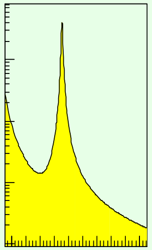

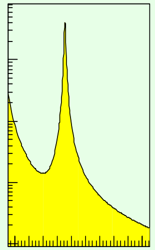

Event 4

High P_T Muons: Experiences in the New CMSSW

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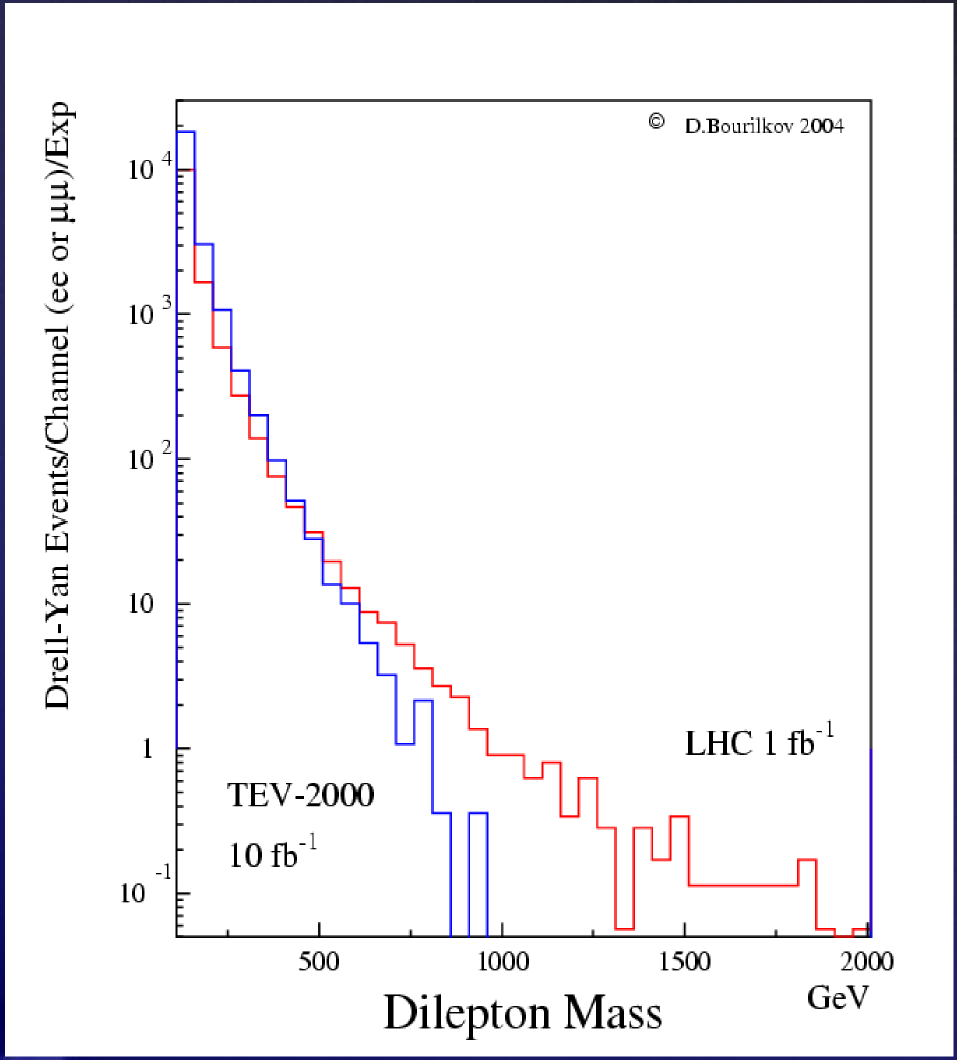
University of Florida

2nd Southeastern CMS Physics Workshop,

February 7, 2007, Miami, Florida

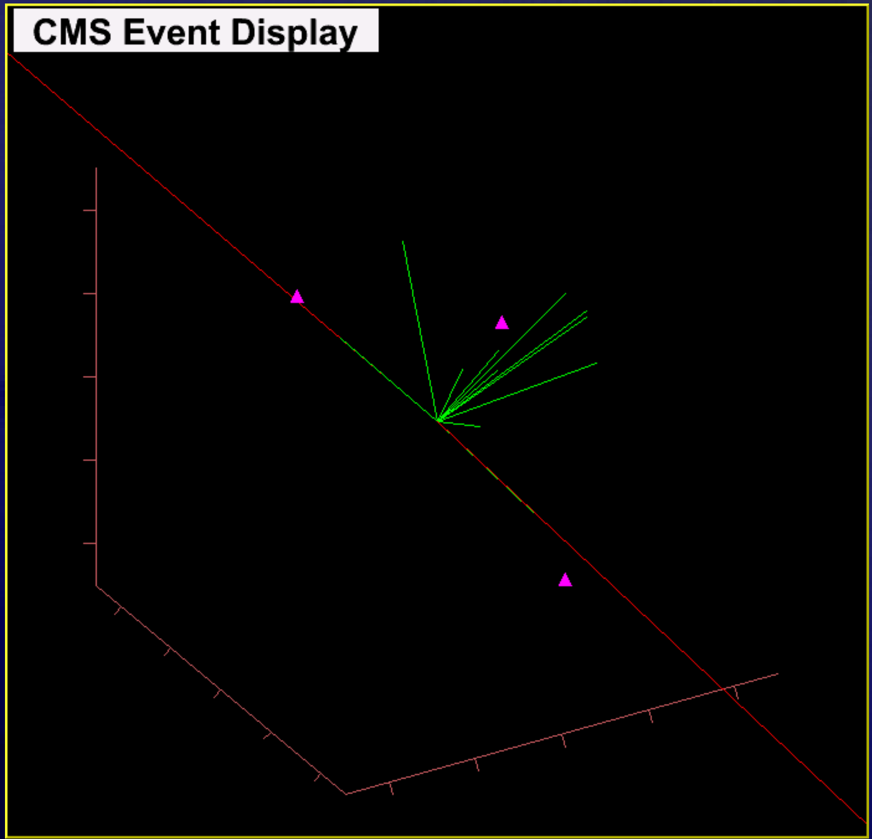
Introduction

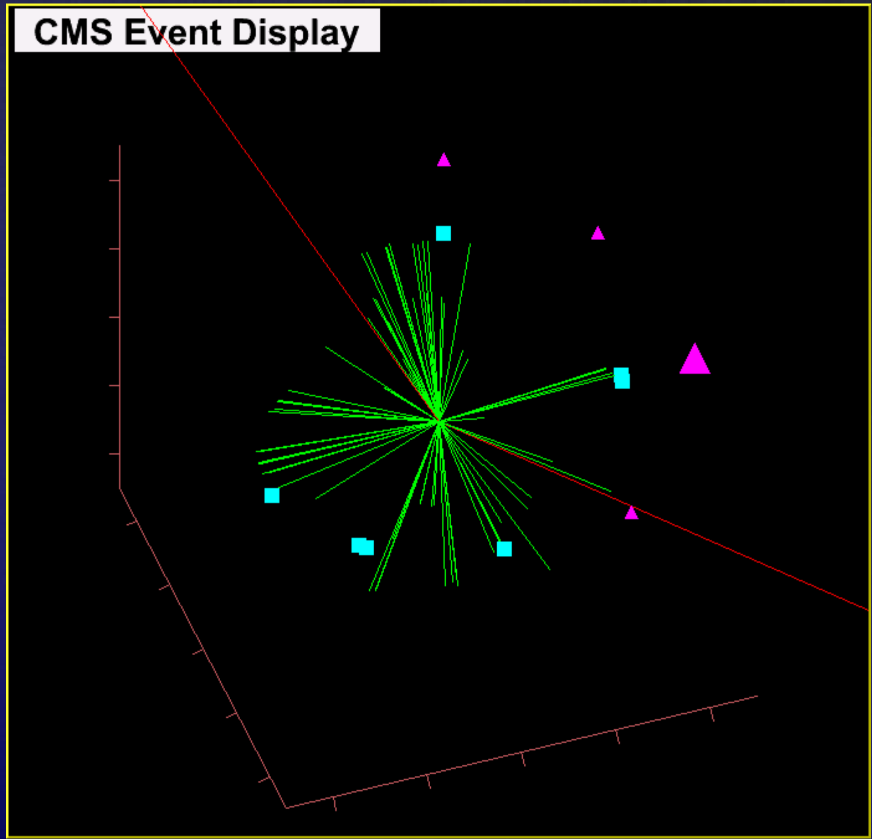
- LHC is a Dilepton Factory
- The Drell-Yan process produces clean final states
- Test Standard Model to highest momentum transfers
- Background for many new physics scenarios: compositeness, Z', extra dimensions …



