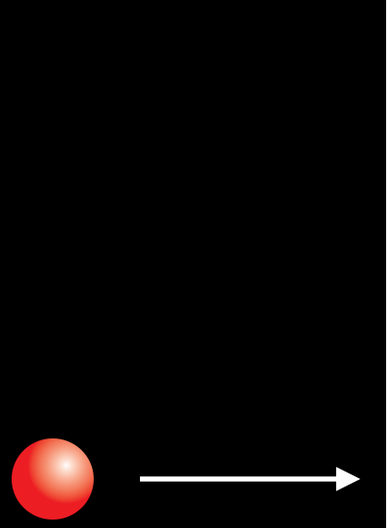
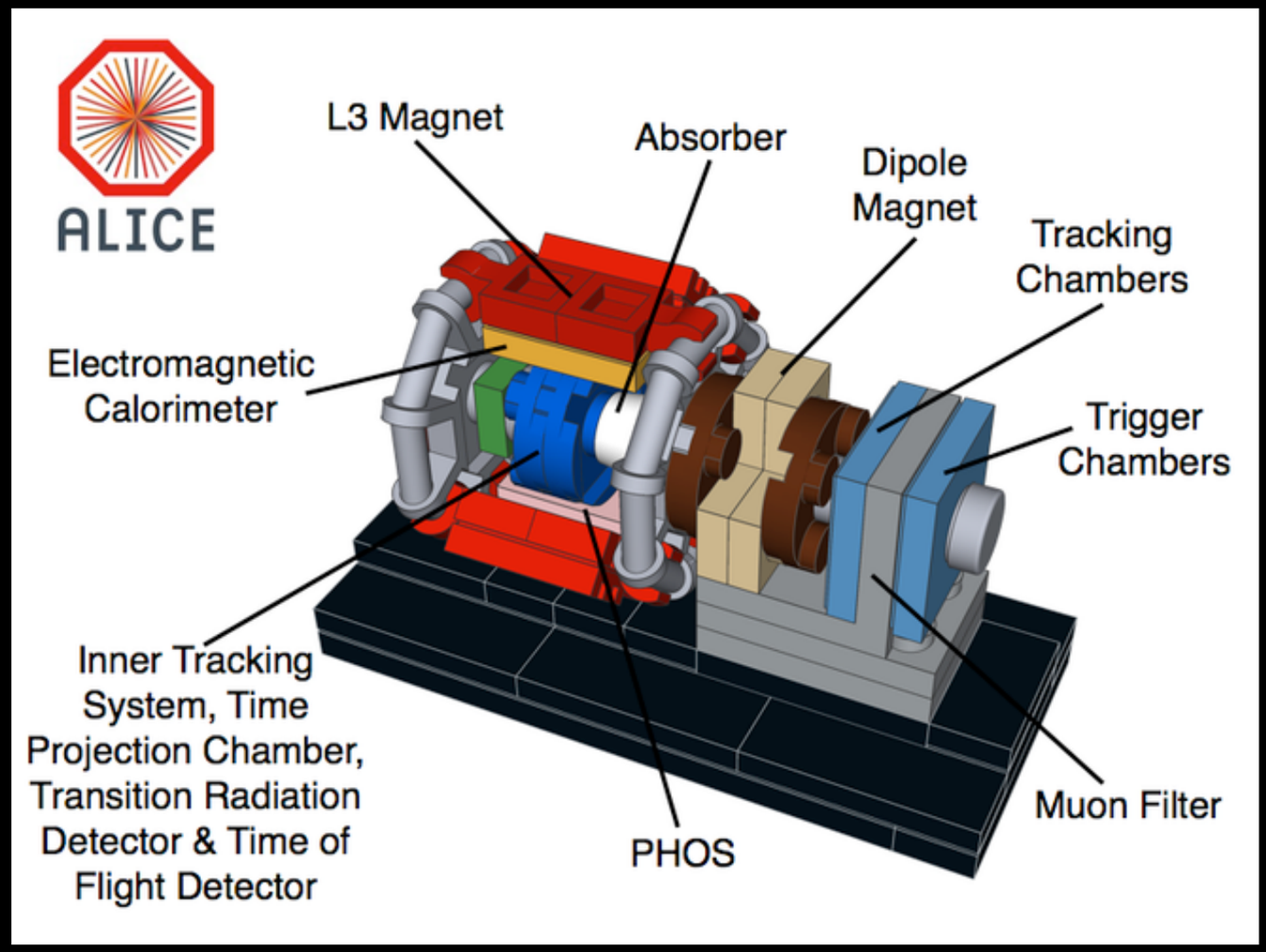
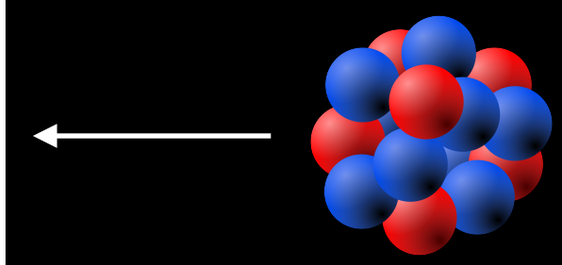
Minijets and MPI in p-Pb collisions





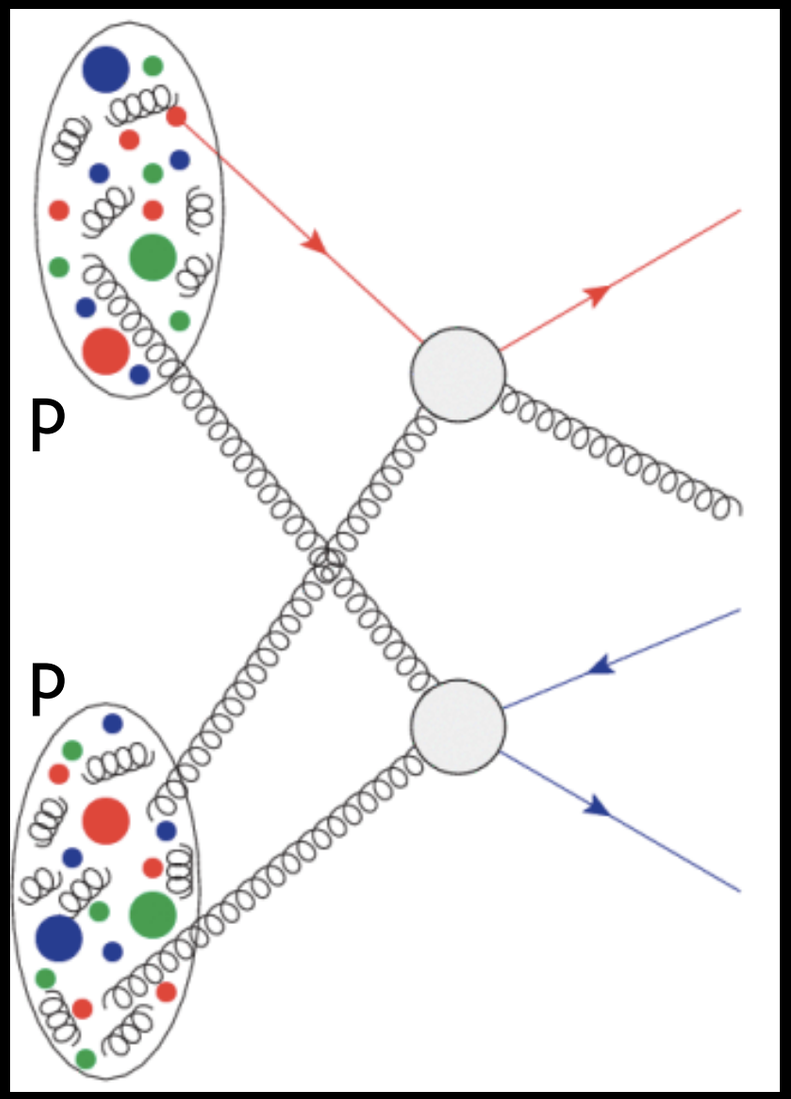


Emilia Leogrande - Utrecht University (NL)

NIKHEF Jamboree - 14th Dec 2015

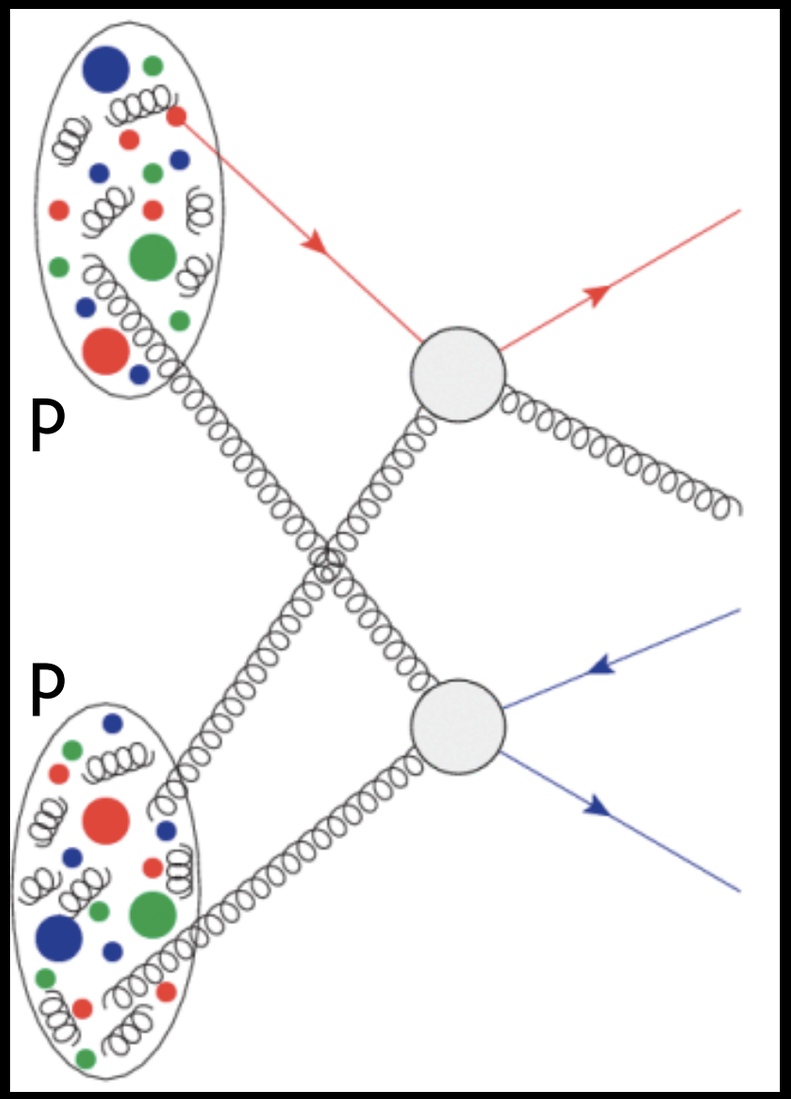
Multiple Parton Interactions

- Nucleon - nucleon collision == collision between bunches of partons



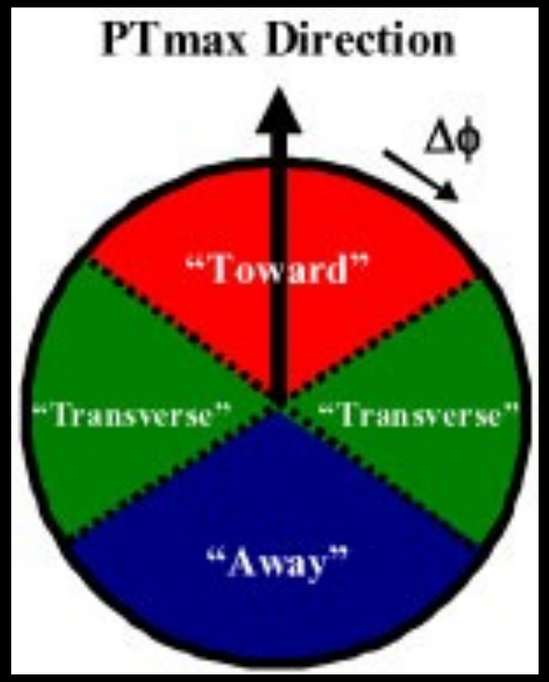
Multiple Parton Interactions

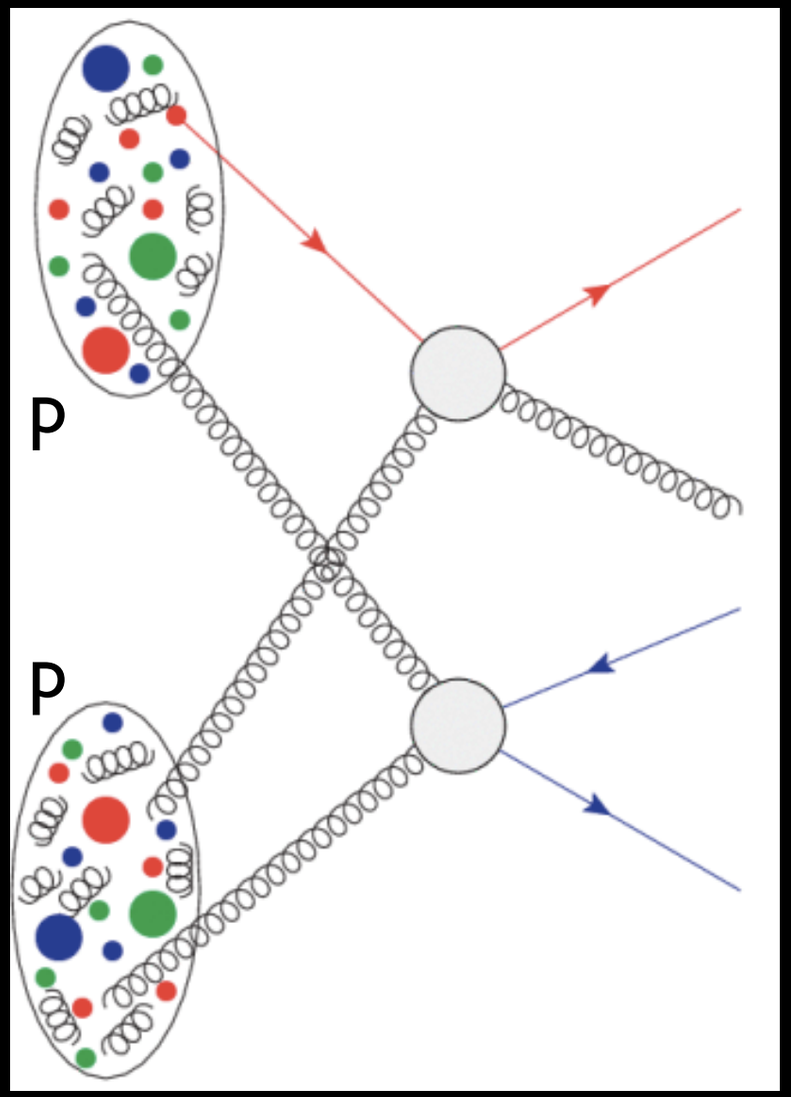
- Nucleon - nucleon collision == collision between bunches of partons
- The higher the collision energy, the higher the resolvable parton density in the nucleon
  - At LHC mostly gluon-gluon



Multiple Parton Interactions

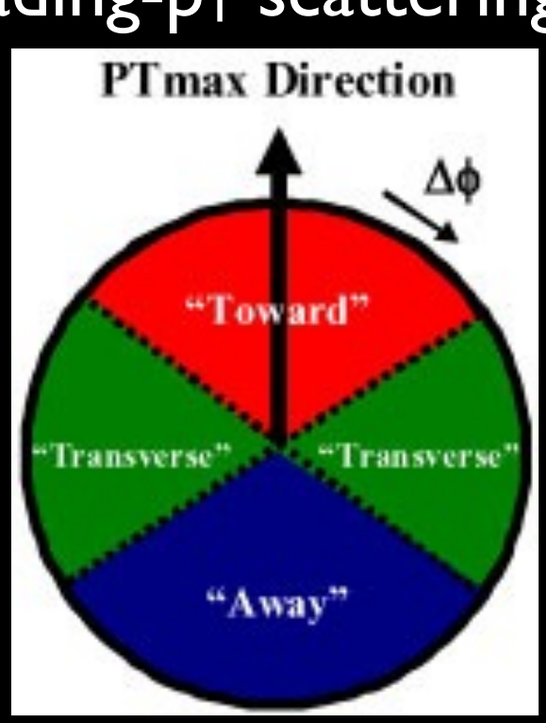
- Nucleon - nucleon collision == collision between bunches of partons
- The higher the collision energy, the higher the resolvable parton density in the nucleon
  - At LHC mostly gluon-gluon
- MPI belong to Underlying Event
  - activity accompanying the leading-p_T scattering

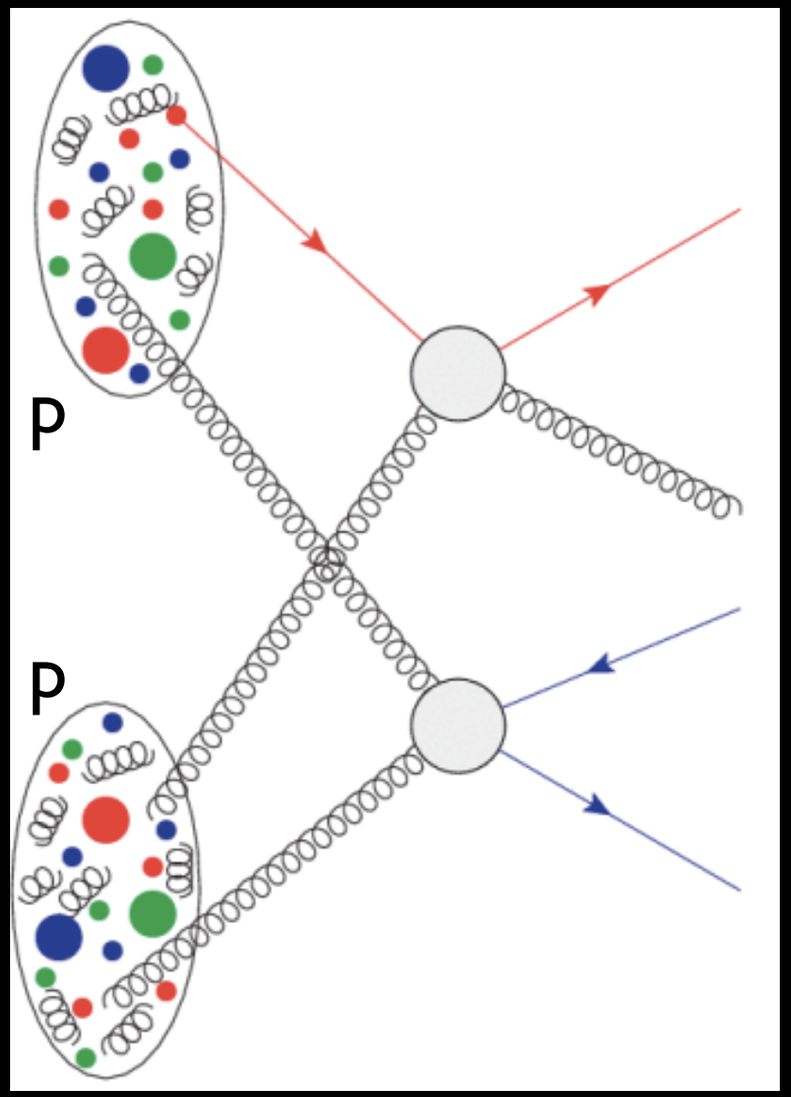




Multiple Parton Interactions

- Nucleon - nucleon collision == collision between bunches of partons
- The higher the collision energy, the higher the resolvable parton density in the nucleon
  - At LHC mostly gluon-gluon
- MPI belong to Underlying Event
  - activity accompanying the leading-p_T scattering





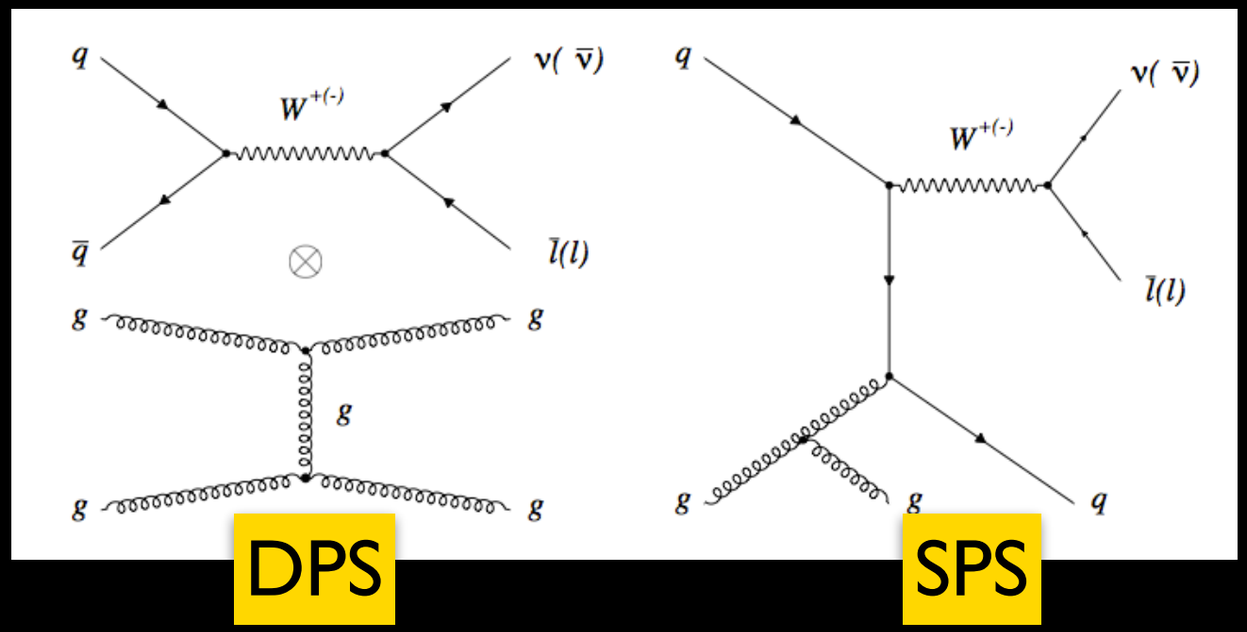
- Hard (high-p_T scale) and semi-hard (low-p_T scale) MPI

Multiple Parton Interactions

- Hard MPI
  - characteristic topology of the event, e.g. 4 jets with pair-balanced p_T

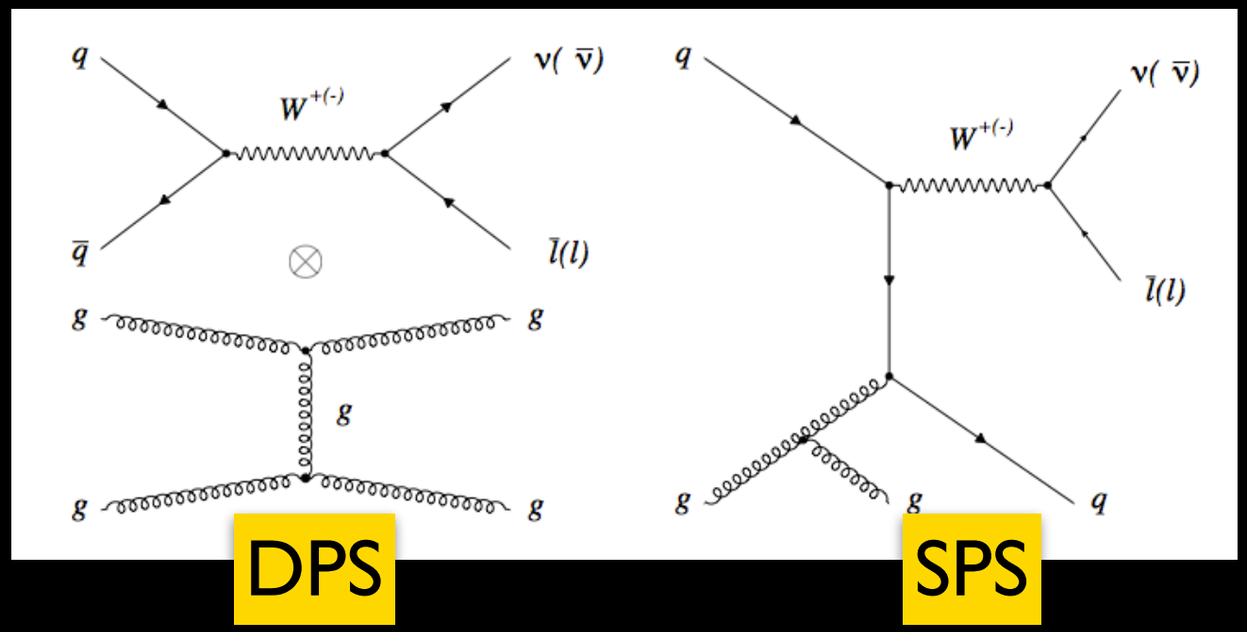
Multiple Parton Interactions

- Hard MPI
  - characteristic topology of the event, e.g. 4 jets with pair-balanced p_T



Multiple Parton Interactions

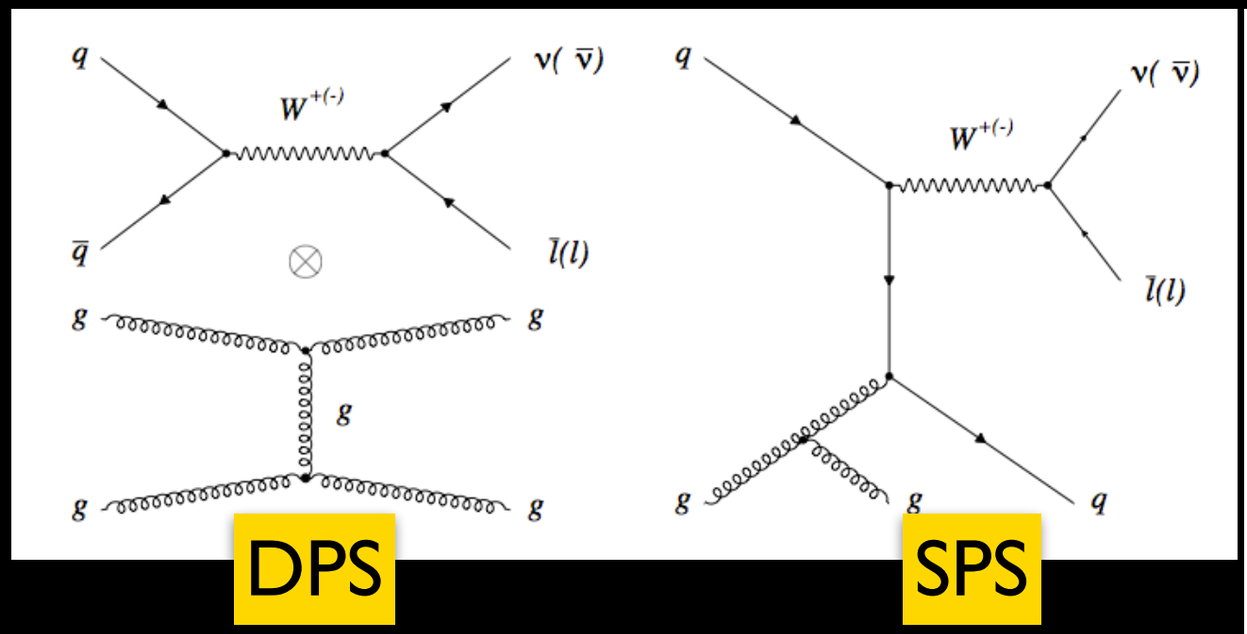
- Hard MPI
  - characteristic topology of the event, e.g. 4 jets with pair-balanced p_T



$$\sigma_{A+B}^{DPS} = \frac{m}{2}\frac{\sigma_A \cdot \sigma_B}{\sigma_{eff}}$$

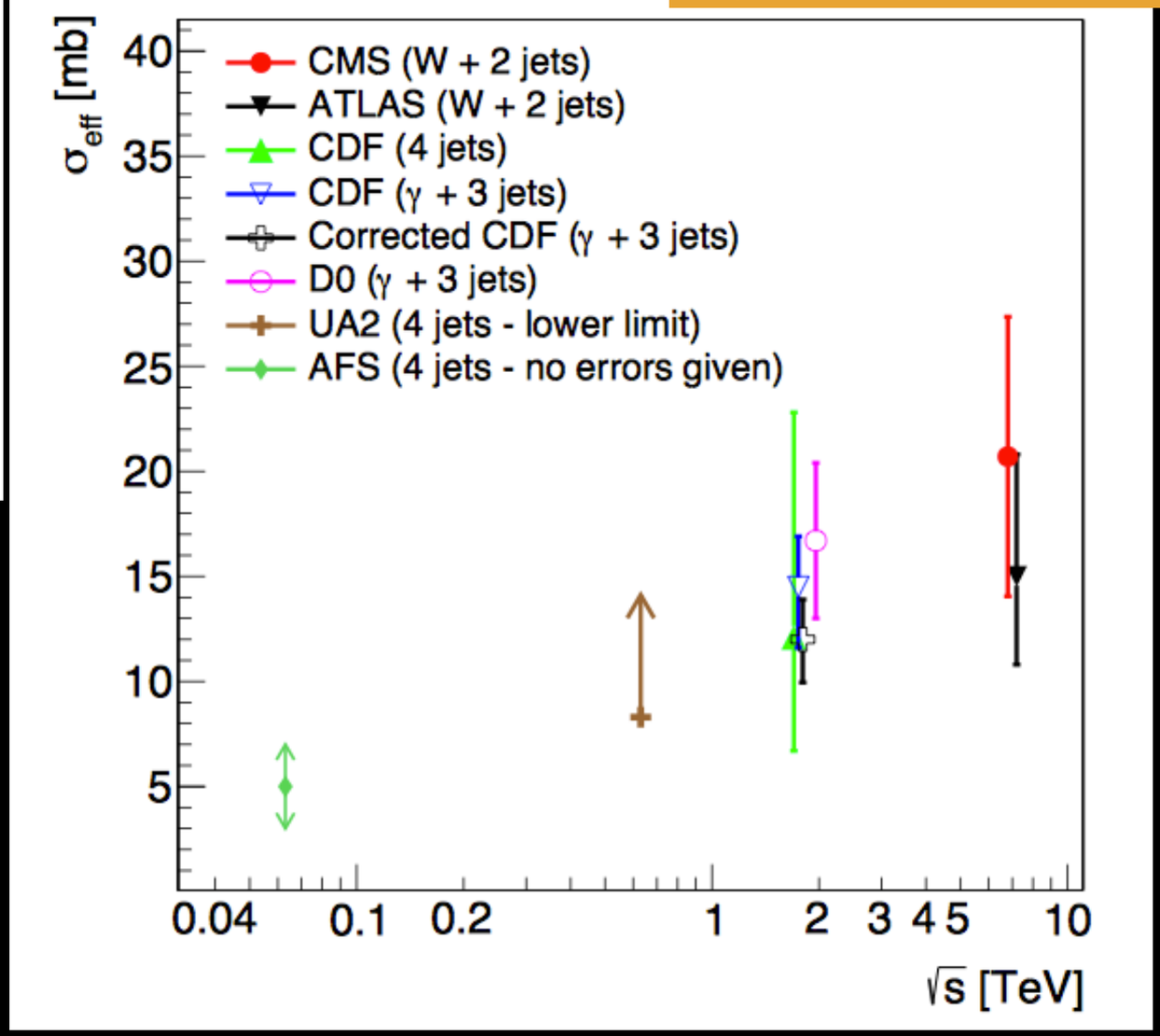
Multiple Parton Interactions

- Hard MPI
  - characteristic topology of the event, e.g. 4 jets with pair-balanced p_T



$$\sigma_{A+B}^{DPS} = \frac{m}{2}\frac{\sigma_A \cdot \sigma_B}{\sigma_{eff}}$$

[http://arxiv.org/abs/1410.6664]



Multiple Parton Interactions

- Semi-hard MPI
  - Low-p_T scale <=> non-perturbative region

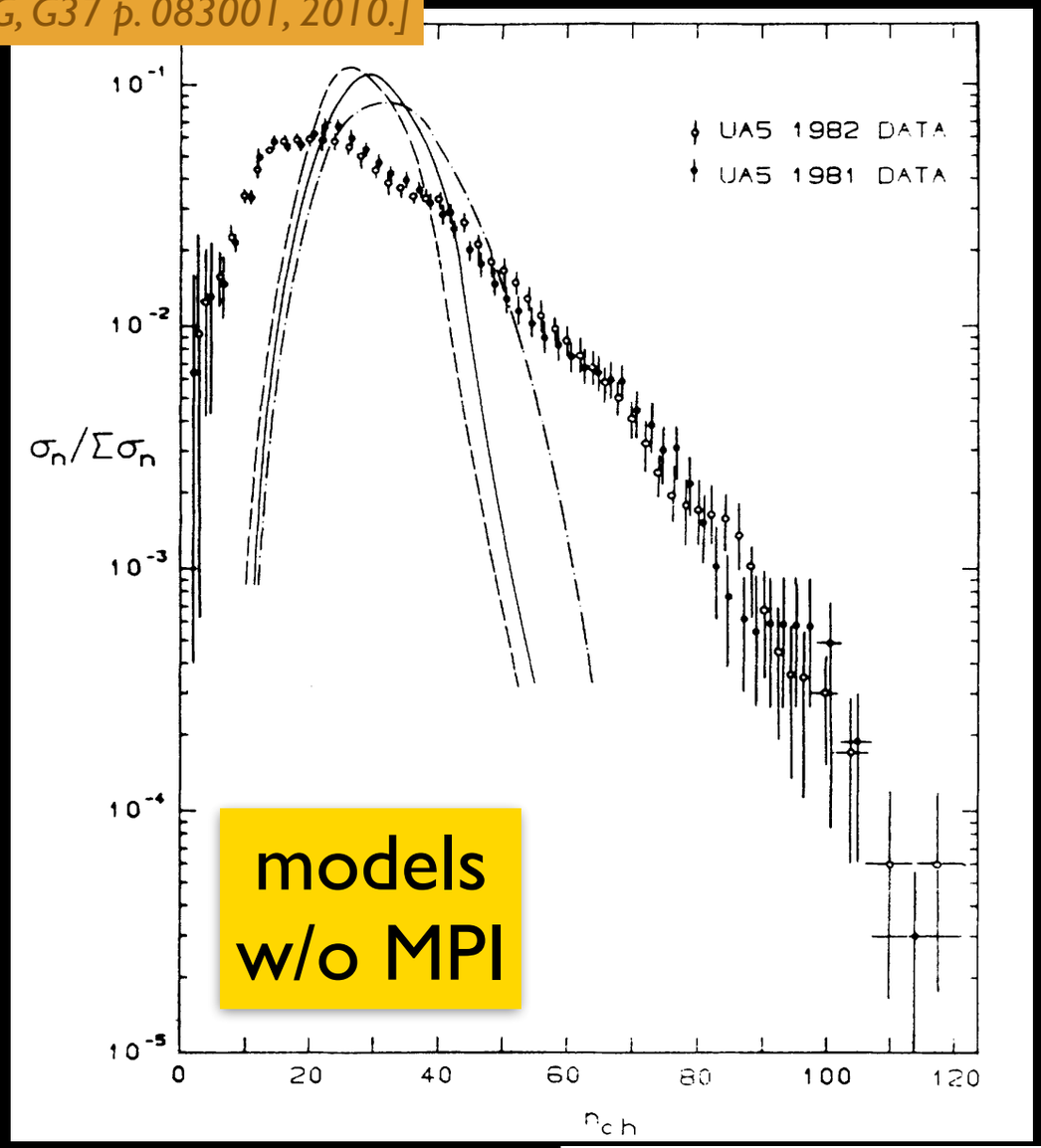
Multiple Parton Interactions

- Semi-hard MPI
  - Low-p_T scale <=> non-perturbative region
  - Evidence from charged-particle multiplicity distribution

Multiple Parton Interactions

- Semi-hard MPI
  - Low-p_T scale <=> non-perturbative region
  - Evidence from charged-particle multiplicity distribution

[J.Phys.G, G37 p. 083001, 2010.]

