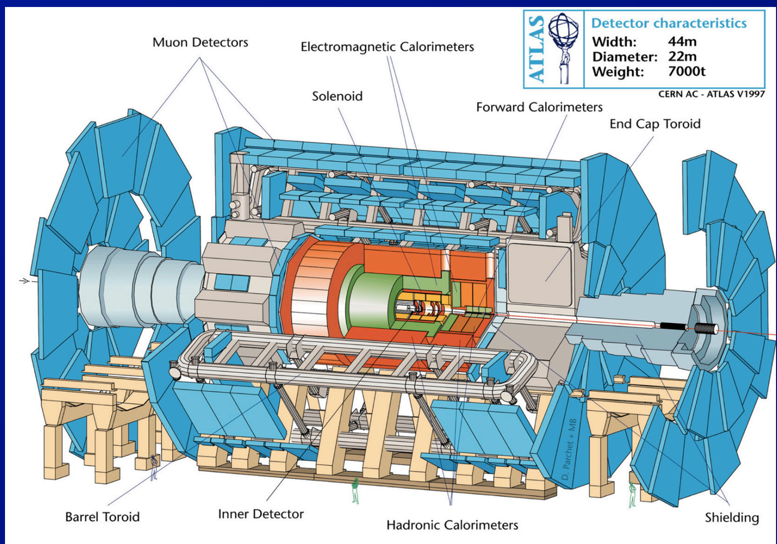
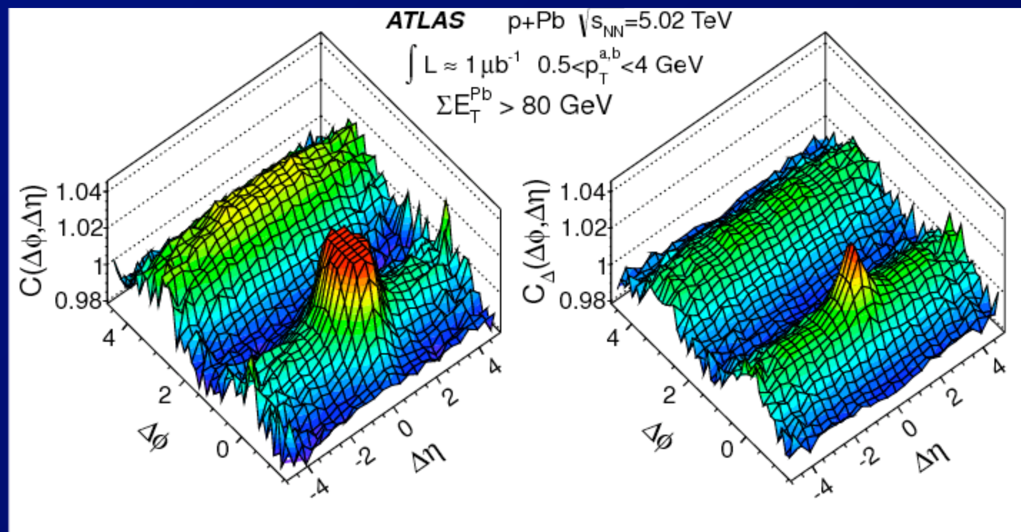
p+Pb at LHC: pilot run results and prospects for 2013 run from an ATLAS perspective

Brian A. Cole,
Columbia University

January 7, 2013





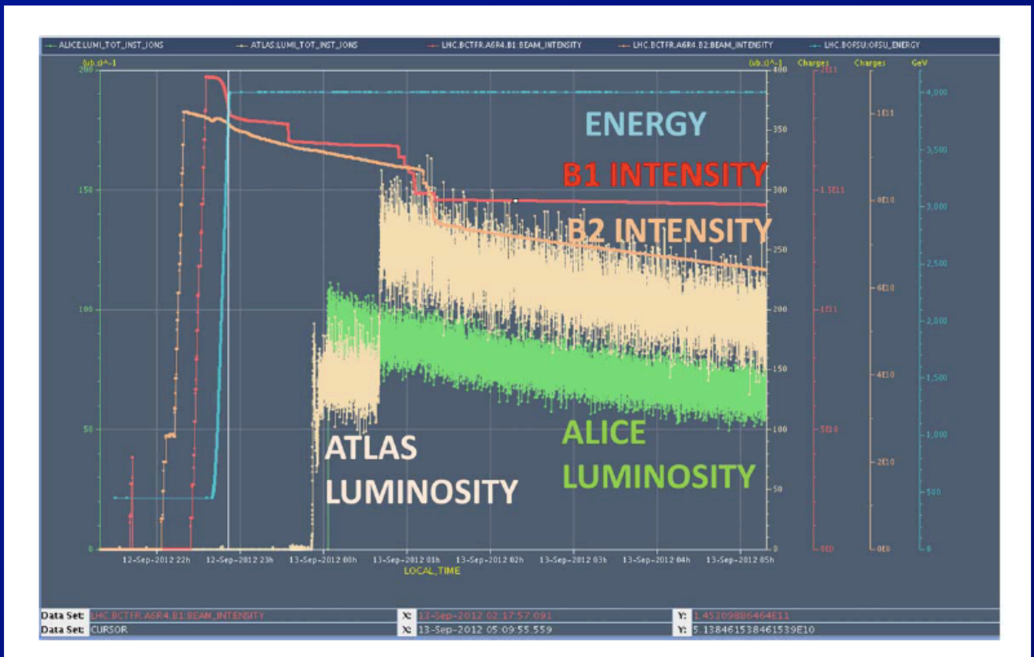
p+Pb pilot run

- LHC was operated with:
  - 4 TeV proton beam colliding with
  - 1.57 TeV/nucleon lead (Pb) beam

    ⇒Center of mass energy 5.02 TeV/nucleon

    ⇒Center of mass rapidity shift Δy = -0.47
- 5 hour run w/ integrated lumi of ~ 1 μb^{-1}

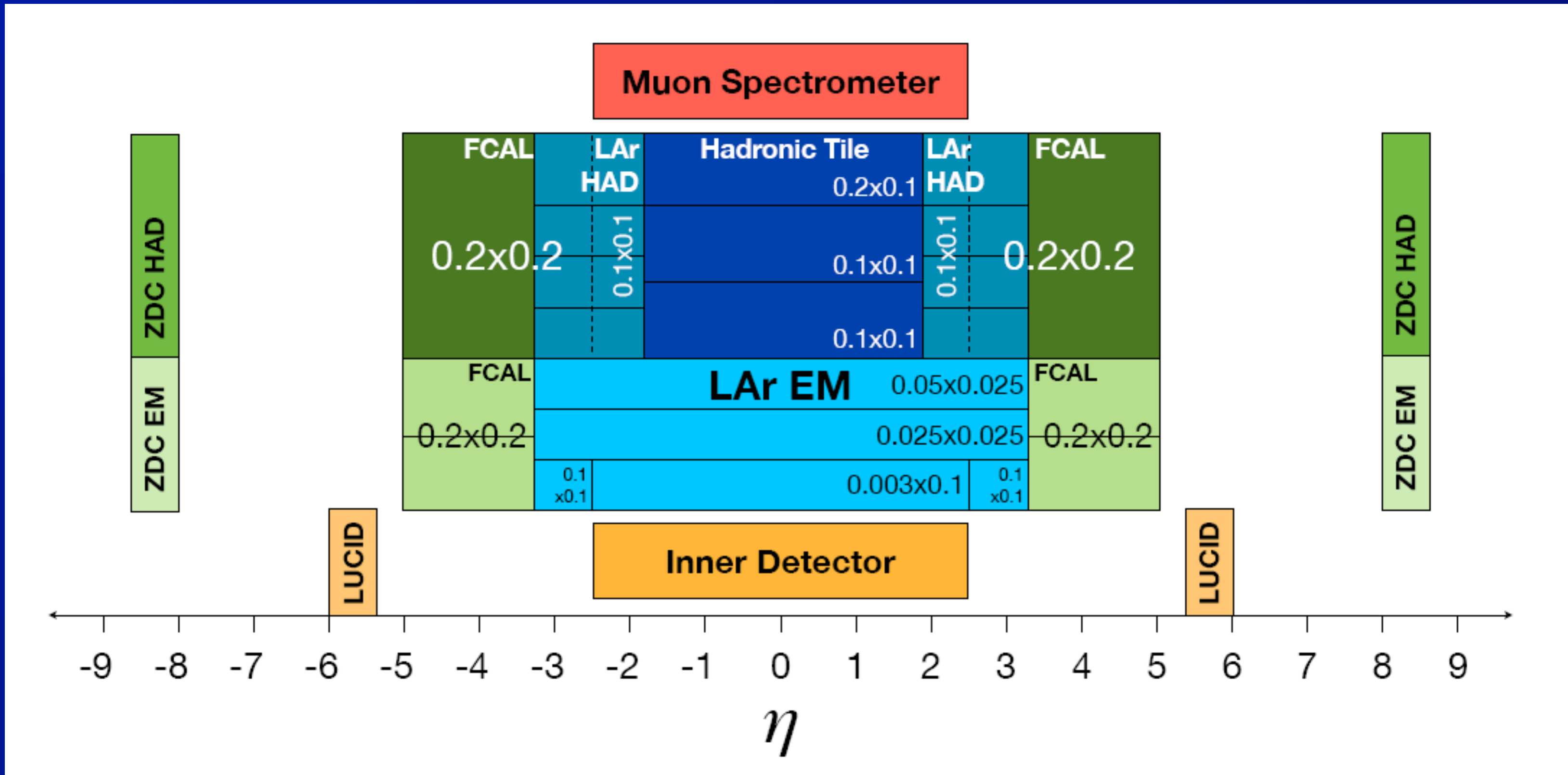
  ⇒2 million events (in ATLAS).

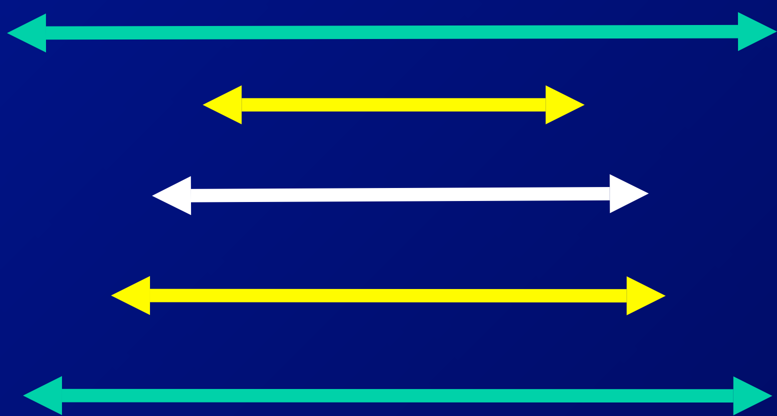


From R. Alemany *et al*, CERN-ATS-Note-2012-094 MD

http://cds.cern.ch/record/1496101

ATLAS Acceptance





Bulk observables

charged particles

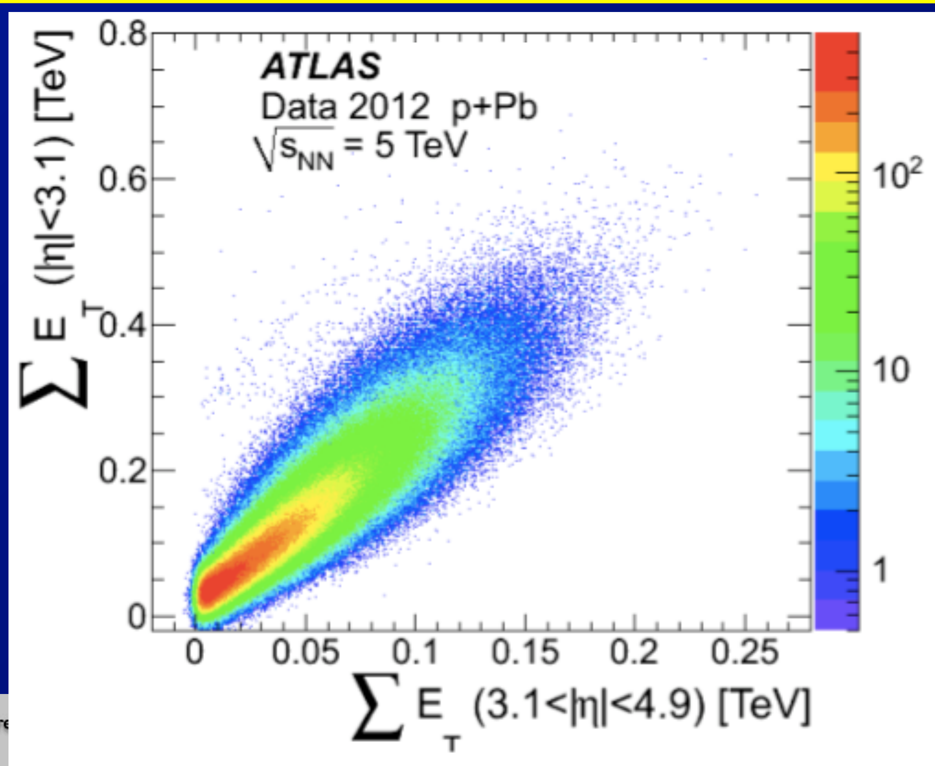
γ, π^0, isolated γ

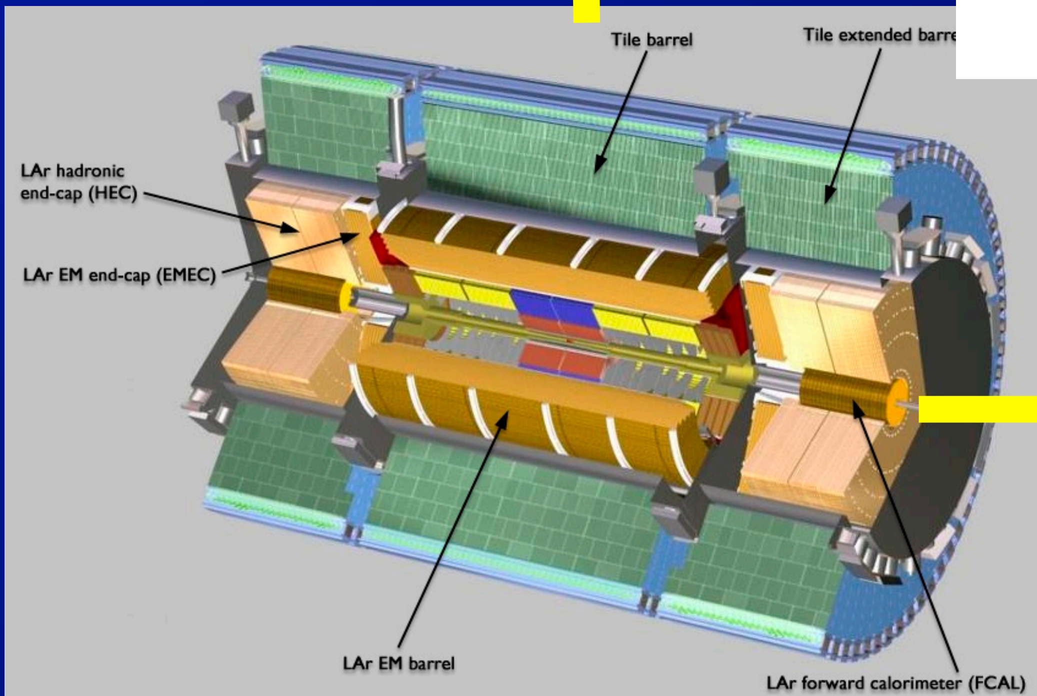
Υ, Υ’

