

BLOCKKURS: SOFTWARE IN DER TEILCHENPHYSIK

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Ludwig-Maximilians-Universität München

07 April 2014



① ORGANISATORISCHES

② LHC, ATLAS UND ANALYSE

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② LHC, ATLAS UND ANALYSE

- Dozenten:
Günter Dückeck, guenter.duckeck@physik.uni-muenchen.de
Johannes Elmsheuser, johannes.elmsheuser@physik.uni-muenchen.de
Unterstützung: Alexander Mann, Michael Bender
Lehrstuhl Schaile, Experimentelle Teilchenphysik
- Übungen und Kursvorlesungen:
Mo-Fr 9:30-12:30 Uhr, 14-17:00 Uhr,
2.Stock, Zi. 219 Am Coulombwall 1, Garching
- Vorlesungswebseite:
<http://www.etp.physik.uni-muenchen.de/kurs/comp14/>
- Klausur/Schein:
Am Ende des Semesters
Inhalt: Software-Kurs und Teilchenphysik Vorlesung

- Ein/Ausgabe von Daten
- Graphische Darstellung
- ATLAS ATLANTIS Event Display
- ROOT tuples und eine kleine Analyse
- Analyse von OPAL Z0 daten
- Fitten von Daten
- HistPresent

Für die Übungen wird das ROOT Programmpaket verwendet, das eine umfangreiche Klassen- und Funktionenbibliothek in C++ bereitstellt.

- Übungen zu Themen der Vorlesung an Hand von konkreten Beispielen
- Programmierung von kleinen Beispielen in C/C++ (für Experten auch in Python)
- Verwendung von ROOT:
 - Object-Oriented Data Analysis Framework
 - Standard-Werkzeug in Teilchenphysik und darüber hinaus
 - <http://root.cern.ch/>
- Anleitungen zu C/C++:
 - u.a. Kurs: C++ für Physiker
<http://www.etp.physik.uni-muenchen.de/kurs/Computing/ckurs>

- ATLAS Experiment:
<http://www.iop.org/EJ/abstract/1748-0221/3/08/S08003/>
bzw. http://www.iop.org/EJ/article/1748-0221/3/08/S08003/jinst8_08_s08003.pdf
- ATLAS Physik: <http://arxiv.org/abs/0901.0512> bzw.
<http://arxiv.org/pdf/0901.0512v2>
- B.Blobel/E.Lohrmann, Statistische und numerische Methoden der Datenanalyse, Teubner, 1998
- W.-M. Yao et al., The Review of Particle Physics, Journal of Physics, G 33, 1 (2006), Anfangskapitel
<http://pdg.lbl.gov/>

- Teilchenphysik an Hadron Collidern für Bachelor/Master Studenten
Vorlesung: Physik am Tevatron und LHC
Termin: Mo 10:00-12:30, (Hörsaal EG), wegen geplanter Bauarbeiten
eher in Zi. 219
Otmar Biebel, Johannes Elmsheuser
- Seminar: Moderne Aspekte der Teilchenphysik
N/A

- Verbindlich: Abgabe der Bachelorarbeit in gebundener Form nach 10 Wochen (dieses Jahr wegen Osterns im Semester: \approx 11 Wochen)
 - \approx 11 Wochen: 15.April-30.Juni; Abgabe bis 30.6. bei Frau Epp - 2 Exemplare in gebundener Form.
 - Stil der Arbeit: max. 20-30 Seiten
-
- Arbeitsplatz im 3. Stock, Am Coulombwall 1, Garching
 - Haus ist ab 8 Uhr offen, wer nach 16-16:30 (Fr. 13:00) noch mal rein möchte, braucht die Telefonnummer von jemand, der ihn reinlässt.
 - Gruppenschlüssel vorhanden

