Soft Tracks - a probe of New Physics at LHC

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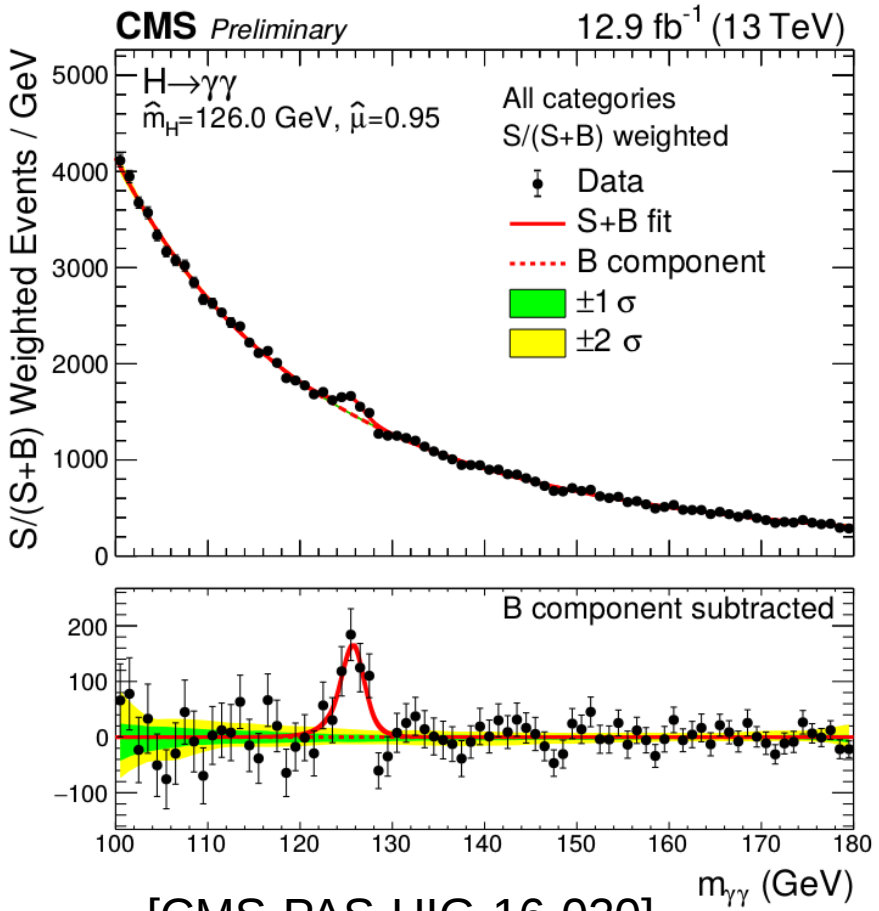
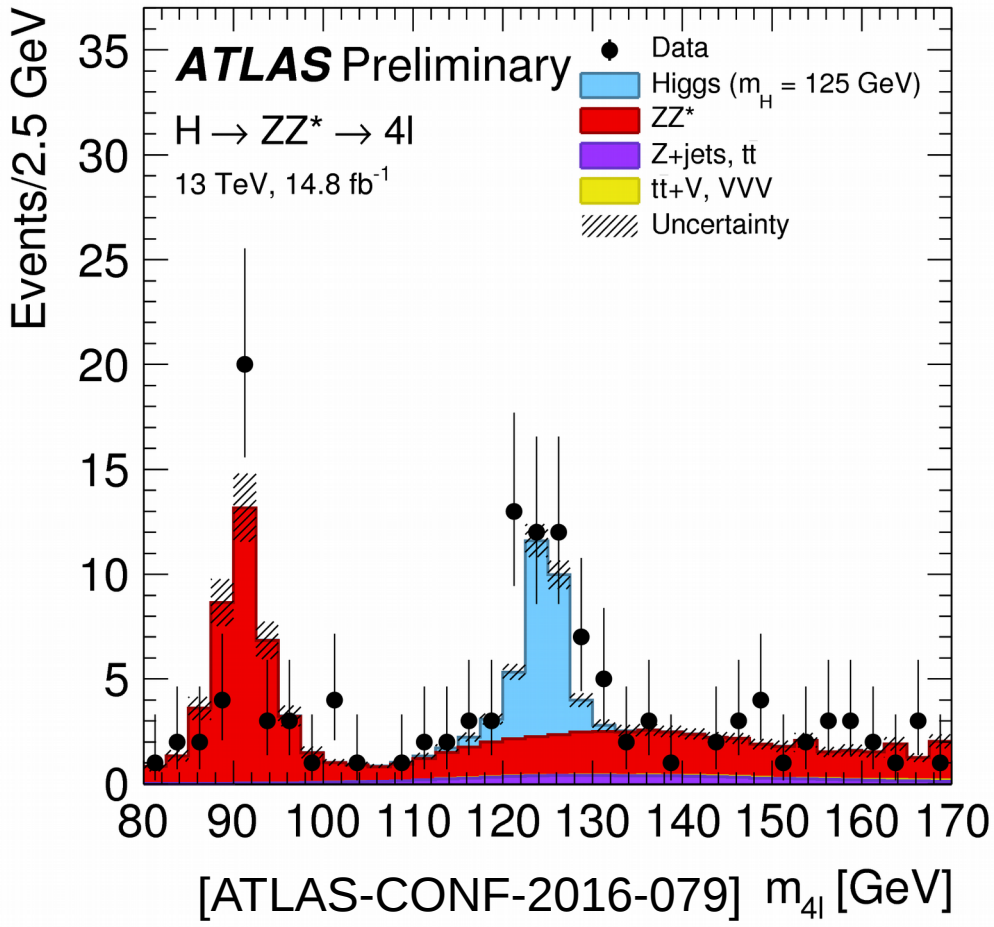
Based on: AC, Sabyaschi Chakraborty and Tuhin S. Roy
[PRD 94, 111703 (2016) (Rapid)]

Higgs update



[CMS-PAS-HIG-16-020]

