Quark Matter 2018 overview

What I've learnt in this conference

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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

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INITIAL STATE PHYSICS

Why Initial State Physics?

Understanding initial state fluctuations:

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

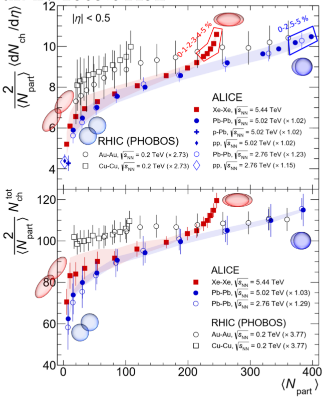
Need to probe partonic distributions within the nucleon/nucleus. How?

- 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

$\frac{2}{\langle N_{\rm part}\rangle}\langle {\rm d}N_{\rm ch}/{\rm d}\eta\rangle$ and $\frac{2}{\langle N_{\rm part}\rangle}N_{\rm ch}^{\rm tot}$ as a function of $\langle N_{\rm part}\rangle$

arXiv:1805.04432



Data are scaled to $\sqrt{s}$, $\sqrt{s_{\rm NN}}$ = 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 ⟨Npart⟩ for the top 10 % central collisions
  - RHIC data show hint of same behaviour

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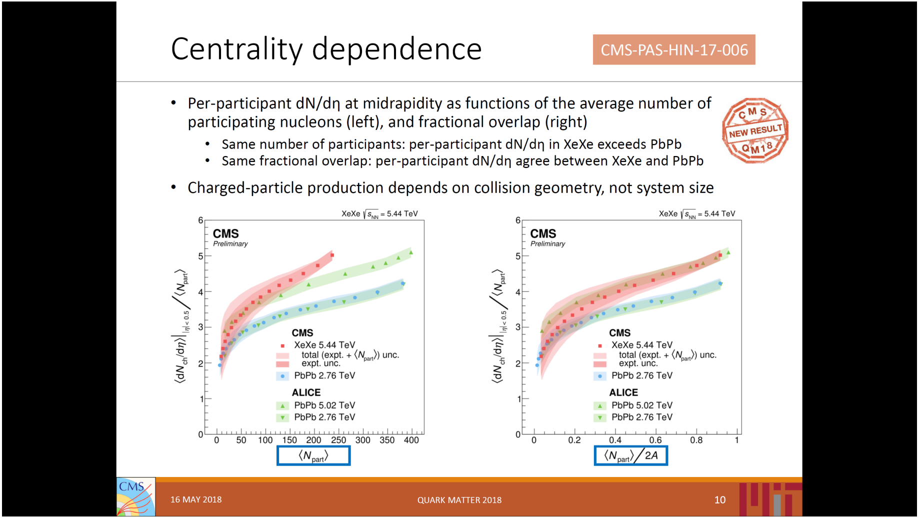
scale violation of charged multiplicity for different systems at similar N_{part}.

CMS Xe-Xe measurement



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

ALICE J/Ψ measurement

Exclusive J/ψ photoproduction in p-Pb

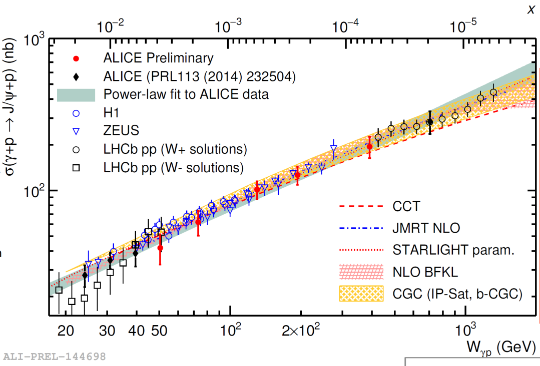
CCT
energy-dependent hot spot model
PLB766 (2017) 186

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

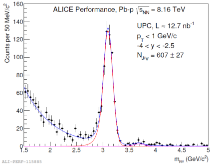
STARLIGHT
Parameterization of HERA and fixed-target data
CPhC 212 (2017) 258

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

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



New RUN2 data will allow ALICE to explore the region above 1 TeV:



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Good description by all models

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

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model consistent with data with or without saturation effect.

LHCb J/Ψ measurement

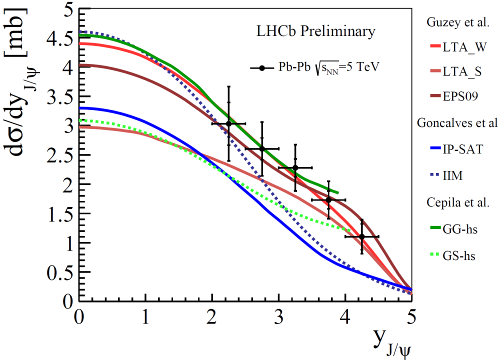
analysis *result*

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

large rapidity acceptance, coherent collision.

CMS $\Upsilon(1S)$ measurement

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

CMS-FSQ-13-009

- Differential cross section estimated

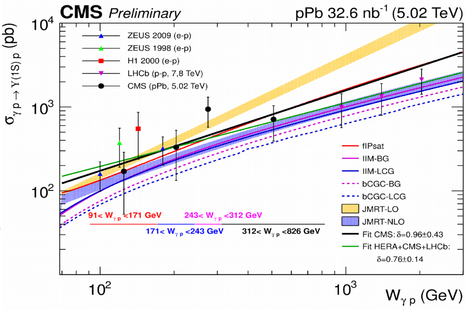
$$\frac{d\sigma_{\Upsilon(nS)}}{dy}\mathcal{B}_{\Upsilon(nS)\to\mu^+\mu^-} = \frac{N^{corr}_{\Upsilon(nS)}}{\mathcal{L}\times\Delta y}.$$

$$W^2_{\gamma p} = 2E_p m_\Upsilon \exp(\pm y)$$

- The differential Υ(1S) cross-section extracted by correcting for branching ratio, feed-down, Υ(1S) fraction
- The cross-section as a function of $W_{\gamma p}$ is estimated by

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

- A fit with power-law **A X ($W_{\gamma p}$/400)$^\delta$** to the CMS data gives,
  δ = 0.96 ± 0.43
  A = 655 ± 196 pb
- ZEUS: δ = 1.2 ± 0.8
  Phys.Lett. B680 (2009) 4

