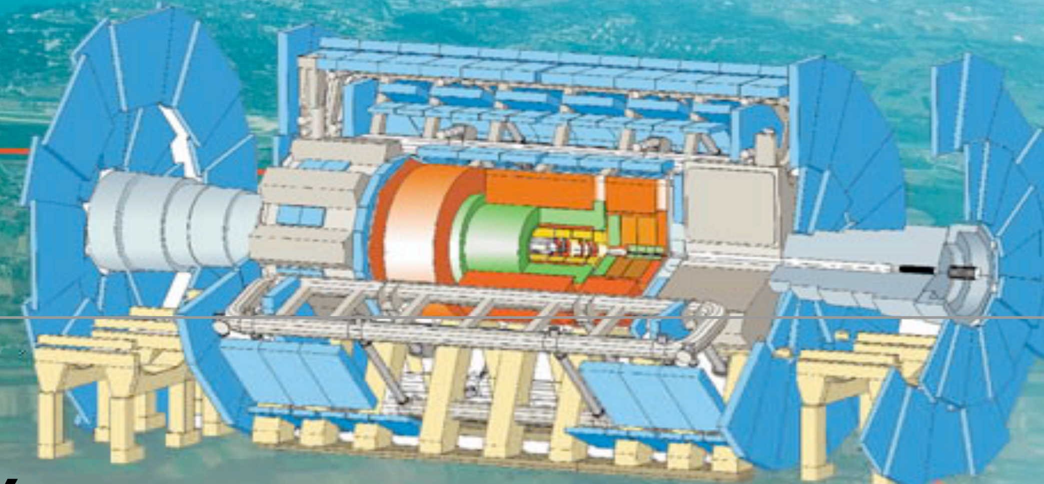
Top Quark physics with ATLAS @ LHC

LPNHE, Paris, 24th March 2011



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Outline

- **Why top quark?**
- **The LHC is back:** a top factory at work
- **The ATLAS detector**: a top observer
- Measuring **top quark production** (and **mass)**
- Towards new physics with top quark

Data results: hot off the press!

Most recent: approved 48 hours ago. Oldest ~ 1 week.

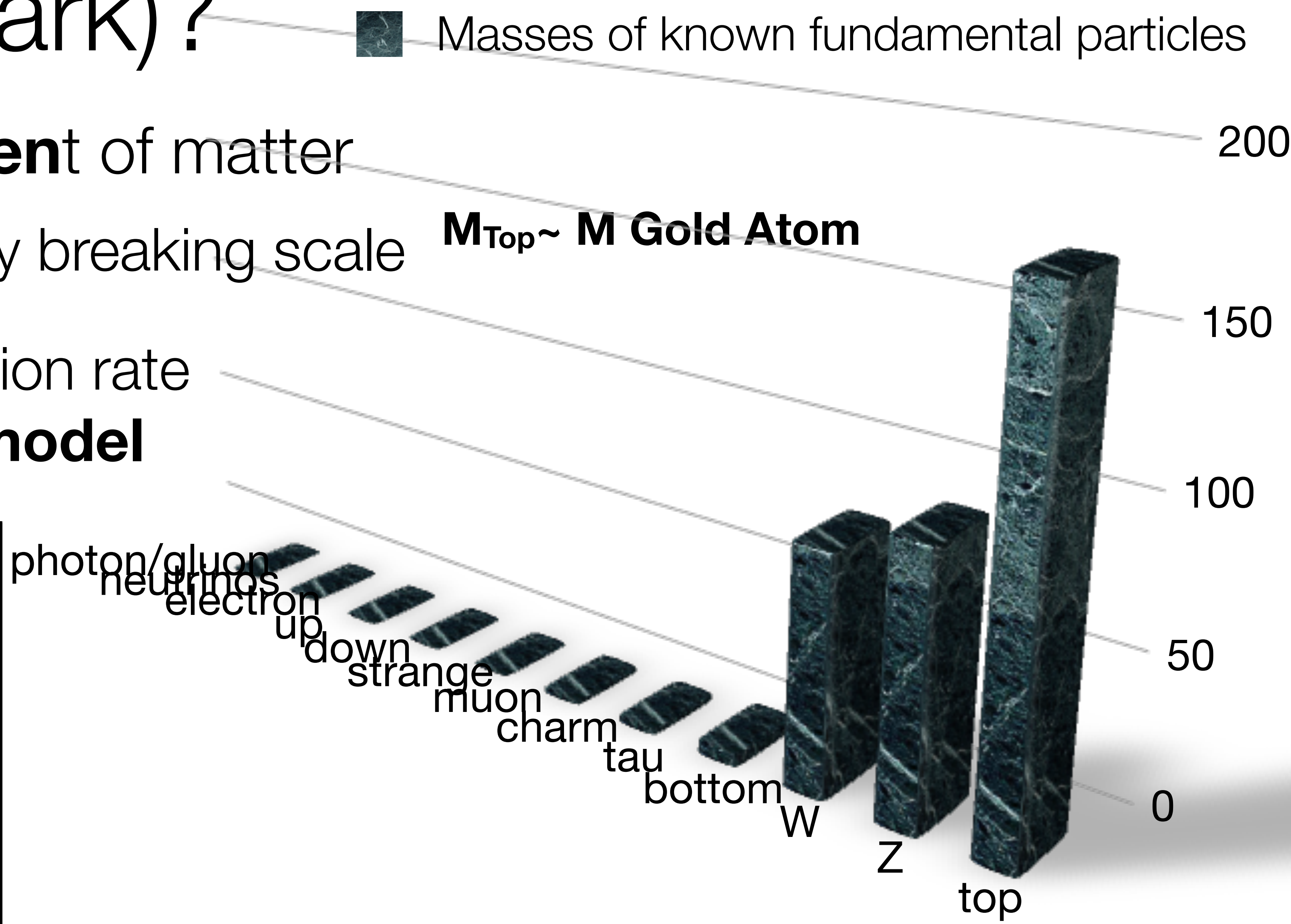
Disclaimer: wide field, concentrate on selected topics

Why Top (quark)?

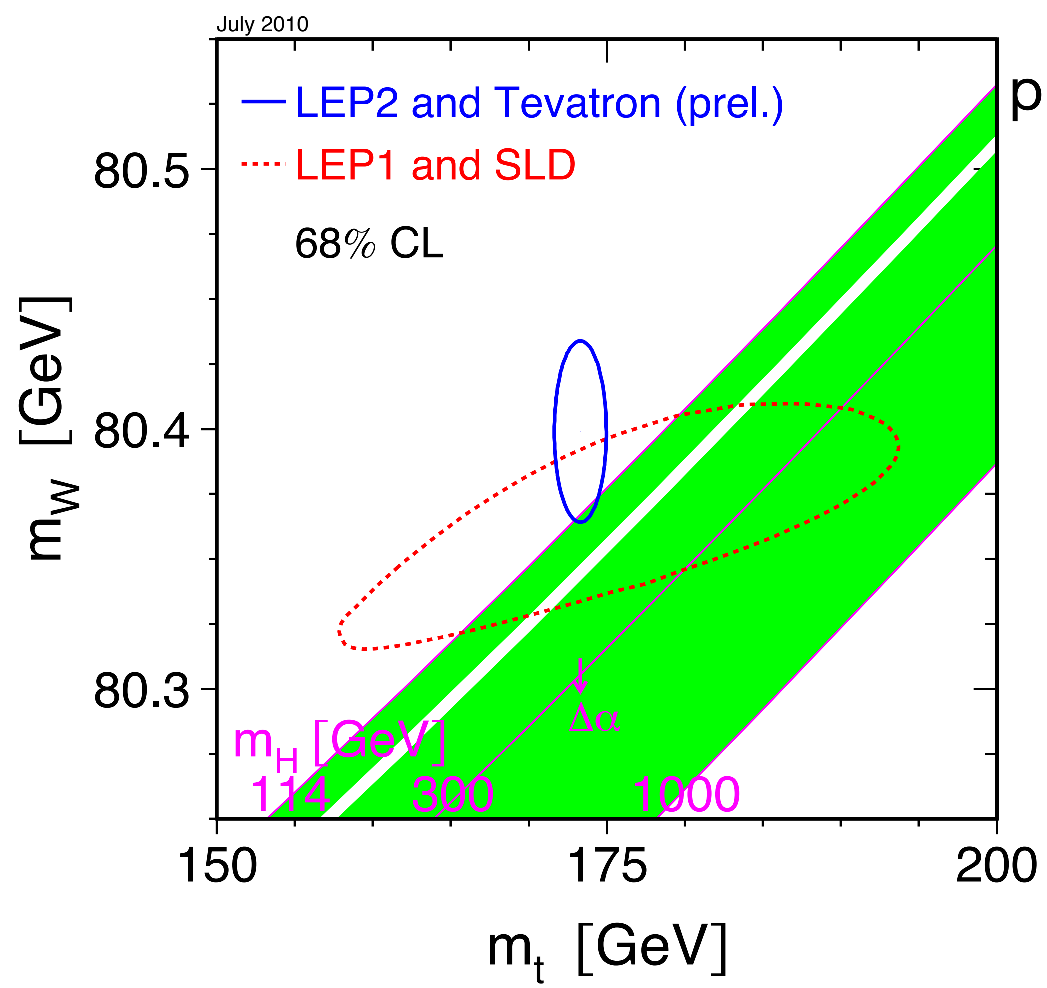
Most massive constituent of matter

M_{top}~ electroweak symmetry breaking scale

M_{Top}~ M Gold Atom

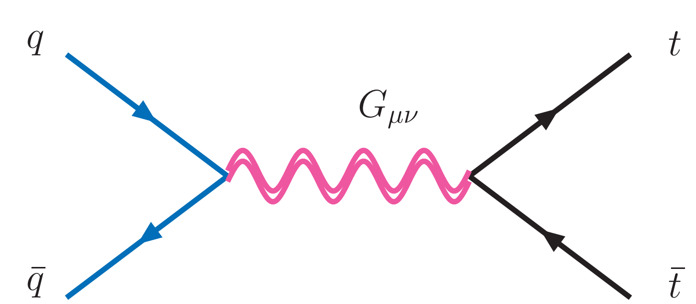


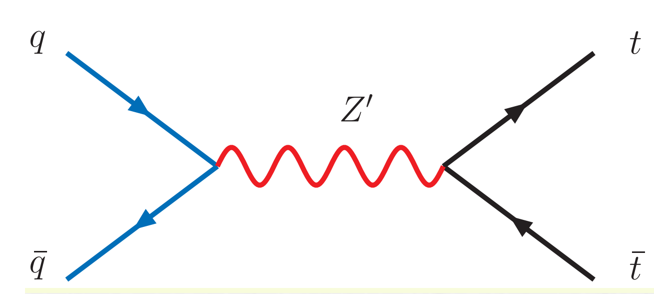
Decay and strong production rate are **tests of standard model**



Background to possible **new physics** (Higgs, SUSY)

Various scenarios with **direct/indirect coupling to new physics:** from extra dimensions to new strong forces

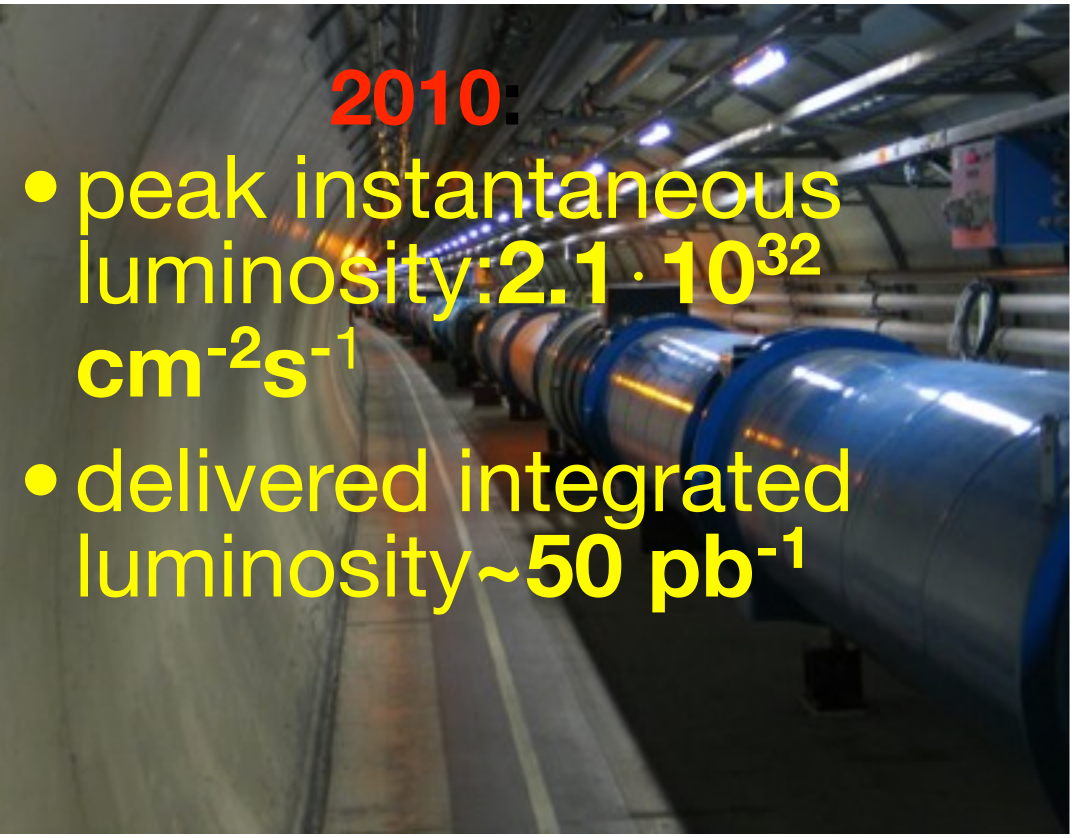


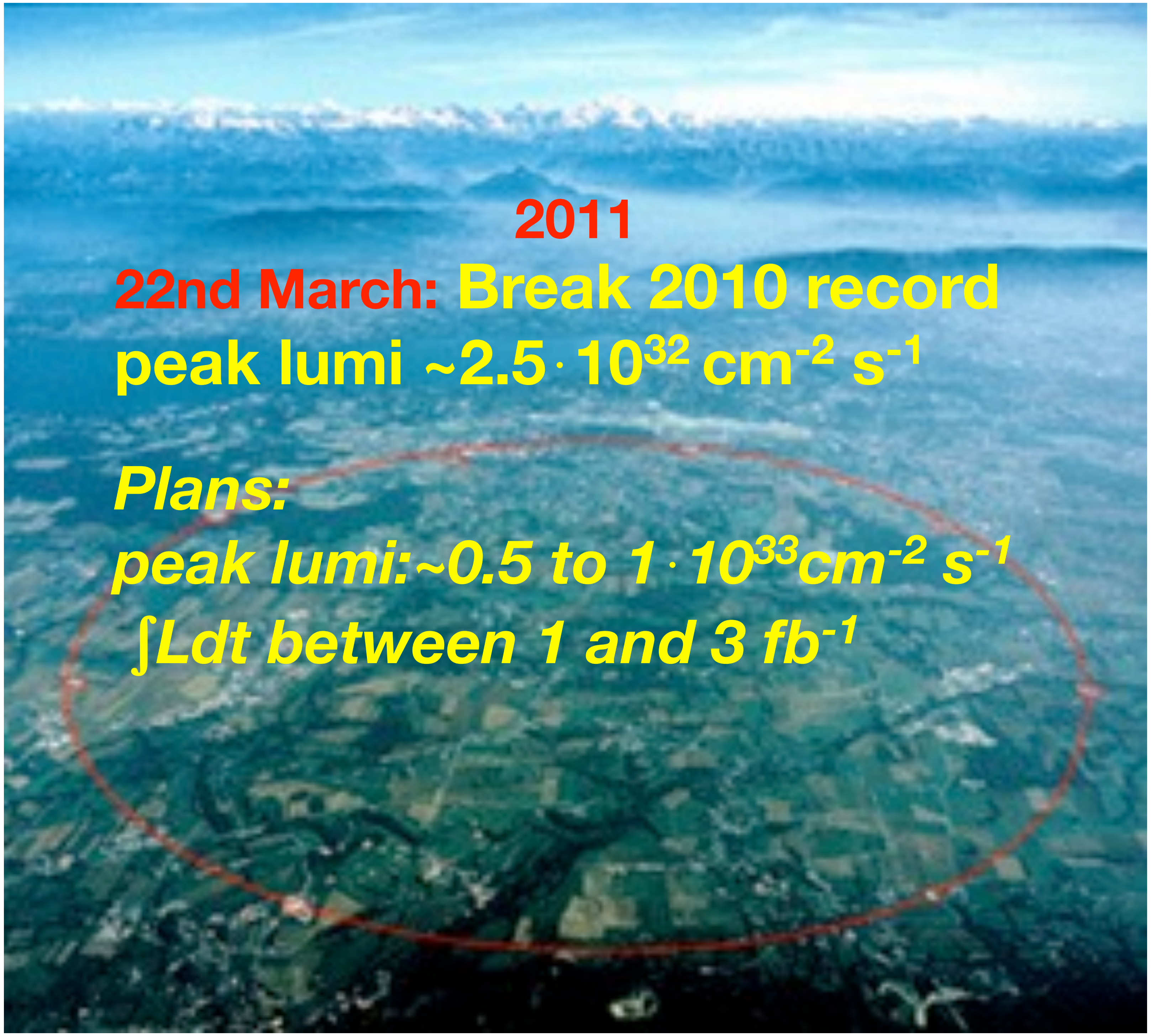


LHC : a *Top* producer

counter-rotating high intensity proton bunches colliding with 3.5 TeV/beam (E_{CM}=7 TeV) in 27 Km tunnel

eventually: E_{CM}=14TeV (7 TeV per beam, design value)

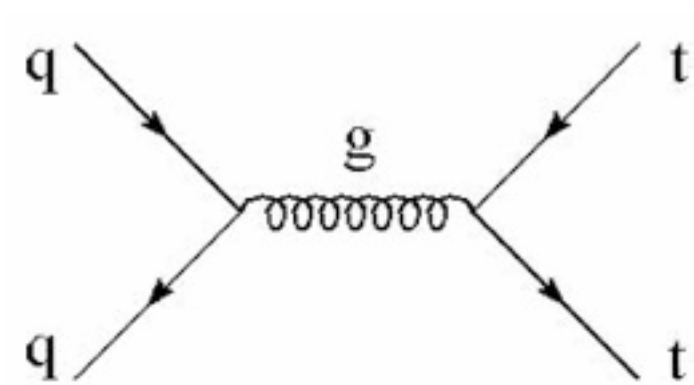




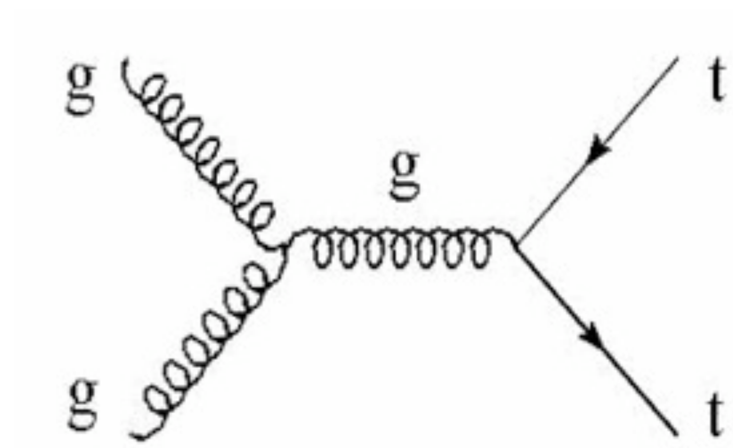
Top quark (pair) production @ E_{CM} = 7 TeV LHC

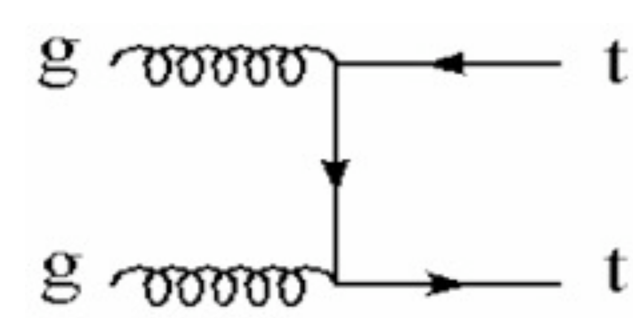
proton-proton collisions

qq annihilation



gluon fusion





~30%

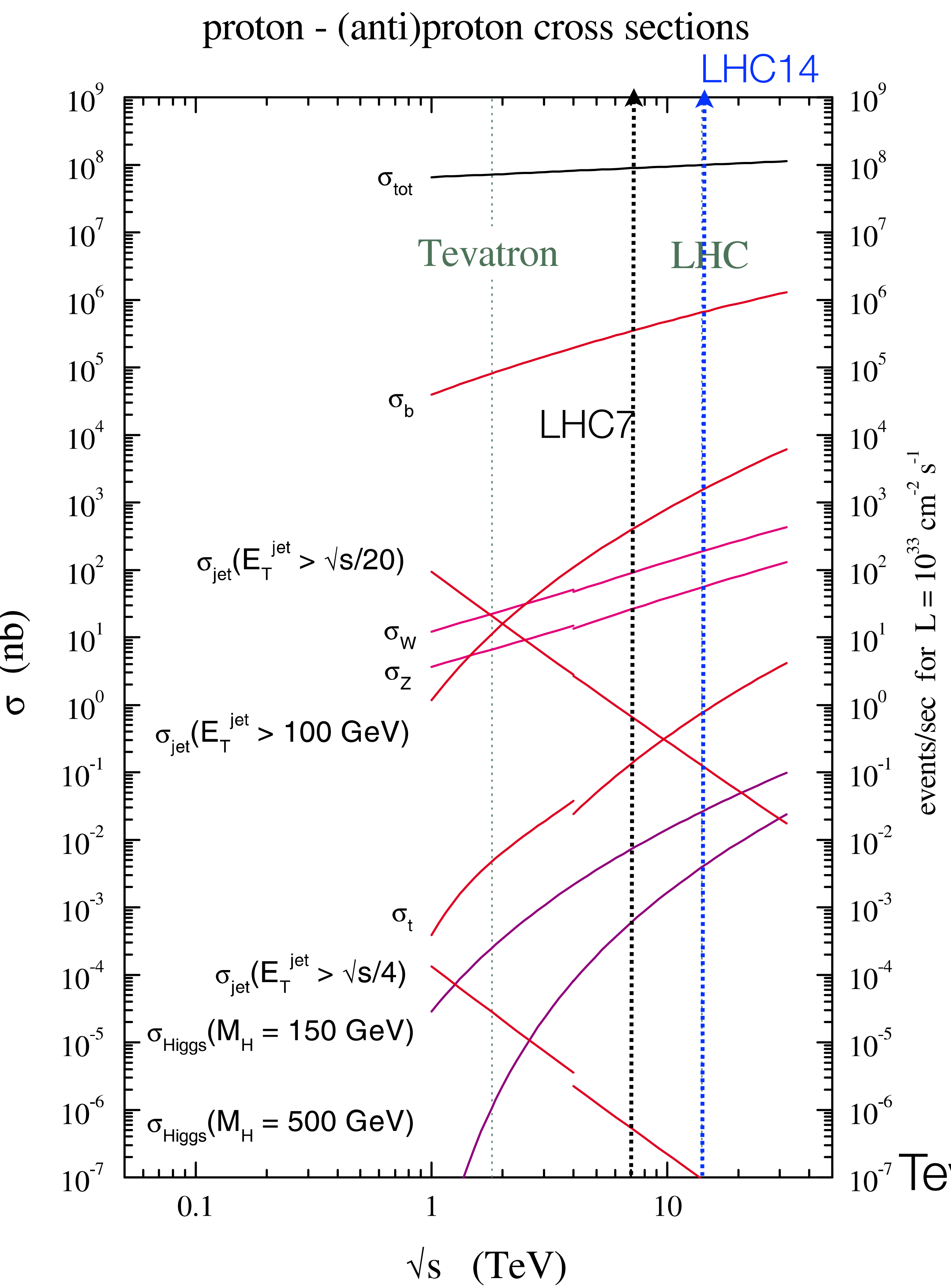
~70%

total xsec $=165^{+11}_{-11}$ pb

@ 14 TeV : qq~10%, gg ~90%

top is also singly produced, but ***focus on dominant pair production***

Top @ LHC: in the context



$t\bar{t}$ cross section

$\sqrt{s}$(TeV)	xsec (pb)
1.96 ($p\bar{p}$)	~7
7 (pp)	~165
14 (pp)	~900

Rate at L= $10^{33}\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

0.2Hz

0.9Hz

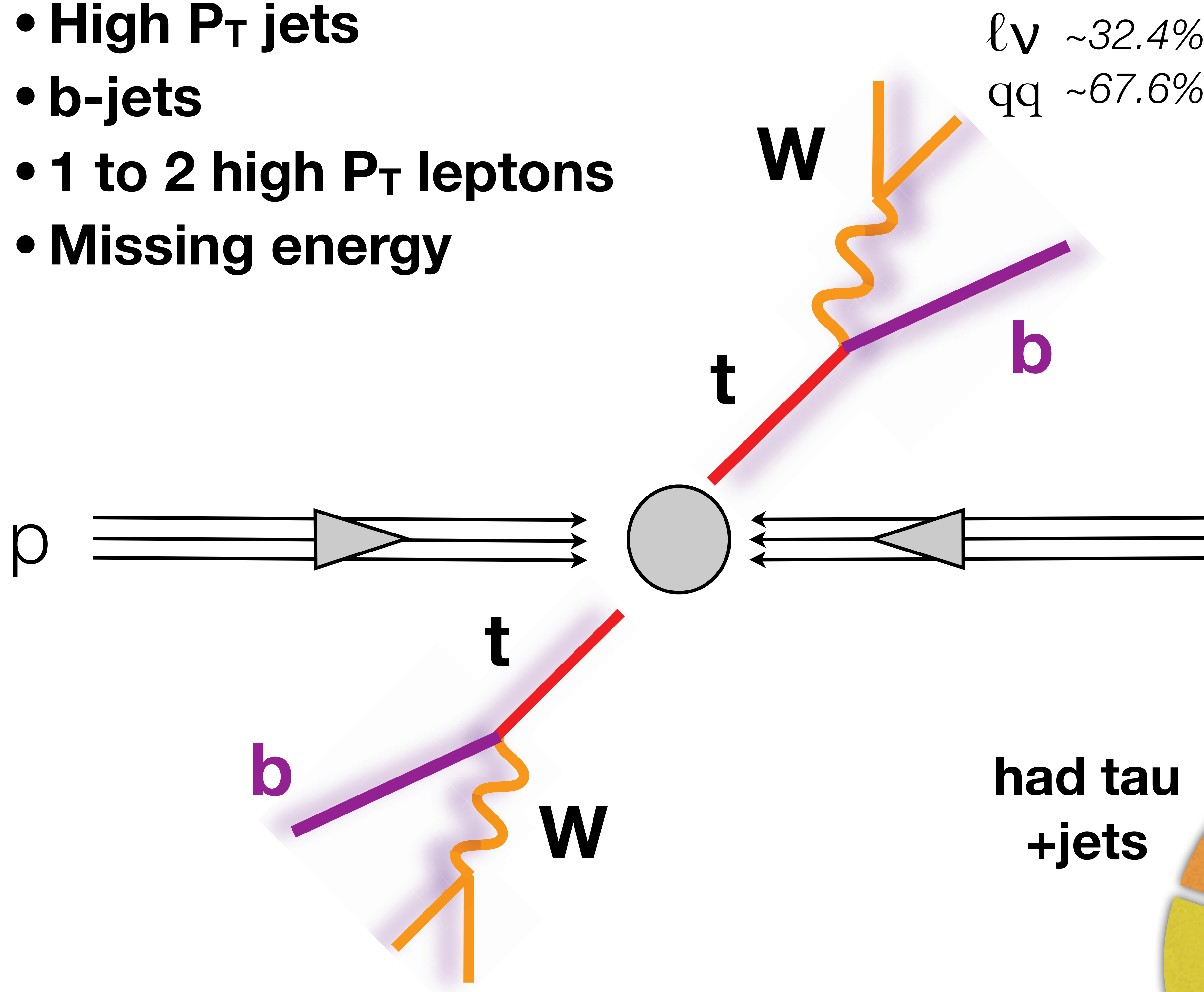
Theory uncertainty: ~ 8 to 6% at Tevatron, 6 to 4% at LHC

