Inclusive Search for Same-Sign Dileptons at ATLAS

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on behalf of the

ATLAS Collaboration

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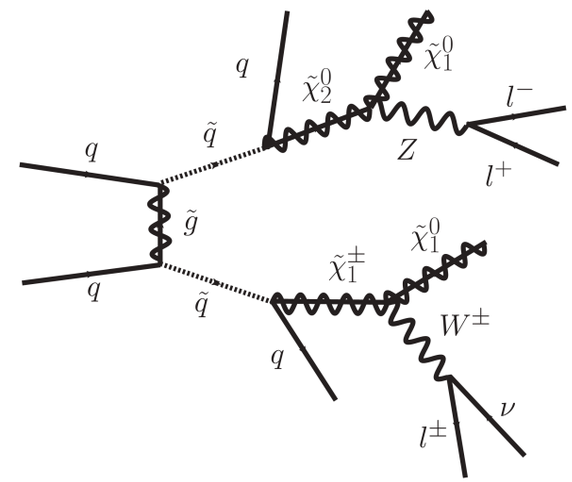
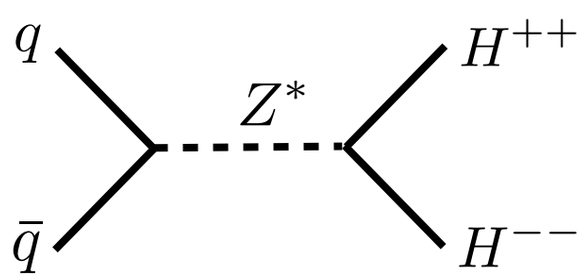
Same-sign leptons

Same-sign leptons appear in a range of models

- SUSY - produced in lepton cascade topologies
- Heavy Majorana neutrinos
- Universal extra dimensions
- Doubly-charged Higgs bosons

  eg) Type-II Seesaw





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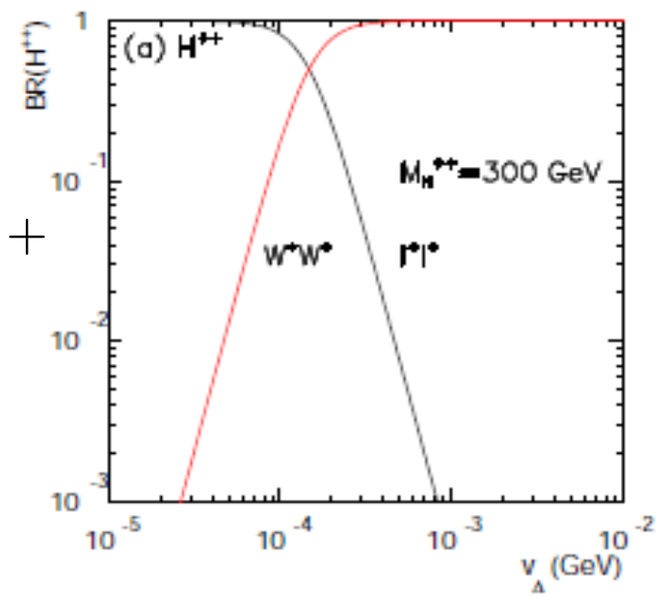
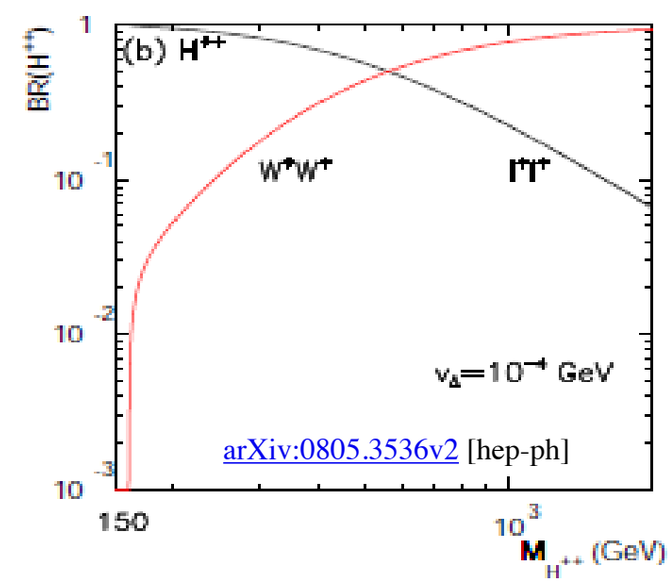




arXiv:0805.3536v2 [hep-ph]

$H^{\pm\pm} \to l^\pm l^\pm$ <u>OR</u> $H^{\pm\pm} \to W^\pm W^\pm \to l^\pm \nu l^\pm \nu$

An *inclusive* search is a promising testing ground for new physics

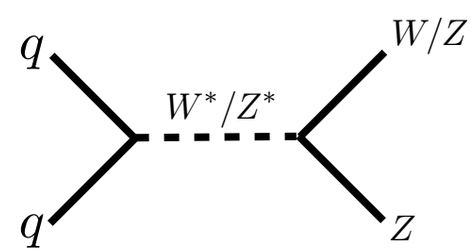
Selection with lepton kinematics, not other event activity

Backgrounds

- Understanding and estimating the backgrounds is the most challenging part of the SS analysis
- Three SM background contributions:

1. Production of same sign dileptons in diboson processes

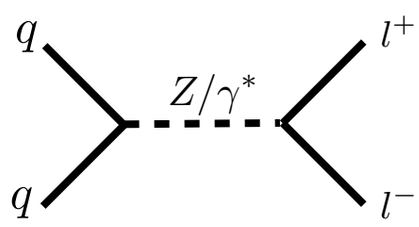
main contribution from ZZ, WZ



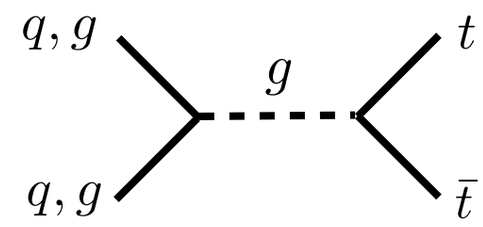
less significant contribution from $WWjj$ and $t\bar{t}W$

2. SM processes with opposite sign leptons and the charge of one lepton is mis-measured -- called charge flip more dominant with electrons

