Physics in Collision

40th International Symposium on Physics in Collision

RWTH Aachen University, Aachen, Germany | September 14-17, 2021

Heavy Ion Physics

Hard probes for QGP at LHC: a selection of recent results

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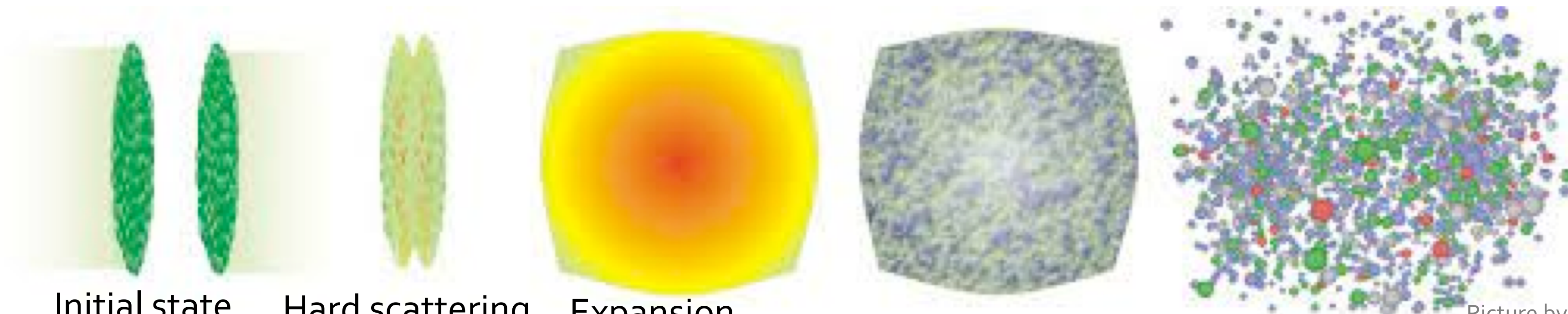
Université de Nantes

Stages of a heavy ion collision

Time →



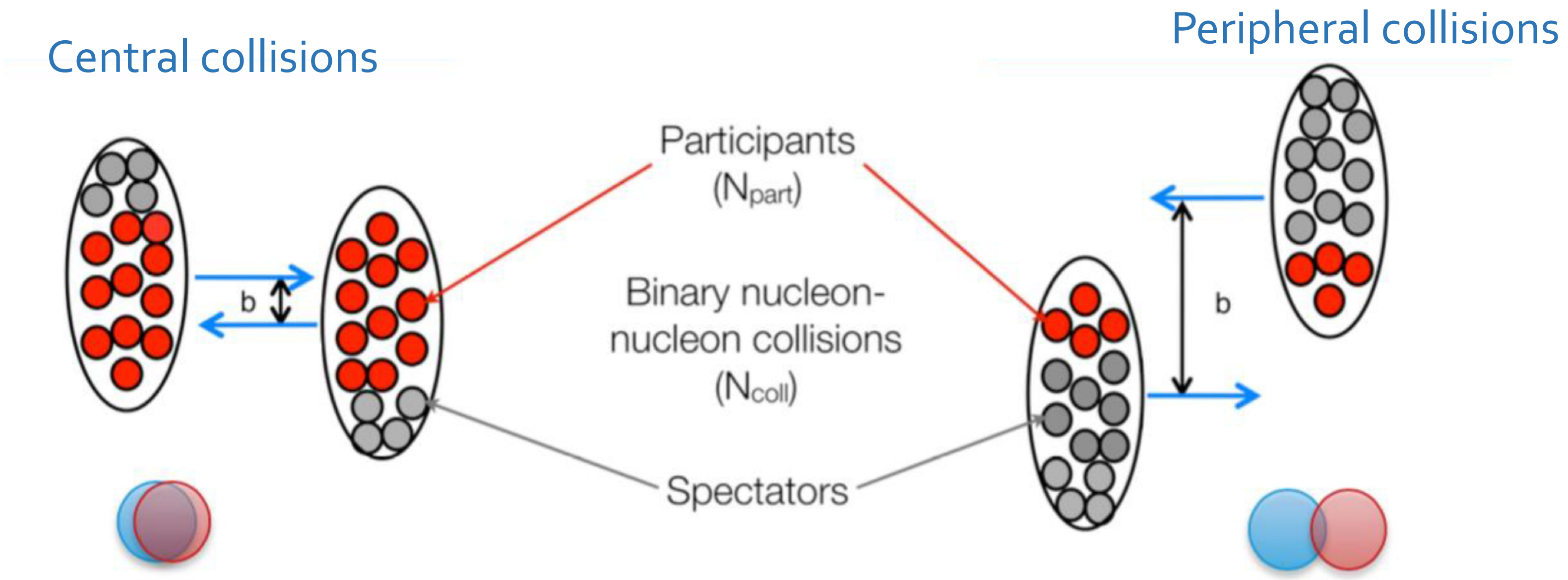
Initial state | Hard scattering | Expansion QGP | Hadronization | Freeze out

Picture by S. bass

Hard probes of QGP: experience whole collision, produced in the hard scattering at the early stage of the collision.

- Probe **initial state** and **interaction with medium**
  - EW bosons (W, Z , direct photons)
  - Heavy flavour & Quarkonia
  - Jets

Heavy Ion collisions: Centrality



Centrality characterized by:

- Impact parameter: b
- Number of participants: N_{part}
- Number of binary (nucleon-nucleon) collisions: N_{coll}

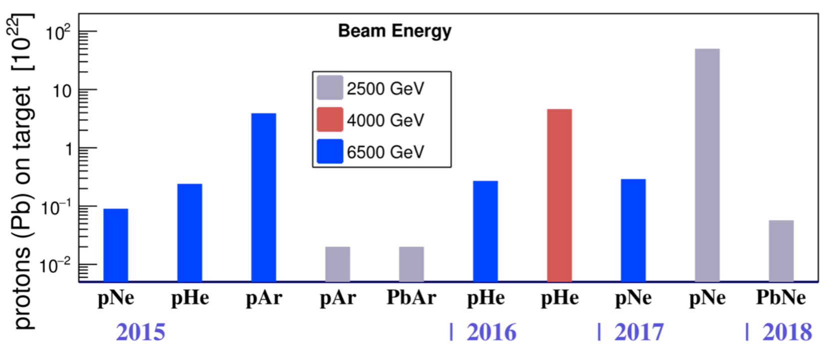
Experimentally:

- Glauber models used to estimate them from collision multiplicity observables: multiplicity of collision, transverse energy

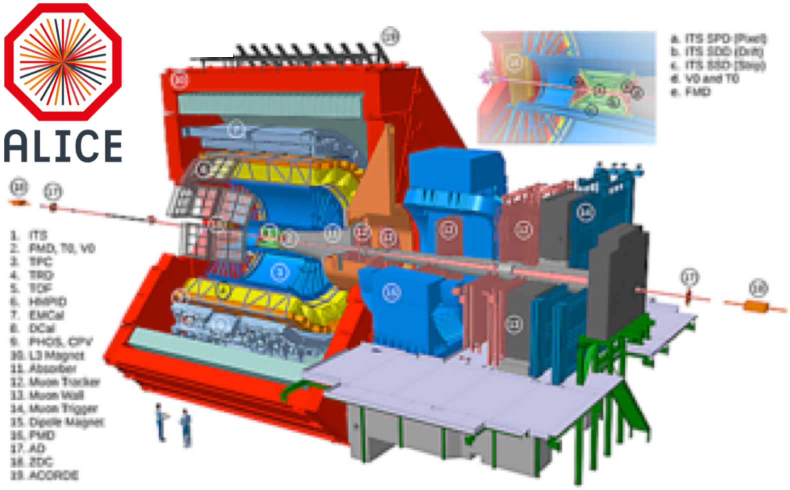
LHC with ions

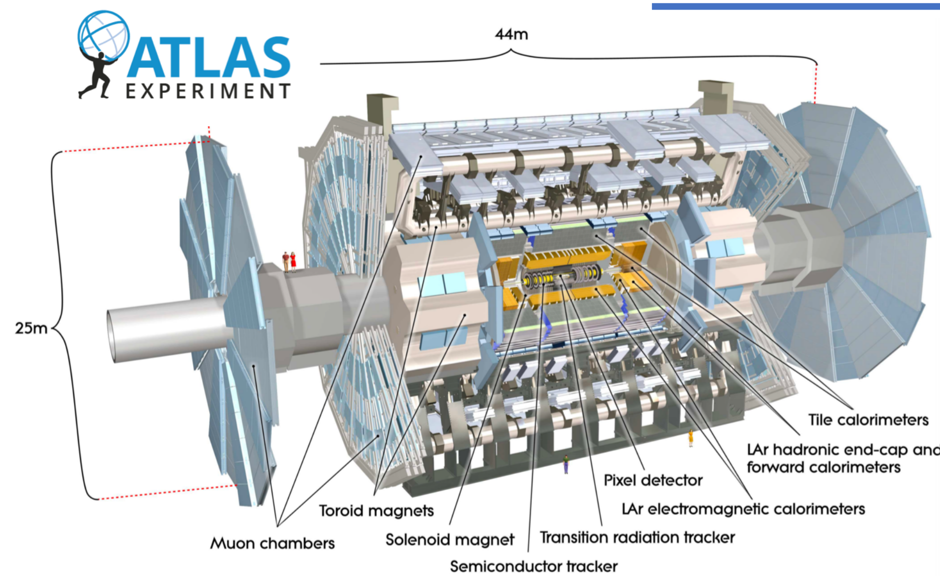
Collider Mode	$\sqrt{s} - \sqrt{s_{NN}}$	
System	Run 1 (2010-2013)	Run2 (2015-2018)
pp	8 TeV 7 TeV 0.9 TeV	13 TeV 5.02 TeV
p-Pb	5.02 TeV	8.16 TeV
Xe Xe		5.44 TeV
Pb-Pb	2.76 TeV	5.02 TeV

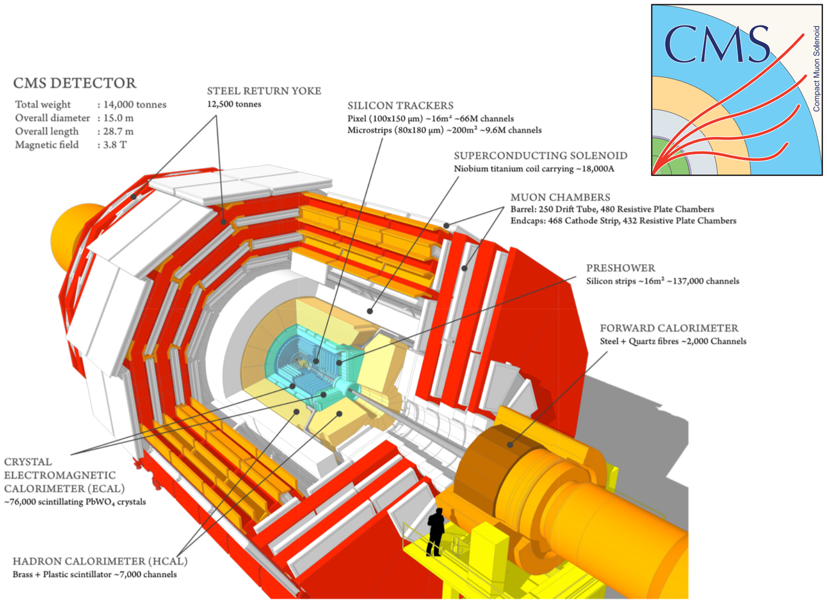
Fixed Target at LHCb

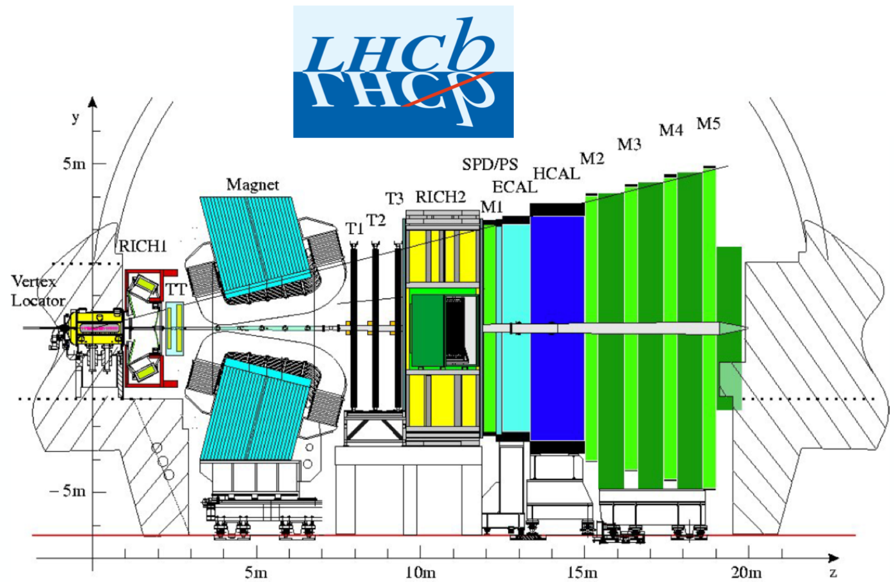


Experiments at LHC









Content

- Recent results on Electroweak measurements
- Recent results on Heavy flavour and Quarkonia
  - Energy loss in medium
  - Collectivity: azimuthal anisotropy
- Recent results on Jets

- Summary and outlook

Electroweak measurements

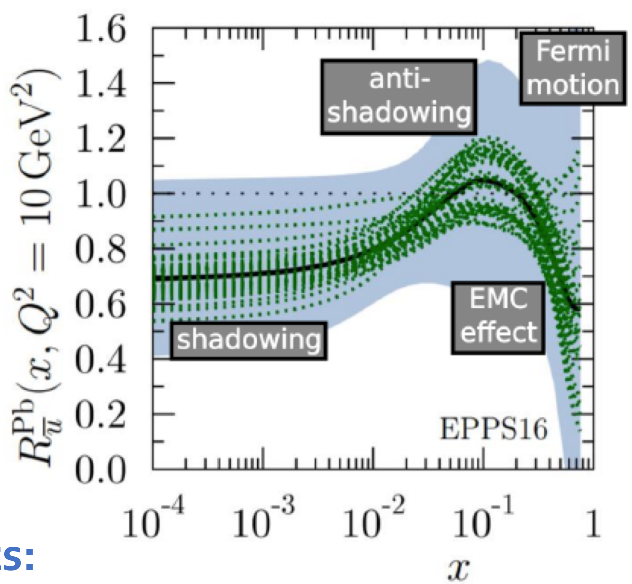
Electroweak Measurements in HIC

W/Z boson productions

- Predominantly via a quark – antiquark pair annihilation : $u\bar{d} \rightarrow W^{+}$, $d\bar{u} \rightarrow W^{-}$, $q\bar{q} \rightarrow Z$
- Sensitive to quark and antiquark content in nucleon / nucleus
- Difference in pp vs p-Pb (Pb-Pb) : nuclear Parton Distribution Function (nPDF)

Prompt direct γ production:

- Predominantly: $qg \rightarrow \gamma q$ and $\bar{q}q \rightarrow \gamma g$
- Constraints on PDF/nPDF



Important to investigate initial condition of the collision.

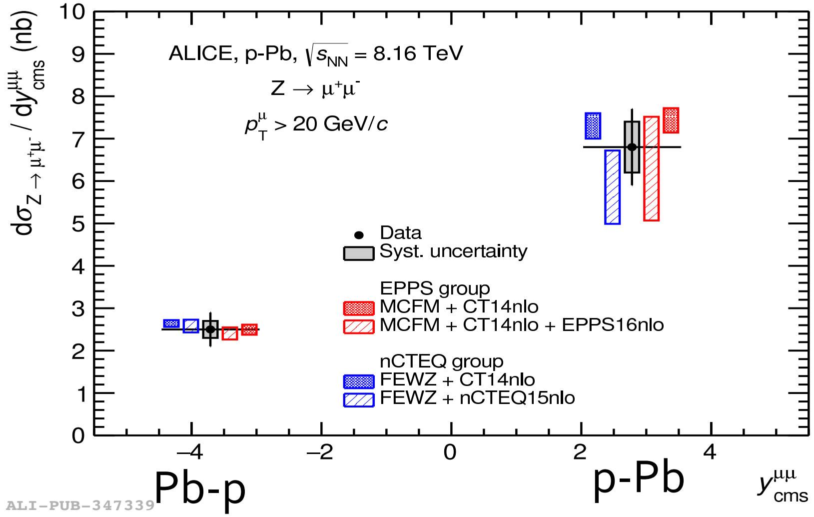
Eur. Phys. J. C 77, 163 (2017)

Z/γ tagged jets:

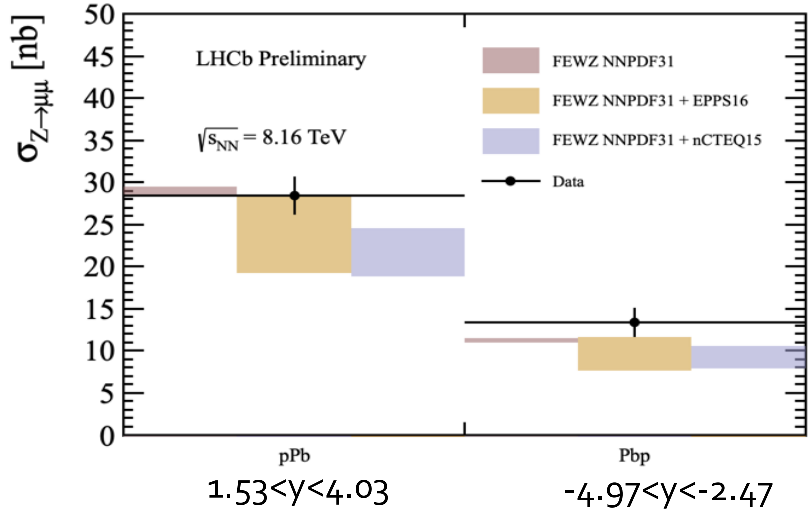
- In Pb-Pb and p-Pb: calibrated probes for Final state effects & Energy loss

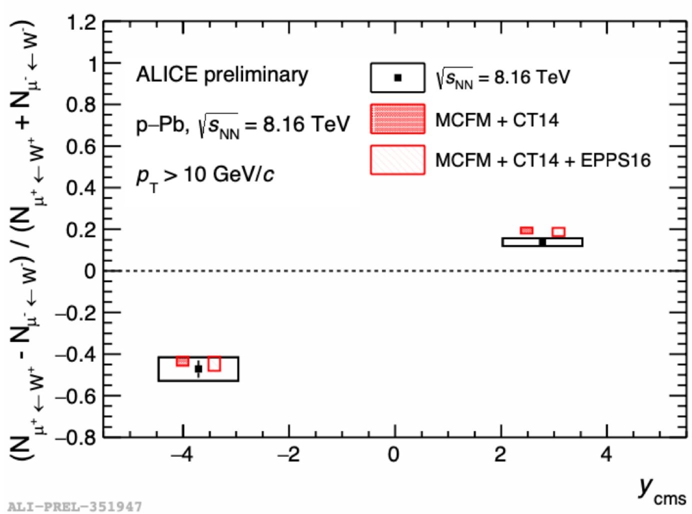
Z,W production in p-Pb at 8.16 TeV

JHEP09(2020)076



LHCb-CONF-2019-003





(x < 10⁻¹) (x ~10⁻³)

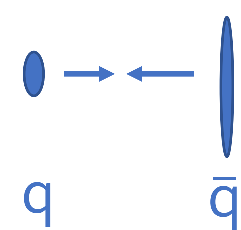
FEWZ: arXiv:1011.3540.
MCFM: EPJC 77 (2017)7
CT14: Phys. Rev. D 93 (2016) 033006
EPS16: EPJC 77 (2017) 163
nCTEQ15: Phys. Rev. D 93, 085037

