DPS, MPI, underlying event and identified hadrons

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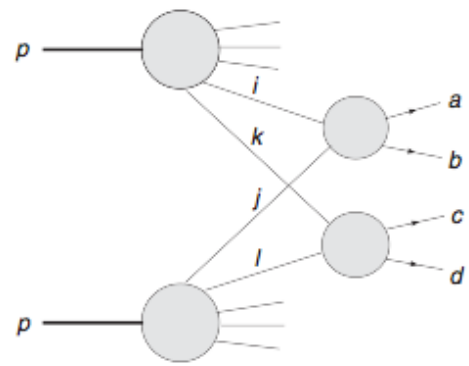
(and many thanks to C. Loizides, A. Morsch, J.F. Grosse-Oethringhaus, J. Hollar, G. Veres, K. Mueller, V. Belyaev, D. Volyanskyy, S. Glazov from the LHC experiments)

Outline

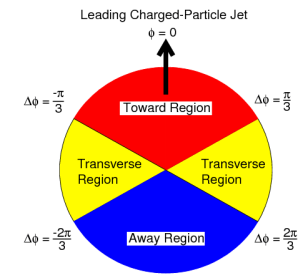
Multi-parton interactions (MPI) and DPS

- increasingly important at LHC
- results on Double Parton Scattering
- studying MPI with correlations



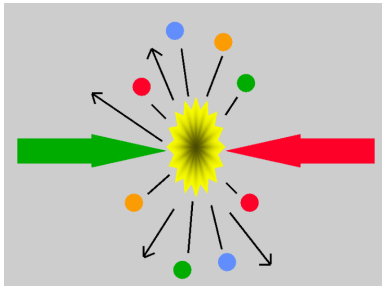
Underlying event (UE)

- LHC approaches so far keeping an eye on MPI



Identified hadrons

- highlights and puzzles
- particle production and multiplicity

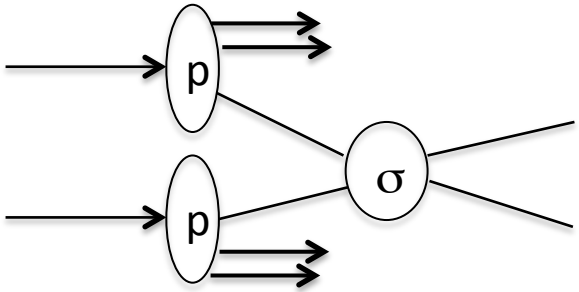


Summary and outlook

DISCLAIMER: a selection of topics with some emphasis on more recent results, not a comprehensive summary

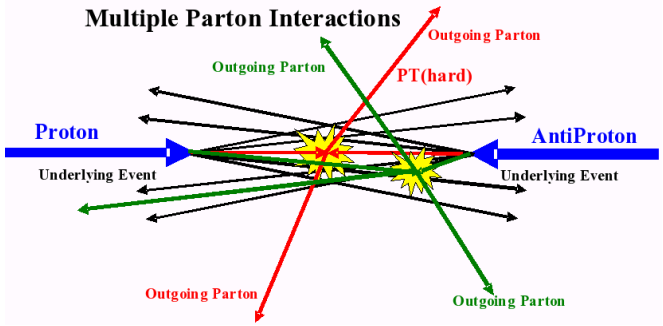
Multi-Parton Interactions and Double Parton Scattering

The simple picture: *"One hard scattering between two partons, the spectator partons contribute to the underlying event"*

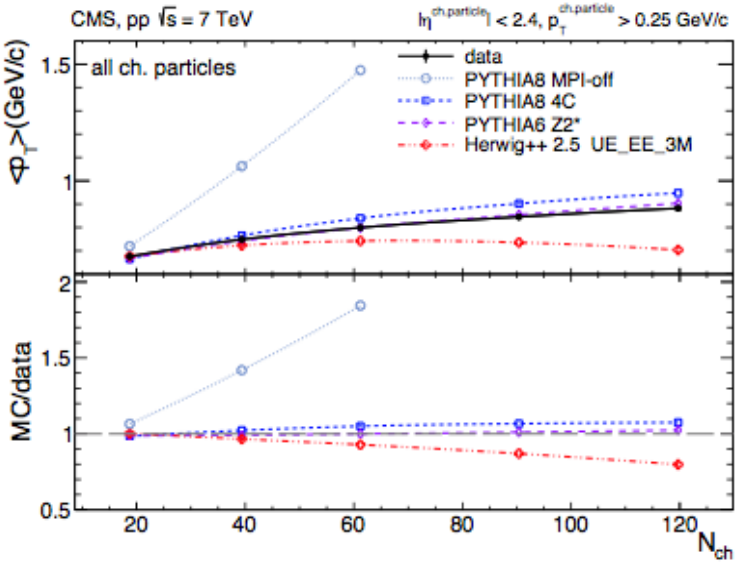


- But the probability of other partons in each nucleons to also undergo additional scatterings (MPI) is not zero..
- increasing √s → access low-x → increase parton density → MPI probability
- @LHC 'MPI-off' is just not an option
- 'Soft' MPI (semi-hard second interaction) required by underlying event studies and many other observables.

O(some GeV)



courtesy: R. Field



CMS, EPJ C 73 (2013) 2674

- But large p_T/mass are possible with second interaction ('hard' MPI -> DPS)?

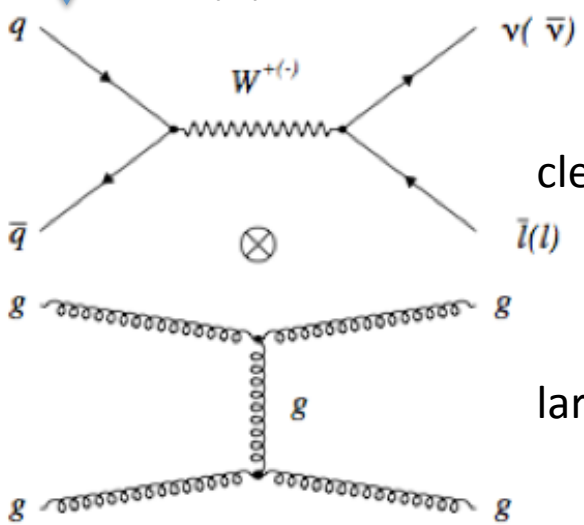
O(some tens of GeV)

Important for LHC: DPS can create critical background to exclusive physics channels under study!

Double Parton Scattering at the LHC

Experiment	Channel	Reference
LHCb	J/ψ C and CC	JHEP 06 (2012) 141 JHEP 03 (2014) 108 (Addendum)
LHCb	Z + C	JHEP 04 (2014) 91
ATLAS	W + 2 jets	New J. Phys. 15 (2013) 033038
CMS	W + 2 jets	JHEP 03 (2014) 032

(A)



(B)

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

C=1/4 for A=B identical and non self-conjugate
C=1 for A≠B and either A or B self-conjugate
C=1/2 otherwise

M.H. Seymour and A. Siódmok, arXiv:1308.6749

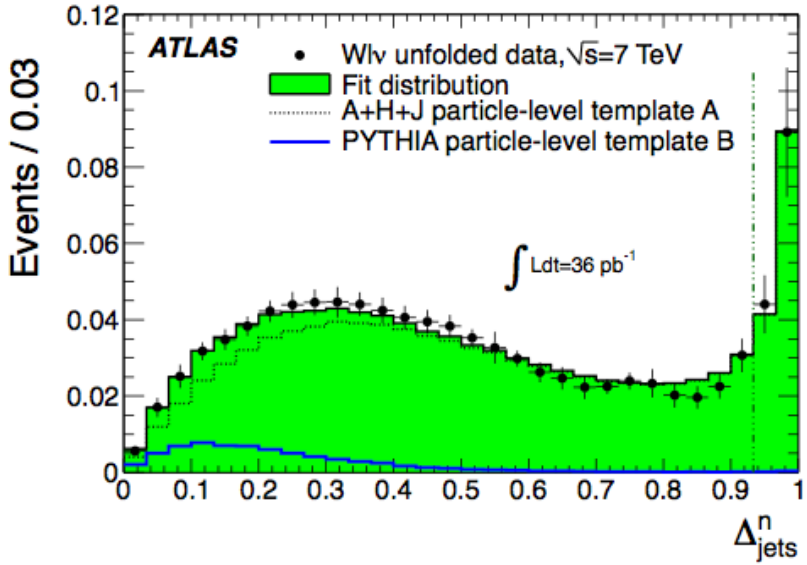
clean tag

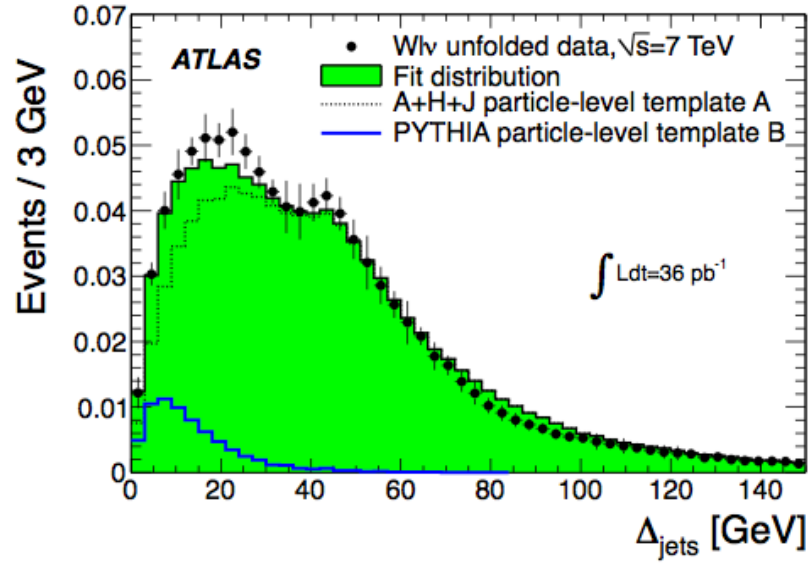
large cross section

Increase probability to observe DPS

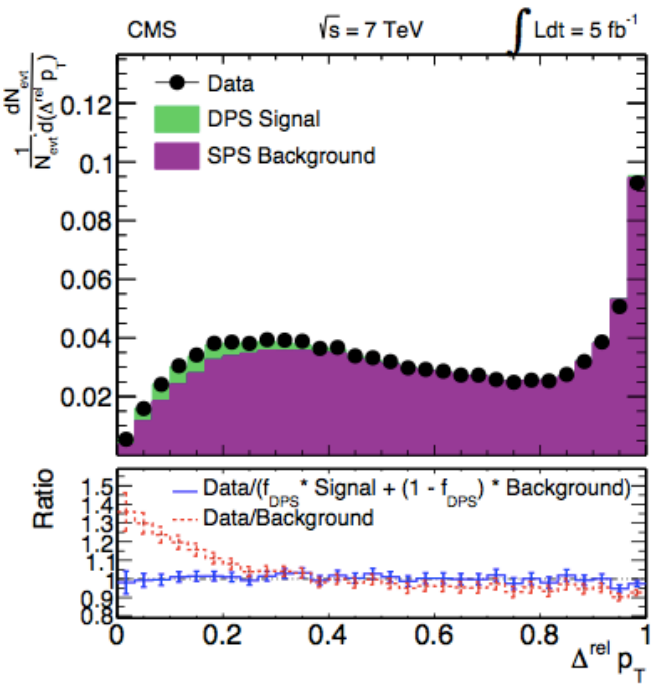
ATLAS analysis includes both e and μ, CMS μ only

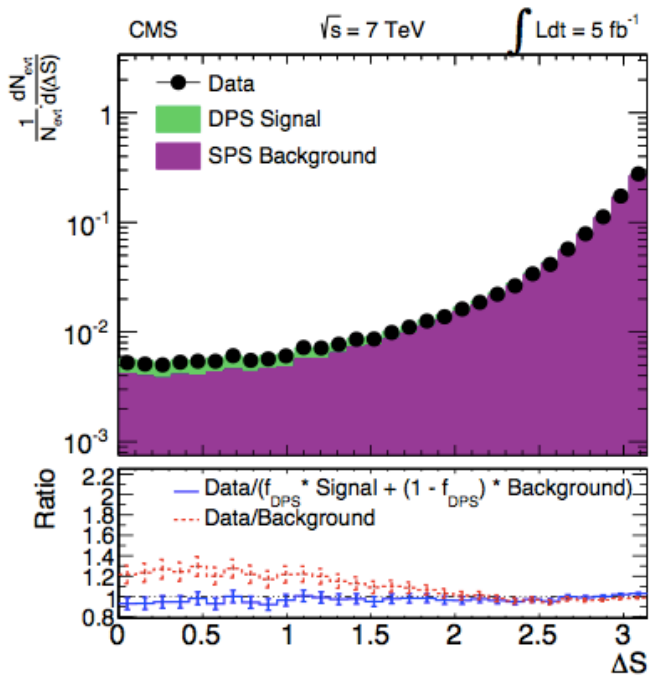
DPS extraction in W + 2jets





New J. Phys. 15 (2013) 033038





In general fit f_{DPS} with:

$$(1-f_{DPS})\cdot B + f_{DPS}\cdot S$$

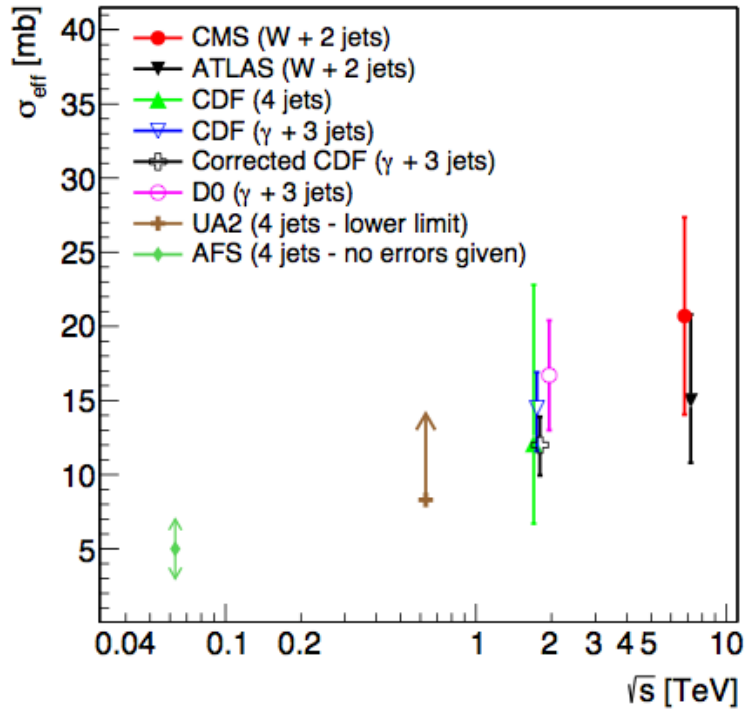
and then use:

$$\sigma_{\mathrm{eff}} = \frac{N'_{\mathrm{W+0j}}}{f_{\mathrm{DPS}}\cdot N'_{\mathrm{W+2j}}}\cdot\sigma'_{\mathrm{2j}}$$

JHEP 03 (2014) 032

Double Parton Scattering: σ_{eff}

JHEP 03 (2014) 032

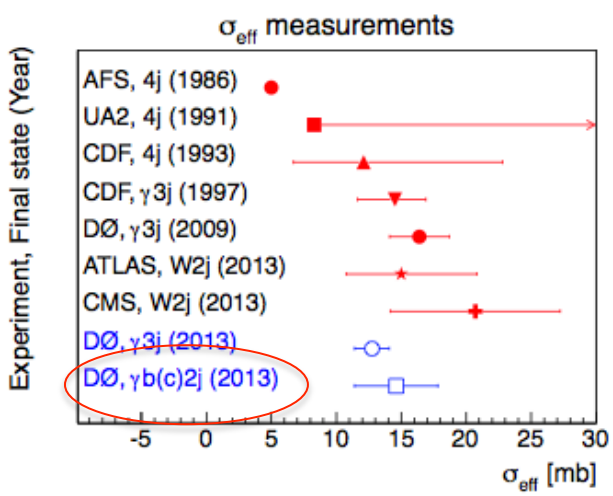


f_{DPS} = 0.076±0.013(stat.)±0.018(syst.) (ATLAS)
f_{DPS} = 0.055±0.002(stat.)±0.014(syst.) (CMS)

σ_{eff} = 15 ± 3 (stat) +5/-3 (syst) mb (ATLAS)
σ_{eff} = 20.7 ± 0.8 (stat) ± 6.6 (syst) mb (CMS)

- ATLAS and CMS results consistent
- hard to draw conclusions on √s dependence (but RUN2 could tell us more)

towards cleaner DPS channels



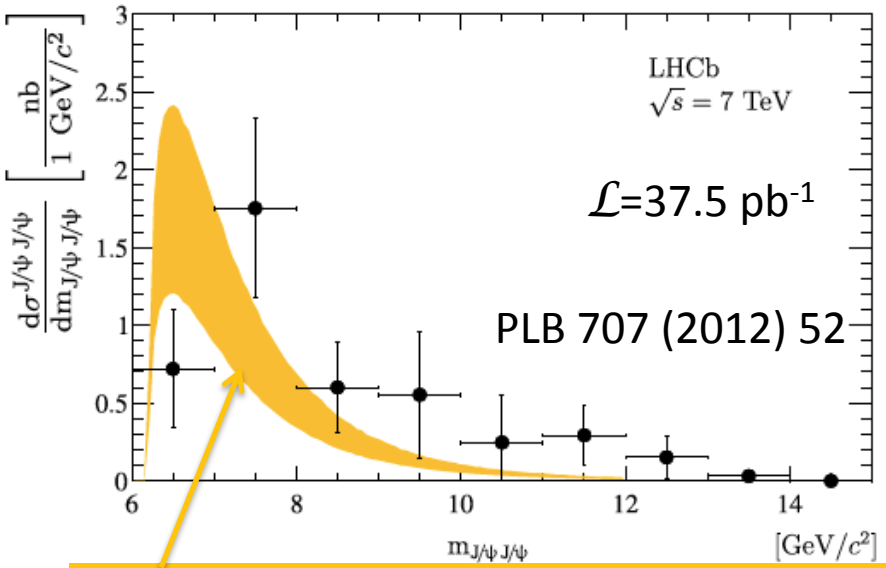
D0 arXiv:1402.1550
first measurement with heavy flavor jets in the final state

