Search for Universal Extra Dimensions in the Likesign Dimuon Channel at DØ

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for the DØ Collaboration

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Overview

- The DØ experiment
- Introduction:
  Universal Extra Dimensions
- Samples used
- Backgrounds
  - QCD multijet
  - Charge mismeasurement
- Multivariate analysis
- Conclusions

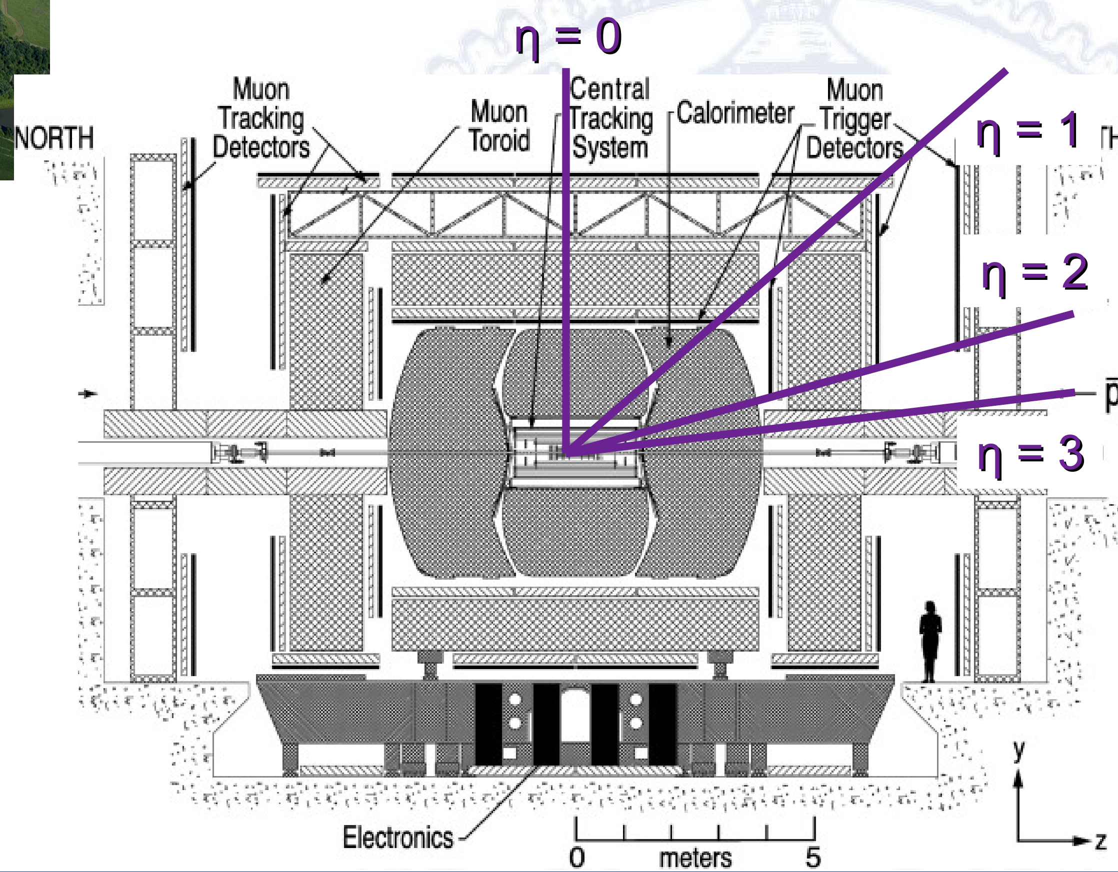
The DØ Experiment

Tevatron @ Fermilab

- Proton-Antiproton-Collider
- $\sqrt{s}$ = 1.96 TeV
- Run II int. Luminosity: 10.38 fb^{-1}
- 2 Detectors: DØ and CDF

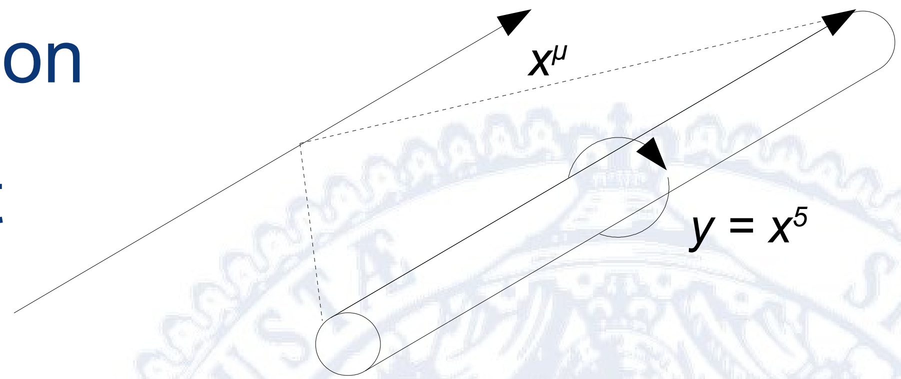
The DØ Detector

- General purpose detector, 4π coverage
- Track reconstruction:
  - Silicon Microstrip Tracker (SMT), $|\eta| < 3$,
  - Central Fiber Tracker (CFT), $|\eta| < 2$
- LiAr/Uranium sampling calorimeter
- Muon chambers, $|\eta| < 2$
- 2 Tesla solenoid + toroid



Universal Extra Dimensions (UED)

- Historically: Attempt to unify electromagnetism and GR by Kaluza & Klein (KK) (1921/26)
- One additional spatial dimension
- … which we don't see, since it is compactified (“rolled up”)



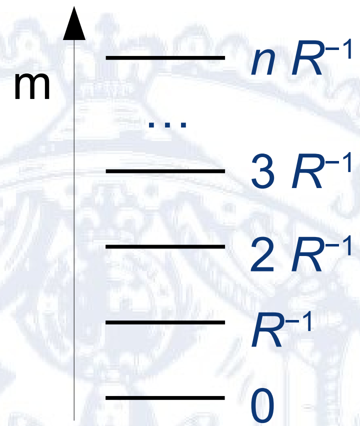
- “Universal”: All fields propagate in extra dimension, not just gravity
- Particles moving in extra dim. have higher E_{Kin}
  $\rightarrow$ seemingly higher mass in 4D
  $\rightarrow$ Kaluza-Klein excitation

Minimal UED

- Minimal UED – parameters:
  inv. Radius $R^{-1} \approx 200...320$ GeV,
  Cutoff scale $\Lambda \approx 10000$ GeV

