Hard processes in small systems

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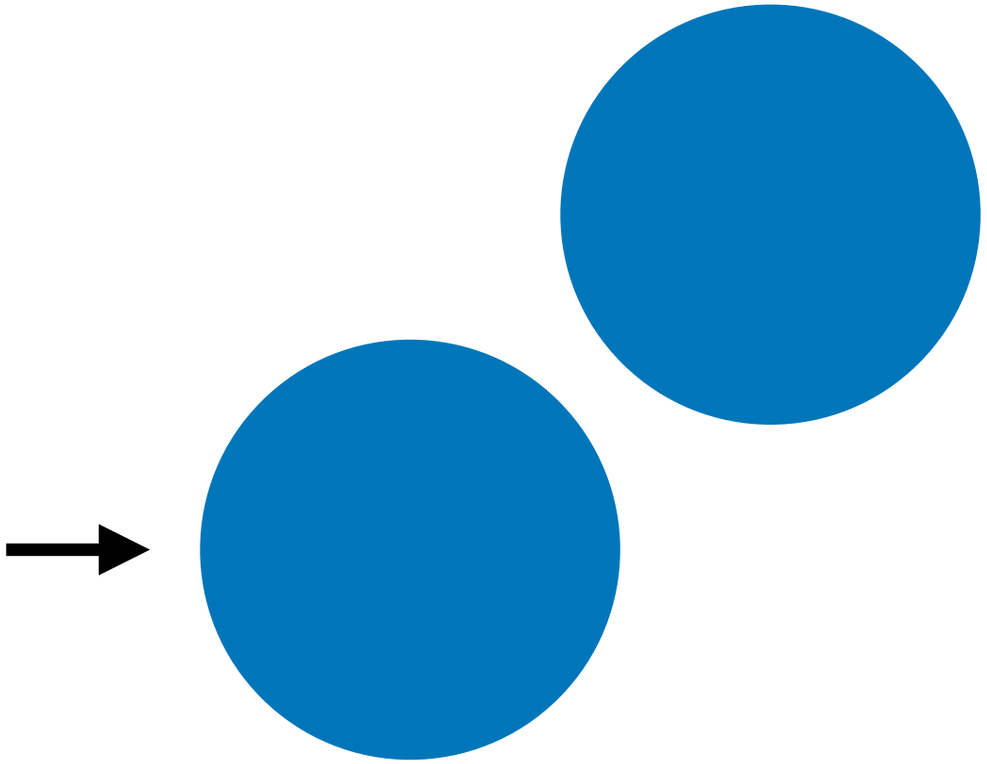
University of Colorado Boulder

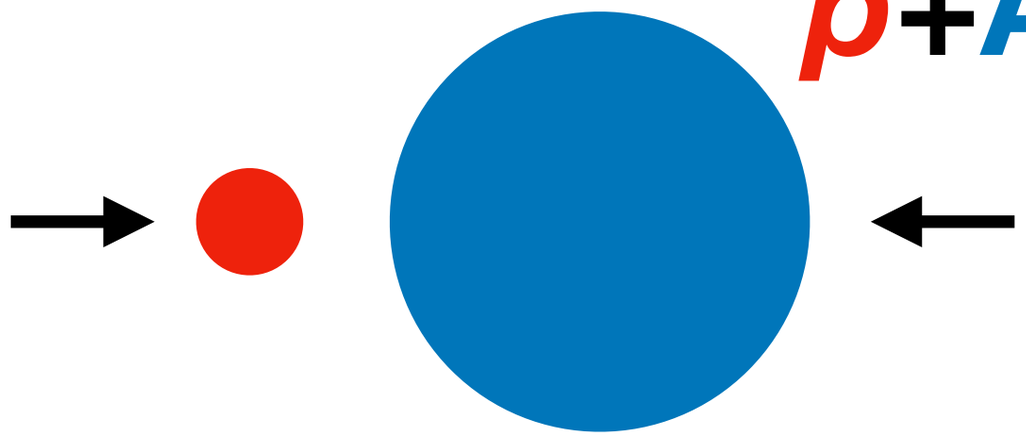
2 October 2017
Bergen, Norway

(peripheral)

A+A



***p*+A**



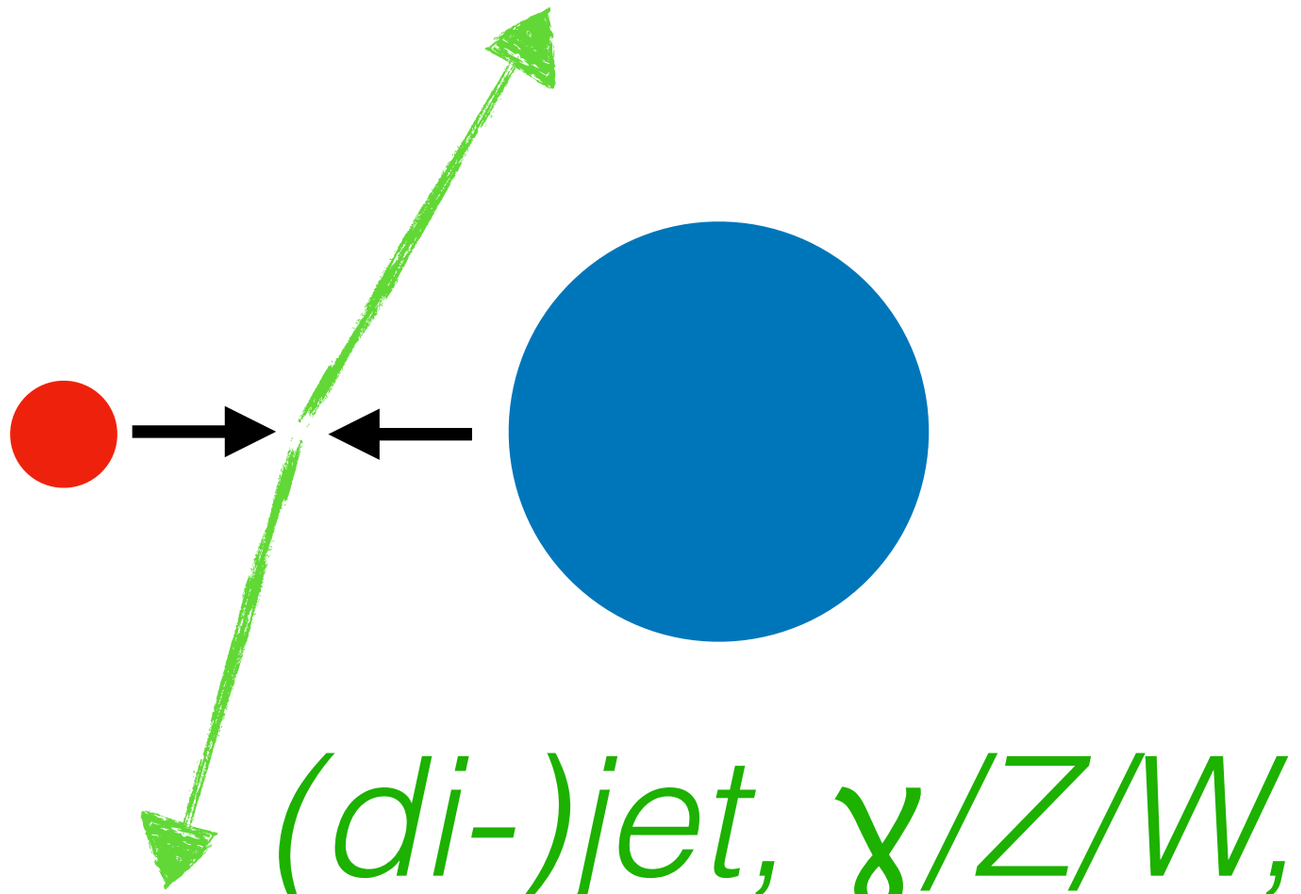
(UPC)

γ+A

“small”

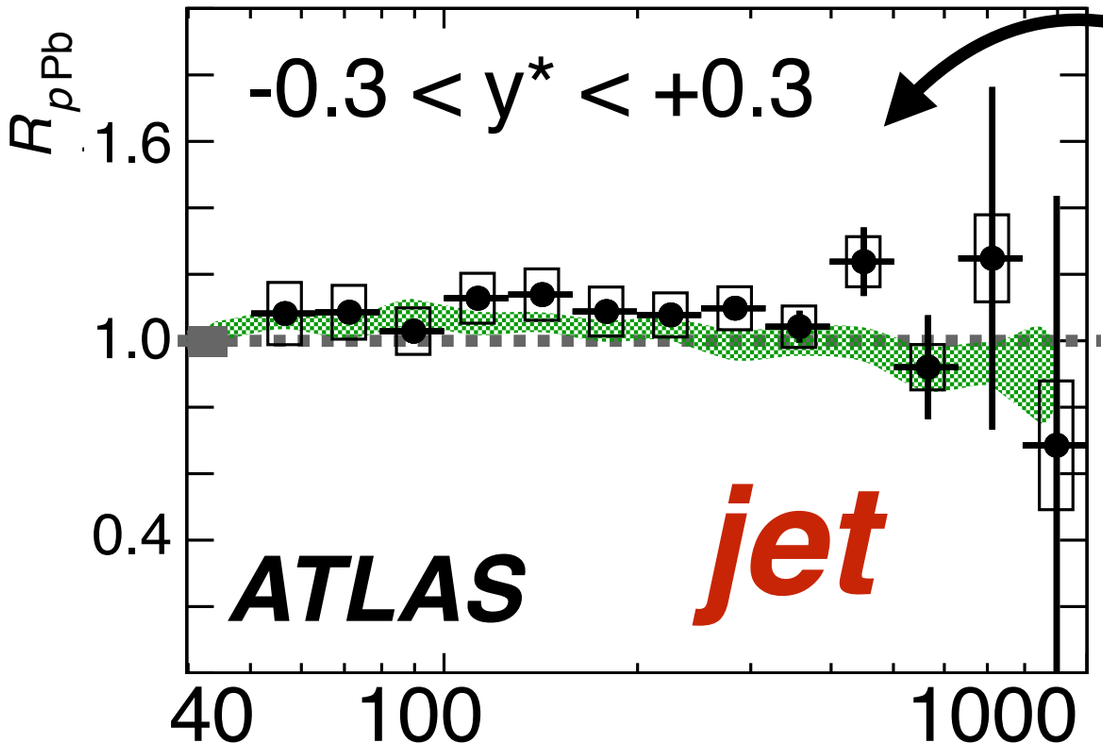
focus: new since QM

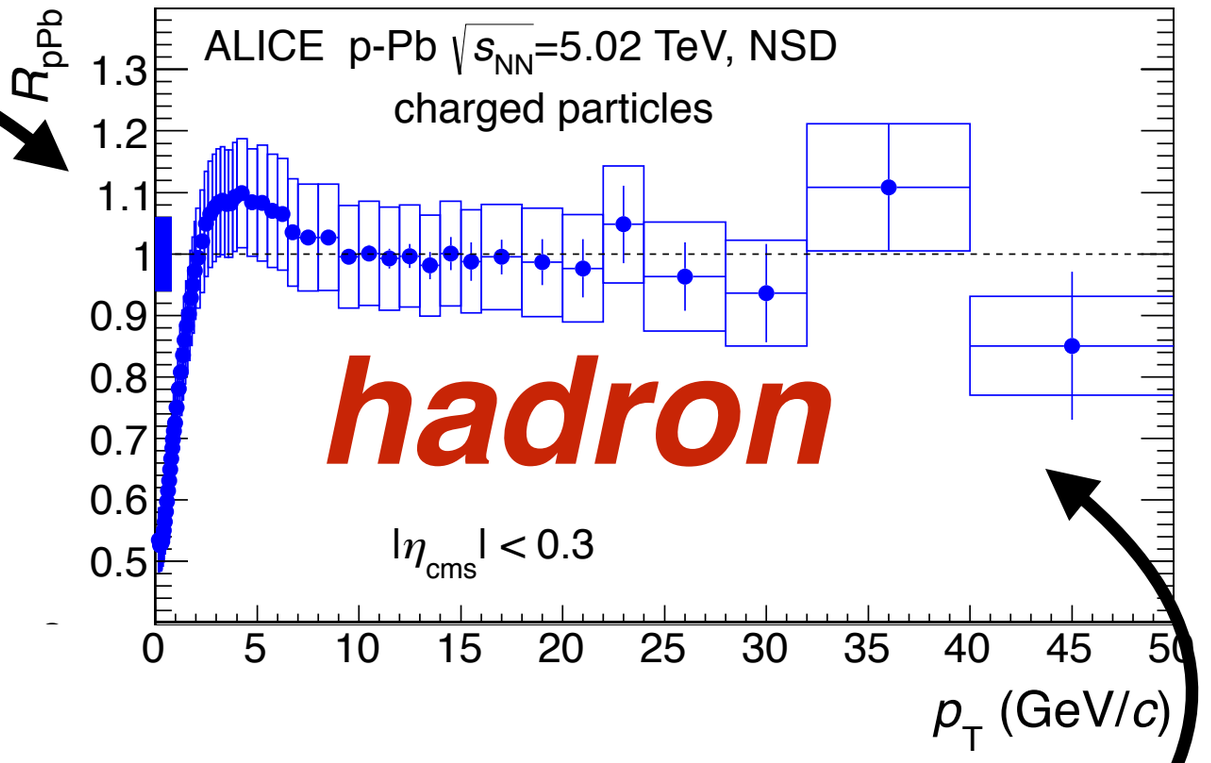
inclusive rates (nPDF's, initial state *E*-loss)

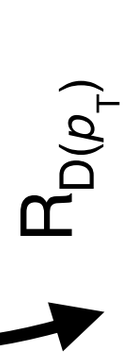


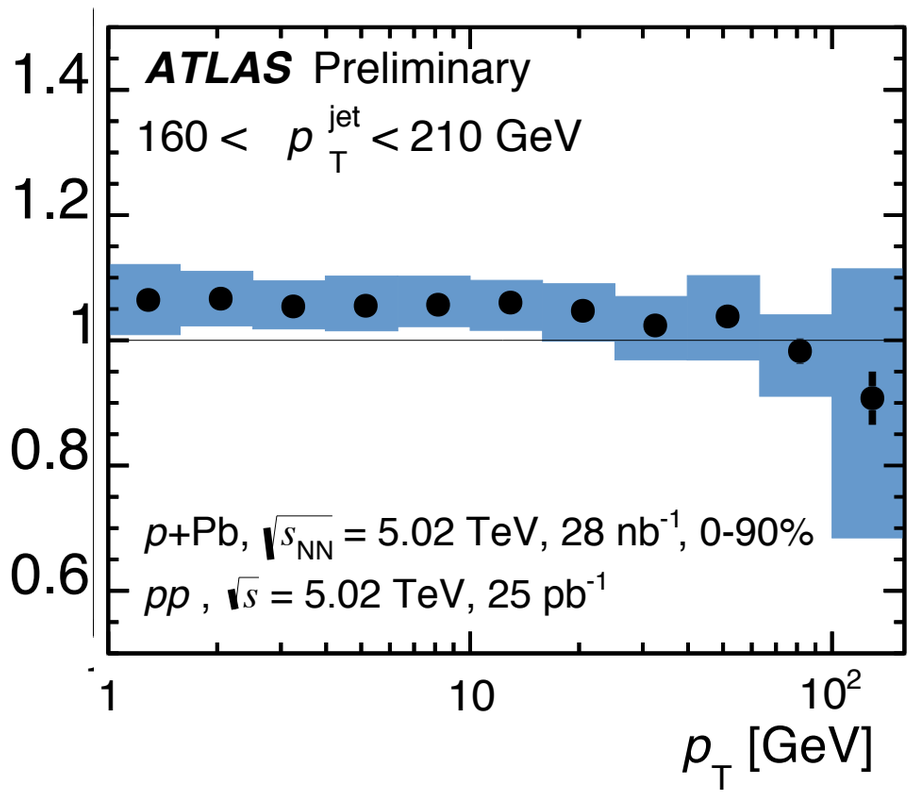
(di-)jet, ɣ/Z/W, b/c/t, etc.

