Prompt D^0 nuclear modification factor and v_n harmonics in PbPb at 5.02 TeV with CMS

Jian Sun

Purdue University

for the CMS Collaboration

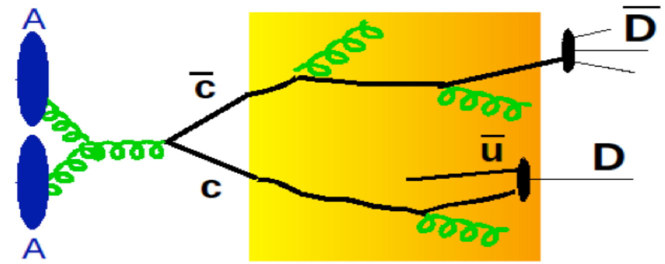
Quark Matter 2017, Chicago, USA

Motivation

- Heavy quarks produced early

→Experience the full evolution of the medium

→Good probes of the medium

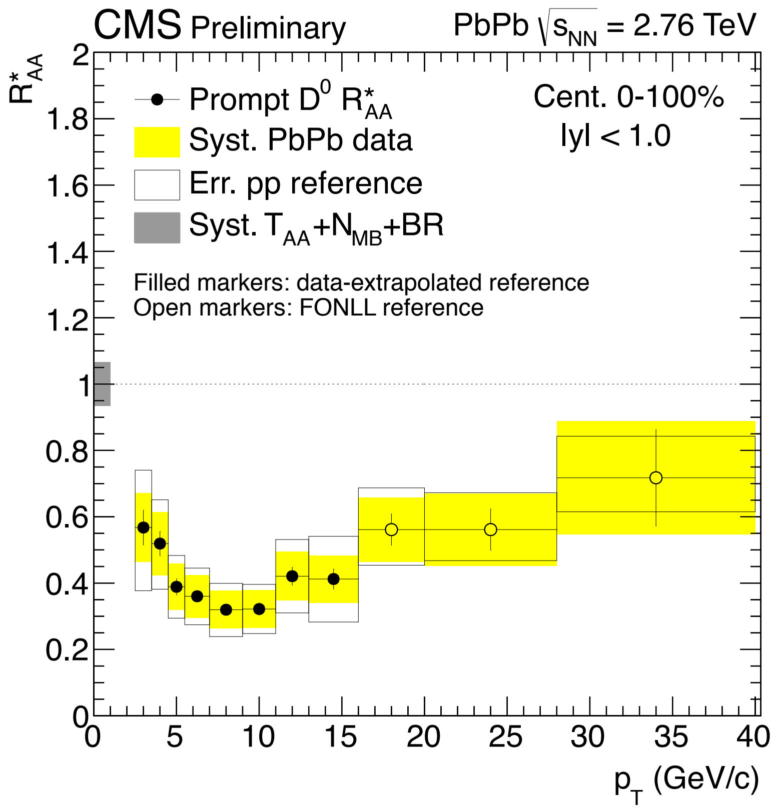


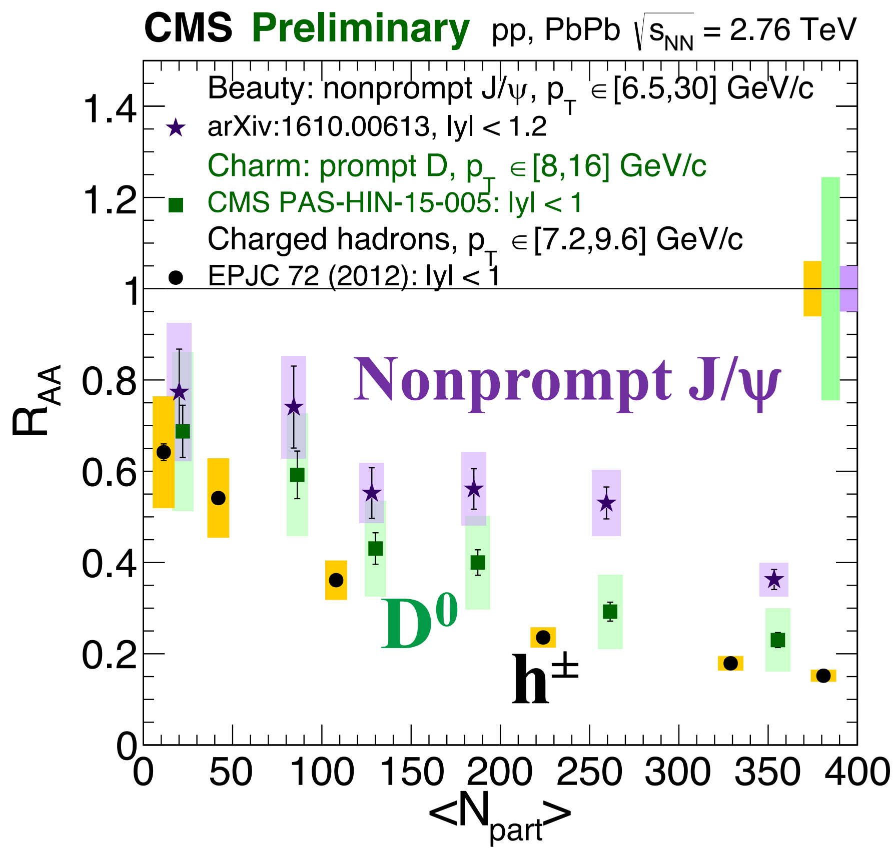
- **R_{AA}:** nuclear clear modification factor
  - Flavor dependent energy loss
  - Dead cone effect: heavy quarks loss less energy than light quarks

[1] Y.L. Dokshitzer, D. E. Kharzeev, Phys. Lett. B 519 (2001) 199

- **v_n harmonics:** the azimuthal anisotropy
  - At low p_T, the degree of medium thermalization
  - At high p_T, the path length dependence of energy loss
    - complementary to R_{AA}

D meson measurement with CMS in Run-I

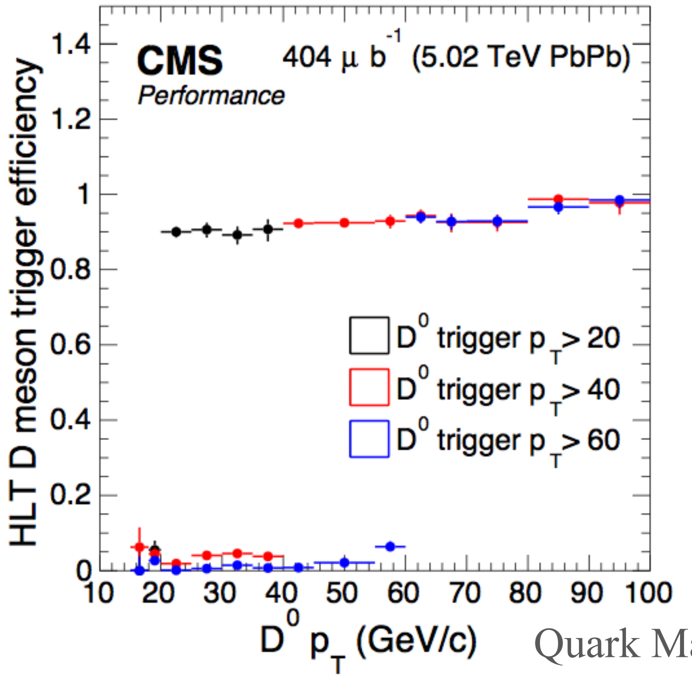




- ❑ Run I data: 30M MB PbPb events at 2.76 TeV
- ❑ D^0 R_{AA} both as functions of p_T and centrality
  - ➢ pp reference: data-extrapolated and FONLL
- ❑ Hint of flavor dependent R_{AA}

Dataset and trigger in Run-II

- 2015 HI run at 5.02 TeV at LHC
- Low p_T: MB and centrality triggered events
  - pp: 2B MB events
  - PbPb (preliminary): 170M 0-100% and 270M 30-100% events
- High p_T: dedicated D^0 triggers for both PbPb and pp



High quality data for D meson production and flow measurements!

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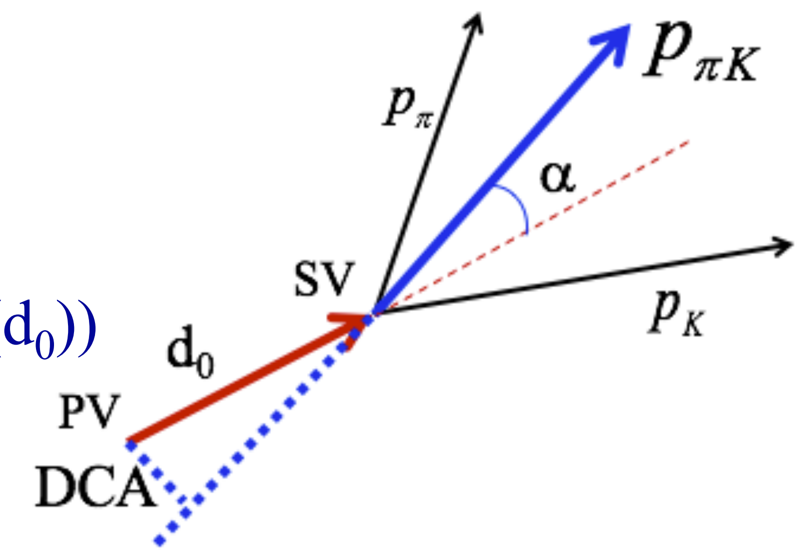
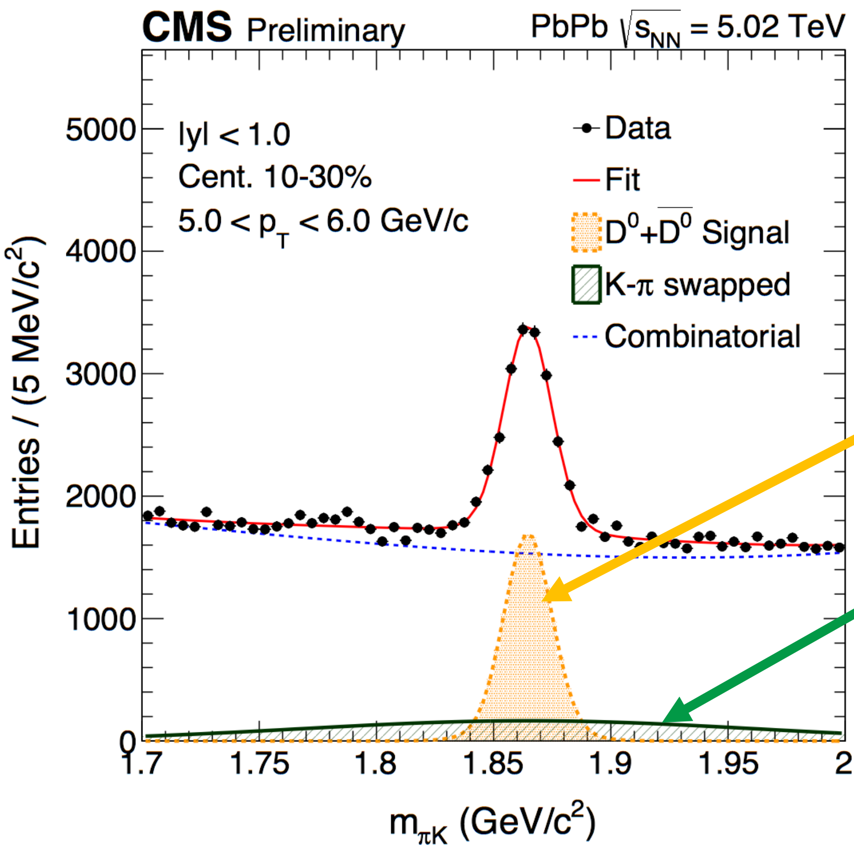
D^0 Reconstruction

- $D^0 \rightarrow K\pi$, BR = 3.88±0.05%, $c\tau(D^0)$ = 122.9 μm
- **D^0 candidates**
  - Pairing oppositely charged tracks
  - Secondary vertex reconstruction
- **Topological selections :**
  - 3D decay length significance ($d_0/\sigma(d_0)$)
  - Pointing angle α
  - Secondary vertex probability
  - **DCA of D^0 candidates (only applied in v_n measurement)**
    - **DCA < 0.008 cm**
    - **Suppress non-prompt D^0**