	$\sqrt{s}$ (GeV)	final state	p_T^{cut} (GeV)	η range	σ_{eff}
AFS [11]	63	4 jets	$p_T^{jet} > 4$	$\lvert\eta^{jet}\rvert < 1$	≈ 5 mb
UA2 [12]	630	4 jets	$p_T^{jet} > 15$	$\lvert\eta^{jet}\rvert < 2$	> 8.3 mb (95% C.L.)
CDF [13]	1800	4 jets	$p_T^{jet} > 25$	$\lvert\eta^{jet}\rvert < 3.5$	$12.1^{+10.7}_{-5.4}$ mb
CDF [14]	1800	$\gamma + 3$ jets	$p_T^{jet} > 6$ $p_T^{\gamma} > 16$	$\lvert\eta^{jet}\rvert < 3.5$ $\lvert\eta^{\gamma}\rvert < 0.9$	14.5 ± 1.7 (stat) $^{+1.7}_{-2.3}$ (syst) mb
D0 [15]	1960	$\gamma + 3$ jets	$60 < p_T^{\gamma} < 80$ $p_T^{jet} > 15$	$\lvert\eta^{\gamma}\rvert < 1.0$ $1.5 < \lvert\eta^{\gamma}\rvert < 2.5$	16.4 ± 0.3 (stat) ± 2.3 (syst) mb
ATLAS [17]	7000	$W + 2$ jets	$p_T^{jet} > 20$	$\lvert\eta^{jet}\rvert < 2.8$	15 ± 3 (stat) $^{+5}_{-3}$ (syst) mb
CMS [18]	7000	$W + 2$ jets	$p_T^{jet} > 20$	$\lvert\eta^{jet}\rvert < 2.0$	20.7 ± 0.8 (stat) ± 6.6 (syst) mb

Charm production at LHC & DPS

LHCb:
PLB 707 (2012) 52 $J/\psi\, J/\psi$
JHEP 06 (2012) 141: J/ψ C and CC
(C=open charm hadrons)
JHEP 4(2014) 91 Z+open charm meson

Early LHCb result on double J/ψ, where contribution from DPS can be significant, is however consistent with predictions without including DPS



prediction from Berezhnoy et al, PRD 84(2011) 094203 (not including DPS)

$\sigma^{J/\psi J/\psi} = 5.1 \pm 1.0 \pm 1.1$ nb

$\sigma^{J/\psi J/\psi}/\sigma^{J/\psi} = (5.0 \pm 1.0 \pm 0.6^{+1.2}_{-1.0})$ x 10^{-4}

$\sigma_{SPS}^{pp\to J/\psi J/\psi X} \approx 4nb$ PRD 84 (2011) 094023

$\sigma_{DPS}^{pp\to J/\psi J/\psi X} \approx 2nb$ arXiv:1106.2184

For future studies it will be important to study channels where one of the two mechanisms is dominant.

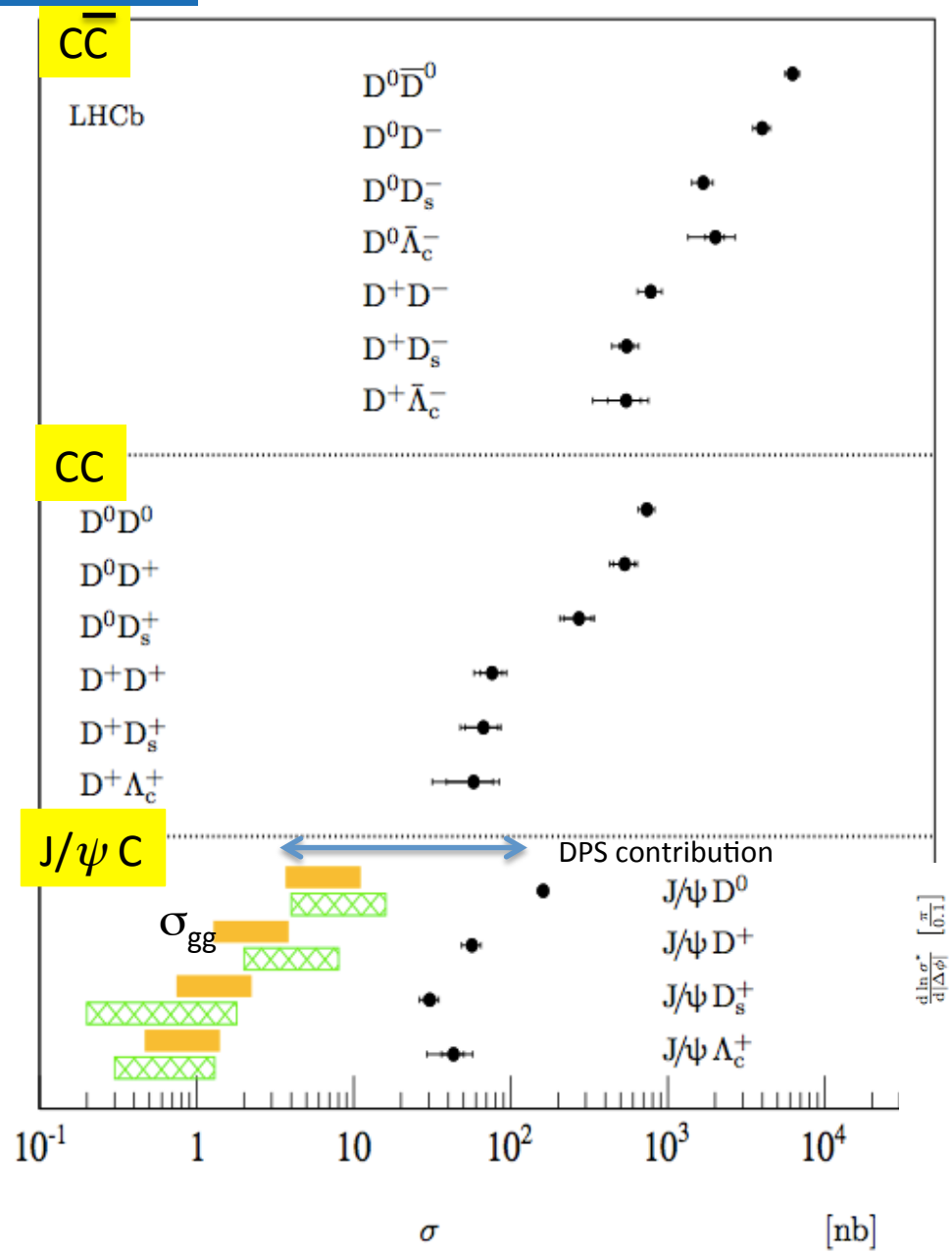
$$\sigma_{SPS}^{J/\psi\Upsilon} < \sigma_{SPS}^{\Upsilon\Upsilon} < \sigma_{SPS}^{J/\psi J/\psi}$$

$$\sigma_{DPS}^{\Upsilon\Upsilon} < \sigma_{DPS}^{J/\psi\Upsilon} < \sigma_{DPS}^{J/\psi J/\psi}$$

$$\left(\frac{\sigma_{DPS}}{\sigma_{SPS}}\right)^{J/\psi\Upsilon} \approx 35$$

A. Novoselov
arXiv:1106.2184

DPS: J/ψ and open charm



S_σ > 8σ if not indicated !

$p^T_{J/\psi}$ < 12 GeV/c
3<p^T_C < 12 GeV/c

5σ

8σ

8σ

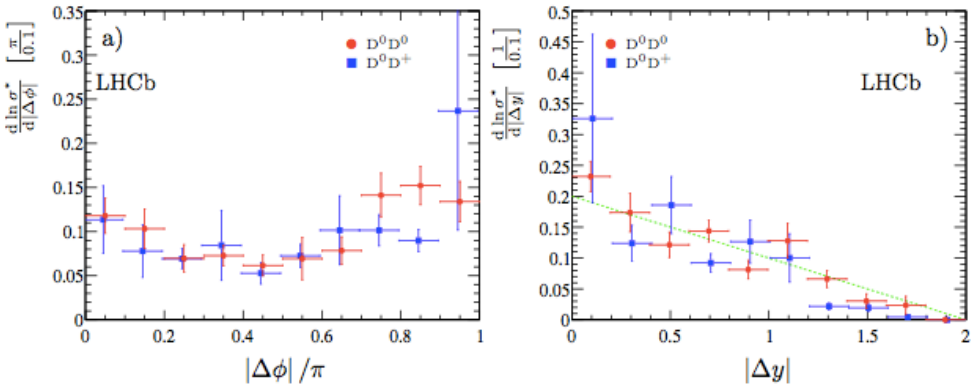
5σ

2.5σ

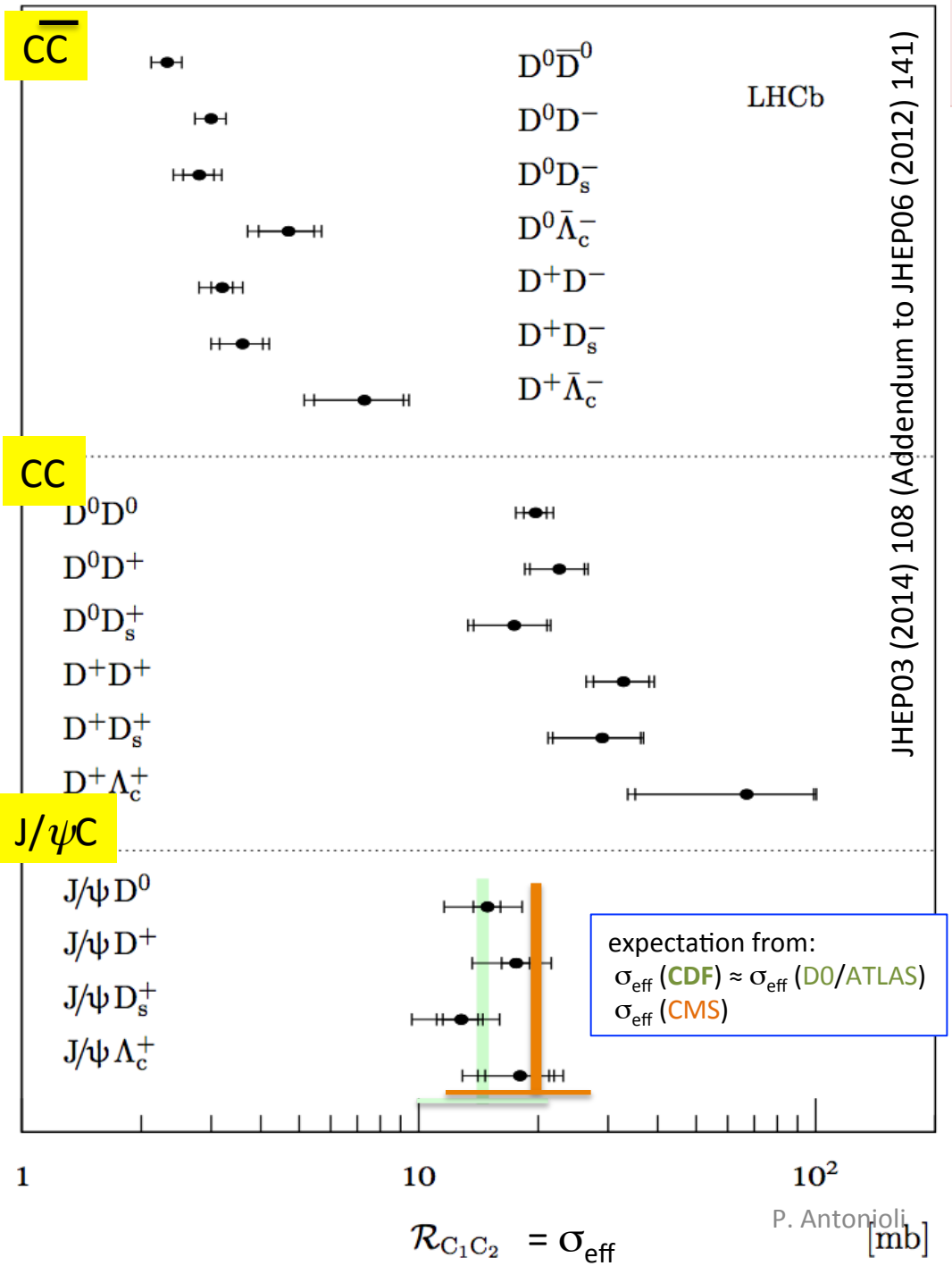
first observation of J/ψ C events in hadron production

$C\bar{C}$/CC ratio relatively large (10-15% with respect to 10^{-4} $\sigma^{J/\psi J/\psi}/\sigma^{J/\psi}$)

absence of azymuthal or rapidity correlations provides support for DPS hypothesis for J/ψ C and CC events



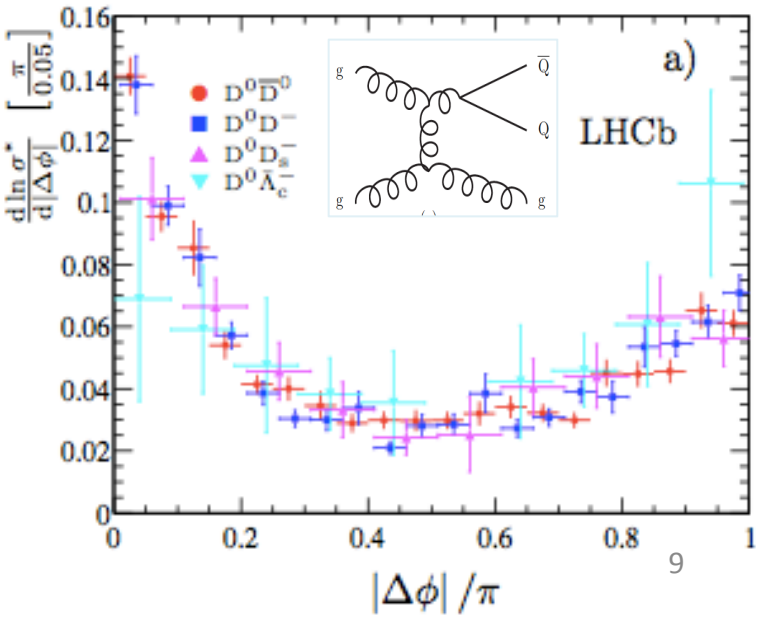
and on σ_{eff}



agreement with Tevatron result (and now CMS/ATLAS) using J/ψ C sample

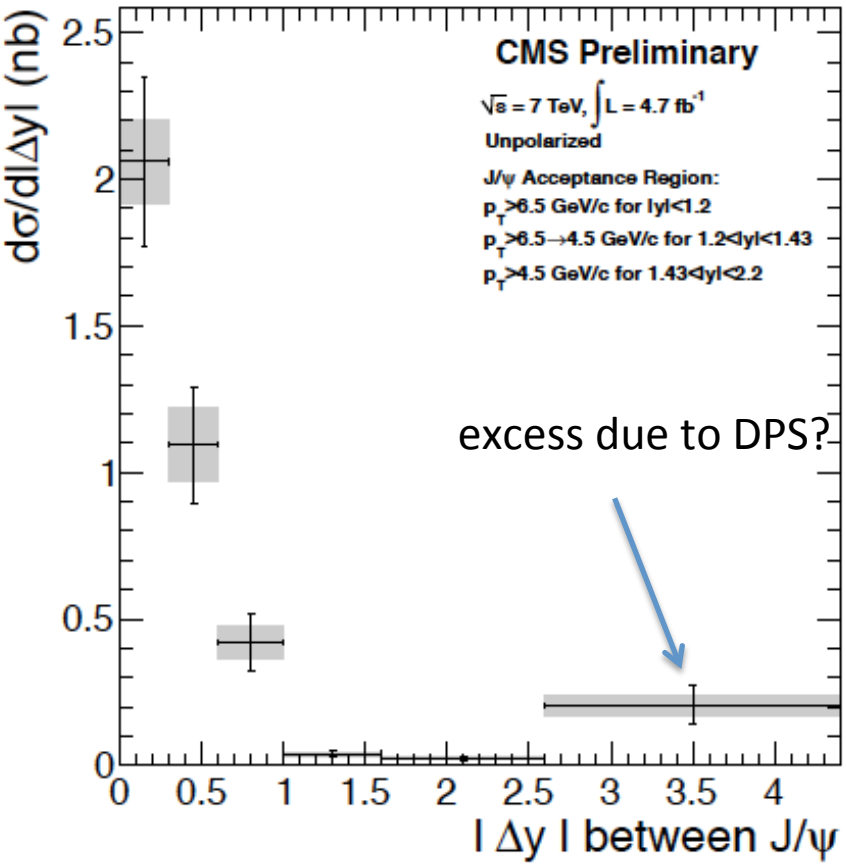
σ_{eff} values for CC agreement also reasonable but higher values

For $C\bar{C}$ events observation of rapidity and azimuthal correlations support gluon splitting explanation



