Recent Results from CMS

Jing Wang (MIT)
For the CMS Collaboration

The 20th International Conference on Strangeness in Quark Matter (SQM 2022)
13 June 2022 Busan, Republic of Korea

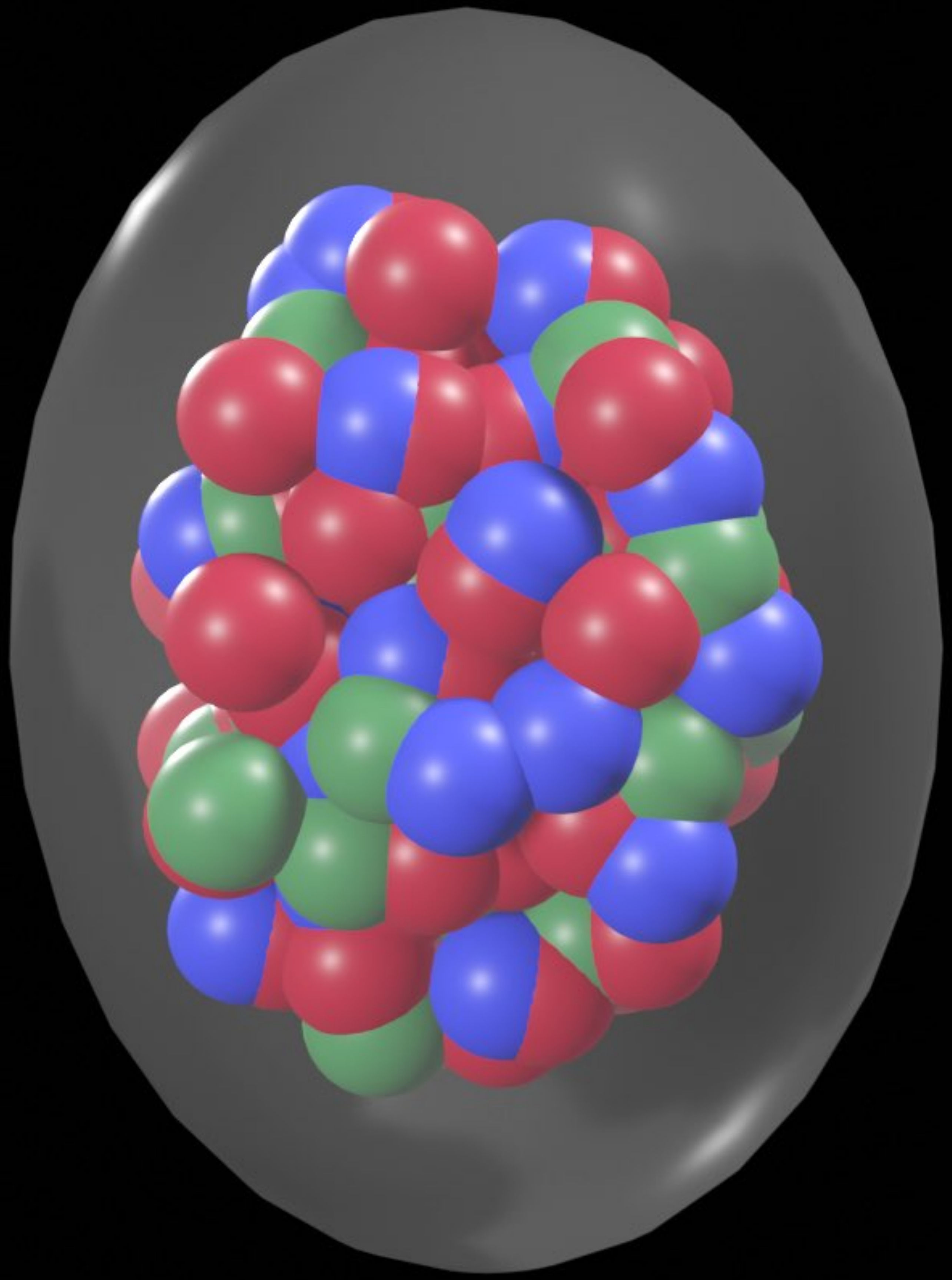
MITHIG group's work was supported by US DOE-NP

The Road: Past, Present and Future

Run 1	Run 2	Long Shutdown 2	Run 3	LS 3	Run 4	LS 4
	2015 - 2018	2019 2020 2021	2022 2023 2024 2025	2026 2027 2028	2029 2030 2031 2032	
	PbPb (2.2 nb^{-1}) pPb (0.18 pb^{-1})	We are here !	PbPb (6 nb^{-1}) pPb (0.5 pb^{-1}) pO/OO	CMS Phase-2 upgrades	PbPb (7 nb^{-1}) pPb (0.5 pb^{-1})	

- Great success of CMS heavy-ion project in Run 2
- Run 3 is around the corner
- Here we discuss part of our latest inputs contributing to the knowledge of HIC!

Section I



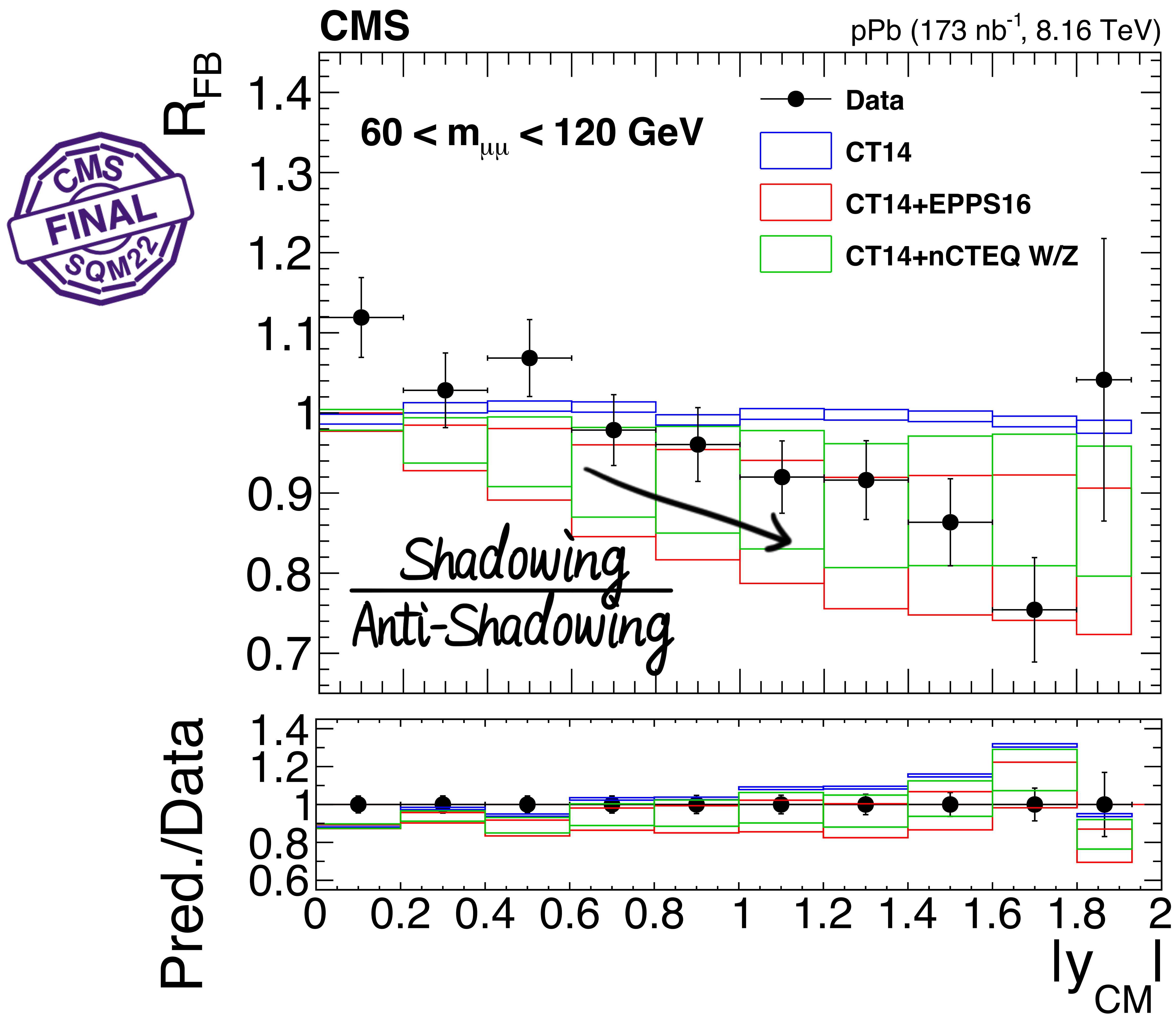
Initial stage

Click to see animation ➥

nPDF: Drell-Yan in pPb

H. Kim [06/14 15:20]

Forward-Backward ratio



JHEP 05 (2021) 182

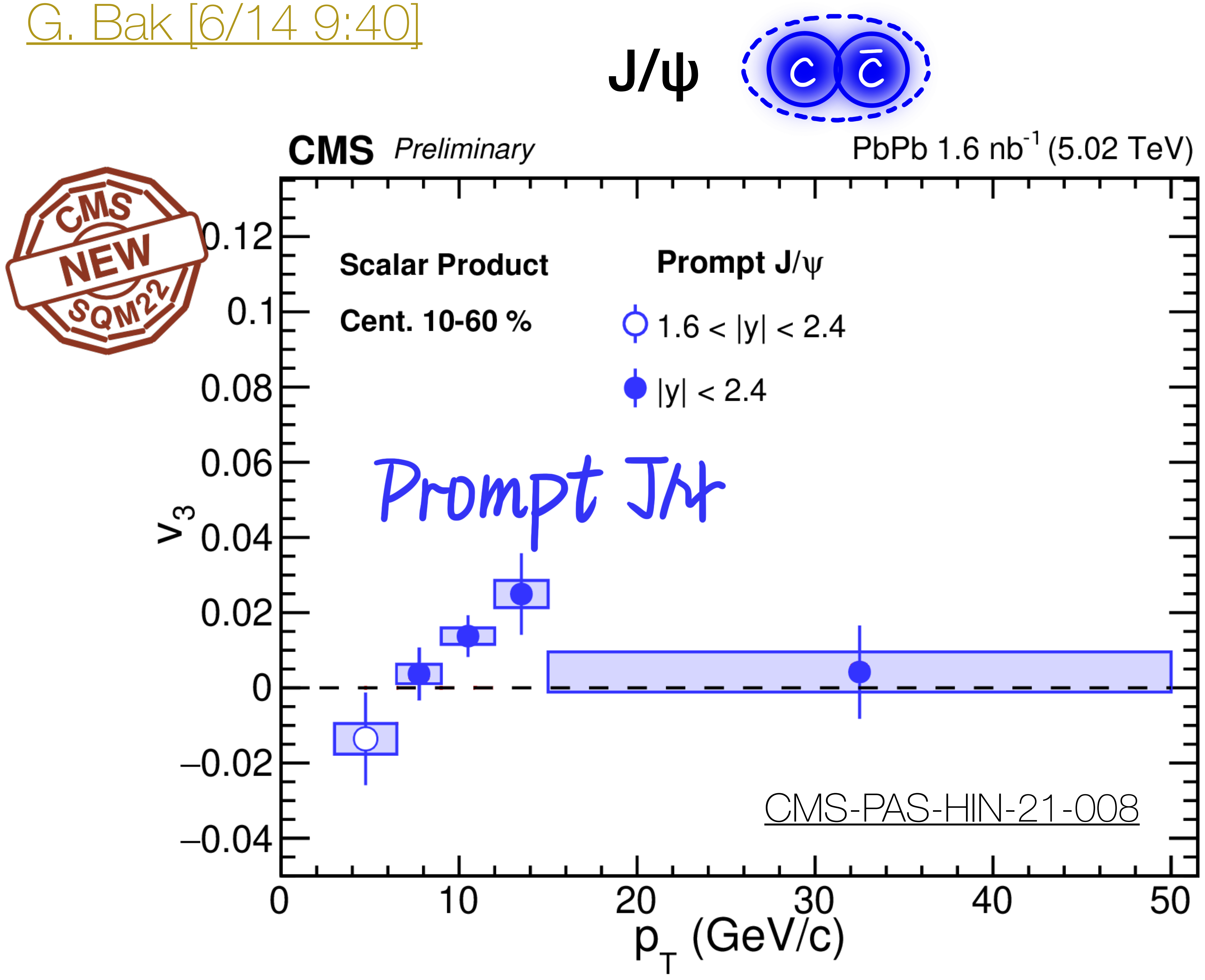
- Drell-Yan: $Z/\gamma^* \to \mu\mu$
  - Access small x with $m_{\mu\mu}$ down to 15 GeV

$$x \propto m_{\mu\mu} e^{-y_{CM}}$$

- Smaller data uncertainty than nPDF
- Prefer nPDF (EPPS16, nCTEQ) to proton PDF around Z mass

Probe Initial State with Charm v_3

G. Bak [6/14 9:40]



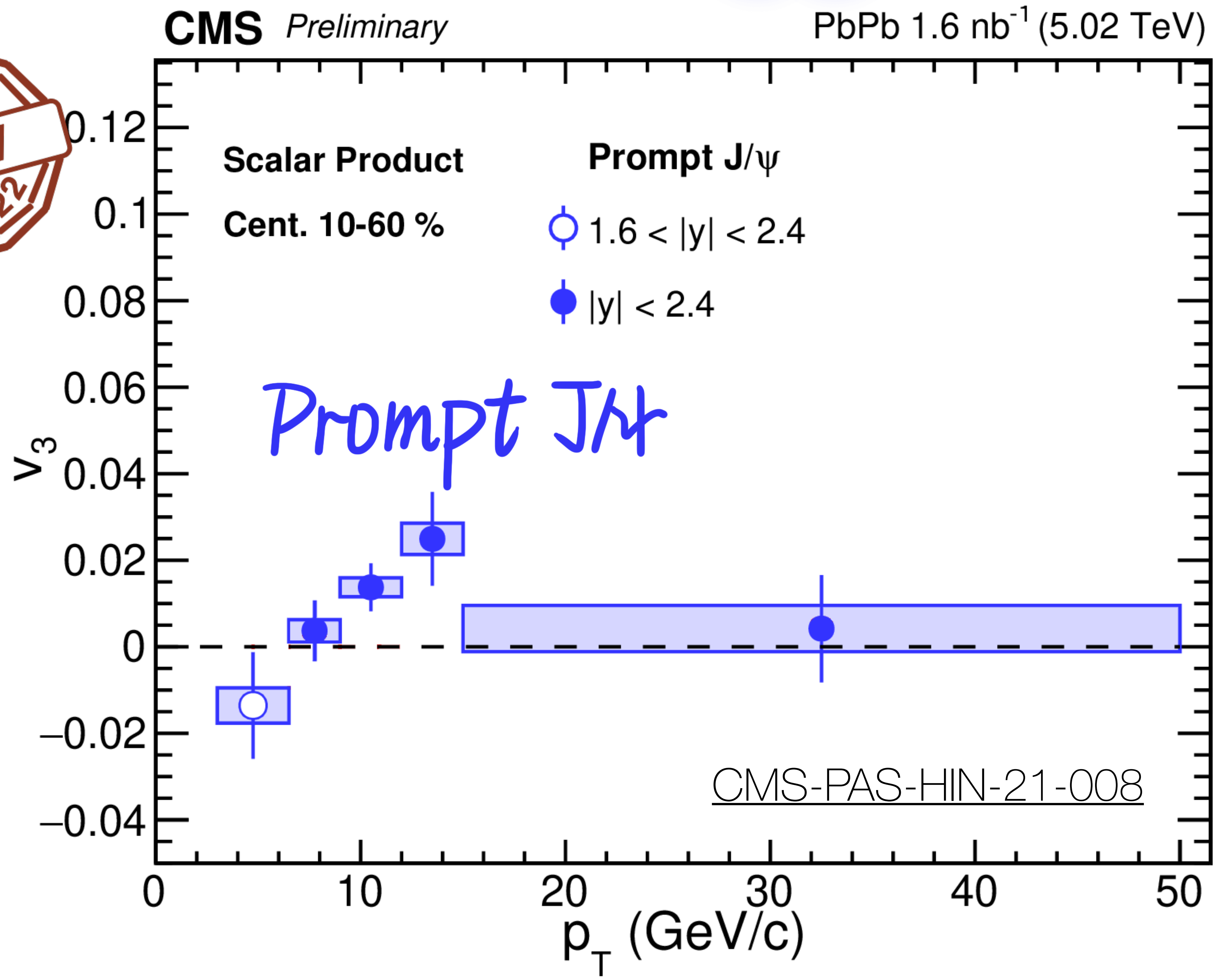
- First J/ψ v_3 measurement of prompt component

Probe Initial State with Charm v_3

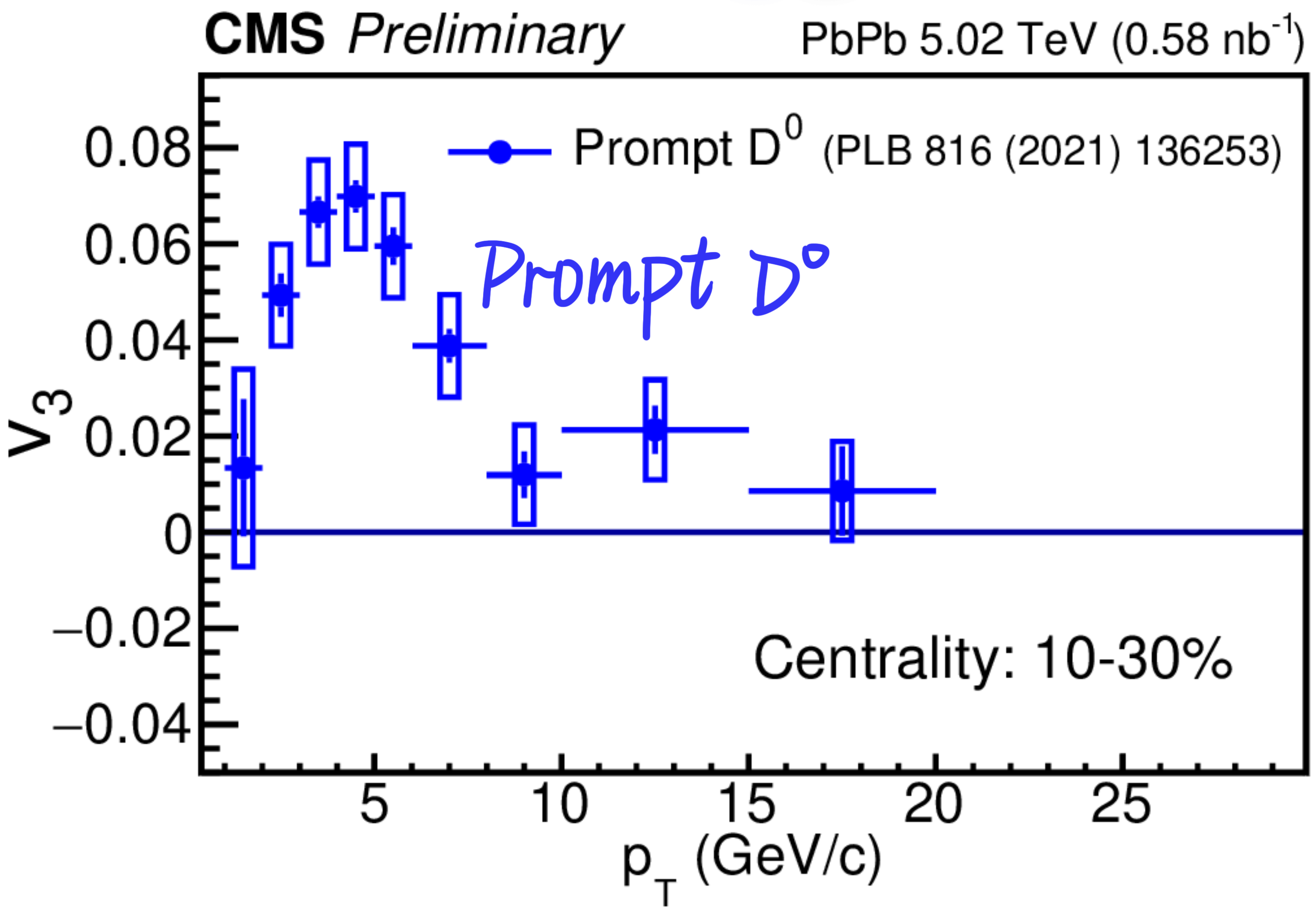
G. Bak [6/14 9:40]

M. Stojanovic [6/14 10:50]

J/ψ



D0



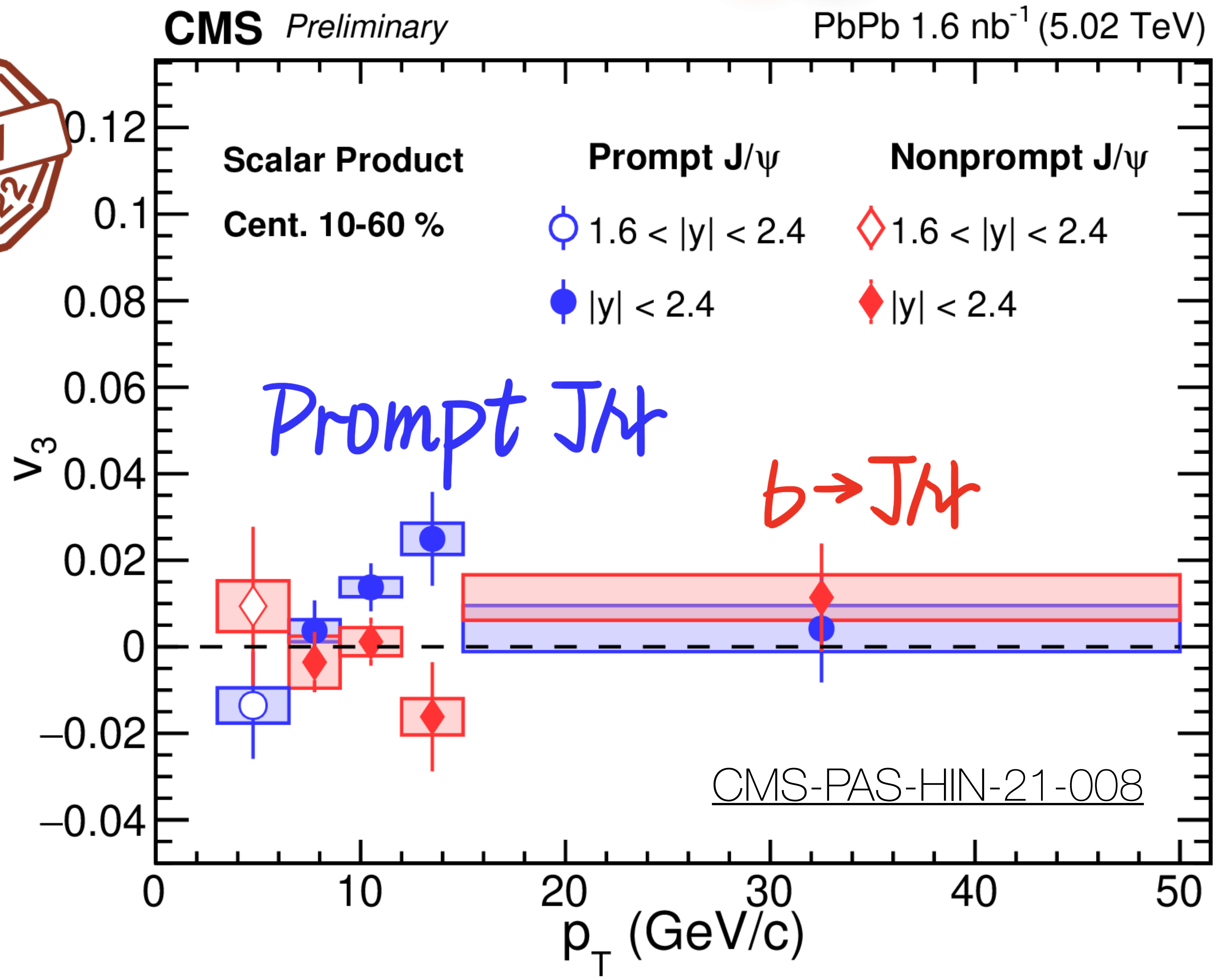
- First J/ψ v_3 measurement of prompt component
- Prompt D^0 v_3 > Prompt J/ψ v_3 ➜ charm is less sensitive to initial fluctuations than light quarks?

