SEPTEMBER 3-9, 2023 | HOUSTON, TEXAS

QuarkMatter 2023

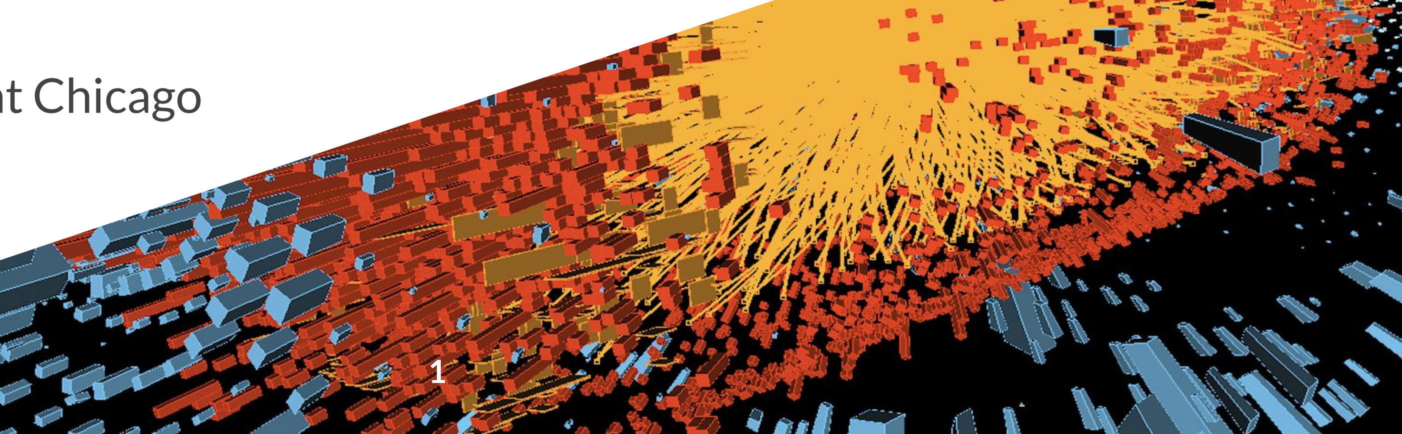
The 30th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions

Small-system properties as measured with jets and high-p_T azimuthal anisotropy by the CMS experiment

Dener De Souza Lemos from the CMS Collaboration

University of Illinois at Chicago

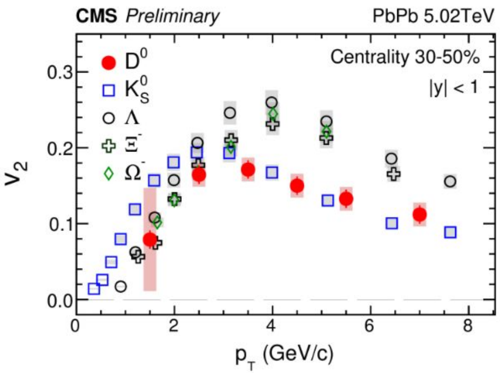
September 5th, 2023



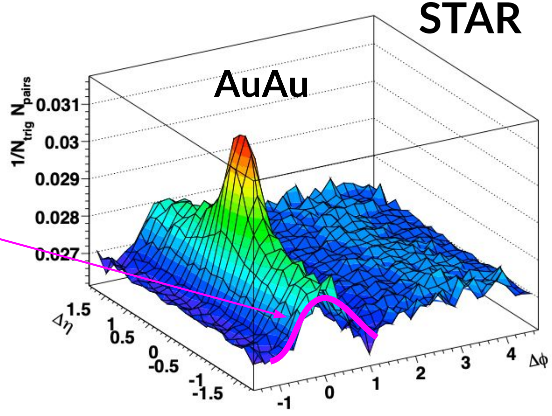
The “Ridge”

- Two particle azimuthal correlations
  - Ridge: structure at Δϕ~0
    - Hydrodynamic behavior
      - Collective effect
      - Flow harmonics

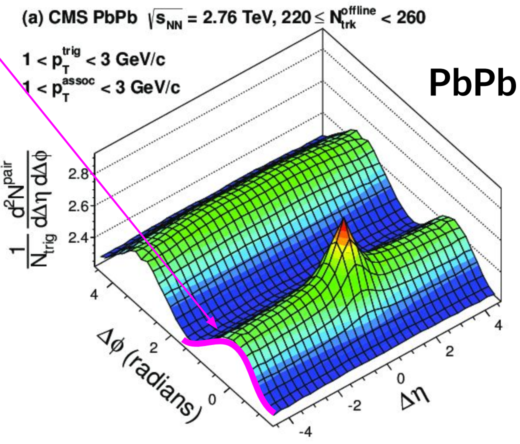
$$\frac{1}{N_{trig}}\frac{dN^{pair}}{d\Delta\phi} = \frac{N_{assoc}}{2\pi}\left[1+\sum_n 2V_{n\Delta}\cos(n\Delta\phi)\right]$$



PRL 121, (2018) 082301

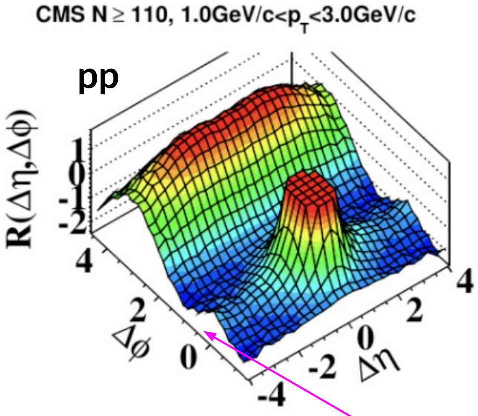


J.Phys.: Conf. Ser. 110 032003

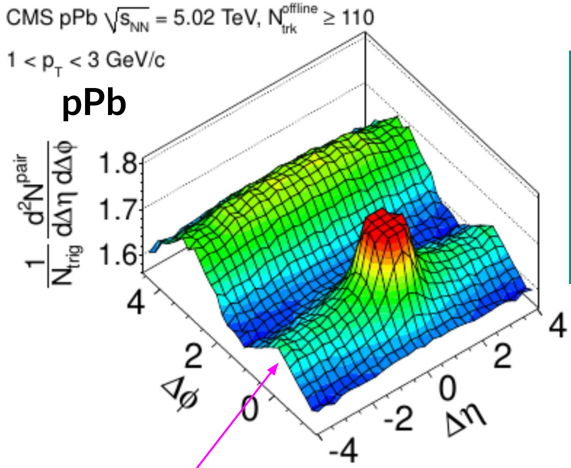


JHEP 07 (2011) 076

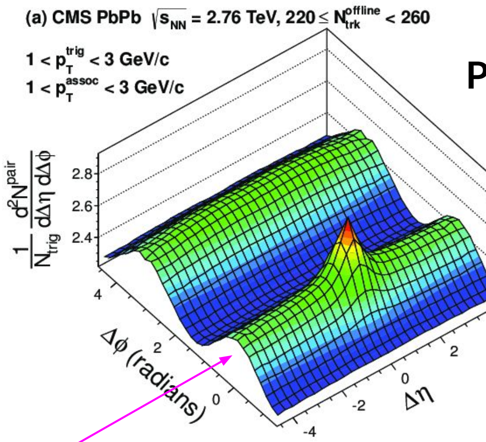
What about small systems?