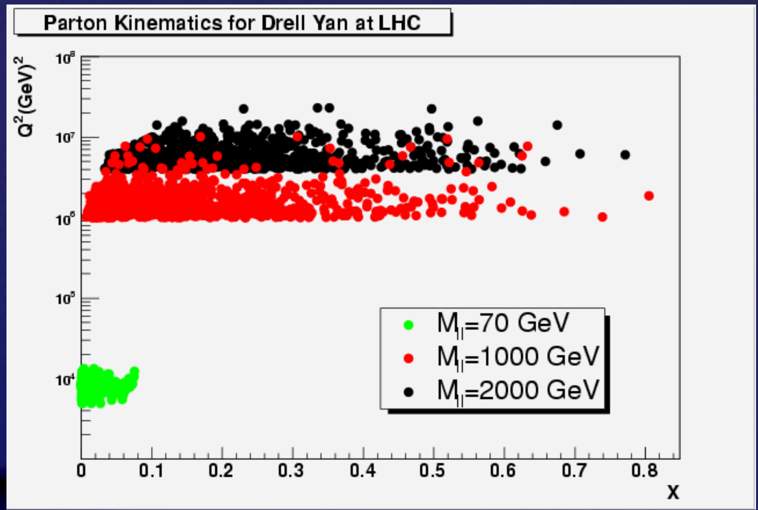
DY Event Displays

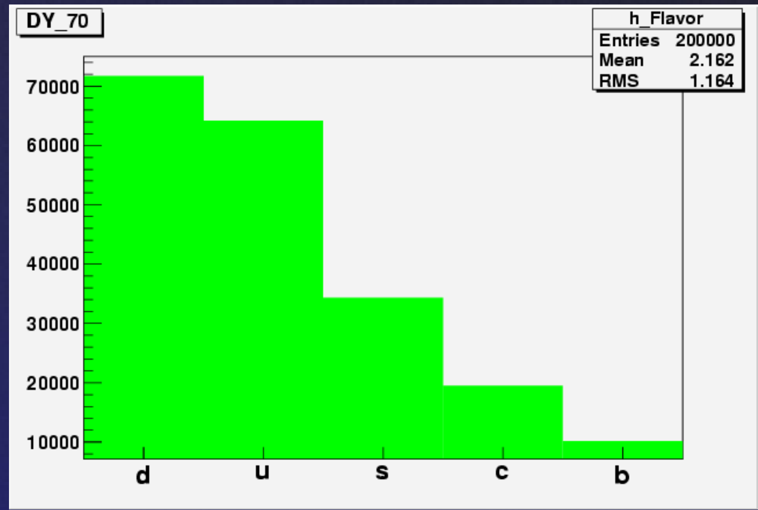
Dimuon events are clean … **most of the time**

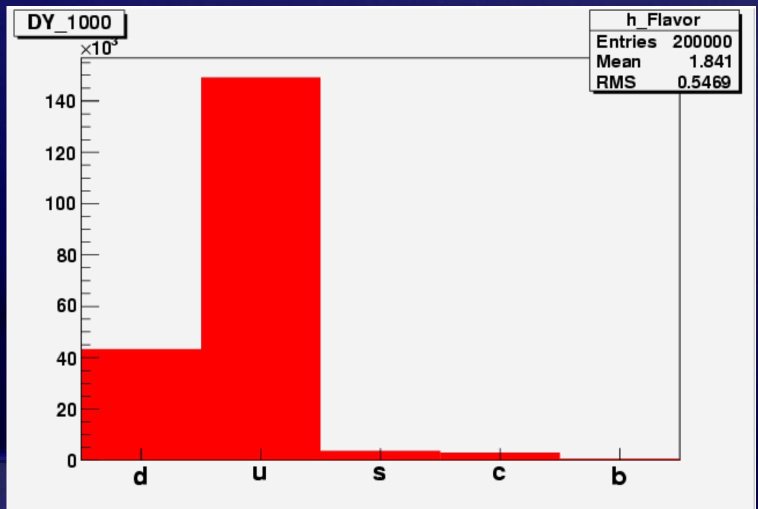


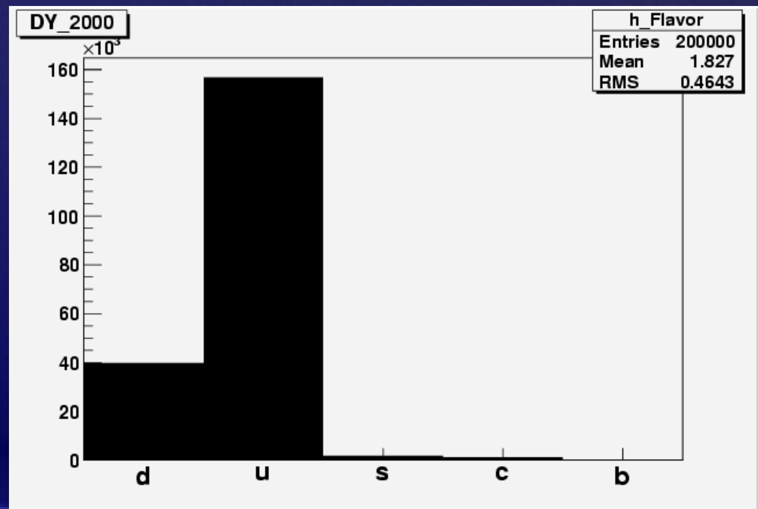


Drell-Yan Parton Kinematics & Flavor Composition

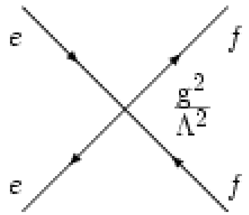








Contact Interactions



$$\frac{d\sigma}{d\Omega} = SM(s,t) + \varepsilon \cdot C_{Int}(s,t) + \varepsilon^2 \cdot C_{NewPh}(s,t)$$

general framework for new interactions:

- scale $\Lambda >> \sqrt{s}$ (virtual effects) or resonances if $\Lambda \approx \sqrt{s}$
- coupling g (convention $g^2 = 4\pi$)
- we constrain g / Λ
- operators with canonical dimension N > 4 $\Rightarrow$ terms ~ $1 / \Lambda^{N-4}$

Model	LL	RR	LR	RL	VV	AA	V0	A0
	Non-parity conserving				Parity conserving			
η_{LL}	±1	0	0	0	±1	±1	±1	0
η_{RR}	0	±1	0	0	±1	±1	±1	0
η_{LR}	0	0	±1	0	±1	∓1	0	±1
η_{RL}	0	0	0	±1	±1	∓1	0	±1

Muon Pairs: Signal OR Background

- **Active high-mass dimuon group** (B.Cousins; Dubna, NWU, UCLA, UF, Warsaw ...; focusing on Z' and full analysis; many things in common with SM group or non-resonant searches)
- **Test Standard Model at highest momentum transfers** (crosscheck with results from the SM group – DY signal)
- **Rich search field for new physics** (SUSY/BSM group – DY background or amplitudes to interfere with)
- **Experimentally we measure the cross section and the forward-backward asymmetry**

Cross Section Measurement

On the theory side:

- To control the DY signal / background we need QCD at N(N)LO; generate with PYTHIA … and apply K functions (depend on mass etc)
- PDF and uncertainties
- EW radiative corrections
- TEV4LHC workshop: no generator today able to do decently both QCD and EW (put pressure on phenomenologists)

On the experimental side: what can be determined from data itself and what has to come from Monte Carlo?

