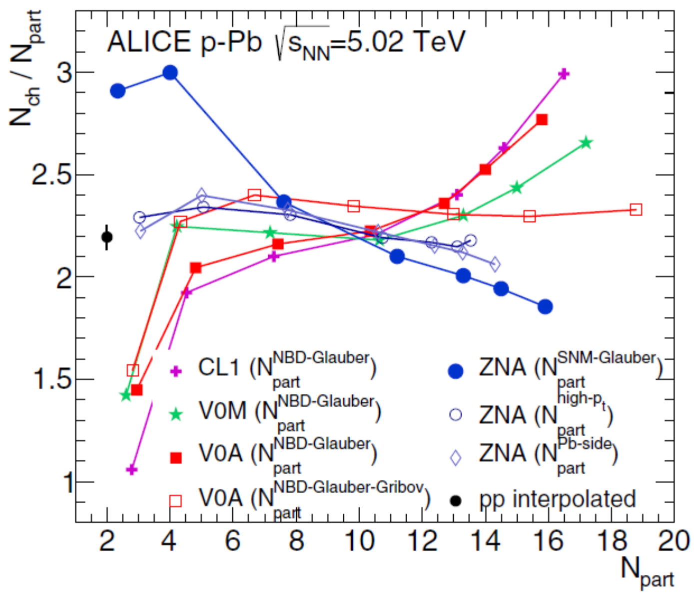
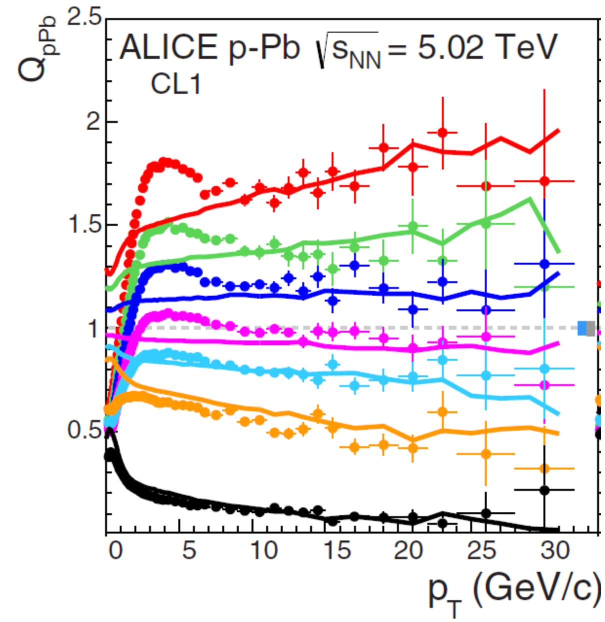
Figures from ALICE: Phys. Rev C 91 (2015) 064905





Ideas for a data driven model for dN/dη and high p_T production in p-Pb collisions based on pp data

P. Christiansen (Lund University)

Big and small questions

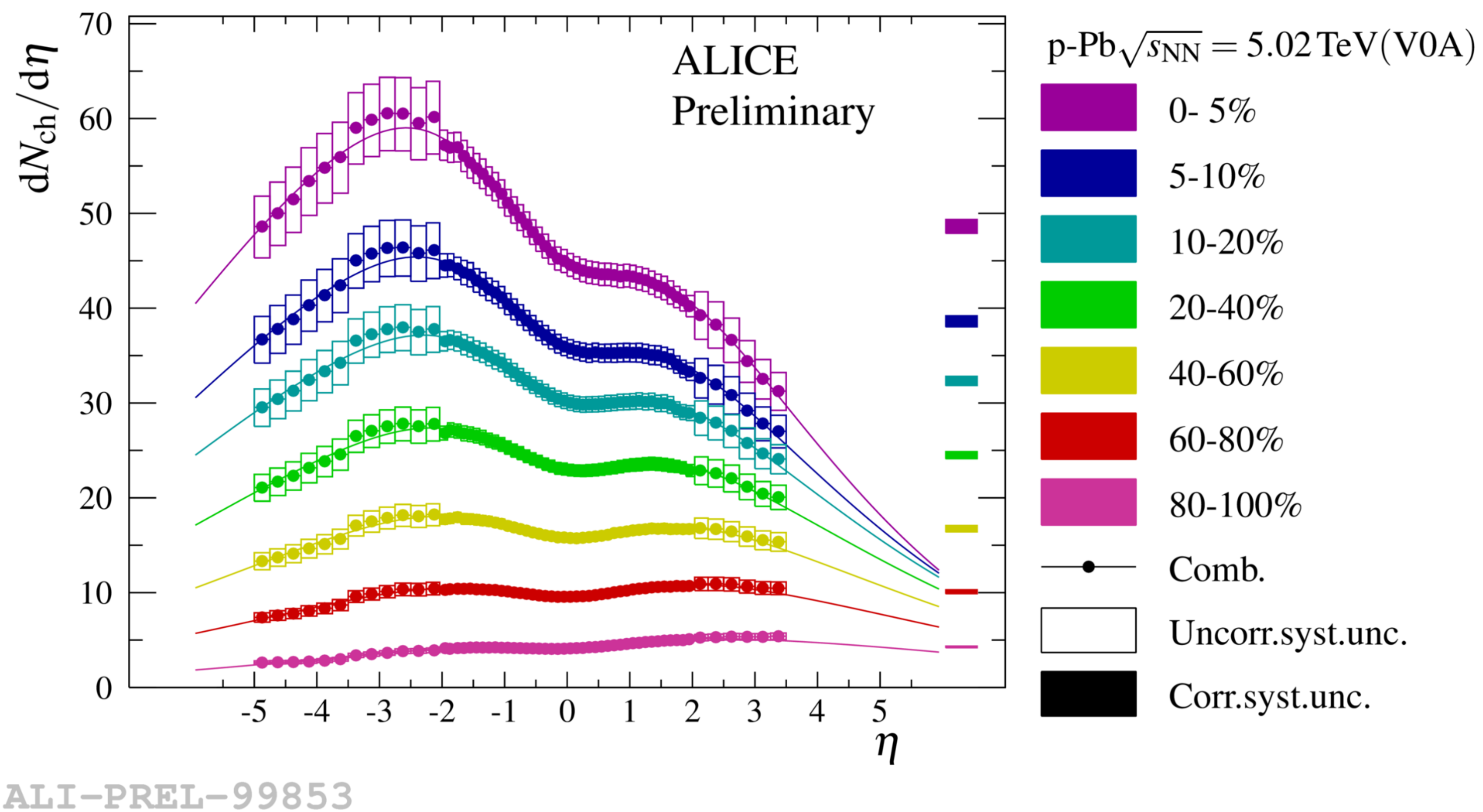
- Ridges in Pb-Pb, p-Pb, and pp collisions can be explained in terms of a common origin (hydrodynamics)
- **Big question: is a unified phenomenological modelling of the (UE in the) 3 systems possible?**
  - Pb-Pb success with strongly coupled macroscopic picture: initial medium, hydrodynamics, thermal model hadronization
  - pp success with weakly coupled microscopic picture: parton-parton scatterings, radiation, and strings ("building pp from ee→ qq")
    - Alternative descriptions: pp physicists models with color reconnection what Pb-Pb physicists models with radial flow
  - p-Pb seems to be a good place to start to test the idea of a unified modelling and dN/dη and Q_{pPb} seems good observables (covers soft bulk production and hard processes)
    - **Small question: can we get a simple modelling of these observables in p-Pb collisions?**

Outline

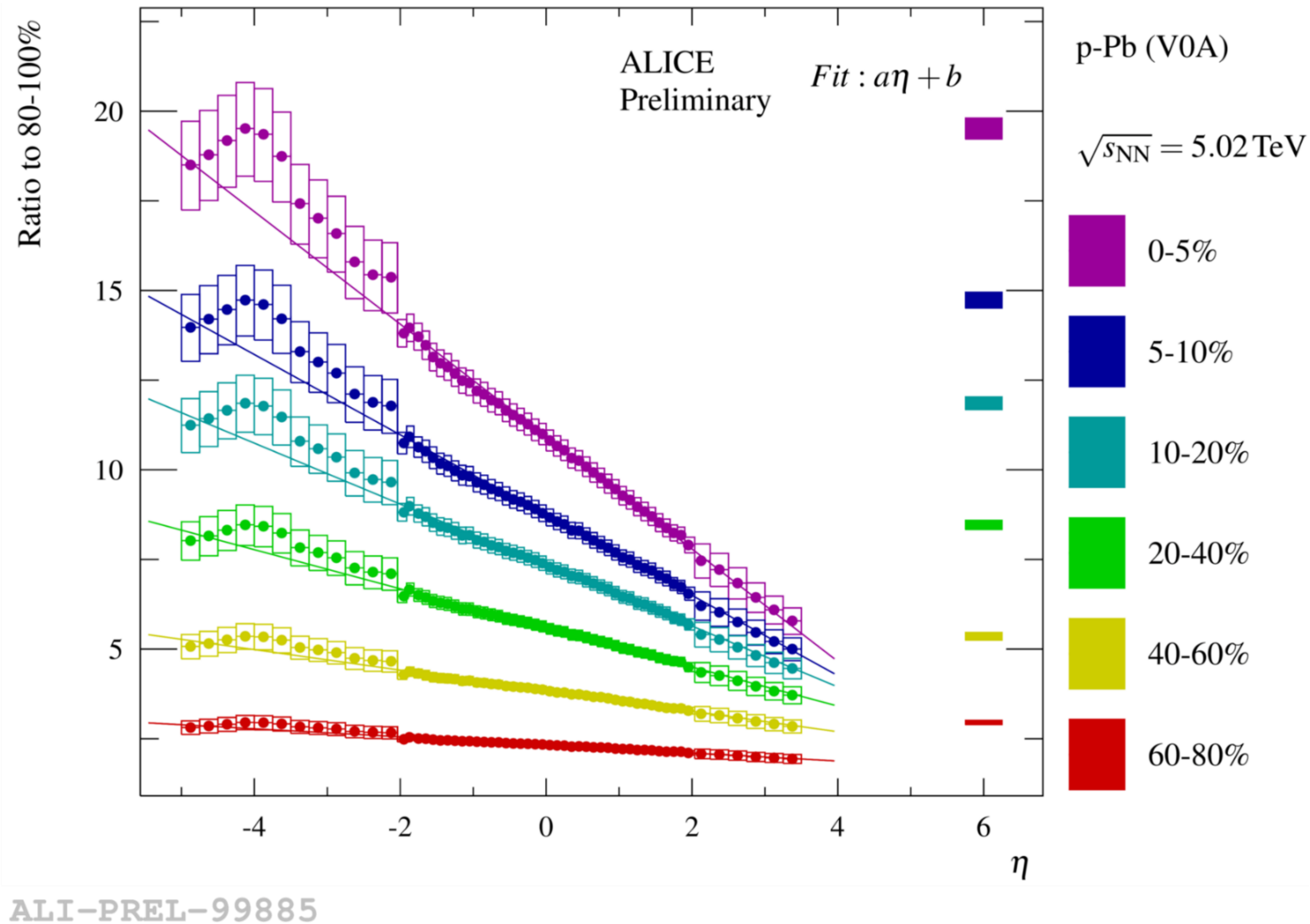
- Approach (will be explained): mix Glauber calculations (Pb-Pb side) with "factorized" pp events inspired by an old model of Brodsky, Gunion, and Kuhn

