Universiteit Antwerpen

Search for mono-jet events in CMS: ADD vs unparticle

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on behalf of the CMS Collaboration

Research conducted with the support of FWO - Vlaanderen

Outline

- Large extra dimensions (ADD)
- The unparticle model
- Signature: the mono-jet+MET final state
- The analysis tool: CMS
- Signal & background analysis
- CMS discovery/exclusion potential at 10 TeV
- CMS discovery/exclusion potential at 7 TeV

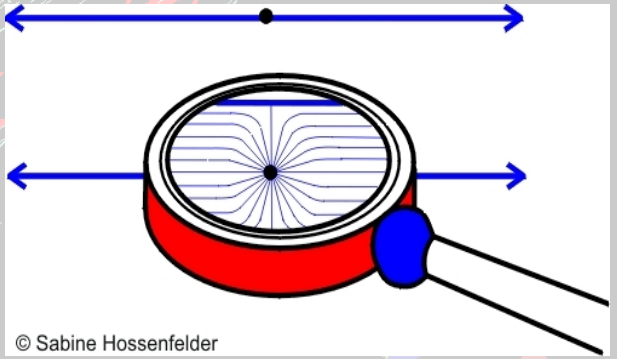
Large extra dimensions (ADD)

- N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali: Phys. Lett. B429 (1998) 263, arXiv:hep-ph/9803315
- δ compact extra dimensions, compactified on a torus with radius R

  M_D: quantum gravity scale in $\delta+4$ dimensions (possibly ~ TeV)

$$M_P^2 \sim R^\delta M_D^{\delta+2}$$

- gravity tests: $R \leq$ ~0,1 mm => $\delta \geq 2$



Large extra dimensions (ADD)

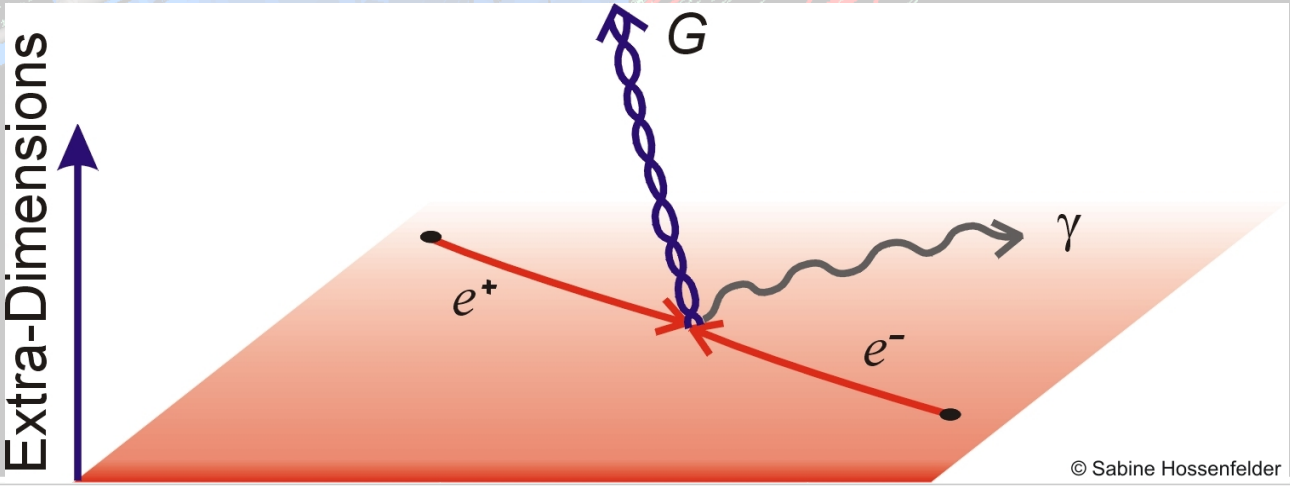
- SM localized on a 4D brane
- Gravity propagates in all dimensions
- Graviton is massless but is observed in 4D as a tower of KK modes with masses:

$$m_{KK} = j/R \; ; \; j = 0,1,2,\ldots$$

- For limited δ (2 to 6 extra dimensions) R is large (up to μm scale): spacing between KK masses is of eV order, continuous spectrum
- Model parameters: M_D, δ

Large extra dimensions (ADD)

- Spin-2 KK excitations in 4D
- Couple to SM matter with gravitational strength
- Gravity is weak in 4D due to "dilution"
- Signature: missing energy (KK gravitons escape into the bulk)



Large extra dimensions (ADD)

- Current limits: V. Krutelyov, arXiv:0807.0645v1 (2008)

δ	LEP $\gamma + E_T^{miss}$	DØ jet$+E_T^{miss}$	DØ $\gamma + E_T^{miss}$	CDF jet$+E_T^{miss}$	CDF $\gamma + E_T^{miss}$	CDF combined
2	1.600	0.99	0.921	1.310	1.080	1.400
3	1.200	0.80	0.877	1.080	1.000	1.150
4	0.940	0.73	0.848	0.980	0.970	1.040
5	0.770	0.66	0.821	0.910	0.930	0.980
6	0.660	0.65	0.810	0.880	0.900	0.940

Unparticles

- H. Georgi: Phys. Rev. Lett. 98 (2007) 221601
- Existence of a new sector of scale-invariant particles
- Coupled to SM through a high-mass connector sector > weak interaction with SM particles
- Phenomenologically similar to ADD model
- Model parameters:
  - S: unparticle spin
  - d_U: scale dimension parameter
  - Λ_U: renormalization scale
  - λ: coupling constant

G/U identification

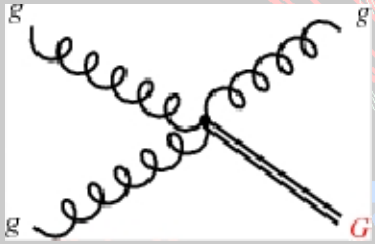
- ADD, unparticle emission processes share phenomenology
- Common effective MC implementation (PYTHIA8)
- Parameter identification:

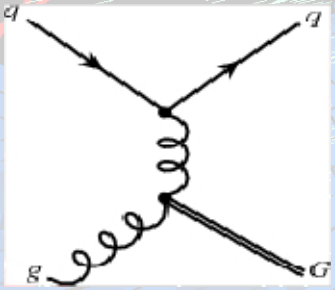
$$d_U = \frac{\delta}{2} + 1$$

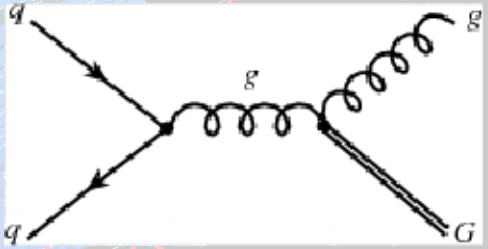
$$\Lambda_U = M_D$$

G/U production at colliders

- Three production channels:







- Cross section scales with M_D/Λ_U:

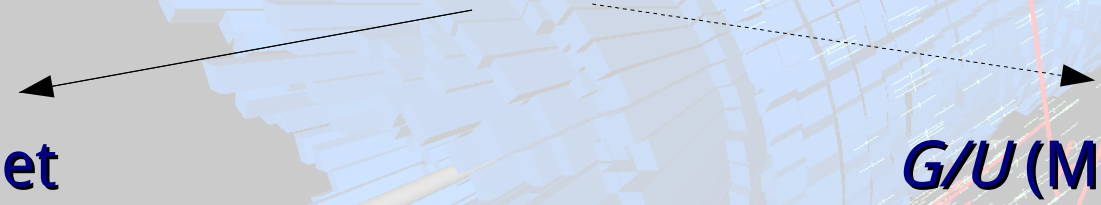
$$\sigma \approx \frac{1}{M_D^2}\left(\frac{\sqrt{\hat{s}}}{M_D}\right)^{\delta}$$

