# A new Colour Reconnection model within PYTHIA

Jesper Roy Christiansen

Lund University

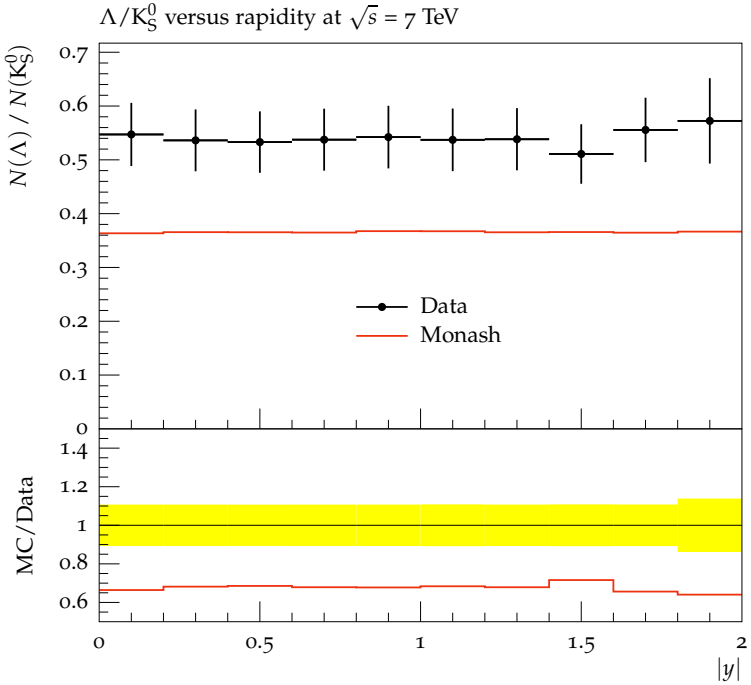
October 8-10, 2014
MCnet meeting

# Talk overview

- Motivation
- New beam remnant model
- New colour reconnection model
- Conclusion

# Motivation

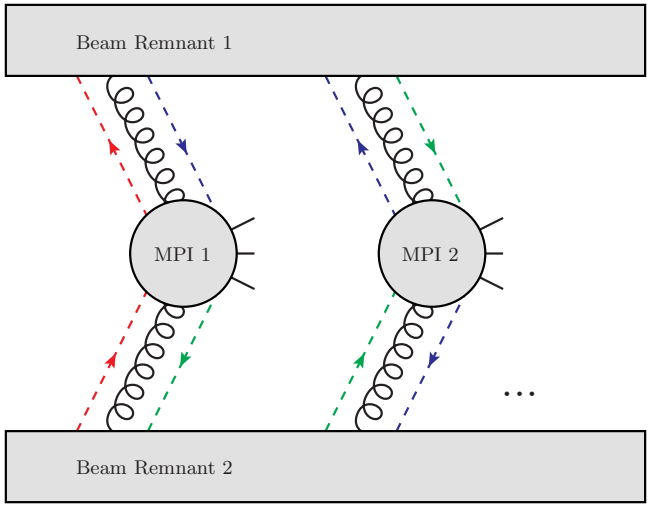
- We want to introduce more of the SU(3) structure from QCD into the description
- Provide a better description of especially $\Lambda$ production at hadron colliders.




(arXiv:1102.4282)

# New beam remnant model

- The beam remnant model comes after the perturbative machinery
- Overall idea of the model:
  - A game of conservation laws
  - Add the minimal required amount of extra particles




- Example of two scattered gluons from a proton:

## Flavour conservation

Add two up and one down quark

## Baryon number conservation

Turn two quarks into a diquark

## Energy/momentum conservation

Choose x according to modified PDFs and rescale to match overall momentum conservation

# New beam remnant model - colour conservation

Possible colour states for the two gluons:

$$\mathbf{8} \otimes \mathbf{8} = \mathbf{27} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{1}$$