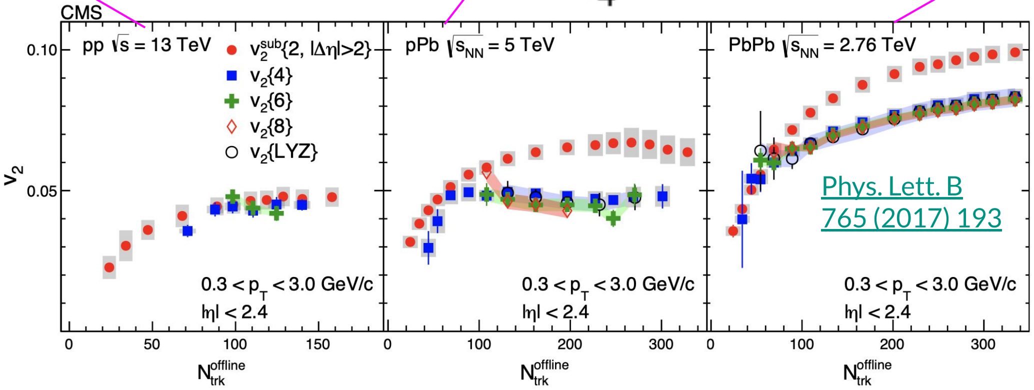
JHEP 09 (2010) 091



PLB 718 (2013) 795



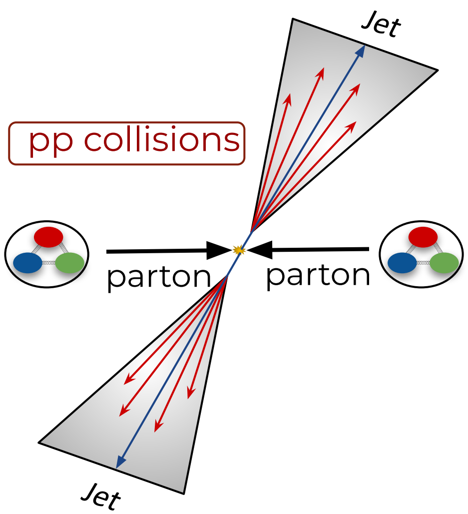
JHEP 07 (2011) 076



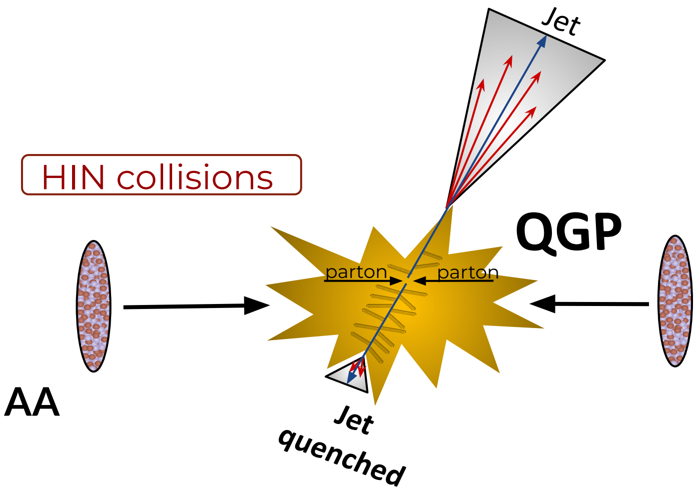
Phys. Lett. B 765 (2017) 193

Unexpected "ridge-like" effect in small systems

Searches for jet quenching at CMS

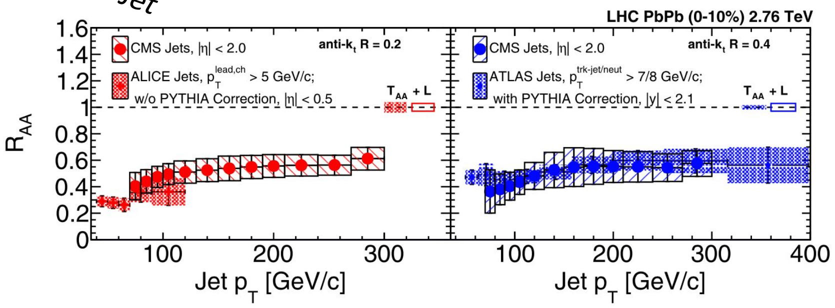


pp used as baseline



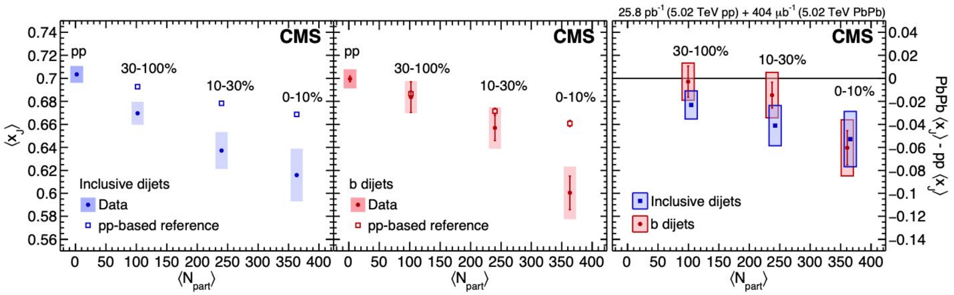
Suppression due to the medium in AA

“jet quenching”



$$R_{AA} = \frac{d^2N^{AA}_{\text{jets}}/dp_T\, d\eta}{\langle T_{AA}\rangle d^2\sigma^{pp}_{\text{jets}}/dp_T\, d\eta}$$

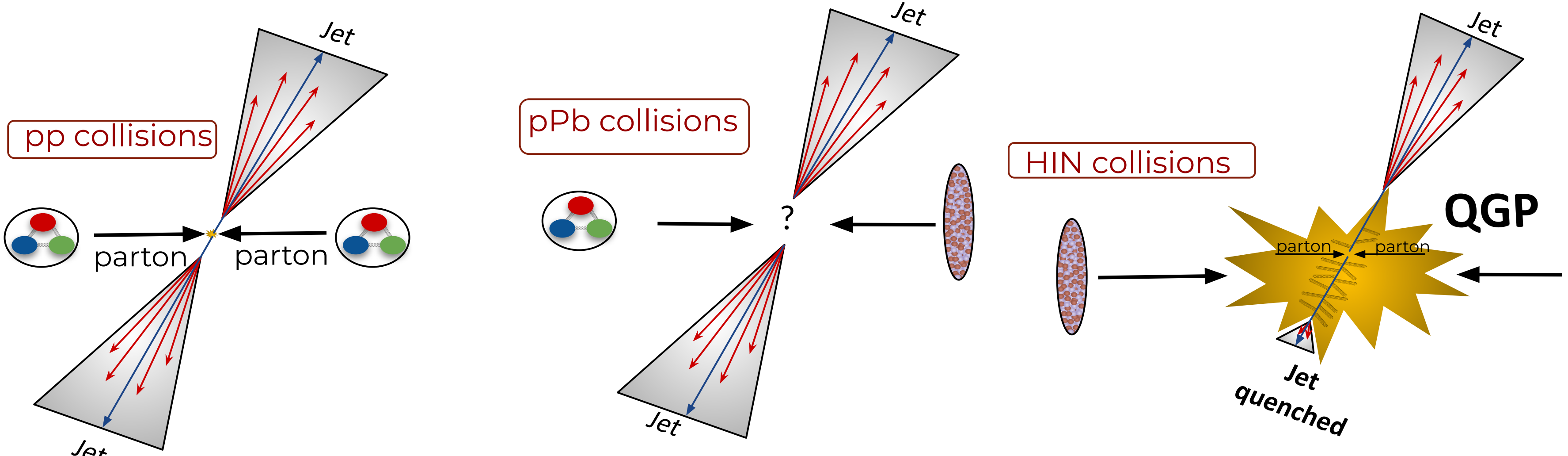
Phys. Rev. C 96 (2017) 015202

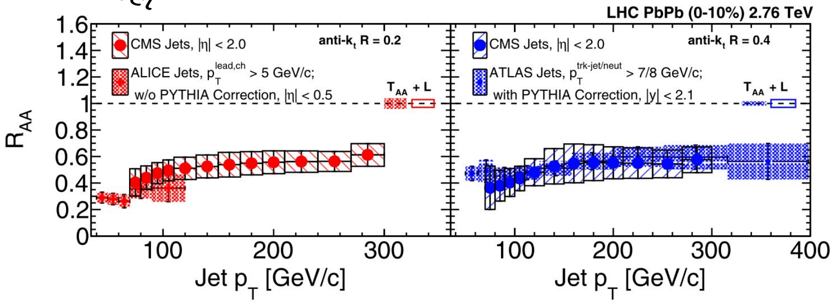


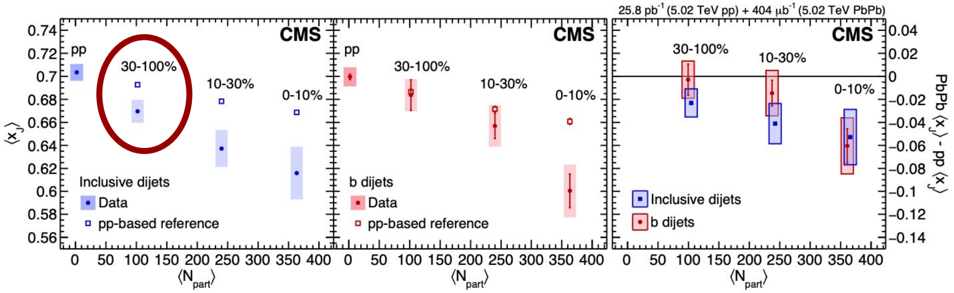
JHEP 03 (2018) 181

$$x_j = \frac{p_T^{\text{Subleading jet}}}{p_T^{\text{Leading jet}}}$$

Searches for jet quenching at CMS







$$R_{AA} = \frac{d^2N^{AA}_{\text{jets}}/dp_T\,d\eta}{\langle T_{AA}\rangle d^2\sigma^{pp}_{\text{jets}}/dp_T\,d\eta}$$

Phys. Rev. C 96 (2017) 015202

What about pPb?

