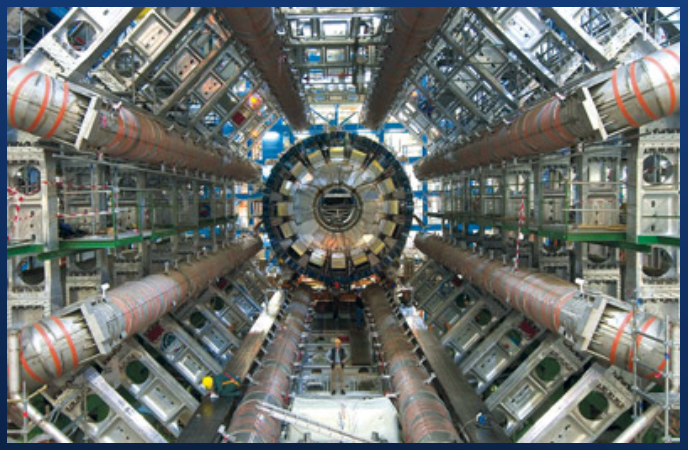
Search for SUSY via slow long-lived particles with the ATLAS detector

Pheno 2011



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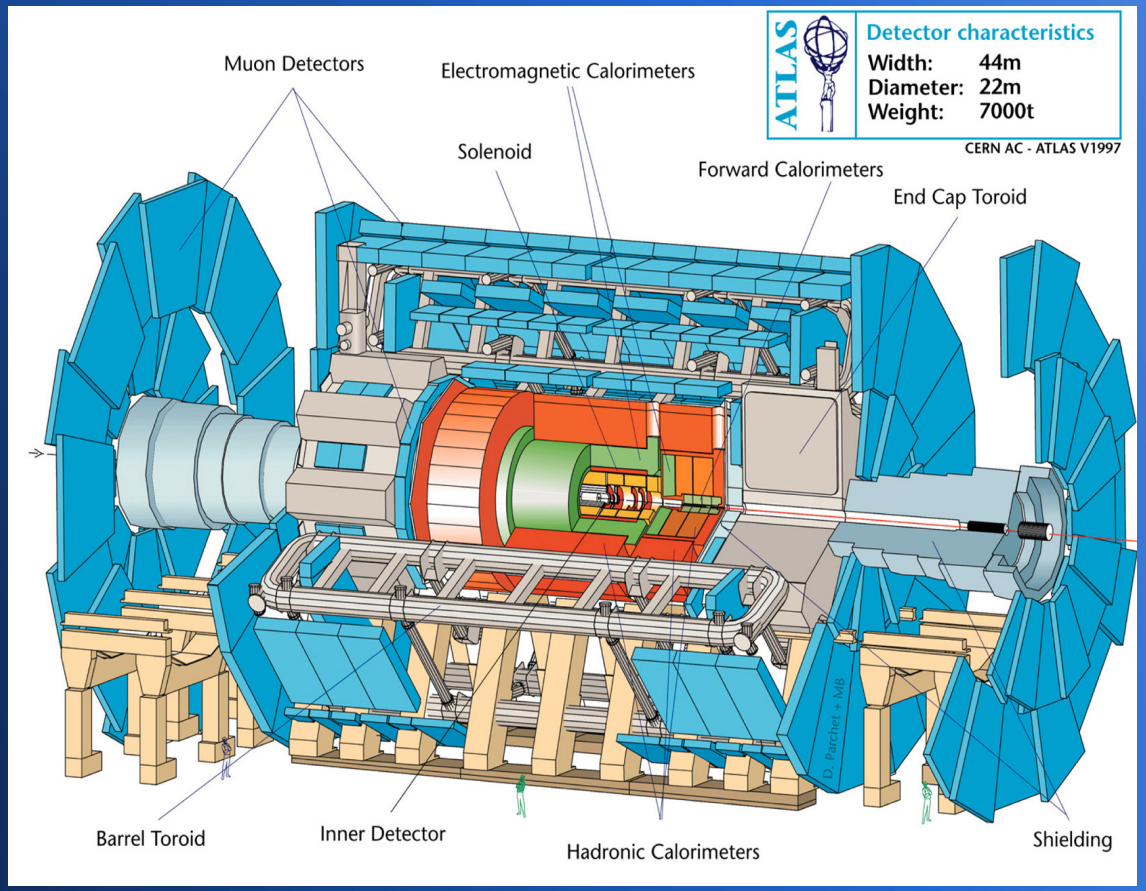
On behalf of the ATLAS Collaboration

The ATLAS Experiment

- **Tracking system** (Inner Detector)
  - Pixels (~3 hits/track)
  - SCT (~8 hits/track)
  - TRT (~30 hits/track)
- **Calorimetry**
  - Electromagnetic
  - Hadronic
- **Muon system**
  - Air core toroid



