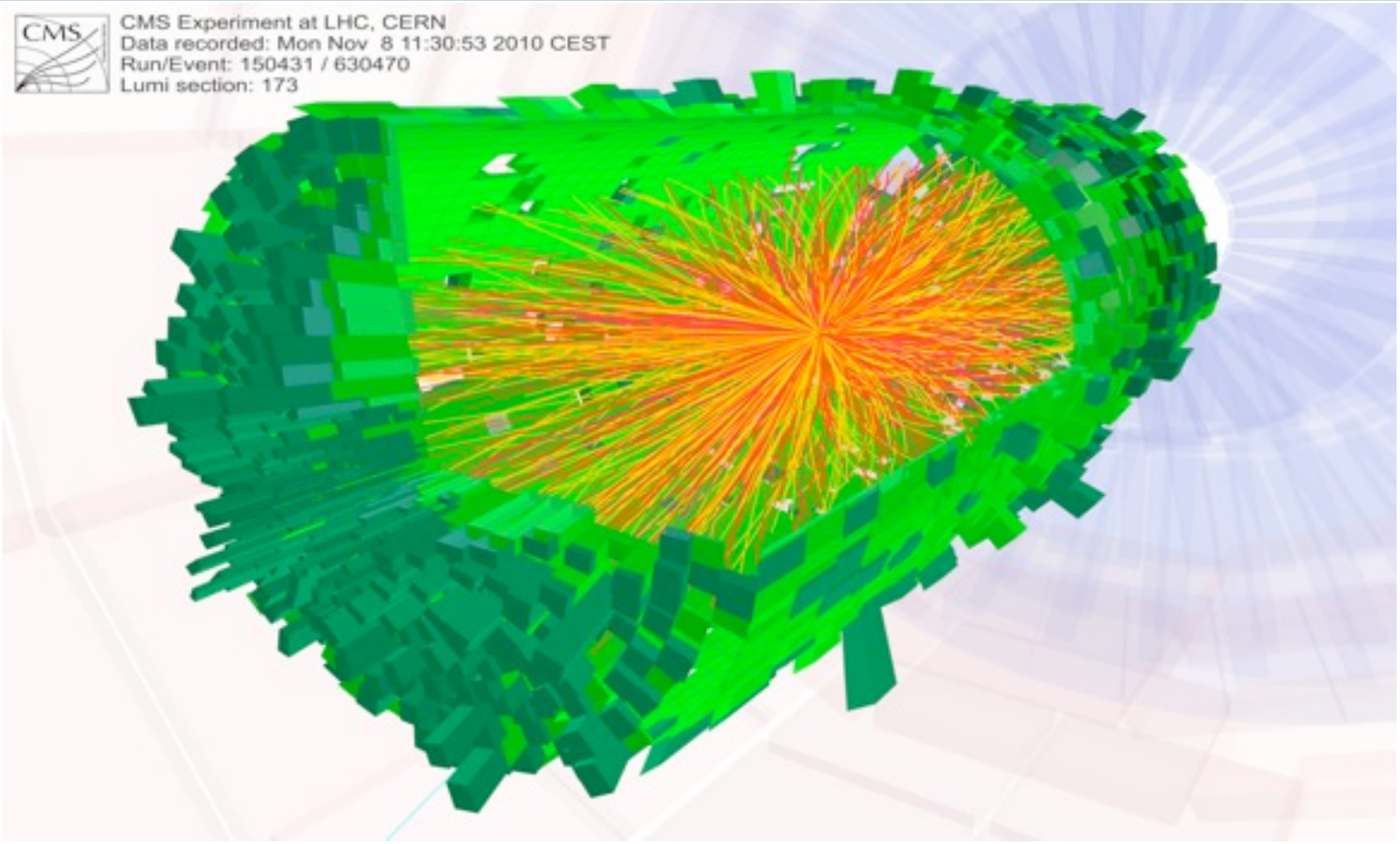
Measurement of high-p_T azimuthal anisotropy in charged hadron production from 2.76 TeV PbPb collisions at CMS



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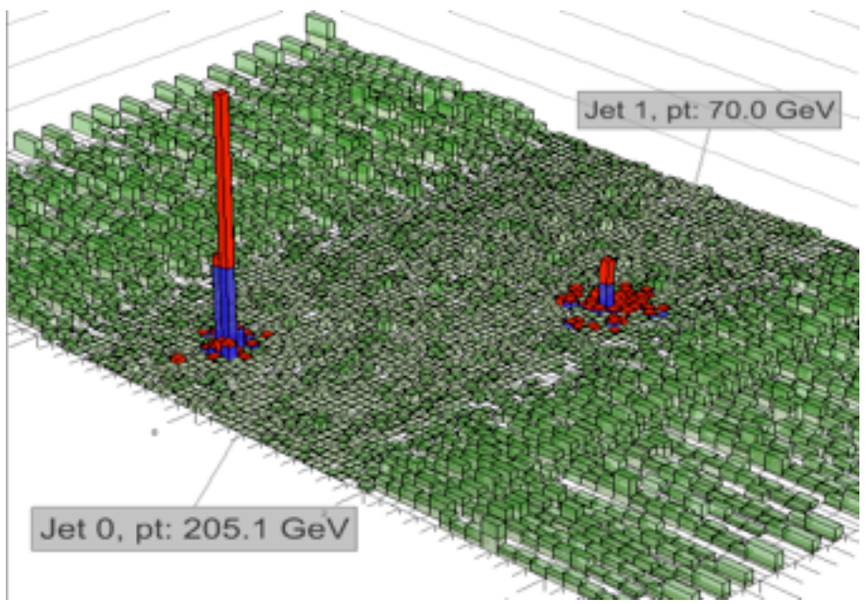
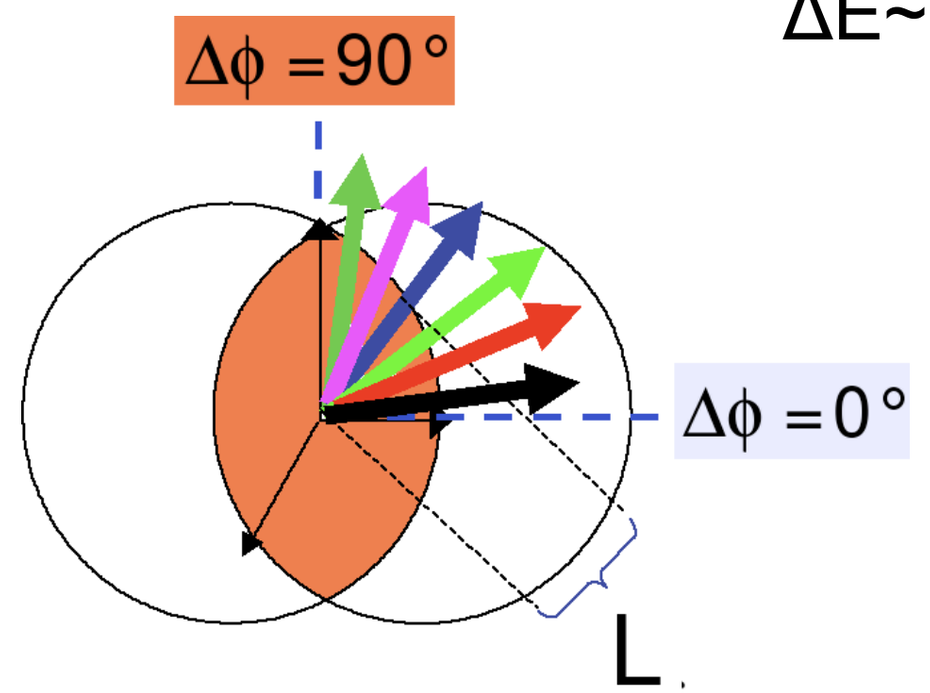
(On behalf of the CMS Collaboration)

Jet Quenching and Azimuthal Anisotropy

Path length (L) dependence of jet energy loss (ΔE)



$\Delta E \sim L^{\alpha}$

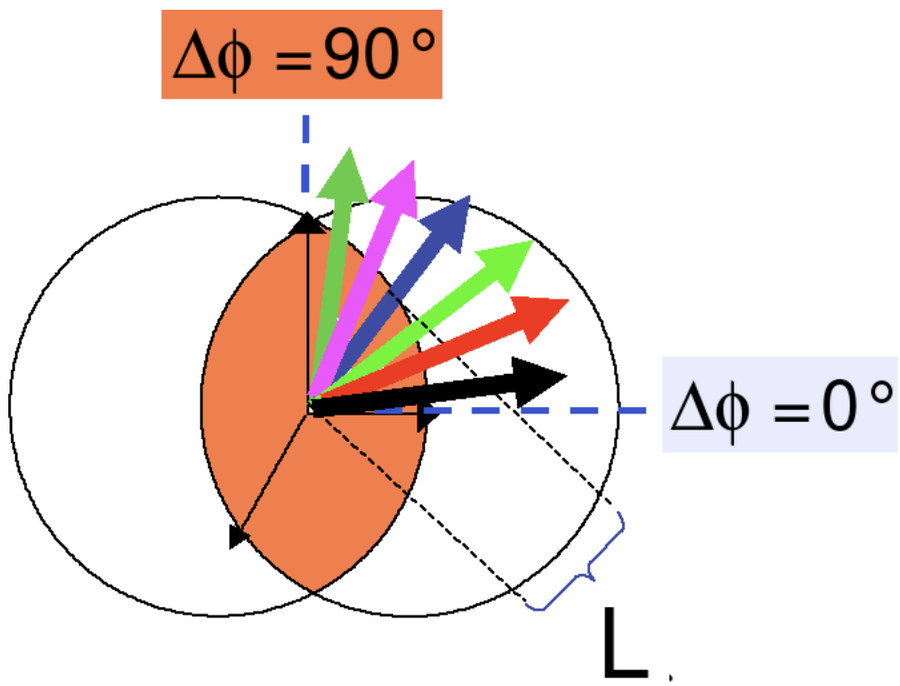


Fourier decomposition of charged hadron yields:

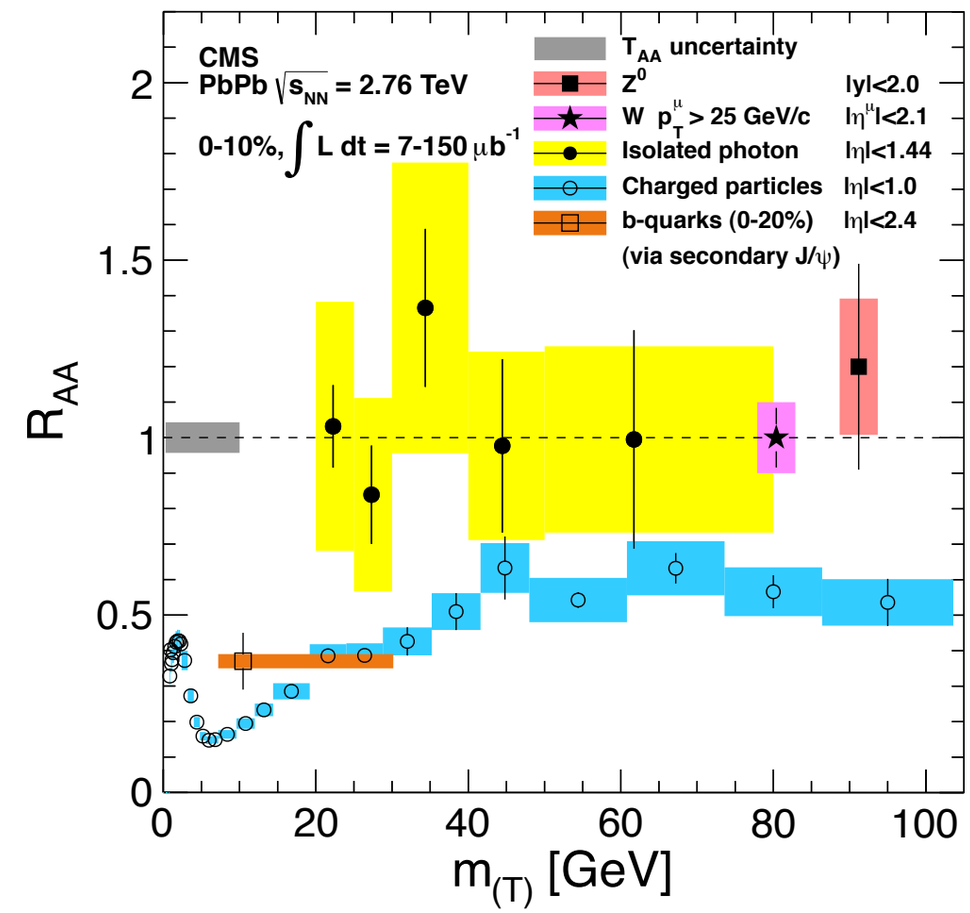
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + \sum_{n=1}^{\infty} 2v_n \cos\left[n\left(\varphi - \Psi_R\right)\right]\right)$$

Azimuthal anisotropy (v_2) of high p_T jets

Physics Motivation



$$R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta}$$



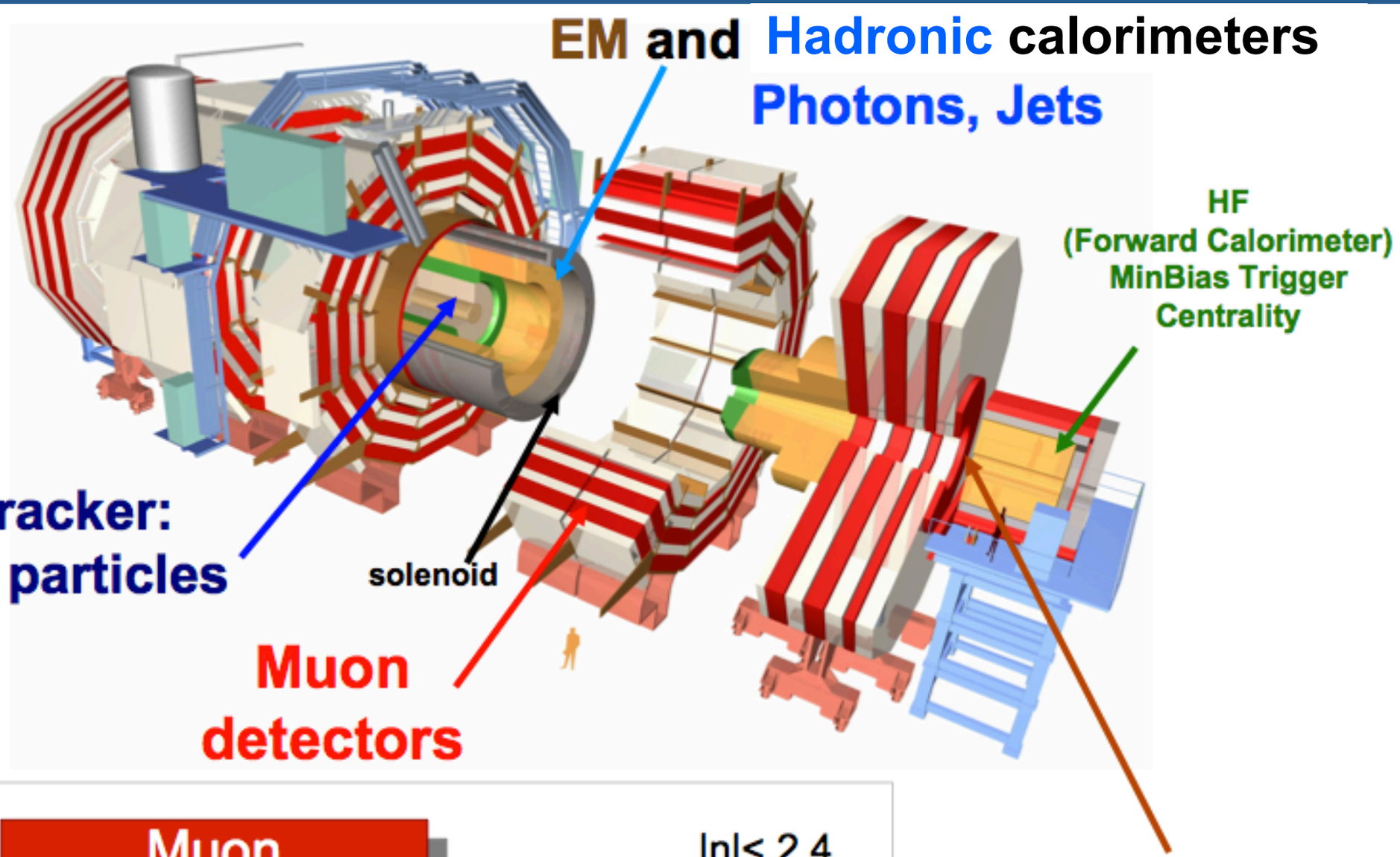
Phys. Lett. B (2012) 710 256
Phys. Rev. Lett. (2011) 106 312301
Eur. Phys. J. C. (2012) 72 1945
JHEP 1205 (2012) 063

<u>$\Delta E \sim L^{\alpha}$</u>

α = 1 for pQCD, collisional
α = 2 for pQCD, radiative
α = 3 for AdS/CFT

<u>Initial Conditions:</u>
-Glauber
-Color Glass Condensate

CMS Detector



Muon	$\lvert\eta\rvert < 2.4$
Hadronic Calorimeter	$\lvert\eta\rvert < 5.2$
EM Calorimeter	$\lvert\eta\rvert < 3.0$
Tracker	$\lvert\eta\rvert < 2.5$

