CMS Overview

Yi Chen (MIT) for the CMS Collaboration

Initial Stages 2021, Jan 10-15, 2021

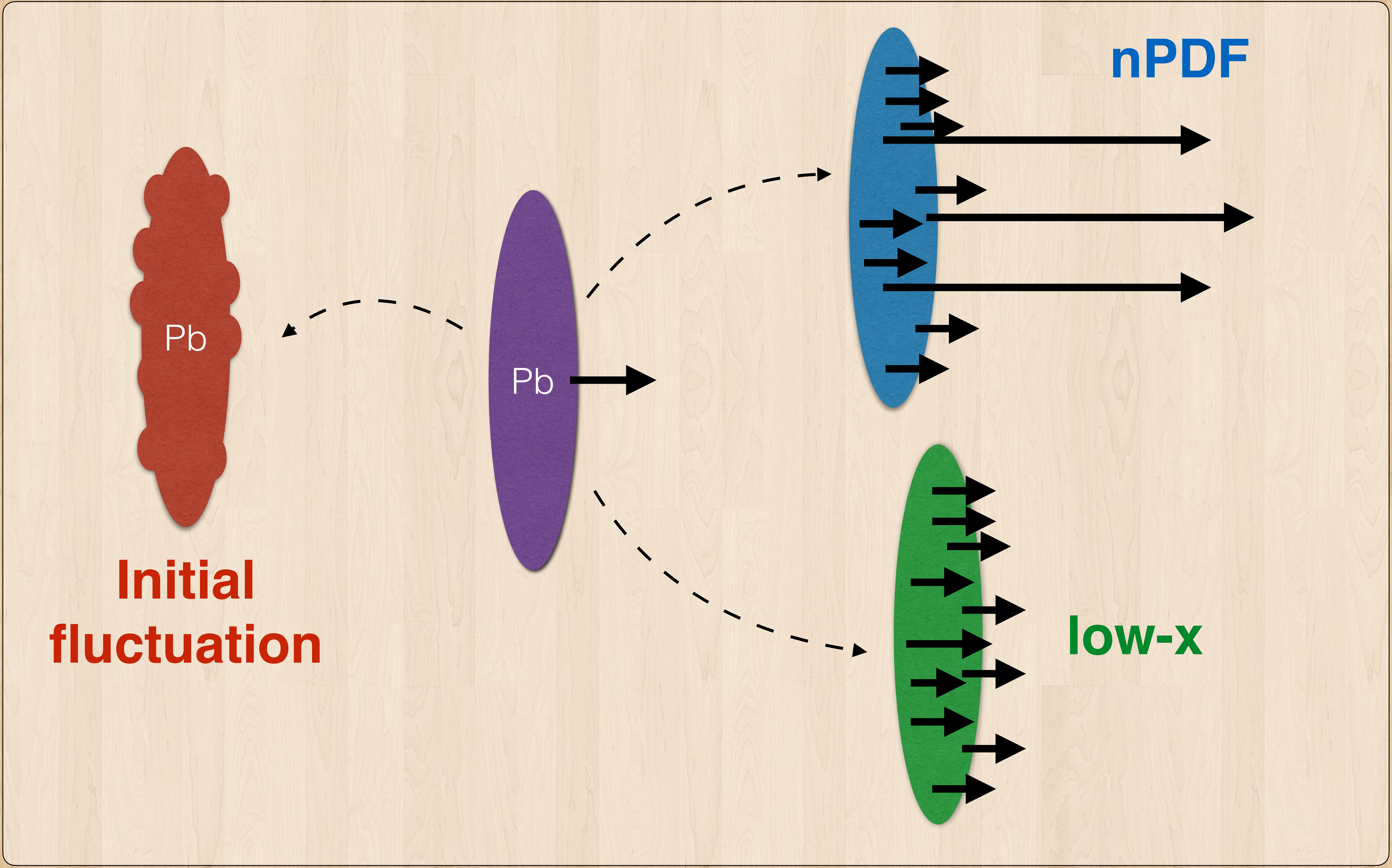
The MIT HIG's work is supported by US DOE-NP

CMS Heavy-Ion Data

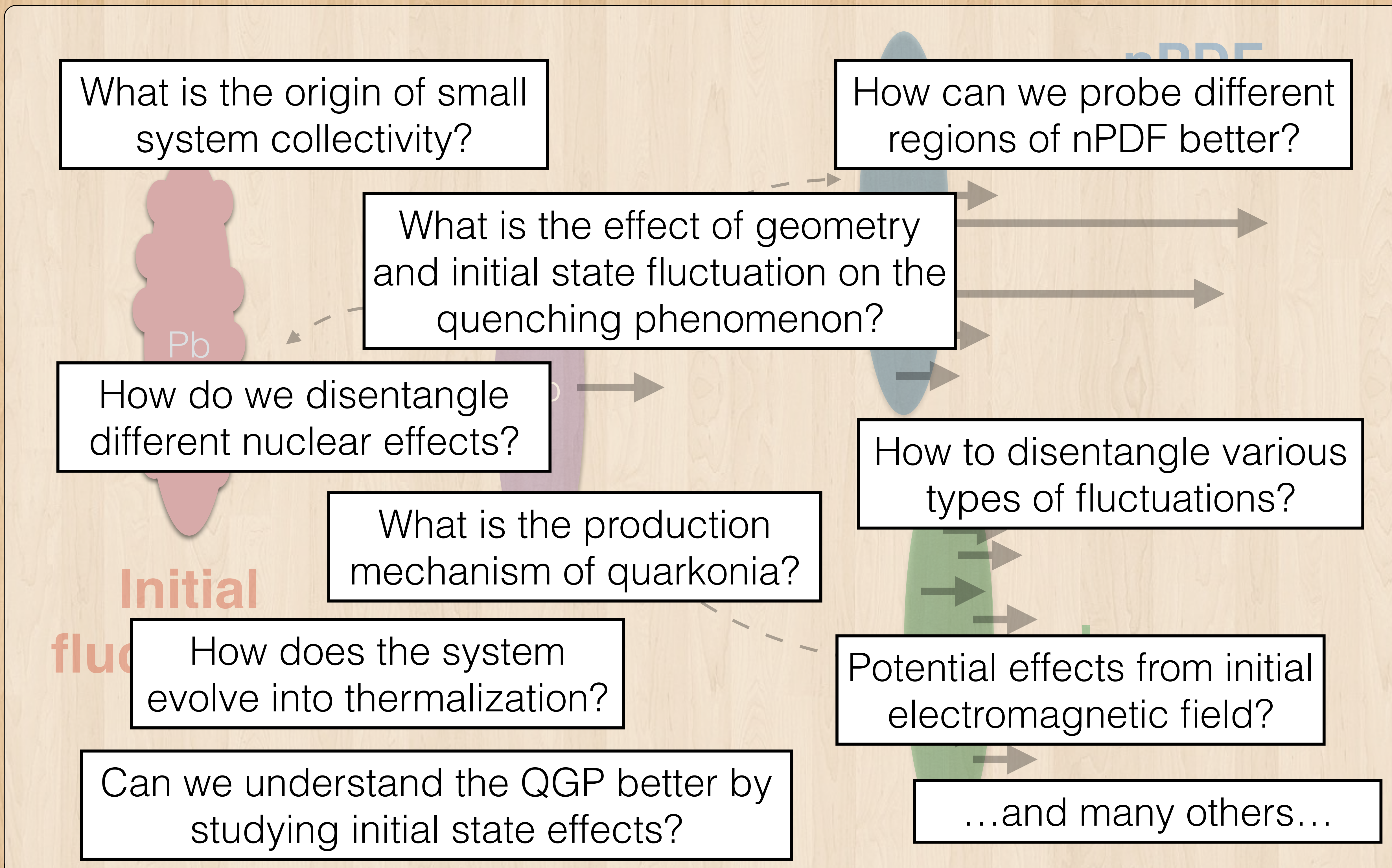
Year	System	E (TeV)	Data
2011	PbPb	2.76	174.3 μb^{-1}
2013	pPb	5.02	35.5 nb^{-1}
2015	PbPb	5.02	0.55 nb^{-1}
2016	pPb	8.16	180.2 nb^{-1}
2017	XeXe	5.44	6.0 μb^{-1}
2018	PbPb	5.02	1.7 nb^{-1}

Special thanks to the LHC team and everyone involved in data taking

Topics

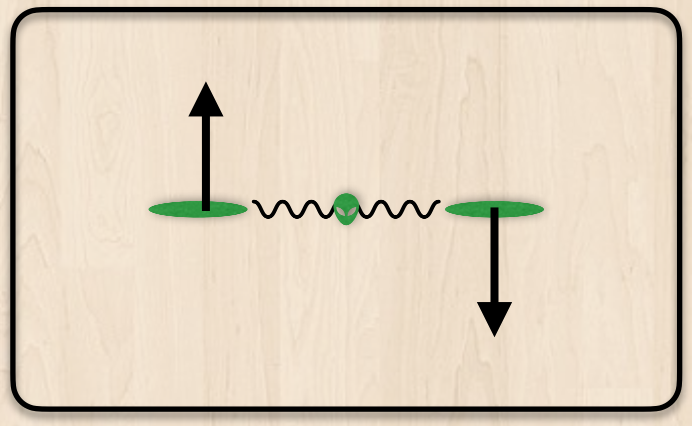


(Some of the) questions

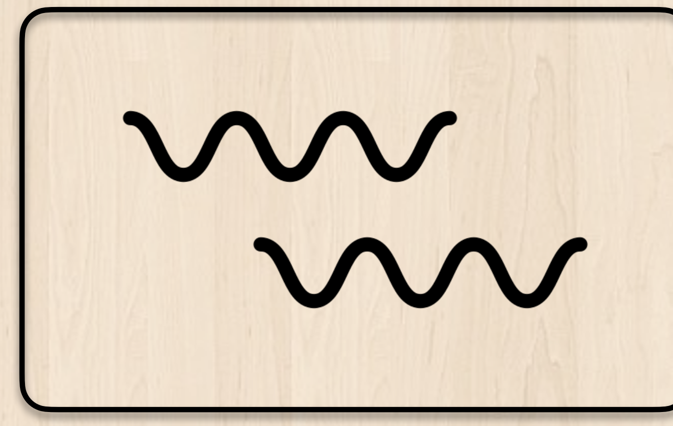


- What is the origin of small system collectivity?
- How can we probe different regions of nPDF better?
- What is the effect of geometry and initial state fluctuation on the quenching phenomenon?
- How do we disentangle different nuclear effects?
- How to disentangle various types of fluctuations?
- What is the production mechanism of quarkonia?
- How does the system evolve into thermalization?
- Potential effects from initial electromagnetic field?
- Can we understand the QGP better by studying initial state effects?
- …and many others…

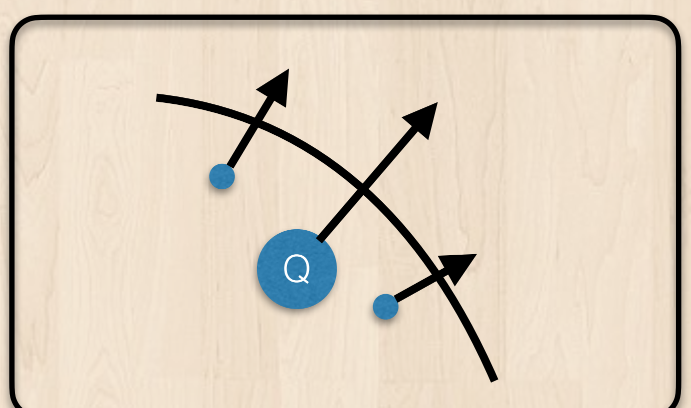
Broad categories



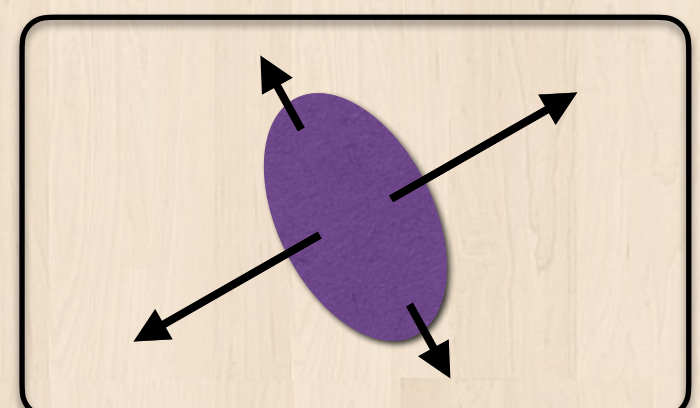
Ultra-peripheral



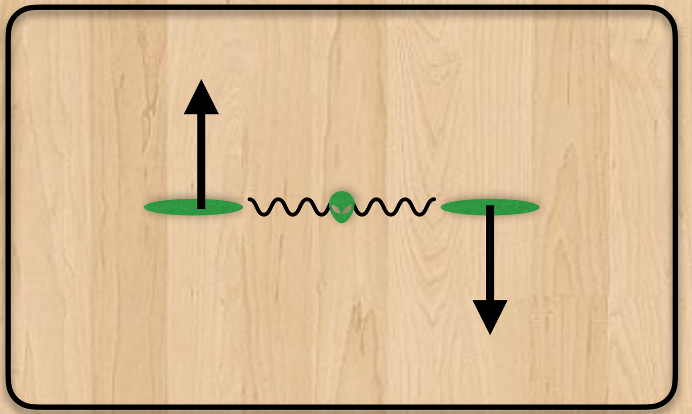
Electroweak



Heavy-flavor

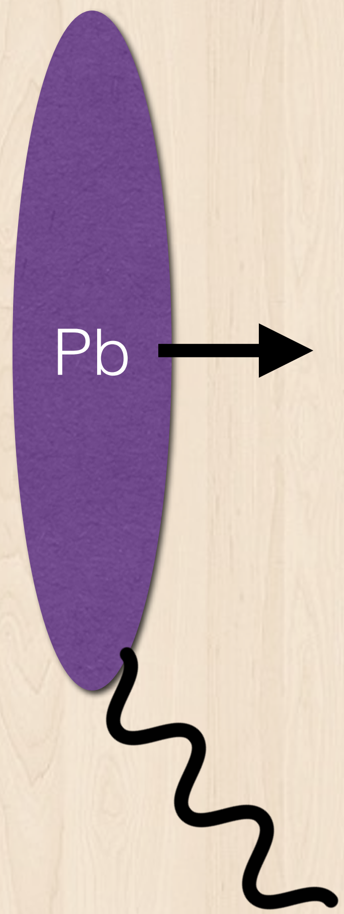


Correlations



Ultra-peripheral collisions (UPC)