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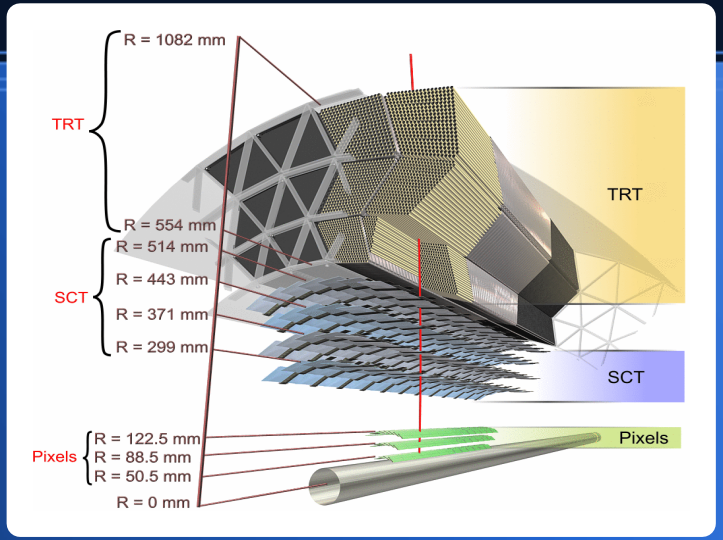
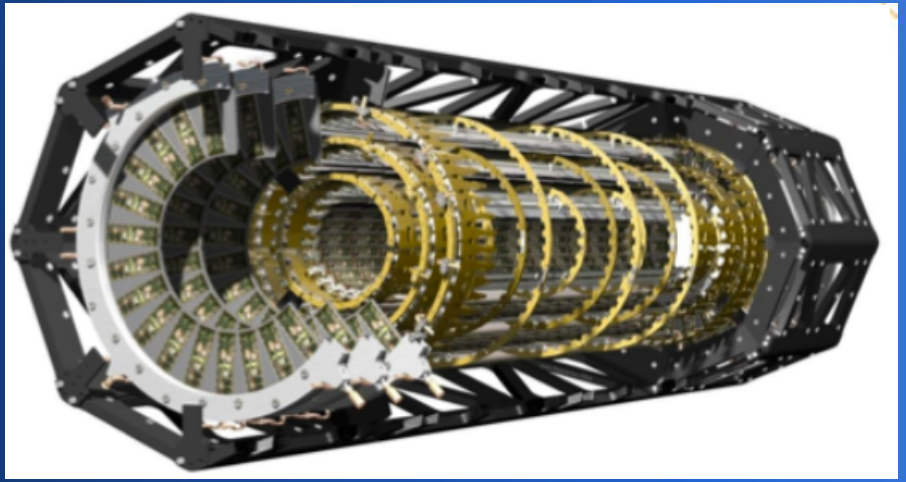
Used in this search & discussed in the next slides

The Pixel Detector

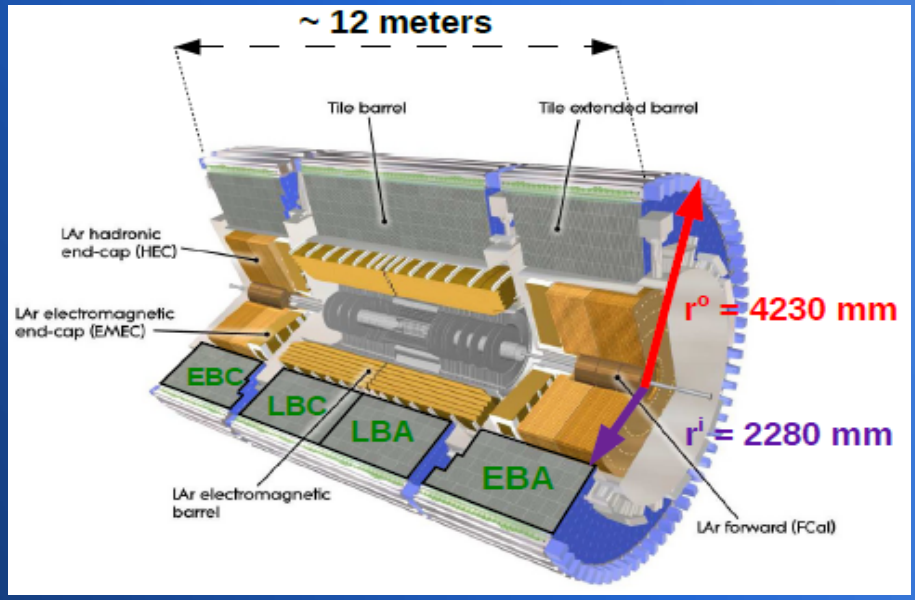
- 82 million Pixels distributed on:
  - 1 barrel of 3 layers,
  - 2 end-caps with 3 disks
- Covers the region |η|<2.5
- Each pixel signal is read out using 255 time bins →time over threshold (ToT) is measured to very high accuracy
- By calibrating on known particles, the ToT measurement is related to dE/dx