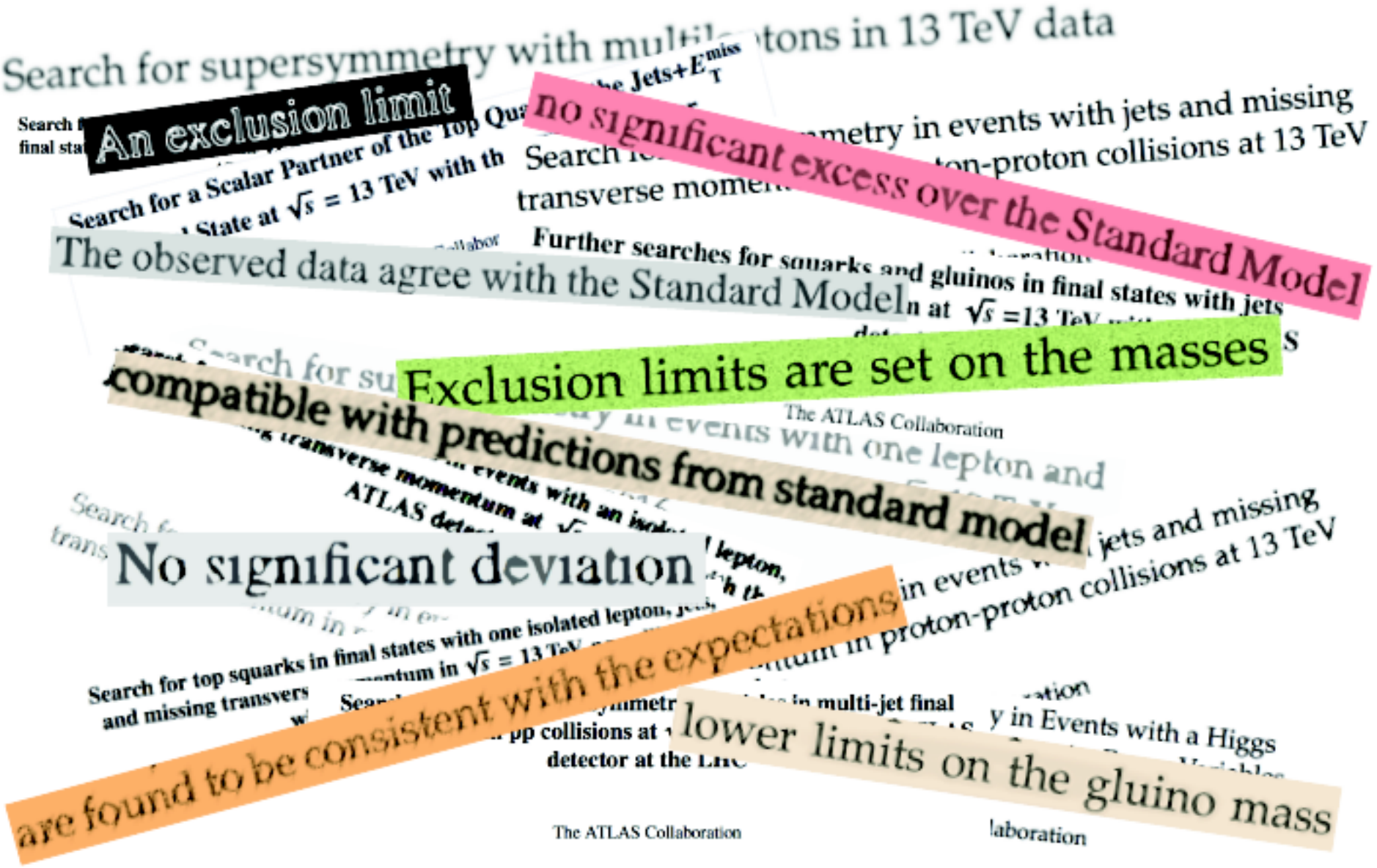


[ATLAS-CONF-2016-079]

- Confirmation of Higgs discovery
- Measurements are consistent with SM Higgs
- More detailed study, more luminosity

(comprehensive review by Djouadi)

Beyond Standard Model

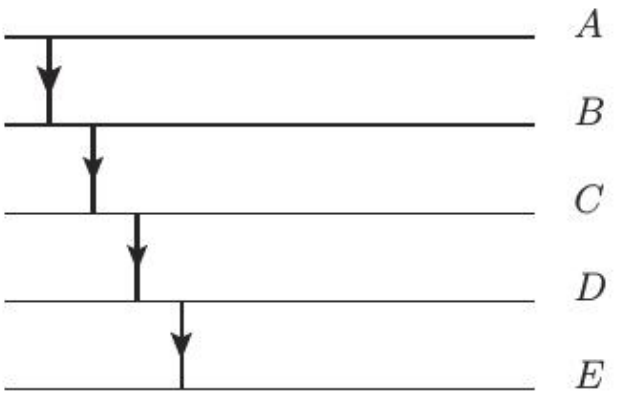


Courtesy: Ian Low, ICTP 2016 talk

Interpretations

Where SUSY could be hiding ?

1. **Compressed spectra** - small mass differences, long decay chain, soft leptons/jets, fail analysis Cuts, Limits are rather weak at LHC



[Martin PRD 75 (115005); Fan et. al. JHEP 11, 012; Murayama et. al. PRD 86 (115014)]

2. **Long-lived particles** - cuts fail to identify jets or leptons. (**similar to prompt limits**) [Monteux JHEP 1603 (215), ...]

Numerous study, challenging scenarios ! Baer et. al., Martin et. al., Bhattacherjee et. al., Nojiri et. al., Harigaya et al., ... many more

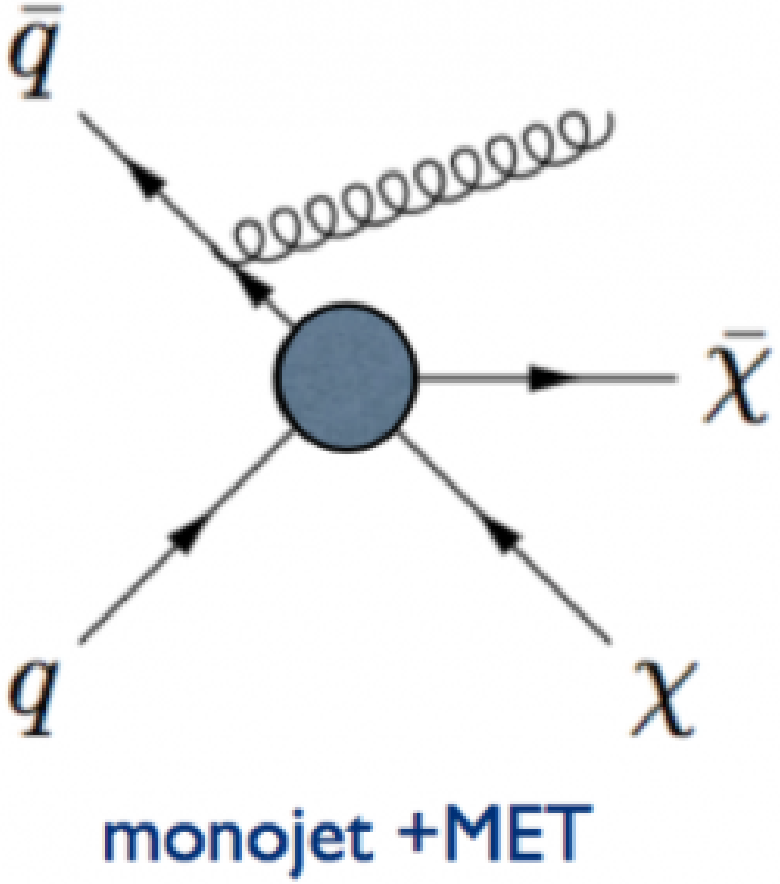
Goal:

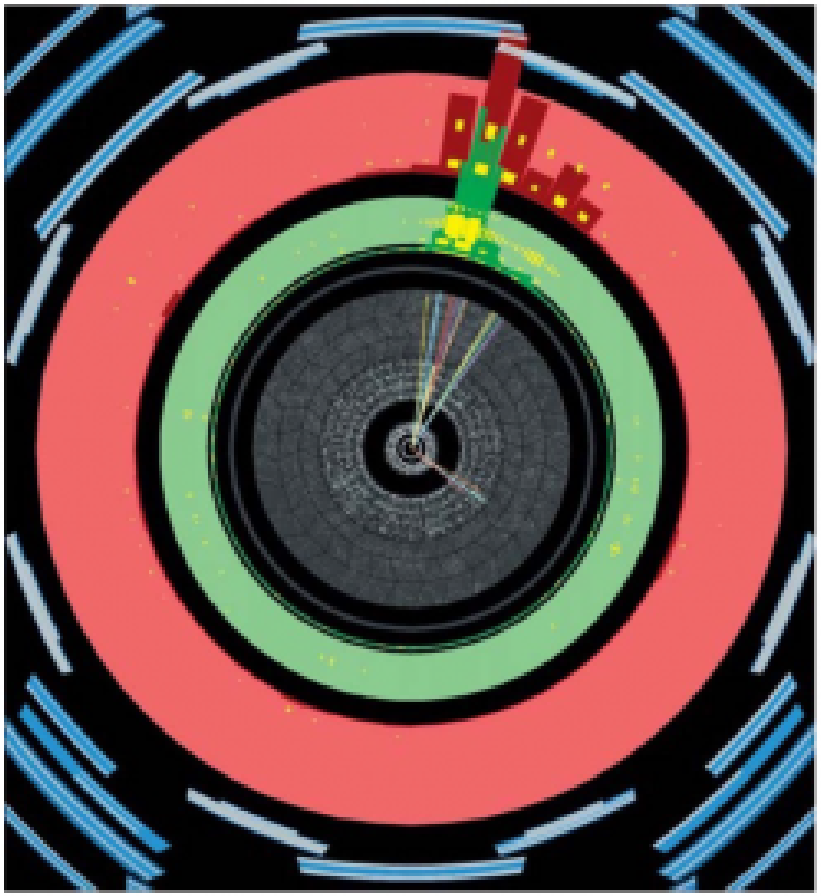
Compressed SUSY, device a search strategy to improve sensitivity at LHC

Outline

- Compressed spectra
  - Mono-jet search
  - Traditional methodology
  - Soft Tracks variables
- Collider phenomenology
- Comparison (and improvements)
- Summary

Mono Jet search





Mono-jet event from ATLAS (credit: CERN courier)

Visible parts do not cross the threshold

Topology: **An energetic Jet with large MET**

Image courtesy: Google.com

Mono Jet search

- Extremely challenging !
- **Theory: Sensitive to NP models -** SUSY, Extra-dimension, DM searches, ...
- **Expt. information**:

  I. Reco level: 4-momentum of the jet and MET.

  II. Detector level: energy in caloremeters and/or trackers, muon chambers

  ==> More **information** at the detector level
- Can we study/utilize the complete Event information ??

