Can the Underlying Event be Hard?

Measuring the Double Parton Scattering (DPS) in ALICE

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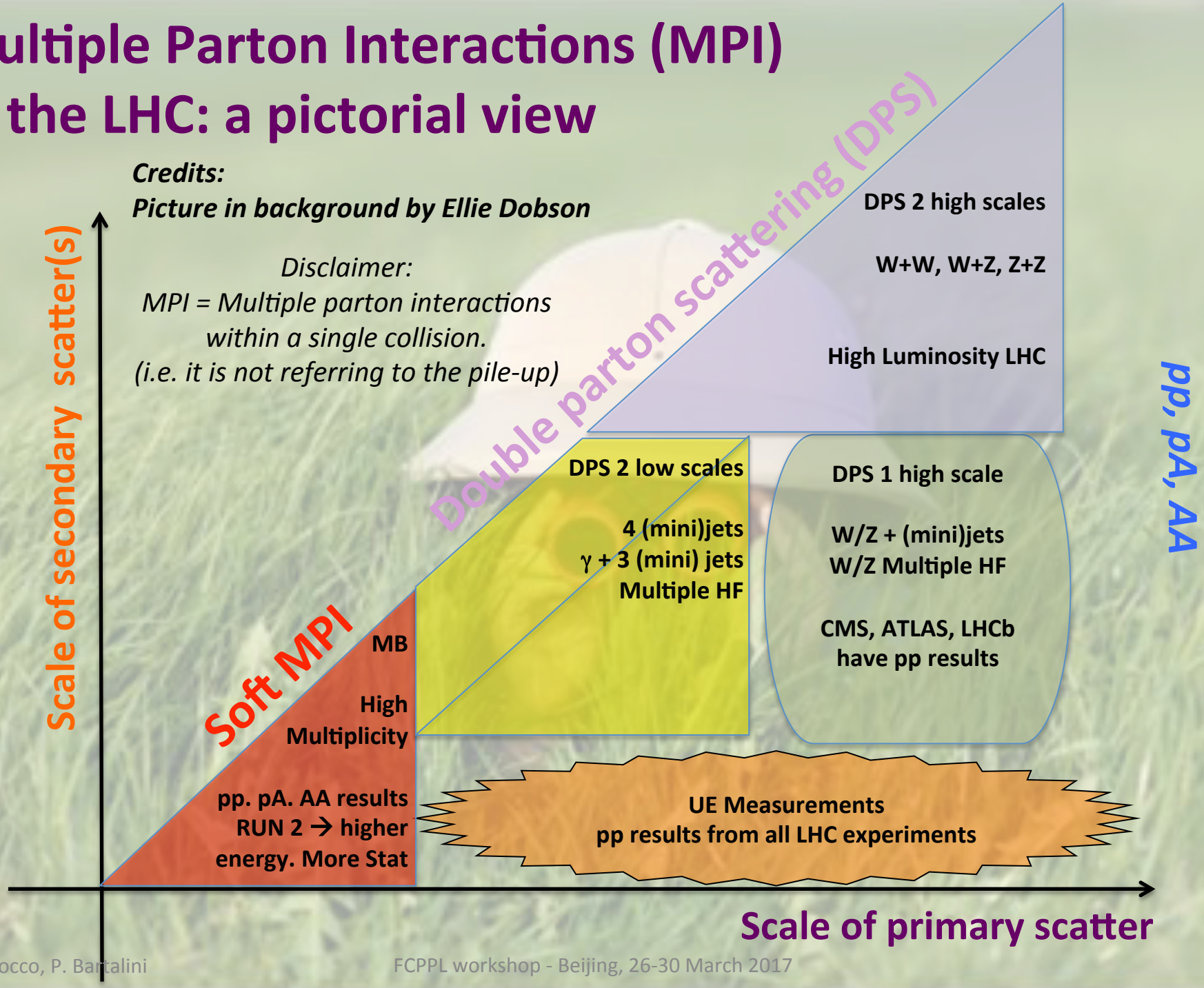
Outline

- **Introduction**
  - Double Parton Scattering (DPS)
  - Underlying Event (UE)
- **UE measurement with ALICE**
- **DPS with ALICE: feasibility study**
- **Conclusions & outlook**