Ultra-peripheral



Pomeron / γ

Clean environment:
no hot medium effects

Large EM flux around the ion

γ-Pb & Pomeron-Pb topologies

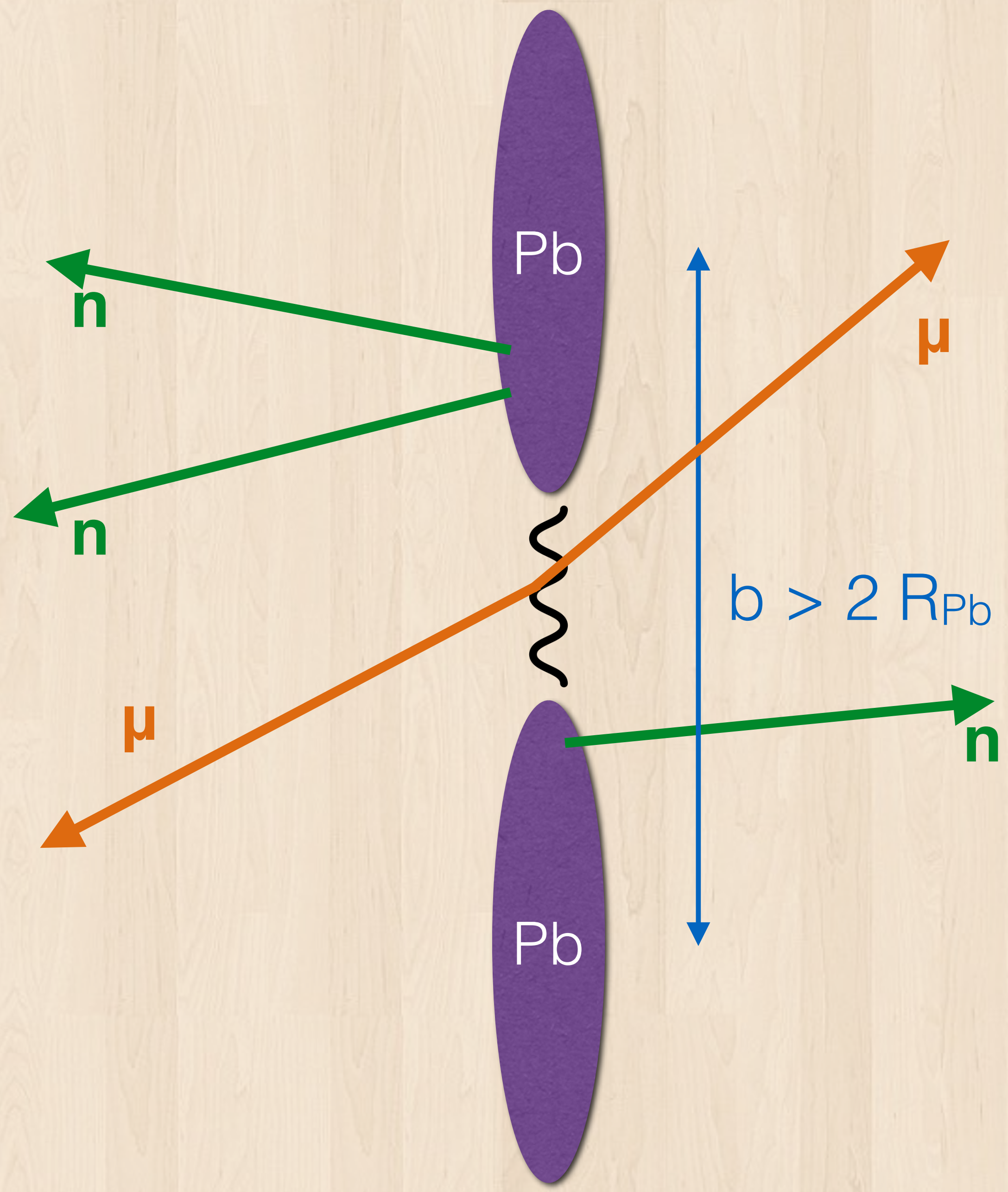
Exclusive dimuon

$$\gamma\gamma \rightarrow \mu^+\mu^-$$

Impact parameter =>
photon energy

Photon energy (p_T) =>
dimuon back-to-back-ness

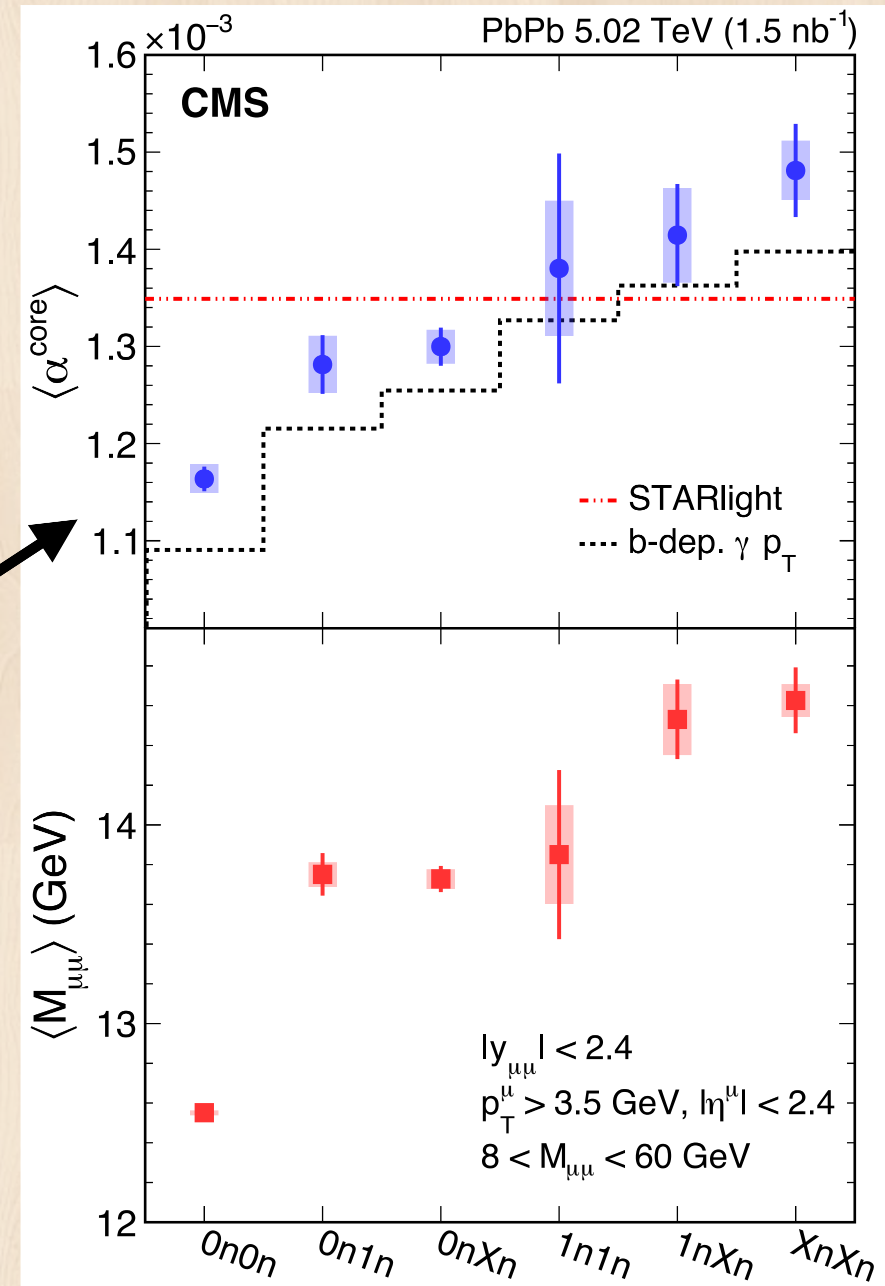
impact parameter =>
number of forward
neutrons



Exclusive dimuon

Acoplanarity

$$\alpha \equiv 1 - \frac{\Delta\phi_{\mu\mu}}{\pi}$$



Less back-to-back

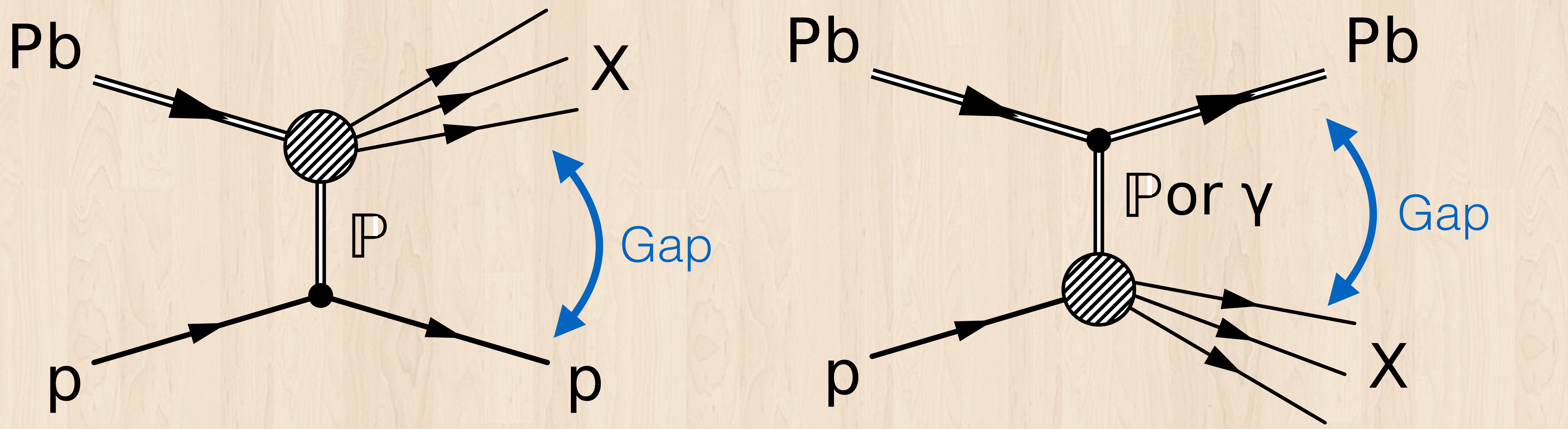
More back-to-back

Correlation: dimuon and forward neutron!

Fewer neutrons — More neutrons

α broadening is seen as a function of impact parameter without a hot QCD medium

Forward Rapidity Gap



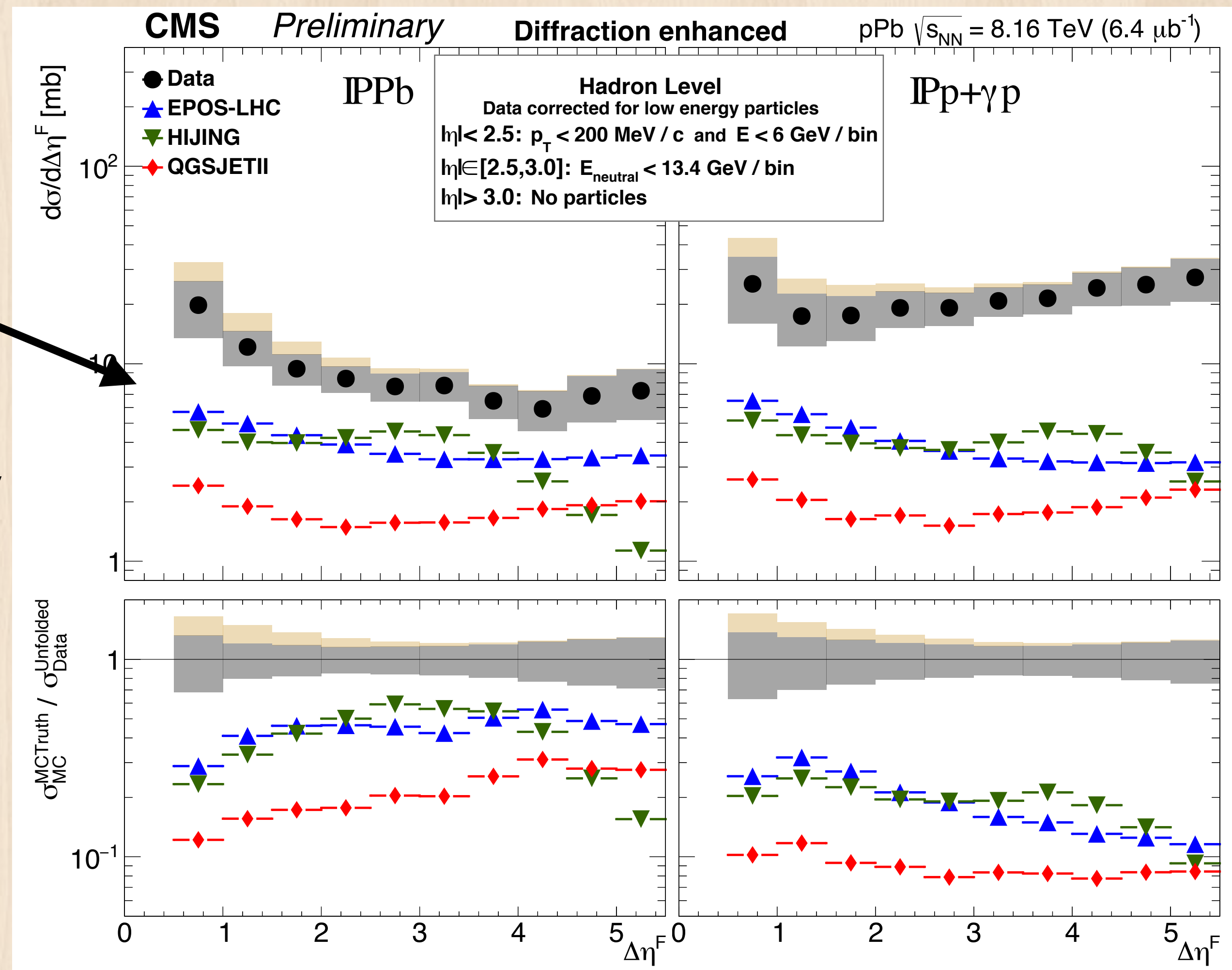
By looking into non-hadronic events, we gain access to pomeron / photon interactions

Characteristics: large forward rapidity gap in the detector (region with no visible activity)

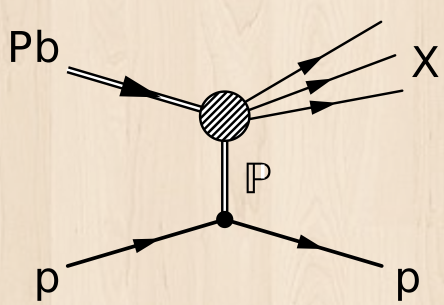
Forward Rapidity Gap

Pomeron-Pb

Trend generally captured by generators

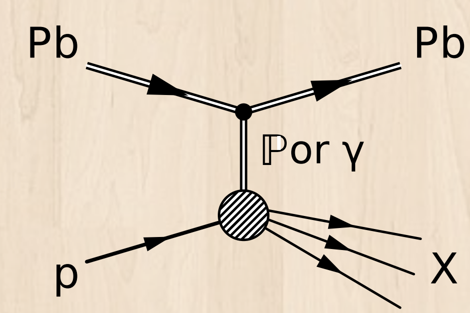


Also sensitive to **γ-p**

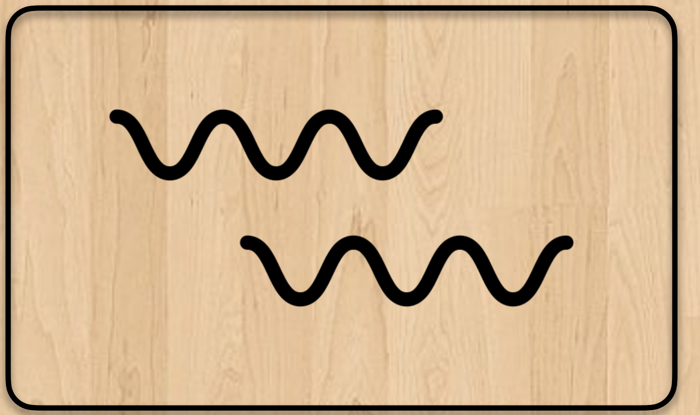


Larger gap

Larger gap

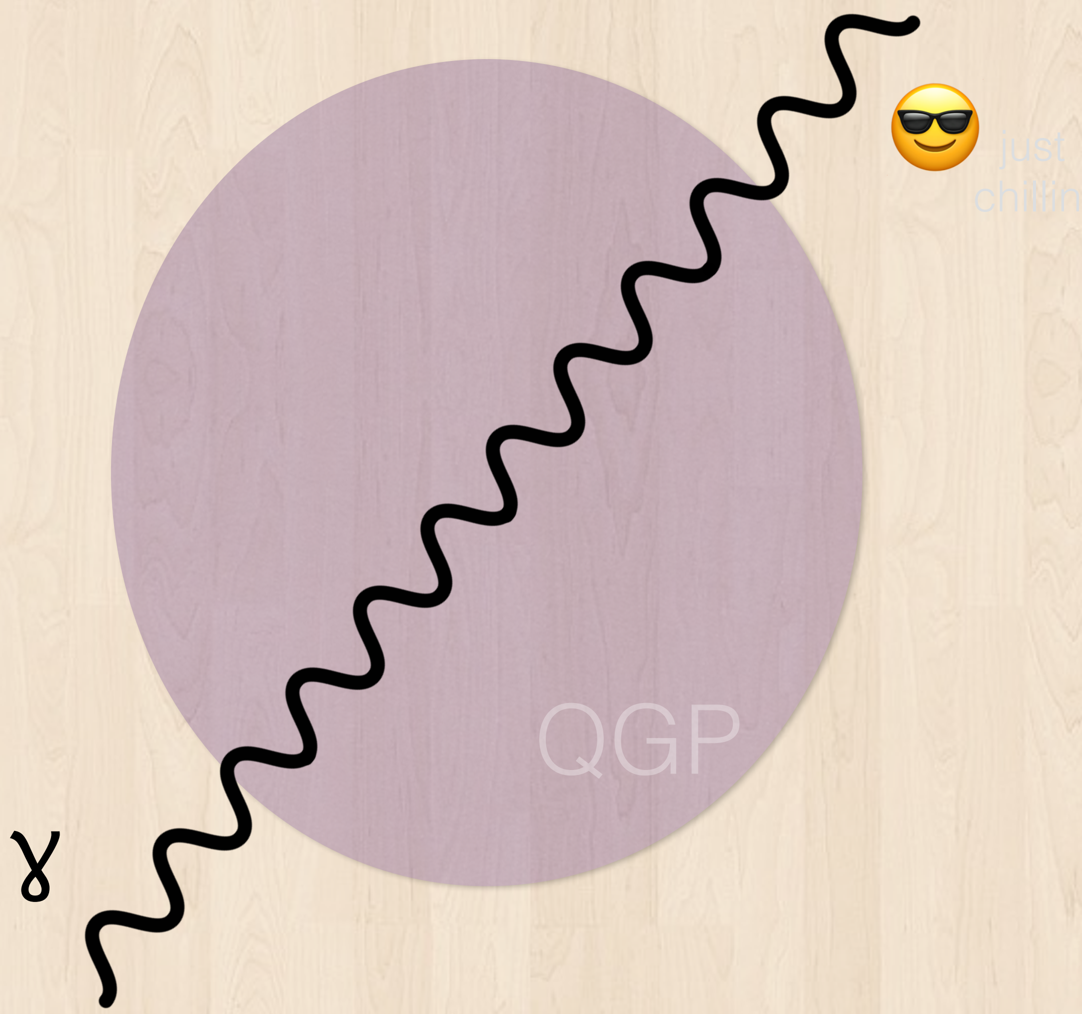


Valuable input to generators



Electroweak results

Electroweak

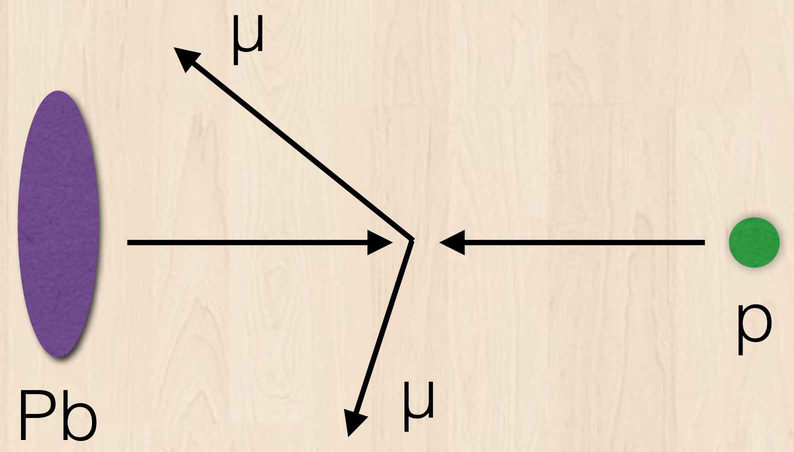


Do not interact strongly with the hot QCD medium

Probes initial state

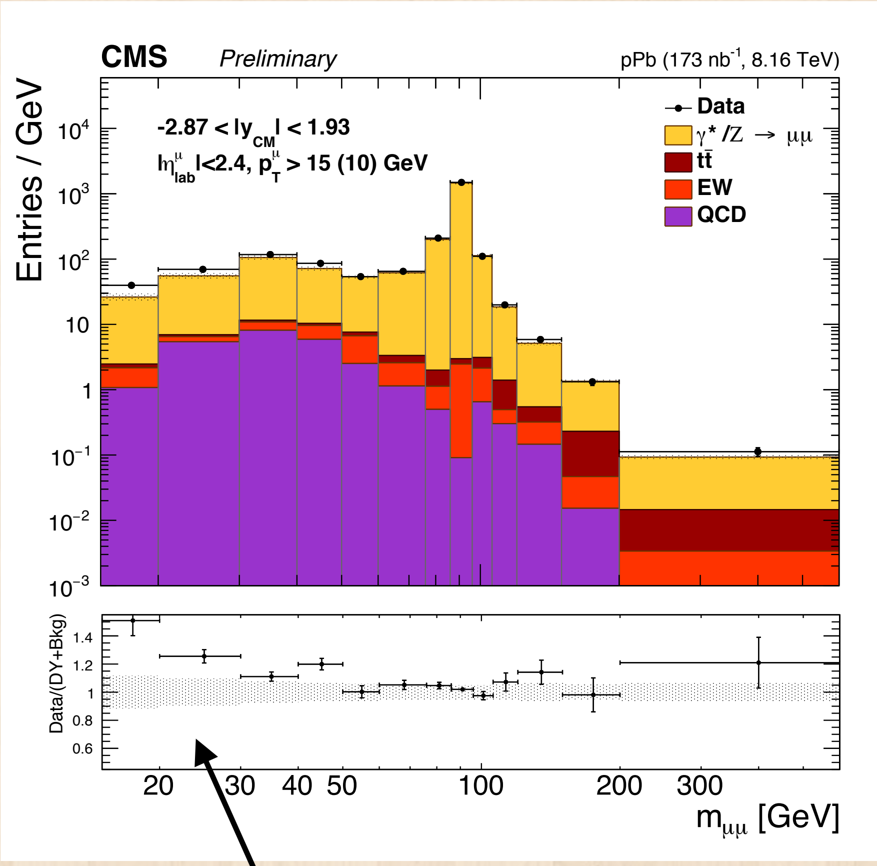
Good reference for other measurements

Z/γ* in pPb



Measurement of dimuon mass, p_T, rapidity, and for the first time in heavy-ion, φ*