**27**

2 C & 2 AC
+ 1 gluon

**$\overline{10}$**

0 C & 3 AC
+ 0 gluon
(junction)

**10**

3 C & 0 AC
+ 1 gluon
(junction)

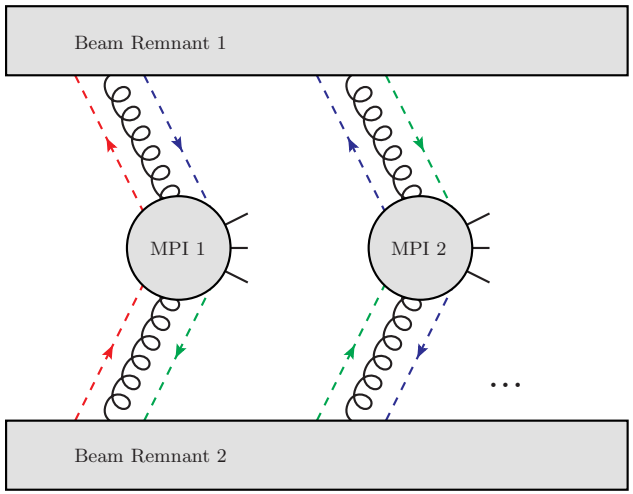
**8**

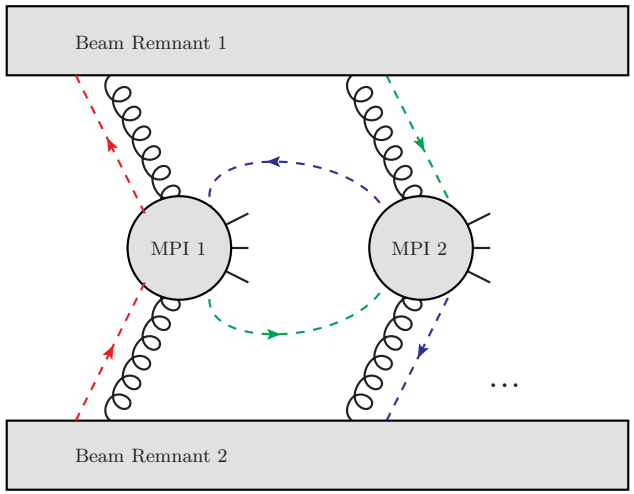
1 C & 1 AC
+ 0 gluon

**1**

0 C & 0 AC
+ 0 gluon
(not allowed)

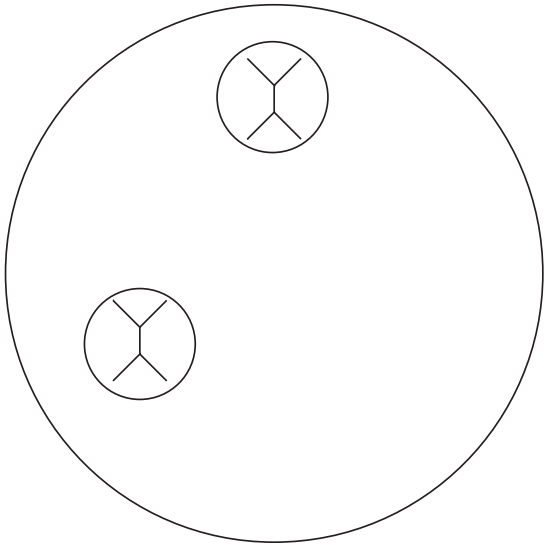
Examples of the **27** and the **8** configurations:

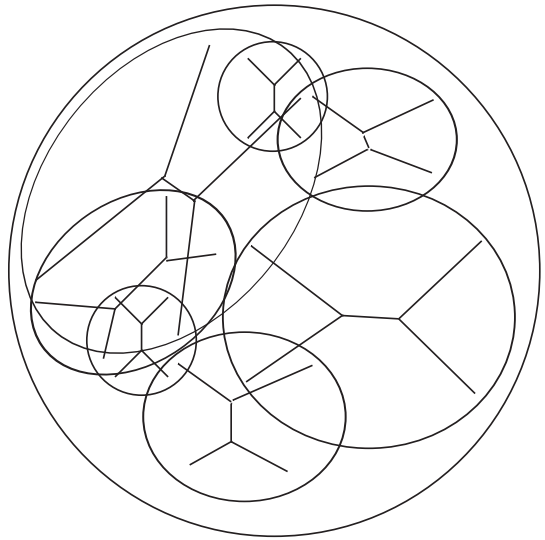


# Saturation

Are the partons uncorrelated?