Jets

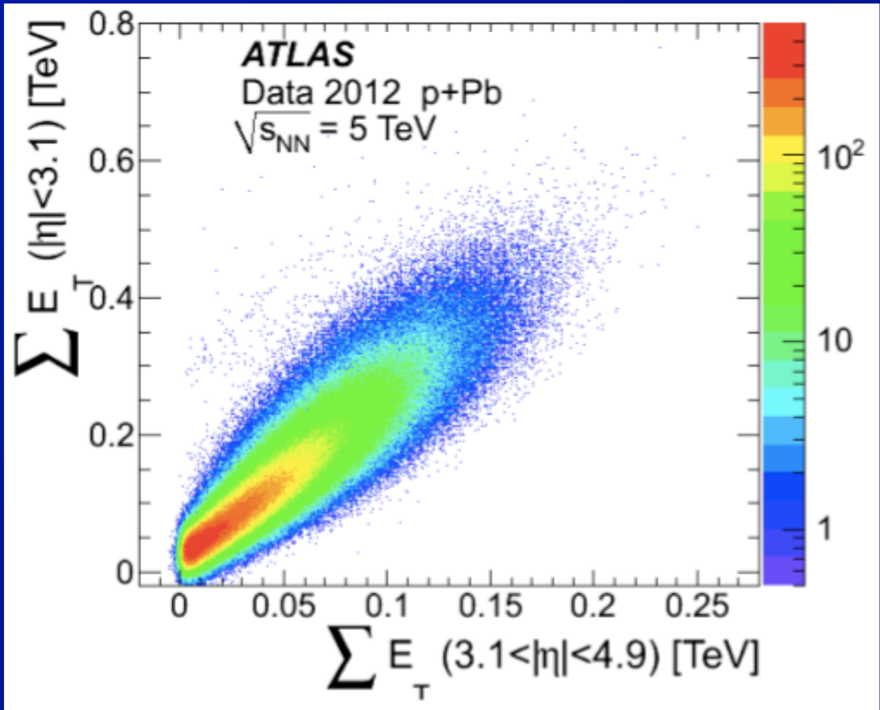
p+Pb transverse energy measurement

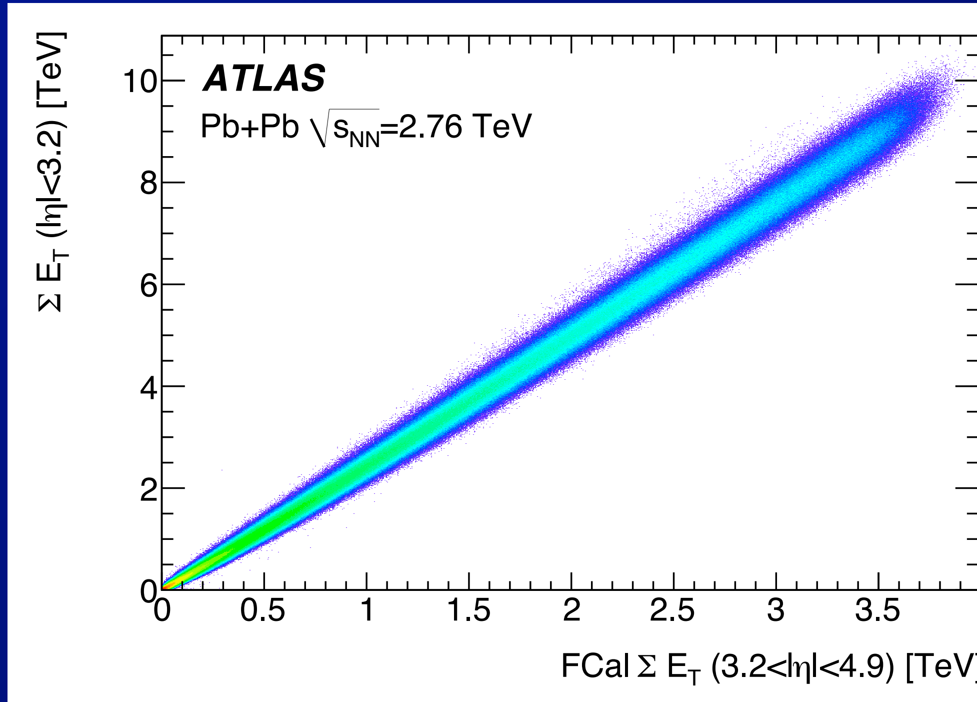
ΣE_T over different parts of calorimeter





ΣE_T: Compare p+Pb and Pb+Pb

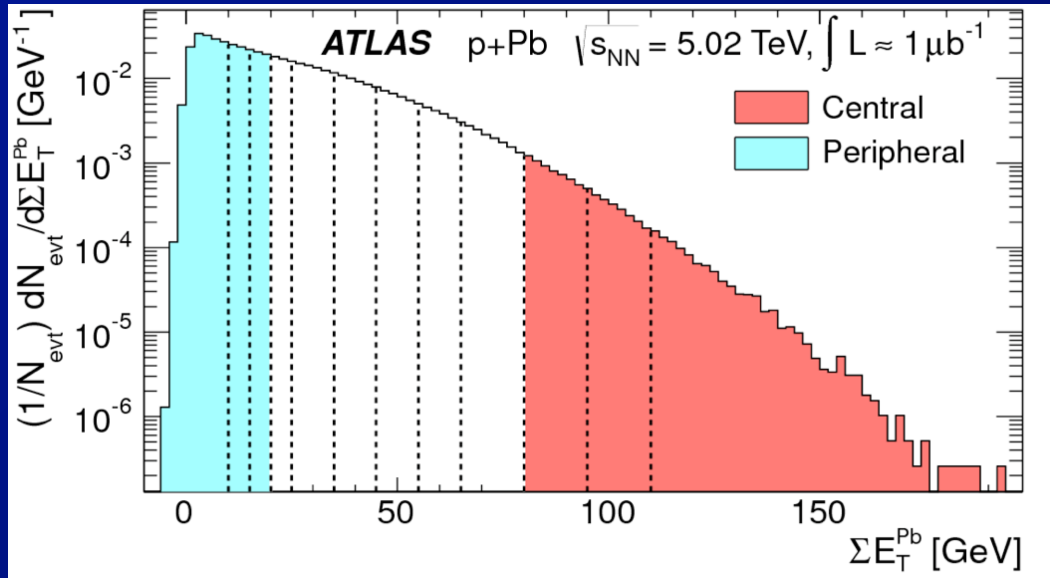




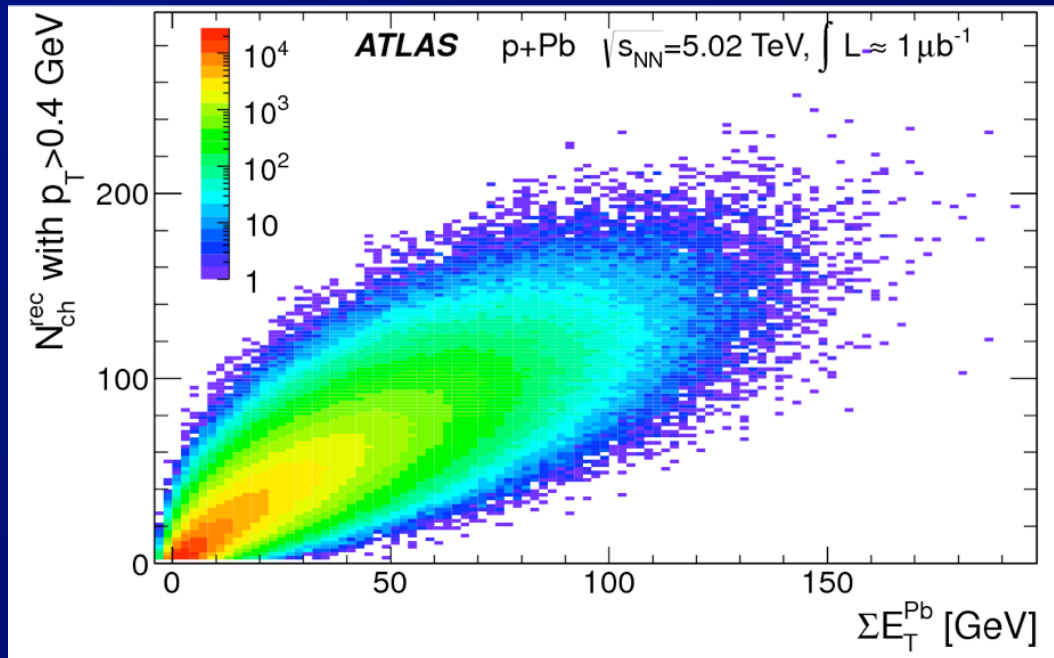
- In p+Pb, see "global" correlations in centrality observables similar to Pb+Pb.
  - Over scale that differs by factor of ~ 20.
  - But, much larger fluctuations in p+Pb.
    - ⇒No surprise.

Pb-going ΣE_T (4.9 < η < 3.1)

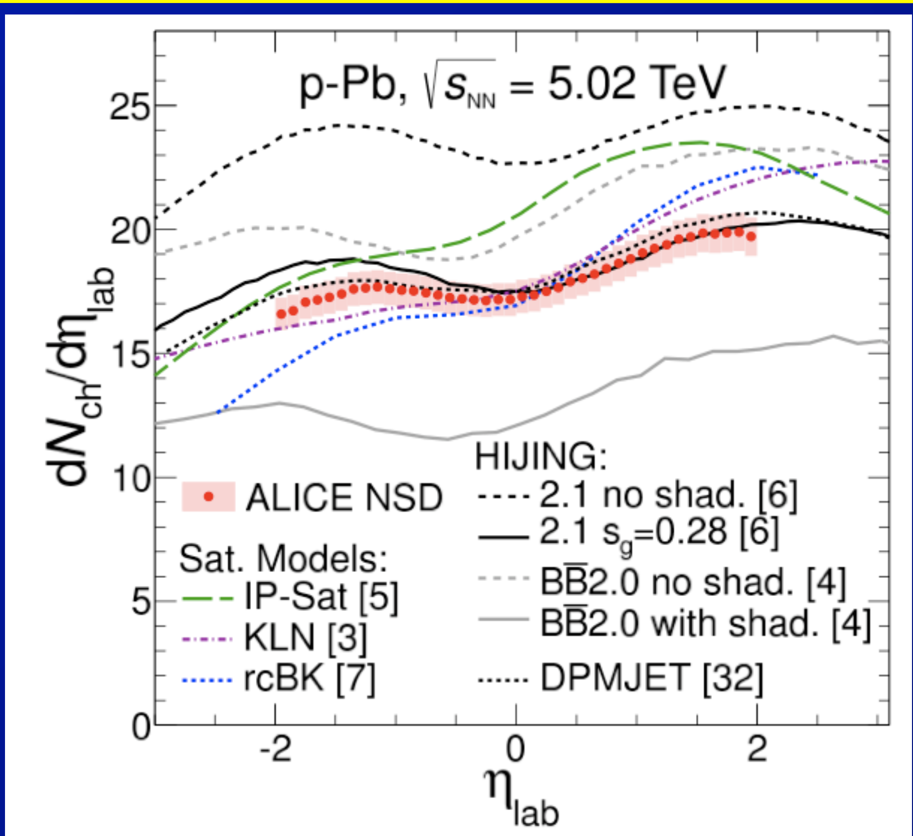
- For physics, we have concluded that Pb-going ΣE_T is useful centrality observable

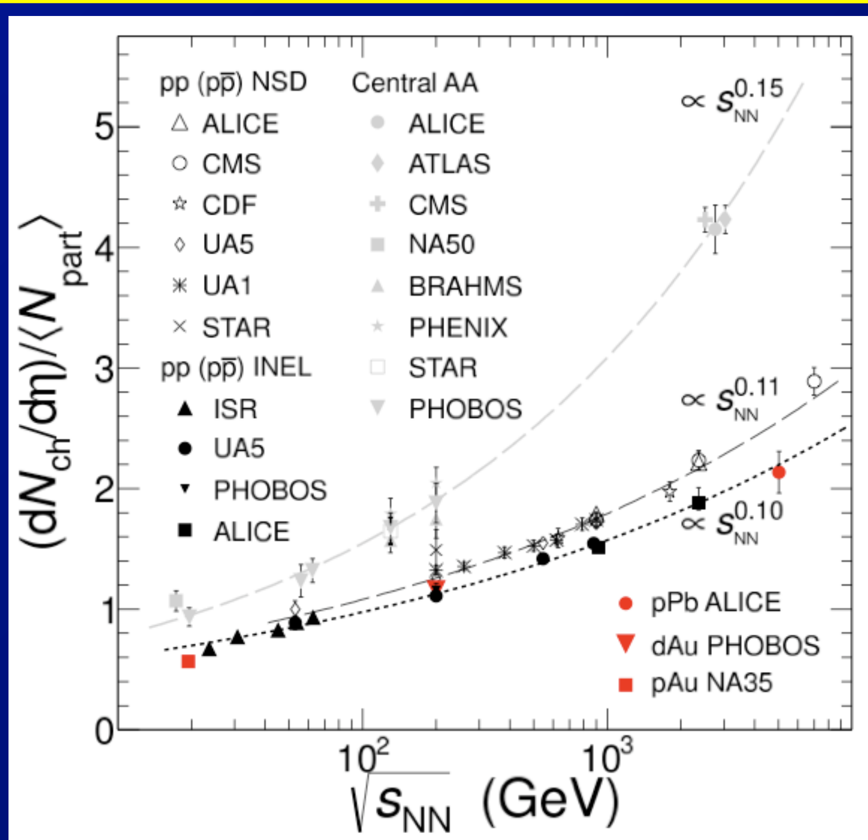


- Compare to reconstructed charged particle multiplicity
  - $p_T > 0.4$ GeV
  - $|\eta| < 2.5$