Multiple Parton Interactions (MPI) at the LHC: a pictorial view

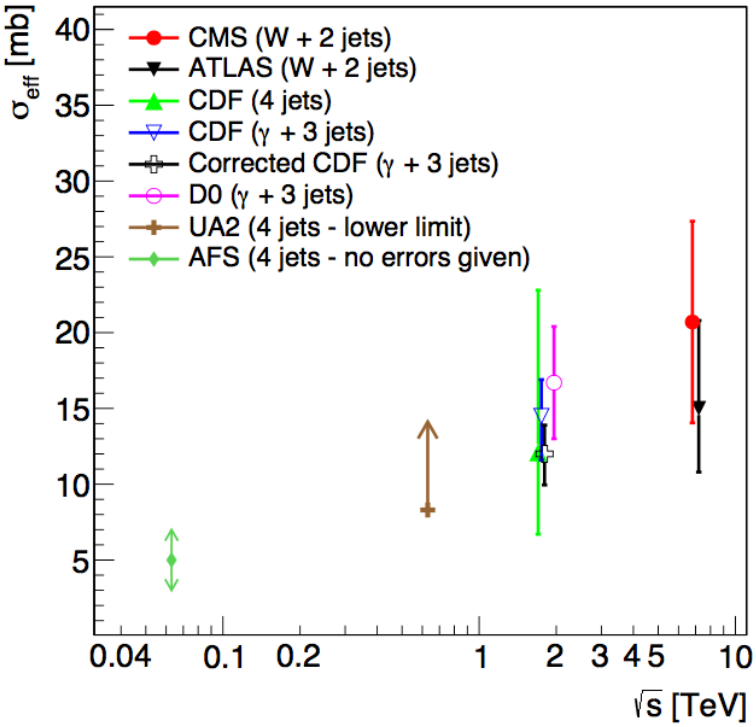


DPS & The Effective Cross Section σ_{eff}

- **$\sigma_{DPS}(A+B+X) = m * \sigma(A+X) * \sigma(B+X) / \sigma_{eff}$**
  - m = ½ for identical interactions, m = 1 otherwise
  - Probabilistic interpretation: $P(B|A) = P(B) * (\sigma_{inel}/\sigma_{eff})$
  - Formalism applies to inclusive processes only
  - σ_{eff} can be regarded as a hadronic form factor
  - Huge ongoing TH effort to understand correlations: IP, Flavour, Spin, Color, …
- **Under the assumption of no correlations:**
  - σ_{eff} ≈ geometrical quantity, in principle scale and √s independent [D.Treleani et al.]
  - Prediction: σ_{eff} = 20÷60 mb
- **Measurements use the relationship in the following way:**
  - $\sigma_{eff} = m * \sigma(A+X) * \sigma(B+X) / \sigma_{DPS}(A+B+X)$
  - Need an accurate Single Parton Scattering (SPS) background
  - Checking Scale and √s independency is in the EXP TODO list
  - Statistics often limits the possibility to extract σ_{eff} in a differential way

Measurement of σ_{eff}

- First results on 4jets already 30 years ago: AFS , UA2: $\sigma_{eff} < 10$ mb
- Tevatron measurements from the years nineties: $\sigma_{eff} \approx 10 \div 15$ mb
- Insufficient effort on background modeling in early measurements!
- LHC (W+2jet, etc.) $\sigma_{eff} \approx 15 \div 20$ mb
  - Compatible with the Underlying Event measurement!
  - $\langle N_{MPI}\,(UE)\rangle / \langle N_{MPI}\,(MB)\rangle \approx \sigma_{inel} / \sigma_{eff}$



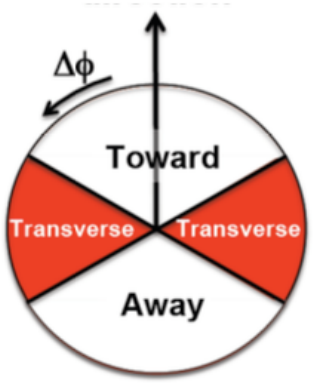
Large systematics from SPS background modeling

[JHEP 03 (2014) 032]

The Underlying Event (UE)

- Measuring the complementary activity in the presence of a leading interaction (usually a hard scattering)

Leading object (i.e. track, charged jet, jet, γ, Z, etc.)

