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General Search for New Phenomena in *ep* Scattering at HERA

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Collaboration

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General Search for New Phenomena at HERA-I

HERA-I (1994-2000, $e^\pm p$ scattering at $\sqrt{s} \sim 320$ GeV, $\mathcal{L} = 115 \text{ pb}^{-1}$)

- Complete and well understood data set
- Important goal at HERA \Rightarrow Search for new physics beyond the SM
- New physics \Rightarrow Final state topologies with high transverse momenta P_T

General search

- Investigate **all high** P_T final states in a **coherent** way in one analysis
- Search for deviations from SM in a **BSM-independent** way
- Already existing deviations at H1 in isolated lepton and multi-lepton events

\Rightarrow Have we missed something?

Analysis Strategy

▷ Investigate all final state topologies of ep -interactions with ≥ 2 particles

▷ Considered particles are

electrons, muons, photons, jets, neutrinos

neutrinos \Rightarrow non-interacting particles

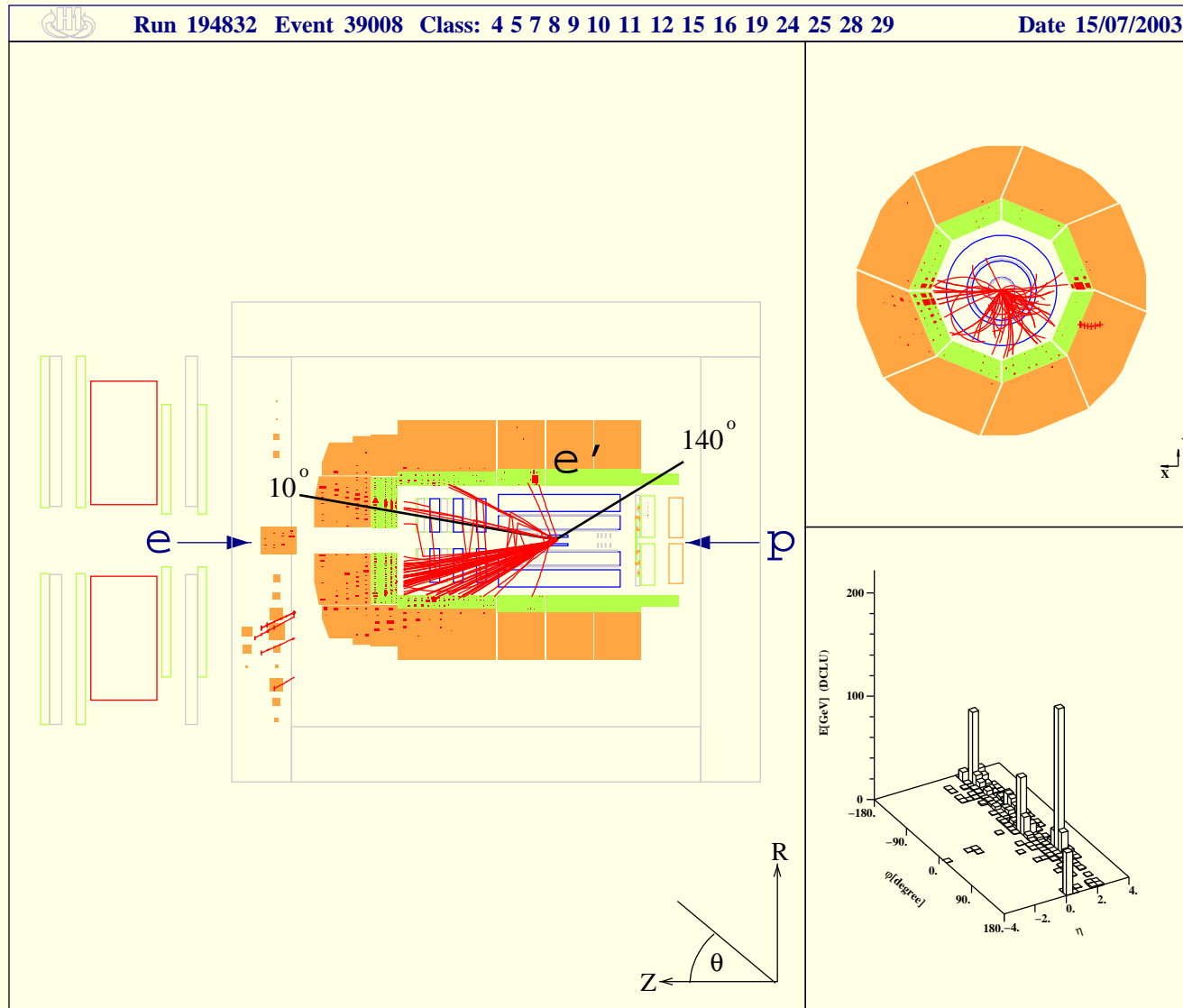
▷ Common phase-space at high P_T for all particles

$$P_T^{\text{part}} > 20 \text{ GeV} \quad 10^\circ < \theta^{\text{part}} < 140^\circ \quad D_{\eta-\phi}^{\text{part}} > 1$$