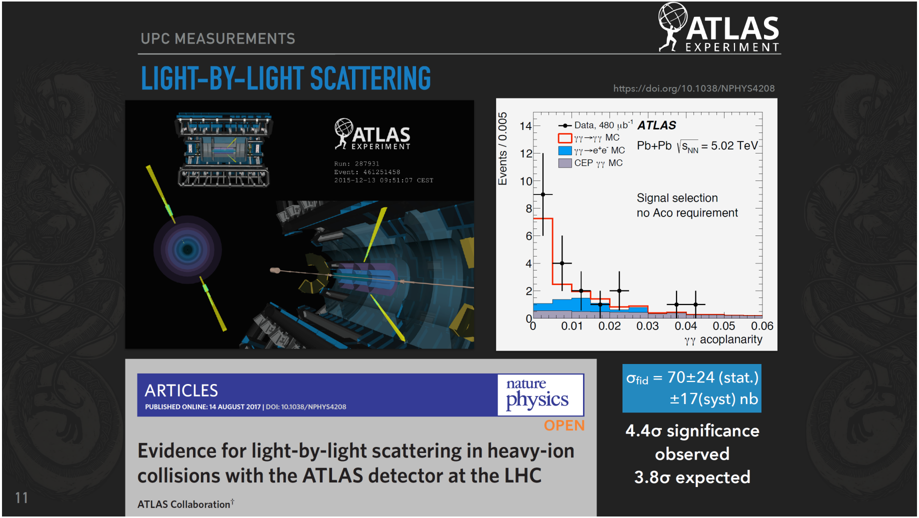


Data compatible with power-law dependence of $\sigma(W_{\gamma p})$, disfavours (fast rising) LO pQCD predictions

Ruchi Chudasama (BARC, Mumbai) 10

compatible with HERA data and pQCD predictions.

ATLAS Light-by-Light measurement

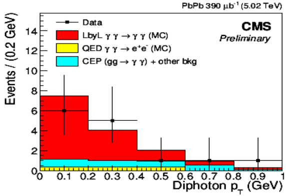


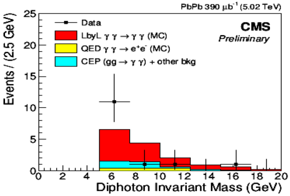
strong QED proof.

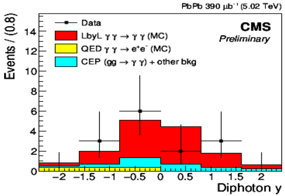
CMS Light-by-Light measurement

γγ differential distributions (after LbyL cuts)

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







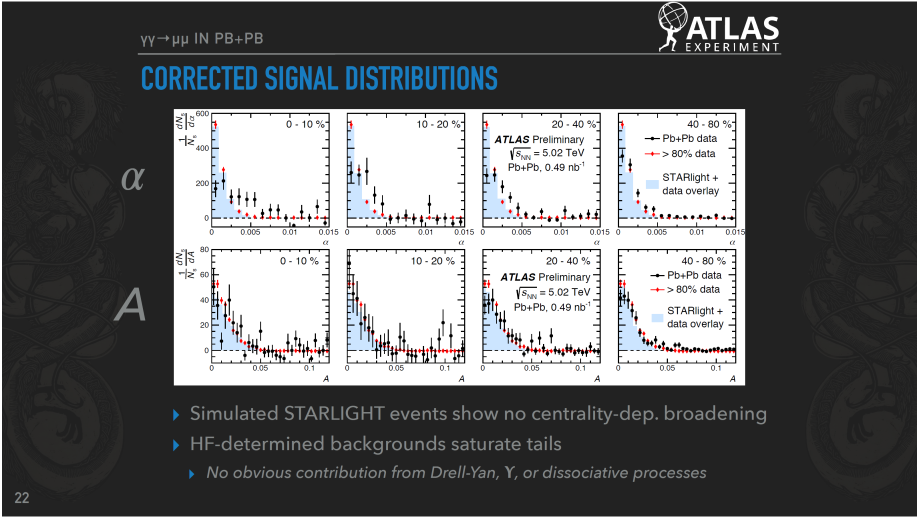
Good agreement of data with sum of MC predictions (also for cut-flow numbers):

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)

Quark-Matter'18, Venezia, May 2018 16/21 David d'Enterria (CERN)

strong QED proof.

ATLAS dimuon measurement



clear broadening but no sign of momentum imbalance.

CMS Forward/Backward dijet measurement

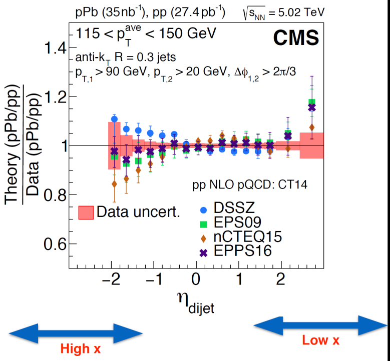
HIN-16-003

CMS FINAL QM18

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



Daniel Tapia Takaki QM 2018 – *Venice, Italy* 14 May 2018 15

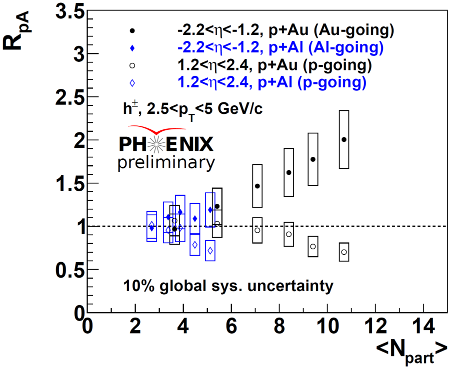
suppression of large-x gluon PDF (EMC).