Model calculations

- Based on QCD
- Including isospin effects
- With/without nPDF

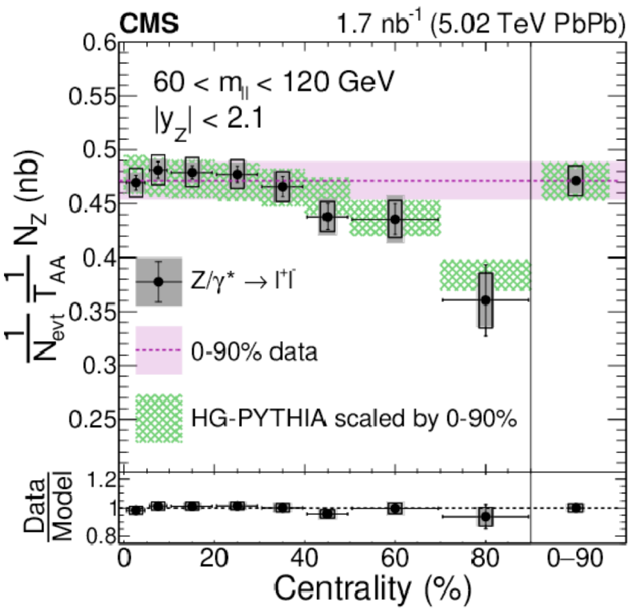
Compatibility of measurements with models

- ➢ charge asymmetry
- $-4.46 < y < -2.96$: $d\bar{u}$ W^- dominant
- $2.03 < y < 3.53$: $u\bar{d}$ W+ dominant



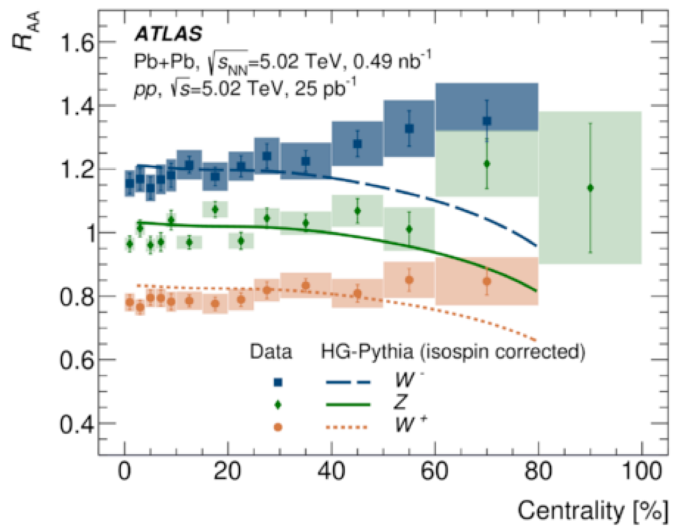
Electroweak W/Z bosons in PbPb

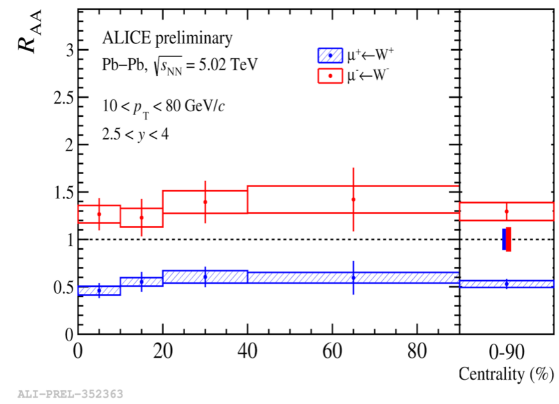
arXiv:2103.14089



Phys. Lett. B 802 (2020) 135262

Eur. Phys. J. C 79 (2019) 935]



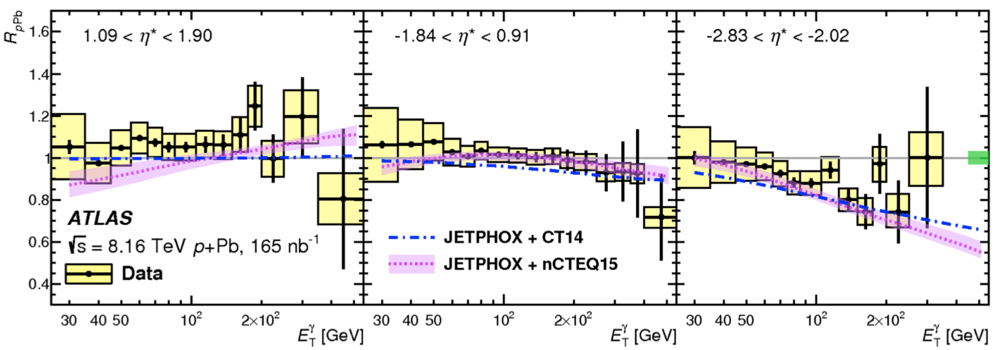


- Indication on no final state effects on W,Z production,
- Consistent with expectation that no modification of boson yield in the QGP
- Decrease in most peripheral events attributed to bias in centrality selection.

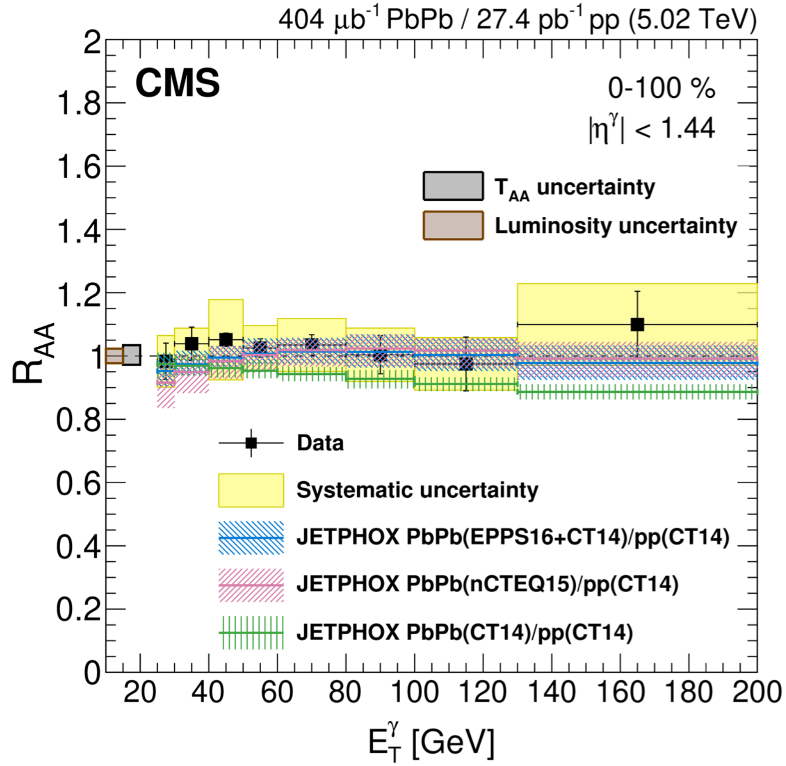
HG-Pythia: arXiv:1412.8393 + JHEP **05**, 026 (2006)

Photon production in p-Pb and Pb-Pb

PLB 796 (2019) 230



JHEP 07 (2020) 116



- Good agreement with predictions
- **Consistent with expectations:** No modification of prompt isolated photon yield in p-Pb and Pb-Pb

JETPHOX: Phys. Rev. D, 73 (2006), 094007
CT14: Phys. Rev. D 93 (2016) 033006
EPS16: EPJC 77 (2017) 163
nCTEQ15: Phys. Rev. D 93, 085037

Heavy Flavour and quarkonia

Heavy Flavour Measurements in HIC

- **Heavy quark** produced by hard-scattering with cross sections calculable with pQCD
  - $m_Q >> \Lambda_{QCD}$: early production controlled baseline calculable via pQCD ($Q^2 >> \Lambda_{QCD}$)
  - $m_Q >> T_{QGP}$: no thermal production
- **Allow to study the quark hadronisation**

QGP properties with heavy quarks:

- **Open Heavy flavour energy loss : R_{AA}**
  - Collisional & radiative
  - Mass hierarchy (dead cone effect)
- **Quarkonia:**
  - Suppression via colour screening
  - QGP temperature

Hadronisation & Recombination Mechanisms

- Charm vs beauty relative abundances
- In medium hadronization
- In jet heavy hadron fragmentation

Nuclear modification Factor

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

R_{AA}=1 in case of binary scaling (incoherent superposition of nucleon nucleon collisions)

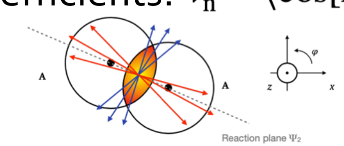
Heavy quark diffusion properties:

Azimuthal anisotropies

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{i=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]\right\}$$

Flow harmonic coefficients: $v_n = \langle \cos[n(\varphi - \Psi_n)] \rangle$

Elliptic flow: v_2



Heavy Flavour and quarkonia

Energy loss

Mass hierarchy energy loss in pp

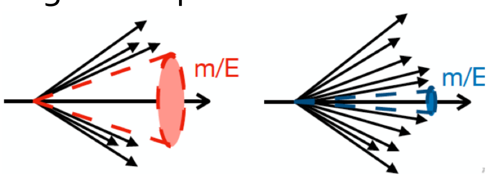
Dead cone effect:

Radiation suppressed in vacuum and in medium for $\theta < m/E_{radiator}$

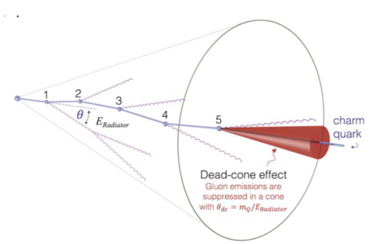
arXiv:2106.05713

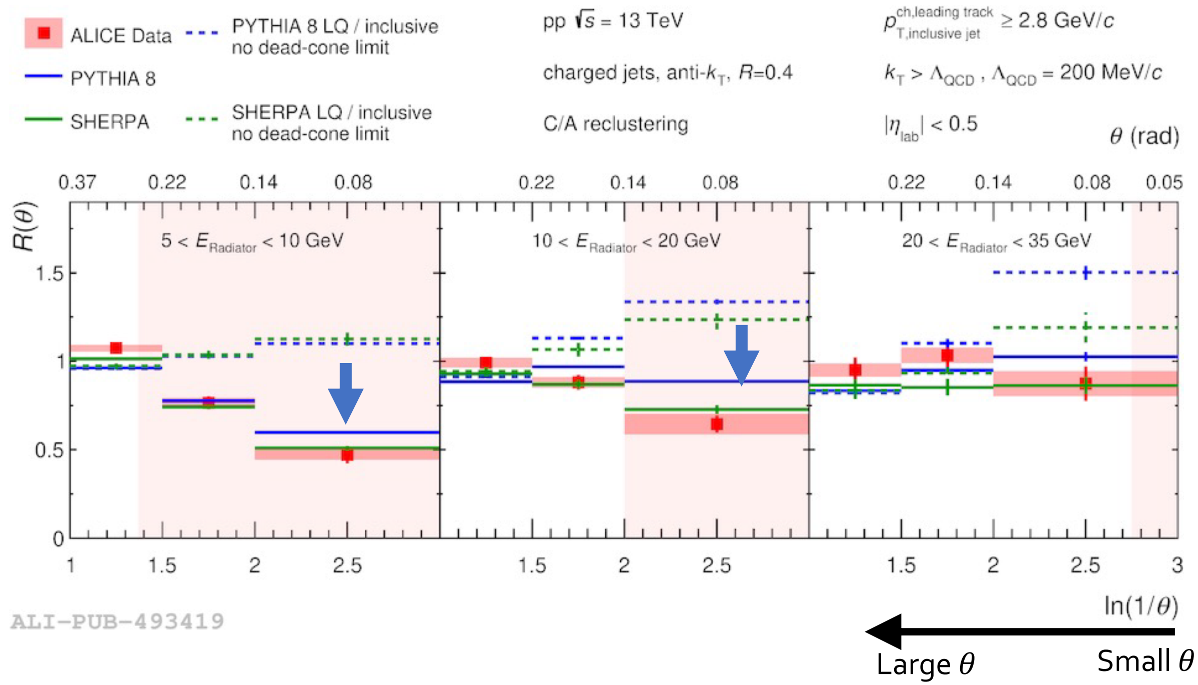
D⁰ tagged jets / inclusive jets

High mass partons   Low mass partons



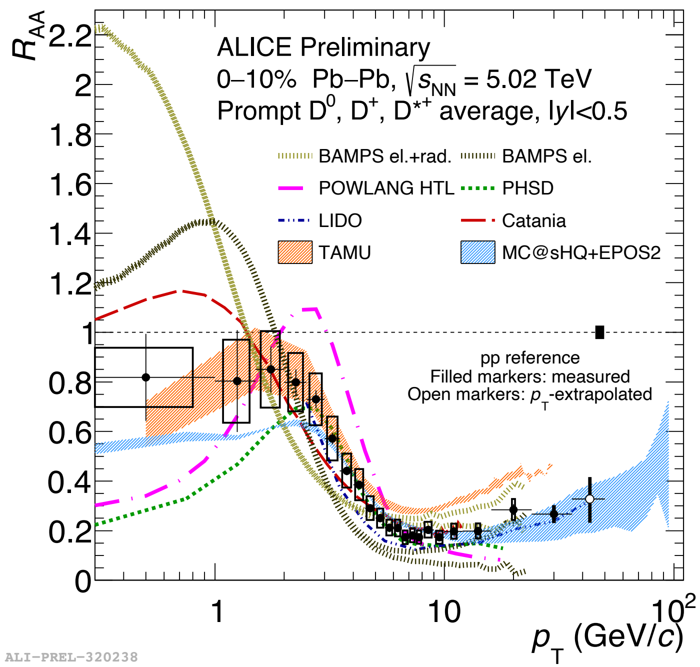
$$R(\theta) = \frac{1}{N^{D^0\,\text{jets}}} \frac{dn^{D^0\,\text{jets}}}{d\ln(1/\theta)} \Big/ \frac{1}{N^{\text{inclusive jets}}} \frac{dn^{\text{inclusive jets}}}{d\ln(1/\theta)} \Bigg|_{k_T, E_{\text{Radiator}}}$$



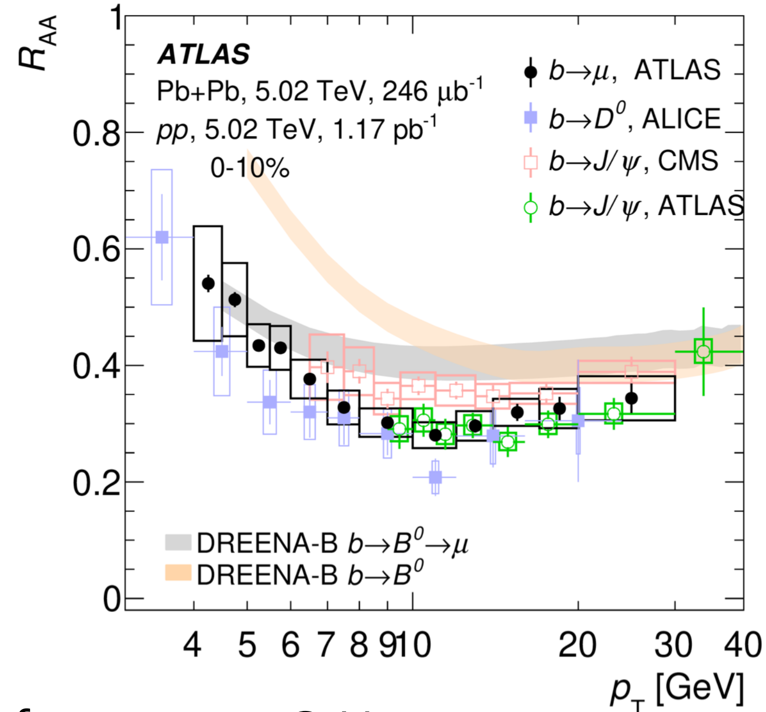


- ➢ First direct observation of dead cone effect
- ➢ Suppression of radiation in D⁰ tagged jets toward low angles

Charm and beauty energy loss in Pb-Pb



ATLAS: arXiv 2109.00411
CMS: b→J/ψ: EPJ. C 78 (2018) 509
ALICE b →D0: JHEP 10 (2018) 174

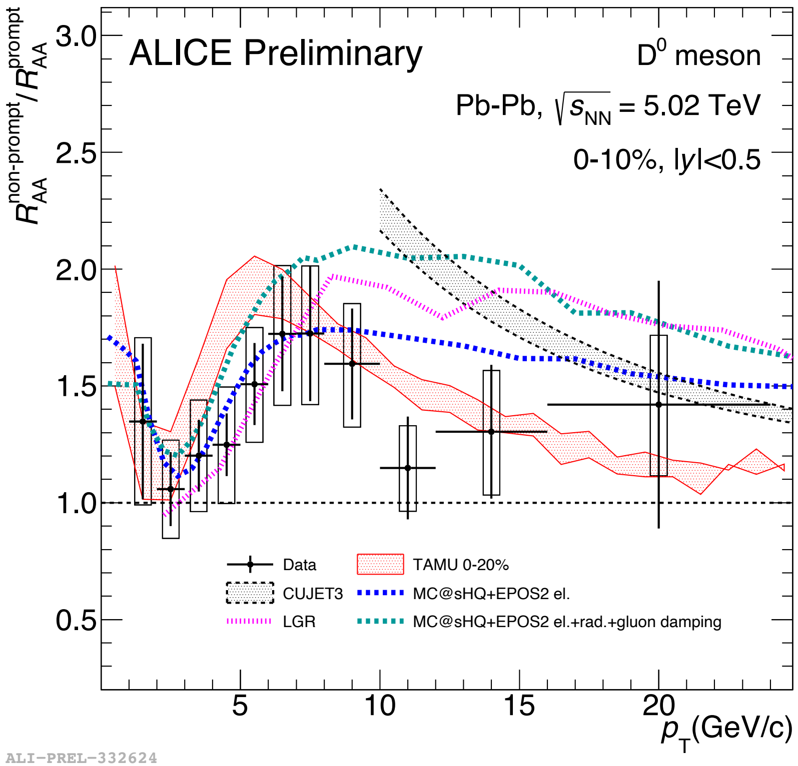


- ❑ Charm and beauty loose energy
- ❑ Charm suppression measured in a wide range, from 0 to 100 GeV
- ❑ First measurement of prompt D0 down to p_T = 0 GeV/c

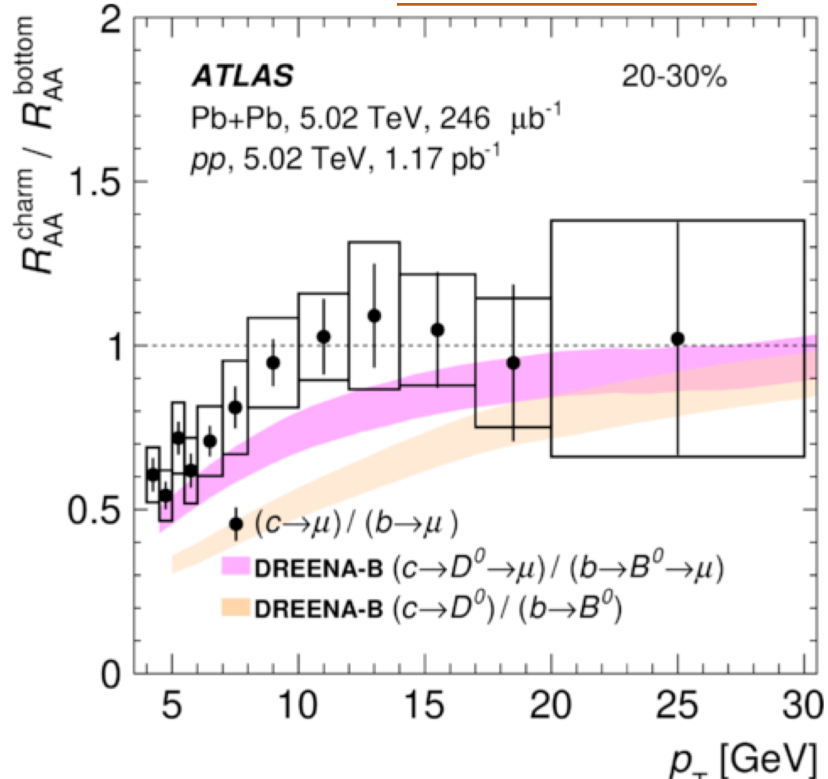
DAMPS: *J. Phys. G* 42 (2015) 11, 115106
LIDO: PRC 98(2018)064901

