Soft Tracks: Tool and Applications

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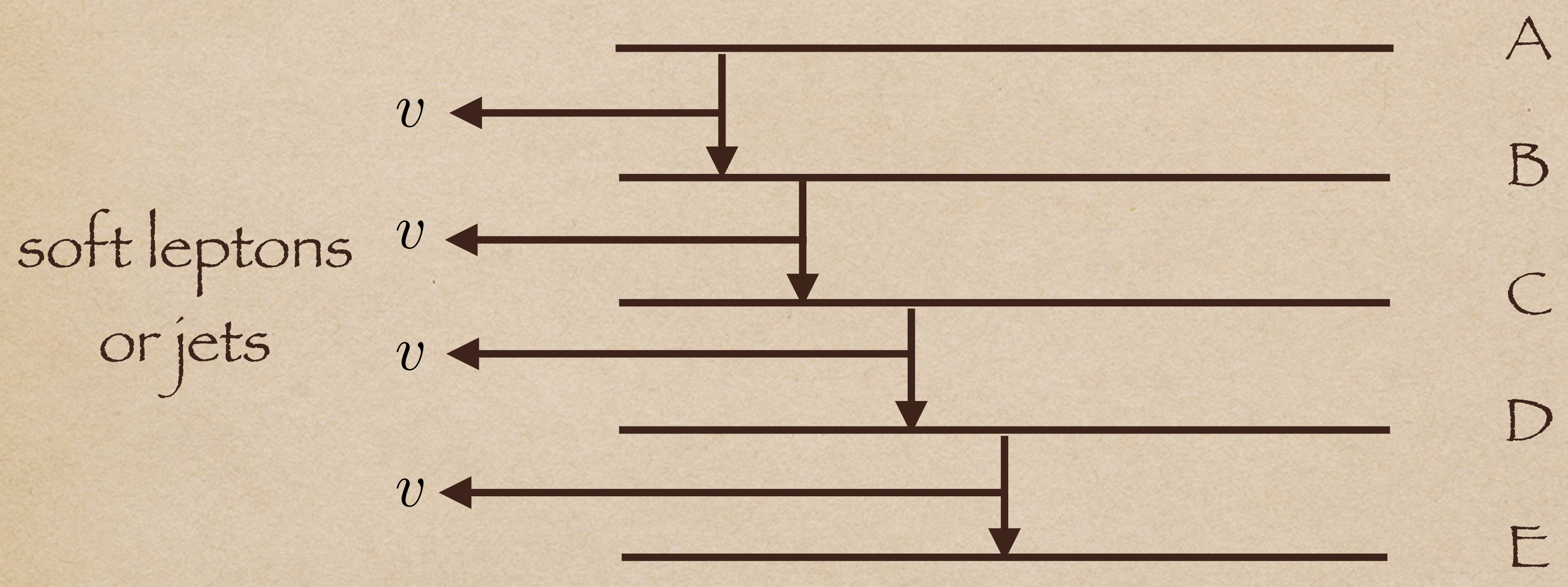
Based on: Phys.Rev. D94 (2016) no.11, 111703 (R)
with Amit Chakraborty, Tuhin S. Roy
and JHEP 1707 (2017) 105
with Saurabh Niyogi, K. Sridhar