- Problem 1 (dN/dη): multiplicity fluctuations and long range correlations
  - Simple model based on Lund-string-like objects
- Problem 2 (Q_{pPb}): soft-vs-hard biases
  - Chopped up PYTHIA events as a proxy for a data-driven model

dN/dη in p-Pb collisions



dN/dη in p-Pb collisions relative to low multiplicity collisions



Reminiscent of triangles!

Origin of the triangle (?)

Slide from:
http://indico.cern.ch/event/223909/contribution/11/attachments/367751/511867/MGyulassy-MIT051713v2.pdf

Recalling BGK p+A "Rapidity Triangle"

- Multiple independent wee parton dx/x collisions produce ~uniform in rapidity color charges between valence p and valence wounded A.
- Color neutralizes via pair production between wee and valence partons
-
- Leaves a stack of
- $A^{1/3} \sim 10$ Target beam jets
- For rare Nch~300 maybe 30 Pb nucleons line up
- There is just 1 Proj beam jet
-
- Y *Slope* δ = Ntr / log(s)
- RHIC $\delta \sim 2 \times$ LHC δ

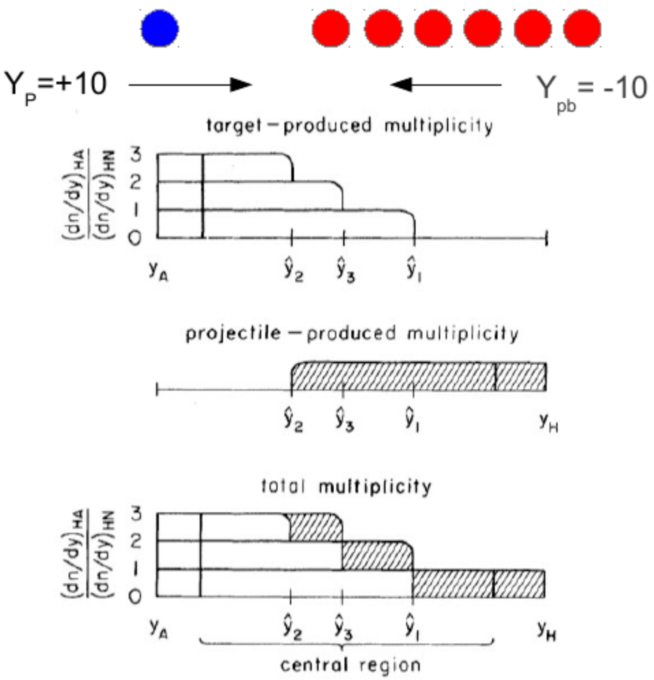


Figure from Brodsky, Gunion, Kuhn 1977

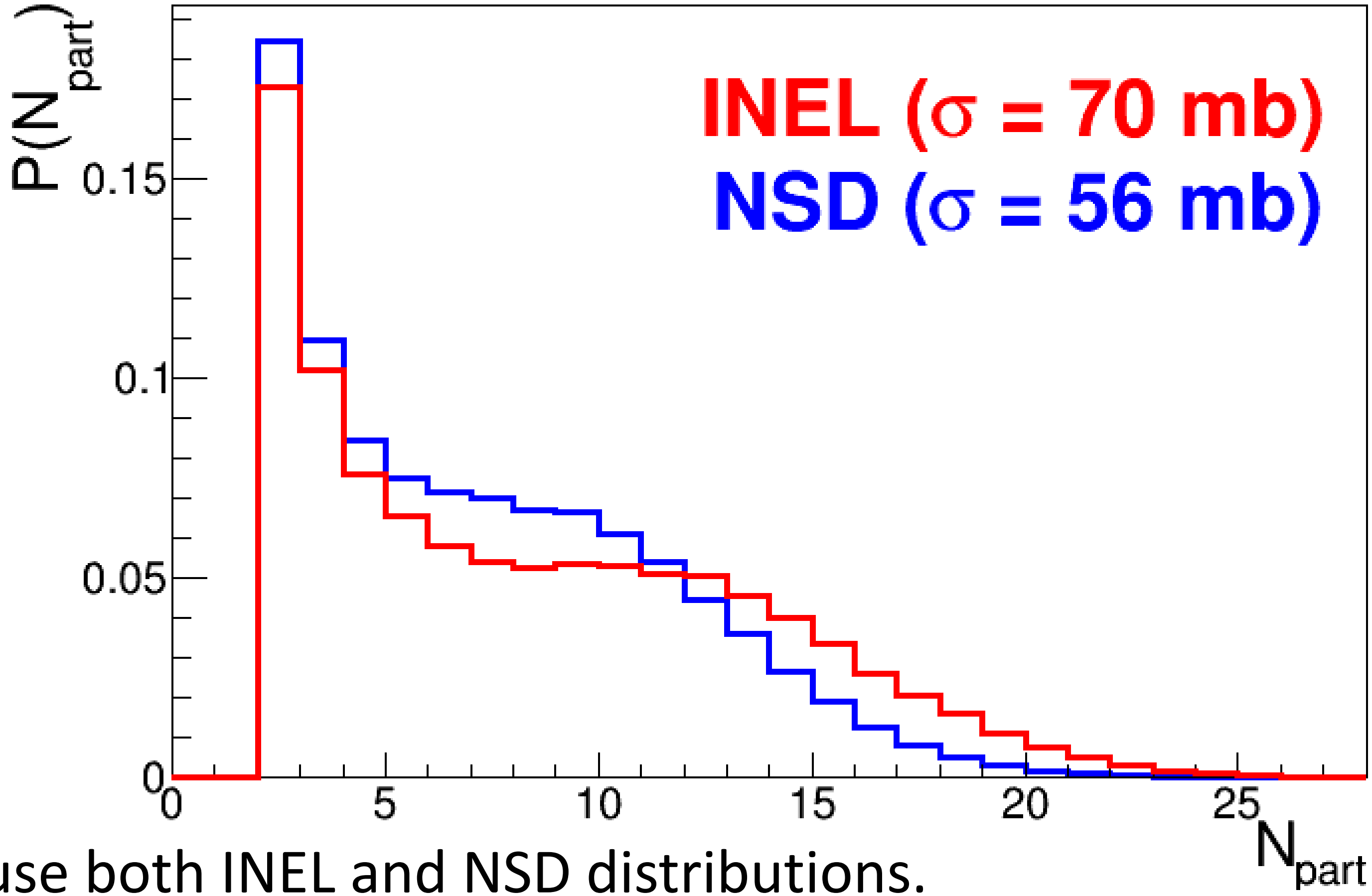
http://journals.aps.org/prl/pdf/10.1103/PhysRevLett.39.1120

I want to construct simple models based on this idea that particle production factorizes into a sum of "triangles"!

p-Pb collisions with a Glauber perspective (details follows)

- Glauber: $N_{part(icipants)}$ and $N_{coll(illisions)}$
  - For p-Pb it is very simple: $N_{part} = N_{coll}+1$
- Fold with Negative Binomial Distribution (NBD) to account for multiplicity fluctuations to be able to describe the experimental centrality estimator
- **Problem 1: what N_{part} do we assign to take into account NBD fluctuations?**
  - UA5: Forward-Backward long range correlations → so if the NBD fluctuates up we on average have higher multiplicity everywhere