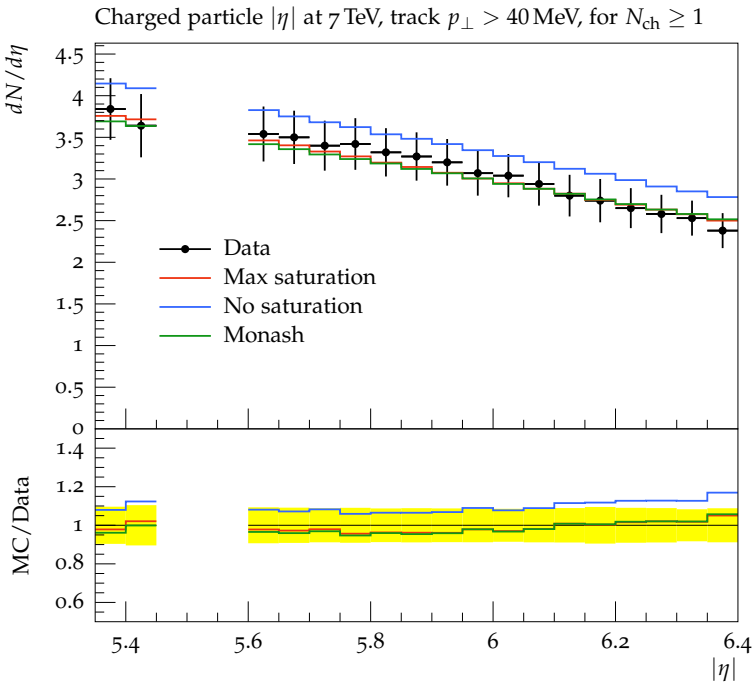




Included as a simple suppression: $\exp(-M/k)$,
where M is the multiplet size and k is a free parameter

# Comparisons to data

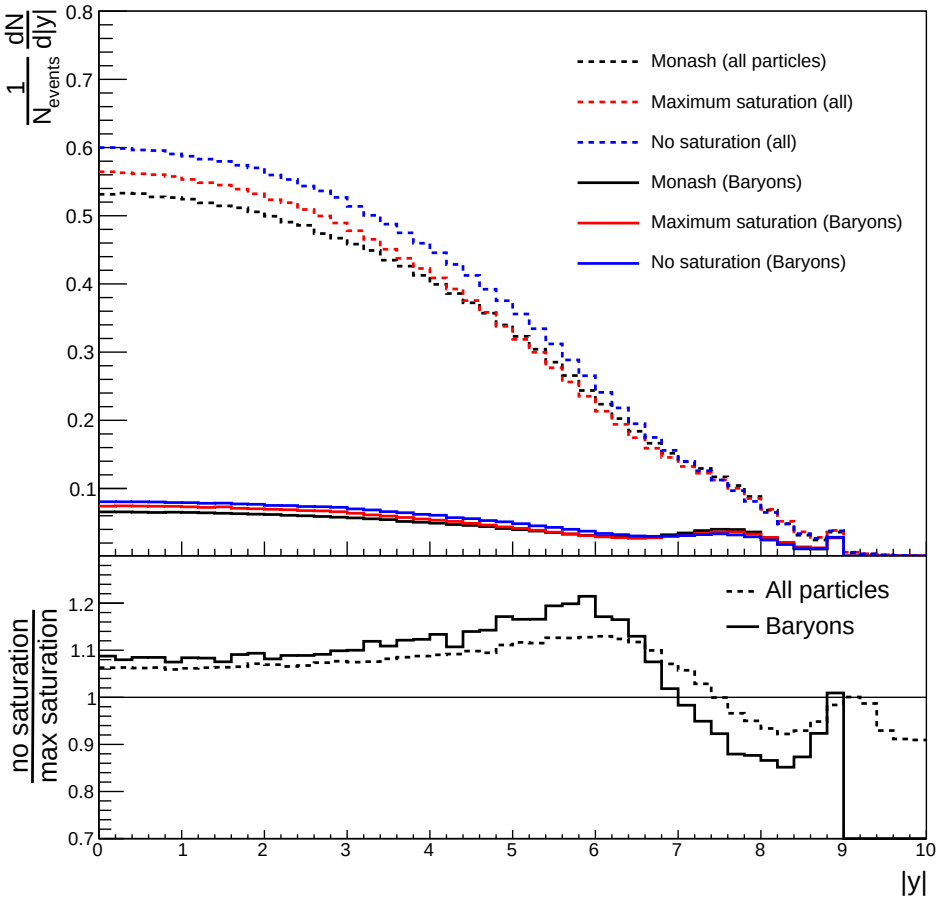
- Relative large x and small $p_\perp \Rightarrow$ forward physics
- Comparison to forward TOTEM measurements.
- 10 % difference between no and maximal saturation
- The old model is similar to maximal saturation