jets & $h^{\pm}$ in 5.02 TeV p+Pb





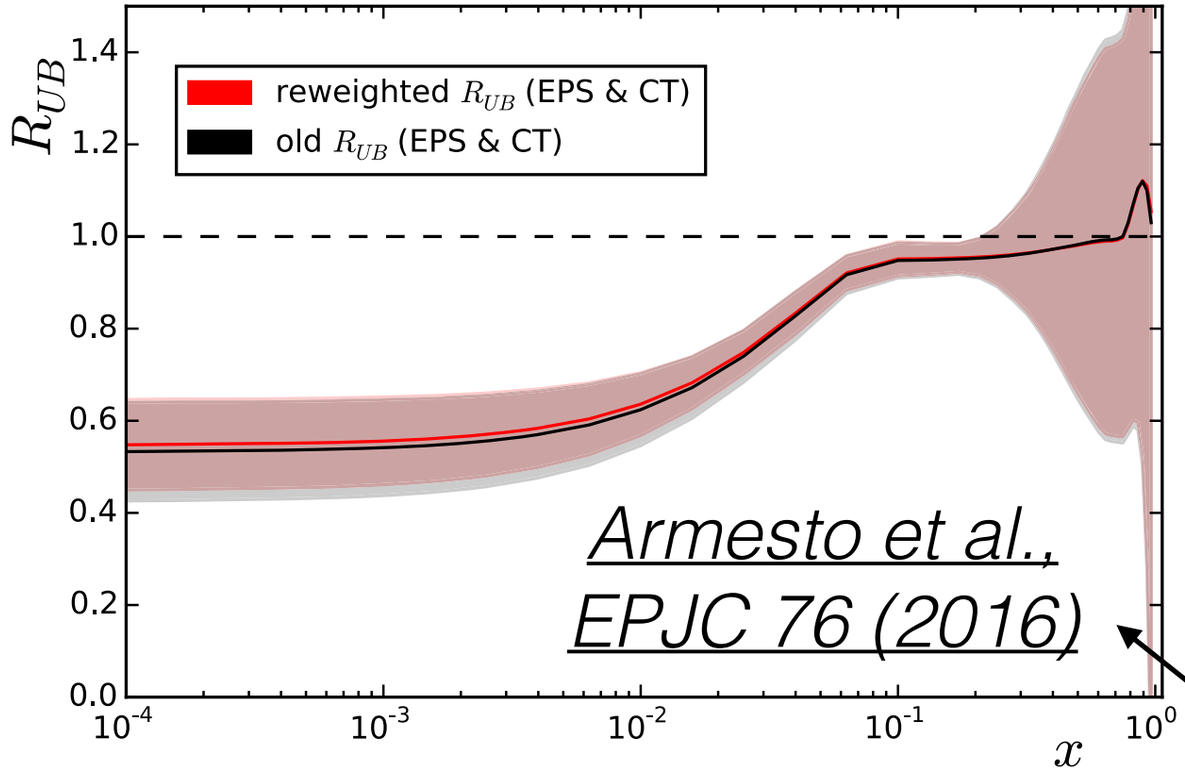


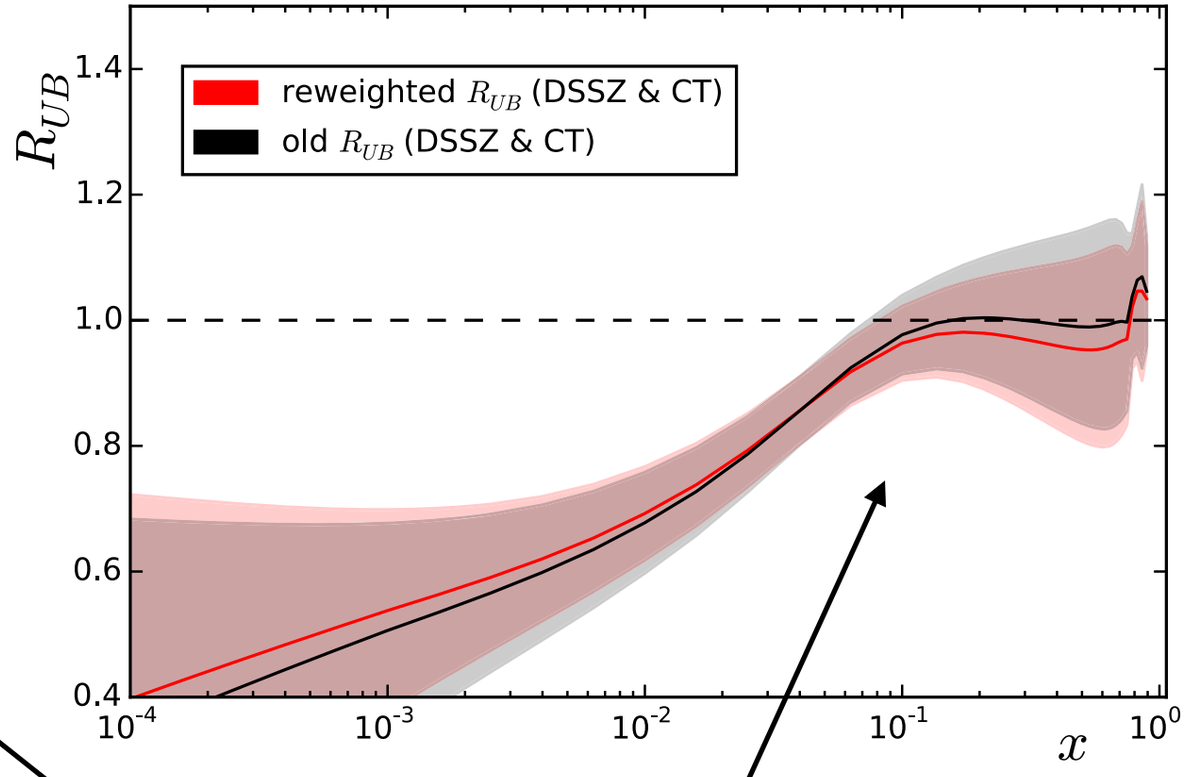


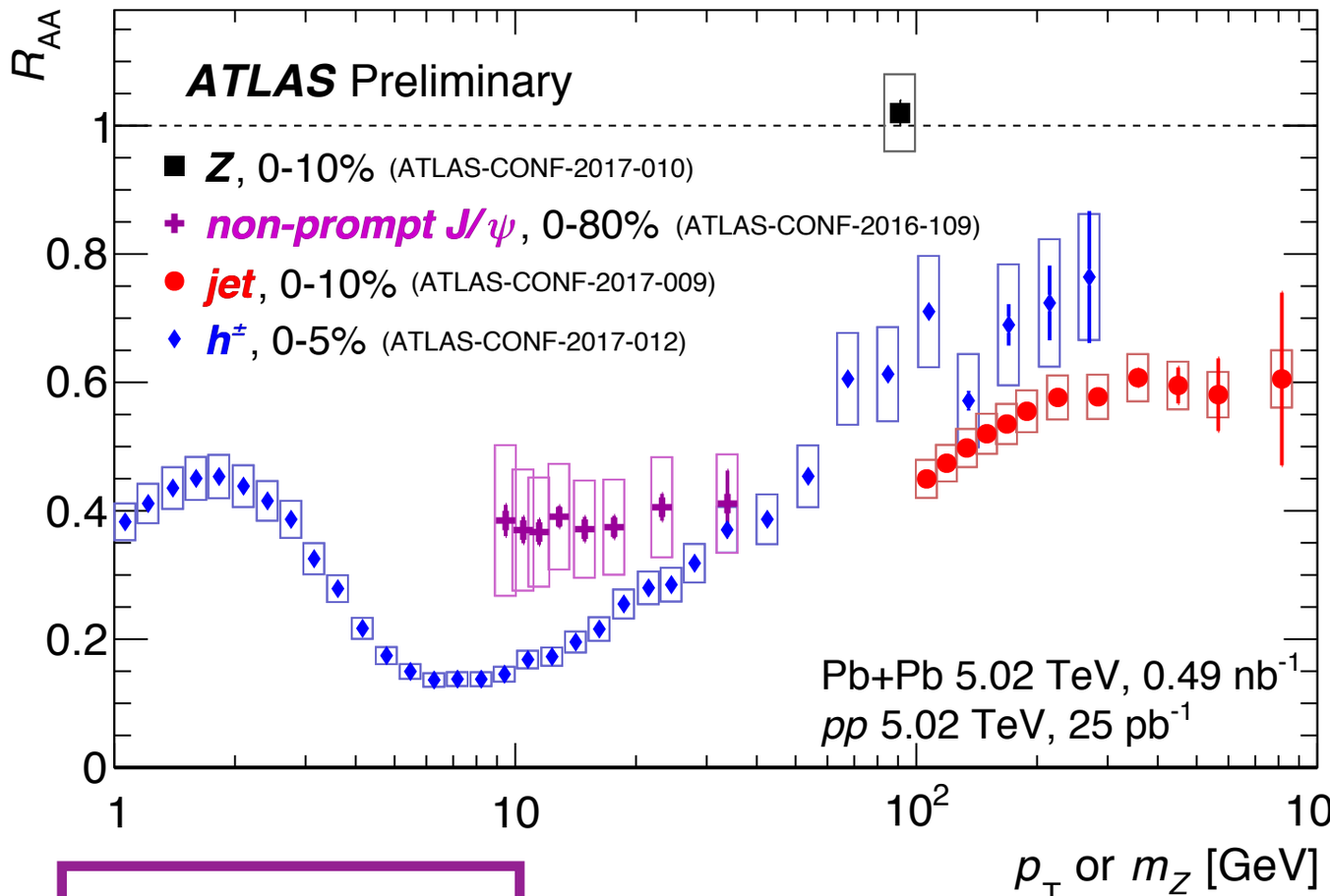
fragmentation

⇒ ***hep-ex/1706.02859***

final since QM





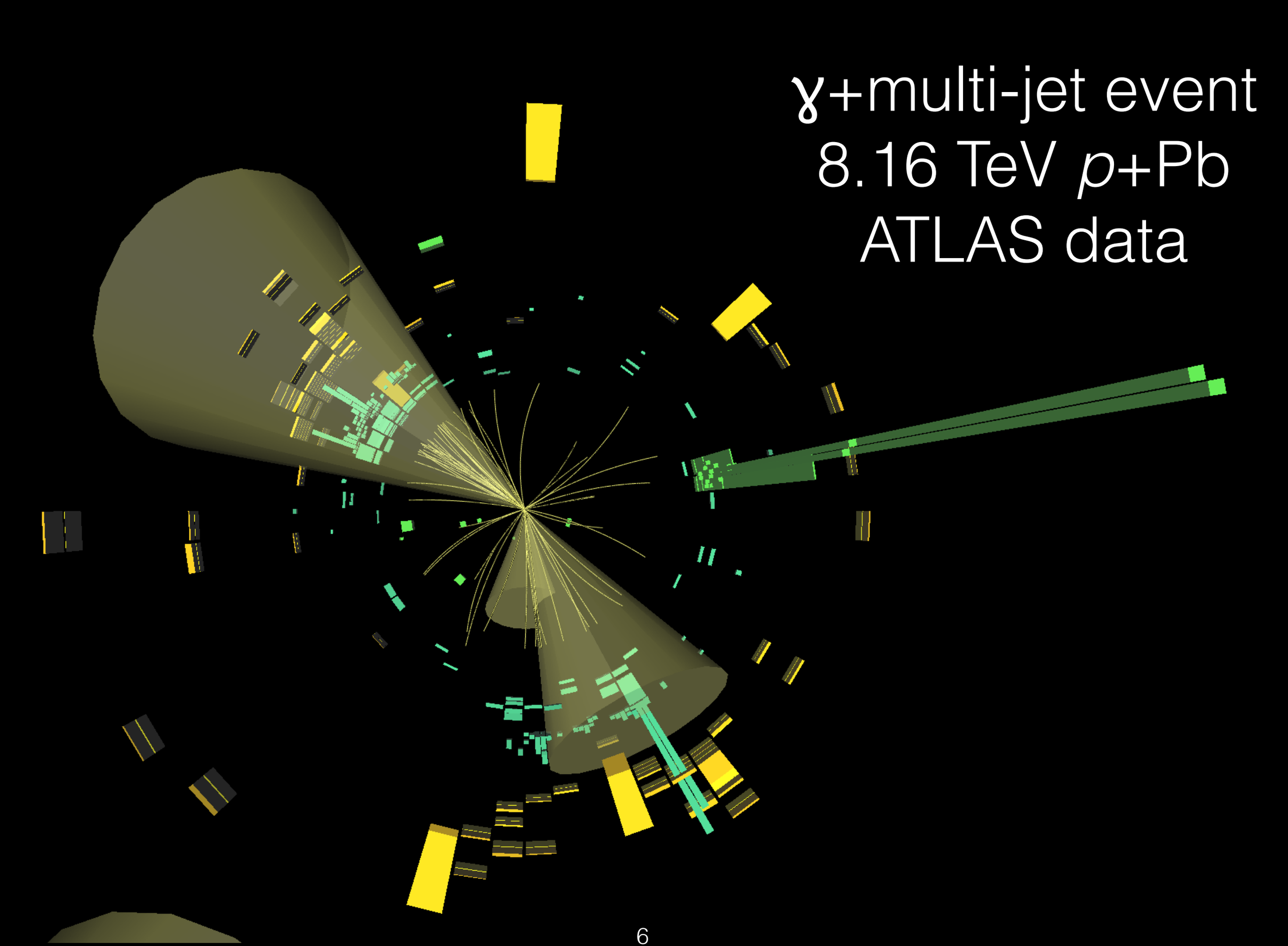


QM result

Impact of LHC Run 1 data on nPDF sets

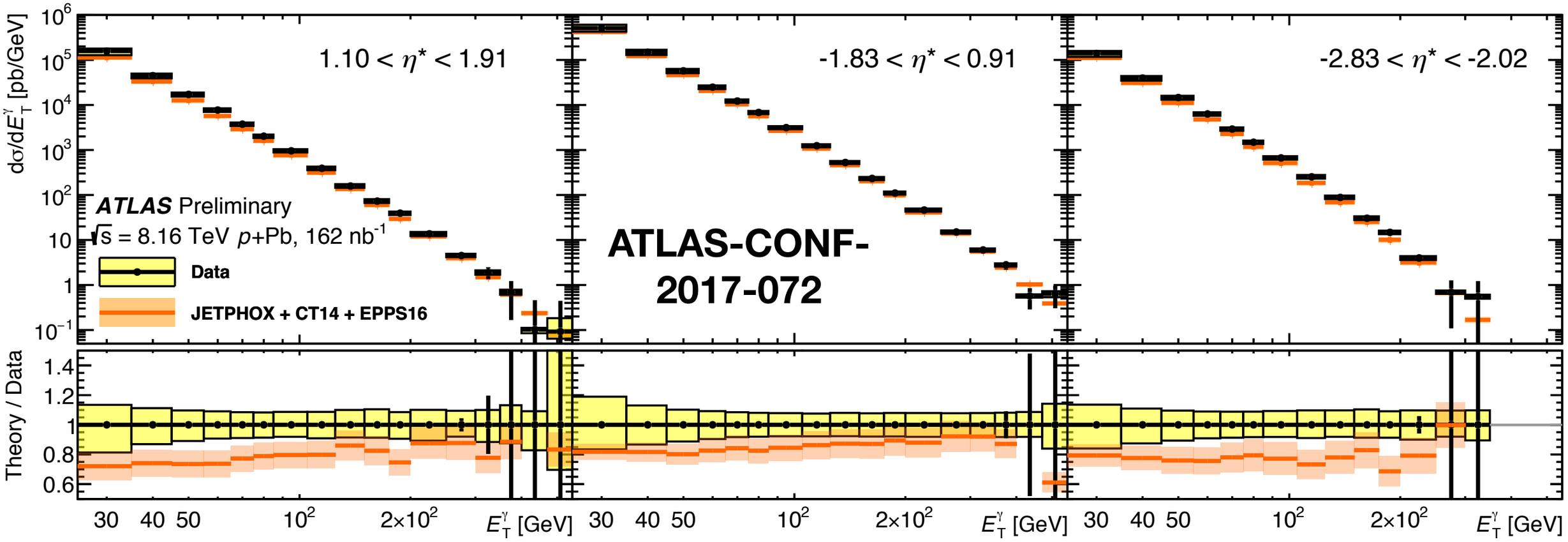
$R_{AA} < 1$ at ~TeV scale

➡ role of initial state effects ($x_A = 0.4$)?


γ+multi-jet event
8.16 TeV p+Pb
ATLAS data

photons in *p*+Pb

new since QM

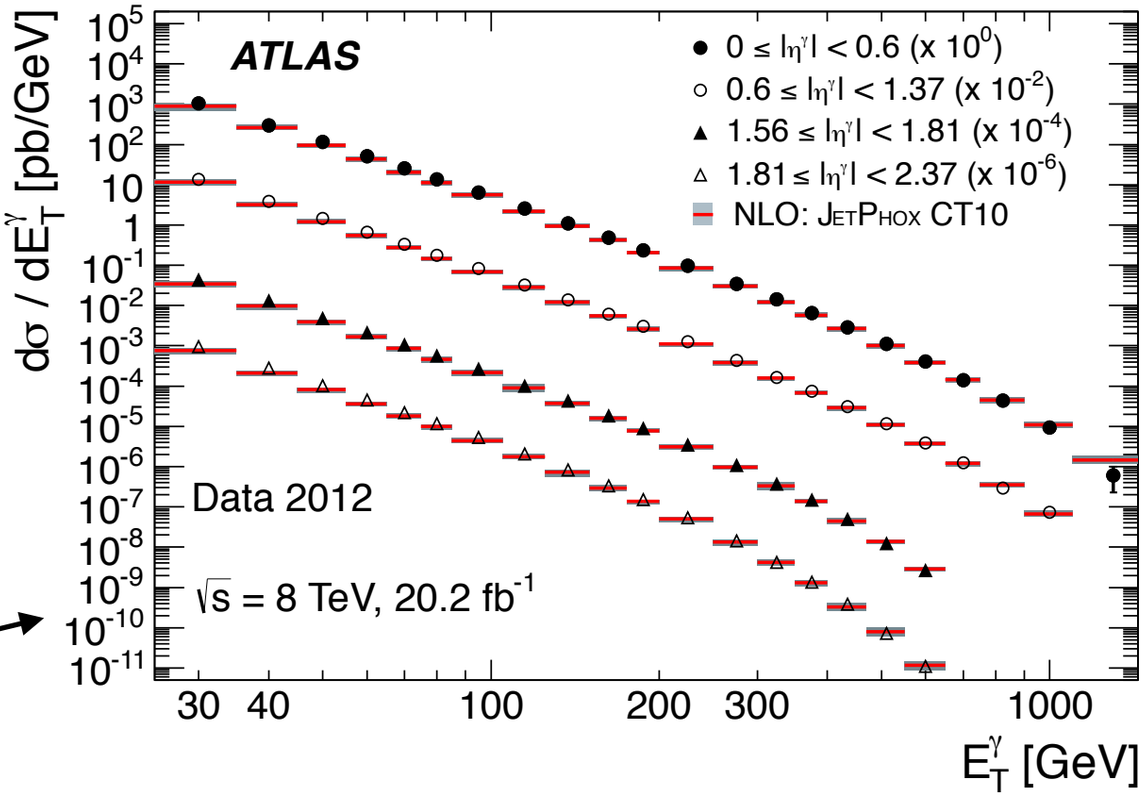


25-500 GeV,

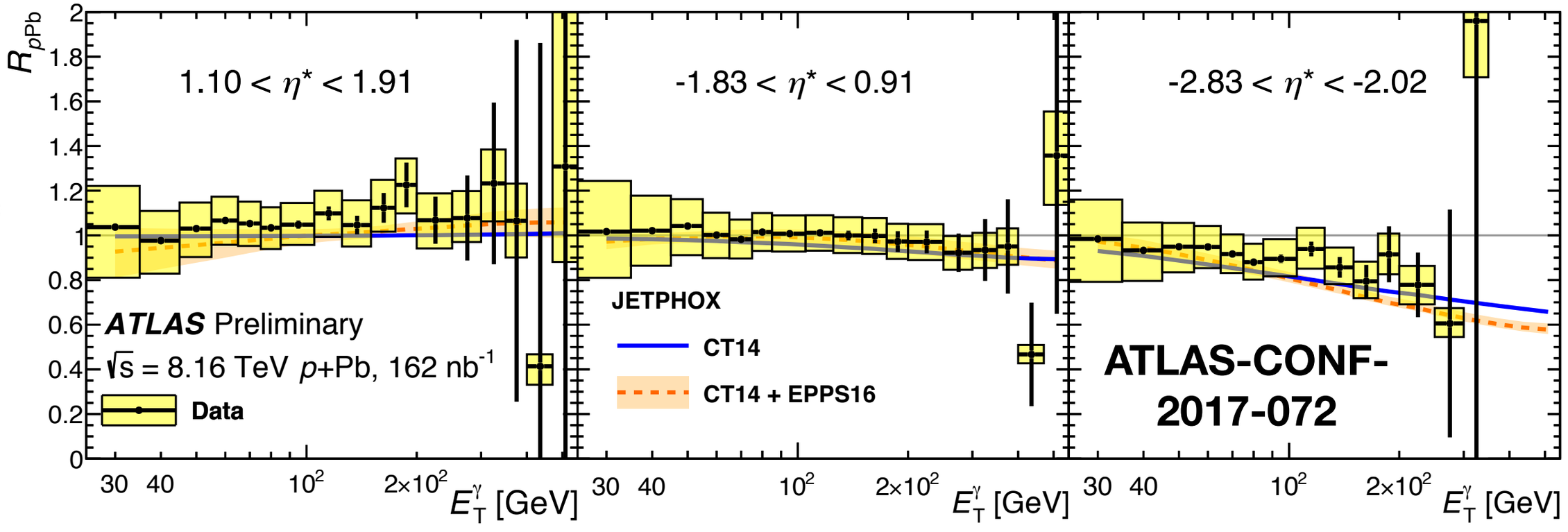
$|\eta^{lab}| < 2.37$

<u>Comparison spectra:</u>

8 TeV pp Standard Model measurements

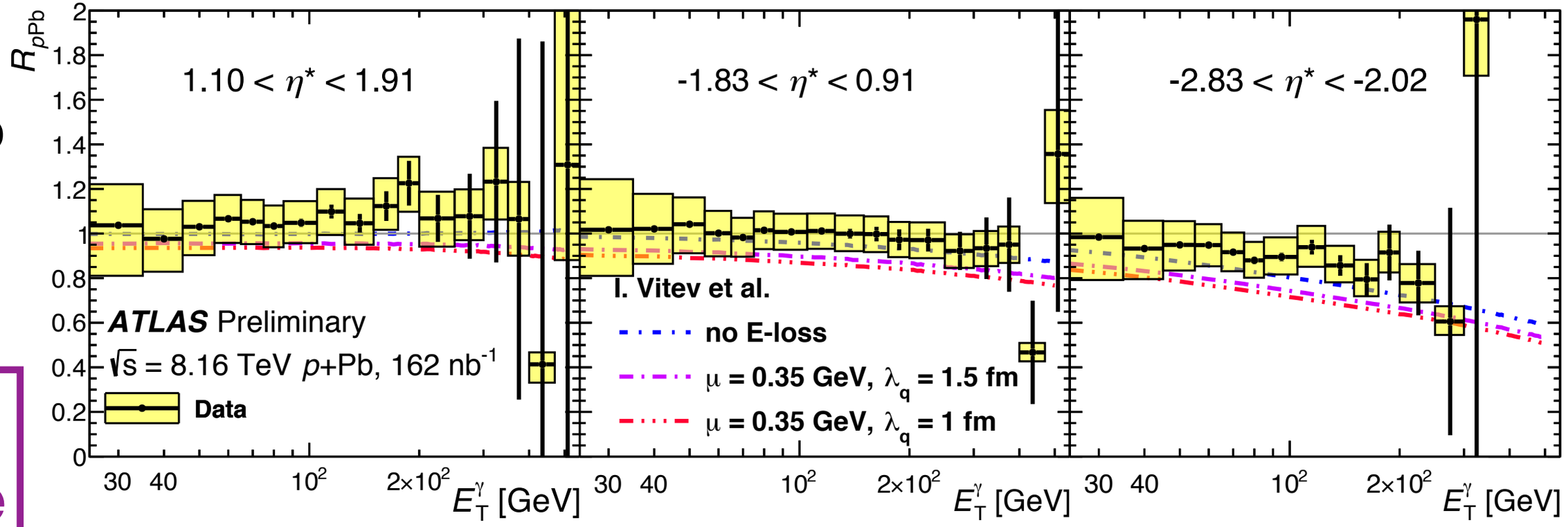


R_{pPb}



➡ *favorable comparison to pQCD & nPDF*

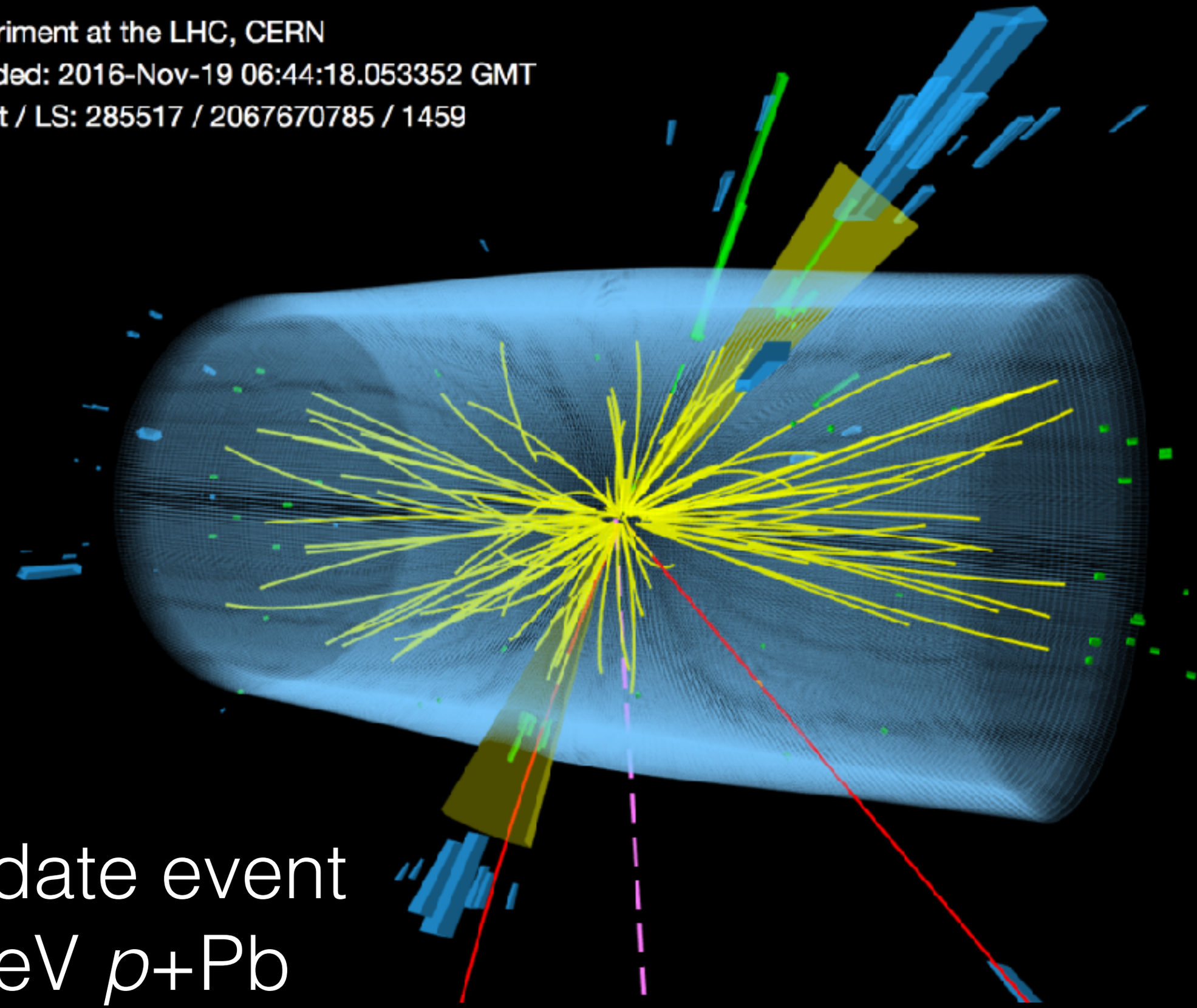
R_{pPb}



new since QM

➡ *disfavors large initial state E-loss*

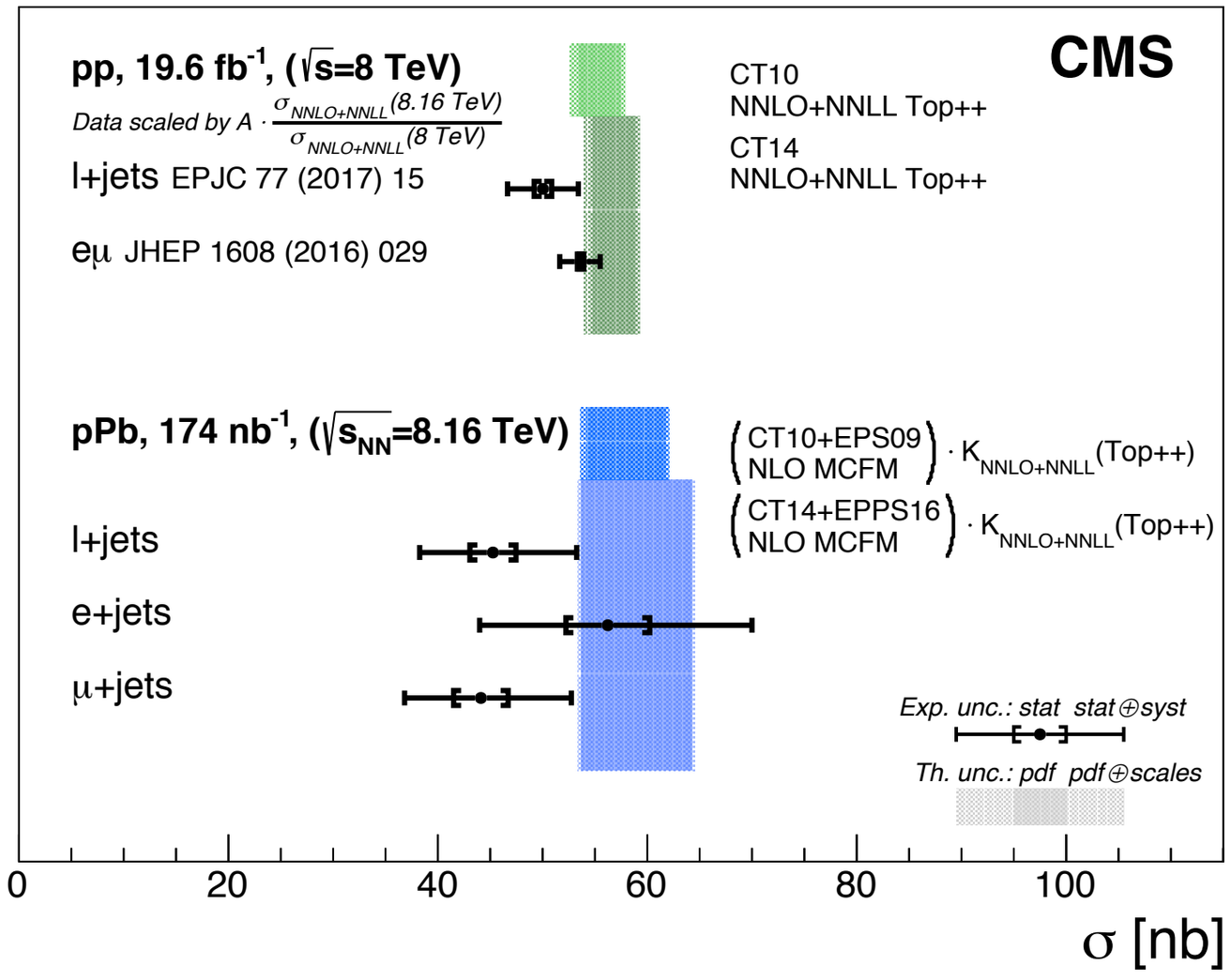
CMS Experiment at the LHC, CERN
Data recorded: 2016-Nov-19 06:44:18.053352 GMT
Run / Event / LS: 285517 / 2067670785 / 1459

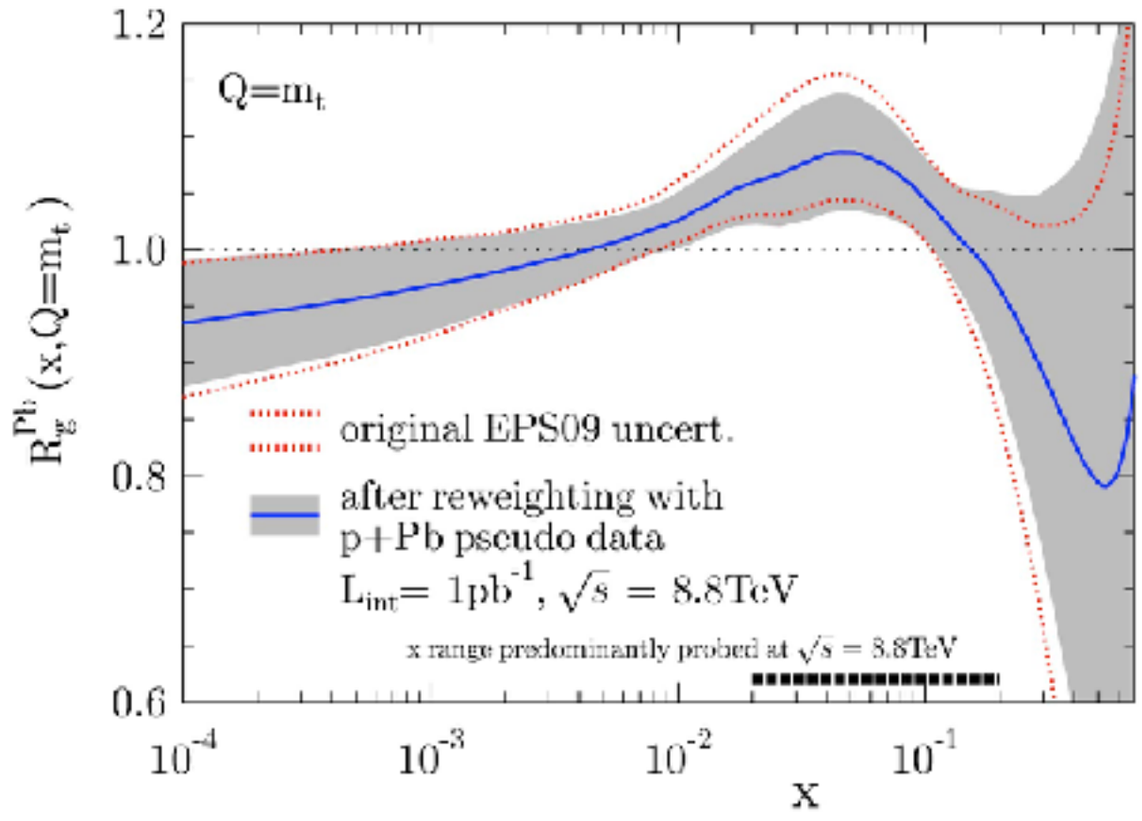


$t\bar{t}$ candidate event
8.16 TeV *p*+Pb
CMS data

$t\bar{t}$ in p+Pb

new since QM





PLB 746 (2015) 64

d'Enterria, Krajczar, Paukkunen

new particle observed (for HI collisions)

… modest impact for large-x gluon PDFs

ATLAS EXPERIMENT

Run: 286717
Event: 43643466
2015-11-26 09:53:40 CEST
Pb+Pb, $\sqrt{s_{NN}}$ = 5.02 TeV