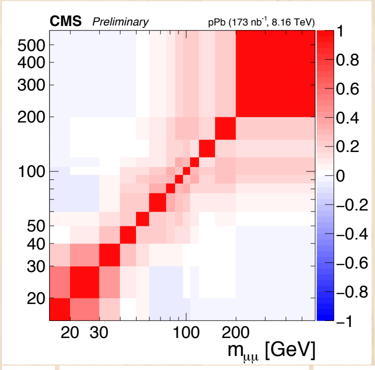
Highly correlated to p_T/mass but constructed entirely from angular quantities



Low mass => low x

Input to nPDF

Full correlation matrix provided



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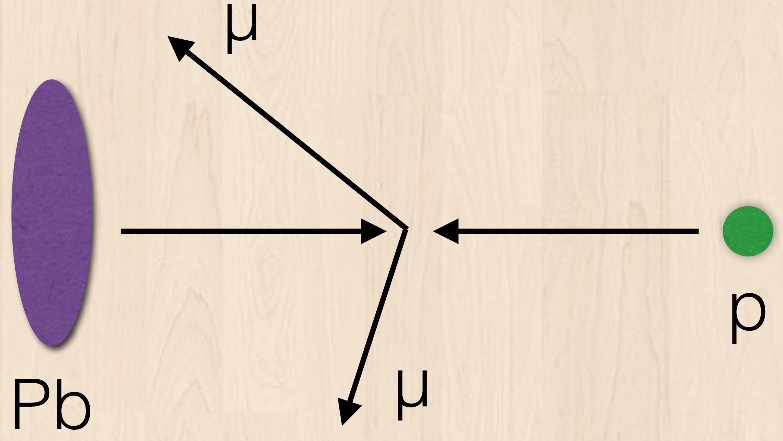
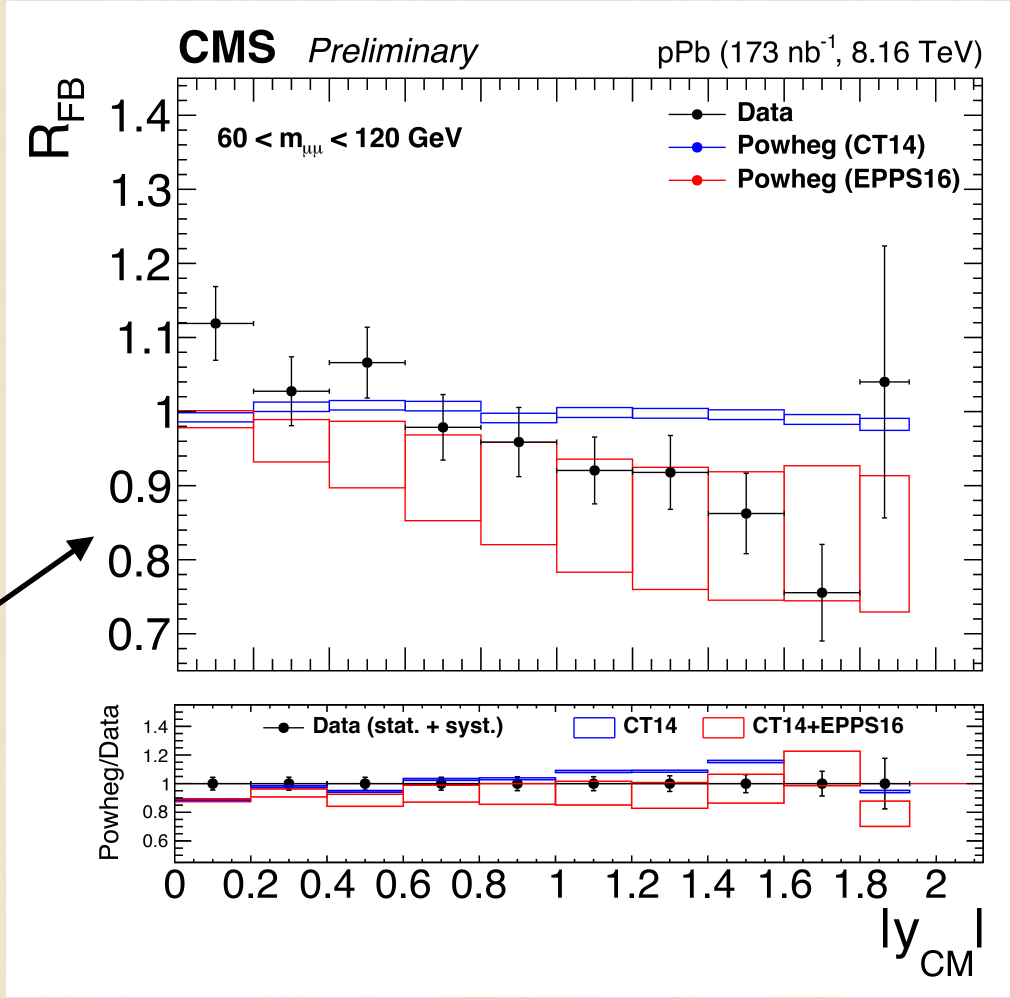


Measurement of dimuon mass, p_T, rapidity, and for the first time in heavy-ion, ϕ^*

Forward-backward ratio

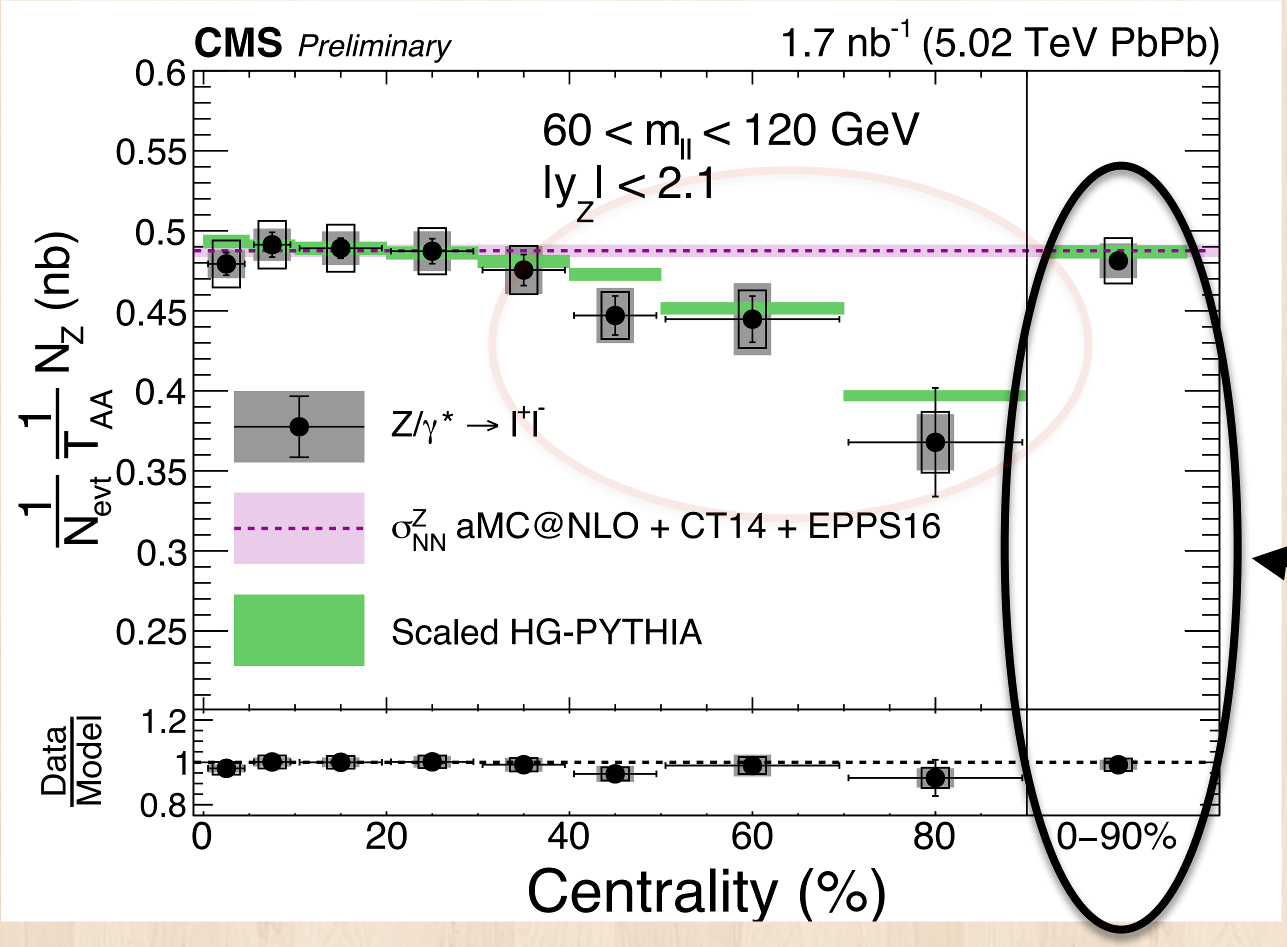
$$R_{FB} = \frac{d\sigma/dy\,|_{y>0}}{d\sigma/dy\,|_{y<0}}$$

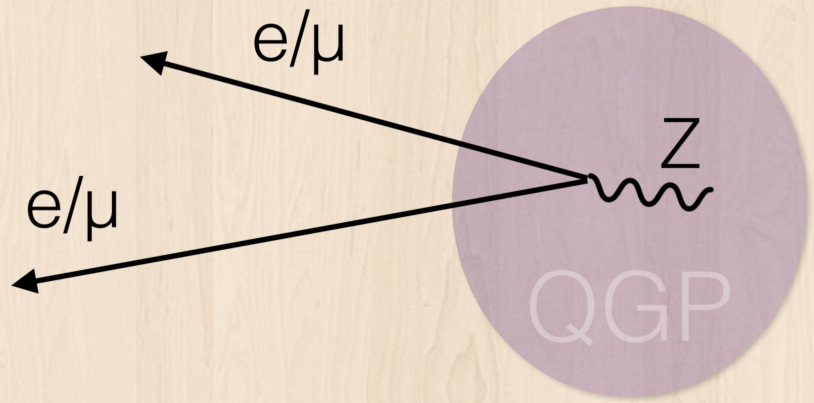
Prediction from **nPDF** matches better than **free proton PDF**



Z boson in PbPb

Z boson yield as a function of centrality





Overall no suppression

Some apparent "suppression" in peripheral 😱

Trend captured with selection+geometry (HG-PYTHIA)

Z boson in PbPb

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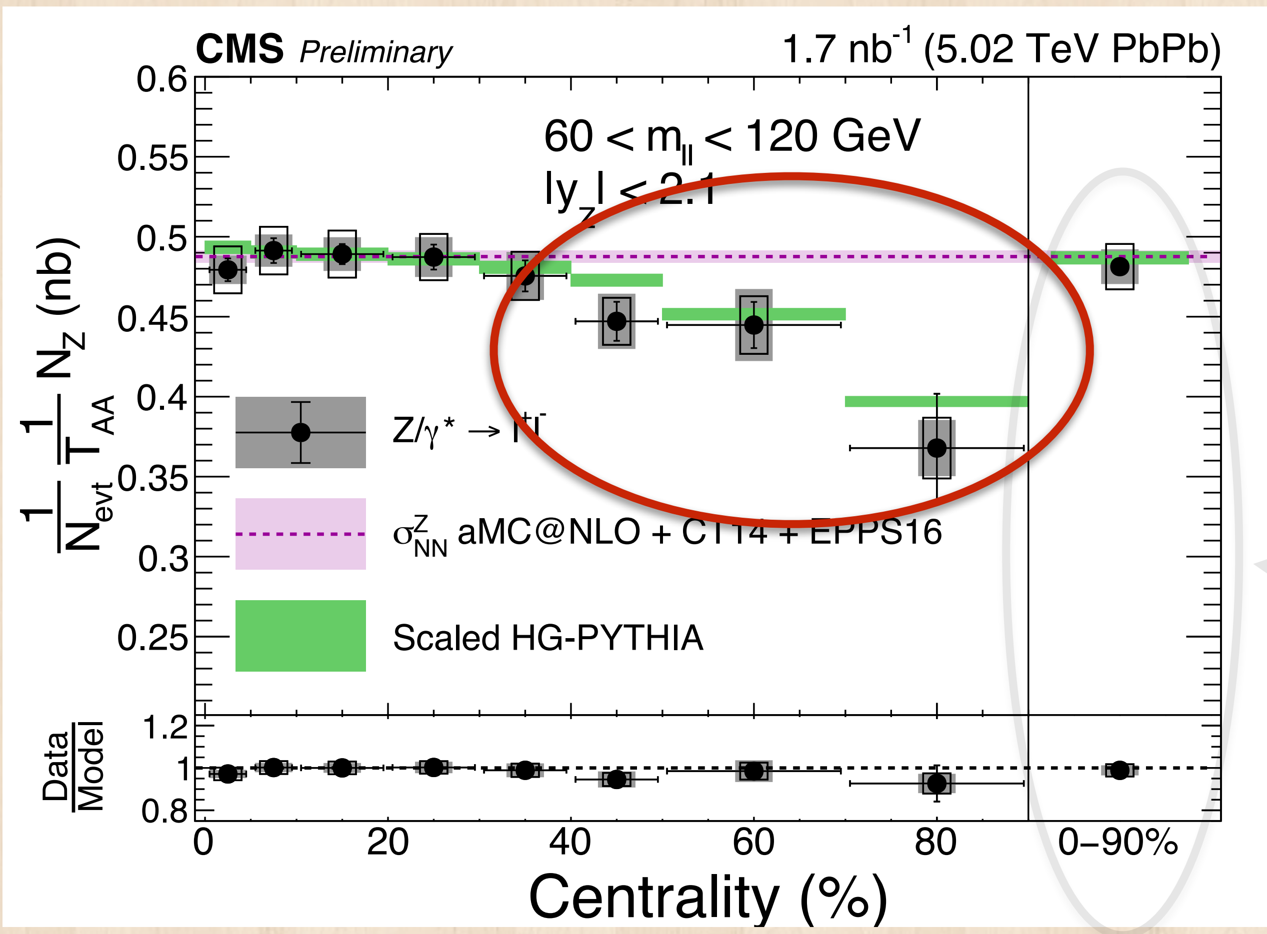

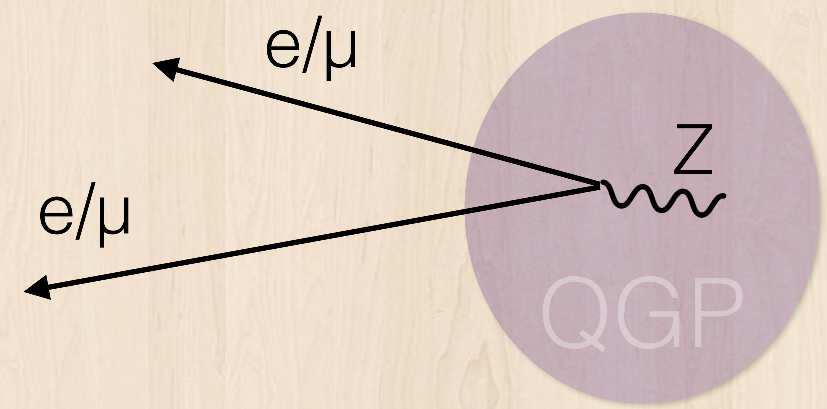

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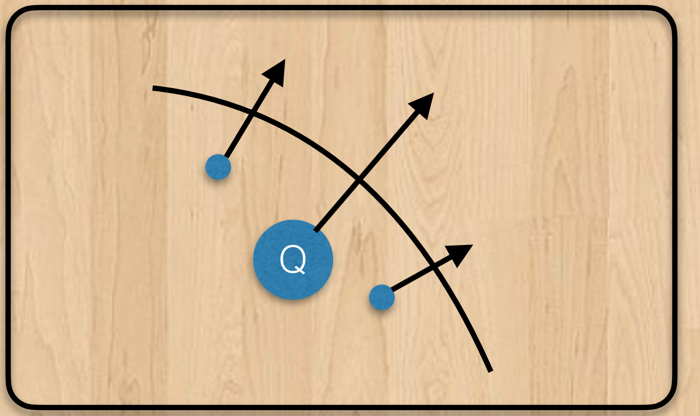
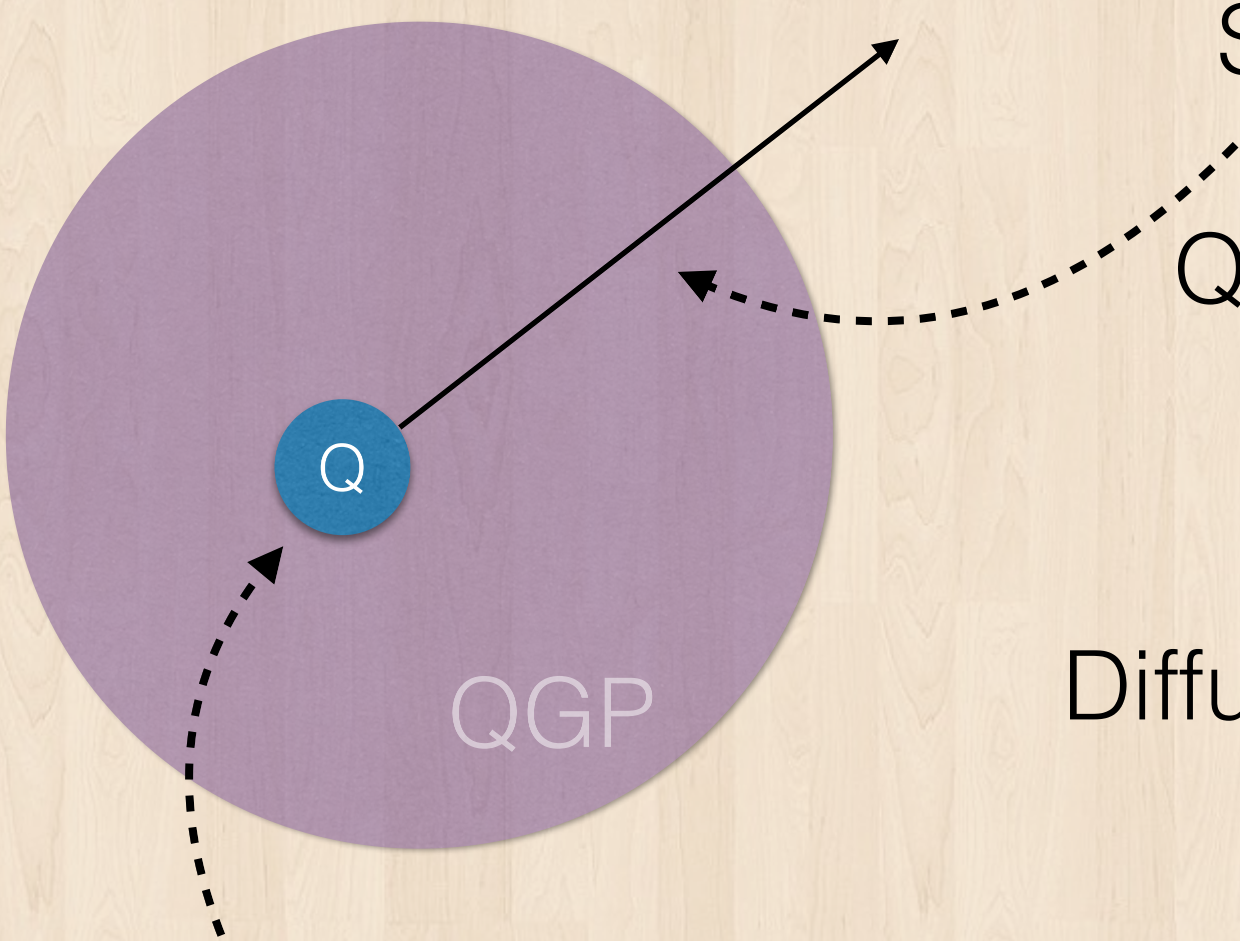