The Tile Calorimeter

- Central part of the hadronic calorimeter |η| <1.7
- Sampling calorimeter: iron/scintillating tiles, double PMT readout using wave length shifting fibers.
- ~ 5000 channels
- Each collecting the signal from a group of tiles → cell
- Precise timing allows the time of flight (ToF) to be measured



Stable Massive Particles

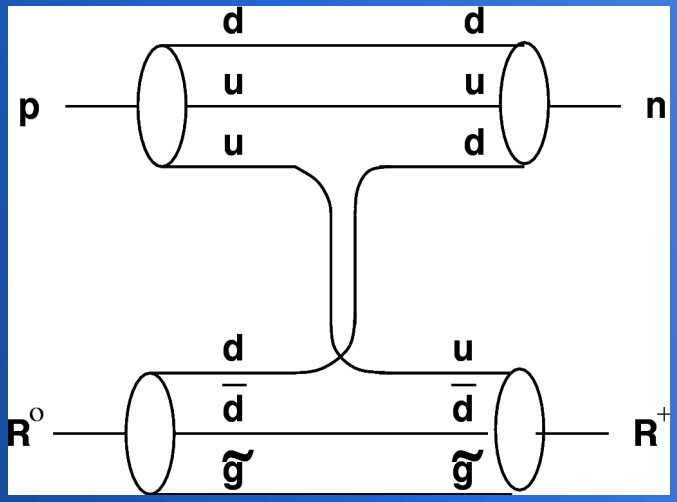
- Stable Massive Particles (SMPs) predicted in a range of SUSY and other BSM scenarios
- Within SUSY: SMPs with different color and electric charges ~q /~g could form bound states with a light quark system: **R-hadrons**

<u>Characterization:</u>

- No physics background, potentially large cross sections
- Slow: produced with $\beta < 1$

  → Use Time-of-Flight from the Tile Calorimeter

  → dE/dx from the Pixel Detector: exploiting that slow particles give anomalous ionization energy loss
- Convert β into mass: $m = p/\beta\gamma$



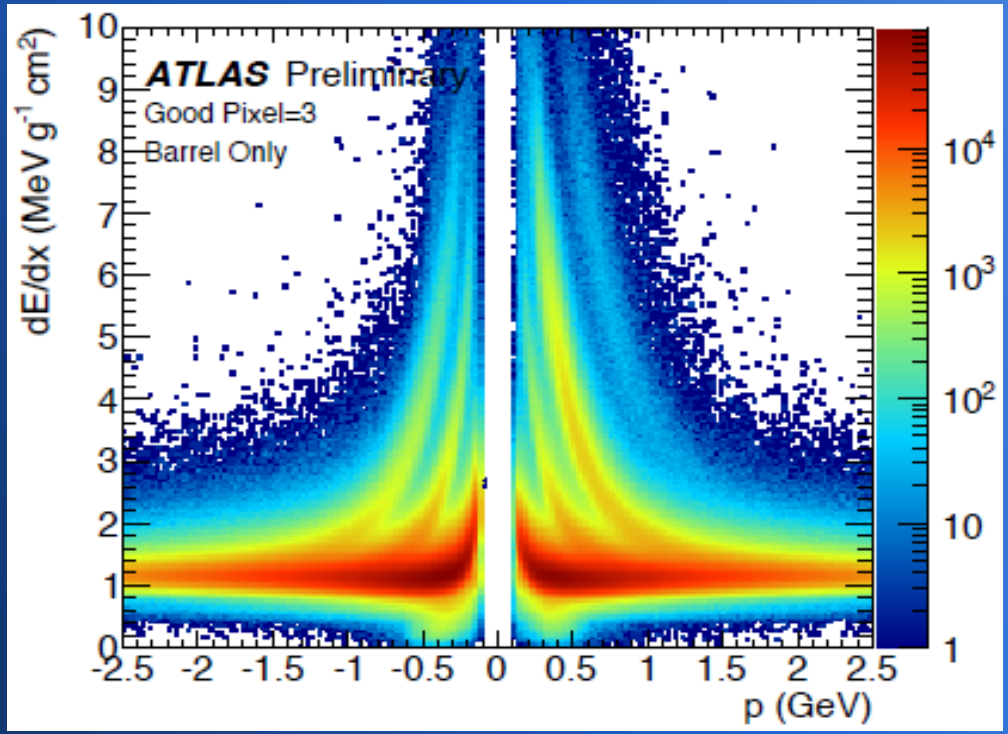
- Charge-flipping possible through interactions with the detector

~g muon signature: 398/397 GeV (CMS/Tevatron)
~g muon-spectrometer agnostic: 311 GeV (CMS)
~t: 249 GeV (CDF), ~b:92 GeV (LEP)

