

# Results of a Global Search for New Physics at CDF

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XLIIIth Rencontres de Moriond:  
QCD and High-Energy Interactions

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# Overview of the CDF Global Search

- Motivation: perform model-independent global search of high- $p_T$  data, to make sure we do not miss new physics in the Tevatron data
- Vista: study bulk features of high- $p_T$  data
- Bump Hunter: search for resonances in invariant mass distributions
- Sleuth: search for significant excesses at high sum- $p_T$



# Overview of Vista

- Identify physics objects

- $e^\pm, \mu^\pm, \tau^\pm, \gamma, j, b, \cancel{E}_T$

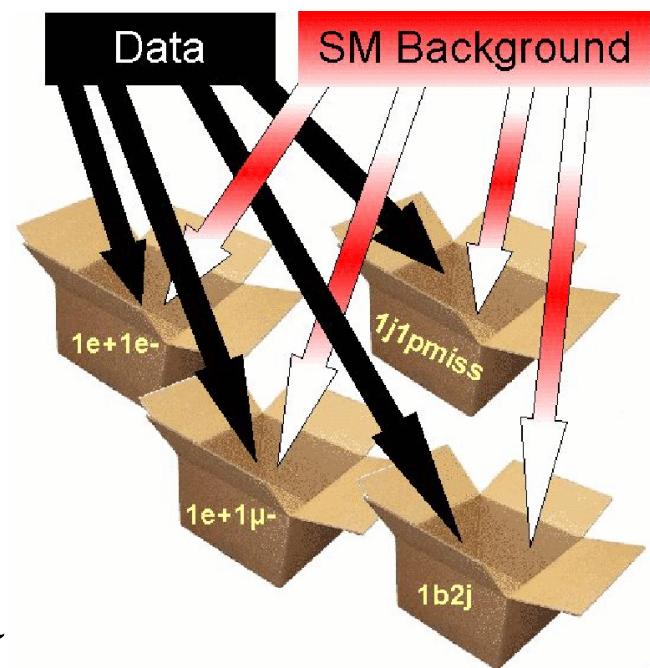
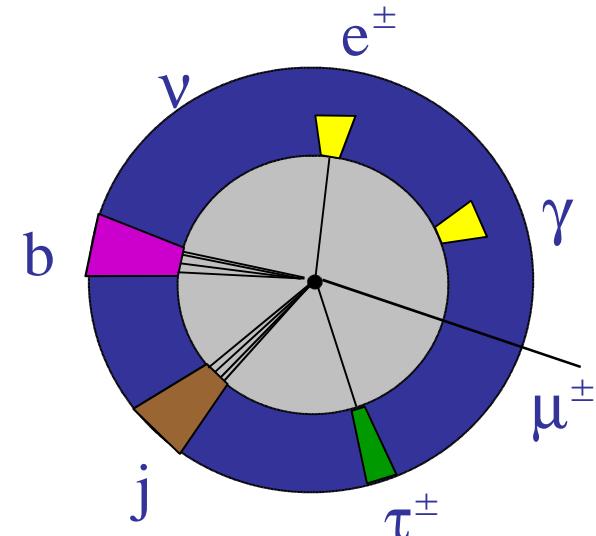
- require  $p_T > 17 \text{ GeV}$

- Select events

- require high- $p_T$  lepton,  
photon, jet triggers

- Partition events into  $\sim 400$  exclusive final states

- boxes created if populated by data



# Overview of Vista

- Generate our implementation of Standard Model
  - primarily use Pythia and MadEvent
  - simulate detector with CDFSim
- Determine correction factors for true SM prediction
  - 43 used in total
  - theoretical k-factors for SM processes: QCD multi-jet, W/Z+jets, etc...
  - experimental efficiencies for object reconstruction and 'fake rates'
- Perform Vista global comparison; look for discrepancies in:
  - final state populations
  - shapes of kinematic variables

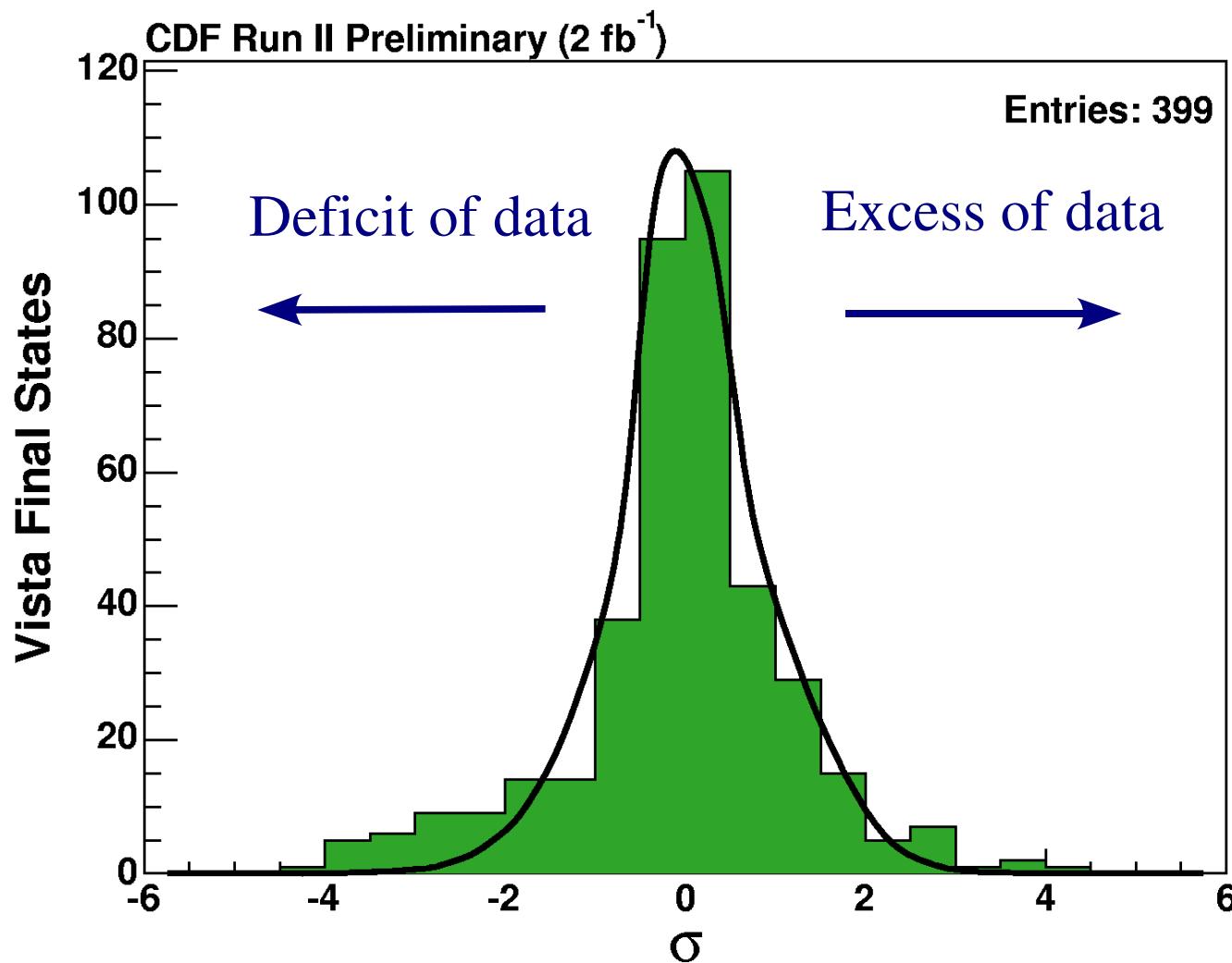
# Vista Global Comparison

- 399 exclusive final states considered
- Data compared to SM events in each final state
- Statistical discrepancy accounts for trials factor

CDF Run II Preliminary (2.0  $\text{fb}^{-1}$ )  
The calculation of  $\sigma$  accounts for the trials factor

