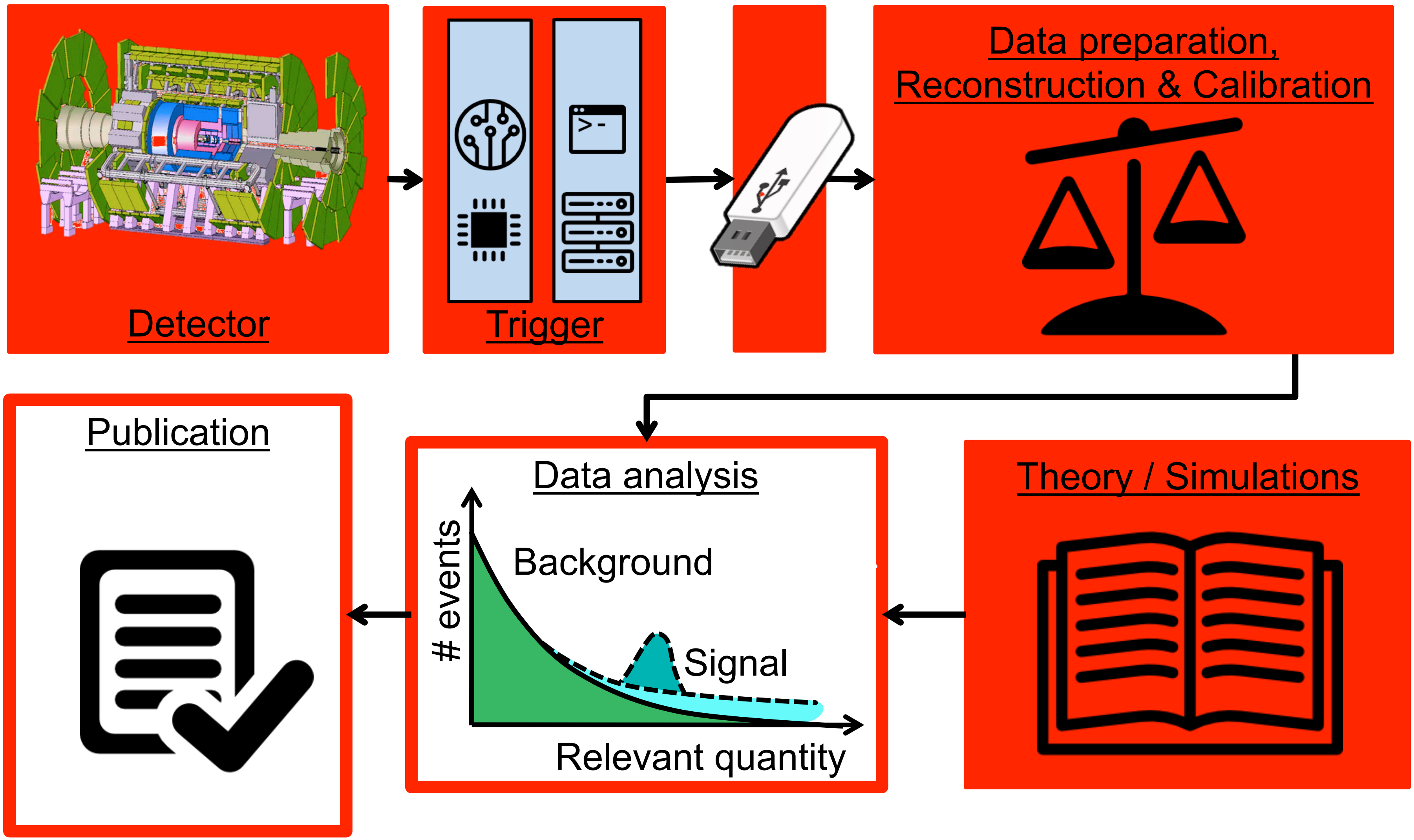
FROM RAW DATA TO PHYSICS

LECTURE 3

LECTURE 3

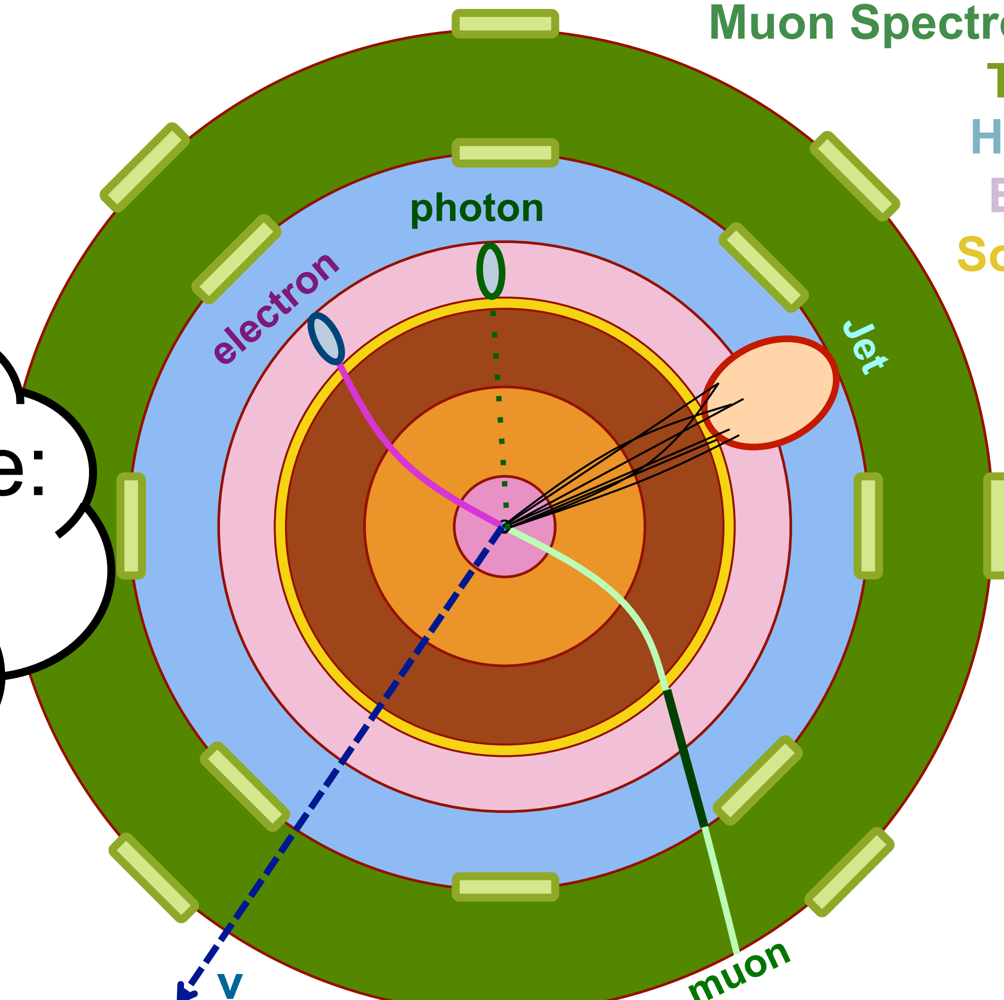

Detector
Trigger
Data preparation,
Reconstruction & Calibration
Publication
Data analysis
events
Background
Signal
Relevant quantity
Theory / Simulations

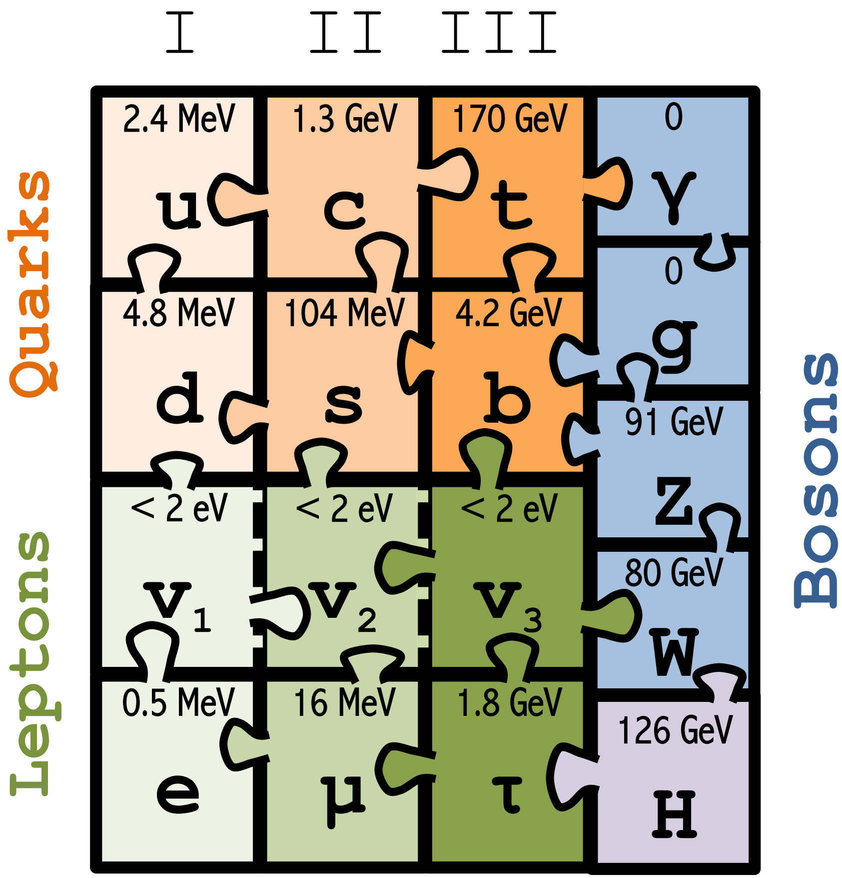
WHAT DO WE RECONSTRUCT

Tracks and Clusters

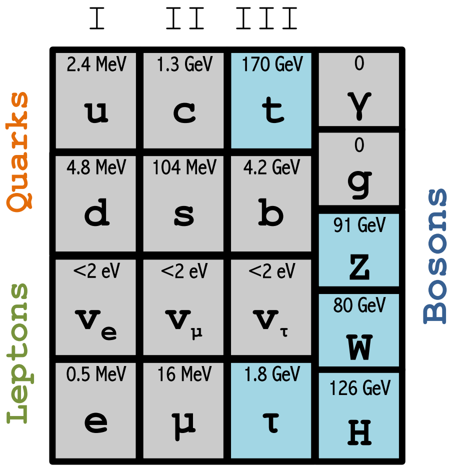
Combining those: "objects" ("particles")

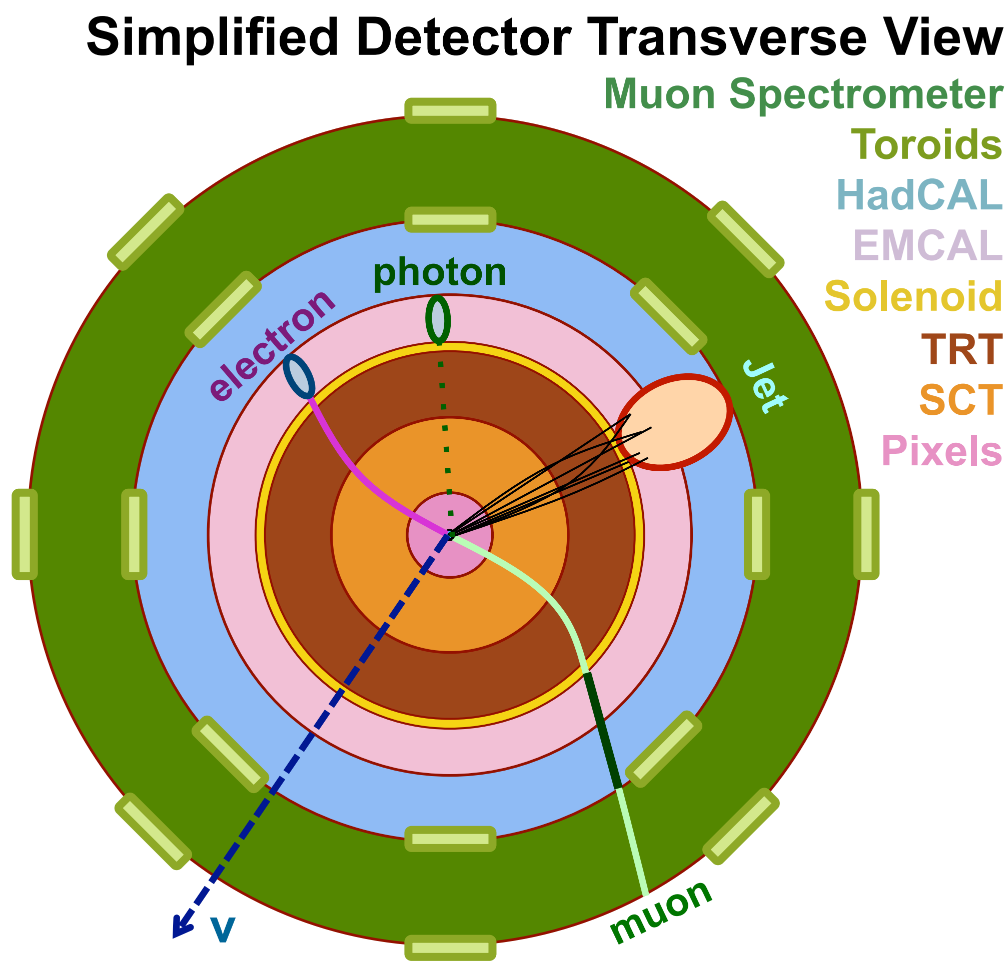
Simplified Detector Transverse View




I
II
III
Quarks
Leptons
Bosons
2.4 MeV
u
1.3 GeV
c
170 GeV
t
0
γ
4.8 MeV
d
104 MeV
s
4.2 GeV
b
0
g
91 GeV
Z
< 2 eV
ν1
< 2 eV
ν2
< 2 eV
ν3
80 GeV
W
0.5 MeV
e
16 MeV
μ
1.8 GeV
τ
126 GeV
H

RECONSTRUCTING PARTICLES



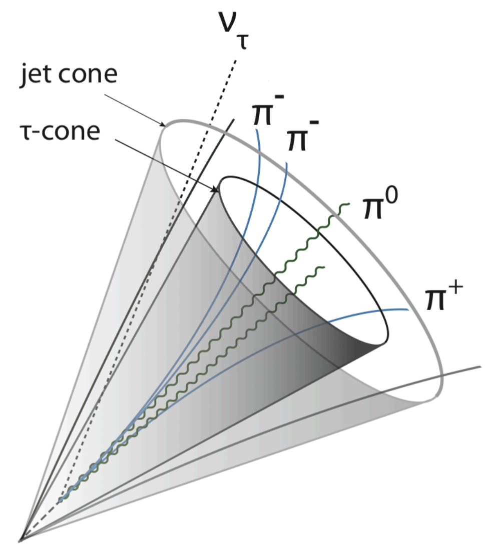


TAUS

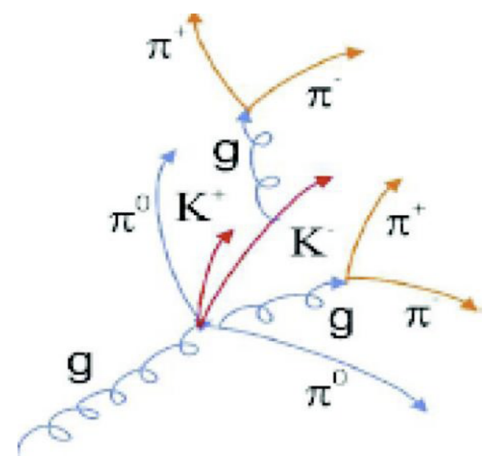
Tau Decay Mode			B.R.
Leptonic		$\tau^{\pm} \rightarrow e^{\pm} + \nu + \nu$	17.8%
		$\tau^{\pm} \rightarrow \mu^{\pm} + \nu + \nu$	17.4%
Hadronic	1-prong	$\tau^{\pm} \rightarrow \pi^{\pm} + \nu$	11%
		$\tau^{\pm} \rightarrow \pi^{\pm} + \nu + n\pi^{0}$	35%
	3-prong	$\tau^{\pm} \rightarrow 3\pi^{\pm} + \nu$	9%
		$\tau^{\pm} \rightarrow 3\pi^{\pm} + \nu + n\pi^{0}$	5%
Other			~5%

- Hadronic tau reconstruction extremely challenging.
- Using **multi-variate** techniques based on track multiplicity and shower shapes.

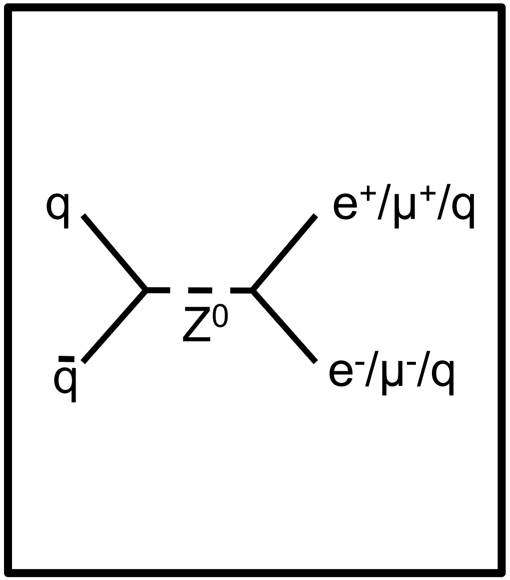
A tau jet (signal)...

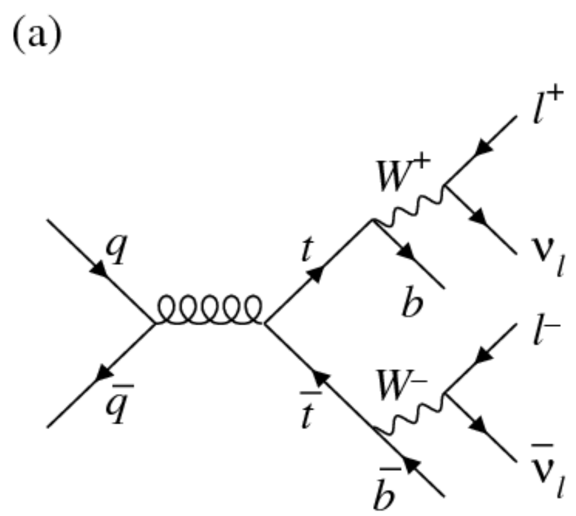


...vs. a QCD jet (background)



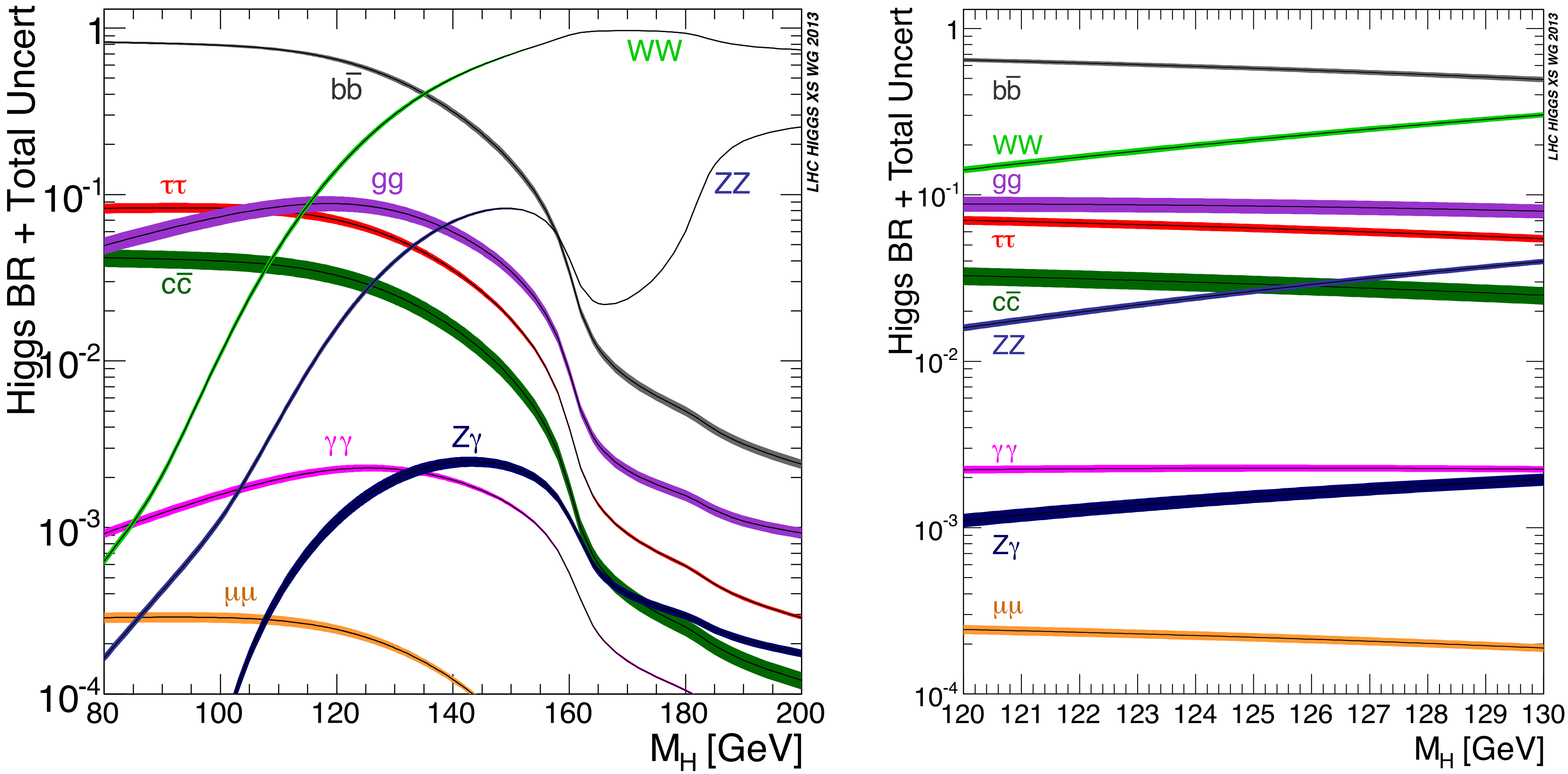
t,W,Z



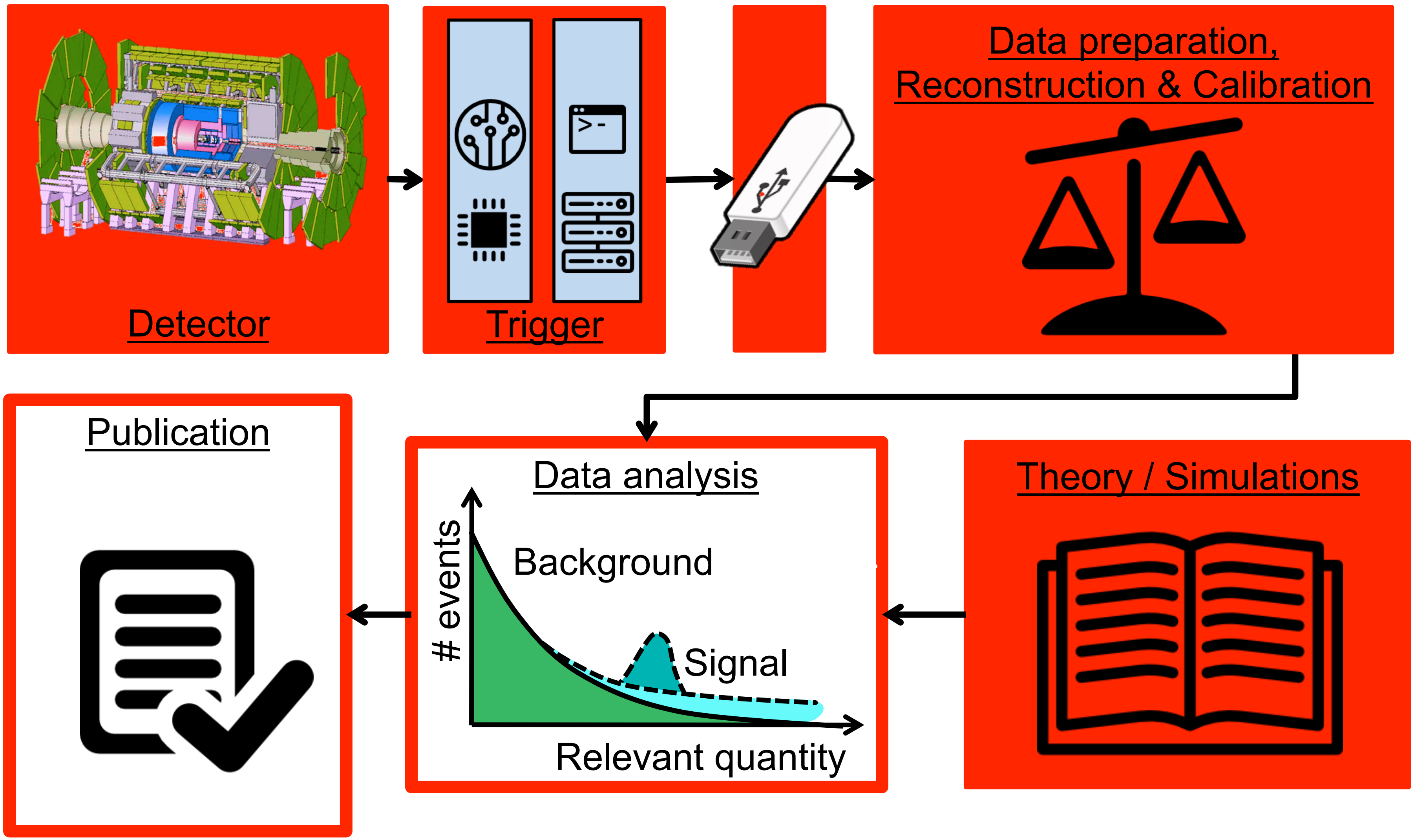


Diagrams from http://arxiv.org/pdf/1004.1181.pdf

AND THE HIGGS!



LECTURE 3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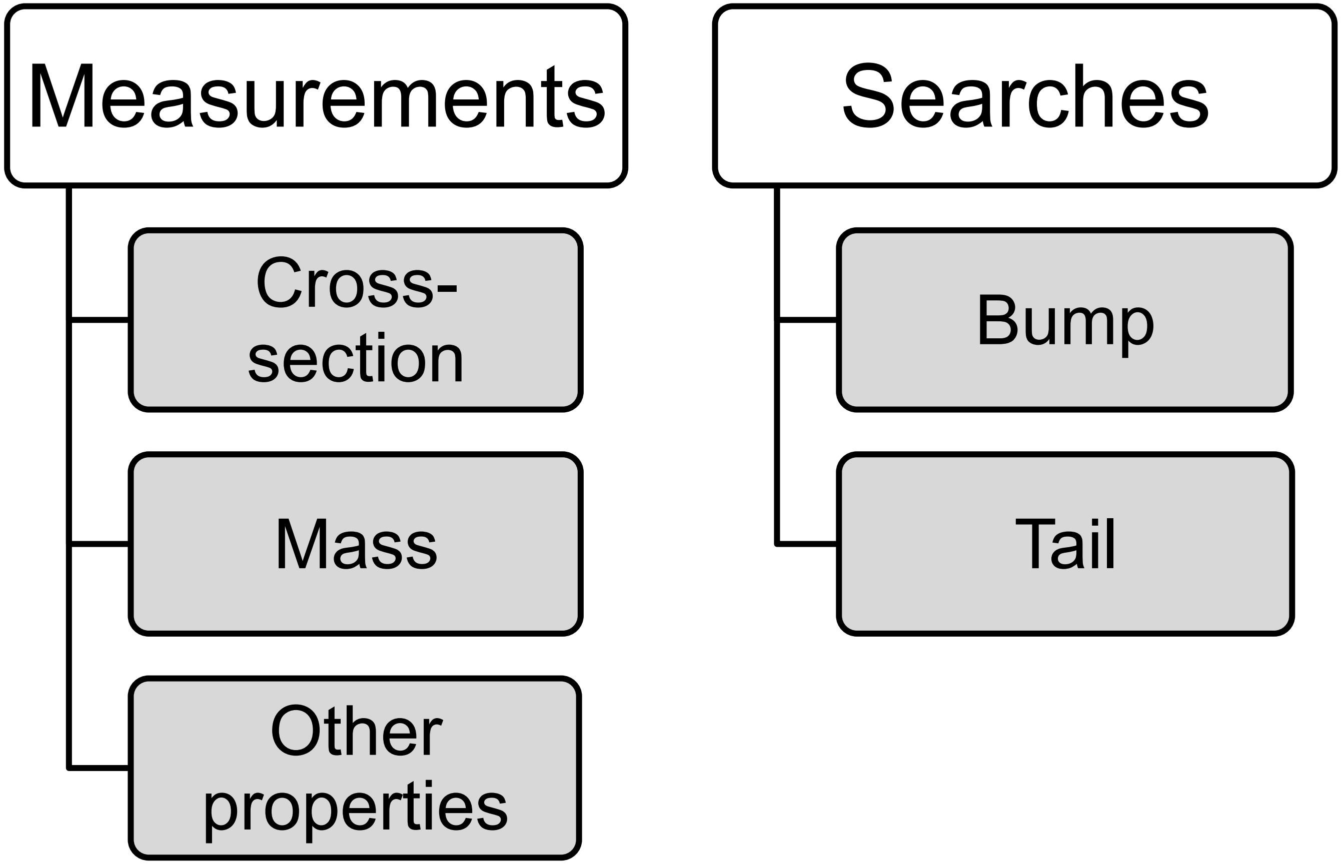
PHYSICS ANALYSES



PHYSICS ANALYSES

Measurements

- Allow important tests of the consistency of the theory.
- Typically limited by systematic uncertainties.

Searches

- … For new particles.
- If no signal, set limits on some model.
- If signal, a potential discovery!
- More data typically improve a search.

PHYSICS ANALYSES

Measurements

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Searches

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“Systematic” uncertainties are introduced by inaccuracies in the methods used to perform the measurement.

PHYSICS ANALYSES

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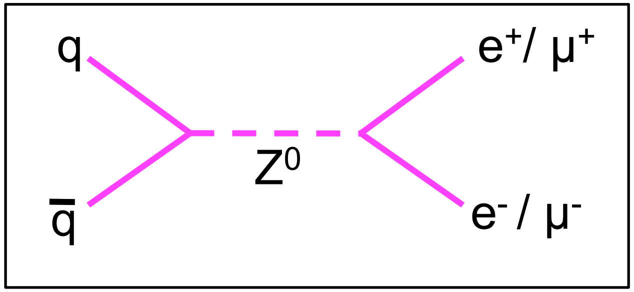
SIMPLE EXAMPLE:

MEASURING Z^0 CROSS-SECTION AT LHC

MEASURING Z^0 CROSS-SECTION AT LHC

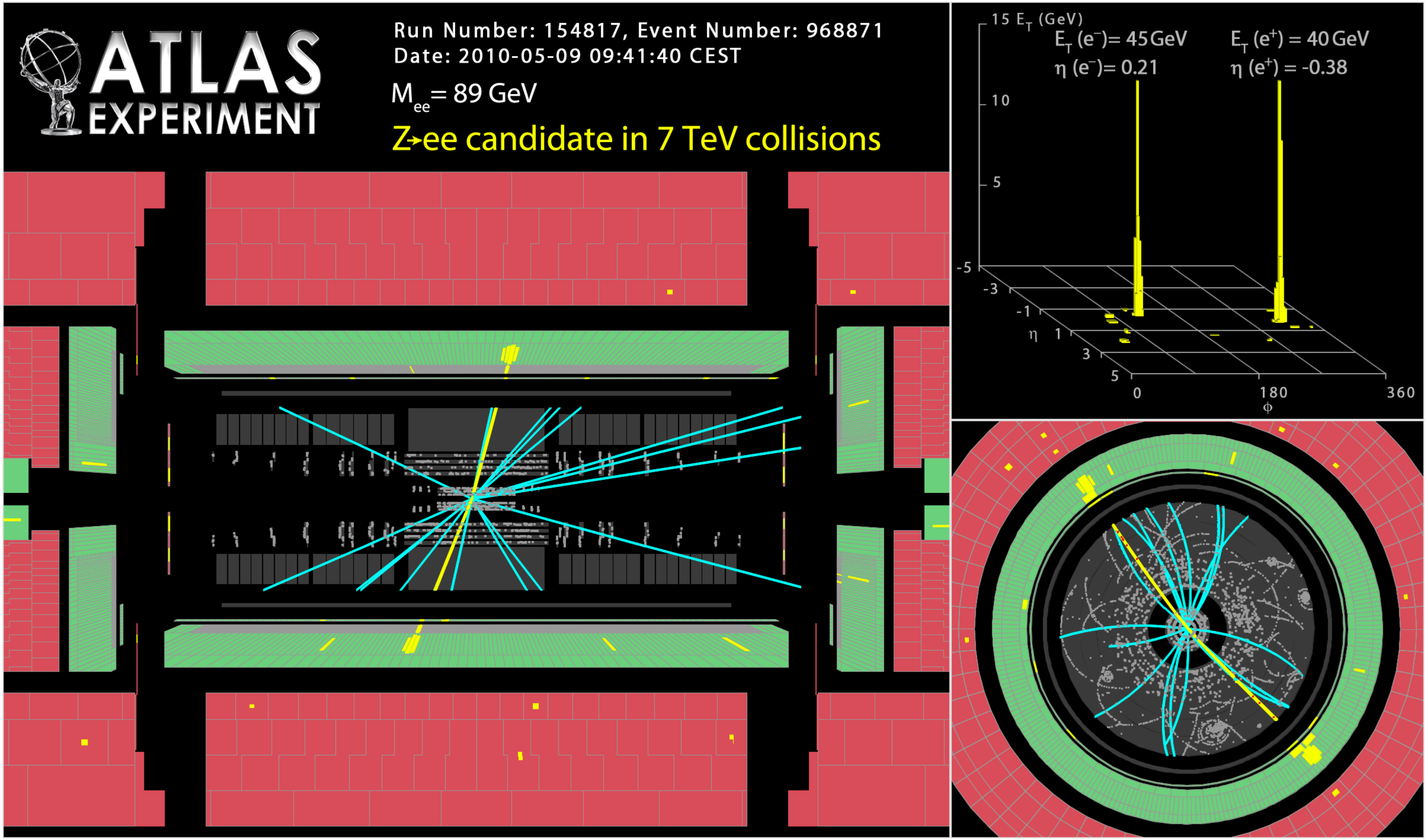
- **Z^0 boson decays to lepton or quark pairs**
  - We can reconstruct it in the e^+e^- or $\mu^+\mu^-$ decay modes



- Discovery and study of the Z^0 boson was a critical part understanding the electroweak force.

- And now, at the LHC?
  - **Important test of theory**: does the measurement agree with the theoretical prediction at LHC collision energy?
  - **A standard candle** for studying reconstruction and deriving calibrations.
  - Can be used for luminosity determination!

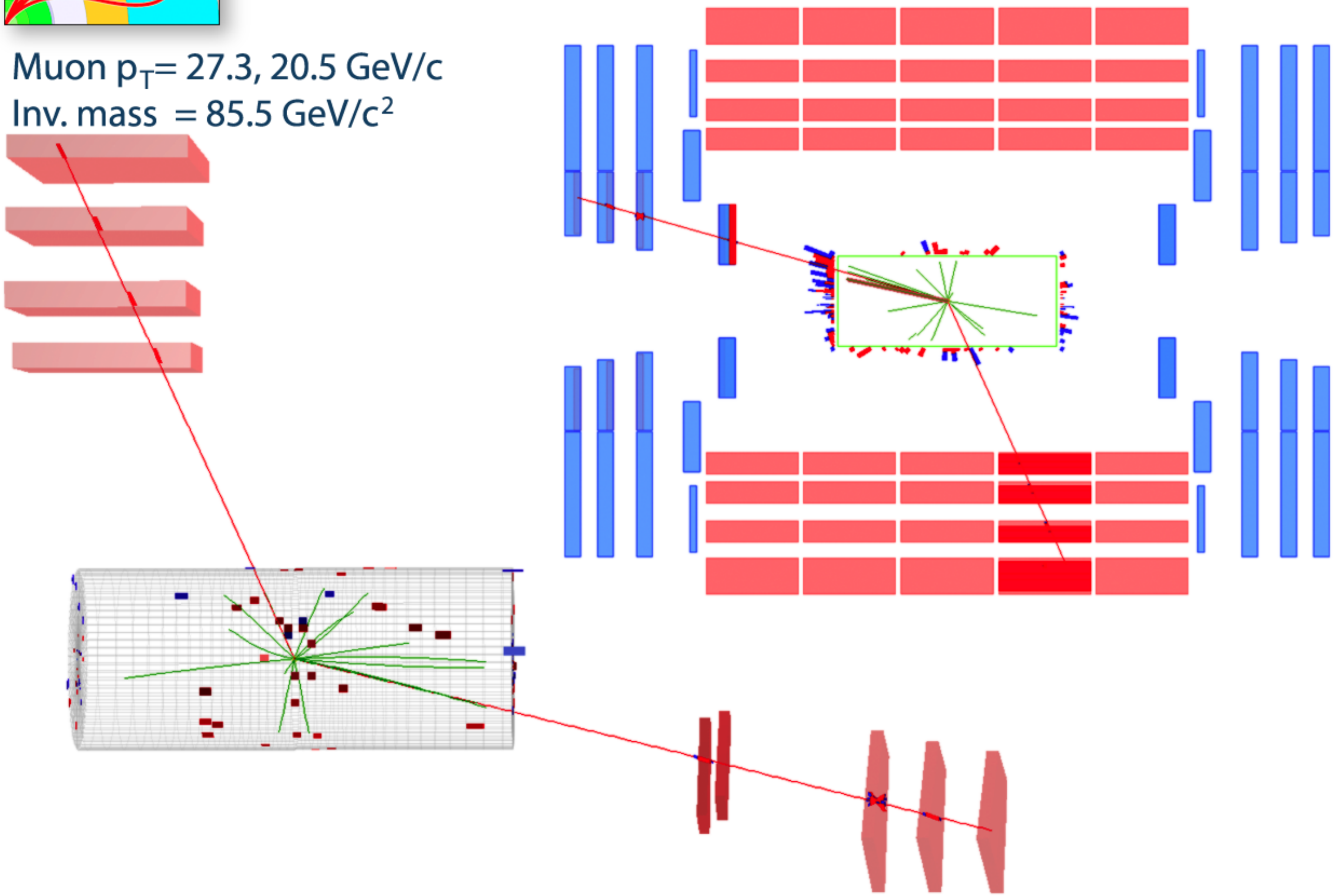
MEASURING Z^0 CROSS-SECTION AT LHC



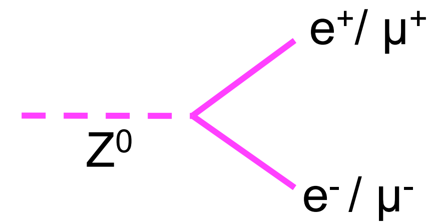
MEASURING Z^0 CROSS-SECTION AT LHC

CMS Experiment at LHC, CERN
Run 136087 Event 39967482
Lumi section: 314
Mon May 24 2010, 15:31:58 CEST

Muon p_T= 27.3, 20.5 GeV/c
Inv. mass = 85.5 GeV/c^2



RECONSTRUCTING Z^0'S



How do we know it's a Z^0?