▷ Classification of events into **exclusive** classes according to their final state

$e-j$, $j-j$, $\mu-j$, $j-\nu$, $j-\gamma$, ... , $e-e-j$, $j-j-j$, ...

Interesting Events



Interesting final state topologies observable in this analysis

e - j - j - j - j event

Analysis Strategy

- ▷ Investigate all final state topologies of ep -interactions with ≥ 2 particles
- ▷ Considered particles are **electrons, muons, photons, jets** and **neutrinos**
- ▷ Common phase-space at high P_T for all particles

$$P_T^{\text{part}} > 20 \text{ GeV} \quad 10^\circ < \theta^{\text{part}} < 140^\circ \quad D_{\eta-\phi}^{\text{part}} > 1$$

- ▷ Classification of events into **exclusive** classes according to their final state

$$e-j, j-j, \mu-j, j-\nu, j-\gamma, \dots, e-e-j, j-j-j, \dots$$

- ▷ Search for deviations between data and SM prediction in

invariant mass M_{all}

and

$\sum P_T$ distributions

of all classes with a new algorithm

- ▷ Quantification of the found deviations (statistical significance)

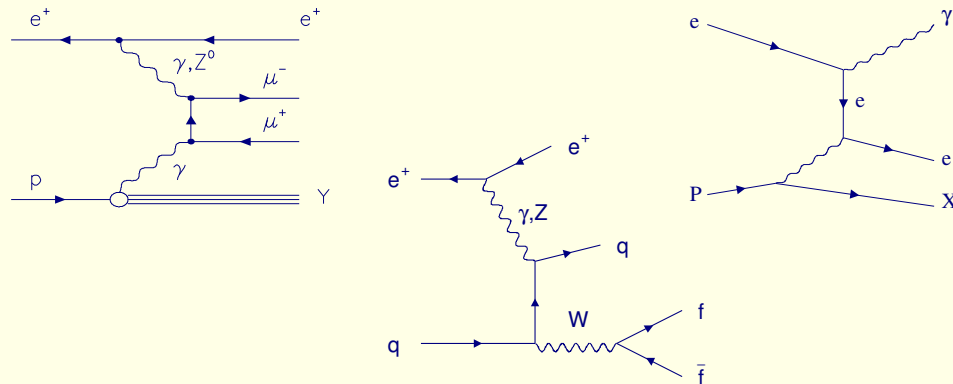
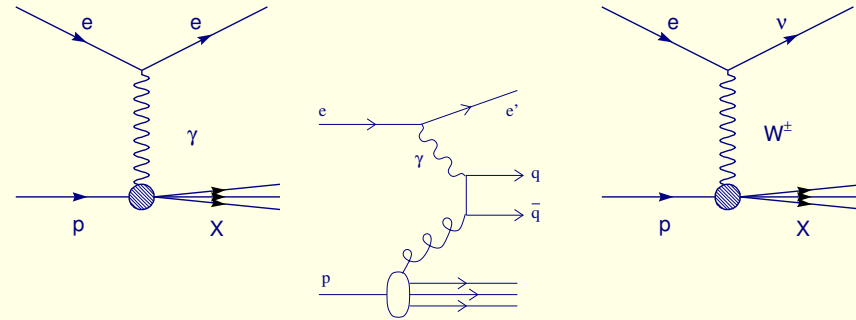
SM Processes and MC generation

⇒ General Search needs SM predictions for all processes at HERA

▷ DIS Neutral Current (Rapgap)

▷ DIS Charged Current (Django)

▷ Photoproduction (Pythia)