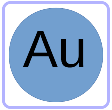
PHENIX *RpA* measurements for p-Au and p-Al

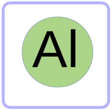
R_{pA} vs. N_{part}

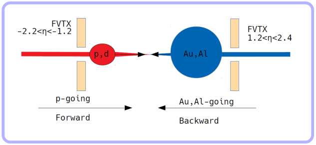
R_{pA} vs. N_{part}

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









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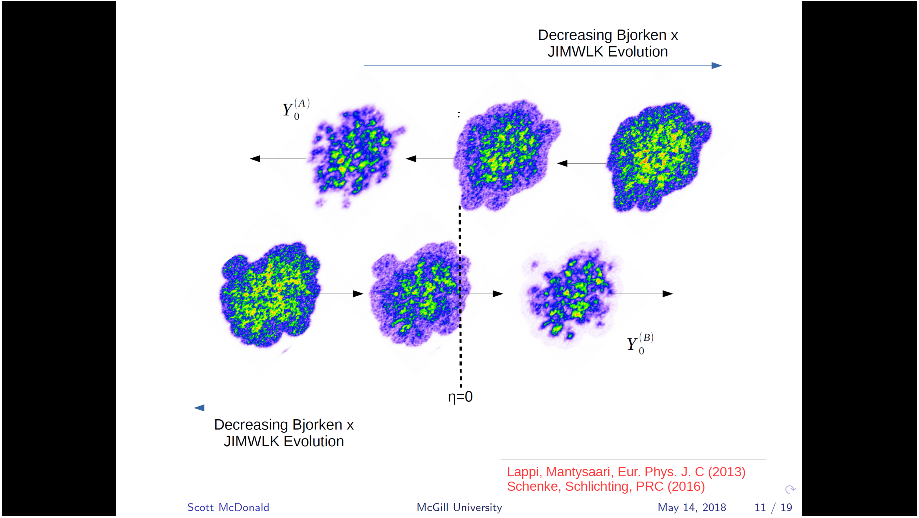
Backward (A-going, large-x) enhancement scale with N_{part}.

IP-Glasma 3+1D generalization



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

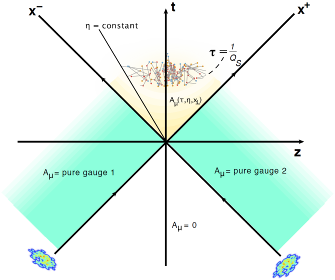
CGC+PYTHIA incorporation

CGC meets Lund String fragmentation of PYTHIA

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

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

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



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.

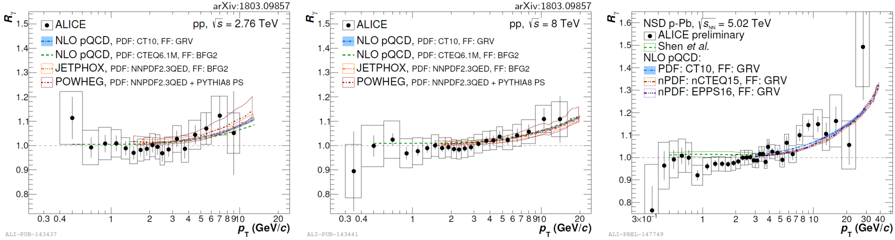
ELECTROMAGNETIC AND WEAK PROBES

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.
  $\rightarrow$ 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
  $R_{NLO} = 1 + (\gamma_{dir}^{NLO} \cdot N_{Coll})/\gamma_{dec}$
- Within uncertainties no significant excess at low p_T observed

$\rightarrow$ supports interpretation in Pb–Pb as medium effects

- About $1 - 2\sigma$ deviation from unity for $p_T > 7$ GeV/c

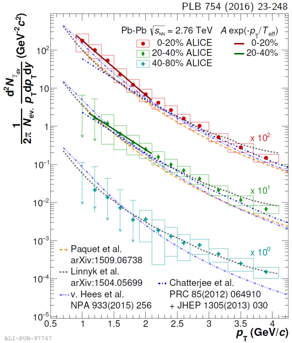
F. Bock (CERN) Direct Photons at the LHC May 14, 2018 5

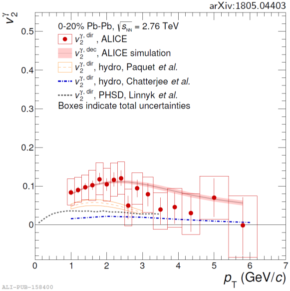
no excess in thermal region, consistent with pQCD calculations.

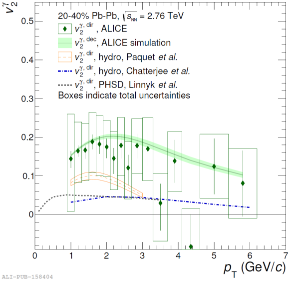
ALICE direct-photon v_2

Direct Photon Yield and Flow

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







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

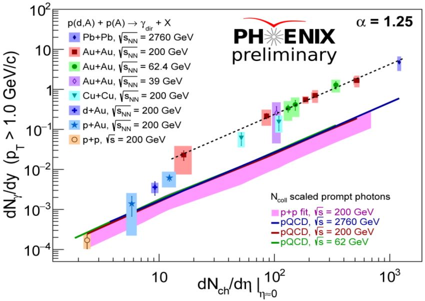
F. Bock (CERN) Direct Photons at the LHC May 14, 2018 11

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

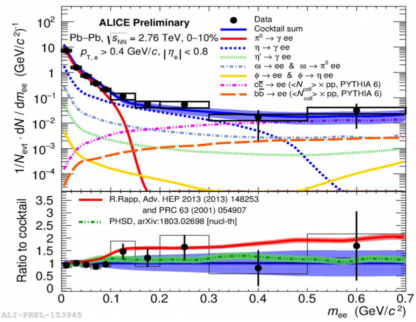


26 Vladimir Khachatryan, Quark Matter 2018, Venice

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 ρ

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

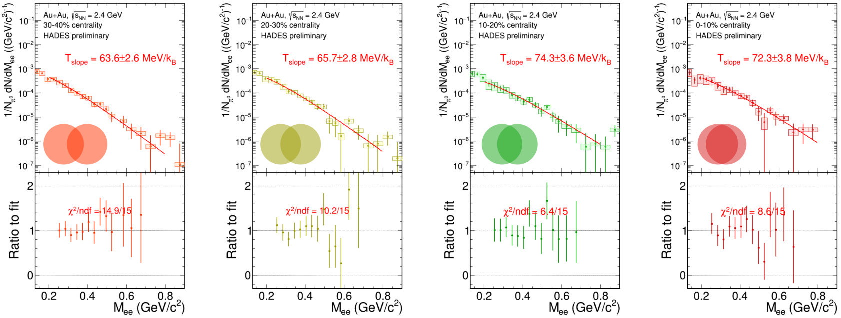
R.Rapp, Adv. HEP 2013 (2013) 148253, Phys. Rev. C63 (2001) 054907
T.Song, W.Cassing, P.Moreau, E.Bratkovskaya arXiv:1803.02698 [nucl-th]

cocktail of di-electron production consistent with simulation.

