



Corrélations à longue portée en collisions proton-proton à 7 TeV vues par l'expérience CMS

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Avertissement



- Tout tourne autour de ce papier :
 - J. High Energy Phys. 09 (2010) 091
 - <http://arxiv.org/abs/1009.4122>
 - Communiqué de presse
 - <http://cms.web.cern.ch/cms/News/2010/QCD-10-002/index.html>
 - La première d'une longue série de surprises...
- Nombreuses diapos empruntées à Gunther Roland, présentation au CERN et séminaire au LLR...

Sommaire



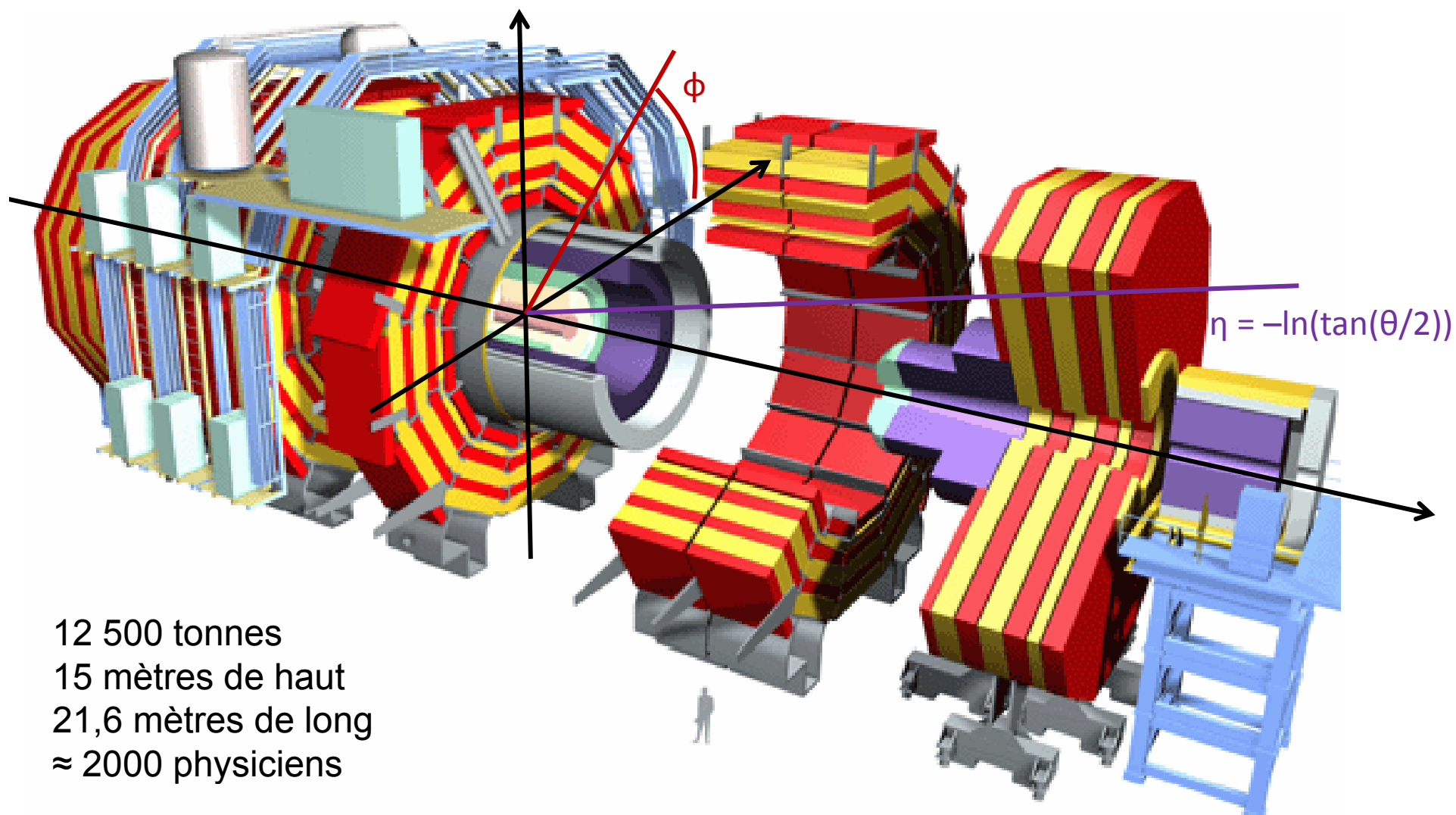
- Définitions
- Minimum bias
 - $3,3 / 0,2 / 3,0 \mu\text{b}^{-1}$ @ $0,9 / 2,36 / 7 \text{ TeV}$
- Haute multiplicité
 - eq. 980 nb^{-1} @ 7 TeV
- Interprétations possibles
- Quelques vérifications



Que présentons-nous exactement ?

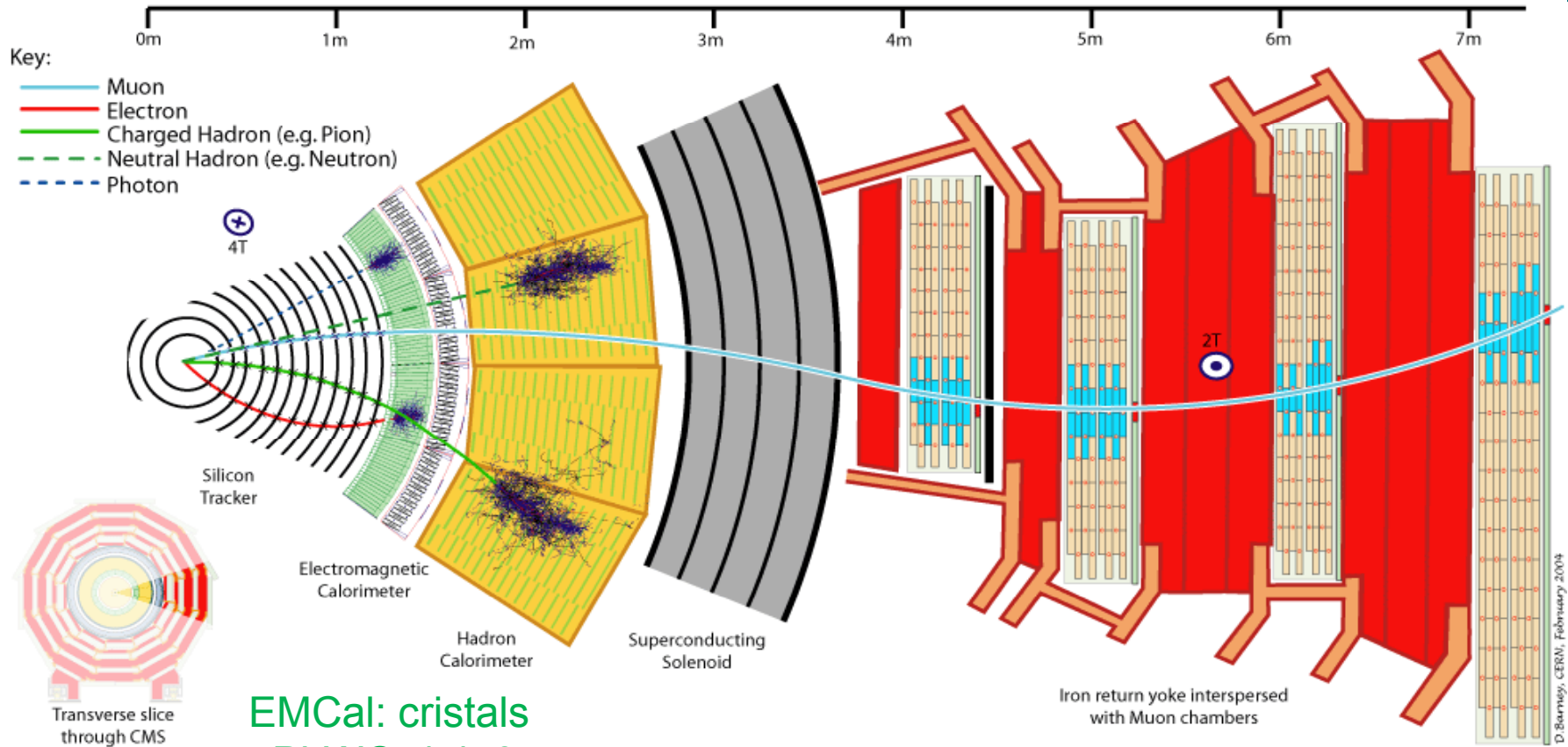
DÉFINITIONS

Compact Muon Solenoid



12 500 tonnes
15 mètres de haut
21,6 mètres de long
≈ 2000 physiciens

Détection des particules ($|\eta| < 2,4$)



EMCal: cristals
 PbWO_4 $|\eta| < 3$

Muon: drift tubes + RPC $|\eta| < 2.4$

Silicium: pixels (3)
 and strips (10) $|\eta| < 2.4$

HCal: Scintillation
 $|\eta| < 5$

+ Higher rapidity extension

Quelques caractéristiques utiles



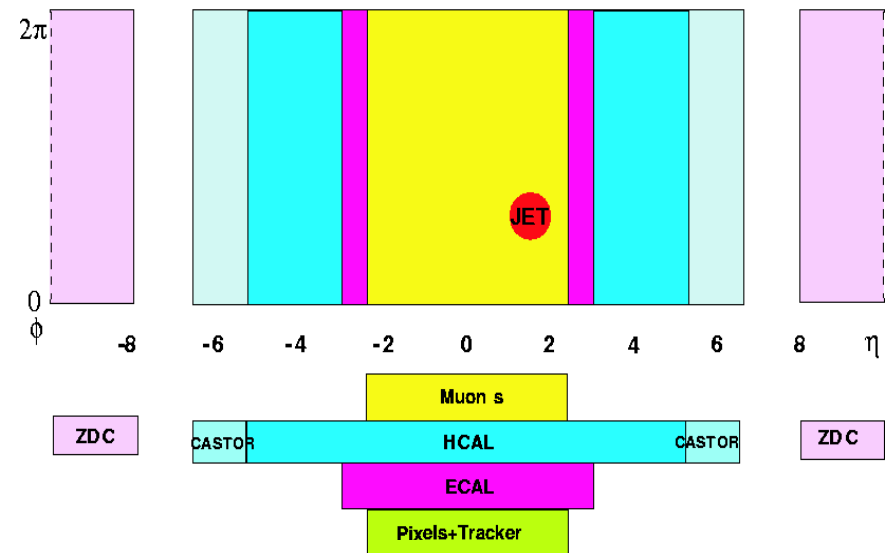
2. Fort champ magnétique

- 3,8 Teslas

3. Large bande passante

- Niveau 1 = Tout Pb-Pb collisions (≈ 5 kHz)
- Trigger de haut niveau (HLT) \rightarrow 10 à 100 Hz

1. Grande couverture angulaire

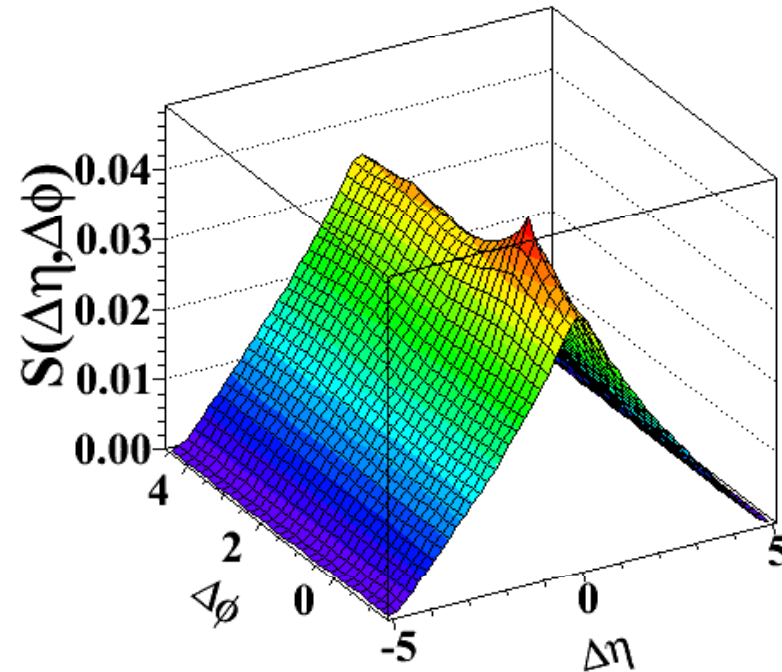


\rightarrow Grande acceptance, en particulier à grand p_T

Le signal



- Idée : regarder la corrélation des particules dans tout l'espace des phases
 - $\Delta\eta = \eta_1 - \eta_2$
 - $\Delta\phi = \phi_1 - \phi_2$
- Dans chaque événement de multiplicité N
 - Toute paire de particules
 - Normalisé au nombre de paires

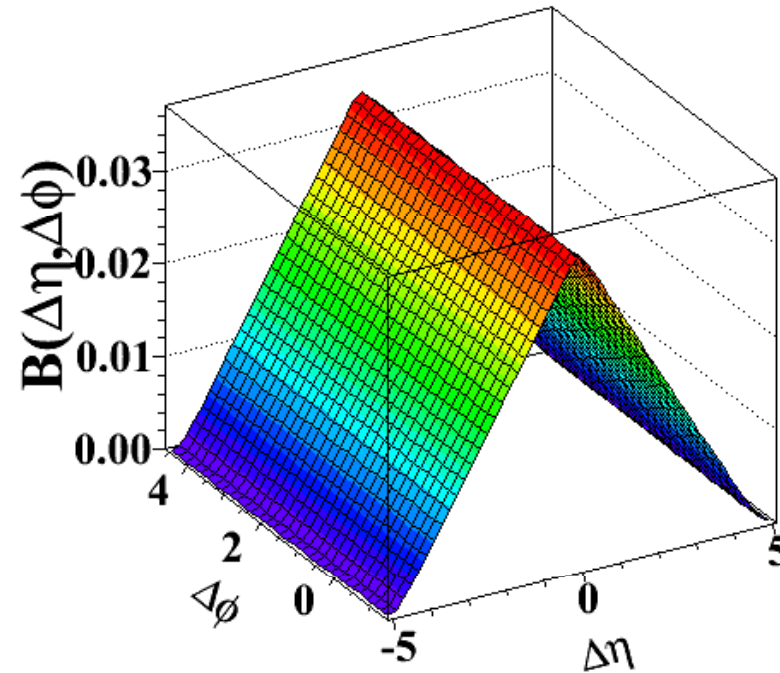


$$S_N(\Delta\eta, \Delta\phi) = \frac{1}{N(N-1)} \frac{d^2 N^{\text{signal}}}{d\Delta\eta d\Delta\phi}$$

Le fond combinatoire



- Événements différents de même multiplicité N
 - Reflet de l'acceptance

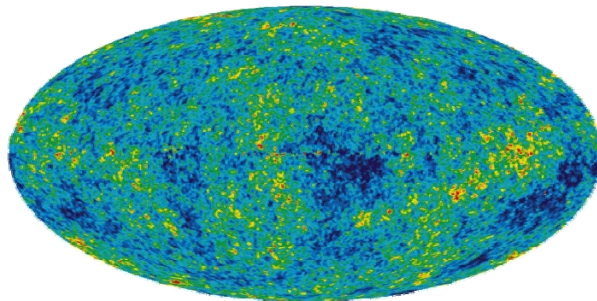


$$B_N(\Delta\eta, \Delta\phi) = \frac{1}{N^2} \frac{d^2 N^{\text{mixed}}}{d\Delta\eta d\Delta\phi}$$

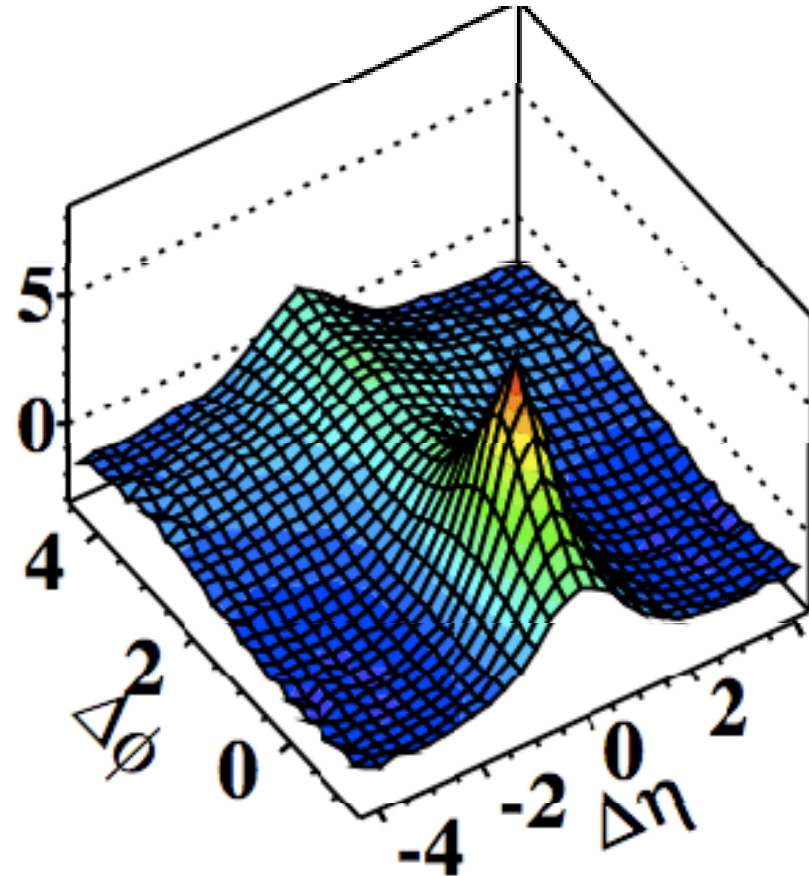
La fonction de corrélation R



- Signal / Bruit – 1
 - Resommer et pondérer par la multiplicité
- « Cartographie » des collisions
 - Longue portée = temps courts



Le ciel vu par wmap



$$R(\Delta\eta, \Delta\phi) = \left\langle \left(\langle N \rangle - 1 \right) \left(\frac{S_N(\Delta\eta, \Delta\phi)}{B_N(\Delta\eta, \Delta\phi)} - 1 \right) \right\rangle_{bins}$$



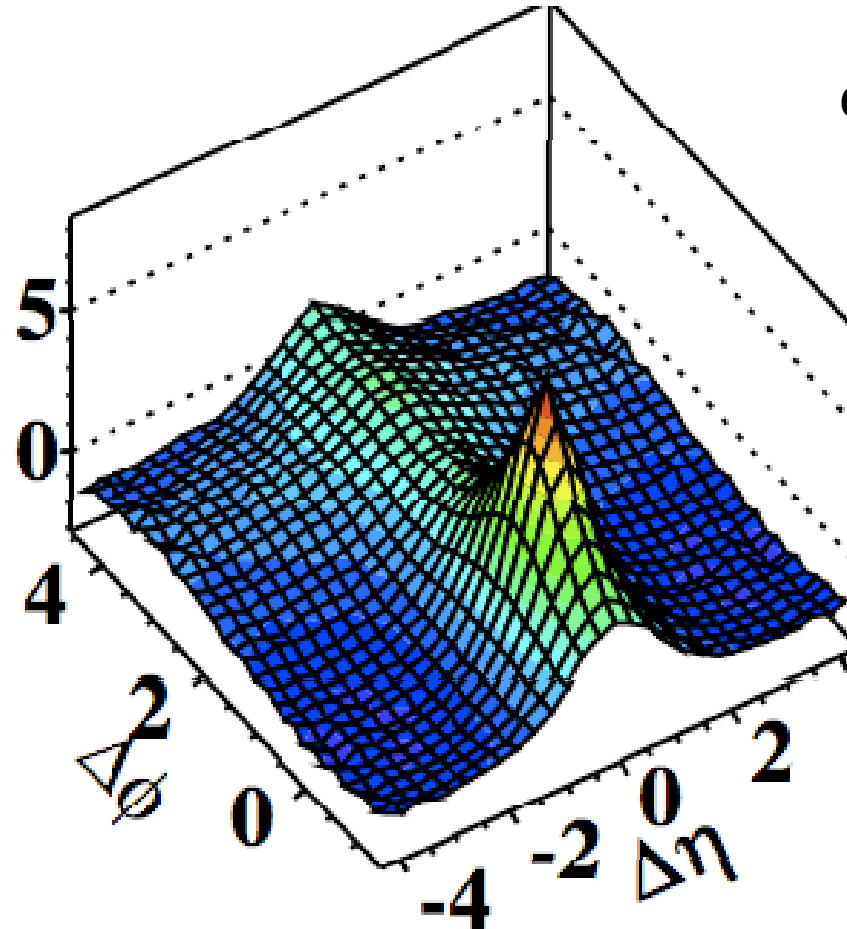
Jusqu'ici tout va bien...