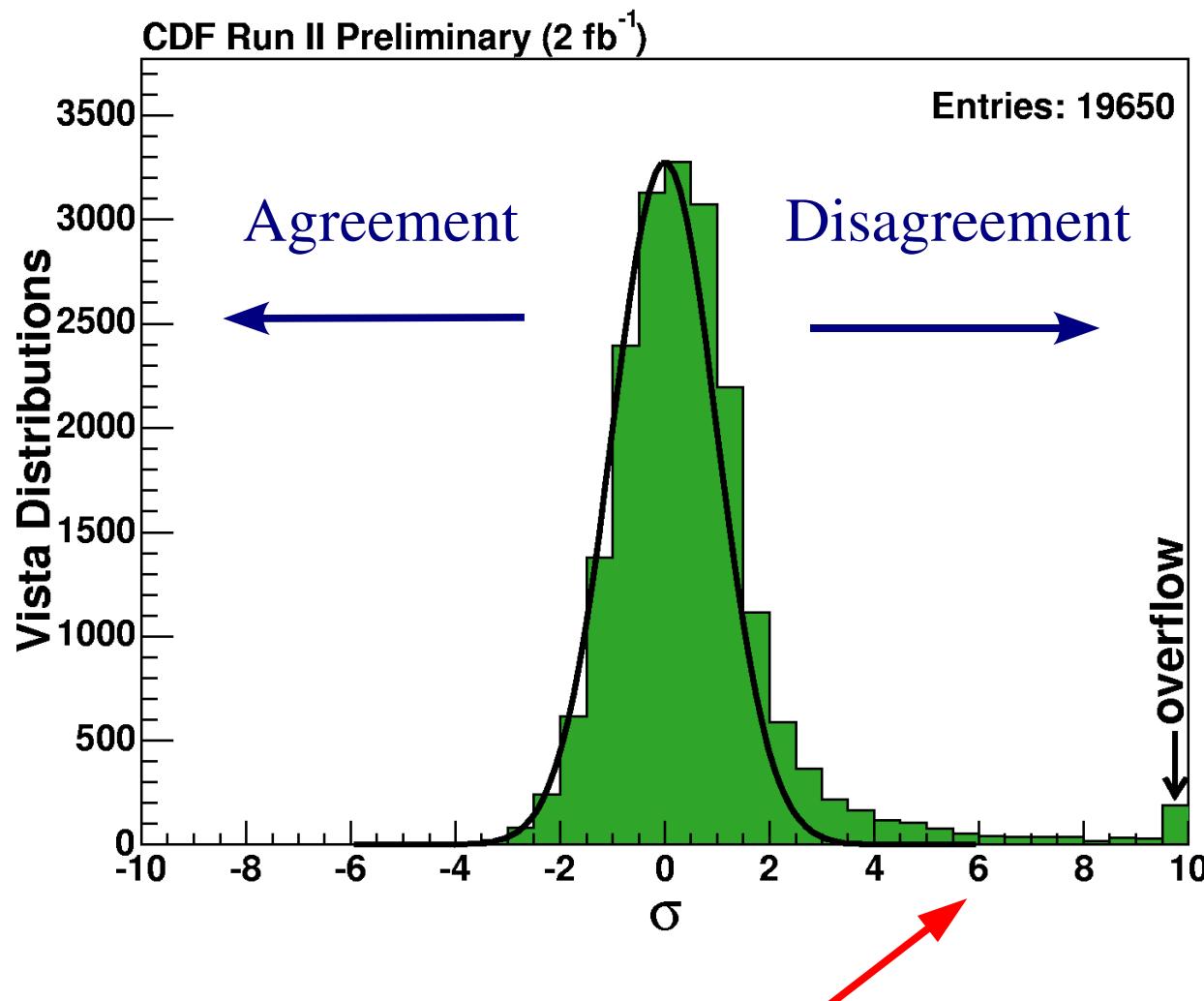
Final State	Data	Background	$\sigma$	Final State	Data	Background	$\sigma$	Final State	Data	Background	$\sigma$
$b\bar{e}\pm p$	690	817.7 $\pm$ 9.2	-2.7	$2j\bar{p}$ high- $\Sigma_{pT}$	87	80.9 $\pm$ 6.8	0	$j\mu\pm\mu\mp\bar{p}$	32	32.2 $\pm$ 10.9	0
$\gamma\tau^\pm$	1371	1217.6 $\pm$ 13.3	+2.2	$2j\bar{p}$ low- $\Sigma_{pT}$	114	79.5 $\pm$ 100.8	0	$j\mu\pm\mu\mp\gamma$	14	11.5 $\pm$ 2.6	0
$\mu^\pm\tau^\pm$	63	35.2 $\pm$ 2.8	+1.7	$2j\bar{\mu}\tau^\pm$	18	13.2 $\pm$ 2.2	0	$j\mu\pm\mu\mp$	4852	4271.2 $\pm$ 185.4	0
$b2j\bar{p}$ high- $\Sigma_{pT}$	255	327.2 $\pm$ 8.9	-1.7	$2j\gamma\tau^\pm$	142	144.6 $\pm$ 5.7	0	$j\mu\pm$	77689	76987.5 $\pm$ 930.2	0
$2j\tau^\pm$ low- $\Sigma_{pT}$	574	670.3 $\pm$ 8.6	-1.5	$2j\gamma\bar{p}$	908	980.3 $\pm$ 63.7	0	$e^\pm 4j\bar{p}$	903	830.6 $\pm$ 13.2	0
$3j\tau^\pm$ low- $\Sigma_{pT}$	148	199.8 $\pm$ 5.2	-1.4	$2j\gamma$	71364	73021.4 $\pm$ 595.9	0	$e^\pm 4j\gamma$	25	29.2 $\pm$ 3.6	0
$e^\pm\bar{\mu}\tau^\pm$	36	17.2 $\pm$ 1.7	+1.4	$2j\mu^\pm\bar{p}$	17927	18340.6 $\pm$ 201.9	0	$e^\pm 4j$	15750	16740.4 $\pm$ 390.5	0
$2j\tau^\pm\tau^\mp$	33	62.1 $\pm$ 4.3	-1.3	$2j\mu^\pm\gamma\bar{p}$	31	27.7 $\pm$ 7.7	0	$e^\pm 3j\tau^\mp$	15	21.1 $\pm$ 2.2	0
$e^\pm j$	741710	764832 $\pm$ 6447.2	-1.3	$2j\mu^\pm\gamma$	57	58.2 $\pm$ 13	0	$e^\pm 3j\bar{p}$	4054	4077.2 $\pm$ 63.6	0
$j2\tau^\pm$	105	150.8 $\pm$ 6.3	-1.2	$2j\mu^\pm\mu\mp\bar{p}$	11	7.8 $\pm$ 2.7	0	$e^\pm 3j\gamma$	108	79.3 $\pm$ 5	0
$e^\pm 2j$	256946	249148 $\pm$ 2201.5	+1.2	$2j\mu^\pm\mu^\mp$	956	924.9 $\pm$ 61.2	0	$e^\pm 3j$	60725	60409.3 $\pm$ 723.3	0
$2bj$ low- $\Sigma_{pT}$	279	352.5 $\pm$ 11.9	-1.1	$2j\mu^\pm$	22461	23111.4 $\pm$ 366.6	0	$e^\pm 2\gamma$	41	34.2 $\pm$ 2.6	0
$j\tau^\pm$ low- $\Sigma_{pT}$	1385	1525.8 $\pm$ 15	-1.1	$2e^\pm j$	14	13.8 $\pm$ 2.3	0	$e^\pm 2j\tau^\pm$	37	47.2 $\pm$ 2.2	0
$2b2j$ low- $\Sigma_{pT}$	108	153.5 $\pm$ 6.8	-1	$2e^\pm e^\mp$	20	17.5 $\pm$ 1.7	0	$e^\pm 2j\tau^\mp$	109	95.9 $\pm$ 6.8	0
$b\mu^\pm\bar{p}$	528	613.5 $\pm$ 8.7	-0.9	$2b$ high- $\Sigma_{pT}$	666	689 $\pm$ 9.4	0	$e^\pm 2j\bar{p}$	25725	25403.1 $\pm$ 209.4	0
$\mu^\pm\gamma\bar{p}$	523	611 $\pm$ 12.1	-0.8	$2b$ low- $\Sigma_{pT}$	323	313.2 $\pm$ 10.3	0	$e^\pm 2j\bar{\gamma}$	30	31.8 $\pm$ 4.8	0
$2b\gamma$	108	70.5 $\pm$ 7.9	+0.1	$2b3j$ low- $\Sigma_{pT}$	53	57.4 $\pm$ 6.5	0	$e^\pm 2j\mu^\pm\bar{p}$	398	342.8 $\pm$ 15.7	0
$8j$	14	13.1 $\pm$ 4.4	0	$2b2j$ high- $\Sigma_{pT}$	718	803.3 $\pm$ 12.7	0	$e^\pm 2j\mu^\pm$	22	14.8 $\pm$ 1.9	0
$7j$	103	97.8 $\pm$ 12.2	0	$2b2j\bar{p}$ high- $\Sigma_{pT}$	15	21.8 $\pm$ 2.8	0	$e^\pm 2j\tau^\pm$	23	15.8 $\pm$ 2	0
$6j$	653	659.7 $\pm$ 37.3	0	$2b2j\gamma$	32	39.7 $\pm$ 6.2	0	$e^\pm \tau^\pm$	437	387 $\pm$ 5.3	0
$5j$	3157	3178.7 $\pm$ 67.1	0	$2b2j\mu^\pm\bar{p}$	14	17.3 $\pm$ 1.9	0	$e^\pm \tau^\mp$	1333	1266 $\pm$ 12.3	0
$4j$ high- $\Sigma_{pT}$	88546	89096.6 $\pm$ 935.2	0	$2b2j\mu^\pm$	22	21.8 $\pm$ 2	0	$e^\pm p^\mp$	109	106.1 $\pm$ 2.7	0
$4j$ low- $\Sigma_{pT}$	14872	14809.6 $\pm$ 186.3	0	$2b\bar{j}\gamma$	71	54.5 $\pm$ 7.1	0	$e^\pm p^\pm$	960826	956579 $\pm$ 3077.7	0
$4j2\gamma$	46	46.4 $\pm$ 3.9	0	$2be^\pm 2j\bar{p}$	12	10.7 $\pm$ 1.9	0	$e^\pm \gamma$	497	496.8 $\pm$ 10.3	0
$4j\tau^\pm$ high- $\Sigma_{pT}$	29	26.6 $\pm$ 1.7	0	$2be^\pm 2j\bar{\gamma}$	30	27.3 $\pm$ 2.2	0	$e^\pm \gamma$	3578	3589.9 $\pm$ 24.1	0
$4j\tau^\pm$ low- $\Sigma_{pT}$	43	63.1 $\pm$ 3.3	0	$2be^\pm 2j$	72	66.5 $\pm$ 2.9	0	$e^\pm j_2\gamma$	13	16.1 $\pm$ 3.9	0
$4j\bar{p}$ high- $\Sigma_{pT}$	1064	1012 $\pm$ 62.9	0	$2be^\pm \bar{p}$	22	19.1 $\pm$ 2.2	0	$e^\pm j_2\tau^\mp$	386	418 $\pm$ 18.9	0
$4j\gamma\tau^\pm$	19	10.8 $\pm$ 2	0	$2be^\pm \bar{p}$	19	19.4 $\pm$ 2.2	0	$e^\pm j_2\tau^\pm$	160	162.8 $\pm$ 3.5	0