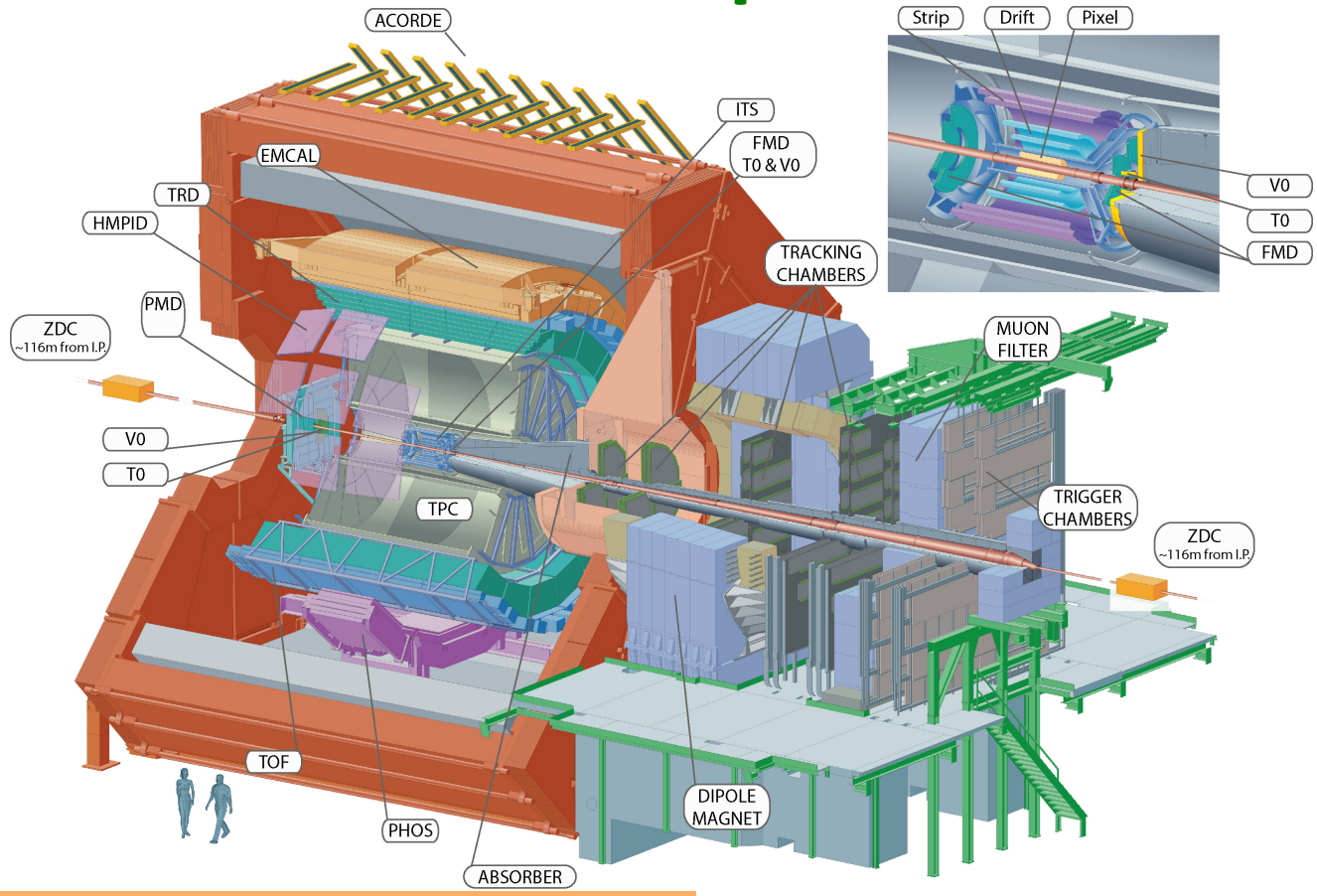


Toward: $|\Delta\phi|<\pi/3$
Transverse: $\pi/3<|\Delta\phi|<2\pi/3$
Away: $|\Delta\phi|>2\pi/3$

- Traditional methodology (à la Rick Field):
- Relying on charged tracks is very convenient: tracker detectors @ LHC allow to reconstruct tracks with p_T as low as ≈ 100 MeV
- Impact on isolations, jet pedestals, vertex reconstruction etc.