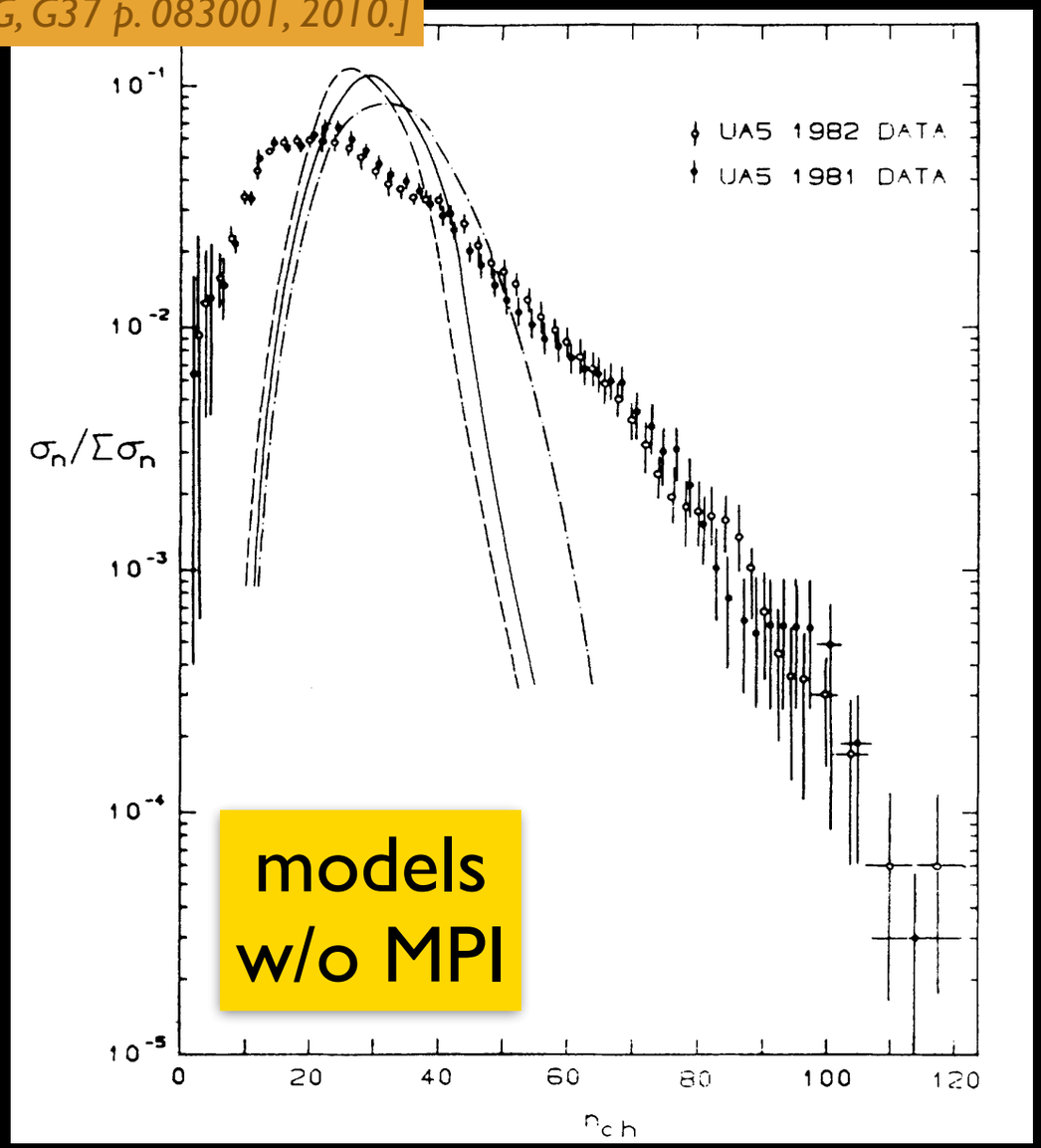


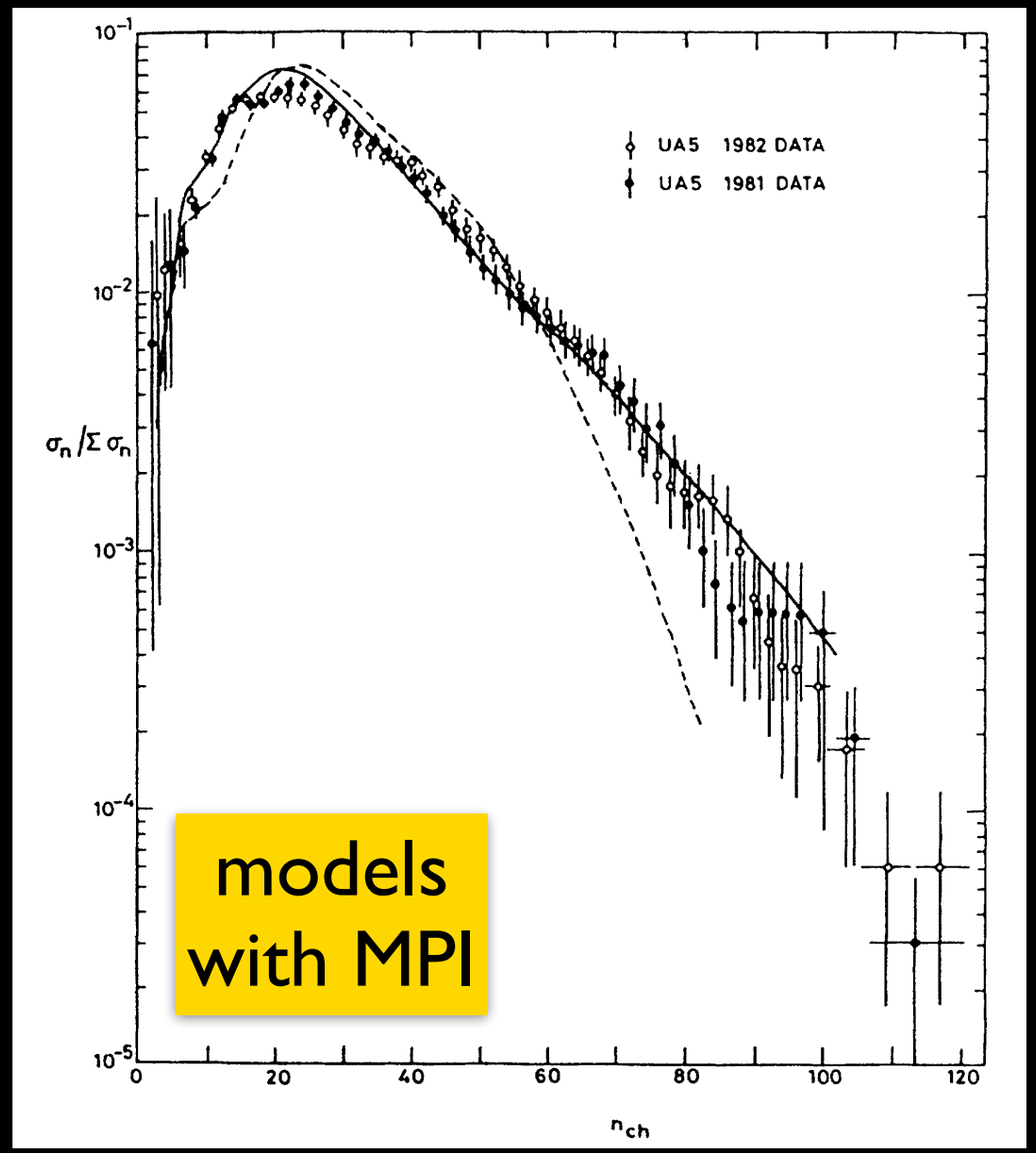
Number of charged particles

Multiple Parton Interactions

- Semi-hard MPI
  - Low-p_T scale <=> non-perturbative region
  - Evidence from charged-particle multiplicity distribution

[J.Phys.G, G37 p. 083001, 2010.]





Number of charged particles

Measuring semi-hard MPI experimentally: minijets in p-Pb collisions in ALICE

Measuring semi-hard MPI experimentally: minijets in p-Pb collisions in ALICE

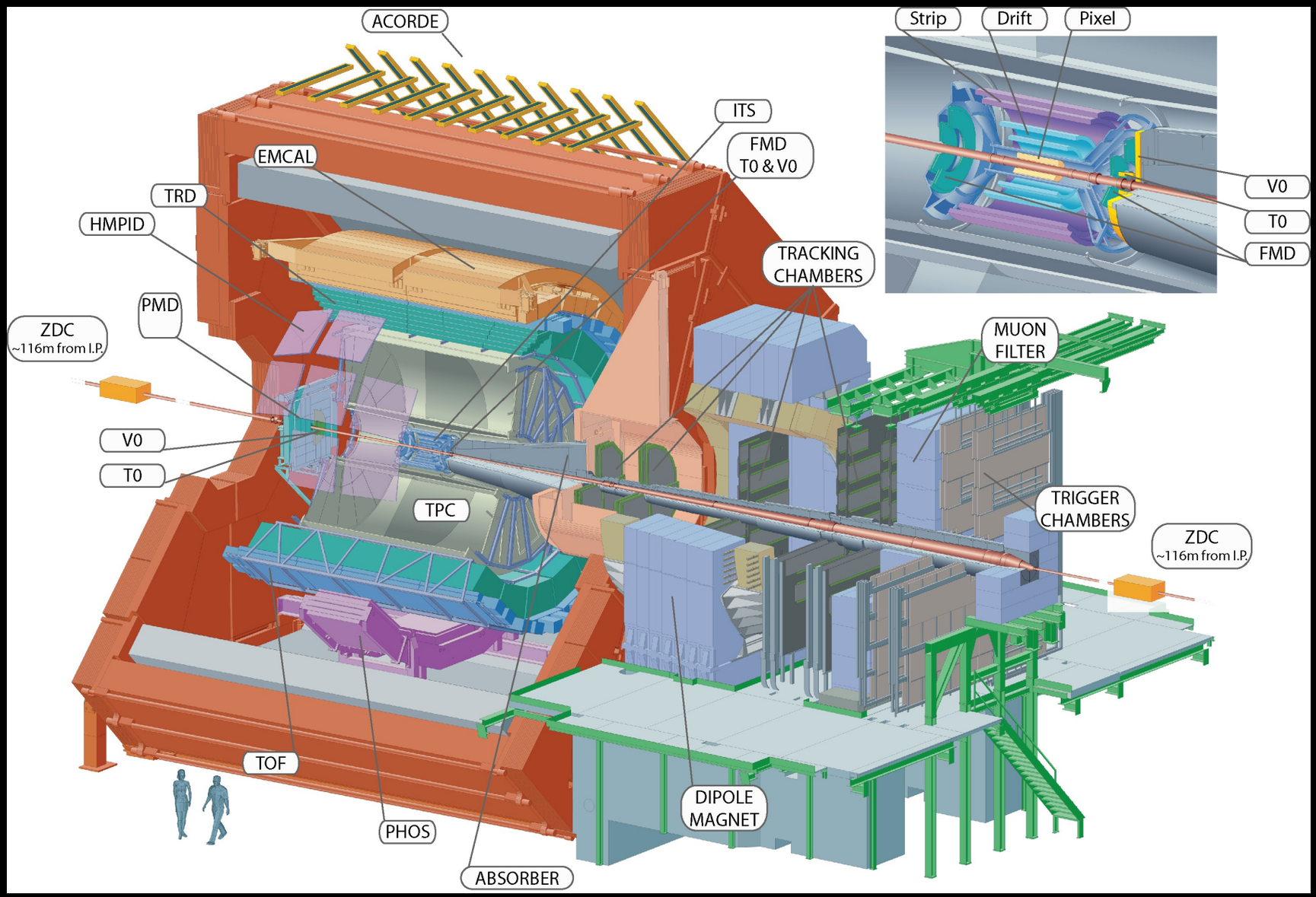
- Semi-hard MPI produce minijets (jets at low p_T)

Measuring semi-hard MPI experimentally: minijets in p-Pb collisions in ALICE

- Semi-hard MPI produce minijets (jets at low p_T)

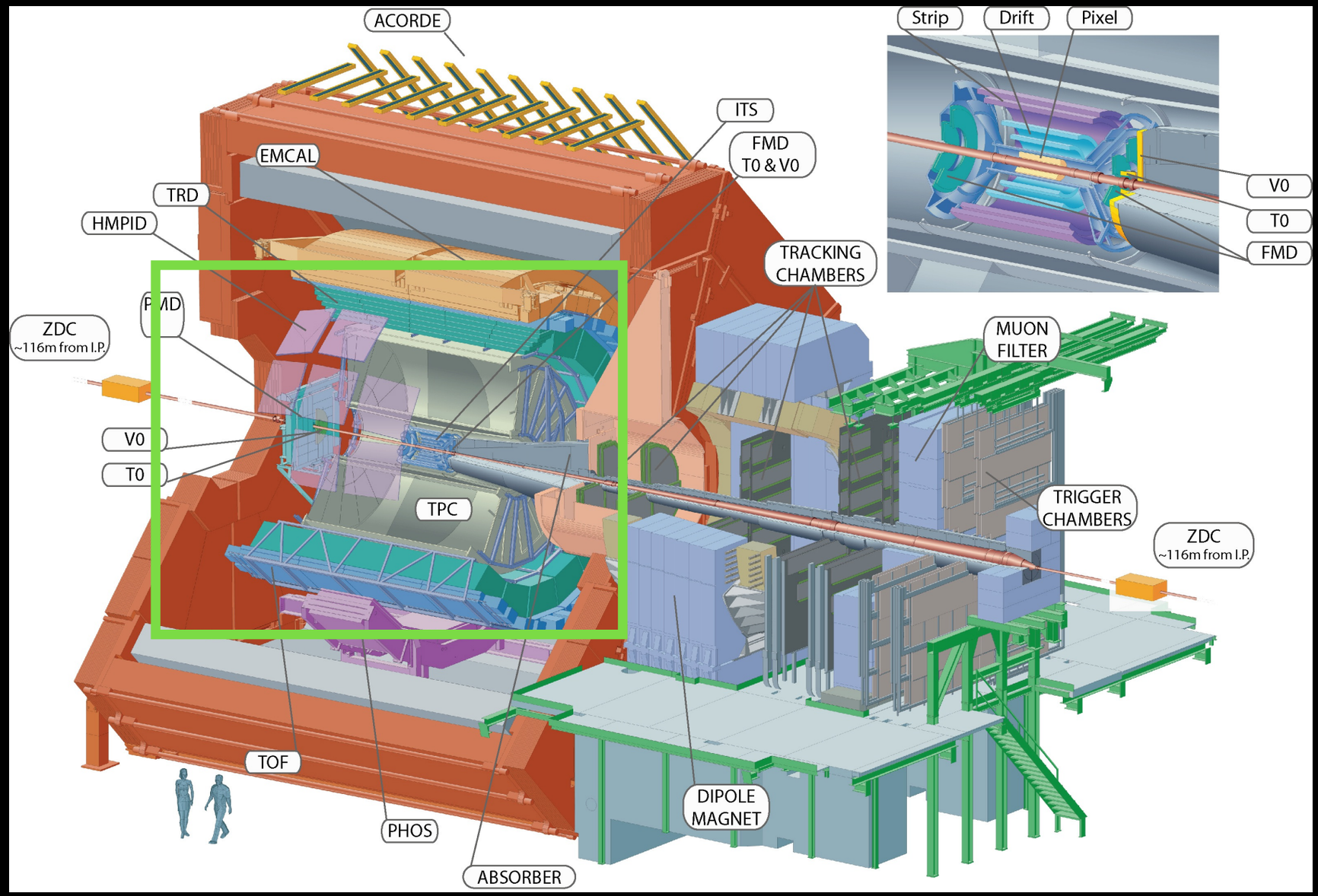
- Minijets overlap in high multiplicity collisions
  - not reconstructable with standard jet-reco algorithms
    => two-particle correlation method
  - even more important in p-Pb collisions!

The ALICE detector



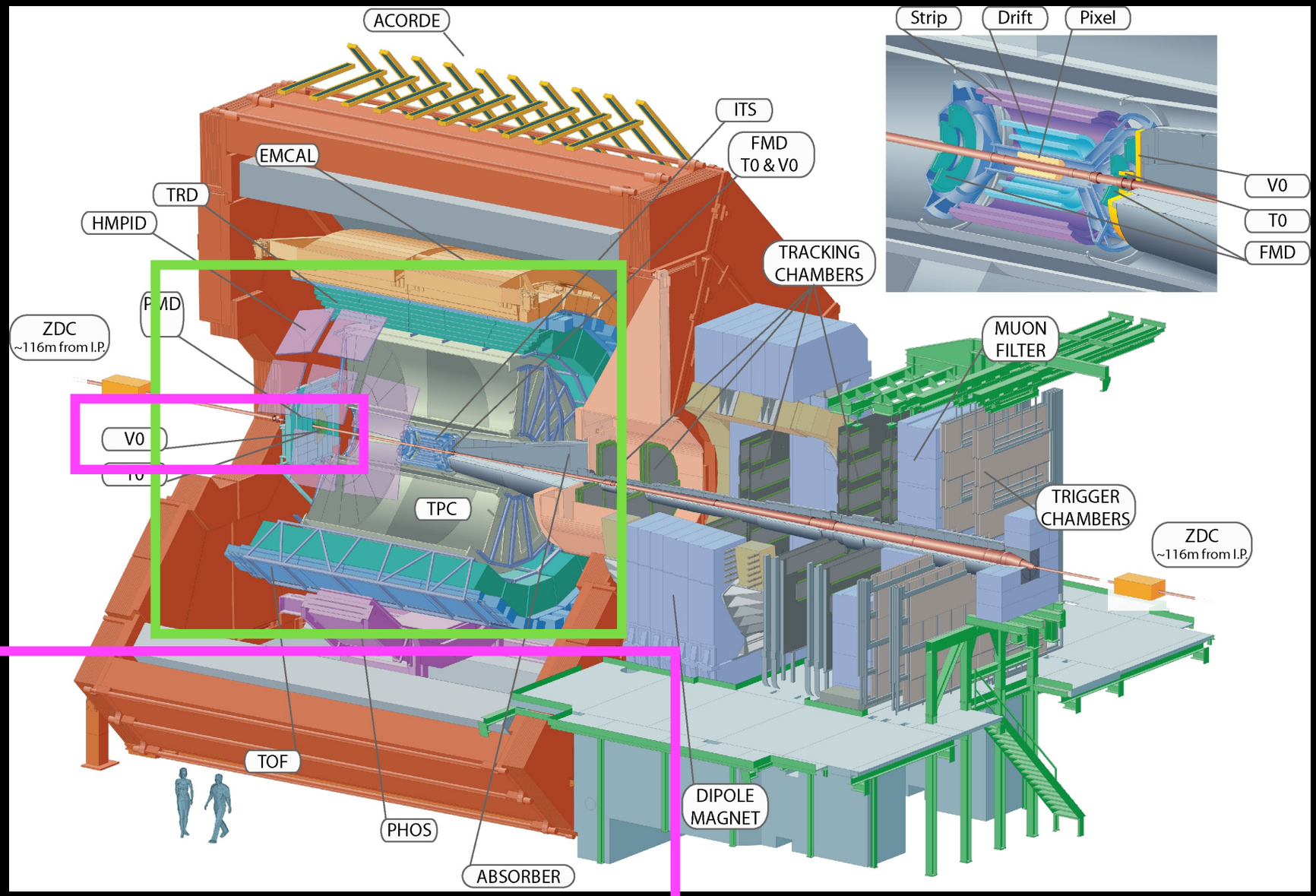
The ALICE detector

- ITS
  - $|\eta| < 0.9$
- TPC
  - $|\eta| < 0.9$
  - PID (dE/dx)

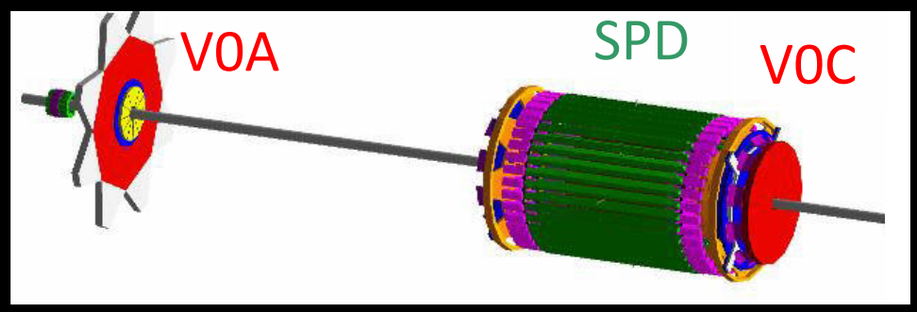


The ALICE detector

- ITS
  - |η| < 0.9
- TPC
  - |η| < 0.9
  - PID (dE/dx)



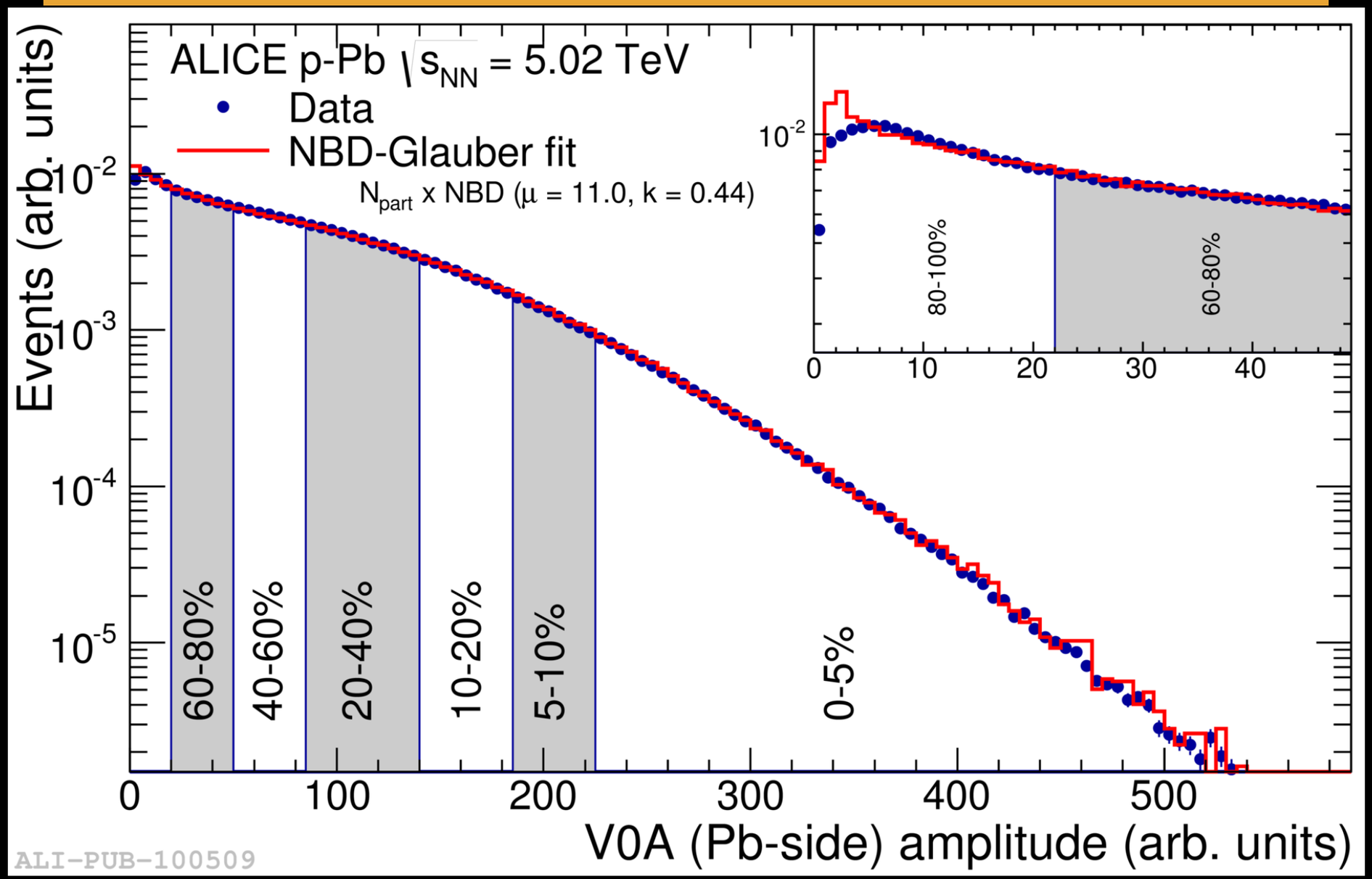
- VZERO-A
  - direction of Pb remnants
  - 2.8 < η < 5.1
  - trigger
  - multiplicity determination



[Phys. Rev. C 91 (2015) 064905]

"Centrality" classes for p-Pb collisions

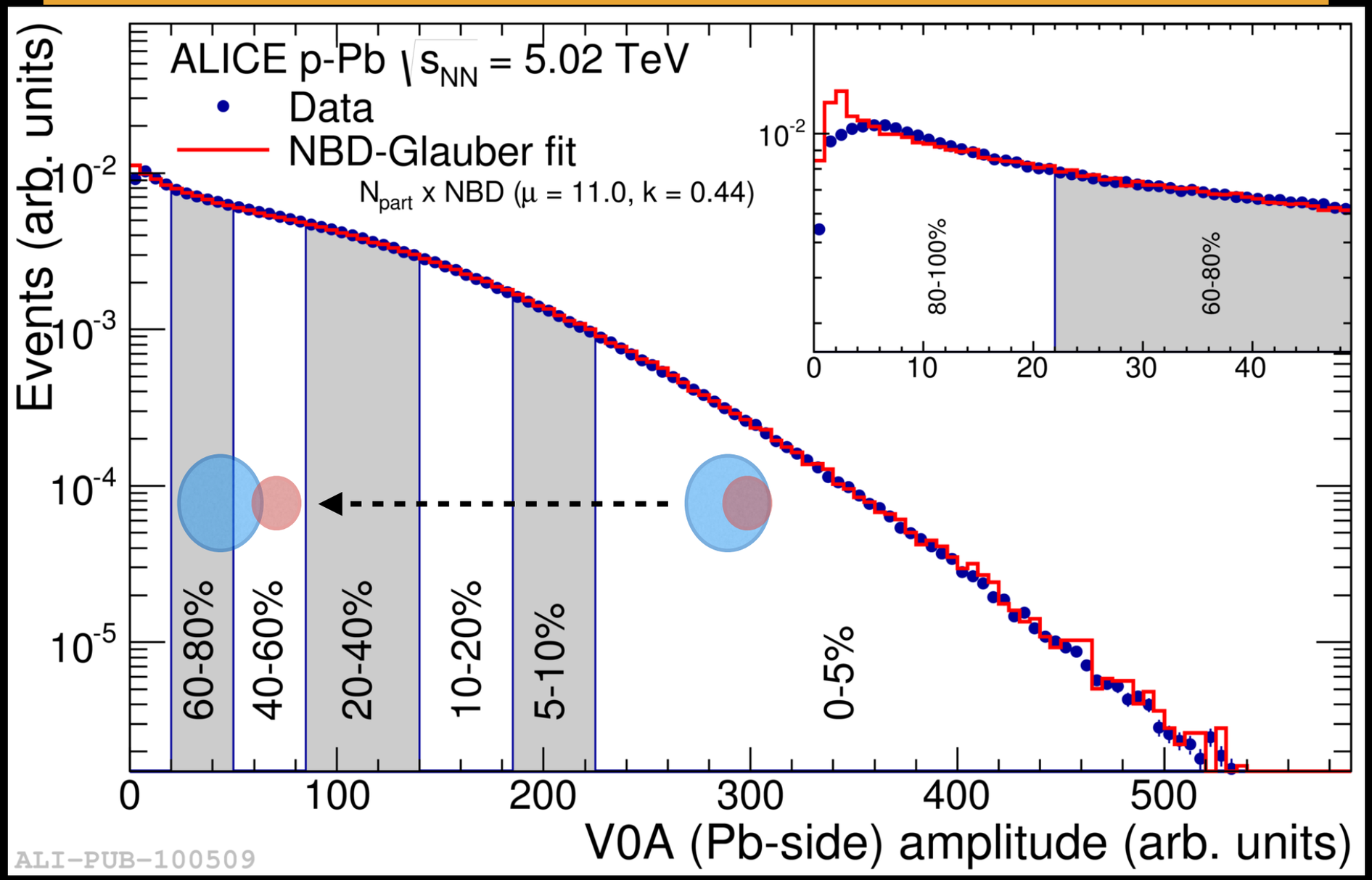
V0A multiplicity sliced in percentiles of cross section