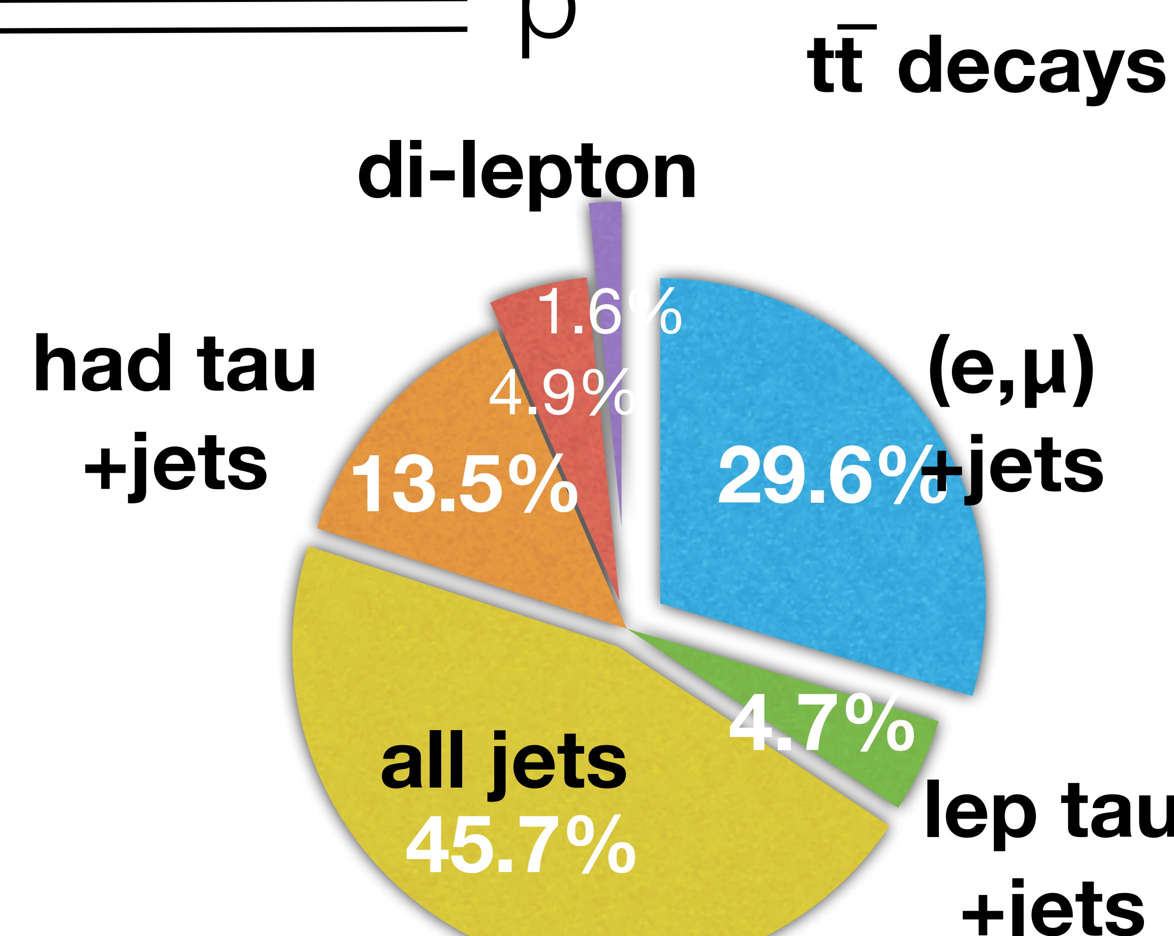
for $\int Ldt$ =1 fb^{-1} @ 7TeV, expect $16*10^4$ events

Tevatron: 9.4 fb^{-1} on tape, expect ~ $6.6*10^4$ events

Top signatures

- **High P_T jets**
- **b-jets**
- **1 to 2 high P_T leptons**
- **Missing energy**

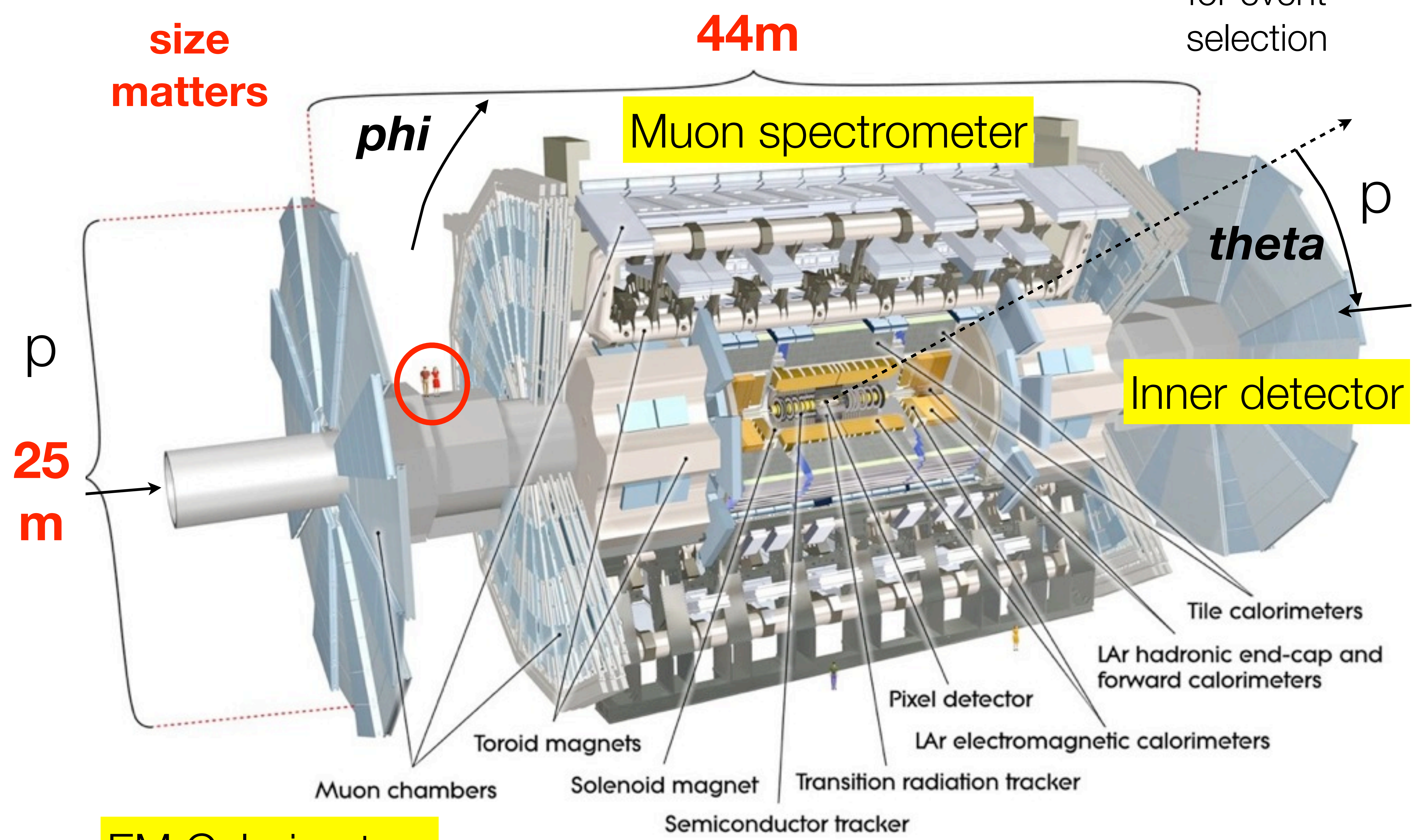




bkgs_tt̄: W/Z(+jets), single top, QCD, Di-bosons

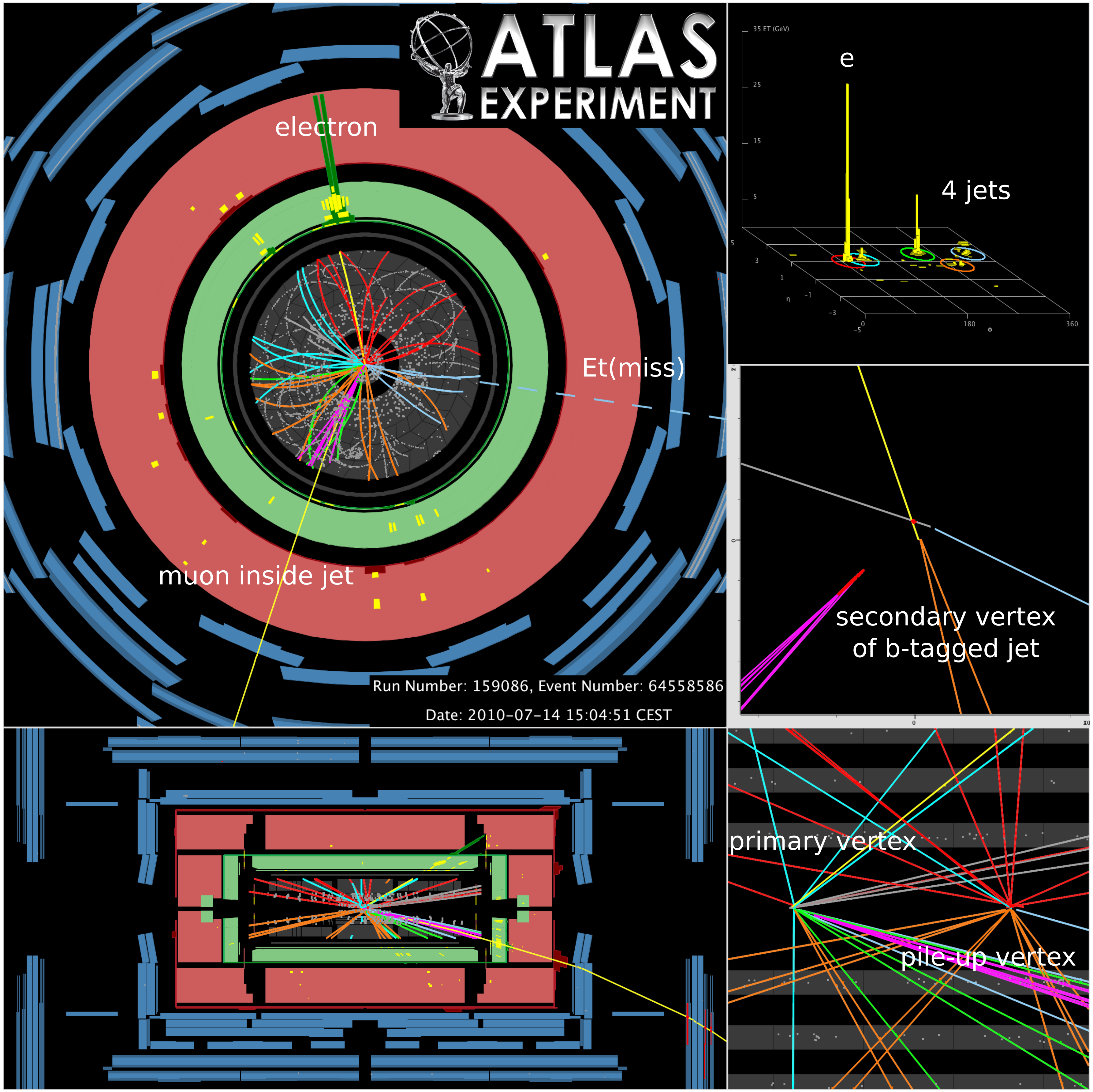
***ATLAS* : a *Top* observer**

3 trigger levels for event selection



η= pseudorapidity =-ln (tan(theta/2))

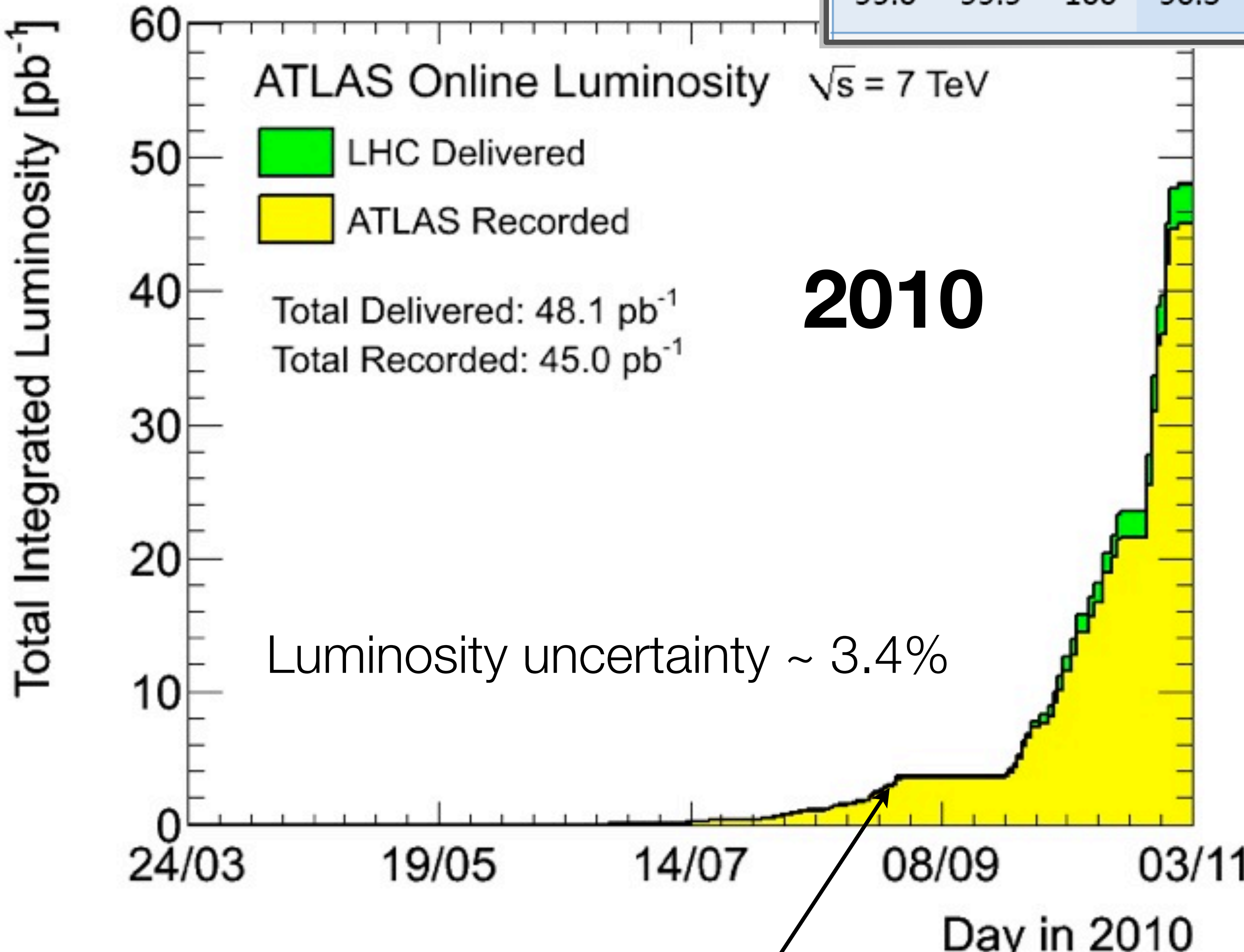
***ATLAS* : a *Top* observer.....**



Top events are real commissioning tool: full detector at play

...with excellent data taking performance

Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC
99.0	99.9	100	90.5	96.6	97.8	94.3	99.9	99.8	96.2	99.8



Data sample for first top paper~3 pb^{-1}

For top analyses using 35 pb^{-1}

expect ~5700 $t\bar{t}$ events

2011

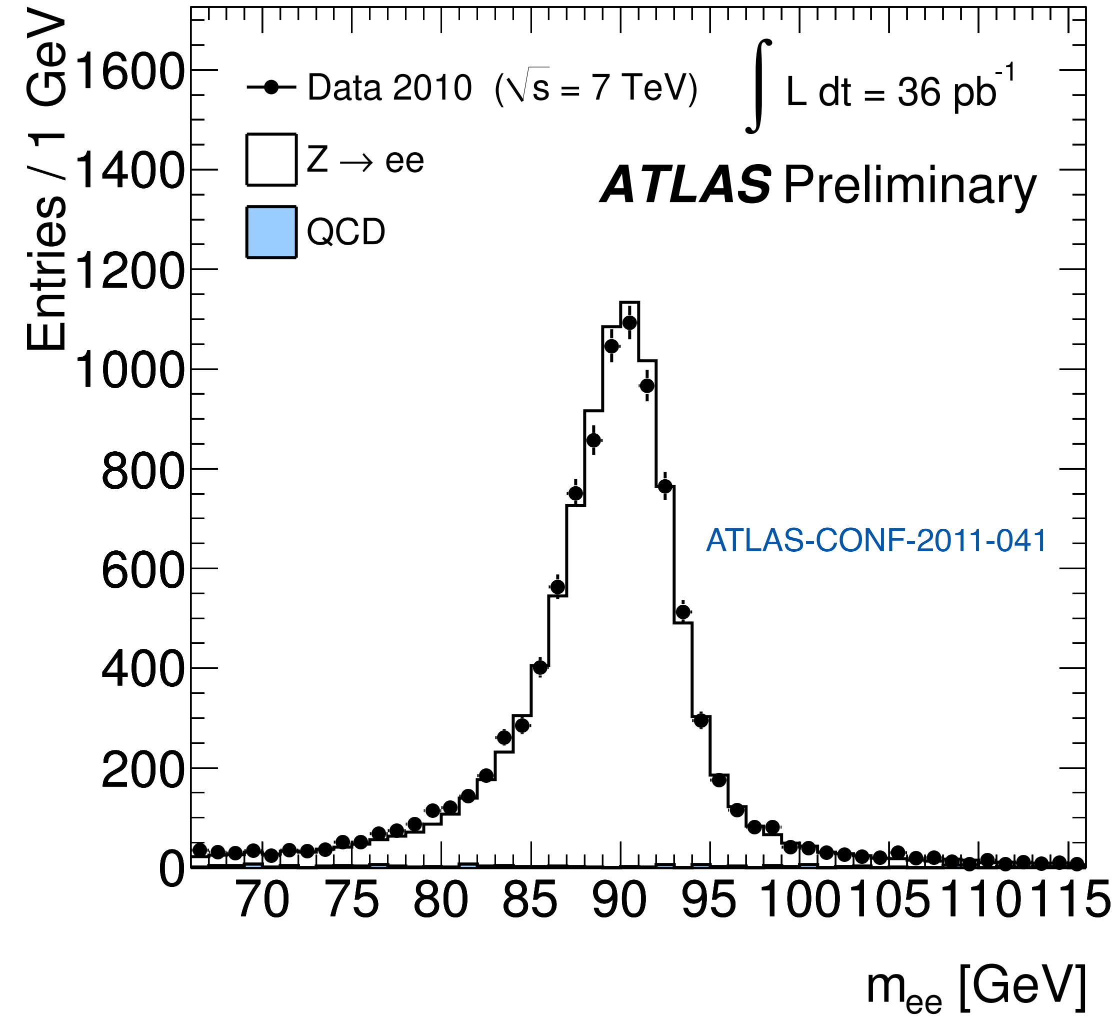
Already collected ~ a few pb^{-1}

Ingredients I : leptons

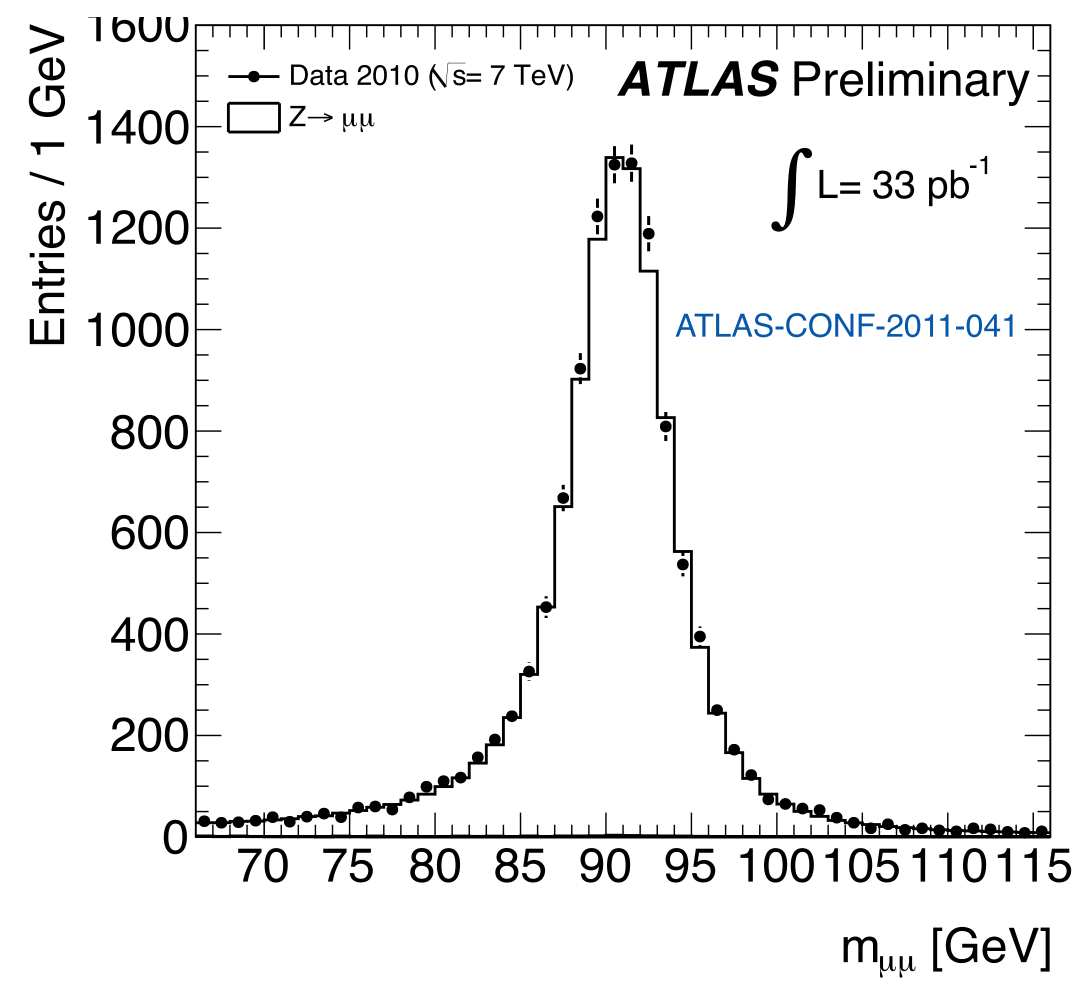
- Electrons

  * $|\eta_{cluster}| \notin$ [1.37,1,52]

  - **tight definition** using shower shape variables, track quality, track-cluster matching, E/p, transition radiation
  - **isolated**
  - **central***: $|\eta_{cluster}|<2.4$, $p_T>20$ GeV
  - remove close-by duplicate jets