- Actually UE is interesting per se: handle on soft MPI and beam remnants

The ALICE experiment



|η|<0.9:

- ITS, TPC, TOF: vertexing, tracking PID
- EMCal, TRD, HMPID: PID
- Charged particles, strange particles, D mesons, quarkonia, …

-4<η<-2.5:

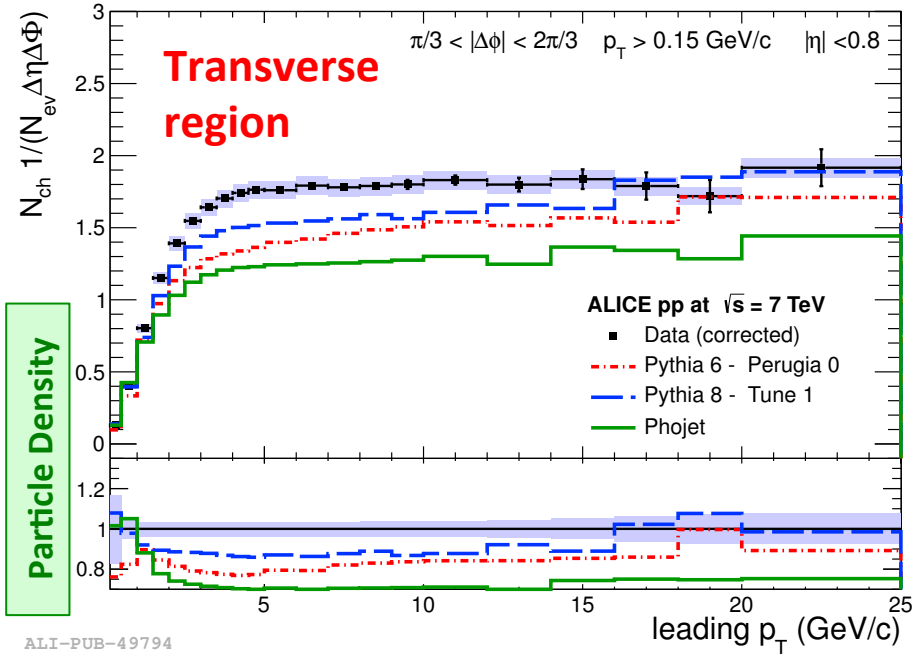
- MUON spectrometer: tracking, PID, trigger
- HF, W/Z, quarkonia,…

ALICE: the UE measurement in pp collisions

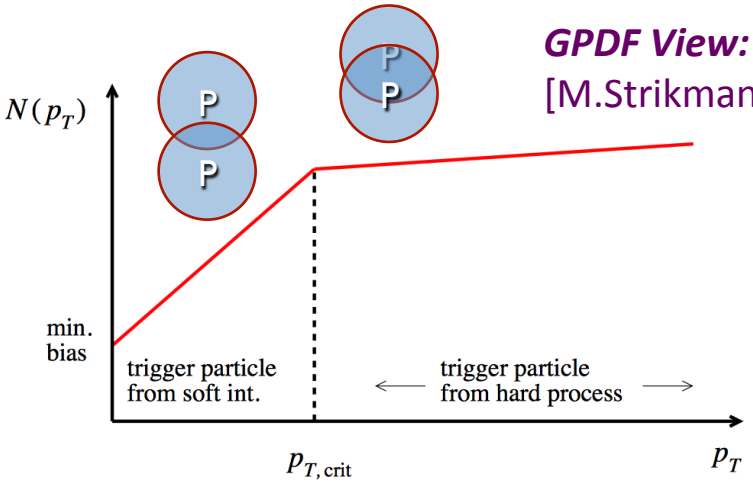
CCNU group active to extend the UE measurement at √s =13 TeV

[JHEP 07 (2012) 116]

Paolo Bartalini, Feng Fan, Yaxian Mao, Prabhakar Palini, Xiaowen Ren



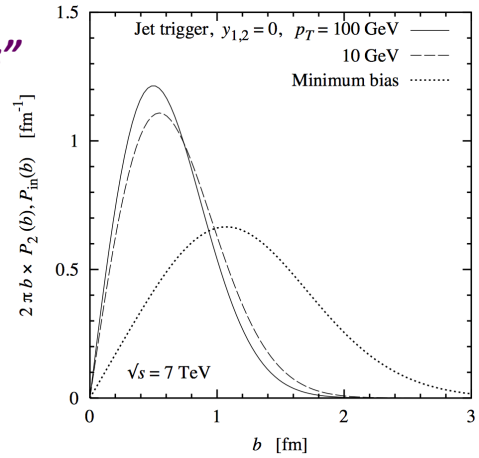
- **Energy scale quoted as the leading charged track**
- Toward & Away regions dominated by the leading interaction
- **Transverse region:** fast rise for $p_T < 4$ GeV/c mostly attributed to the increase of the MPI rate, followed by a plateau-like region (interpreted as saturation of the MPI rate)