COLLISIONS DE BIAIS MINIMUM

Corrélations angulaires (0/4)



CMS 7 TeV pp min bias
 $p_T > 0,1 \text{ GeV}/c$

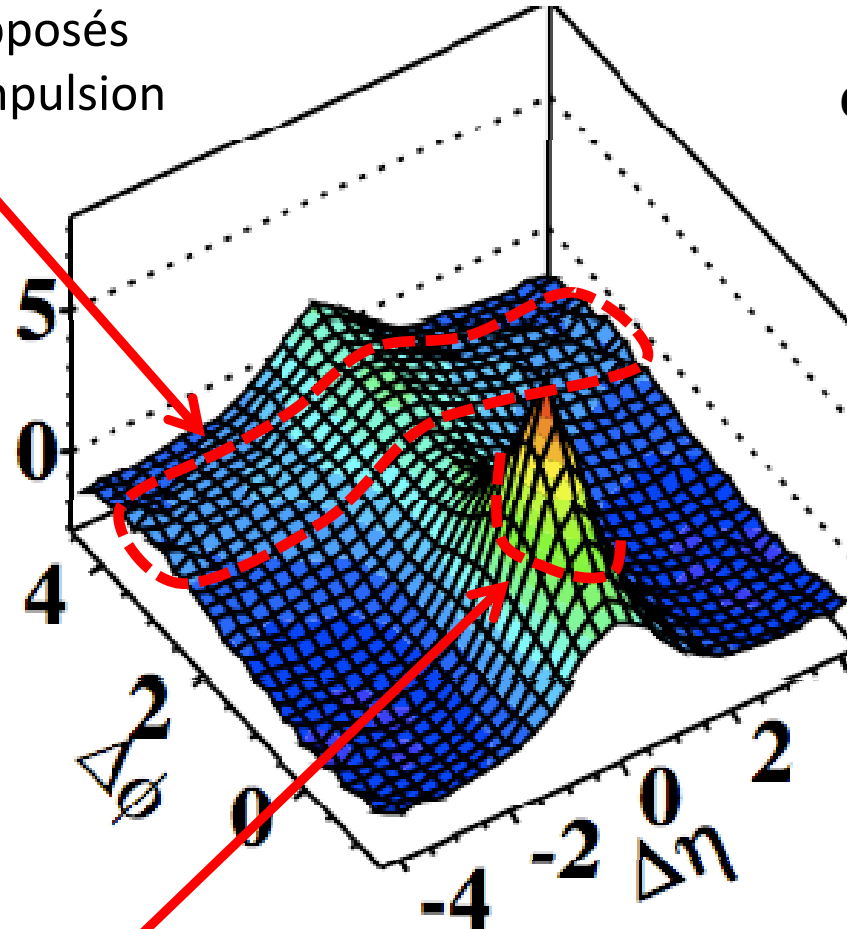


Corrélations angulaires (1/4)



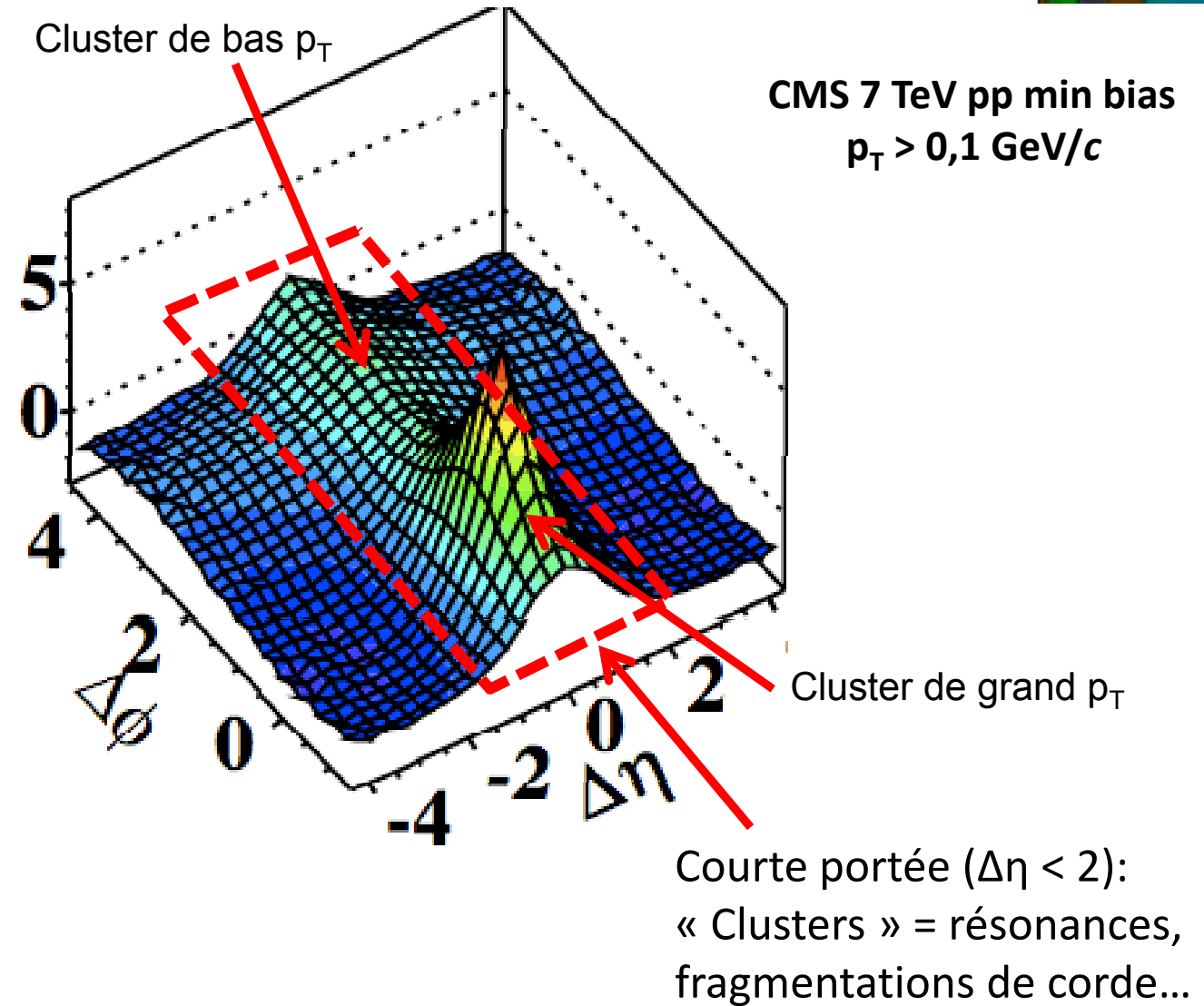
Particules de jets opposés
 \approx conservation de l'impulsion
($\Delta\phi \approx \pi$)

CMS 7 TeV pp min bias
 $p_T > 0,1 \text{ GeV}/c$

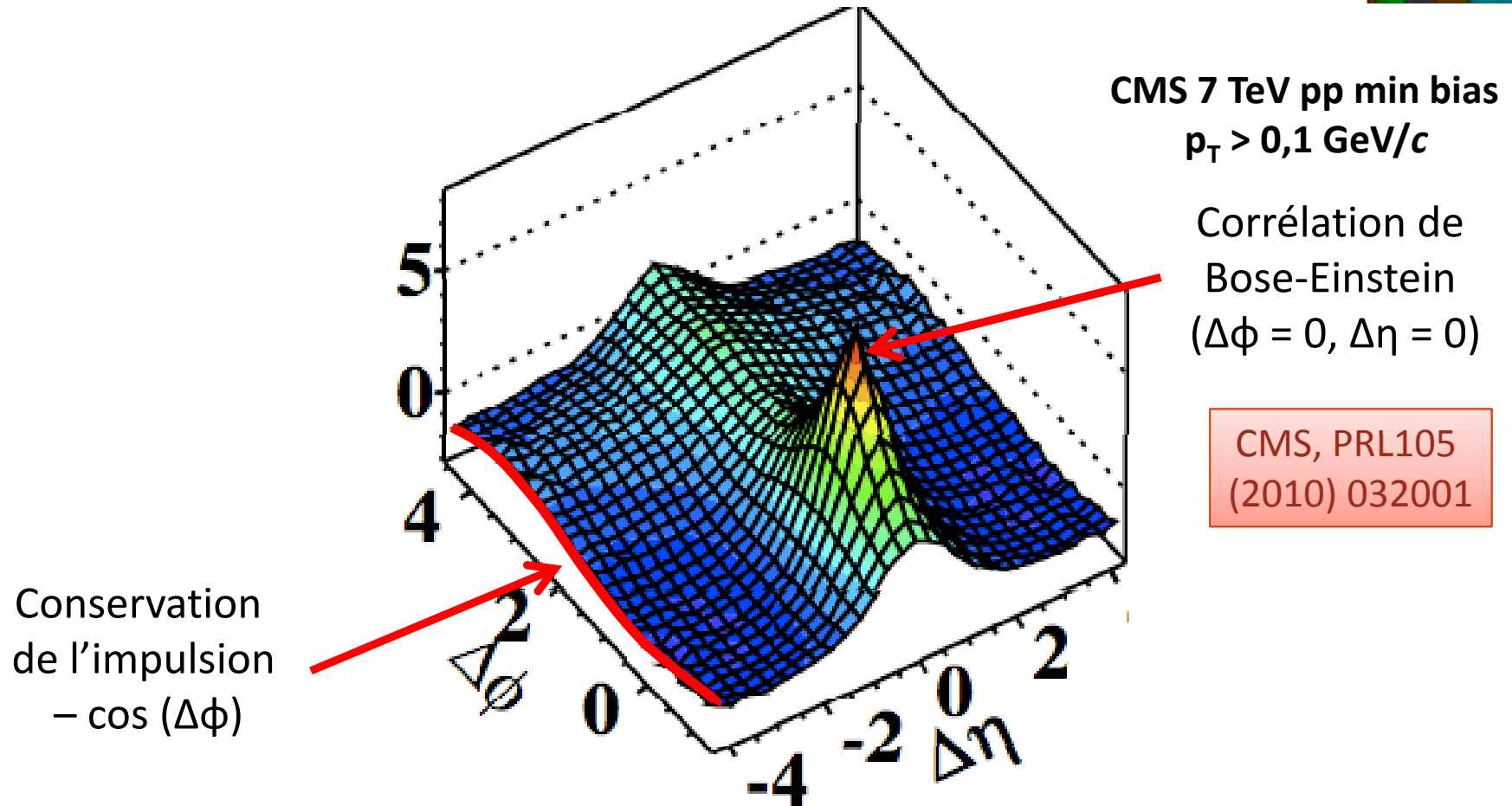


Particules d'un même jet
($\Delta\phi \approx 0, \Delta\eta \approx 0$)

Corrélations angulaires (2/4)



Corrélations angulaires (3/4)



Corrélations angulaires (4/4)



Particules de jets opposés
 \approx conservation de l'impulsion
($\Delta\phi \approx \pi$)

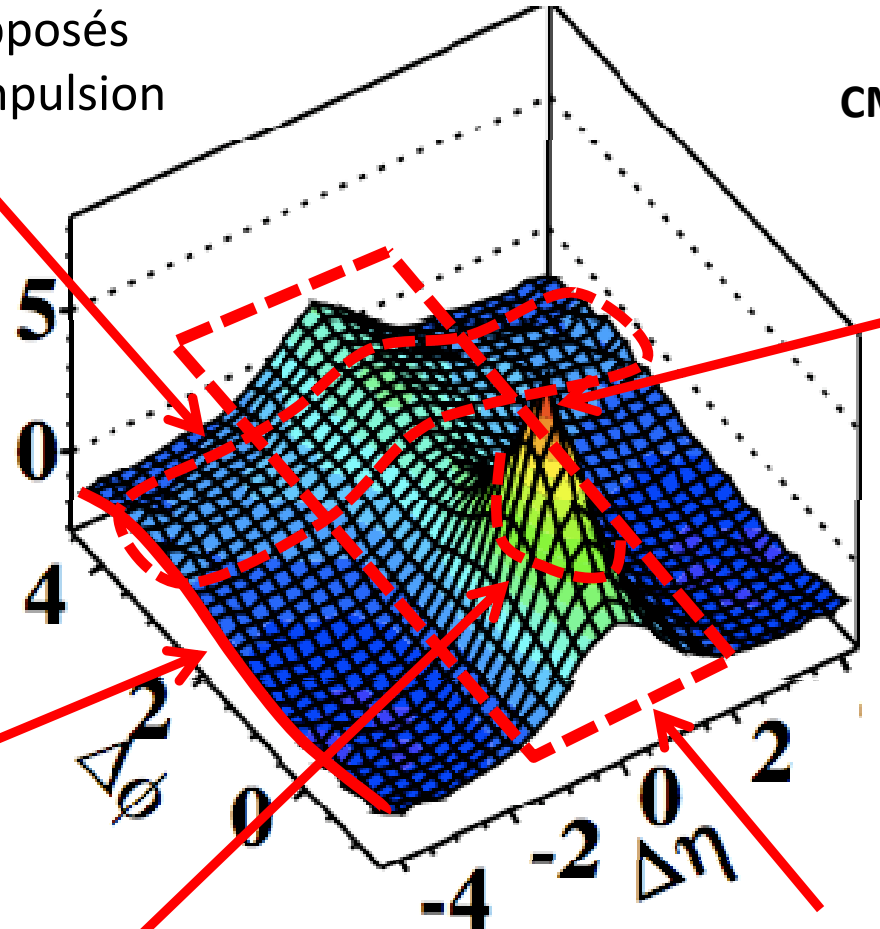
CMS 7 TeV pp min bias
 $p_T > 0,1 \text{ GeV}/c$

Corrélation de
Bose-Einstein
($\Delta\phi = 0, \Delta\eta = 0$)

Conservation
de l'impulsion
 $-\cos(\Delta\phi)$

Particules d'un même jet
($\Delta\phi \approx 0, \Delta\eta \approx 0$)

Courte portée ($\Delta\eta < 2$):
« Clusters » = résonances,
fragmentations de corde...

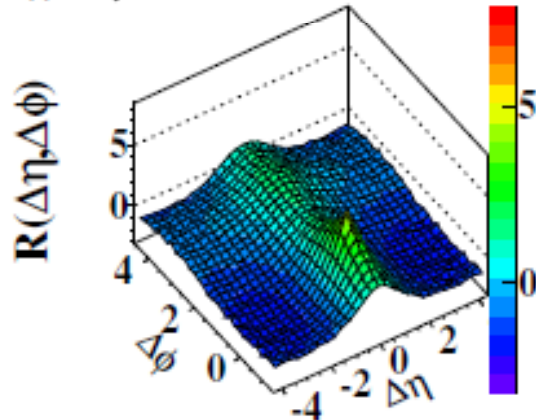


Corrélations versus \sqrt{s}

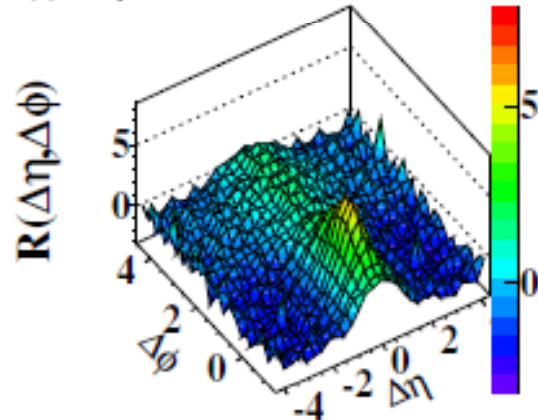


CMS, données de biais minimum

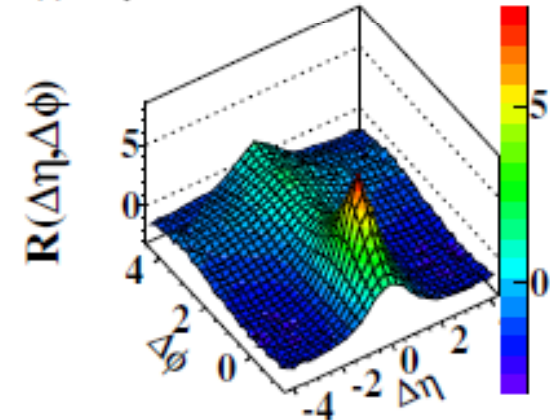
(a) CMS $\sqrt{s} = 0.9\text{TeV}$



(b) CMS $\sqrt{s} = 2.36\text{TeV}$

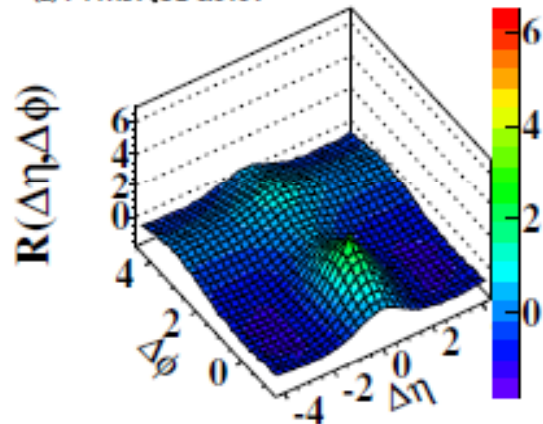


(c) CMS $\sqrt{s} = 7\text{TeV}$

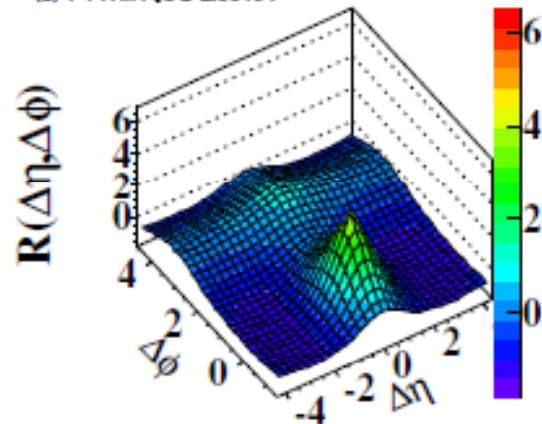


Pythia, D6T tune

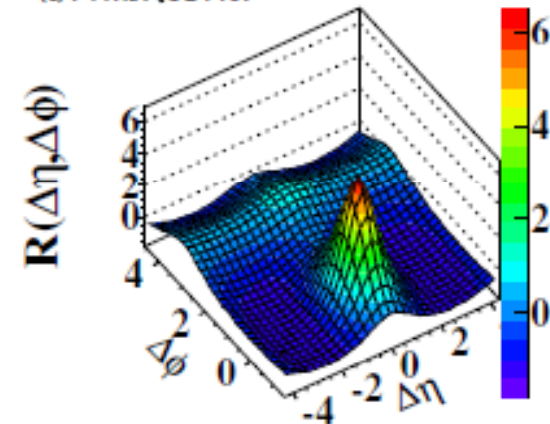
(a) PYTHIA $\sqrt{s} = 0.9\text{TeV}$



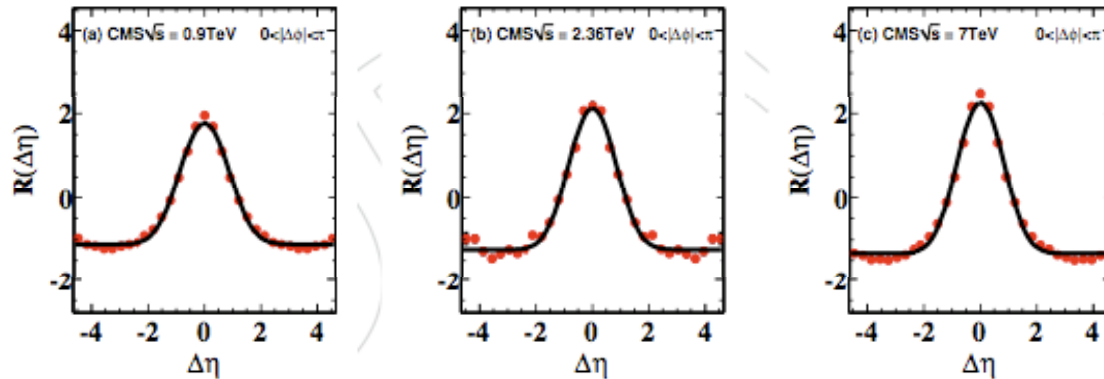
(b) PYTHIA $\sqrt{s} = 2.36\text{TeV}$



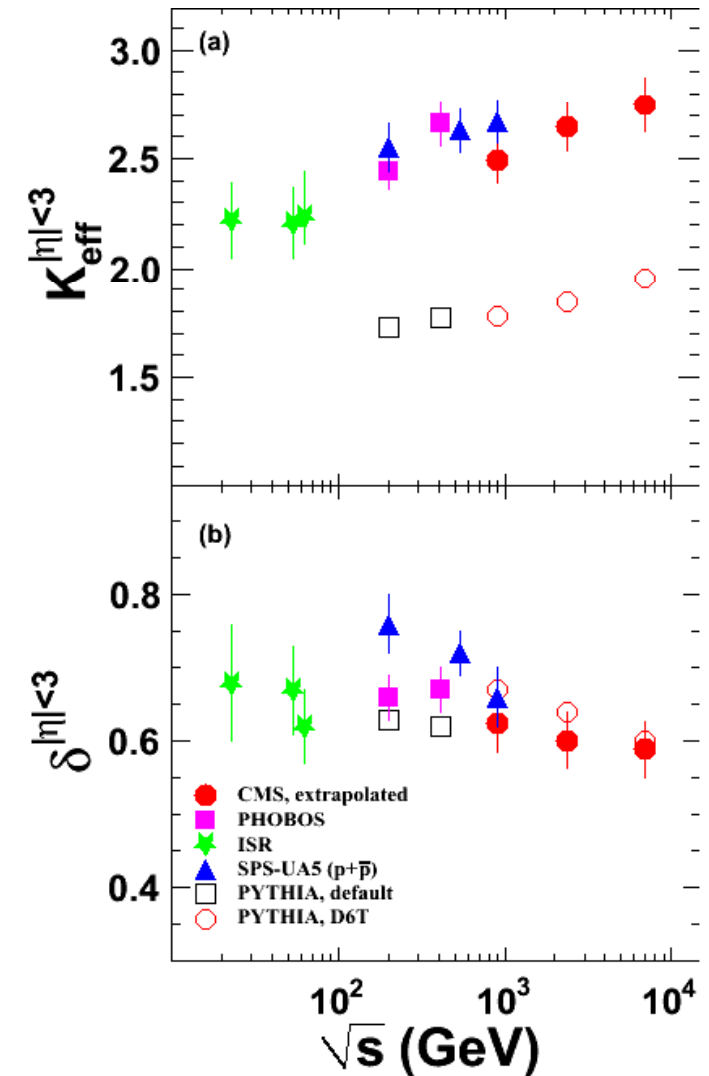
(c) PYTHIA $\sqrt{s} = 7\text{TeV}$



Projection sur l'axe $\Delta\eta$



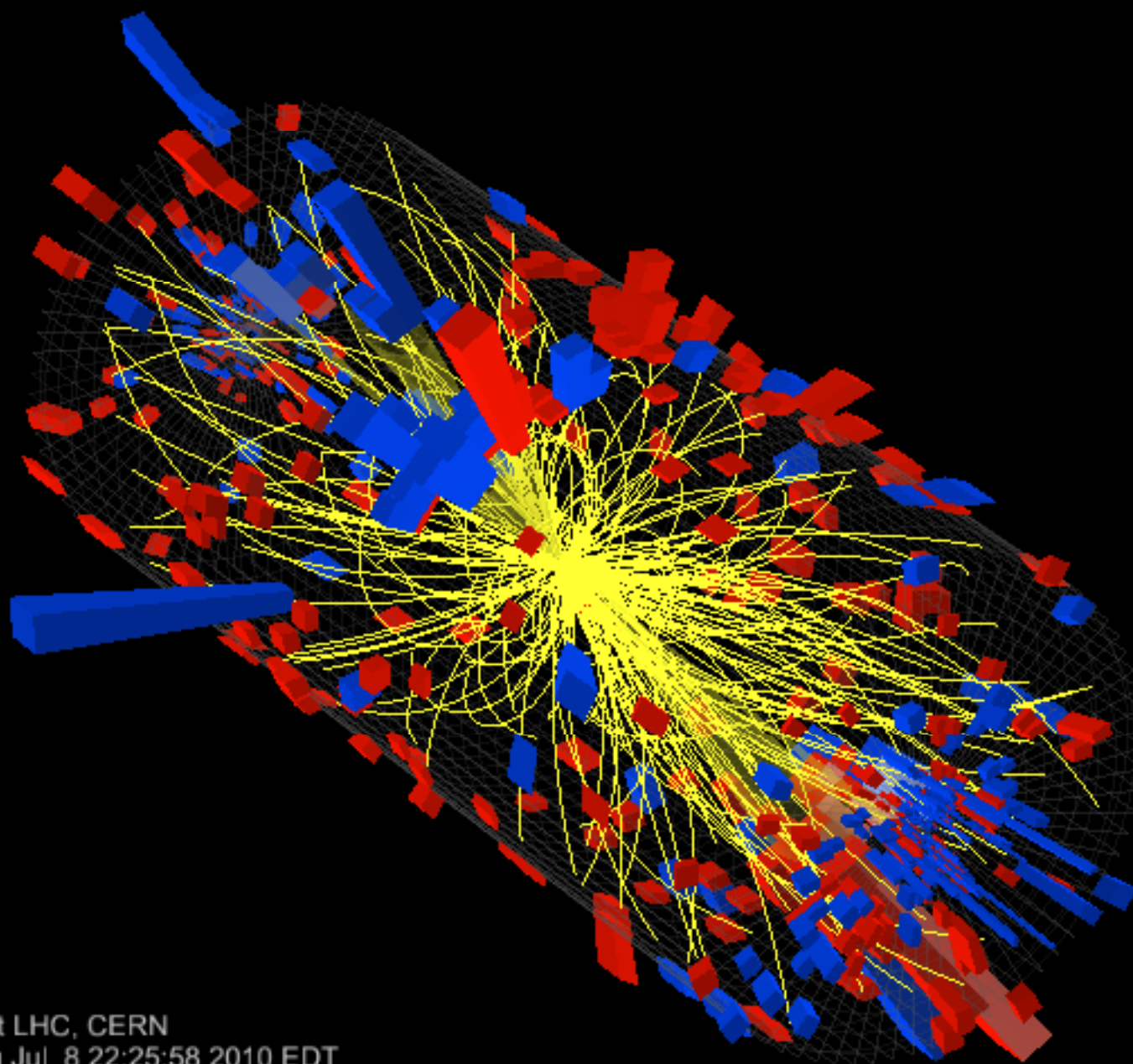
- Ajuste une hauteur (K_{eff} force ou taille du cluster) et une largeur δ
 - K_{eff} augmente avec \sqrt{s}
 - Sous-estimée par Pythia (D6T)
 - δ constante
- Ici extrapolé à $p_T = 0$ et $|\eta| < 3$ pour comparaison \rightarrow





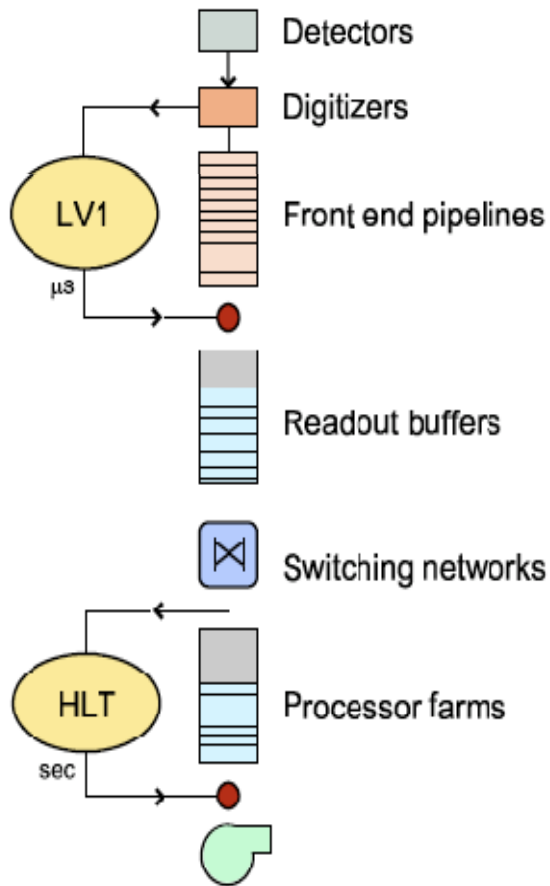
C'est ici que ça se passe...