(arXiv:1205.4105)

# Baryon production

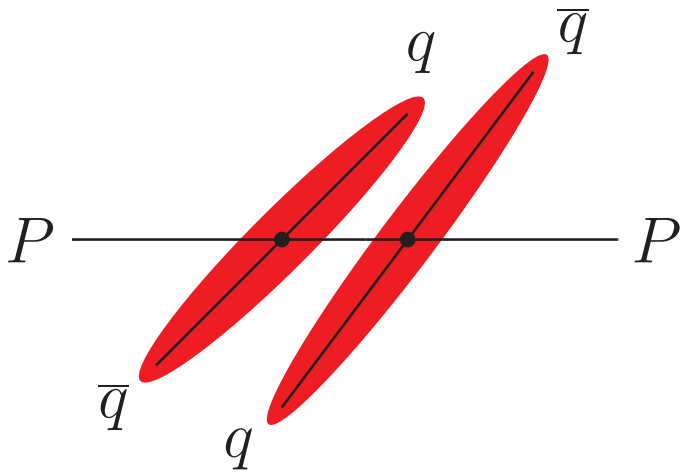
- The new models allow for additional production of junction structures
- Comparison between maximal saturation and no saturation as a function rapidity.
- Only directly produced particles (HadronLevel:decay = off)



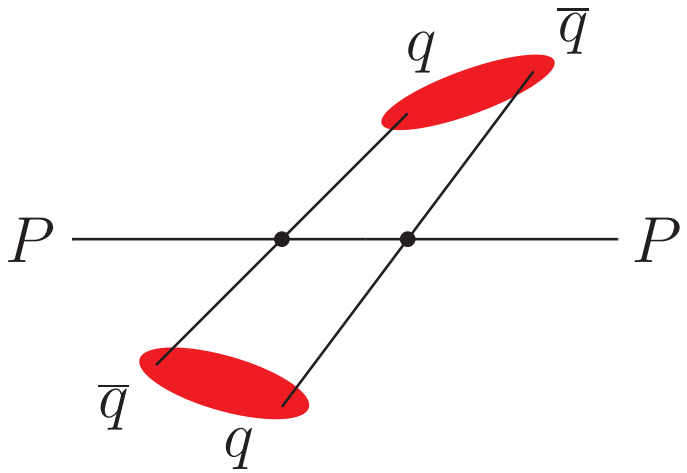
# New colour reconnection model

- Colour reconnection allows us to reshuffle the colours before hadronization
- Experimentally observed in average $p_\perp$ vs multiplicity
- New model relies on two main principles
  - SU(3) colour rules from QCD - tells us which reconnections are allowed
  - minimize $\lambda$ measure - tells us which reconnections are preferred

Before colour reconnection




After colour reconnection

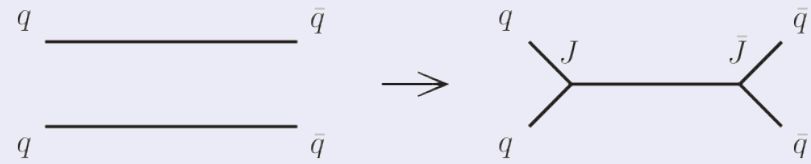


# Possible reconnections

## Ordinary string reconnection

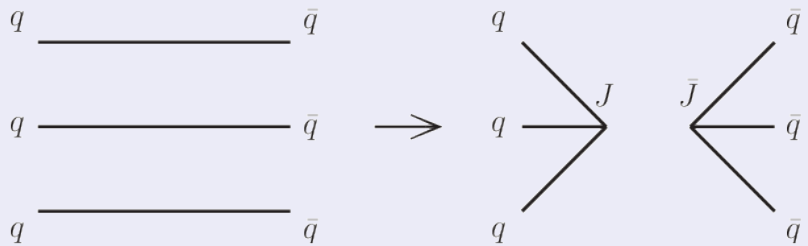
(q$\bar{\text{q}}$: 1/9, gg: 1/8, model: 1/9)