Search strategy

- Look events with hard Initial State Radiation (ISR)
- Event selection (typical choices):

  Leading jet: $P_T > 100$ GeV, $|\eta|<3$

  MET > 200 GeV

  $\Delta\Phi$(j,MET) > 1.0

  $H_T > 500$ GeV [H_T = MET + scalar P_T sum]

- Backgrounds: Z($\nu\nu$)+jets, W($\ell\nu$)+jets, QCD

These observables are highly correlated !!

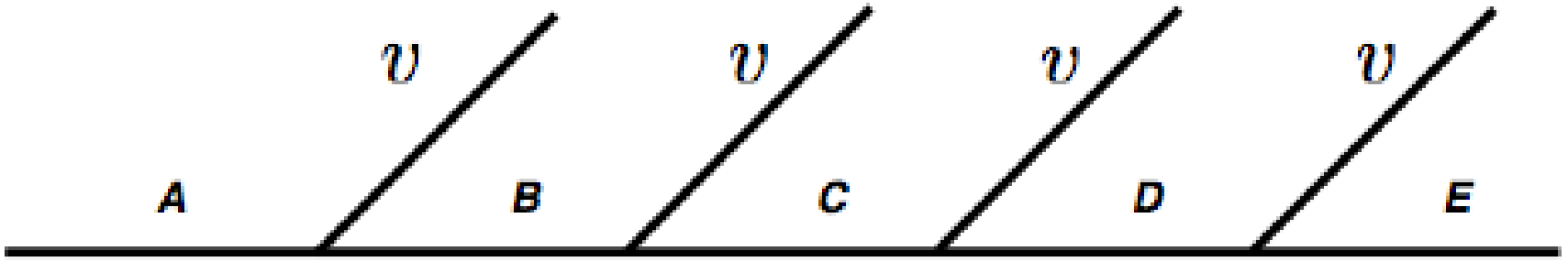
Recent analysis by Dutta et. al. JHEP 1601, 051 (2016)

Our strategy

- A sample Compressed SUSY spectra
- Calculate S/B and S/√B combining track based variables with conventional ones (P_T of visible objects).
- Compare the performance of an optimized MVA analysis.

The Process

Long cascade decay



A, B, C, D, E == squark, gluino, stop, chargino, neutralino

Assume,

$(m_A - m_B) = (m_B - m_C) = (m_C - m_D) = (m_D - m_E) =$ **25 GeV,**

with m_A **= 1.5 TeV**

Degree of compression $\Delta \equiv (m_A - m_E)/m_A = 1/15$

Most generic study, application in several extensions of SM !

Track observable

- Number of tracks that are

  I. Associated to the Primary vertex

  II. NOT part of any reconstructed object

  ($\Delta R(t,j) >$ jet radius R)

- Bin them according to P_T (IR safe)

  $P_T > 5$ GeV $\equiv \xi(5)$

  1 GeV $< P_T <$ 5 GeV $\equiv \xi(1)$

  0.5 GeV $< P_T <$ 1 GeV $\equiv \xi(0.5)$

Variable sets

- 4-momentum of single jet
- Large center-of-mass energy, many particles
- Large recoil again ISR jet, more jets and leptons fail to pass the threshold, large MET.

$$\mathbf{V_C = \{p_T(j_1),\ MET,\ H_T,\ M_{eff}\}}$$

$$\mathbf{V_{all} = \{\xi(5)\ ,\ \xi(1),\ \xi(0.5),\ p_T(j_1),\ MET,\ H_T,\ M_{eff}\}}$$

$H_T = P_T$ sum, $M_{eff} = H_T$ + MET

Phenomenology

- **Signal**: Pair produced 'A' with a hard 'j' at the ME level (AAj process) [MadGraph]
- **Backgrounds**:

  Z(νν)+jets, W(ℓν)+jets, QCD;

  one hard 'j' at the ME level - MadGraph
- Parton Shower & Hadronization - PYTHIA8.
- **Pileup <N> = 20 and 40, CMS card -** Delphes
- **Jets: anti-k_T R = 0.5 with p_T = 50 GeV -** FastJet
- **We count PU subtracted tracks with p_T bin**

