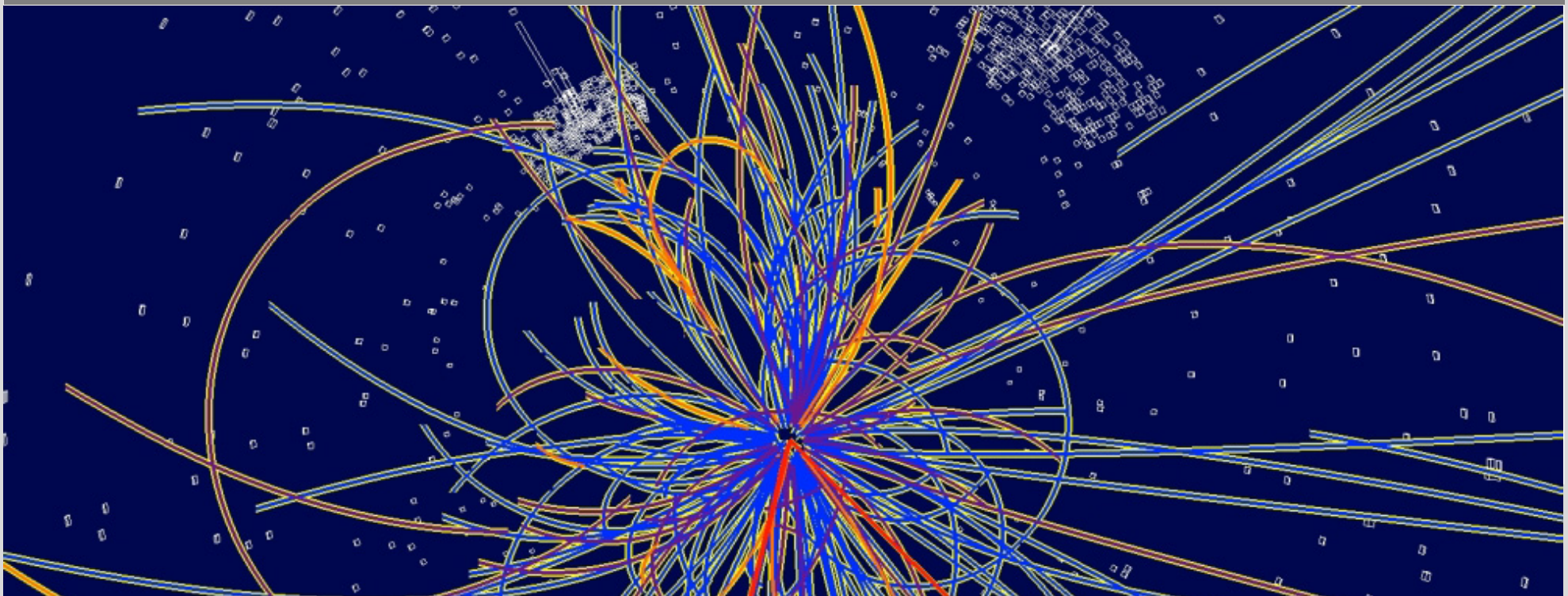
INSTITUTE FOR THEORETICAL PHYSICS, HEIDELBERG UNIVERSITY

W/Z+jets and multijets

Christoph Englert | 22.07.2011

INTERNATIONAL EUROPHYSICS CONFERENCE ON HIGH ENERGY PHYSICS, GRENOBLE



physics baseline by today

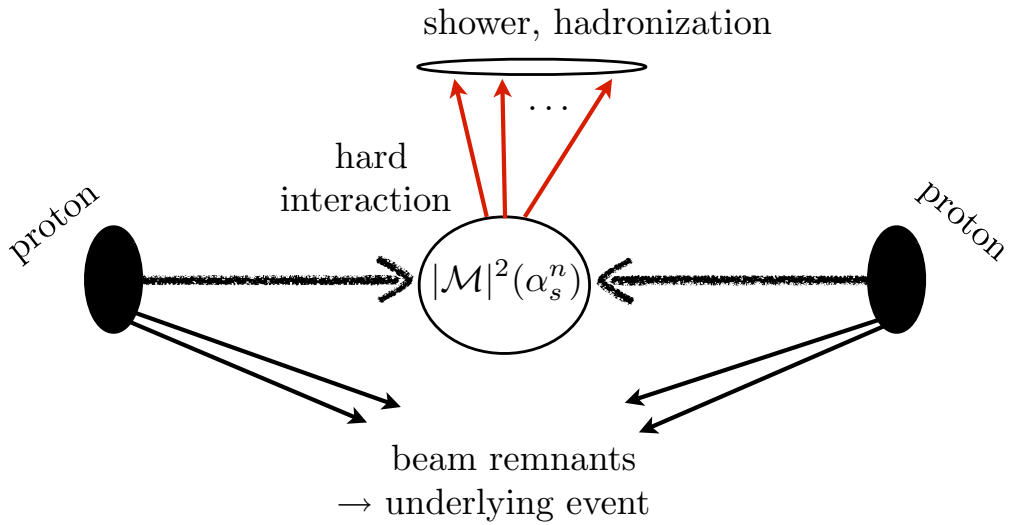
we have not explored the Fermi scale with our own eyes until now, but [LEPEWG '10]

$\Lambda \lesssim m_W$:

$$SU(3)_C \times SU(2)_L \times U(1)_Y \xrightarrow{?} SU(3)_C \times U(1)_Q$$
$$W^{\pm}, Z \sim [SU(2)_L \times U(1)_Y]/U(1)_Q$$

+ indirect constraints from high scales leaving low-energy footprints: S, T, U, $Z\bar{b}b$, ...

BSM phenomenology means entering the regime $\Lambda \gg m_W$ in the electroweak sector:



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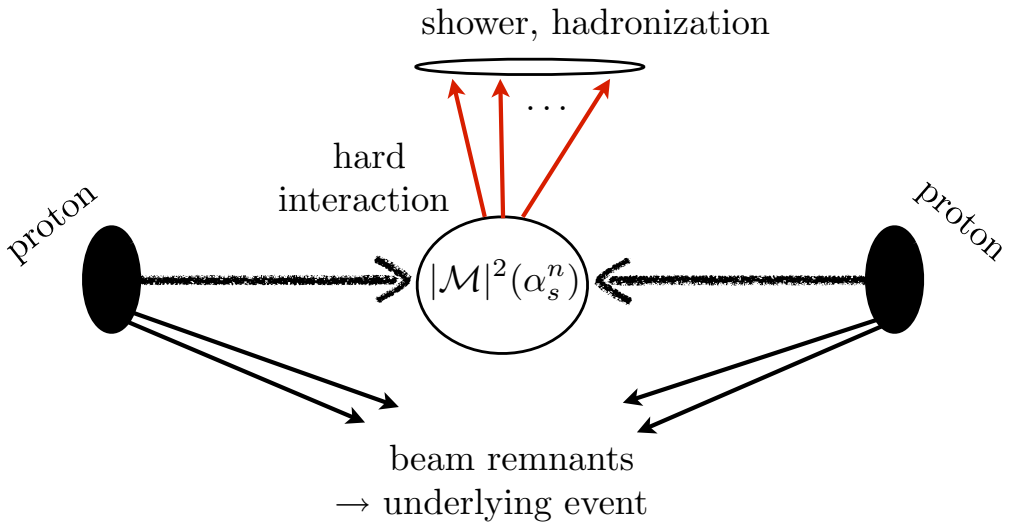

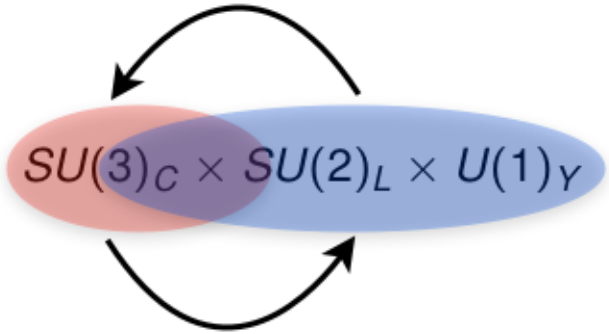

- sectors communicate $\sim \Lambda$
- re-establish known physics & MCs at new scales

S/B $\sim$ 1: busy multijet final states, missing energy

yesterday's sensation...

...is already yesterday's calibration!

