Drell-Yan Cross Section Measurement

CDF Run II at the Tevatron

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for the
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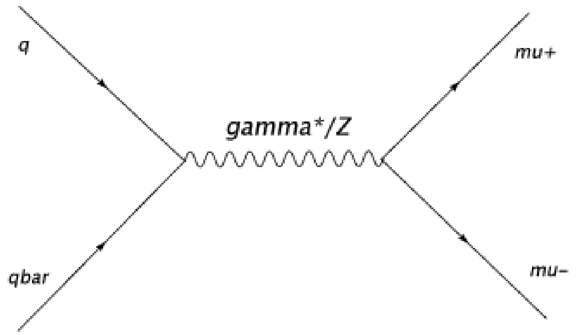
- motivation
- event and muon selection
- data analysis
- results
- conclusions

Motivation

Drell-Yan: production of quark – anti-quark pairs in hadron collisions

One of the most basic processes in QCD !



- a basic "meat & potatoes" measurement at p-pbar colliders!
  - no measurement done since Run I
  - we have nearly 10x the amount of data!
- provides information on parton distribution functions
  - test of the Standard Model, in principle
- helps ground searches for new physics, such as
  - searches for extra neutral gauge bosons
  - lepton-based searches for supersymmetric particles

Muon and Event Selection

event selection:

- two opposite-sign muons with $p_{T1} > 20$ GeV and $p_{T2} > 10$ GeV
- $M_{\mu\mu} > 20$ GeV
- muons must be "isolated" - small calorimeter energy in a cone around each muon
- reject cosmic rays using timing information from the drift chamber
- small alignment corrections to remove p_T bias in the real data

muon selection:

- both muons must have good track "stubs" in the muon chambers
- the match to a high-quality drift-chamber track must be good
- muon identification:
  - calorimeter energy consistent with min-I particle
  - impact parameter consistent with the beam line

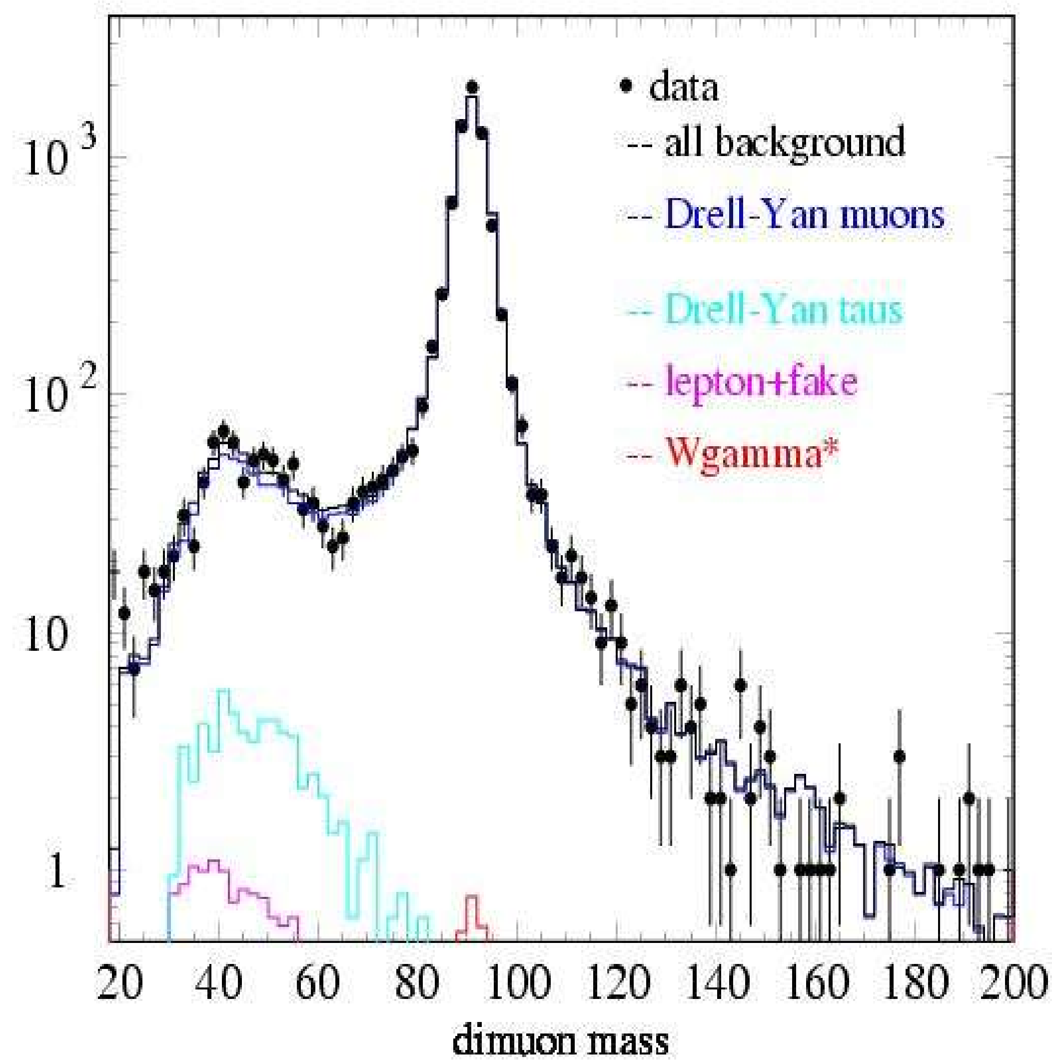
Data Analysis

There are four basic steps to obtain the cross-section from the yields:

- **subtract the backgrounds**
- **unfold the binned data**
- **correct for the acceptance**
- **convert into a cross-section using the luminosity**

Backgrounds

- due to the strict muon requirements, backgrounds are quite small
- main background is from DY $\rightarrow \tau^+\tau^-$
- fakes estimated from data by counting isolated tracks and applying a 1% fake rate.
- we have estimated these bin-by-bin



Unfolding

- take the simplest approach possible
- use large bins so that mass resolution has a small impact
- construct a "response" or "transfer" matrix using full simulation

$$\vec{R} = \boldsymbol{M}\ \vec{T}$$

reconstructed *transfer matrix* *truth*

$$\vec{S} = \boldsymbol{M}^{-1}\ \vec{D}$$

true spectrum *unfolding matrix* *data*

- mass resolution for CDF is excellent
- central outer tracker (COT) provides up to 96 precise space-points
- beam spot is well known, so beam constraint is also powerful

$$\frac{\sigma_M}{M^2} \approx 1.6 \times 10^{-4}\ GeV^{-1}$$

$$\sigma_M = 0.16\,GeV \quad for \quad M = 20\,GeV$$

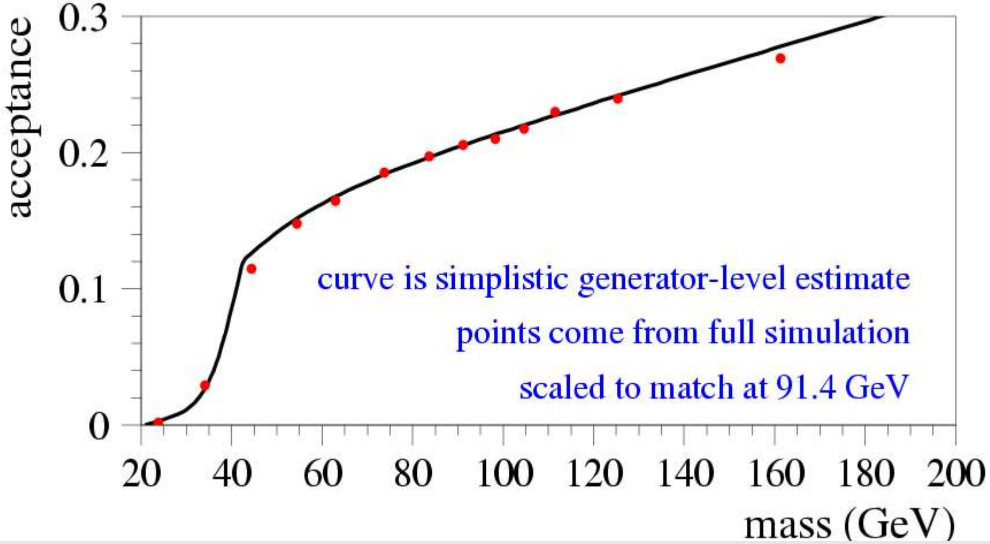
$$\sigma_M = 1.64\,GeV \quad for \quad M = 100\,GeV$$

Here are the 14 bins we have defined for the current analysis:

number	range (GeV)	width (GeV)	mean (GeV)	$\int d\sigma/dM$ (pb)
1	20 – 30	10	23.5	162.2
2	30 – 40	10	33.9	43.2
3	40 – 50	10	44.1	16.6
4	50 – 60	10	54.3	8.3
5	60 – 66	6	62.7	3.5
6	66 – 80	14	73.5	8.9
7	80 – 86	6	83.4	10.8
8	86 – 96	10	91.1	211.8
9	96 – 102	6	98.0	11.6
10	102 – 108	6	104.3	3.3
11	108 – 116	8	111.2	2.0
12	116 – 140	24	125.1	2.0
13	140 – 200	60	160.3	1.2
14	200 – 600	400	259.2	0.4

Acceptance Estimate

bin	acceptance
1	0.00071 ± 0.00002
2	0.0105 ± 0.0002
3	0.0415 ± 0.0006
4	0.0534 ± 0.0010
5	0.0595 ± 0.0017
6	0.0670 ± 0.0011
7	0.0713 ± 0.0010
8	0.0743 ± 0.0002
9	0.0758 ± 0.0011
10	0.0785 ± 0.0020
11	0.0831 ± 0.0027
12	0.0866 ± 0.0026
13	0.0972 ± 0.0037
14	0.1193 ± 0.0069



- Our acceptance estimates comes from the full simulation.
- The main part is kinematic and fiducial:
  $p_{T1} > 20$ GeV, $p_{T2} > 10$ GeV $|\eta| < 1$

Systematics

- procedure has been checked carefully
- statistical error correctly propagated
- normalize Z-peak region to the CDF measurement of $\sigma(Z)$:

$$\sigma \times Br(Z) = 254.9 \pm 16.2\ pb$$

- systematics come mainly from the acceptance $\times$ efficiency, and from the unfolding procedure.