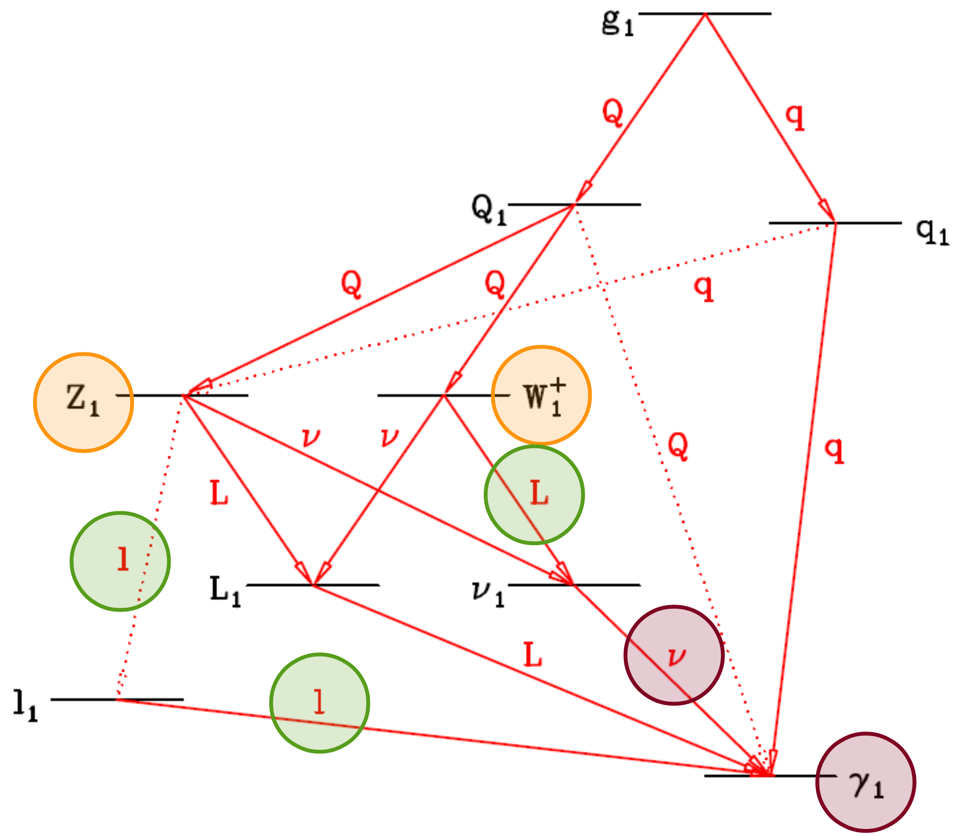
Size of extra dimension:
$\hbar c$ / 200 $\text{GeV}^{-1} \approx 10^{-3}$ fm

- Quantisation
  → Periodic boundary conditions
  → Discrete masses,
  $m_n^2 \sim m_0^2 + (n / R)^2$



- Conversation of momentum in extra dimension
  → Conservation of KK-Excitation, KK-Parity $P_{KK} = (-1)^n$
  → Lightest KK-Partner (LKP) stable
  → Candidate for dark matter!

mUED: Production & Decay



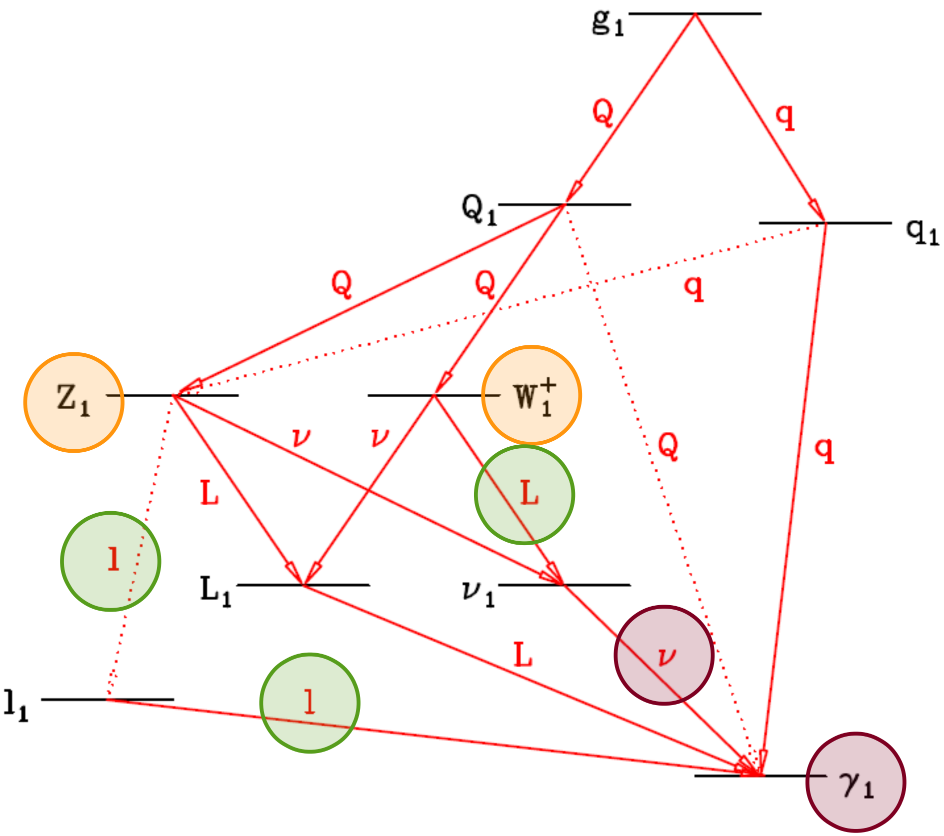
- ← Typical mass spectrum
- Possible leptonic decay chain:

  $p\,\bar{p} \rightarrow Q_1 Q_1 \rightarrow$

  $Z_1 Z_1 \,/\, Z_1 W_1 \,/\, W_1 W_1 \rightarrow$

  2-4 leptons ○ & MET ○

mUED: Production & Decay



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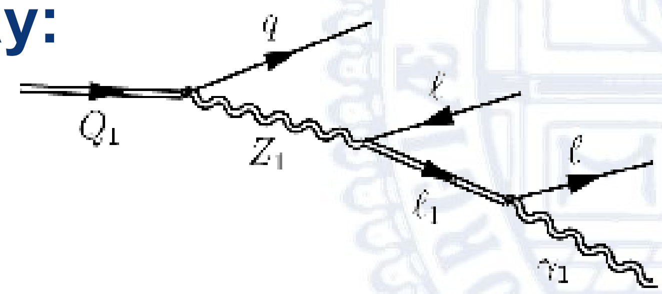
Decay:



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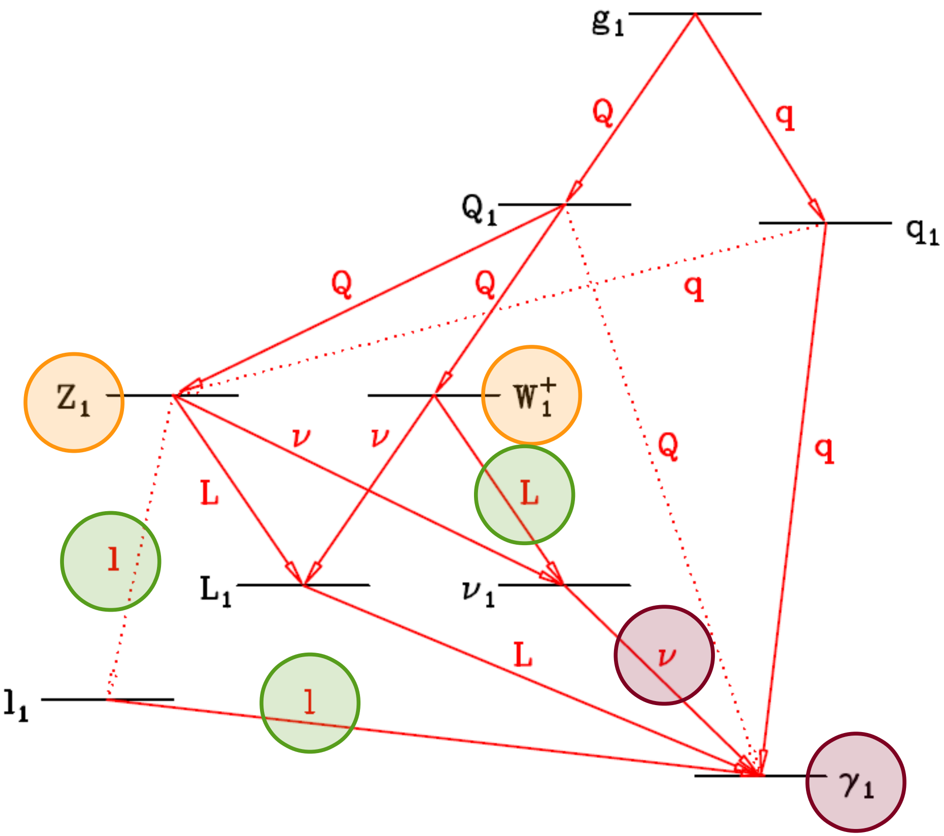

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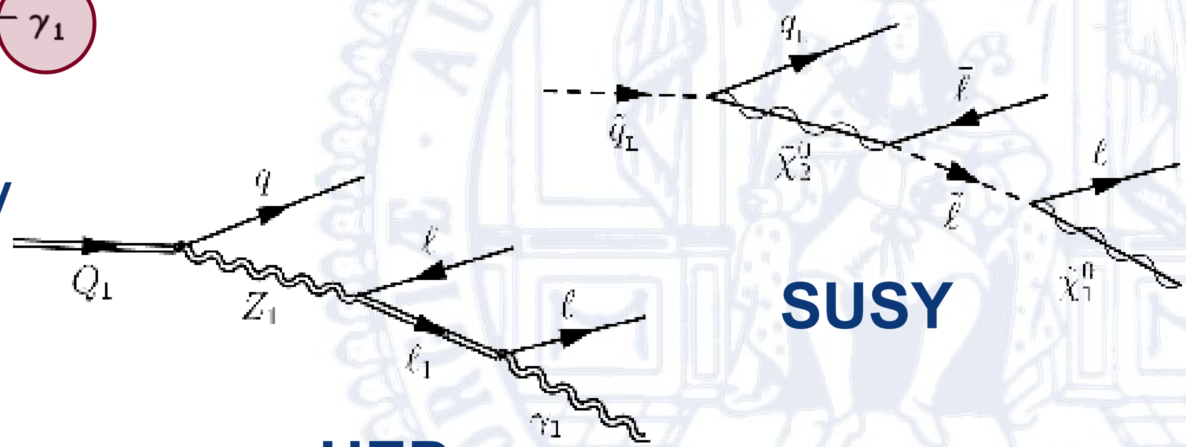
- Phenomenology: very similar to R-Parity conserving SUSY:

  Neutralinos ↔ γ_1 / Z_1

  Sleptons ↔ KK-Leptons

  etc.

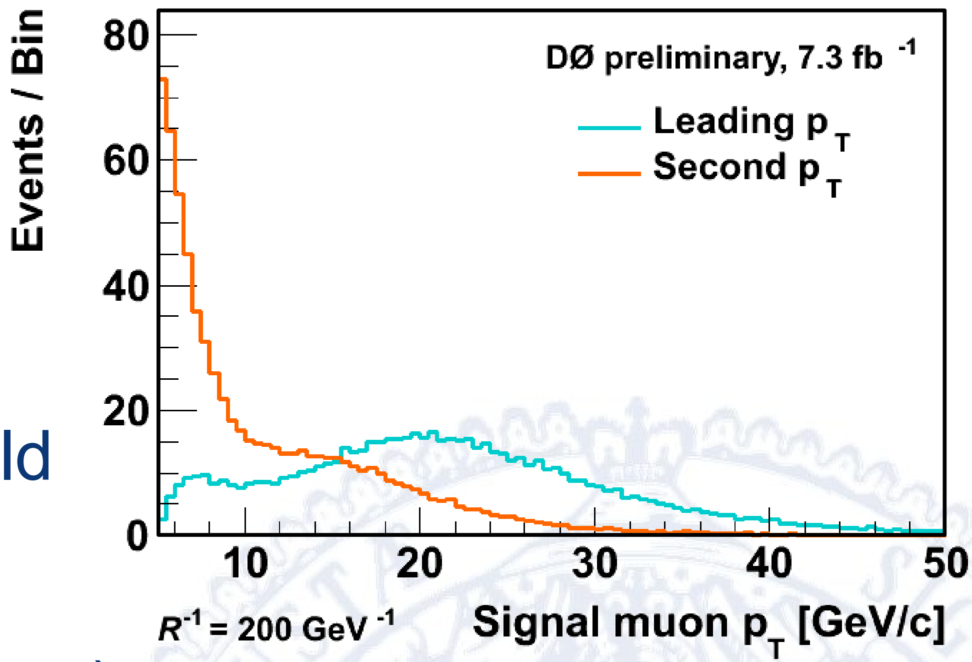


SUSY

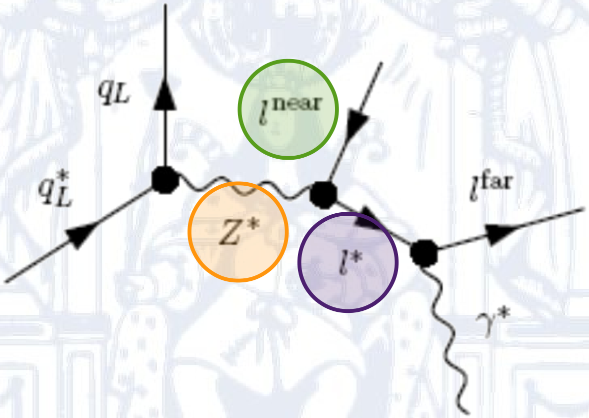
UED

Final State / Why Dimuon?

- 2-4 leptons & MET
- If masses of the KK-Bosons and KK-leptons similar
  → leptons very "soft"
  → below reconstruction threshold



- Demand two muons and MET
  → but: large backgrounds ($Z \rightarrow \mu\mu$)
- So: Two muons of same sign and MET
- Compromise between low SM-background and sensitivity for soft leptons
- Sensitive for new physics, esp. UED and SUSY



Samples used

Data:

- Using 7.3 fb^{-1} of Run II data
- Single muon triggers

Background Monte Carlo:

- ALPGEN+PYTHIA for Z+Jets, W+Jets, ttbar
- PYTHIA for Diboson (WW, ZZ, WZ)
- Normalized to NLO (prediction by MCFM)
- Luminosity profile reweighed to data,
  Z+jets: Z Boson p_T distribution reweighed to NLO prediction.