W/Z+jets

- in-situ jet energy scale calibration
  [ATL-PHYS-PUB-2009-000]
  [CMS-PAS-JME-09-005]
- $W, Z, \ell^{\pm}, \not\!\!E_T$ reconstruction
  [ATLAS-CONF-2010-057]
  [CMS-JME-10-009]
- $\tau^{\pm}$ identification [CMS arXiv:1104.1617]
- MC validation [ATLAS arXiv:1012.5382]

QCD jets

- fake-$\not\!\!E_T$ [ATLAS-CONF-2010-065]
  [CMS-PAS-JME-10-004]
- MC validation [ATLAS-CONF-2010-084]
  [CMS-PAS-QCD-10-011]
- Central Jet Veto performance
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Get everything in place for SUSY and Higgs searches

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theoretical status

W/Z+jets

- NLO precision for $W/Z + 0, 1$ jet
  [Giele, Glover, Kosower Nucl. Phys. **B403** (1993) 633]
  [Brensing *et al.* arXiv:0710.3309]
  [Denner *et al.* arXiv:1103.0914, arXiv:0906.1656]
- NNLO precision for W/Z
  [Anastasiou *et al.* hep-ph/0312266]
- approx. NNLO for $Z + 1$ jet
  [Rubin, Salam, Sapeta arXiv:1006.2144]
- NLO precision for $W/Z + 2$ jets
  [Campbell, Ellis hep-ph/0202176, MCFM]
- NLO precision for $Z + 3$ jets
  [BLACKHAT+SHERPA, arXiv:1004.1659]
- NLO precision for $W + 3$ jets
  [BLACKHAT+SHERPA, arXiv:0902.2760]
  [ROCKET, arXiv:0910.3671]
- NLO precision for $W + 4$ jets
  [BLACKHAT+SHERPA, arXiv:1009.2338]

- NLO precision for diboson+jet, triboson+jet
  [Dittmaier *et al.* 0710.1577] [Binoth *et al.* 0911.3181]
  [VBFNLO, 1107.4038] [Campanario *et al.* 1106.4009]

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theoretical status

QCD jets

- NLO precision for 2 jets
  [Ellis, Kunszt, Soper Phys. Rev. Lett. **69**, 1496 (1992)]
- NNLO precision for $qq \to qq$, $gq \to gq$
  [Anastasiou *et al.* hep-ph/0101304, hep-ph/0012007]
  [Bern, De Freitas, Dixon hep-ph/0304168]
- NLO precision for 3 jets
  [Frixione, Kunszt, Signer hep-ph/9512328]
  [Nagy hep-ph/0110315, hep-ph/0307268, NLOJET++]

pQCD $\oplus$ shower matching approaches

- MC@NLO [Frixione *et al.* arXiv:1010.0568]
- POWHEG box [Alioli *et al.* arXiv:1002.2581]
  - HERWIG++ [D'Errico, Richardson arXiv:1109.1127]
  - HERWIG, PYTHIA [Alioli *et al.* arXiv:1012.3380]
  - SHERPA [Höche *et al.* arXiv:1008.5399]
- MENLOPS [Höche *et al.* arXiv:1009.1127]

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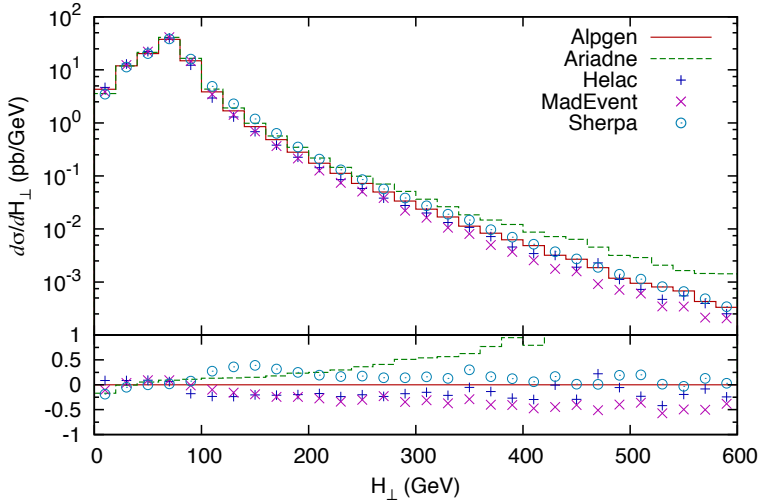
MC validation

tree level matching of W/Z+jets and multijets

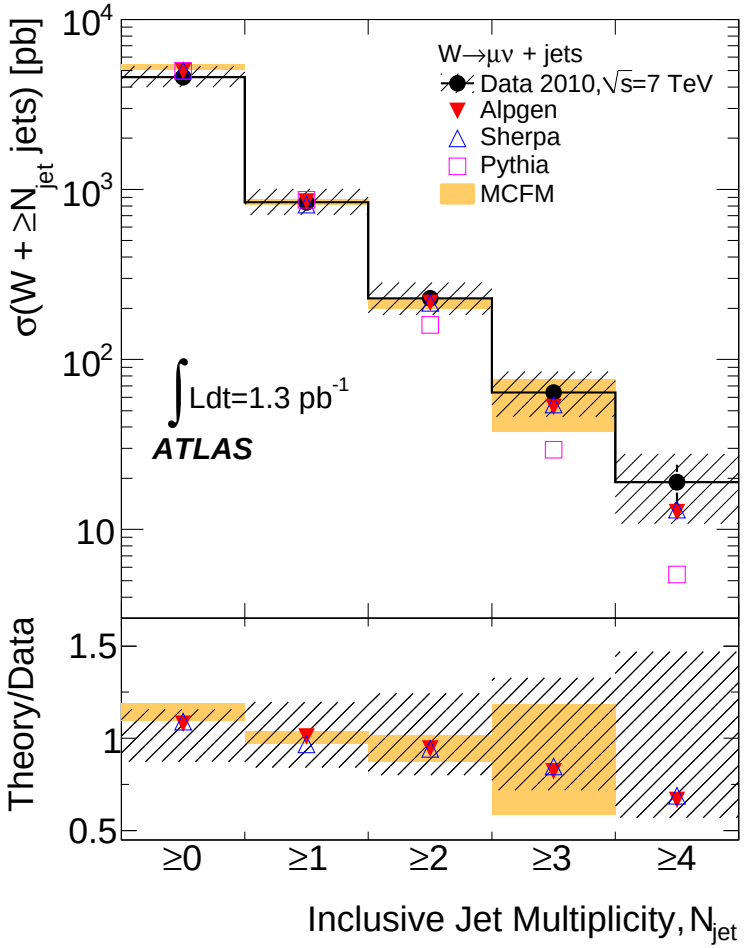
- MLM in ALPGEN [Mangano *et al.* hep-ph/0206293]
- MLM in MADGRAPH/MADEVENT
  [Alwall *et al.* arXiv:1106.0522]
- MLM in HELAC-PHEGAS
  [Cafarella, Papadopoulos, Worek arXiv:0710.2427]
- ARIADNE [Lönnblad hep-ph/0112284]
- CKKW in SHERPA [Catani *et al.* hep-ph/0109231]
  [Gleisberg *et al.* arXiv:0811.4622]
- dedicated matched MC comparison for W+jets @ Tevatron [Alwall *et al.* arXiv:0706.2569]

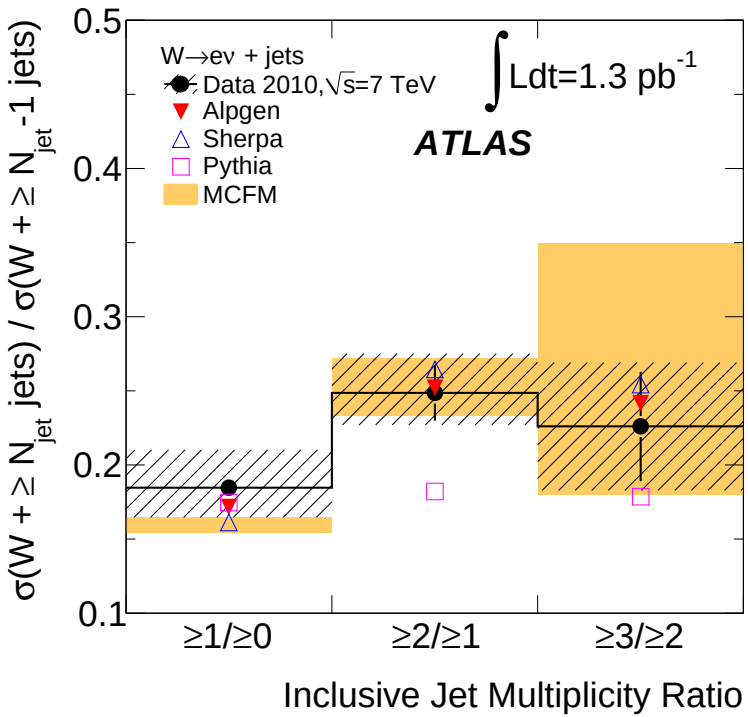


First LHC measurements

W+jets with ATLAS [arXiv:1012.5382]

. . . updates at this conference. . .