HADES $\gamma^* \to e^+e^-$ measurement

Fit to the invariant mass in centrality bins

Total e+e– yield

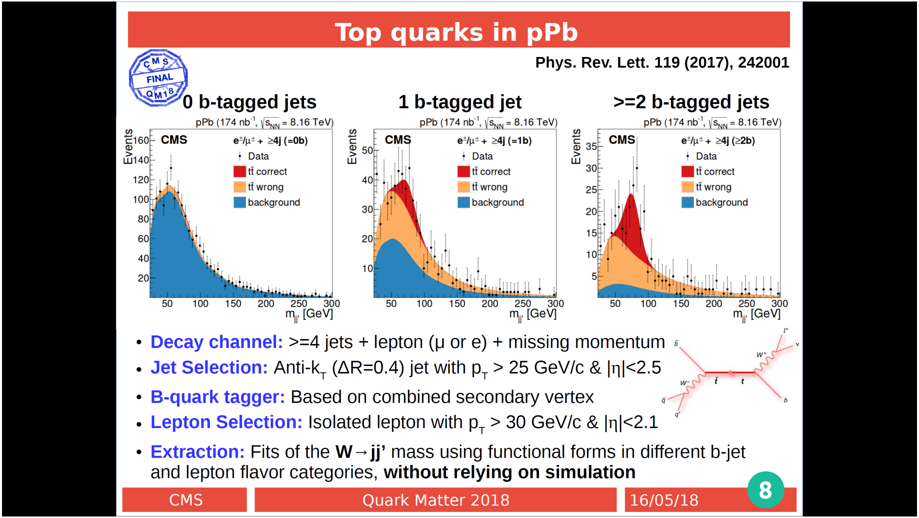


Hotter radiation source in more central collisions

5/31/2018 | Quark Matter 2018, Venice | Szymon Harabasz | 8

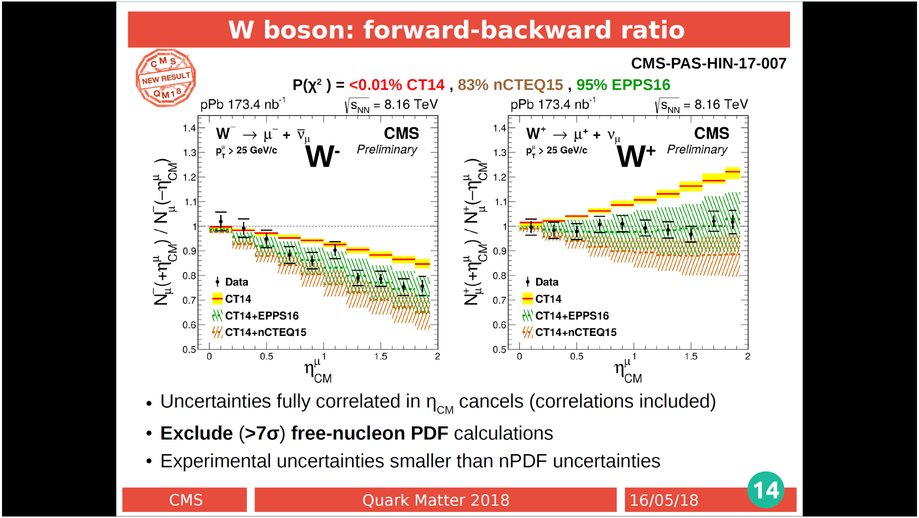
di-electron yield measurement for different sources of photon production.

CMS top quark measurement



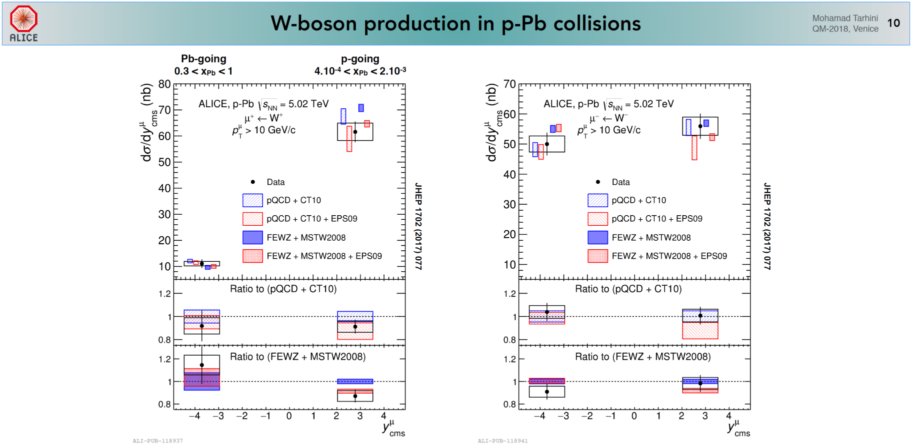
first CMS observation for top quark in pPb, probe gluon nuclear distribution.