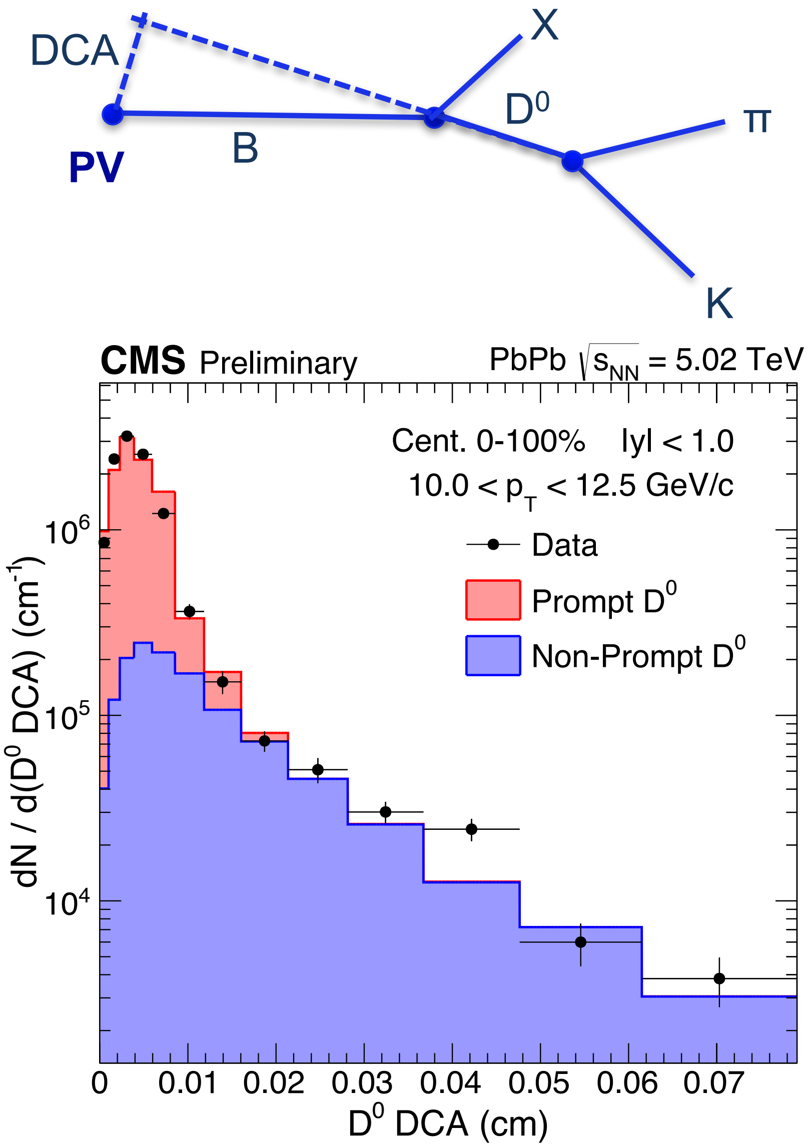
Invariant mass spectra fit



Invariant mass fitted with:

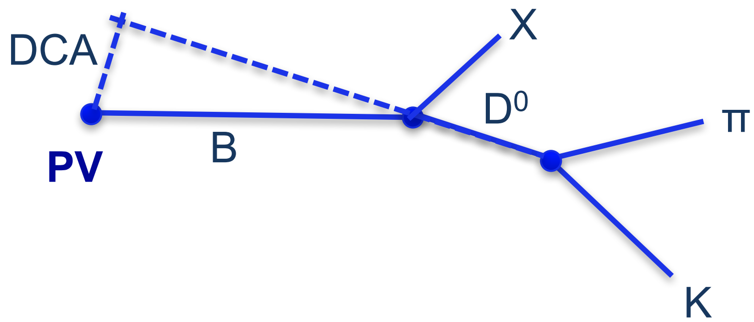
- **3rd order polynomial for combinatorial background**
- **Double gaussian for signal**
- **Single gaussian for k-π swapped candidates**
  - **No PID. Candidates with wrong mass assignment on tracks**

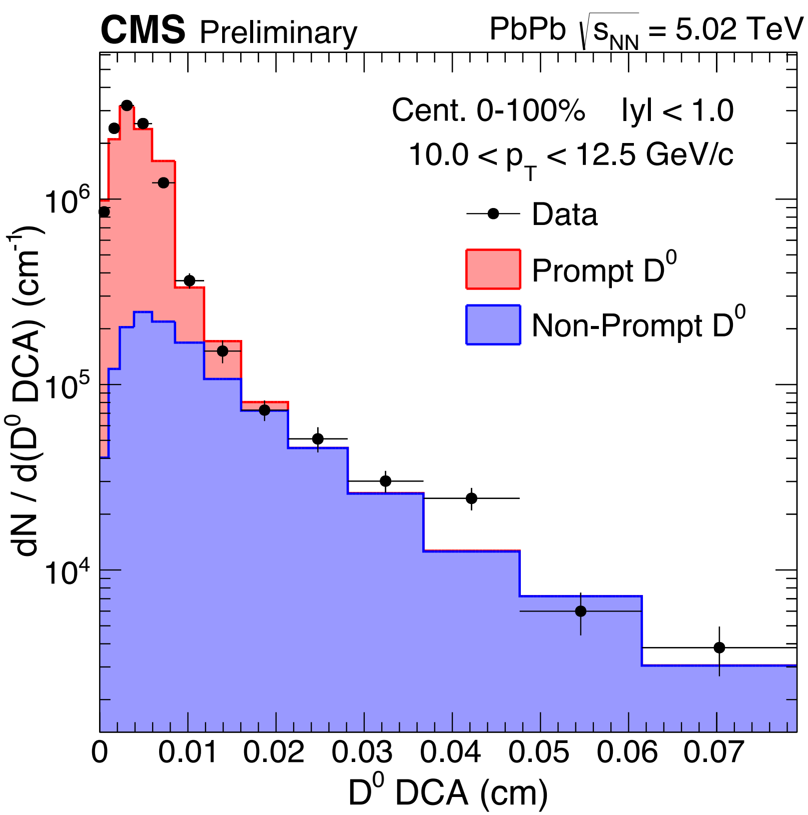
Prompt D^0 fraction study



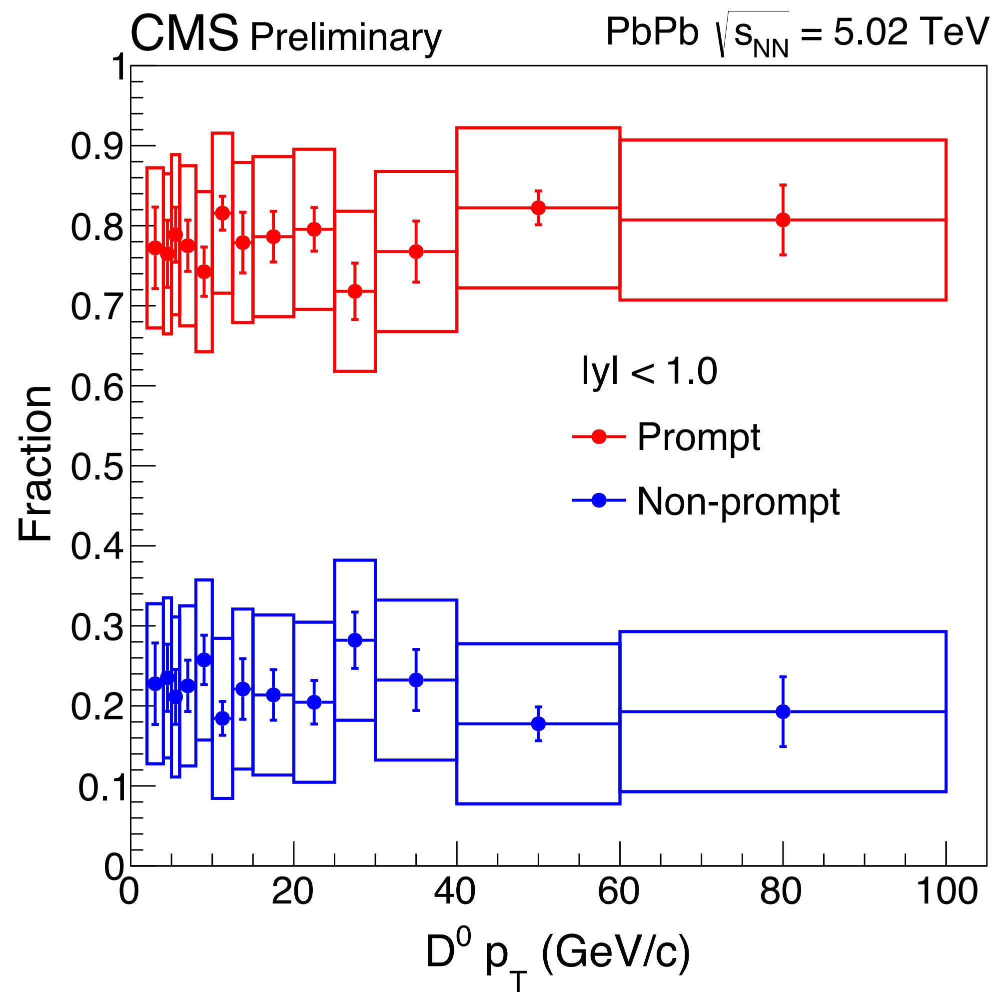
- ❑ D^0 in data is a mixture of prompt and non-prompt D^0
- ❑ The DCA shapes of prompt and non-prompt D^0 are different
- ❑ Prompt D^0 fraction from MC template fit on DCA distributions
- ❑ DCA < 0.008 cm cut suppress non-prompt D^0 by ~ 50%