Prompt Double J/ψ at CMS

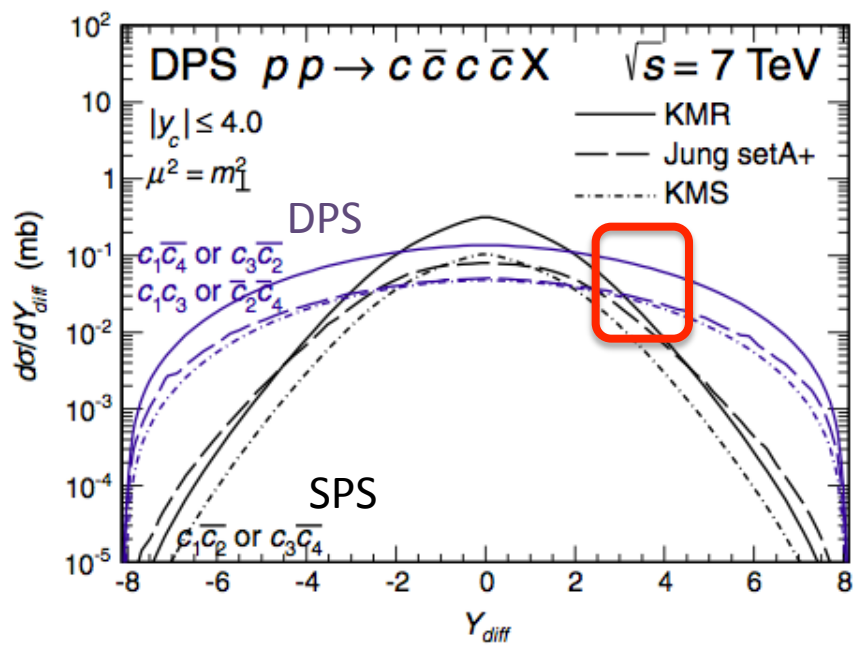
CMS PAS: BPH-11-021



Analysis presented at MPI@2013

Complementarity with LHCb measurement (|y|<2.2 and higher p_T)

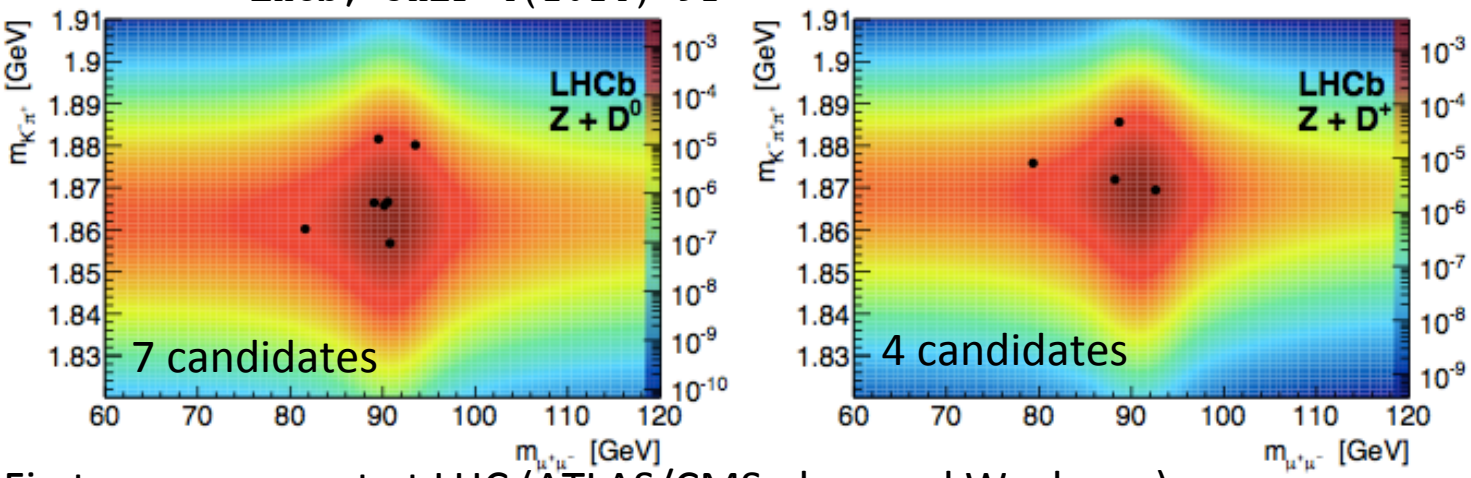
σ as a function of Δy between J/ψ pair is sensitive to DPS



R. Maciula and A. Szczurek, PRD 87(2013) 074039

Z + open charm

LHCb, JHEP 4(2014) 91



$\mathcal{L}$=1 fb^{-1}

Z in di-muon channel
usual cuts for D mesons

First measurement at LHC (ATLAS/CMS observed W+charm)
Combined 5.1σ significance

- SPS + DPS within expectations for Z + D^0
- below expectations for Z + D^+

assuming CDF σ_{eff}

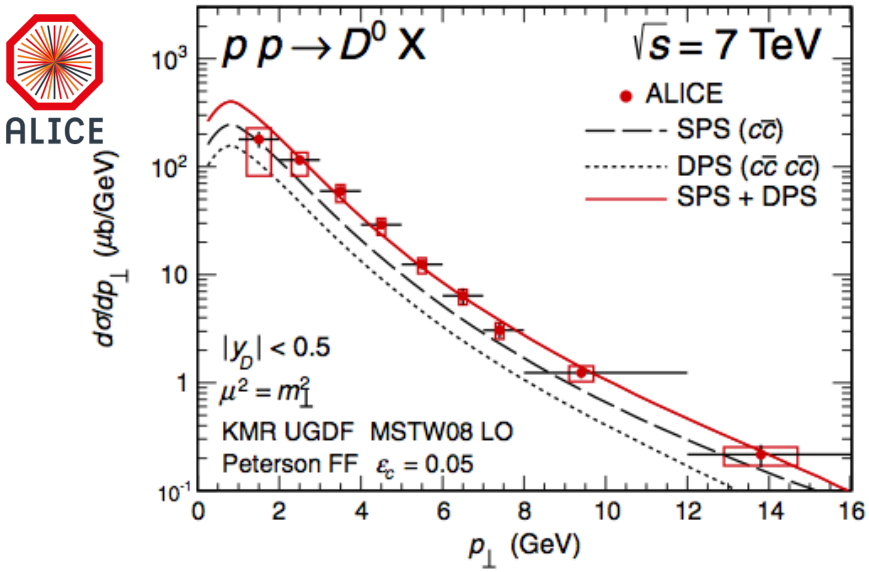
$$\sigma^{DPS}_{Z\to\mu^+\mu^-,D} = \frac{\sigma_{Z\to\mu^+\mu^-}\,\sigma_D}{\sigma_{eff}}$$

	measured	NLO MCFM massless	NLO MCFM massive	DPS
$Z + D^0$	$2.50 \pm 1.12 \pm 0.22$	$0.85^{+0.12}_{-0.07}\,^{+0.11}_{-0.17} \pm 0.05$	$0.64^{+0.01}_{-0.01}\,^{+0.08}_{-0.13} \pm 0.04$	$3.28^{+0.68}_{-0.58}$
$Z + D^+$	$0.44 \pm 0.23 \pm 0.03$	$0.37^{+0.05}_{-0.03}\,^{+0.05}_{-0.07} \pm 0.03$	$0.28^{+0.01}_{-0.01}\,^{+0.04}_{-0.06} \pm 0.02$	$1.29^{+0.27}_{-0.23}$

important to look now at differential distributions with more statistics

DPS and charm at LHC

R. Maciula and A. Szczurek, PRD 87(2013) 074039

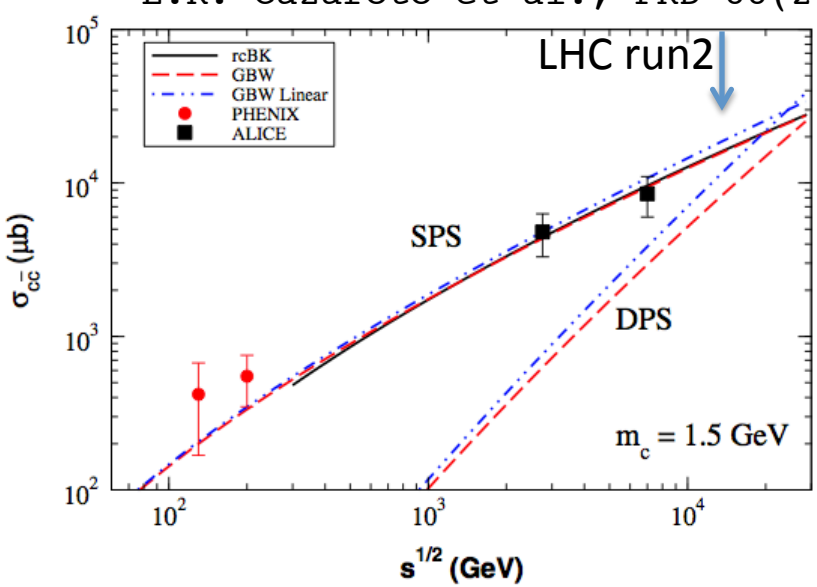


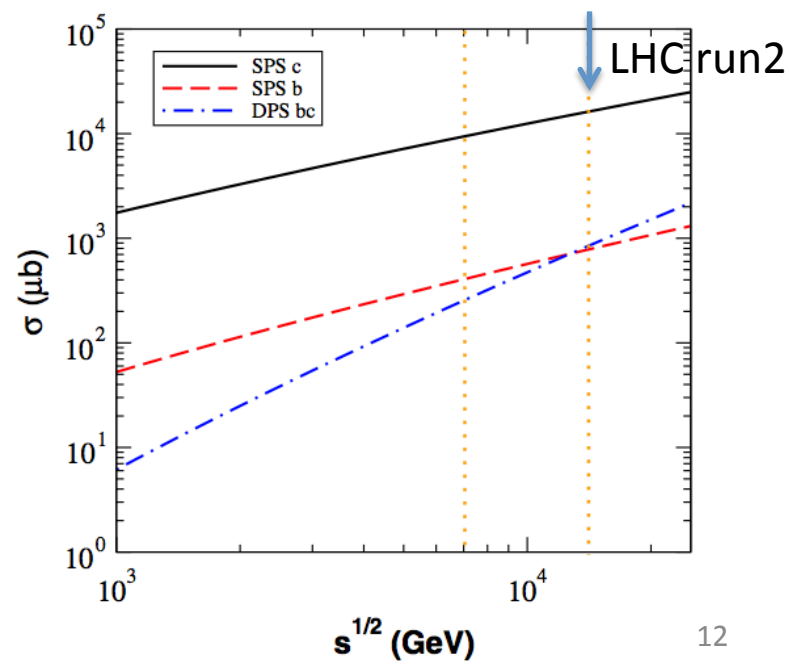
Many papers in recent years include DPS contribution in single mesons production fits of experimental results from ALICE/CMS/ATLAS/LHCb

DPS contribution similar to SPS being comparable at run2. This holds true even taking into account saturation.

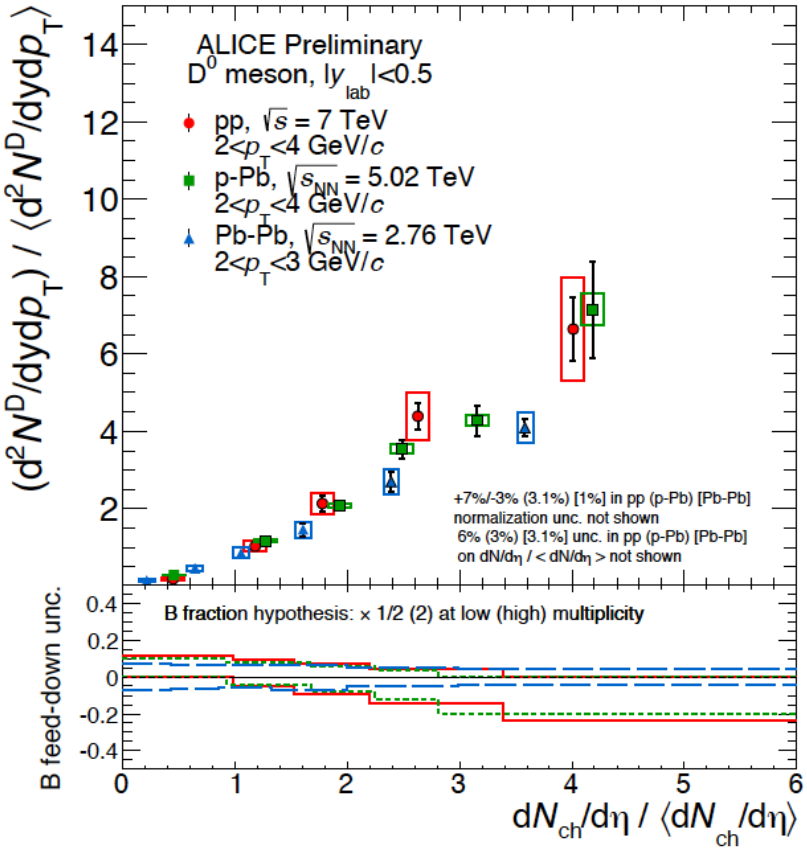
RUN2 promising for DPS and b production

E.R. Cazaroto et al., PRD 88(2013)034005

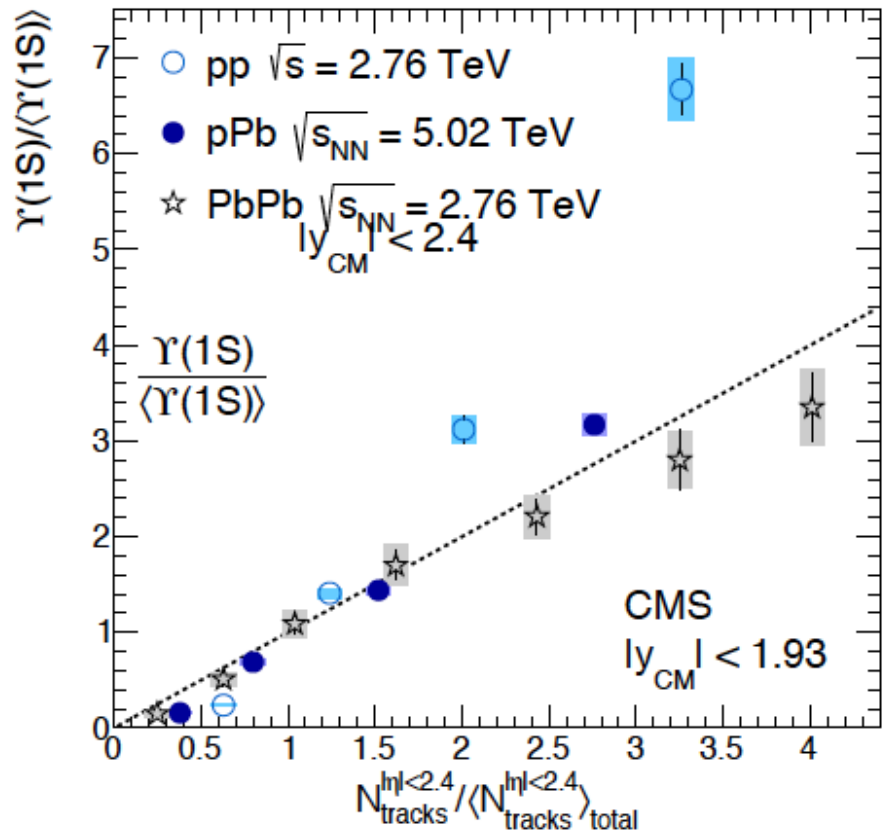




MPI at harder scale: c and b vs multiplicity



JHEP04 (2014) 103



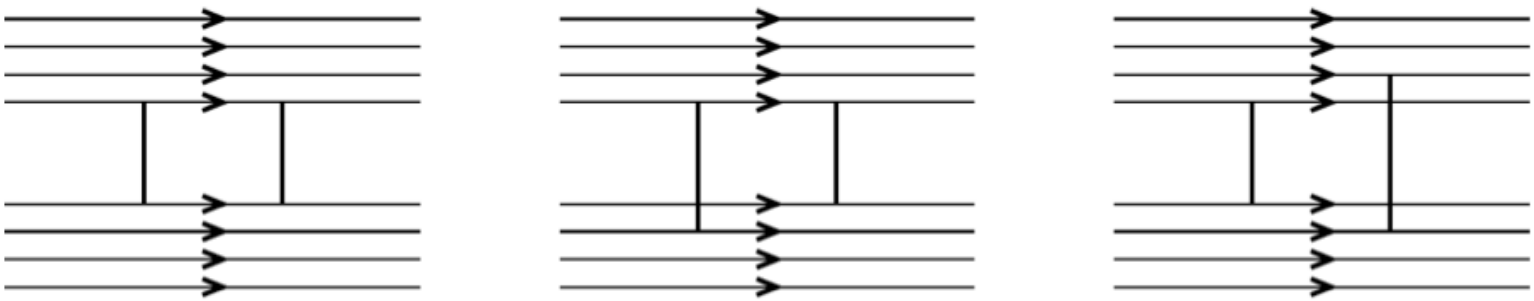
- relative yields measured vs relative charged particle density
- results with D mesons from ALICE similar to the previous one about J/ψ (PLB 712(2012) 165)
- similar analysis published now by CMS with Υ
- for pp linear increase with multiplicity can be interpreted as MPI happening at harder scale

pPb / PbPb results discussed in E. Scomparin talk

DPS (and MPI) not only in pp

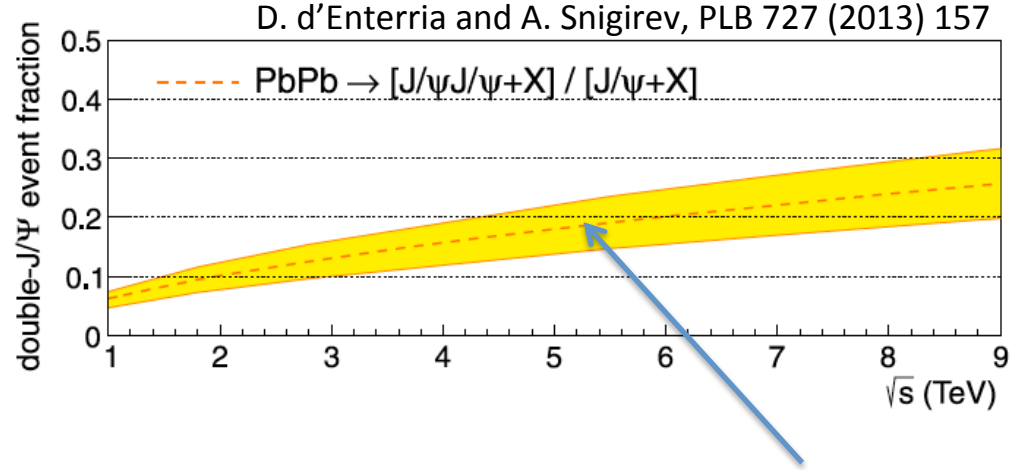
DPS in pPb and PbPb

D. d'Enterria and A. Snigirev, subm. to Nucl. Phys. A (arXiv:1403.2335)



- long-waited smoking gun for DPS (like-sign W pair) could be seen in pPb (estimated 10 DPS events with $\mathcal{L}$=2 pb^{-1})
- PbPb events have also sizeable fraction of double J/ψ due to DPS (estimated 240 events per unit of rapidity with $\mathcal{L}$=1 nb^{-1})
- pPb DPS study suggested as a mean to filter out longitudinal correlations (B. Blok et al, EPJ C 73 (2013) 2433)

