CMS discovery potential for Minimal Universal Extra Dimensions

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Universal Extra Dimensions

- Universal ED : all SM fields propagate in D>4 dimensions with **flat** metric

(Appelquist, Cheng and Dobrescu, hep-ph/0012100)

→ KK parity, a discrete symmetry within the extra dimensions, implies a stable BSM particle (LKP), which is a viable dark matter candidate

- **SM in 5D – Minimal UED (MUED)**
  - electroweak observables are insensitive to the unknown physics above the cutoff scale
  - **1/R** and Λ are the only parameters relevant for collider phenomenology

(Cheng, Matchev and Schmaltz, hep-ph/0205314)

  - Experimental Bounds
    - Tevatron direct search $\rightarrow$ 1/R > 280 GeV (C.Lin, fermilab-thesis-2005-069)
    - Inclusive $\bar{B} \rightarrow X_s \gamma$ decay $\rightarrow$ 1/R > 600 GeV (Haish and Weiler, hep-ph/0703064)
    - Dark matter $\rightarrow$ 600 GeV <1/R< 1050 GeV (Servant and Tait , hep-ph/0206071)

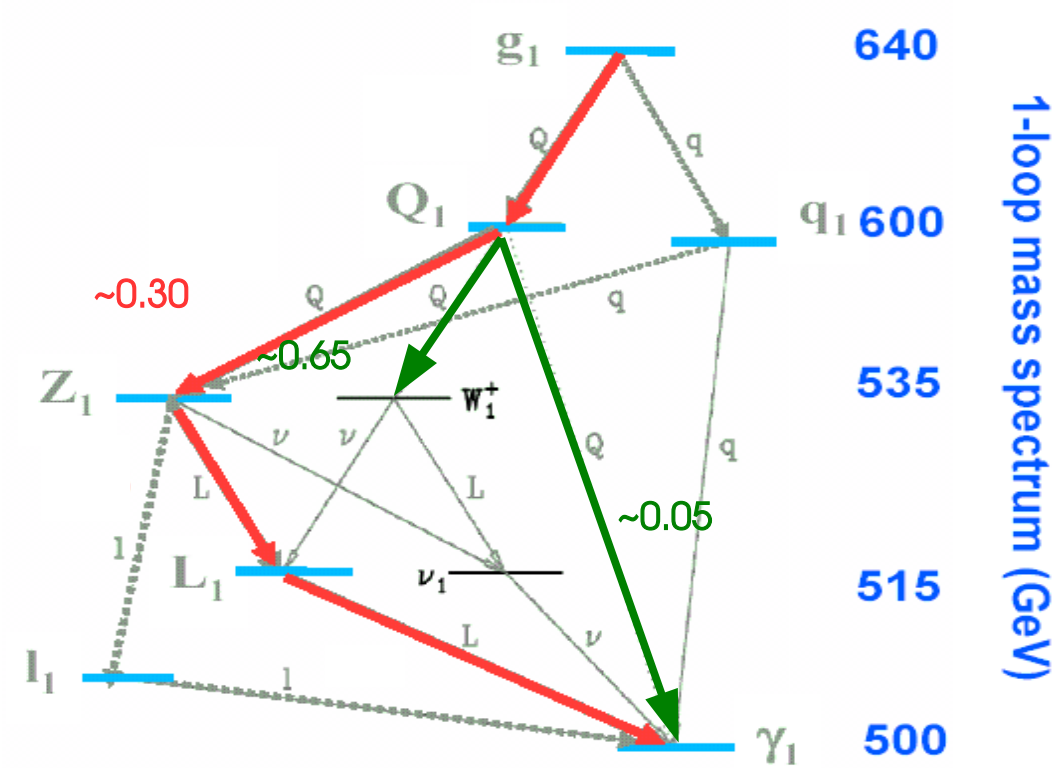
- SM in 6D
  - anomaly cancellations predict that # fermion generations = 3n
  - remnant of 6D Lorentz symmetry enforces long proton lifetime

(Dobrescu, Kong and Mahbubani, hep-ph/0703231)

  - Experimental Bounds : 1/R >~270 GeV (trilepton search, CDF Note 8653 and D0 Note 5127-Conf)

MUED signature

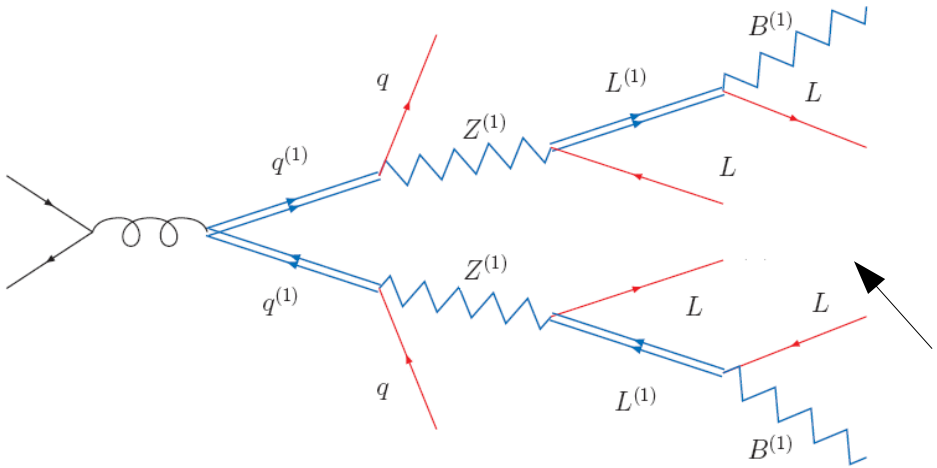
Spectroscopy of first KK level in MUED
1/R=500 GeV, ΛR=20 and m_h=120 GeV



- Interesting signature at LHC — "golden channel"
  - **pair production of coloured KK modes**
  - **cascade decay into 4 isolated leptons + jets + MET**

- However mass difference between heaviest mode and LKP = O(100) GeV
  - Small average momentum of SM leptons produced in cascade decays
  - Small missing energy, comparing with SUSY scenarios