PHSD: PRC 92 014910 (2015)
TAMU: PLB 735 445-450 (2014)
Catania: EPJC 78 348 (2018)
POWLANG: JHEP 03 (2016) 123
MC@sHQ+EPOS: PRC 89, 014905 (2014)

Charm vs beauty energy loss



ArXiv 2109.00411



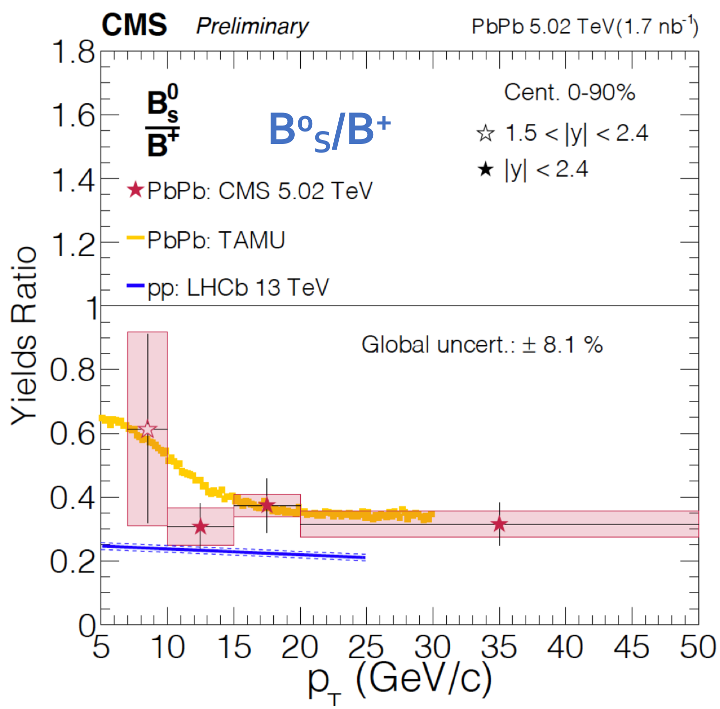
- ❑ R_{AA} non prompt > R_{AA} prompt
  Low p_T depletion: charm quark coalescence
- ❑ R_{AA} beauty > R_{AA} charm for intermediate p_T
  - ➢ Hint of **$\Delta E_b < \Delta E_c$** : dead cone effect
    gluon radiation suppressed at small angles θ < m/E

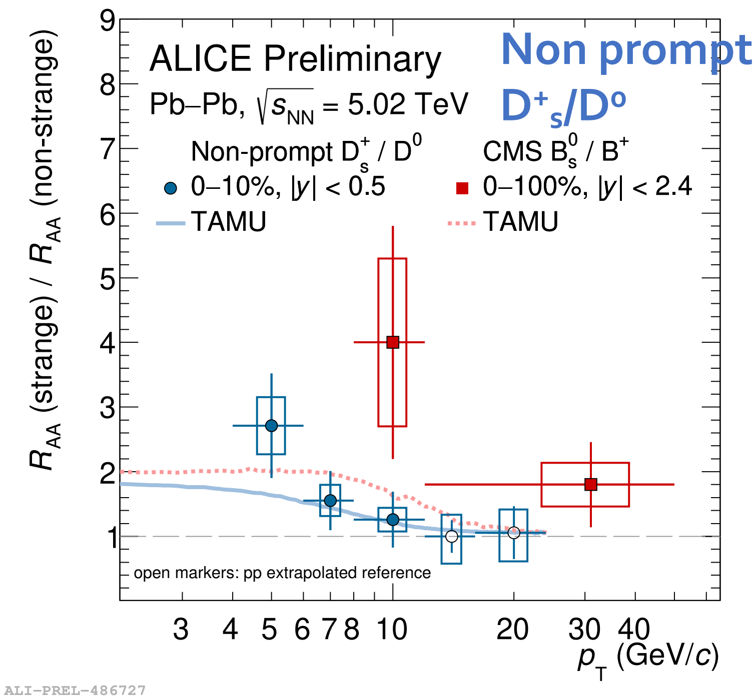
MC@sHQ+EPOS: PRC 89, 014905 (2014)
TAMU: PLB 735 (2014) 445-450
CUJET3: Chin.Phys.C 43, (2019) 044101
LGR: EPJC 80 (2020) 1113
DREENA-B: arXiv:1805.04786:

Open heavy flavour with strangeness: Beauty

CMS-PAS-HIN-19-011

CMS: PLB 796 (2019) 168



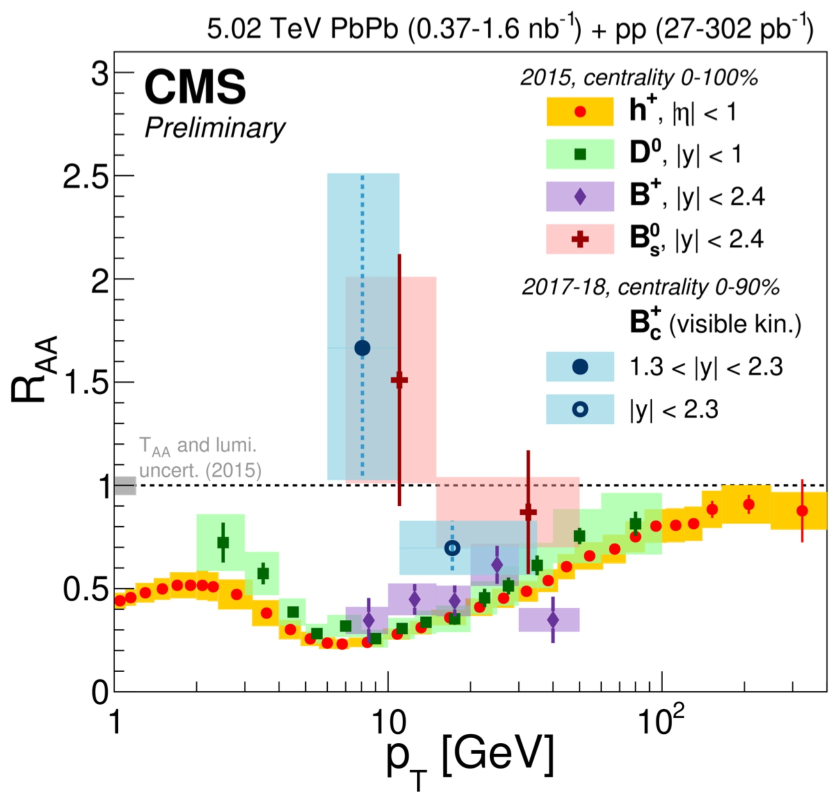


- $R_{AA}(D_s^+)/R_{AA}(D^o)$ ratio for non-prompt larger than one at low p_T
  - about 50% of non prompt D_s^+ mesons originate from B_s^o meson decays
    - B_s^o production expected by beauty hadronisation via coalescence
- Larger $R_{AA}(B_s^o)/R_{AA}(B^+)$ ratio wrt non-prompt D
  - D_s^+ from non-strange B-meson decays
  - B to D decay kinematics
- TAMU model (including supression and regeneration) describes the observed trend

TAMU: PLB 735 (2014)445

Open heavy flavour with strangeness/charm: Beauty

CMS-PAS-HIN-20-004



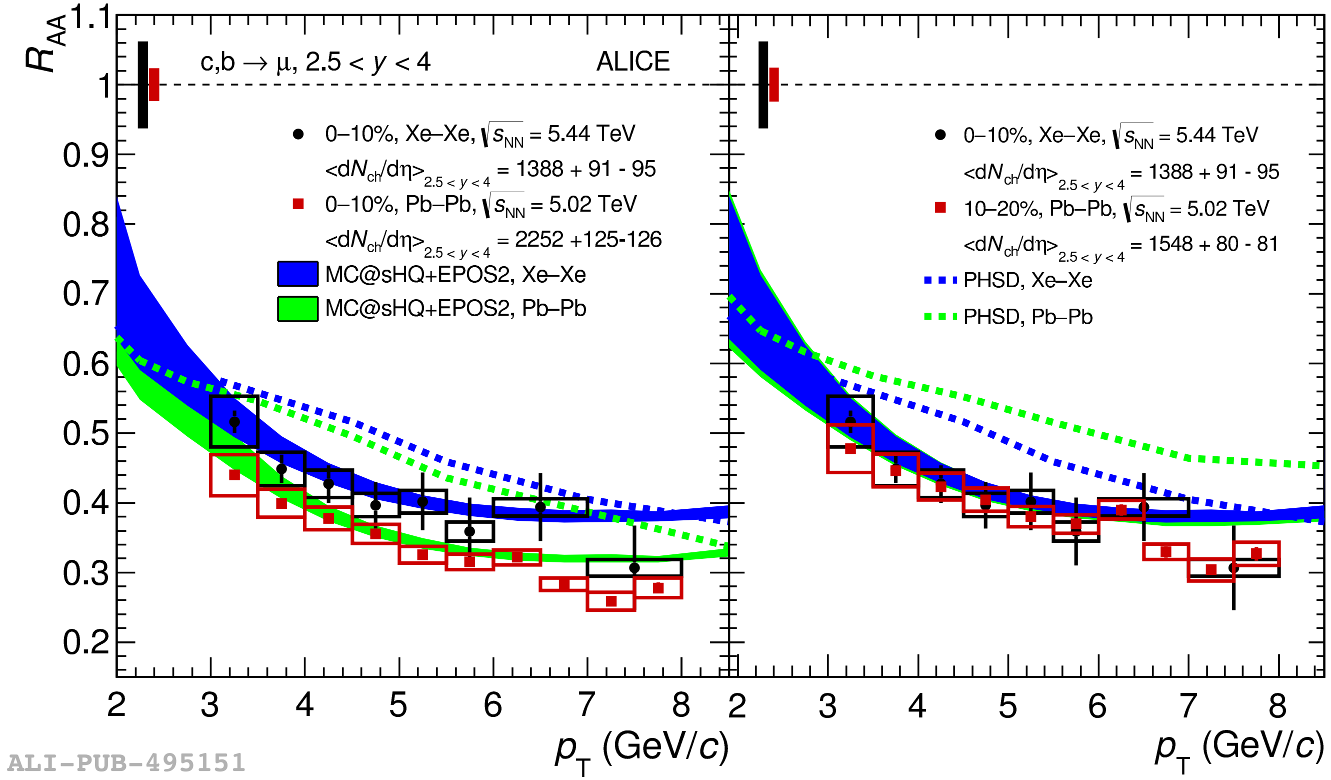
Beauty measured in several states by several detectors

Sensiblity of Bs' to hadronization mechanism

Eloss hierarchy at low/moderate p_T and convergence at high p_T

System size dependence of Heavy Flavor muons

PLB 819 (2021) 136437



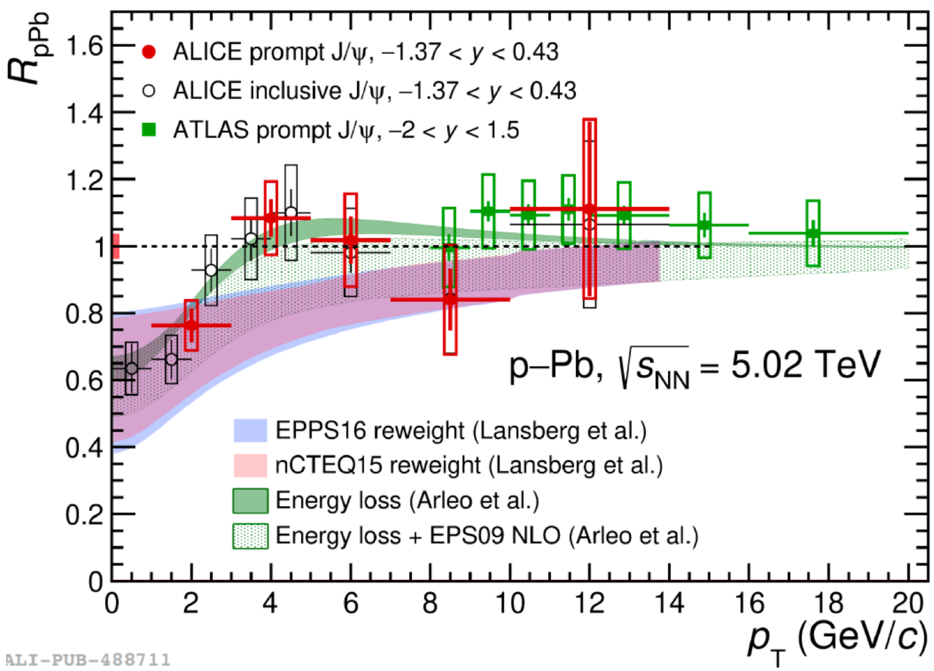
MC@sHQ+EPOS:
PRC 89, 014905 (2014)
PHSD:
PRC 93, 034906 (2016)

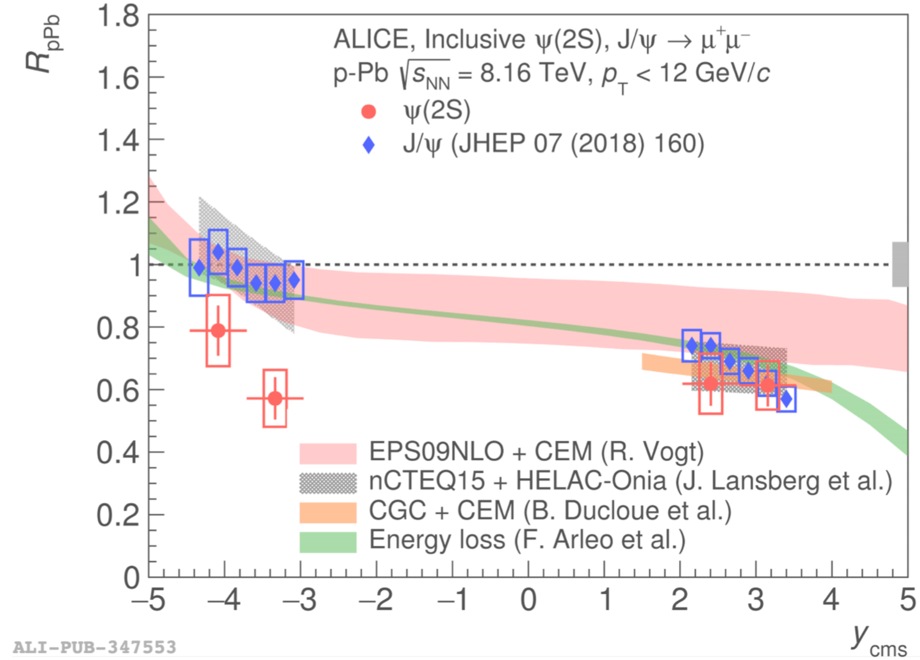
- Similar RAA for HF μ in Pb-Pb and Xe-Xe at similar $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$
- Results well described by models with collisional+ radiative energy loss

Charmonia measurements in p-Pb

ALICE: arXiv:2105.04957
ATLAS: Eur. Phys. J C78(2018)171
LHCb: J. High Energ. Phys. 02 (2014) 072

JHEP 02 (2021) 002



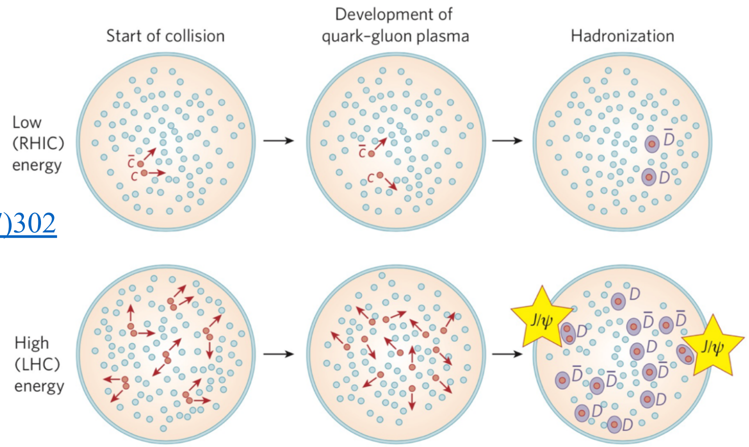


Lansberg et al: EPJC77(2017)1
Energy loss Arleo et al. : JHEP(2013)155
EPS09+CEM: Phys. Rev. C 87, 054910
CGC+CEM: Phys. Rev. D 91, 114005
Helac-OniaarXiv.1212.5293

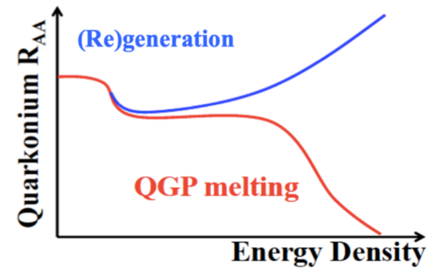
J/ψ and $\psi(2S)$ in pPb

suppression at low p_T in p-Pb, described by models, with modified nuclear PDFs and also including energy loss