Drell-Yan

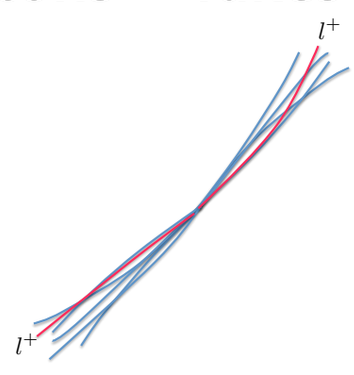


Top pair

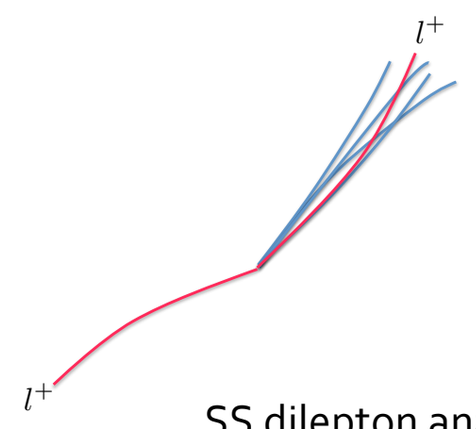


3. Hadronic decay leptons - "fakes"

Dijet events



$Wj \to l\nu j$



2010 Analysis

- Three channels: $\mu\mu, e\mu, ee$
- 34 pb^{-1}

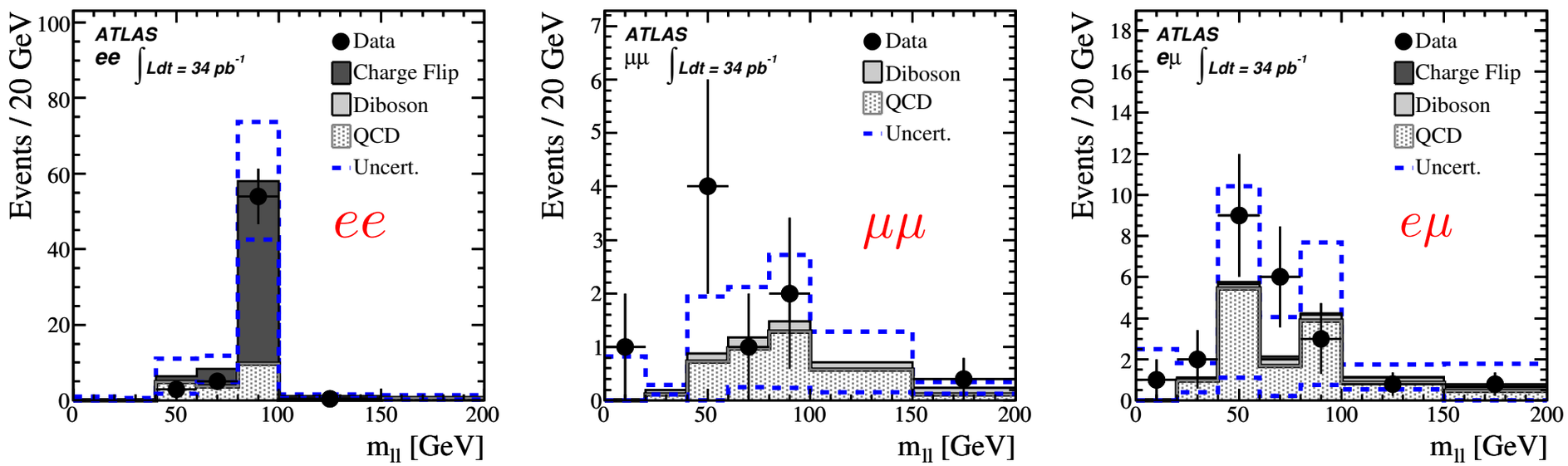
arXiv:1108.0366v1 [hep-ex]: submitted to JHEP

lepton candidates required to have p_T > 20 GeV
one lepton must have triggered the event
$\|\eta\|$ < 2.47
high quality tracks: requirements on the minimum number of track hits; for muons, the charge as measured in the inner detector matches that measured by the muon system
isolation: sum of transverse energy in calorimeter deposition in cone of radius ΔR = 0.2 required to be less than 15% of lepton transverse energy
leptons must originate from the same primary vertex and have same charge

- Analysis-approach:
  - data-driven fake background estimate
  - simulation used to estimate background from dibosons
  - data and simulation used to estimate charge flip

2010 Analysis Results

- Agreement between observed data and the SM prediction for all channels



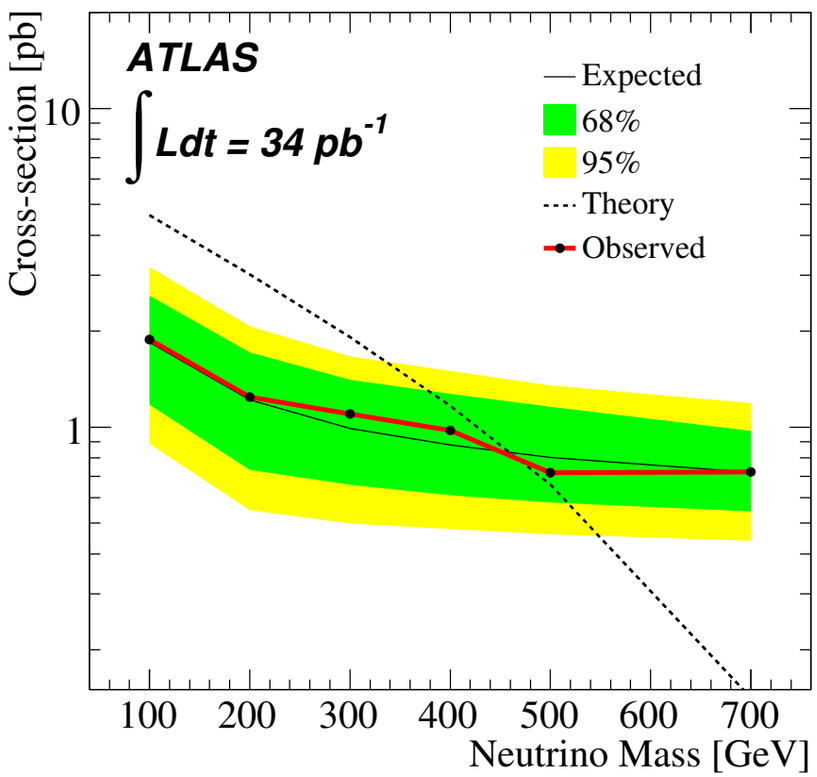
- Fiducial cross section limit set on generic same-sign production cross section:

$m_{ll} > 110$ GeV

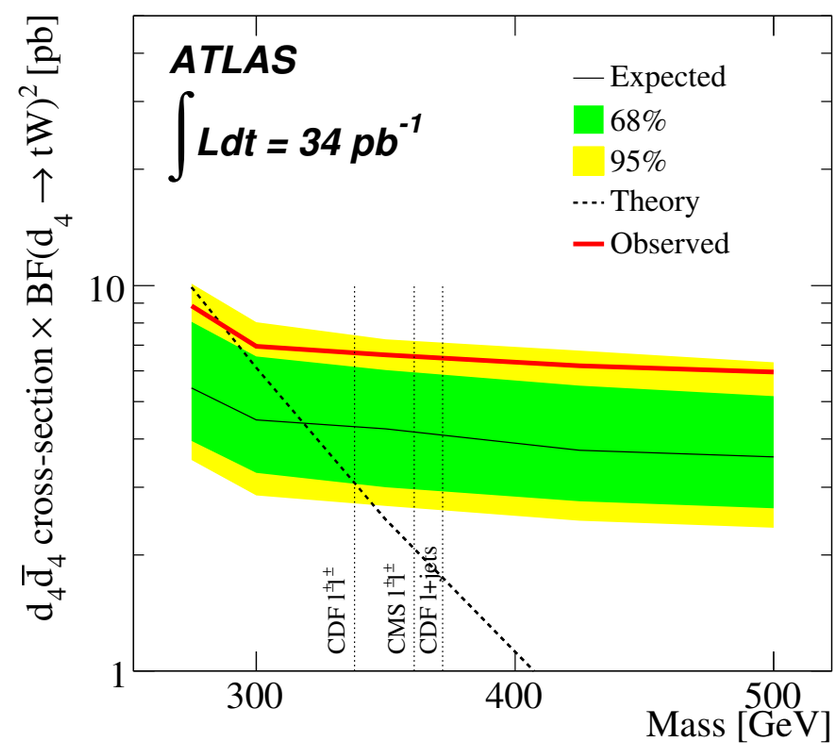
	$n_{\rm obs}$	$n_{\rm pred}$	$\sigma^{95}_{\rm obs}$ [pb]	$\sigma^{95}_{\rm exp}$ [pb]
ee	0	3.1±2.1±0.5	0.15	0.46
$\mu\mu$	1	2.2±1.4±0.4	0.17	0.25
$e\mu$	3	3.2±2.9±0.5	0.28	0.28

2010 Analysis Limits

- Cross section upper limits on specific models
  - Heavy Majorana neutrinos
  - Lepton cascades
  - L-R symmetric model
  - Fourth generation d quark



- Exclusion below 460 GeV, assuming Majorana neutrinos are produced by a four fermion operator, and Λ ~ 1 TeV.