Signal and background processes



$$pp \to g_1 g_1 \quad \to 2(\ell^\pm \ell^\mp) + 4q + 2\,\gamma_1^{\mathrm{LKP}} \quad \to 4\ell + 4\mathrm{jets} + \not{E}_T$$

$$pp \to g_1 q_1 \quad \to 2(\ell^\pm \ell^\mp) + 3q + 2\,\gamma_1^{\mathrm{LKP}} \quad \to 4\ell + 3\mathrm{jets} + \not{E}_T$$

$$pp \to q_1 q_1 \quad \to 2(\ell^\pm \ell^\mp) + 2q + 2\,\gamma_1^{\mathrm{LKP}} \quad \to 4\ell + 2\mathrm{jets} + \not{E}_T$$

- four points: 1/R = 300, 500, 700, 900 GeV ; ΛR=20 ; m_h=120 GeV
- σ_{tot} = 2190, 165, 26, 5.9 pb
- three leptonic decay channels : 4e, 4μ, 2e2μ
- B.R. to each leptonic channel ~ 10^{-4} — 10^{-3}

SM backgrounds considered :

$$t\,\bar{t}$$
$$Z\,Z(Z^*/\gamma^*)$$
$$Z\,b\,\bar{b}$$
$$b\,\bar{b}\,b\,\bar{b}$$

Event simulation

- Signal and background events generated at LO with matrix element MC
- MUED samples generated with CompHEP, using model files by Matchev et *al*
- Private code (UEDDECAY) used to produce cascade decay to SM particles
  - phase space decay, spin correlations not considered
- tt, tt+1 and tt+2 jet samples generated with ALPGEN (v1.33)
  - Matrix element/Parton shower matching not included

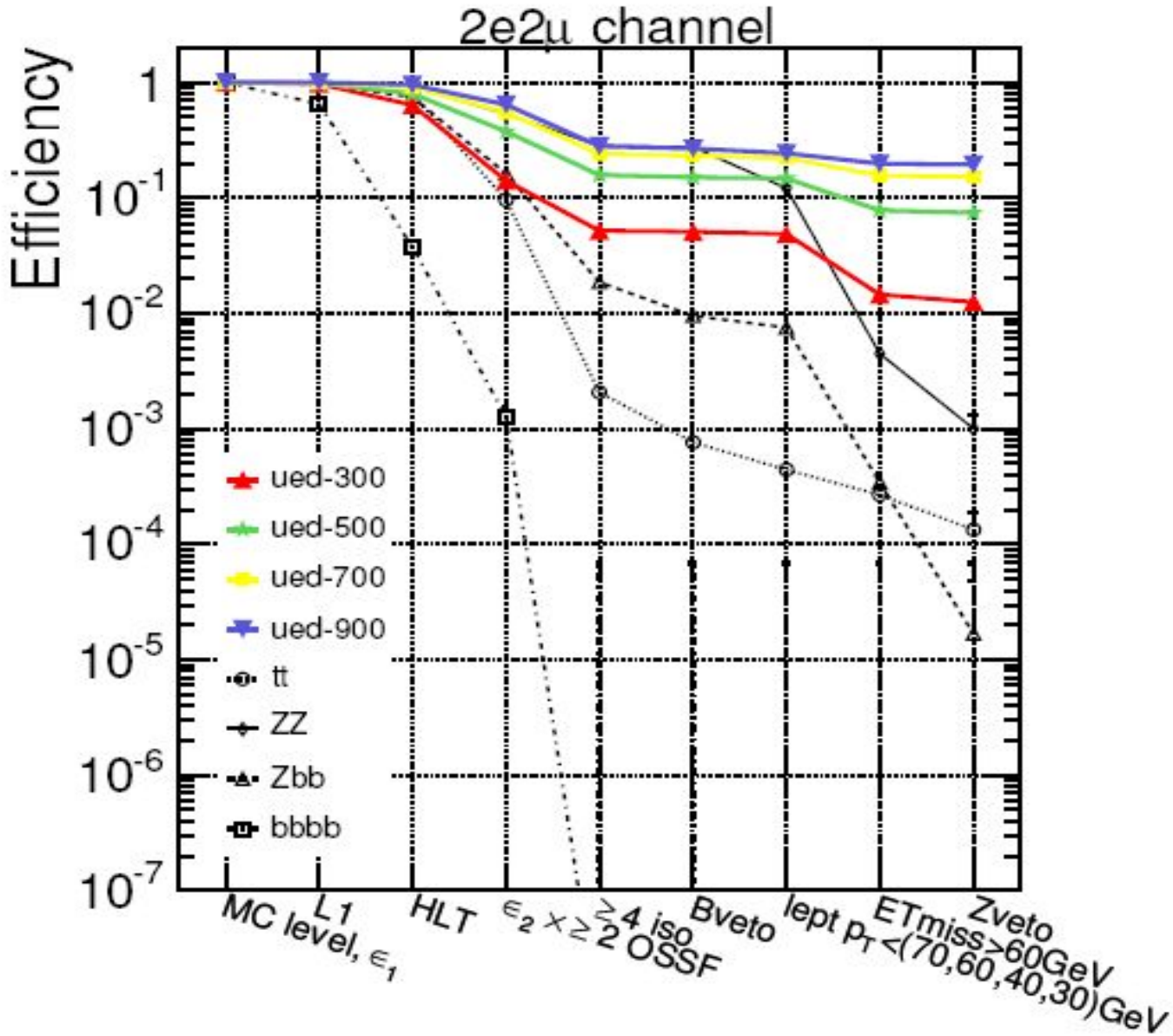
- Detector simulation and physics objects reconstruction performed with
  OSCAR v3.6.5 and ORCA v.8.7.x $\rightarrow$ official CMS software, now deprecated

- Events from minimum bias interactions were superimposed on signal and background events, according to Poisson probability with a mean of 5 events , simulating effect of pile up at LHC Luminosity = 2×10^{33} cm^{-2} s^{-1}