bin	$A \times \epsilon$	unfolding	total
1	0.15	0.05	0.16
2	0.08	0.05	0.09
3	0.08	0.05	0.09
4	0.08	0.05	0.09
5	0.08	0.05	0.09
6	0.08	0.16	0.18
7	0.08	0.05	0.09
8	0.08	0.05	0.09
9	0.08	0.05	0.09
10	0.08	0.19	0.21
11	0.08	0.26	0.28
12	0.08	0.30	0.31
13	0.08	0.05	0.09
14	0.08	0.05	0.09

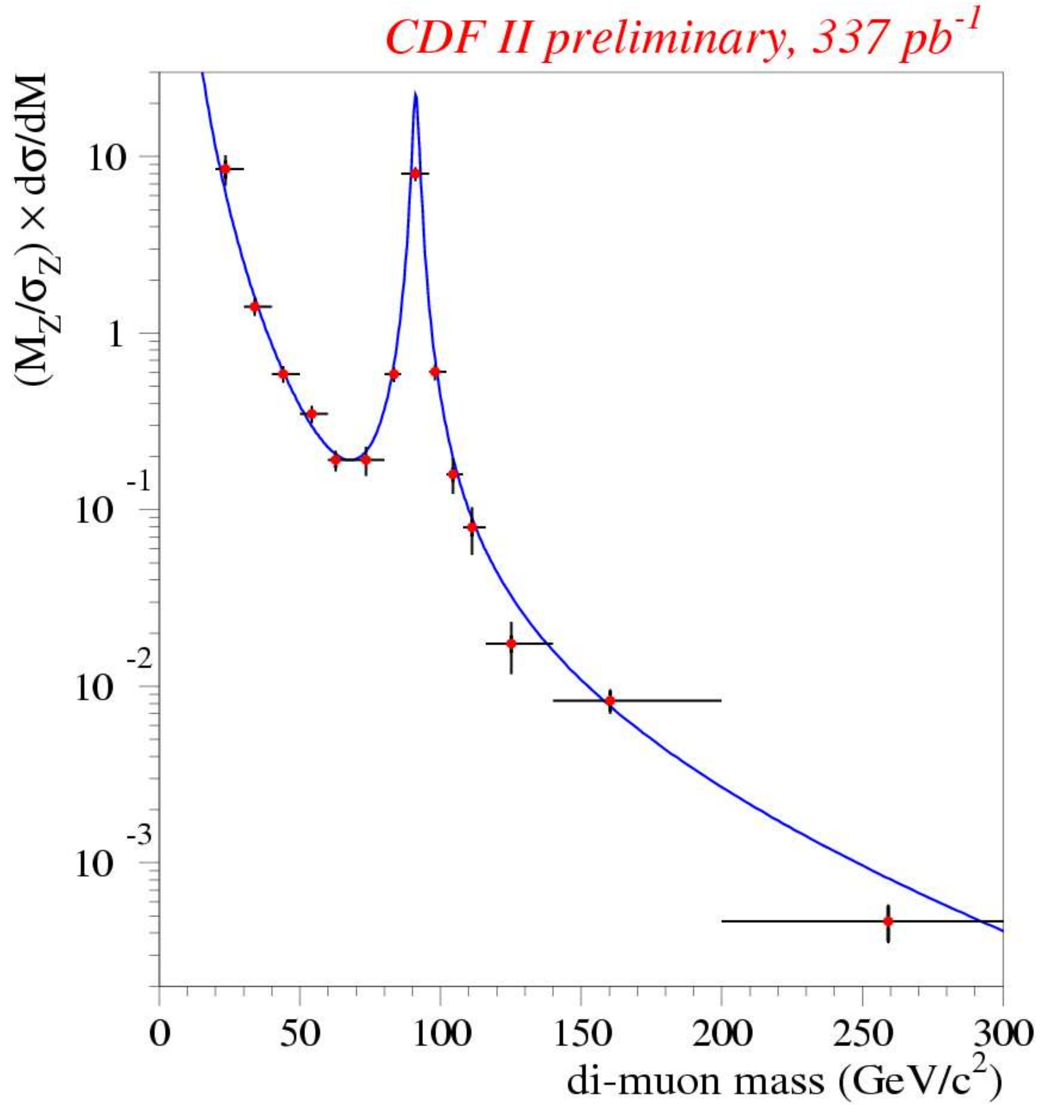
preliminary measurement:

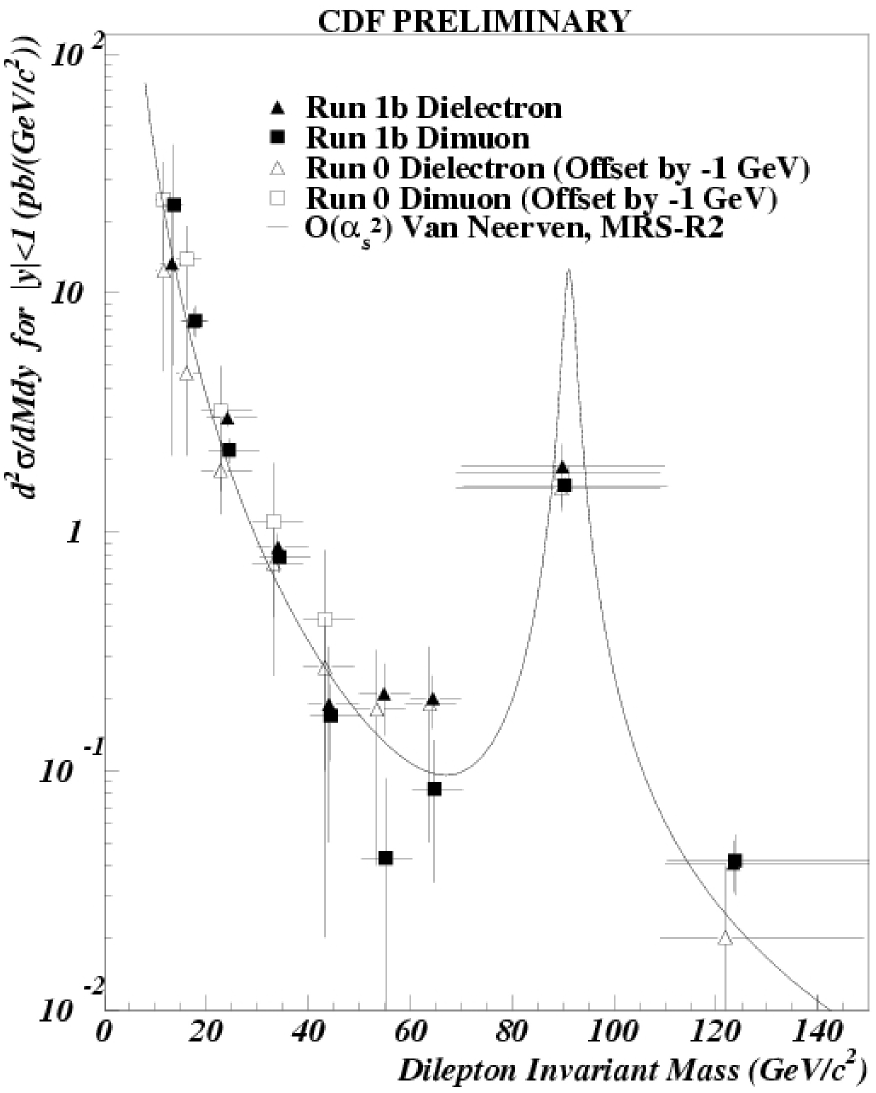
CDF Run II

number	range (GeV)	mean (GeV)	$d\sigma/dM$ (pb/GeV) theory	measurement
1	20 – 30	23.5	16.22	$23.8 \pm 2.8 \pm 3.8$
2	30 – 40	33.9	4.32	$4.0 \pm 0.3 \pm 0.4$
3	40 – 50	44.1	1.66	$1.64 \pm 0.09 \pm 0.15$
4	50 – 60	54.3	0.83	$0.98 \pm 0.06 \pm 0.09$
5	60 – 66	62.7	0.58	$0.53 \pm 0.05 \pm 0.05$
6	66 – 80	73.5	0.64	$0.53 \pm 0.03 \pm 0.10$
7	80 – 86	83.4	1.80	$1.64 \pm 0.07 \pm 0.15$
8	86 – 96	91.1	21.18	$22.32 \pm 0.28 \pm 2.00$
9	96 – 102	98.0	1.93	$1.68 \pm 0.08 \pm 0.15$
10	102 – 108	104.3	0.55	$0.44 \pm 0.04 \pm 0.09$
11	108 – 116	111.2	0.24	$0.22 \pm 0.02 \pm 0.06$
12	116 – 140	125.1	0.082	$0.049 \pm 0.005 \pm 0.015$
13	140 – 200	160.3	0.020	$0.023 \pm 0.003 \pm 0.002$
14	200 – 600	259.2	0.0010	$0.0013 \pm 0.0003 \pm 0.0001$

Theory calculation by van Neerven at NNLO, with CTEQ6M pdf's.

Note: the Run I measurement is restricted to $|y_{\mu\mu}| < 1$, while this one allows for all $y_{\mu\mu}$.





