Blockkurs: Software in der Teilchenphysik

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based on work from Johannes Elmsheuser and Gnter Duckeck
Ludwig-Maximilians-Universität München

13 April 2015

Inhalt

Organisatorisches

- Dozenten:
  Alexander Mann, a.mann@physik.uni-muenchen.de
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  Unterstützung: C. Bock, J. Heinrich, J. Lorenz, O. Schaile
  Lehrstuhl Schaile, Experimentelle Teilchenphysik
- Übungen und Kursvorlesungen:
  Mo-Fr 10:00-12:30 Uhr, 14-17:00 Uhr,
  2.Stock, Zi. 219 Am Coulombwall 1, Garching
- Vorlesungswebseite:
  www.etp.physik.uni-muenchen.de/kurs/comp15
- Klausur/Schein:
  Am Ende des Semesters
  Inhalt: Software-Kurs und Teilchenphysik Vorlesung

Inhalt

- 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

- Übungen zu Themen der Vorlesung an Hand vom 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`

Literatur

- 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/

Weitere Veranstaltungen

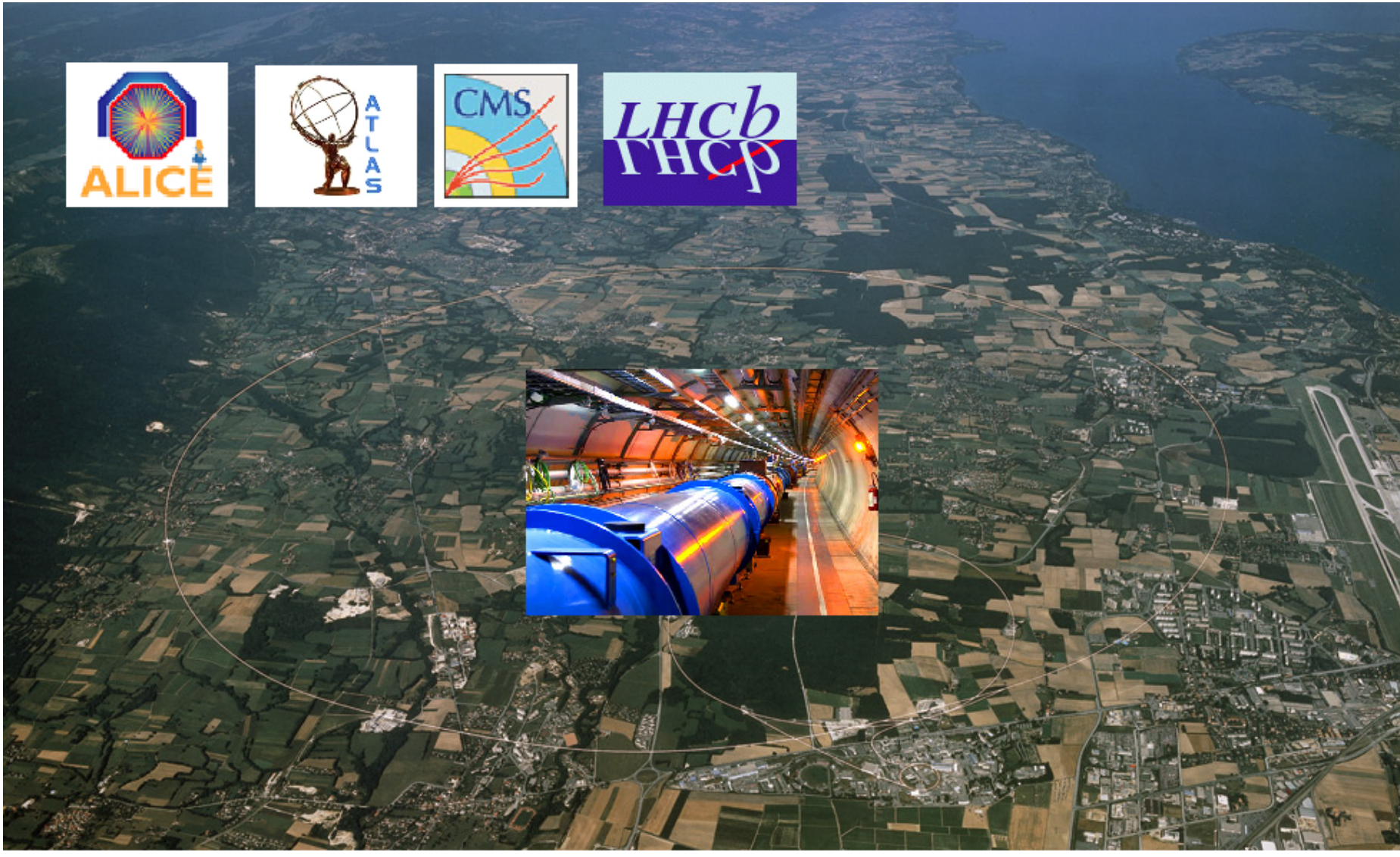
- Teilchenphysik an Hadron Collidern für Bachelor/Master Studenten
  Vorlesung: Physik am Tevatron und LHC
  Termin: Mo 10:00-12:30, Zi. 219
  Otmar Biebel, Johannes Elmsheuser
- Seminar: Moderne Aspekte der Teilchenphysik
  Termin: wahrscheinlich Fr 10-12
  Sascha Mehlhase

Bachelorarbeit

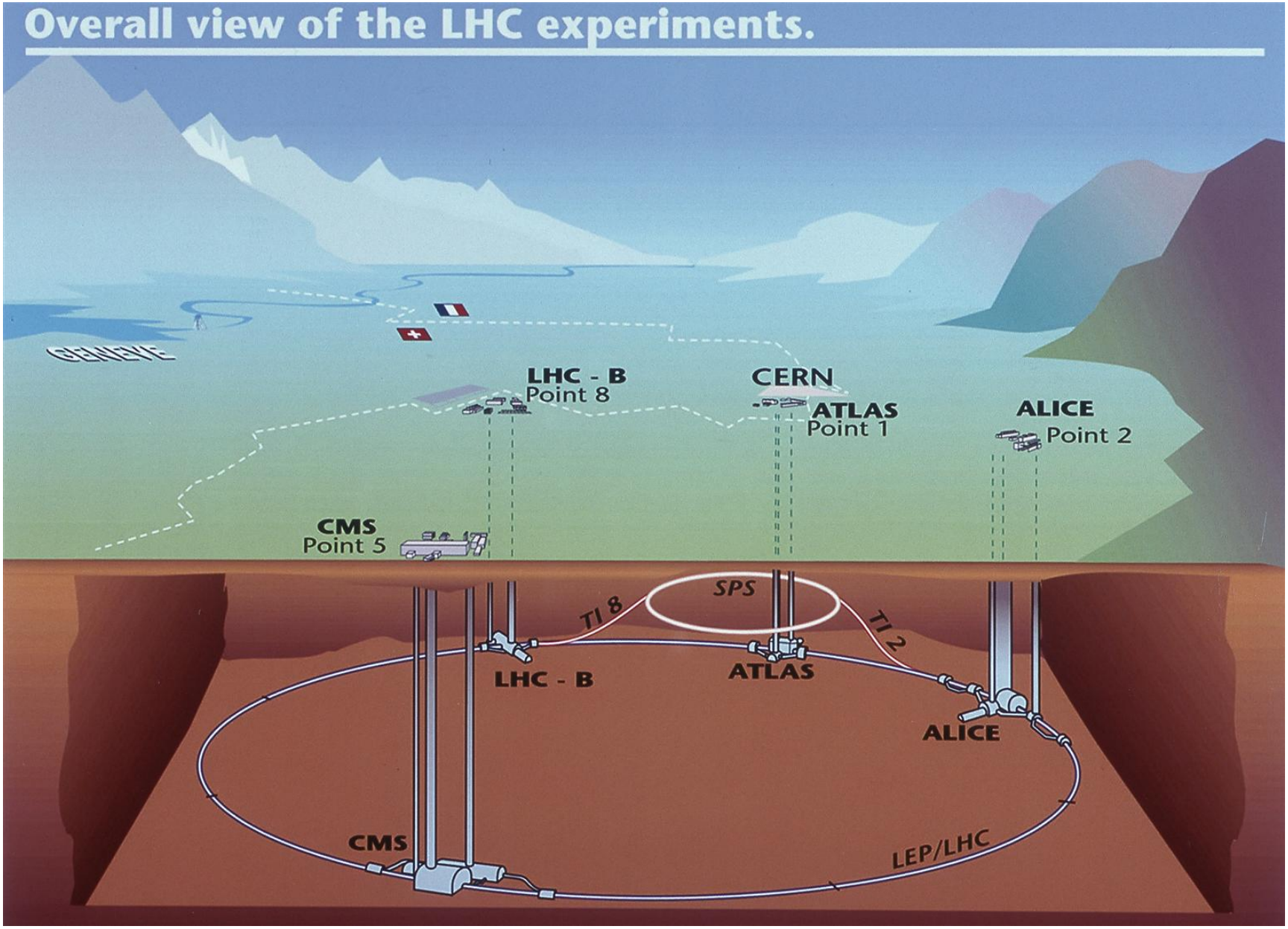
- Verbindlich: Abgabe der Bachelorarbeit in gebundener Form nach 10 Wochen
- $\approx$10 Wochen: 20. April-3. Juli; Abgabe bis 3. Juli bei Frau Epp - 2 Exemplare in gebundener Form.
- Stil der Arbeit: max. 20-30 Seiten