Heavy Flavor

Heavy Flavor

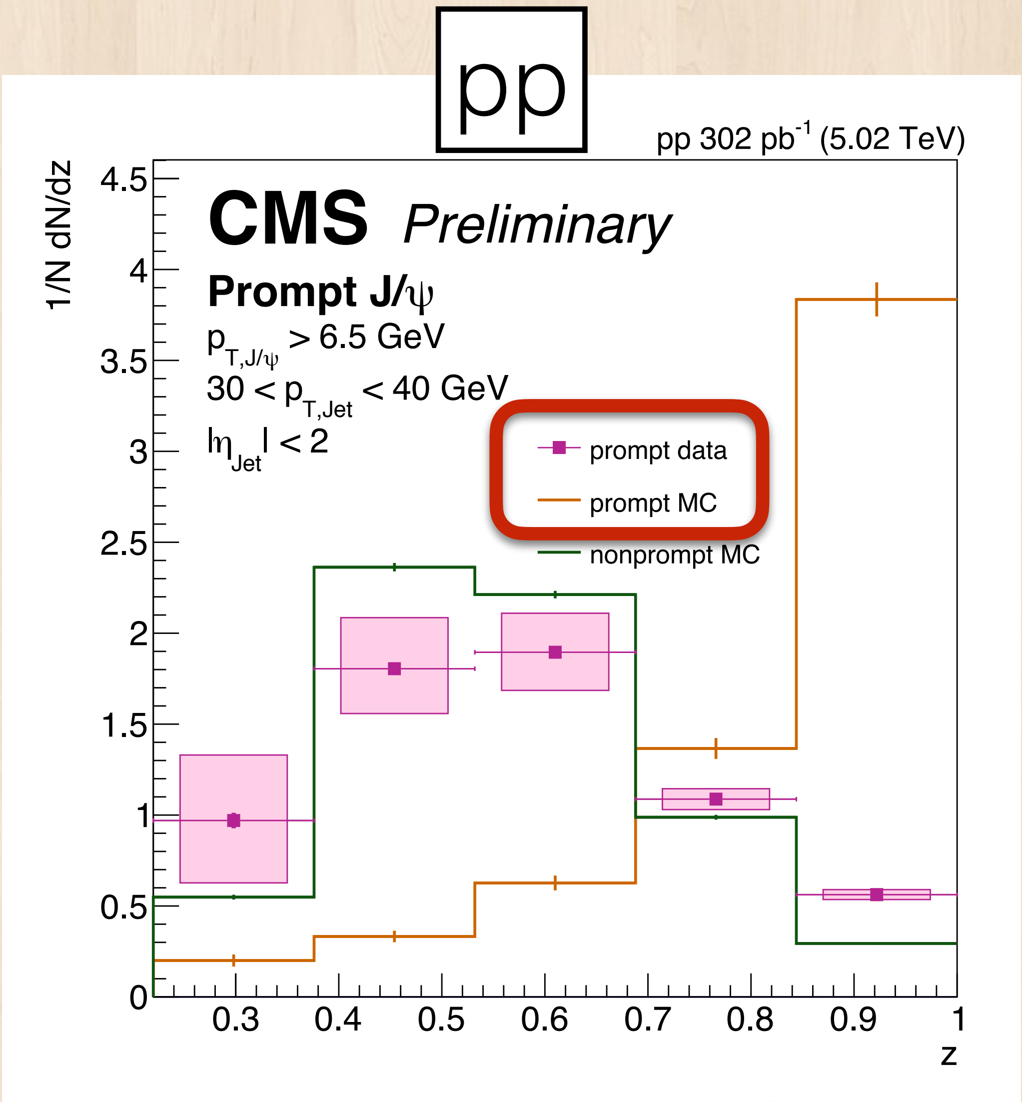


Samples the entirety of QGP evolution

Diffusive movement in QGP

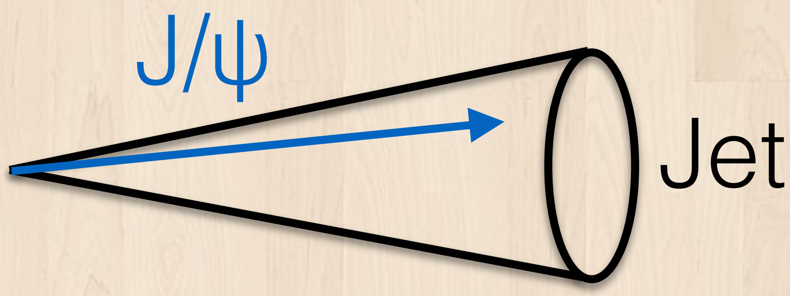
Produced early-on

J/ψ in Jet

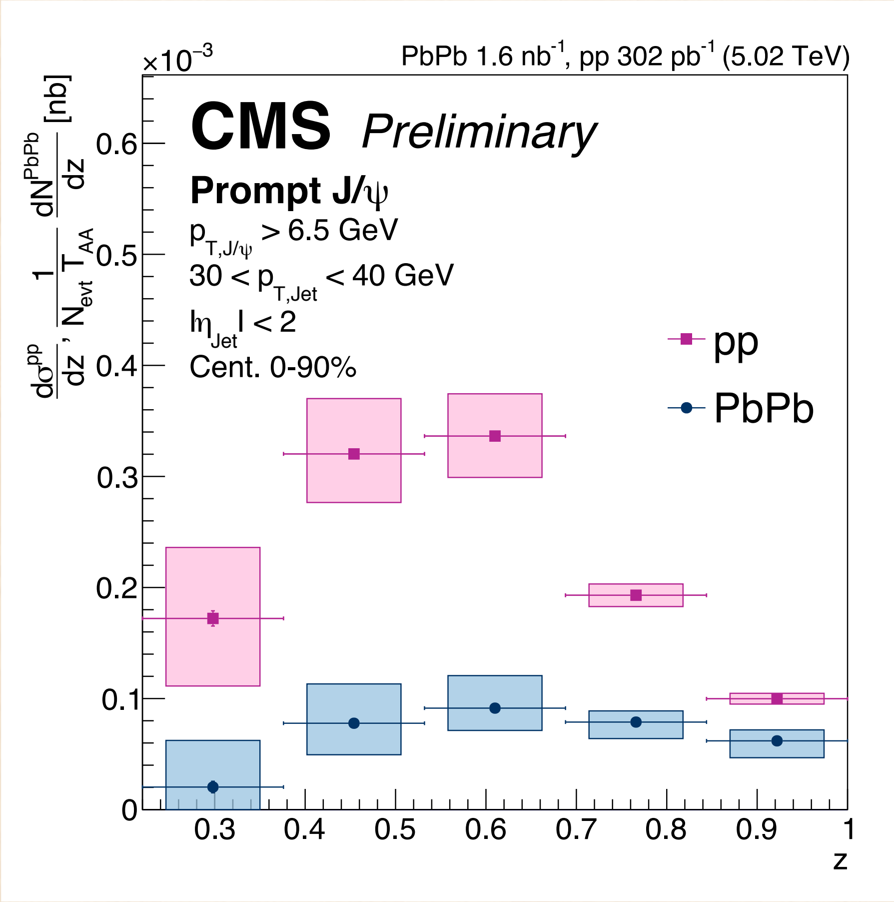


Not reproduced by generator!

Production mechanism

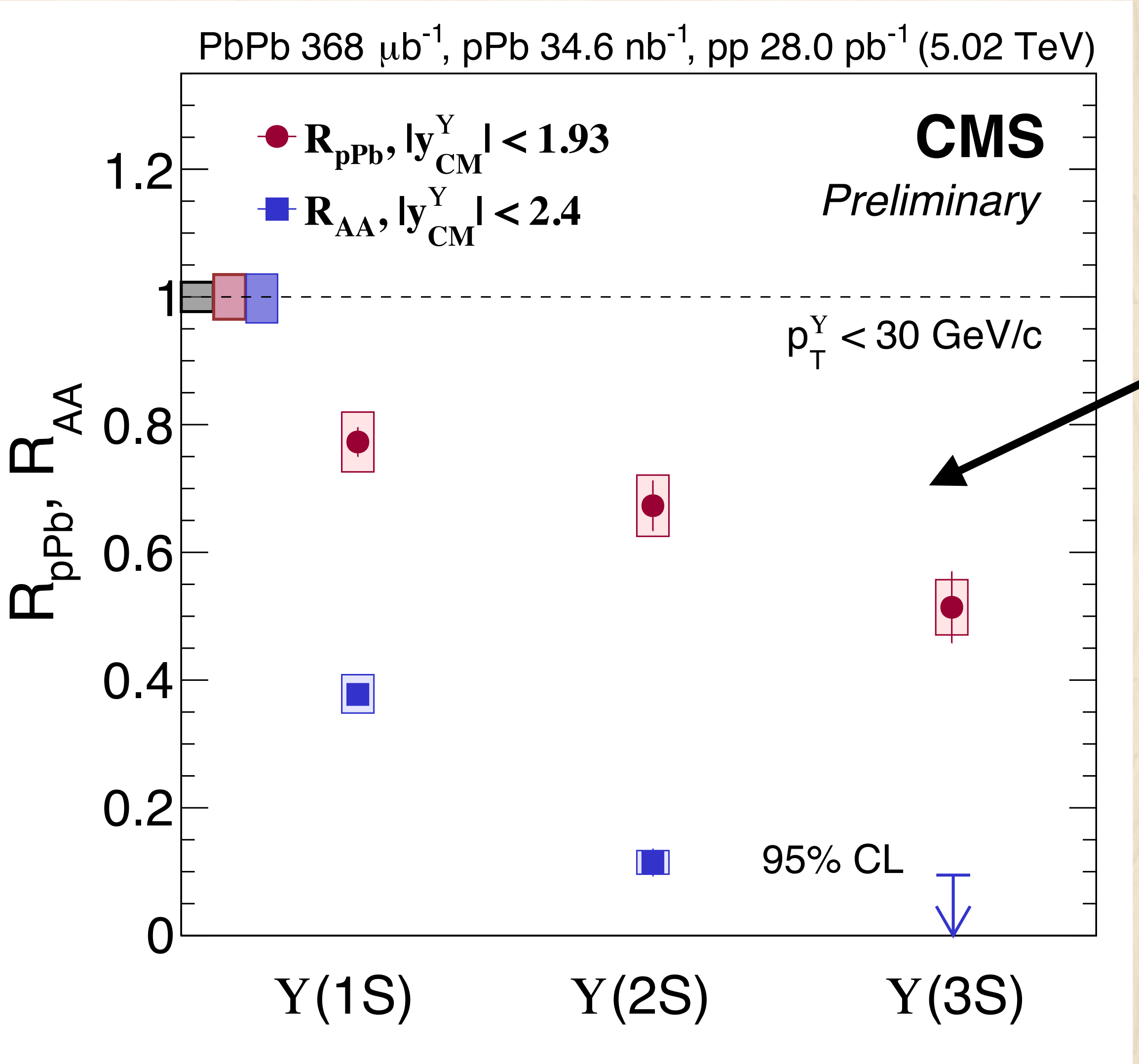


$$z = \frac{J/\psi}{\text{Jet}}$$



PbPb: connection to quenching & hot nuclear effect

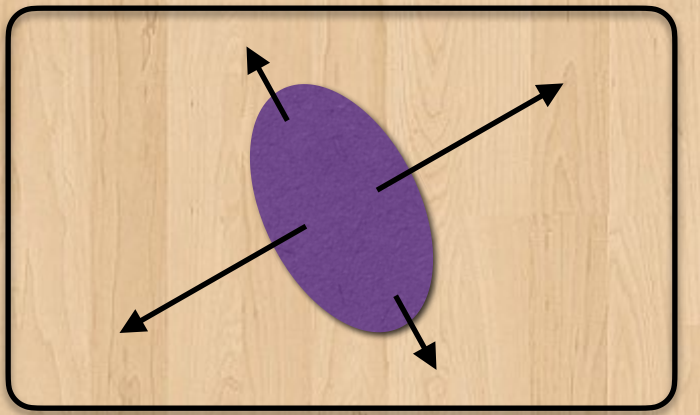
Quarkonia suppression



Ordering in pPb: suggest some final state effect

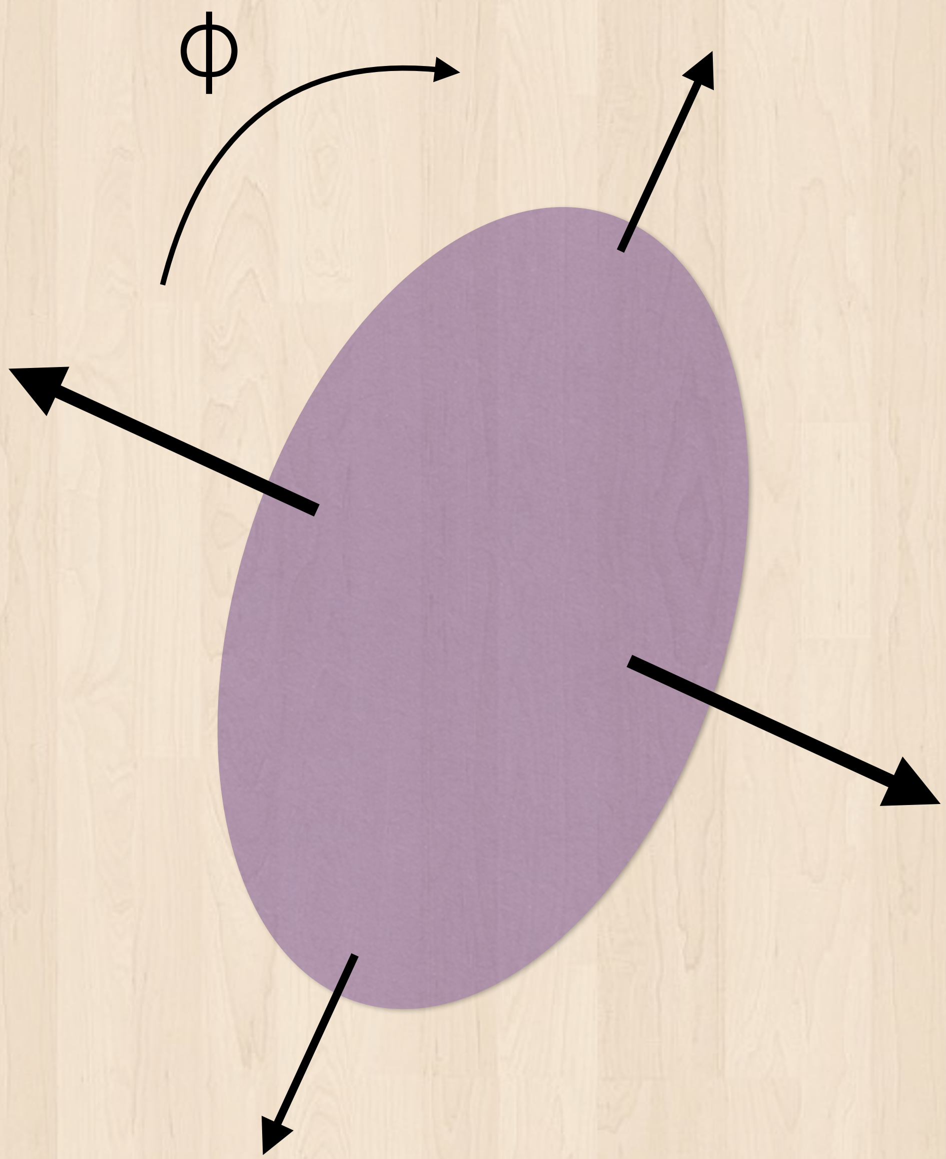
Large effect from hot nuclear effect

Helps disentangle cold nuclear effects and hot nuclear effects



Correlations

Correlations

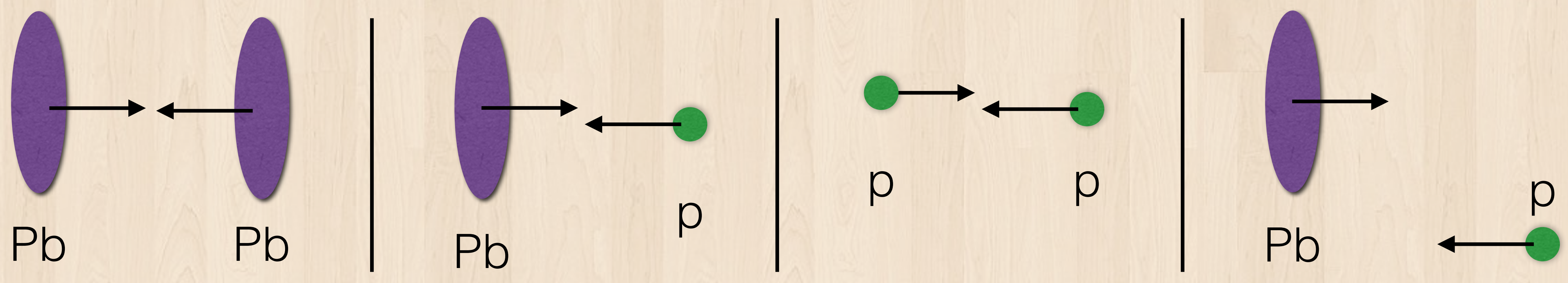


Initial geometry +
hydrodynamic expansion +
fluctuation (+non-flow) =>
collective behavior

Information encoded in the detail of the correlations

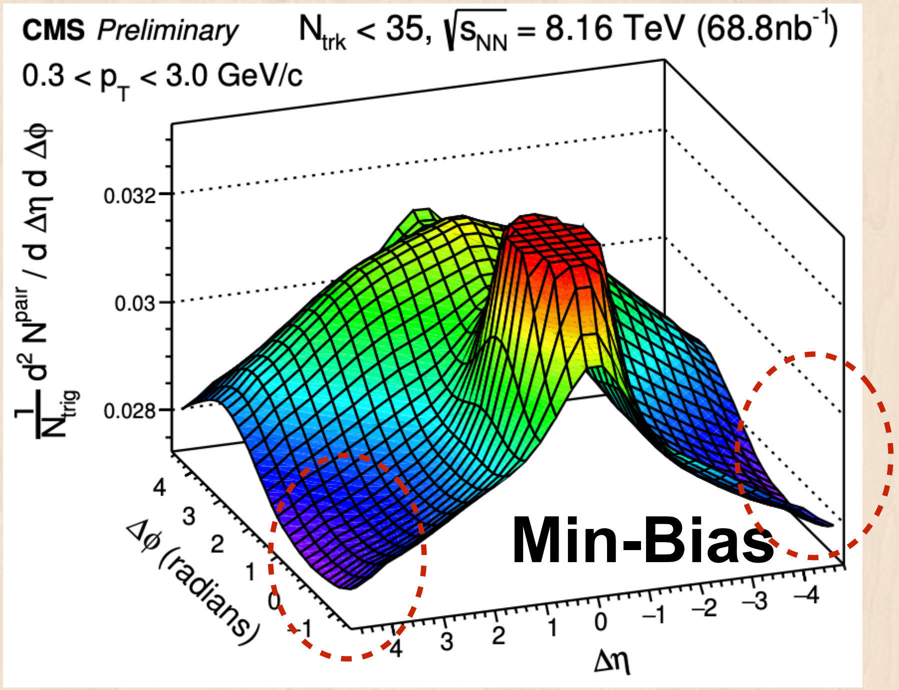
$$f(\phi) \propto 1 + 2\sum_n v_n \cos(\phi - \Phi_n)$$

