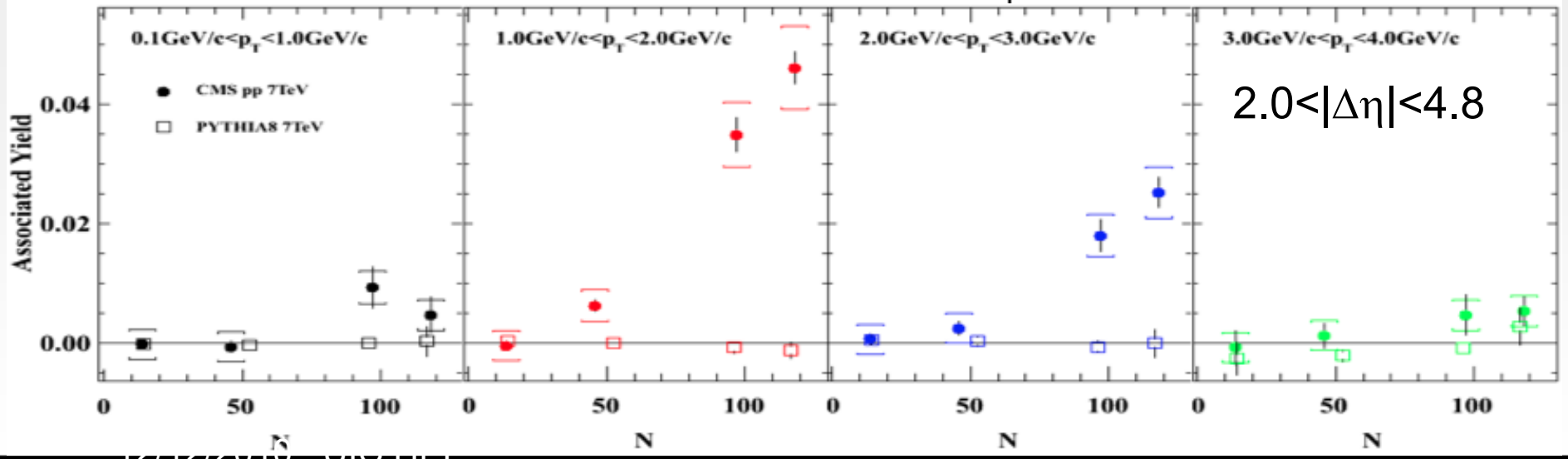
Zero Yield At Minimum (ZYAM)

Associated yield:
correlated multiplicity per particle



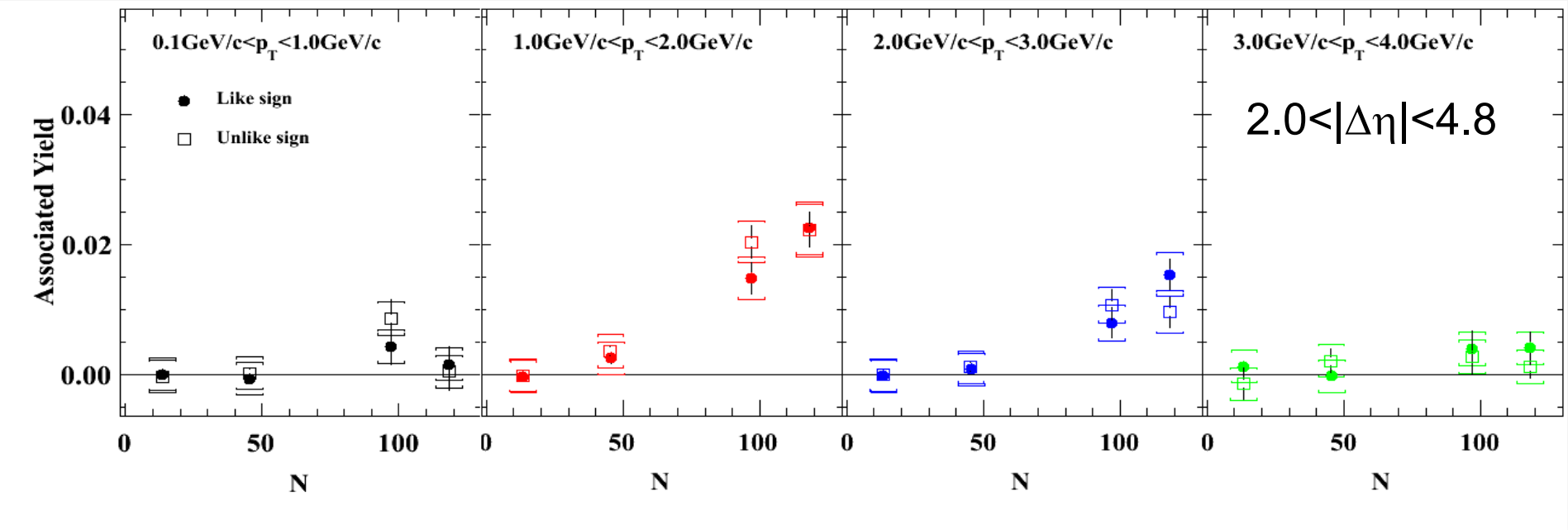
N>110
$2.0<|\Delta\eta|<4.8$
$1GeV/c<p_T<2GeV/c$