$4j\gamma\bar{p}$	62	104.2 $\pm$ 22.4	0	$2be^\pm j$	63	63 $\pm$ 3.4	0	$e^\pm j_2p^\mp$	48	44.6 $\pm$ 3.3	0
$4j\gamma$	7962	8271.2 $\pm$ 245.1	0	$2be^\pm$	96	92.1 $\pm$ 4.1	0	$e^\pm j_2p^\pm$	11	8.3 $\pm$ 1.5	0
$4j\mu^\pm\bar{p}$	574	590.5 $\pm$ 13.6	0	$\tau^\pm\tau^\mp$	856	872.5 $\pm$ 19	0	$e^\pm j_2\bar{p}$	121431	121023 $\pm$ 747.6	0
$4j\mu^\pm\mu^\mp$	38	48.4 $\pm$ 6.2	0	$\gamma\bar{p}$	3793	3770.7 $\pm$ 127.3	0	$e^\pm j_2\gamma$	159	192.6 $\pm$ 10.9	0
$4j\mu^\pm$	1363	1350.1 $\pm$ 37.7	0	$\mu^\pm\tau^\mp$	381	440.9 $\pm$ 7.3	0	$e^\pm j_2\gamma$	1389	1368.9 $\pm$ 38.9	0
$3j$ high- $\Sigma_{pT}$	159926	159143 $\pm$ 1061.9	0	$\mu^\pm\mu^\mp\bar{p}$	60	75.7 $\pm$ 3.4	0	$e^\pm j_2\mu^\pm\bar{p}$	42	33 $\pm$ 2.9	0
$3j$ low- $\Sigma_{pT}$	62681	64213.1 $\pm$ 496	0	$\mu^\pm\tau^\mp$	15	12 $\pm$ 2	0	$e^\pm j_2\mu^\pm$	16	9.2 $\pm$ 1.9	0
$3j2\gamma$	151	177.5 $\pm$ 7.1	0	$\mu^\pm\bar{p}$	734290	734296 $\pm$ 4897.8	0	$e^\pm j_2\mu^\mp$	62	63.8 $\pm$ 3.2	0
$3j\tau^\pm$ high- $\Sigma_{pT}$	68	76.9 $\pm$ 3	0	$\mu^\pm\gamma$	475	469.8 $\pm$ 12.5	0	$e^\pm j_2\mu^\pm$	13	8.2 $\pm$ 2	0
$3j\bar{p}$ high- $\Sigma_{pT}$	1706	1899.4 $\pm$ 77.6	0	$\mu^\pm\tau^\mp$	169	198.5 $\pm$ 8.2	0	$e^\pm e^\mp 4j$	148	159.1 $\pm$ 7	0
$3j\bar{p}$ low- $\Sigma_{pT}$	42	36.2 $\pm$ 5.7	0	$\mu^\pm\mu^\mp\gamma$	83	60 $\pm$ 3.1	0	$e^\pm e^\mp 3j$	717	743.6 $\pm$ 24.4	0
$3j\gamma\tau^\pm$	39	37.8 $\pm$ 3.6	0	$\mu^\pm\mu^\mp$	25283	25178.5 $\pm$ 86.5	0	$e^\pm e^\mp 2j\bar{p}$	32	41.4 $\pm$ 5.6	0
$3j\gamma\bar{p}$	204	249.8 $\pm$ 24.4	0	$\mu^\pm\bar{p}$	36	30.4 $\pm$ 4.2	0	$e^\pm e^\mp 2j\gamma$	10	11.4 $\pm$ 2.9	0
$3j\gamma$	24639	24899.4 $\pm$ 372.4	0	$\mu^\pm\gamma$	1822	1813.2 $\pm$ 27.4	0	$e^\pm e^\mp 2j$	3638	3566.8 $\pm$ 72	0
$3j\mu^\pm\bar{p}$	2884	2971.5 $\pm$ 52.1	0	$\mu^\pm\bar{p}$	71	98 $\pm$ 3.9	0	$e^\pm e^\mp\tau^\pm$	18	16.1 $\pm$ 1.7	0
$3j\mu^\pm\gamma\bar{p}$	10	3.6 $\pm$ 1.9	0	$\mu^\pm\mu^\mp\gamma$	83	60 $\pm$ 3.1	0	$e^\pm e^\mp\bar{p}$	822	831.8 $\pm$ 13.6	0
$3j\mu^\pm\gamma$	15	7.9 $\pm$ 2.9	0	$\mu^\pm\mu^\mp$	25283	25178.5 $\pm$ 86.5	0	$e^\pm e^\mp\gamma$	191	221.9 $\pm$ 5.1	0
$3j\mu^\pm\mu^\mp$	175	177.8 $\pm$ 16.2	0	$2j\bar{p}$	526	476 $\pm$ 9.3	0	$e^\pm e^\mp j\bar{p}$	155	170.8 $\pm$ 12.4	0
$3j\mu^\pm$	5032	4989.5 $\pm$ 108.9	0	$2j\gamma$	1882	1791.9 $\pm$ 72.3	0	$e^\pm e^\mp j\gamma$	48	45 $\pm$ 3.9	0
$3b2j$	23	28.9 $\pm$ 4.7	0	$j\tau^\pm$ high- $\Sigma_{pT}$	52	56.2 $\pm$ 2.5	0	$e^\pm e^\mp j\gamma$	17903	18258.2 $\pm$ 204.4	0
$3bj$	82	82.6 $\pm$ 5.7	0	$j\tau^\pm$ low- $\Sigma_{pT}$	203	252.2 $\pm$ 8.7	0	$e^\pm e^\mp\bar{p}$	98901	99086.9 $\pm$ 147.8	0
$3b$	67	85.6 $\pm$ 7.7	0	$j\bar{p}$ high- $\Sigma_{pT}$	4432	4431.7 $\pm$ 45.2	0	$b6j$	51	42.3 $\pm$ 3.8	0
$2\tau^\pm$	498	512.7 $\pm$ 14.2	0	$j\gamma\tau^\pm$	526	476 $\pm$ 9.3	0	$b5j$	237	192.5 $\pm$ 7.1	0
$2\gamma\bar{p}$	128	107.2 $\pm$ 6.9	0	$j\gamma\bar{p}$	103319	102124 $\pm$ 570.6	0	$b4j$ high- $\Sigma_{pT}$	26	23.4 $\pm$ 2.6	0
$2\gamma$	5548	5562.8 $\pm$ 40.5	0	$j\gamma$	71	98 $\pm$ 3.9	0	$b4j$ low- $\Sigma_{pT}$	836	821.7 $\pm$ 15.9	0
$2j$ high- $\Sigma_{pT}$	190773	190842 $\pm$ 781.2	0	$\mu^\pm\tau^\mp$	15	12 $\pm$ 2	0	$b3j$ high- $\Sigma_{pT}$	12081	12071 $\pm$ 84.1	0
$2j$ low- $\Sigma_{pT}$	165984	162530 $\pm$ 1581	0	$\mu^\pm\bar{p}$	26	30.8 $\pm$ 2.6	0	$b3j$ low- $\Sigma_{pT}$	2974	2873 $\pm$ 31	0
$2j2\tau^\pm$	22	40.6 $\pm$ 3.2	0	$\mu^\pm\bar{p}$	109081	108323 $\pm$ 707.7	0				
$2j2\gamma\bar{p}$	11	8 $\pm$ 2.4	0	$\mu^\pm\bar{p}$	171	171.1 $\pm$ 31	0				
$2j2\gamma$	580	581 $\pm$ 13.7	0	$\mu^\pm\gamma\bar{p}$	152	190 $\pm$ 39.3	0				
$2j\tau^\pm$ high- $\Sigma_{pT}$	96	114.6 $\pm$ 3.3	0	$\mu^\pm\gamma$							