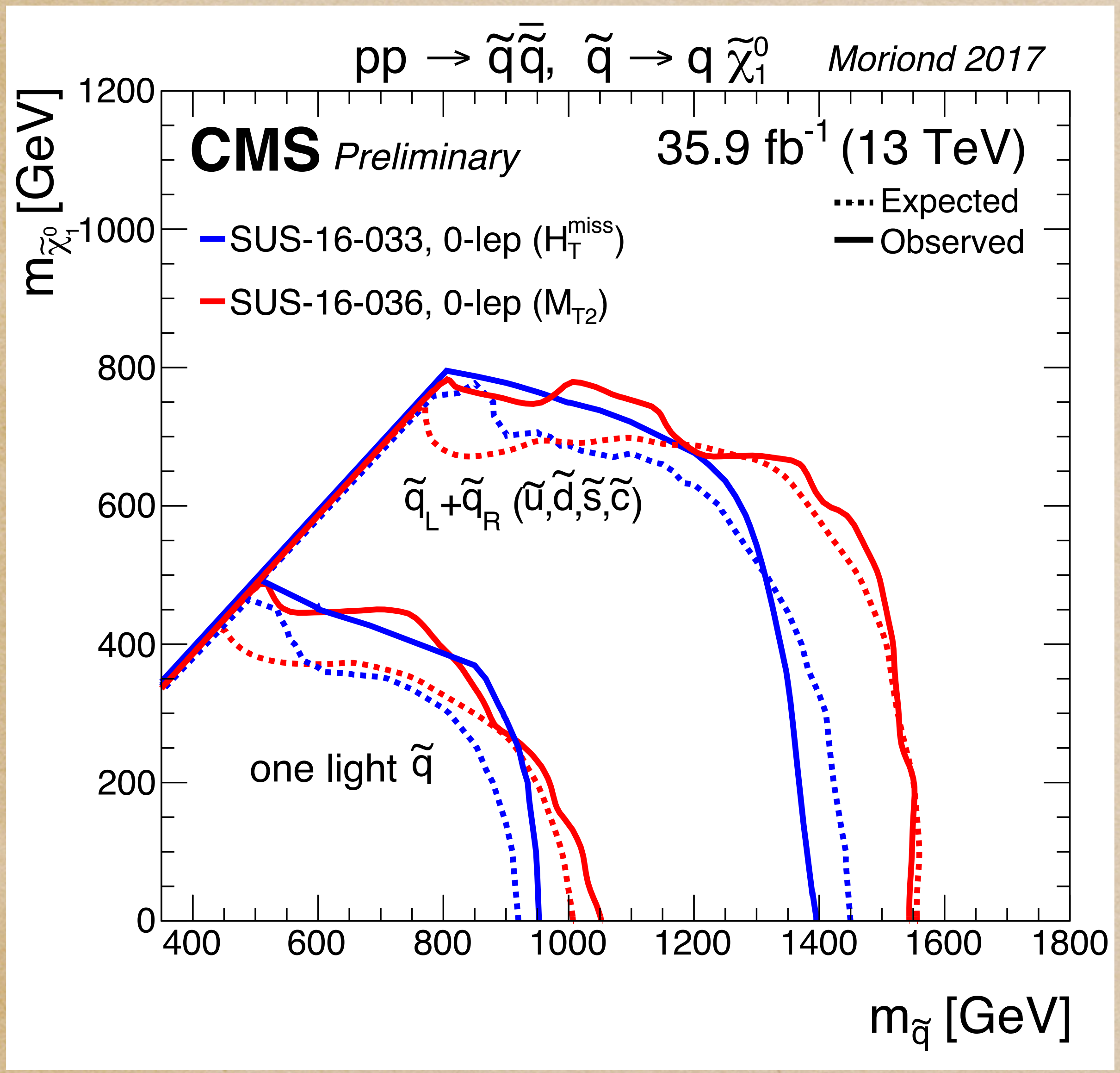
Compressed Spectra

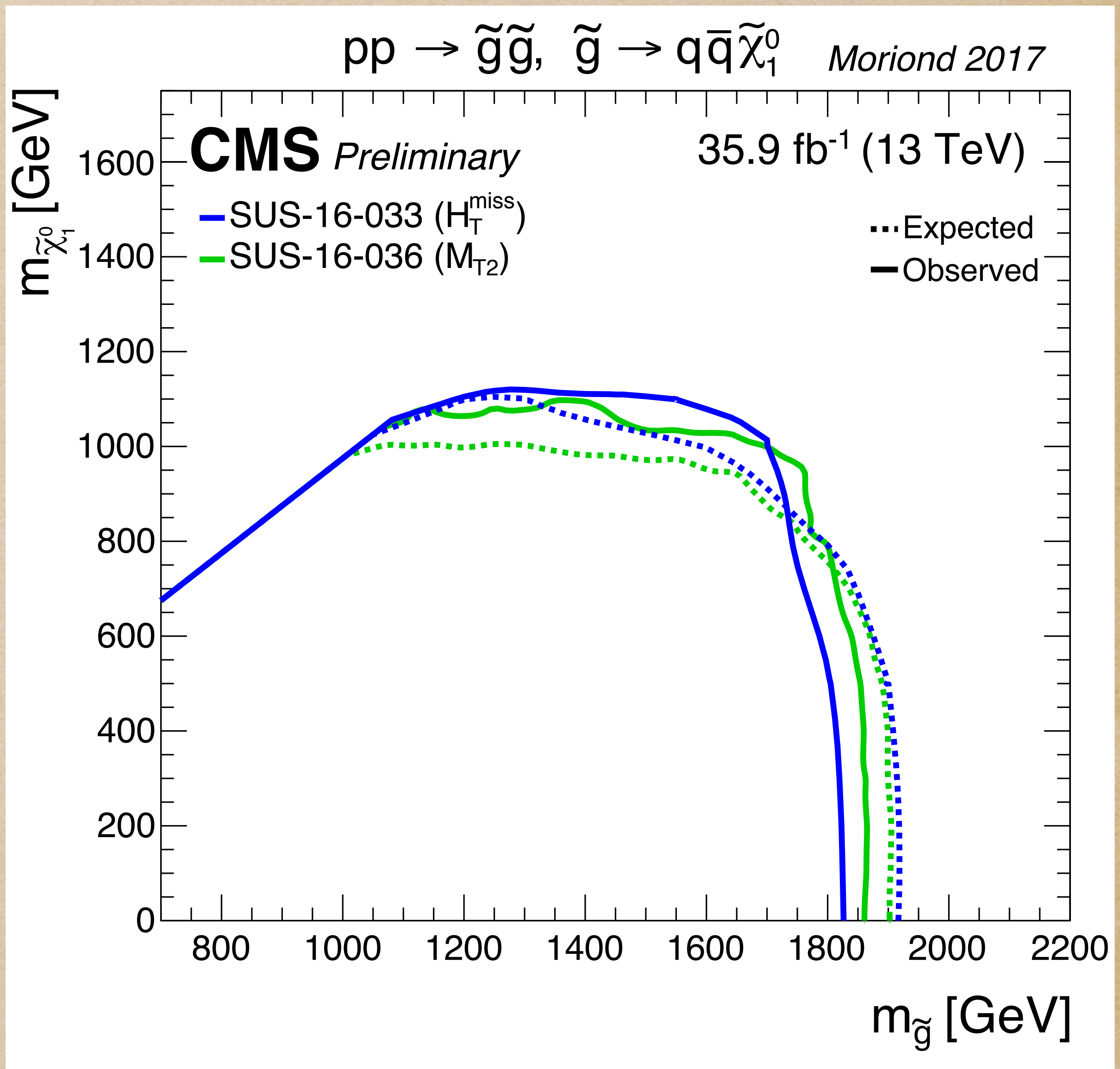


- Typical hierarchical spectra
- Examples are MUED, MSSM

S. P. Martin: Phys. Rev. D 75 (2007) 115005

13 TeV results

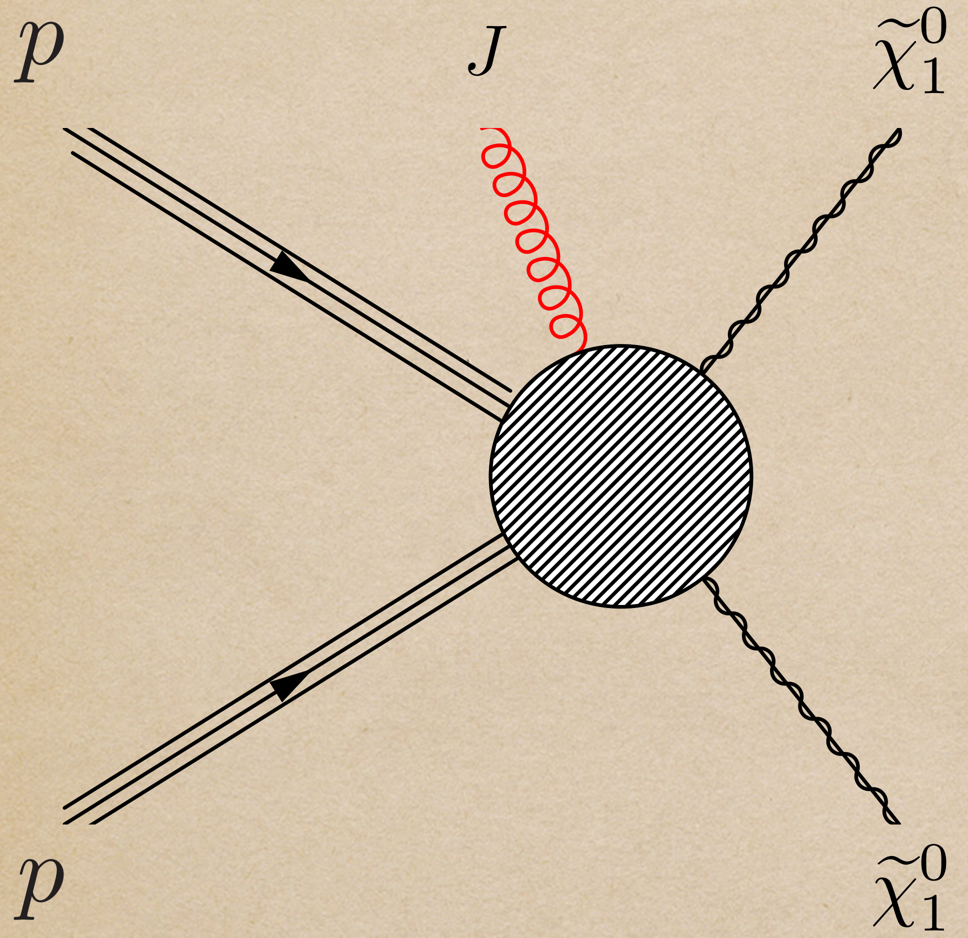




Limits on compressed squarks and gluinos 800-1000 GeV

CMS-Moriond 2017

Usual Search Strategy



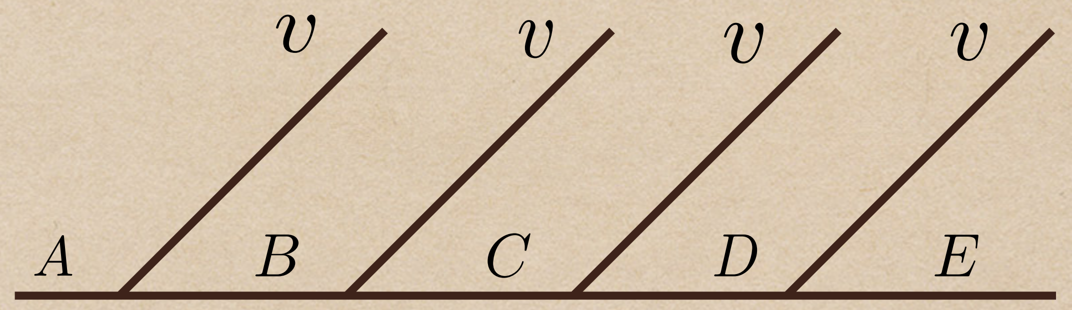
- Lack of visible energy
- Solitary hard-jet and MET
- SM backgrounds: V+jets, QCD
- Typical Cuts

$p_T^{\text{jet}} > 100$ GeV $\quad \not{E}_T > 400$ GeV

$M_{\text{EFF}} > 500$ GeV $\quad \Delta\phi(\text{jet}, \text{MET}) > 1.0$

<u>Compare S/B and $S/\sqrt{B}$ with tracks</u>

Process



$$\Delta m = m_A - m_B = m_B - m_C ... = m_D - m_E$$

- Case 1

Compressed Spectrum

$$\Delta m = 25 \text{ GeV}$$

$$D = \frac{\Delta m}{m_A} = 1/15$$

- Case 2

Super-compressed Spectrum

$$\Delta m = 5 \text{ GeV}$$

$$D = \frac{\Delta m}{m_A} = 1/75$$

Track Observables

- Associated with the primary vertex
- Not part of any reconstructed objects such as jets or leptons
- Angular separation between the jet and tracks > size of jet
- Number of tracks are IR unsafe objects
- Tracks binned in p_T

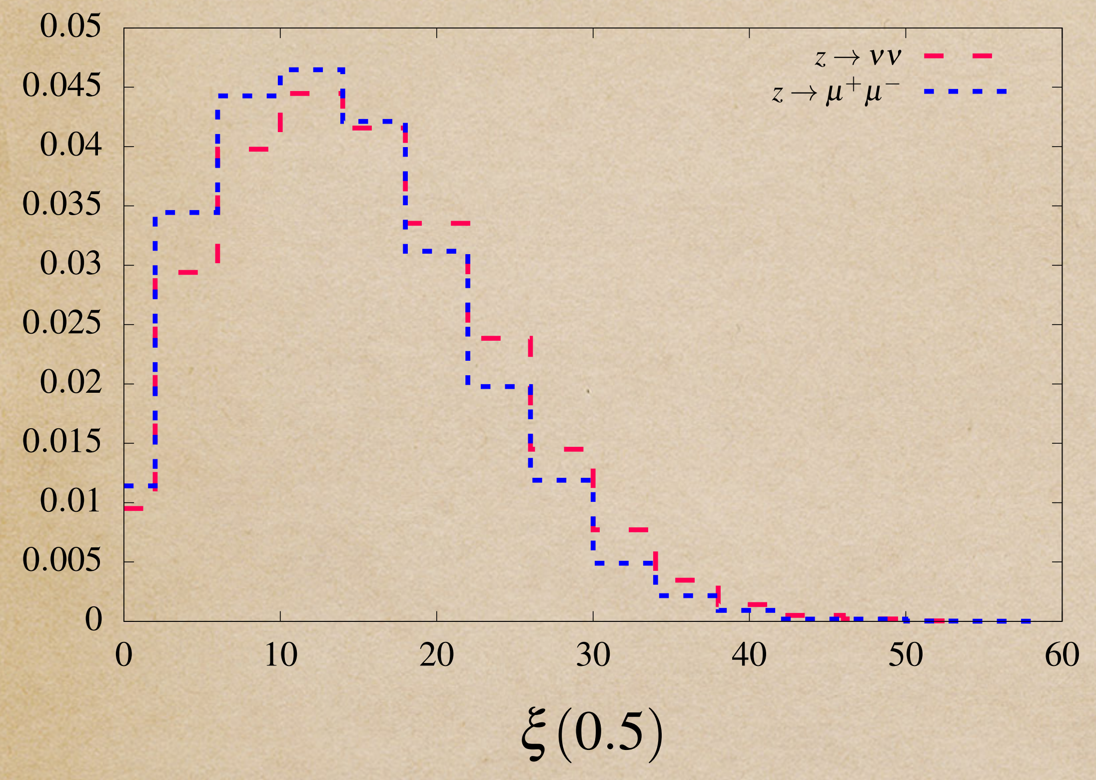
I. $\xi(5) \equiv p_T^{\text{track}} > 5 \text{ GeV}$

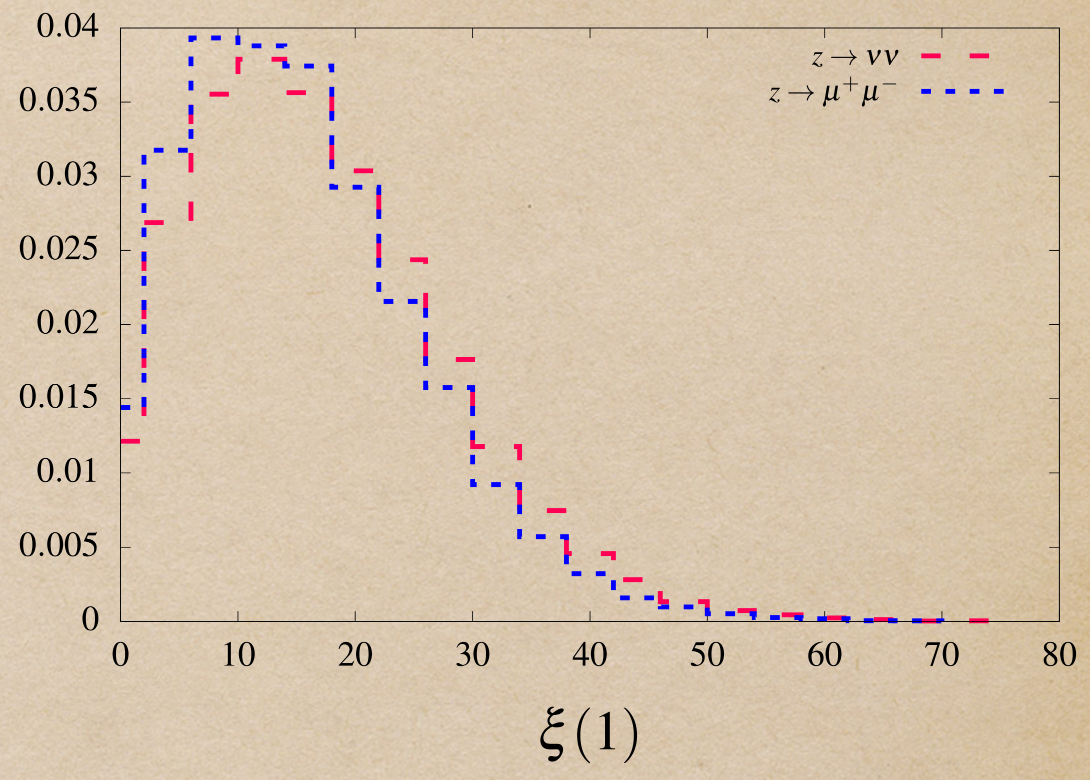
II. $\xi(1) \equiv 1 \text{ GeV} < p_T^{\text{track}} < 5 \text{ GeV}$