- Absolute / relative normalization (luminosity / data etc)
- Acceptance
- Efficiency
- Resolution
- Backgrounds: mainly Drell-Yan $\tau^+\tau^-$; other: WW, WZ, ZZ, Zγ, cc, bb, tt, fakes, cosmics … well under control

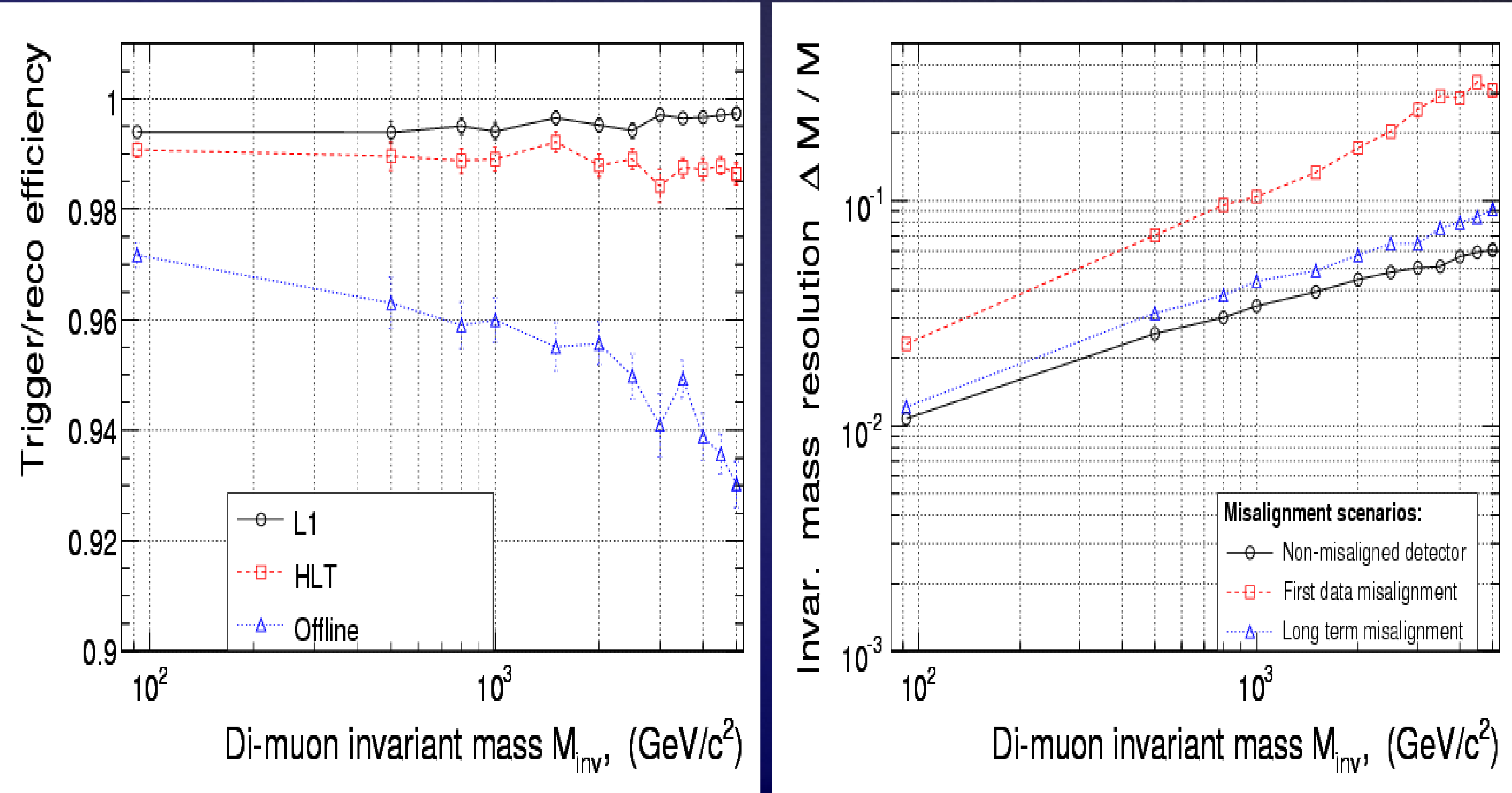
Backgrounds – under control

Sources of background to Drell-Yan $\mu^+\mu^-$:

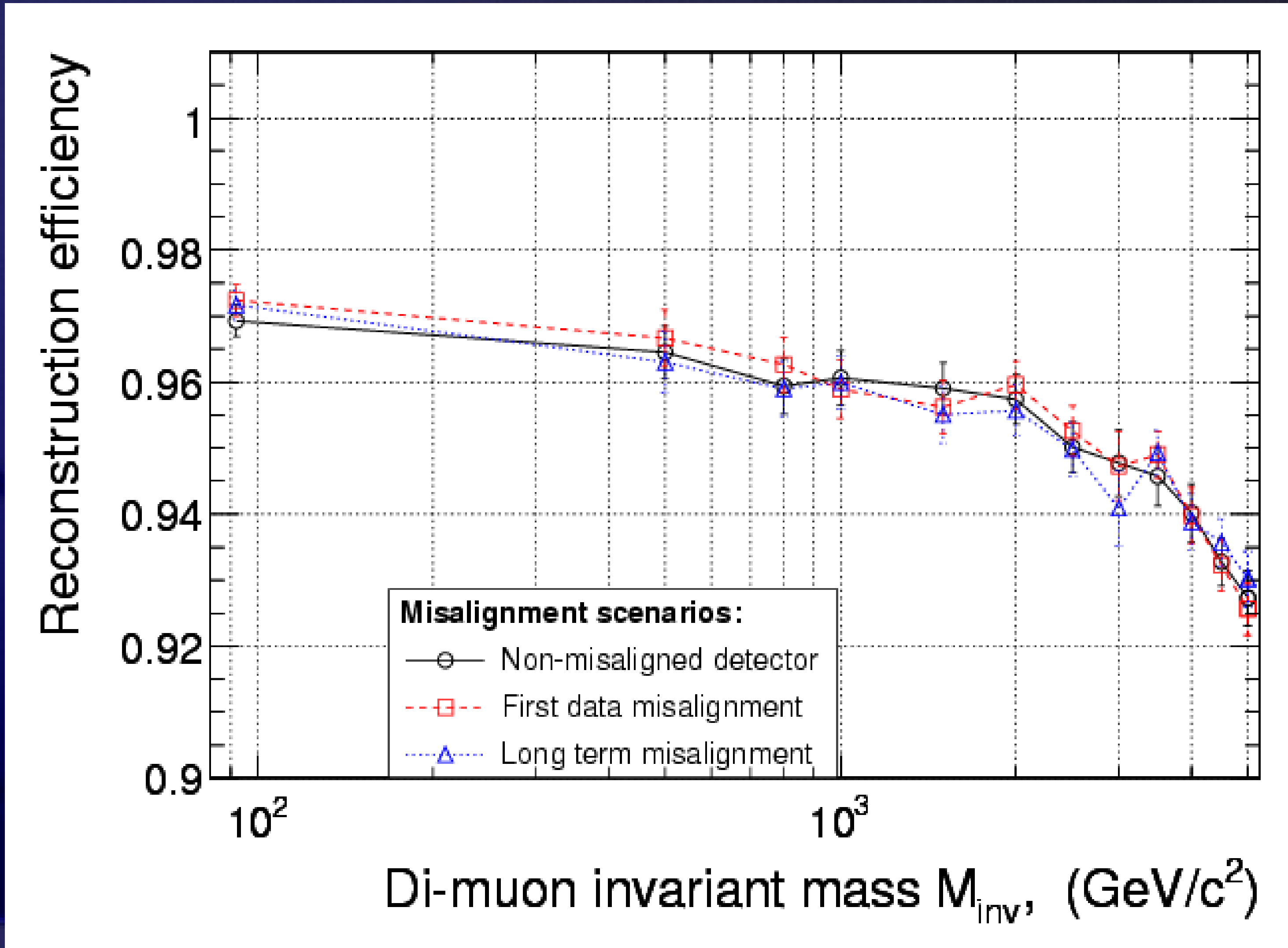
- **Drell-Yan $\tau^+\tau^-$:**
  - 0.8 % for 70-120 GeV
  - 0.7 % for > 1000 GeV
- **Drell-Yan qq (mostly b/c):**
  - 0.3 % (no isol) for 70-120 GeV
  - < 0.1 % for > 1000 GeV
- **tt: negligible for > 1000 GeV**

