



The 27th International Conference
on Ultrarelativistic
Nucleus-Nucleus Collisions

14-19 May Palazzo del Cinema

Lido di Venezia, Italy

Quark Matter 2018 overview

What I've learnt in this conference

Chen Lin

IoPP, CCNU, Wuhan

May 31, 2018

Introduction

Theme this year: small systems

- (3) Correlation and Fluctuation
- (2) Electromagnetic and Weak Probes
- (3) Initial State Physics and Approach to Equilibrium
- (3) Collectivity in Small Systems
- (3) Quarkonia
- (5) Jet Modification and High- p_T hadrons
- (2) Future Facilities, Upgrades and Instrumentation
- (2) QCD at High Temperature
- (4) Collective Dynamics
- (3) Chirality, Vorticity and Polarization Effects
- (1) High Baryon Density and Astrophysics
- (1) Thermodynamics and Hadron Chemistry
- (3) Open Heavy Flavour
- (2) New Theoretical Developments
- (3) Phase Diagram and Search for the Critical Point

A vast amount of information

- 11 plenary session
- 34 plenary talks
- 40 parallel session
- 230 parallel talks
- more than 400 posters

Focus on:

- New Experimental data and measurements
- New theoretical analysis and development
- new puzzles and problems

Introduction

Theme this year: small systems

- (3) Correlation and Fluctuation
- **(2) Electromagnetic and Weak Probes**
- **(3) Initial State Physics and Approach to Equilibrium**
- (3) Collectivity in Small Systems
- (3) Quarkonia
- **(5) Jet Modification and High- p_T hadrons**
- (2) Future Facilities, Upgrades and Instrumentation
- (2) QCD at High Temperature
- (4) Collective Dynamics
- (3) Chirality, Vorticity and Polarization Effects
- (1) High Baryon Density and Astrophysics
- (1) Thermodynamics and Hadron Chemistry
- (3) Open Heavy Flavour
- (2) New Theoretical Developments
- (3) Phase Diagram and Search for the Critical Point

A vast amount of information

- 11 plenary session
- 34 plenary talks
- 40 parallel session
- 230 parallel talks
- more than 400 posters

Focus on:

- New Experimental data and measurements
- New theoretical analysis and development
- new puzzles and problems

INITIAL STATE PHYSICS

Why Initial State Physics?

Understanding initial state fluctuations:

- transverse (sub-nucleonic) fluctuations \Rightarrow transverse flow anisotropy (IP-Glasma, Glauber, EKRT, ...)
- longitudinal fluctuation \Rightarrow rapidity decorrelation (AMPT, Scott McDonald, XiangYu, ...)
- pre-equilibrium dynamics \Rightarrow temporal evolution of the medium (multi-stage: field, kinetic, hydro)

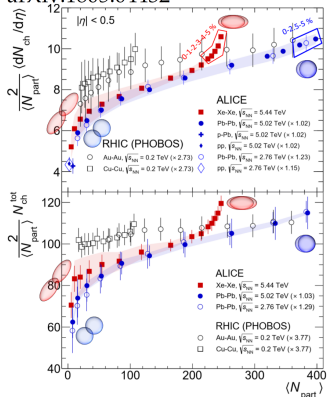
Need to probe partonic distributions within the nucleon/nucleus. How?

- UPC via Light-by-Light, di-lepton, vector-meson and jet production. Probes gluon distribution at small- x , nuclear PDF (CNM).
- Forward/Backward scattering via pA/Ap or fixed-target. probe small/large- x gluon distribution, CNM effect.
- potential tool by the EIC.

ALICE Xe-Xe measurement

$$\frac{2}{\langle N_{\text{part}} \rangle} \langle dN_{\text{ch}}/d\eta \rangle \text{ AND } \frac{2}{\langle N_{\text{part}} \rangle} N_{\text{ch}}^{\text{tot}} \text{ AS A FUNCTION OF } \langle N_{\text{part}} \rangle$$

arXiv:1805.04432



Data are scaled to \sqrt{s} , $\sqrt{s_{NN}} = 5.44$ TeV (prev.) to match with Xe-Xe results.

- ▶ ALICE data decreasing by 2 from the most central to the peripheral
- ▶ smoothly connect to pp and p-Pb
- ▶ Xe-Xe shapes exceed Pb-Pb at similar $\langle N_{\text{part}} \rangle$ for the top 10% central collisions
 - ▶ RHIC data show hint of same behaviour

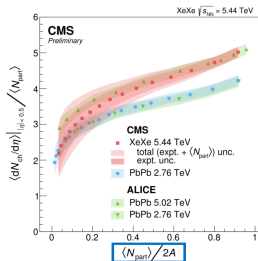
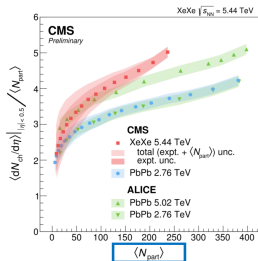
7/11

scale violation of charged multiplicity for different systems at similar N_{part} .

Centrality dependence

CMS-PAS-HIN-17-006

- Per-participant $dN/d\eta$ at midrapidity as functions of the average number of participating nucleons (left), and fractional overlap (right)
 - Same number of participants: per-participant $dN/d\eta$ in XeXe exceeds PbPb
 - Same fractional overlap: per-participant $dN/d\eta$ agree between XeXe and PbPb
- Charged-particle production depends on collision geometry, not system size



16 MAY 2018

QUARK MATTER 2018

10

Per-participant $dN/d\eta$ at mid-rapidity is driven by collision geometry, not system size.

Exclusive J/ψ photoproduction in p-Pb

CCT
energy-dependent hot
spot model
PLB766 (2017) 186

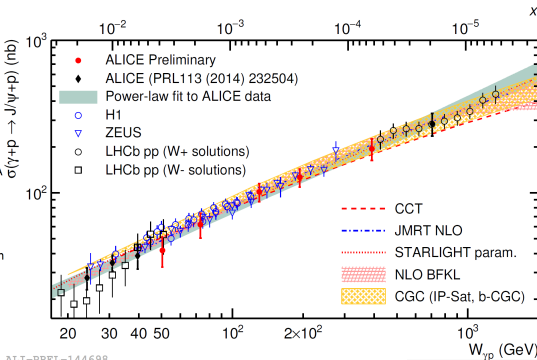
JMRT NLO
DGLAP formalism +
main NLO contributions
EPJC76 (2016) 633

STARLIGHT
Parameterization of HERA
and fixed-target data
CPHC 212 (2017) 258

NLO-BFKL
proton impact factor from
F2 HERA data
PRD94 (2016) 054002

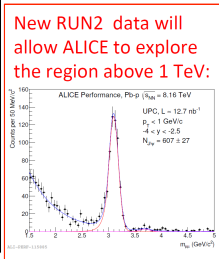
CGC
color-gluon-condensate
models with saturation
PRD90 (2014) 054003

5/14/18



ALI-PREL-144698

Good description by all models



for LHCb measurements in pp
at 13 TeV see LHCb-CONF-2016-007 12

model consistent with data with or without saturation effect.

