# Multiparton Interactions from a Higgs physicst

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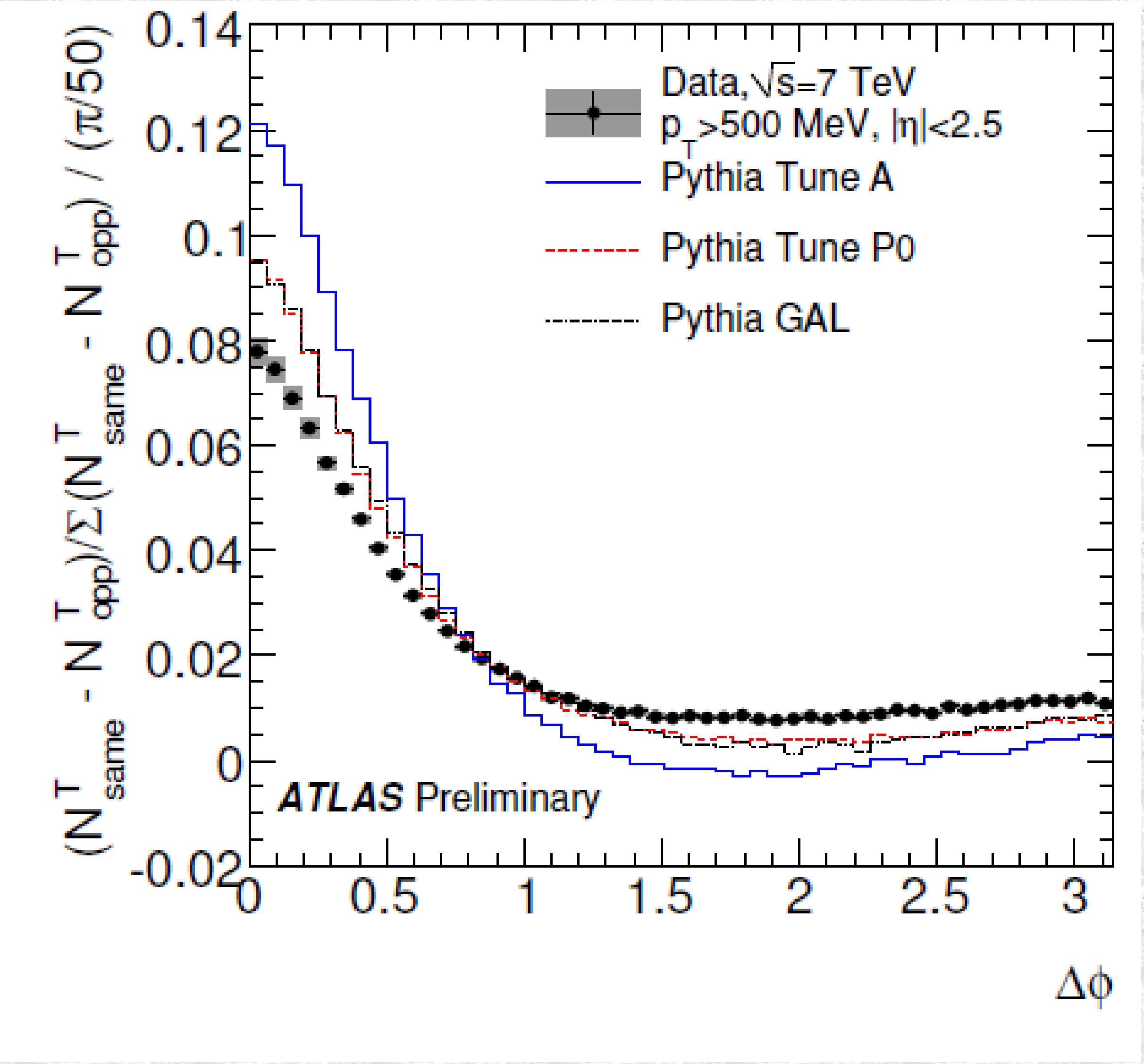
- **Motivation**
- **MPI through jets**
- **(Lack of) results**

# Motivation

- Why is a Higgs convenor studying this?
  - Because its there
    - MPI rates slightly above Higgs in early LHC data
  - Because I can
    - Political tensions in working on Higgs analysis
  - Because it matters
    - Extra energy (jets) complicate all hard processes
    - Especially VBF $H\rightarrow\tau\tau$
      - Central Jet veto applied
      - Also pileup rejection depends upon track based quantities – poor resolution so soft jets matter.

# Public ATLAS UE studies

- **Track based distributions will be discussed later**
- **Same-opposite shown as example**
- **Clearly rich source of information**
- **But low $p_T$, many tune parameters together**



# ATLAS models

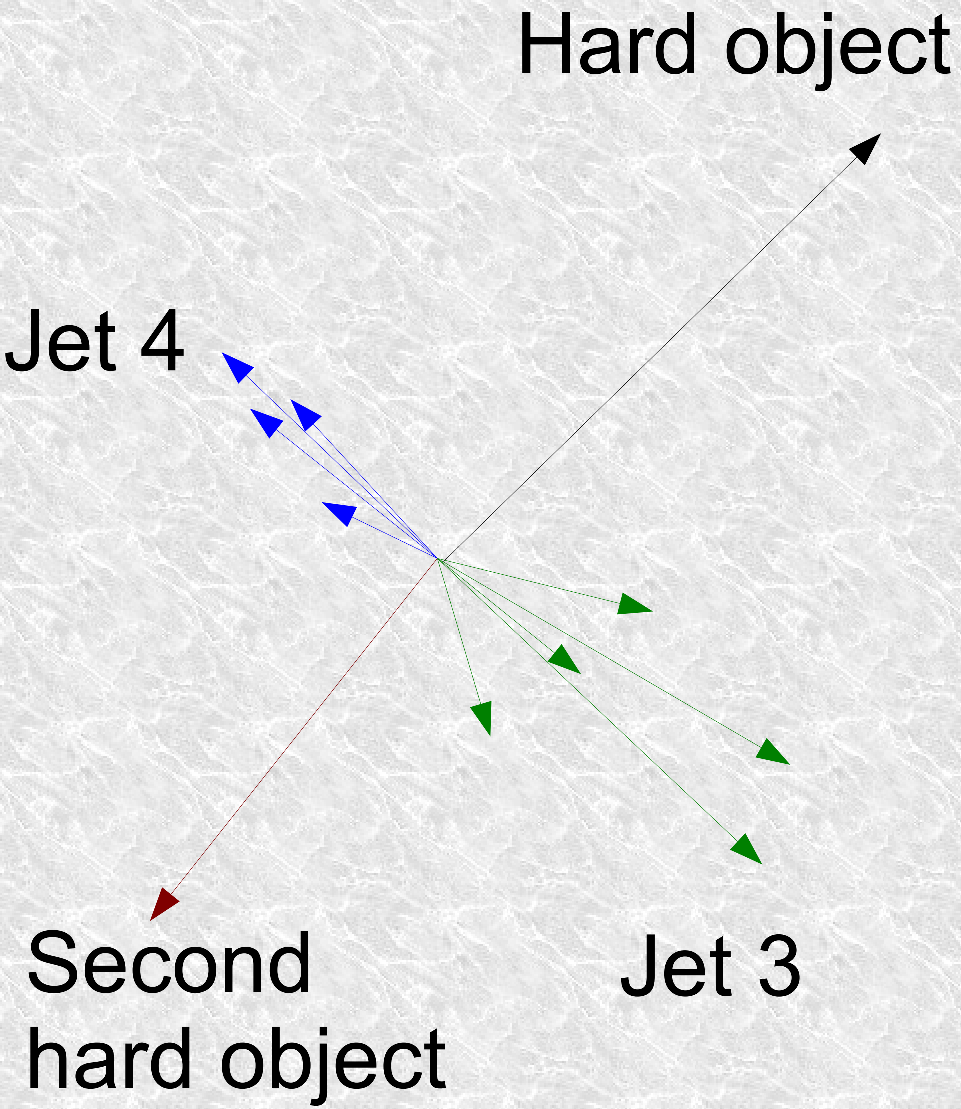
- The mean DPI rate varies a lot:
  - Perugia0: 3.5
  - DW: 7.4
  - MC09C: 2.8
  - AMBT1: 2.8
- Of course the model spectra differ too
- But the 4-jet rate above say 10GeV $p_T$ is very high in DW c/f the others

# MPI through jets

- Separate hard process and second interaction
  - Needed for trigger control
- Various approaches have been tried/proposed
  - $\gamma$+3 jets
    - D0 with $1fb^{-1}$
    - http://arxiv.org/abs/0912.5104
  - $b\bar{b}$+2 jets
    - Theoretical treatment, not tried experimentally
    - http://arxiv.org/pdf/0911.5348v1
  - 4 jets
    - My preferred approach – stats. are much better
- Experimental versions have standard assumption:
  - The second scattering looks like minimum bias
  - Not for cross-section, but characteristics

# The idea:

- **Identify Hard process**
  - **Two jets**
  - **γ+jet**
  - **$b\bar{b}$**
- **'Separately' identify soft process**
- **Analyse fraction of DPI**
  - **Using independent conservation of momentum**
- **Obvious gotchas:**
  - **Trigger bias**
  - **Hard/soft confusion**



# Does MPI look like minbias?

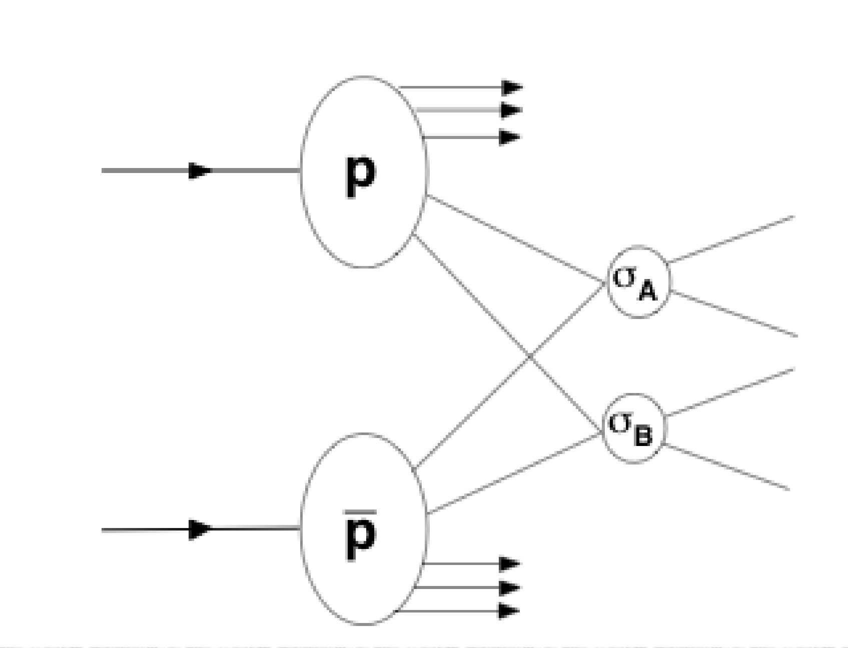
- Clearly not at low $p_T$
  - Proton fragmentation is distorted
  - Diffractive processes destroy independence
- But as scale rises, approximation improves.
  - Where can we use it?
    - Pythia 8 seems suggests very hard diffractive?
  - D0 rely on it from 15GeV
- We have great statistics of minbias control samples

