Latest news on collectivity in high multiplicity p-p collisions at CMS

Maxime Guilbaud\textsuperscript{(1)}

On behalf of the CMS collaboration

\textit{(1) RICE University, Houston TX}
Double ridge in Pb-Pb:

- Perfect fluid property of QGP
- Geometry + fluctuation

PLB 724 (2013) 213
A bit of history ...

**Double ridge in Pb-Pb:**
- Perfect fluid property of QGP
- Geometry + fluctuation

**Breaking news in 2010 ...**
- Ridge visible in p-p data
- Where does it come from?

CMS $N \geq 110$, $1.0 \text{GeV/c} < p_T < 3.0 \text{GeV/c}$

---

A bit of history ...

Double ridge in Pb-Pb:
- Perfect fluid property of QGP
- Geometry + fluctuation

Breaking news in 2010 ...
- Ridge visible in p-p data
- Where does it come from?

CMS $N \geq 110$, $1.0\text{GeV/c} < p_T < 3.0\text{GeV/c}$

... and also observed in p-Pb
- QGP droplet? Something else?

A bit of history ...

**Double ridge in Pb-Pb:**
- Perfect fluid property of QGP
- Geometry + fluctuation

**Breaking news in 2010 ...**
- Ridge visible in p-p data
- Where does it come from?

CMS N ≥ 110, 1.0 GeV/c < p_T < 3.0 GeV/c

**... and also observed in p-Pb**
- QGP droplet? Something else?

PLB 724 (2013) 213

What is the origin of the long range near side correlation in small system?

PLB 724 (2013) 213

Collectivity in small system: the p-Pb case

Extensive study on the Ridge nature was performed in p-Pb

- Similar feature to the Pb-Pb case were observed
  - Multi-particle cumulant analysis
  - Measurement of higher Fourrier harmonics
  - $v_n$ of identified particle

$v_2\{2\} > v_2\{4\} \approx v_2\{6\} \approx v_2\{8\}$

$v_3$ Similar to Pb-Pb
Collectivity in small system: the p-Pb case

Extensive study on the Ridge nature was performed in p-Pb

- Similar feature to the Pb-Pb case were observed
  - Multi-particle cumulant analysis
  - Measurement of higher Fourrier harmonics
  - $v_n$ of identified particle

- What do we learn?
  - Collective effect
  - Fluctuation driven
  - Clear mass ordering for $V^0$

$\Delta \eta$, $\Delta \phi$

$\eta$, $\phi$

$v_2(2) > v_2(4) \approx v_2(6) \approx v_2(8)$

$v_3$ Similar to Pb-Pb

PLB 742 (2015) 200
PLB 724 (2013) 213
PRL 115 (2015) 012301


23/05/16
As it is a collective effect, the interpretation is restricted to mainly two different pictures

- Initial state interactions (CGC, ...)
- Initial state fluctuations + final state interactions (hydrodynamic, ...)

What about the Ridge in p-p collisions? What is new?
What are the possible explanations?

As it is a collective effect, the interpretation is restricted to mainly two different pictures

- Initial state interactions (CGC, ...)
- Initial state fluctuations + final state interactions (hydrodynamic, ...)

Fluctuations in the initial state is probably what matter the most in small systems

- Initial state fluctuations has to be very well understood
- Main incertitude comes from the proton fluctuations
  - p-Pb and of course p-p collisions can help to constrain these fluctuations
As it is a collective effect, the interpretation is restricted to mainly two different pictures

- Initial state interactions (CGC, ...)
- Initial state fluctuations + final state interactions (hydrodynamic, ...)