Prompt D^0 fraction study



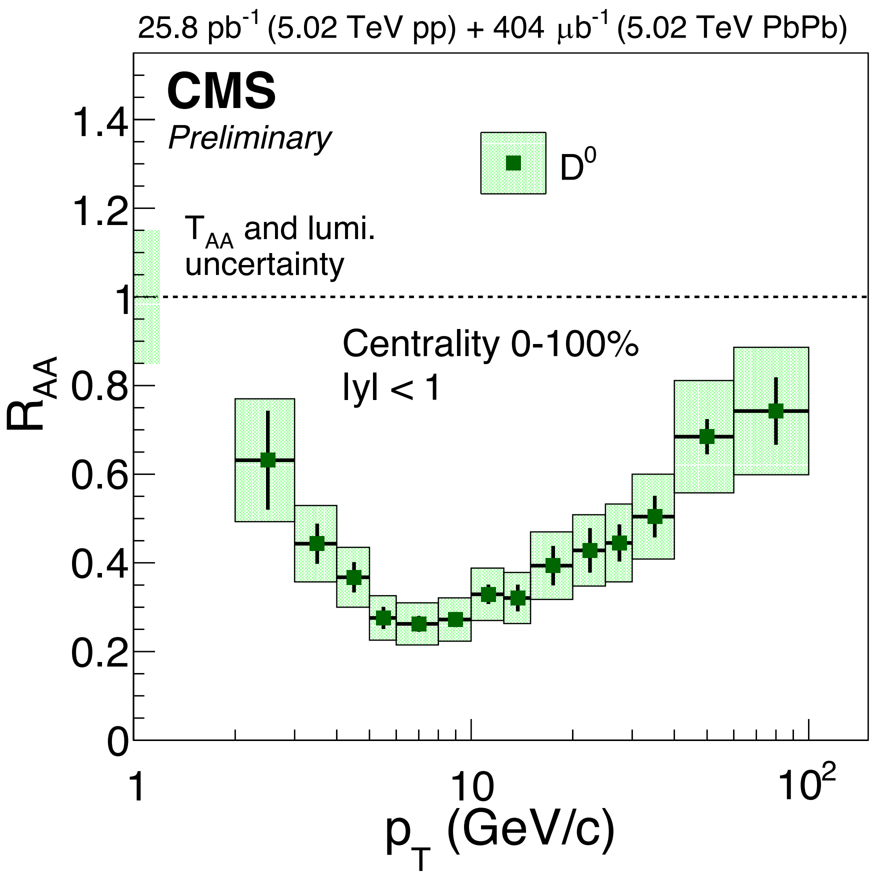


PbPb, Centrality 0-100%

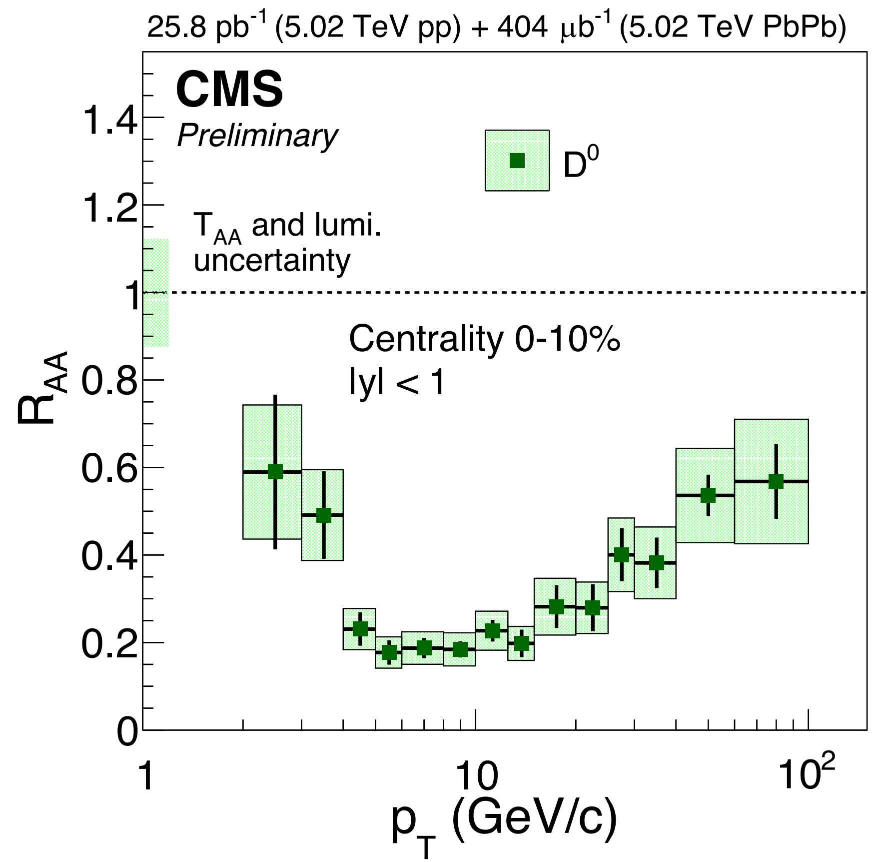


Prompt D^0 R_{AA} in PbPb at 5.02 TeV

Centrality 0-100%



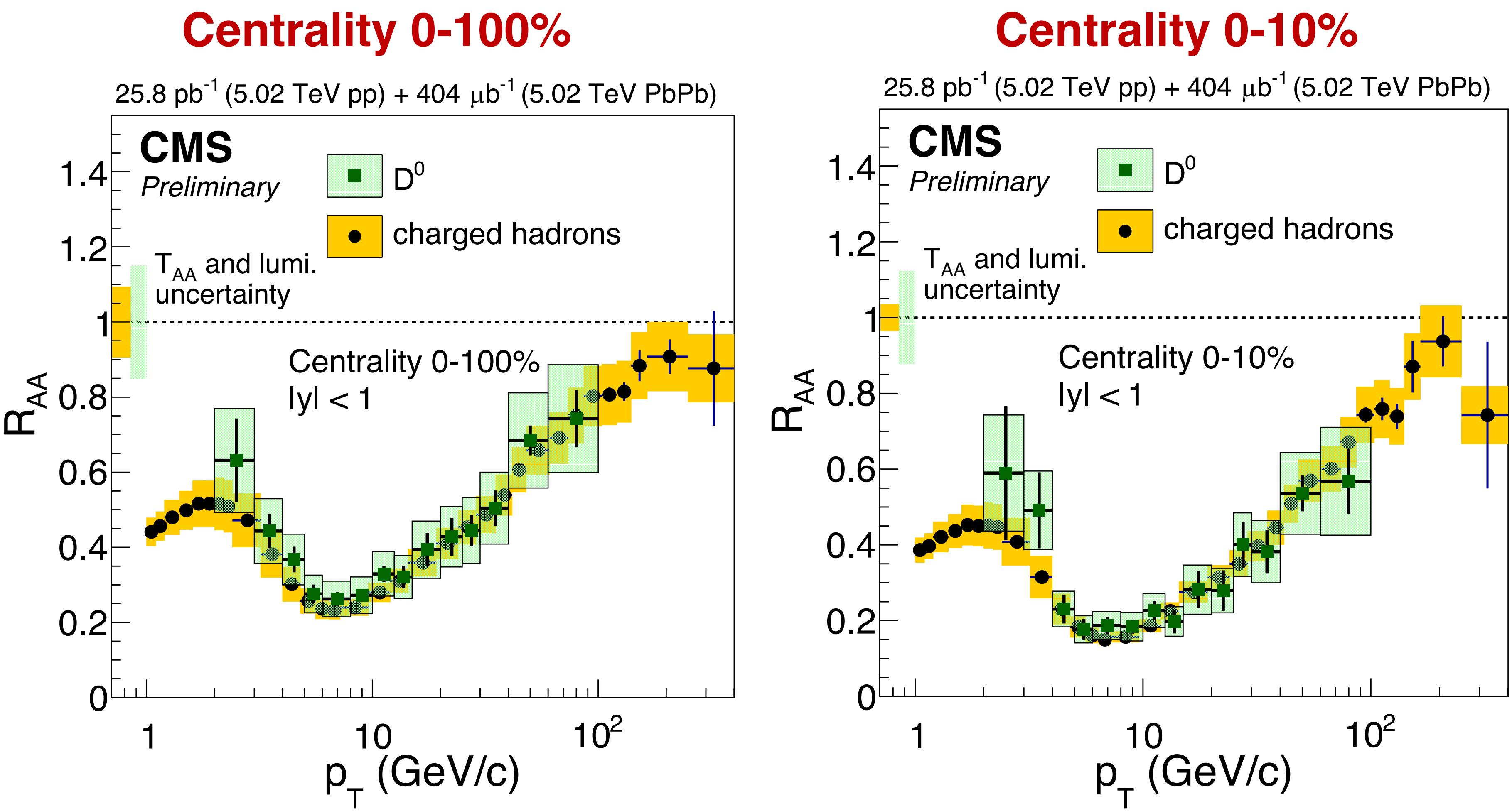
Centrality 0-10%



- ❑ Strongest suppression at p_T 5-8 GeV
- ❑ Similar suppression with 2.76 TeV

See poster by Jing Wang

Prompt D^0 R_{AA} compared with charged particle R_{AA}

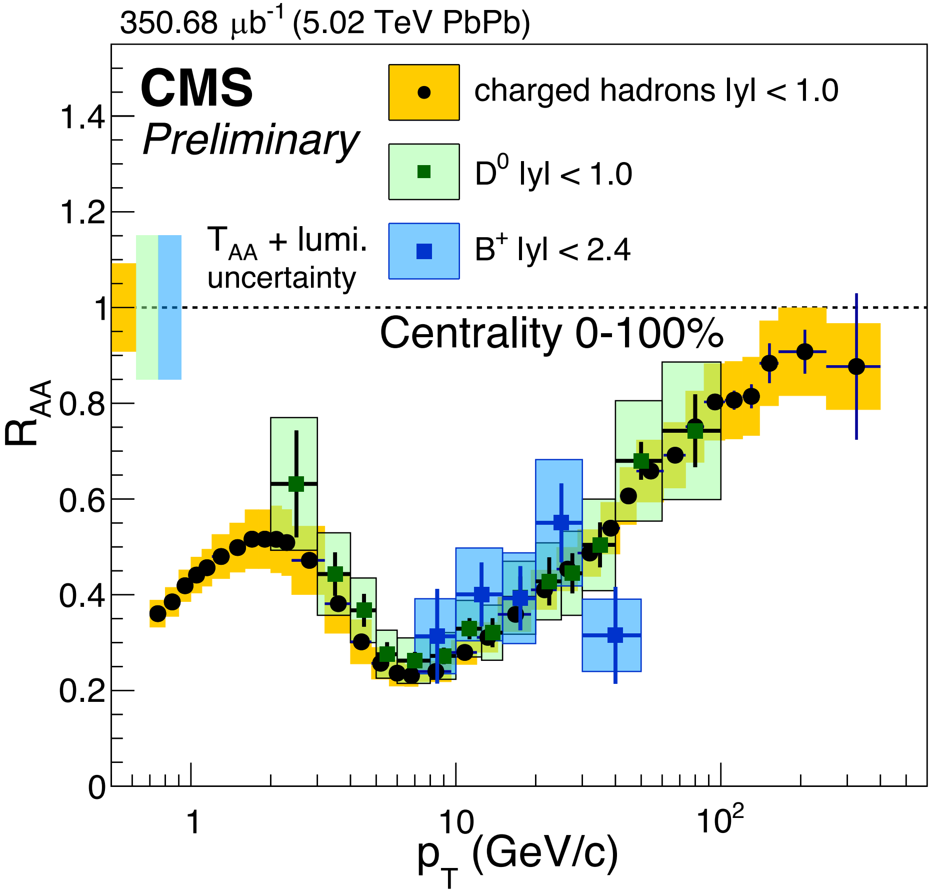


- Similar suppression with **charged hadrons** in a wide kinematic range

arXiv: 1611.01664

Prompt D^0 R_{AA} compared with B meson R_{AA}

Centrality 0-100%



- At high p_T, comparable suppressions with **B meson**
- More accurate measurements to be done for conclusions

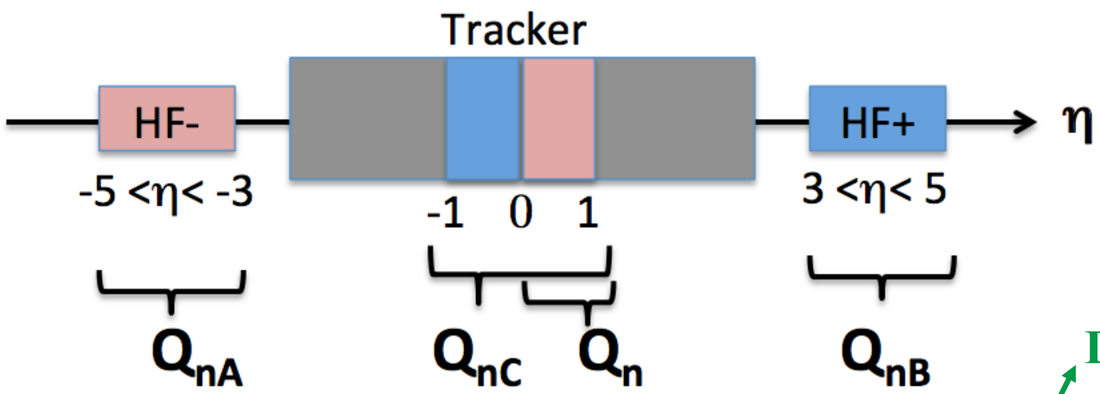
See talk by Ta-Wei Wang

CMS PAS HIN-16-011

arXiv: 1611.01664

CMS PAS HIN-16-001

Flow measurement: Scalar Product Method



$$Q_n = \sum_j w_j e^{in\phi_j}$$

Sum over tracks (tracker), or towers (HF)
w_j: tower E_T for HF, track p_T for tracker

D⁰ candidate

$$v_n\{SP\} = \frac{\langle Q_n \cdot Q_{nA}^* \rangle}{\sqrt{\dfrac{\langle Q_{nA} \cdot Q_{nB}^* \rangle \langle Q_{nA} \cdot Q_{nC}^* \rangle}{\langle Q_{nB} \cdot Q_{nC}^* \rangle}}}$$