The p-Pb ingredient: N_{part} from a Glauber calculation

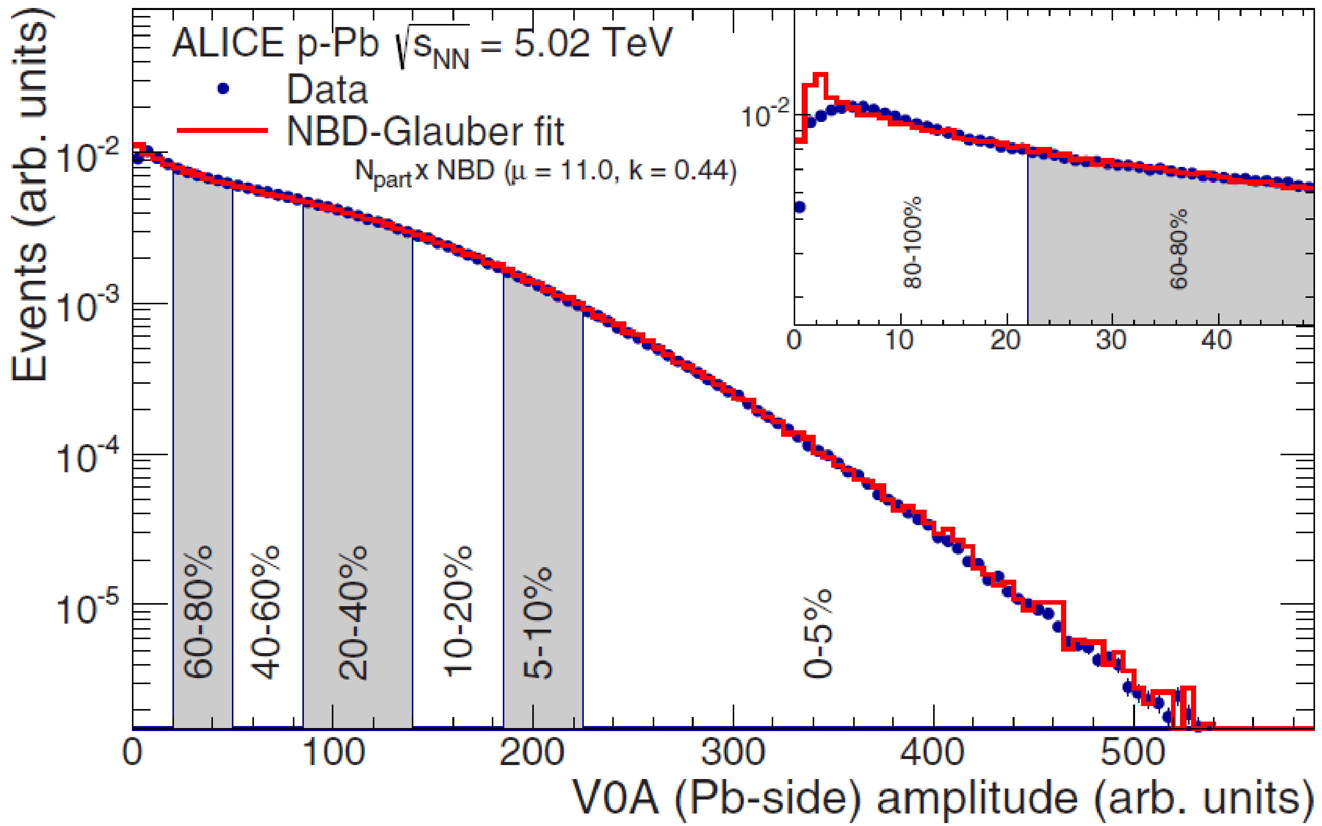


I will use both INEL and NSD distributions.

I think one should explore this a bit also experimentally as one quotes that p-Pb results are for NSD events (and supposedly ND collisions dominates particle production)

Estimating N_{part} in data

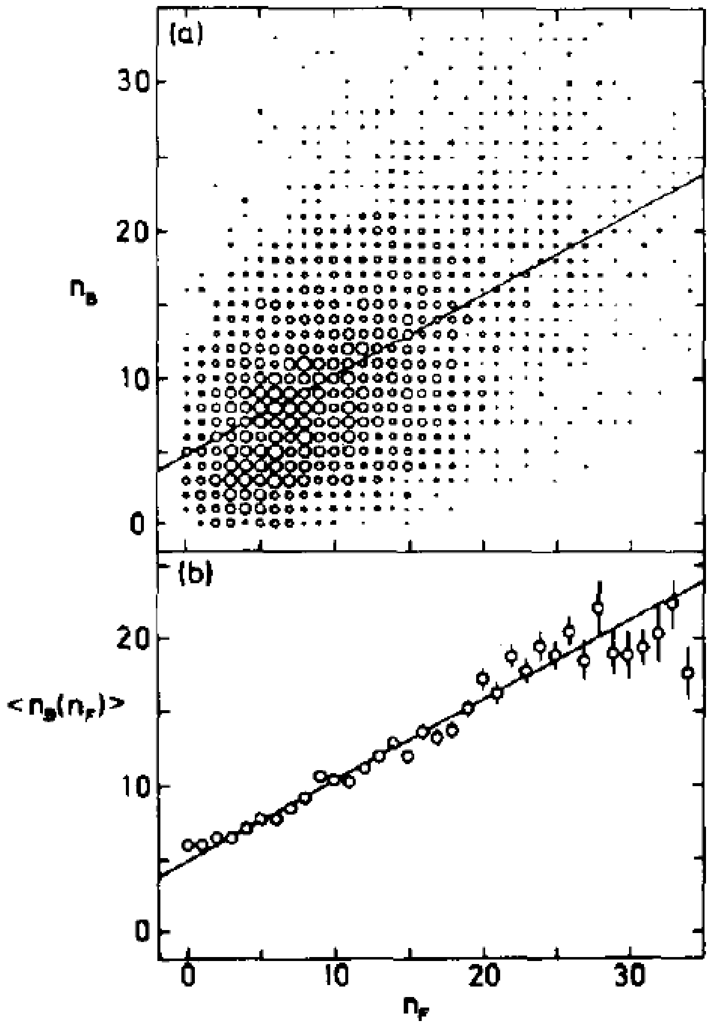
ALICE: Phys. Rev C 91 (2015) 064905



Model experimental signal as Glauber folded with NBD multiplicity fluctuations

Multiplicity fluctuations are long ranged

UA5: Phys. Lett. B 123 (1983) 361



- If the multiplicity fluctuates up or down where we estimate the centrality, it likely also fluctuates up or down where we measure the dN/dη
  - How should we take this into account?
    - Either effective N_{part} or we need a full model (a la Rivet idea)
  - A natural feature of Lund strings
- We need a good observable to understand these fluctuations

ATLAS studies of pseudorapidity correlations (1/3)

Observable

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- 2-D pseudorapidity correlation function

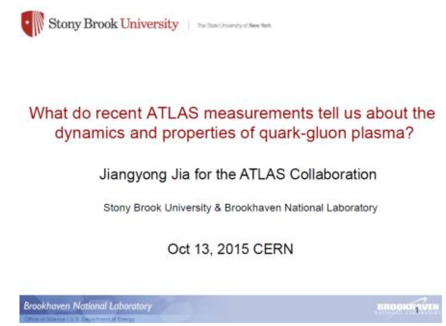
$$C = \frac{\langle N(\eta_1) N(\eta_2) \rangle}{\langle N(\eta_1) \rangle \langle N(\eta_2) \rangle} = \langle R_S(\eta_1) R_S(\eta_2) \rangle_{events}$$

$|\eta|<Y=2.4$

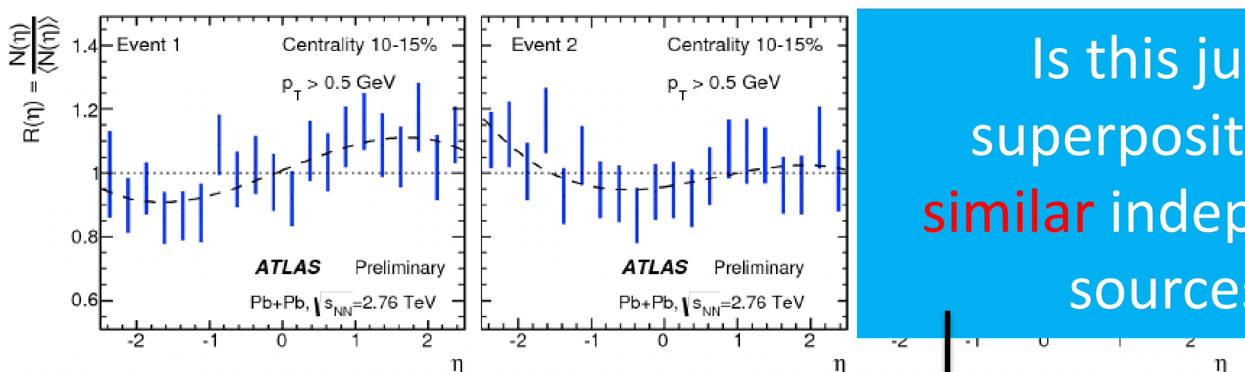
Mixed events

$$R_S(\eta) \equiv \frac{N(\eta)}{\langle N(\eta) \rangle}$$

Single particle distribution



https://indico.cern.ch/event/442430/



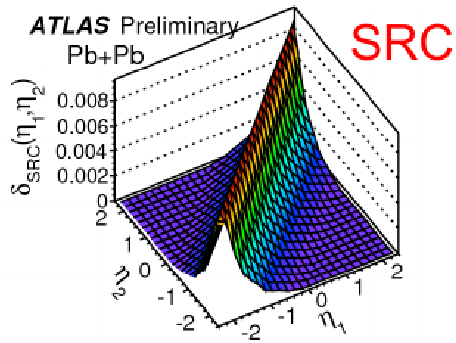
Is this just a superposition of similar independent sources?