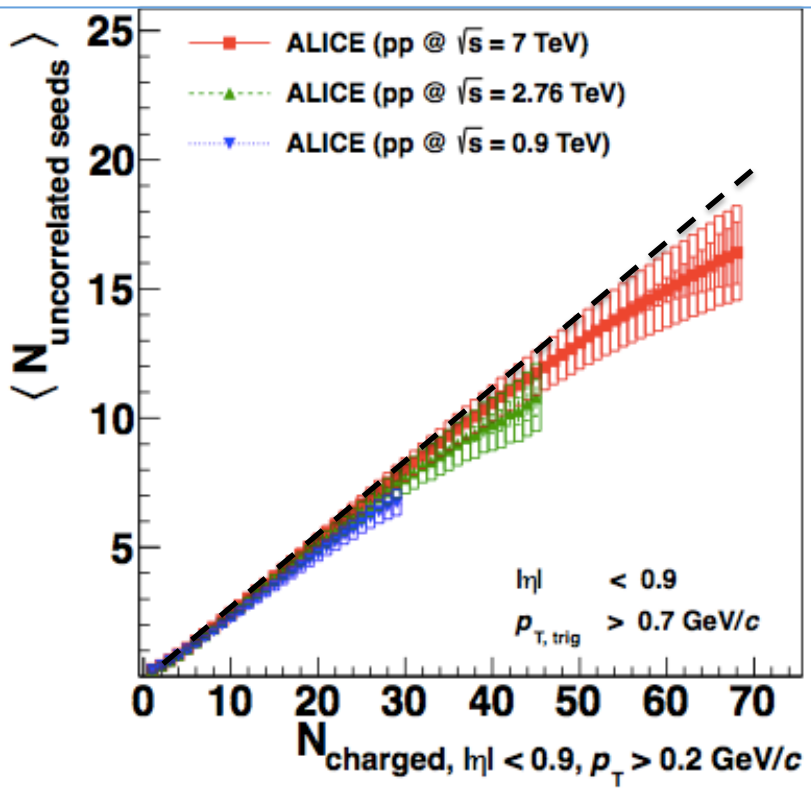
D. d'Enterria and A. Snigirev, PLB 727 (2013) 157



up to 35% in most central

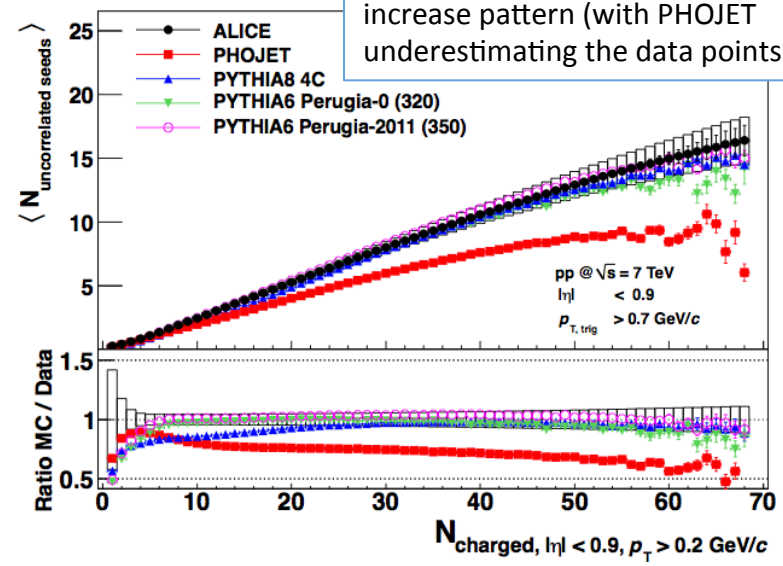
MPI and correlation studies: pp and pPb

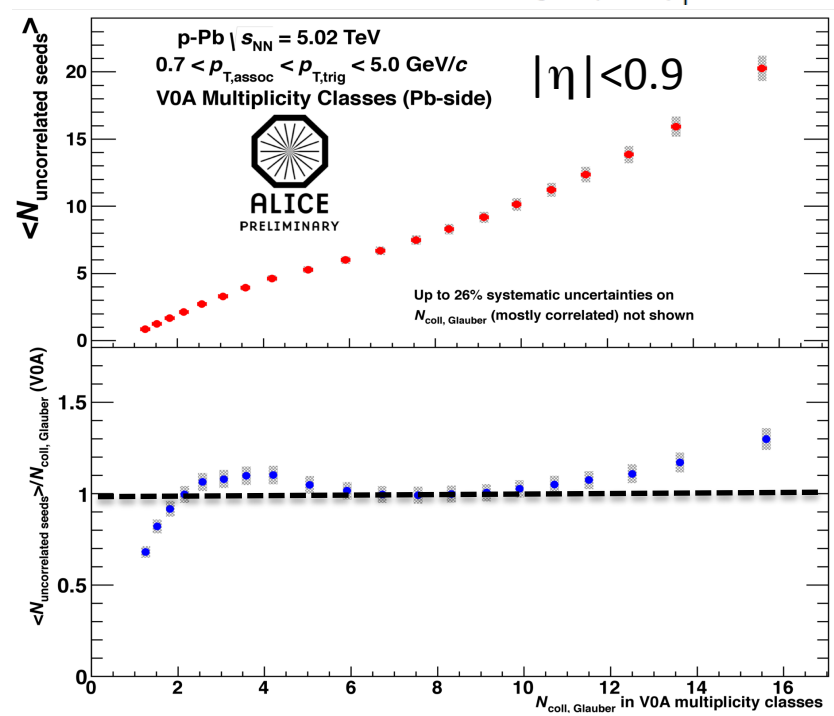
two particle azymuthal correlations in pp and pPb
→ new observable (uncorrelated seeds) constructed to study contribution of MPI to particle production



JHEP09 (2013) 049

All tunes describes qualitatively the increase pattern (with PHOJET underestimating the data points)

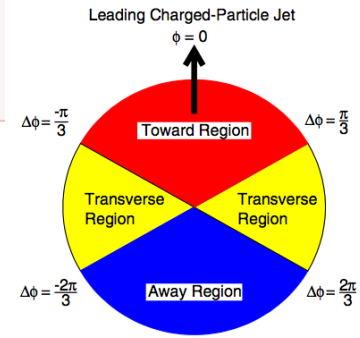




- $N_{unc.\ seeds}$ increases with $N_{charged}$ but evidence of N_{MPI} saturation in pp
- in pPb number of uncorrelated seeds increases linearly with multiplicity at midrapidity (no evidence of saturation)

nioli

Underlying event studies



A non-exhaustive list:

Exp	√s (TeV)	Approach/leading oject/observables	Reference
CMS	0.9	"traditional"/track ✔	Eur. Phys. J C70 (2010) 555
ATLAS	0.9, 7	"traditional"/track ✔	PRD 83 (2011) 112001
CMS	7	"traditional"/track ✔	JHEP 1109 (2011) 109
ATLAS	0.9, 7	Inc. neutral/charged part. flow	EPJ C71 (2011) 1636
ALICE	0.9, 7	"traditional"/track ✔	JHEP 1207 (2012) 116
CMS	7	UE in DY events: as a function of $M_{\mu\mu}$ ✔	EPJ C72 (2012) 2080
ATLAS	7	"traditional"/jet/ dependency on the R of the jet ✔	PRD 86 (2012) 072004
ATLAS	7	Includes transMIN/MAX/DIFF	ATLAS-CONF-2012-164
CMS	0.9, 7	Jet area/median approach	JHEP 1208 (2012) 130
LHCb	7	Forw. charged particle mult./density	EPJ C72 (2012) 1947
LHCb	7	Forw. energy	EPJ C73 (2013) 2421
CMS	0.9, 2.76, 7	Forward energy density ratio	JHEP 1304 (2013) 072
CMS	7	Neutral strange production (K^0_s/Λ) ✔	PRD 88 (2013) 052001
CMS	7	Charged mult. for intrajet and UE particles ✔	EPJC 73 (2013) 2674
CMS	7	UE in t-tbar events ✔	CMS PAS TOP-13-007
LHCb	7	Forward p_T distr.	arXiv:1402.4430
ATLAS	7	Jet: inclusive and exclusive (2 jets) + transMIN/MAX/DIFF ✔	arXiv:1406.0392

✔ mentioned/covered in this talk

$1 / \Delta\eta\, \Delta(\Delta\phi)\ \langle N_{ch} \rangle$

$1 / \Delta\eta\, \Delta(\Delta\phi)\ \langle \Sigma p_T \rangle$

$\langle \Sigma p_T \rangle / \langle N_{ch} \rangle$

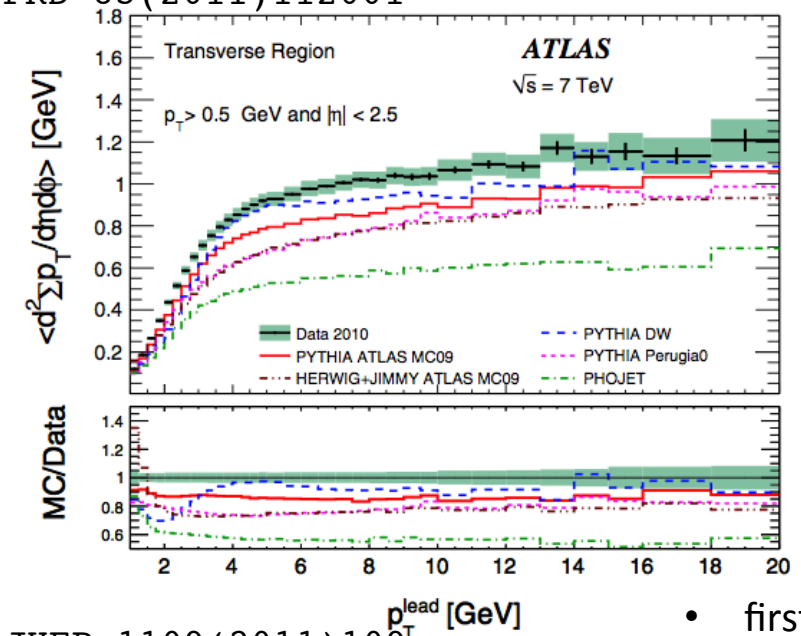
- a rich combination of papers/analyses/approaches so far, still evolving
- UE made of particles that arise from BBR and the MPI that accompany the hard scattering

Forward results in S. Tourneur talk

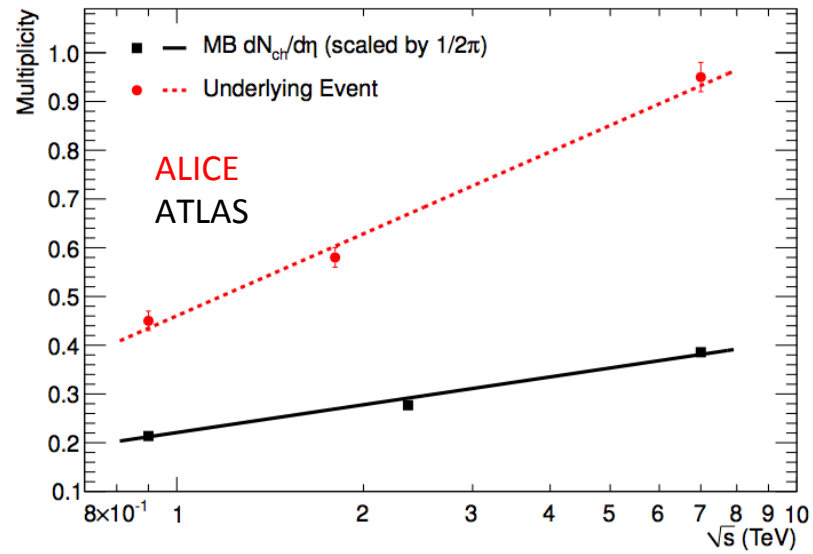
"From a certain point of view, there is no such thing as an UE in a hadron-hadron collision. There is only an event and one cannot determine where a given particle in the event originated" (R. Field)

The “traditional” approach

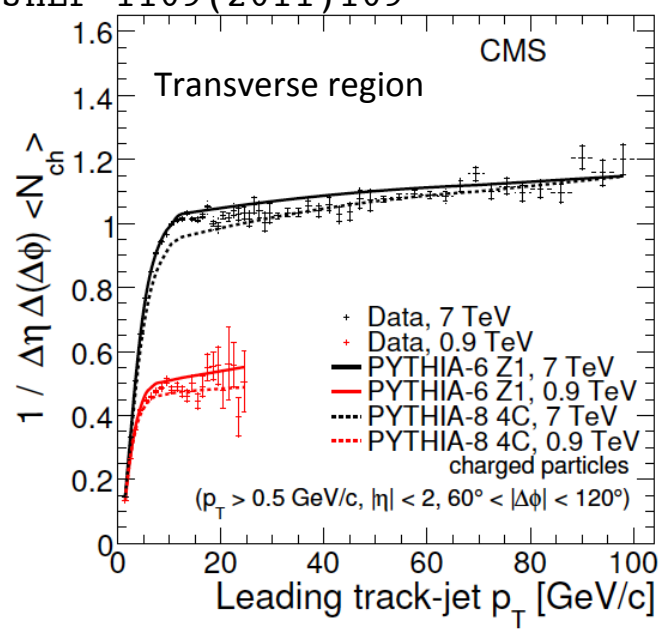
PRD 83(2011)112001



JHEP 1207 (2012) 116



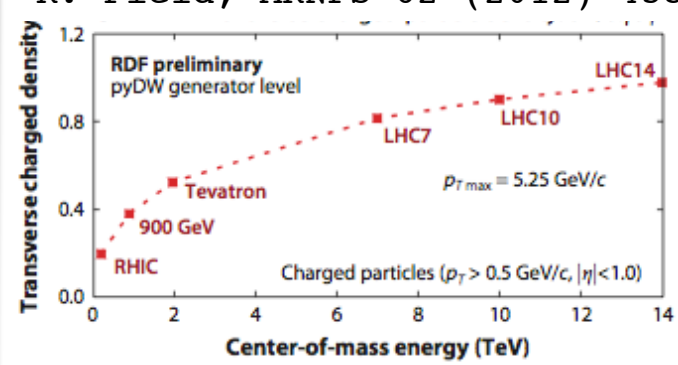
JHEP 1109(2011)109



- first bunch of LHC results with track with highest p_T as leading object
- increasing activity in UE was a prediction of models with MPI
- increase of hadron activity at different √s supports MPI description

predictions (and observables) firmly based on seminal work at Tevatron

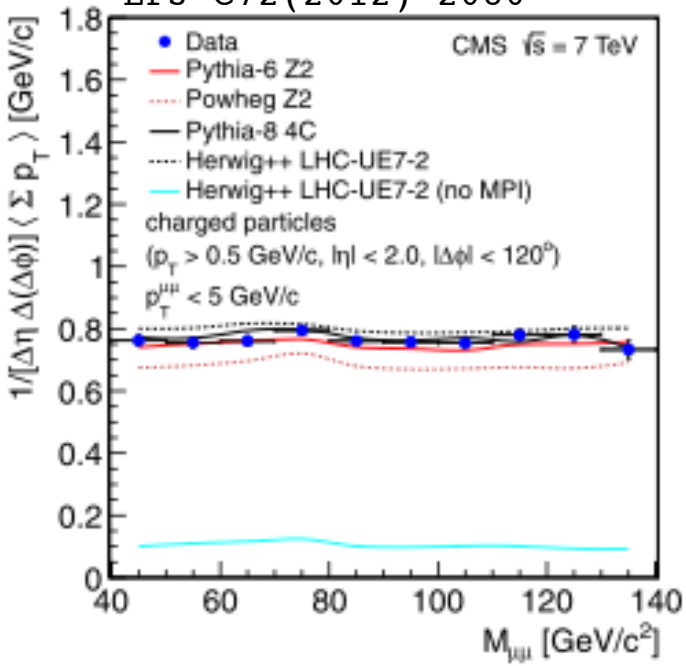
R. Field, ARNPS 62 (2012) 453



P. Antonioli

Refining the traditional approach

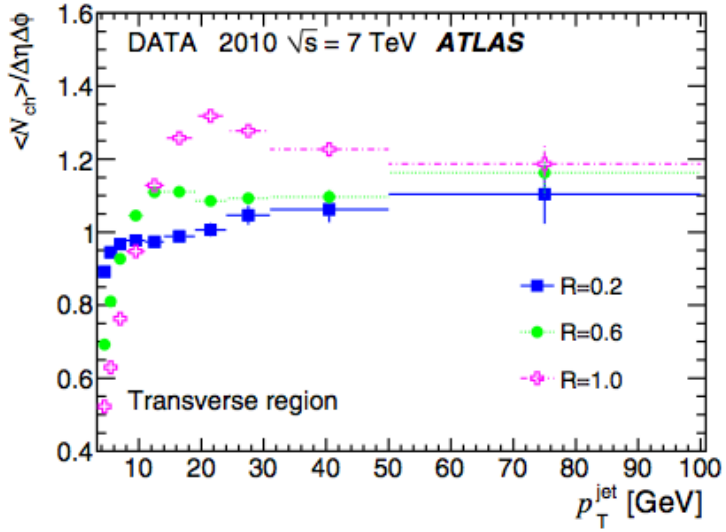
EPJ C72(2012) 2080



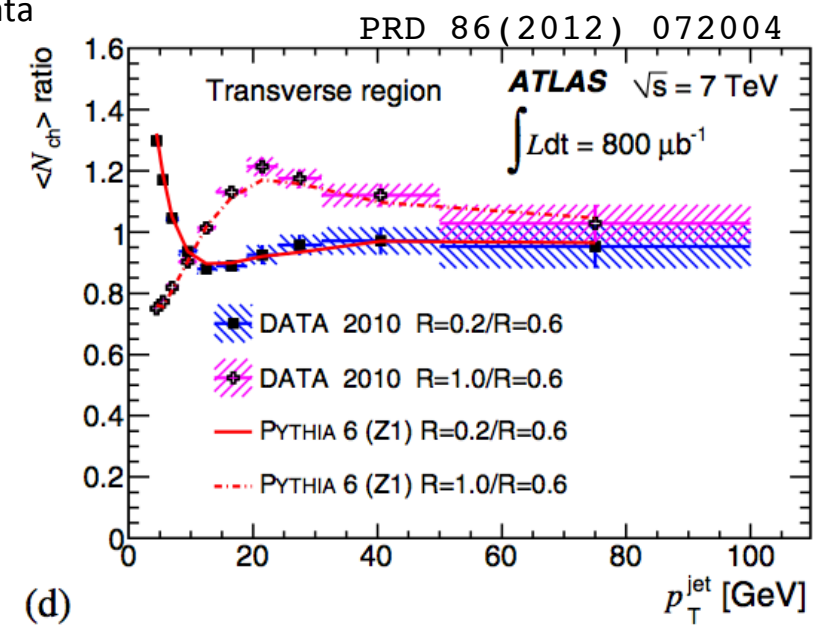
- DY events: test UE universality
- cut on $p^T_{\mu\mu}$ limits ISR presence and "select" MPI
- independence of UE from $M_{\mu\mu}$ indicates MPI constant down to 40 GeV
- [transMAX/MIN/DIF observables (help separation of MPI from ISR/ FSR) studied by ATLAS (ATLAS-CONF-2012-164) at LHC) and CMS (PAS-GEN-14-001)]