Identify Z decays using the invariant mass of the 2 leptons
$M^2 = (L_1+L_2)^2$ where $L_i = (E_i,\mathbf{p}_i)$ = 4-vector for lepton i

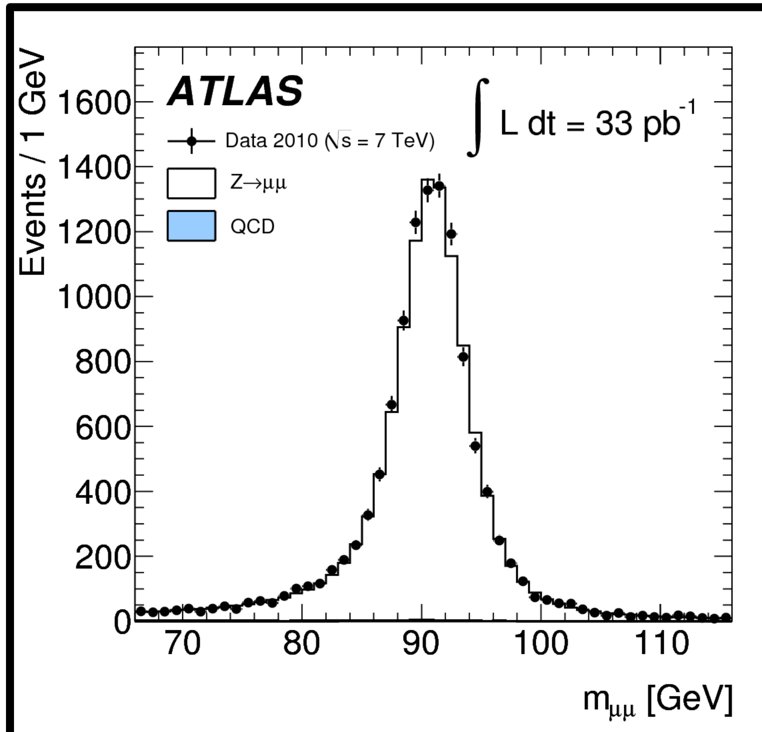
Under assumption that lepton is massless compared to mass of Z^0
=> $M^2 = 2 E_1 E_2 (1-\cos\vartheta_{12})$ where ϑ_{12}= angle between the leptons

- So need to reconstruct the electron and muon energy and direction. Then can calculate the mass.

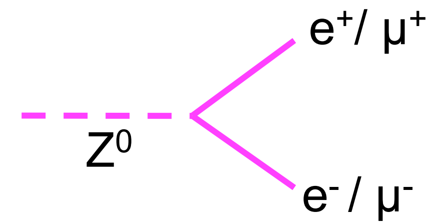
Select Z^0 events with 'analysis cuts':

- Events with 2 high momentum electrons or muons
- Require the electrons or muons are of opposite charge
- With di-lepton mass close to the Z^0 mass (e.g. $70<m_{l+l-}<110$ GeV)

Very little background in Z^0 mass region!



RECONSTRUCTING Z⁰'S



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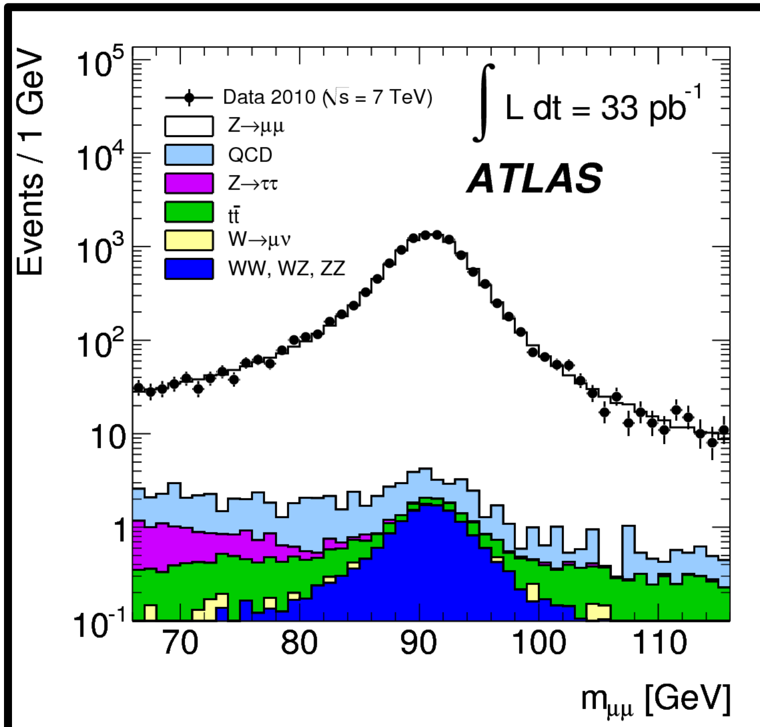
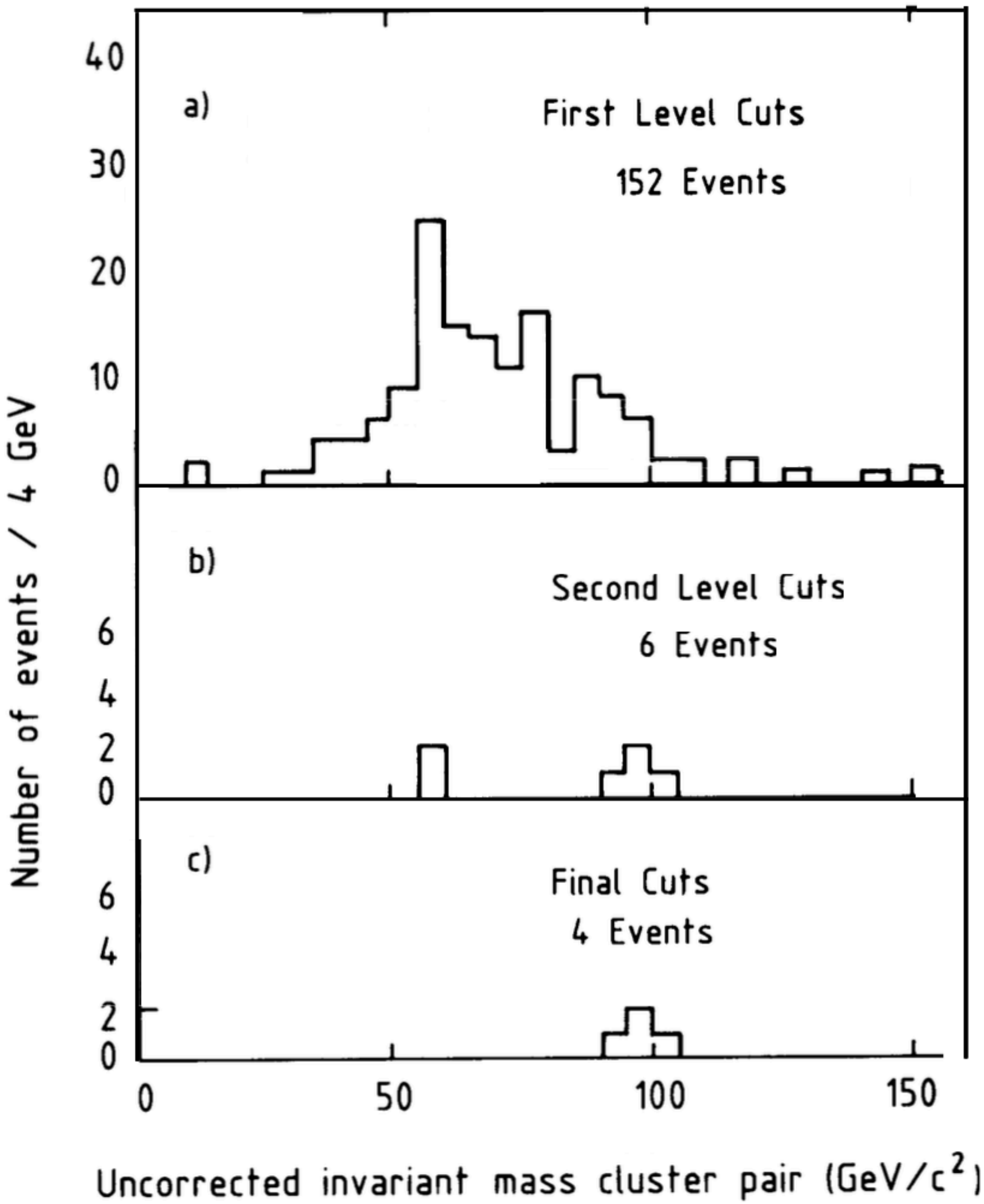




A STEP BACK IN TIME…

Z->ee in UA1

Two EM clusters with E_T>25GeV.

As above plus a track with p_T>7GeV pointing to the cluster. Hadronic and track isolation requirements applied.

A second custer has also an isolated track.

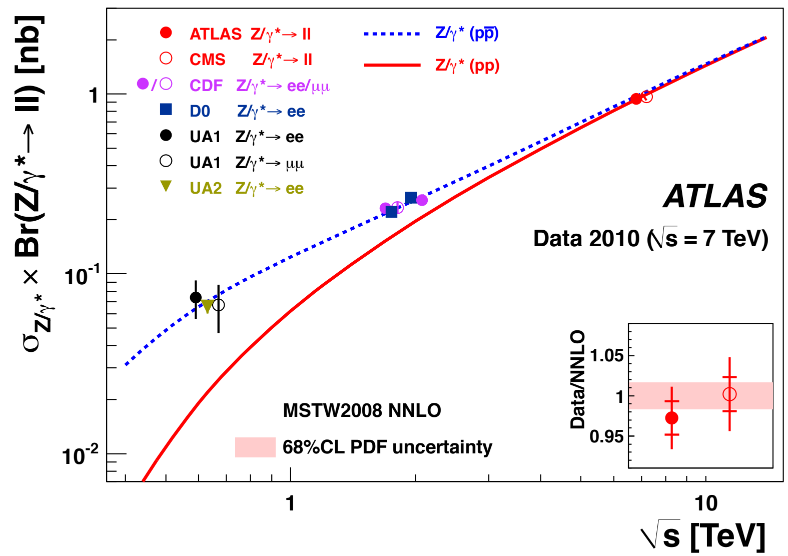
http://www.nobelprize.org/nobel_prizes/physics/laureates/1984/rubbia-lecture.pdf

MEASURING THE Z^0 CROSS-SECTION

Theoretically

Cross-section calculated for:

- Specific production mechanism (pp, $p\bar{p}$, e^+e^-)
- Centre-of-Mass of the collisions (7, 8, 13 TeV at LHC)



Experimentally

$$\sigma \cdot \mathrm{BR} = \frac{\mathrm{Number\ of\ events}}{\alpha \cdot \epsilon \cdot \mathrm{L}}$$

N of events:

N of events on data – N of expected background events

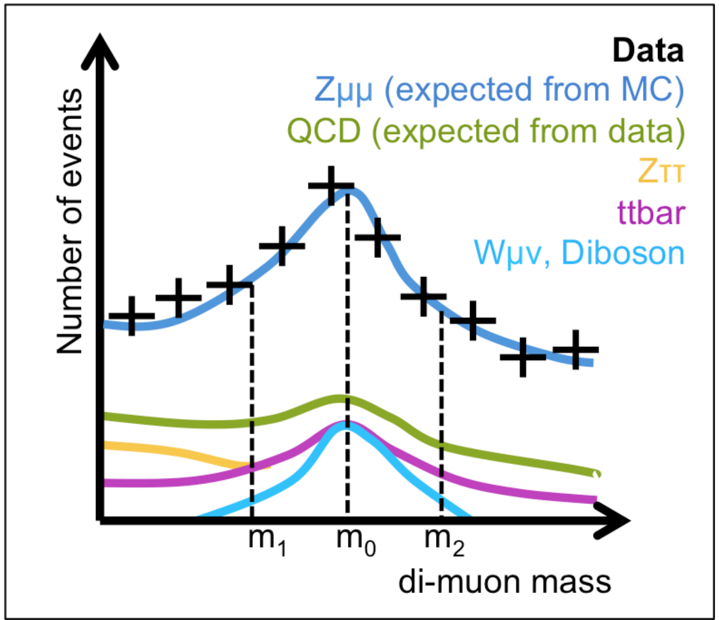
α – acceptance:

fraction of events passing selection requirements

ε – efficiency:

reconstruction efficiency of relevant objects

L – luminosity



MEASURING THE Z^0 CROSS-SECTION

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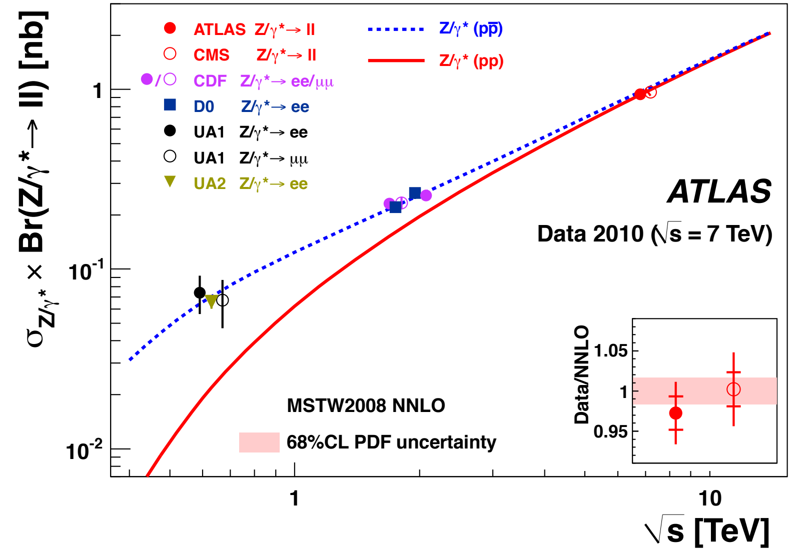

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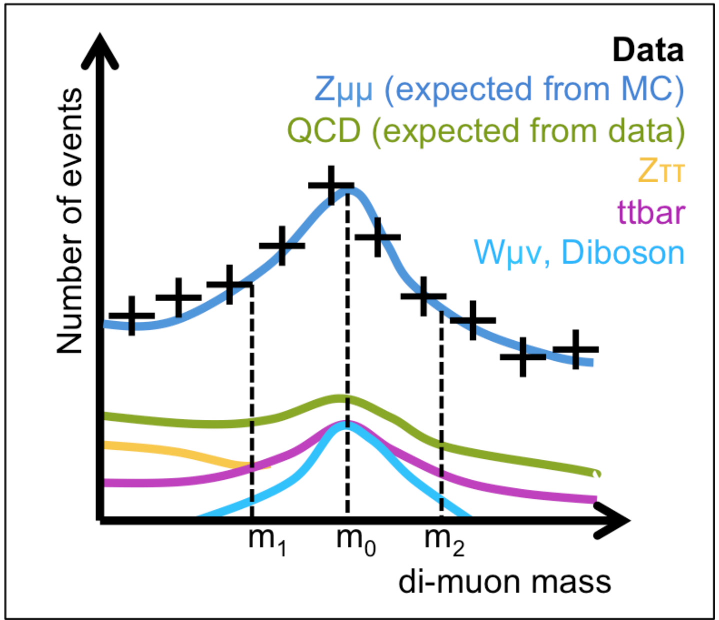
fraction of events passi

ε – efficiency:

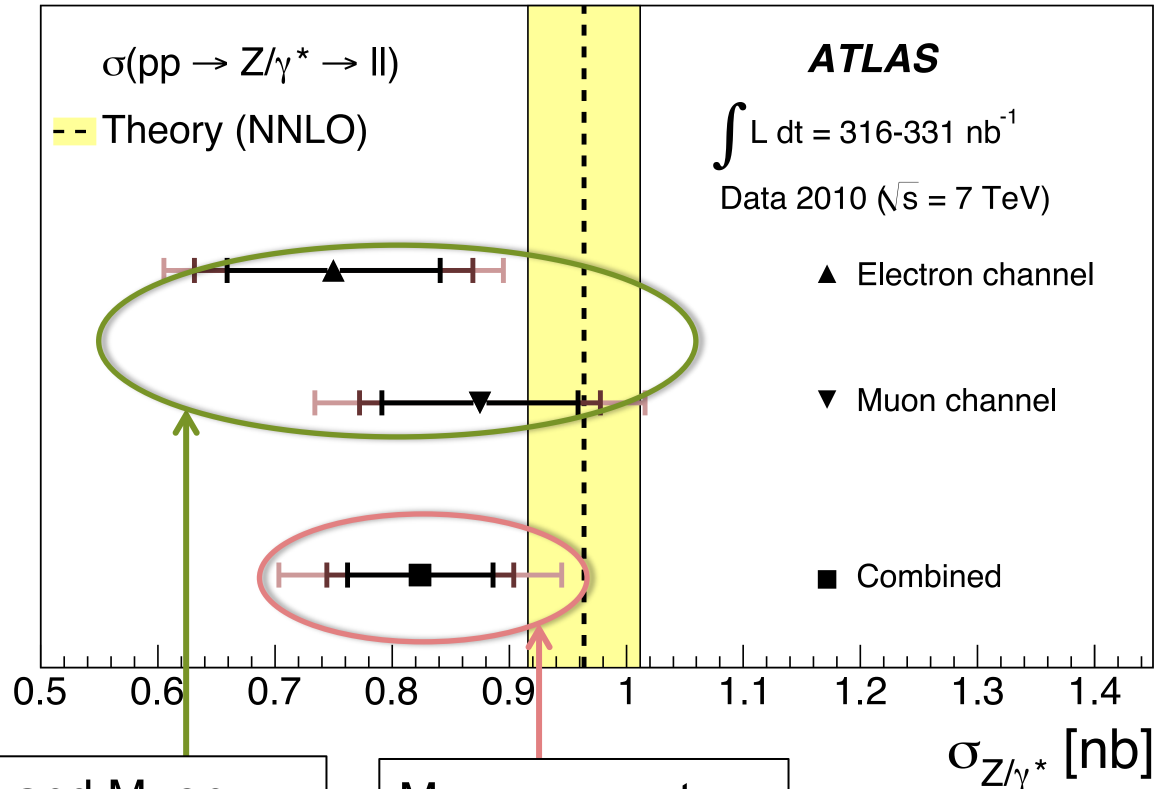
reconstruction efficienc

L – luminosity

All numbers carry **uncertainties** – both **"statistical"** and **"systematic"**!



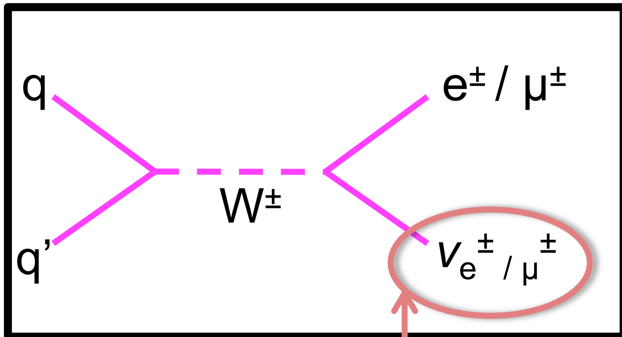
MEASURING THE Z^0 CROSS-SECTION



Electron and Muon channel agree within uncertainties

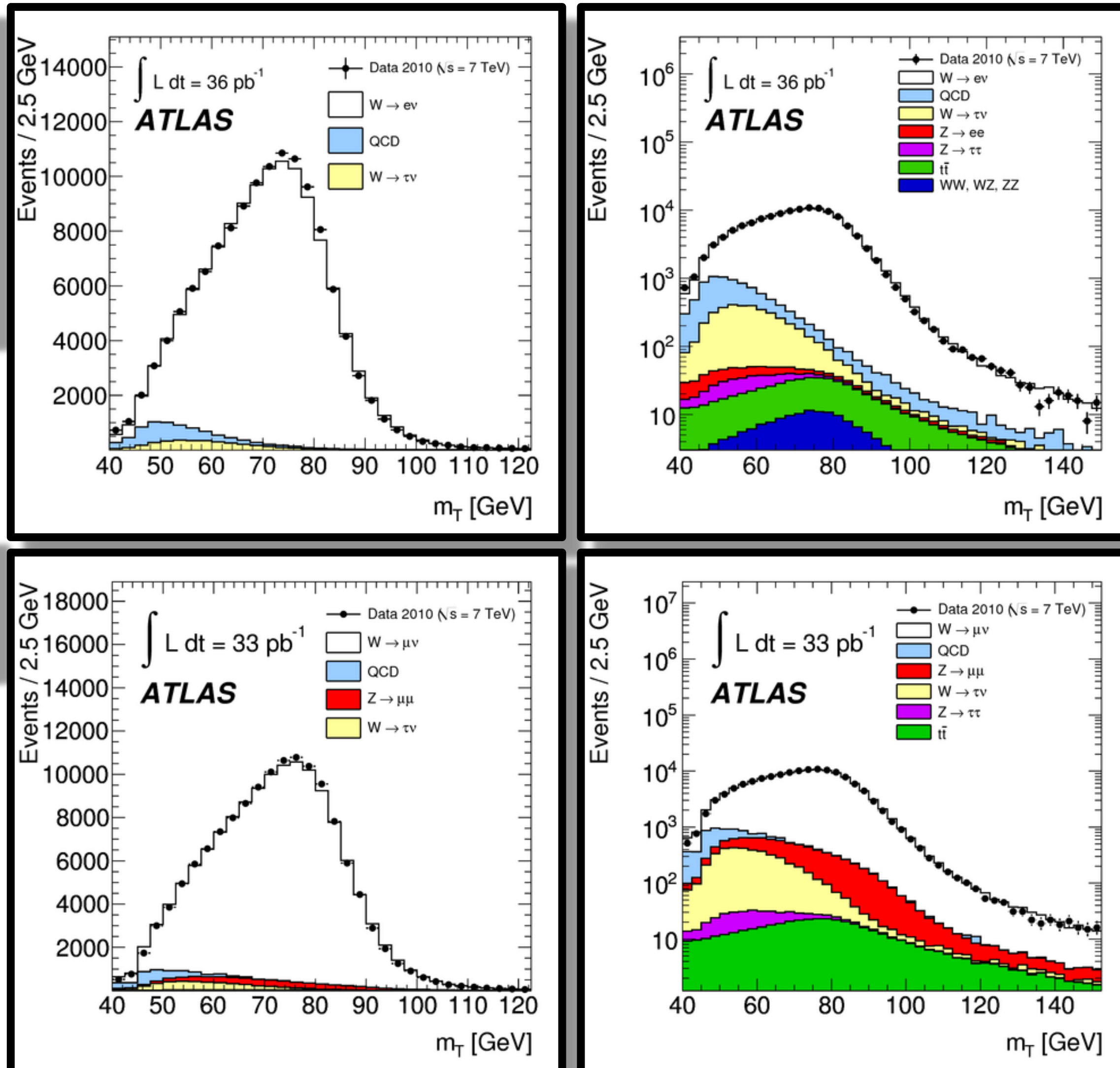
Measurement consistent with prediction within uncertainties

MEASURING THE W CROSS-SECTION

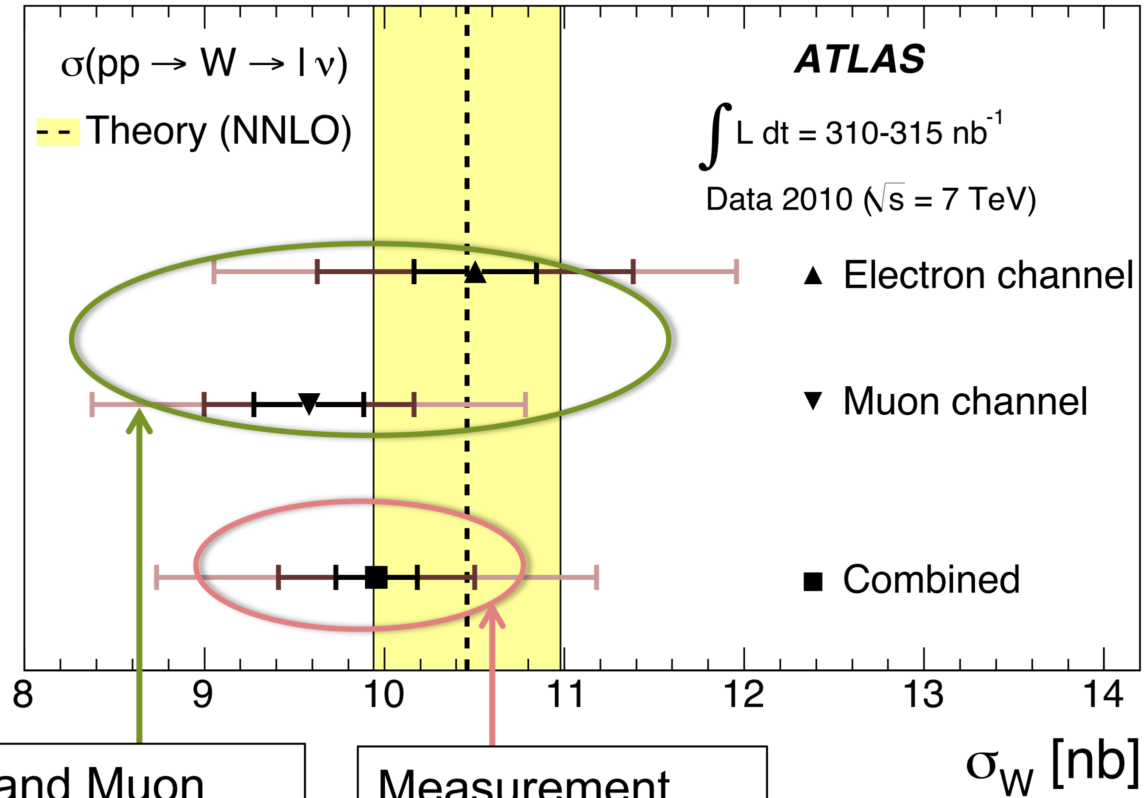


Available in the transverse plane only!

$$M_T^2 = 2\, E_{T1}\, E_{T2}\, (1-\cos\vartheta_{12})$$



MEASURING THE W CROSS-SECTION



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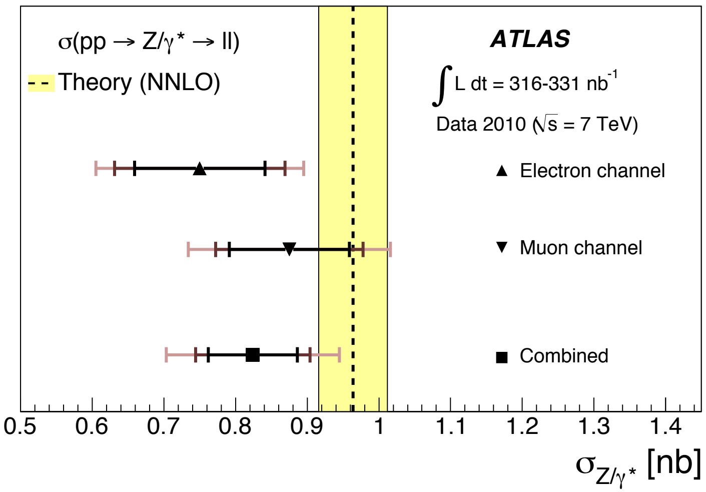
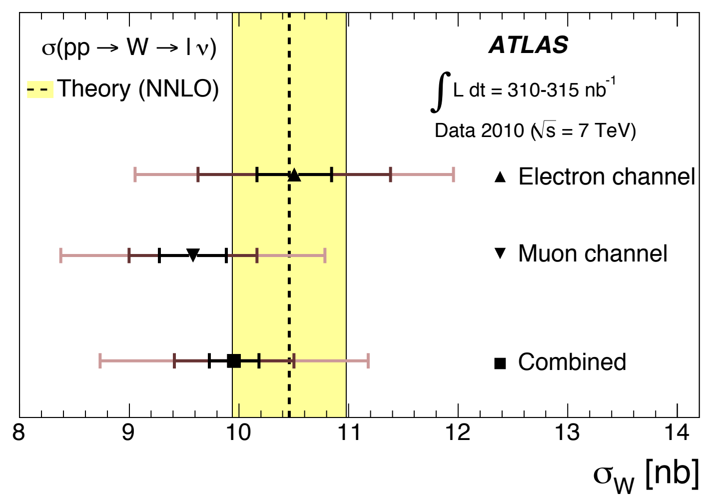
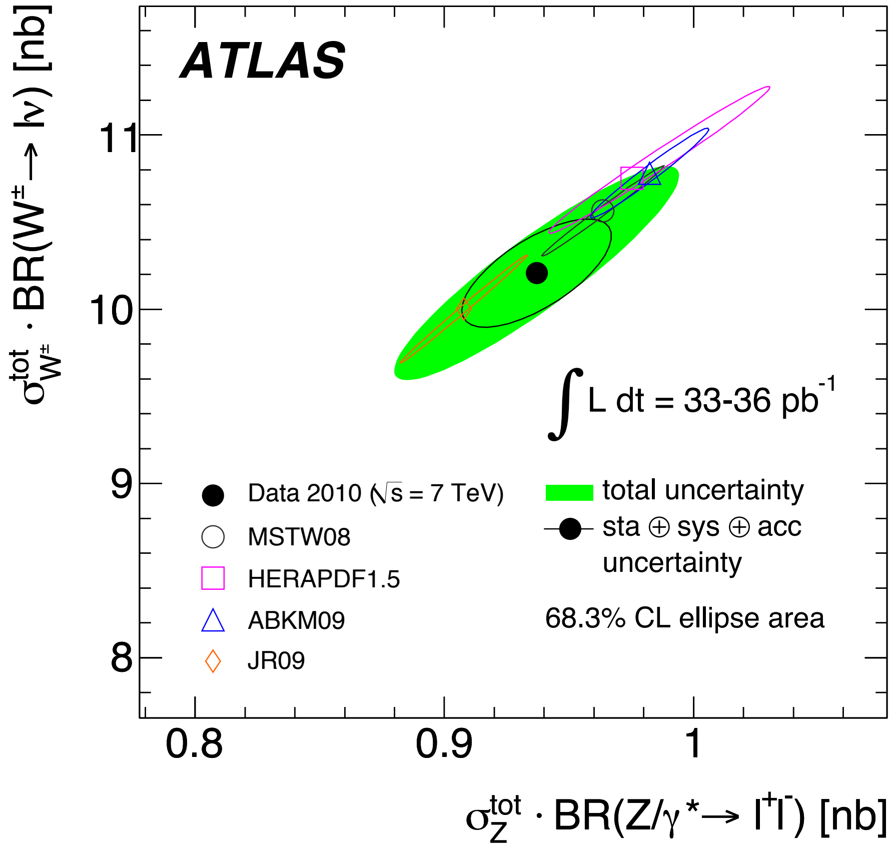
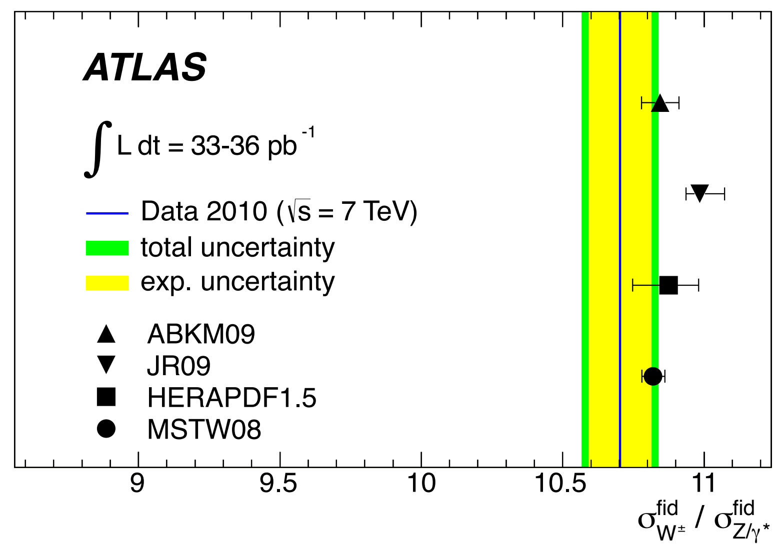
Measurement consistent with prediction within uncertainties