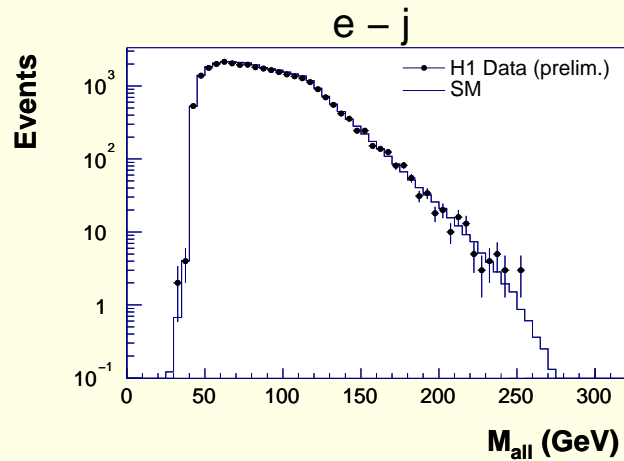
▷ Lepton Pair Production (Grape)

▷ QED Compton (Wabgen)

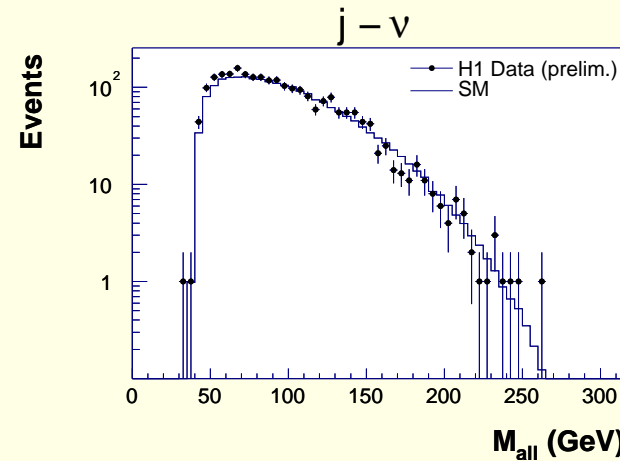
▷ W Production (Epvec)

⇒ QCD processes: $\mathcal{O}(\alpha_s) + \text{PS}$ or QED processes: $\mathcal{O}(\alpha^2) + \text{PS}$