GPDF View: "Inter-parton correlations and MPIs"

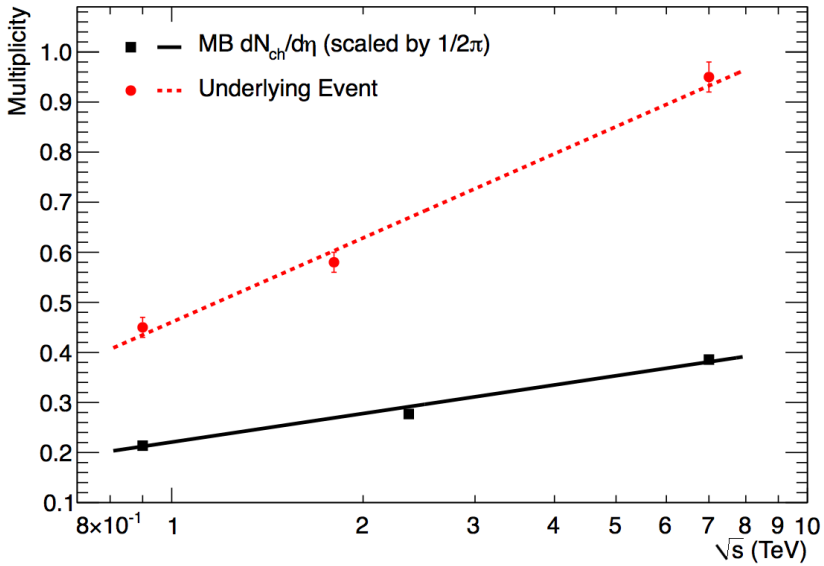
[M.Strikman, **Phys. Rev. D83 (2011) 054012**]

Lower average transverse dimension of gluons with respect to quarks also explains UE in DY < UE in Jets [CMS]



ALICE: the UE measurement in pp collisions

- Comparison of the charged particle density in the plateau of the Transverse Region and the average charged particle density per unit of pseudorapidity (<$dN_{ch}/d\eta$>) in minimum bias events (scaled by $1/2\pi$)



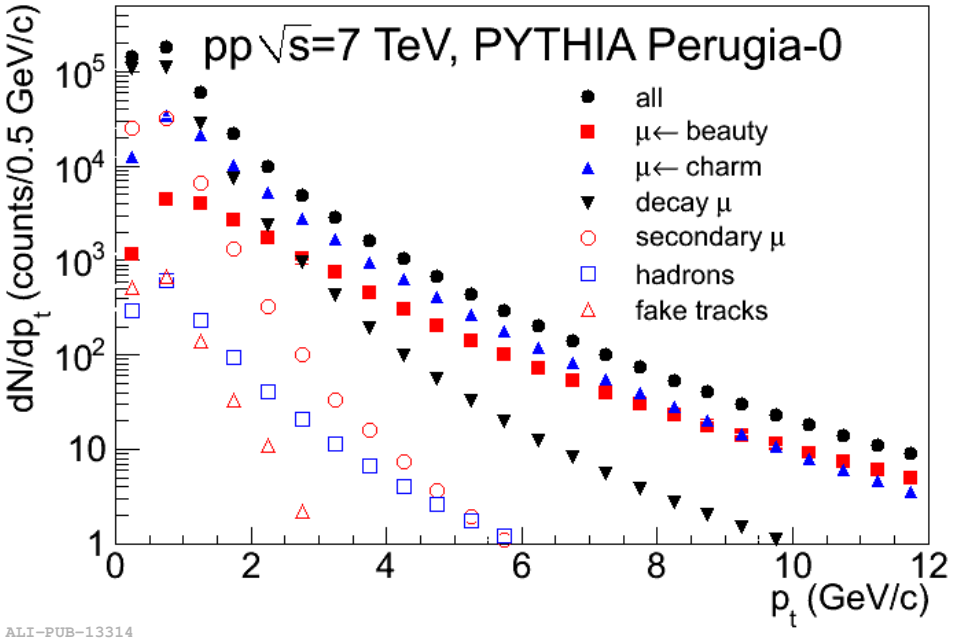
- Under the assumption that most of the activity is due to MPI, the ratio between the UE and the MB curves is:
  ≈ <N_{MPI} (UE)> / <N_{MPI} (MB)>