MEASURING CROSS-SECTION RATIOS

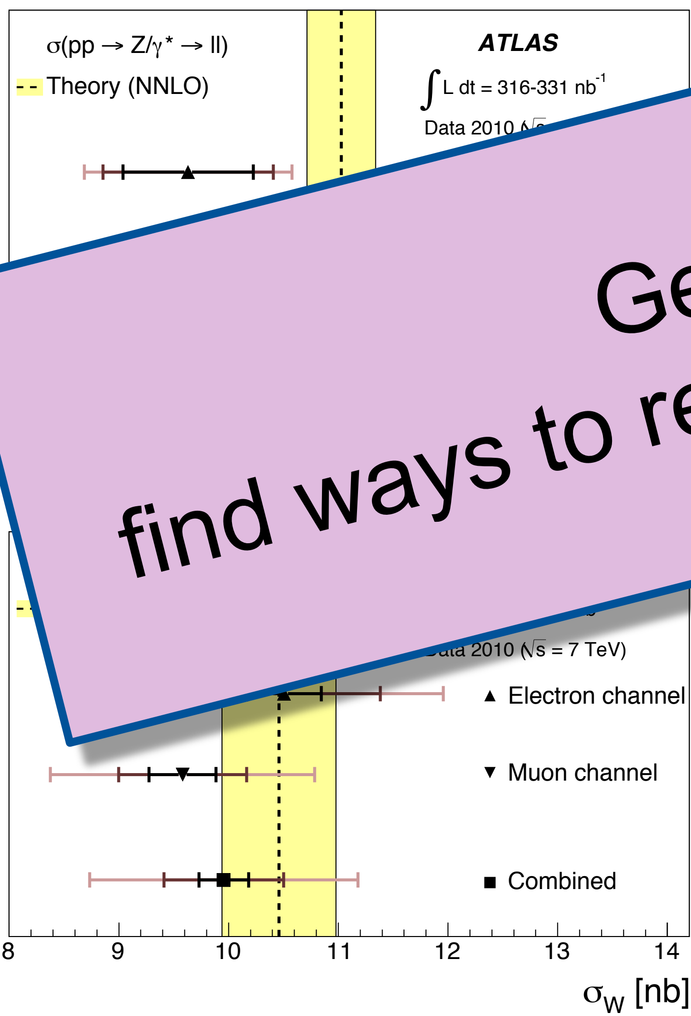


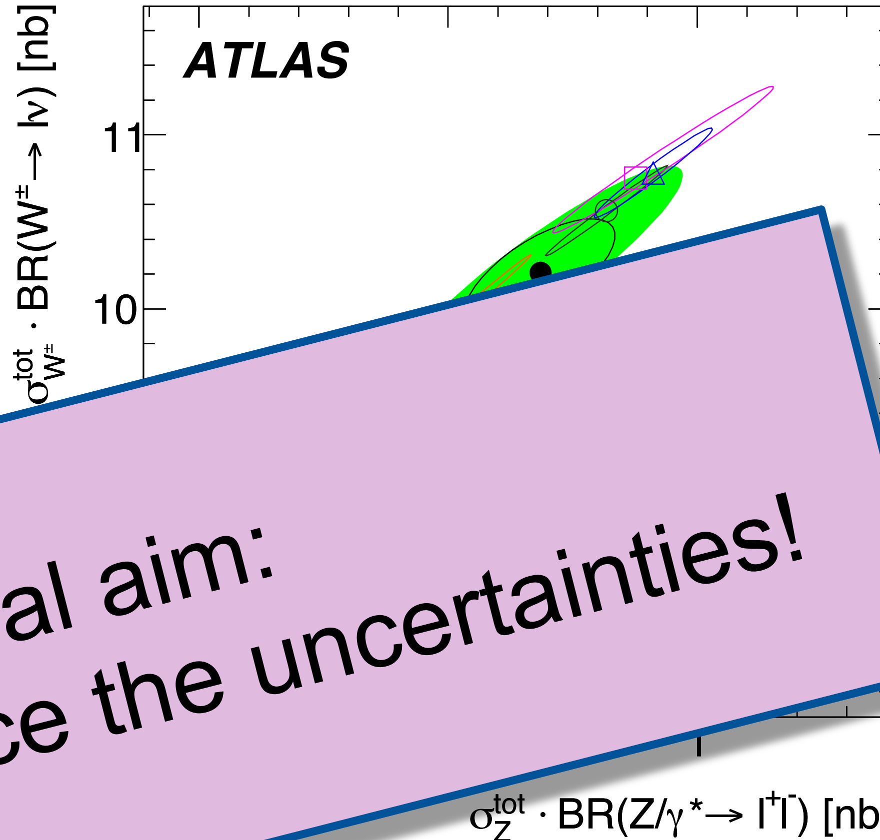


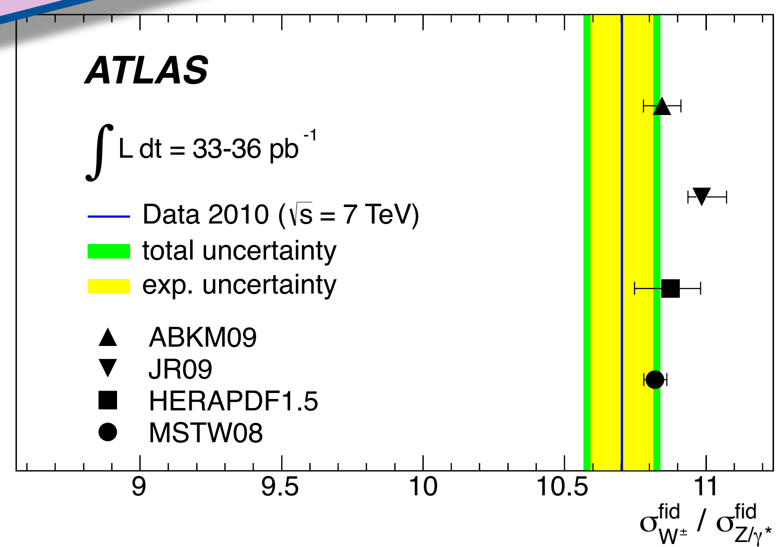




MEASURING CROSS-SECTION RATIOS

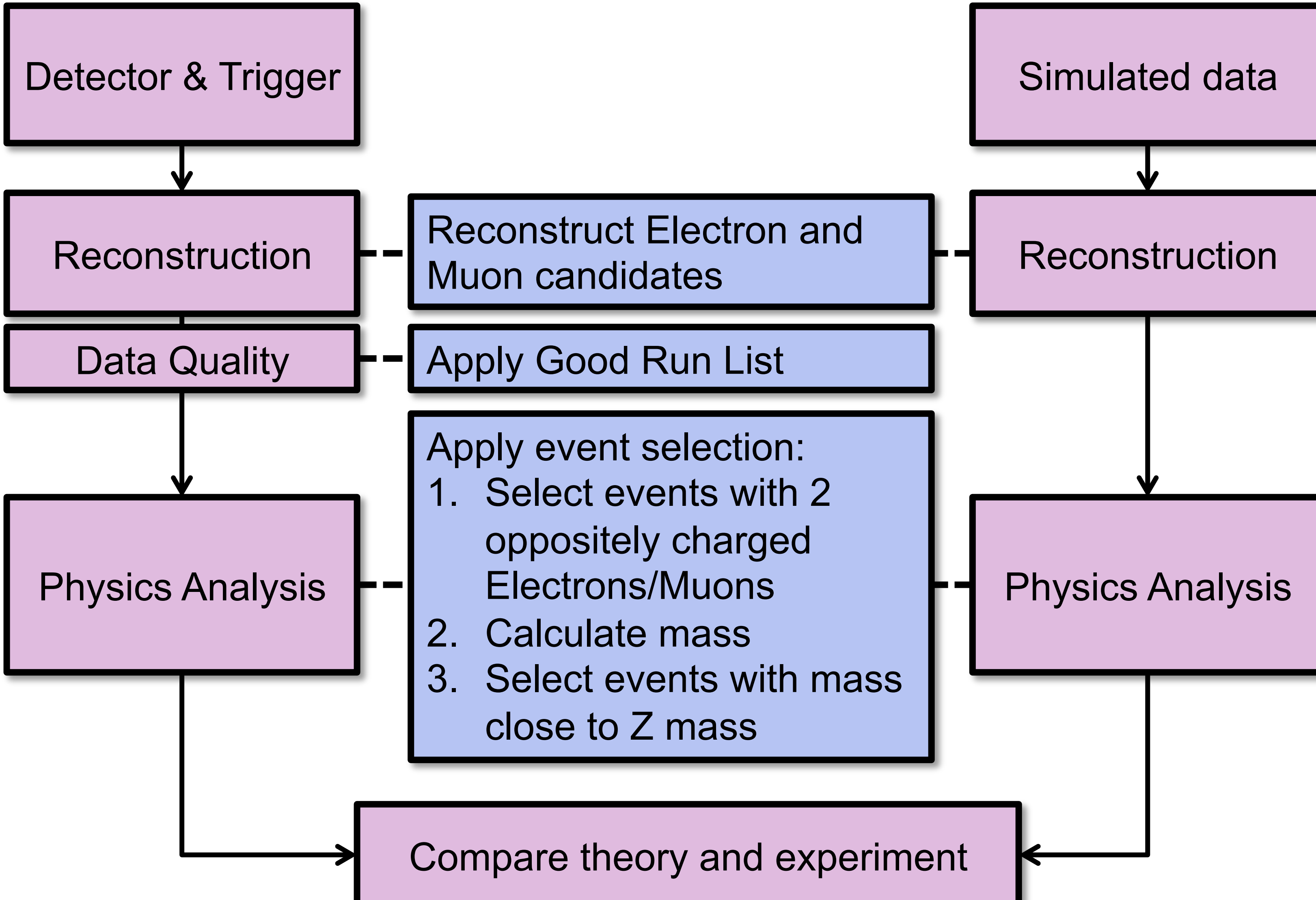




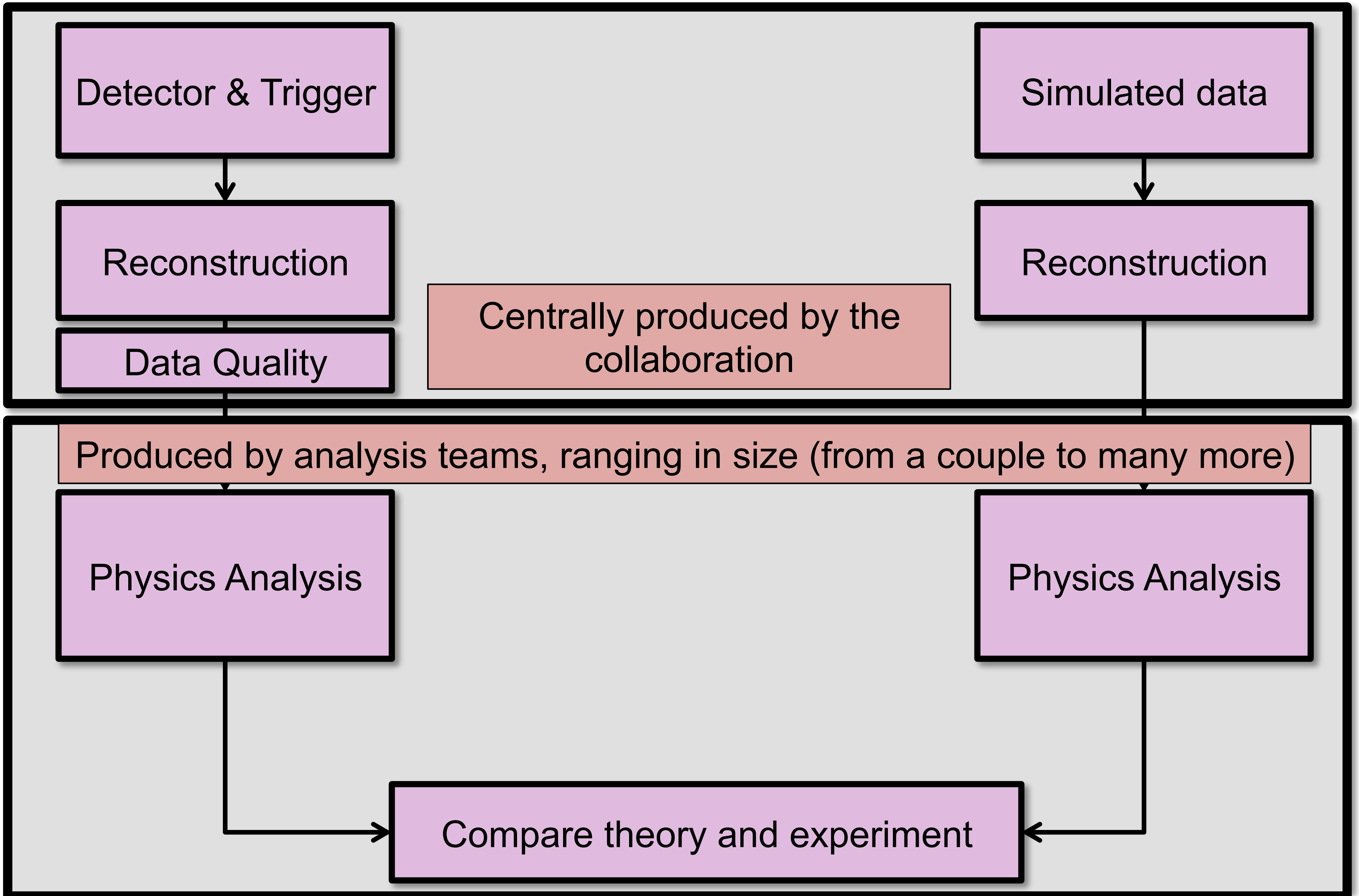


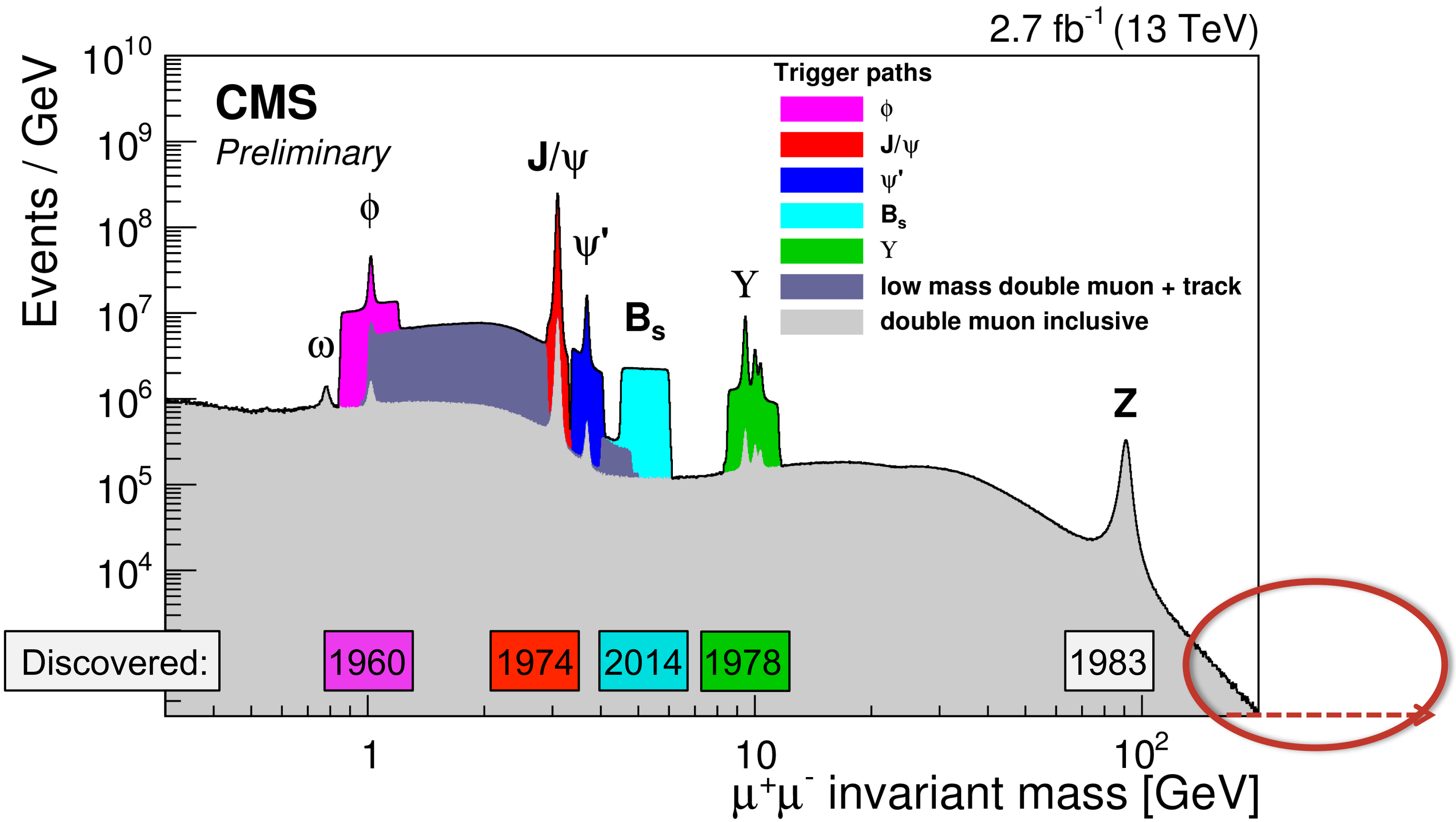
General aim:
find ways to reduce the uncertainties!

ANALYSIS FLOW IN Z^0 CROSS-SECTION MEASUREMENT



ANALYSIS FLOW IN Z^0 CROSS-SECTION MEASUREMENT





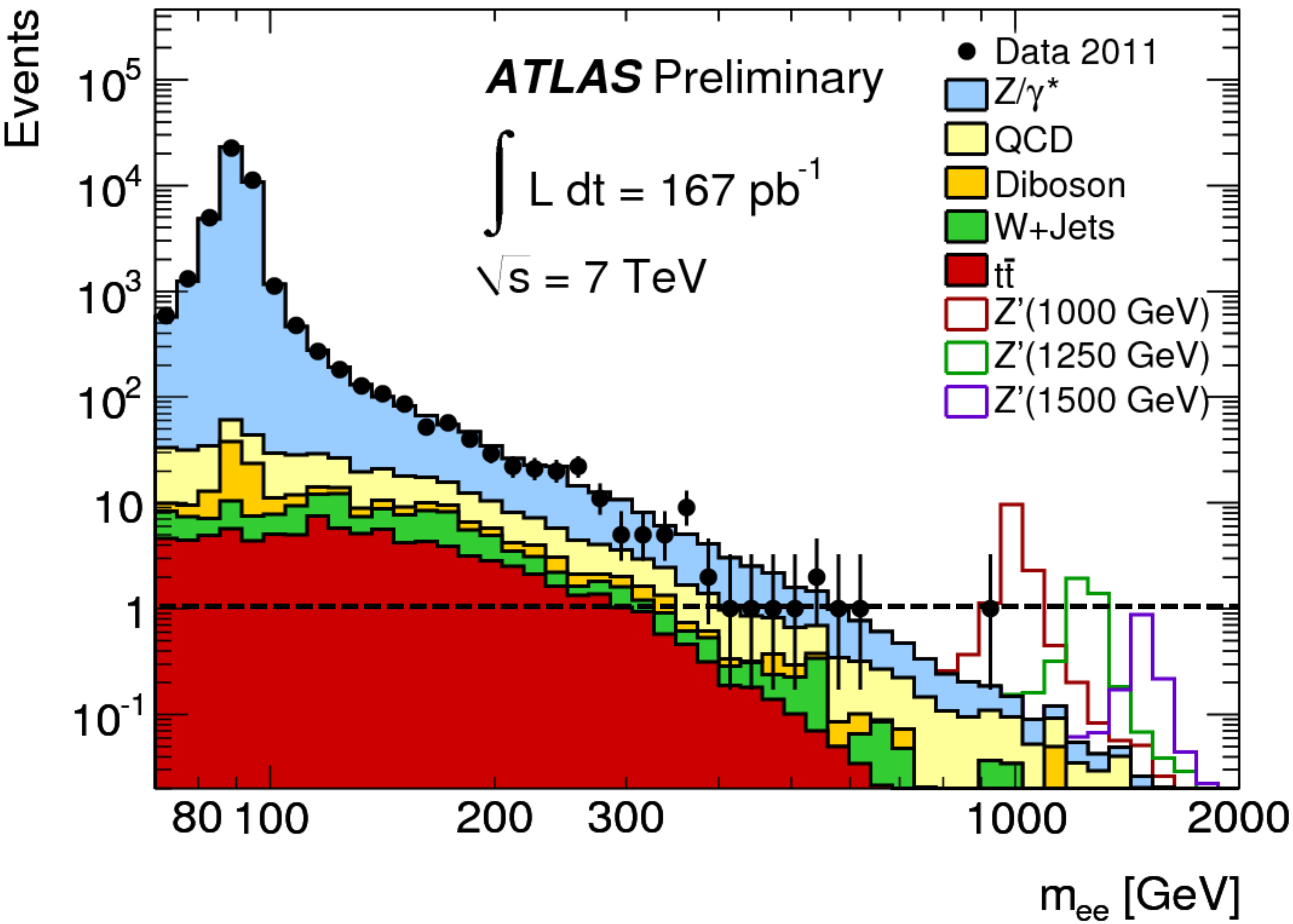
What's out there?

SIMPLE SEARCH EXAMPLE:

SEARCH FOR A HEAVY Z’

SEARCH FOR A NEW HEAVY Z'

- Like Z->ee but at higher mass.



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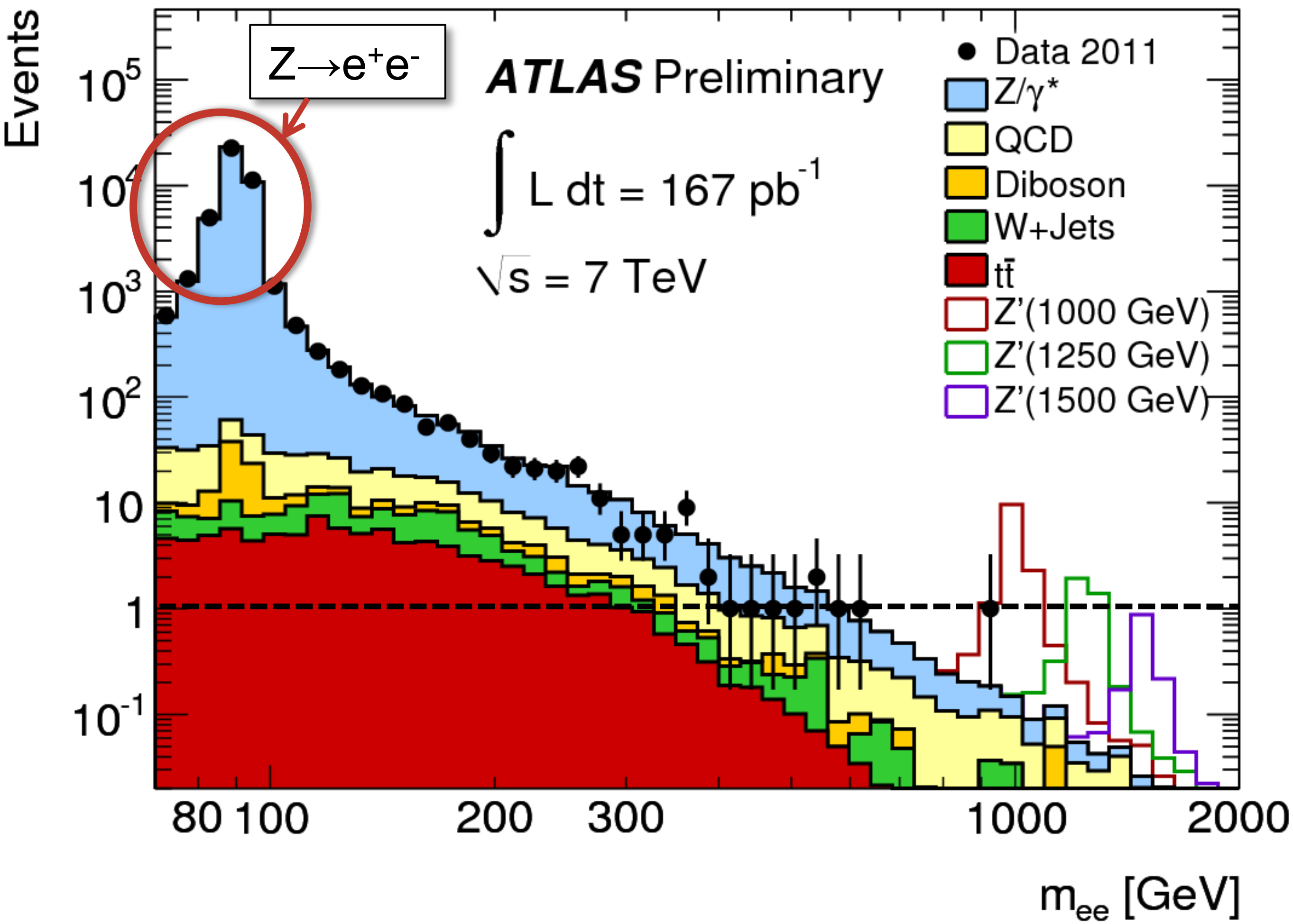
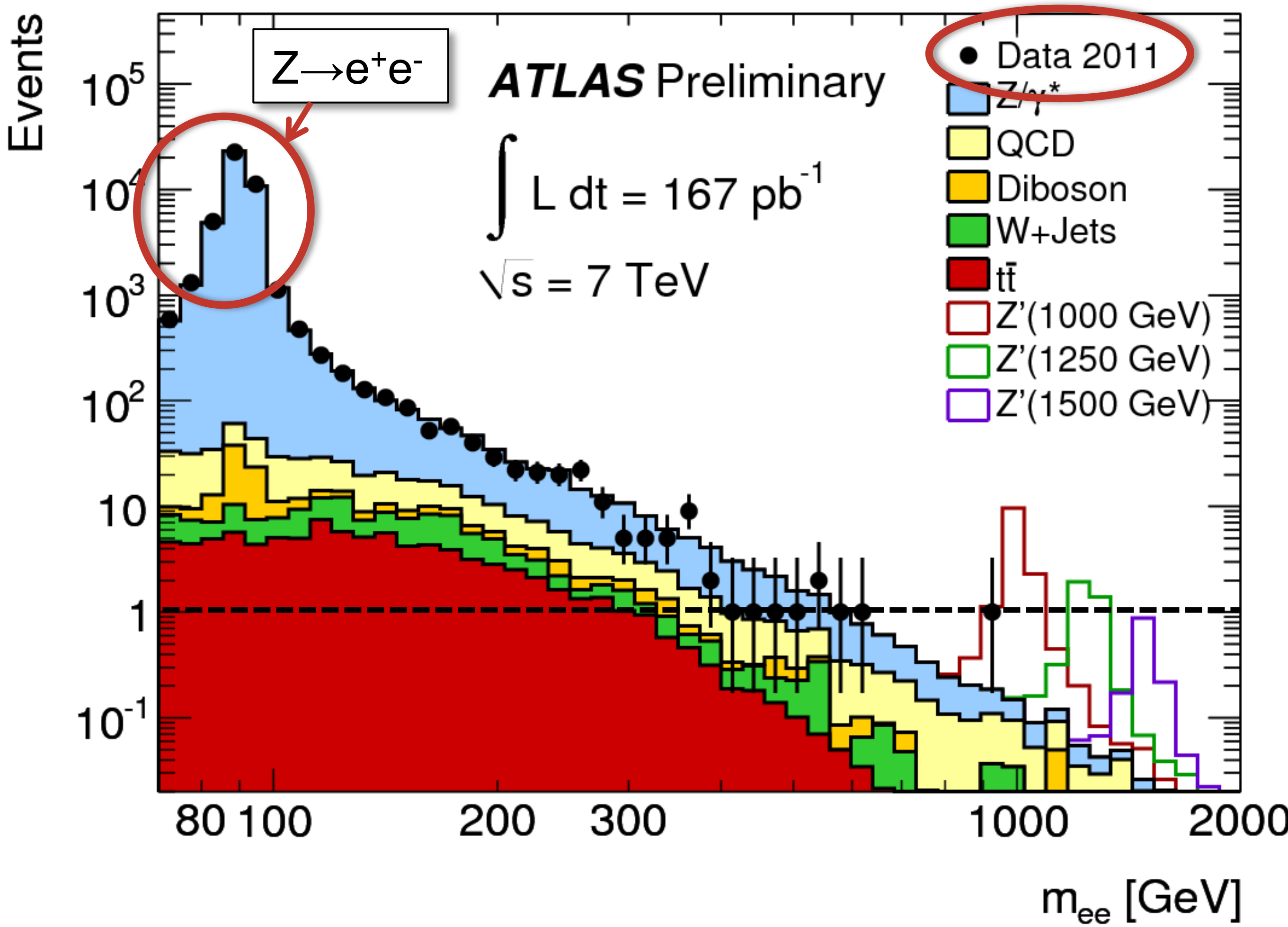


SEARCH FOR A NEW HEAVY Z'

- **Like Z->ee but at higher mass.**



Select 2 electron candidates and plot their invariant mass for:

1. **Data**

SEARCH FOR A NEW HEAVY Z'

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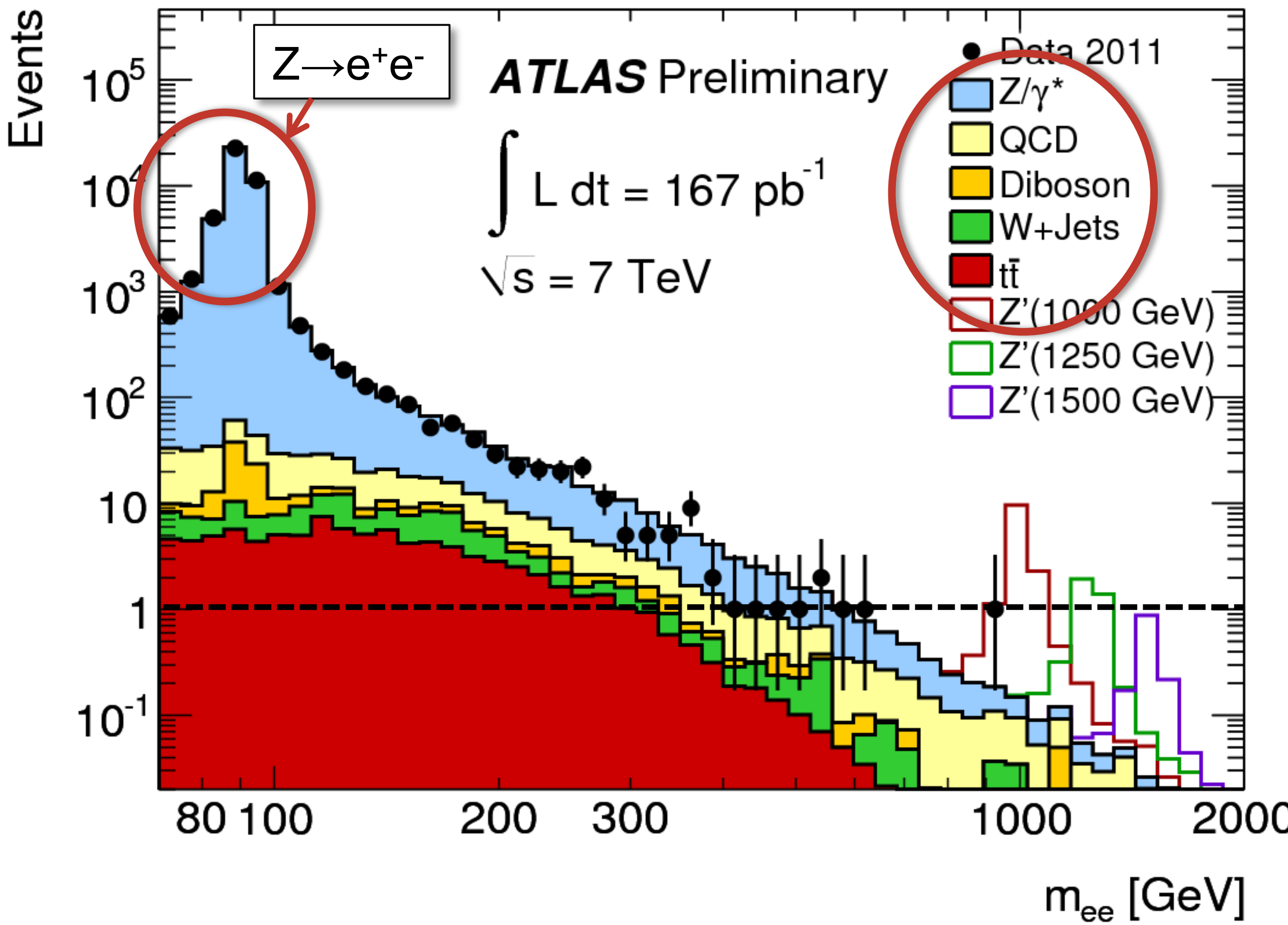

Select 2 electron candidates and plot their invariant mass for:

1. **Data**
2. **Simulated background events**

SEARCH FOR A NEW HEAVY Z'

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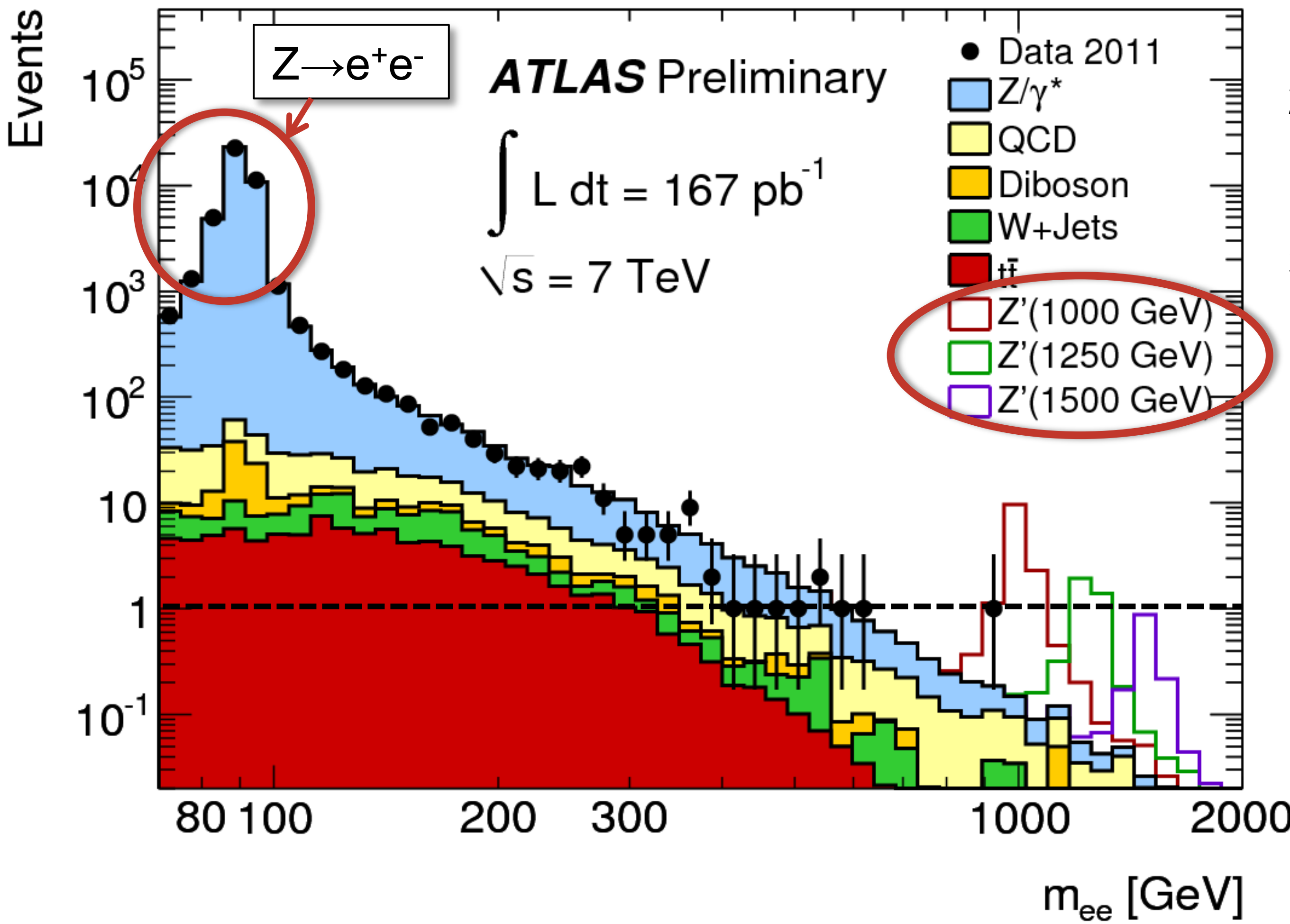
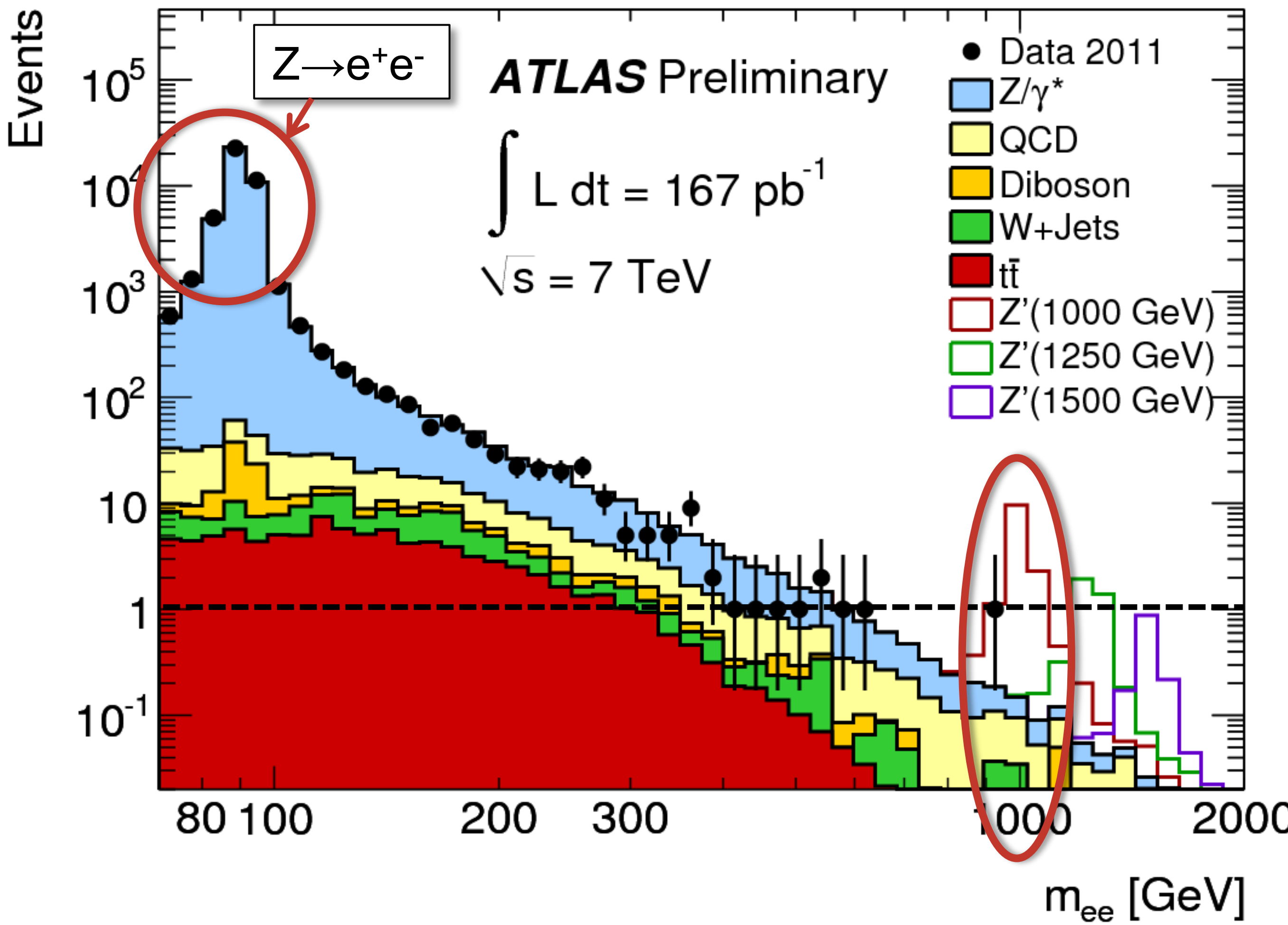


Select 2 electron candidates and plot their invariant mass for:

1. **Data**
2. **Simulated background events**
3. **Simulated signal with different masses**

SEARCH FOR A NEW HEAVY Z'

◎ **Like Z->ee but at higher mass.**



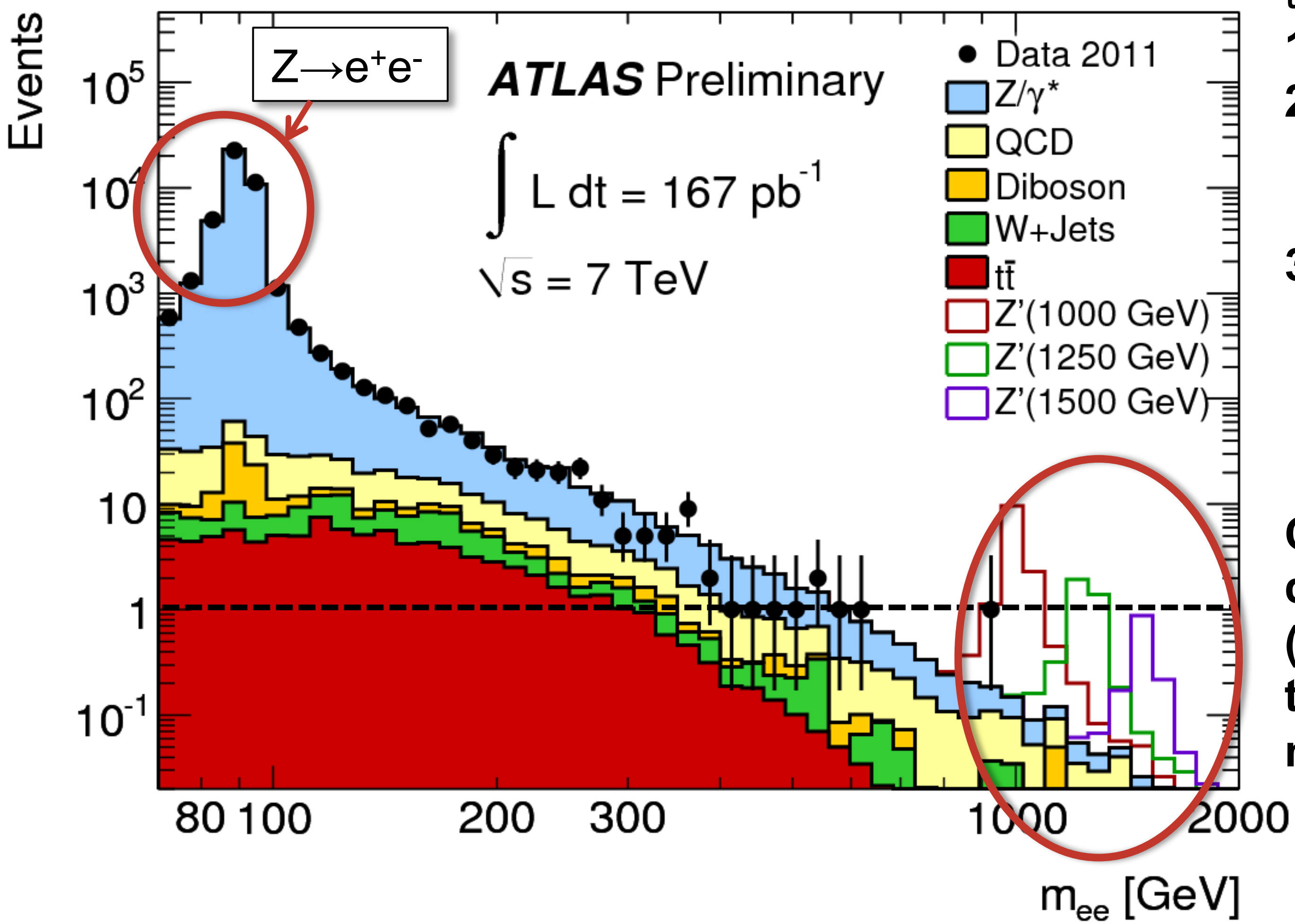
Select 2 electron candidates and plot their invariant mass for:

1. **Data**
2. **Simulated background events**
3. **Simulated signal with different masses**

Data inconsistent with a 1TeV Z'

SEARCH FOR A NEW HEAVY Z'

- Like Z->ee but at higher mass.