## Double junction reconnection



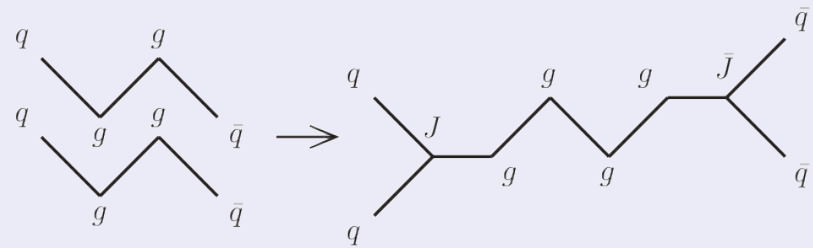

(qq: 1/3, gg: 10/64, model: 2/9)

## Triple junction reconnection




(q$\bar{\text{q}}$: 1/27, gg: 5/256, model: 2/81)

## Zipping reconnection




(Depends on number of gluons)

# The $\lambda$ measure

- The $\lambda$-measure is the rapidity span of a string
- For a $q\bar{q}$ dipole: $\lambda = \log(1 + \frac{s}{2m_0^2})$
- Sum over all $q\bar{q}$-, qg- and gg-dipoles to get total string length
- Add free parameter for minimum gain for junction structures (allow negative for enhancement)

Generalization of $\lambda$-measure ($s \gg m_0^2$)

$\lambda = \log(1 + \frac{s}{2m_0^2}) \Rightarrow$

$\lambda = \log(\frac{s}{2m_0^2}) \quad (s \gg m_0^2) \Rightarrow$

$\lambda = \log(\frac{4E_1E_2}{2m_0^2})$ (restframe) $\Rightarrow$

$\lambda = \log(\frac{\sqrt{2}E_1}{m_0}) + \log(\frac{\sqrt{2}E_2}{m_0})$

Interpret as contributions from each dipole end, similar for junctions except for three legs:

$$\lambda = \log(\frac{\sqrt{2}E_1}{m_0}) + \log(\frac{\sqrt{2}E_2}{m_0}) + \log(\frac{\sqrt{2}E_3}{m_0})$$

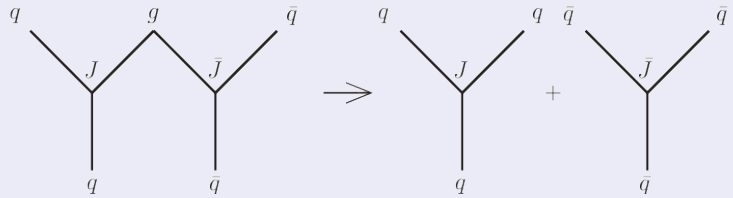
To handle ($s \sim m_0^2$):

$\log(\frac{\sqrt{2}E_1}{m_0}) \rightarrow \log(1 + \frac{\sqrt{2}E_1}{m_0})$

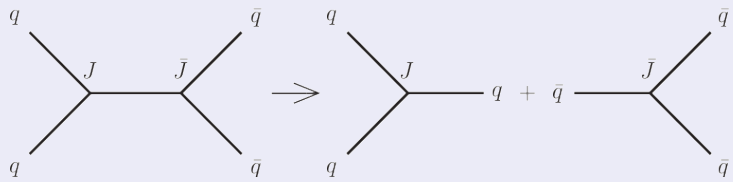
# Additional details

- Only local minimization
- Ignore dipoles with invariant mass below $m_0$
- No annihilation of junctions - Start with ordinary reconnection
- The hadronization can not handle junction connected with other junctions - need to split them up (see examples)

