ISMD2013
XLIII International Symposium on Multiparticle Dynamics

Searches for BSM physics in multi-objects final states Introduction

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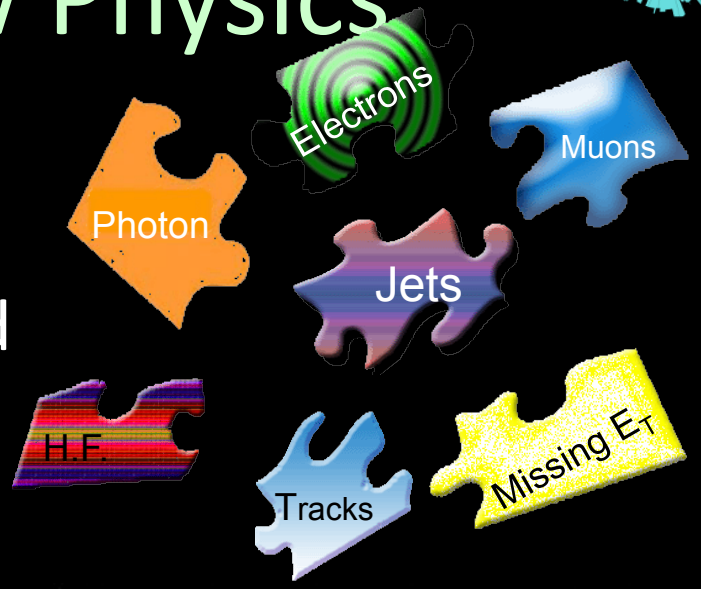
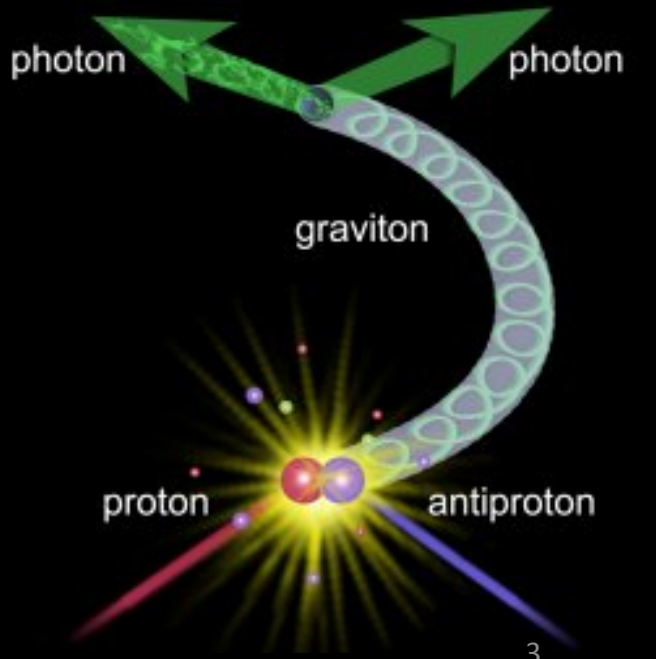
Welcome!

- To a session about searches for physics beyond the Standard Model and the techniques used to look for it in *complex final states*
- 5 presentations
  - 3 on experimental results
    - ATLAS, CMS and Tevatron
  - 2 Theoretical Overviews
    - BSM processes involving multileptons and multijets.

Searching for New Physics

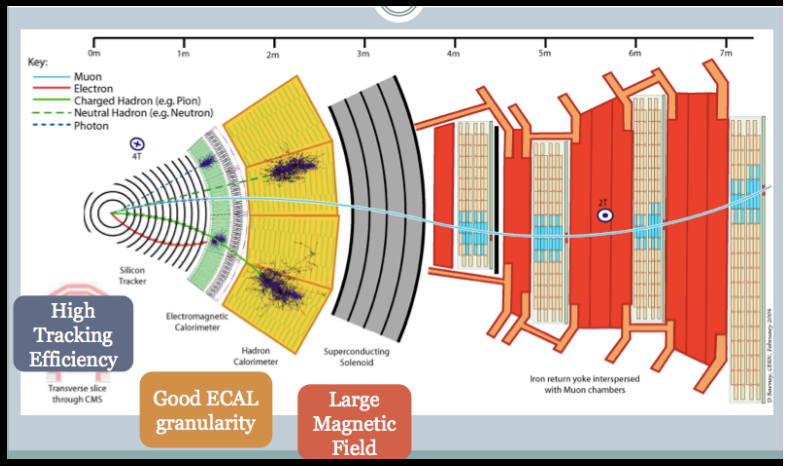
- When searching for new physics every corner is to be explored for possible new physics processes and their signatures
  - from simple objects to complex final states
    - **leptons-only final states (and isolated tracks)**
    - **… + Missing Energy and Photons**
    - **… + Jets and heavy flavors**
  - Algorithms and selection procedures need to look for the needle in the haystack
    - Particle flow, multivariate analysis techniques