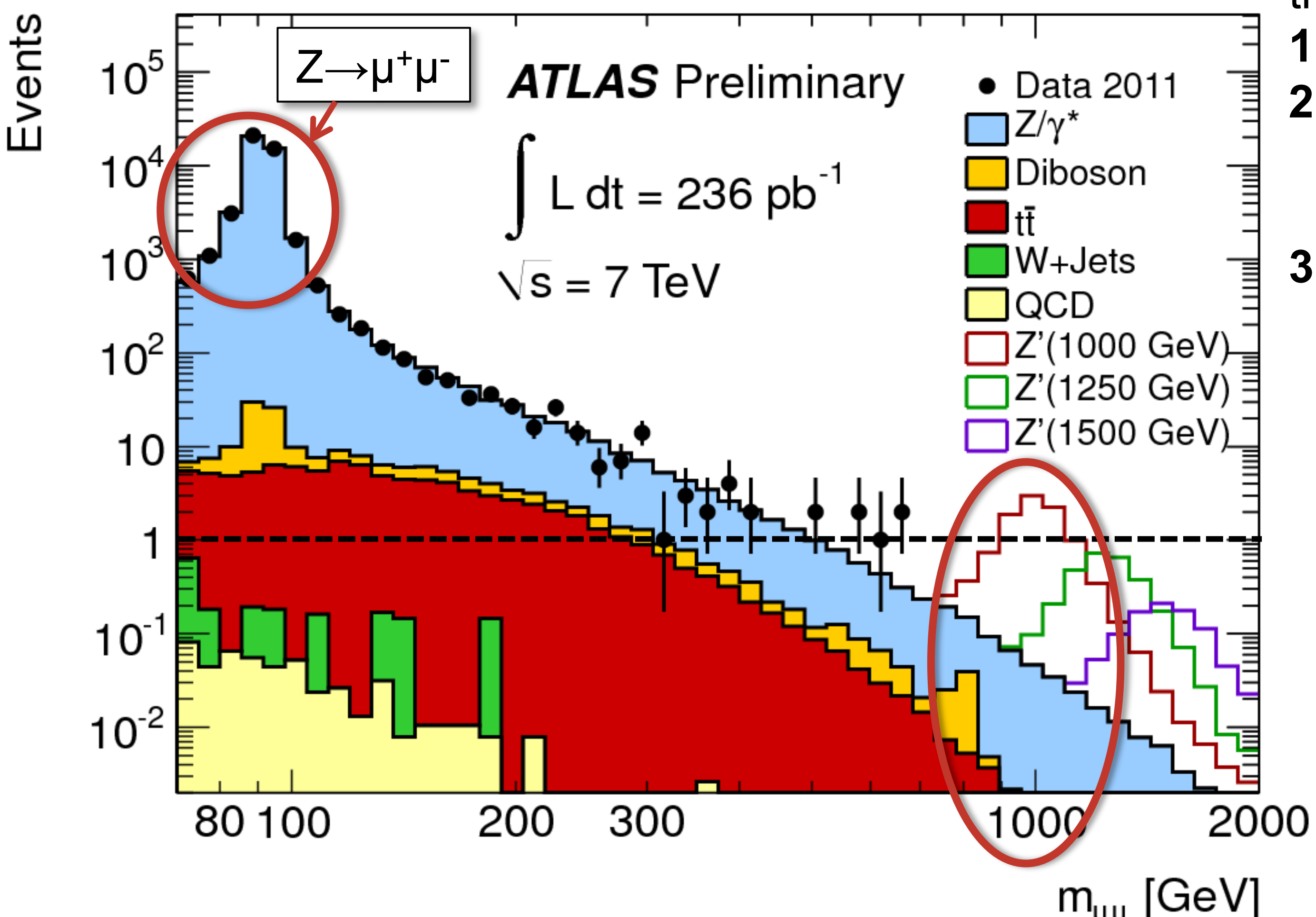
Select 2 electron candidates and plot their invariant mass for:

1. **Data**
2. **Simulated background events**
3. **Simulated signal with different masses**

Cross-section decreases with mass (higher the mass of the Z', the more data needed to discover it)

SEARCH FOR A NEW HEAVY Z'

- **And similar for muons**

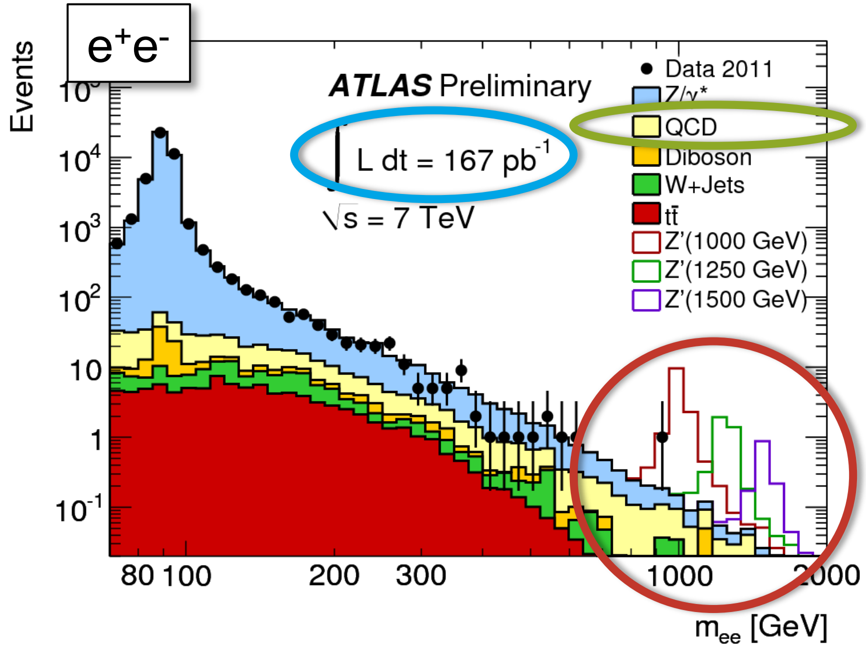


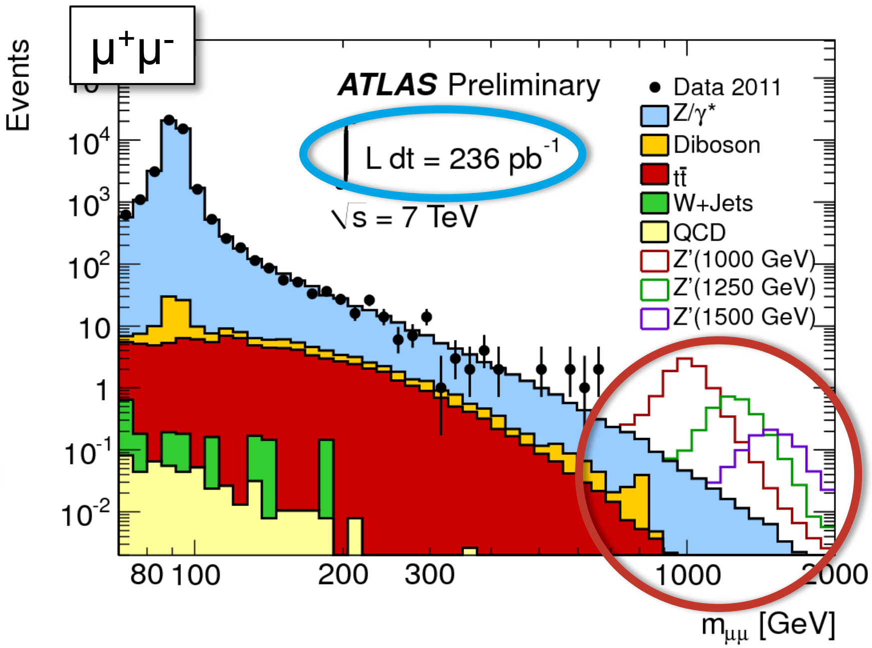
Select 2 muon candidates and plot their invariant mass for:

1. **Data**
2. **Simulated background events**
3. **Simulated signal with different masses**

Data inconsistent with a 1TeV Z'

A SMALL COMPARISON

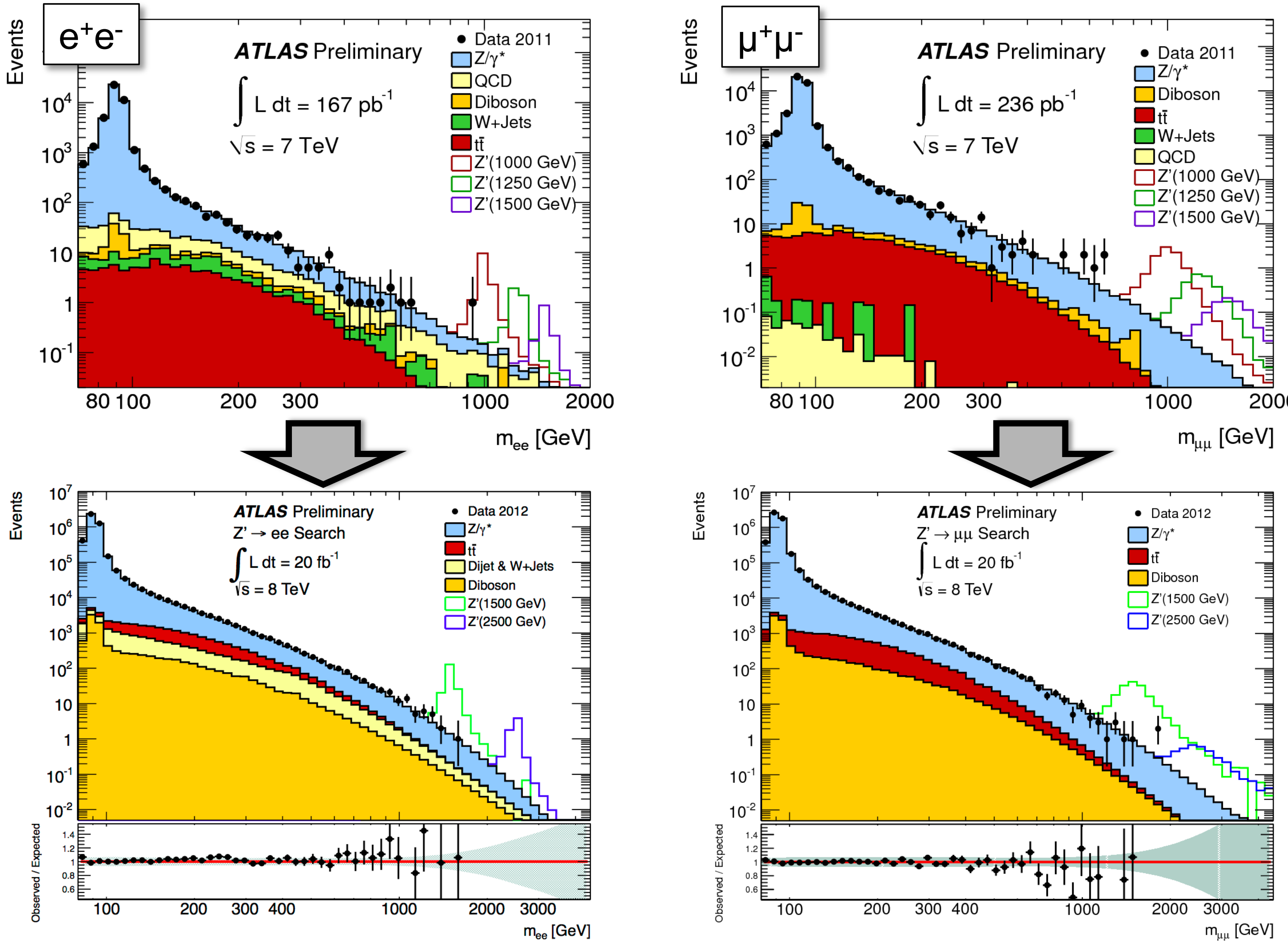




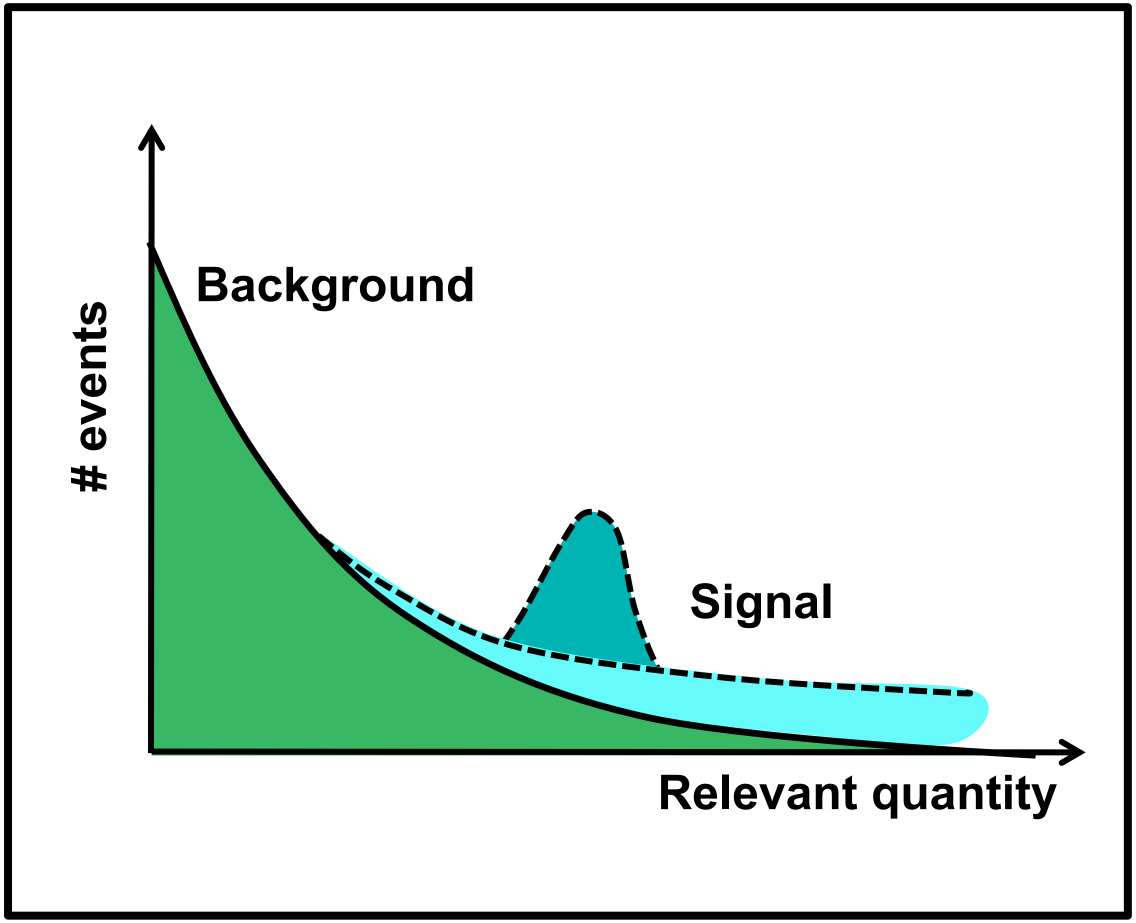
Differences in:

- **Resolution**
- **Background composition**
- **Dataset**

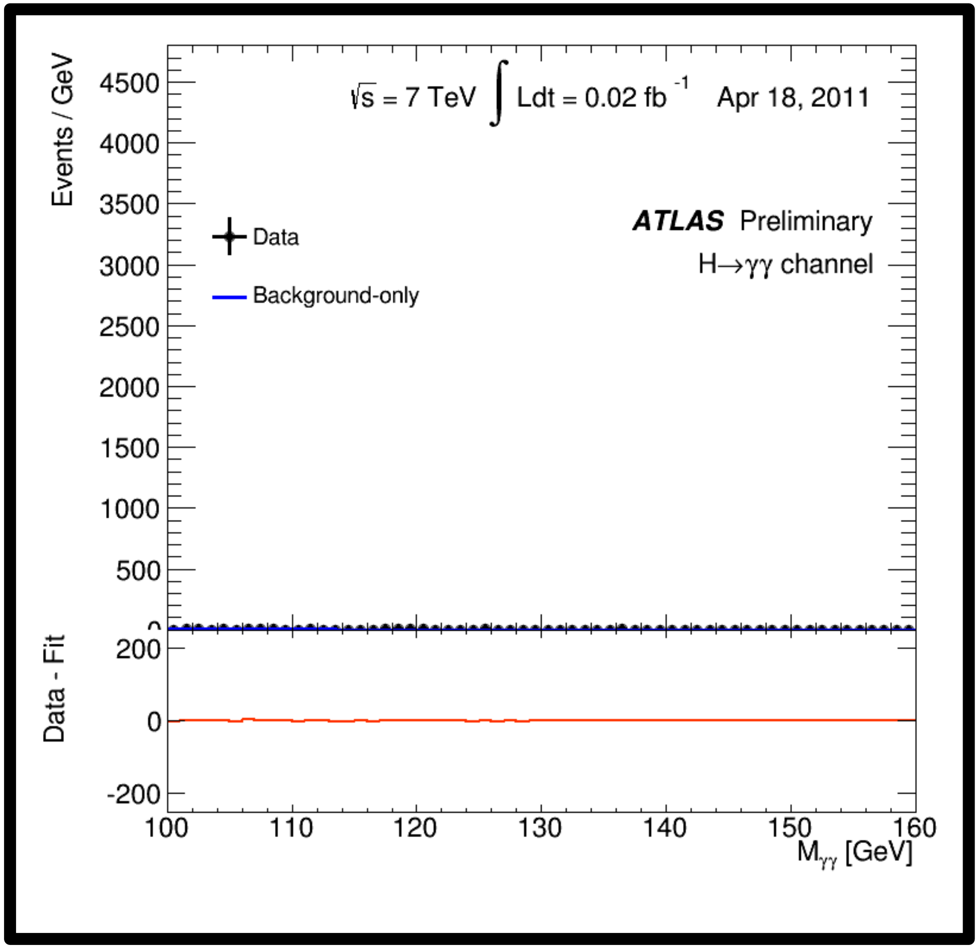
EVOLUTION...

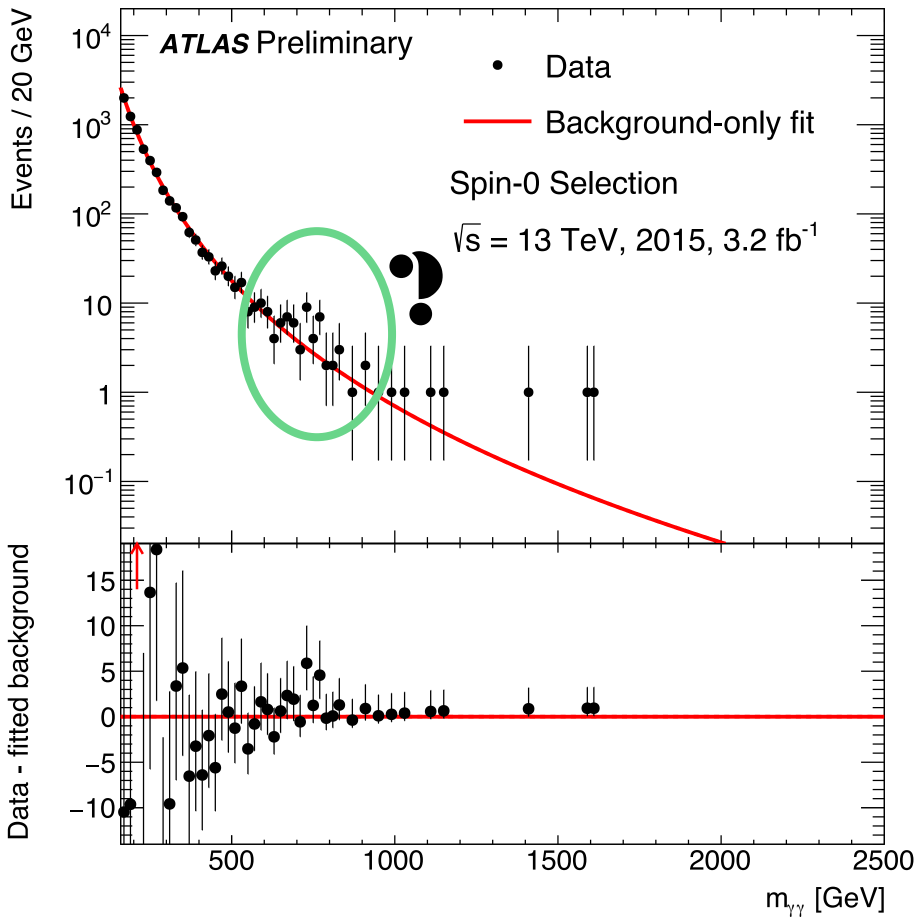

e+e-
Events
ATLAS Preliminary
∫ L dt = 167 pb-1
√s = 7 TeV
Data 2011
Z/γ*
QCD
Diboson
W+Jets
tt̄
Z'(1000 GeV)
Z'(1250 GeV)
Z'(1500 GeV)
m_ee [GeV]
μ+μ-
Events
ATLAS Preliminary
∫ L dt = 236 pb-1
√s = 7 TeV
Data 2011
Z/γ*
Diboson
tt̄
W+Jets
QCD
Z'(1000 GeV)
Z'(1250 GeV)
Z'(1500 GeV)
m_μμ [GeV]
Events
ATLAS Preliminary
Z' → ee Search
∫ L dt = 20 fb-1
√s = 8 TeV
Data 2012
Z/γ*
tt̄
Dijet & W+Jets
Diboson
Z'(1500 GeV)
Z'(2500 GeV)
Observed / Expected
m_ee [GeV]
Events
ATLAS Preliminary
Z' → μμ Search
∫ L dt = 20 fb-1
√s = 8 TeV
Data 2012
Z/γ*
tt̄
Diboson
Z'(1500 GeV)
Z'(2500 GeV)
Observed / Expected
m_μμ [GeV]

SEARCHES...

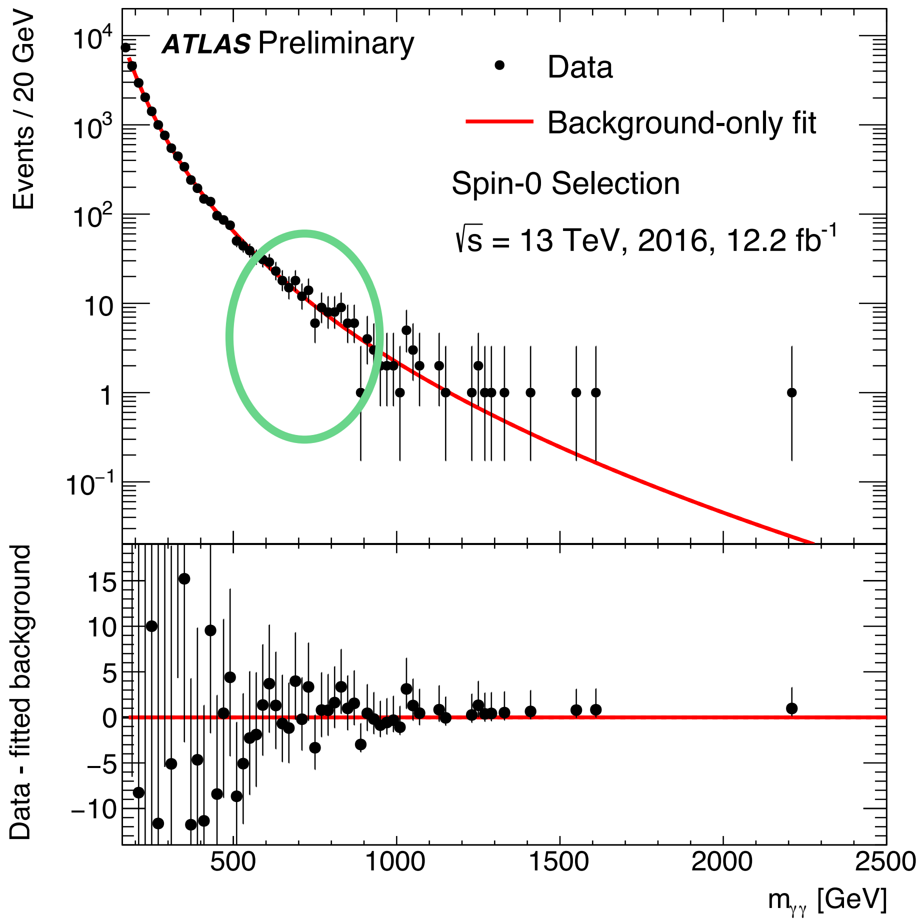


A "WELL KNOWN" BUMP SEARCH





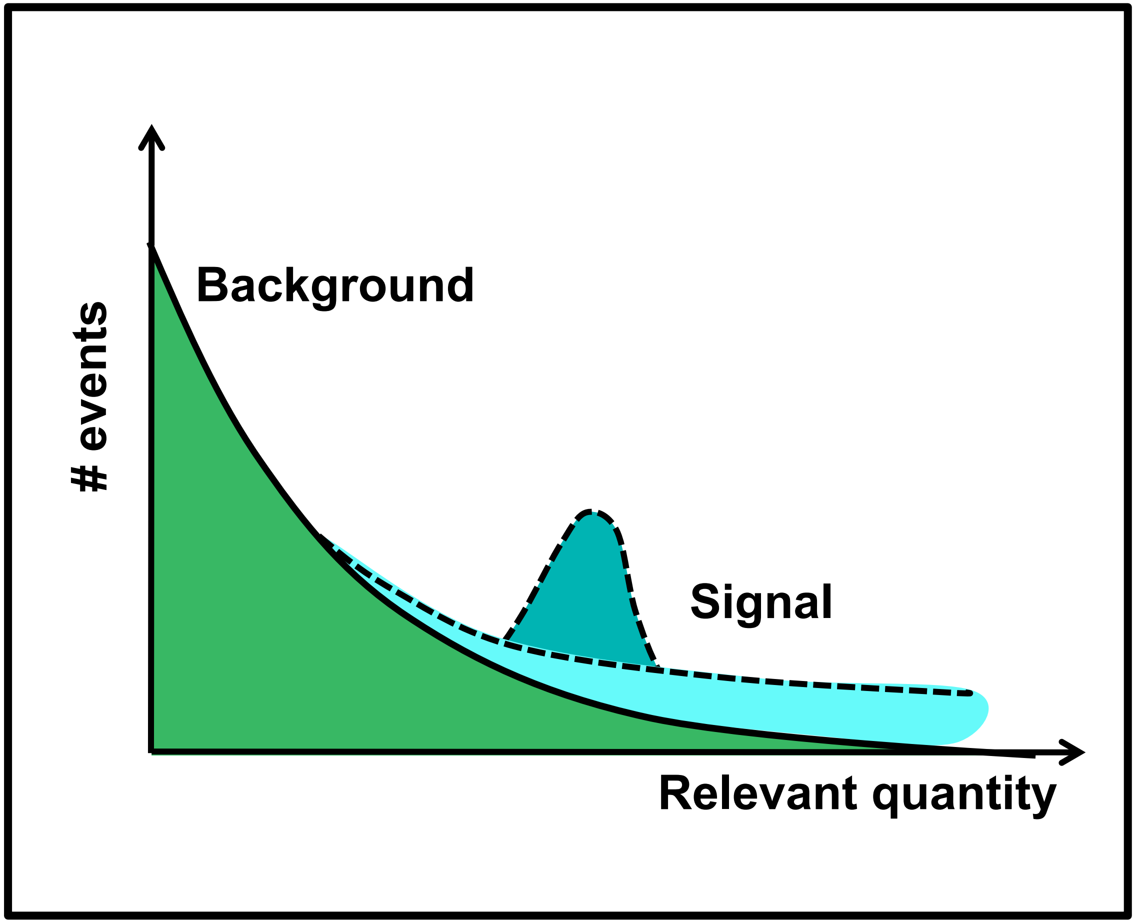
ATLAS Preliminary
Data
Background-only fit
Spin-0 Selection
$\sqrt{s}$ = 13 TeV, 2015, 3.2 fb^{-1}
Events / 20 GeV
Data - fitted background
$m_{\gamma\gamma}$ [GeV]



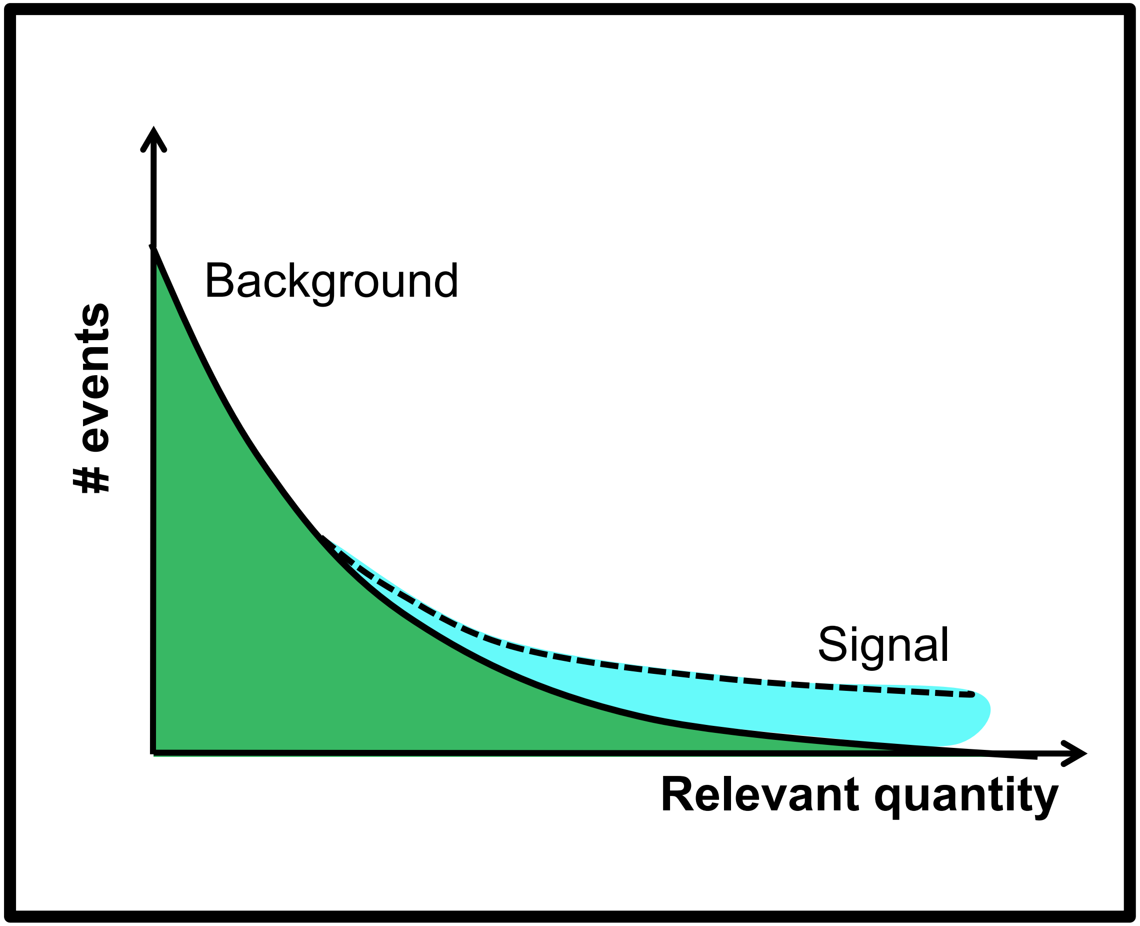
ATLAS Preliminary
Data
Background-only fit
Spin-0 Selection
√s = 13 TeV, 2016, 12.2 fb⁻¹
Events / 20 GeV
Data - fitted background
m_γγ [GeV]


MARIO
096950
x23
WORLD
1-4
TIME
593
THANK YOU MARIO!
BUT OUR PRINCESS IS IN
ANOTHER CASTLE!

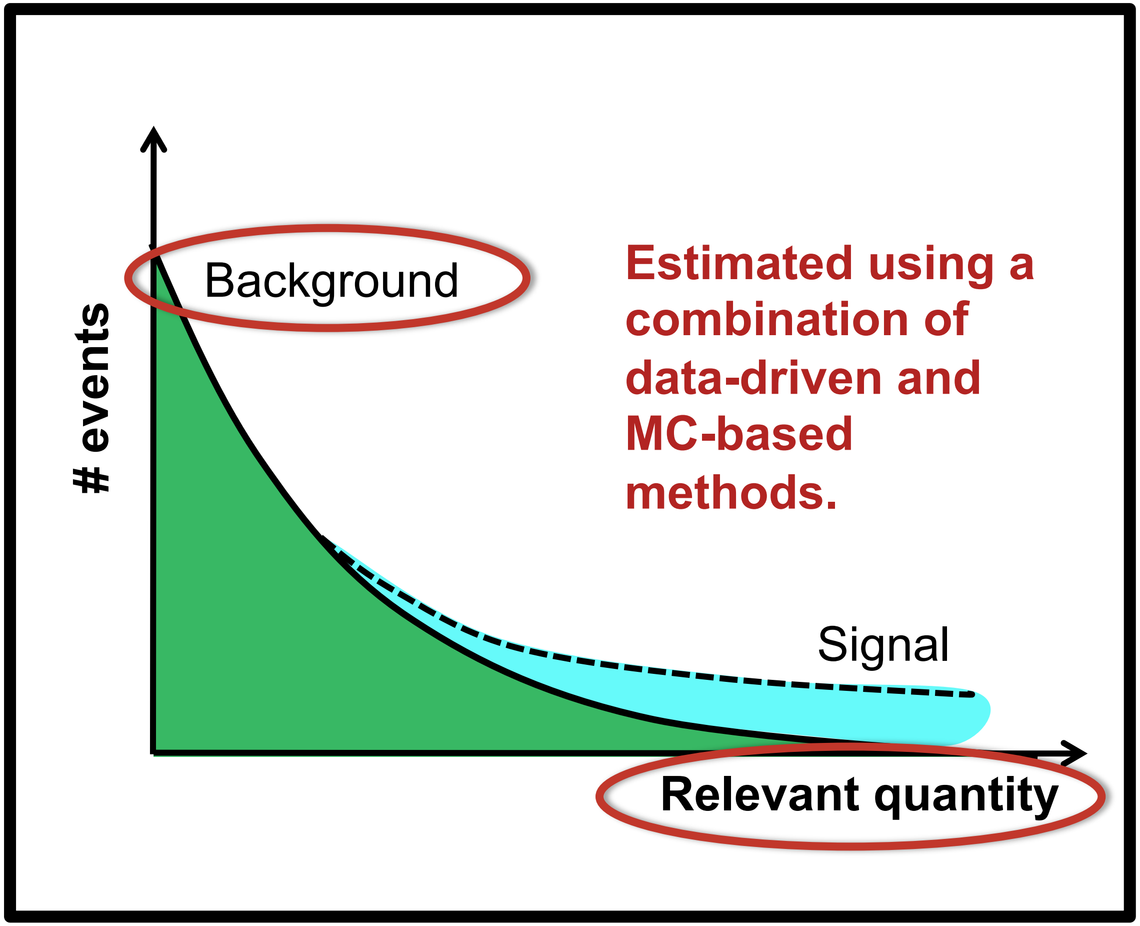
SEARCHES...



TYPICAL SUSY SEARCHES



TYPICAL SUSY SEARCHES

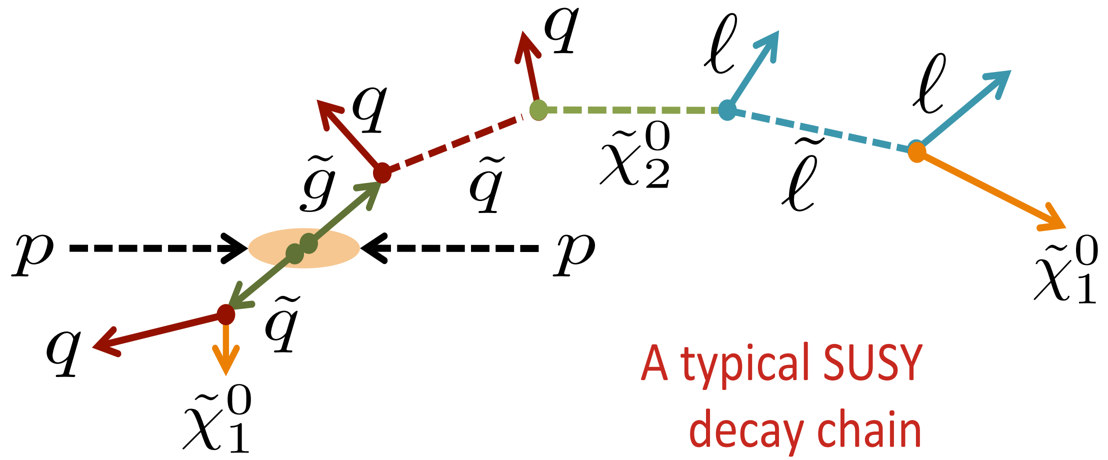


Estimated using a combination of data-driven and MC-based methods.