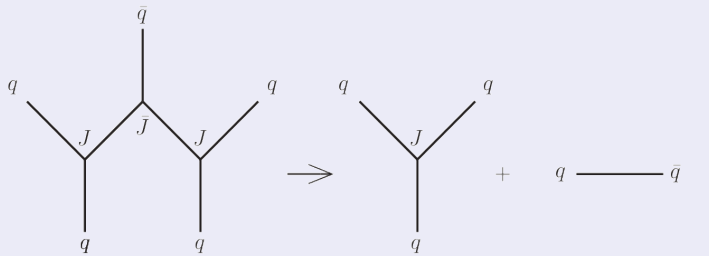
## Gluon splitting




## Double junction




## Multi junction



# Tuning

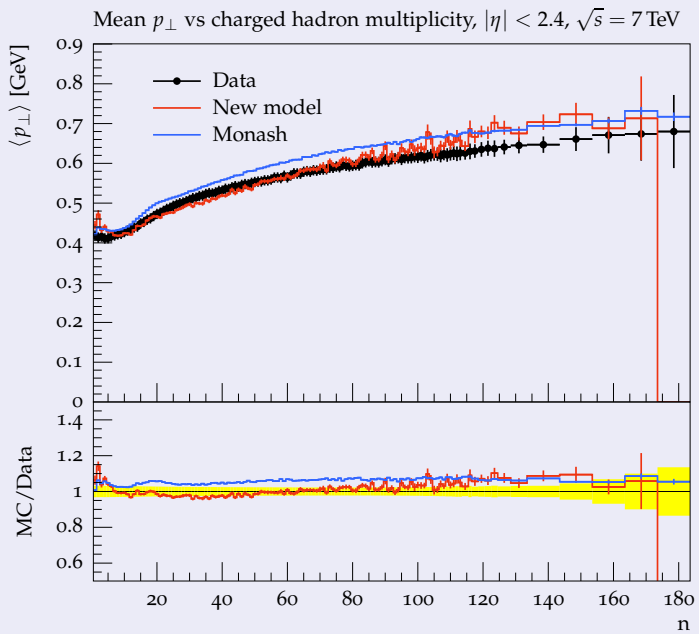
## LEP tuning

| par | Monash | new |
|---|---|---|
| $\sigma_{p_\perp}$ | 0.335 | 0.305 |
| aLund | 0.68 | 0.38 |
| bLund | 0.98 | 0.64 |
| StoUD | 0.217 | 0.19 |

- First tune iteration, still needs several additional iterations

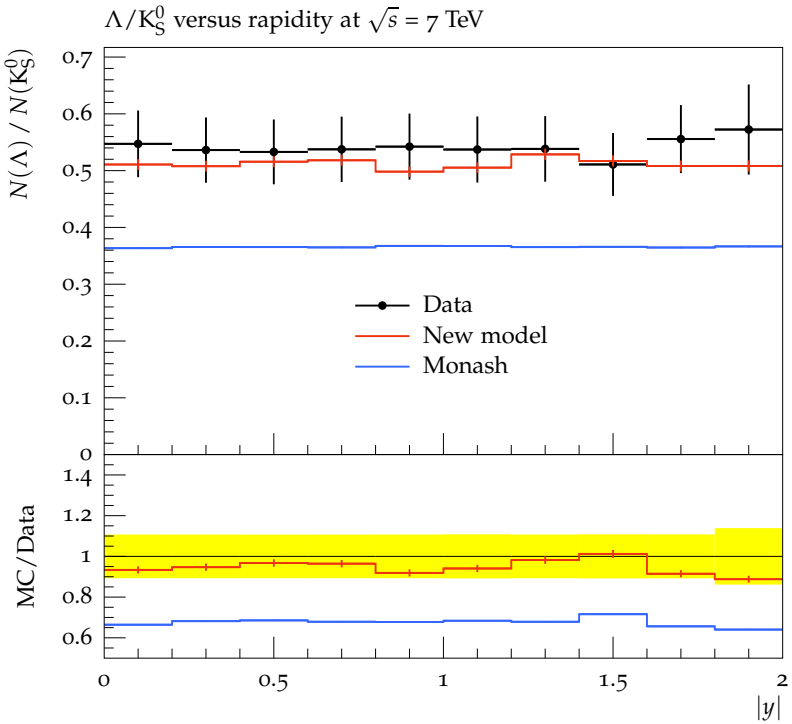
## LHC tuning

| par | Monash | new |
|---|---|---|
| $p_{\perp 0}^{\text{ref}}$ | 2.28 | 2.15 |
| $m_0$ | - | 2.8 |
| MinGainJun | - | -0.65 |