- 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

Der LHC und die Experimente I



Der LHC und die Experimente II

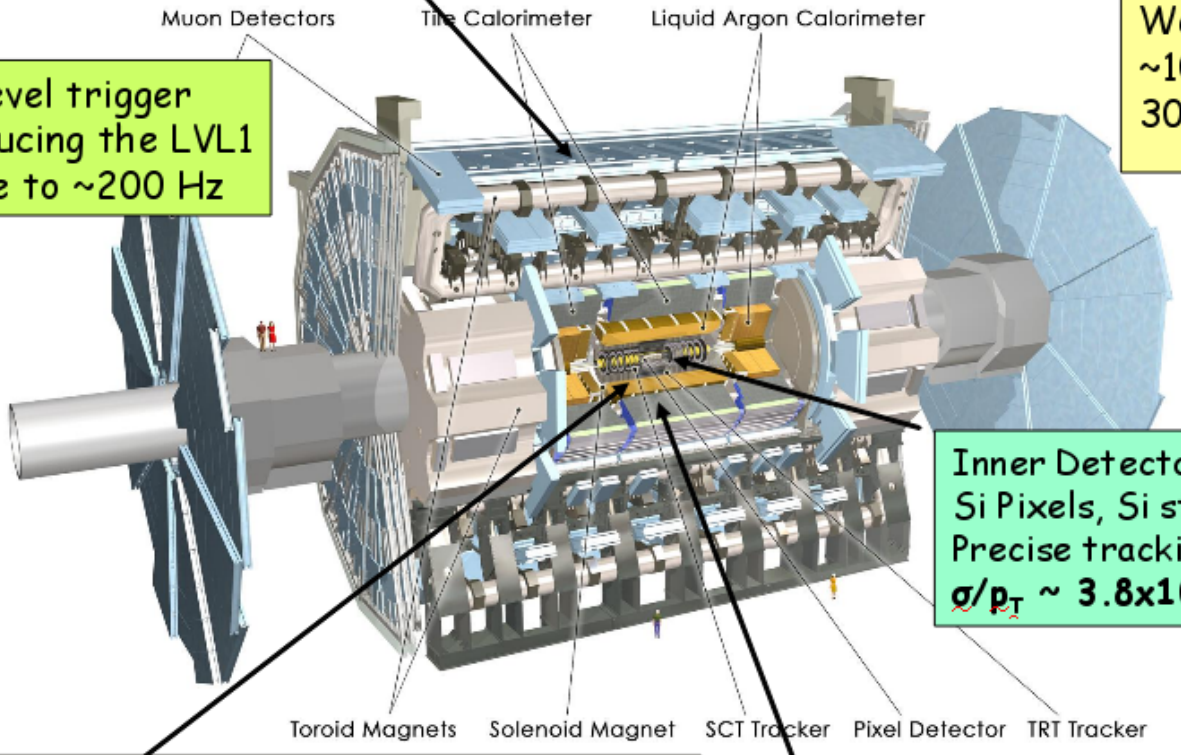


Das ATLAS Experiment

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

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

3-level trigger reducing the LVL1 rate to ~200 Hz



Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, TRT
Precise tracking and vertexing,
σ/p_T ~ 3.8×10^{-4} p_T (GeV) ⊕ 0.015

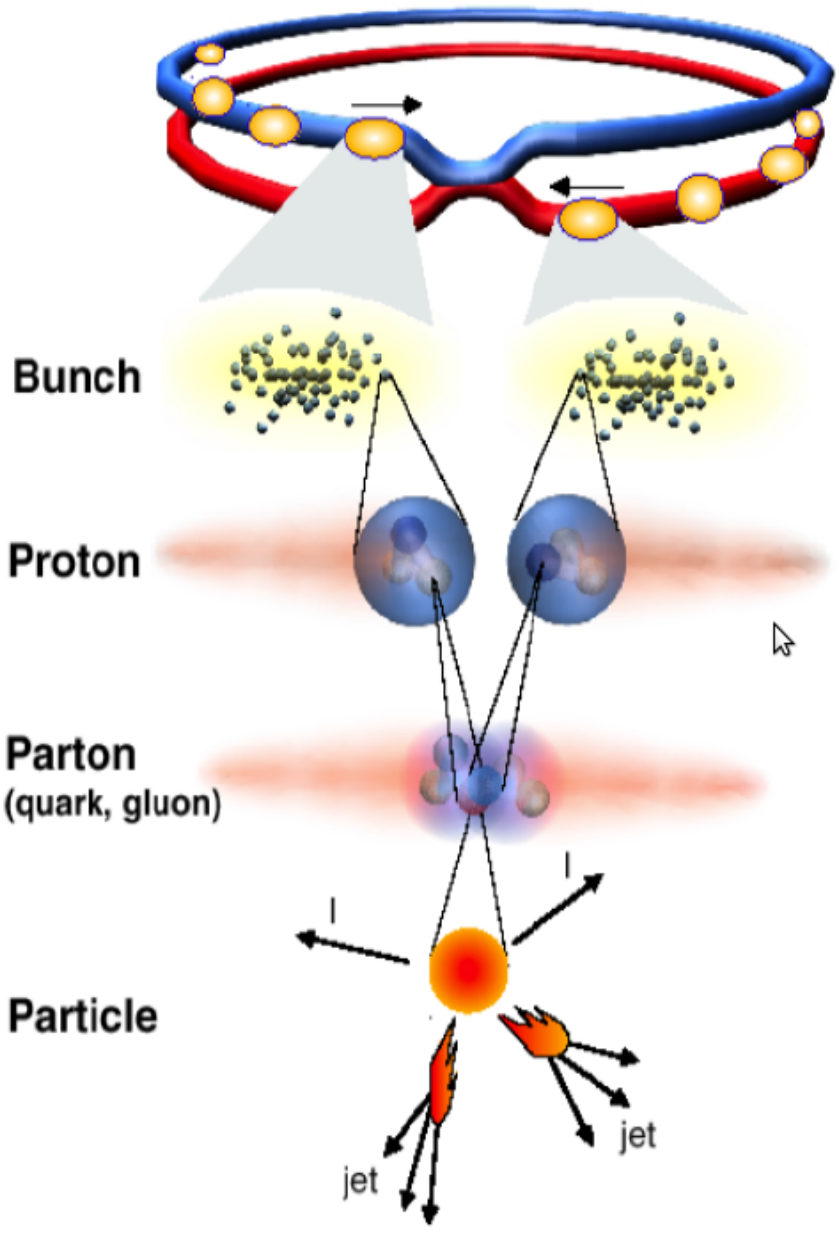
EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: **σ/E ~ 10%/$\sqrt{E}$ ⊕ 0.007**
granularity : .025 x .025 ⊕ strips

HAD calorimetry ($|\eta|<3$): segmentation **0.1 x 0.1**
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
E-resolution:**σ/E ~ 50%/$\sqrt{E}$ ⊕ 0.03**
FWD calorimetry:W/LAr **σ/E ~ 90%/$\sqrt{E}$ ⊕ 0.07**

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)

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

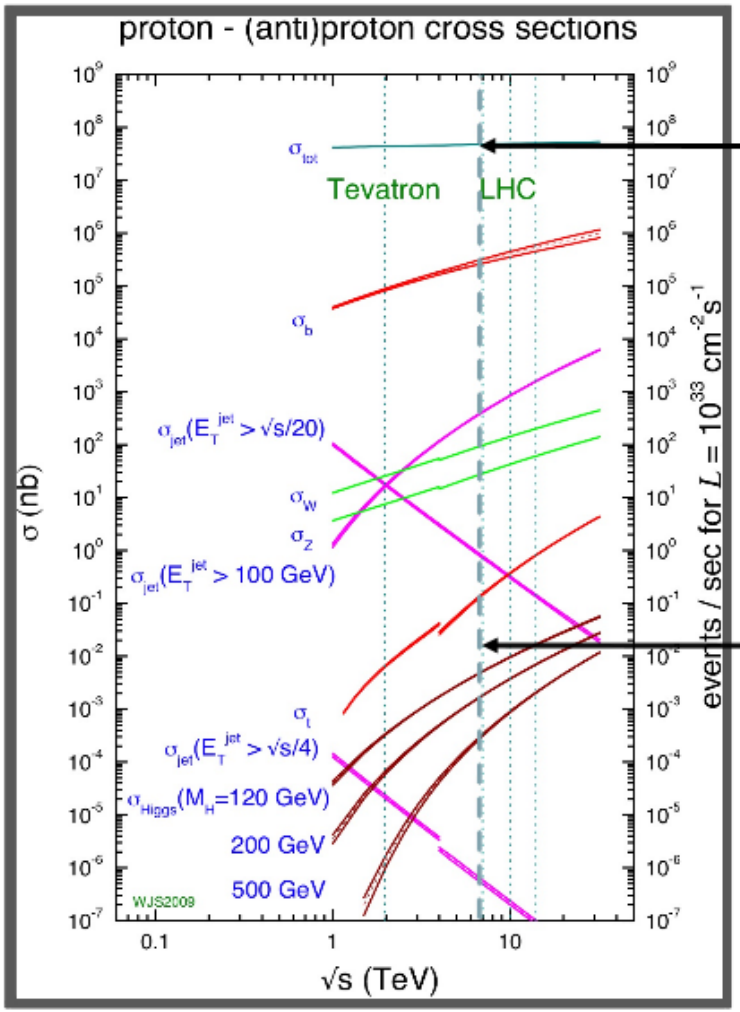
Schwerpunktsenergie der
kollidierenden Quarks und Gluonen
bis einige TeV

~25 pp-Kollisionen pro
Bunch-Kollision

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

Wirkungsquerschnitte I

Number of events in 45pb^{-1}



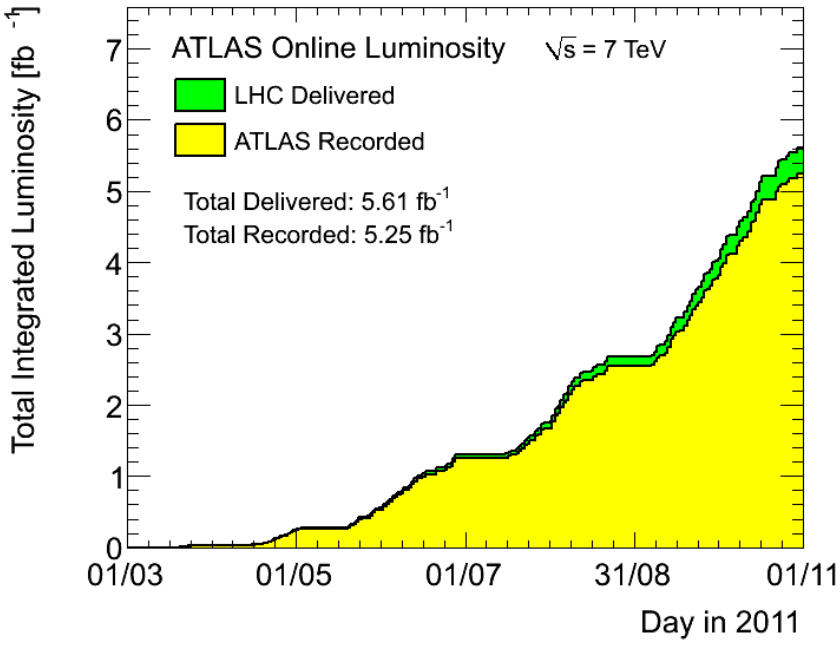
70 billion (10^9) pb -> **3 trillion (10^{12}) events! ***