$M_{\mu^+\mu^-}$ [TeV]	1.0	1.5	2.0	2.5	3.0	4.0
Drell-Yan [fb]	6.61	1.04	$2.39 \cdot 10^{-1}$	$6.53 \cdot 10^{-2}$	$1.97 \cdot 10^{-2}$	$2.09 \cdot 10^{-3}$
Pre-selected Drell-Yan [fb]	5.77	$9.53 \cdot 10^{-1}$	$2.24 \cdot 10^{-1}$	$6.14 \cdot 10^{-2}$	$1.87 \cdot 10^{-2}$	$2.00 \cdot 10^{-3}$
Di-bosons [fb]	$2.59 \cdot 10^{-4}$	$1.51 \cdot 10^{-4}$	$5.6 \cdot 10^{-5}$	$2.26 \cdot 10^{-5}$	$9.06 \cdot 10^{-6}$	$1.66 \cdot 10^{-6}$
$t\bar{t}$ [fb]	$2.88 \cdot 10^{-4}$	$2.58 \cdot 10^{-4}$	$1.55 \cdot 10^{-4}$	$7.02 \cdot 10^{-5}$	$2.93 \cdot 10^{-5}$	$3.65 \cdot 10^{-6}$

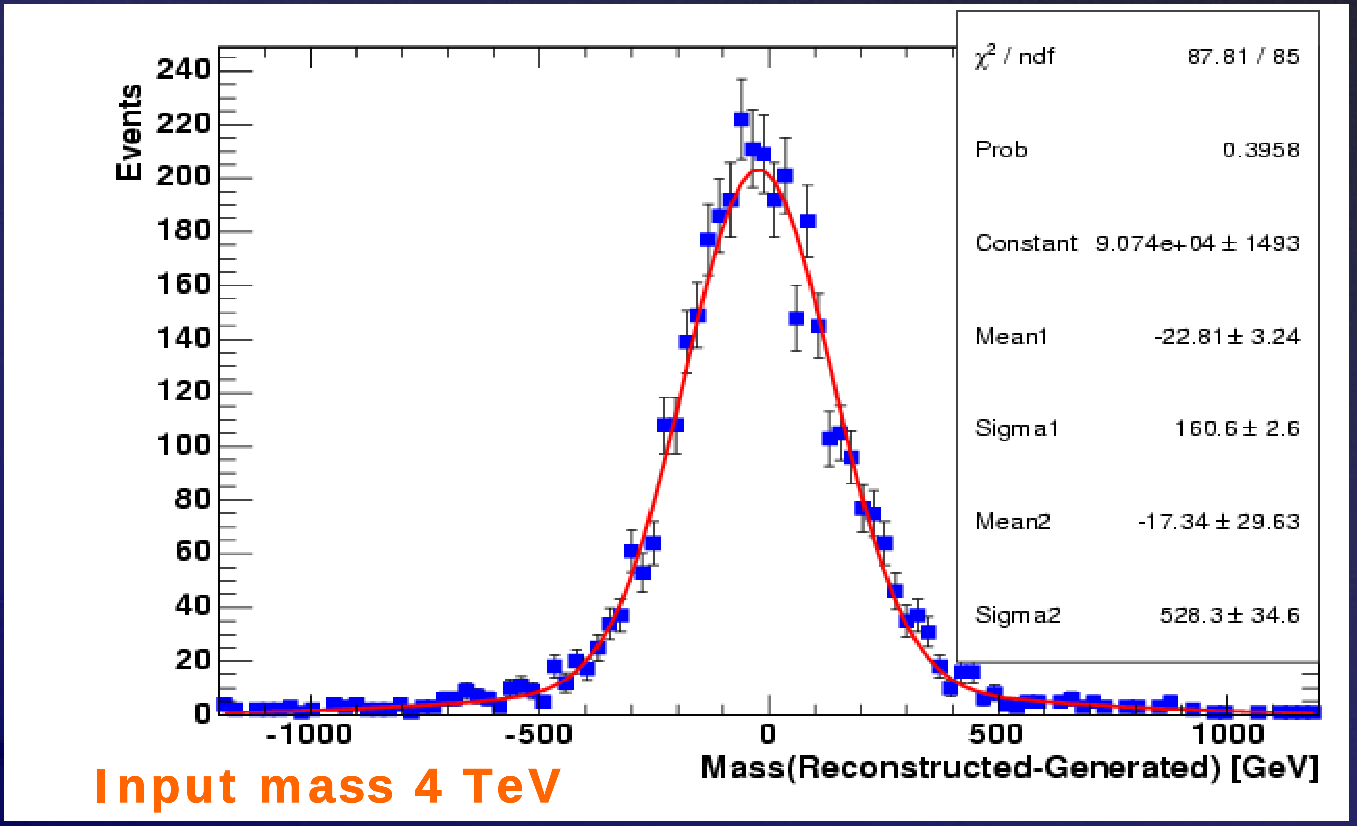
Di-muon Efficiency/Resolution PTDR



Efficiency and Misalignment PTDR