Signal:

- Selected points covering R^{-1} = 200 - 320 GeV
- Generated with PYTHIA 6.421, using CTEQ5L PDFs

Backgrounds

- "Real" LS Dimuon
  - (e.g. Diboson, $ZZ \rightarrow 4\ell$)
- Muons from Jets
  - Z + jets $\rightarrow \mu^+\mu^- + \mu + \ldots$
  - W + jets
  - QCD multijet ($b\bar{b}$, $c\bar{c}$)
- Charge mismeasurement
  - $Z \rightarrow \mu^+\mu^- \rightsquigarrow \mu^+\mu^+$

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QCD is hard:

- Perturbation theory breaks down at low energies ($\alpha \approx 1$)
- Heuristic models exist, but don't agree very well with data:
  - angular distributions ($\Delta\varphi$),
  - $b\bar{b}$ cross section, ...
- Small BR to likesign => would have to generate lots of MC

=> Model multijet from data!

QCD background

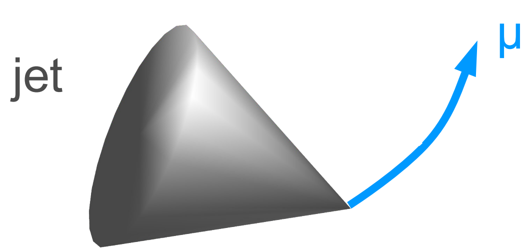
What distinguishes signal from QCD?

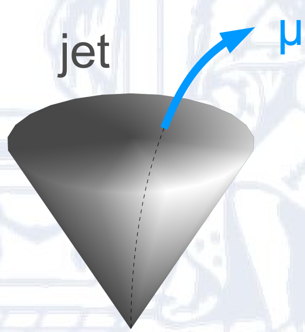
Signal:

- 2 LS muons + MET
- Jets due to ISR, underlying event. Prompt muons.
- Muon angles uncorrelated
- Direction of jets uncorrelated to muons

QCD background:

- Jets + muons due to b/c decay
- Muons coming from jets. Non-prompt muons.
- Muons tend to be back to back
- Directions of muons and jets correlated

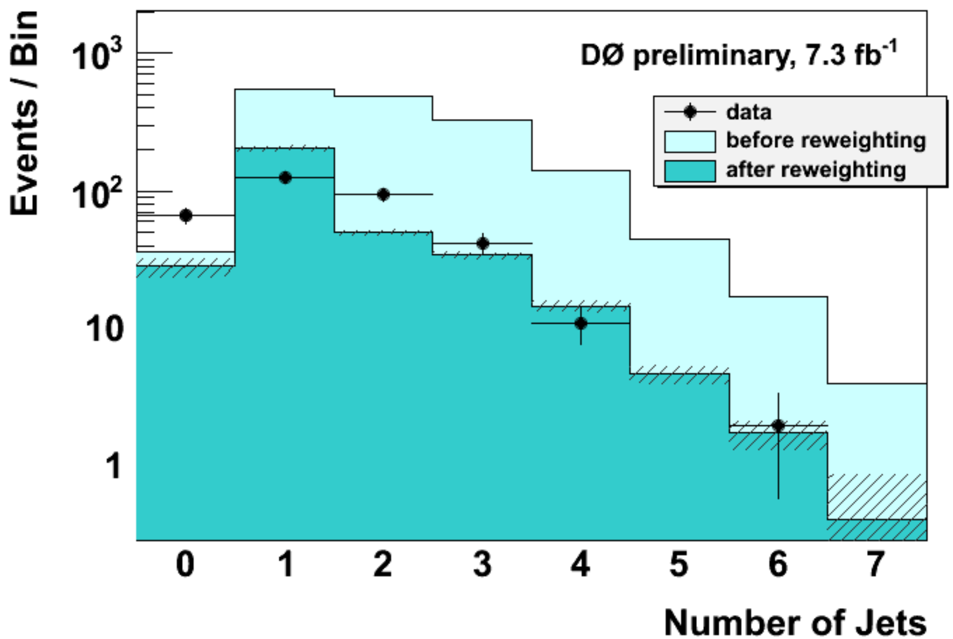




=> use muon *isolation* to separate signal from QCD

QCD estimation

- Signal sample with isolated muons, QCD enriched sample with one non-isolated muon.
- Reweight QCD sample to be an estimation of QCD BG in signal sample
  - Determine reweightings in QCD dominant region (isolated muon pt < 10 GeV)



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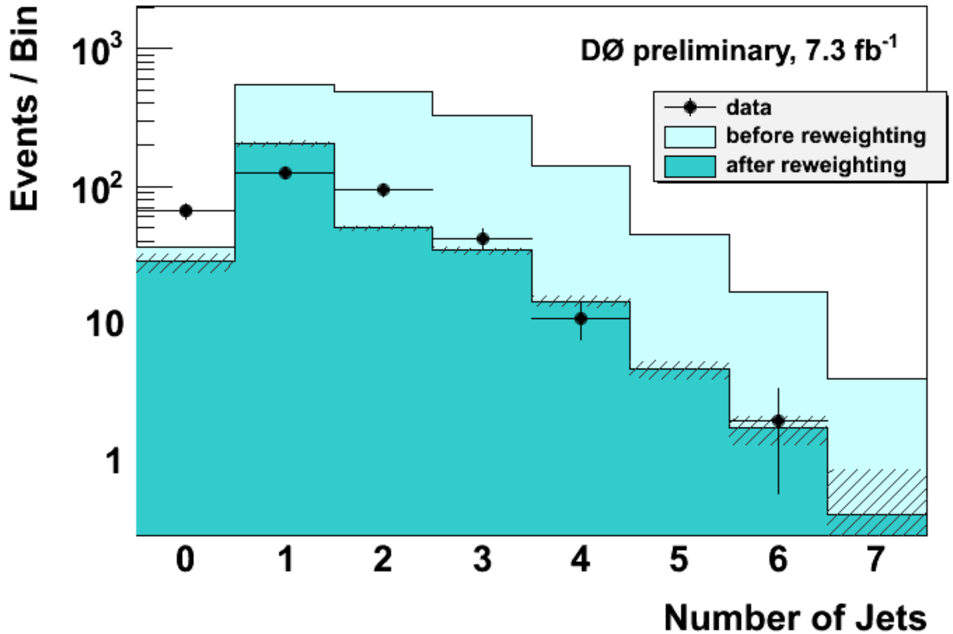
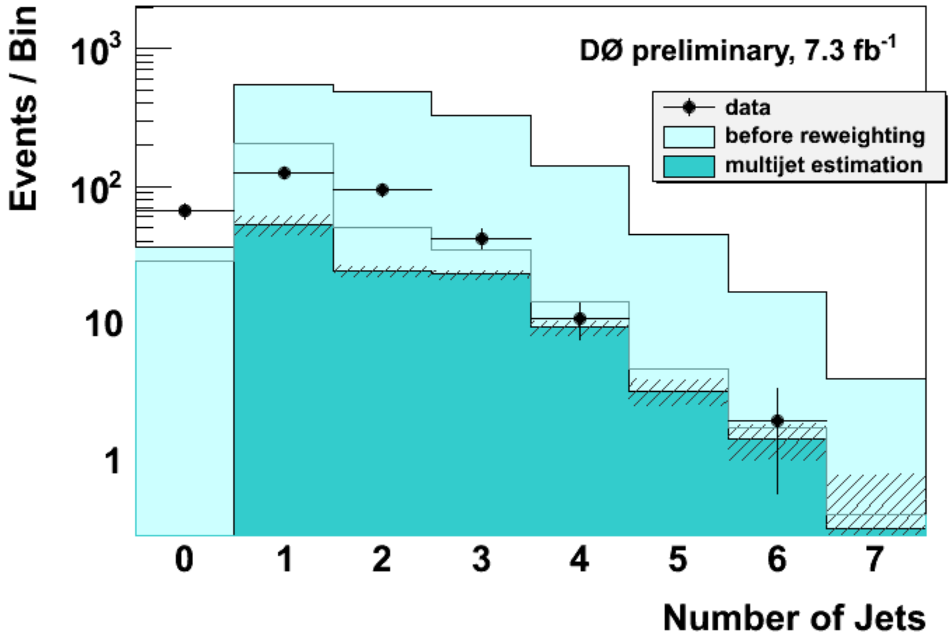
- "Contamination" in QCD enriched sample from electroweak processes (W/Z+jets)
- Estimate this from MC, and subtract