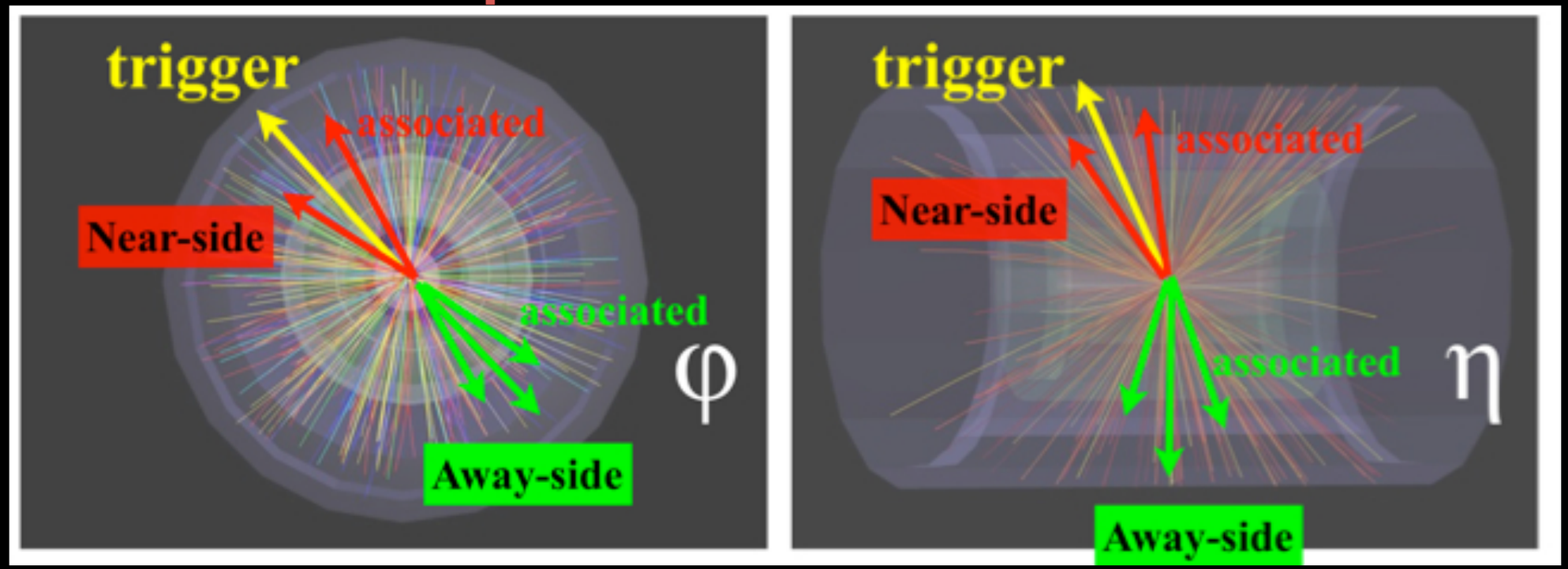
[Phys. Rev. C 91 (2015) 064905]

"Centrality" classes for p-Pb collisions

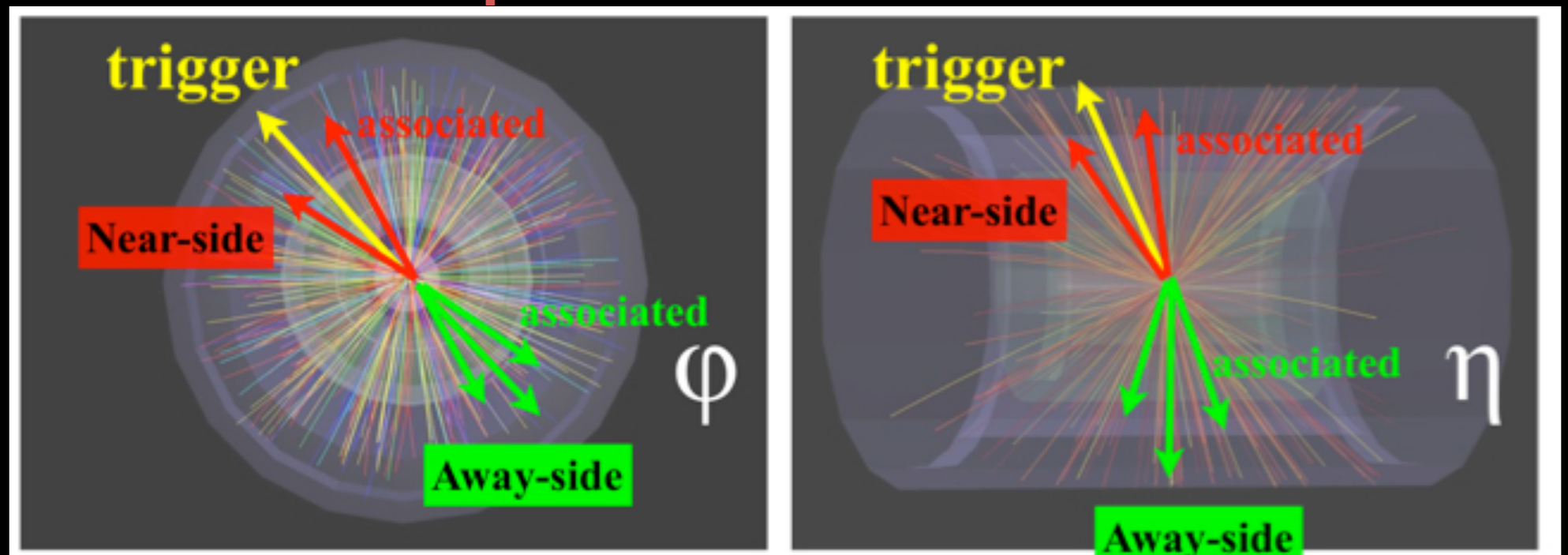
V0A multiplicity sliced in percentiles of cross section



Two-particle correlations

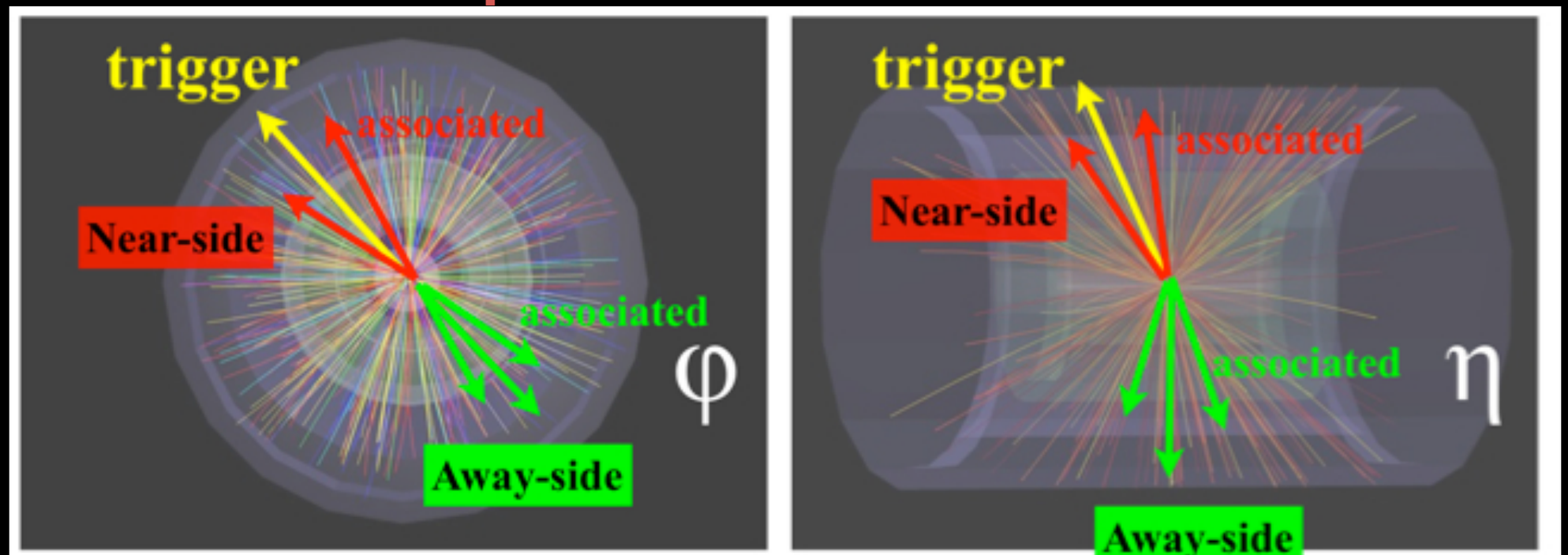


Two-particle correlations



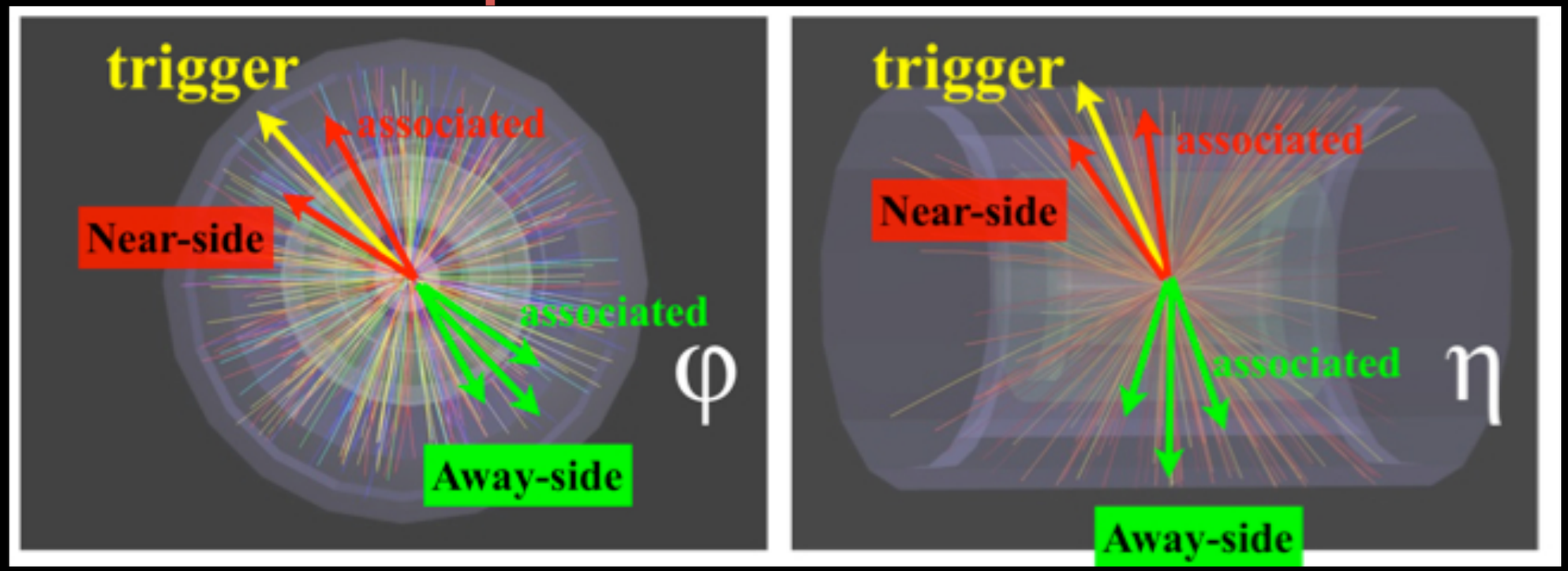
- For each event:
  - trigger particles: i.e. those with $p_{T,trig} > p_{T,trig\ min}$ (= 0.7 GeV/*c*)

Two-particle correlations



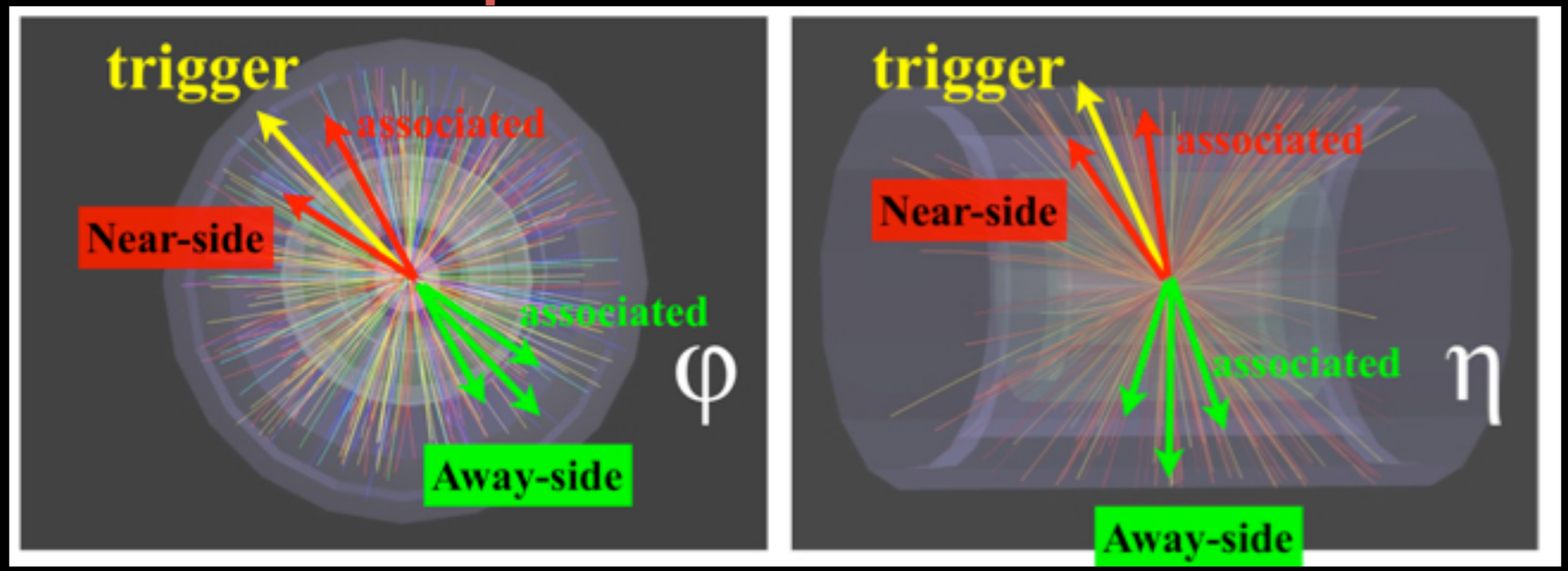
- For each event:
  - trigger particles: i.e. those with $p_{T,trig} > p_{T,trig\ min}$ (= 0.7 GeV/*c*)
  - associated particles: i.e. $p_{T,assoc\ min}$ (= 0.7 GeV/*c*) < $p_{T,assoc} < p_{T,trig}$

Two-particle correlations



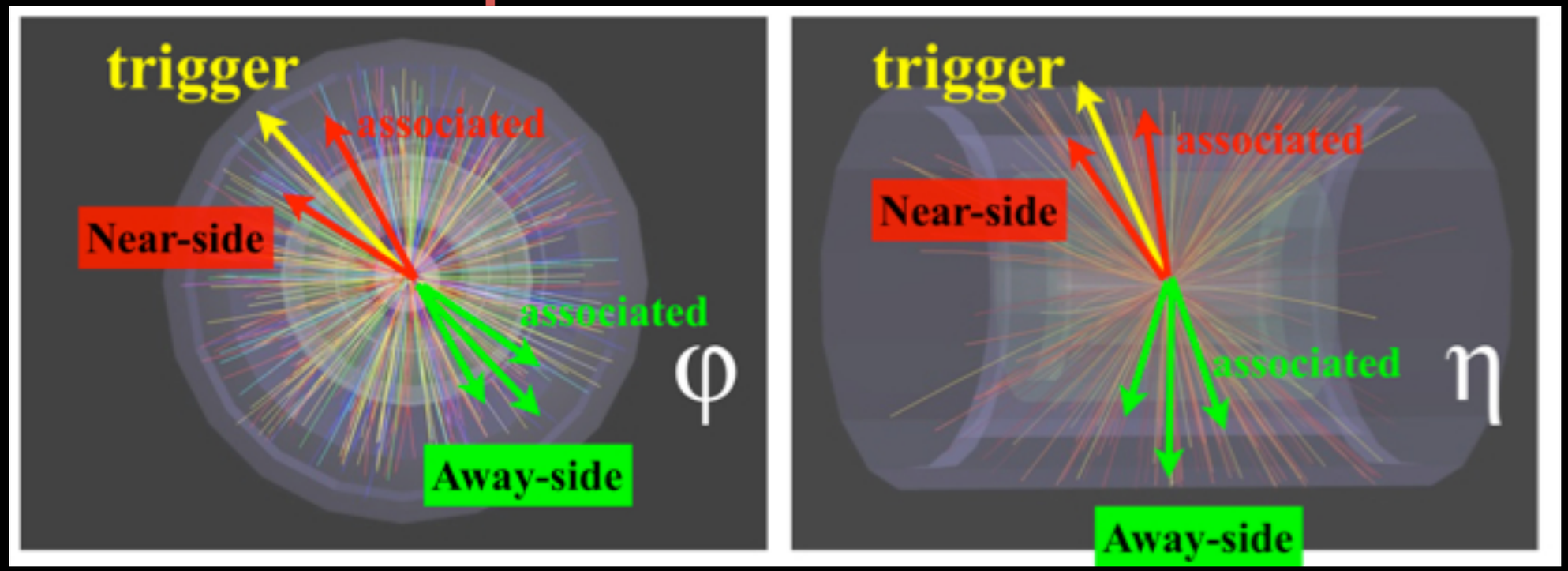
- For each event:
  - trigger particles: i.e. those with $p_{T,trig} > p_{T,trig\ min}$ (= 0.7 GeV/*c*)
  - associated particles: i.e. $p_{T,assoc\ min}$ (= 0.7 GeV/*c*) < $p_{T,assoc} < p_{T,trig}$
  - count associated particles per trigger particle
    - as function of azimuthal and pseudorapidity difference of the pair

Two-particle correlations



- For each event:
  - trigger particles: i.e. those with $p_{T,trig} > p_{T,trig\ min}$ (= 0.7 GeV/*c*)
  - associated particles: i.e. $p_{T,assoc\ min}$ (= 0.7 GeV/*c*) < $p_{T,assoc} < p_{T,trig}$
  - count associated particles per trigger particle
    - as function of azimuthal and pseudorapidity difference of the pair
- Average over all events

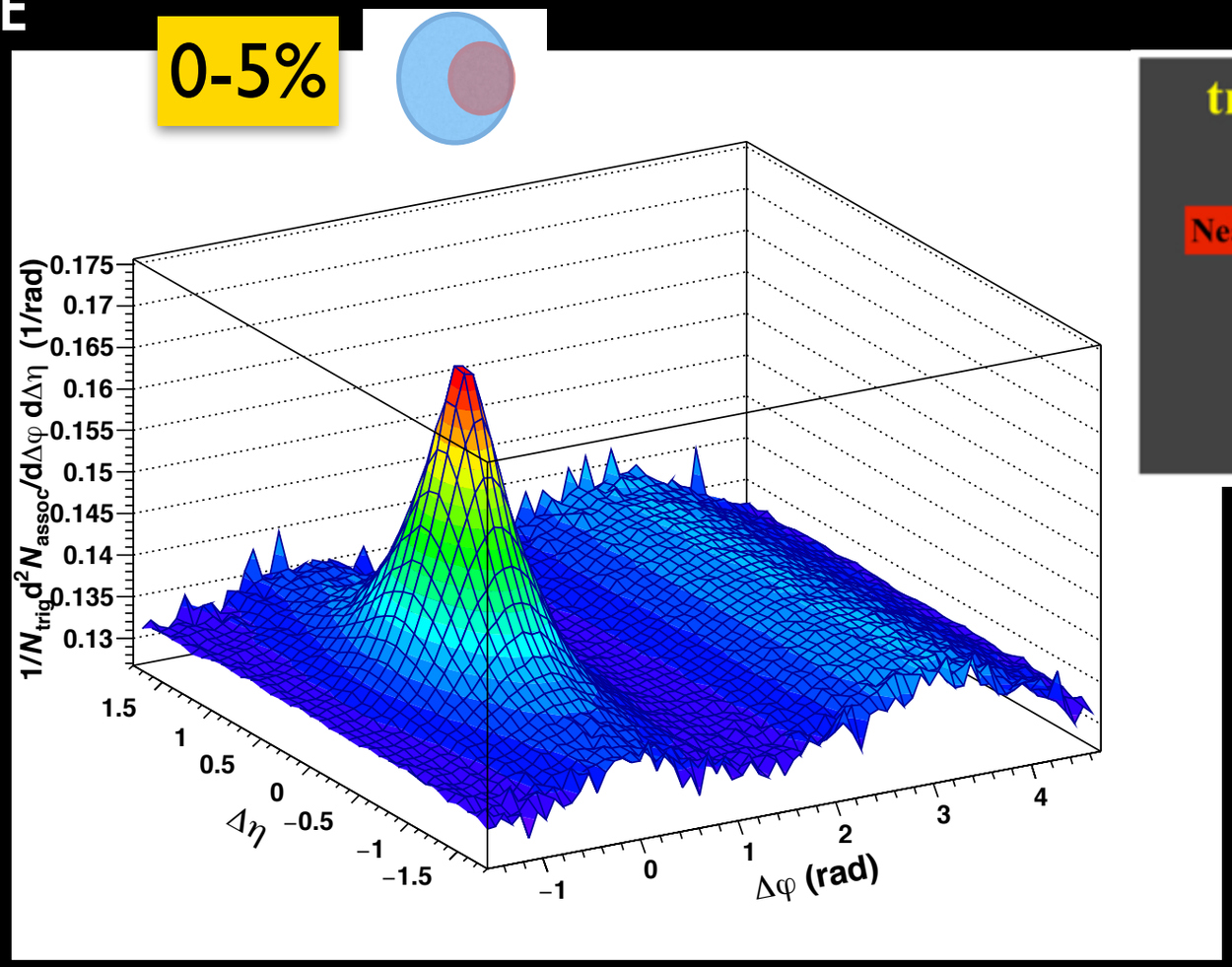
Two-particle correlations

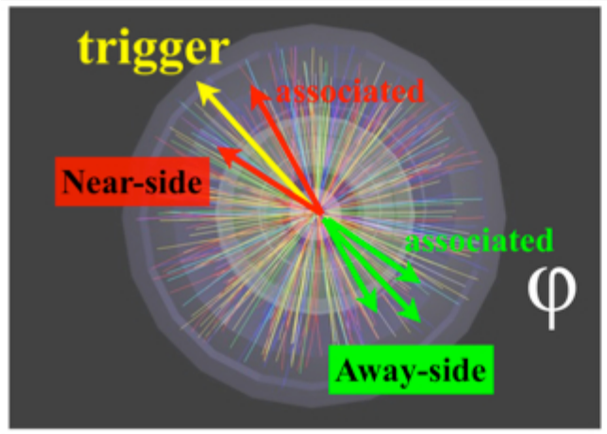


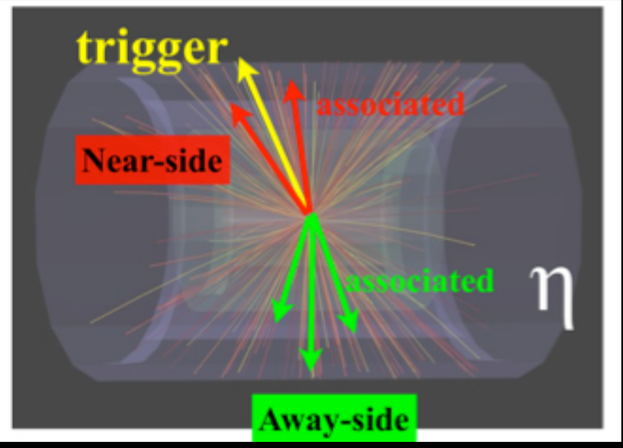
- For each event:
  - trigger particles: i.e. those with $p_{T,trig} > p_{T,trig\ min}$ (= 0.7 GeV/*c*)
  - associated particles: i.e. $p_{T,assoc\ min}$ (= 0.7 GeV/*c*) < $p_{T,assoc} < p_{T,trig}$
  - count associated particles per trigger particle
    - as function of azimuthal and pseudorapidity difference of the pair
- Average over all events

★ Associated particles in near- and away-side: minijet fragmentation => from semi-hard process