E.g. MET

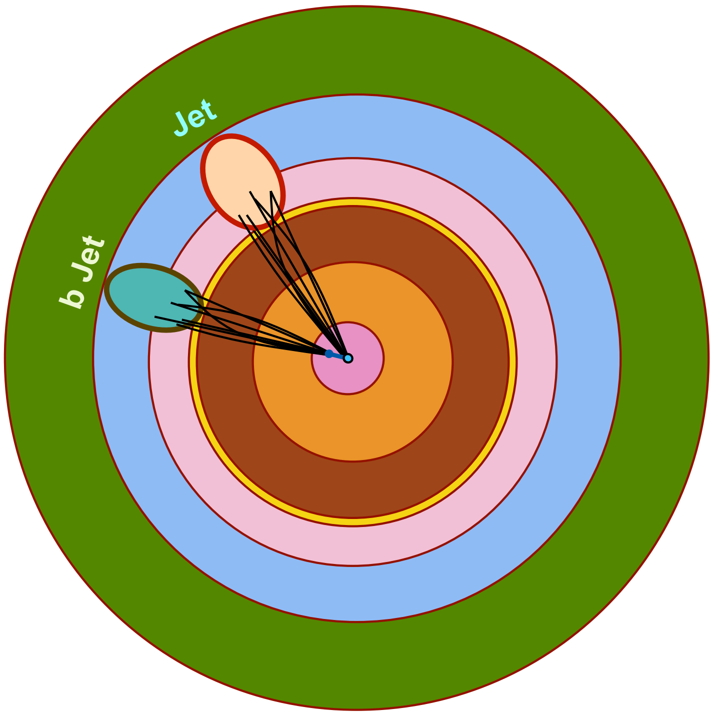
ANOTHER SEARCH EXAMPLE:

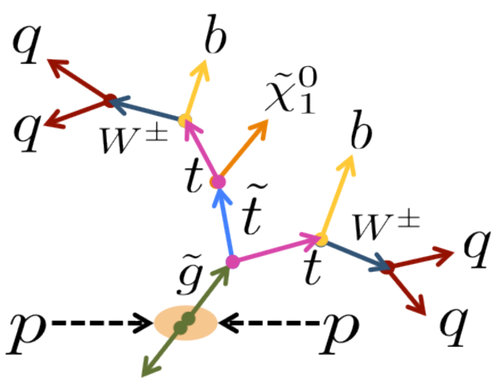
SEARCH FOR SUSY IN EVENTS WITH LARGE JET MULTIPLICITIES



EVENT SELECTIONS

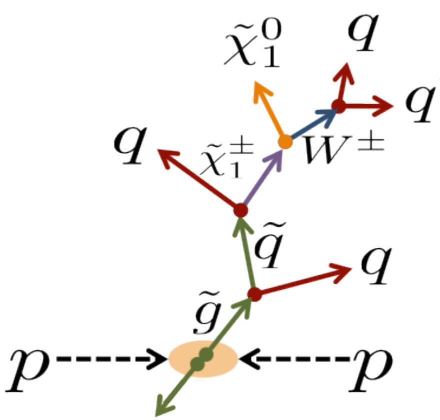
b-jets

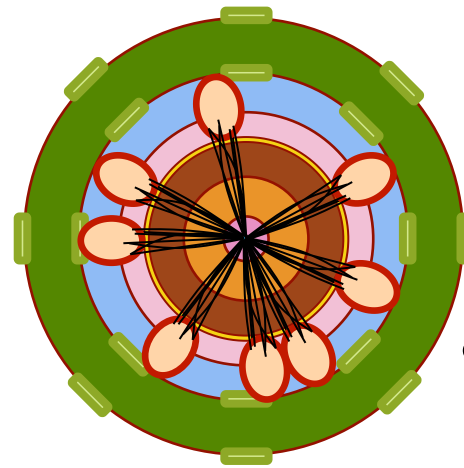




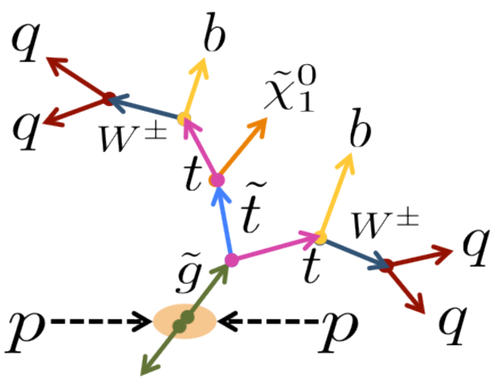
EVENT SELECTIONS

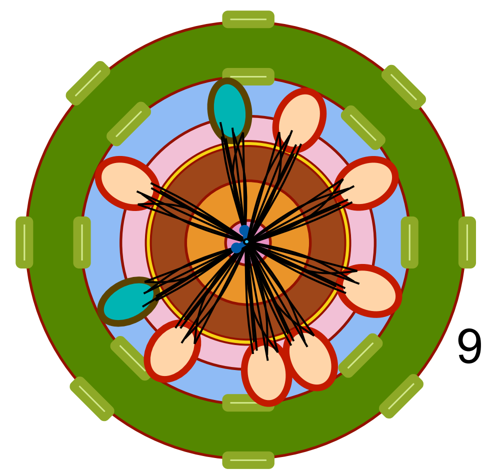
b-jets





8 jets, 0 b-jets



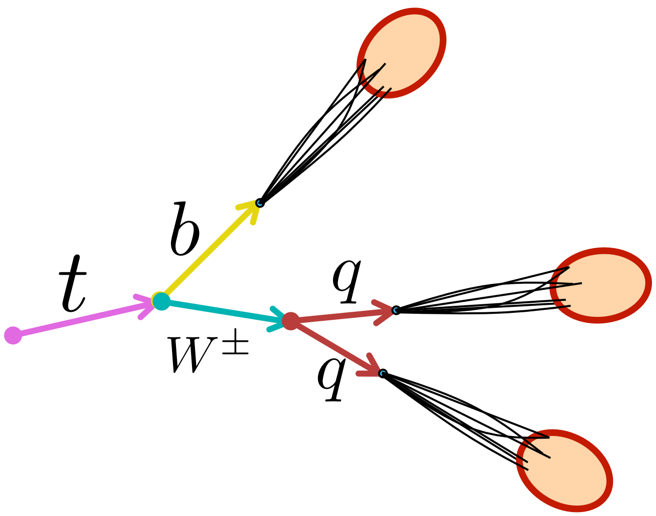


9 jets, ≥2 b-jets

Signal regions can range in jet p_T and jet & b-jet multiplicity.

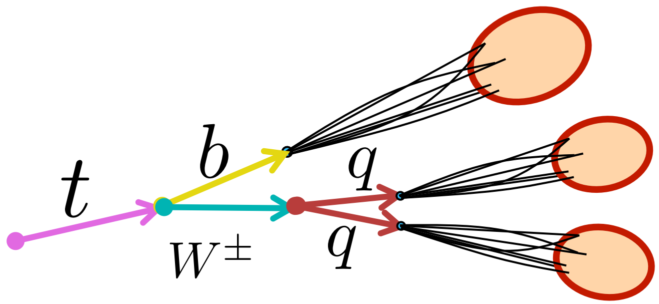
EVENT SELECTIONS

"fat-jets"



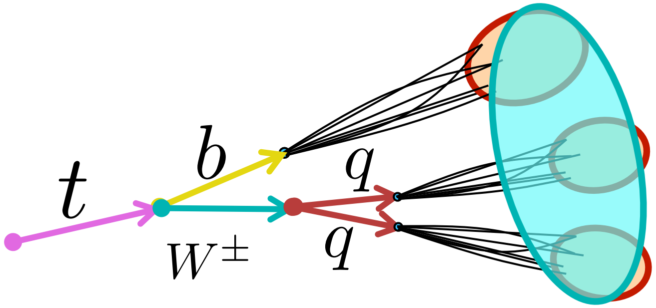
EVENT SELECTIONS

“fat-jets”



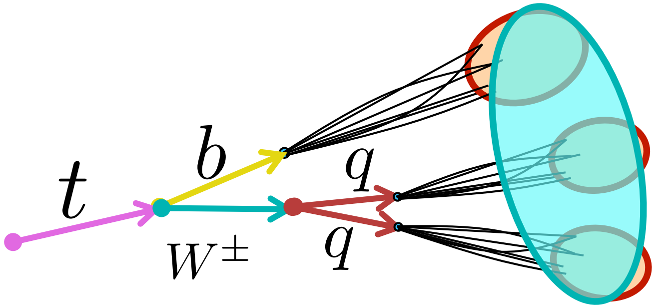
EVENT SELECTIONS

“fat-jets”



EVENT SELECTIONS

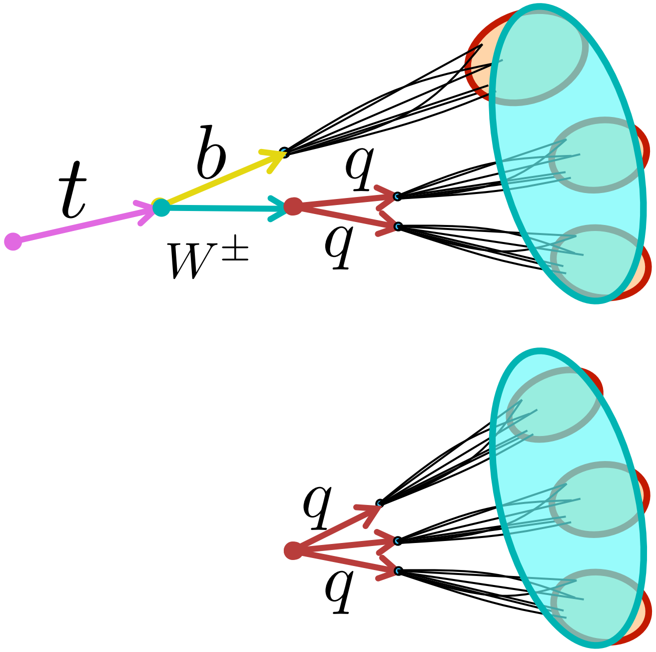
"fat-jets"



Fat-jets are a key signature in searches for boosted objects, e.g. boosted tops.

EVENT SELECTIONS

"fat-jets"

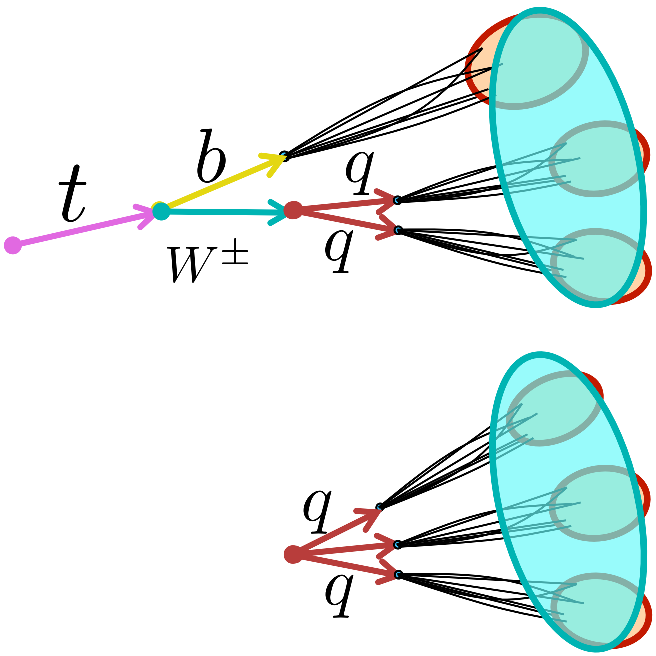


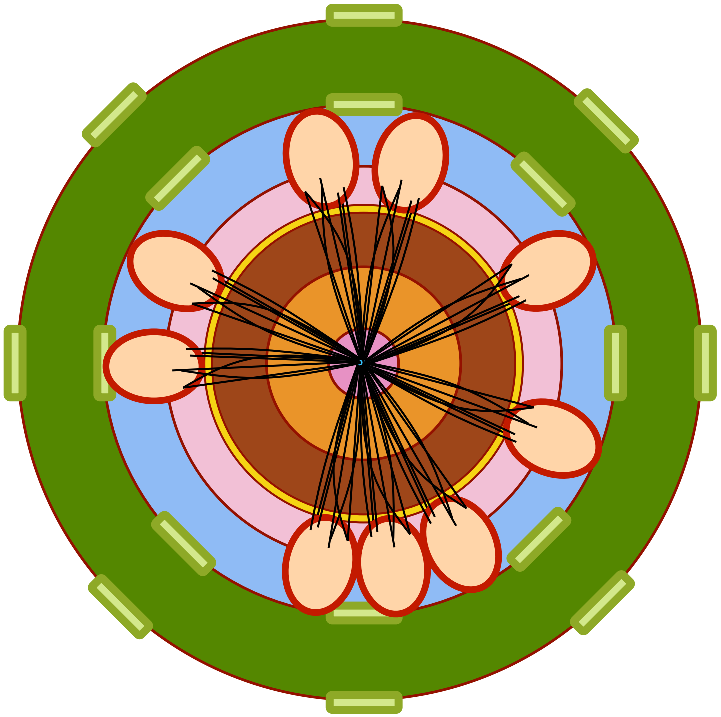
m_j (QCD) $< m_j$ (SUSY)

Proposed in arXiv:1202.0558

EVENT SELECTIONS

"fat-jets"



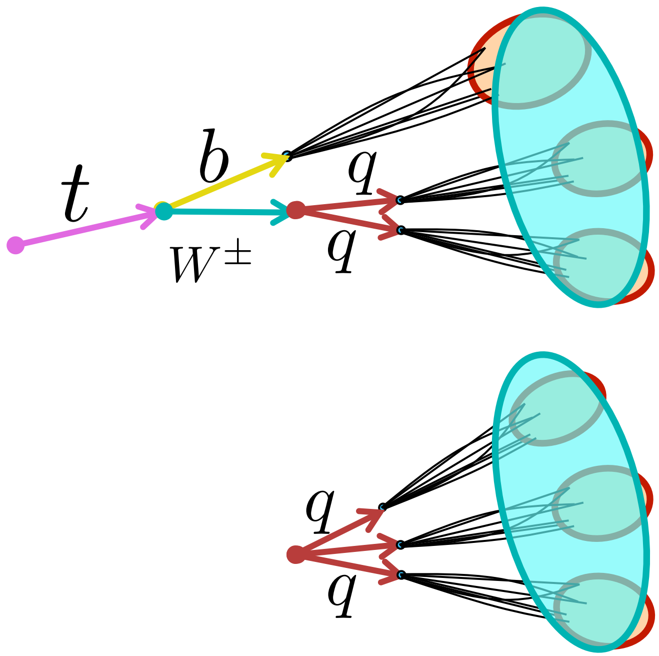


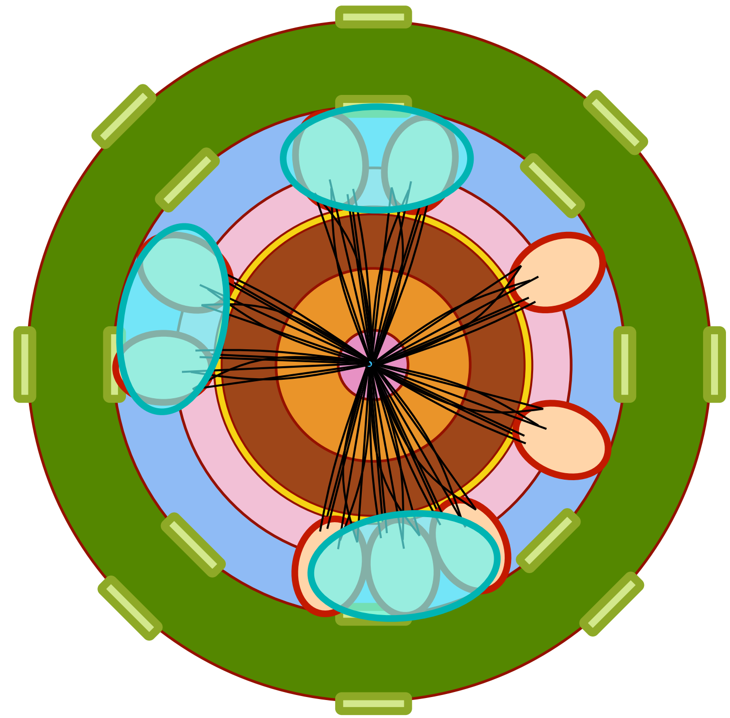
$$m_j \text{ (QCD)} < m_j \text{ (SUSY)}$$

Proposed in arXiv:1202.0558

EVENT SELECTIONS

"fat-jets"





$$m_j\ (\mathrm{QCD}) < m_j\ (\mathrm{SUSY})$$

Proposed in arXiv:1202.0558

$$M_J^{\Sigma} = \sum_{i=1}^{nJ} m_{j_i}$$

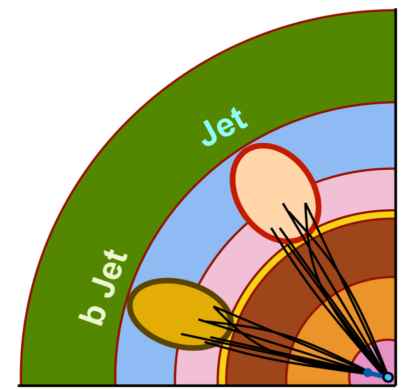
Signal regions can range in jet multiplicity and M_J^{Σ} cuts.

An example of a search

EVENT SELECTIONS

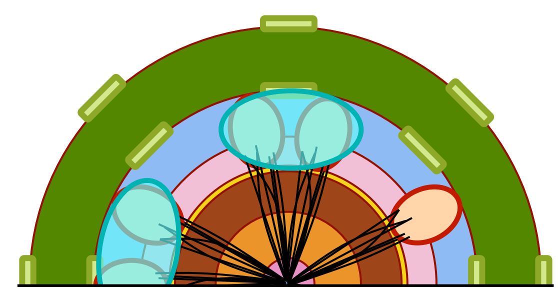
"b-jet stream"

ID	8j50			9j50			≥10j50	7j80			≥8j80		
Jet $\lvert\eta\rvert$	< 2.0												
Jet p_T	50 GeV							80 GeV					
Jet count	=8			=9			≥10	=7			≥8		
b-jets	0	1	≥2	0	1	≥2	-	0	1	≥2	0	1	≥2
$ME_T/\sqrt{H_T}$	> 4 GeV ½												



"fat-jet stream"

ID	≥8j50		≥9j50		≥10j50	
Jet $\lvert\eta\rvert$	< 2.8					
Jet p_T	50 GeV					
Jet count	≥8		≥9		≥10	
M_J^{Σ} (GeV)	>340	>420	>340	>420	>340	>420
$ME_T/\sqrt{H_T}$	> 4 GeV ½					



Proposed in arXiv:1202.0558

$$M_J^{\Sigma} = \sum_{i=1}^{nJ} m_{j_i}$$

RESULTS

b-jet stream

ID	8j50			9j50			≥10j50
b-jets	0	1	≥2	0	1	≥2	0
Expected evts	35±4	40±10	50±10	3.3±0.7	6.1±1.7	8.0±2.7	1.37±0.35
Observed evts	40	44	44	5	8	7	3
Significance (σ)	0.7	-0.02	-0.6	0.8	0.6	-0.28	1.11

ID	7j80			≥8j80		
b-jets	0	1	≥2	0	1	≥2
Expected evts	11.0±2.2	17±6	25±10	0.9±0.6	1.5±0.9	3.3±2.2
Observed evts	12	17	13	2	1	3
Significance (σ)	0.05	-0.14	-1.0	0.9	-0.28	-0.06

fat-jet stream

ID	≥8j50		≥9j50		≥10j50	
M_J^{Σ} (GeV)	340	420	340	420	340	420
Expected evts	75±19	45±14	17±7	11±5	3.2±3.7	2.2±2.0
Observed evts	69	37	13	9	1	1
Significance (σ)	-0.27	-0.6	-0.6	-0.34	-0.8	-0.6

RESULTS

b-jet stream

ID	8j50			9j50			≥10j50
b-jets	0	1	≥2	0	1	≥2	0
Expected evts	35±4	40±10	50±10	3.3±0.7	6.1±1.7	8.0±2.7	1.37±0.35
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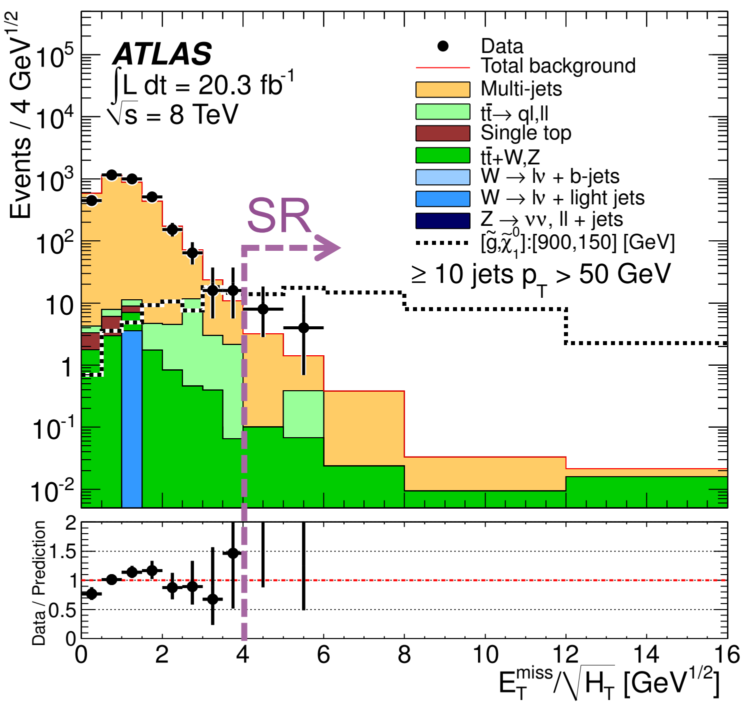
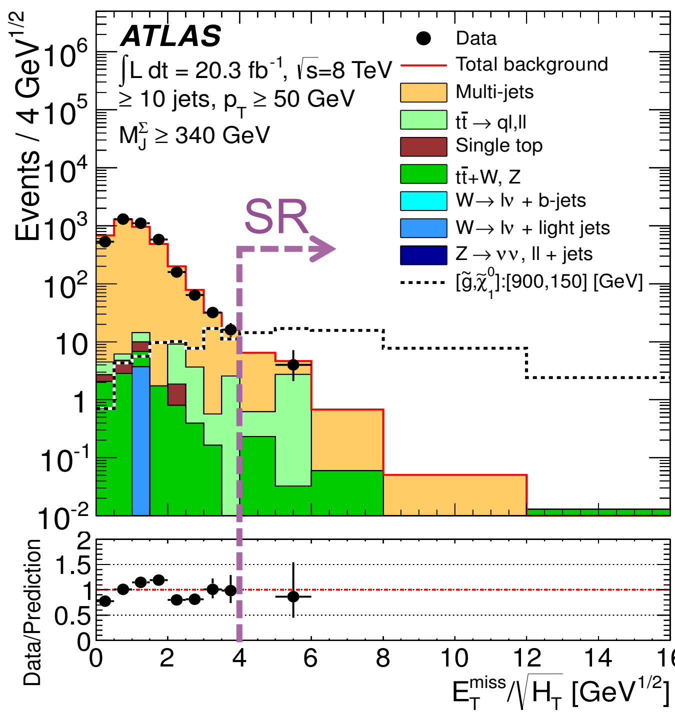
RESULTS

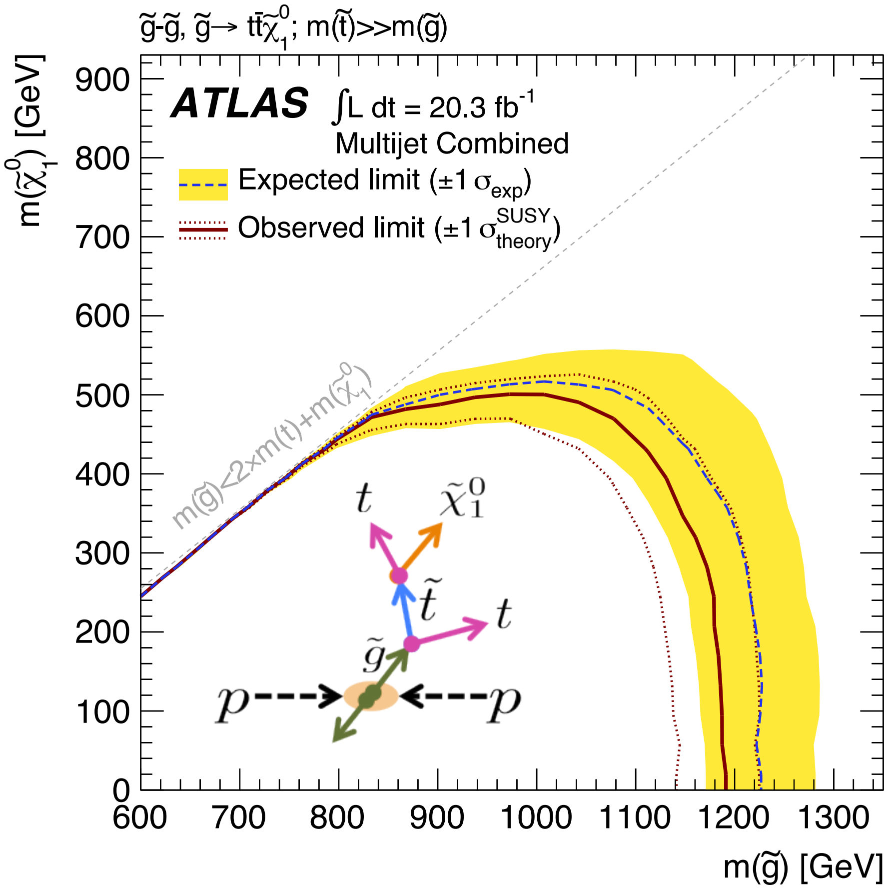

ATLAS
∫L dt = 20.3 fb⁻¹
√s = 8 TeV
Data
Total background
Multi-jets
tt̄→ ql,ll
Single top
tt̄+W,Z
W → lν + b-jets
W → lν + light jets
Z → νν, ll + jets
[g̃,χ̃⁰₁]:[900,150] [GeV]
≥ 10 jets p_T > 50 GeV
SR
Events / 4 GeV^1/2
Data / Prediction
E_T^miss/√H_T [GeV^1/2]


ATLAS
∫L dt = 20.3 fb⁻¹, √s=8 TeV
≥ 10 jets, p_T ≥ 50 GeV
M_J^Σ ≥ 340 GeV
Data
Total background
Multi-jets
tt̄ → ql,ll
Single top
tt̄+W, Z
W→ lν + b-jets
W→ lν + light jets
Z → νν, ll + jets
[g̃,χ̃⁰₁]:[900,150] [GeV]
SR
Events / 4 GeV^1/2
Data/Prediction
E_T^miss/√H_T [GeV^1/2]

INTERPRETATIONS

<u>Real or Simplified models</u>

- Simplified topologies include typically one production and one decay process. Provide useful information for theorists.



INTERPRETATIONS

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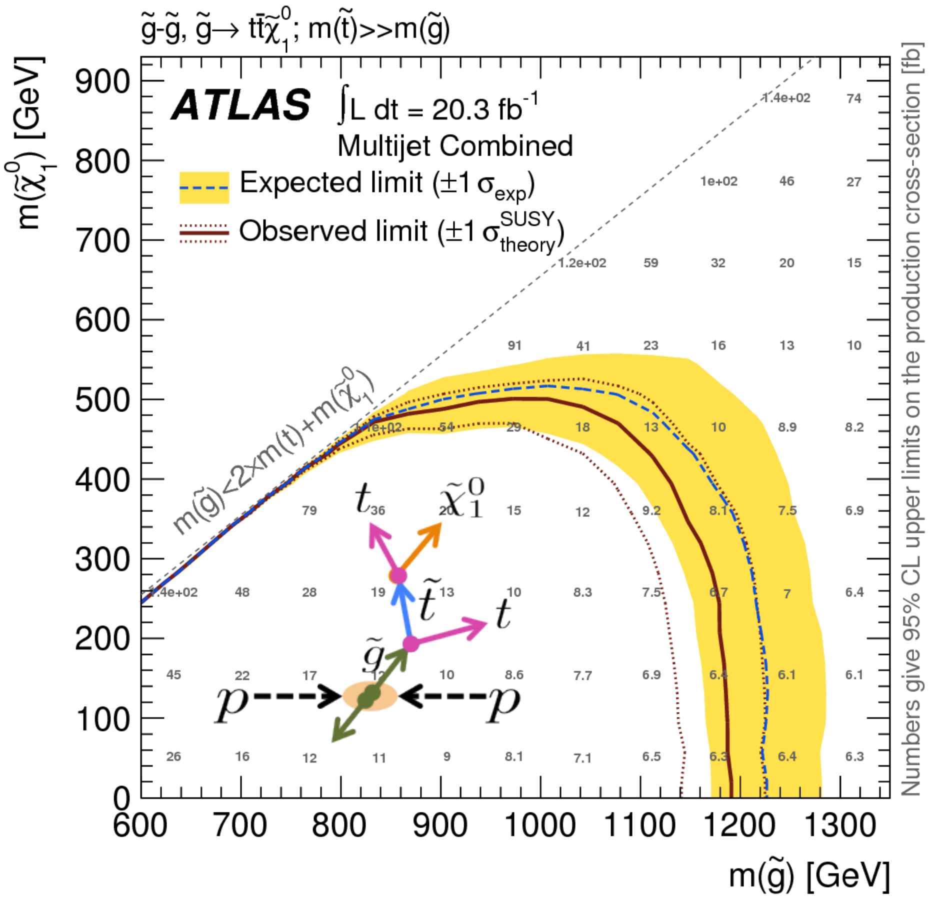

CONTENTS OF A RANDOM SEARCH INTERNAL DOCUMENTATION

Contents

COMPONENTS OF A PHYSICS ANALYSIS

- Data-set and Monte Carlo samples
- Trigger
- Object definitions and event selections
- Background determination
- Systematic uncertainties
- Statistical methods
- Results
- [Interpretations]

COMPONENTS OF A PHYSICS ANALYSIS

- Data-set and Monte Carlo samples
- Trigger
- Object definitions
- Background dete
- Systematic unce
- Statistical metho
- Results
- [Interpretations]

The data and simulation samples used in the analysis. Data for the measurement / search, simulation to compare data to predictions.

Data-set specifics:

- Data quality ⇒ Good run list.
- Luminosity.

Monte carlo sample specifics:

- Generator, tunes.
- Statistics.

COMPONENTS OF A PHYSICS ANALYSIS

- Data-set and Monte Carlo samples
- Trigger
- Object defin
- Background dete
- Systematic uncer
- Statistical metho
- Results
- [Interpretations]

The trigger used to collect the data with.

Trigger specifics:

- Prescales; typically unprescaled triggers are used, prescaled triggers for QCD / high stat measuments.
- Trigger (in)efficiencies.

COMPONENTS OF A PHYSICS ANALYSIS

- Data-set and Monte Carlo samples
- Trigger
- Object definitions and event selections
- Backg
- Sy
- Stati
- Resu
- [Inter

The exact definition of objects (electrons, muon, jets, …) and how these are combined in selecting events to be analyzed.

Object definition specifics:

- "Flavor" of the identification (loose, medium, tight).
- Calibrations.

Event selection specifics:

- Event cleaning (e.g. from noise and cosmics).
- Momentum, geom. acceptance and multiplicity of objects.
- Higher level cuts, such as invariant mass.
- "**Signal regions**".

COMPONENTS OF A PHYSICS ANALYSIS

- Data-set and Monte Carlo samples
- Trigger
- Object definitions and event s
- Background determination
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- [Interpretations]

Events that are imitating the signal we are searching for or measuring.

Background determination specifics:

- Can/must be **data-driven** or **simulation-based**.
- "**Validation regions**" and "**control regions**" required. These can use different triggers wrt signal regions.

COMPONENTS OF A PHYSICS ANALYSIS

- Data-set and Monte Carlo
- Trigger
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- Systematic uncertainties
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- Any 'intermediate' measurement we have performed carries uncertainties (statistical and systematic).
- **"Systematic" uncertainties are introduced by inaccuracies in the methods used to perform the measurement.**
- Efficiencies, acceptance, number of events, luminosity, cross sections used in Monte Carlo scaling…
- Some of them are "centrally" assessed by the performance groups of an experiment. Some of them are analysis-specific.

COMPONENTS OF A PHYSICS ANALYSIS

- Data-set and Monte Carlo
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Dealing with large data-sets, we use statistical methods to make sense of the numbers we measure.

Typical method:

- Do a fit to extract signal from background.

Methodologies can vary a lot, but nowdays they are pretty unified within and across experiments.

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Dealing with large data-sets, we use statistical methods to make sense of the numbers we measure.

Typical method:

- Do a fit to extract signal from background.

Methodologies can vary a lot, but nowdays they are pretty unified within and across experiments.

Neural nets and other machine learning methods are broadly used, primarily to improve signal over background discrimination!

COMPONENTS OF A PHYSICS ANALYSIS

- Data-set and Monte Carlo samples
- Trigger
- Object definitions and event selections
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- Systematic uncertainties
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- Results
- [Interpretations]

Produce the results in tables and plots. These include details of what is found in the signal region.

COMPONENTS OF A PHYSICS ANALYSIS

- Data-set and Monte Carlo samples
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- Systematic uncertainties
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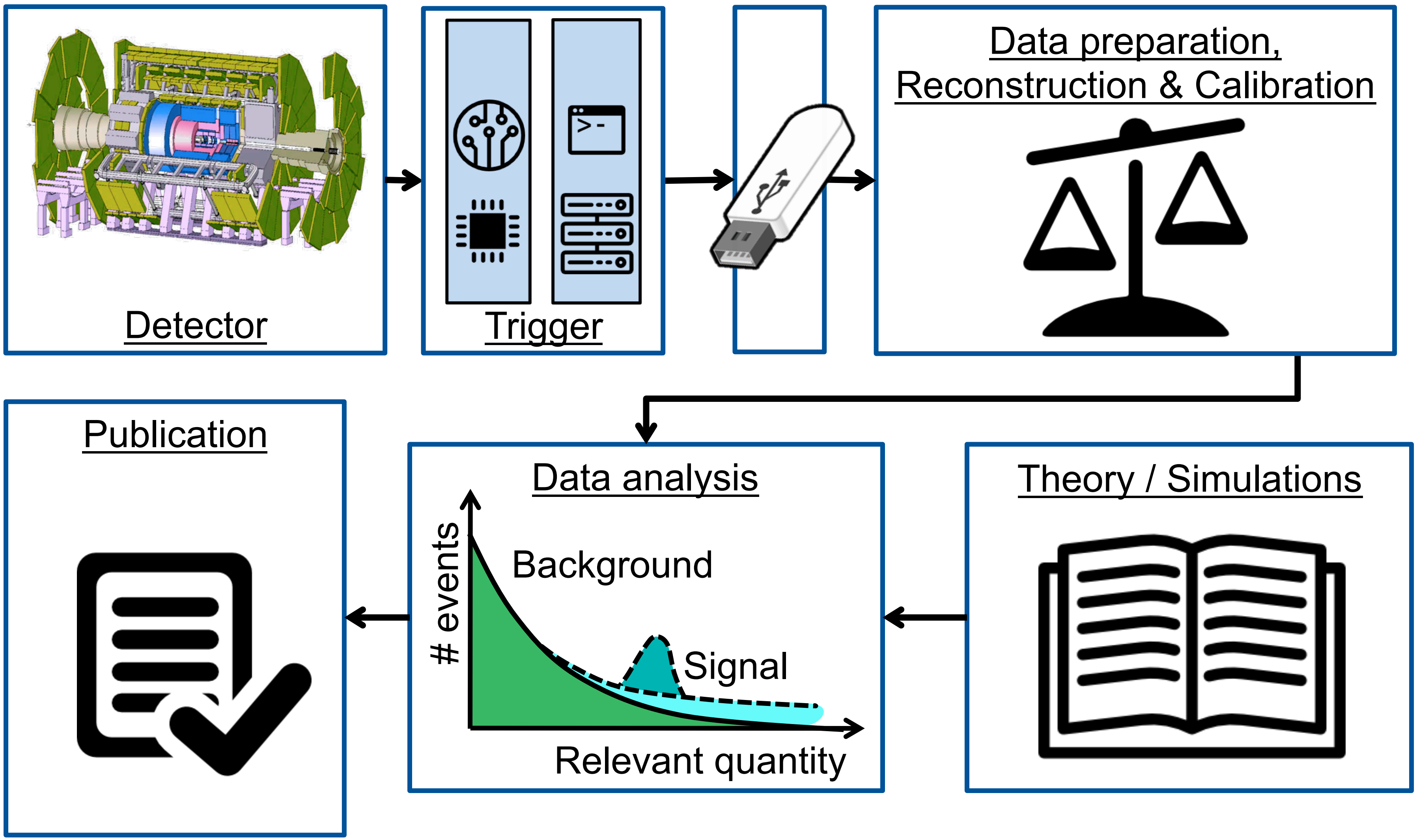
- Results
- [Interpretations]

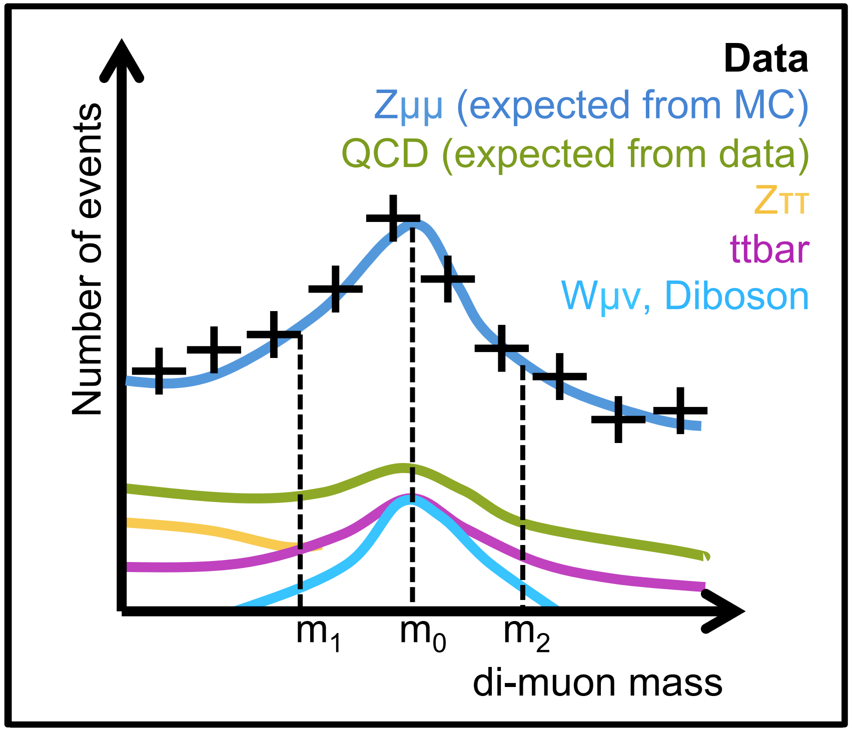
Put the results into context: interpret them in theoretical models.