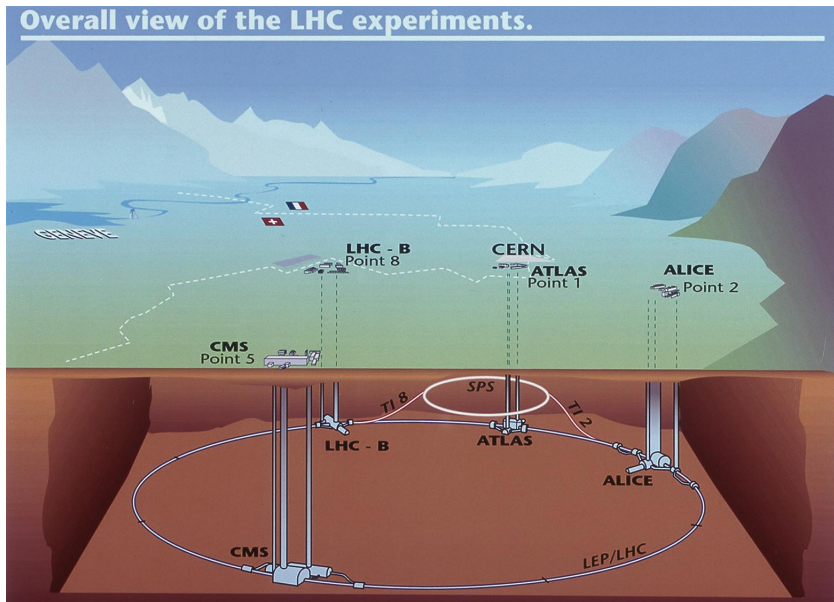
① ORGANISATORISCHES

② LHC, ATLAS UND ANALYSE

DER LHC UND DIE EXPERIMENTE I

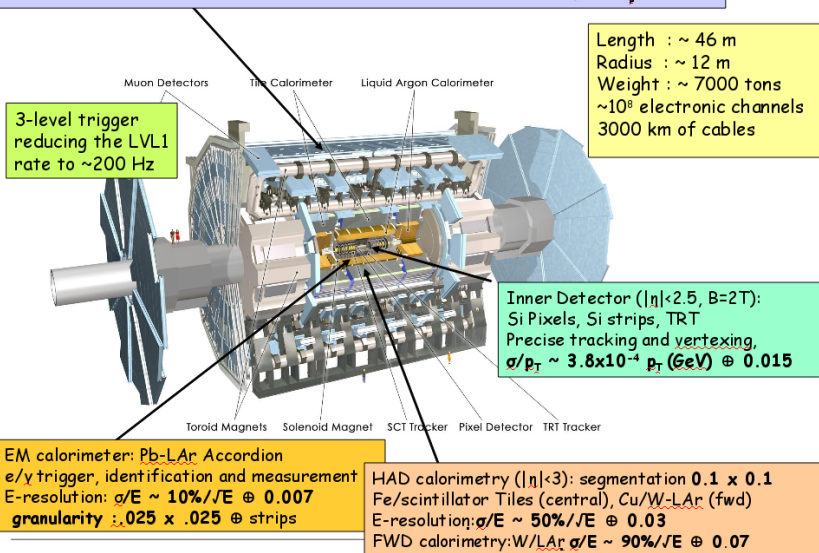


DER LHC UND DIE EXPERIMENTE II



DAS ATLAS EXPERIMENT

Muon Spectrometer ($|\eta| < 2.7$): air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution $< 10\%$ up to $E_\mu \sim 1$ TeV

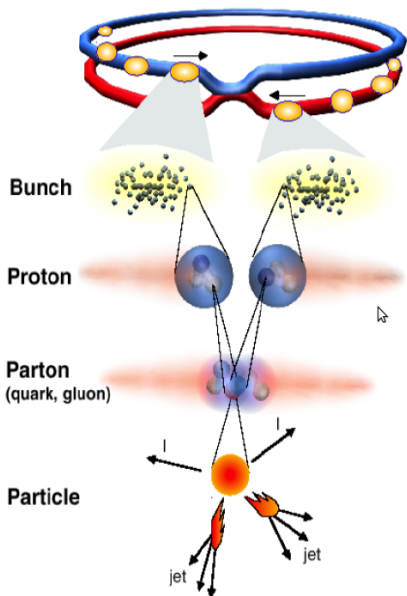


DAS ATLAS EXPERIMENT

~3000 scientists from 174 Institutions and 38 Countries



KOLLISIONEN IM LHC



Proton-Proton-Kollisionen
2835 Teilchenbündel (Bunch)

10^{11} Protonen / Bunch
Kollisionsrate 40 MHz (25 ns)

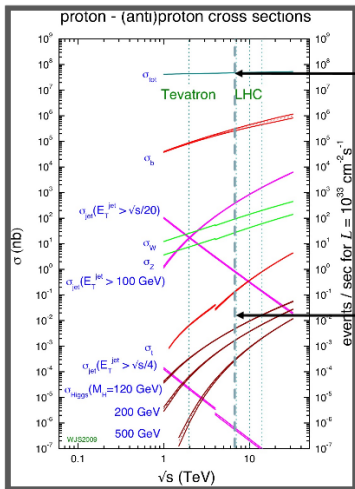
Schwerpunktenergie 14 TeV
(= 7400 x Ruheenergie der kollidierenden Teilchen)

Schwerpunktenergie der kollidierenden Quarks und Gluonen bis einige TeV

~25 pp-Kollisionen pro Bunch-Kollision

Interessante Ereignisse: 10^{-9} – 10^{-11} unterdrückt!

Number of events in 45pb^{-1}



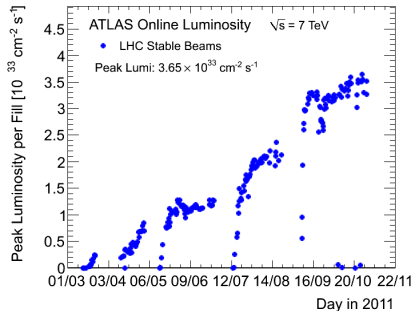
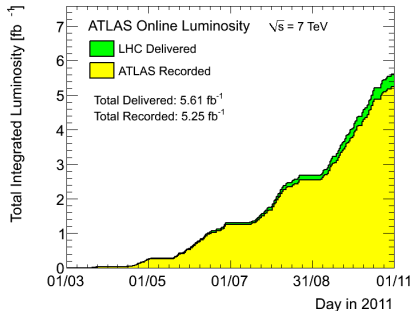
70 billion (10^9) pb \rightarrow 3 trillion (10^{12}) events! *

* N.B. only a very small fraction saved!