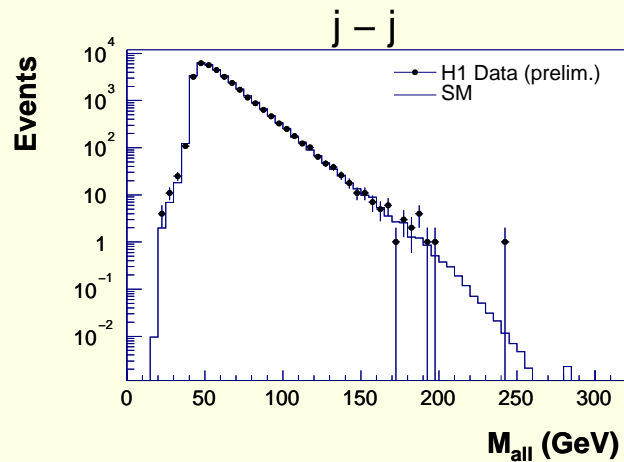
Results – Dominant Processes at HERA



⇐ Neutral Current DIS



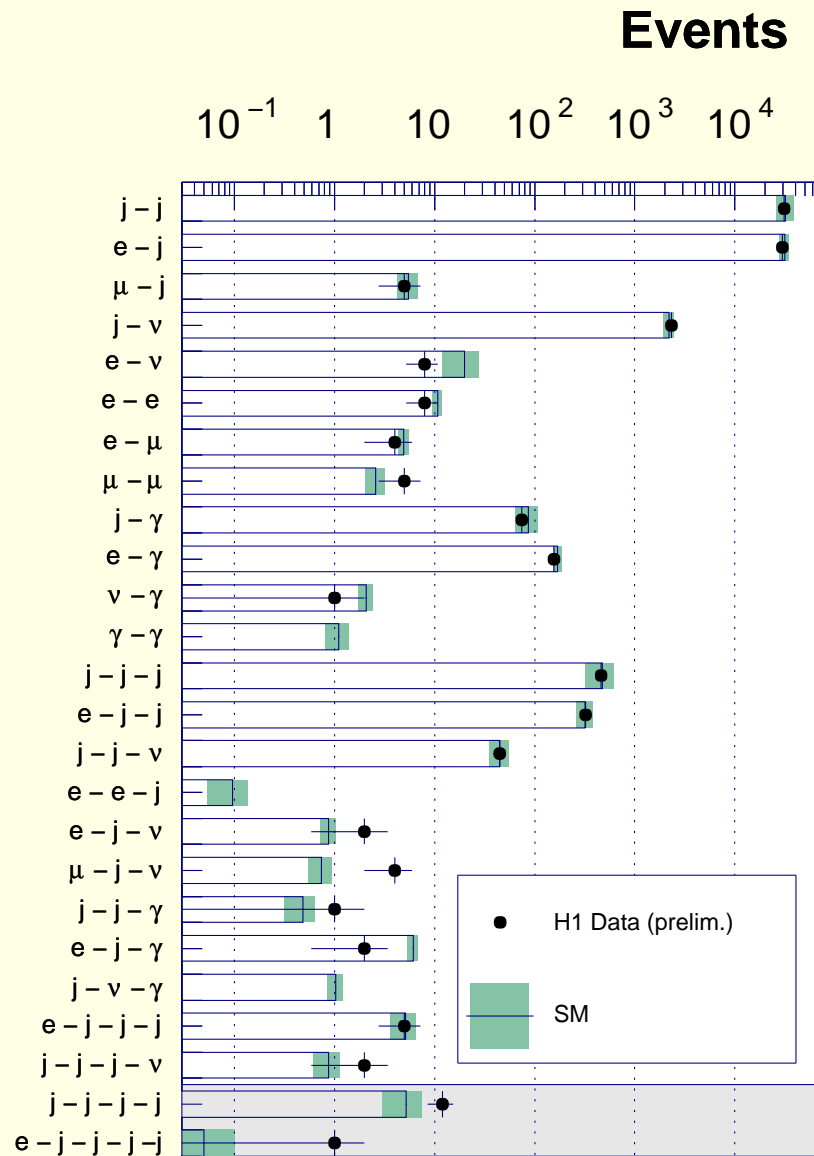
Charged Current DIS ⇒



⇐ Photoproduction

⇒ Good understanding of SM physics up to borders of phase space

Results – Event Yields



⇒ All possible event classes with ≥ 2 particles investigated

⇒ High efficiencies and purities in most event classes

⇐ Representation of all event classes with $N_{\text{data}} \geq 1$ or $N_{\text{SM}} \geq 0.1$

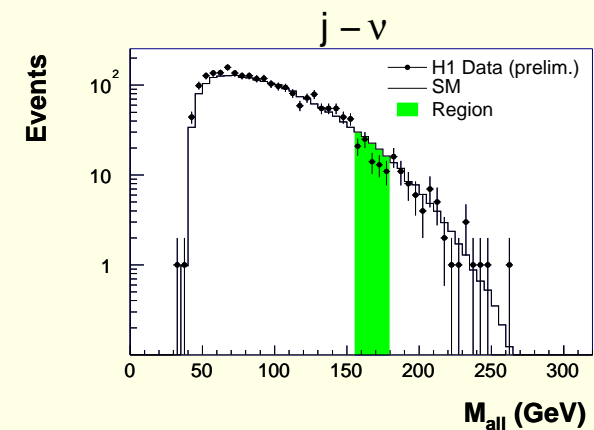
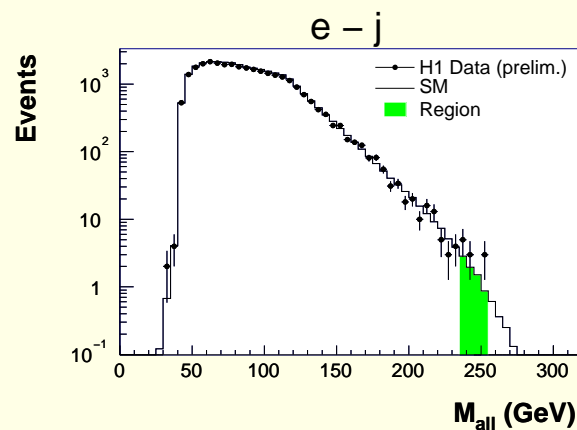
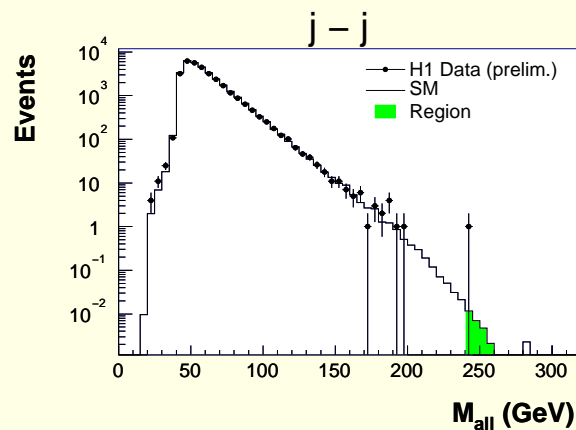
⇐ $j-j-j-j$ and $e-j-j-j-j$ event class will not be passed through the statistical analysis