GRANDE MULTIPLICITÉ

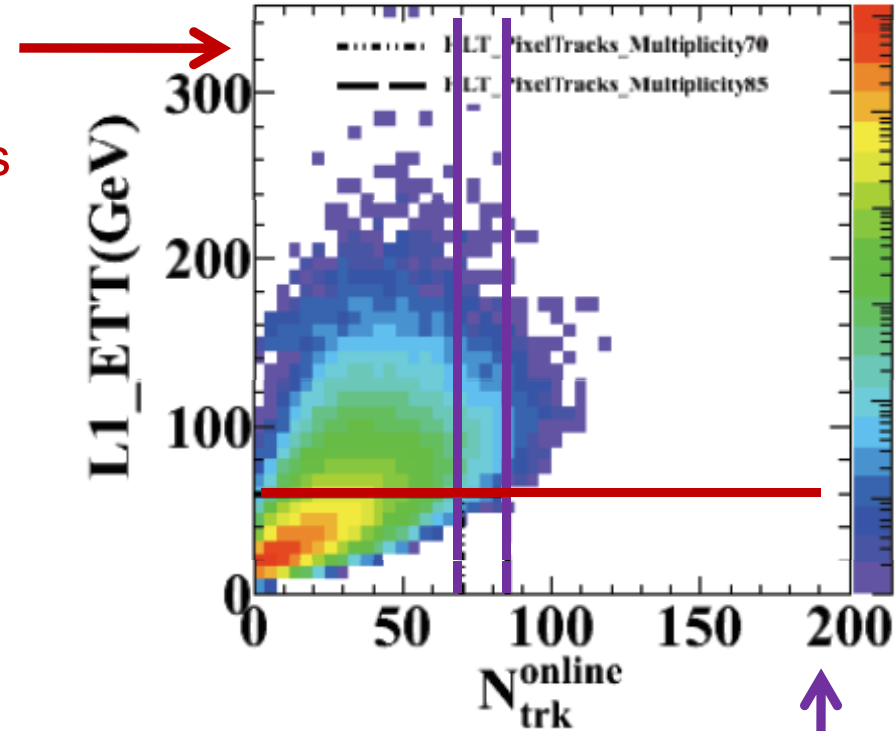


CMS Experiment at LHC, CERN
Data recorded: Thu Jul 8 22:25:58 2010 EDT
Run/Event: 139779 / 4994190
Lumi section: 5
Orbit/Crossing: 1302609 / 401

Déclenchement dédié

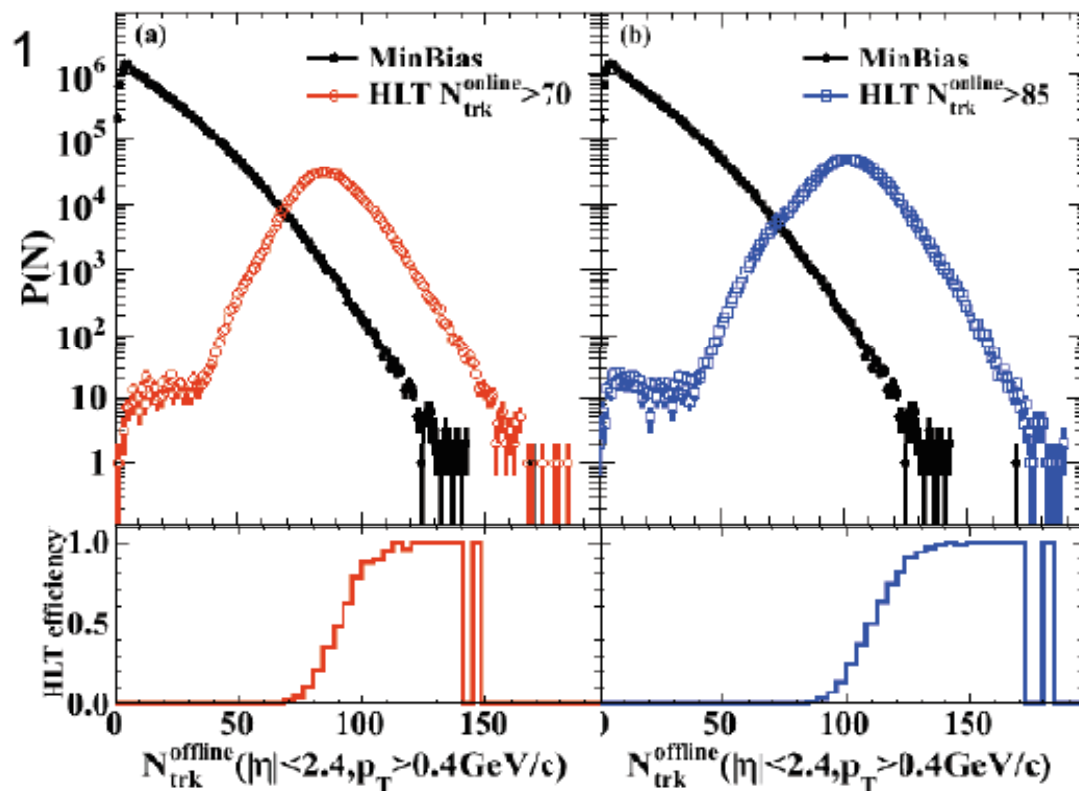


Au niveau 1
 $E_T > 60 \text{ GeV}$
dans les calos



Au trigger de haut niveau (HLT)
Nombre de traces de $p_T > 0,4 \text{ GeV}/c$, $|\eta| < 2$,
dans $dz < 0,12 \text{ cm}$ d'un unique vertex de $z < 10 \text{ cm}$

Déclenchement dédié



Deux seuils utilisés :
 $N^{\text{online}} > 70$ and $N^{\text{online}} > 85$

Pas de présélection
 du HLT85 jusqu'à 980 nb^{-1}
 (\approx moitié du CPU)

Multiplicités
 $p_T > 0,4 \text{ GeV}/c$
 $|\Delta\eta| < 2,4$

out of 5×10^{10} collisions



Multiplicity bin ($N_{\text{trk}}^{\text{offline}}$)	Event Count	$\langle N_{\text{trk}}^{\text{offline}} \rangle$
MinBias	21.43M	15.9
$N_{\text{trk}}^{\text{offline}} < 35$	19.36M	13.0
$35 \leq N_{\text{trk}}^{\text{offline}} < 90$	2.02M	45.3
$90 \leq N_{\text{trk}}^{\text{offline}} < 110$	302.5k	96.6
$N_{\text{trk}}^{\text{offline}} \geq 110$	354.0k	117.8

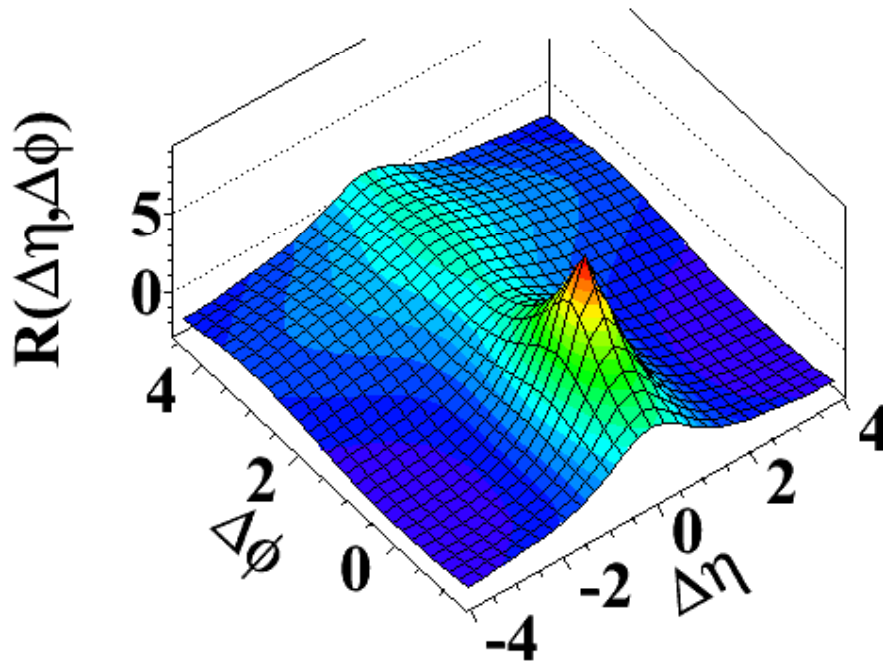
Résultats pour tout p_T



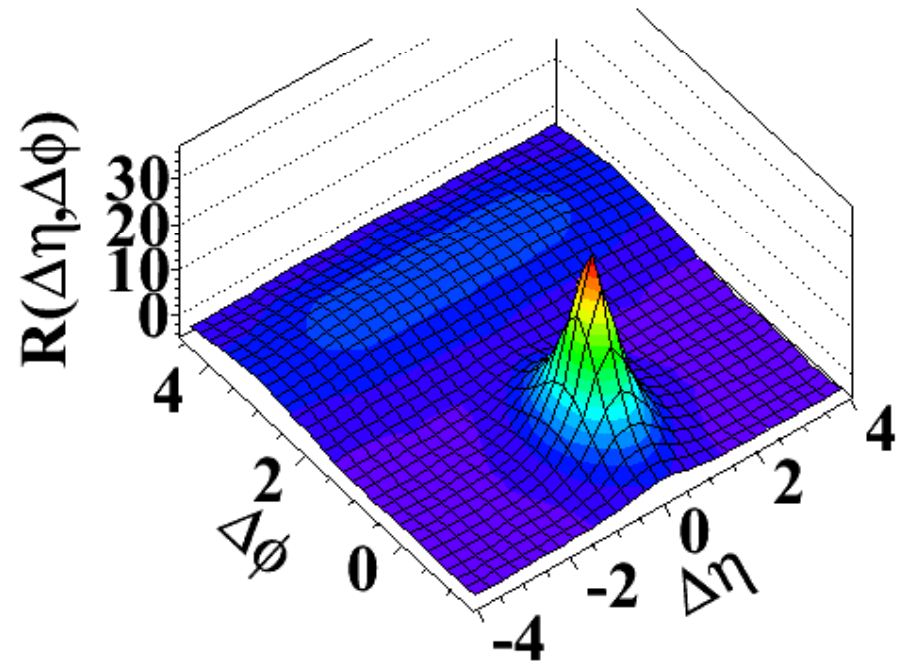
Biais minimum

Haute multiplicité ($N > 110$)

(a) MinBias, $p_T > 0.1 \text{ GeV}/c$



(c) $N > 110$, $p_T > 0.1 \text{ GeV}/c$



Davantage de jets à haute multiplicité ($\Delta\phi \approx 0$)

Même figures
coupées en z

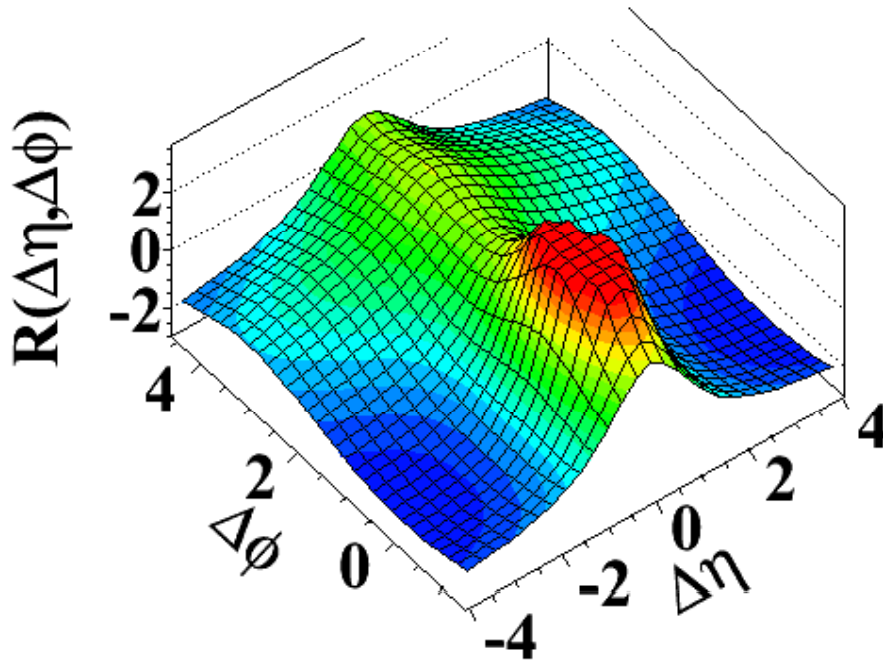
Résultats pour tout p_T



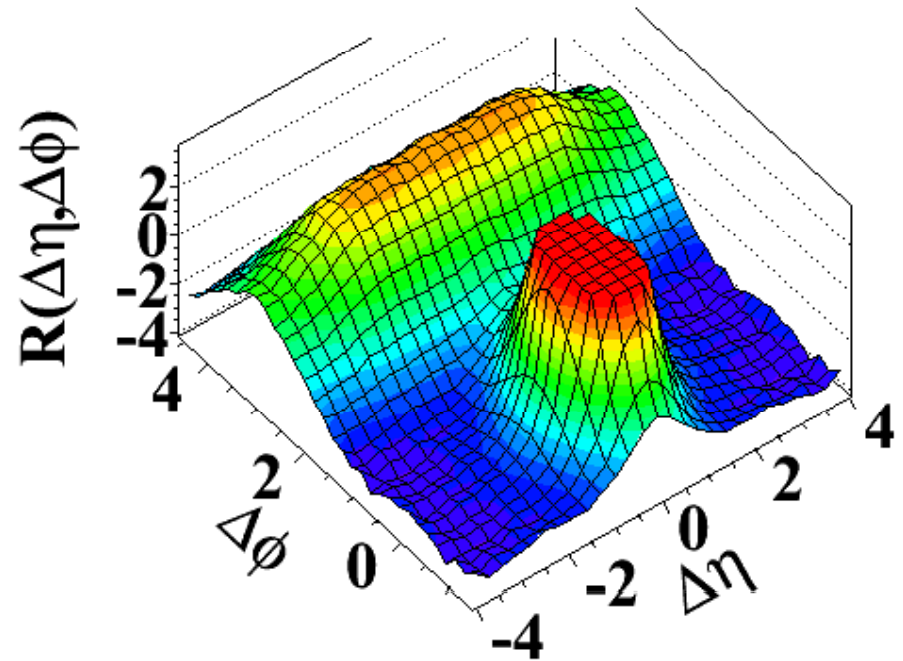
Biais minimum

Haute multiplicité ($N > 110$)

(a) MinBias, $p_T > 0.1 \text{ GeV}/c$



(c) $N > 110$, $p_T > 0.1 \text{ GeV}/c$



Davantage de jets à haute multiplicité ($\Delta\phi \approx \pi$)

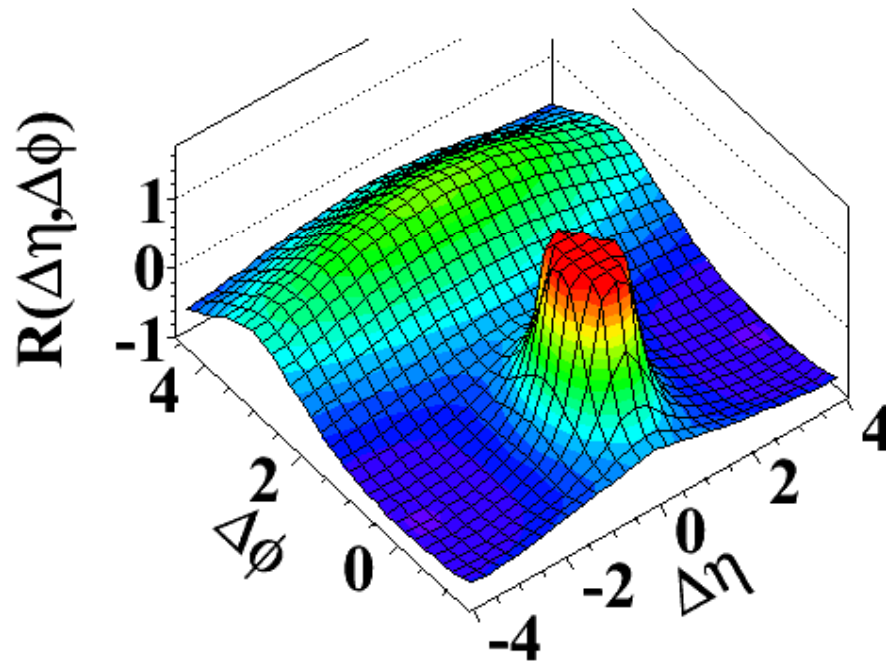
Résultats pour $p_T = 1-3 \text{ GeV}/c$



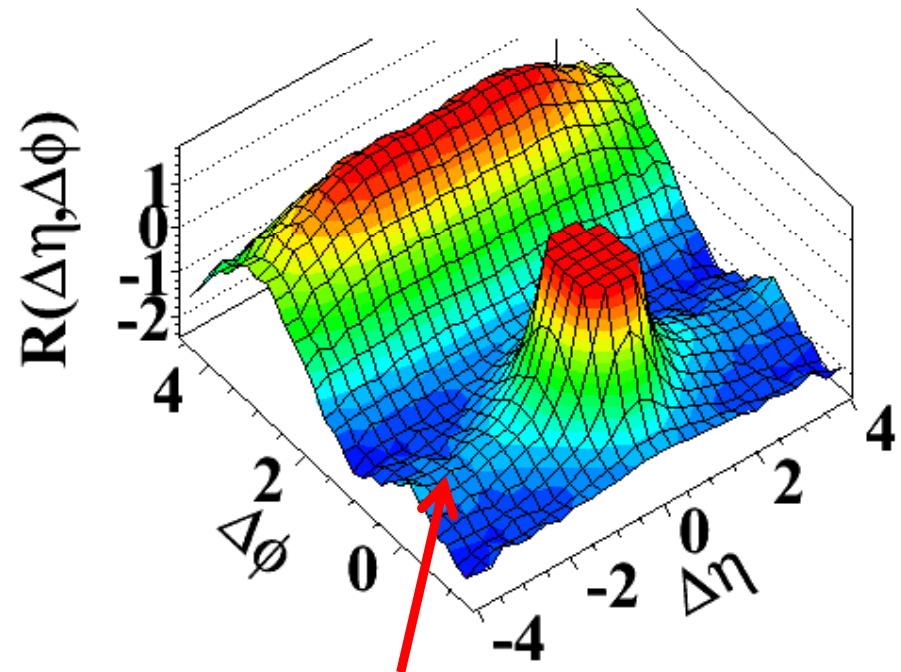
Biais minimum

Haute multiplicité ($N > 110$)

(b) MinBias, $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



(d) $N > 110$, $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



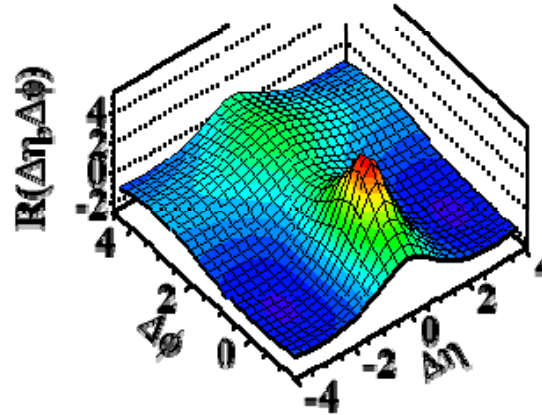
Une nouvelle structure à $\Delta\phi \approx 0$ et large $\Delta\eta$
dans le paysage, une « crête » alias le « ridge »

Que dit PYTHIA* ?

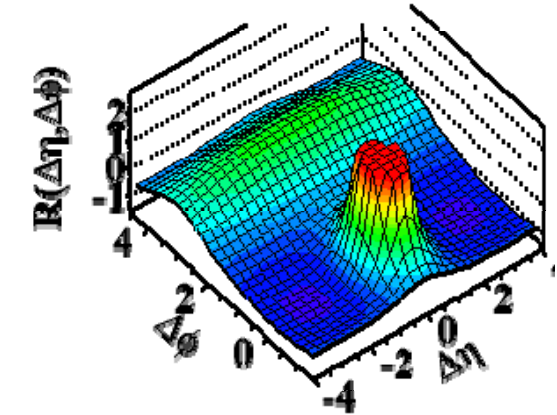


- Qualitativement, tout y est, sauf le « ridge »
- Idem avec d'autres générateurs
 - Herwig++, madgraph, Pythia6...