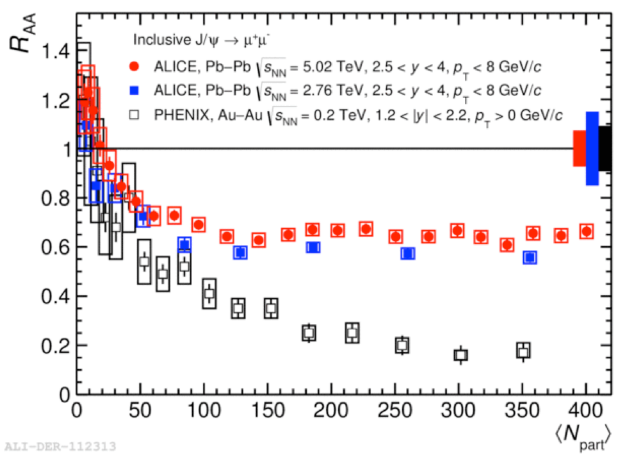
Charmonia in Pb-Pb

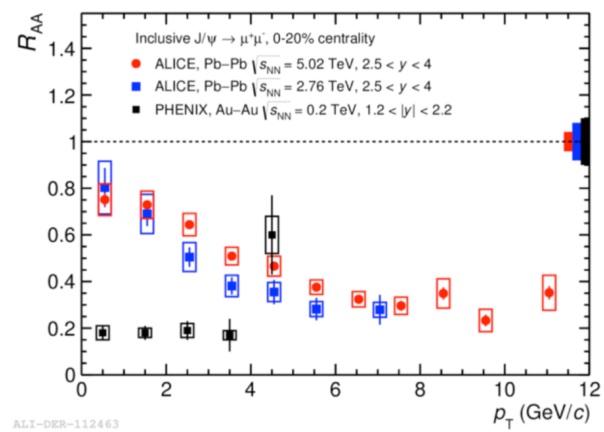


Nature 448(2007)302



ALICE: Phys. Lett. B 766 (2017) 212-224
PHENIX: Phys. Rev. C84(2011)054912

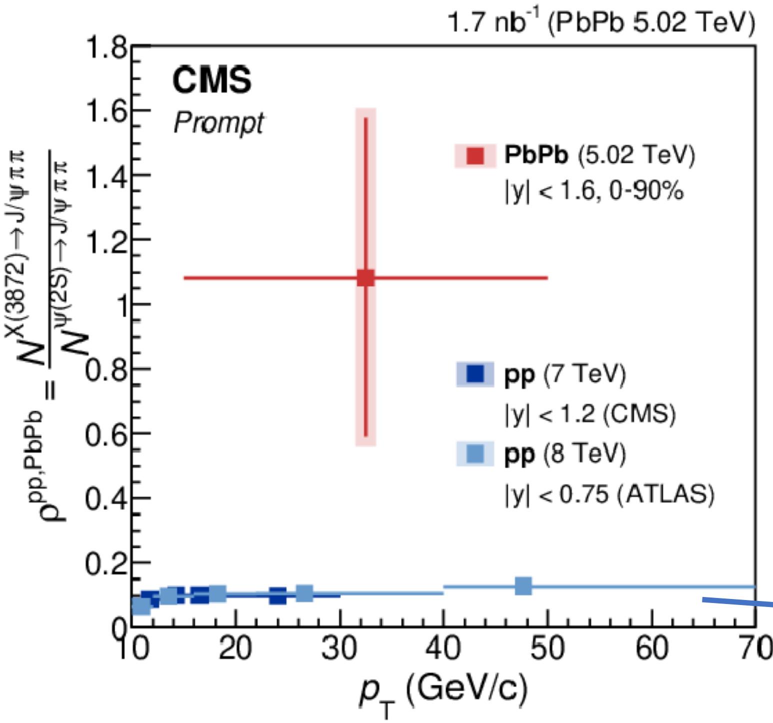


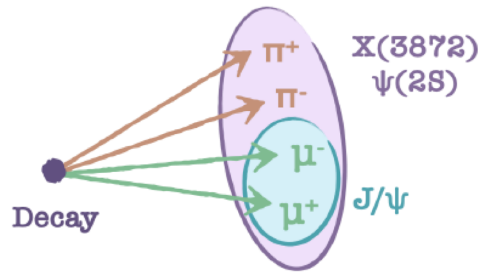


Important contribution from regeneration at LHC

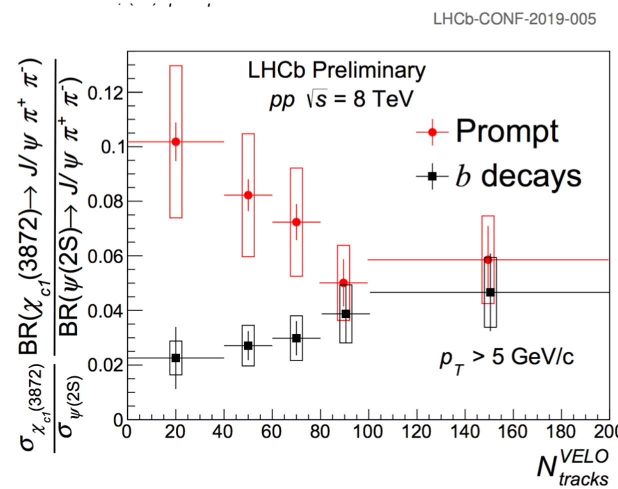
X(3872) in PbPb

arXiv:2102.13048





LHCb-conf-2019-005



measured by LHCb in different y range

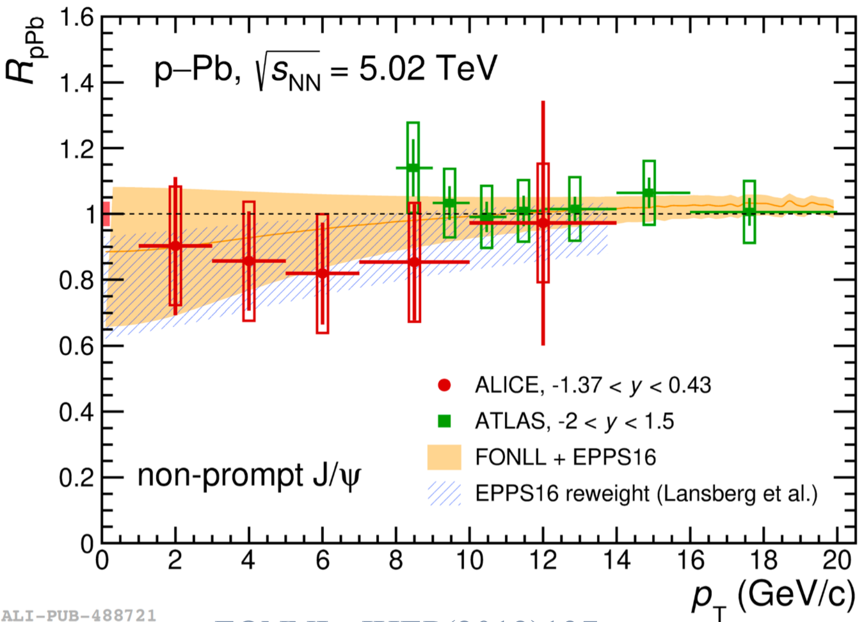
X to ψ(2s) ratio

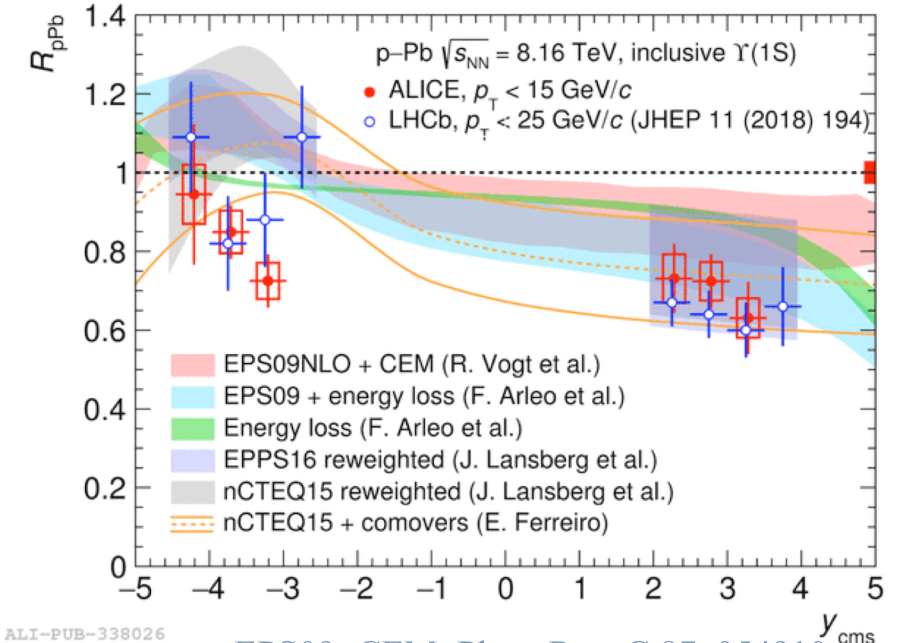
- pp: X(3872) suppressed more than ψ(2S) at both mid and forward rapidities
- PbPb: Hint of reduced suppression for X compared to ψ(2s)

Bottomonium in small system

ALICE: arXiv:2105.04957
ATLAS: Eur. Phys. J C78(2018)171

ALICE: PLB806(2020)135486
LHCb: JHEP11(2018)194





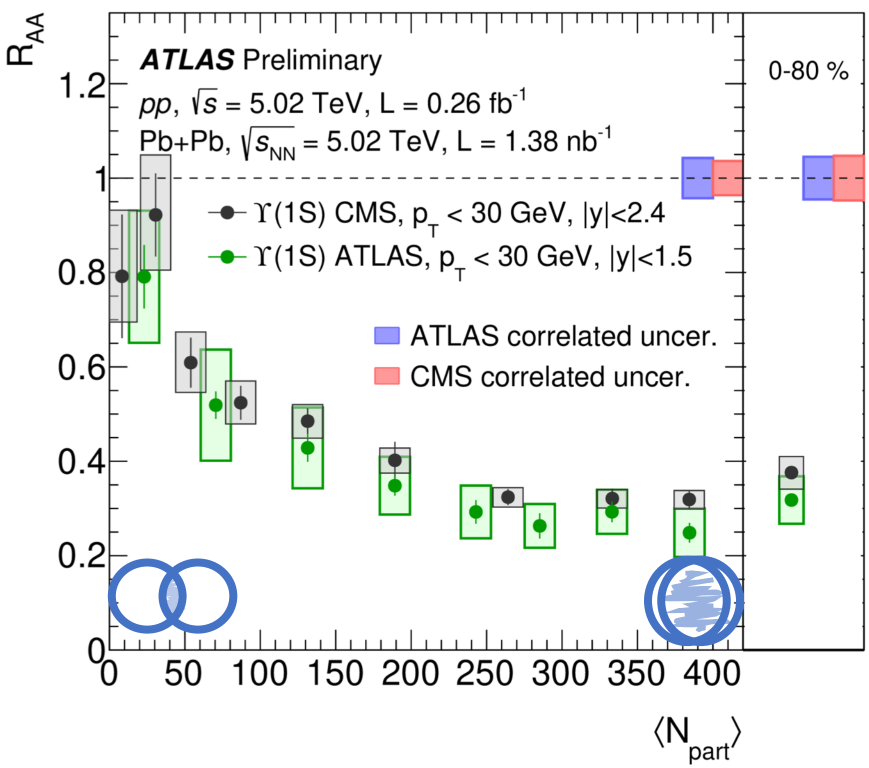
FONNL: JHEP(2012)137
Lansberg et al: EPJC77(2017)1
Energy loss Arleo et al. : JHEP(2013)155

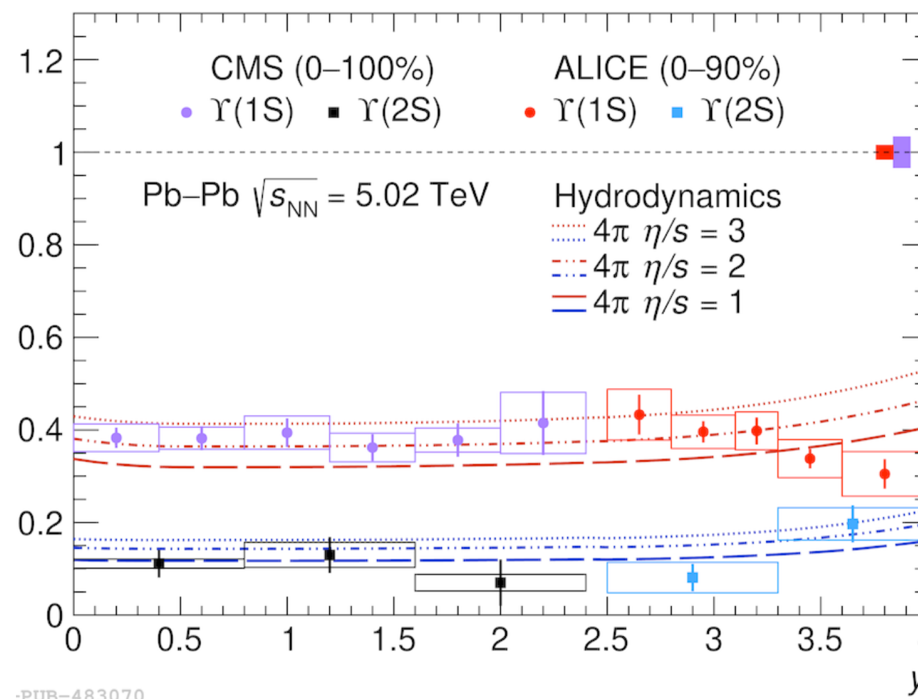
EPS09+CEM: Phys. Rev. C 87, 054910
CGC+CEM: Phys. Rev. D 91, 114005
Helac-OniaarXiv.1212.5293
Comovers: arXiv:1804.04474

- Agreement and complementarity within the different experiments
- Data in agreement with mild degree of suppression as described by FONLL
- Fair description of R_{PPb} at forward rapidities by models including nuclear shadowing, energy loss or interaction with comovers while overestimation at backward.

Bottomonium Υ(1S), Υ(2S) in Pb –Pb

CMS: Phys. Lett. B, 790 (2019)270-293
ALICE: arXiV: 2011.05758
ATLAS: ATLAS-CONF-2019-054





Hydro arXiv: 1605.03561

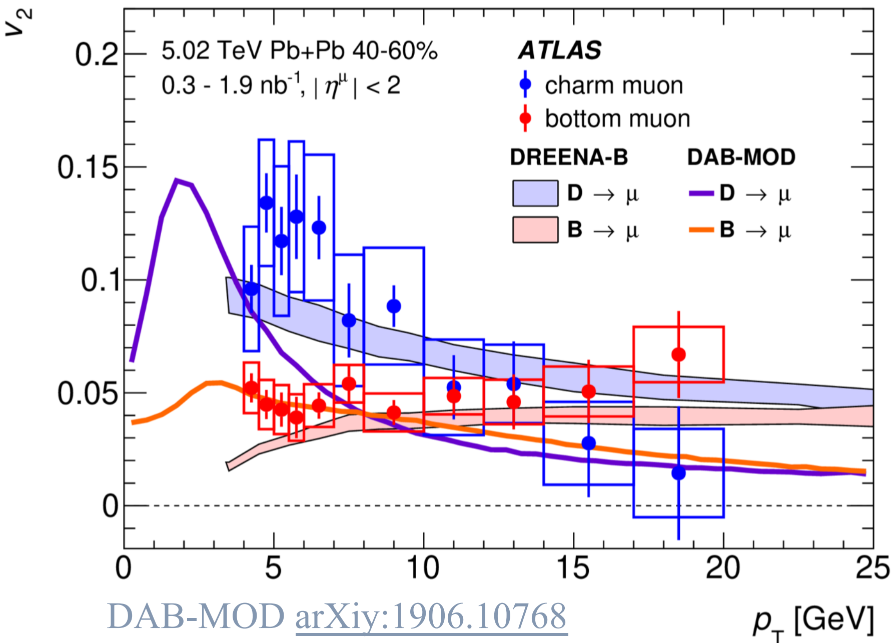
- Consistent and complementary results within LHC experiments
- Υ(1S) at most forward rapidities at the limit of the models
- Sequential suppression observed R_{AA}(Υ(1S))>R_{AA} (Υ(2S))

Heavy Flavour and quarkonia

Azimuthal anisotropy: elliptic flow

Charm and beauty elliptic flow

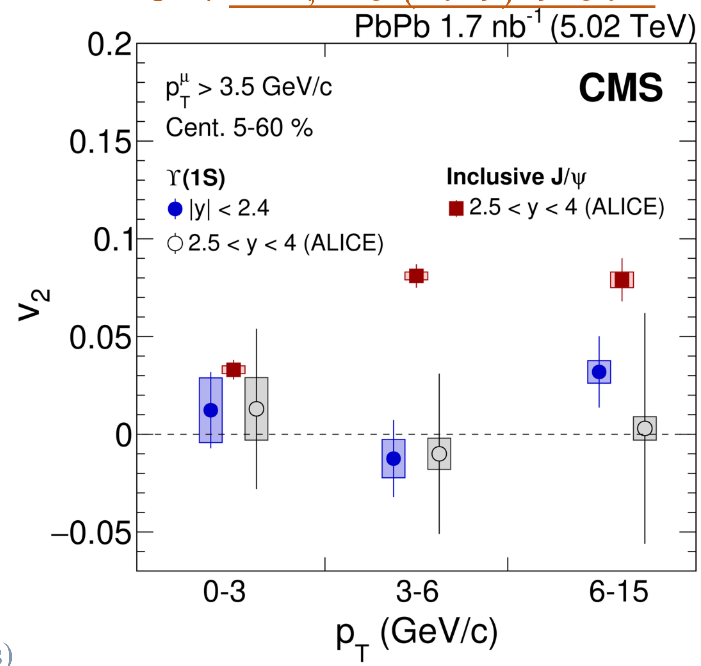
ATLAS: PLB 807(2020)135595



DAB-MOD arXiy:1906.10768
(2D+1 viscous hydrodynamic expansion with event-by-event fluctuations)

DREENA-B arXiv:1805.04786
(dynamic energy loss in 1+1D expanding QCD medium)

CMS: PLB 819 (2021) 136385
ALICE: PRL, 123 (2019)192301

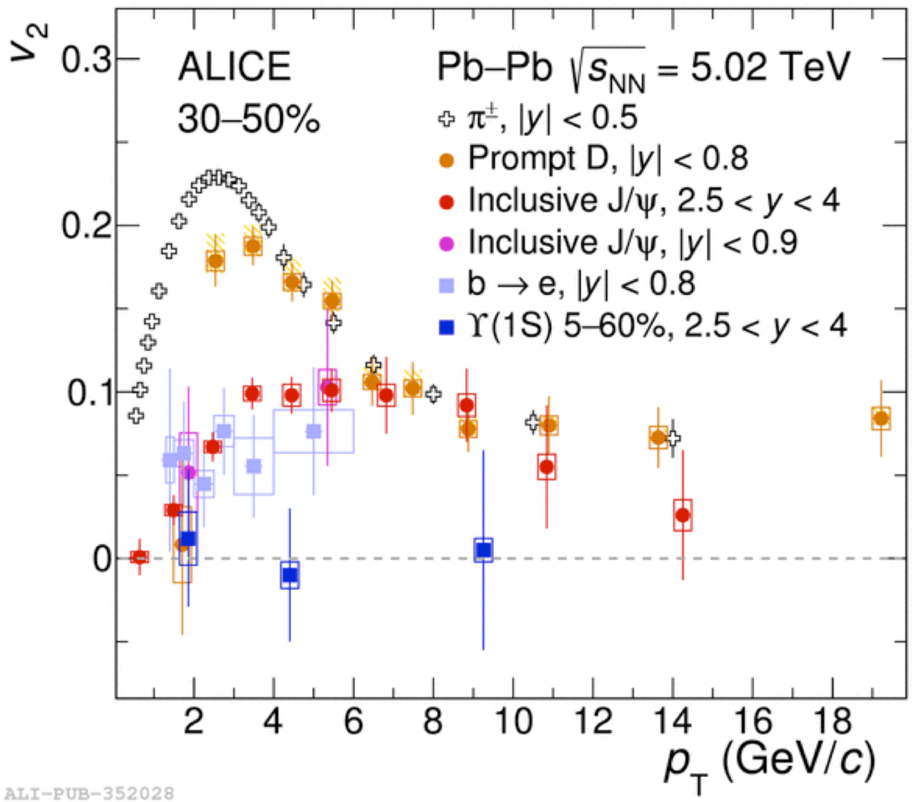


v2(charm) > v2(open beauty) > v2(hidden beauty)~0

Beauty smaller than charm flow but non zero
Different medium effect for charmonia and bottomonia

Heavy flavour elliptic flow

J/ψ: JHEP 10 (2020) 141
b→e: Phys. Rev. Lett. 126 (2021) 162001
Υ: Phys. Rev. Lett. 123, 192301 (2019)
Prompt D: JHEP 02 (2019) 150
π: JHEP09(2018)006



p_T < 3 GeV/c

➢ v2(J/ψ) < v2(D) < v2(π)
consistent with hydrodynamics

3 < p_T < 6 GeV/c

➢ v_2(J/ψ) < v_2(D) ~ v_2(π)
heavy quark hadronization via coalescence with flowing light quark

p_T > 6-8 GeV/c

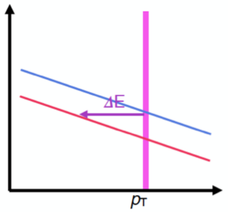
➢ v_2(J/ ψ) ~ v_2(D) ~ v_2(π)
Similar path-length energy loss for heavy and light quark

No flow for Υ: expected from smaller regeneration contribution

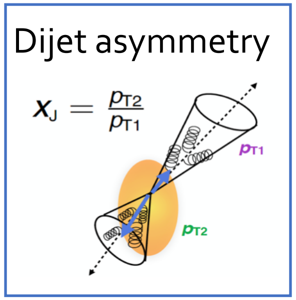
Jet and high p_T hadrons

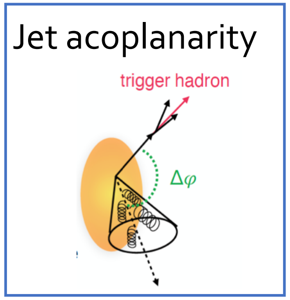
Jet and high p_T in heavy ion collisions

Jet quenching: parton interact with the medium



- Suppression of high p_T particle yield
- Jet energy loss: **suppression of high p_T jet yield**