CF disentangles statistical fluctuation from dynamical fluctuation

ATLAS studies of pseudorapidity correlations (2/3)

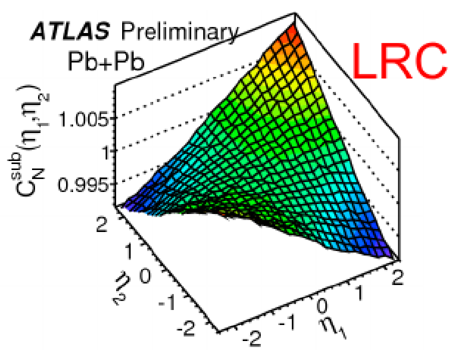
Quantifying the SRC and LRC

45



$p_T > 0.2$ GeV

$100 \le N_{ch}^{rec} < 120$



Quantify by average amplitude:

$$\Delta_{SRC} = \frac{\int \delta_{SRC}(\eta_1,\eta_2)d\eta_1 d\eta_2}{4Y^2} \qquad |\eta|<Y=2.4$$

This is a way to remove the hard component

$$\eta_+ = \eta_1 + \eta_2$$
$$\eta_- = \eta_1 - \eta_2$$

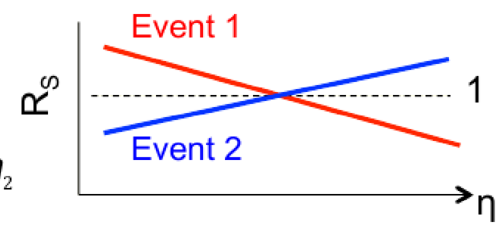
Shape approximate by:

$$C_N^{sub}(\eta_1,\eta_2) \approx 1 + \langle a_1^2 \rangle \eta_1\eta_2 = 1 + \frac{\langle a_1^2 \rangle}{4}(\eta_+^2 - \eta_-^2)$$

Implication: deviation from average is linear in η

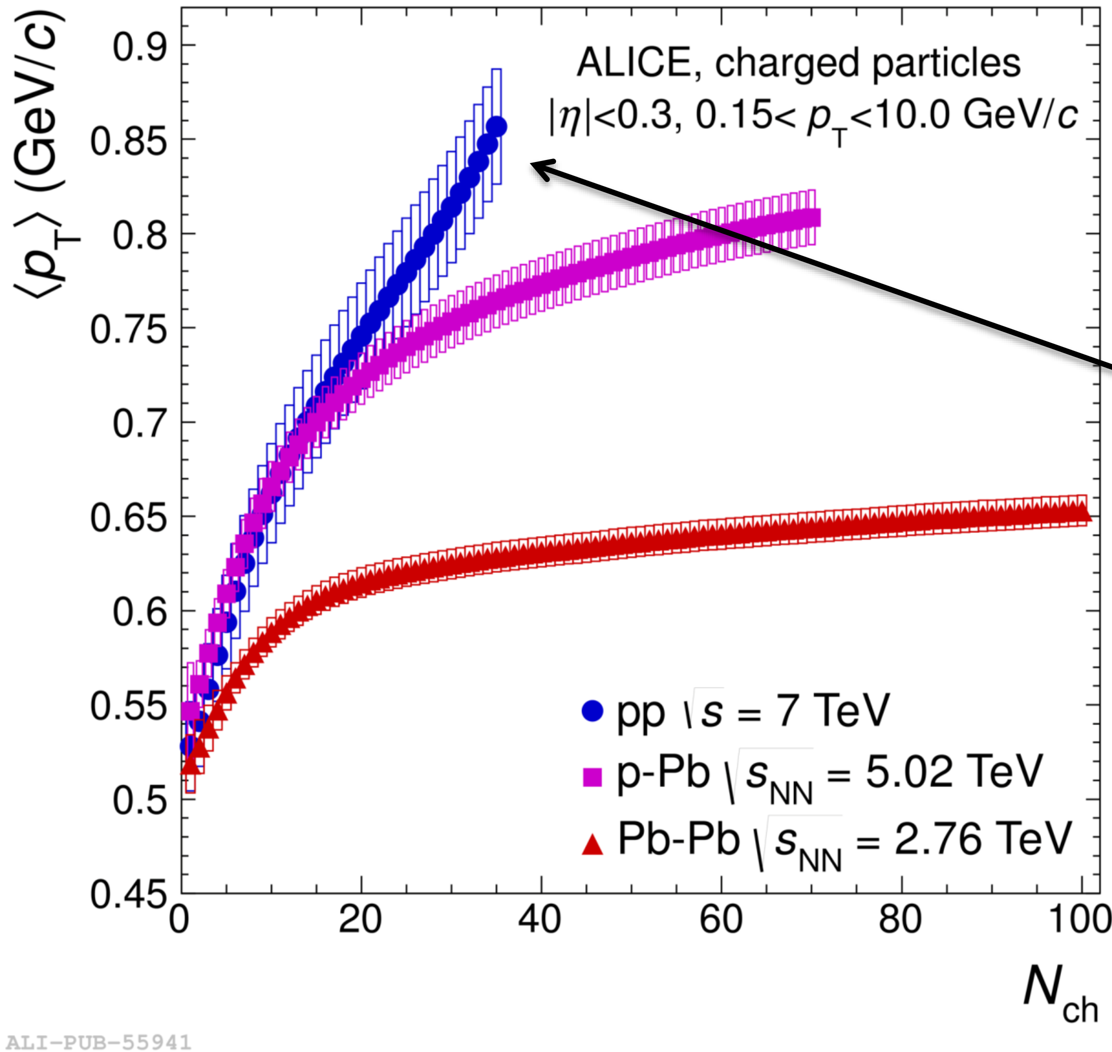
$$R_S(\eta) \equiv \frac{N(\eta)}{\langle N(\eta) \rangle} \approx 1 + a_1\eta$$

$$C = \langle R_S(\eta_1) R_S(\eta_2) \rangle \approx 1 + \langle a_1^2 \rangle \eta_1\eta_2$$



A reminder about the difference for the hard component

ALICE: Phys. Lett. B 727 (2013) 371



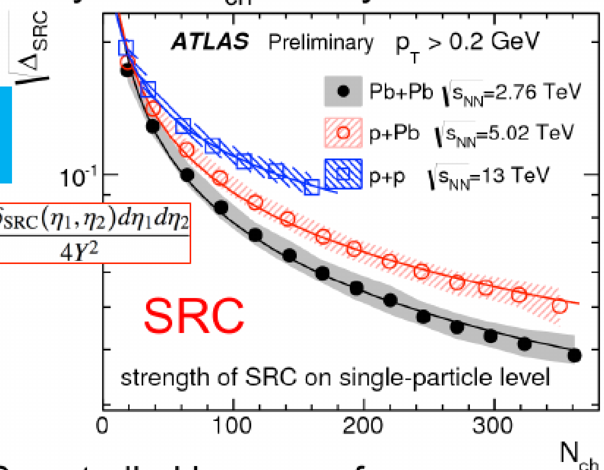
We need to control the hard scattering!

ATLAS studies of pseudorapidity correlations (3/3)

Dependence on N_{ch} and collision systems 48

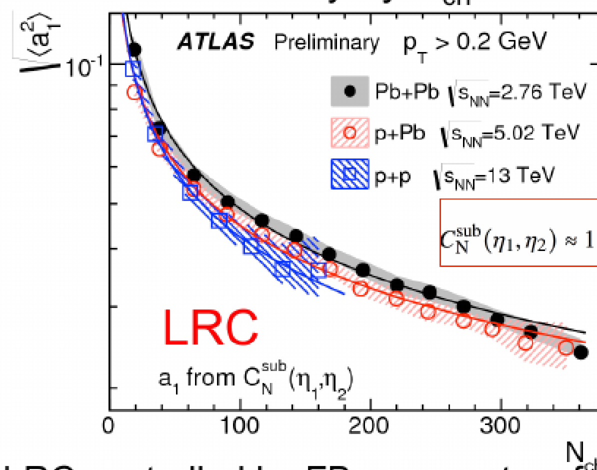
“HARD” By both N_{ch} and system size

$\Delta_{SRC} = \frac{\int \delta_{SRC}(\eta_1,\eta_2) d\eta_1 d\eta_2}{4Y^2}$



only by N_{ch} “SOFT”

$C_N^{sub}(\eta_1,\eta_2) \approx 1 + \langle a_1^2 \rangle \eta_1 \eta_2$



SRC controlled by num. of sources

$$n = n_f + n_b \propto N_{ch}$$

LRC controlled by FB asymmetry of sources

$$\langle a_1^2 \rangle \propto \langle A_n^2 \rangle \qquad A_n = \frac{n_f - n_b}{n_f + n_b}$$