→ Final QCD estimation:





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  - (e.g. Diboson, $ZZ \to 4\ell$) ✓
- Muons from Jets
  - Z + jets $\to \mu^+\mu^- + \mu + \ldots$ ✓
  - W + jets ✓
  - QCD multijet ($b\bar{b}$, $c\bar{c}$) ✓
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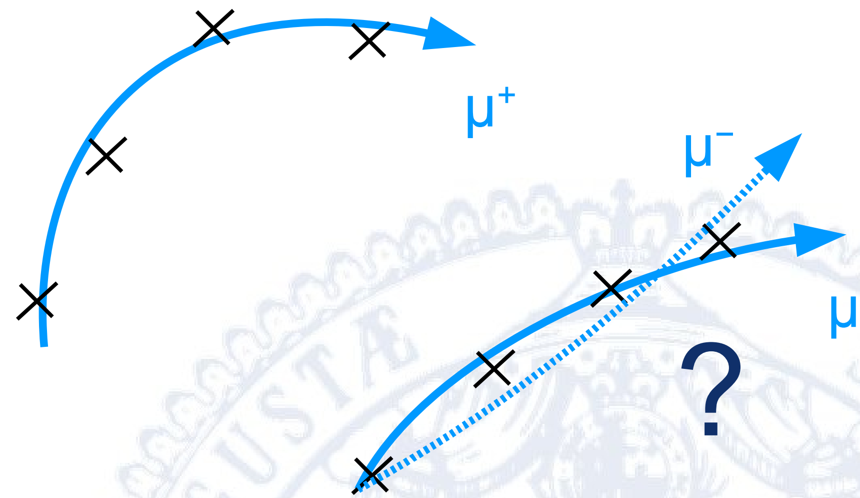
- Charge flip (CF): Event with μ+μ- gets mismeasured as likesign

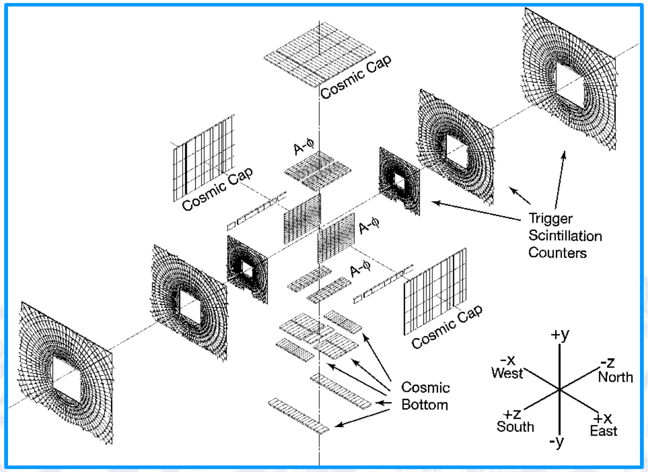


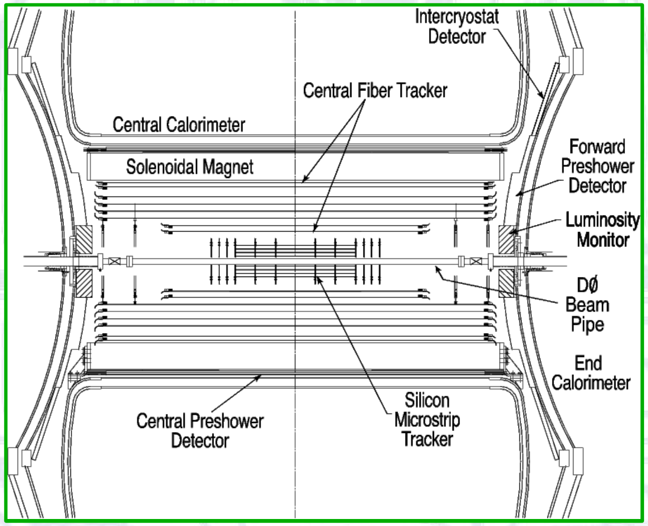
- Occurs more often at high pt, as muon track straightens
- Tiny fraction can lead to big contamination, due to Z peak
- Included in detector simulation, but is that good enough?

Charge flip estimation

Estimate charge flip content in our selection:

- Idea: Two independent charge measurements: Muon system (Q_{muon}) and matched central track (Q_{trk}, default)
  - Tracker measurement is much more accurate. (Charge measurement efficiency $\varepsilon_{trk} >> \varepsilon_{muon}$)
- Number of (dis-)agreements between Q_{muon} and Q_{trk} is related to the probability of charge mis-measurement