Event selection

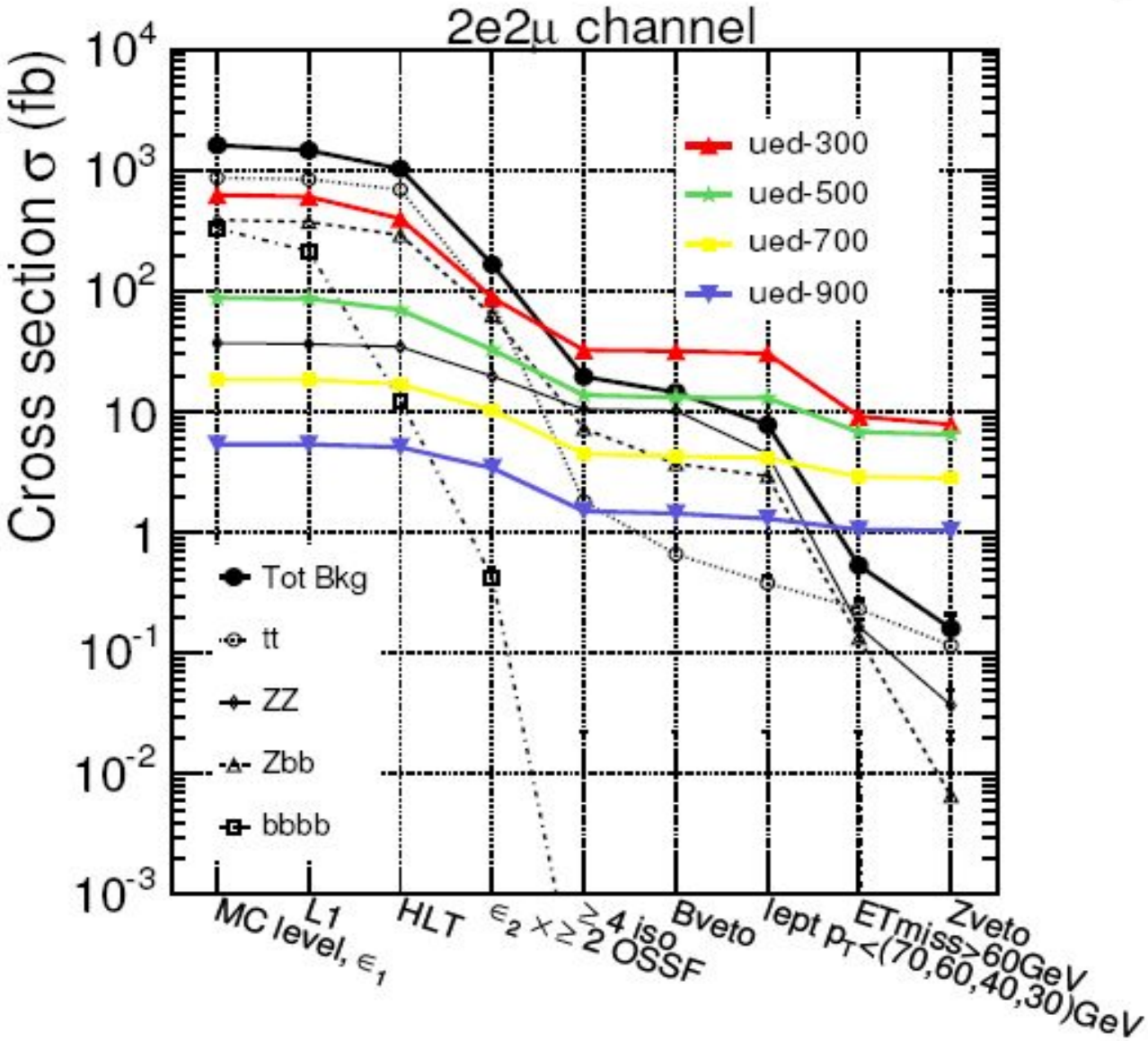
- Preselection (ε_2)
  - all muons with $p_T \geq 5$ GeV/c and $|\eta| \leq 2.4$
  - all electrons with $p_T \geq 7$GeV/c and $|\eta| \leq 2.5$ ($E_{HCAL}/E_{ECAL} < 0.1$ & $0.9 < E_{ECAL}/P_{tracker} < 1.5$)
- $\geq$ 2 pairs of OSSF leptons
- $\geq$ 4 Isolated leptons (tracker p_T isolation)
- b-tag veto (Combined b-tag algo)
  - event is rejected if it has $\geq$ 1 tagged b-jet
- lepton p_T (1st,2nd,3rd,4th) < (70,60,40,30) GeV/c
- missing p_T > 60 GeV/C (from Iterative Cone Jet algo)
- Invariant mass veto
  - event is rejected if it has $\geq$1 OSSF lepton pair with M_{inv} < 5 GeV or M_{inv} > 80 GeV

Selection efficency



- **Selection cuts were chosen so that efficiency is maximum for 1/R = 900 GeV where cross section is lower**