LHCb J/ψ measurement

analysis result

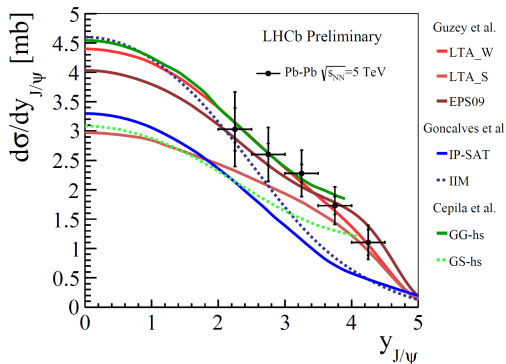
differential coherent cross section

LHCb preliminary

$$\sigma = 5.27 \pm 0.21 \pm 0.49 \pm 0.68 \text{ mb}$$

- The analysis is repeated in bins of half unit rapidity $y_{J/\psi}$
- Uncertainties for statistics, systematic and luminosity are of comparable magnitude
- The LHCb acceptance is interesting to discriminate between the models

LHCb-CONF-2018-003



Albert Bursche

UPC J/ψ

14th May 2018

9 / 14

large rapidity acceptance, coherent collision.

CMS $\Upsilon(1S)$ measurement

Excl. $\Upsilon(1S)$ photoproduction cross section vs $W_{\gamma p}$

CMS-FSQ-13-009

- Differential cross section estimated

$$\frac{d\sigma_{Y(1S)}}{dy} \mathcal{B}_{Y(1S) \rightarrow \mu^+ \mu^-} = \frac{N_{Y(1S)}^{\text{corr}}}{\mathcal{L} \times \Delta y} \cdot W_{\gamma p}^2 = 2E_p m_Y \exp(\pm y)$$

- The differential $\Upsilon(1S)$ cross-section extracted by correcting for branching ratio, feed-down, $\Upsilon(1S)$ fraction

- The cross-section as a function of $W_{\gamma p}$ is estimated by

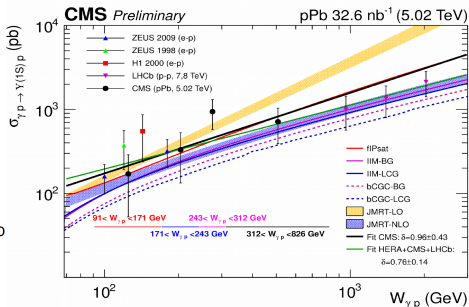
$$\sigma_{\Upsilon p \rightarrow \Upsilon(1S) p} = \frac{1}{\Phi} \frac{d\sigma_{Y(1S)}}{dy}$$

- A fit with power-law $A X (W_{\gamma p} / 400)^\delta$ to the CMS data gives,

$$\delta = 0.96 \pm 0.43$$

$$A = 655 \pm 196 \text{ pb}$$

- ZEUS: $\delta = 1.2 \pm 0.8$
Phys.Lett. B680 (2009) 4



Data compatible with power-law dependence of $\sigma(W_{\gamma p})$,
disfavours (fast rising) LO pQCD predictions

Ruchi Chudasama (BARC, Mumbai)

10

compatible with HERA data and pQCD predictions.

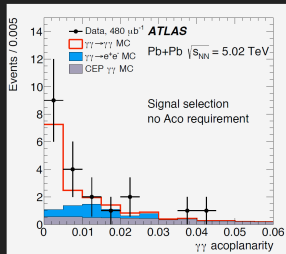
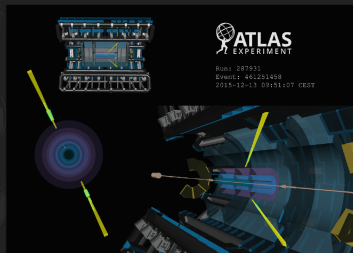
ATLAS Light-by-Light measurement

UPC MEASUREMENTS



LIGHT-BY-LIGHT SCATTERING

<https://doi.org/10.1038/NPHYS4208>



ARTICLES

PUBLISHED ONLINE: 14 AUGUST 2017 | DOI: 10.1038/NPHYS4208

nature
physics

OPEN

Evidence for light-by-light scattering in heavy-ion collisions with the ATLAS detector at the LHC

ATLAS Collaboration[†]

$$\sigma_{\text{fid}} = 70 \pm 24 \text{ (stat.)} \pm 17 \text{ (syst) nb}$$

4.4σ significance
observed
 3.8σ expected

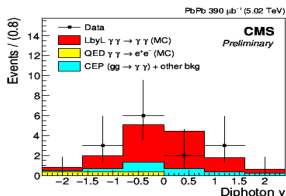
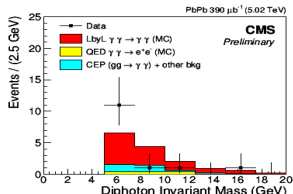
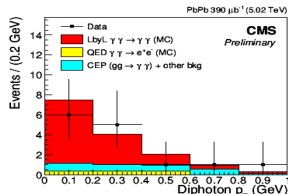
11

strong QED proof.

$\gamma\gamma$ differential distributions (after LbyL cuts)



- Final diphoton distributions ($p_T, m_{\gamma\gamma}, y$) for LbyL+QED+CEP:



Good agreement of data with sum of MC predictions (also for cut-flow numbers):

Selection criteria	Data	LbyL MC	QED e^+e^- MC	CEP MC + other (normalised to data)
Charged exclusivity	649	13.7 ± 1.4 (th)	9.8 ± 1.9 (stat)	21.9 ± 8.3 (stat)
Neutral exclusivity	107	13.3 ± 1.4 (th)	9.8 ± 1.9 (stat)	21.2 ± 8.1 (stat)
Diphoton $p_T < 1$ GeV	38	12.5 ± 1.3 (th)	9.0 ± 1.8 (stat)	17.5 ± 6.7 (stat)
Diphoton acoplanarity < 0.01	14	11.1 ± 1.1 (th)	1.1 ± 0.6 (stat)	2.7 ± 1.1 (stat)

strong QED proof.