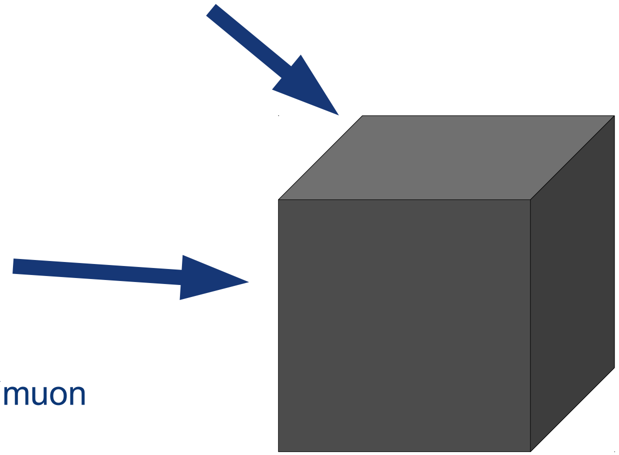




Charge flip estimation II

Number of disagreements btw. Q_{muon} and Q_{trk}

Efficiency of secondary measurement ε_{muon}



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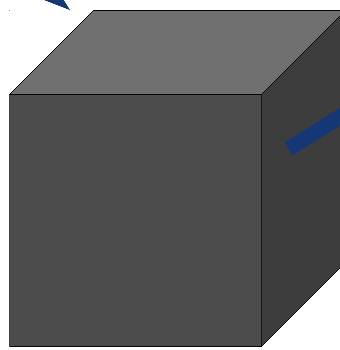
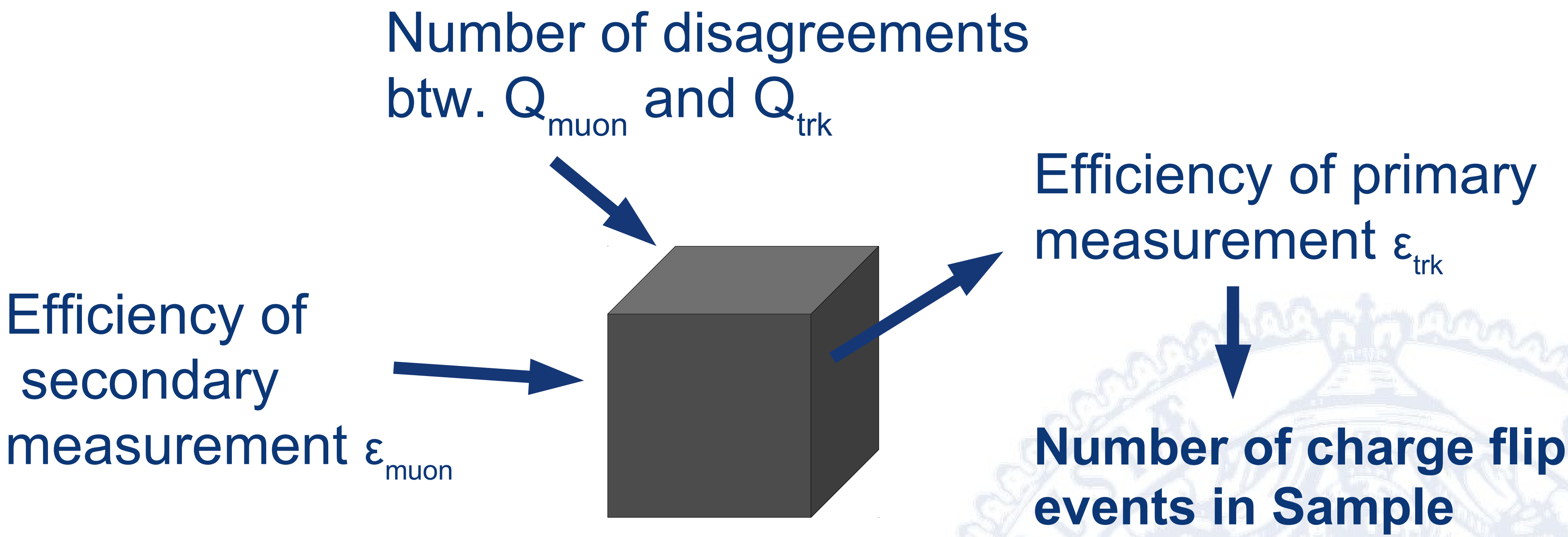