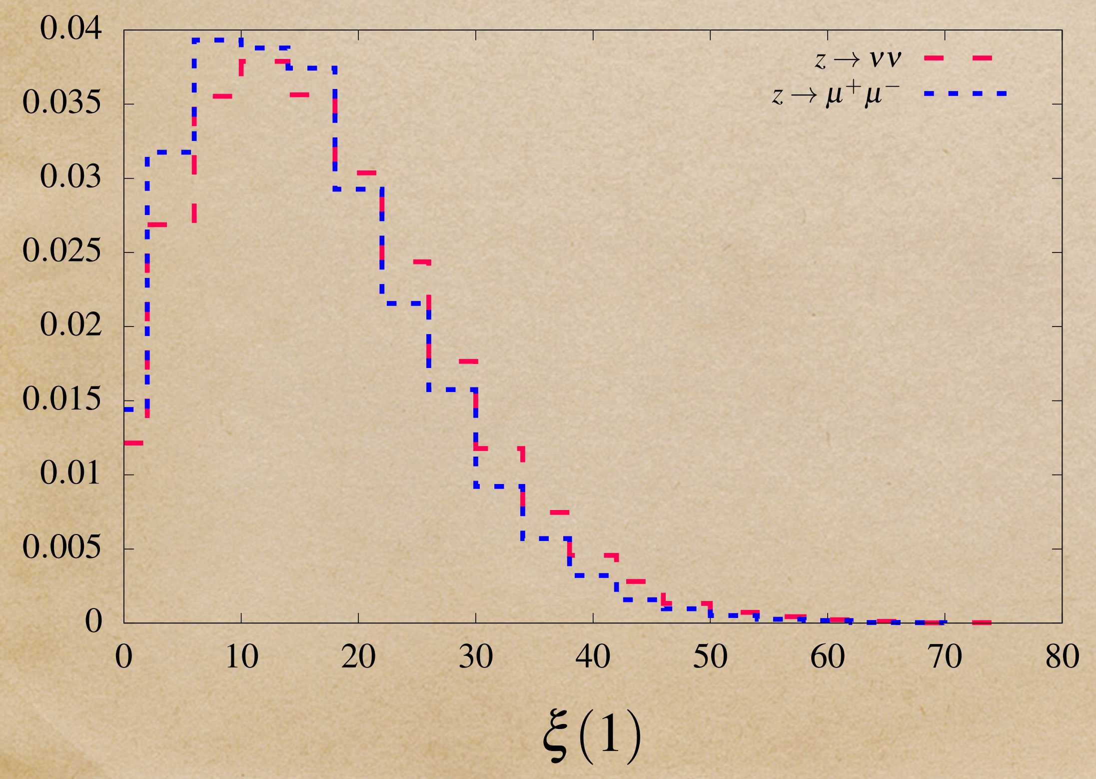
III. $\xi(0.5) \equiv 0.5 \text{ GeV} < p_T^{\text{track}} < 1 \text{ GeV}$

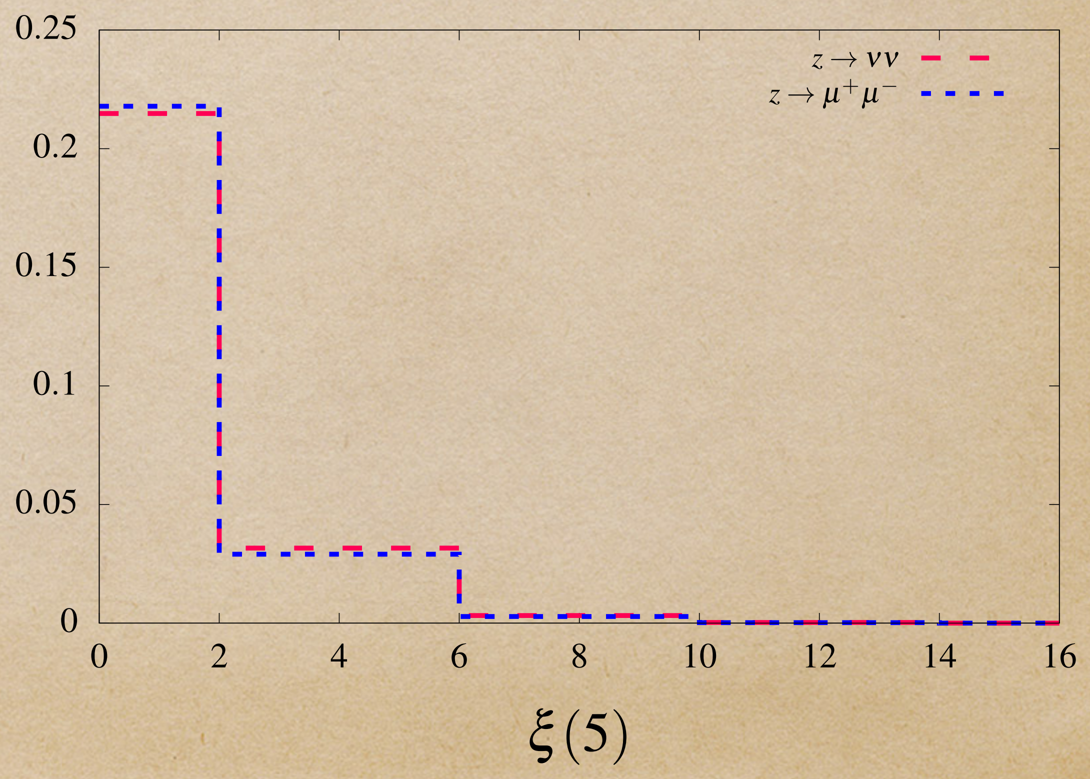
- Conventional variables: $p_T, \text{MET}, H_T, M_{\text{EFF}}$
- Additional variables: $\xi(0.5), \xi(1), \xi(5)$