Fluctuations in the initial state is probably what matter the most in small systems

- Initial state fluctuations has to be very well understood
- Main incertitude comes from the proton fluctuations

p-Pb and of course p-p collisions can help to constrain these fluctuations

What about the Ridge in p-p collisions? What is new?
CMS has published Ridge yield up to very high multiplicity

- Highest multiplicity reached so far
- First comparison with model (CGC)

PRL 116 (2016) 172302
Status of p-p ridge studies

- CMS has published Ridge yield up to very high multiplicity

  - Highest multiplicity reached so far
  - First comparison with model (CGC)

- Interesting results on $v_2$ from ATLAS

  - A new method is used (template fit)
  - First measurement of $v_2$ in p-p
CMS has published Ridge yield up to very high multiplicity

- Highest multiplicity reached so far
- First comparison with model (CGC)

Interesting results on \( v_2 \) from ATLAS

- A new method is used (template fit)
- First measurement of \( v_2 \) in p-p

Origin of the ridge?
Detailed study of \( v_2 \) and higher harmonics needed
What are we trying to address?

1) Does the ridge arise from a collective behavior in p-p?

2) Mass ordering for identified particles as in p-Pb and Pb-Pb?

3) Can we understand better fluctuations in the IS in p-p collisions?
Long range dihadron correlations: technique

- $V_{n\Delta}$ coefficients extracted using a Fourier fit

$$\frac{1}{N_{\text{trig}}} \frac{dN^\text{pair}}{d\Delta \phi} = \frac{N_{\text{assoc}}}{2\pi} \left[ 1 + \sum_n 2V_{n\Delta} \cos(n\Delta \phi) \right]$$

- Single $v_n$ coefficients are computed with:

$$v_n(p_T^{\text{trg}}) = \frac{V_{n\Delta}(p_T^{\text{trg}}, p_T^{\text{ref}})}{\sqrt{V_{n\Delta}(p_T^{\text{ref}}, p_T^{\text{ref}})}}, \quad n = 2, 3.$$
Long range dihadron correlations: technique

- $V_n$ coefficients extracted using a Fourier fit

$$\frac{1}{N_{\text{trig}}} \frac{dN_{\text{pair}}}{d\Delta \phi} = \frac{N_{\text{assoc}}}{2\pi} \left[ 1 + \sum_n 2V_n \cos(n\Delta \phi) \right]$$

- Single $v_n$ coefficients are computed with:

$$v_n(p_T^{\text{trg}}) = \frac{V_n(p_{T_{\text{trg}}}, p_{T_{\text{ref}}})}{\sqrt{V_n(p_{T_{\text{ref}}}, p_{T_{\text{ref}}})}}$$

$n = 2, 3$. 

---

1 < $p_T^{\text{trig}}, p_{T_{\text{assoc}}}$ < 3 GeV/c

Long range ($|\Delta \eta| > 2$)
Long range dihadron correlations: technique

- $V_{n\Delta}$ coefficients extracted using a Fourrier fit

$$\frac{1}{N_{\text{trig}}} \frac{dN_{\text{pair}}}{d\Delta \phi} = \frac{N_{\text{assoc}}}{2\pi} \left[ 1 + \sum_n 2V_{n\Delta} \cos(n\Delta \phi) \right]$$

- Single $v_n$ coefficients are computed with:

$$v_n(p_T^{\text{trg}}) = \frac{V_{n\Delta}(p_T^{\text{trg}}, p_T^{\text{ref}})}{\sqrt{V_{n\Delta}(p_T^{\text{ref}}, p_T^{\text{ref}})}}, \quad n = 2, 3.$$
Low multiplicity subtraction is applied on $V_{n\Delta}$

- Remove jet correlation contribution
- Assuming jet-induced correlations invariant with multiplicity
- $v_2(N_{trk}^{\text{offline}} < 20) = 0$ by construction
Low multiplicity subtraction is applied on $V_{n\Delta}$

- Remove jet correlation contribution
- Assuming jet-induced correlations invariant with multiplicity
- $v_2(N_{\text{trk}}^{\text{offline}} < 20) = 0$ by construction

$$V_{n\Delta}^{\text{sub}} = V_{n\Delta} - V_{n\Delta}(10 \leq N_{\text{trk}}^{\text{offline}} < 20) \times \frac{N_{\text{assoc}}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)}{N_{\text{assoc}}} \times \frac{Y_{\text{jet}}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)}{Y_{\text{jet}}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)}$$
Low multiplicity subtraction is applied on $V_{n\Delta}$