# Formalism: factorisation

- **Total double-parton cross-section:**

$$\sigma_{DP} = m \frac{\sigma_A \sigma_B}{2\sigma_{eff}}$$

  - **$\sigma_A$ and $\sigma_B$ are independent processes**
  - **m is 2 if A and B are distinguishable, otherwise 1**
  - **$\sigma_{eff}$ is a process-independent scaling factor**
    - **Note – it is inversely proportional to DP rate.**



# Prior Art

- AFS collaboration: 63 GeV, $p_T > 4$ GeV
  - $\sigma_{DP}/\sigma$dijet = (6 ± 1.5 ± 2.0) %
- UA2: 630 GeV, $p_T > 15$ GeV
  - $\sigma_{eff} > 8.3$ mb
  - $\sigma_{DP} = (0.49 \pm 0.20)$ nb
- CDF: 1.8 TeV, 4 jets, pT > 25 GeV
  - $\sigma_{eff} = (12.1 +10.5-5.4)$ mb
  - $\sigma_{DP} = (63 +32-28)$ nb
  - $f_{DP} = (5.4 +1.6-2.0)$ %
  - σeff ~ 5 mb
- CDF: 1.8 TeV, $\gamma$ + 3 jets, $p_T(\gamma)>15$ GeV, $p_T$(jet) > 16 GeV
  - $\sigma_{eff} = (14.5 \pm 1.7 +1.7-2.3)$ mb
  - $f_{DP} = (52.6 \pm 2.5 +/- 0.9)$ %
- DØ: 1.96 TeV, $\gamma$ + 3 jets, 60 GeV < $p_T(\gamma)$ < 80 GeV, 15<$p_T$(jet)>30
  - $\sigma_{eff} = (16.4 \pm 0.3 +/- 2.3)$ mb
  - $0.23 < f_{DP} < 0.47$

# Jet $p_T$ scale

- Jet $p_T$ scale is tricky to establish
  - Pileup,
  - calorimeter noise,
  - Theoretical meaning
- ATLAS does not estimate jet pT scale below 20GeV
  - Shame, because that is where most of the DP scattering is
- Even above 20GeV, scale errors ~10%
  - Changes rate by a factor two
- Can we avoid it?
  - Use track based jets?
  - Measure *fraction* of DPI only

# Analysis variables

- **Analysis variables used in references given:**

$$S_{p_T} = \frac{1}{\sqrt{2}} \sqrt{\left( \frac{p_T(\gamma, j1)}{\delta p_T(\gamma, j1)} \right)^2 + \left( \frac{p_T(j2, j3)}{\delta p_T(j2, j3)} \right)^2}$$

$$S_{p'_T} = \frac{1}{\sqrt{2}} \sqrt{\left( \frac{p_T(\gamma, j1)}{p_T(\gamma) + p_T(j1)} \right)^2 + \left( \frac{p_T(j2, j3)}{p_T(j2) + p_T(j3)} \right)^2}$$

$$S_{\phi} = \frac{1}{\sqrt{2}} \sqrt{\left( \frac{\pi - \phi(\gamma, j1)}{\delta \phi(\gamma, j1)} \right)^2 + \left( \frac{\pi - \phi(j2, j3)}{\delta \phi(j2, j3)} \right)^2}$$

- **Careful! $S_{\Phi}$ is also used without error normalisation**
- **Why not: $\Phi$(j2,j3)?**

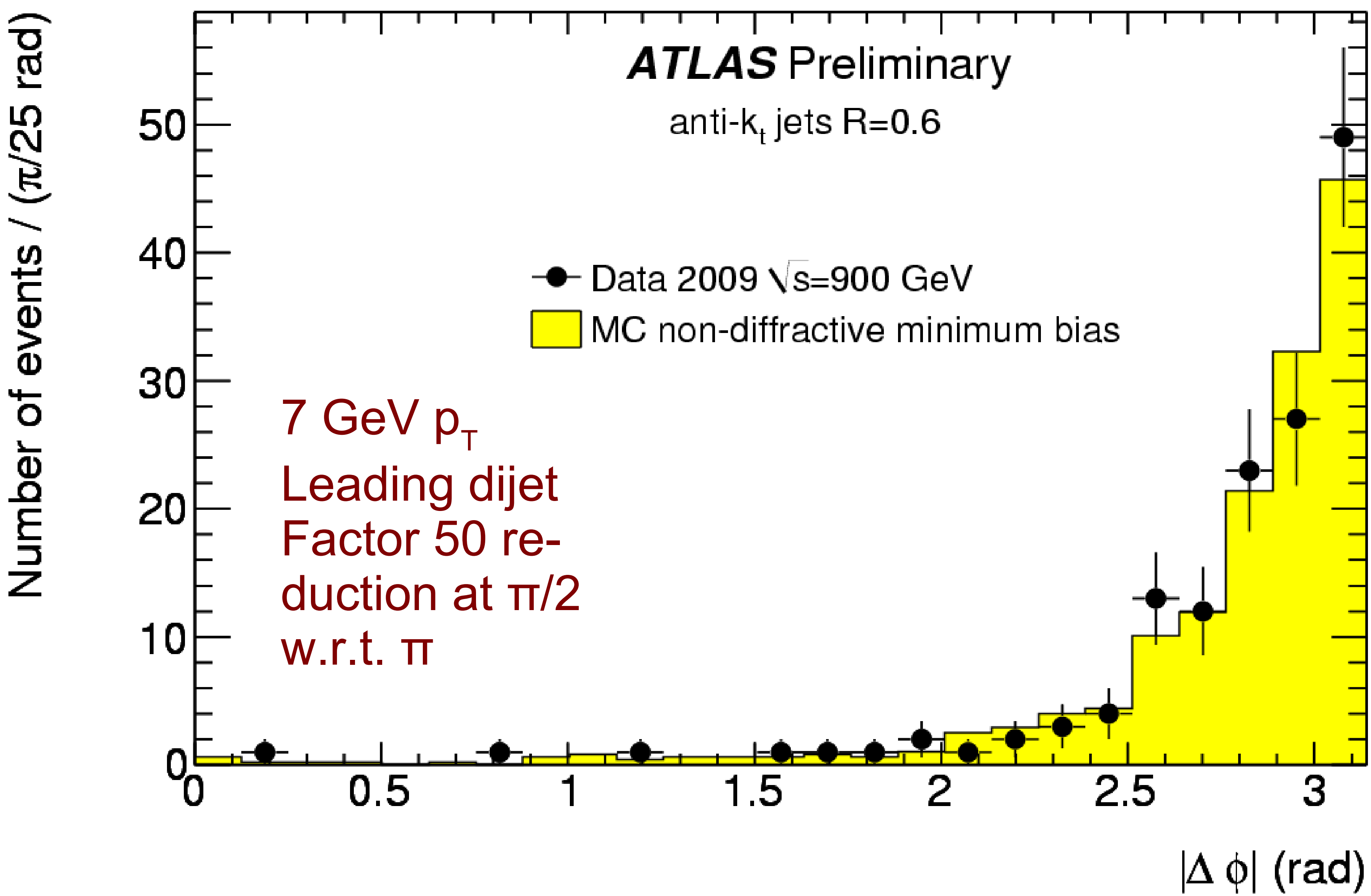
# Signal model

- Taking signal from data means model is given
  - To the approximation of factorisation introduced earlier
- No concern about $p_T$ scale!
- Can relate to measured data cross-sections
- No MC uncertainties

# Use of data minbias

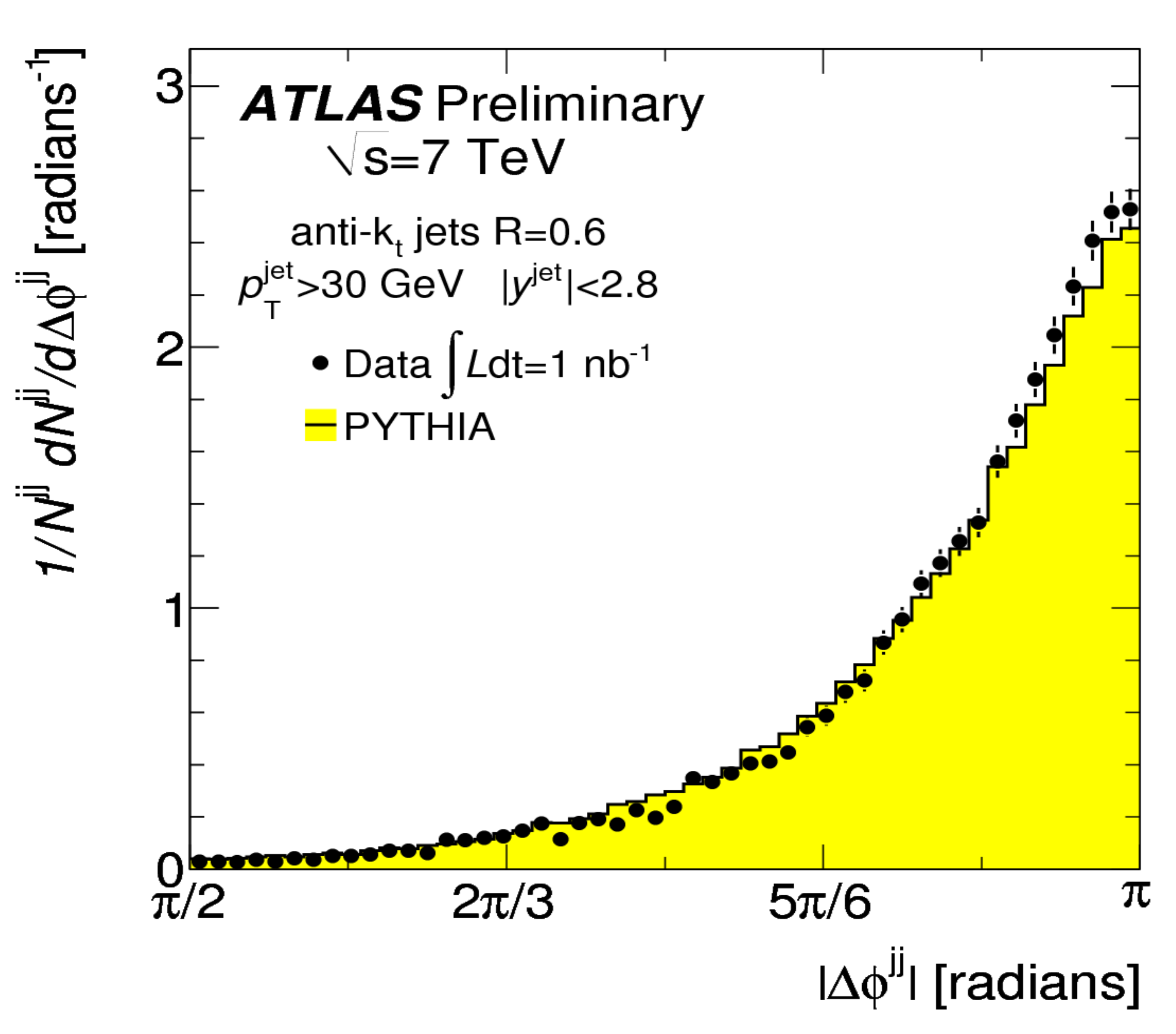
- Need to mix events. Two methods
- Independent data events
  - Two real events,
    - One passing the hard process selection
    - The other the soft dijet requirements
  - May need to be from different trigger streams
  - Superimpose the information
    - Reject events which would now fail – efficiency
  - Calculate your favourite variable
- Pileup
  - Identify events with two pp interactions
    - Hard and soft processes connected to them
  - Events are now mixed automatically
  - But rate is lower, and possible vertex bias