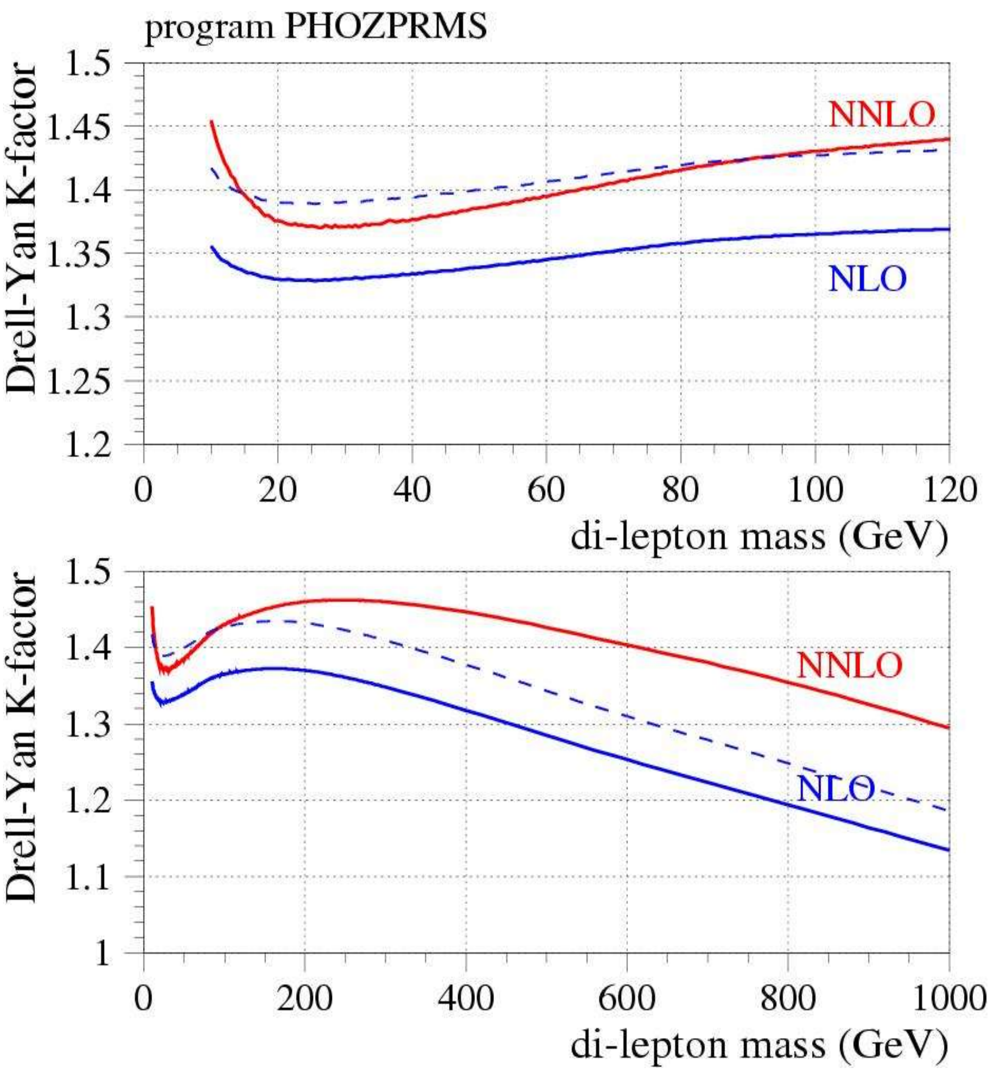
Summary & Conclusions

- a preliminary measurement of the di-muon Drell-Yan cross-section for $M_{\mu\mu} > 20$ GeV is presented, based on approx. 337 pb^{-1}.
- this is the first such measurement with Run II data.
- pessimistic systematic uncertainties will be improved.
- statistical uncertainty is much better than Run I measurement.
- theoretical predictions agree with the data.
- long-term potential is to constrain PDF's and/or test the mass-dependence of the (N)NLO calculations.

BACK-UP SLIDES

Sensitivity to the *K*-factor

We used PHOZPRMS to obtain NLO and NNLO *K*-factors:



- **The difference between NLO and NNLO cross-sections is about 5% up to 120 GeV.**
- **Our luminosity uncertainty won't allow us to make an absolute measurement at that level, unfortunately.**
- **The differences in the *K*-factor at, say, 30 GeV, 91 GeV, and 200 GeV are also about 5%, however.**
- **With a larger data set we should be able distinguish this shape from a flat *K*-factor.**

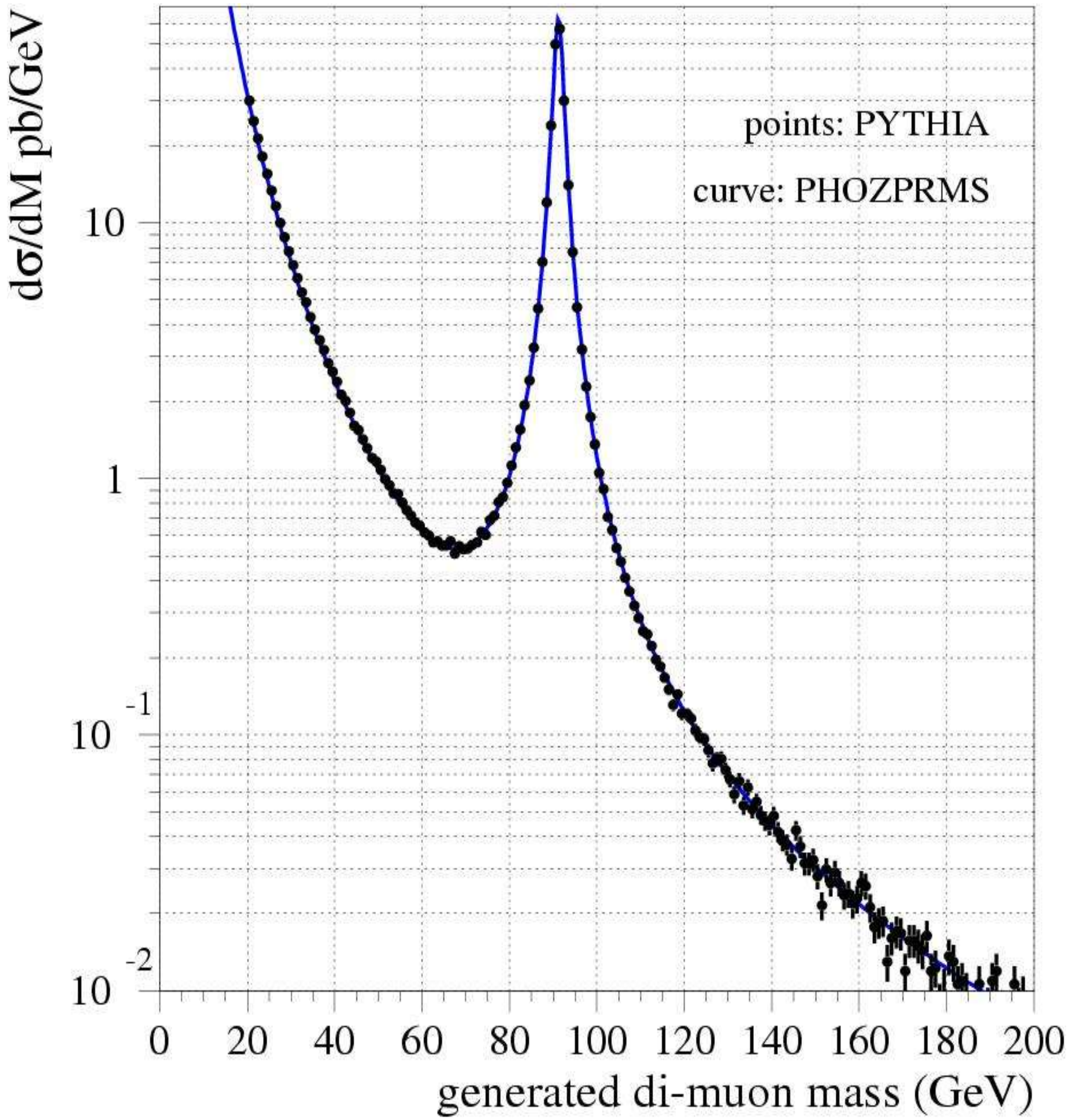
Here is the matrix itself (all entries have been multiplied by 100):