- Confirms DPS results: at the LHC, MPI are enhanced of a factor 2−3 from a rather modest energy scale
- The Pedestal Effect: Increasing at higher energies as $\sigma_{inel}/\sigma_{eff}$

[JHEP 07 (2012) 116]

DPS in p-Pb collisions with ALICE

- The probability of extra interactions is expected to be enhanced in p-Pb collisions compared to pp ones
  - in addition: ALICE collected luminosity in p-Pb compatible with the ones of other LHC experiments (not the case of pp collisions)
- Possible way to measure σ_{eff} in p-Pb: high-p_T muons at forward rapidity
  - single muon spectrum dominated by HF decay at high-p_T

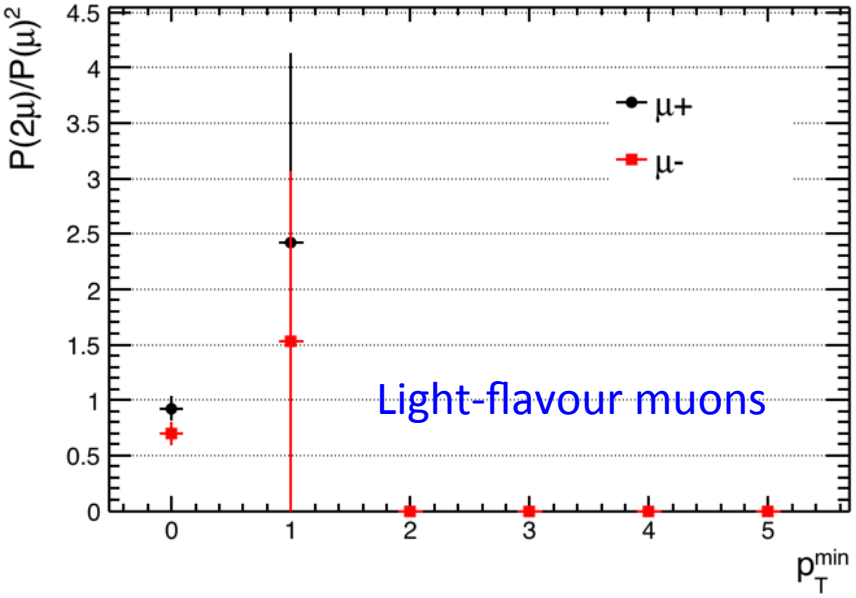


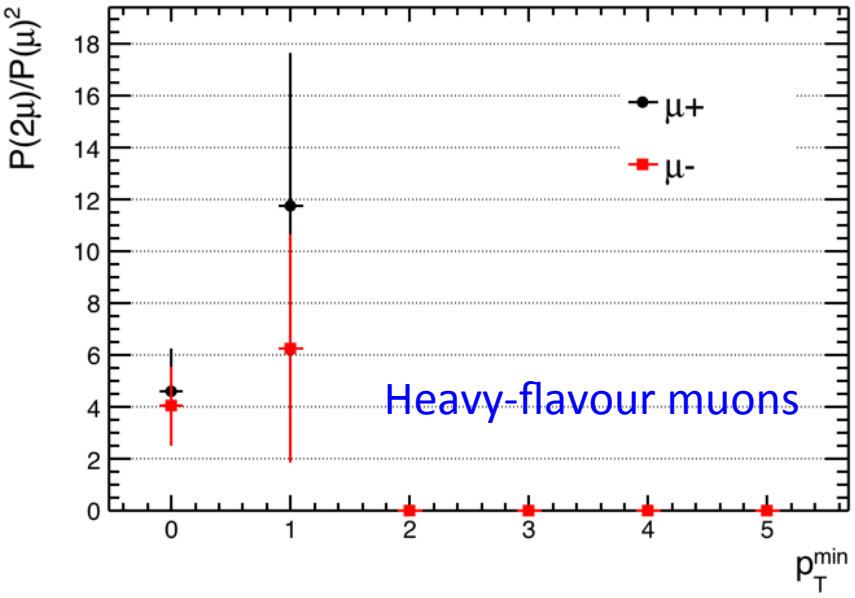
- Search for same-sign muons with high-p_T

