Obtaining the CMS Ridge with Multiple Partonic Interactions

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Pierre Van Mechelen and
Sara Alderweireldt

Universiteit Antwerpen

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Outline

- Introduction
  - Existing tunes used in this study
  - The CMS ridge effect
- Using Multiple Partonic interactions to describe the CMS ridge effect
  - Aligning the collision plane of individual MPIs to the event plane
  - Modification of PYTHIA6
- Tuning
  - Tuning strategy
  - Case one: using a limited set of tuning observables to understand effects
  - Case two: two-step tune using more CMS minimum bias and underlying event data
- Results on two-particle angular correlations
  - Reminder: the ridge effect in CMS data
  - The ridge effect with modified PYTHIA6
- Conclusions

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Disclaimer

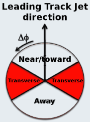
- Only a limited set of CMS data was used
- All tuning activity was based on the Z2 tune for PYTHIA6
- More global tuning including other experiments' data was not within the scope of this study, but may be added later

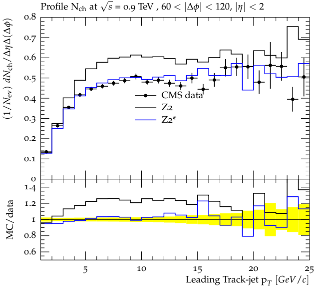
Tunes with PYTHIA6

- Z1 tune: PROFESSOR tunes to ATLAS minimum bias (MB) data, manually retuned multiple interaction parameters to CMS data (R. Field)
- Z2 tune: Manual retune of Z1 with CTEQ6L (R. Field)
- Z2* tune: PROFESSOR retune of Z2 to CMS underlying event (UE) data (A. Knutsson)

Performance

- Z2,Z2* describe increasingly well the CMS UE data
- Looking at multiplicity distributions in CMS MB data, there is room for improvement





(a) Transverse charged multiplicity vs. leading jet-p_T

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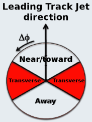
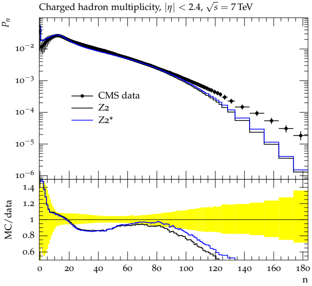




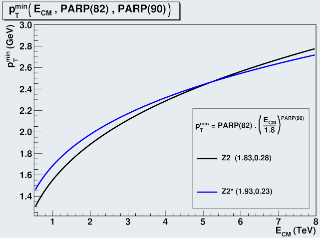
(b) Total charged multiplicity ($|\eta| < 2.4$)

Important parameters: effect of the p_T-cutoff

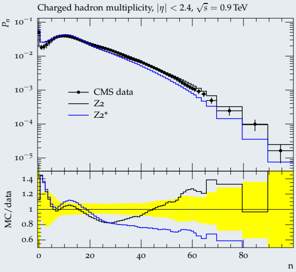
- p_T^{min}: lower cutoff for which MPIs are generated (lower = more MPI activity)

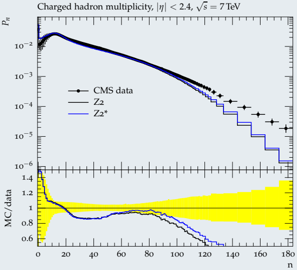
$$p_T^{min}(E_{CM}) = PARP(82) \cdot \left(\frac{E_{CM}}{E_{REF}}\right)^{PARP(90)}$$

- PARP(82): p_T^0 cutoff
- PARP(90): energy dependence



- 0.9 TeV:
  - Z2 lowest p_T^{min} = highest activity
  - Z2* highest p_T^{min} = lowest activity
- 7.0 TeV:
  - Z2 highest p_T^{min} = lowest activity
  - Z2* lowest p_T^{min} = highest activity



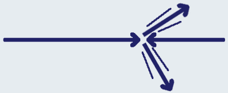


Reminder on the CMS ridge effect

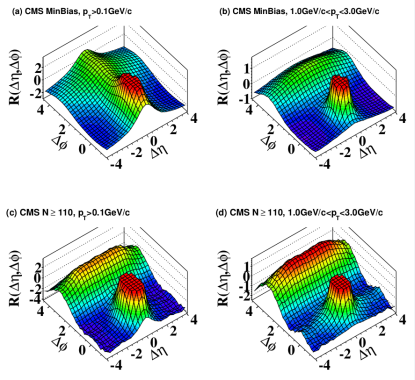
- Correlation function $R(\Delta\eta, \Delta\phi)$:
  - data binned $\sim$ track multiplicity
  - per bin:
    - signal: charged two-particle density
    - background: distribution of uncorrelated particle pairs = product of two single-particle distributions
  - $R(\Delta\eta, \Delta\phi)$: averaging $\left(\frac{S}{B} - 1\right)$, weighted with bin multiplicity, over all bins

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

- Effects explained by a single 2$\rightarrow$ 2 partonic interaction:
- Effects requiring a different explanation:



(a) 2$\longrightarrow$2 partonic interaction



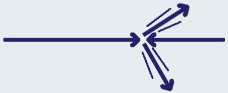
(b) 2-particle correlation functions for 7 TeV pp (arXiv:1009.4122v1, 21 Sep 2010)

Reminder on the CMS ridge effect

- Correlation function $R(\Delta\eta, \Delta\phi)$:

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

- Effects explained by a single 2$\longrightarrow$ 2 partonic interaction:
  - near-side peak at $(\Delta\eta, \Delta\phi) = (0, 0)$:
    - jets, clustered in η and ϕ
  - away-side ridge at $(\Delta\eta, \Delta\phi) = (\Delta\eta, \pi)$:
    - away-side jets, back-to-back in ϕ
    - incoming p = variable $\longrightarrow$ broad in $\Delta\eta$
  - Gaussian ridge at $(\Delta\eta, \Delta\phi) = (0, \Delta\phi)$:
    - decay of lower-p_T clusters
    - $\longrightarrow$ spreading out in $\Delta\eta$
- Effects requiring a different explanation:
  - near-side ridge at $(\Delta\eta, \Delta\phi) = (\Delta\eta, 0)$:
    - in high multiplicity events
    - at moderate p_T: $1 < p_T < 3$ GeV
    - not predicted by any Monte Carlo



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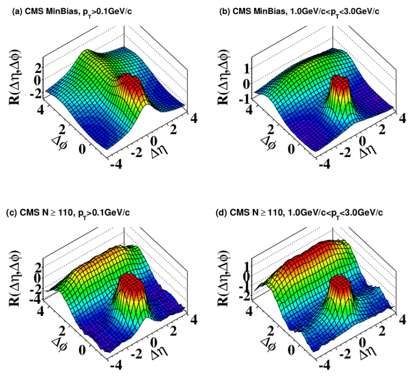
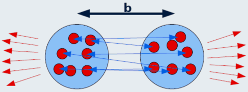


(b) 2-particle correlation functions for 7 TeV pp (arXiv:1009.4122v1, 21 Sep 2010)

Can multiple partonic interactions explain the ridge effect? (1)

- MPIs tend to lie in the 'collision plane' of the hardest interaction
  - $\longrightarrow$ for large enough impact parameter b
  - $\longrightarrow$ final state particles will have similar azimuthal angle ϕ
- Explanation with MPIs would require many MPIs:
  - $\longrightarrow$ we're discussing high-multiplicity events
- MPIs are semi-hard:
  - $\longrightarrow$ we're discussing moderate-p_T particles
- MPIs are spread in pseudo-rapidity η since incoming partons have different x_{bj}:
  - $\longrightarrow$ we're discussing long-range correlations

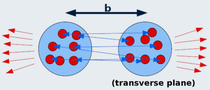


$\longrightarrow$ All that matches with the observations by CMS

Still a problem

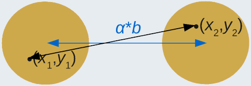
- High-multiplicity events are generally central collisions:
  - $\longrightarrow$ impact parameter $b \sim 0$, while definition of 'collision plane' needs large b
  - $\longrightarrow$ possibly a small upward fluctuation in #MPI for moderate impact parameter suffices to explain the CMS ridge effect

Can multiple partonic interactions explain the ridge effect? (2)



- Currently in PYTHIA 6.425:
  - → #MPI ∼ activity ∼ 1/impact parameter b (parameter b rescaled to $b_{avg} = 1$ for MB)
  - → azimuthal angle ϕ = random
  - → With the random azimuthal angle, long-range near-side angular correlations would be missing in PYTHIA6
- Proposed modification:

$$\phi_i = \phi_{hardest} + \arctan\left(\frac{y_2 - y_1}{(x_2 + \alpha \cdot b/b_{avg}) - x_1}\right)$$



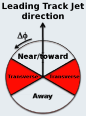
- sample random points (x_i, y_i) in Gaussian proton profiles
- separate protons by impact parameter b, with scalable unit α/b_{avg} (α introduced to allow some tuning freedom, ideally $\alpha = 1$)(b = VINT(139))
- calculate ϕ-offset from hardest interaction

- the modification is implemented for two different settings of the new MPI model in PYTHIA6 (set by MSTP(82)): options 4 and 5 both use hadronic overlap according to Gaussian distributions, in which case the above ϕ-definition makes sense

Implications of the modification

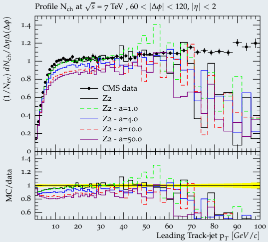
Original situation:

- activity $\sim$ #MPI $\sim$ 1/impact parameter
- typical underlying event (UE) tunes use activity transverse to a jet: $N_{transverse}$
- minimum bias (MB) plots are integrated over azimuth $\Delta\phi$



Modified situation:

- MPIs get shifted to toward/away regions: plateau for $N_{transverse}$ drops
- re-raising plateau to describe data requires retune
- important parameters include PARP(82) and PARP(90), describing the p_T-cutoff and thus the activity ($N_{transverse}$)
- minimum bias plots are integrated over azimuth $\Delta\phi$ $\rightarrow$ not sensitive to modification
- existing tension between UE and MB $\rightarrow$ released by modification?