Mass Resolution PTDR



- **First approach – just use RMS**
- **Actually we observe long tails**

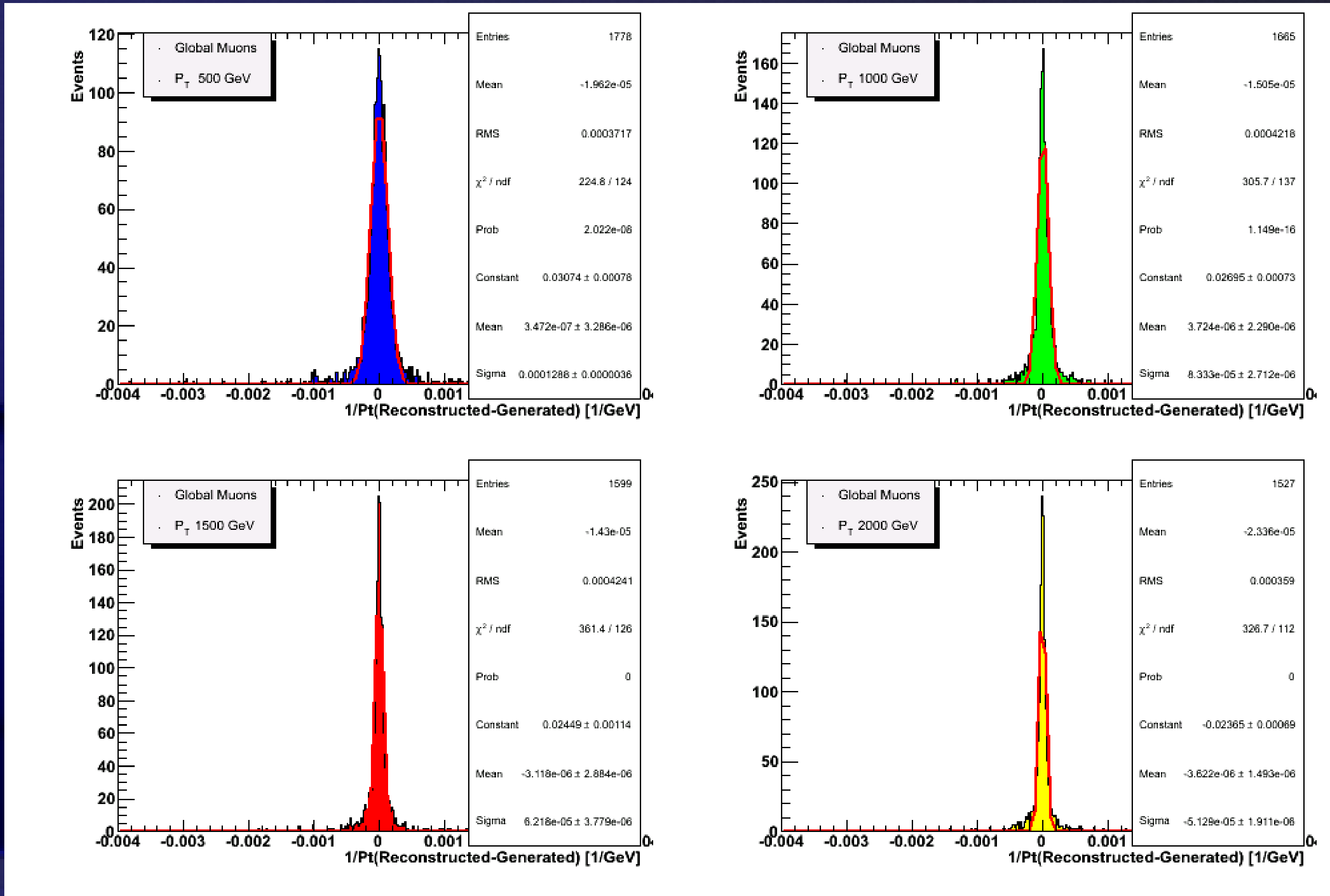
Alternatively we fit with 2 Gaussians

The second Gaussian contributes ~ 14 % and has ~ 3.3 bigger σ - quite stable with mass

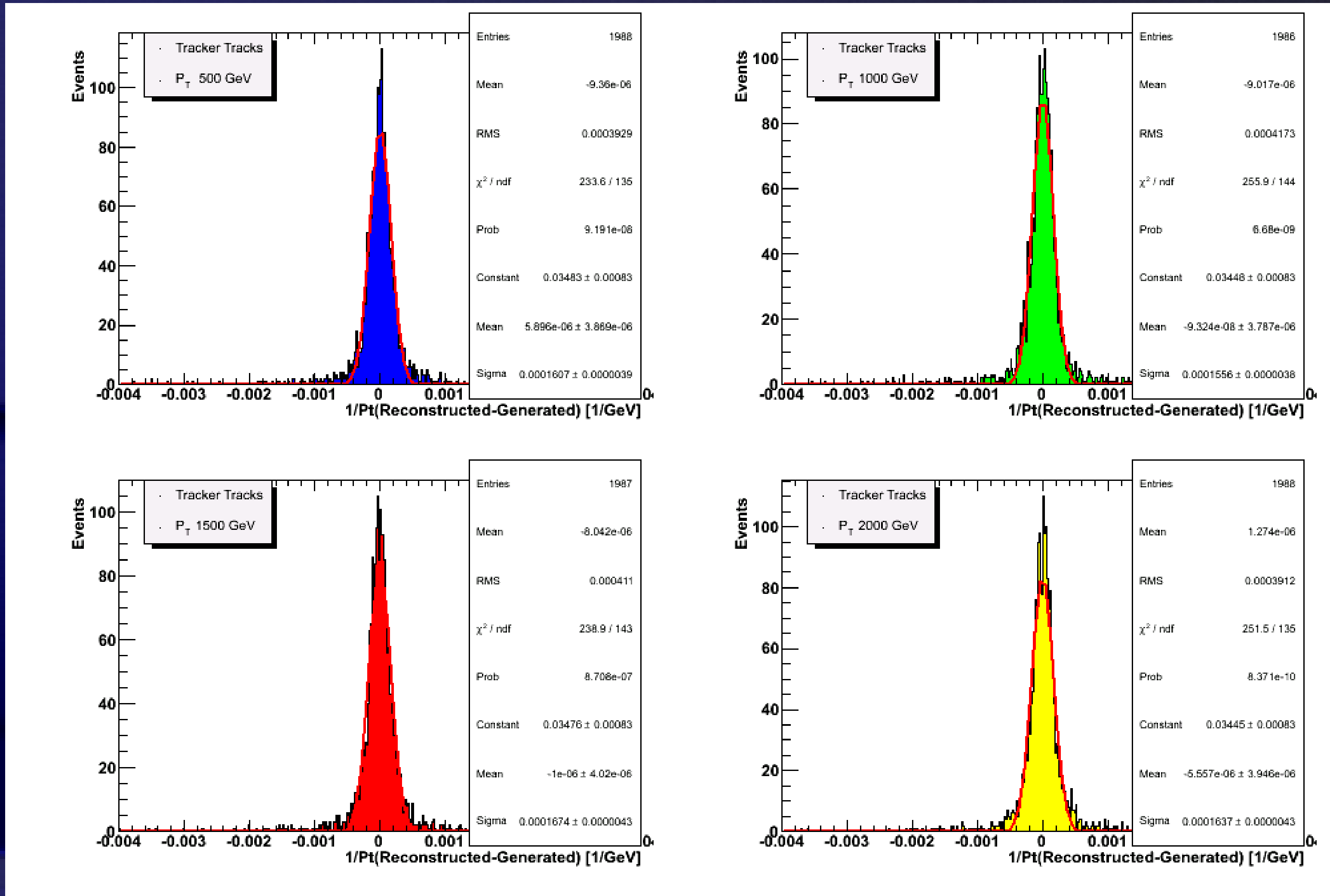
Event Simulation & Reconstruction

- All samples with CMSSW_1_0_6
- High P_T di-muons (4 samples with fixed P_T 500, 1000, 1500, 2000 GeV, 1000 events each)
- Z': 8 samples of 10000 events each generated with invariant mass around 0.2, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0 TeV
- Both muons in $|\eta| < 2.4$ and with $P_T > 7$ GeV
- Acceptance, efficiency, resolution