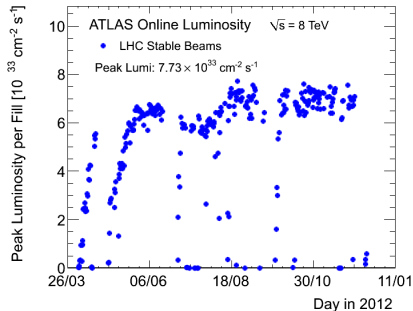
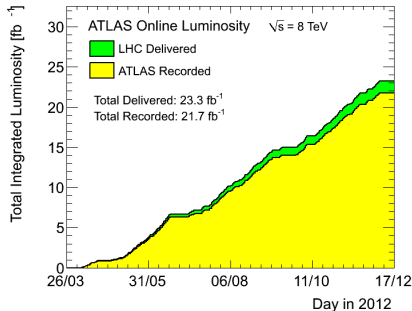
Higgs ($m_H=120$): 17 pb \rightarrow 750 events

e.g. potentially ~ 1 Higgs in every 300 billion interactions!

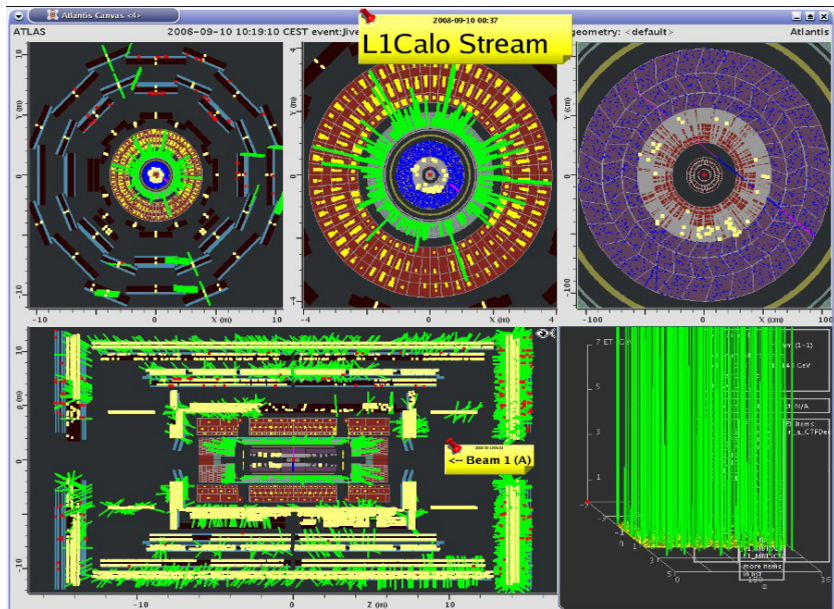
ATLAS STATUS 2011



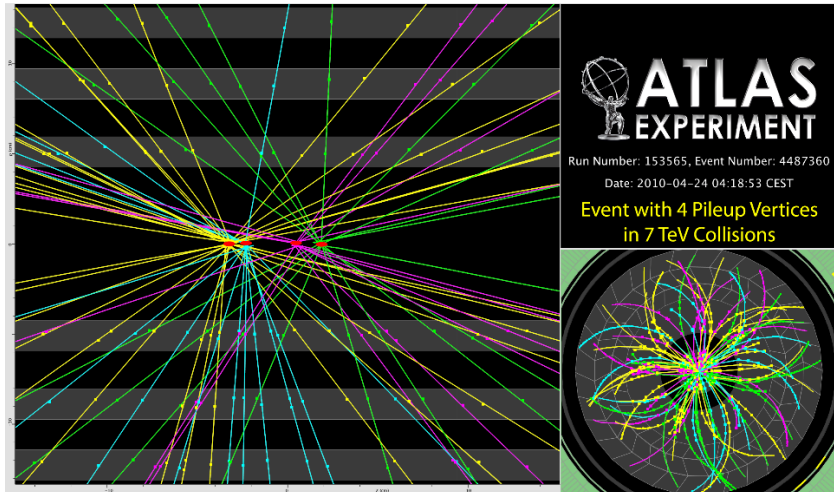
ATLAS STATUS 2012



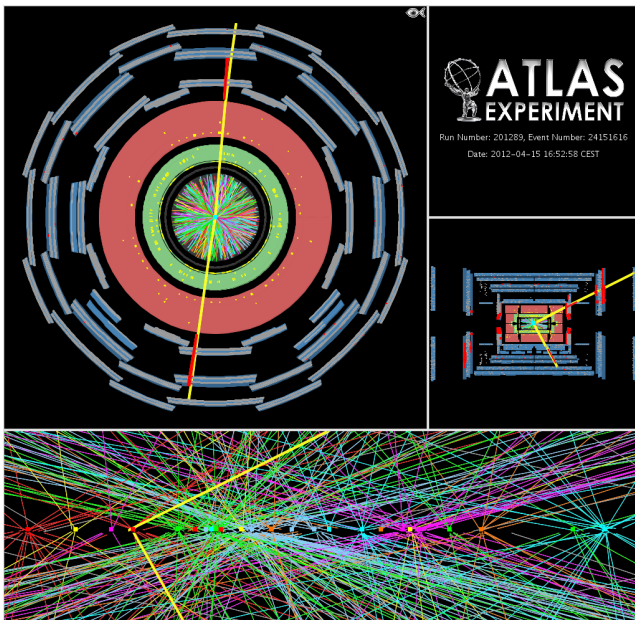
EIN ERSTES LIVE-EREIGNIS 2009



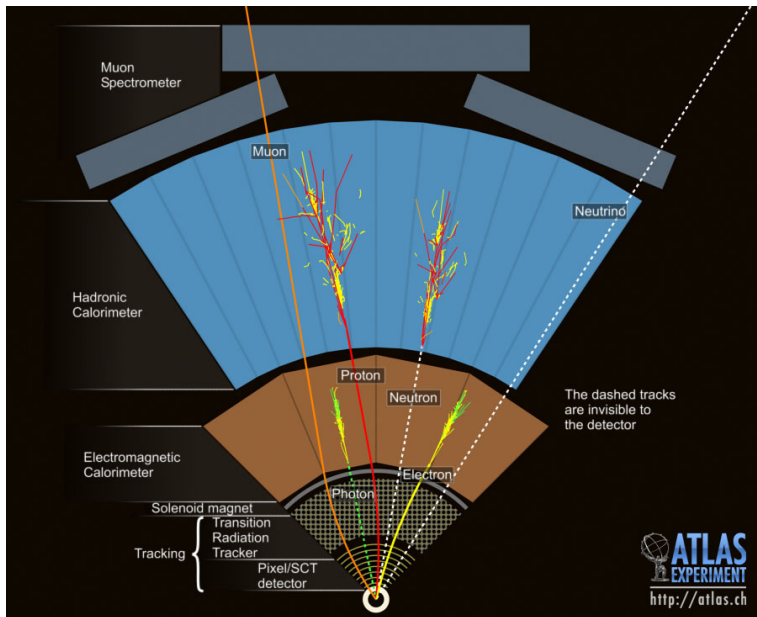
Event with 4 pileup vertices in same pp-collision



REKONSTRUKTION: $Z \rightarrow \mu^+ \mu^-$ UND PILE-UP


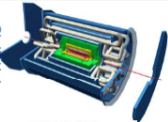
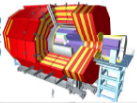
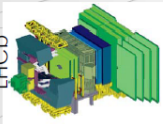