⇒ **Overall agreement**
in most event classes

Search for Deviations – Regions of Interest

Search for deviations between data and SM prediction in distributions of invariant mass M_{all} and $\sum P_t$ in all event classes

- ➔ Check all possible connected regions with a size \geq resolution in a histogram (i.e. calculate probability p via Poisson and Gaussian statistics, that data agrees with SM)
- ➔ Region of greatest interest is the one with the smallest probability p



Search for Deviations – Global Significance

Quantify deviation by calculating the probability \hat{P} to find such a deviation anywhere in the distribution

➔ Dice random histograms H_{ran} according to the probability density function of the expectation

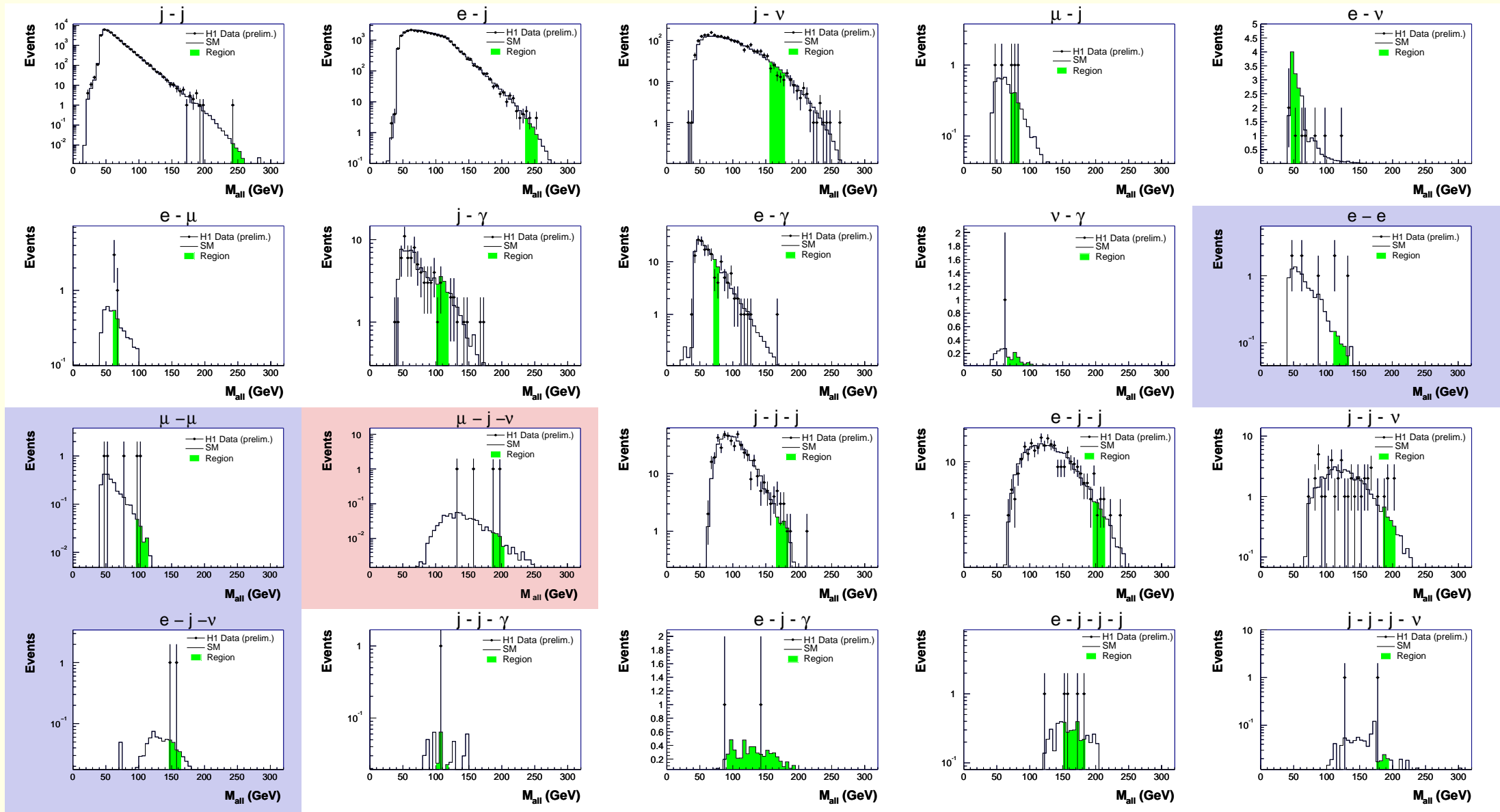
$$\hat{P} = \frac{\text{number of } H_{\text{ran}} \text{ with } p_{\text{ran}} < p_{\text{min,data}}}{\text{number of } H_{\text{ran}}}$$