Probe Initial State with Beauty v_3

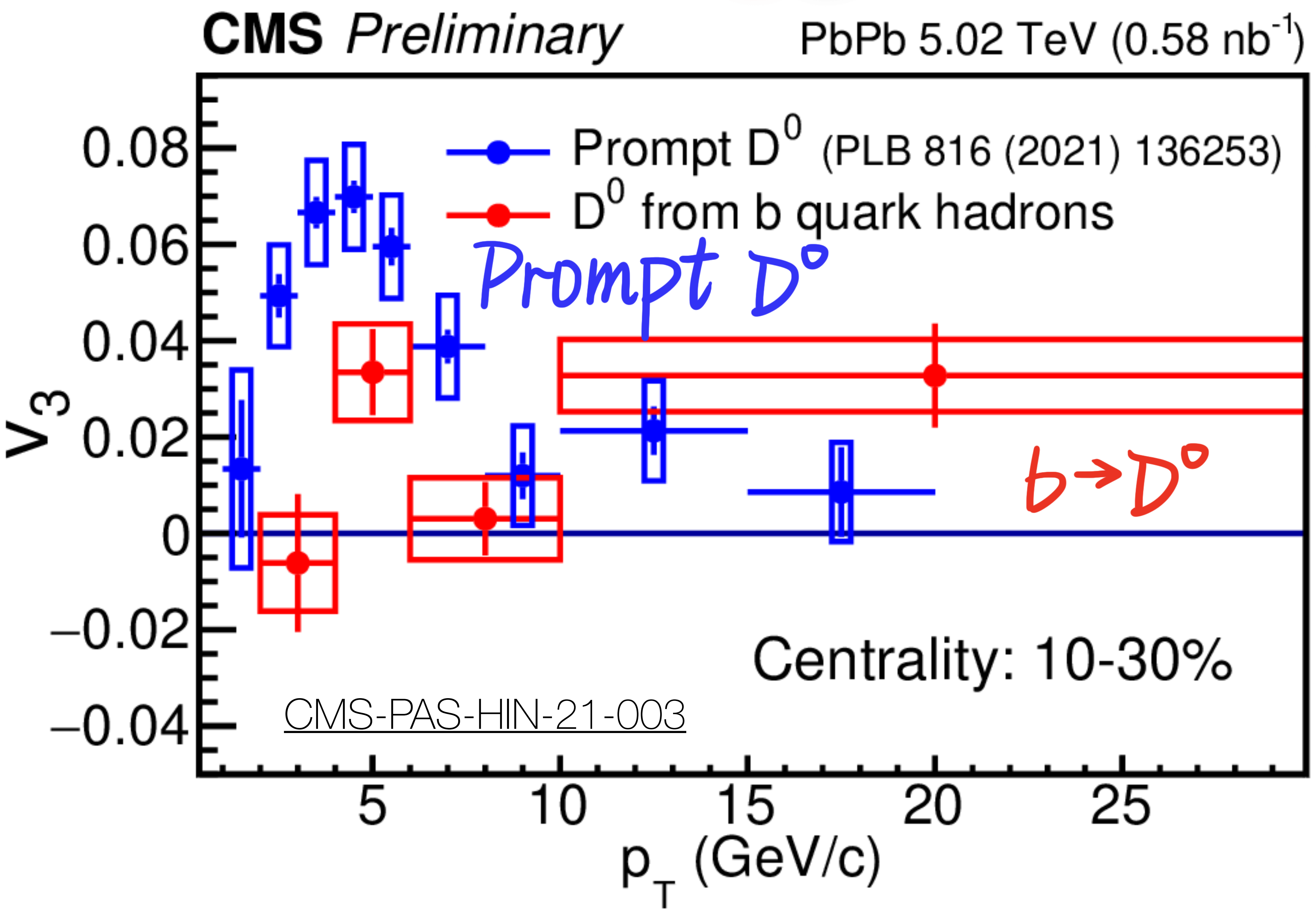
G. Bak [6/14 9:40]

M. Stojanovic [6/14 10:50]

b→J/ψ



b→D⁰



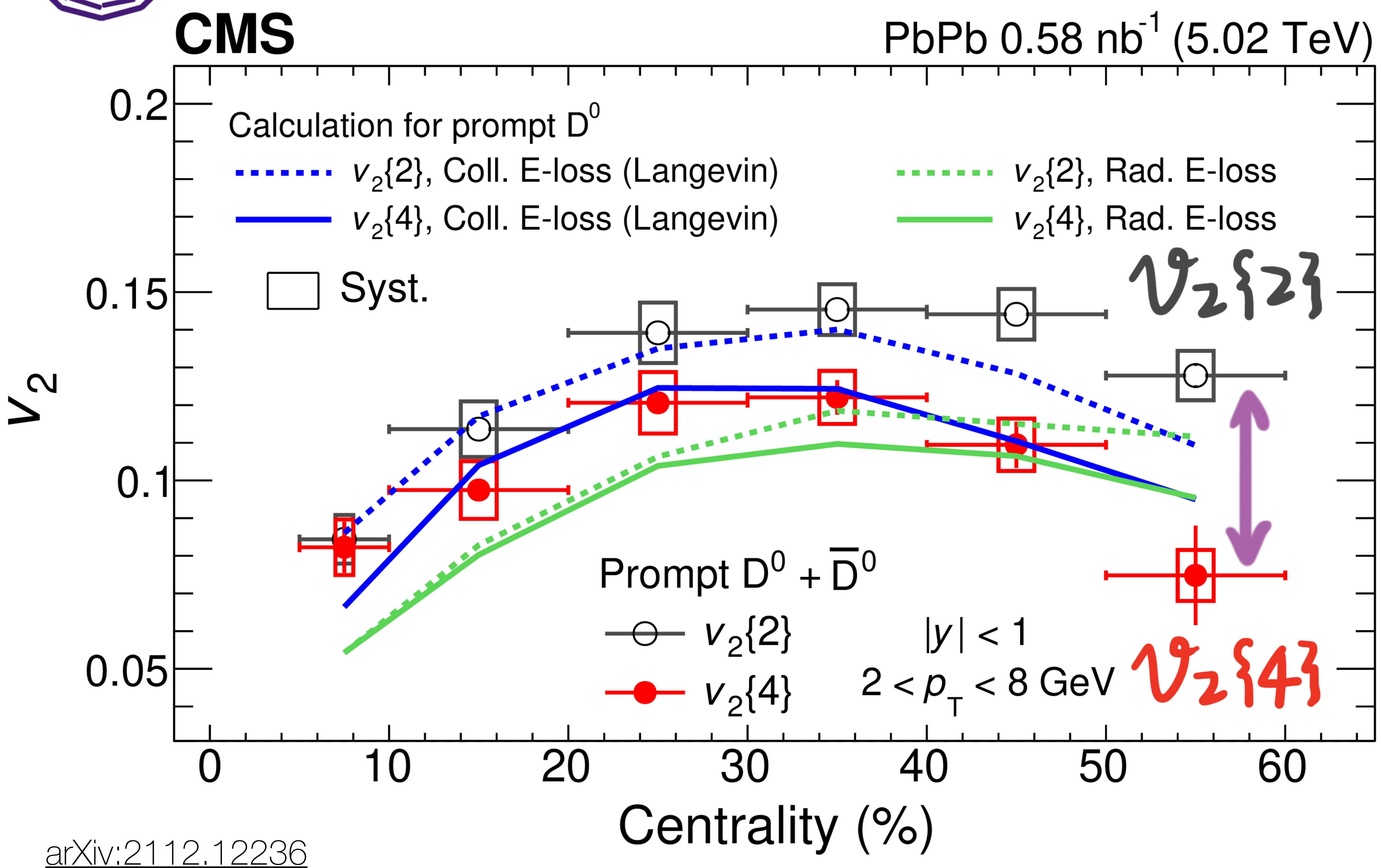
- (b→) D⁰ v_3 ≈ (b→) J/ψ v_3 are consistent and reflect beauty v_3
- (b→) D⁰ v_3 < Prompt D⁰ v_3 ➜ beauty less sensitive to initial state than charm?

Probe Initial State with D^0 $v_2\{4\}$

M. Stojanovic [6/14 10:50]

CMS FINAL SQM22

Prompt D^0 $v_2\{2\}$ vs. $v_2\{4\}$



arXiv:2112.12236

- Probe event-by-event fluctuation
  - $v_2\{2\}^2 \approx \langle v \rangle^2 + \sigma^2$
  - $v_2\{4\}^2 \approx \langle v \rangle^2 - \sigma^2$

flow fluctuation

- Indeed $v_2\{4\} < v_2\{2\}$ for D^0
- Fluctuations of both initial geometry (soft) and energy loss (hard)
  - distinguished by $v_2\{4\}/v_2\{2\}$ vs. p_T

    ➜ see Milan's talk

Section II

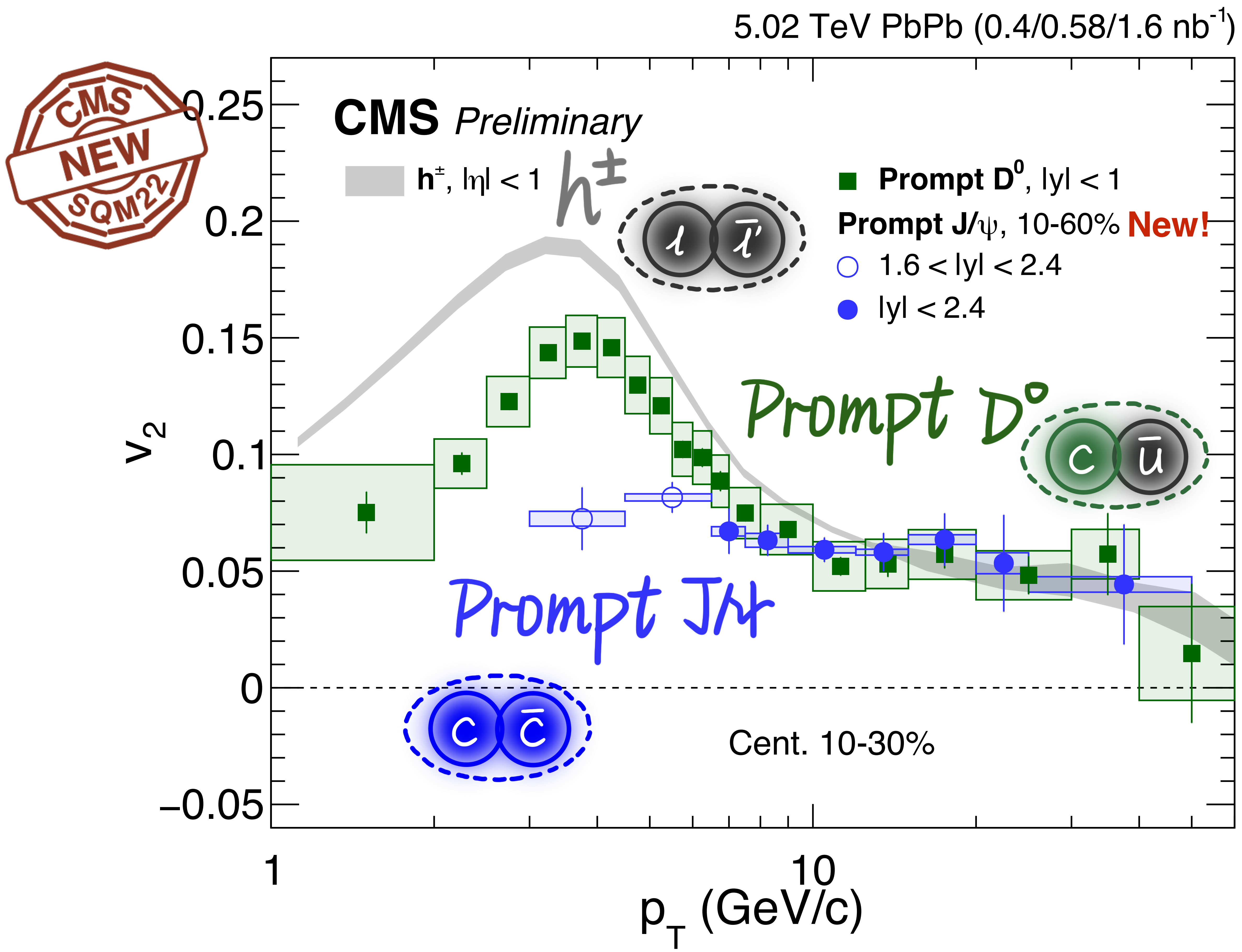
Click to see animation ↪

Charm v_2 in PbPb: Open vs. Hidden

G. Bak [6/14 9:40]

M. Stojanovic [6/14 10:50]

v_2 vs. p_T



- High precision measurement over wide p_T range
- Low p_T: $v_2(h^{\pm})$ > v_2(Prompt D^0) > v_2(Prompt J/ψ)
  - ➡ Different constituent quarks
  - ➡ Recombination
- High p_T: $v_2(h^{\pm})$ ≈ v_2(Prompt D^0) ≈ v_2(Prompt J/ψ)
  - ➡ Mass effect disappears
  - ➡ Path-length dependence of energy loss
  - ➡ Non-zero v_2 up to high p_T = 50 GeV

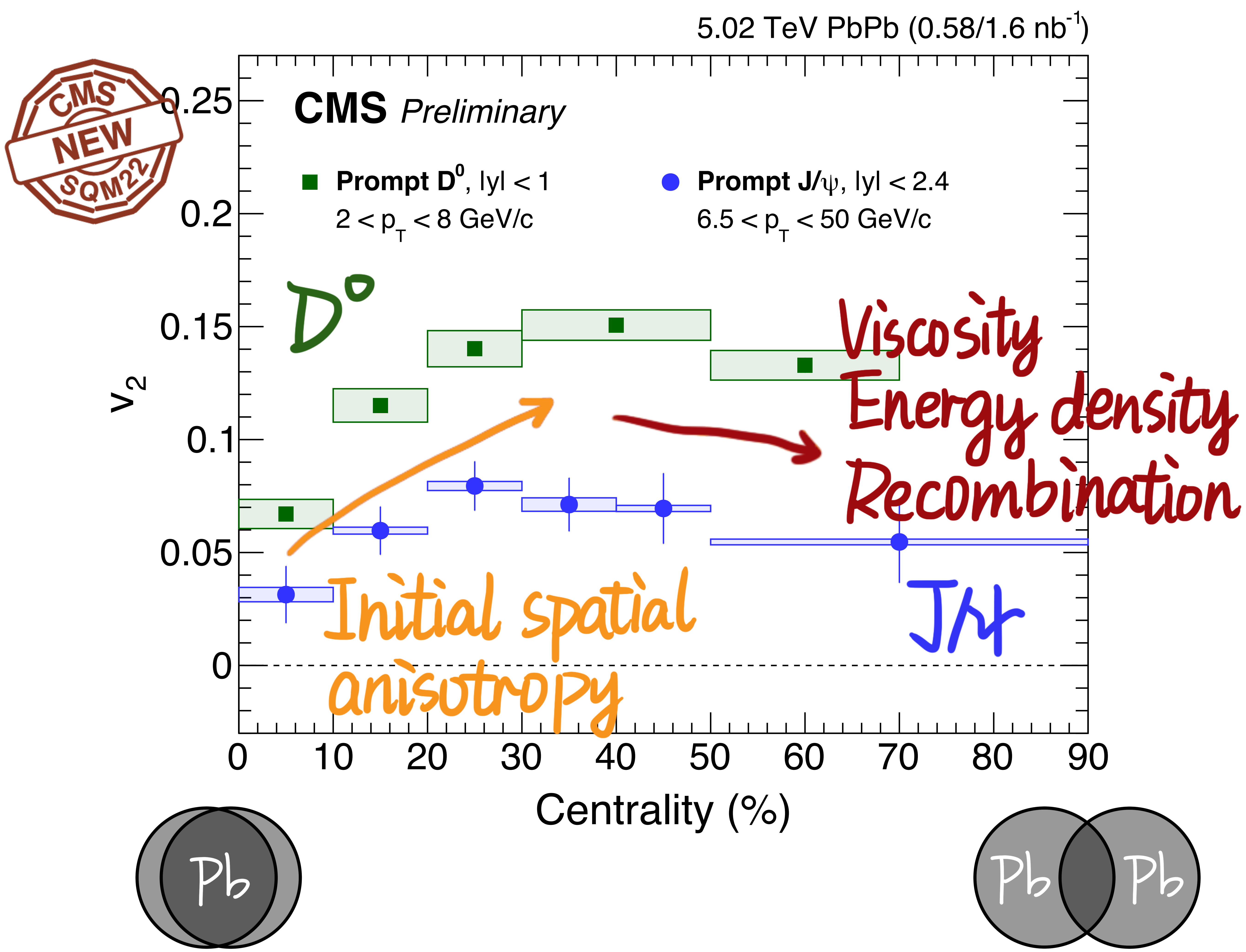
CMS-PAS-HIN-21-008

PLB 816 (2021) 136253

Charm v_2 in PbPb: Open vs. Hidden

M. Stojanovic [6/14 10:50]
G. Bak [6/14 9:40]

v_2 vs. centrality



- v_2 increase and then decrease from central to peripheral events for both D⁰ and J/ψ
  ➜ as expected by hydrodynamics
  ➜ but different effects work differently for Prompt D⁰ and J/ψ

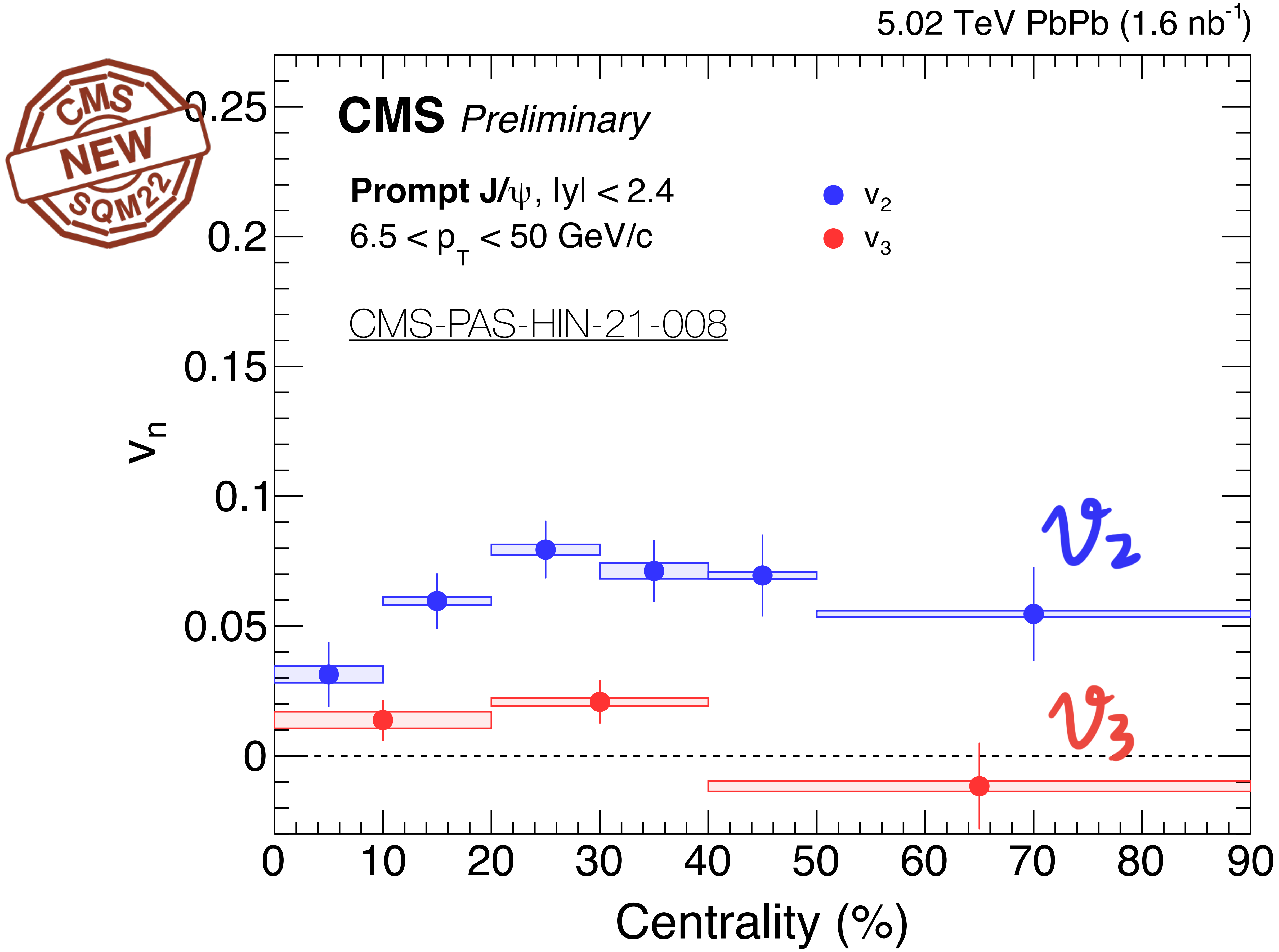
CMS-PAS-HIN-21-008
PLB 816 (2021) 136253

Charm v_2 in PbPb: v_2 vs. v_3

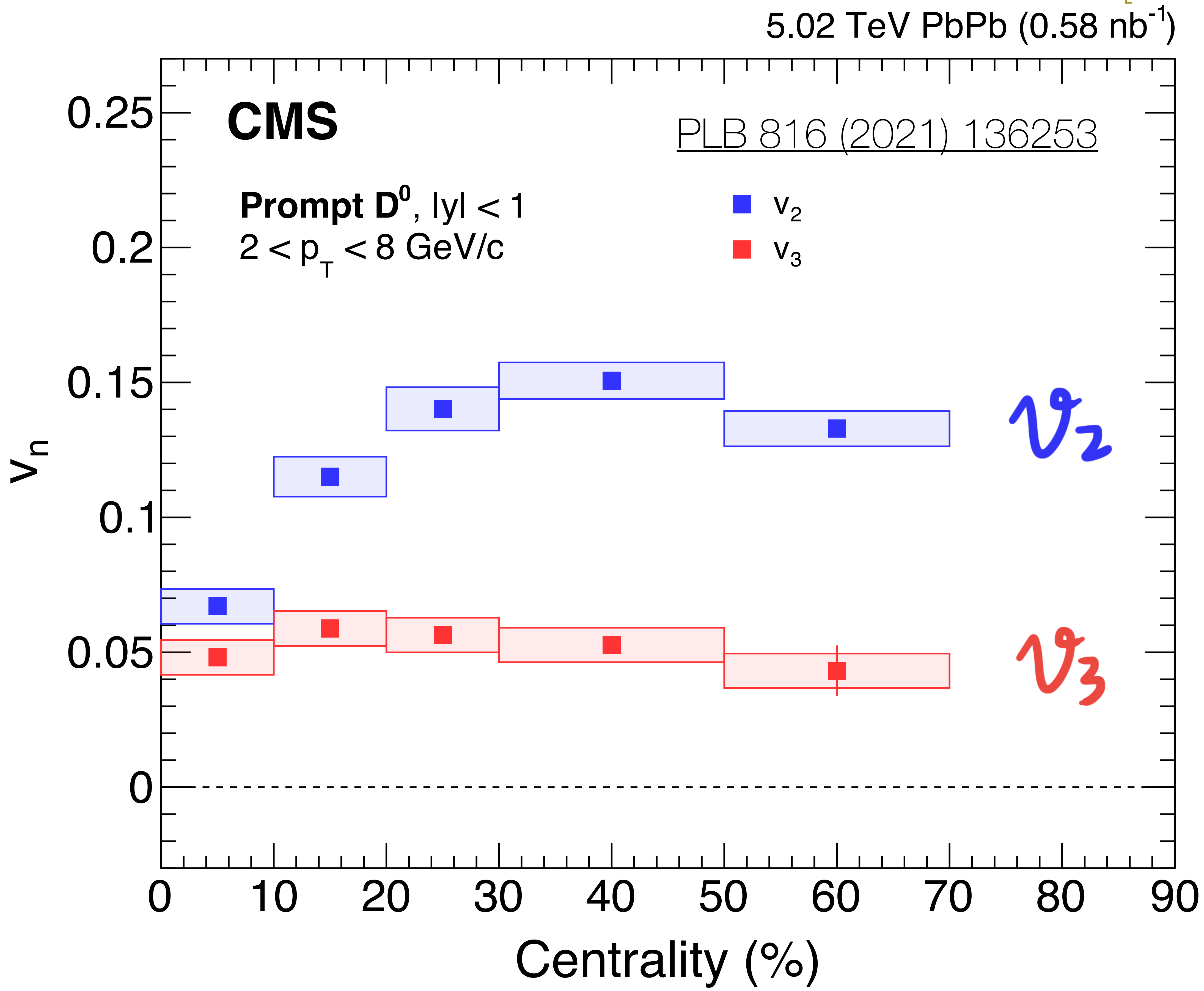
G. Bak [6/14 9:40]

M. Stojanovic [6/14 10:50]

Prompt J/ψ



Prompt D^0

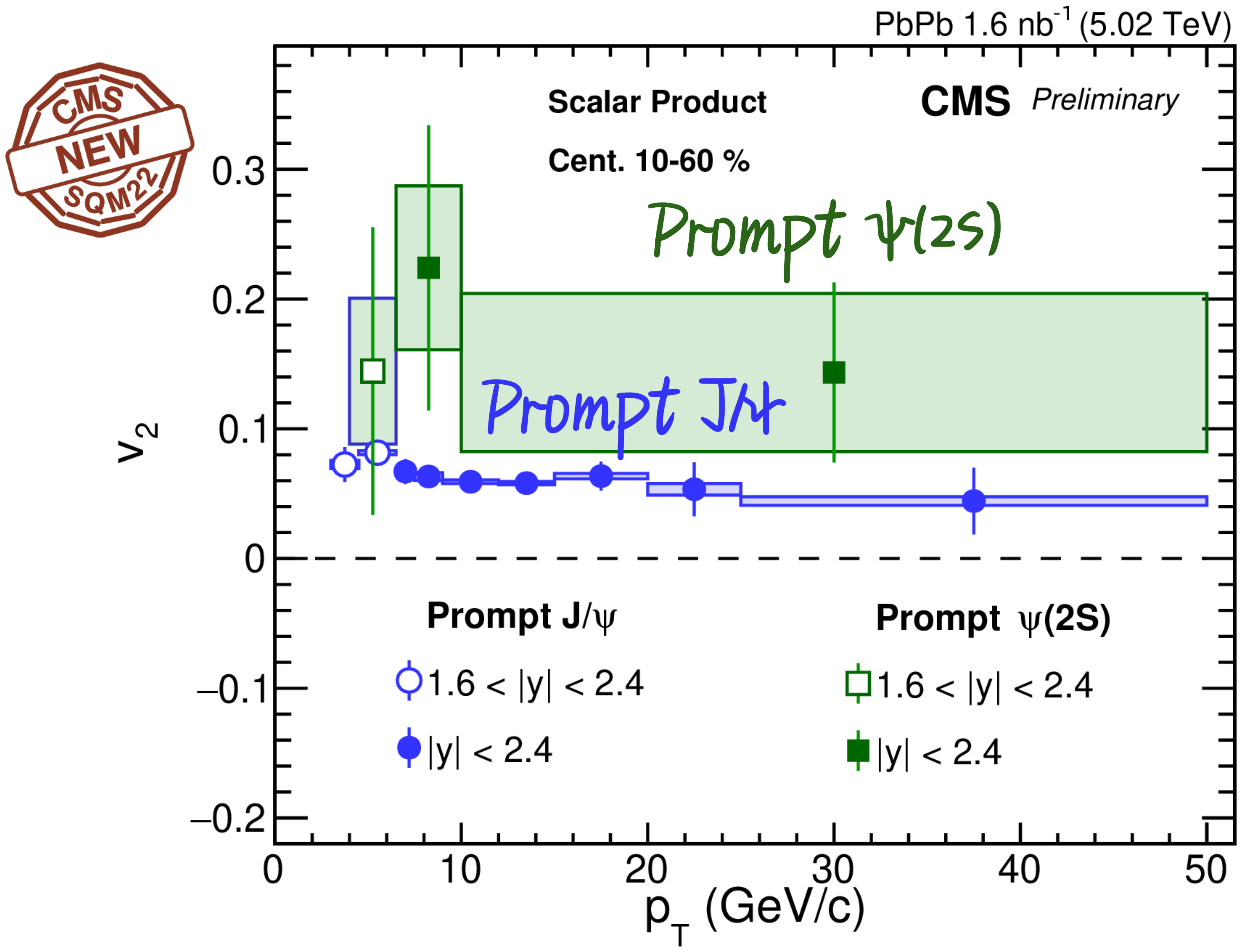


- Centrality dependence: strong for v_2 vs. weak for v_3 for both D^0 and J/ψ ➜ hydrodynamics

Charm v_2 in PbPb: J/ψ vs. ψ(2S)

G. Bak [6/14 9:40]

ψ(2S) v_2 vs. p_T



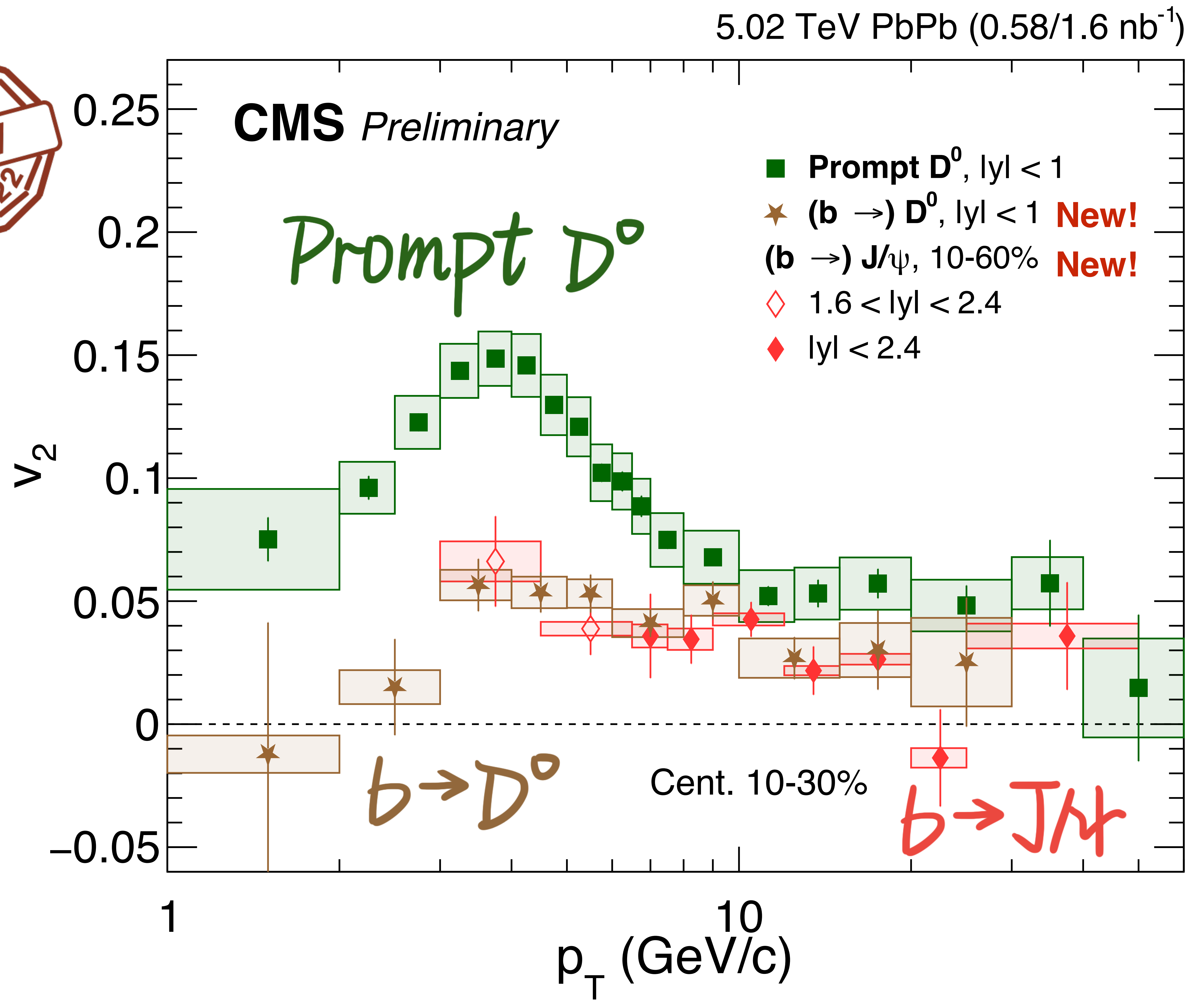
- First measurement of ψ(2S) v_2, v_3!
- Hint of v_2(ψ(2S)) > v_2(J/ψ)
  - Different relative contribution of recombination?