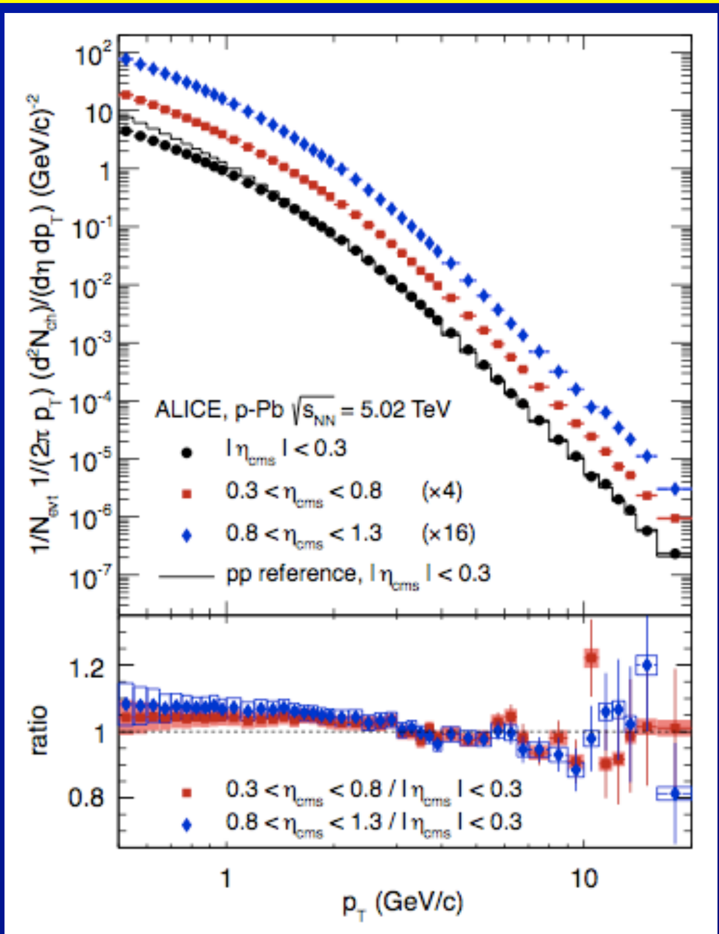
p+Pb inclusive $dN_{ch}/d\eta$

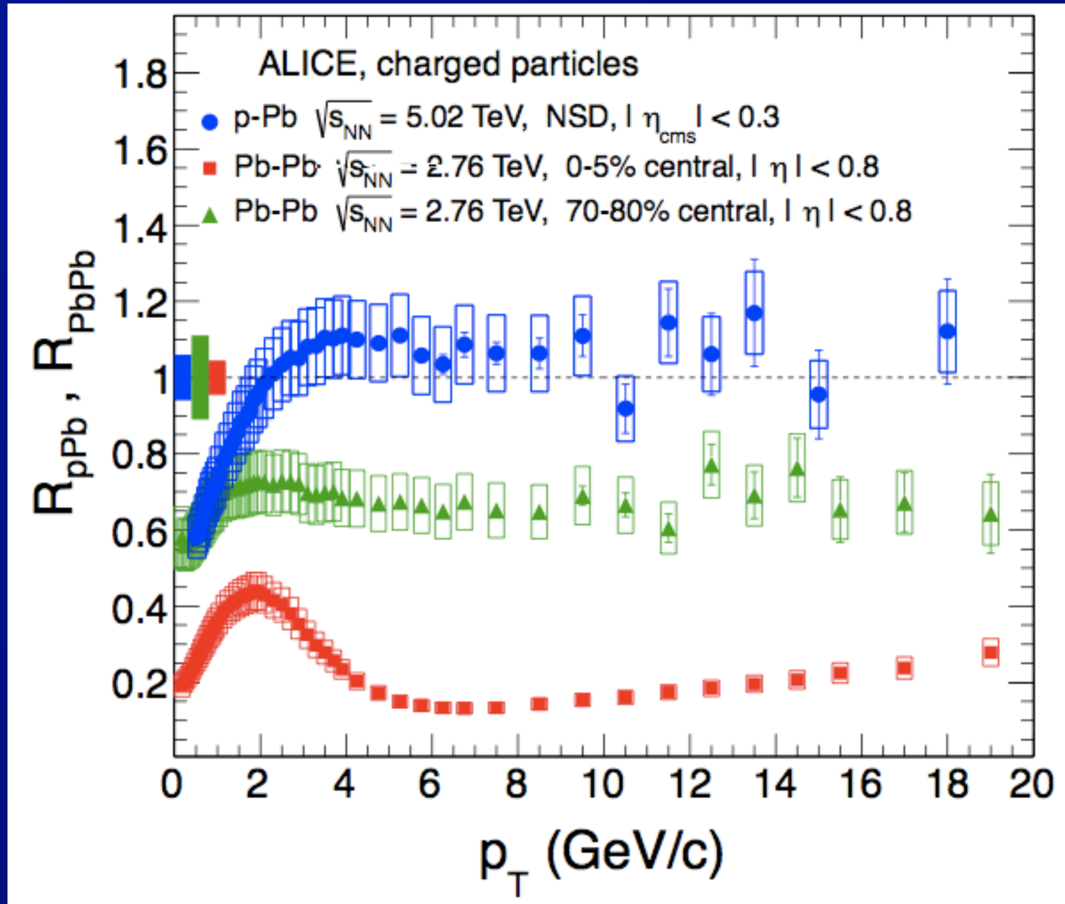




- 1^{st} look at charge particle multiplicity:
  - arXiv:1210.3615: ALICE inclusive, NSD
    - ⇒ $dN_{ch}/d\eta/N_{part}$ 16% lower than in (est.) p-p
- note: in ATLAS, similar trigger has non-negligible SD contribution

p+Pb inclusive spectra





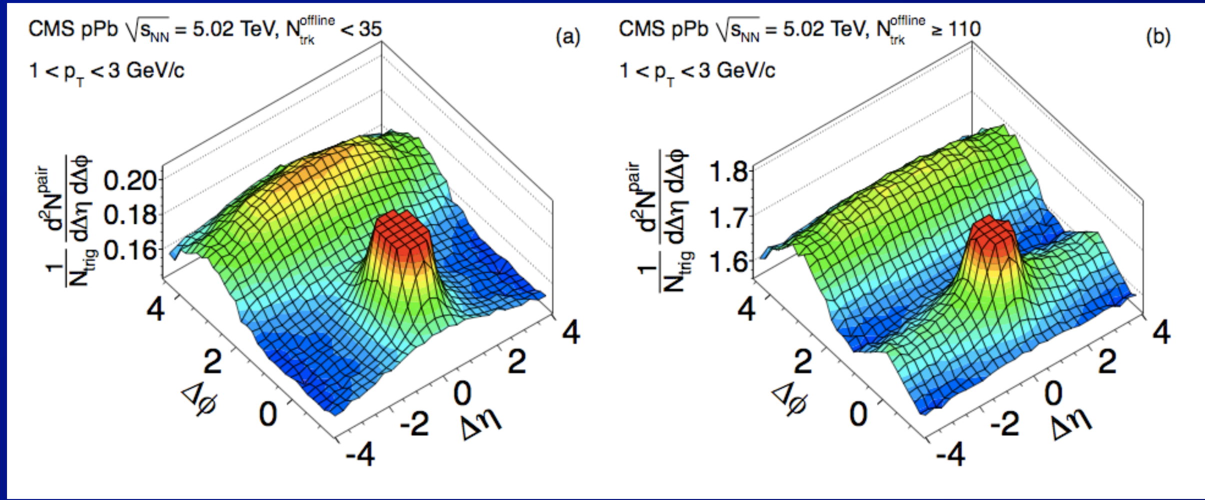
- **1st look at charged particle spectra**
  - arXiv:1210.4520, ALICE inclusive, NSD
    - ⇒ R_{pPb} consistent with 1, no suppression at mid-rapidity, also little or no “Cronin”

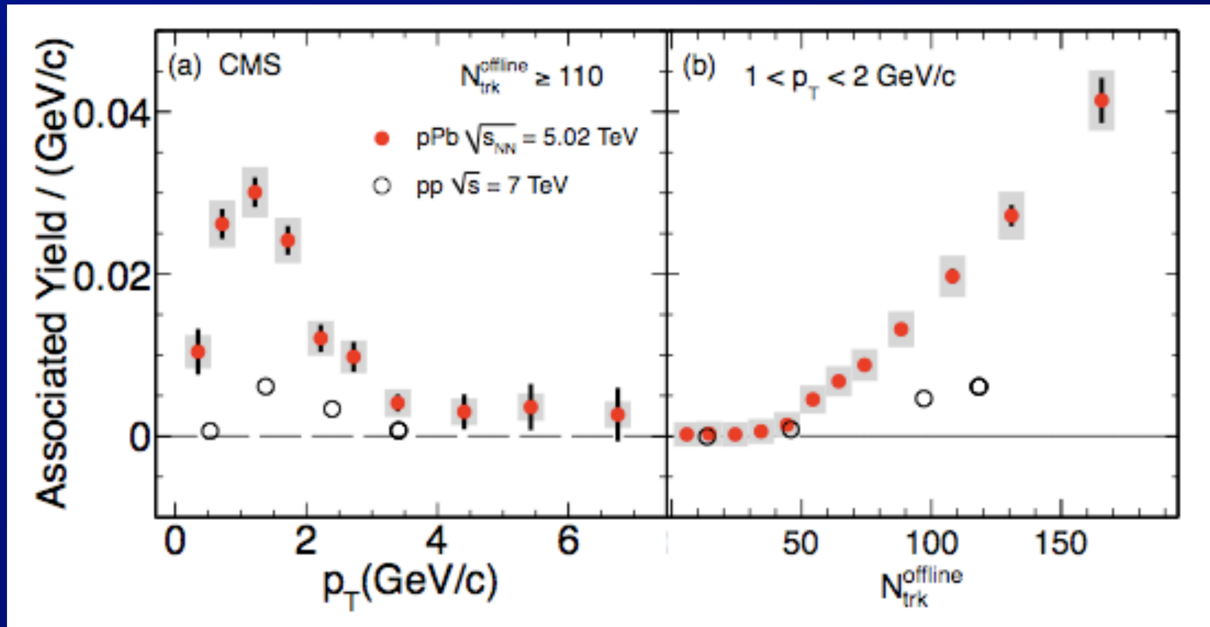
Multiplicity and spectra

- Clearly, next step is to study multiplicity and spectra as a function of centrality.
  - And to measure spectra over larger range of pseudo-rapidities.
- Why no results so far?
  - speaking for ATLAS only, ∃ a significant diffractive contribution to minimum-bias p+Pb cross-section that has complicated the "usual" analysis previously applied @ RHIC & LHC
    - ⇒ e.g. application of usual naive Glauber model analysis fails for diffractive excitation of the proton and at large impact parameter
    - ⇒ Likely that same problem exists @ RHIC

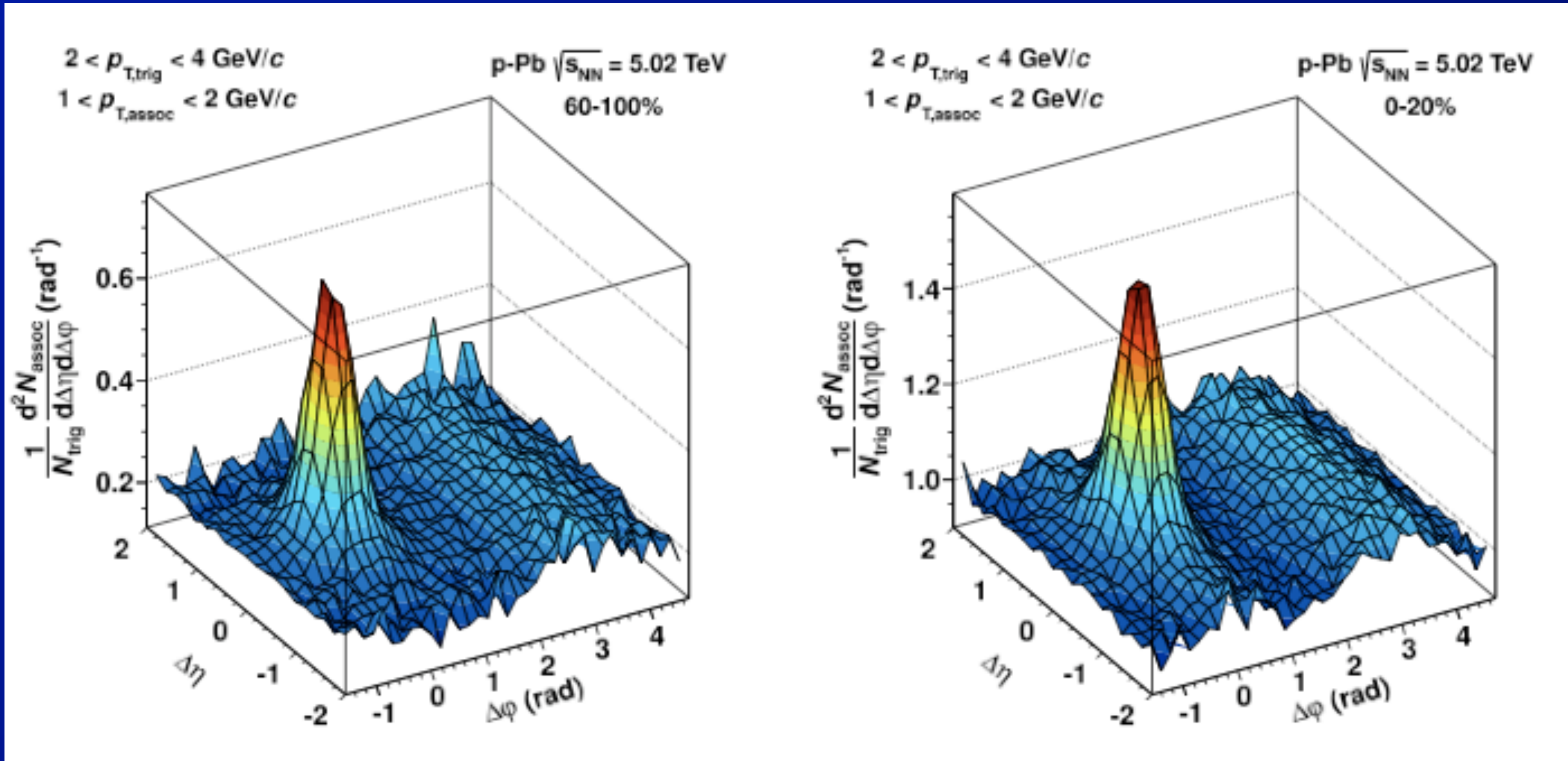
CMS 2-particle correlations

- 1^{st} observation of ridge in p+Pb collisions.
  - in 2-charged particle correlations
- Growth in yield with multiplicity
  - ⇒Much larger than in p-p
- rapid variation with p_T
  - ⇒due to common p_T bins for both particles