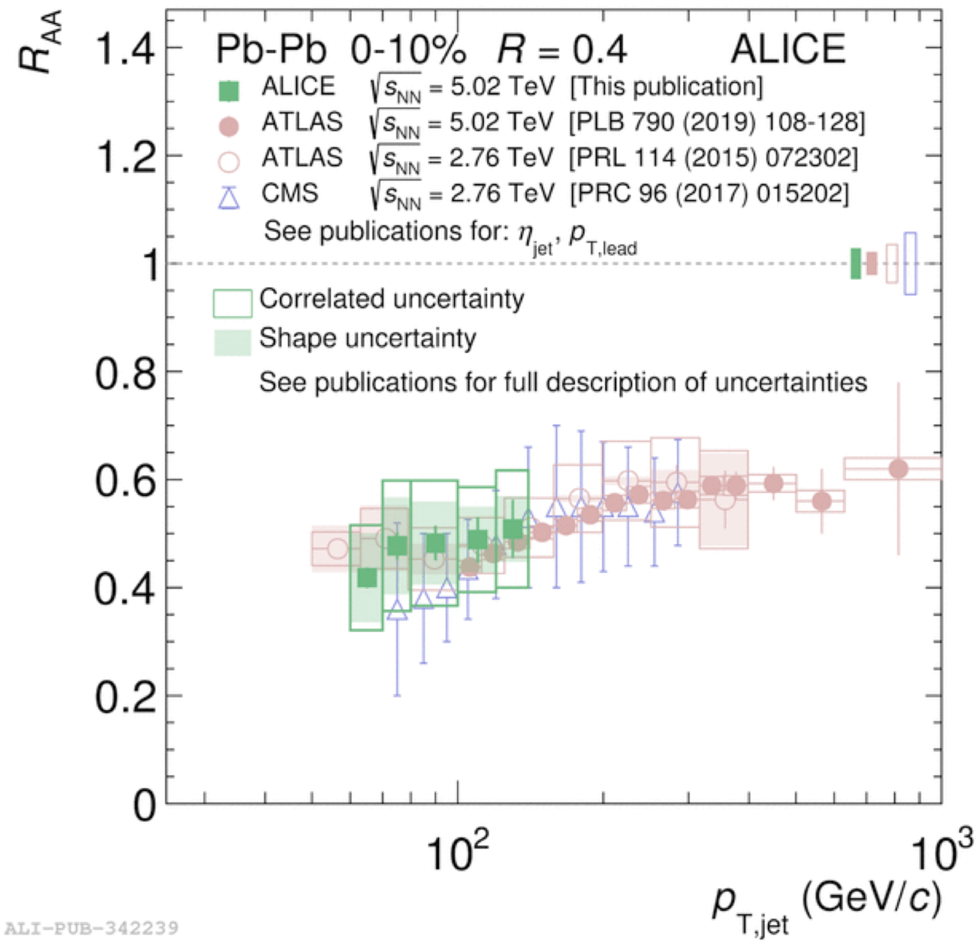




- Jet sub-structure modifications:
  - angular deflection and path length dependence through jet correlation
  - Intra-jet modifications (jet structure/substructure)

- Depends on the path travelled in medium
- Flavour dependence

Jet suppression at LHC

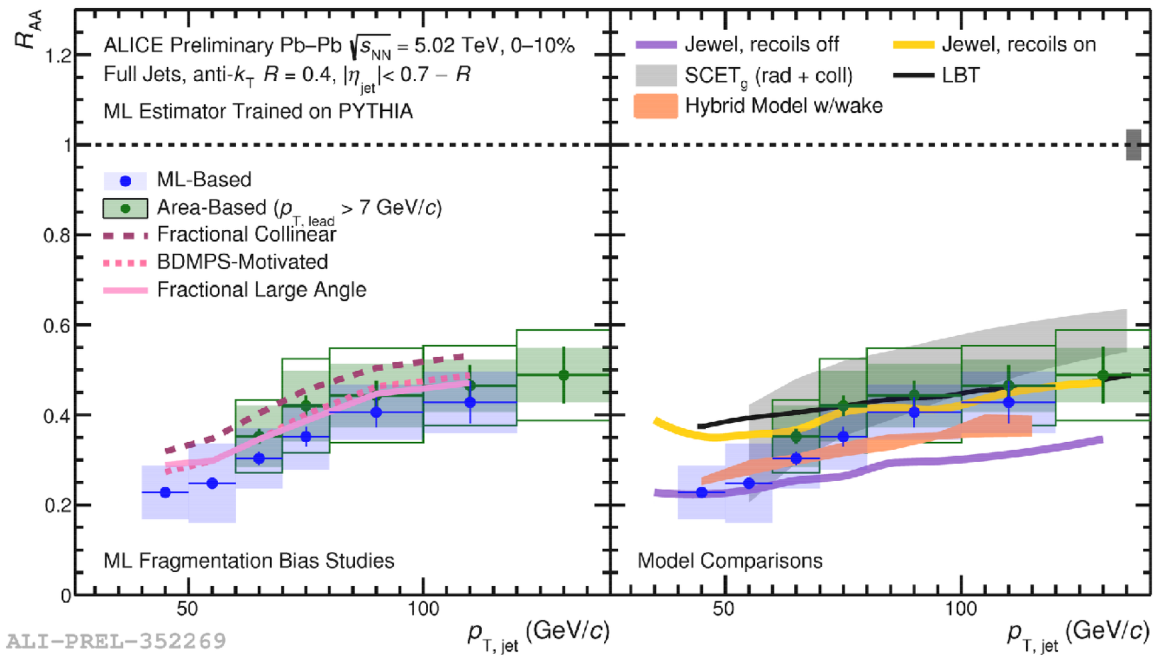


ALICE @ 5.02 TeV Phys. Rev. C 101 (2020) 034911
ATLAS: 5.02 TeV: PLB790(2019)108
ATLAS @ 2.76 TeV: PRL114(2015)072302
CMS @ 2.76 TeV: PRC96(2017)015202

- Jet are quenched
- Complementarity of experiments at LHC
- Suppression independent of Collision Energy

Jet suppression at low p_T

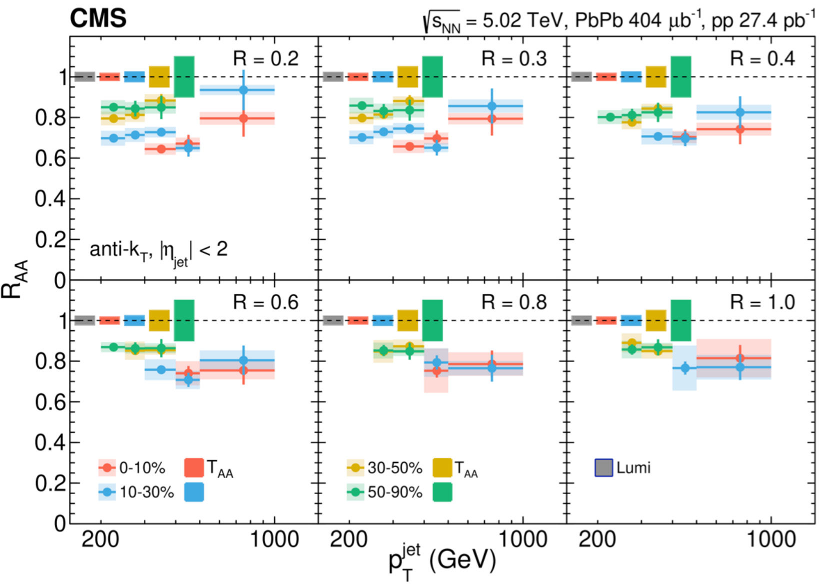
- Machine Learning (ML) background estimator
  Phys. Rev. C 99, 064904 (2019)
- ML allow to extend down to p_T 40 GeV/c
- ML based and area based methods consistent (fragmentation bias explored)
- New contraints for models at low p_T



JEWEL: arXiV: 1311.0048
SCETG:PRD 80 (2009) 054022
Hybrid Model: PRL 124 (2020) 052301
LBT: PRC 99 (2019) 054911

Jet suppression at high p_T: R dependence

CMS JHEP 05 (2021) 28

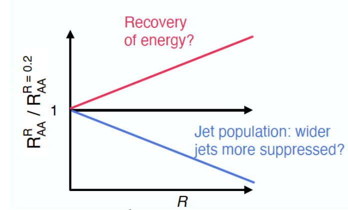


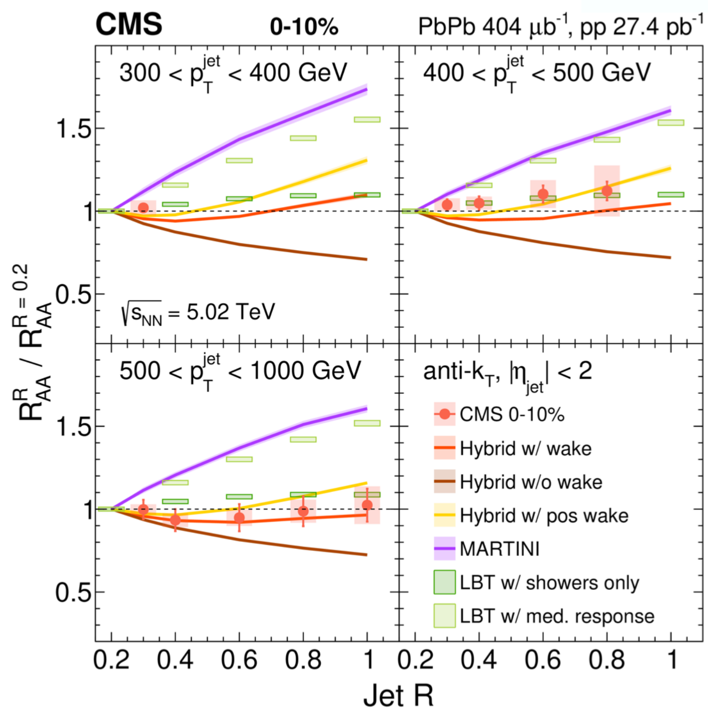
Suppression at large R observed

MARTINI: Phys. Rev. C 80 (2009) 054913
Hybrid: PRL124 (2020)052301
LBT: Phys. Rev. C 99 (2019) 054911

Large R:

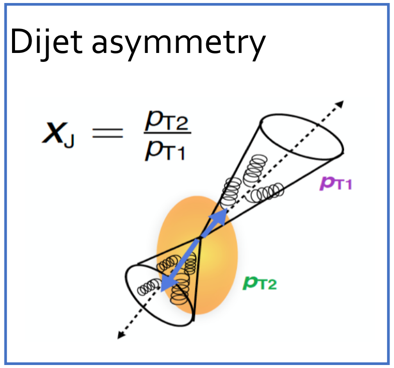
- ❑ Recovery of out of cone radiation ?
- ❑ Difference in modification for larger jets?

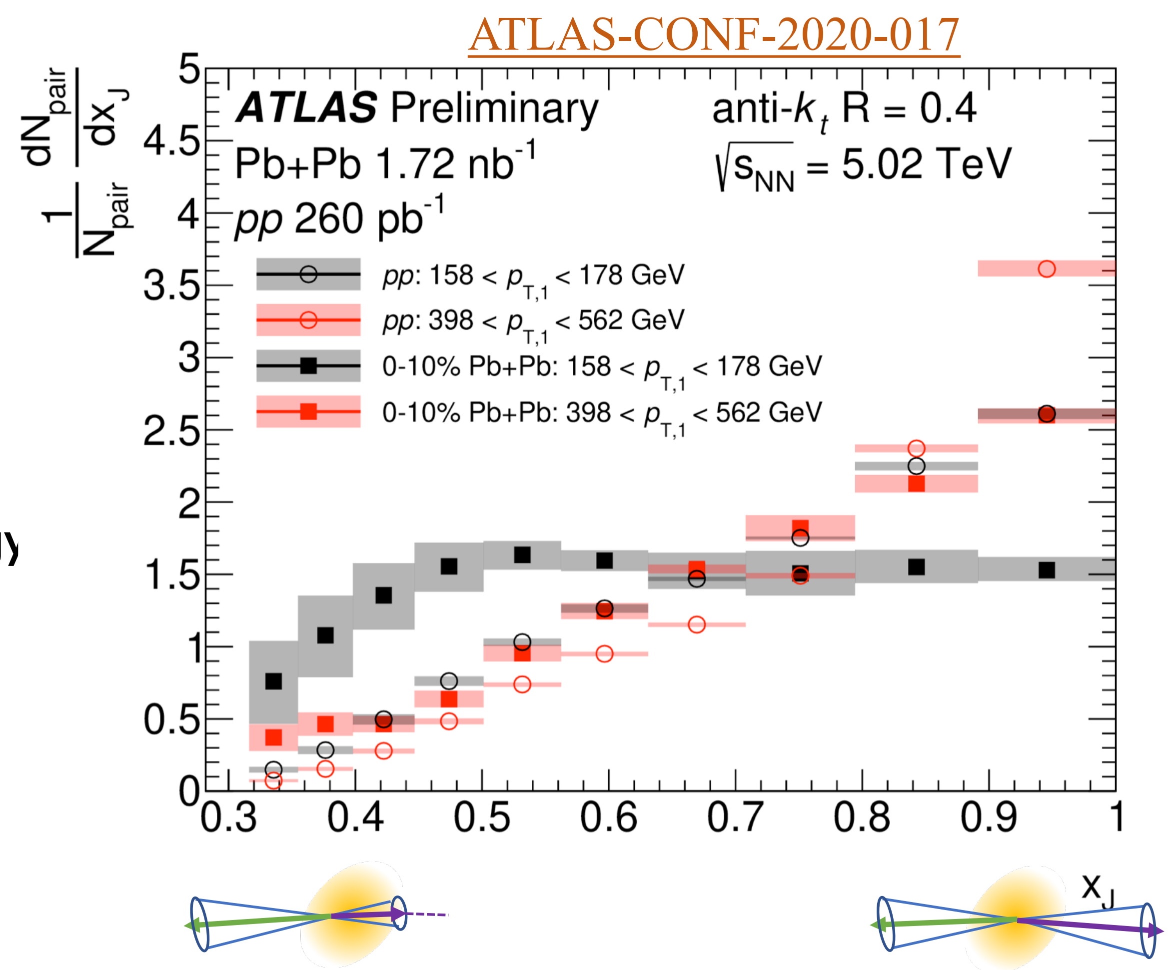




- ➢ **No R dependence seen.**
- ➢ **Strong discrimination of models**

Jet correlations : Dijet asymmetry



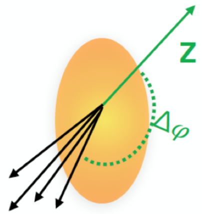


The 2 jets loose different energy

- ➢ **travel different path**
- ➢ **jet-by jet fluctuations of energy loss**

- ➢ **Low p_T dijets:**
  - ➢ Significant asymmetry for Pb-Pb
  - ➢ Large difference between pp and Pb-Pb
- ➢ **High p_T:**
  - ➢ Less difference between pp and Pb-Pb: same amount of Energy loss?

Z- tagged particles

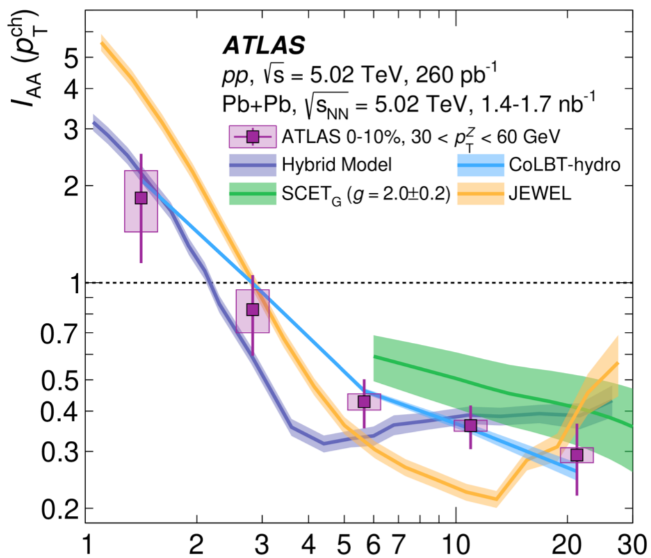


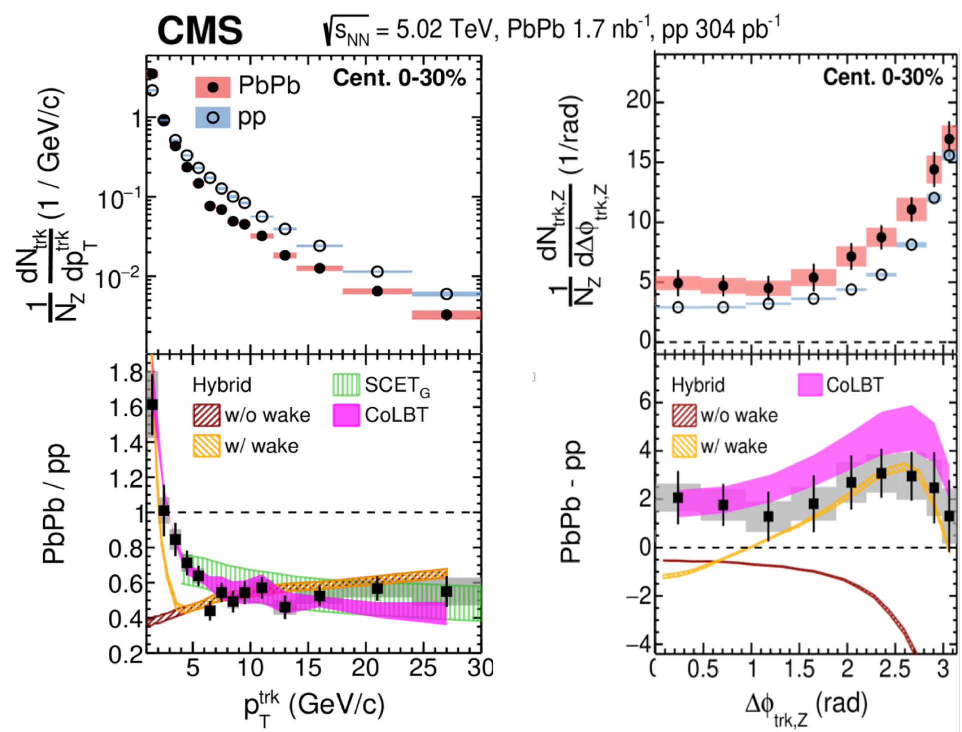
Boson-jet dominated by quark jets.
Boson tag provide initial jet momentum
Z-tag: lower momentum than photon-tag (less background)

Phys. Rev. Lett. 126 (2021) 072301

arXiv:2103.04377

I_{AA}= recoil charged particle yield in PbPb /pp





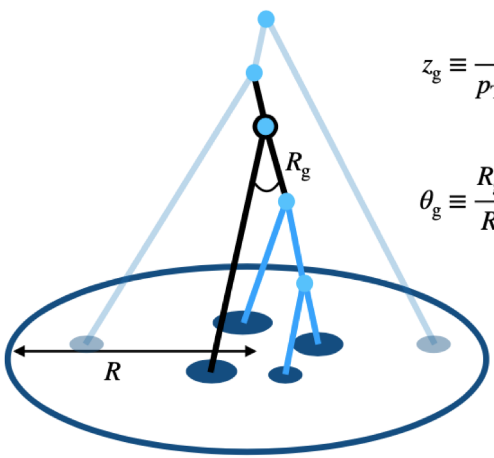
STET$_G$: Phys. Rev. D 93,(2016)074030
Hybrid: JHEP03(2016)053
ColBT-hydro: Phys. Lett. B 777, 86(2018).
JEWEL: EPJC 76, 695 (2016)

- ➢ Enhancement of soft particles similar in photon-jet and inclusive jet
- ➢ Excess of charged particles at all $\Delta\varphi$: medium or MPI ? (away side expected from momentum broadening)

Jet Splitting: R_g

Remove soft wide angle radiation in order to access hard parton splitting inside jet.
In HI
- does the medium modifies hard sub structure of jet ?
- Does jet loose energy coherently?