CMS-PAS-HIN-21-008

Beauty v_2 in PbPb: b→D and b→J/ψ

M. Stojanovic [6/14 10:50]
G. Bak [6/14 9:40]

v_2 vs. p_T



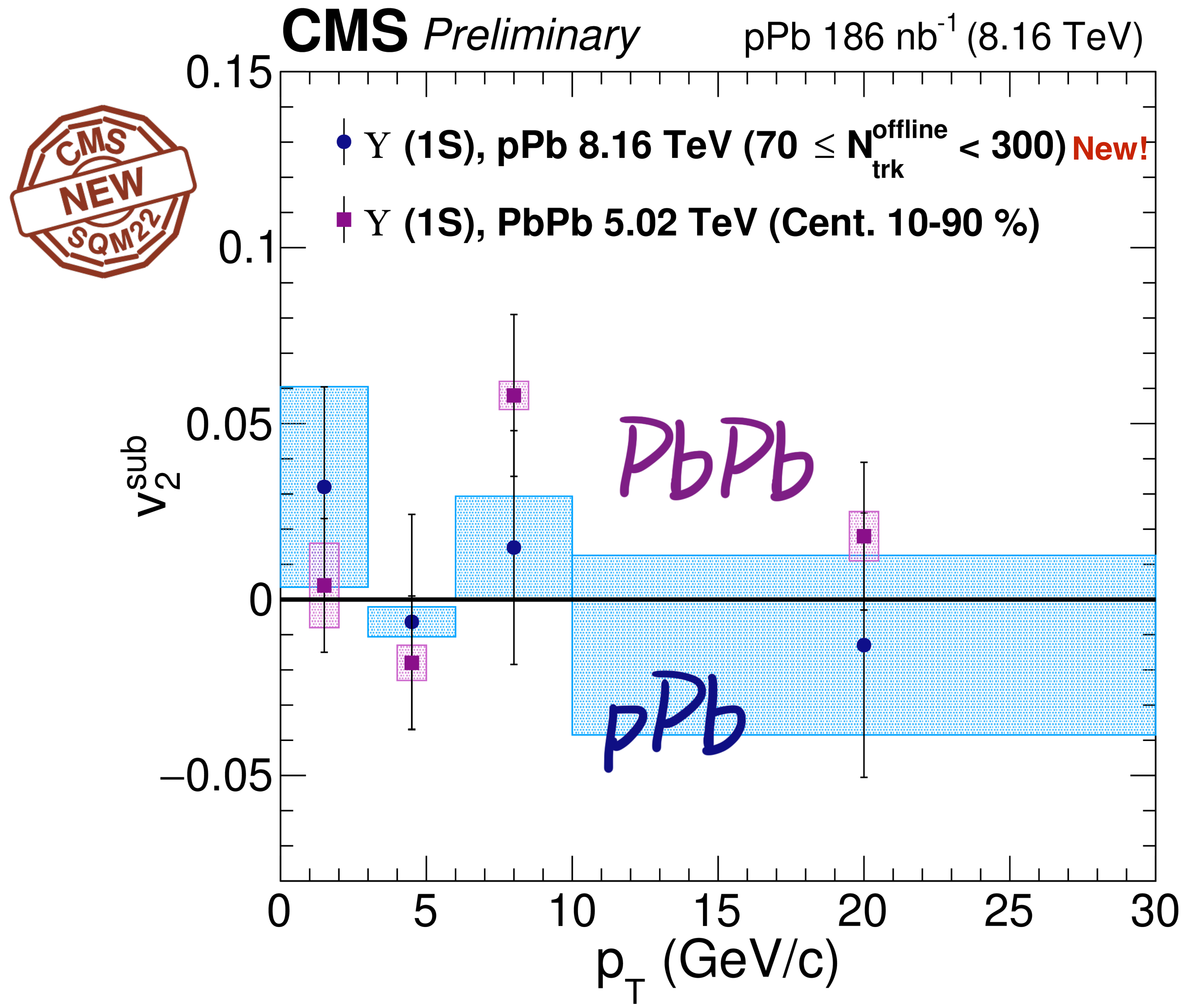
- Probe collectivity of beauty quark using different channels
  - Unique measurements covering wide kinematic range

- (b→) D^0 v_2 consistent with (b→) J/ψ v_2
- Low p_T: Smaller than prompt D^0 v_2
  ➜ Weaker collective motion of beauty than charm
- High p_T: All flavors tend to converge

CMS-PAS-HIN-21-008
PLB 816 (2021) 136253
CMS-PAS-HIN-21-003

Beauty v_2: Υ(1S) in pPb and PbPb

K. Lee [6/14 9:50]

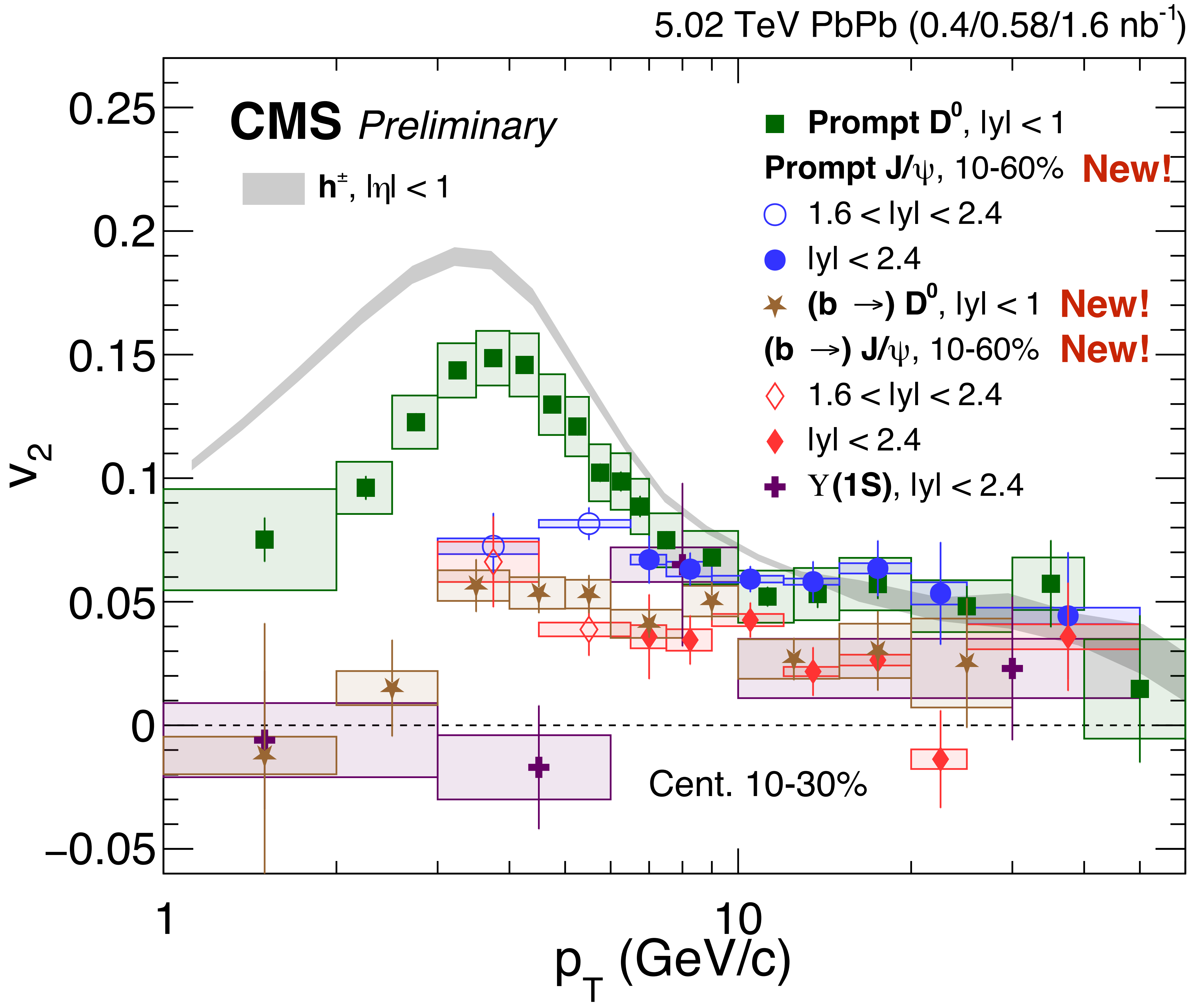


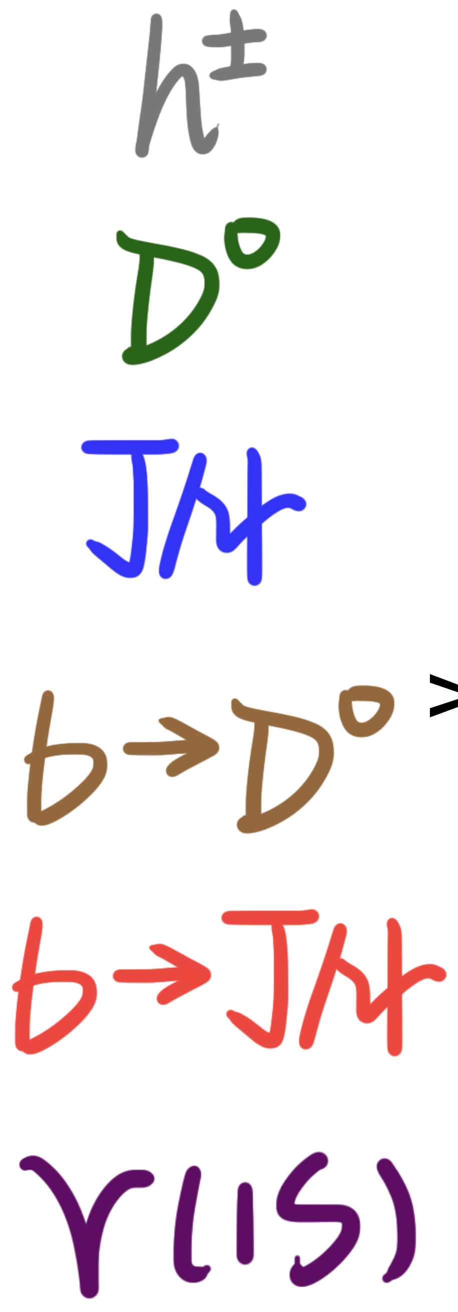
- No significant non-zero v_2 of Υ(1S) in both PbPb and high multiplicity pPb

CMS-PAS-HIN-21-001

Summary: CMS Heavy Flavor v_2 Zoo

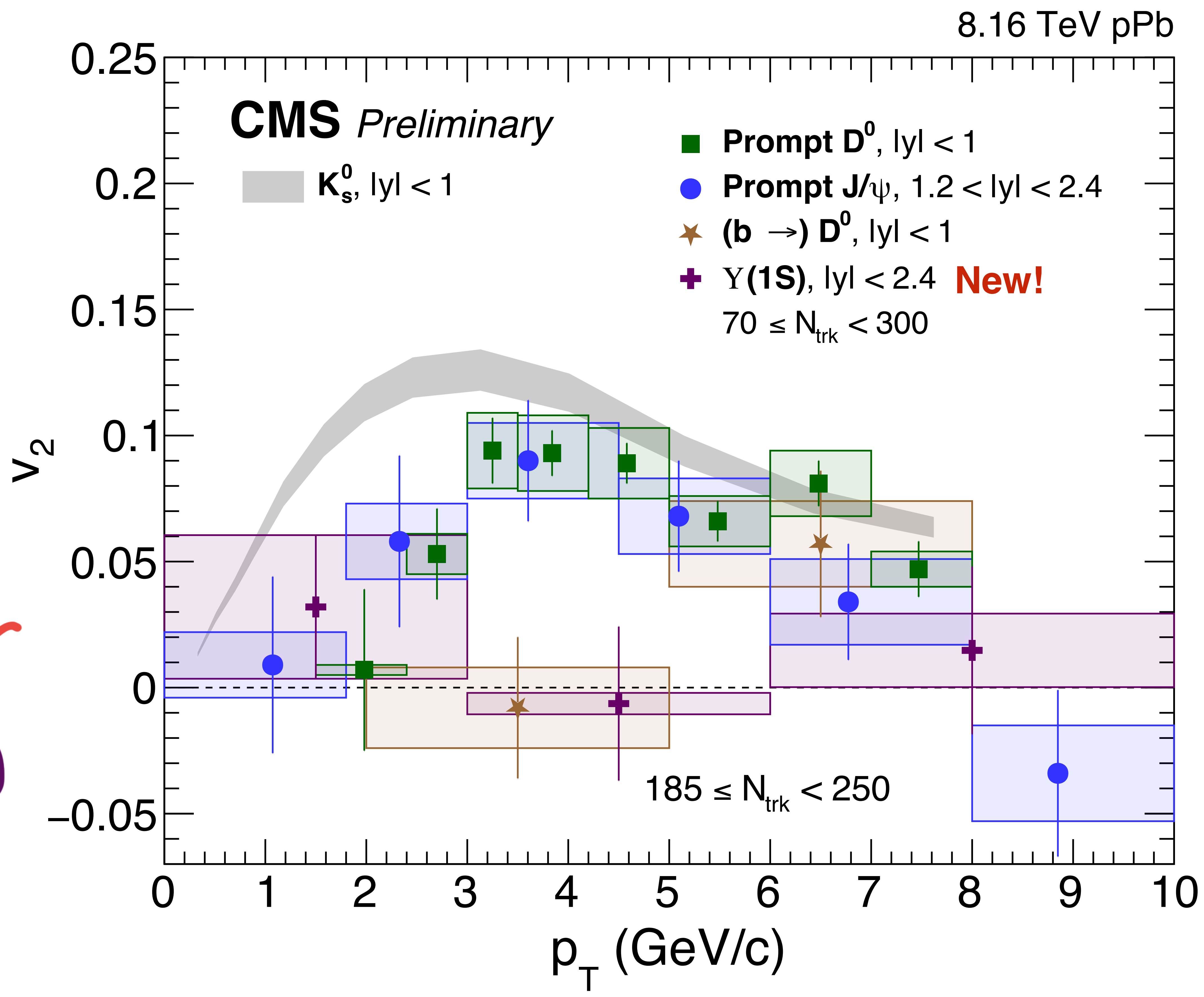
PbPb @ 5.02 TeV





Reference

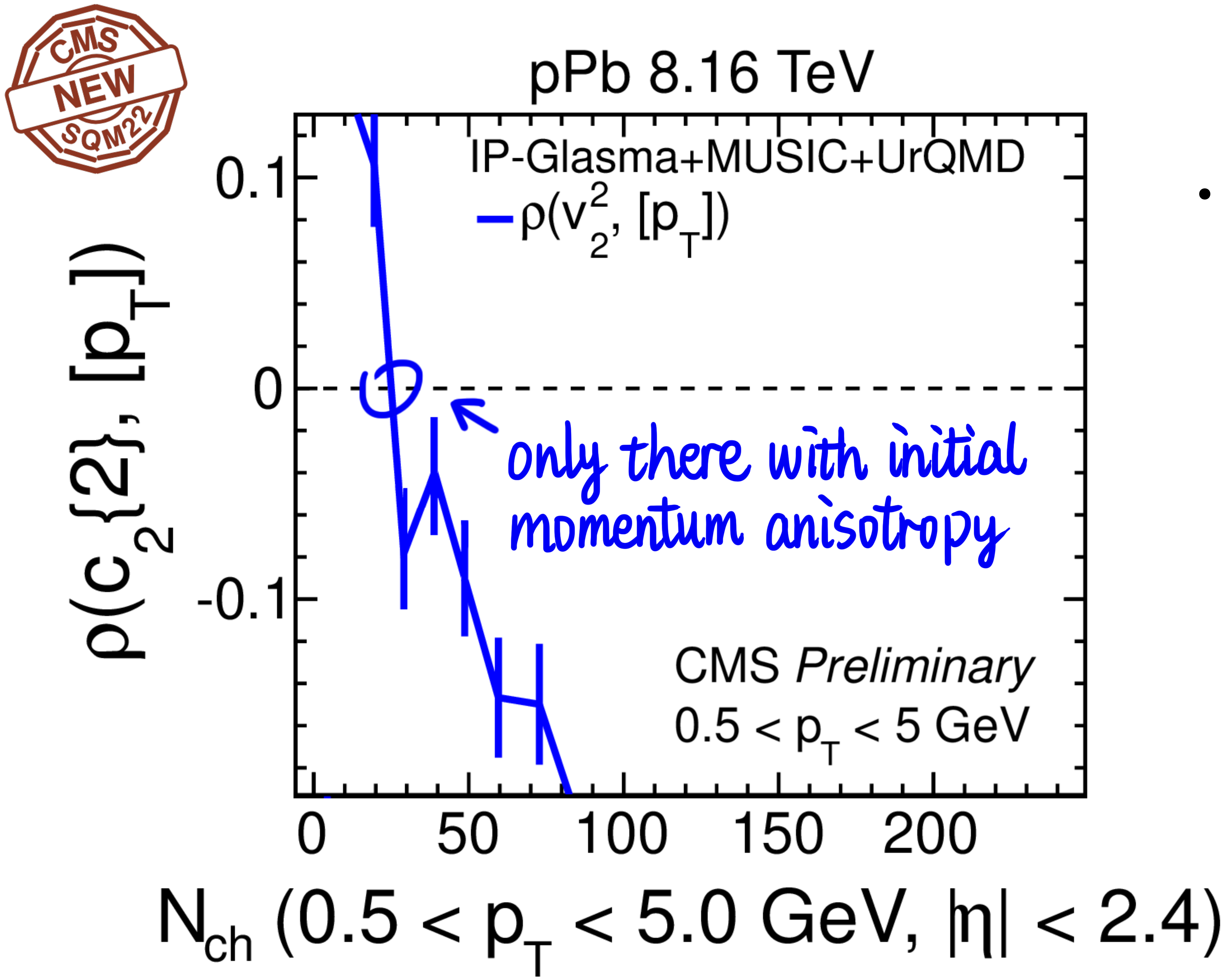
pPb @ 8.16 TeV



- Abundant physics behind these high precision and unique measurements from CMS!
- Strong constraint on theoretical calculations in different collision systems

Cumulant-mean p_T Correlation in pPb

S. Tuo [POS-BLK-03]



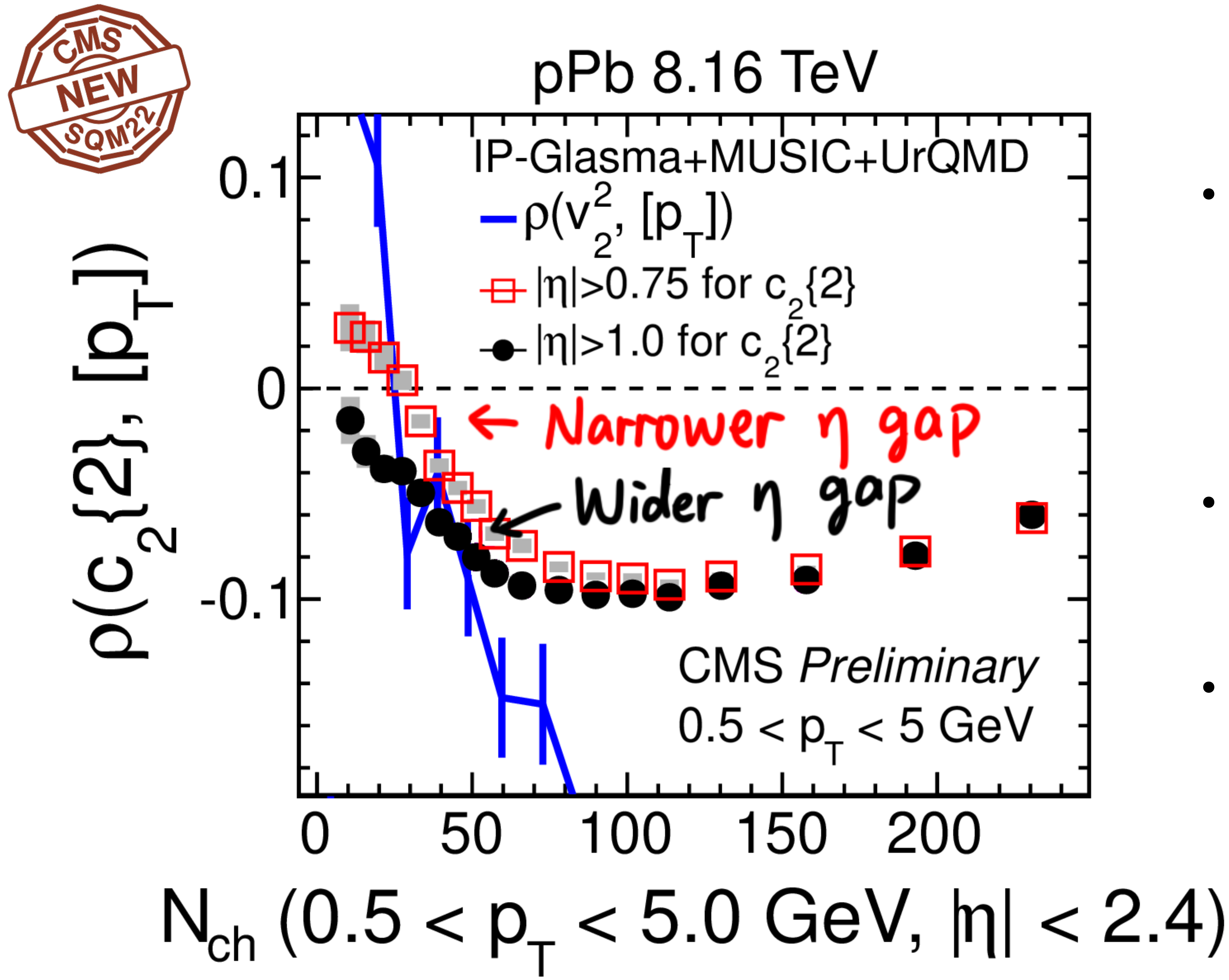
- Correlation of v_2 and average p_T carries info on the origin of v_2 in small systems
  - Sign change predicted with initial momentum anisotropy in CGC[1]

CMS-PAS-HIN-21-012

[1]PRL 125 (2020) 192301

Cumulant-mean p_T Correlation in pPb

S. Tuo [POS-BLK-03]



- Correlation of v_2 and average p_T carries info on the origin of v_2 in small systems
  - Sign change predicted with initial momentum anisotropy in CGC[1]
- No sign change with wider η gap
  - Sensitive to nonflow contribution
- Multi-particle correlation and v_3 results in multiple collision systems see S. Tuo's poster

