Search for 2nd generation Leptoquarks with ATLAS at the LHC

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Gernot Krobath
Ludwig-Maximilians-Universität München
E-Mail: gernot.krobath@physik.uni-muenchen.de

Overview

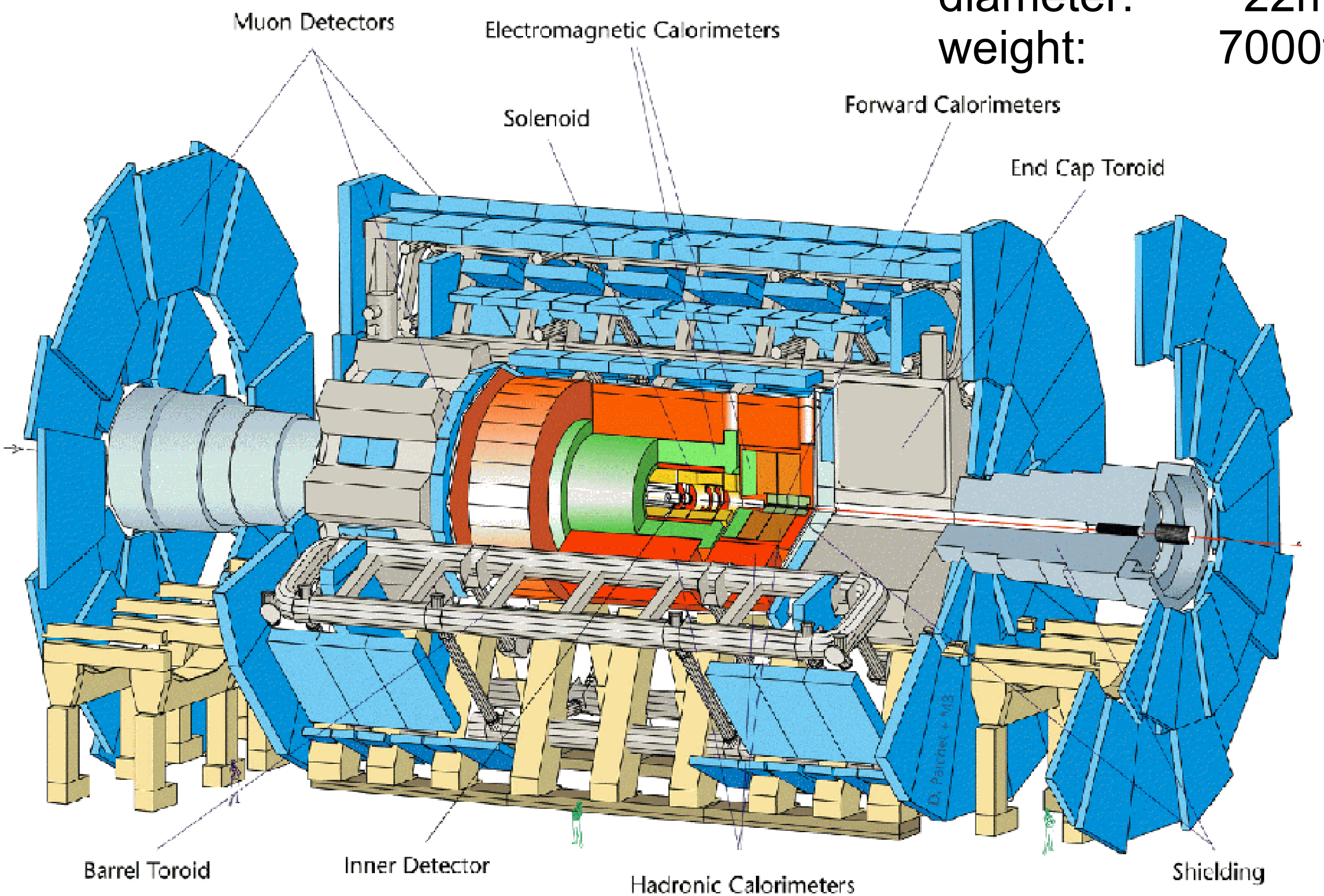
- LHC/ATLAS
- Leptoquarks
- Signal and main background
- Selection variables
- Higher m_{LQ}
- Other backgrounds
- Summary and Outlook