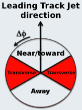


Conclusion:

- If the modification desccribes a real effect, existing tunes should be wrong?

Illustration of the effects

- PARP(82) & PARP(90) affect all activity:
- Modification with α-parameter affects the transverse activity, but not the total:



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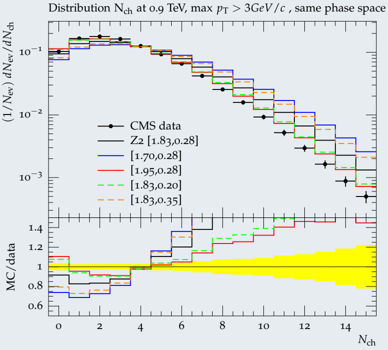
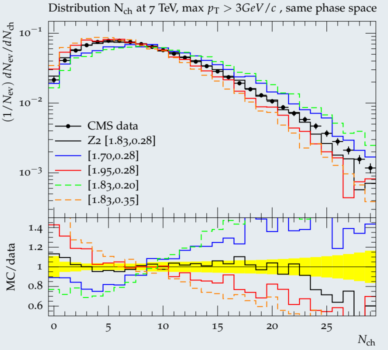


(a) 0.9 TeV: both parameters affect transverse activity



(b) 7.0 TeV: both parameters affect transverse activity

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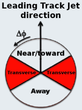
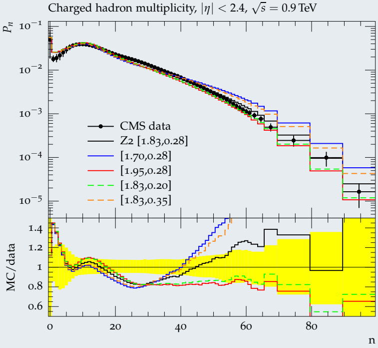
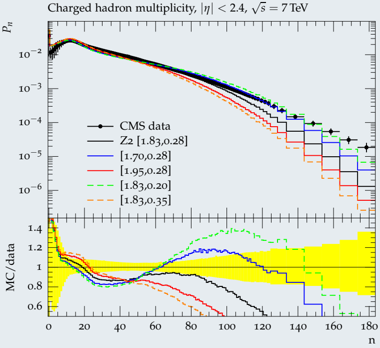


TOTAL



(c) 0.9 TeV: both parameters affect total activity



(d) 7.0 TeV: both parameters affect total activity

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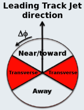

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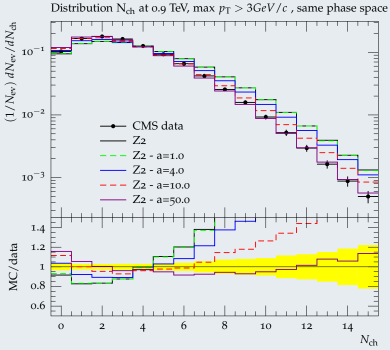
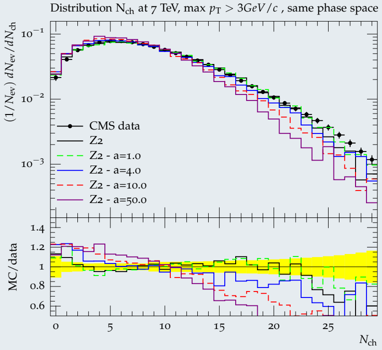


(e) 0.9 TeV: higher α = lower transverse activity



(f) 7.0 TeV: higher α = lower transverse activity

Illustration of the effects

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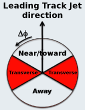
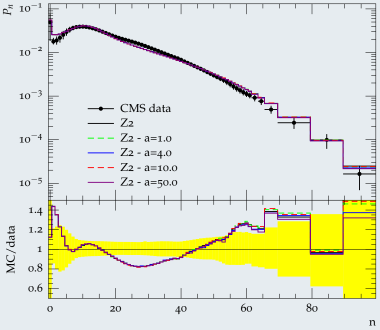
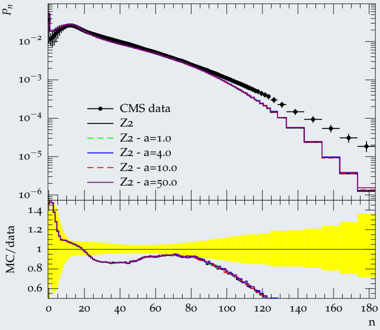


TOTAL



(g) 0.9 TeV: $\pm$ no effect



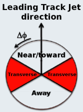
(h) 7.0 TeV: $\pm$ no effect

Tuning: used datasets

- CMS_QCD_10_010 (CMS_2011_S9120041): CMS, $\sqrt{s} = 0.9$ & 7.0 TeV [CMS UE data]
  - traditional UE measurement in the central region
  - measurement of activity transverse to leading charged particle jet
- CMS_QCD_10_004 (CMS_2011_S8884919): CMS, $\sqrt{s} = 0.9, 2.36$ & 7.0 TeV [CMS MB data]
  - measurement of NSD charged particle multiplicity
  - five η regions