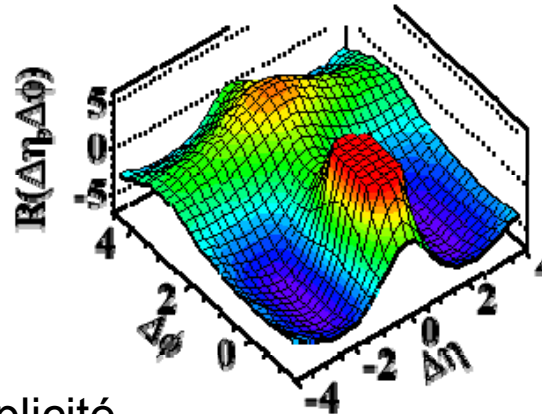
(a) MinBias, $p_T > 0.1 \text{ GeV}/c$



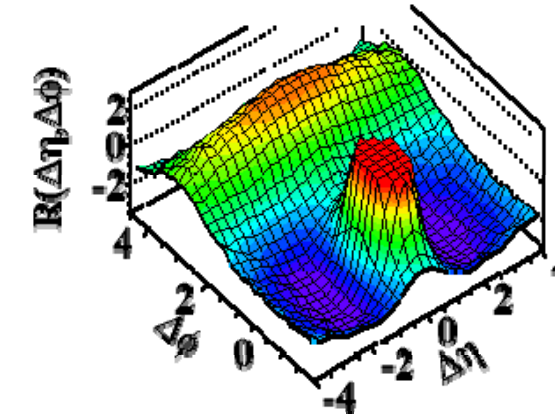
(b) MinBias, $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



(c) $N > 110$, $p_T > 0.1 \text{ GeV}/c$



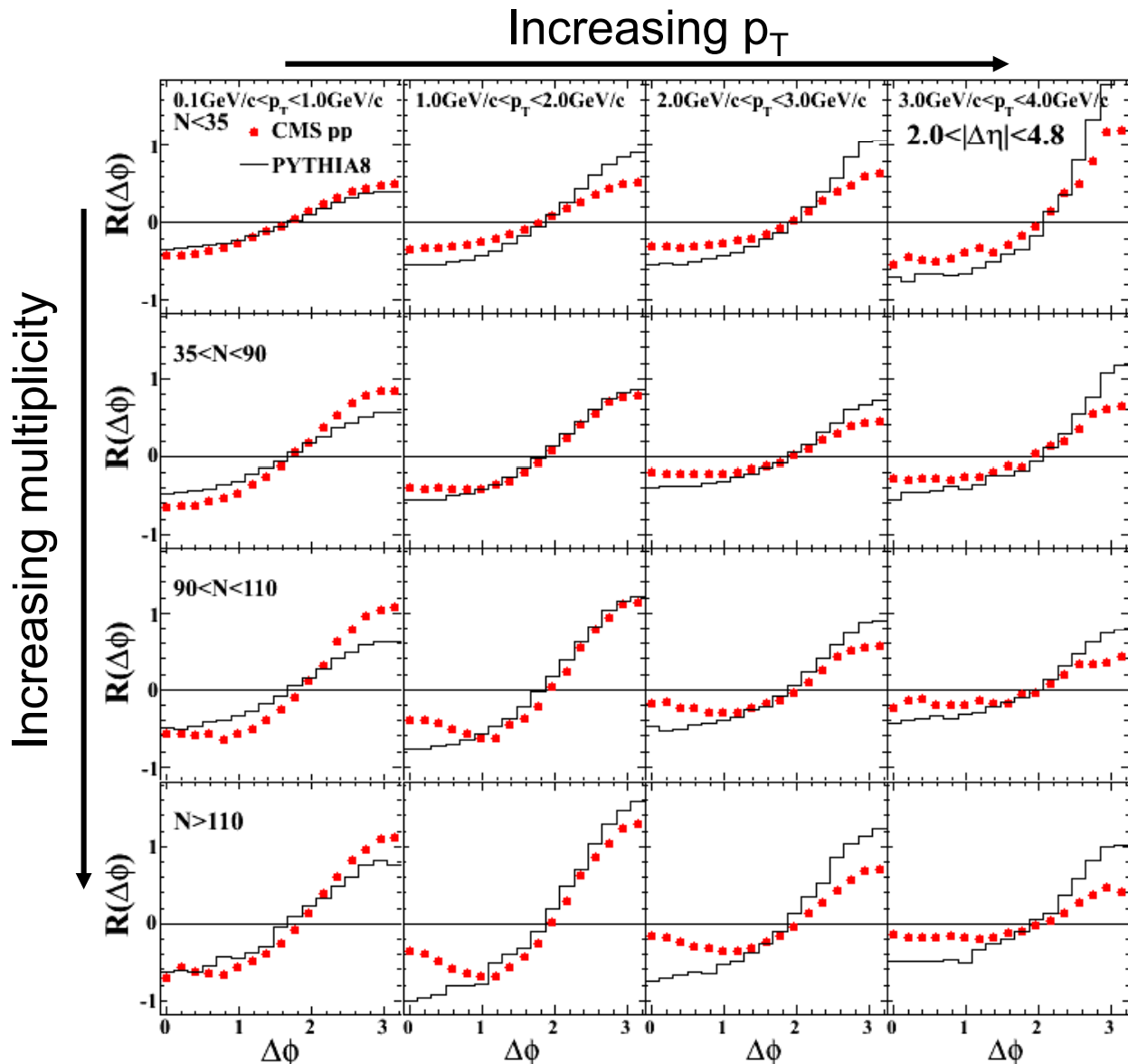
(d) $N > 110$, $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



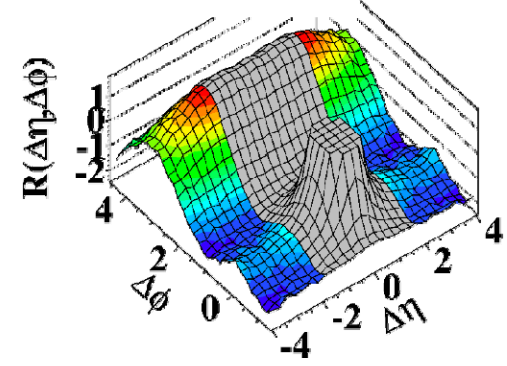
* Pythia 8, qui traite mieux la multiplicité



Projection sur $\Delta\phi$ ($|\Delta\eta|>2$)



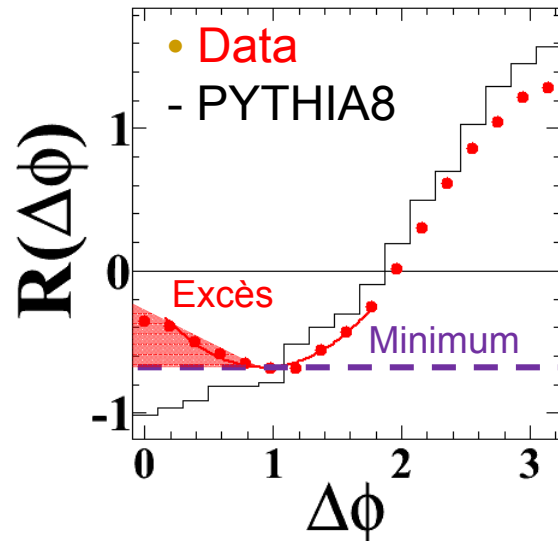
(d) $N>110, 1.0\text{GeV}/c < p_T < 3.0\text{GeV}/c$



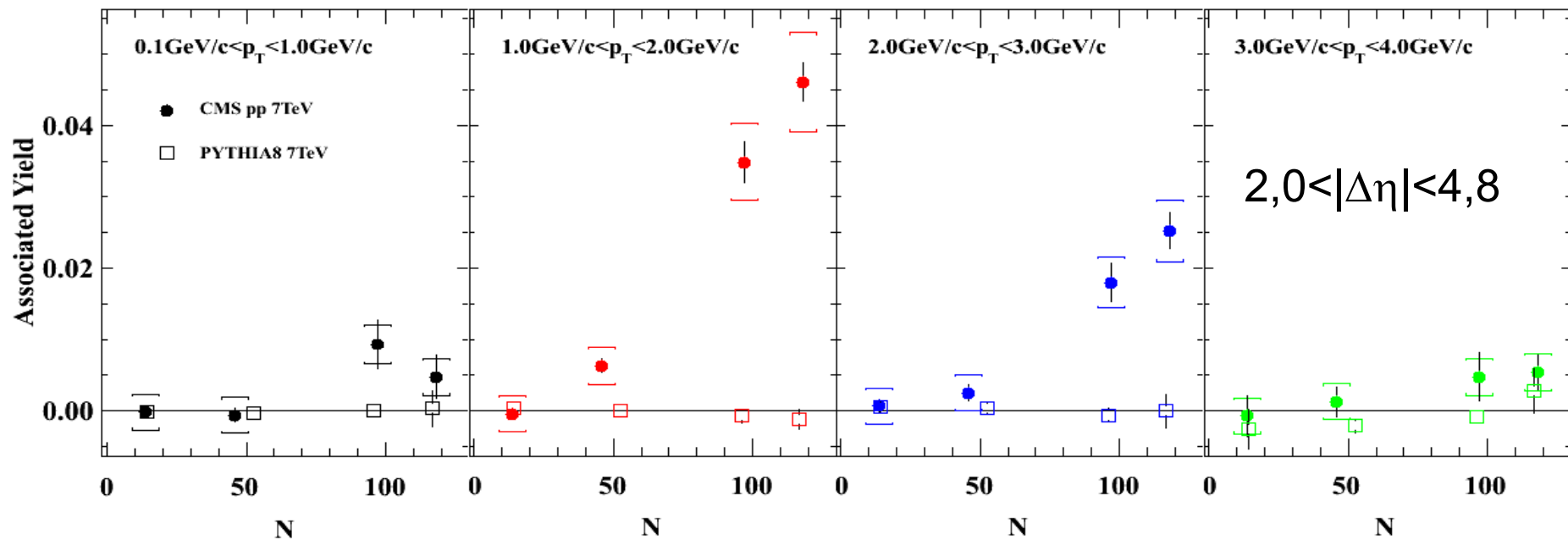
- Le « ridge » à
- Grande multiplicité
 - $p_T = 1-3 \text{ GeV}/c$



Quantification



- Trouver le minimum de R
- Intégrer l'excès à gauche
- Grandit avec multiplicité





Honnêtement, c'est encore très flou...

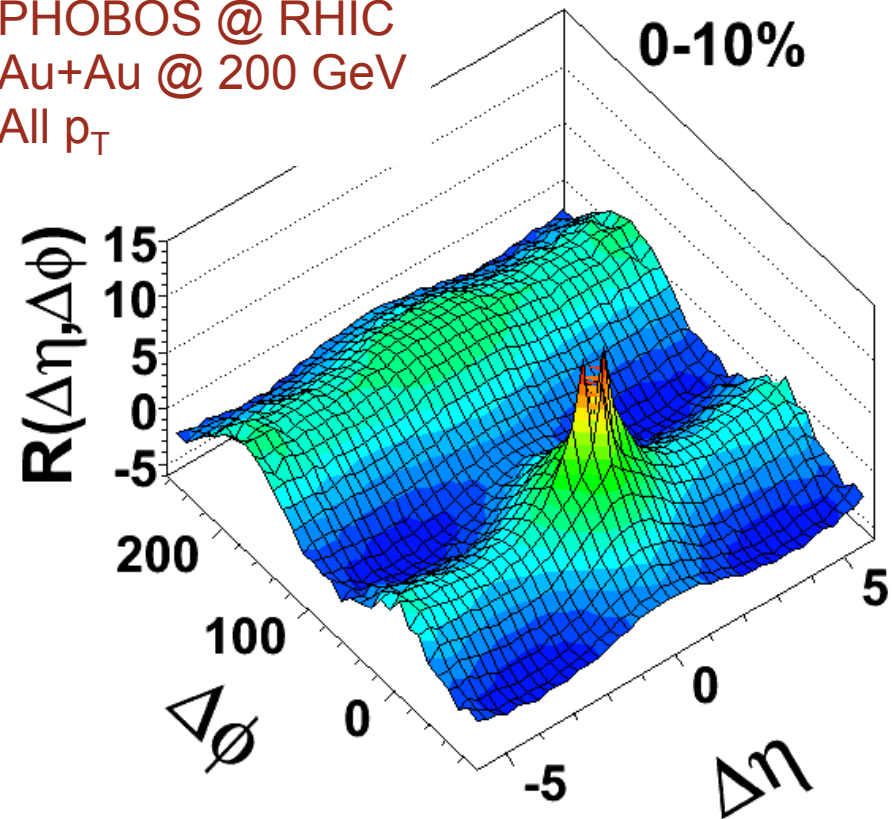
POSSIBLES INTERPRÉTATIONS

Déjà vu quelque part !



- Dans des collisions d'ions lourds à RHIC
 - $\sqrt{s_{NN}} = 200$ GeV
 - Par plusieurs expériences

PHOBOS @ RHIC
Au+Au @ 200 GeV
All p_T

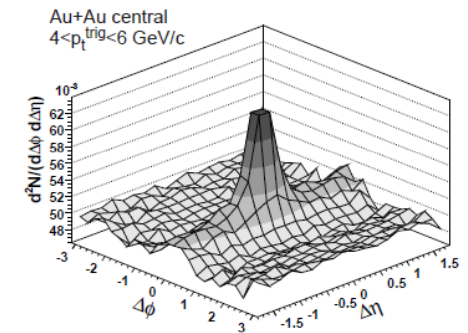
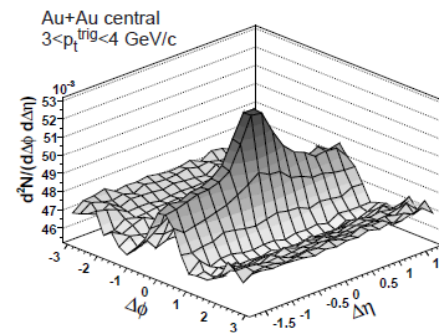


Vu où exactement ?



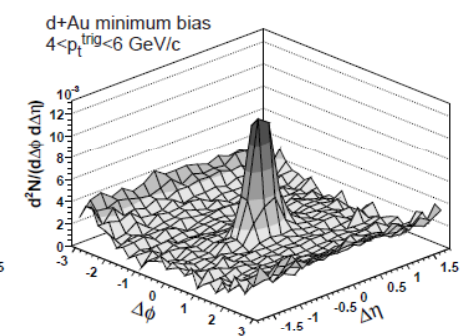
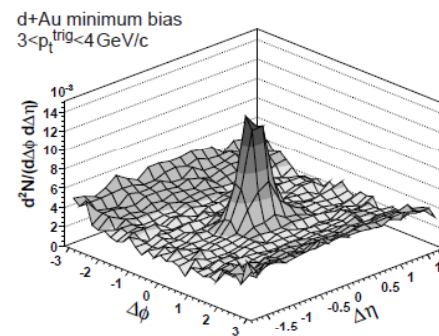
- Vu dans

- Collisions p+p @ 7 TeV, de haute multiplicité
- Collisions Au+Au et Cu+Cu @ 200 GeV



- Absent dans

- Collisions p+p @ 7 TeV de basse multiplicité
- Collisions p+p et d+Au @ 200 GeV



d+Au: STAR, PRC80 (2009) 064912 ↑
Cu+Cu: PHOBOS, PRC81 (2010) 024904

Un peu de logique



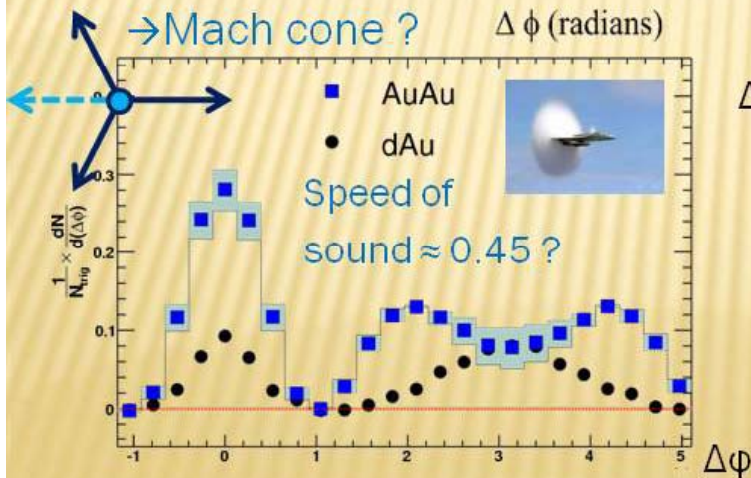
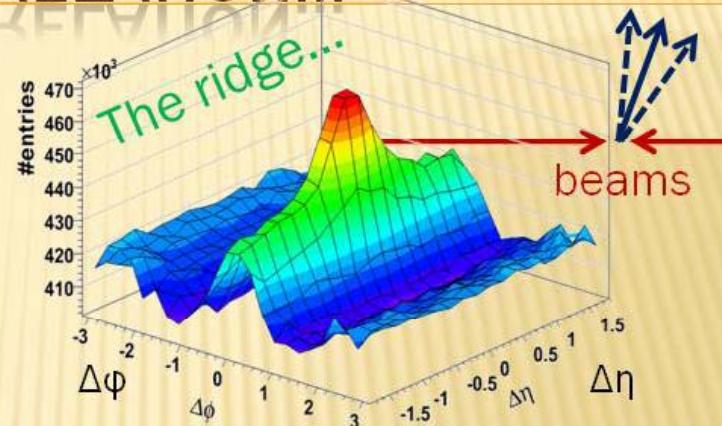
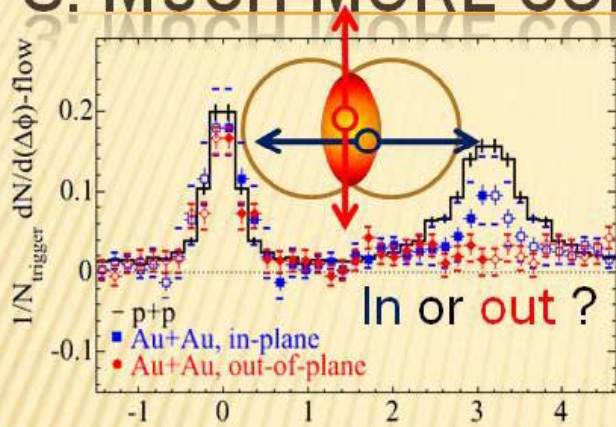
- <http://cms.web.cern.ch/cms/News/2010/QCD-10-002/index.html>
- *« Bien qu'il n'y ait pas d'explication définitive à la cause de cet effet, la structure nouvelle observée n'est pas sans rappeler des caractéristiques similaires vues dans des expériences au RHIC [...] qui furent interprétées comme dues à la présence de matière dense et chaude formée dans les collisions d'ions lourds relativistes. »*
- Tout est vrai, mais attention :
 - Pas forcément la seule interprétation
 - Pas la seule mesure qui permet de conclure à la présence d'une matière chaude et dense

À titre d'exemple...

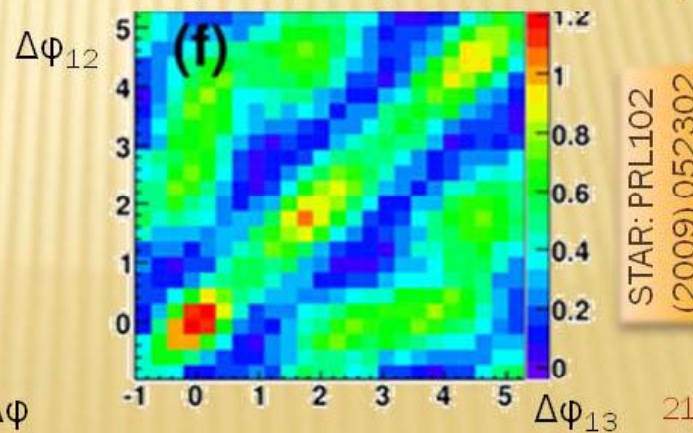


Here, all plots from STAR, see also PHENIX: PRC78 (2008) 014901

3. MUCH MORE CORRELATION...



\rightarrow Three particles (central Au+Au)



Extrait d'une revue sur la matière produite à RHIC, donnée en 2009 (par un orateur sans doute biaisé...)
Le « ridge » y occupe 1/4 de diapo sur 36 !

En revanche...



What's the matter at RHIC? - raphael@in2p3.fr 23/04/2009

4. IDEAL HYDRODYNAMICS

✗ Ideal hydrodynamics...

+ QGP equation of state,

+ Early thermalization

✗ (0.6 fm/c)

+ High density

✗ ($\approx 30 \text{ GeV}/\text{fm}^3$)

✗ Little need for viscosity!

+ First estimations are

✗ approaching the quantum limit $\eta/s = \hbar/4\pi$

✗ lower than Helium at T_c

... reproduces fairly well

1. Single hadron p_T spectra

✗ (mass dependence)

✗ $\langle \beta_T \rangle \approx 0.6$

2. Elliptic flow

✗ Not the foreseen ideal partonic gas!

→ “sQGP” (s stands for strong, not super 😊)

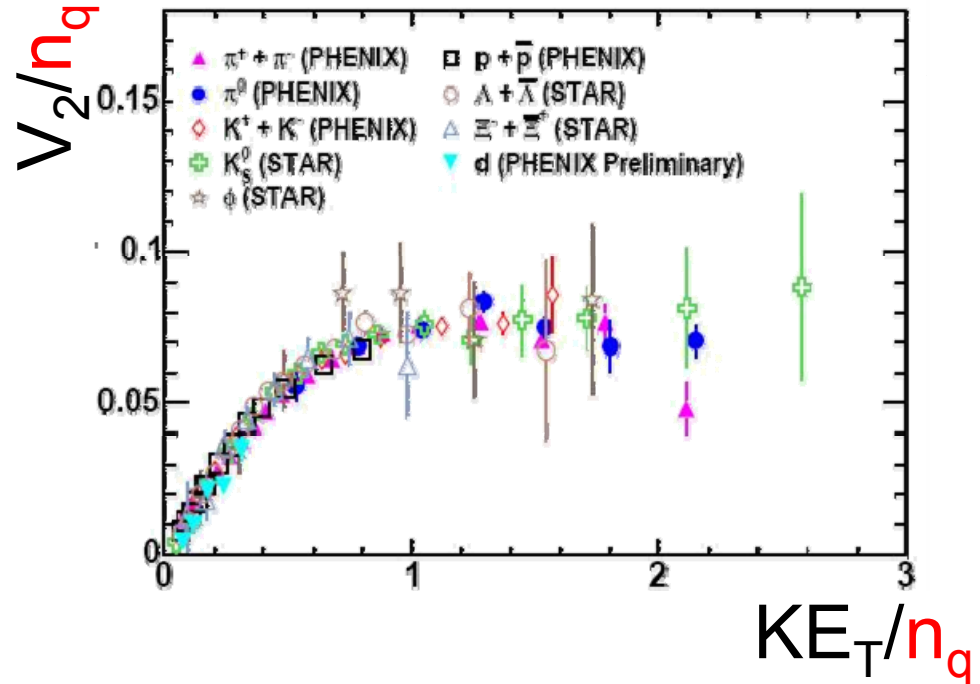
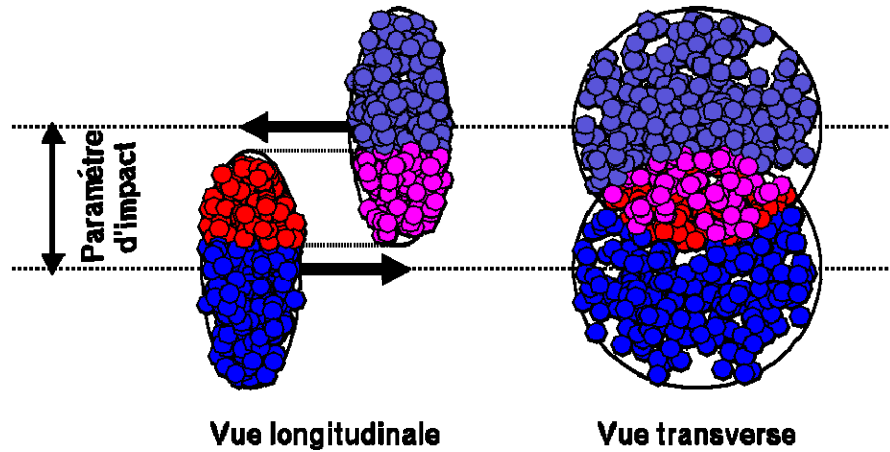
→ “Perfect fluid”

→ The matter is strongly interacting and liquid like @ LHC, could it approach a quark gluon gas?