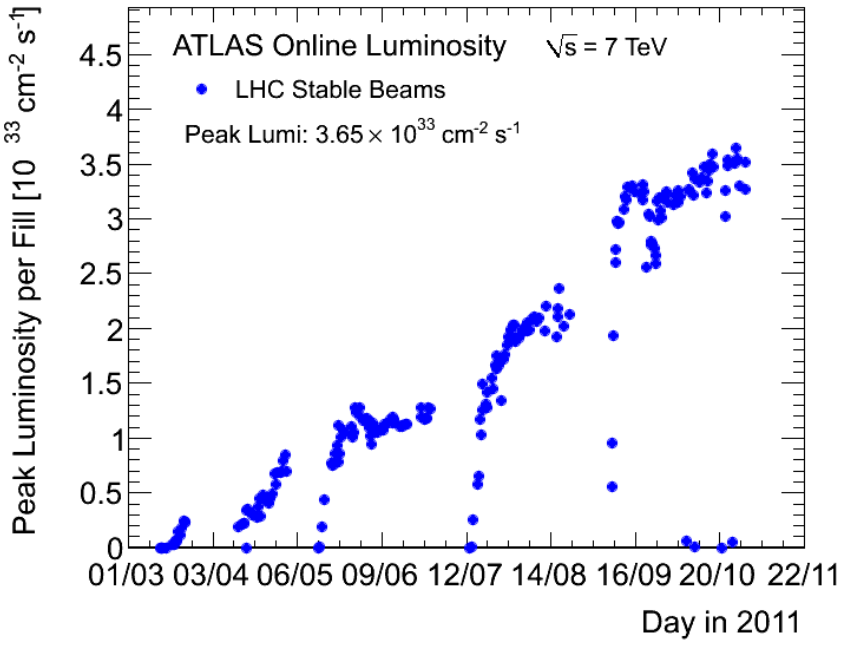
* N.B. only a very small fraction saved!

Higgs (mH=120) : 17 pb -> **750 events**

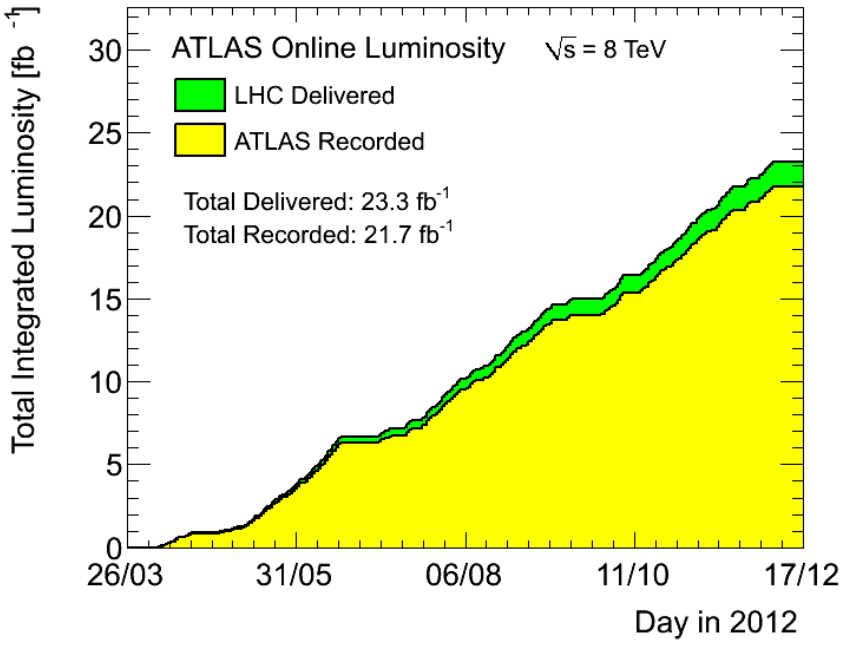
e.g. potentially ~1 Higgs in every 300 billion interactions!