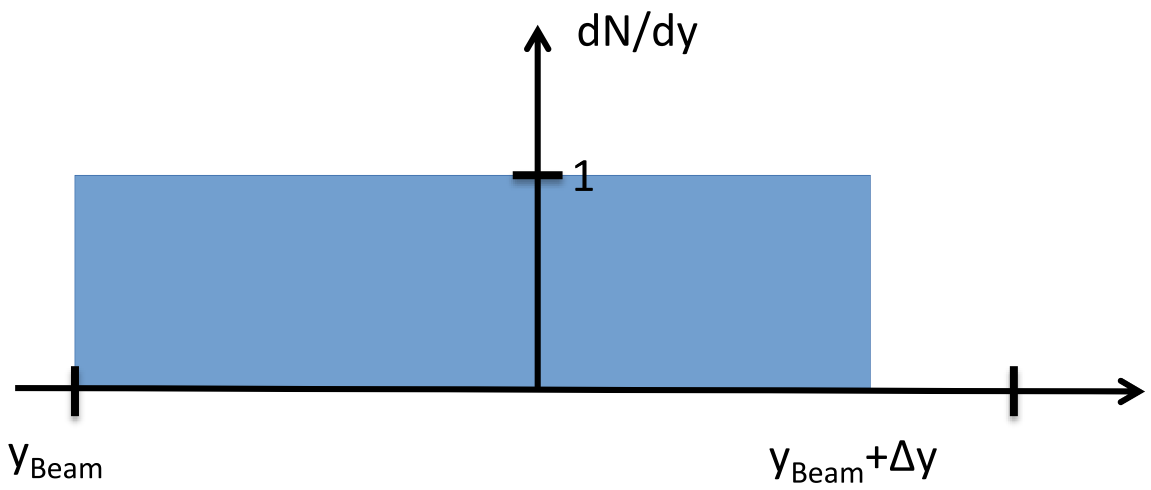
Assume “independent source picture”: $\sqrt{\Delta_{SRC}} \sim \sqrt{\langle a_1^2 \rangle} \sim \frac{1}{n^\alpha} \sim \frac{1}{N_{ch}^\alpha}, \alpha \sim 0.5$

- Fit with c/N_{ch}^α

	Pb+Pb	p+Pb	pp
α for $\sqrt{\Delta_{SRC}}$	0.502 ± 0.022	0.451 ± 0.020	0.342 ± 0.030
α for $\sqrt{\langle a_1^2 \rangle}$	0.467 ± 0.011	0.448 ± 0.019	0.489 ± 0.032

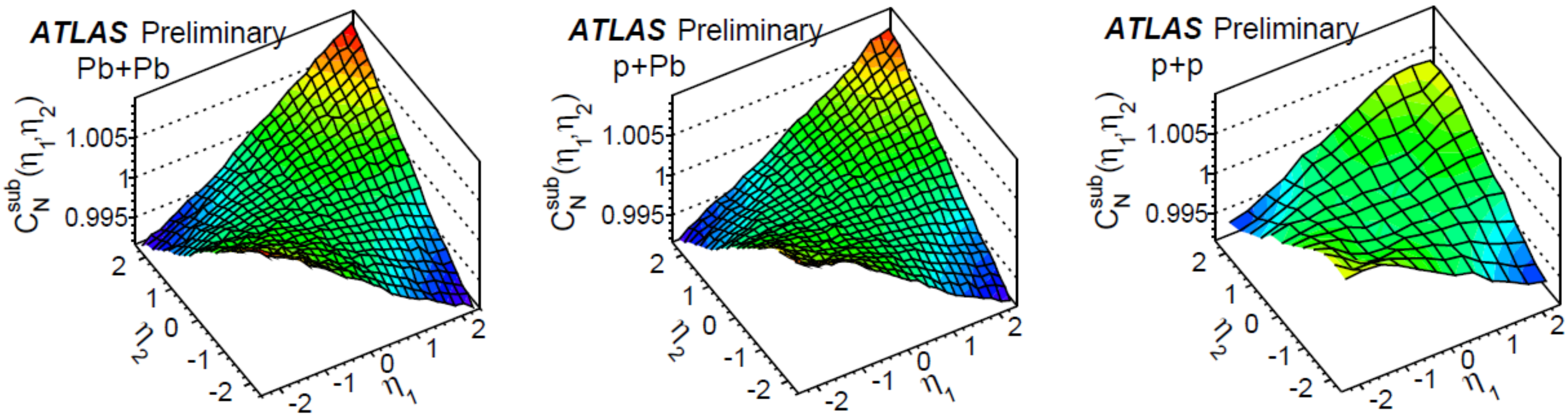
- ➢ LRC: num. of sources, n, controlled by N_{ch}, think in terms of partons !
- ➢ SRC: pp vs PbPb at same N_{ch} → n is similar but pairs/source is larger?

Start with a generic Lund-like string



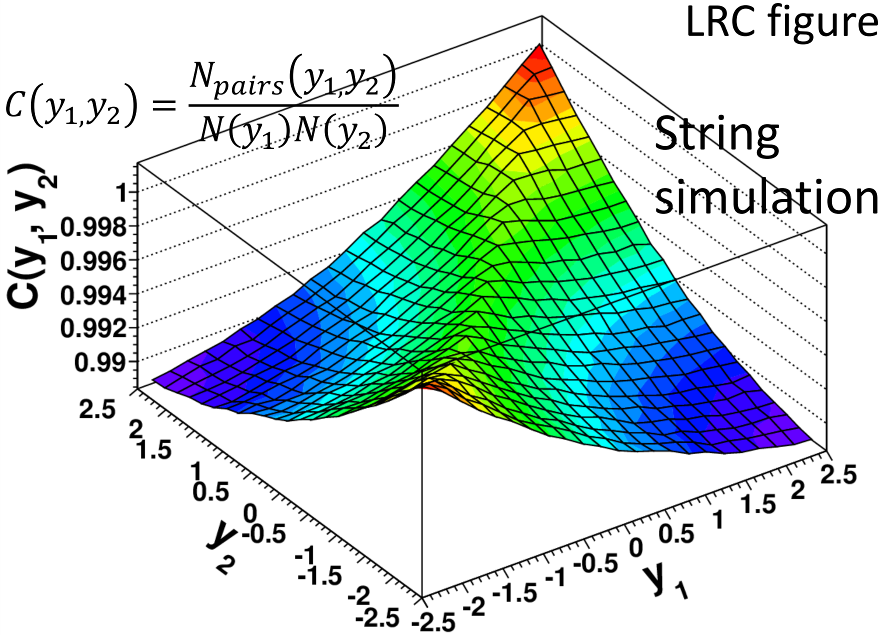
- Inspired by BGK triangle
  - Start: y_{Beam}, Stop: flat in rapidity: $P(\Delta y)=1/(2y_{Beam})$
  - Each string produces on average <Nch>= Δy particles (random in y) – Nch is taken from Poisson distribution
    - Particles are randomly distributed in rapidity

Simulation of long range correlations for $100 \leq N_{ch} < 120$



LRC figures from ATLAS-CONF-2015-051

$$C(y_1, y_2) = \frac{N_{pairs}(y_1, y_2)}{N(y_1)N(y_2)}$$



The simple string simulation reproduces both the saddle point shape and the relative magnitude of the dynamic fluctuations

Extend string model to p-Pb collisions

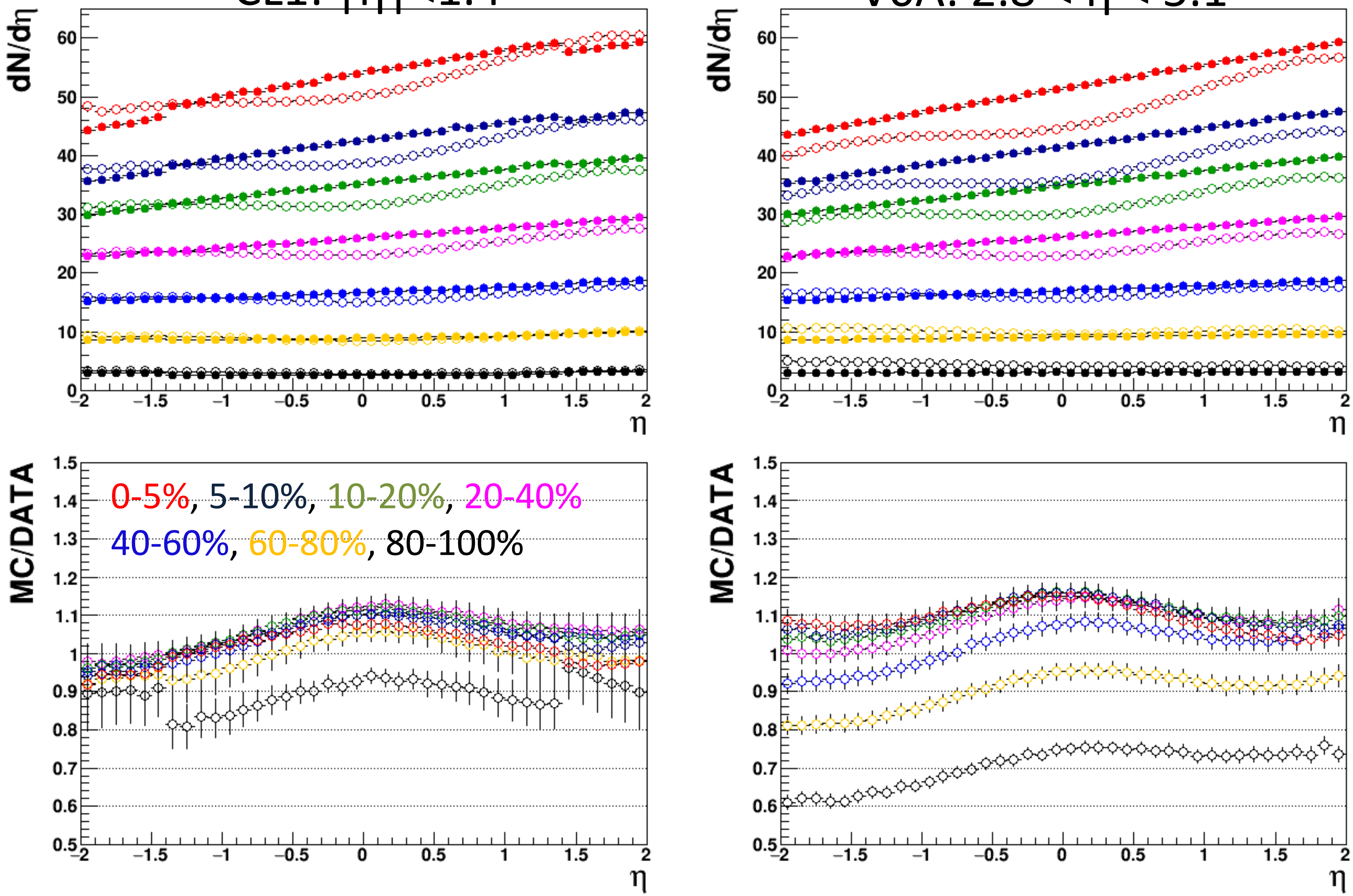
- Select N_{part} from Glauber INEL calculation
  - N_{part} p = 1, N_{part} Pb = N_{part} – 1
- <Nstrings> is fixed by ALICE results for dN/dη
  - <Nstrings> = 2* dN/dη (MB) / $\langle N_{part} \rangle$ (MB) = 4.28
- Fluctuations of Nstrings are modelled via NBD matched to pp data
- Each string is assigned random rapidity end point and boosted from CM to LAB frame
- Essentially only 2 choices:
  - Default: proton is assigned Nstrings as largest Pb participant (the proton can get more "wounded")
  - proton is treated all other nucleons (independent)
- The goal was to restrict parameters to avoid tuning