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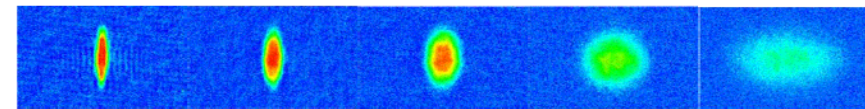


Par exemple : le flot elliptique



PHENIX, PRL98 (2007) 162301

- Asymétrie initiale en ϕ
+ gradient de pression
= Asymétrie finale en ϕ
- Mesure de $v_2 = \langle \cos 2\phi \rangle$
– $\phi = \phi_{\text{part}} - \phi_{\text{réaction}}$

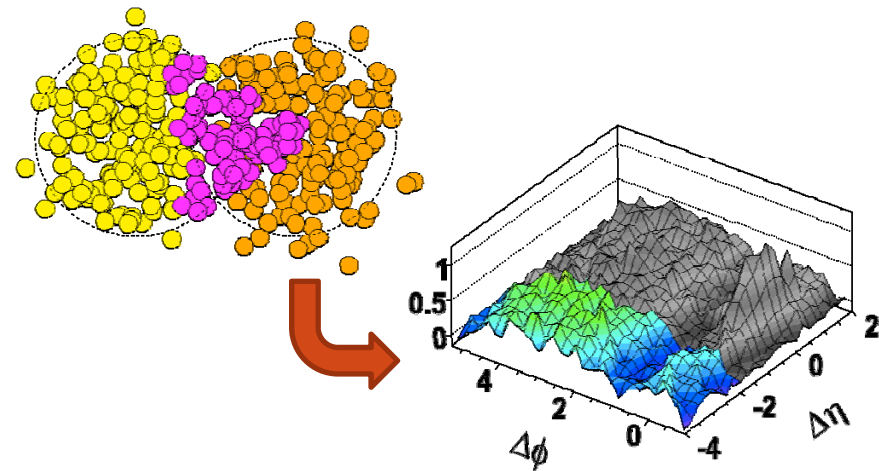


(atomes ultrafroids après ouverture du piège)

1. Un « ridge » dû au flot ?



- Idée : l'explosion « pousse » des clusters dans une direction azimutale donnée
 - Effets de flot maximum à la bonne échelle :
 - $1 < p_T < 3 \text{ GeV}/c$
 - Ok pour A+A, hydro atteinte pour p+p ?
- Un exemple : flux triangulaire dû aux fluctuations géométriques peut contribuer



Shuryak, arXiv:1009.4635

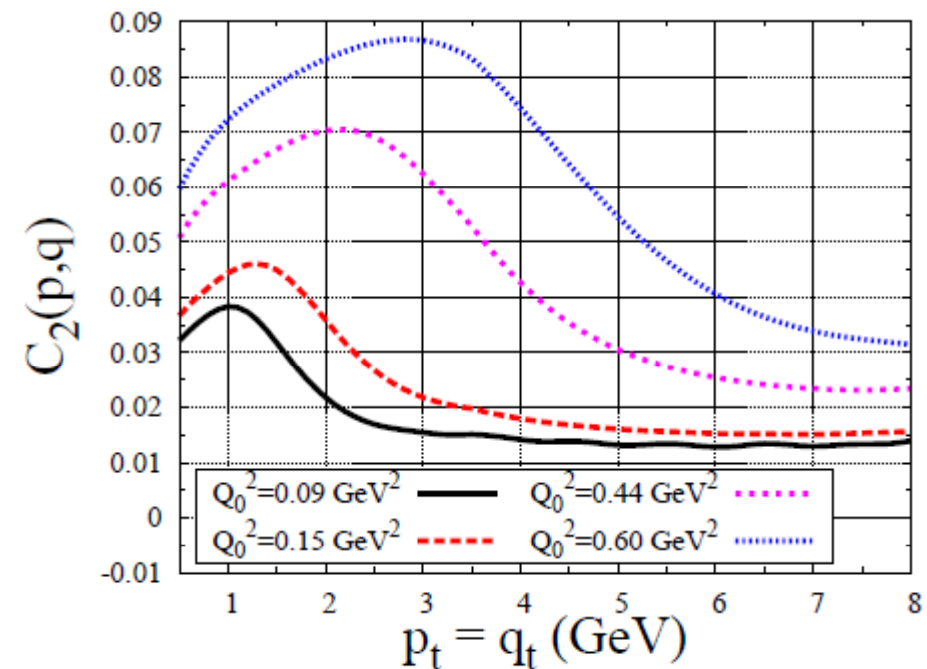
Alver & Roland, arXiv:1003.0194
To appear in Phys. Rev. C

2. au « Glasma » ?



- À haute énergie, saturation de gluon
- « Colour Glass Condensate » comme état initiale des collisions
- Flux de couleur
- Expliqueraient le ridge en A+A et p+p ?

Dumitru et al, arXiv:1009.5295



$Q_0^2 \approx$ multiplicité

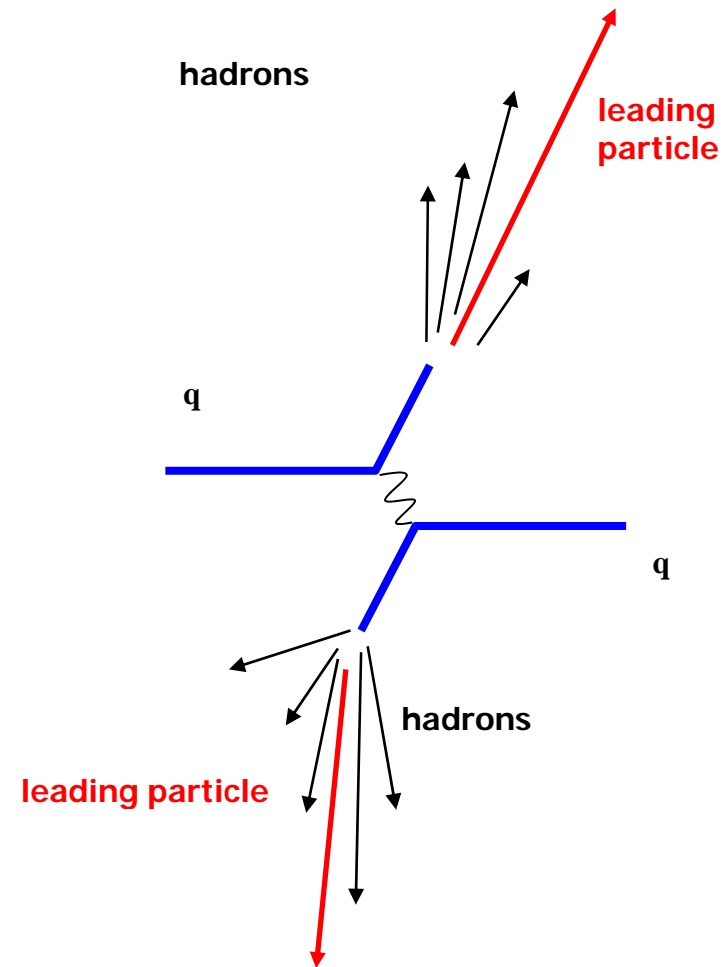
$C_2 \approx$ corrélation

$q_t = p_t$ du gluon

3. aux jets ?



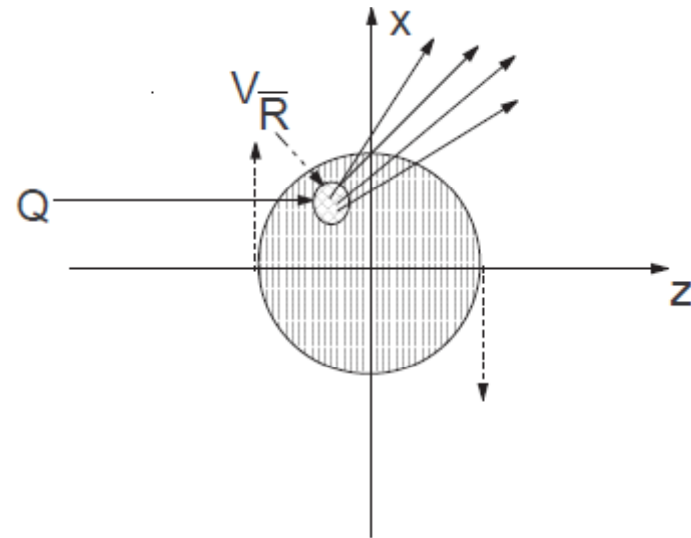
- 5-6 (mini)jets dans les événements p+p de haute multiplicité, c'est nouveau !
- Partons initiaux colorés
- Connectés par des flux de couleur qui produiraient des particules dans leur plan ?
- Événements à trois jets ?
- À suivre...



4. À quoi d'autre ?



- « *We briefly comment on the ridge-like structure origin in the nuclear and hadronic reactions emphasizing that this structure [...] can result from the rotation of the transient state of matter* »



Troshin and Turyin, arXiv:1009.5229

Interprétations du ridge



- Au moins trois effets concurrentiels:
 1. Hydrodynamique, collectivité → Plasma
 2. État initial, saturation → Colour Glass
 3. Jets → Physique p+p standard
- Possible superposition des trois...
 - Beaucoup d'arguments jet+milieu pour RHIC
 - Le flot radial focalise les particules
- Autres observables pour discriminer



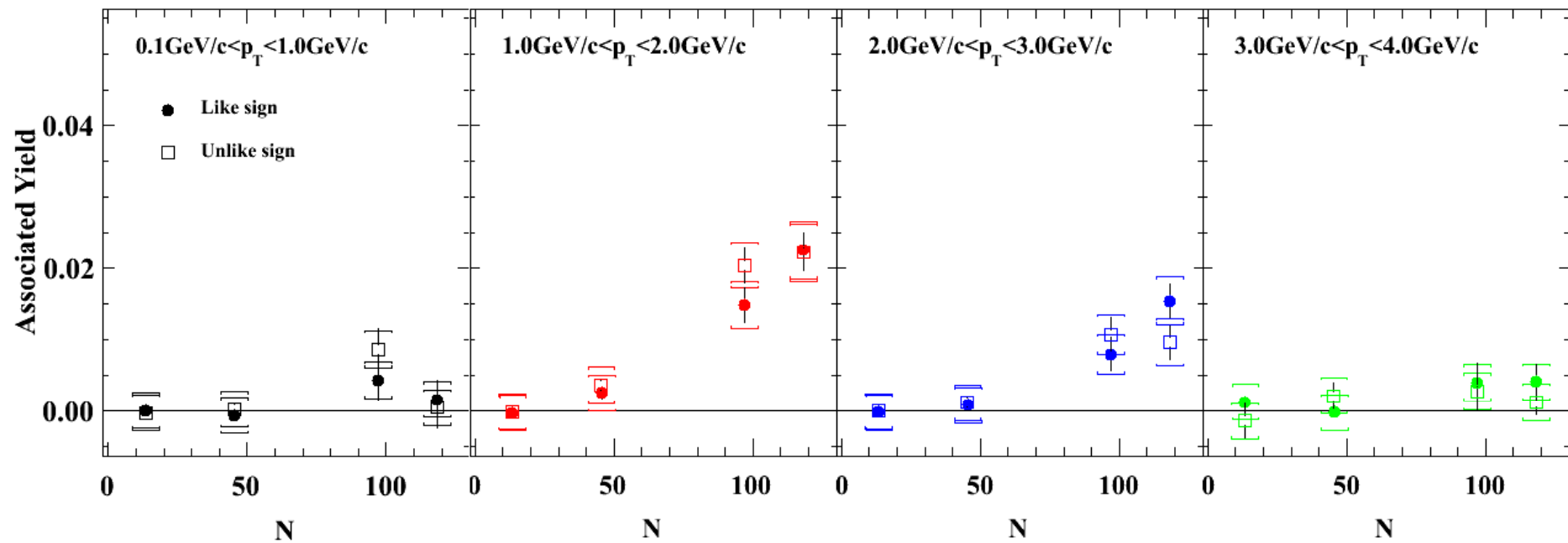
L'a-t-on bien vu ?

QUELQUES VÉRIFICATIONS

Signes identiques et opposés



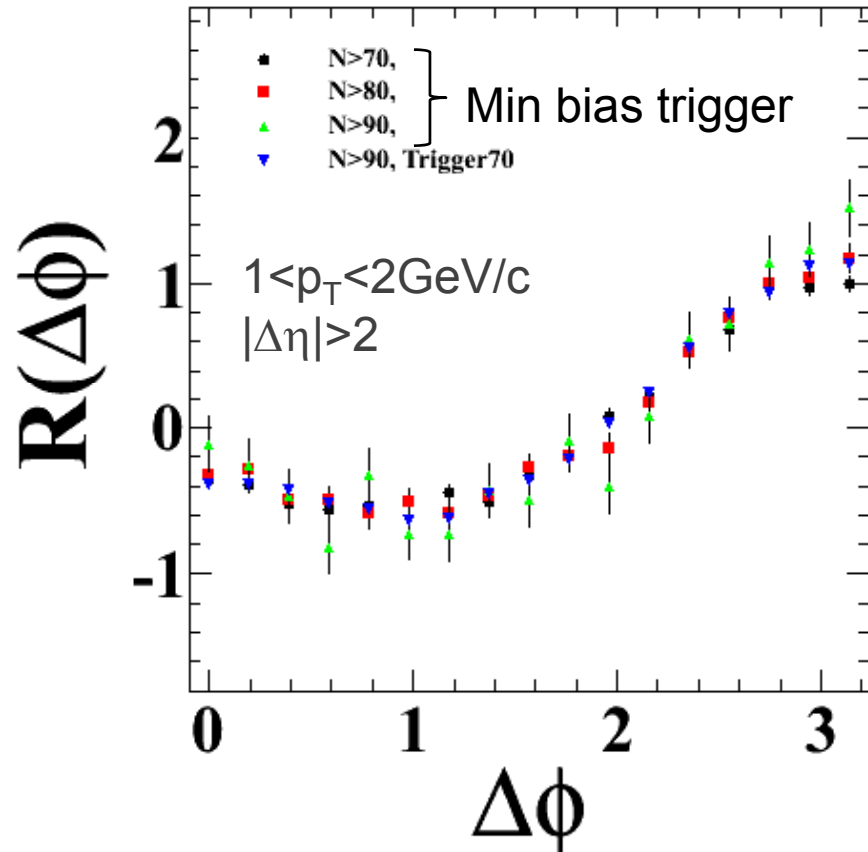
- Pas de différence notable



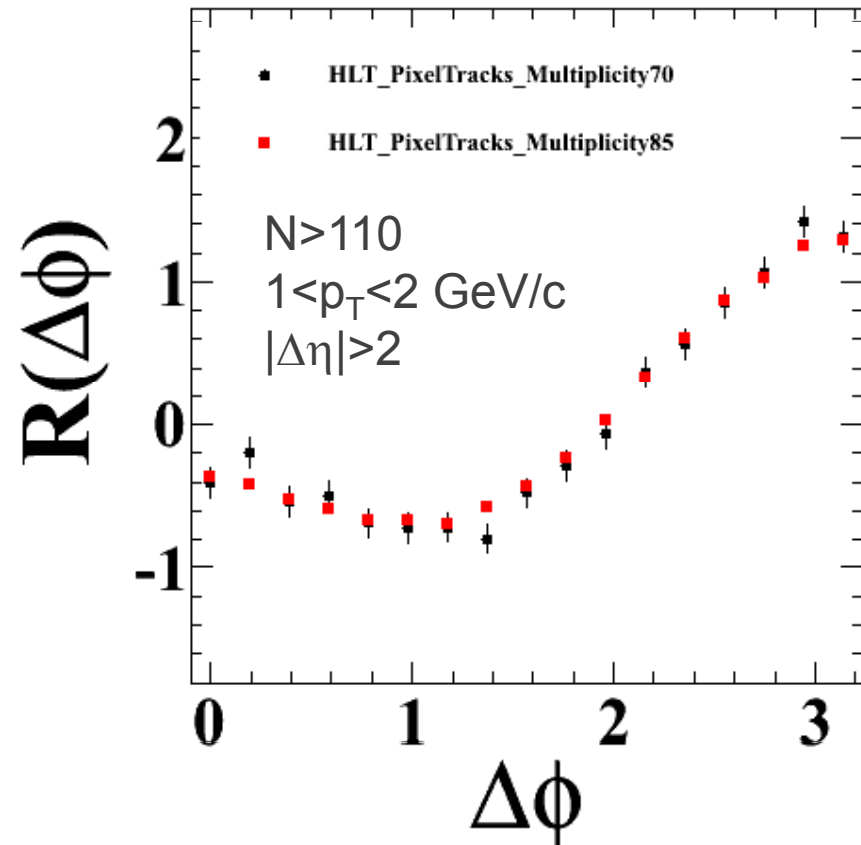
Déclenchements



Biais minimum vs haute multiplicité



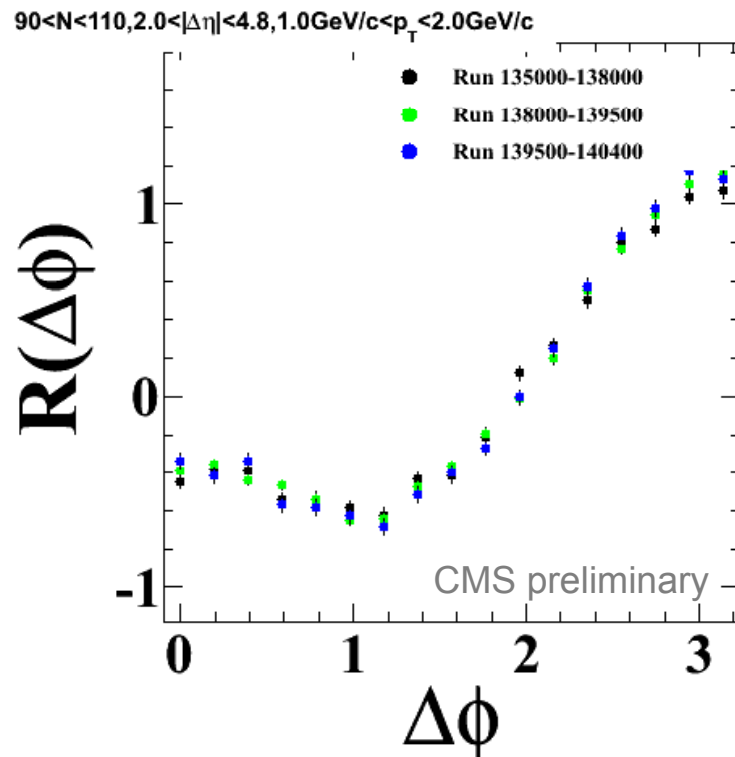
HLT 70 vs HLT 85 pour $N > 110$



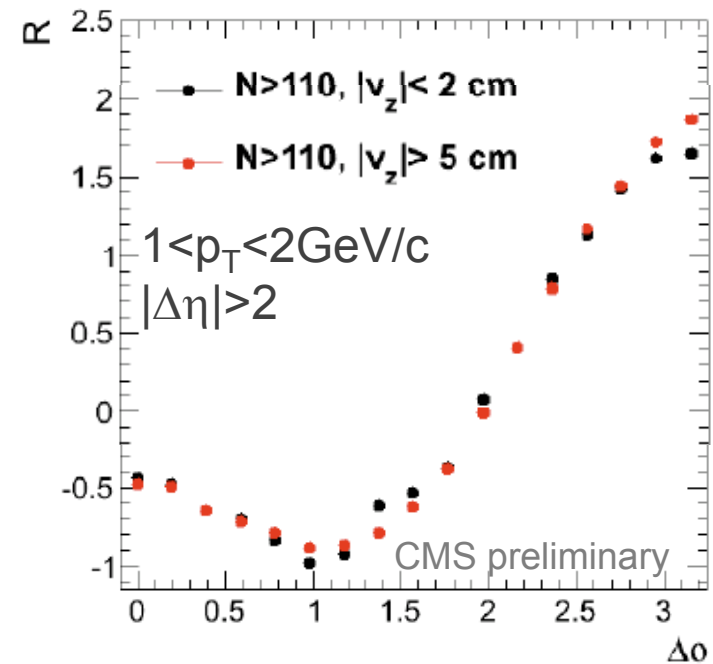
Empilement



Différentes périodes
Empilement varie d'un facteur 4-5



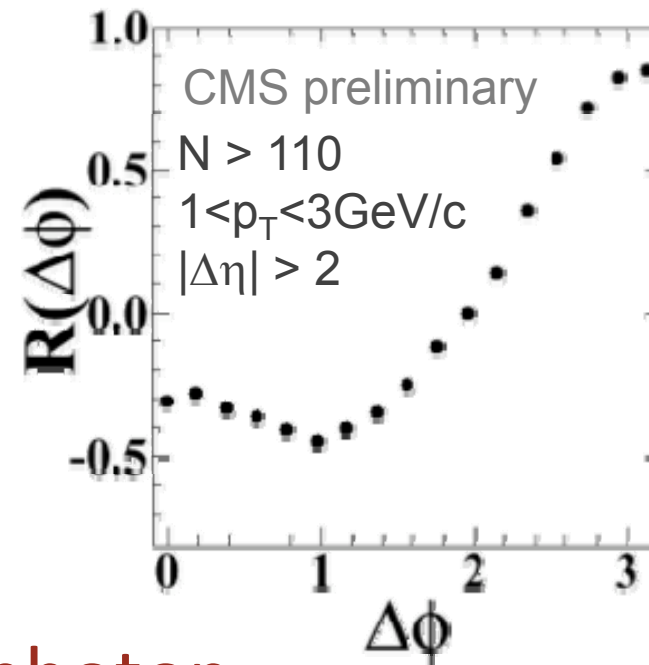
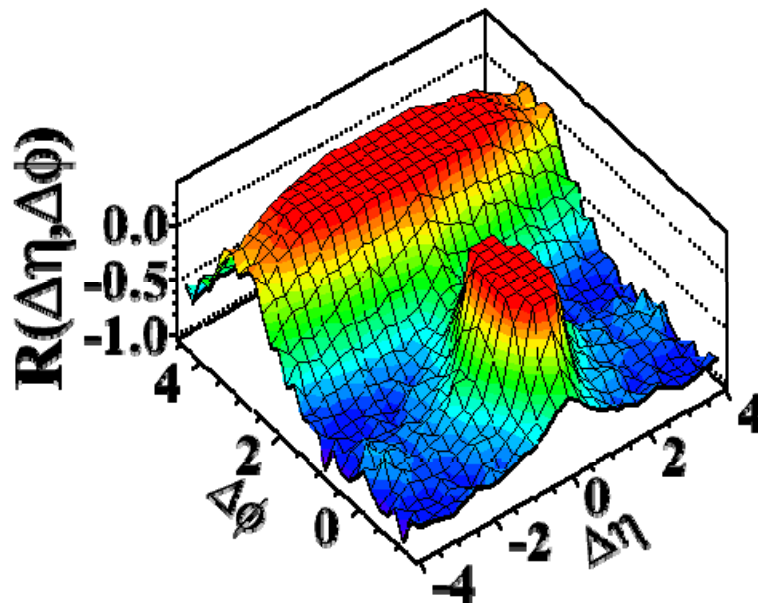
Differentes zones de vertex
(Empilement ~ dN/dvtx_z)



Test ultime : mesure calorimétrique



- Le ridge apparaît aussi avec des « photons » !
 - Cluster Ecal, majoritairement des π^0
 - Préliminaire (pflow, pas d'efficacité, de correction...)