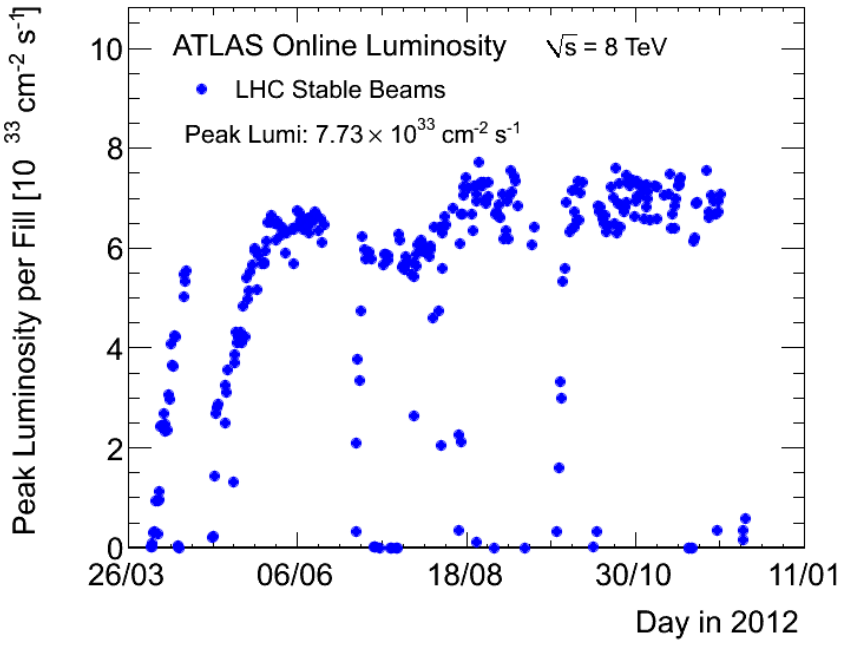
ATLAS status 2011



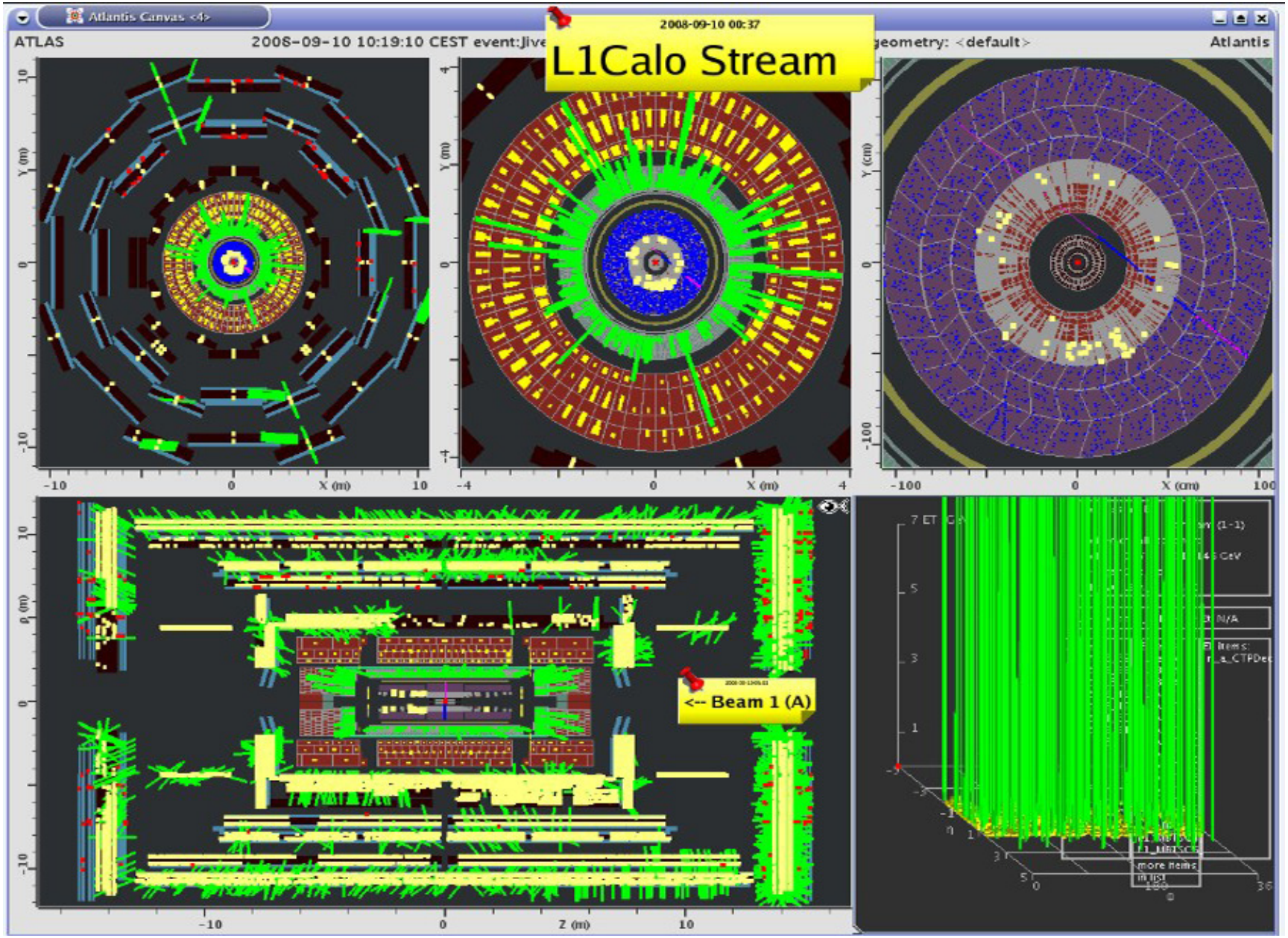


ATLAS status 2012



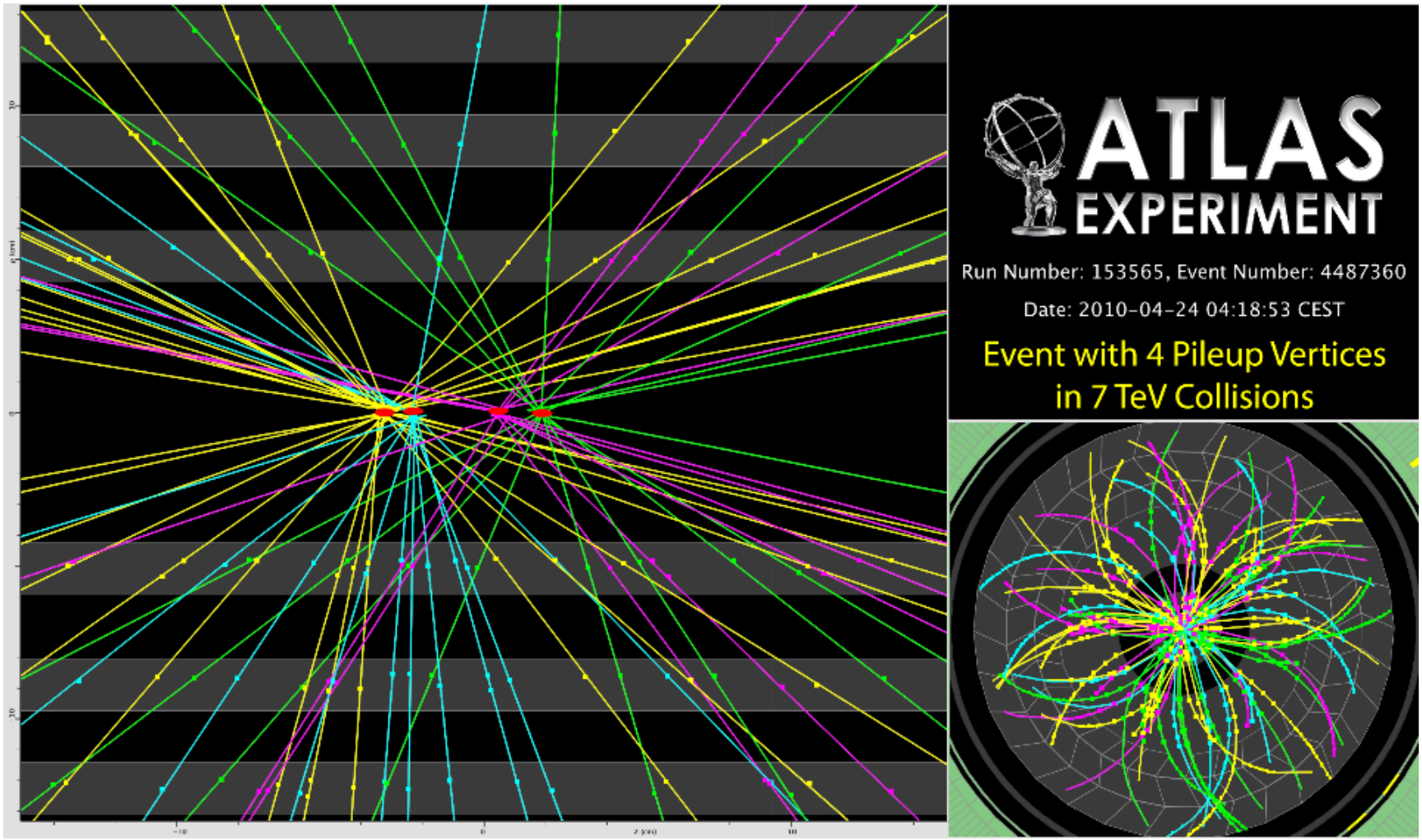


Ein erstes Live-Ereignis 2009

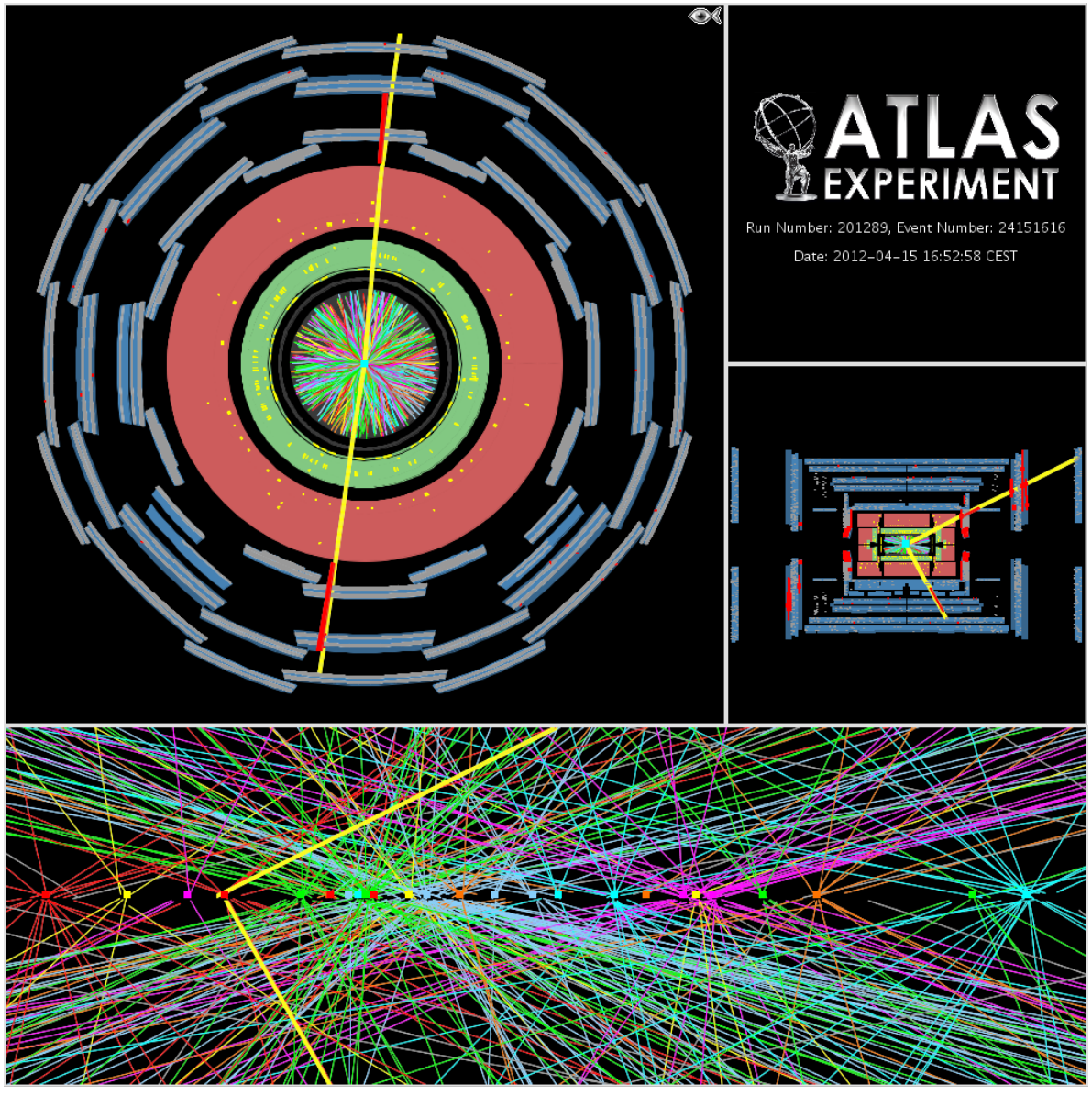


Weiteres ATLAS Ereignis

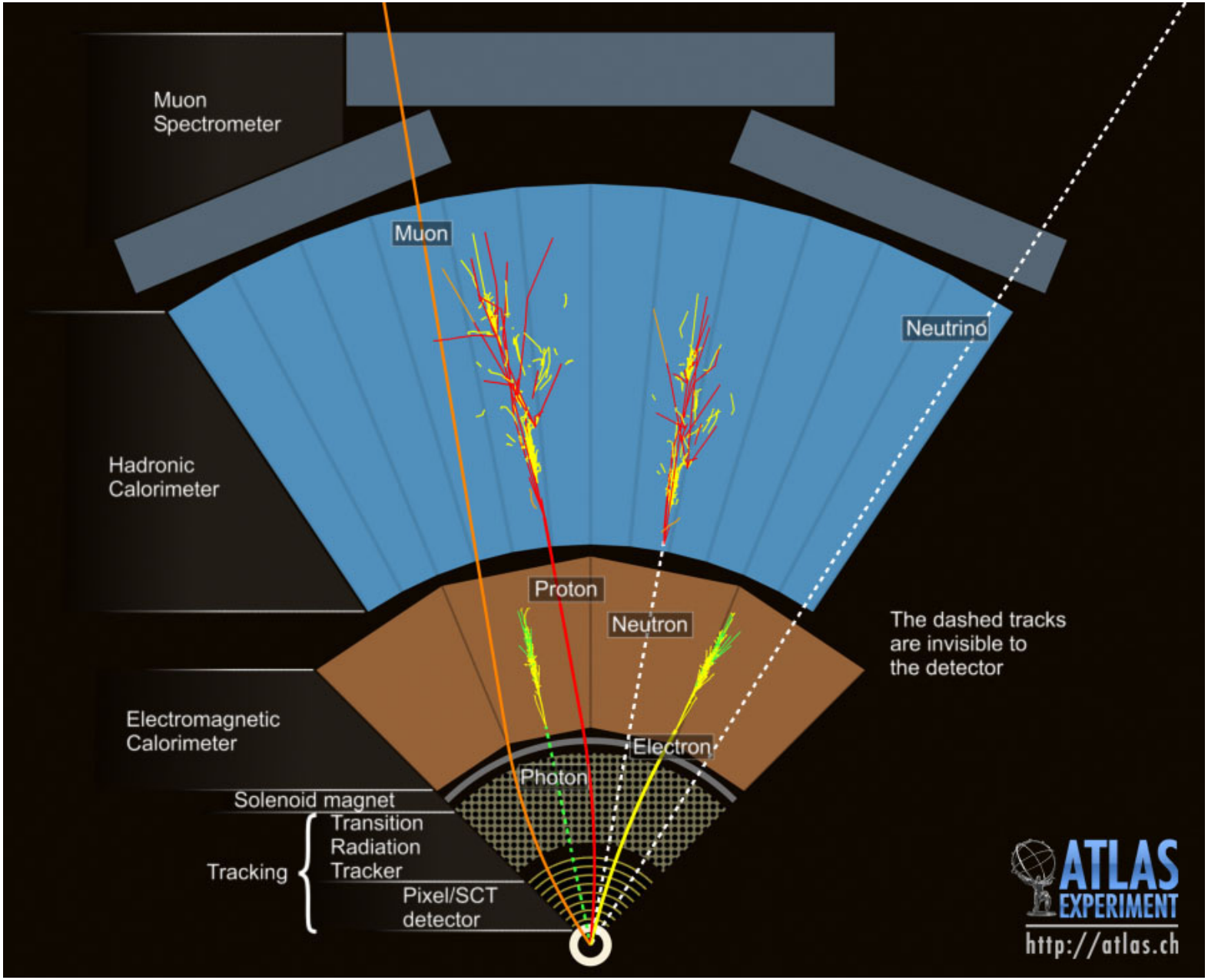
Event with 4 pileup vertices in same pp-collision