Soft tracks from Data



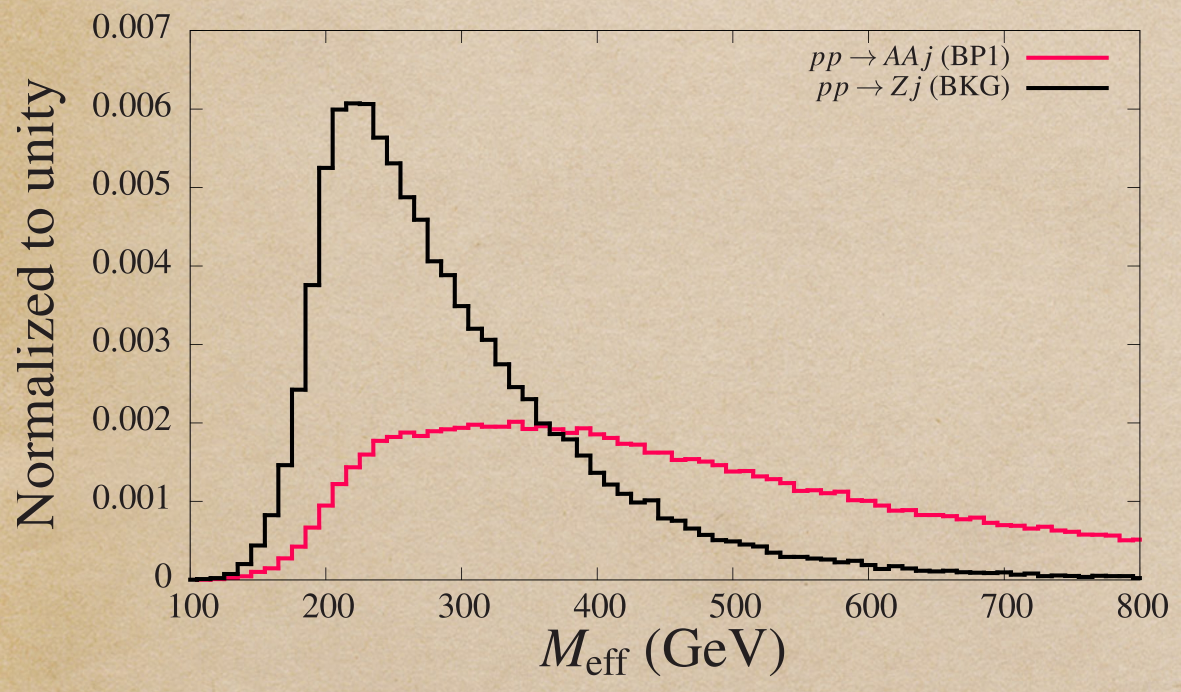


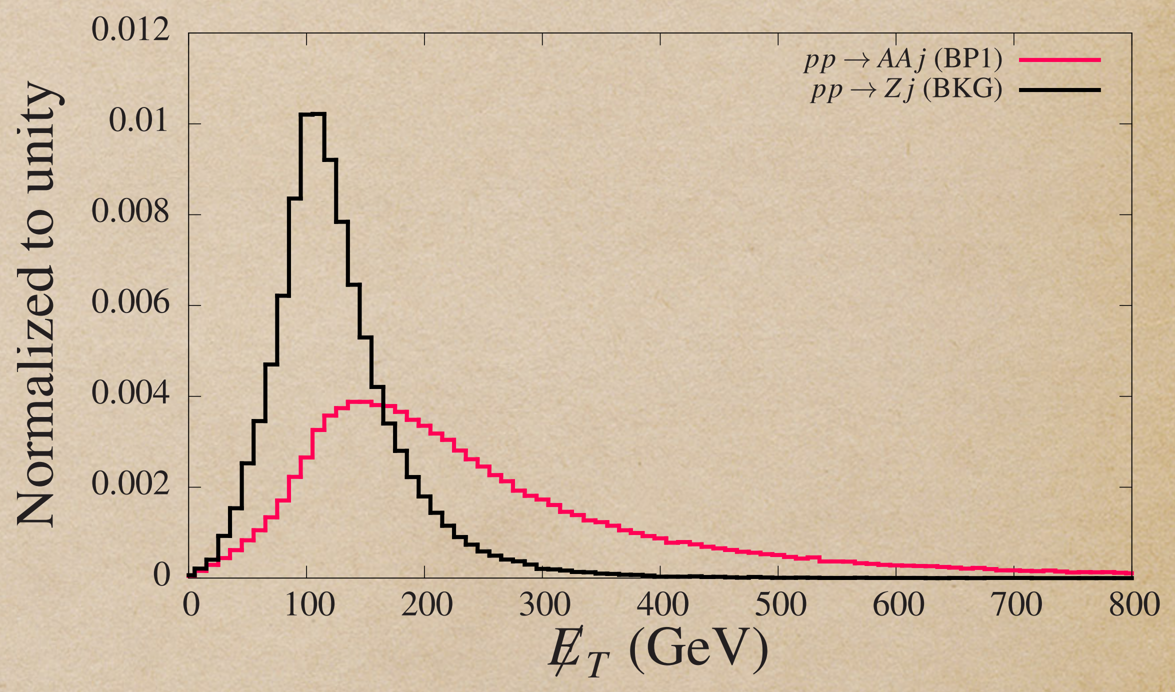




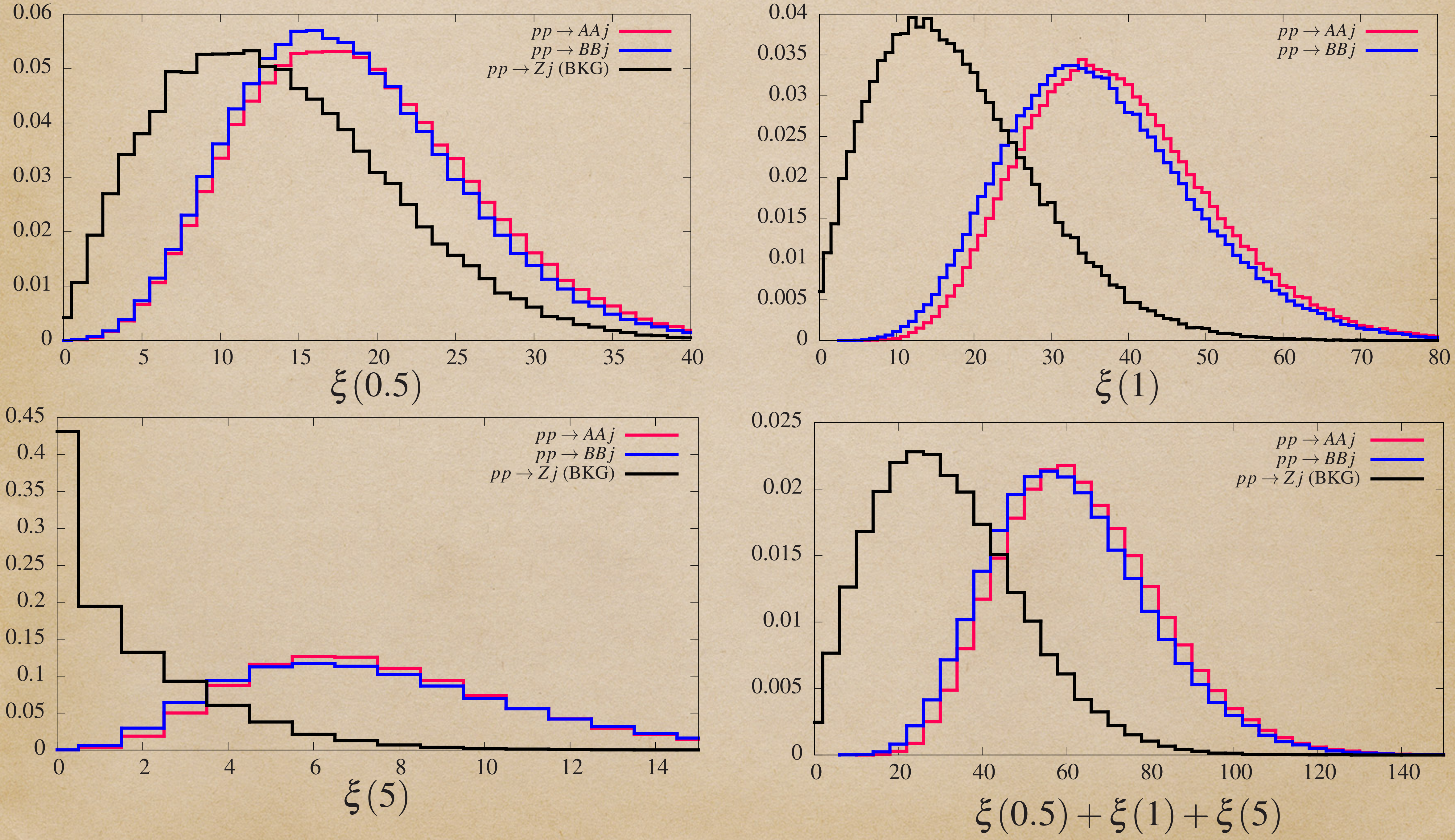
Procedure

- Zj, AAj (MadGraph), showering and hadronization (Pythia-8)
- Detector simulation with Delphes, used pile-up $\langle N_{\mathrm{PU}} \rangle = 20, 40$
- Used in built pile-up subtractor

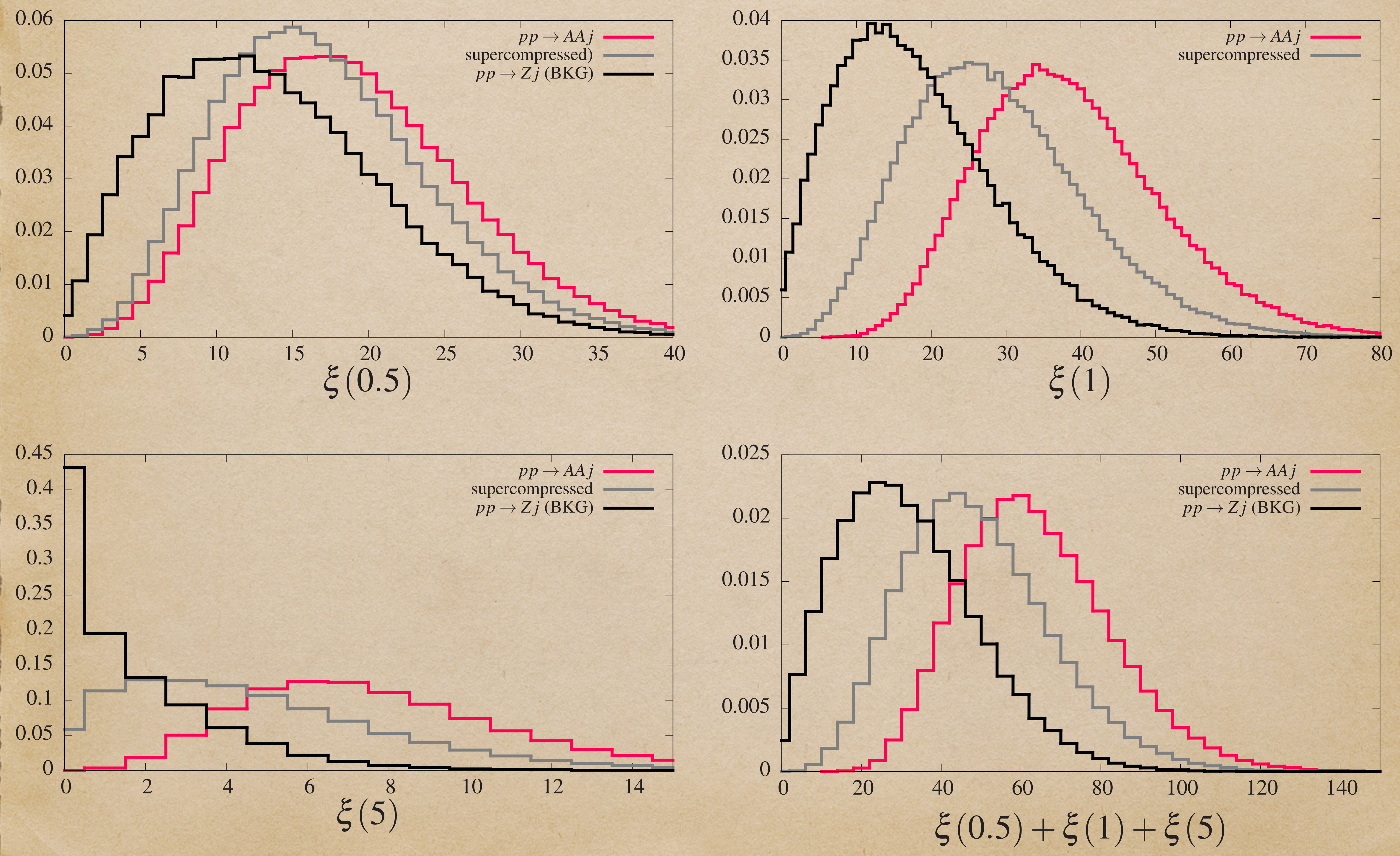




Track variables



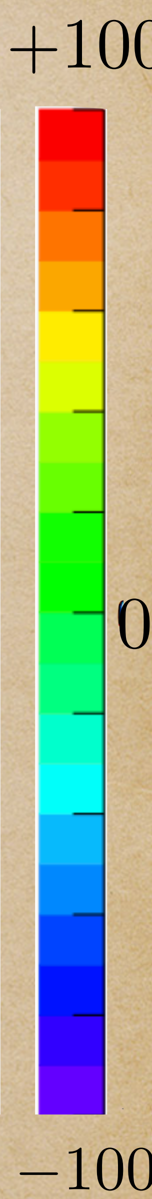
Tracks: Compressed & super-compressed



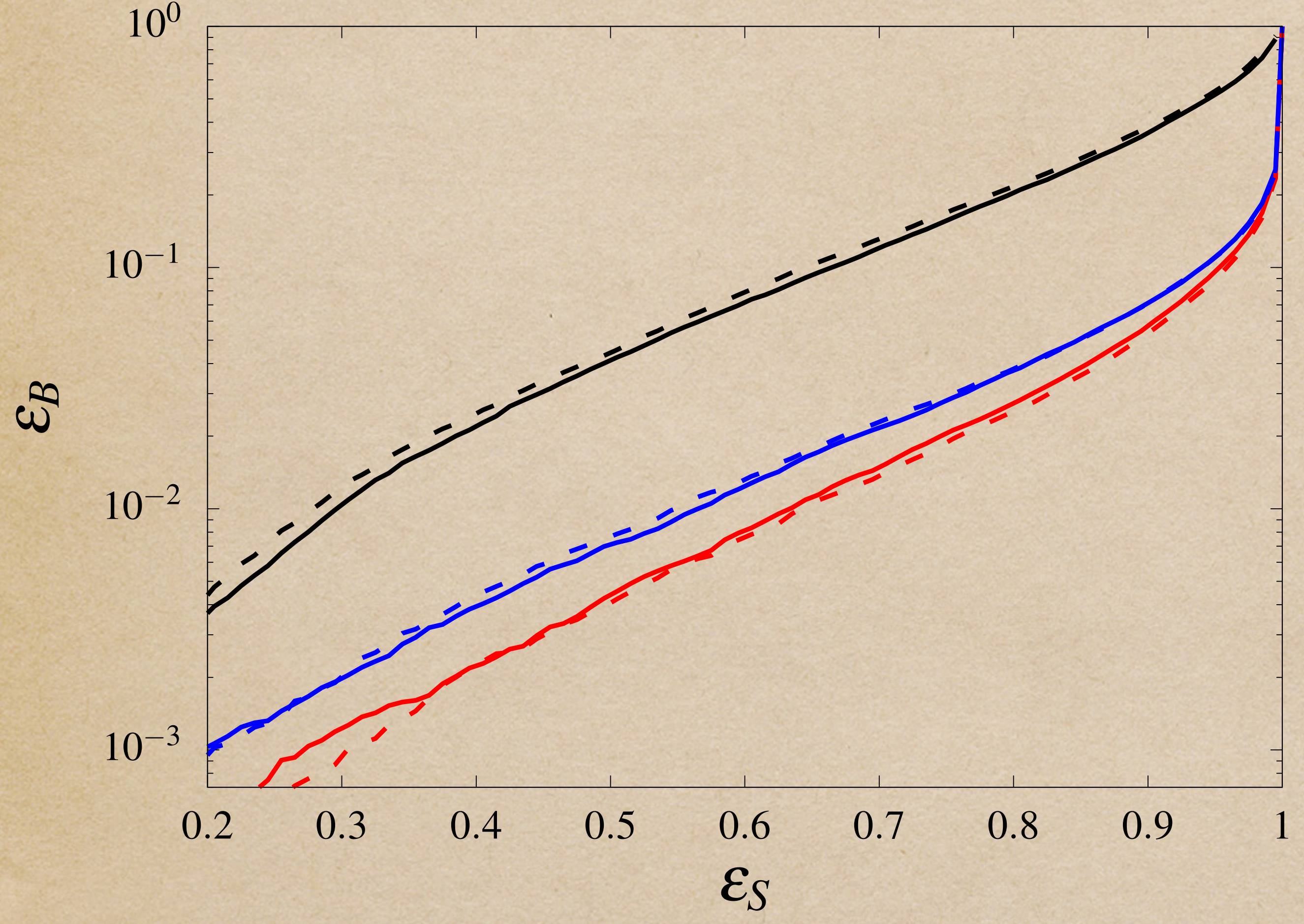
Correlations

	p_T	$\not{E}_T$	H_T	$M_{\rm eff}$	$\xi(0.5)$	$\xi(1)$	$\xi(5)$
$\xi(5)$	1	5	29	19	9	32	100
$\xi(1)$	-1	2	15	10	57	100	32
$\xi(0.5)$	-2	-1	2	1	100	57	9
$M_{\rm eff}$	92	94	96	100	1	10	19
H_T	87	81	100	96	2	15	29
$\not{E}_T$	88	100	81	94	-1	2	5
p_T	100	88	87	92	-2	-1	1

	p_T	$\not{E}_T$	H_T	$M_{\rm eff}$	$\xi(0.5)$	$\xi(1)$	$\xi(5)$
$\xi(5)$	6	-1	52	34	14	35	100
$\xi(1)$	3		24	16	71	100	35
$\xi(0.5)$			10	6	100	71	14
$M_{\rm eff}$	78	78	87	100	6	16	34
H_T	65	37	100	87	10	24	52
$\not{E}_T$	65	100	37	78			-1
p_T	100	65	65	78		3	6