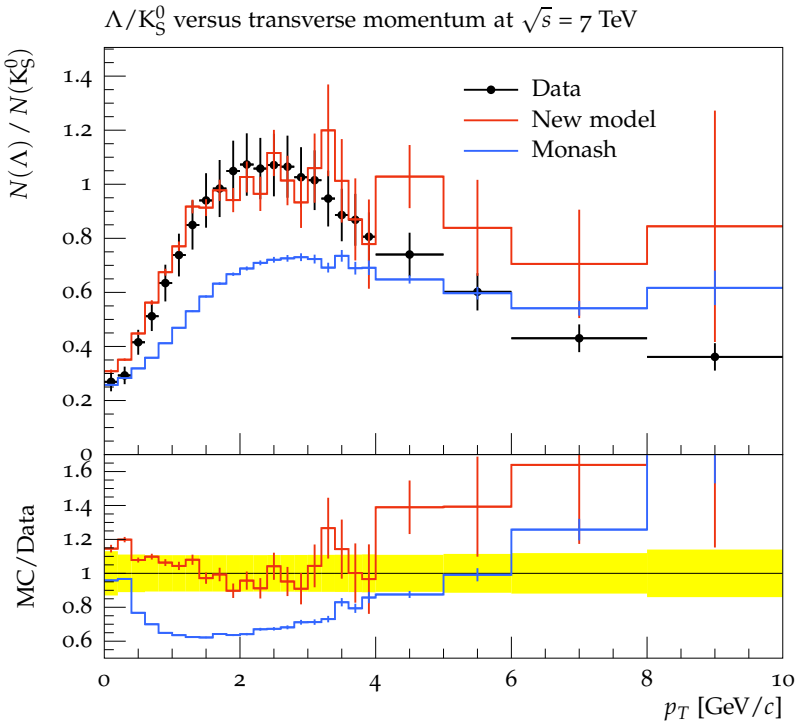



(arXiv:1011.5531)

# Comparison to LHC data




(arXiv:1102.4282)

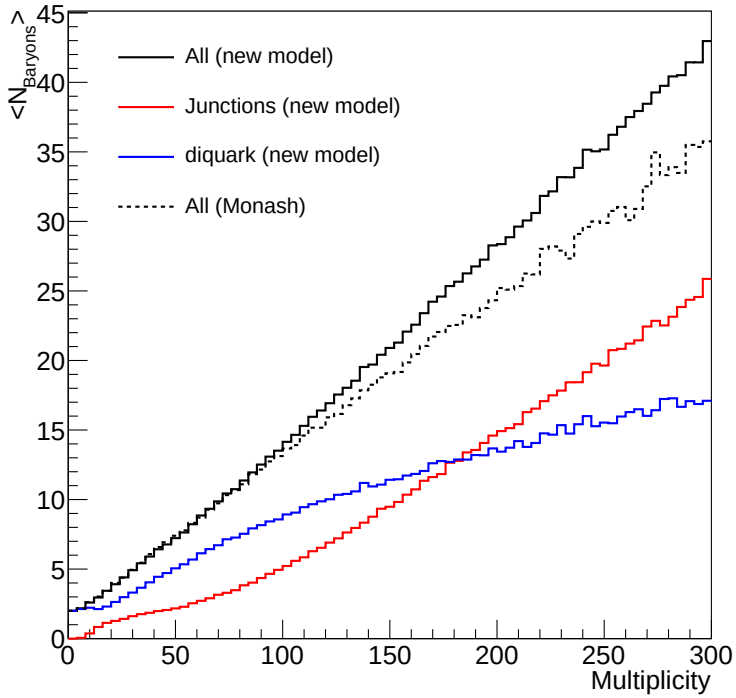



(arXiv:1102.4282)

- Can describe $\Lambda/K_s$ ratios (tuned)