Two-particle correlations

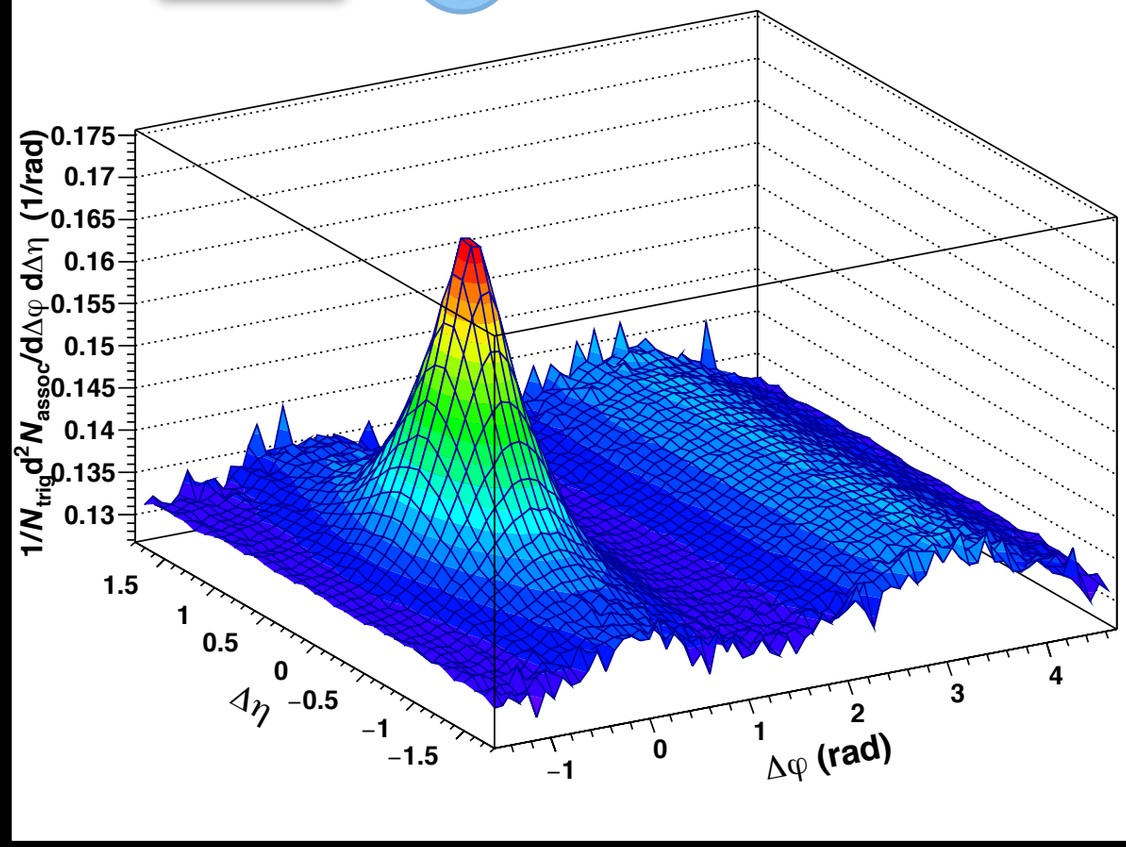


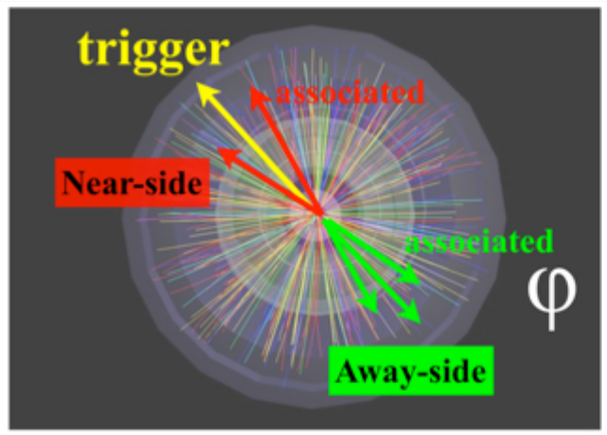


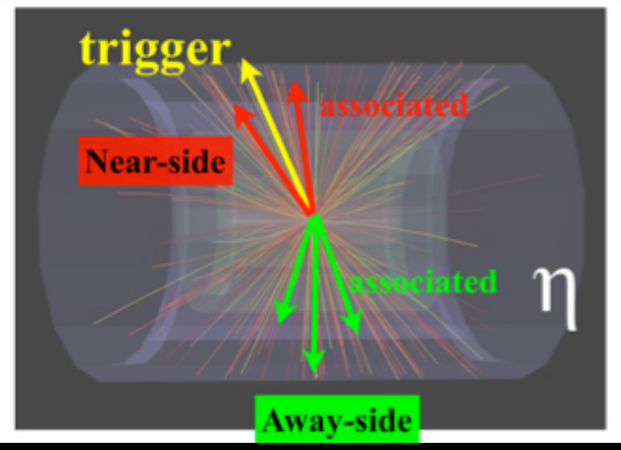


Two-particle correlations

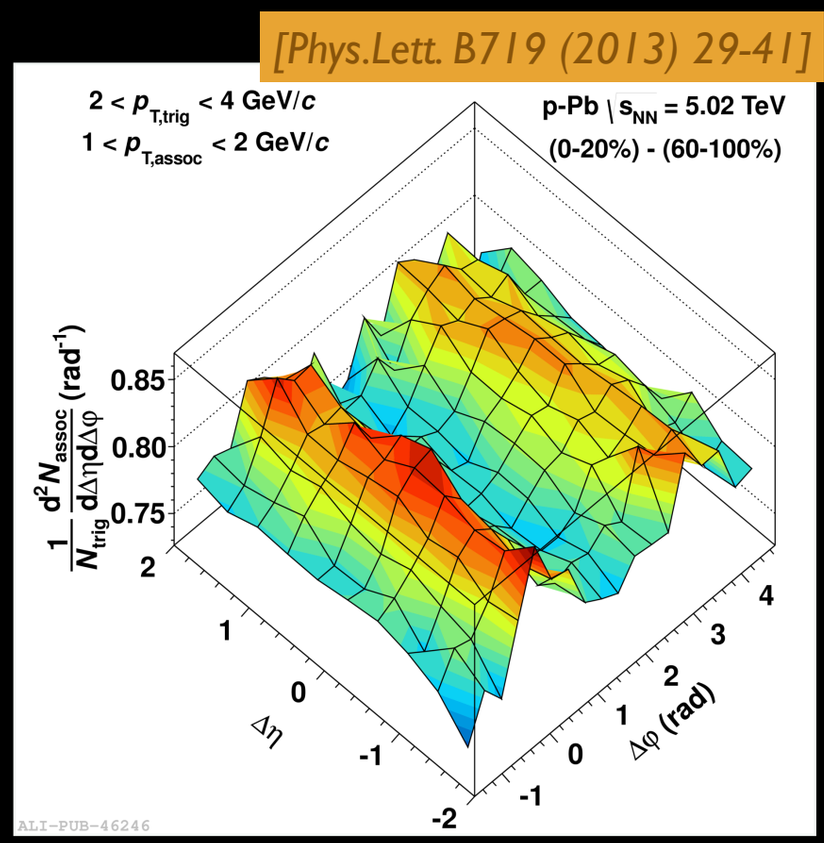
0-5%



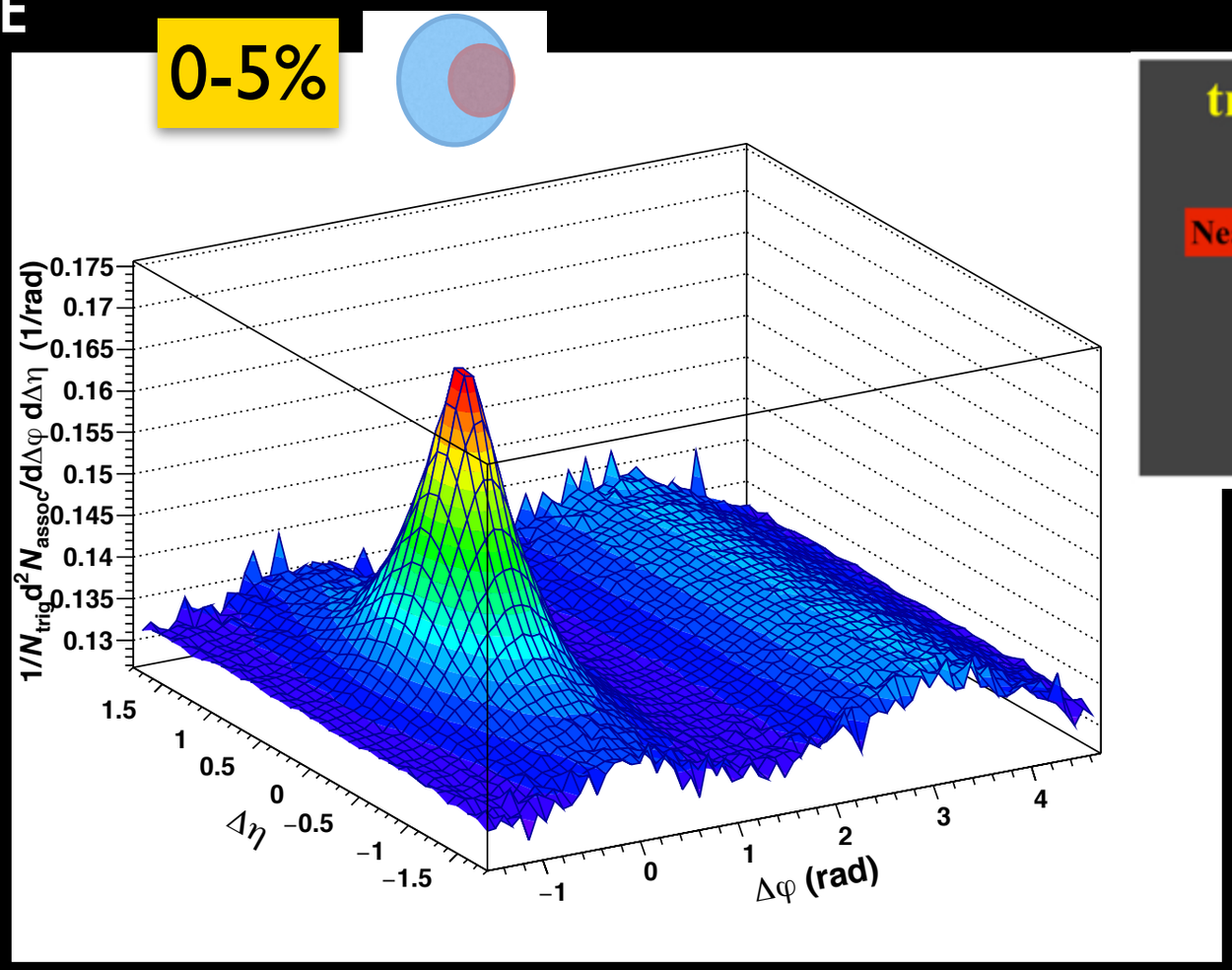


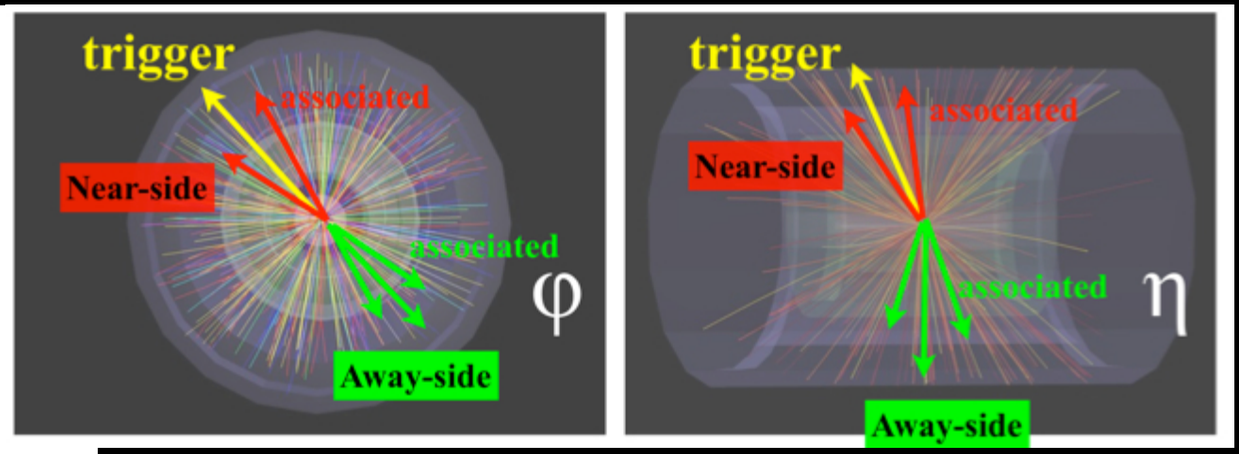


[Phys.Lett. B719 (2013) 29-41]

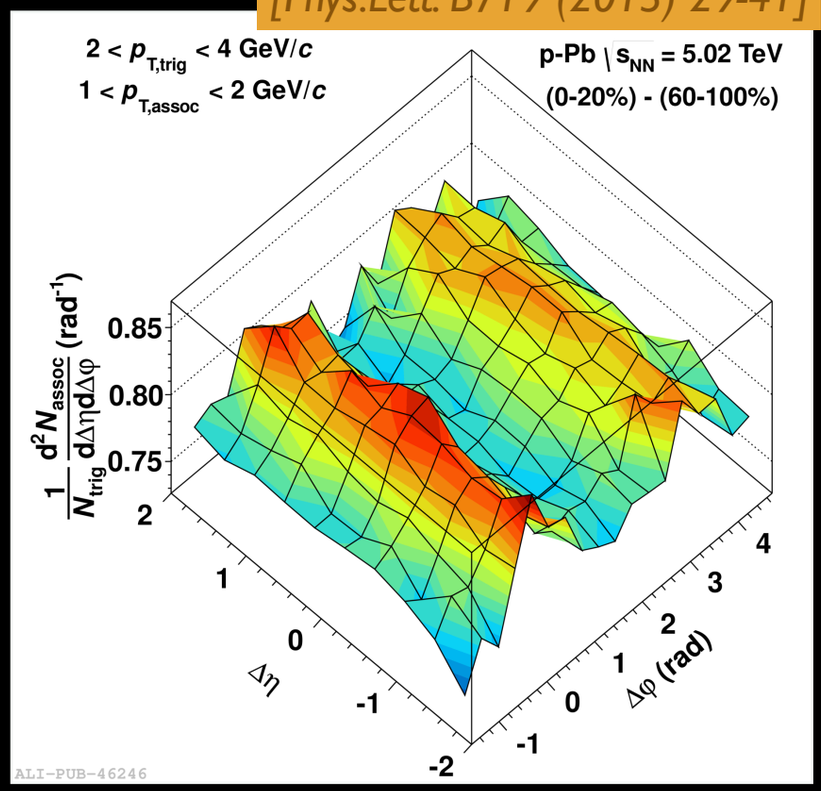


Two-particle correlations





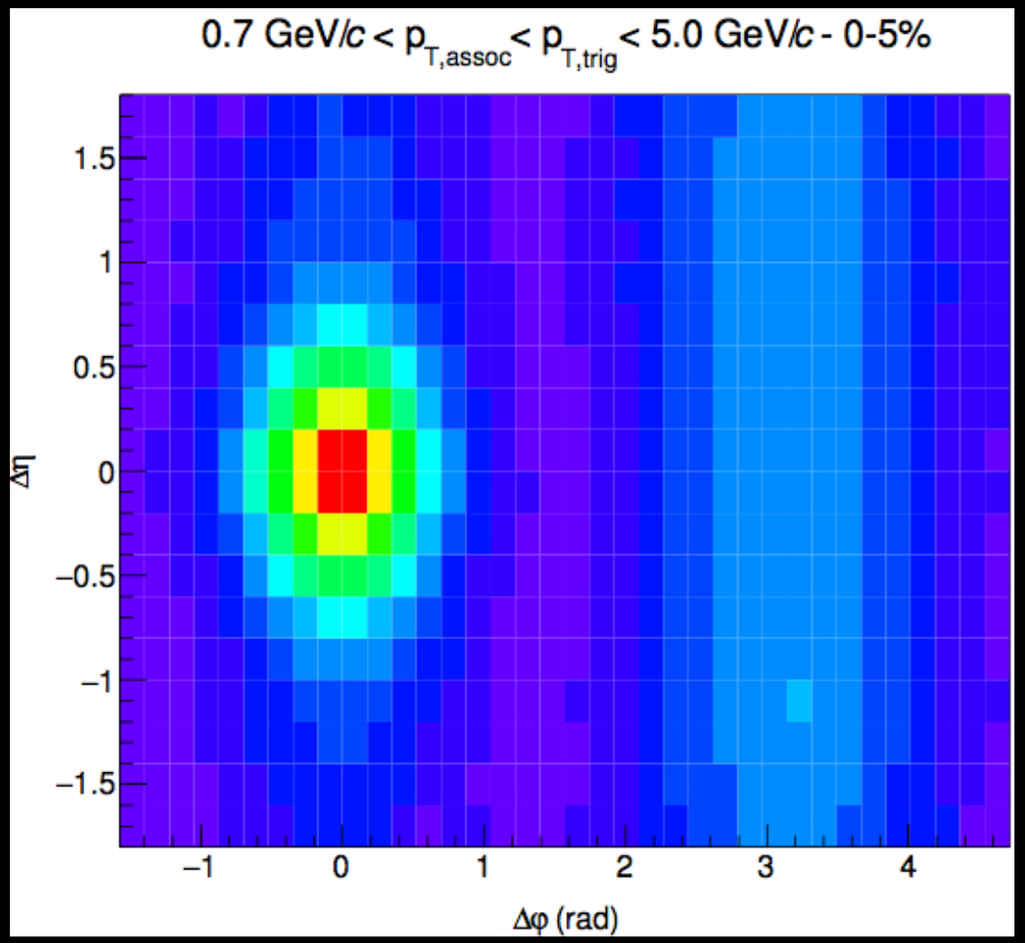
[Phys.Lett. B719 (2013) 29-41]



- Away side ($\pi/2 < \Delta\varphi < 3\pi/2$)
  - short + long range ($|\Delta\eta| < 1.8$): recoil jet + ridge
- Near side ($-\pi/2 < \Delta\varphi < \pi/2$)
  - short range ($|\Delta\eta| < 1.2$): jet peak + ridge
  - long range ($1.2 < |\Delta\eta| < 1.8$): ridge

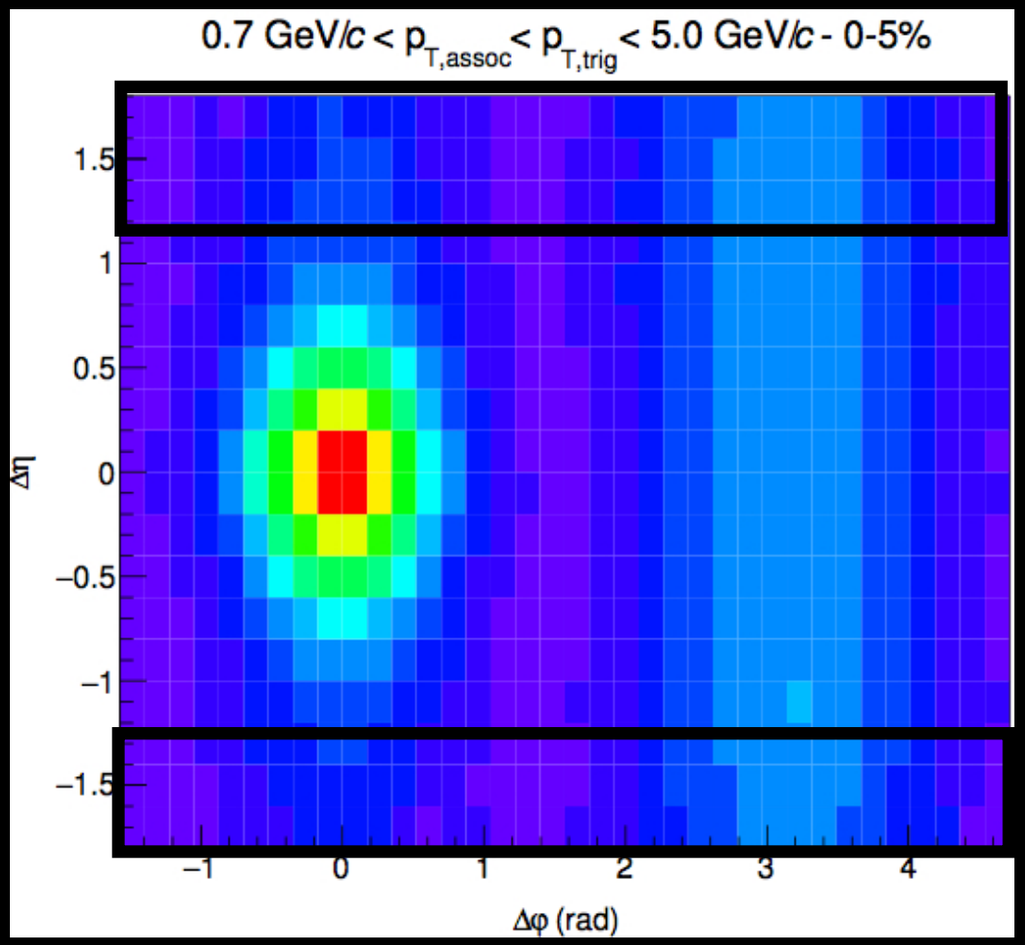
[Phys. Lett. B 741 (2015) 38-50]

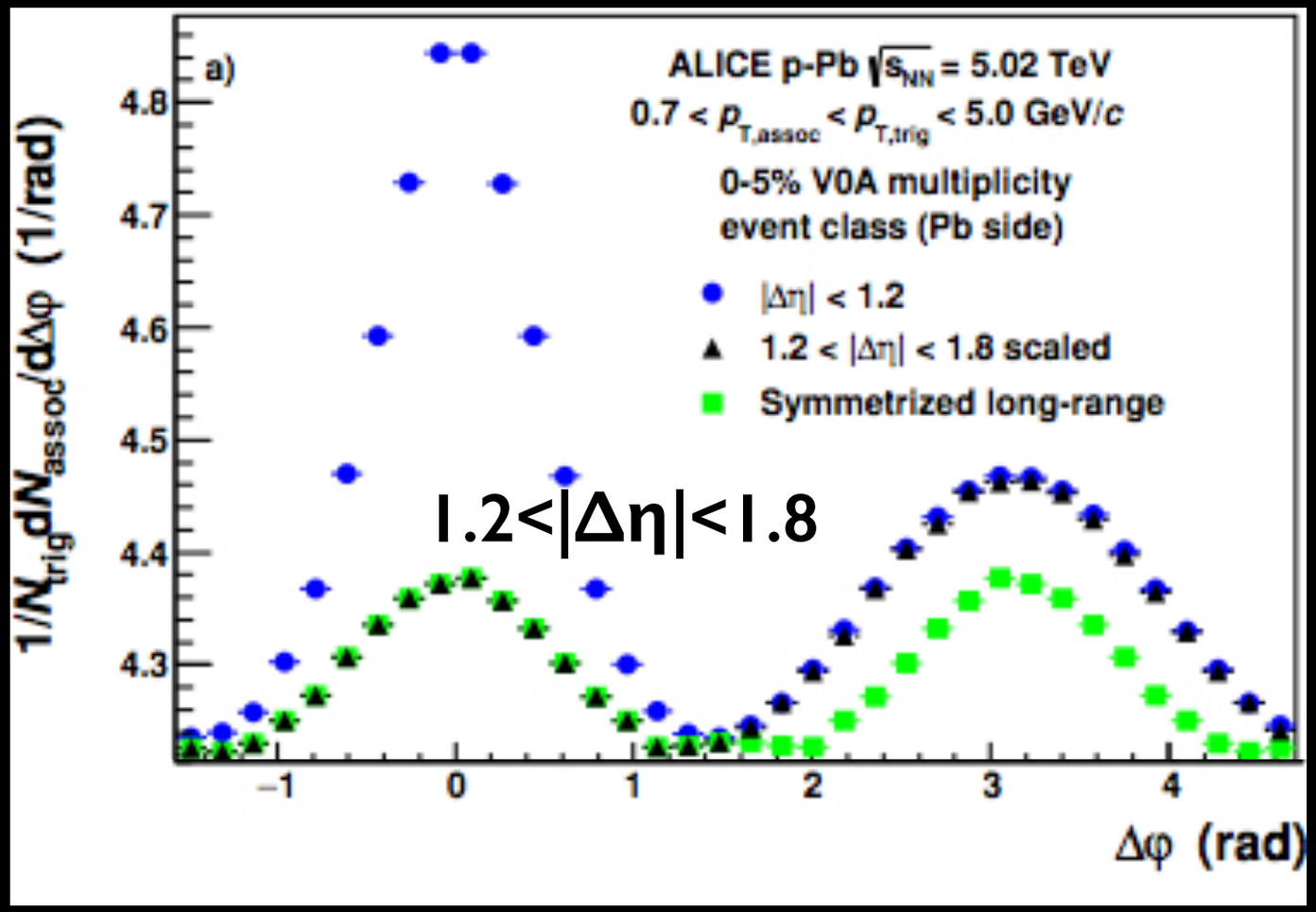
Minijet correlations above the ridge



[Phys. Lett. B 741 (2015) 38-50]

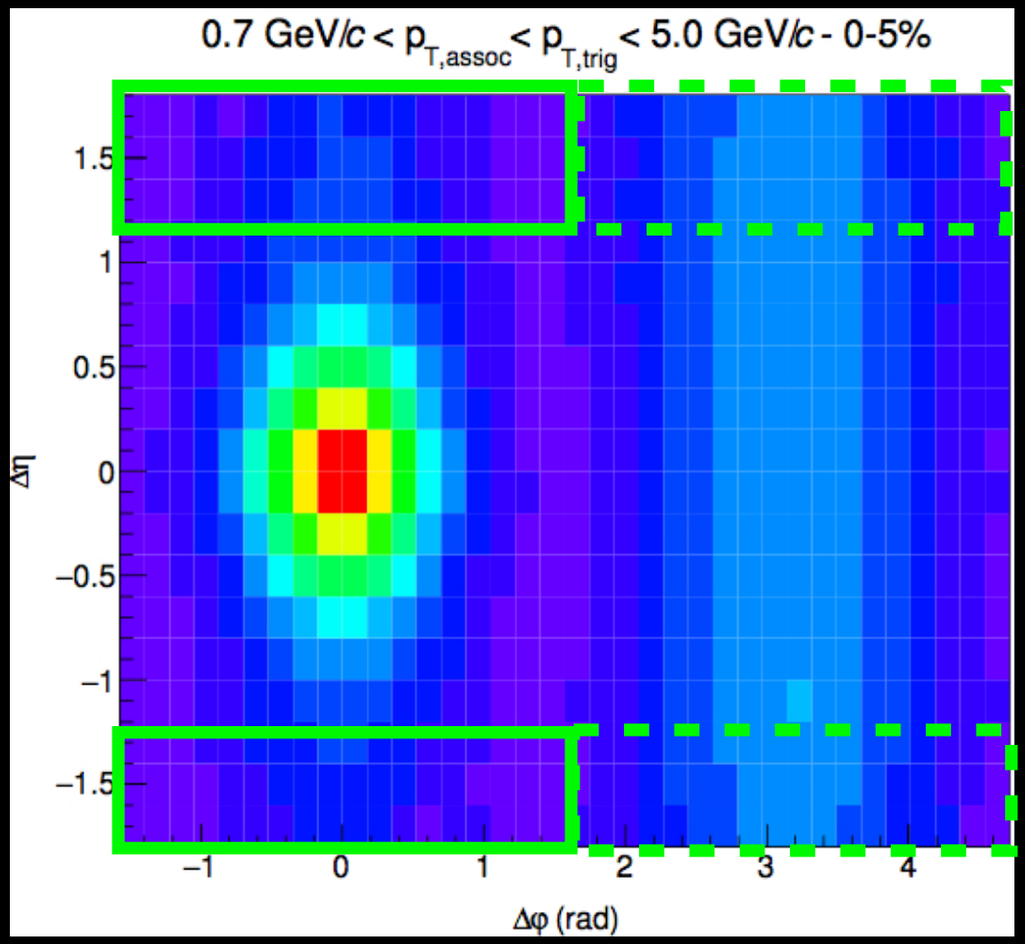
Minijet correlations above the ridge

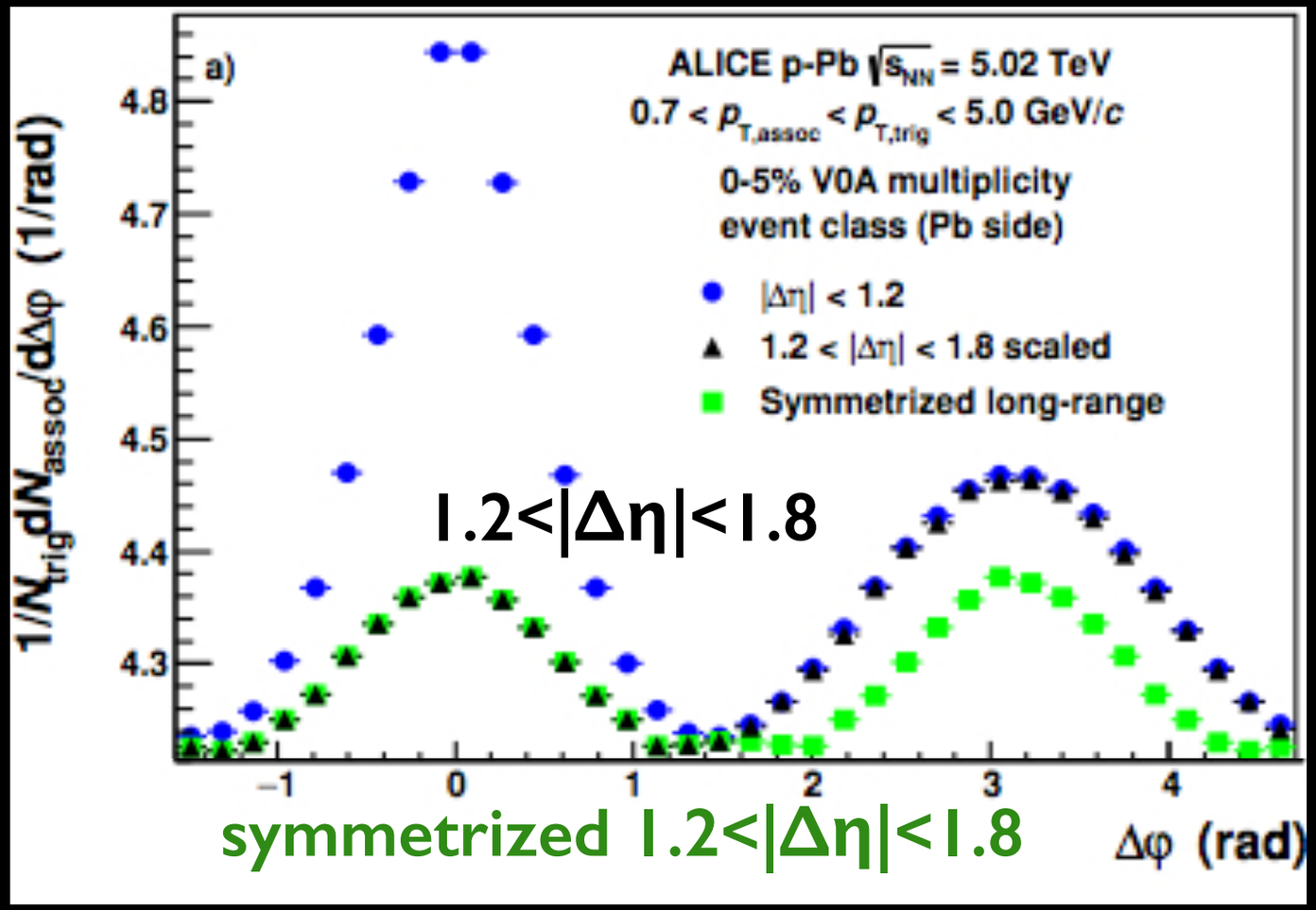




[Phys. Lett. B 741 (2015) 38-50]

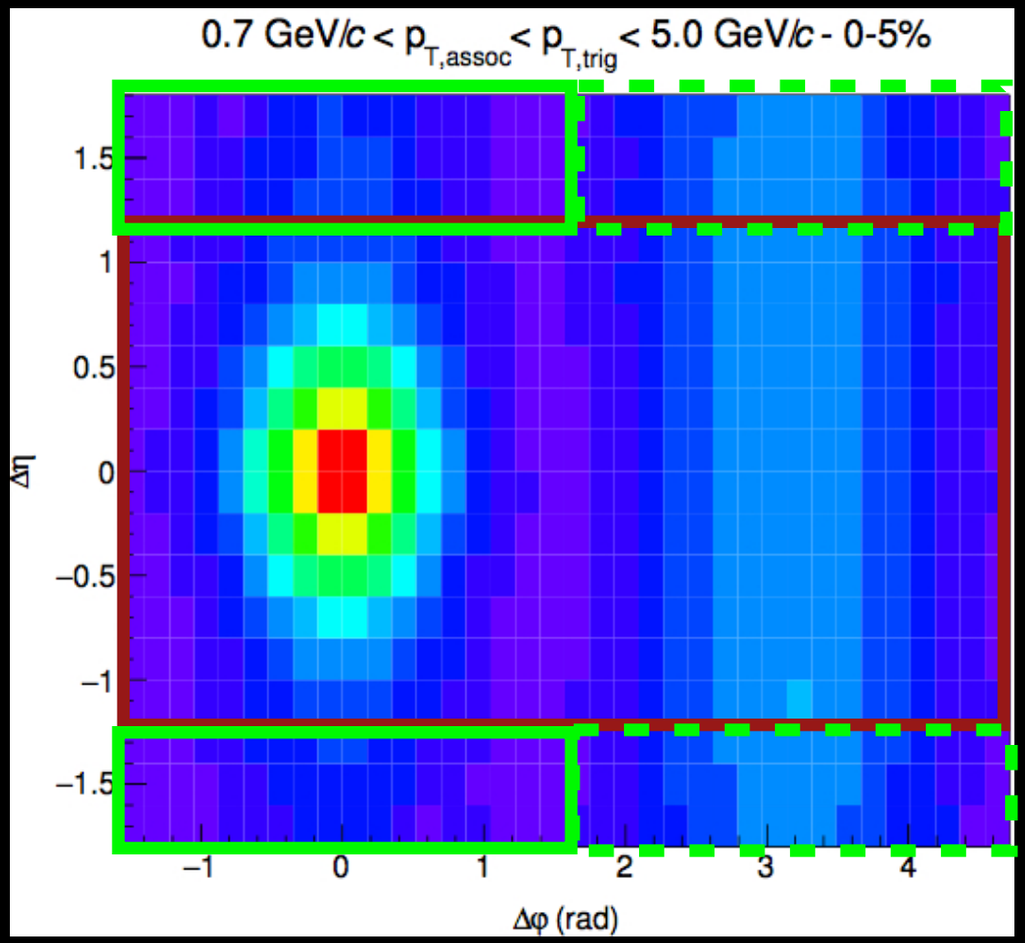
Minijet correlations above the ridge

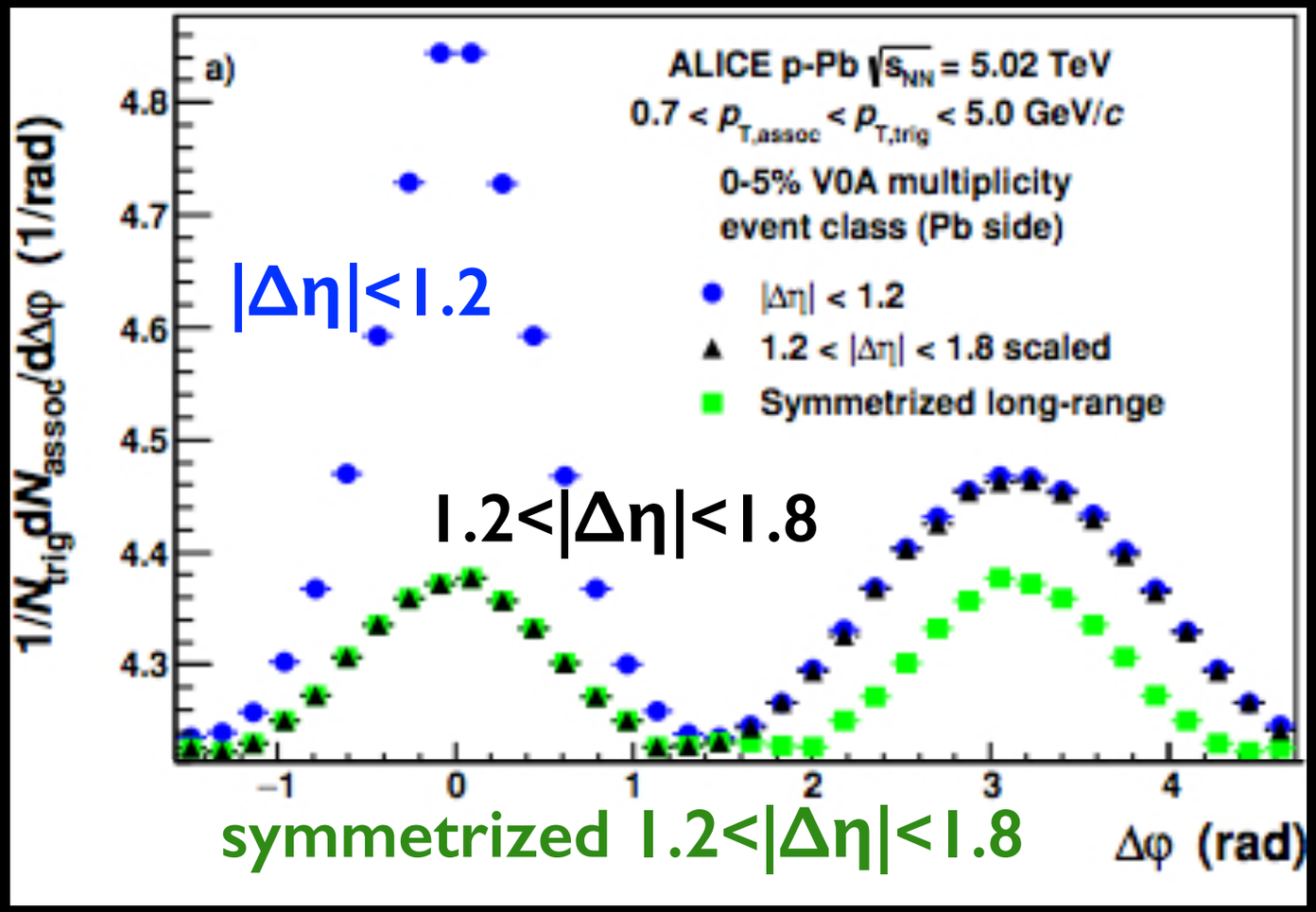




[Phys. Lett. B 741 (2015) 38-50]