TEILCHENNACHWEIS

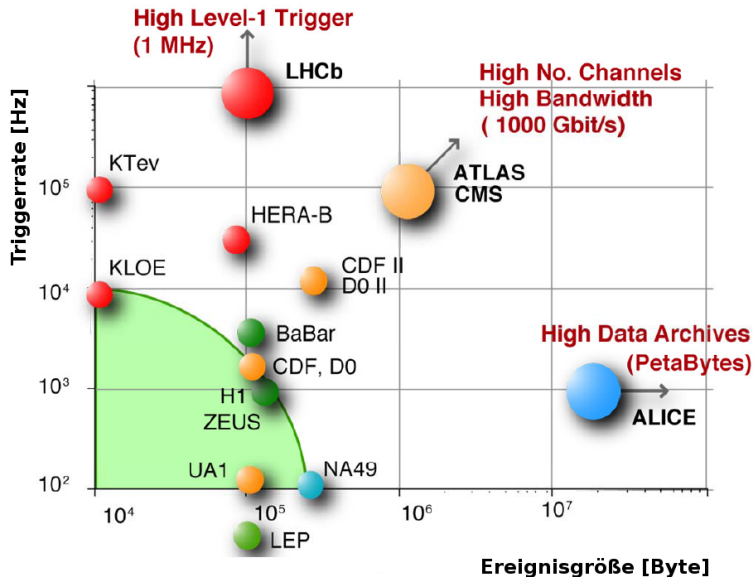




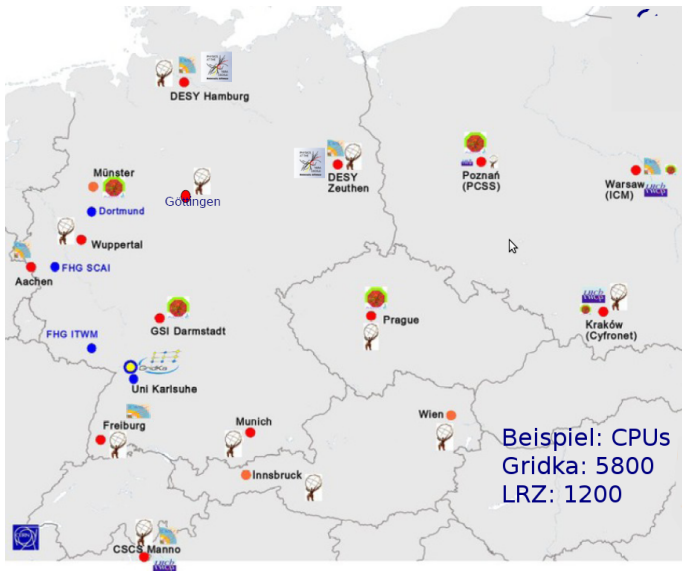
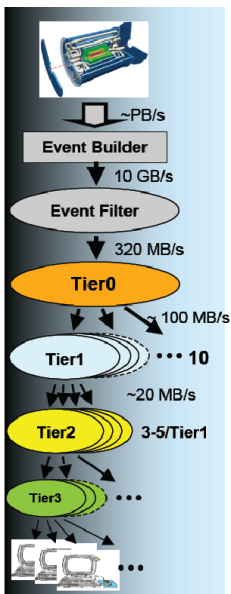
Trigger/DAQ parameters

	No.Levels Trigger	Level-0,1,2 Rate (Hz)	Event Size (Byte)	Readout Bandw.(GB/s)	HLT Out MB/s (Event/s)
ALICE 	4	Pb-Pb 500 p-p 10 ³	5x10 ⁷ 2x10 ⁶	25	1250 (10 ²) 200 (10 ²)
ATLAS 	3	LV-1 10 ⁵ LV-2 3x10 ³	1.5x10 ⁶	4.5	300 (2x10 ²)
CMS 	2	LV-1 10 ⁵	10 ⁶	100	~1000 (10 ²)
LHCb 	2	LV-0 10 ⁶	3.5x10 ⁴	35	70 (2x10 ³)

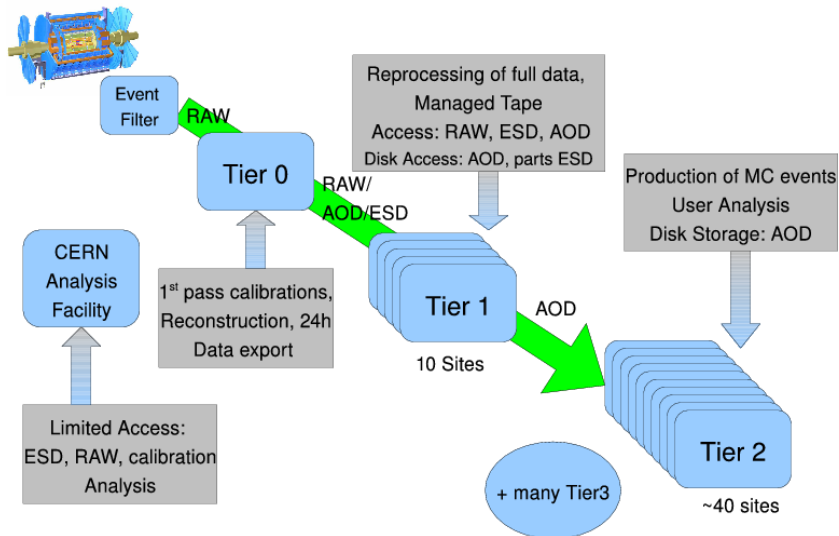
TRIGGER UND EREIGNIS-GRÖSSE



RECHENZENTREN- UND GRIDKA-ORGANISATION



DATEN VERTEILUNG: ATLAS

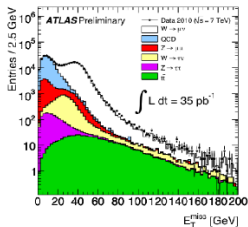
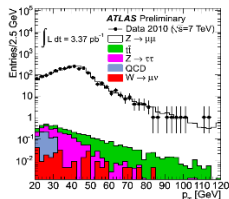


Analysis ingredients in a nutshell

Cross section measurement:

$$\sigma = \frac{N_{\text{Observed}} - N_{\text{BG}}}{\epsilon_{\text{Total}} * L}$$

N_{Observed} : number of observed events
 N_{BG} : Number of background events
 ϵ_{total} : Overall detection efficiency
 L : Luminosity provided by collider



Select interesting events based signal event characteristics:

- e.g. leptons, jets, E_T^{Miss} , angular correlations etc.