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inclusive jets with ATLAS [ATLAS arXiv:1107.2092]

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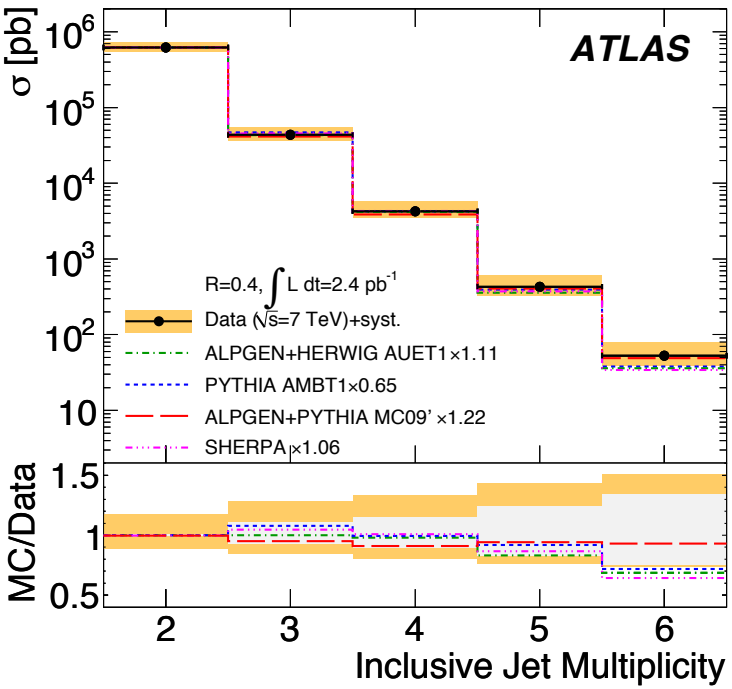

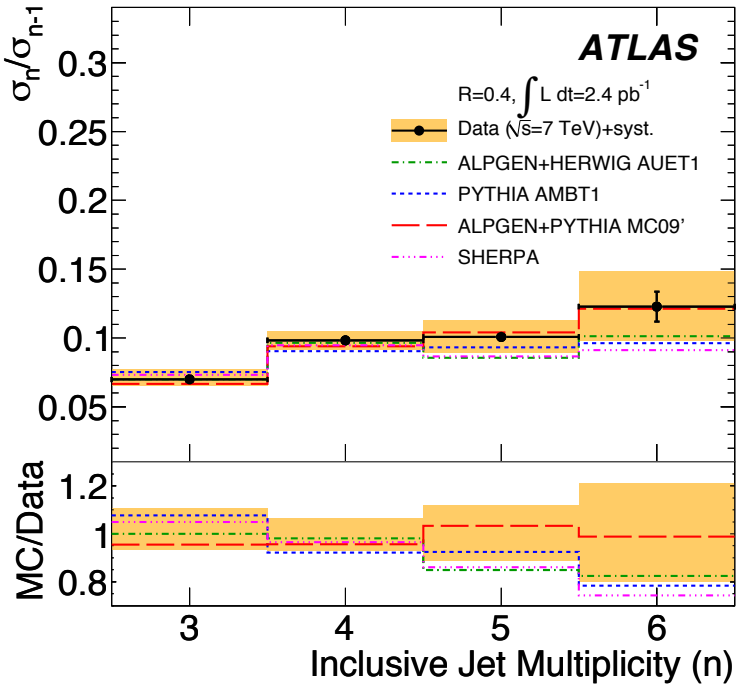

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fake $\not{E}_T$ with ATLAS [ATLAS-CONF-2010-065]

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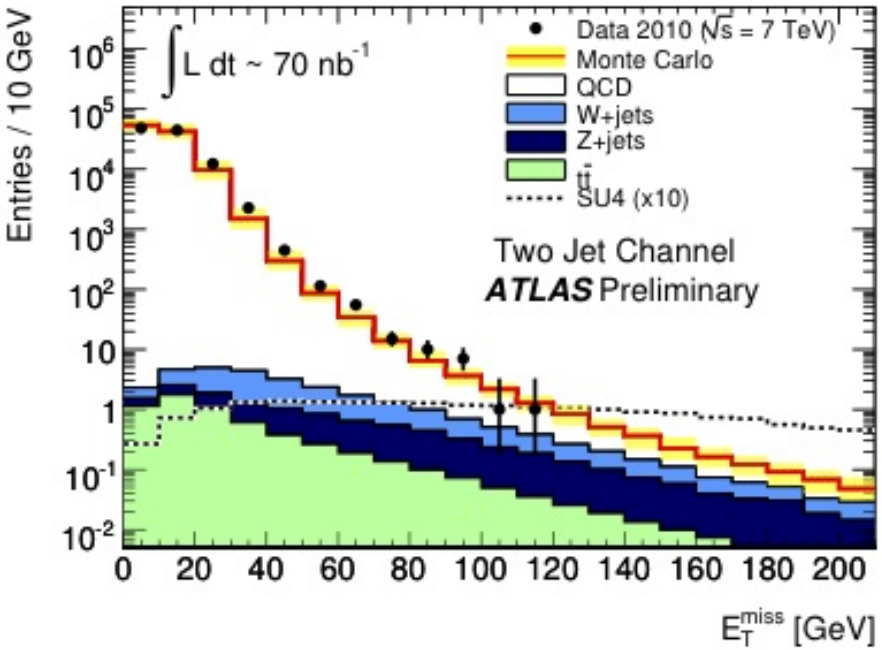
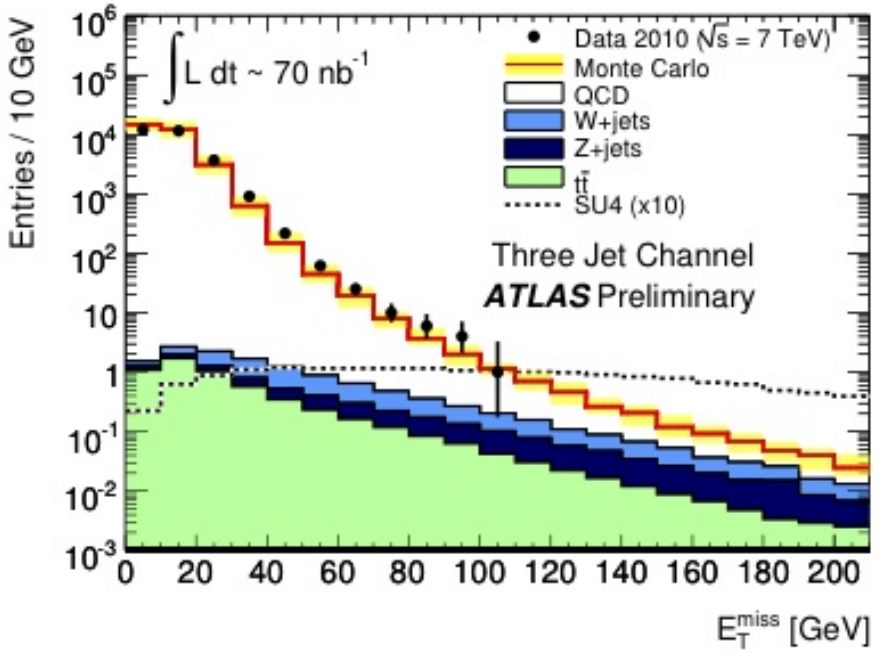




early data & theory $\rightsquigarrow$ new physics

lesson learned from early data & theory

- $\not\!\!E_T$ under control $\rightsquigarrow$ jets + $\not\!\!E_T$ searches

  [ATLAS-CONF-2010-065] [CMS arXiv:1101.1628, arXiv:1106.4503]