Tuning strategy

- Case one:
  - try to understand effects
  - limit to just 4 plots: $N_{ch,transv}$ & $N_{ch,total}(|\eta| < 2.4)$ for both 0.9 and 7.0 TeV



- Case two:
  - fix PARP(82) and PARP(90) using MB plots: integrated over ϕ = insensitive to α
  - tune α-parameter using UE plots: transverse activity fixes α

Tuning: Case one (Z2R) (1)

- Observables:
  - include both 0.9 and 7.0 TeV data
  - $N_{ch,transverse}$ is very sensitive to PARP(82)/PARP(90) and to α [CMS UE data]
  - N_{ch} ($|\eta| < 2.4$) is sensitive to PARP(82)/PARP(90) [CMS MB data]

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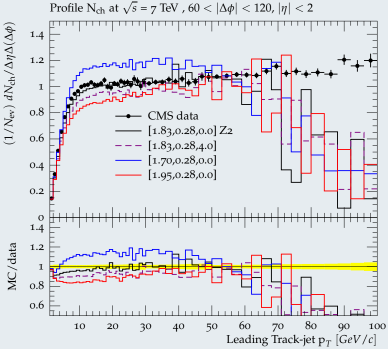
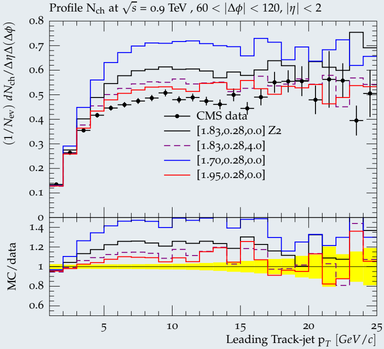


(a) 0.9 TeV UE data



(b) 7.0 TeV UE data

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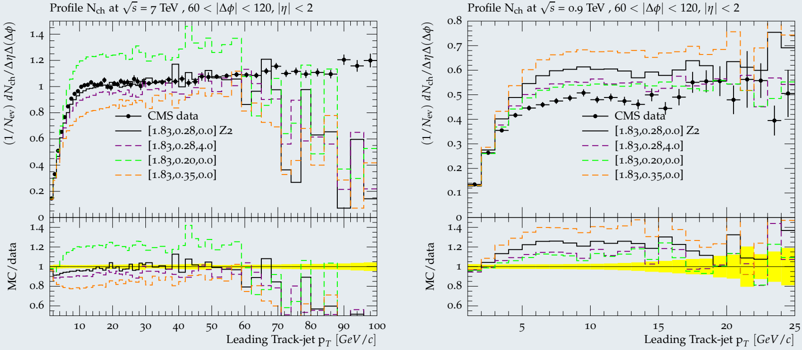

(a) 0.9 TeV UE data (b) 7.0 TeV UE data

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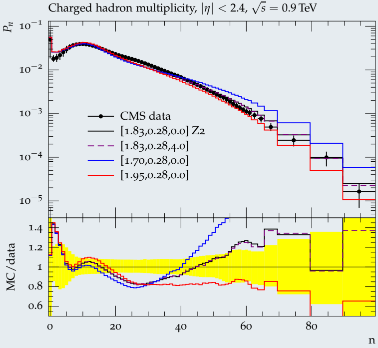
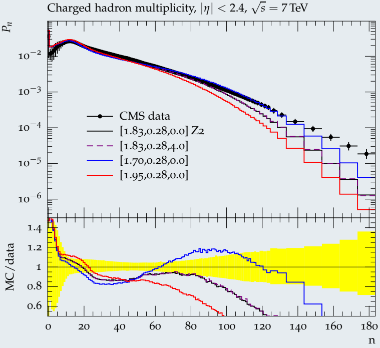
TOTAL



(c) 0.9 TeV MB data



(d) 7.0 TeV MB data

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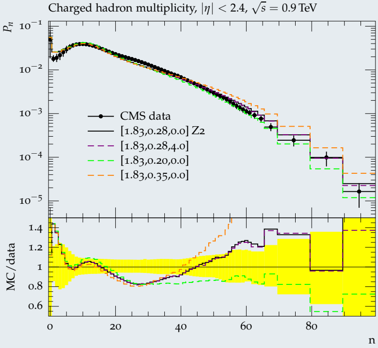

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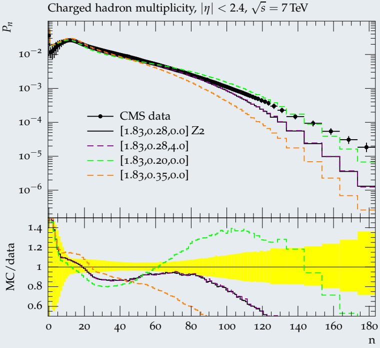

(d) 7.0 TeV MB data

Tuning: Case one (Z2R) (2)

- Tuning with PROFESSOR:

	PARP(82)	PARP(90)	α
Z2	1.83	0.28	0.0
Z2*	1.93	0.23	0.0
Z2R	1.87	0.23	4.15

- UE improvement over Z2 remains, extra parameter α allows to slightly improve MB (without degrading UE):