Correlation in UPC pPb

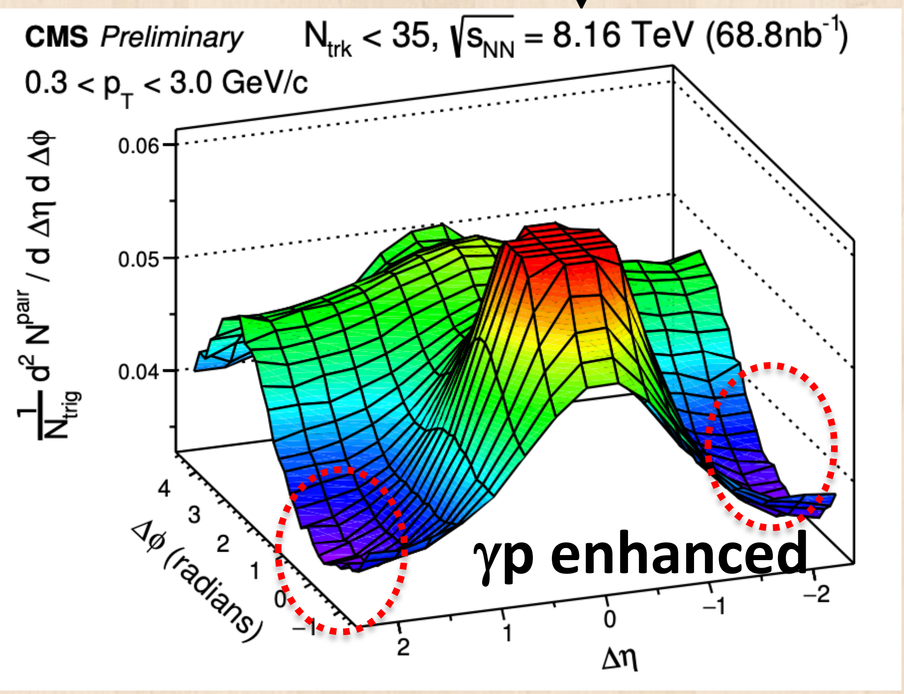


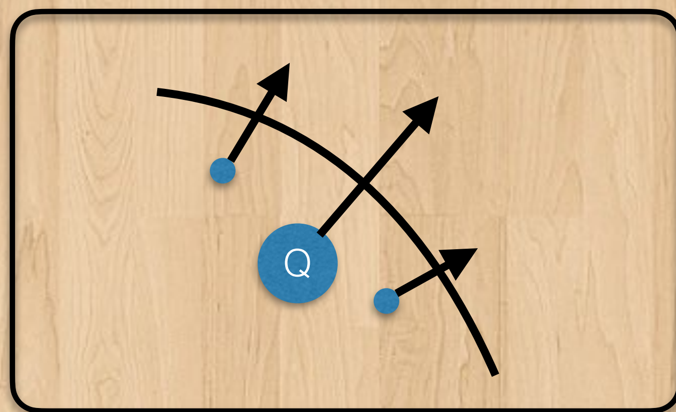
(not shown) | Minimum-Bias | (not shown) | γp enhanced

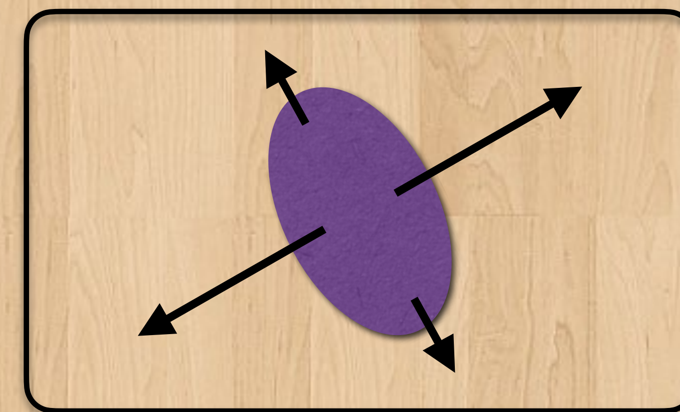
Extending correlation measurement into smaller systems



No evidence of ridge-like structures



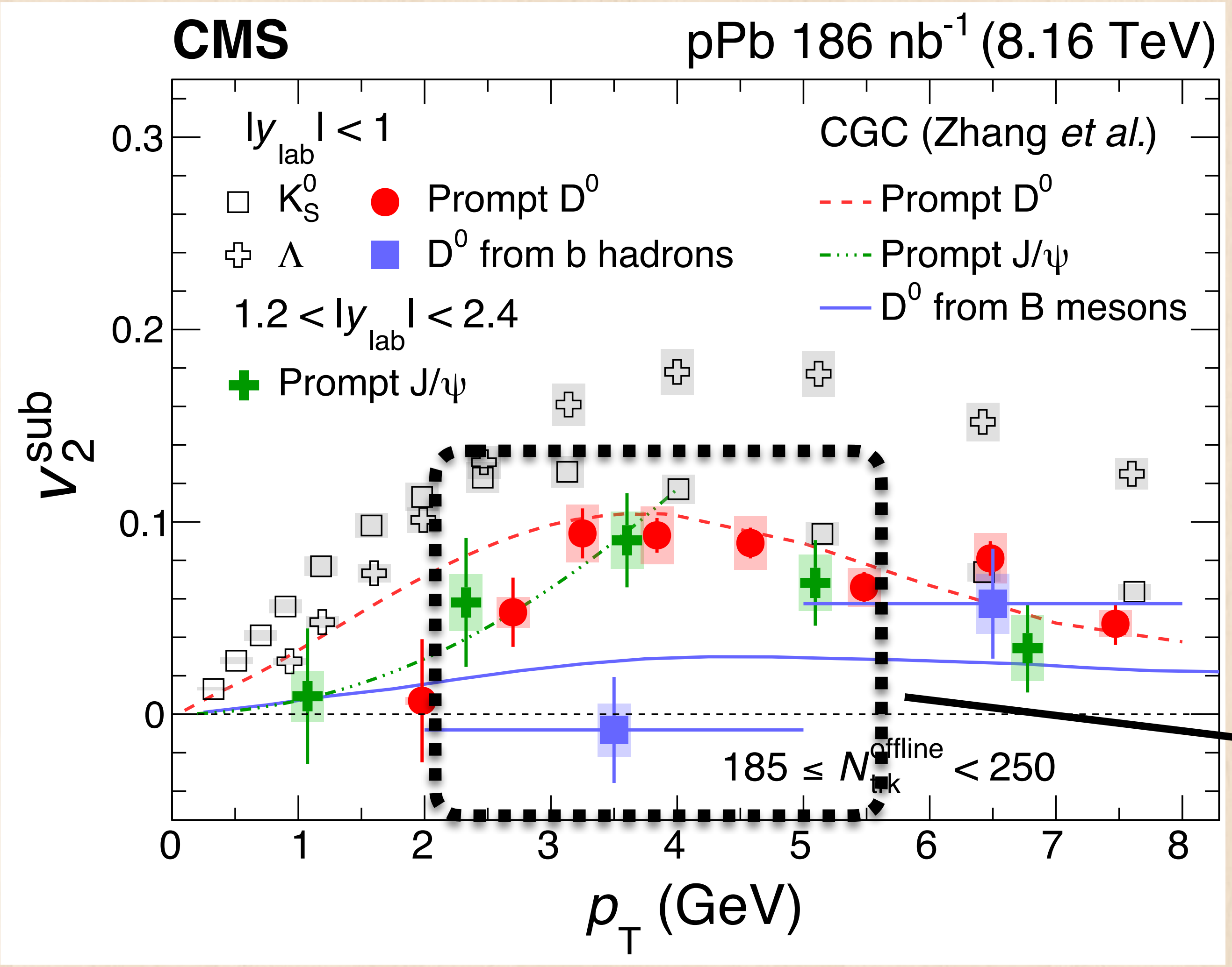




Heavy Flavor Collectivity

Collectivity: D^0

Non-prompt D^0 ~ D^0 from b decay

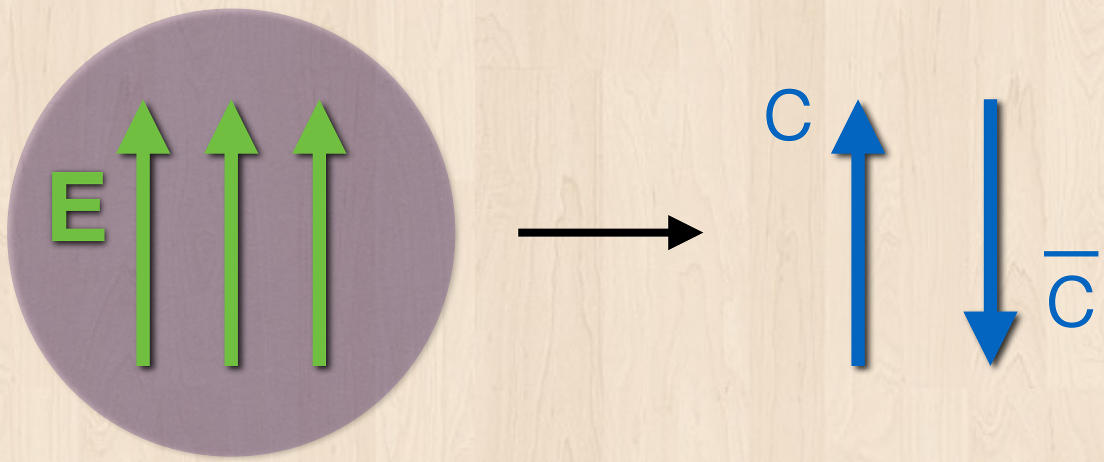


First time:
v_2(Non-prompt D^0)
proxy for v_2(B)

Hints of mass dependence of v_2

v_2(Prompt D^0) > v_2(Non-prompt D^0)

(Initial) Electric Field



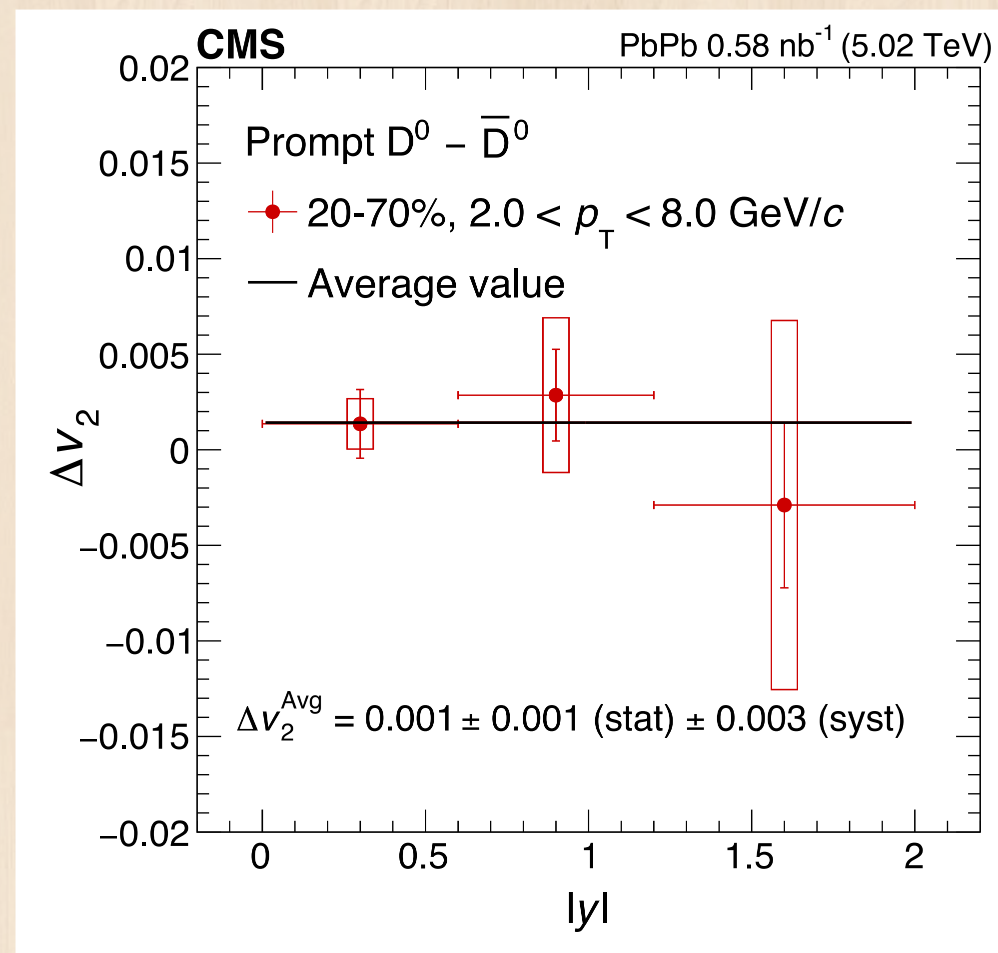
$$v_2(D^0) \neq v_2(\overline{D^0})$$

Transient electric field in the beginning stages of collision

→ different v_2 between c meson and $\bar{c}$ meson

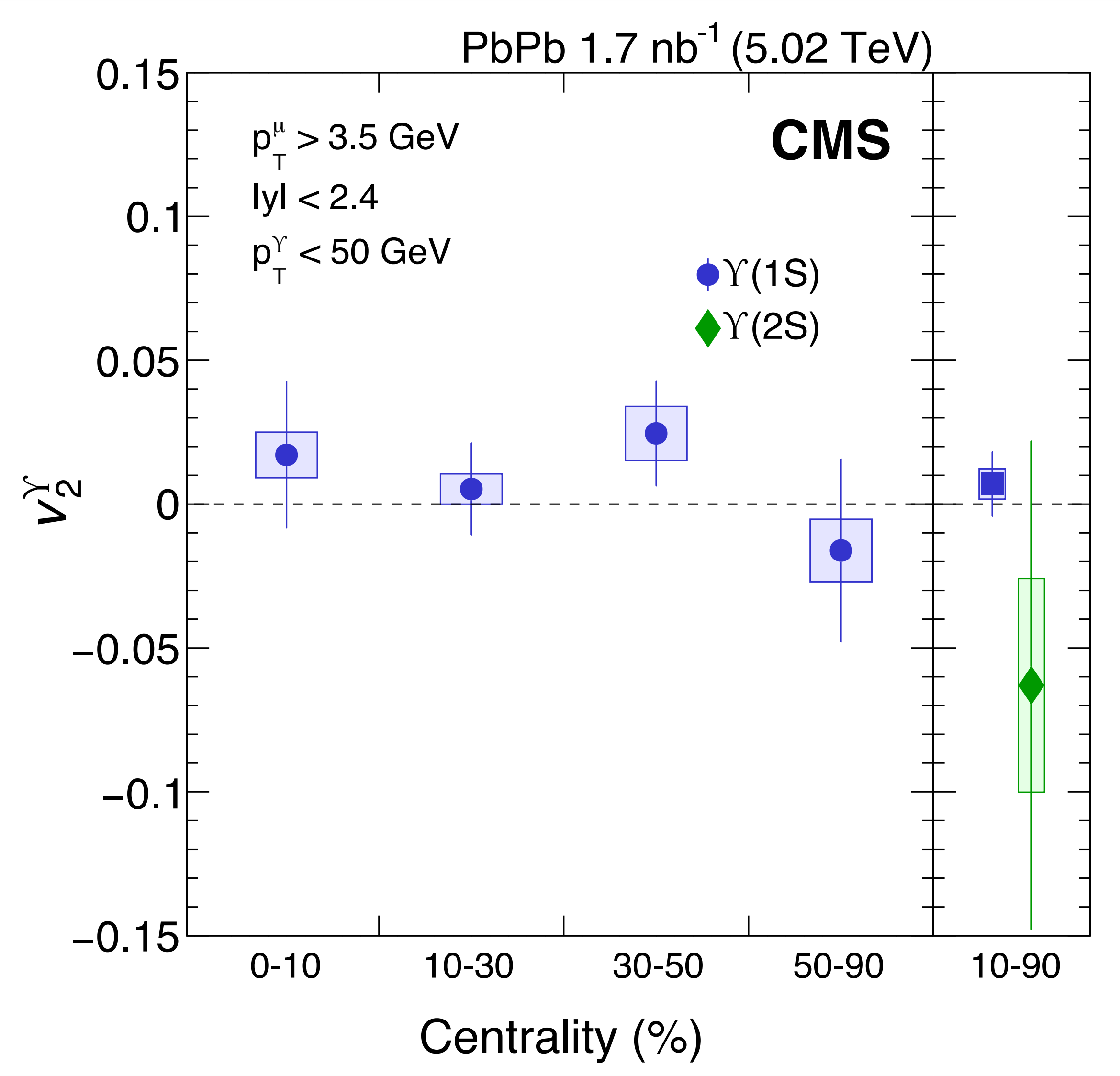
Consistent with zero

Constrain: size of E-field effect



arXiv:2009.12628

Collectivity: Y(1S), Y(2S)



High precision!

v_2[Y(1S)] consistent with 0

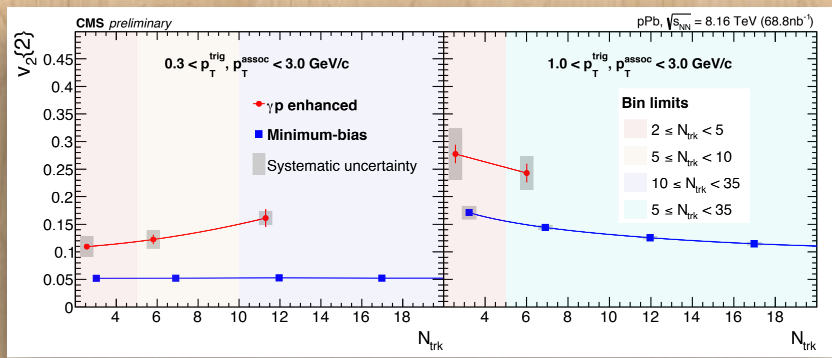
(contrast to v_2[J/ψ] ≠ 0)