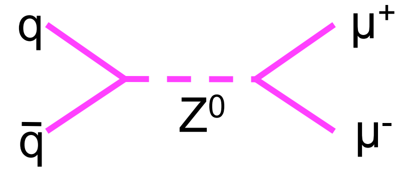
(INSTEAD OF) CONCLUSIONS



BACKUP

MEASURING Z^0 CROSS-SECTION AT LHC

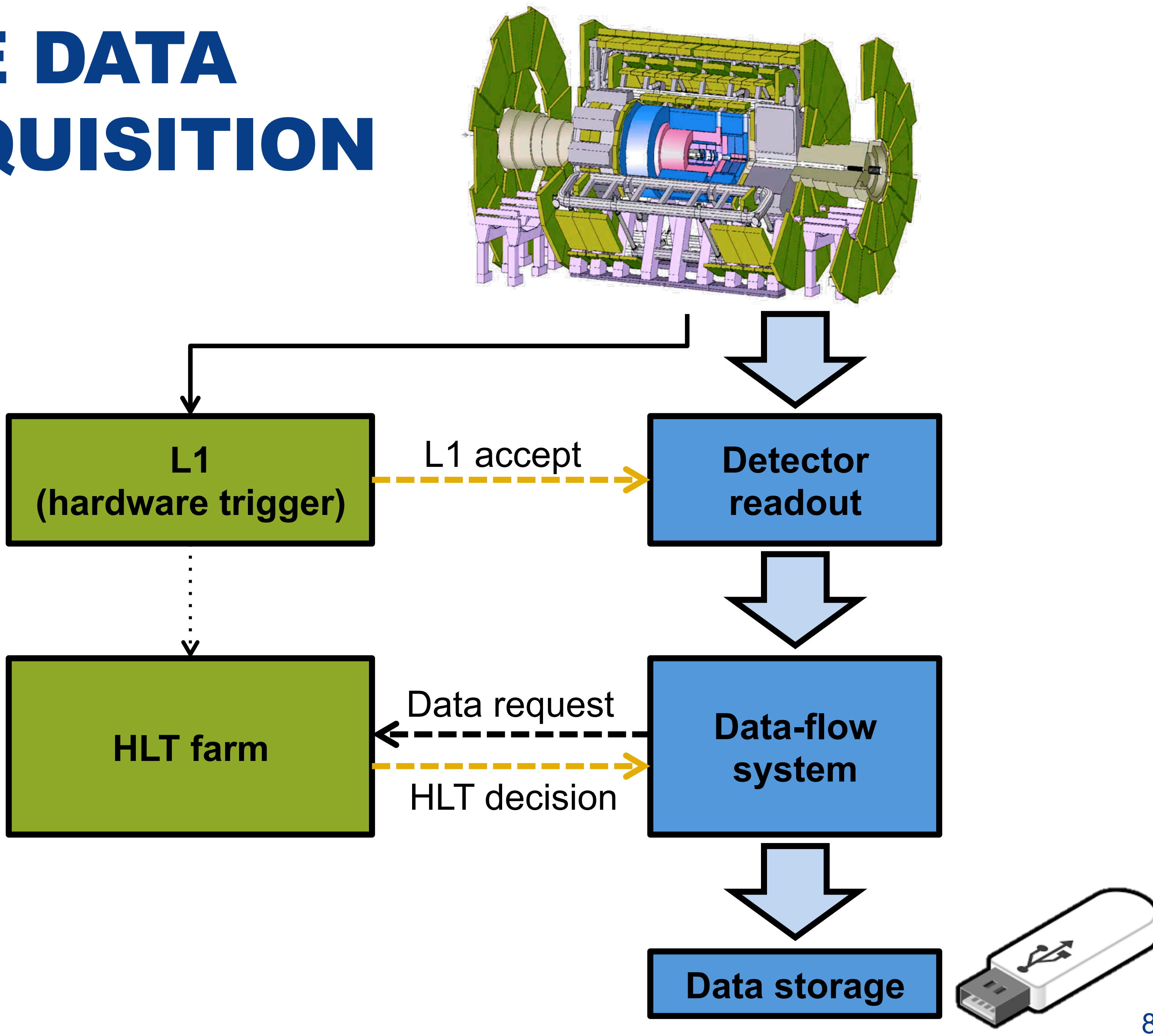




$$\sigma \cdot \mathrm{BR} = \frac{\text{Number of events}}{\alpha \cdot \epsilon \cdot \mathrm{L}}$$

N of events
= N events on data – N expected background events
α – acceptance
= fraction of events passing selection requirements
ε – efficiency
= reconstruction efficiency of relevant objects

THE DATA ACQUISITION



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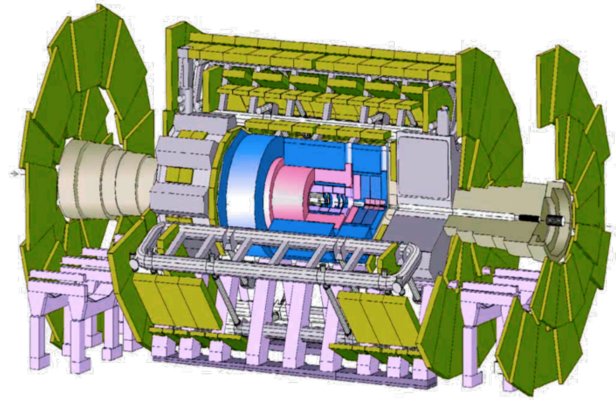
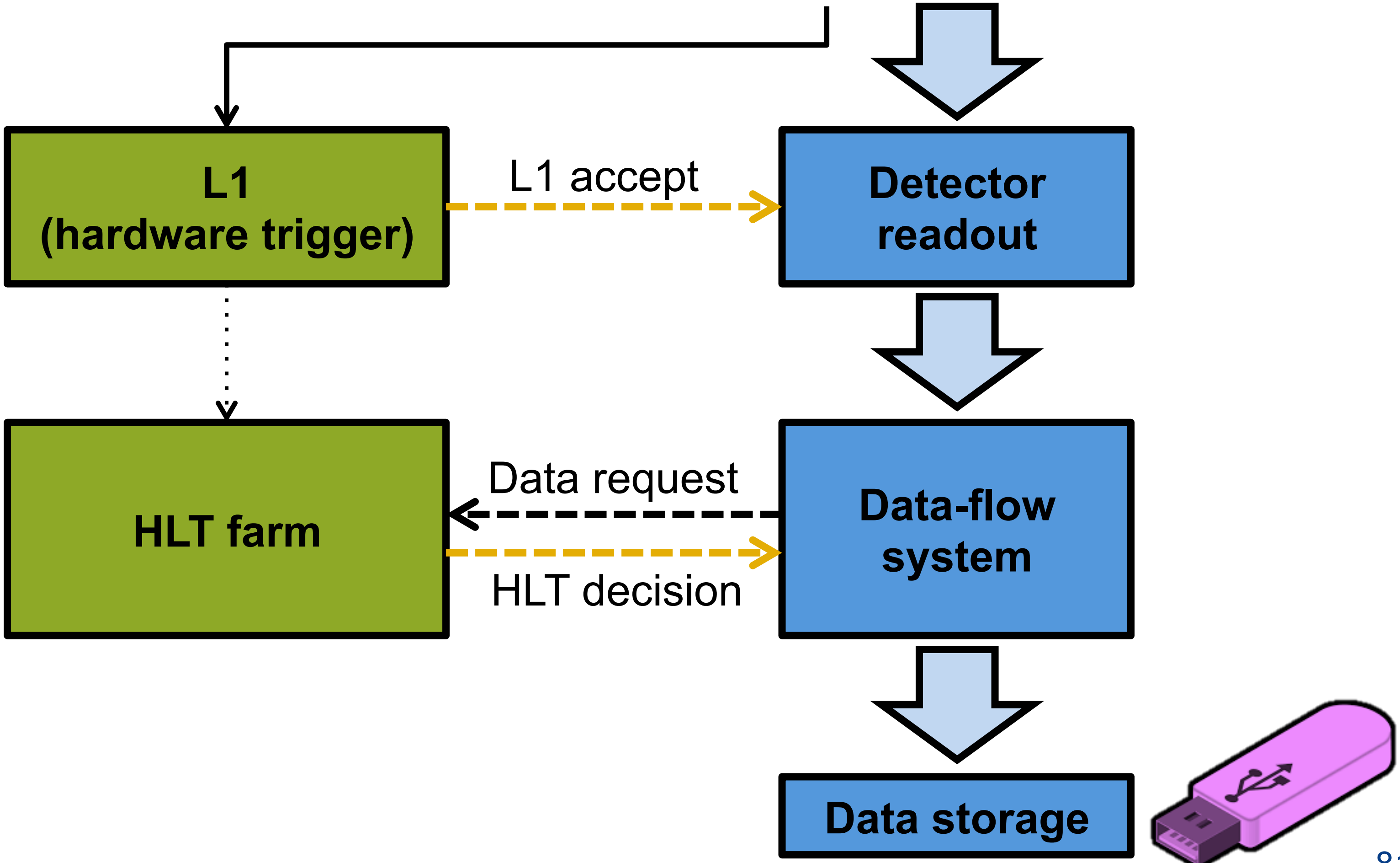
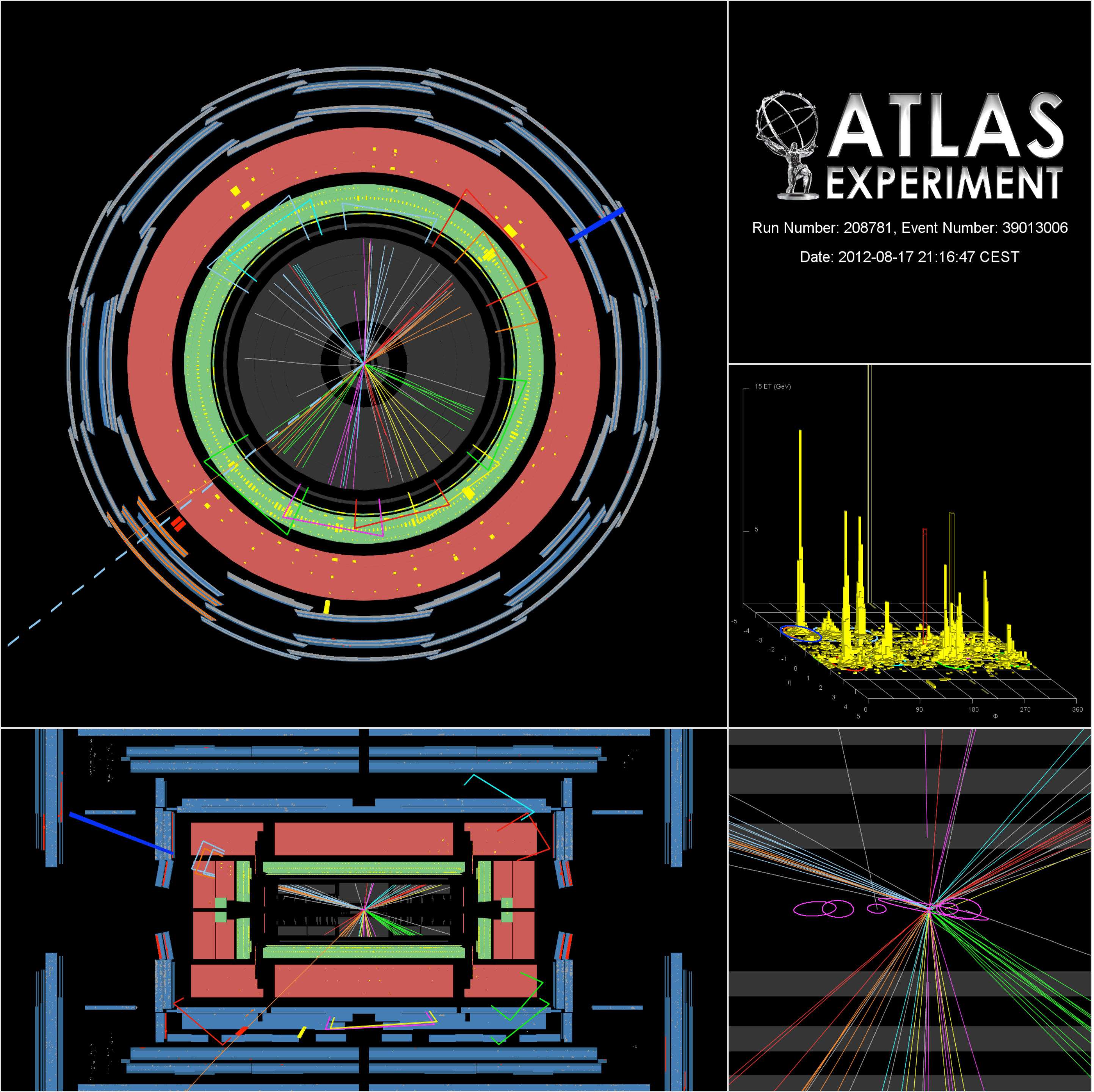




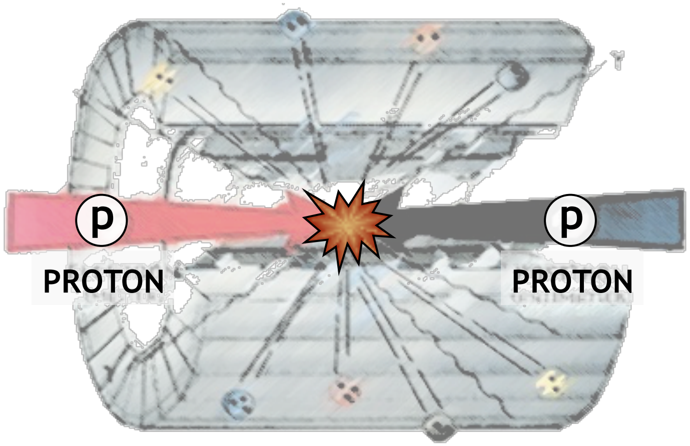


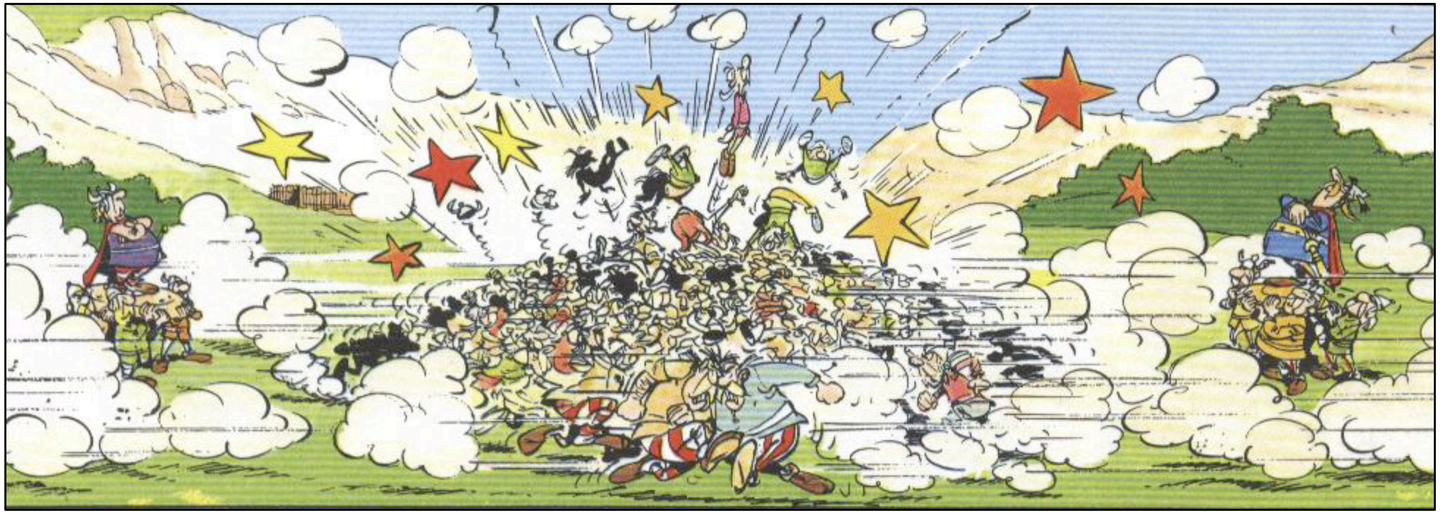
10 jets

with pT > 50GeV

ME_T = 120 GeV

IN A P-P COLLISION





MISSING TRANSVERSE MOMENTUM

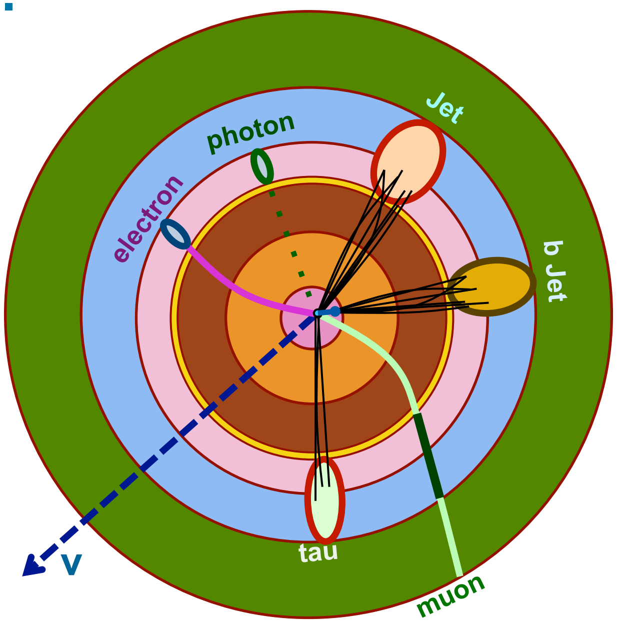
Impossible to measure particles that don't interact in the detector.

➲ Instead, measure everything else & require momentum conservation in the transverse plane.

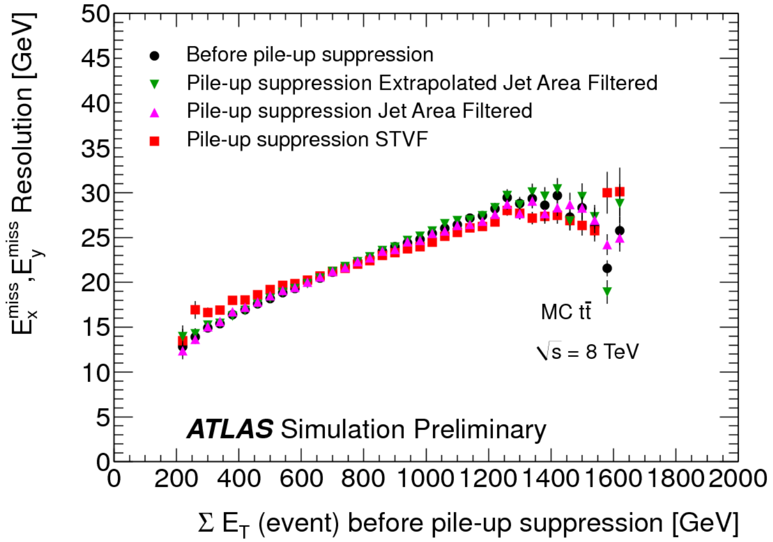
- Sensitive to pile-up and detector problems.

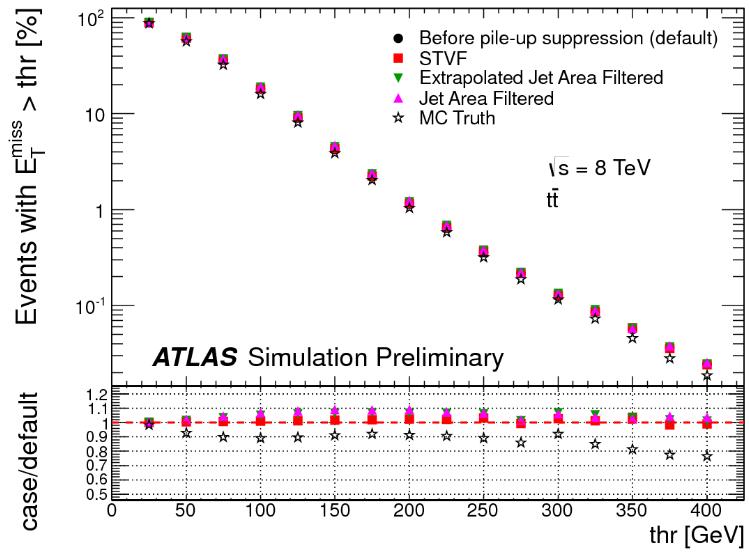
Only as good as its inputs.

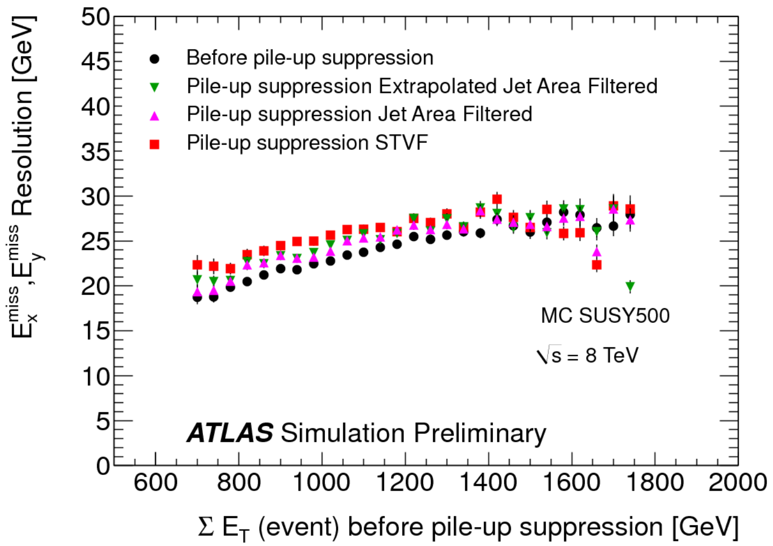
- Use calibrated physics objects: electrons, photons, muons, taus, jets.
- Add remaining soft energy.

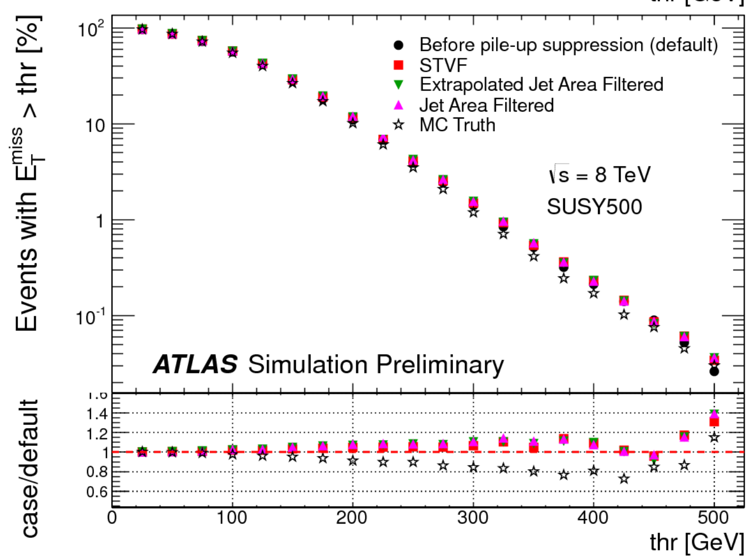


MISSING ET – PILEUP & TAILS

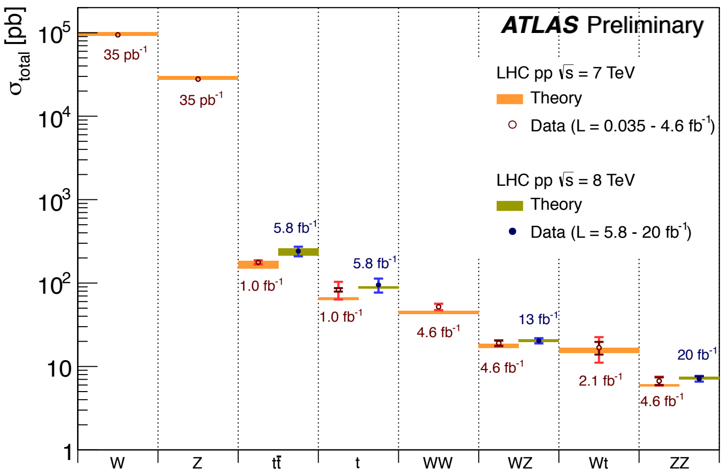


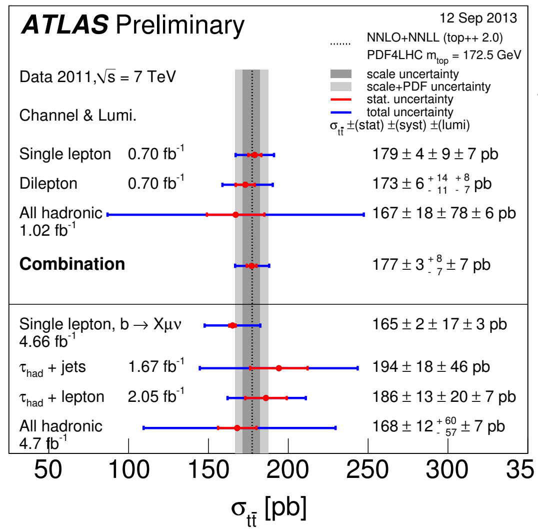


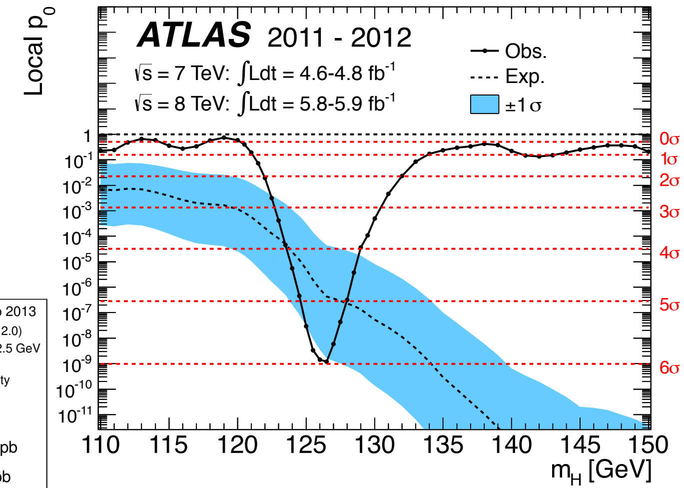


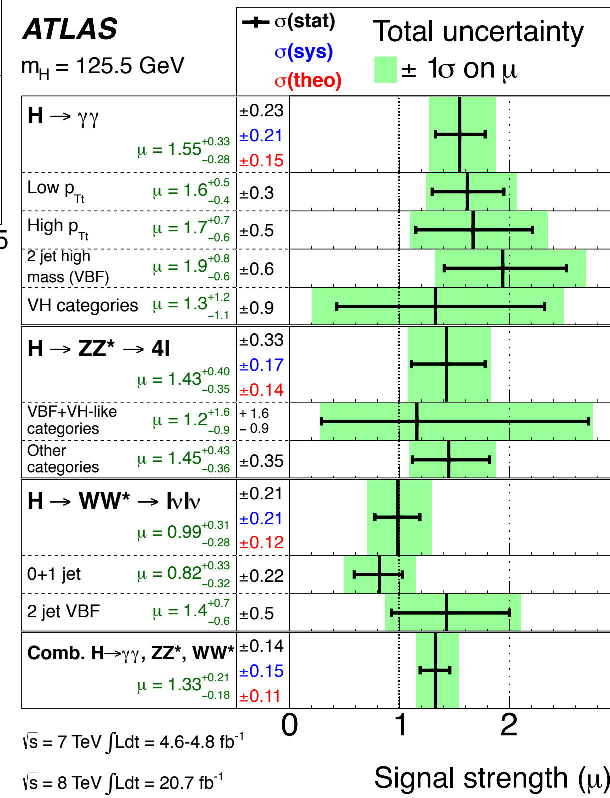


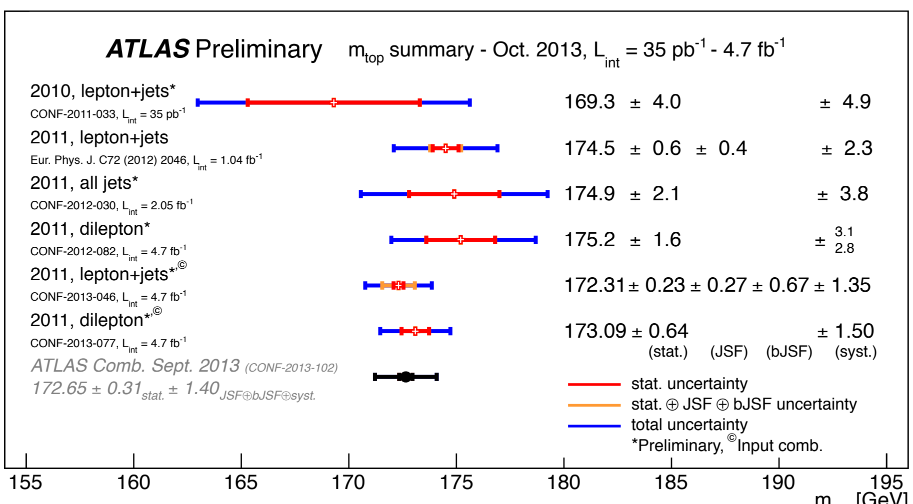
GRAND ATLAS (non-BSM) PHYSICS SUMMARY



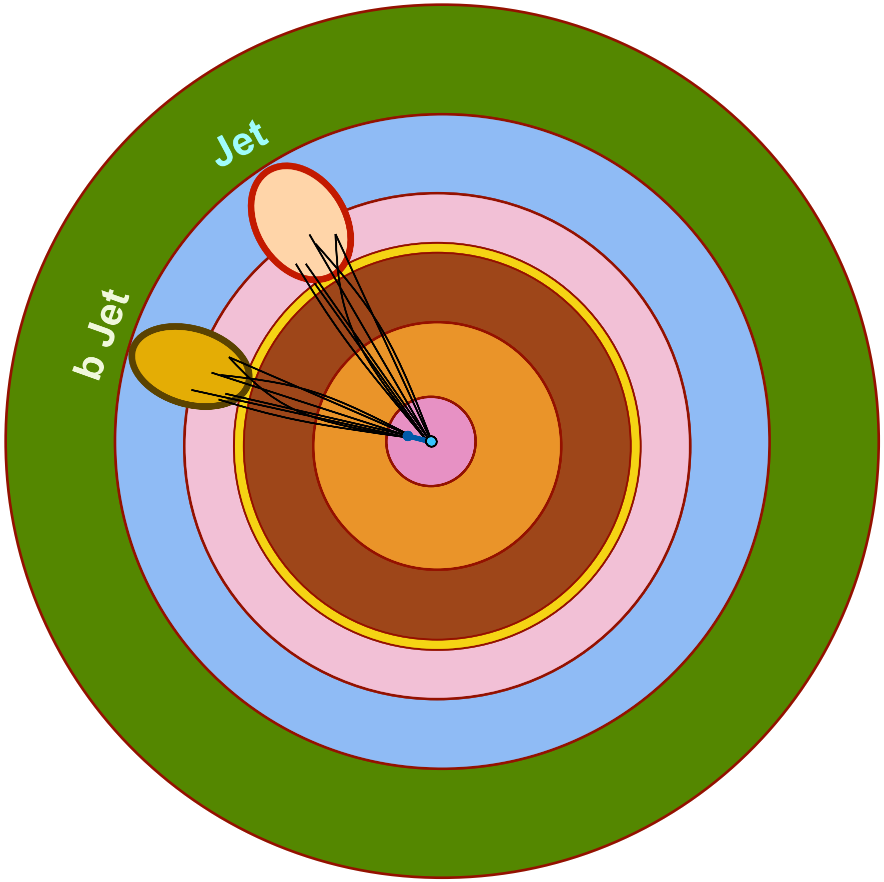








B-JET



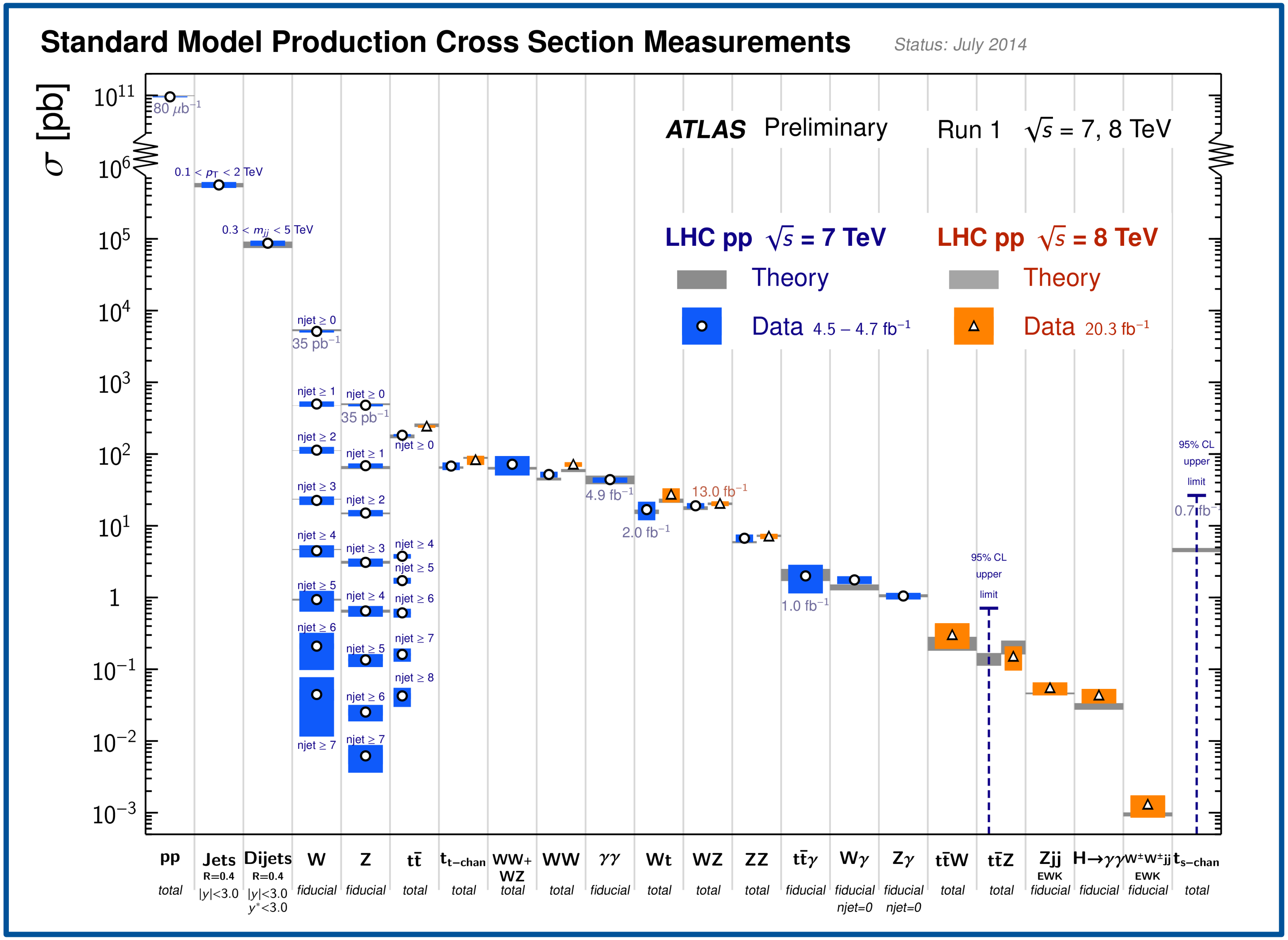
TRIGGER MENUS FOR SUSY

Selection	EF trigger election	EF Avg. Rate (Hz) L_{avrg}=5e33/cm^{2}s
Single jet & E_T^{miss}	Jet E_T >145 GeV & EF-only E_T^{miss} >70 GeV	8
Single jet & E_T^{miss} & $\Delta\phi$(jet,E_T^{miss})	Jet E_T >80 GeV & E_T^{miss} >70 GeV & $\Delta\phi$ >1.0 rad	8
H_T	>700 GeV	8
Single electron & E_T^{miss}	Electron p_T >25 GeV & EF-only E_T^{miss} >35 GeV	26
Single muon & single jet & E_T^{miss}	Muon p_T >24 GeV & jet E_T >65 GeV & EF-only E_T^{miss} >40 GeV	15
Single photon & E_T^{miss}	Photon p_T >40 GeV & EF-only E_T^{miss} >60 GeV	5
3 electrons	p_T > 18, 2×7 GeV	<1
3 muons	p_T > 18, 2×4 GeV	<1
3 electrons & muons	p_T > 2×7 (e), 6 (μ) GeV	<1
	p_T > 7 (e), 2×6 (μ) GeV	<1

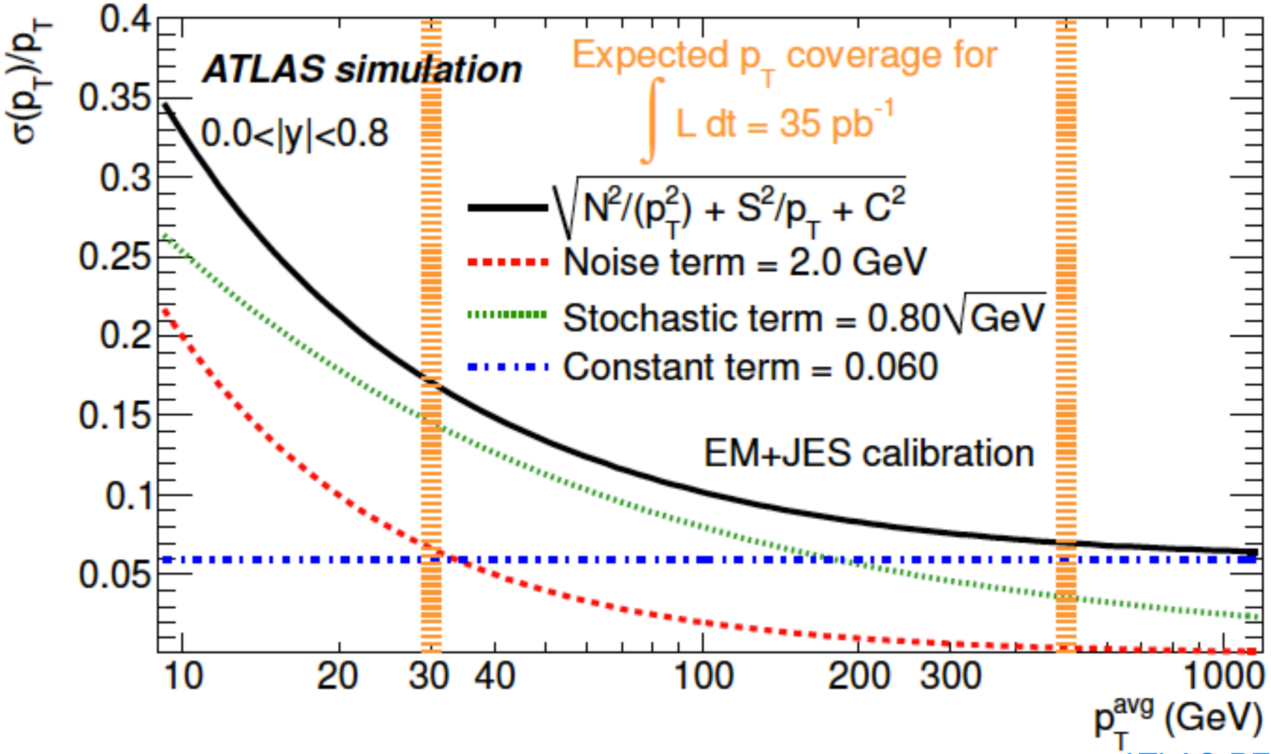
'DELAYED' TRIGGERS

Trigger	EF trigger Selection	
	Prompt Stream	**Delayed Stream**
Multi-jets	4×80 GeV	4×65 GeV
	5×55 GeV	5×45 GeV
	6×45 GeV	
H_T	700 GeV	500 GeV
Single jet (R = 1.0)	460 GeV	360 GeV
E_T^{miss}	80 GeV	60 GeV