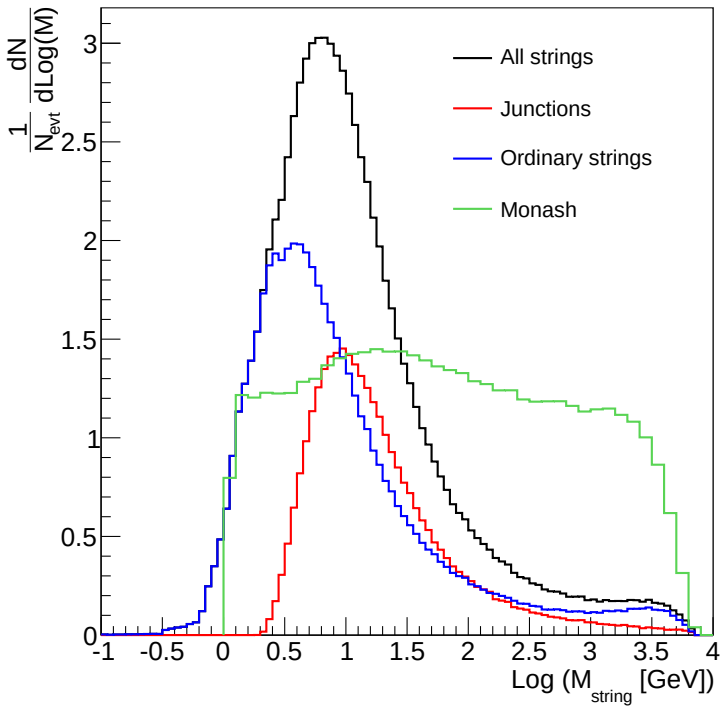
# Distinguish new model from old model

- Observables to distinguish junction baryons from diquark baryons
- Best observable found so far can be seen on the right (again hadron decays are turned off)
- Still looking for more observables
- The difference between Monash and the diquark curve can be understood by looking at the masses of the strings



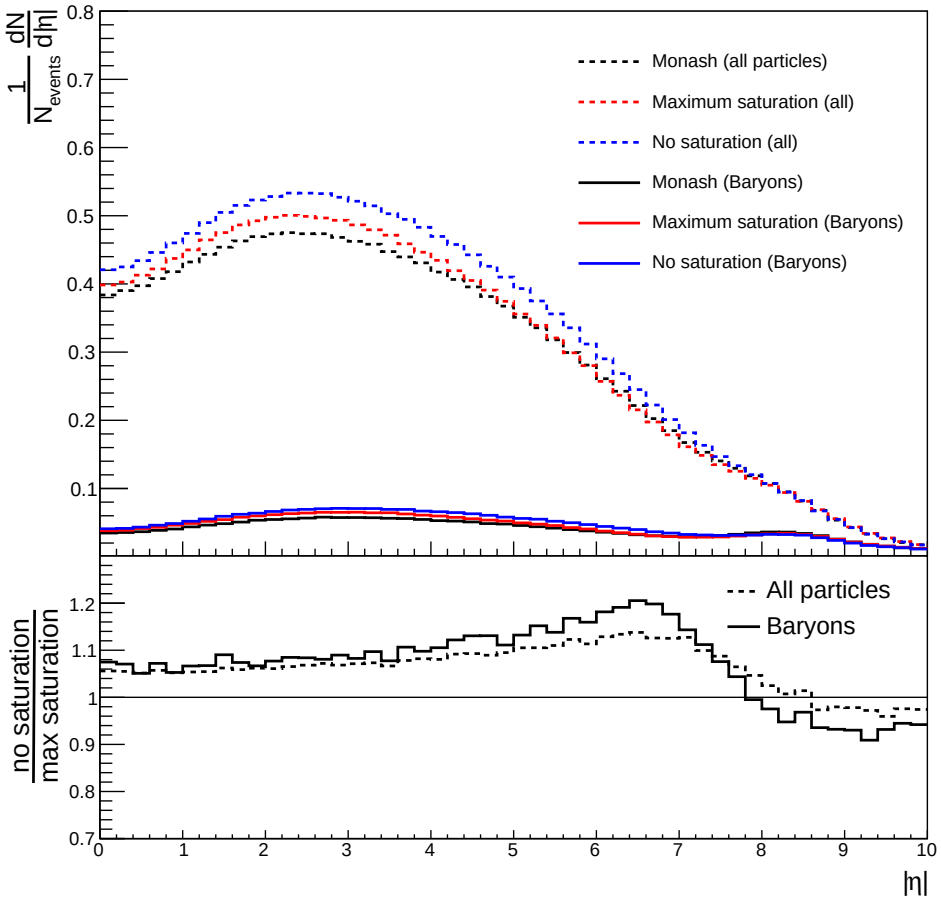
# Distinguish new model from old model

- Observables to distinguish junction baryons from diquark baryons
- Best observable found so far can be seen on the right (again hadron decays are turned off)
- Still looking for more observables
- The difference between Monash and the diquark curve can be understood by looking at the masses of the strings



# Conclusion

- Only possible to distinguish new beam remnant model from old model in very forward regions
- The new colour reconnection model can be used to describe the $\Lambda$-production
- Both models will be released along with PYTHIA 8.2
- Future plan:
  - Identify more observables that can distinguish junction baryons from diquark baryons
  - Apply model to the top mass measurement

# Baryon production

- The new models allow for additional production of junction structures
- Comparison between maximal saturation and no saturation as a function rapidity.
- Only directly produced particles (HadronLevel:decay = off)