- Exclusion below 320 GeV, using

$$d_4\bar{d}_4 \to tW\bar{t}W$$

assuming

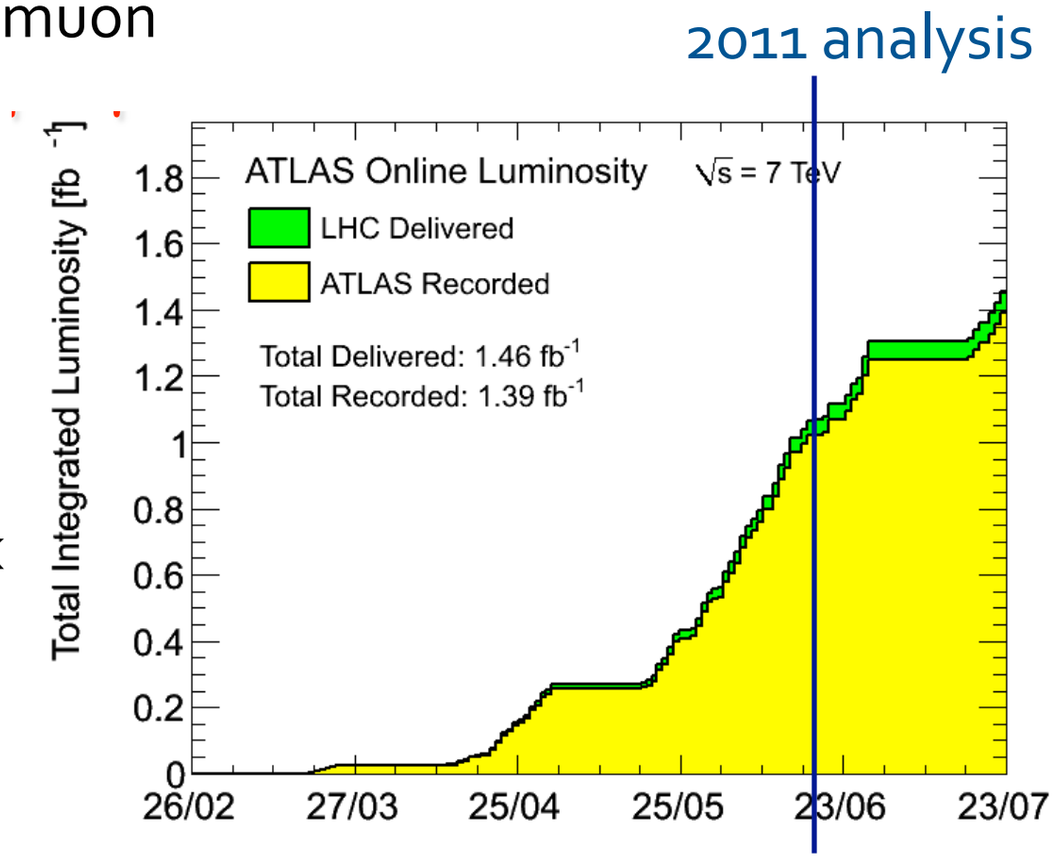
$$Br(d_4 \to tW) = 100\%$$

2011 Analysis

- same channels as 2010 analysis, but focus on dimuon
- MUCH more data: 1.07 fb^{-1}

Selection improvements

- only one muon with $p_T > 20$ GeV, the other with $p_T > 10$ GeV
  greater signal acceptance
- track-based isolation requirement: sum of track p_T within cone of $\Delta R = 0.4$ less than 10% of muon p_T AND less than 5 GeV
  shown to have less pileup dependence
  pileup bigger issue in 2011, with ~6 interactions per bunch crossing
- impact parameter significance: $|d_0|/\sigma(d_0) < 3$
  ~99% efficient for prompt muons; rejection factor of ~3 for b hadron decays



Background estimation

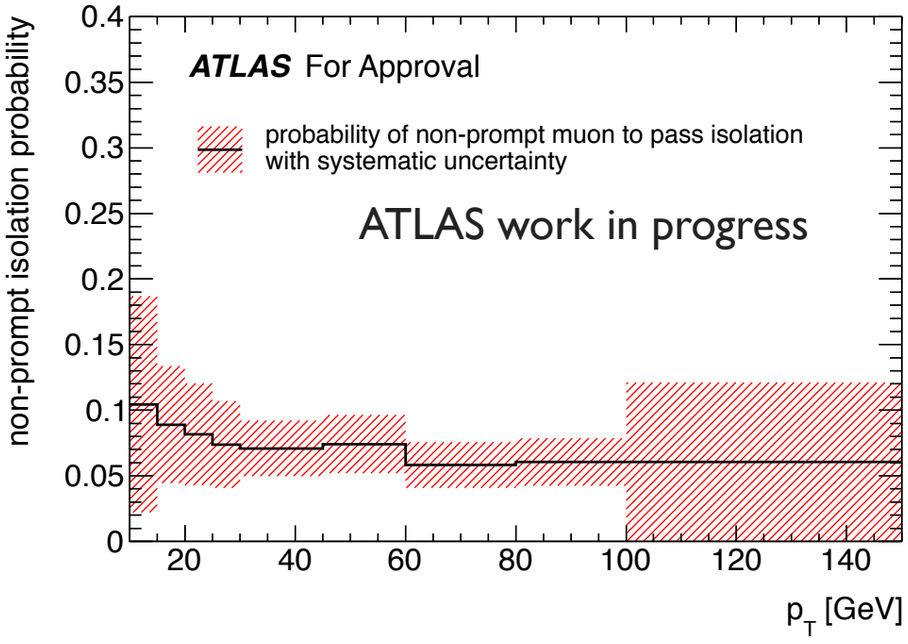
Non-prompt ("fake") muons are **dominant** background (83%)

1) semi-leptonic b-hadron decays
2) pion and kaon decay-in-flight

- Data-driven technique applied to obtain event yield for fakes
- From heavy-flavor-enriched control samples, obtain fake rate

  fake rate = fraction of non-prompt muons that pass isolation requirement (among those passing other selection requirements)
- differences among control samples used to derive systematic uncertainty
- at least 30% uncertainty
- 80% systematic in low p_T bins
- fake rate approximately flat (7%) above 100 GeV

- With fake rate, extract background estimate from pairs where one or both muons in the signal region are non-prompt
- Other backgrounds
  - charge-flip: estimate obtained from data driven upper limit on charge-flip rate
  - SM background from dibosons: estimate obtained from MC