- Remove jet correlation contribution
- Assuming jet-induced correlations invariant with multiplicity
- $v_2(N_{\text{trk}} < 20) = 0$ by construction

\[ V_{\text{sub}}^{n\Delta} = V_{n\Delta} - V_{n\Delta}(10 \leq N_{\text{trk}}^{\text{offline}} < 20) \times \frac{N_{\text{assoc}}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)}{N_{\text{assoc}} \times Y_{\text{jet}}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)} \times \frac{Y_{\text{jet}}}{Y_{\text{jet}}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)} \]
Low multiplicity subtraction is applied on $V_{n\Delta}$
- Remove jet correlation contribution
- Assuming jet-induced correlations invariant with multiplicity
- $v_2(N_{\text{trk}}^{\text{offline}} < 20) = 0$ by construction

$V_{n\Delta}^{\text{sub}} = V_{n\Delta} - V_{n\Delta}(10 \leq N_{\text{trk}}^{\text{offline}} < 20) \times \frac{N_{\text{assoc}}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)}{N_{\text{assoc}}} \times \frac{Y_{\text{jet}}}{Y_{\text{jet}}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)}$
Low multiplicity subtraction is applied on $V_{n\Delta}$
- Remove jet correlation contribution
- Assuming jet-induced correlations invariant with multiplicity
- $v_2(N_{\text{trk}}^{\text{offline}} < 20) = 0$ by construction

$$V_{n\Delta}^{\text{sub}} = V_{n\Delta} - V_{n\Delta}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)\times \frac{N_{\text{assoc}}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)}{N_{\text{assoc}}} \times Y_{\text{jet}}(10 \leq N_{\text{trk}}^{\text{offline}} < 20)$$
Long range dihadron correlations: \( v_2 \) & \( v_3 \) vs. multiplicity

- Low multiplicity subtraction applied

- \( v_2 \):
  - No energy dependence observed
Probing novel long-range correlations in pPb (collisions with identified particles at CMS) for the CMS Collaboration at Hot Quarks Workshop 2014.

- Low multiplicity subtraction applied

- **v₂**:
  - No energy dependence observed
  - Similar shape as p-Pb and Pb-Pb
  - Smaller than bigger system

**Similar effect involved with different magnitude?**
Long range dihadron correlations: $v_2$ & $v_3$ vs. multiplicity

- Low multiplicity subtraction applied

- $v_2$:
  - No energy dependence observed
  - Similar shape as p-Pb and Pb-Pb
  - Smaller than bigger system
  - **Similar effect involved with different magnitude?**

- $v_3$:
  - No energy dependence observed
  - Different from p-Pb and Pb-Pb
  - **Difference in initial state fluctuations?**
Long range dihadron correlations: $v_2$ & $v_3$ vs. $p_T$

No energy dependence observed within systematics before or after peripheral subtraction
Ridge structure also observed for $V^0$

CMS pp $\sqrt{s} = 13$ TeV Preliminary

$105 \leq N_{\text{offline}}^{\text{trk}} < 150$

$1 < p_{T}^{\text{trig}}, p_{T}^{\text{assoc}} < 3$ GeV/$c$

Does $K^0$ and $\Lambda$ shows a mass ordering in p-p collisions?
Identified particles ($V^0$) long range correlations: $v_2$

- Before jet correlation subtraction:
  - $v_2^2$ consistent for all particles at low multiplicity
  - Clear ordering for $p_T < 2.5$ GeV/c at high multiplicity

Similar pattern to what is observed in p-Pb and Pb-Pb? Similar origin?
Identified particles ($V^0$) long range correlations: mass splitting

- Low multiplicity subtraction applied
- Clear mass splitting observed up to 2 GeV/c
Identified particles ($V^0$) long range correlations: mass splitting