Minimum of R



Charge Dependence of the Ridge

Like-sign and unlike-sign pair correlations:



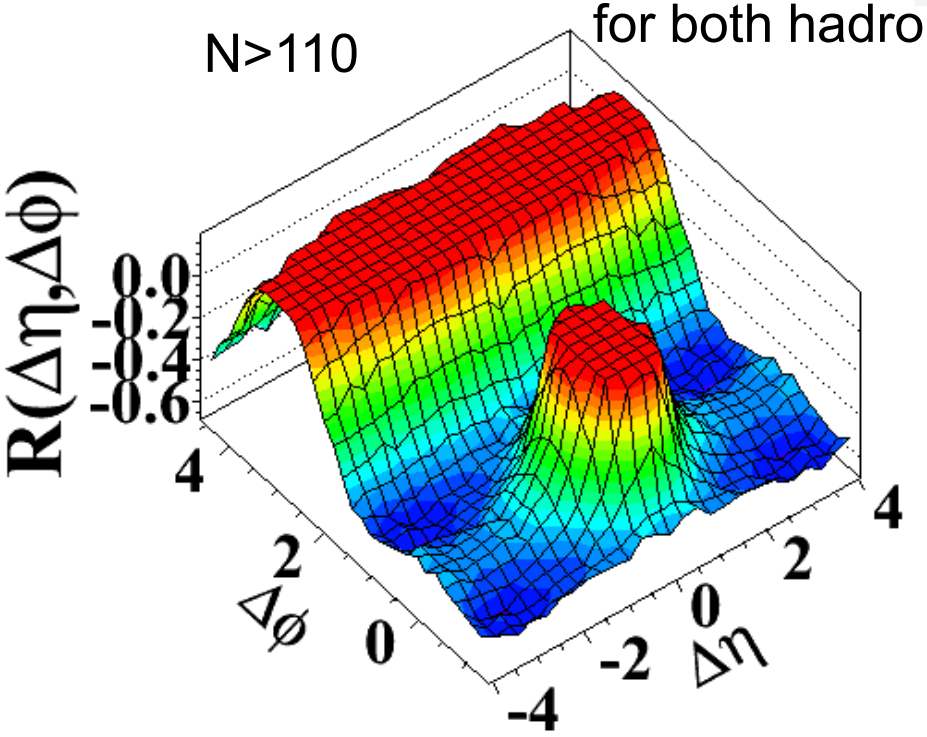
No charge sign dependence of the ridge!