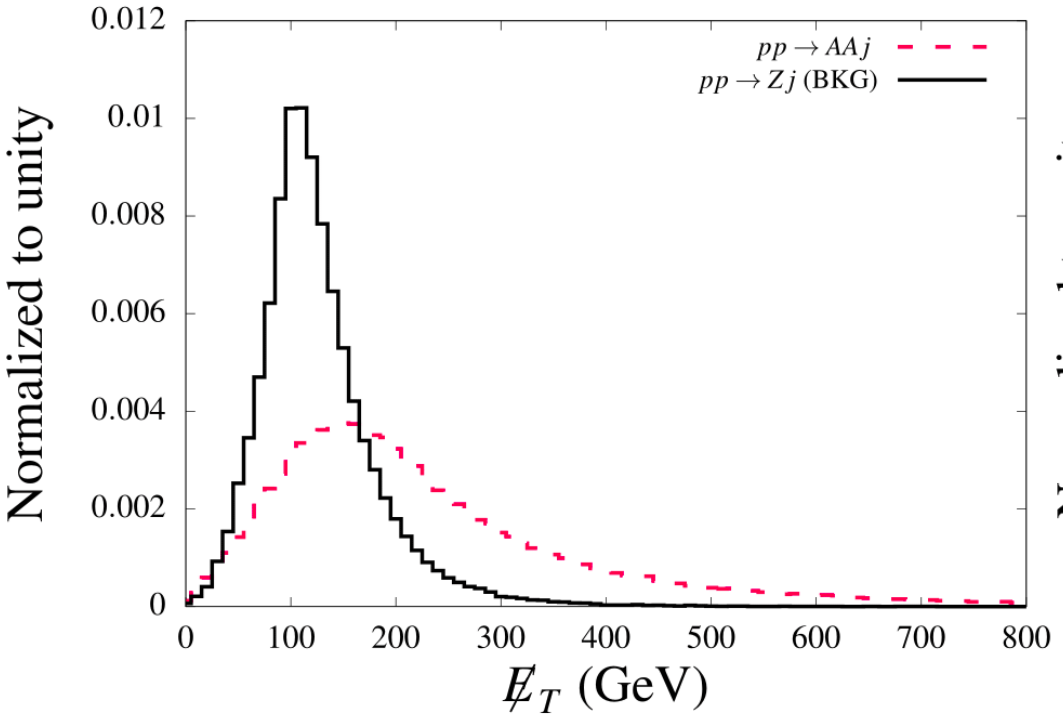
Distributions

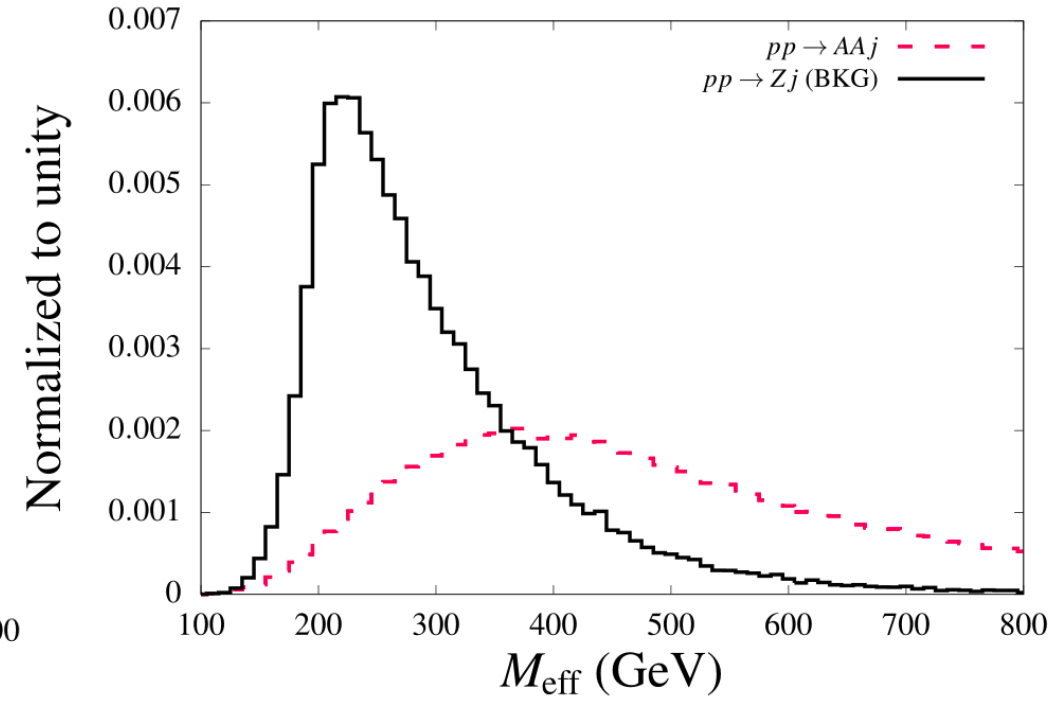
- Pre-selection: **Events with exactly ONE jet with p_T > 100 GeV with |η|<2**

$$\vec{\not{p}}_T = -\sum_i \vec{p}_T^{\,i}, \qquad H_T = \sum_i \left|\vec{p}_T^{\,i}\right|,$$

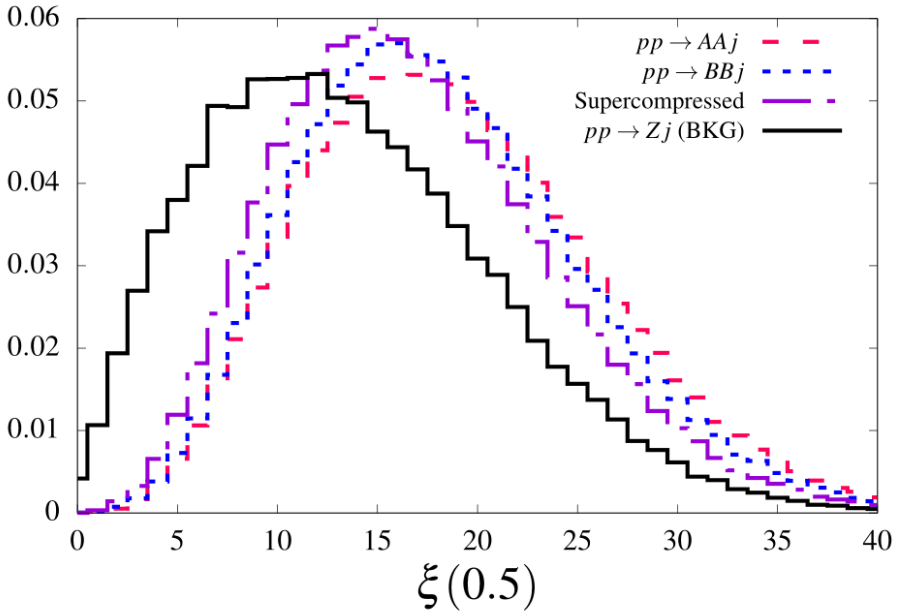
$$M_{\rm eff} = H_T + |\vec{\not{p}}_T|$$