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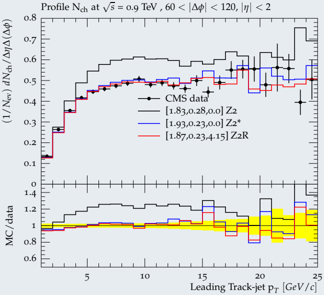

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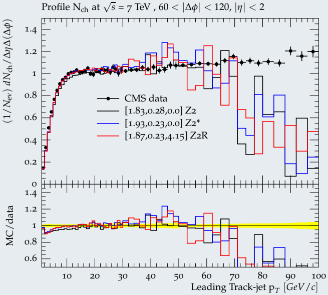

(b) 7.0 TeV UE data

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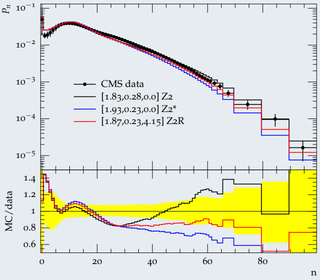

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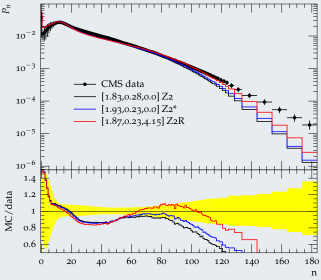

(d) 7.0 TeV MB data

Tuning: Case one (Z2R) (3)

- p_T^{min}: lower cutoff for which MPIs are generated (lower = more MPI activity)

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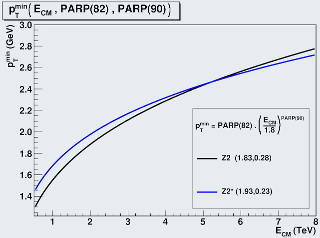
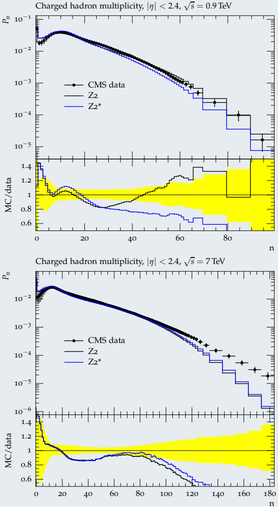


- 0.9 TeV:
  - Z2 lowest p_T^{min} = highest activity
  - Z2* highest p_T^{min} = lowest activity
- 7.0 TeV:
  - Z2 highest p_T^{min} = lowest activity
  - Z2* lowest p_T^{min} = highest activity

p_T^{min} before

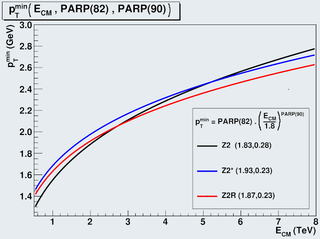


Tuning: Case one (Z2R) (3)

- p_T^{min}: lower cutoff for which MPIs are generated (lower = more MPI activity)

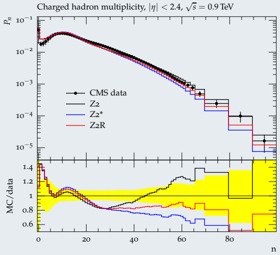
$$p_T^{min}(E_{CM}) = PARP(82) \cdot \left(\frac{E_{CM}}{E_{REF}}\right)^{PARP(90)}$$

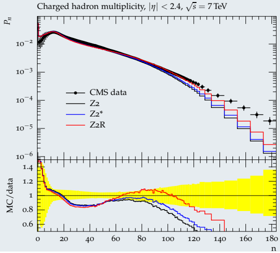
- PARP(82): p_T^0 cutoff
- PARP(90): energy dependence



- 0.9 TeV:
  - Z2 lowest p_T^{min} = highest activity
  - Z2* highest p_T^{min} = lowest activity
- 7.0 TeV:
  - Z2 highest p_T^{min} = lowest activity
  - Z2R lowest p_T^{min} = highest activity

p_T^{min} looking at Z2R





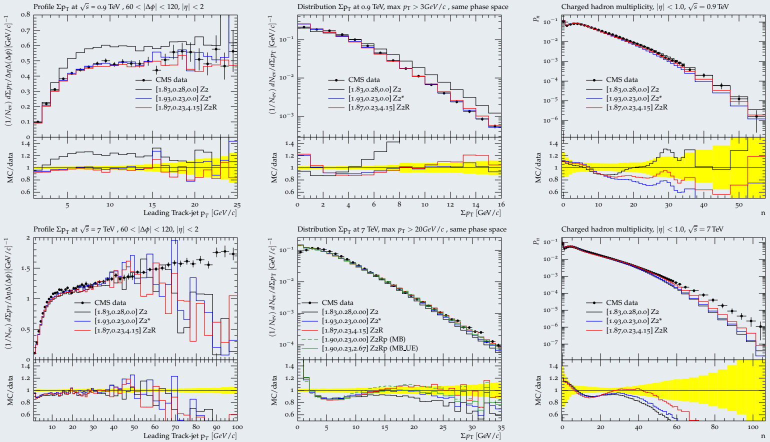
Tuning: Case one (Z2R) (4)