bins in true mass →

bins in reconstructed mass ↓

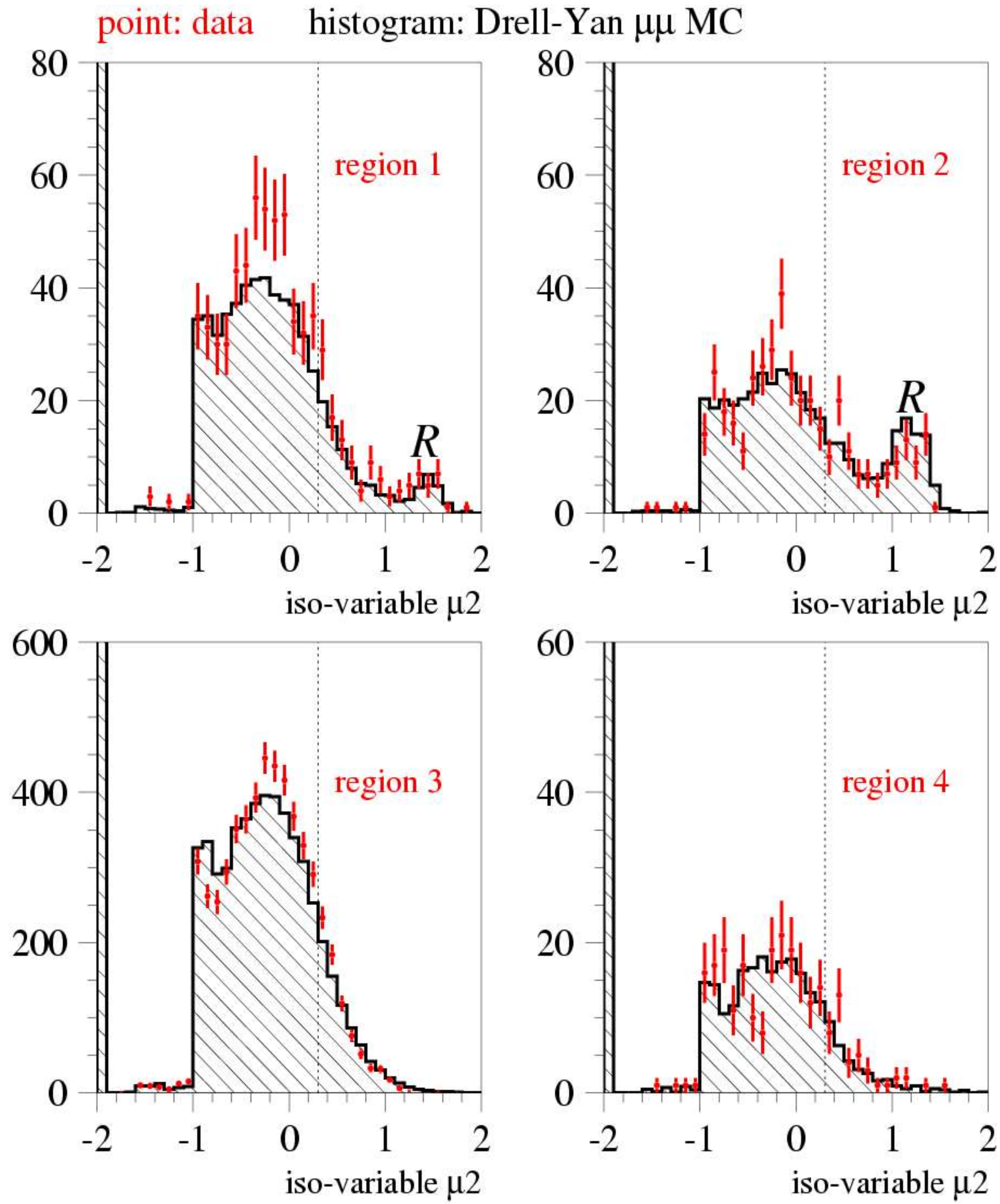
$$
M = \begin{pmatrix}
95 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
4 & 94 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 4 & 92 & 6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 3 & 89 & 11 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 2 & 81 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 6 & 88 & 10 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 5 & 72 & 4 & 1 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 15 & 88 & 24 & 2 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 64 & 20 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 7 & 64 & 18 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 10 & 67 & 9 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 9 & 83 & 7 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 88 & 4 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 94
\end{pmatrix}
$$