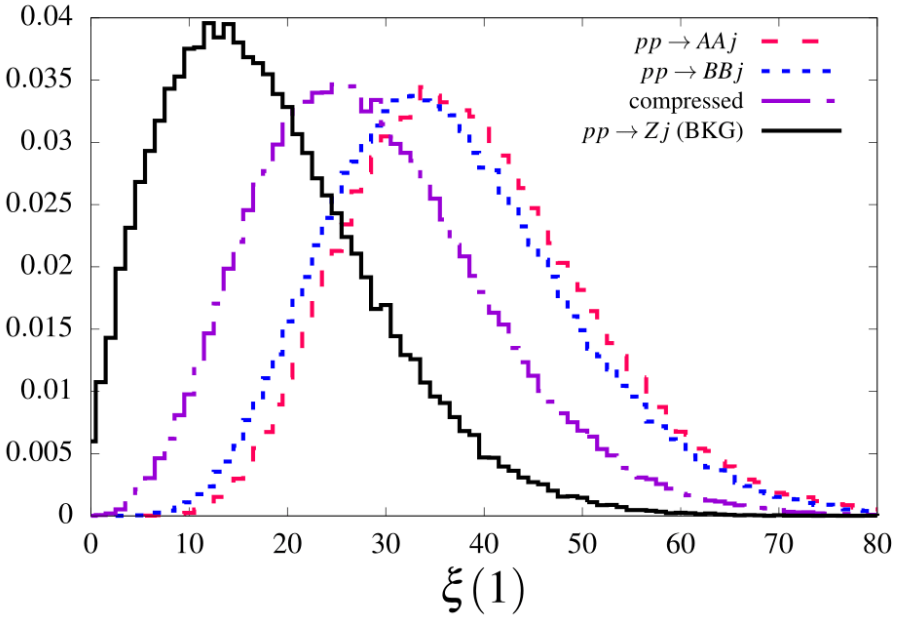
A hard cut on these reduces SM bkgs

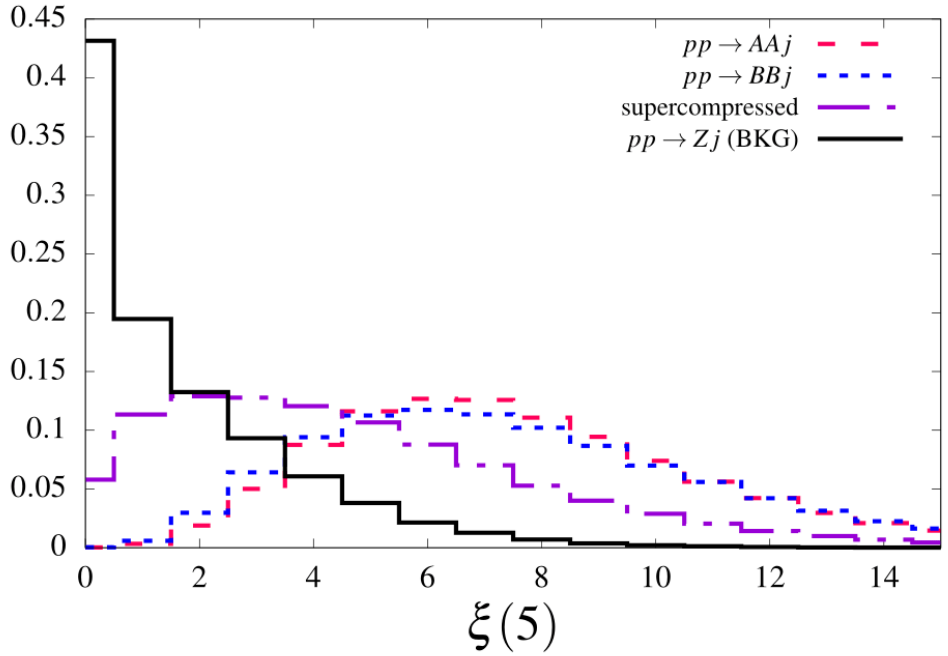




Number of Track distributions







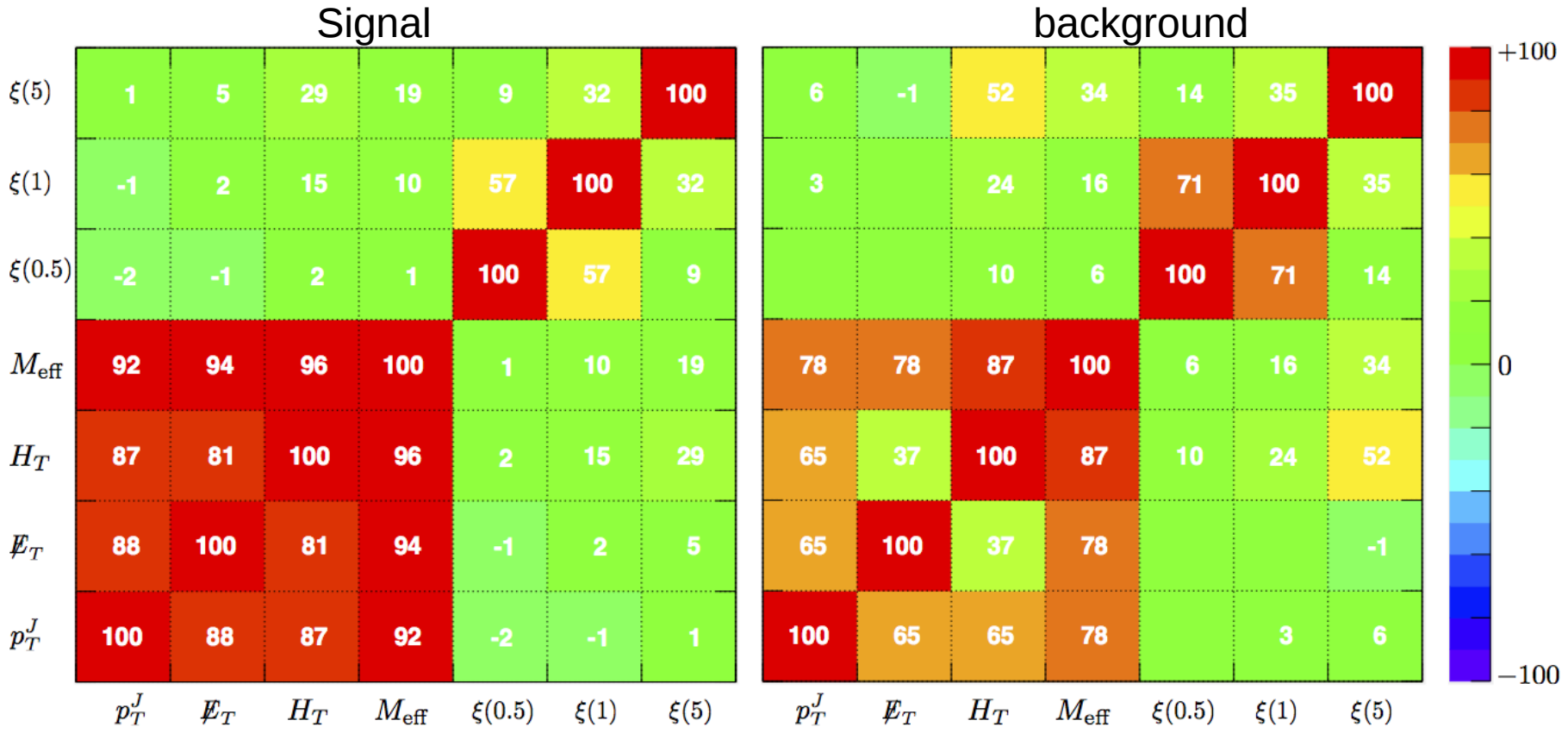
1. **Good discriminating variable !**
2. **Hard cut on track P_T, still effective**
3. **Super-compressed:**

   $\Delta = 1/75$ with

   mass difference 5 GeV each.

   works well !!

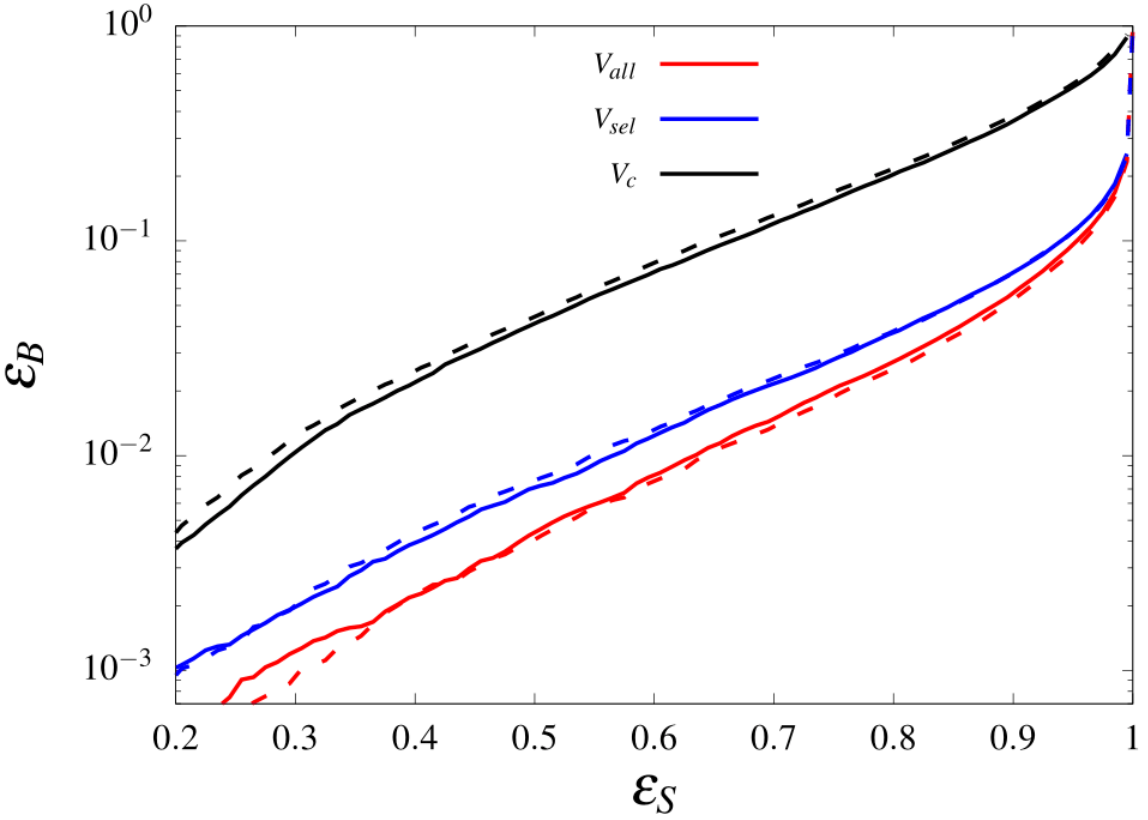
Correlations



- Linear Correlation coeff. = $\text{Cov}(x,y)/\sigma_x\sigma_y$
- Conventional variables: **Highly Correlated !!**
- **Lack of correlation with ξ**
- Minimal set $V_{sel} = \{\xi(5), \xi(1), \xi(0.5), M_{eff}\}$

MultiVariate Analysis

- BDT technique using TMVA framework.
- **Pile up: PU = 40 (solid),** PU=20 (dashed)
- Signal efficiency (ε_s) vs background efficiency (ε_B)