Unprecedented kinematic range and acceptance

High p_T Single Track Trigger

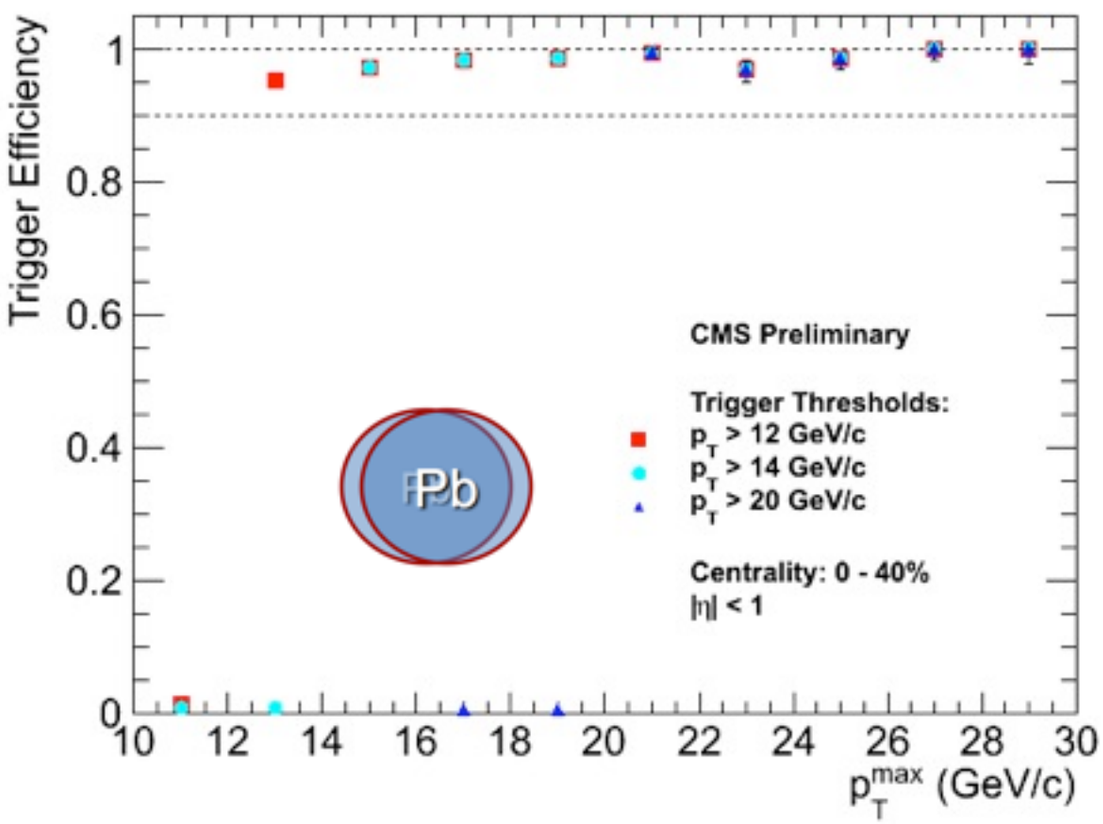
- Full 2011 HI Data set: L_{int} = 150 μb^{-1}
- Single-Track High-p_T Triggers

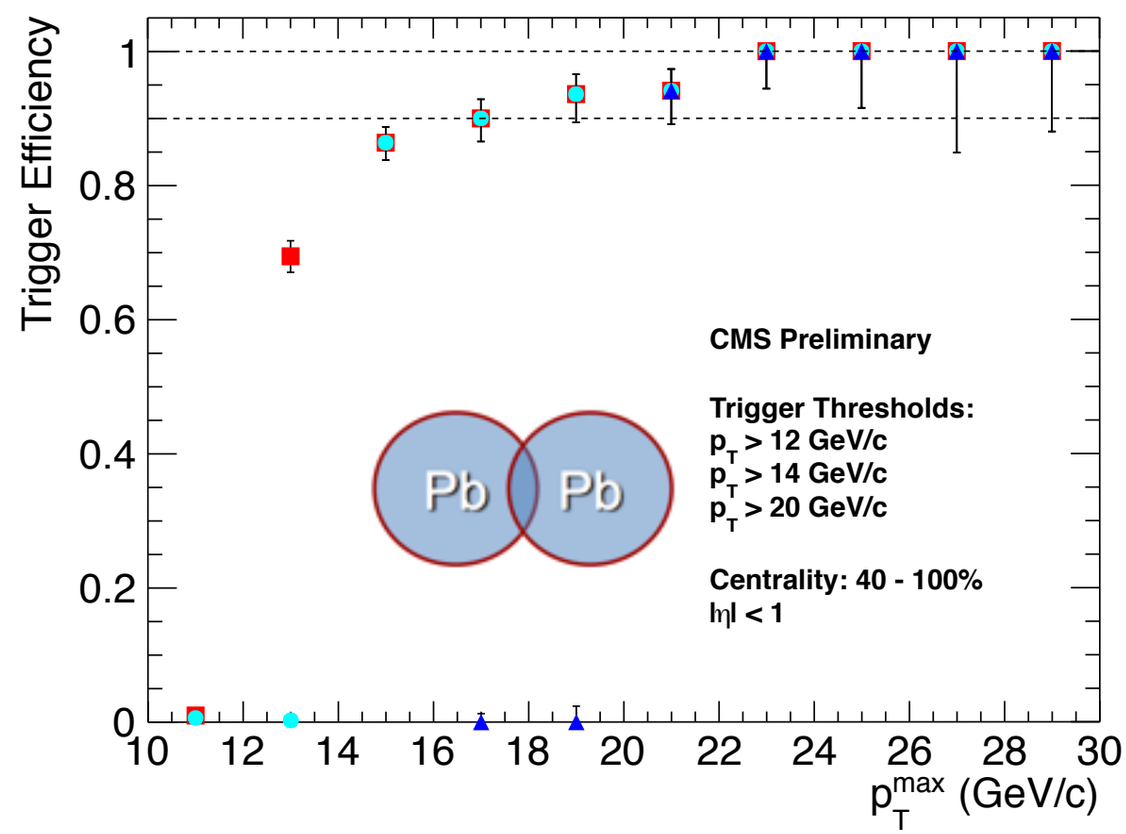
(Total # of events: ~1.55M with p_T > 20 GeV/c)

p_T > 12 GeV/c: ~ 9 million
p_T > 20 GeV/c: ~1.55 million

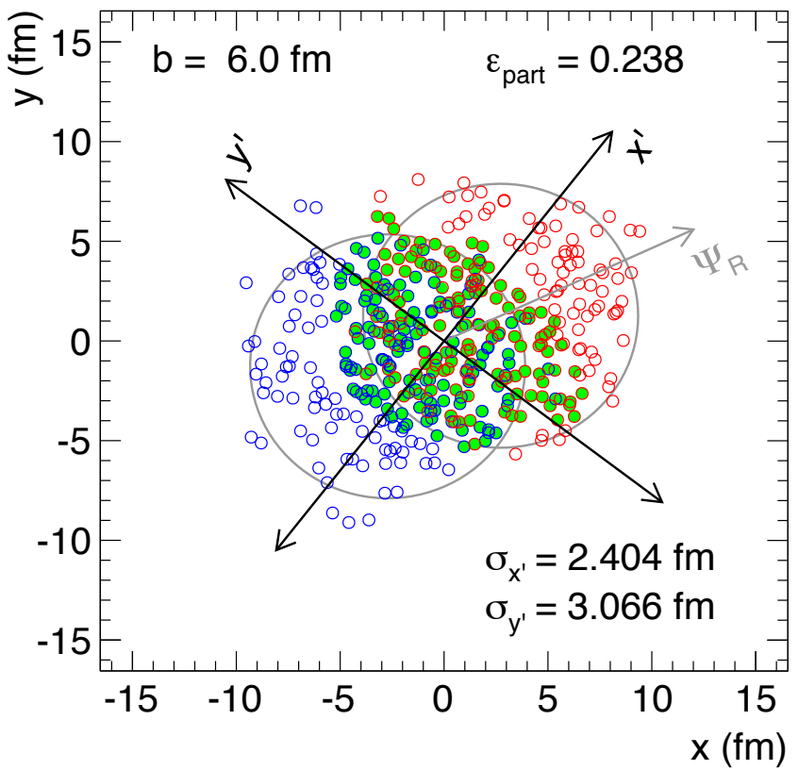
20x more data in 2011!!