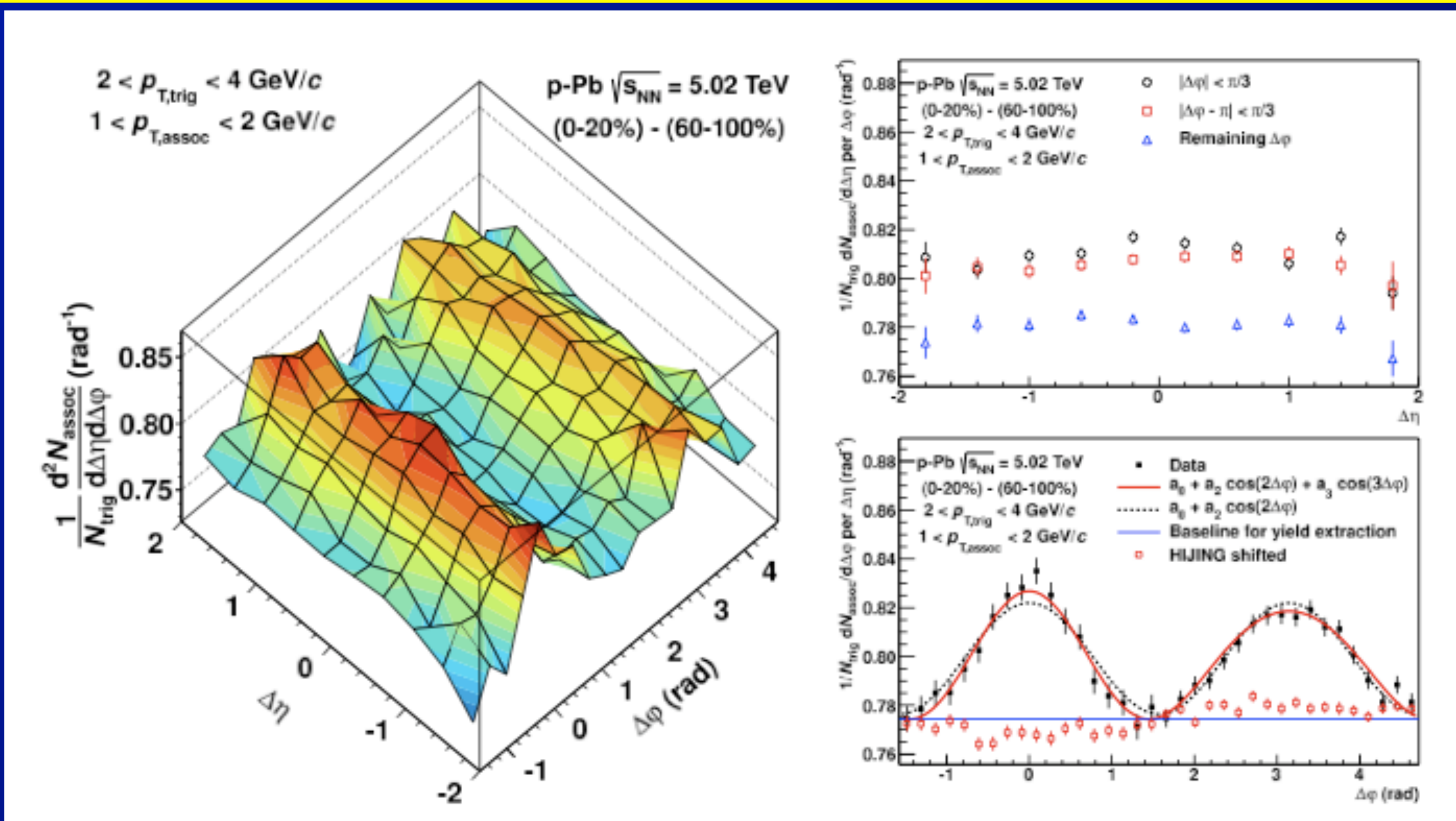


ALICE: 2-particle correlations



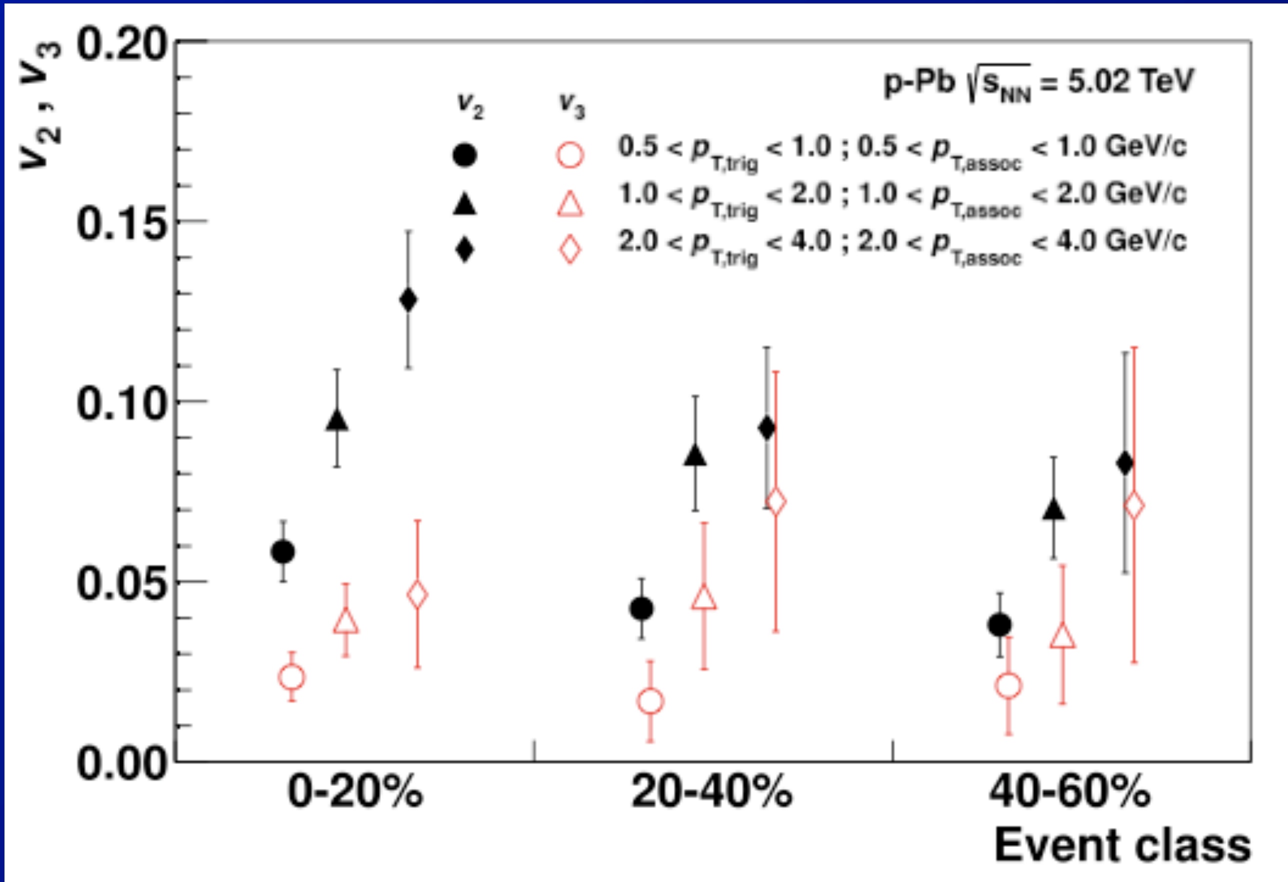
- ALICE measurement of 2-charged particle correlations in 60-100% and 0-20% bins
  - based on V0 detector multiplicity
    - ⇒ see additional near-side correlation in more central events over $|\Delta\eta| < 1.8$

ALICE: 2-particle correlations



- ALICE: consider difference between central and peripheral vs Δη and Δφ
  - with fits to $a_0 + a_2 \cos\left(2\Delta\phi\right)$
  - and $a_0 + a_2 \cos\left(2\Delta\phi\right) + a_3 \cos\left(3\Delta\phi\right)$

ALICE: 2-particle correlations

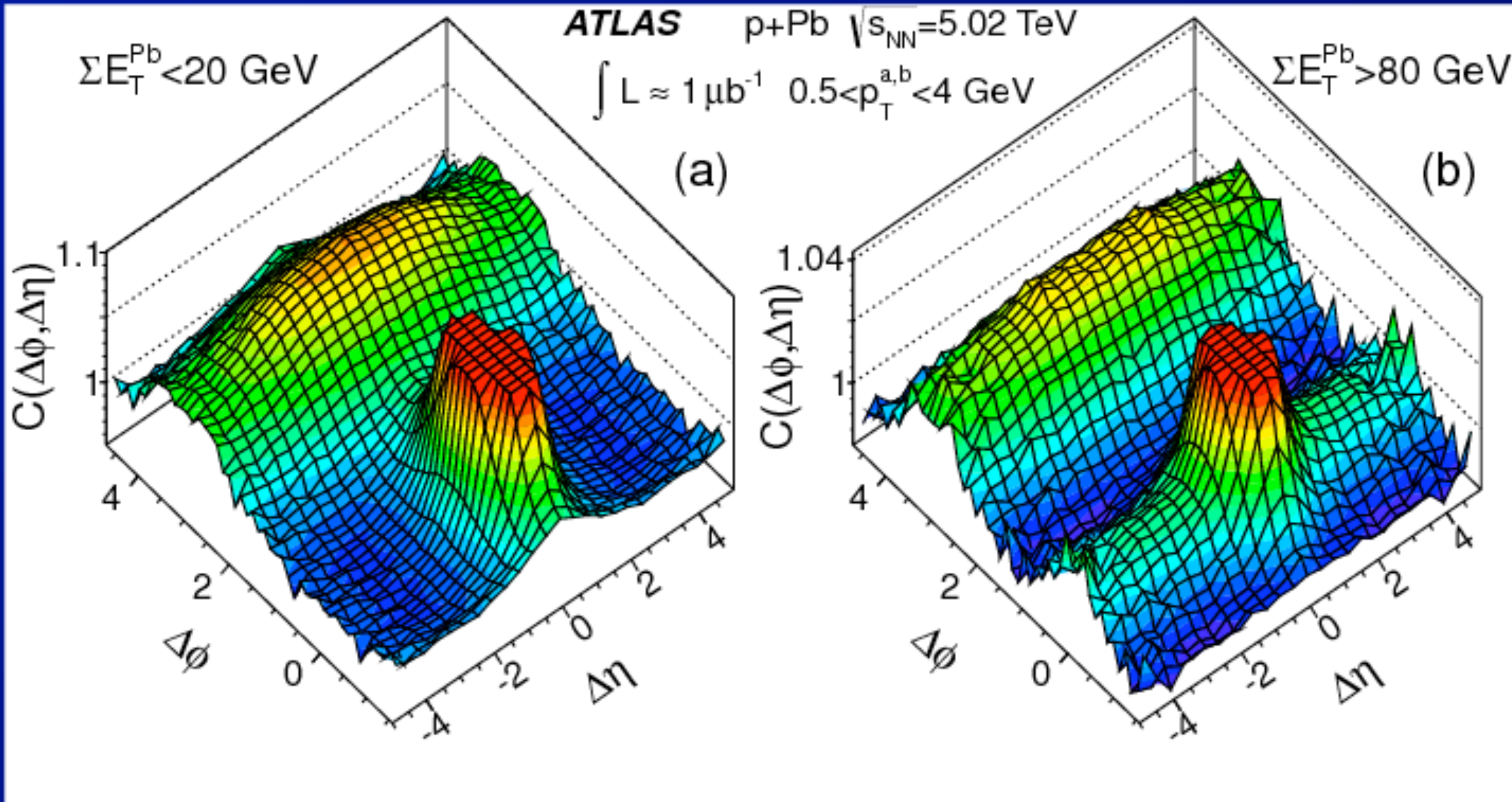


- Convert the a_2 and a_3 to analog of single particle flow coefficients v_2 and v_3
  - assumes factorization (below)

    ⇒significant v_2 and v_3 values

ATLAS 2-particle correlations

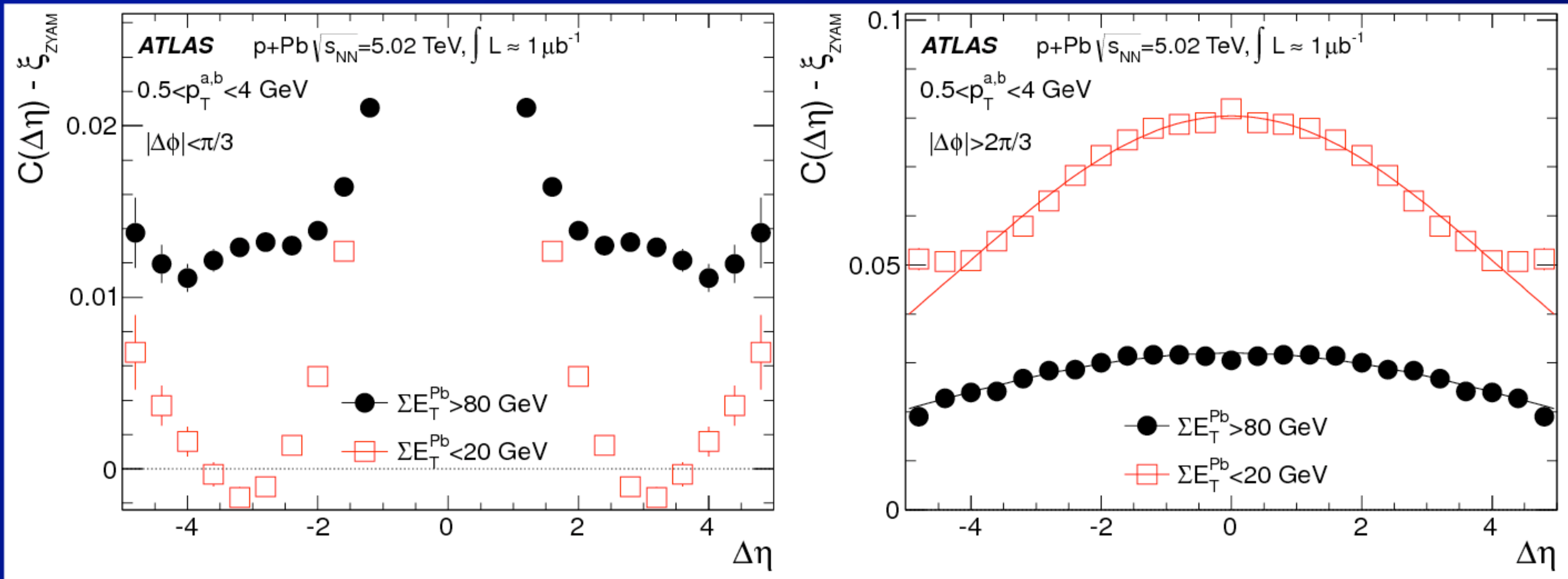
"peripheral" "central"



- charged particles, $|\eta| < 2.5$, $0.5 < p_T < 4$ GeV
  - see "usual" correlations in peripheral
  - see ridge + away-side broadening in central

ATLAS 2-particle correlations (2)

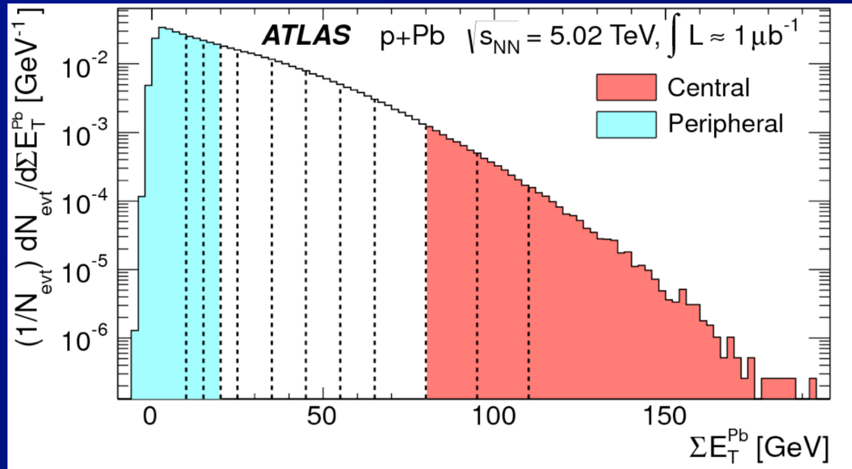
"peripheral" "central"

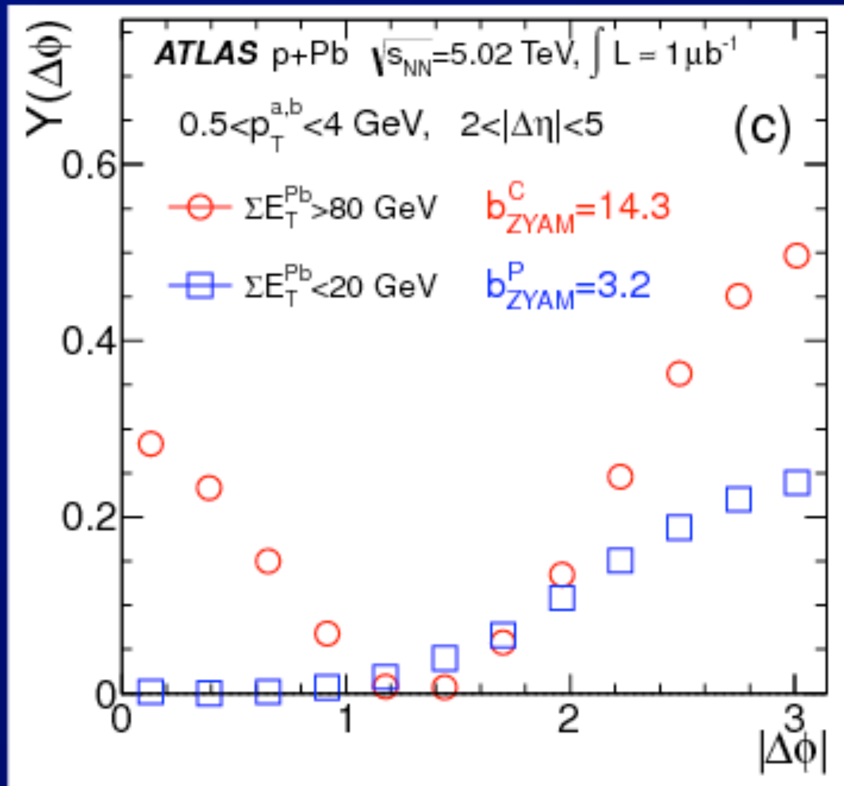


- To better see Δη dependence, project ZYAM-subtracted correlation function.
  - For near (Δφ<π/3) and away (Δφ>2π/3) sides.
    - ⇒ In central collisions see ridge and broadening of away-side component relative to peripheral collisions.