Large Hadron Collider (LHC)

- startup summer 2007
- accelerator for pp
- $\sqrt{s} = 14$ TeV
- 27 km circumference
- design luminosity: 10^{34} cm^{-2} s^{-1}
- one bunch crossing every 25 ns
- at design luminosity ≈ 22 pp collisions per bunch crossing expected

The ATLAS Detector

width: 44m
diameter: 22m
weight: 7000t



- 1 of 2 universal detectors at the LHC

- toroidal magnetic field in the muon detectors, solenoid magnetic field in the inner detector

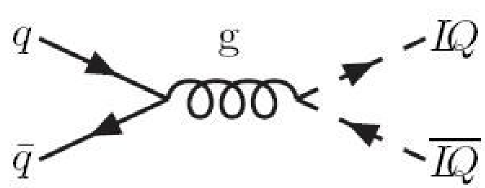
- very good muon measurement by combining the inner and the muon detector

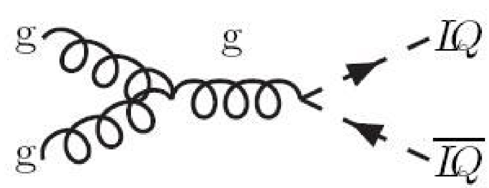
Leptoquarks

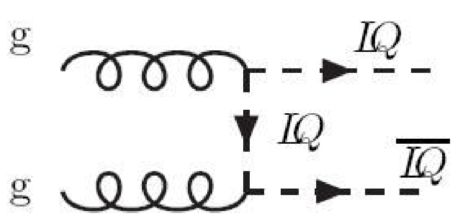
- What are Leptoquarks ?
  - Leptoquarks (LQ) are hypothetical particles, which carry both lepton- and baryon-numbers. LQ interactions conserve the lepton- and baryon-numbers separately.
  - LQ have not been observed yet, but many extensions of the Standard Model predict them:
    - Grand Unifying Theories (GUTs)
    - Supersymmetry with R-parity violation
    - superstring-inspired E_6 models
    - technicolor models
    - etc.

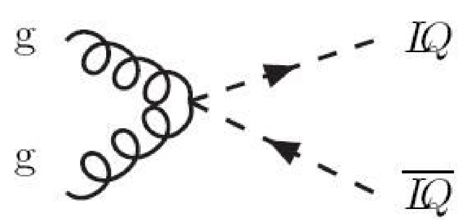
How are LQ produced ?

- only pair production considered here, because single production depends on the unknown q-ℓ-LQ coupling









- all shown processes do not depend on the (unknown) q-ℓ-LQ coupling → cross-section only depends on mass of LQ and QCD.
- 2nd Generation: LQ → q + (μ or ν_μ)
- excluded mass limit for 2nd generation LQ: ~250 GeV (β=1) β = BR(LQ_2 → q + μ)

LQ properties

- LQ couple only on one generation of quarks and on one generation of leptons of the standard model, because neither flavor changing neutral currents nor lepton number violations have been observed.

- It is assumed that LQ interactions are chiral, otherwise LQ would mediate rare decays.

- With the assumptions above there are 14 kinds (mBRW model) of LQ, that differ by:
  - spin (scalar or vector)
  - fermion number F = 3 B + L
  - isospin
  - chirality of the coupling

- LQ carry non-integer charges (± 5/3e, ± 4/3e, ± 2/3e, ± 1/3e)

- LQ $\rightarrow \ell^{\pm}$ q or LQ $\rightarrow \nu$ q

Signal and Standard Model background

- signal (β=1):

m(LQ) in GeV	σ(NLO) (in pb)
400	2.24000
600	0.22500
800	0.03780
1000	0.00836
1200	0.00221
1400	0.00066
1600	0.00021