ATLAS dimuon measurement

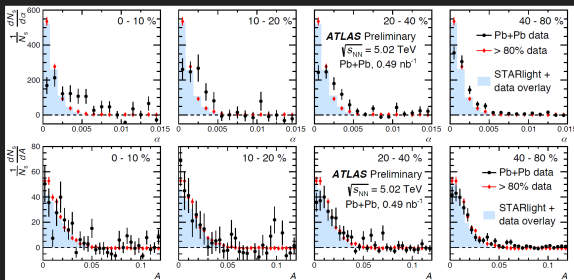
$\gamma\gamma \rightarrow \mu\mu$ IN Pb+Pb



CORRECTED SIGNAL DISTRIBUTIONS

α

A



- ▶ Simulated STARLIGHT events show no centrality-dep. broadening
- ▶ HF-determined backgrounds saturate tails
 - ▶ No obvious contribution from Drell-Yan, Υ , or dissociative processes

22

clear broadening but no sign of momentum imbalance.

CMS Forward/Backward dijet measurement

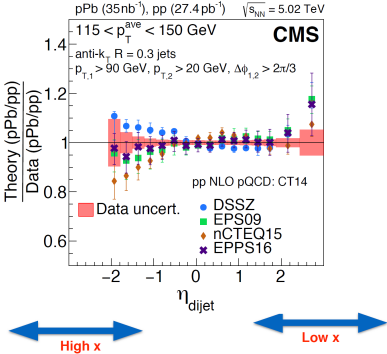
HIN-16-003



First evidence that the gluon PDF at large Bjorken x in lead ions is strongly suppressed

Data are incompatible with predictions using nucleon PDFs or using nPDFs **without large- x gluon suppression.**

Based on a statistical analysis, the EPS09 nPDF provides the best overall agreement with the data



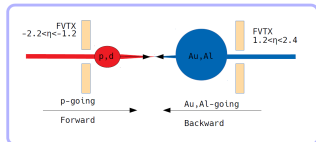
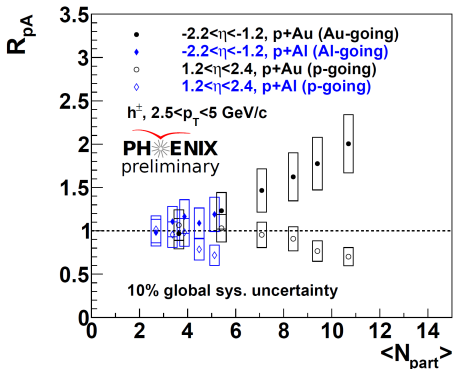
suppression of large- x gluon PDF (EMC).

PHENIX R_{pA} measurements for p-Au and p-Al

R_{pA} vs. N_{part}

R_{pA} vs. N_{part}

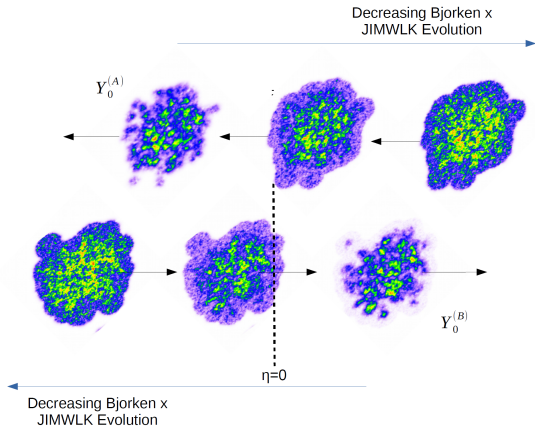
- **Backward enhancement scales with N_{part} across collision systems**



Backward (A-going, large- x) enhancement scale with N_{part} .

9

IP-Glasma 3+1D generalization



Lappi, Mantysaari, *Eur. Phys. J. C* (2013)
Schenke, Schlichting, *PRC* (2016)

Scott McDonald

McGill University

May 14, 2018

11 / 19

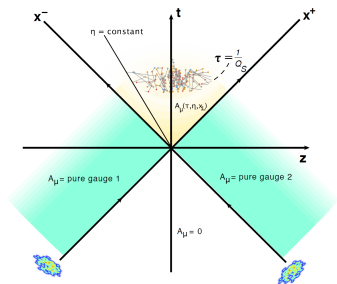
provides 3+1D initial condition with transverse dynamics and longitudinal fluctuations.

CGC meets Lund String fragmentation of PYTHIA

CGC + PYTHIA : A new approach to simulate p+p & p+A collisions

- 1) Output distribution of Gluons from CGC based **IP-Glasma** model
- 2) Sample gluons in momentum space
- 3) Connect the gluons close in phase space to color neutral strings
- 4) Input to **PYTHIA** and fragment into final particles

Schenke, PT, Venugopalan Phys. Rev. Lett. 108 (2012) 252301



PYTHIA (realistic mechanism of hadronization) → partonic correlations
from initial state dynamics → correlated production of final-state particles

P.Tribedy, Quark Matter 2018, Venice, Italy

8

Description of particle yields, long range correlations, collective effect.

ELECTROMAGNETIC AND WEAK PROBES

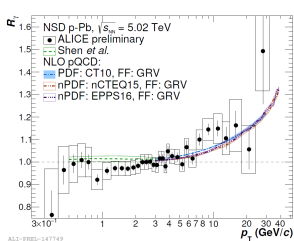
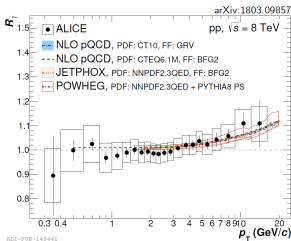
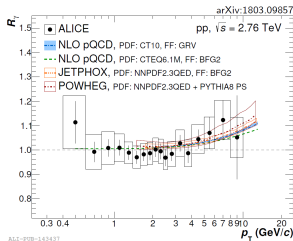
Why Electro-Weak Probes?