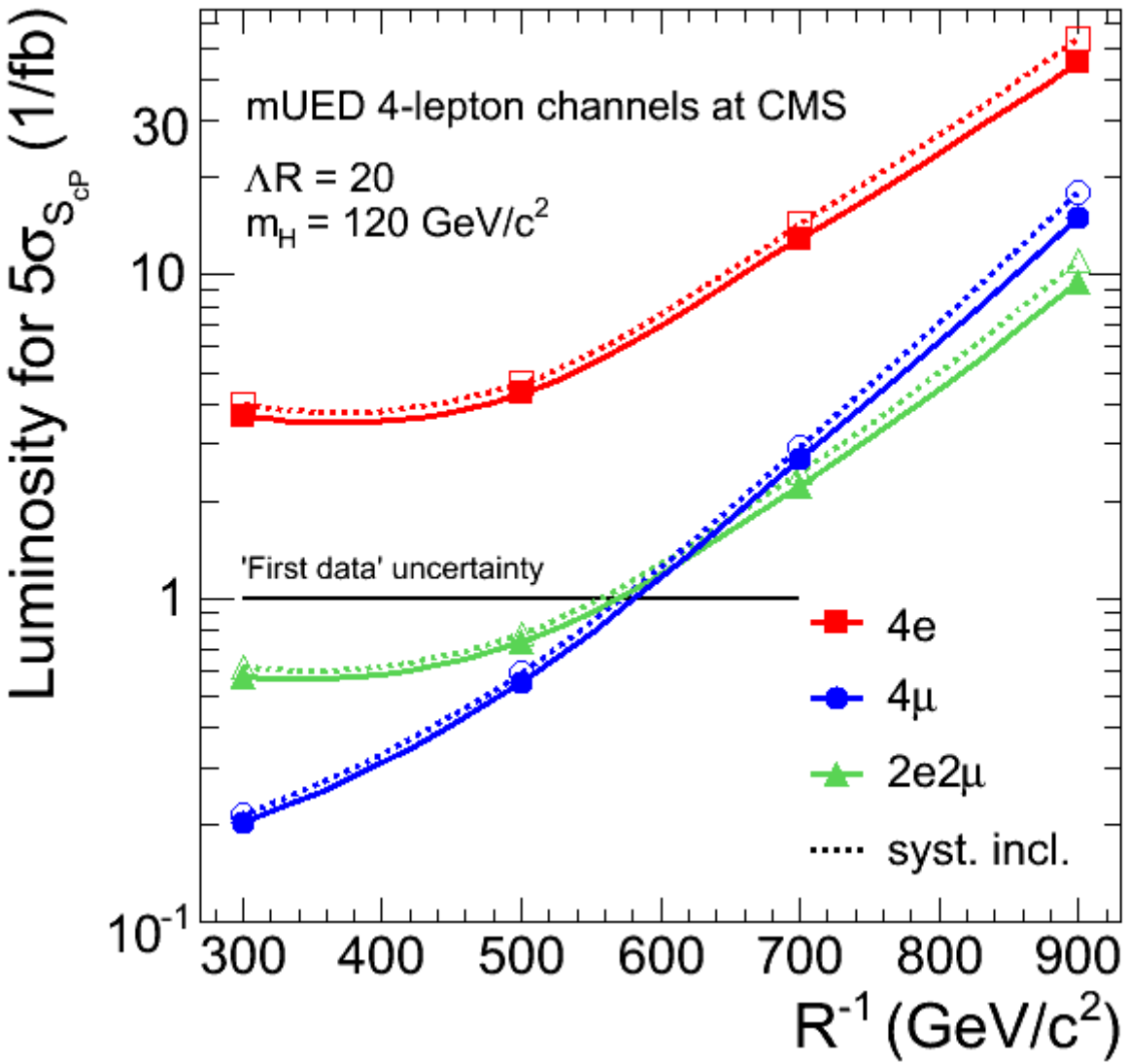
Cross section after selection



- **Large S/B (> 5) after all selection cuts**

CMS Discovery potential

Integrated luminosity required to observe MUED signal with 5σ significance using S_{cP} as estimator ($P(N_{obs} \geq N_S + N_B;\ \mu = \mu_B)$)



Systematical uncertainties include

- 20 % uncertainty on background σ
- effect of jet energy scale on missing energy (~ 3 – 10 %, jet p_T dependent)
- b-tagging (~5%)

4e channel yields lowest significance due to :

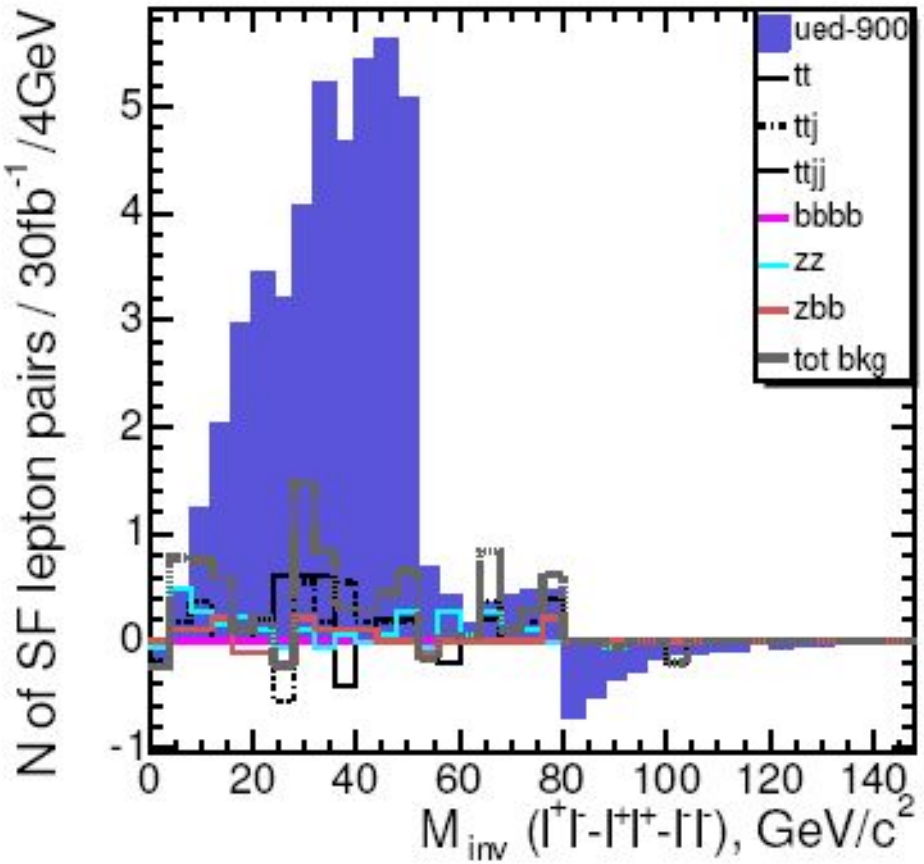
- lower lepton reconstruction efficiency
- higher trigger thresholds

Excess of multilepton events due to MUED signal can be detected in the first couple of years of LHC running