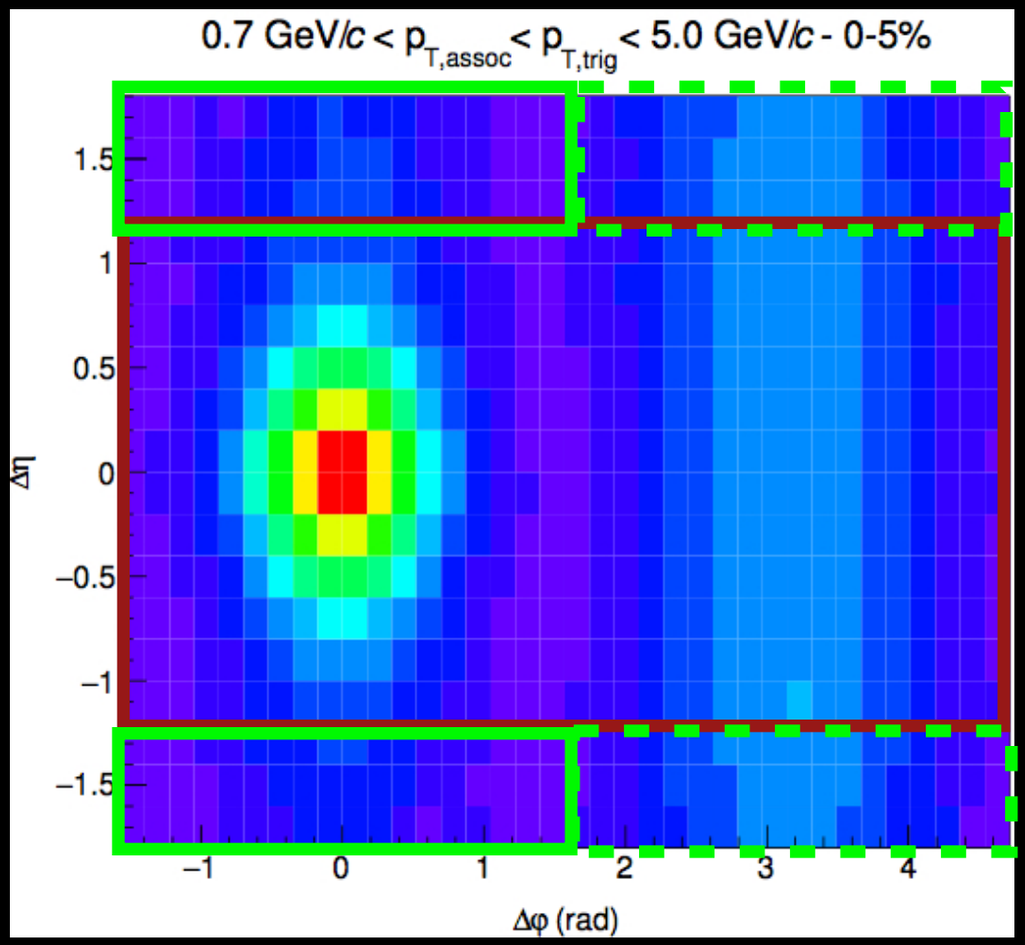
Minijet correlations above the ridge

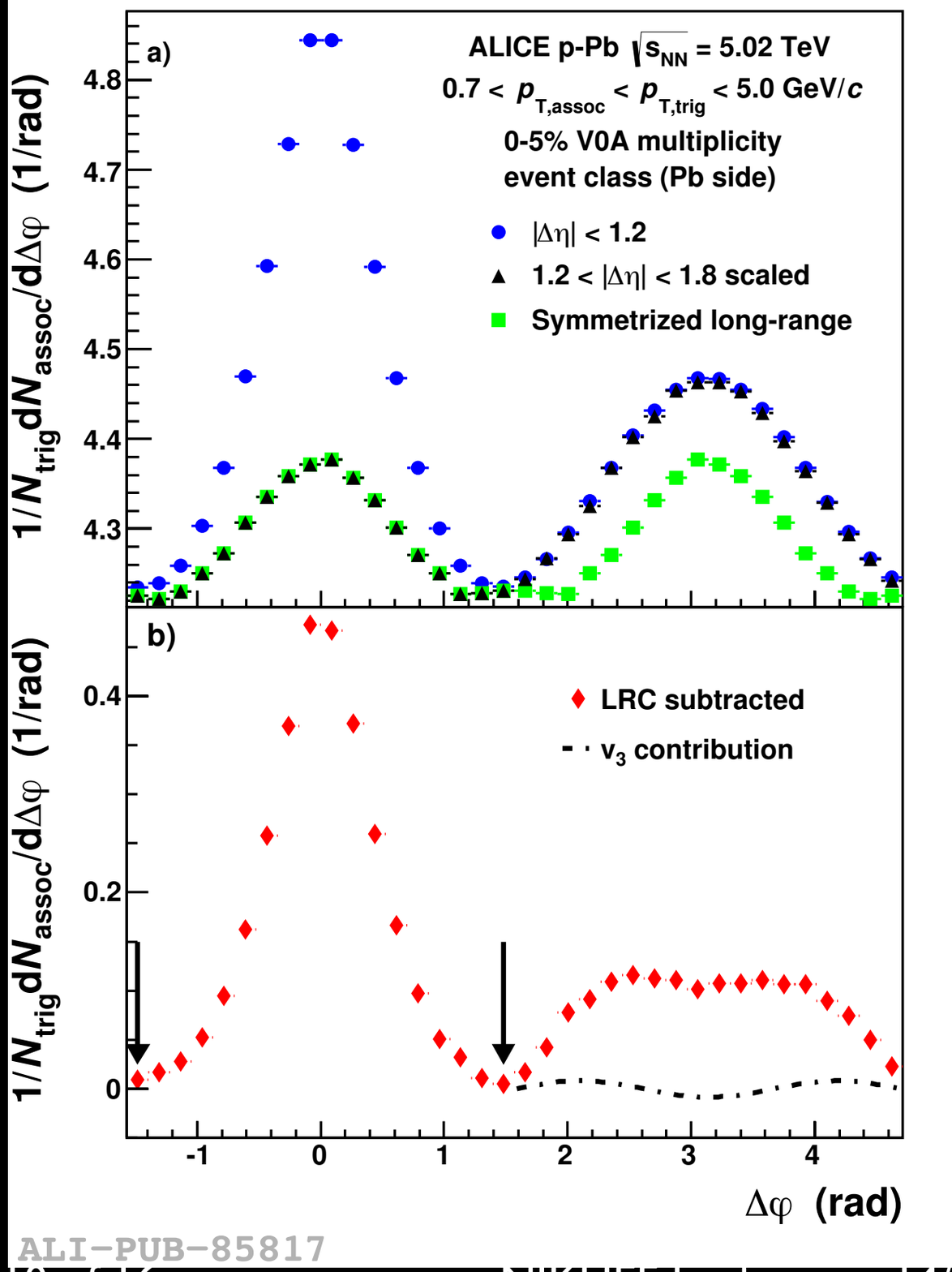




[Phys. Lett. B 741 (2015) 38-50]

Minijet correlations above the ridge

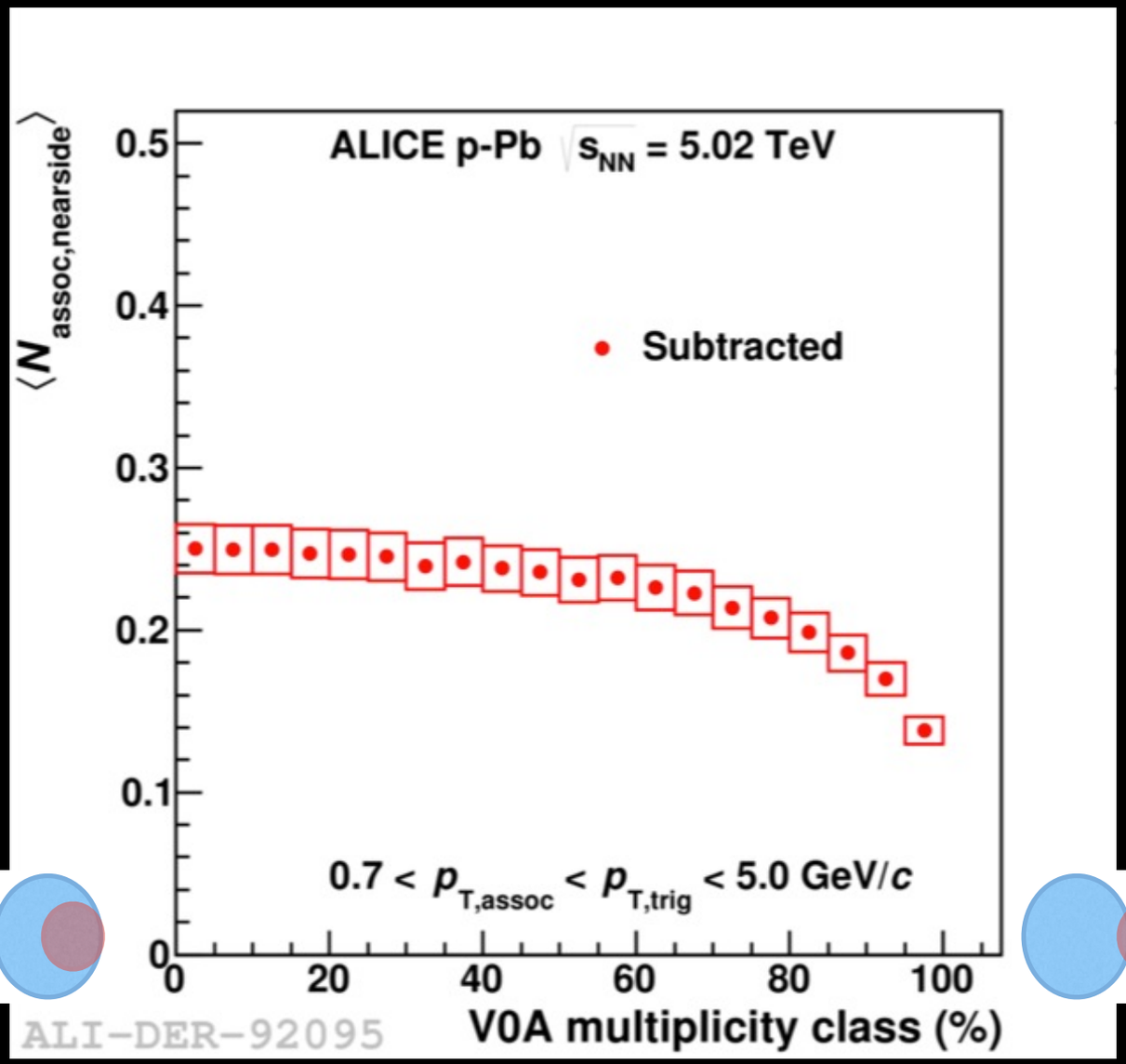




RESULTS

[Phys. Lett. B 741 (2015) 38-50]

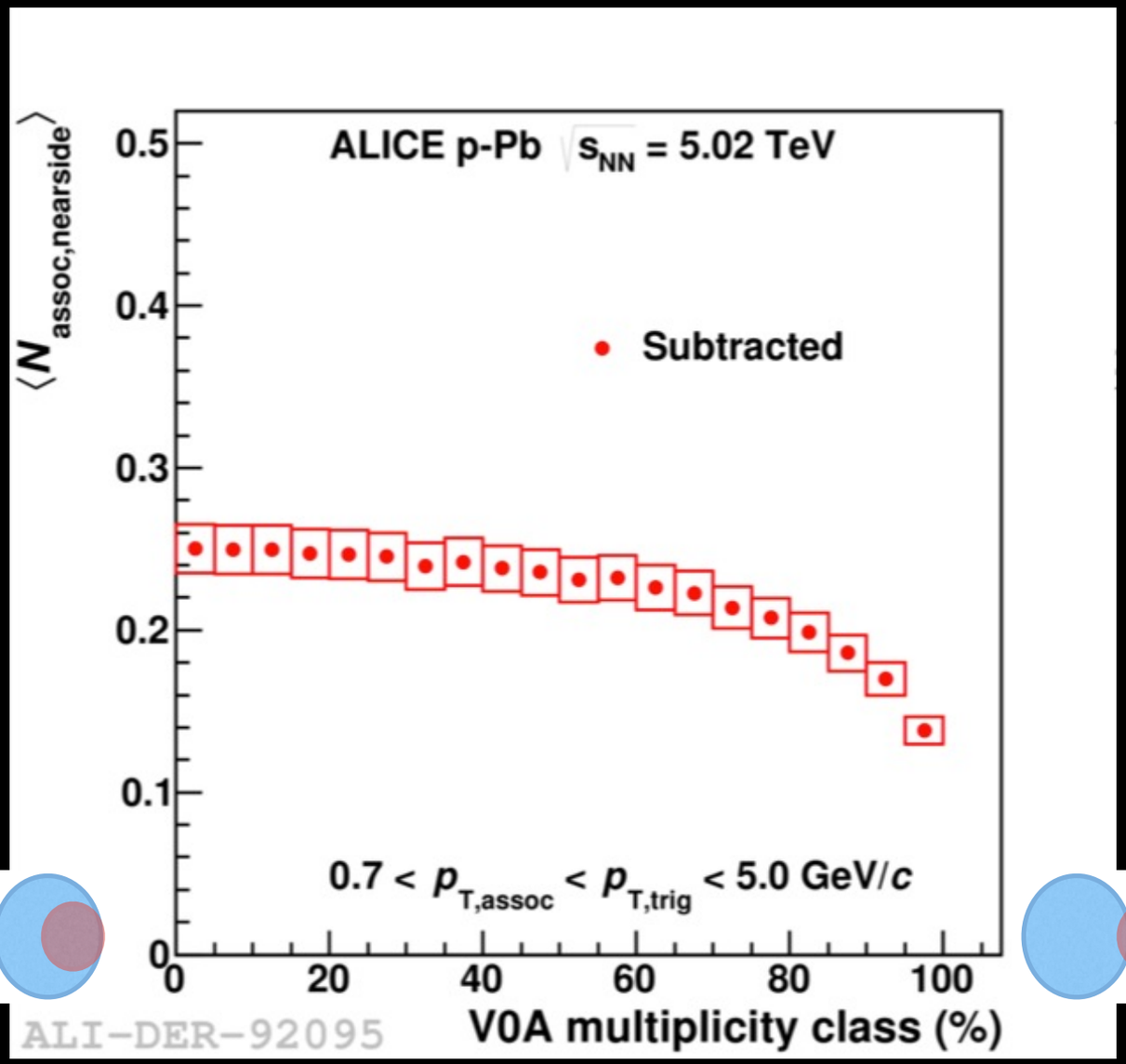
Per-trigger minijet yields vs multiplicity



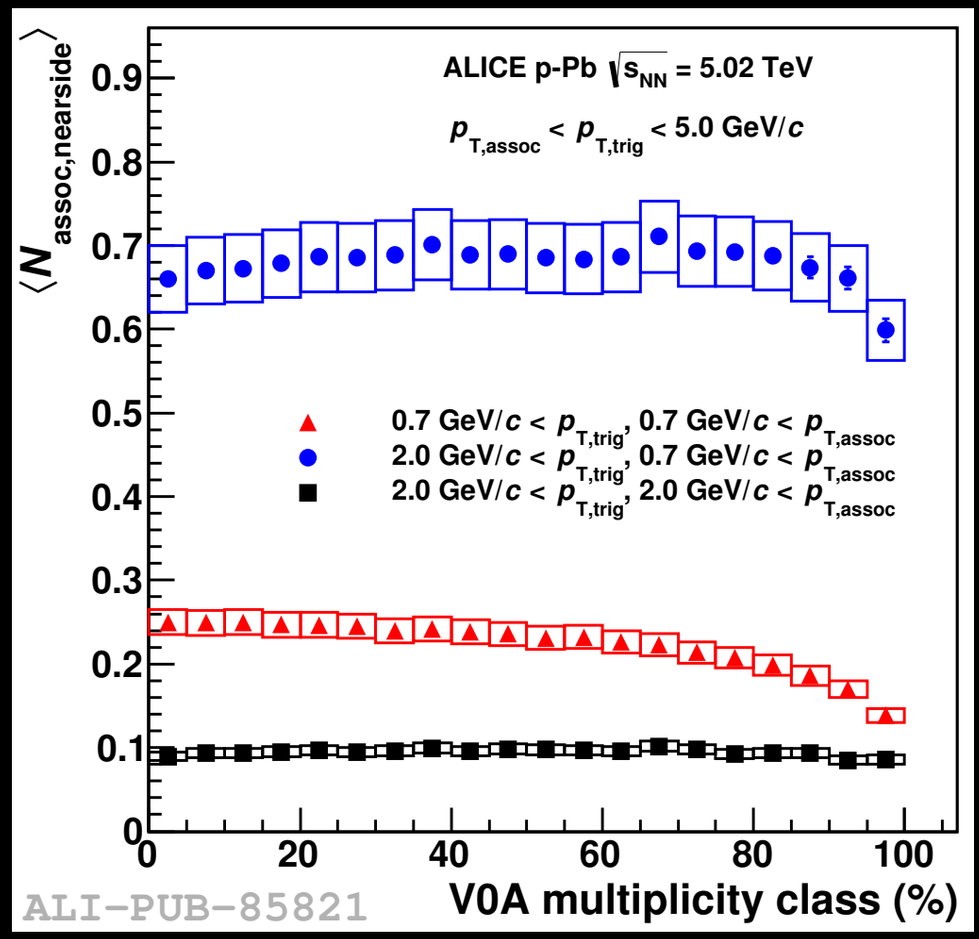
- From intermediate to high multiplicity
  - associated and trigger particles scale with the same factor with multiplicity

[Phys. Lett. B 741 (2015) 38-50]

Per-trigger minijet yields vs multiplicity

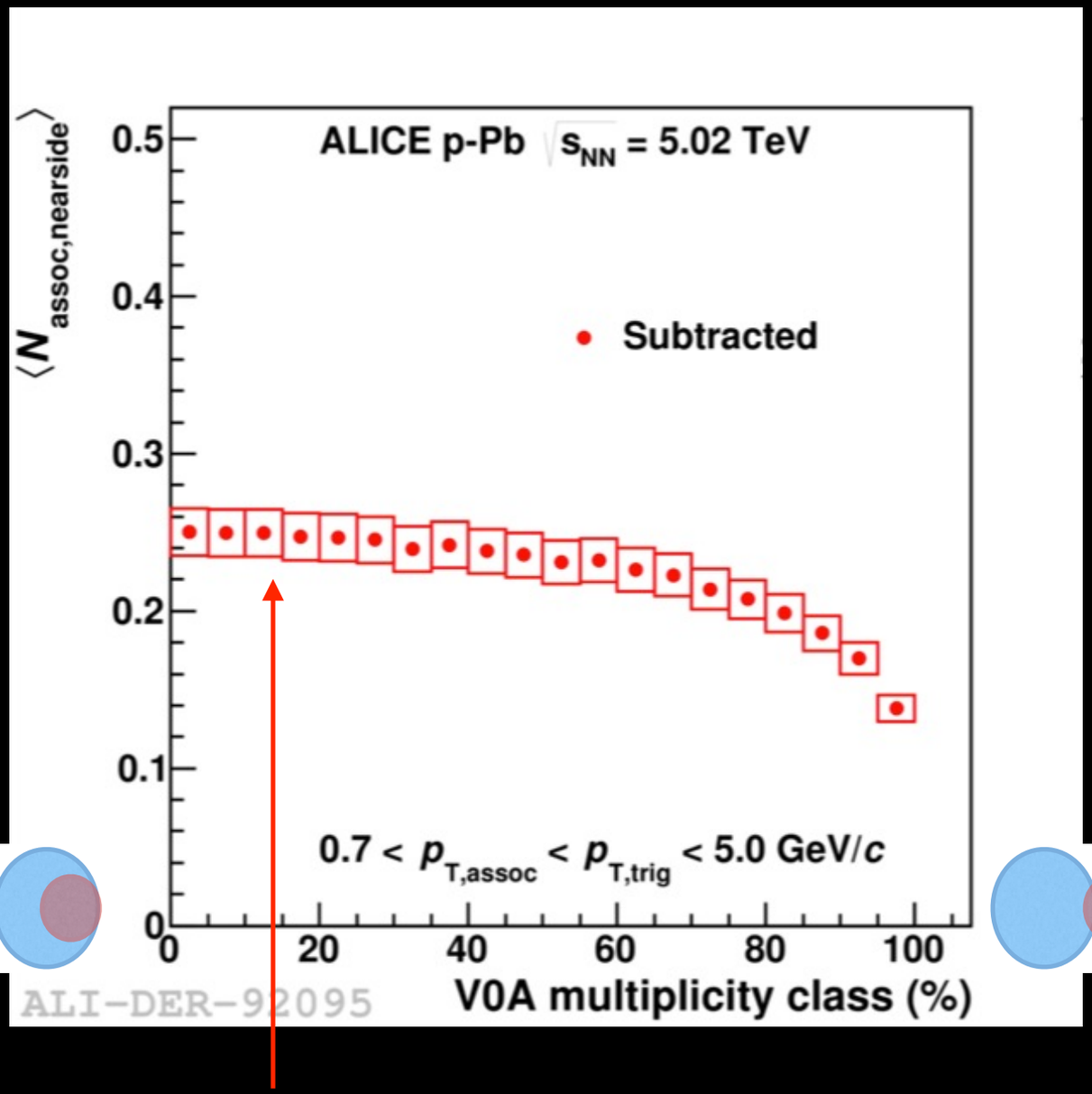


- From intermediate to high multiplicity
  - associated and trigger particles scale with the same factor with multiplicity

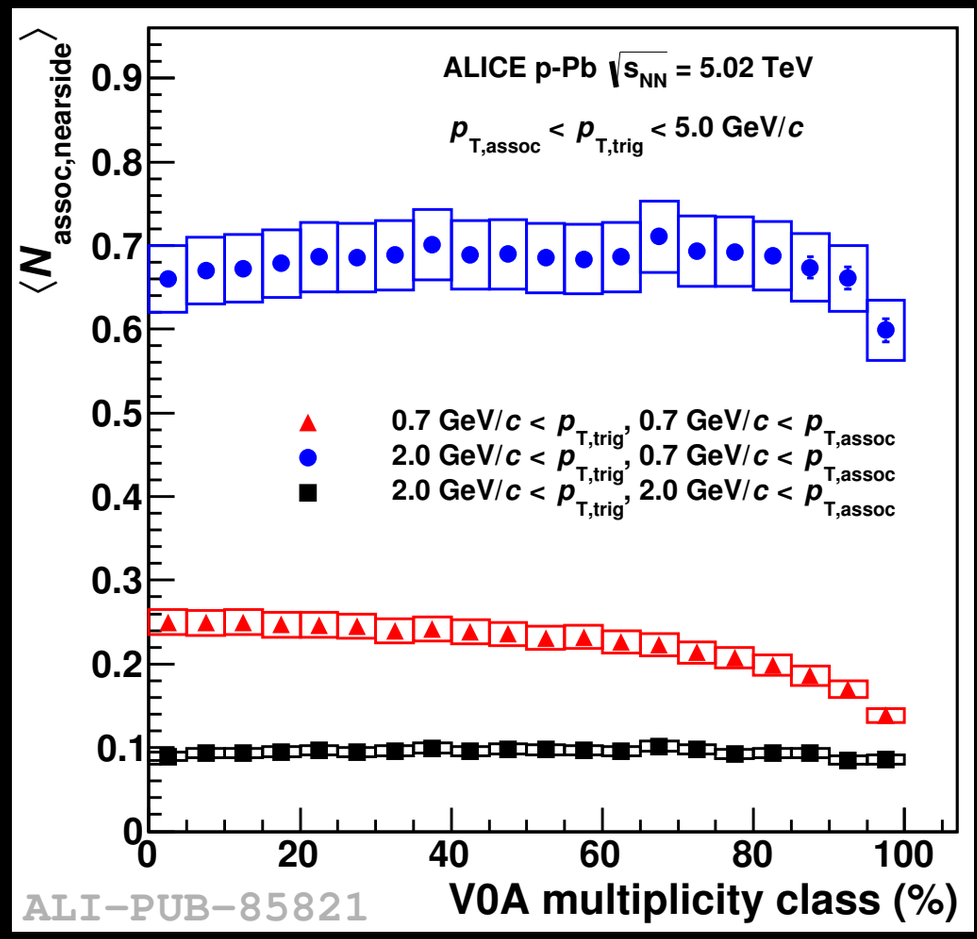


[Phys. Lett. B 741 (2015) 38-50]

Per-trigger minijet yields vs multiplicity



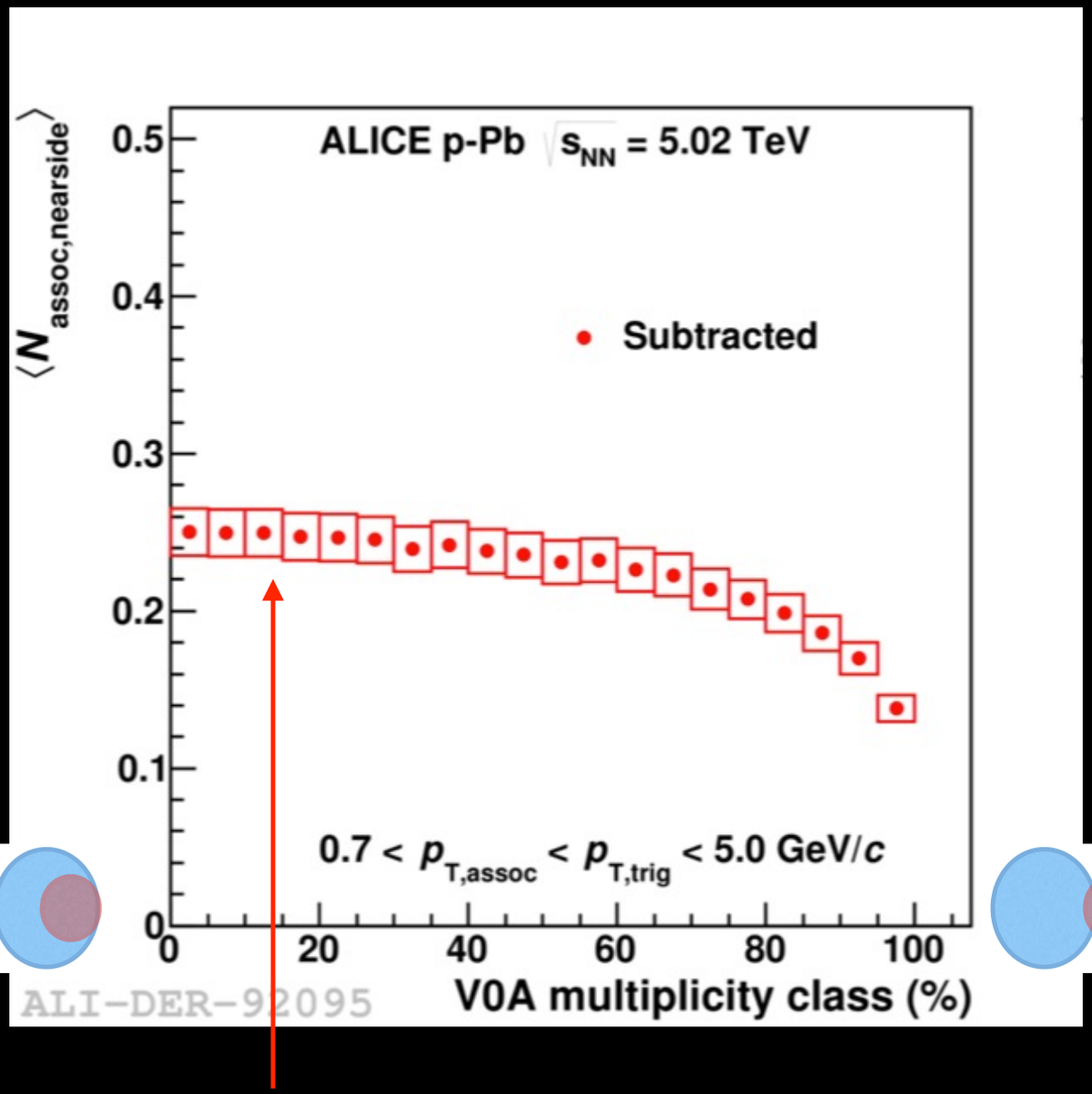
- From intermediate to high multiplicity
  - associated and trigger particles scale with the same factor with multiplicity



- high multiplicity p-Pb jet-like events are not build up by more populated jets, but rather by a higher number of jets (i.e. parton-parton scatterings)

[Phys. Lett. B 741 (2015) 38-50]

Per-trigger minijet yields vs multiplicity

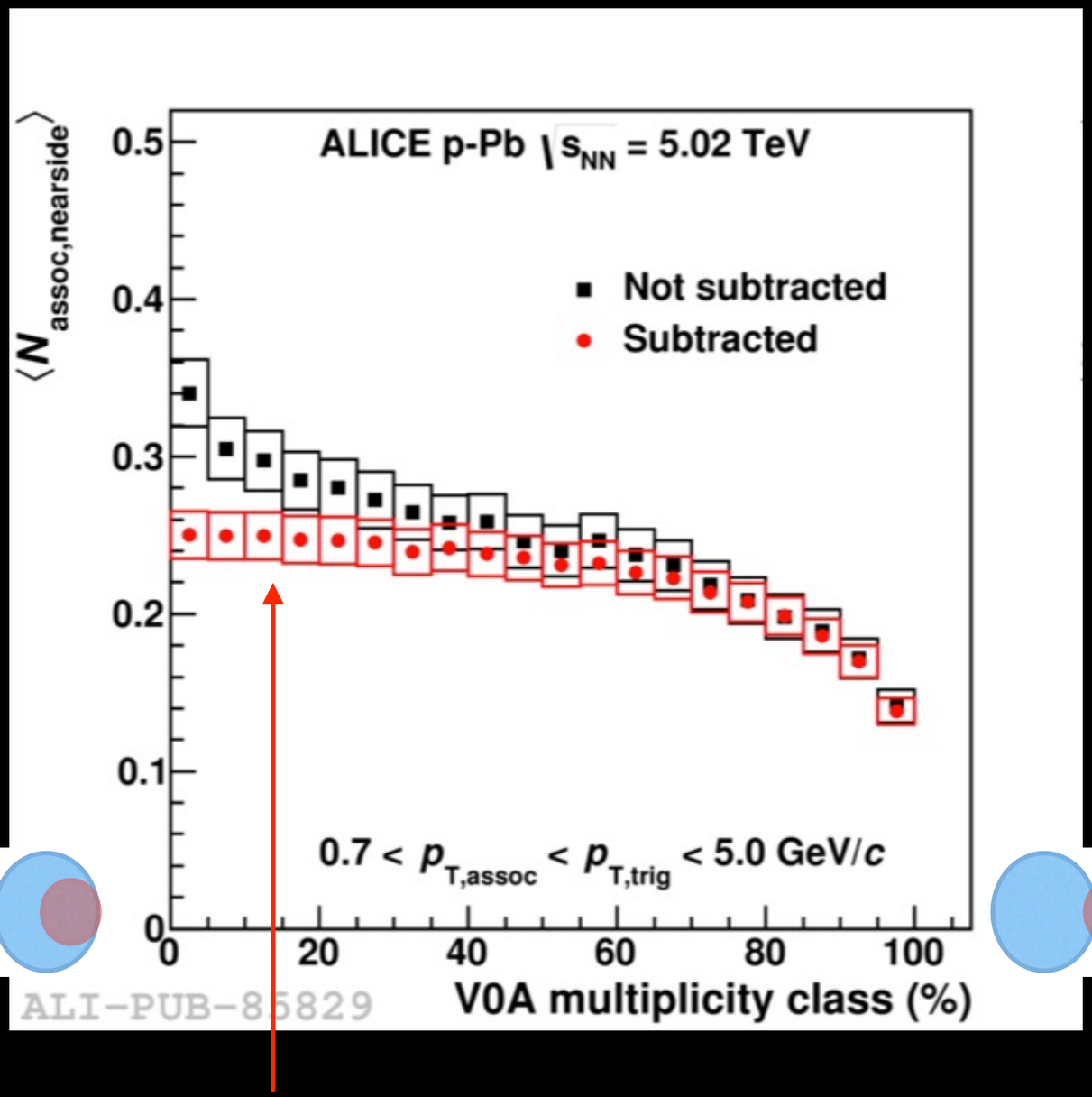


- From intermediate to high multiplicity
  - associated / triggers scale with the same factor with multiplicity