# Vista Final State Summary



No final state exhibits a significant population discrepancy,  
after accounting for the trials factor

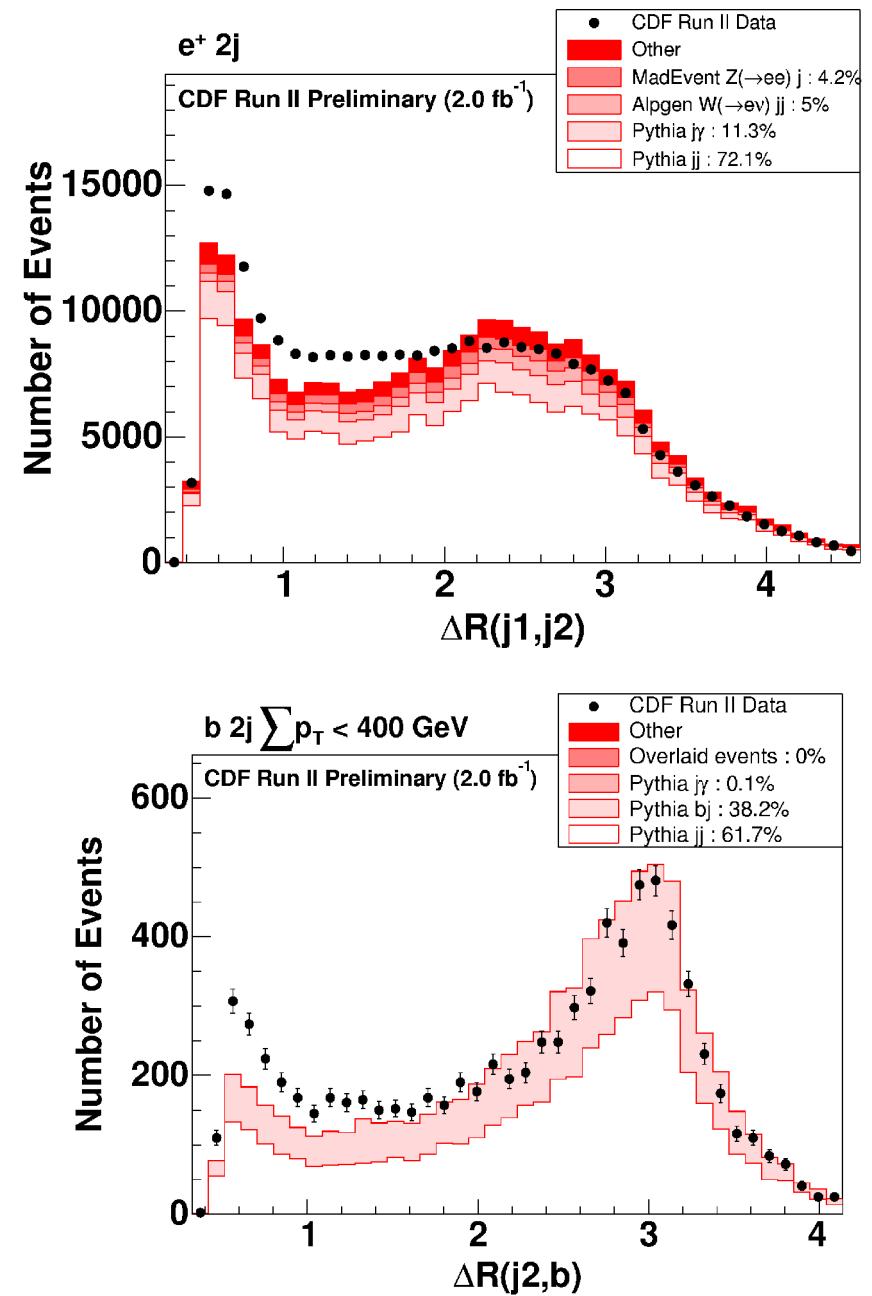
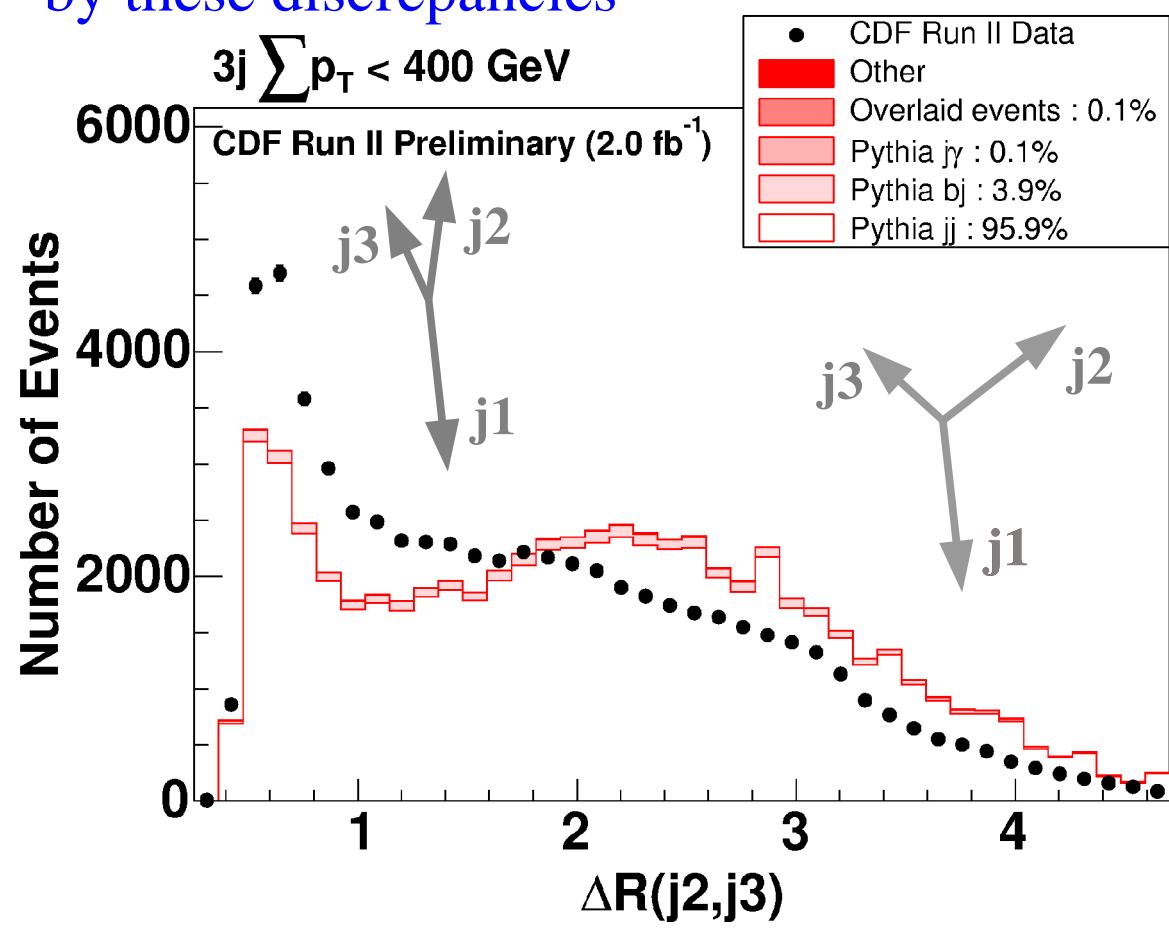
# Vista Shapes Summary