Example: $Z \rightarrow \mu\mu$:

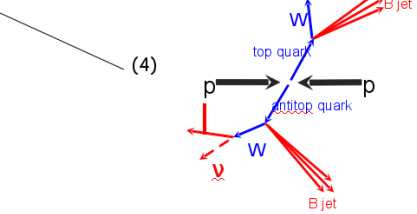
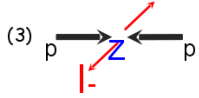
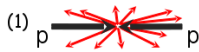
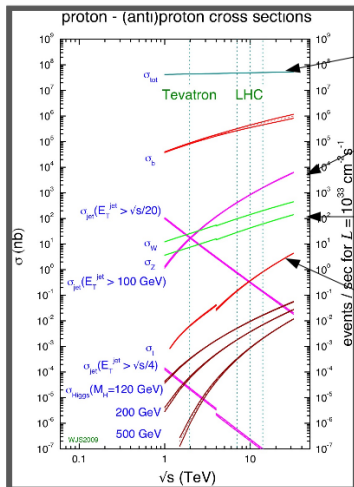
- 2 isolated μ -tracks, back-to-back, low E_T^{Miss} , high transverse momentum, low jet activity

Determine N_{BG} or Signal prediction from Monte Carlo or data driven methods

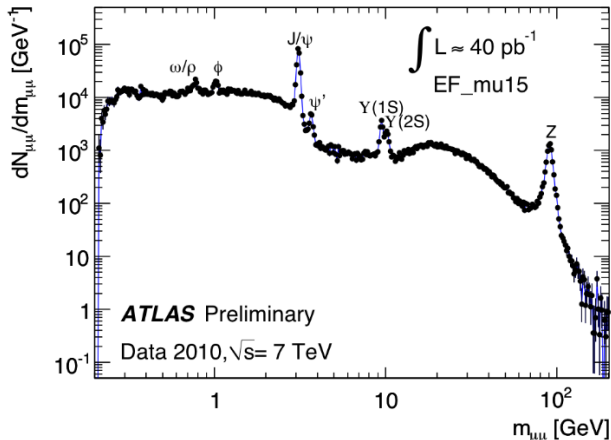
ϵ_{total} : Combination of Efficiencies:

- Trigger, Reconstruction, Acceptance, Cuts etc.

Different Analysis



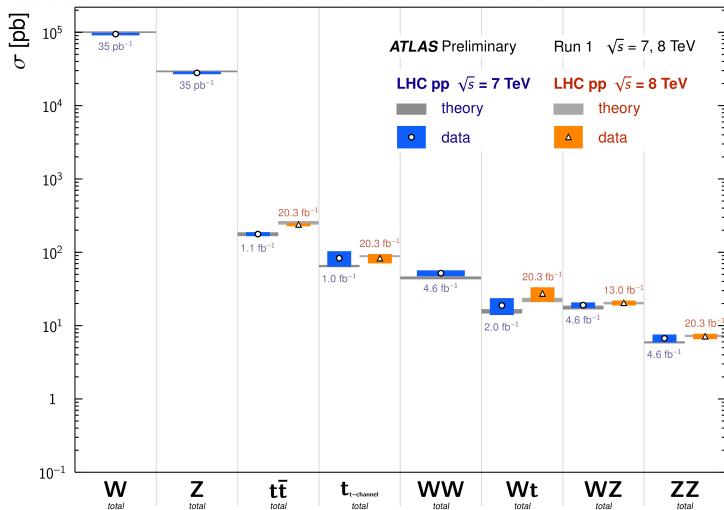
Di-muon invariant mass

Leading muon, $p_{T1} > 15$ GeV, second muon, $p_{T2} > 2.5$ GeV

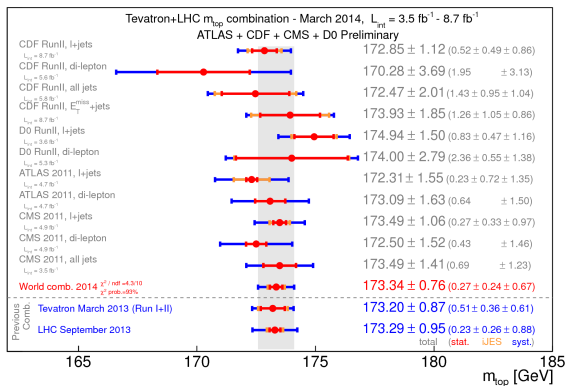
ATLAS RESULTS I

Standard Model Total Production Cross Section Measurements

Status: March 2014



ATLAS RESULTS II



ATLAS RESULTS III

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Moriond 2014

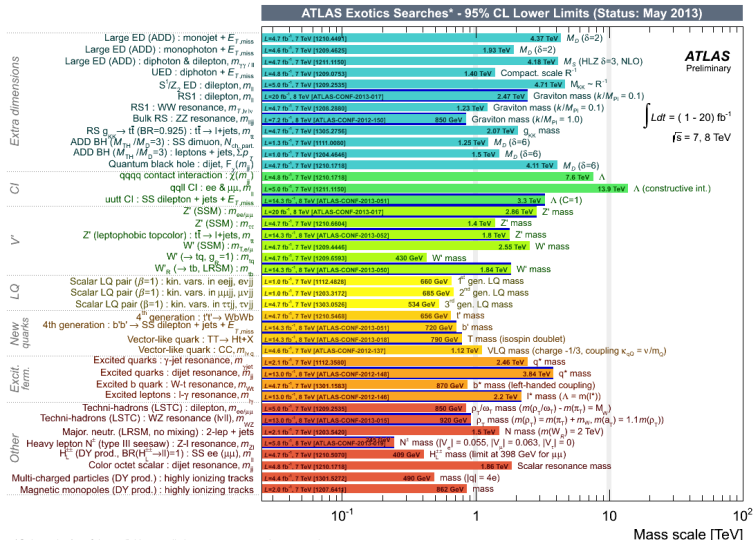
ATLAS Preliminary

$$\int \mathcal{L} dt = (4.6 - 22.9) \text{ fb}^{-1} \quad \sqrt{s} = 7, 8 \text{ TeV}$$