Results from string model (1/2)

CL1: |η|<1.4 V0A: 2.8 < η < 5.1

Default

Default



Data from ALICE: Phys. Rev C 91 (2015) 064905

Data driven model of p-Pb collisions (P. Christiansen, Lund)

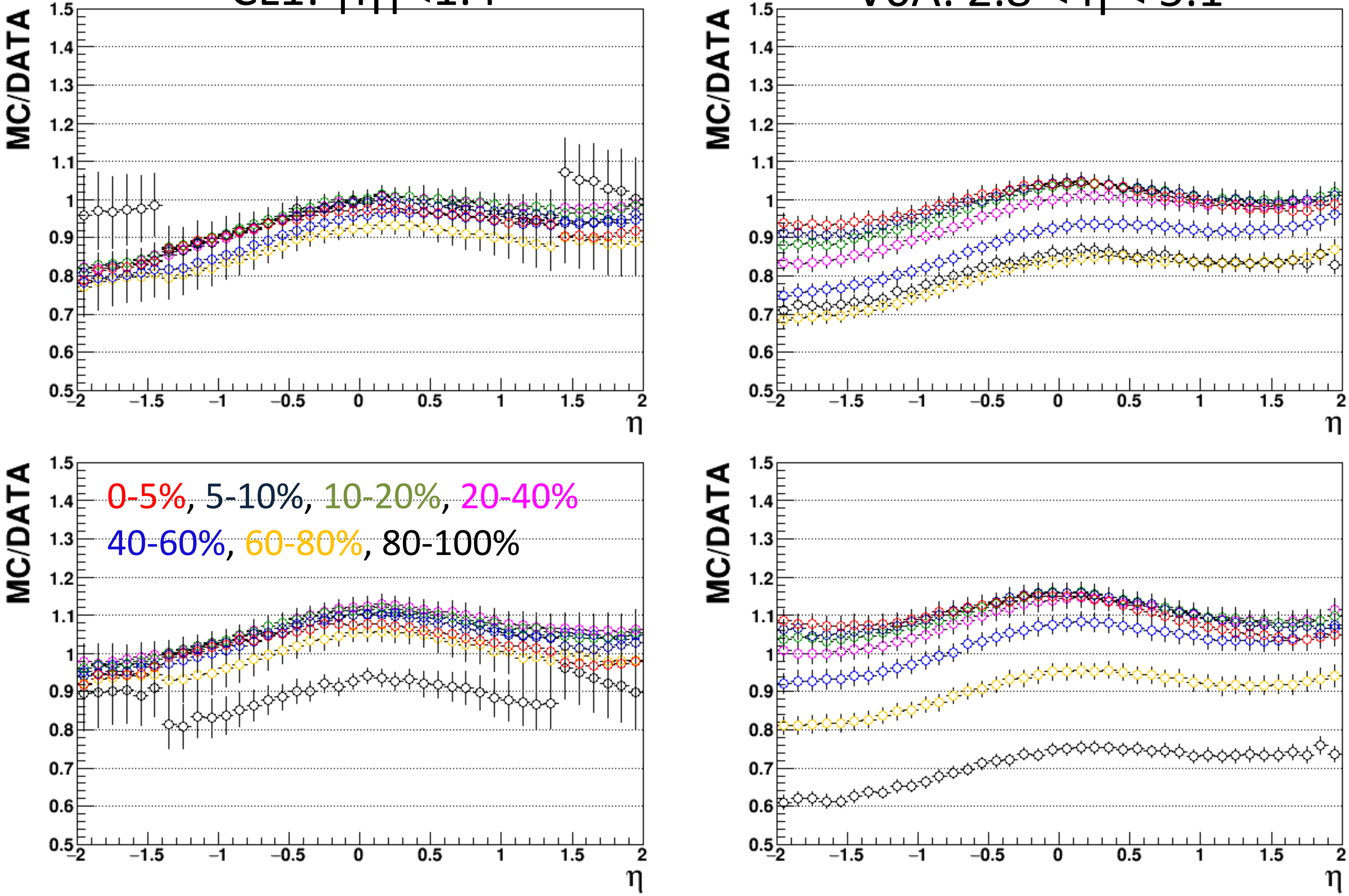
Results from string model (2/2)

CL1: |η|<1.4

V0A: 2.8 < η < 5.1

Proton is independent

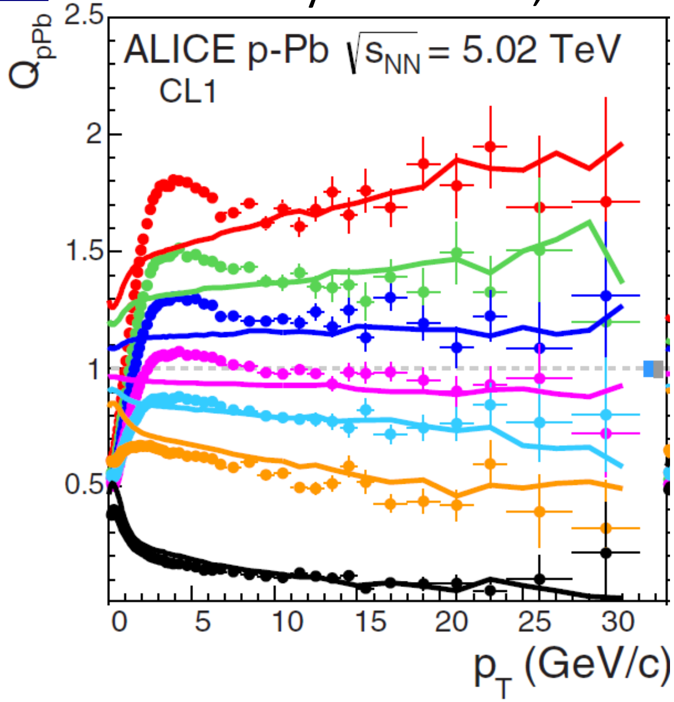
Default



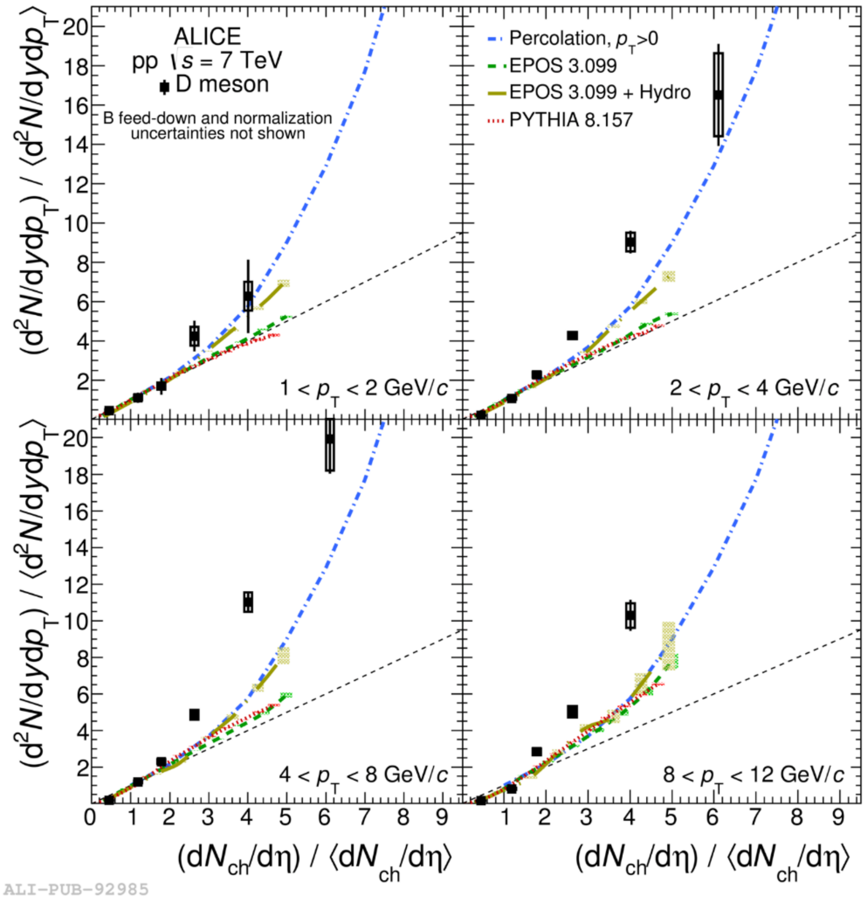
Data from ALICE: Phys. Rev C 91 (2015) 064905