Control region with intermediate isolation

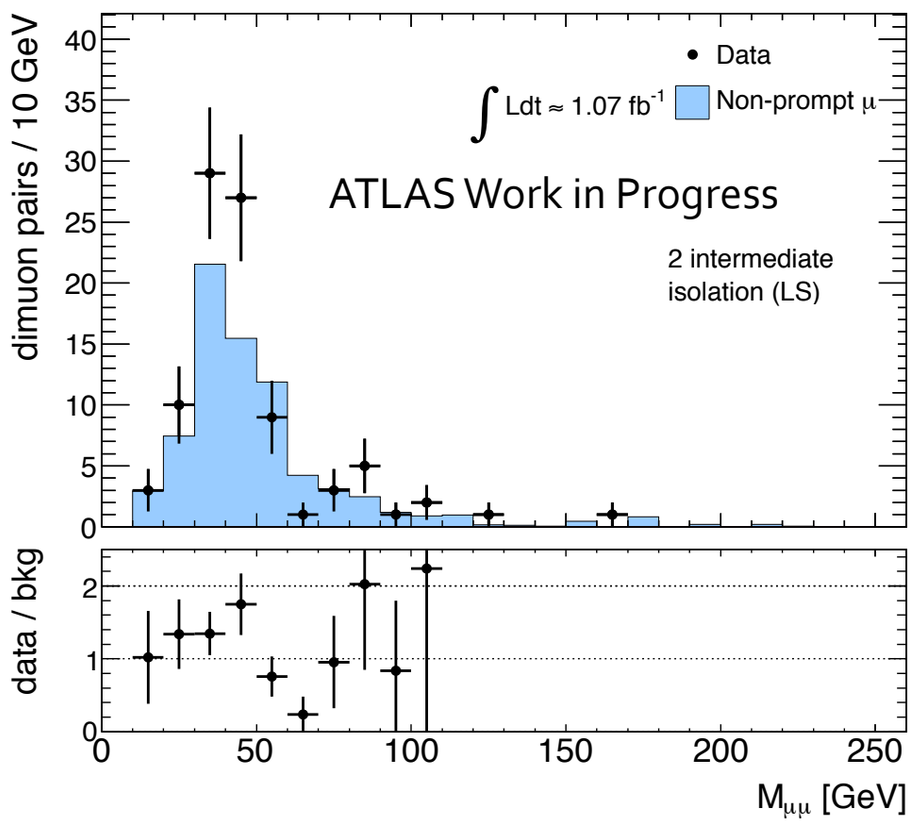
- To test the fake rate method, fake enhanced control region considered
- All other muon selections the same, except for intermediate isolation:

  if p_T < 50 GeV: $0.2 > p_T\mathrm{cone}0.4/p_T > 0.1$

  if p_T > 50 GeV: $5 > p_T\mathrm{cone}0.4 > 10\ \mathrm{GeV}$

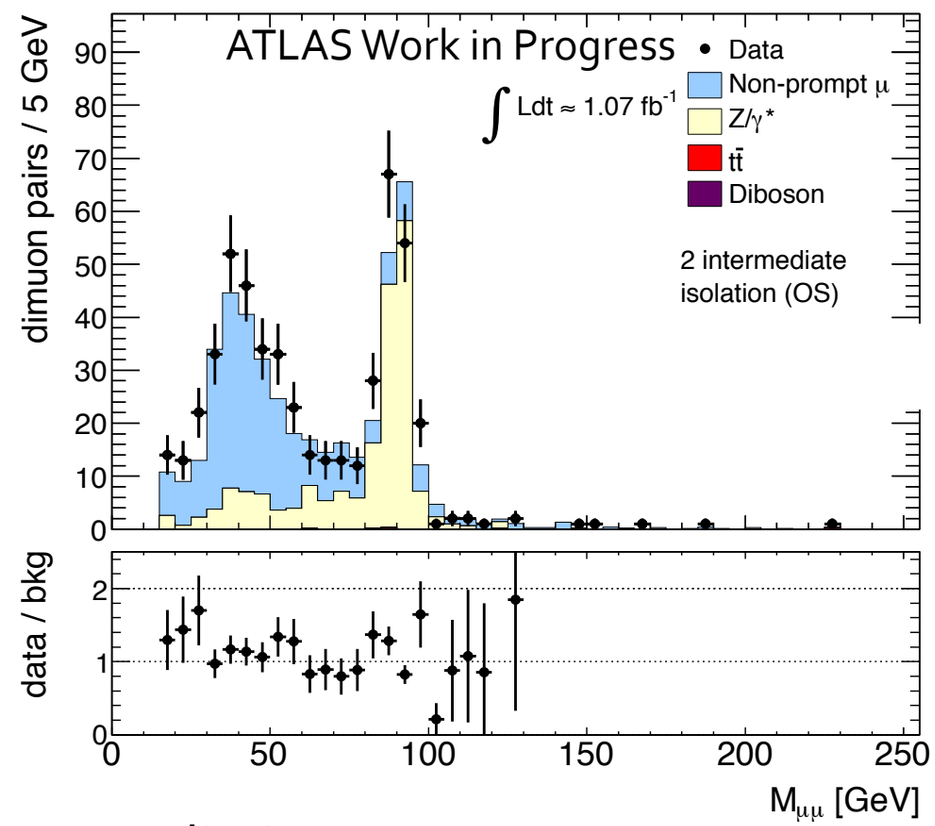
- Agreement between observation and prediction within systematic uncertainties