Scaling factor from 3 sub events

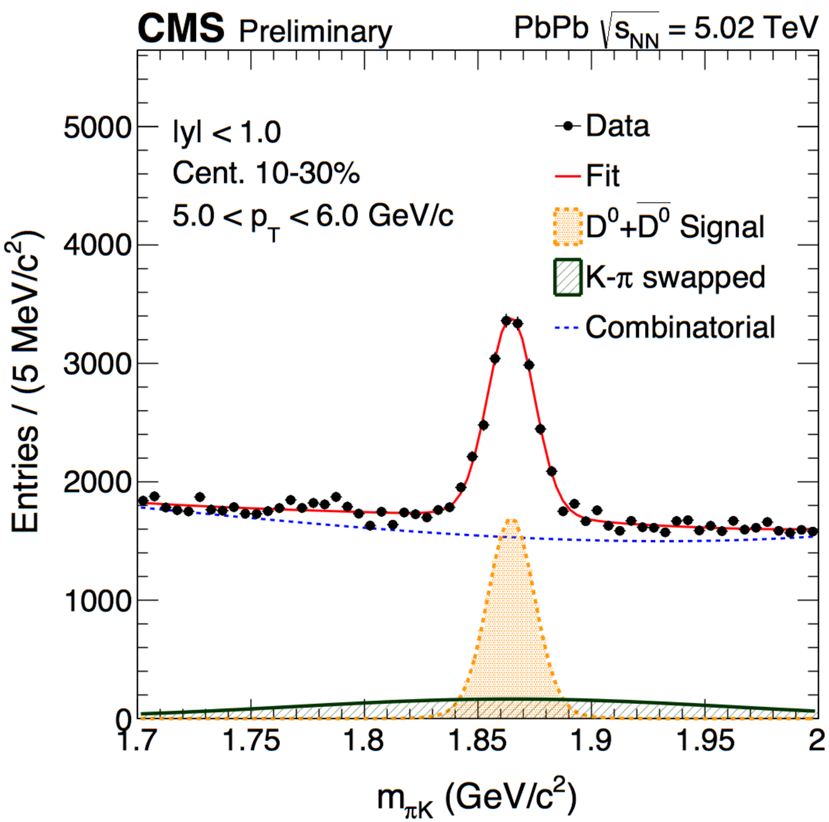
- Large η gap applied (|Δη|>3.0)
- $v_n\{SP\}$, non-ambiguous measure of $\sqrt{\langle v_n^2 \rangle}$

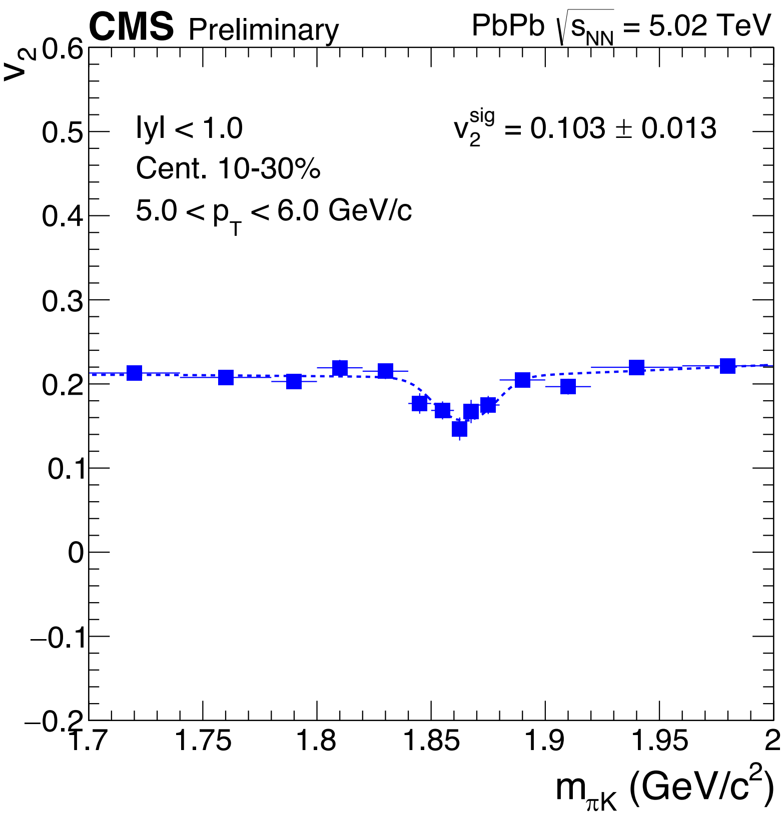
See poster by Hao Qiu

Luzum, Ollitrault PRC87 (2013), 044907

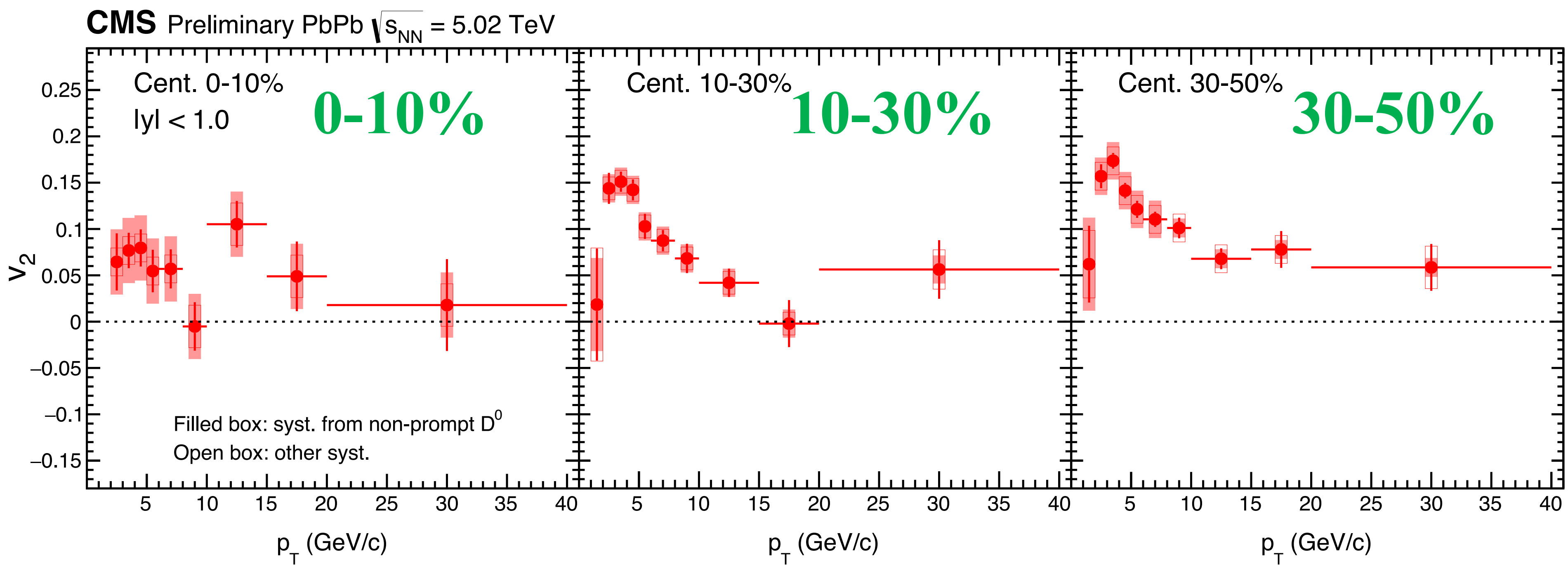
Extract v_n of D^0

- Simultaneous fit on mass distribution and v_n (v_2 or v_3) vs mass



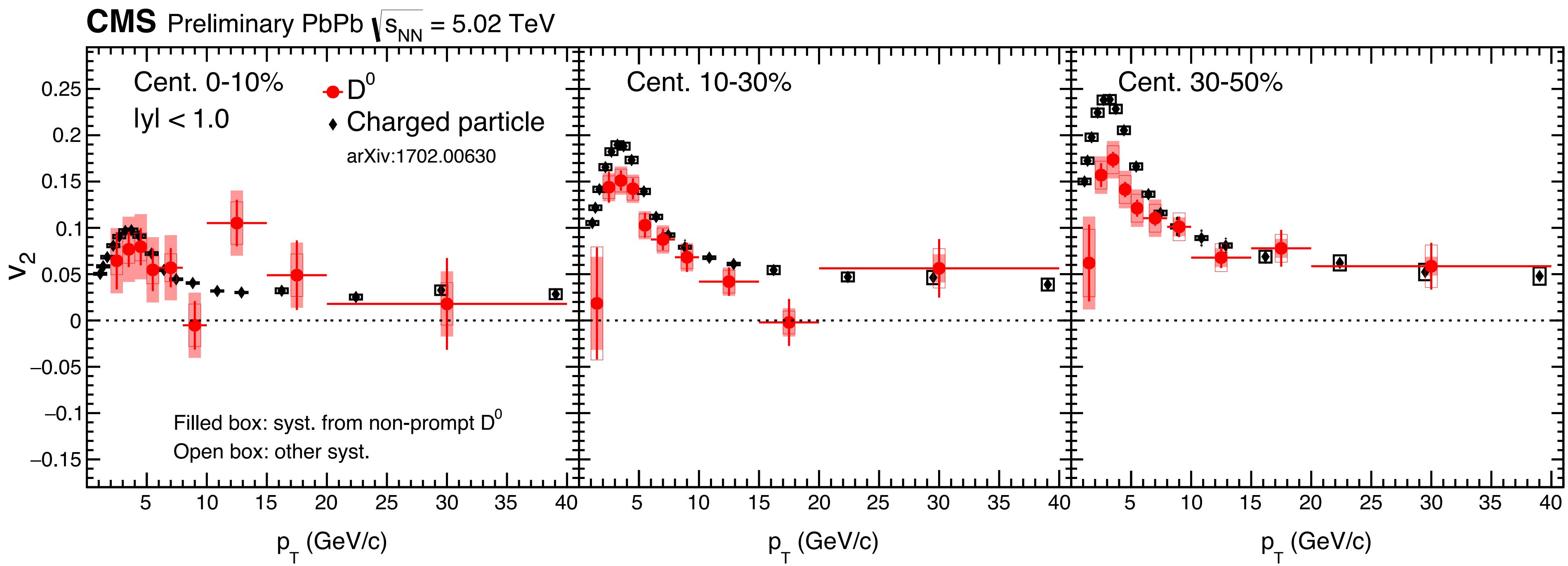


Prompt D^0 v_2 results



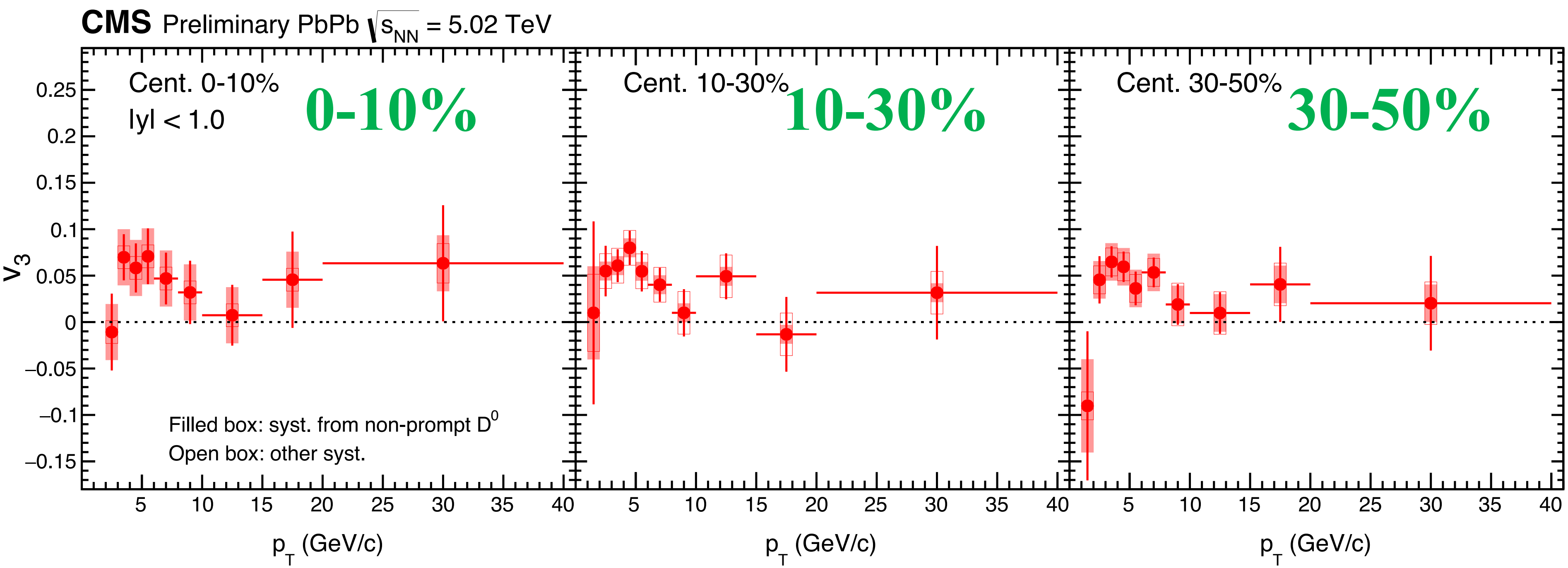
- **Positive prompt D^0 v_2 observed in studied p_T range**
  - Low p_T: charm quark collective motion
  - High p_T: path length dependence of energy loss
- **Peaks around 3 GeV, then decrease vs p_T**
- **Centrality dependence**