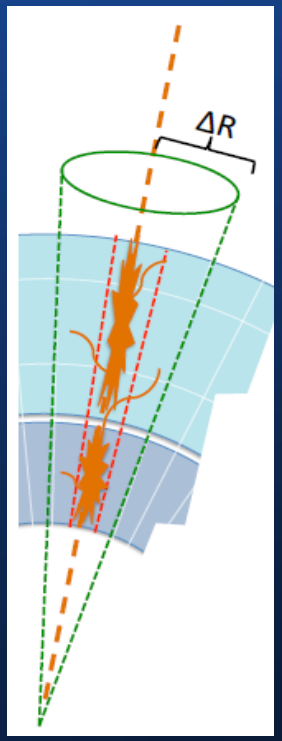
Previous limits

The dE/dx measurement from the Pixel Detector

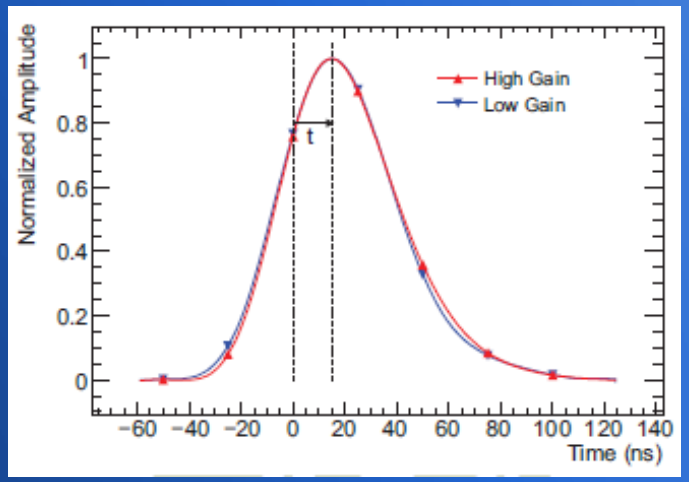
- Plot shows dE/dx vs. measured p in low-p region. Clear separation between deuteron, p, K and π
- Track dE/dx: truncated mean of the path-length compensated energy depositions in the clusters
- dE/dx only relies on $\beta\gamma \rightarrow$ given dE/dx outside MIP band, $\beta\gamma$ can be extracted $\rightarrow$ mass estimate



The beta measurement from the Tile Calorimeter



- Tile cell timing is arround 1ns for relevant energy depositions (>1 GeV)
- Upon a Level-1 trigger, 7 samples are read out, spaced by 25 ns.
- The cells assigned to a given track are combined in a weighted average using energy dependent weights
  → improved timing resolution



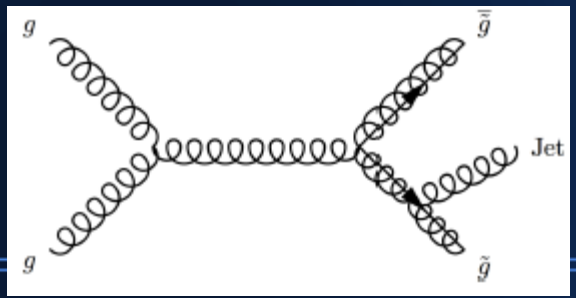
- Cell time spectra in data have been aligned at β=1 using Z→μμ in data and MC

Data samples & triggering

Data

- 34 pb^{-1} of 2010 data
- Trigger: hard to trigger directly on R-hadrons (no guaranteed signal in muon spectrometer, small energy loss in calorimeter) →

  Use data collected with missing E_T trigger, exploiting additional jets from initial/final state radiation of hard QCD processes



Monte Carlo

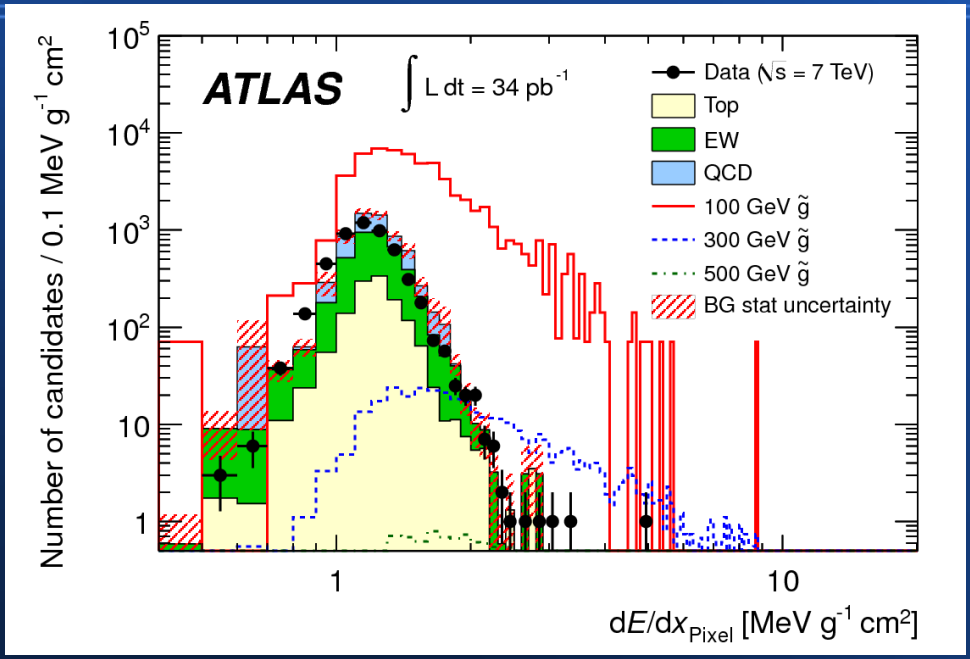
- Background: QCD, EW (incl. Z/W →μ), top: Not used for results, only for understanding background composition!
- Signal: stable ~g, ~t and ~b with masses 100, 200, . . . , GeV, using several different scattering models and settings