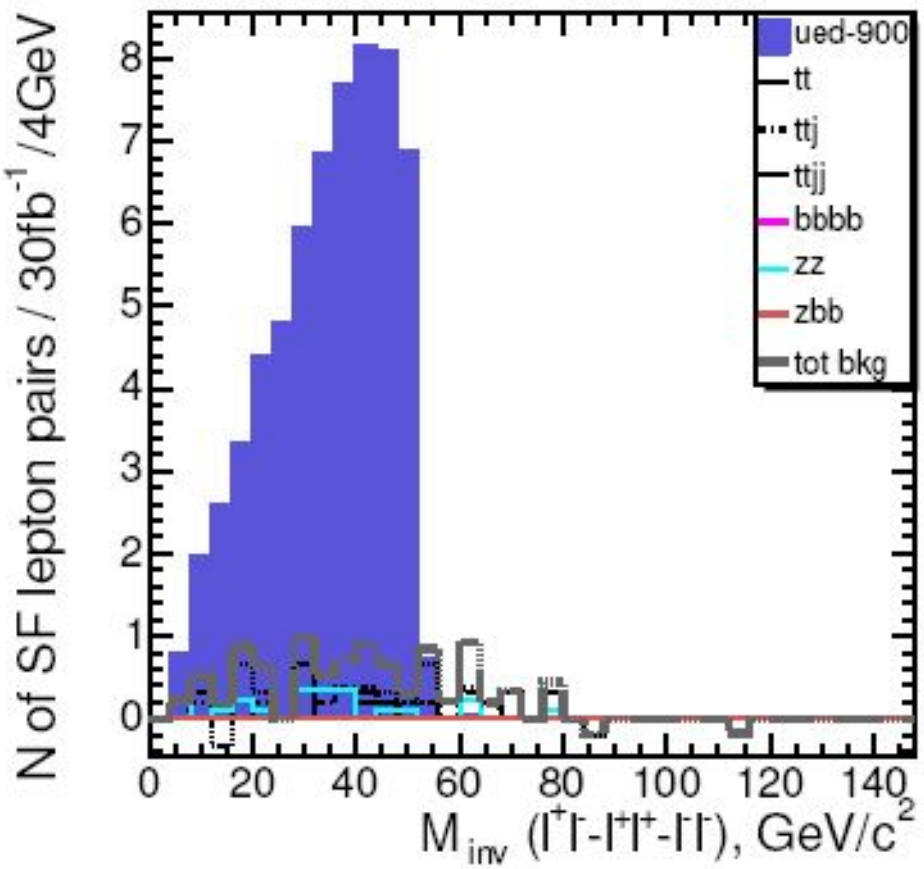
Dilepton kinematic endpoints

1/R = 900 GeV

4μ channel



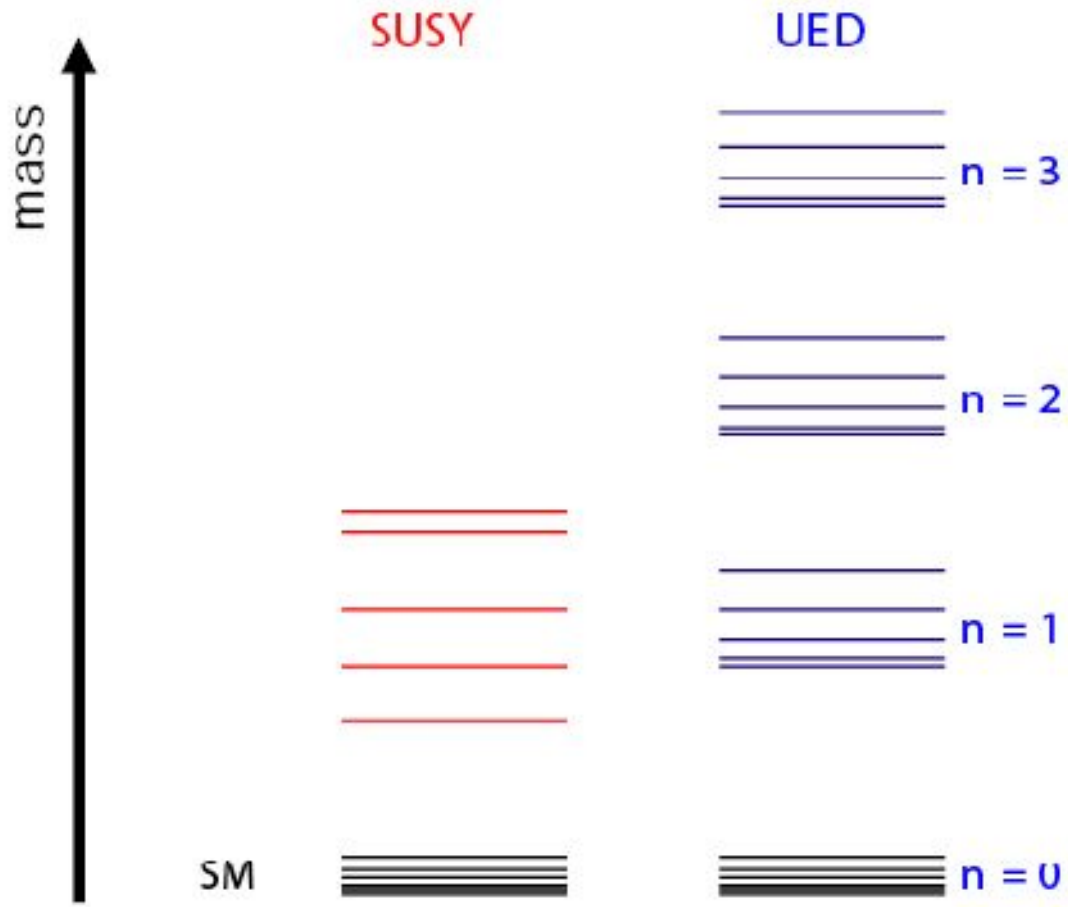
2e2μ channel



- Distributions after final event selection
- Suppression of combinatorial background by subtracting the M_{inv} distributions for SSOF dileptons from the distribution of M_{inv} for all possible combinations of OSSF dileptons
- **Observation of dilepton edge is an evidence of a new parity**

Future Directions

Supersymmetry or Extra Dimensions ?