- Low multiplicity subtraction applied
- Clear mass splitting observed up to 2 GeV/c
- Clearer effect in p-p than in p-Pb (or Pb-Pb)
- Where does this come from?
Identified particles ($V^0$) long range correlations: mass splitting

- Low multiplicity subtraction applied
- Clear mass splitting observed up to 2 GeV/c
- Clearer effect in p-p than in p-Pb (or Pb-Pb)
- Where does this come from?
  - Connected to radial flow
  - p-p is a more explosive system

![Graphs and plots showing mass splitting and correlations between different particle species.](image_url)
**Goal:** Probe the collective nature of the “Ridge” in p-p collisions

- 4- and 6-particle cumulant distributions were measured at different energies

![Graph showing cumulative distributions](image-url)
**Goal:** Probe the collective nature of the “Ridge” in p-p collisions

- 4- and 6-particle cumulant distributions were measured at different energies

![Graph showing 4- and 6-particle cumulant distributions](image)
**Goal:** Probe the collective nature of the “Ridge” in p-p collisions

- 4- and 6-particle cumulant distributions were measured at different energies

**Clear signal observed in 13 TeV sample!**
Is it collective?

**Goal:** Probe the collective nature of the “Ridge” in p-p collisions

- 4- and 6-particle cumulant distributions were measured at different energies
- Shape similar to p-Pb but different magnitude

*Clear signal observed in 13 TeV sample!*

![Graph showing cumulant distributions for pp and pPb collisions at different energies.](image-url)
**Goal:** Probe the collective nature of the “Ridge” in p-p collisions

- 4- and 6-particle cumulant distributions were measured at different energies
- Shape similar to p-Pb but different magnitude

**Clear signal observed in 13 TeV sample!**

---

- **CMS Preliminary**
- **Preliminary CMS**
- **N_{offline}^{trk}**
- **N_{offline}**
- **C_2\{4\}**
- **C_2\{6\}**
- **pPb \sqrt{s_{NN}} = 5 TeV**
- **pp \sqrt{s} = 13 TeV**
- **pp \sqrt{s} = 7 TeV**
- **pp \sqrt{s} = 5 TeV**
- **0.3 < p_T < 3 GeV/c**
- **|\eta| < 2.4**
Multi-particle cumulant results compared to $v_2\{2\}$

- $v_2^{\text{sub}\{2, |\Delta\eta|>2\}}$

- Preliminary CMS results

- $N_{\text{trk}}^{\text{offline}}$

- $0.3 < p_T < 3.0 \text{ GeV/c}$

- $|\eta| < 2.4$

- $\sqrt{s} = 13 \text{ TeV}$
Multi-particle cumulant results compared to $v_2\{2\}$

- Probe collectivity
  
  $$v_2\{4\} = 4\sqrt{-c_n\{4\}},$$

Comparison between $v_2\{2\}$, $v_2\{4\}$

- $v_2\{2\} \approx v_2\{4\}$
Multi-particle cumulant results compared to $v_2\{2\}$
- Probe collectivity
  \[
  v_2\{4\} = \sqrt[4]{-c_4\{4\}},
  \]
  \[
  v_2\{6\} = \sqrt[6]{\frac{1}{4}c_6\{6\}},
  \]

Comparison between $v_2\{2\}$, $v_2\{4\}$ and $v_2\{6\}$:
- $v_2\{2\} \approx v_2\{4\} \approx v_2\{6\}$

⇒ Collectivity!
Comparison across different systems of $v_2\{2\}$, $v_2\{4\}$ and $v_2\{6\}$

**CMS Preliminary**

- **pp $\sqrt{s} = 13$ TeV**
  - $v_2^{sub}\{2, |\Delta\eta|>2\}$
  - $v_2\{4\}$
  - $v_2\{6\}$
  - $v_2\{8\}$
  - $v_2\{LYZ\}$