All triggers are at least 95% efficient (0-40%)





Event Plane Formalism



Event Plane

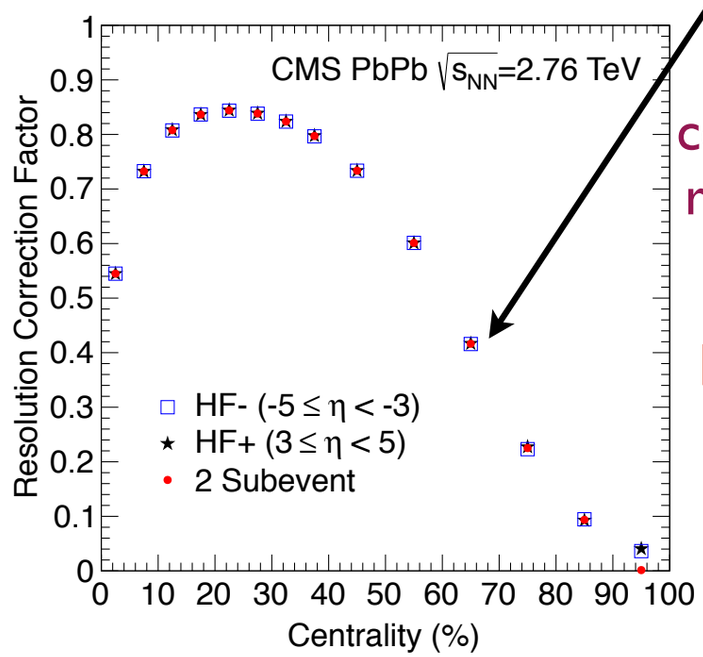
Experimentally observable, used to estimate the true participant plane.

$$\Psi'_n = \frac{1}{n}\tan^{-1}\frac{\sum_i w_i \sin(n\varphi_i)}{\sum_i w_i \cos(n\varphi_i)}$$

v_2 Coefficient

$$v_2^{obs}\{EP\} = \langle\cos 2(\varphi - \Psi'_2)\rangle = \frac{1}{N_{ev}}\sum_j\left[\frac{1}{M_j}\sum_i \cos 2\left(\varphi_i^j - \Psi_2^j\right)\right]$$

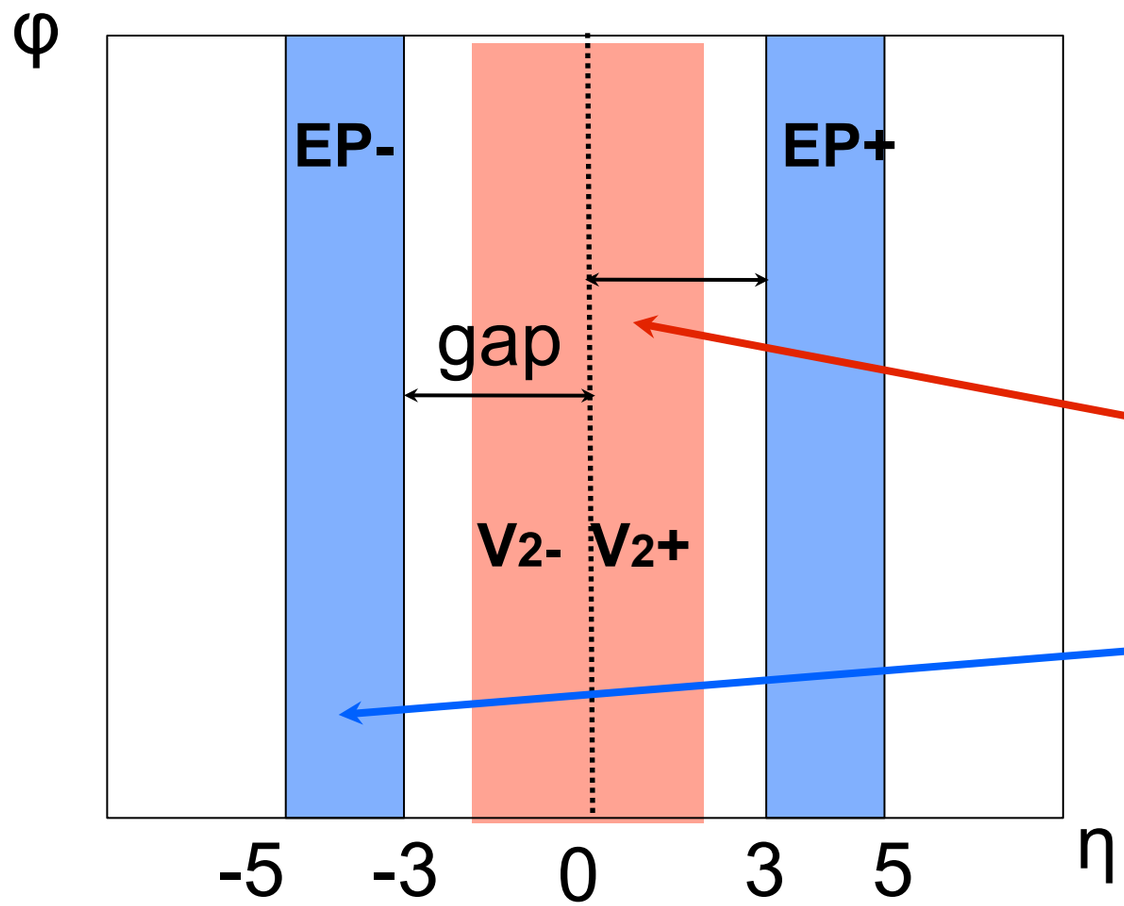
$$v_n\{EP\} = \frac{v_n^{obs}\{EP\}}{R}$$



Need to correct for Ψ_{EP} resolution (R).

Resolution Correction: (3-subevent method)

Avoiding Di-Jet Correlations



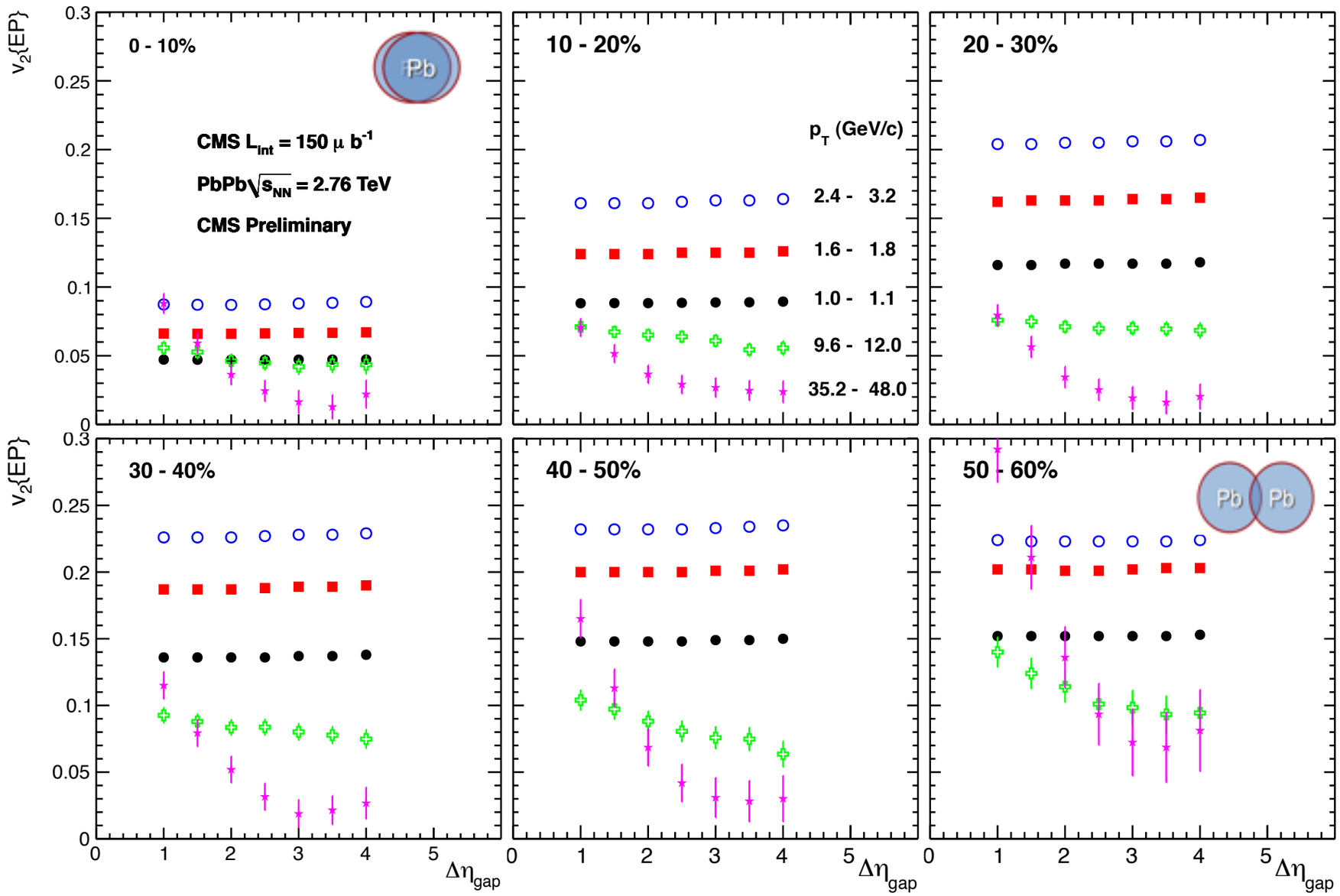
To calculate v_2 :
v_2+ with EP- and v_2- with EP+

Particles from the positive η region are correlated with the event plane calculated in the negative η region.

Event Planes:
EP+ (3<η<5)
EP- (-5<η<-3)
*Hadronic Forward Calorimeters used for determining the Event Plane.