High P_T Di-muons: Global Muon P_T Resolution



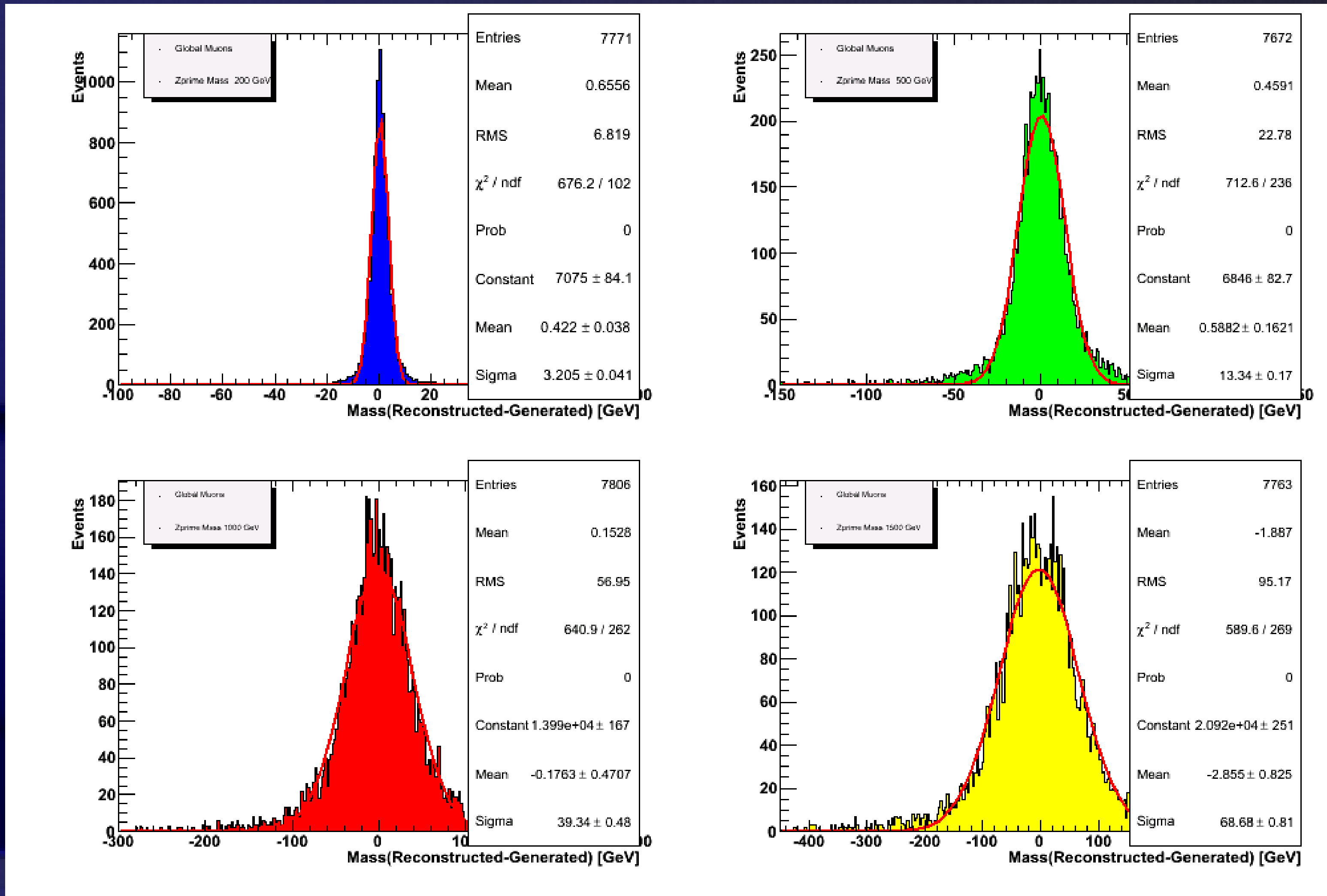
High P_T Di-muons: Tracker P_T Resolution



High P_T Di-muons (1000 events each)

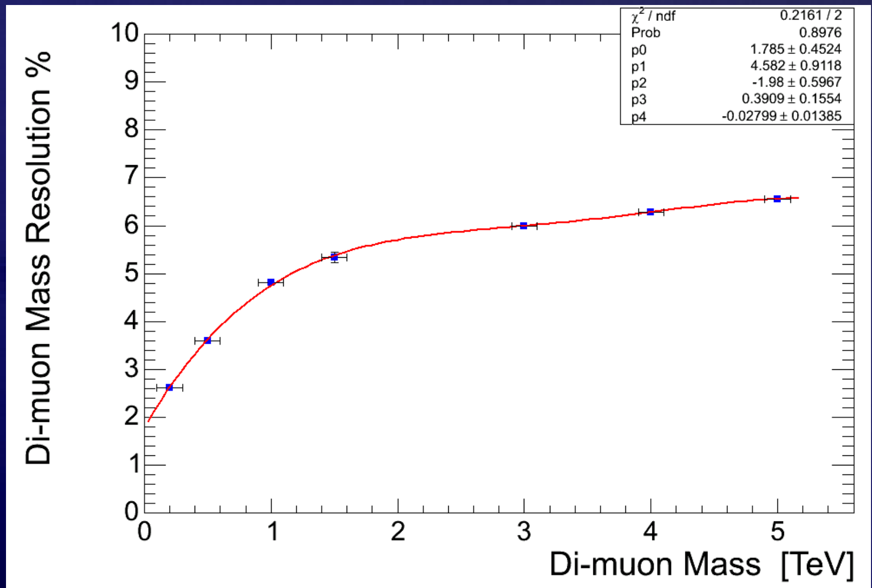
P_T [TeV]	Track ε [%]	$\sigma(P_T)/P_T$ RMS	Fit 1 Gauss	GlMu ε [%]	$\sigma(P_T)/P_T$ RMS	Fit 1 Gauss
0.5	99.4	0.00039	0.00016	88.9	0.00037	0.00013
1.0	99.3	0.00042	0.00016	83.2	0.00042	0.00008
1.5	99.4	0.00041	0.00017	80.0	0.00042	0.00006
2.0	99.4	0.00039	0.00016	76.4	0.00036	0.00005

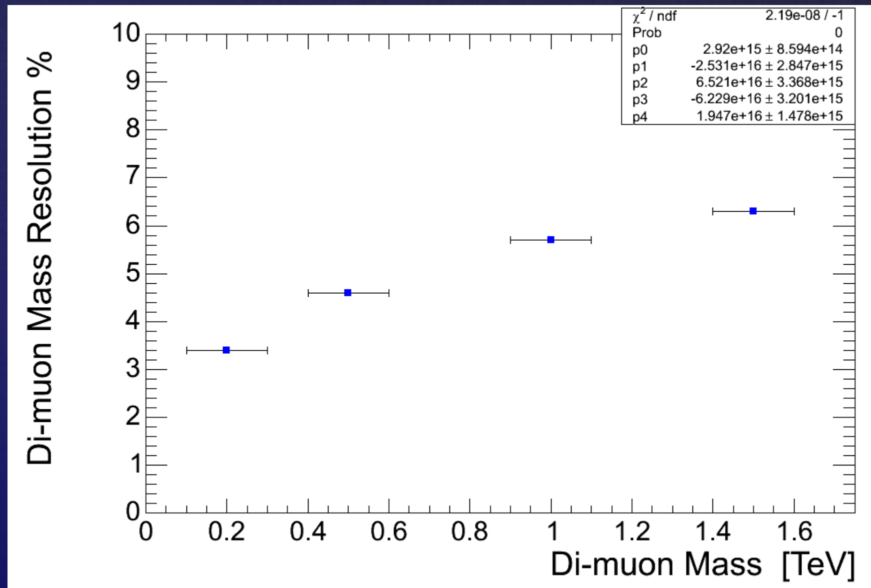
Z': Mass Resolution



Z': Mass Resolution PTDR - CMSSW

Resolution slightly worse in CMSSW





CMSSW: Event Generation with PYTHIA

```
# read PTDR ntuples

source = H2RootNtplSource
{
      untracked vstring fileNames =
   {"file:/state/partition1/dimitri/zprime5000mumu.root"}
# untracked int32 maxEvents = 10
   untracked int32 maxEvents = -1
}

# OR generate them yourself!

include "IOMC/GeneratorInterface/data/ZpeakDiMu.cfi"
Replace PythiaSource.maxEvents = 500
```