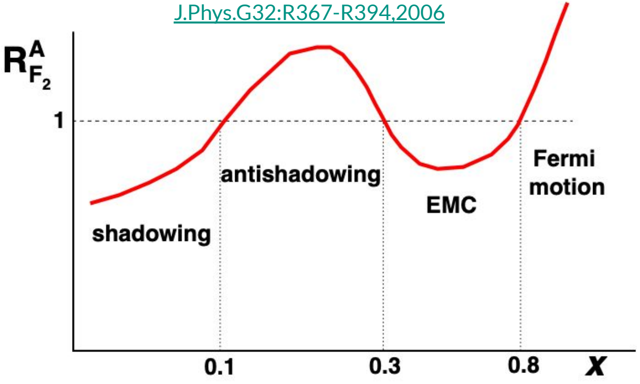
JHEP 03 (2018) 181

$$x_j = \frac{p_T^{\text{Subleading jet}}}{p_T^{\text{Leading jet}}}$$

Study of cold nuclear matter effects in pPb

- Understand initial stage/CNM is essential
  - Dijet pseudorapidity allows to map the distributions and add constraints for nPDFs
    - Can be used to access the Bjorken-x (Shadowing, anti-shadowing and EMC)

J.Phys.G32:R367-R394,2006



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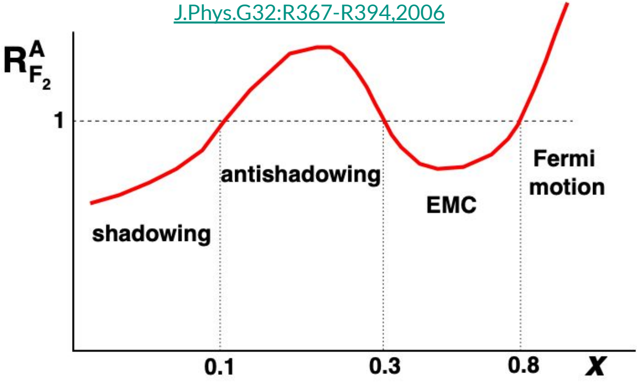
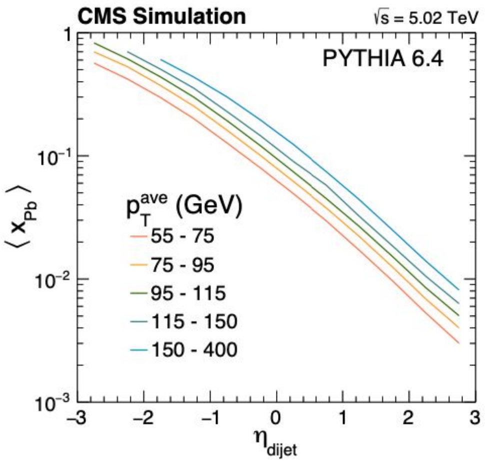


Phys. Rev. Lett. 121, 062002 (2018)



$$\eta^{dijet} = (\eta_1 + \eta_2)/2$$

Study of cold nuclear matter effects in pPb

- Understand initial stage/CNM is essential
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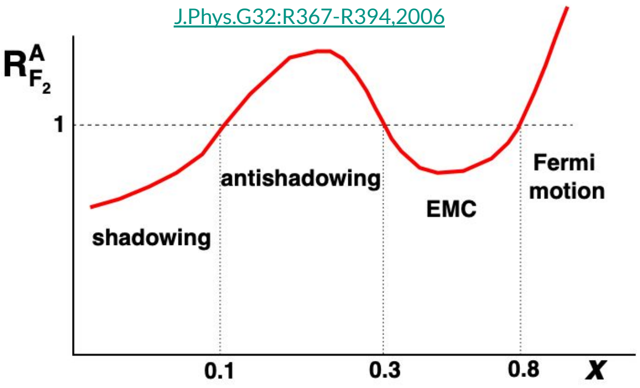
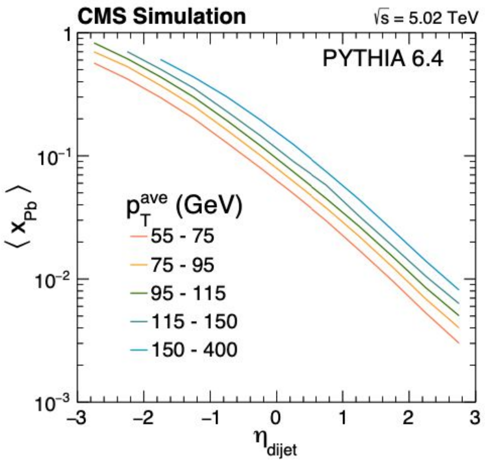
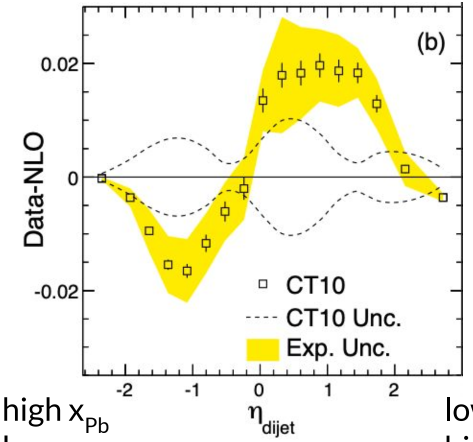


Phys. Rev. Lett. 121, 062002 (2018)



Eur. Phys. J. C 74 (2014) 2951

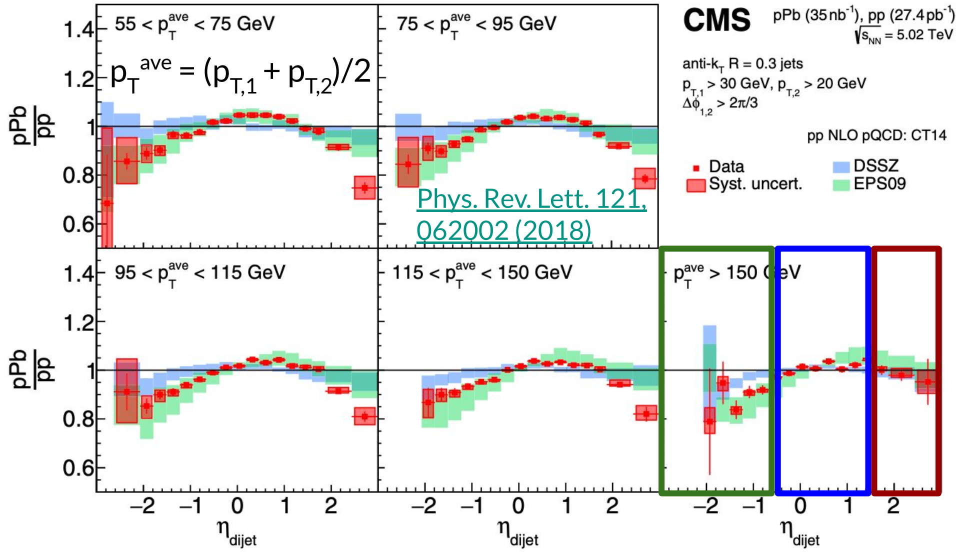


high x_{Pb}
low x_p

low x_{Pb}
high x_p

$$\eta^{dijet} = (\eta_1 + \eta_2)/2$$

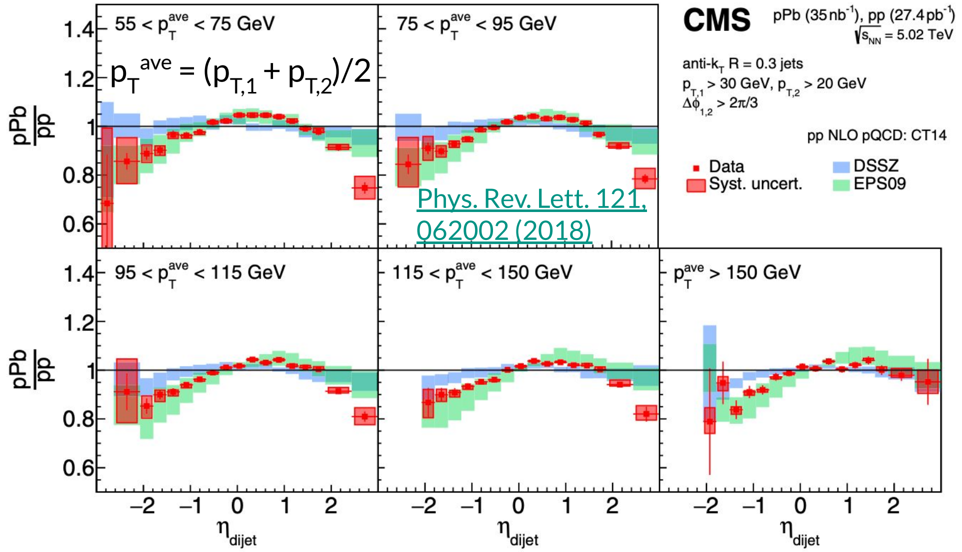
Dijets: nPDF constraints at CMS



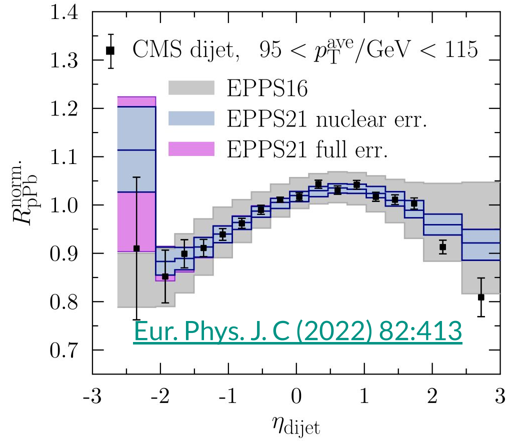
[Phys. Rev. Lett. 121, 062002 (2018)]