- Également en trace + photon

Nombreuses autres vérifications



- Cf. présentation du CERN pour détails
- (diapositives de secours)

Sources	Syst. on ridge yield
Pileup	15%
HLT efficiency	4-5%
Tracking	1-2%
ZYAM	0.0025



RÉSUMÉ

Résumé



- Phénomène nouveau en collisions p+p @ 7 TeV
- Similaire à celui observé en A+A @ 200 GeV
- L'idée qu'un « plasma » pourrait être créé dans les collisions p+p au LHC est à la mode...
 - Effets collectifs observés à RHIC à des multiplicités équivalentes (Cu+Cu, $N \approx 100$)
- **Vérifions le !**
 - Mesures d'autres observables collectives : flots radial et elliptique, composition (du ridge, baryon/méson, étrangeté...), etc.
 - Études des jets vs multiplicité, etc.

Plasma testable en p+p



Eccentricity fluctuations make flow measurable in high multiplicity p-p collisions

Jorge Casalderrey-Solana¹ and Urs Achim Wiedemann¹

¹ *Physics Department, Theory Unit, CERN, CH-1211 Genève 23, Switzerland*

Elliptic flow is a hallmark of collectivity in hadronic collisions. Its measurement relies on analysis techniques which require high event multiplicity and could be applied so far to heavy ion collisions only. Here, we delineate the conditions under which elliptic flow becomes measurable in the samples of high-multiplicity ($dN_{\text{ch}}/dy \geq 50$) p-p collisions, which will soon be collected at the LHC. We observe that fluctuations in the p-p interaction region can result in a sizable spatial eccentricity even for the most central p-p collisions. Under relatively mild assumptions on the nature of such fluctuations and on the eccentricity scaling of elliptic flow, we find that the resulting elliptic flow signal in high-multiplicity p-p collisions at the LHC becomes measurable with standard techniques.

Wiedemann and Casalderrey-Solana
PRL104 (2010) 102301



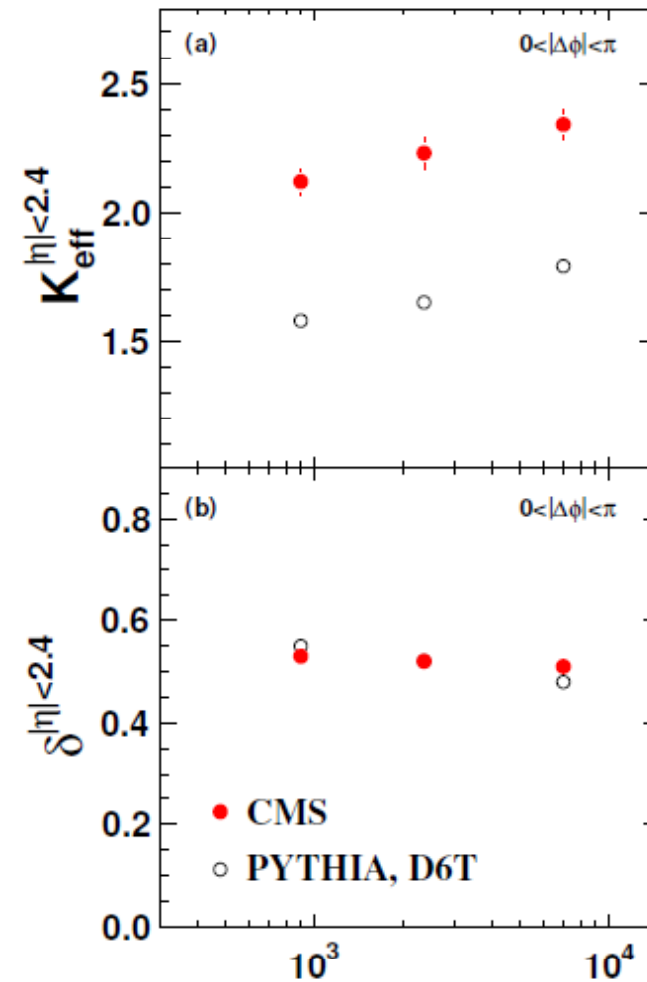
DIAPPOSITIVES DE SECOURS...

Paramétrisation des clusters



$$R(\Delta\eta) = \alpha \left[\frac{\Gamma(\Delta\eta)}{B(\Delta\eta)} - 1 \right]$$

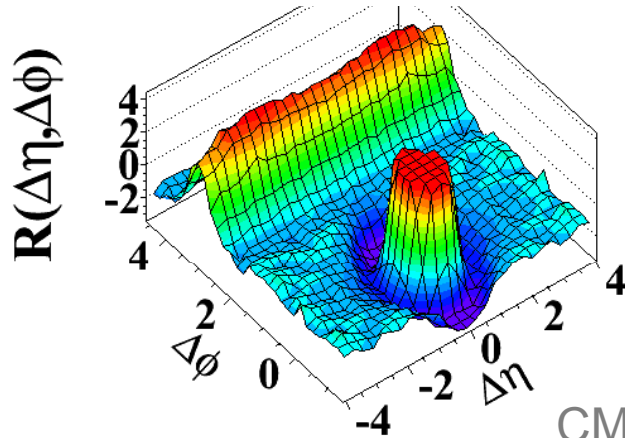
\uparrow
 $\exp [-(\Delta\eta)^2 / (4\delta^2)]$
 \downarrow
 $K_{\text{eff}} = \alpha + 1 :$



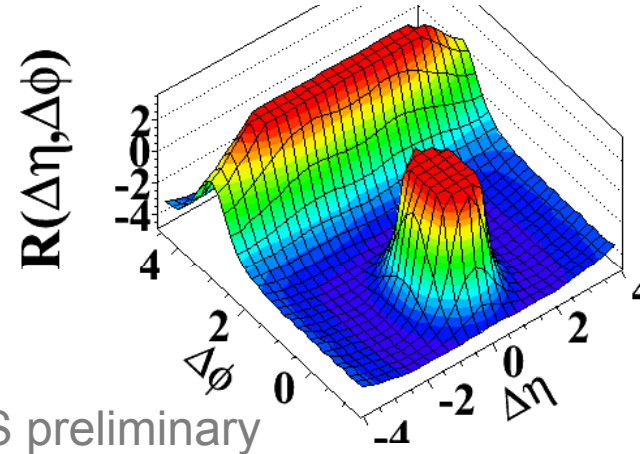
Autres générateurs



PYTHIA D6T MinBias, $N > 70$



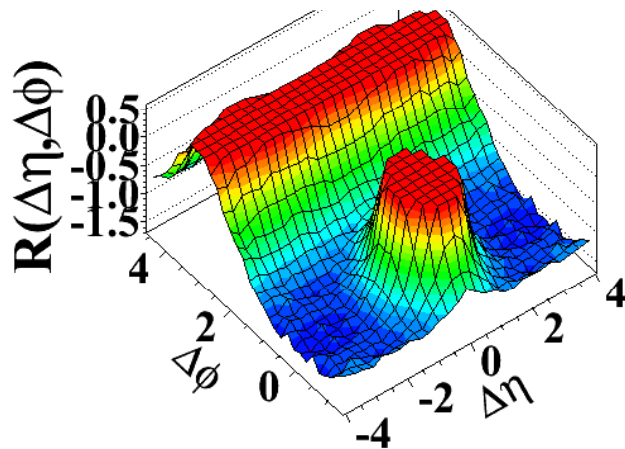
PYTHIA D6T, Dijet 80-120GeV



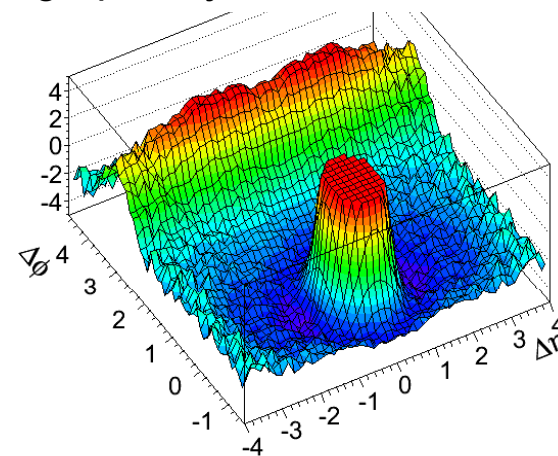
CMS preliminary

$1 < p_T < 3 \text{ GeV}/c$

HERWIG++, $N > 110$



Madgraph, Dijet 100-250GeV, $N > 90$



No ridge effect in these models (with the tunes used)



Indices du QGP



What's the matter at RHIC? - raphael@in2p3.fr 23/04/2009

WHICH SIGNATURES?

- | | | |
|---------------------------|---|------------------------------------|
| 1. Total multiplicity | } | \approx “Color Glass Condensate” |
| 2. High p_T suppression | | \approx “Jet quenching” |
| 3. Back to back jets | | |
| 4. Elliptic flow | | \approx “Perfect fluid” |
| 5. Baryon/meson | | 7. J/ψ suppression |
| 6. Heavy flavour | | 8. Thermal radiation |

But they are not the only ones!

“There was a general feeling that if the quark-gluon plasma was indeed produced, it would manifest itself in a variety of unknown but dramatic ways, including...”

H. Satz @ Lattice 2000 hep-ph/0009099

7



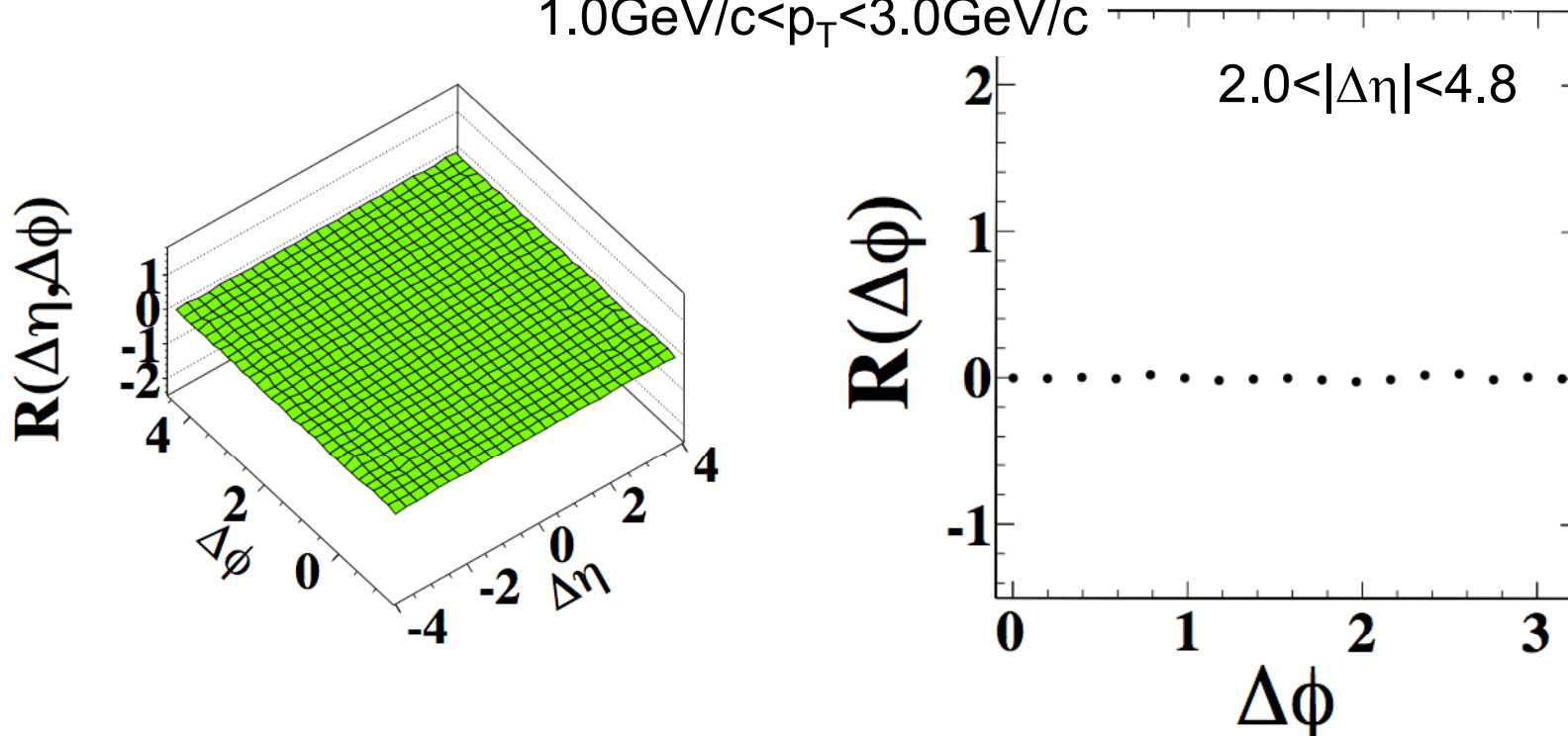
Event Backgrounds



Correlate tracks from high multiplicity vertex with tracks from different collision (vertex) in same bunch crossing

$N > 110$

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



No background or noise effects seen in cross-collision correlations

BSC High Multiplicity Trigger

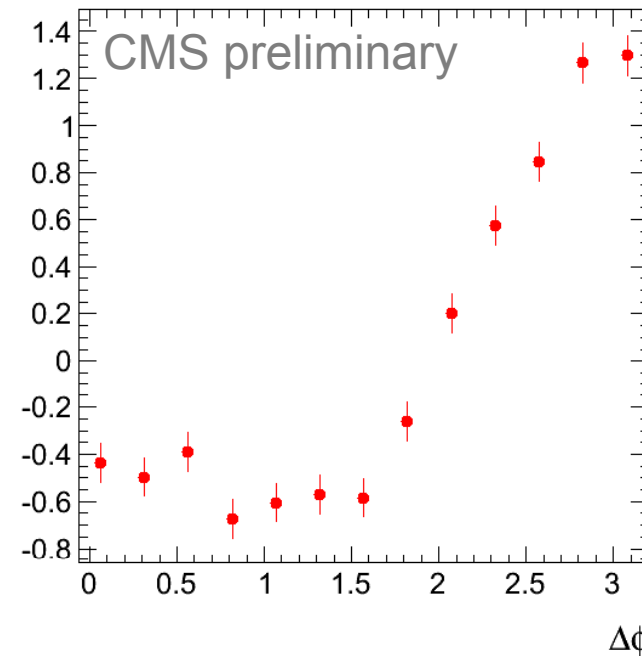
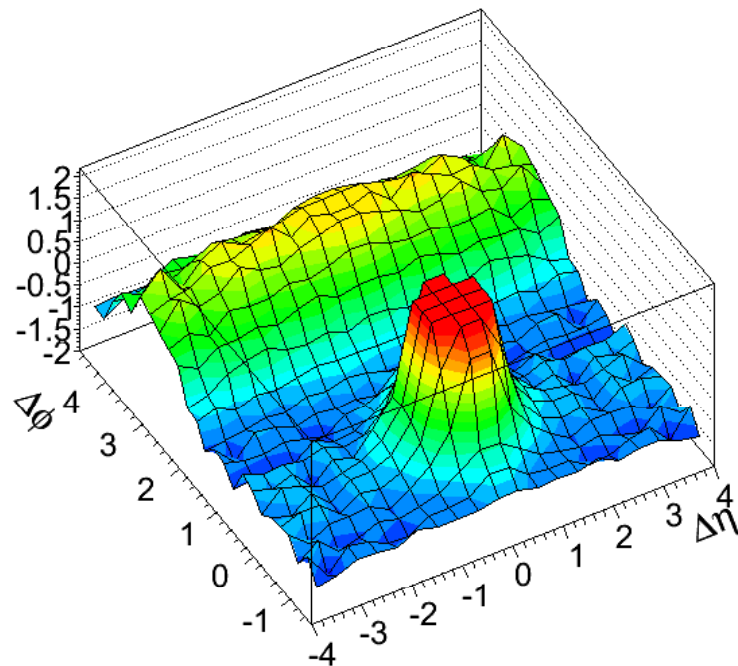


Preliminary results from BSC high multiplicity trigger

$N > 65$

$|\Delta\eta| > 2.0$

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

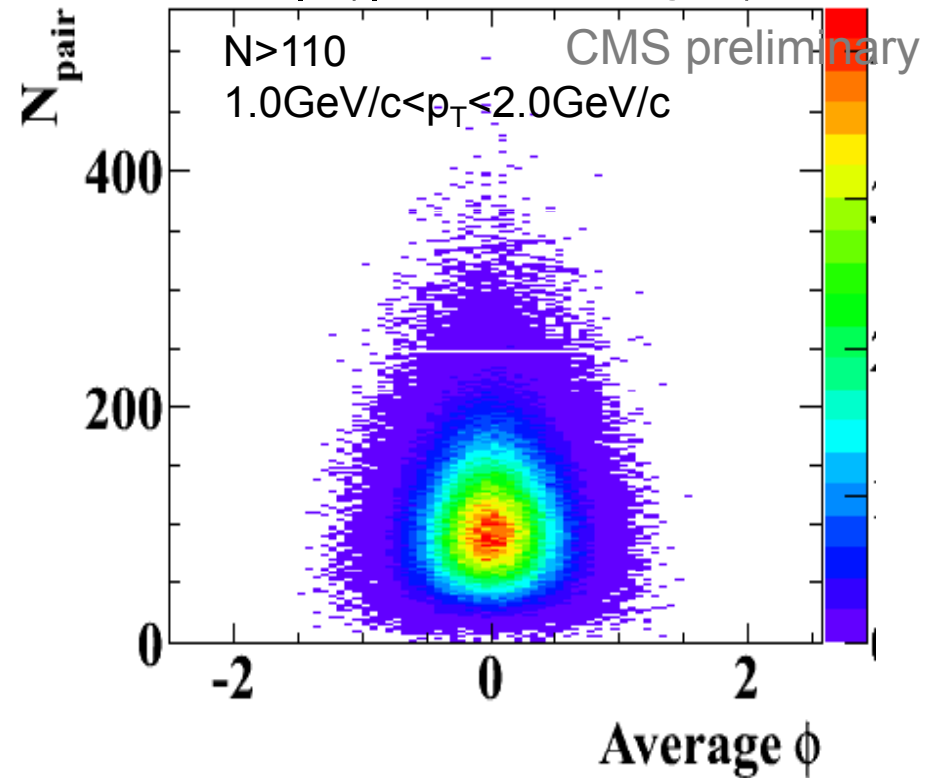


Agreement with standard results within statistical uncertainty



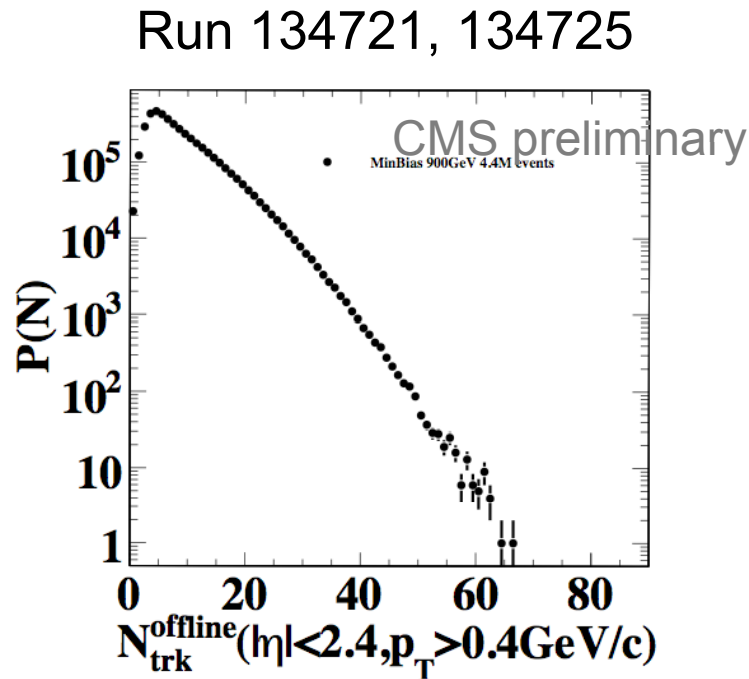
ϕ Symmetry

Pair multiplicity at $|\Delta\eta|>2$
and $|\Delta\phi|<1$ vs average ϕ



No indication of “hot spots” in event-by-event ϕ distribution

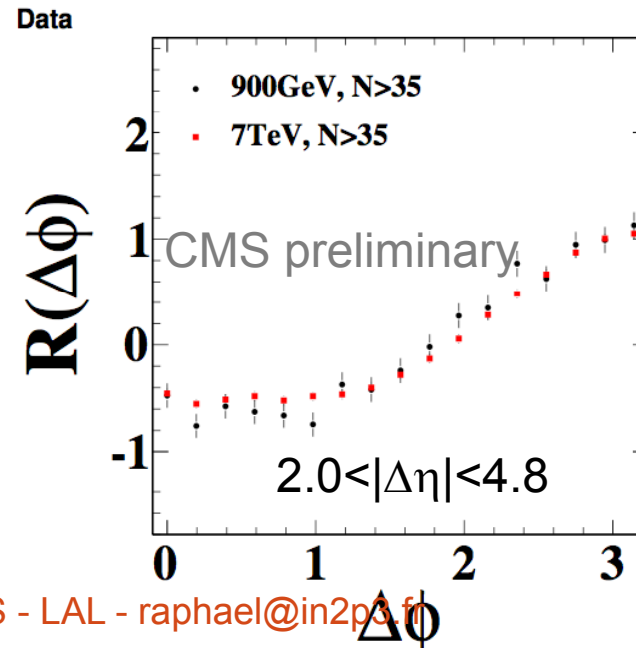
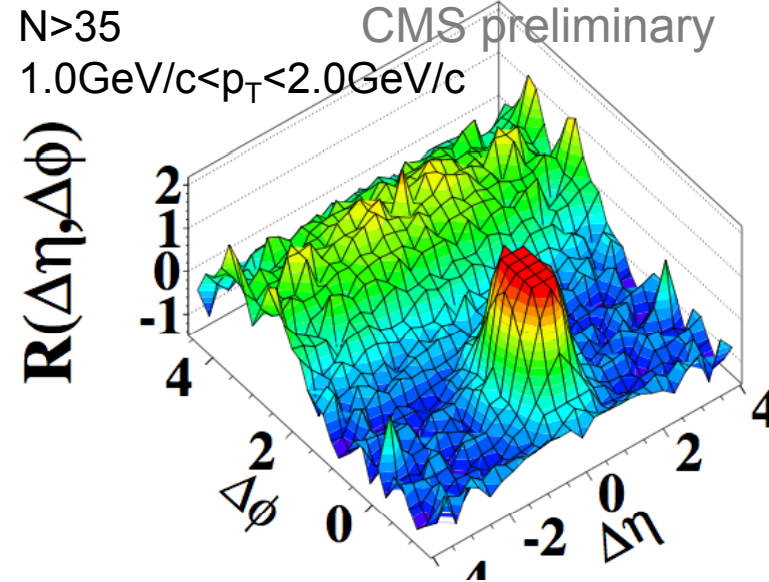
Preliminary 900 GeV Analysis