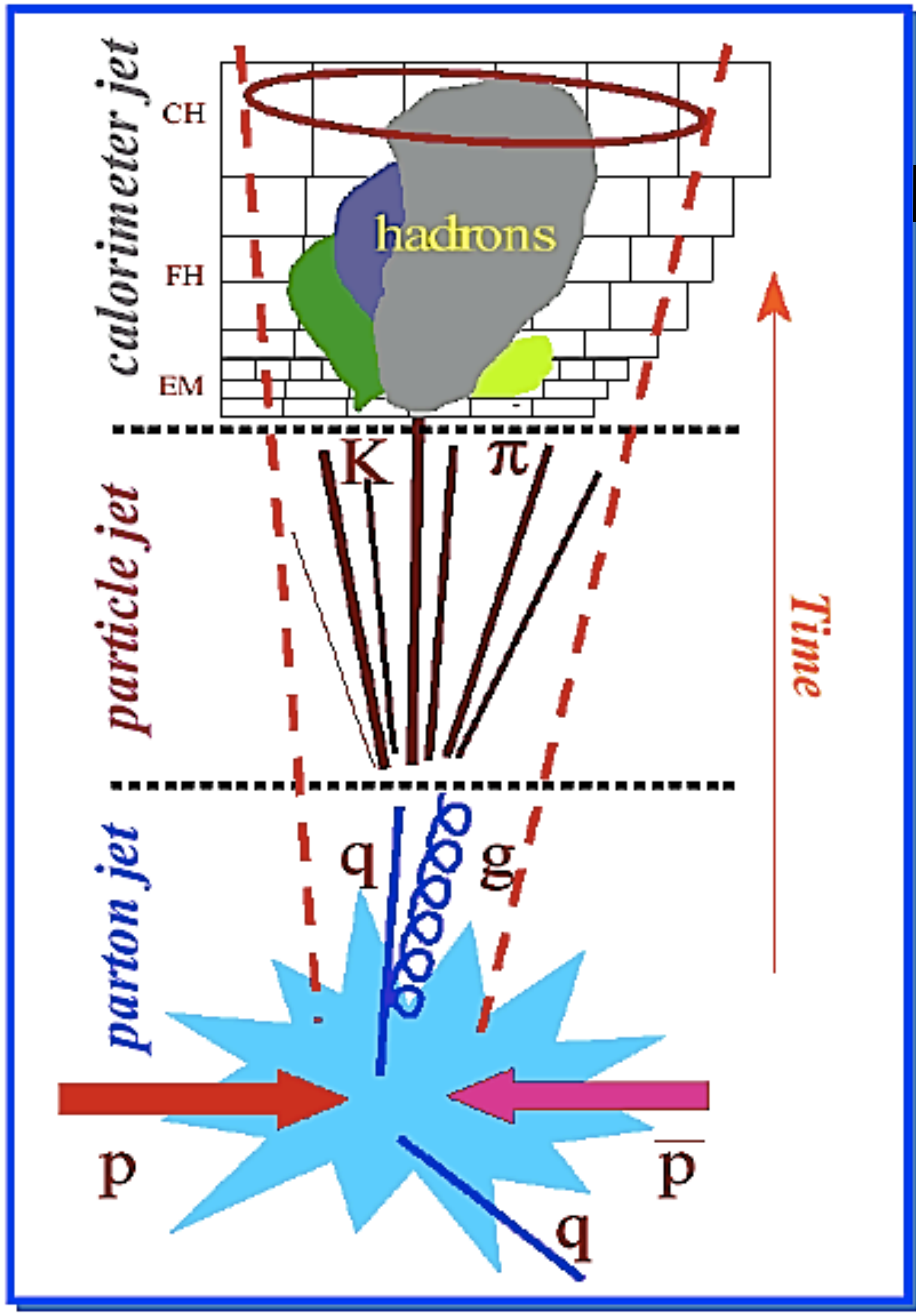
- Muons
  - **combined** fitted **track**
  - **isolated**
  - **central** $|\eta_{track}|<2.5$, $p_T>20$ GeV
  - **suppress heavy flavour decays**: no muon within DR< 0.4 of a jet



scale factors to correct small data/MC mismatch

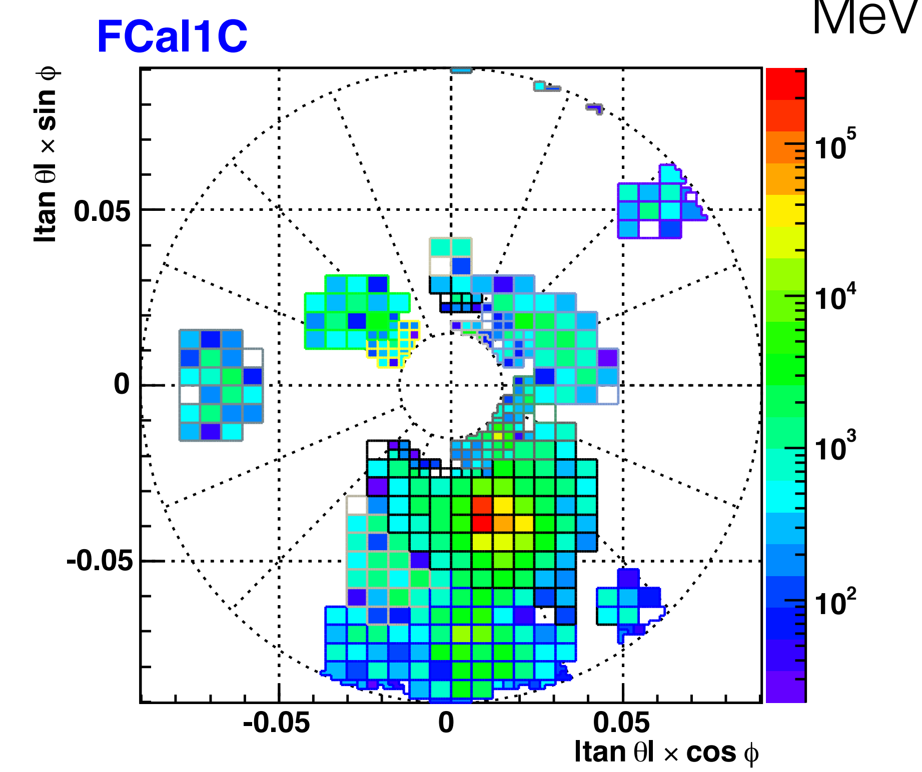
Ingredient: jets

- set of colour-less particles “remembering” momentum/colour flow from parton interaction

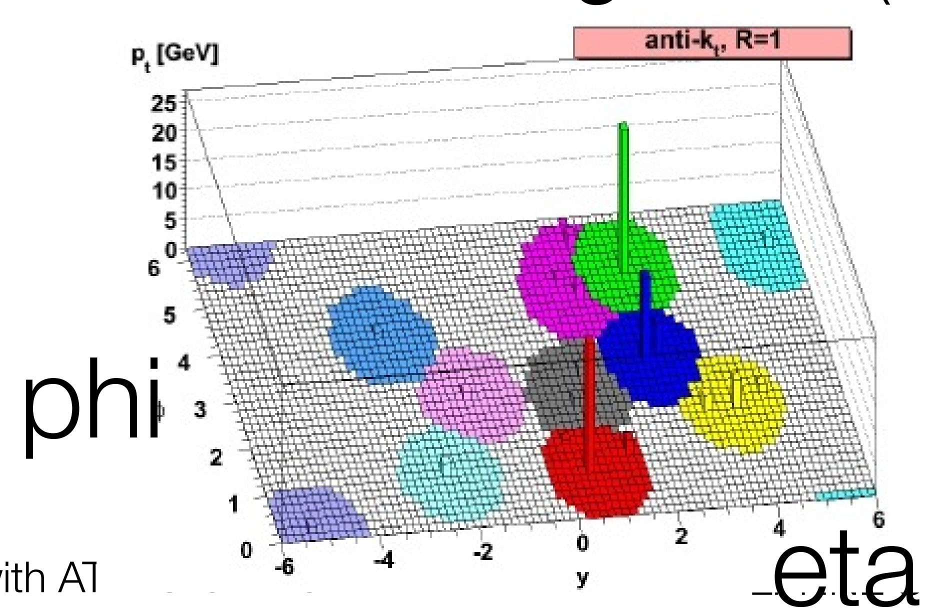


Cluster significant (E_{cell} / exp_noise_{cell}) energy deposits in calorimeters

Simulated QCD di-jet



clusters → jet
with **anti-k_T algorithm**(R=0.4) *(Cacciari,Salam, Soyez,2008)*

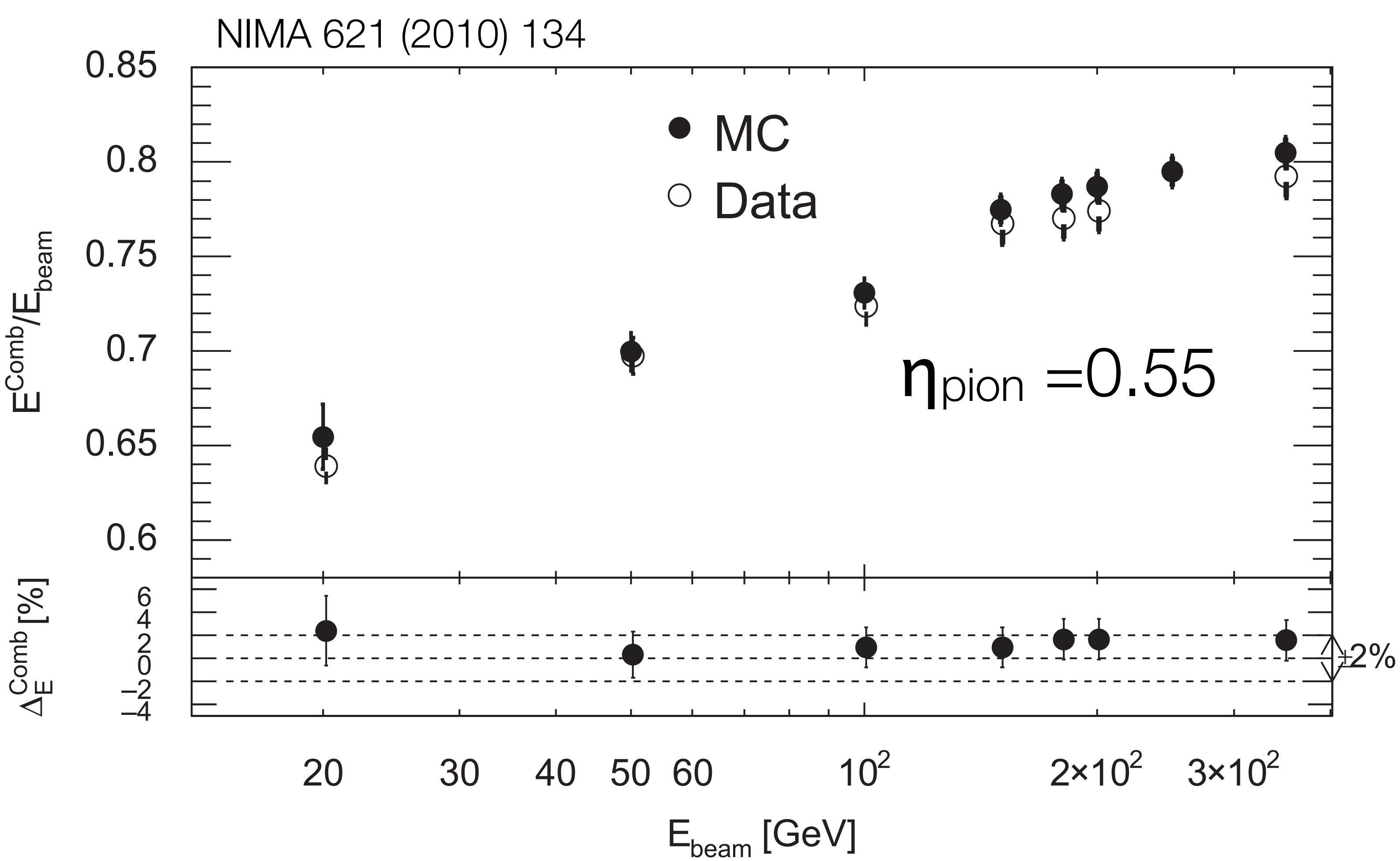


“hard stuff clusters with nearest neighbour”

Ingredients II : jets (in the making)

Extensive validation of simulation in test-beam data →good collision data description

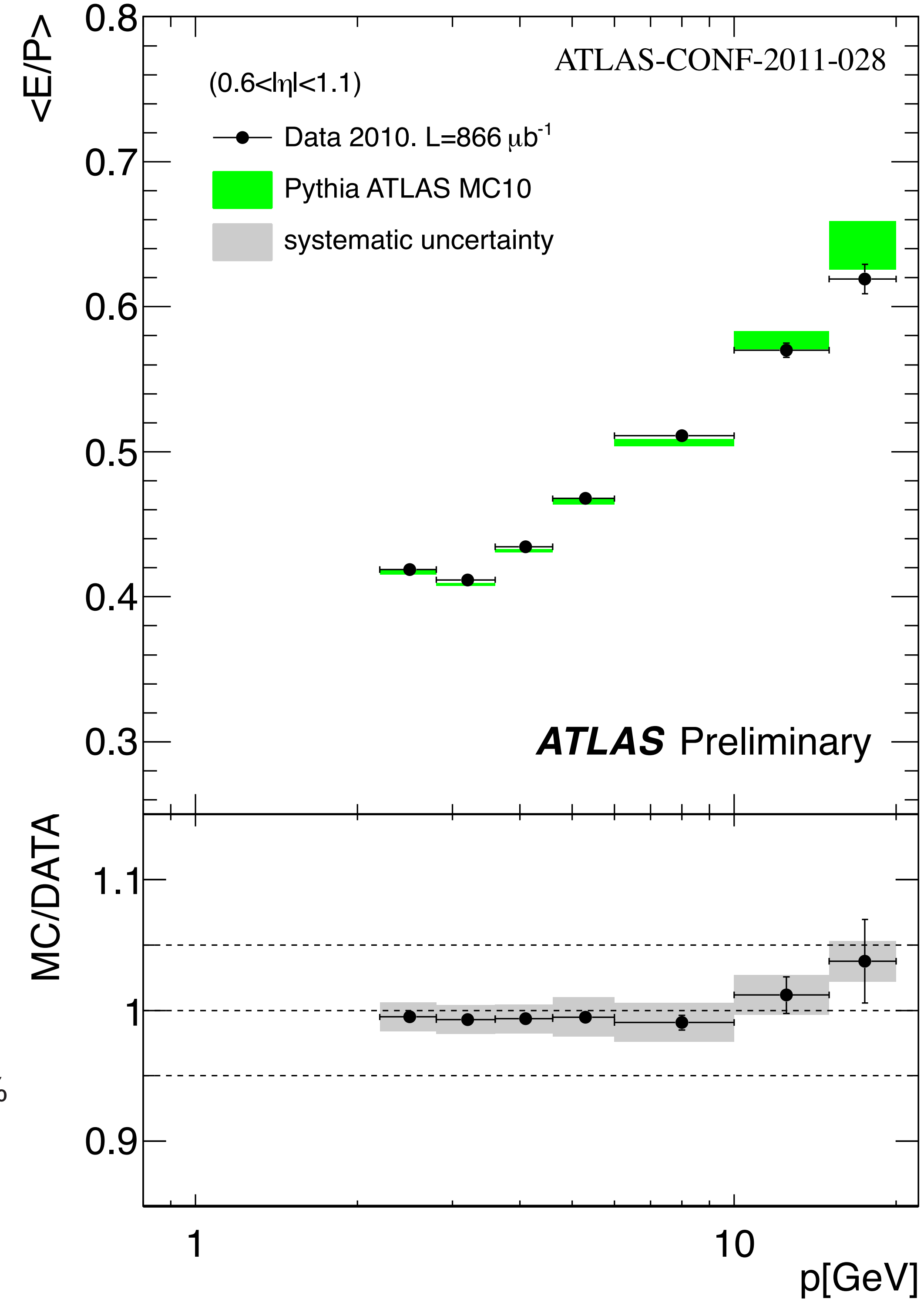
ATLAS test beam 2004



Linearity within ~2%

single pion response for known beam energy

ATLAS colllisions 2010



Data/MC within 2% for p<10 GeV

single isolated charged hadron response vs track momentum

Ingredients II : jets (scale)

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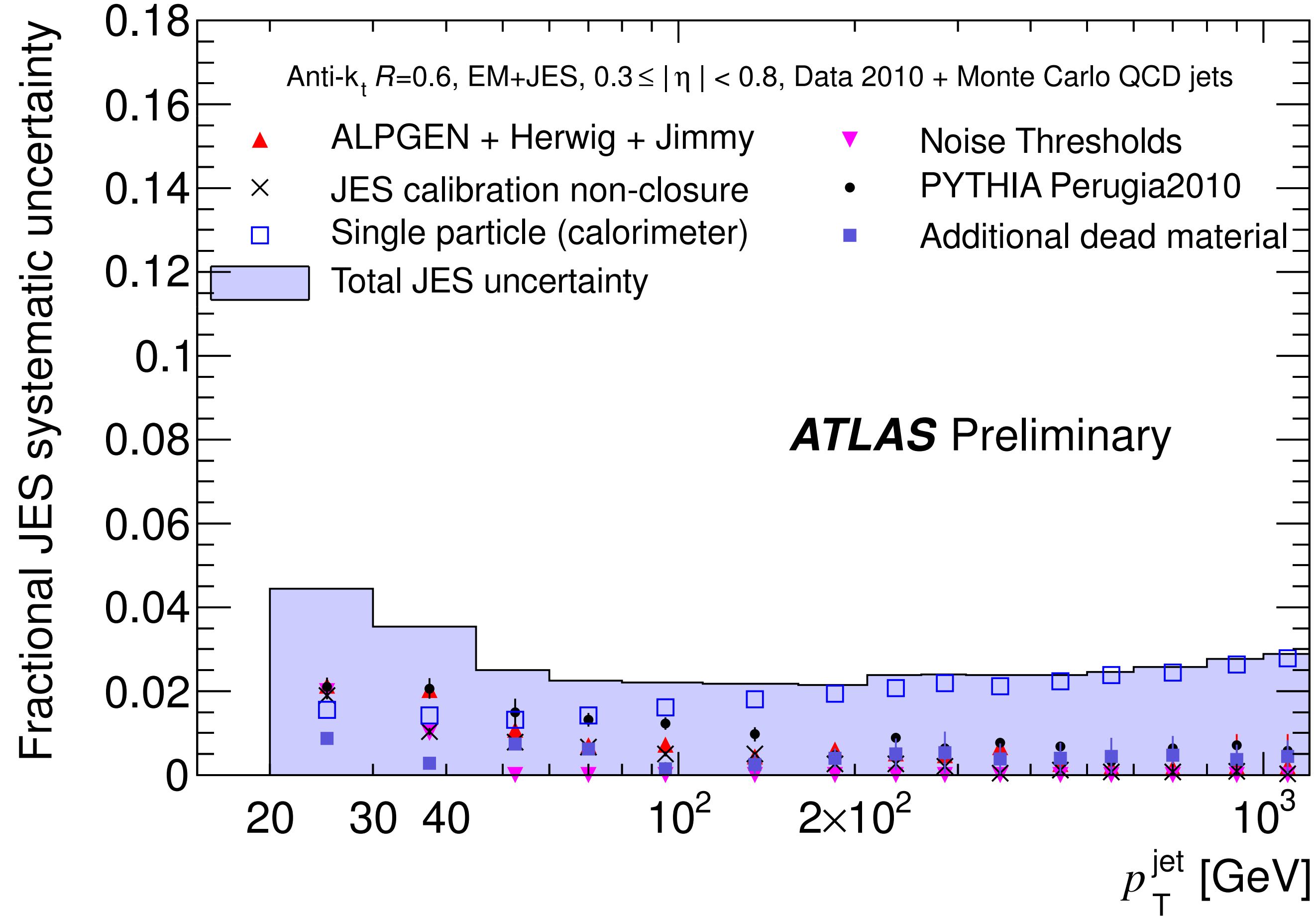
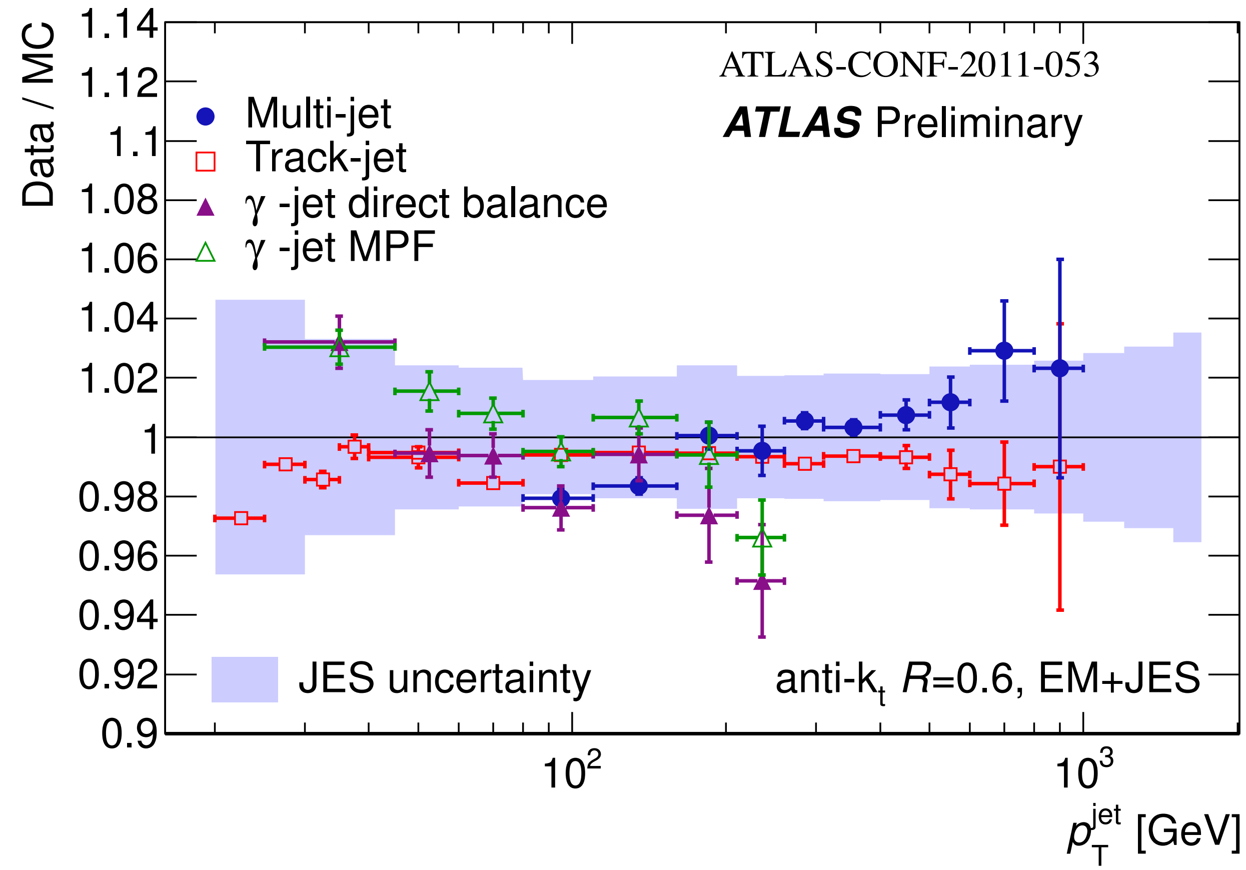
- **Calibrate jet energy scale** with (η,p_T) dependent weight ***from simulated "true" jet kinematics***

- **Scale uncertainty:** range between 2% to 8% in $\mathbf{p_T}$ and η

- Contributions from
  - Physics models for generation and hadronization
  - Calorimeter response: collision single particle data, test beam
  - Detector simulation

- Validation in control samples





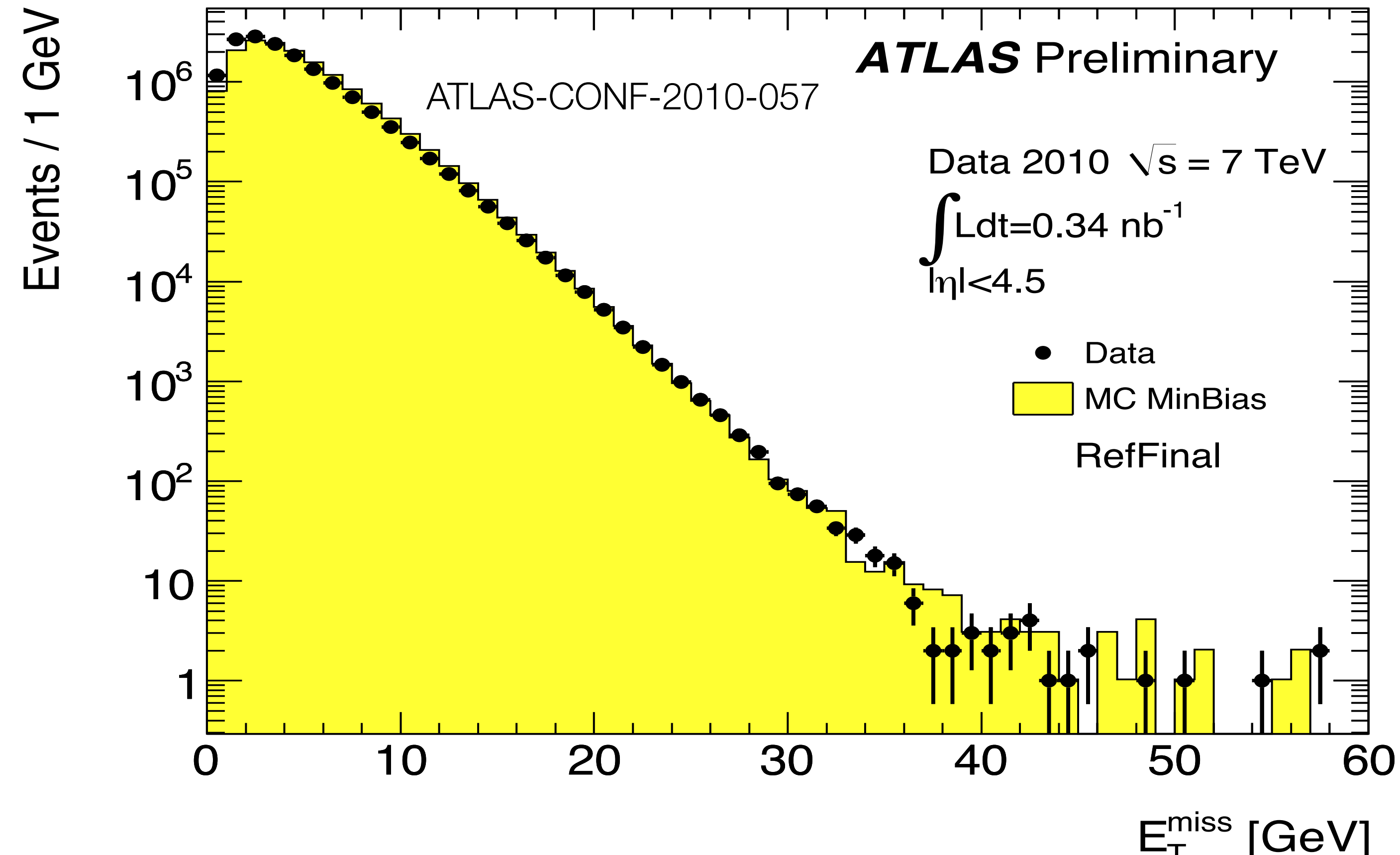
Ingredients III: missing transverse energy (E_T^{miss})