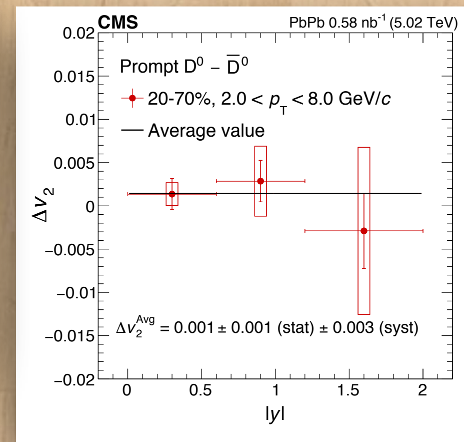
First measurement of v_2[Y(2S)]

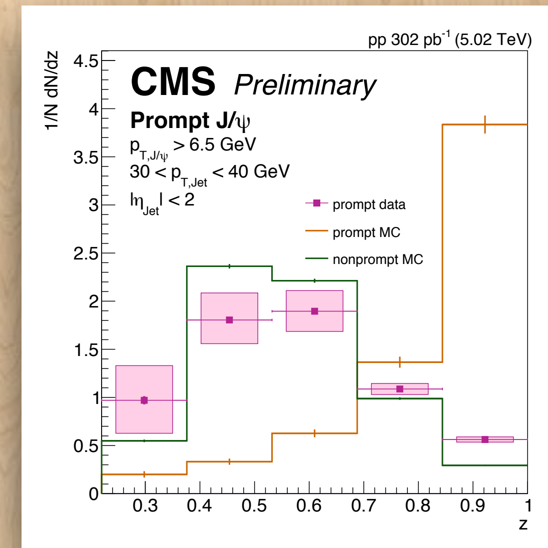
Provides input to understand the regeneration effects

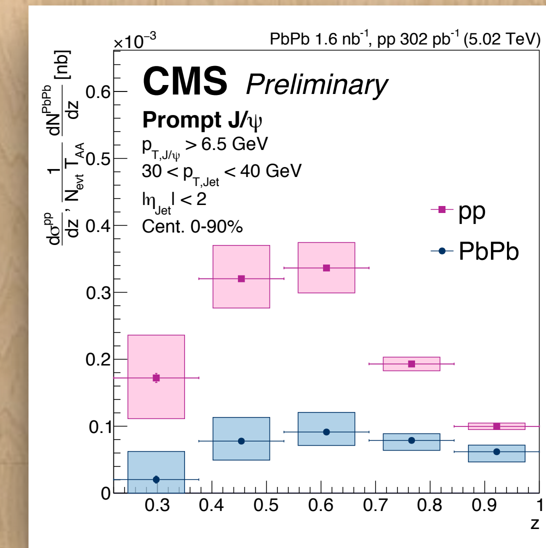
arXiv:2006.07707

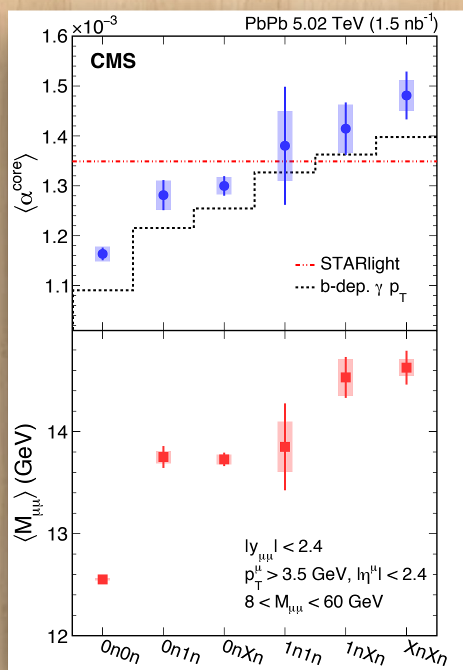
Summary

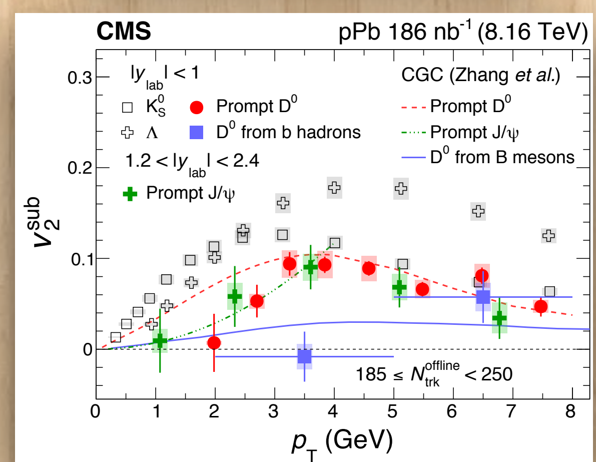


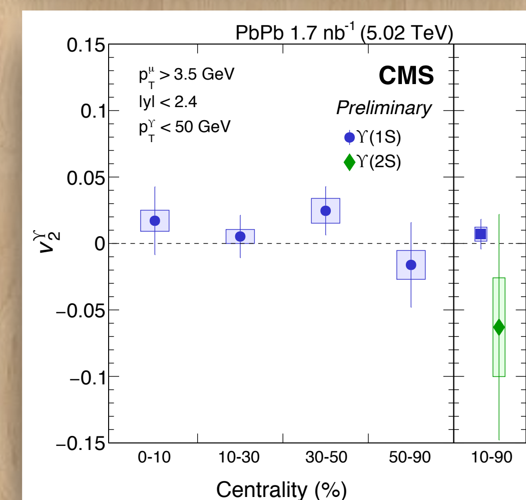


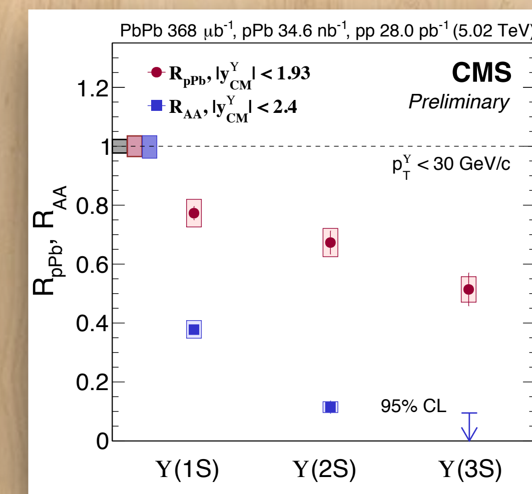


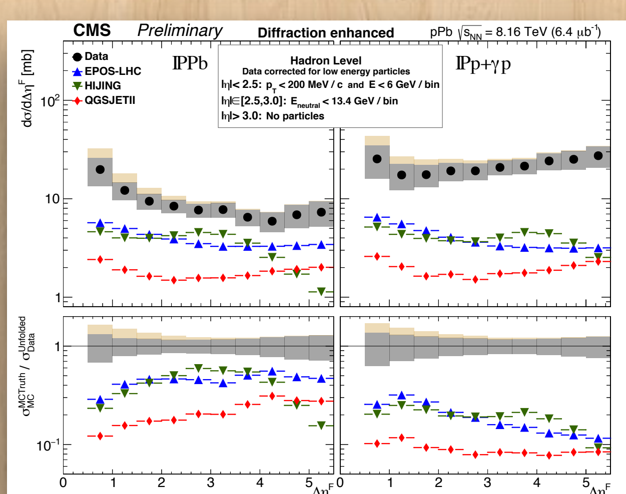


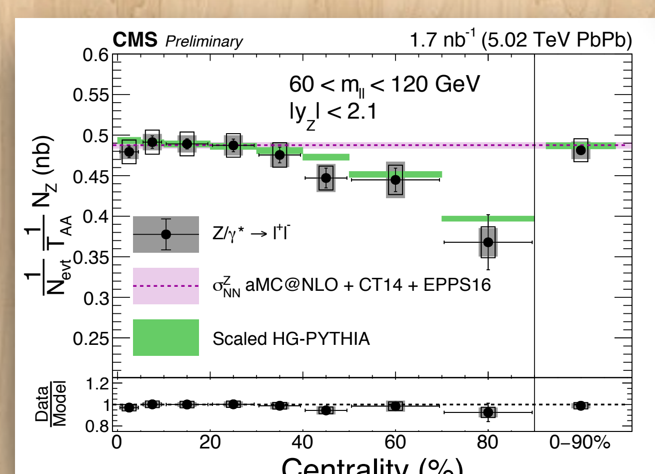


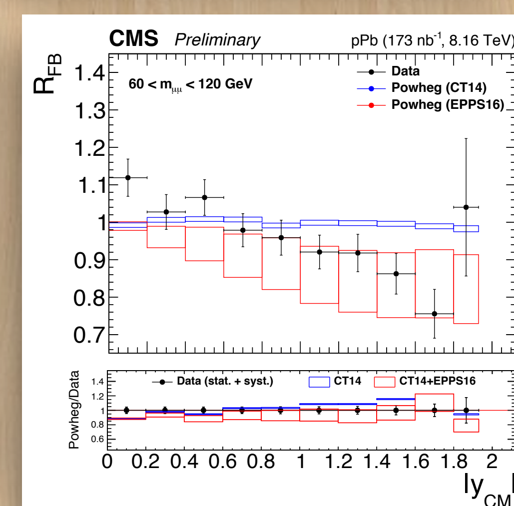


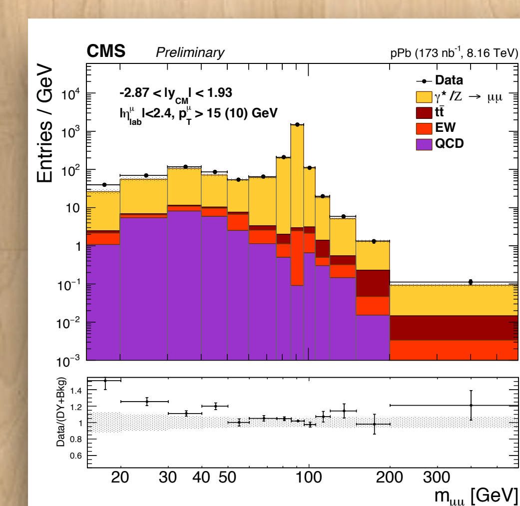




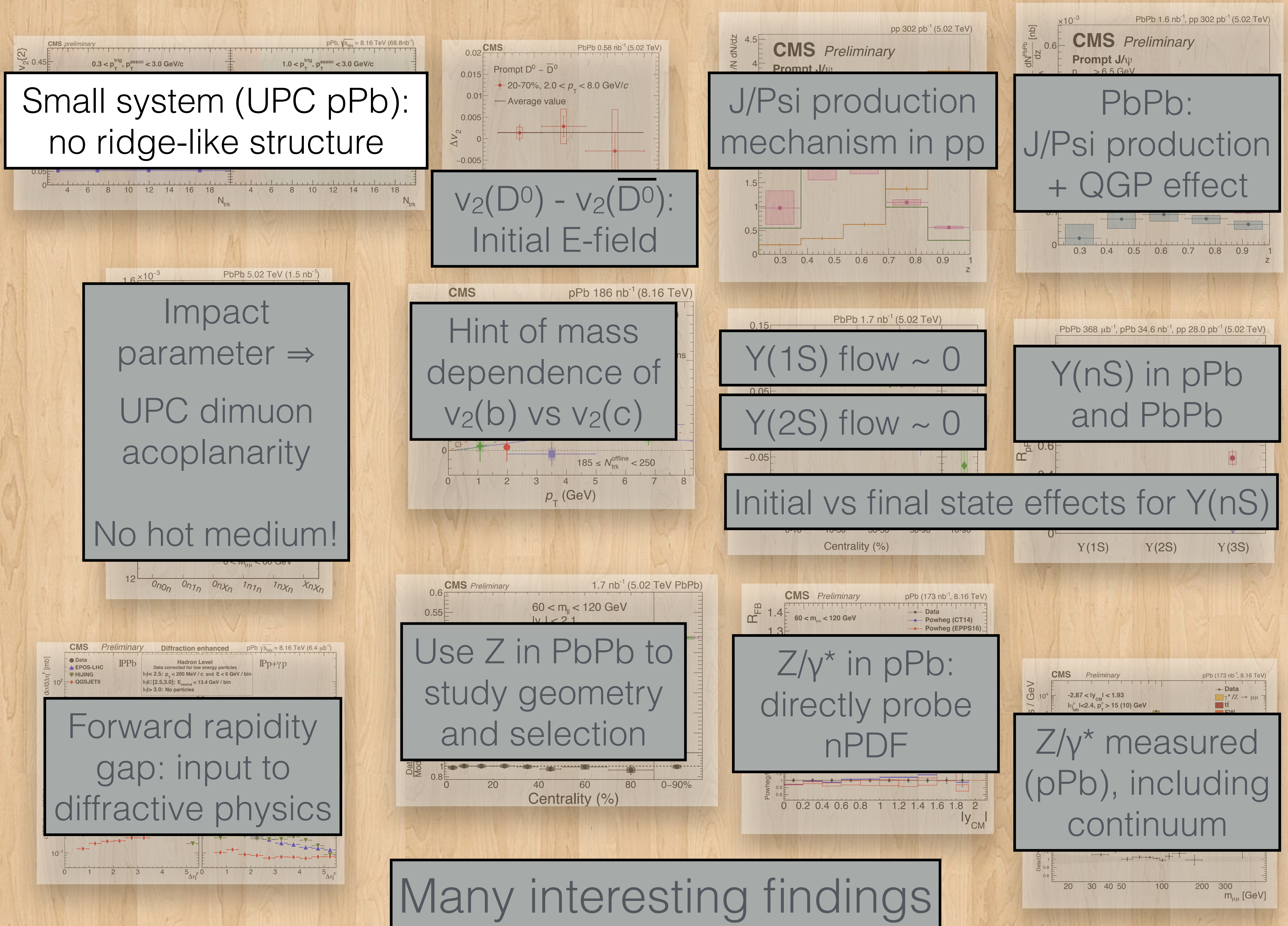








Many interesting results!


Small system (UPC pPb): no ridge-like structure
$v_2(D^0) - v_2(\overline{D^0})$: Initial E-field
J/Psi production mechanism in pp
PbPb: J/Psi production + QGP effect
Impact parameter ⇒ UPC dimuon acoplanarity
No hot medium!
Hint of mass dependence of v_2(b) vs v_2(c)
Υ(1S) flow ~ 0
Υ(2S) flow ~ 0
Υ(nS) in pPb and PbPb
Initial vs final state effects for Υ(nS)
Forward rapidity gap: input to diffractive physics
Use Z in PbPb to study geometry and selection
Z/γ* in pPb: directly probe nPDF
Z/γ* measured (pPb), including continuum
Many interesting findings

Small system (UPC pPb): no ridge-like structure

$v_2(D^0) - v_2(\overline{D}^0)$: Initial E-field

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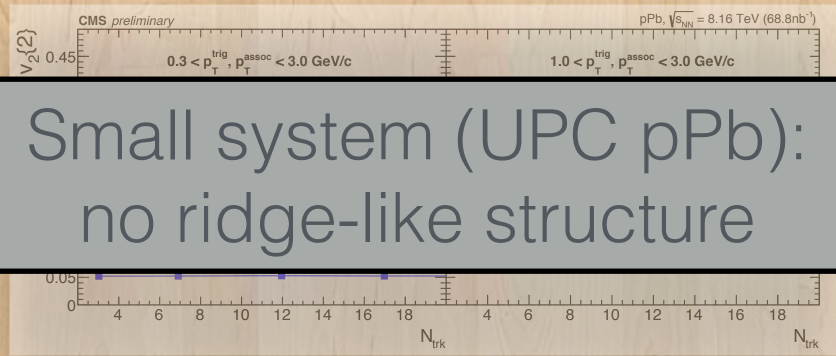

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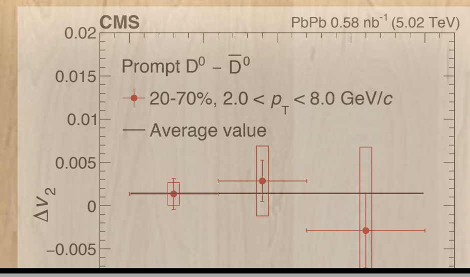
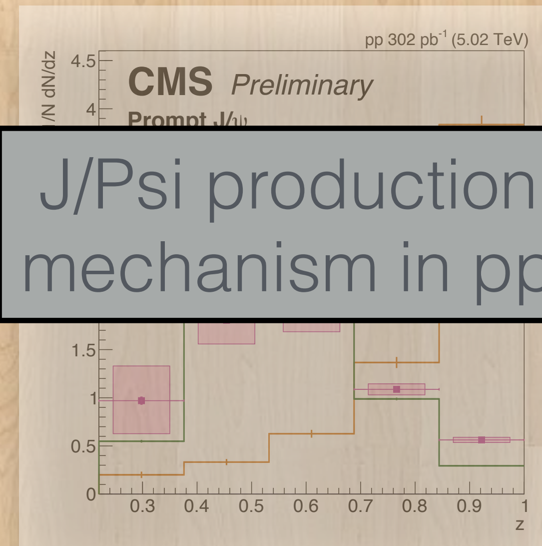
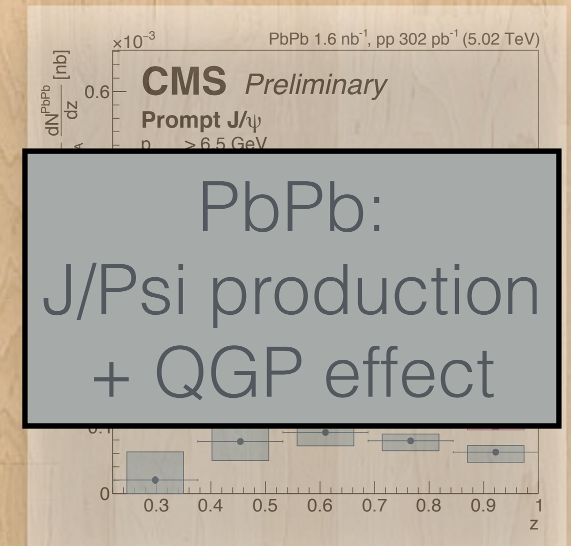


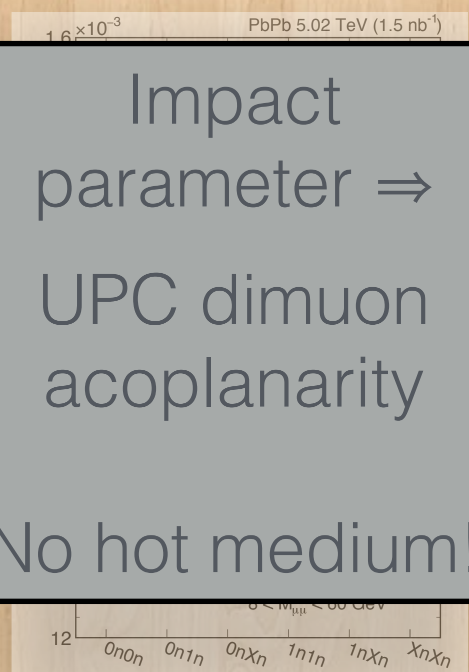
$v_2(D^0) - v_2(\overline{D}^0)$: Initial E-field



J/Psi production mechanism in pp

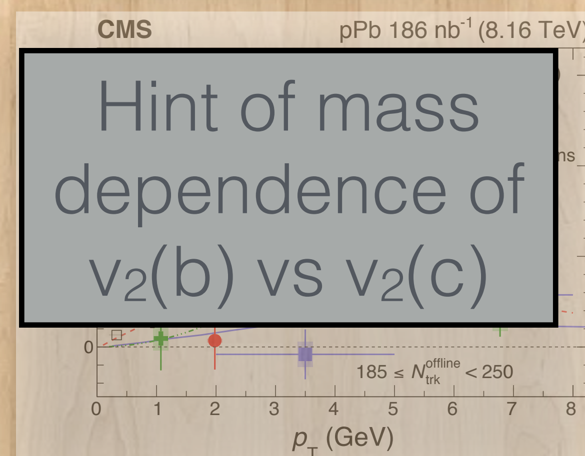


PbPb: J/Psi production + QGP effect

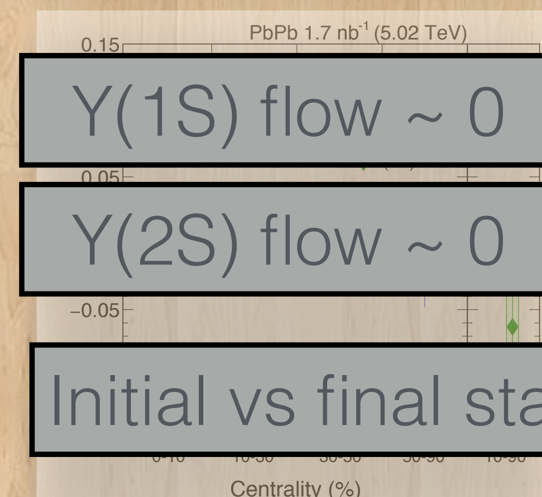


Impact parameter ⇒ UPC dimuon acoplanarity

No hot medium!