➔ Event Class of most interest is the one with the smallest \hat{P}

Compare the obtained \hat{P} values with the expectation by replacing all data distributions with hypothetical MC distributions (MC experiments)

If deviations are only due to statistical or systematical fluctuations the \hat{P} distributions of MC experiments and real H1 data are compatible

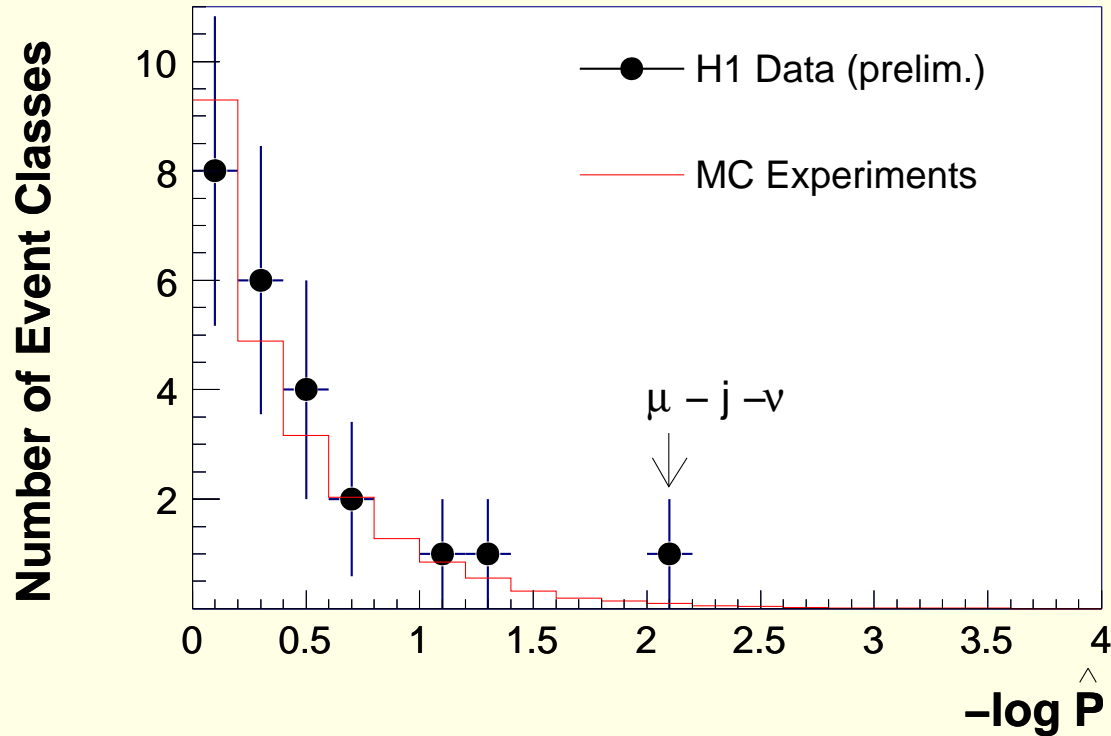
Selected Regions – M_{all} Scan



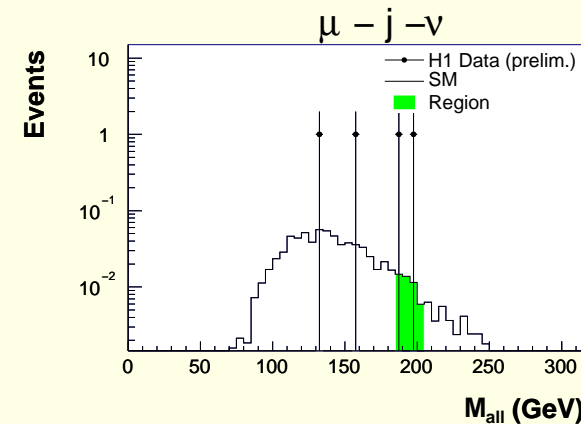
Results – M_{all} Scan

Interesting and/or
previously published event classes:

H1 General Search – M_{all} results



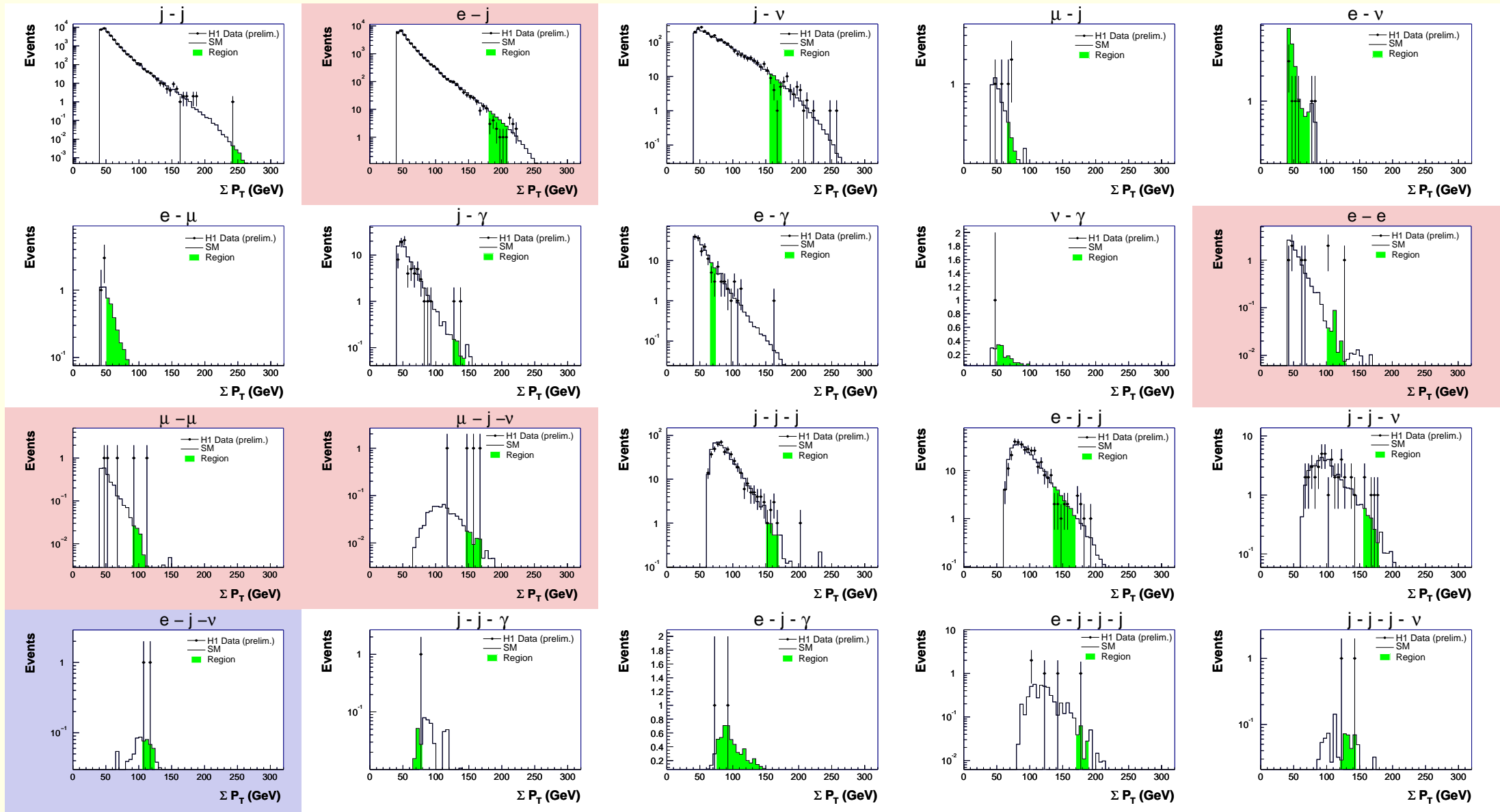
Event class	\hat{P}
$e-e$	0.28
$\mu-\mu$	0.05
$e-j-\nu$	0.10
$\mu-j-\nu$	0.01



▷ Good agreement between data and MC experiments

▷ Probability to find one event class with $\hat{P} \leq 0.01$ ($\mu-j-\nu$) is $\sim 25\%$