Efficiency of primary measurement ε_{trk}

Number of charge flip events in Sample

Charge flip estimation II

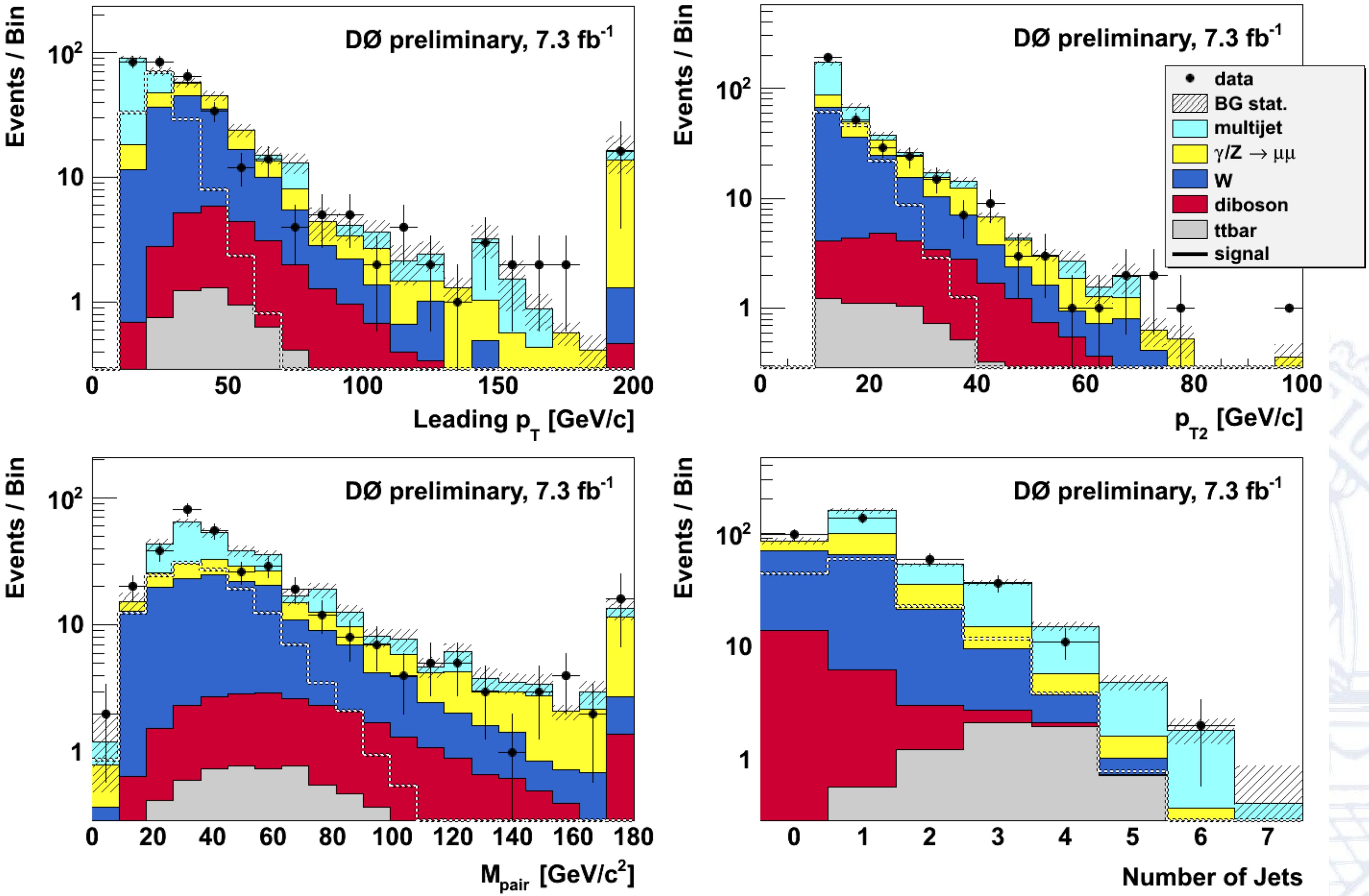


	CF Estimation	$Z \rightarrow \mu^{+}\mu^{-}$ MC
Events	161.7 ± 32.4	170.6

DØ Preliminary 7 fb^{-1}

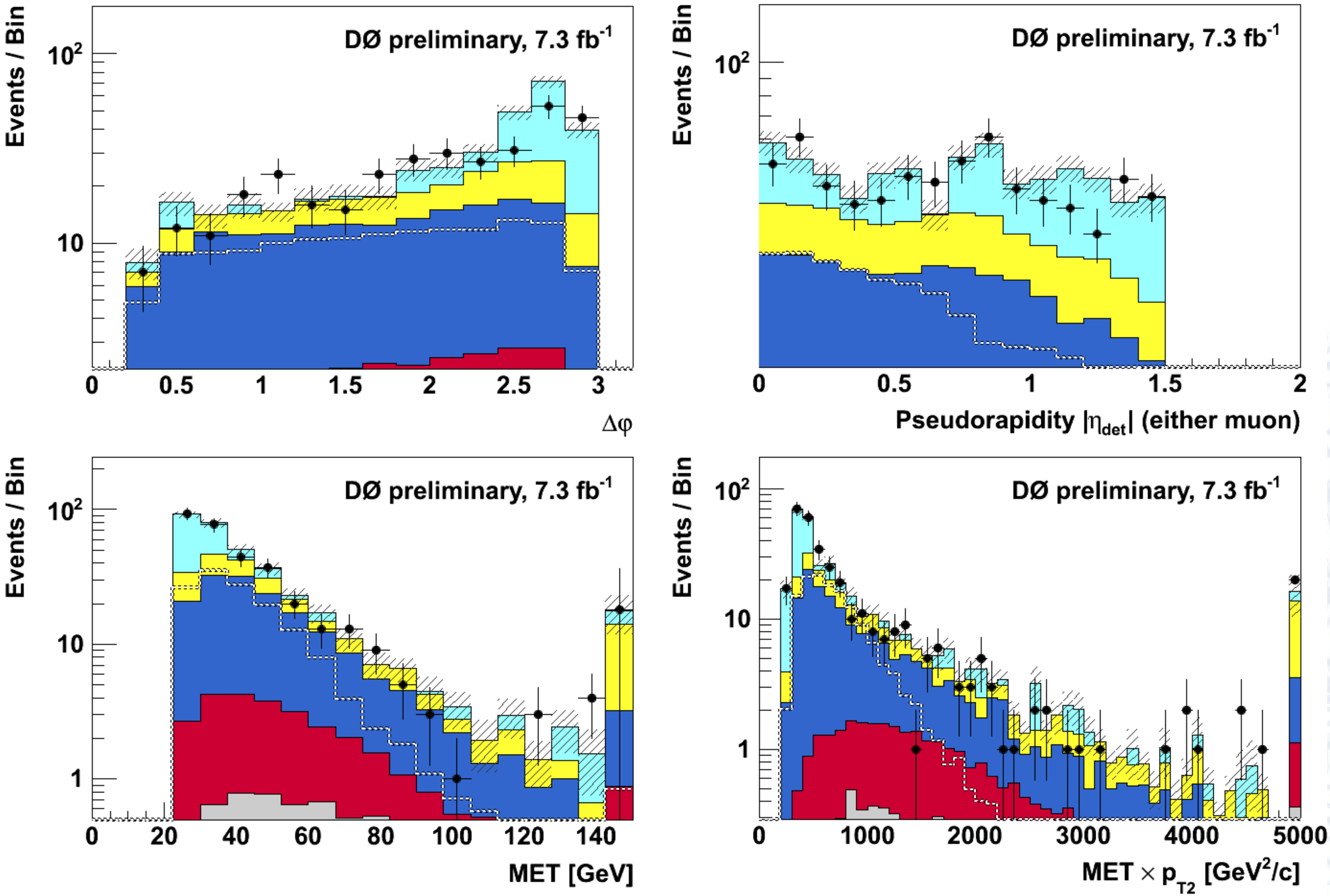
=> Estimation from MC consistent with data

Data vs. BG



DØ preliminary, 7.3 fb-1
Events / Bin
Leading pT [GeV/c]
pT2 [GeV/c]
Mpair [GeV/c2]
Number of Jets
data
BG stat.
multijet
γ/Z → μμ
W
diboson
ttbar
signal

Data vs. BG II



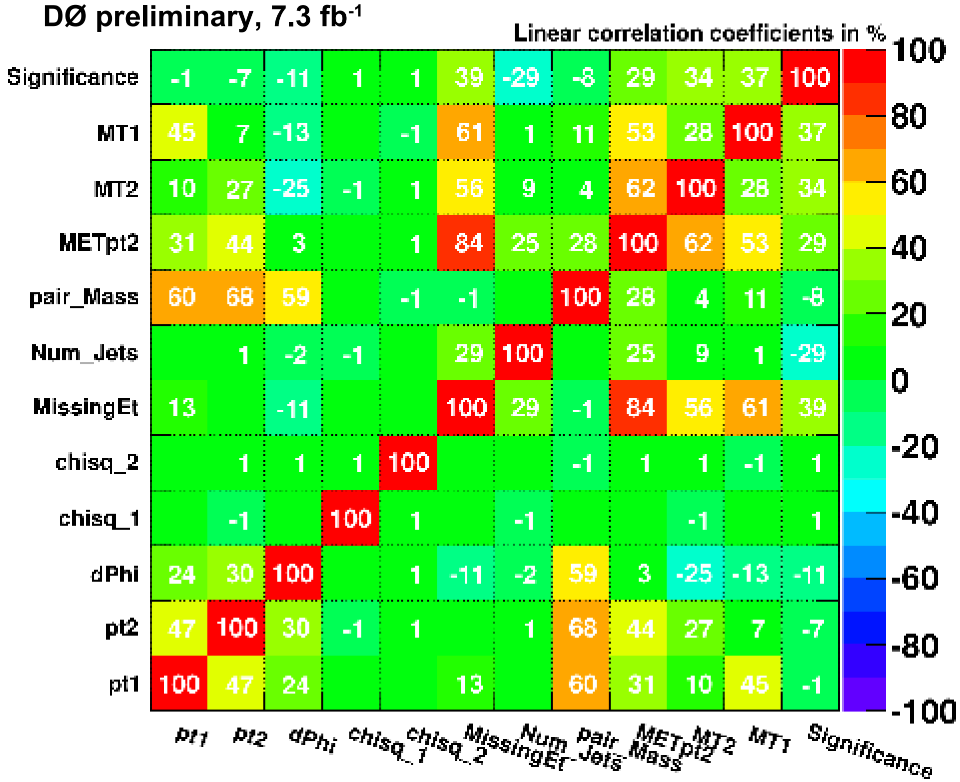
DØ preliminary, 7.3 fb-1
Events / Bin
10^2
10
0
0.5
1
1.5
2
2.5
3
Δφ
DØ preliminary, 7.3 fb-1
Events / Bin
10^2
0
0.5
1
1.5
2
Pseudorapidity |η_det| (either muon)
DØ preliminary, 7.3 fb-1
Events / Bin
10^2
10
1
0
20
40
60
80
100
120
140
MET [GeV]
DØ preliminary, 7.3 fb-1
Events / Bin
10^2
10
1
0
1000
2000
3000
4000
5000
MET × p_T2 [GeV^2/c]