Prompt D^0 v_2 compared with v_2 of charged particle



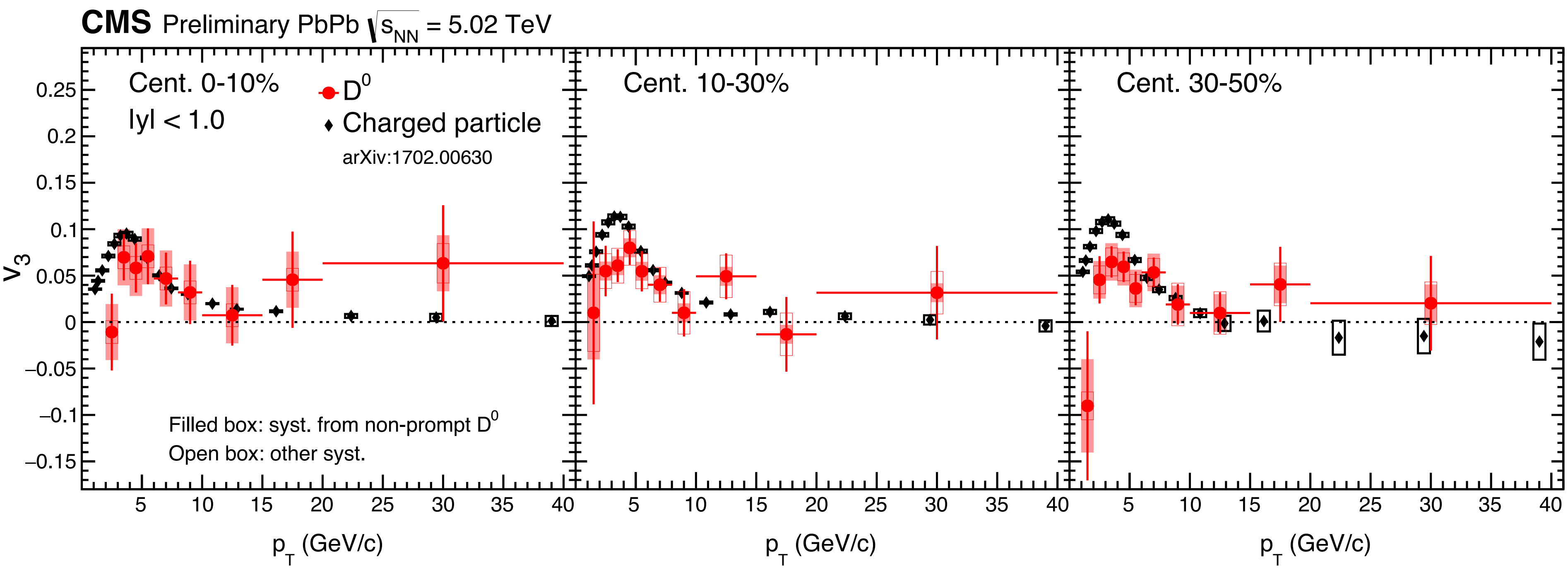
- **Low p_T: v_2 (prompt D^0) < v_2 (charged particle)**
- **High p_T: v_2 (prompt D^0) ≈ v_2 (charged particle)**
  - ΔE (charm) ≈ ΔE (light quark) at high p_T from R_{AA} and v_2
- **Similar p_T dependence**
- **At low p_T, weaker centrality dependence than charged particle**

Prompt D^0 v_3 results



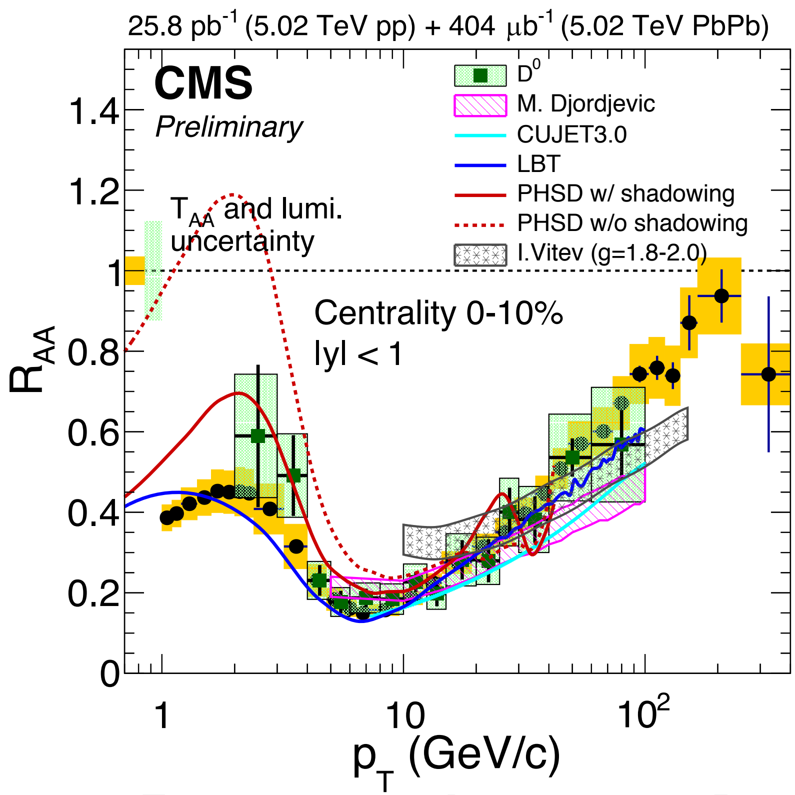
- **First measurement of D^0 v_3**
- **Low p_T: v_3 (prompt D^0) > 0; High p_T: v_3 (prompt D^0) ≈ 0**
- **Peaks around 3 GeV, then decrease vs p_T**
- **Little centrality dependence**

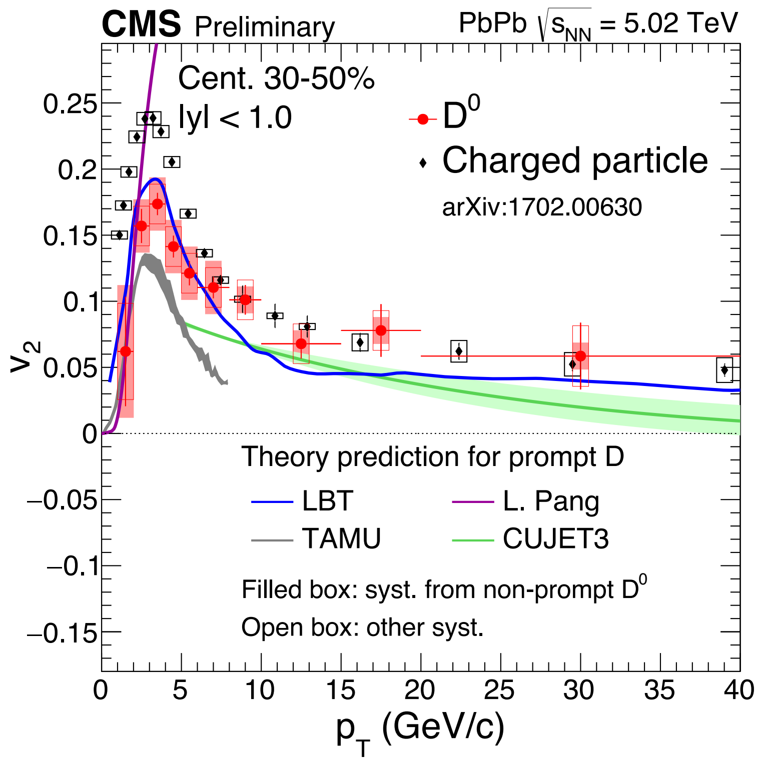
Prompt D^0 v_3 compared with v_3 of charged particle



- ❑ **Low p_T: v_3 (prompt D^0) < v_3 (charged particle)**
- ❑ **High p_T: v_3 (prompt D^0) ≈ v_3 (charged particle)**
- ❑ **Similar p_T dependence**
- ❑ **Both have little centrality dependence**

Comparison with model calculations



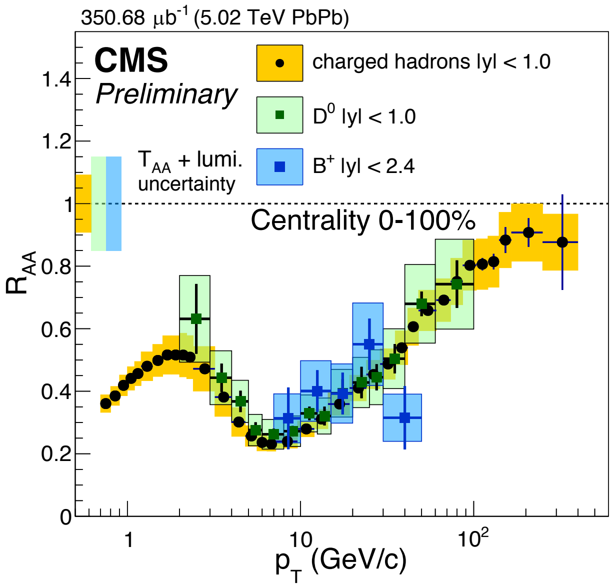


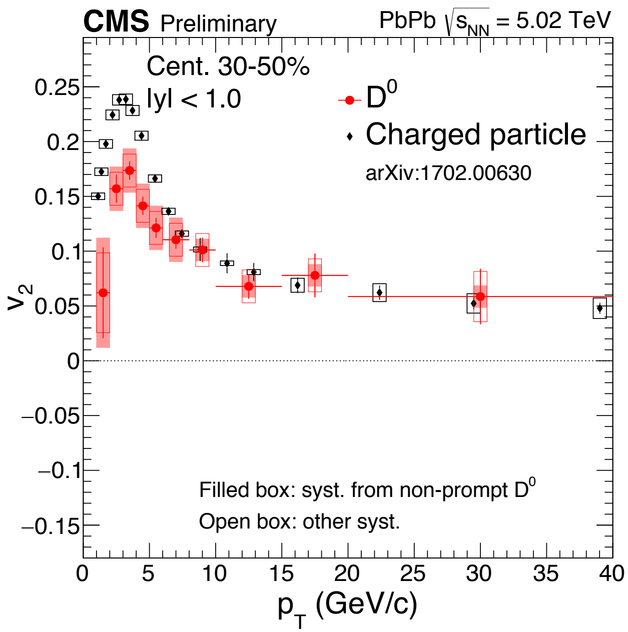
Important inputs and strong constraints on theory:

- **Theoretical calculations need to describe D^0 R_{AA} and v_n results simultaneously in a wide kinematic range**
- **Good progress has been made recently**

M. Djordjevic: PRC 92, 024918 (2015)
PHSD: PRC 93, 034906 (2016)
I. Vitev: PRD 93, 074030 (2015)
CUJET3: JHEP 1602 (2016) 169
LBT: PRC 94 014909 (2016)
TAMU: PLB 735 (2014) 445
L. Pang: PRD 91, 074027 (2015)