Interest is focused on these 559 shapes  
that show significant discrepancy

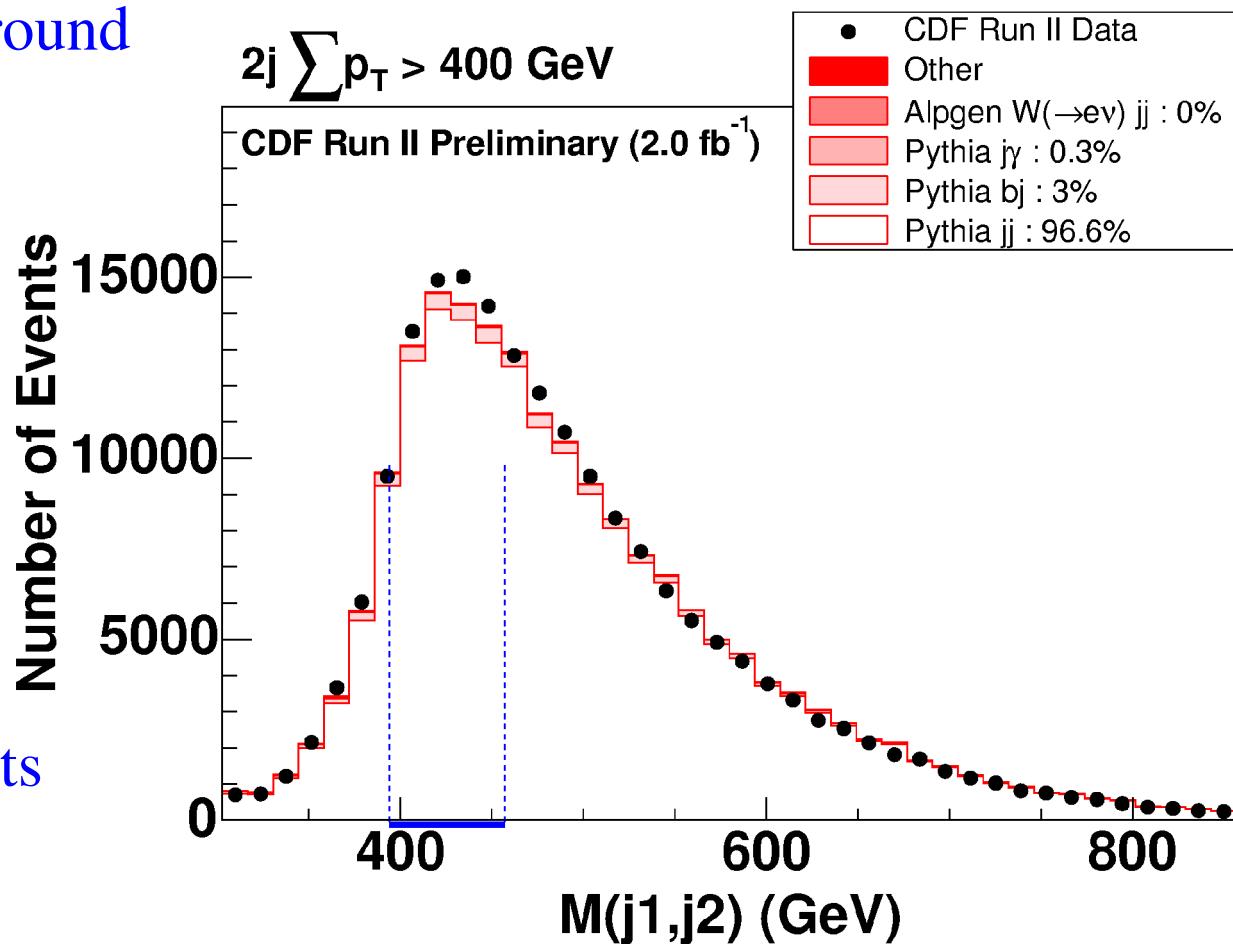
# Vista Shape Discrepancies

- Most shape discrepancies caused by difficulty in modelling soft jet emission
- No claim for new physics is motivated by these discrepancies

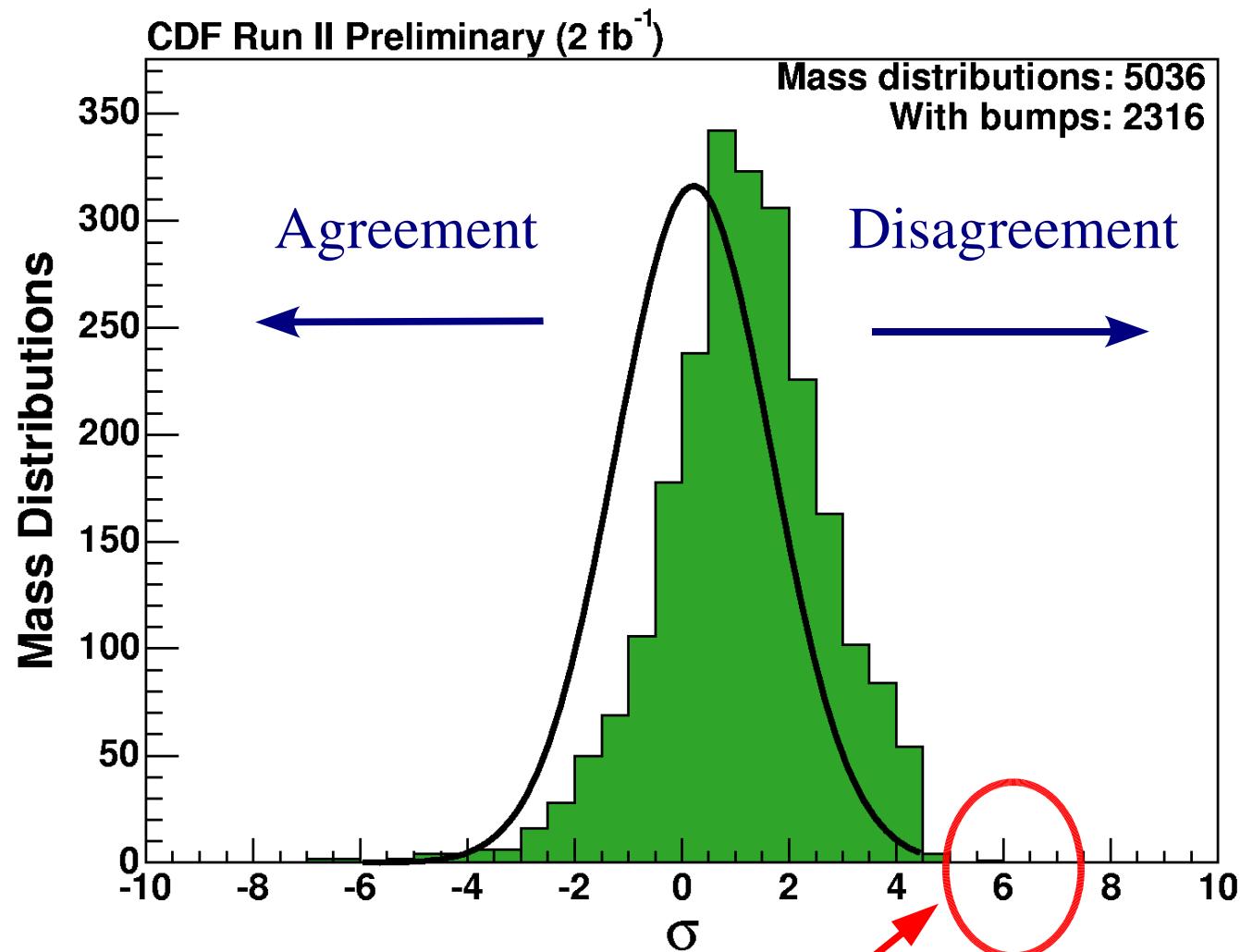


# Bump Hunter

- Search for narrow resonances in invariant masses
- Define a search window of  $2\Delta M$  ( $\Delta M$  = expected detector mass resolution)
- Compare data to SM background
- Define a possible 'bump':
  - at least 5 data events
  - verify that 'side-bands' agree better than center
- Estimate significance of bumps by pseudo-experiments