- Ratios are consistent with expectation from
  - shadowing ($x \lesssim 10^{-2}$; $\eta_{dijet} > 1.5$)
  - antishadowing ($10^{-1} \lesssim x \lesssim 10^{-2}$; $-0.5 < \eta_{dijet} < 1.5$)
  - EMC ($x \gtrsim 10^{-1}$; $\eta_{dijet} < -0.5$)
- Evidence that gluon PDF (large Bjorken *x*) in Pb is strongly suppressed with respect to that in unbound nucleons

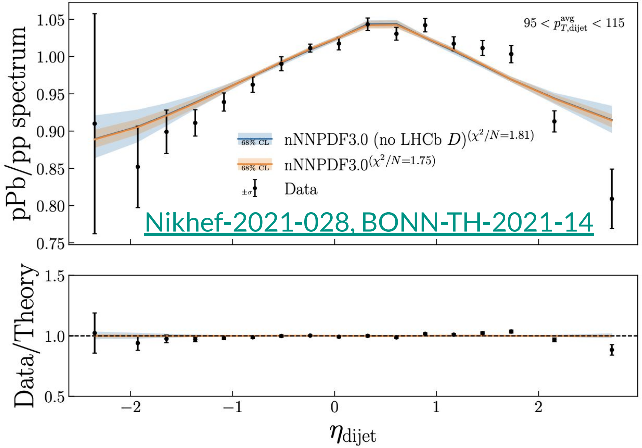
Dijets: nPDF constraints at CMS



[Phys. Rev. Lett. 121, 062002 (2018)]



[Eur. Phys. J. C (2022) 82:413]



[Nikhef-2021-028, BONN-TH-2021-14]

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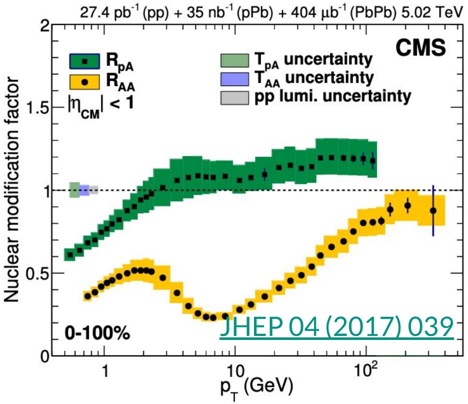
  - EMC ($x \gtrsim 10^{-1}$; $\eta_{dijet} < -0.5$)
- Evidence that gluon PDF (large Bjorken *x*) in Pb is strongly suppressed with respect to that in unbound nucleons
- Data has been used to constrain nPDF's

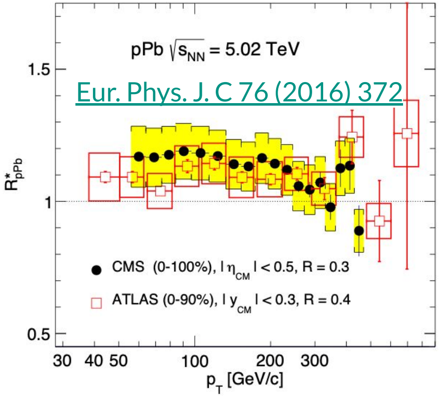
Search for quenching in pPb collisions at CMS

➤ Nuclear modification factor

⇨ $$R_{\mathrm{pPb}} = \frac{1}{A}\frac{\mathrm{d}^2\sigma^{\mathrm{pPb}}_{\mathrm{jet}}/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta}{\mathrm{d}^2\sigma^{\mathrm{pp}}_{\mathrm{jet}}/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta} = \frac{1}{A}\frac{1}{L}\frac{\mathrm{d}^2 N^{\mathrm{pPb}}_{\mathrm{jet}}/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta}{\mathrm{d}^2\sigma^{\mathrm{pp}}_{\mathrm{jet}}/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta}$$



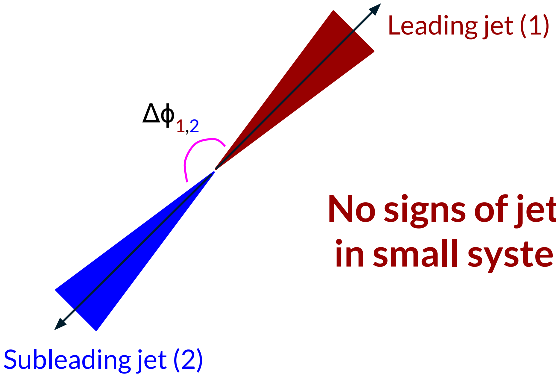
JHEP 04 (2017) 039



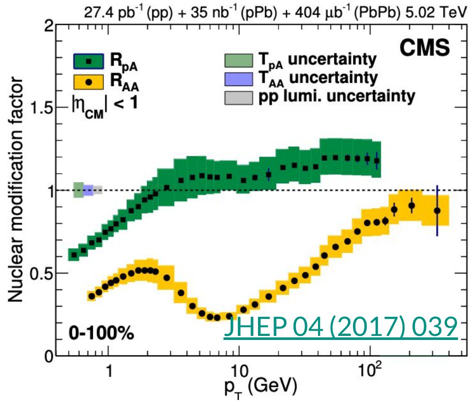
Eur. Phys. J. C 76 (2016) 372

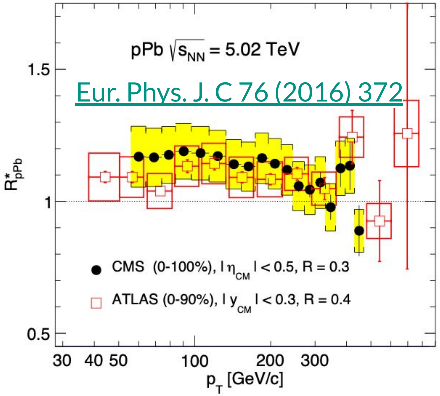
Search for quenching in pPb collisions at CMS

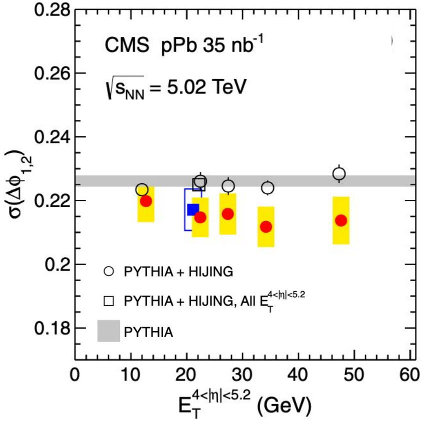
- Nuclear modification factor
  - $$R_{\mathrm{pPb}} = \frac{1}{A}\frac{\mathrm{d}^2\sigma^{\mathrm{pPb}}_{\mathrm{jet}}/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta}{\mathrm{d}^2\sigma^{\mathrm{pp}}_{\mathrm{jet}}/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta} = \frac{1}{A}\frac{1}{L}\frac{\mathrm{d}^2 N^{\mathrm{pPb}}_{\mathrm{jet}}/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta}{\mathrm{d}^2\sigma^{\mathrm{pp}}_{\mathrm{jet}}/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta}$$
- Dijets
  - Azimuthal difference: $\Delta\phi_{1,2}$
  - Momentum imbalance x_j: $p_{T,2}$ / $p_{T,1}$

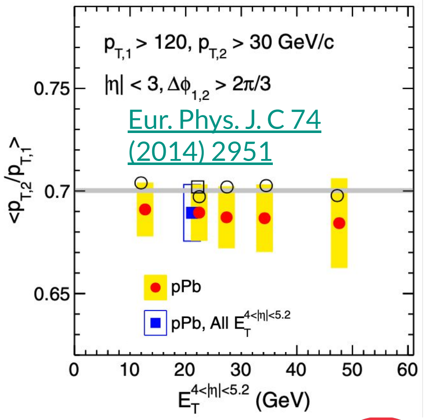


No signs of jet quenching in small systems so far at CMS!