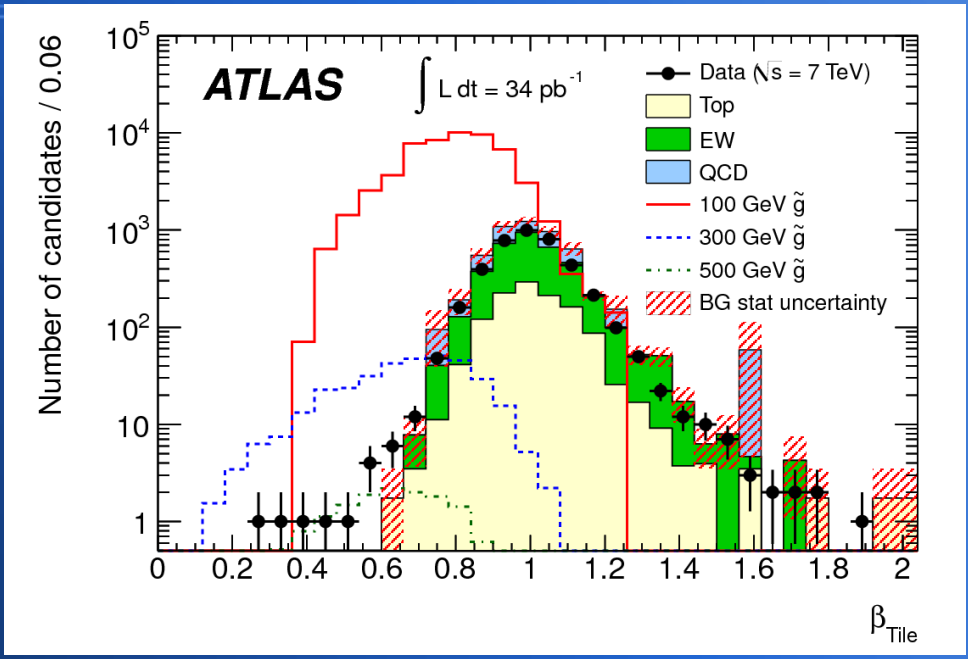
Event Selection

Cut level	Data	Background	300 GeV $\tilde{g}$	500 GeV $\tilde{g}$	600 GeV $\tilde{g}$	200 GeV $\tilde{t}$	200 GeV $\tilde{b}$
No cuts	-	-	2.13×10^3	80.4	21.8	405	405
Trigger	-	-	616	25.6	6.96	109	108
Candidate	75466	68.0×10^3	416	17.6	4.80	87.4	67.9
Vertex	75461	68.0×10^3	416	17.6	4.80	87.4	67.9
$\|\eta\| < 1.7$	64618	60.5×10^3	364	15.7	4.32	75.2	56.8
Track quality	59872	58.1×10^3	355	15.3	4.20	73.3	54.9
$\Delta R > 0.5$	49205	49.4×10^3	349	15.1	4.13	72.7	54.5
$p_T > 50$ GeV	5116	6.56×10^3	330	14.5	3.95	68.9	50.0
Mass preselection	36	56.0	184	9.70	2.75	32.6	18.9
Final selection	-	-	173	9.17	2.62	30.6	17.5

- Vertex cut: 1 good vertex with 3 associated tracks
- Track cuts: ≥2 pixel hits, ≥6 SCT hits. ≥6 TRT hits
- ΔR: candidate track satisfies $\Delta R_{SMP-jet} = \Delta\phi^2 + \Delta\eta^2 > 0.5$ from any jet with $E_T \geq 40$GeV