- Limited set of tuning observables is not a problem for the other observables:

UE	UE	MB
(a) profile Σp_T	(b) distribution Σp_T	(c) $N_{ch,total}$

0.9 TeV

7 TeV



Tuning: Case two (1)

- Observables:
  - include both 0.9 and 7.0 TeV data
  - tune-step one: use all CMS_2011_S8884919 MB observables to tune PARP(82)/PARP(90)
    - $\longrightarrow$ these observables are insensitive to α
    - $\longrightarrow$ this will disregard any match with UE data
  - tune-step two: use all CMS_2011_S9120041 UE observables to tune α
    - $\longrightarrow$ this allows to fix the damage done to the match with UE

- Tuning with PROFESSOR:

	PARP(82)	PARP(90)	α
Z2	1.83	0.28	0.0
Z2*	1.93	0.23	0.0
Z2R	1.87	0.23	4.15
Z2R'	1.90	0.23	2.67

$\longrightarrow$ The step-one result lies between Z2* and Z2R for PARP(82): very clear in the MB observable plots, but also causes non-optimal UE results

$\longrightarrow$ The step-two result will restore the non-optimal UE results to something similar to Z2* and Z2R

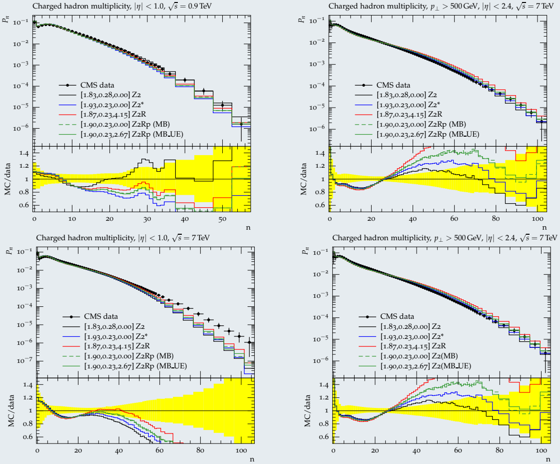
Tuning: Case two (2)

- Larger set of observables: MB fixed in first tune-step: $N_{ch,tot}$ ($p_T > 500$) which was not tuned in case one, looks slightly better

TOTAL

0.9 TeV MB

7 TeV MB



(a) $N_{ch,tot}(|\eta| < 1.0)$ (b) $N_{ch,tot}(|\eta| < 2.4, p_T > 500)$

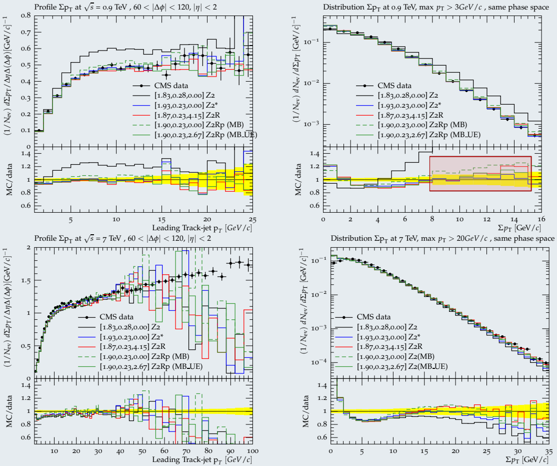
Tuning: Case two (2)

- Larger set of observables: after first tune-step UE is worse than Z2*/Z2R, after the second it's better again

TRANSVERSE

0.9 TeV UE

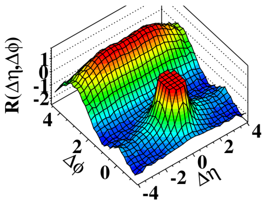
7 TeV UE



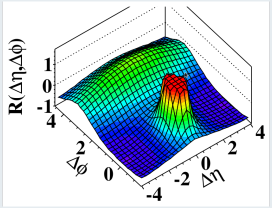
(c) profile Σp_T (d) distribution Σp_T

Ridge plot: CMS data

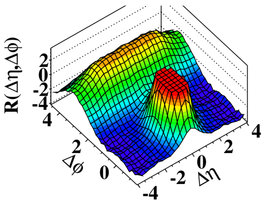
- CMS data, high-multiplicity moderate-p_T events (arXiv:1009.4122v1, 21 Sep 2010):
  → long-range near-side correlations only at moderate p_T and high-multiplicity



(a) $N(|\eta| < 2.4, p_T > 0.4) > 110$
$1.0 < p_T < 3.0$ *GeV*



(b) MB, $1.0 < p_T < 3.0$ *GeV*

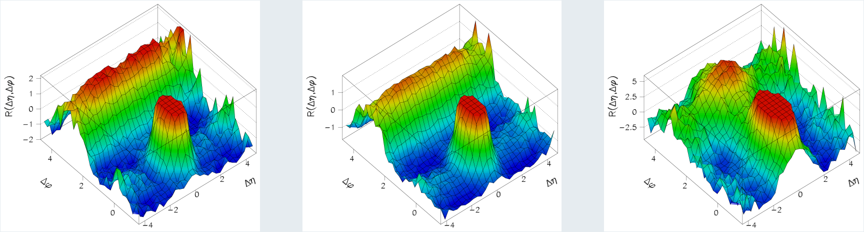


(c) $N > 110$, all p_T

- Monte Carlo, existing tunes (arXiv:1009.4122v1, 21 Sep 2010):
  → no long-range near-side correlations