ROC for D=1/15



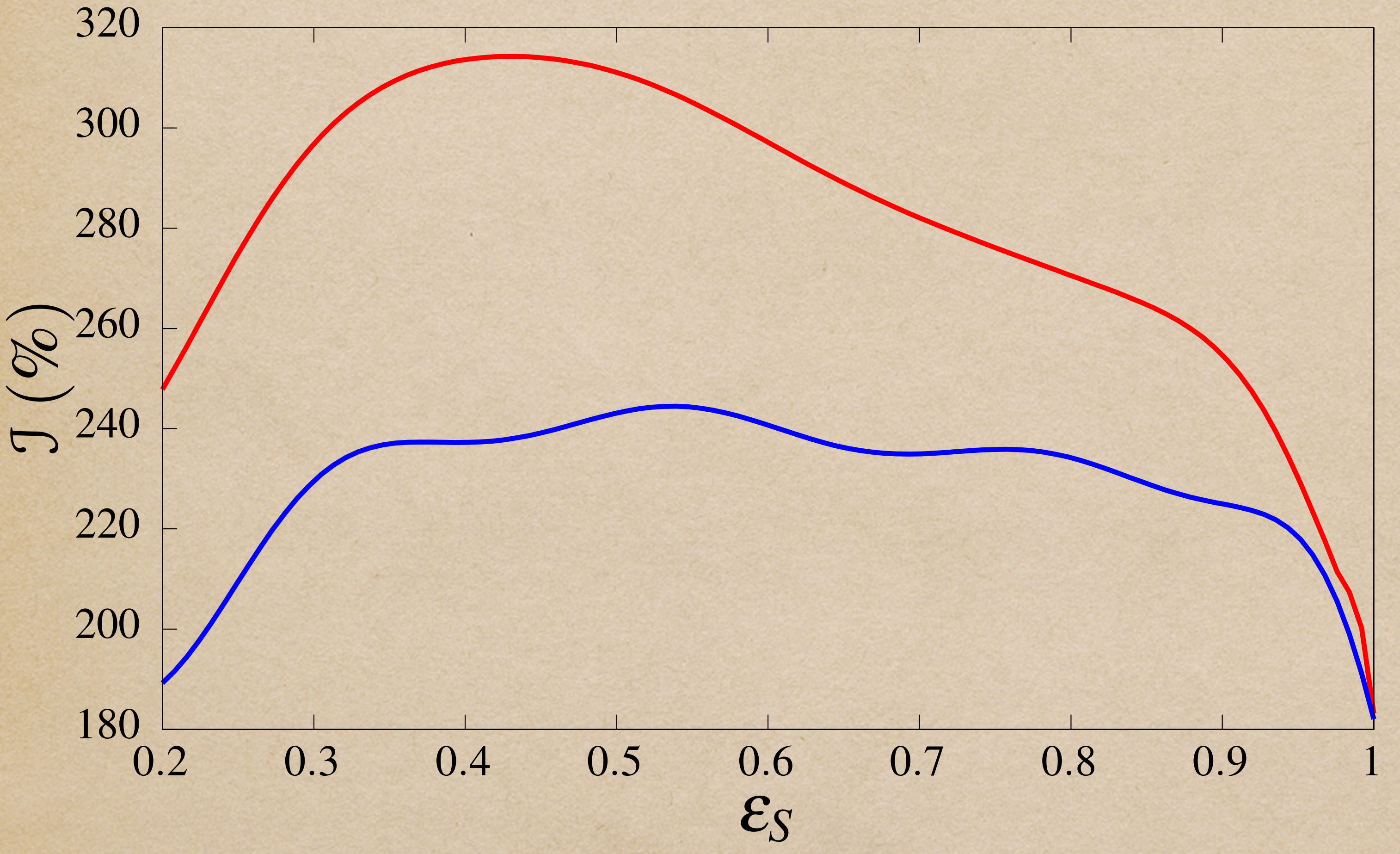
$V_{\rm sel} = \{M_{\rm eff}, \xi(0.5), \xi(1), \xi(5)\}$

$V_{\rm con} = \{p_T^{\rm jet}, M_{\rm eff}, MET, H_T\}$

$V_{\rm all} = \{V_{\rm con}, \xi(0.5), \xi(1), \xi(5)\}$

- Solid line with $\langle N_{\rm PU}\rangle = 20$, Dashed line with $\langle N_{\rm PU}\rangle = 40$
- Black: Conventional, Blue: Selected, Red: All variables
- Pile-up robust
- Selected variables outperforms conventional variables

Results

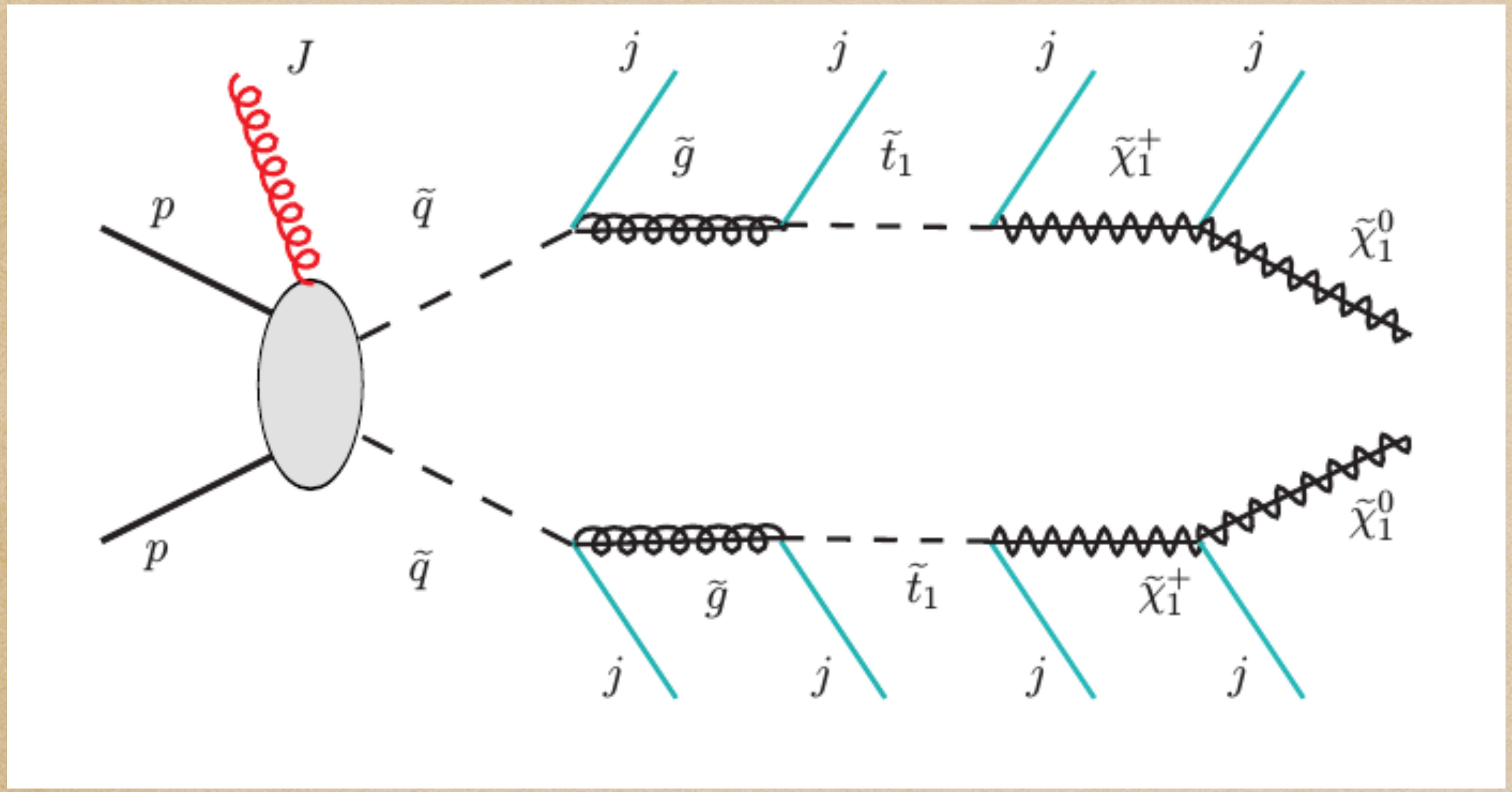


$$\mathcal{I}_{\mathcal{S}} = \frac{(\epsilon_S/\sqrt{\epsilon_B})_M}{(\epsilon_S/\sqrt{\epsilon_B})_C}$$

Compressed: $\mathcal{I}_{\mathcal{S}}|_{D=1/15} \sim 200\%$

Super Compressed: $\mathcal{I}_{\mathcal{S}}|_{D=1/75} \sim 30\%$

Applications: SUSY and MUED



SUSY

Ex: Mirage mediation, Scherk-Schwarz

MUED

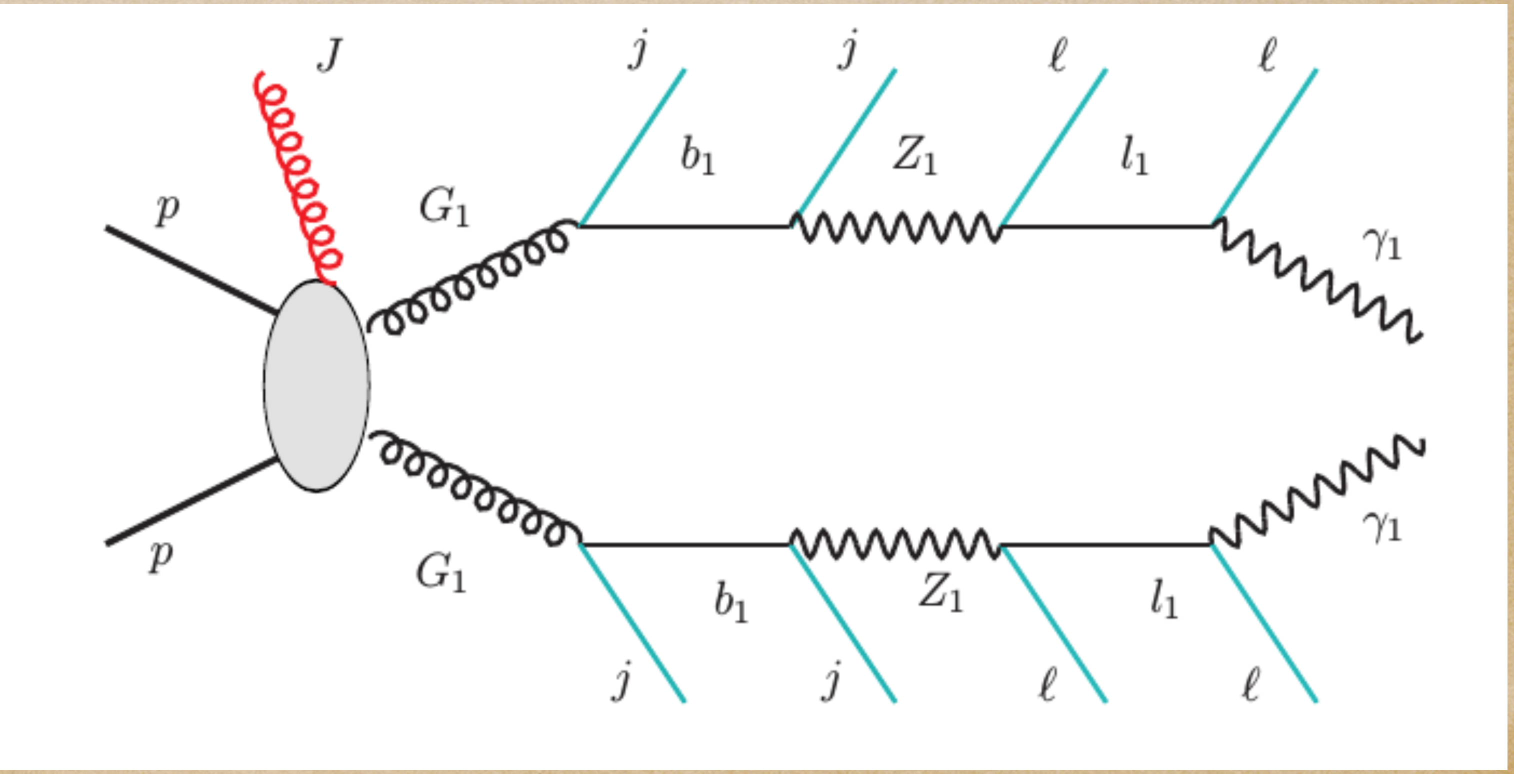
Relic density const.