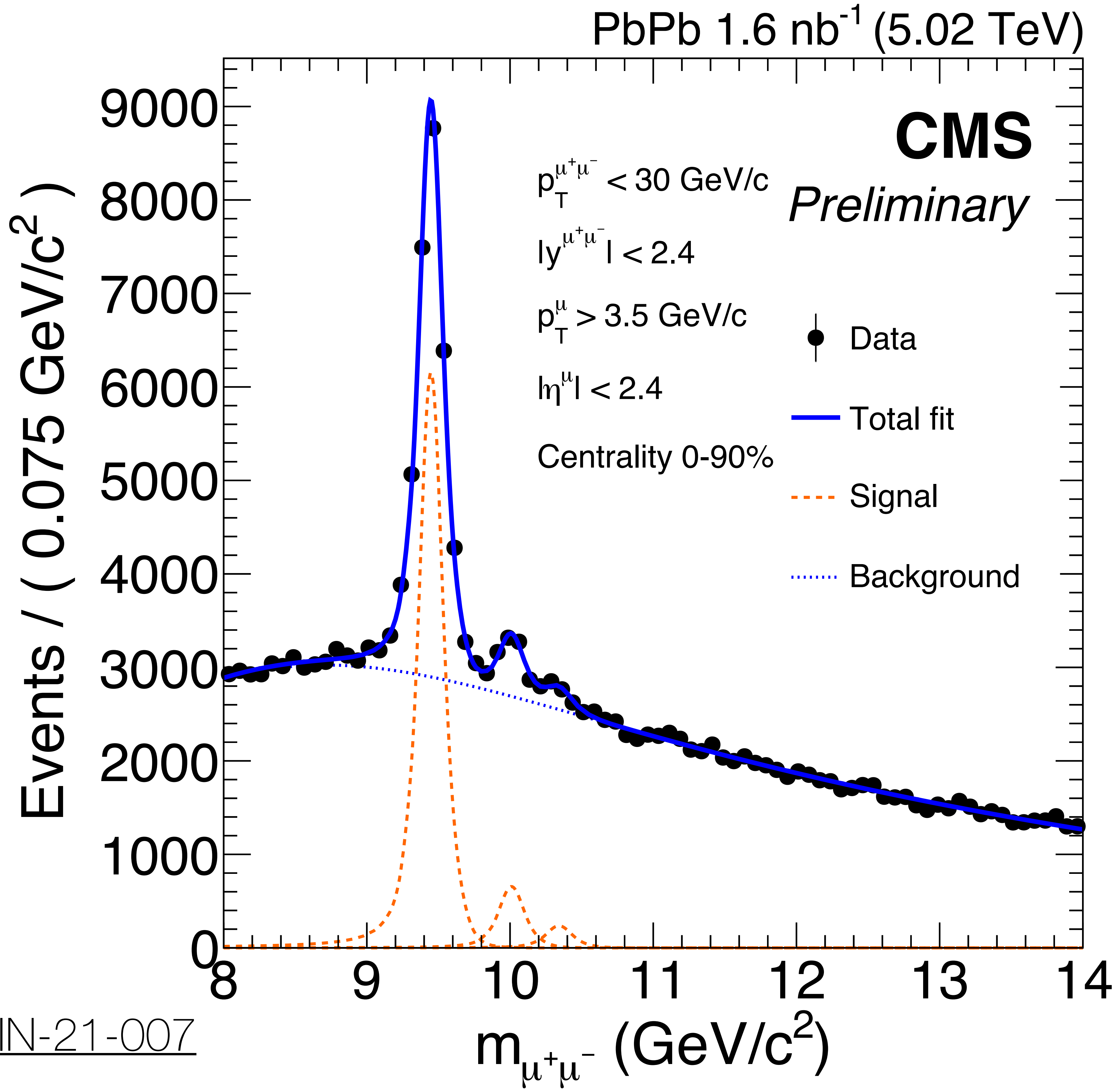
CMS-PAS-HIN-21-012

[1]PRL 125 (2020) 192301

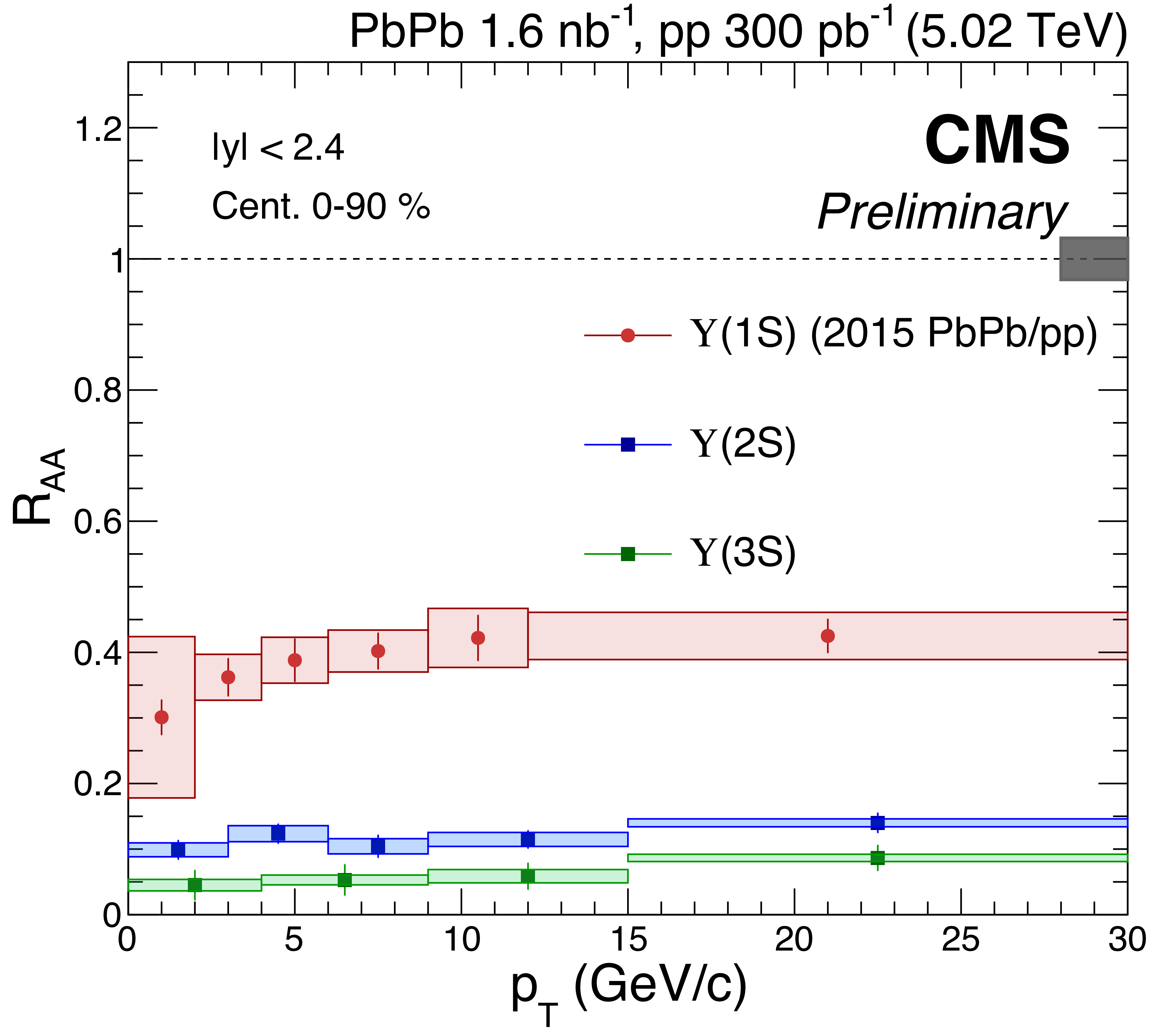
First Υ(3S) Observation in HIC

S. Lee [06/14 9:20]

CMS NEW SQM22



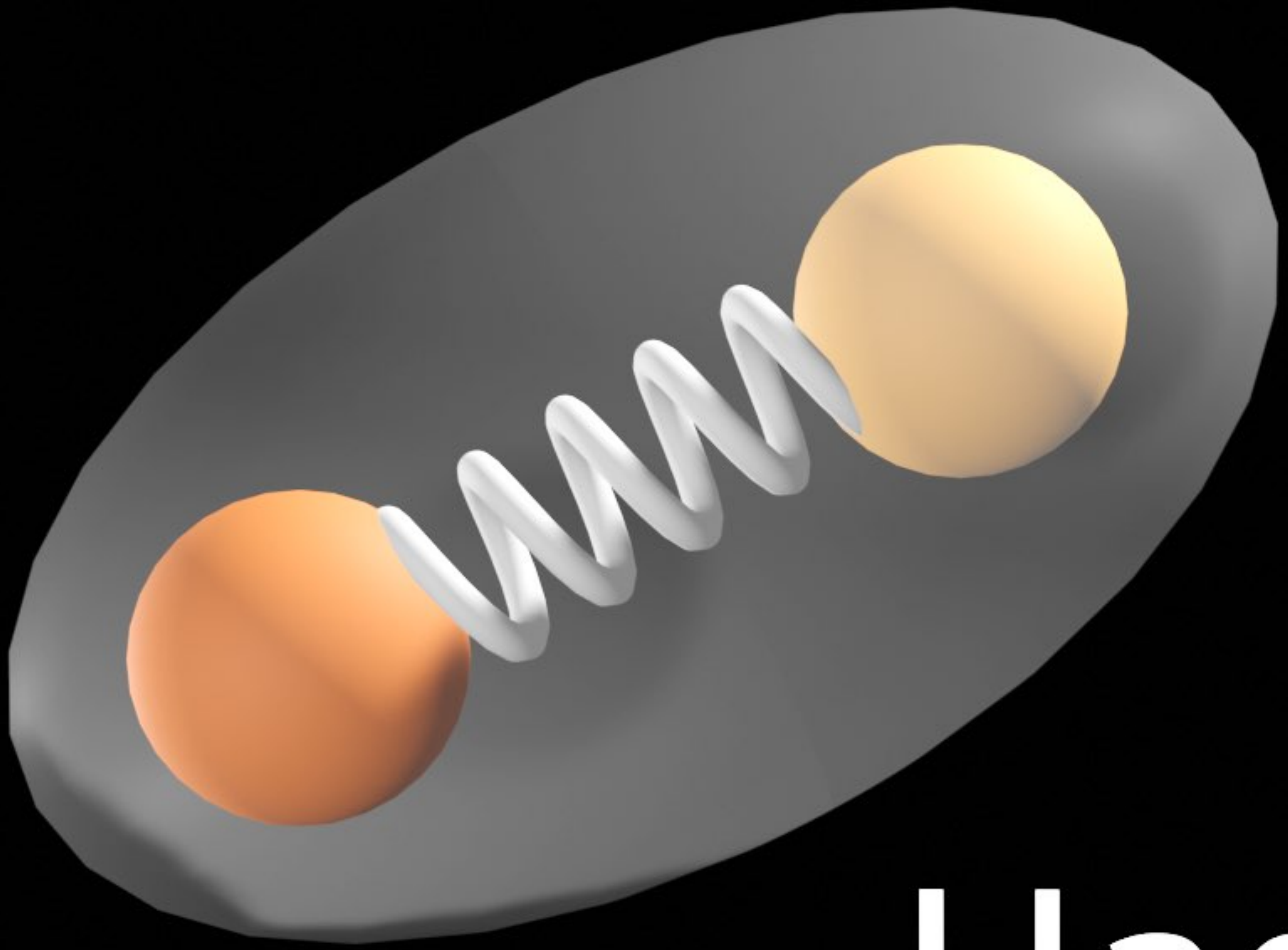
CMS-PAS-HIN-21-007



- First observation of Υ(3S) in PbPb!
- Signal significance > 5σ

- Smaller R_{AA} of Υ(3S) than Υ(2S)
- Strong constraint to theoretical models

Section III



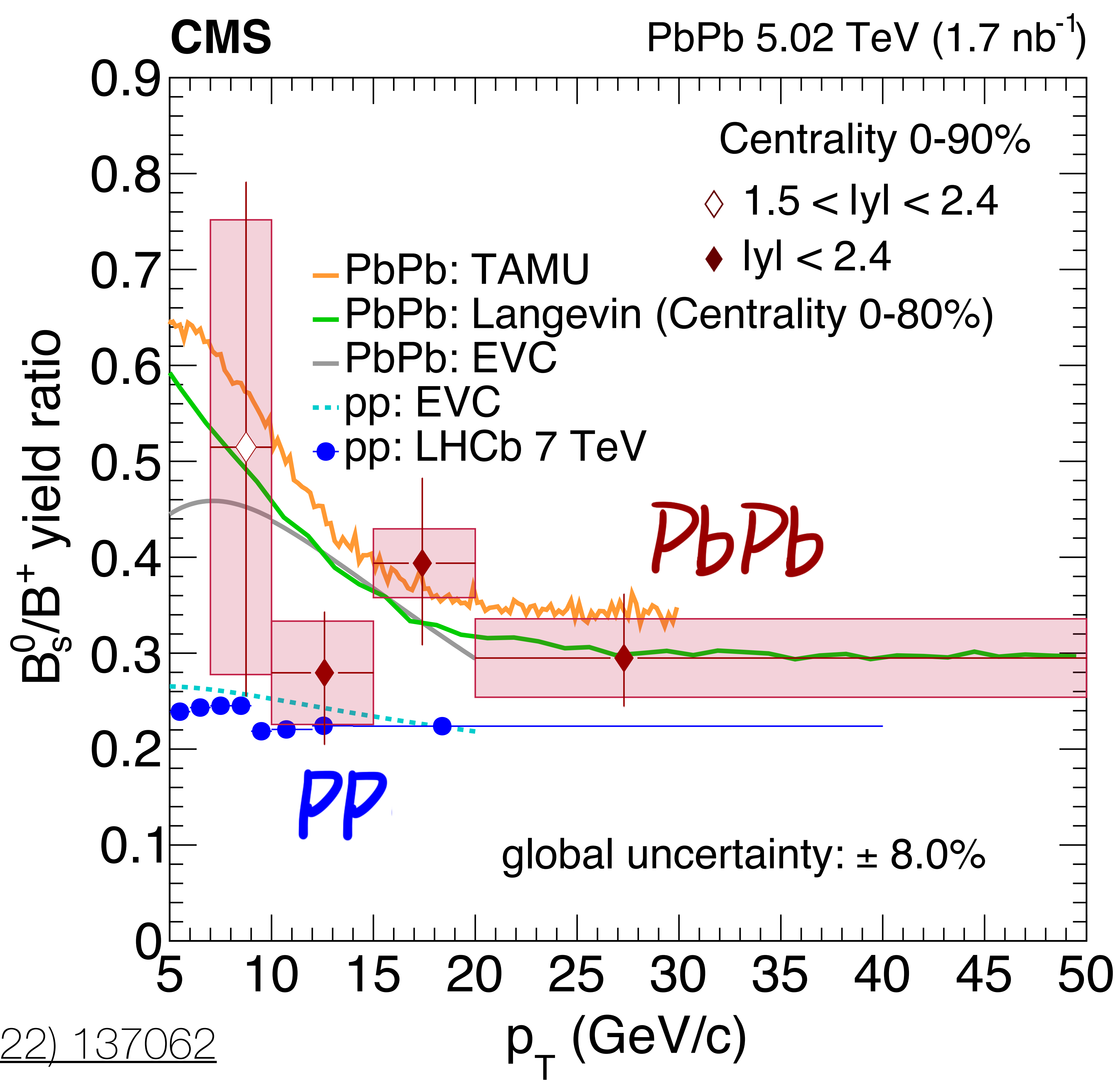
Hadronization

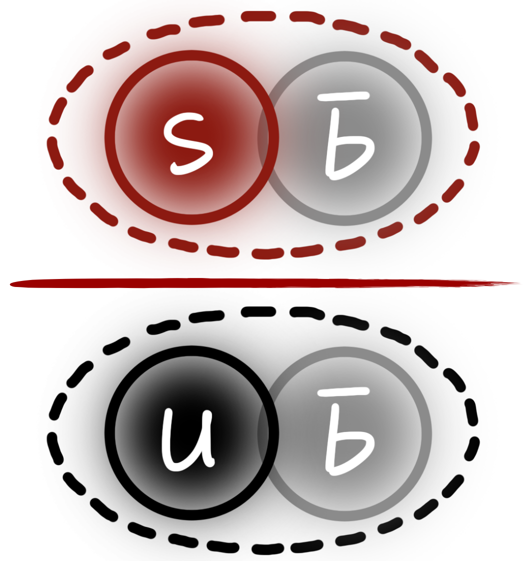
Click to see animation ↪

Hadronization: B_s and B_c in PbPb

F. Damas [06/14 11:30]

B_s/B^+ ratio





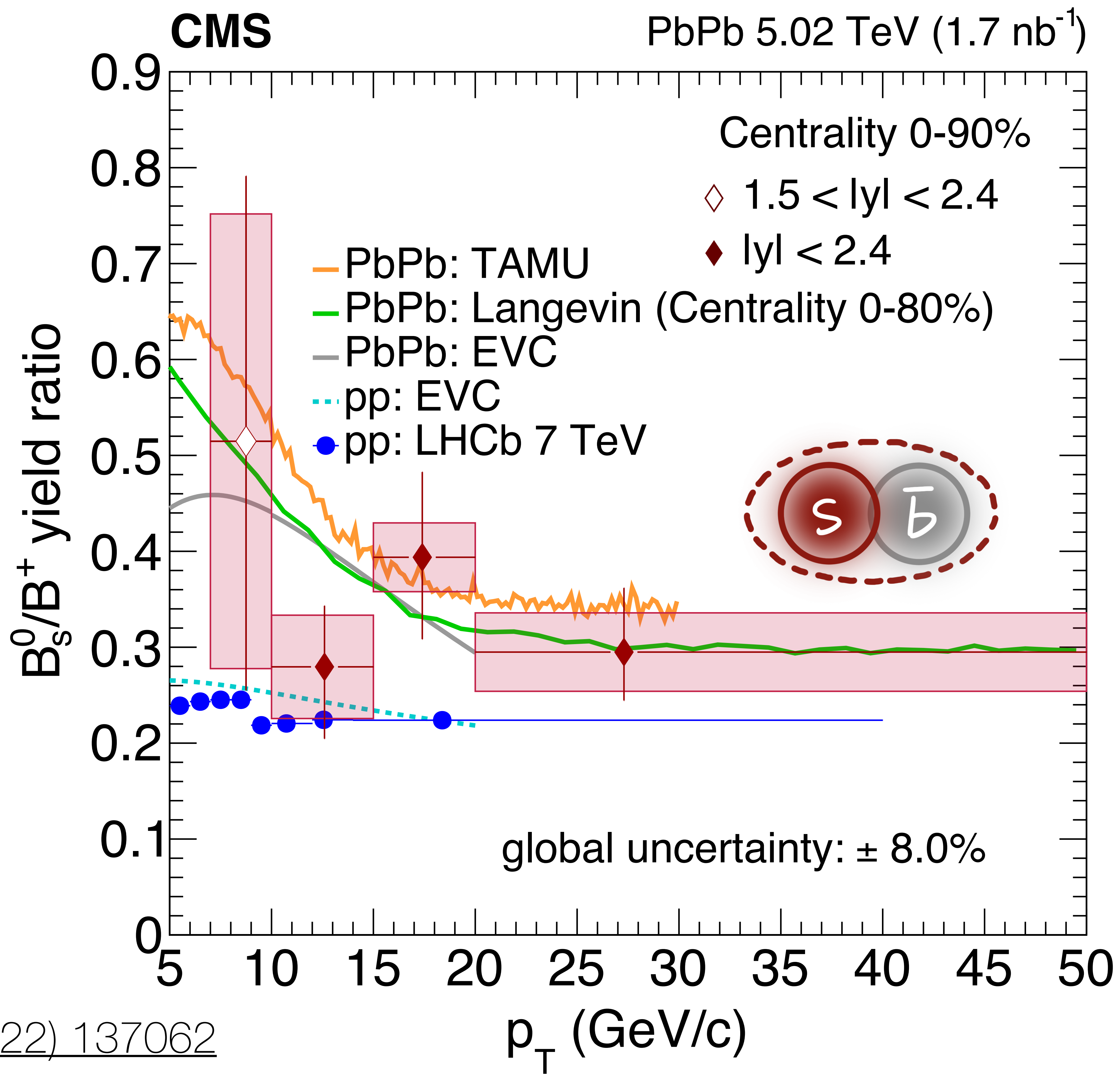
PLB 829 (2022) 137062

- Statistically compatible b/w PbPb and pp

Hadronization: B_s and B_c in PbPb

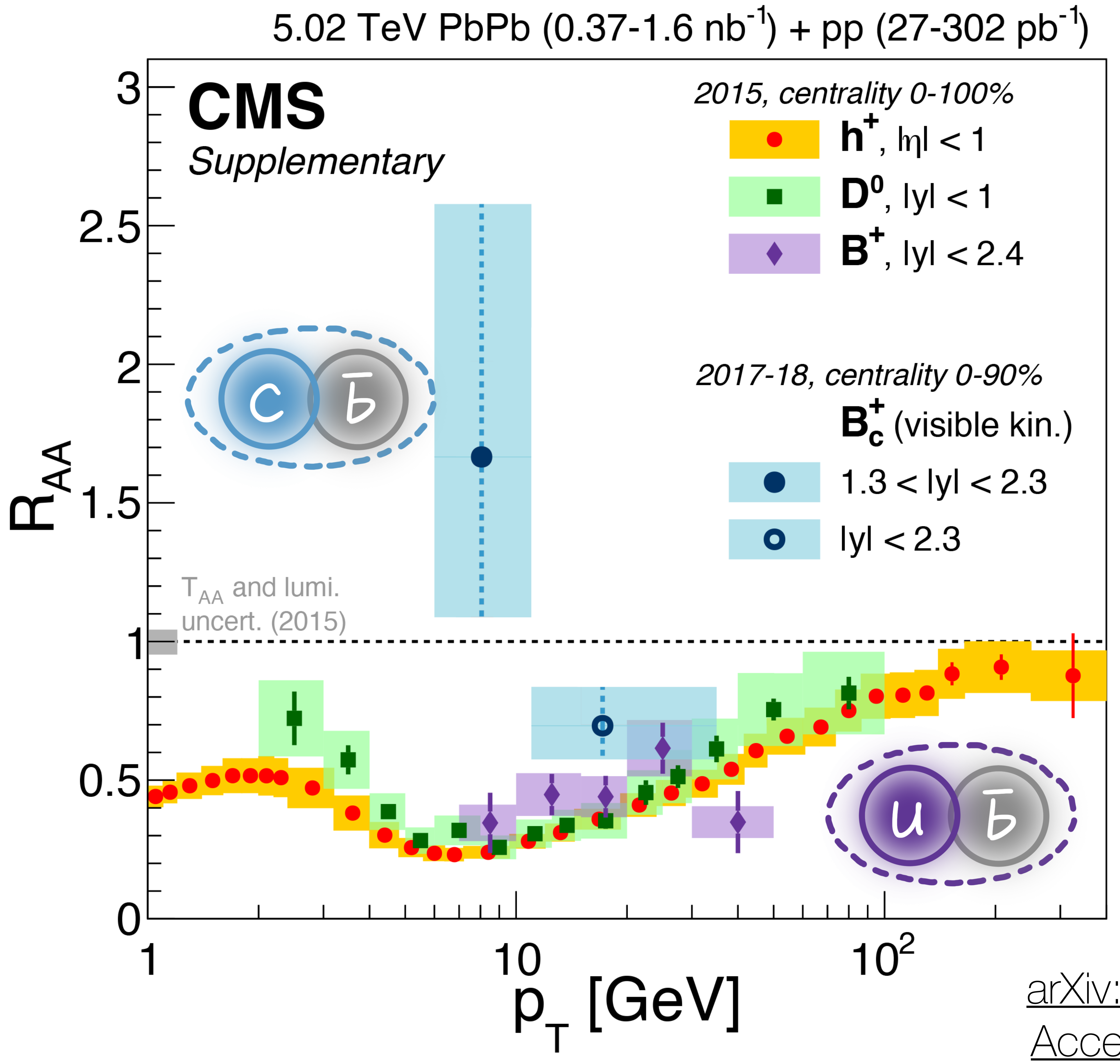
F. Damas [06/14 11:30]

B_s/B^+ ratio



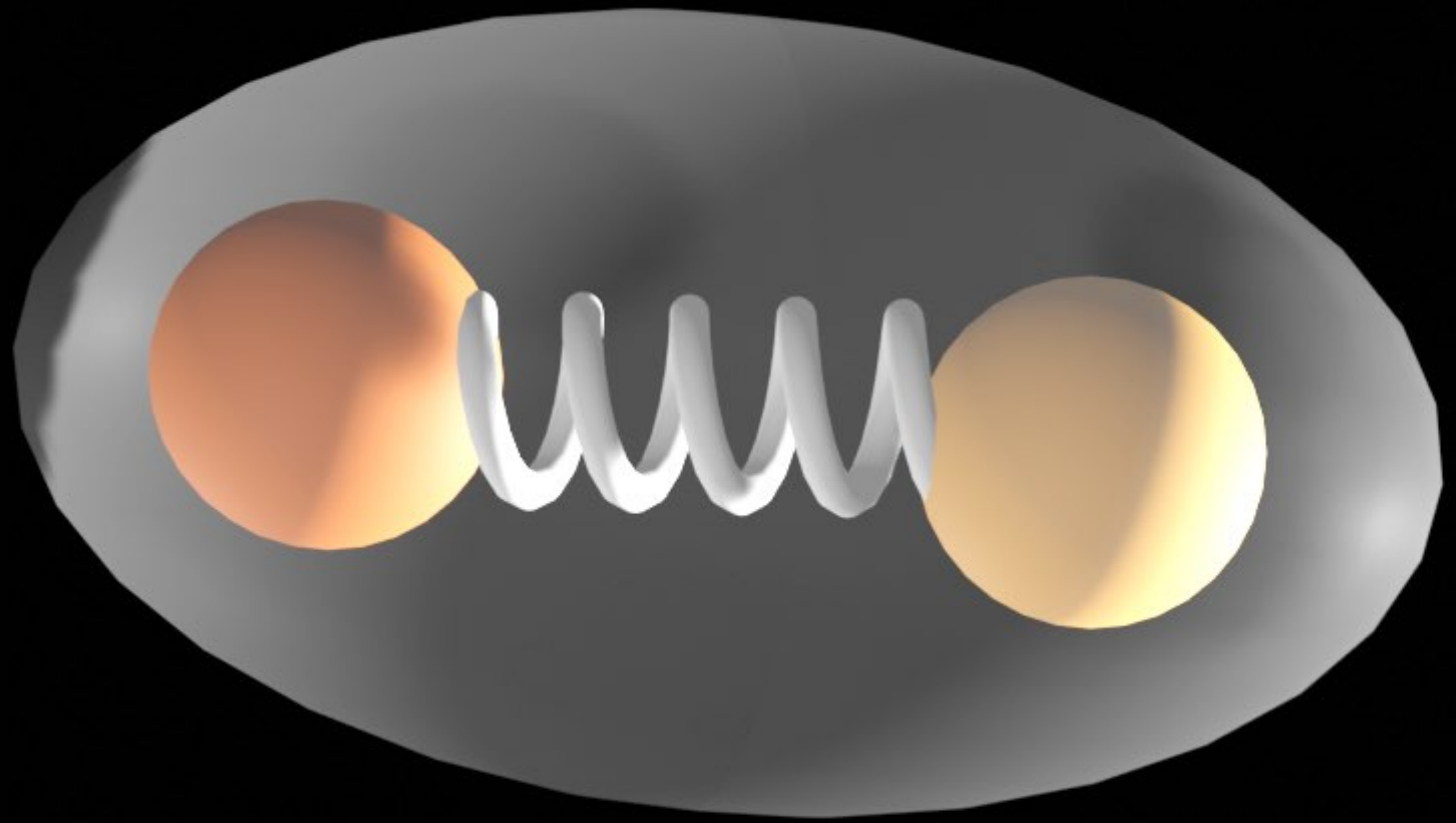
PLB 829 (2022) 137062

B_c R_{AA}

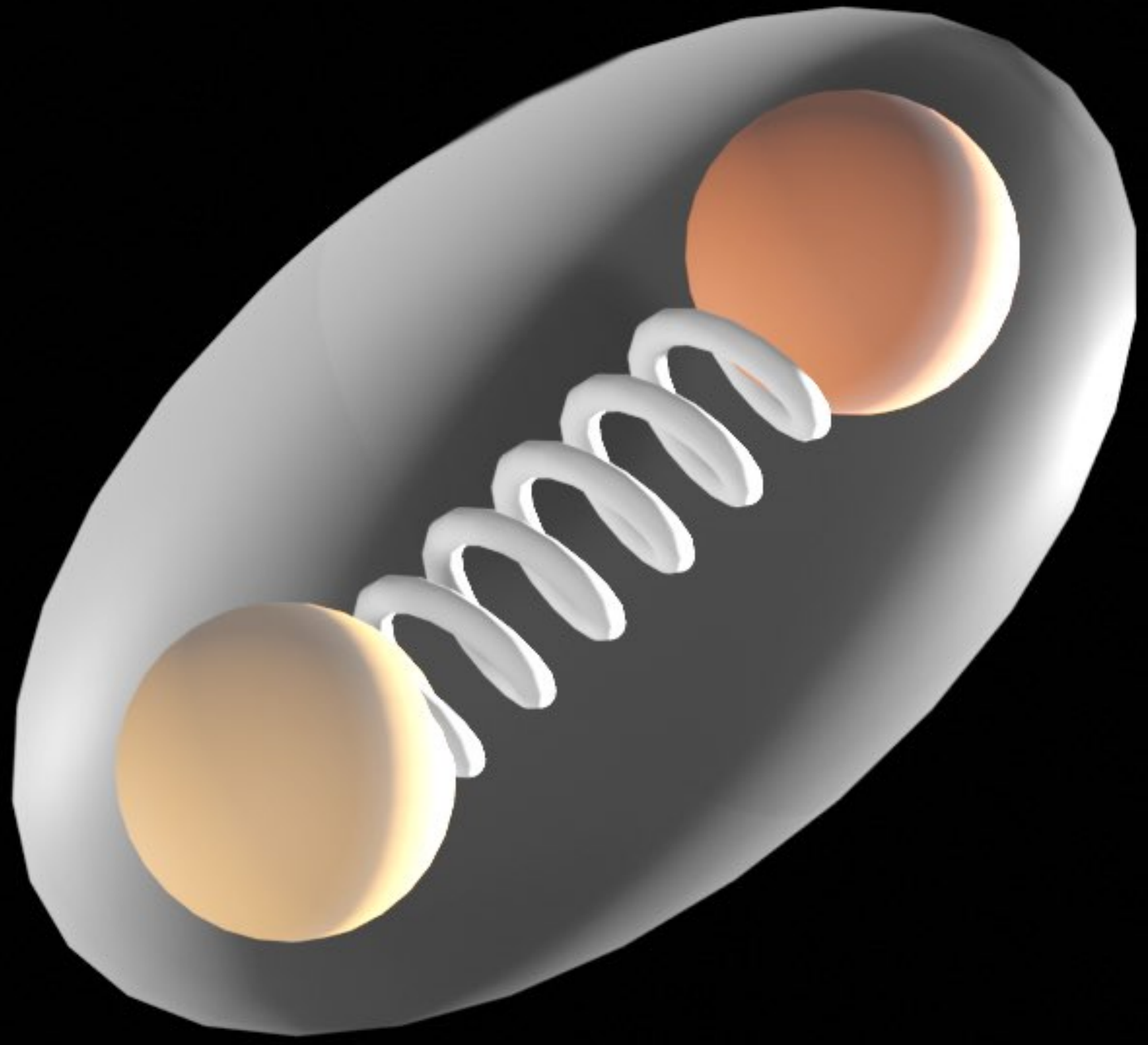


arXiv:2201.02659
Accepted by PRL

- Statistically compatible b/w PbPb and pp
- Hint of larger B_c R_{AA} than B^+ R_{AA} at low p_T