# ATLAS dijet acolinearities



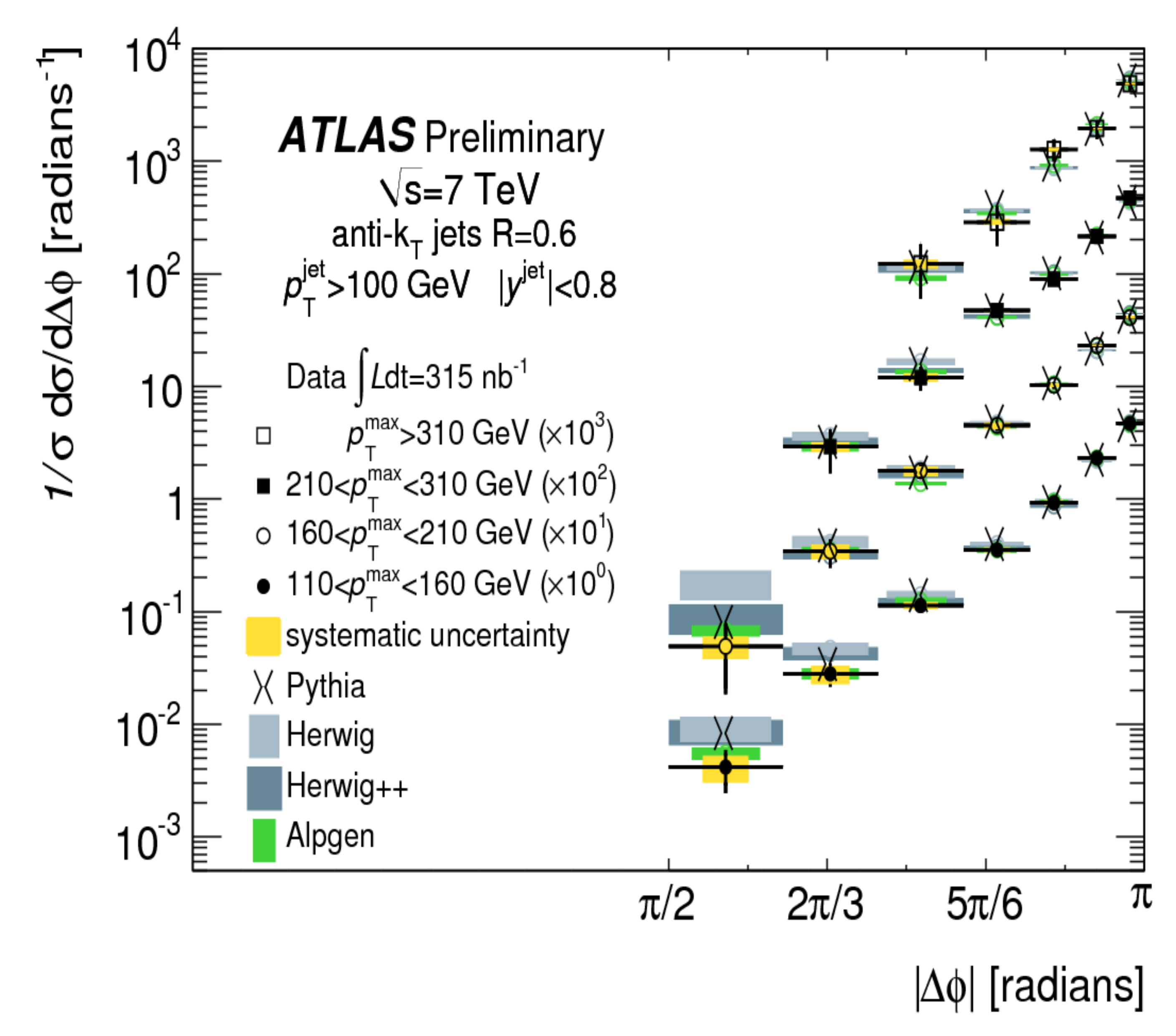
# ATLAS dijet acolinearities

- **Leading dijets**
- **30GeV+ pT**
- **Factor ~100 reduction at π/2**



# ATLAS dijet acolinearities

Summer conference
100 GeV $P_T$ plus
Factor 500 reduction by π/2



# What scale for soft dijet?

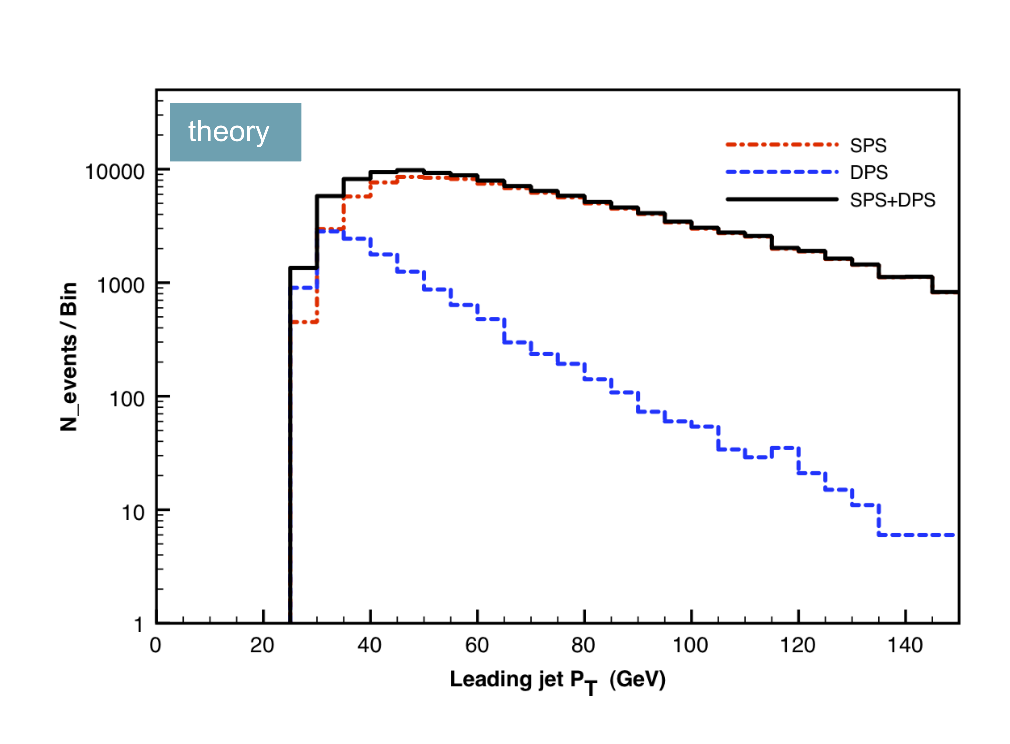
- The harder the better?
  - Improved colinearity – easier fits
  - Less concern about diffractive effects
- But....
  - Jet rate drops rapidly
  - Presumably smaller DPI fraction
  - Both argue against raising $p_T$
- Conclusion: 15-30 GeV has been used elsewhere
  - LHC maybe finds harder better...

# Background model

- Harder to take from data
- 2→4 MC not very reliable
  - Especially with jet energy scale issue
- D0 use variation of $f_{DP}$ with $p_T$
  - Knowing signal shape from signal model, use MC to give ratio of background in adjacent $p_T$ bins – can then extract absolute level
- Can we construct a 'flat' background?
  - δφ is a candidate
  - No obvious correlation in soft jets φ...
  - If so, then can fit and no $p_T$ scale dependence

# Two b jets, 2 light

- New approach, so far theory only
- Reduce ambiguity by requiring 2 b-jets
- Suggests that MPI could be dominant contribution in soft jets



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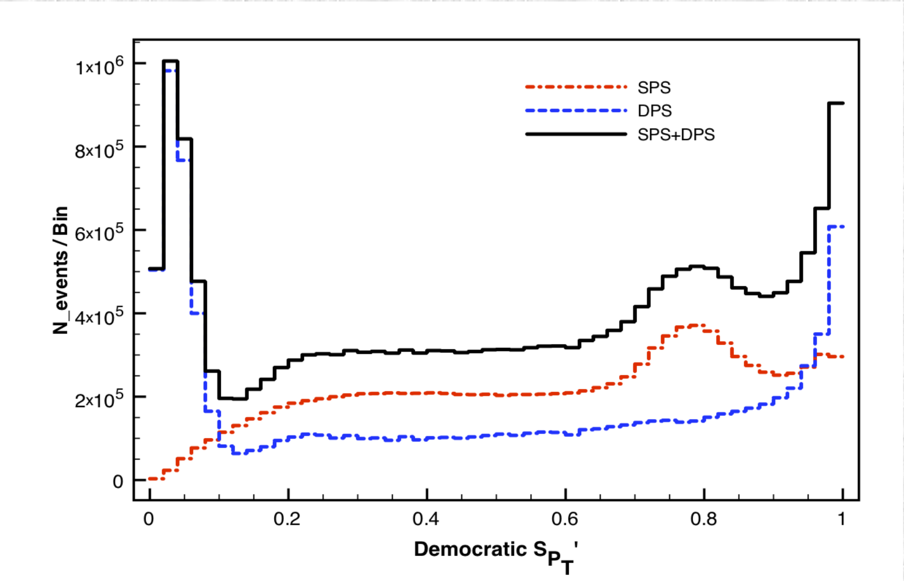
# A concern