$1.40 \text{ TeV} \leq R^{-1} \leq 1.46 \text{ TeV}$

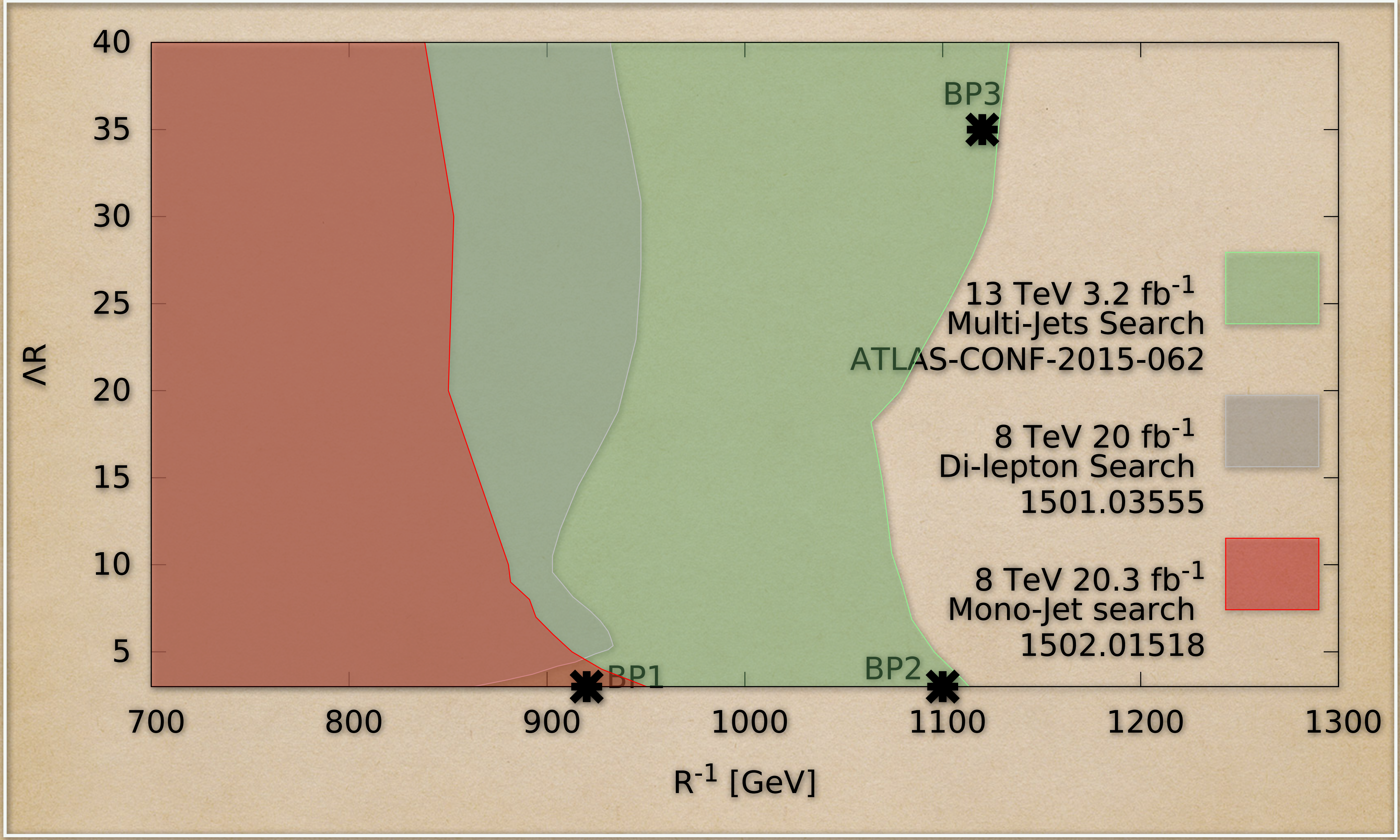
Vacuum Stability

$\Lambda R \leq 4$

Particle physics of Brane worlds and Extra Dimensions: Sreerup, Sridhar



MUED Limits



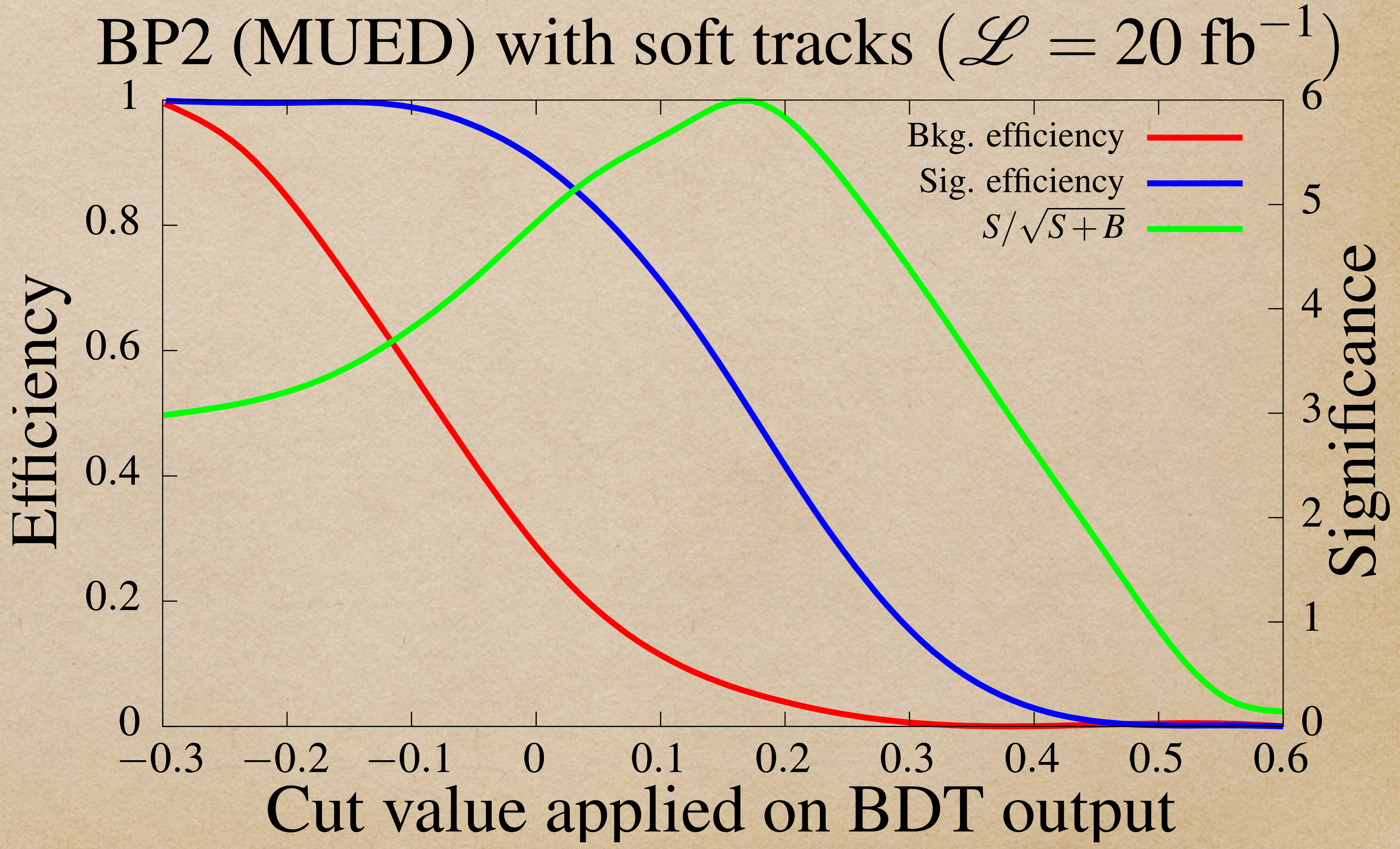
Debajyoti Choudhury, Kirtiman Ghosh Phys.Lett. B763 (2016) 155-160

Cut based Analysis (MUED)

		$\not{E}_T$	H_T	M_{eff}	$\xi(1)$	$\xi(5)$	Luminosity (fb^{-1})
BP2	w/o track	400.0	700.0	800.0	–	–	500.0
	with track	400.0	500.0	1000.0	5.0	5.0	40.42