Problem 2: soft vs hard processes

ALICE: Phys. Rev C 91, 064905 (2015)



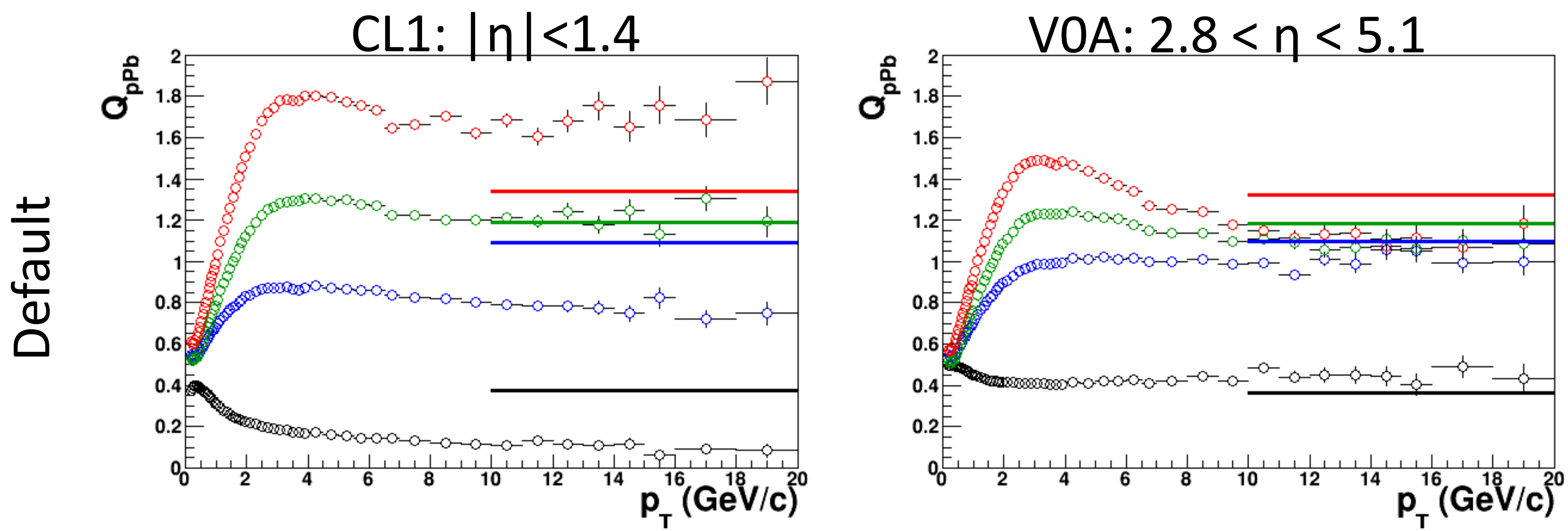
ALICE: JHEP 09 (2015) 148



- We find that the R_{pPb} is also biased and so we denote it Q_{pPb}
- Can be understood from ALICE pp results that show that hard processes are strongly biased by multiplicity fluctuations

Implementation in the simple string model

- I can implement a simple soft-hard correlation
  – Npart_effective = Σ (Nstrings / <Nstrings>)
  – Ncoll_effective = Npart_effective - 1



0-5%, 10-20%, 40-60%, 80-100%

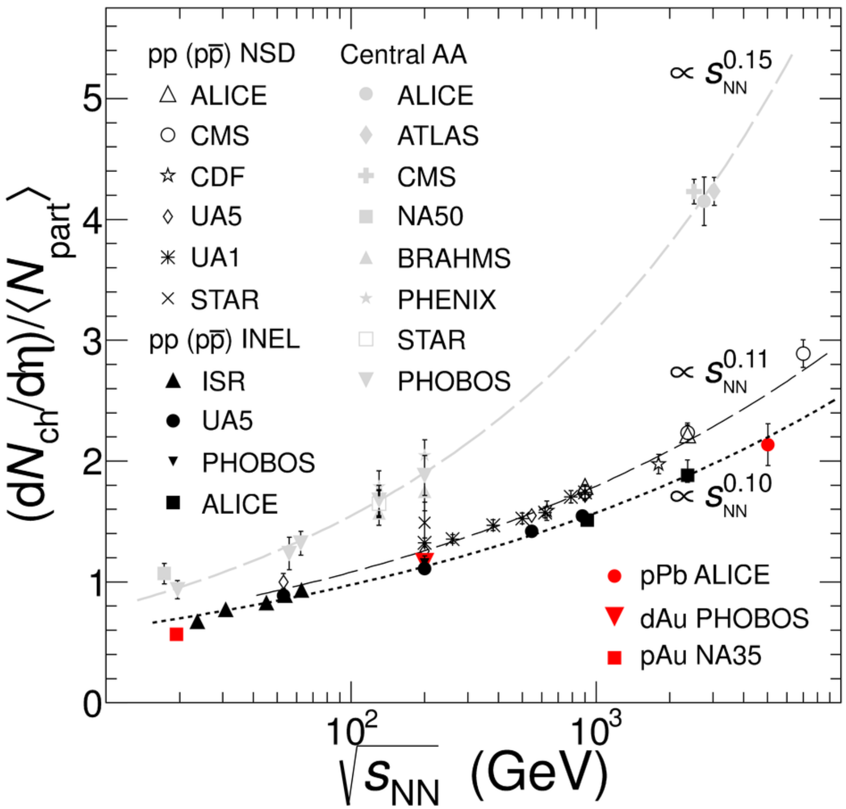
Data from ALICE: Phys. Rev C 91 (2015) 064905

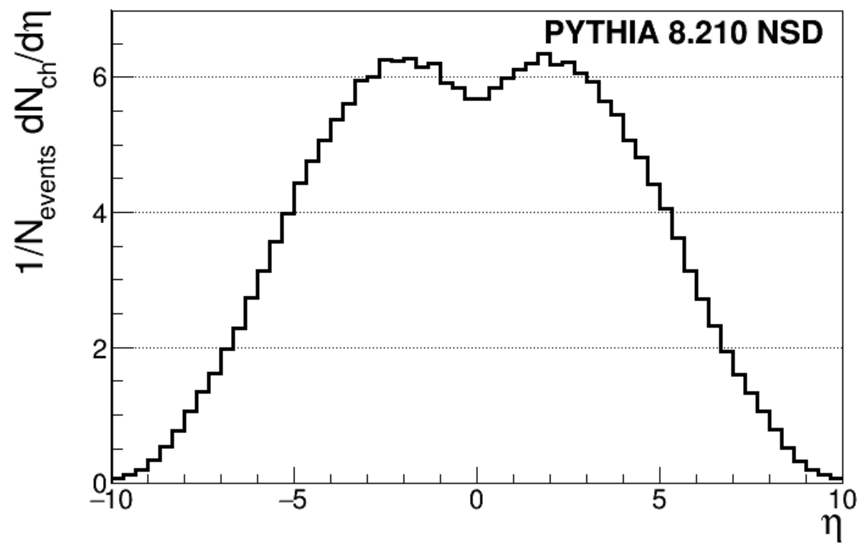
A triangle model based on PYTHIA

- Instead of the simple string model I now want to use PYTHIA events (can be seen as a proxy for real data)
  - Motivated by ALICE p-Pb centrality paper
- Specific choices
  - Randomly reject particles according to the triangle, $P(y_{beam})=1 \rightarrow P(y_{target}) = 0$
  - Use the hardest (p_T transfer) event for the proton
  - Accept all particles at high p_T (hard scatterings)