CMS W-boson measurement



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

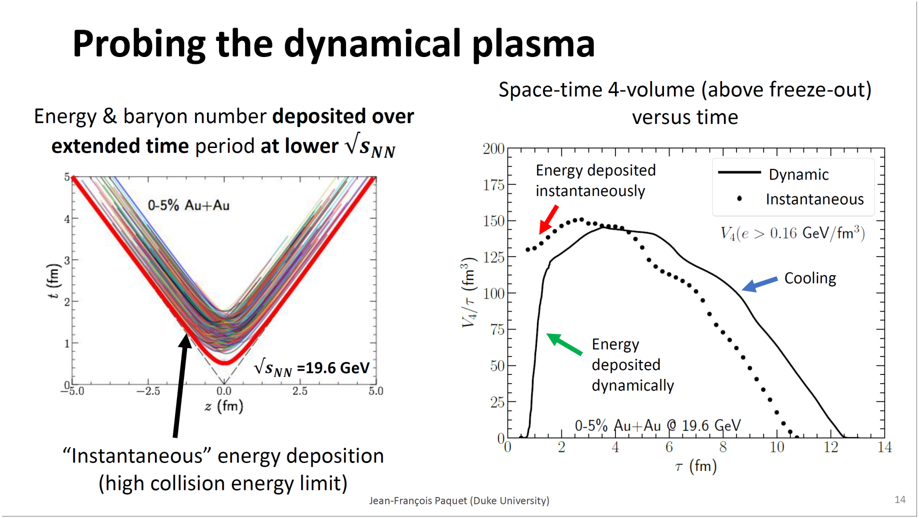
ALICE Electroweak boson measurement



- 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.

Thermal photon study



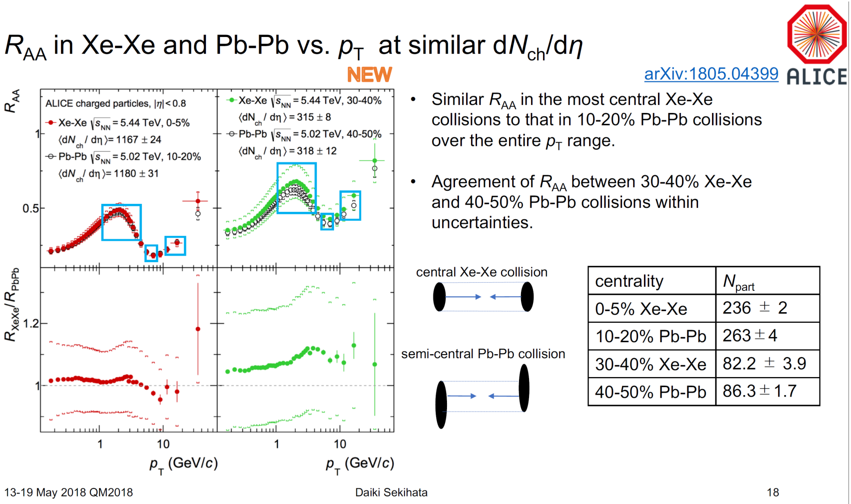
Significant thermal photon at low collision energies using dynamically initialized hydro profile.

JET MODIFICATION AND HIGH-P_T HADRONS

Why Jets?

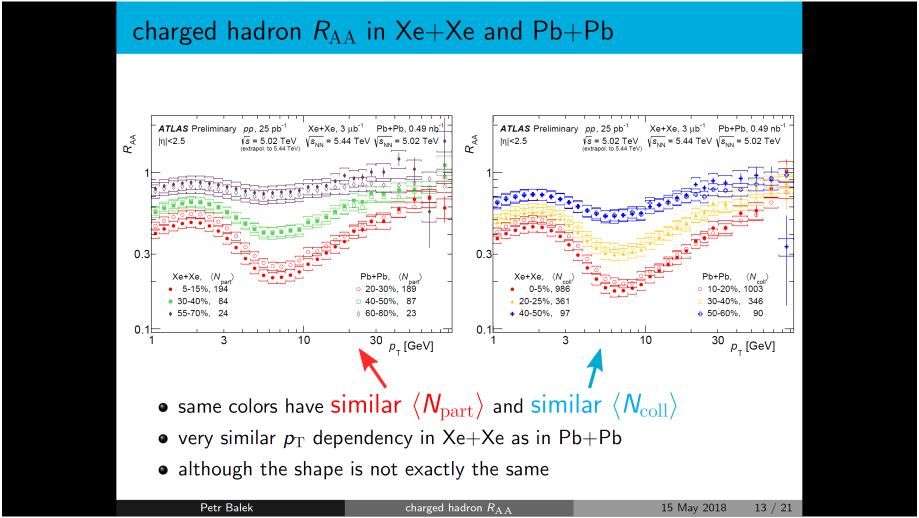
- R_{AA} - smoking gun for QGP formation
- EM jets - probes the coloured medium unaffected, calibrate away-side jet energy
- jet correlations ($\Delta\phi$, x_J) - probes medium effect and transport coefficient via broadening and energy-loss.
- jet fragmentation function - medium response

ALICE R_{AA} measurement



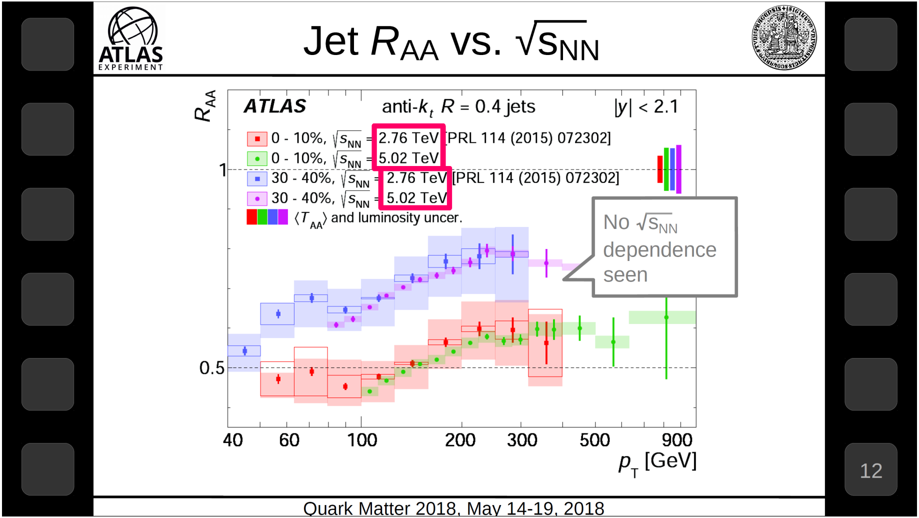
New R_{AA} measurement for Xe-Xe and Pb-Pb (similar multiplicity) showing the effect of Cronin and suppression.