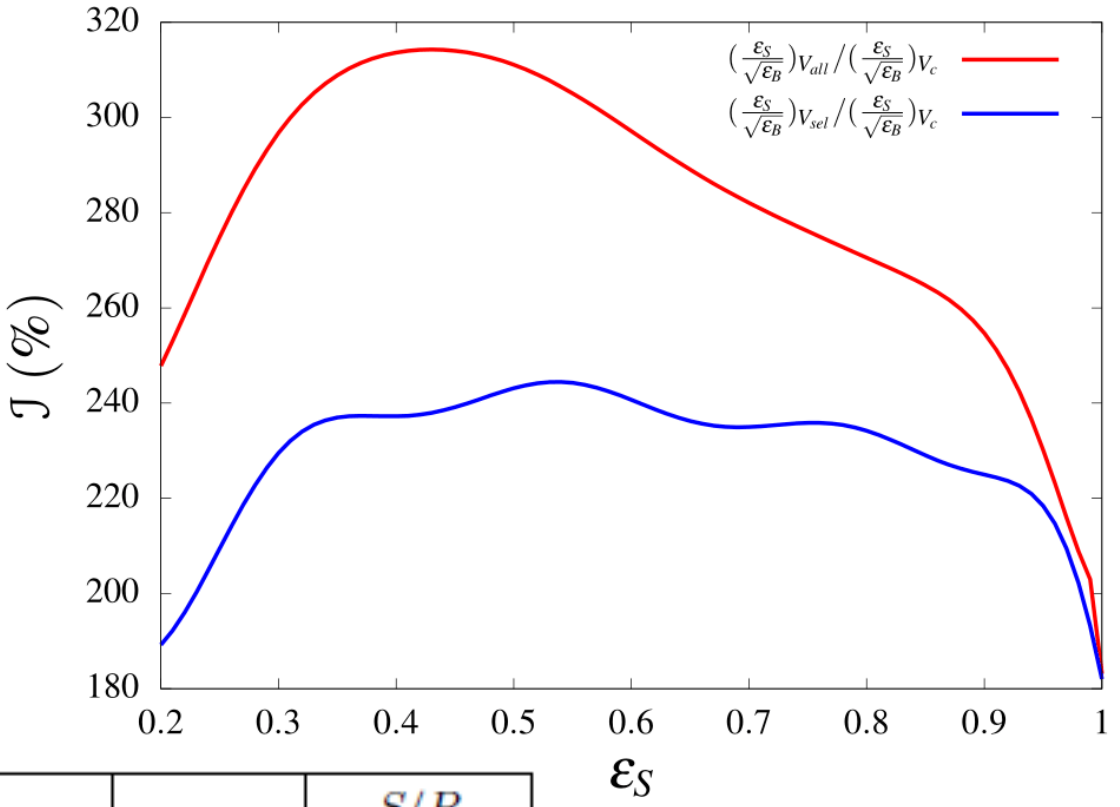


Lessons: **1. Our analysis is pileup robust**
2. Significant bkg reduction using tracks as BDT input
3. V_{sel} (Blue): out-performs conventional set !

MultiVariate Analysis

- **Improvement in S/√B**

$$\mathcal{I}_a \equiv \frac{\left(\epsilon_S/\sqrt{\epsilon_B}\right)_a}{\left(\epsilon_S/\sqrt{\epsilon_B}\right)_{V_c}}, \qquad a \in \{V_{\rm all}, V_{\rm sel}\}$$

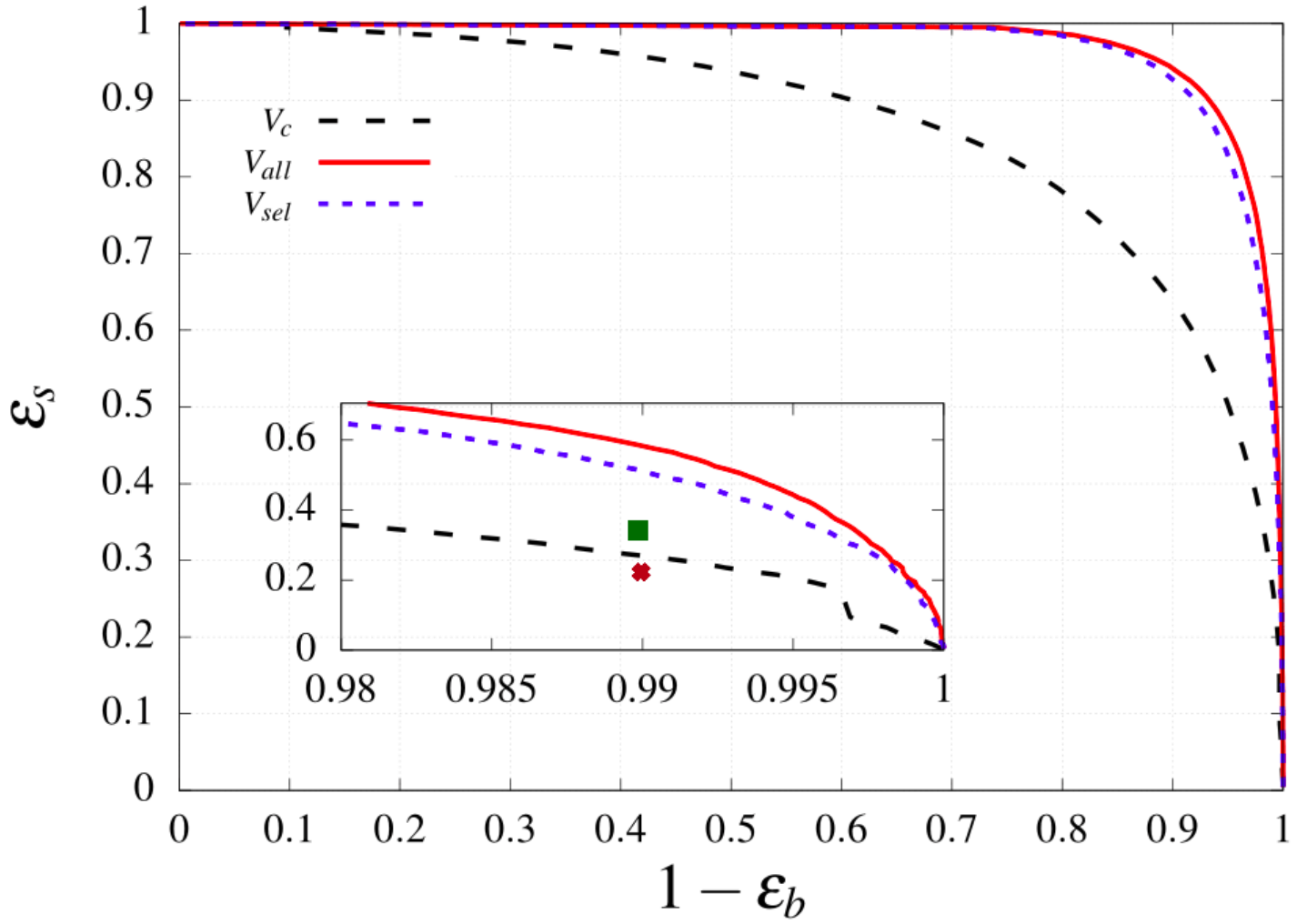


Simple Cut-based analysis

Sample Cutflow	ϵ_S	ϵ_B	$\frac{S/B}{(S/B)_C}$
BDT with all variables in V_C	0.3	0.010	1
$\xi(1) > 18$, $\xi(5) > 3$, $\not{E}_T > 135$ GeV, $M_{\rm eff} > 200$ GeV	0.3	0.007	1.43