$$\Lambda R = 2$$

$$R^{-1} = 1.45 \text{ TeV}$$



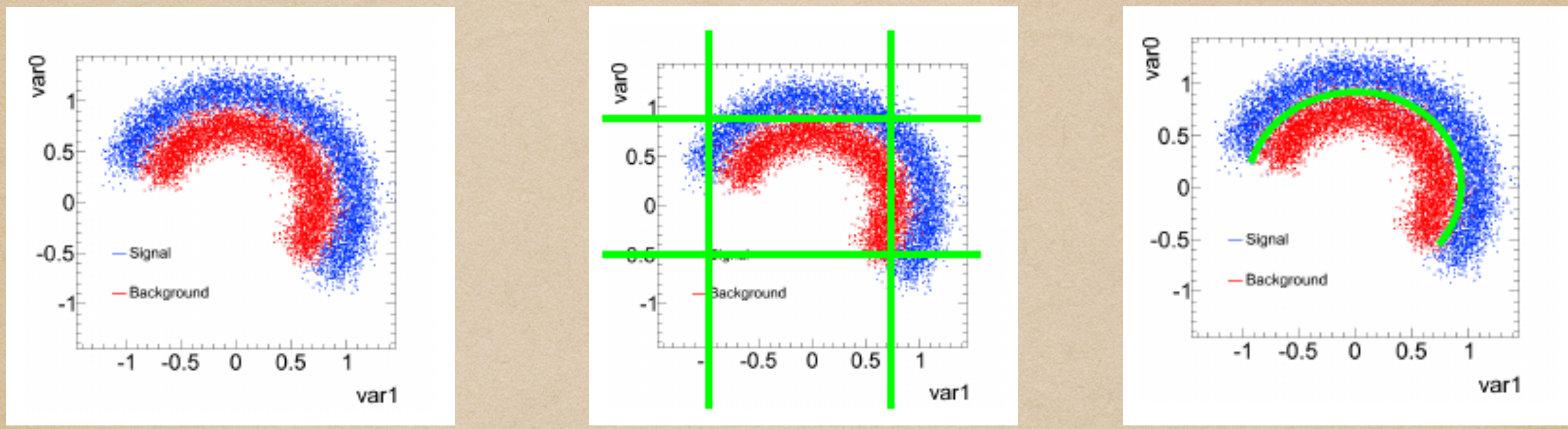
Conclusion

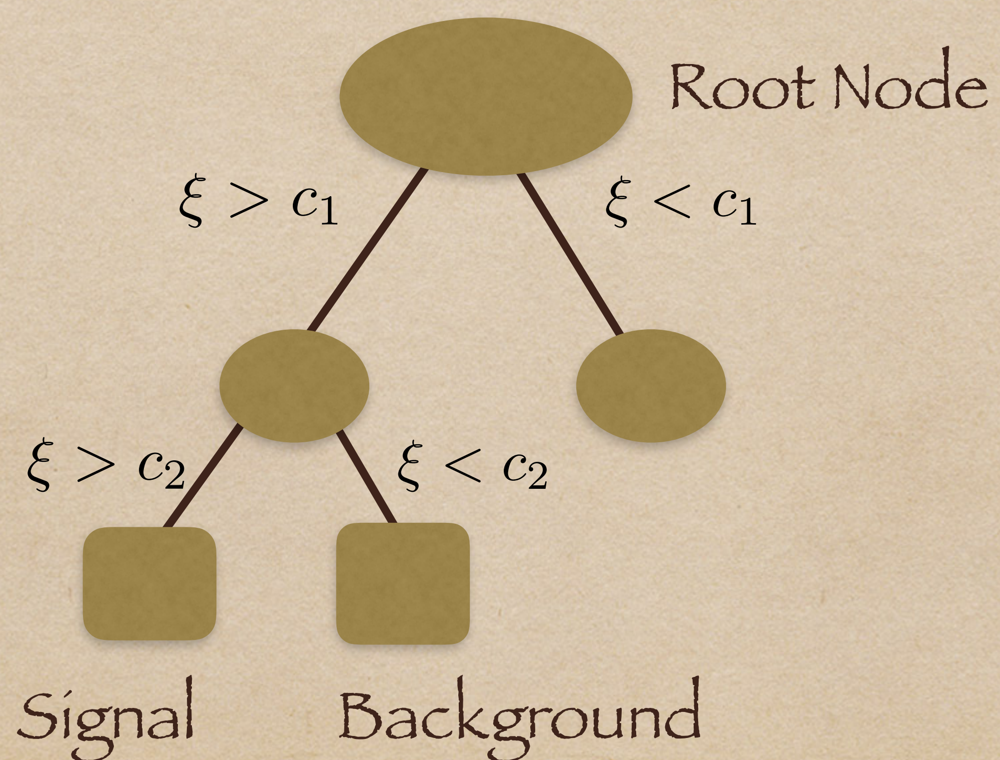
- Monojet + MET: Challenging scenario at LHC
- Conventional analysis fails to utilise the full event information
- Soft tracks, associated with primary vertex is pile up robust
- Carries the information of particle multiplicity in an event
- Uncorrelated with the conventional variables
- Increases the signal purity and signal significance by many orders
- Compressed MUED can already be ruled out with soft tracks
- Significant enhancement in $S/\sqrt{B}$ can be obtained in MSSM
- Soft tracks can be estimated in a data driven way

Take Home Message

[Follow the tracks]

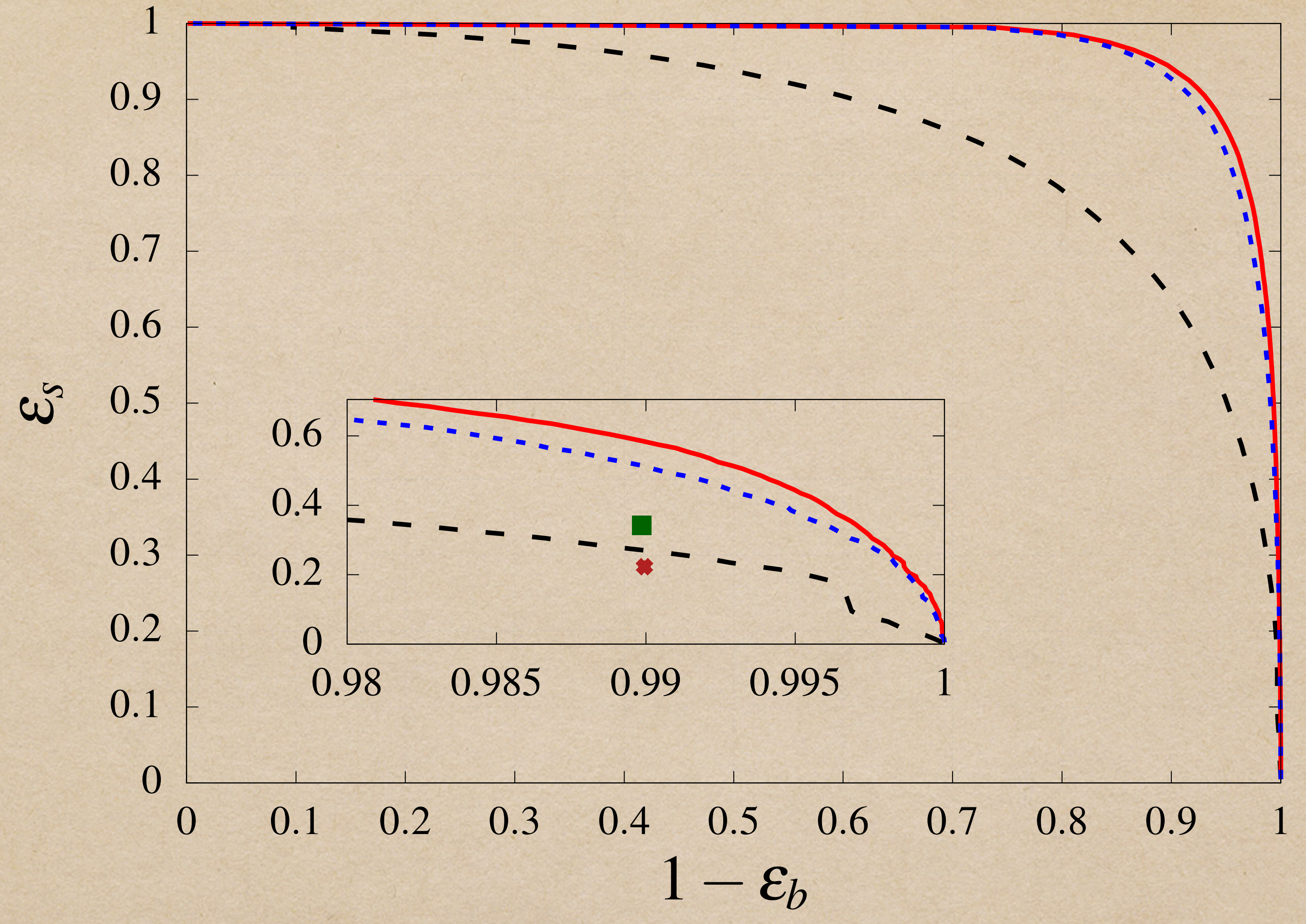
Backup1: Multivariate Analysis





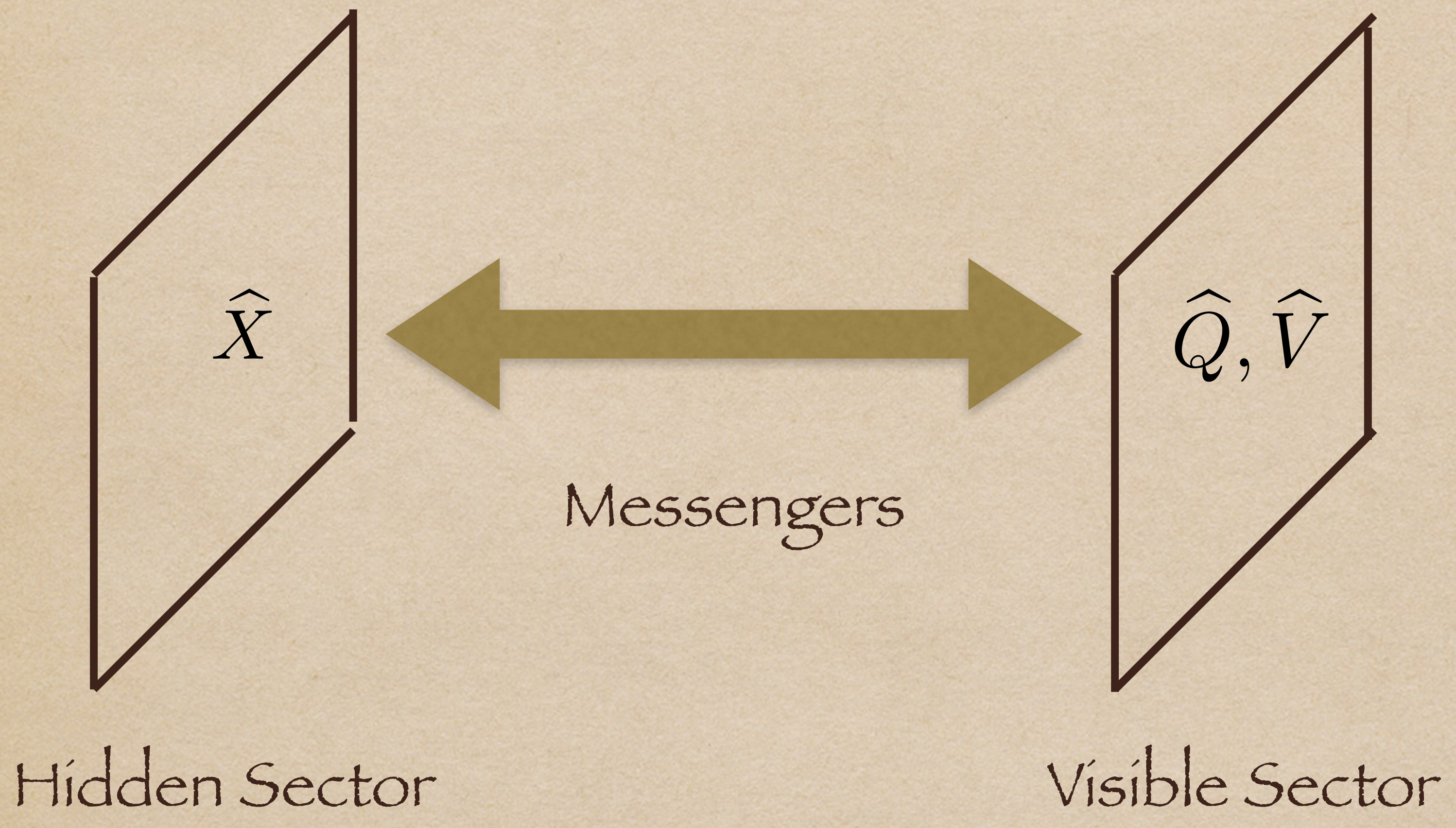
Talk by Christian Boser, Institut für Experimentelle Kernphysik, KIT

ROC for D=1/15



- For a fixed bkg. efficiency, signal efficiency is increased by 50% in a simple cut based analysis
- Cut based analysis with ξ outperforms MVA analysis with conventional variables