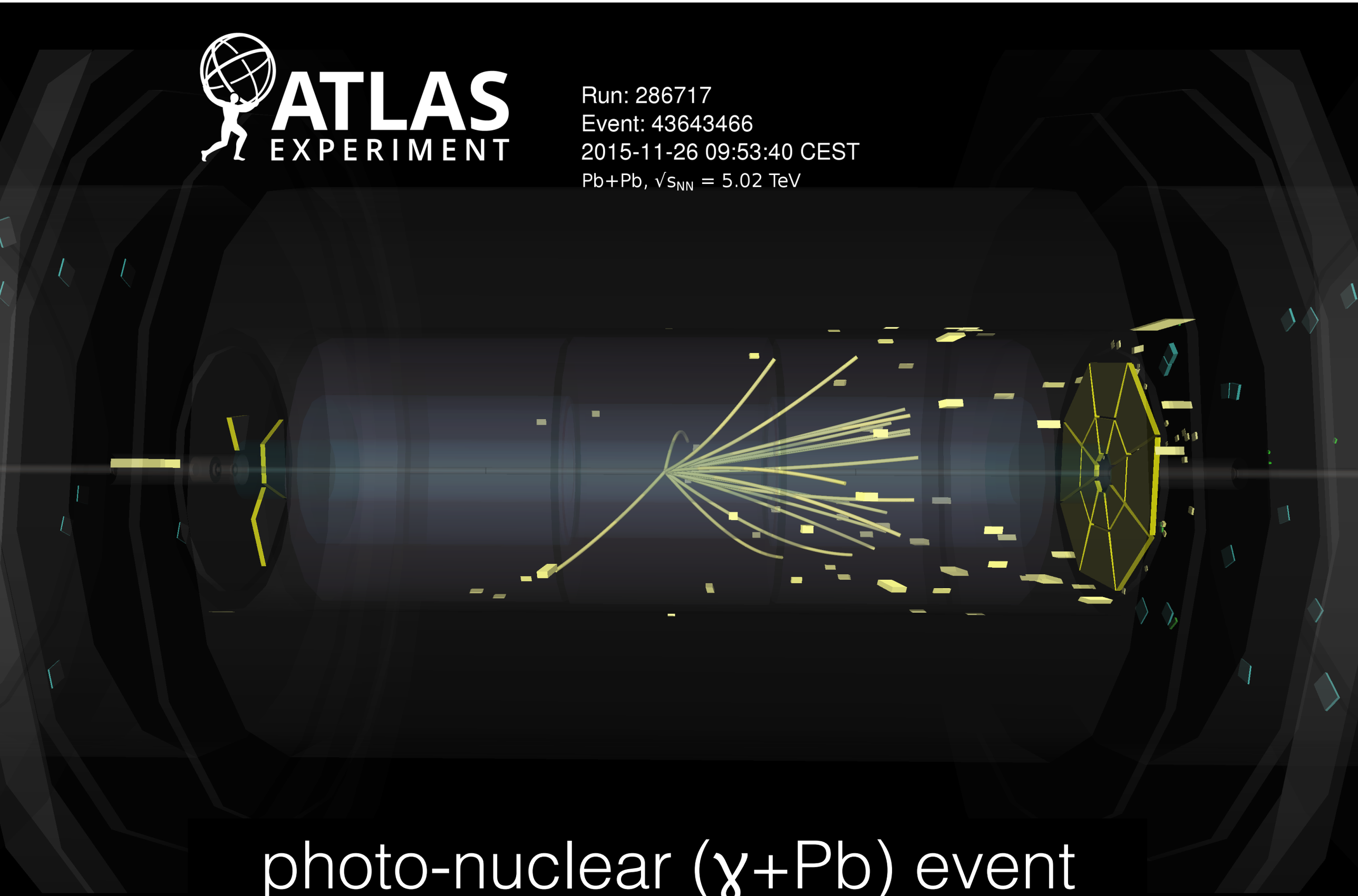
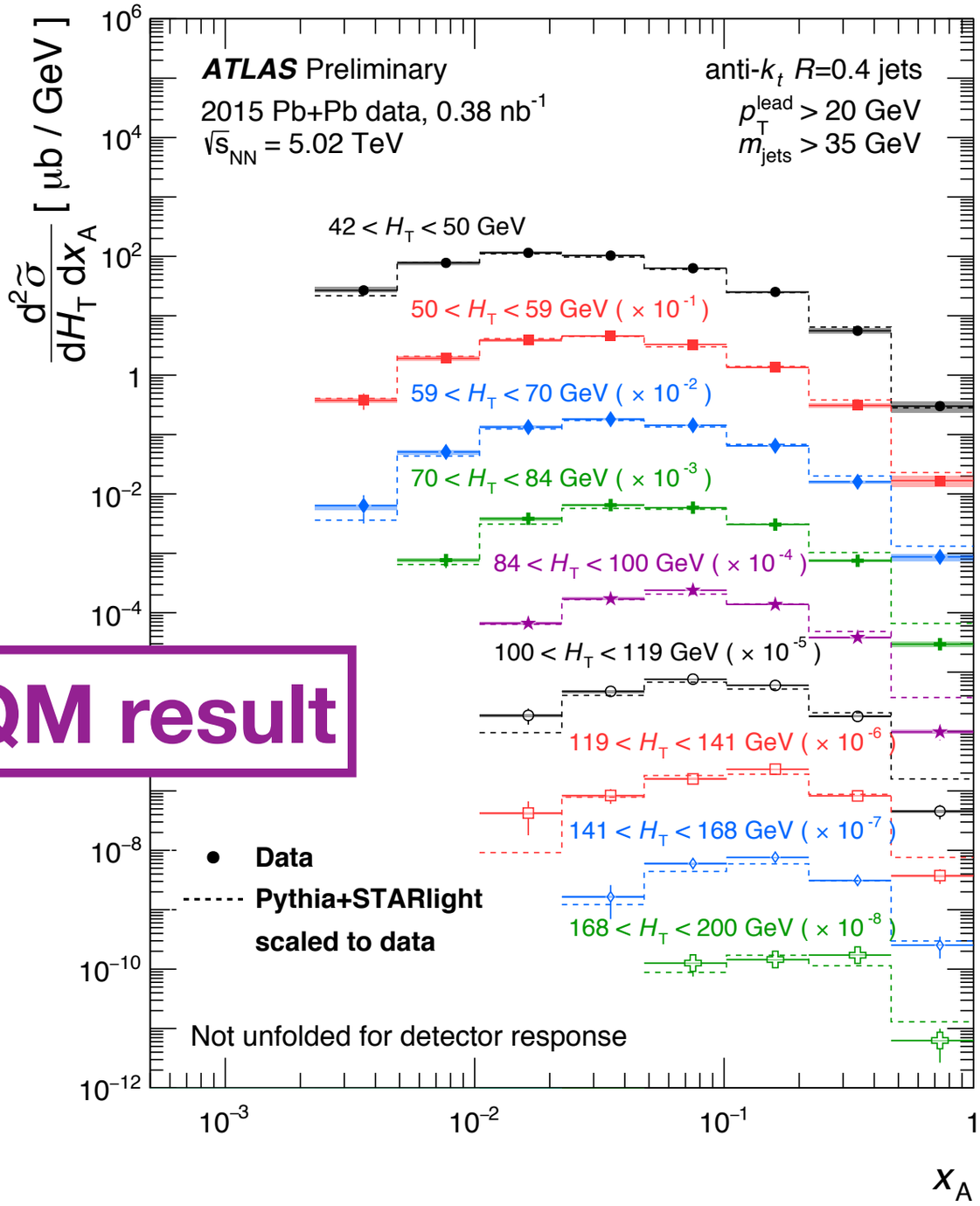


photo-nuclear (γ+Pb) event
5.02 TeV Pb+Pb, ATLAS data

dijets in γ+Pb



QM result

cleanly access nPDF effects in entirely new (x_A, Q^2) range

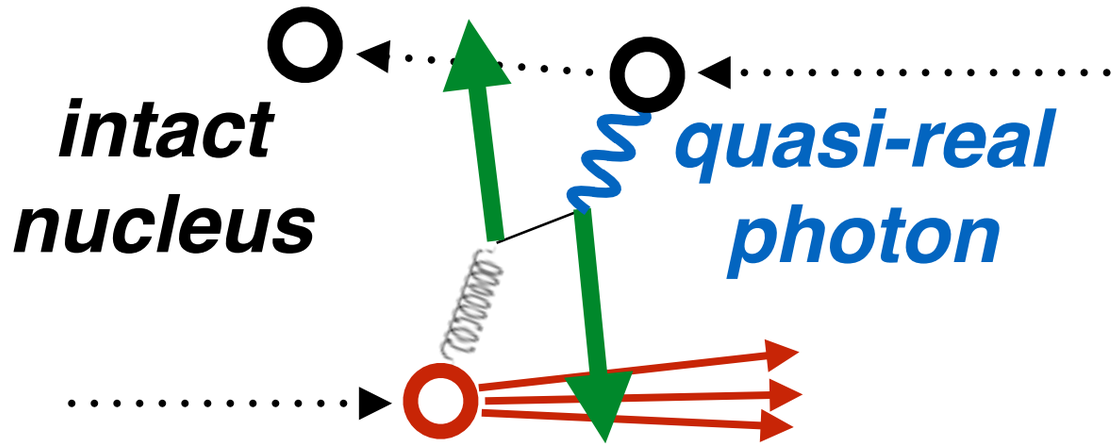
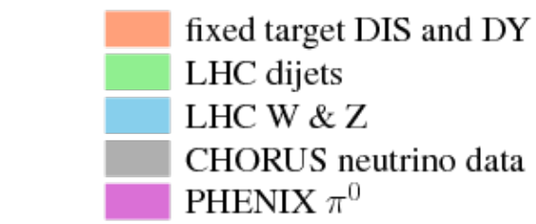


photo-nuclear dijets ***nuclear breakup***



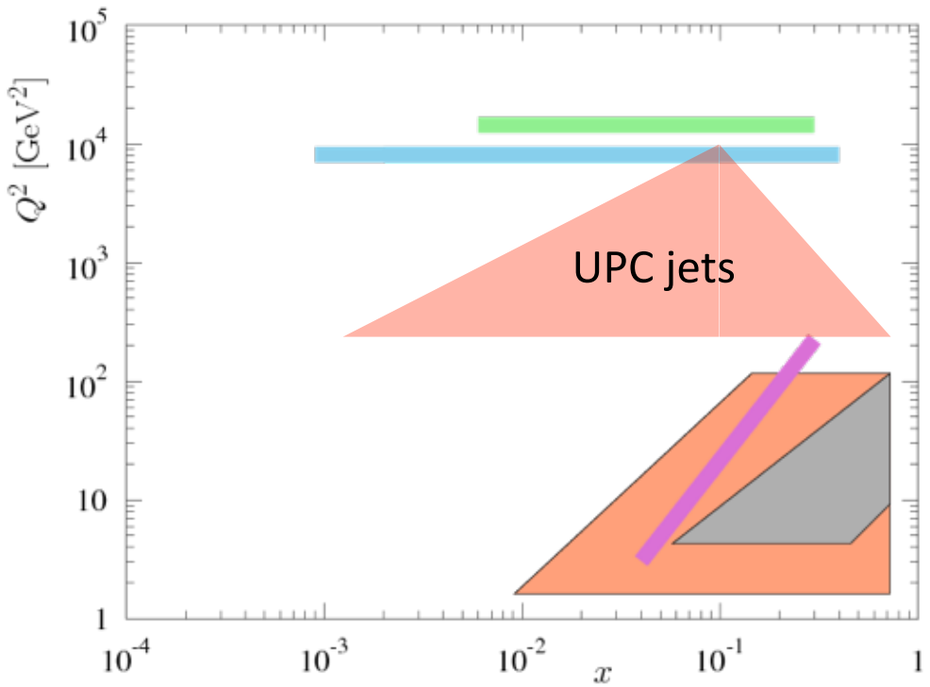
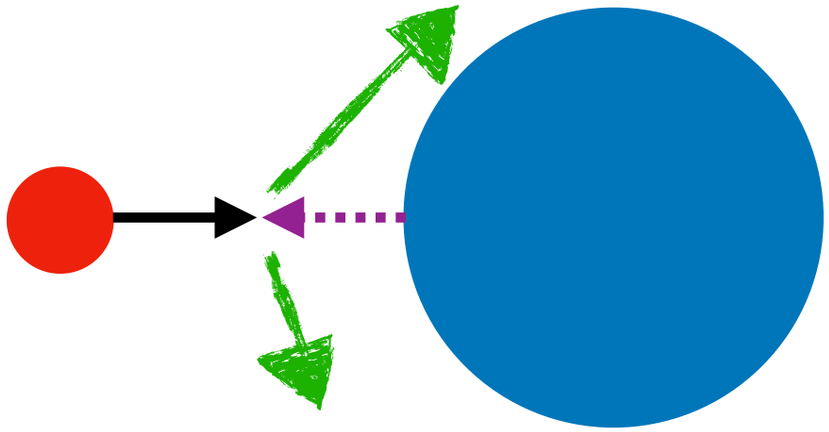
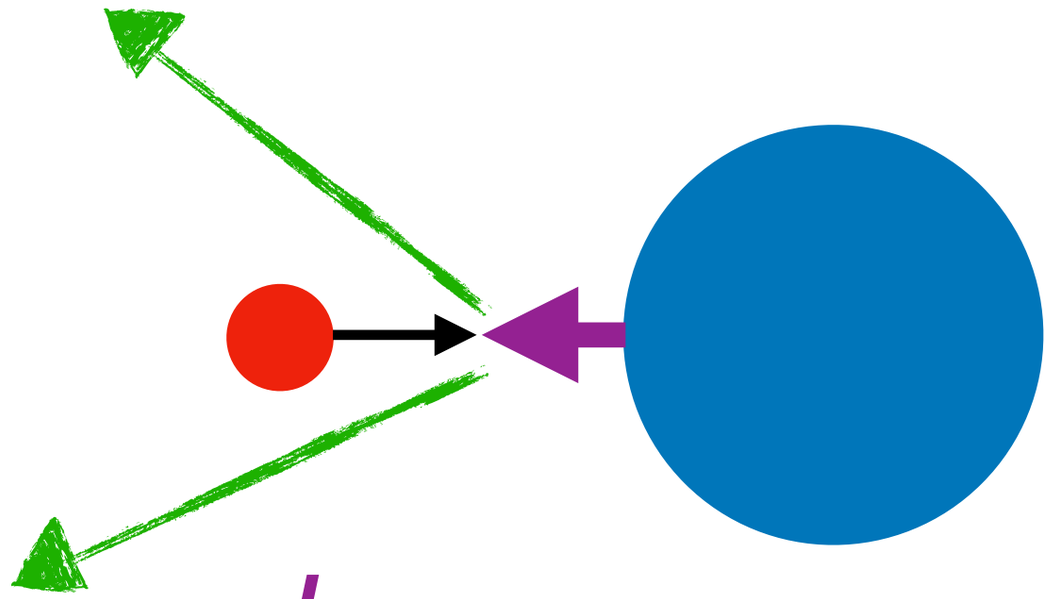


Figure adapted from EPPS16
1612.05741 [hep-ph]

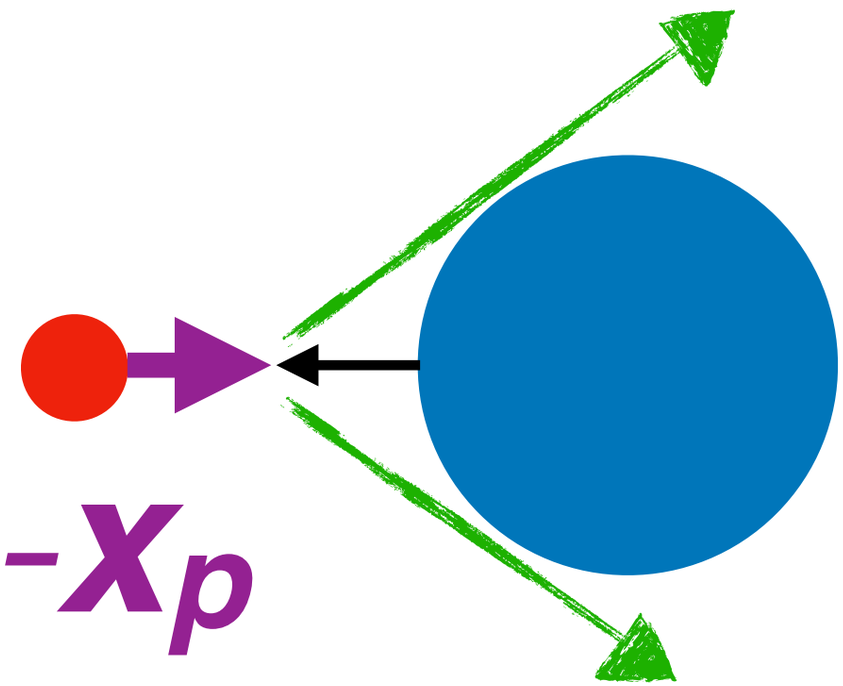
interesting kinematic regions:



small-x_A



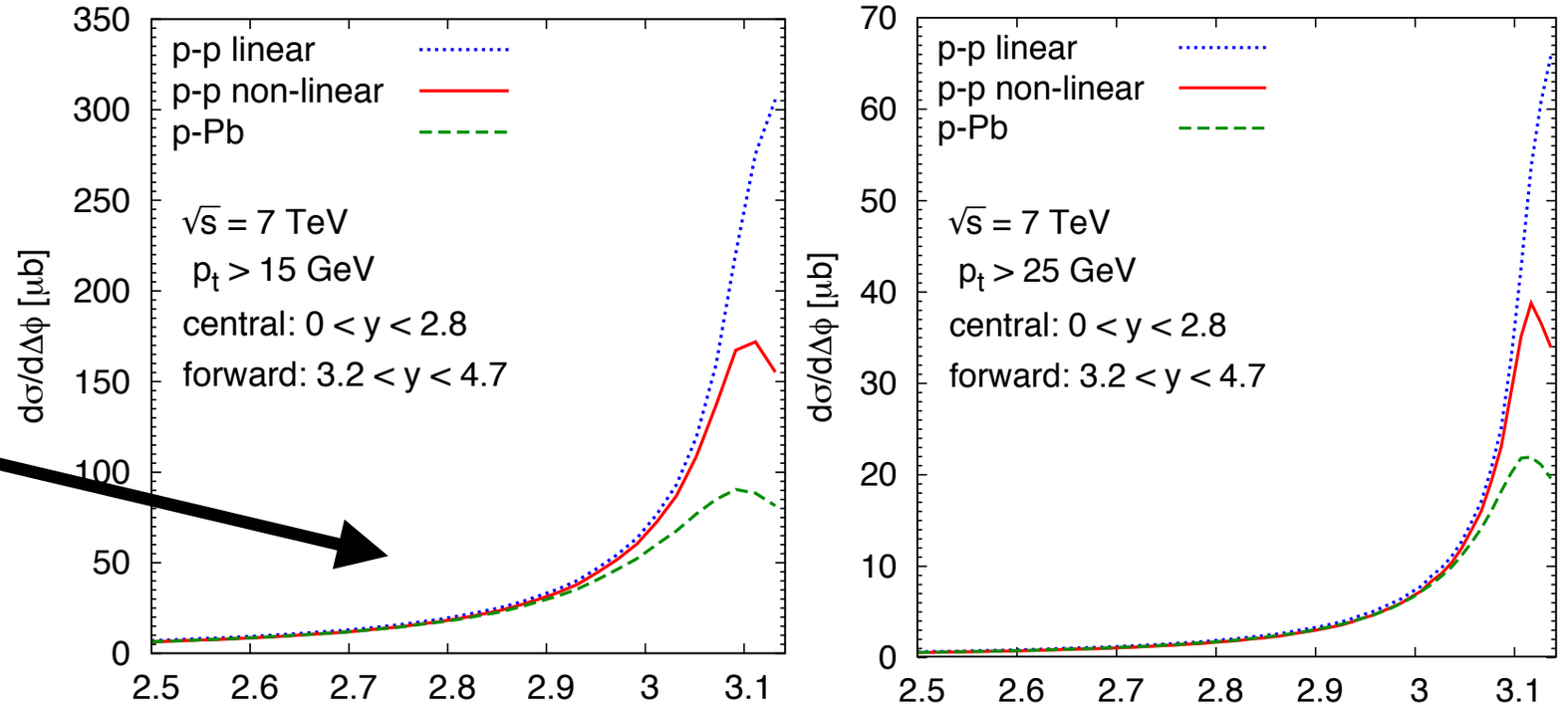
large-x_A



large-x_p

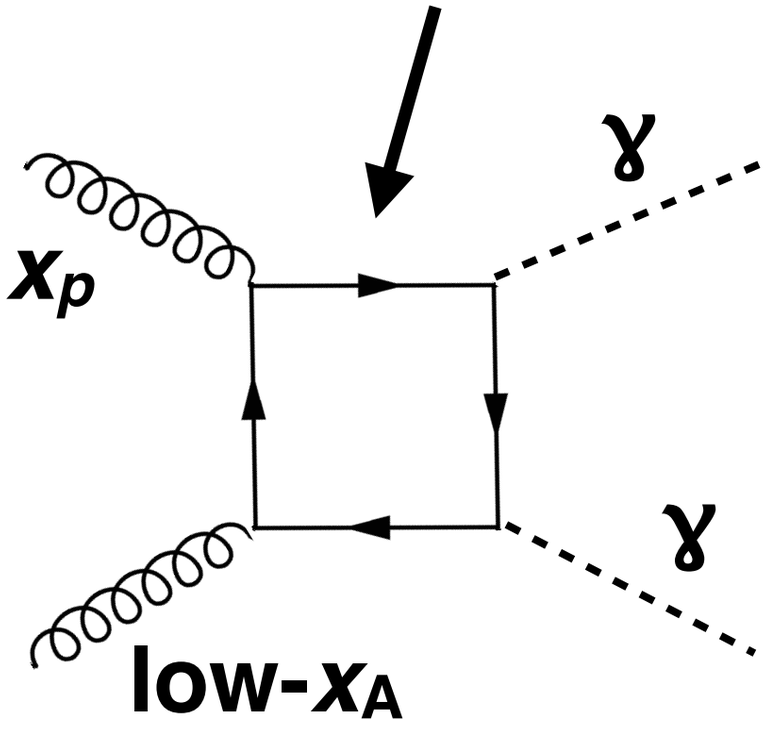
Low-x_A : di-jets and di-photons

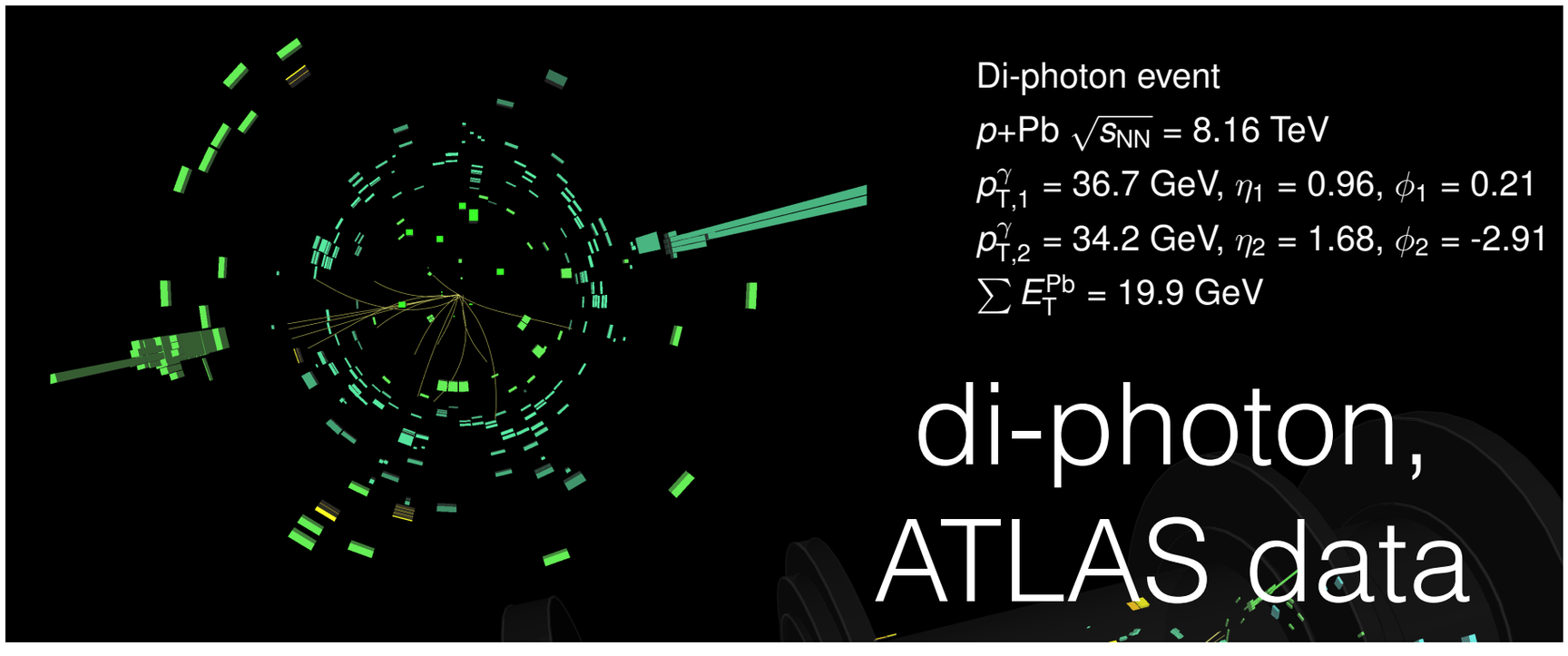
Low-p_T central + forward dijet correlations



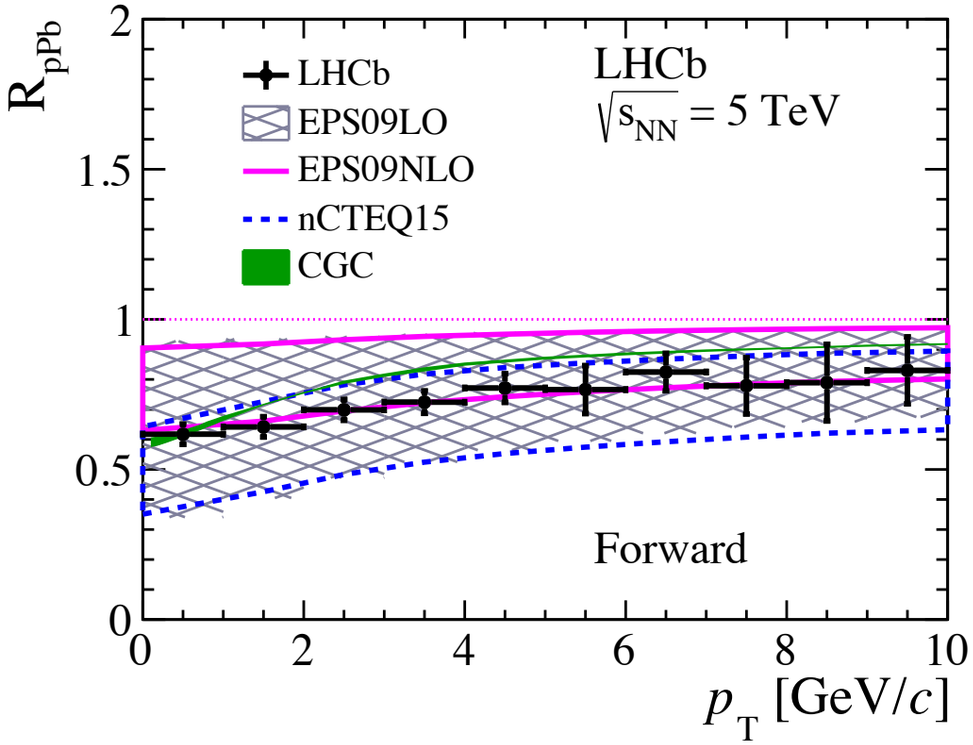
Kutak, Sapeta, hep-ph/1205.5035 (& other papers)