Ridge plot: modified Monte Carlo (1)

- Modified Monte Carlo, Z2R tune ($\alpha = 4.15$):
  - large amount of statistics needed
  - high-multiplicity, moderate-p_T: near-side ridge is visible, as in data
  - moderate-multiplicity, moderate-p_T: near-side ridge is visible but too strong
  - minimum bias: ridge disappears (not shown)
  - high-multiplicity, all p_T: near-side ridge is not there, same as in data
    $\longrightarrow$ away-side ridge changes shape



(a)
$N\,(|\eta| < 2.4, p_T > 0.4) > 110$
$1.0 < p_T < 3.0$ GeV

(b)
$\langle N\,(|\eta| < 2.4, p_T > 0.4)\rangle = 78$
$1.0 < p_T < 3.0$ GeV

(c)
$N\,(|\eta| < 2.4, p_T > 0.4) > 110$
$0.1 < p_T < 10.0$ GeV

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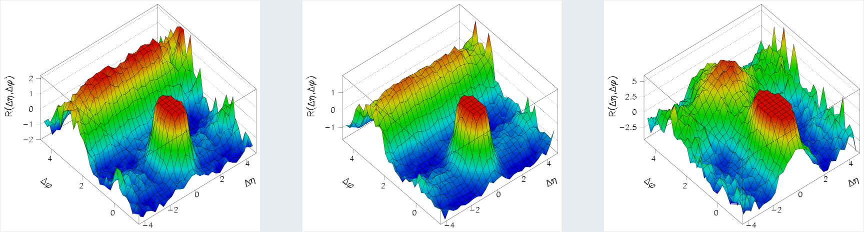

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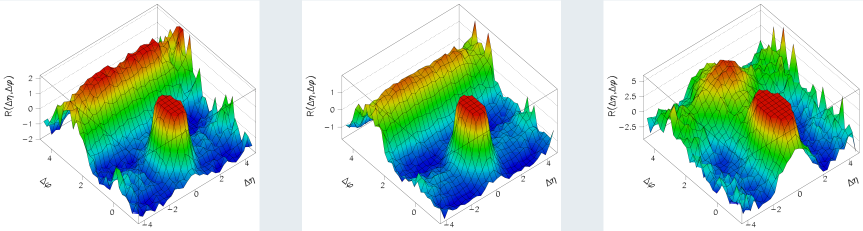

(a) $N\,(|\eta| < 2.4, p_T > 0.4) > 110$ $1.0 < p_T < 3.0$ GeV

(b) $\langle N\,(|\eta| < 2.4, p_T > 0.4)\rangle = 78$ $1.0 < p_T < 3.0$ GeV

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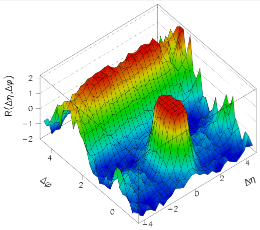

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$N(|\eta| < 2.4, p_T > 0.4) > 110$
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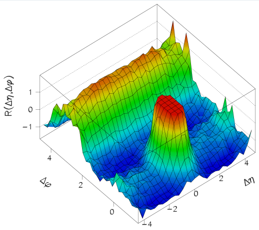
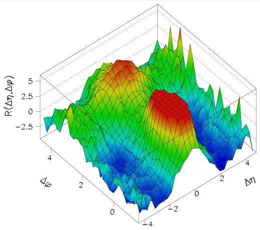


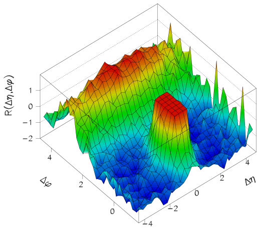
(b)
$\langle N(|\eta| < 2.4, p_T > 0.4) \rangle = 78$
$1.0 < p_T < 3.0$ GeV



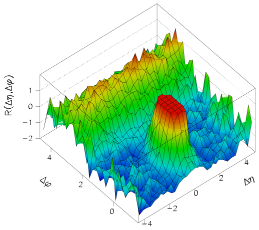
(c)
$N(|\eta| < 2.4, p_T > 0.4) > 110$
$0.1 < p_T < 10.0$ GeV

Ridge plot: modified Monte Carlo (2)

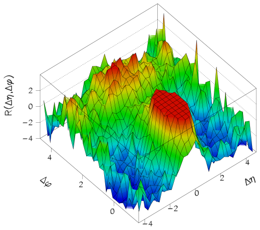
- Modified Monte Carlo, Z2R' tune ($\alpha = 2.67$):
  - high-multiplicity, moderate-p_T: near-side ridge is not visible
    $\longrightarrow$ higher scaling parameter α = necessary?
  - moderate-multiplicity, moderate-p_T: near-side ridge is not visible
  - high-multiplicity, all p_T: near-side ridge is not there, same as in data
    $\longrightarrow$ shape change in away-side ridge seems to be still there