same-sign



prediction: 73
observation: 90

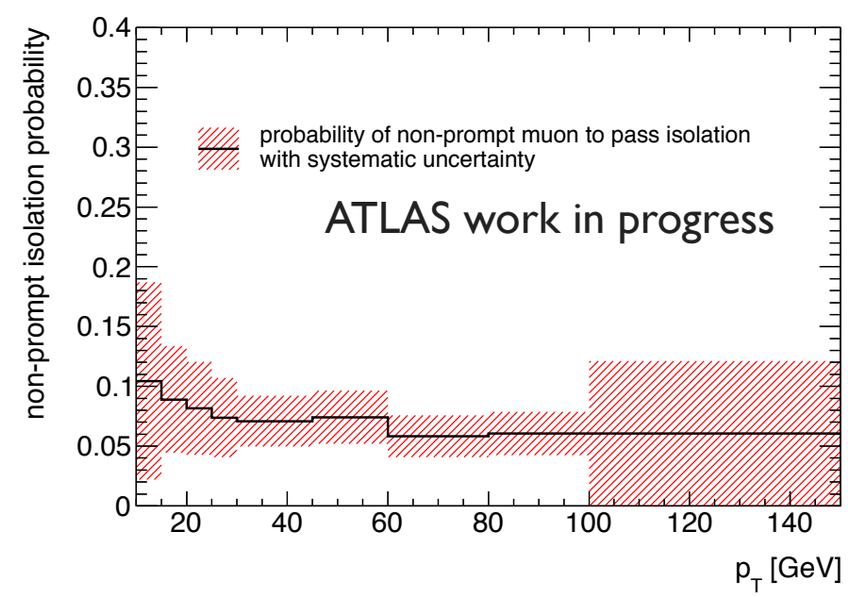
opposite-sign



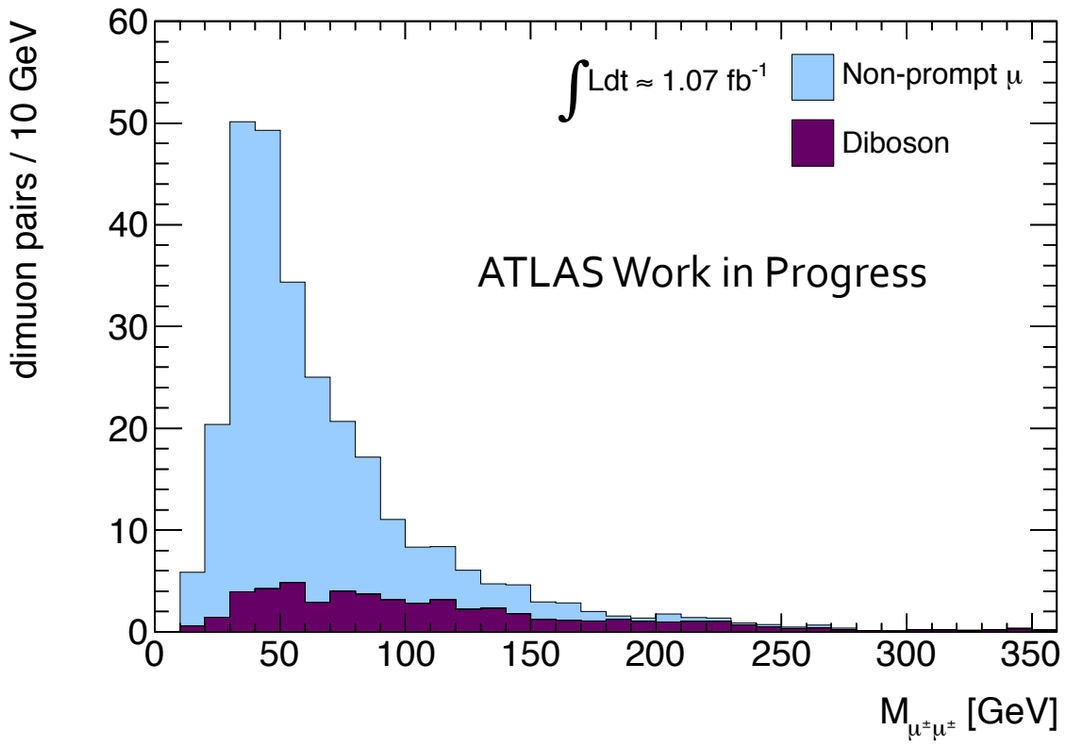
prediction: 224
observation: 267
($m_{\mu\mu}$ < 60 GeV)

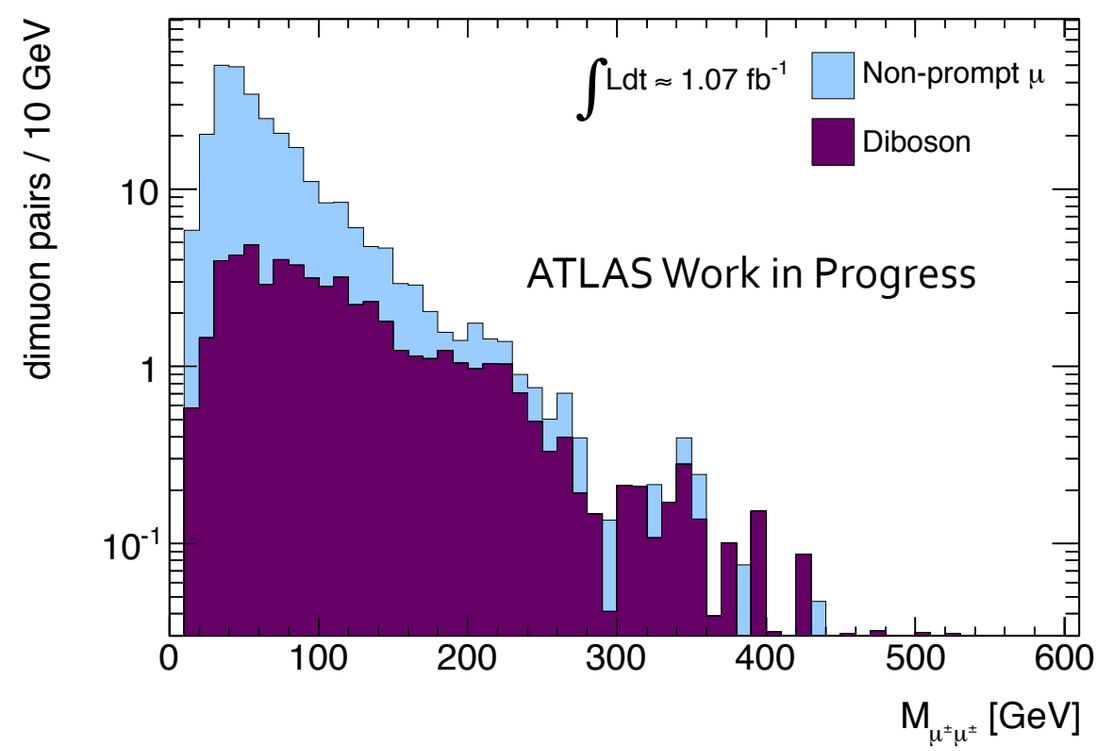
Systematic uncertainties

▸Muon identification efficiency	1%
▸Muon isolation efficiency	2.5%
▸Muon momentum measurement	0.5%
▸Trigger efficiency	0.4%
▸Luminosity uncertainty	3.7%
▸Non-prompt background estimate (binned in p_T and η)	30-100%
▸Diboson cross section	15%



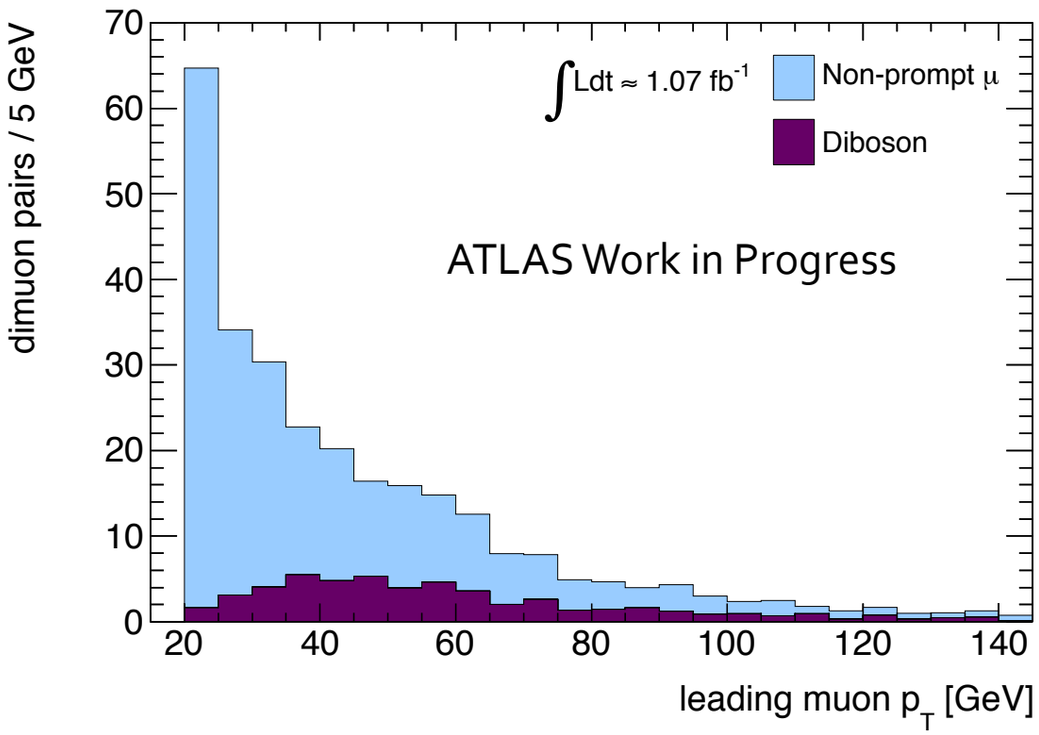
Signal region prediction: invariant mass