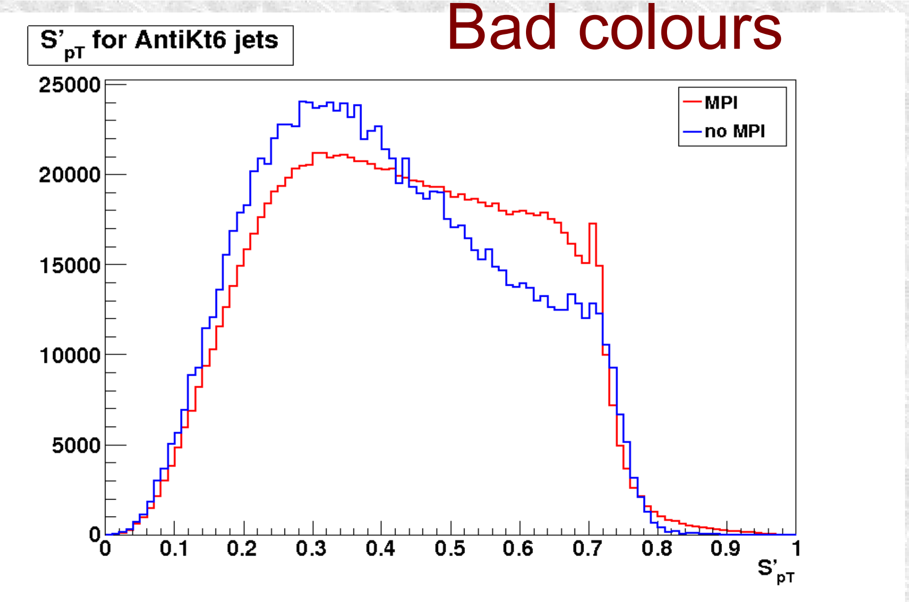
## Distinguishing variable: pairwise $p_T$ imbalance

$$S'_{pT} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|p_T(j_a j_b)|}{|p_T(j_a)|+|p_T(j_b)|}\right)^2 + \left(\frac{|p_T(j_c j_d)|}{|p_T(j_c)|+|p_T(j_d)|}\right)^2}$$

- Top: prediction from, http://arxiv.org/pdf/0911.5348v1
  - parton level
  - All combinations
- Bottom: Sherpa truth jets, 4 jet samples, with and without MPI
  - lowest $S'p_T$

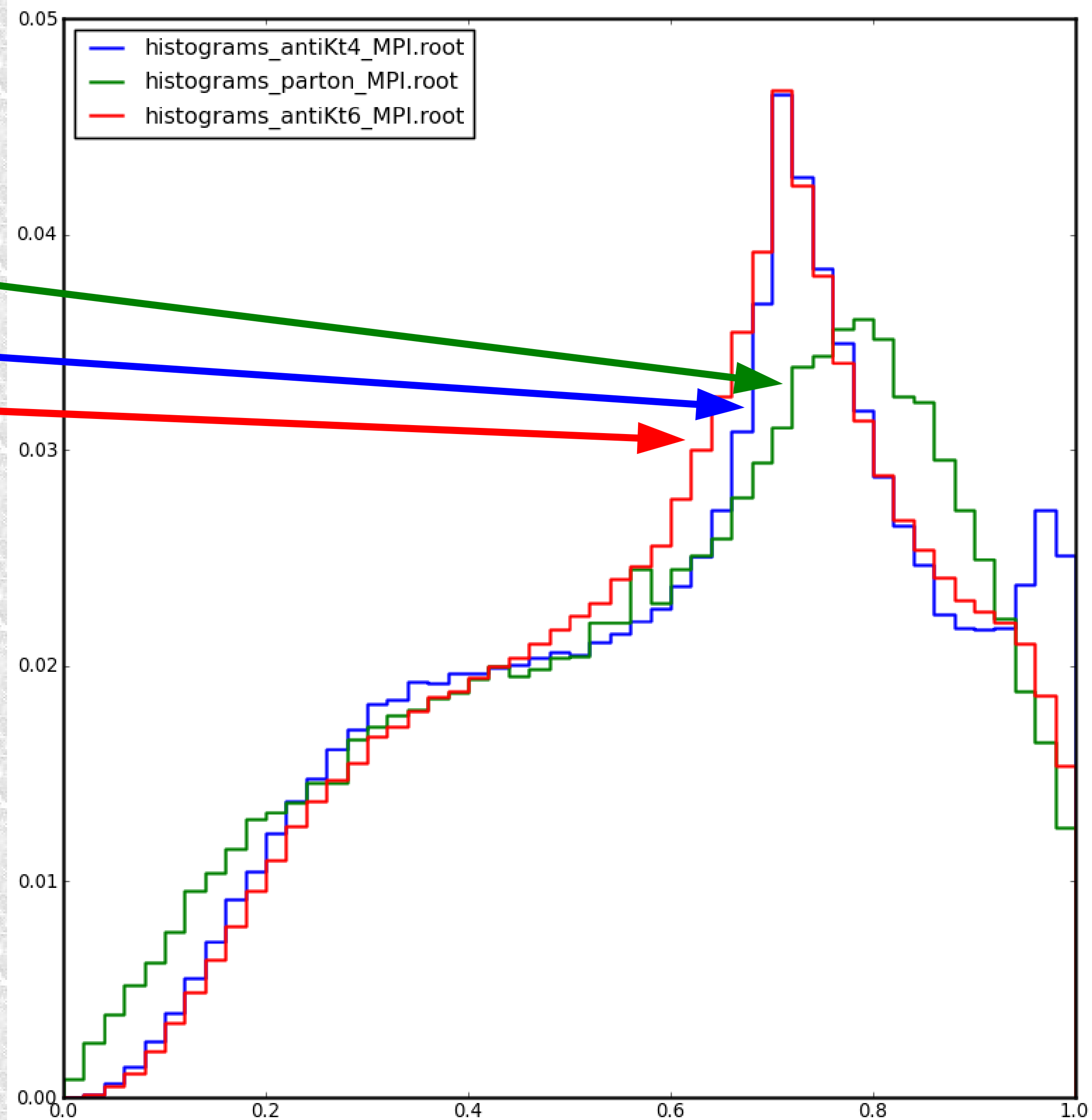



Bad colours



# Beware jet algorithms!

- $Sp_T$
- Sherpa studies
  - Parton
  - Anti-kT 4
  - Anti-kT_6
- Jet algorithms are important too!



# Fake QCD models

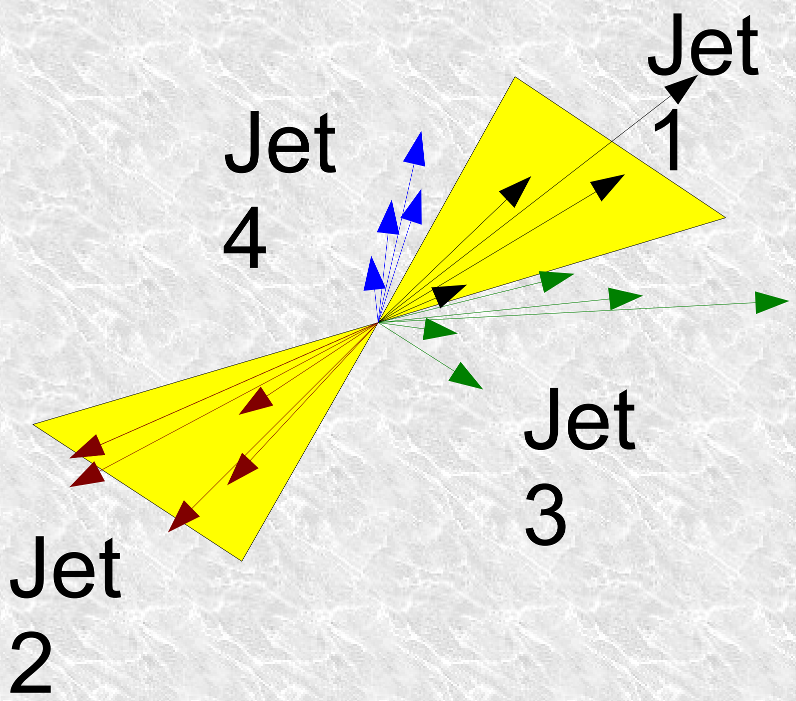
- Jet angular/$p_T$ correlation studies
- I can show these outside ATLAS
- Also, this way I control what assumptions go in.

- Need a model for background in 2→4 process
  - Hope to get insight from this

# Analysis outline

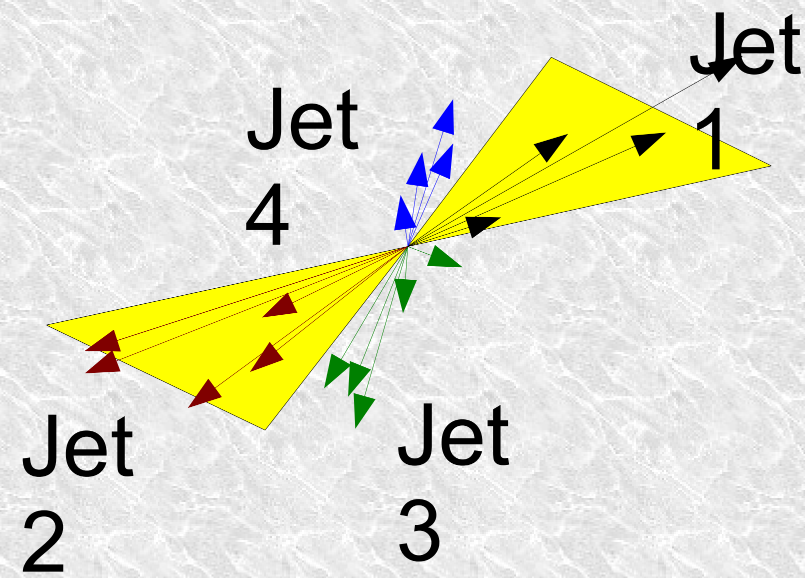
- Simulate 4 jets in some way...
  - Request highest-momentum pair back-to-back
    - This may not have been a good idea...
  - Request isolation between soft and hard jets
    - This is a parameter one can tweak
- Plot acolinearity of second pair
  - In real events DPI would peak back to back.