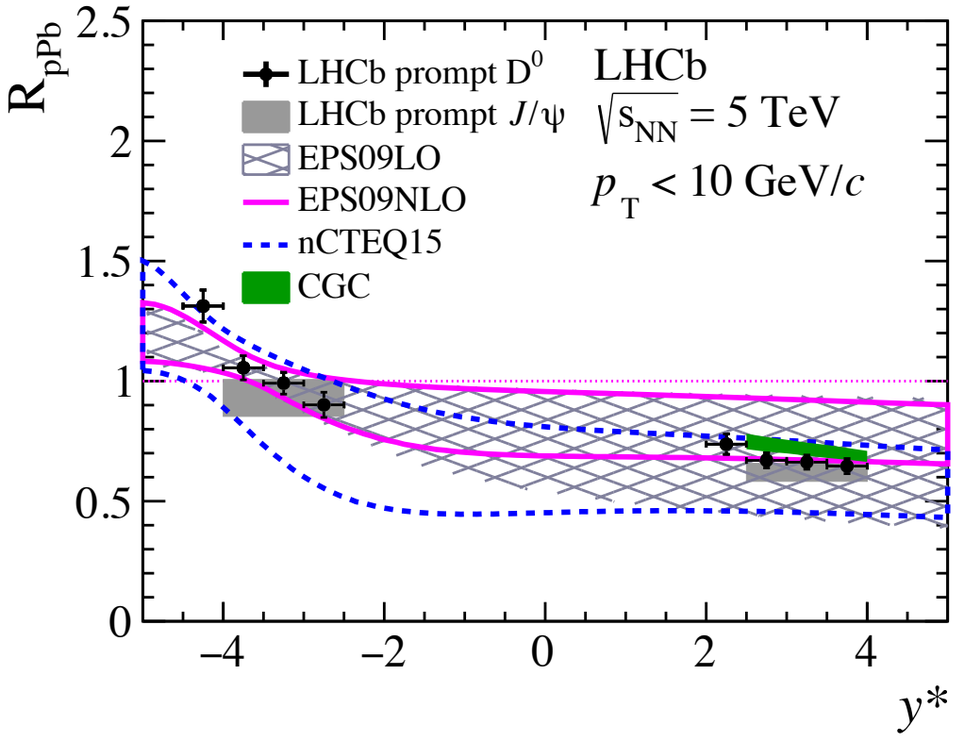
Di-photon production





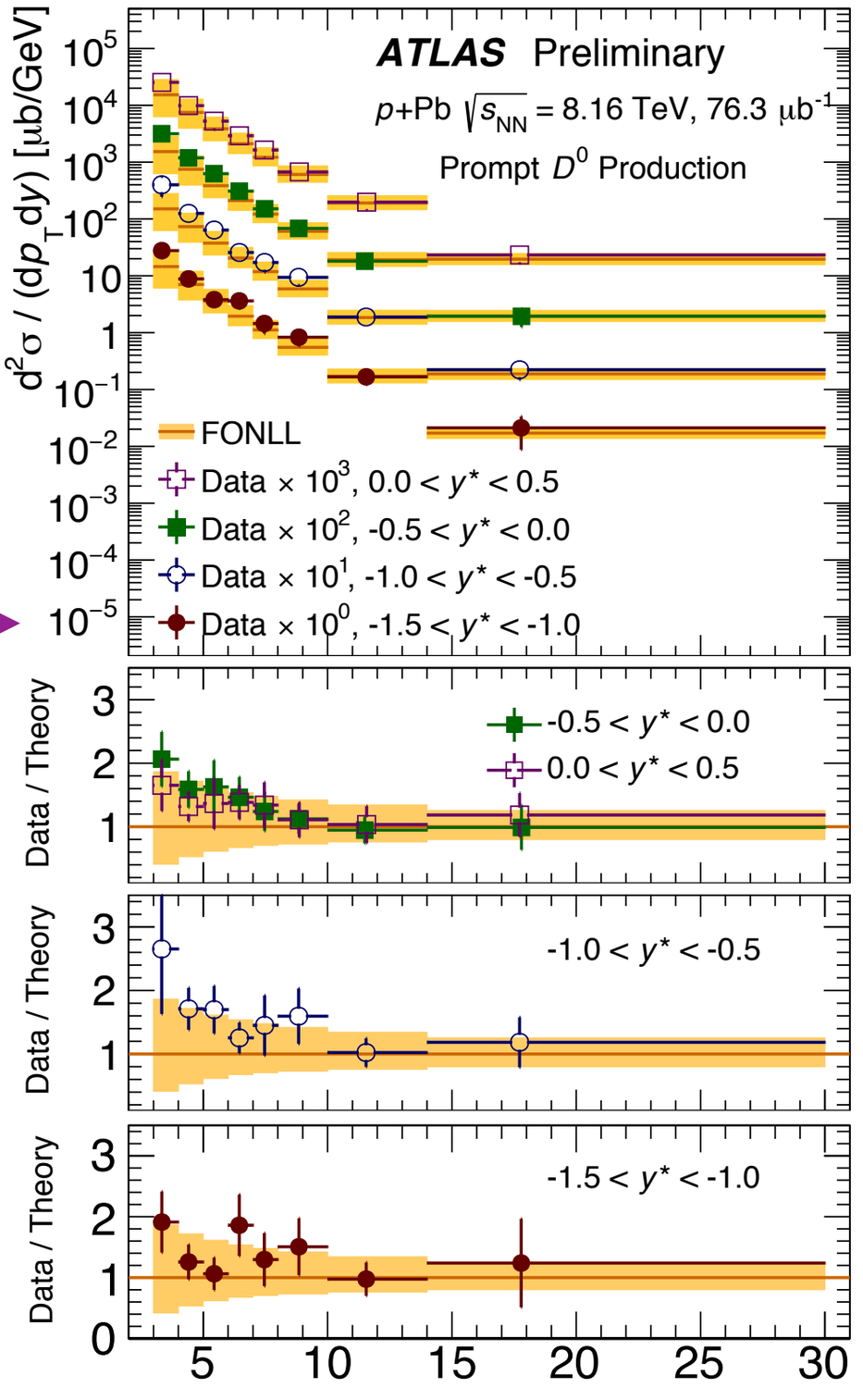
Low-x_A: heavy flavor mesons





hep-ex/1707.02750

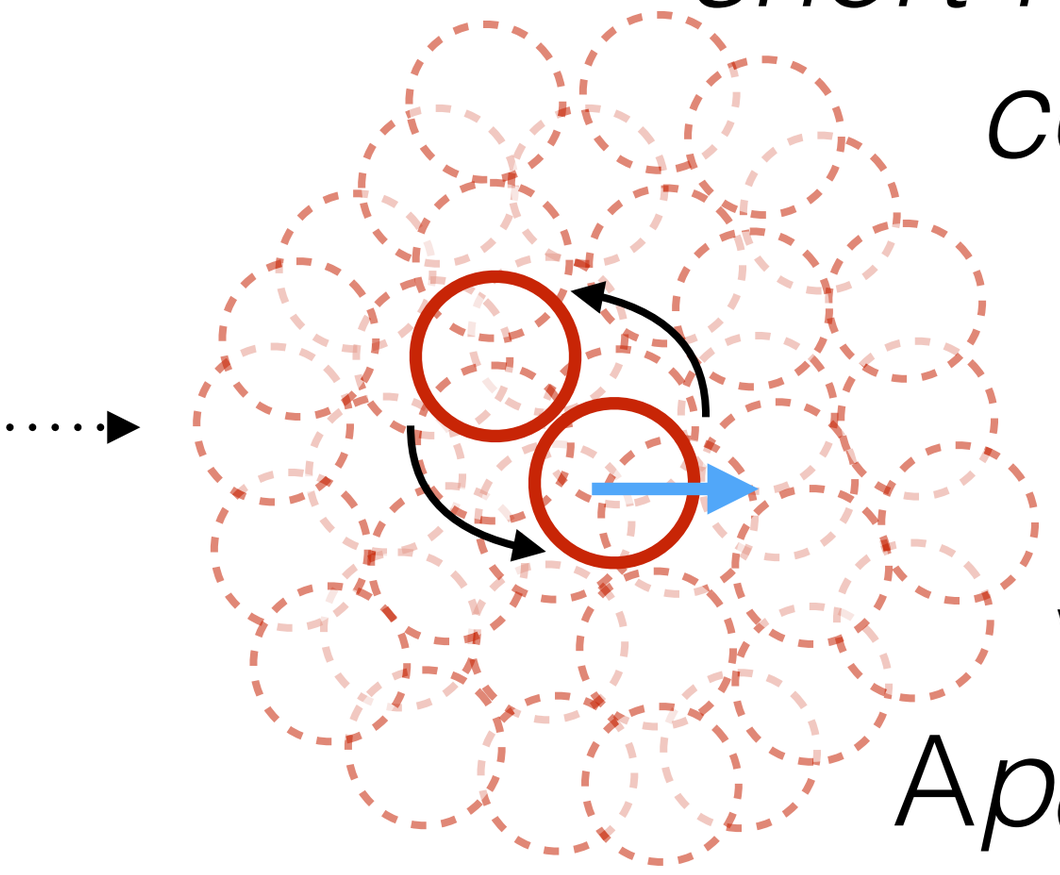
both new since QM



ATLAS-CONF-2017-073

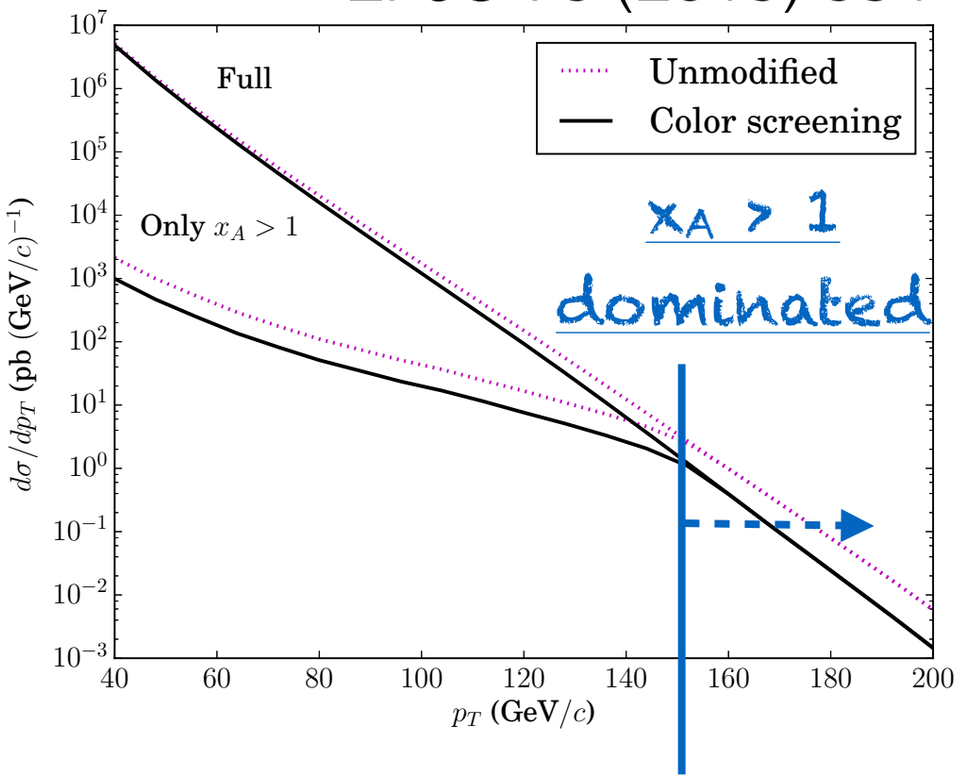
(Very) large-x_A: "superfast" quarks

*short-range **p-n** correlation*



quark with $x_A = Ap_q^-/p_A^- > 1$

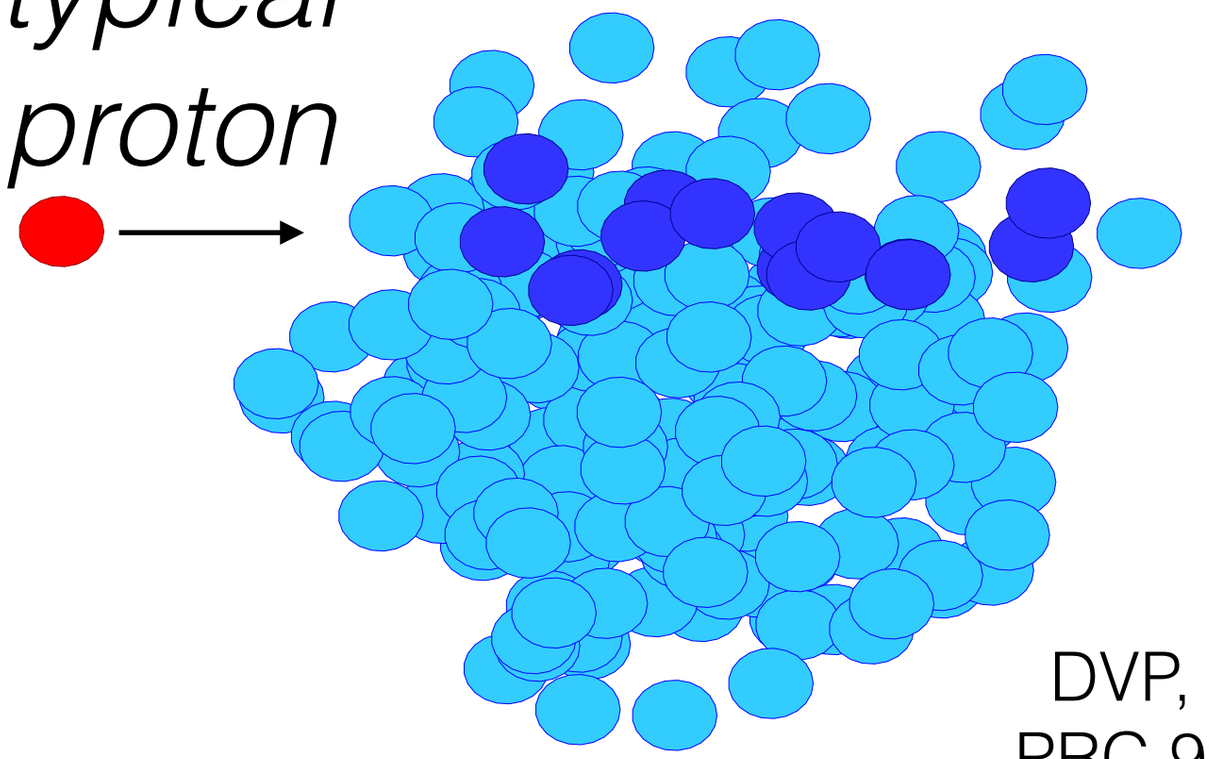
EPJC 75 (2015) 534



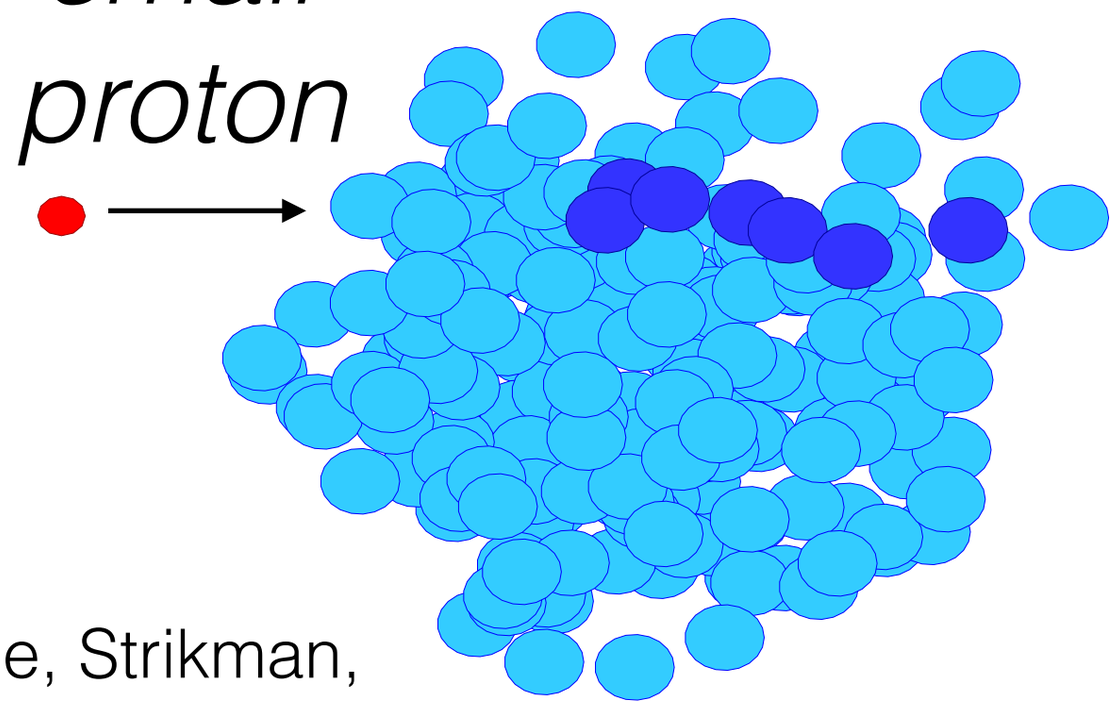
- Possibility to observe $x_A > 1$ configurations!
- Rates are sensitive to details of 2-*N* and 3-*N* Short-Range Correlations (SRCs)

(Very) Large-x_p, >0.1: centrality distorted by "*shrinking*" of the proton

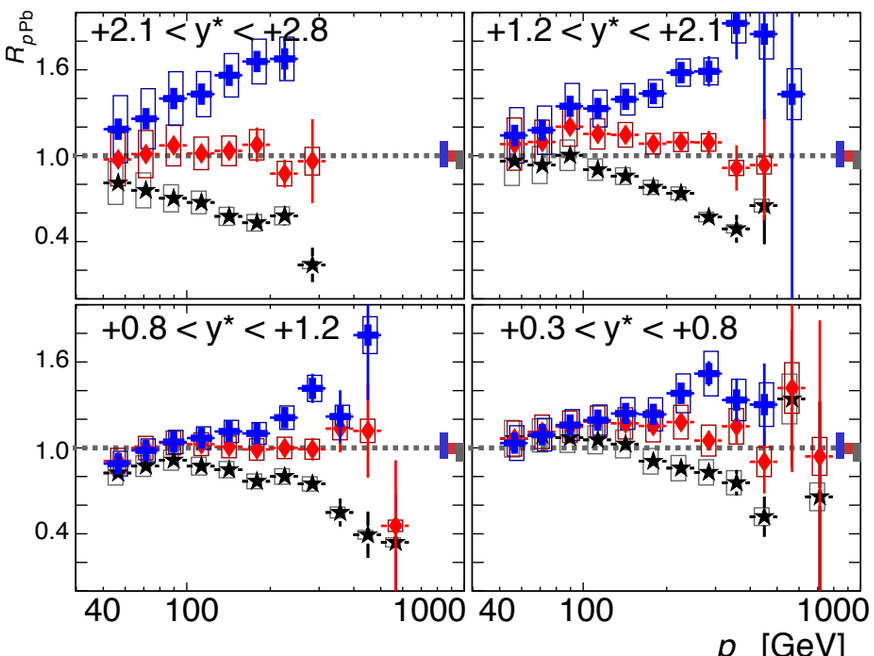
typical proton



small proton

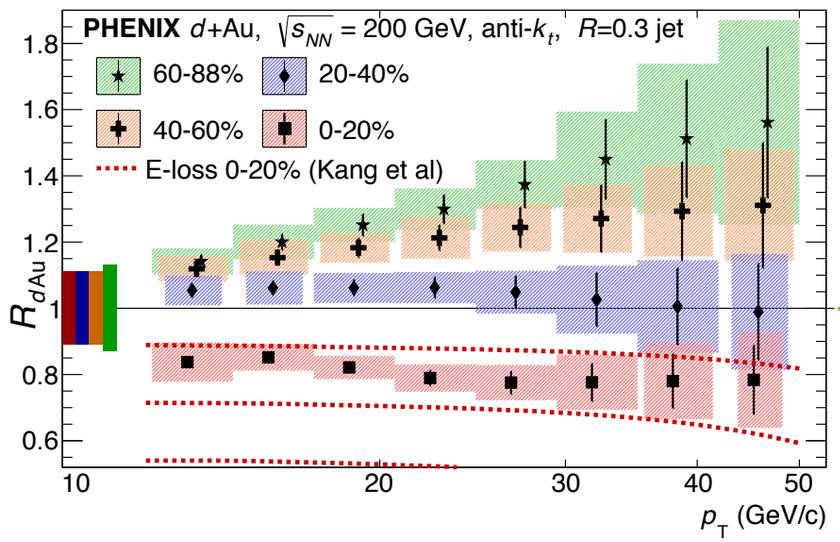


DVP, Cole, Strikman, PRC 93 (2016) 011902



peri.

cent.



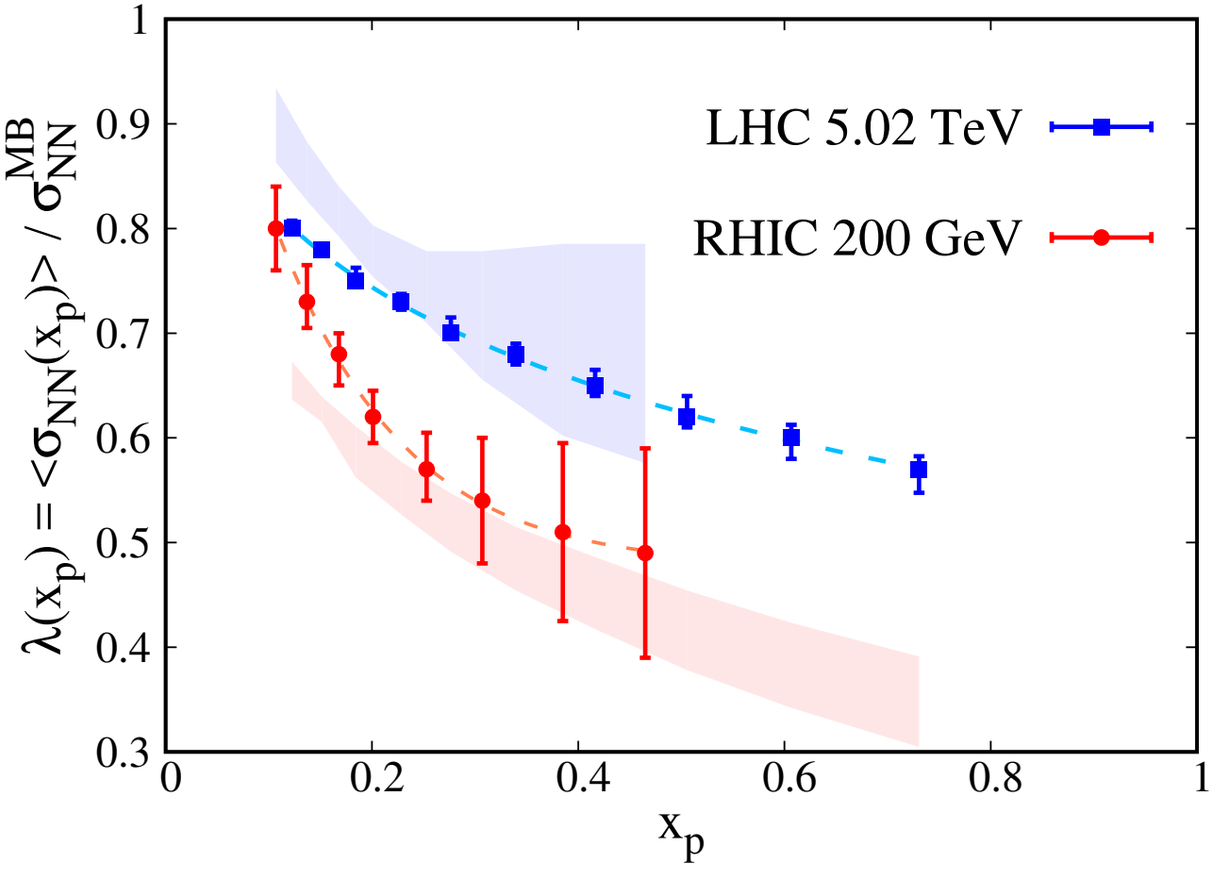
peri.

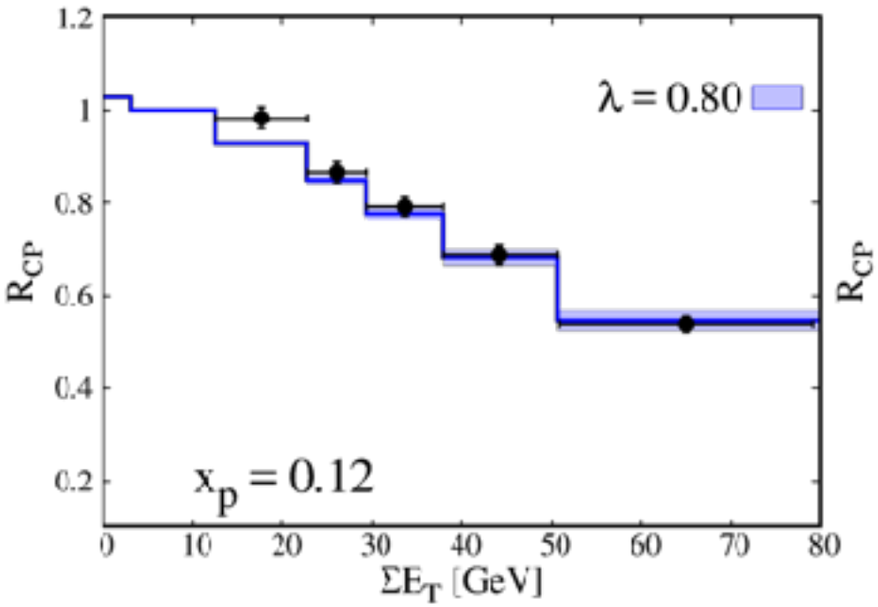
cent.