Freeze-out & Rescatterings

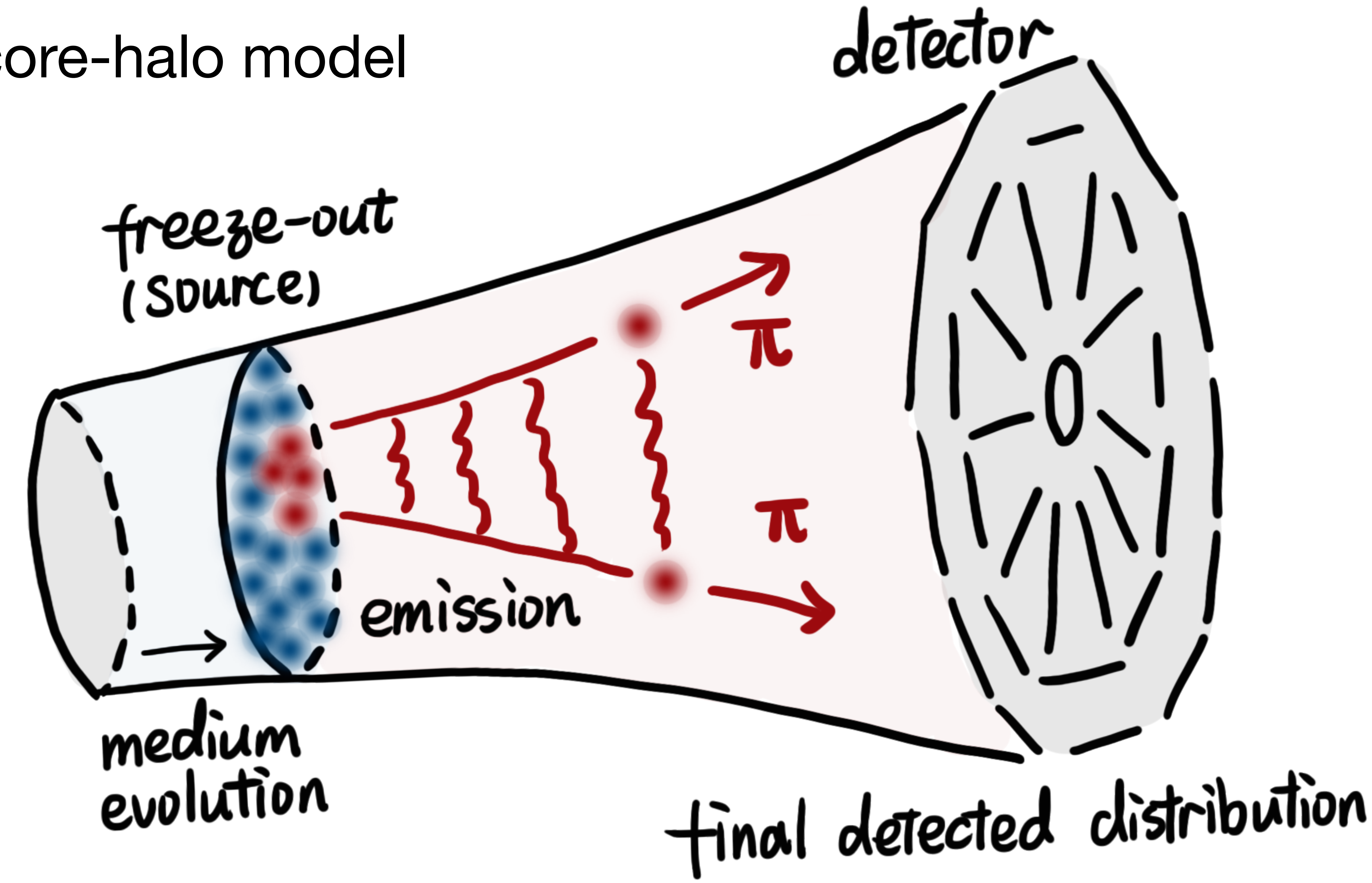


Click to see animation ↪

Femtoscopy

- Femtoscopy: Use final state particle correlations to probe the particle emitting source on the femtometer scale

- Parameterization: Lévy-type source & core-halo model
  ➡ Source shape: α
  ➡ Spacial scale: R
  ➡ Core-halo ratio: λ



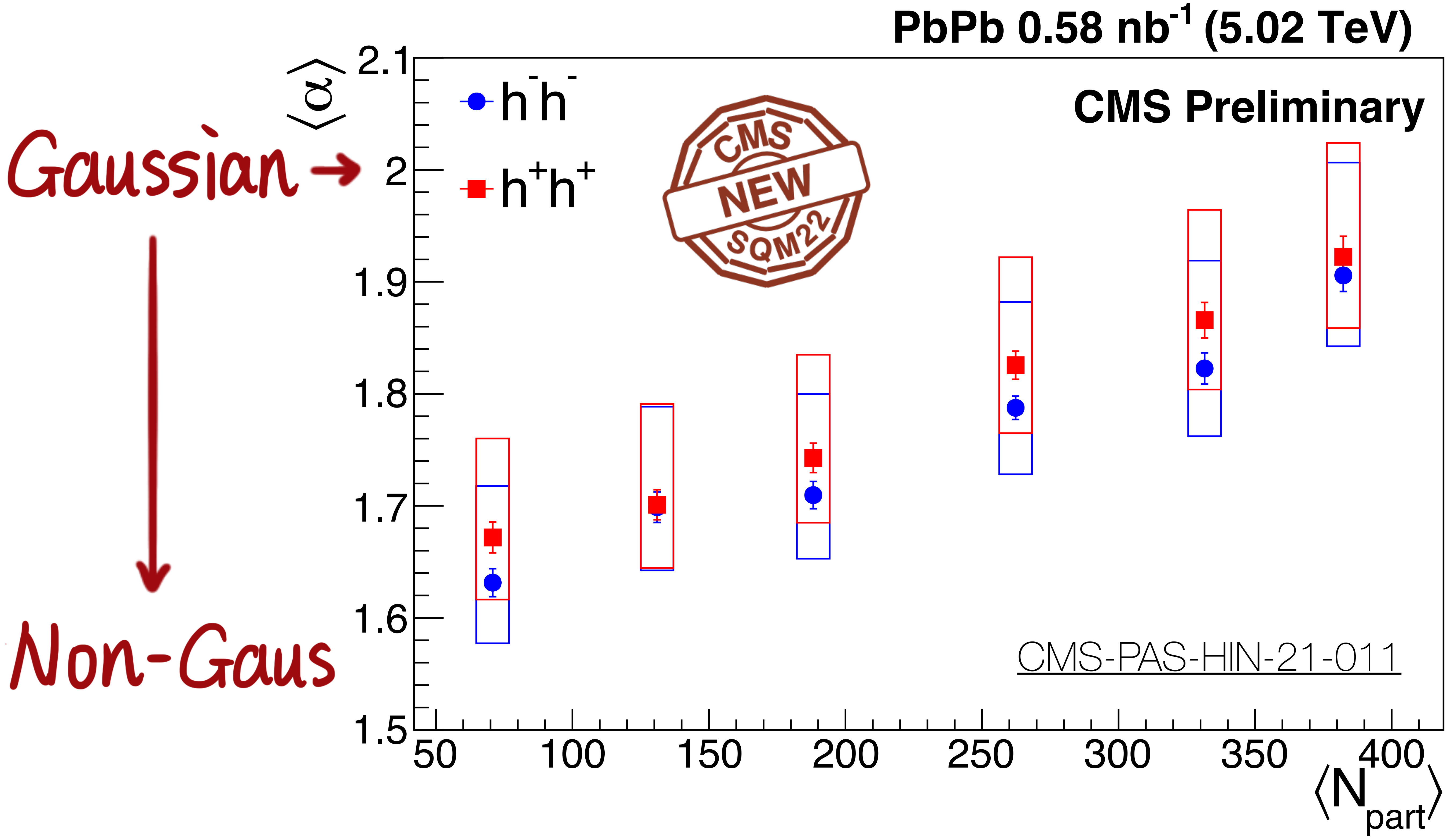
Femtoscopy: h± - h± Correlation

R. Pradhan [06/14 9:20]

- Femtoscopy: Use final state particle correlations to probe the particle emitting source on the femtometer scale

- Parameterization: Lévy-type source & core-halo model
  - ➡ Source shape: α
  - ➡ Spacial scale: R
  - ➡ Core-halo ratio: λ

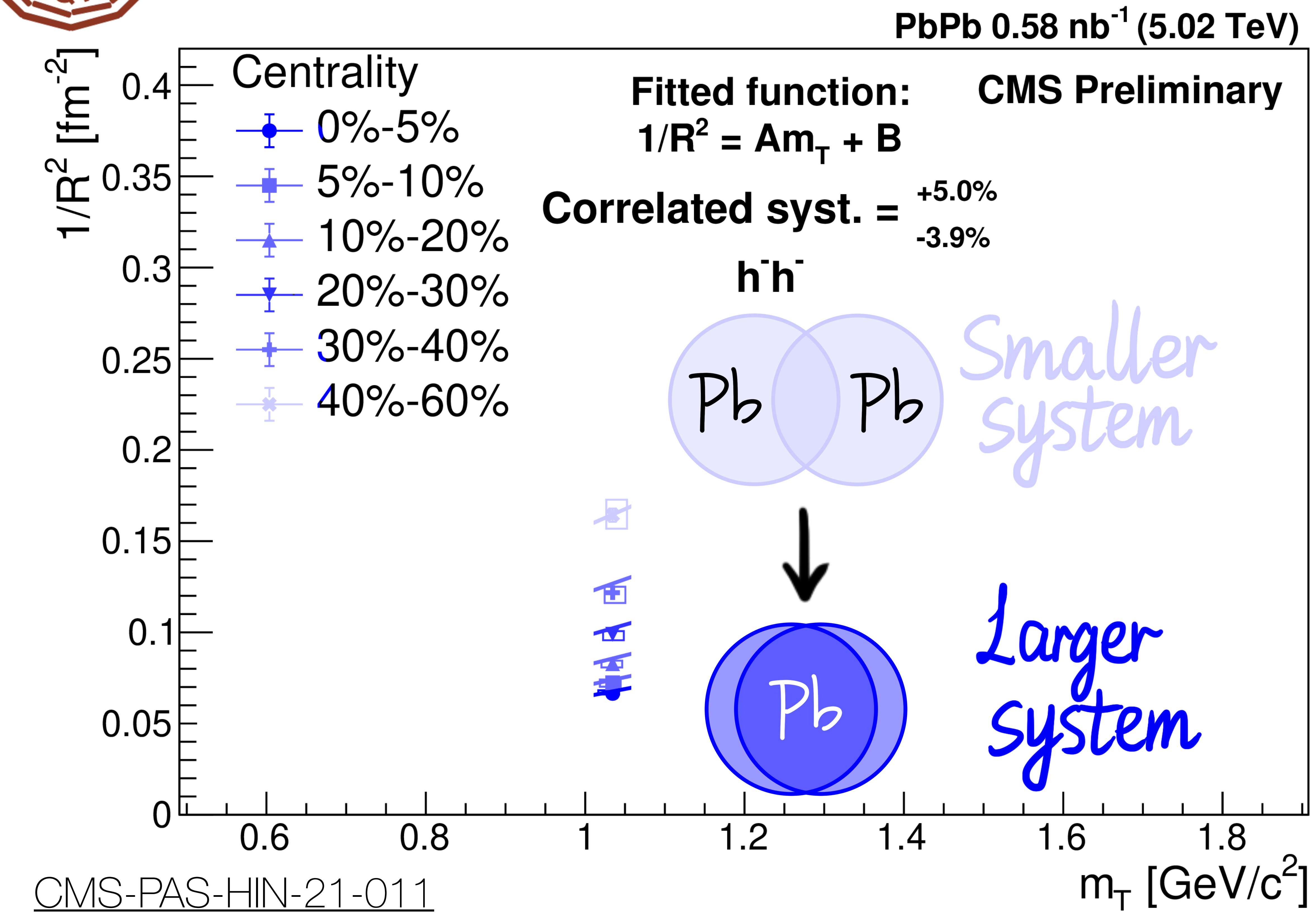
- Non-Gaussian behavior observed
  - ➡ α < 2



Femtoscopy: h± - h± Correlation

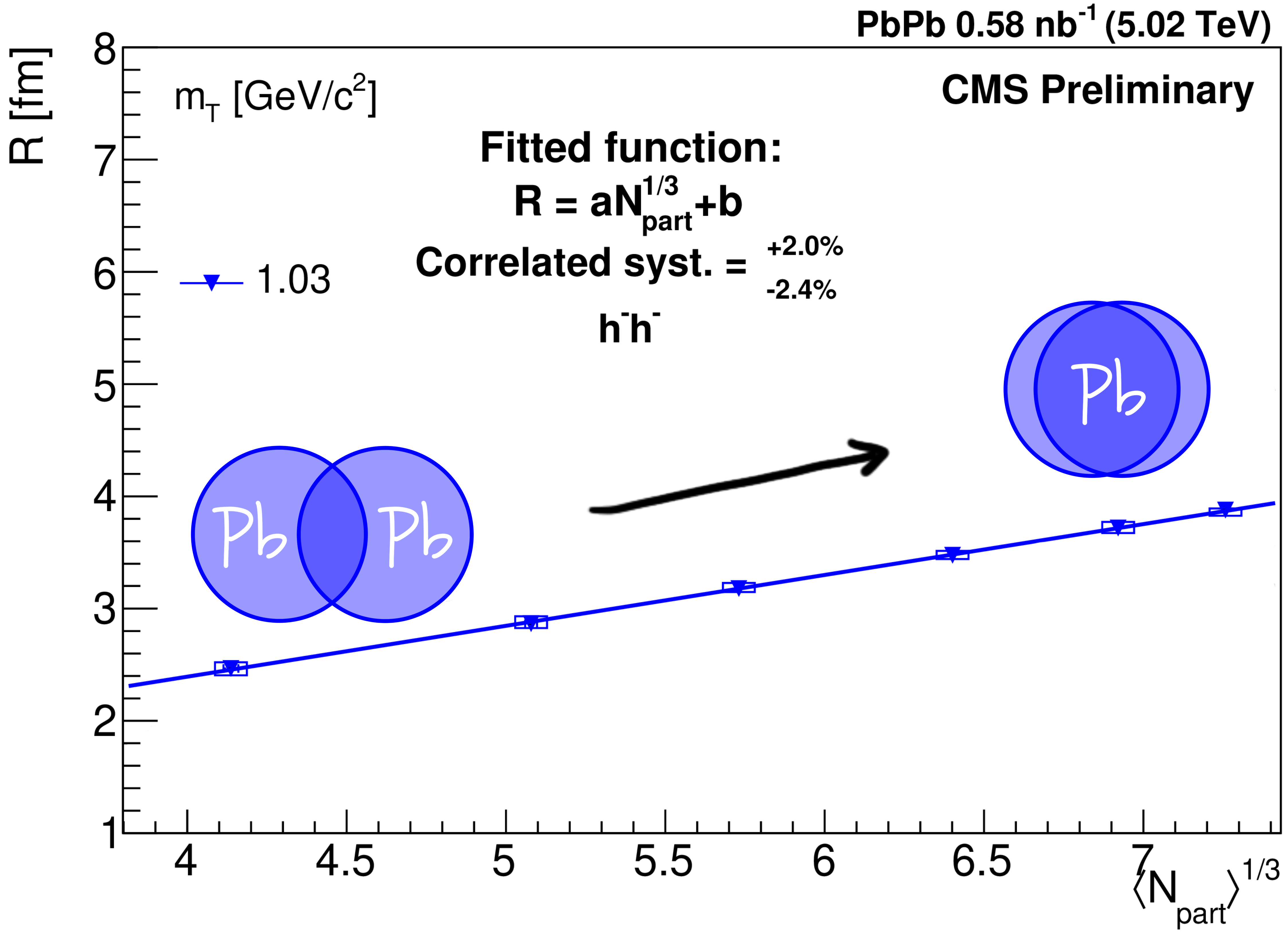
R. Pradhan [06/14 9:20]

1/R² for specific mT



CMS-PAS-HIN-21-011

R vs. ⟨Npart⟩1/3



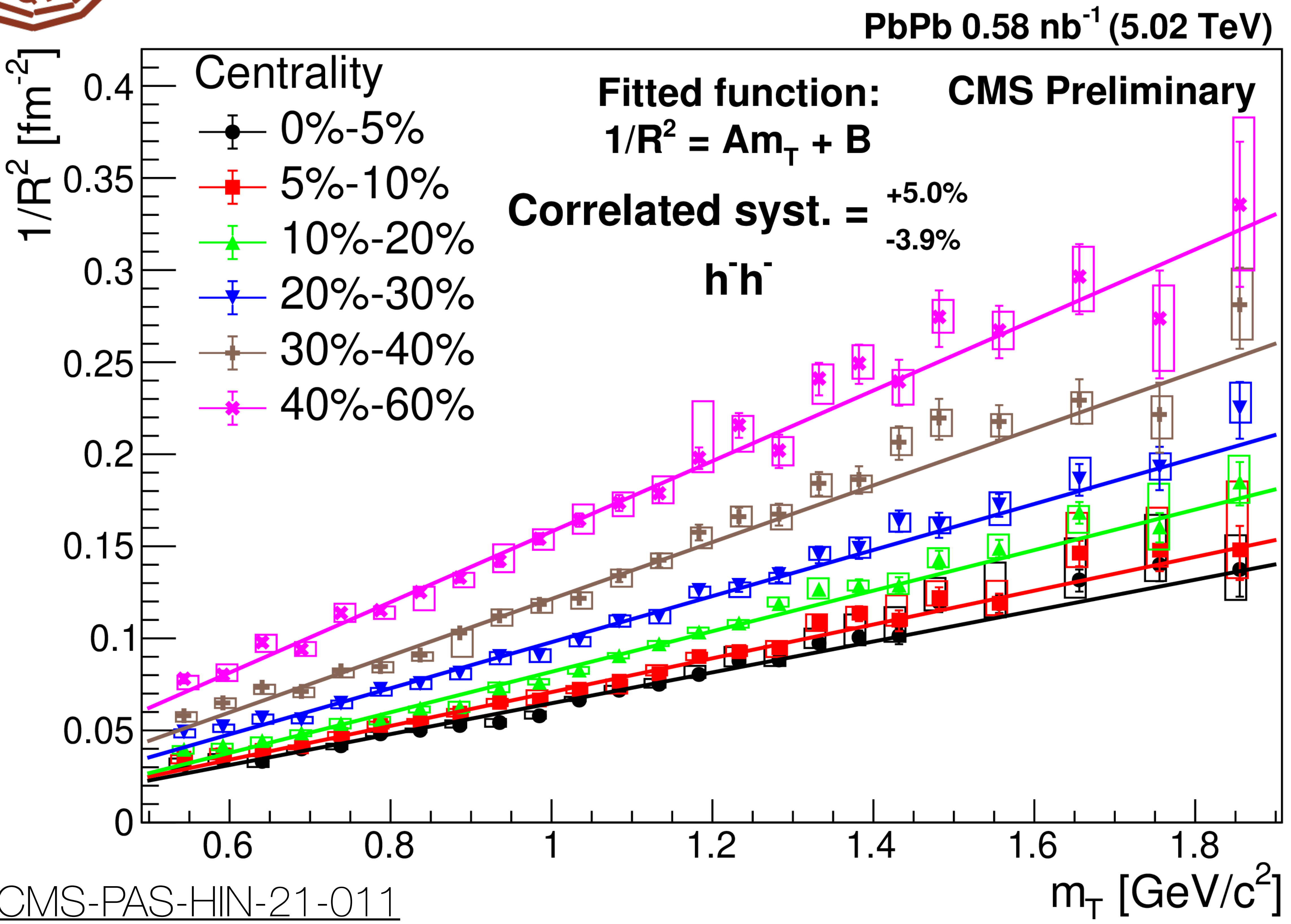
- R extracted indeed reflects the spatial scale of system (homogeneity region for specific mT)

Femtoscopy: h± - h± Correlation

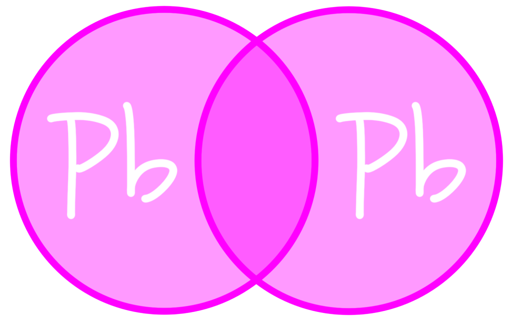
R. Pradhan [06/14 9:20]

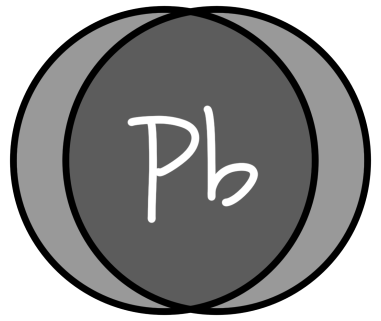
CMS NEW SQM22

$1/R^2$ vs. m_T



CMS-PAS-HIN-21-011

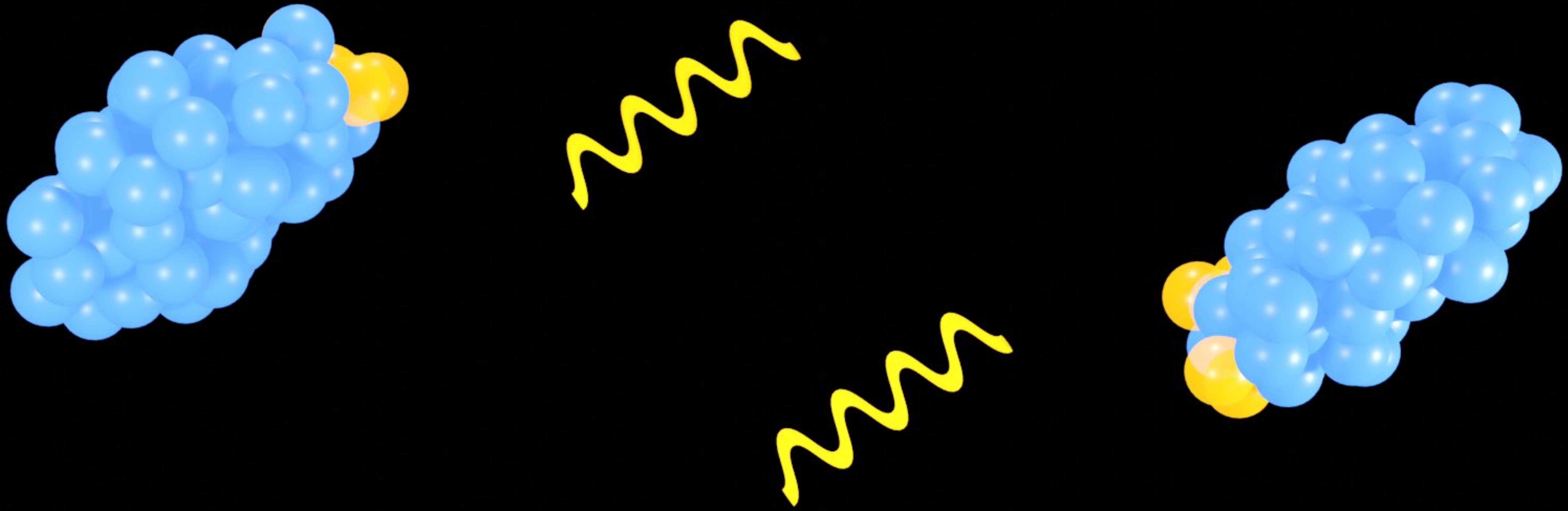




- Linear scaling $1/R^2 = Am_T + B$
  - Predicted by hydrodynamics for Gaussian source
  - Also holds for Lévy source
  - Larger slope for peripheral events
    - ➡ Related with expansion velocity, freeze-out temperature, etc…

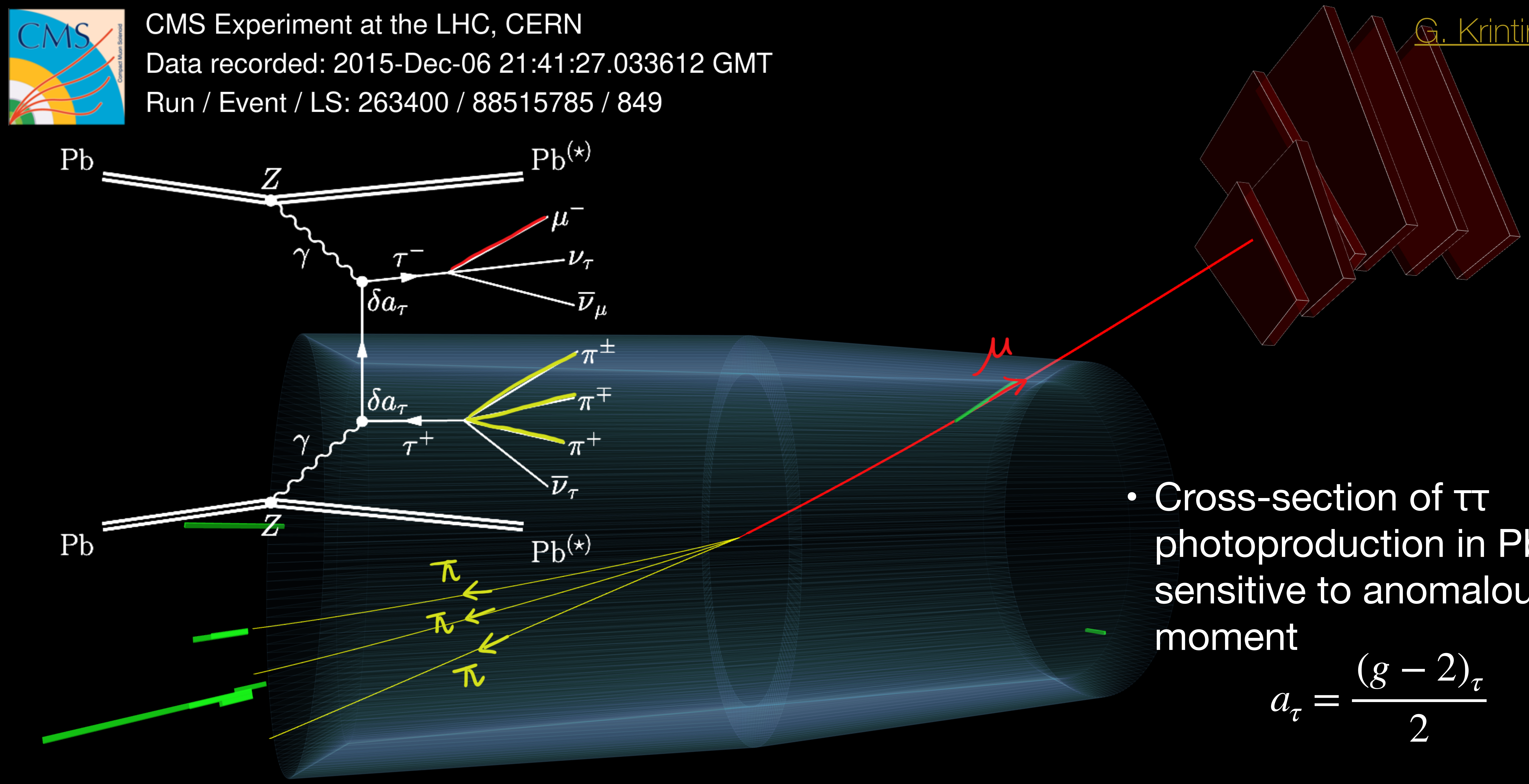
➜ More parameters and differential results see R. Pradhan's talk

Section V



Ultra-Peripheral Collisions

Click to see animation ➥



G. Krintiras [06/14 16:10]

- Cross-section of ττ photoproduction in PbPb UPC sensitive to anomalous magnetic moment