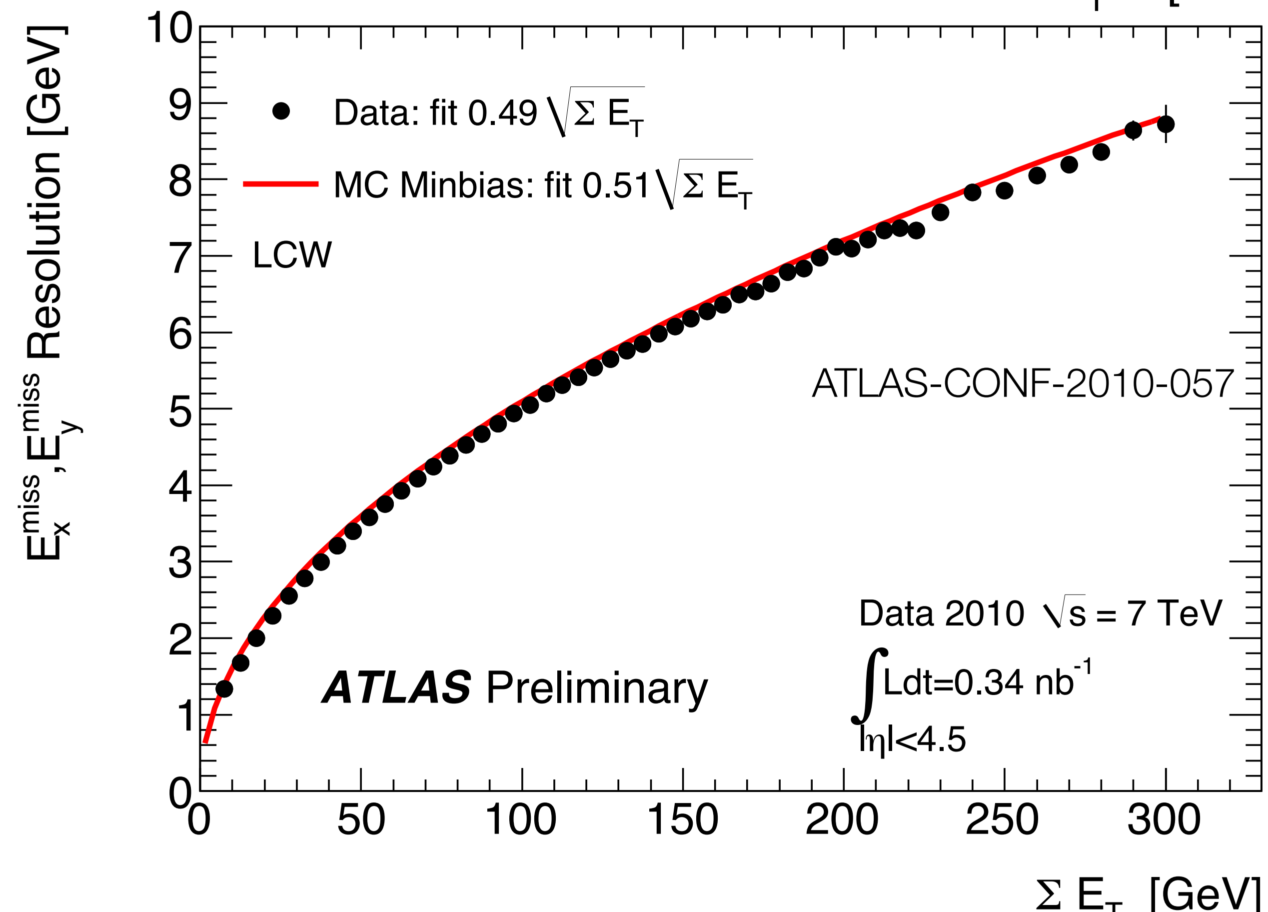
- **Negative vector sum** of
  - **energy in calorimeter cells,** projected in transverse plane **associated with high pt object**
  - **muon** momentum
  - ***dead material loss***

  projected in transverse plane

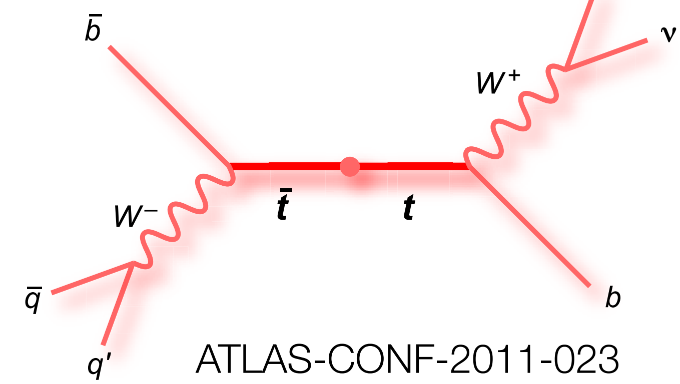
- Cells are **calibrated according to association** to high p_T object (electron, photon,tau, jet, muon)

- Remove overlapping calo cells involving jets and electrons





Selecting top pairs - single lepton



$\int L dt$ =35 pb^{-1}

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- **Trigger on** high p_T **single lepton**
- Good collision and good quality for jets
- **only one** high p_T central **lepton** *matching the trigger object*
- **high E_T^{miss}** *> 20 (35) GeV for e (mu) channel*
- **Large transverse leptonic W mass*** *> 25 GeV(60GeV - E_T^{miss}) for e (mu) channel*
- **≥ 1 central** high p_T **jet**

  p_T> 25 GeV

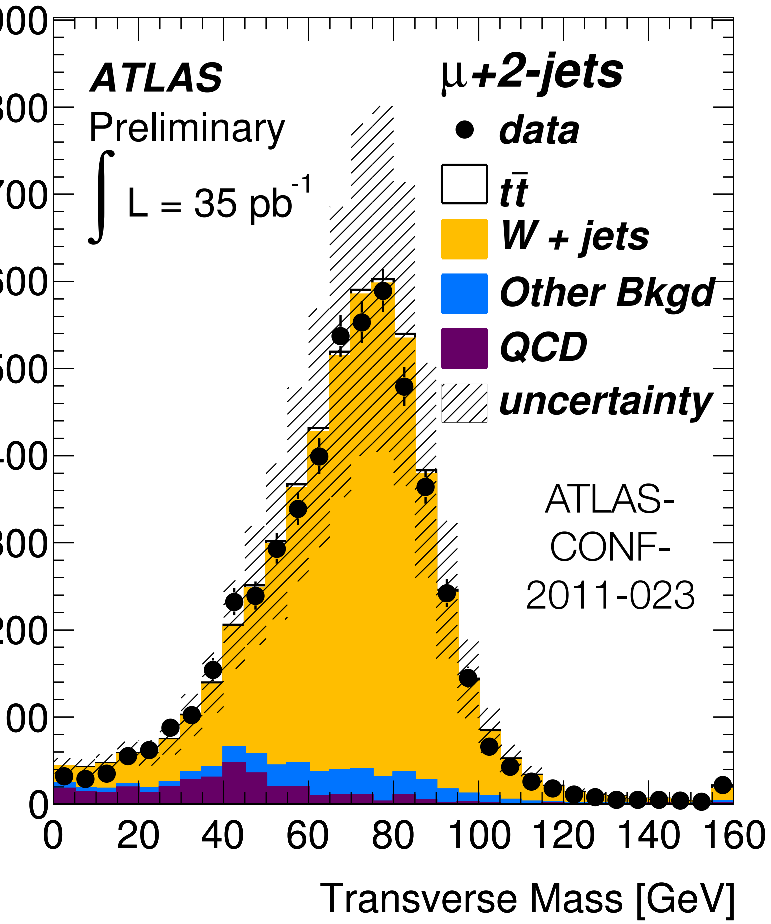
	e		mu	
	3jets	4jets	3jets	4jets
tt	116	194	161	273
QCD	***62***	***22***	***121***	***51***
W+jets	580	180	1100	310
Z+jets	32	18	69	25
Single t	22	11	32	15
WW,WZ,ZZ	9	3	16	4
Total Exp	**830**	**430**	**1500**	**680**
Data	**781**	**400**	**1356**	**653**

$$^{*} = \sqrt{2 p_T^{\ell} p_T^{\nu} (1 - \cos(\phi^{\ell} - \phi^{\nu}))}$$

Background estimates: QCD multi-jet

- "Fake" leptons: mis-id jets, $\gamma \to e^+e^-$, non-prompt leptons (b/c-decays)

Looser lepton definition: control region. Assume same shape in default and control region



μ channel: matrix method

- Measure N^{tight} (isolated-μ) and N^{loose}(non-iso-μ) events and find real fake muons from

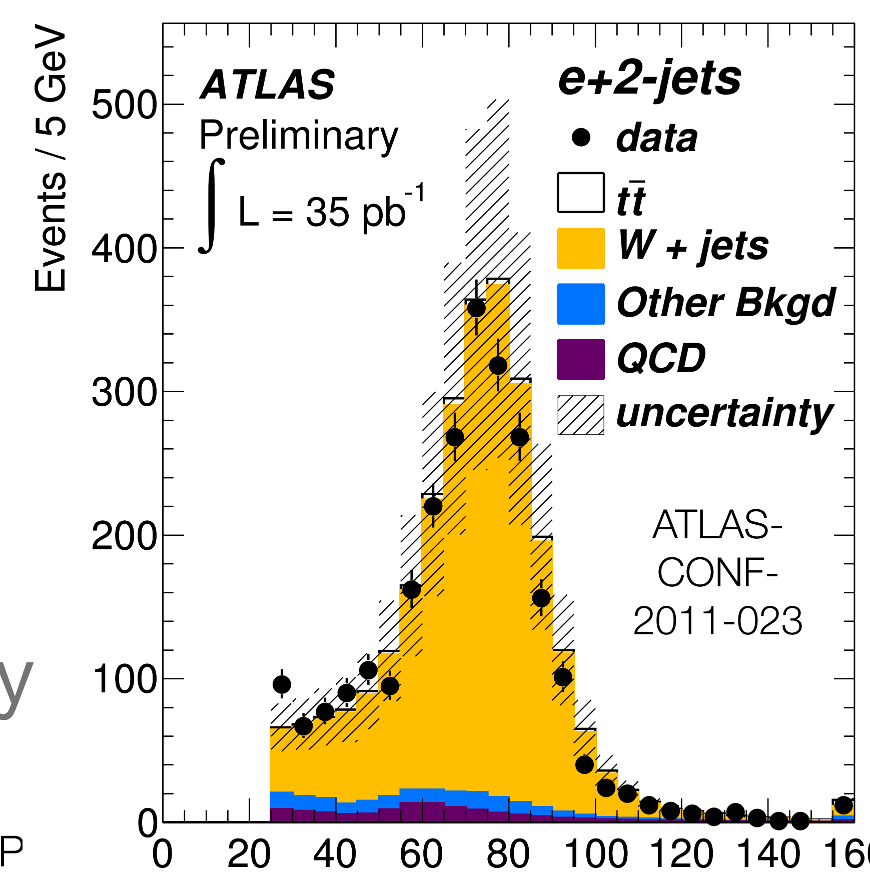
$$N^{loose} = N^{loose}_{fake} + N^{loose}_{real}$$

$$N^{tight} = \varepsilon_{fake} N^{loose}_{fake} + \varepsilon_{real} N^{loose}_{real}$$

ε_{fake} from low E_T^{miss}, M_T^W and ε_{real} from $Z \to \mu^+\mu^-$

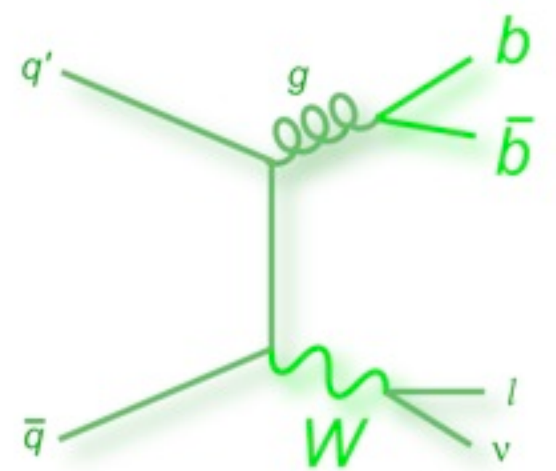
e channel: template method

- Extract QCD E_T^{miss} shape from control region (electron fail one/more selection criteria)
- Fit E_T^{miss} in low E_T^{miss} region, then extrapolate by apply tight selection



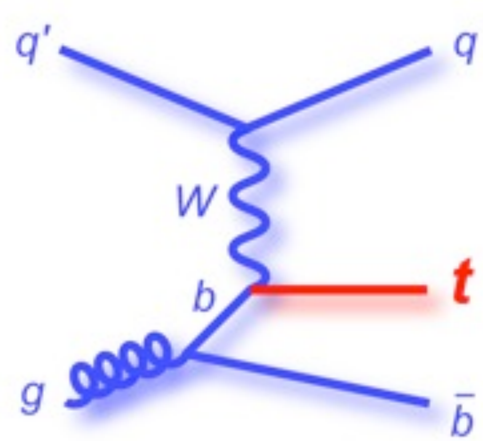
Backgrounds - single lepton

- **W(/Z)+jets**

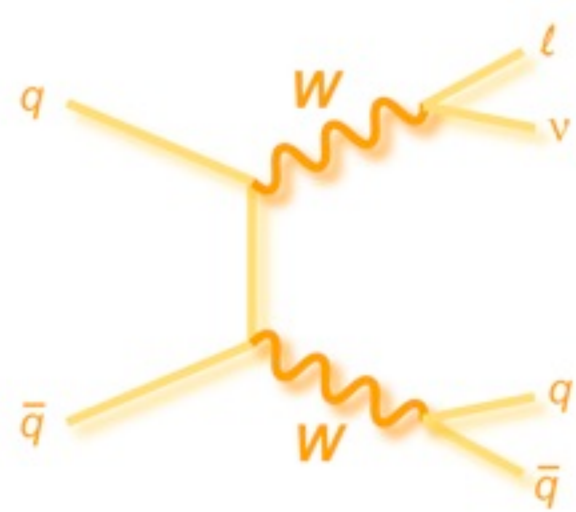


Shape from simulation
rate from final fit

- **Single top**



- **Di-bosons (WW,WZ,ZZ)**



Simulated
+
rate set to SM prediction

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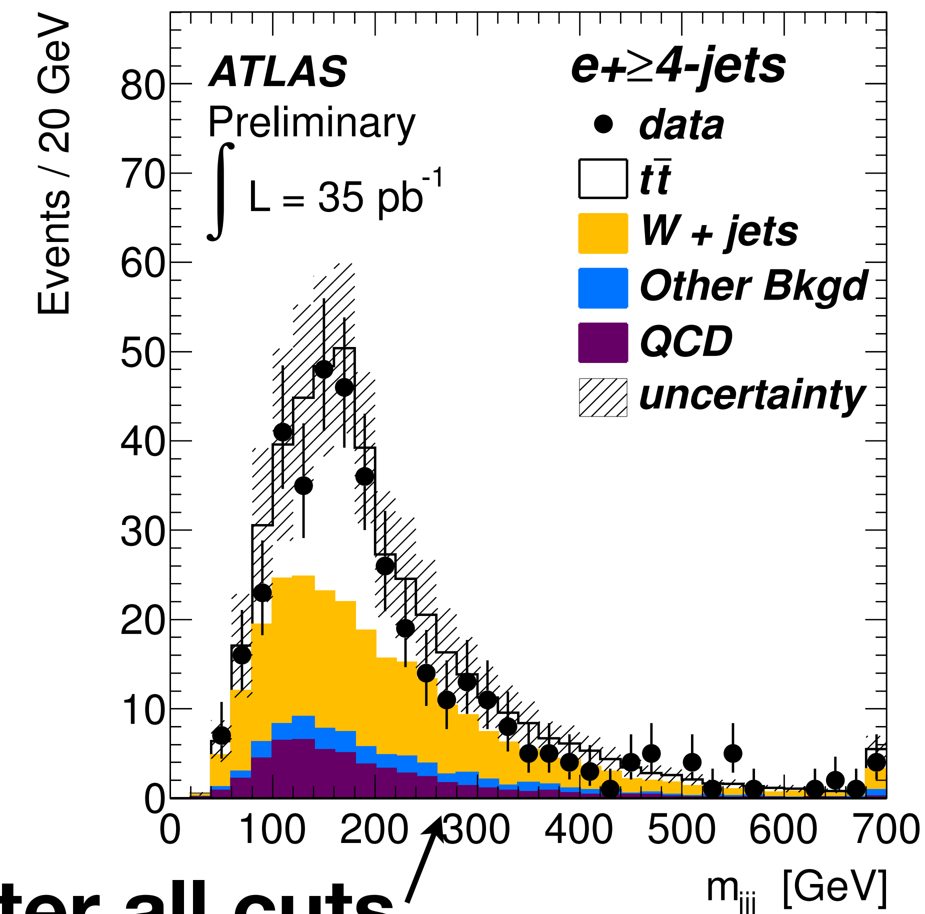
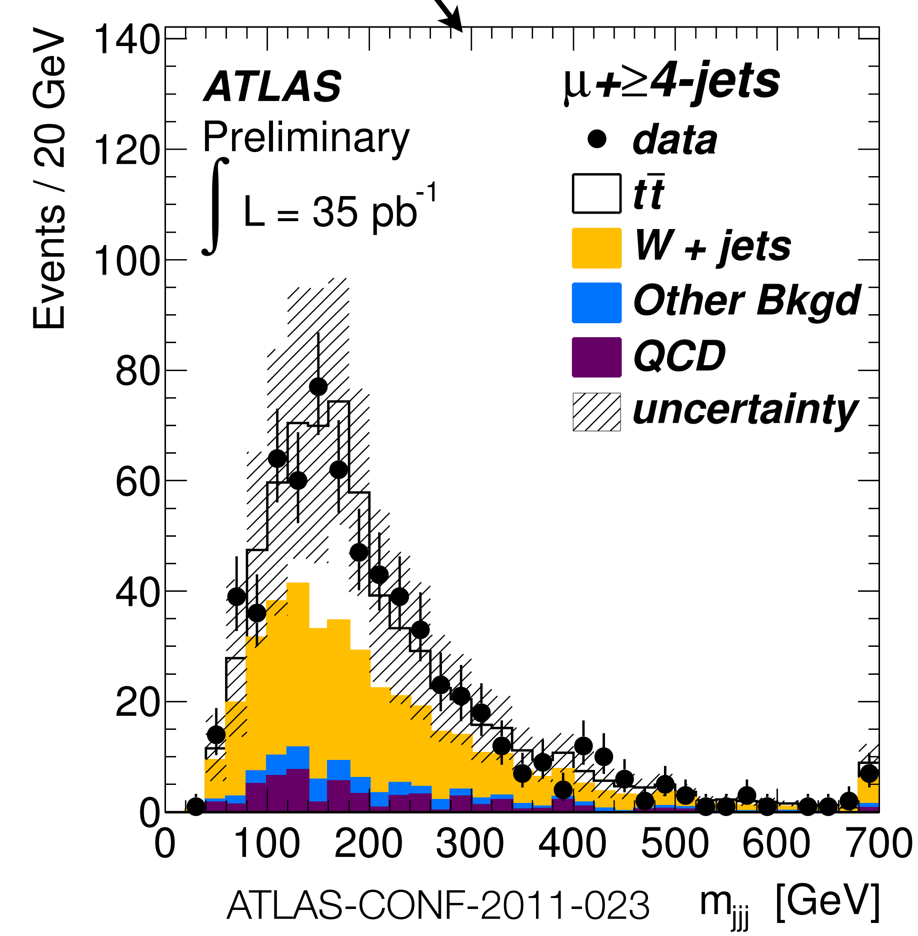


after all cuts



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Extract top cross section (I) - single lepton

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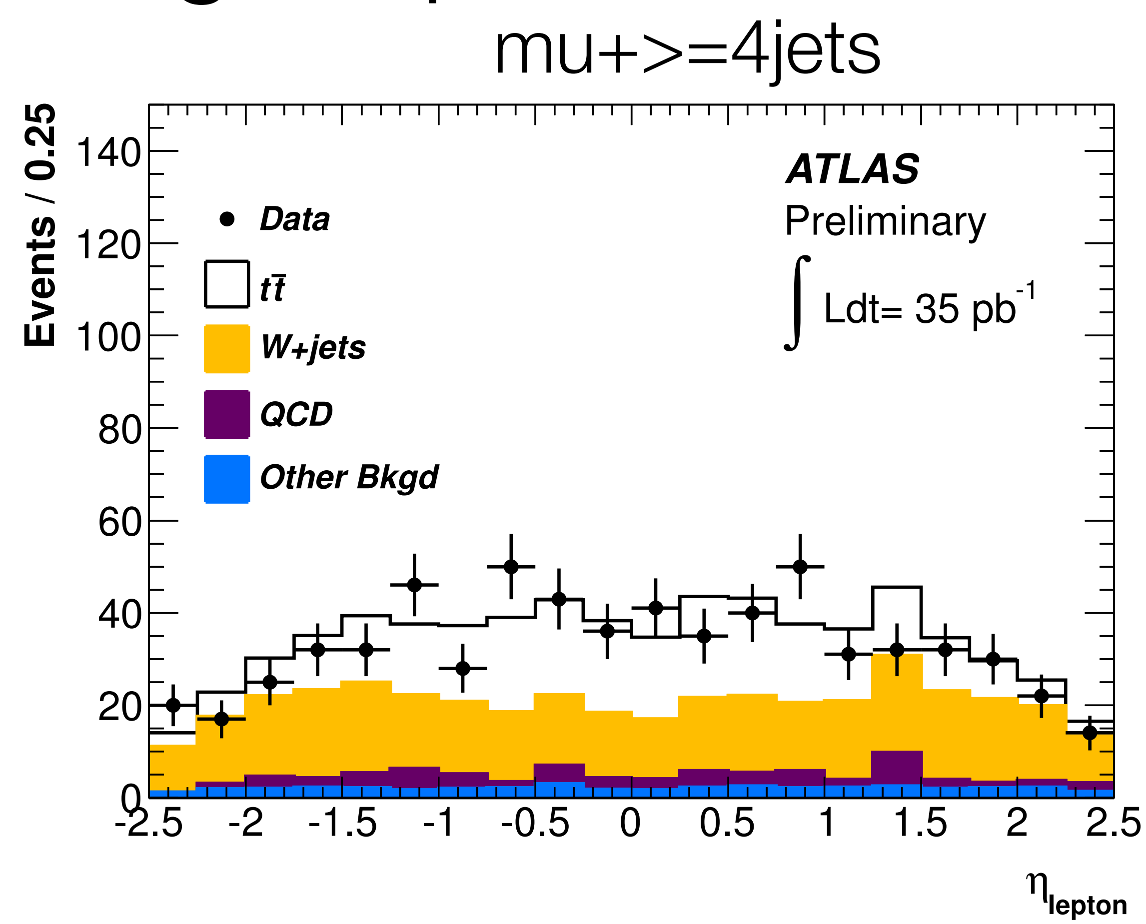
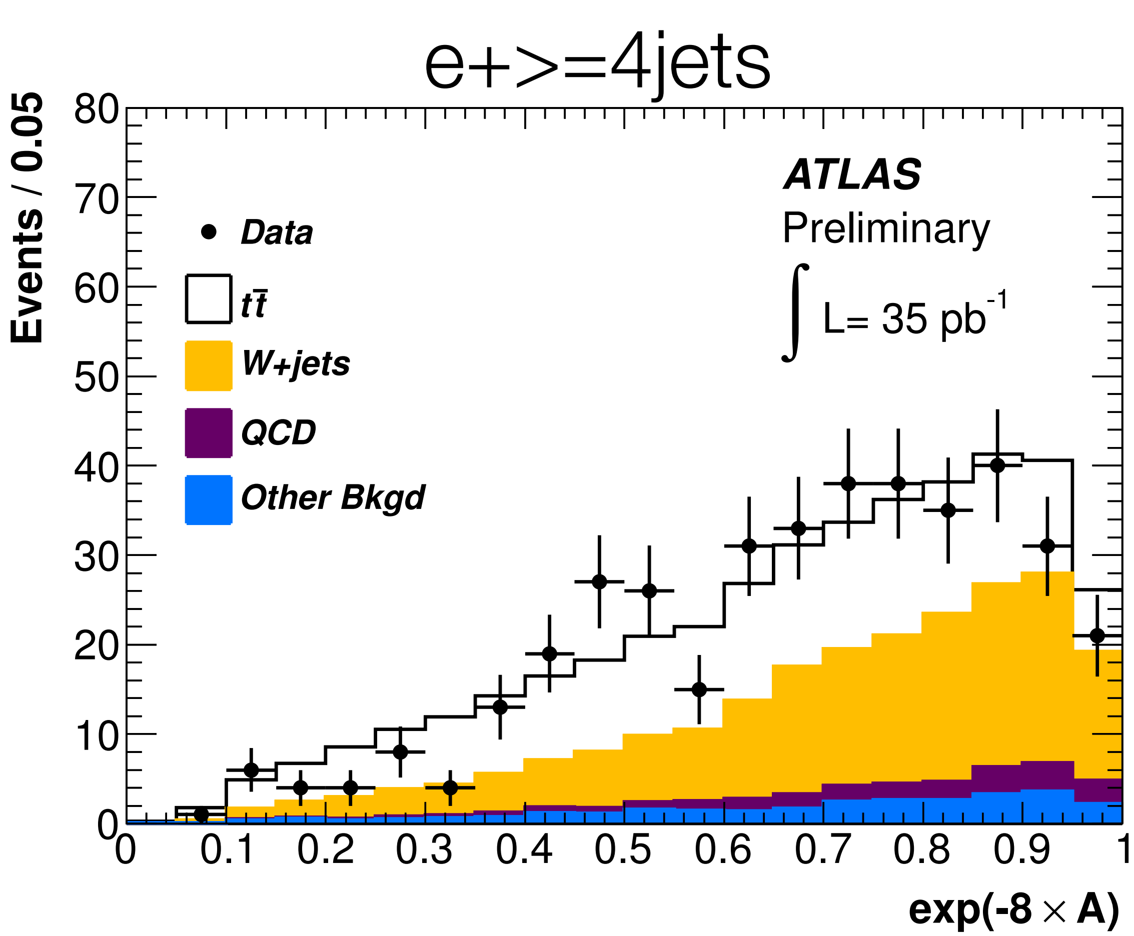
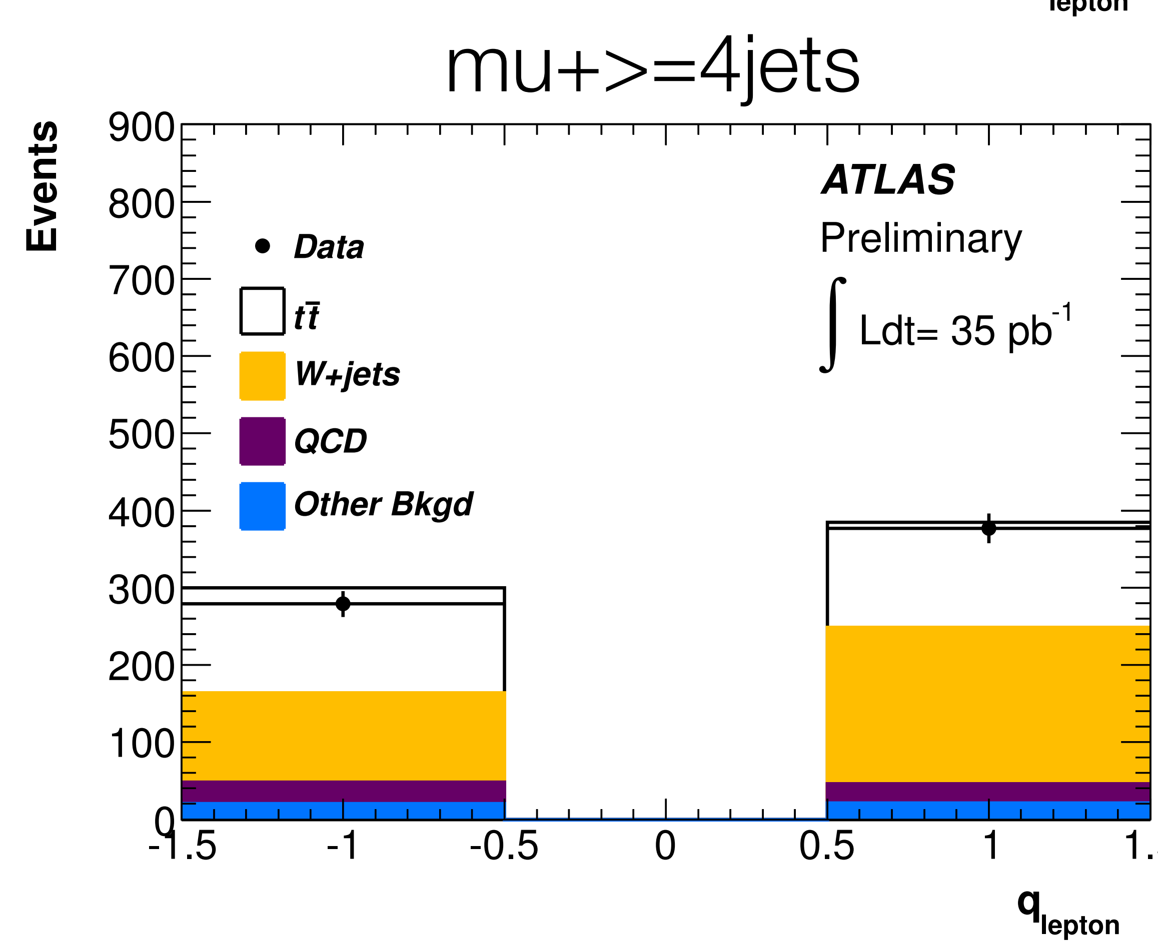
- For Njets=3, 4 an 5 , build discriminant from distributions of
  - ***lepton pseudorapidity*** ←top is more central
  - ***lepton charge*** ←top is symmetric,W+jets isn't
  - ***aplanarity*** ←top is more spherical