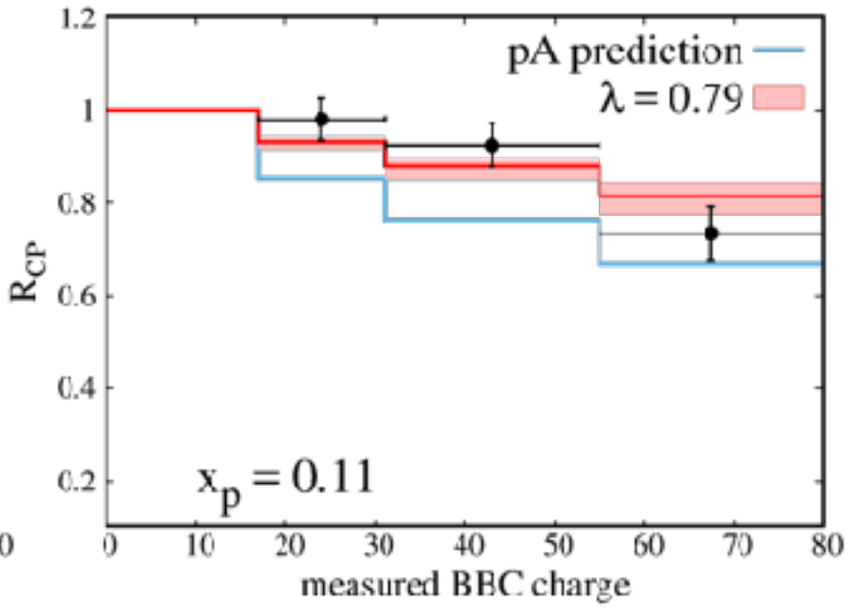
Global analysis of large-x_p color fluctuation ("shrinking proton") effects

new since QM

Systematic extraction of $\lambda(x_p) = <\sigma^{NN}(x_p)>/<\sigma^{NN}>$ vs. x_p and energy

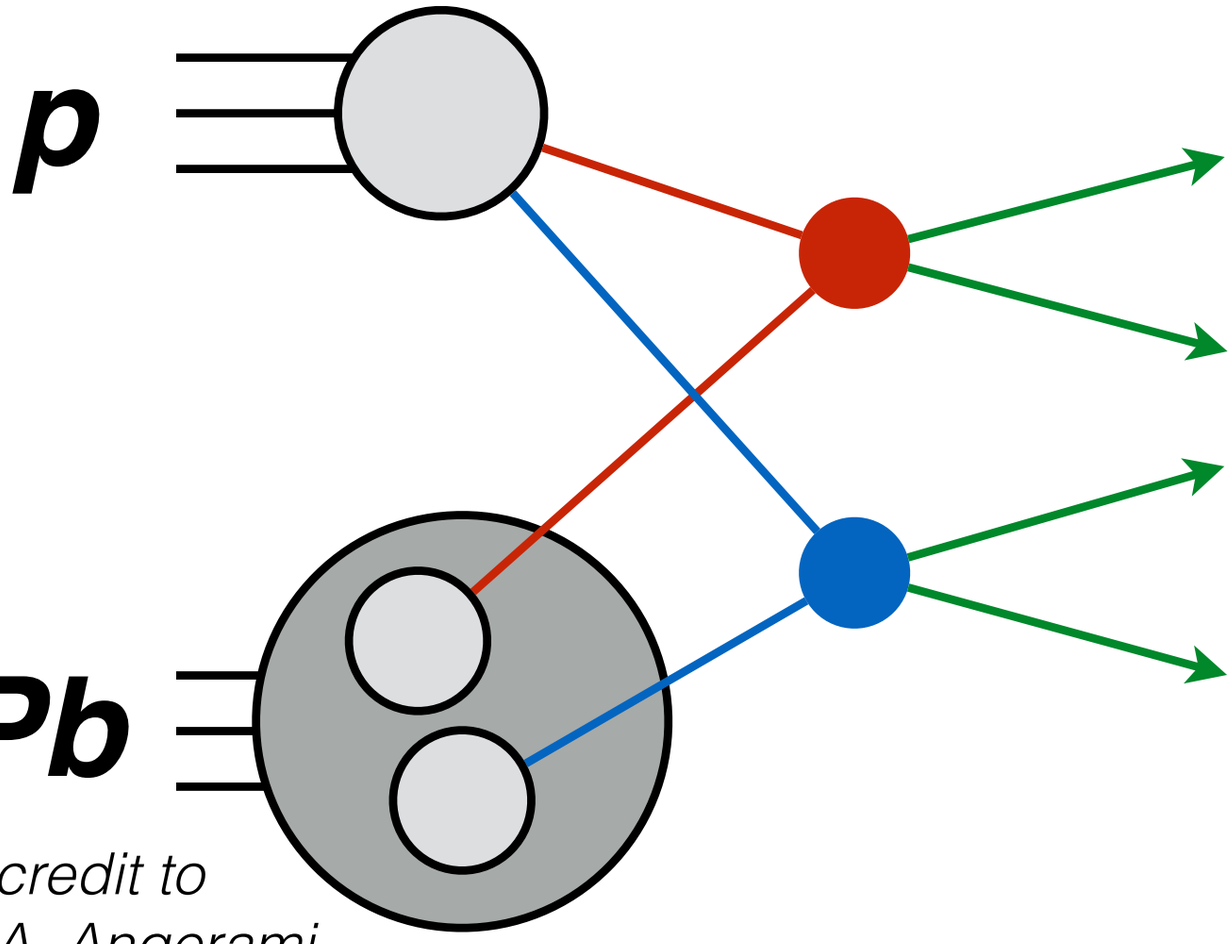






Alvioli, Frankfurt, DVP, Strikman
hep-ph/1709.04993

double parton scattering in *p*+A ("MPI" but at very large p_T)



credit to A. Angerami

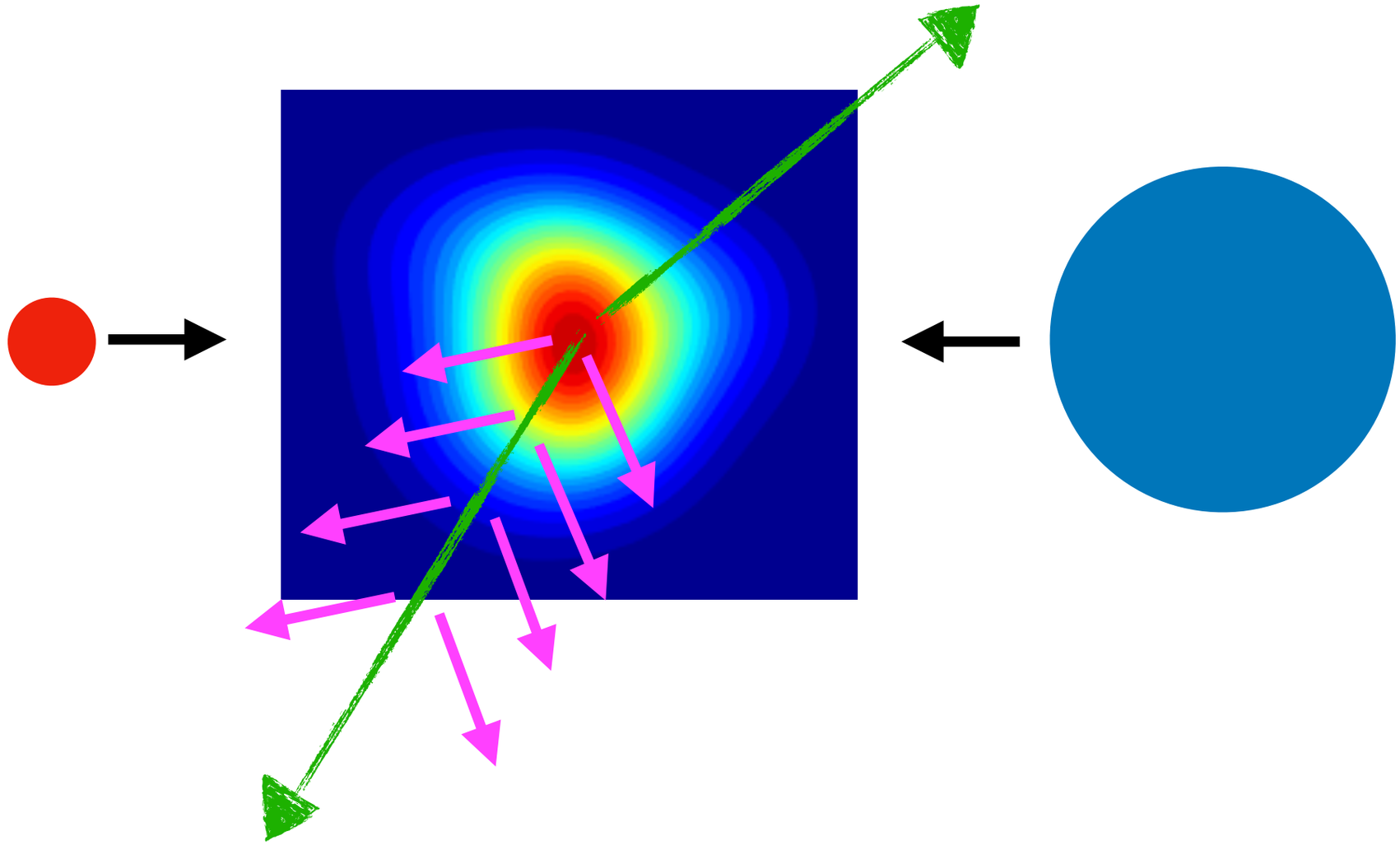
Select ***large-x_p*** *configuration*

Look for ***independent parton scattering***

Image the structure of the beam remnant (${}_2$GPD's)

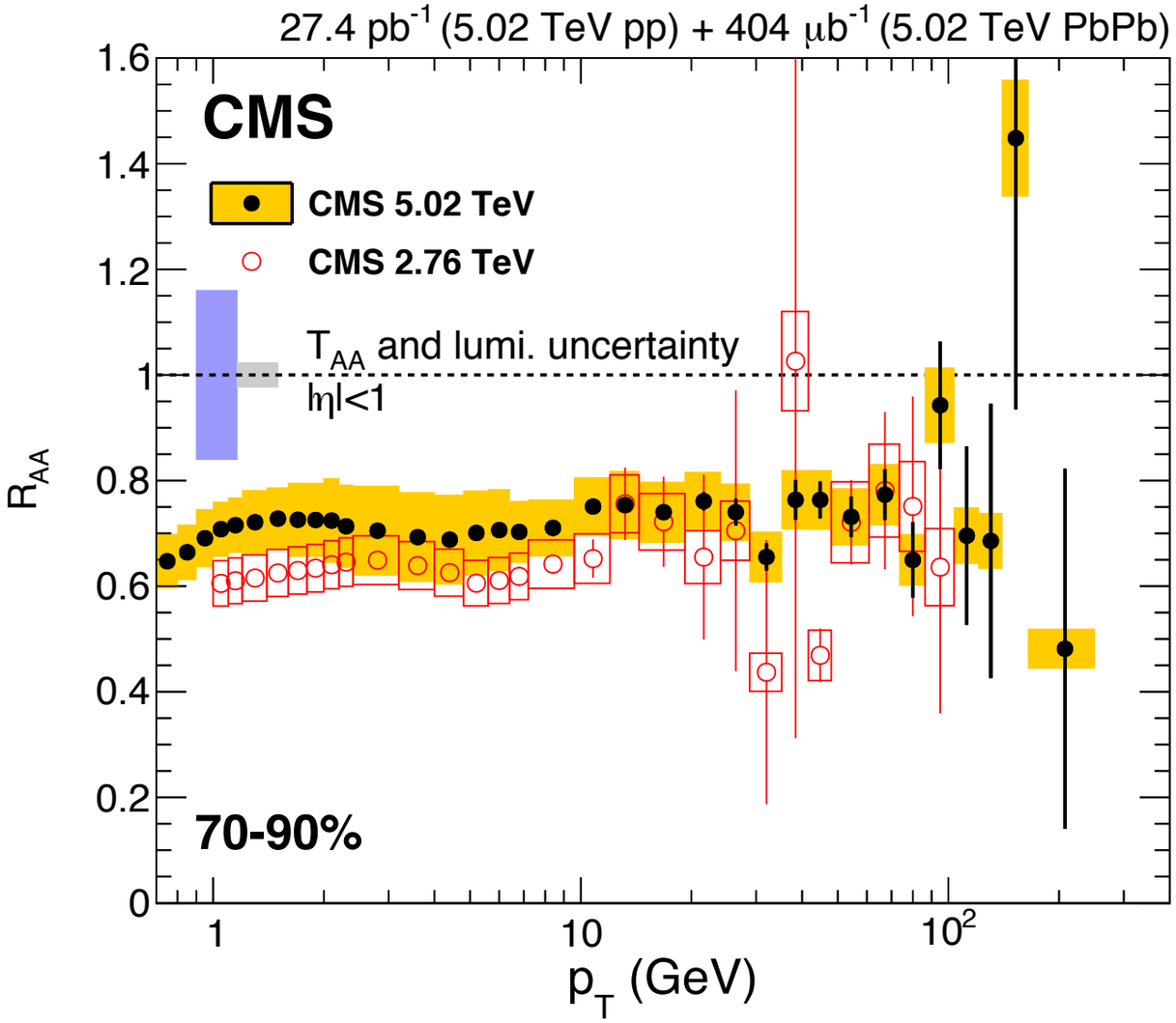
4-jets: Blok, Strikman, Wiedemann EPJC 73 (2013) 2433

jet quenching in small systems?

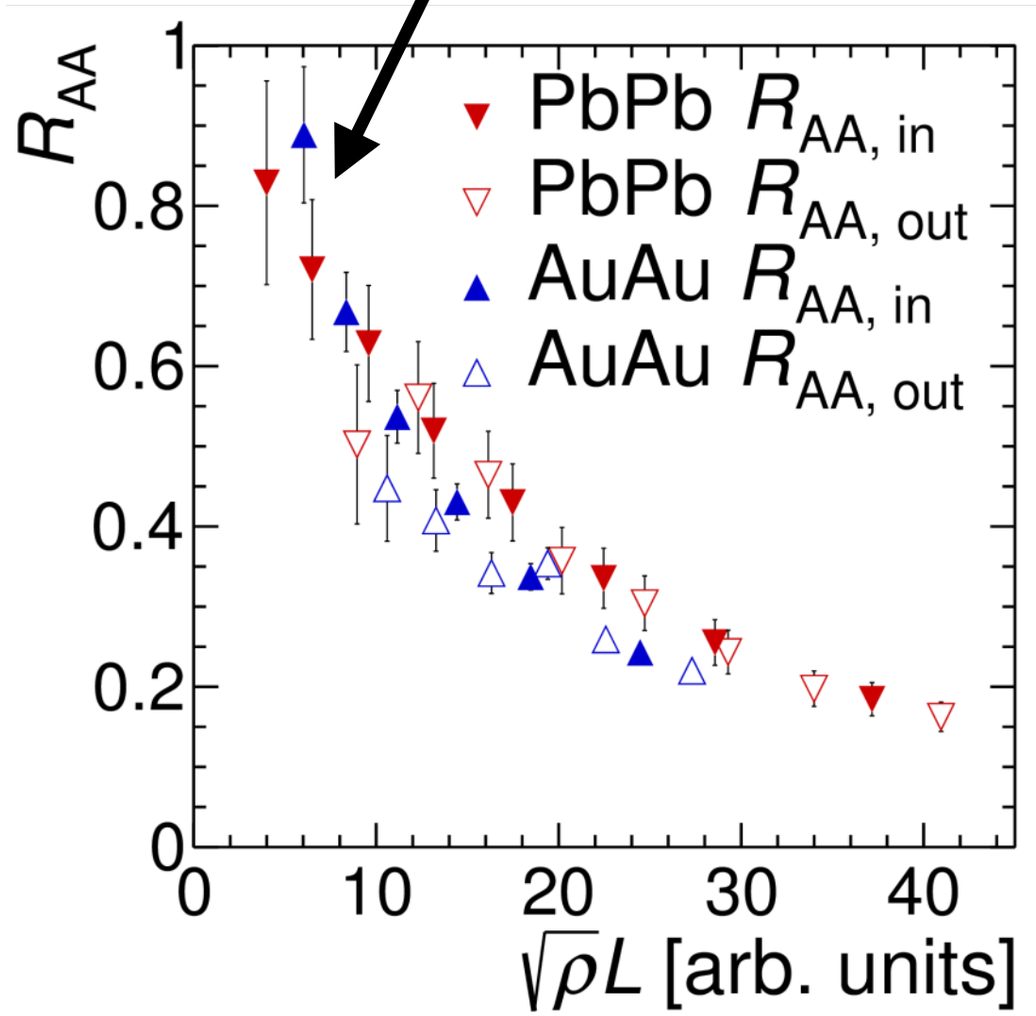


Energy loss in small systems?

R_{AA} < 1 even in very peripheral collisions…



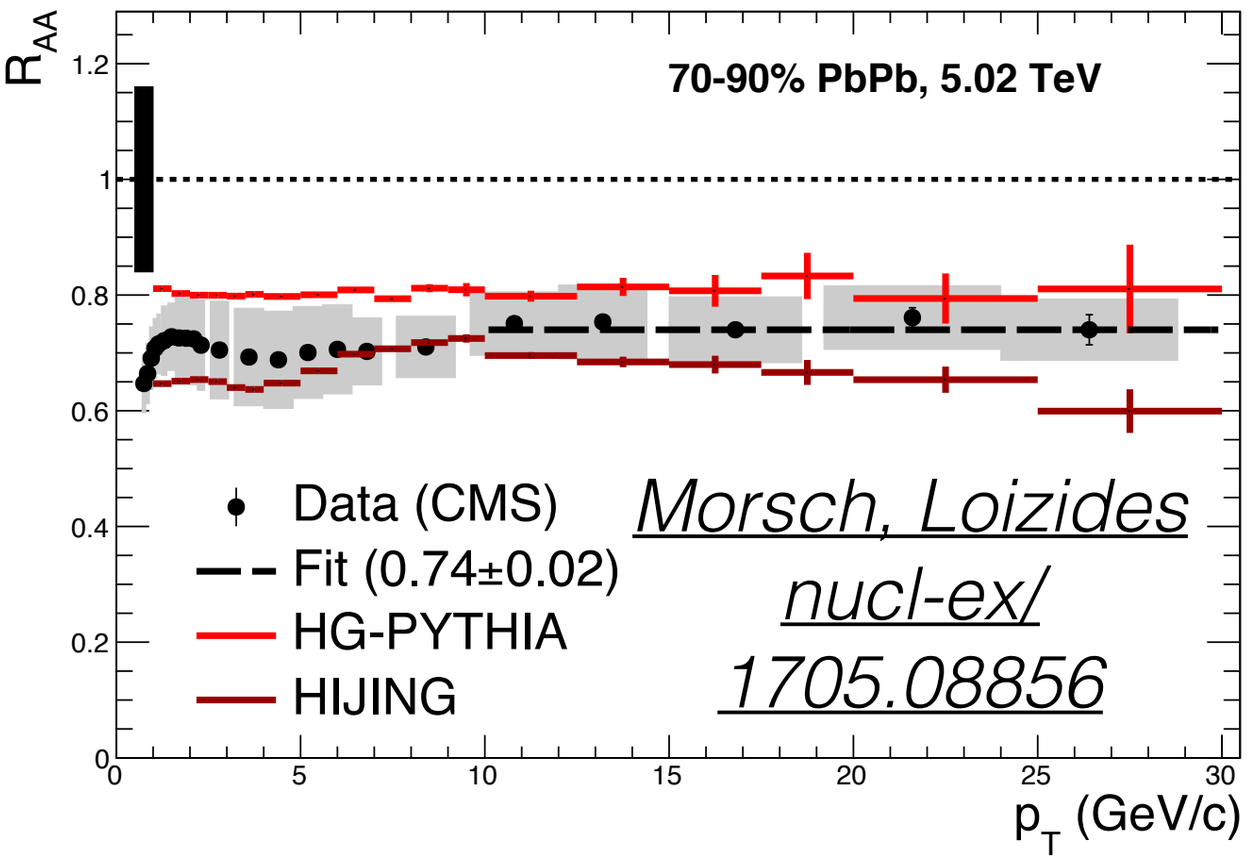
Systematic extractions: E_{loss} in p+Pb sized systems?



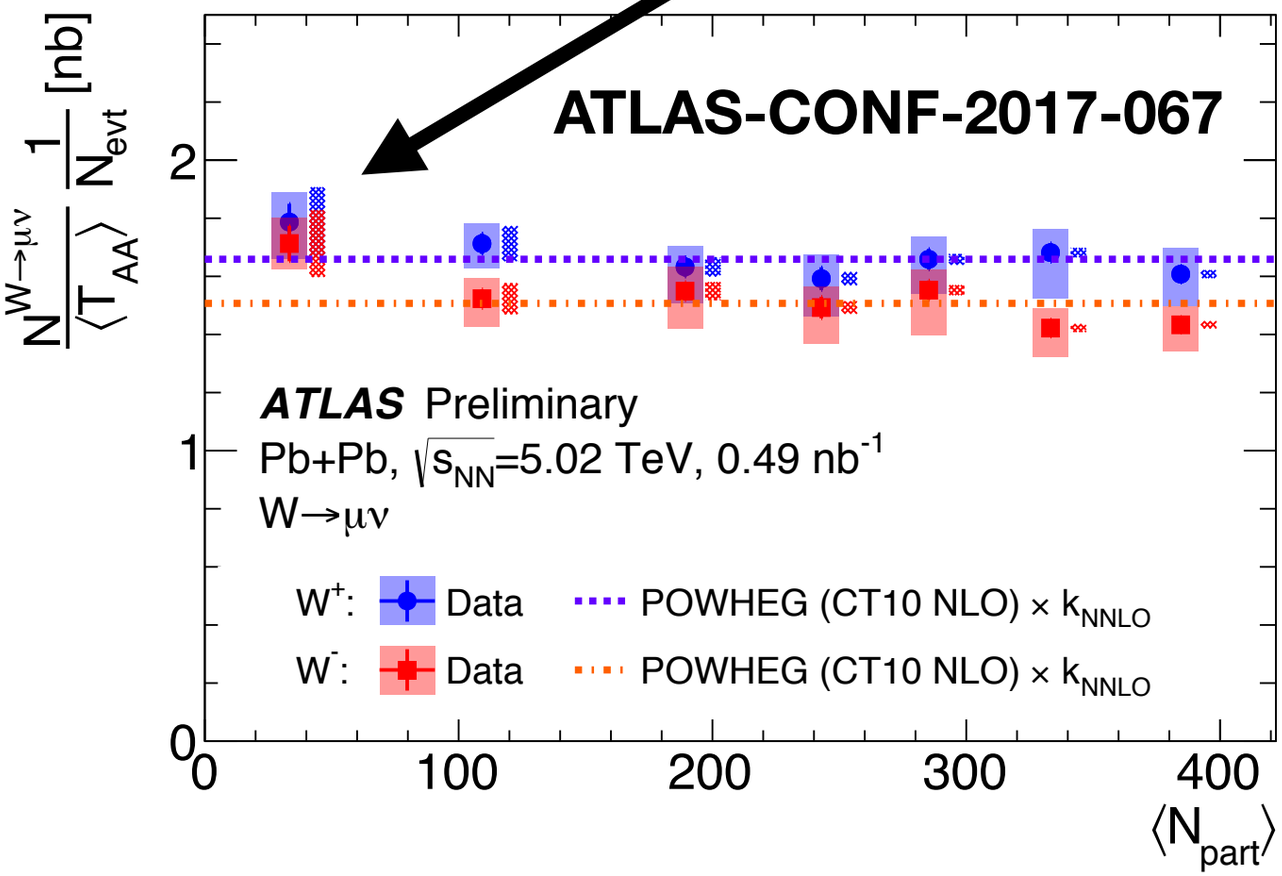
(P. Christiansen, this conf.)

both new since QM

Bias in peripheral A+A events?