- prompt photon (γ)
probes the medium unaffected, use as calibration for jets.
- thermal photon, decayed di-electrons
records time evolution of the medium, gives information about the system temperature.
- W- and Z-boson
constrain nuclear parton distribution function in p-A collisions.

ALICE direct-photon measurement



Direct Photons in pp & p-Pb (1)



- Systematic uncertainties of individual meas.
 - dominated by p_T -independent material unc. of 4.5% PCM, 2.8% EMC & global E-scale unc. 3% PHOS
- p_T reach
 - $0.4 < p_T < 10$ GeV/c in pp, $\sqrt{s} = 2.76$ TeV
 - $0.3 < p_T < 14$ GeV/c in pp, $\sqrt{s} = 8$ TeV
 - $0.3 < p_T < 32$ GeV/c in p-Pb $\sqrt{s_{NN}} = 5.02$ TeV

- Combination of 3 (4) reconstruction techniques via BLUE method
- NLO prediction plotted as

$$R_{\text{NLO}} = 1 + (\gamma_{\text{dir}}^{\text{NLO}} \cdot N_{\text{Coll}}) / \gamma_{\text{dec}}$$
- Within uncertainties no significant excess at low p_T observed
 - supports interpretation in Pb-Pb as medium effects
- About $1 - 2\sigma$ deviation from unity for $p_T > 7$ GeV/c

no excess in thermal region, consistent with pQCD calculations.

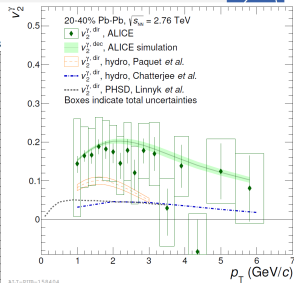
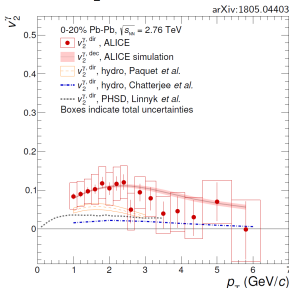
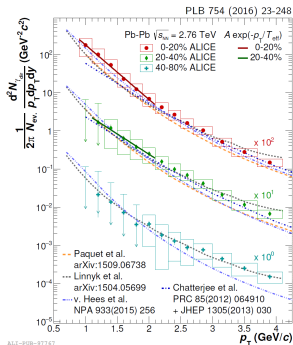
ALICE direct-photon v_2



Direct Photon Yield and Flow



- Central points for direct photon yield and $v_2^{\gamma,dir}$ underestimated by most theoretical calculations by factors of 2-5



- $v_2^{\gamma,dir}$ compatible with $v_2^{\gamma,dir} = 0$ within $1.4(1.0)\sigma$ in p_T range ($0.9 < p_T < 2.1$ GeV/c)
- No deviation beyond 2σ from theory observed for spectra or v_2
- Similar observations for all theoretical calculations despite very different setups

ALICE-PHOB-97747

F. Bock (CERN)

Direct Photons at the LHC

May 14, 2018

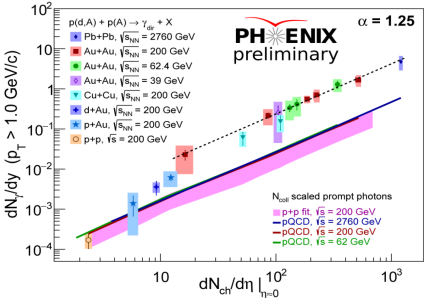
11

non-zero v_2 observed, late production time.

PHENIX direct-photon measurement

Direct Photon Connection Between Large and Small Systems

- There seems to be another trend from small systems, different from that of large systems
- Both trends suggest an “intersection region” or “intersection point”
- p+Au 0-5% data point shows a sign of existence of QGP small droplet

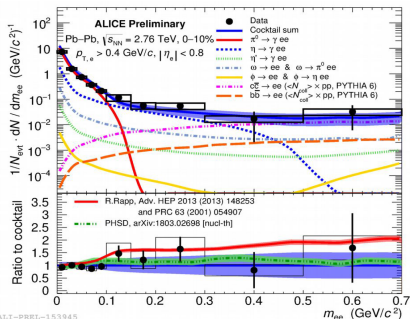


26 Vladimir Khachatryan, Quark Matter 2018, Venice

generalized scaling for direct photon production across energies and systems.

ALICE di-electron measurement

Central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV



Corrected e^+e^- yield in the ALICE acceptance
($p_{T,e} > 0.4$ GeV/c and $|\eta_e| < 0.8$)

Cocktail without vacuum p

Cocktail with thermal radiations:

- **R.Rapp:** expanding fireball model with $T_c = 170$ MeV and hadronic many-body theory
- **PHSD:** Parton-Hadron-String Dynamics transport approach

Paper should come very soon

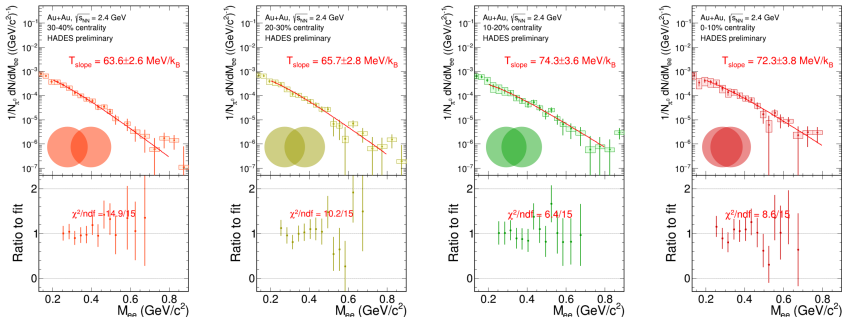
No sensitivity yet for possible thermal radiations from the medium
Run-2 and Run-3 (after upgrades) → more precise measurements

R. Rapp, Adv. HEP 2013 (2013) 148253, Phys. Rev. C63 (2001) 054907
T. Song, W. Cassing, P. Moreau, E. Bratkovskaya arXiv:1803.02698 [nucl-th]

cocktail of di-electron production consistent with simulation.