# Features in background




A jet with two gluons can give 4-jet topology

- Acolinear soft dijet
- Esp. loose isolation




Two radiating jets can give 4-jet topology

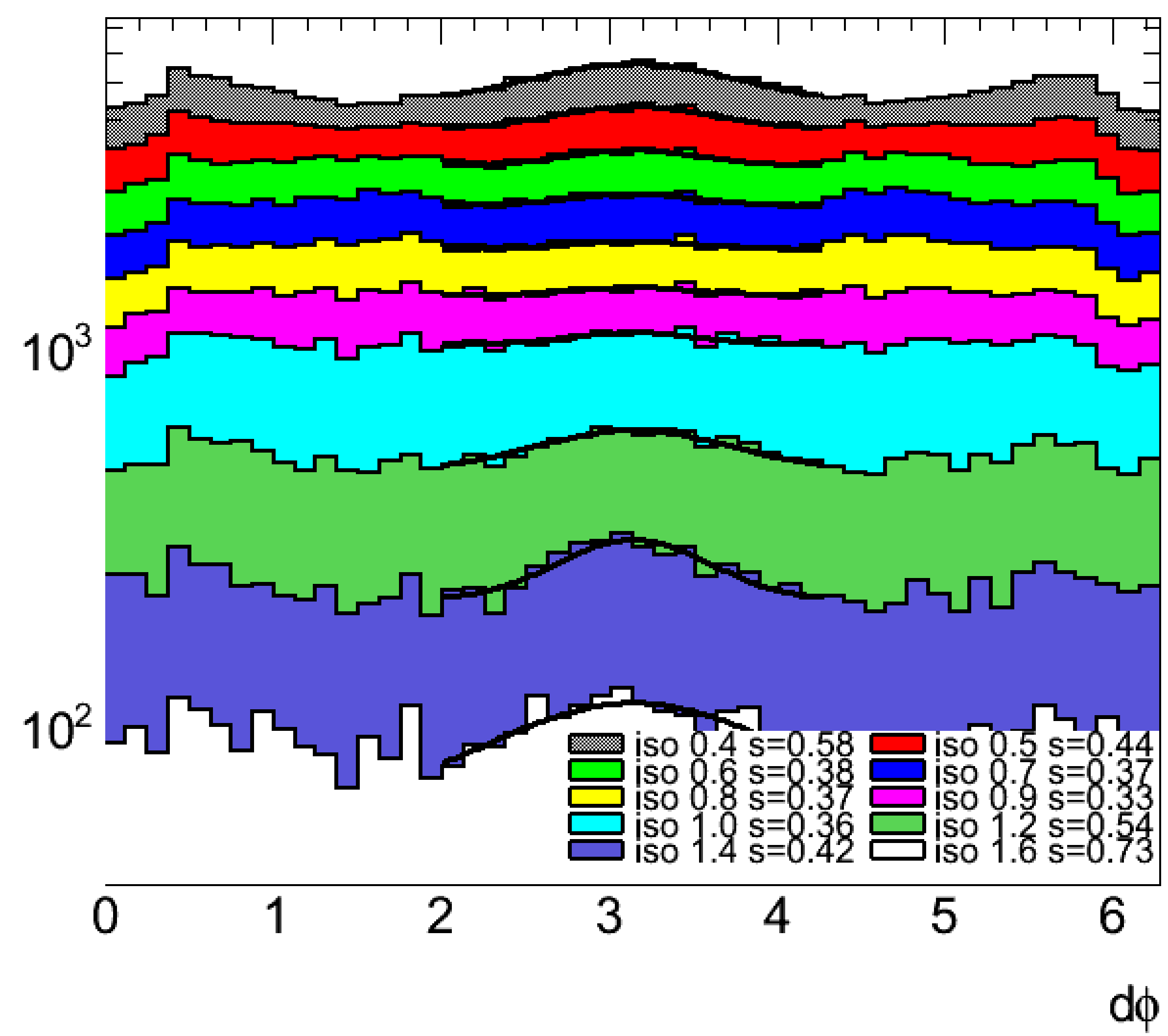
- colinear soft dijet
- Nasty – looks like MPI

# Fake QCD 1

- Assumption:
  - Start from dijet, colinear
    - Random eta ± 2.5
  - Soft jets generated close to parents
    - Random which parent
    - dR given by Gaussian, >0.4
    - Rotate round parent.
  - No conservation of momentum
    - Momentum not calculated at all!
- Then vary isolation between soft and hard jets
  - As is done in analysis

# Fake QCD1: dR 1

- **Gaussian width 1 in dR**
- **Peaks at 0, π from definition**
- **Isolation 0.8 accepts 1/3 of events – but distribution is ~ flat**

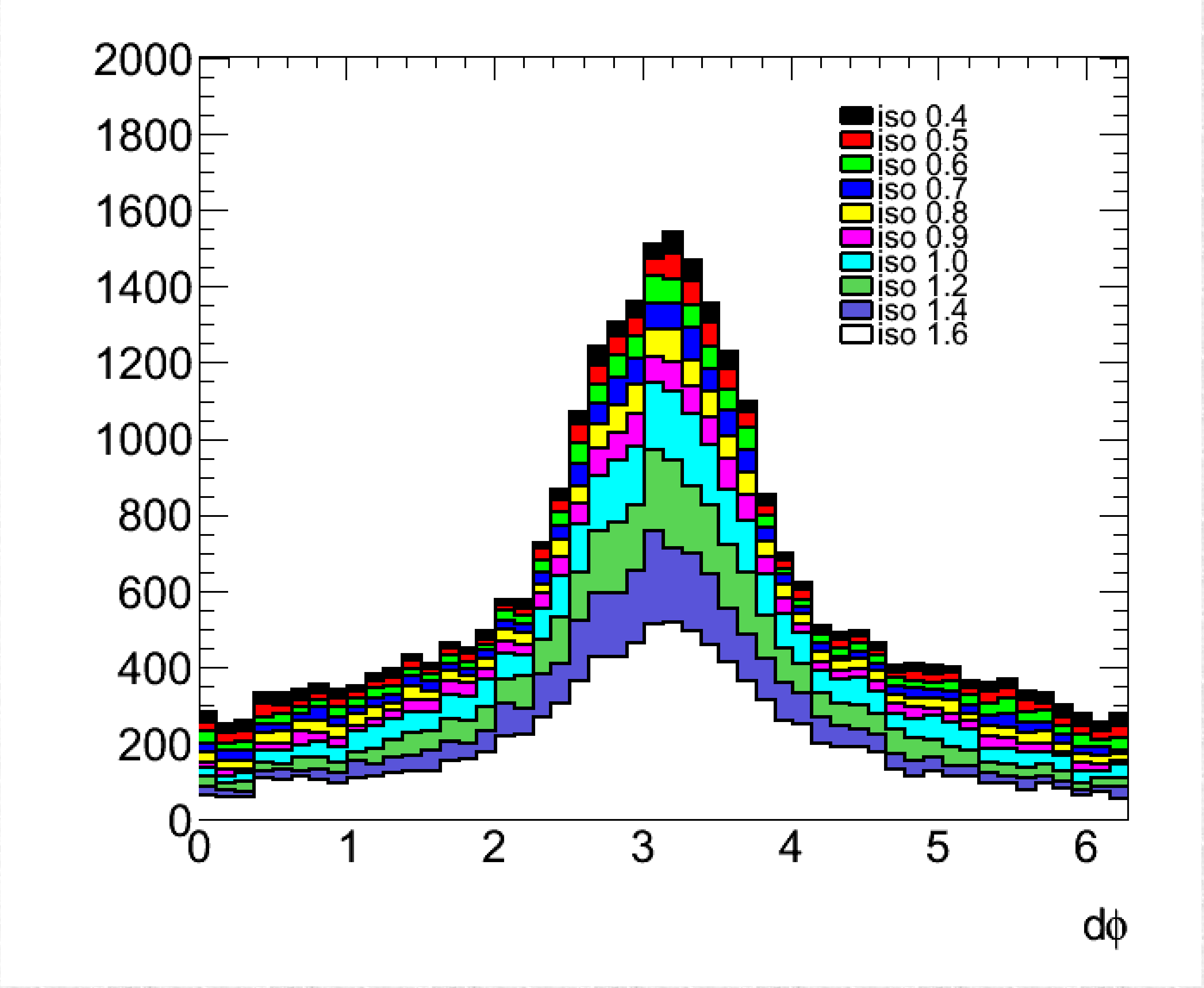


# Fake QCD 2

- Assumption:
  - Generate 3 random vectors (jets)
    - Random eta ± 2.5
    - Φ is 0 to 2π
    - Momentum >7, exponentially drop
  - $4^{th}$ jet from conservation of momentum
    - Random eta ± 2.5
  - Ensure isolation 0.4 is respected
  - Apply momentum separation
    - (two above 20GeV, two 7-20GeV)
- Then vary isolation between soft and hard jets
  - As is done in analysis

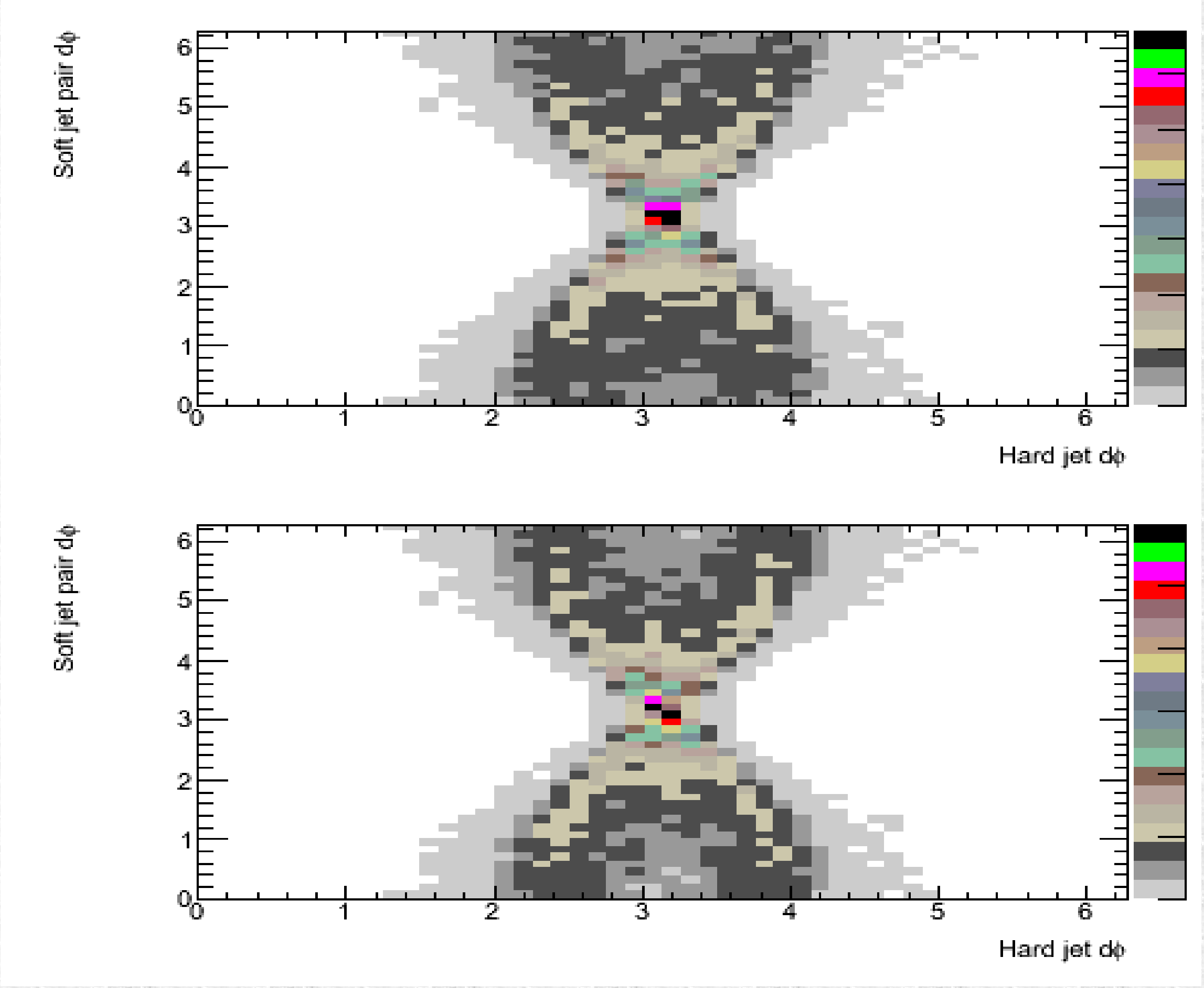
# Fake QCD2: dφ

- Peak back to back in phi
- Conservation of momentum imposes this
- Bother.
  - This was the shape I was looking for in signal