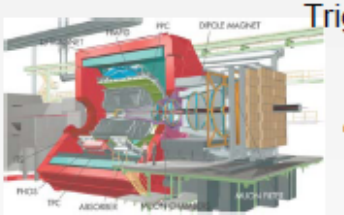
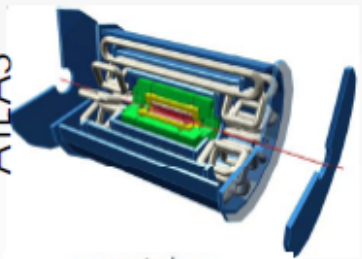
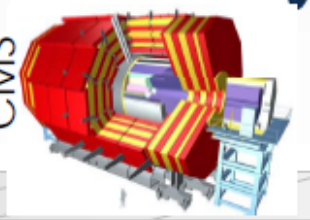
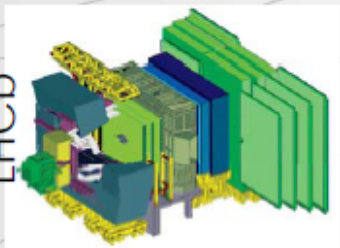
Rekonstruktion: $Z \to \mu^+\mu^-$ und Pile-Up



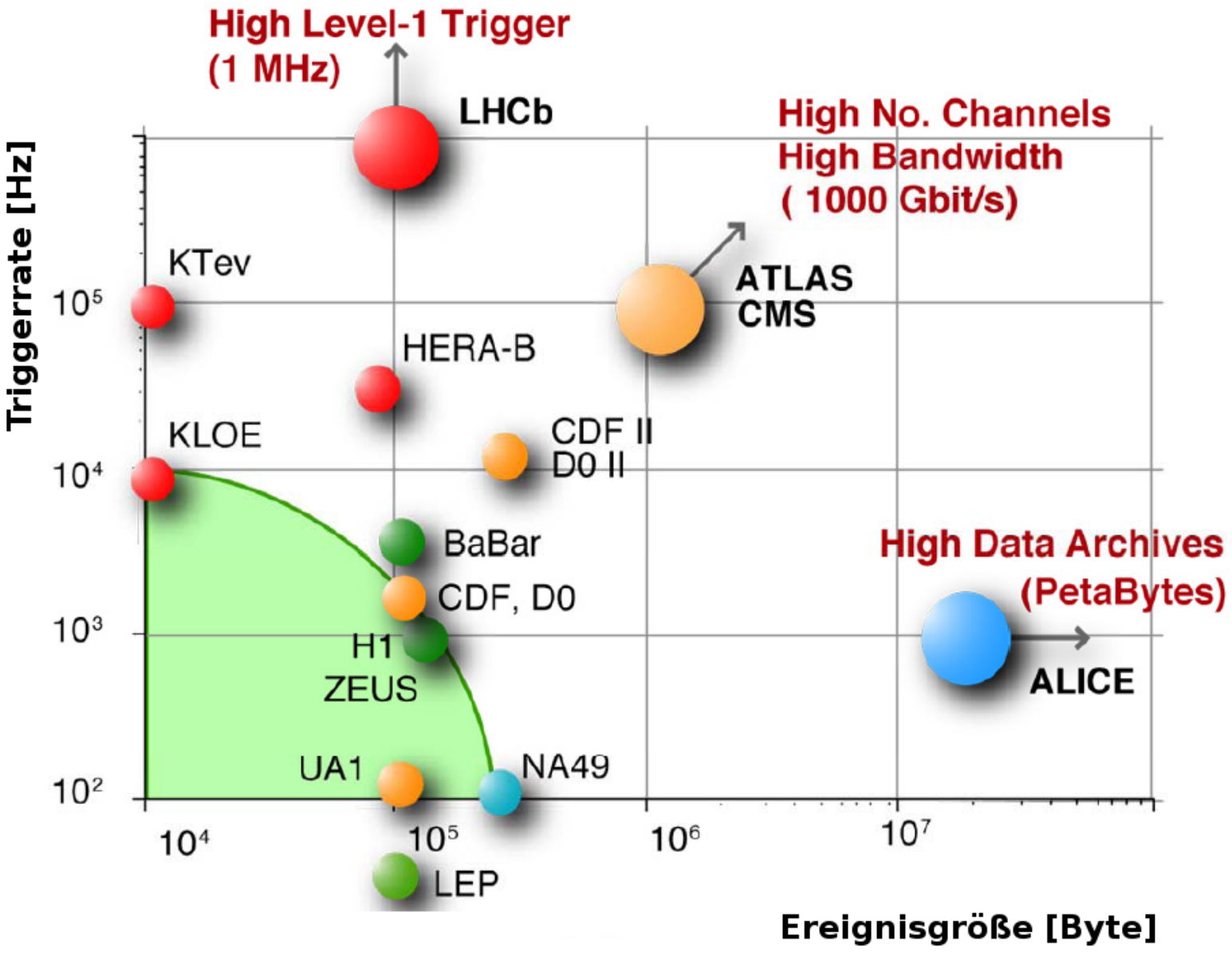
Teilchennachweis



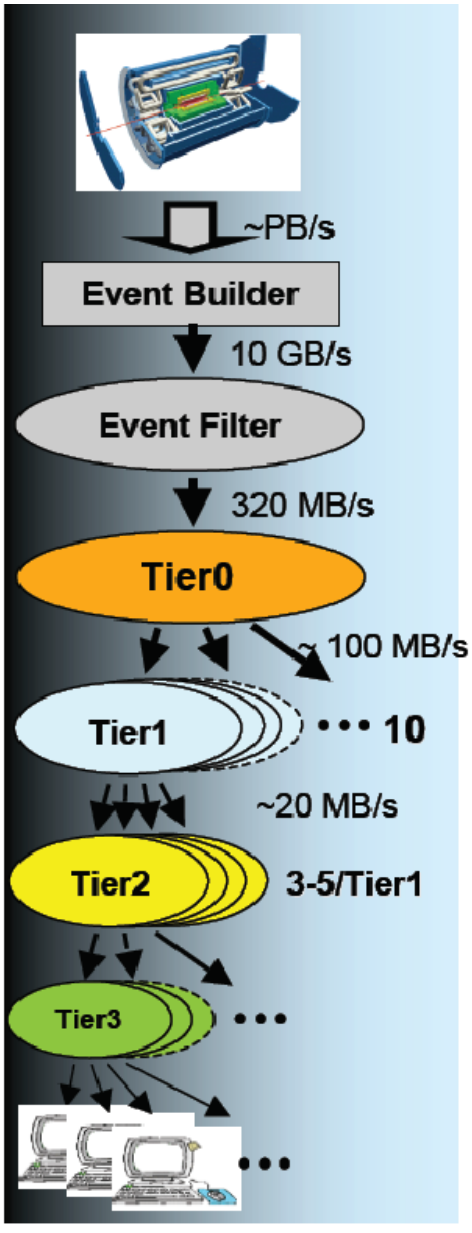
Trigger/DAQ parameters

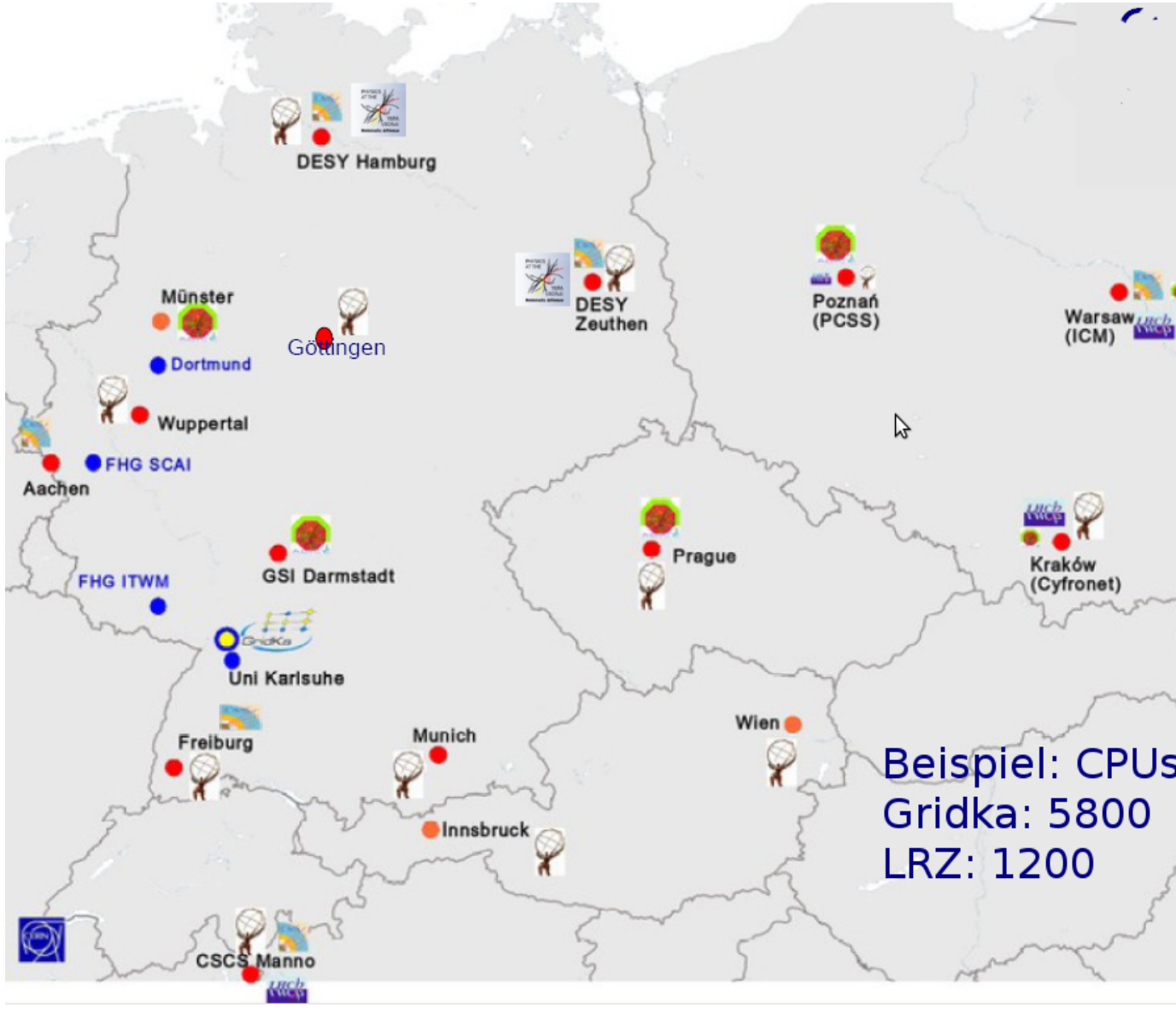
	No.Levels Trigger	Level-0,1,2 Rate (Hz)	Event Size (Byte)	Readout Bandw.(GB/s)	HLT Out MB/s (Event/s)
ALICE 	4	Pb-Pb **500** p-p **10^3**	**$5x10^7$** **$2x10^6$**	**25**	**1250** (10^2) **200** (10^2)
ATLAS 	3	LV-1 **10^5** LV-2 **$3x10^3$**	**$1.5x10^6$**	**4.5**	**300** ($2x10^2$)
CMS 	2	LV-1 **10^5**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