ATLAS R_{AA} measurement



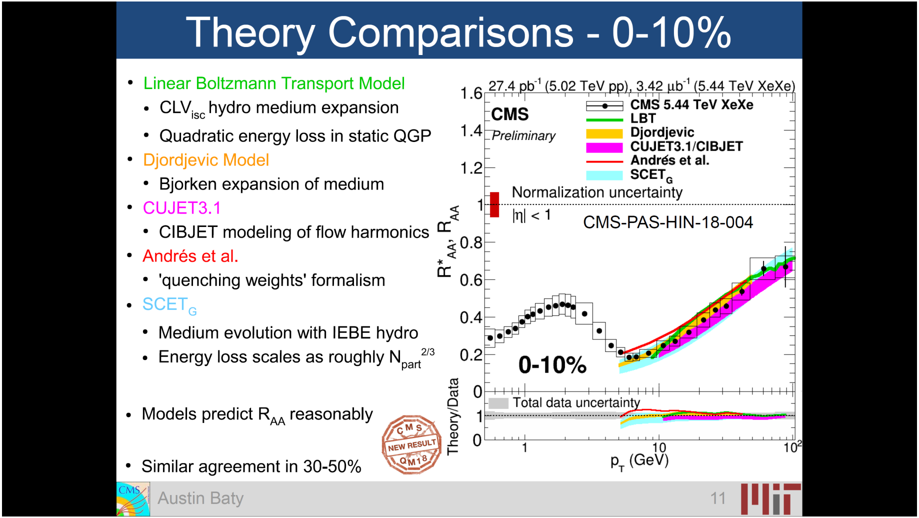
R_{AA} scales with $\langle N_{part} \rangle$ or $\langle N_{coll} \rangle$.

ATLAS R_{AA} measurement



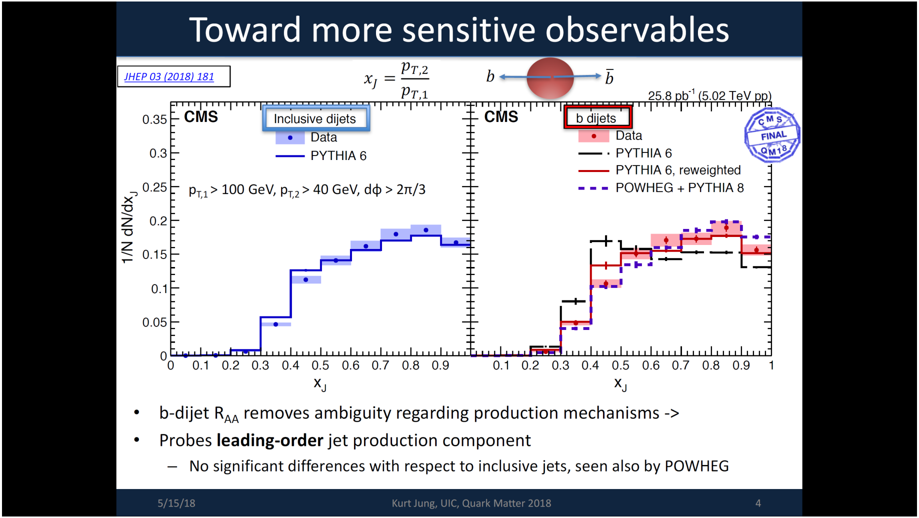
R_{AA} have no dependence on beam energy.

CMS R_{AA} measurement



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

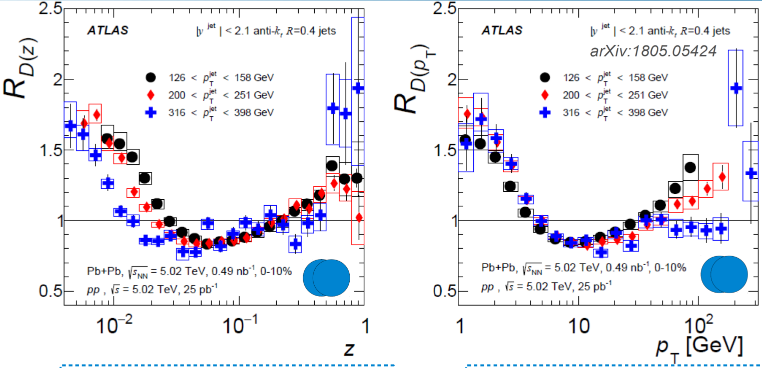
CMS b-jet measurement



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

ATLAS Jet-FF measurement

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.

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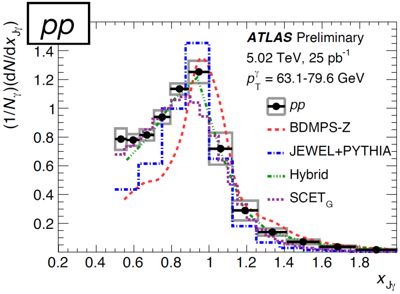
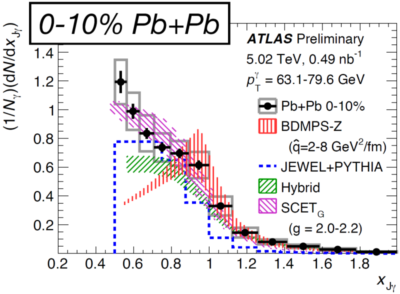
Soft and hard fragments are enhanced in *AA* compared to *pp*

ATLAS $x_{j\gamma}$ measurement

Direct comparisons to theory (no smearing)





Test description of vacuum (*pp*) baseline

Can models describe centrality / p_T^γ evolution?

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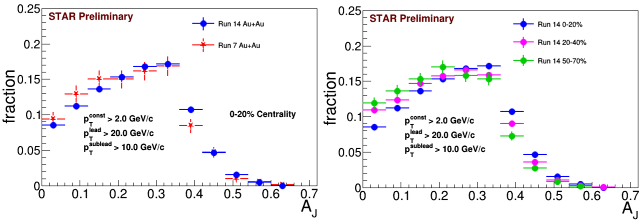
unfolded $x_{j\gamma}$ distribution agree directly with unsmeared theoretical prediction.