Summary

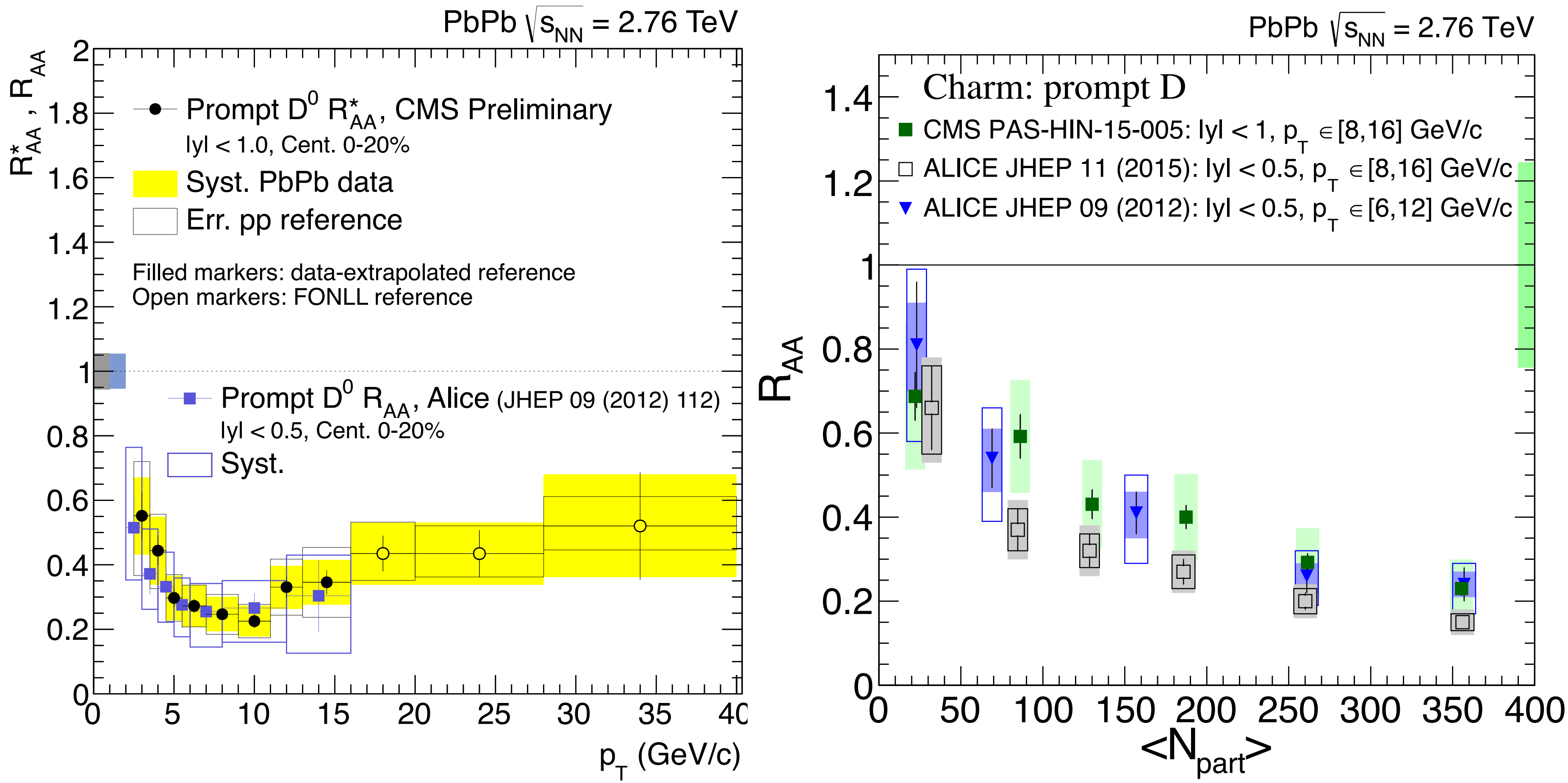




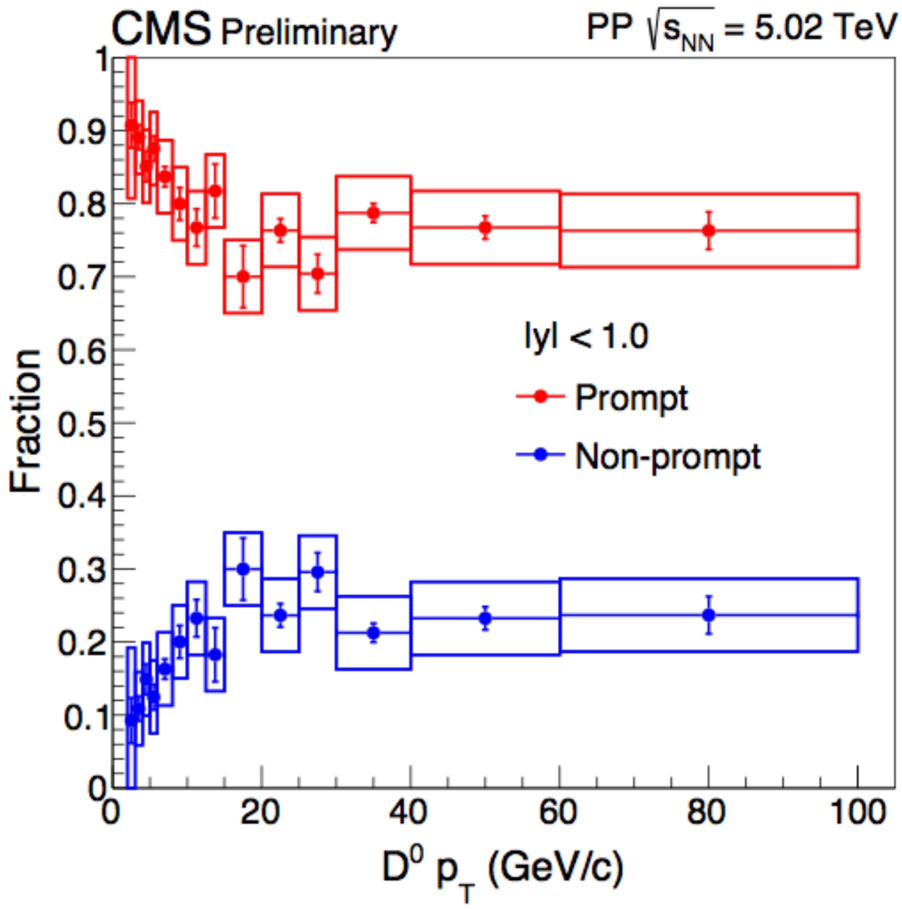
- **D^0 R_{AA} is measured in PbPb at 5.02 TeV**
  - $R_{AA}(D^0) \approx R_{AA}$(charged hadron)
  - $R_{AA}(D^0) \sim R_{AA}$(B meson) at high p_T
  - Similar suppression with 2.76 TeV
- **D^0 v_2 and v_3 is measured for 3 centrality classes in PbPb at 5.02 TeV**
  - First measurement of D^0 v_3
  - $v_2 > 0$, at both low and high p_T; $v_3 > 0$, at low p_T
  - Low p_T: v_n (prompt D^0) < v_n (charged particle)
  - High p_T: v_n (prompt D^0) $\approx$ v_n (charged particle)
- **The results provide important inputs for theory studies**

Backup

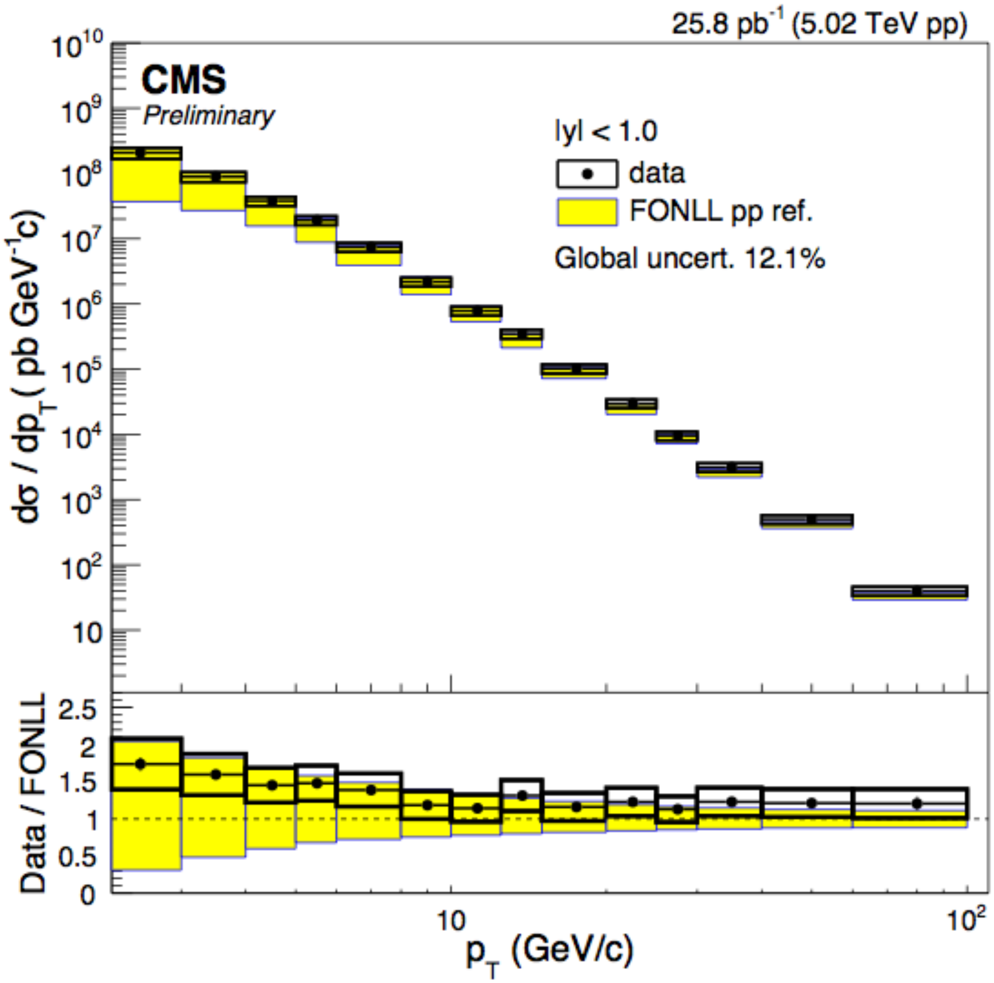
D^0 R_{AA} from CMS and ALICE with Run-I data



Prompt D^0 fraction in pp

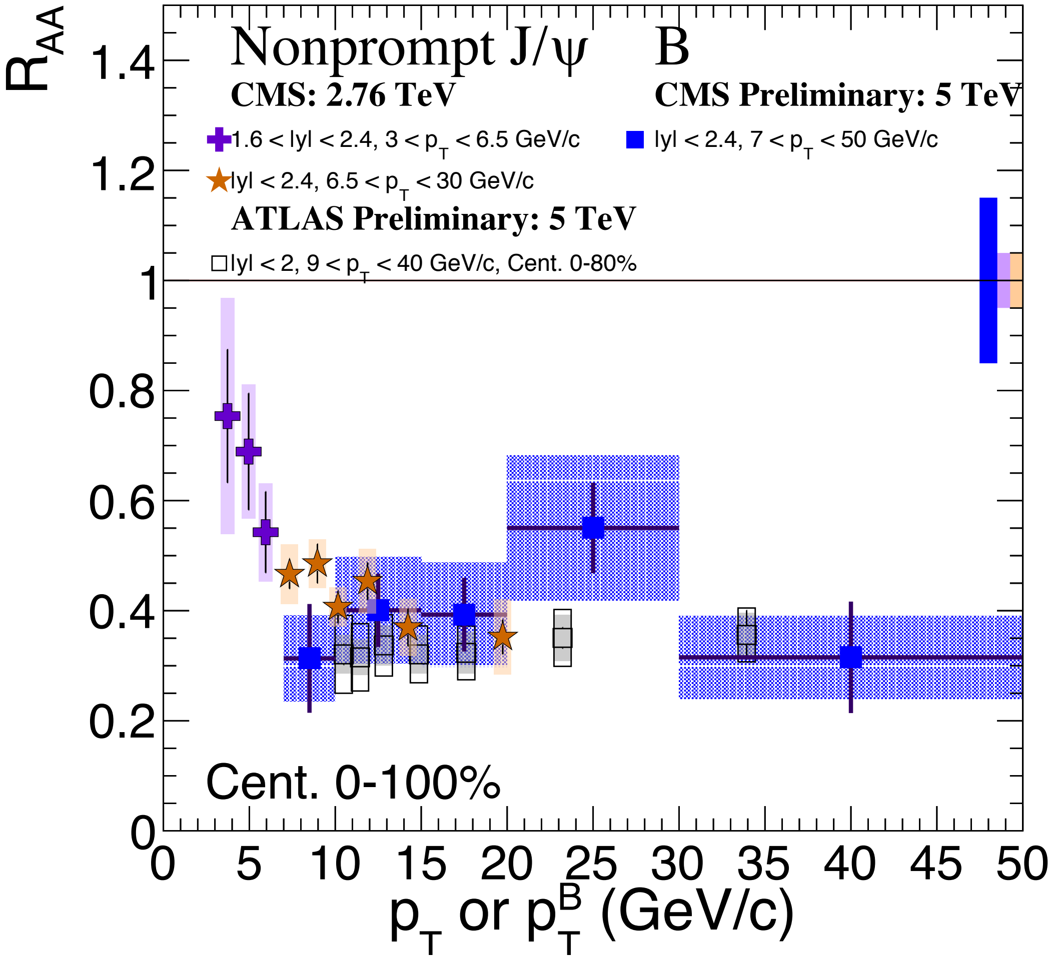


Prompt D^0 cross section in pp at 5.02 TeV



- ❑ The first measured D0 cross section in pp collisions at 5.02 TeV
- ❑ Consistent with the upper bound of FONLL calculations

Non-prompt J/ψ R_{AA} and B meson R_{AA}



To be handled with care!!