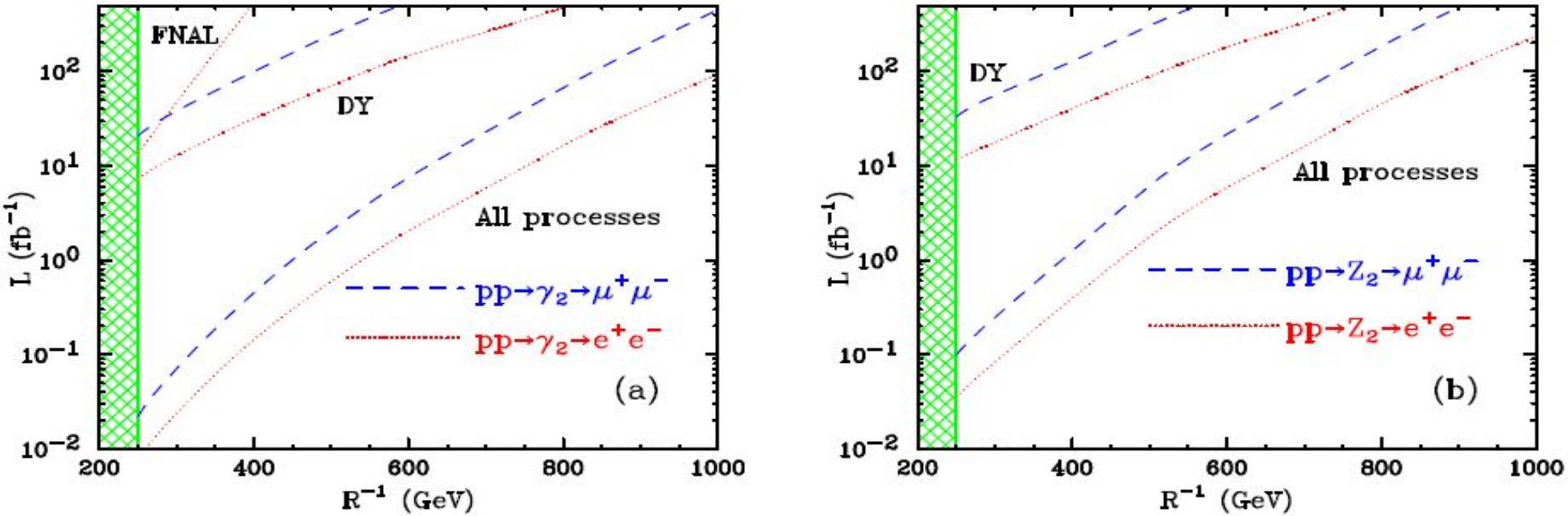


•Spins	differ by 1/2	same as SM
•Higher levels	no	yes

KK level 2 discovery potential

hep-ph/0509246 Datta, Kong and Matchev

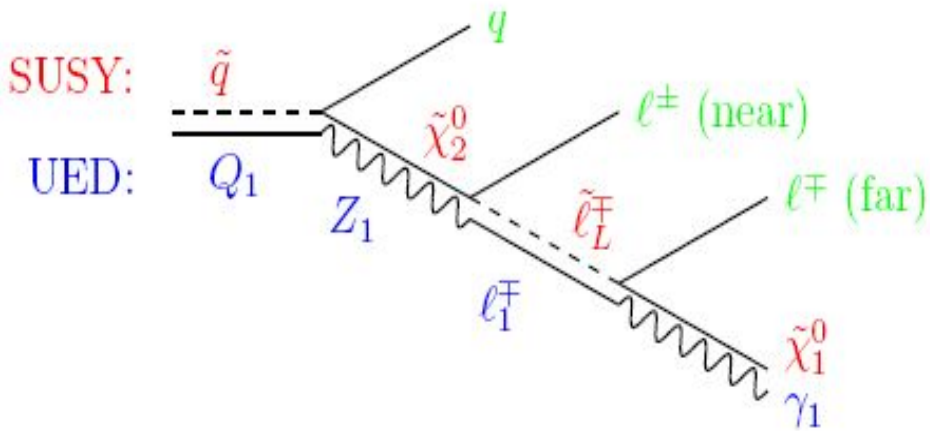
Discovery potential for Gauge Boson KK level 2 is the most promising



An integrated luminosity of 10 fb^{-1} is required for 1/R < 750 GeV

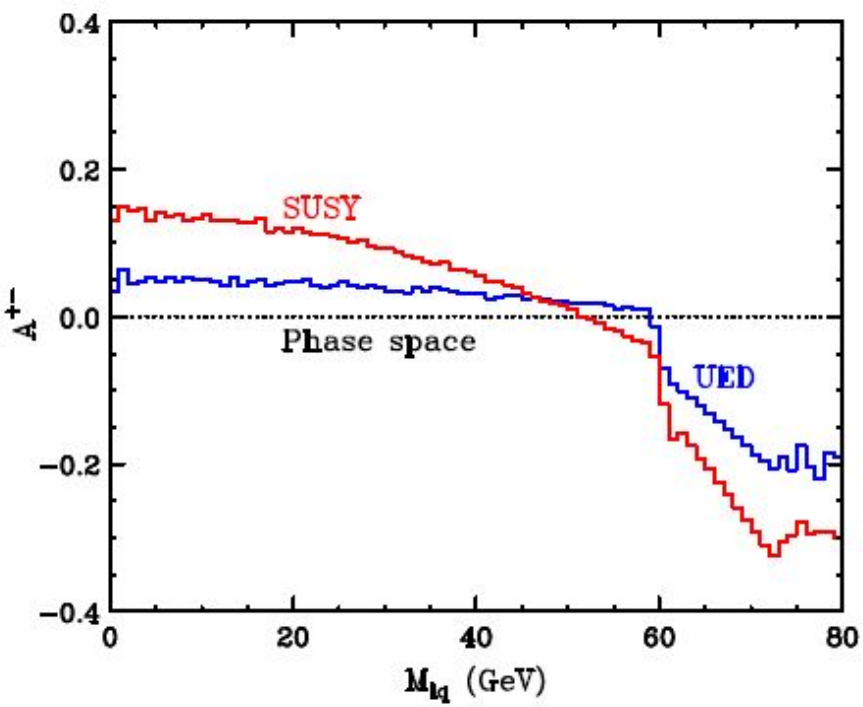
Spin discrimination

hep-ph/0509246 Datta, Kong and Matchev



Measure charge asymmetry distribution in lepton-jet invariant mass

$$A^{+-} \equiv \left(\frac{dN(q\ell^+)}{dM_{ql}} - \frac{dN(q\ell^-)}{dM_{ql}}\right) \Big/ \left(\frac{dN(q\ell^+)}{dM_{ql}} + \frac{dN(q\ell^-)}{dM_{ql}}\right)$$



Comparison of charge assymetry distribution for UED with 1/R=500 GeV and SUSY model with matched mass spectrum

- Clean discrimination is challenging
- Low statistics in the edges, detector effects and backgrounds can degrade the technique

UED in Herwing ++

- M. Gigg has implemented MUED model in Herwig++ trough Matrix Elements
  - Spin correlations in cascade decays can be studied