- **pPb $\sqrt{s_{NN}} = 5$ TeV**

- **PbPb $\sqrt{s_{NN}} = 2.76$ TeV**

- **Graphs:**
  - $0.3 < p_T < 3.0$ GeV/$c$
  - $|\eta| < 2.4$

- **Figure:**
  - Offline tracks
  - Number of offline tracks vs. $v_2$

23/05/16
Comparison across different systems of $v_2\{2\}$, $v_2\{4\}$ and $v_2\{6\}$

- Comparison between $v_2\{2\}$, $v_2\{4\}$ and $v_2\{6\}$ in p-p and p-Pb:
  - $v_2\{2\}/v_2\{4\}$ (p-p) ≤ $v_2\{2\}/v_2\{4\}$ (p-Pb) ➔ Related to IS fluctuations
Comparison across different systems of $v_2\{2\}$, $v_2\{4\}$ and $v_2\{6\}$

- Comparison between $v_2\{2\}$, $v_2\{4\}$ and $v_2\{6\}$ in p-p and p-Pb:
  - $v_2\{2\}/v_2\{4\}$ (p-p) ≤ $v_2\{2\}/v_2\{4\}$ (p-Pb) ➔ Related to IS fluctuations

- One possible explanation: **PRL 112 (2014) 082301**
  - smaller $v_2\{2\}/v_2\{4\}$ ➔ Less IS fluctuating sources

**Comparison across different systems**

**CMS Preliminary**

| System | $\sqrt{s}$ (TeV) | $v_2\{2\}$, $|\Delta \eta|>2$ | $v_2\{4\}$ | $v_2\{6\}$ | $v_2\{8\}$ | $v_2\{LYZ\}$ |
|--------|-----------------|-------------------|------------|------------|------------|----------------|
| **pp** | 13              | $v_2^{sub}\{2\}$  | $v_2\{4\}$ | $v_2\{6\}$ | $v_2\{8\}$ | $v_2\{LYZ\}$ |
| **pPb** | 5               |                   |            |            |            |                |
| **PbPb** | 2.76           |                   |            |            |            |                |

$v_2\{2\}/v_2\{4\}$ (p-p) ≤ $v_2\{2\}/v_2\{4\}$ (p-Pb) ➔ Related to IS fluctuations

- Related to IS fluctuations
- Smaller $v_2\{2\}/v_2\{4\}$ ➔ Less IS fluctuating sources

**Figure:**

- Comparison of $v_2$ values for different systems and track multiplicity.
- $0.3 < p_T < 3.0$ GeV/c, $|\eta| < 2.4$.
- $N_{\text{offline}}^{\text{trk}}$ vs. $v_2$ for different $p_T$ bins and track multiplicity bins.
Comparison across different systems of $v_2\{2\}$, $v_2\{4\}$ and $v_2\{6\}$

- Comparison between $v_2\{2\}$, $v_2\{4\}$ and $v_2\{6\}$ in p-p and p-Pb:
  - $v_2\{2\}/v_2\{4\}$ (p-p) ≤ $v_2\{2\}/v_2\{4\}$ (p-Pb) → Related to IS fluctuations

- One possible explanation: PRL 112 (2014) 082301
  - smaller $v_2\{2\}/v_2\{4\}$ → Less IS fluctuating sources
  - Still true before subtraction → Upper limit

![Graphical representation of the comparison between $v_2\{2\}$, $v_2\{4\}$, and $v_2\{6\}$ in p-p and p-Pb collisions.](image-url)
A clear long-range near-side structure is observed in p-p collisions at high-multiplicity

Significant $v_2$ and $v_3$ are measured with CMS at 5, 7 and 13 TeV using dihadron correlations and low-multiplicity subtraction technique

- Similar shape for $v_2$ as p-Pb but smaller magnitude
- $v_3$ is different from p-Pb and Pb-Pb: suggest that initial state fluctuations in p-p and bigger systems have different patterns
- Clear mass ordering is observed

$v_2\{4\}$ and $v_2\{6\}$ were measured at high multiplicity

- Results indicate that the Ridge in p-p is collective!
- May provide important insight of the initial state fluctuations of the proton
As in p-Pb, it is a collective effect, the interpretation is restricted to mainly two different pictures

- Initial state interactions (CGC, ...)
- Initial state fluctuations + final state interactions (hydrodynamic, ...)