- high multiplicity p-Pb jet-like events are not build up by more populated jets, but rather by a higher number of jets (i.e. parton-parton scatterings)

[Phys. Lett. B 741 (2015) 38-50]

Per-trigger minijet yields vs multiplicity



- From intermediate to high multiplicity
  - associated / triggers scale with the same factor with multiplicity

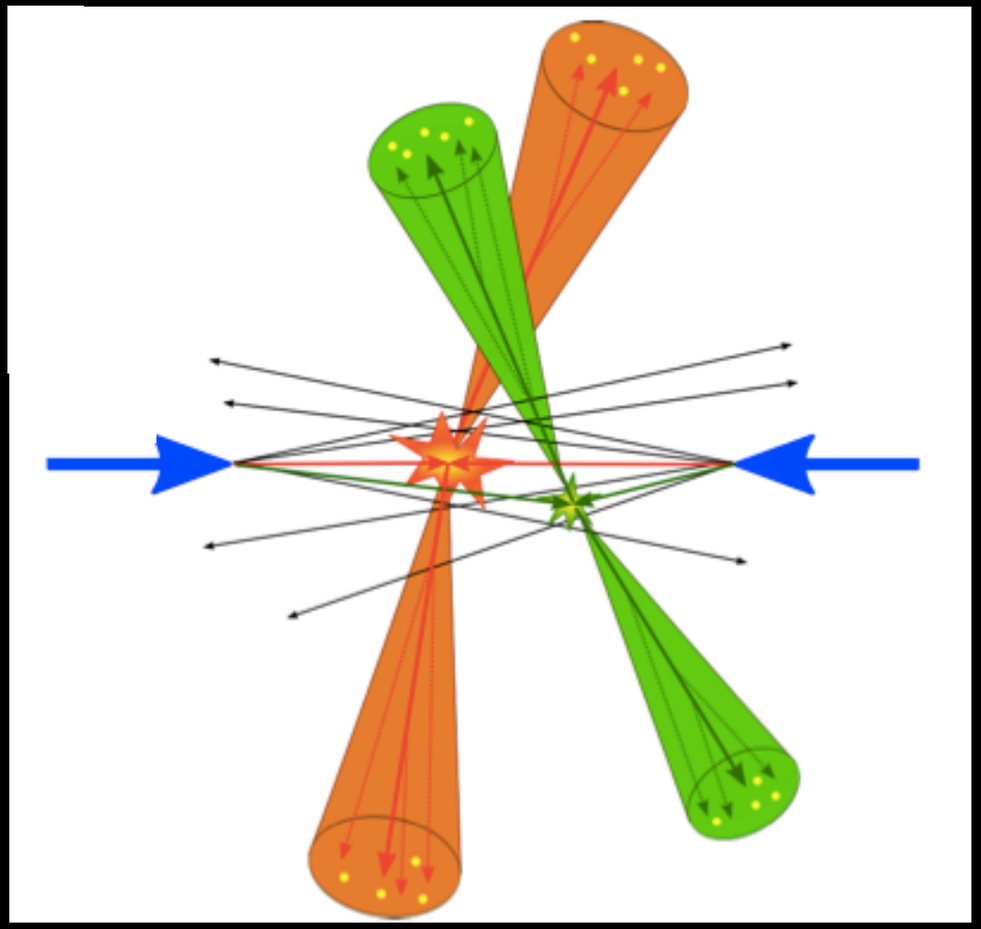
- Scaling observed only if ridge is subtracted
  - collective-like and jet-like yields arise from different physical phenomena and are additive

- high multiplicity p-Pb jet-like events are not build up by more populated jets, but rather by a higher number of jets (i.e. parton-parton scatterings)

[Phys. Lett. B 741 (2015) 38-50]

Uncorrelated parton-parton scatterings

When p_T-range for trigger and associated particles is the same, each trigger comes with $N_{assoc,NS+AS}$ => correlated triggers = trigger + assoc,NS + assoc,AS

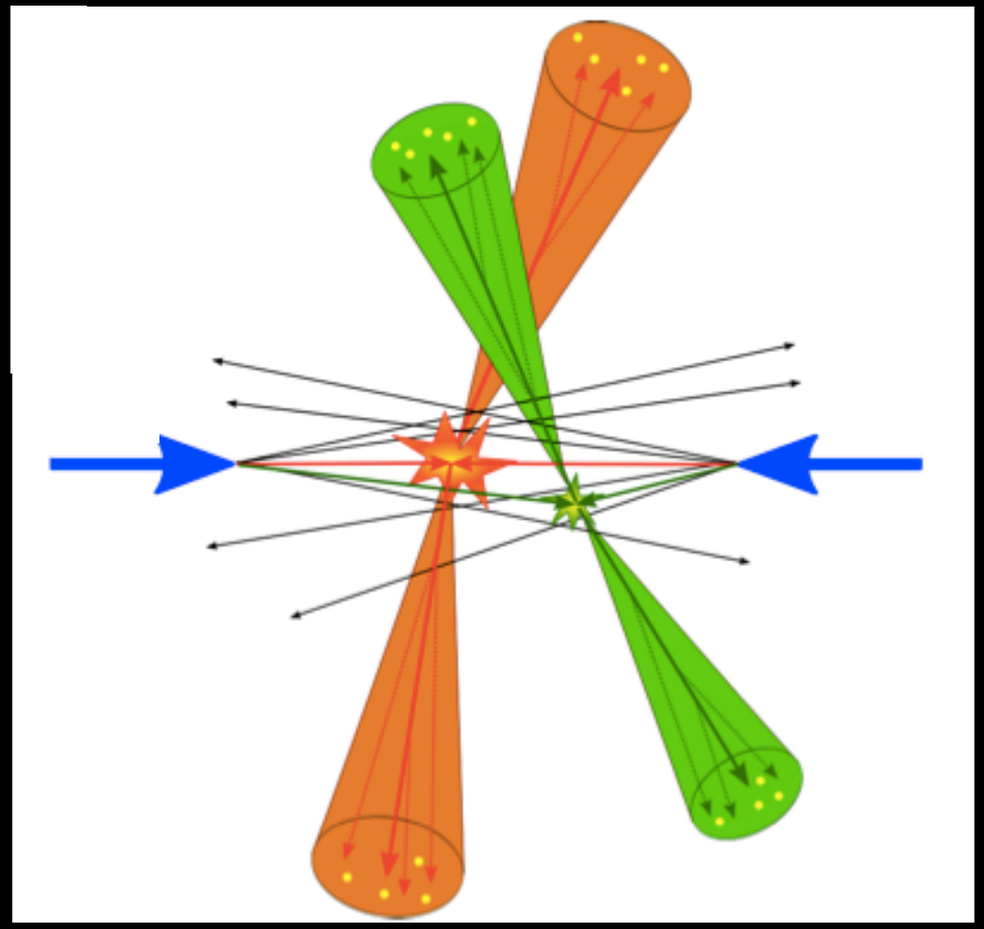


[Phys. Lett. B 741 (2015) 38-50]

Uncorrelated parton-parton scatterings

When p_T-range for trigger and associated particles is the same, each trigger comes with $N_{assoc,NS+AS}$ => correlated triggers = trigger + assoc,NS + assoc,AS

$$\frac{\langle N_{\rm triggers}\rangle}{\langle N_{\rm correlated\ \ triggers}\rangle} = \frac{\langle N_{\rm triggers}\rangle}{1+\langle N_{\rm assoc,near-side}\rangle+\langle N_{\rm assoc,away-side}\rangle} = \langle N_{\rm uncorrelated\ \ seeds}\rangle$$

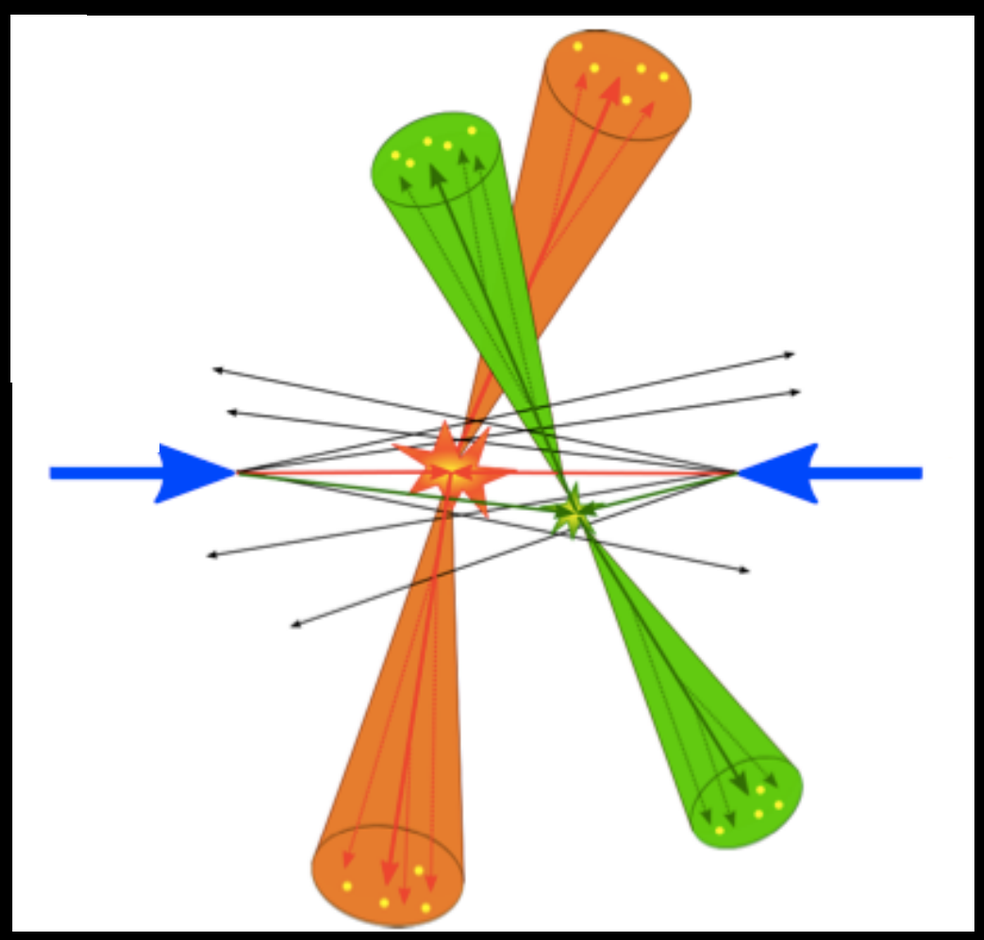


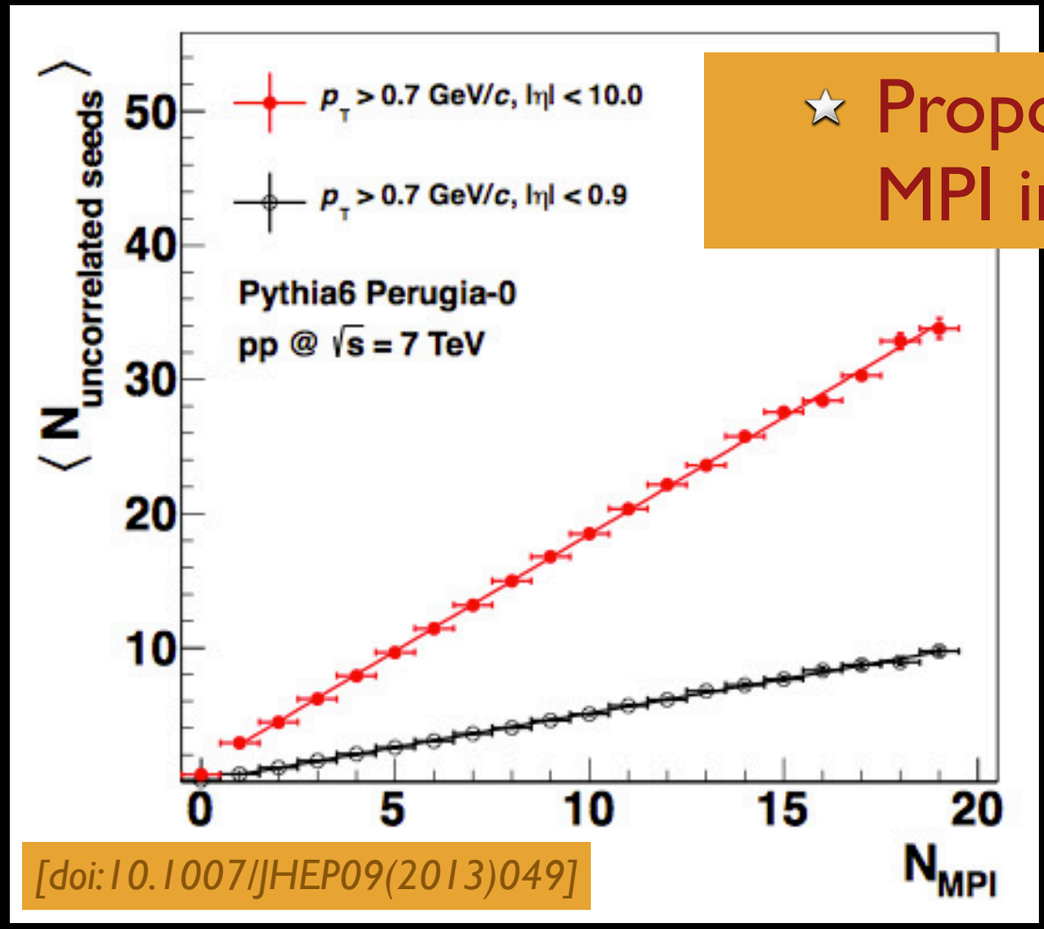
[Phys. Lett. B 741 (2015) 38-50]

Uncorrelated parton-parton scatterings

When p_T-range for trigger and associated particles is the same, each trigger comes with $N_{assoc,NS+AS}$ => correlated triggers = trigger + assoc,NS + assoc,AS

$$\frac{\langle N_{\text{triggers}}\rangle}{\langle N_{\text{correlated triggers}}\rangle} = \frac{\langle N_{\text{triggers}}\rangle}{1+\langle N_{\text{assoc,near-side}}\rangle+\langle N_{\text{assoc,away-side}}\rangle} = \langle N_{\text{uncorrelated seeds}}\rangle$$



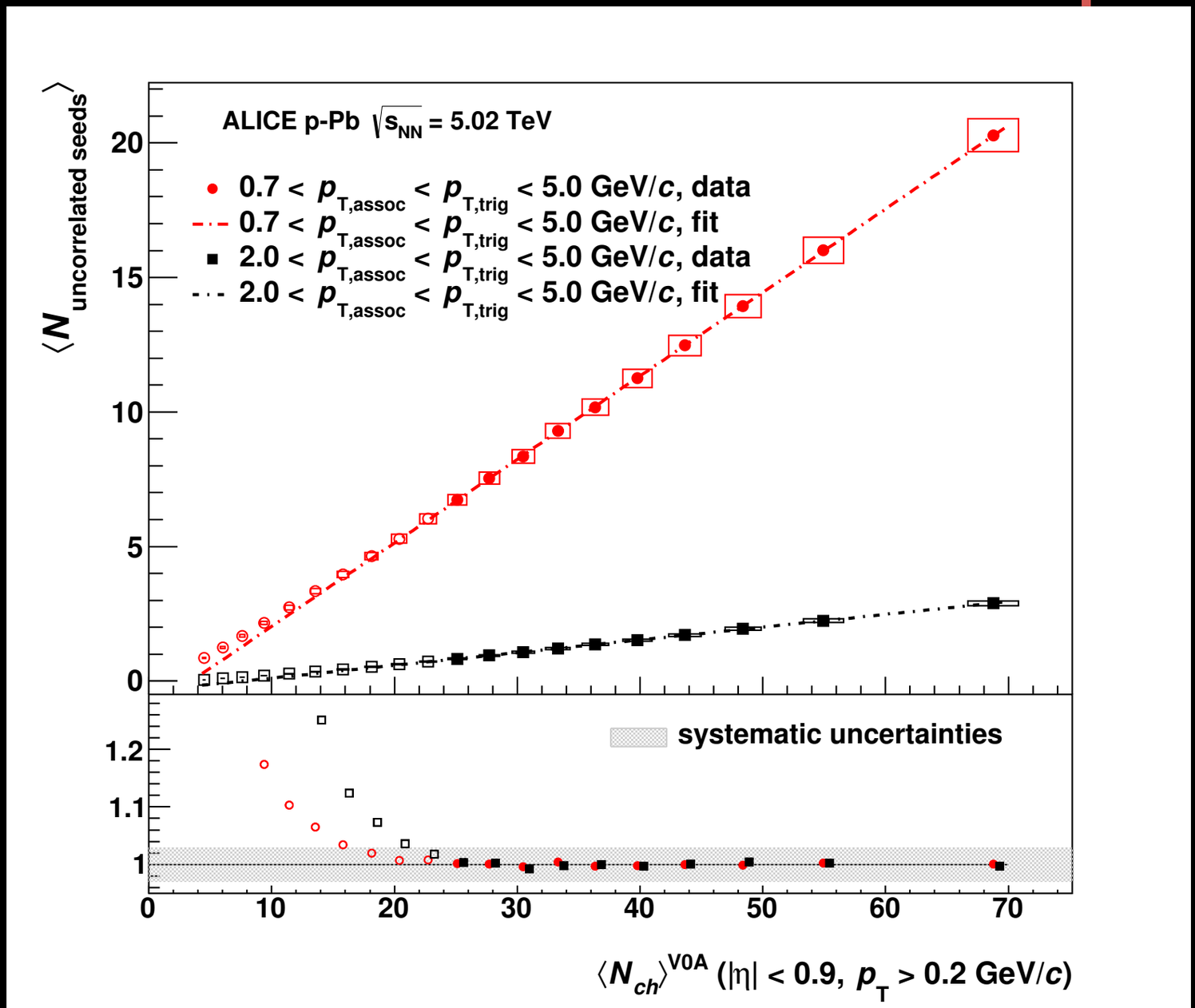


★ Proportional to MPI in PYTHIA

[doi:10.1007/JHEP09(2013)049]

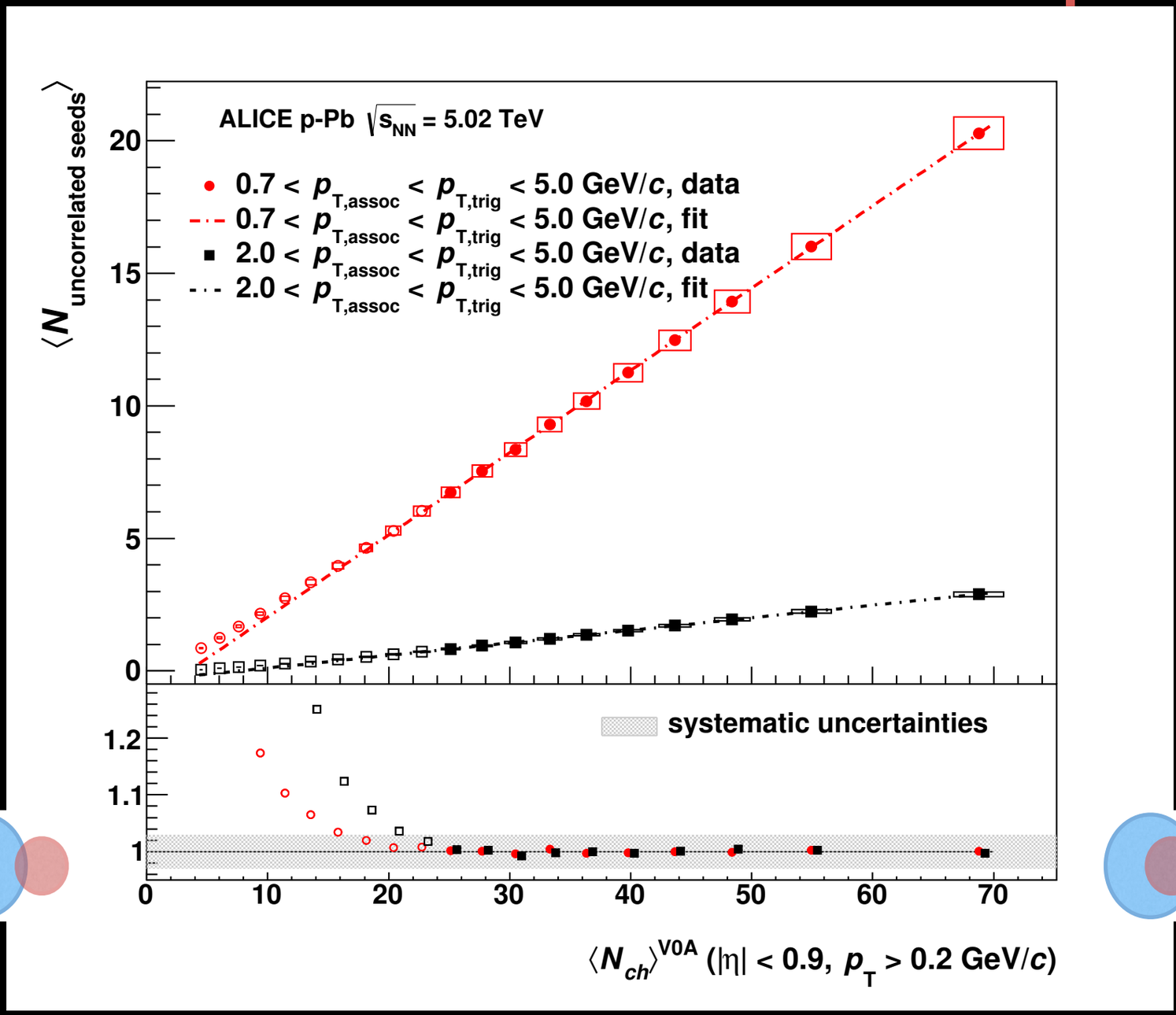
[Phys. Lett. B 741 (2015) 38-50]

Uncorrelated seeds vs multiplicity



[Phys. Lett. B 741 (2015) 38-50]

Uncorrelated seeds vs multiplicity



- ★ high multiplicity: MPI increase linearly with multiplicity
  - ★ dominate the particle production mechanism at high multiplicity
- ★ low multiplicity: change in dynamics

Physics Letters B 741 (2015) 38–50

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Multiplicity dependence of jet-like two-particle correlation structures in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

ALICE Collaboration *

ARTICLE INFO

Article history:
Received 23 June 2014
Received in revised form 8 October 2014
Accepted 15 November 2014

ABSTRACT

Two-particle angular correlations between unidentified charged trigger and associated particles are measured by the ALICE detector in p–Pb collisions at a nucleon–nucleon centre-of-mass energy of 5.02 TeV. The transverse-momentum range $0.7 < p_{T,assoc} < p_{T,trig} < 5.0$ GeV/c is examined, to

- Two-particle correlations allow to measure the number of MPI in the low-p_T region by studying the minijet fragmentation

Physics Letters B 741 (2015) 38–50

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Multiplicity dependence of jet-like two-particle correlation structures in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

ALICE Collaboration *

ARTICLE INFO

Article history:
Received 23 June 2014
Received in revised form 8 October 2014
Accepted 15 November 2014

ABSTRACT

Two-particle angular correlations between unidentified charged trigger and associated particles are measured by the ALICE detector in p–Pb collisions at a nucleon–nucleon centre-of-mass energy of 5.02 TeV. The transverse-momentum range $0.7 < p_{T,assoc} < p_{T,trig} < 5.0$ GeV/c is examined, to

- **Two-particle correlations allow to measure the number of MPI in the low-p_T region by studying the minijet fragmentation**

- minijet fragmentation independent of multiplicity
- jet- and collective-like correlations have different physical origin
- uncorrelated sources of particle production
  - first estimate of semi-hard MPI in high multiplicity environments

Physics Letters B 741 (2015) 38–50

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Multiplicity dependence of jet-like two-particle correlation structures in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

ALICE Collaboration *

ARTICLE INFO

Article history:
Received 23 June 2014
Received in revised form 8 October 2014
Accepted 15 November 2014

ABSTRACT

Two-particle angular correlations between unidentified charged trigger and associated particles are measured by the ALICE detector in p–Pb collisions at a nucleon–nucleon centre-of-mass energy of 5.02 TeV. The transverse-momentum range $0.7 < p_{T,assoc} < p_{T,trig} < 5.0$ GeV/c is examined, to

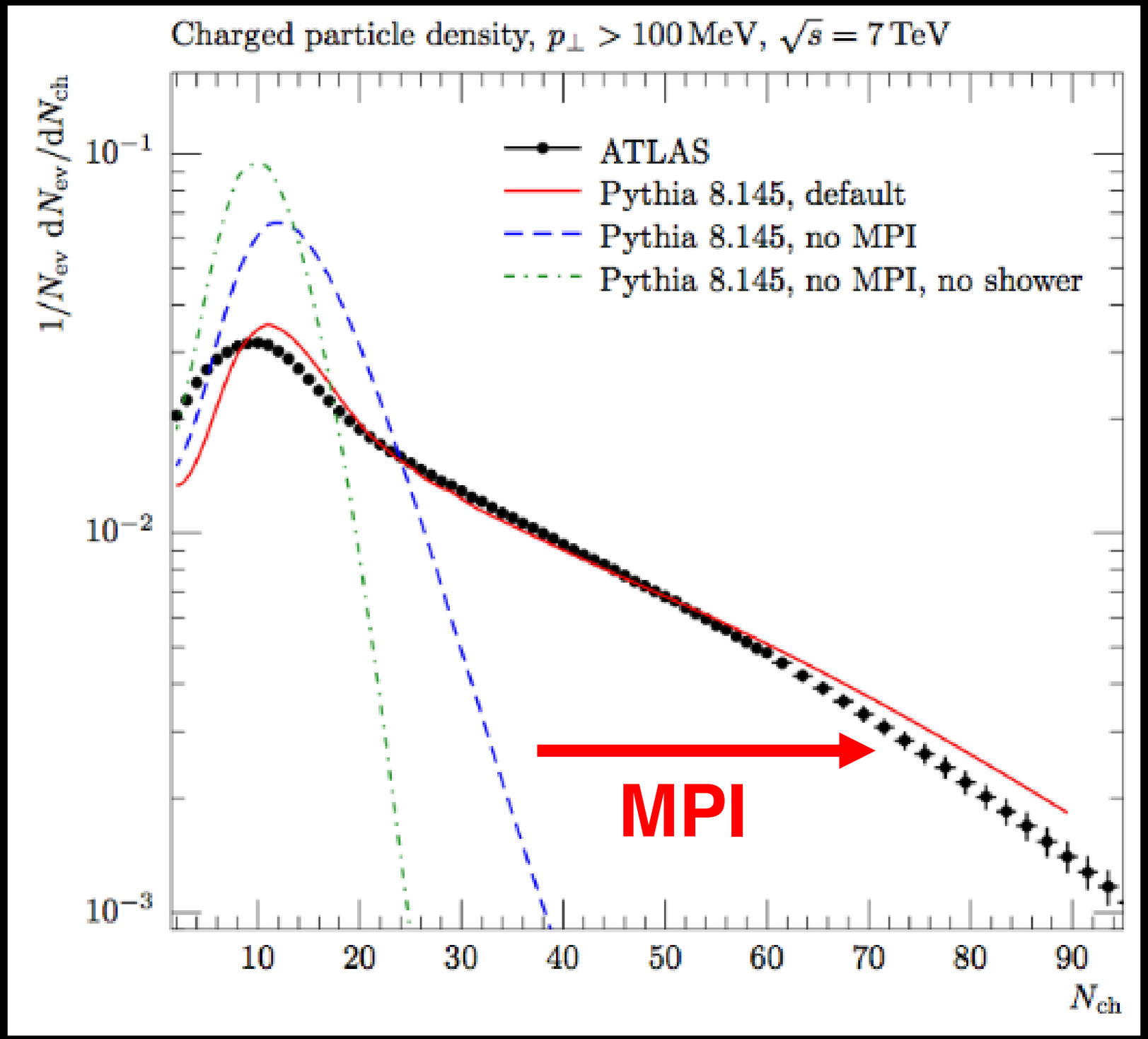
- **Two-particle correlations allow to measure the number of MPI in the low-p_T region by studying the minijet fragmentation**

- minijet fragmentation independent of multiplicity
- jet- and collective-like correlations have different physical origin
- uncorrelated sources of particle production
  - first estimate of semi-hard MPI in high multiplicity environments