- jet as leading object
- study UE activity as a function of R parameter to define the jet → study the interplay between pQCD and soft QCD in MC models
- Pythia 6 LHC-based tunes (as Z1) able to reproduce the pattern seen in the data

PRD 86(2012) 072004



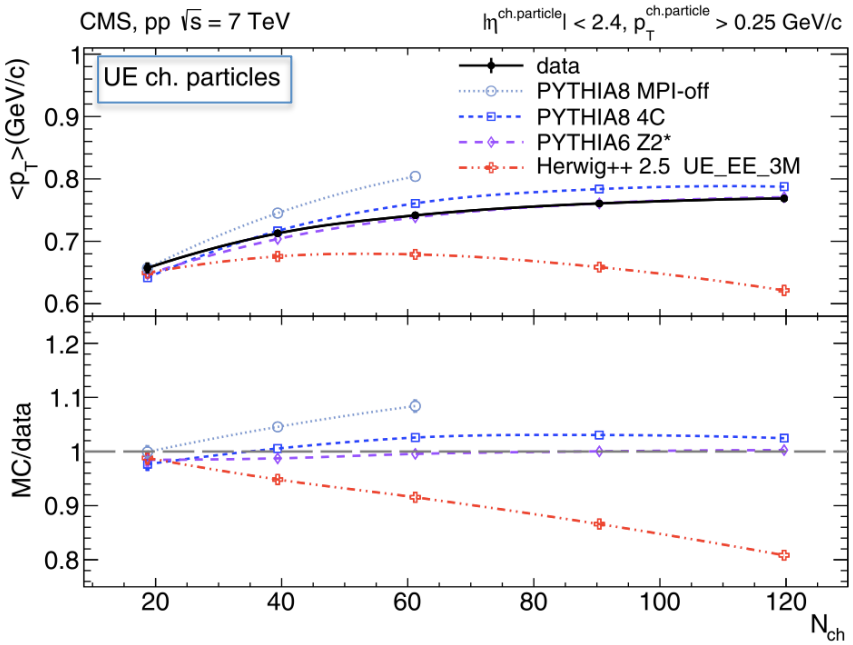
PRD 86(2012) 072004



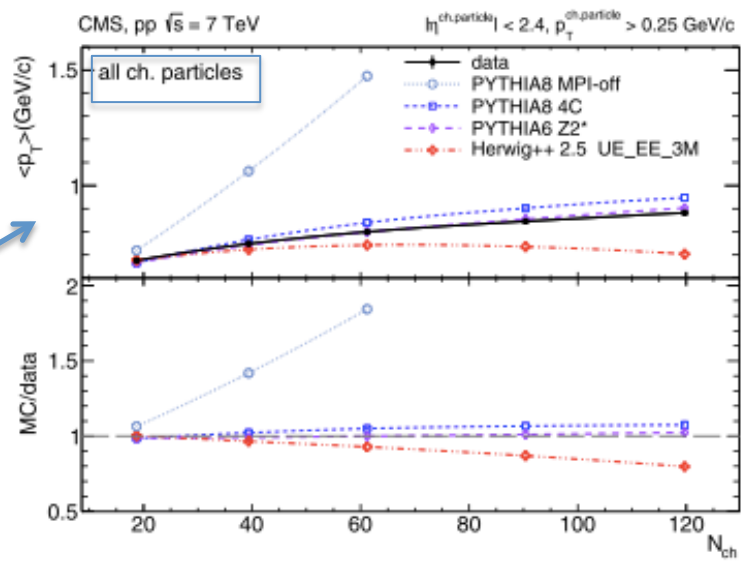
(d)

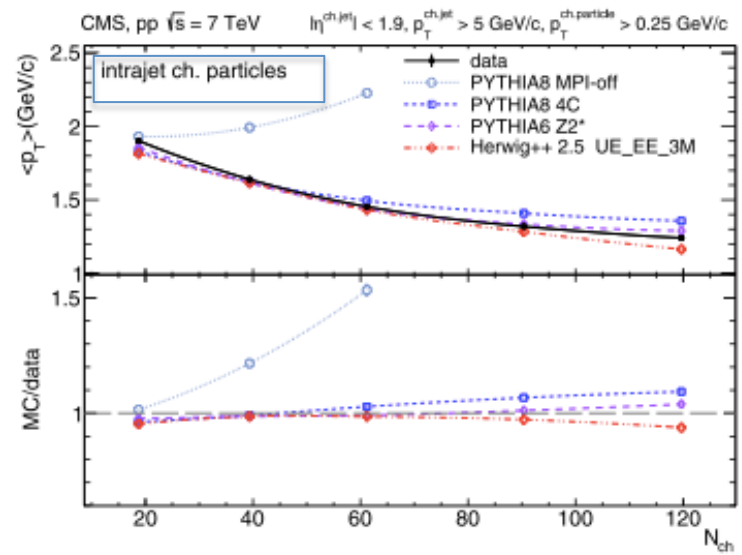
UE: subtracting the jets

CMS, EPJC 73 (2013) 2674



- different approach presented by CMS
- define UE subtracting jets (p_T^{min}>5 GeV/c) and considering everything else as UE (removal of intrajet particles)
- study as a function of multiplicity
- UE behaviour not predicted by HERWIG, PYTHIA predicts harder spectra, failure of prediction not including MPI (more visible for intrajet and all particles)



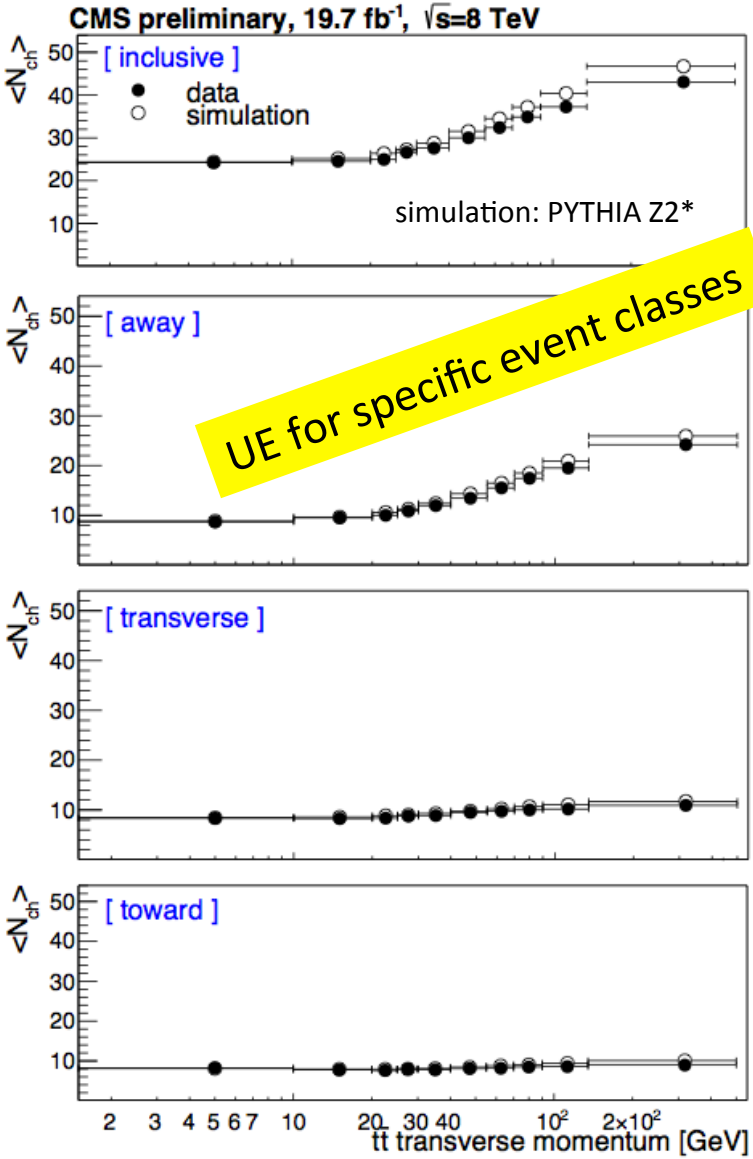


increase with N_{ch} expected by increase of semi-hard scatterings

UE: adding observables and event categories

$t\bar{t}$ events

CMS PAS TOP 13-007



UE for specific event classes

- complementarity to DY due to high FSR expected by b jets
- good agreement with simulation especially at low tt p_T
- CMS is testing different tuning varying factorization/ renorm scale, CR and MPI in these events

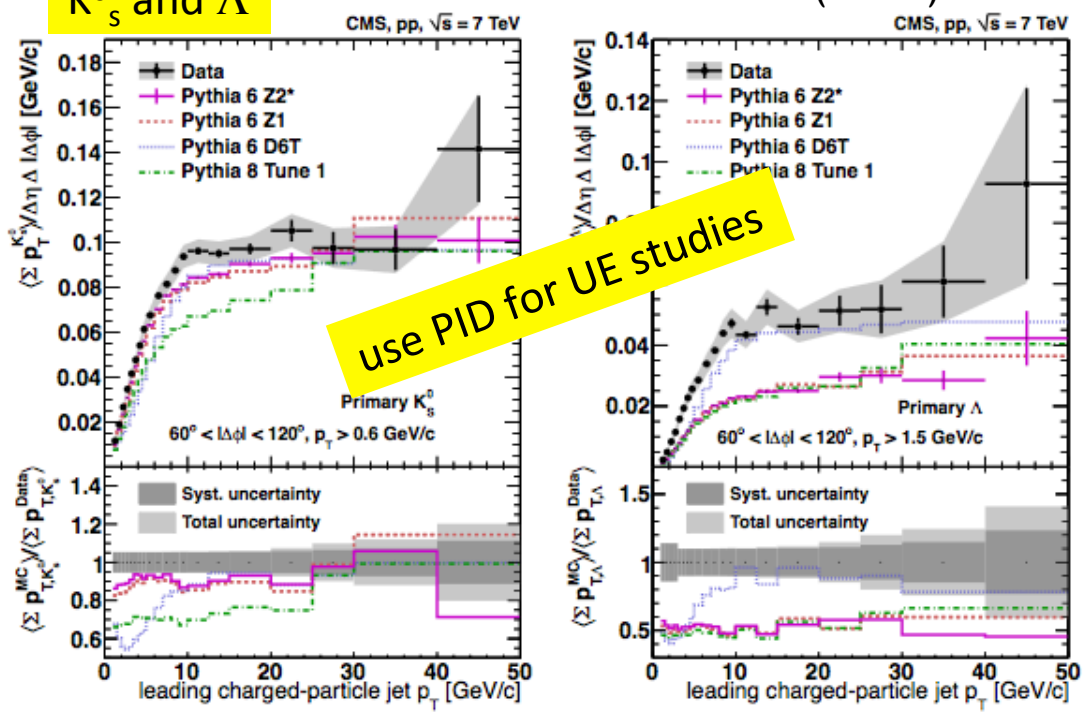
- s underestimation seen in MB is in UE
- similar trends with respect to charged particles (plateau at 10 GeV/c) and for baryon/meson

→ consistent with MPI activity depending on impact parameter

→ hadronization and MPI decoupled

K^0_s and Λ

PRD 88 (2013) 052001



use PID for UE studies

Refining UE studies with jets

arXiv.org > hep-ex > arXiv:1406.0392

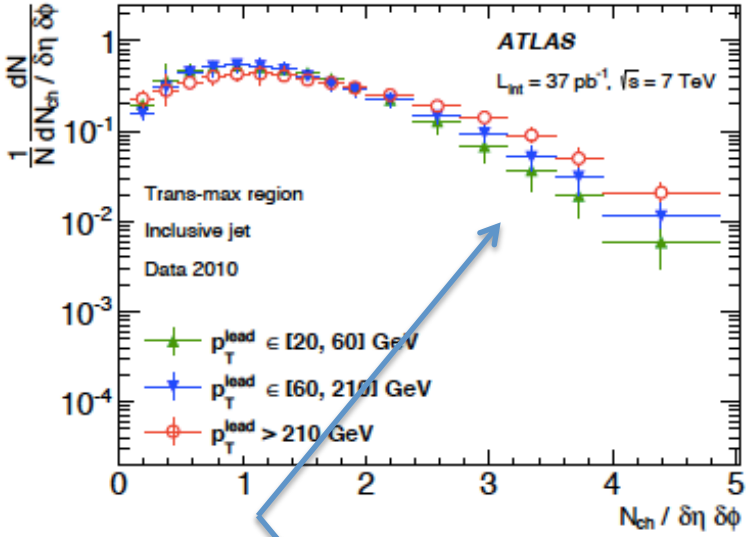
High Energy Physics - Experiment

Measurement of the underly collisions with the ATLAS de

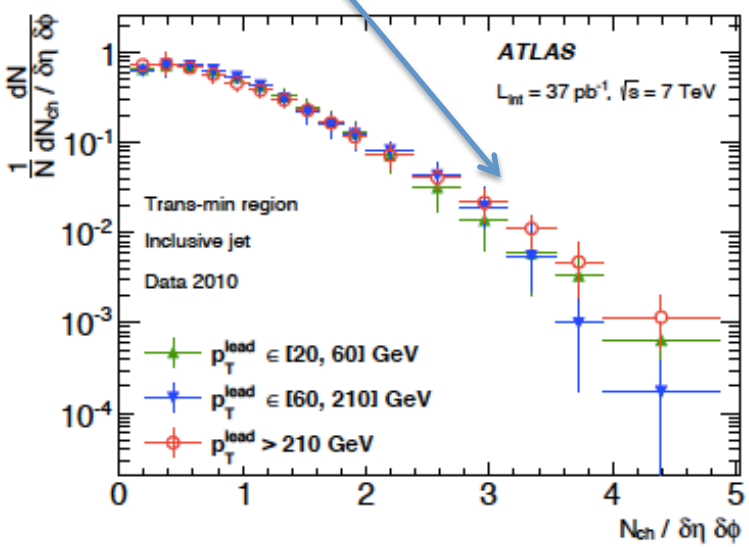
ATLAS Collaboration

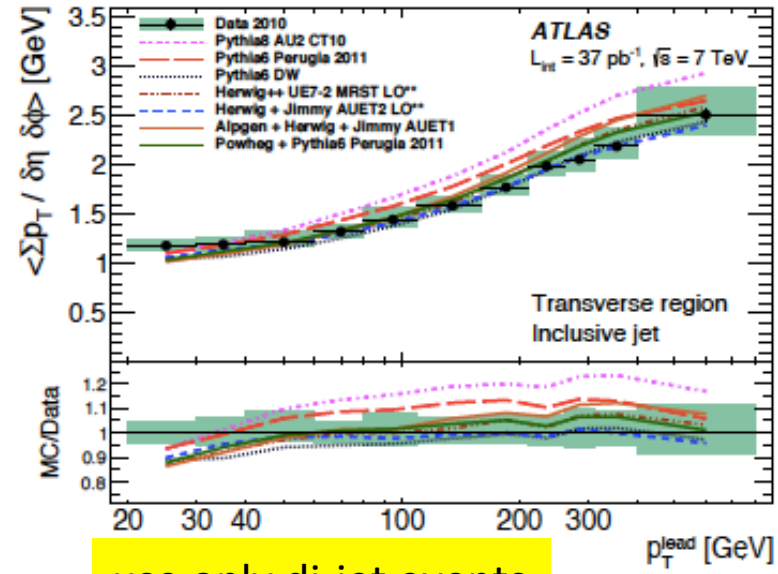
(Submitted on 2 Jun 2014)