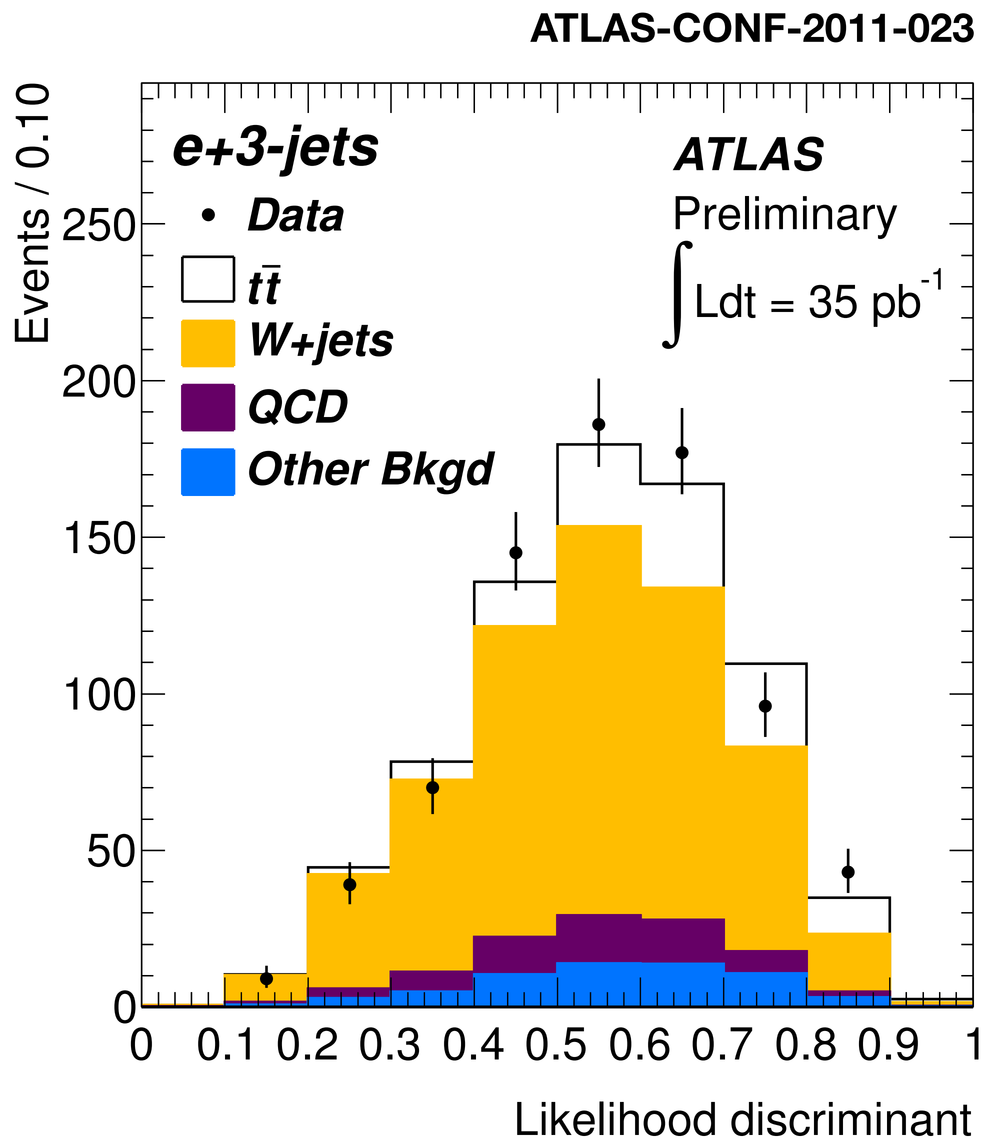


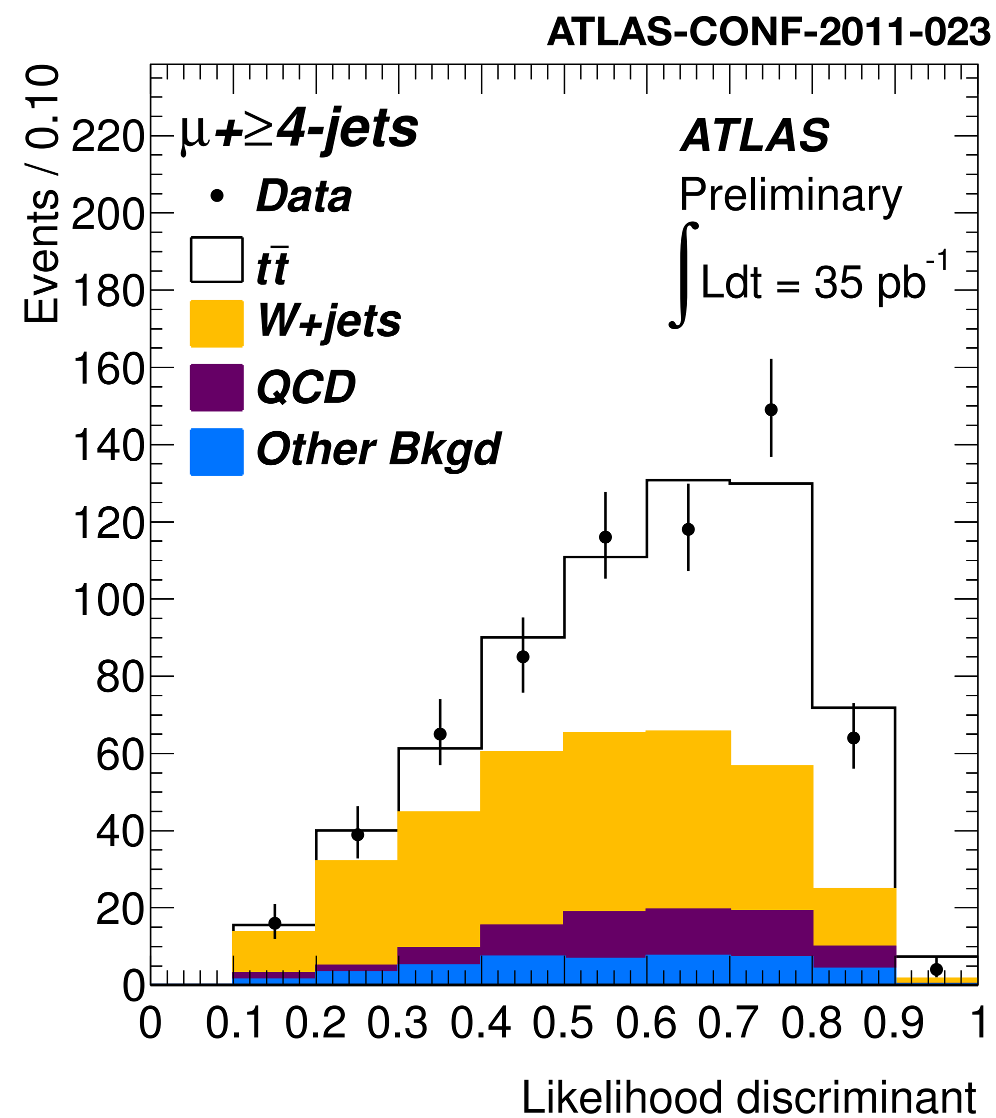
Extracting cross section (II) - single lepton

- **Perform maximum likelihood fit** to discriminant in 3,>=4 jet bin for both channels. Fix QCD and smaller bkg, **fit top and W+jets contrib**

- Cross section found as

$$\sigma_{t\bar{t}} = \frac{N_{sig}}{\int \mathcal{L}dt \times \epsilon_{sig}},$$





where

ϵ_{sig} signal acceptance, efficiency and branching ratio from simulation + data/MC scaling factors

Systematic uncertainties - single lepton

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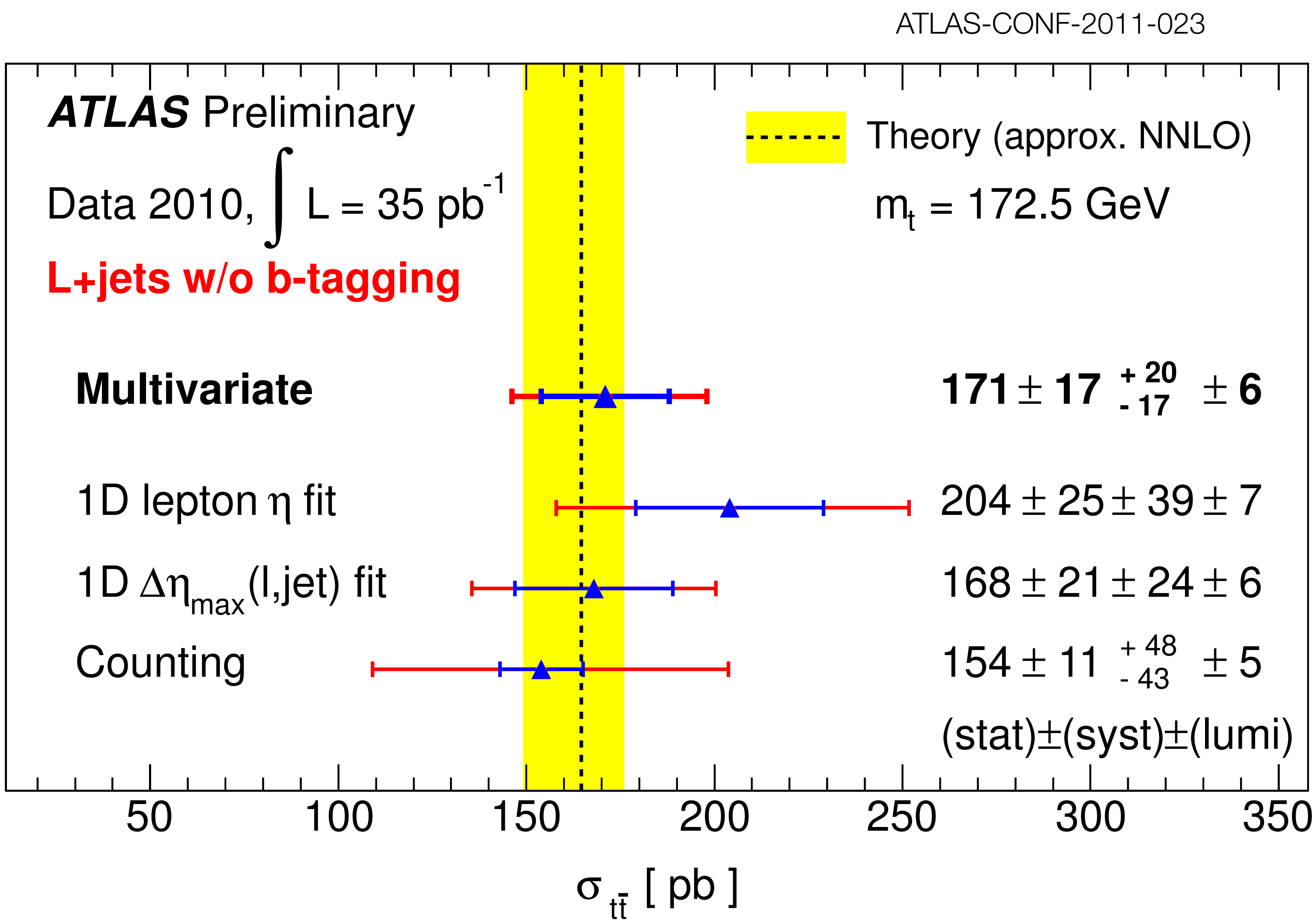
Source	Relative cross-section uncertainty [%]
Object selection	
Lepton reconstruction, identification, trigger	-1.9 / +2.6
Jet energy scale and reconstruction	-6.1 / +5.7
Background rates and shape	
QCD normalisation	±3.9
QCD shape	±3.4
W+jets shape	±1.2
Other backgrounds normalisation	±0.5
Simulation	
Initial/final state radiation	-2.1 / +6.1
Parton distribution functions	-3.0 / +2.8
Parton shower and hadronisation	±3.3
Next-to-leading-order generator	±2.1
MC statistics	±1.8
Pile-up	±1.2
Total systematic uncertainty	-10.2 / +11.6

jet properties (scale, multiplicity) and background normalization are the dominant contributors

Cross section summary - single lepton



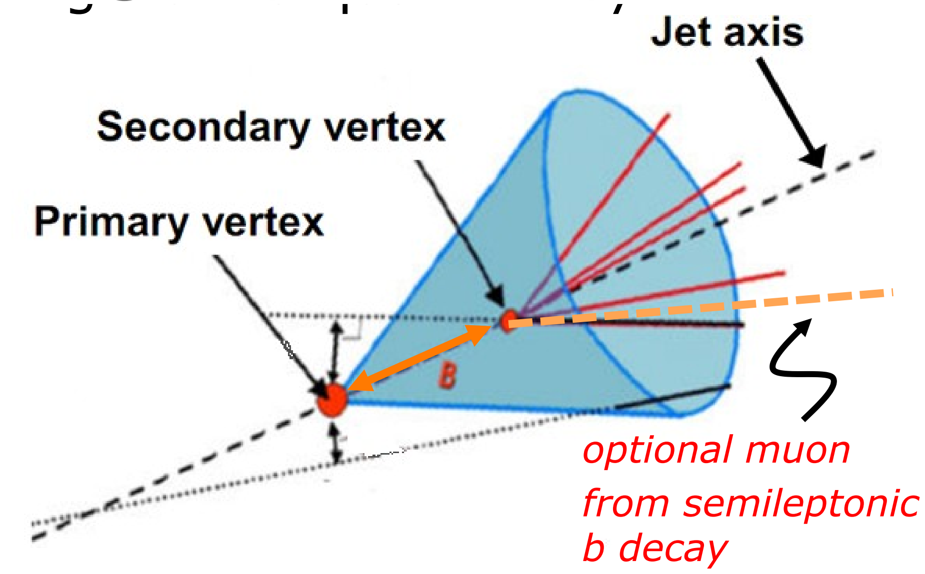
- **Consistency** with SM prediction and amongst techniques
- Statistical (10%) and systematic (11%) uncertainties have the same order of magnitude

Ingredients IV : enter b-jets

- B-hadrons have long lifetime ~observable flight (few mm)

Tagging

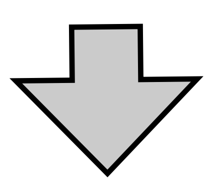
d_0/σ_{d_0}



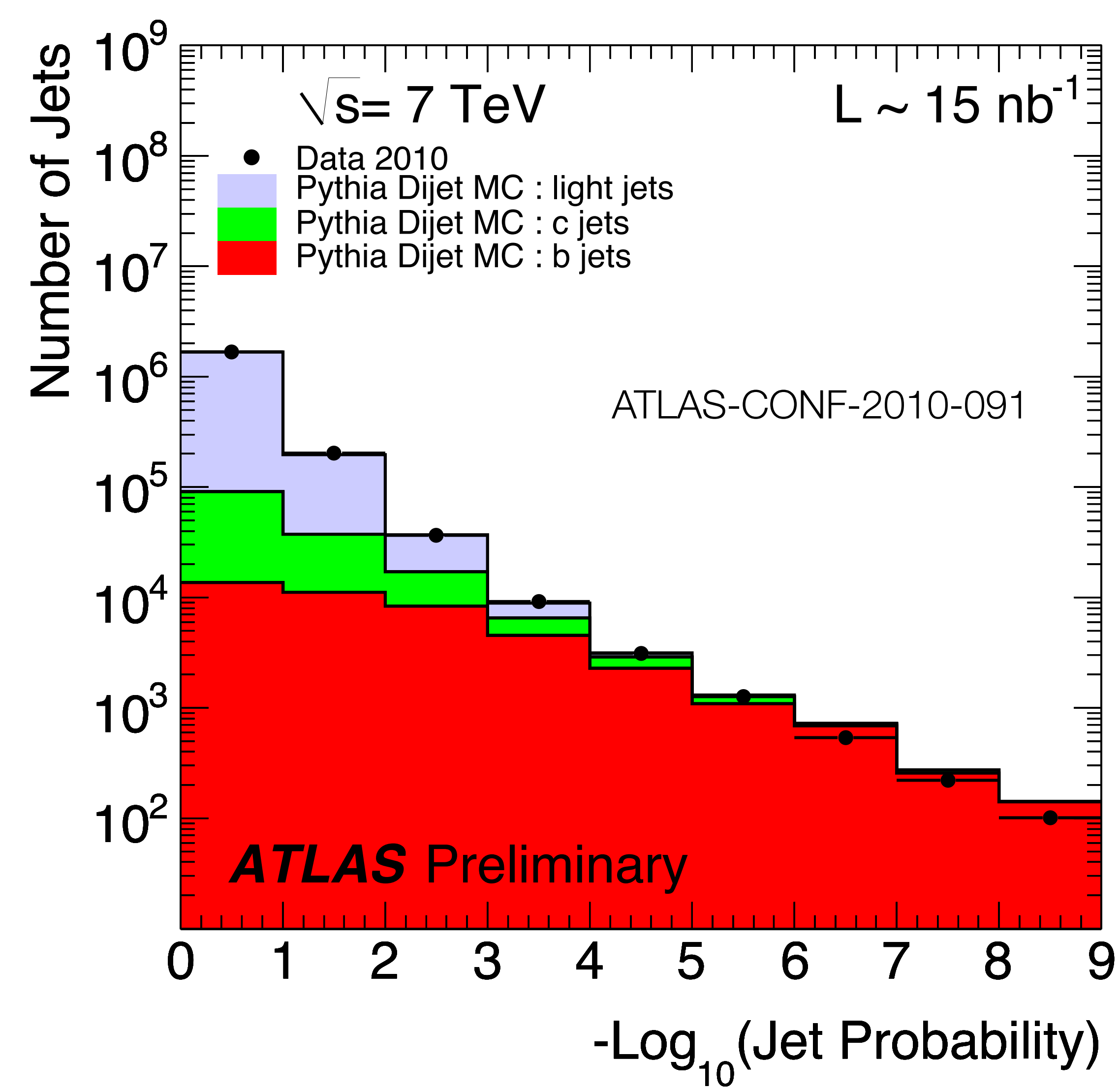
- track impact parameter resolution d0/ sigma_do-> different probability for jet origin for b-jets

Performance in data

- Fit fraction of b-jets in sample with muons in jets, count how many are b-tagged
- Mistag rate from secondary vertex properties *(invariant mass tracks, rate of negative decay length significance)*