Many thanks to Martyn for providing me his code
and to Peter for allowing it

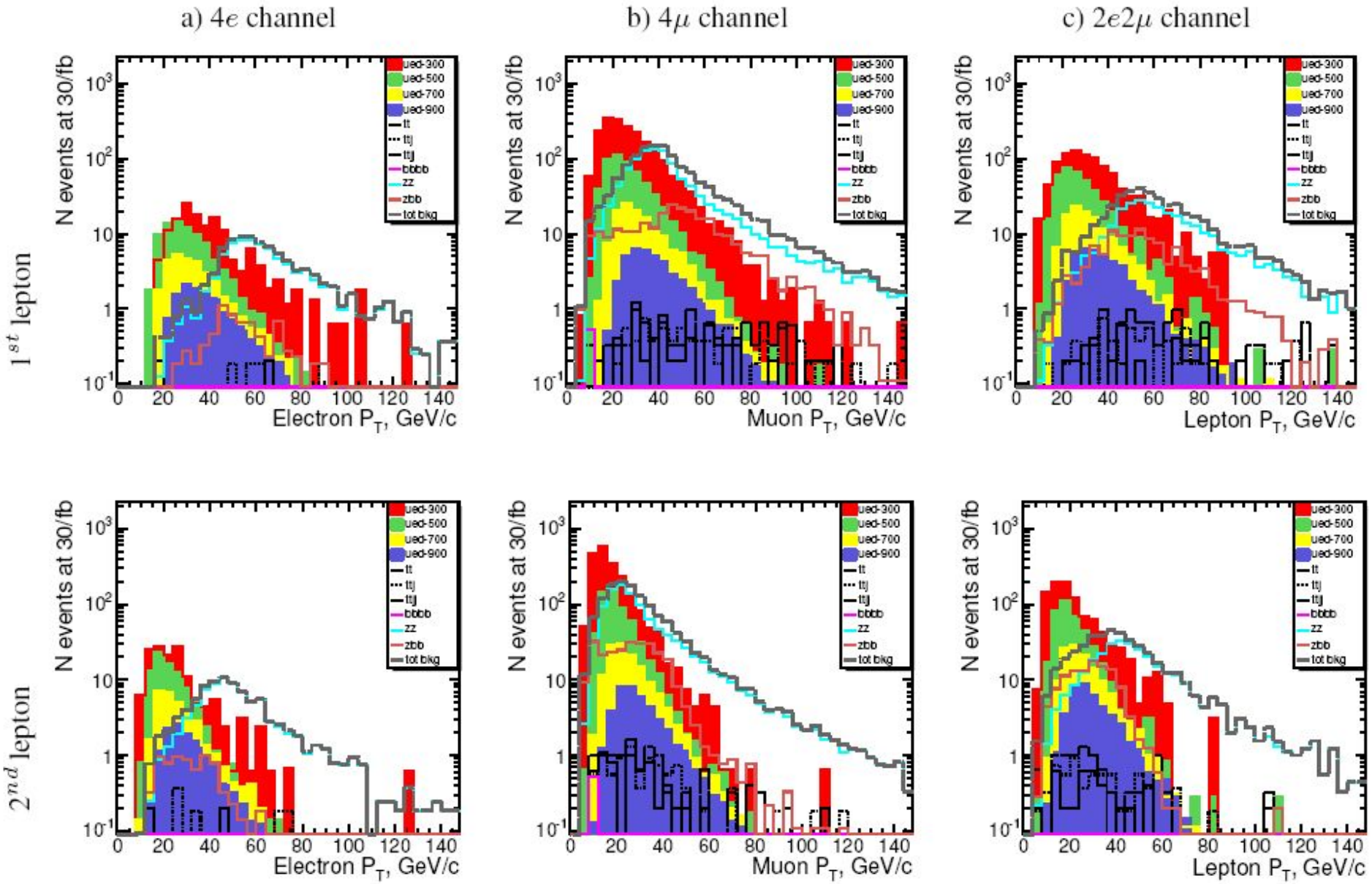
UED project worklist

- Development of strategy to provide early exclusion limits,
  combining different channels when possible
- Improvement of reconstruction efficiency for soft electrons
- Usage of Neural Networks for further optimization of selection cuts
- Investigation of t tbar background sample with proper ME/PS matching
- Study of CMS discovery potential for level 2 KK gauge bosons
- Investigation of lepton-jet invariant mass charge asymmetry using realistic detector simulation

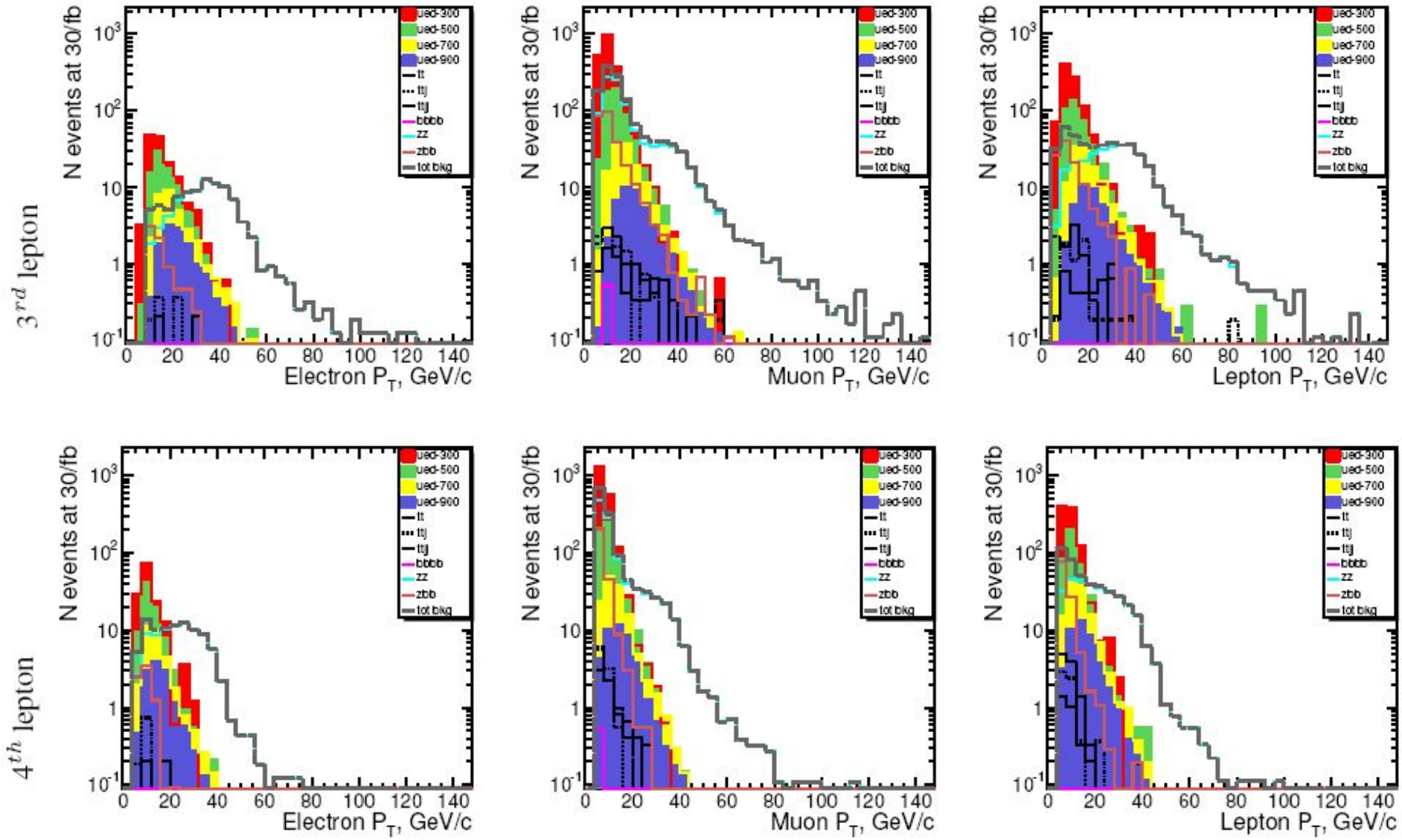
Feedback and suggestion are welcome !!