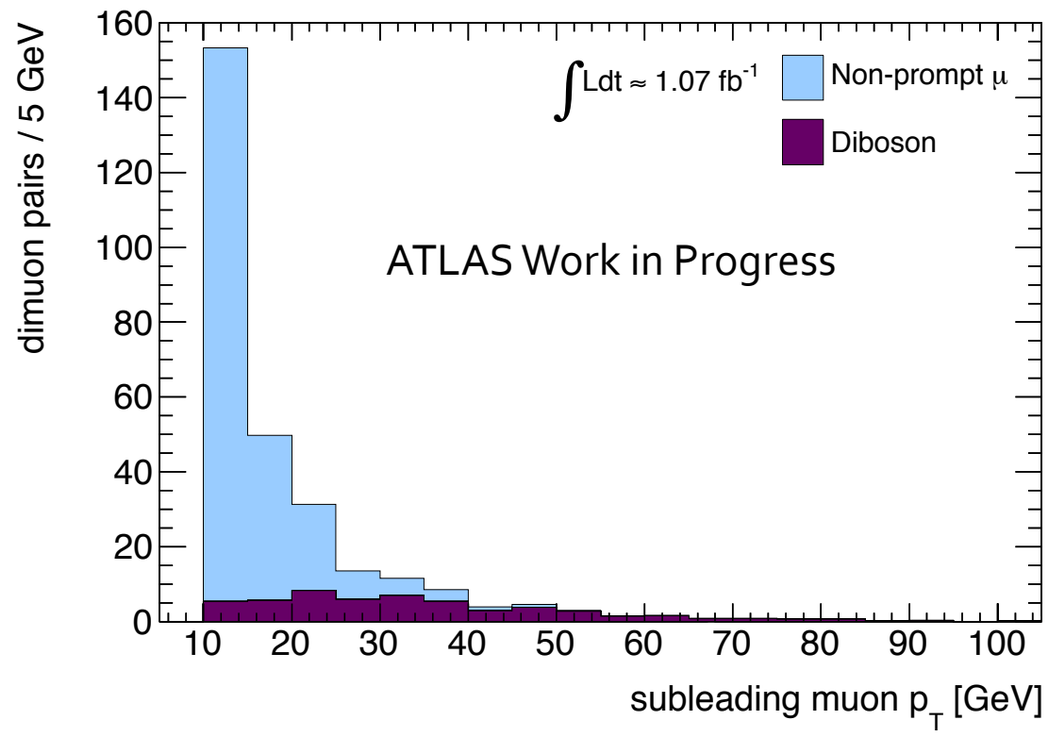




- non-prompt background is dominant
- smaller contribution from dibosons
- since charge flip rate is small for muons, no contribution

Signal region muon kinematics





- data comparison coming soon!

Event yield with systematics

2010 with 34 pb^{-1}:

	n_{obs}	n_{pred}	n_{fake}	$n^{\text{sim}}_{\text{charge-flip}}$	$n^{\text{sim}}_{\text{diboson}}$
ee	10	$21.8\pm9.4\pm3.8$	$11.1\pm9.4\pm2.8$	$10.1\pm0.9\pm2.5$	$0.6\pm0.0\pm0.1$
$\mu\mu$	9	$6.1\pm2.8\pm1.2$	$4.8\pm2.8\pm1.2$	—	$1.3\pm0.0\pm0.1$
$e\mu$	25	$17.5\pm9.3\pm3.7$	$15.0\pm9.3\pm3.7$	$0.5\pm0.2\pm0.1$	$2.1\pm0.0\pm0.2$

2011 with 1.07 fb^{-1} ($\mu\mu$):

Sample	Number of Events			
	$M_{ll} > 15$ GeV	$M_{ll} > 100$ GeV	$M_{ll} > 200$ GeV	$M_{ll} > 300$ GeV
non-prompt muons	227^{+67}_{-119}	$26.1^{+11.2}_{-12.4}$	$3.25^{+1.97}_{-1.79}$	0.49 ± 0.35
charge flip	$0.0^{+2.0}_{-0.0}$	$0.0^{+0.6}_{-0.0}$	$0.0^{+0.4}_{-0.0}$	$0.0^{+0.4}_{-0.0}$
$W^{\pm}Z$	34.9 ± 5.2	16.2 ± 2.7	5.08 ± 0.98	1.17 ± 0.33
ZZ	7.97 ± 1.22	3.04 ± 0.52	0.56 ± 0.11	0.16 ± 0.045
$W^{\pm}W^{\pm}$ jj	1.79 ± 0.91	1.16 ± 0.59	0.53 ± 0.27	0.17 ± 0.09
$t\bar{t}W^{\pm}$	0.81 ± 0.40	0.41 ± 0.21	0.12 ± 0.06	0.042 ± 0.025
sum	272^{+67}_{-119}	$46.9^{+11.5}_{-12.7}$	$9.55^{+2.22}_{-2.06}$	$2.03^{+0.63}_{-0.49}$
data	observed yield coming soon!			