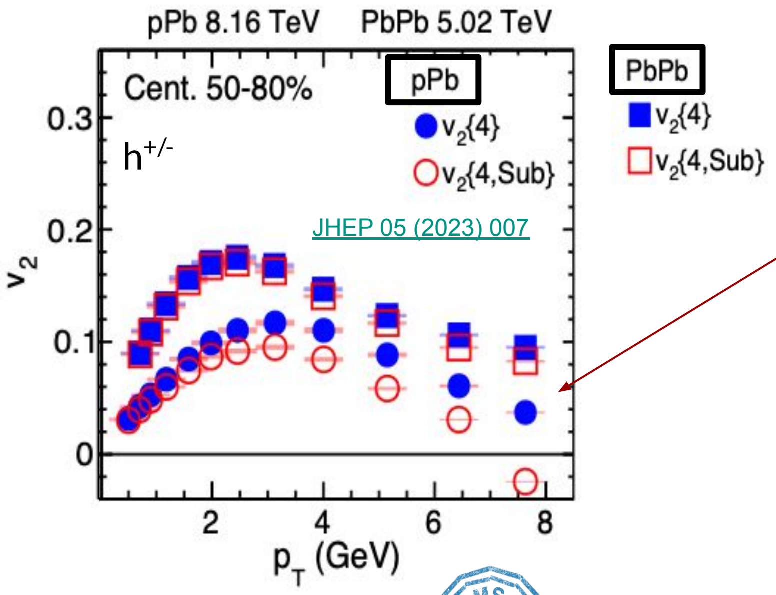


$$\frac{1}{N_{\mathrm{dijet}}}\frac{\mathrm{d}N_{\mathrm{dijet}}}{\mathrm{d}\Delta\phi_{1,2}} = \frac{\mathrm{e}^{(\Delta\phi-\pi)/\sigma}}{(1-\mathrm{e}^{-\pi/\sigma})\,\sigma}$$

E_T: energy deposit at HF

High p_T flow

- No signs of quenching, but non-zero elliptic flow in high-p_T is observed
  - Different non-flow subtraction methods studied



From fragmentation of hard scattered partons

PbPb interpretation: path-length dependency of energy loss

See J. Viinikainen talk
Wed. 9/6, 11:20AM

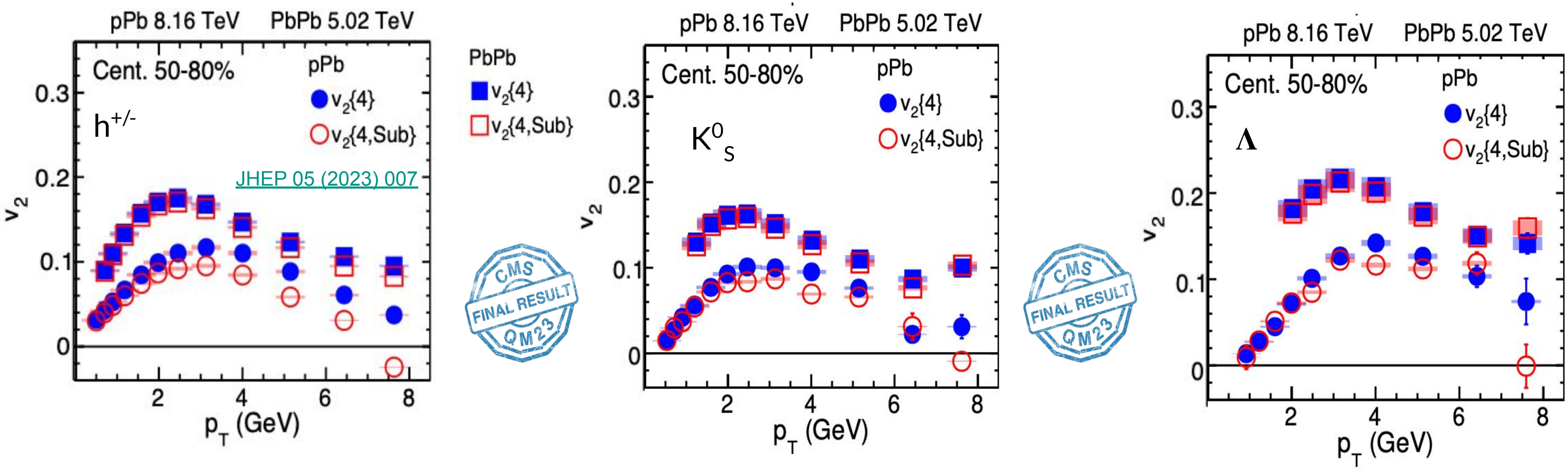
How about pPb? If no quenching is there?

CMS FINAL RESULT QM23

pPb high multiplicity events: 250 > N ≥ 185

High p_T flow

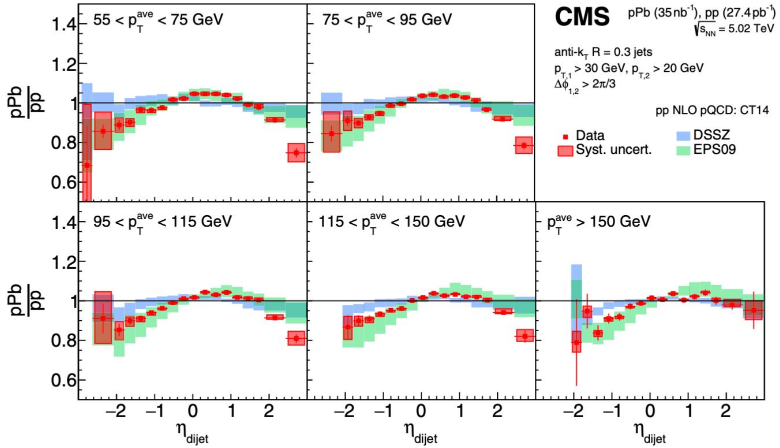
- No signs of quenching, but non-zero elliptic flow in high-p_T is observed
  - Different non-flow subtraction methods studied
  - Study also performed for different particle species

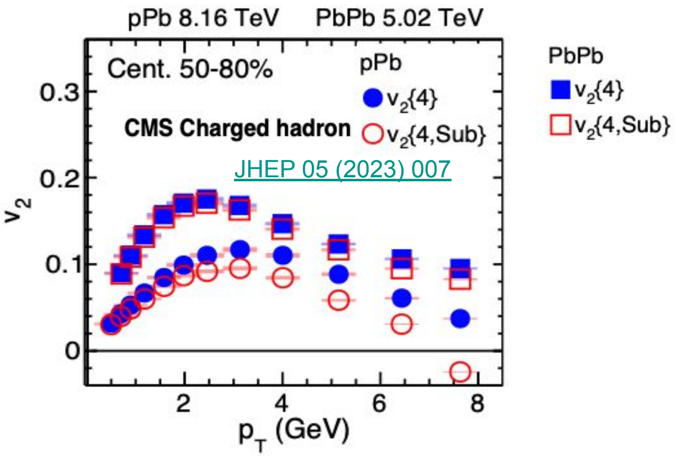


pPb high multiplicity events: 250 > N ≥ 185

Summary

- pPb is an important tool to study and understand nuclear matter
  - Useful to study both initial and final states
    - **So far, no evidence of quenching**
    - **Non-zero v_2 observed in higher-p_T in pPb collisions**
      - observed for different particle species



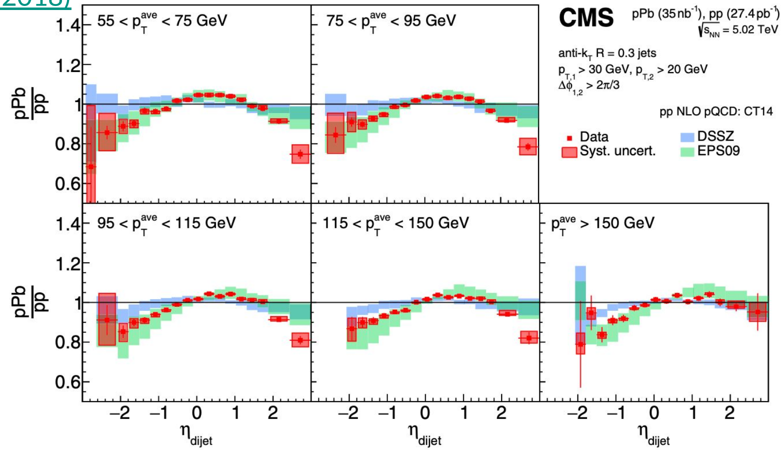


Phys. Rev. Lett. 121, 062002 (2018)