	$\delta = 2$	$\delta = 3$	$\delta = 4$	$\delta = 5$	$\delta = 6$
$M_D = 1\,\mathrm{TeV}$	279.11	171.79	109.98	70.50	44.45
$M_D = 2\,\mathrm{TeV}$	33.03	17.41	10.64	6.92	4.58
$M_D = 3\,\mathrm{TeV}$	7.28	3.02	1.57	0.93	0.58

- Generators: SHERPA (*G*), PYTHIA8 (*G/U*)

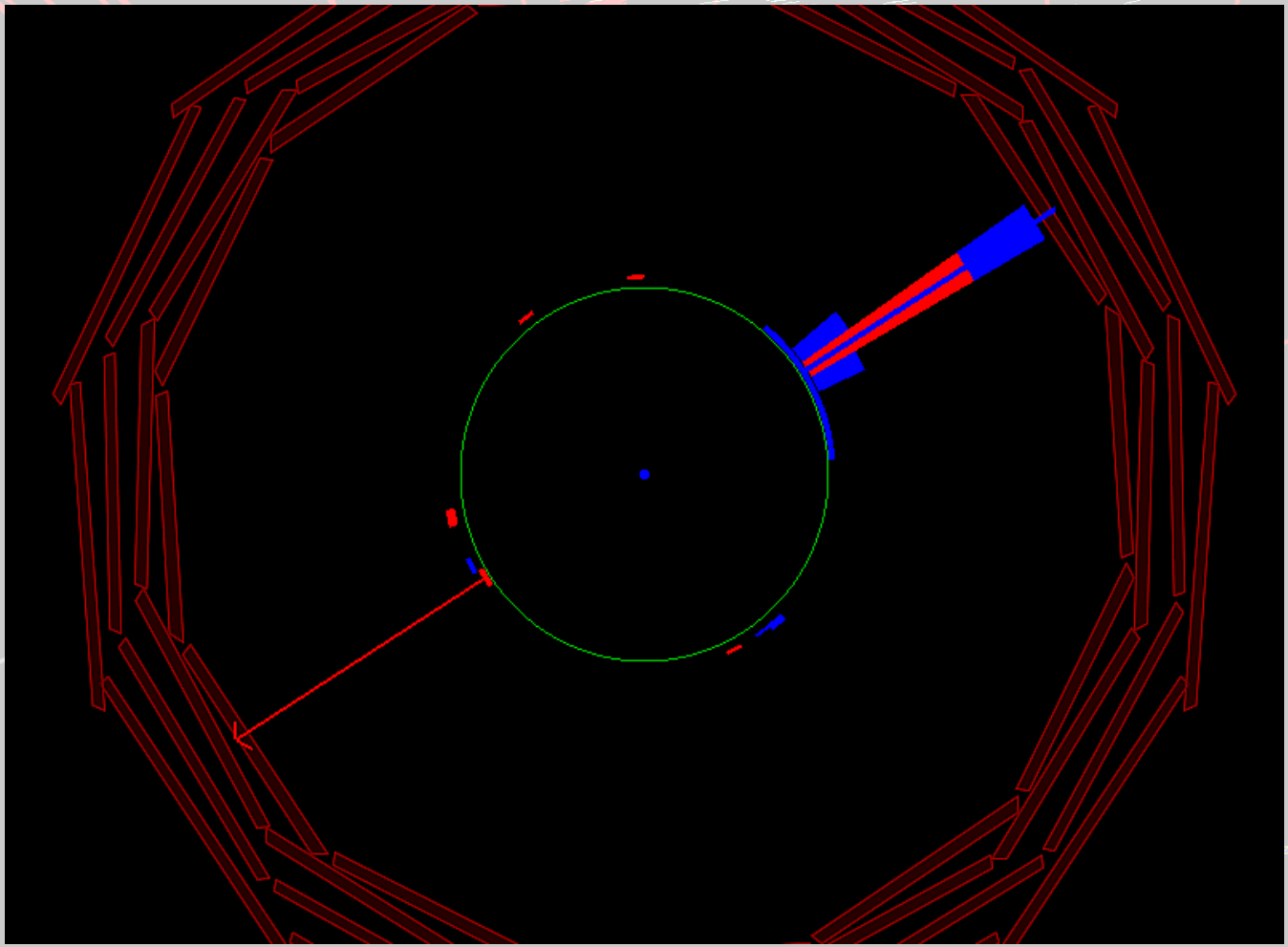
The mono-jet final state

- Signature:



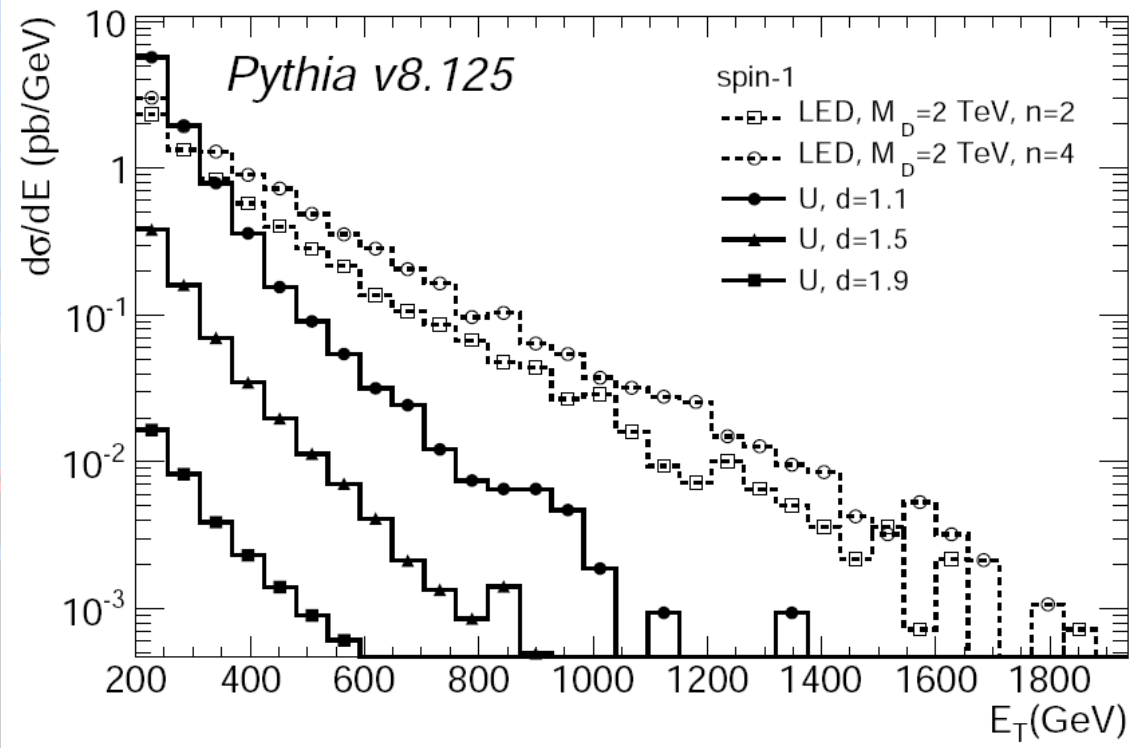
- 1 high-p_T jet (> 200 GeV) in the central region
- large missing transverse energy (same order) recoiling back-to-back