use transMAX/MIN

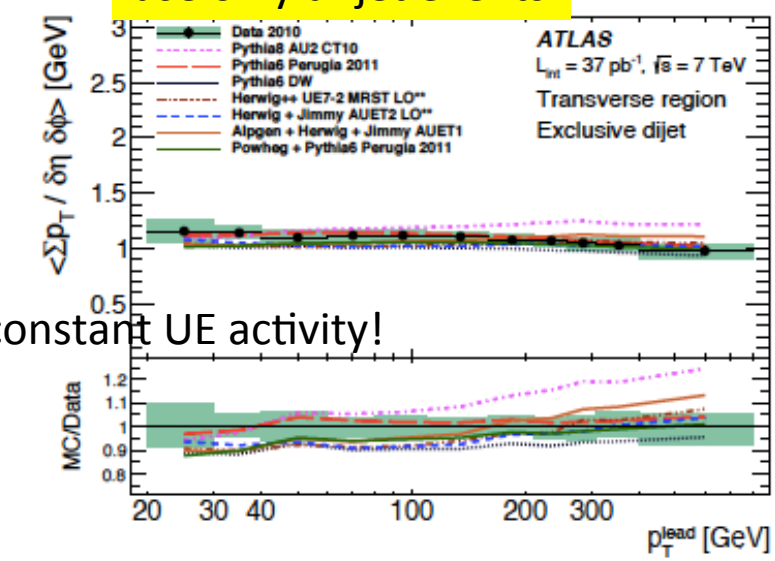


less actiivity in transMIN increasing jet energy





use only di-jet events

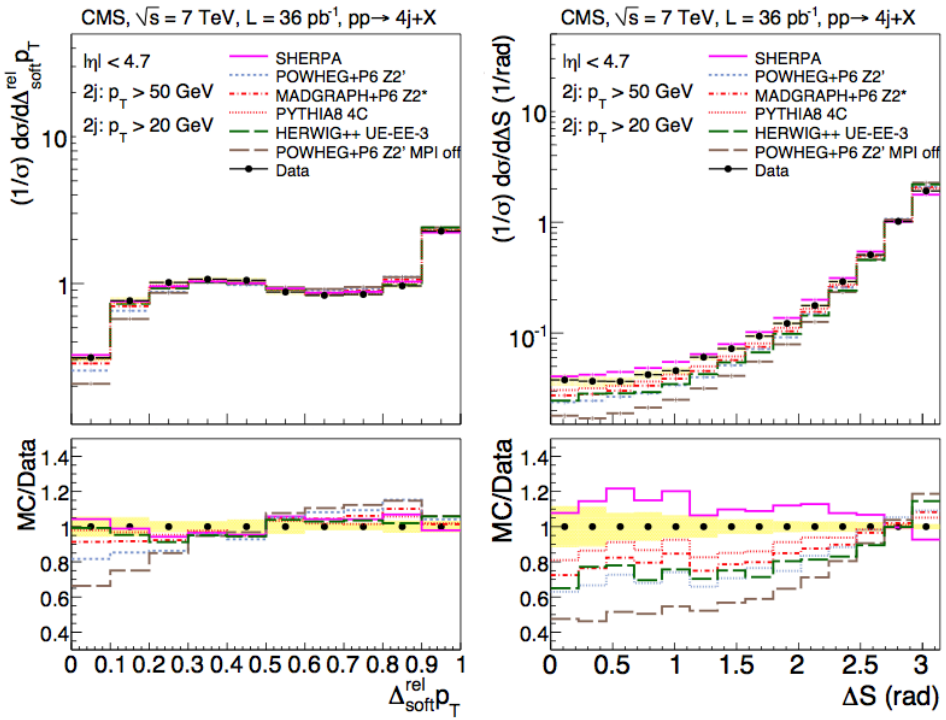


almost constant UE activity!

MPI, DPS and underlying event

Four jets analysis revisited in terms of MPI/DPS

CMS arXiv:1312.6440



(variables relative to the soft pair of jets)

MPI off doesn't describe data: need of additional contributions

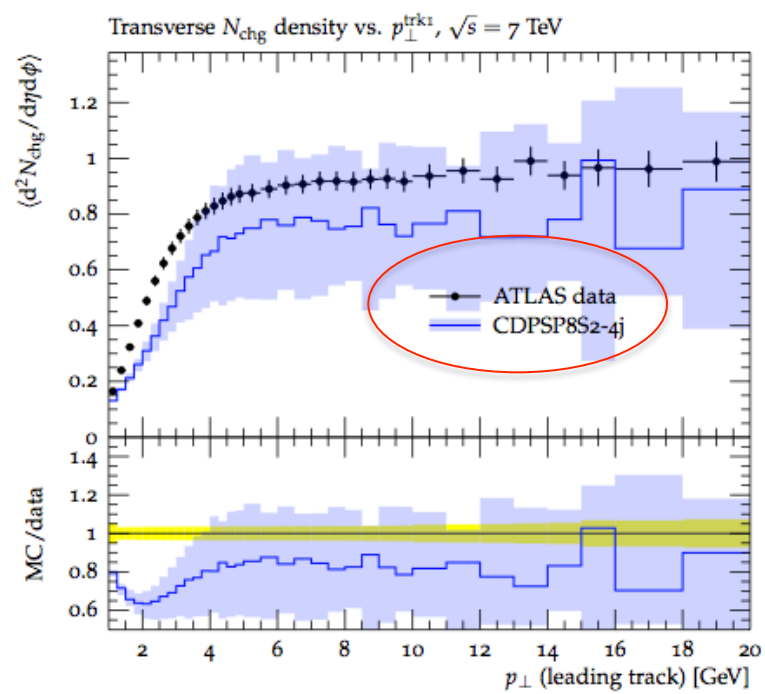
Contribution from SPS can be improved

UE tuning needed before DPS can be extracted

CMS GEN-14-001 PAS "UE Tunes and DPS"

PYTHIA 8Tune	PYTHIA 8 σ_{eff} value (mb)
Tune 4C	30.3
CUETP8S1-CTEQ6L1	$27.8^{+1.2}_{-1.3}$
CUETP8S1-HERAPDF1.5LO	$29.1^{+2.3}_{-2.0}$
CDPSTP8S1-4j	$21.3^{+1.2}_{-1.6}$
CDPSTP8S2-4j	$19.0^{+4.7}_{-3.0}$

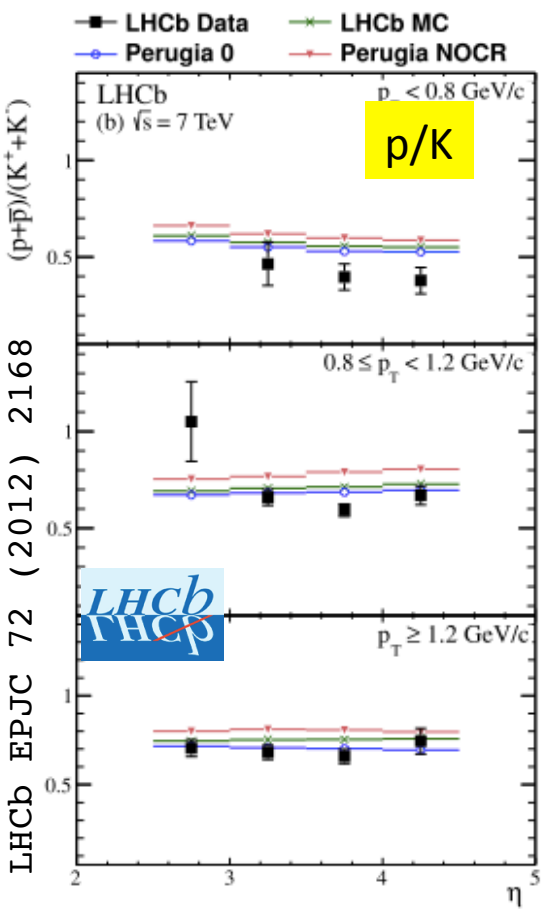
- UE tunes include Fermilab data
- DPS tunes cross-checked against UE: indication of some tension in the simultaneous description of softer and harder MPI
- A HERWIG++ tune with DPS+UE: arXiv:1307.5014 (M.H. Seymour and A. Siódmok)

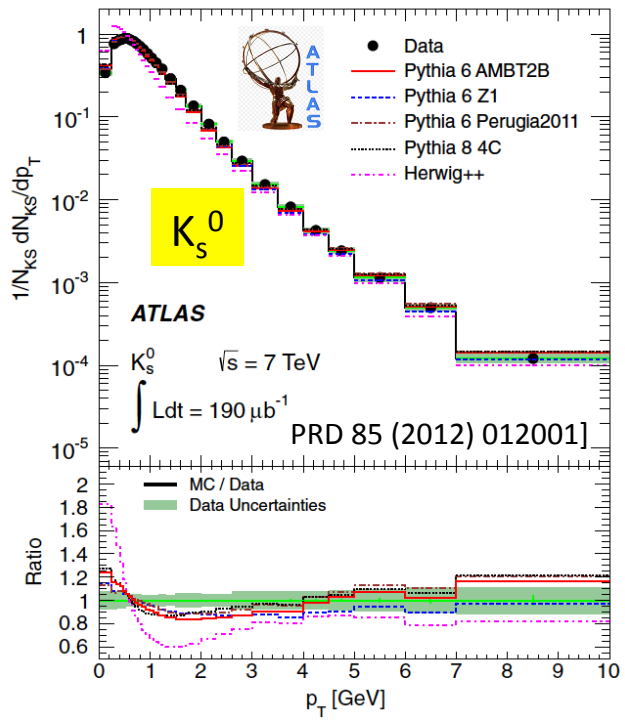


Identified hadrons: some highlights & puzzles

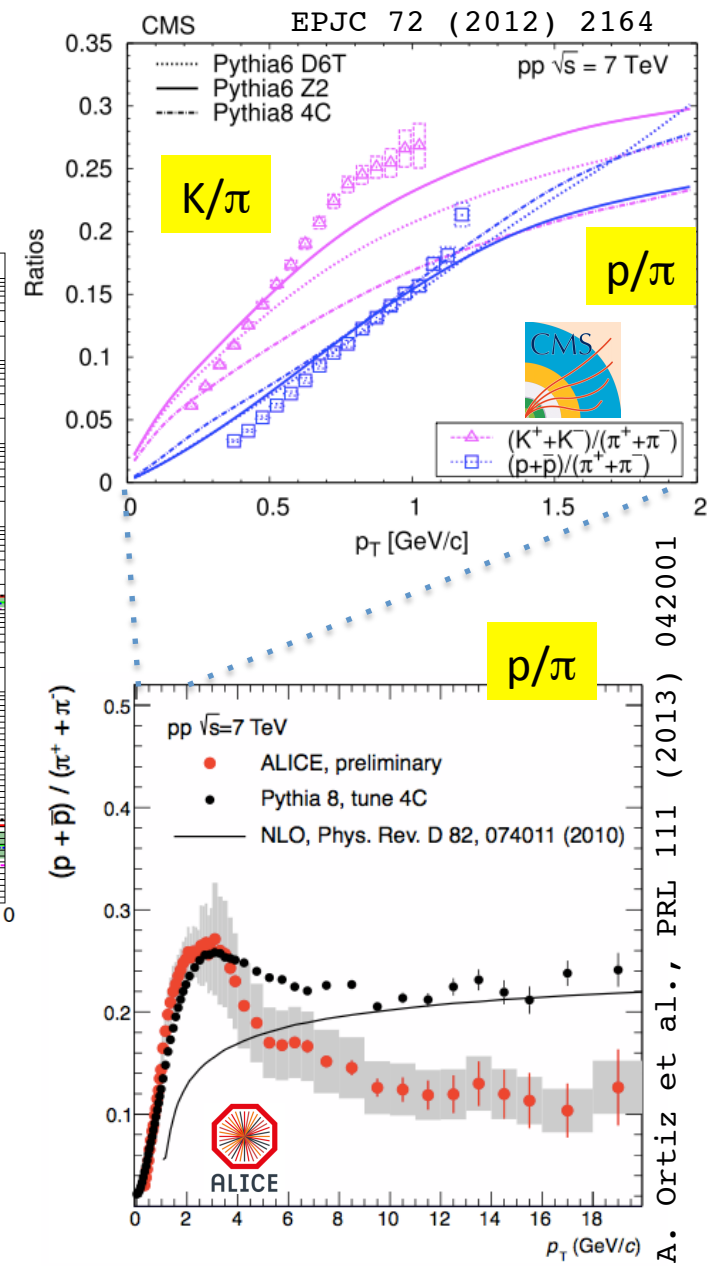
Early results at LHC showed **strangeness** underprediction in the various pre-LHC tunes (CMS JHEP 5 (2011) 64 / ALICE EPJC 71 (2011) 1594 / LHCb PLB 693 (2010) 69). LHC tunes partially addresses this but however fails with multi-strange baryons up to factor 4 [ALICE PLB 712 (2012) 309]

baryon/meson ratio
not well described by PYTHIA



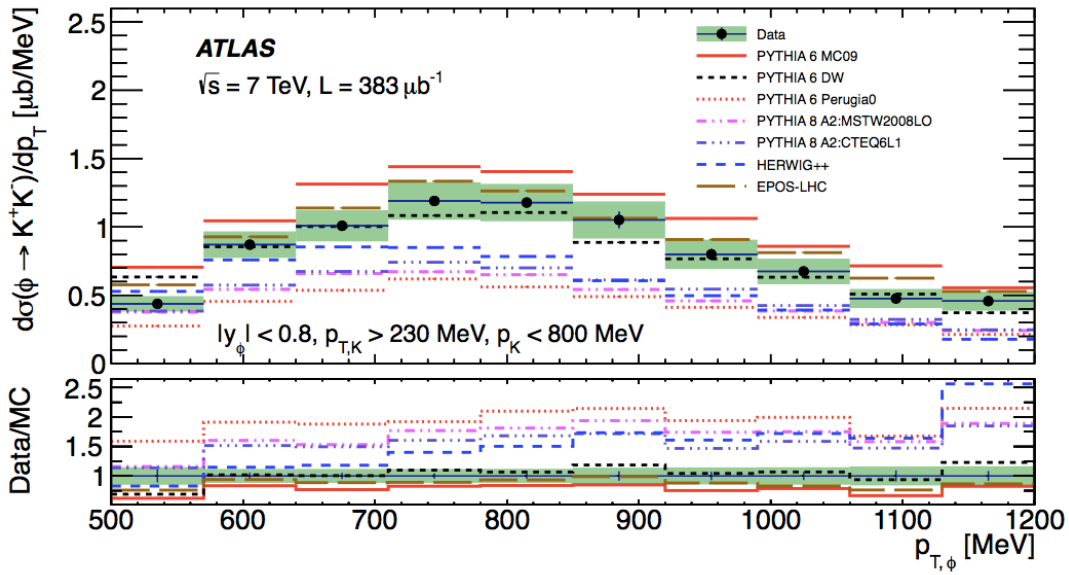


PYTHIA 8 4C with CR helps to describe p/π ratio up to 4 GeV/c, but CR helps less at LHCb rapidities for p/K, especially at very low p_T



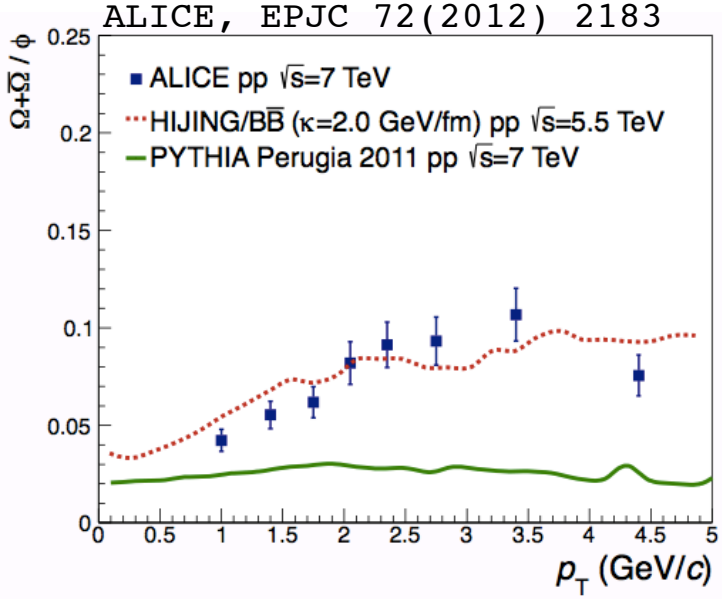
Strangeness at LHC in pp is still strange...