Fit to the invariant mass in centrality bins

Total e^+e^- yield



Hotter radiation source in more central collisions

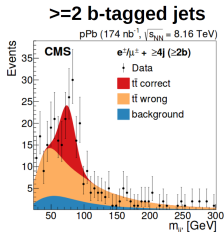
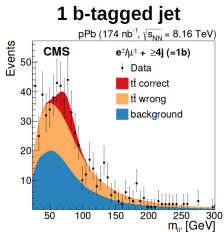
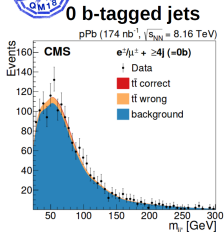


di-electron yield measurement for different sources of photon production.

CMS top quark measurement

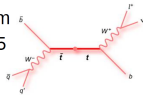
Top quarks in pPb

Phys. Rev. Lett. 119 (2017), 242001



- **Decay channel:** ≥ 4 jets + lepton (μ or e) + missing momentum
- **Jet Selection:** Anti- k_T ($\Delta R=0.4$) jet with $p_T > 25$ GeV/c & $|\eta| < 2.5$
- **B-quark tagger:** Based on combined secondary vertex
- **Lepton Selection:** Isolated lepton with $p_T > 30$ GeV/c & $|\eta| < 2.1$

- **Extraction:** Fits of the $W \rightarrow jj'$ mass using functional forms in different b-jet and lepton flavor categories, **without relying on simulation**



CMS

Quark Matter 2018

16/05/18

8

first CMS observation for top quark in pPb, probe gluon nuclear distribution.

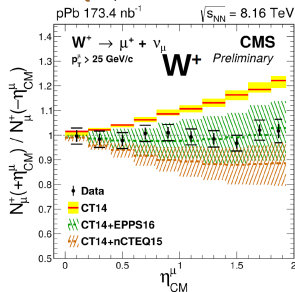
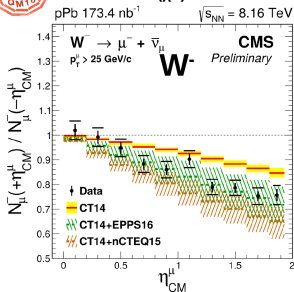
CMS W-boson measurement

W boson: forward-backward ratio



CMS-PAS-HIN-17-007

$P(\chi^2) < 0.01\%$ CT14, 83% nCTEQ15, 95% EPPS16



- Uncertainties fully correlated in η_{CM} cancels (correlations included)
- **Exclude (>7 σ) free-nucleon PDF calculations**
- Experimental uncertainties smaller than nPDF uncertainties

CMS

Quark Matter 2018

16/05/18

14

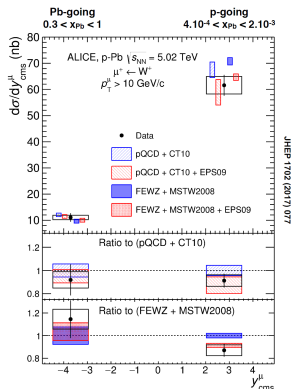
W boson measurement agrees with existing quark nuclear PDFs, good with EPPS.

ALICE Electroweak boson measurement

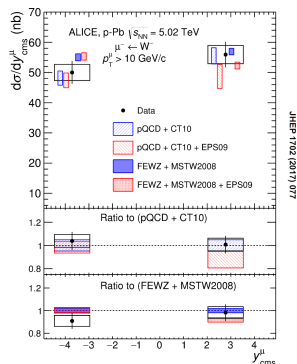


W-boson production in p-Pb collisions

Mohamad Tarhini
QM-2018, Venice 10



ALICE-Pb-118937



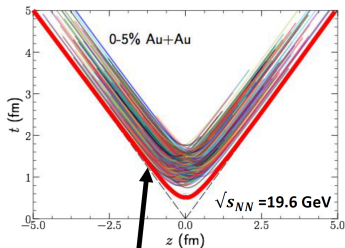
ALICE-Pb-118941

- Calculations **with** and **without** nPDF can reproduce the results
- As for the Z-boson results, more precision is needed to constrain nPDFs

W/Z production require more precision to constrain nuclear PDF.

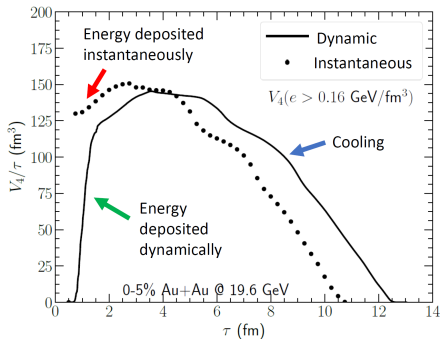
Probing the dynamical plasma

Energy & baryon number deposited over extended time period at lower $\sqrt{s_{NN}}$



“Instantaneous” energy deposition (high collision energy limit)

Space-time 4-volume (above freeze-out) versus time



Jean-François Paquet (Duke University)

14

Significant thermal photon at low collision energies using dynamically initialized hydro profile.

JET MODIFICATION AND HIGH- P_T HADRONS

Why Jets?

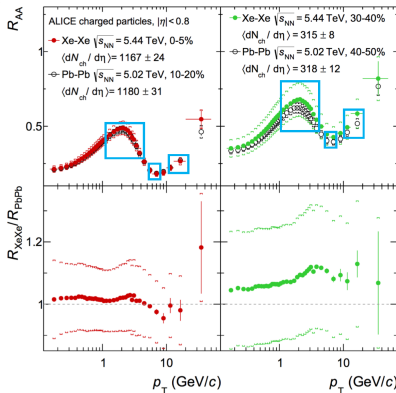
- R_{AA} - smoking gun for QGP formation
- EM jets - probes the coloured medium unaffected, calibrate away-side jet energy
- jet correlations ($\Delta\phi, x_J$) - probes medium effect and transport coefficient via broadening and energy-loss.
- jet fragmentation function - medium response



R_{AA} in Xe-Xe and Pb-Pb vs. p_T at similar $dN_{ch}/d\eta$

[arXiv:1805.04399](https://arxiv.org/abs/1805.04399)

NEW



- Similar R_{AA} in the most central Xe-Xe collisions to that in 10-20% Pb-Pb collisions over the entire p_T range.
- Agreement of R_{AA} between 30-40% Xe-Xe and 40-50% Pb-Pb collisions within uncertainties.

central Xe-Xe collision



semi-central Pb-Pb collision



centrality	N_{part}
0-5% Xe-Xe	236 ± 2
10-20% Pb-Pb	263 ± 4
30-40% Xe-Xe	82.2 ± 3.9
40-50% Pb-Pb	86.3 ± 1.7

13-19 May 2018 QM2018

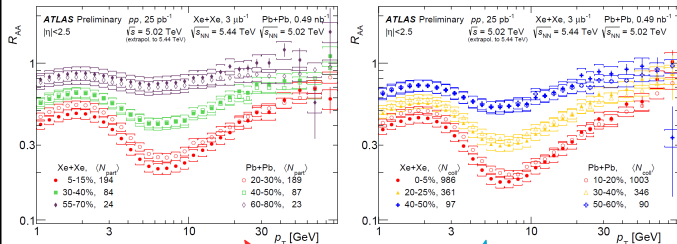
Daiki Sekihata

18

New R_{AA} measurement for Xe-Xe and Pb-Pb (similar multiplicity) showing the effect of Cronin and suppression.