Hint of mass dependence of $v_2(b)$ vs $v_2(c)$



Y(1S) flow ~ 0

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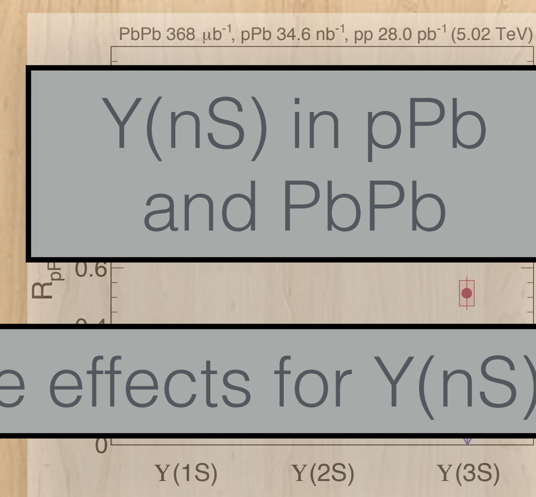
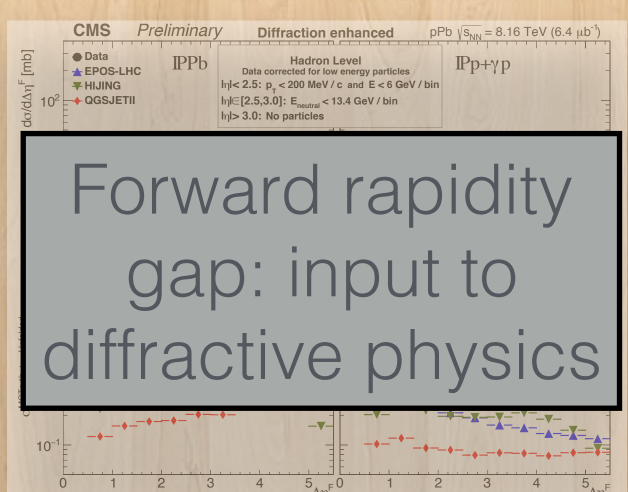
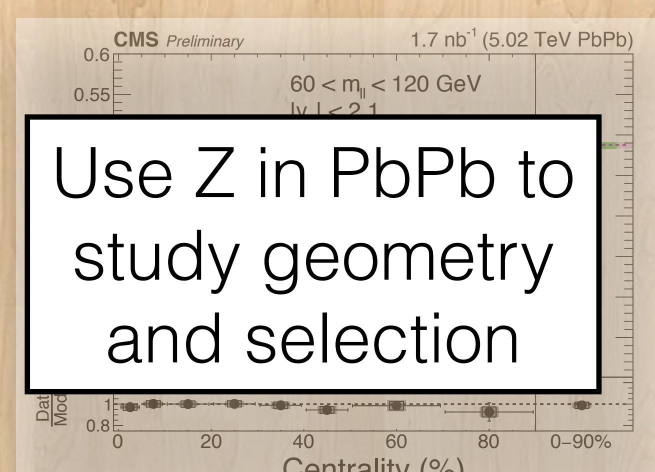


Y(nS) in pPb and PbPb

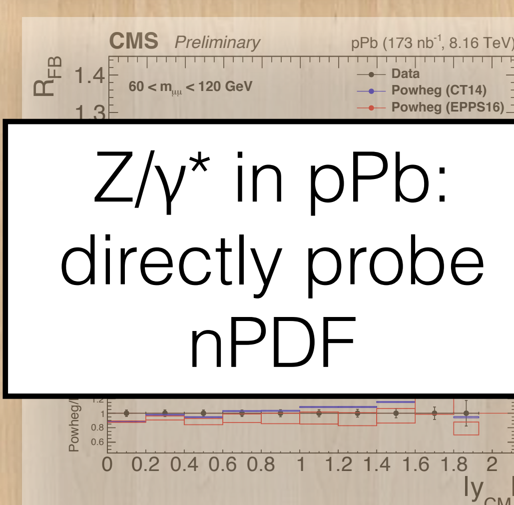
Initial vs final state effects for Y(nS)



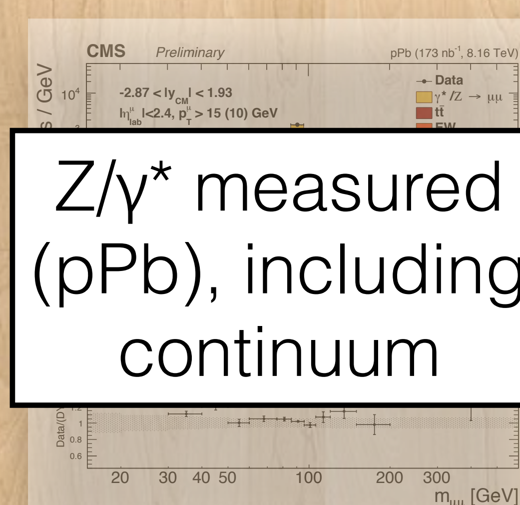
Forward rapidity gap: input to diffractive physics



Use Z in PbPb to study geometry and selection

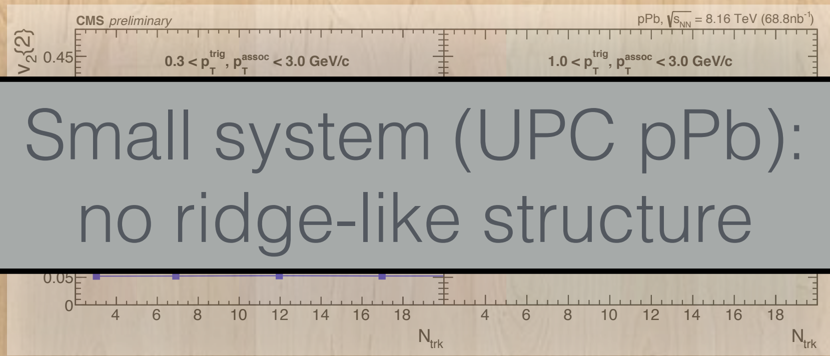


Z/γ* in pPb: directly probe nPDF

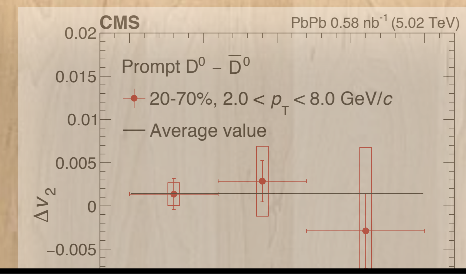


Z/γ* measured (pPb), including continuum

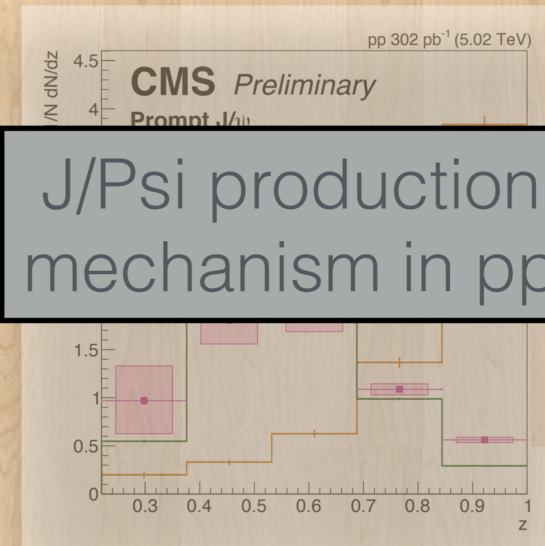
Many interesting findings



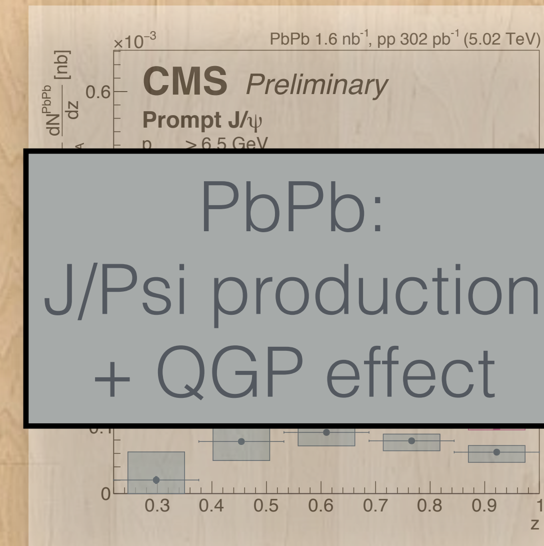
Small system (UPC pPb): no ridge-like structure



$v_2(D^0) - v_2(\overline{D^0})$: Initial E-field



J/Psi production mechanism in pp



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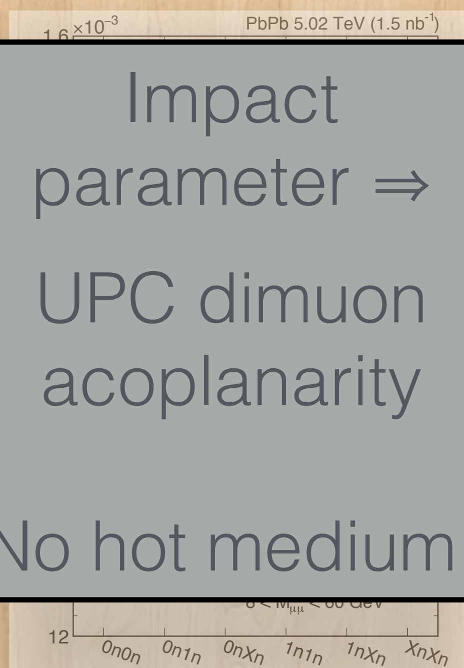

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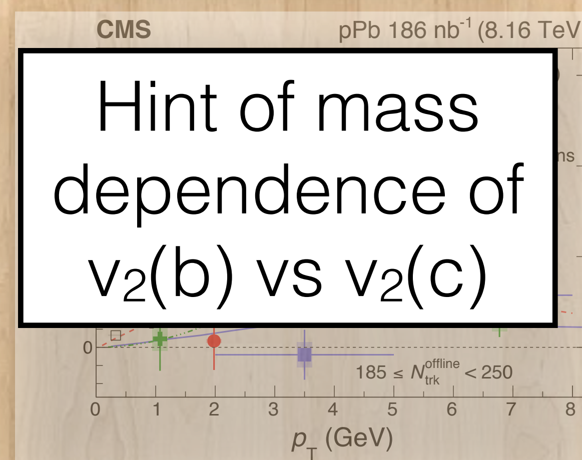

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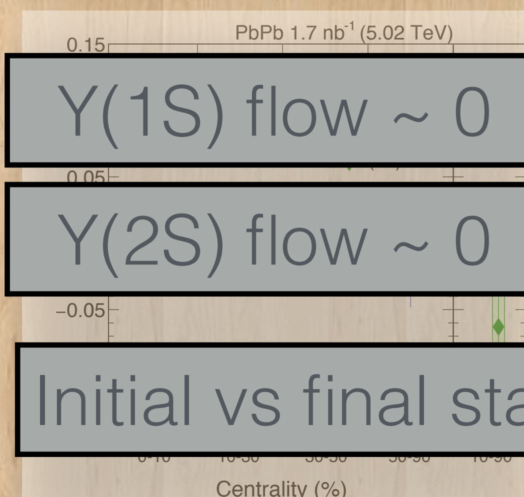

Υ(1S) flow ~ 0

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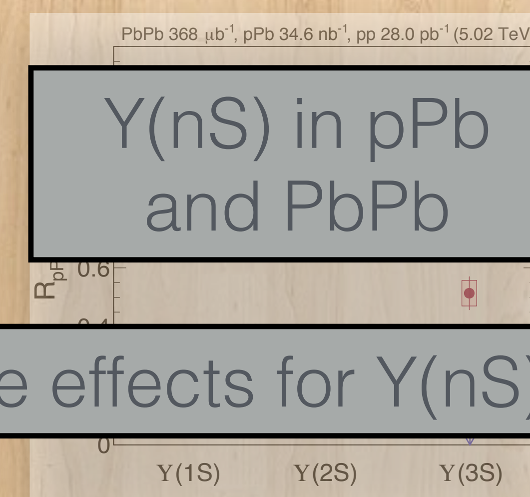

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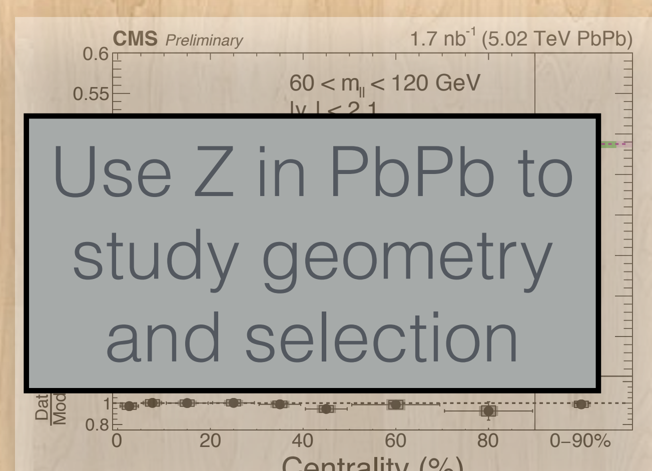

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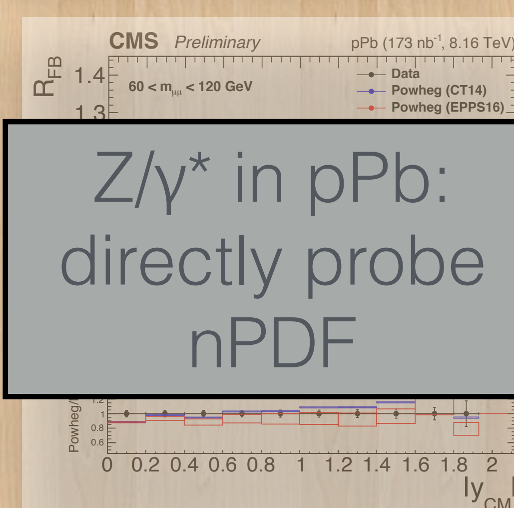
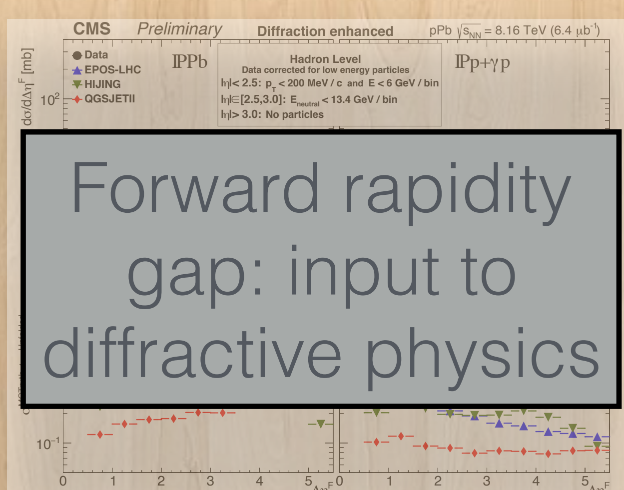


Z/γ* in pPb: directly probe nPDF



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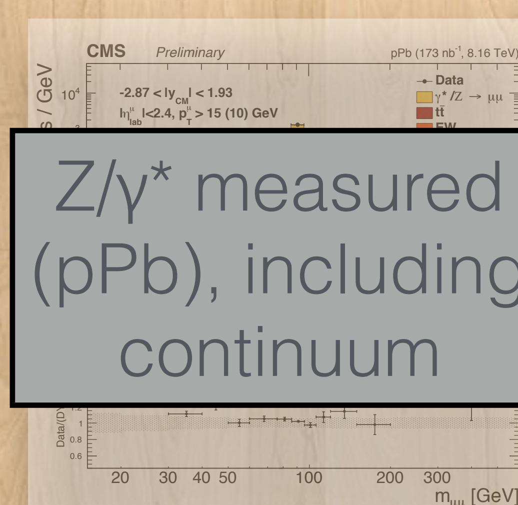