A comment on dN/dη in PYTHIA

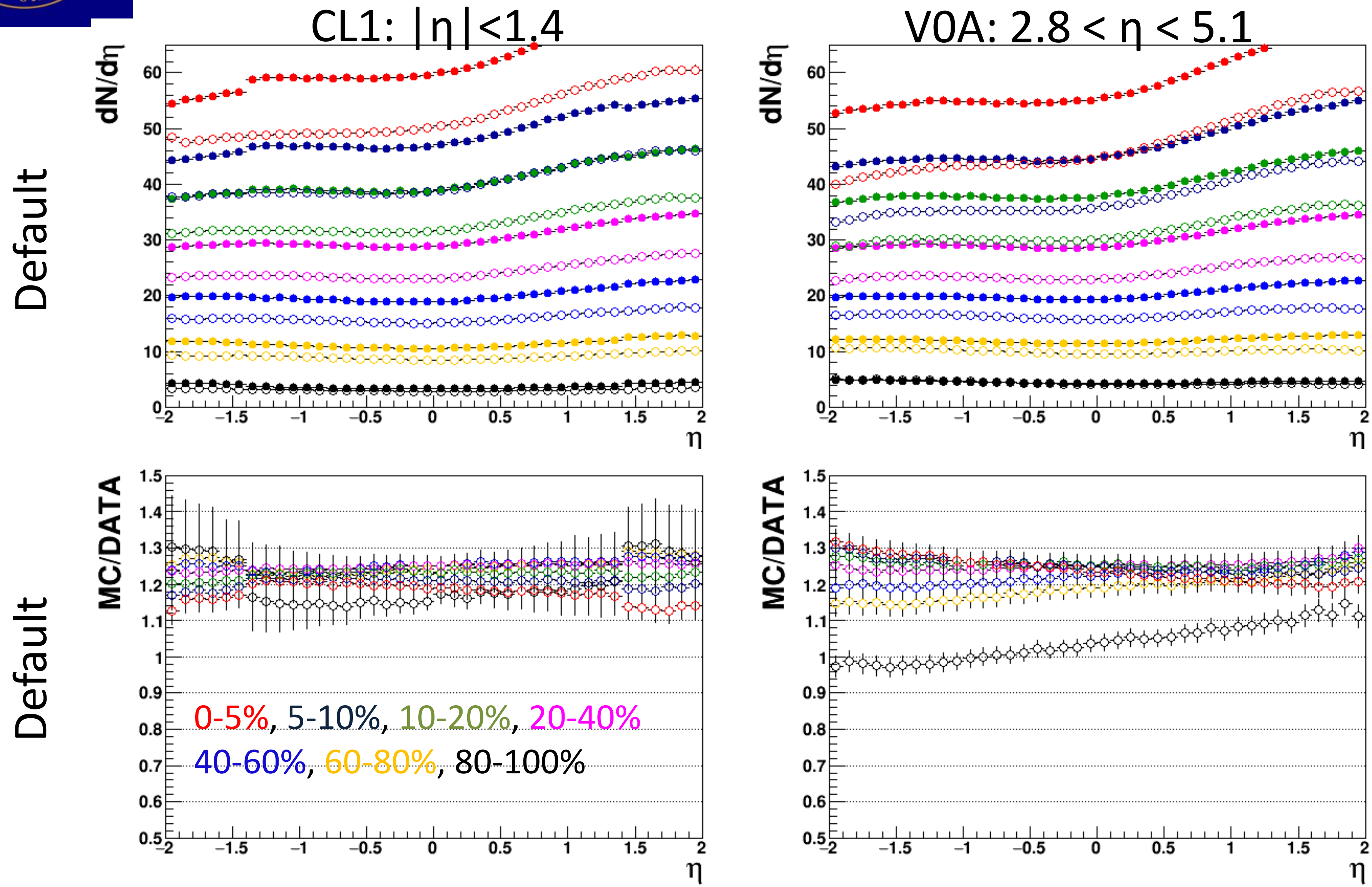
ALICE: Phys. Rev. Lett. 110 (2013) 032301





ALICE results suggests that for NSD events that dN/dη should be around 5.0-5.2

dN/dη from PYTHIA triangle model

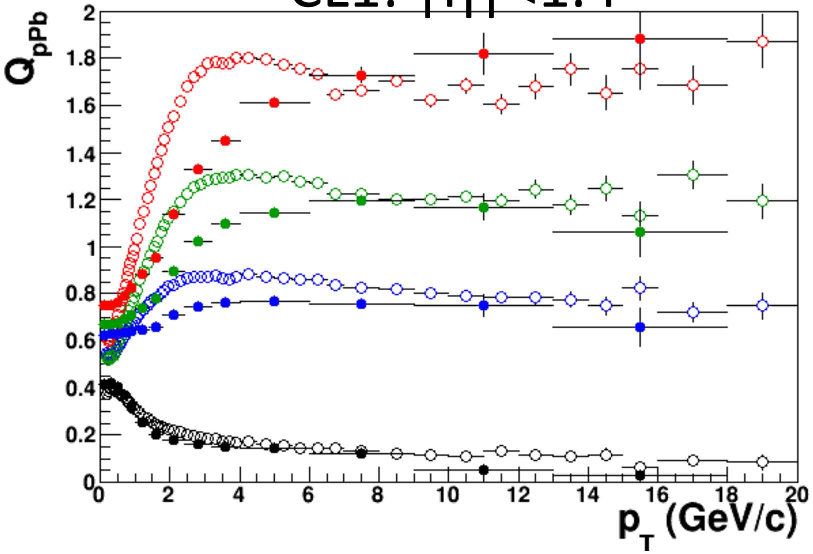


Data from ALICE: Phys. Rev C 91 (2015) 064905

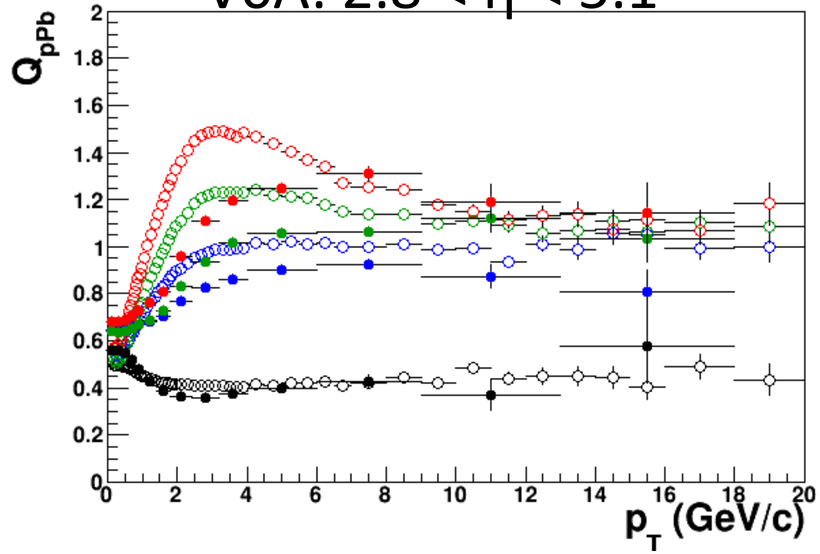
Q_{pPb} from the PYTHIA triangle model

Default

CL1: |η|<1.4



V0A: 2.8 < η < 5.1



0-5%, 10-20%, 40-60%, 80-100%

Data from ALICE: Phys. Rev C 91 (2015) 064905

- The hard bias is well described by the triangle model using PYTHIA events when all high p_T particles are accepted
- The disagreement for p_T < 10 GeV/c is expected as the model does not take into account radial flow

Proposal for data driven implementation

The basic model is in place:

- Select N_{part} from the Glauber distribution
  - NB! IMO one needs to use the visible pp cross section for the Glauber calculation, i.e., the cross section that is actually triggered on
- Take 1 full pp event + (N_{part}-2) pp events where a fraction of tracks are rejected
  - Ignore that p-Pb data are boosted (CM is not LAB)
- Make a fake p-Pb event by summing the pp events
  - One can even just calculate some self normalized observable (if one does not have the correct pp energy), e.g.,
    (dN/dη) / (dN/dη(MB))
  - This also means that efficiency effects cancels → simple

Physics conclusions for specific models

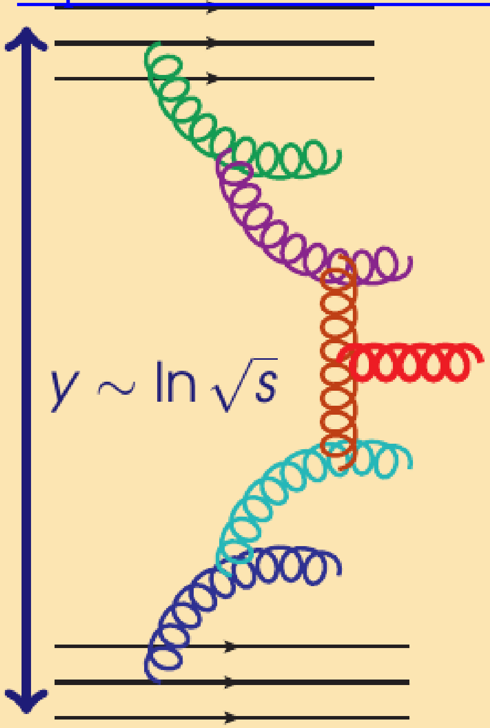
- The triangle model of Brodsky, Gunion, and Kuhn is surprisingly good at capturing basic features of p-Pb collisions
- No evidence that dN/dη in p-Pb collisions is to first order more then just a sum of factorable distributions
  - Some indications that proton is special
- Some indications that hard scatterings does not factorize

Thank you!

Backup slides

Wee partons are flat in rapidity in CGC

https://indico.triumf.ca/contributionDisplay.py?contribId=93&sessionId=10&confId=1922



- Gluons ending in central rapidity region: multiple splittings from valence quarks
- Emission probability $\alpha_s\,dx/x$
  $\Longrightarrow$ rapidity plateau for $\Delta y \ll 1/\alpha_s$
- Many gluons, in fact

$$N \sim \sum_n \frac{1}{n!}(\alpha_s \ln\sqrt{s})^n \sim \sqrt{s}^{\alpha_s}$$

In CGC α_s typically ~0.3 → Rapidity plateau is good approximation for Δy >> 3

Much better at LHC than at RHIC!

p_T dependent rejection at mid-rapidity in PYTHIA simulation