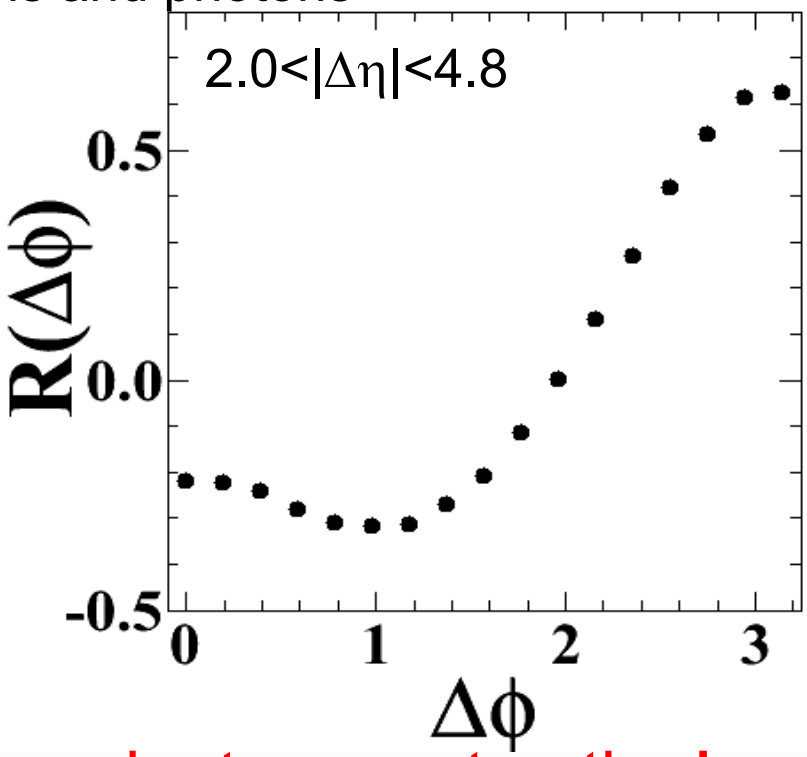
Cross check: ECAL Photons

Charged hadron - photon correlations

(photons are mostly from π^0 decay)

$1.0\text{GeV/c}<p_T<3.0\text{GeV/c}$
for both hadrons and photons





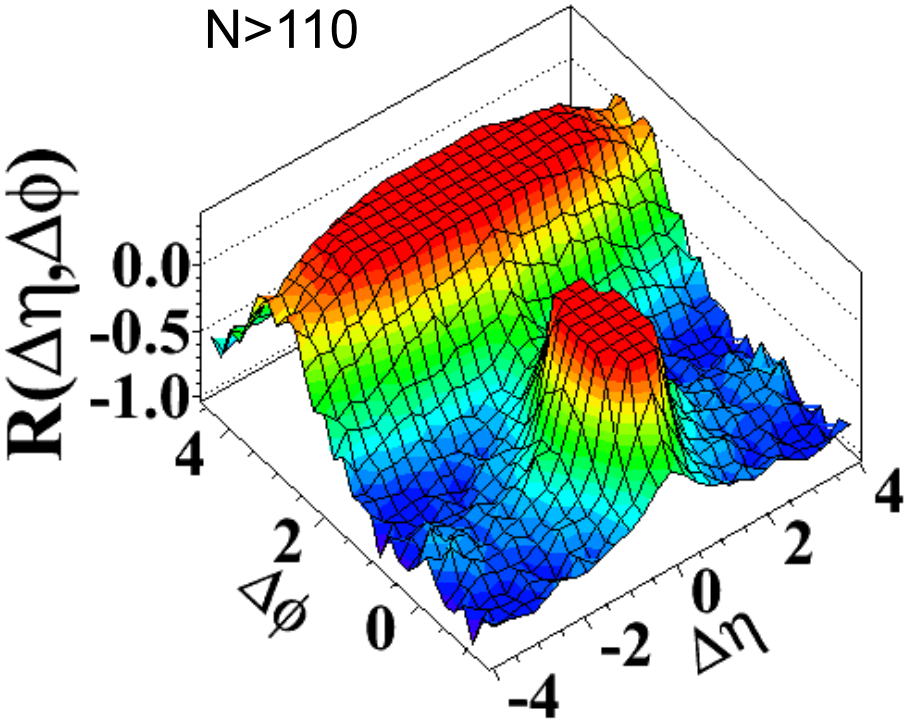
Independent detector, independent reconstruction!