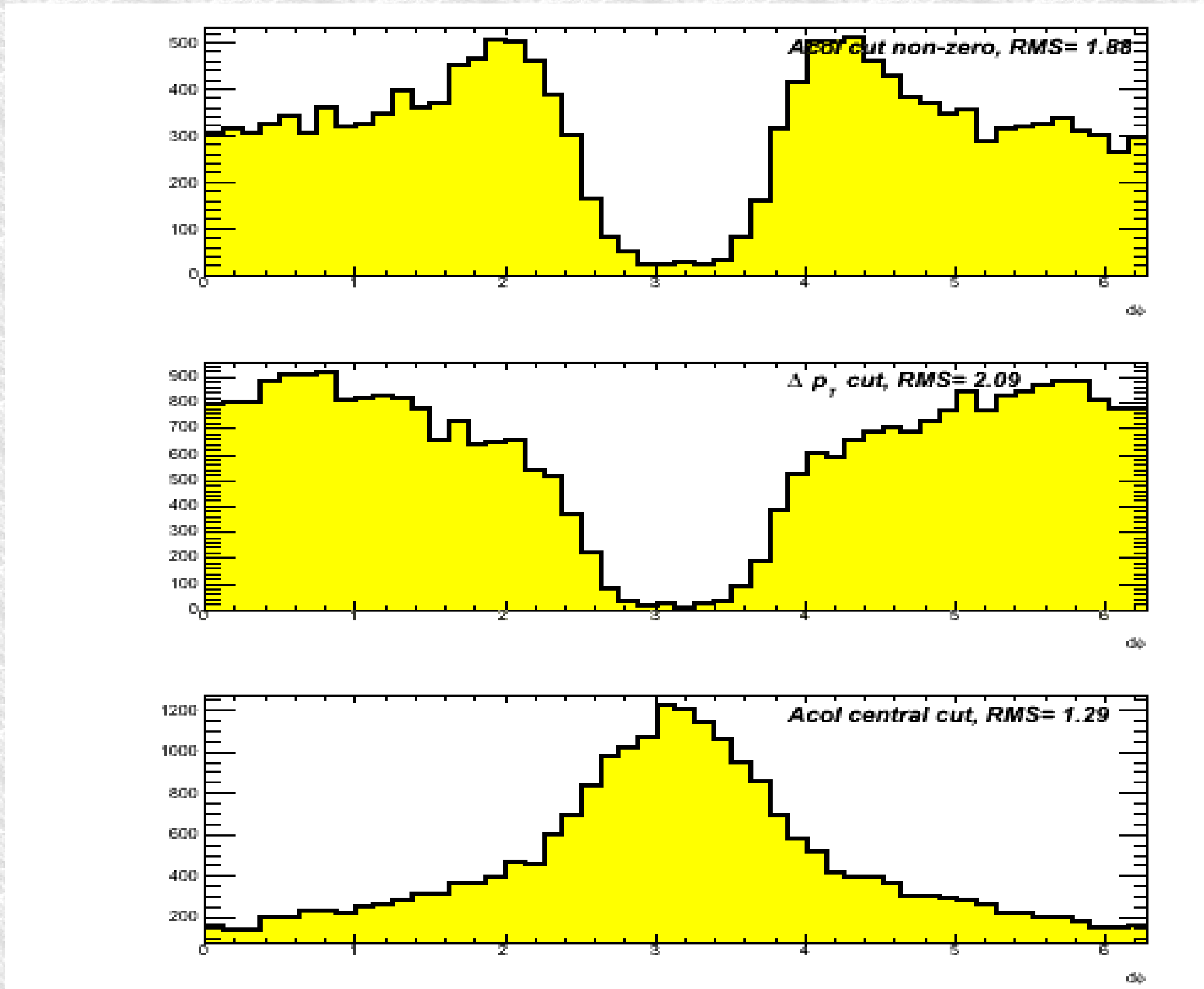
# Fake QCD2: dφ correlation

- Compare dφ of soft and hard jet pairs
- Top is all events, bottom is with isolation tightened
- If soft jets are collinear then hard pair must be (little $p_T$ to bend them)



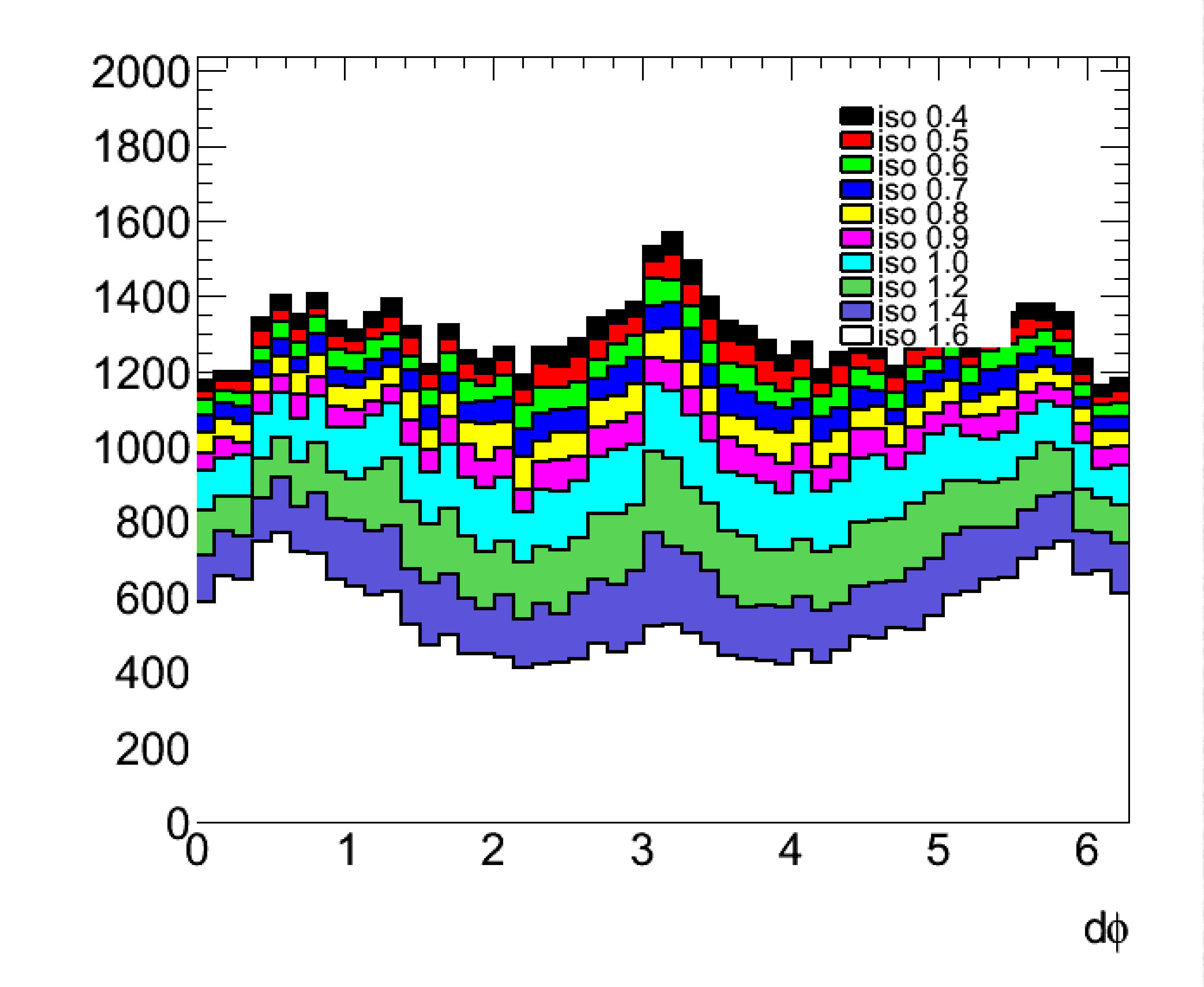
# Fake QCD2: dφ with cuts

- **Try different hard jet selections**
- **Top: hard jets must be acolinear**
- **Middle hard jets must be 1GeV apart**
- **Bottom Hard jets collinear to 0.3 - default**



# Fake QCD2: dφ no cuts

- Remove colinearity requirement on hard jet pair
- Allows more events in
- ~all away from π
- Much flatter distribution



# Summary

- LHC data contains a major component of multi-parton interactions
- Despite tuning particle level studies there is significant uncertainty on the rate
- ATLAS is looking at the problem from several directions
  - Track level – see later talk
  - γj – well tried
  - bb – theoretical interest.
  - jj – high rates
- $p_T$ scale is major issue for jet based studies
- Expect to see developments here