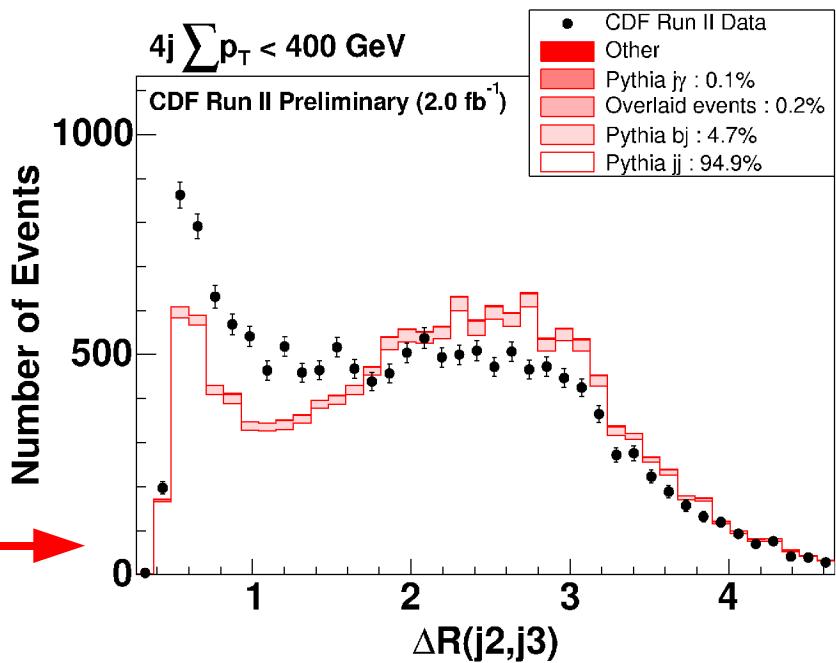
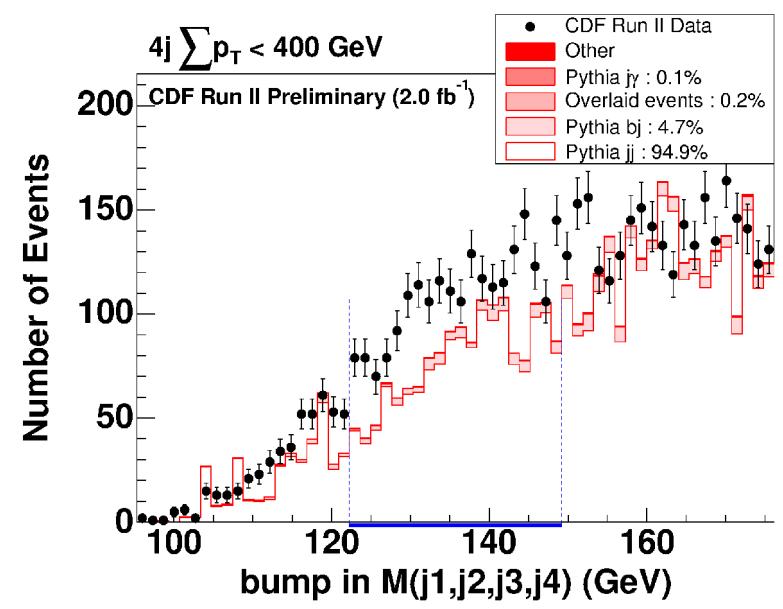
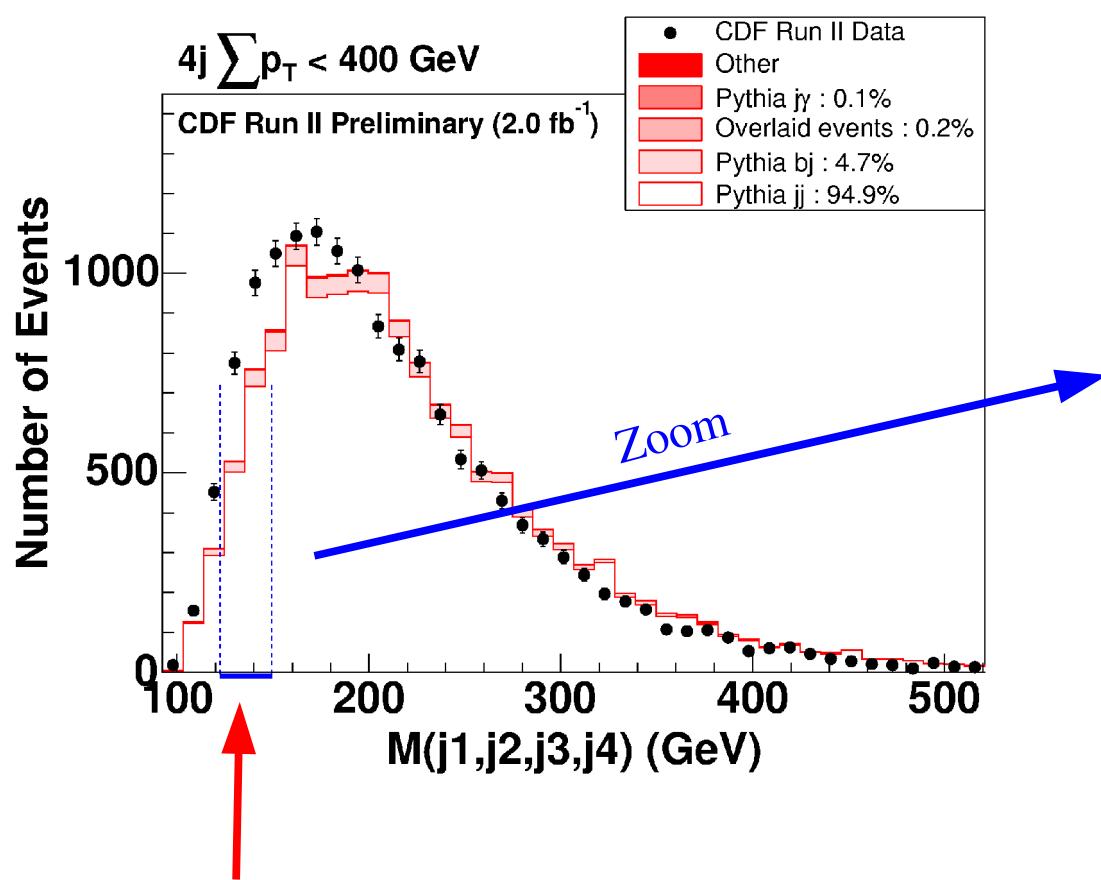


# Bump Hunter Results Overview



Only 1 invariant mass distribution has a bump with significance above the discovery threshold

# Bump Hunter Results



- This is the only 'discovery-level' bump found
- But we do not believe this indicates new physics – attribute it to the QCD  $\Delta R$  modelling problem seen earlier

# Sleuth

- Sleuth assumption:

- new physics will appear as an excess of data at high  $\Sigma p_T$   
predominantly in one final state