The mono-jet final state



The mono-jet final state

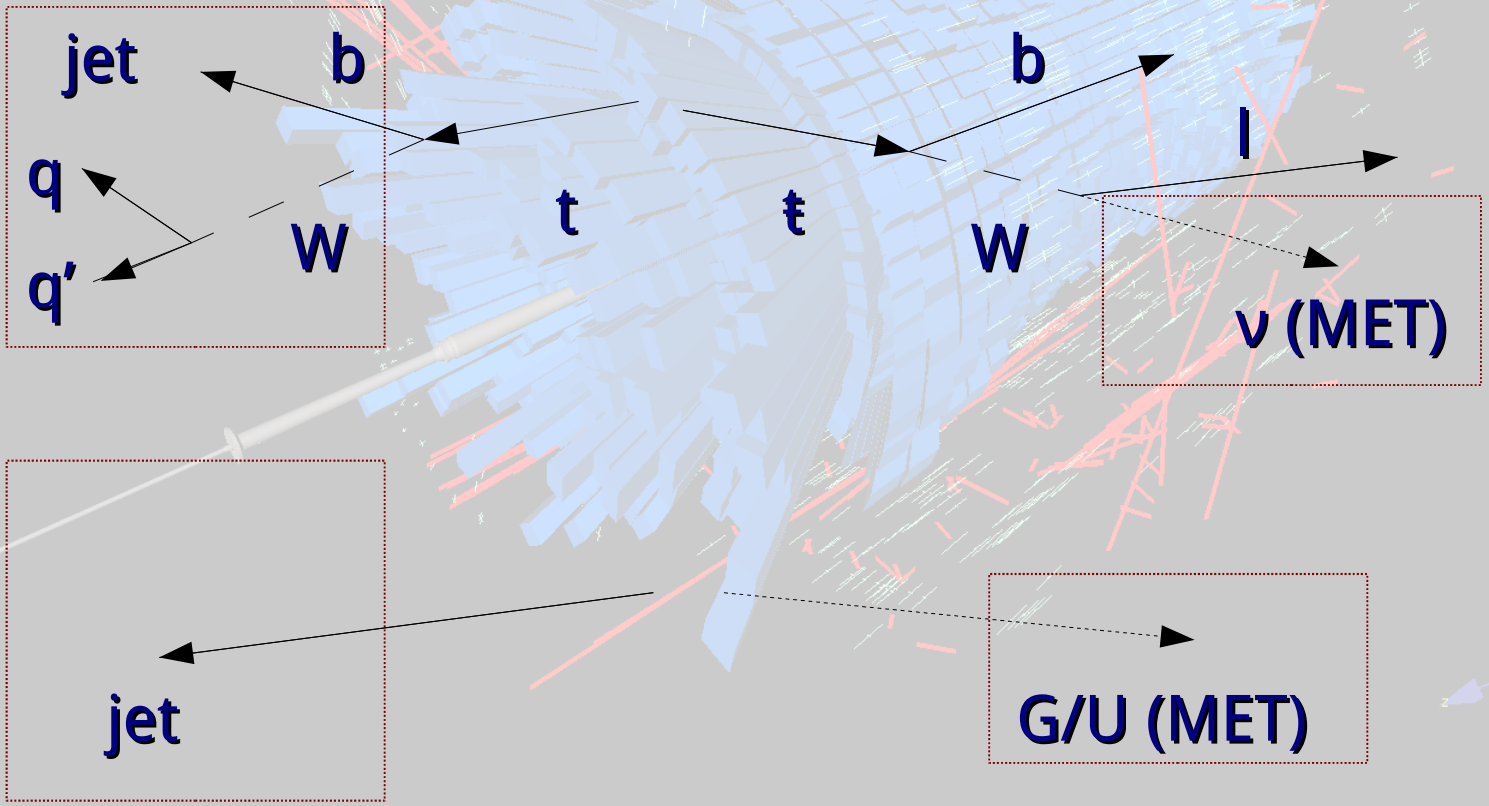
- MET distribution at generator level, 14 TeV running: ADD and unparticle can be distinguished by cross-section and slope