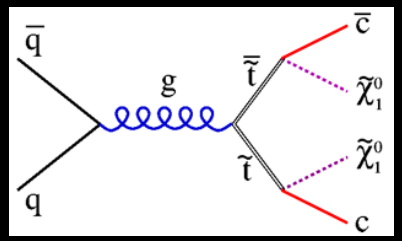
Experimental Tools

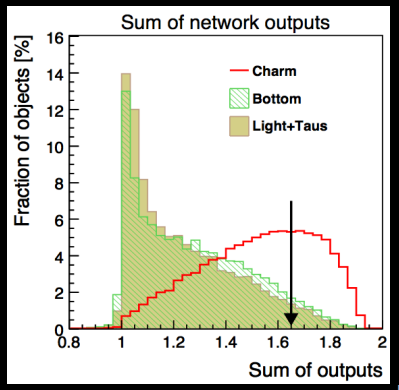
- In general, signatures of New Physics appear in final states containing:
  - Charged leptons including hadronic taus
  - High PT jets
  - b--quarks
  - Missing transverse energy due to weakly interacting neutral particles.
- To study these signatures experimentalists need methods to reconstruct and identify all particles in events as accurately as possible.
  - Particle Flow attempts to reconstruct all stable particles in an event. Photons, charged and neutral hadrons, electrons, muons.
    - Information from sub--detectors is combined in best possible way.
    - List of particles is returned, as if it came from a MC generator.
    - Higher level physics objects can be built from list of particles.

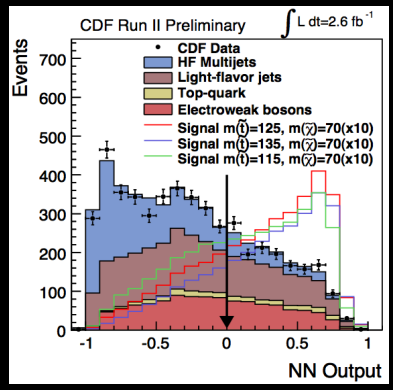


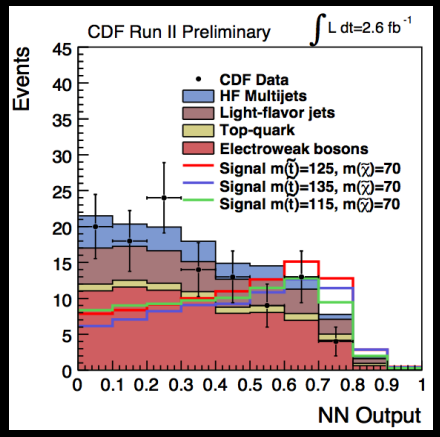
Experimental Tools

Multivariate Analysis Techniques:
Optimization process using a Neural Network (NN) plus a flavour saparator (CHAOS) to reduce the background contribution.









Casting a Wider Net

- Signature-based and model-based searches

  - **A) Benchmark-model driven analyses**
    - pick a favorite theoretical model ☹ **might become soon outdated!**
    - pick a process, choose the best signature(s): optimize selection acceptances based on signal MC
    - Estimate backgrounds (MC or data) ☺ **best optimization!**
    - Set a limit or discover a signal ☺ **in timely fashion allows theory testing!**
  - **B) Signature based approach**
    - pick a specific signature ☺ **open to a whole lot of models!**
    - Define the sample in terms of known processes ☹ **Sometime not the best optmization !**
    - publish estimates of acceptances & cross section information useful for further theoretical interpretations
    - Observe an inconsistency with the SM expectation? Test several models…

Which New Physics?

- So far there are no sign of it at the highest energy frontier…
- How to cast our net wider?
  - Simplified models for LHC searches for new physics
    - Many signatures from SM to BMS and their interplay
    - Supplementing both signature-based results and benchmark model interpretations
- SUSY and beyond
  - While the 8 TeV searches killed a lot of natural SUSY models, for each one killed there are at least two other natural models, as improbable as the one we killed, just harder to find
    - Squeezed, RPV, complex cascades, etc, etc

Must there be new physics? Where will we find it?