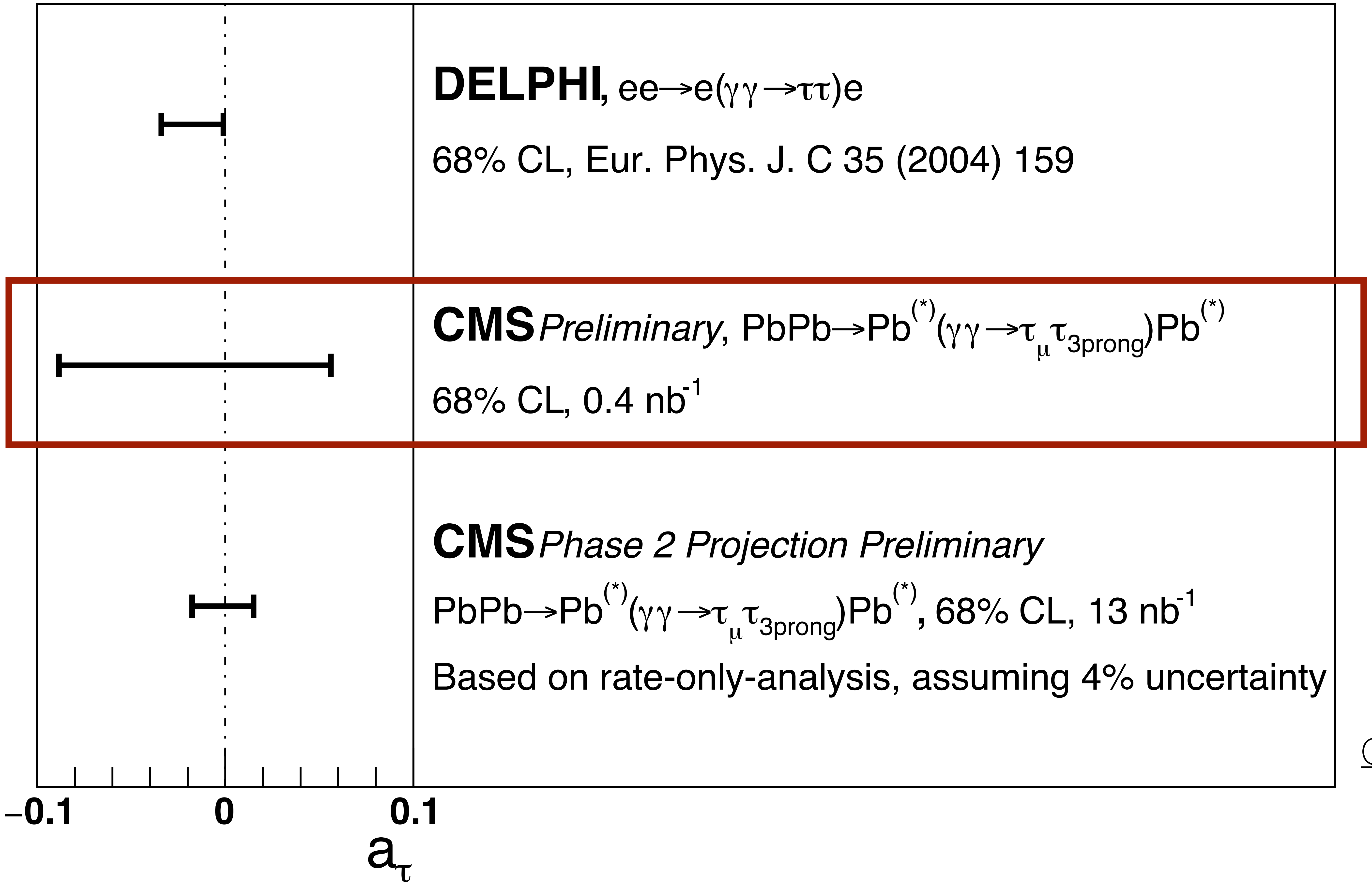
$$a_\tau = \frac{(g-2)_\tau}{2}$$

CMS-PAS-HIN-21-009

(g-2)$_\tau$: $\gamma\gamma \to \tau\tau$ in PbPb UPC

G. Krintiras [06/14 16:10]

$$a_\tau = (g-2)_\tau/2$$

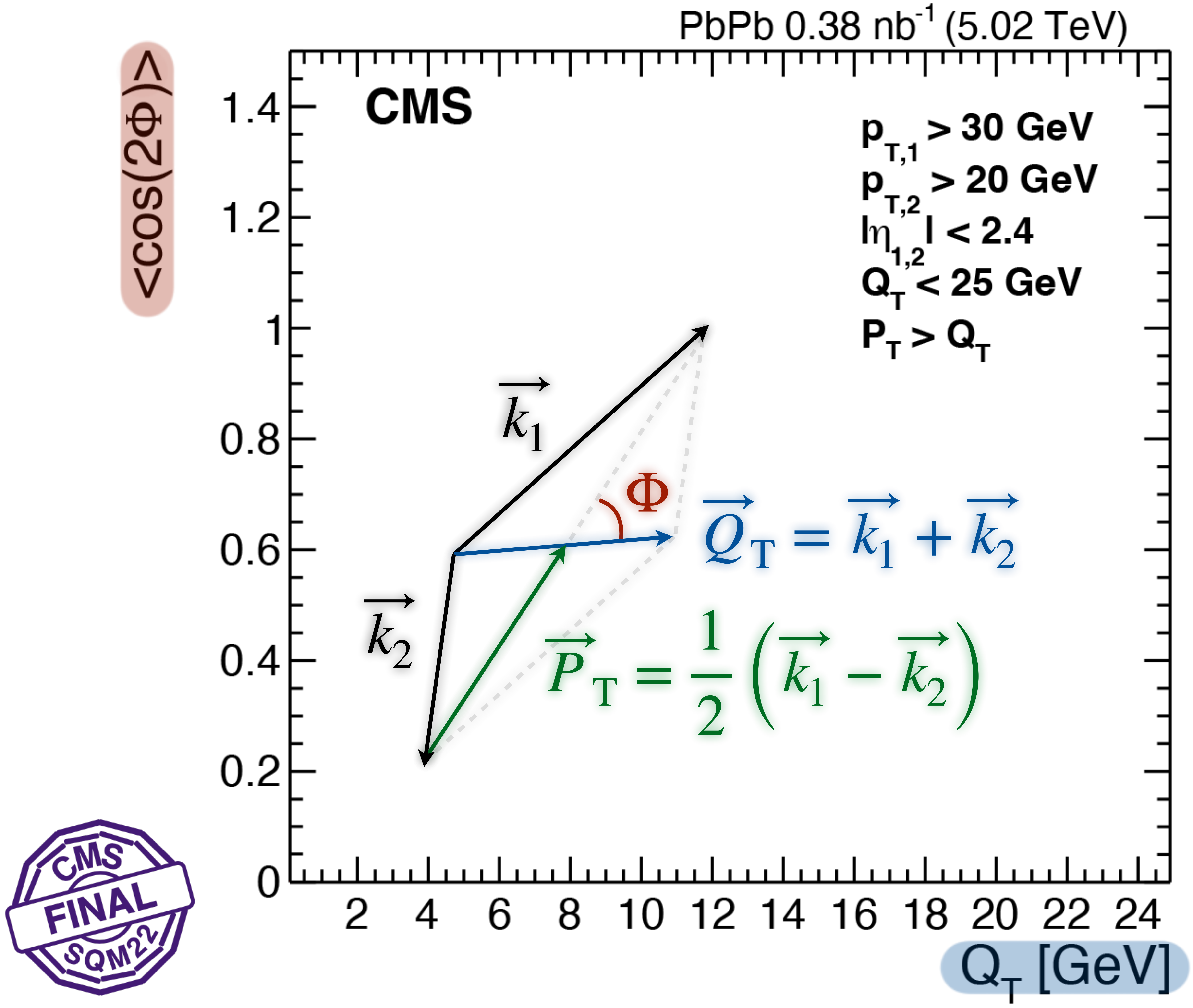


- Signal number N_{sig} = 77 ± 12
  - Significance above 5σ
- Constraint on a_τ from the LHC
- Strong constraint with Run 3+4

CMS-PAS-HIN-21-009

Dijet Angular Correlation in PbPb UPC

A. Bylinkin [06/14 11:10]

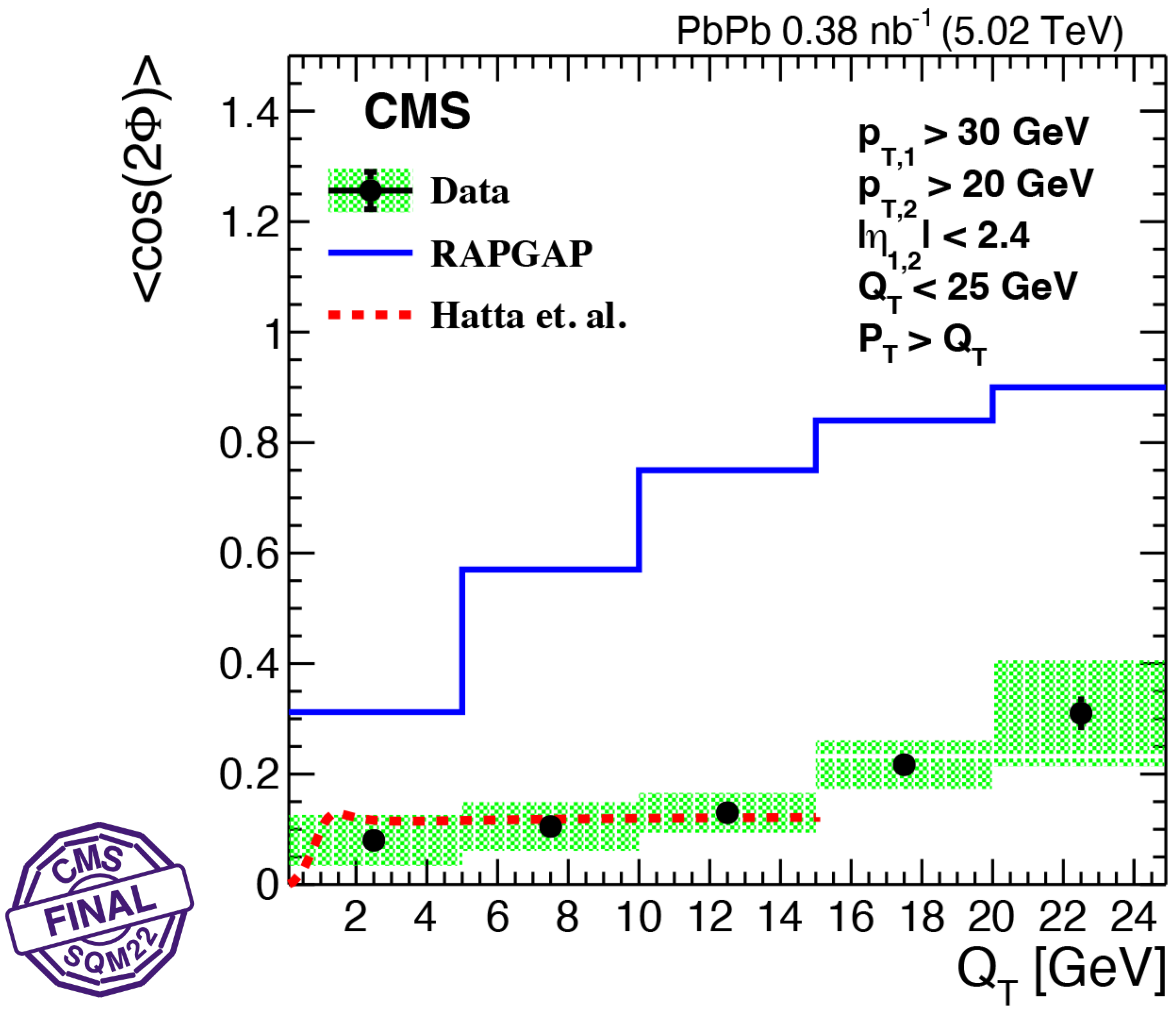


arXiv:2205.00045

- Dijet photoproduction sensitive to multi-dimensional structure of the gluons
  - Gluon elliptical polarization
    ➜ Dijet azimuthal angular correlations
- P_T > Q_T: back-to-back limit

Dijet Angular Correlation in PbPb UPC

A. Bylinkin [06/14 11:10]



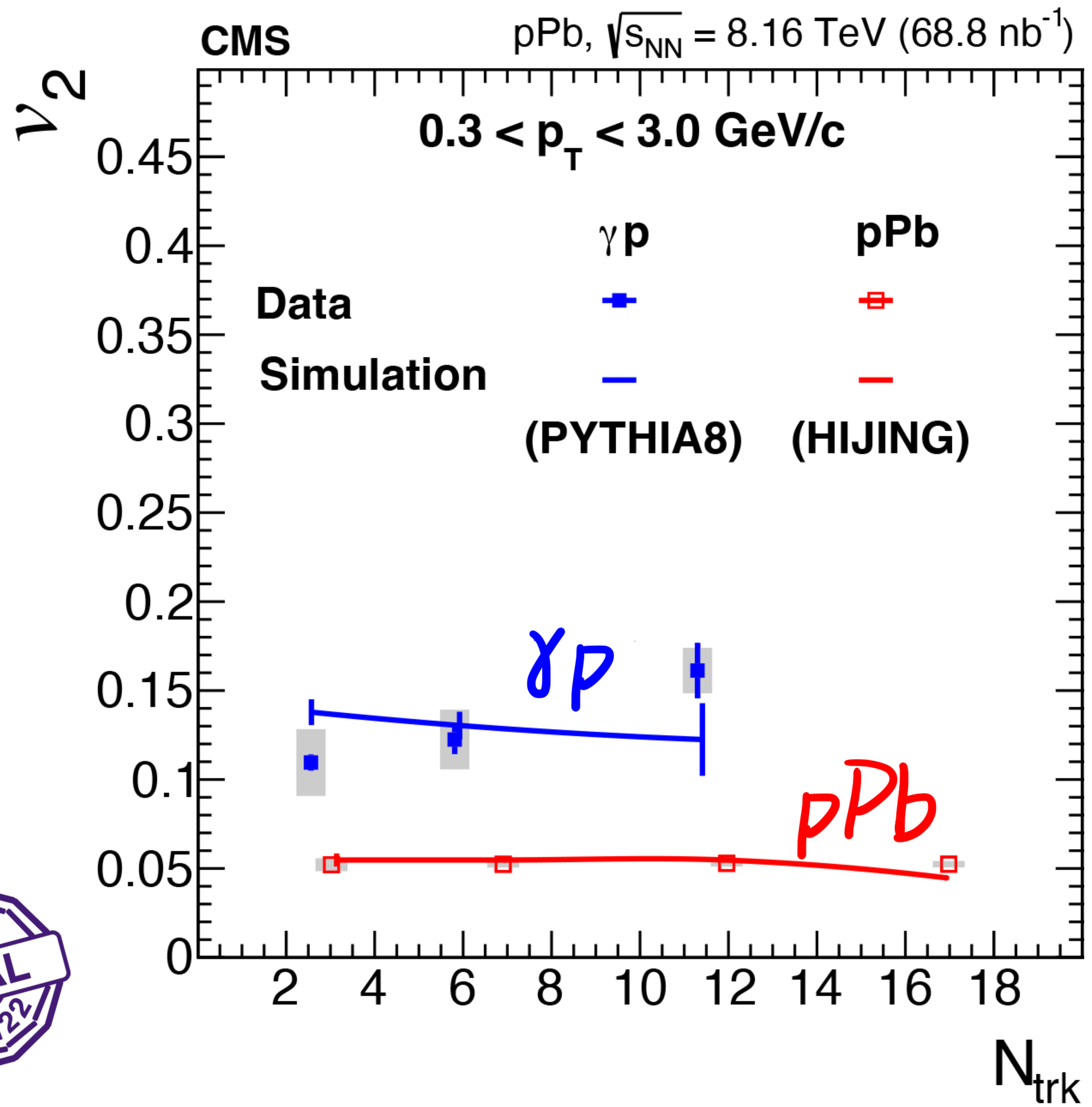
arXiv:2205.00045

- Probe gluon elliptical polarization
- Data compared to simulation and calculation without effect of gluon polarization
  - ➡ RAPGAP overestimates correlation
  - ➡ Calculation[1]
    - Final state soft gluon radiation
    - Reaches constant at Q_T > 2 GeV ➜ different from data trend

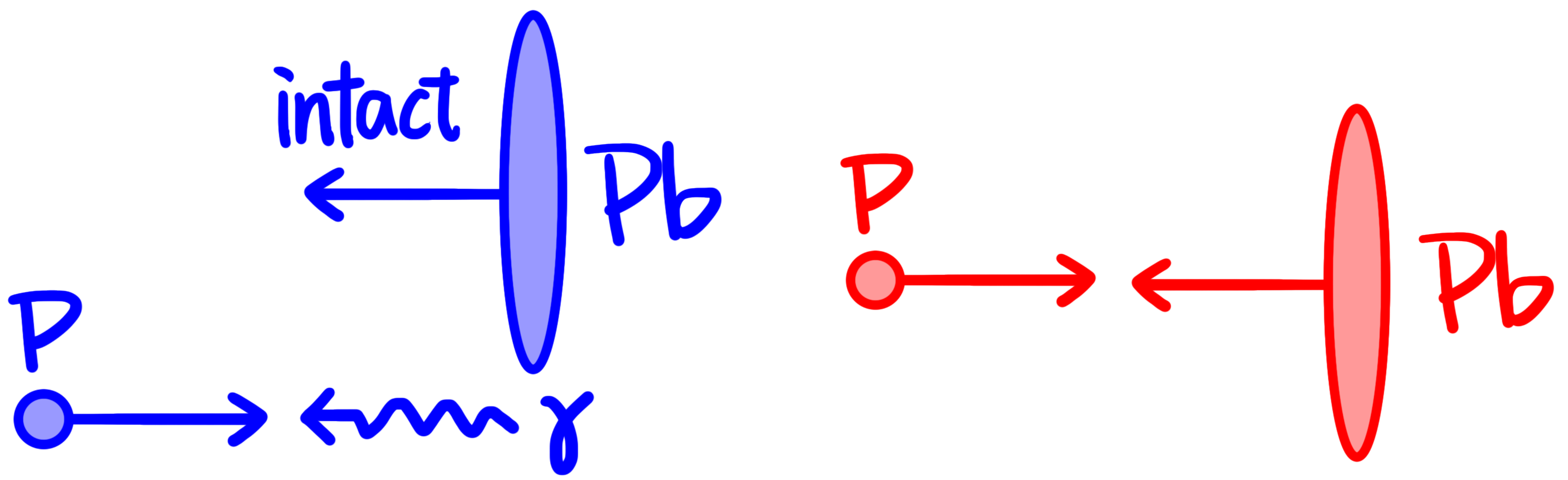
[1]PRL 126 (2021) 142001

Two-particle Correlation in γp Interactions

S. Behera [POS-BLK-04]



- Search for azimuthal anisotropy in γp interactions with pPb UPC
- Non-flow subtraction not applied
- Consistent with simulations without collective effects for both γp and pPb in the N_{trk} range



arXiv:2204.13486

Summary: Recent Results in SQM'22

Parton distribution in Pb	• Drell-Yan process in pPb • Dijet decorrelation in UPC
Initial state and hot medium effect	• Charmonium v_n in PbPb • Prompt and (b→) D^0 v_n in PbPb • Υ(3S) production in PbPb
Heavy quark hadronization	• B_S, B_C production in PbPb
Collective behavior in small systems	• Υ(1S) v_2 in pPb • Cumulant-[p_T] correlation • v_2 in γp interactions with pPb UPC
Freeze-out and rescatterings	• Femtoscopic correlations
τ lepton (g-2)	• γγ→ττ in PbPb UPC

➜ CMS HIN Publication

➜ CMS HIN Preliminary

Summary: Talks & Posters in SQM'22

Hyunchul Kim	Drell-Yan process in pPb	[06/14 15:20]
Aleksandr Bylinkin	Dijet decorrelation in UPC	[06/14 11:10]
Subash Chandra Behera	Vector meson photoproduction	[06/14 16:30]
Gyeonghwan Bak	Charmonium v_n in PbPb	[06/14 09:40]
Milan Stojanovic	Prompt and (b→) D^0 v_n in PbPb	[06/14 10:50]
Soohwan Lee	Υ(3S) production in PbPb	[06/14 09:20]
Florian Damas	B_S, B_C production in PbPb	[06/14 11:30]
Soumik Chandra	Λ_C production in PbPb	[06/14 11:10]
Kisoo Lee	Quarkonium v_2 in pPb	[06/14 09:00]
Shengquan Tuo	Cumulant-[p_T] correlation	[POS-BLK-03]
Subash Chandra Behera	v_2 in γp interactions with pPb UPC	[POS-BLK-04]
Sunil Manohar Dogra	B^+ production in pPb	[POS-HF-08]
Raghunath Pradhan	Femtoscopic correlations	[06/14 09:20]
Georgios Krintiras	γγ→ττ in PbPb UPC	[06/14 16:10]
Riccardo Longo	ZDC upgrade for HL-LHC	[06/14 16:30]


Isabelle
Thanks for your attention!

Back up

Thanks for your attention!

Heavy Flavor v_2 Reference List

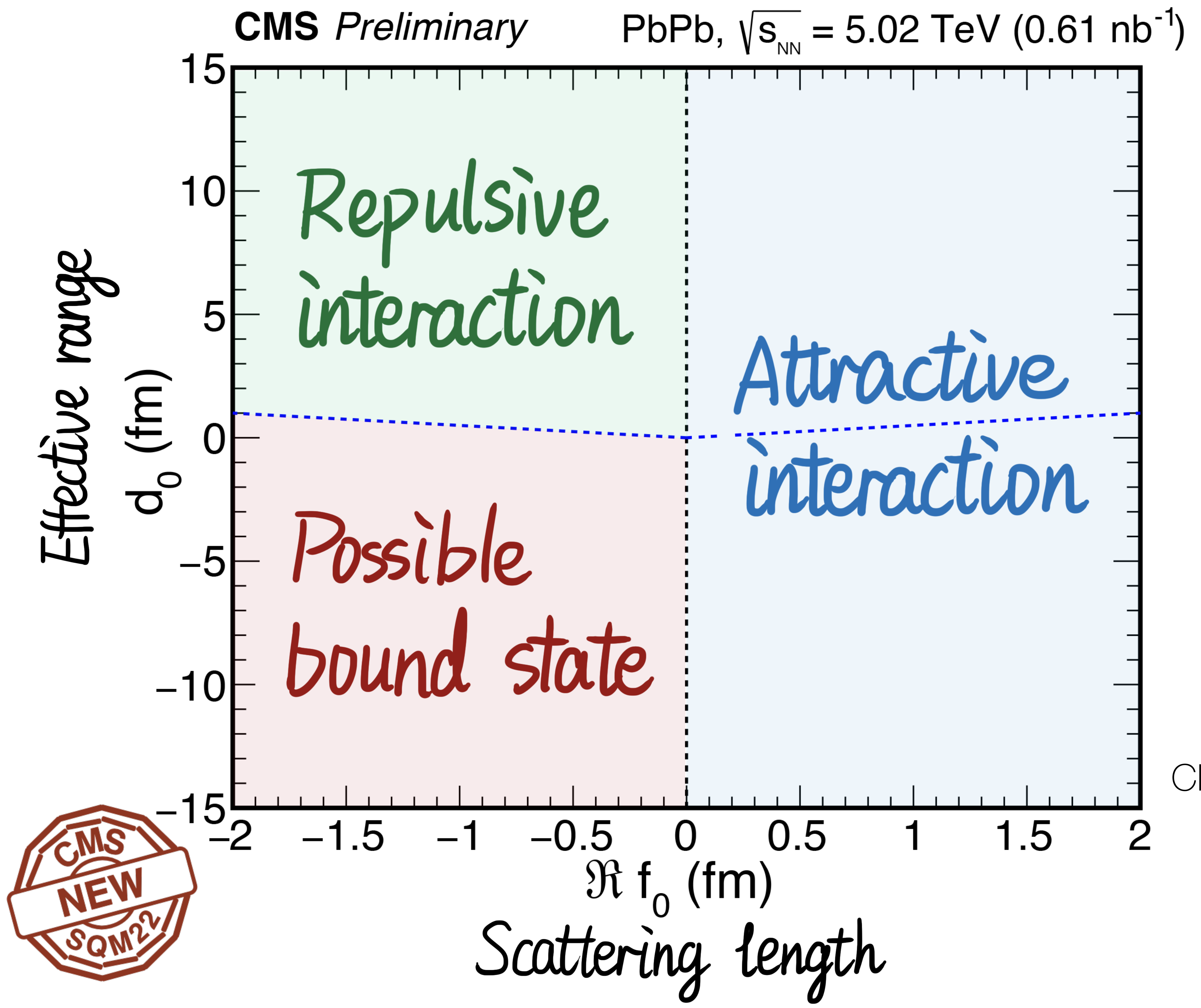
	PbPb	High-multiplicity pPb	High-multiplicity pp
Charged hadrons	PLB 776 (2017) 195	(K_S^0) PRL 121 (2018) 082301	-
Prompt D^0	PLB 816 (2021) 136253	PRL 121 (2018) 082301	PLB 813 (2021) 136036
Prompt J/ψ	CMS-PAS-HIN-21-008	PLB 791 (2019) 172	-
(b→) D^0	CMS-PAS-HIN-21-003	PLB 813 (2021) 136036	-
(b→) J/ψ	CMS-PAS-HIN-21-008	-	-
Υ(1S)	PLB 819 (2021) 136385	CMS-PAS-HIN-21-001	-

➜ Back

Femtoscopy: V^0 - V^0 Correlation

R. Pradhan [06/14 9:20]

Scattering parameters



CMS-PAS-HIN-21-006

- Particle correlation also sensitive to
  - Quantum statistical effect
  - ~~Coulomb interactions ➜ Vanish for V^0~~
  - Strong interactions

➜ So we can
  - Probe strong interaction scatterings
  - Search dibaryon bound states

CMS Phase-2 upgrades for HL-LHC

Table 1: Main features of CMS detector at present and Phase 2 upgrades.