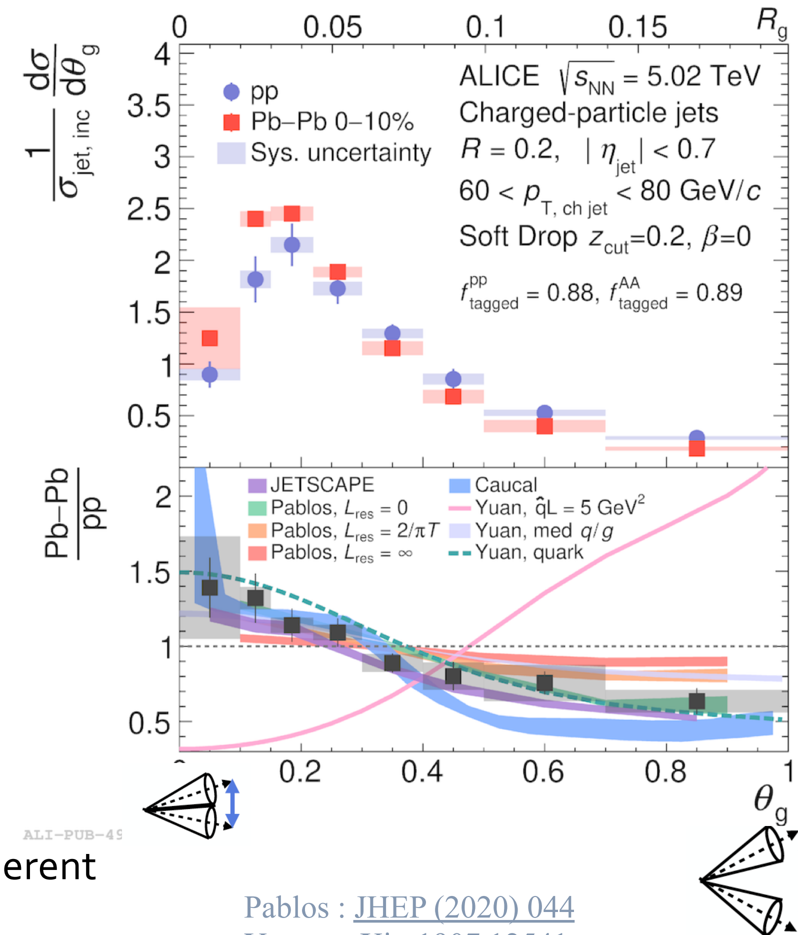
arXiv:2107.12984



$$z_g \equiv \frac{p_{T,\mathrm{subleading}}}{p_{T,\mathrm{leading}} + p_{T,\mathrm{subleading}}}$$

$$\theta_g \equiv \frac{R_g}{R} \equiv \frac{\sqrt{\Delta y^2 + \Delta\varphi^2}}{R}$$

Soft Drop grooming algorithm
JHEP. 05 (2014)146
z cut = 0.1, β= 0: Only splittings where the subleading prong carries at least 10% of the combined transverse momentum are accepted.



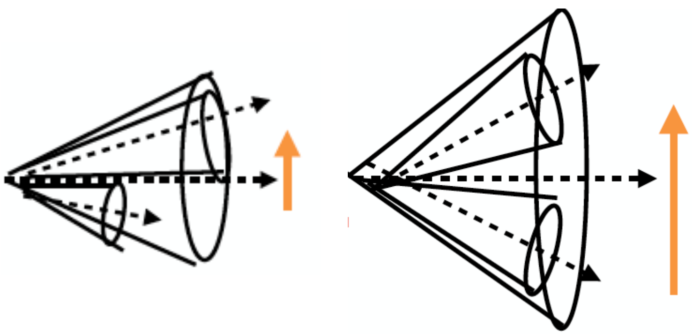
- ➢ **Narrower θ_g in Pb-Pb**
- Sensitive to role of colour coherence
- described by models with incoherent Eloss or coherent Eloss with large quark jet fraction

Pablos : JHEP (2020) 044
Yuan: arXiv:1907.12541
Jetscape: arXiv:1903.0770
Caucal: J.HEP 10 (2019) 273.

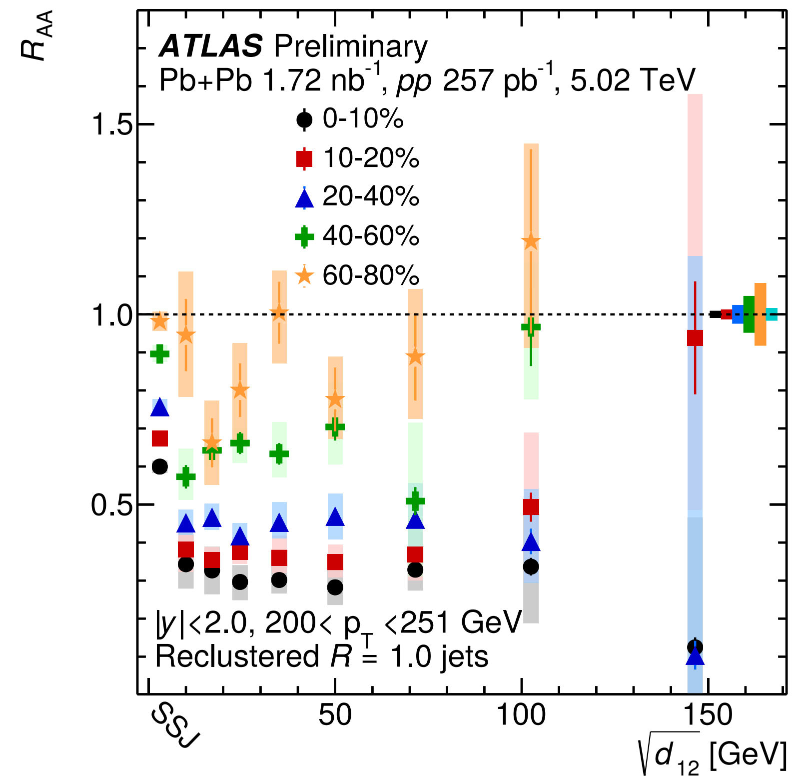
Jet Splitting: large R

ATLAS-CONF-2019-056

Combining *R*=0.2 into *R*=1.0 jets removes energy radiated between subjets



$$\sqrt{d_{12}} = p_{T2}\Delta R_{12}$$



$\sqrt{d_{12}}$ is evaluated from the last clustering step in the k_T jet finding algorithm, corresponding to the hardest splitting in the jet. It characterizes the jet substructure scale.

- ➢ Jet with a substructure more suppressed than jets without (Single sub Jet (SSJ))

Summary: Hard probes in HI collisions

Initial state and cold nuclear effects:

- New precise measurements of **electroweak bosons** W/Z/γ will constrain the nPDF and indicates no modification in medium.
- **Heavy flavours**: charm and beauty production well described by models including nPDF and energy loss in nuclear matter or comovers.

Energy loss and medium modification:

Heavy flavour & quarkonia

- Intermediate p_T R_{AA}(beauty)>R_{AA}(strange)>R_{AA}(charm)~R_{AA}(light)
    - Hint of strange enhancement
- High p_T: R_{AA}(beauty)~R_{AA}(charm)~R_{AA}(light)
- Sequential suppression observed for bottomonium
- **Dead cone effect directly observed** using D-tagged jets in *pp*

Jet quenching:

- Many new results on jet quenching and **new observables** to explore **jet substructure** and in medium modification

Collectivity:

- Non-zero open-beauty v_2 in Pb+Pb collisions
- Hidden beauty v_2 consistent with zero
- Low-p_T flavor hierarchy in Pb+Pb collisions v_2(light) > v_2(charm) > v_2(beauty)

Conclusions & Perspectives

- ➢ Many new measurements of hard probe for QGP characterisation
- ➢ Complementarity between experiments

........**But still needs of precision**

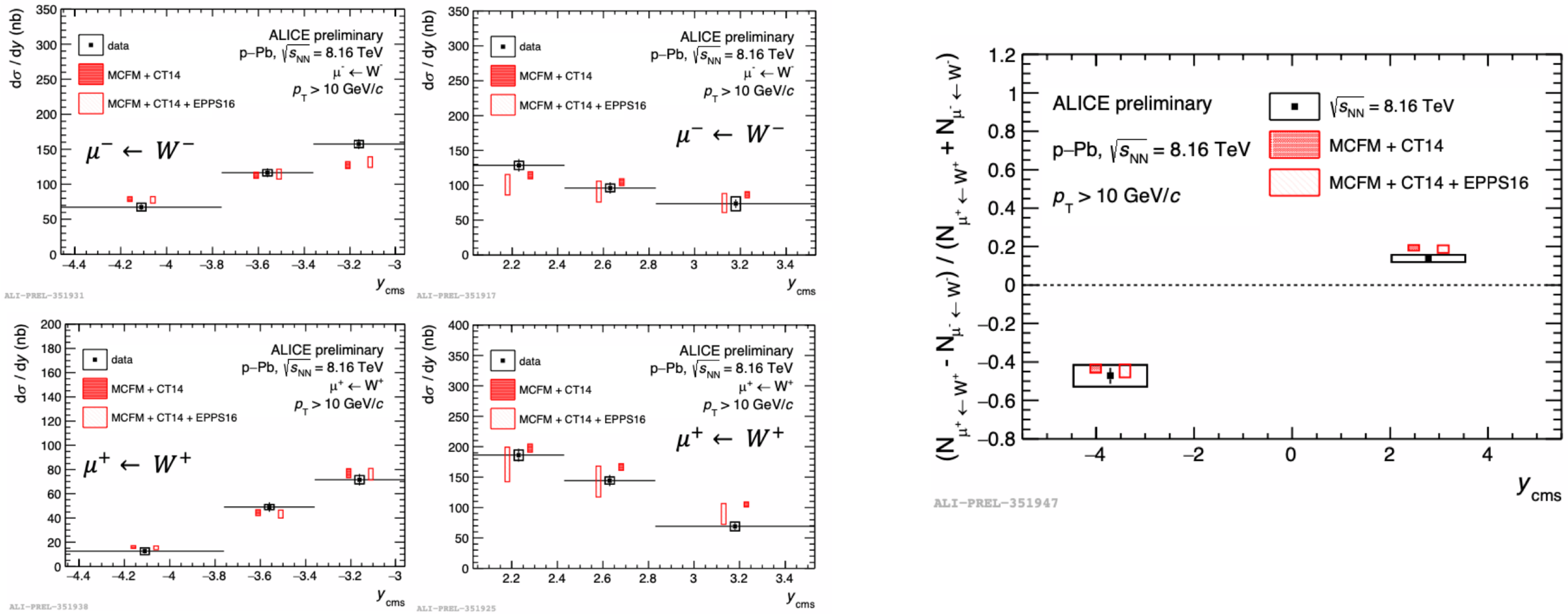
RUN3 will be provide higher statistics, higher precision measurements, access to differential measurements and rarer probes.

Many upgrades of the ALICE & LHCb for Run3 and CMS/ATLAS for Run4

Heavy ion publications:
- ALICE
- ATLAS
- CMS
- LHCb

Backup

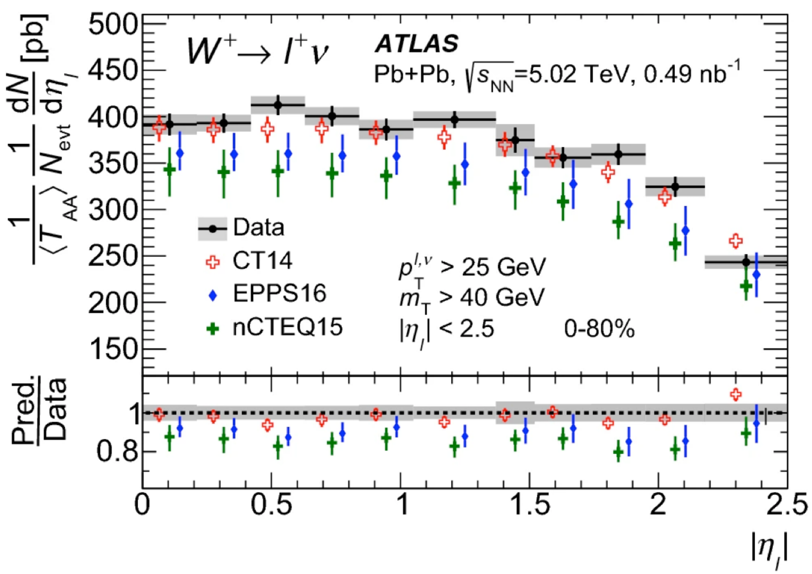
$W^\pm$ in p-Pb at 8.16 TeV: cross sections

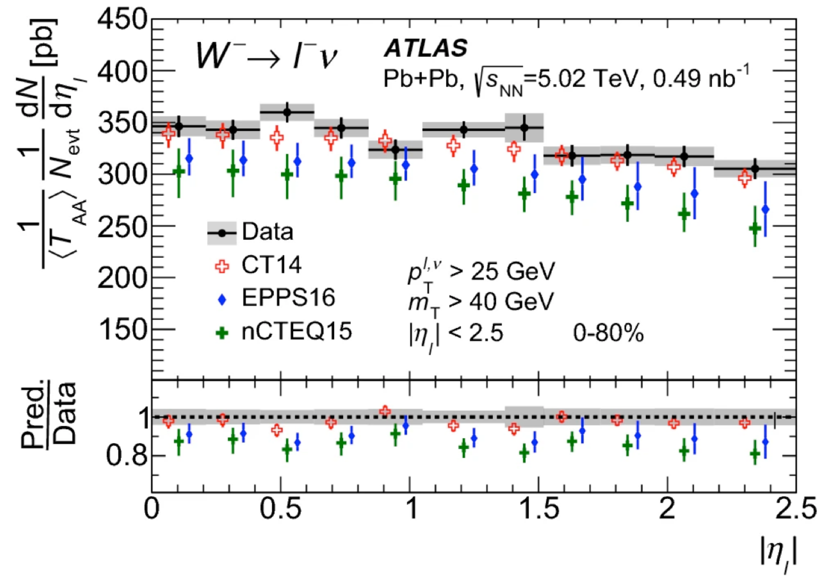


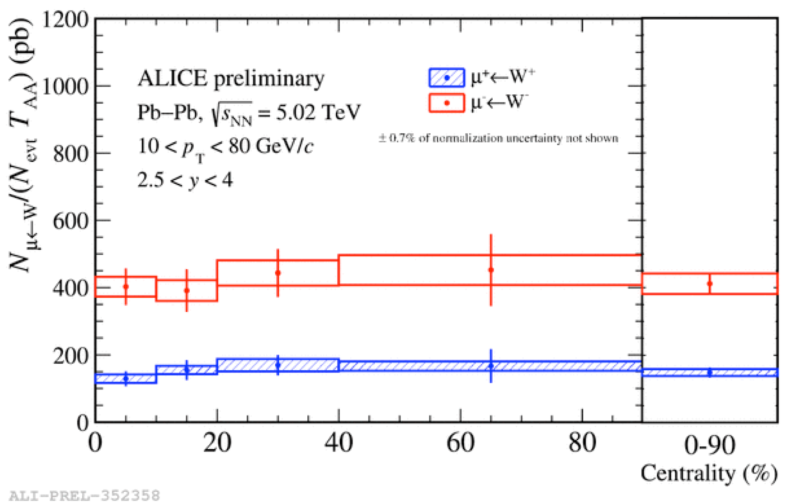
- pQCD + isospin effect with/without nPDF consistent with ALICE data and reproduces the rapidity dependence
- charge asymmetry
  - $-4.46 < y < -2.96$: du W^- dominant ($x < 10^{-1}$)
  - $2.03 < y < 3.53$: ud W+ dominant ($x \sim 10^{-3}$)

W in PbPb at 5.02 TeV

[Eur. Phys. J. C 79 (2019) 935]





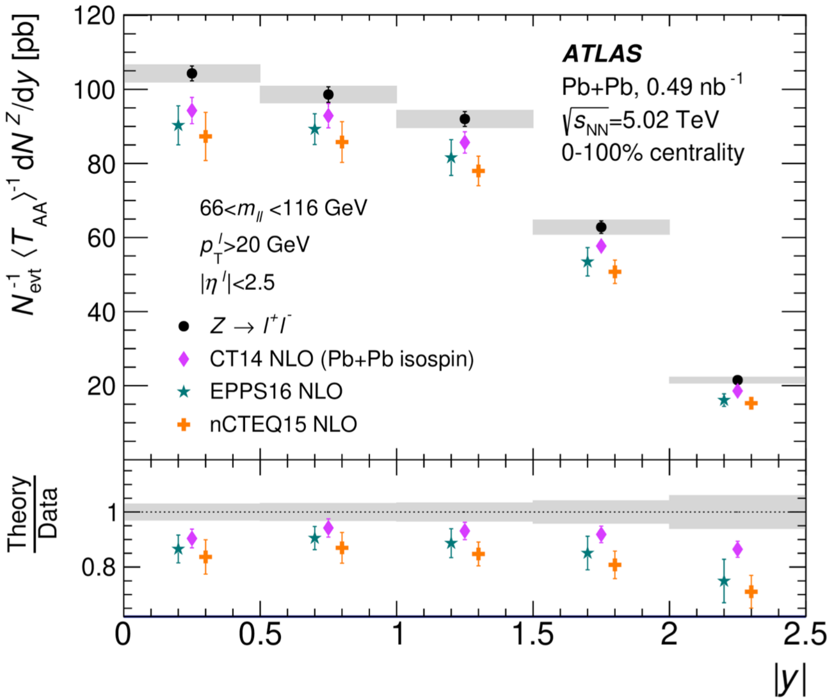


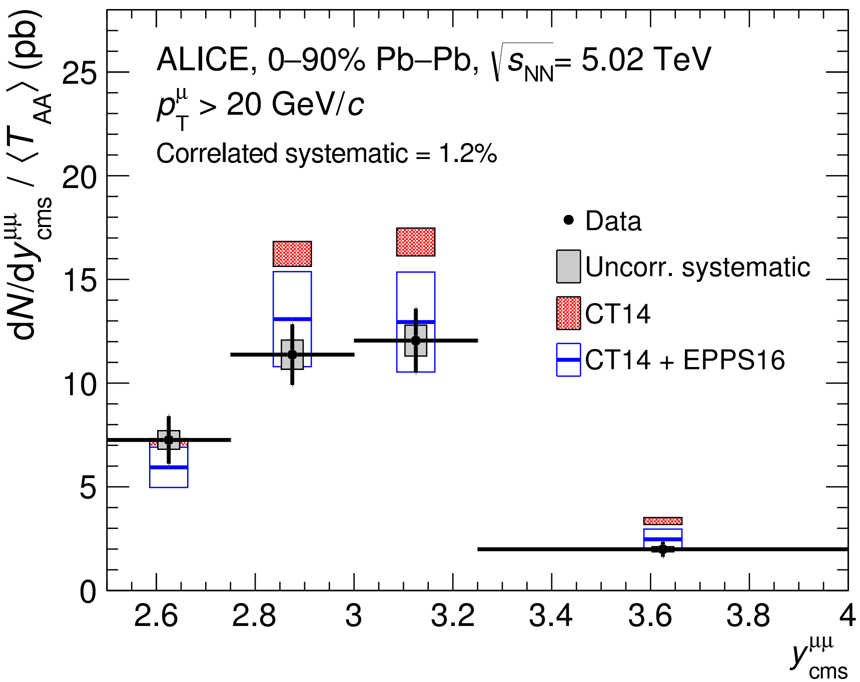
- ATLAS: rapidity dependence described by models but overall excess in data wrt predictions
- ALICE: production described by nPDF
  - centrality dependence followed by binary scaling <T_{AA}>
  - Indication on no final state effects on W production,

Z in Pb-Pb at 5.02 TeV (y dependence)

