Early Spin Measurements at the LHC

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Outline

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Introduction and Basic idea

- Solving the hierarchy problem usually requires some SM partners to cancel the quadratic divergence in SM.
- A leading example is SUSY. Experimentally to confirm it, one wants to determine the spins of the new particles.
- The standard way to do this is through the spin correlation; Many studies in the literatures A. J. Barr; P. Meade, M. Reece; J. M. Smillie, B. R. Webber; L. T. Wang, I. Yavin, ......

This workshop – Talks of J. Lykken, S. Thomas and M. Graesser

May work for light sleptons or high statistics.
Introduction and Basic Idea

- What we are emphasizing is that a proper use of the rate information is extremely helpful in the early determination of the spin.

- The basic observation is that the cross sections of particles with different spin will differ significantly in many cases.

- Experimentally one will estimate the cross section and mass of the new particle. In most situations, this would immediately imply the spin.

- Method works best when one production mechanism dominants, e.g. color octets at LHC.
Introduction and Basic idea

- Initially test most reasonable hypotheses
  - color octet if $M \sim 1 \text{ TeV}$, $\sigma \gtrsim \text{ pb}$
  - no fine-tuned mass degeneracies that could confuse results. (Works even then, but more effort needed)

- Then later repeat with more alternatives
  - color triplet, etc
  - special mass splittings (return to this later in the talk)
Consider Simple Example: Top at Tevatron

- The cross section at Tevatron

- Large differences in the cross section between spin-$\frac{1}{2}$ and spin-0. $\implies$ Spin of top was measured by $\sigma + M$. 
Gluino at LHC

- The cross sections for gluino and other spin candidates

- These cross sections are essentially determined by the spin and color structure.
Some discussion

• There are uncertainties in the calculated cross section: higher order QCD corrections and scale dependence. However the ratios of the cross sections depend less on them.

• For example, consider the mass of a new color octet to be $M = 800\text{GeV}$. If we choose scales $\mu_F = \mu_R = M_Z$, then the cross section for the spin-$\frac{1}{2}$ and spin-1 are given by

$$\sigma_{pp\rightarrow\tilde{g}\tilde{g}} \approx 2.8\text{pb}, \quad \sigma_{pp\rightarrow g_Vg_V} \approx 24.1\text{pb}. \quad \text{ratio} \approx 8.5$$

• For scales $\mu_F = \mu_R = M$

$$\sigma_{pp\rightarrow\tilde{g}\tilde{g}} \approx 0.95\text{pb}, \quad \sigma_{pp\rightarrow g_Vg_V} \approx 7.79\text{pb}. \quad \text{ratio} \approx 8.2$$
Some discussion

- For the same production rate, particles with different spin must have different mass. However, determination of the mass may not be trivial.
- In special cases may need further efforts to untangle the degeneracy. Usually the mass difference $\Delta M$ between the color particle and the invisible particle can be determined, for example from the $P_T$ distribution. After fixing both the rate and $\Delta M$, can we find any observable differences in the kinematical distributions, e.g., $H_t$, $E_T$, $m_{ij}$, $\Delta R_{ij}$ ... ?
- Yes, in principle.
- Then we can fit these distributions to the data and resolve the “degeneracy”.
For example

- Fix the production rate and $\Delta M = 660 \text{ GeV}$:
  
  Gluino with $M_{\tilde{g}} = 800 \text{ GeV}$, KK gluon with $M_{g_V} = 1100 \text{ GeV}$.
  Both of them undergo 3-body decay into 2 jets plus $E_T$.

- The effective mass distribution

![Ht distribution graphs](attachment:image.png)

X-section = 2.833E+00(pb)  AVG = 1.300E+03  RMS = 3.407E+02
Tot # Dets = 2999 Entries = 2995 Underbc = 5 Overs

X-section = 2.720E+00(pb)  AVG = 1.508E+03  RMS = 3.781E+02
Tot # Dets = 2997 Entries = 2990 Underbc = 2 Overs
Continue

- Maybe $\Delta M$ can be adjusted so these peaks are closer? Probably can be dealt with also.
- Adjust LKP mass ($\Delta M = 560\text{GeV}$) in the KK gluon case such that $H_t$ peak at the same position as the gluino case. We find differences in other distributions, e.g. $\Delta R$ and $\Delta \phi$ both give distinguishable distributions:
**R(jet1,jet4)**

![Graph showing distribution of DeltaR between jet1 and jet4](image)

**Dphi(jet1,jet4)**

![Graph showing distribution of DeltaPhi between jet1 and jet4](image)

**Ht**

![Graph showing distribution of Ht](image)

**Missing ET**

![Graph showing distribution of Missing ET](image)
Summary

- The cross section information can be used to determine the spin early at LHC. $100 \text{pb}^{-1}$? The result can be checked later by examining the spin correlation.
- It works well in most “worlds”, but may need more work for complicated situations. The detailed study is under-way.