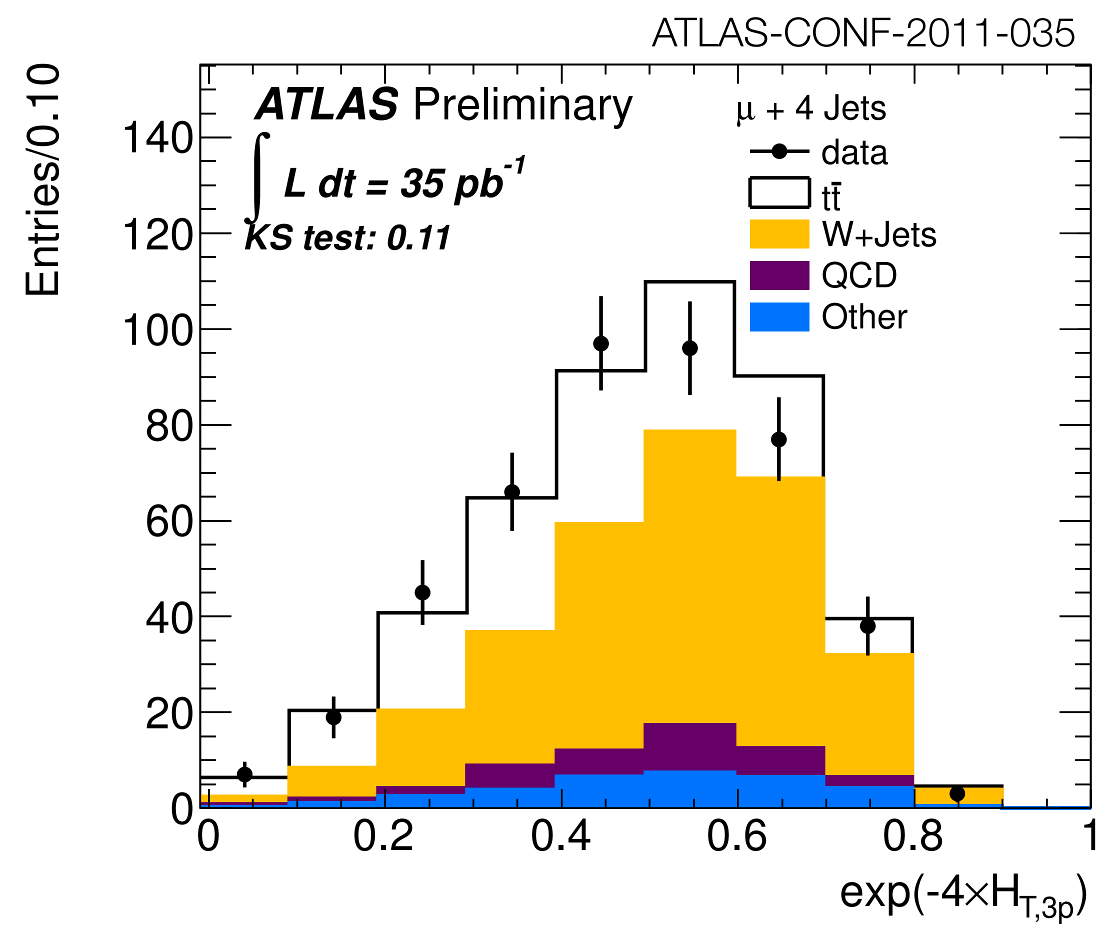


p_T dependent scale factors to correct MC



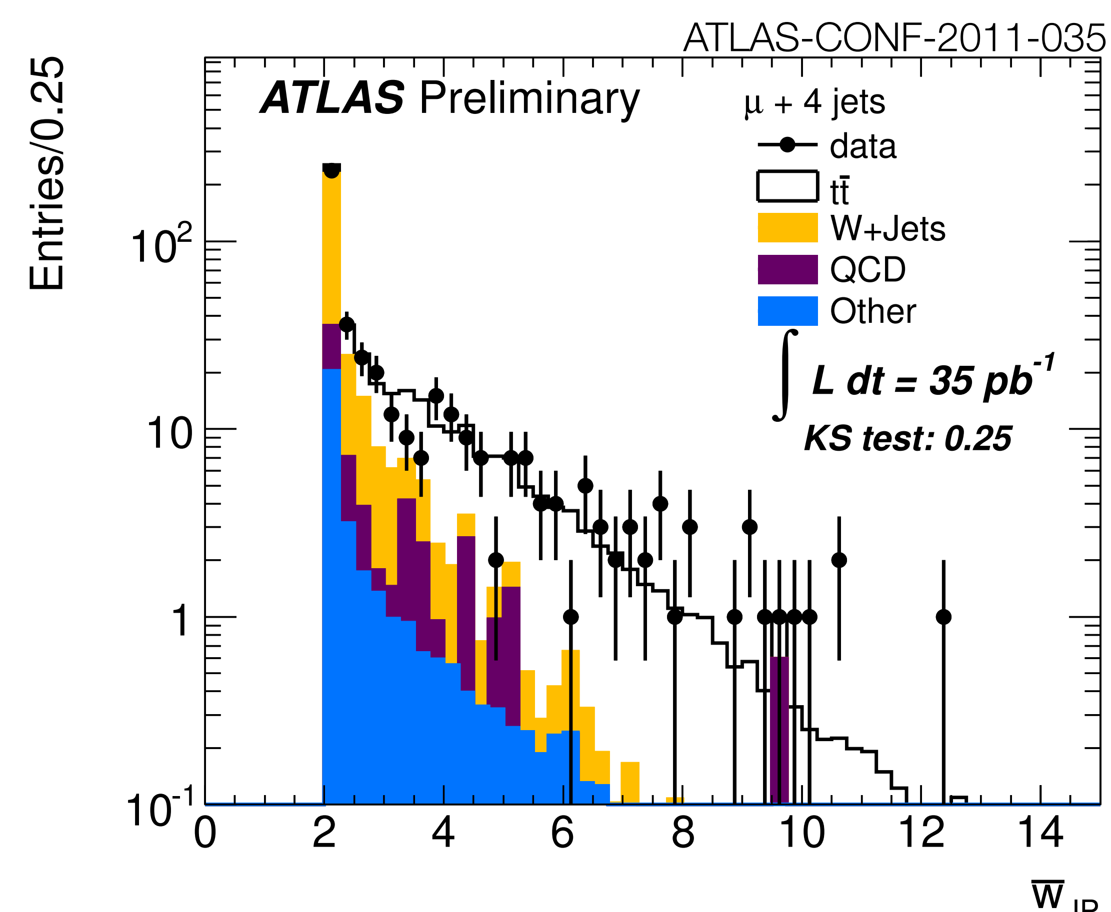
Cross section - single lepton *with b-tagging*

- Build discriminant from
  - **lepton eta, aplanarity**
  - **$H_{T,3p}$** ratio of transverse to longitudinal activity ←top is more transverse
  - **average** of two largest **jet b-tagging** probability←top has more b-jets



- **Extract σ_{tt} from likelihood fit of discriminant** to data in 3,4 and 5 jet bins

- **Systematic uncertainties part of fit** as Gaussian nuisance parameters



Backgrounds estimates - single lepton *with b-tagging*

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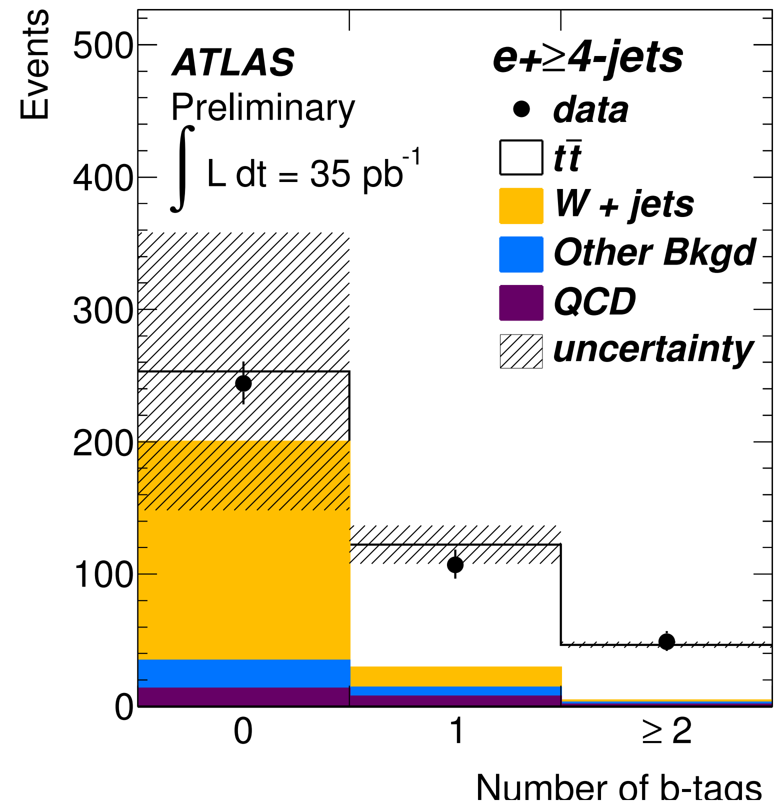
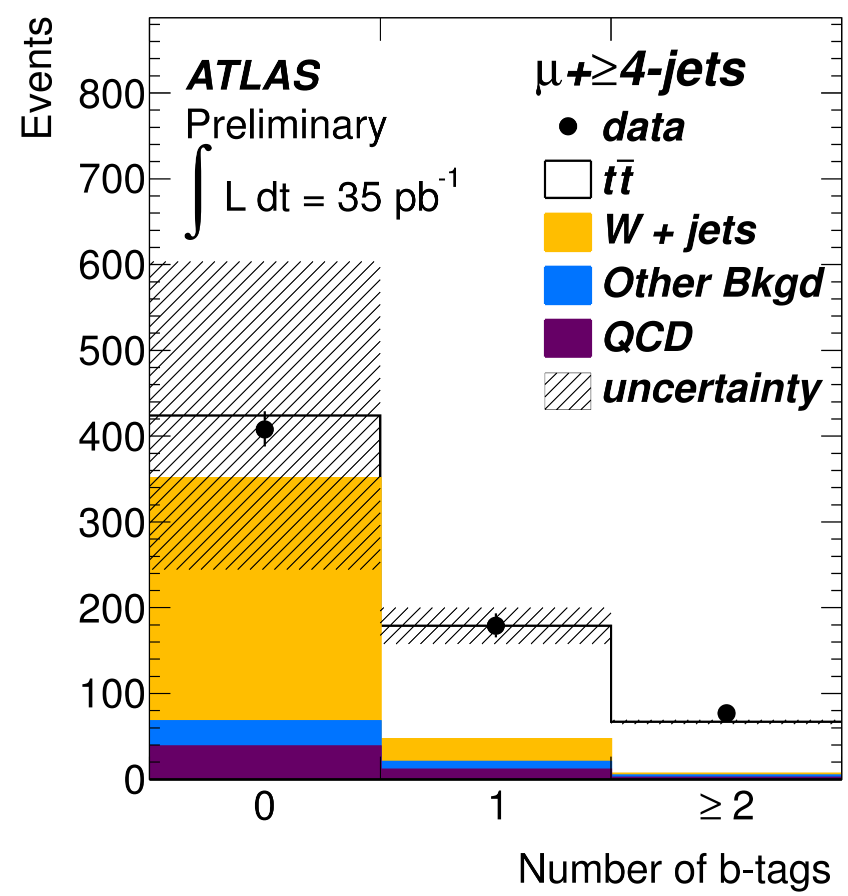
- ***QCD*** with matrix and template methods
- ***W+jets***
  - shape from simulation
  - data-driven normalization for high jet multiplicity bins (3,4 and 5) ←extrapolate content of 1 and 2 jet bins before tagging
- Other (small) backgrounds: simulated + rate set to SM expectation

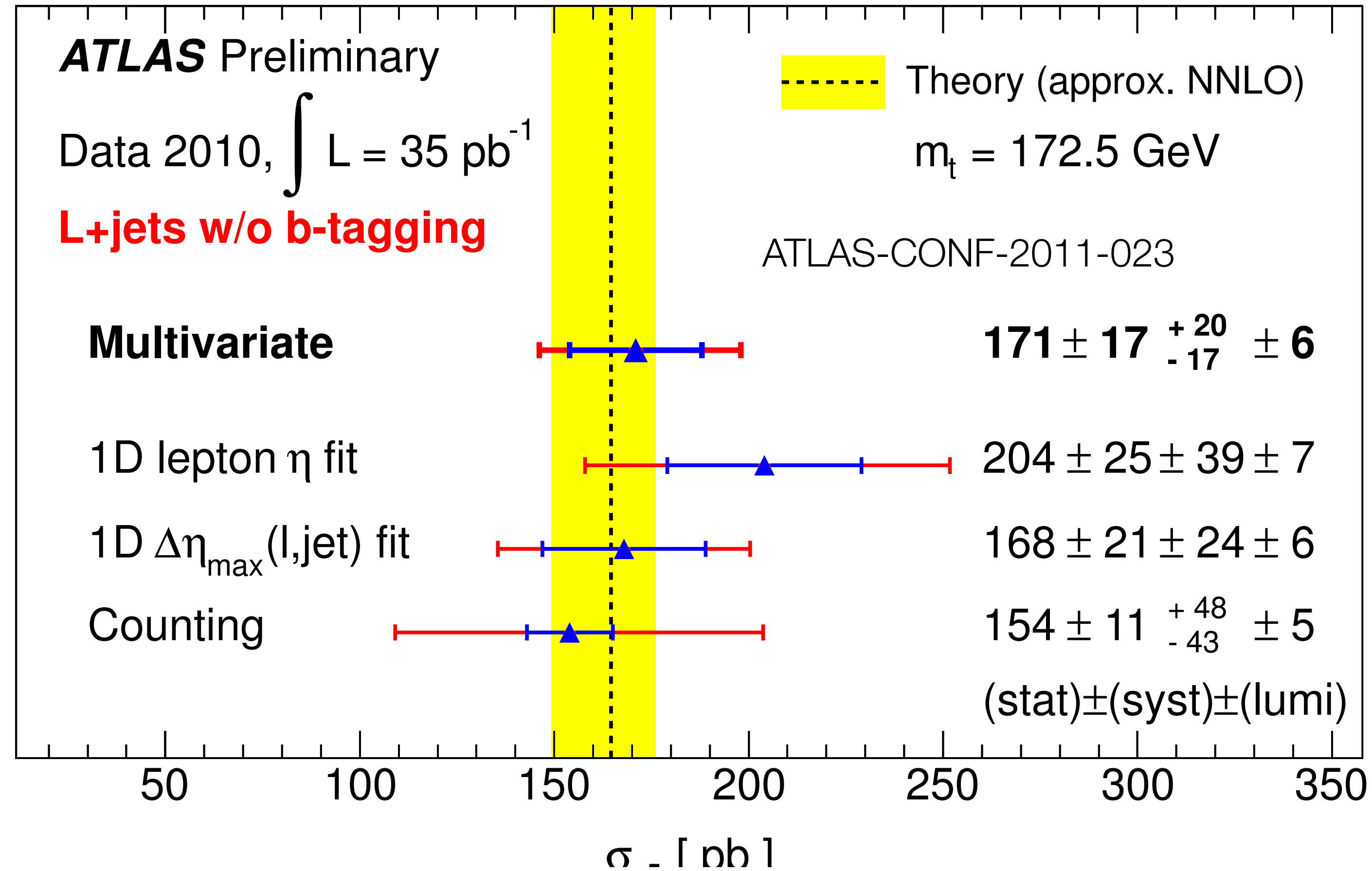
After all cuts



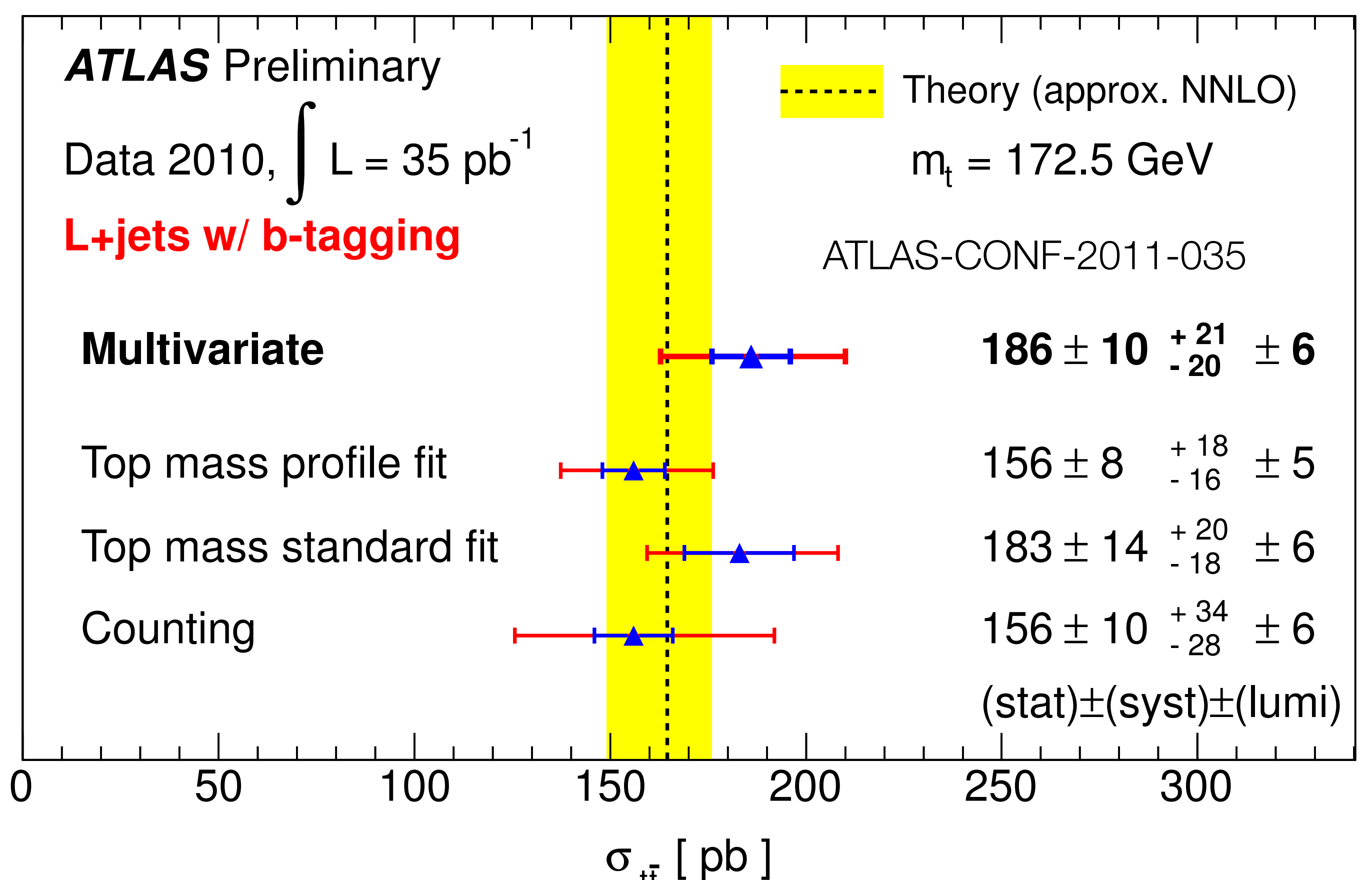


Summary for single lepton

- Use of ***b-tagging improves statistical uncertainty*** (enhanced background reduction)

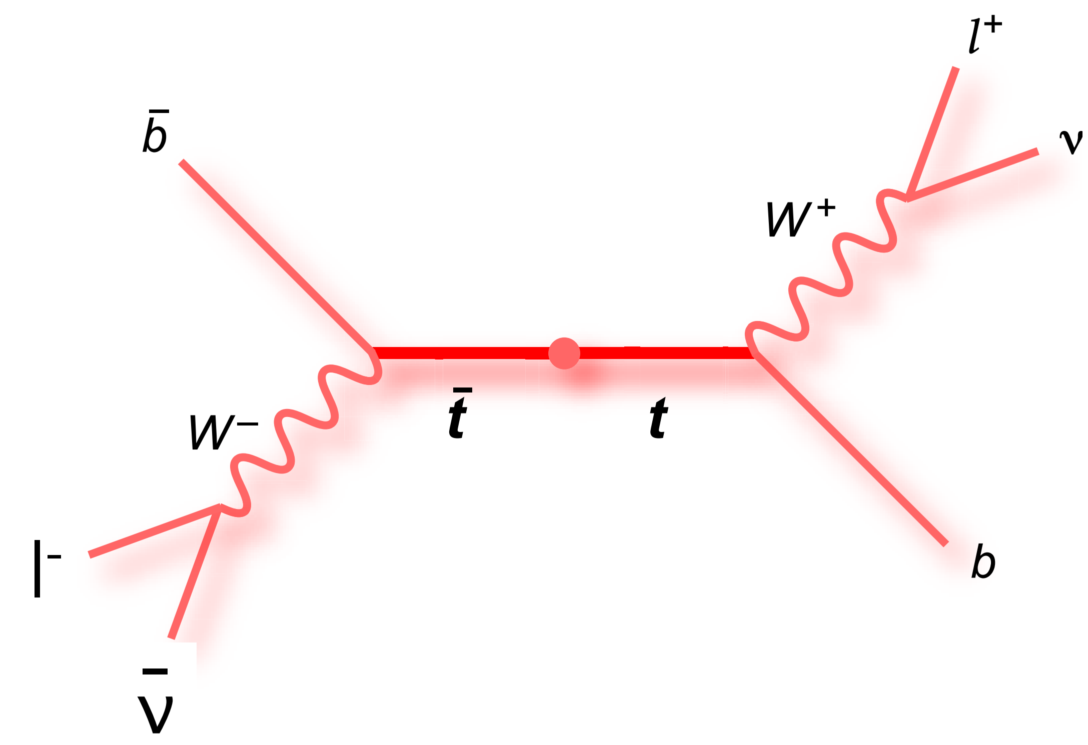


- Systematics are as large as statistics; already dominant ***in b-tagging case***



Selecting top pairs : di-lepton

- After single lept trigger, **exactly two opposite sign** high p_T central **leptons (ee, eμ, μμ)** *and* **≥ 2 central** high p_T **jet**
- High **E_T^{miss} or trasverse activity**
- **veto Z-like events**

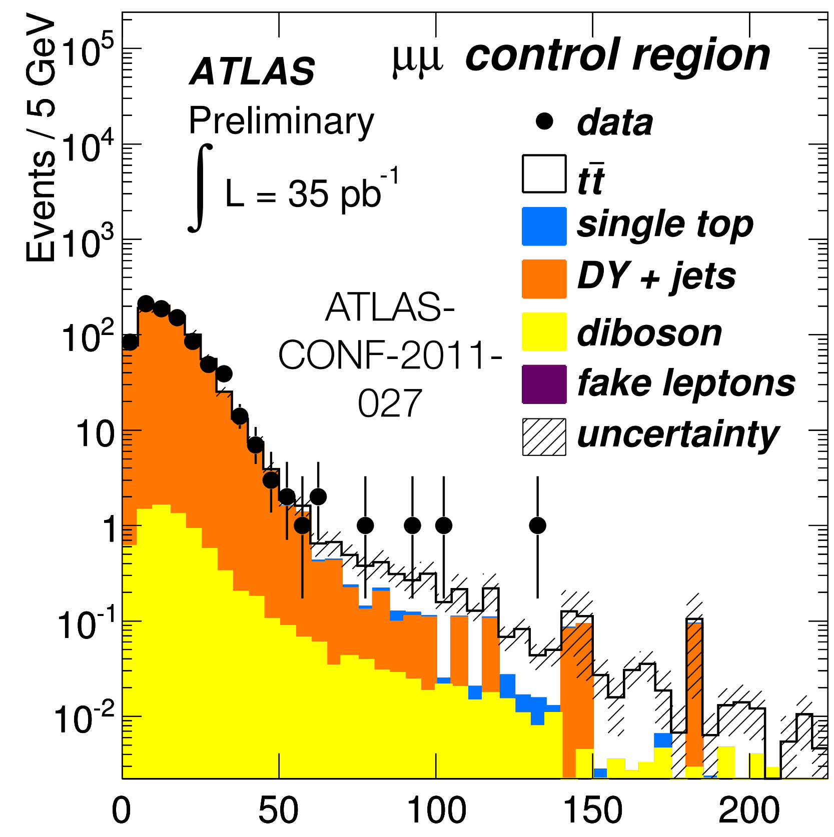


Backgrounds

Z/γ^*+jets
QCD, Di-bosons
single lepton

Di-lepton main backgrounds

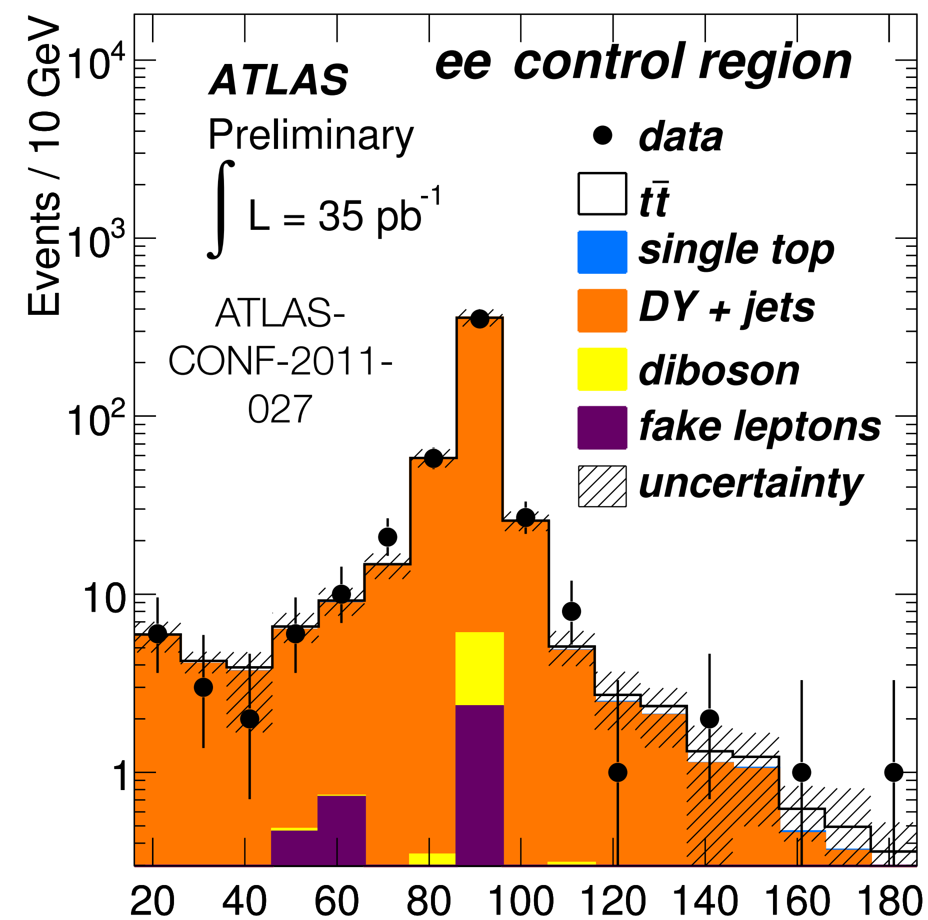
- "Fake" leptons from data (matrix method)
  - **Invert** high E_T and Z window **cuts** → **control samples** enriched with real and "fake" leptons
  - **Derive probability** for "fake" and real leptons ***to be in signal region***
  - **Estimate "fakes"** as a function of events in signal and control samples



in Z window

- Z/γ^* bkg : scale control region with simulation
  - in Z mass window, >=2 jets, E_T^{miss}>30
  - $N_{Z/\gamma}$ (SigReg) = **Data**(ConReg)-OtherMC(CR)*[$MC_{Z/\gamma}$ (SigReg)/**$MC_{Z/\gamma}$ (ConReg)**]

	ee	*μμ*	*eμ*
Z/γ^*+jets (DD)	$1.2^{+0.5}_{-0.6}$	$3.4^{+1.9}_{-1.4}$	-
$Z(\to\tau\tau)$+jets (MC)	$0.4^{+0.4}_{-0.3}$	$1.2^{+0.7}_{-0.6}$	$3.2^{+1.6}_{-1.3}$
Non-Z leptons (DD)	0.8 ± 0.8	0.5 ± 0.6	3.0 ± 2.6
Single top (MC)	0.7 ± 0.1	1.3 ± 0.2	2.5 ± 0.4
Dibosons (MC)	0.5 ± 0.1	0.9 ± 0.2	$2.1^{+0.5}_{-0.3}$
Total (non $t\bar{t}$)	3.5 ± 1.1	$7.3^{+1.8}_{-1.5}$	10.8 ± 3.4
$t\bar{t}$ (MC)	11.5 ± 1.3	20.1 ± 1.7	47.4 ± 4.0
Total expected events	15.0 ± 1.7	27.4 ± 2.4	58.2 ± 5.2
Observed events	16	31	58