STAR A_J measurement

Centrality Dependence of A_J

RUN7: STAR *PRL 119, 062301 (2017)*

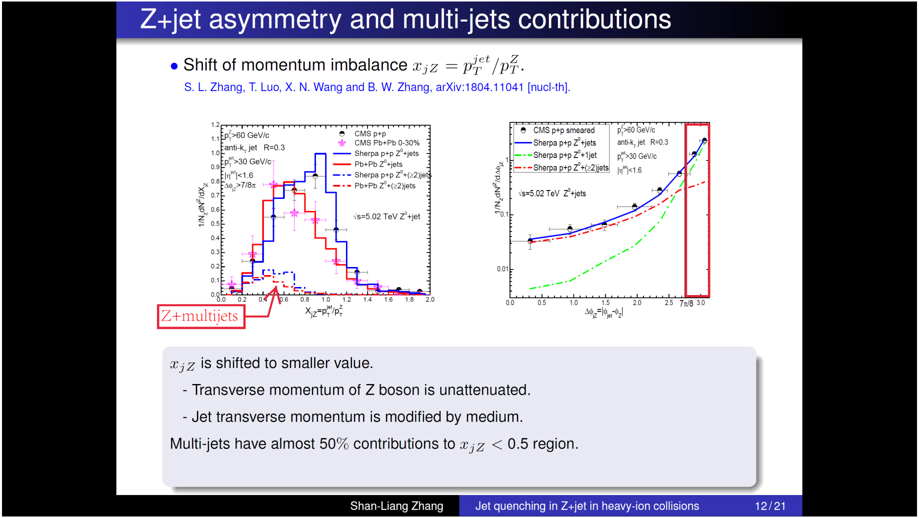


- Comparable between Au+Au Run 14 and Run 7 in 0-20% centrality (detector level)
- Run14: large increase in statistics
  →enable to study centrality dependence
- Apparent evolution of A_J to more balanced jets in peripheral Au+Au collisions

Kun Jiang Quark Matter 2018, Venice, Italy 5

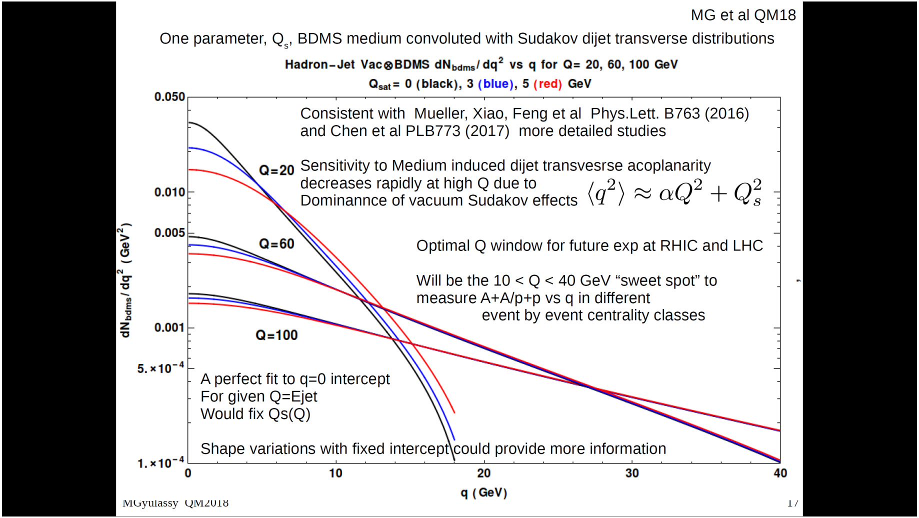
STAR dijet measurement with centrality dependence.

Z-jet with Sherpa+LBT



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

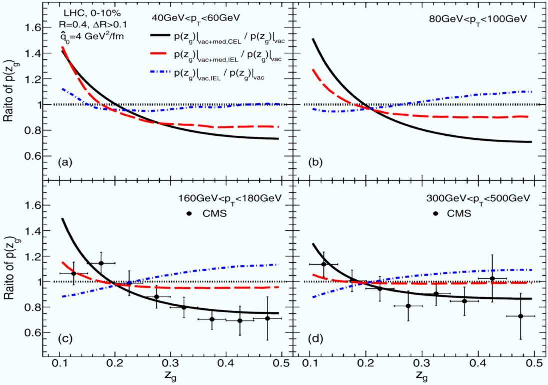
Dijet acoplanarity



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

Coherent/Incoherent jet energy loss

Coherent vs. incoherent energy loss



Only CEL can describe current experimental data.

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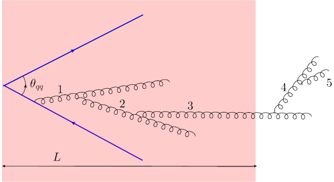
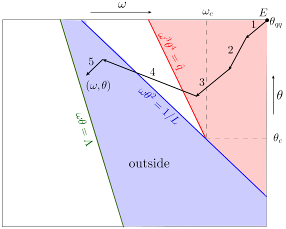
Non-monotonic p_T dependence favours coherent jet energy loss picture.

VLE in medium

First emission outside the medium

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



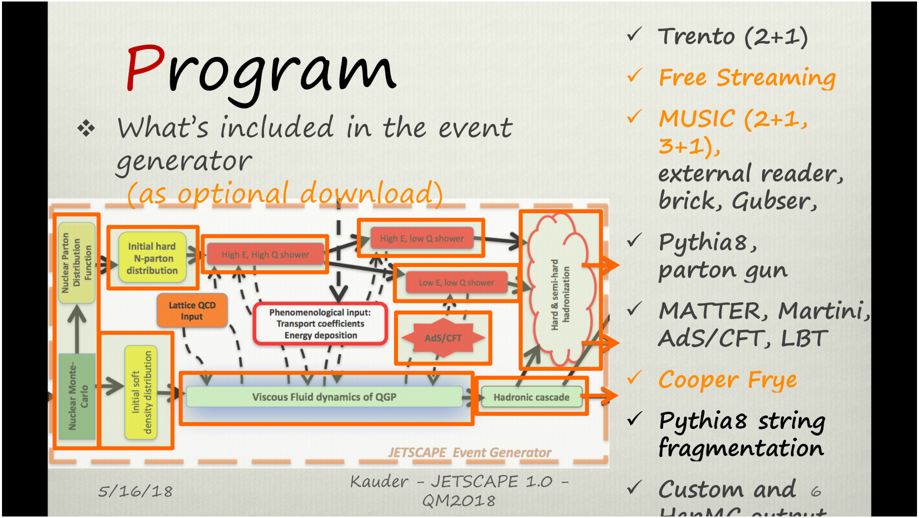


- In-medium sources lose color coherence and can also radiate at larger angles
- After the first "outside" emission, one returns to angular-ordering, as usual
- Medium effects at DLA (leading twist):
  vetoed region + lack of angular-ordering for the first "outside" emission