S. Ask, L. Benucci et al.: arXiv:hep-ph/0912.4233v2

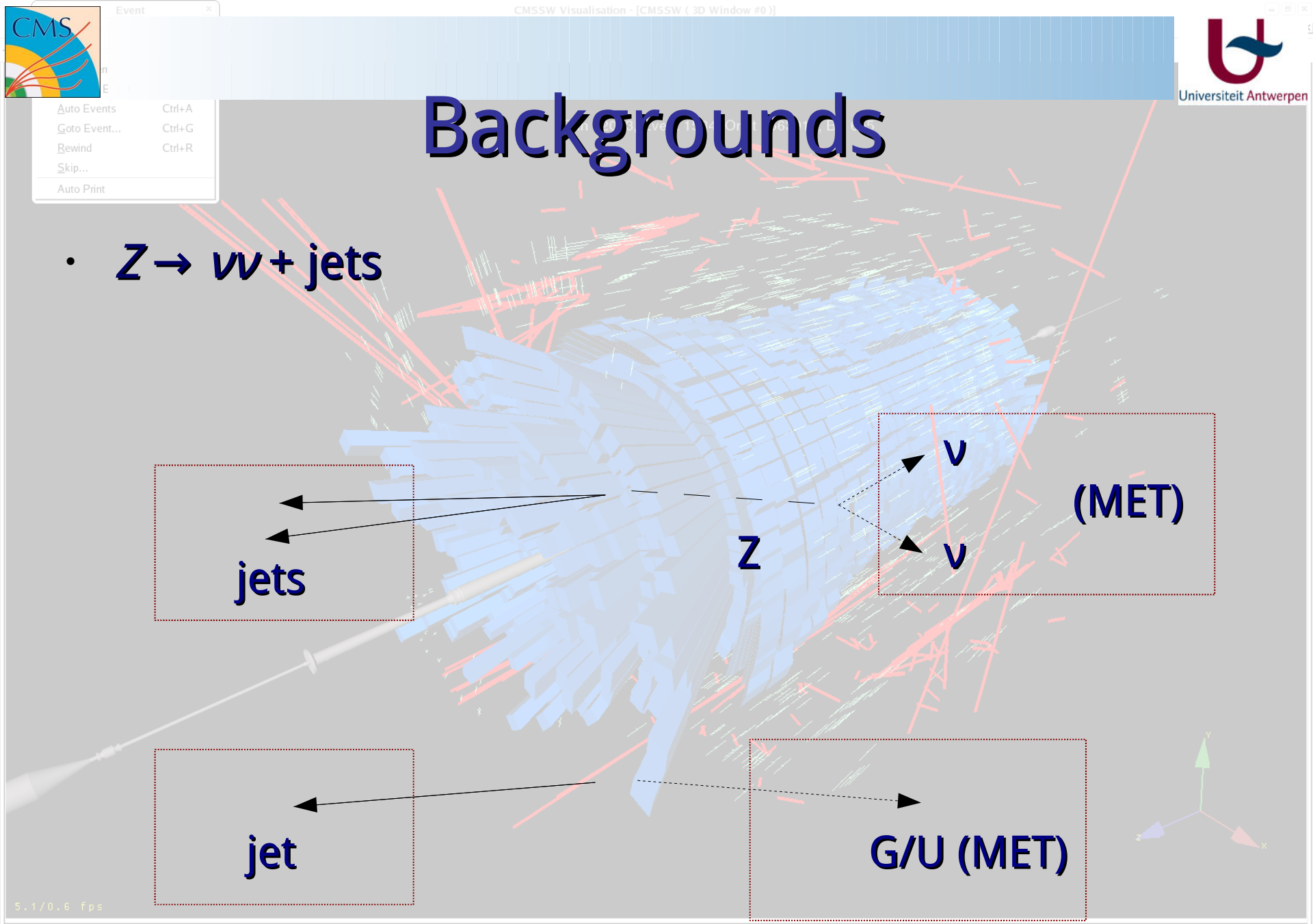
Backgrounds

- $t\bar{t} \rightarrow WbWb \rightarrow bbqq'l\nu$



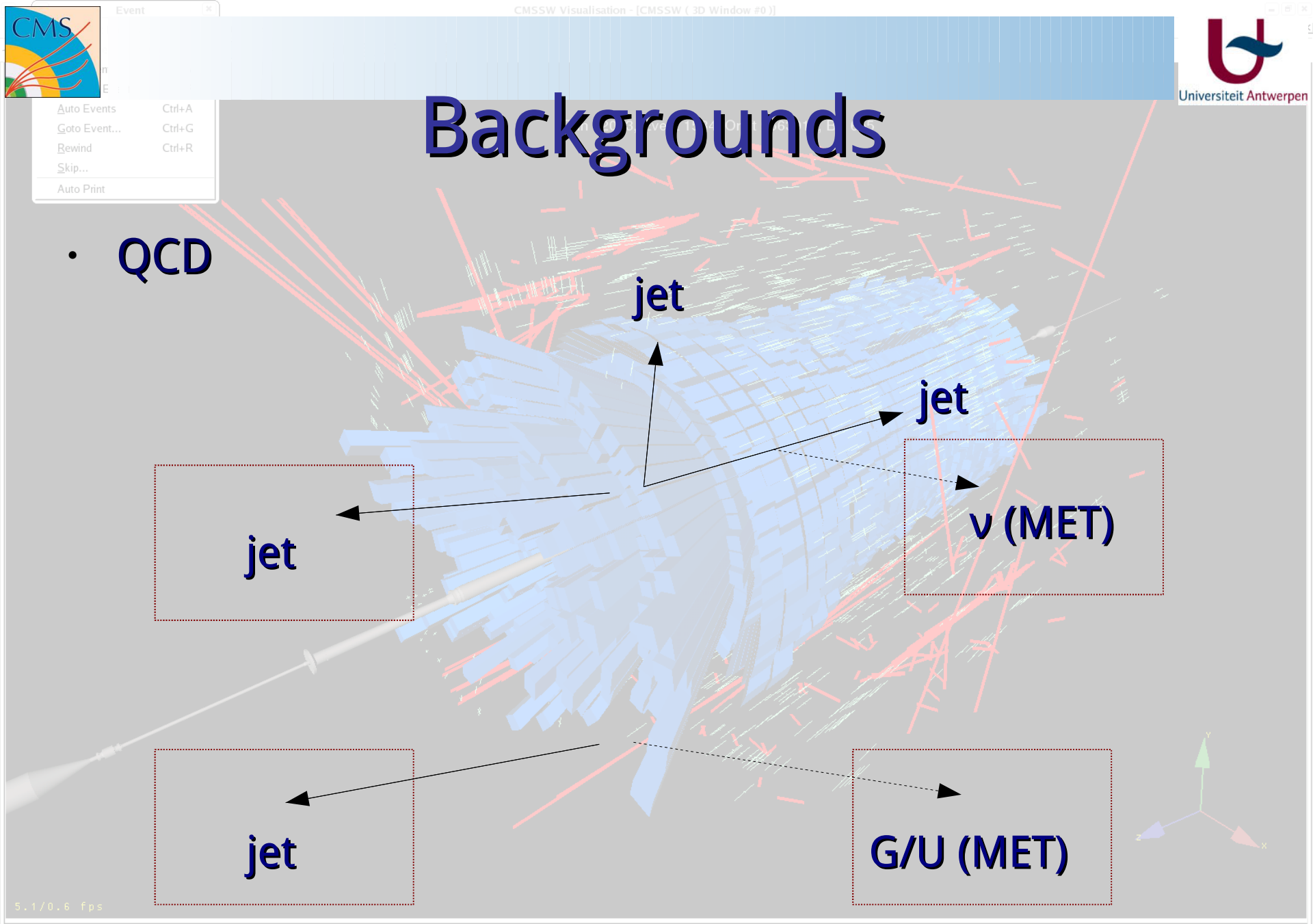
Backgrounds

- $Z \rightarrow \nu\nu$ + jets



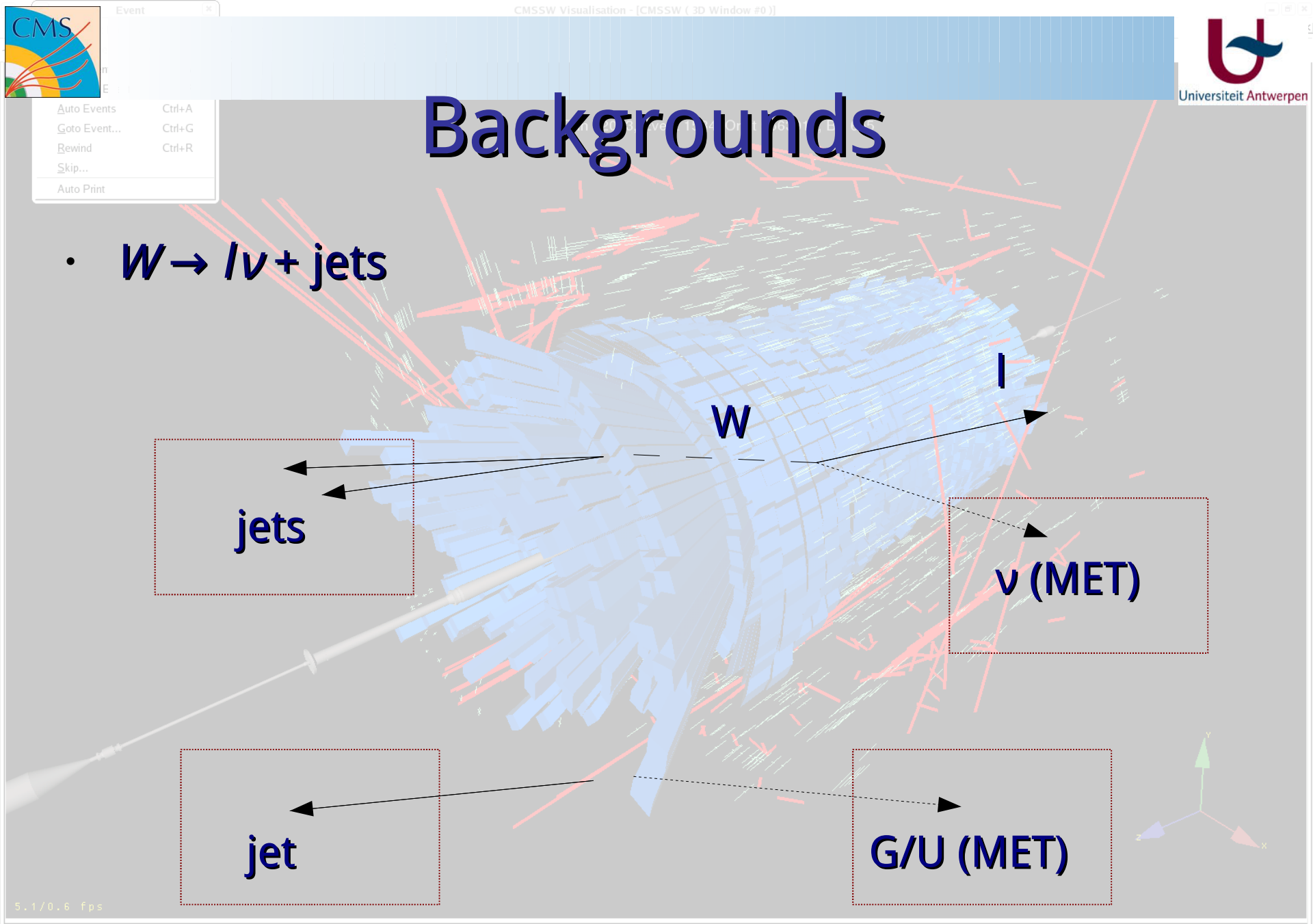
Backgrounds

- QCD



Backgrounds

- $W \rightarrow l\nu$ + jets

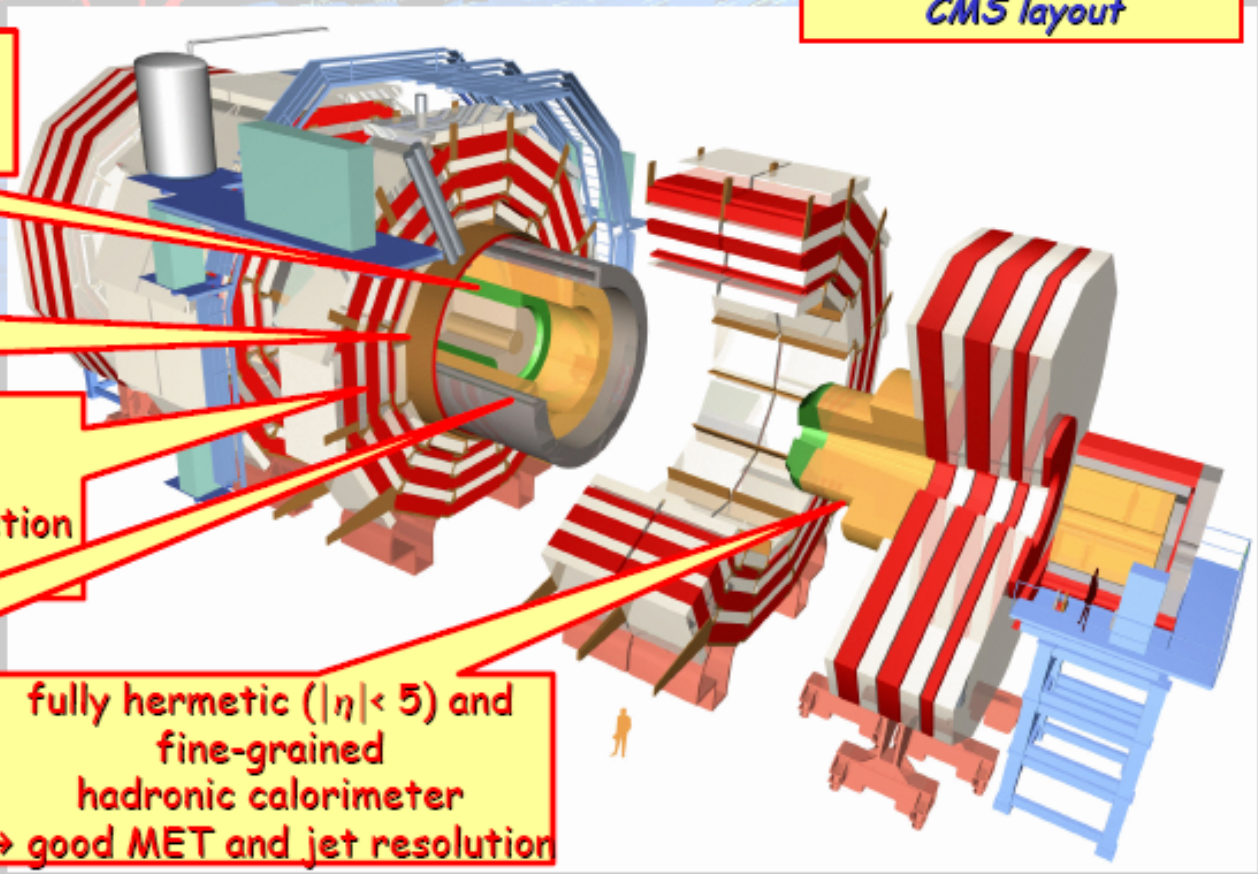


The tool for mono-jet analysis

The proposed studies are performed @LHC, with a 14 TeV center of mass energy

- 10^{32} - 10^{33} cm^{-2} s^{-1} initial luminosity
- 10^{34} cm^{-2} s^{-1} design luminosity
  - → It can be an ideal tool to study the MET+jet signature

CMS layout



efficient tracking system
→ detection of isolated leptons

4 T B field
→ precise pT measurement

redundant muon system
→ efficient high pT lepton rejection

excellent resolution electromagnetic calorimeter
→ efficient γ + e rejection

fully hermetic ($|\eta|$< 5) and fine-grained hadronic calorimeter
→ good MET and jet resolution

Signal & background analysis