STANDARD MODEL SUMMARY



THE SUSY MULTIJET SEARCH



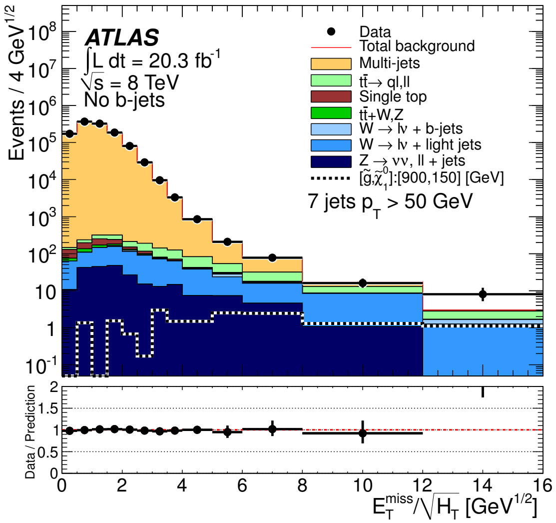
ATLAS-PERF-2011-04-001

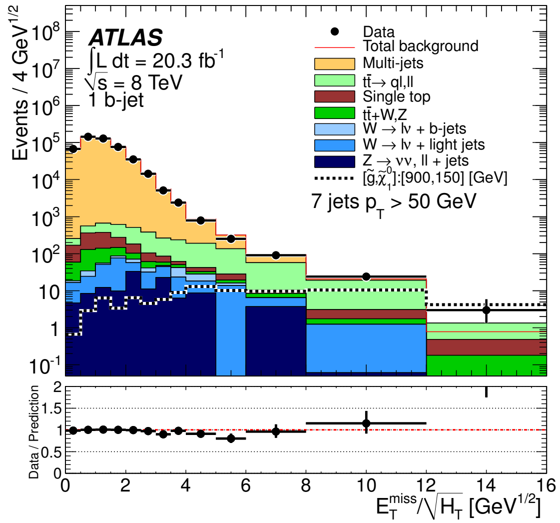
Why $ME_T/\sqrt{H_T}$?
⇒ a measure of ME_T in units of standard deviations of the fake ME_T

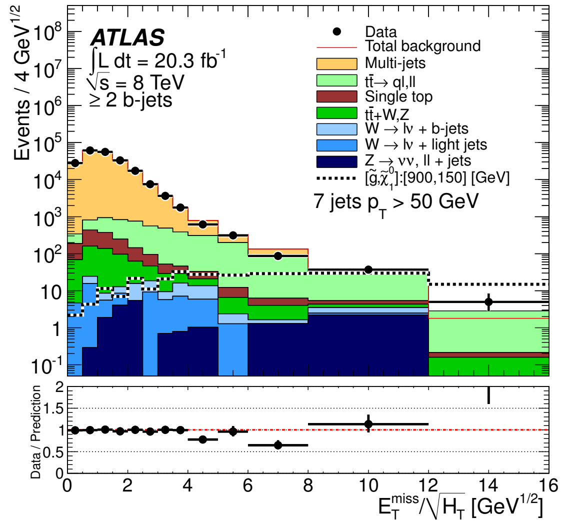
$$\frac{\sigma_{p_T}}{p_T} = \frac{N}{p_T} \oplus \frac{S}{\sqrt{p_T}} \oplus C$$

MULTI-JET BACKGROUND

Flavour stream

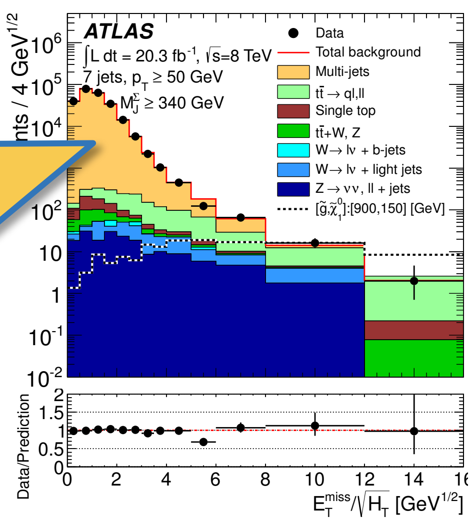


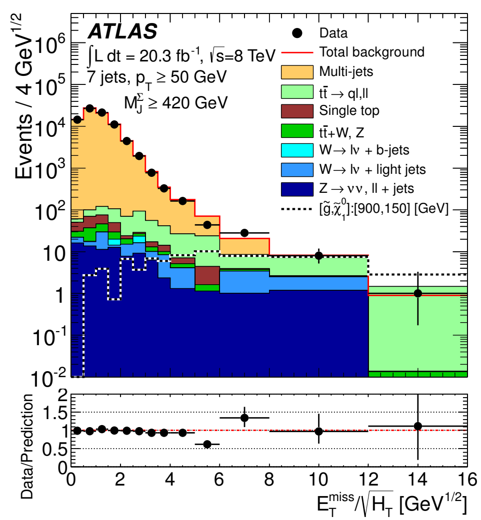




MJ stream

Template extracted from '6j50' and validated in '7j50'





Discrepancies in control regions become uncertainties – dominant, on top of heavy flavour and 'leptonic' backgrounds.

LEPTONIC BACKGROUNDS

- ttbar (non-full-hadronic) + jets and W/Z + jets.
- Scale MC in control regions in data (through a multi-bin fit).

Single-lepton validation region	
Lepton p_{T}	$> 25\,\mathrm{GeV}$
Lepton multiplicity	Exactly one, $\ell \in \{e, \mu\}$
$E_{\mathrm{T}}^{\mathrm{miss}}$	$> 30\,\mathrm{GeV}$
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$	$> 2.0\ \mathrm{GeV}^{1/2}$
m_{T}	$< 120\,\mathrm{GeV}$
Jet p_{T}	As for signal regions (table 1)
Jet multiplicity	
b-jet multiplicity	
M_J^{Σ}	

Control region (additional criteria)	
Jet multiplicity	Unit increment if $p_{\mathrm{T}}^{\ell} > p_{\mathrm{T}}^{\mathrm{min}}$
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}\ (+p_{\mathrm{T}}^{\ell})}$	$> 4.0\ \mathrm{GeV}^{1/2}$

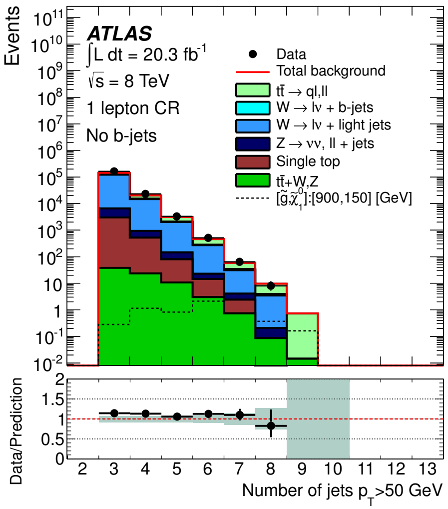
Two-lepton validation region	
Lepton p_{T}	$> 25\,\mathrm{GeV}$
Lepton multiplicity	Exactly two, $e\,e$ or $\mu\,\mu$
$m_{\ell\ell}$	$80\,\mathrm{GeV}$ to $100\,\mathrm{GeV}$
Jet p_{T}	As for signal regions (table 1)
Jet multiplicity	
b-jet multiplicity	
M_J^{Σ}	

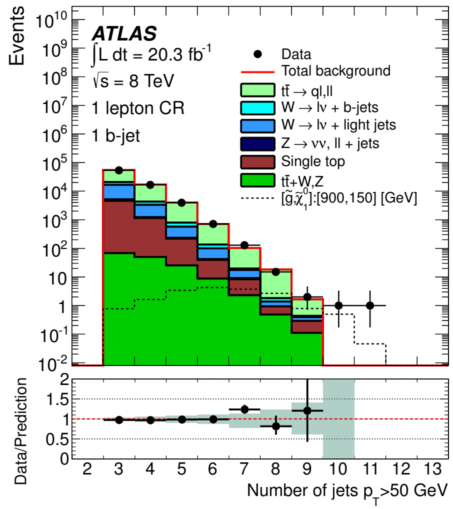
Control region (additional criteria)	
$\lvert \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}} + \mathbf{p}_{\mathrm{T}}^{\ell_1} + \mathbf{p}_{\mathrm{T}}^{\ell_2} \rvert / \sqrt{H_{\mathrm{T}}}$	$> 4.0\ \mathrm{GeV}^{1/2}$

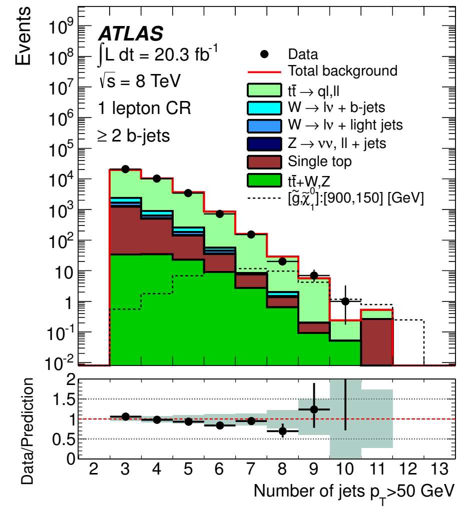
- Uncertainties dominating the leptonic background determination: JES/JER, b-tagging, pile-up and theory.

LEPTONIC BACKGROUND

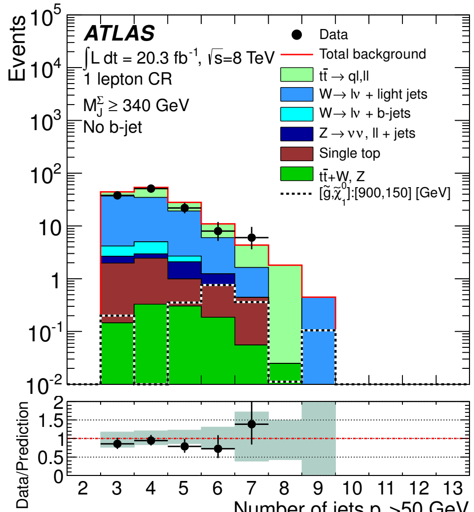
Flavour stream

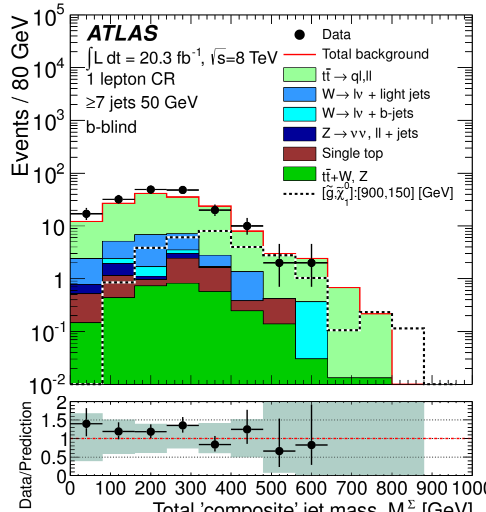






MJ stream





Uncertainties dominating the leptonic background determination: JES/JER, b-tagging, pile-up and theory.

THE STATISTICAL TREATMENT

Flavour stream

Simultaneous fit in the 'j50' and 'j80' signal regions separately.

- **ttbar & W+jets:** one control region per signal region. **Normalization allowed to vary freely in the fit.**
- **Other less significant backgrounds;** determined using MC. **Constrained by their uncertainties.**
- **Multijet background;** not constrained by control regions. **Constrained by its uncertainties.**

MJ stream

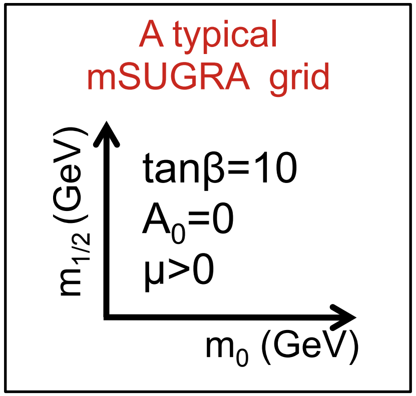
A fit performed in each signal region to adjust the normalization of ttbar and W backgrounds.

INTERPRETATIONS

‘Real models’

◎ **A minimal model, Constraint Minimal SUSY (CMSSM) (mSugra, i.e. gravity-mediated, based) only has 5 free parameters:**

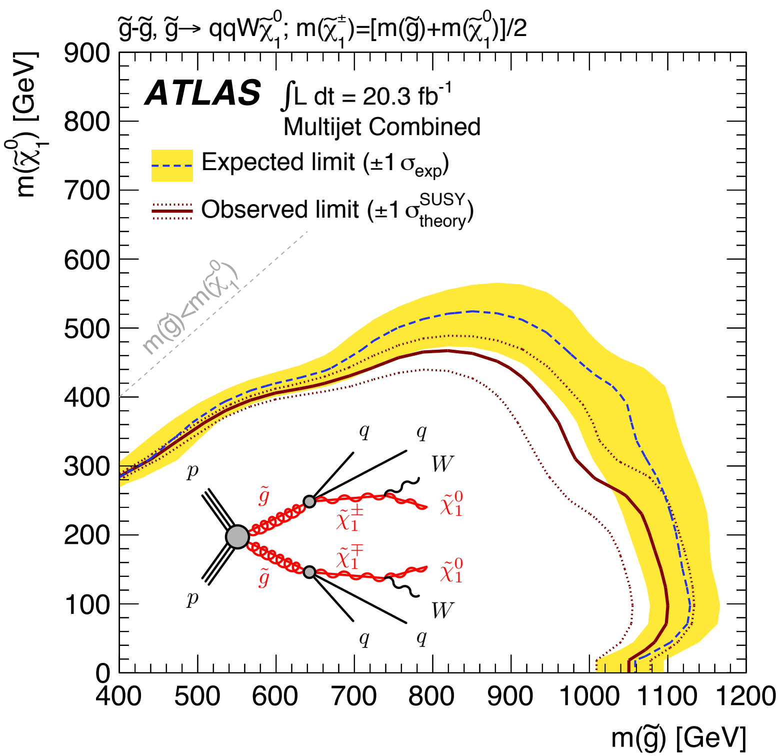
- Scalar mass parameter, $\mathbf{m_0}$
- Gaugino mass parameter, $\mathbf{m_{1/2}}$
- Trilinear Higgs-sfermion-sfermion coupling, $\mathbf{A_0}$
- Ratio of Higgs vaccum expectation values, **tanβ**
- Sign of SUSY Higgs parameter, **sign(μ)**

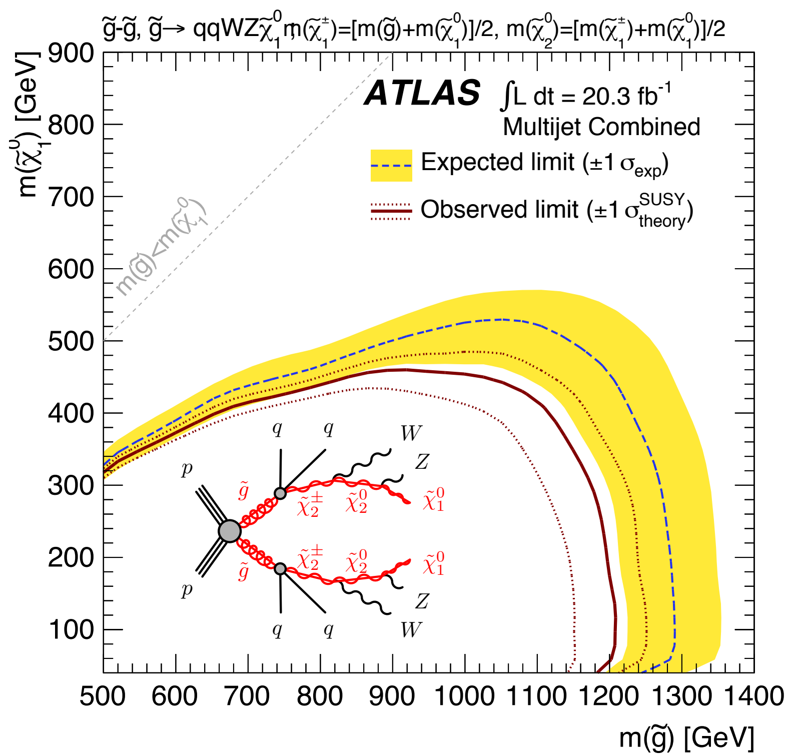


‘Simplified models’

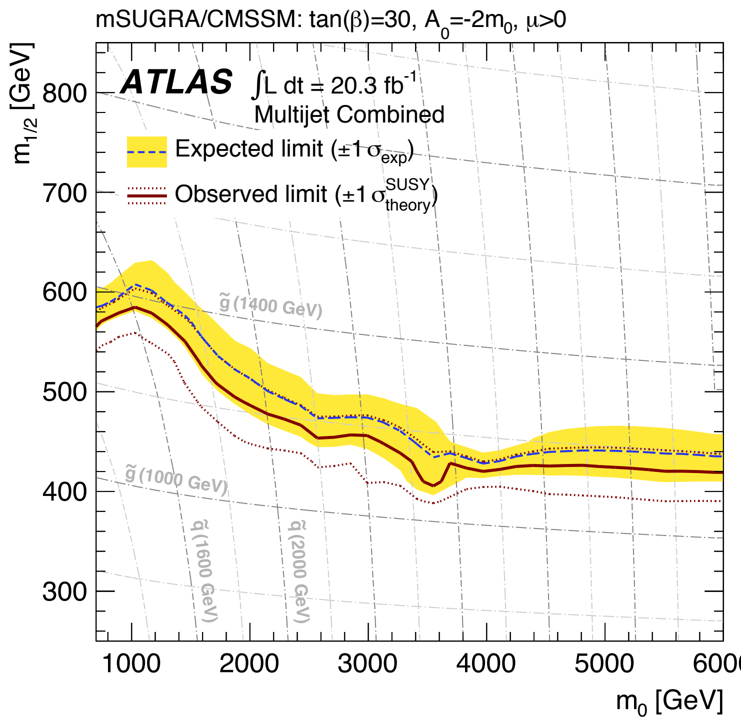
◎ **Simplified topologies with typically one production and one decay process. Provide useful information for theorists.**

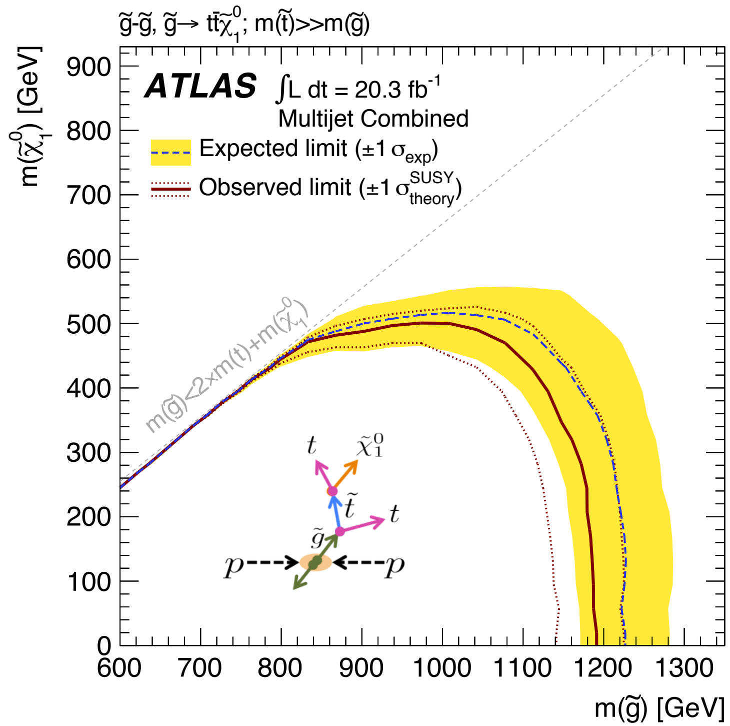
INTERPRETATIONS



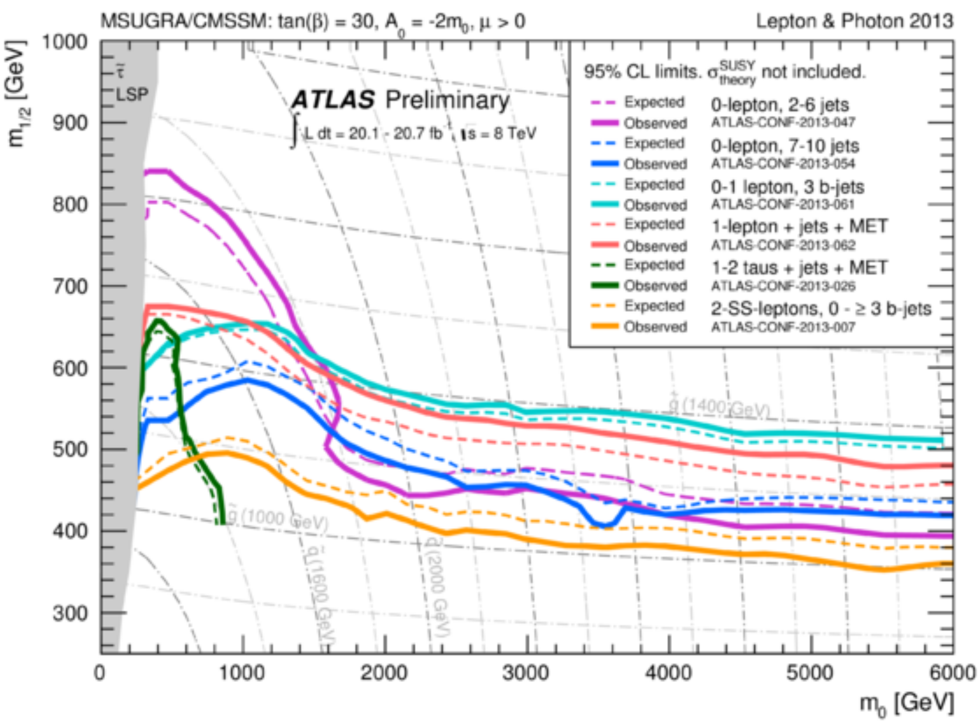


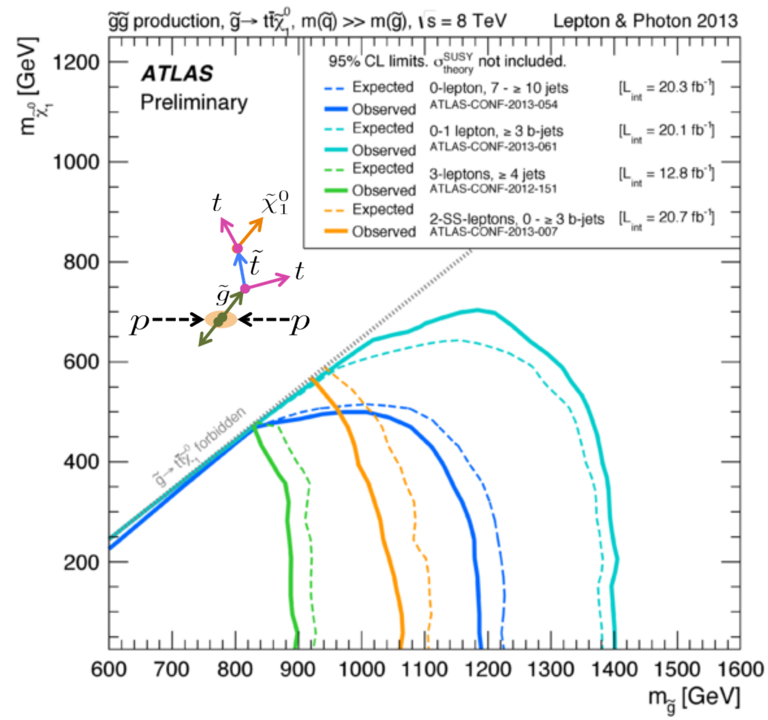
INTERPRETATIONS





INTERPRETATIONS





- **Note that the multijet analysis is not optimized for a specific model, it is built to be as model-independent as possible.**
- **Multijet analysis is strong in other simplified models, e.g. gluino pair production via 2-step decay to 12 jets.**

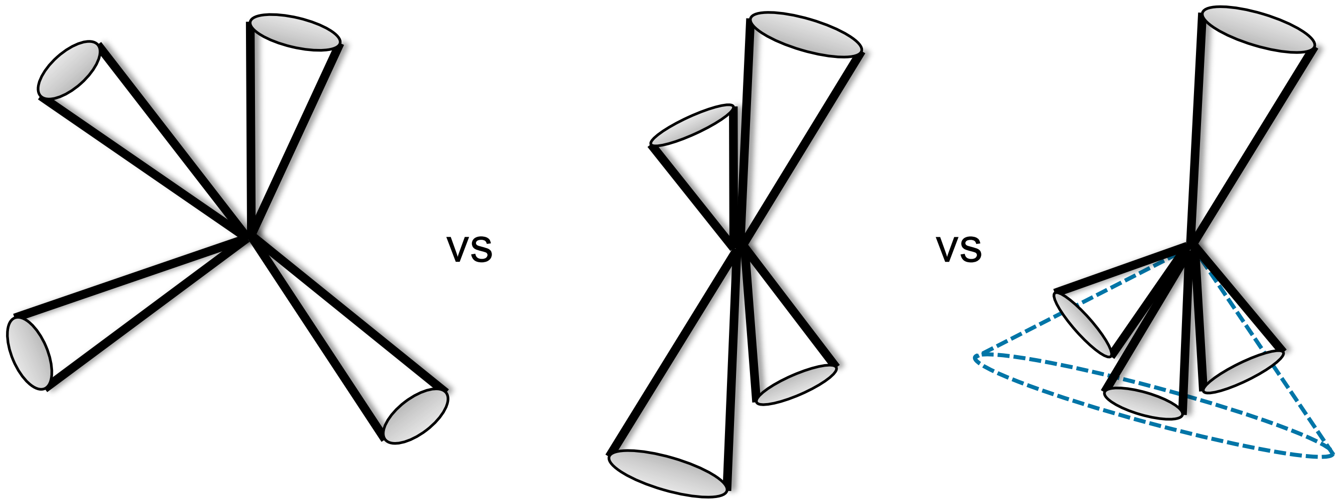
QCD BACKGROUNDS IN SUSY

All (SUSY) analyses use data-driven methods for assessing multi-jet SM production.

Monte Carlo can not be used when large multiplicities are involved:

- Inclusive multi-jet / multi-parton samples provided by Monte Carlo generators recently only.
  - E.g. only very latest Sherpa release provides NLO calculations up to four jets.
- Monte Carlo predictions have not yet been validated with multi-jet data.
- **Detailed comparisons between data and various Monte Carlo generators and theoretical predictions would provide extremely useful input to the theory community in understanding QCD.**
  - They would also provide a great understanding of a dominant SUSY background in view of run2.

E.G. FOUR-JET TOPOLOGIES & OBSERVABLES



Category	Variable
Simple kinematic & ratios	pT, η, φ, HT, p_{Ti}/p_{Tj}
Angles	$\Delta\eta_{ij}$, $\Delta\varphi_{ij}$, ΔR_{ij}
Masses & ratios	m_{ij}, m_{ijk}, m_4, m_i/m_{ij}, m_i/m_{ijk}, m_i/m_4
Event shapes	$\Sigma\, p_T^2 / \Sigma\, p^2$

E.G. FOUR-JET TOPOLOGIES & OBSERVABLES

Name	Definition	Comment
$p_{\mathrm{T}i}$	Transverse momentum of the ith jet	Sorted descending in p_{T}
Y_i	Rapidity of the ith jet	(sorted descending in p_{T})
H_{T}	$\sum_{i=1}^{4} p_{\mathrm{T}i}$	Scalar sum of the p_{T} of the four jets
M_{jjjj}	$\left(\sum_{i=1}^{4} E_i\right)^2 - \left(\sum_{i=1}^{4} \mathbf{p}_i\right)^2$	Invariant mass of the four jets
$M_{\mathrm{jj}}^{\mathrm{min}}$	$\min_{\substack{i,j\in[1,4]\\ i\neq j}}\left(\left(E_i + E_j\right)^2 - \left(\mathbf{p}_i + \mathbf{p}_j\right)^2\right)$	Minimum invariant mass of any two jets
$\Delta\phi_{ij}^{\mathrm{min}}$	$\min_{\substack{i,j\in[1,4]\\ i\neq j}}\left(\lvert\phi_i - \phi_j\rvert\right)$	Min azimuthal separation of two jets
$\Delta Y_{ij}^{\mathrm{min}}$	$\min_{\substack{i,j\in[1,4]\\ i\neq j}}\left(\lvert Y_i - Y_j\rvert\right)$	Min rapidity separation of two jets
$\Delta\phi_{ijk}^{\mathrm{min}}$	$\min_{\substack{i,j,k\in[1,4]\\ i<j<k}}\left(\lvert\Delta\phi_{ij}\rvert + \lvert\Delta\phi_{jk}\rvert\right)$	Min azimuthal separation between three jets
$\Delta Y_{ijk}^{\mathrm{min}}$	$\min_{\substack{i,j,k\in[1,4]\\ i<j<k}}\left(\lvert\Delta Y_{ij}\rvert + \lvert\Delta Y_{jk}\rvert\right)$	Min rapidity separation between three jets
$\Delta Y_{ij}^{\mathrm{max}}$	$\Delta Y_{ij}^{\mathrm{max}} = \max_{i,j\in[1,4]}\left(\lvert Y_i - Y_j\rvert\right)$	Max rapidity difference between two jets
$\Sigma p_{\mathrm{T}}^{\mathrm{central}}$	Sum of p_{T} of the two central-rapidity jets	Excludes jets having $\Delta Y_{ij}^{\mathrm{max}}$

E.G. FOUR-JET MONTE CARLO SAMPLES

Name	Hard process	PDF	Parton shower	Underlying event	Tune
Pythia8-CT10	PYTHIA 8	CT10	PYTHIA 8	PYTHIA 8	AU2-CT10
Pythia8-CTEQ6L1	PYTHIA 8	CTEQ6L1(†)	PYTHIA 8	PYTHIA 8	AU2-CTEQ6L1
Herwig++	Herwig++	CTEQ6L1	Herwig++	Herwig++	UE-EE-3-CTEQ6L1
Alpgen+Herwig	Alpgen	CTEQ6L1	HERWIG 6	JIMMY	AUET2-CTEQ6L1
Alpgen+Pythia	Alpgen	CTEQ6L1	PYTHIA 6	PYTHIA 6	Perugia 2011C
Madgraph+Pythia	Madgraph	CTEQ6L1	PYTHIA 6	PYTHIA 6	AUET2B-CTEQ6L1
Sherpa	Sherpa		Sherpa	Sherpa	

Table 2: The different Monte Carlo generators used for comparison against the data are listed, together with the parton distribution functions, parton shower algorithms, underlying event and parameter tunes. (†) The Pythia8-CT6L1 sample uses CT10 when calculating the Matrix Element but CTEQ6L1 when simulating the parton shower and underlying event. The first listed sample (Pythia8-CT10) is used for the deconvolution of detector effects.

THE ATLAS TRIGGER SYSTEM

Rate (2012 conditions)

Hardware

20 MHz
Bunch crossing rate

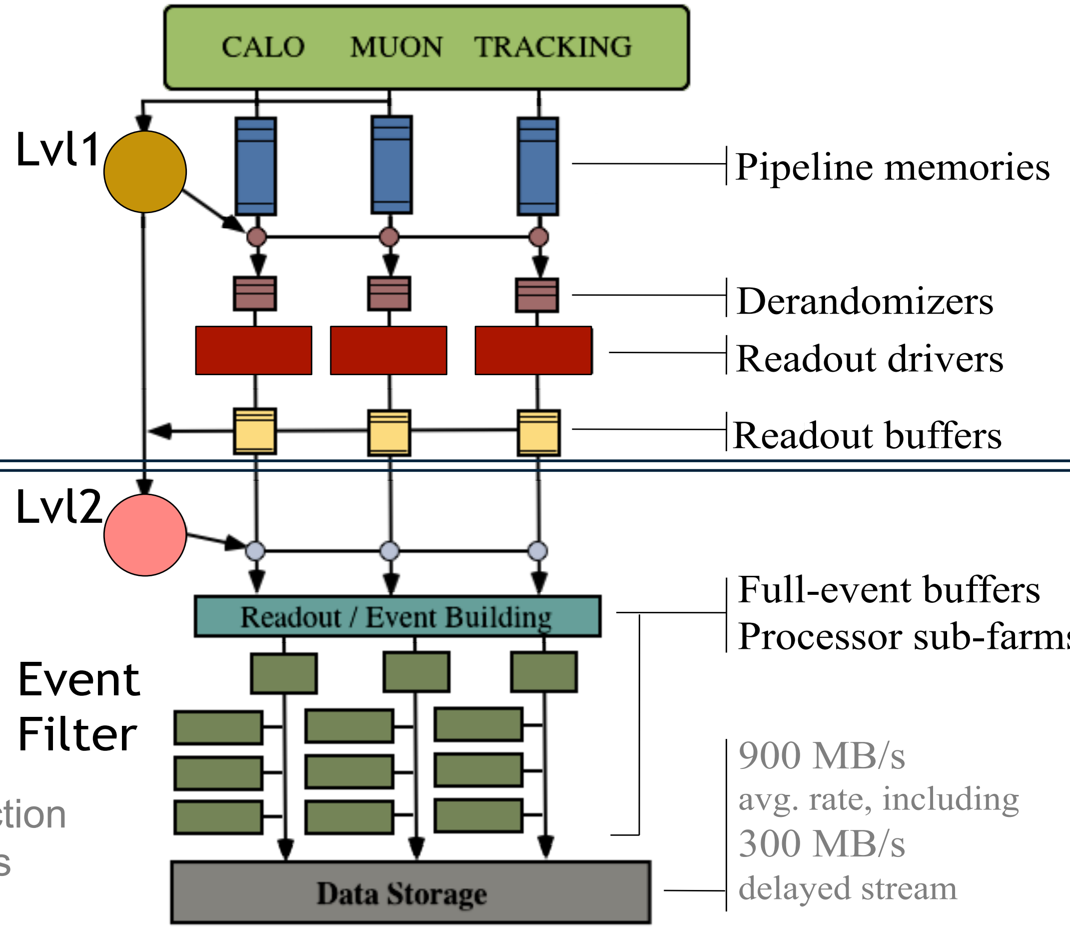
6.4×10^8
Interactions/s

75 kHz
Peak rate

Software

6 kHz
Peak rate

600 Hz
Avg. rate, including
200 Hz delayed stream
(stored for later reconstruction
when computing resources
available)

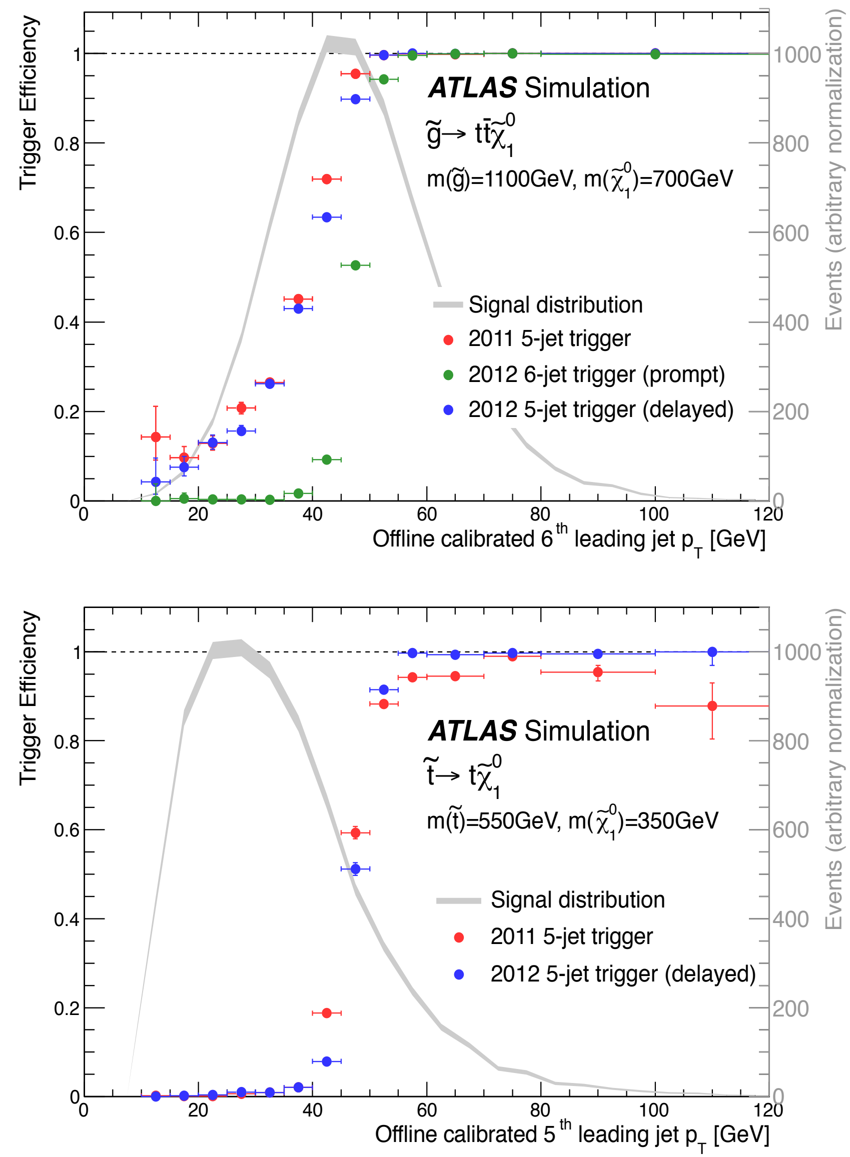


TRIGGER

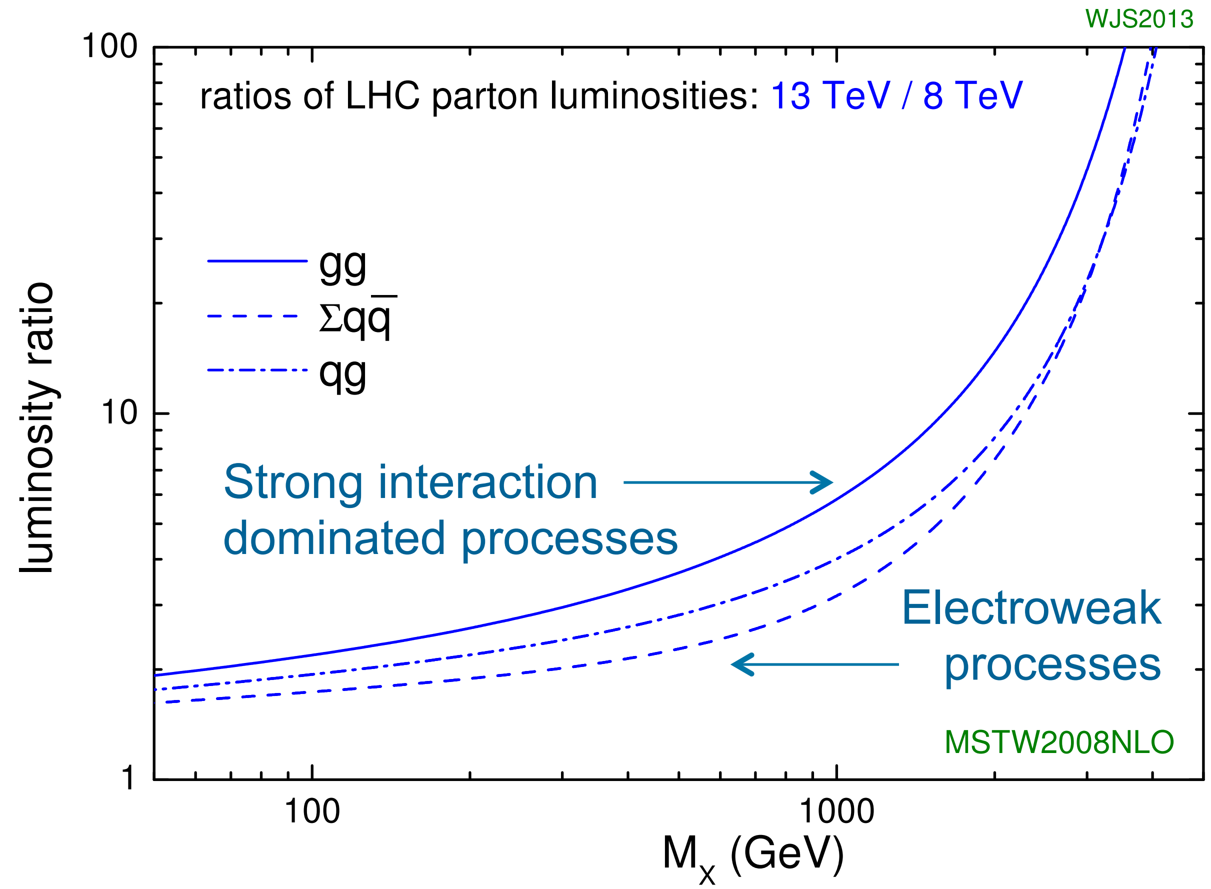
Signal triggers		
Jet Multiplicity	pT cut	|η|
6	45	3.2
5	55	