ATLAS R_{AA} measurement

charged hadron R_{AA} in Xe+Xe and Pb+Pb



- same colors have **similar** $\langle N_{part} \rangle$ and **similar** $\langle N_{coll} \rangle$
- very similar p_T dependency in Xe+Xe as in Pb+Pb
- although the shape is not exactly the same

Petr Balek

charged hadron R_{AA}

15 May 2018

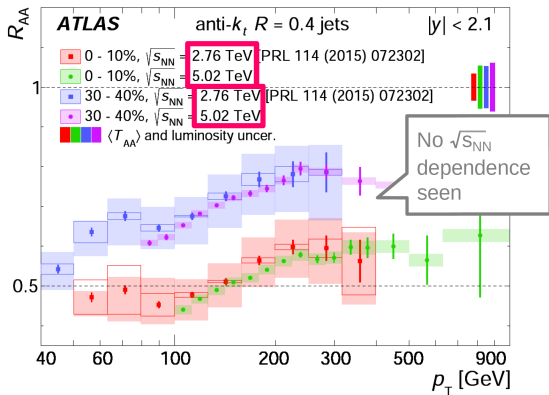
13 / 21

R_{AA} scales with $\langle N_{part} \rangle$ or $\langle N_{coll} \rangle$.

ATLAS R_{AA} measurement



Jet R_{AA} vs. $\sqrt{s_{NN}}$



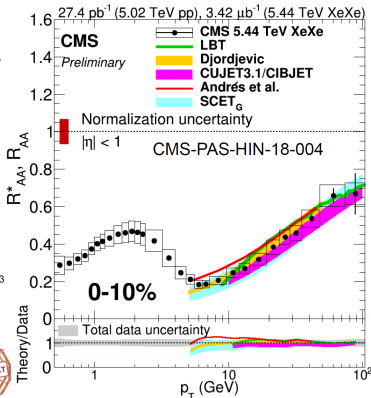
Quark Matter 2018, May 14-19, 2018

R_{AA} have no dependence on beam energy.

12

Theory Comparisons - 0-10%

- **Linear Boltzmann Transport Model**
 - CLV_{isc} hydro medium expansion
 - Quadratic energy loss in static QGP
- **Djordjevic Model**
 - Bjorken expansion of medium
- **CUJET3.1**
 - CIBJET modeling of flow harmonics
- **Andrés et al.**
 - 'quenching weights' formalism
- **SCET_G**
 - Medium evolution with IEBE hydro
 - Energy loss scales as roughly $N_{part}^{2/3}$
- Models predict R_{AA} reasonably
- Similar agreement in 30-50%



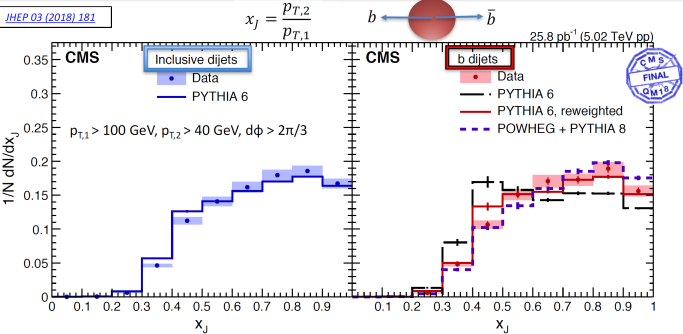
Austin Baty

11



measurement of R_{AA} showing agreement with model prediction from mid to high p_T .

Toward more sensitive observables



- b-dijet R_{AA} removes ambiguity regarding production mechanisms ->
- Probes **leading-order** jet production component
 - No significant differences with respect to inclusive jets, seen also by POWHEG

5/15/18

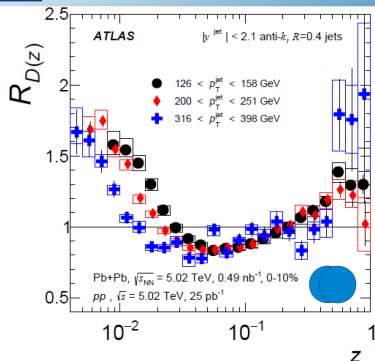
Kurt Jung, UIC, Quark Matter 2018

4

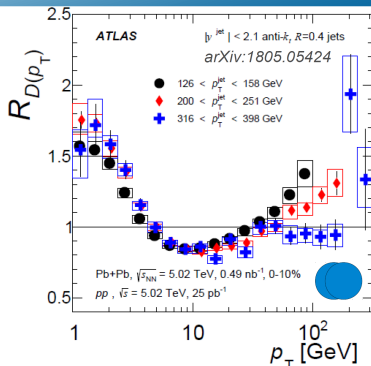
CMS b-jet measurement provide probe to final gluon splitting and removes soft gluon contribution.



Jet p_T dependence to the FF modification



No dependence on jet p_T observed at high z for jets up to 400 GeV.

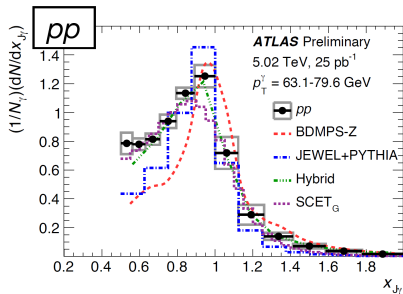


Enhancement of soft fragments increases for high p_T jets.