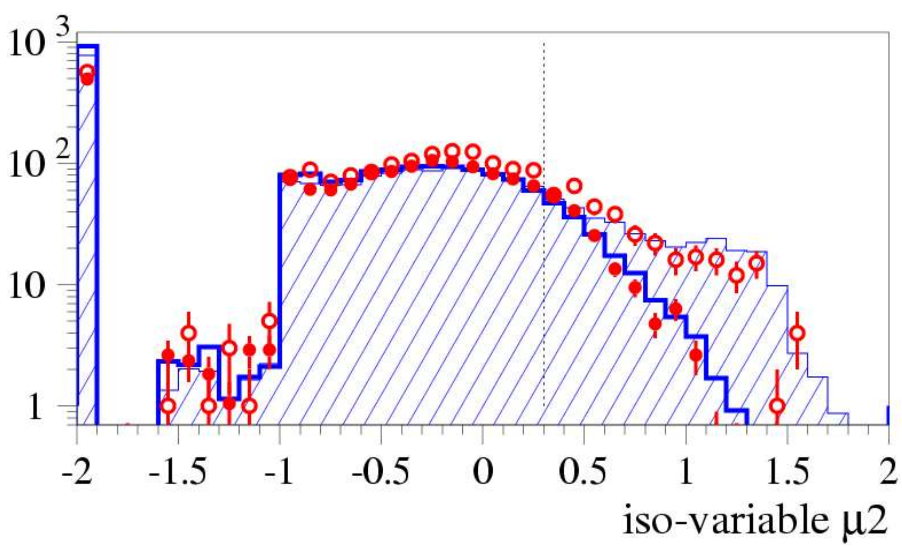
(3) verify that PYTHIA has the correct generated mass distribution:



What about FSR?

- look at the calorimeter isolation for the second muon below and on the Z-peak.
- here, we plotted log10(Iso)
- the radiative bump “R” is well-reproduced by the simulation.





mass resolution studies from fully simulated & reconstructed data

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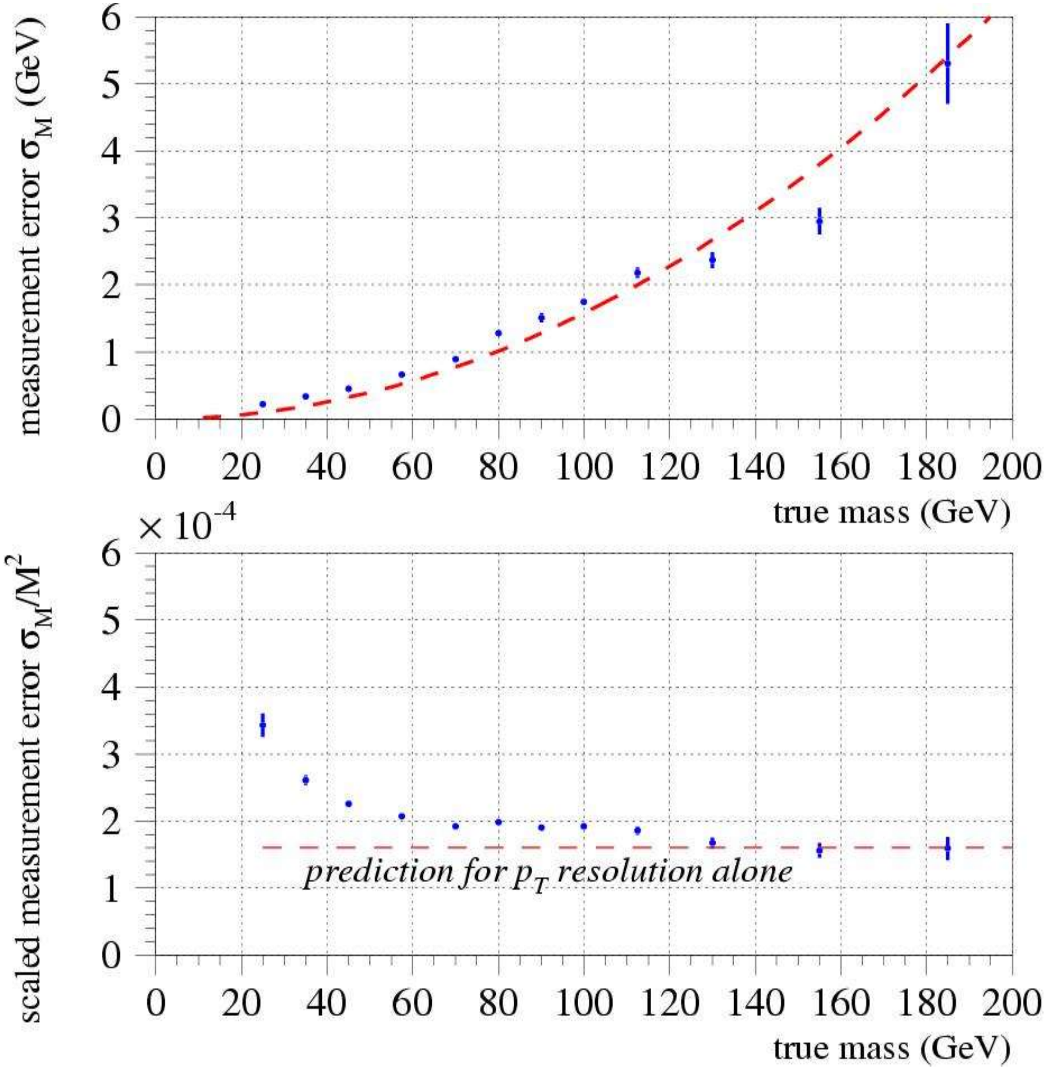