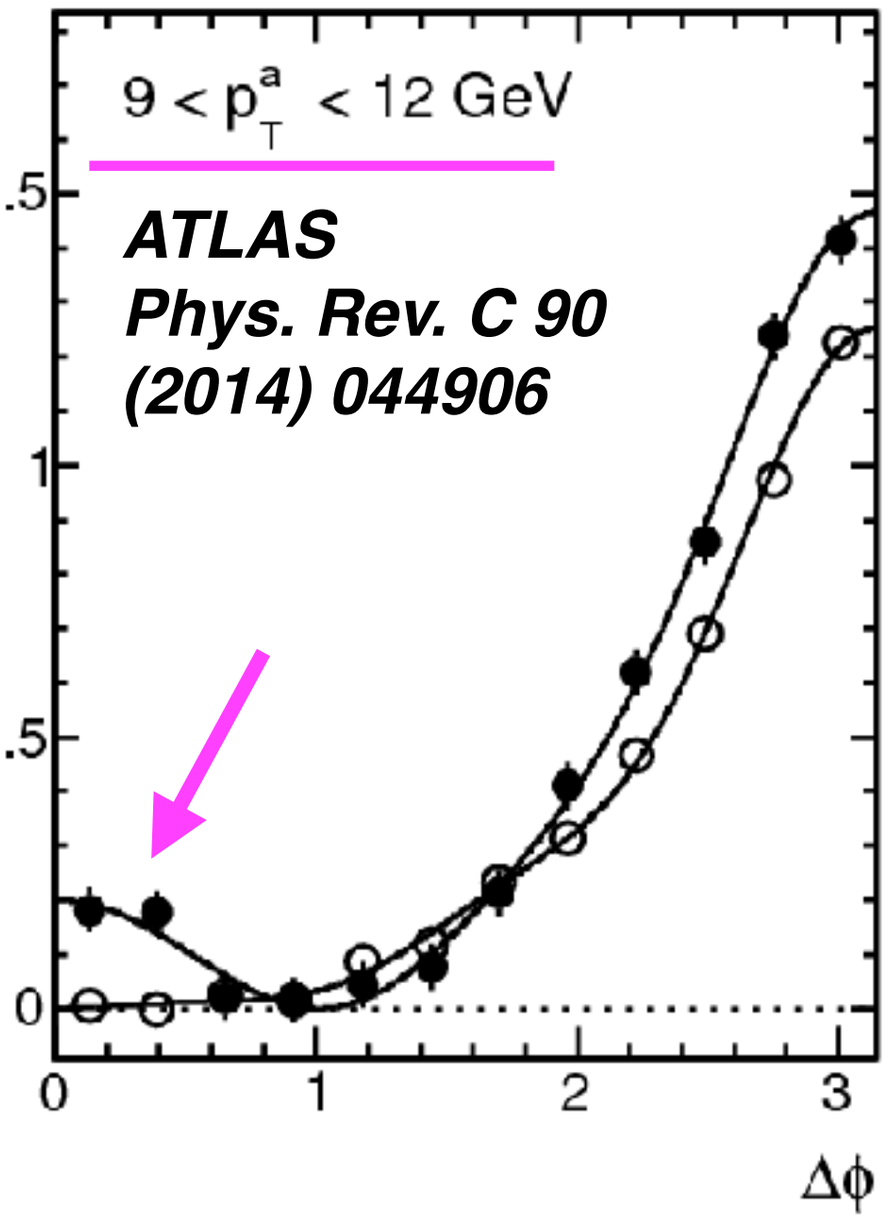


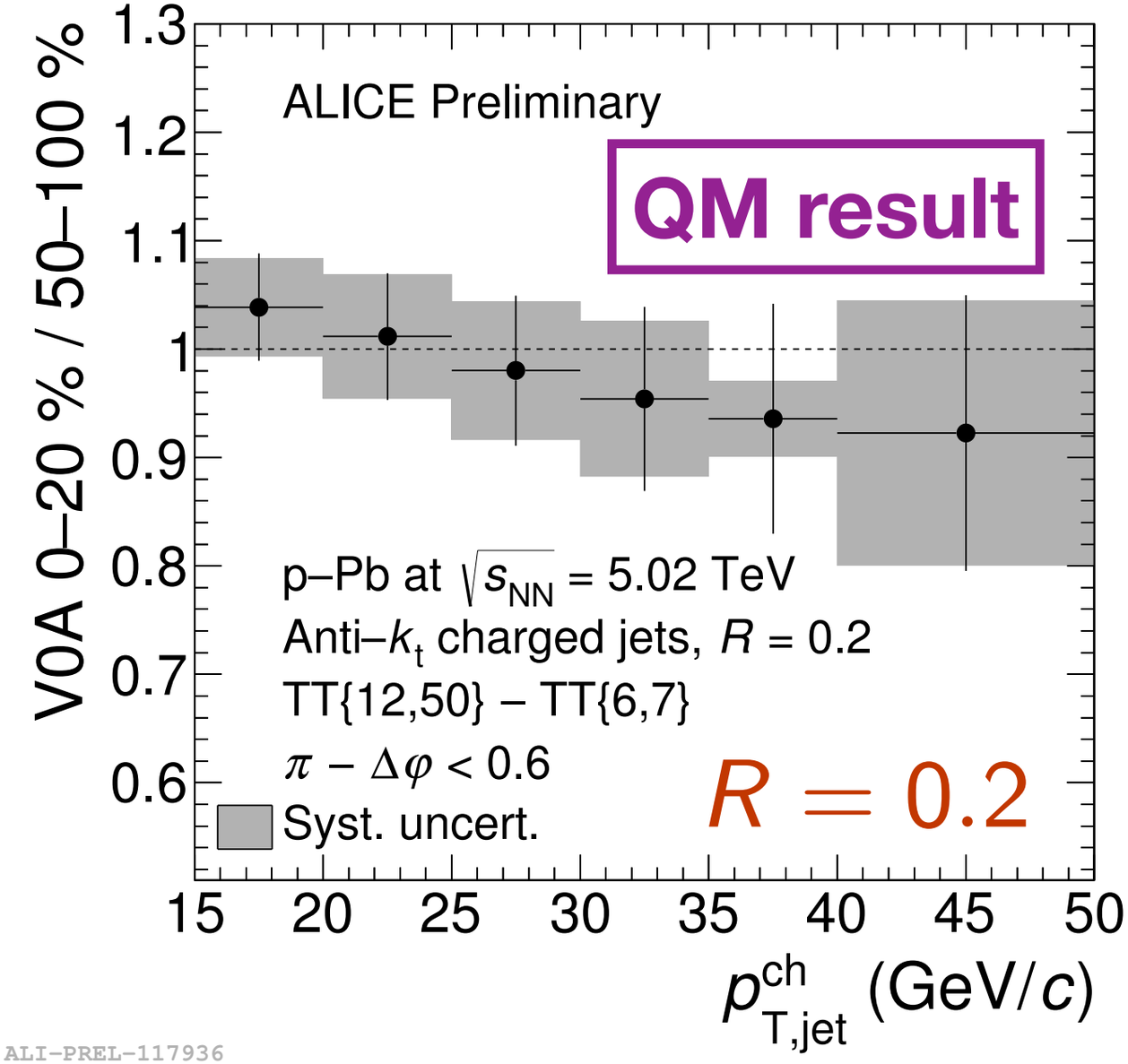
50-80%



Suppression from "centrality bias" (e.g. low-mult. jet veto?)

Check this with high-statistics *W*± yields… … similarly with *Z*'s





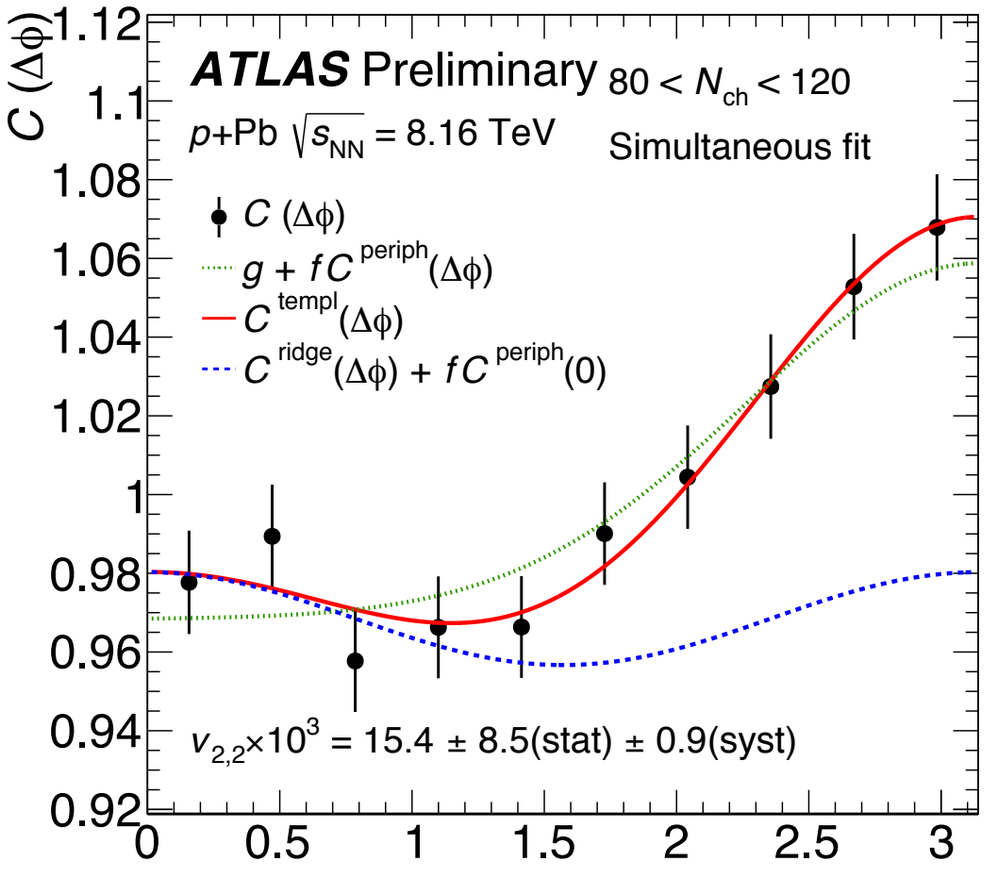
high-p_T near-side ridge in <1%

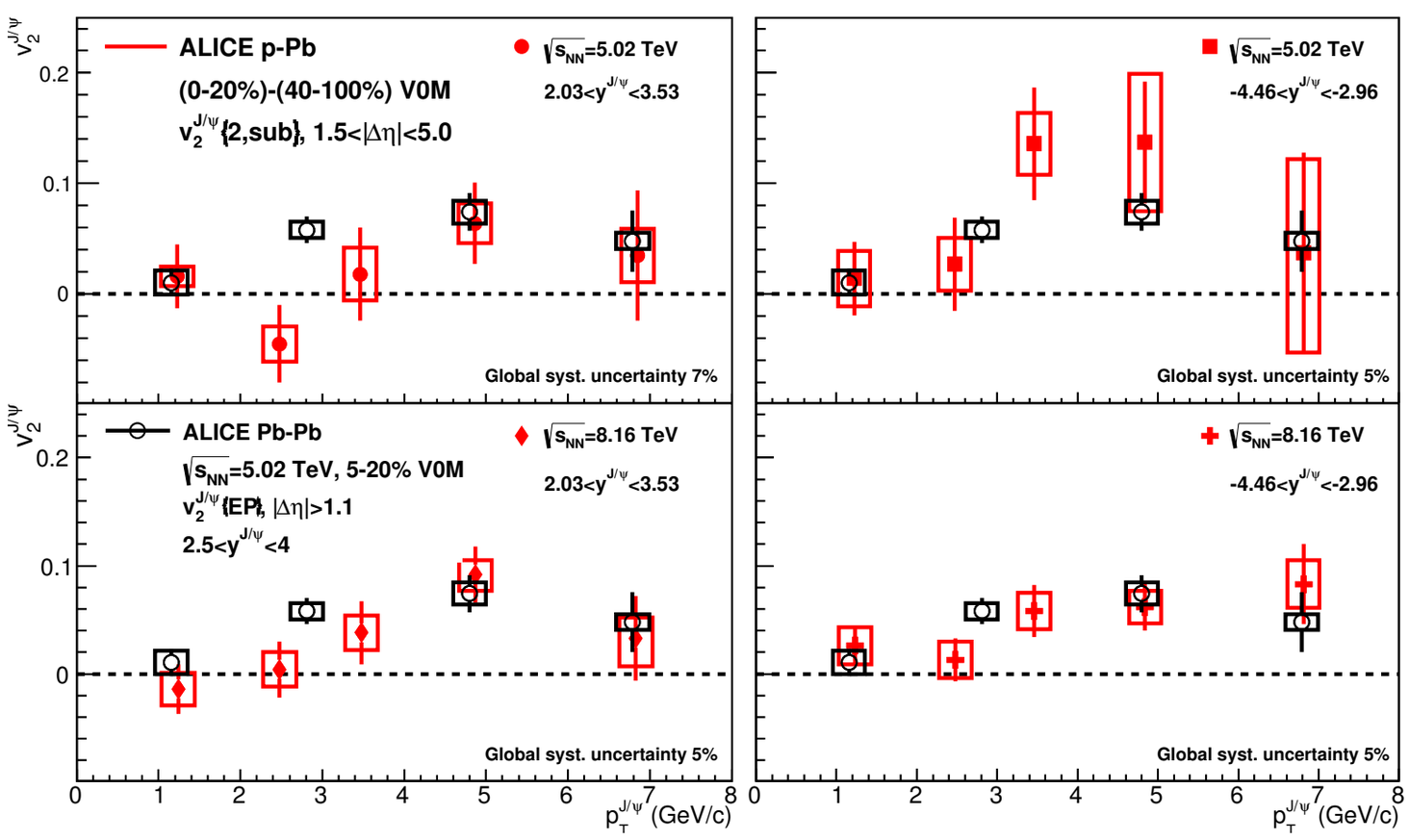
unmodified recoil jet distributions in 0-20% events

… search for onset of jet quenching?

High-p_T D meson & J/Ψ flow in p+A (?!)

both new since QM





ATLAS long-range, near-side ***D*+h*** correlation, p_T > 3 GeV

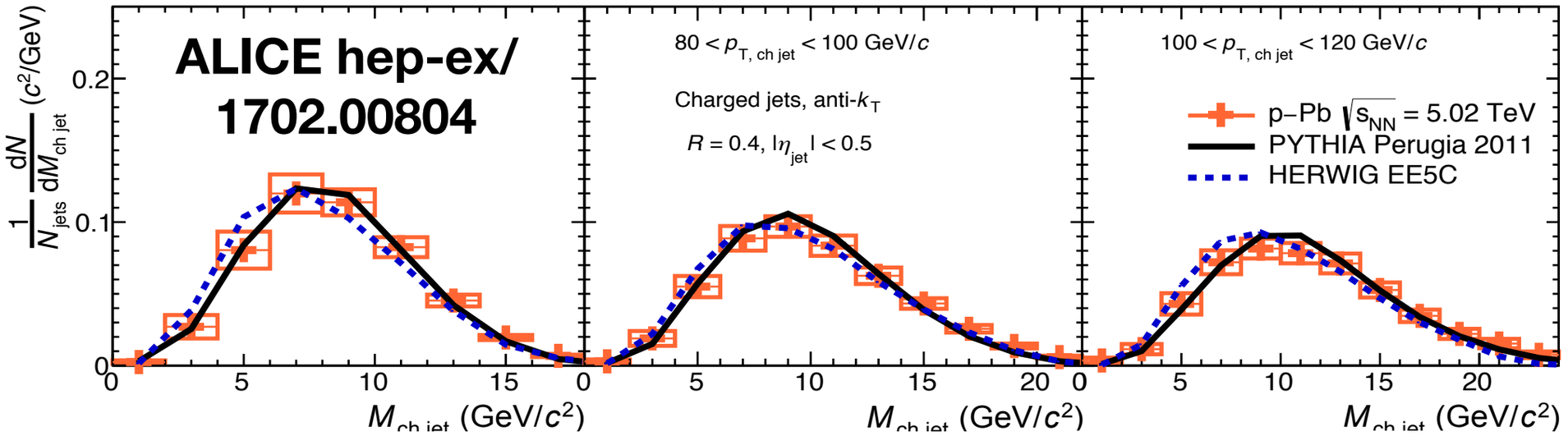
ATLAS-CONF-2017-073

ALICE ***J/Ψ v_2*** (from + hadron correlation), p_T = 4-6 GeV

nucl-ex/1709.06807

QM result

Jet shapes in *p*+Pb



new since QM

Z+jet effects in high-mult. *pp*

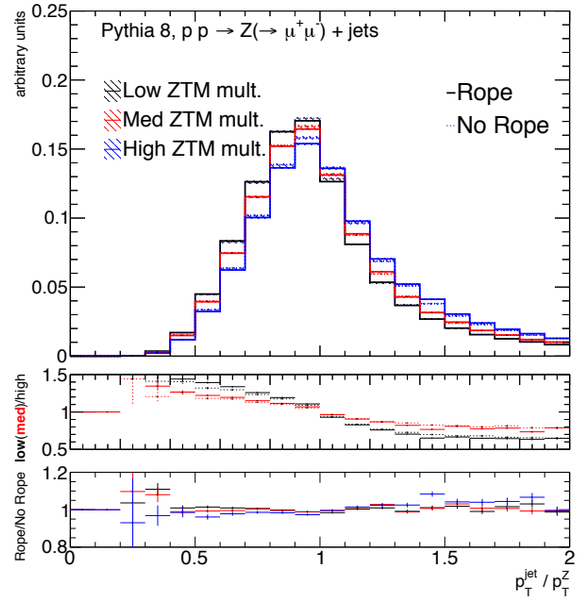
hep-ph/1708.08369

Observables for possible QGP signatures in central *pp* collisions

Michelangelo L. Mangano[a] and Benjamin Nachman[b]

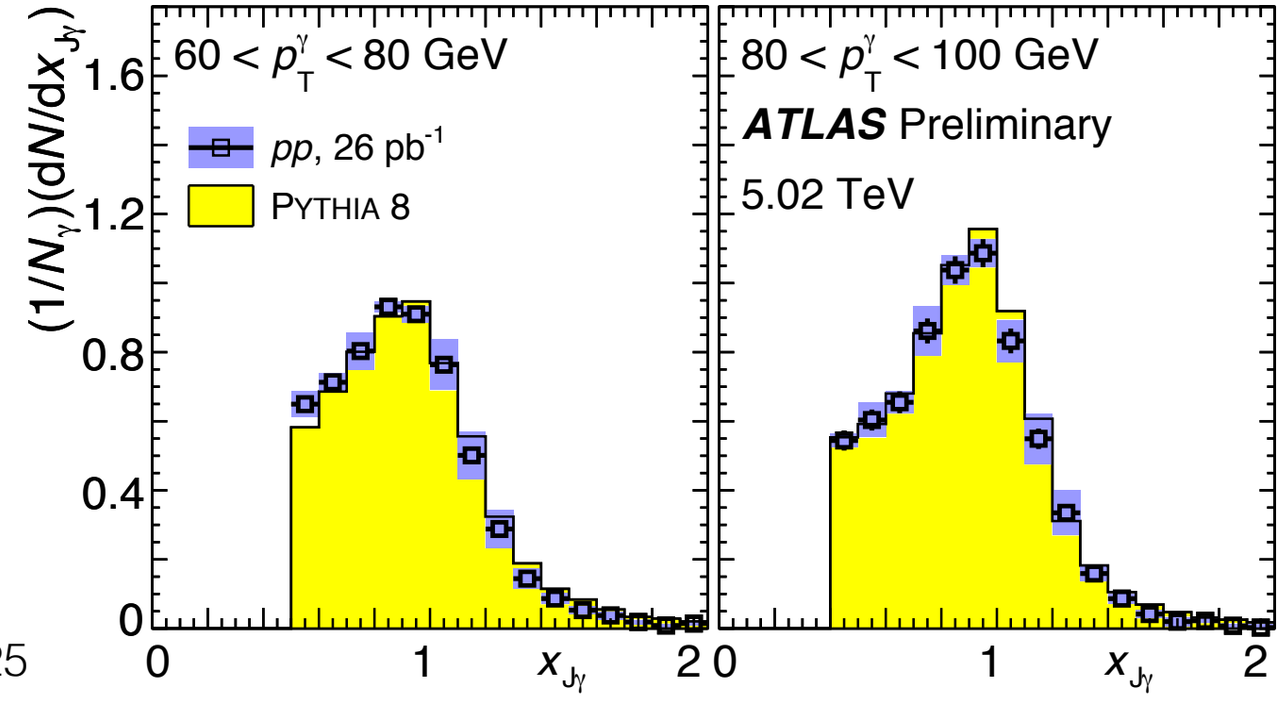
[a] *Theoretical Physics Department, CERN, 1211 Geneva 23, Switzerland*

[b] *Physics Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94704, USA*



γ+jet p_T balance vs. *p*+Pb event multiplicity…

➡ … excellent control demonstrated in *pp*



Detour: γ+jet in Pb+Pb

ATLAS EXPERIMENT

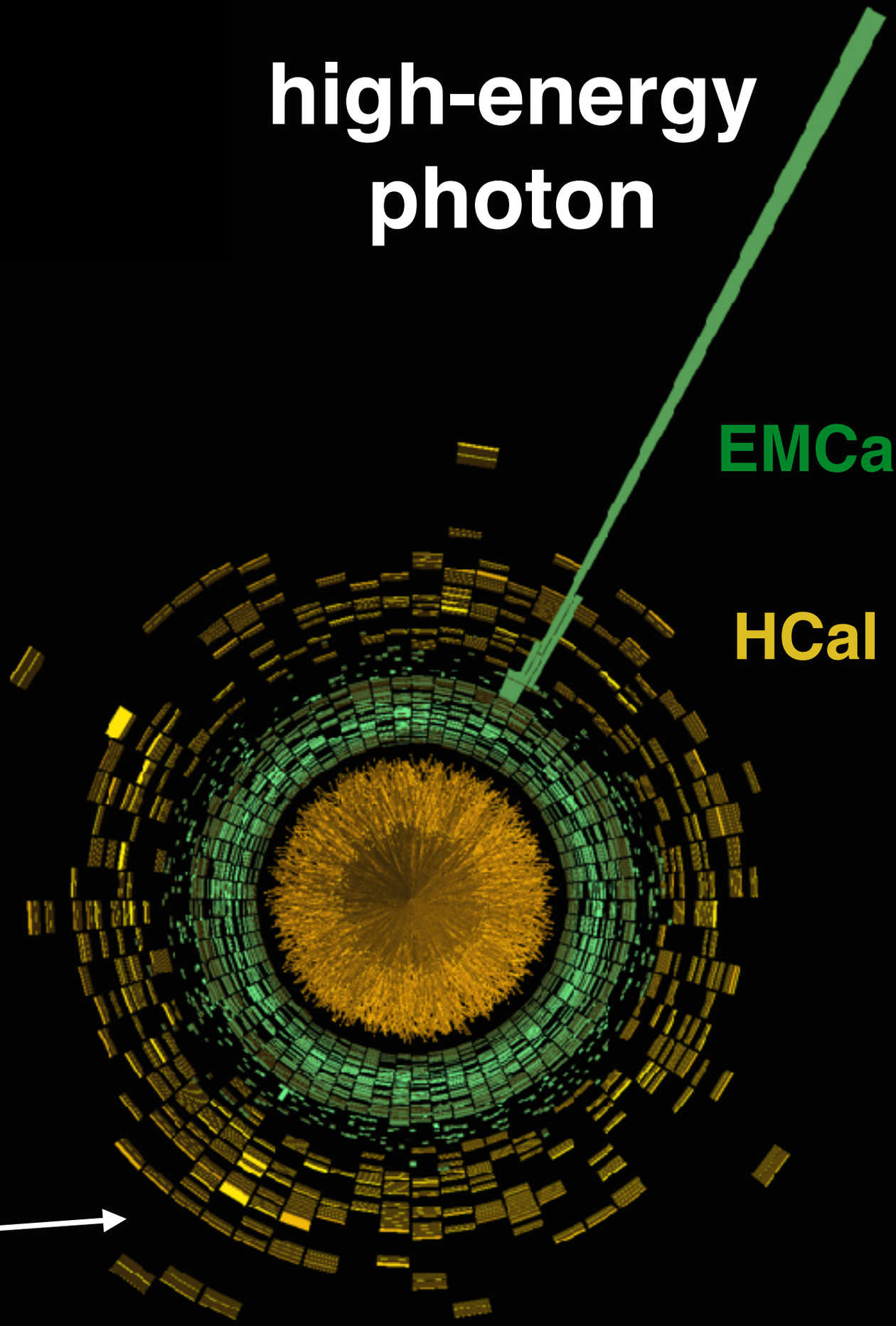
Run: 286834
Event: 124877733
2015-11-28 01:15:42 CEST

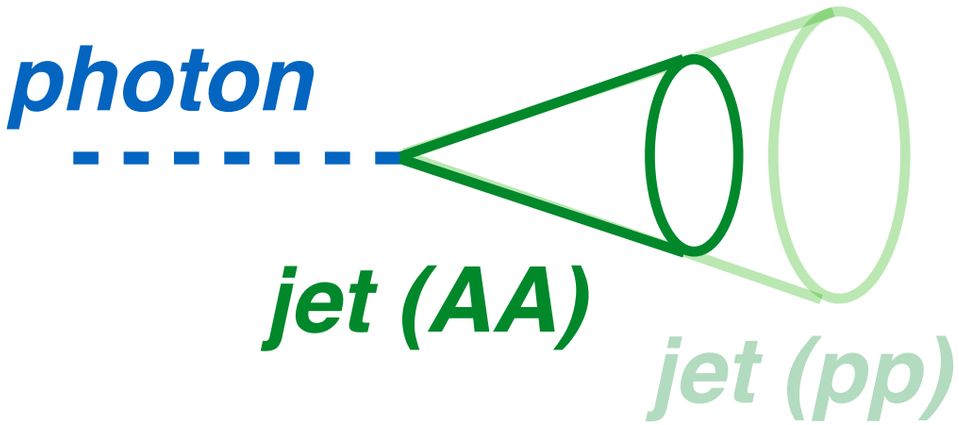
Pb+Pb $\sqrt{s_{NN}}$ = 5.02 TeV
photon + multijet event
ΣE_T^{FCal} = 4.06 TeV

Pb+Pb 5.02 TeV
LHC Run 2

high-energy photon

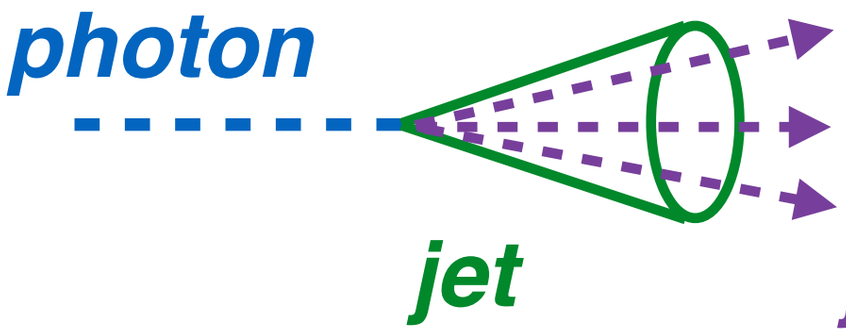
balancing jet?