- background:

process	σ x BR (in pb)
$Z/\gamma^*(\mu\mu)$+jets p_T^{jet}>20GeV	690
tt (μνj μνj)	5.5
ZZ (μμ jj)	0.6
ZW (μμ jj)	0.6
WW (μν μν)	1.7

expected $\int L\,dt$ of the LHC:

1st month: 20 pb^{-1}

1 year at design *L*: 10 fb^{-1}

→

expected number of events:

Z/γ^*+jets:13.8k LQ_{400}:44.8 LQ_{1200}:0.04

Z/γ^*+jets:6.9M LQ_{400}:22.4k LQ_{1200}:22.1

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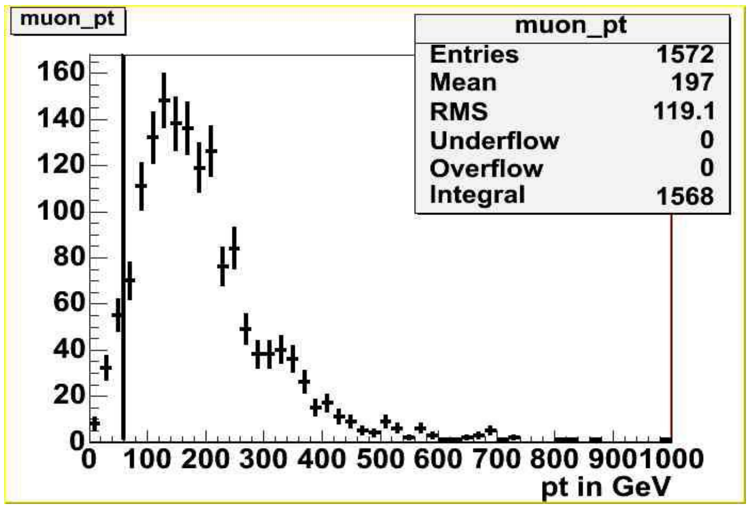
Monte Carlo samples

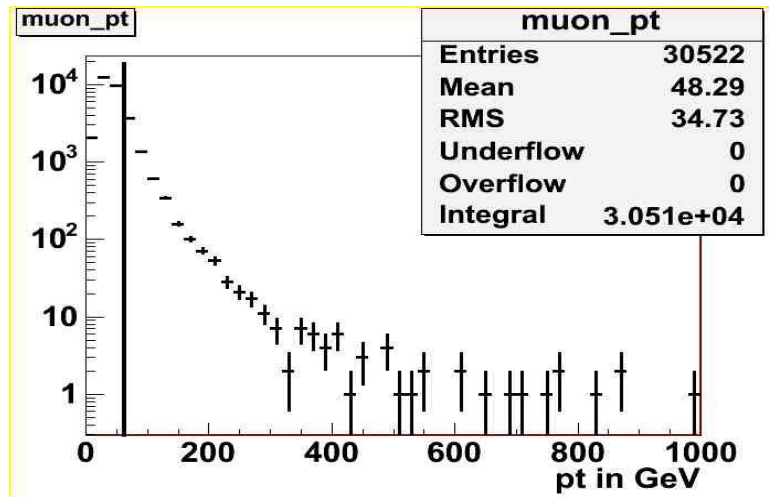
- For the generation of the MC-samples PYTHIA (LQ) and SHERPA (Z+jets) respectively have been used.
- The LQ and $Z/\gamma^*(\rightarrow\mu\mu)$ + jets samples were produced with a full simulation of the ATLAS detector (ATHENA version 10.0.4)
- As signal-sample 1000 LQ-pair events with a mass of 400, 800 and 1200 GeV respectively were available
- As background-sample 80.000 $Z/\gamma^*(\rightarrow\mu+\mu)$+jets events were available