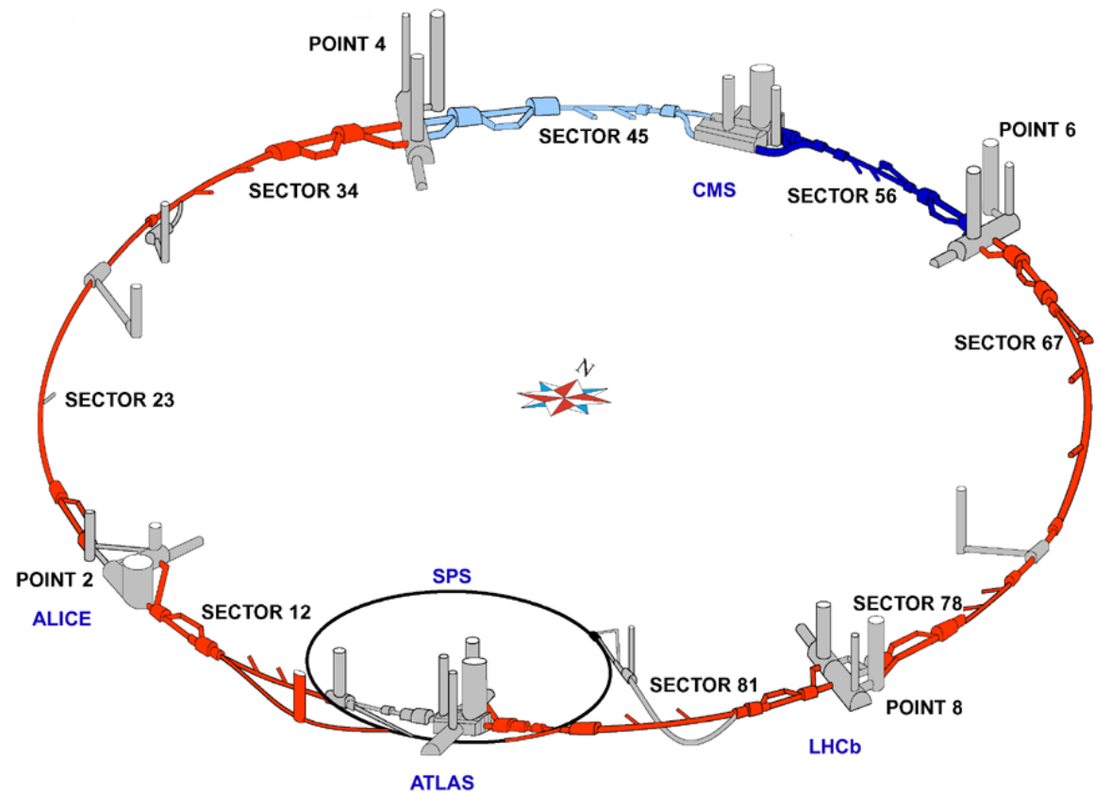
Conclusion

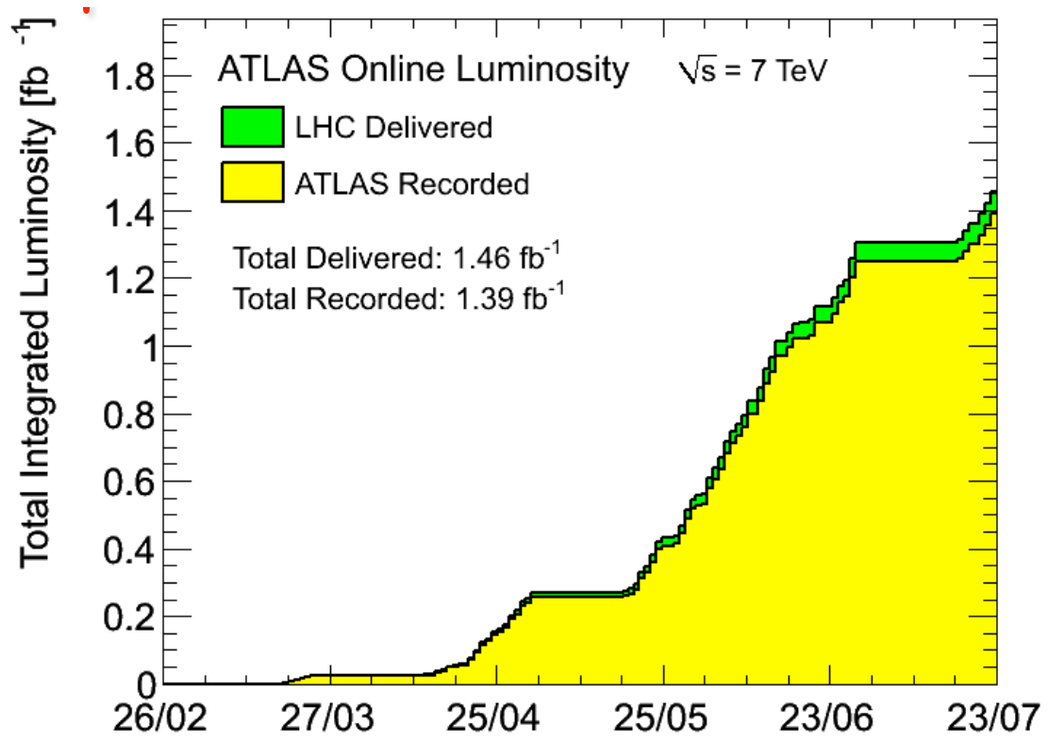
- An inclusive search for anomalous production of same-sign dileptons was performed with the 2010 dataset, and is in progress for the 2011 data
- In 2010, no excess beyond the Standard Model was observed, and competitive limits were placed on four BSM models
- With a factor of 30 more data, expect that the limits with the 2011 dataset will be MUCH more stringent, if no disagreement with SM is found
- Currently investigating limits on specific model: doubly charged Higgs bosons

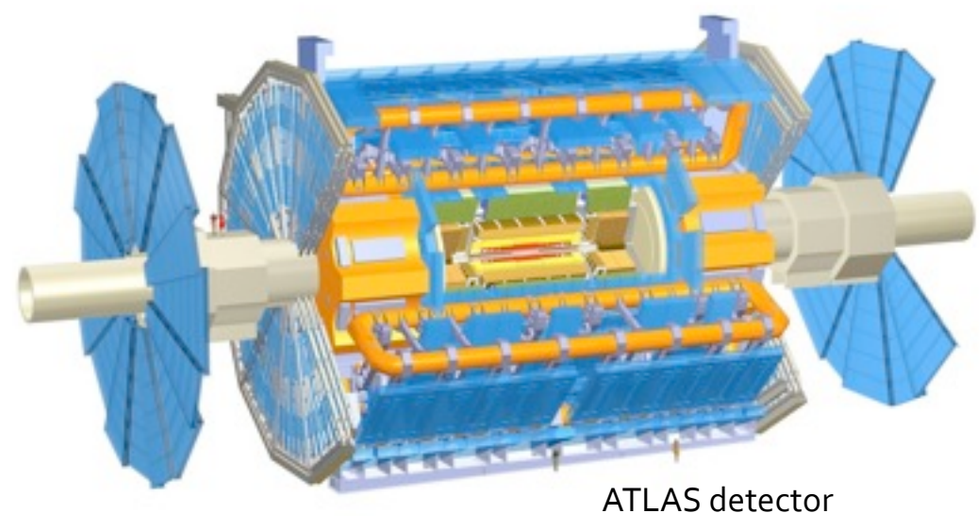
Backup

Large Hadron Collider

- proton-proton collider
- four detectors along beamline
  - ATLAS
  - CMS
  - LHCb
  - ALICE