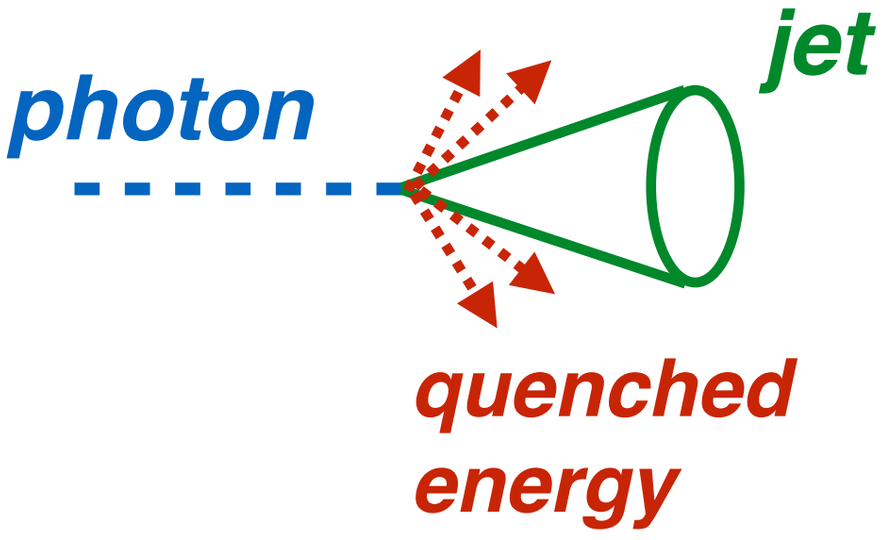
1. What is the (absolute) amount of energy lost in cone?

➡ ***photon*+*jet*** *p_T-balance*



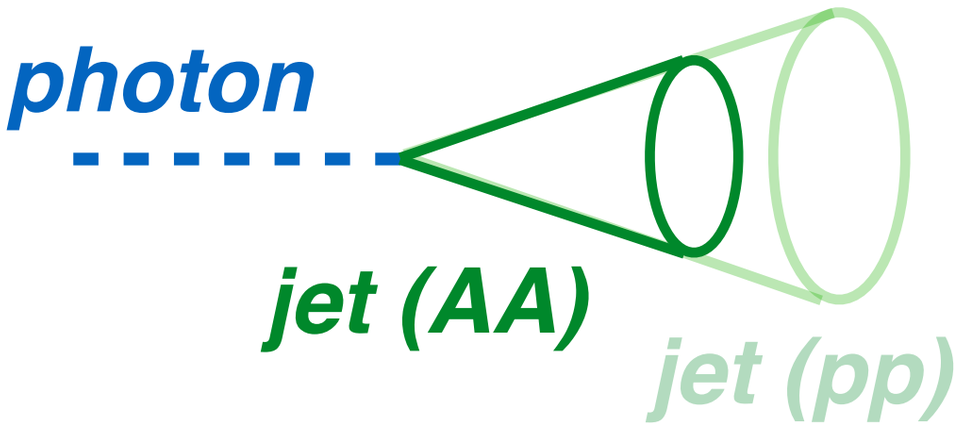
2. How is the parton shower in cone modified by medium?

➡ ***photon***-tagged ***frag. function*** (w.r.t. ***jet***)



3. Where does the lost energy end up?

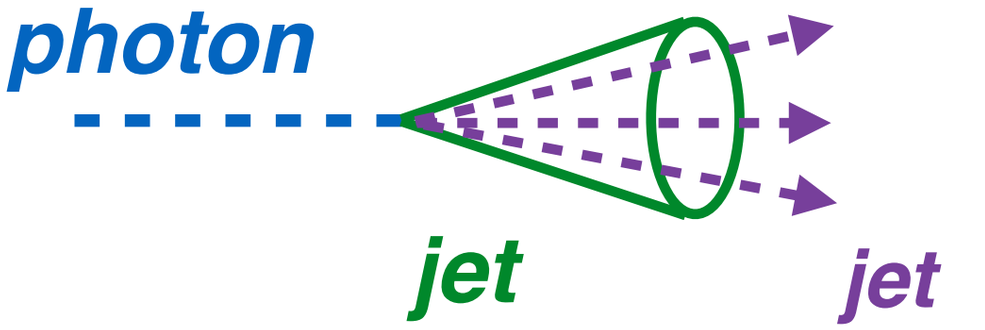
➡ ***photon*-*hadron*** corr. broadly in angle / momentum



1. What is the (absolute) amount of energy lost in cone?

➡ ***photon*+*jet*** *p_T-balance*

Preliminary: ATLAS-CONF-2016-110

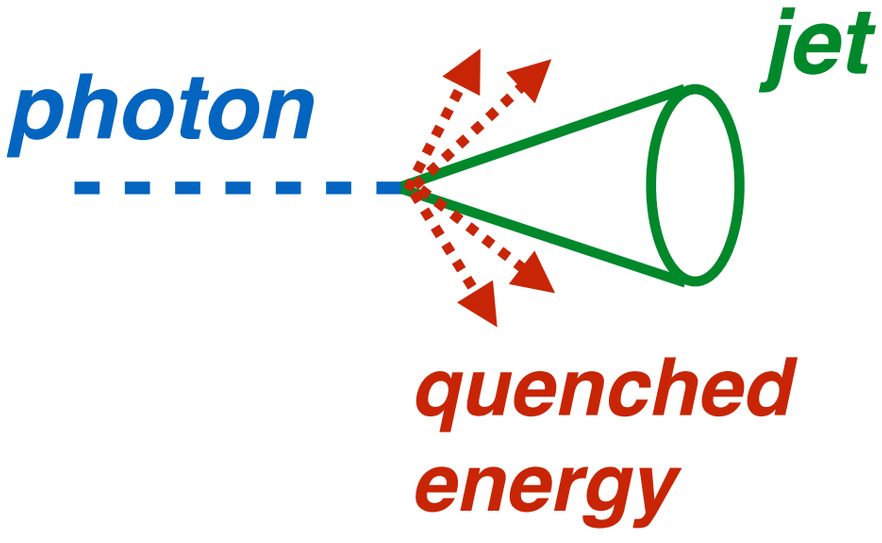


2. How is the parton shower in cone modified by medium?

➡ ***photon***-tagged ***frag. function*** (w.r.t. ***jet***)

new since QM

Preliminary: ATLAS-CONF-2017-074



3. Where does the lost energy end up?

➡ ***photon*-*hadron*** corr. broadly in angle / momentum

$x_{J\gamma} = p_T^{jet} / p_T^{\gamma}$

vary system size

ATLAS-CONF-2016-110

vary initial *E* before quenching

pp | 50-80% Pb+Pb | 30-50% Pb+Pb | 20-30% Pb+Pb | 10-20% Pb+Pb | 0-10% Pb+Pb

ATLAS Preliminary
5.02 TeV
Pb+Pb, 0.49 nb^{-1}
pp, 26 pb^{-1}
Simulation
Data

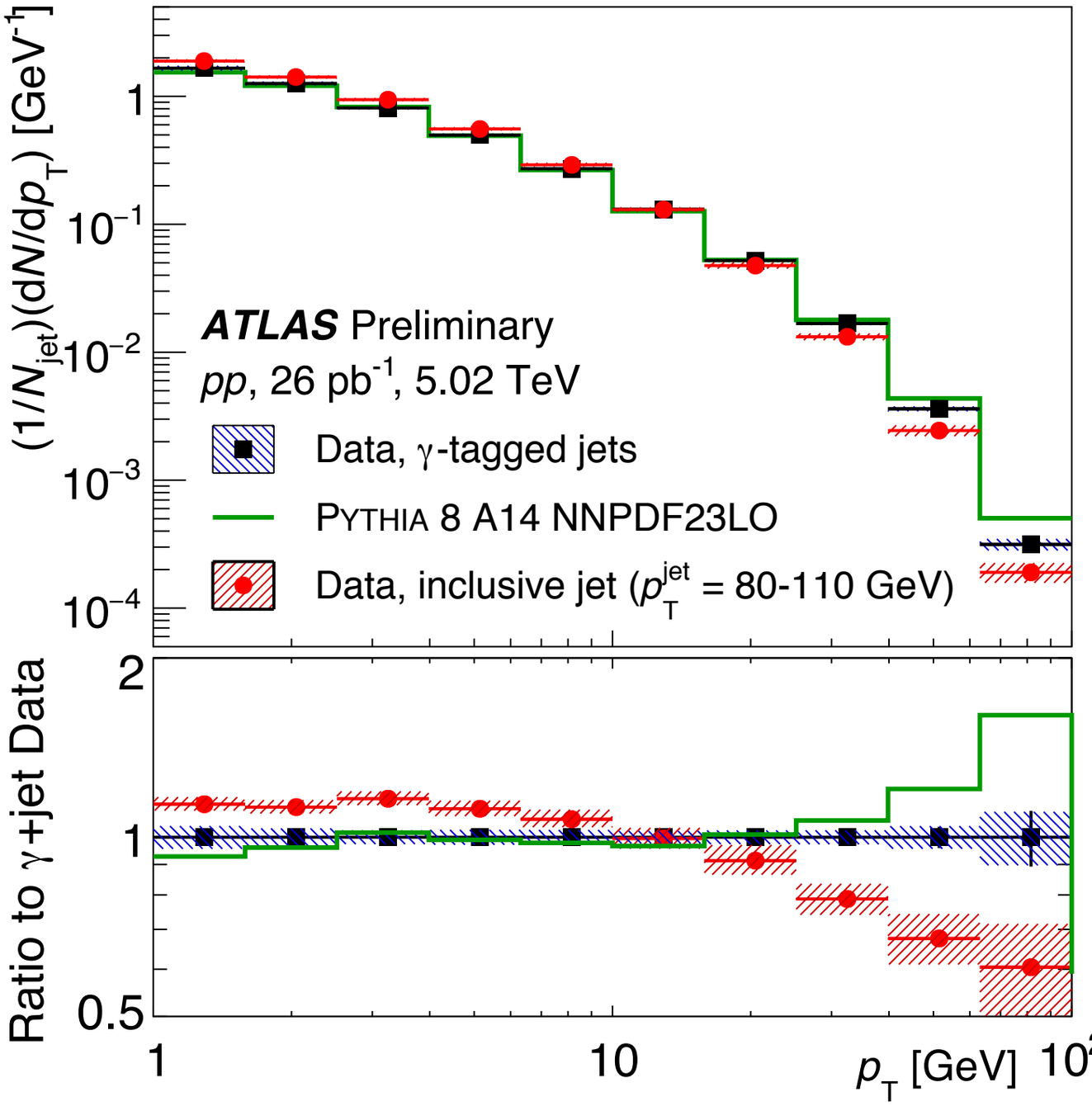
$60 < p_T^{\gamma} < 80$ GeV
$80 < p_T^{\gamma} < 100$ GeV
$100 < p_T^{\gamma} < 150$ GeV
$150 < p_T^{\gamma} < 200$ GeV

$(1/N_{J\gamma})(dN/dx_{J\gamma})$

$x_{J\gamma}$

Photon-tagged jet fragmentation functions: *pp*

new since QM



Photon-tagged jet

(quark jet-dominant)

Inclusive jet

(gluon jet-dominant)

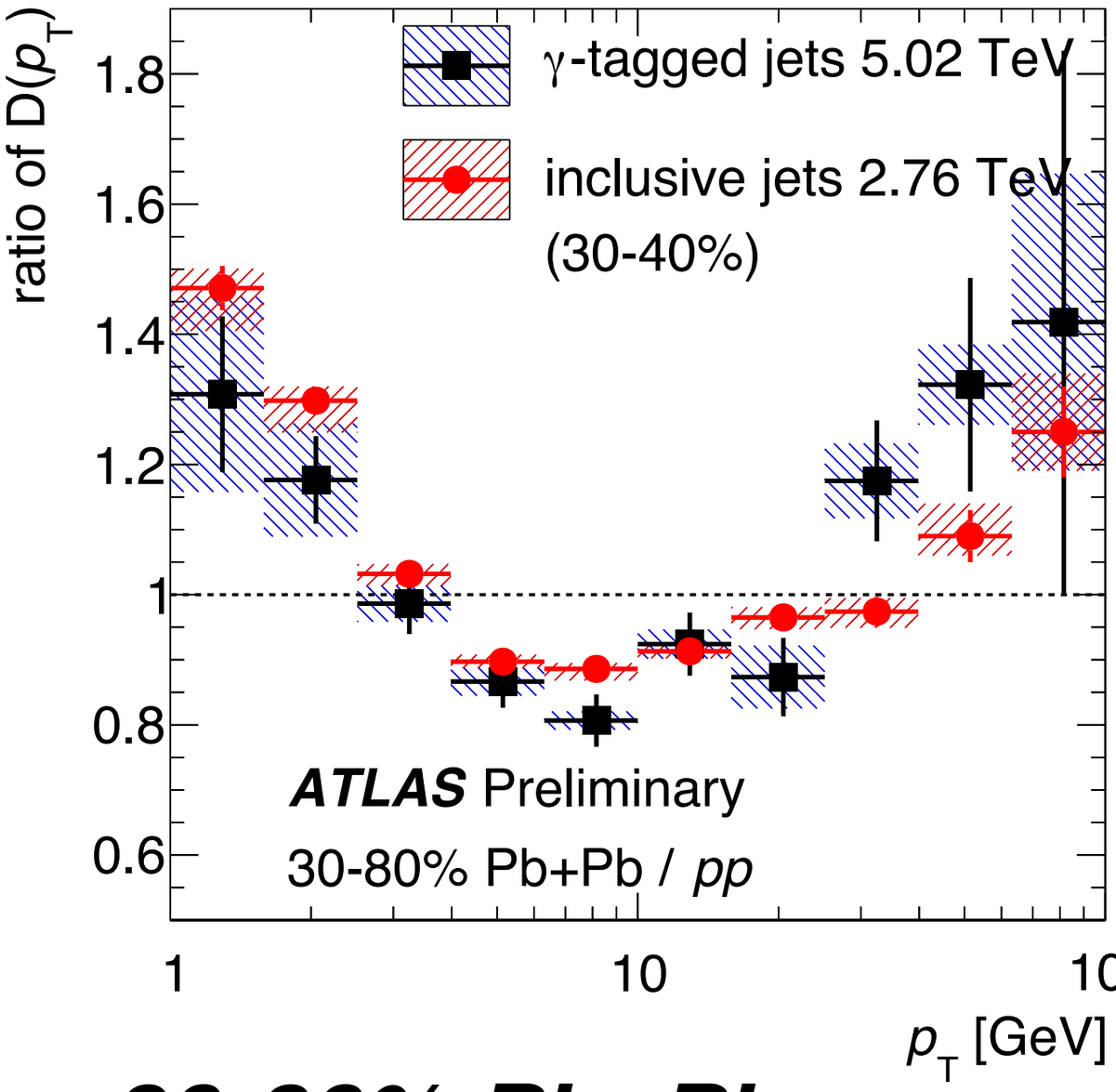
gluons fragment softer!

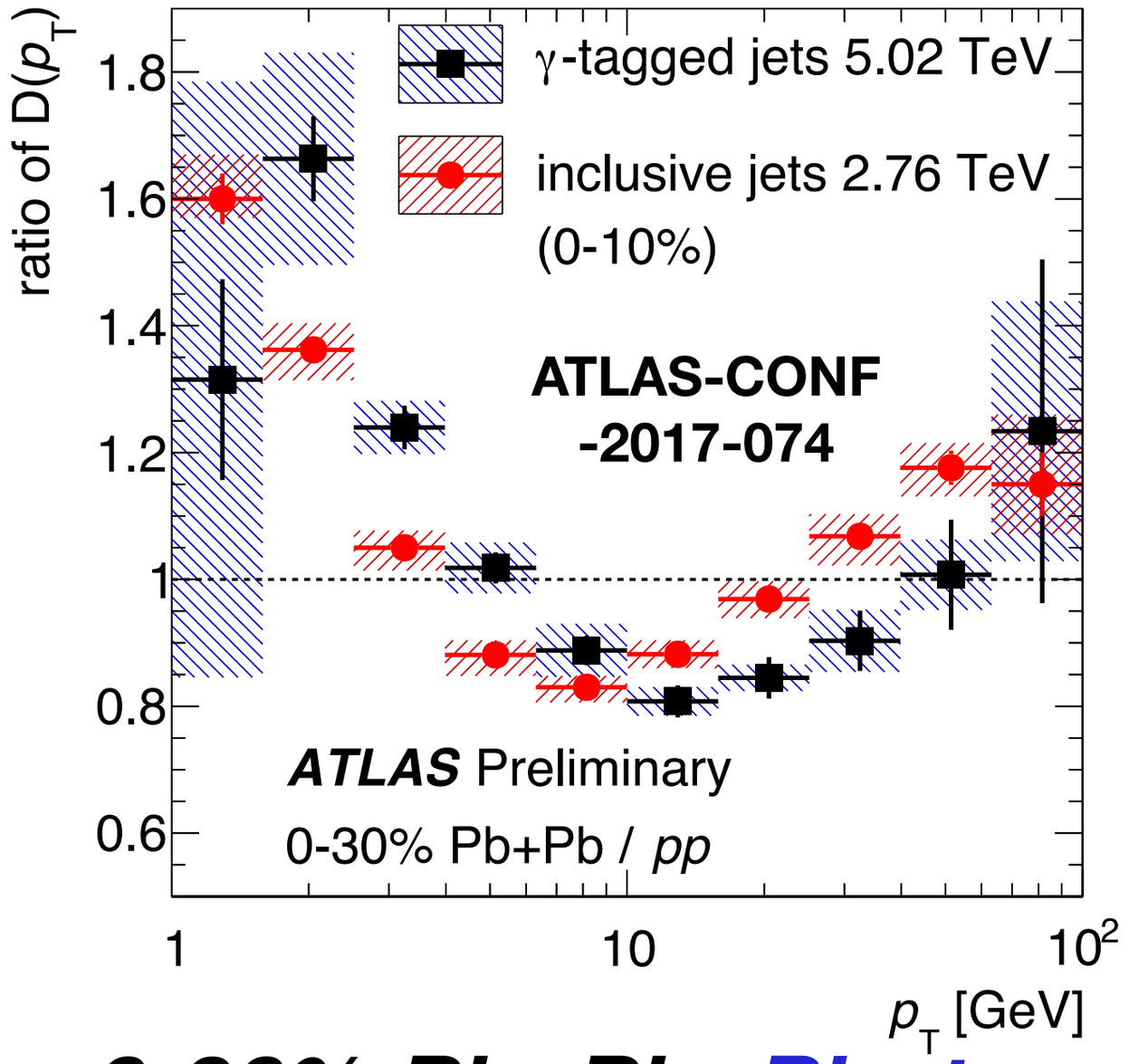
ATLAS-CONF-2017-074

talks: C. Nattrass, A. Milov

γ-tagged jet FF: Pb+Pb / *pp*

new since QM

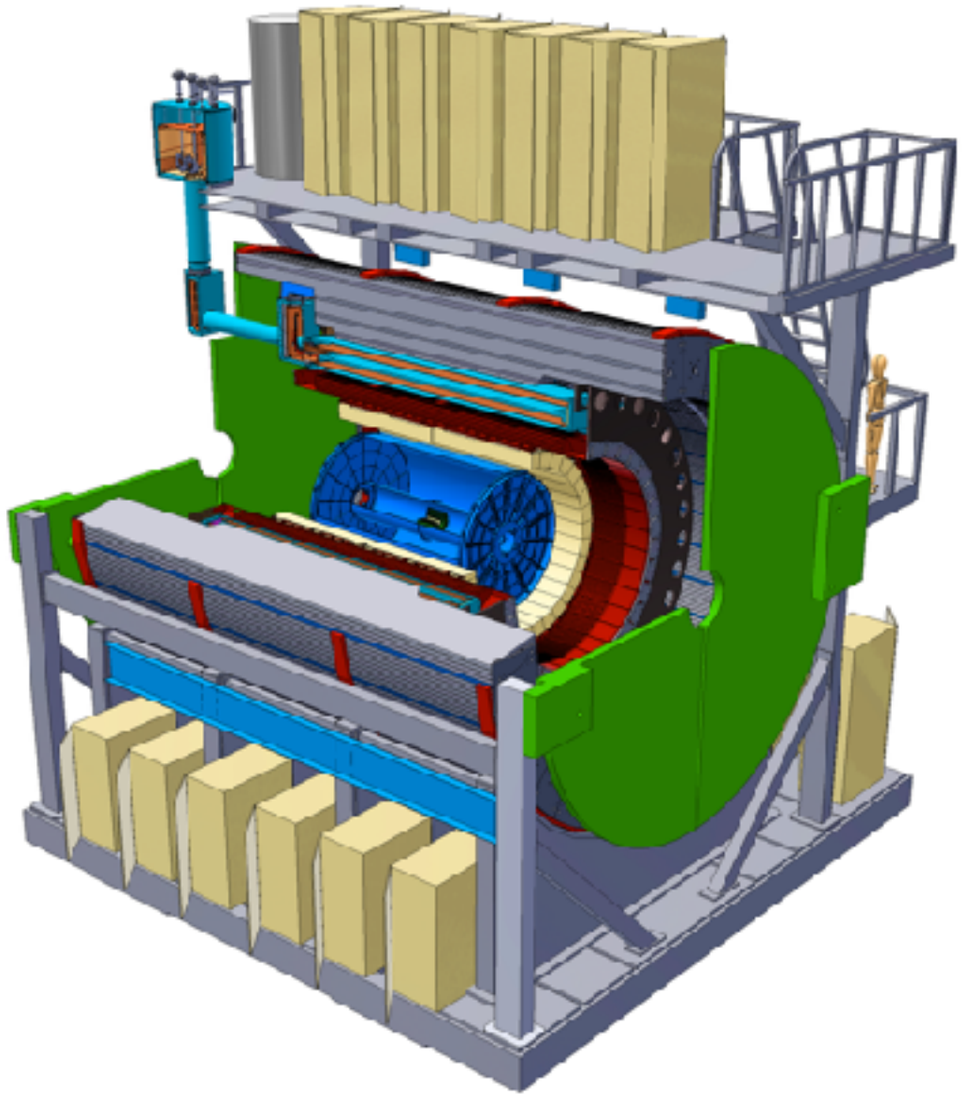




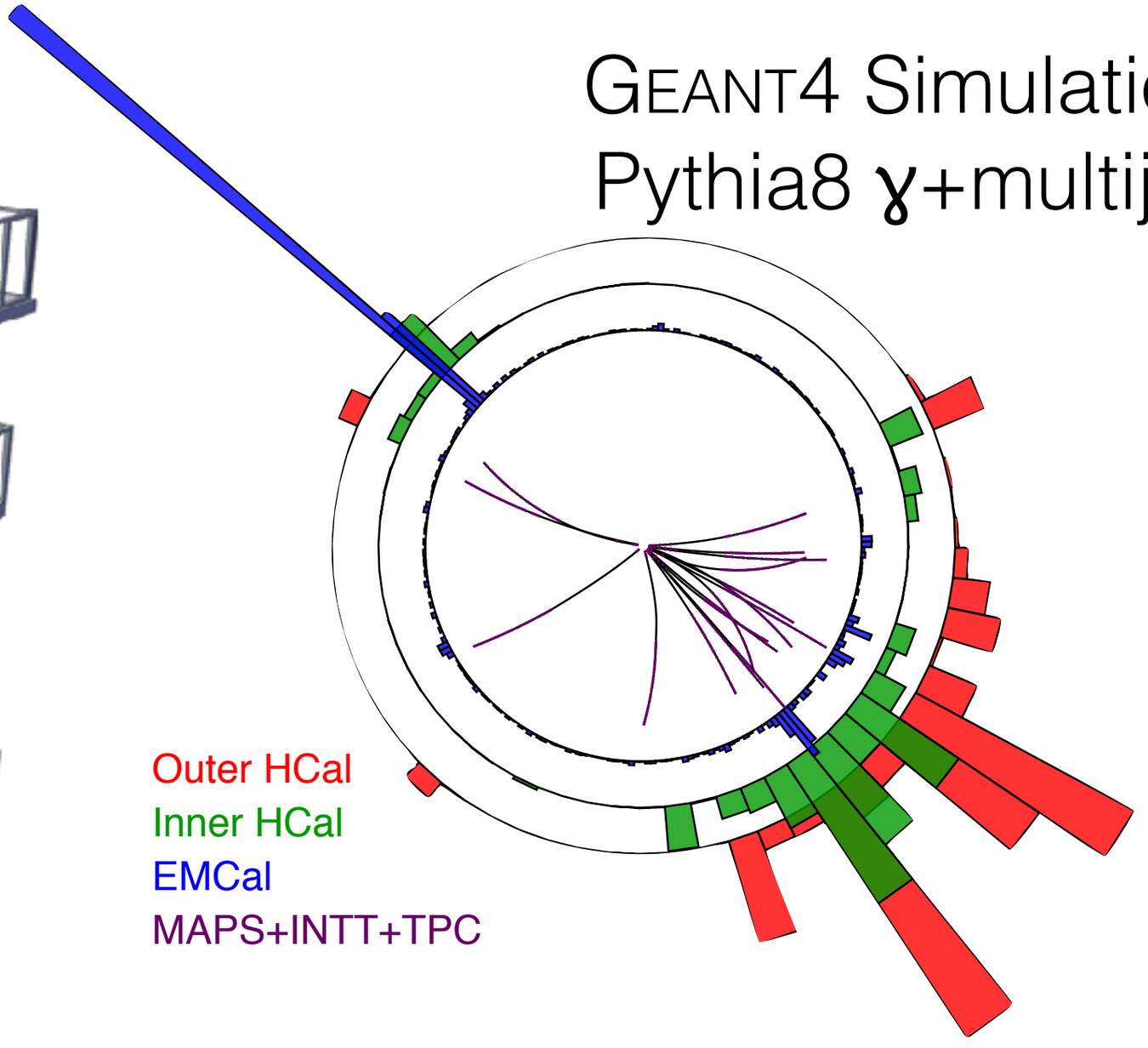
30-80% Pb+Pb: ***Photon-tagged jets*** *modified similar to* ***inclusive jets***