Model	$\epsilon, \mu, \tau, \gamma$	Jets	$E_{\text{miss}}^{\text{min}}$	$[\mathcal{L} dt(\text{fb}^{-1})]$	Mass limit	Reference			
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	0.8	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-047	
	MSUGRA/CMSSM	1, e, μ	3-6 jets	Yes	20.3	1.2 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-052	
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	1.1 TeV	$m(\tilde{g}, \tilde{u}_L)$	1305.1841	
	$\tilde{g}, \tilde{g} \rightarrow \tilde{g} \tilde{g}$	0	2-6 jets	Yes	20.3	740 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-047	
	$\tilde{g}, \tilde{g} \rightarrow \tilde{g} \tilde{g}$	0	2-6 jets	Yes	20.3	1.3 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-047	
	$\tilde{g}, \tilde{g} \rightarrow \tilde{g} \tilde{g}$	1, e, μ	3-6 jets	Yes	20.3	1.18 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-052	
	$\tilde{g}, \tilde{g} \rightarrow \tilde{g} \tilde{g}$	2, e, μ	0-3 jets	Yes	20.3	1.12 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-059	
	GMSB (\tilde{g} NLSP)	2, e, μ	2-4 jets	Yes	20.3	1.24 TeV	$m(\tilde{g}, \tilde{u}_L)$	1208.4598	
	GMSB (\tilde{g} NLSP)	1-2 τ	0-2 jets	Yes	20.7	1.4 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-026	
	GGM (bino NLSP)	2 γ	-	Yes	20.3	1.28 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2014-001	
	GGM (wino NLSP)	1, $e, \mu + \gamma$	-	Yes	4.8	1.619 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2012-144	
	GGM (higgsino-bino NLSP)	γ	1-1	Yes	4.8	900 GeV	$m(\tilde{g}, \tilde{u}_L)$	1211.1167	
	GGM (higgsino NLSP)	2, e, μ (Z)	0-3 jets	Yes	5.8	895 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-152	
	Gravitino LSP	0	mono-jet	Yes	10.5	277.5 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2012-147	
	3 γ gen. \tilde{g} med.	$\tilde{g} \rightarrow \tilde{g} \tilde{g}$	0	3-6	Yes	20.1	1.2 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-061
$\tilde{g} \rightarrow \tilde{g} \tilde{g}$		0	7-10 jets	Yes	20.3	1.1 TeV	$m(\tilde{g}, \tilde{u}_L)$	1308.1841	
$\tilde{g} \rightarrow \tilde{g} \tilde{g}$		0-1, e, μ	3-6	Yes	20.1	1.34 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-061	
$\tilde{g} \rightarrow \tilde{g} \tilde{g}$		0-1, e, μ	3-6	Yes	20.1	1.3 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-061	
3 γ gen. squarks direct production	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	0	2-6	Yes	20.1	100-620 GeV	$m(\tilde{g}, \tilde{u}_L)$	1308.2631	
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	2, e, μ (SS)	0-3-6	Yes	20.7	275-430 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-027	
	$\tilde{t}_1 \tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	2, e, μ	1-2-6	Yes	4.7	110-167 GeV	$m(\tilde{g}, \tilde{u}_L)$	1208.935, 1209.2102	
	$\tilde{t}_1 \tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	2, e, μ	0-2 jets	Yes	20.3	130-210 GeV	$m(\tilde{g}, \tilde{u}_L)$	1403.4853	
	$\tilde{t}_1 \tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	2, e, μ	2 jets	Yes	20.3	215-530 GeV	$m(\tilde{g}, \tilde{u}_L)$	1403.4853	
	$\tilde{t}_1 \tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	0	2-6	Yes	20.1	150-580 GeV	$m(\tilde{g}, \tilde{u}_L)$	1308.2631	
	$\tilde{t}_1 \tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	1, e, μ	1-6	Yes	20.7	200-610 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-037	
	$\tilde{t}_1 \tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	0	2-6	Yes	20.5	320-660 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-024	