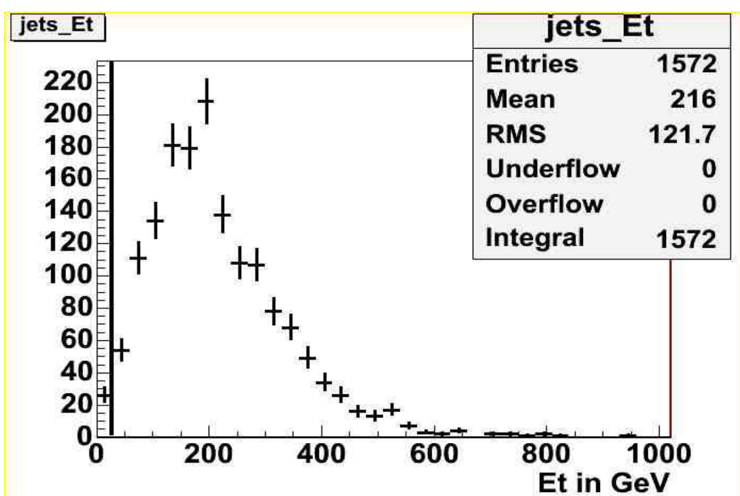
Selection Variables I

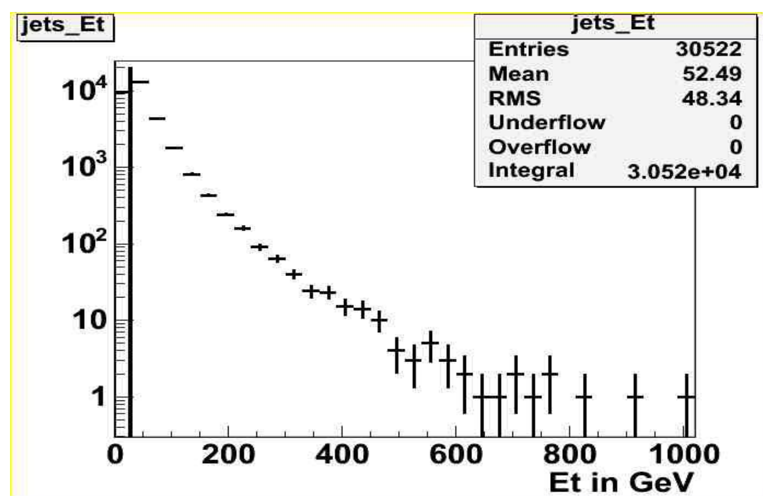
signal: m_{LQ} = 400 GeV
sample: 1000 LQ pairs

background: 50740 Z/γ^* ($\rightarrow\mu+\mu$) + jets events with at least 2 jets each with E_T^{jet} > 20GeV









best cuts:

p_T^μ > 60 GeV

R=0.7 cone jet-algorithm

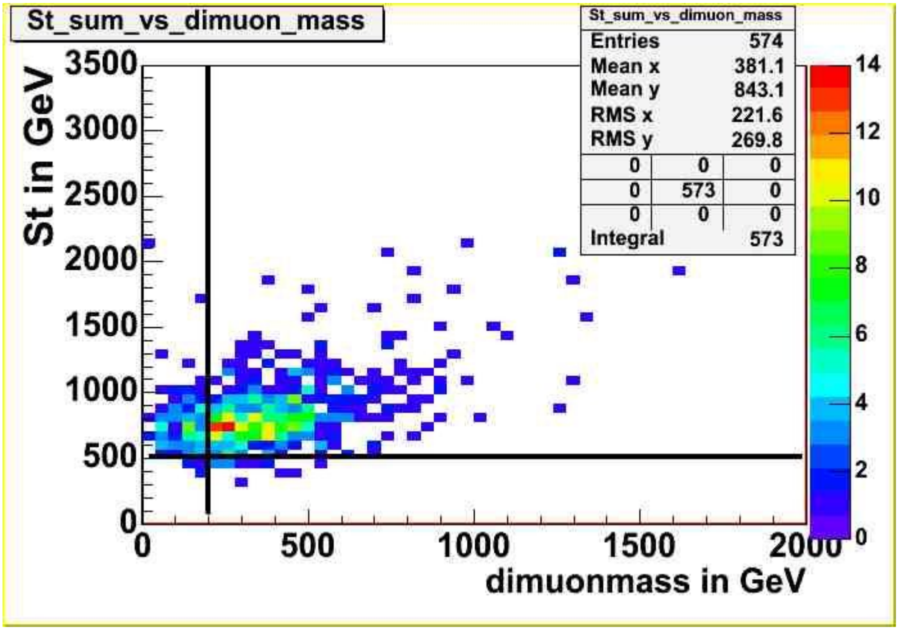
E_T^{jet} > 25 GeV

Selection variables II

after: $p_T^{\mu} >$ 60 GeV (both muons)
$E_T^{jet} >$ 25 GeV (both jets)
2μ opposite charge
no μ / jet isolation R = 0.4, $R = \sqrt{(\Delta\eta^2 + \Delta\Phi^2)}$

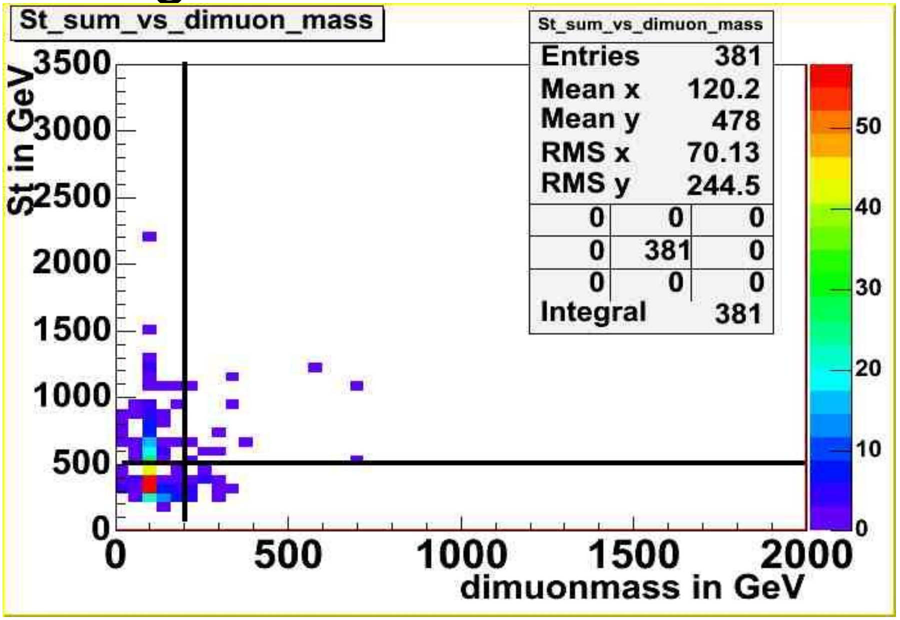
$S_T = \Sigma E_T$

Signal:



451 (=45,1%) LQ events left

Background:



12 Z + jets events left
(=0.16 per sel. LQ, m_{LQ}=400GeV)

cuts for higher m_{LQ}

for higher m_{LQ}: smaller cross-section,but cuts, especially S_T-cut, can be increased → background is more suppressed