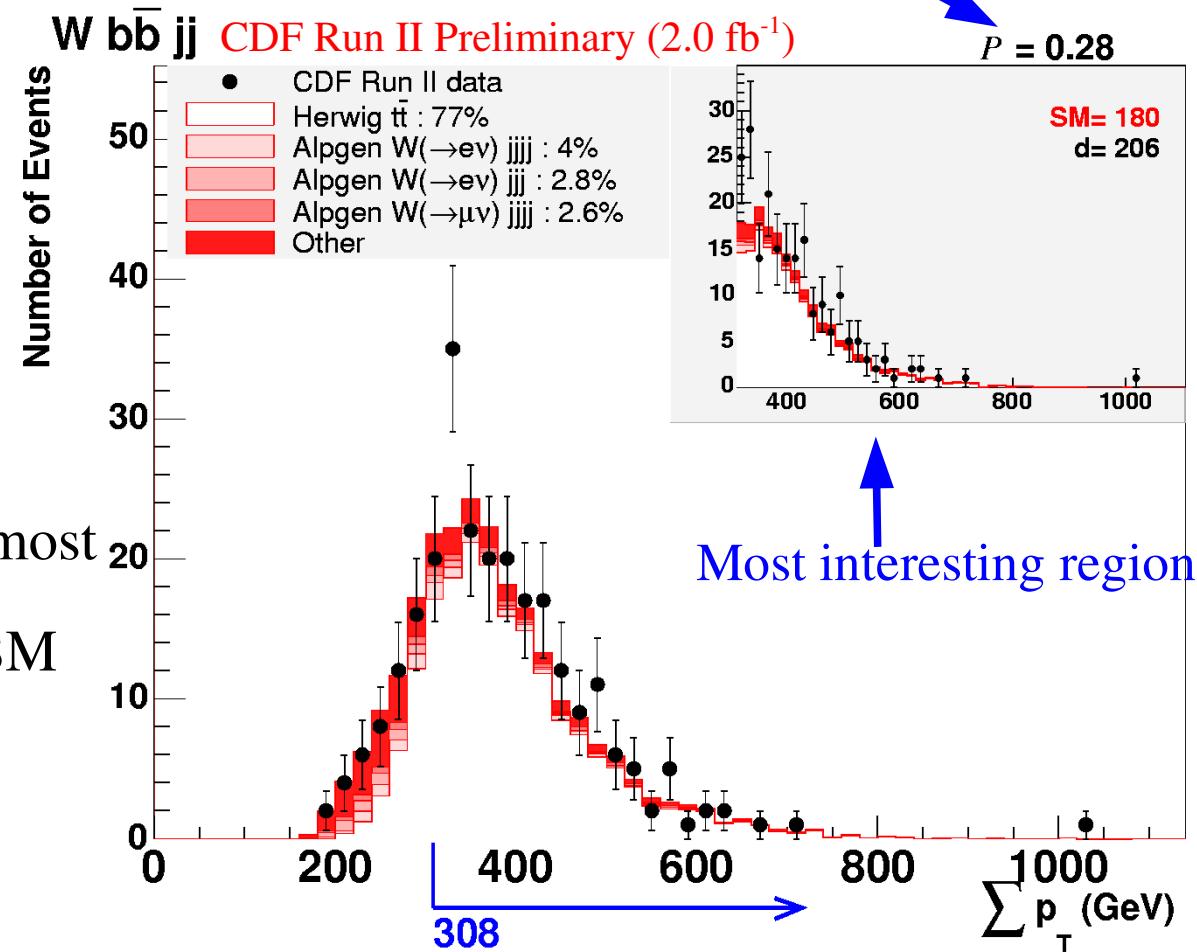
- Sleuth's variable:

$$\sum p_T \equiv \sum_i |\vec{p}_i| + |\vec{\text{uncl}}| + |\vec{p}|,$$

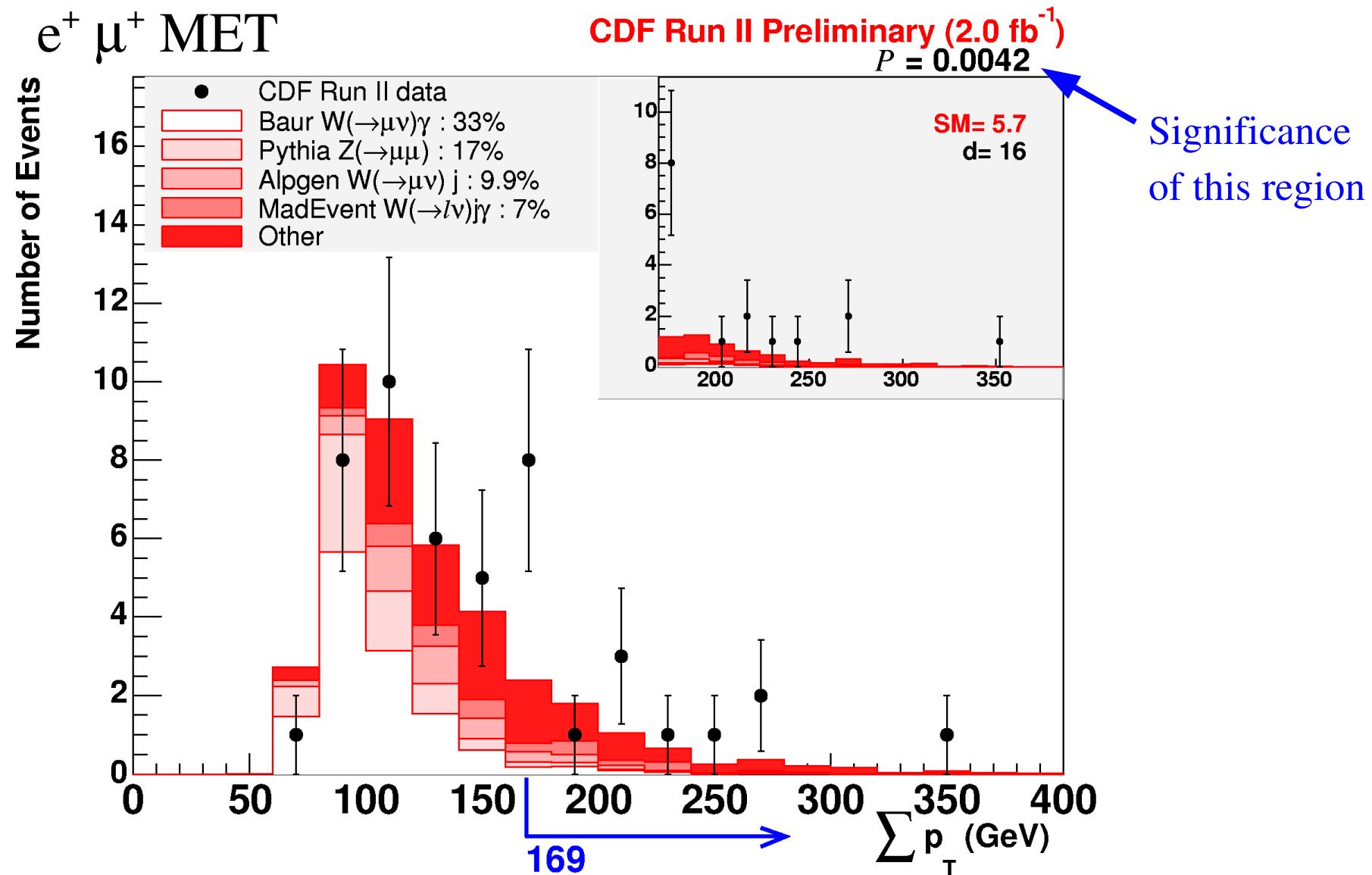
- For each Sleuth final state:

- scan the  $\Sigma p_T$  spectrum
- select one-sided region with most significant excess of data over SM