Phys. Lett. B 802 (2020) 135262

JHEP09(2020)076



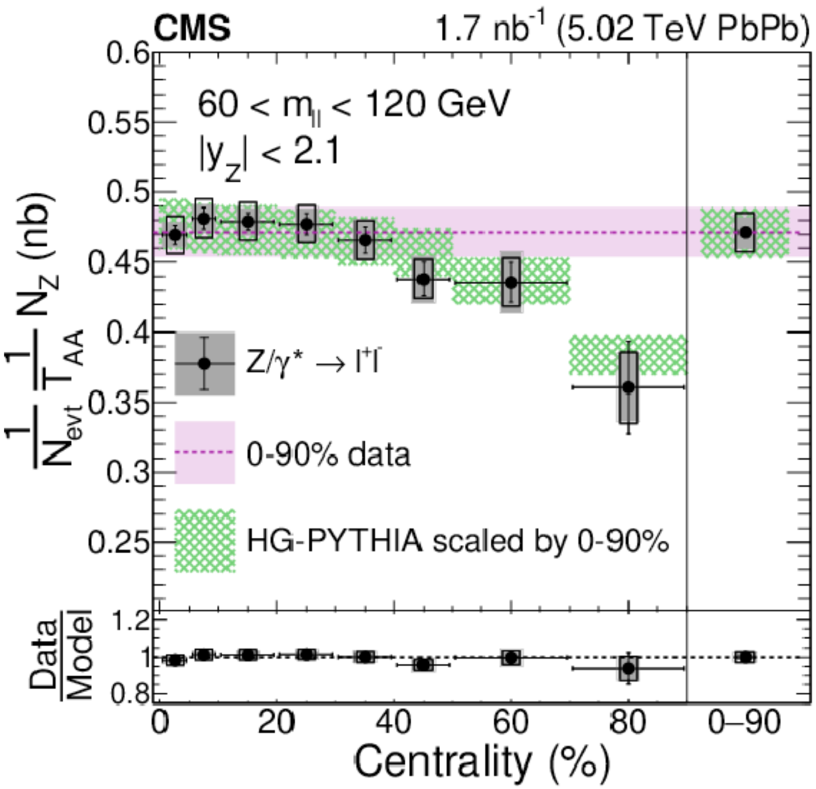


ALI-PUB-347349

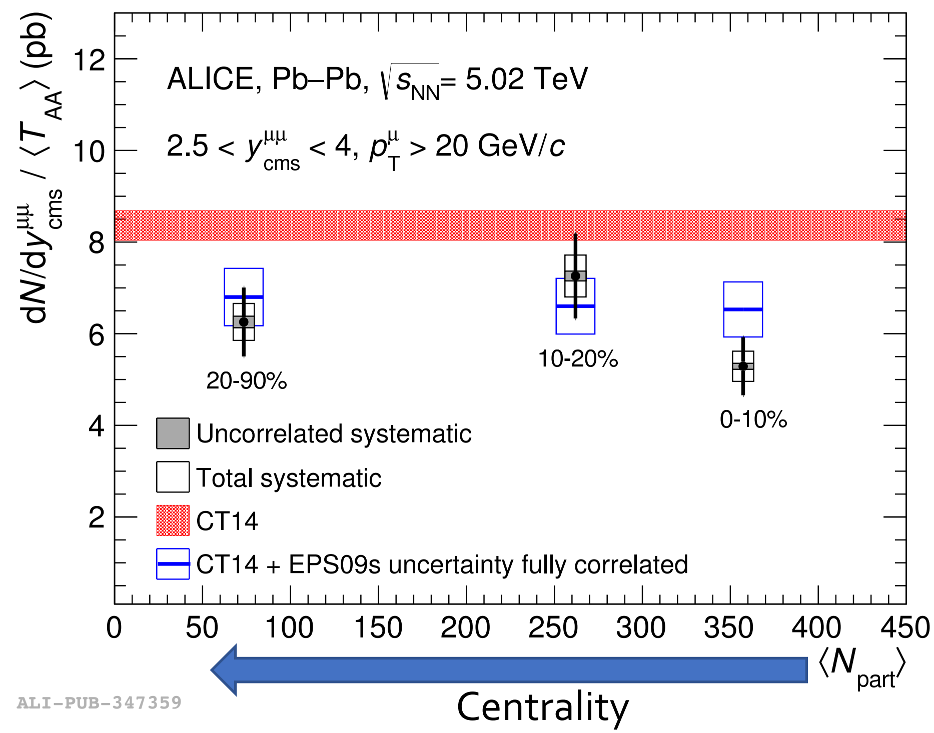
- ALICE data: evidence of modification of Z production in Pb-Pb collisions
  - $2 < y < 4$: $x < \sim 10^{-3}$ shadowing region
  - Models with nPDF reproduces the cross section; 3.4 σ deviation from free-nucleon PDF
- ATLAS data systematically higher than model predictions and without nPDF

Z in Pb-Pb at 5.02 TeV (centrality dependence)

arXiv:2103.14089

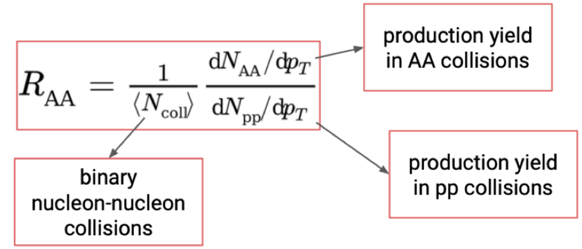


JHEP09(2020)076

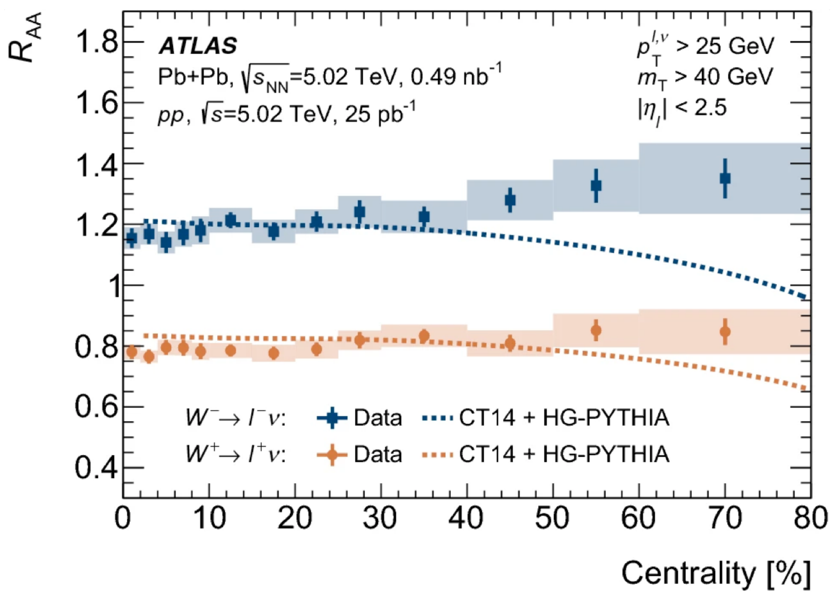


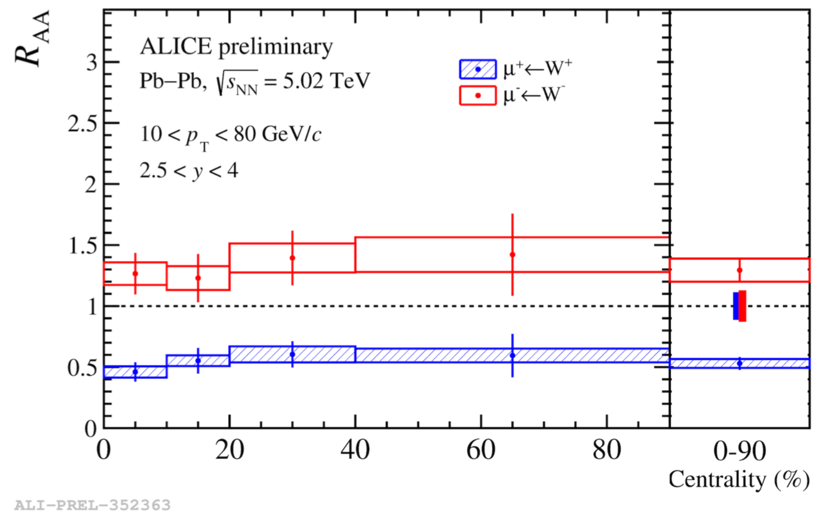
- CMS trend of suppression in most peripheral collisions (described by –HG Pythia [Phys. Lett. B773(2017)408] : effects of initial state geometry and centrality selection in peripheral;
- General agreement of ALICE data with models including centrality dependant nPDF;

W in PbPb at 5.02 TeV



[Eur. Phys. J. C 79 (2019) 935]





Indication on no final state effects on W production,
Consistent with expectation that no modification of boson yield in the QGP

Heavy Flavour Measurements in HIC

- **Heavy quark** produced by hard-scattering with cross sections calculable with pQCD

- Heavy flavour production cross section in hadronic collisions: **factorisation theorem**

$$\frac{d\sigma^{H_c}}{dp_T} = \text{PDF}(x_1, \mu_F)\ \text{PDF}(x_2, \mu_F) \otimes \frac{d\sigma^c}{dp_T^c}(x_1, x_2, \mu_R, \mu_F) \otimes D_{c\to H_c}(z = p_{H_c}/p_c, \mu_F)$$

Parton Distribution Functions

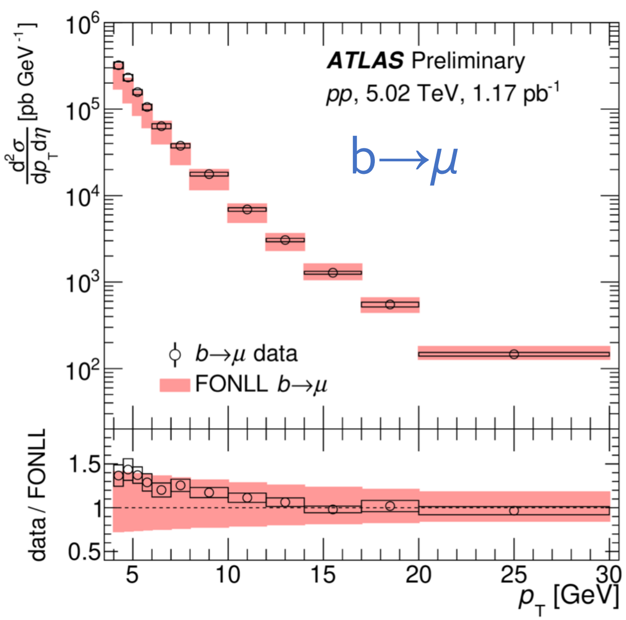
Hard scattering cross section (*p*QCD)

Fragmentation Function (FF)

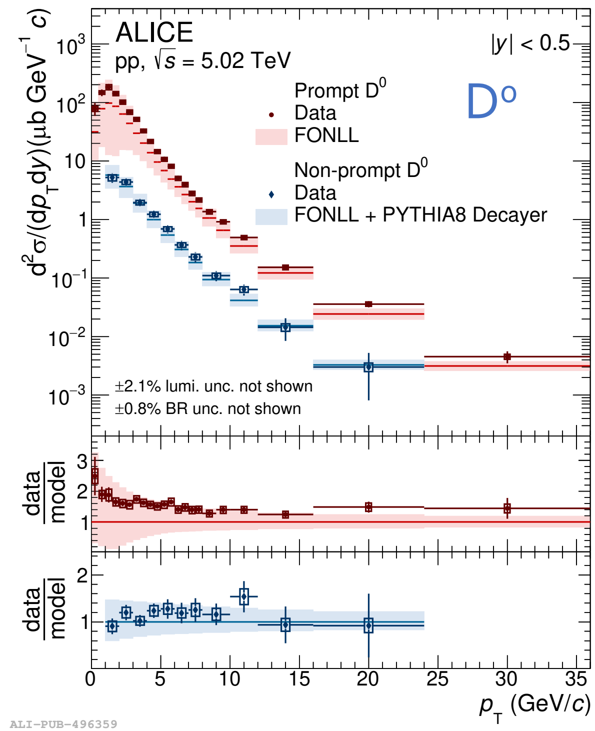
Open charm and beauty cross section in pp

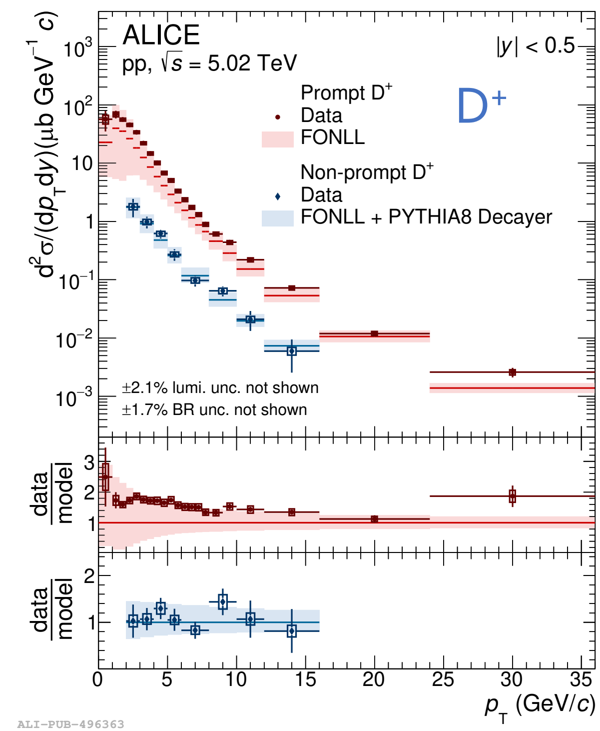
D^0 quark content: $\bar{u}$ c
D^+ quark content: $\bar{d}$ c
D^{*+} quark content: $\bar{d}$ c
D_s^+ quark content: $\bar{s}$ c

arXiv:2109.00411



JHEP 05 (2021) 220





New precise measurements in agreement with predictions
D^0, D^+, D^s across wide p_T range; down to p_T ~0 for D^0 and D^+ meson
D's cross section and muons from HF well described by FONLL

PYTHIA8: JHEP 05 026 (2006)
FONLL: JHEP 1210 137 (2012)

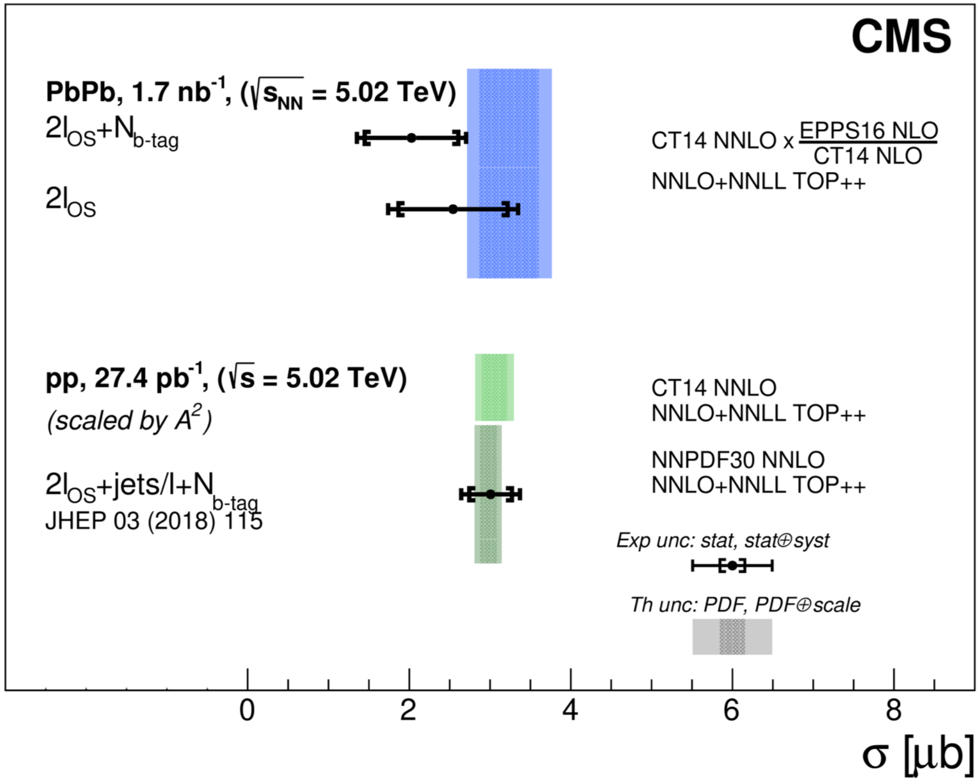
$t\bar{t}$ pairs in Pb-Pb

PRL 125 (2020) 222001

tt pairs produced mostly through gluon-gluon fusion at LHC
Probe of the nPDF

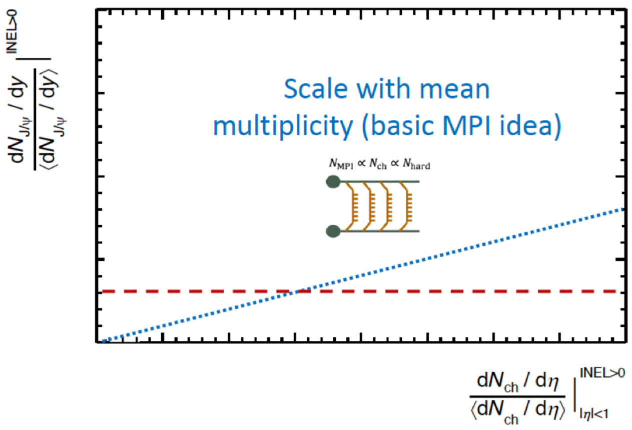
Primary background is Drell-Yan
BDT is trained on dilepton kinematic variables

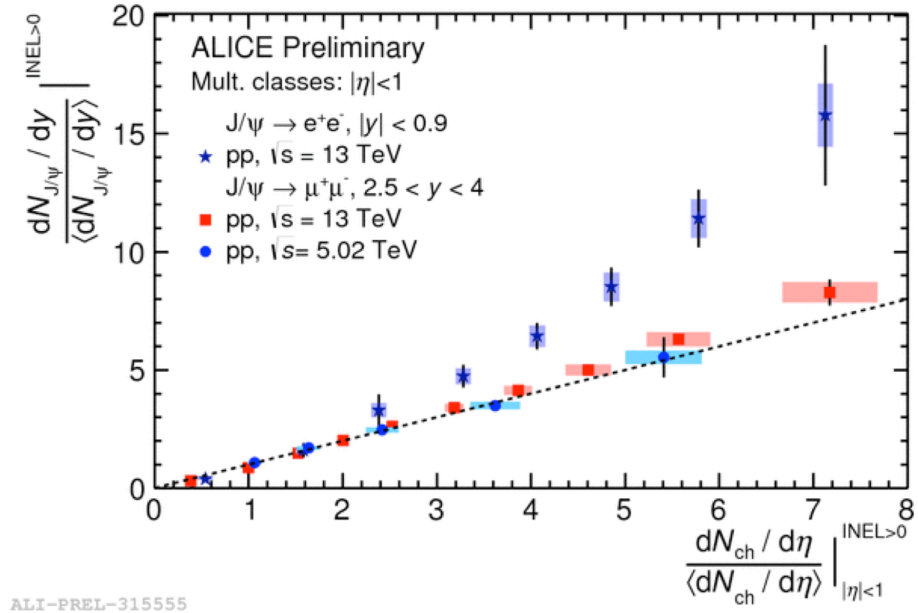
2 analysis (leptons only and lepton –b jet



- ➢ 4σ signal significance
- ➢ Compatible with theoretical prediction however hint of lower than scaled pp predictions.