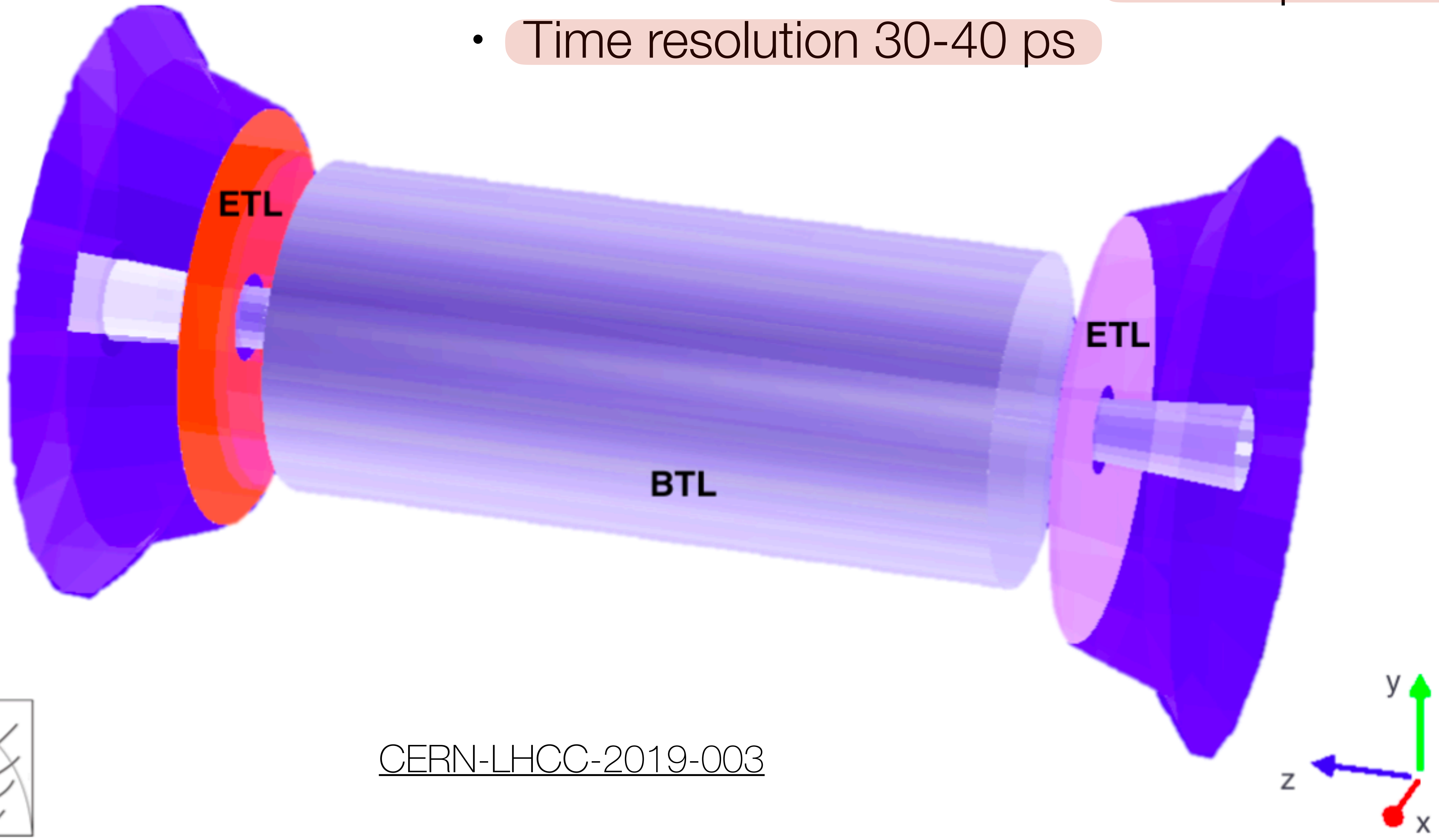
Subdetector	CMS present	CMS Phase-2
Inner Tracker	$\|\eta\| < 2.4$, $100\times150\ \mu m^2$ pixel size	$\|\eta\| < 4$, $50\times50\ \mu m^2$ pixel size
Calorimeter	Low-granularity	High-granularity end-cap with silicon sensors
Muon detector	$\|\eta\| < 2.4$	$\|\eta\| < 2.8$
L1 trigger bandwidth	30 kHz for PbPb, 100 kHz for pp and pPb	750 kHz (pass through all PbPb events)
DAQ throughput	6 GB/s	60 GB/s
Time-of-flight for Particle ID	**N/A**	**MTD for charged hadron PID over $\|\eta\| < 3.0$**

- New MIP Timing Detector (MTD) for TOF-PID!
- Unique PID up to $|\eta| = 3$

Precision determination of the arrival time of the signal

CMS MIP Timing Detector (MTD)

- Large acceptance
  - Barrel Timing Layer (BTL): |η| < 1.5
  - End-cap Timing Layer (ETL): 1.6 < |η| < 3
- Serve as TOF detector for hadron particle identification
- Time resolution 30-40 ps

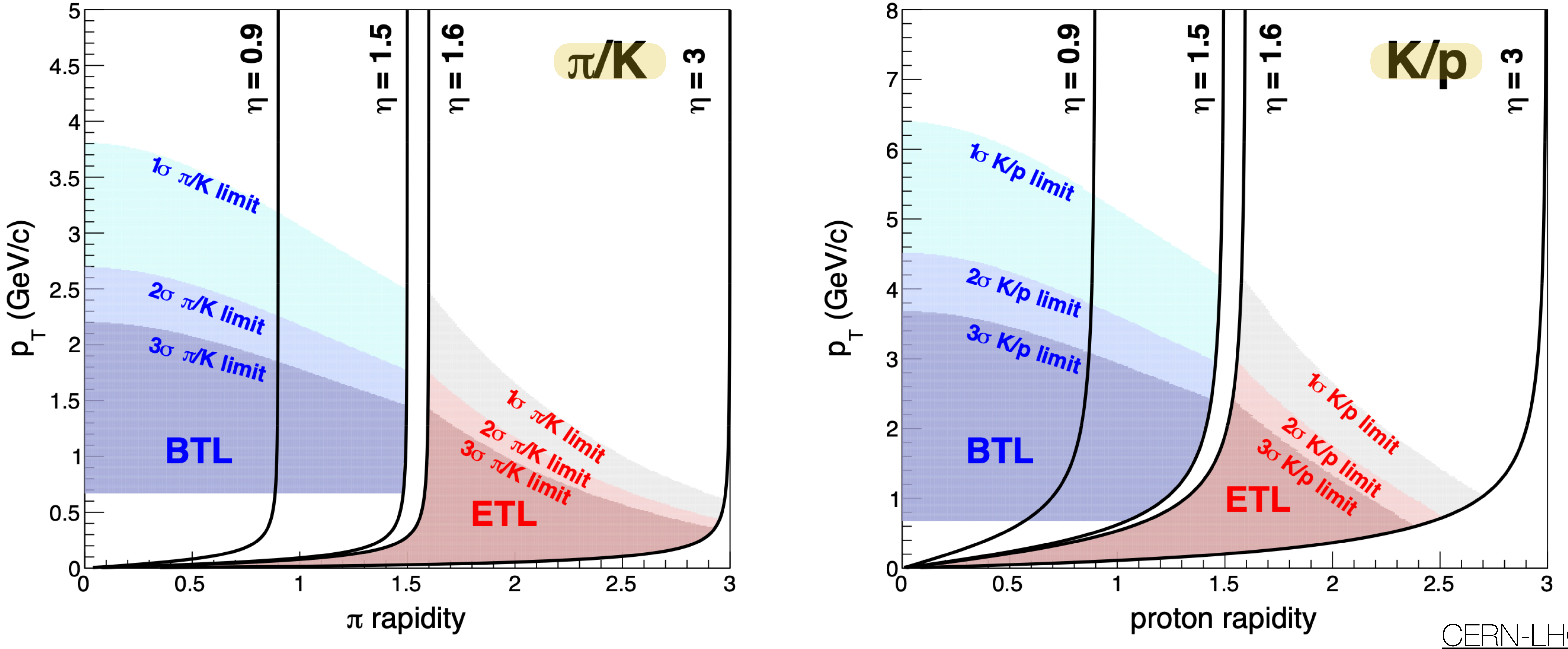


Experiment	r (m)	σ_T (ps)	r/σ_T ($\times$100) (m $\times$ ps^{-1})
STAR-TOF	2.2	80	2.75
ALICE-TOF	3.7	56	6.6
CMS-MTD	1.16	30	3.87

CERN-LHCC-2019-003

CMS MIP Timing Detector (MTD)

Separation Power vs. kinematic phase space



CERN-LHCC-2019-003

- CMS MTD brings complementarity and uniqueness in PID

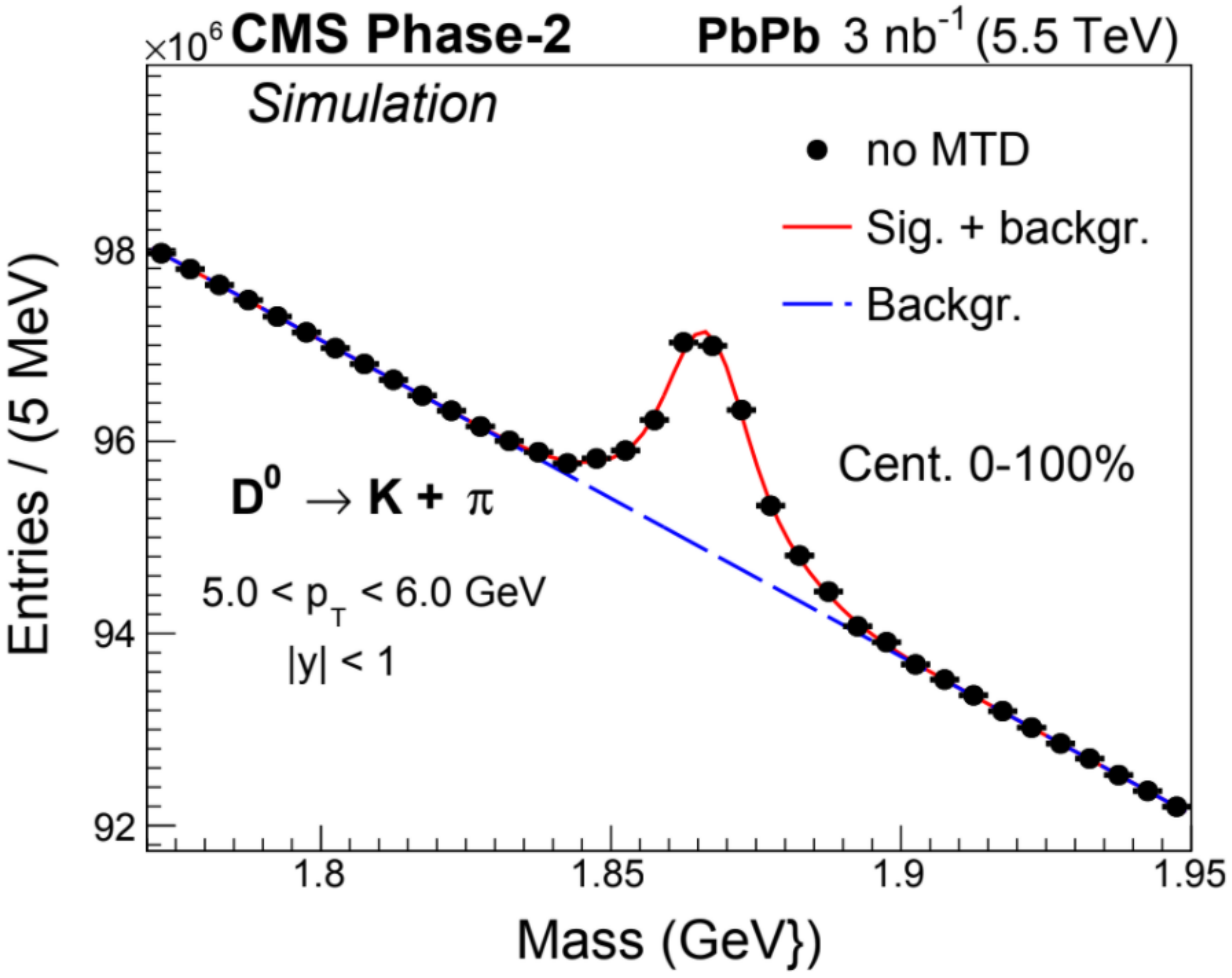
CMS MTD ($|\eta| < 3$) vs. ALICE: mid-rapidity ($|\eta| < 0.9$)
LHCb: forward ($2 < \eta < 5$)

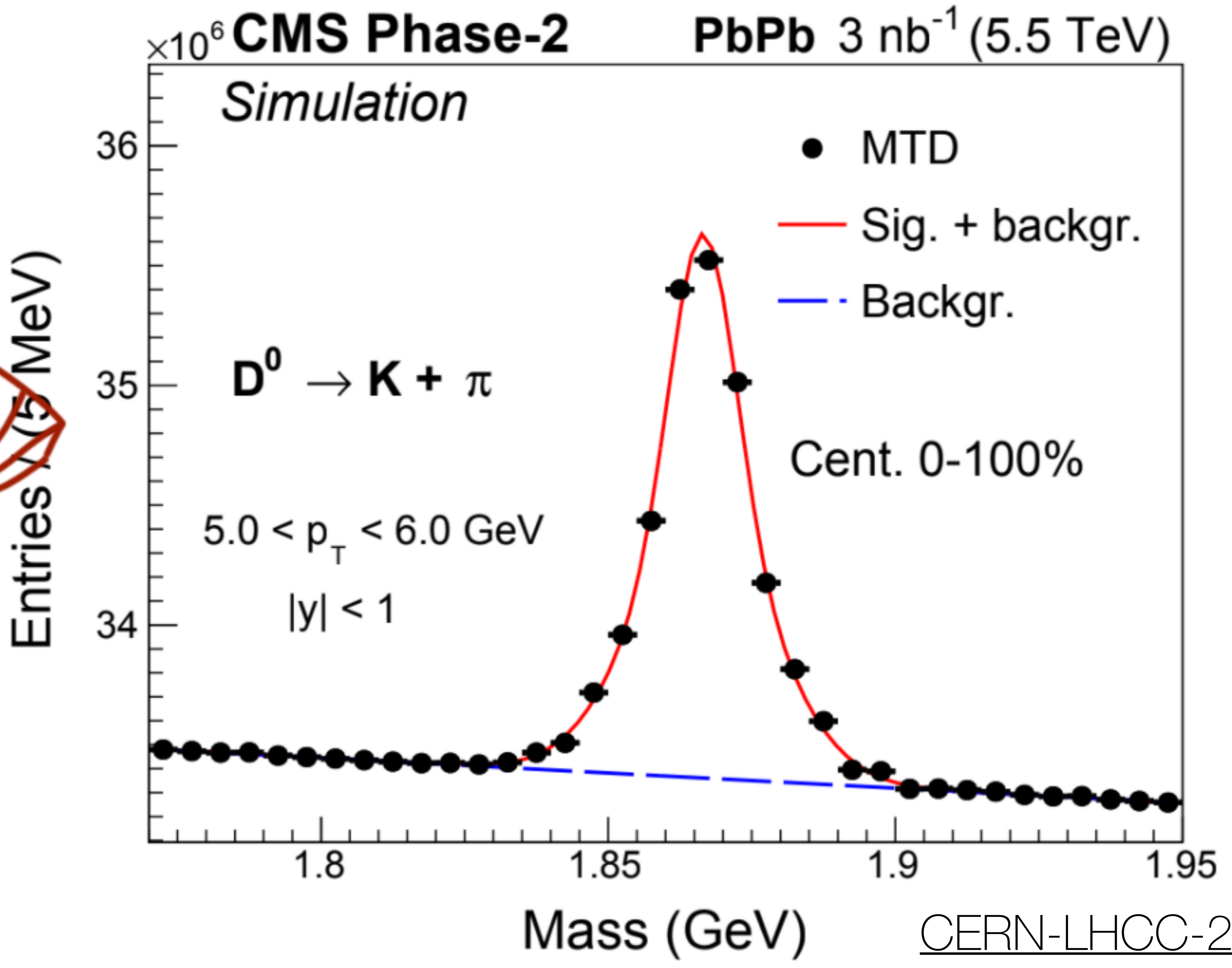
MTD Impact on HF hadron reconstruction

Without MTD

CMS 1 year of Run 4

With MTD





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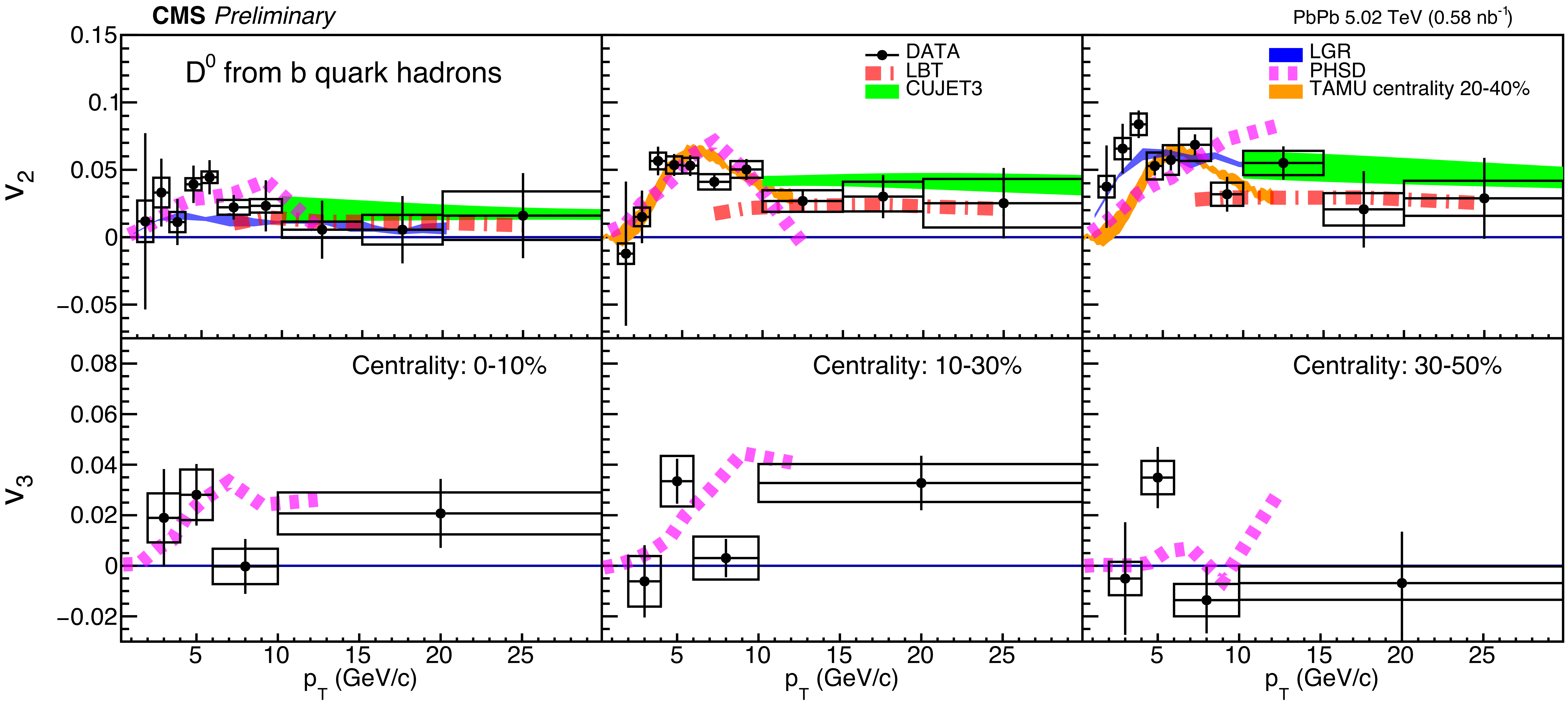
- Significant improvement of signal to background ratio with PID information from MTD