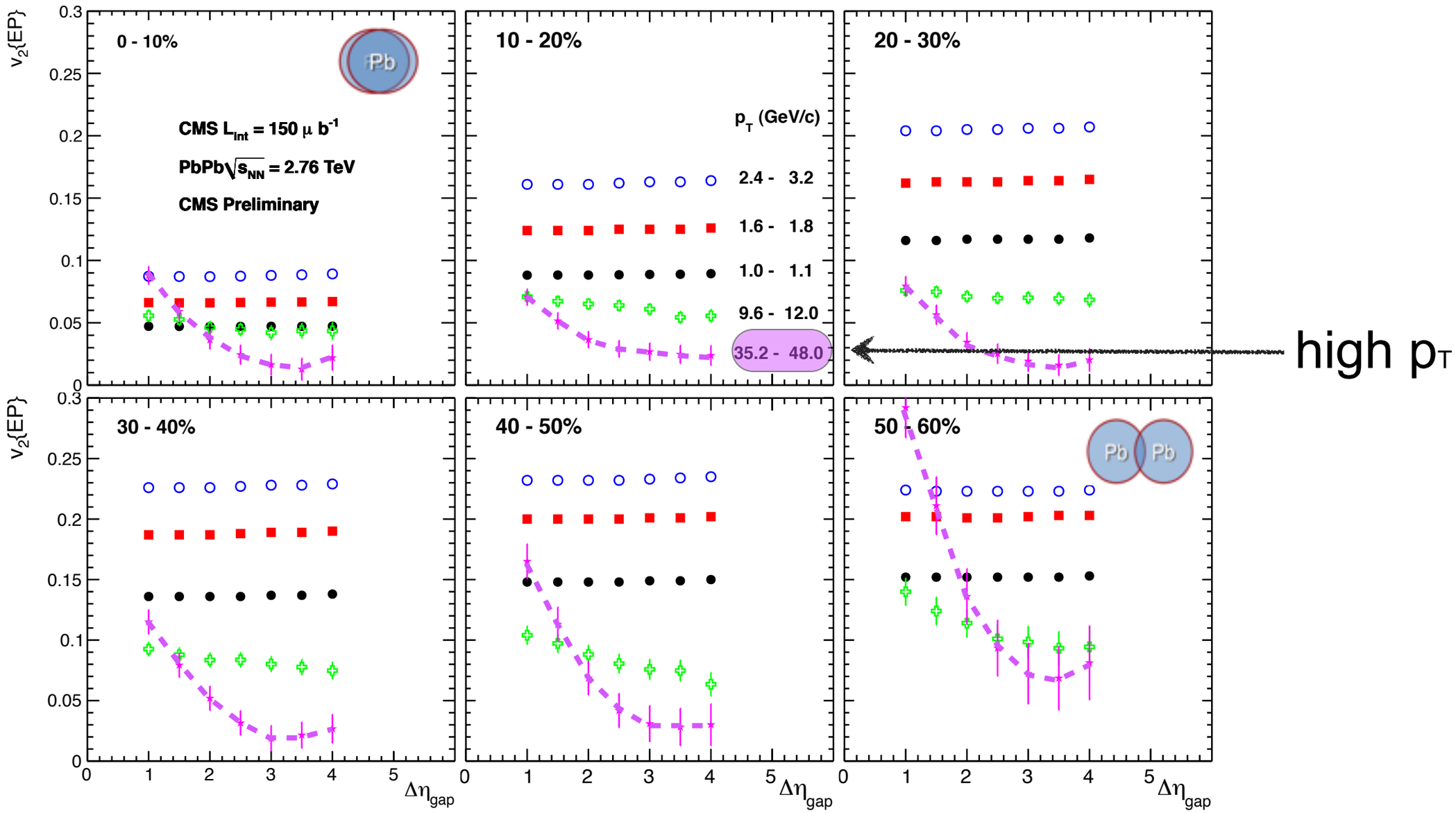
This minimizes systematic effects that result from back-to-back di-jets

η-Gap Study



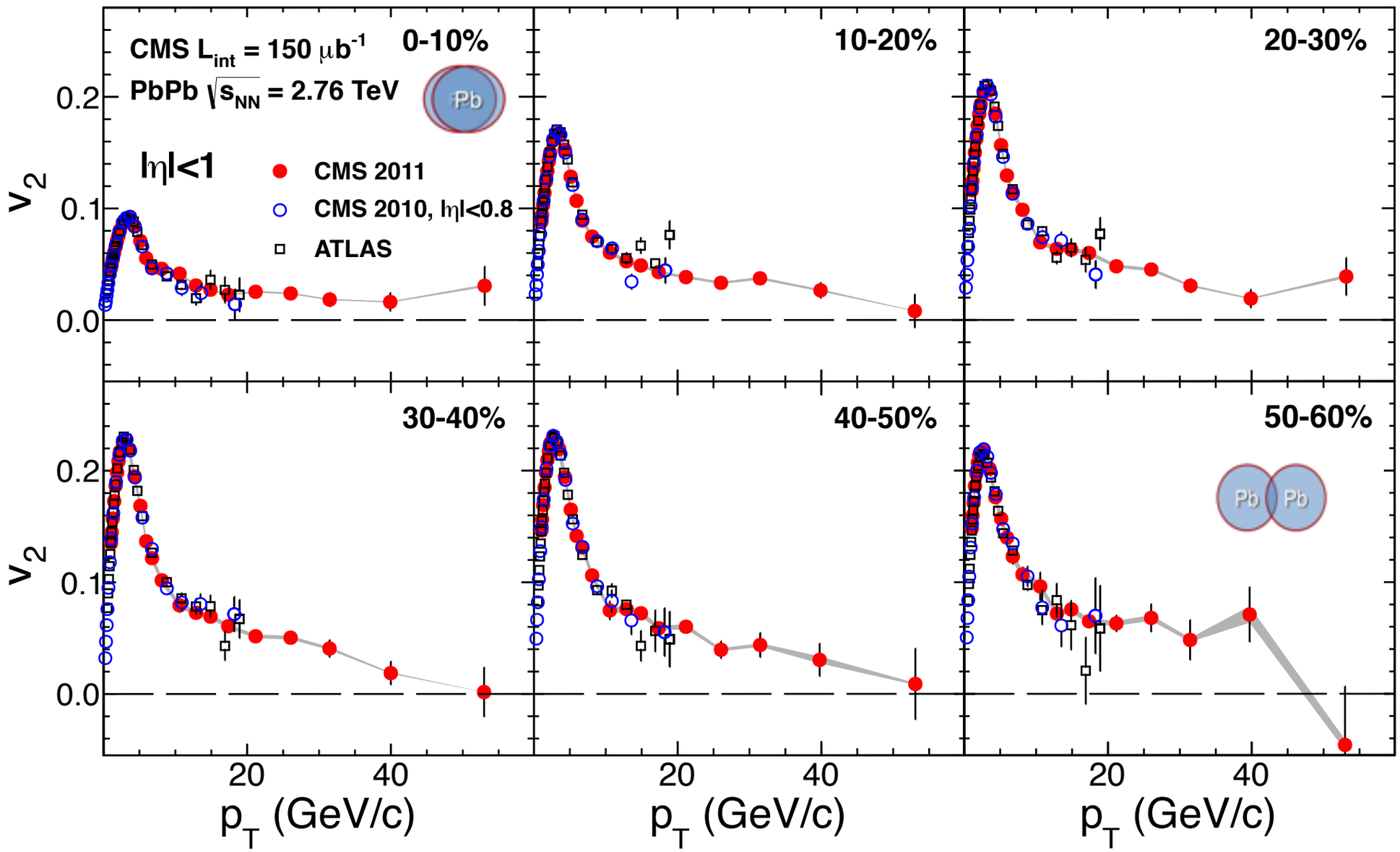
Based on this study we conclude that the gap size of 3 is sufficient to suppress most of the back-to-back di-jet effects