ADD signal selection optimized for:

- LHC running at 14 TeV: CMS PAS EXO-08-011
- LHC running at 10 TeV: CMS PAS EXO-09-013
- LHC running at 7 TeV: rescaled from 10 TeV results

Signal & background analysis

Specific discriminating variables:

MHT variable (vectorial sum of jet p_T)

$$MHT = \left| \sum_{p_T(jet)_i > p_T^0} \vec{p}_T(jet)_i \right|$$

TIV: track isolation veto

$$TIV = \frac{1}{p_T(tk1)} \sum_{R \in \Delta R} p_T^j$$

(sum over all tracks with p_T > 1 GeV in a hollow cone

0,02 < ΔR < 0,3 around each track with p_T > 10 GeV)

=> reject tracks with TIV < 0,1

Signal & background analysis

- Cut optimization performed for LHC at 10 TeV:
  - Use of a jet high-level trigger (jet p_T > 110 GeV)
  - MHT > 250 GeV: select signal
  - JEMF > 0,1: suppress instrumental background
  - JEMF < 0,9: suppress high-energy *e*, *γ*
  - TIV > 0,1: suppress *W*+jets, *tt̄*
  - Leading jet *pT* > 200 GeV, $|\eta|$<1,7
  - # jets < 3: suppress multijet events
  - $\Delta\varphi$(jet 1,MHT) > 2,8, $\Delta\varphi$(jet 2,MHT) > 0,5: select back-to-back emissions