~ 40% enhancement in S/B for ε_s = 30%

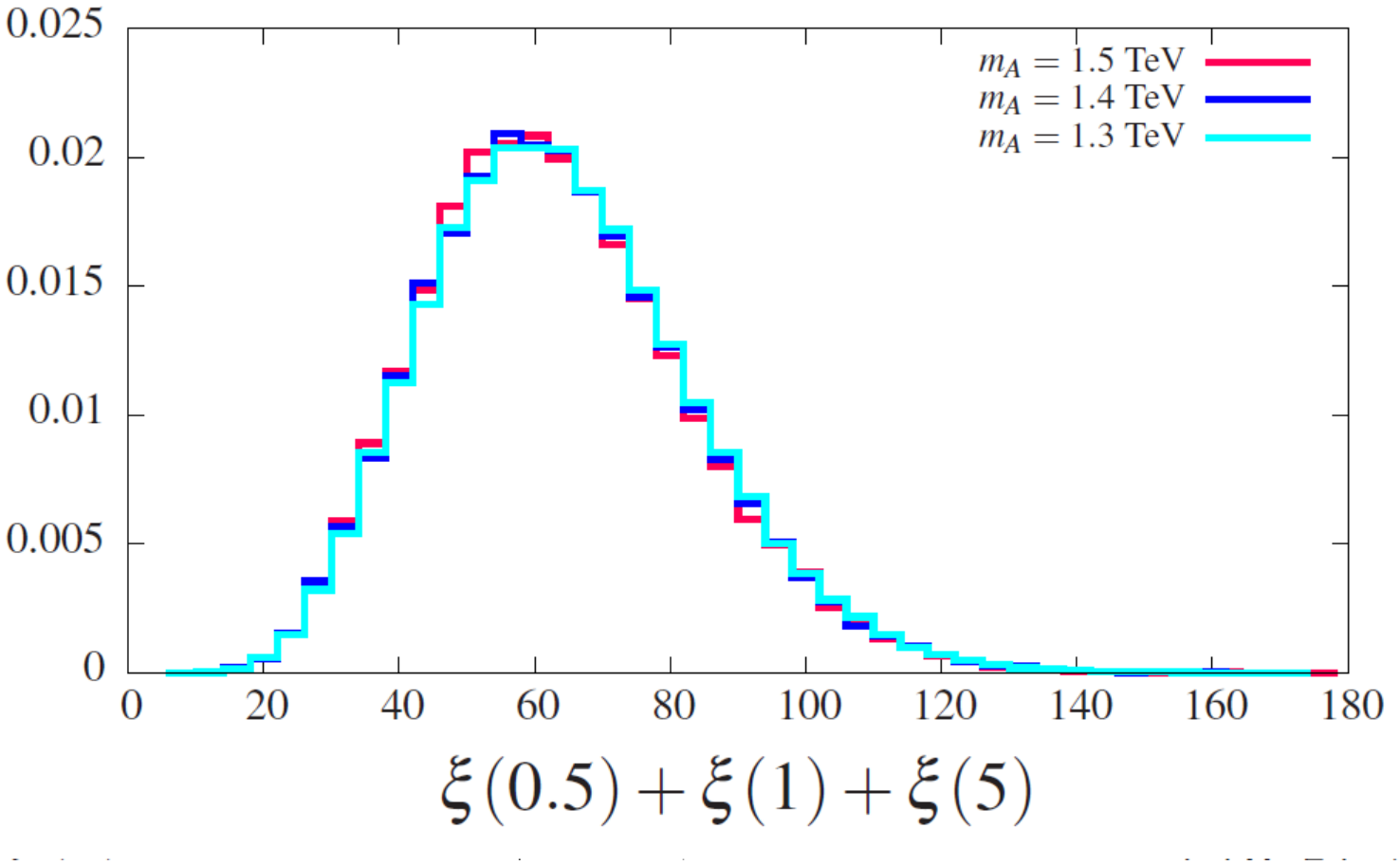
Comparison: Cut based analysis



Red Cross: without soft tracks ; **Green square**: with soft tracks

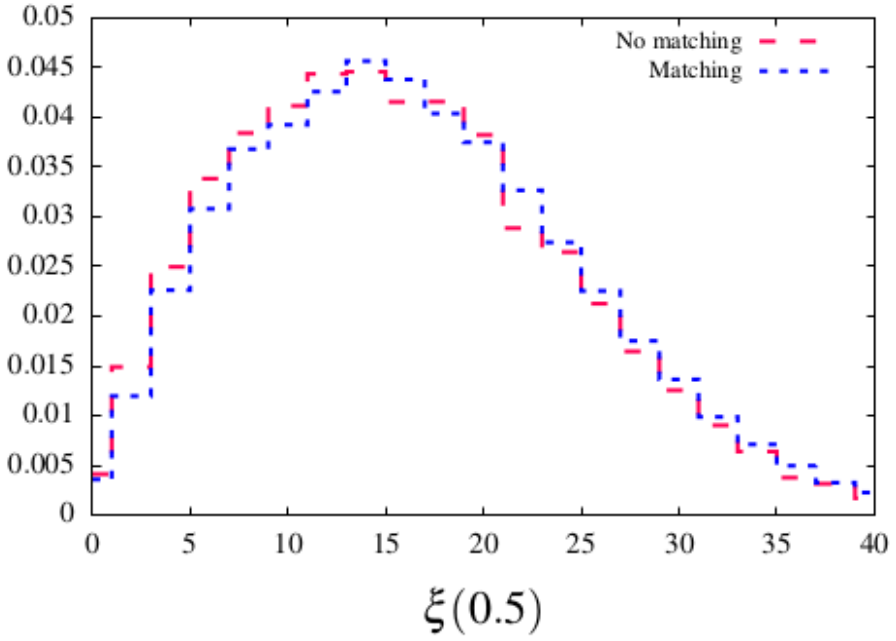
<u>For a fixed bkg. Efficiency</u> => around 50% or more improvement in signal effs even in a simple minded cut-based analysis