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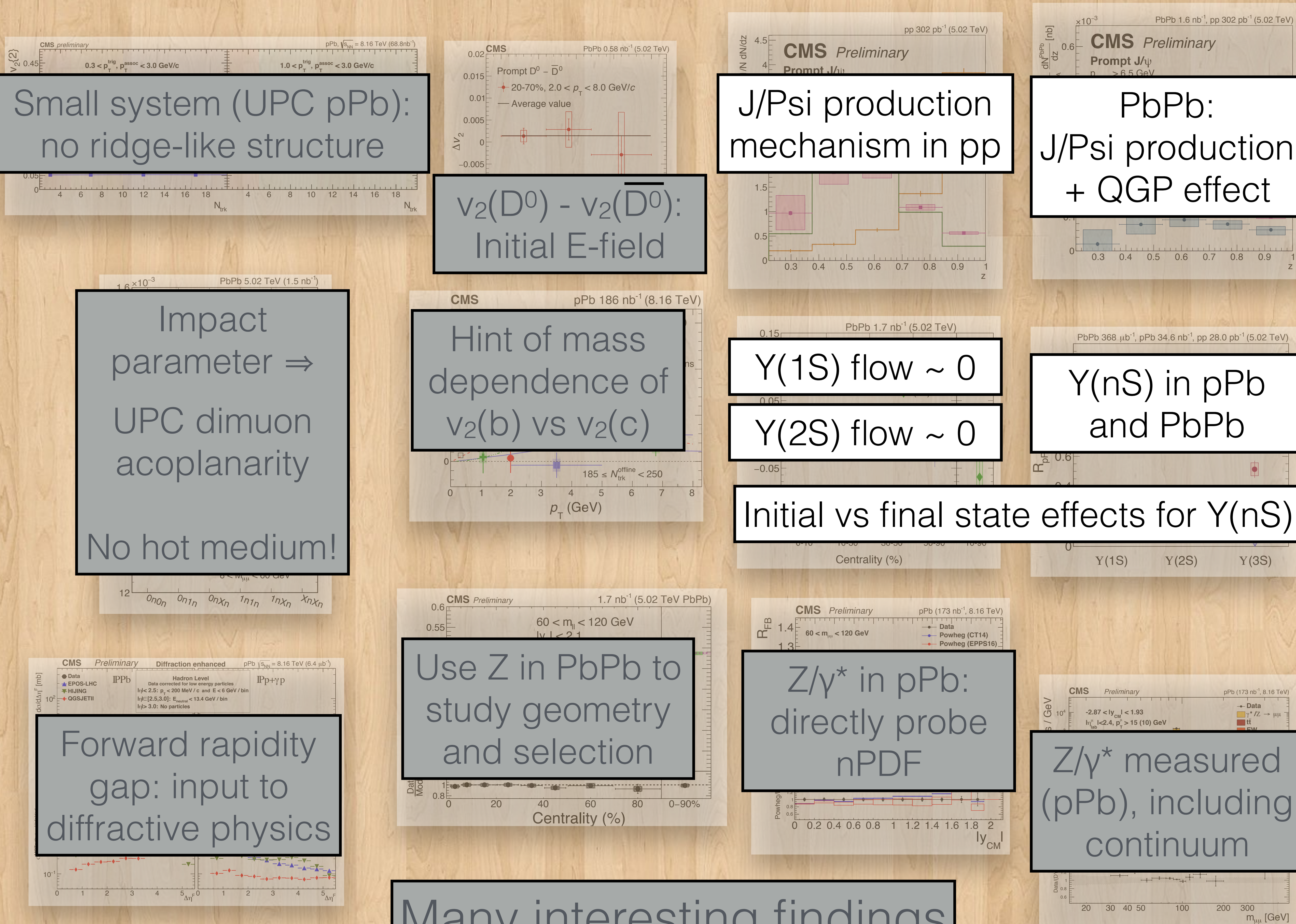

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Many interesting findings

L. Zhang
Jan. 13

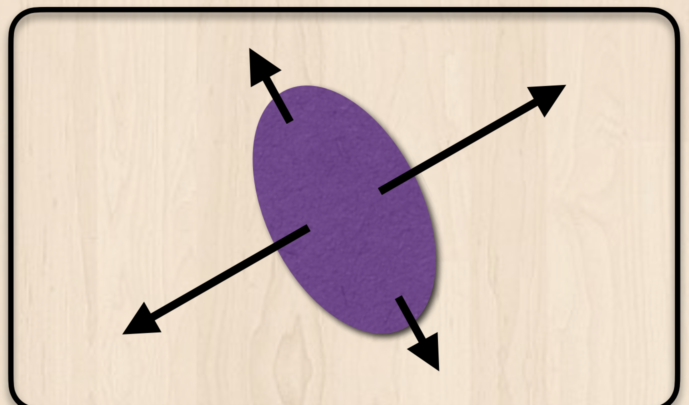
R. Pradhan
Jan. 13

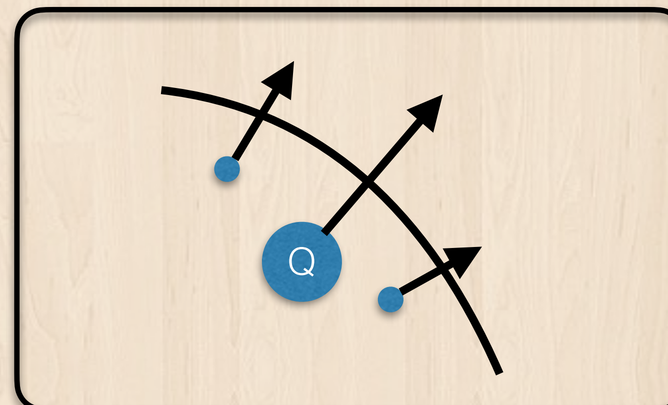
Y. Kim
Jan. 13

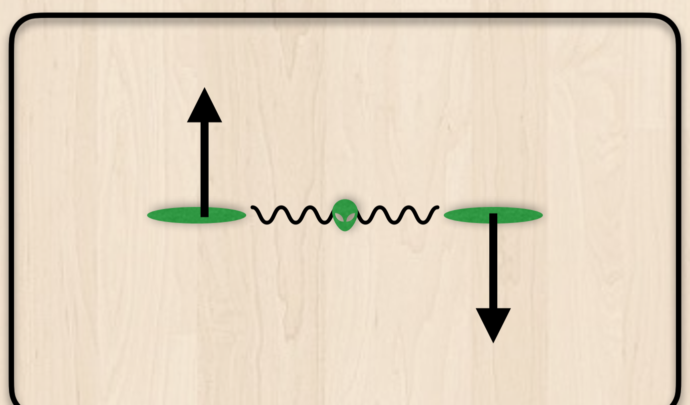
Q. Wang
Jan. 11

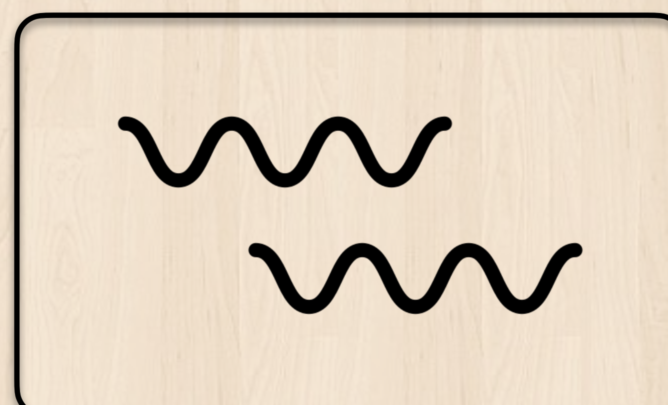
J. Wang
Jan. 11

S. Yang
Jan. 13









K. Kuznetsova
Jan. 12

A. Baty
Jan. 14

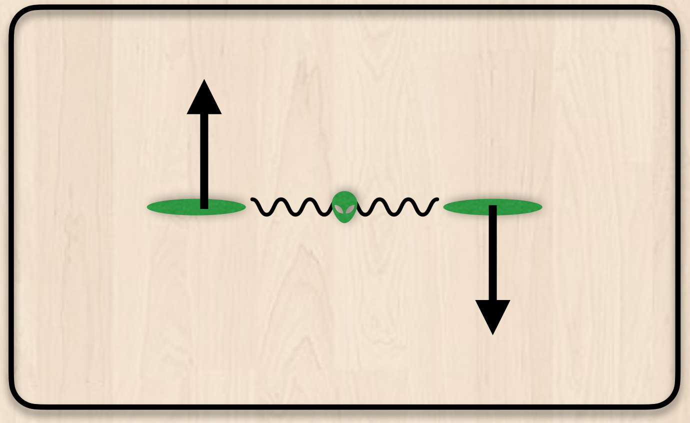
Join us in the parallel sessions!

Thank you!

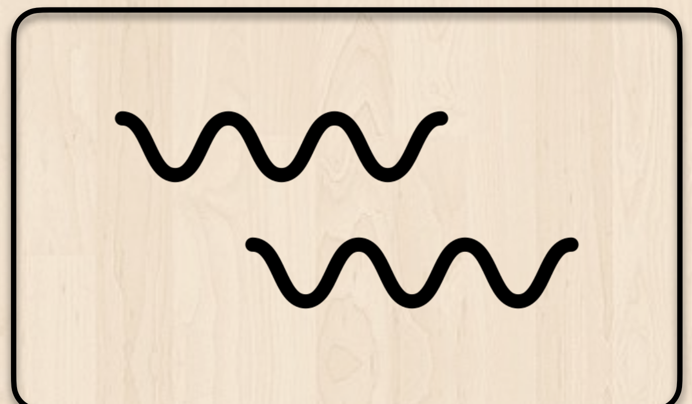
All CMS results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

Backup Slides Ahead

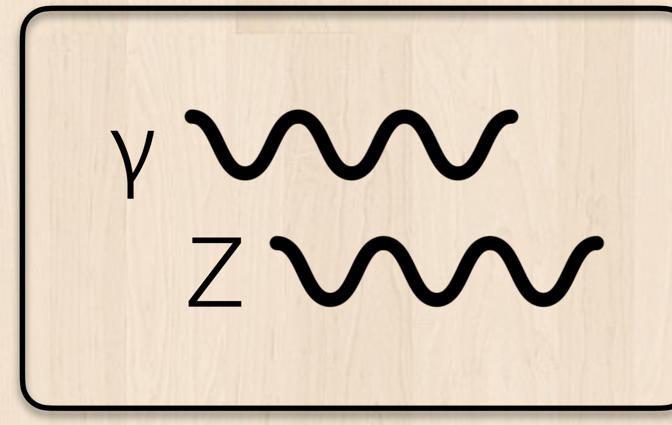
Category Icons



Ultra-peripheral



Electroweak



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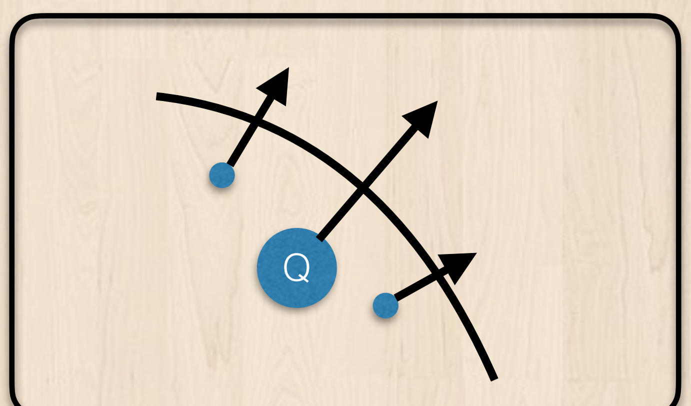
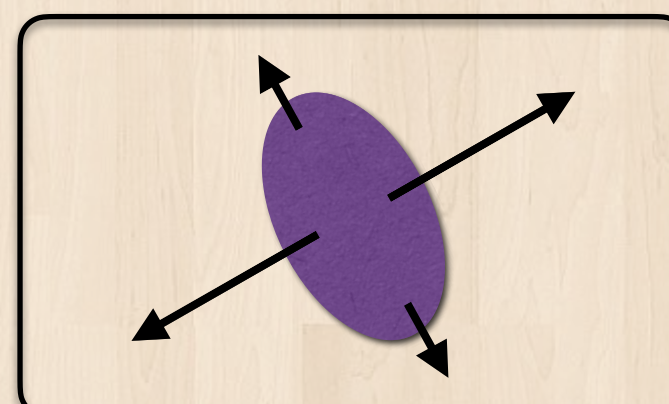


Heavy-flavor



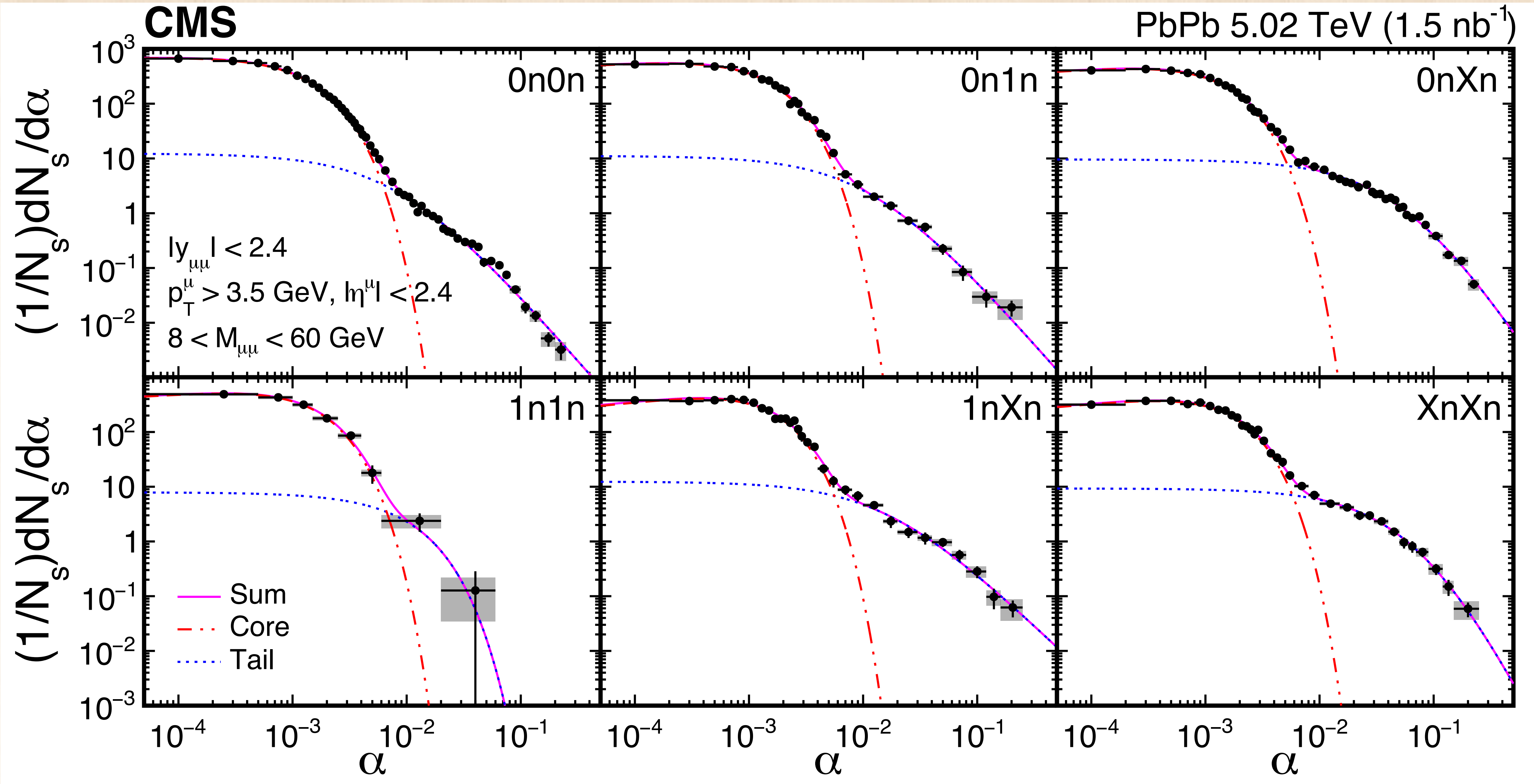
Correlations

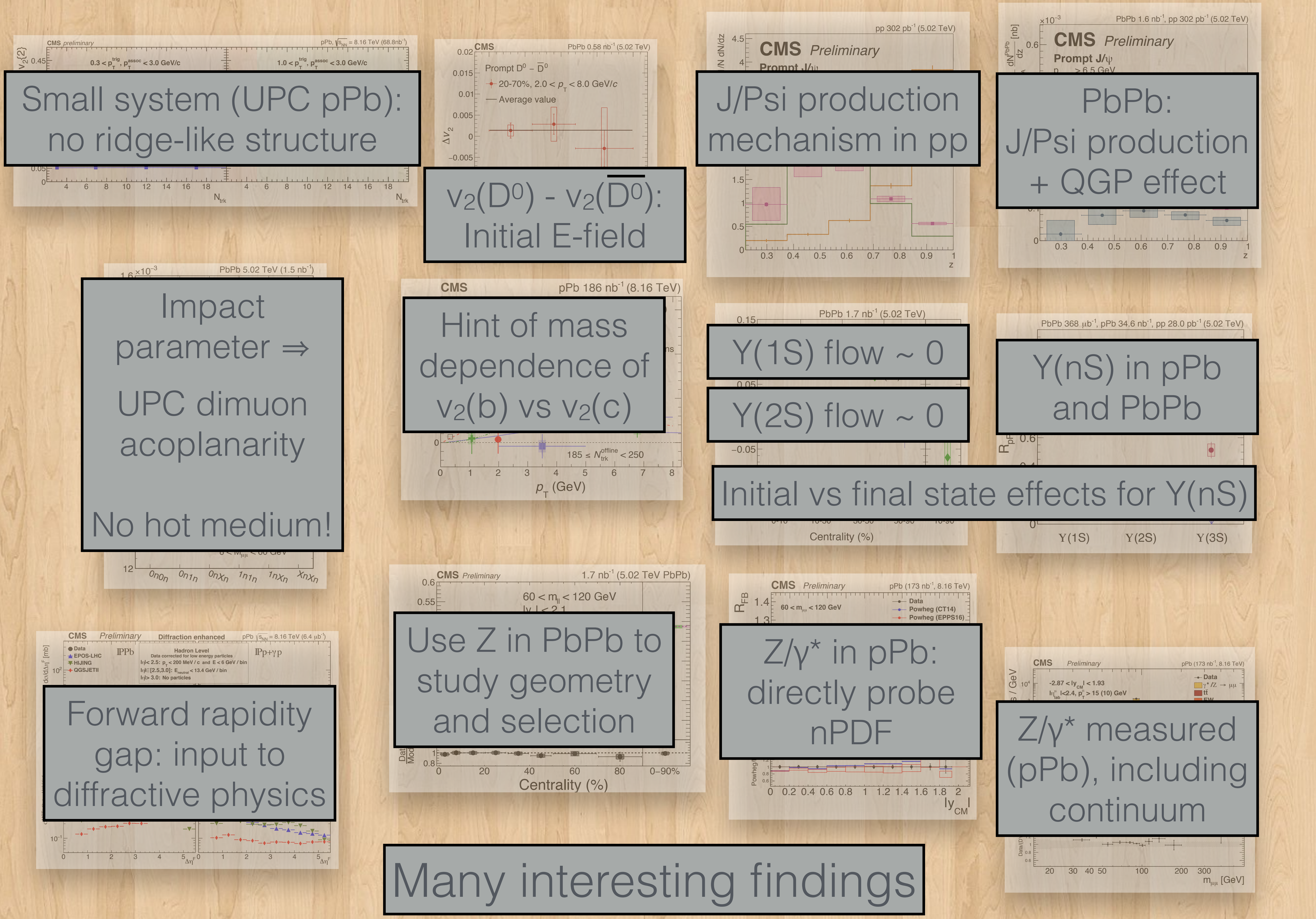
Definition of ϕ* observable

$$\phi^* = \tan\left(\frac{\pi - \Delta\phi}{2}\right)\sin\left(\theta^*_\eta\right)$$

$$\cos(\theta^*_\eta) = \tanh\left(\Delta\eta/2\right)$$

Example alpha

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