η-Gap Study



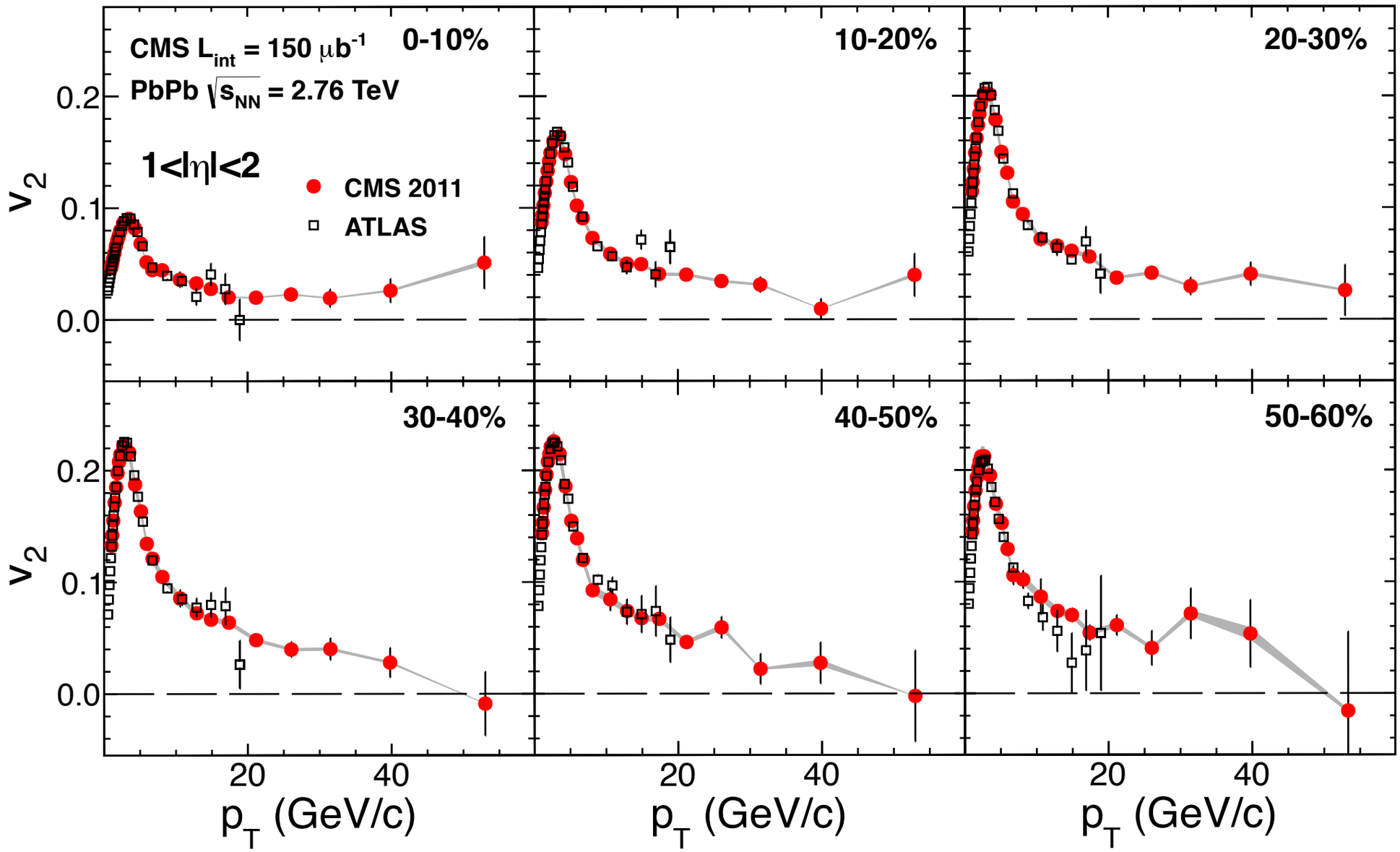
Based on this study we conclude that the gap size of 3 is sufficient to suppress most of the back-to-back di-jet effects

v_2 as a function of p_T ($0<|\eta|<1$)



-First v_2 measurements for p_T > 20GeV/c
-Gradual decrease of v_2 above p_T ~ 10 GeV/c

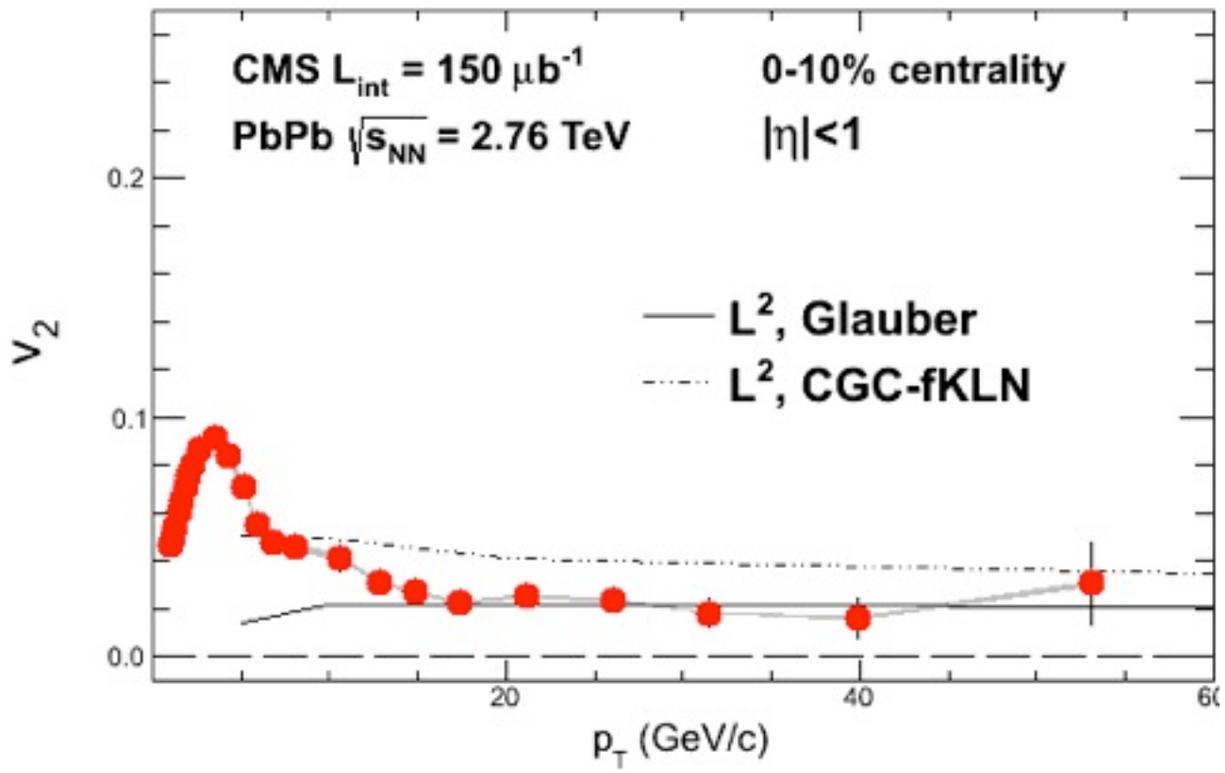
v_2 as a function of p_T ($1<|\eta|<2$)