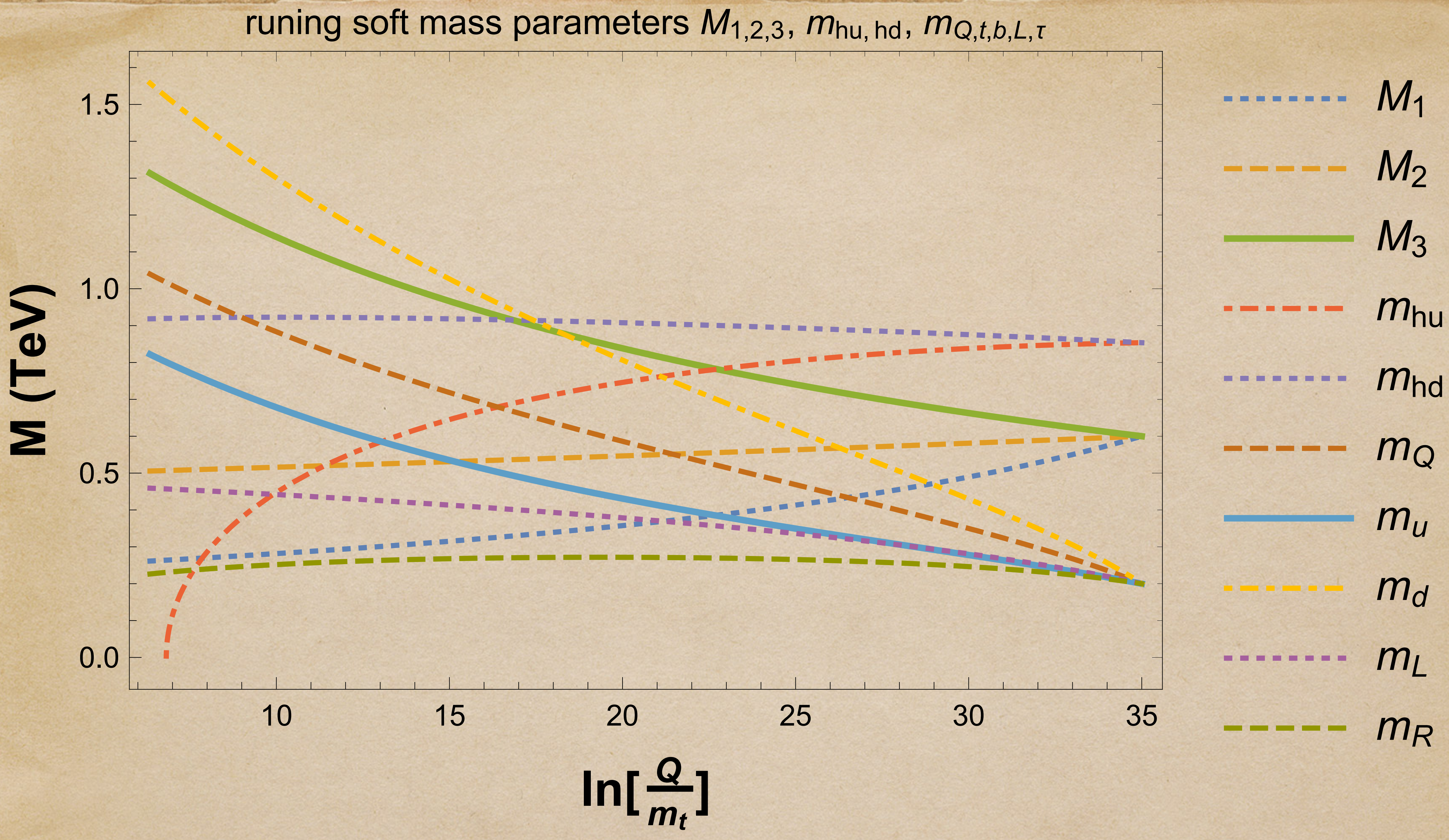
SUSY



$$\frac{1}{M^2} X^\dagger X \; Q^\dagger Q$$

$$\frac{1}{M} X W^\alpha W_\alpha$$

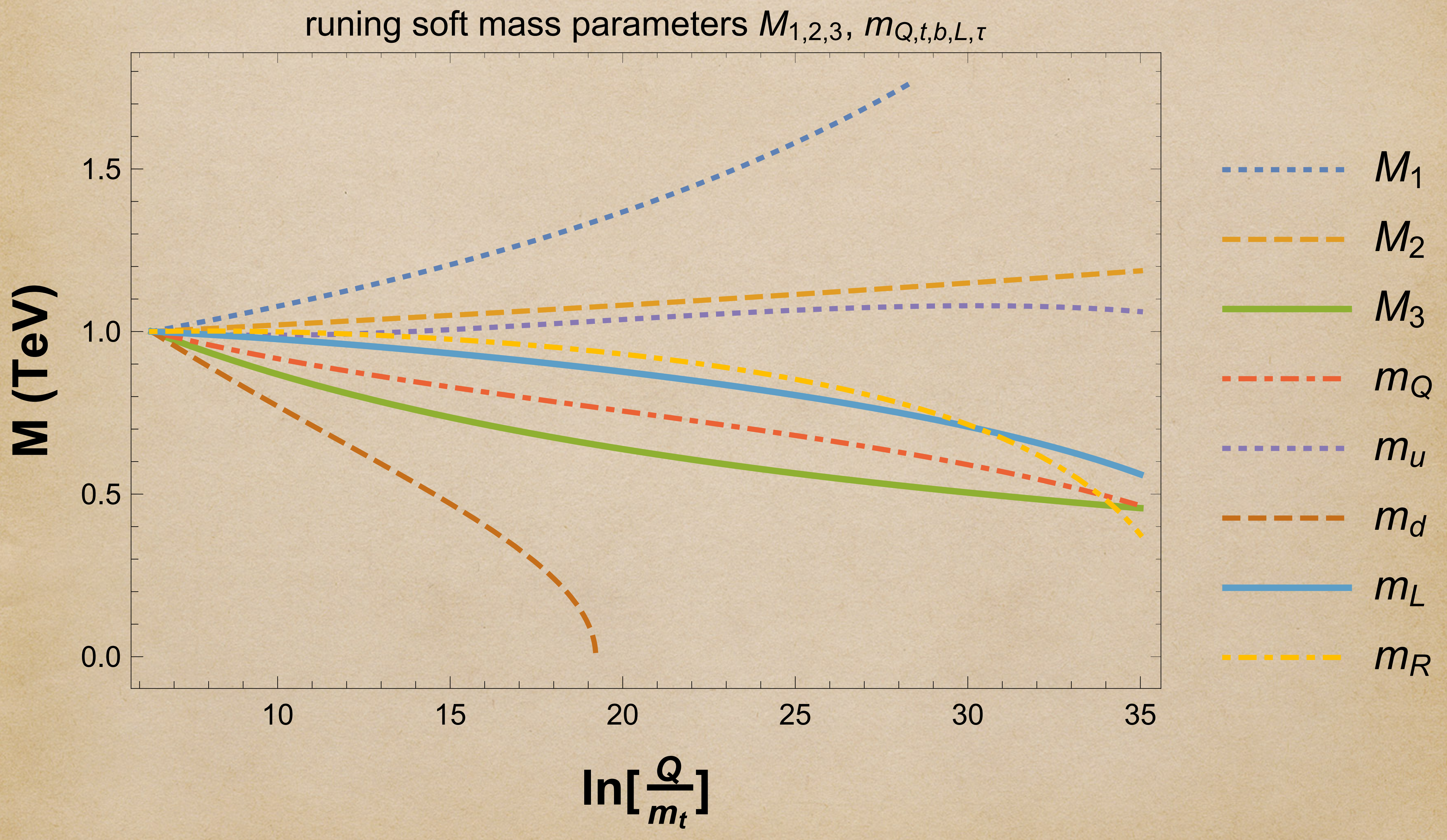
The spectrum depend on the mediation mechanism



DM: Bino overabundance
Coannihilation solves
the problem

Compressed Spectra:
Low scale mediation
Scherk-Schwarz

Other way around



MUED Constraints

- Mass of nth KK state: $m_n^2 = m_0^2 + \dfrac{n^2}{R^2}$
- For small R, all the particles have degenerate tree level mass
- Loop corrections creates slight splitting in these masses
  Cheng, Matchev, Schmaltz, PRD 66 (2002) 66, 056006
- Loop corrections depend on the cut-off scale Λ
- The spectrum is completely fixed with two parameters
- $1.40 \text{ TeV} \leq R^{-1} \leq 1.46 \text{ TeV}$, Relic density constraints
- $\Lambda = 2,$ compressed. Vacuum stability: $\Lambda \leq 4$
  A Dutta, S Raychaudhuri Phys.Rev. D87 (2013) no.3, 035018

Particle physics of Brane worlds and Extra Dimensions: Chapter 9: S Raychaudhuri, K. Sridhar

Benchmark points

Parameters MSSM	BP1	BP2	Parameters MUED	BP1	BP2
M_1	1.440	1.200	ΛR	2	2
M_2	1.380	1.200	R^{-1}	1.2	1.45
M_3	1.300	1.150	m_{G_1}	1.285	1.553
A_t	3.700	3.700	m_{D_1}	1.254	1.515
μ	2.000	2.000	m_{U_1}	1.254	1.515
$\tan\beta$	20	20	m_{S_1}	1.254	1.515
$m_{\widetilde{g}}$	1.422	1.264	m_{C_1}	1.254	1.515
$m_{\widetilde{q}_L}$	1.470	1.310	m_{B_1}	1.246	1.506
$m_{\widetilde{q}_R}$	1.460	1.301	m_{T_1}	1.244	1.499
$m_{\widetilde{t}_1}$	1.409	1.225	m_{L_1}	1.208	1.460
$m_{\widetilde{t}_2}$	1.712	1.564	m_{Z_1}	1.214	1.466
$m_{\widetilde{b}_1}$	1.451	1.409	m_{W_1}	1.214	1.466
$m_{\widetilde{b}_2}$	1.597	1.457	m_{H_1}	1.196	1.447
$m_{\widetilde{\ell}_L}$	1.413	1.410	m_{d_1}	1.247	1.507
$m_{\widetilde{\ell}_R}$	1.406	1.405	m_{u_1}	1.247	1.507
$m_{\widetilde{\tau}_1}$	1.482	1.229	m_{s_1}	1.247	1.507
$m_{\widetilde{\tau}_2}$	1.532	1.285	m_{c_1}	1.247	1.507
$m_{\widetilde{\nu}_L}$	1.410	1.407	m_{b_1}	1.247	1.507
$m_{\widetilde{\chi}_2^0}$	1.423	1.210	m_{t_1}	1.258	1.516
$m_{\widetilde{\chi}_1^\pm}$	1.388	1.210	m_{l_1}	1.203	1.454
$m_{\widetilde{\chi}_1^0}$	1.387	1.187	m_{γ_1}	1.189	1.436
m_h (GeV)	126.0	125.0	m_h (GeV)	125.0	125.0
Ωh^2	0.109	0.110	Ωh^2	0.082	0.119
$\sigma_{\rm SI}^p$ (pb)	8.01×10^{-10}	1.21×10^{-10}	$\sigma_{\rm SI}^p$ (pb)	1.03×10^{-10}	3.23×10^{-11}
Δm_i (GeV)	83.0	123.0	Δm_i (GeV)	96.0	117.0

Comparison between MSSM and MUED