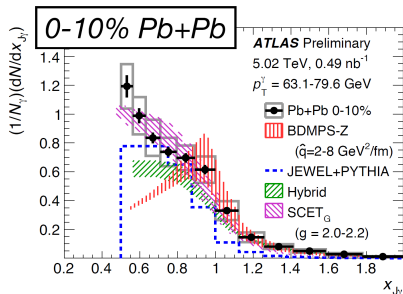
11

Soft and hard fragments are enhanced in AA compared to pp

Direct comparisons to theory (no smearing)



Test description of
vacuum (pp) baseline



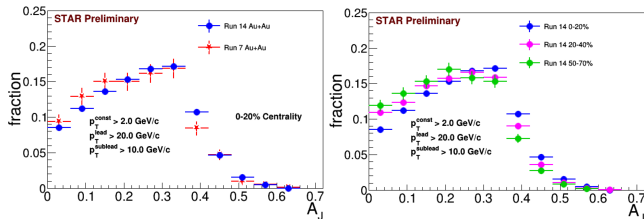
Can models describe
centrality / p_T^γ evolution?

unfolded $x_{J\gamma}$ distribution agree directly with unsmeared theoretical prediction.

Centrality Dependence of A_J



RUN7: STAR PRL 119, 062301 (2017)



- Comparable between Au+Au Run 14 and Run 7 in 0-20% centrality (detector level)
- Run14: large increase in statistics
→enable to study centrality dependence
- Apparent evolution of A_J to more balanced jets in peripheral Au+Au collisions

Kun Jiang

Quark Matter 2018, Venice, Italy

5

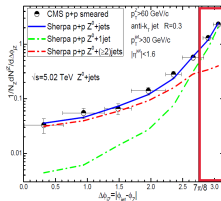
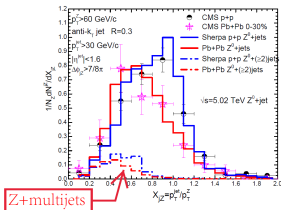
STAR dijet measurement with centrality dependence.

Z-jet with Sherpa+LBT

Z+jet asymmetry and multi-jets contributions

- Shift of momentum imbalance $x_{jZ} = p_T^{jet} / p_T^Z$.

S. L. Zhang, T. Luo, X. N. Wang and B. W. Zhang, arXiv:1804.11041 [nucl-th].



x_{jZ} is shifted to smaller value.

- Transverse momentum of Z boson is unattenuated.
- Jet transverse momentum is modified by medium.

Multi-jets have almost 50% contributions to $x_{jZ} < 0.5$ region.

Shan-Liang Zhang

Jet quenching in Z-jet in heavy-ion collisions

12 / 21

Z-jet momentum asymmetry showing shift to small-x in the presence of a medium.

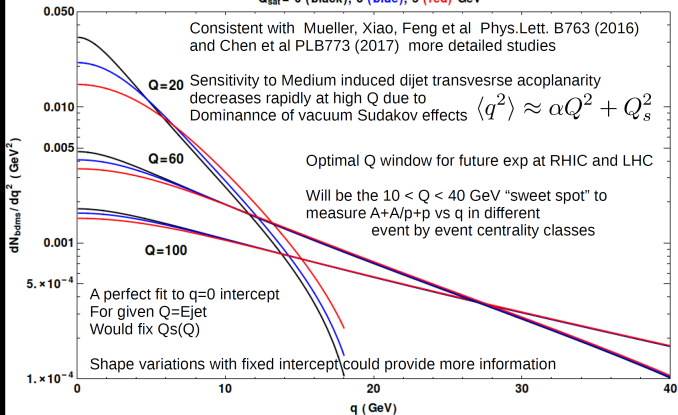
Dijet acoplanarity

MG et al QM18

One parameter, Q_s , BDMS medium convoluted with Sudakov dijet transverse distributions

Hadron-Jet Vac ⊗ BDMS dN_{bdms}/dq^2 vs q for $Q = 20, 60, 100$ GeV

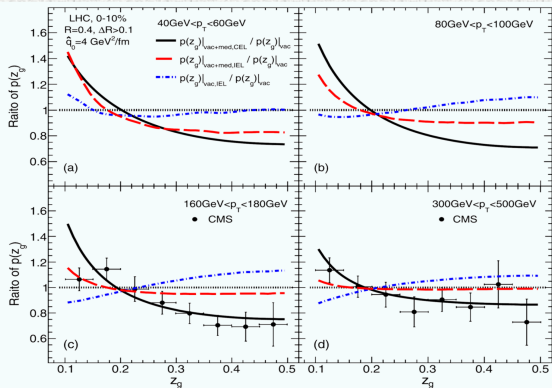
$Q_{sat} = 0$ (black), 3 (blue), 5 (red) GeV



Acoplanarity measurements could prove to be important in falsifying competing models.

Coherent/Incoherent jet energy loss

Coherent vs. incoherent energy loss



Only **CEL** can describe current experimental data.

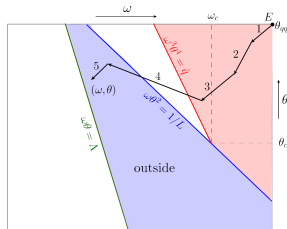
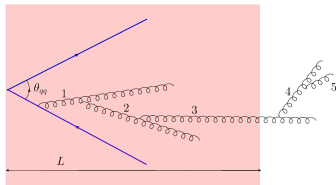
15

Non-monotonic p_T dependence favours coherent jet energy loss picture.

VLE in medium

First emission outside the medium

- The respective formation time is necessarily large: $t_f \gtrsim L$
- An antenna with opening angle $\theta \gg \theta_c$ loses coherence in a time $t_{\text{coh}} \ll L$



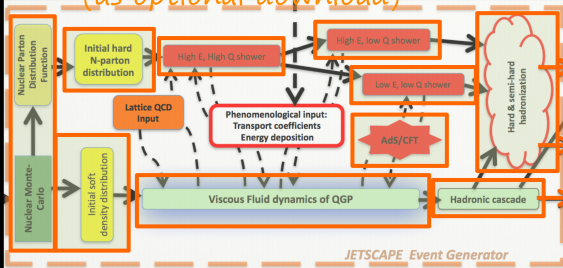
- In-medium sources lose color coherence and can also radiate at larger angles
- After the first “outside” emission, one returns to angular-ordering, as usual
- Medium effects at DLA (leading twist):
vetoed region + lack of angular-ordering for the first “outside” emission

Vacuum like emissions in the medium could affect jet shape.