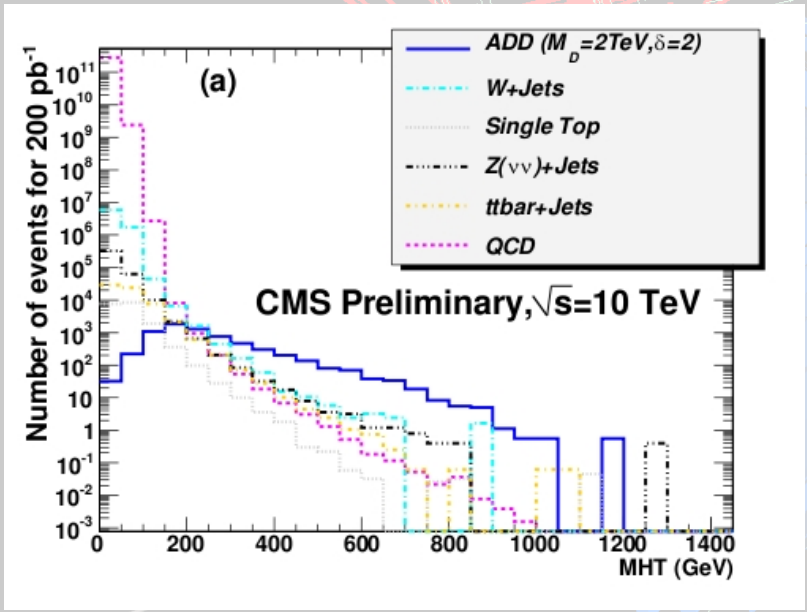
Signal & background analysis

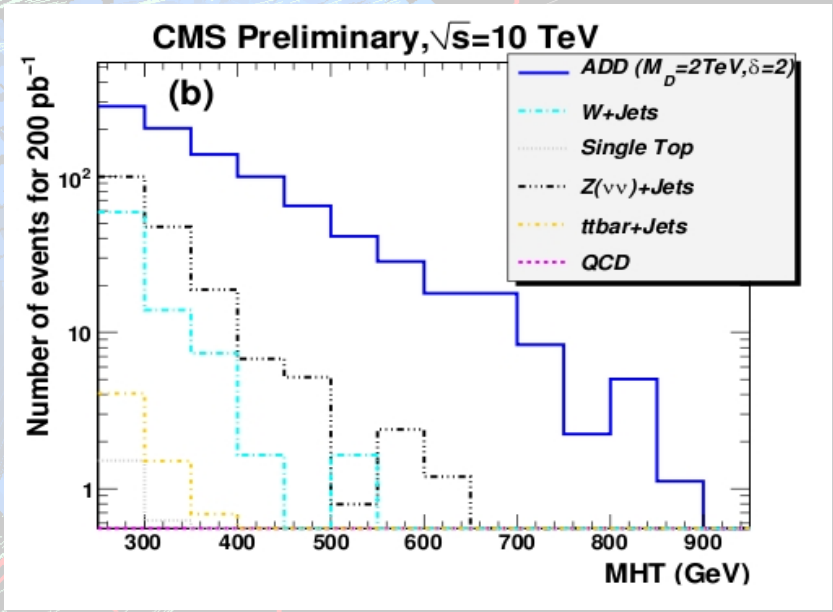
	$\delta = 2$			$\delta = 4$	
	$M_D = 1$ TeV	$M_D = 2$ TeV	$M_D = 3$ TeV	$M_D = 2$ TeV	$M_D = 3$ TeV
Trigger	51,000	6180	1370	2010	301
$MHT > 250$ GeV	11,140	2123	498	753	133
$0.1 < JEMF < 0.9$ $TIV > 0.1$	9572	1825	426	641	113
$p_T(\text{jet}\,1) > 200$ GeV $\lvert\eta(\text{jet}\,1)\rvert < 1.7$	6785	1368	314	487	88.4
number of jets<3	5605	1044	401	374	64.4
$\Delta\phi(\text{jet}\,1, MHT) > 2.8$ $\Delta\phi(\text{jet}\,2, MHT) > 0.5$	4934	906	206	322	55.8
Total Efficiency (%)	8.8 ± 0.1	13.7 ± 0.4	14.1 ± 0.4	13.2 ± 0.4	17.7 ± 0.4

	$t\bar{t}$	$Z(\nu\nu)$+j	QCD	$W(e\nu)$+j	$W(\mu\nu)$+j	$W(\tau\nu)$+j	single-t
Trigger	28,970	11,390	$143 \cdot 10^6$	31,320	19,320	20,600	4460
$MHT > 250$ GeV	318	358	288	90	391	230	44
$0.1 < JEMF < 0.9$ $TIV > 0.1$	52.5	305	214	31.9	38.5	90.9	7.2
$p_T(\text{jet}\,1) > 200$ GeV $\lvert\eta(\text{jet}\,1)\rvert < 1.7$	37.4	245	187	24.6	24.6	72.1	4.5
numb. jets<3	8.2	205.6	70.9	18.8	22.9	59.8	2.8
$\Delta\phi(\text{jet}\,1, MHT) > 2.8$ $\Delta\phi(\text{jet}\,2, MHT) > 0.5$	6.4	182.5	0.2	17.2	19.7	46.7	2.3