Feasibility study

- Activity supported in the ALICE PAG-UD
- Enhancement factor: $E(\mu,p_T^{min}) = P(2\mu,p_T^{min})/P(\mu,p_T^{min})^2$
  - E = 1 => uncorrelated MPI
  - E ≠ 1 => correlation among MPI

Pythia 8 simulations





- Light-flavour muons: compatible with 1 (large uncertainties)
- HF muons: large enhancement
  - CAVEAT: correlated decay chain of $b\bar{b}$ pairs

Conclusions

- Multiple Parton Interaction studies needed for a full understanding of the hadronic collisions
- Dedicated working group in ALICE (PAG-UE in the PWG-MM)
  - measurement of the charged particle production in the Transverse region in pp collisions at √s=0.9 and 7 TeV: saturation with leading p_T tends to be underestimated by MC
  - similar ongoing measurement in pp collisions at √s=13 TeV
  - also explore alternative methods to study MPIs (jets, muons, etc.)

- Collaboration CCNU+Subatech to study the feasibility of a DPS measurement in p-Pb collisions with muons at forward rapidity
  - ~10 nb^{-1} collected in 2013 at √s=5.02 TeV. Factor of ~2 more in 2016 at √s=8 TeV
  - first studies on MC ongoing. Main issue: irreducible background from chain decay of $b\bar{b}$ pairs

Perspectives:

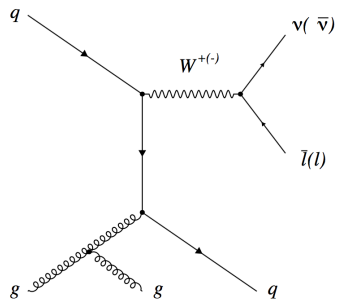
- Dedicated high-statistics MC
- Correlated background subtraction

CMS: DPS in W→μν + 2jets

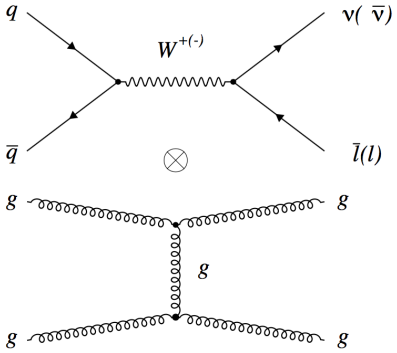
- Along the lines of the ATLAS experience [J.Phys.15 (2013) 033038] with more MCs, unfolding, higher stat. (5 fb^{-1}), etc.

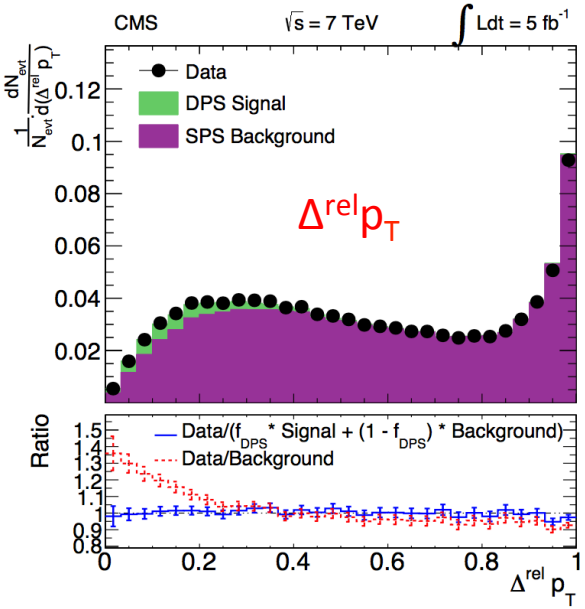
- DPS signal extraction from simultaneous fit of:
  - $\Delta^{rel}p_T$ = relative p_T balance of di-jet system
  - ΔS = angle between total momenta of paired objects (μν,di-jets) projected in the transverse plane