Pixel Detector dE/dx and Tile Calorimeter β distributions

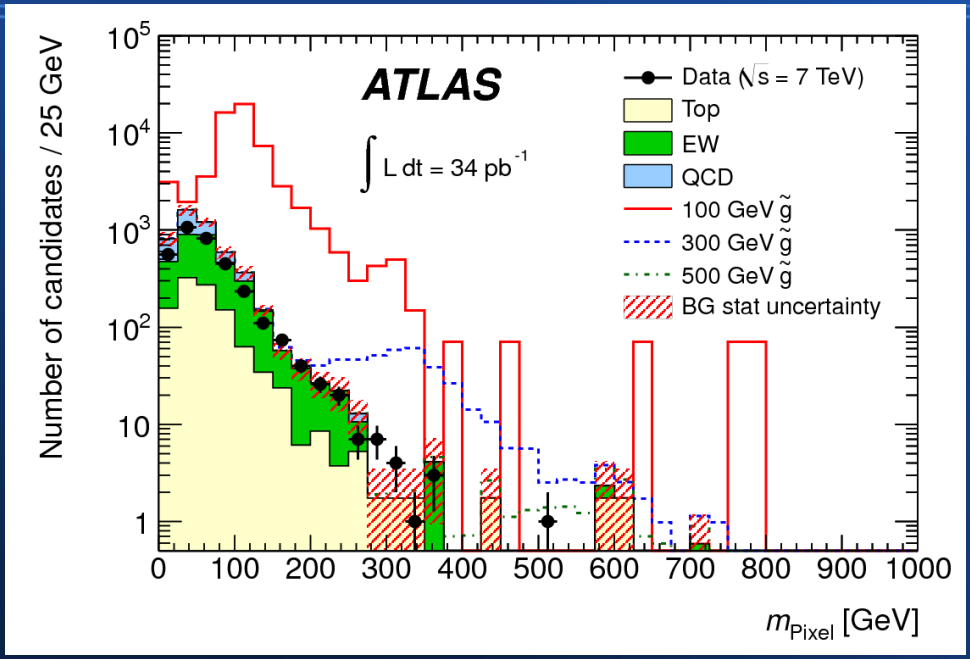


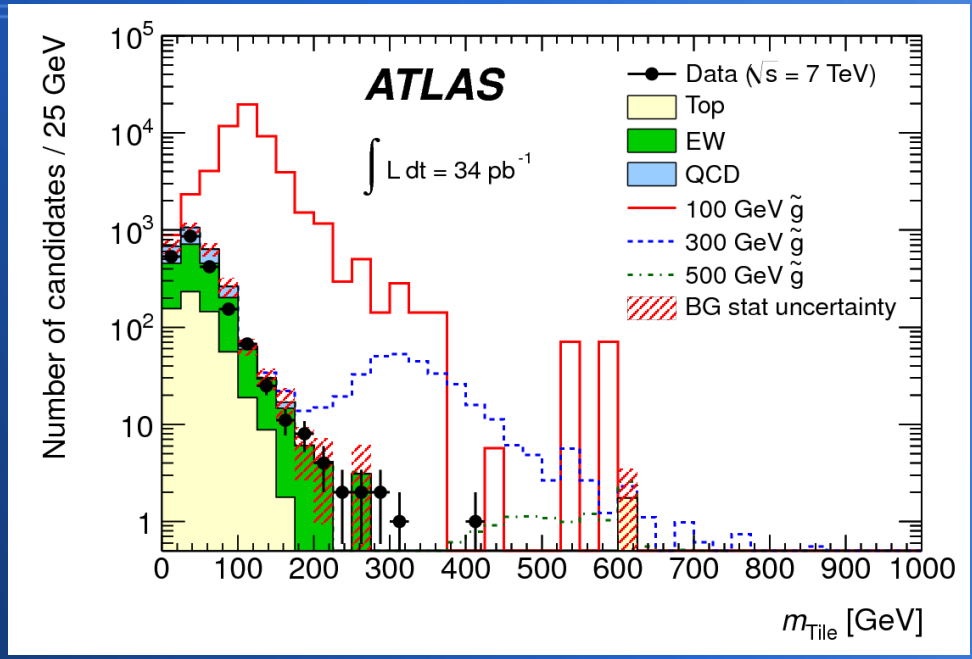


- Distributions of dE/dx Pixel Detector (left) and Tile Calorimeter β (right) in data after the transverse momentum cut in the table of the previous slide.

  Spectra for simulated background processes are plotted for comparison.