- W+jets, Z+jets and QCD jets follow "staircase" scaling

$$\frac{\sigma_n^{\text{incl}}}{\sigma_{n-1}^{\text{incl}}} = R_n \approx R = \text{const} \iff R = \frac{\hat{\sigma}_{n+1}}{\hat{\sigma}_n} \; !$$

- theoretically conjectured behavior for W/Z+jets

  [Ellis, Kleiss, Stirling Phys. Lett. **B154** (1985) 435]

  [Berends et al., Phys. Lett. **B224** (1989) 237]

- consolidated for higher multiplicities by higher order corrections

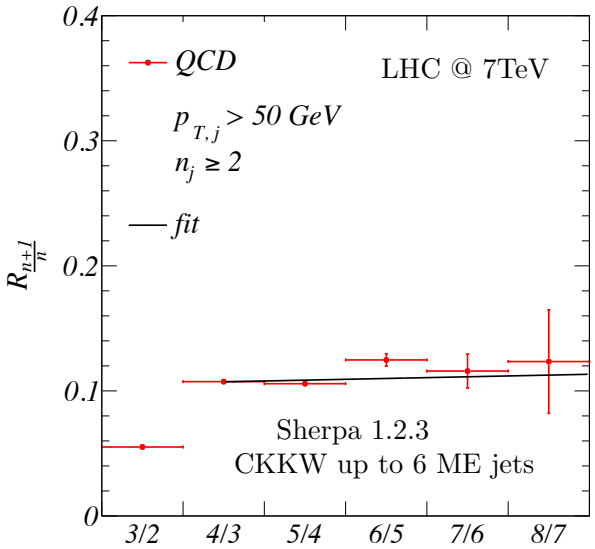
- data well reproduced by matched Monte Carlos

- no deep theoretical understanding (yet)

W+jets, $\sqrt{s} = 7$ TeV

$R_n \equiv \hat{\sigma}_n/\hat{\sigma}_{n-1}$	LO	NLO
R_2	0.2805(1)	0.235(2)
R_3	0.2483(5)	0.223(2)
R_4	0.2394(4)	0.226(2)

[BLACKHAT+SHERPA arXiv:1009.2338]



Can we make use of this?

and the answer is yes in two ways...

[CE, Plehn, Schichtel, Schumann arXiv:1102.4615]

impact of scales

- cuts sufficiently hard yet inclusive

  $\rightsquigarrow$ no intrinsic / cut-induced hard scale

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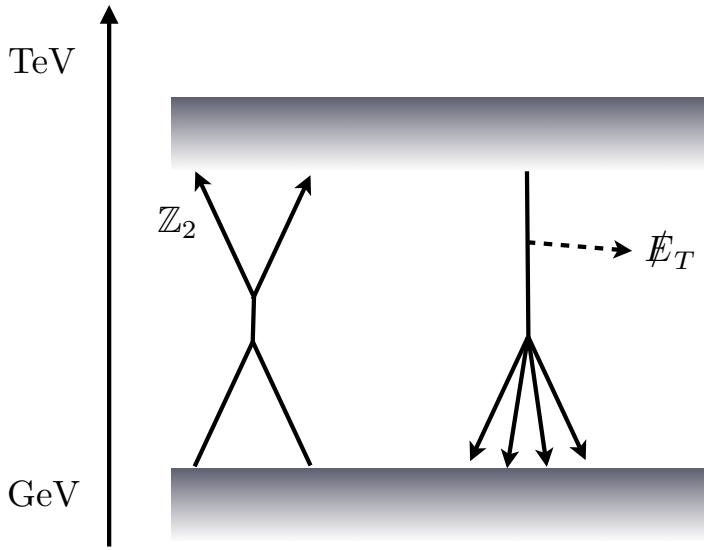
generic strongly-coupled new physics spectrum with a DM candidate

($\rightsquigarrow$ low $\mathcal{L}$ reach)



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$\rightsquigarrow$ offset #jets spectrum

$\rightsquigarrow$ "tilted" radiation pattern wrst QCD

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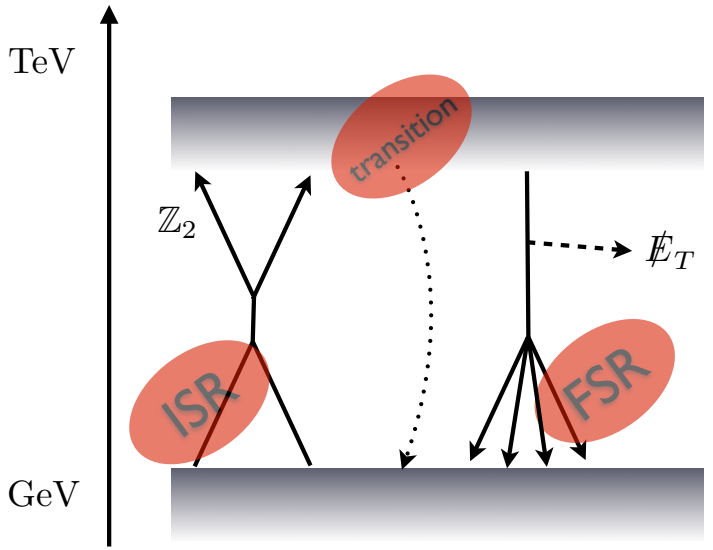

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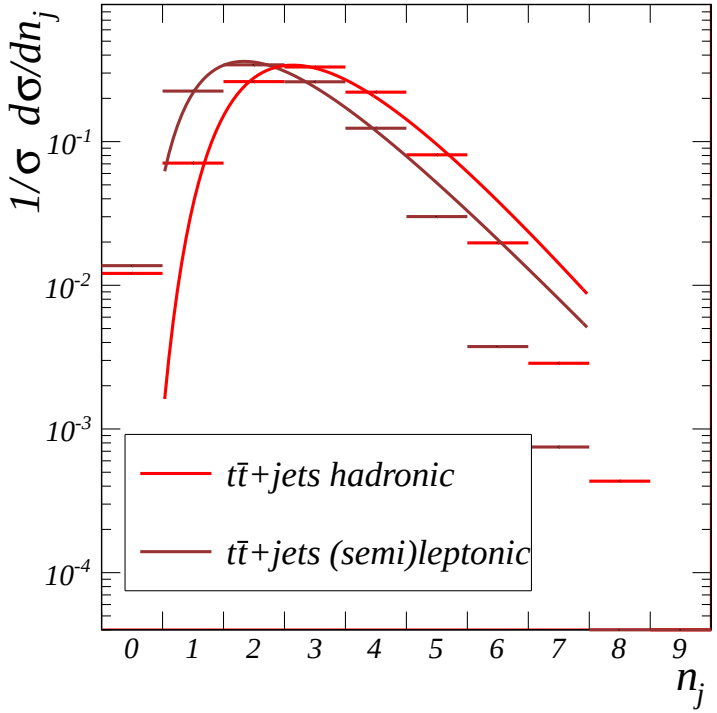
[CMS, EWK-08-006-PAS]



$$\frac{d \log \sigma(n_j)}{dn_j} = -b \frac{n_j^2 - a_1 n_j + a_0^2}{n_j}$$

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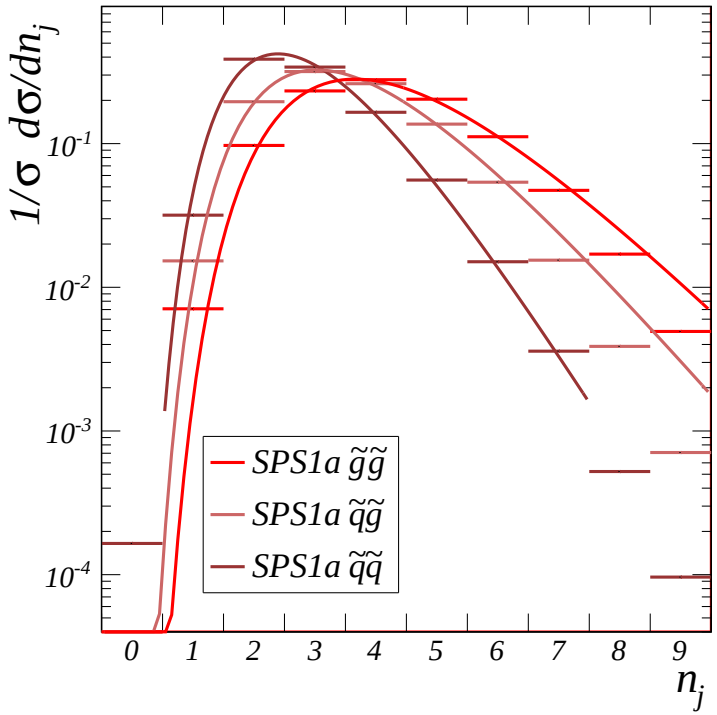