Need of theoretical inputs in high multiplicity p-p collisions
As in p-Pb, it is a collective effect, the interpretation is restricted to mainly two different pictures

- Initial state interactions (CGC, ...)

- Initial state fluctuations + final state interactions (hydrodynamic, ...)

Need of theoretical inputs in high multiplicity p-p collisions

Initial state and its fluctuations is different from p-Pb and Pb-Pb

- Less fluctuating sources

- Can we constrain the proton initial state fluctuations?
As in p-Pb, it is a collective effect, the interpretation is restricted to mainly two different pictures

- Initial state interactions (CGC, ...)
- Initial state fluctuations + final state interactions (hydrodynamic, ...)

Need of theoretical inputs in high multiplicity p-p collisions

Initial state and its fluctuations is different from p-Pb and Pb-Pb

- Less fluctuating sources
- Can we constrain the proton initial state fluctuations?

More results on small systems will come with the Run-2 p-Pb run this year!!!
Outlook (II)

➔ Extend measurements to higher $p_T$:
  • Collectivity
  • Jet quenching

➔ More constrains on IS fluctuations

LPC meeting

Probing novel long-range correlations in PbPb (collisions with identified particles at CMS)

Zhenyu Chen (Rice University) for the CMS Collaboration

Hot Quarks Workshop 2014
ATLAS and CMS method comparison

Fundamental difference between ATLAS and CMS method:

*Subtract or not the combinatoric pedestal in the correlation function of low multiplicity from those of high multiplicity*

\[
\Upsilon(\Delta \phi) = N \left\{ 1 + \sum_n 2V_n \Delta \cos(n \Delta \phi) \right\}
\]

Baseline of the correlation:
Related to number of pairs involved in the correlation

Amplitude of sinusoidal modulation

if \( N \sum_n 2V_n \Delta \cos(n \Delta \phi) = cste \) and \( N \downarrow \)
then \( V_n \Delta \uparrow \)
ATLAS and CMS method comparison

\[ \gamma^{HM}(\Delta \phi) = F \gamma^{LM}(\Delta \phi) + \gamma^{Ridge}(\Delta \phi) \]

\[ N^{HM}\left\{ 1 + \sum_n 2V_{n\Delta}^{HM} \cos(n\Delta \phi) \right\} = F N^{LM}\left\{ 1 + \sum_n 2V_{n\Delta}^{LM} \cos(n\Delta \phi) \right\} + G\left\{ 1 + \sum_n 2V_{n\Delta}^{ridge} \cos(n\Delta \phi) \right\} \]

\[ G = N^{HM} - F N^{LM} \]

\[ G V_2^{ridge} = N^{HM} V_2 - F N^{LM} V_2^{LM} \]

\[ \text{if } N \sum_n 2V_{n\Delta} \cos(n\Delta \phi) = \text{cste and } N \downarrow \]

then \( V_{n\Delta} \uparrow \)

G smaller than \( N^{HM}, V_2 \uparrow \)
Smaller G can be interpreted as correlation wrt a subset of particle

HM: High Multiplicity
LM: Low Multiplicity
2D correlation functions
1D correlation functions

CMS pp $\sqrt{s} = 13$ TeV Preliminary

1D correlation functions for different ranges in $|\Delta\eta|$ and $p_T$.
Identified particles ($V^0$) long range correlations: double ridge

- Clear double ridge structure also observed for $V^0$ after subtracting jet correlations.
Probing novel long-range correlations in PbPb (collisions with identified particles at CMS)