Mass reconstruction

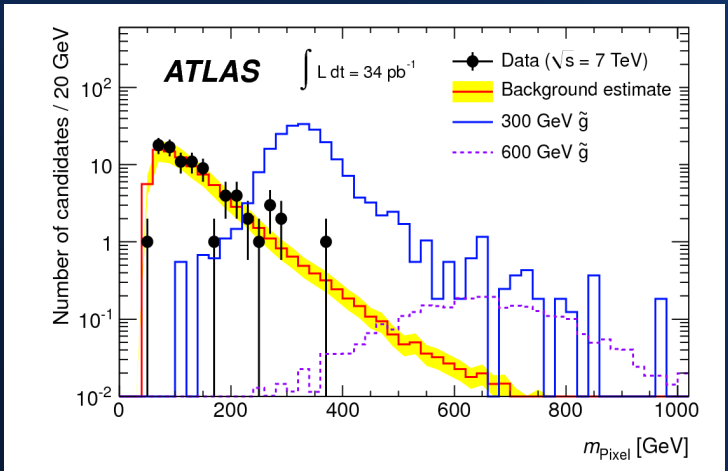




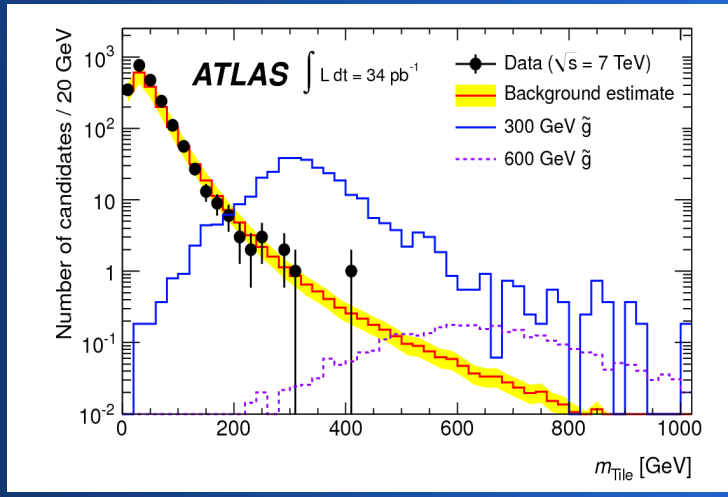
- Mass reconstructed by the pixel detector (left) and the tile calorimeter (right).
- To reconstruct a mass, a cut of $dE/dx_{Pixel} > 1.1$ MeVg^{-1}cm^{-2} is imposed for the pixel detector distribution. This is a looser cut than used in the analysis itself.
- For the tile calorimeter, the requirement is that $\beta_{Tile} < 1$.

Background estimation

- Build up PDFs from candidates in data for pixel dE/dx and β_{Tile}, and use *p* spectrum after preselection
- 1) Draw random *p*. 2) Pair *p* with values from pixel dE/dx and β_{Tile} PDFs
- Repeat many more times than observed candidates in data, then normalize for smooth background prediction, even in the tail

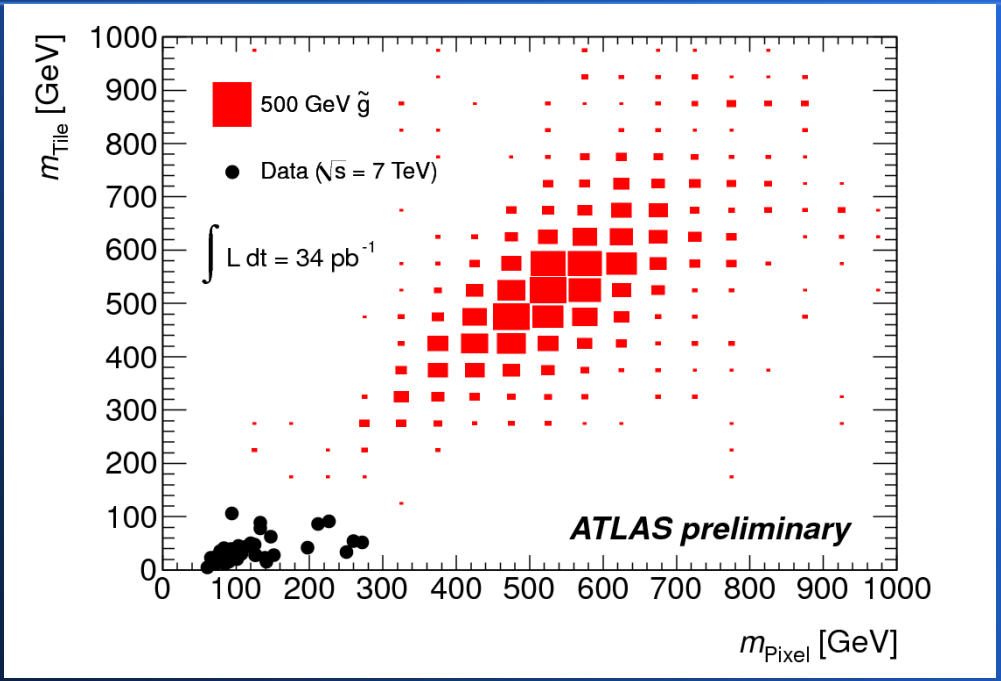


- Pixel detector background estimate



- Tile Calorimeter background estimate

Combining measurements



- As no significant deviations from the background-only hypothesis are observed, the data yield can be assumed to be due to instrumental effects, and thus strongly suppressed by defining signal regions as combined from mass estimates from pixel and tile – i.e. 2D mass regions:
- $(m_{Pixel}, m_{Tile}) \in R^2 : (m_{Pixel} > \mu_{Pixel} - 2\sigma_{Pixel},\ m_{Tile} > \mu_{Tile} - 2\sigma_{Tile})$

Results

Nominal mass (GeV)	μ_{Pixel} (GeV)	σ_{Pixel} (GeV)	μ_{Tile} (GeV)	σ_{Tile} (GeV)	No. of signal cand. ($\tilde{g}$) Pixel	Tile	Comb.	Est. no. of bkg. cand. Pixel	Tile	Comb.	N_{Data} Comb.
100	107	10	109	19	15898	49300	13912	61	330	5.4	5
200	214	24	211	36	1417	2471	1235	19	61	0.87	0
300	324	40	315	56	202	304	173	6.5	17	0.22	0
400	425	67	415	75	43	57	37	3.4	7.2	0.082	0
500	533	94	513	106	11	13	9.2	1.82	4.4	0.044	0
600	641	125	624	145	3.1	3.5	2.6	1.08	3.2	0.028	0
700	727	149	714	168	0.99	1.07	0.84	0.74	2.1	0.018	0