♦♦♦♦♦ PUZZLES
Neutrino Mass / Theory of Flavor
Higgs Boson Naturalness
Dark Matter
Dark Energy and Modified Gravity
Matter Asymmetry
Inflation

- Naturalness
- Higgs as a portal into exotics
- Dark Matter
- Flavor

SM all the way at the Energy Frontier? Implications of the Higgs discovery…

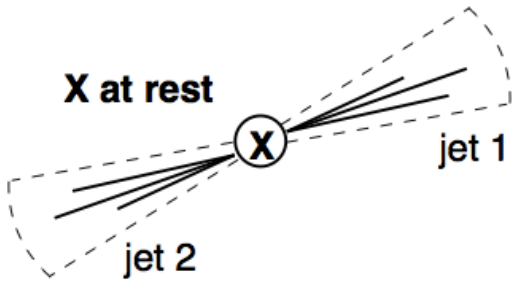
- A discovery or an exclusion of SUSY particles at such mass scales, will indicate a path to follow between several possible future scenario for fundamental physics:
  - The small value of the Higgs mass (in Planck units) has a "natural" explanation, most likely using SUSY, in which case we spend the rest of our lives unraveling the complexities of a SUSY-extended Standard Model.
  - The LHC has just shown that the hierarchy/naturalness argument was mistaken and EWSB is "fine-tuned" and a compelling theoretical explanation for it will be needed. However, from the "hierarchy" angle, the problem is why the ratio of the electroweak-breaking scale to the GUT or Planck scale is such a small number. We don't actually have any evidence for GUT physics or for quantum gravitational physics yet, so there is no good reason to be sure that such high scales are relevant to anything or the cause of a hierarchy problem. There might alternatives to the naturalness argument and these might point to observable new physics at LHC scales.
  - Finally, as argued in some string theory circles, the small value of the Higgs mass (in Planck units) indicates "fine-tuning" that can only have an anthropic explanation. In that case, we live in a multiverse, with physics determined by something like the string theory landscape.

Theoretical Tools: Simplified Models

- A simplified model is defined by an effective Lagrangian describing the interactions of a small number of new particles.
- Simplified models can equally well be described by a small number of masses and cross-sections. These parameters are directly related to collider physics observables
  - effective framework for evaluating searches
  - useful starting point for characterizing positive signals of new physics.

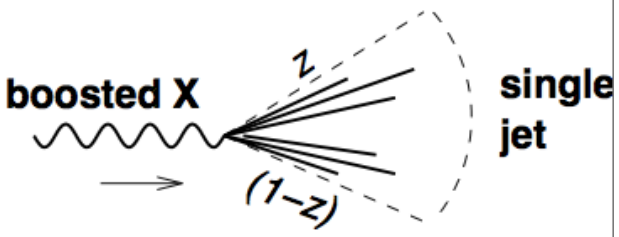
Theoretical Tools: boosted objects

Normal analyses: two quarks from $X \to q\bar{q}$ reconstructed as two jets



As LHC explores far above EW scale these configurations become of interest

High-p_t regime: EW object X is boosted, decay is collimated, $q\bar{q}$ both in same jet



Happens for $p_t \gtrsim 2m/R$

$p_t \gtrsim 320$ GeV for $m = m_W$, $R = 0.5$

New heavy particles can decay to boosted W, Z, H, top, χ0 (RPV); WW scattering at high pt

- leptonic decays easily tagged, but rare and/or have MET
- hadronic decays more common and fully reconstructible
- Multijets resonances
- Exotic Top partners
- …

Key Ingredients:

Resolving the underlying 1 → 2 splitting and using its characteristic kinematics to help reject background

Protecting jet-mass resolution from the effects of underlying event and pileup

Exploiting different colour structures of signal and background and resulting different energy flows

Let's Start!

Ray Culbertson -**BSM searches in multi-objects final states at TEVATRON**

Jane NACHTMAN- **BSM searches in multi-objects final states with the CMS detector**

Patrick MEADE -**Multi-lepton new physics searches**

Thijs CORNELISSEN -**BSM searches in multi-objects final states with the ATLAS detector**

David KROHN -**Jet and new physics searches**