normalized to 200 pb^{-1}

Signal & background analysis





BEFORE

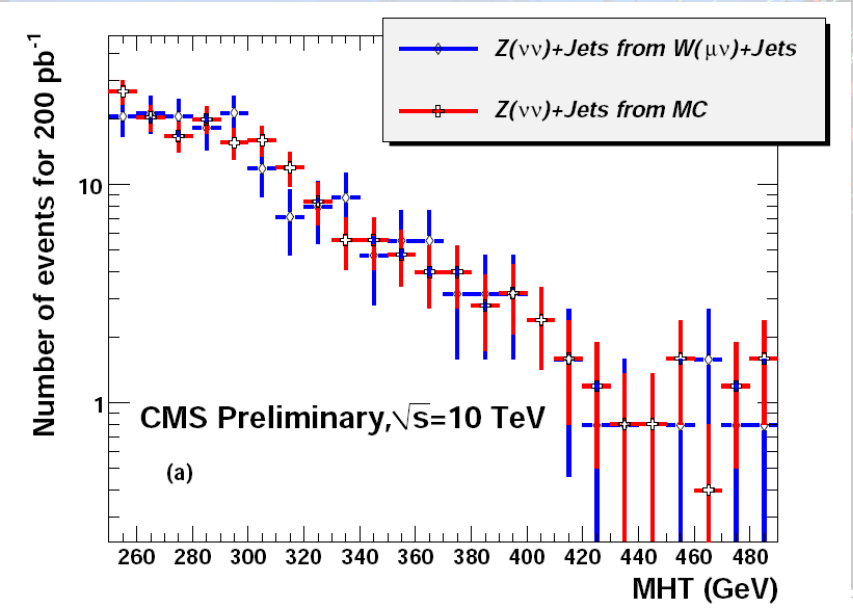
AFTER

Systematic effects

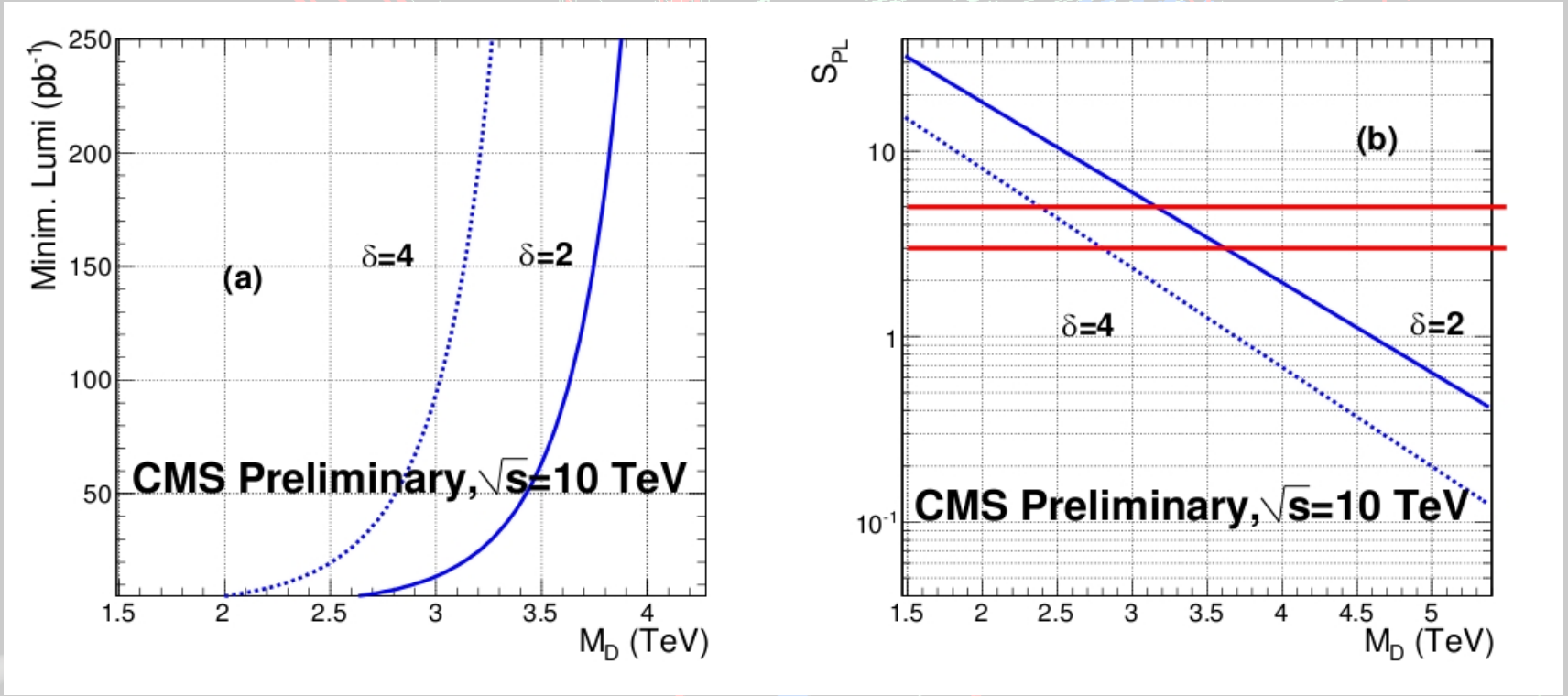
- No mass peak expected, systematics important:
  - Renormalization/factorization scale: +7,5%/-6,7%
  - PDF uncertainties: +11,5%/-9,5%
  - Jet energy resolution/direction/JES: ±10%-16%
  - Luminosity uncertainty: ±10%

Data-driven background estimation

- Main remaining backgrounds: $Z(\nu\nu)$+jets, $W(l\nu)$+jets
- Estimated using $W(\mu\nu)$+jets control region:
  - Same as signal region, but require one hard, isolated muon
- $Z(\nu\nu)$+jets rescaled from W+jets sample:

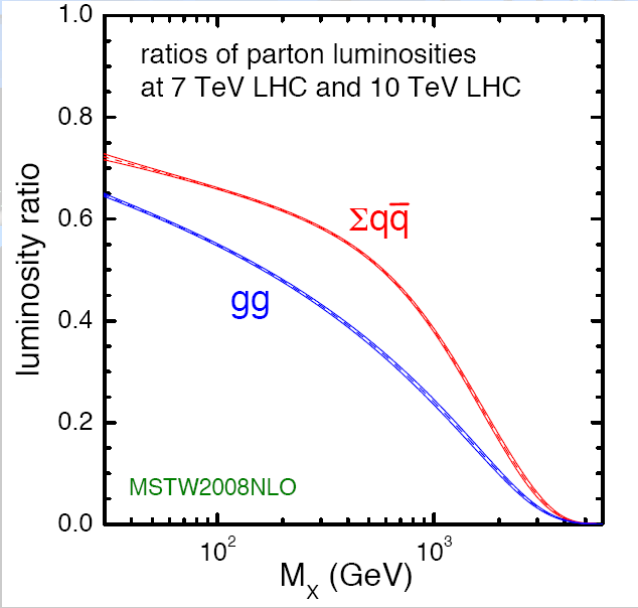


Discovery/exclusion potential



7 TeV reach

7 TeV reach was rescaled from 10 TeV results using parton luminosity ratio:
7 TeV running requires ~3 times as much integrated luminosity to reach the 10 TeV limits