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	0	mono-jet+tag	Yes	20.3	90-200 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-068	
	$\tilde{t}_1 \tilde{t}_1$ (natural GMSB)	2, e, μ (Z)	1-6	Yes	20.3	150-580 GeV	$m(\tilde{g}, \tilde{u}_L)$	1403.5222	
$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1 + Z$	3, e, μ (Z)	1-6	Yes	20.3	290-600 GeV	$m(\tilde{g}, \tilde{u}_L)$	1403.5222		
EW direct	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	2, e, μ	0	Yes	20.3	90-325 GeV	$m(\tilde{g}, \tilde{u}_L)$	1403.5294	
	Stable, stopped \tilde{t}_1 production	2, e, μ	0	Yes	20.3	146-465 GeV	$m(\tilde{g}, \tilde{u}_L)$	1403.5294	
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	2, e, μ	2 τ	0	Yes	20.7	180-330 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-028
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	3, e, μ	0	Yes	20.3	700 GeV	$m(\tilde{g}, \tilde{u}_L)$	1402.7039	
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	2-3, e, μ	0	Yes	20.3	420 GeV	$m(\tilde{g}, \tilde{u}_L)$	1403.5294, 1402.7029	
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	1, e, μ	2-6	Yes	20.3	285 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-093	
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	1, e, μ	2-6	Yes	20.3	270 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-069	
Long-lived particles	Direct $\tilde{t}_1 \tilde{t}_1$ prod., long-lived \tilde{t}_1	Disapp. trk	1 jet	Yes	20.3	270 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-069	
	Stable, stopped \tilde{t}_1 production	0	1-5 jets	Yes	22.9	0	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-057	
	GMSB, stable $\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	1-2 μ	-	Yes	4.7	832 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-056	
	GMSB, $\tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$, long-lived \tilde{t}_1	2 γ	-	Yes	4.7	475 GeV	$m(\tilde{g}, \tilde{u}_L)$	1304.6131	
	$\tilde{g}, \tilde{g} \rightarrow \tilde{g} \tilde{g}$ (RPV)	1, e, μ , displ. vtx.	-	Yes	20.3	1.0 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-092	
RPV	LFV $pp \rightarrow \tilde{t}_1 + X, \tilde{t}_1 \rightarrow \nu e + \mu$	2, e, μ	-	-	4.6	1.61 TeV	$X_{11}, X_{12}, X_{21}, X_{22}, X_{31}, X_{32}, X_{33}$	1212.1272	
	LFV $pp \rightarrow \tilde{t}_1 + X, \tilde{t}_1 \rightarrow \nu e(j) + \tau$	1, $e, \mu + \tau$	-	-	4.6	1.1 TeV	$X_{11}, X_{12}, X_{21}, X_{22}, X_{31}, X_{32}, X_{33}$	1212.1272	
	Bilinear RPV CMSSM	1, e, μ	7 jets	Yes	4.7	1.2 TeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-140	
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	1, e, μ	4 jets	Yes	20.7	760 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-036	
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 \tilde{t}_1$	3, $e, \mu + \tau$	-	Yes	20.7	350 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-036	
	$\tilde{g} \rightarrow \tilde{g} \tilde{g}$	0	6-7 jets	Yes	20.3	916 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-091	
	$\tilde{g} \rightarrow \tilde{g} \tilde{g}$	2, e, μ (SS)	0-3-6	Yes	20.7	880 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-007	
Other	Scalar gluon pair, sgluon $\rightarrow \tilde{g} \tilde{g}$	0	4 jets	-	4.6	100-287 GeV	incl. limit from 1110.2693	1210.4826	
	Scalar gluon pair, sgluon $\rightarrow \tilde{g} \tilde{g}$	2, e, μ (SS)	2-6	Yes	14.3	350-609 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2013-051	
	WIMP interaction (DS, Dirac χ)	0	mono-jet	Yes	10.5	768 GeV	$m(\tilde{g}, \tilde{u}_L)$	ATLAS CONF-2012-147	