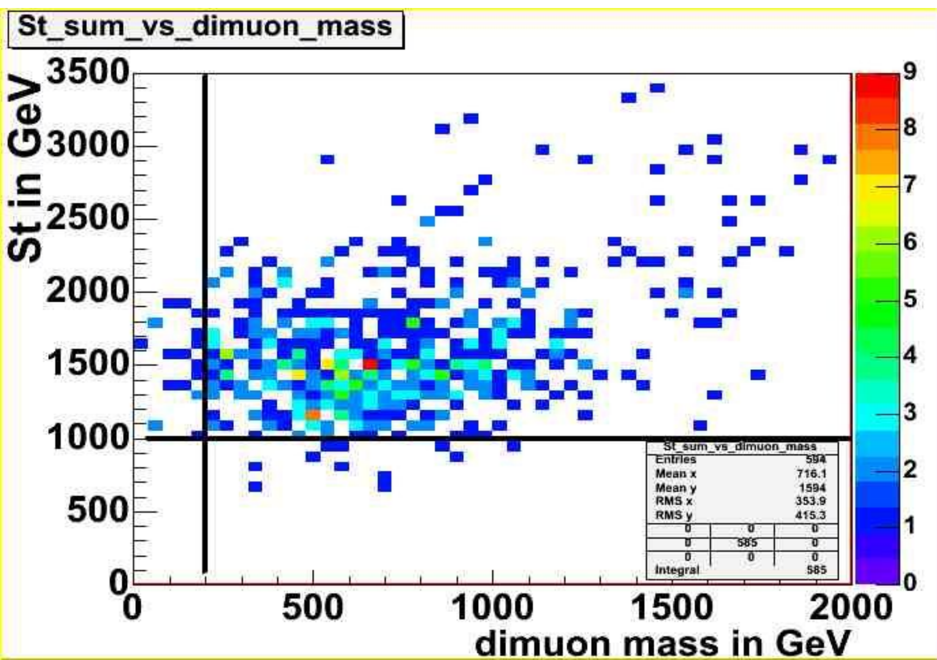
p_T^{μ} > 125 GeV

E_T^{jet} > 100 GeV

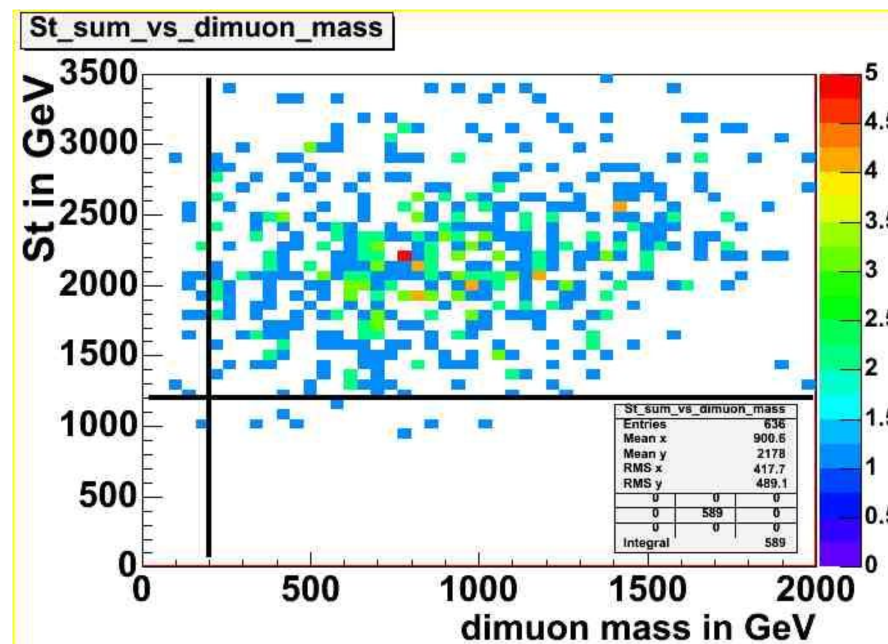
$m_{\mu\mu}$ > 200 GeV

no μ/jet isolation

m_{LQ}= 800 GeV
S_t^{cut}=1000 GeV



m_{LQ}= 1200 GeV
S_t^{cut}=1200 GeV



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main background processes

process	σ * Br(pb)	∫ L dt (pb^{-1}) of available sample (v10)	# of events left per sel. LQ m = 400GeV S_T > 500GeV	# of events left per sel. LQ m = 800GeV S_T > 1000GeV	# of events left per sel. LQ m = 1200GeV S_T > 1200GeV
tt→μνjμνj	5.5	200	0.145	0	0
ZZ→μμjj	0.6	7666	0.003	0.014	0.150 (m±200) 0
WW→μνμν	1.7	2500	0.023	0.046 (m±200)0.023	0.918 (m±200) 0
ZW→μμjj	0.6	0	-	-	-
Z/γ* →μμ+jets	690	73.5	0.143	3.217 (m±200) 0	15.848 (m±200) 0
		LQ eff.:	38.5%	45.4% (m±200) 36,4%	43.0% (m±200) 27.6%