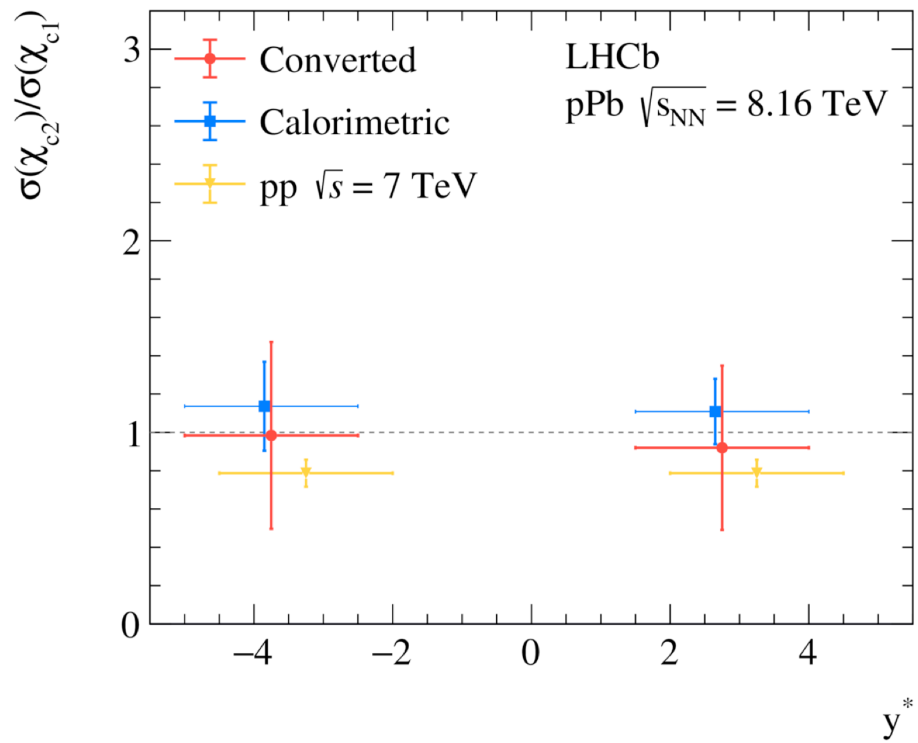
Charmonia measurements in pp





χ_c in small system

Phys. Rev. C103 (2021) 064905



J/ψ and $\psi(2S)$ in pp

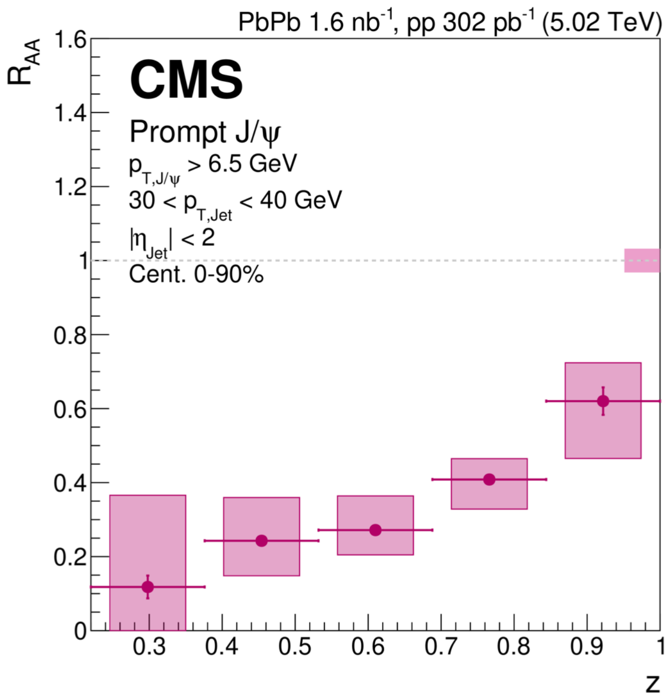
First measurement of χ_c

Final state nuclear effets affects similarly χ_{c1} and χ_{c2}

suppression at low p_T in p-Pb, described by models, with modified nuclear PDFs and also including energy loss

J/ψ in Jets

arXiv:2106.13235

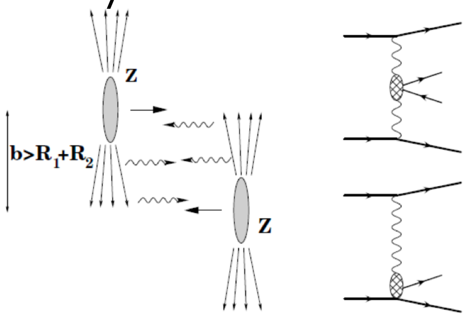


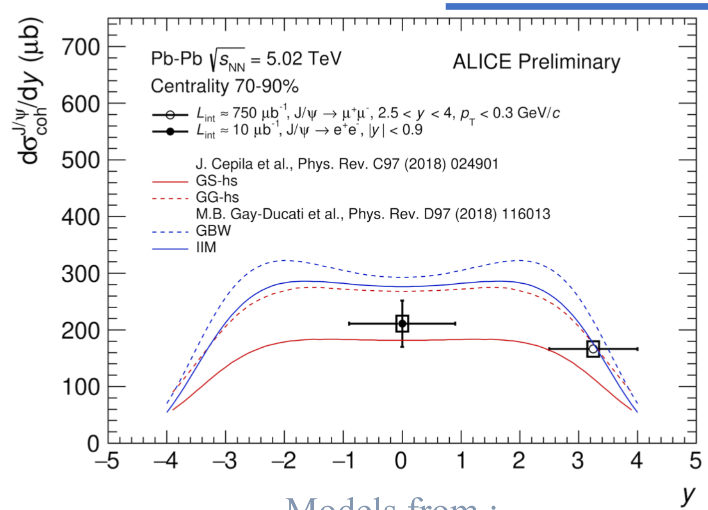
J/ψ-in-jet RAA shows rising R_{AA} as a function of z

➢ Jets with higher multiplicity are more suppressed

Coherent J/ψ photoproduction in peripheral Pb-Pb collisions

Heavy Ion mode at LHC
Powerful source of quasi-real photons with intensity ~ Z^2

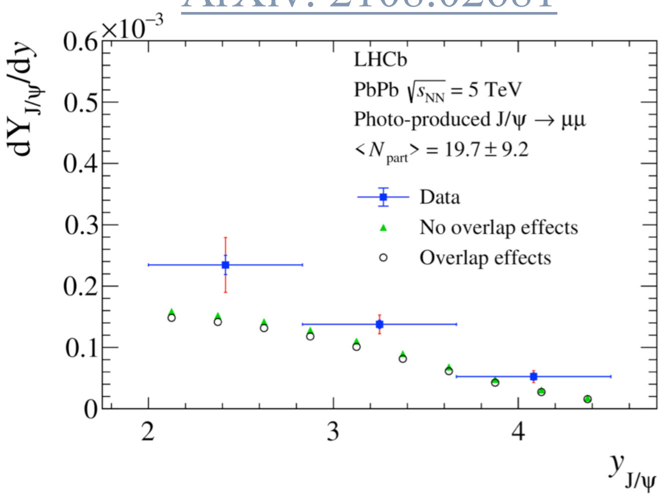




Models from :
Phys. Rev. C97 (2018) 024901
Phys. Rev. D97 (2018) 116013

First J/ψ excess reported by ALICE in Pb—Pb collisions at 2.76 TeV: **Coherent J/ψ photoproduction** suggested as underlying physics mechanism

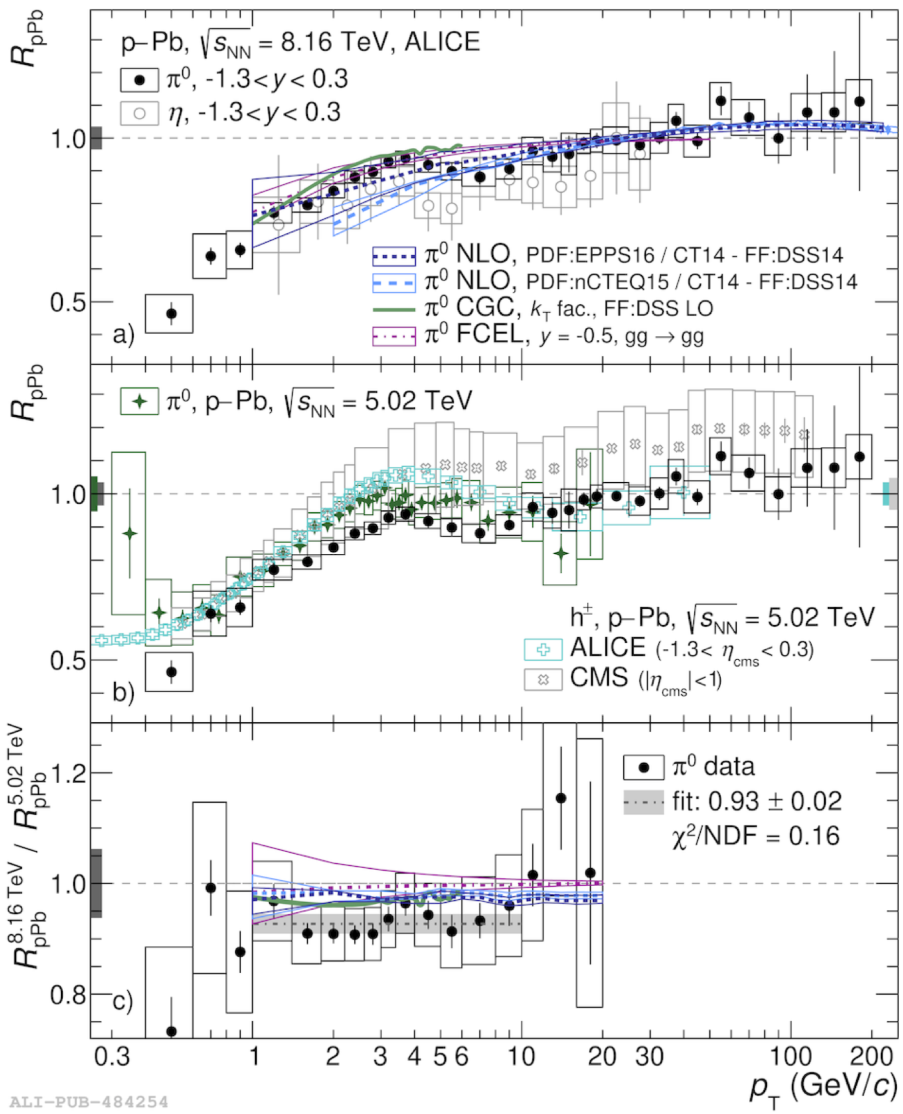
ArXiv: 2108.02681



Photonuclear cross section probes the **gluon density at very low Bjorken-*x***

New theoretical challenges on process knowledge in **hadronic** collisions

Cold Nuclear Matter effects: π^0 R_{pPb}



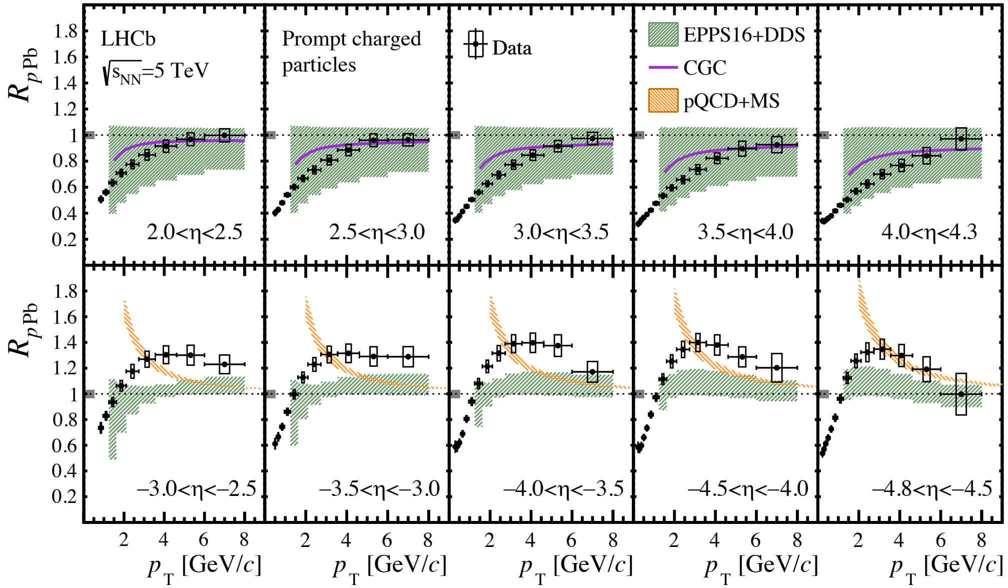
ALICE arXiv:2104.03116

New precise measurements R_{pPb} of π^0 and η up to 200 GeV

New constraints on nPDF

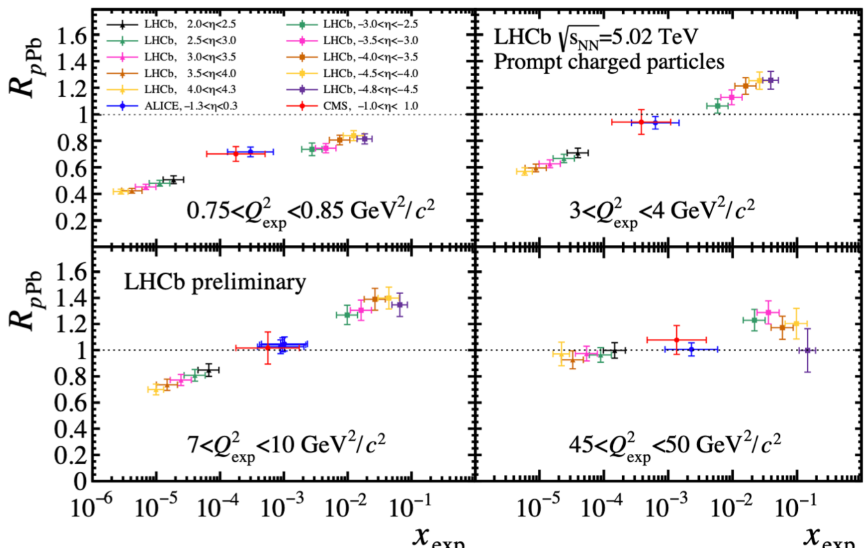
LHCb-PAPER-2021-015

Charged hadron R_{pPb}



EPPS16+DDS JHEP09(2014) 138
CGC PR D88, 114020
pQCD+MS PR D88(2013) 054010, PL B740(2015) 23

- Suppression at forward rapidities
- No model reproduces backward



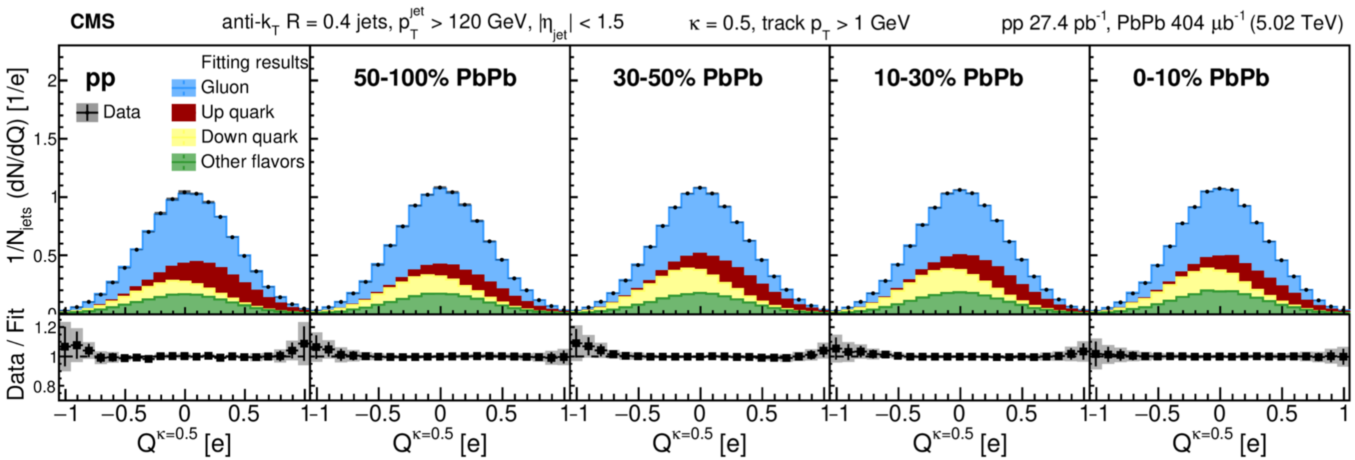
$$Q^2_{exp} \equiv m^2 + p_T^2 \qquad x_{exp} \equiv \frac{Q_{exp}}{\sqrt{s_{nn}}} e^{-\eta}$$

- Continuous evolution of R_{pPb} with x_{exp}
- Nice compatibility between ALICE/CMS/LHCb results

arXiv 2108.13115

Jet Charge

JHEP 07 (2020) 115

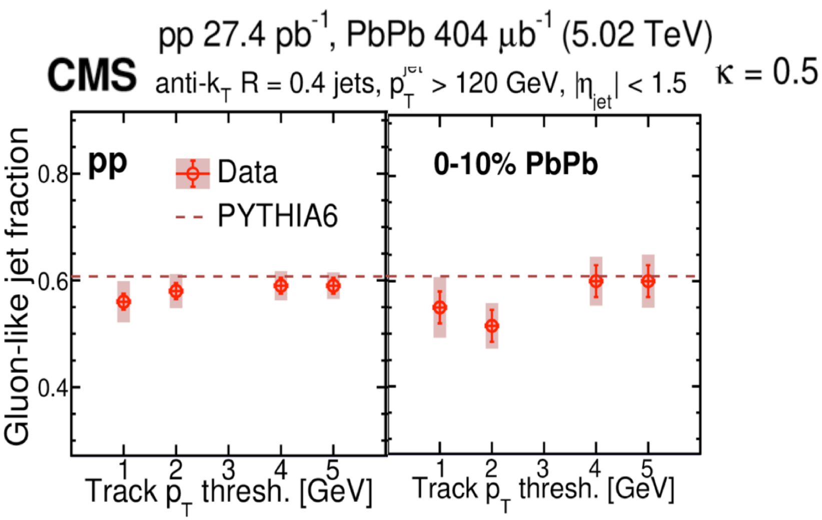


Radiative e-loss different for quarks and gluons

Jet charge sensitive to quark to gluon ratio

$$Q^{\kappa} = \frac{1}{(p_T^{\text{jet}})^{\kappa}} \sum_{i \in \text{jet}} q_i {p_{T,i}}^{\kappa}$$

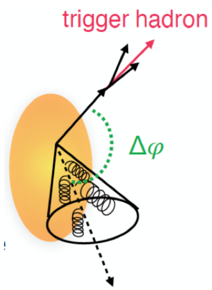
Jet charge unmodified by quenching



Pythia6: JHEP05(2006)026

Jet acoplanarity

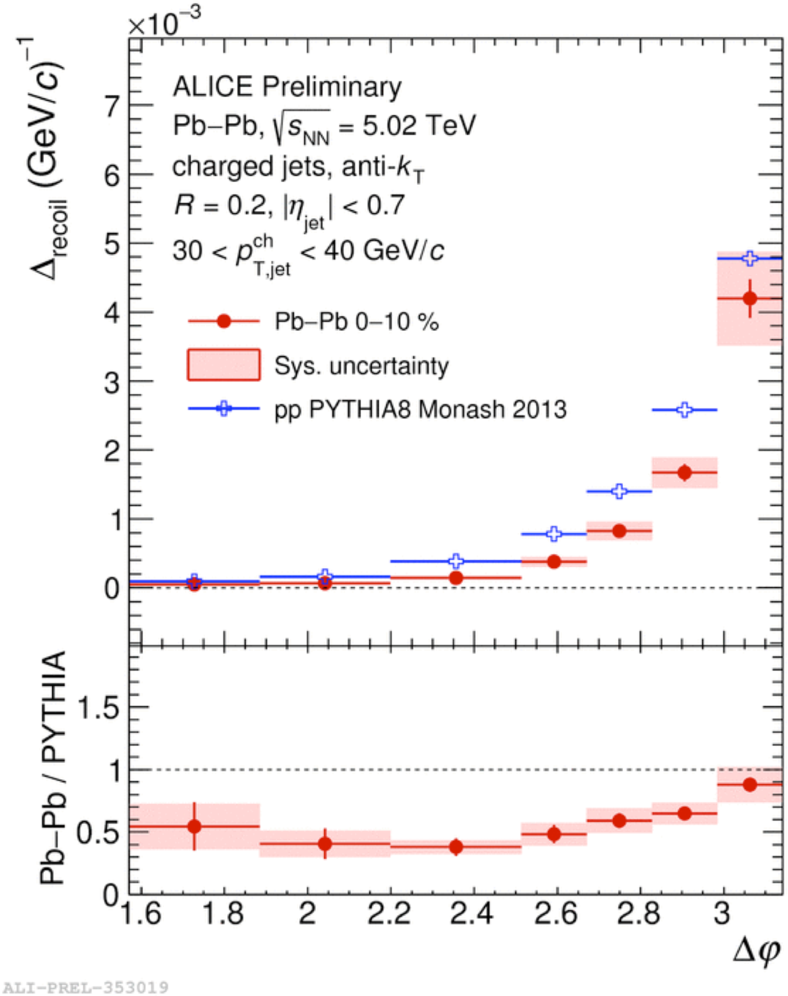
Jet acoplanarity



Recoil jets:

Statistical subtraction of combinatorial background

$$\Delta_{\mathrm{recoil}} = \frac{1}{N_{\mathrm{trig}}^{\mathrm{AA}}} \frac{\mathrm{d}^3 N_{\mathrm{jet}}^{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\Delta\varphi \mathrm{d}\eta_{\mathrm{jet}}} \Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT}_{\mathrm{Sig}}} - c_{\mathrm{ref}} \cdot \frac{1}{N_{\mathrm{trig}}^{\mathrm{AA}}} \frac{\mathrm{d}^3 N_{\mathrm{jet}}^{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\Delta\varphi \mathrm{d}\eta_{\mathrm{jet}}} \Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT}_{\mathrm{Ref}}}$$



Recoil Jet suppressed with respect to PYTHIA
Narrowing of $\Delta\varphi$ distribution with respect to PYTHIA