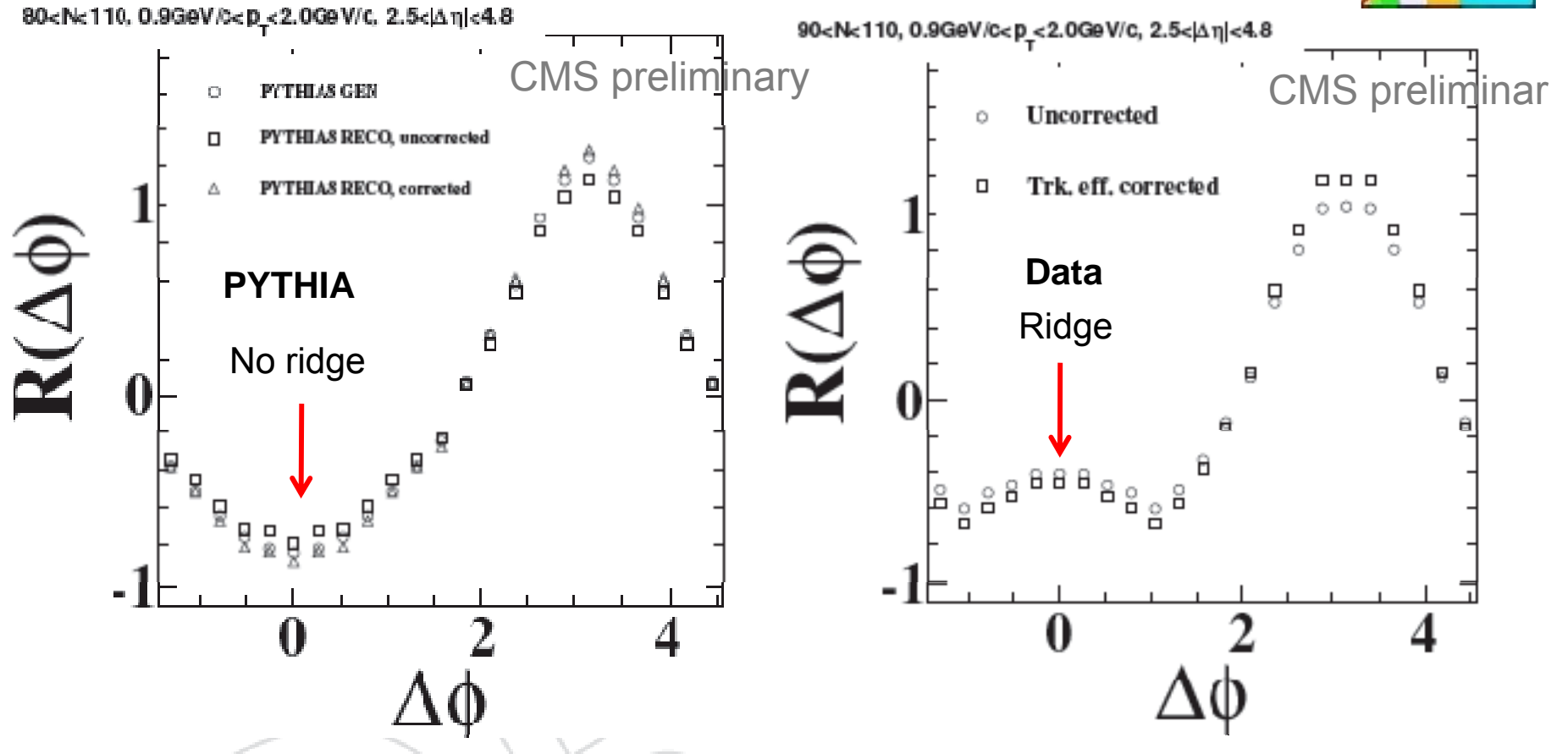
Limited statistics for high multiplicity events in 900GeV

Two energies agree within large uncertainties

27 octobre 2010

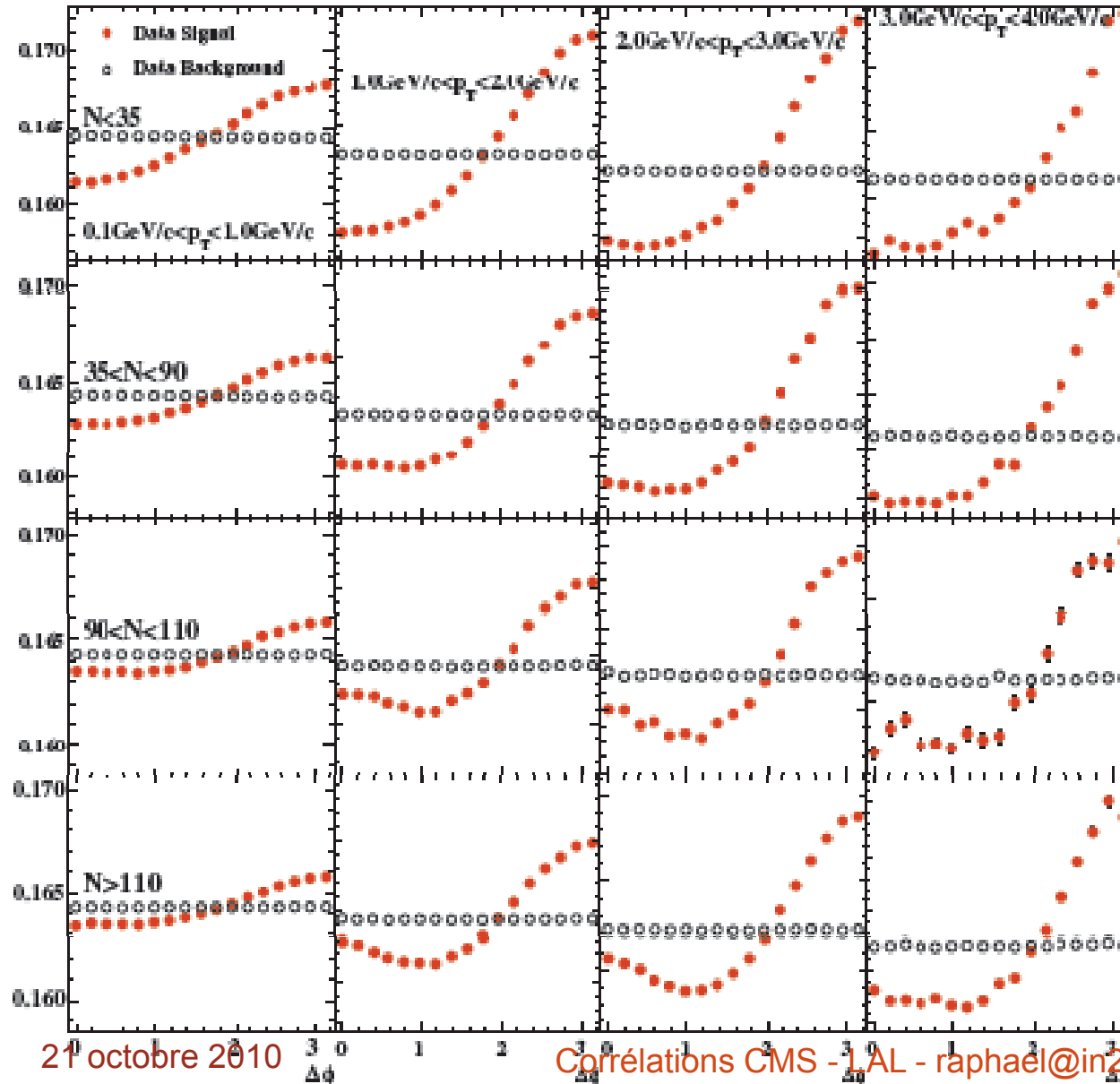


Efficiency Correction



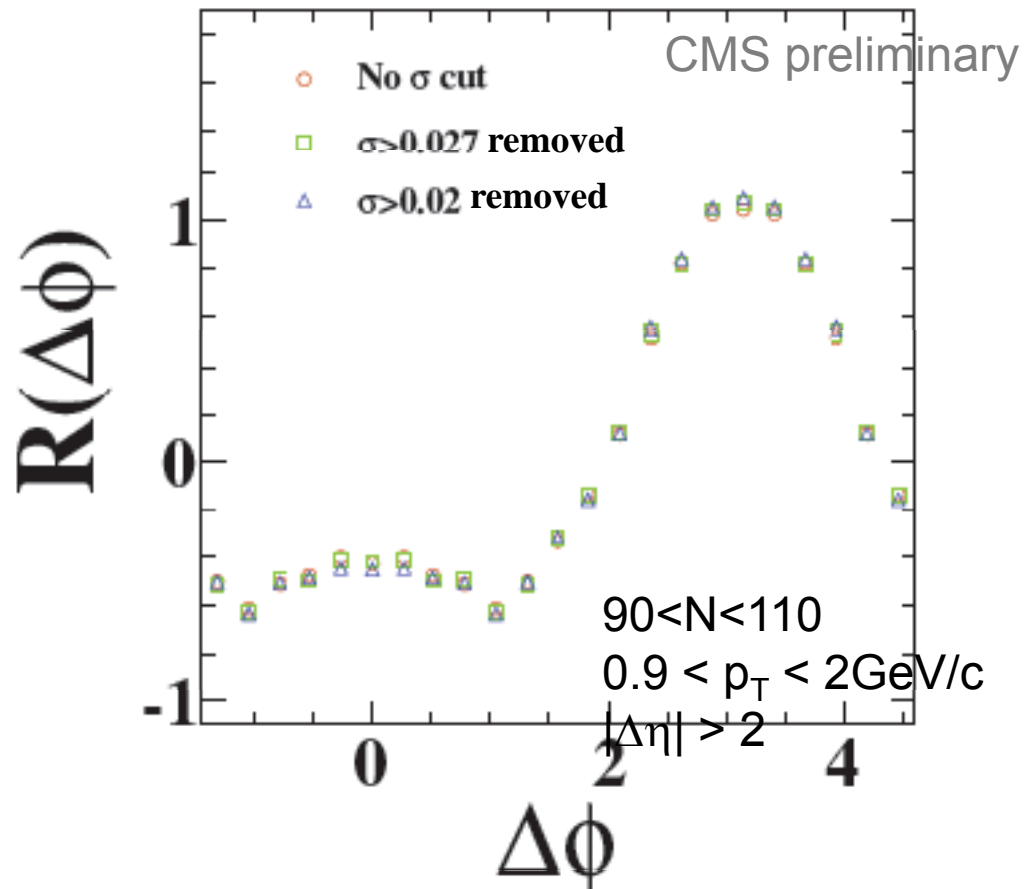
Tracking efficiency correction has small effect on correlation function

Signal and Background

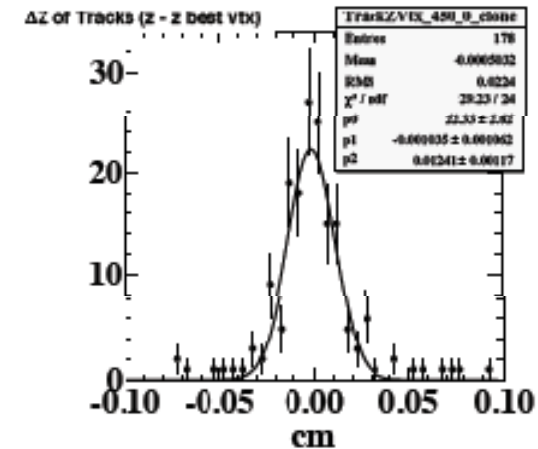


Signal is visible in raw data before dividing by (flat) background

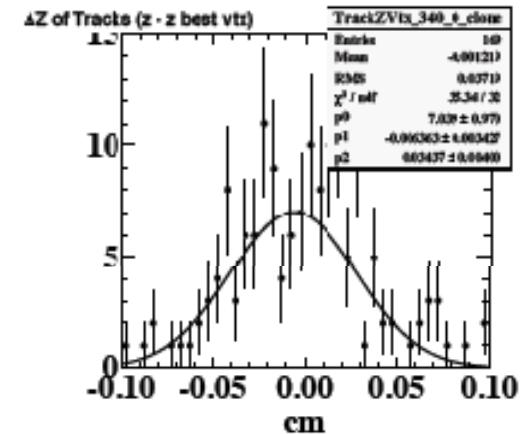
Rejection of “Wide Vertices”



Keep



Remove

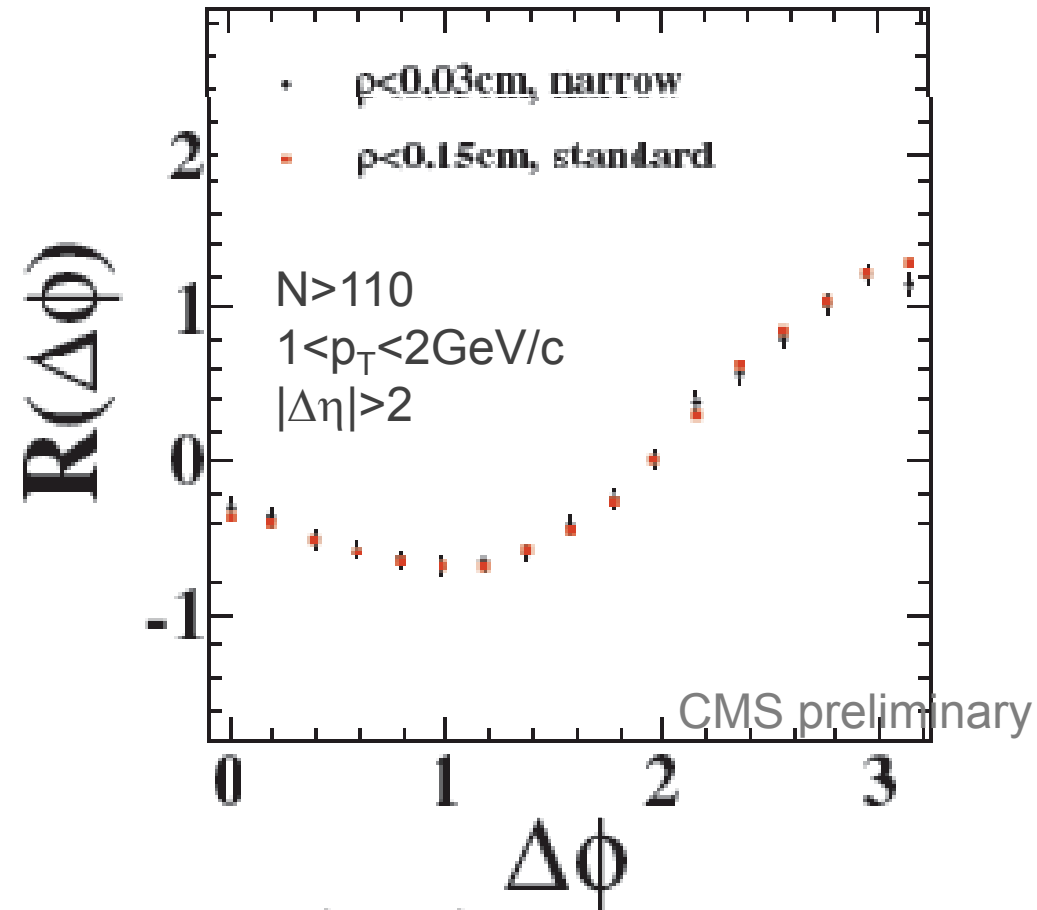


Removing events with “suspicious” vertex distributions does not change result

Select Beamspot “Core”

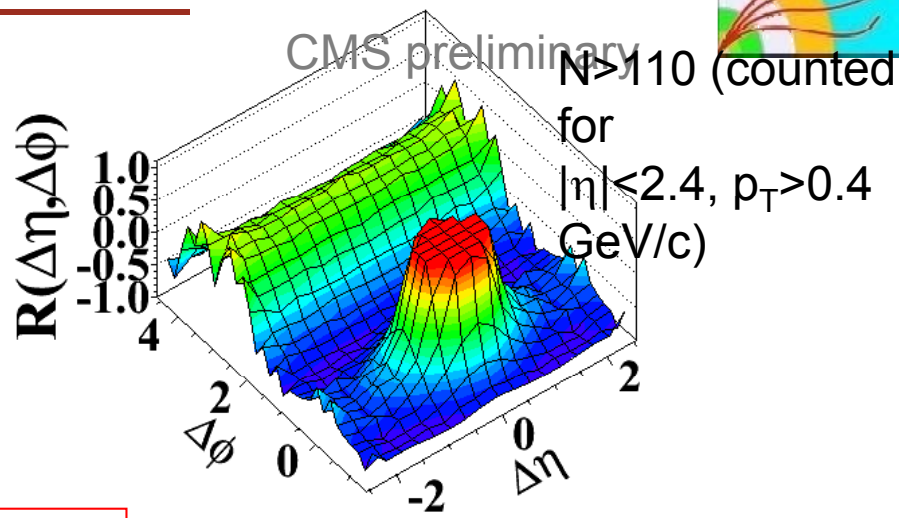
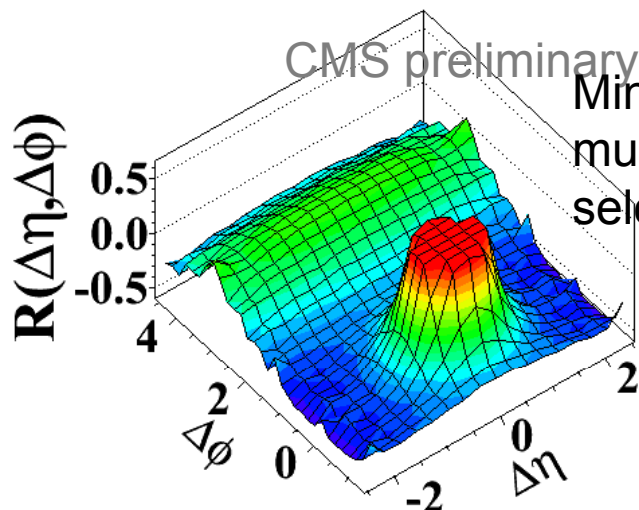


Data

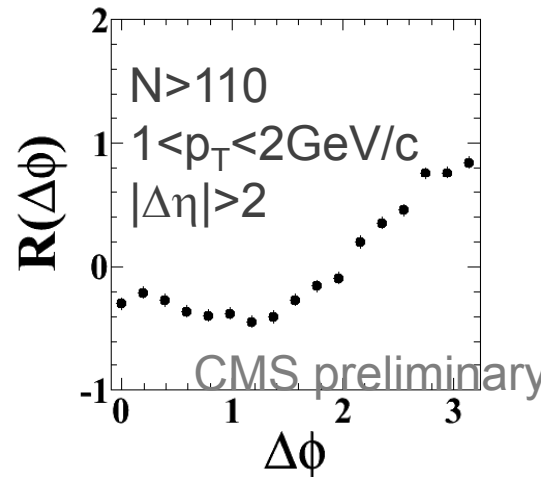
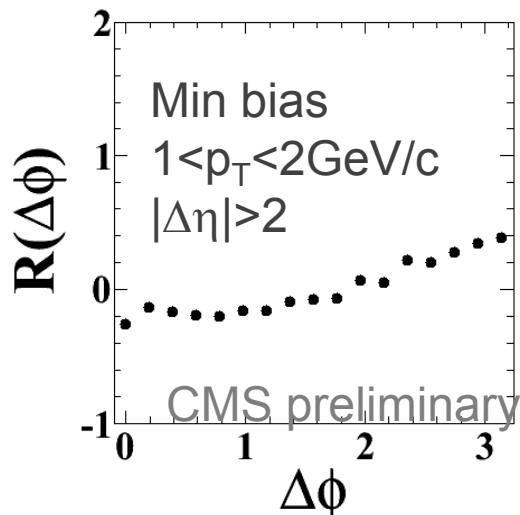


No dependence on radial distance from center of beam

Acceptance Variation



$|\eta| < 1.2$

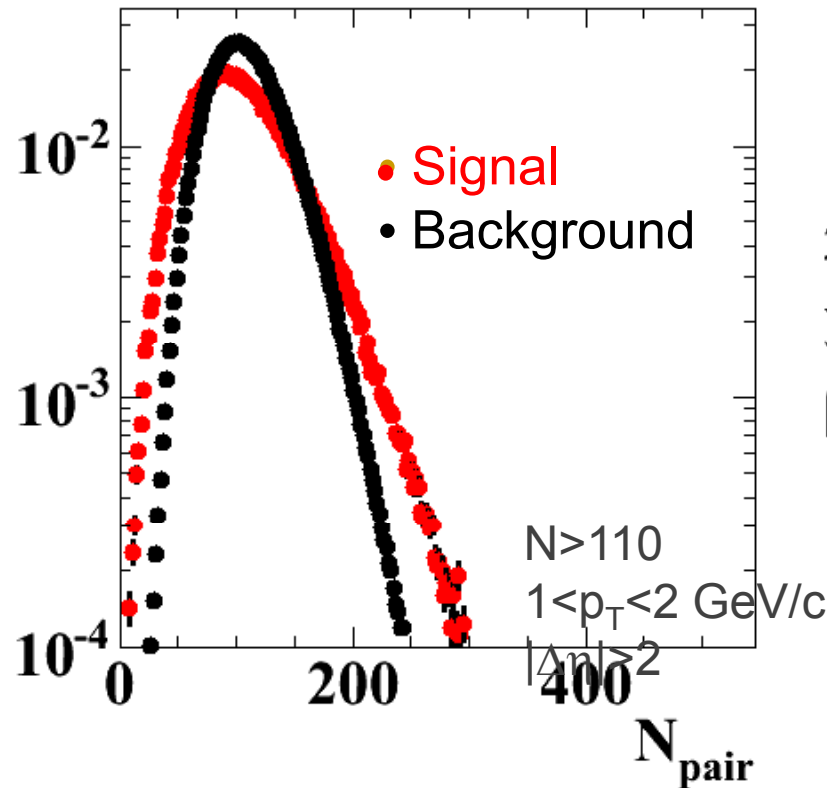


Ridge also seen in reduced acceptance
(but with larger statistical uncertainty)