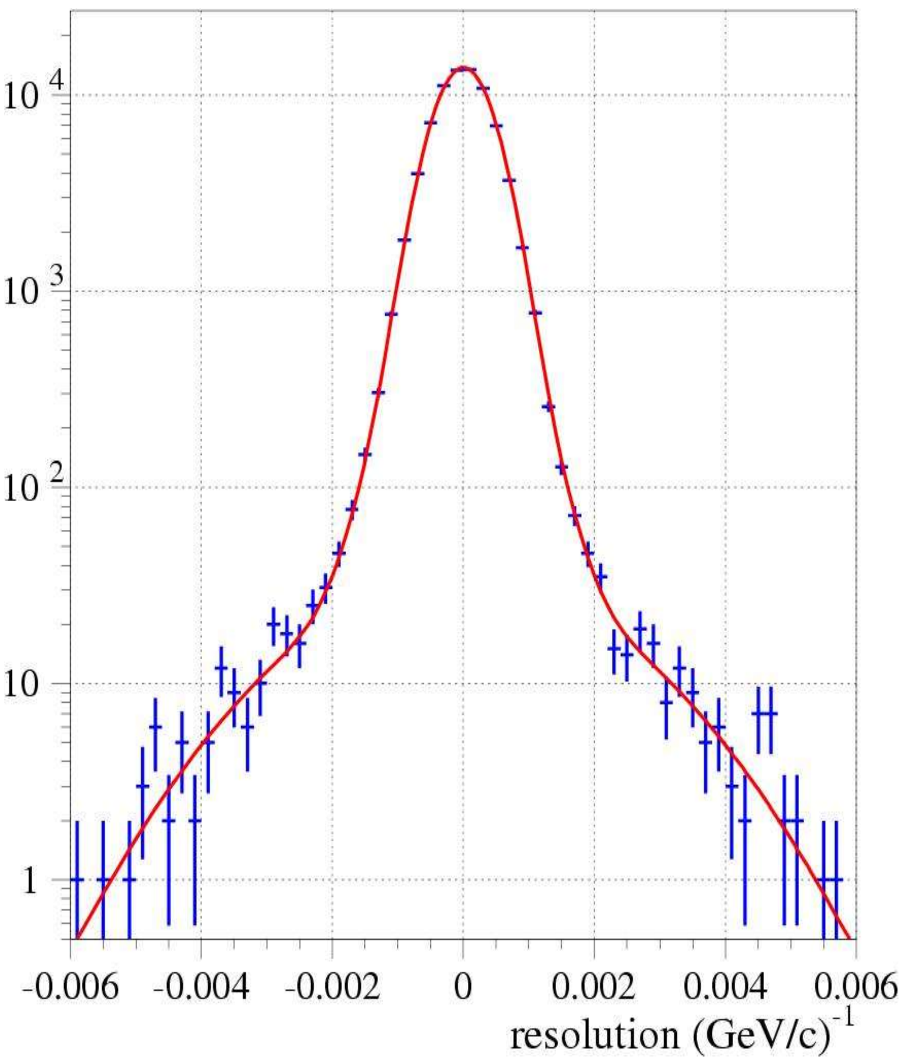

Theoretical Prediction

- We need a precise prediction for the cross section in each of our mass bins.
- We ran PHOZPRMS (van Neerven *et al.*, NNLO with CTEQ6M) and integrated across each bin.
- This also gives us precise predictions for the mean mass in each bin – in some bins this differs significantly from the bin center.

bin	mass range (GeV)	width	mean	cs (pb)	cs/width
1	20.0 -- 30.0	10.0	23.52	162.1669	16.2167
2	30.0 -- 40.0	10.0	33.86	43.1619	4.3162
3	40.0 -- 50.0	10.0	44.08	16.5643	1.6564
4	50.0 -- 60.0	10.0	54.29	8.2715	0.8272
5	60.0 -- 66.0	6.0	62.67	3.4752	0.5792
6	66.0 -- 80.0	14.0	73.46	8.9273	0.6377
7	80.0 -- 86.0	6.0	83.36	10.8339	1.8057
8	86.0 -- 96.0	10.0	91.08	211.7875	21.1787
9	96.0 -- 102.0	6.0	97.96	11.5594	1.9266
10	102.0 -- 108.0	6.0	104.32	3.3113	0.5519
11	108.0 -- 116.0	8.0	111.25	1.9558	0.2445
12	116.0 -- 140.0	24.0	125.12	1.9638	0.0818
13	140.0 -- 200.0	60.0	160.33	1.1829	0.0197
14	200.0 -- 600.0	400.0	259.22	0.3968	0.0010