ATLAS 2-particle correlations (3)

- Per trigger yields Y(Δφ) integrated over η
  - peripheral and central
    - ⇒"Ridge" clearly present in central
    - ⇒Similar increase in the away side yield between peripheral, and central collisions

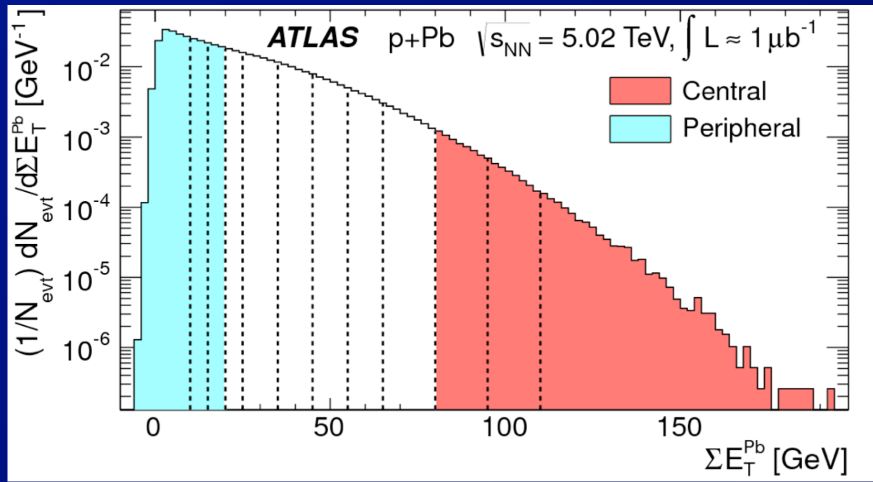


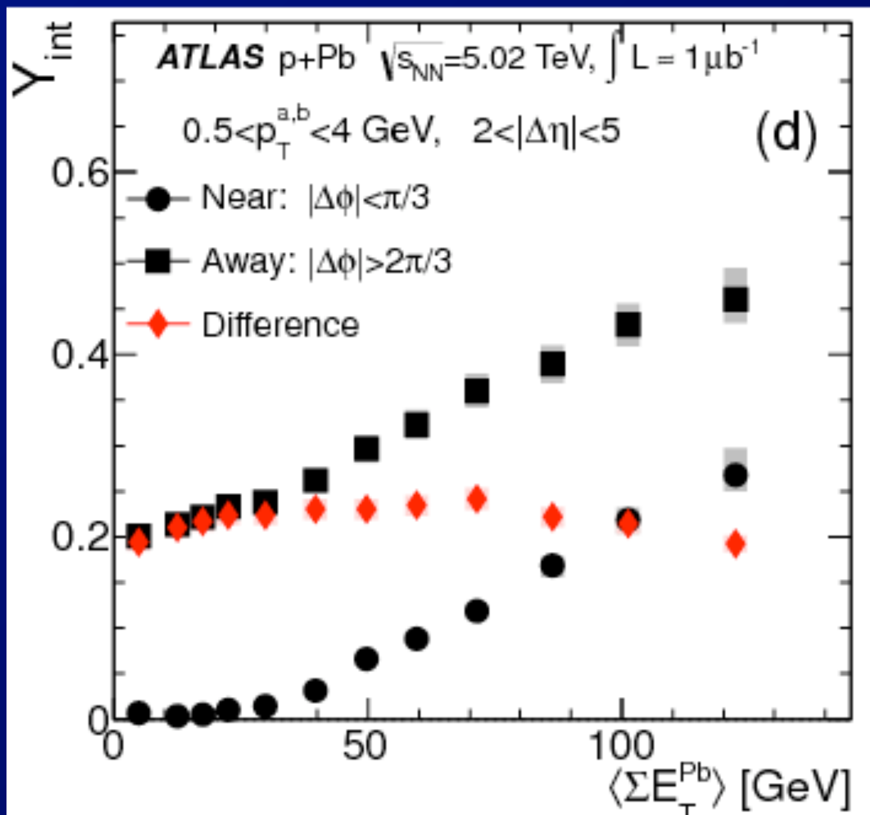


ATLAS 2-particle correlations (4)

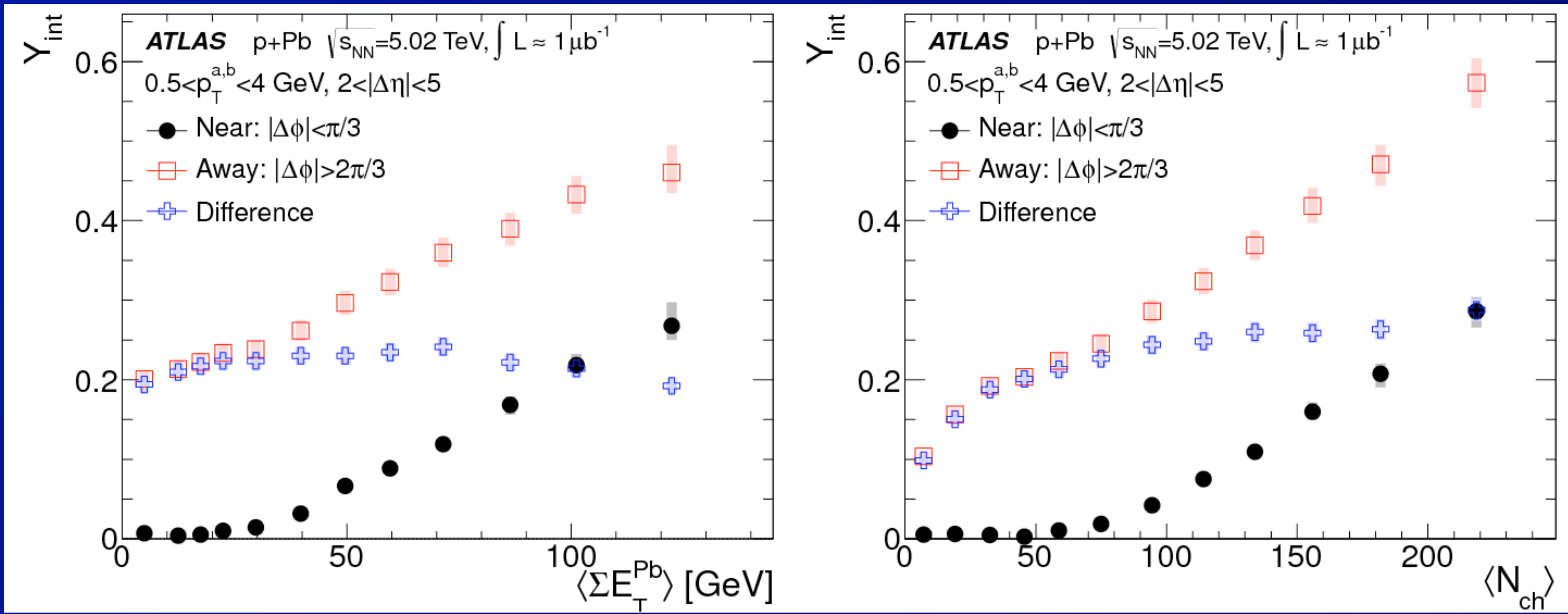
- Evaluate integrated per-trigger yields, Y_{int}, near ($\Delta\varphi < \pi/3$) and away ($\Delta\varphi > 2\pi/3$)
  - Yield grows with increasing ΣE_T similarly on near and away sides
  - Difference between away and near yields ≈ constant

  ⇒ constant "recoil": dijet + p cons. + low-p_T resonances





Why E_T not N_{ch} for "centrality" ?

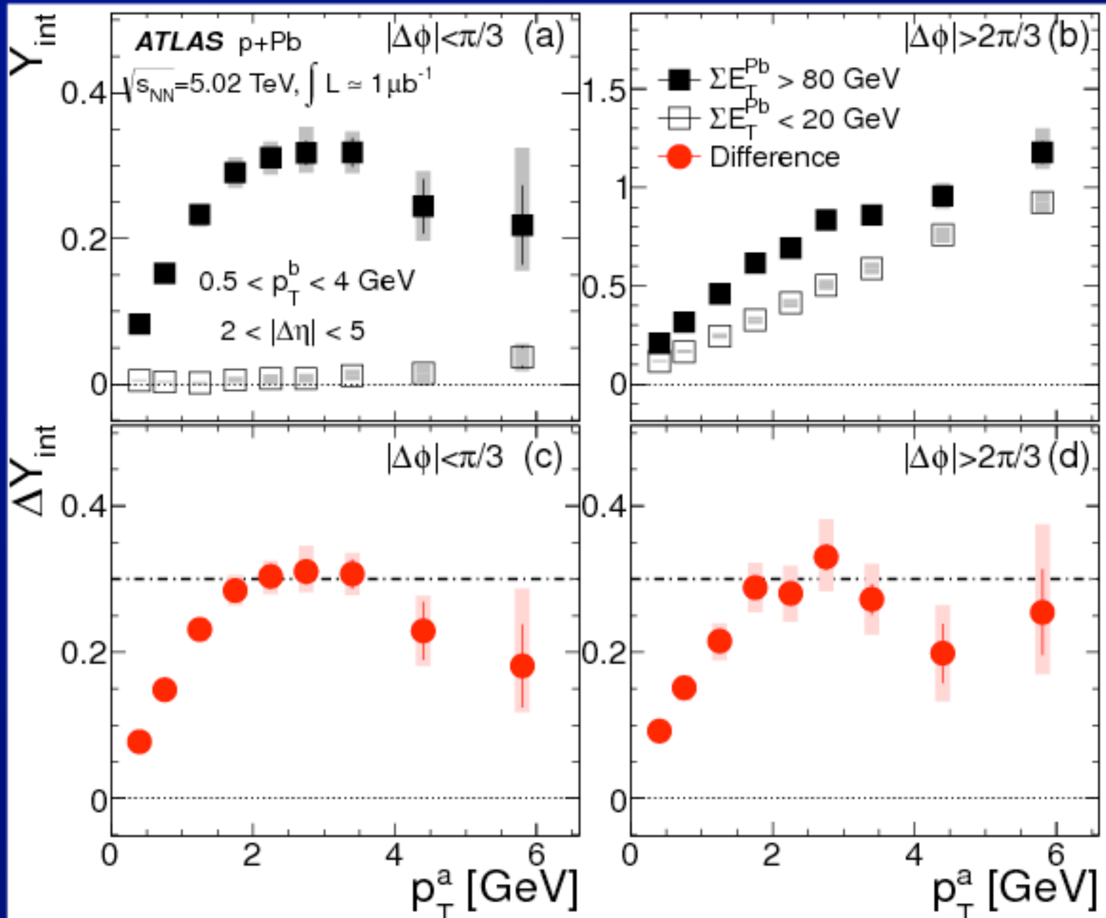


- There is an auto-correlation between N_{ch} and the number of particles & pairs
  - ⇒Distorts the per-trigger yields from the "recoil" contribution at low N_{ch}
  - ⇒Why the different behavior of away-near difference at large N_{ch} / ΣE_T?

ATLAS 2-particle correlations (5)

- Study variation of integrated per-trigger yields with trigger p_T
  - For associated $0.5 < p_T < 4$ GeV
- Evaluate difference between peripheral and central
  - difference ≈ same on near and away sides, and similar p_T dependence

near away

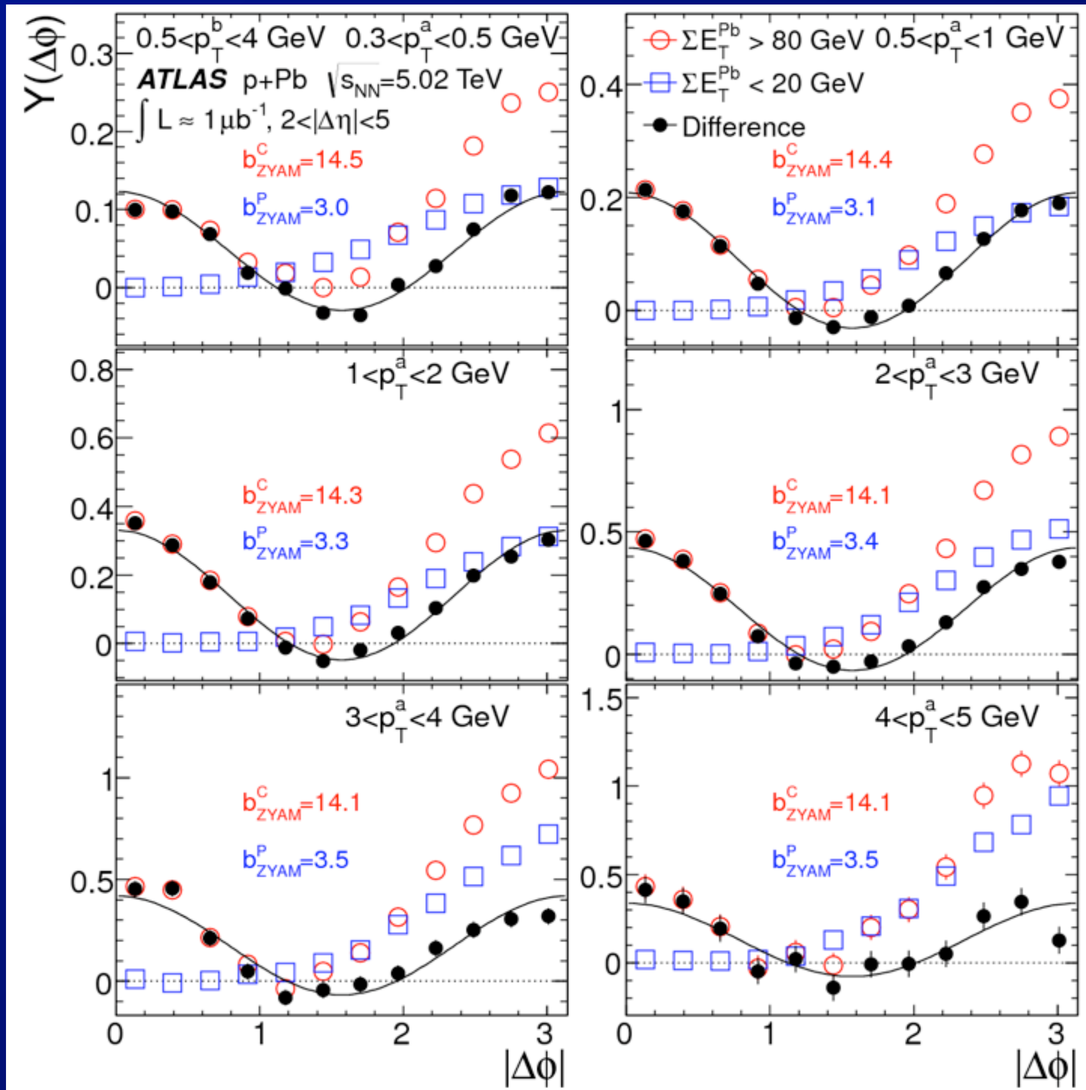


Beware different vertical scales on top panels

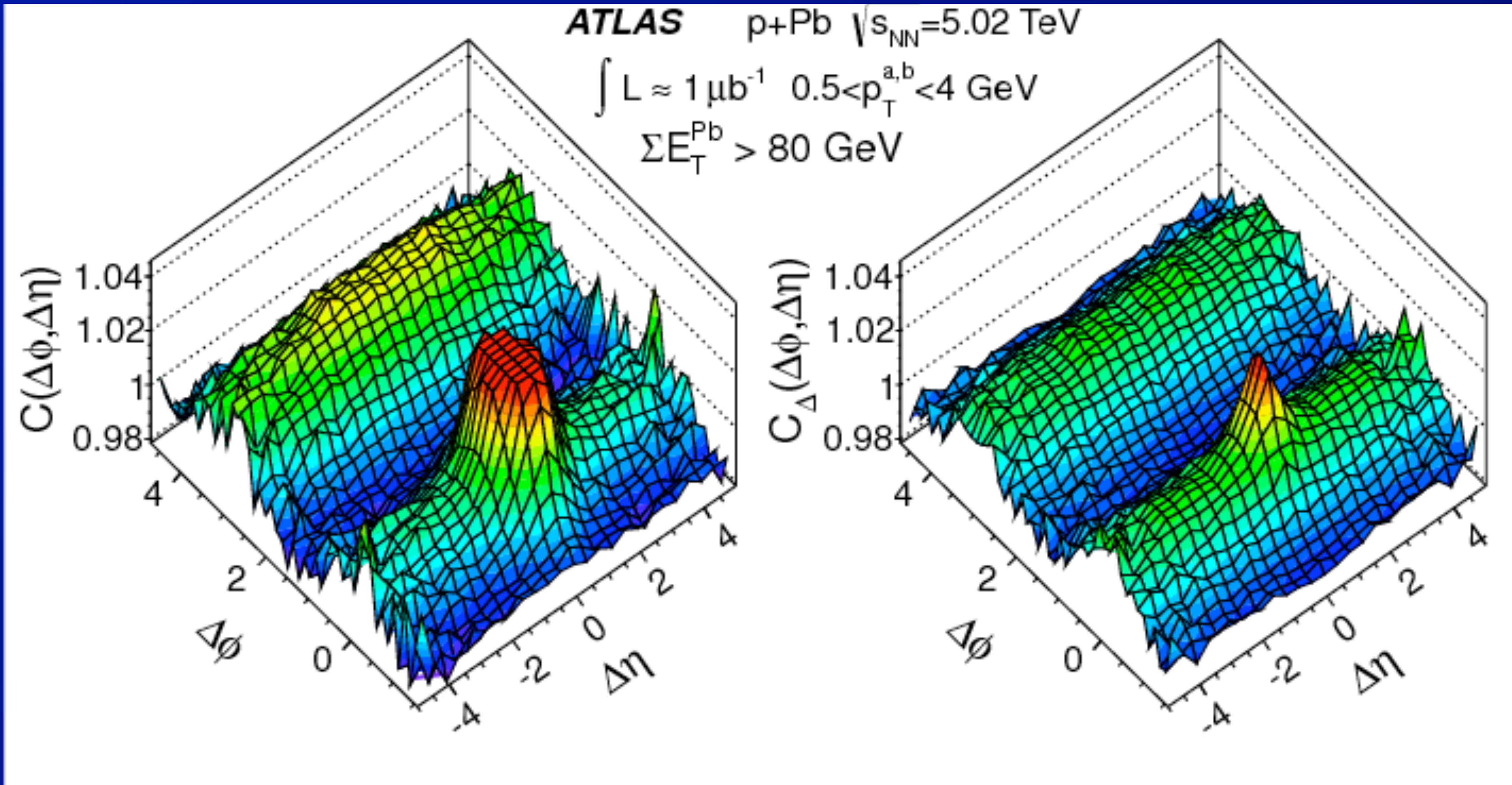
ATLAS 2-particle correlations (6)