In a near future …

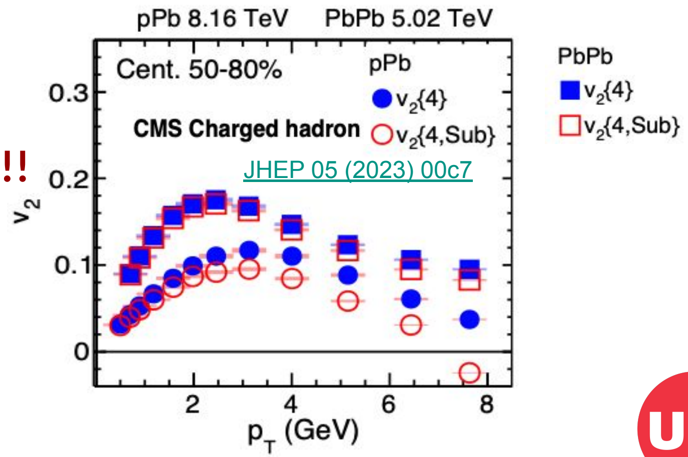
- Measurements at pPb@8.16 TeV are ongoing and coming soon!
  - Study of cold nuclear matter effects
    - ➔ Additional constraints for nPDF models
  - Search for jet quenching using high multiplicity events
  - and more …

Phys. Rev. Lett. 121, 062002 (2018)



Stay tuned!!!

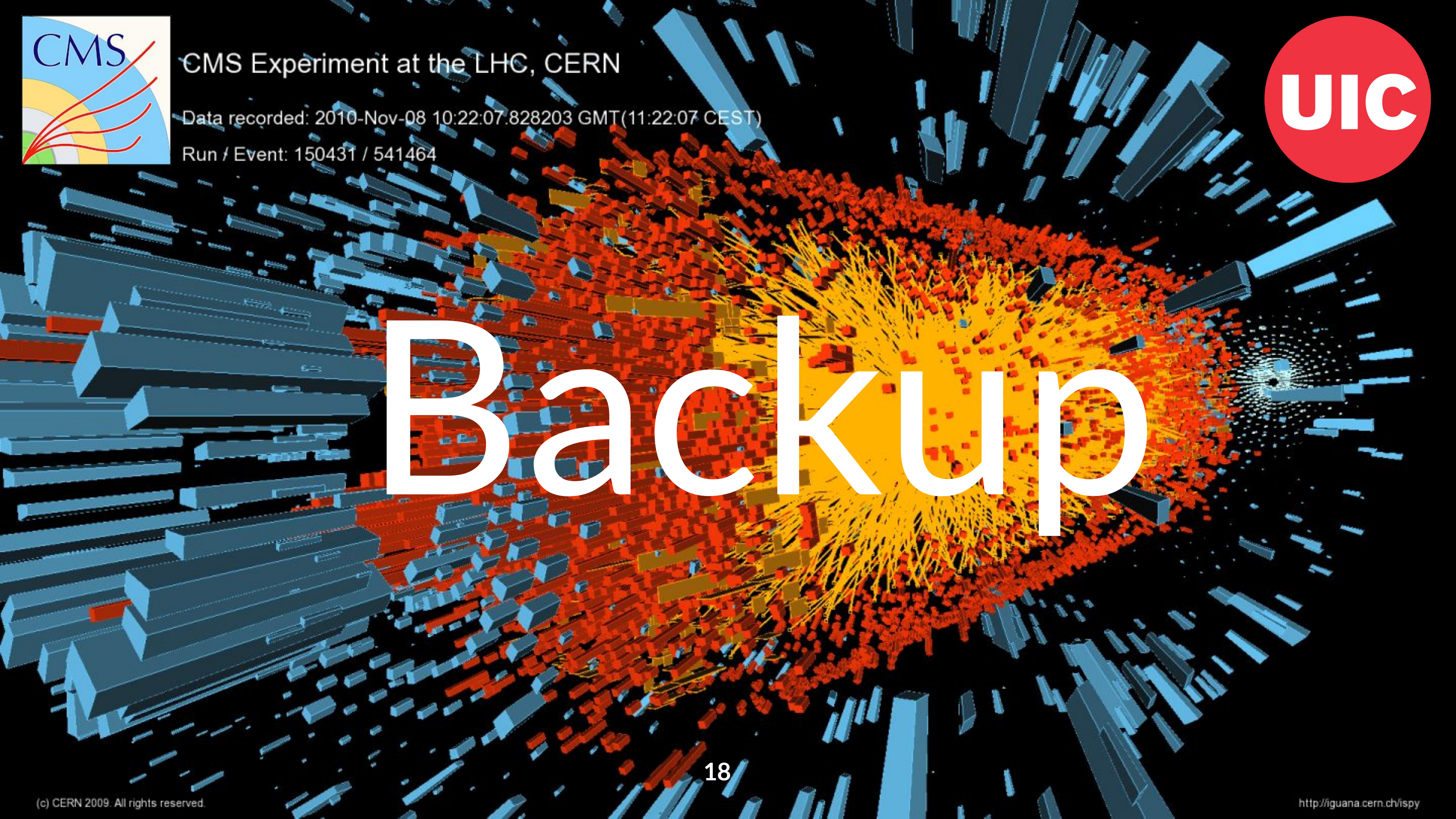
JHEP 05 (2023) 00c7



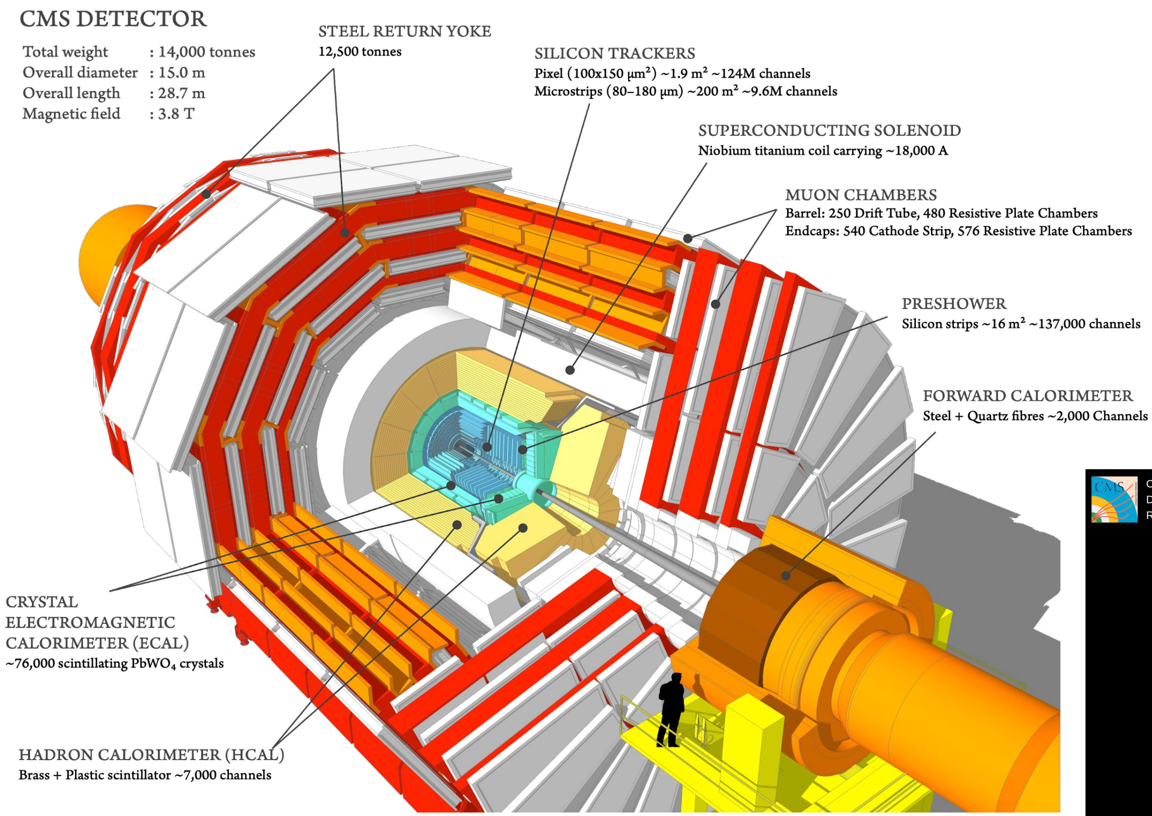
Thank You

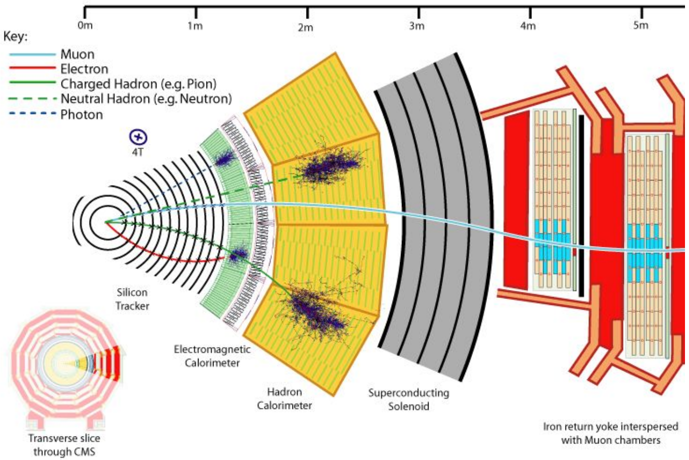
The work of the UIC HENP group is supported by the DOE-NP grant