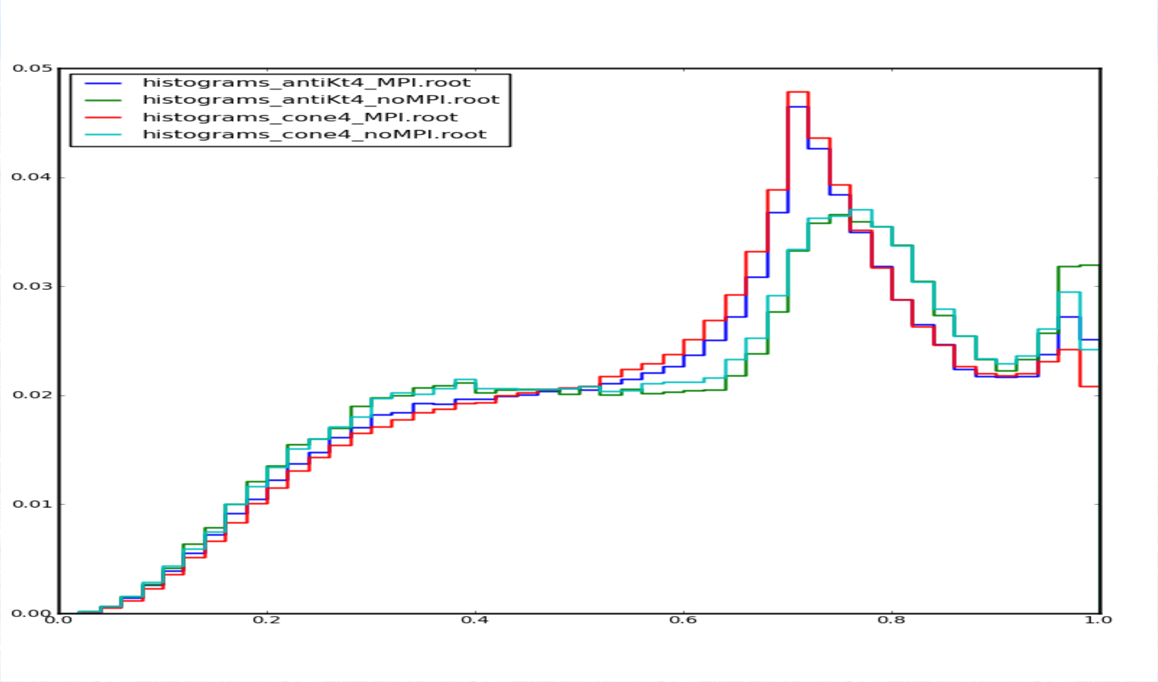
# Pileup

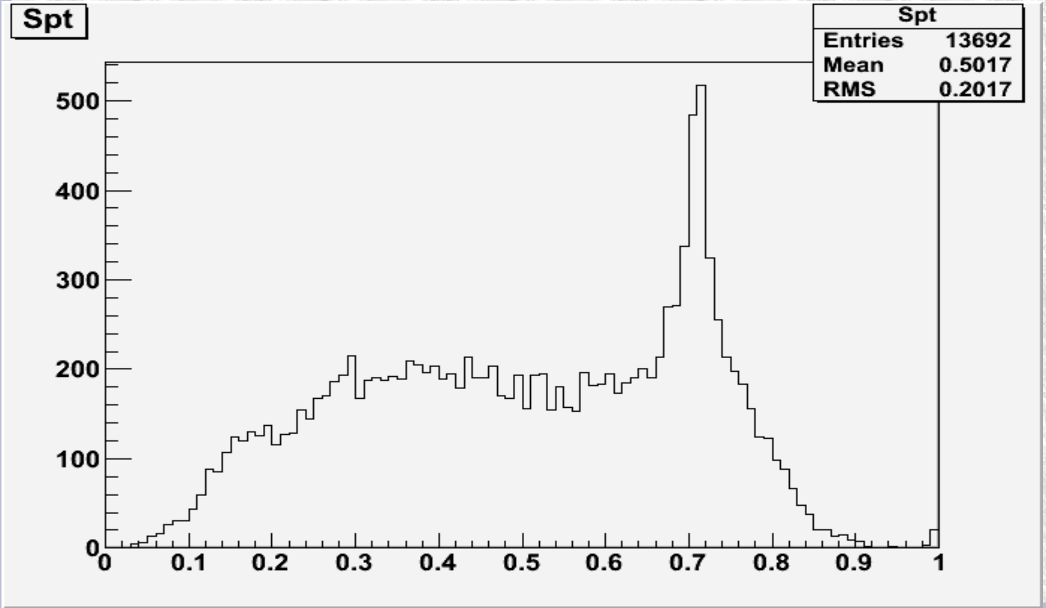
- Ansatz: 2 jets from a primary vertex and 2 jets from a secondary vertex have the same shape as 2+2 jets from a double-parton interaction.
- At the moment: Use as cross-check for analysis strategy.
- Ideally take shapes from pileup rather than simulation

# Summary

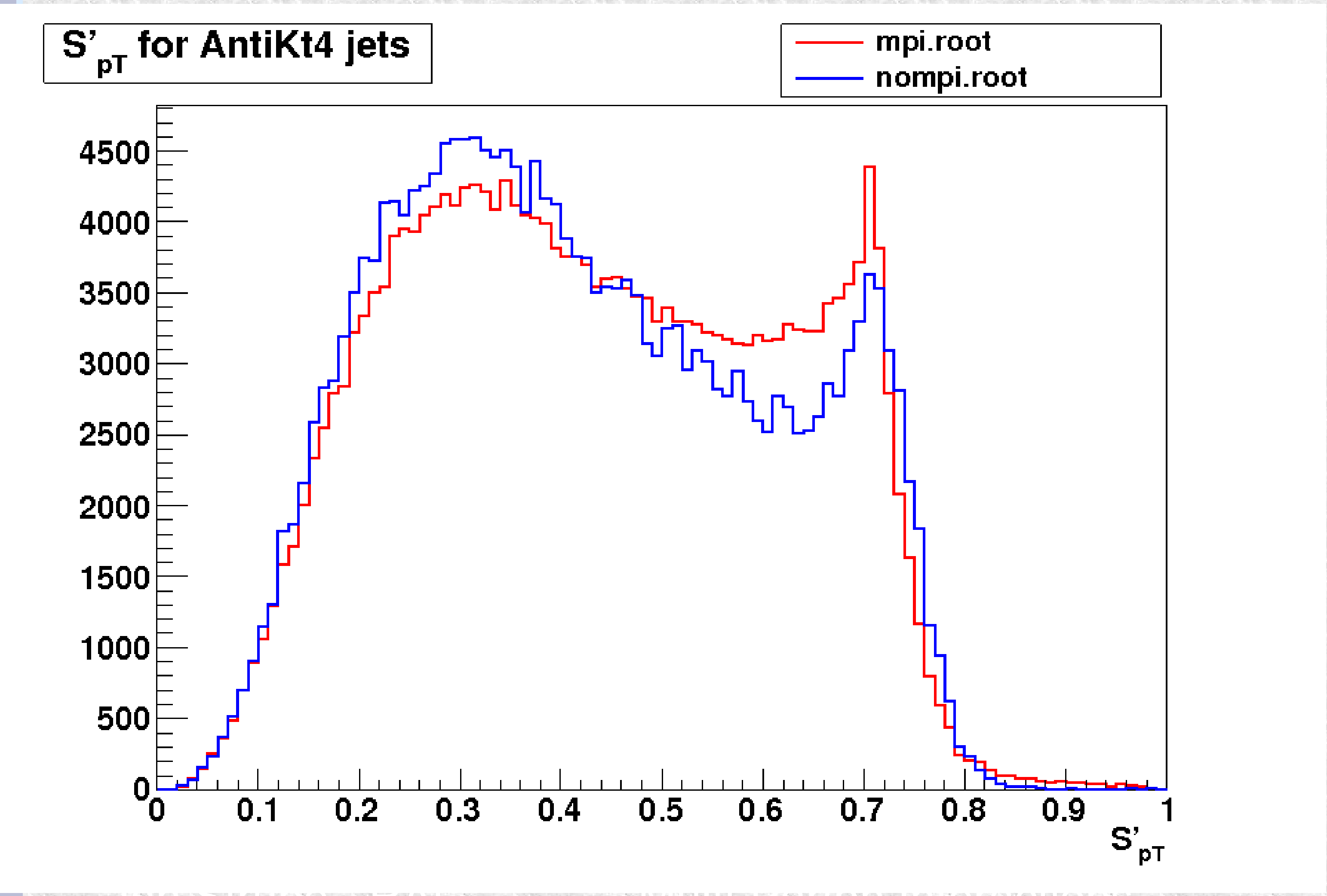
- MPI events could have a sizeable contribution to ATLAS physics, especially with early data.
- We're trying to tackle the problem from 3 sides.
  - The bbjj approach at least hasn't been tried before.
  - This allows for important consistency checks
- Lots of things remain to be understood, however
  - we are sensitive to different rates of MPI events in simulation
  - we are making good progress towards understanding our data
- Need to put current status into text form to facilitate collaboration

# S’pT with no pT cut



# S'pT for AntiKt4 jets



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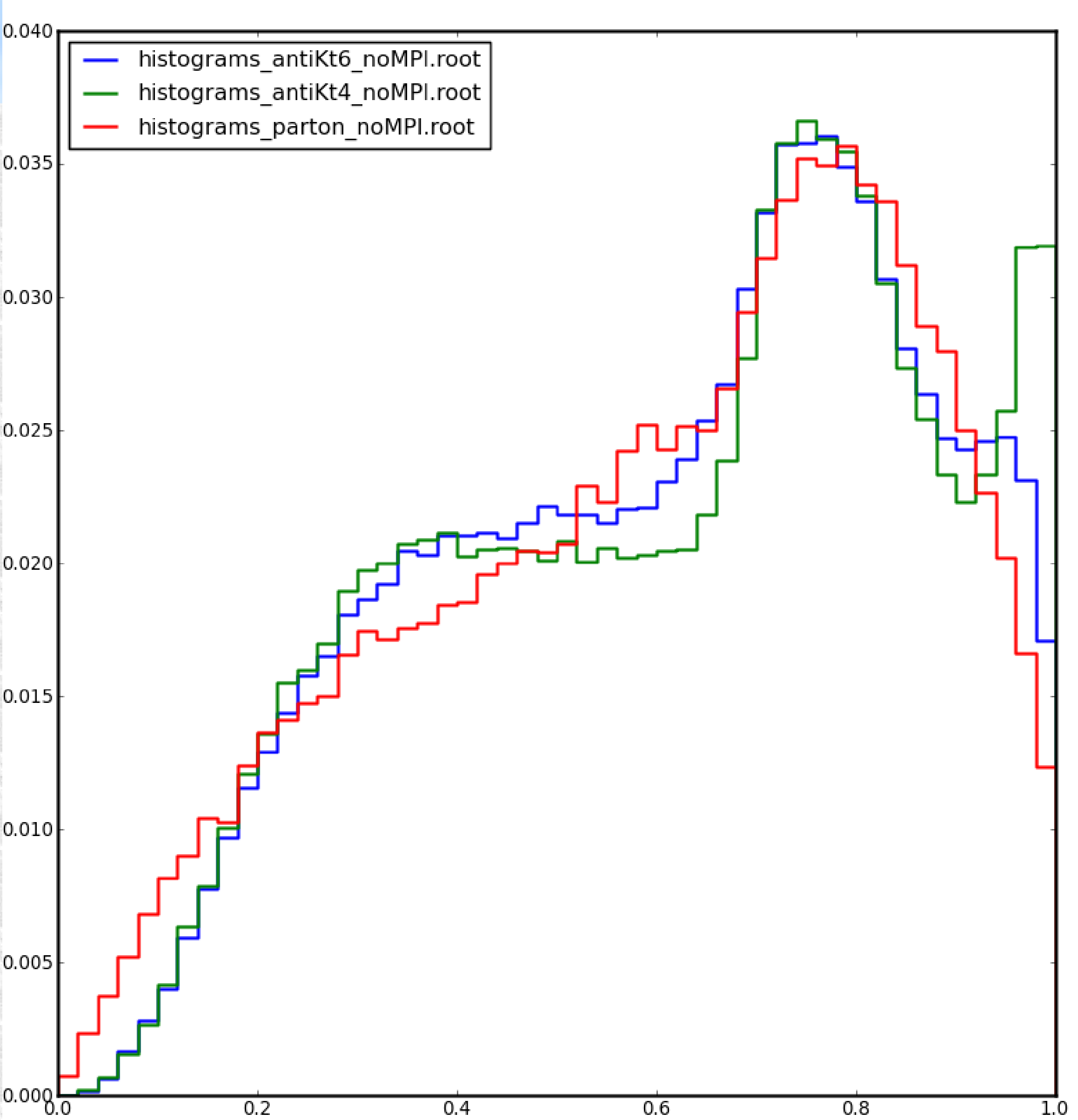