Release of JETSCAPE 1.0

Program

- ❖ What's included in the event generator
(as optional download)



5/16/18

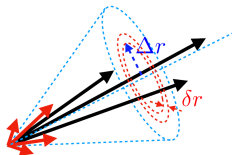
Kauder - JETSCAPE 1.0 -
QM2018

- ✓ Trento (2+1)
- ✓ Free Streaming
- ✓ MUSIC (2+1, 3+1), external reader, brick, Gubser,
- ✓ Pythias, parton gun
- ✓ MATTER, Martini, AdS/CFT, LBT
- ✓ Cooper Frye
- ✓ Pythias string fragmentation
- ✓ Custom and 6 HepMC output

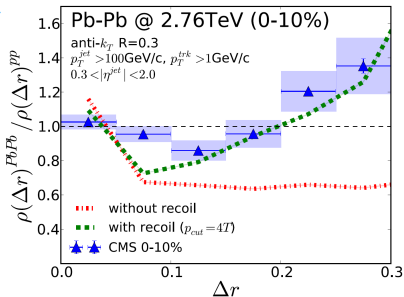
The release of JETSCAPE 1.0.

Jet shape with recoil

$$\rho(\Delta r) = \frac{1}{\delta r} \frac{1}{N^{jet}} \sum_{jet} \frac{\sum_{track \in [\Delta r - \delta r/2, \Delta r + \delta r/2]} p_T^{track}}{p_T^{jet}}$$



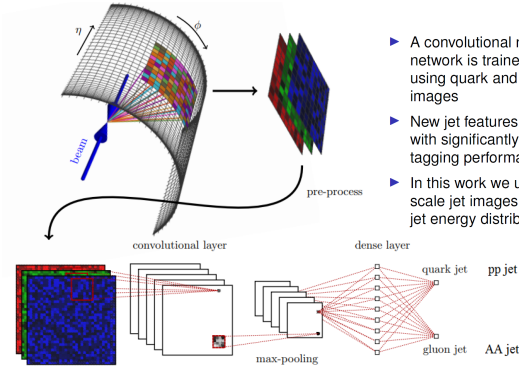
- The ratio shows flat shape without recoil.
- Recoil yields a significant contribution to the jet shape at large angles.



Recoil effect is important in describing jet mass and shape in MARTINI, which is included in JETSCAPE.

Using deep learning for q, g classification

Image recognition using convolutional neural network



- ▶ A convolutional neural network is trained on GPU using quark and gluon jet images
- ▶ New jet features are learned with significantly improved tagging performance
- ▶ In this work we use grey scale jet images encoding jet energy distribution

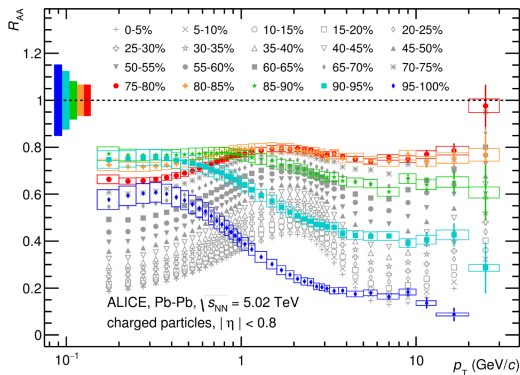
Schwartz et al, Deep learning in color, JHEP01(2017)110

Non-monotonic p_T dependence favours coherent jet energy loss picture.

ALICE R_{AA} puzzle (1)

R_{AA} in very peripheral collisions (1)

M. Kniehl, Tue 10:20



→ R_{AA} measured in very fine centrality bins up to very peripheral.

→ Significant change of behavior found beyond 80% centrality.

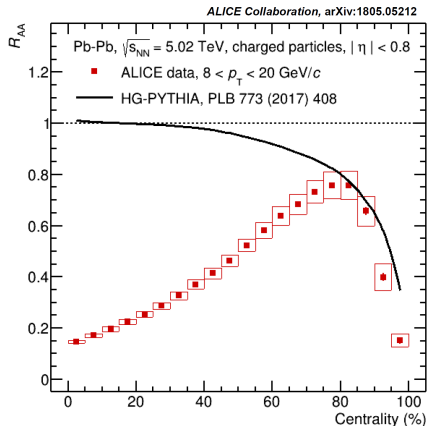
→ Can be explained by biases induced by event selection and collision geometry.

27

Suppression of very peripheral AA collisions found.

ALICE R_{AA} puzzle (2)

R_{AA} at large p_T



- R_{AA} averaged over $8 < p_T < 20$ GeV/c as function of centrality
- central collisions: strong quenching, reduced towards peripheral collisions
- minimal suppression (maximal R_{AA}) around 80%
- beyond 80% centrality: increased suppression because of selection bias

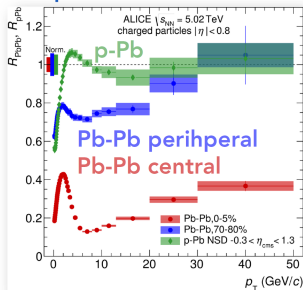
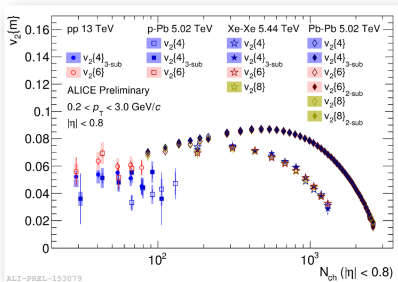
- R_{AA} never reaches unity
- HG-PYTHIA contains no nuclear effects
 - ⇒ no need for jet quenching above 75% centrality
 - ⇒ 5-10% effect for 50-60% central

suppression can be mimic by model without quenching.

ALICE QPG droplet puzzle

R_{AA} and v_2 in peripheral Pb-Pb and p-Pb

[arXiv:1802.09145]



- v_2 is very pronounced in peripheral Pb-Pb and at similar multiplicities in p-Pb.
- However, while no significant nuclear modification is observed in p-Pb, it is still significant in peripheral Pb-Pb. Is there a contradiction? **Not necessarily!**
- In the current understanding, both phenomena arise from the **same QCD interaction kernel**.

26

small system R_{AA} consistent with unity, but have non-zero collectivity?

A fruitful conference