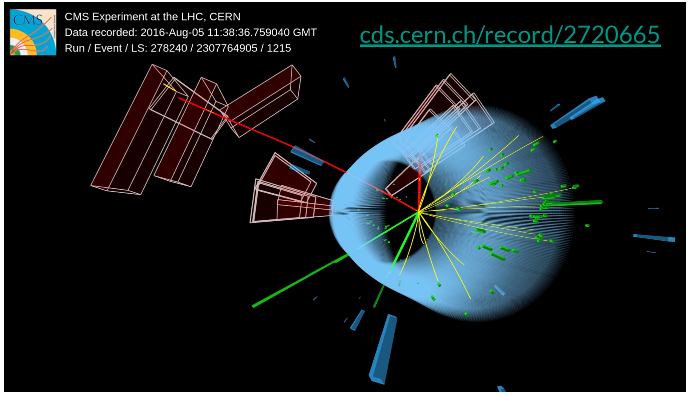
Backup


CMS
CMS Experiment at the LHC, CERN
Data recorded: 2010-Nov-08 10:22:07.828203 GMT(11:22:07 CEST)
Run / Event: 150431 / 541464
(c) CERN 2009. All rights reserved.
http://iguana.cern.ch/ispy

The CMS detector

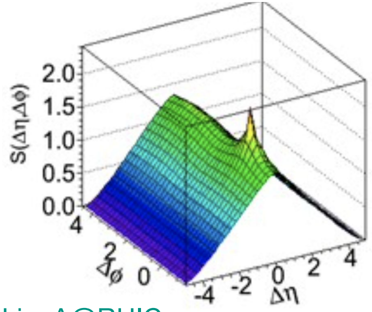






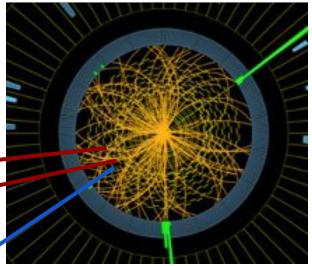
Measurement of two particle correlations (I)

- Two particle correlations
  - trigger particle (in p_T^{trg})
  - associate particle (in p_T^{ass})

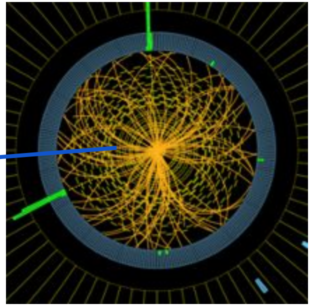


Wei Li, pA@RHIC

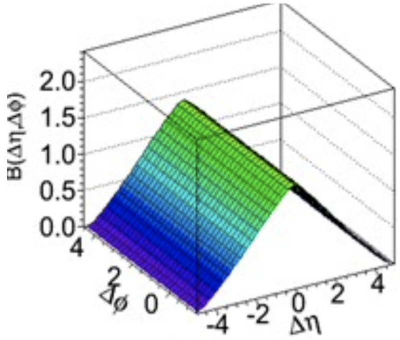
$$S(\Delta\eta,\Delta\phi) = \frac{1}{N_{trig}} \frac{d^2N^{same}}{d\Delta\eta\, d\Delta\phi}$$



cds.cern.ch/record/2736135



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



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

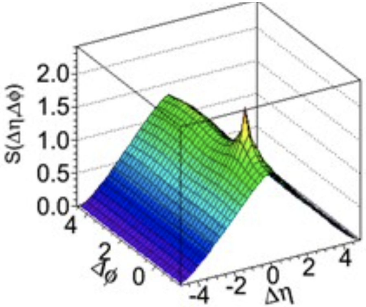
$\Delta\phi = \phi^{assoc} - \phi^{trig}$

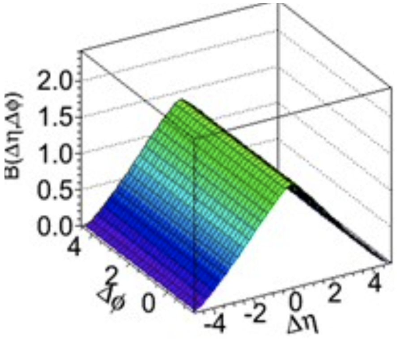
Measurement of two particle correlations (I)

- Two particle correlations
  - trigger particle (in p_T^{trg})
  - associate particle (in p_T^{ass})

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

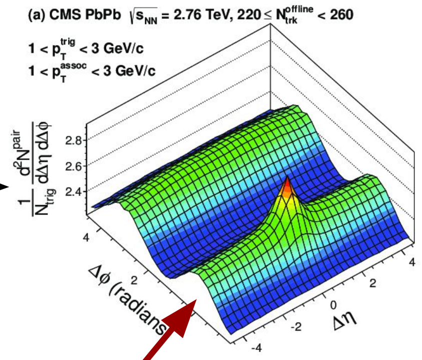
B(0,0) x





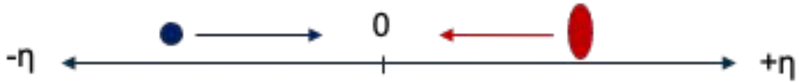
Wei Li, pA@RHIC

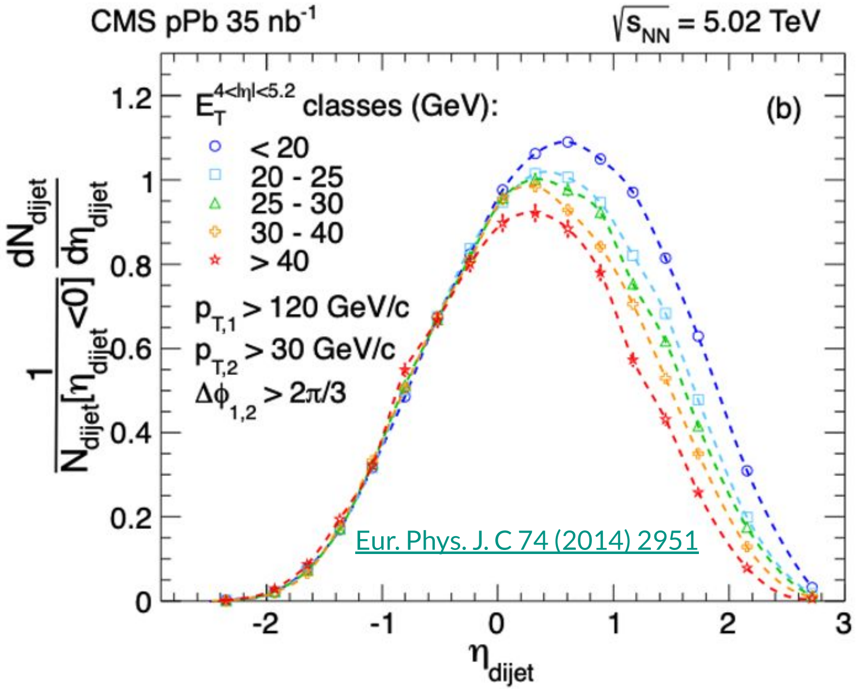
Phys. Lett. B 724 (2013) 213



“ridge”: related with collectivity

Dijet pseudorapidity distributions as function E_T (I)