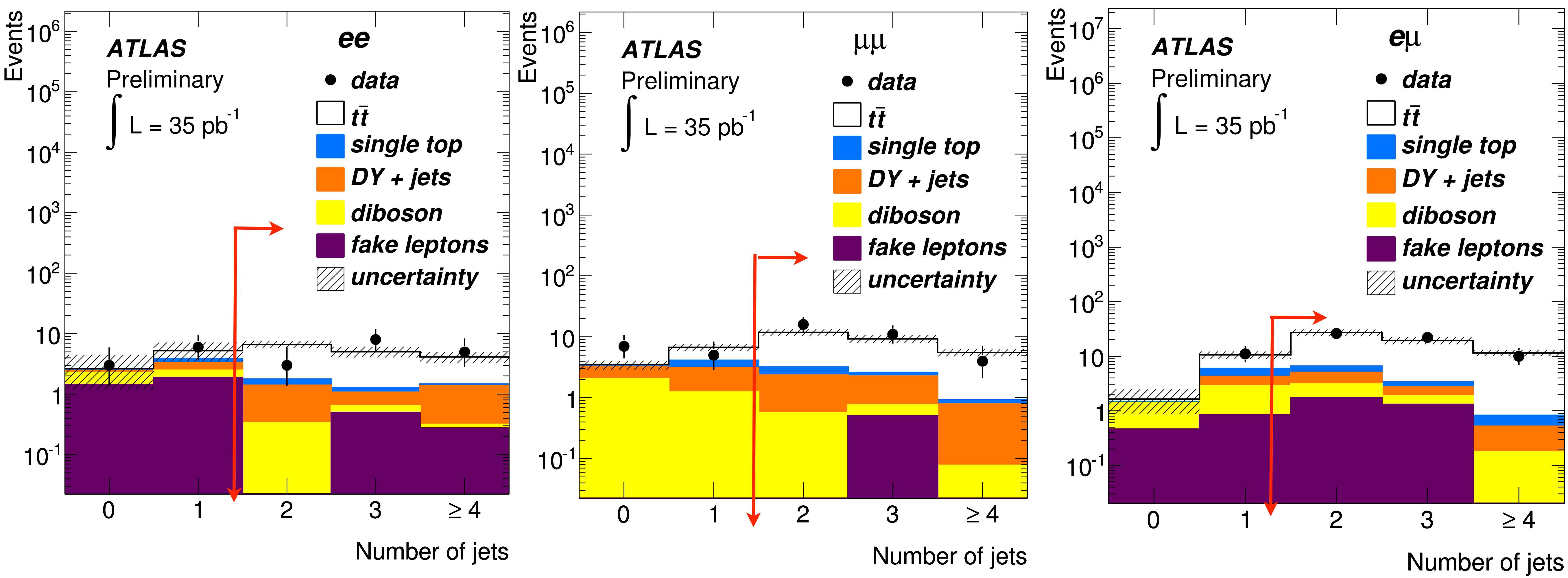
for low E_T^{miss}

Di-lepton results

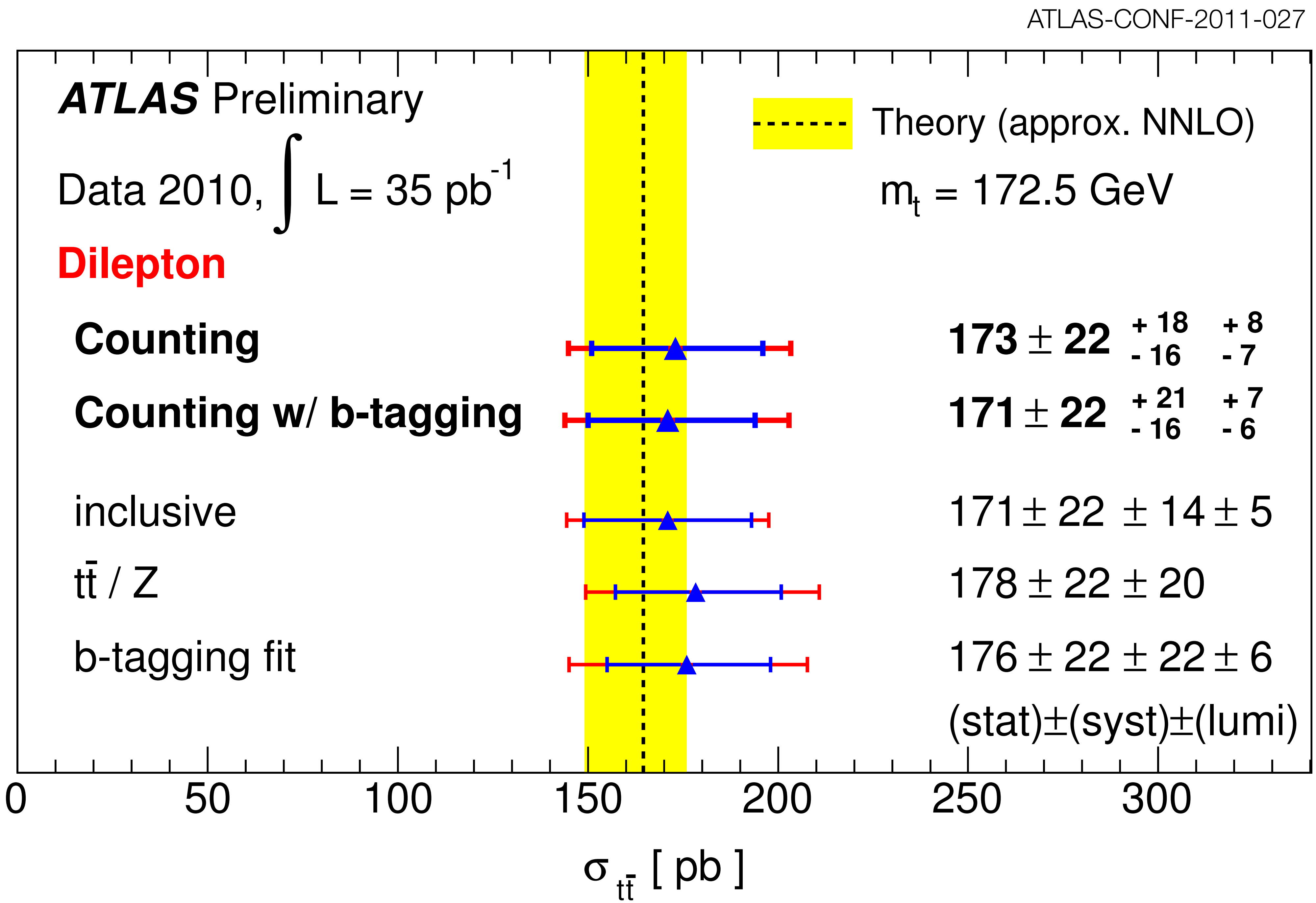
- Subtract estimated background
- Cross section from likelihood fit combining channels and including systematics as nuisance parameters

after all cuts, except N_{jets} (notice log scale)

ATLAS-CONF-2011-027

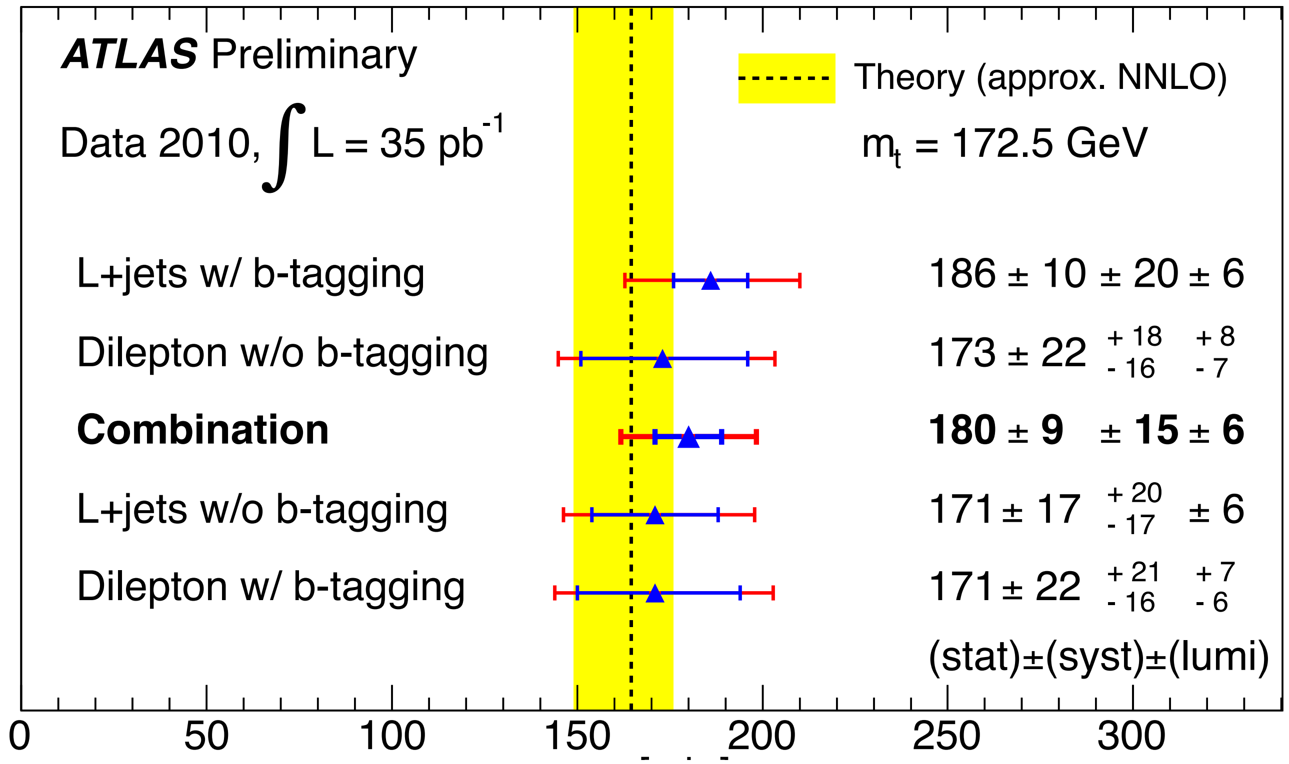


Di-lepton summary



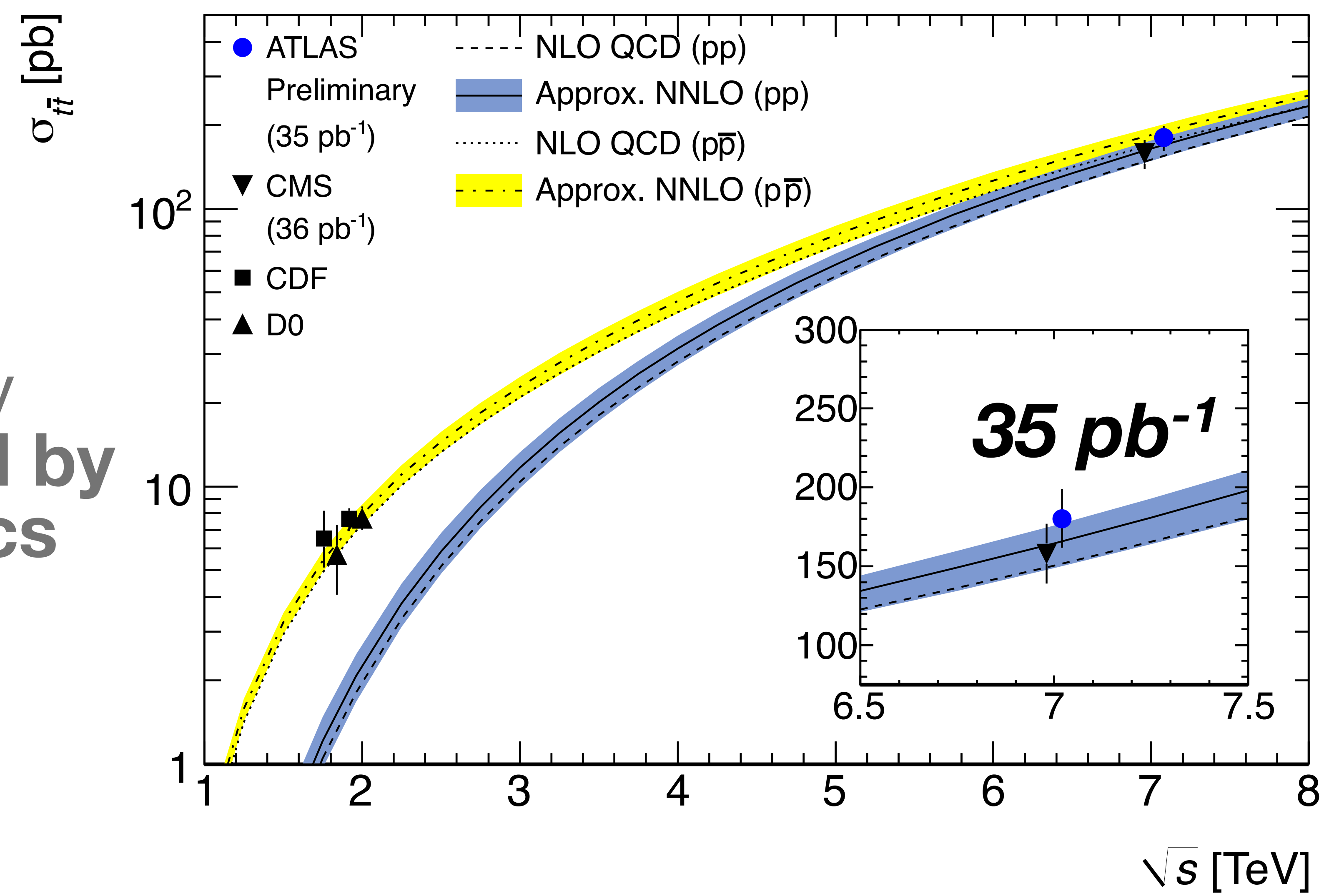
- Cross checks are **consistent** with baselines
- Systematics (10 to 12%) have similar size as statistics (~13%)

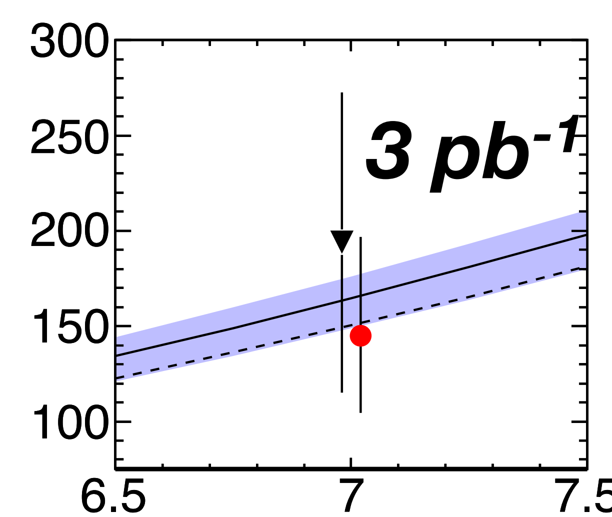
Combined cross section results



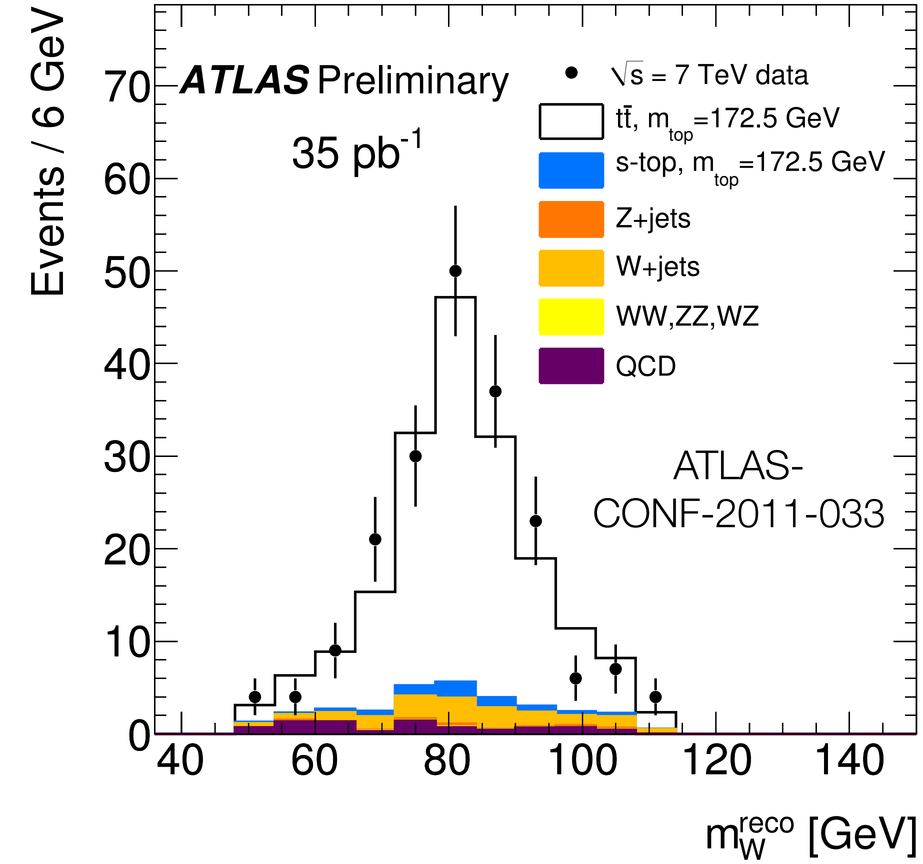
- Combined result uncertainty is **10%: comparable to theory**
  - **ATLAS:** 180 ±18 pb
  - CMS: 158±19 pb (12%)

- Uncertainty **dominated by systematics**

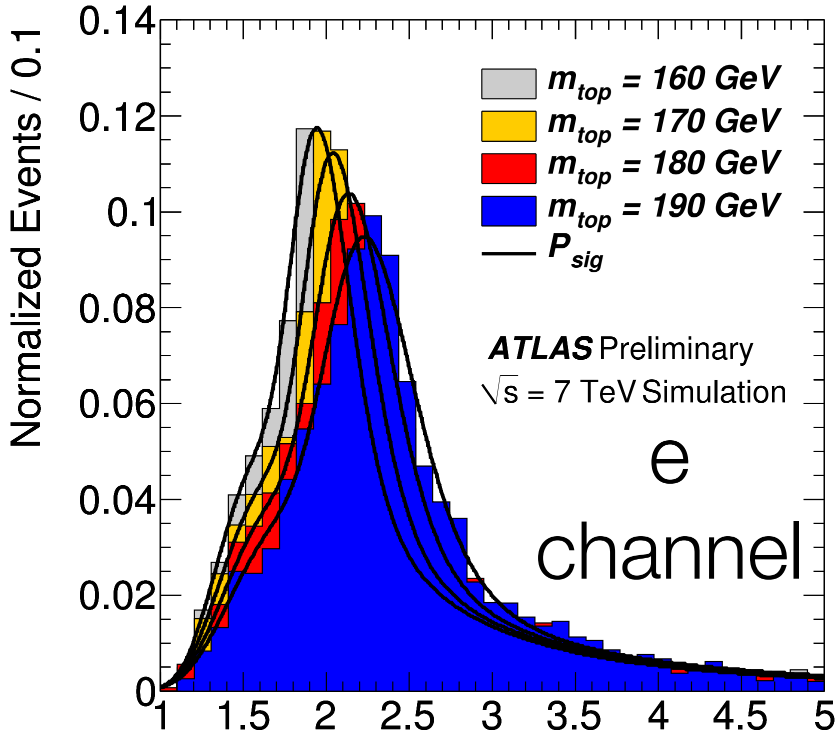




Measuring Top mass

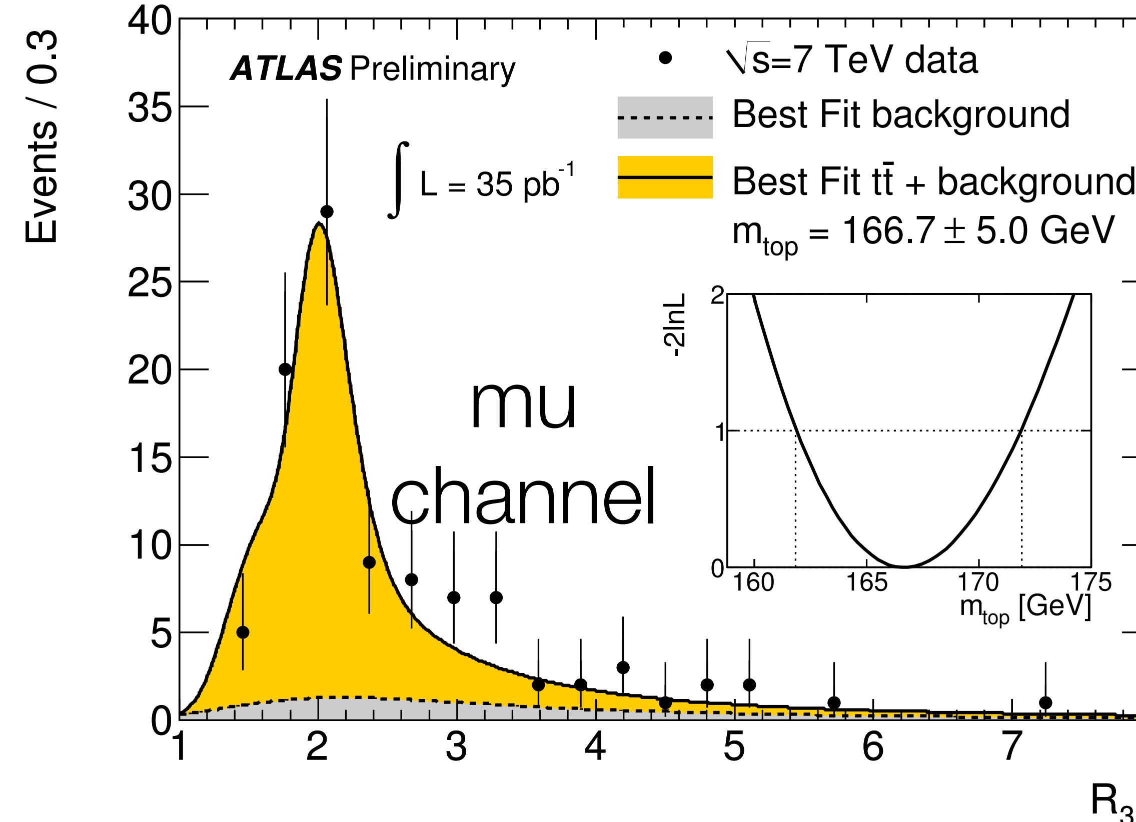


- Same selection as cross section
- Measure mass using hadronic top
  - Jet energy scale is crucial
- Three techniques
  - baseline: fit ratio of reconstructed di-jet (W) and 3-jet (top) mass
  - simultaneous measurement of scale and top mass
  - kinematic fitter based on likelihood



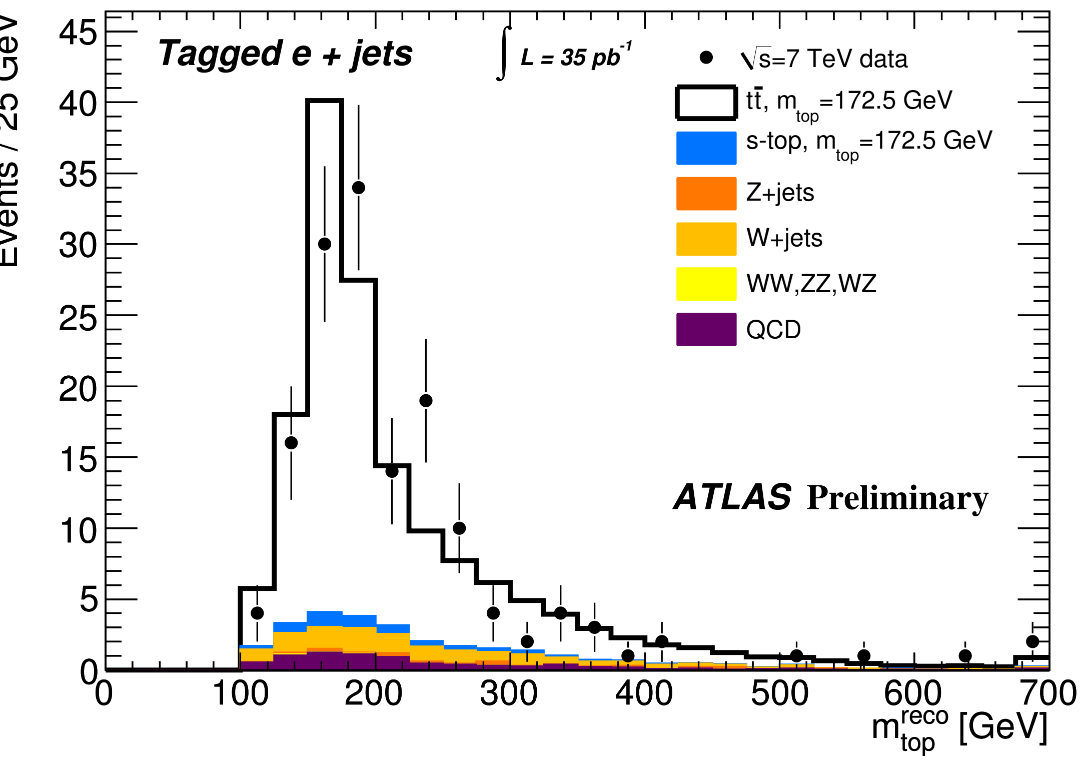
ATLAS-CONF-2011-033

ATLAS-CONF-2011-033



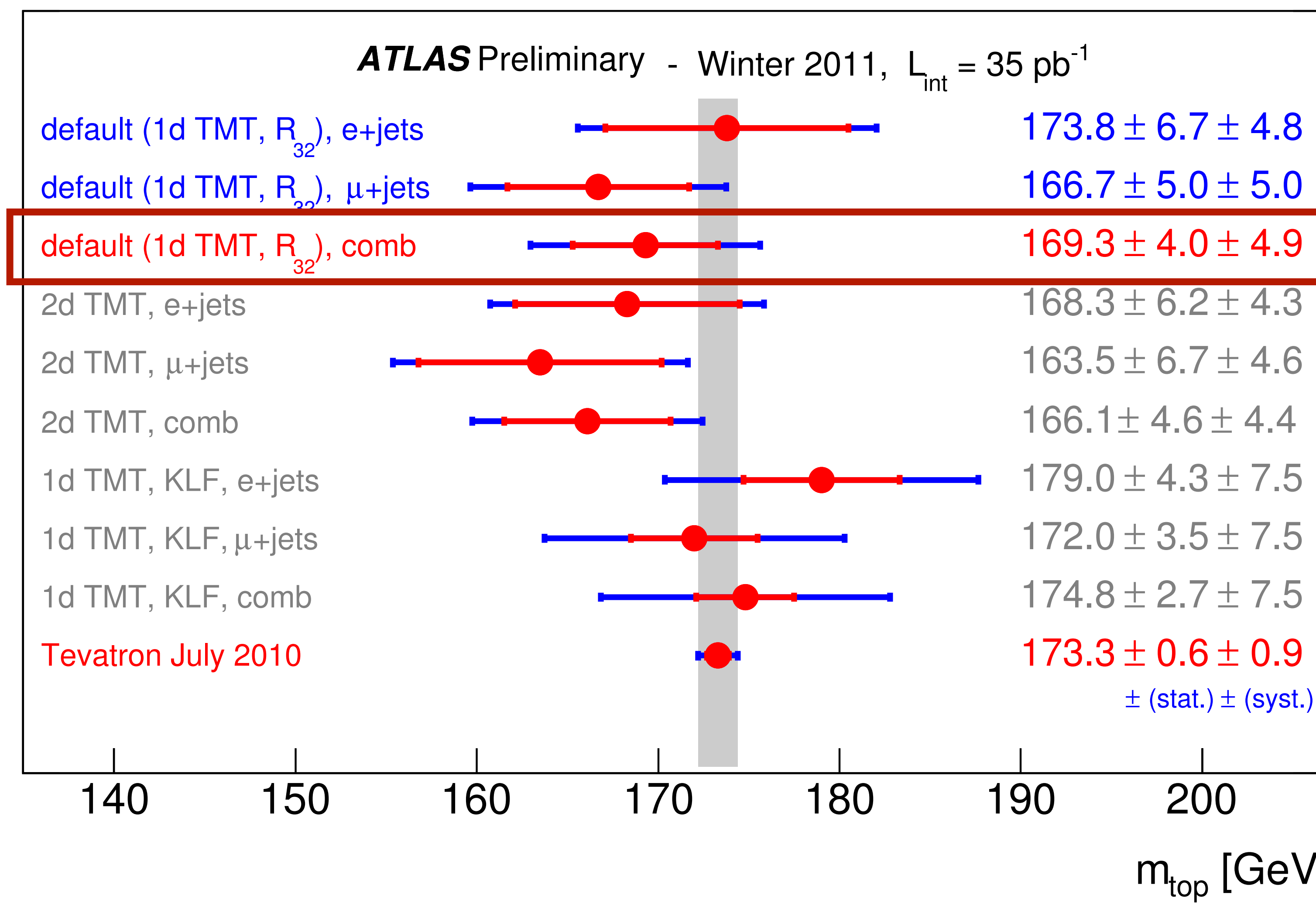
Measuring top mass

ATLAS-CONF-2011-033



top peak from kinematic fitter

ATLAS-CONF-2011-033



Stat. and syst. have the same size

- Largest systematics (baseline): jet energy scale, initial and final state radiation