Thank you for your attention

Back up

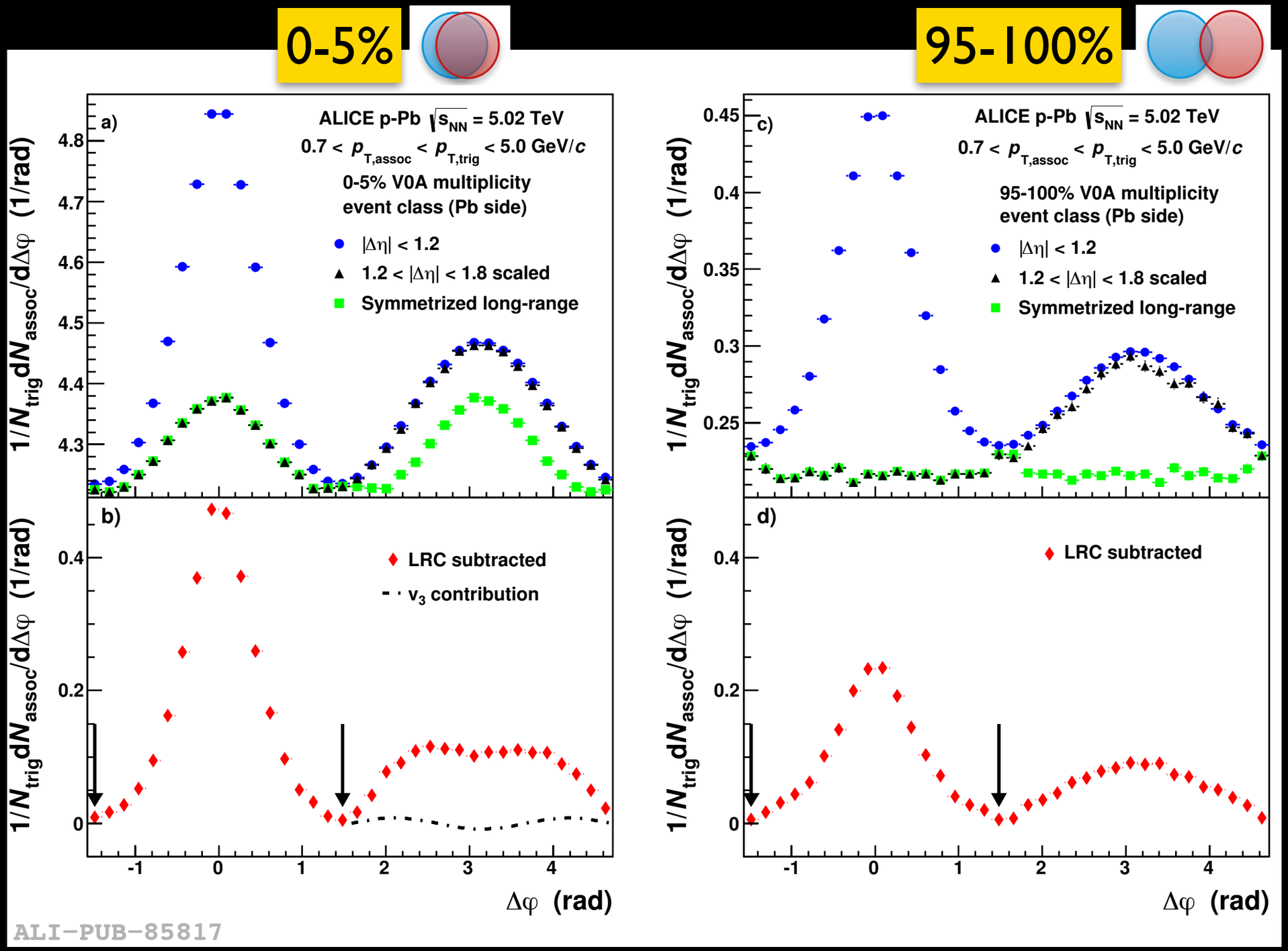
MPI


Charged particle density, $p_\perp > 100\,\mathrm{MeV}$, $\sqrt{s} = 7\,\mathrm{TeV}$
$1/N_{\mathrm{ev}}\ \mathrm{d}N_{\mathrm{ev}}/\mathrm{d}N_{\mathrm{ch}}$
10^{-1}
10^{-2}
10^{-3}
ATLAS
Pythia 8.145, default
Pythia 8.145, no MPI
Pythia 8.145, no MPI, no shower
MPI
10
20
30
40
50
60
70
80
90
N_{ch}

[Phys. Lett. B 741 (2015) 38-50]

Minijet correlations above the ridge

- Subtraction of long-range correlation

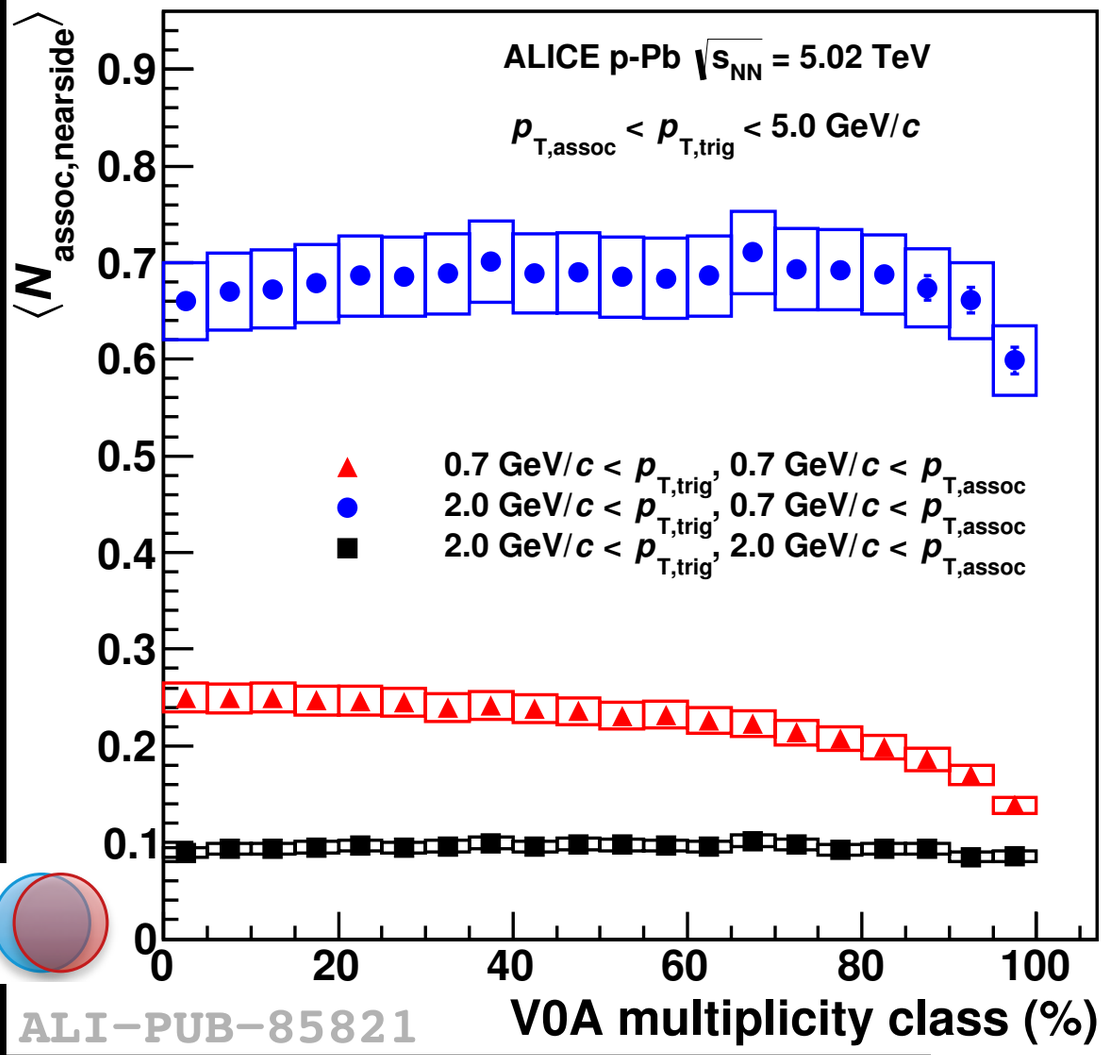


[Phys. Lett. B 741 (2015) 38-50]

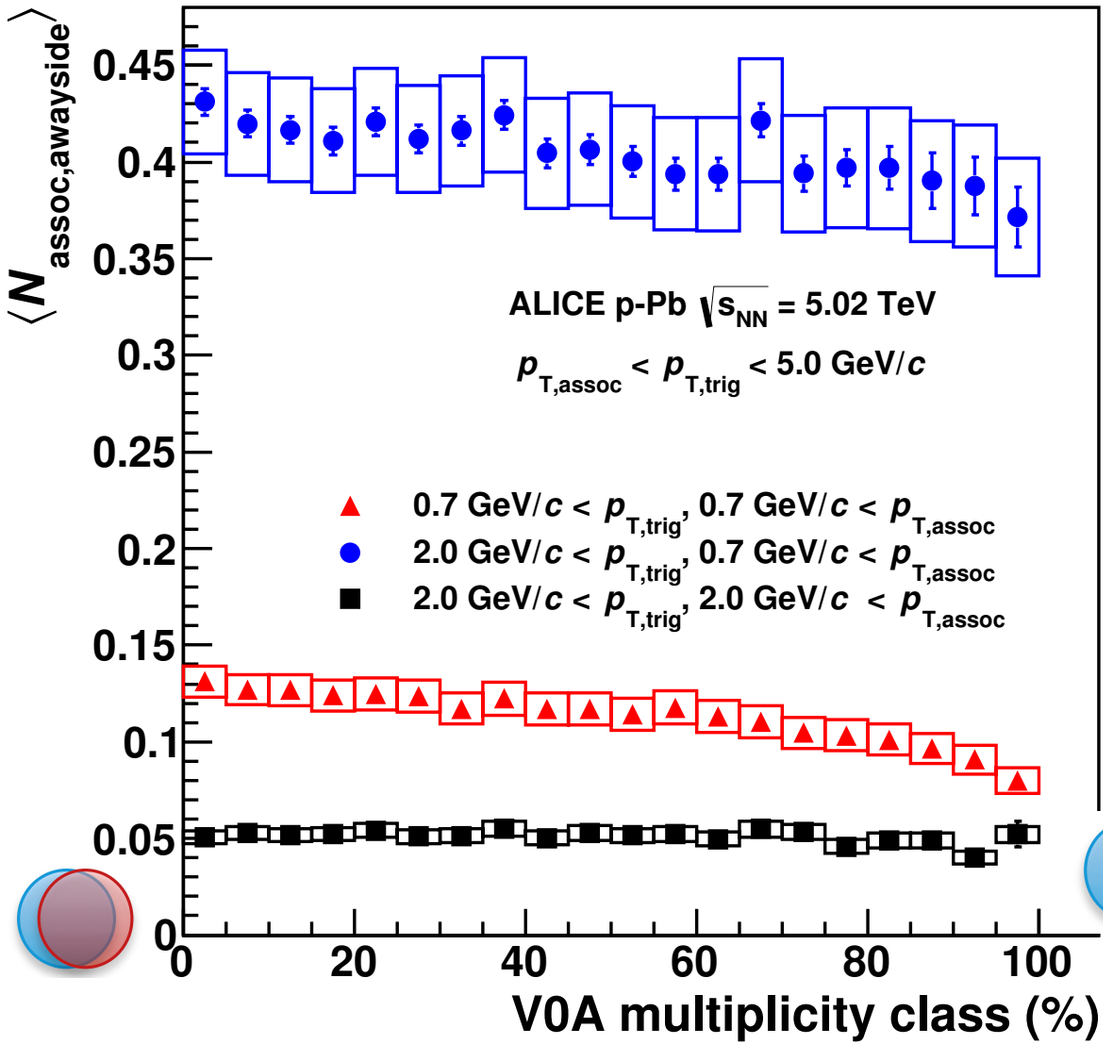
Per-trigger minijet yields vs multiplicity

- ★ Plateau in the near-side (and away-side) per-trigger yields from intermediate to high multiplicity
  - ★ range increases with higher p_T cuts for trigger and associated particles

Near-side



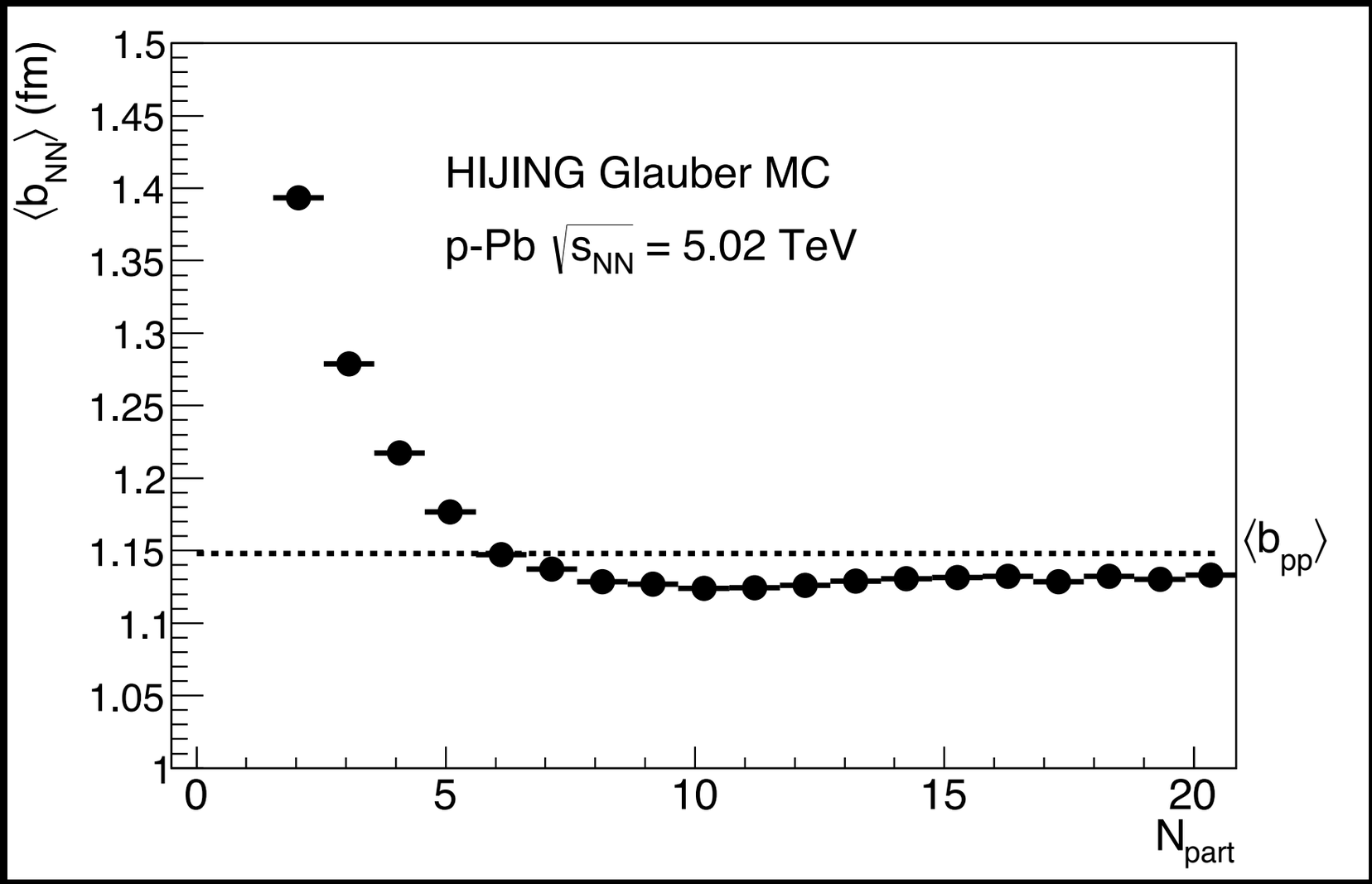
Away-side



[Phys. Lett. B 741 (2015) 38-50]

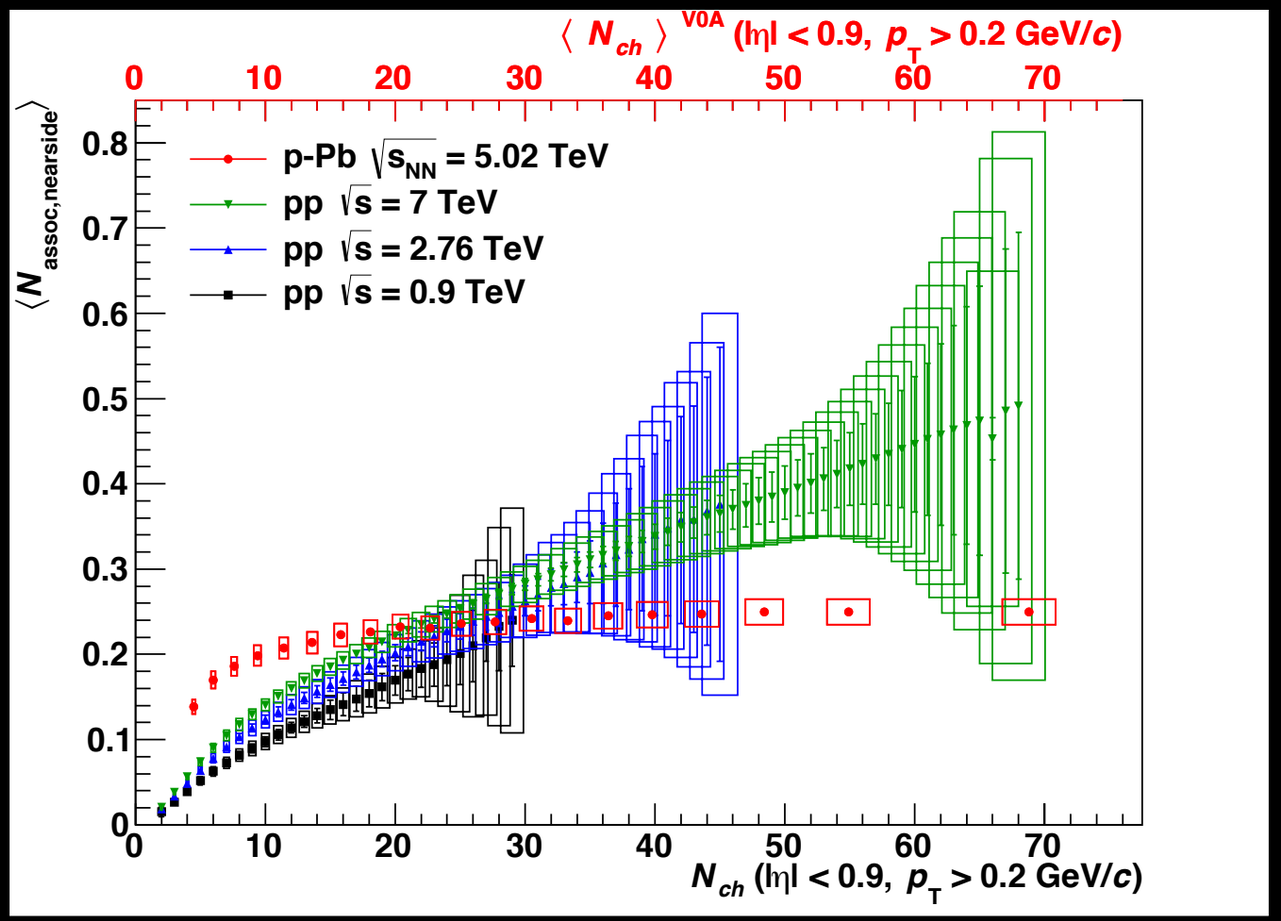
Jet-like correlations above the ridge

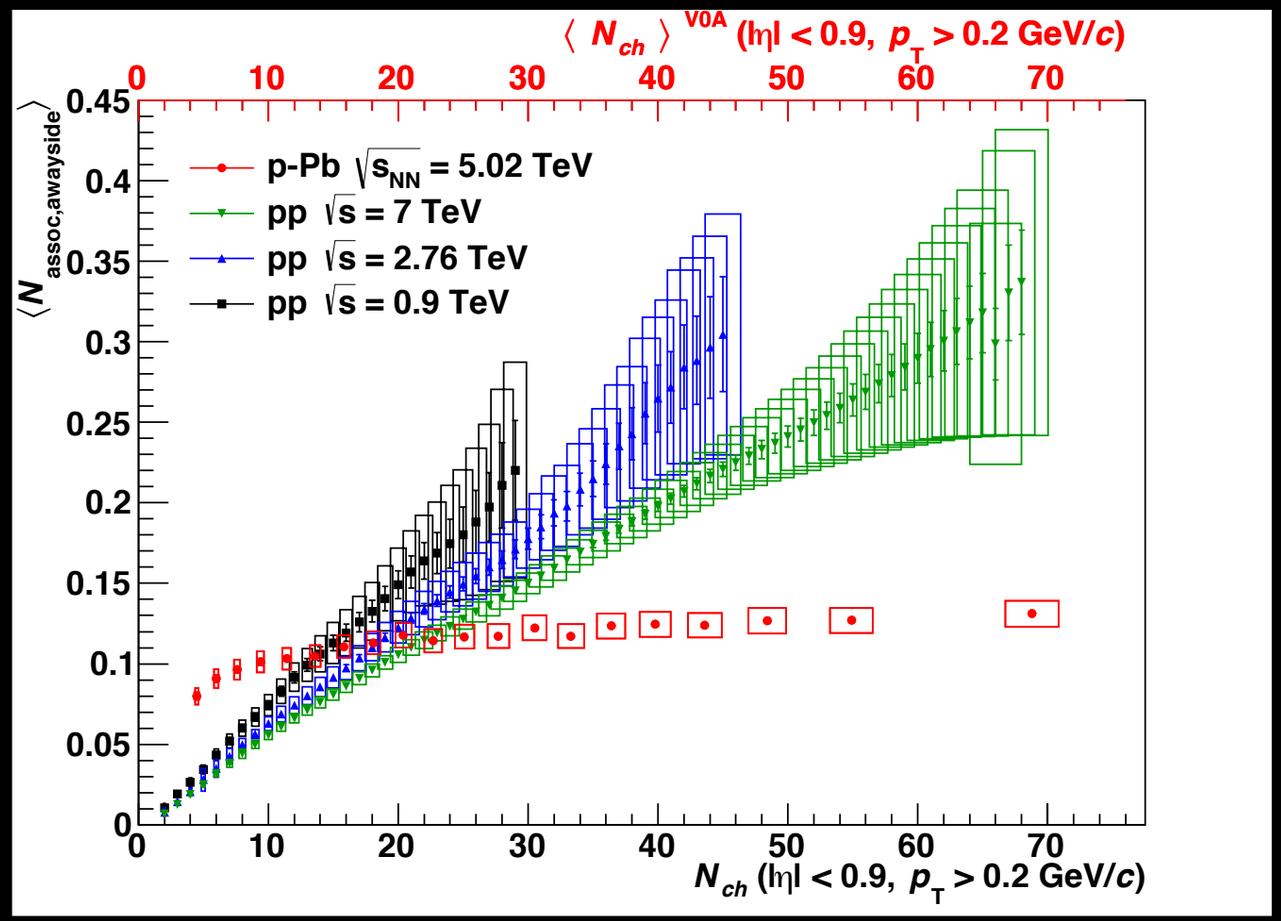
- Mean impact parameter from Glauber
  - decreasing of the average number of MPIs for most peripheral events



[Phys. Lett. B 741 (2015) 38-50]

Per-trigger minijet yields

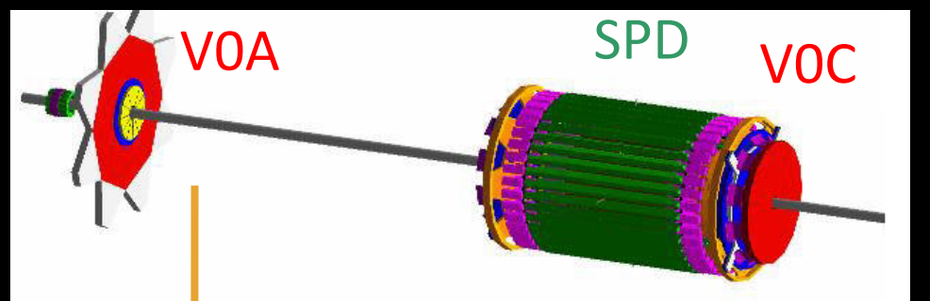




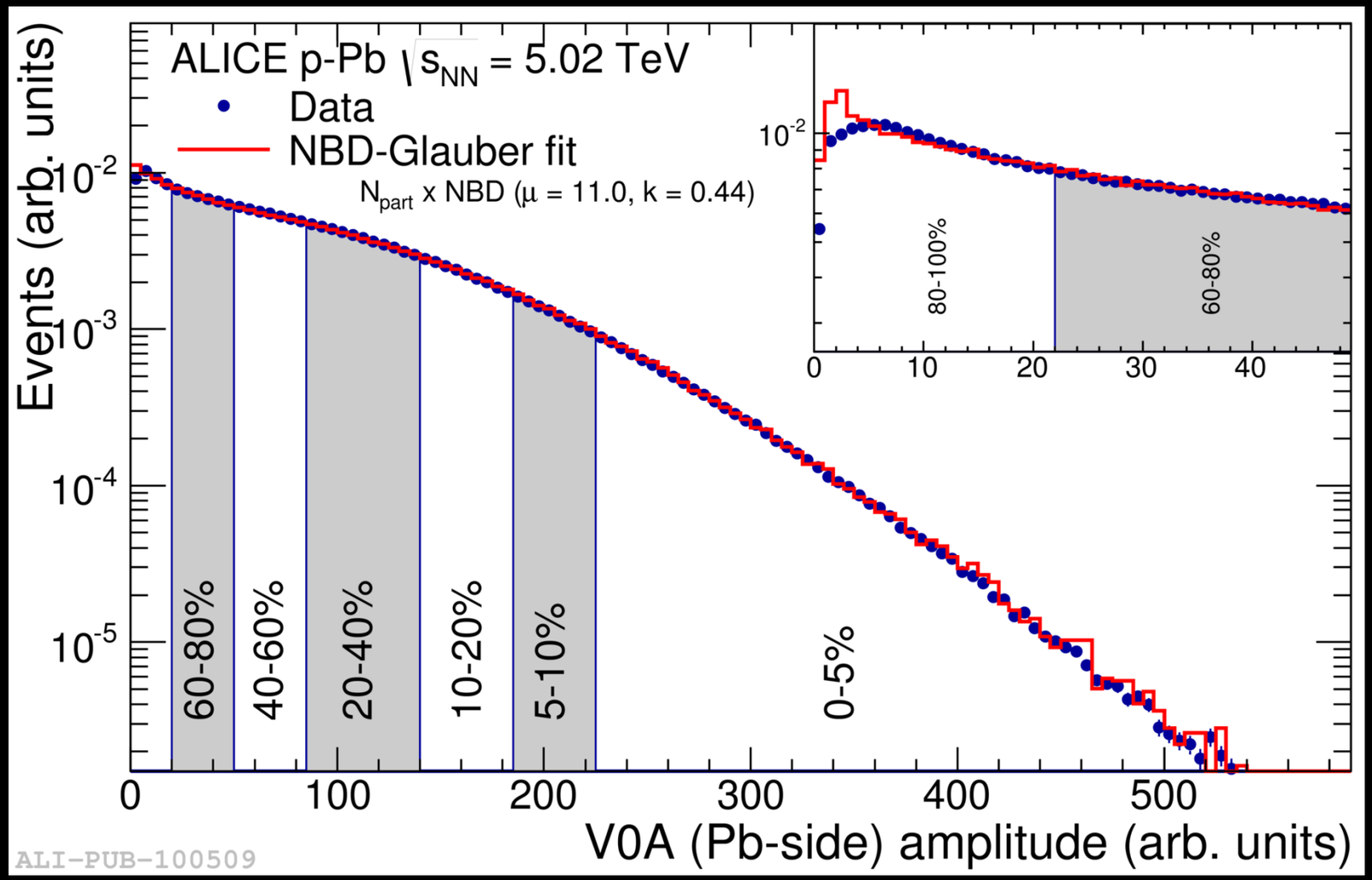
[Phys. Rev. C 91 (2015) 064905]

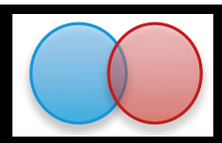
"Centrality" classes for p-Pb collisions

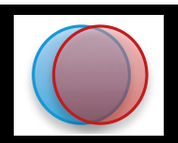
- multiplicity estimator
  - V0A ($2.8 < \eta < 5.1$)
  - V0C ($-3.1 < \eta < -1.7$)



V0A multiplicity sliced in percentiles of cross section





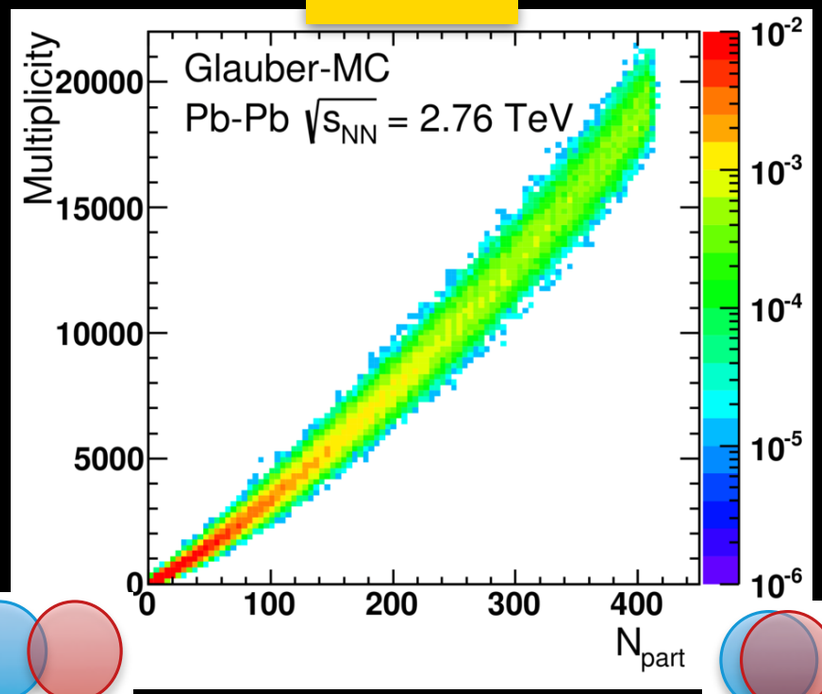


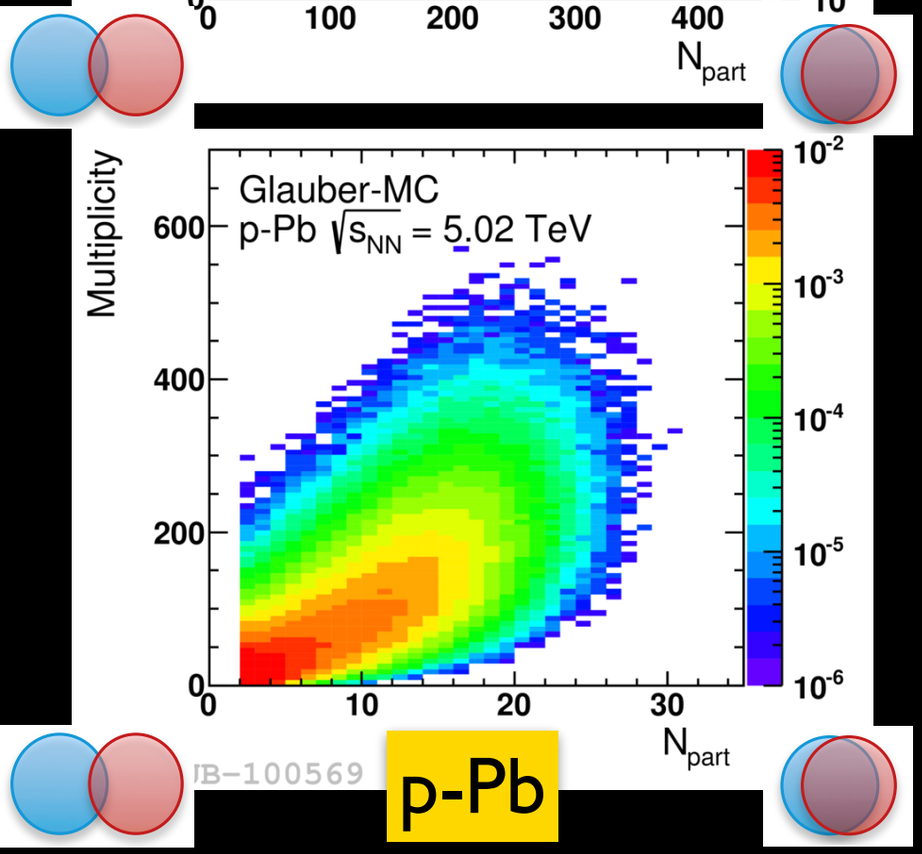
- Alternative classification of events:
  - <Nch> within each V0A percentile class
    - pT > 0.2 GeV/c && | η | < 0.9

[Phys. Rev. C 91 (2015) 064905]