Trigger und Ereignis-Grösse

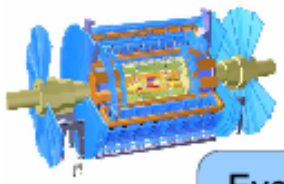


Rechenzentren- und GridKa-Organisation





Daten Verteilung: ATLAS



Event Filter

RAW

Tier 0

1st pass calibrations, Reconstruction, 24h Data export

RAW/ AOD/ESD

Reprocessing of full data, Managed Tape
Access: RAW, ESD, AOD
Disk Access: AOD, parts ESD

Tier 1

10 Sites

AOD

Production of MC events
User Analysis
Disk Storage: AOD

Tier 2

~40 sites

+ many Tier3

CERN Analysis Facility

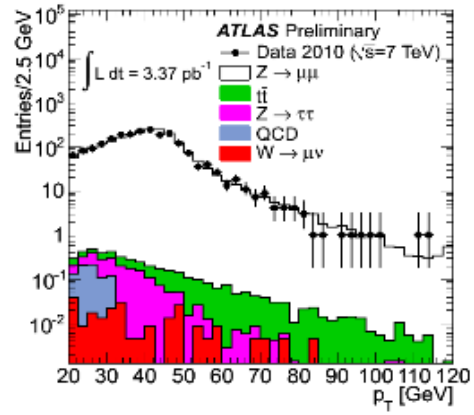
Limited Access:
ESD, RAW, calibration
Analysis

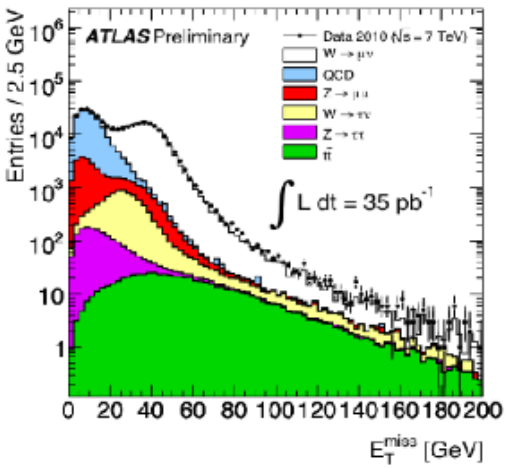
Analysis ingredients in a nutshell

Cross section measurement:

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

$N_{Observed}$: 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.

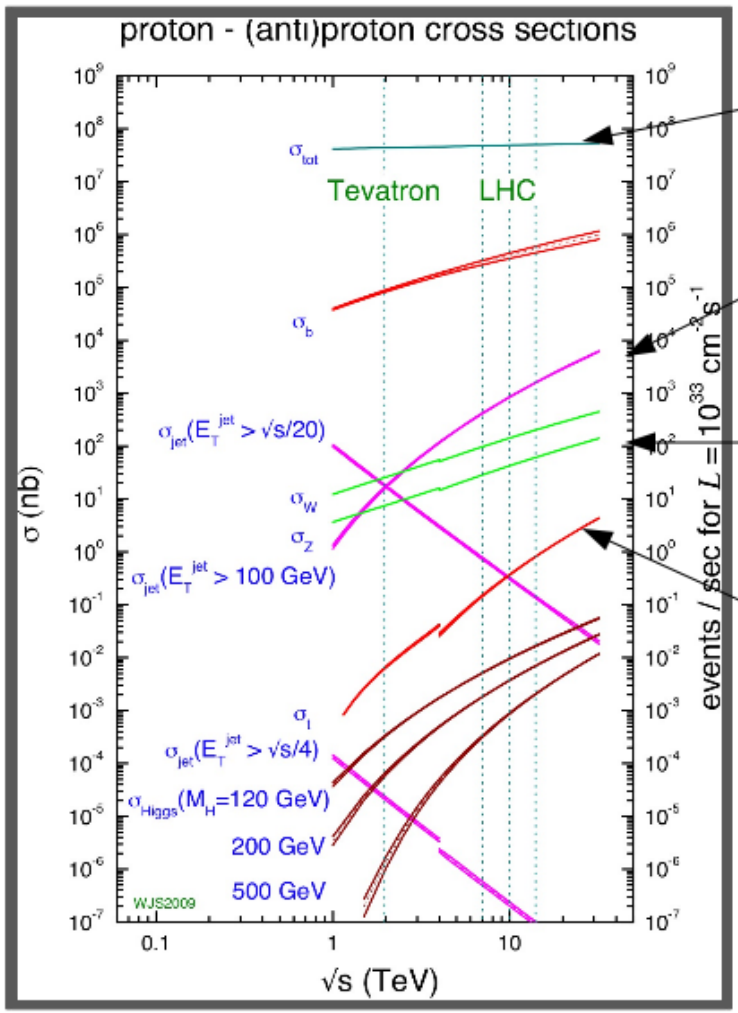
Example: Z->μμ :
- 2 isolated μ-tracks, back-to-back, low E_T^{Miss}, high transverse momentum, low jet activity

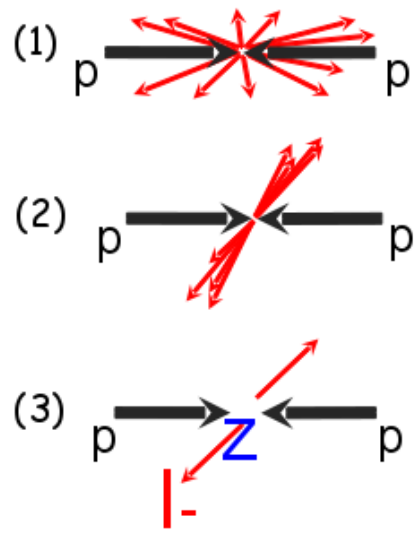
Determine N_{BG} or Signal prediction from Monte Carlo or data driven methods

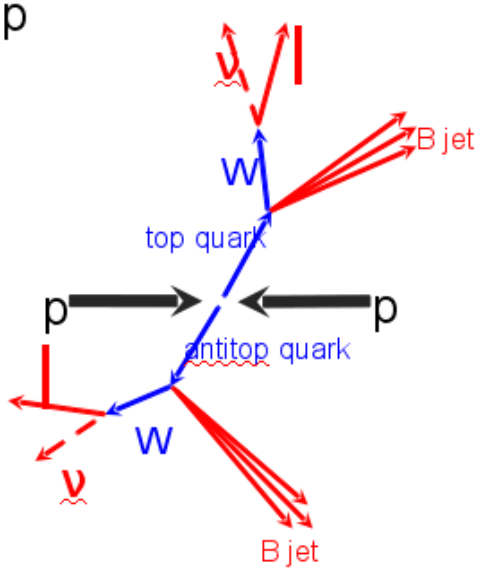
ε_{total}: Combination of Efficiencies:
- Trigger, Reconstruction, Acceptance, Cuts etc.