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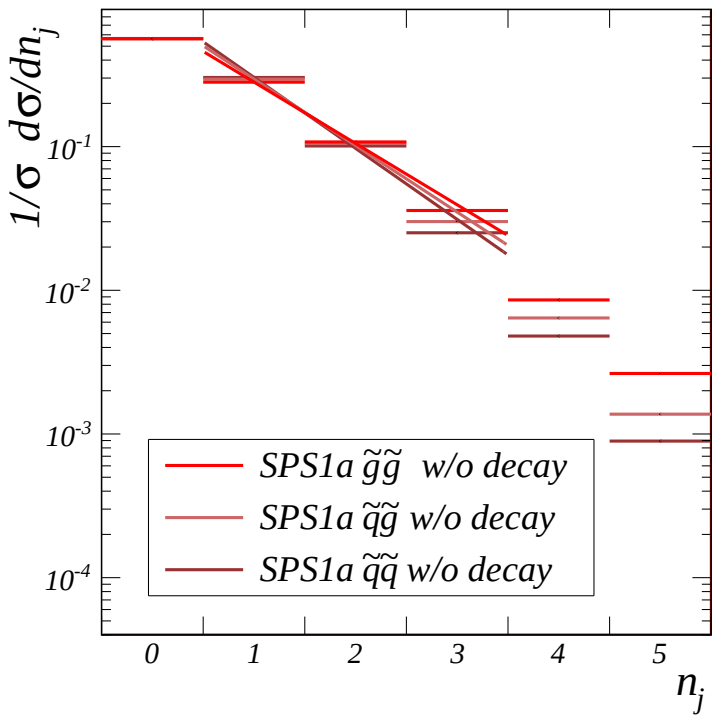

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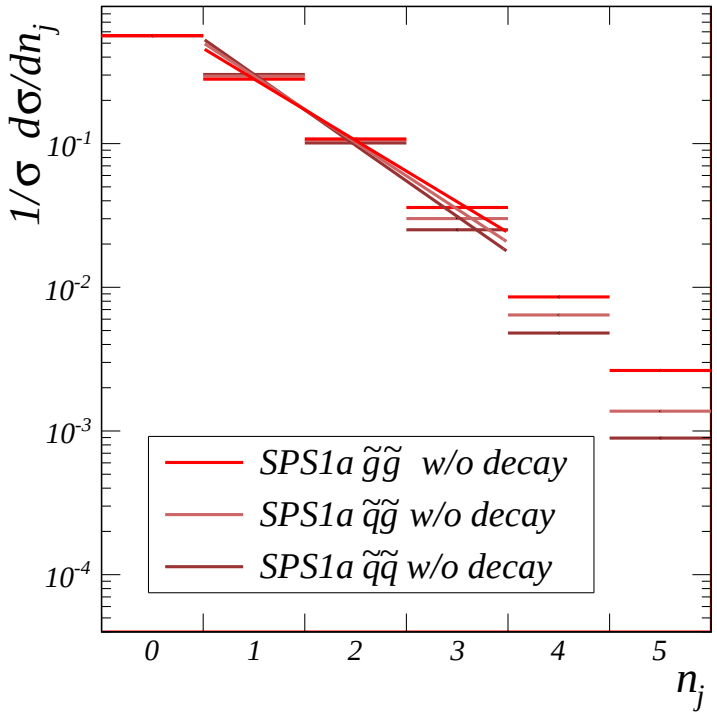


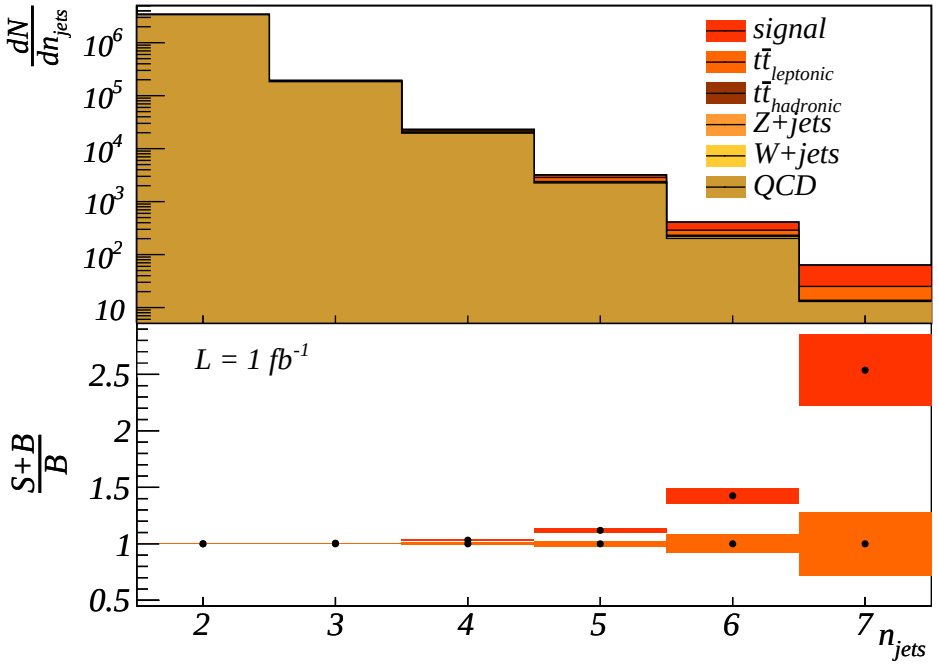
inclusive autofocussing BSM searches $\longleftrightarrow$ data-driven background extrapolation

- departure from jet-scaling properties in binned LLH approach

- control- and signal regions: low n_j bin(s) $\overset{\text{staircase}}{\rightsquigarrow}$ bkg in signal region
- correlated theoretical uncertainty

“Autofocus”

SPS1a [HERWIG++ arXiv:0803.0883]
[SHERPA arXiv:0811.4622]



$$\mathcal{Q}=2\sum_{i\in\text{bins}}\left[s_i - n_i \log\left(1 + s_i/b_i\right)\right]$$

Shape log likelihood analysis $\mathcal{Q}(n_j)$
[LEPHWG ’03]

	signal significance for 35 pb^{-1}
inclusive	$0.2\,\sigma$
n_{jets} (1D)	$1.6\,\sigma$

- cuts as inclusive as possible, fake $\not\!\!E_T$ from early data comparisons
  $\rightsquigarrow$ do not sculpt backgrounds
- uncertainties with all other exclusive quantities are correlated
- resolve energy scale ambiguity and gain statistical sensitivity by singling out the exclusive n_j’s mass scale
  $\rightsquigarrow$ $\mathcal{Q}(n_j, m_{\text{eff}})$ with $m_{\text{eff}} = \not\!\!E_T + \sum_{n_j} p_T^j$