Detector



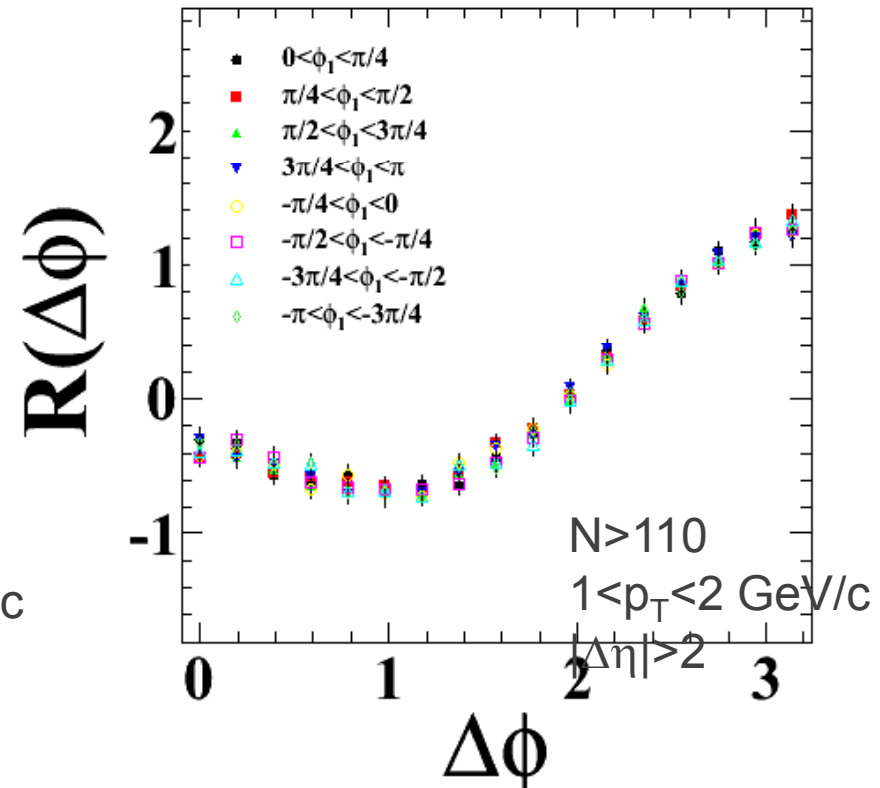
Pair multiplicity distribution
for $|\Delta\eta|>2$ and $|\Delta\phi|<1$



Ridge is not caused by rare events with large # of pairs

Constrain one track to one ϕ octant

Data

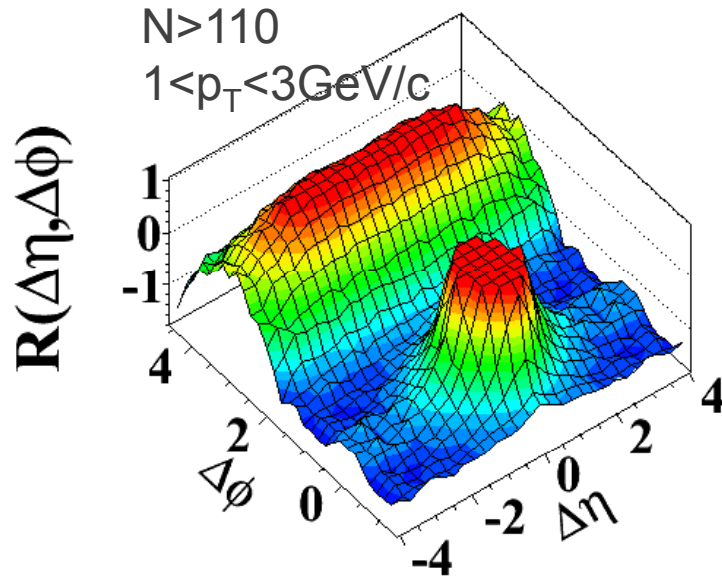


Ridge is ϕ symmetric

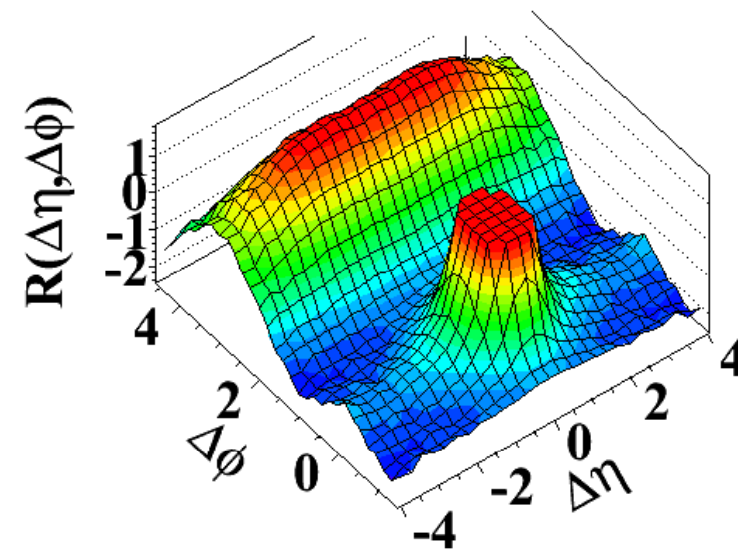
Reconstruction Code



(d) $N > 110$, $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



Pixel-only tracks
3 hits in pixel detector



“HighPurity” tracks
Pixel + Silicon Strip tracker

(Largely) independent code
Independent detectors

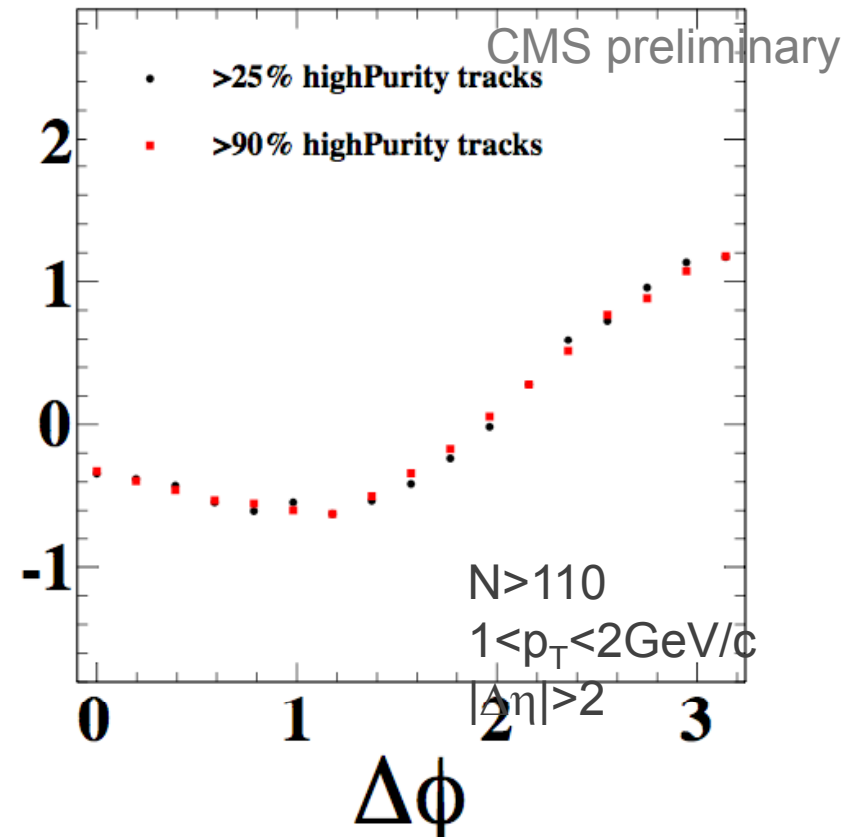
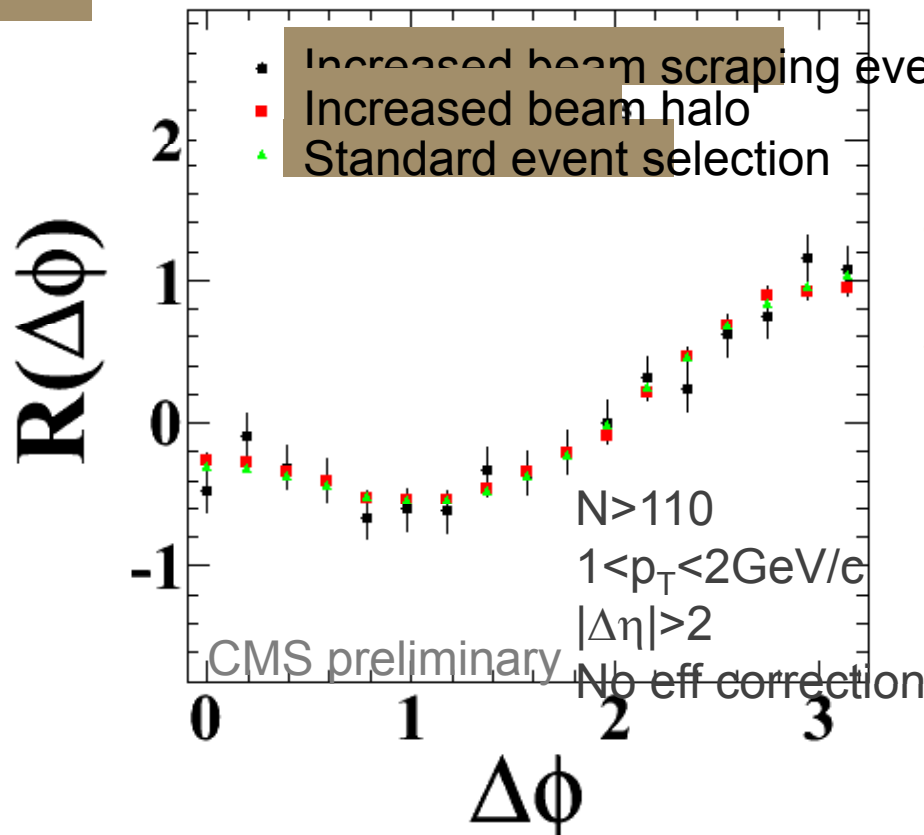
Also: Variation of tracking + vertexing parameters

Event Backgrounds



Select higher fraction of possible beam-gas or beam-scraping events

Reject beam background by veto on fraction of low quality tracks



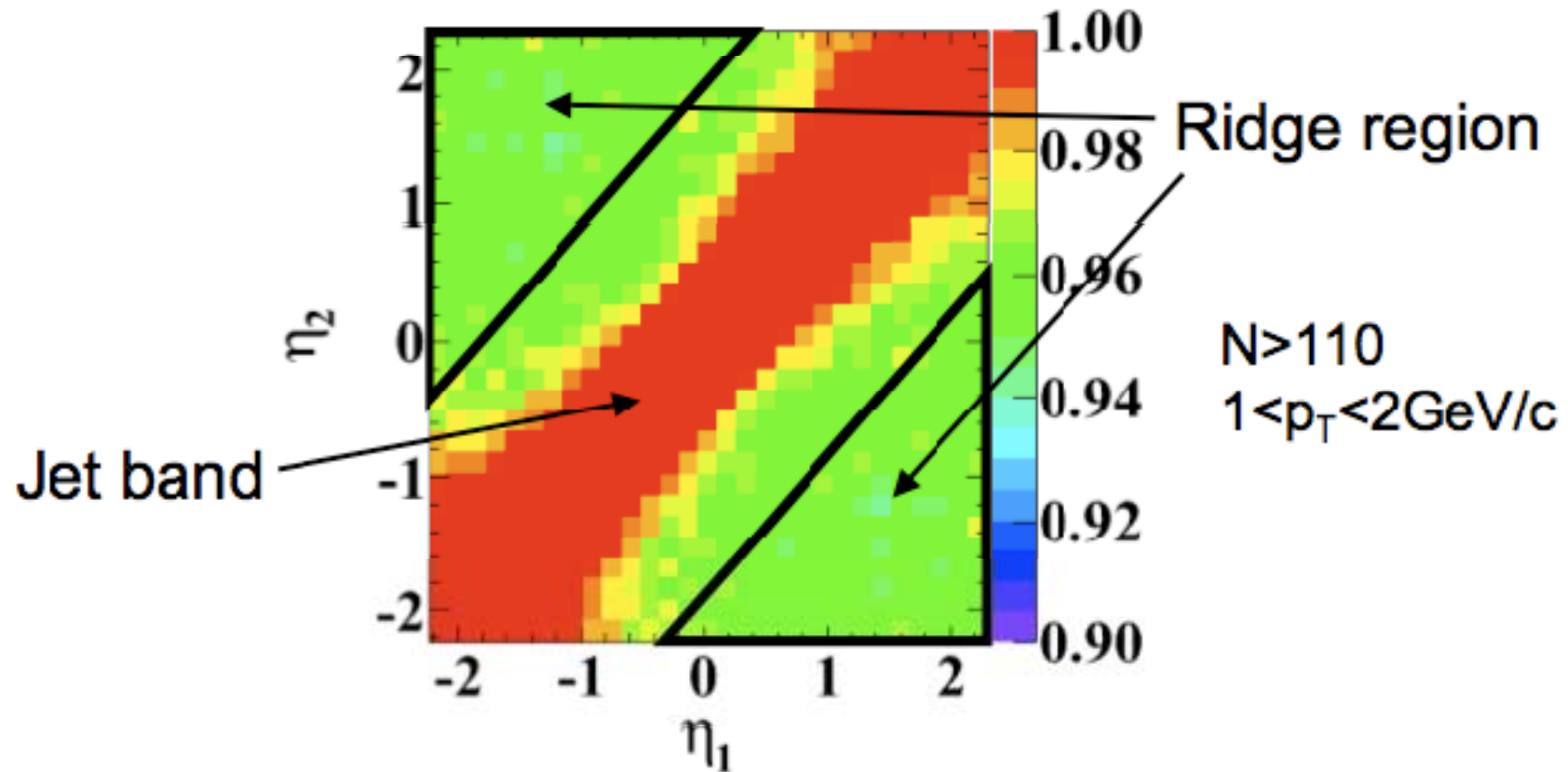
Ridge region shows no sensitivity to beam background

Note: Analysis is done on HighPurity tracks

Detector



η_1 vs η_2 correlations for near-side ($|\Delta\phi| < 1$)

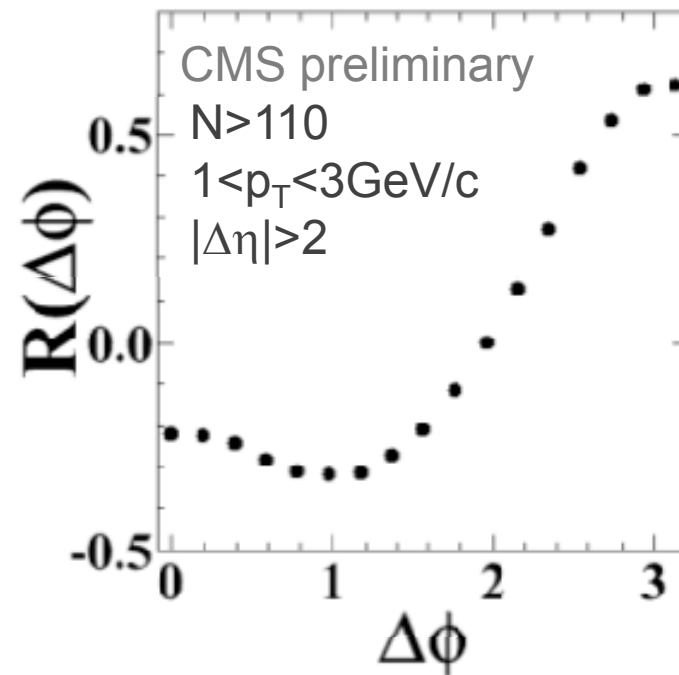
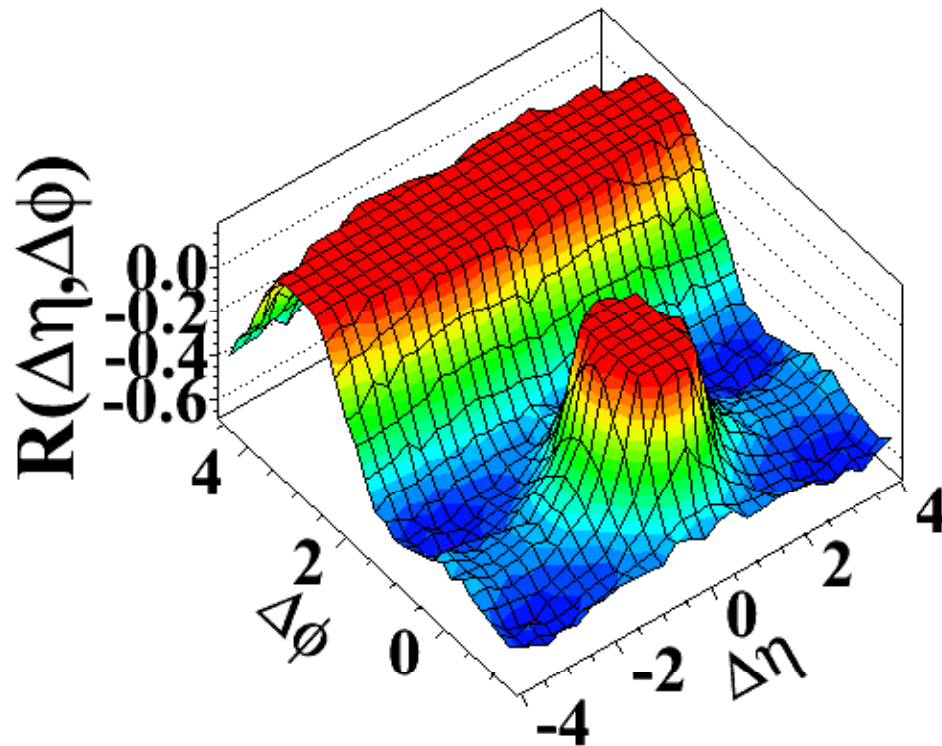


Ridge region shows no structure in η_1 vs η_2

Trace + Photon



- Le ridge apparaît en corrélant avec un photon
 - Préliminaire (pflow, pas d'efficacité, de correction...)



Luminosity and energy



Key Parameters of "Early" Pb Ion Beam (from LHC Design Report)

Parameter	Units	Early Beam	Nominal
Energy per nucleon	TeV	2.76	2.76
Initial ion-ion Luminosity L_0	$\text{cm}^{-2} \text{s}^{-1}$	$\sim 5 \times 10^{25}$	1×10^{27}
No. bunches, k_p		62	592
Minimum bunch spacing	ns	1350	99.8
β^*	m	1.0	0.5 / 0.55
Number of Pb ions/bunch		7×10^7	7×10^7
Transv. norm. RMS emittance	μm	1.5	1.5
Longitudinal emittance	eV s/charge	2.5	2.5
Luminosity half-life (1,2,3 expts.)	h	14, 7.5, 5.5	8, 4.5, 3
		Only possibility for 2009 or early 2010	Goal for 2-3 years (?) beyond

$v_{s_{NN}} \approx 0.4 \times v_{s_{pp}}$
 5.5 TeV nominal
 2.76 TeV for run 1

At full energy, luminosity lifetime is determined mainly by collisions ("burn-off" from ultraperipheral electromagnetic interactions) $\sigma \approx 520$ J.M. Jowett, Chamonix, 2009

Pb+Pb	$v_{s_{NN}}$	Max.	Av.
1st year	2.8 TeV	≈ 150 Hz	≈ 100 Hz
Nominal	5.5 TeV	≈ 8 kHz	≈ 3 kHz

\rightarrow 1st year
 5 to 30 μb^{-1}
 > 40 Mevts

Elliptic flow v_2

$v_2 = \langle \cos 2\phi \rangle$ reflecting pressure gradients in the overlap area
 @ RHIC, close to the hydro limit

- Scaling with constituents x eccentricity x transverse kinetic energy

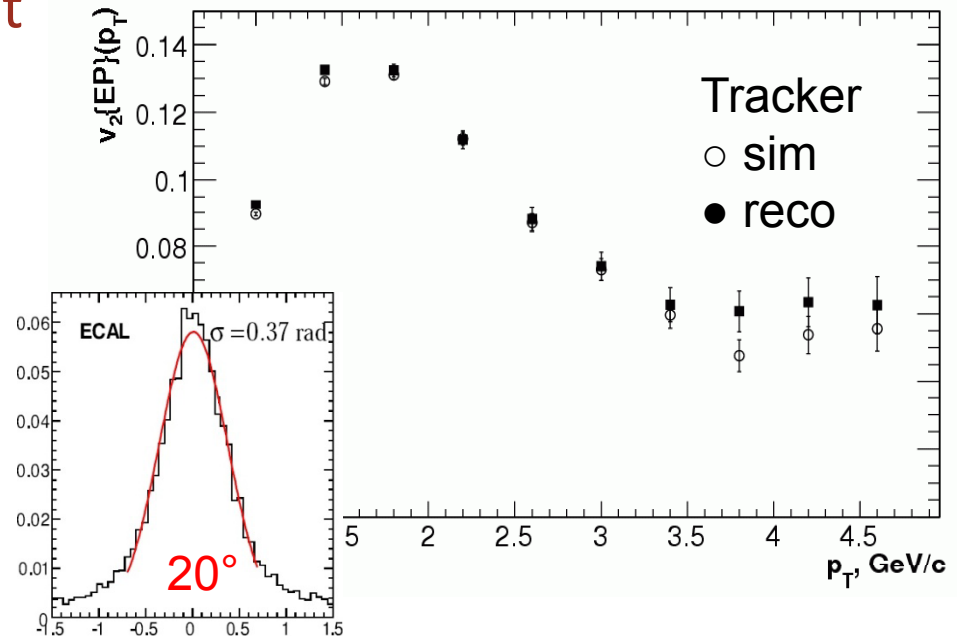
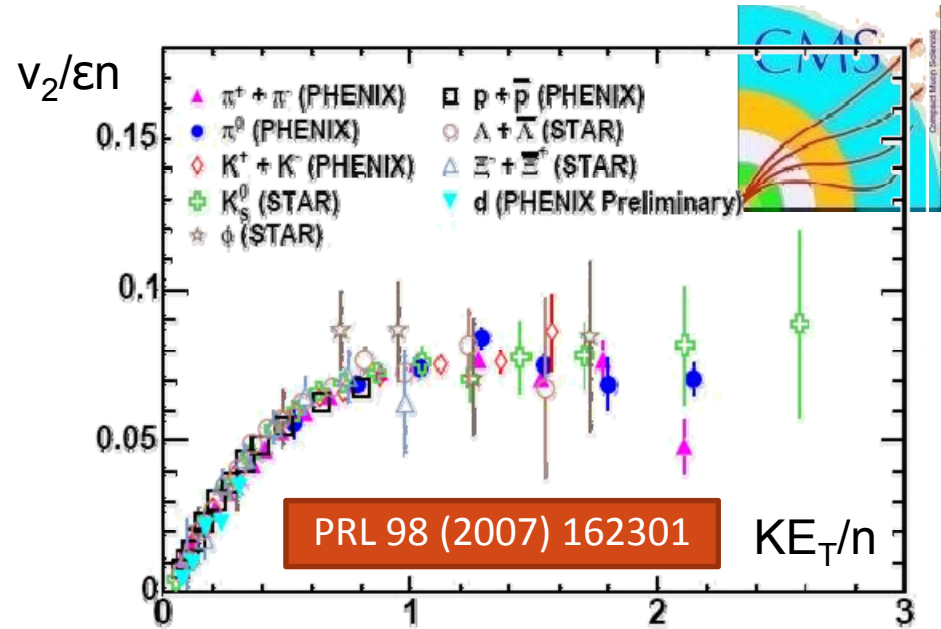
→ « strongly interacting, perfect liquid » sQGP @ RHIC

→ wQGP, gaz @ LHC ?

@ CMS, reaction plane can be measure in ECAL

- $\sigma = 20^\circ$ @ $b = 9$ fm
- $(dN_{ch}/d\eta = 3000)$

- But also in tracker, or forward detectors...



Two hadrons correlations



- Another look at jet quenching :
 - Back to back suppression ($\Delta\phi = \pi$)
 - (after v_2 subtraction)
- A large zoology à RHIC: *near side*, *away side*, *ridge*, *mach cones*, etc.
- In CMS, first run: at least up to $p_T = 20$ GeV/c for the reference particle (*trigger*)