0-30% Pb+Pb: ***Photon-tagged jets*** *are more strongly modified (ask me about this…)*

small systems at sPHENIX

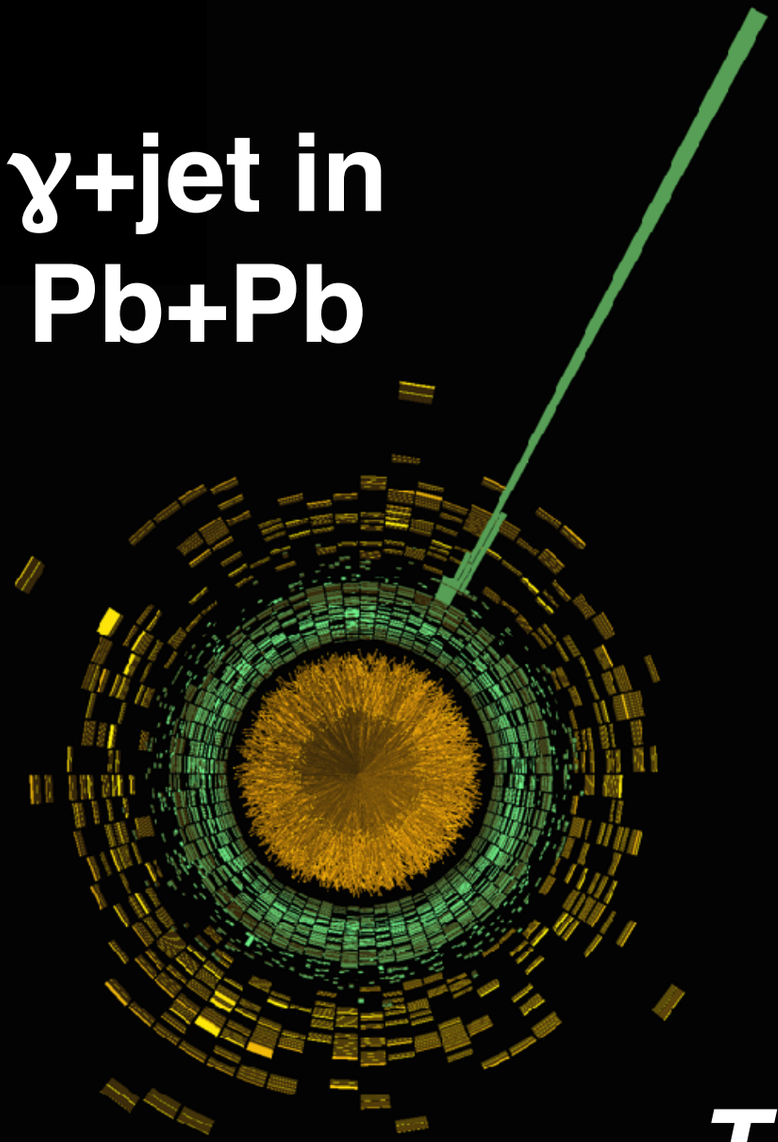


GEANT4 Simulation
Pythia8 γ+multijet

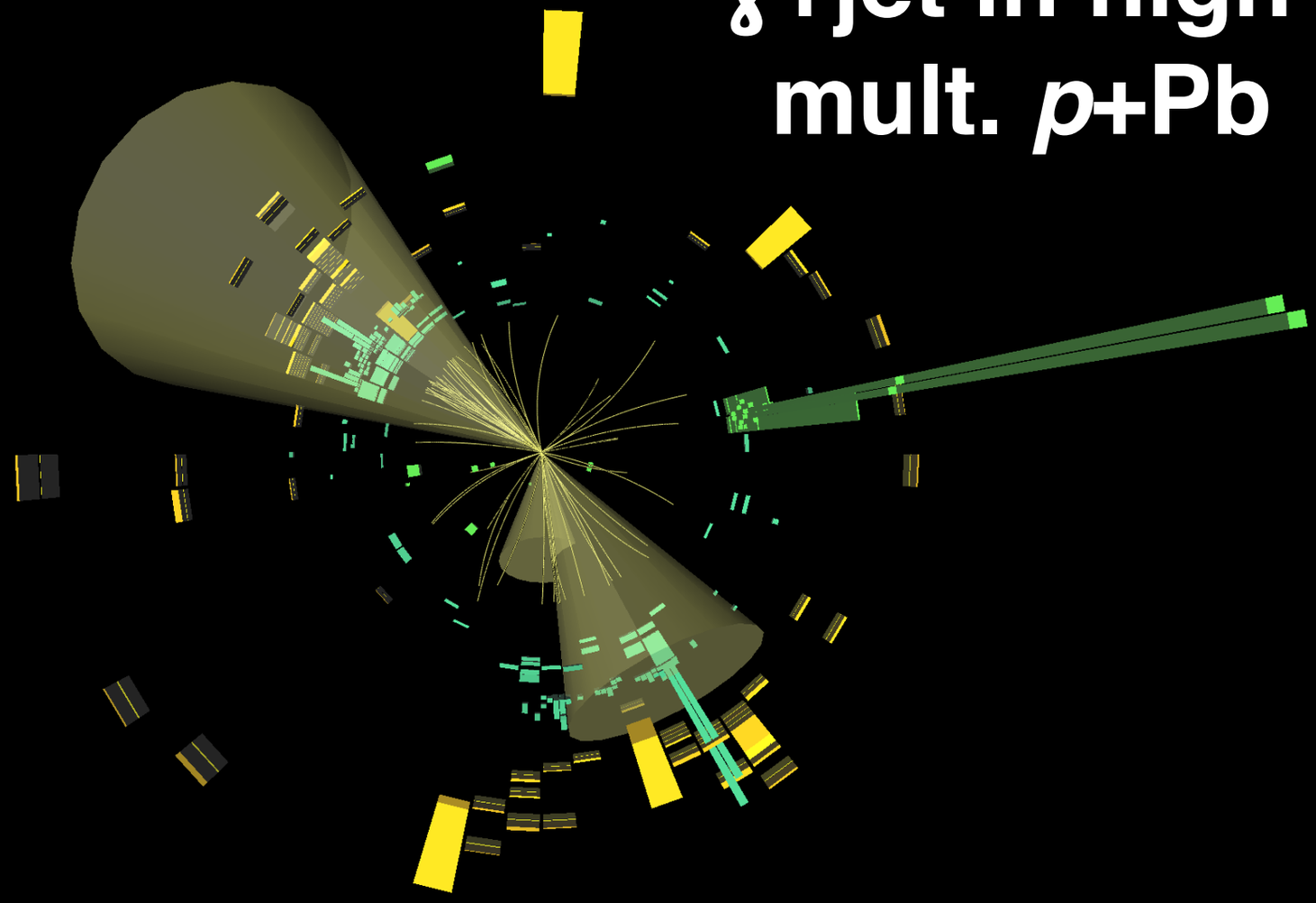


large statistics for precision probes of small systems

γ+jet in Pb+Pb

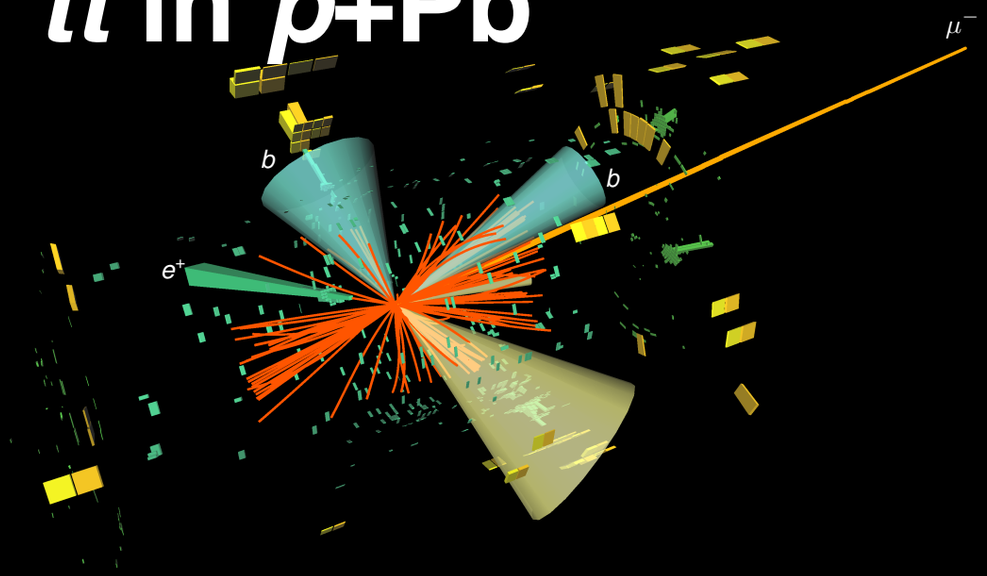


γ+jet in high-mult. *p*+Pb

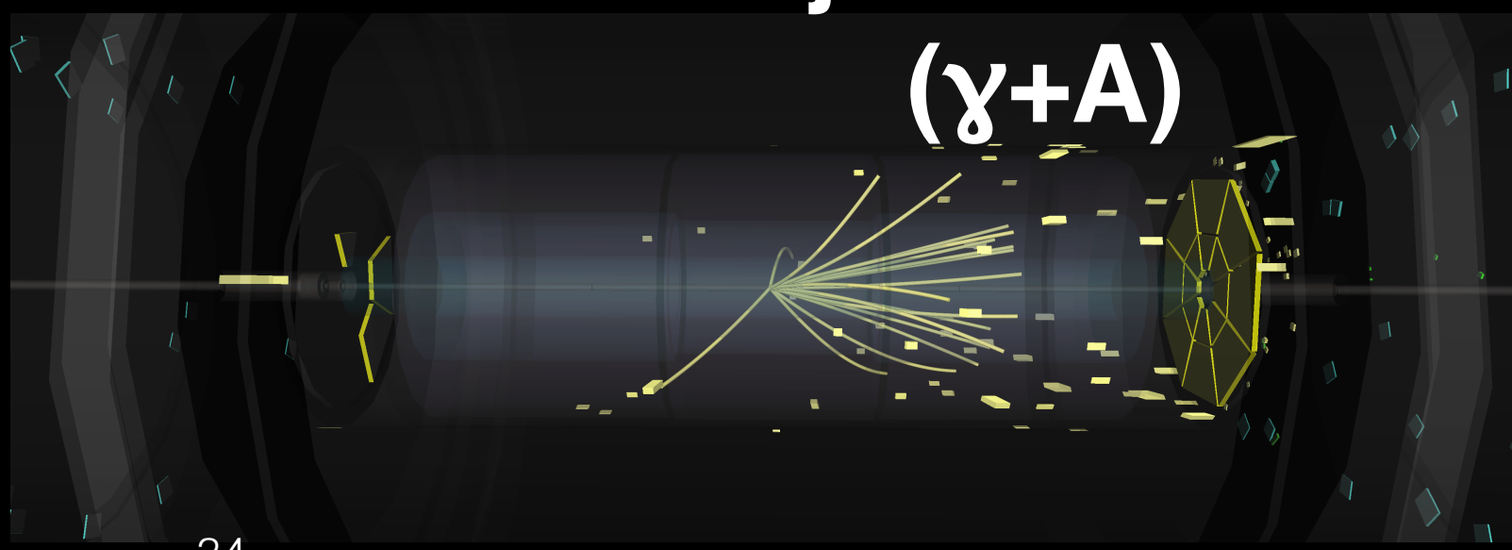


Thank you!

$t\bar{t}$ in *p*+Pb



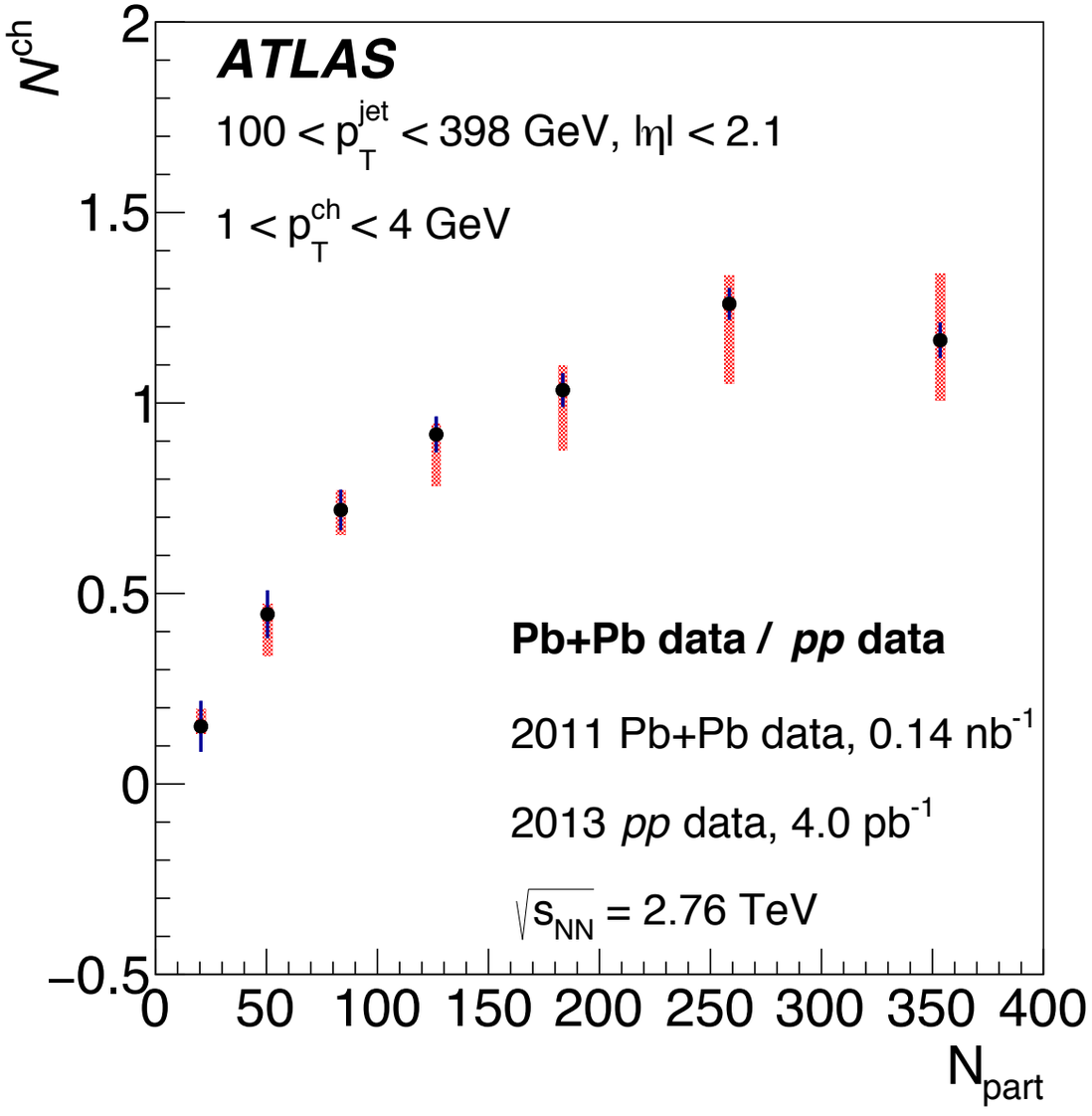
dijets in UPC (γ+A)

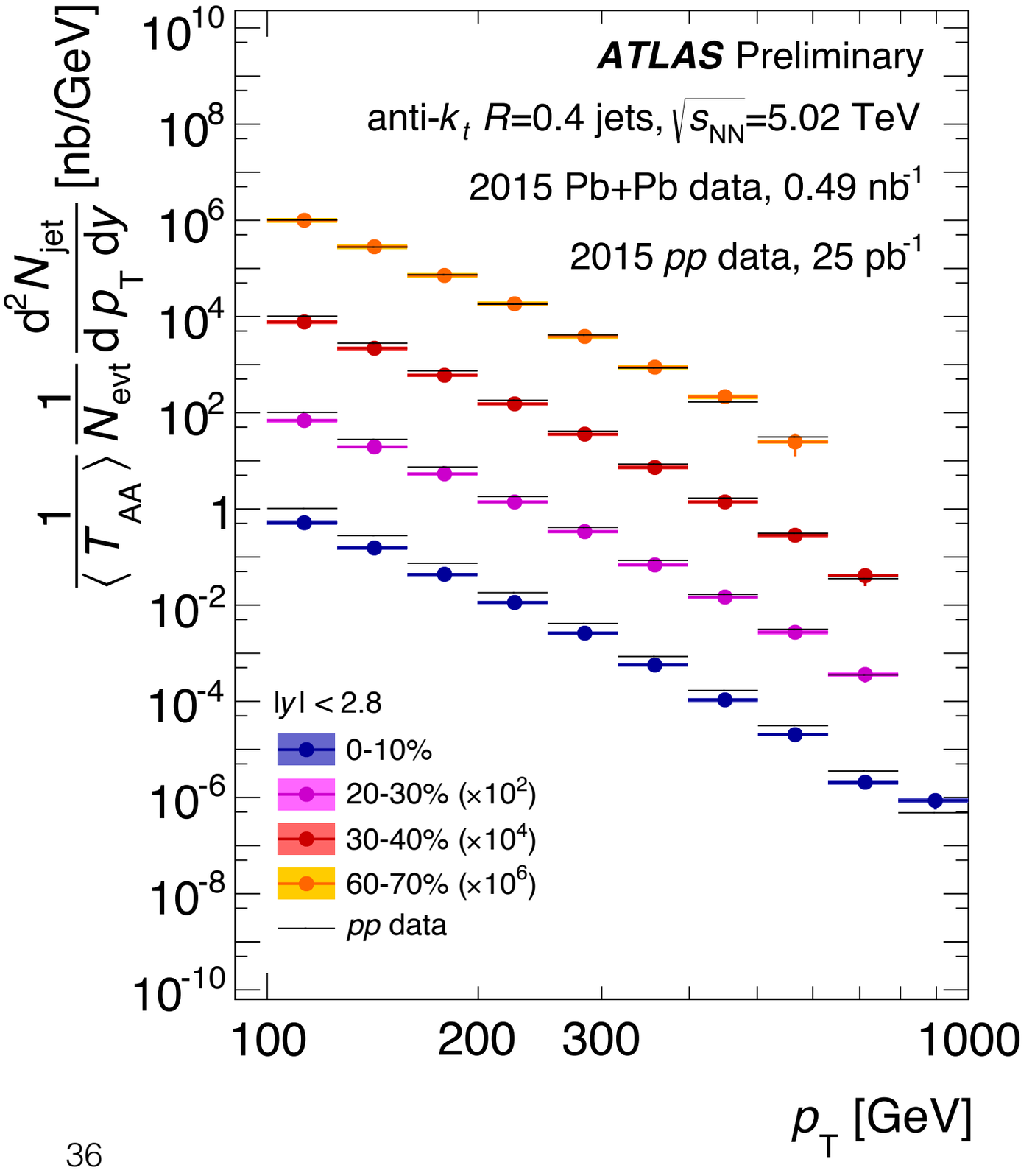


Inclusive jet FF

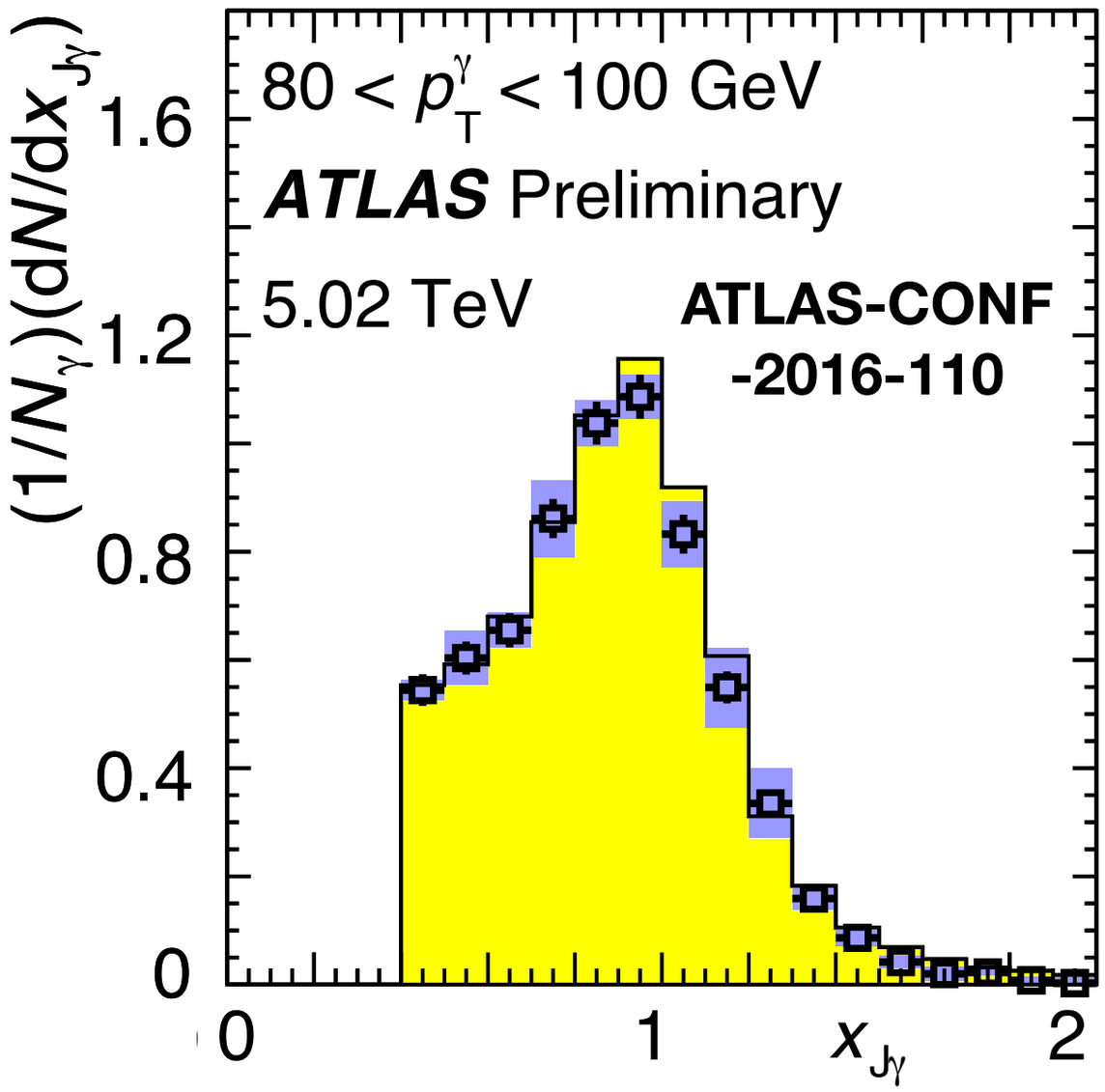
after quenching

$$\frac{D(z;\ p_T^{jet}) \text{ in } \mathbf{A+A}}{D(z;\ p_T^{jet}) \text{ in } \mathbf{p+p}}$$



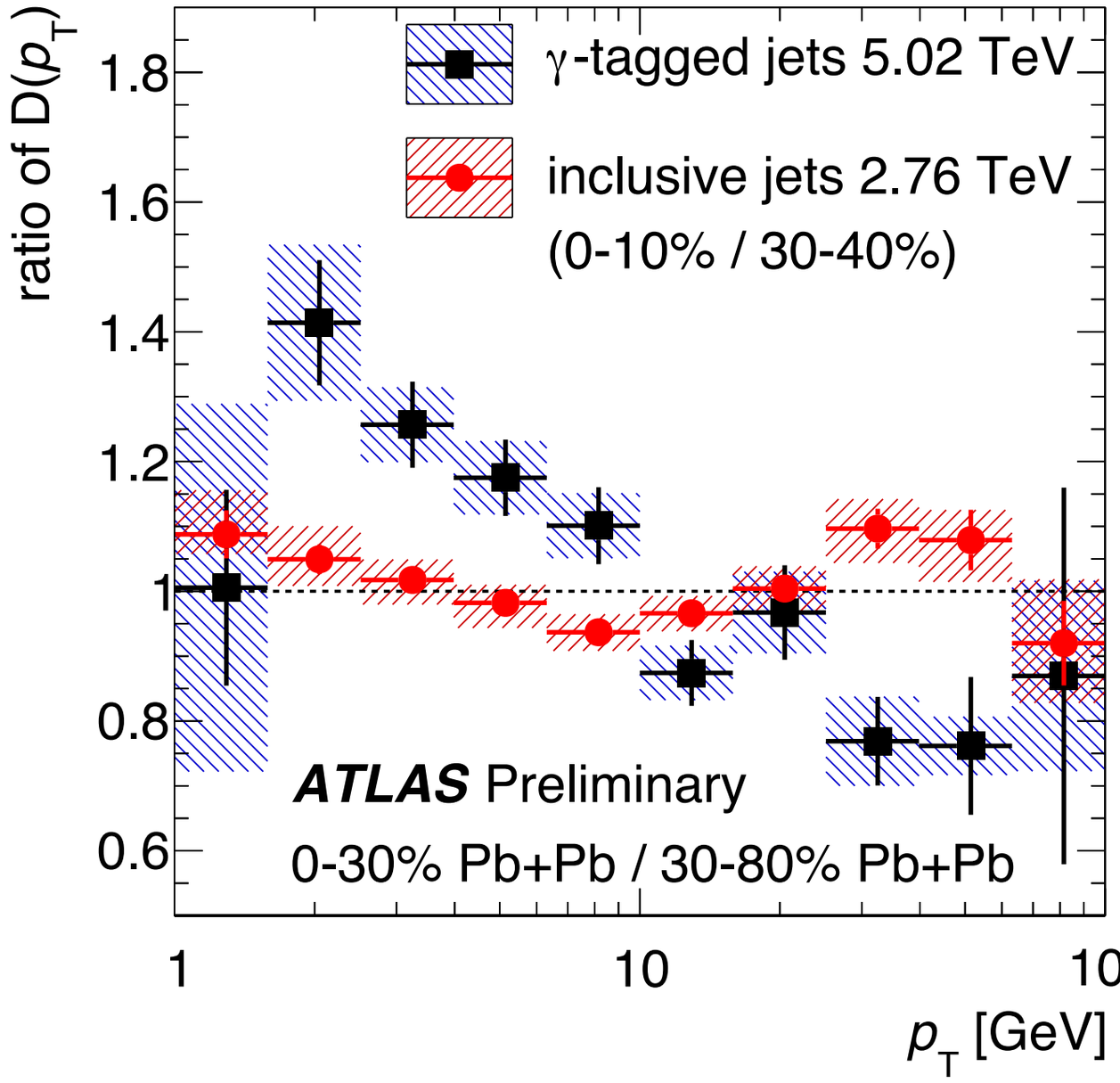


γ-tagged jet FF



Different "unquenched" jet-p_T distribution

ATLAS-CONF-2017-074



0-30%/30-80% ratio:

γ-tagged jets *more strongly modified than* ***inclusive jets***