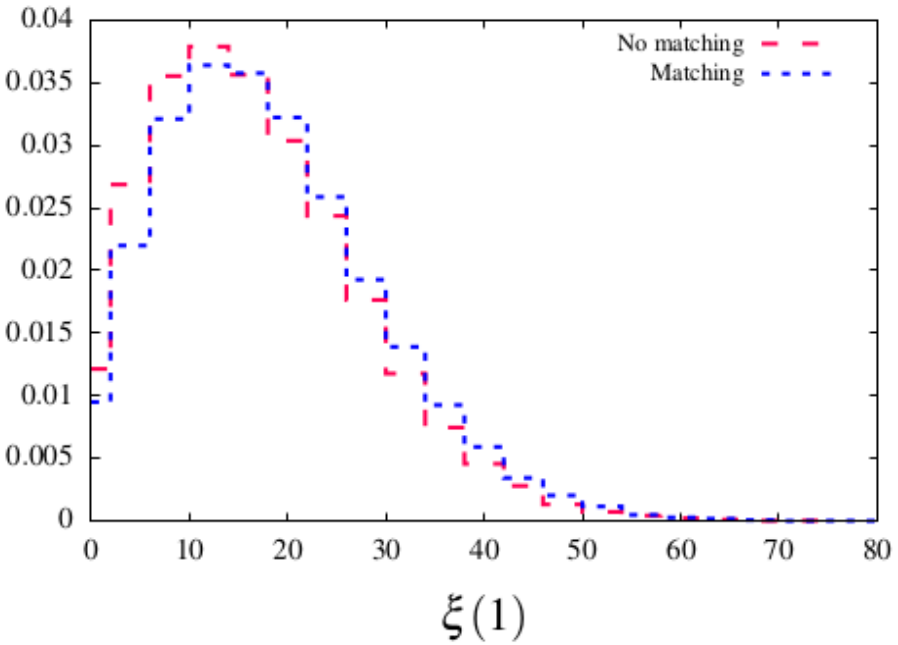
Different √s

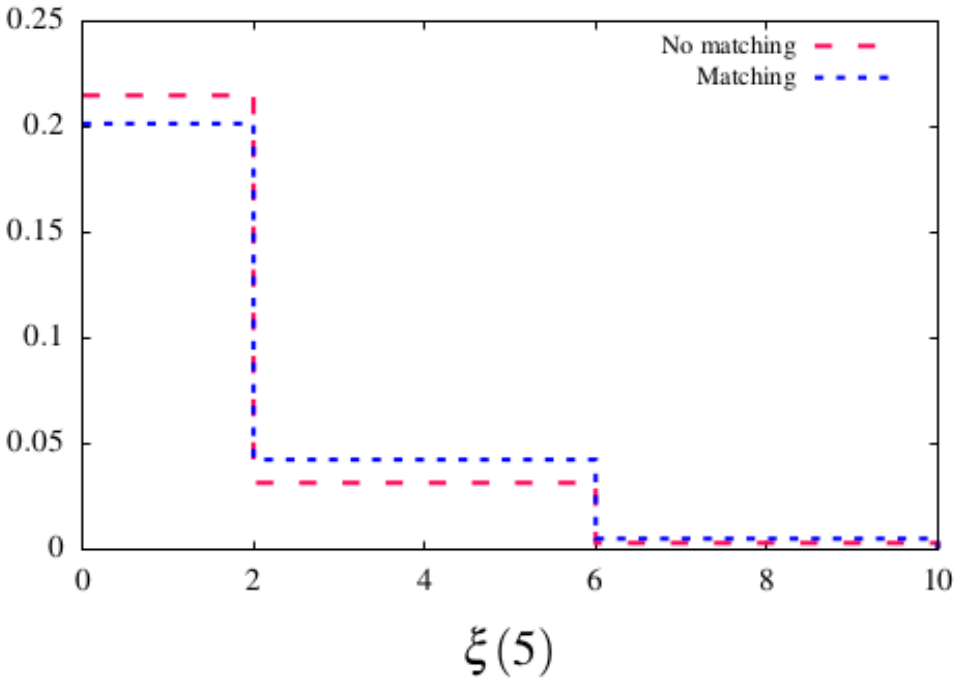


It's NOT the initial COM energy, it's the cascade decay pattern !!!

MEPS matching

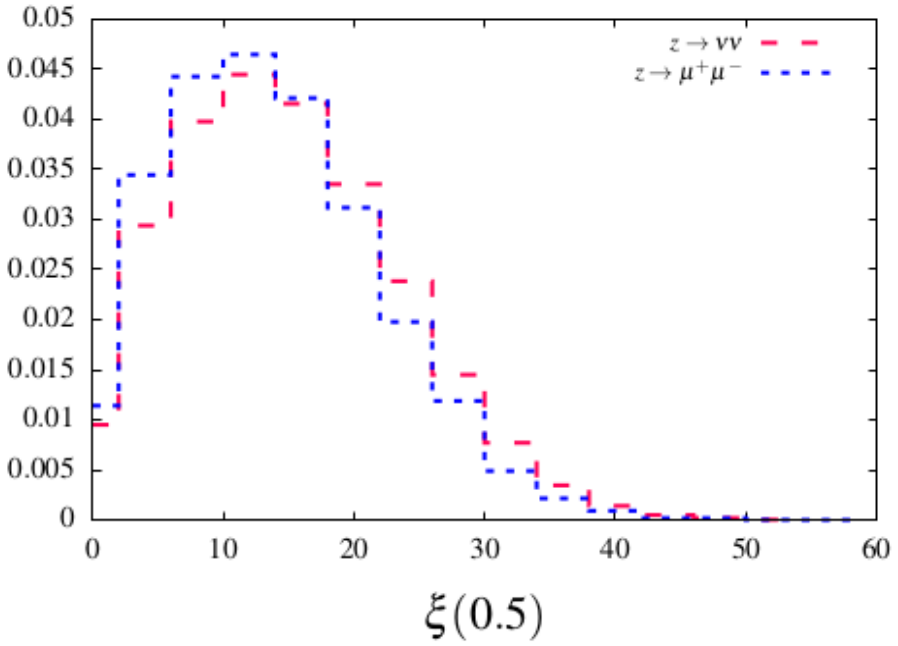


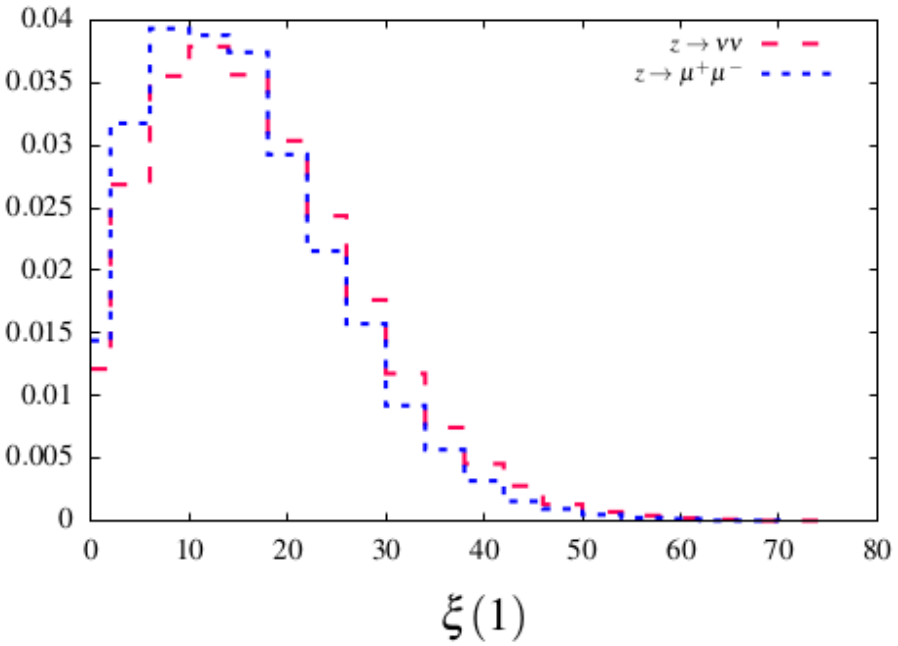


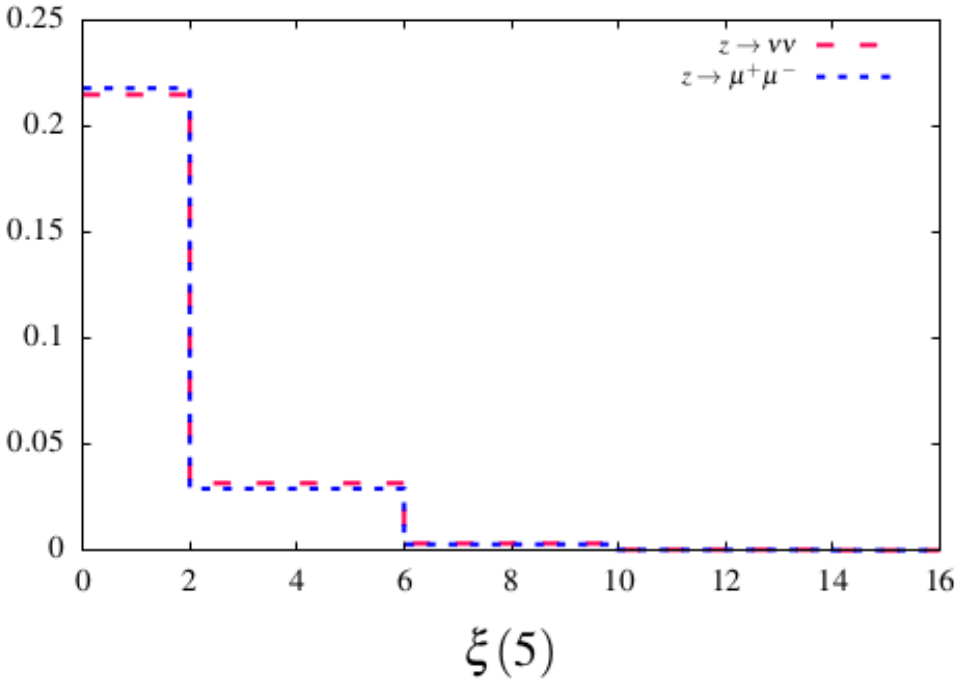


Distributions remain same -
Predictions are rebust under MEPS matching !

Data Driven way







1. **Extremely good μ indentification**

2. **Use them for the track distri.**

3. **Easy to implement at the LHC !**

Summary

- Compressed spectra (monojet + MET): challenging scenario at the LHC
- Conventional analysis fails to utilize the full event information
- We introduce a new variable ξ, a measure of "Soft tracks" in an event, can play a big role in probing the New Physics through mono-jet + MET channel.
- Our observations are Pileup robust.
- Looking forward for implementation with Real Data !