The concept of centrality in p-Pb collisions

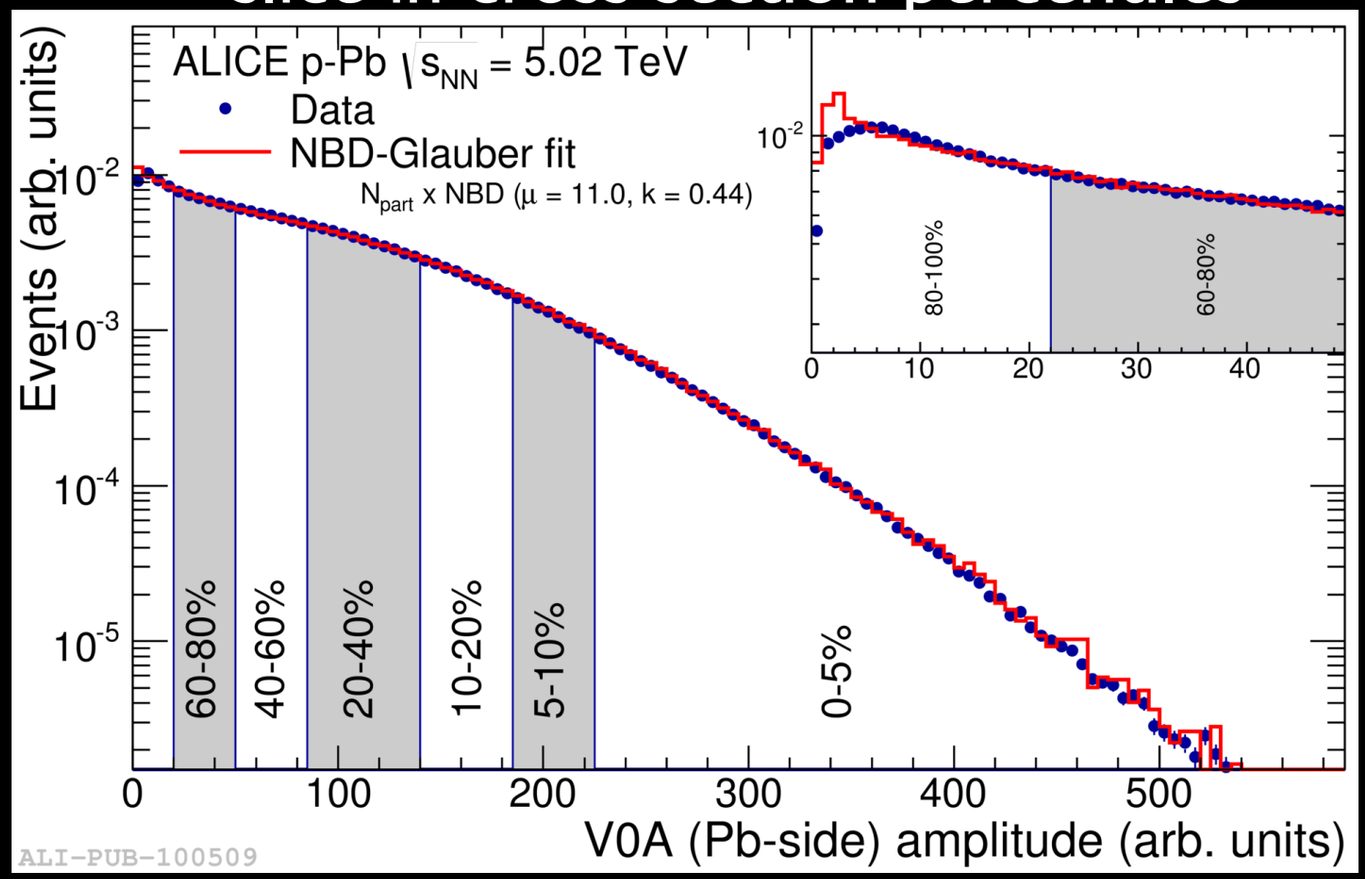
Pb-Pb





p-Pb

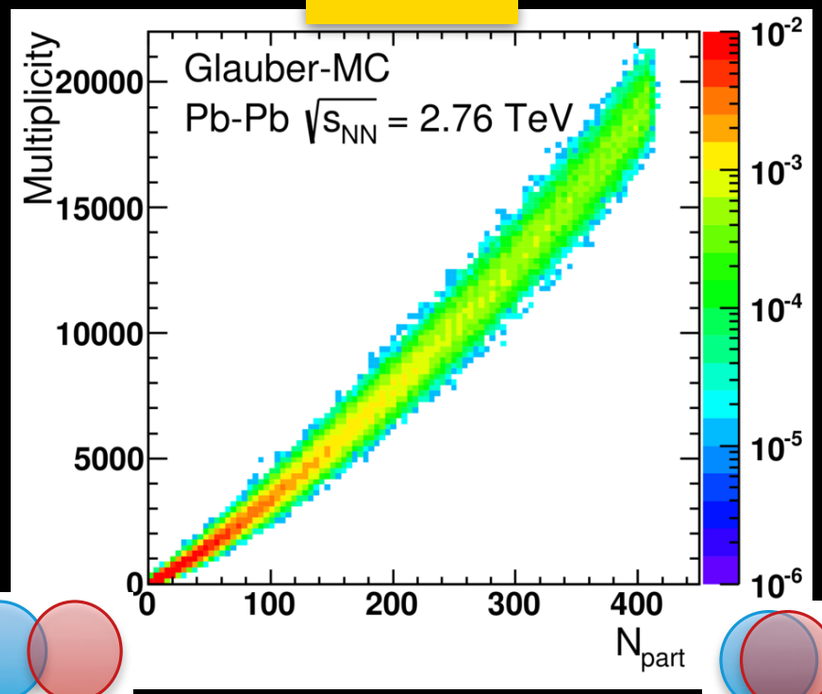
- Glauber MC
  - from impact parameter to N_{part} (N_{coll})
  - experimental observable: multiplicity
  - fit of the multiplicity distribution with a Negative Binomial Distribution
    - slice in cross section percentiles

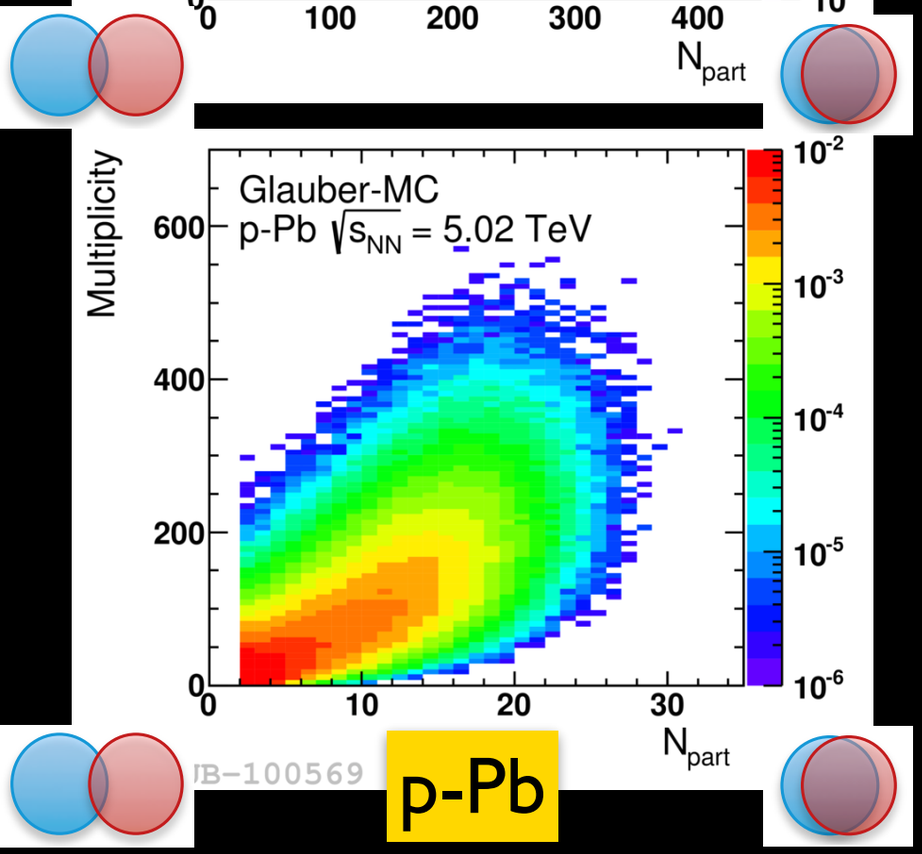


[Phys. Rev. C 91 (2015) 064905]

The concept of centrality in p-Pb collisions

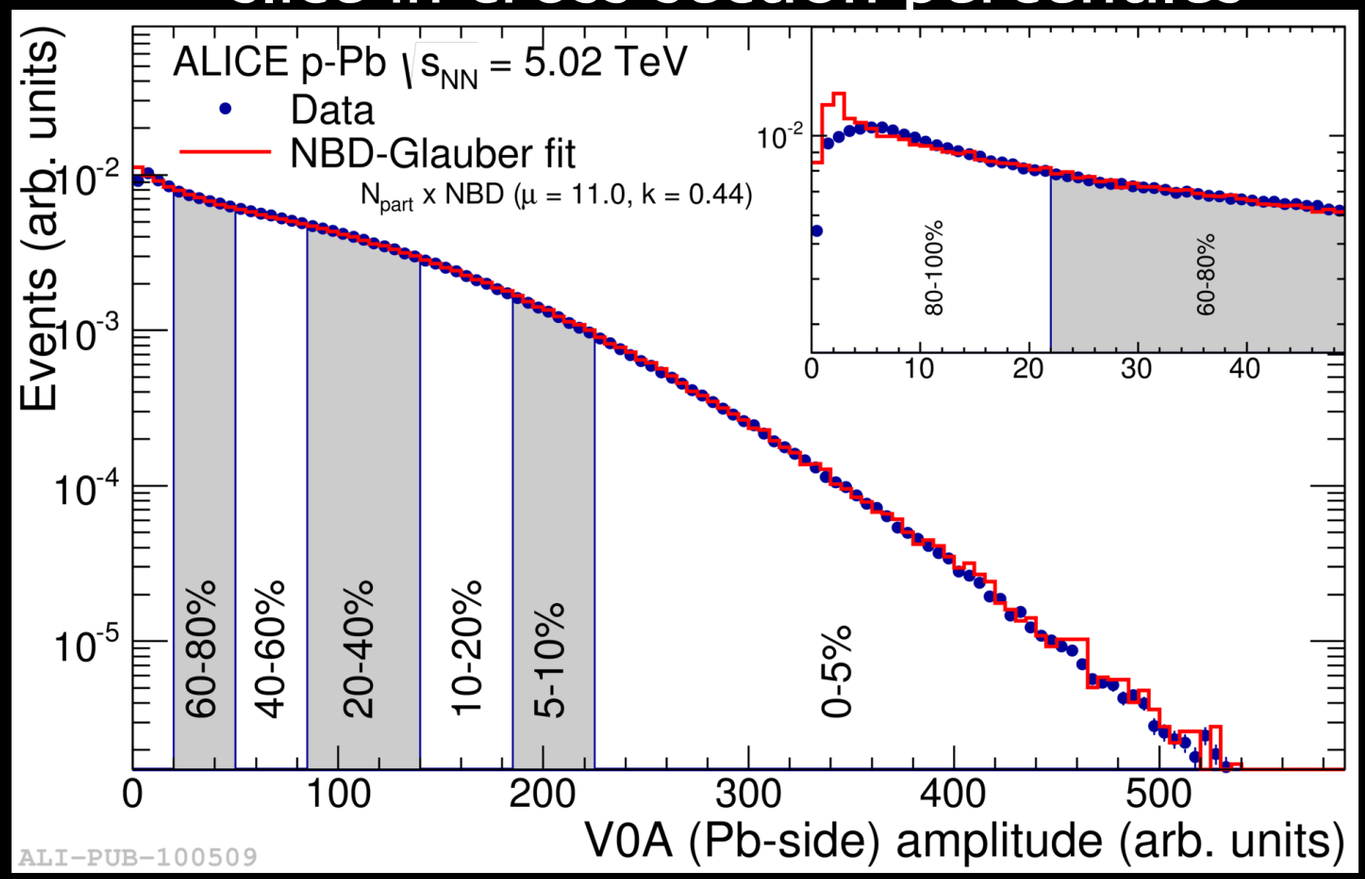
Pb-Pb





p-Pb

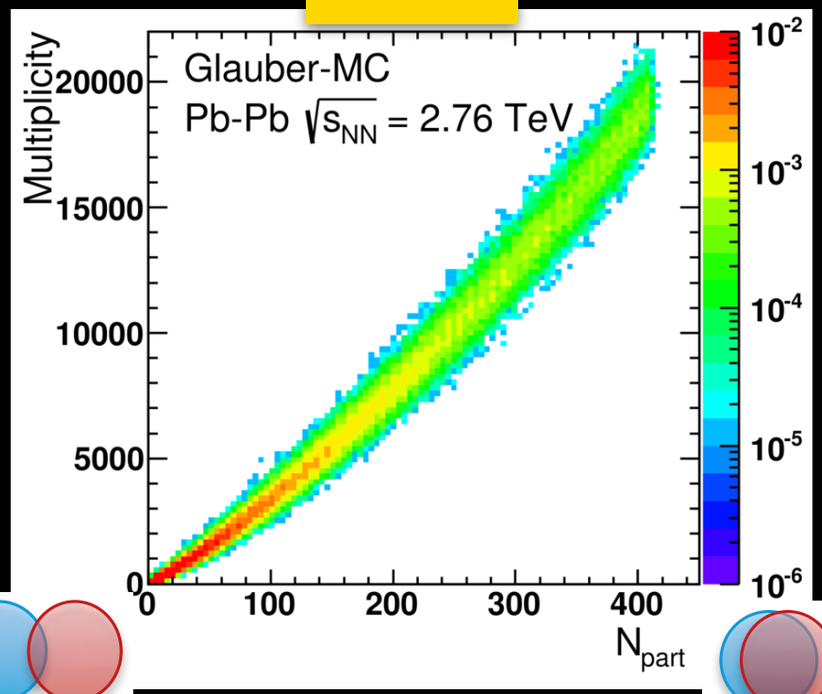
- Glauber MC
  - from impact parameter to N_{part} (N_{coll})
  - experimental observable: multiplicity
  - fit of the multiplicity distribution with a Negative Binomial Distribution
    - slice in cross section percentiles

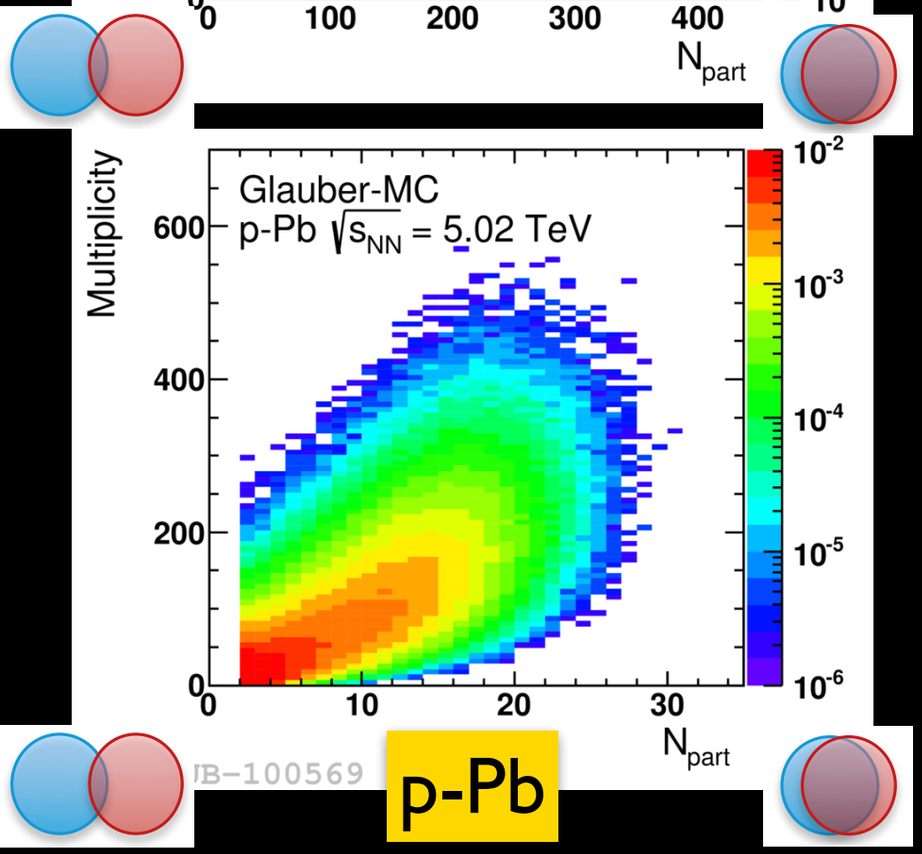


[Phys. Rev. C 91 (2015) 064905]

The concept of centrality in p-Pb collisions

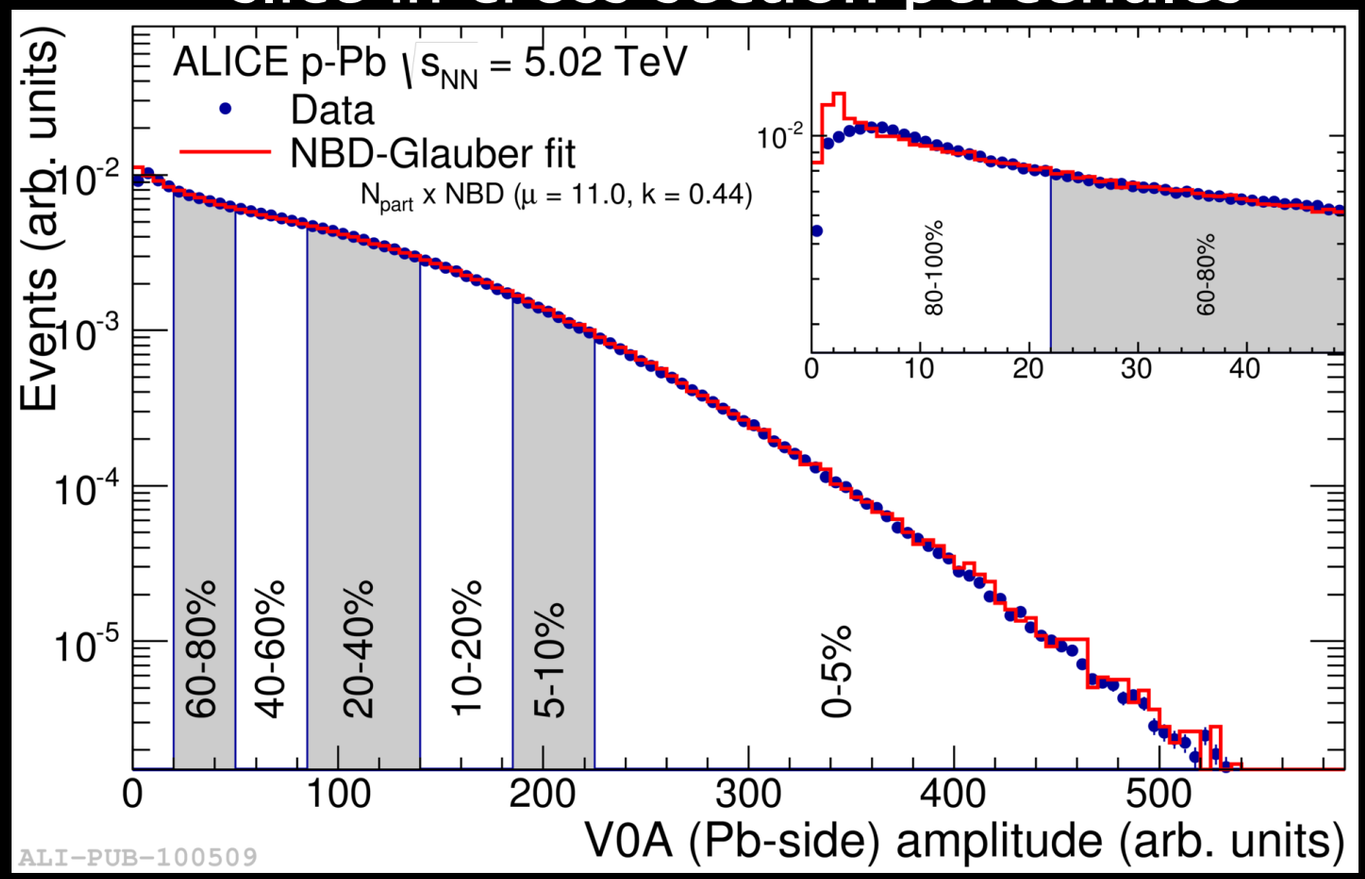
Pb-Pb





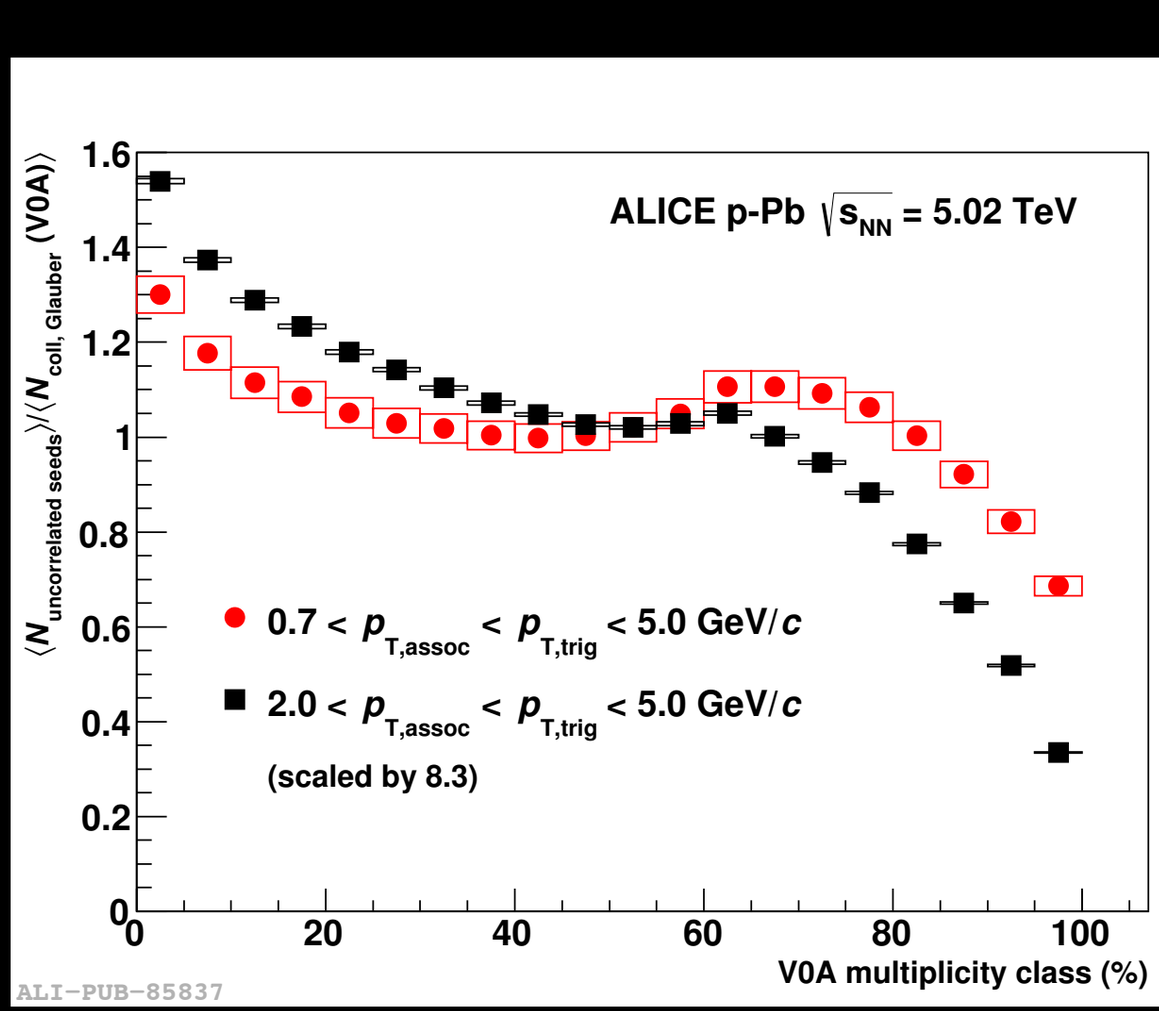
p-Pb

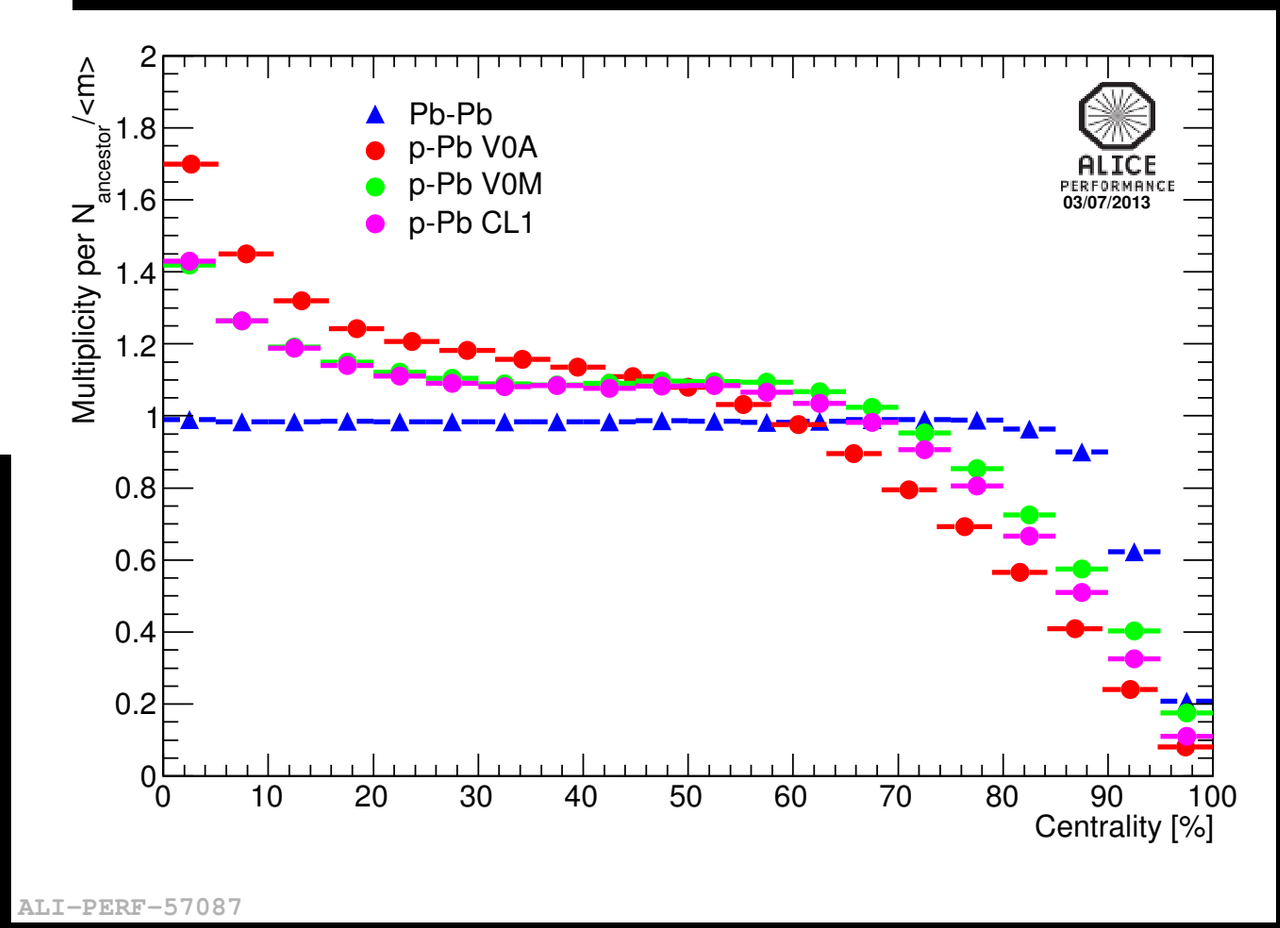
- Glauber MC
  - from impact parameter to N_{part} (N_{coll})
  - experimental observable: multiplicity
  - fit of the multiplicity distribution with a Negative Binomial Distribution
    - slice in cross section percentiles



[Phys. Lett. B 741 (2015) 38-50]

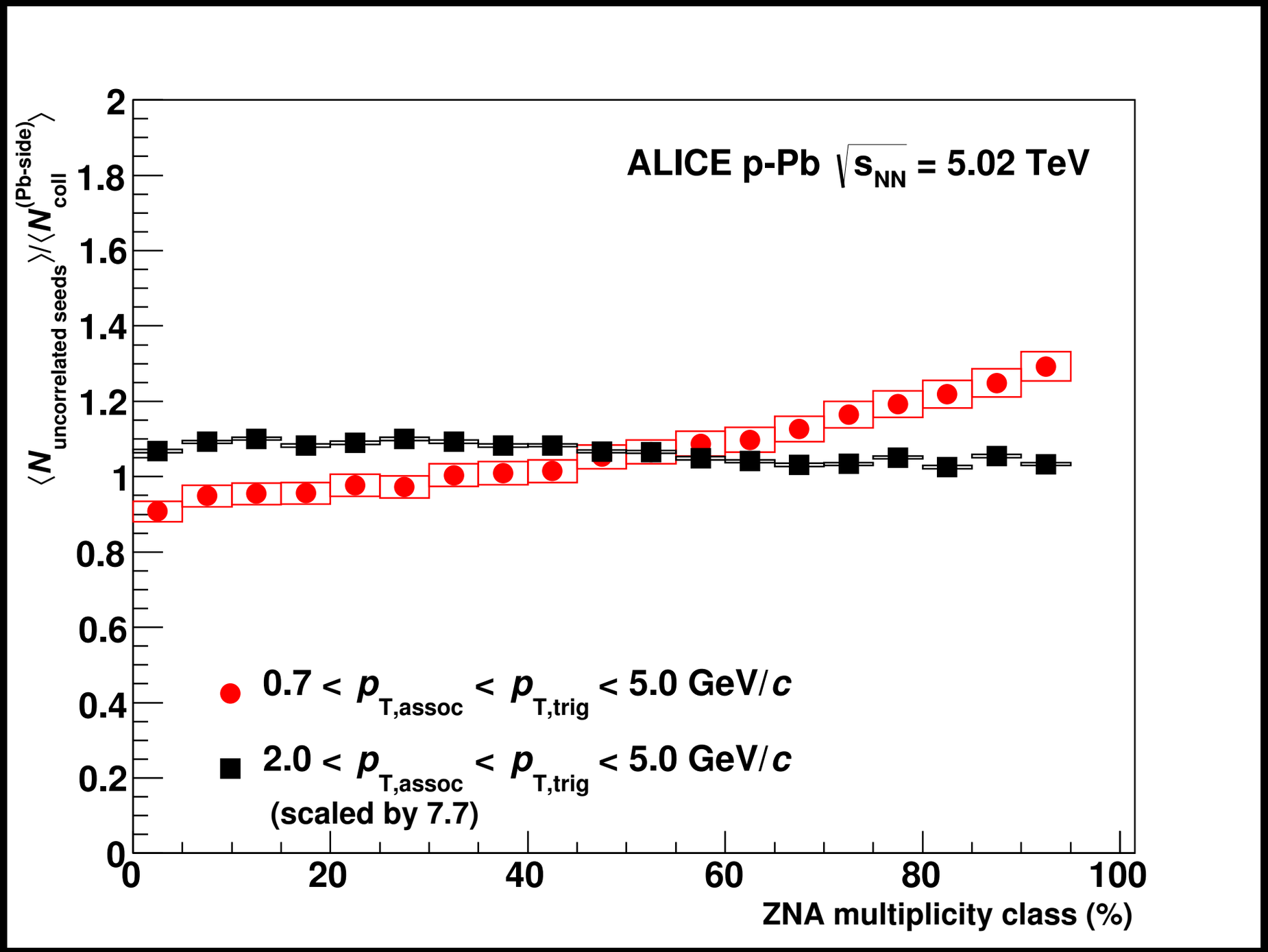
Uncorrelated seeds / Ncoll





[Phys. Lett. B 741 (2015) 38-50]

Uncorrelated seeds / Ncoll



[Phys. Lett. B 741 (2015) 38-50]

Comparison pp and p-Pb