cut-flow table

cuts	LQ m=400 GeV	LQ m=800 GeV	LQ m=1200 GeV	$Z/\gamma^*(\mu\mu)$+jets
without cuts	1000 =100%	1000 =100%	1000 =100%	84150 = 100%
+ both jets E_T > 25 GeV	968	987	985	65279
+OS muons both p_T>60 GeV	674	733	750	449
+ μ/jet exclusion ΔR = 0.4	496	495	695	390
+ dimuon mass> 200 GeV	395	469	401	36
+ S_T-cut	> 500 GeV: 386 = 38,6%	> 1000 Gev: 456 = 45,6%	>1200 GeV: 394 = 39,4%	>500 GeV: 10 = 0,12%

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Summary

- LQ with m_{LQ}= 400 GeV can be discovered already in the beginning of the LHC run; higher m_{LQ} can be discovered with harder cuts
- most backgrounds suppressed quite well; with $m_{LQ} \pm$ 200 cut all (available) backgrounds suppressed quite well
- BUT very low statistics

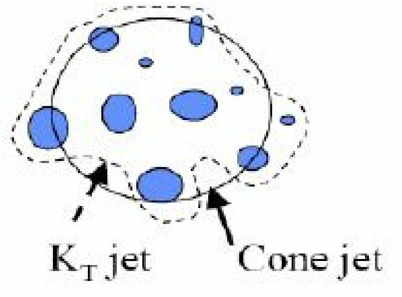
Outlook

- study ZW→μμjj background as soon as it is available
- use background samples of version 11.x.x and compare results with that of version 10.0.4
- production of LQ with version 11.0.41 underway

Jet Algorithms I

- There are 3 different kind of algorithms in ATHENA/ATLAS (taken from the Tevatron):

  - Cone 0.7: standard cone-algorithm with radius $R = \sqrt{(\Delta\eta^2 + \Delta\Phi^2} = 0.7$



  - Cone 0.4: standard cone-algorithm with radius R = 0.4

  - k_T: separate jets according to their relative transverse momentum

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Jet algorithms II

with the cuts: $p_T^\mu >$ 60 GeV (both muons)
$E_T^{jet} >$ 25 GeV (both jets)
2μ opposite charge
μ / jet isolation R = 0.4, $R = \sqrt{(\Delta\eta^2 + \Delta\Phi^2)}$
$\eta_{muon}<2.5$ and $\eta_{jet}<5$:

# of rec. LQ events

	no S_T, dimuon cut	S_T > 500 GeV dimuon>200GeV
cone 0.4	526	397
cone 0.7	496	386
k_T	492	384

m_{LQ} = 400 GeV

m_{LQ} = 800 GeV

	no S_T, dimuon cut	S_T > 500 GeV dimuon>200GeV
cone 0.4	517	450
cone 0.7	517	466
k_T	483	454

	no S_T, dimuon cut	S_T > 500 GeV dimuon>200GeV
cone 0.4	446	397
cone 0.7	448	402
k_T	435	392

m_{LQ} = 1200 GeV

Jet algorithms III

with the cuts: p_T^{μ} > 60 GeV (both muons)
E_T^{jet} > 25 GeV (both jets)
2μ opposite charge
μ / jet isolation R = 0.4, $R = \sqrt{(\Delta\eta^2 + \Delta\Phi^2)}$
η_{muon}<2.5 and η_{jet}<5:

$Z/\gamma^*(\rightarrow\mu+\mu)$+jets

	no S_T, dimuon cut	S_T > 500 GeV dimuon>200GeV	$_T$ dimuon>200GeV	S_T > 1000 GeV dimuon>200GeV
cone 0.4	322	9	4	1
cone 0.7	349	9	4	1
k_T	390	10	3	0

Gernot Krobath
LMU München