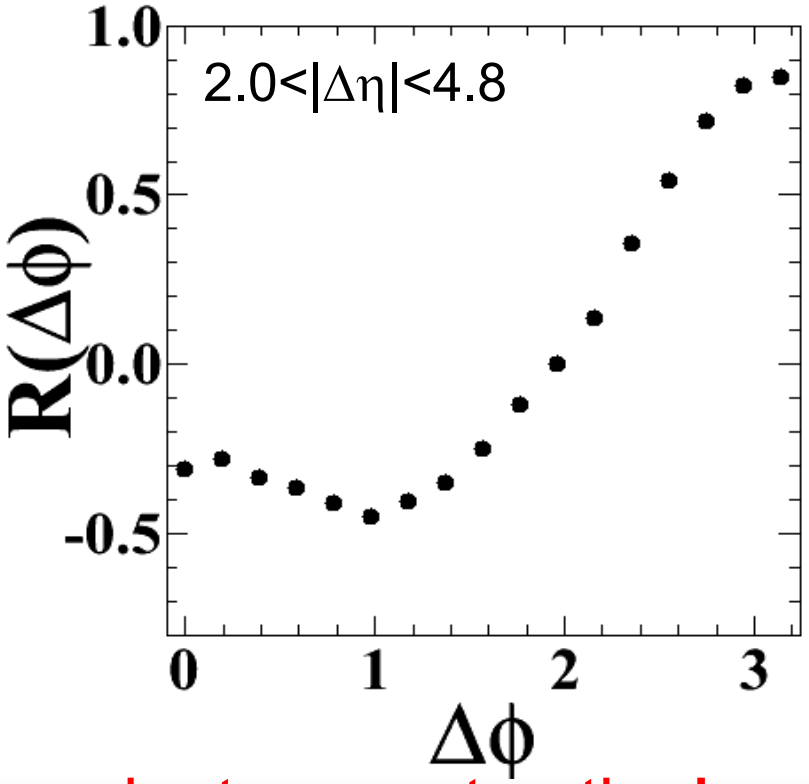
Cross check: ECAL Photons

photon - photon correlations

(photons are mostly from π^0 decay)

$1.0\text{GeV/c}<p_T<3.0\text{GeV/c}$

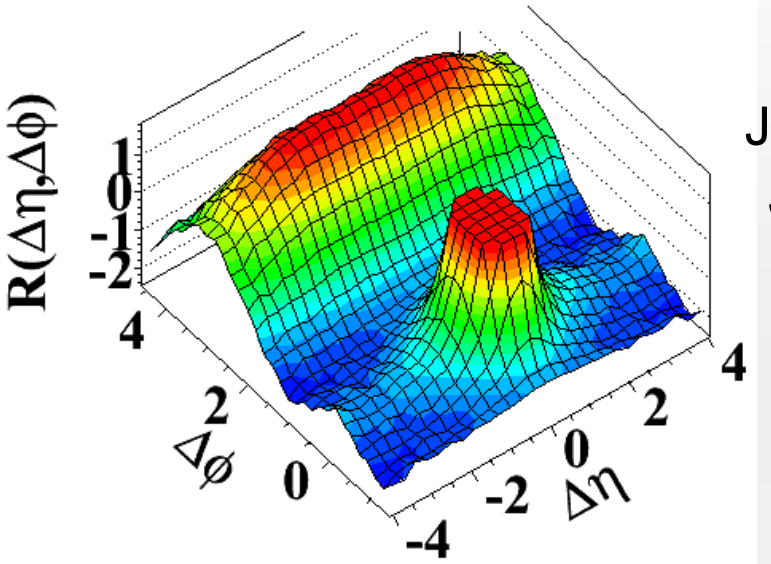




Independent detector, independent reconstruction!