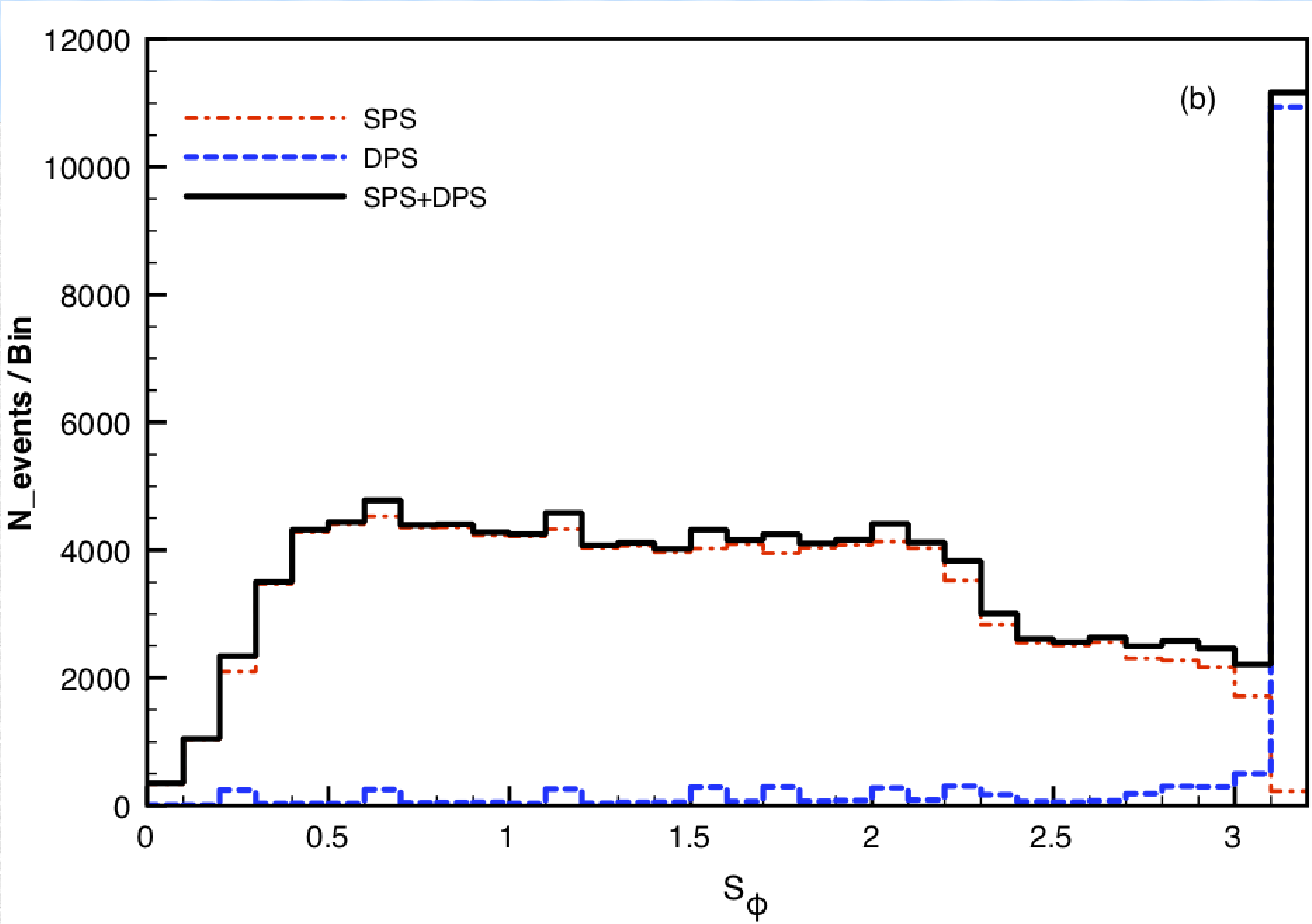
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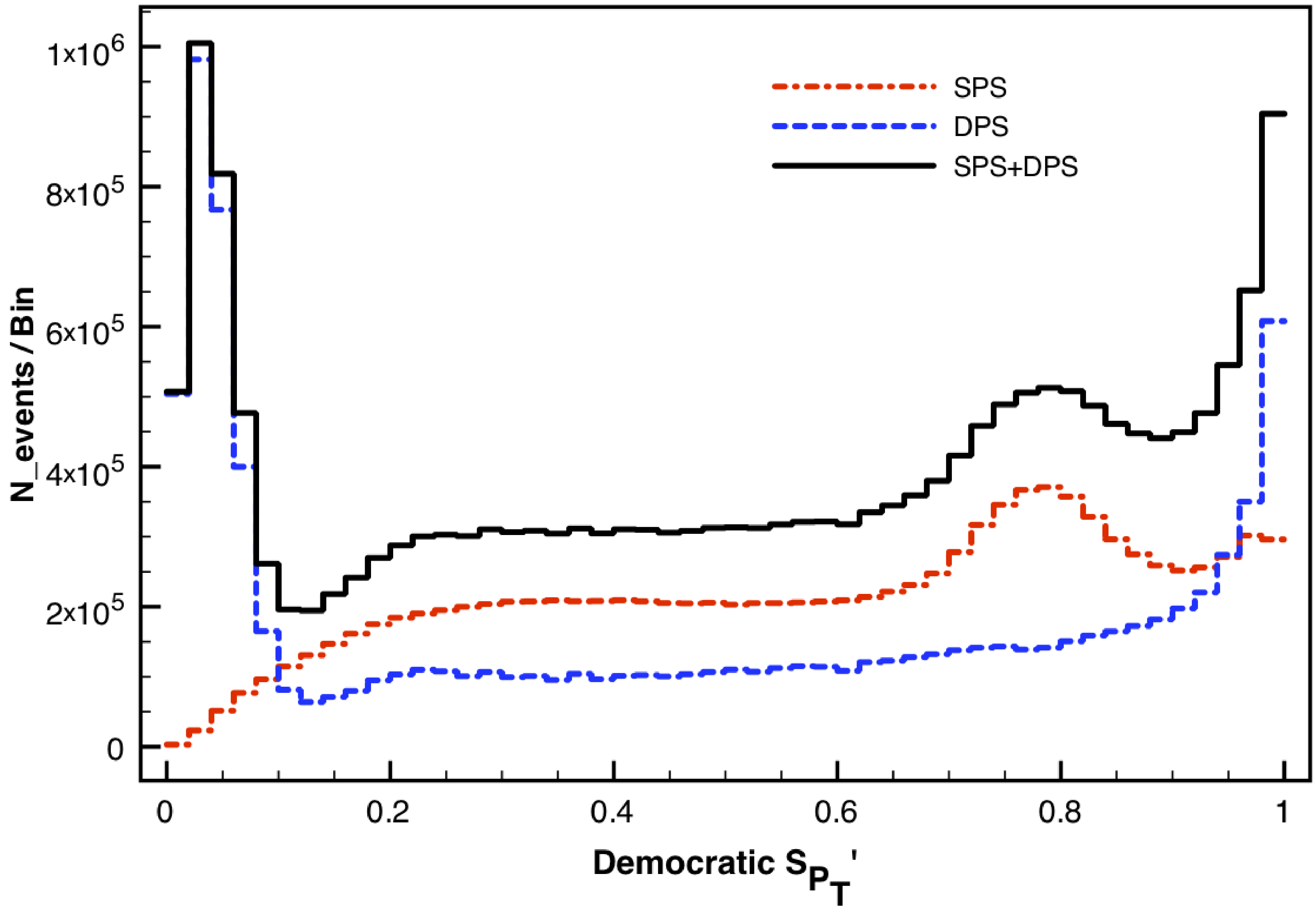
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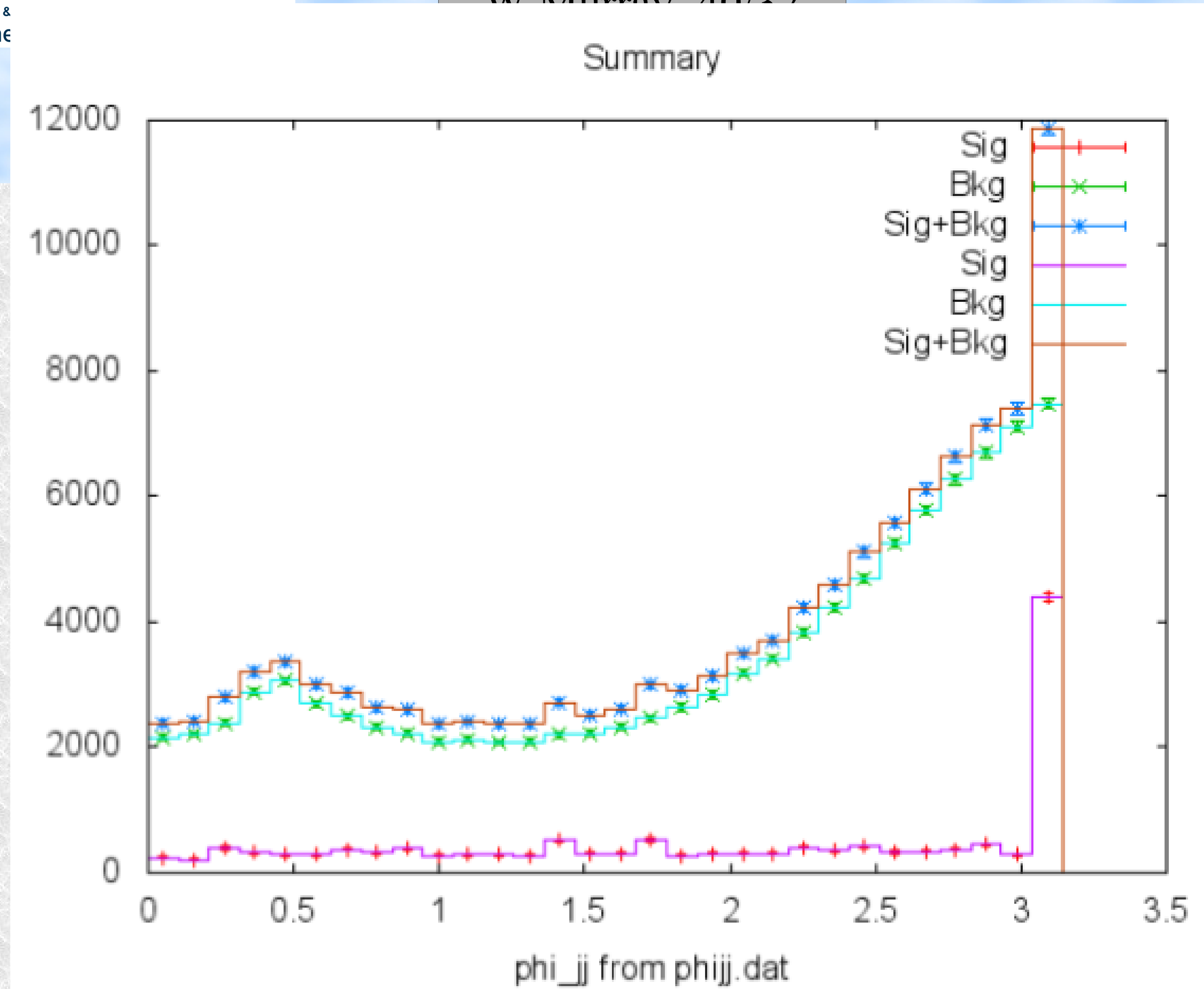
Summary
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phi_jj from phijj.dat