Analyseablauf II

Different Analysis



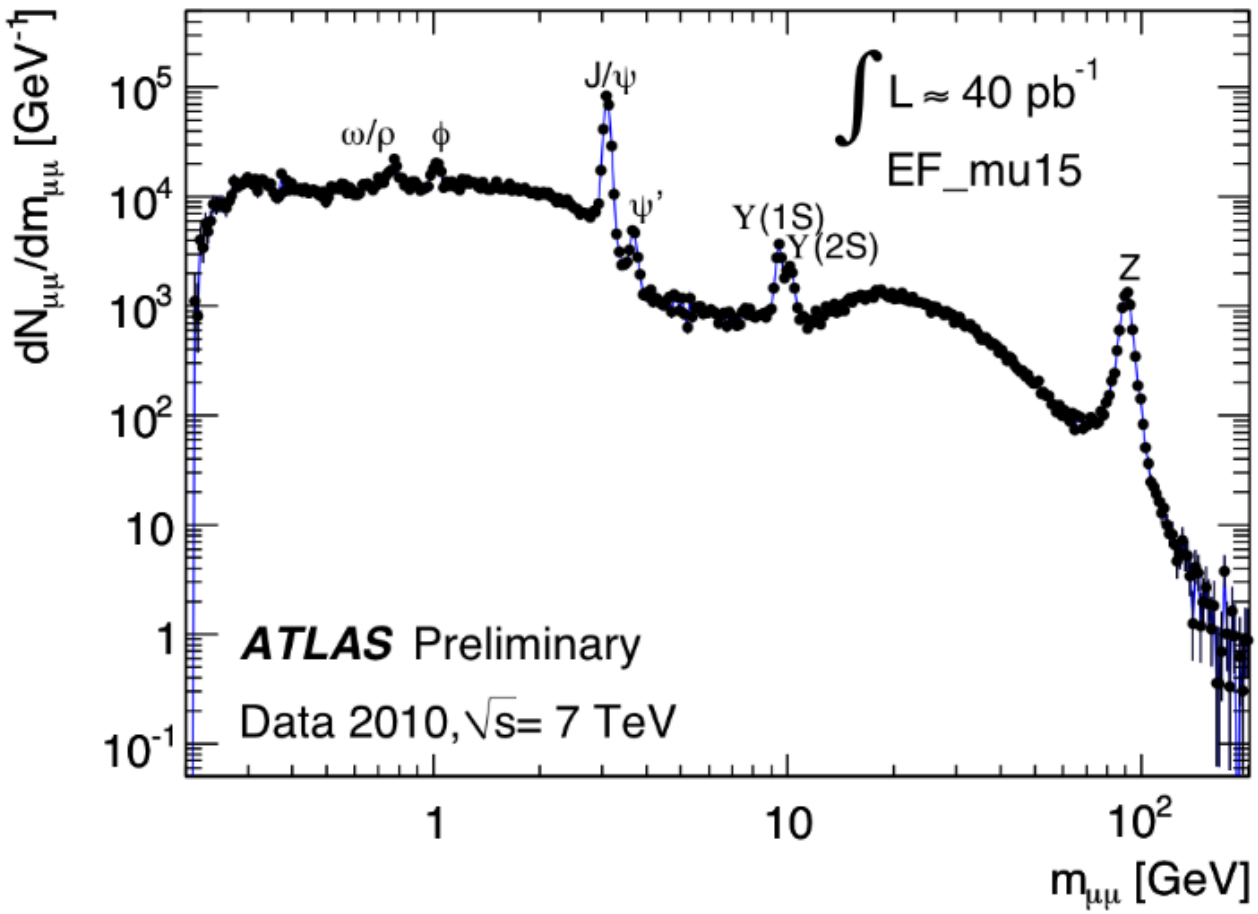




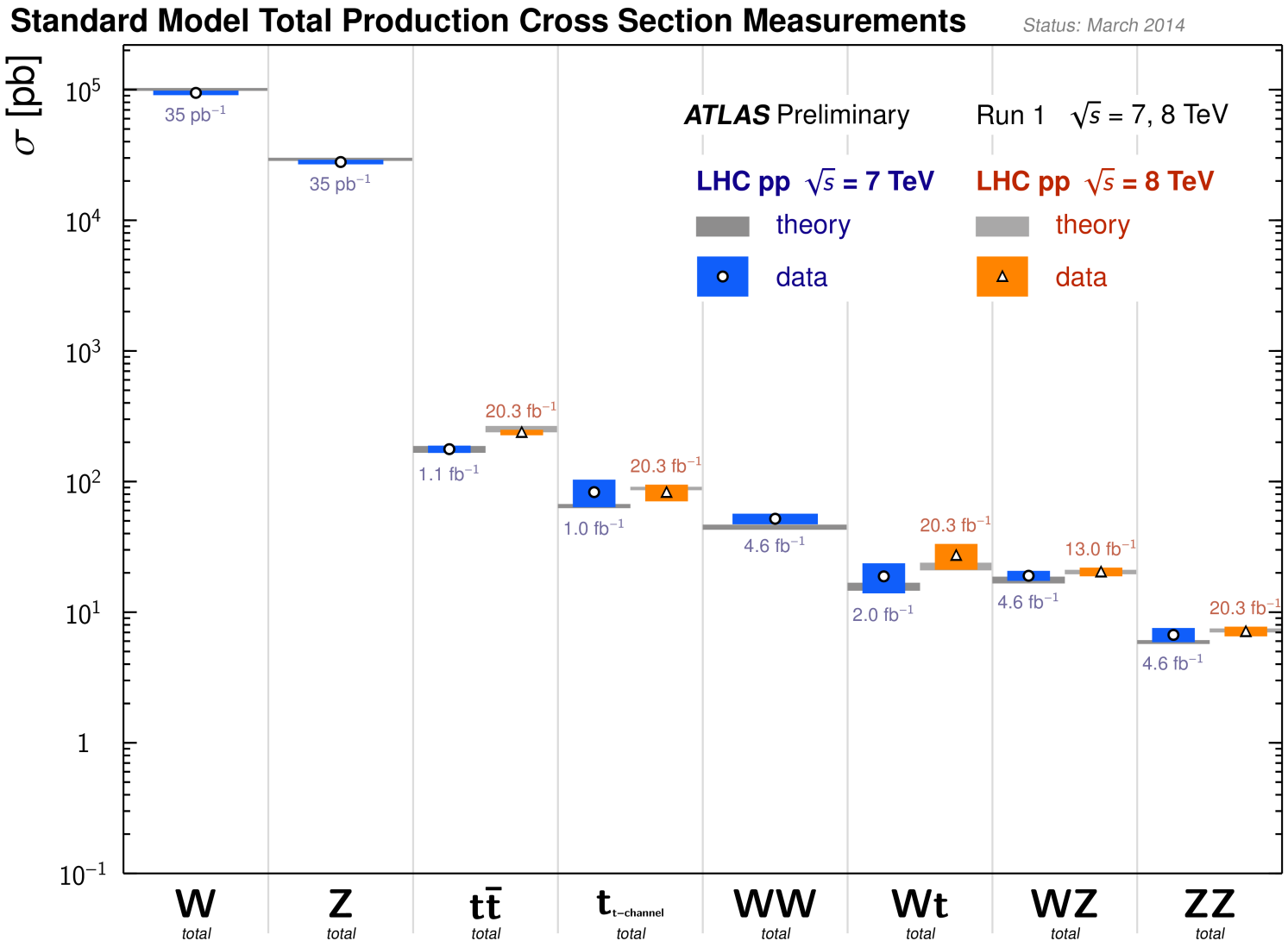
Analyseablauf III

Di-muon invariant mass

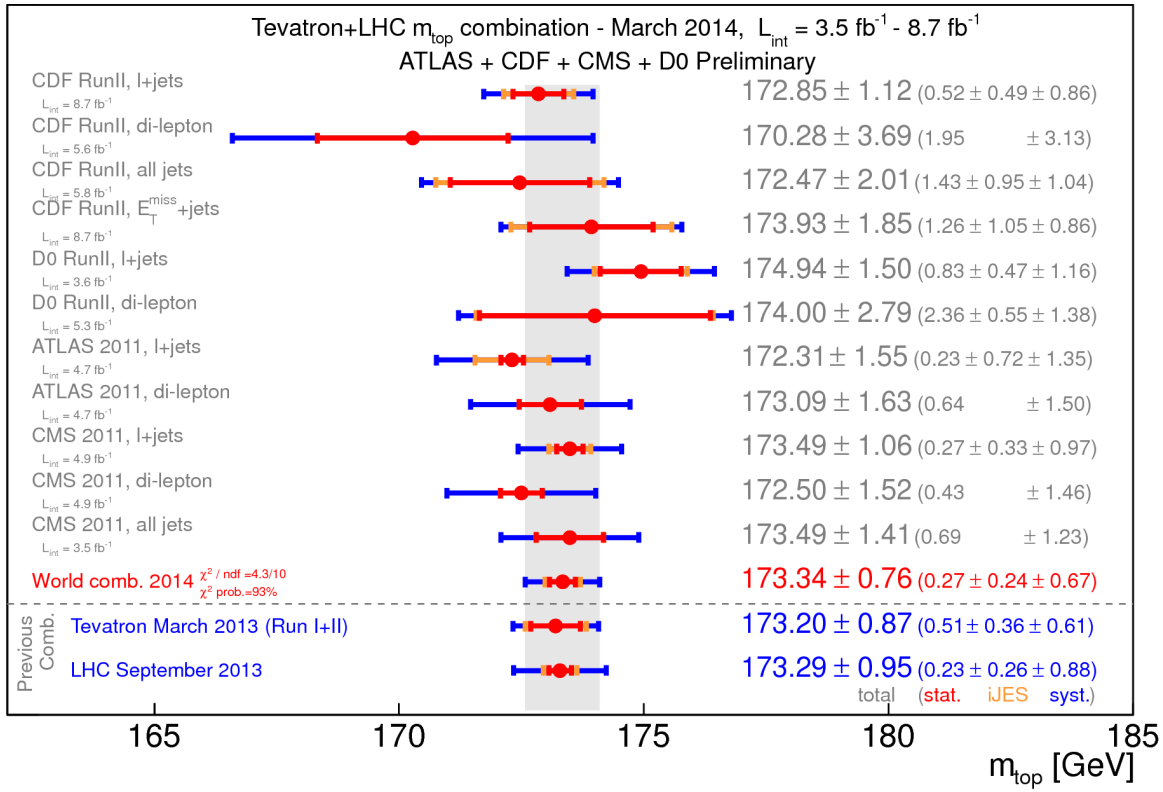
Leading muon, p_T>15 GeV, second muon, p_T>2.5 GeV