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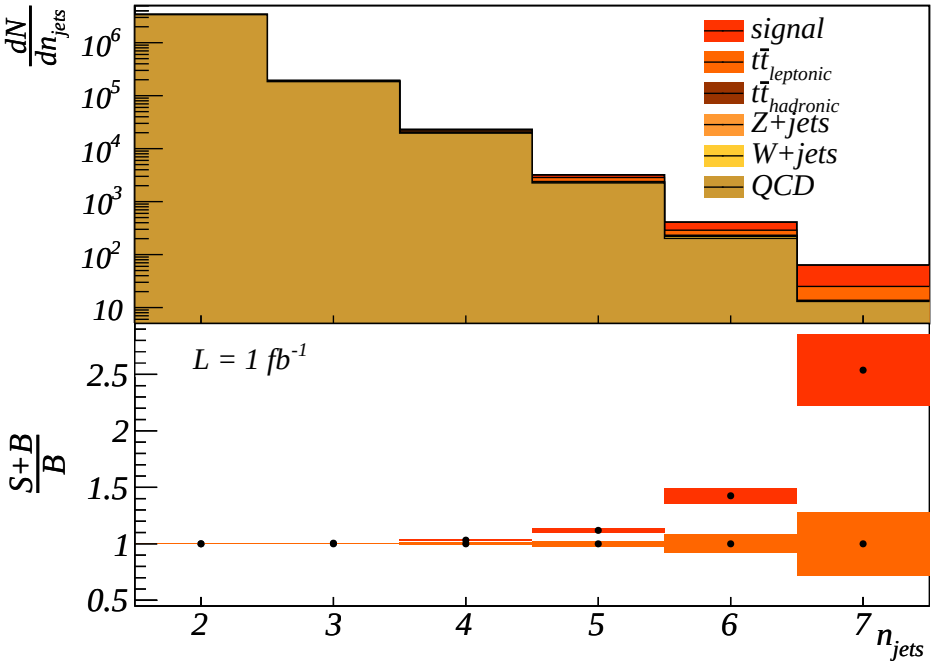

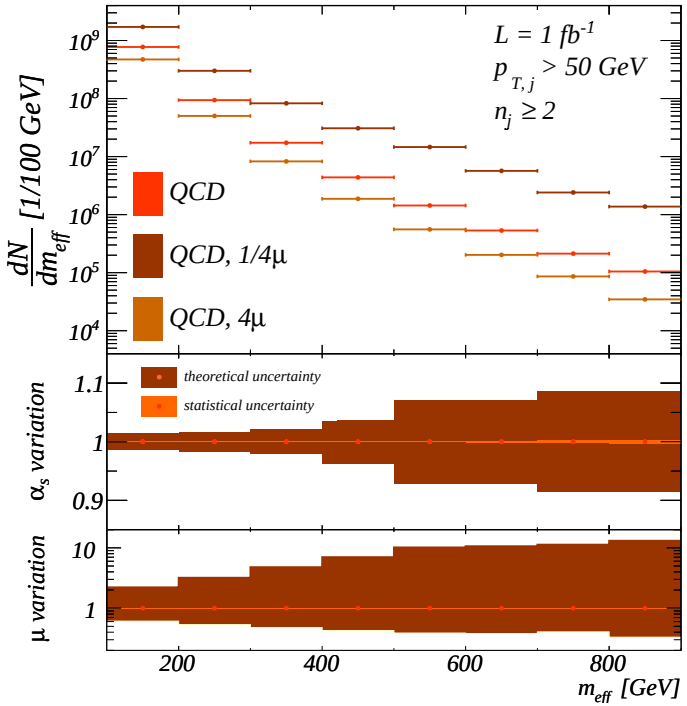

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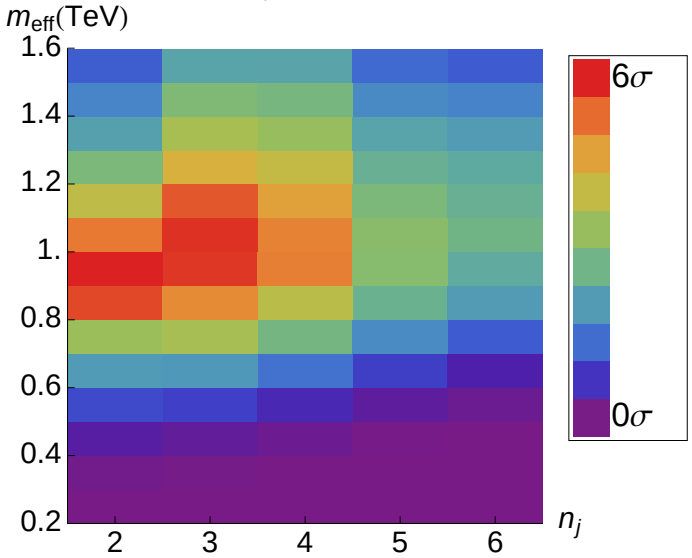
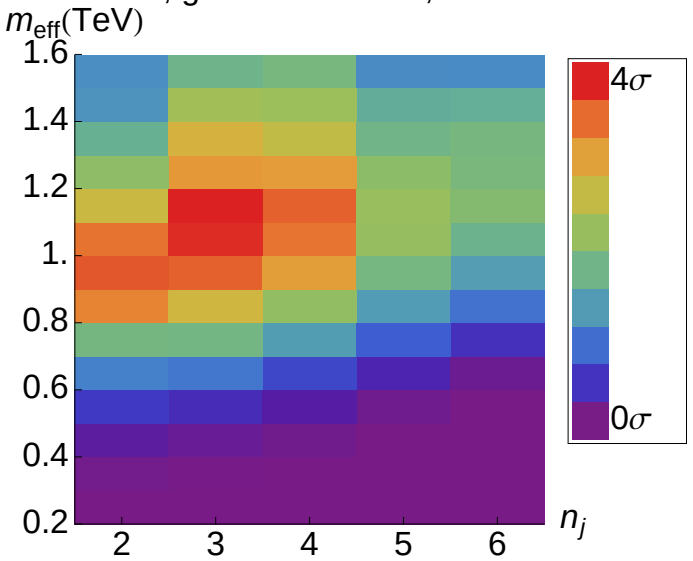
Autofocussing with $\mathcal{Q}(n_j, m_{\text{eff}})$

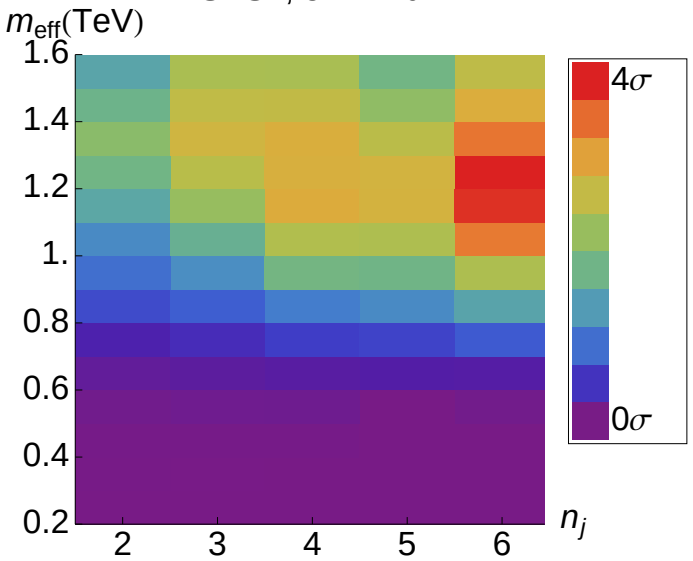
SPS1a, 1 inverse fb



SPS1a, gluino+150 GeV, 1 inv. fb



SPS4, 5 inv. fb

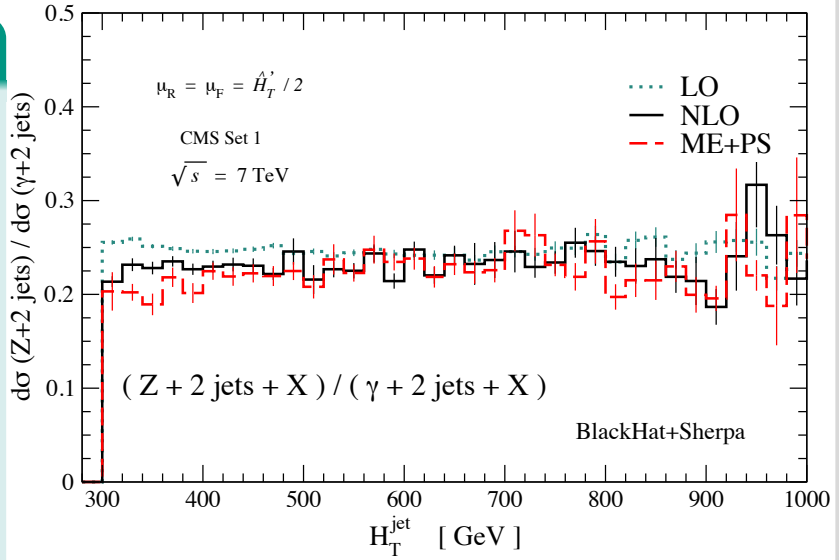


Towards deciphering staircase scaling

photon+jets [CE, Plehn, Schichtel, Schumann in progress]