Main signal systematic uncertainties

- Trigger efficiency:
  7-12% scale unc, 3-5% turn-on curve
- Background estimate: 30%
- Pile-up, ID mom unc, track reco, scale and reso of pixel dE/dx and β_{Tile} all ~1%

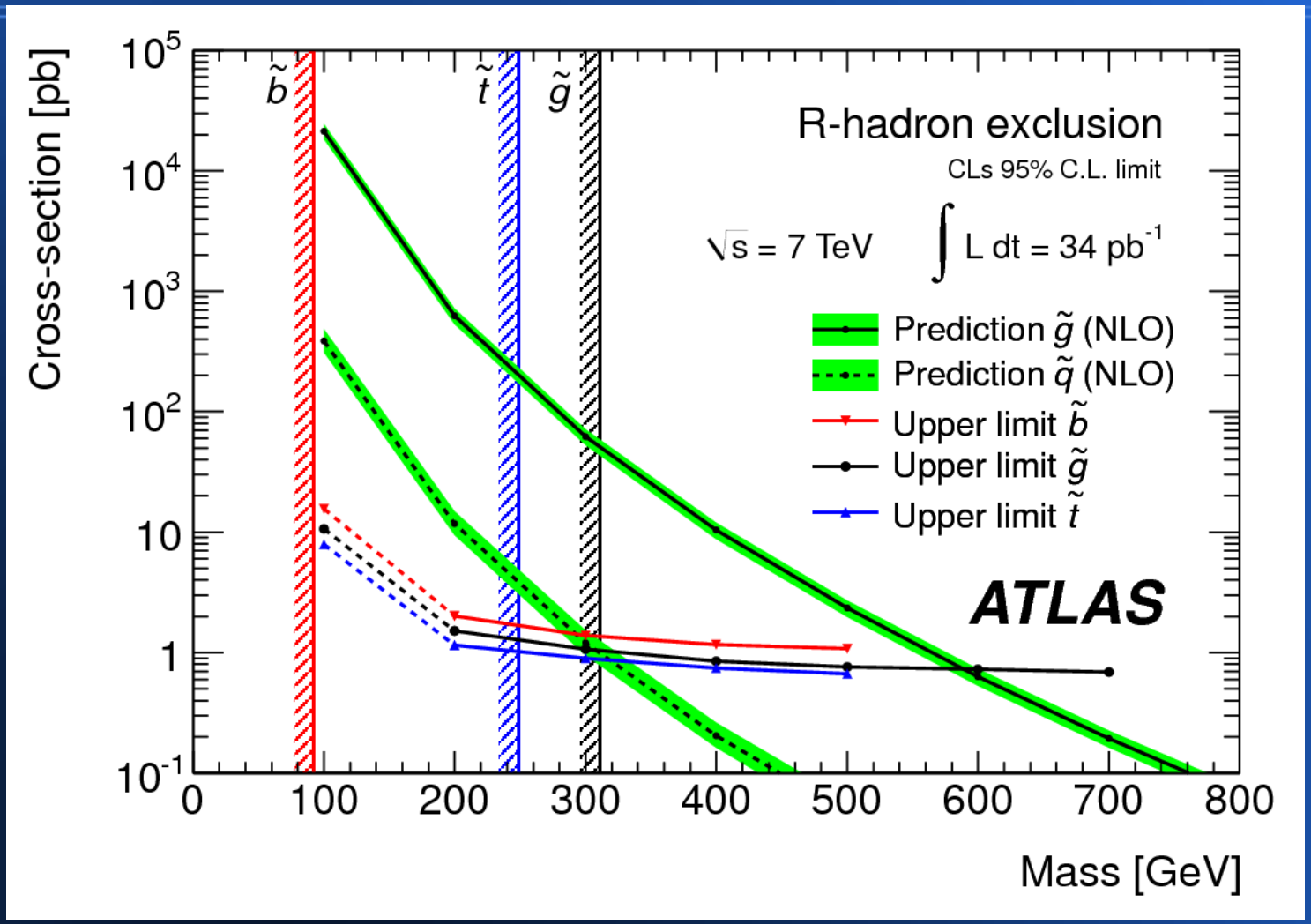
Theoretical:

- ISR: 10%
- Renormalization scale: 15%
- PDF choice: 5%

Other:

- Luminosity: 11%

Limits



Limits (95%, CLs method):

- ~g 562-586 GeV (depending on scattering model)
- ~b 294 GeV
- ~t 309 GeV
- Further reading: arXiv:1103.1984 [hep-ex] / PLB-D-11-00309R1