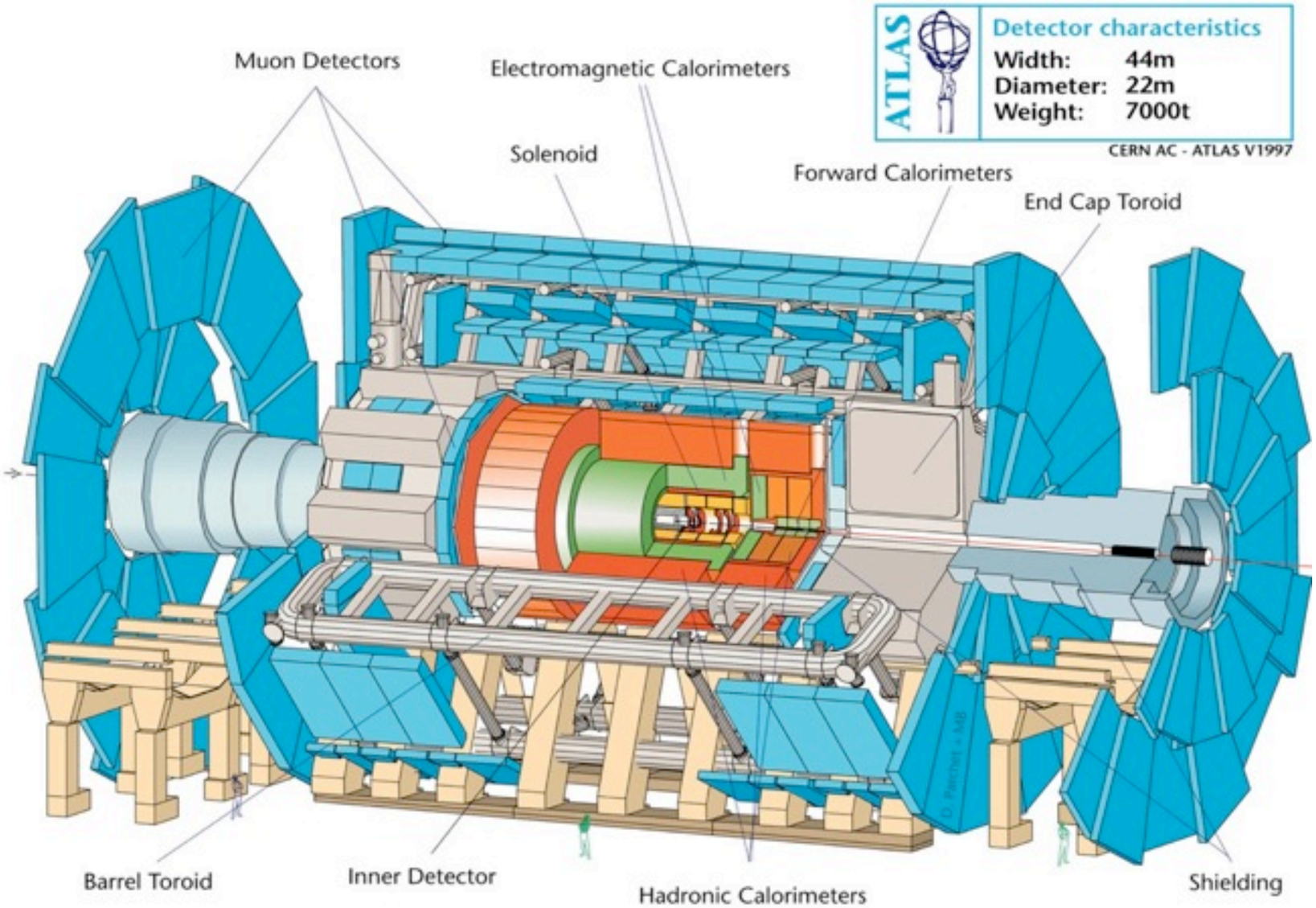






ATLAS detector

ATLAS detector



- Inner detector (yellow) - responsible for particle tracking
- Calorimeters (green and orange) - records energy of electromagnetically and strongly interacting particles
- Muon system (blue) - measures muon momentum

Systematic uncertainties

- Muon identification efficiency: 1%
- Muon isolation efficiency: -2.5%
- Muon momentum measurement: 0.5%
- Trigger efficiency: 0.4%
- Luminosity uncertainty: 3.7%
- Non-prompt background estimate: 30-100%
  evaluated separately in each invariant mass bin
- Diboson cross section
  - WZ/WW: 15%
    depending on cuts, k-factor varied from 1.4 to 1.7
  - WWjj, ttbarW: 50%

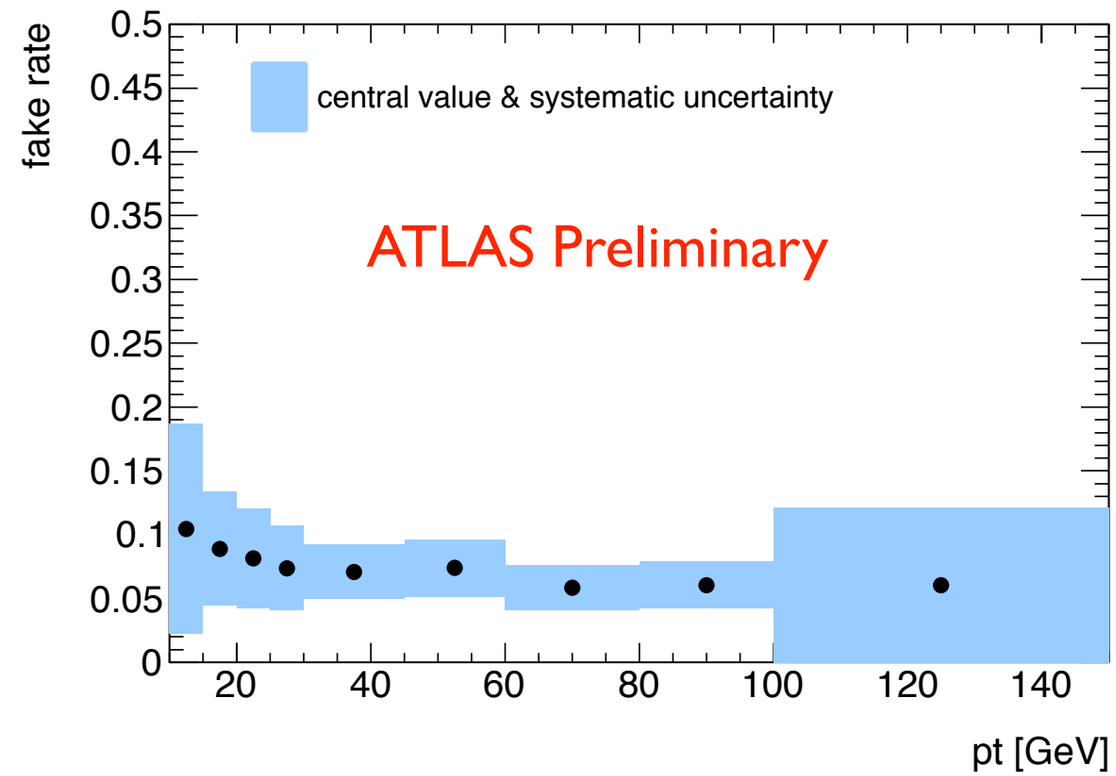
Derivation of fake rate

- Heavy-flavor enhanced control samples used to derive fake rate

1) Dimuon sample
   - two muon trigger with lower threshold of 10 GeV
   - two muons passing selection except for isolation and d_0 significance
   - $15 < M_{\mu\mu} < 45$ GeV
     suppresses Drell-Yan
   - d_0 significance > 5

2) Same trigger sample
   - use same trigger as analysis for $p_T > 20$ GeV
   - d_0 significance > 5
   - control sample factors in fake rate dependence on muon trigger

3) Low m_T sample
   - single muon trigger used, and away side jet with p_T greater than 20 GeV required
   - $m_T < 10$ GeV
     reduces contribution from prompt muons from W
   - this sample probes fake rate from decay-in-flights in addition to heavy flavor decays



- differences among control samples used to derive systematic uncertainty
- at least 30% uncertainty
- 80% systematic in low p_T bins
- fake rate approximately flat (7%) above 100 GeV

Application of fake rate

- Background estimate from matrix method
- Two sets of muons
  - TIGHT - pass isolation
  - LOOSE - fail isolation
- Four observables: N_{TT}, N_{TL}, N_{LT}, N_{LL}

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{pmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{pmatrix} \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

- Fake rate and signal efficiency used to relate observables to true composition in signal region

$$N_f = rfN_{RF} + frN_{FR} + ffN_{FF}$$

- Invert first equation to get signal prediction, N_{TT}

$$N_{TT} = rrN_{RR} + rfN_{RF} + frN_{FR} + ffN_{FF}$$

MC-derived