CMSSW: Event Generation with PYTHIA

```
#
#pythia generator Z(0091) -> mu+mu-
#
  source = PythiaSource
  {
    untracked int32 maxEvents = 5
    untracked int32 pythiaPylistVerbosity = 0
    untracked bool pythiaHepMCVerbosity = false

    PSet PythiaParameters =
    {

      # This is a vector of ParameterSet names to be read, in this order
      # The first two are in the include files below
      # The last one are simply my additional parameters
      vstring parameterSets =
      {
        "pythiaDefault",
        "myParameters"
      }

      # Default (mostly empty - to keep PYTHIA default) card file
      # Name of the set is "pythiaDefault"
      include "IOMC/GeneratorInterface/data/pythiaDefault.cff"

# User cards - name is "myParameters"
      vstring myParameters =
      {

        'MSEL=0          !(D=1) to select between full user control (0, then use MSUB) and some preprogrammed ...',
        'MSUB(1)    = 1          !ffbar_gam/Z0',

        'MDME(174,1)= 0        !d dbar',
        'MDME(175,1)= 0        !u ubar',
        'MDME(176,1)= 0        !s sbar',
        'MDME(177,1)= 0        !c cbar',
        'MDME(178,1)= 0        !b bar',
        'MDME(179,1)= 0        !t tbar',
        'MDME(182,1)= 0        !e e',
        'MDME(183,1)= 0        !neutrino e e',
        'MDME(184,1)= 1        ! mu mu',
        'MDME(185,1)= 0        !neutrino mu mu',
        'MDME(186,1)= 0        !tau tau',
        'MDME(187,1)= 0        !neutrino tau tau',

        'CKIN(1)   = 70.      !Mass min',
        'CKIN(2)   =120.      !Mass max',
        'CKIN(3)   =  0.      !as usual'
      }
    }
  }
```

CMSSW: Simulation with GEANT4

```
# include geant4 and Digi Zero Suppressed simulation
include "SimG4Core/Application/data/SimG4Object.cfi"
include
   "SimG4Core/Application/data/DigiWithEcalZeroSuppression.cff"
```

CMSSW: Reconstruction

```
# include "Configuration/Examples/data/RECO.cff"

# Initialize magnetic field and XML
include "MagneticField/Engine/data/volumeBasedMagneticField.cfi"
include "Geometry/CMSCommonData/data/cmsIdealGeometryXML.cfi"

#
# Local Reco
#

# defines sequence trackerlocalreco
include "Configuration/Examples/data/RecoLocalTracker.cff"

# defines sequence muonlocalreco
include "Configuration/Examples/data/RecoLocalMuon.cff"

# defines  sequence ecalLocalRecoSequence
include "RecoLocalCalo/EcalRecProducers/data/ecalLocalRecoSequence.cff"

# define sequence hcalLocalRecoSequence
include "Configuration/Examples/data/RecoLocalHcal.cff"

######
sequence localreco = { trackerlocalreco& muonlocalreco &  ecalLocalRecoSequence &
hcalLocalRecoSequence}
######

#
# Global  reco
#
```

CMSSW: Analysis (EDAnalyzer)
Get Tracks

```
• // get track collection
•   Handle<TrackCollection> tracks;
•   iEvent.getByLabel(m_tracksSrc, tracks);

• // access tracks
•   for (size_t j = 0; j < tracks->size(); j++)
•     {
•       cout << "->   Track " << j << " pT: " <<
(*tracks)[j].pt()
•       << " eta: " << (*tracks)[j].eta()
•       << " phi: " << (*tracks)[j].phi() << endl;
}
```

CMSSW: Analysis (EDAnalyzer)
Get Muon Tracks

```
// Muons
Handle<MuonCollection> muons;
iEvent.getByLabel(m_muonsSrc, muons);

// access muons. from Riccardo Bellan
MuonCollection::const_iterator muon;
for (muon = muons->begin(); muon != muons->end();
++muon){
   // this is the track which contains both the tracker and the muon's info
   // muon->  will give you exactly the same info as glbTrack for pt, eta, phi
   // TrackRef knows all the methods of the Track class
cout <<" muon pT = " << muon->pt()
   <<" eta = " << muon->eta()
   <<" phi = " << muon->phi() << endl;
}
```

CMSSW: Produce Plots I

- process myprocess = {
- #keep the logging output to a nice level
- include "FWCore/MessageLogger/data/MessageLogger.cfi"

- source = PoolSource {

  untracked vstring fileNames =
  {"file:/raid/raid3/cms/dimitri/zprime/root/mupairs-Zprime-4000.root"}
- untracked int32 maxEvents = -1
- # untracked int32 maxEvents = 20
- }

- service = Tracer { untracked string indention = "$$"}

- # include "Demo/DemoAnalyzer/data/demo.cfi"
- # replace demo.minTracks=0

CMSSW: Produce Plots II

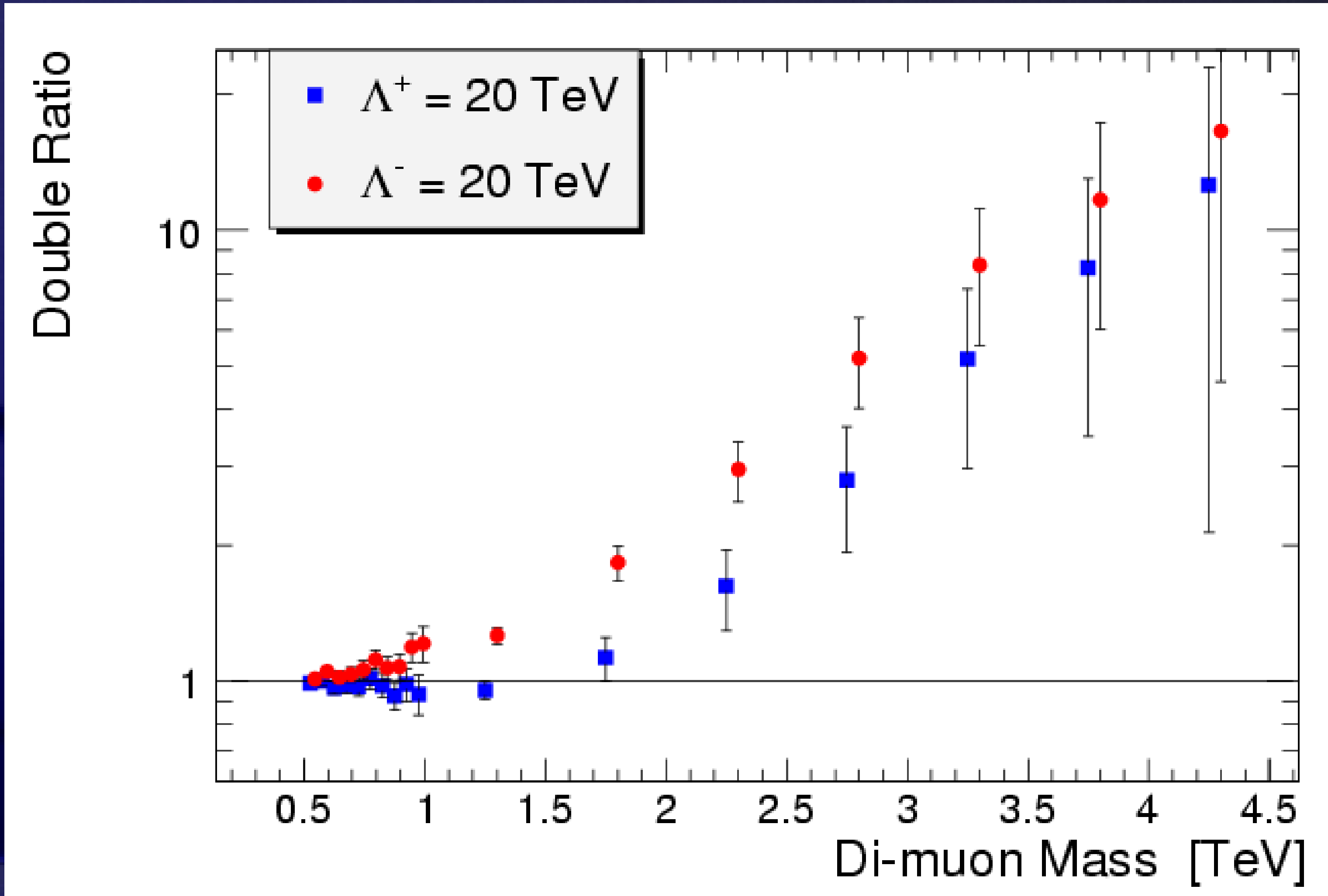
```
module myanalysis = Analyzer {

# names of modules, producing object collections
  string tracks     = "ctfWithMaterialTracks"
  string jets       = "iterativeCone5CaloJets"
  string jetsgen    = "iterativeCone5GenJets"
  string electrons  = "pixelMatchElectrons"
  string muons      = "globalMuons"
  string taujet     = "coneIsolation"
  string ecalbcl    = "islandBasicClusters"

# name of output root file with histograms
  untracked string HistOutFile = "mupairs-Zprime-4000-analysis.root"
}

# module dump = EventContentAnalyzer {}

# path p = {dump}
path p = {myanalysis}
}
```