ATLAS arXiv:1402:6162



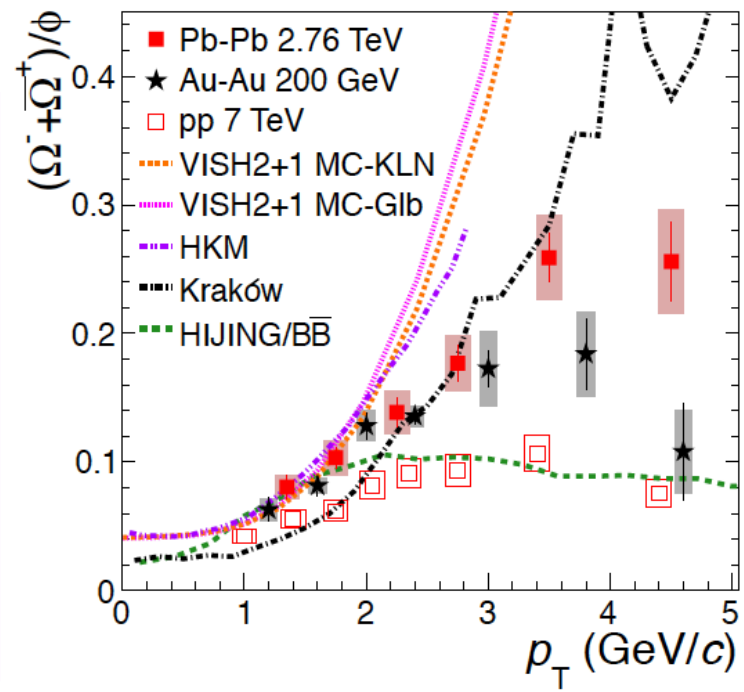
Recent result from ATLAS on ϕ favours EPOS LHC (which has 'collective' hadronization via flow), PYTHIA 6 DW (pre-LHC tune CDF tuned + virtuality-ordered parton shower) while more recent PYTHIA 6 or 8 tunes are disfavoured

ALICE, EPJC 72(2012) 2183



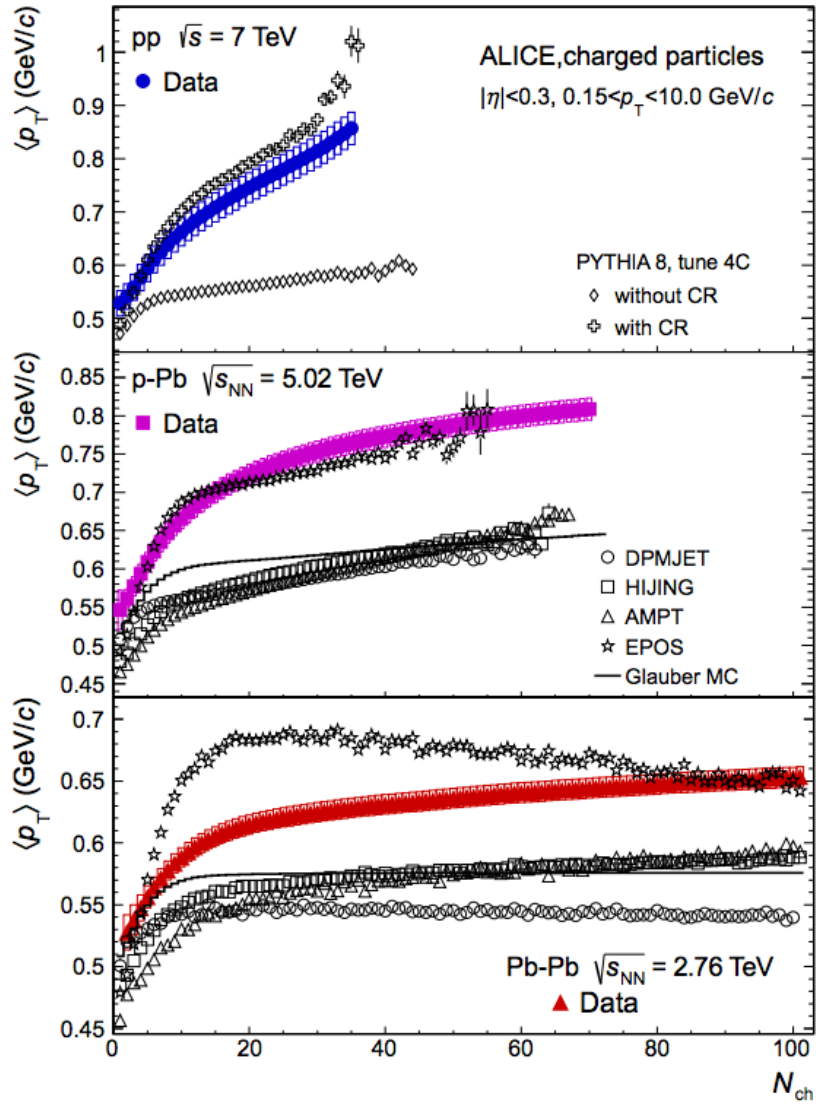
- ALICE noted better agreeement with HIJING/BB for Ω/ϕ ratio in pp, but this doesn't fit PbPb data
- soft particles produced via string fragmentation in HIJING/BB and string tension influences strangeness yield

ALICE arXiv:1404.0495



Particle production and multiplicity (I)

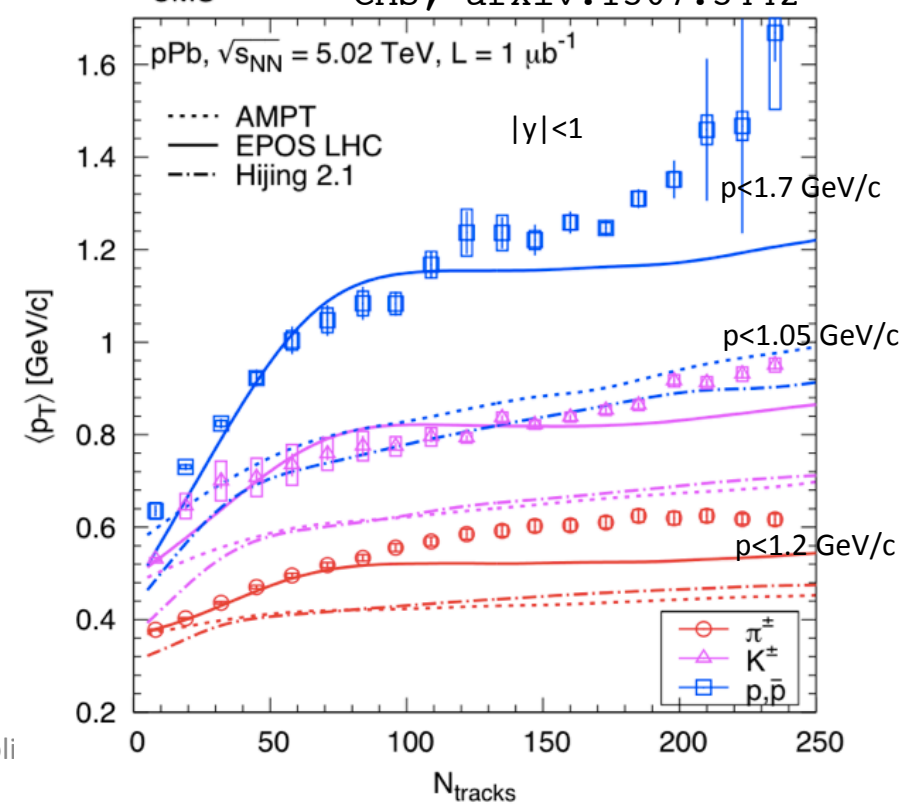
ALICE, PLB 727(2013) 371



PYTHIA with color reconnection enabled gives better description of data

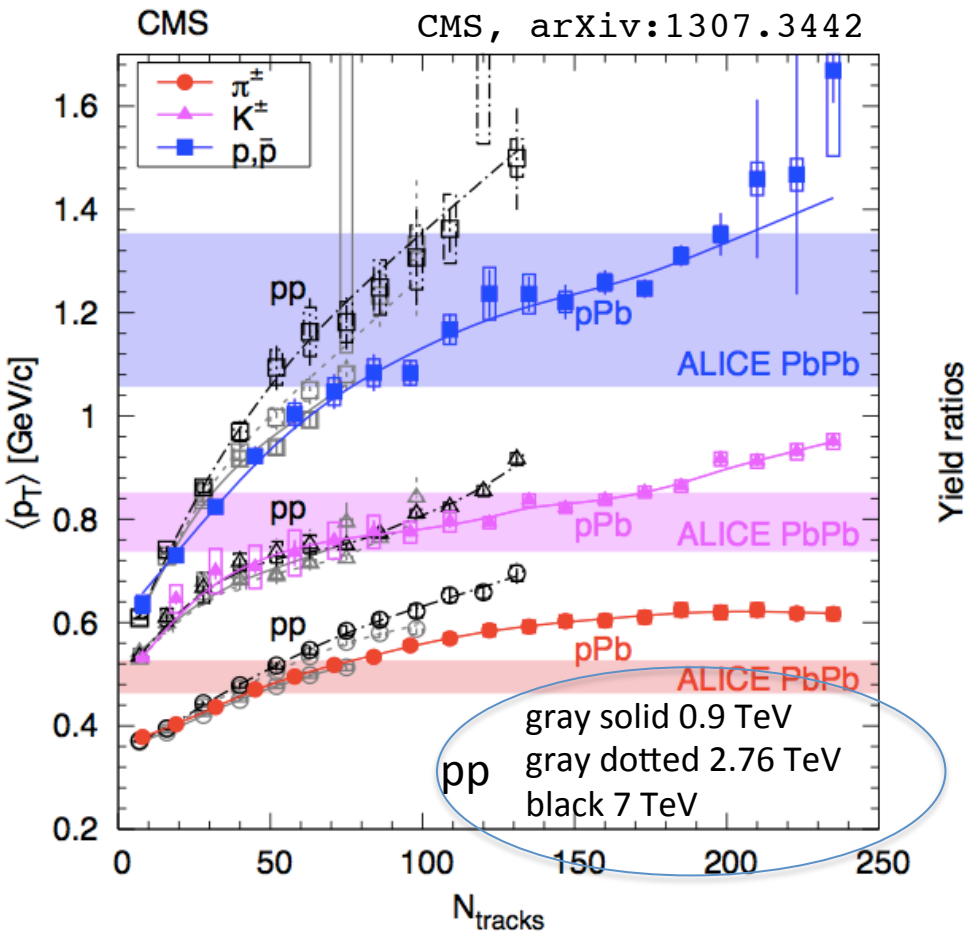
- In pPb EPOS describes data where others fail, but has different trend at low p_T. A pure superposition Glauber model sits similar with DPMJET, HIJING, AMPT
- Same study from CMS with identified particles and larger multiplicities

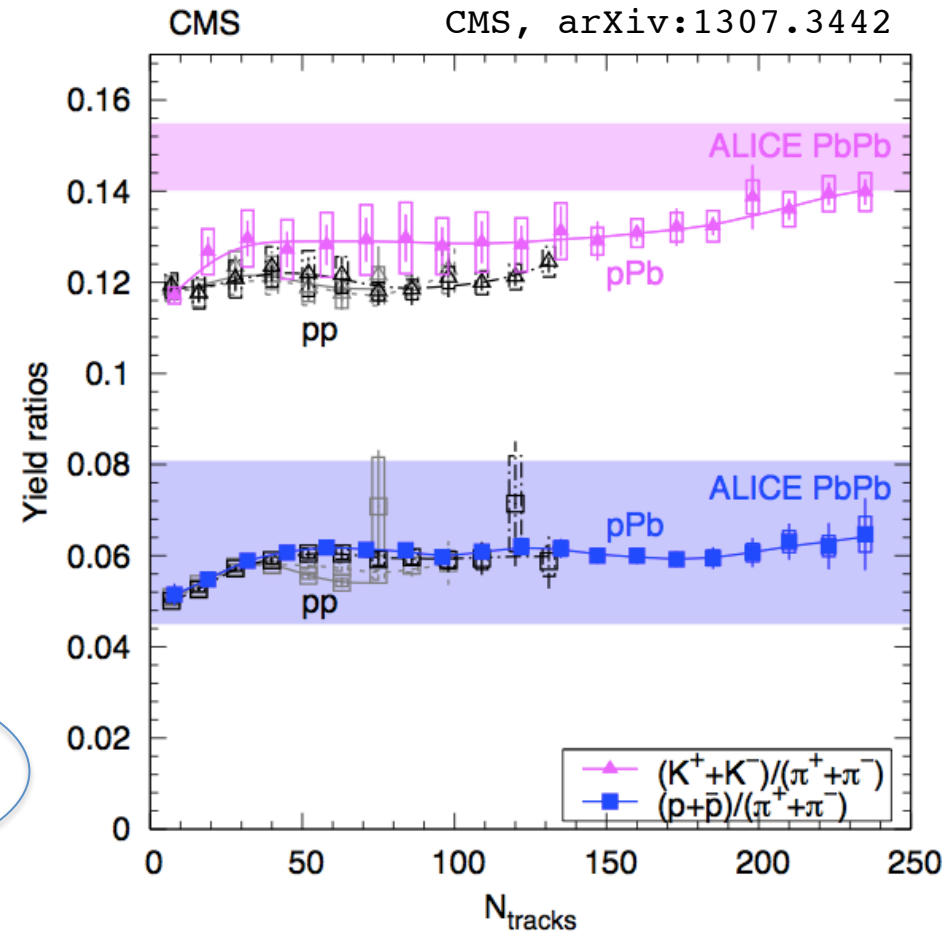
CMS, arXiv:1307.3442



(let's leave PbPb for the heavy ions session)

Particle production and multiplicity (II)



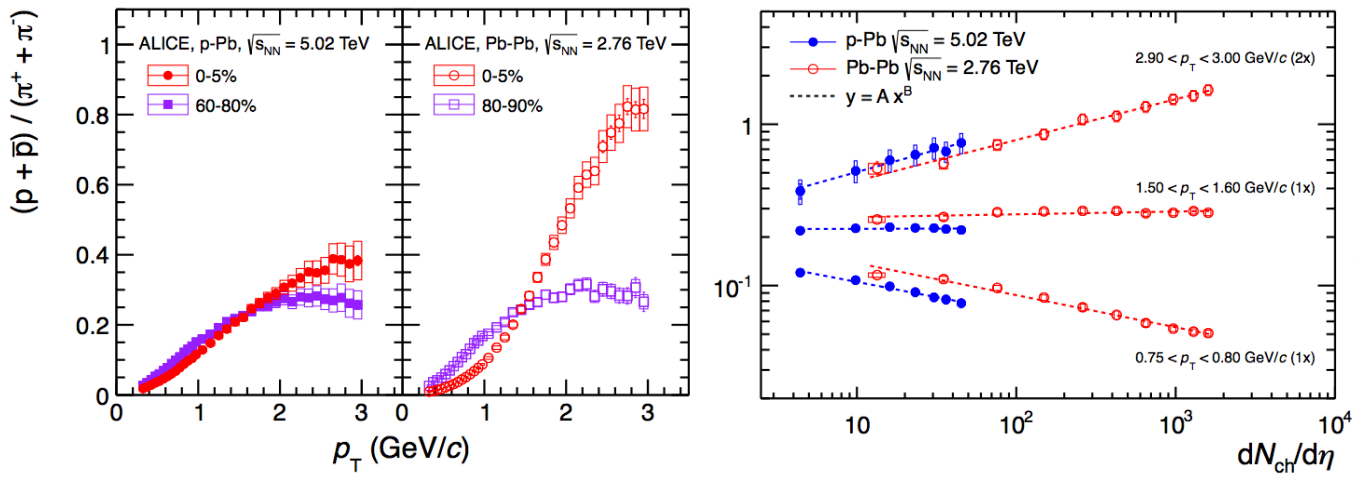


- particle production strongly correlated to multiplicity (more than collision system or center-of-mass energy)
- yields similar in pp pPb

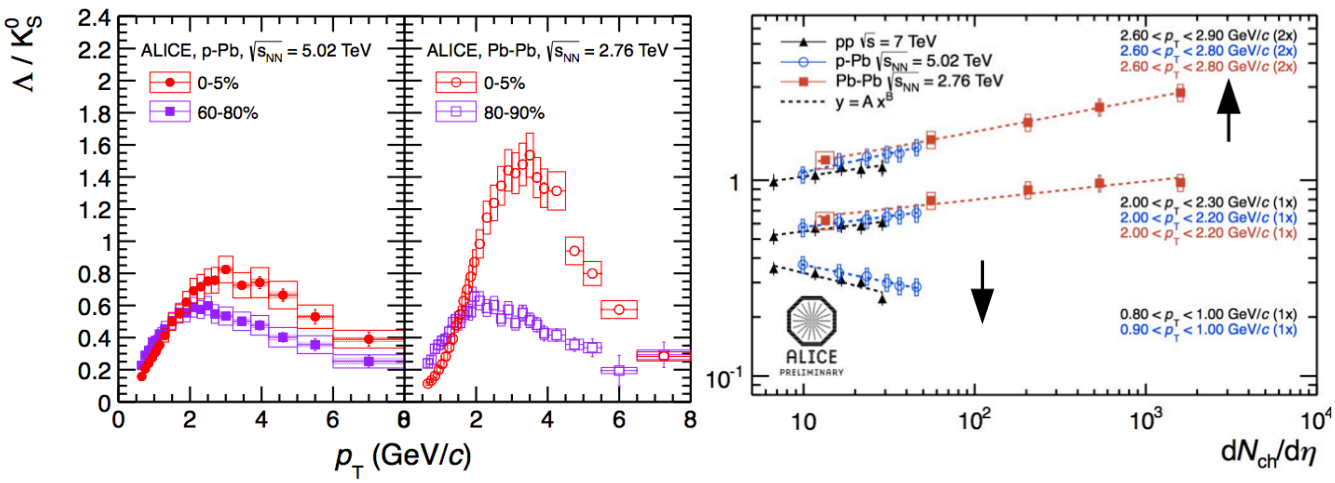
More to come in the heavy ions session!

Particle production and event multiplicity (III)

ALICE, PLB 728(2014) 25



evolution of ratios differs but it has same scaling at fixed p_T values as a function of $dN_{ch}/d\eta$



the same for Λ/K^0_s where pp is also shown

(and Λ/K^0_s ratio overestimated by HIJING/$B\bar{B}$ model with increased string tension (which works for Ω/ϕ))

More to come in the heavy ions session!

Summary and outlook

- Increased comprehension of the role played by MPI at LHC energies seen through different studies/approaches (DPS, correlations, UE).
- Processes directly sensitive to DPS now measured at LHC. Contribution from DPS generally brings predictions closer to measurements. More observables expected in run2.
- Specific UE measurements in different categories of events are emerging further constraining models and tunes. Attempts to dovetail MPI, DPS and UE description in MC tunes all together on-going.
- Strangeness and baryon/meson ratio remain areas where we need to improve predictions/understanding of mechanisms.
- From identified hadrons (and charged hadrons observables) we have a pattern of indications pointing to a better data agreement with MC predictions when we add some 'collectivity' like CR or hydro (EPOS LHC). We observe particle production features more correlated with event multiplicity than collision system.