- important for estimating invisible ($Z \to \nu\bar{\nu}$)+jets

  [Bern *et al.* arXiv:1106.1423] [Ask *et al.* arXiv:1107.2803]



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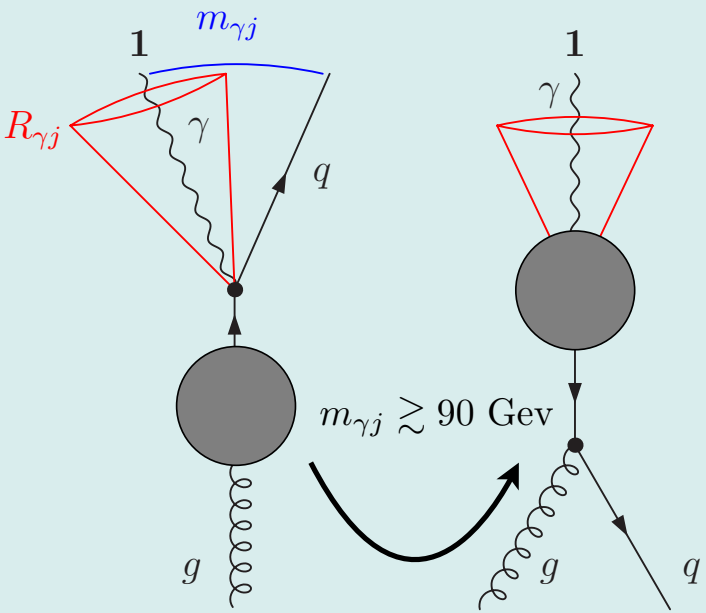
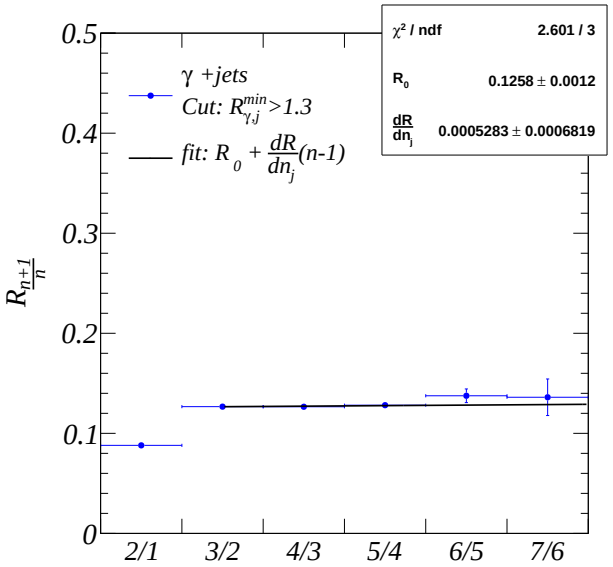
- no obvious scaling behavior due to mixing of dijet-type and γ+jet-like events
- remove collinear contributions

$\rightsquigarrow$ staircase scaling

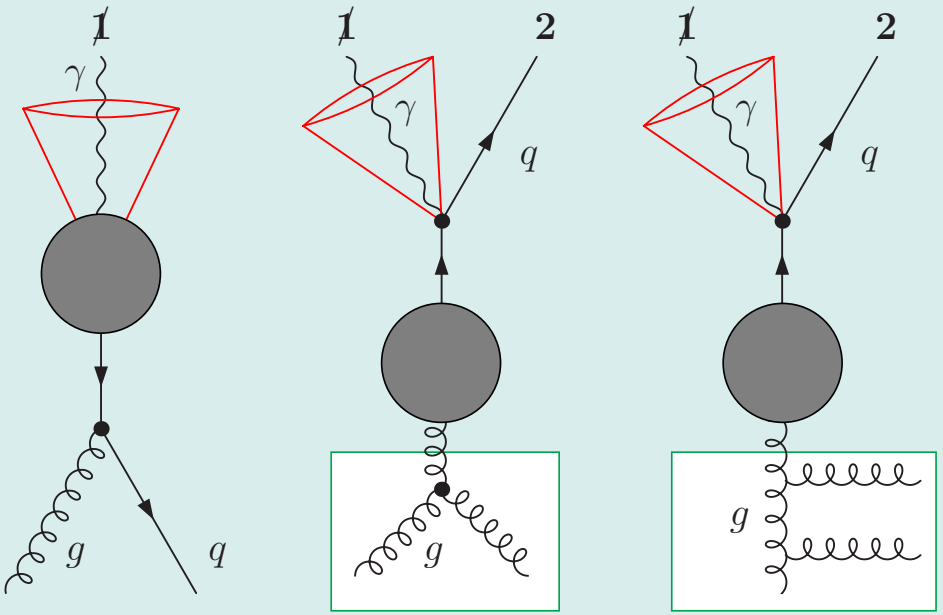


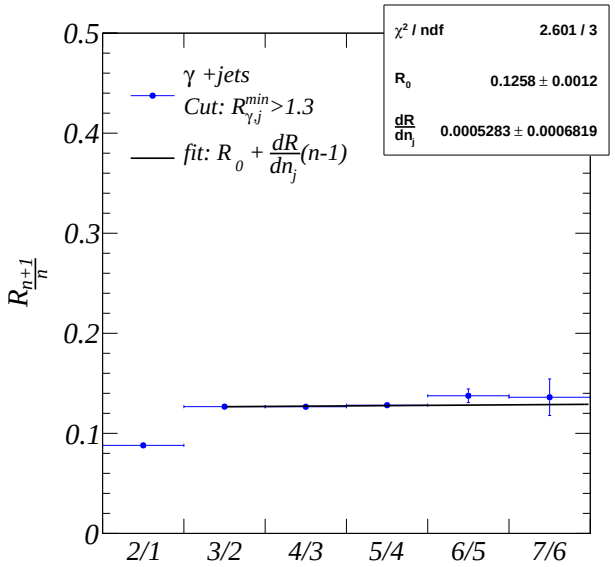


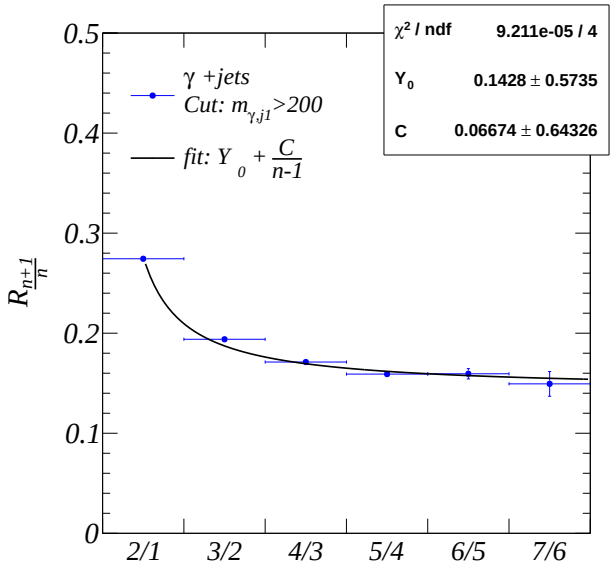
Towards deciphering staircase scaling

photon+jets [CE, Plehn, Schichtel, Schumann in progress]

- important for estimating invisible $(Z \to \nu\bar{\nu})$+jets
  [Bern *et al.* arXiv:1106.1423] [Ask *et al.* arXiv:1107.2803]
- no obvious scaling behavior due to mixing of dijet-type and γ+jet-like events
- remove collinear contributions
  $\rightsquigarrow$ staircase scaling
- induce hard scale $m_{\gamma j} \gtrsim 200\ \mathrm{GeV}$
  $\rightsquigarrow$ QED-like ladder emission $\rightsquigarrow$ Poisson scaling







Summary & Conclusions

- W/Z + jets & multijets are SM candles and important backgrounds to new physics searches
- pQCD theoretical status in good shape, shapes agree for matched MCs

  $\rightsquigarrow$ established QCD $\times$ electroweak phenomenology at a new energy scale
- application in new physics searches with early data, especially SUSY

- three step program that exploits jet scaling behavior:
  1. use jet scaling to consistently reduce correlated uncertainties
  2. use MC to trace the influence of cuts in a data-injected approach
  3. identify regions inconsistent with the background-only hypothesis