- Motivated by above observations subtract peripheral Y(Δφ) from central Y(Δφ)
  - With associated $0.5 < p_T < 4$ GeV
  - In different trigger p_T bins

    ⇒Observe an approximately symmetric modulation in all bins



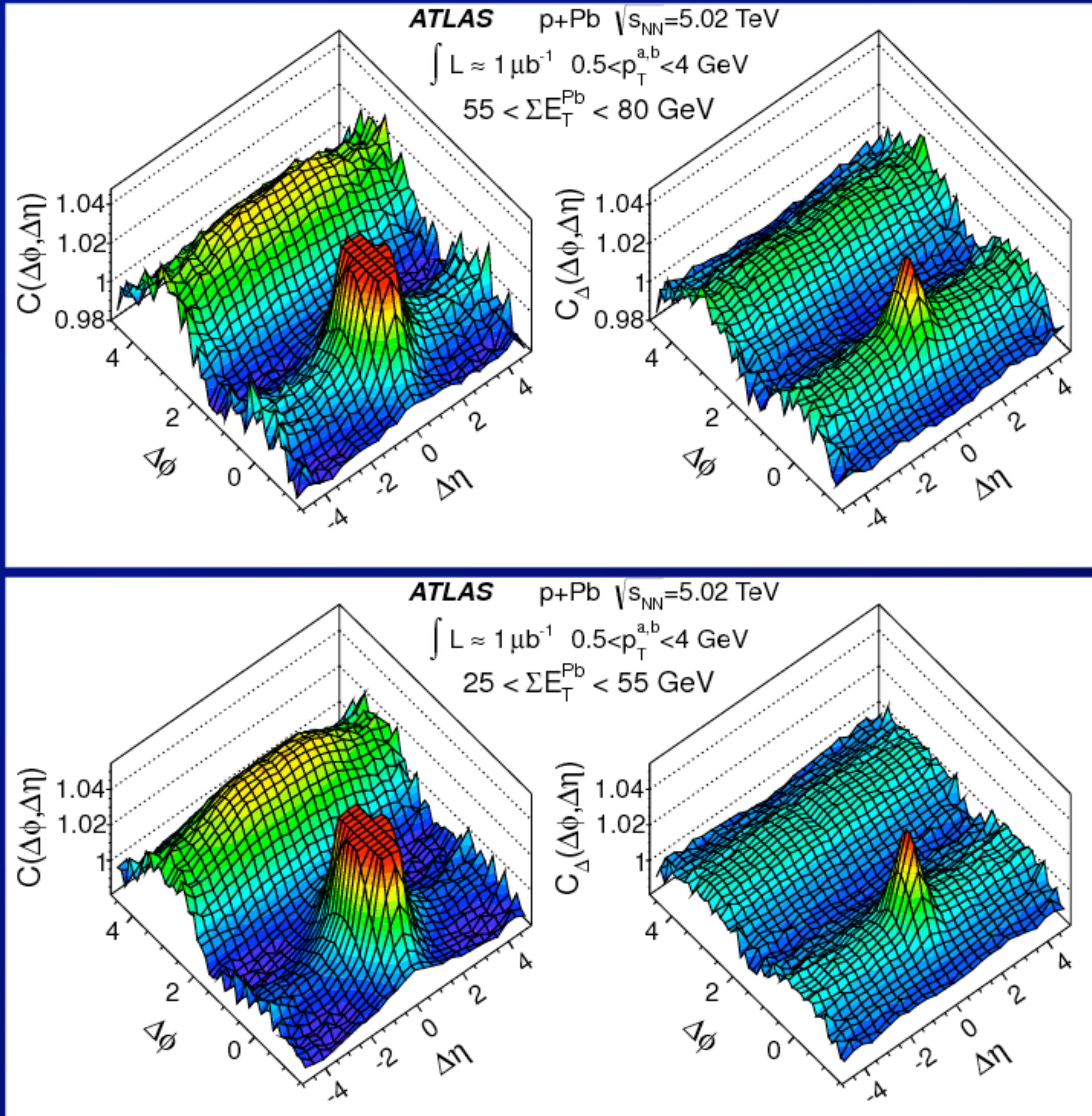
ATLAS 2-particle correlations (7)



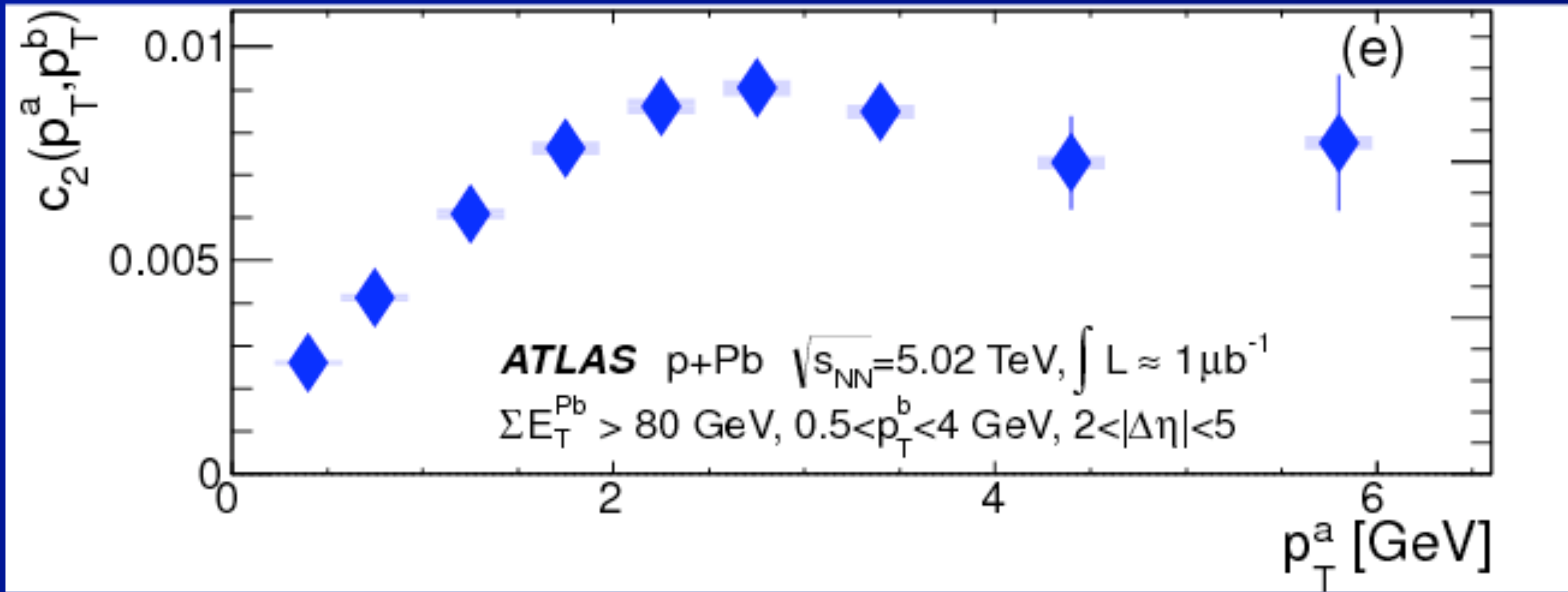
- Central correlation function before and after subtraction of peripheral per-trigger yields, and converting back to C(Δφ,Δη)
  - ⇒Long-range modulation

ATLAS 2-particle correlations (7)

- Subtracted correlation functions for 2 other centrality bins.



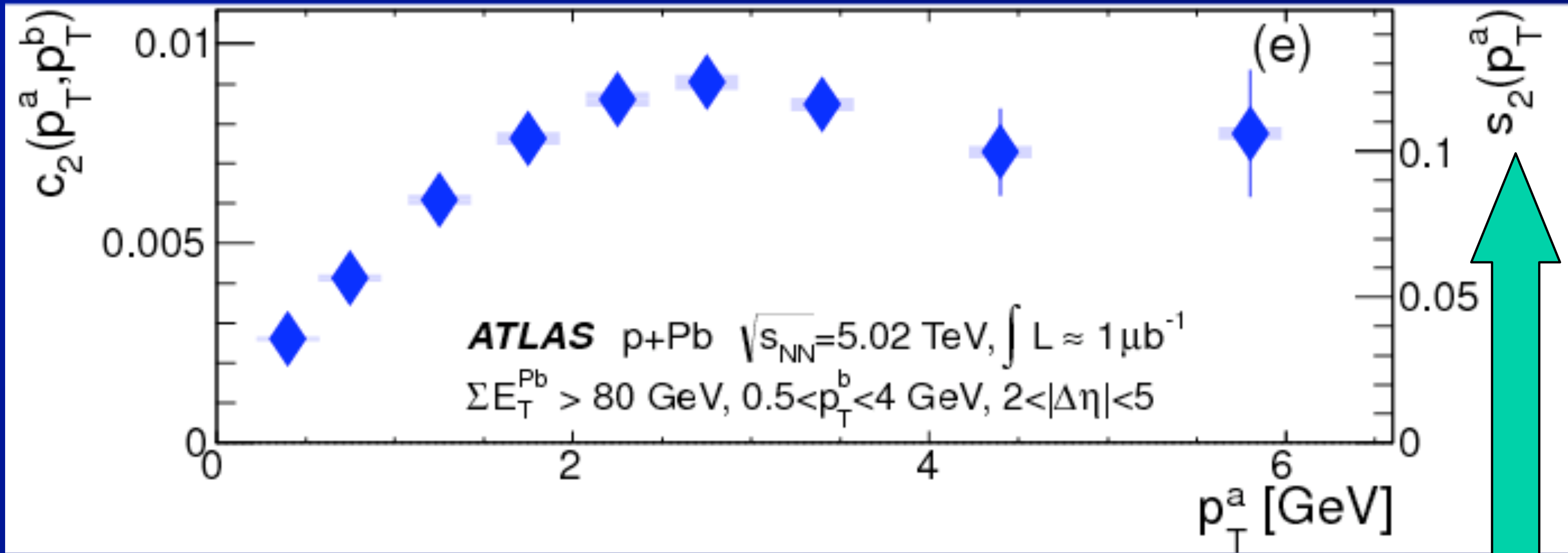
Fourier decomposition



- **Extract leading and second Fourier coefficients from per-trigger yields**
  - $a_0 = \langle Y(\Delta\phi) \rangle \quad a_2 = \langle Y(\Delta\phi) \cos(2\Delta\phi) \rangle$
  - Convert to relative modulation of subtracted correlation function: $C_{sub} = A\,(1 + 2c_2 \cos 2\Delta\phi)$

    $\Rightarrow$ maximum ~ 1% modulation of the 2-particle correlation in central events

Fourier decomposition (2)

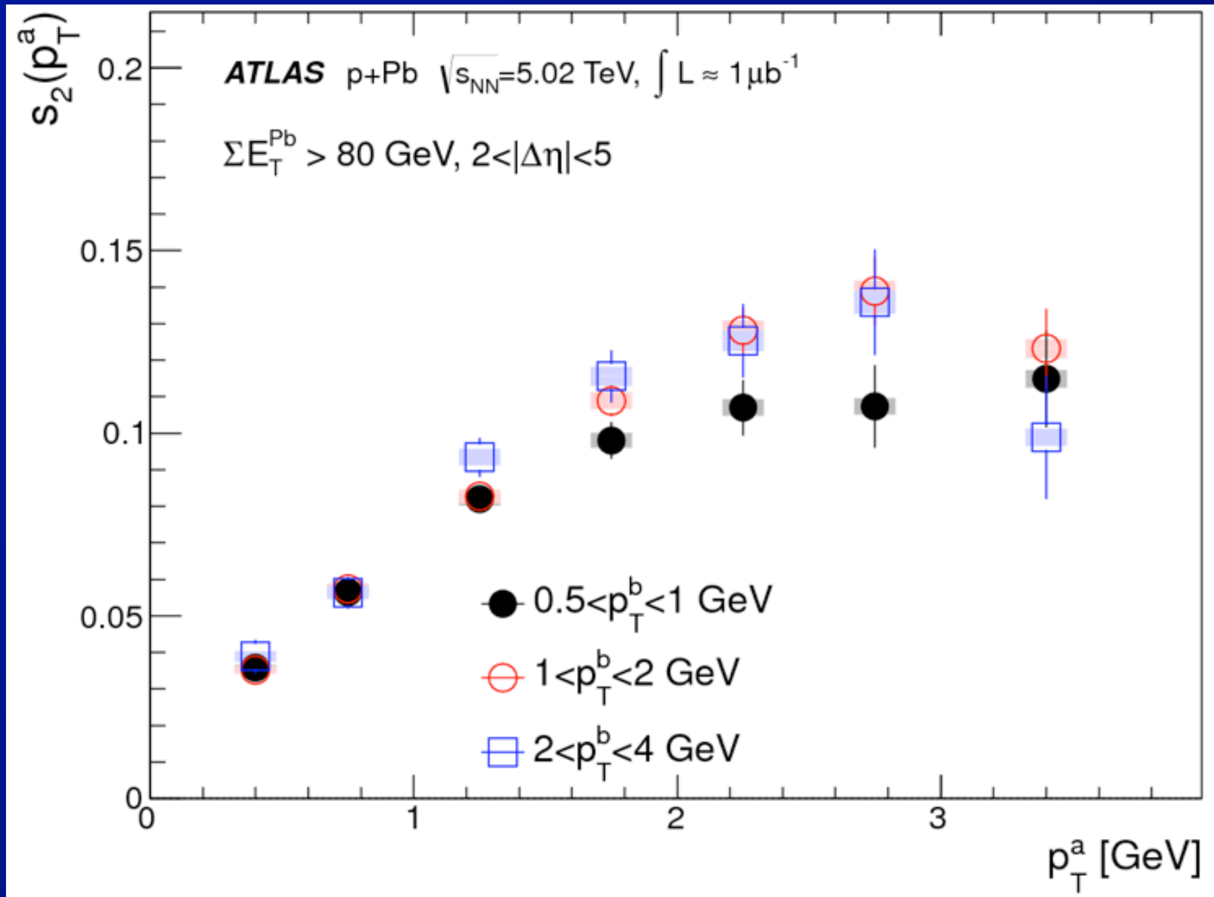


- If we assume that the amplitude of the 2-particle modulation factorizes:
  - $c_2(p_T^a, p_T^b) = s_2(p_T^a)\, s_2(p_T^b)$
  - can calculate the single-particle modulation

    ⇒See s_2 values up to 0.14
- Then, *if* the modulation were due to flow

  ⇒ v_2 values as large as 0.14

Test factorization



- If factorization holds, should obtain same s2 values for different associated p_T
  - ⇒true for p_T < 1 GeV
  - ⇒start to see deviations at higher p_T

2013 p-A Run projected performance

Baseline performance extrapolated from Pilot Fill

$f0 \to 11245.5$ Hertz
$\sigma pPb \to 2.$ Barn
$\gamma p \to 4263.16$
$\gamma Pb \to 1693.45$
$\beta alice \to 0.8$ Meter
$\beta atlas \to 0.8$ Meter
$\beta lhcb \to 2.$ Meter
$NPb \to 1.2 \times 10^8$
$Np \to 1.5 \times 10^{10}$
$kb \to 318$
$kc15 \to 276$
$kc2 \to 276$
$kc8 \to 42$
$Nexp \to 3$
$EmittPbx \to 1.4 \times 10^{-6}$ Meter
$EmittPby \to 1. \times 10^{-6}$ Meter
$Emittpx \to 1.7 \times 10^{-6}$ Meter
$Emittpy \to 1.7 \times 10^{-6}$ Meter

	ATLAS	ALICE	CMS	LHCb
N_{Pb}	1.2×10^8			
N_p	1.5×10^{10}			
β^*	0.8	0.8	0.8	2.
$L/cm^{-2}s^{-1}$	1.01×10^{29}	1.01×10^{29}	1.01×10^{29}	6.14×10^{27}
μ	0.065	0.065	0.065	0.026

Already close to ALICE maximum luminosity with emittances of pilot fill, good Pb intensity, fairly conservative proton intensity – leaves room to try to increase it up to a factor ~3 (level ALICE if necessary).