27th Quark Matter, Venezia, 2018 Vacuum-like emissions in a dense medium Edmond Iancu 15 / 24

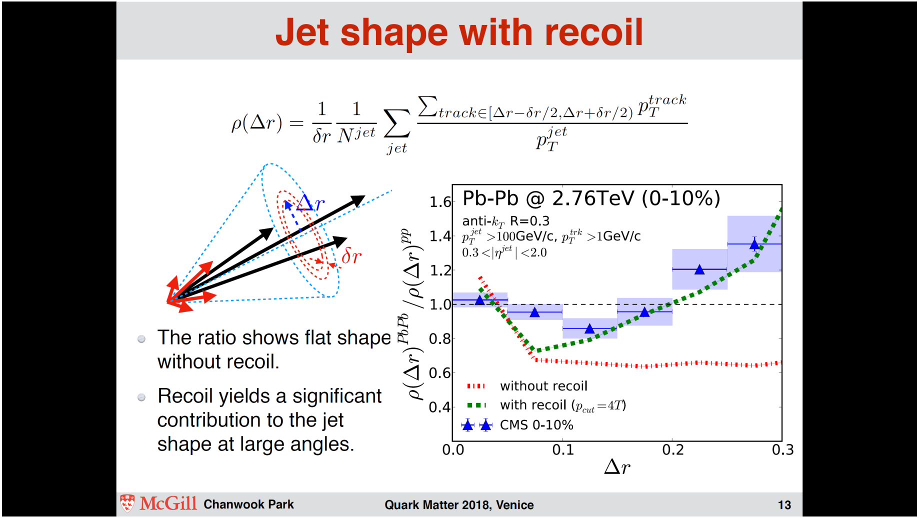
Vacuum like emissions in the medium could affect jet shape.

Release of JETSCAPE 1.0



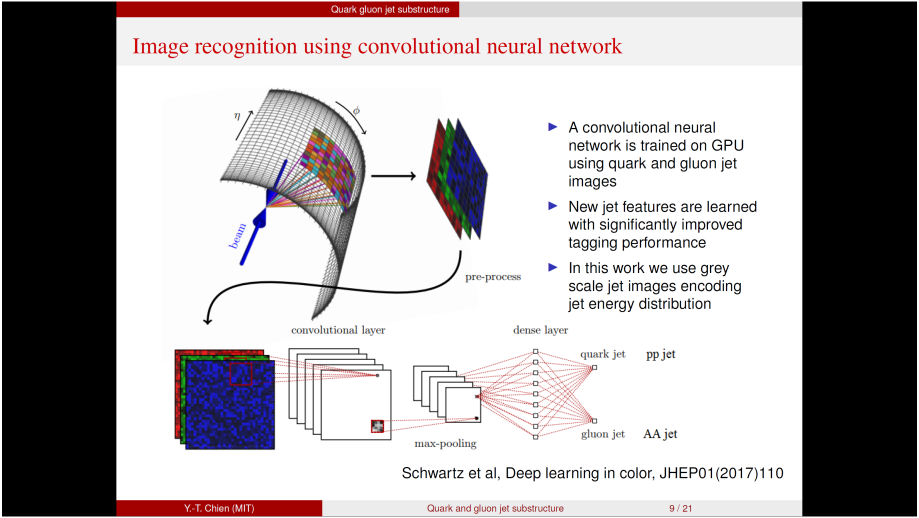
The release of JETSCAPE 1.0.

Jet mass and shape with MARTINI



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

Using deep learning for q, g classification

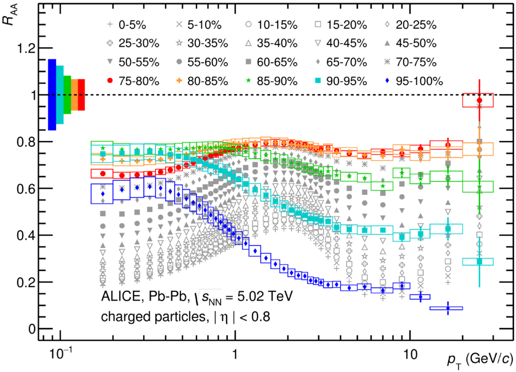


Non-monotonic p_T dependence favours coherent jet energy loss picture.

ALICE R_{AA} puzzle (1)

R_{AA} in very peripheral collisions (1)

M. Knichel, 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.

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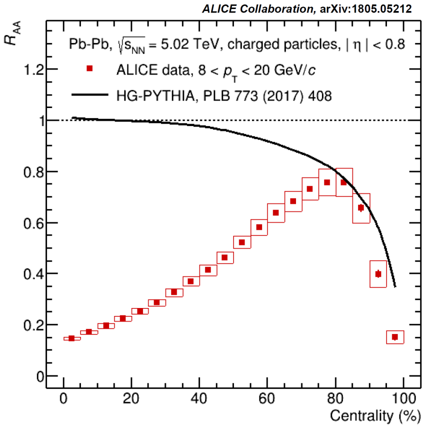
Suppression of very peripheral *AA* collisions found.

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

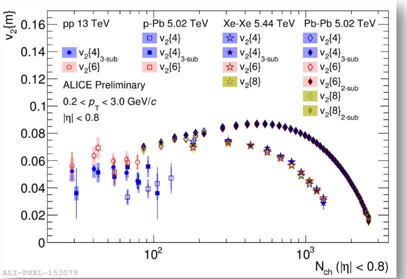
⇒ 5-10% effect for 50-60% central

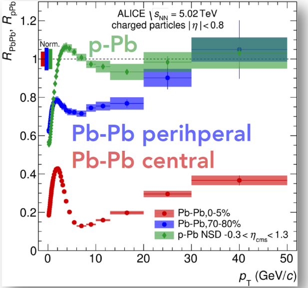
suppression can be mimic by model without quenching.

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.

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

A fruitful conference