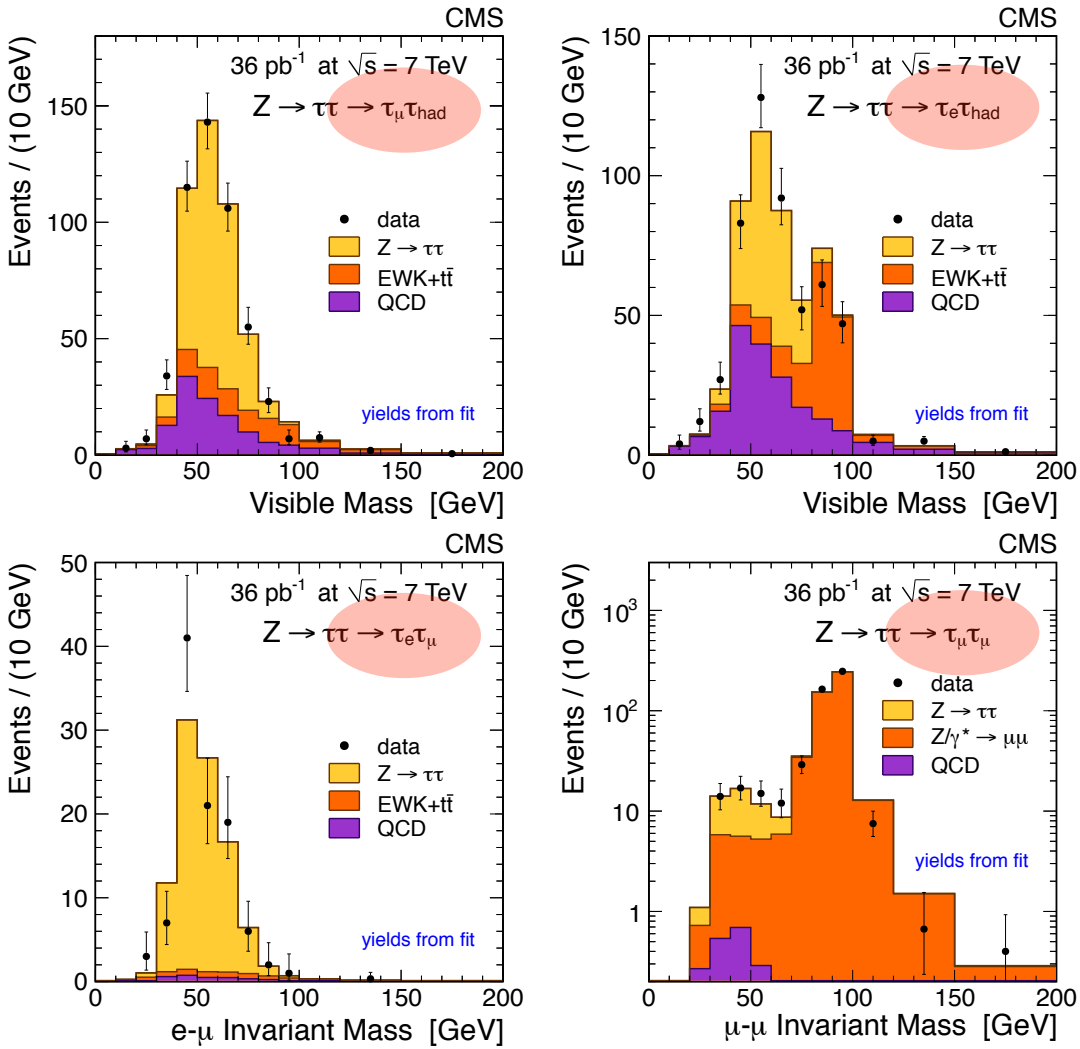
     (not discovery)
  4. further comparisons & measurements needed
- γ+jets is an excellent laboratory to test scaling hypotheses against data
- jet scaling points to a novel way in performing W/Z+jets and γ+jets comparisons

Backup

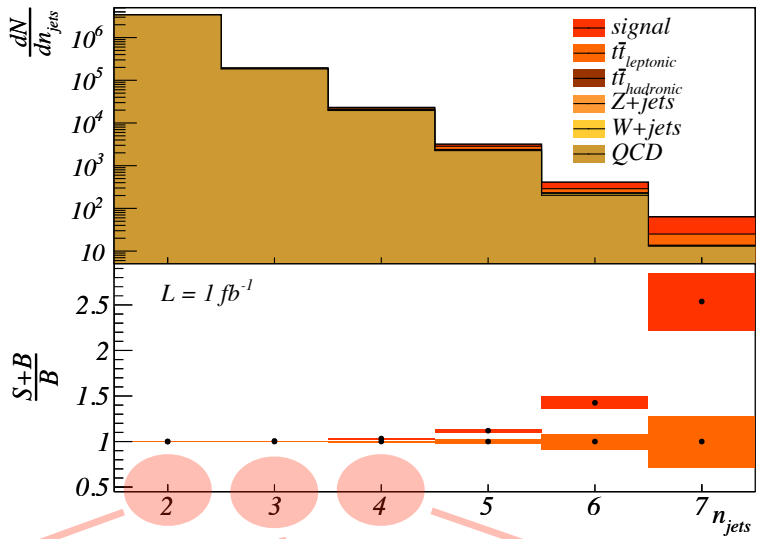
First LHC measurements

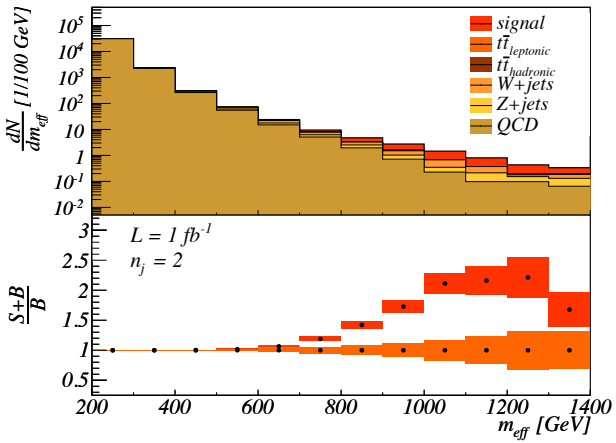
Z, ℓ, τ reconstruction with CMS [arXiv:1104.1617]

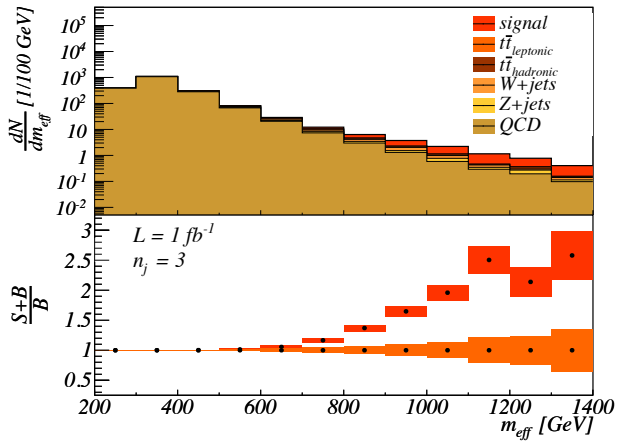
. . . updates at this conference. . .

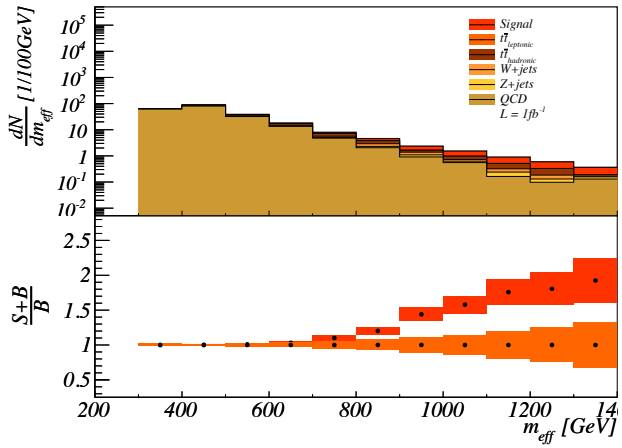


“Autofocus”









[m_{eff} binning 100 GeV $\sim$ experimental resolution]