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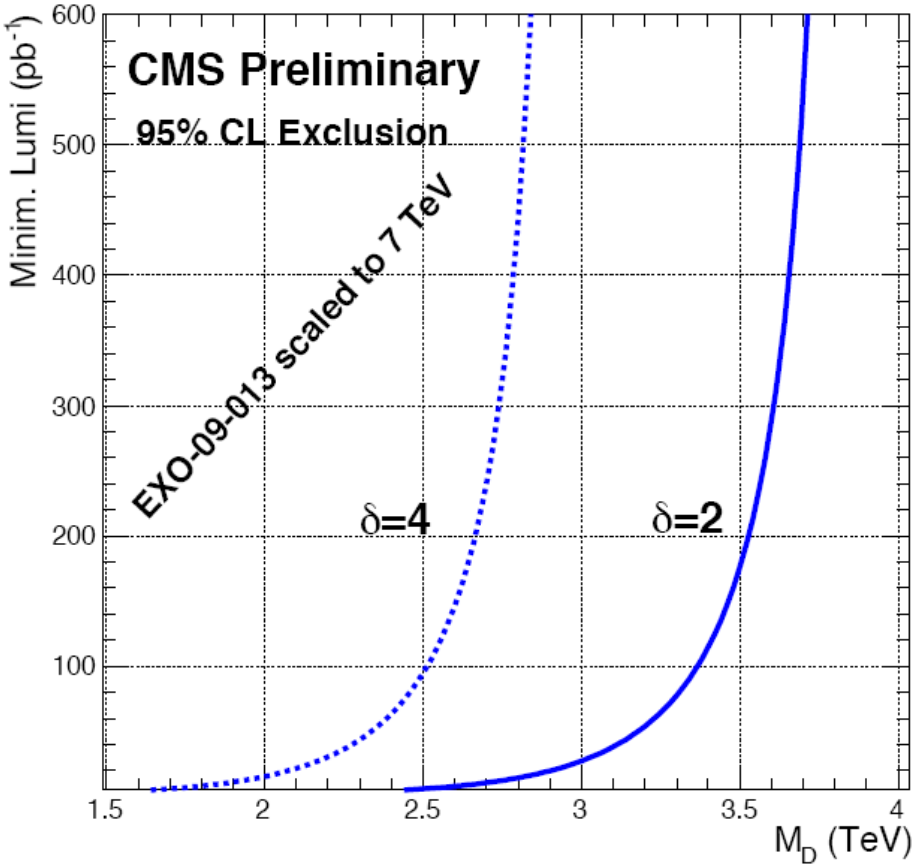
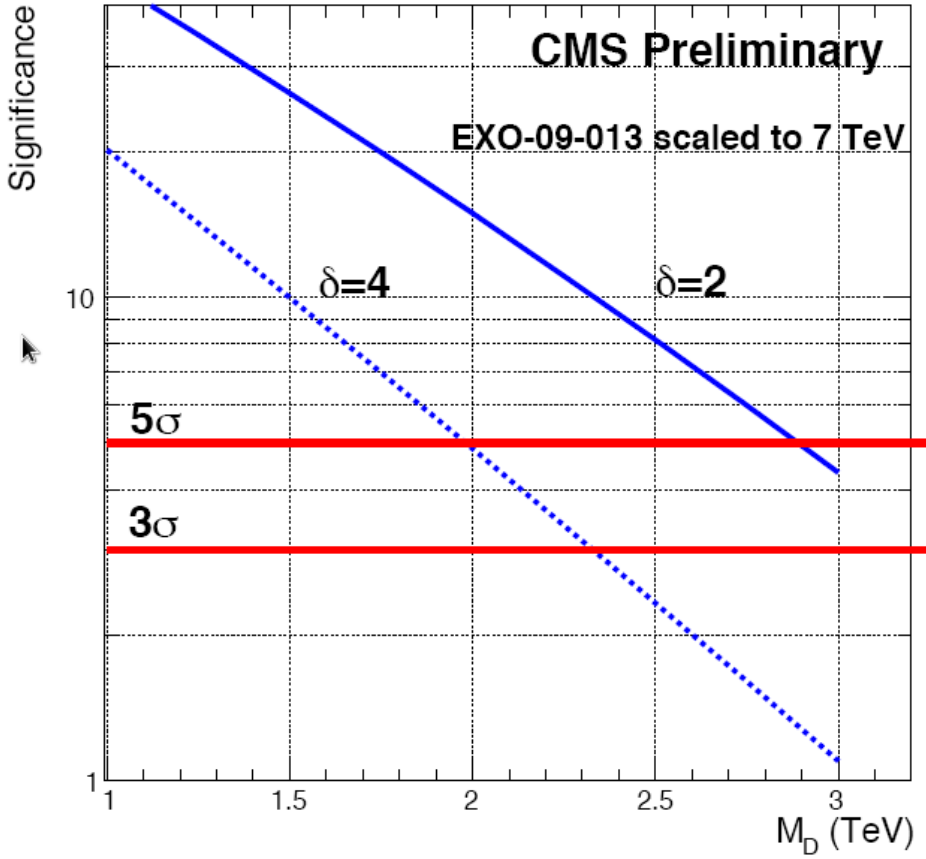
7 TeV reach





CMS NOTE 2010/008

Bibliography & acknowledgements

- Some reading material:
  - CMS PAS EXO-09-013: *"Search for Mono-Jet Final States from ADD Extra-Dimensions at √s=10 TeV"*
  - S. Ask, L. Benucci et al.: *"Real emission and virtual exchange of gravitons and unparticles in Pythia8"*, arXiv:hep-ph/0912.4233v2
  - N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali: Phys. Lett. B429 (1998) 263, arXiv:hep-ph/9803315
  - H. Georgi: *"Unparticle physics,"* Phys. Rev. Lett. 98 (2007) 221601
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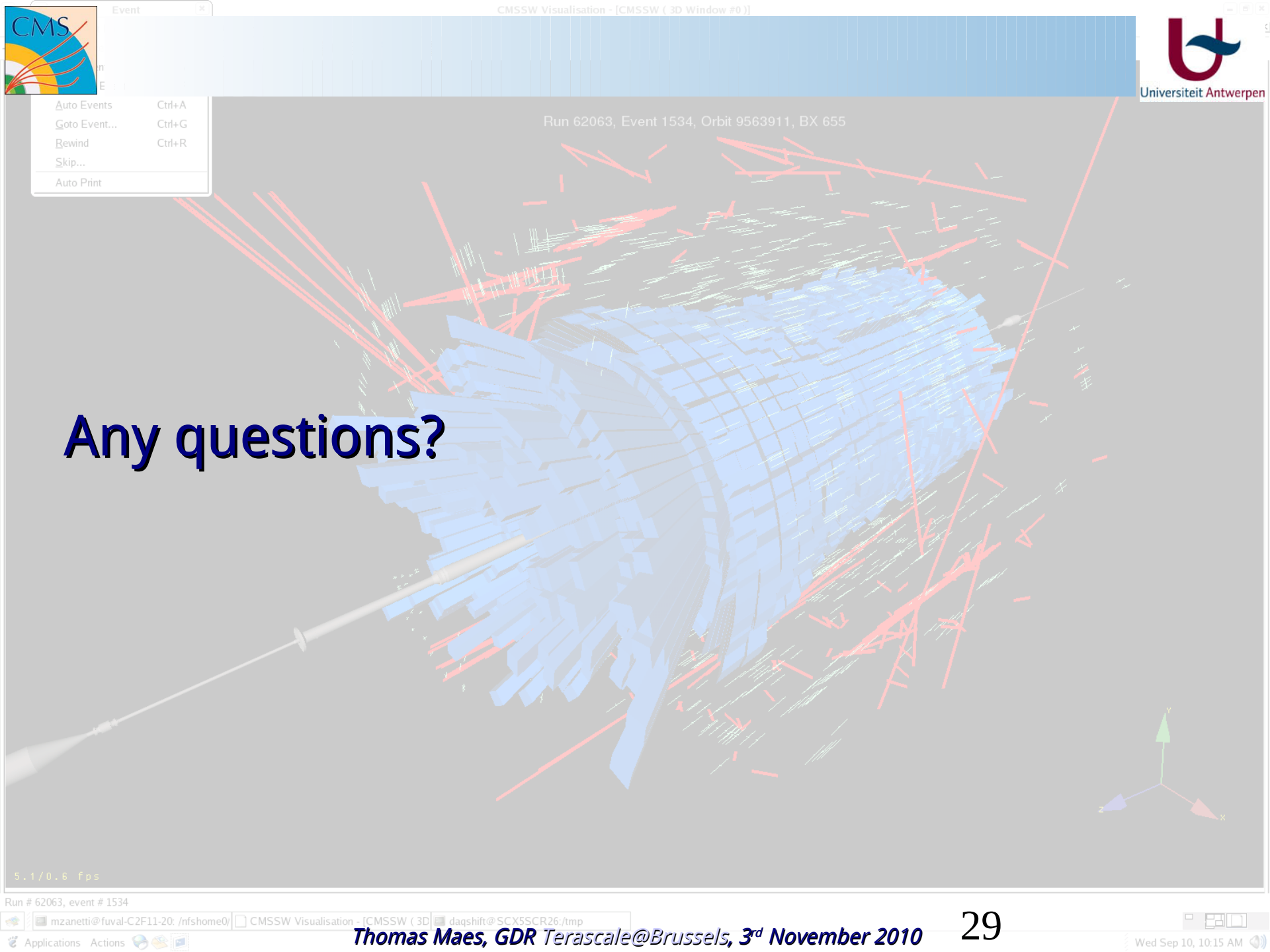
Any questions?