Can easily be worse if we have blow-up or losses at injection or ramp (from moving encounters, IBS, …).

Unequal beam sizes were OK in pilot fill with higher β*. Emittance increase will probably reduce luminosity for all experiments and pile-up for ALICE.

This is our preferred first goal for the run. But, on the basis of present knowledge, it is by no means a "safe set of parameters" (except for optics).

– LHC planning document (Jowett) 12/12/12

2013 p-A Run projected performance

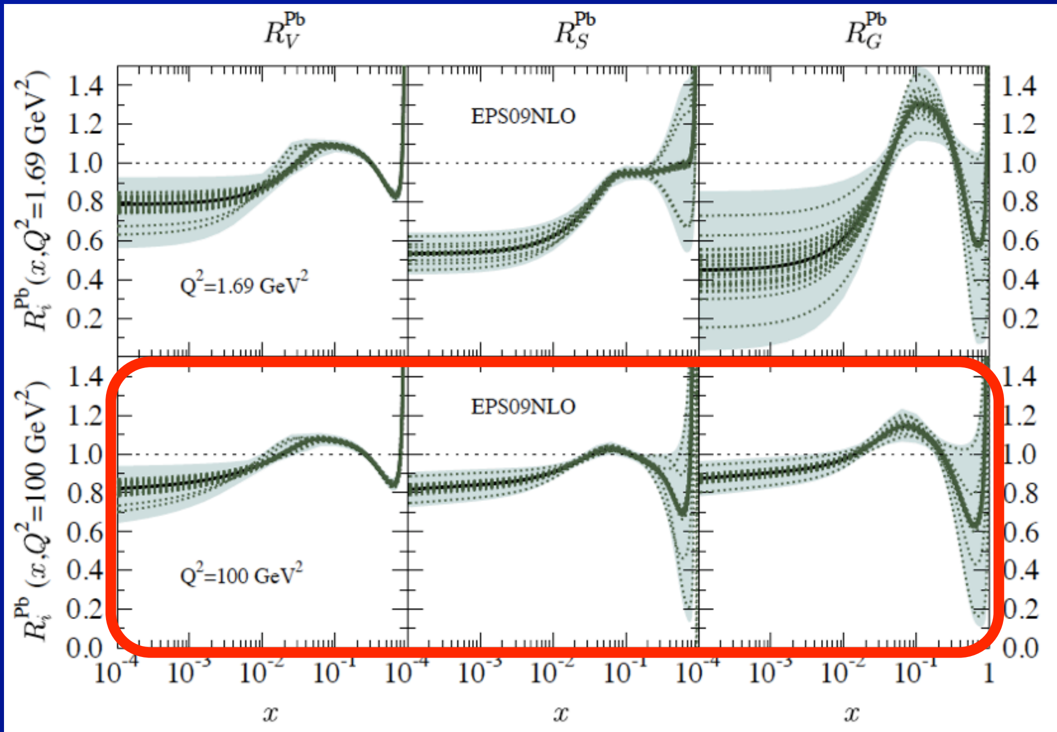
	ATLAS	ALICE	CMS	LHCb
N_{Pb}	1.2×10^8			
N_p	1.5×10^{10}			
β^*	0.8	0.8	0.8	2.
$L/cm^{-2}s^{-1}$	1.01×10^{29}	1.01×10^{29}	1.01×10^{29}	6.14×10^{27}
μ	0.065	0.065	0.065	0.026

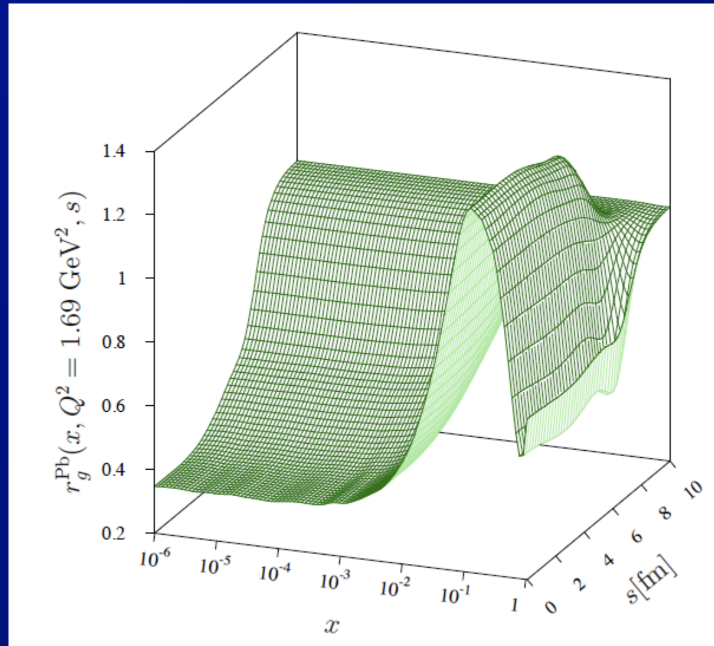
- ATLAS is preparing for maximum instantaneous luminosities up to 3×10^{29}.
- ATLAS goals for 2013 run
  - 25-30 nb^{-1} of 5.02 TeV p+Pb
  - 5 pb^{-1} of 2.76 TeV p+p
- We will not have 5.02 TeV (or comparable) p+p data until 2015 or after.

ATLAS physics goals for 2013 run

- Extend/complete basic measurements already underway with pilot run data
  - e.g. charged particle multiplicity, spectra
- Elucidate physics responsible for the "symmetric ridges"
  - ⇒And look for other consequences of that physics in central p+Pb collisions
- Measure (indirectly) nuclear PDFs
  - Using jets, dijets, γ-jet, W, Z
- Study semi-hard processes @ low x
- Understand the role of diffraction
  - Both as "background" and as intrinsically interesting and important physics

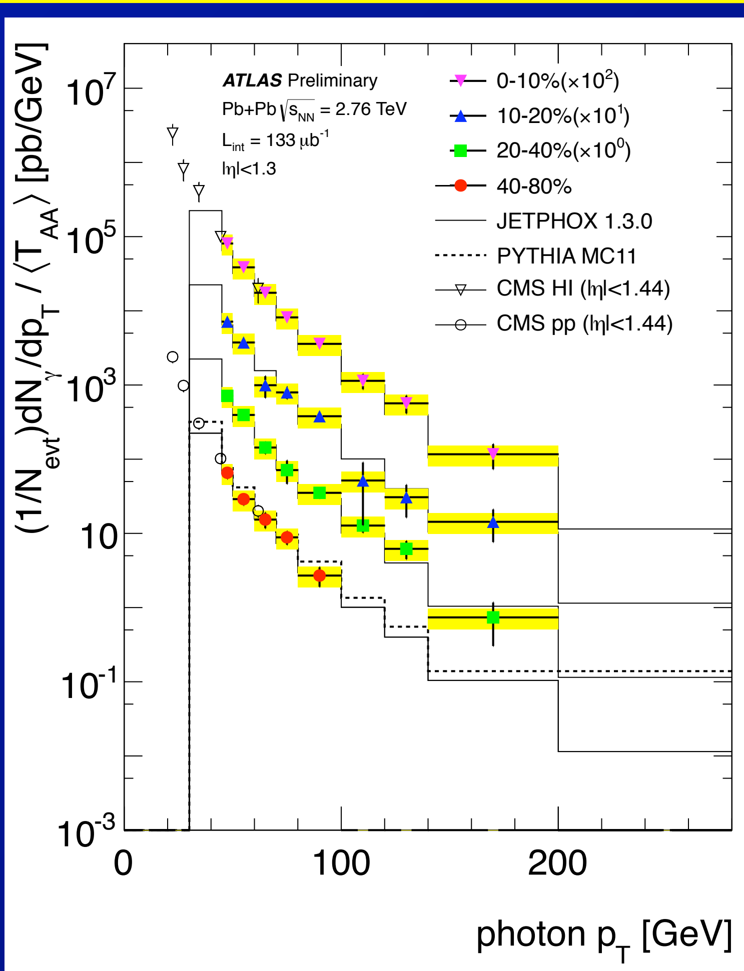
Nuclear PDFs: EPS09 and EPS09s

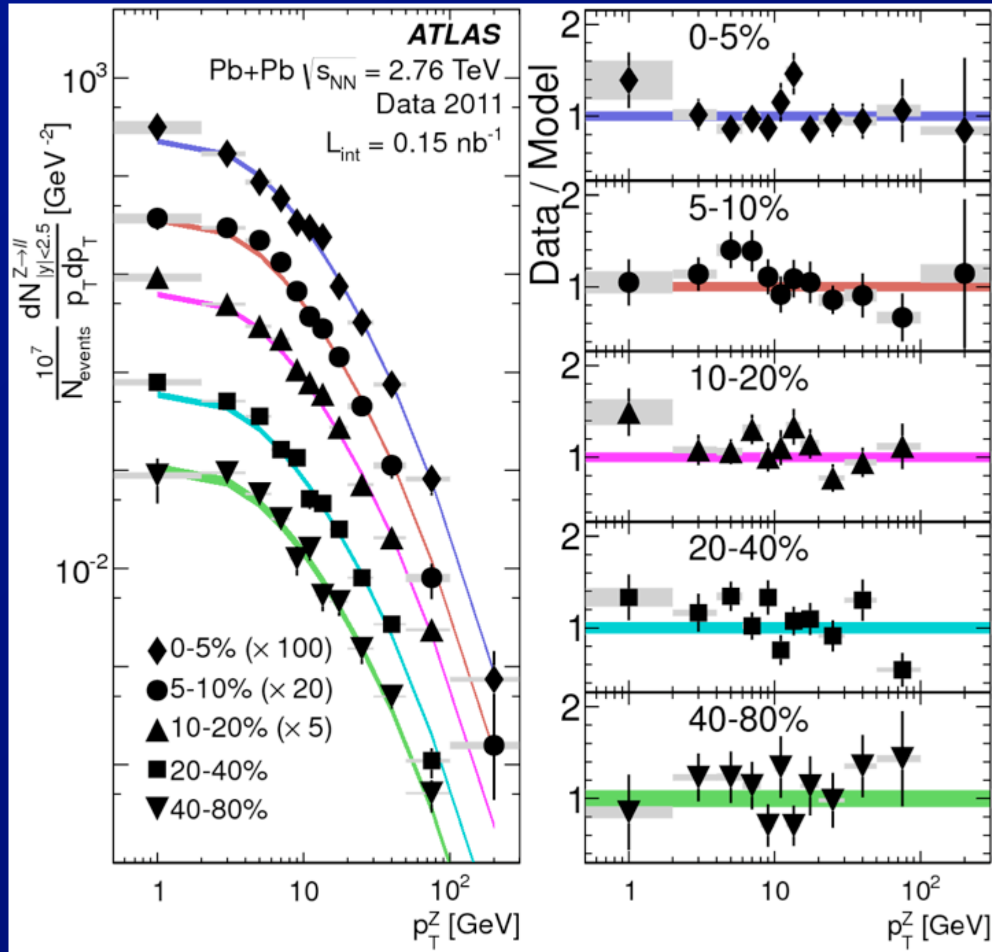




- We must improve our poor knowledge re: nuclear PDFs and their b dependence
  - ⇒Impact parameter dependence especially important for improving precision on theoretical calculations for Pb+Pb

photon and Z yields: illustration





- Integrated luminosity from 2013 p+Pb run should be equivalent to 2011 Pb+Pb run
  - Examples shown of resulting γ and Z spectra

Kinematic reach of LHC p+Pb

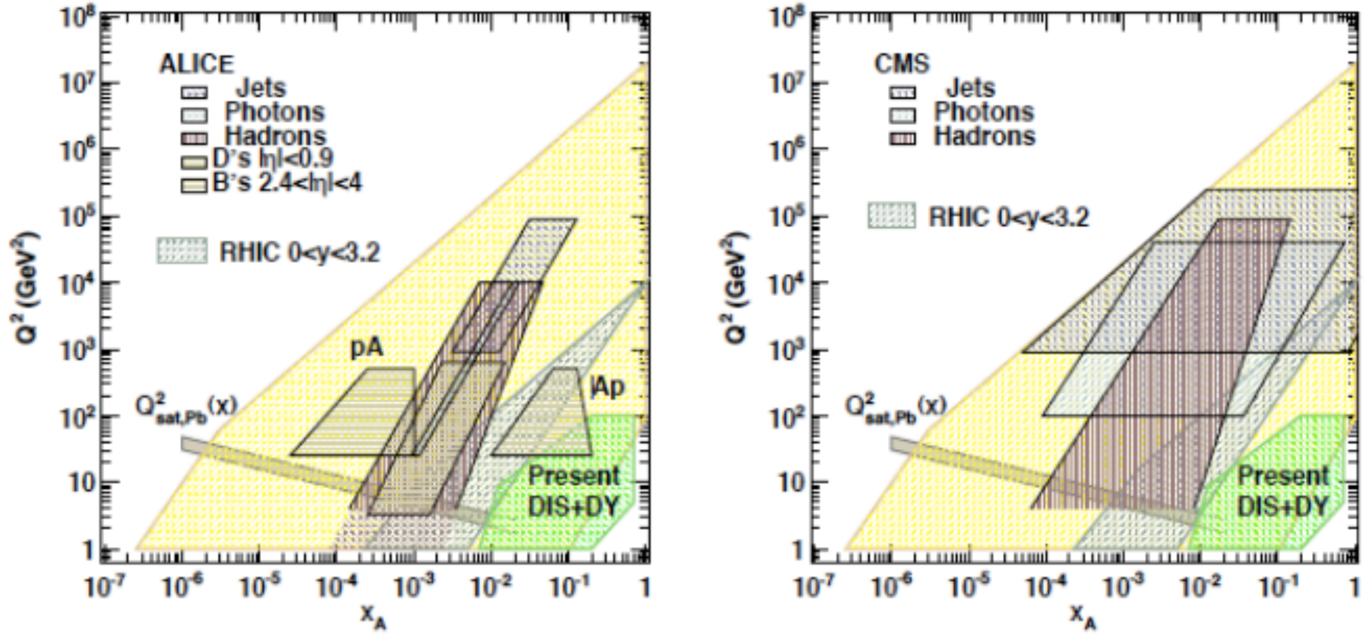


Fig. 9: Total kinematical reach of p+Pb collisions at $\sqrt{s}$ =8.8 TeV at the LHC. Also shown is the reach with an integrated luminosity of 0.1 pb^{-1} for some of the particular probes studied in the present document for ALICE and CMS, respectively.