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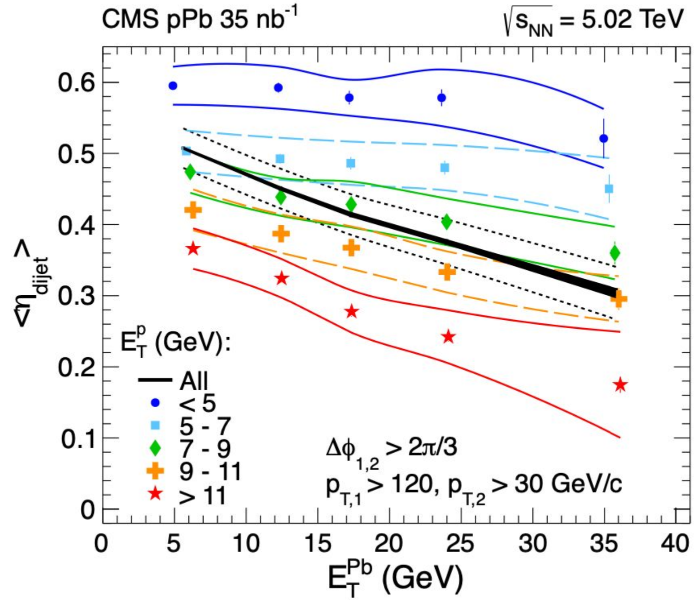
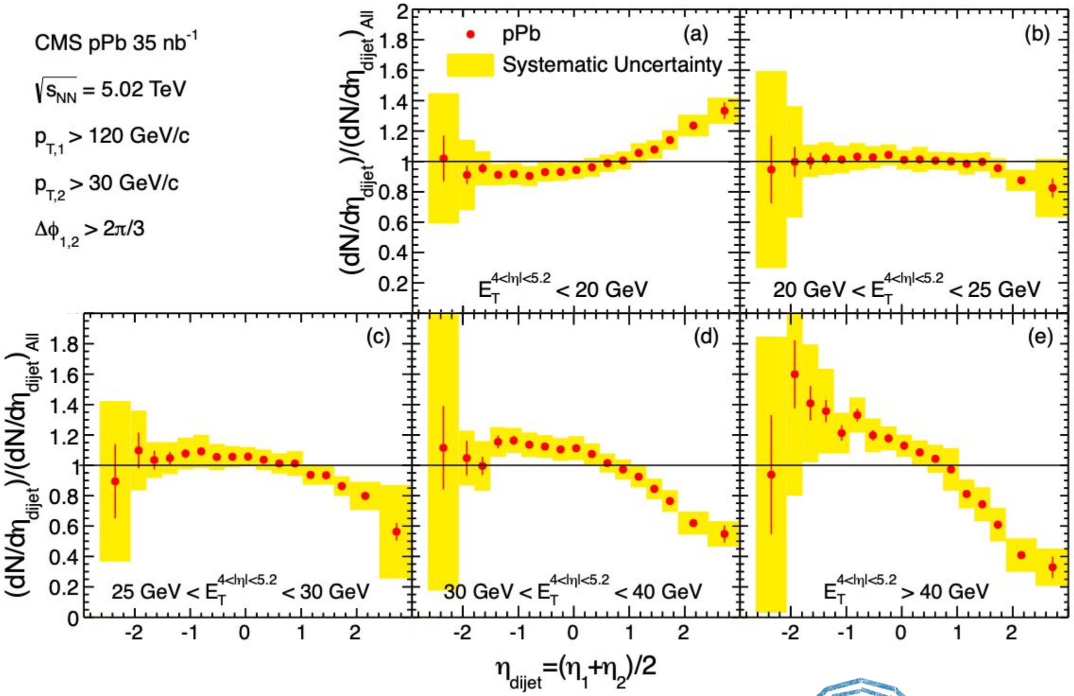


← **Going towards to Pb direction**

Dependency of energy in p and Pb directions

Dijet pseudorapidity distributions as function E_T (II)

- Ratio to all
  - Low E_T : ratio increased from negative to positive
  - high E_T^{Pb}: opposite behavior
- Possible effects
  - modifications of the PDFs due to the fluctuating size of the proton
  - impact parameter dependence of the nPDFs
  - among others…



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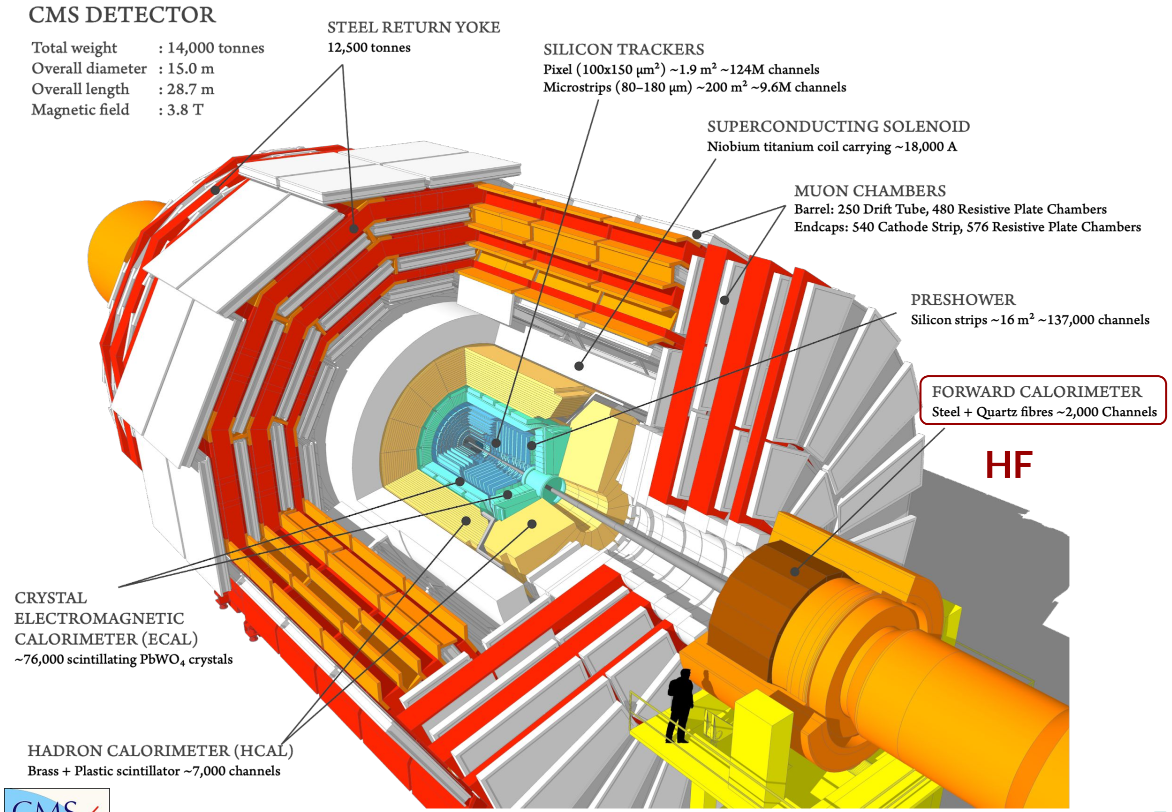
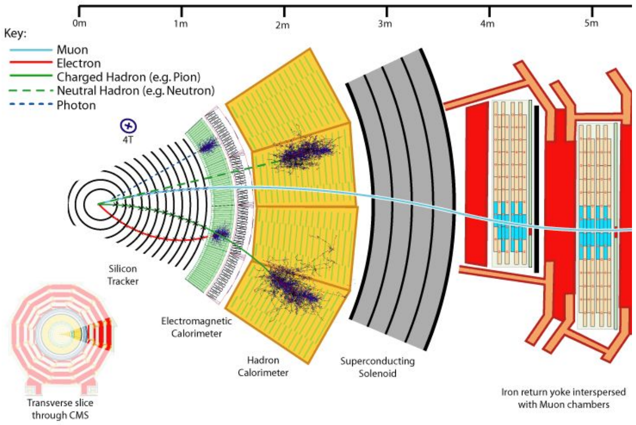
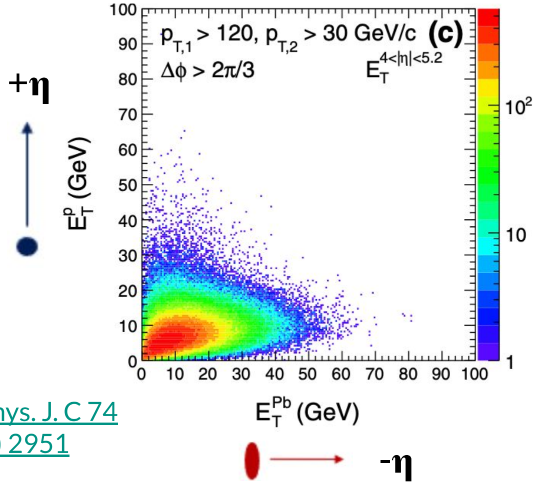
CMS FINAL RESULT QM23

The CMS detector







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Flow with Jet veto

- Jet veto to remove events with jet pT > 20 GeV
  - v_2 increases when removing higher pT jets (as expected → non-flow)
  - Not clear why subevent is showing the opposite behavior