Comparison of variables

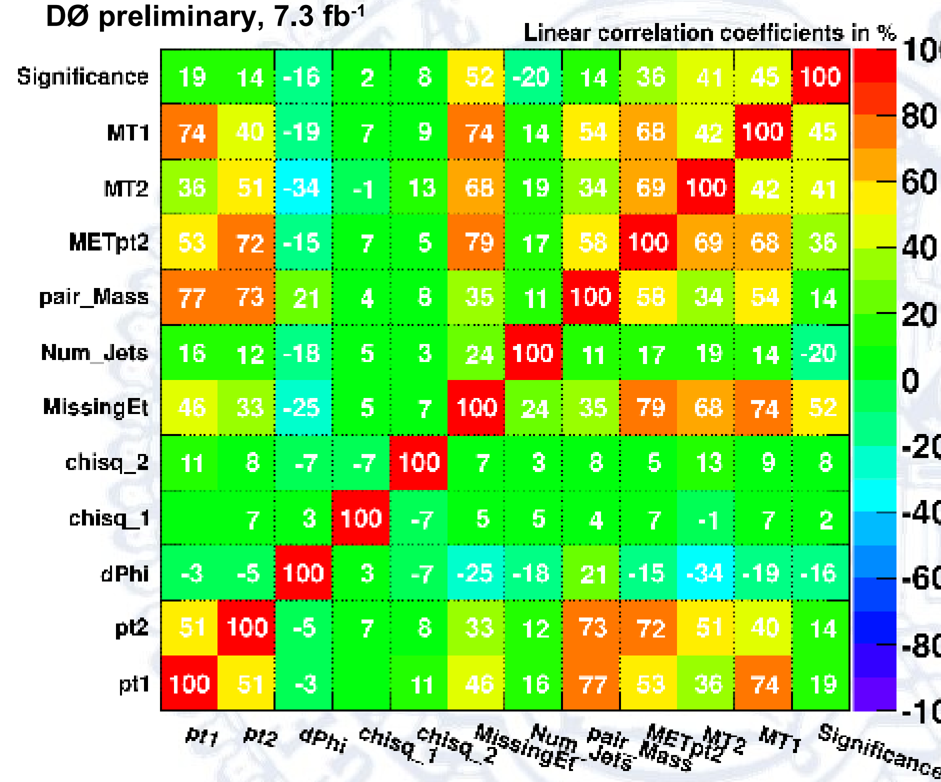
- Most important variables: Δφ(μ,μ), leading pT, MT2
- Njets has lower impact in MVA
- Different correlations in BG/Signal

Rank	Variable	Importance
1	dPhi	0,138
2	pt1	0,127
3	MT2	0,122
4	chisq_2	0,105
5	chisq_1	0,073
6	pt2	0,064
7	pair_Mass	0,048
8	Num_Jets	0,018

Correlation Matrix (signal)

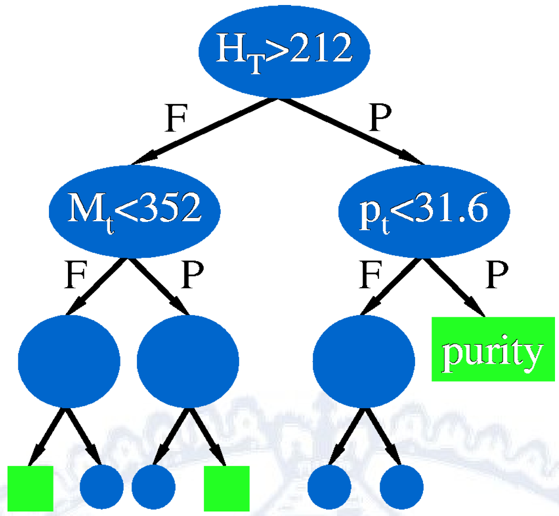


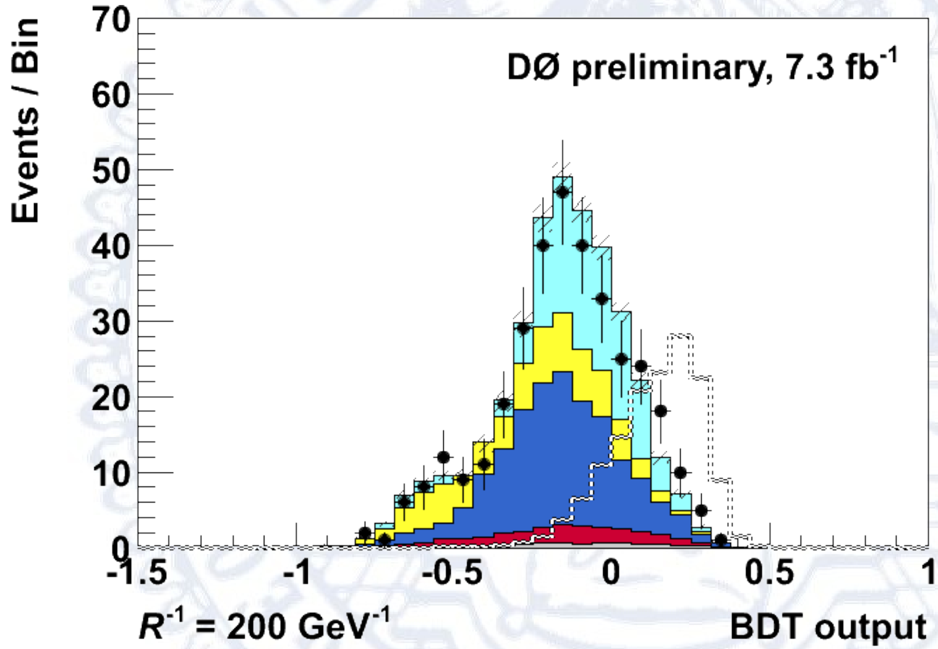
Correlation Matrix (background)



BDT Training + Output

- Multivariate analysis: Take correlations between variables into account
- Using boosted decision tree (BDT)
- Classification
  from −1: maximally BG-like
  to +1: maximally signal-like
- One tree trained for each signal point





Systematics

Source	Rel. uncert.
Luminosity	6.1 %
PDF	2.0 %
JES	1.0 %
QCD	35.0 %
W xsec	8.5 %
Z xsec	3.5 %
Diboson xsec	7.0 %
Ttbar xsec	14.8 %

- Note: ttbar background small → mostly irrelevant
- Largest contributions: Luminosity + QCD
- Now put everything together...

Conclusions

- Performed search for UED in 7.3 fb^{-1} of DØ data
- Simple model of QCD background, working well
- Charge mismeasurement BG well understood

Conclusions:

- No excess over background found
  → Proceed to set limits
- Analysis is in review, expecting PRL shortly

The End

Thank you.