Backup Plots

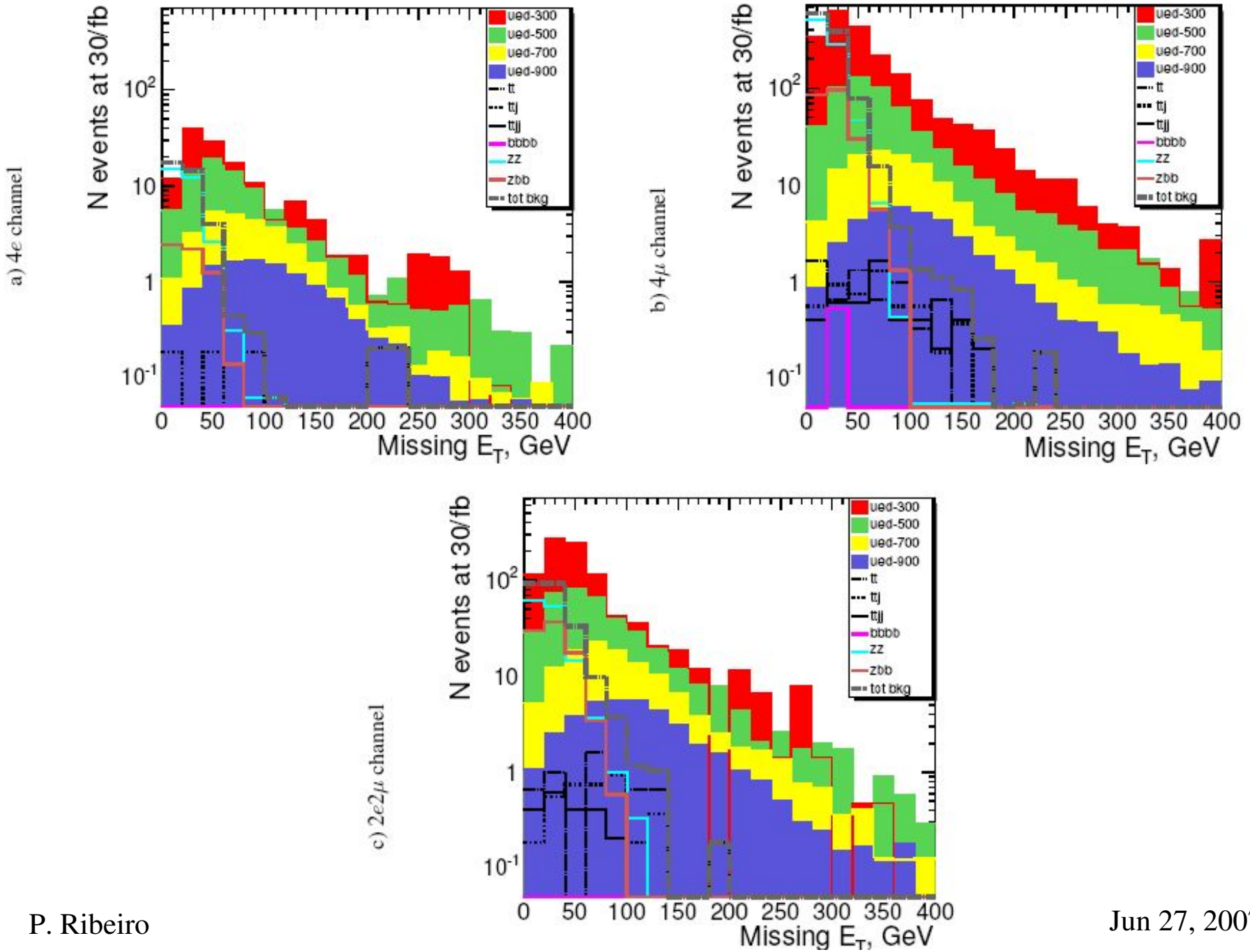
Lepton p_T


a) 4e channel
b) 4μ channel
c) 2e2μ channel
1st lepton
2nd lepton
N events at 30/fb
Electron P_T, GeV/c
Muon P_T, GeV/c
Lepton P_T, GeV/c
ued-300
ued-500
ued-700
ued-900
tt
ttj
ttj
bbbb
zz
zbb
tot bkg

Lepton p_T


3rd lepton
4th lepton
N events at 30/fb
Electron P_T, GeV/c
Muon P_T, GeV/c
Lepton P_T, GeV/c
ued-300
ued-500
ued-700
ued-900
tt
ttj
ttjj
bbbb
zz
zbb
tot bkg

Missing E_T


a) 4e channel
b) 4μ channel
c) 2e2μ channel
N events at 30/fb
Missing E_T, GeV
ued-300
ued-500
ued-700
ued-900
tt
ttj
ttjj
bbbb
zz
zbb
tot bkg