(a)
$N(|\eta| < 2.4, p_T > 0.4) > 110$
$1.0 < p_T < 3.0$ GeV



(b)
$\langle N(|\eta| < 2.4, p_T > 0.4)\rangle = 78$
$1.0 < p_T < 3.0$ GeV



(c)
$N(|\eta| < 2.4, p_T > 0.4) > 110$
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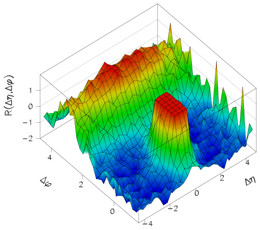

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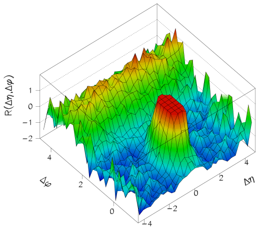

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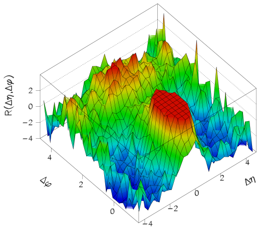
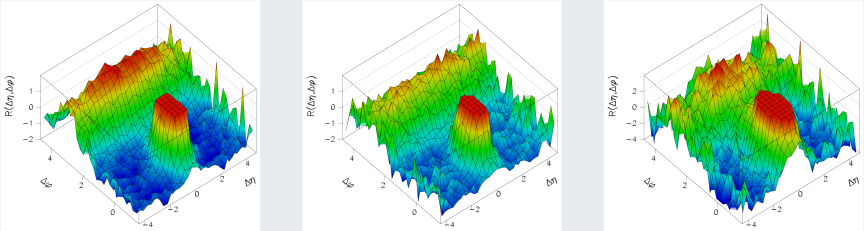


(c)
$N(|\eta| < 2.4, p_T > 0.4) > 110$
$0.1 < p_T < 10.0$ GeV

Ridge plot: modified Monte Carlo (2)

- Modified Monte Carlo, Z2R' tune ($\alpha = 2.67$):
  - high-multiplicity, moderate-p_T: near-side ridge is not visible
    $\longrightarrow$ higher scaling parameter α = necessary?
  - moderate-multiplicity, moderate-p_T: near-side ridge is not visible
  - high-multiplicity, all p_T: near-side ridge is not there, same as in data
    $\longrightarrow$ shape change in away-side ridge seems to be still there



(a) $N\left(|\eta| < 2.4, p_T > 0.4\right) > 110$, $1.0 < p_T < 3.0$ GeV

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(c) $N\left(|\eta| < 2.4, p_T > 0.4\right) > 110$, $0.1 < p_T < 10.0$ GeV

Conclusions

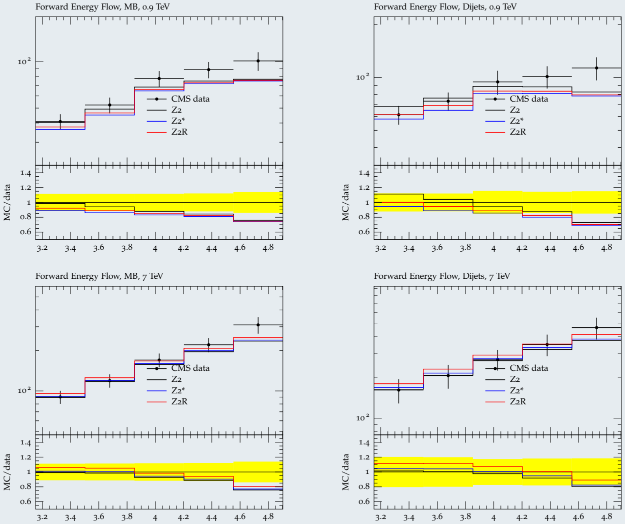
- A modification of PYTHIA6 was proposed, explaining the ridge effect with MPIs:
  - a correlation is introduced between the azimuth of the event planes of individual MPIs and the event plane of the hardest interaction
  - such a correlation can be naturally explained in a physical picture based on the impact parameter between the protons (b as defined by PYTHIA6 needs to be scaled by a factor ~ 4)
- Implications of the modification:
  - using the modification, the ridge effect in high-multiplicity moderate-p_T events becomes visible
  - using the modification, activity gets shifted away from the transverse region, the total activity remains the same, requiring a retune to UE observables
- Tune Z2R was obtained retuning to CMS UE and MB data

Backup

CMS FWD data

0.9 TeV

7 TeV

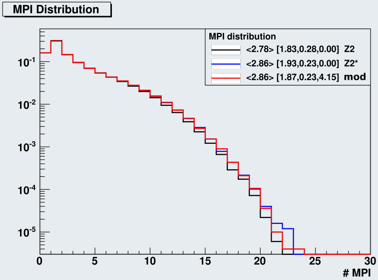


(a) MB, forward energy flow

(b) dijets, forward energy flow

Effect on the amount of MPIs

- The MPI based modification doesn't touch the amount of MPIs, it only reorganises them in ϕ:



(c) Amount of MPI at 7 TeV

	average #MPI
Z2	2.78
Z2*	2.86
mod	2.86

(d) average #MPI