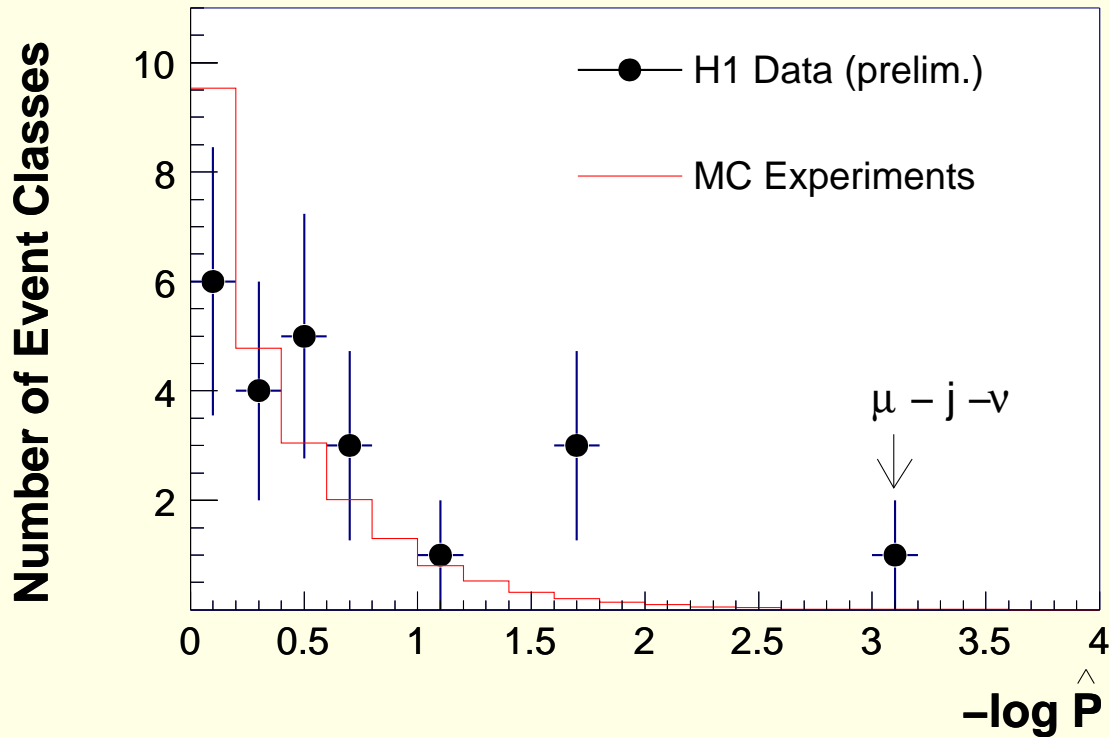
Selected Regions – $\sum P_T$ Scan



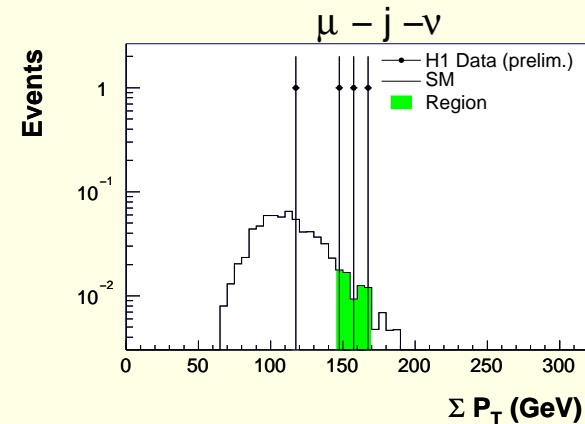
Results – $\sum P_T$ Scan

Interesting and/or
previously published event classes:

H1 General Search – $\sum P_T$ results



Event class	\hat{P}
$e-j$	0.023
$e-e$	0.023
$\mu-\mu$	0.018
$e-j-\nu$	0.16
$\mu-j-\nu$	0.0008



▷ Larger deviations than in the mass distributions

▷ Probability to find one event class with $\hat{P} \leq 0.0008$ ($\mu-j-\nu$) is $\sim \mathcal{O}(2\%)$

Summary

- ▷ Invariant mass M_{all} and $\sum P_T$ distributions have been investigated for all measurable high P_T jet, lepton, photon final states in one analysis
 - ▷ Good agreement between data and SM found in most of the event classes
 - ▷ BSM-independent search for deviations between data and SM has been performed with a new algorithm
 - ▷ No new significant deviation found
 - ▷ Most interesting event class μ - j - ν
(consistent with a previously observed deviation)
- ⇒ Most complete analysis of HERA data at high P_T
- ⇒ Looking forward to HERA-II