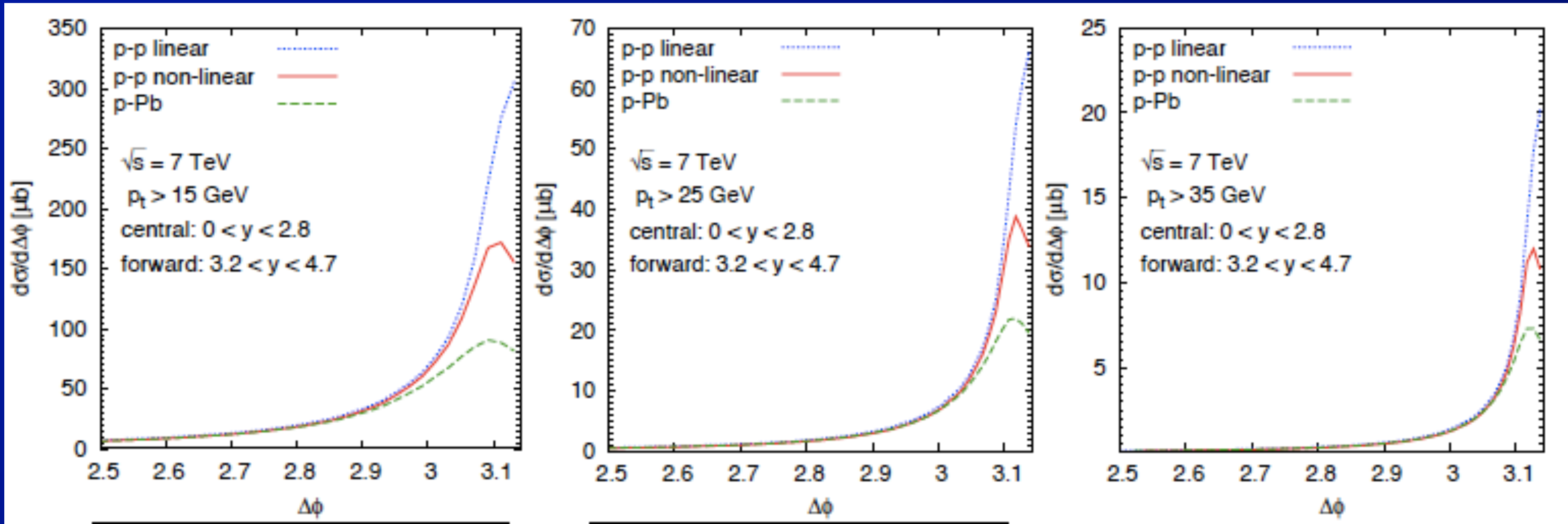
From Salgado *et al*, J.Phys. G39 (2012) 015010

ATLAS ~ CMS

- p+Pb measurements @ LHC will extend the range of nuclear PDF measurements.
  - for b dependence need centrality dependent measurements with good control over geometry
    - ⇒But, precision will be limited without 5.x TeV p-p

Semi-hard physics @ low x

Kutak and Sapeta arXiv:1205.5035



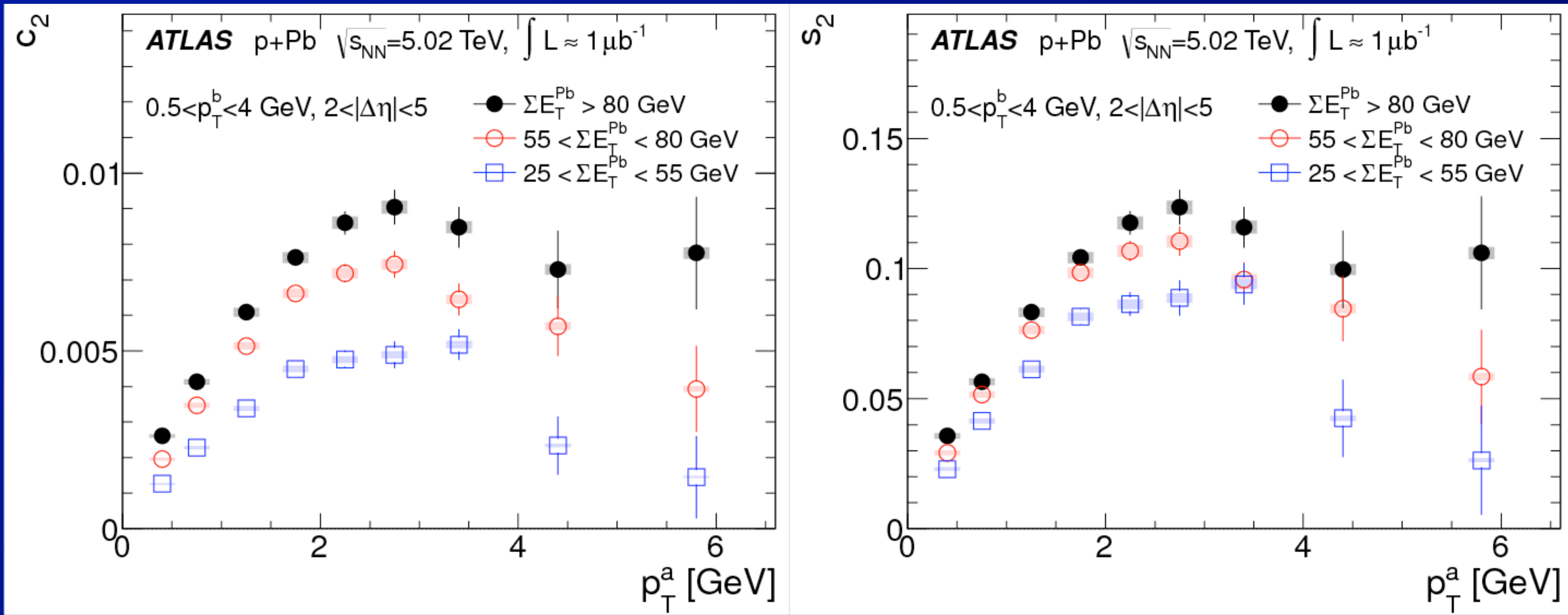
- Wide range of possible measurements.
  - One example shown here: forward-central dijets
    ⇒prediction for visible effects of saturation
  - Kinematic range accessible in ATLAS (e.g.)
    ⇒measurement doable w/ 2013 data

Summary, thoughts

- 6 hour p+Pb pilot run in Sep. 2012 was successful both for machine & physics
  - first results on multiplicity, spectra, ridge++
  - for me, the ridge++ was a surprise
    - ⇒ new territory in p+A physics
    - ⇒ obviously relevant for RHIC p+A plans
    - ⇒ s vs multiplicity dependence very important
  - beware neglect of diffraction
- In 1 week, start of high-luminosity run
  - Expected integrated luminosity: 30 nb^{-1}
    - ⇒ Sufficient to address most of the goals of the LHC p+A program
  - But no 5.x TeV p-p until 2015 or after

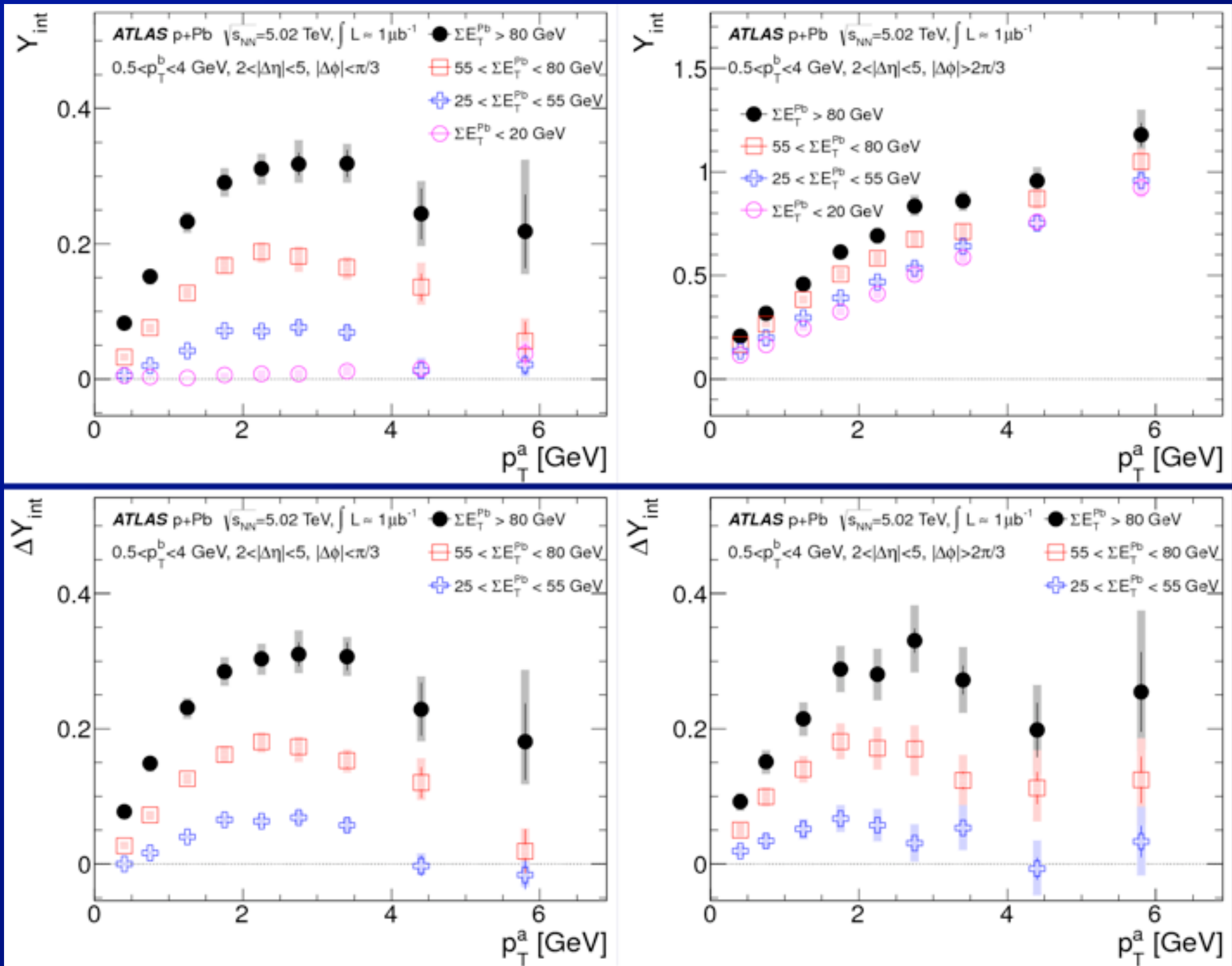
Backup

Centrality dependence of c_2 and s_2

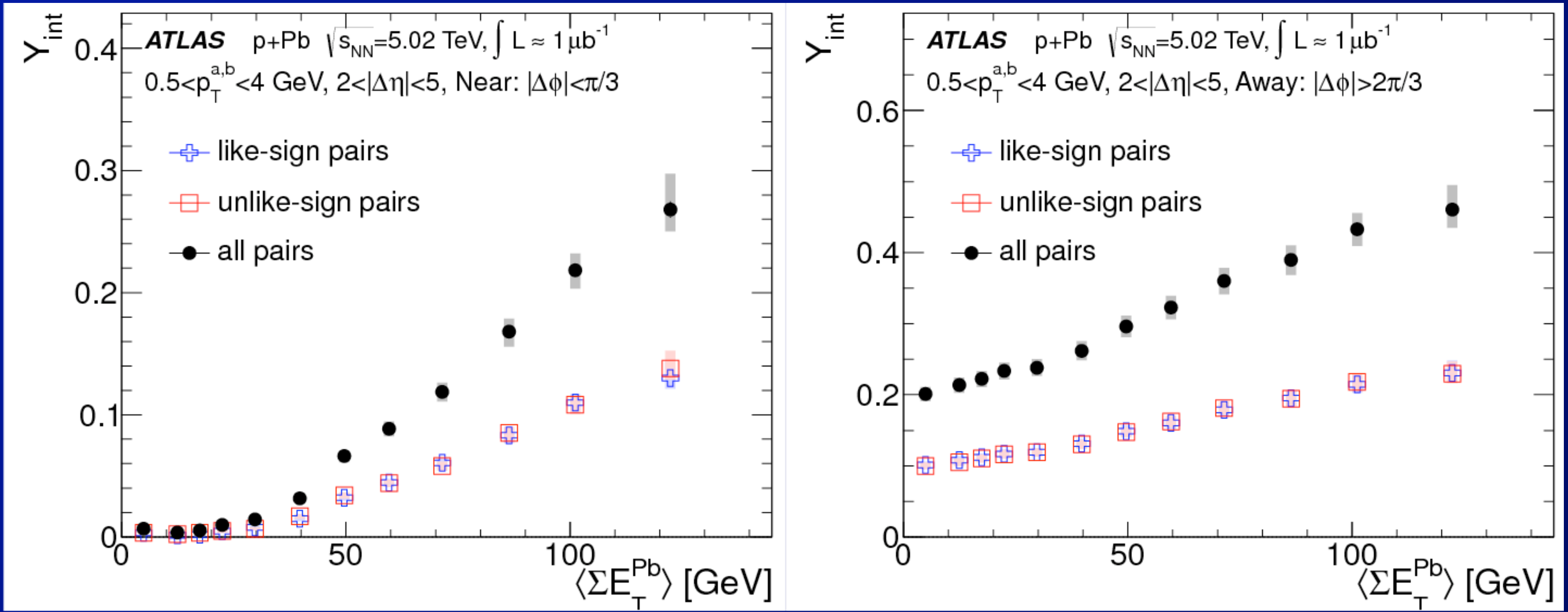


- **Perform c_2 and s_2 measurement in different ΣE_T bins**
  - similar variation of both c_2 and s_2 with p_T in all ΣE_T bins
  - weak dependence of s_2 on centrality

Per-trigger yield systematics



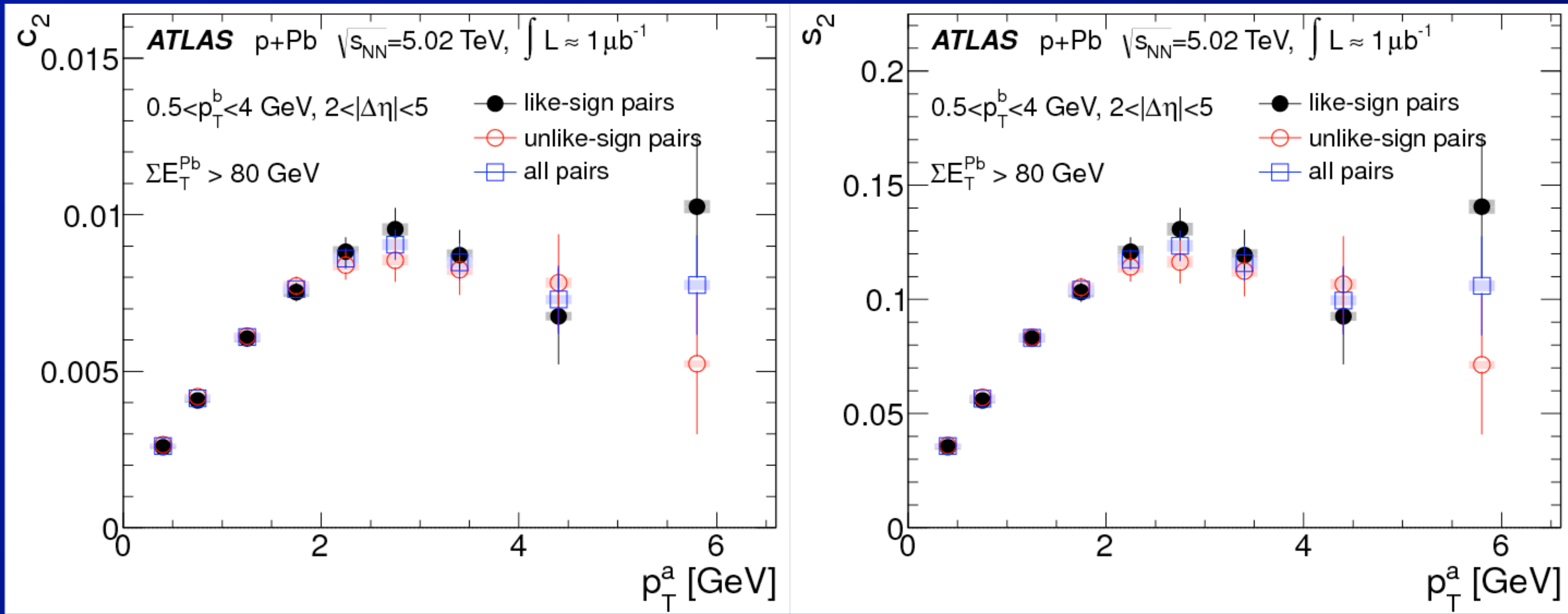
Check for (rel.) charge dependence



- **Perform two-particle correlation analysis for like and unlike-sign pairs**
  - global correlation should not be sign dependent
  - but jet, resonance, other correlations may be

    ⇒ Observe identical behavior for like, unlike sign correlations in the data.

Sign dependence of c_2 and s_2



- Further check on like vs unlike sign correlations.
  - ⇒Identical results for c_2 and s_2 for like and unlike sign pairs