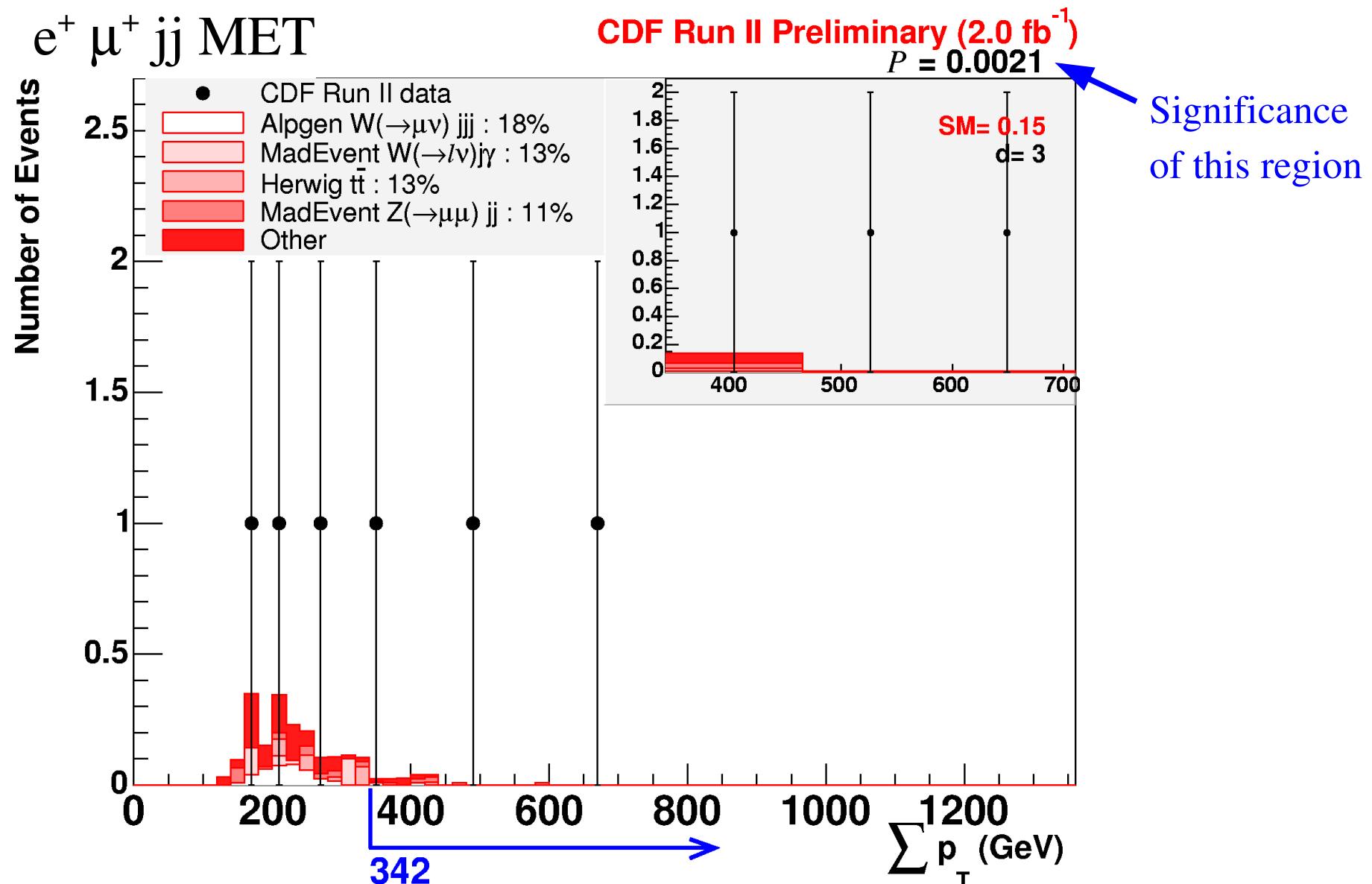
- Perform pseudo-experiments  
to assess the significance



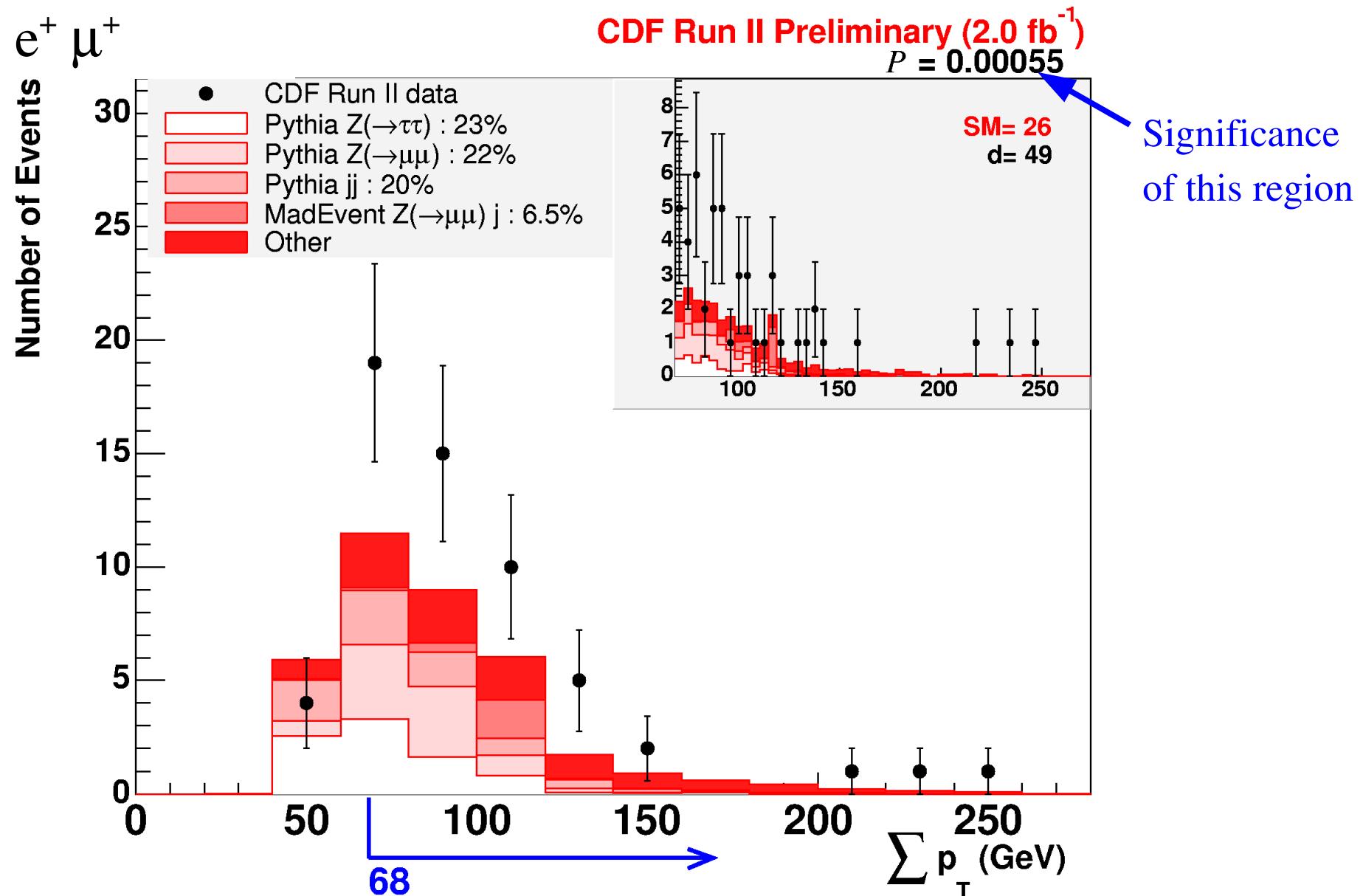
# Sleuth #3 Final State



# Sleuth #2 Final State



# Sleuth #1 Final State



# Sleuth Results

- Summary of top Sleuth final states:

SLEUTH Final State	CDF Run II Preliminary ( $2.0 \text{ fb}^{-1}$ )
$\ell^+ \ell'^+$	0.00055
$\ell^+ \ell'^+ \not{p}_{T,jj}$	0.0021
$\ell^+ \ell'^+ \not{p}_T$	0.0042
$\ell^+ \ell^- \ell' \not{p}_T$	0.0047
$\ell^+ \tau^+ \not{p}_T$	0.0065

- How significant is the most discrepant excess seen by Sleuth, after accounting for the trials factor?

- Sadly, not very significant:

- $\sim 8\%$  of hypothetical similar CDF experiments are expected to give a more interesting excess, purely by chance

- There is no discovery claim arising from Sleuth with  $2.0 \text{ fb}^{-1}$  of data

# Conclusions

- CDF has performed a model-independent global search for new physics in  $2.0 \text{ fb}^{-1}$  of data
- Vista considered the bulk features of the high- $p_T$  data: final state populations and shapes of kinematic distributions
- The Bump Hunter searched for narrow resonances in invariant mass distributions
- Sleuth searched for excesses of data at high sum- $p_T$
- None of these techniques found a significant ( $\sim 5\sigma$ ) effect that could motivate a new physics claim
- The hunt for new physics at the Tevatron will continue!