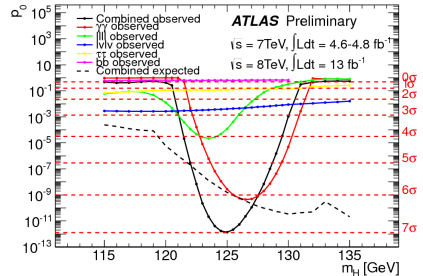
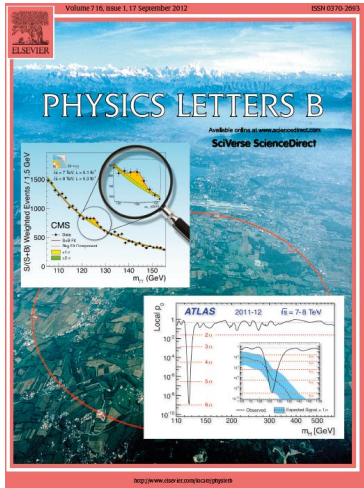
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1 σ theoretical signal cross section uncertainty.

ATLAS RESULTS III



*Only a selection of the available mass limits on new states or phenomena shown

ENTDECKUNG EINES SKALAREN BOSONS



Die lokale Wahrscheinlichkeit p_0 für ein untergrund-artiges Experiment mehr signal-artig zu sein als die tatsächliche Beobachtung als Funktion von m_H für verschiedene individuelle Kanäle

$H \rightarrow \gamma\gamma$ UND $H \rightarrow ZZ$