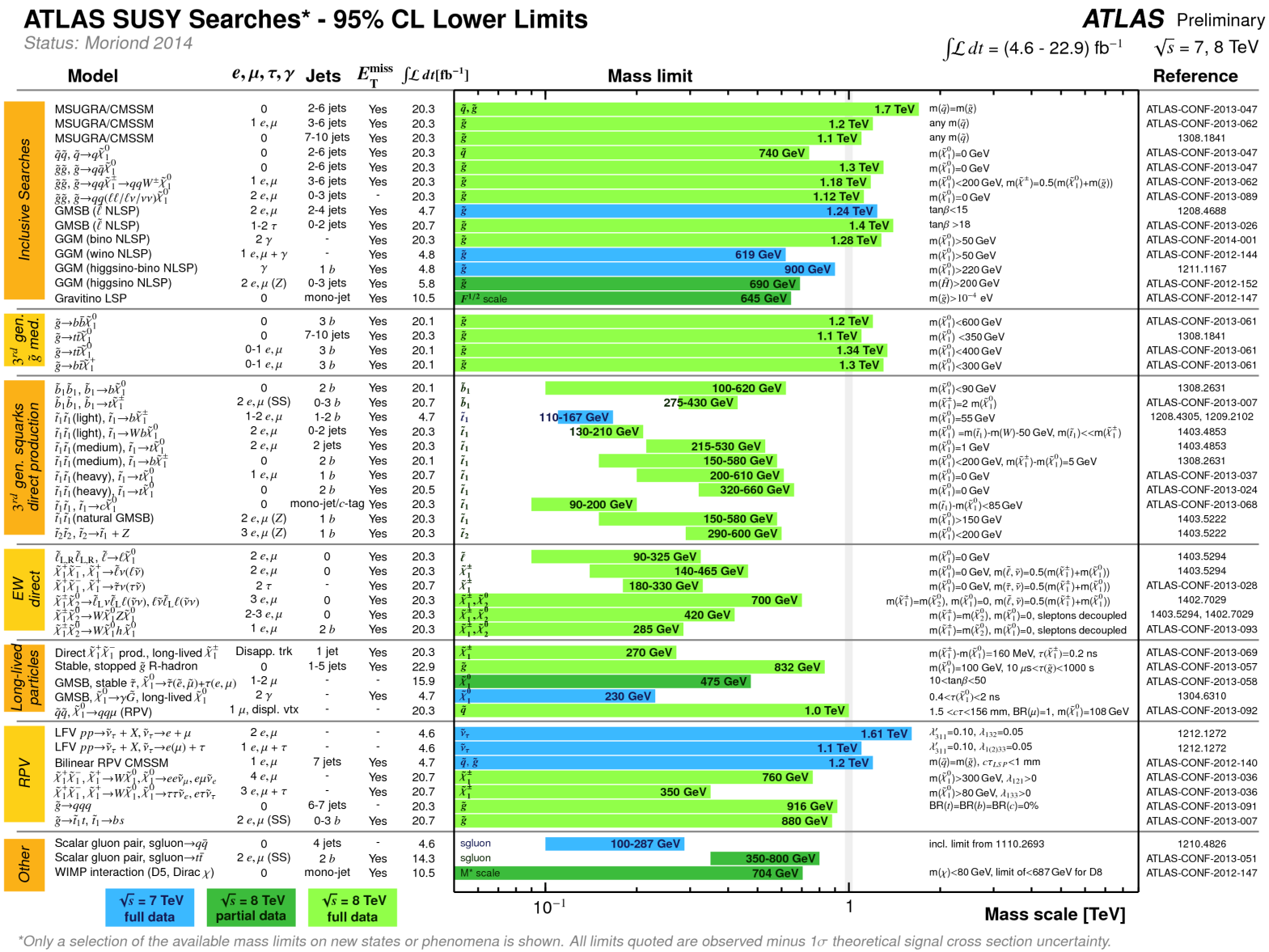
ATLAS Results I



ATLAS Results II

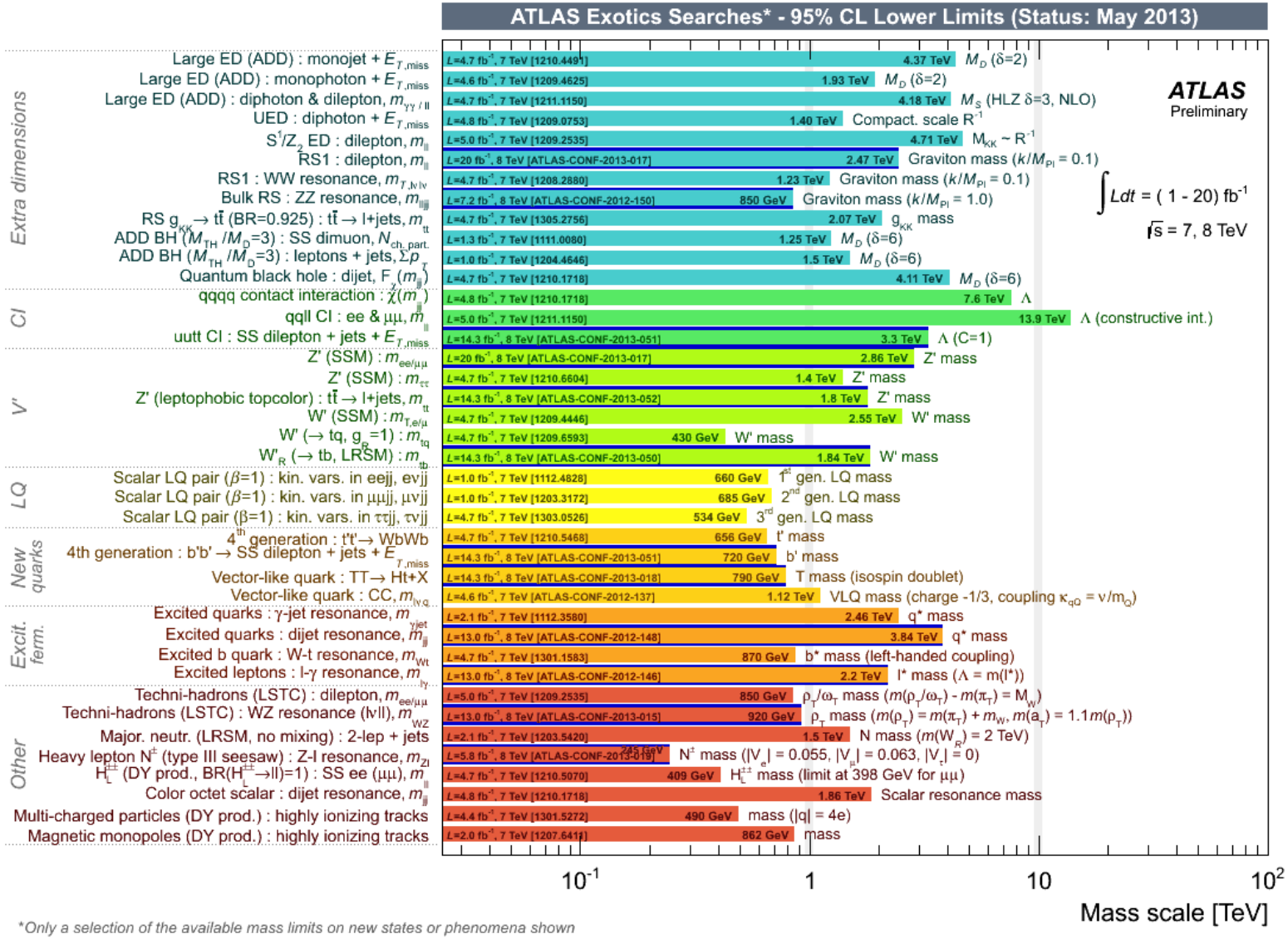


ATLAS Results III



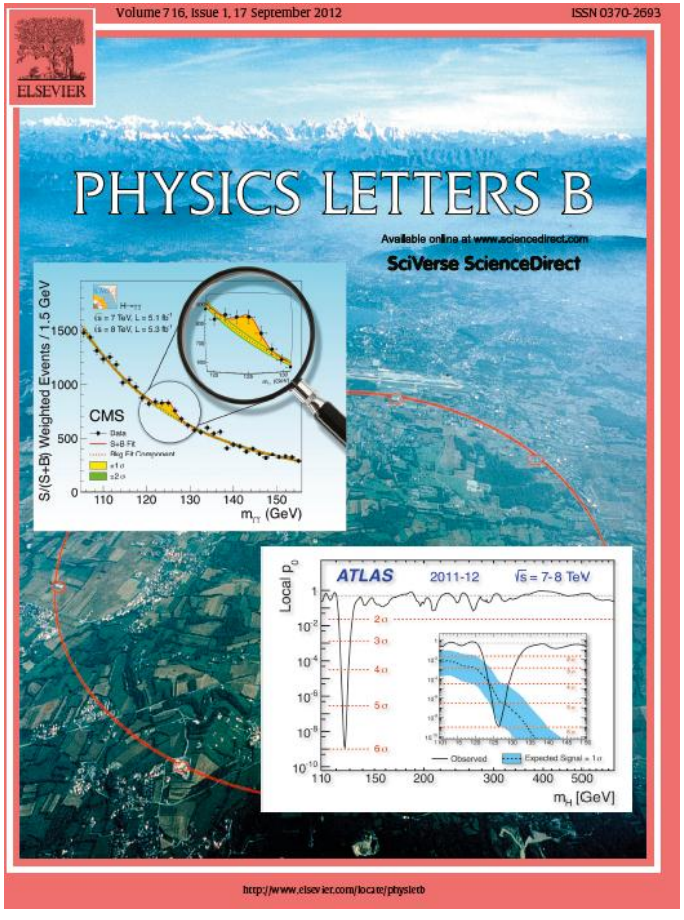
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

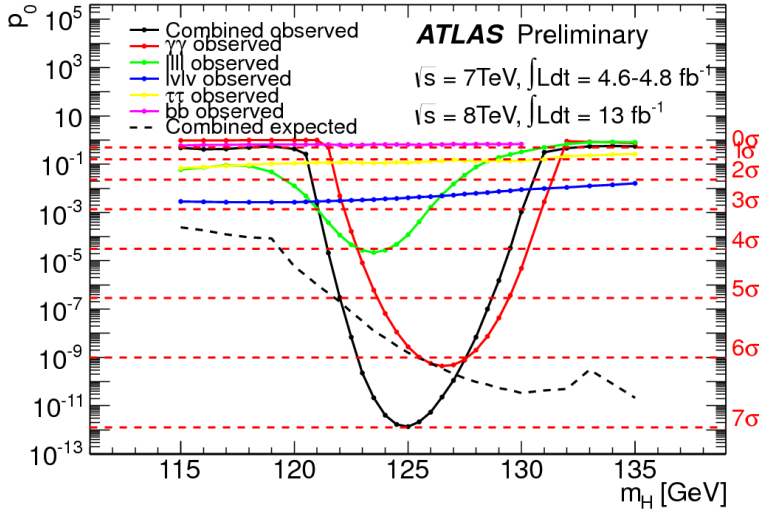
ATLAS Results III



*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

$H \to \gamma\gamma$ UND $H \to ZZ$