<u>In all these studies:</u>

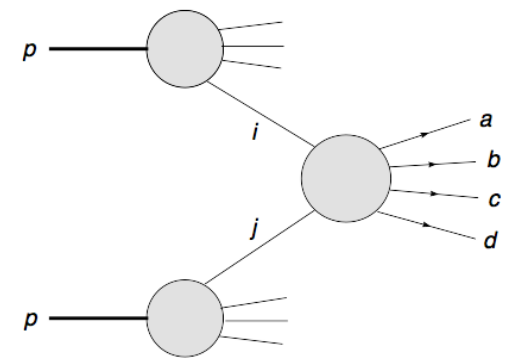
- pPb (and PbPb) collisions at LHC could be much more revealing than originally expected
- LHC@14 TeV will be an excellent test opportunity of what we learned during first 5 years of LHC era

Backup

Double Parton Scattering

Single Parton Scattering: usual pQCD factorization

$$d\sigma^{SPS} = \sum_{i,j} \int D^i(x_1) \cdot D^j(x_2) d\sigma_{(ij \to abcd)}(x_1, x_2) dx_1 dx_2$$



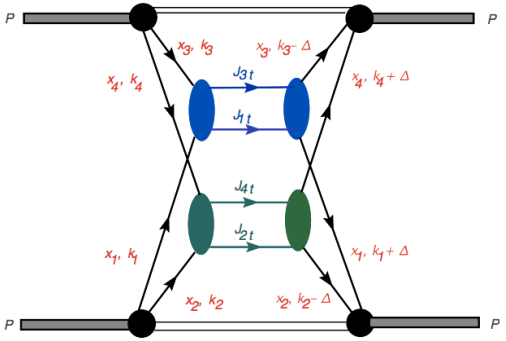
Double Parton Scattering formalism

R. Block, Yu. Dokshitzer et al., EPJ C72 (2012) 1963

$$\sigma_4 = \int \frac{d^2\vec{\Delta}}{(2\pi)^2} \int dx_1 \int dx_2 \int dx_3 \int dx_4 \times D_a(x_1, x_2, p_1^2, p_2^2, \vec{\Delta}) D_b(x_3, x_4, p_1^2, p_2^2, -\vec{\Delta}) \times \frac{d\sigma^{13}}{d\hat{t}_1} \frac{d\sigma^{24}}{d\hat{t}_2} d\hat{t}_1 d\hat{t}_2$$

generalized two-parton distributions

$$\sigma_4 = \sigma_1 \sigma_2 / \pi R_{\rm int}^2 \quad \frac{1}{\pi R_{\rm int}^2} = \int \frac{d^2\vec{\Delta}}{(2\pi)^2} \frac{D(x_1, x_2, \vec{\Delta}) D(x_3, x_4, -\vec{\Delta})}{D(x_1) D(x_2) D(x_3) D(x_4)} = \frac{1}{\sigma_{eff}}$$



σ_{eff} measures the size of the partonic core where the flux of short-distance partons is confined

→ not really a cross section…

→ proportional to the transversal area of parton overlap

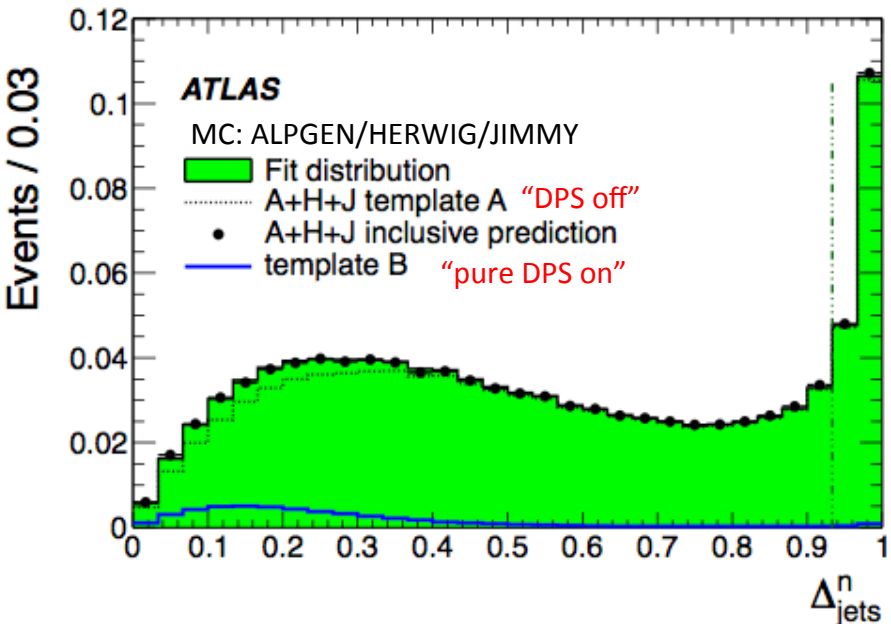
→ reflects longitudinal correlations of partons

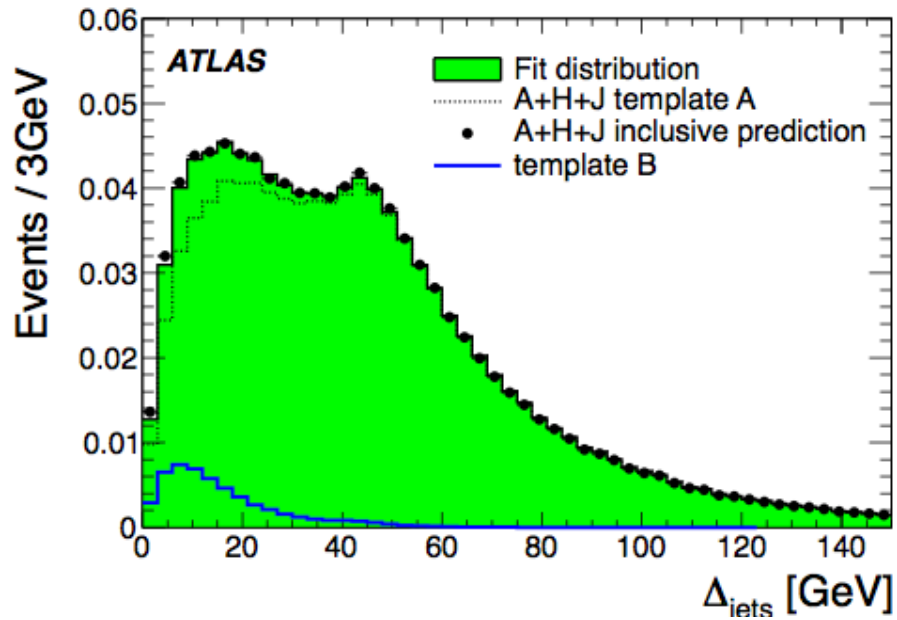
→ DPS probes hadronic structure!

DPS variables in W+2jets

Both ATLAS and CMS construct templates to fit 'DPS discriminating variables'

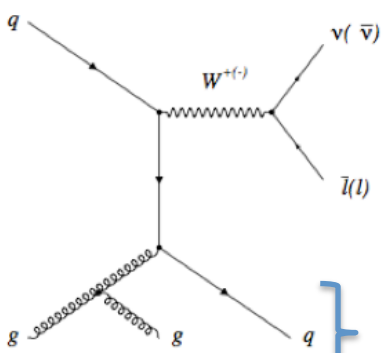
New J. Phys. 15 (2013) 033038





$$\Delta^{n}_{jets} = \frac{|\vec{p}_T^{J_1} + \vec{p}_T^{J_2}|}{|\vec{p}_T^{J_1}| + |\vec{p}_T^{J_2}|}$$

$$\Delta_{jets} = |\vec{p}_T^{J_1} + \vec{p}_T^{J_2}|$$



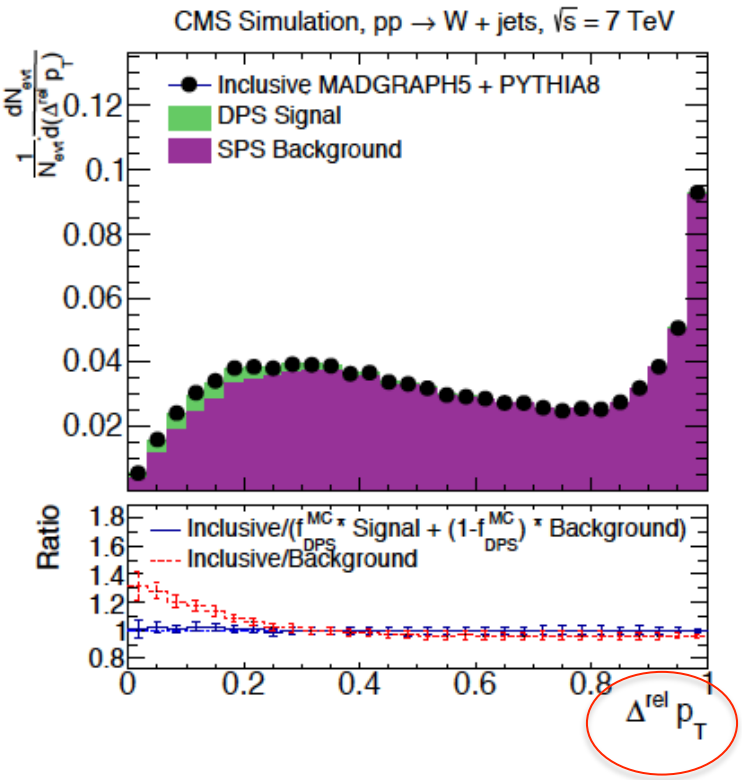
General challenge about how to correctly switch DPS off in MC, choice of a p_T^{max} scale to separate 'soft MPI' from hard DPS

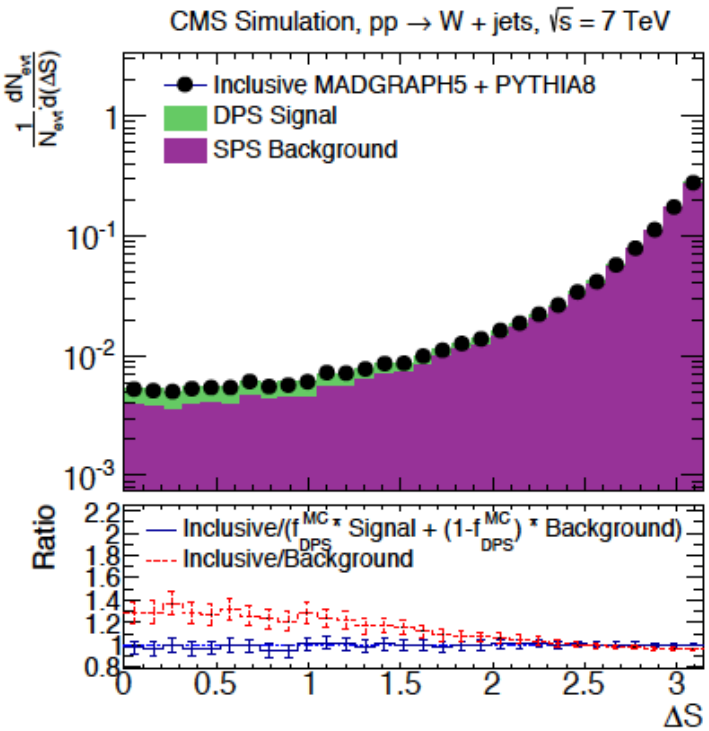
di-jet system not back to back in SPS

DPS variables in W+2jets

Both ATLAS and CMS construct templates to fit 'DPS discriminating variables'

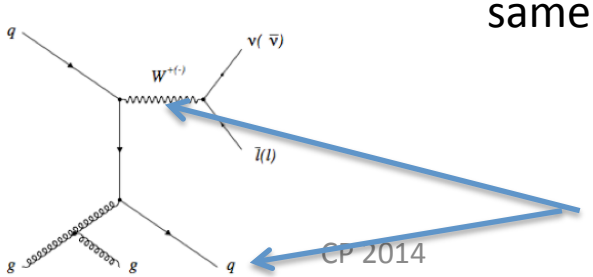
JHEP 03 (2014) 032





same as Δ^{n}_{jets} as ATLAS

azymuthal angle between the W and the di-jet system

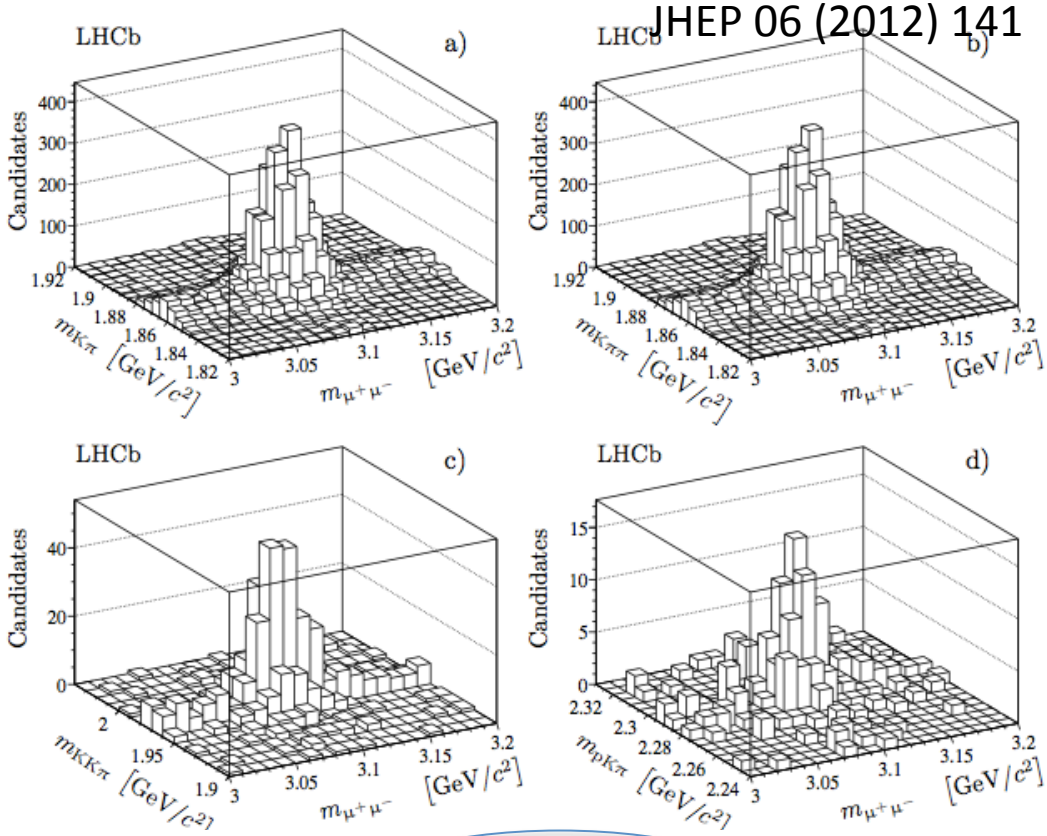


back-to-back at L0 in SPS

DPS: J/ψ and open charm mesons

JHEP 06 (2012) 141

$\mathcal{L}$=355 pb^{-1}



- J/ψ identified in di-muon channel
- Double open charm mesons: CC
- $C\overline{C}$ as control channel

DPS expected dominant over gg but contribution from sea quark can be bigger

Global fit of 2D mass invariant distributions of events with with J/ψ and C, or CC events to establish global yields

$$F(m_i, m_j) \propto N^{S_i \times S_j} \times S_i(m_i) S_j(m_j) + N^{S_i \times B_j} \times S_i(m_i) B_j(m_j)$$
$$+ N^{B_i \times S_j} \times B_i(m_i) S_j(m_j) + N^{B_i \times B_j} \times B_i(m_i) B_j(m_j),$$

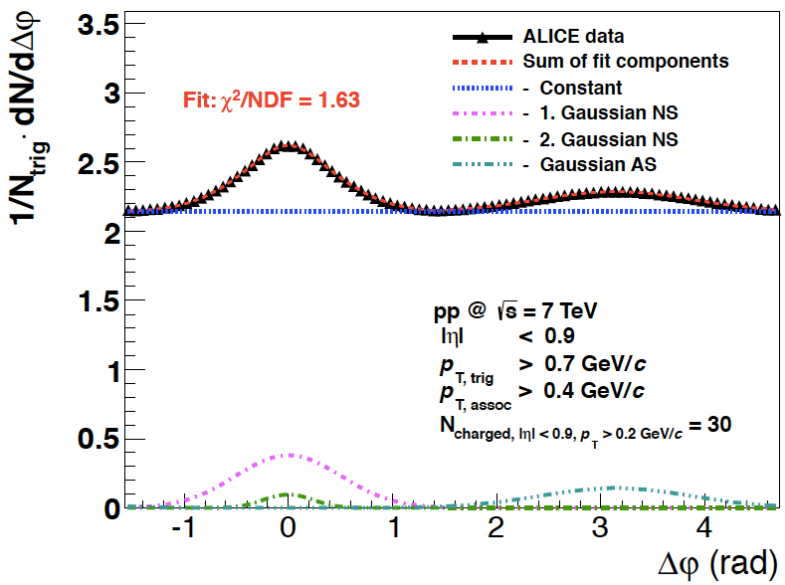
di-charm signal

B=combinatorial background

MPI and correlation studies: uncorrelated seeds

two particle azymuthal correlations in pp and pPb
→ information on parton fragmentation at low p_T
→ contribution of MPI to particle production

p_T^{trig}>0.7 GeV/c
p_T^{ass}>0.4 / 0.7 GeV/c



$$\langle N_{\text{assoc, near-side}} \rangle = \frac{\sqrt{2\pi}}{N_{\text{trigger}}} (A_1 \cdot \sigma_1 + A_2 \cdot \sigma_2)$$

$$\langle N_{\text{assoc, away-side}} \rangle = \frac{\sqrt{2\pi}}{N_{\text{trigger}}} (A_3 \cdot \sigma_3)$$

$$\langle N_{\text{trigger}} \rangle = \frac{N_{\text{trigger}}}{N_{\text{events}}}$$

$$\langle N_{\text{uncorrelated seeds}} \rangle = \frac{\langle N_{\text{trigger}} \rangle}{\langle 1 + N_{\text{assoc, near+away}, p_T > p_{T,\text{trig}}} \rangle}$$

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<u>The basic idea</u>:

1) parton scatterings produced back-to-back in azimuth
→ correlated bundles of particles from different sources
2) at increasing multiplicity, MPI increase
→number of sources ("uncorrelated seeds") of correlated particles increases

$N_{unc.seeds} \propto N_{MPI}$ in PYTHIA