Zhenyu Chen (Rice University) for the CMS Collaboration

Hot Quarks Workshop 2014

V_{2\Delta} subtraction and MC closure

CMS pp $\sqrt{s} = 13$ TeV Preliminary

$0.3 < p_T < 3$ GeV/c

$|\Delta \eta| > 2$

$N_{\text{offline}}^{\text{trk}}$

$V_{2\Delta}$

$V_{3\Delta}$

$N_{\text{offline}}^{\text{trk}}$

- No sub.
- Low mult. sub.
- PYTHIA8 $\times 0.7$
- PYTHIA8 sub. $\times 0.7$

$\times 10^{-3}$

0 50 100 150

0 2 4 6

0 0.5 1 1.5

23/05/16

Δη dependence of $v_2$}{2}

CMS pp \( \sqrt{s} = 13 \text{ TeV} \)

- \( 0.3 < p_T < 3 \text{ GeV/c} \)

- \( 10 \leq N_{\text{trk}} < 20, \) no sub.
- \( 85 \leq N_{\text{trk}} < 95, \) no sub.
- \( 135 \leq N_{\text{trk}} < 150, \) no sub.
- \( 85 \leq N_{\text{trk}} < 95 \)
- \( 135 \leq N_{\text{trk}} < 150 \)

Preliminary
Subtraction as a function of multiplicity for $v_2\{2\}$

CMS pp $\sqrt{s} = 13$ TeV

$0.3 < p_T < 3$ GeV

$|\Delta\eta| > 2$

Preliminary

$\{v_2\}^2$ vs $N_{\text{trk}}^{\text{offline}}$

- $10 \leq N_{\text{trk}}^{\text{offline}} < 20$ Sub.
- $10 \leq N_{\text{trk}}^{\text{offline}} < 15$ Sub.
- $15 \leq N_{\text{trk}}^{\text{offline}} < 20$ Sub.
- $20 \leq N_{\text{trk}}^{\text{offline}} < 25$ Sub.
- $25 \leq N_{\text{trk}}^{\text{offline}} < 30$ Sub.
- $30 \leq N_{\text{trk}}^{\text{offline}} < 35$ Sub.
Probing (novel long range correlations in pp (collisions with identified particles at CMS)

Zhenyu Chen (Rice University) for the CMS Collaboration

Hot Quarks Workshop 2014

V^0 mass fits

CMS pp \( \sqrt{s} = 13\) TeV

\( K_S^0 \) and \( \Lambda/\bar{\Lambda} \)

Preliminary

Mean: 0.4976 GeV
Average \( \sigma: 0.0067 \) GeV

\( 105 \leq N_{\text{trk}}^{\text{offline}} < 150 \)

Mean: 1.1159 GeV
Average \( \sigma: 0.0031 \) GeV

\( 105 \leq N_{\text{trk}}^{\text{offline}} < 150 \)

\( 0.45 \) to \( 0.55 \) GeV

\( 1.08 \) to \( 1.16 \) GeV

Candidates / 0.0005 GeV

\( \times 10^3 \)
Jet subtraction test

Preliminary

CMS pp $\sqrt{s} = 13$ TeV
$0.3 < p_T < 3$ GeV/c
$|\Delta\eta| > 2$

$N_{\text{offline}}$

$N_{\text{trk}}$

$\nu_2^{\text{sub}(2)}$

Nominal

Top 30% $p_T^{\text{Lead}}$

Bottom 30% $p_T^{\text{Lead}}$

Preliminary

CMS pp $\sqrt{s} = 13$ TeV
$0.3 < p_T < 3$ GeV/c
$|\Delta\eta| < 1$

$Y_{\text{jet}}$

Nominal

Top 30% $p_T^{\text{Lead}}$

Bottom 30% $p_T^{\text{Lead}}$
NCQ scaling

- NCQ scaling stand for intermediate $KE_T/n_q$
- Tension a low $KE_T/n_q$ but statistical uncertainties are large

How to explain this scaling?
What can we learn from that?
Number of fluctuating sources

![Graph showing the number of fluctuating sources as a function of N. The graph plots the probability of observing a given number of events for different values of ε, ranging from ε{2} to ε{∞}. The x-axis represents the number of events (N), and the y-axis represents the probability. The graph includes several curves for different values of ε, demonstrating the decay in probability with increasing N.]