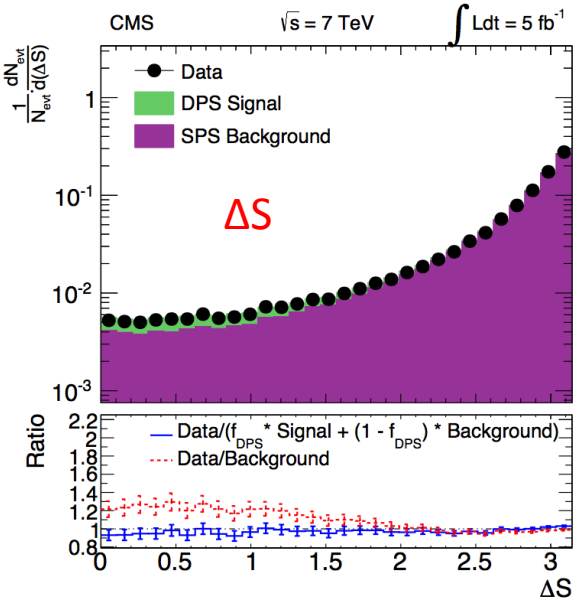
SPS:



DPS:





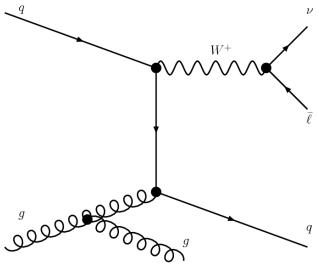


[JHEP 03 (2014) 032]

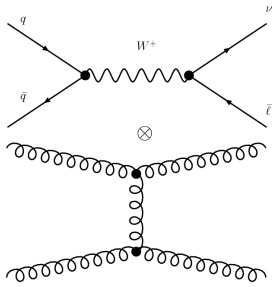
CMS: DPS in W → μν + 2 jets

Along the lines of the ATLAS experience [New J.Phys. 15 (2013) 033038] with more MCs, Unfolding, higher stat, more observables, etc.

SPS:



DPS:



→ DPS signal fractions from fit to templates

Data:
Collision data at √s = 7 TeV, Single Muon data streams with integrated luminosity of ~ 5 fb^{-1}

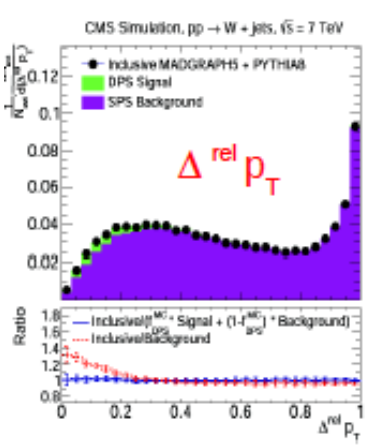
High stat.

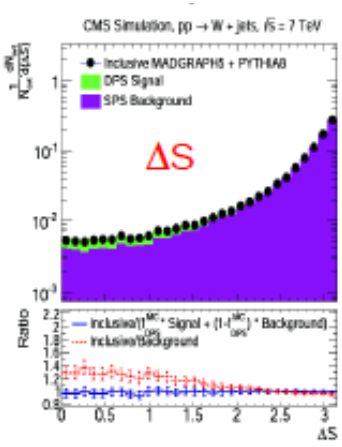
Event selection:
- Exactly one μ
- with p_T > 35 GeV, |η| < 2.1
- Required to be isolated and to pass tight ID criteria
- particle flow Missing Transverse Energy, MET > 30 GeV
- transverse mass of (μ and MET) > 50 GeV
- Exactly 2 anti-KT jets with pT > 20 GeV and |η| < 2.0

(not inclusive, need correction to use the σ_{eff} formalism)

Unfolding

$\Delta^{rel} p_T$ = Relative p_T balance of the di-jet system.
ΔS = Angle between total momenta of paired objects (μν, di-jet) projected in the transverse plane.





- Signal at small ΔS (DPS is flat while SPS is peaked at π) and small $\Delta^{rel} p_T$ (back-to-back di-jet in transverse plane).
- Signal Template combining W+0jets and di-jet samples.
- Backg. Template Madgraph+Pythia 8 (no jets from MPI).
- No double counting or phase space gaps.
- DPS signal fraction from simultaneous fit to $\Delta^{rel} p_T$ and ΔS.
- Extract σ_{eff} from signal fraction.

JHEP 03 (2014) 032