Interpreting the "Ridge" in pp

CMS pp 7TeV, N>110

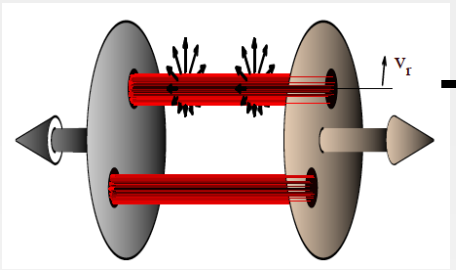


Interpretation:

Multi-jet correlations
Jet-Jet color connections
Jet-proton remnant color connections
Jet-remnant connections + medium

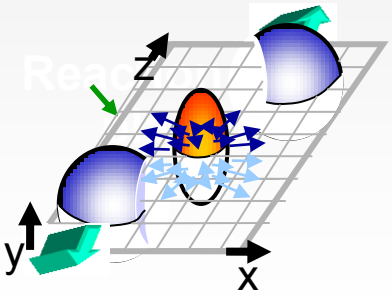
Jet

Glasma (+ radial flow)



Color Glass Condensate

Hydrodynamic flow



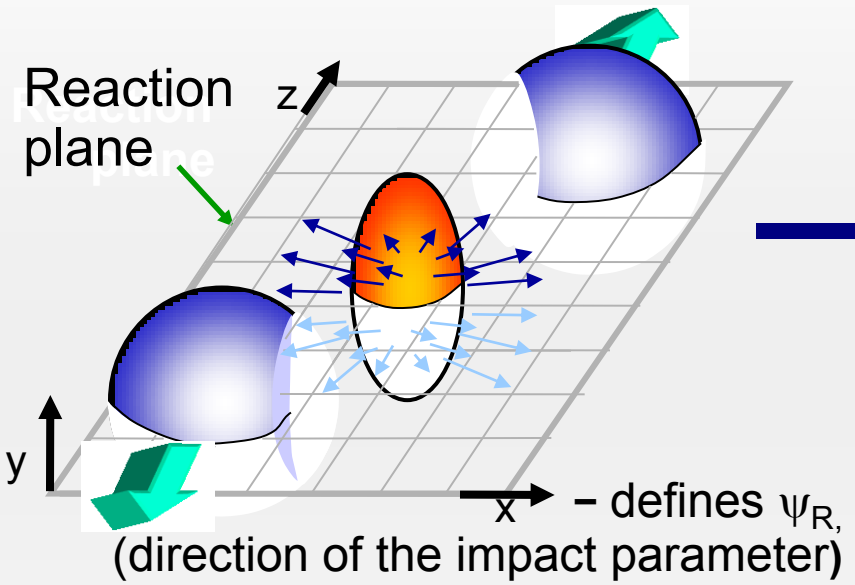
Quark Gluon Plasma

Future analysis:

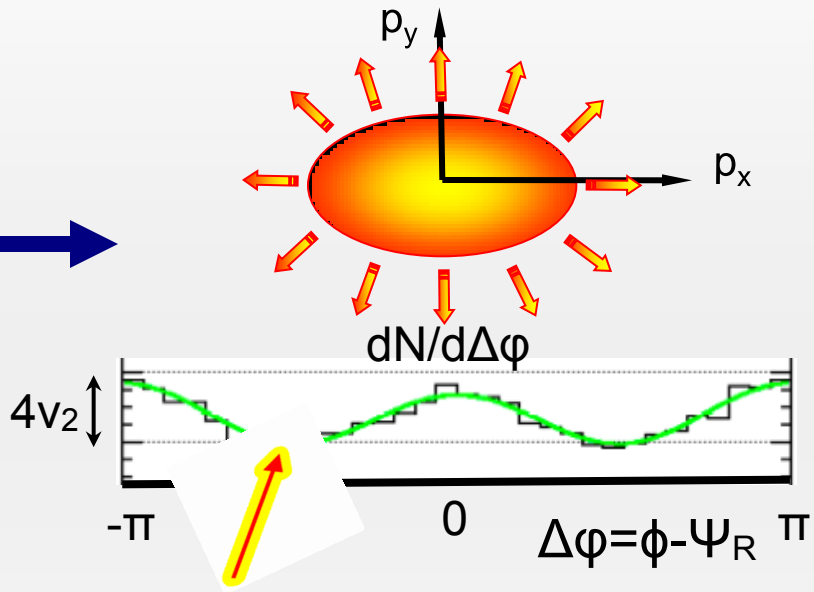
- Jet-hadron correlations
- 3-particle correlations
- Correlations with particle ID
- Radial flow
- ……

Correlations in Heavy Ion Collisions

Collective flow phenomena:



Pressure driven expansion



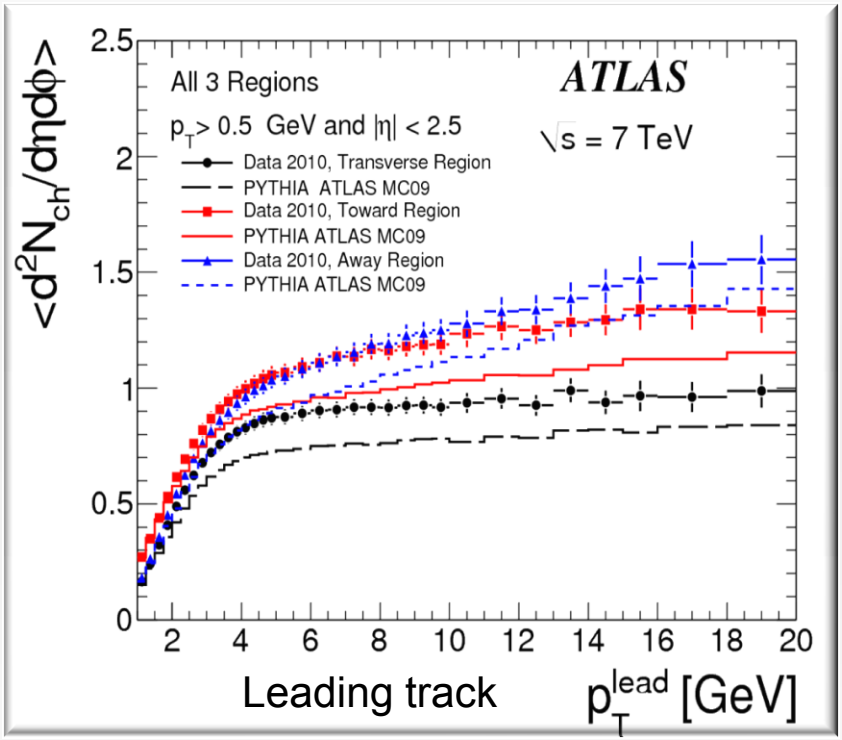
~ cos(2Δφ) (long-range in η)

Extracted shear viscosity of the medium close to theoretical lower bound 1/4π

Most convincing evidence of "perfect liquid" at RHIC!

Underlying Event Studies

How about toward and away region?

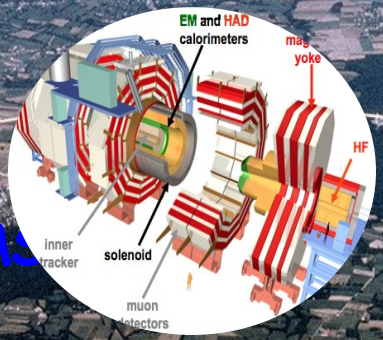


As expected, track multiplicity (energy) density grows with leading track (jet) due to sensitivity to hard processes

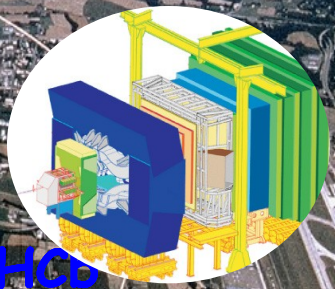
CERN Site

Lake Geneva

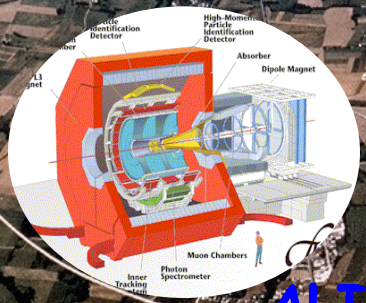
Large Hadron Collider
(27 km circumference)

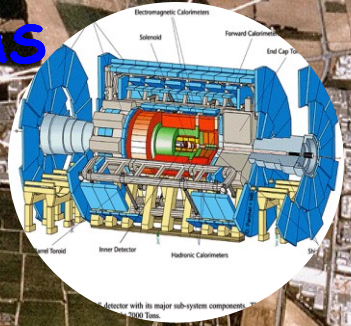


CMS



LHCb



ALICE

ATLAS