Background/support triggers	
Type	Purpose
Multijet (prescaled)	Efficiencies & Control regions
Single lepton	Control regions

Multijet trigger improvements in 2012



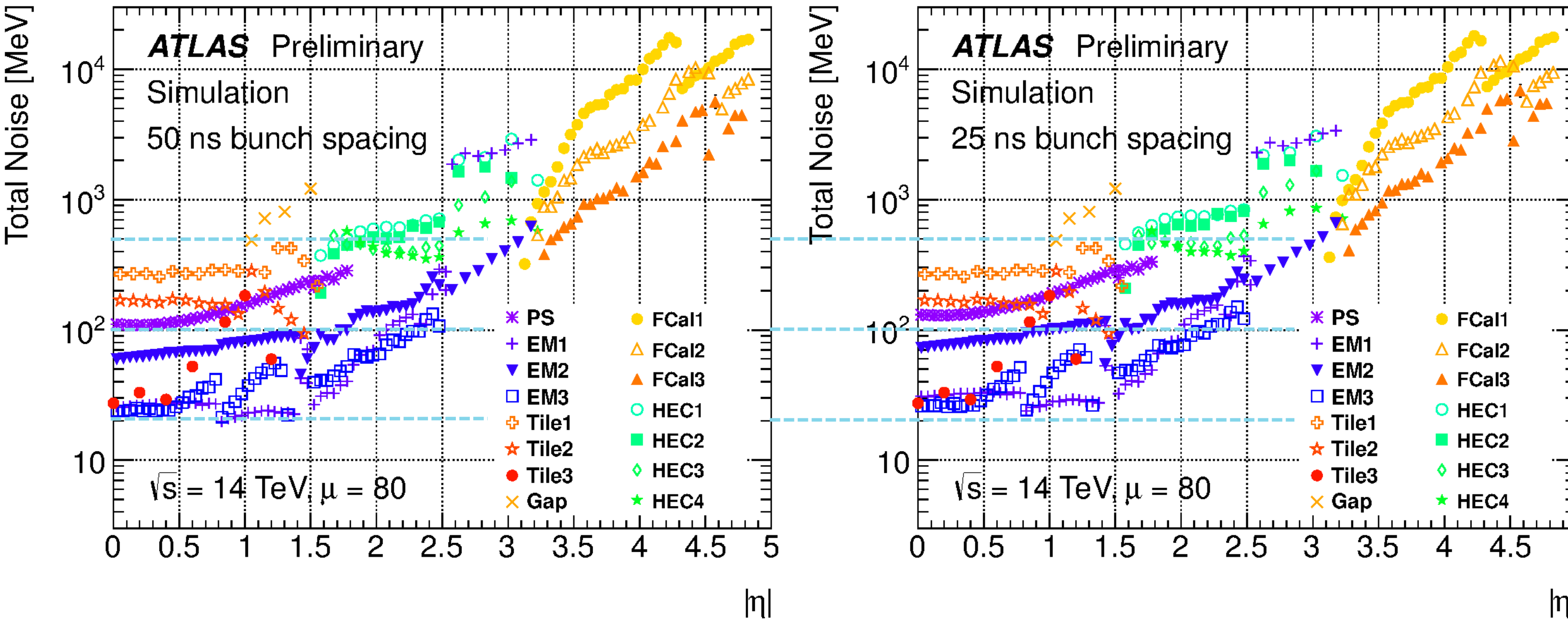
THE BENEFITS



THE CHALLENGES

The calorimeter

Simulated noise in the Liquid Argon and Tile calorimeters at the electron scale



THE 'SOLUTIONS'

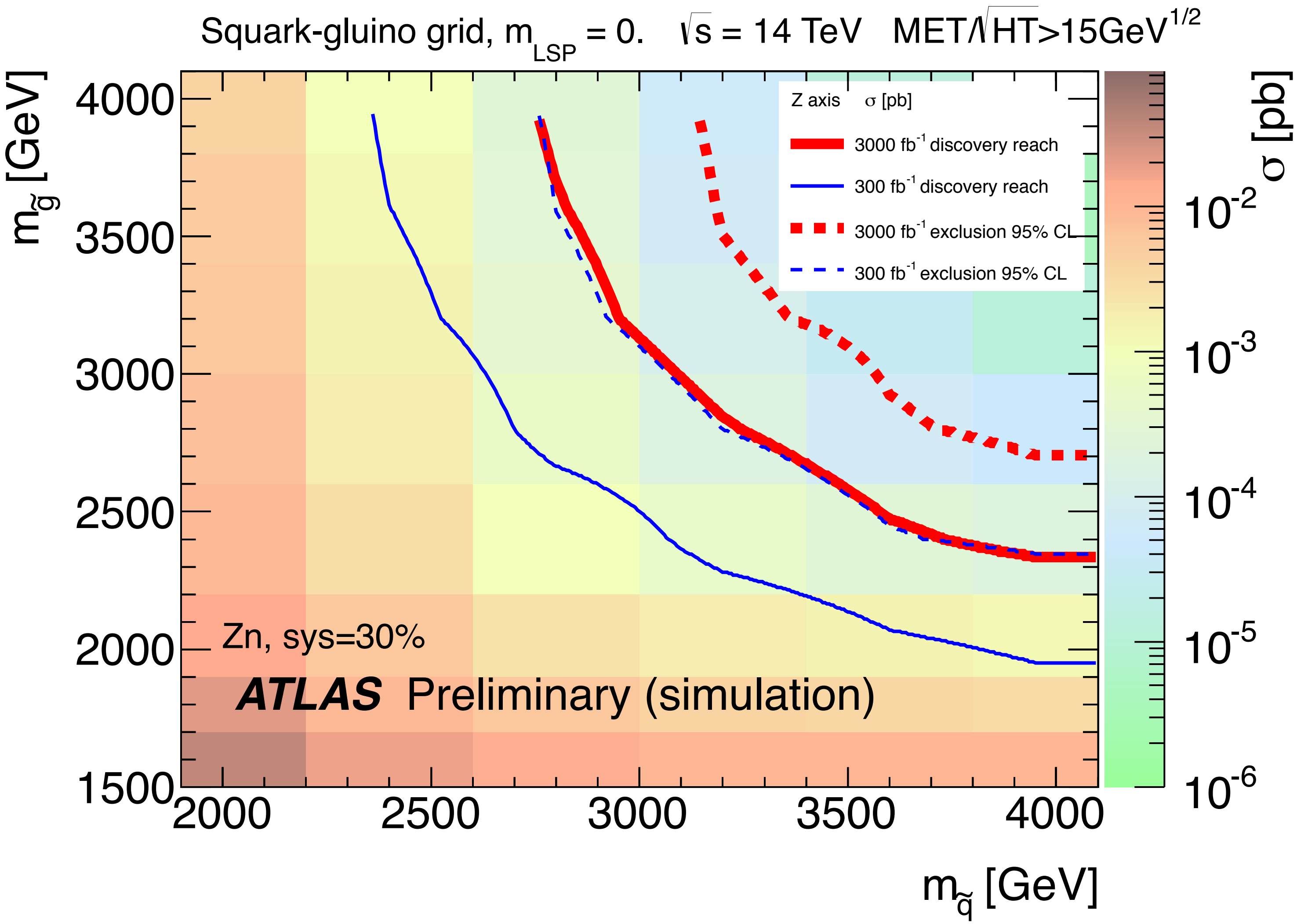
Detector extensions, e.g. extra muon chambers at $1.0<|\eta|<1.3$.

Ongoing trigger upgrade that will:

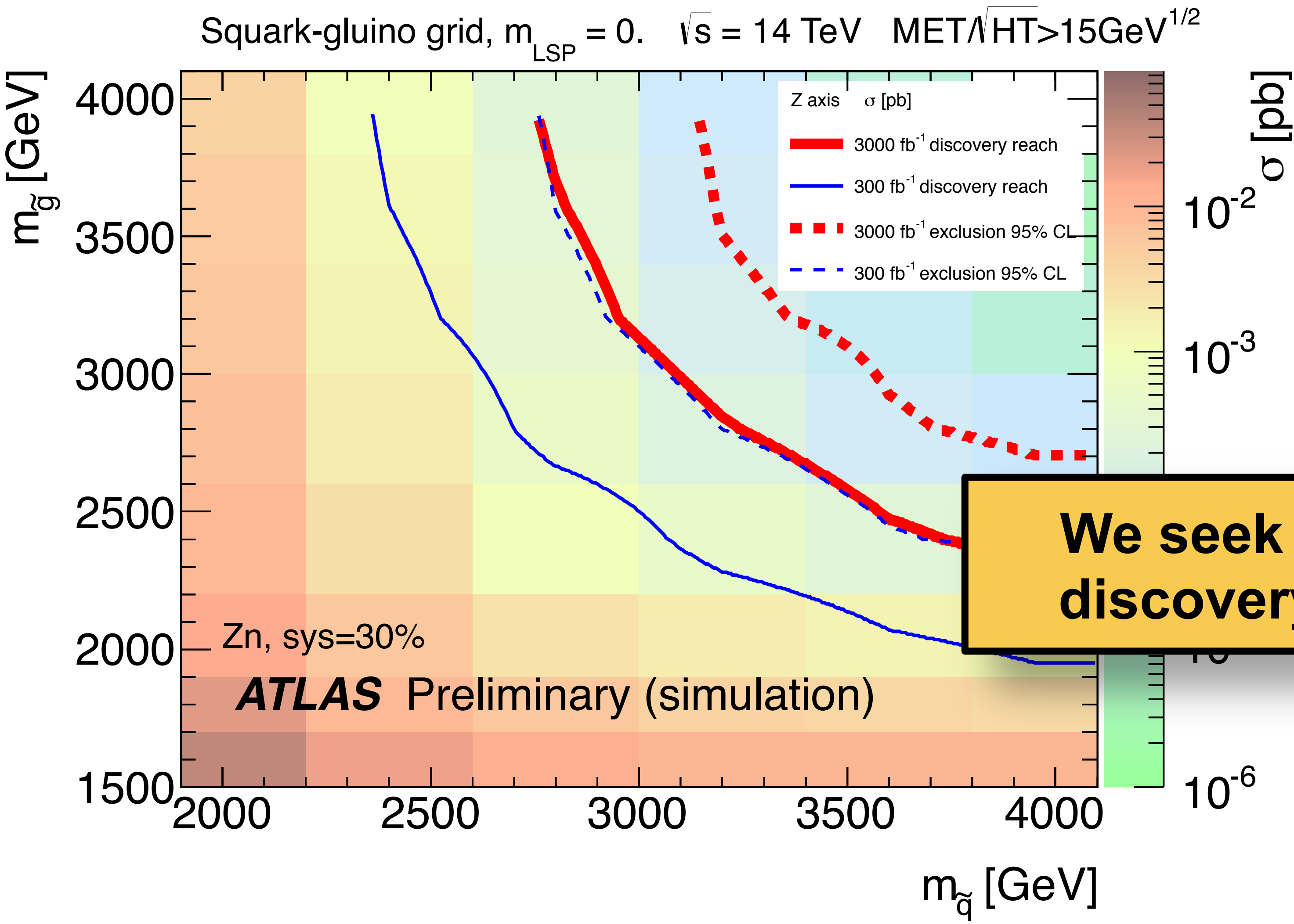
- Increase the peak L1 rate to 100kHz.
- Provide possibility to select on combined L1 quantities (angles, masses, etc).
- Provide tracks at the input of the HLT for better object ID.
- Ensure more efficient and flexible HLT reconstruction with a merged (L2 & EF) HLT.

Clever ideas for better & more robust object reconstruction.

THE PROSPECTS



THE PROSPECTS



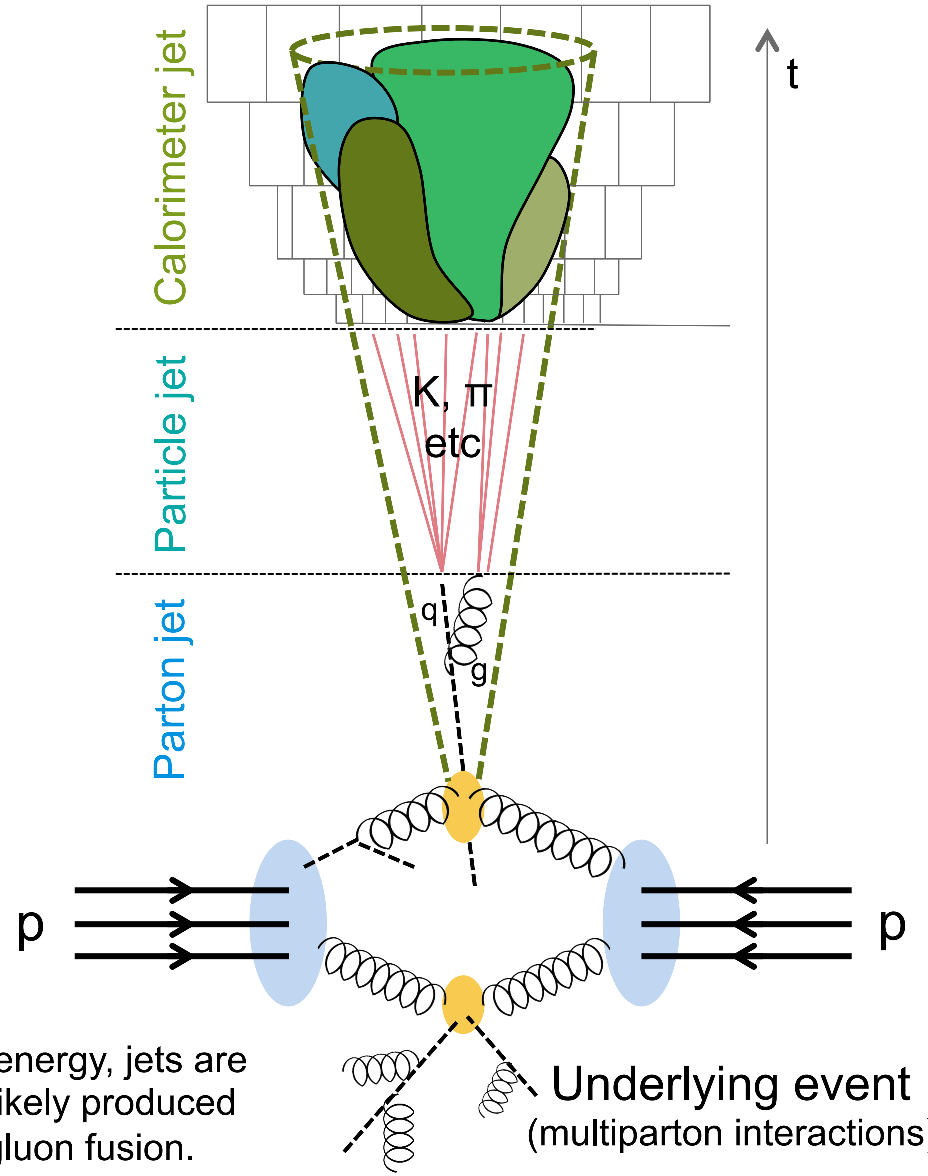
We seek a discovery.

JETS

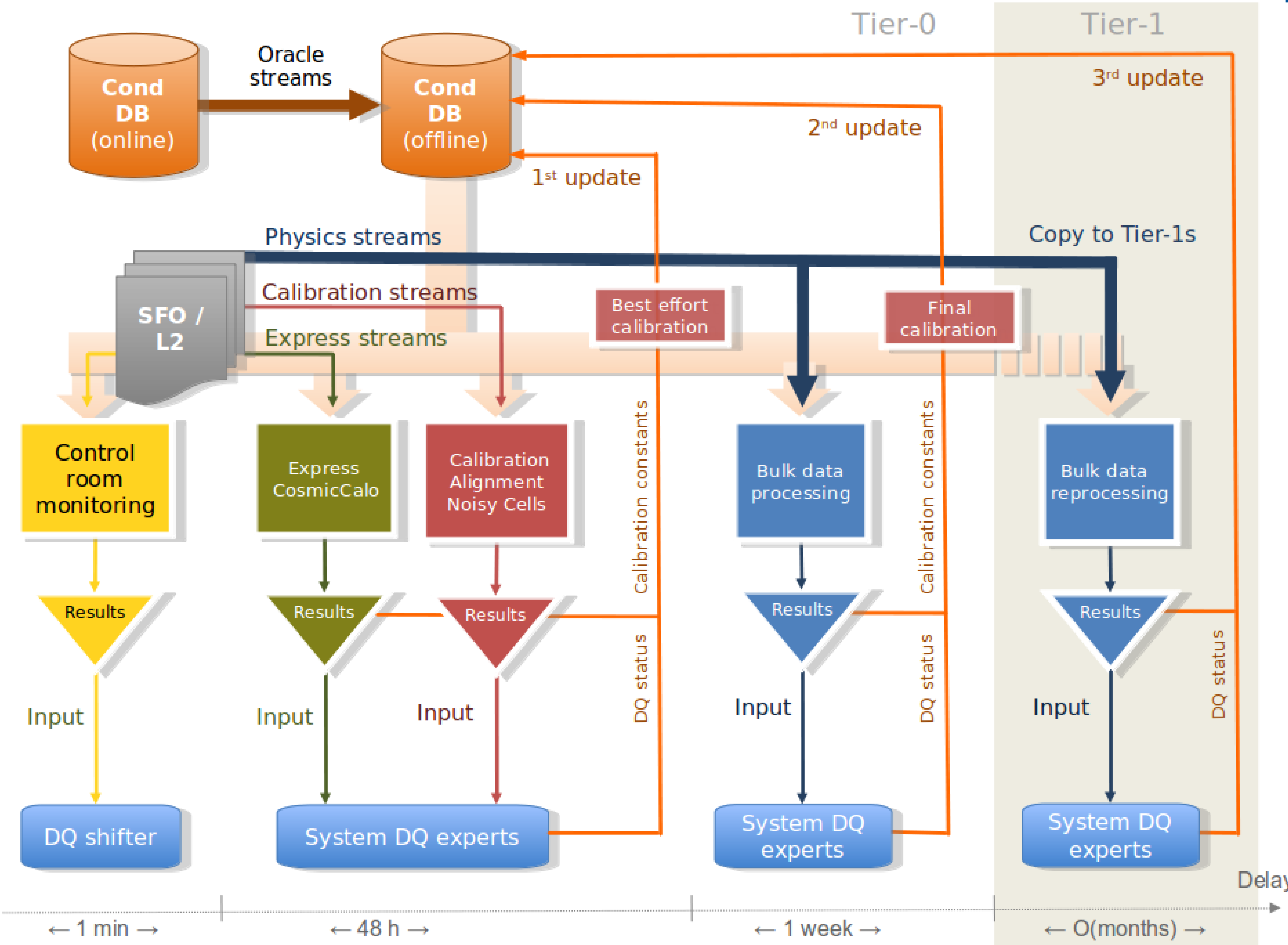
Detector inefficiencies
'Pile-up'
Electronic noise
Clustering, noise suppression
Dead material losses
Detector response
Algorithm efficiency

Algorithm efficiency
'Pile-up'
'Underlying event'

Physics process of interest

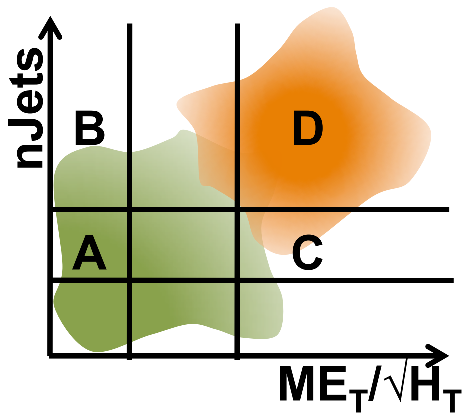


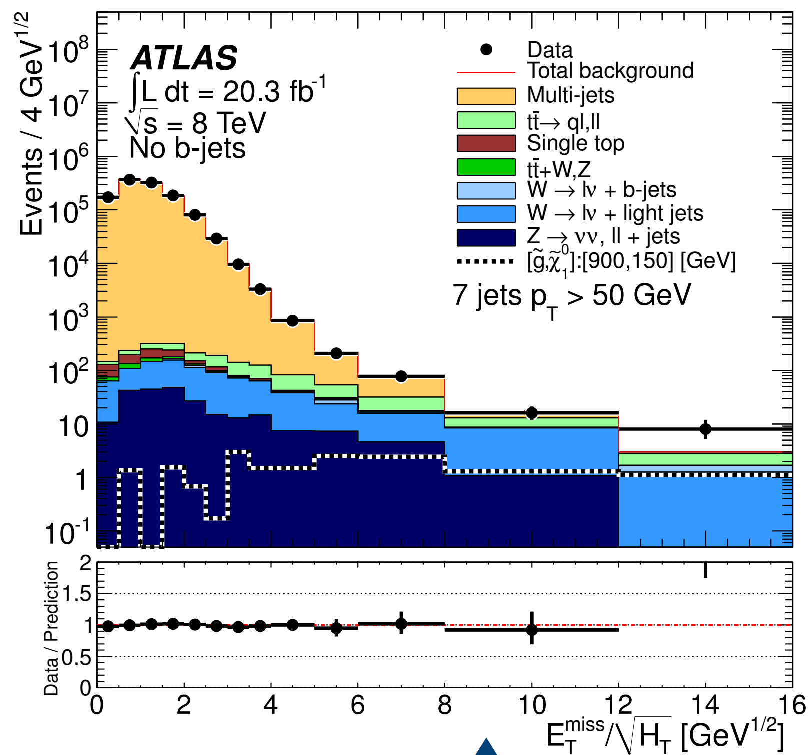
At low energy, jets are more likely produced by gluon fusion.


Tier-0
Tier-1
Cond DB (online)
Oracle streams
Cond DB (offline)
3rd update
2nd update
1st update
Physics streams
Copy to Tier-1s
SFO / L2
Calibration streams
Express streams
Best effort calibration
Final calibration
Control room monitoring
Express CosmicCalo
Calibration Alignment Noisy Cells
Calibration constants
Bulk data processing
Calibration constants
Bulk data reprocessing
Results
Results
Results
Results
Results
DQ status
DQ status
DQ status
Input
Input
Input
Input
Input
DQ shifter
System DQ experts
System DQ experts
System DQ experts
Delay
← 1 min →
← 48 h →
← 1 week →
← O(months) →

BACKGROUNDS & DETERMINATION

QCD & Hadronic ttbar

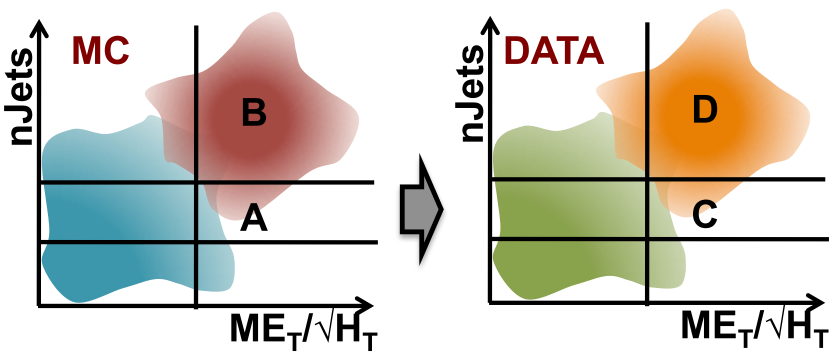


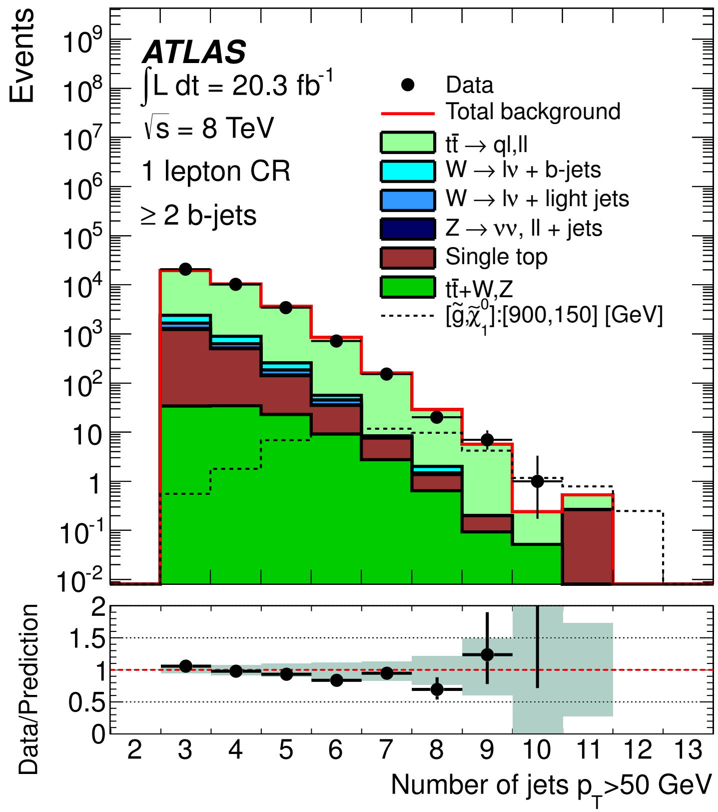


- Template extracted from '6j50' and validated in '7j50'.
- Discrepancies in control regions become uncertainties; dominant, on top of heavy flavor and 'leptonic' backgrounds.

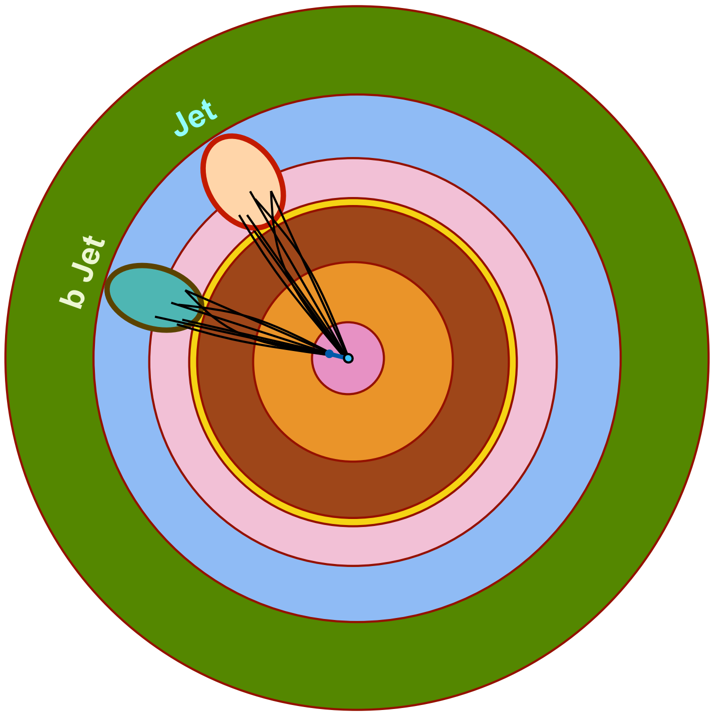
BACKGROUNDS & DETERMINATION

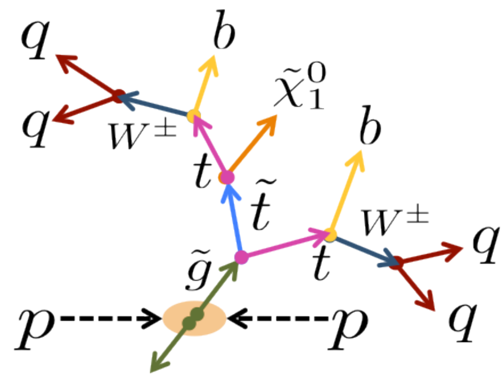
Non-full hadronic ttbar & V+jets

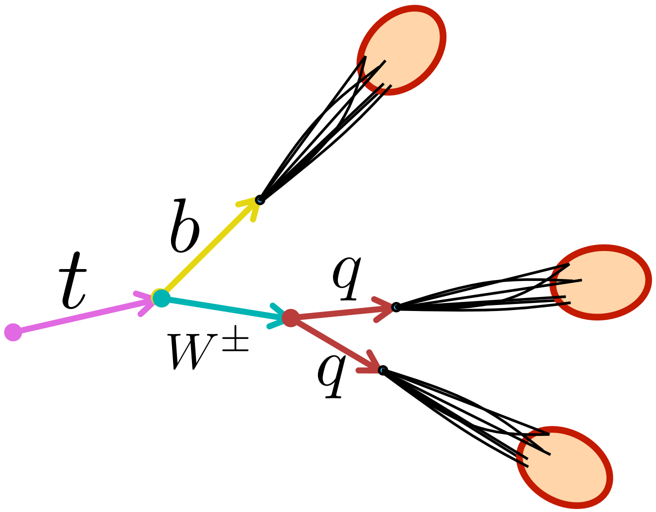




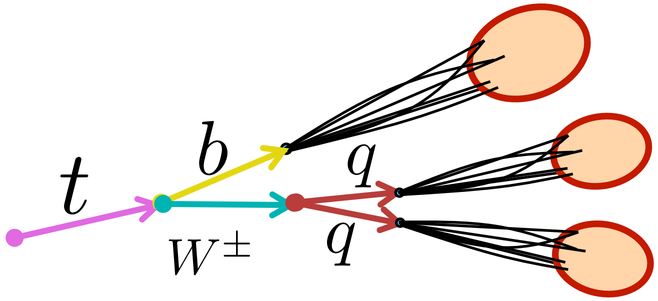
- Extracted from MC normalized on data.
- Uncertainties: JES/JER, b-tagging, pile-up and theory.


Jet
b Jet


q
q
b
$\tilde{\chi}_1^0$
$W^\pm$
t
b
$\tilde{t}$
$W^\pm$
q
$\tilde{g}$
t
p
p
q



t
b
$W^{\pm}$
q
q



t
b
$W^{\pm}$
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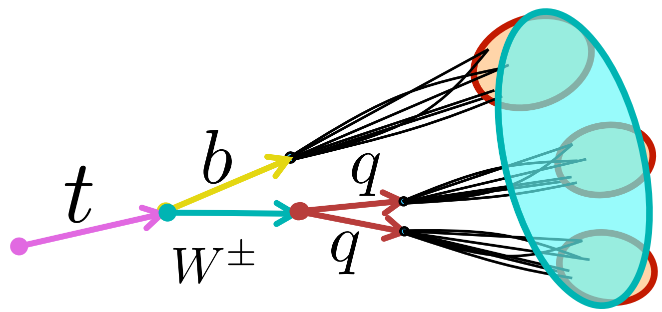
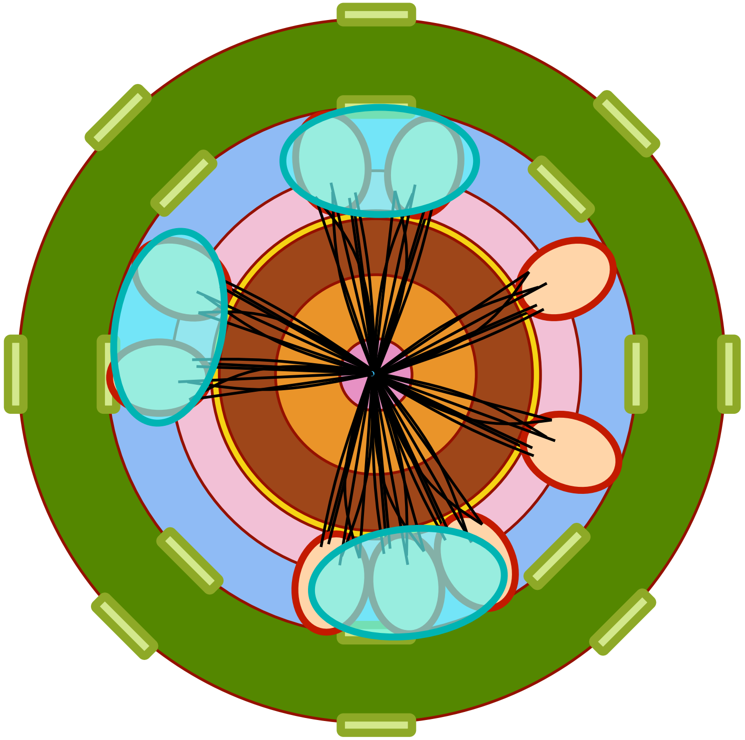
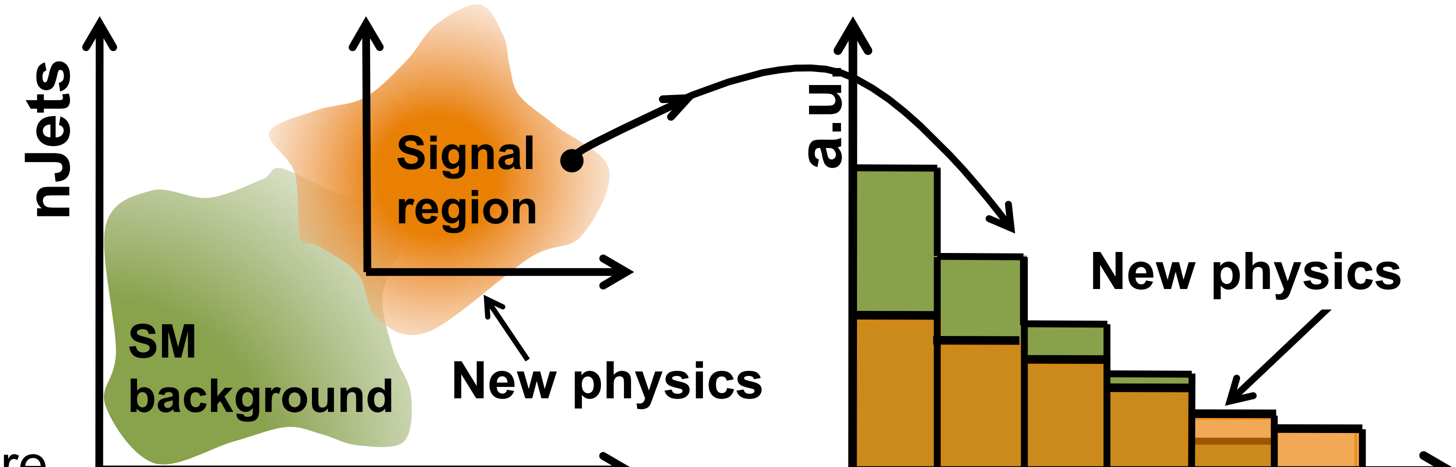


t
b
$W^{\pm}$
q
q



THE SUSY MULTIJET SEARCH



where
$H_T = \sum_j p_T^j$

$ME_T/\sqrt{H_T}$

Dominant background: SM multijet production; fake MET from jet mis-measurements. Estimated using a combination of data-driven methods and Monte-Carlo based methods. Validated in control regions. ***Typical treatment of (SUSY) searches.***

Why $ME_T/\sqrt{H_T}$?
⇒ a measure of ME_T in units of standard deviations of the fake ME_T

$$\frac{\sigma_{p_T}}{p_T} = \frac{N}{p_T} \oplus \frac{S}{\sqrt{p_T}} \oplus C$$