- *B meson p_T and non prompt J/φ are different! Need to correct for different kinematic*

CMS non prompt 1.6<|y|<2.4

CMS non prompt |y|<2.4

ATLAS non prompt |y|<2.9

CMS B+ |y|<2.4

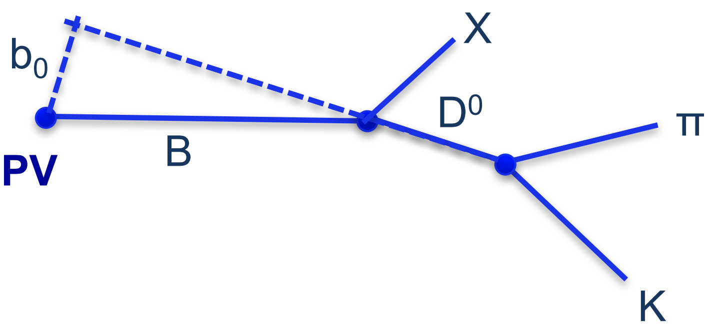
See talk by Ta-Wei Wang

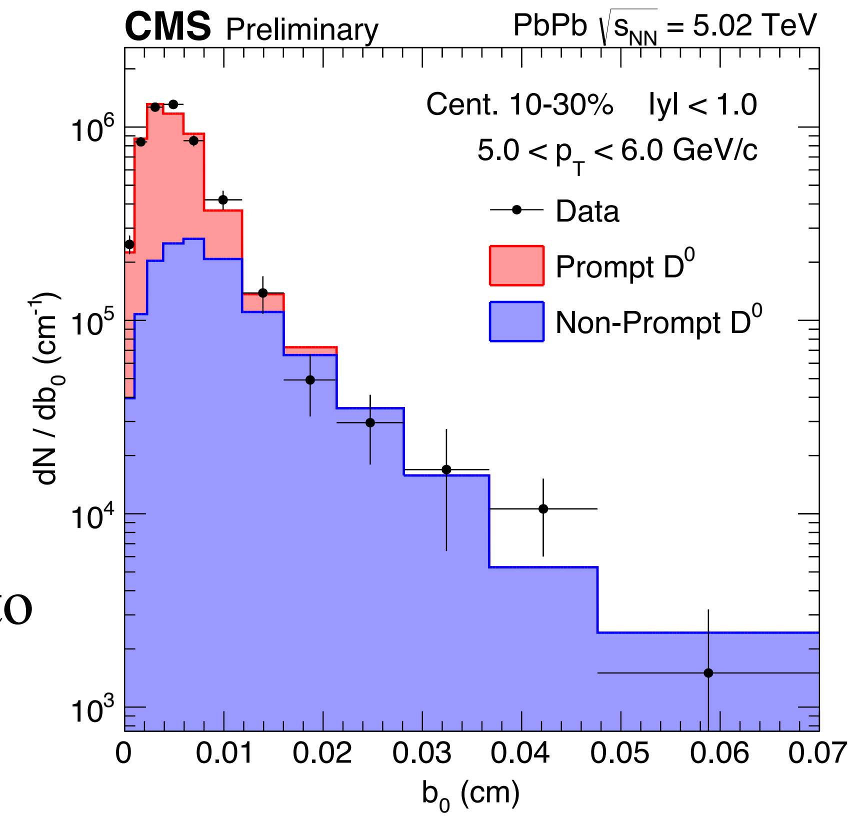
Systematic uncertainty from non-prompt D^0

- D^0 in data is a mixture of prompt and non-prompt D^0

$$v_n^{sig} = f_{prompt}\, v_n^{prompt} + (1-f_{prompt})\, v_n^{non\text{-}prompt}$$

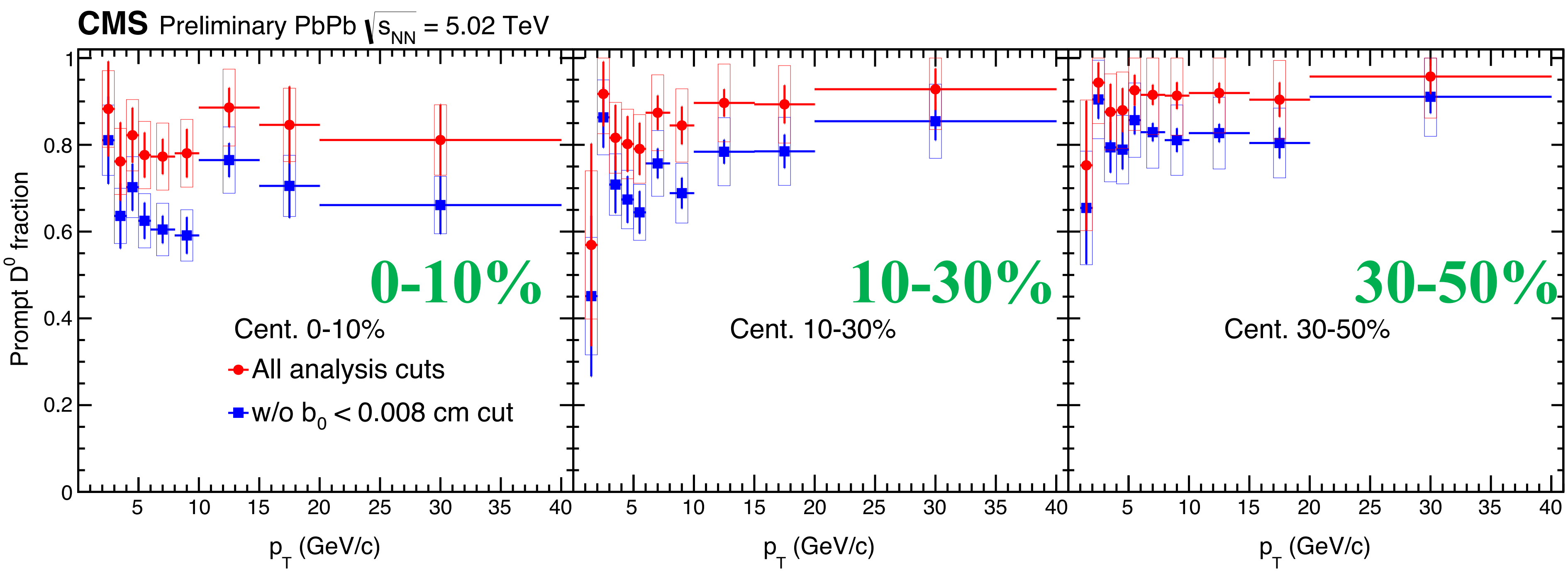
- To evaluate the effect from non-prompt D^0, prompt D^0 fraction is needed





- Different b_0 distributions of prompt D^0 and non-prompt D^0
- Template fit on b_0 distributions to evaluate prompt D^0 fraction
  - Fit in whole b_0 region

Prompt D^0 fraction with DCA (impact parameter) fit



- The prompt D^0 fraction is around 75-95% after all analysis cuts
- The impact parameter cut suppress the non-prompt D^0 by around 50%

Systematic uncertainty from non-prompt D^0

- Systematic uncertainties from non-prompt D^0 are evaluated in a data driven method based on:
  - v_n of D^0 with all analysis cut and w/o b_0 cut
  - Fractions of prompt D^0 with all analysis cut and w/o b_0 cut

All analysis cut: $v_{n,1}^{sig} = f_{p,1}\, v_n^{p} + (1-f_{p,1})\, v_n^{np}$

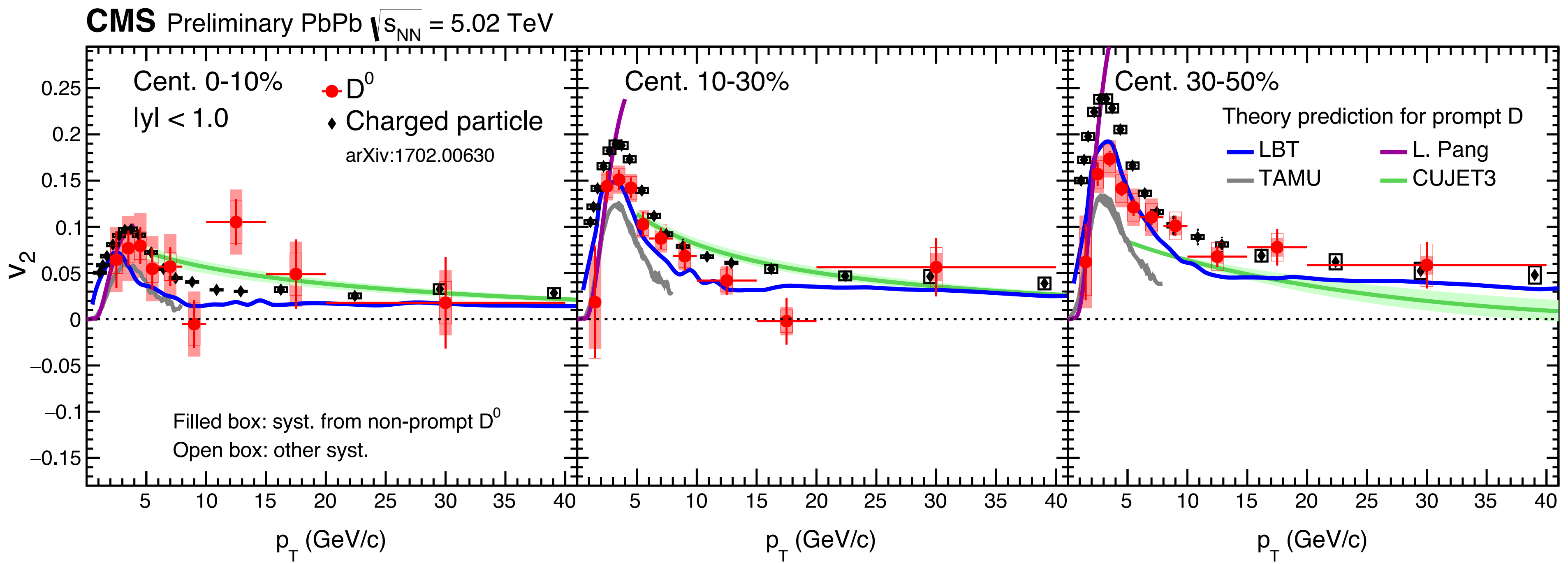
Without b_0 cut: $v_{n,2}^{sig} = f_{p,2}\, v_n^{p} + (1-f_{p,2})\, v_n^{np}$

$$\Rightarrow \quad v_n^{p} = v_{n,1}^{sig} + \frac{1-f_{p,1}}{f_{p,1}-f_{p,2}}\left(v_{n,1}^{sig} - v_{n,2}^{sig}\right)$$

D^0 v_n with all analysis cuts as central value

As systematics from non-prompt D^0

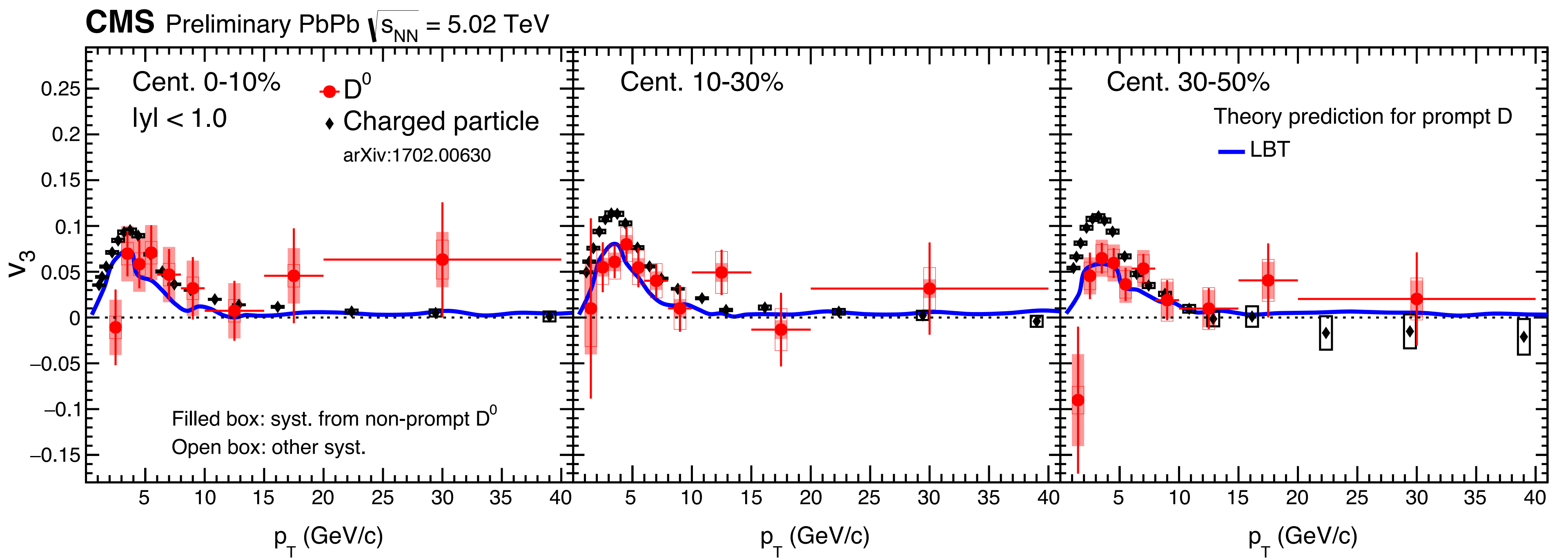
Prompt D^0 v_2 compared with model calculations