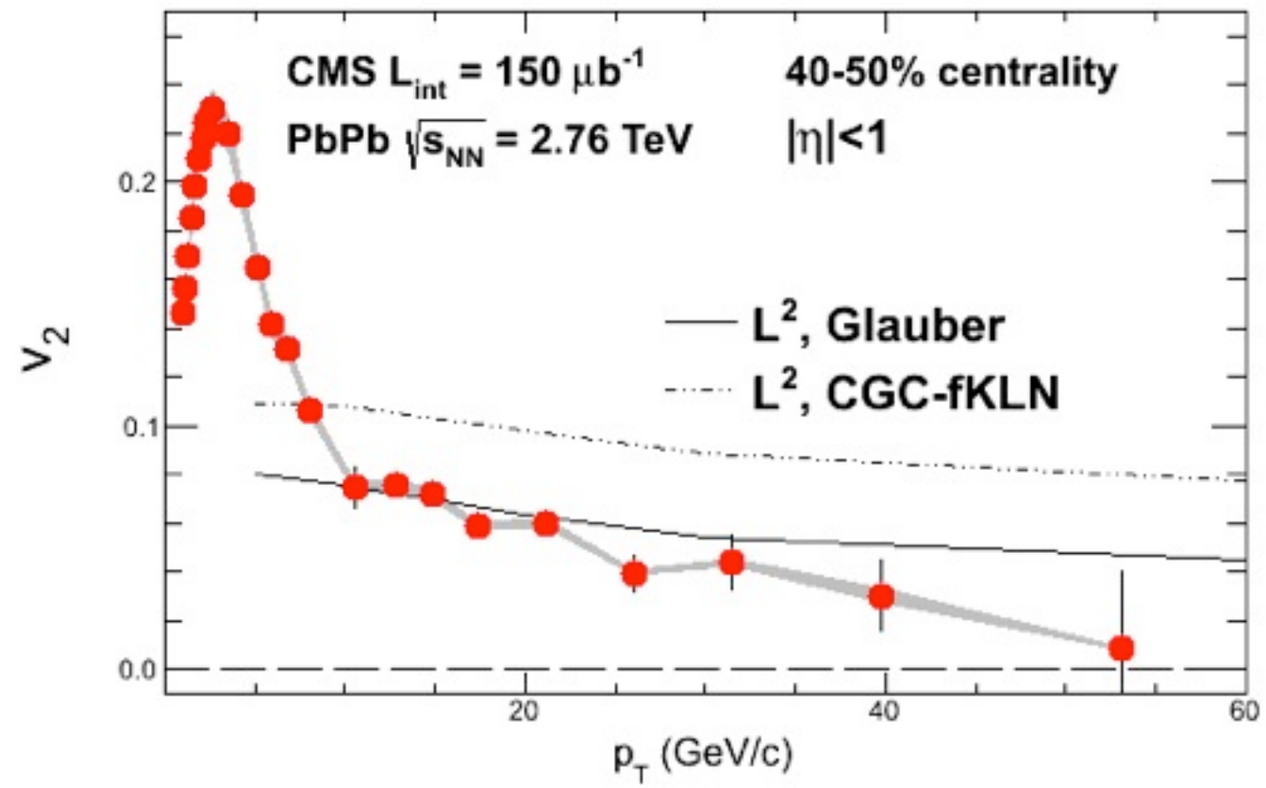


-No significant η dependence of v_2

Theory Comparison

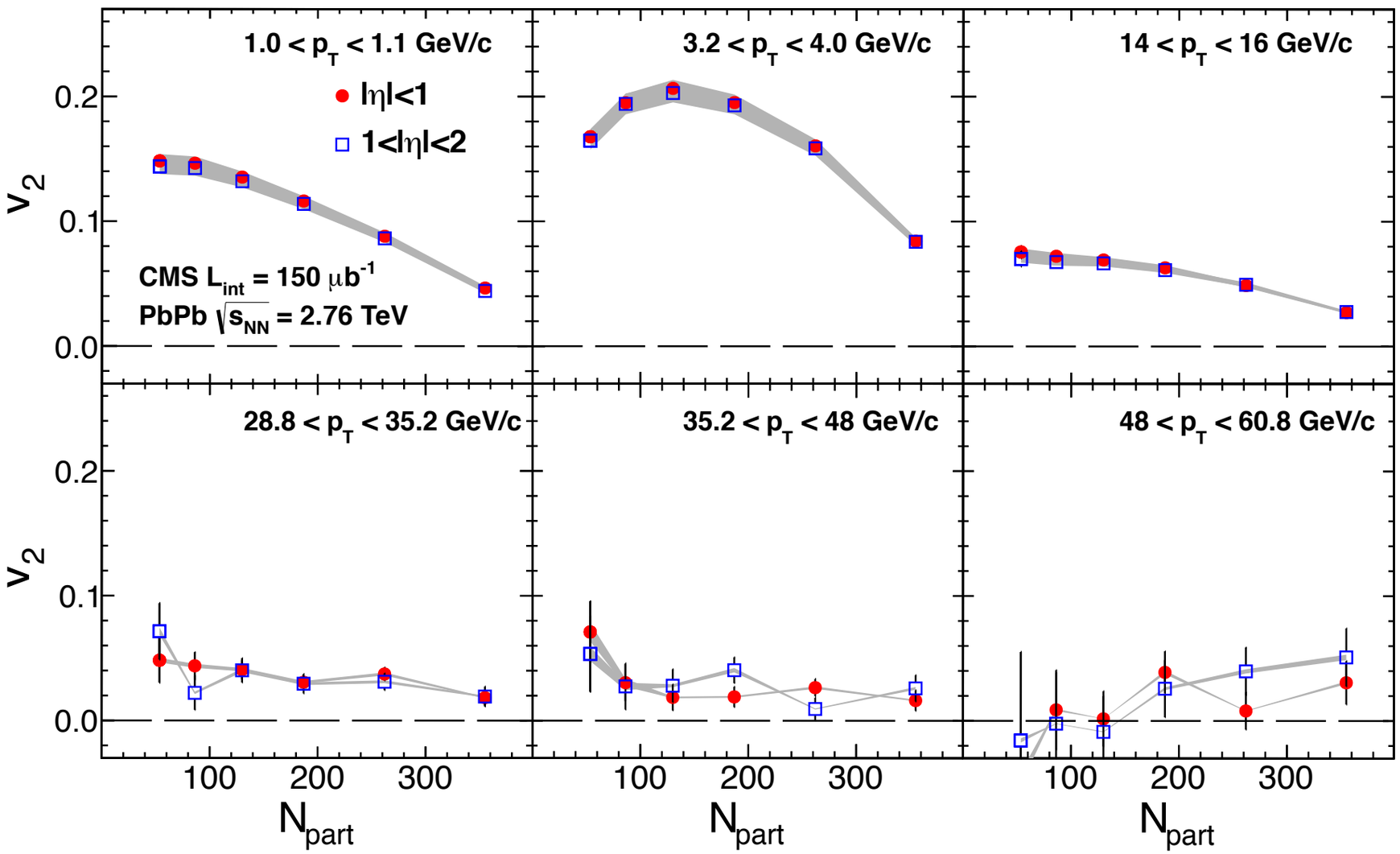
Theory: B. Betz, M. Gyulassy, arXiv:1201.0281





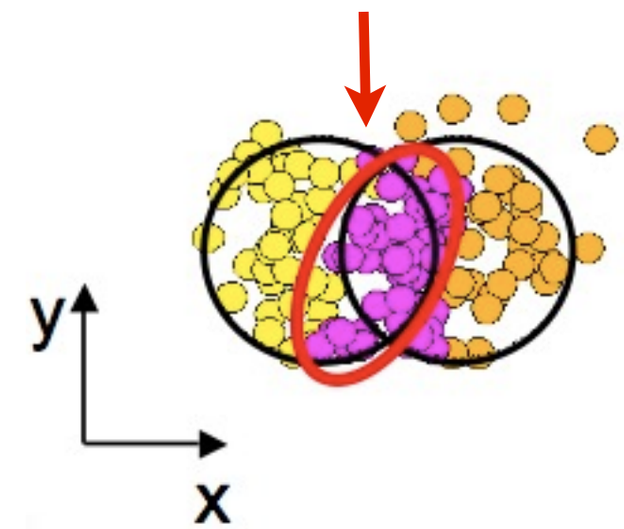
-Data can constrain different theoretical scenarios
-However, a lot of complications in modeling still to be addressed (e.g., expansion of the system)

v_2 as a function of centrality



$$\varepsilon_{part} = \frac{\sqrt{\left(\sigma_y^2 - \sigma_x^2\right)^2 + 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2}$$

participants



ε_{part}: 0.09 (0-10%) to 0.46 (50-60%)

- Significant non-zero v_2 up to p_T~48 GeV/c for all the centralities.
- For p_T > 48 GeV/c v_2 is consistent with 0 for all the centralities.

Summary

- The v_2 azimuthal anisotropy coefficient is determined over a wide coverage in p_T: $1 < p_T < 60$ GeV/c as a function of collision centrality based on the 2011 data sample.

- Above $p_T \sim 10$GeV/c v_2 values show a gradual decrease with p_T, being consistent with zero only above $p_T \sim 48$ GeV/c for all the centralities.

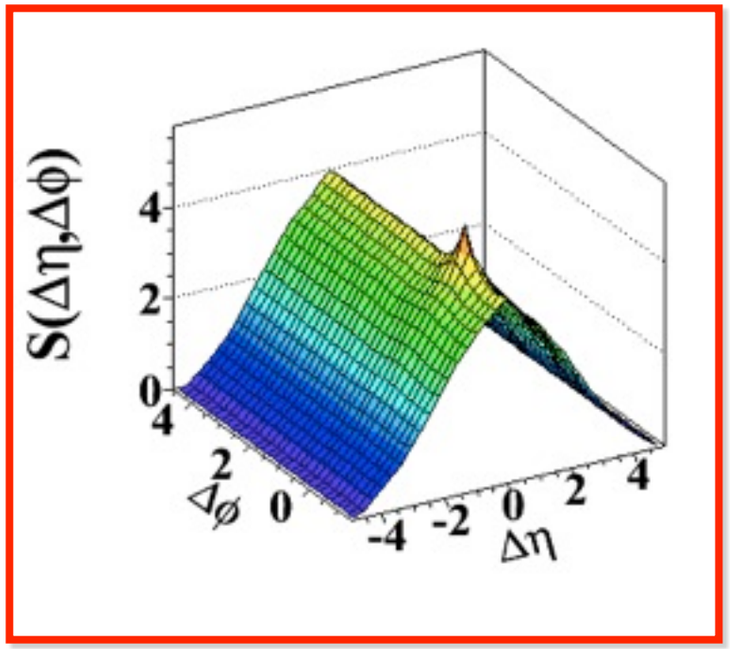
- Centrality dependence of v_2 is observed for both very-low- and high-p_T particles. It is consistent with path-length-dependent energy loss observed at high-p_T up to $p_T \sim 35$ GeV/c.

BACKUP

Di-hadron Correlations Formalism

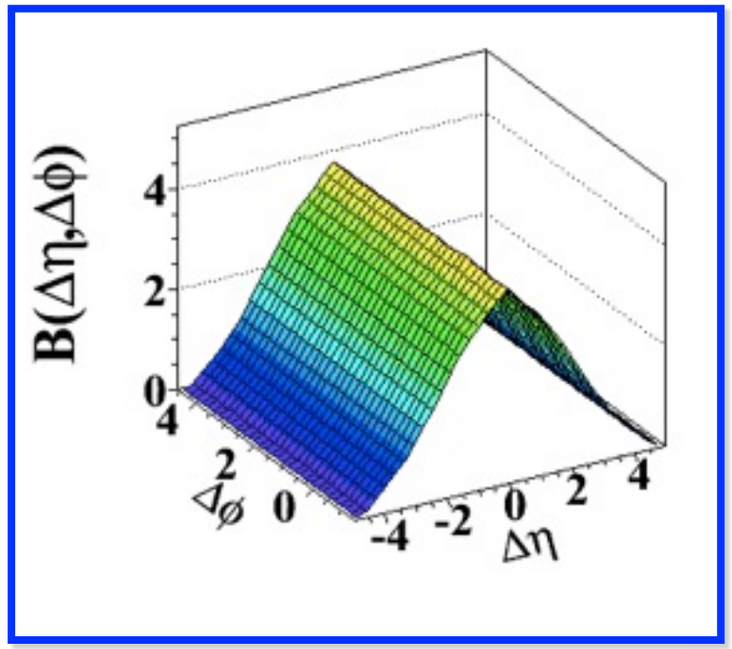
Signal pair distribution:

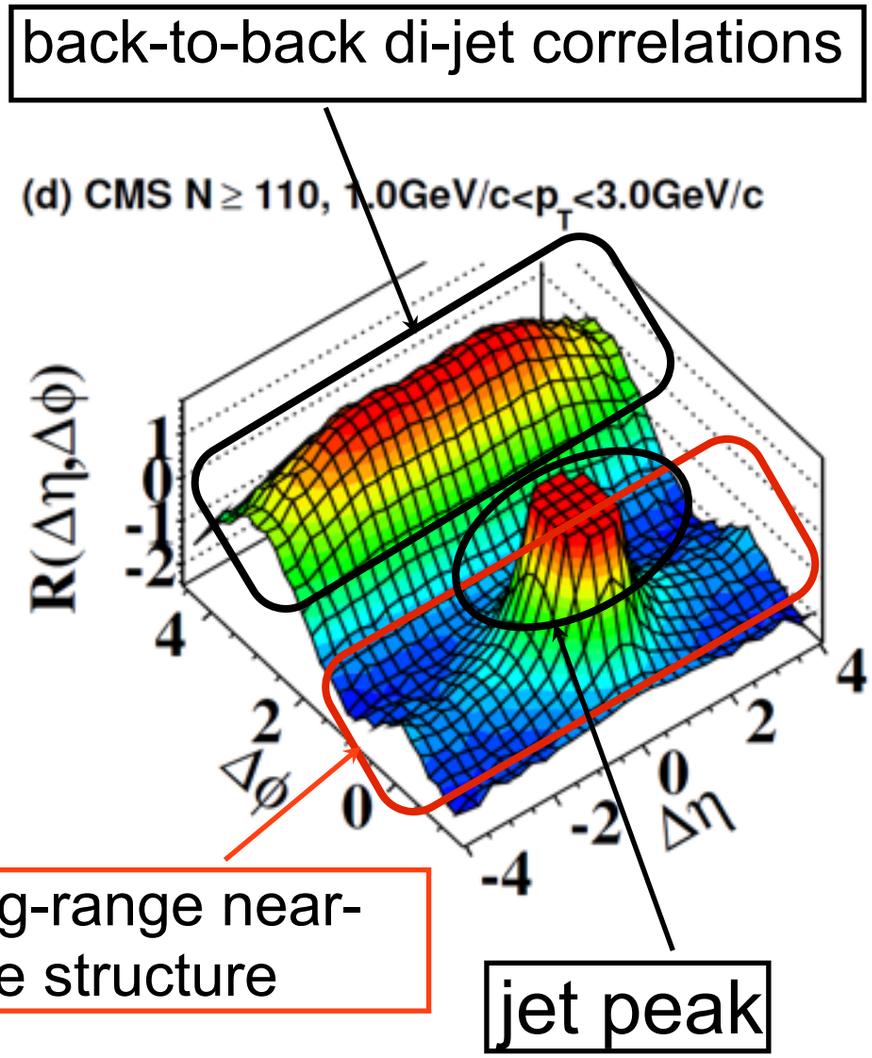
$$S(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{same}}{d\Delta\eta d\Delta\varphi}$$



Background pair distribution:

$$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{mix}}{d\Delta\eta d\Delta\varphi}$$



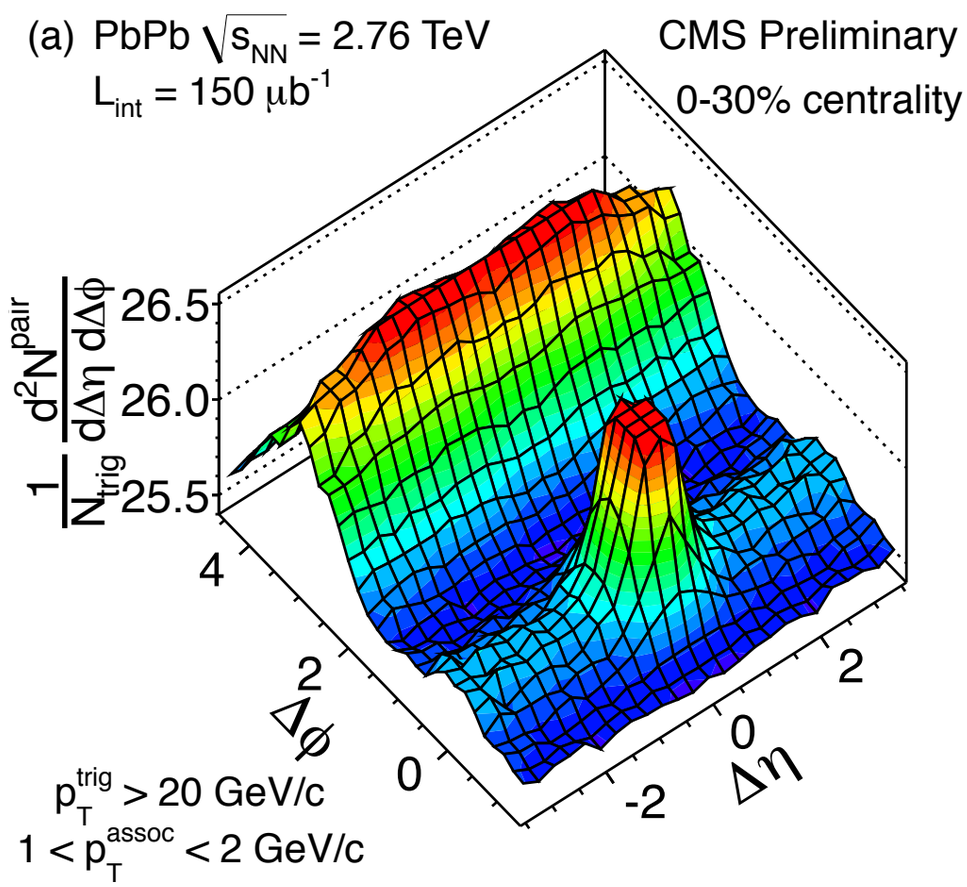


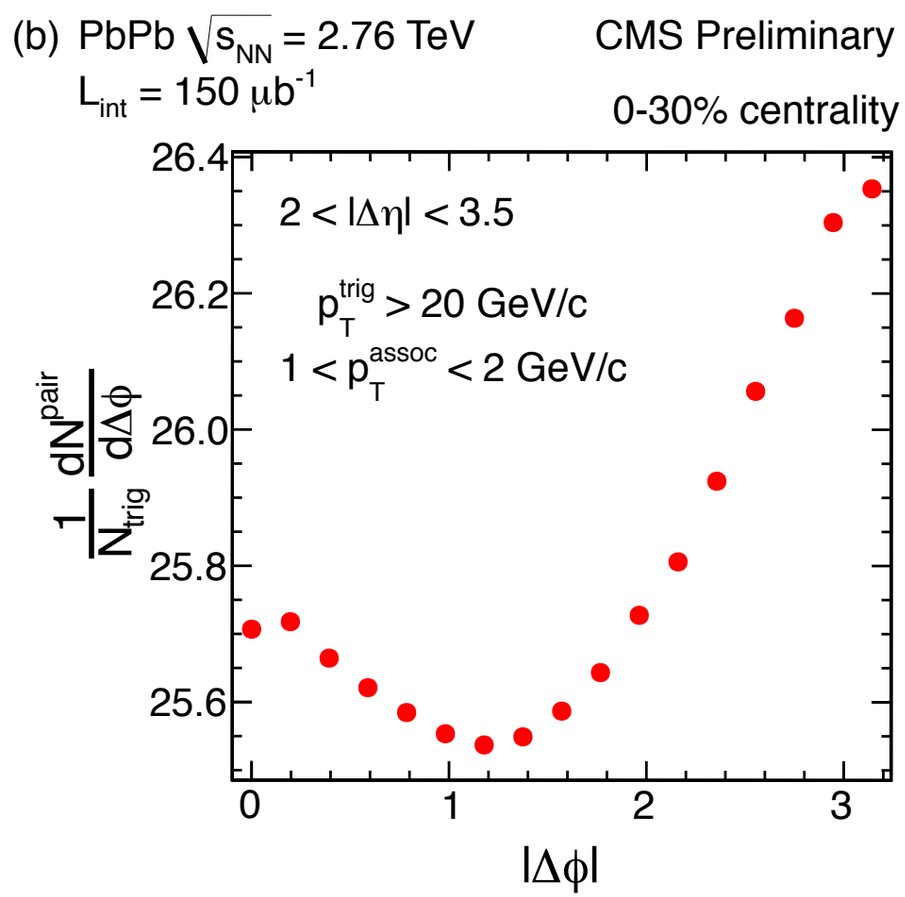
$$\Delta\eta = \eta^{assoc} - \eta^{trig}$$
$$\Delta\phi = \phi^{assoc} - \phi^{trig}$$

Associated hadron yield per trigger:

$$\frac{1}{N_{trig}} \frac{d^2N^{pair}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)}$$

Azimuthal Correlations at High p_T





- Clear and significant long-range near-side structure is observed for the first time for p_T^{trig} > 20 GeV/c.