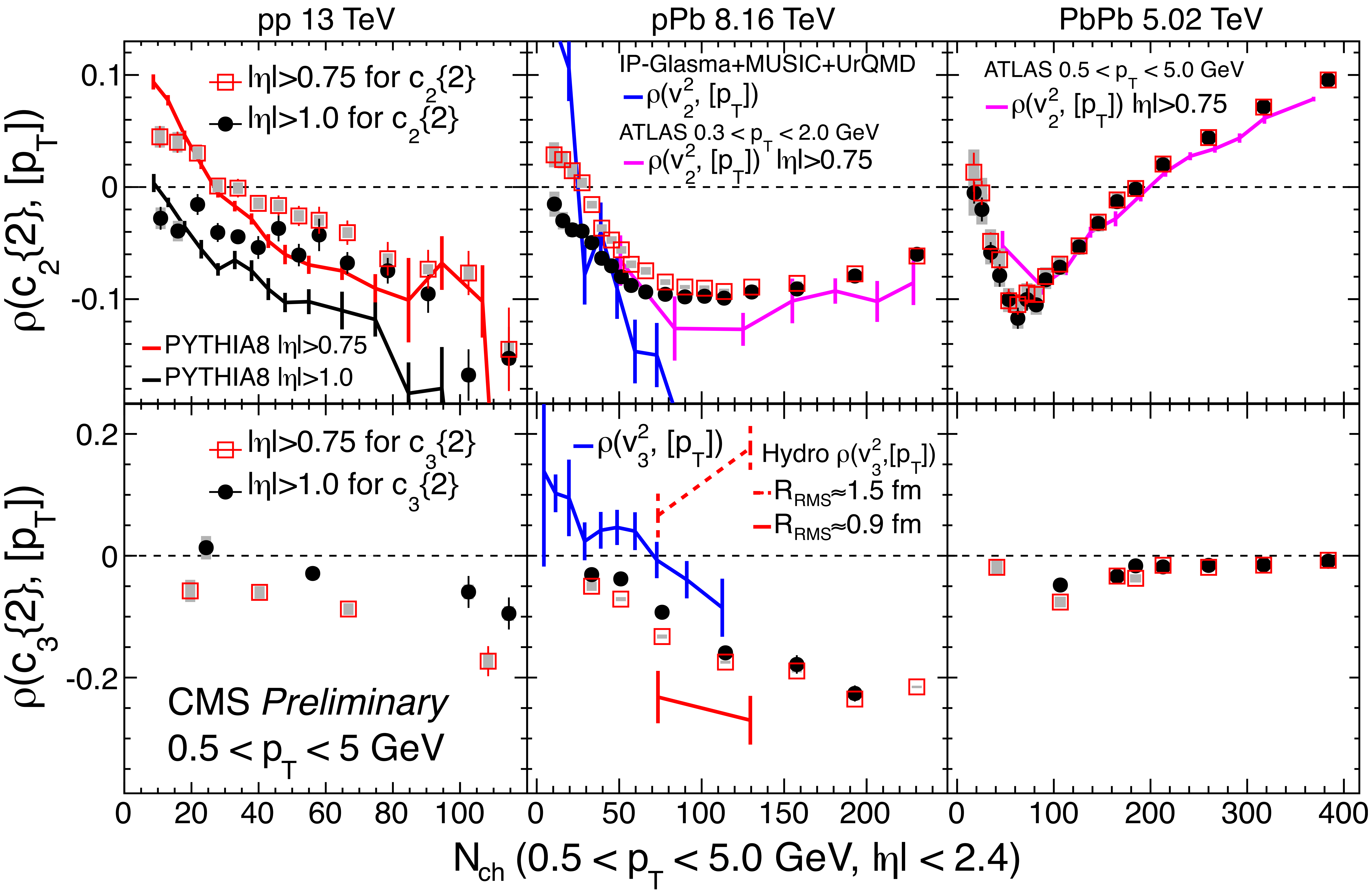
b→D v_n vs. Theory



CMS-PAS-HIN-21-003

Cumulant-mean p_T Correlation in pPb

S. Tuo [POS-BLK-03]

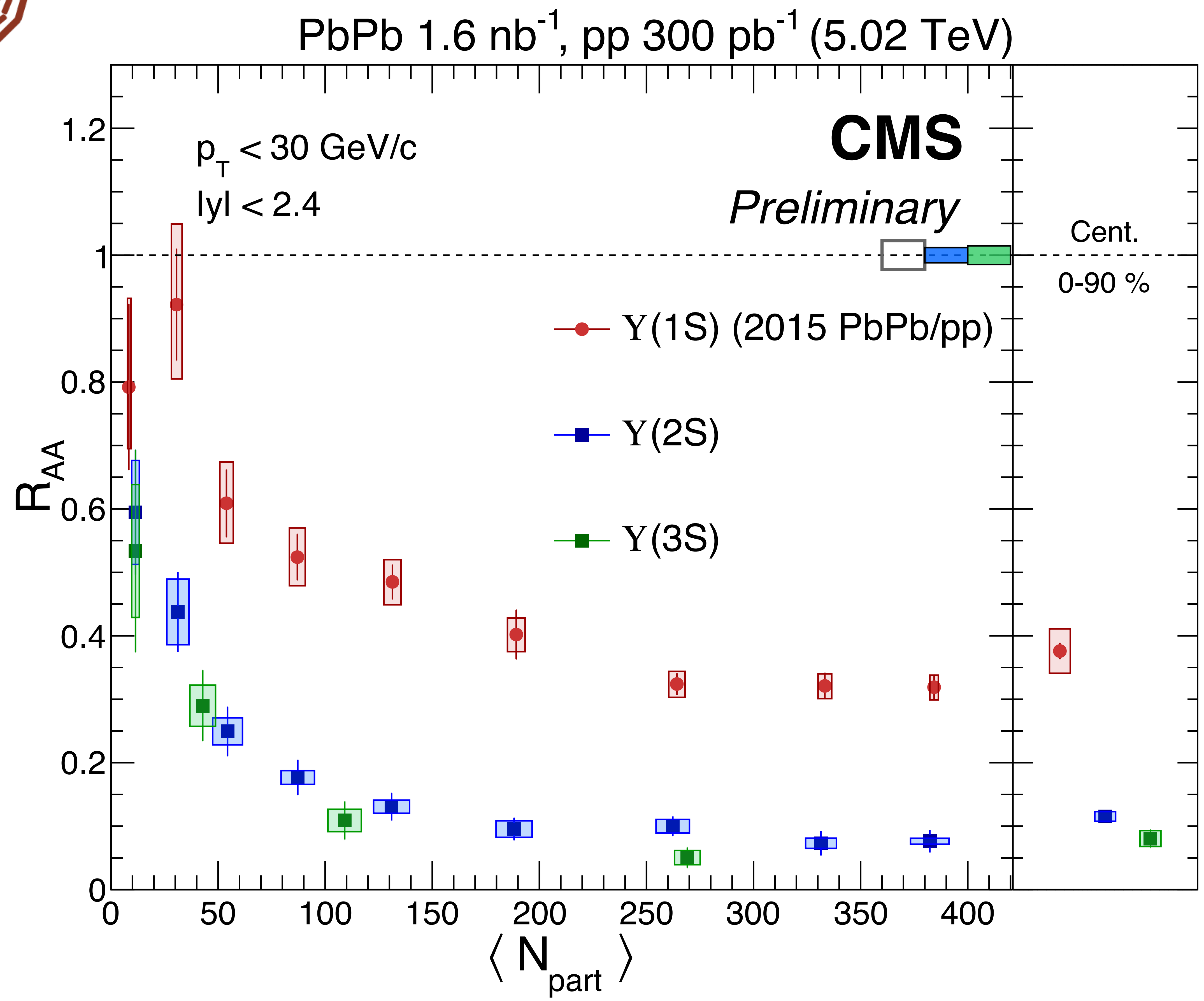


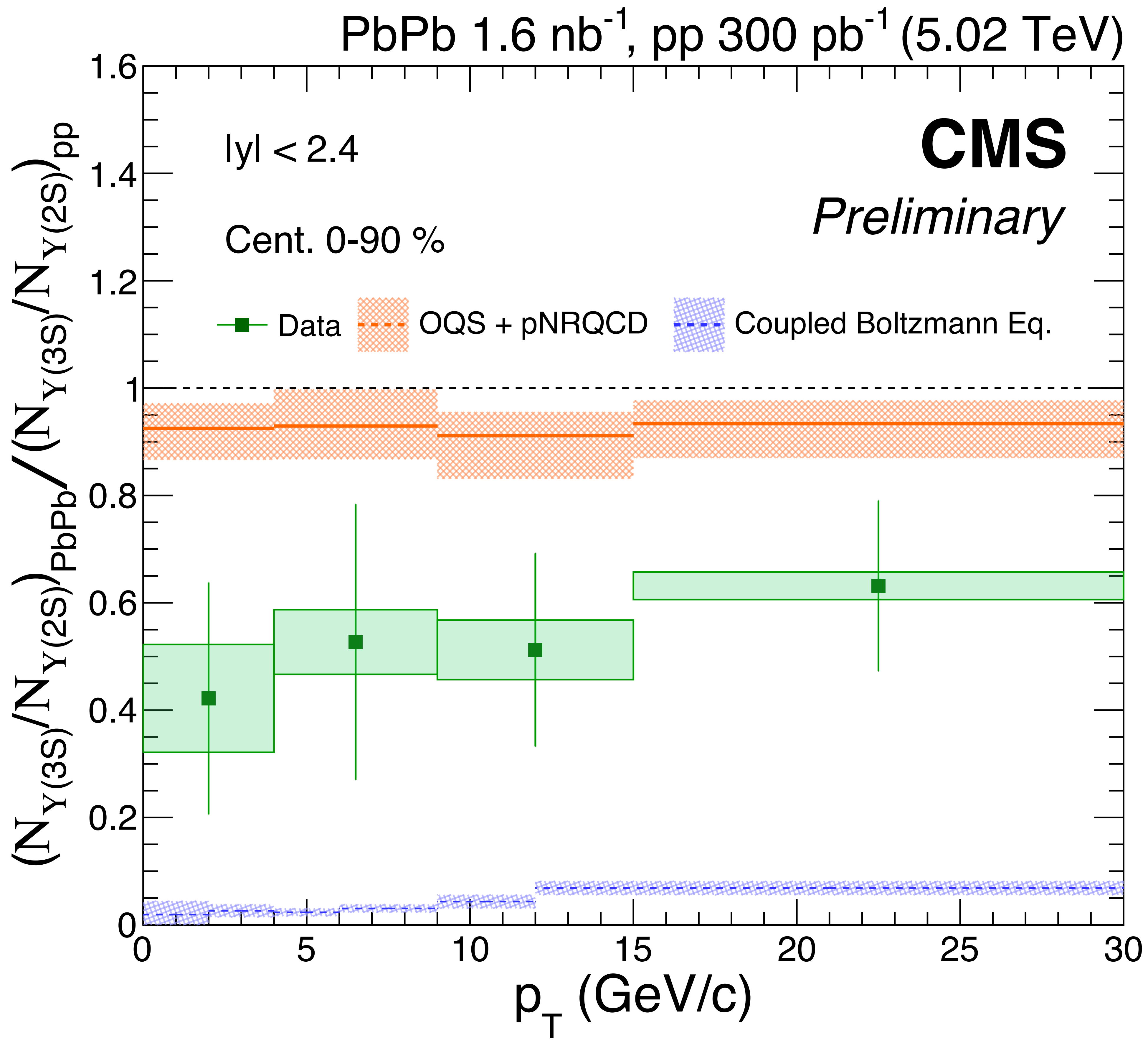
CMS-PAS-HIN-21-012

First Υ(3S) Observation in HIC

S. Lee [06/14 9:20]

CMS NEW SQM22

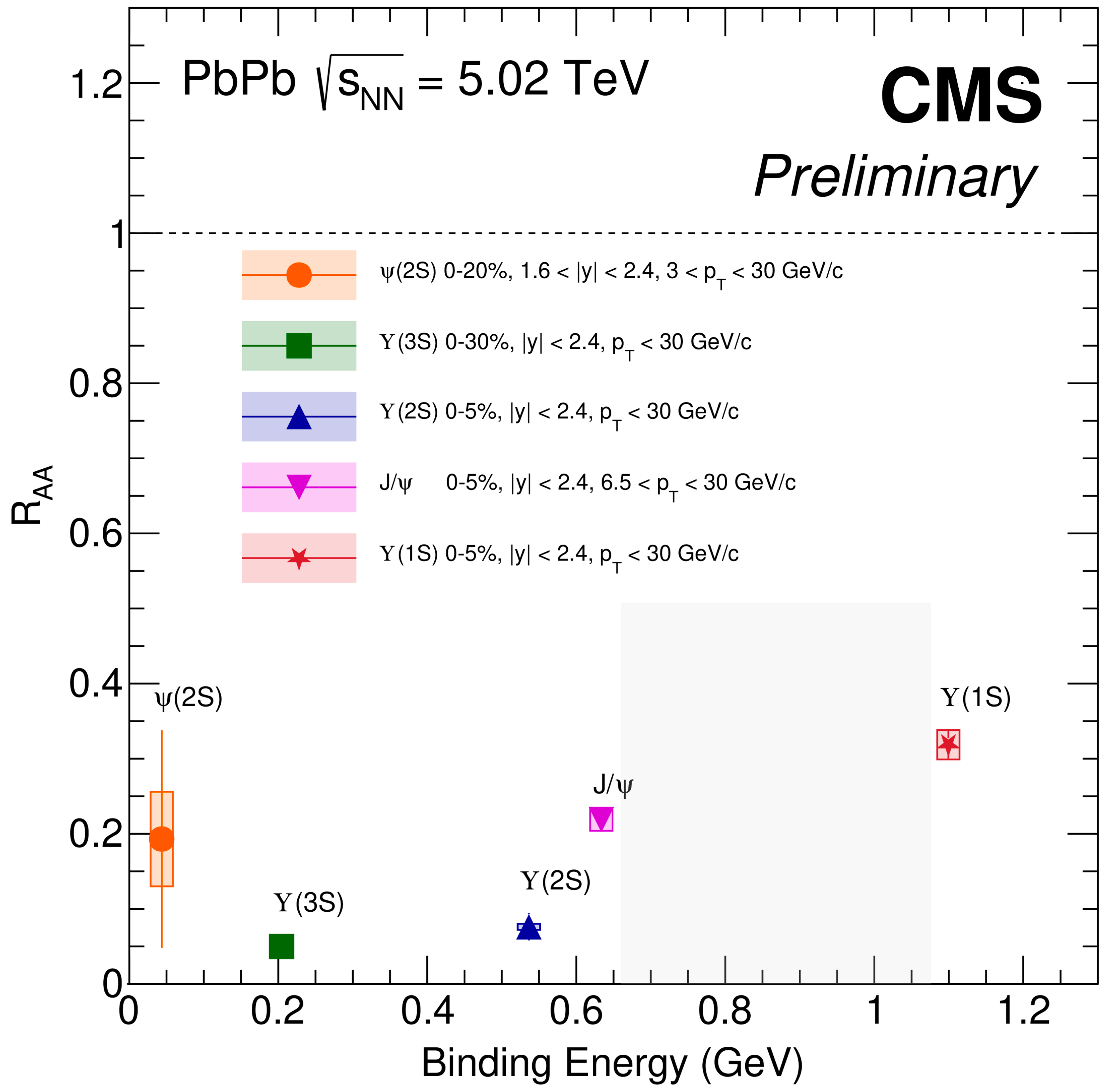


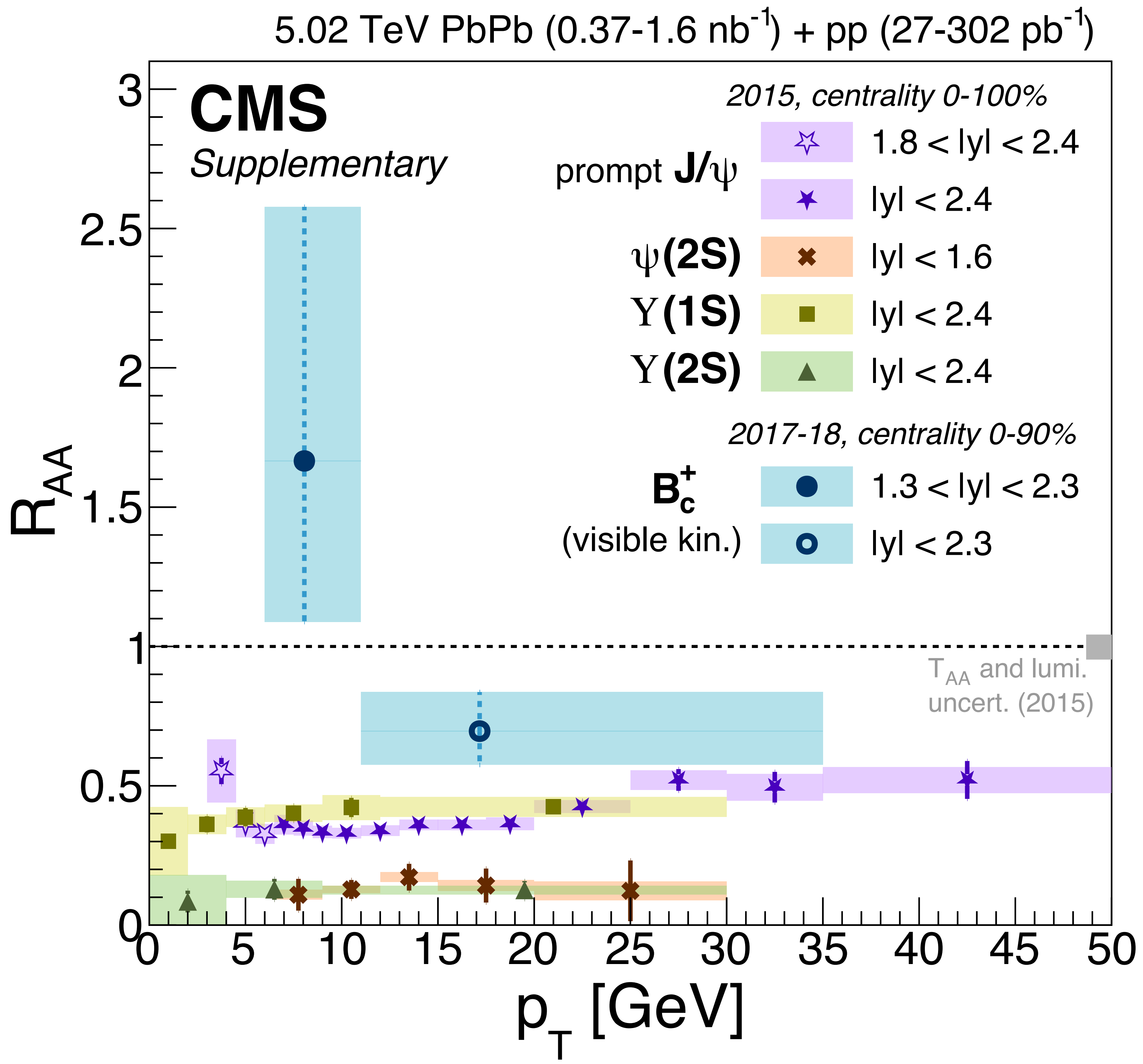


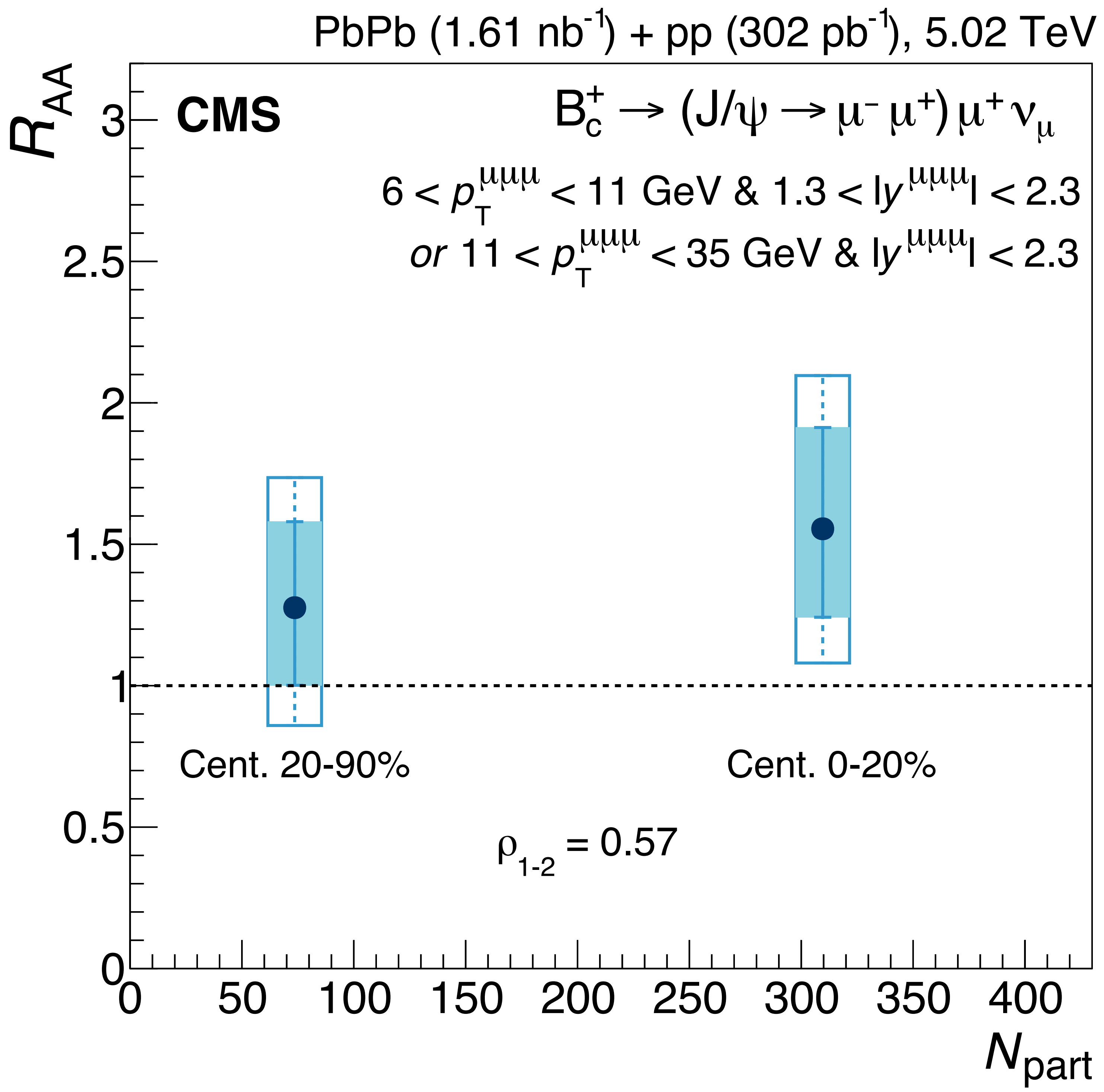
CMS-PAS-HIN-21-007

B_c in PbPb

F. Damas [06/14 11:30]







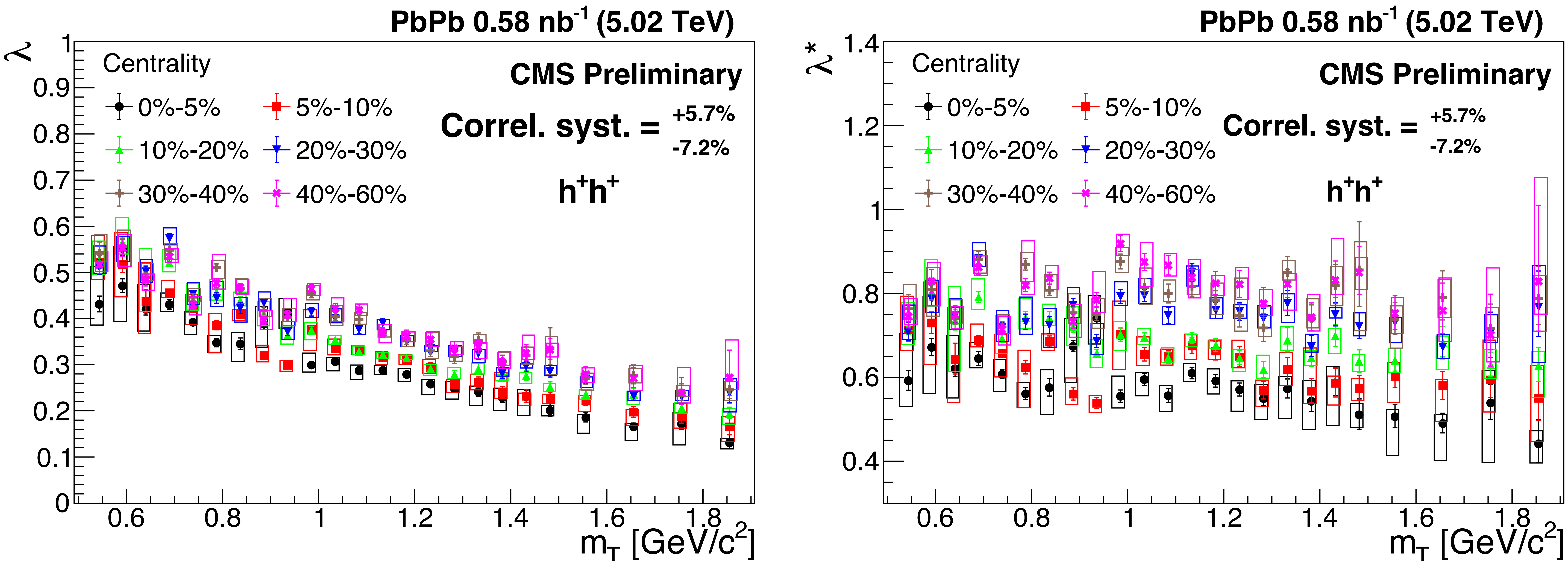
B_c^+ less suppressed than quarkonia despite a binding energy between J/ψ and Υ(1S)

arXiv:2201.02659
Accepted by PRL

Femtoscopy: h± - h± Correlation

R. Pradhan [06/14 9:20]

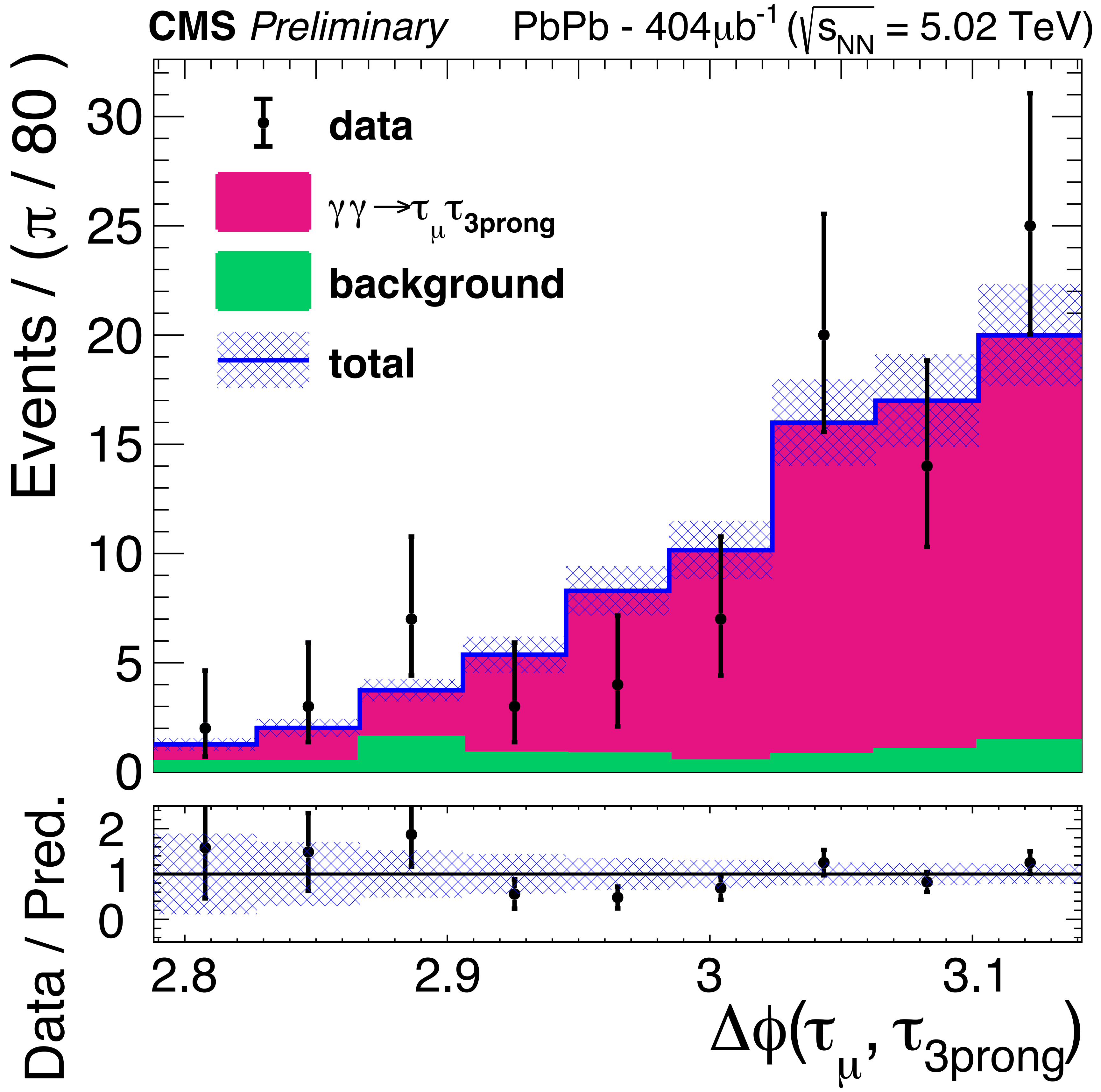
Remove effect of pion ratio $\lambda^* = \frac{\lambda}{(N_{\text{pion}}/N_{\text{hadron}})^2}$

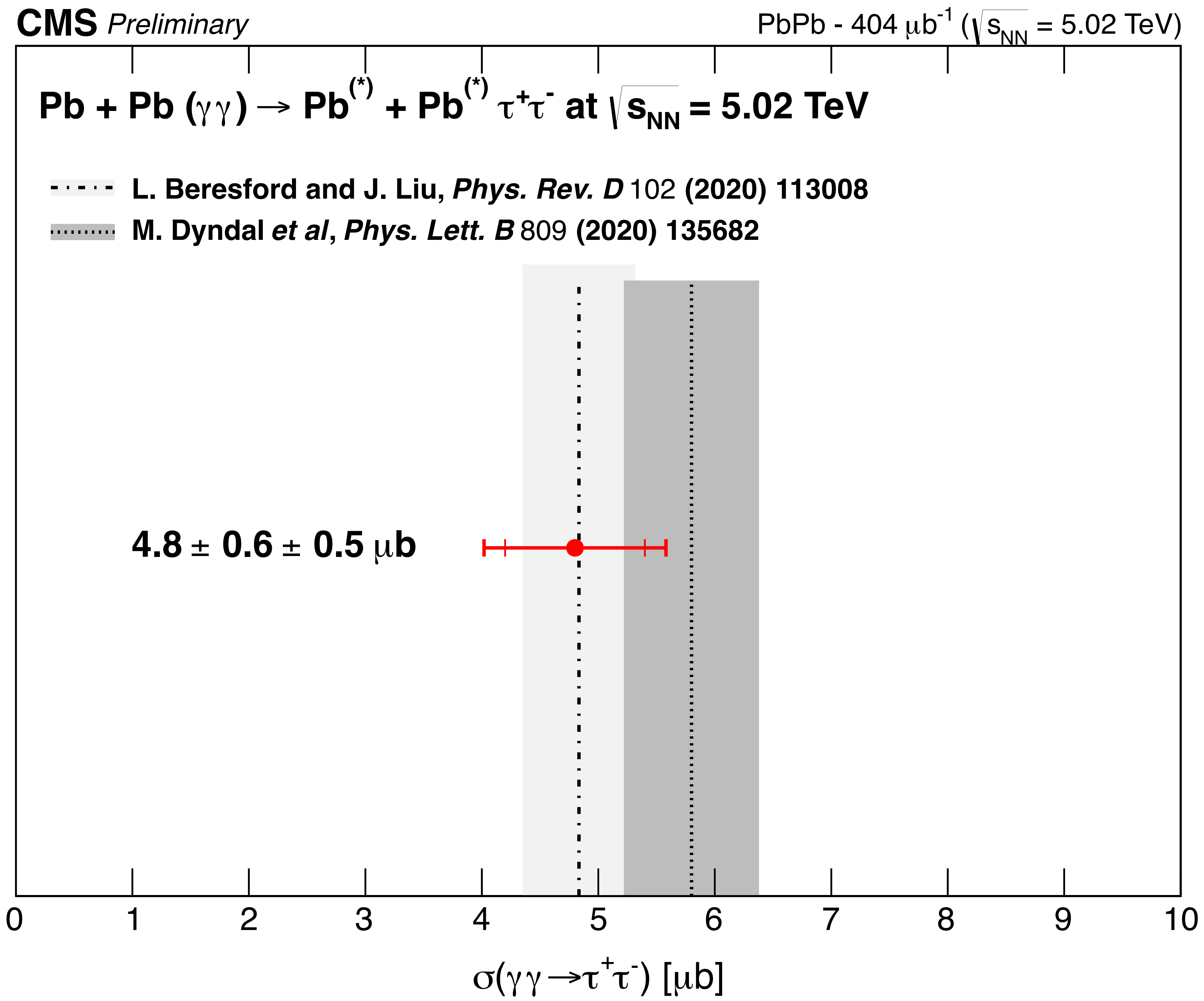


CMS-PAS-HIN-21-011

(g-2)$_\tau$: $\gamma\gamma \to \tau\tau$ in PbPb UPC

G. Krintiras [06/14 16:10]

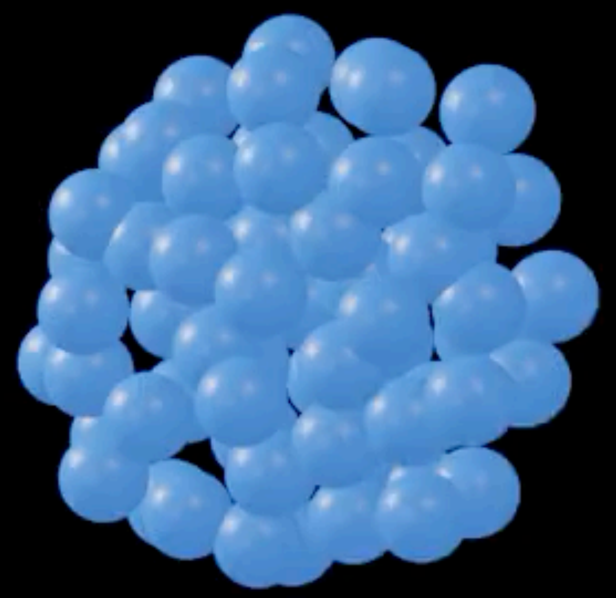




CMS-PAS-HIN-21-009

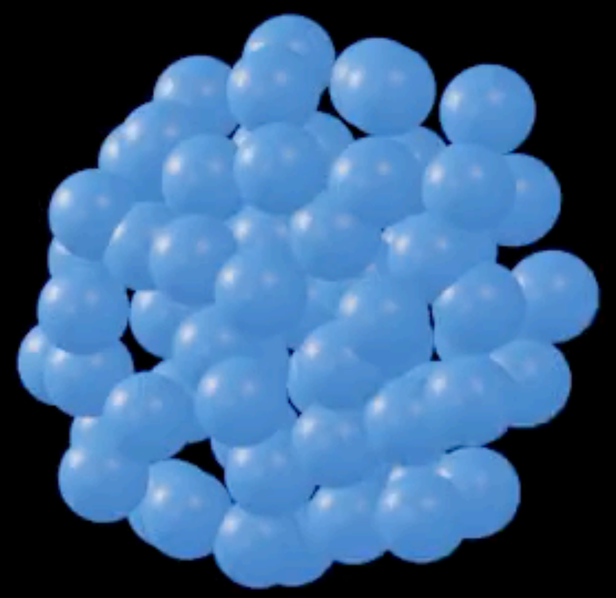
Section I

Click to see animation ➥



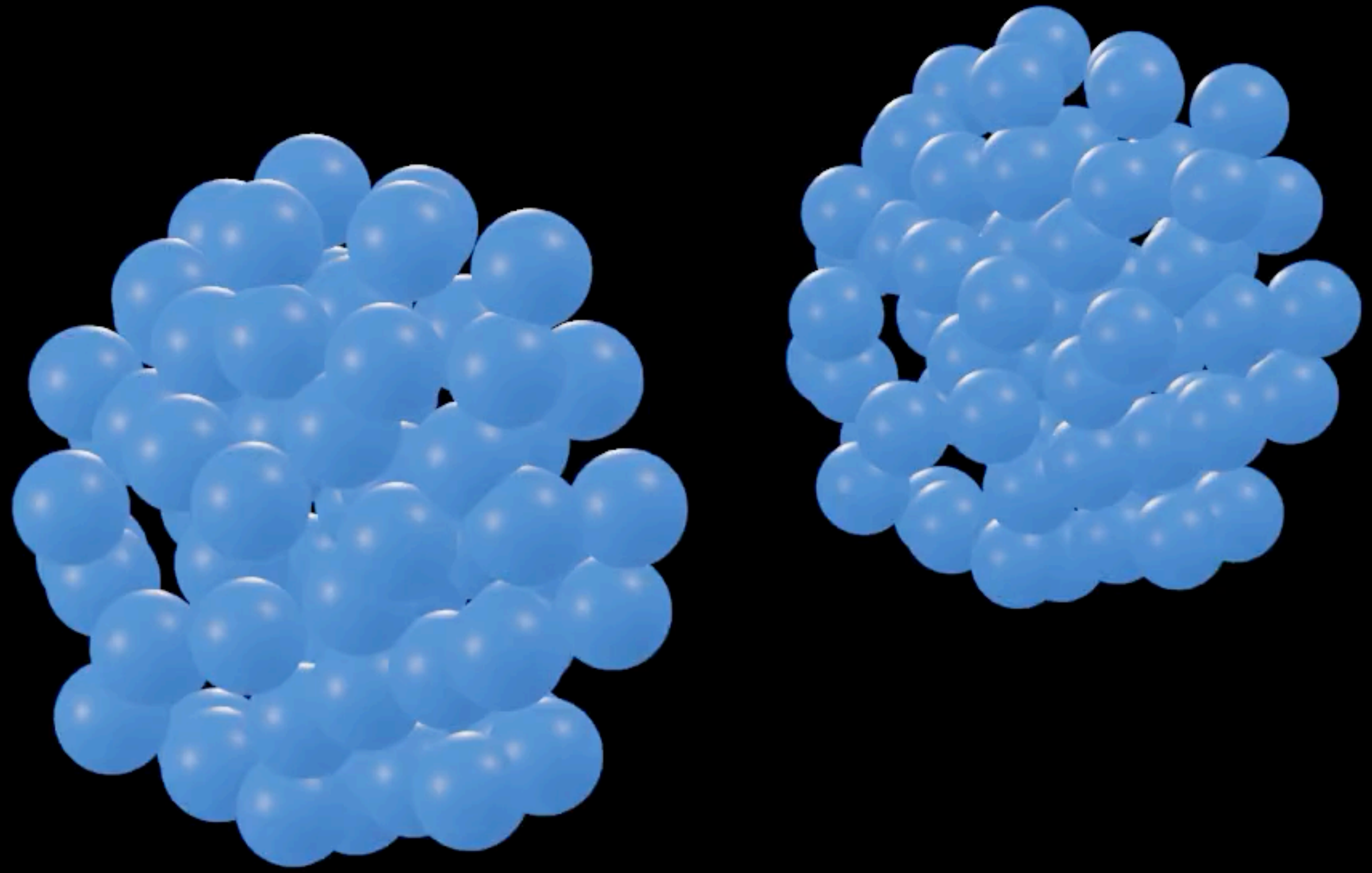
Click to see animation ➥

Section III



Click to see animation ➥

Section IV



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Section V

Click to see animation ➥