- **LBT:** linearized Boltzmann transport model for jet propagation in QGP
- **TAMU:** non-perturbative transport model with thermodynamic T-matrix approach
- **CUJET3:** jet quenching model based on DGLV
- **L. Pang**: second order viscosity hydrodynamic model

LBT: Cao, Luo, Qin, Wang PRC 94 014909 (2016)
TAMU: He, Fries, Rapp PLB 735 (2014) 445
CUJET3: Xu, Liao, Gyulassy JHEP 1602 (2016) 169
L. Pang: Pang, Hatta, Wang, Xiao PRD 91, 074027 (2015)

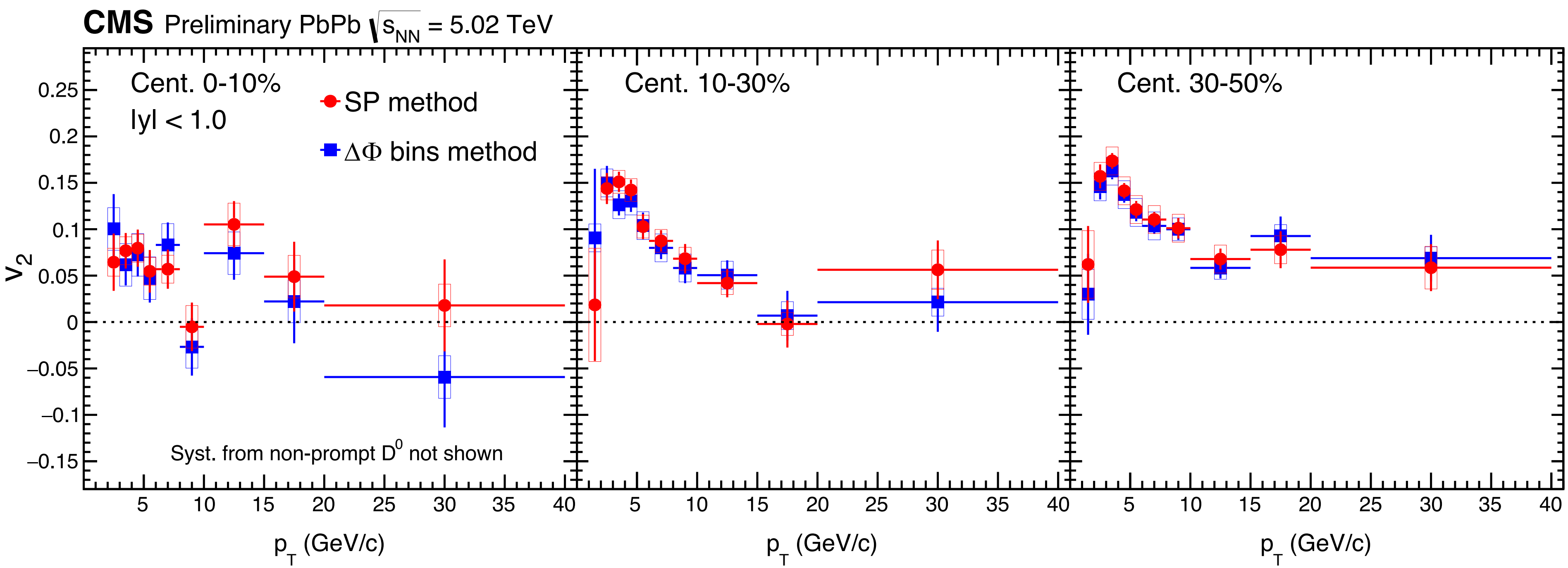
Prompt D^0 v_3 compared with model calculations



- **LBT:** linearized Boltzmann transport model for jet propagation in QGP

LBT: Cao, Luo, Qin, Wang PRC 94 014909 (2016)

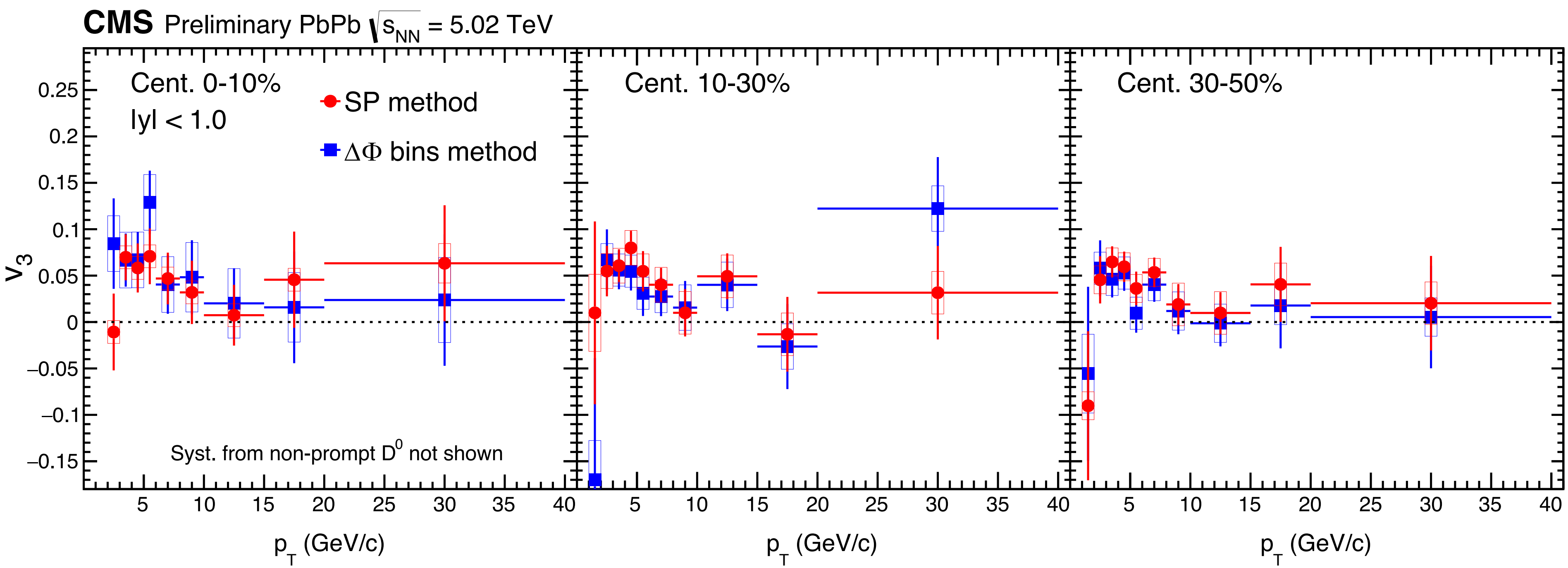
D^0 v_2 from SP and Δϕ bins method



Results from SP method and Δϕ bins method are consistent within uncertainties

- ❖ Small differences are expected

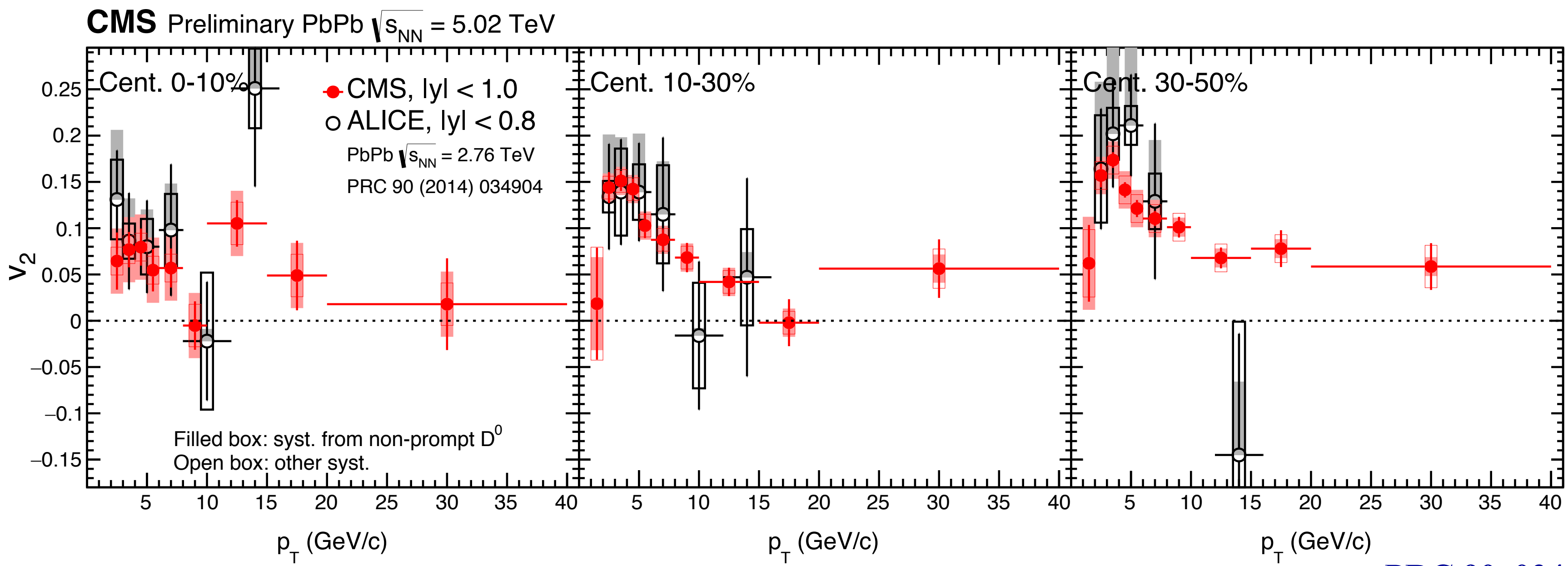
D^0 v_3 from SP and $\Delta\phi$ bins method



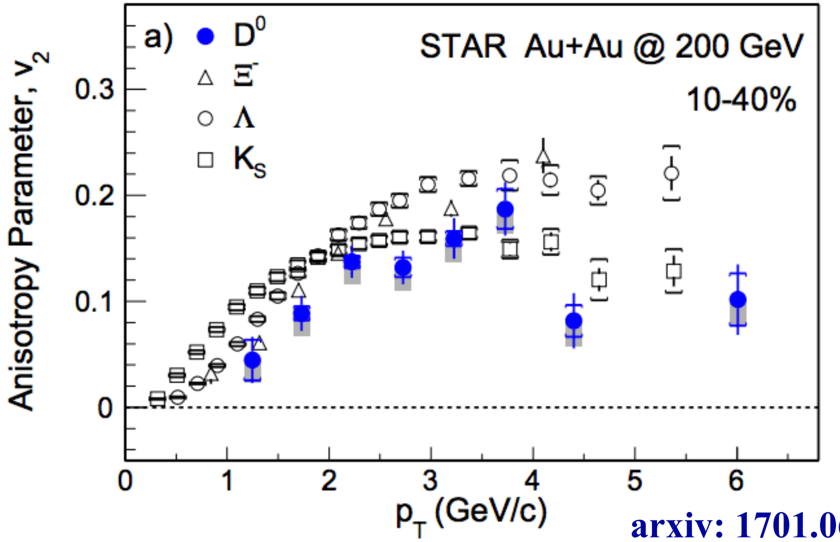
Results from SP method and $\Delta\phi$ bins method are consistent within uncertainties

- Small differences are expected

D^0 v_2 compared with ALICE and STAR results



PRC 90, 034904 (2014)



arxiv: 1701.06060

CMS preliminary results are consistent with ALICE results within uncertainties