Outlook

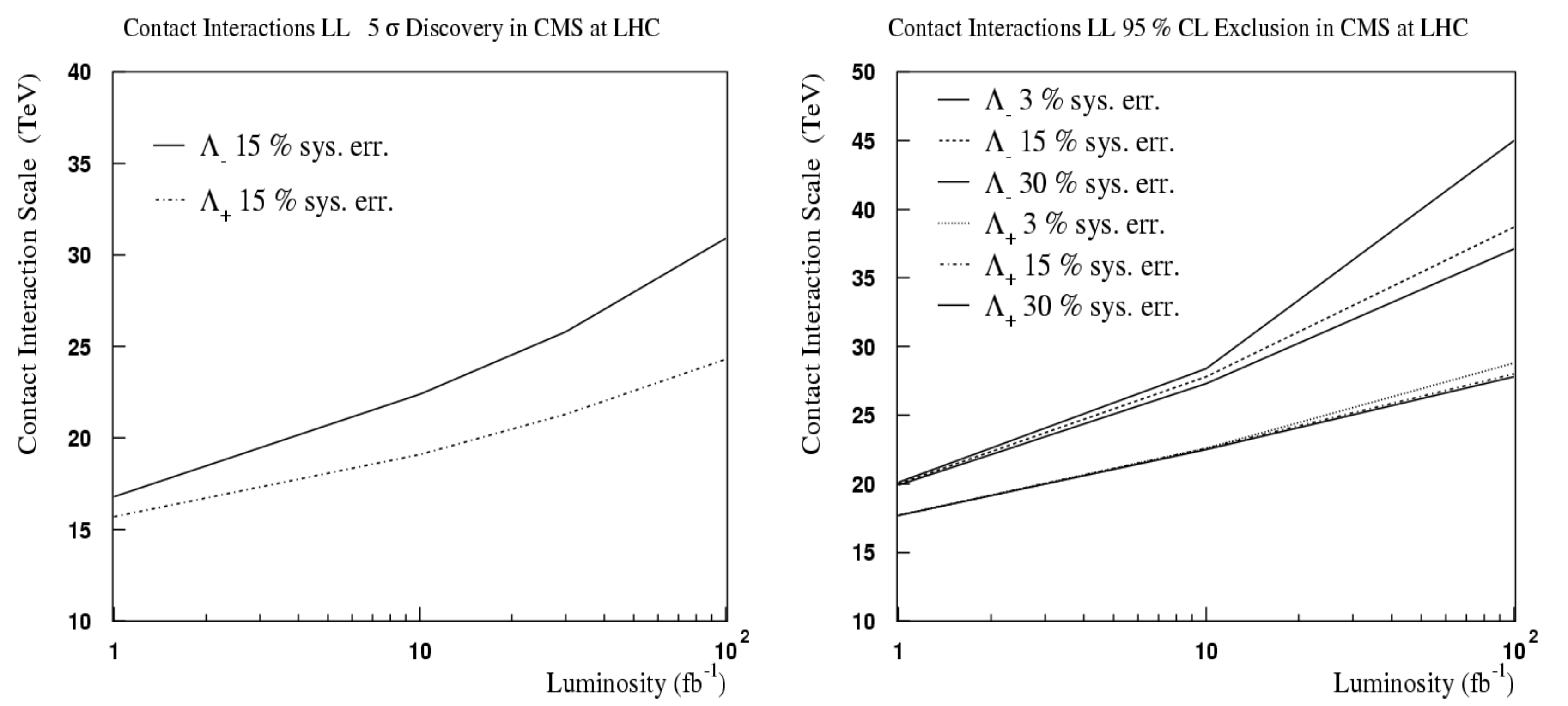
- TeV muons and dimuons open a rich search field for new physics right from the LHC start
- CMS can measure cross sections / forward-backward asymmetries to the highest masses @ LHC
- Be ready for first data: detector, new software CMSSW: muon efficiency / resolution need improvement

Backup Slides

Contact Interactons: Example of Double Ratios (100 fb^{-1})



Contact Interactions Discovery Reach



Up to 10 fb^{-1} (higher for Λ_+) we are dominated by statistical errors: even 30 % systematic errors have small impact

PDF Uncertainties

- **Used CTEQ6m with 41 members: full 41 generations, asymmetric errors**
- **LHAPDF library / LHAGLUE interface - now version 5 - to MC generators PYTHIA and HERWIG available**
- **Collaboration M.Whaley, D.Bourilkov, C.Group, "**THE LES HOUCHES ACCORD PDFS (LHAPDF) AND LHAGLUE", hep-ph/0508110; "LHAPDF: PDF USE FROM THE TEVATRON TO THE LHC", hep-ph/0605240
- **LHAGLUE interface provides seamless, automatic access without changing the MC generator code; see hep-ph/0305126 evolved as a PDFLIB-like interface integrated in LHAPDF**

Drell-Yan Flavor Composition / PDF Uncertainty

Used CTEQ6m with 41 members: full 41 generations, asymmetric errors

Mass [GeV]	d	u	s [%]	c	b	PDF+ [%]	PDF- [%]
Z 70-120	35.9	32.1	17.2	9.77	5.10	+4.7	-5.7
250-500	24.3	61.3	6.22	6.64	1.54	+3.4	-4.2
500-600	22.8	68.4	4.03	3.95	0.89	+3.5	-4.1
1000+	21.7	74.6	1.86	1.48	0.33	+5.0	-5.8
2000+	19.9	78.4	0.91	0.63	0.14	+9.0	-7.7