Looking forward: top as a window on new physics

- Larger data sample: search for new physics in differential properties

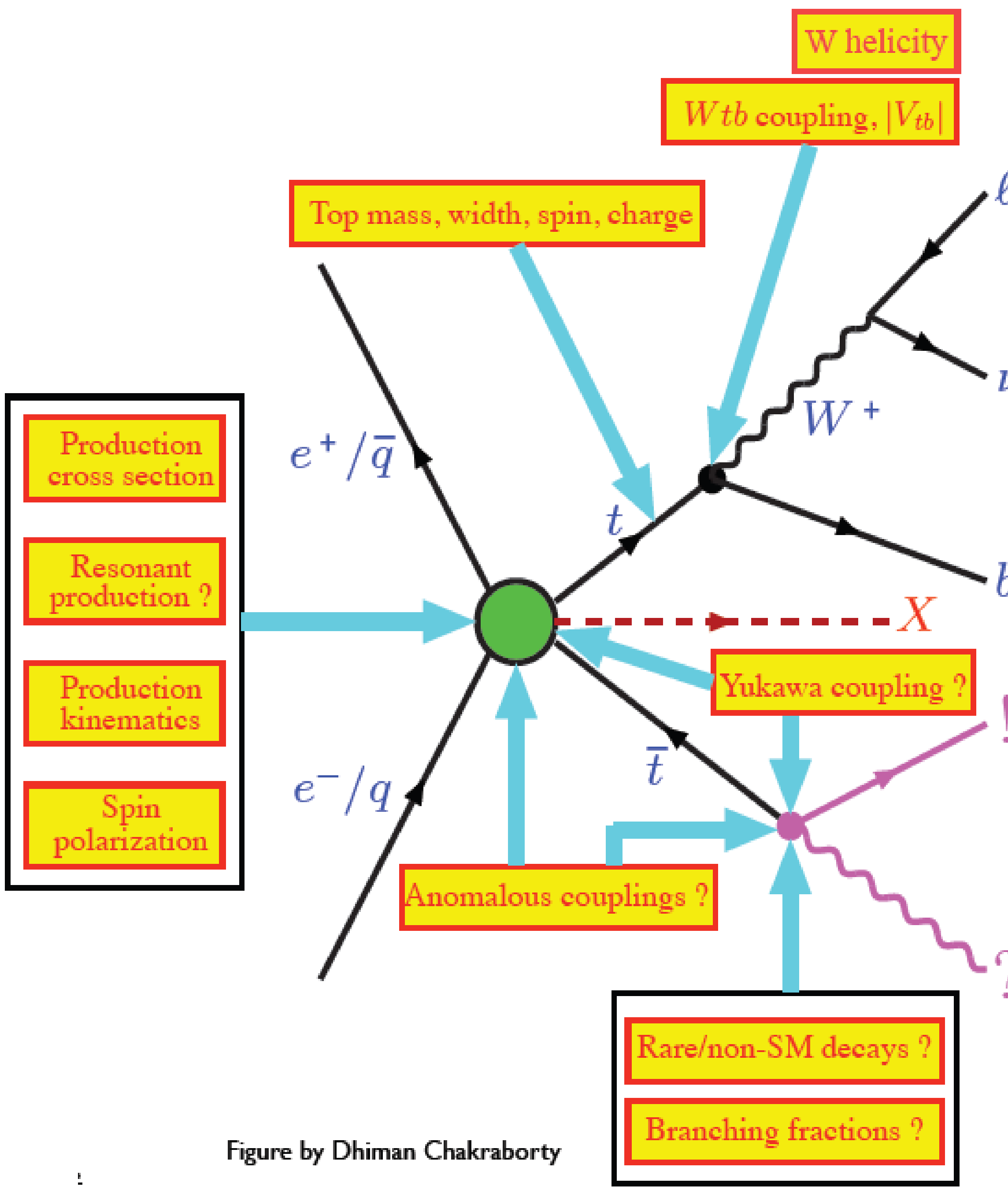
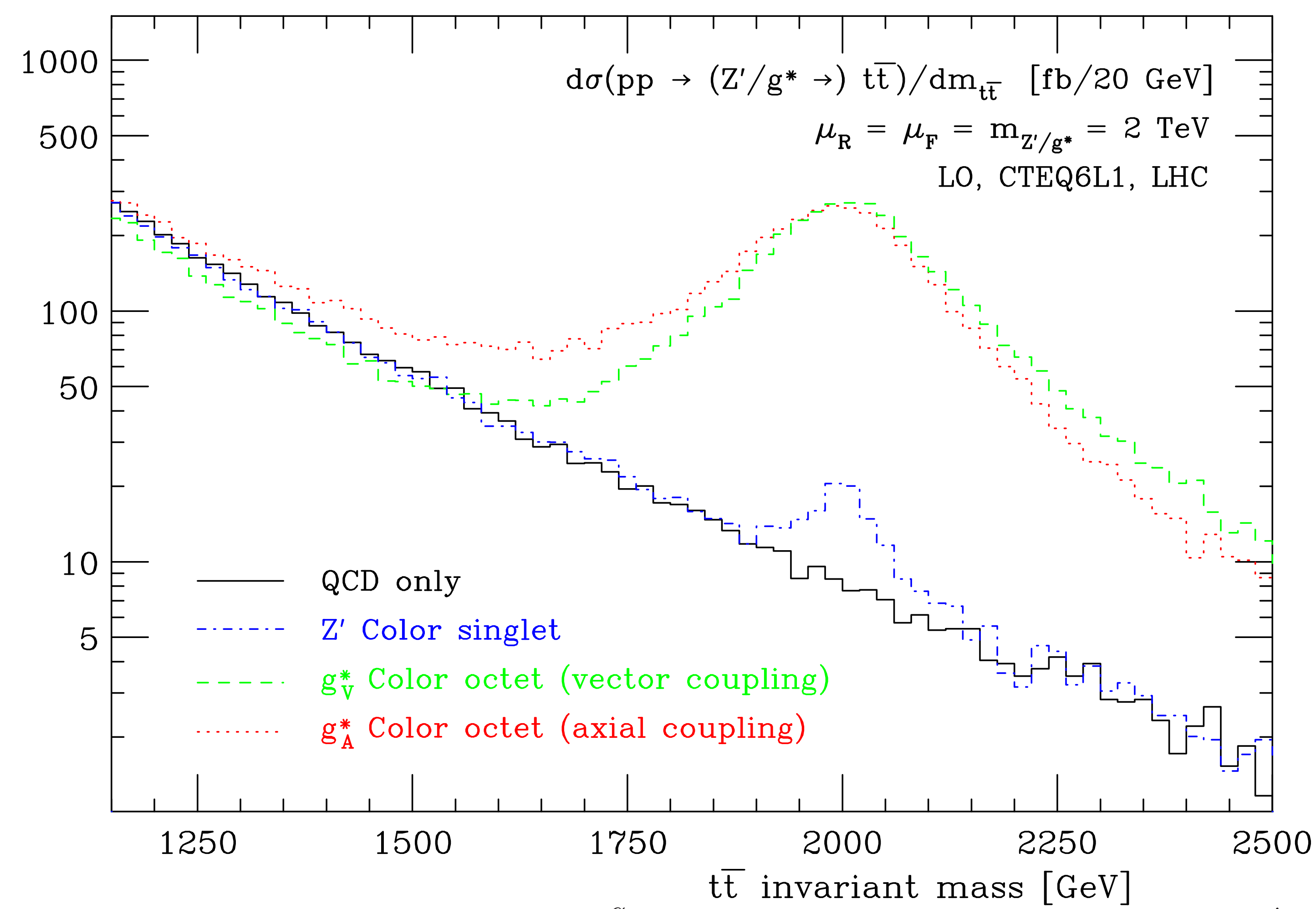


Figure by Dhiman Chakraborty

Example : resonances decaying to top

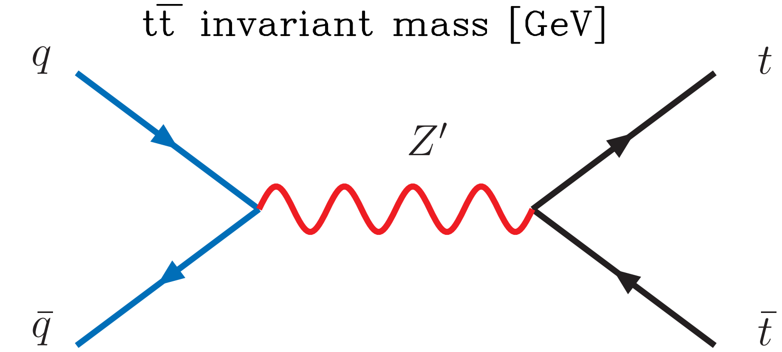
arxiv:0712.2325



Status for Z'

@ Tevatron: Z'mass < 850 GeV @95%CL

@LHC: CMS @ MoriondEWK11 showed upper limits on Z' xsec

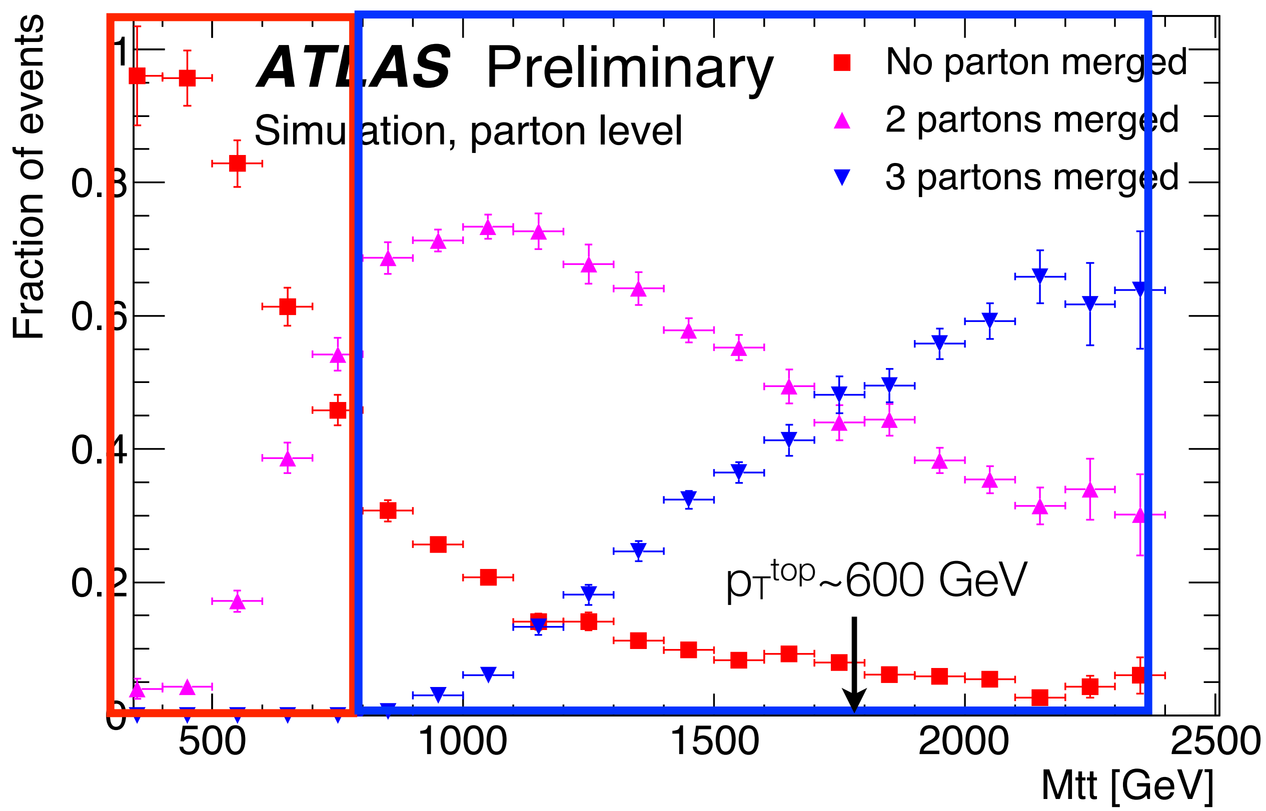


Top/anti-top resonances : ATLAS expectations

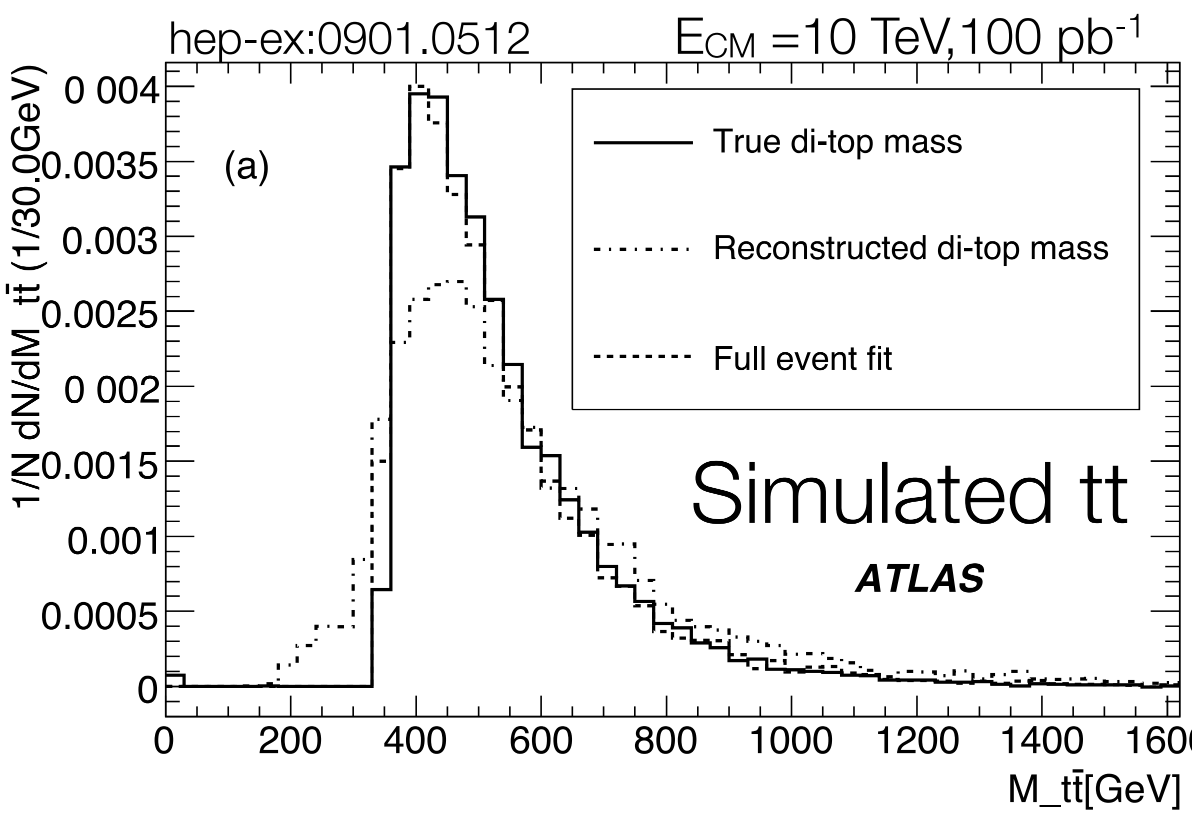
- Search for peaks in M_{tt} → **mass resolution is crucial**

- **At "low" M_{tt}**
  - **add final state objects** + algo to choose jets (p_T order, χ^2)
  - **perform kinematic fit** using M_W, M_{top}

ATLAS-PHYS-PUB-2010-008



Probability to find partons within DR=0.8



- **Higher p_T^{top} (or M_{tt})** → boosted "top jet" → new reco to separate QCD, tt, possible new physics.

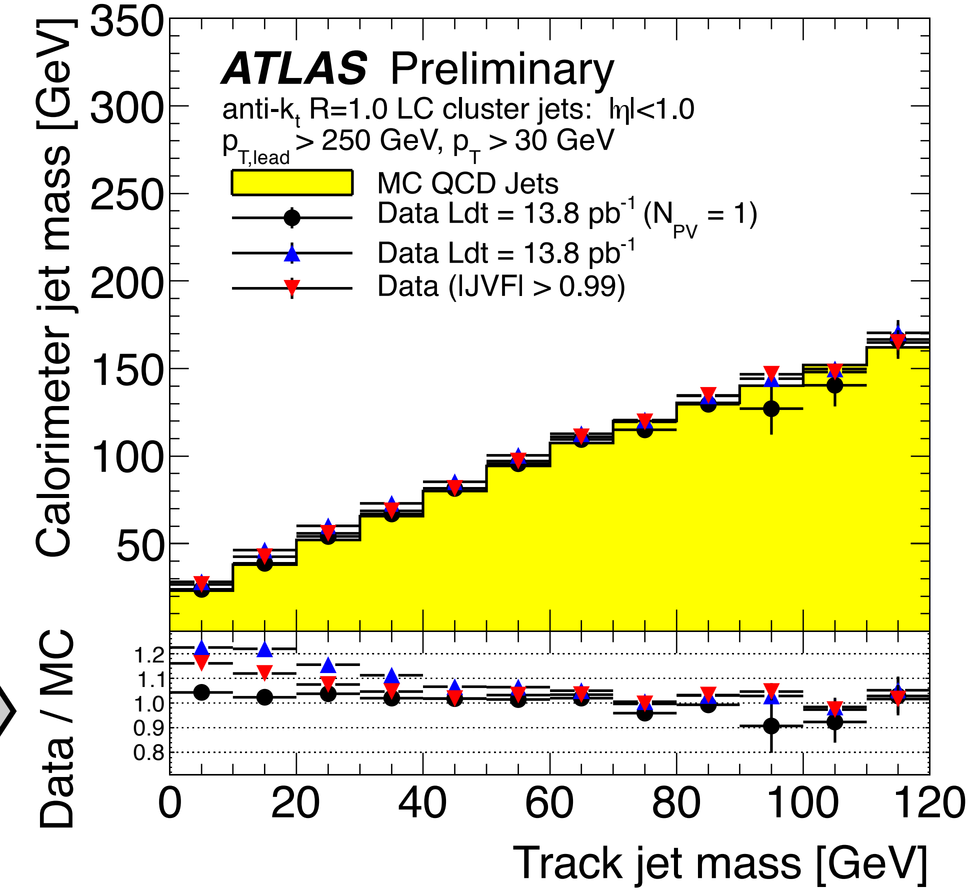
- **ATLAS analysis with 35 pb^{-1} in advanced state**. Expect results soon.

Top/anti-top resonances: ATLAS expectations

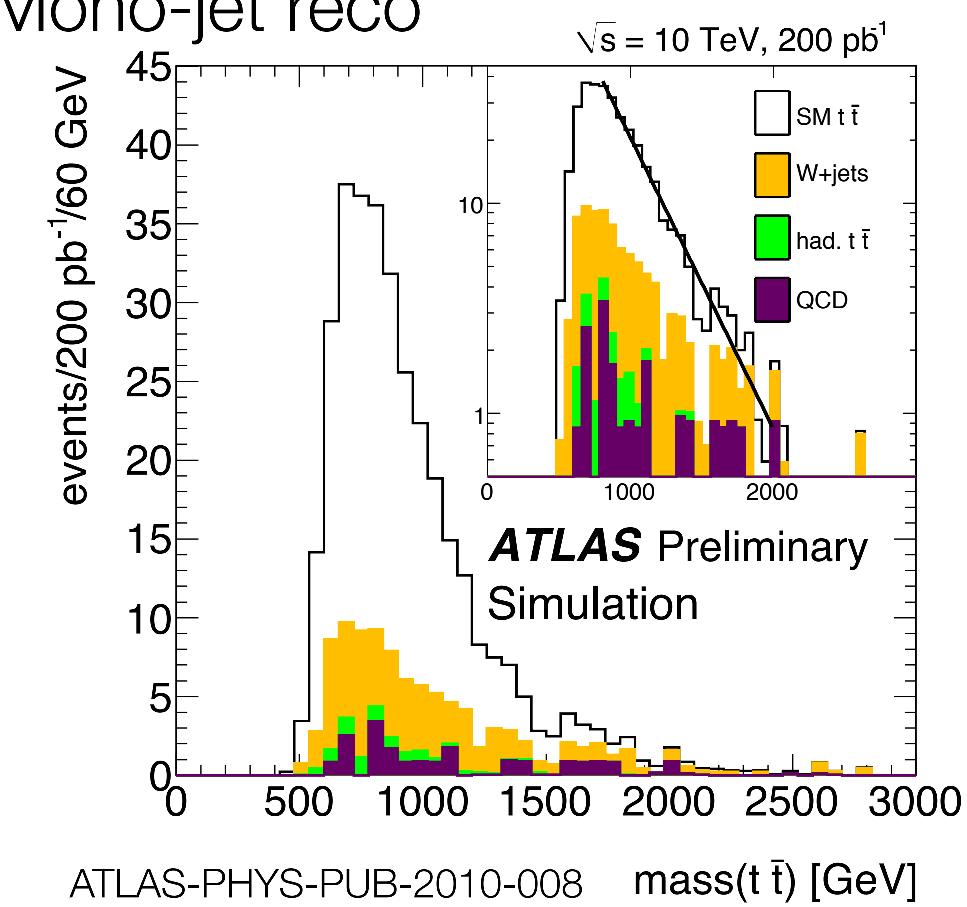
- Reconstruct top with large cone
  - techniques to tag top jets using jet substructure and shapes

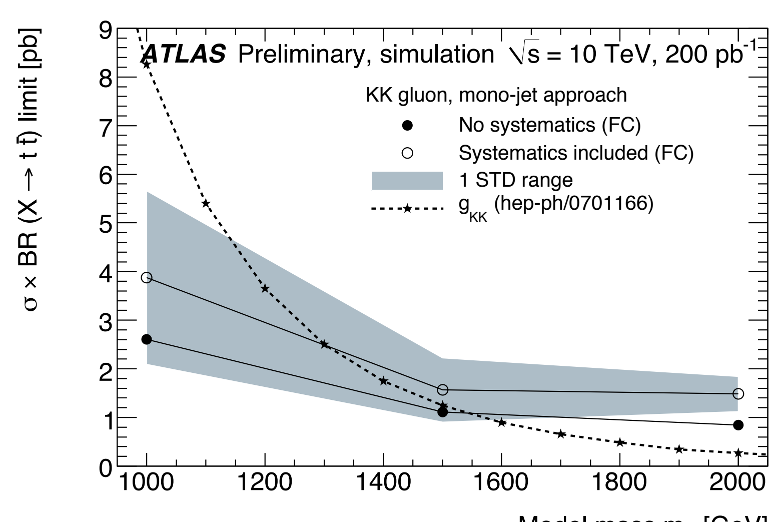
- Start measuring basic properties: **jet mass** and scale for large cones, splitting scales.

- With O(1) fb^{-1} ATLAS sensitivity is expected reach resonance masses well beyond 1 TeV (ATL_PHYS_PUB_2010_008) → exciting time for searches!



Mono-jet reco





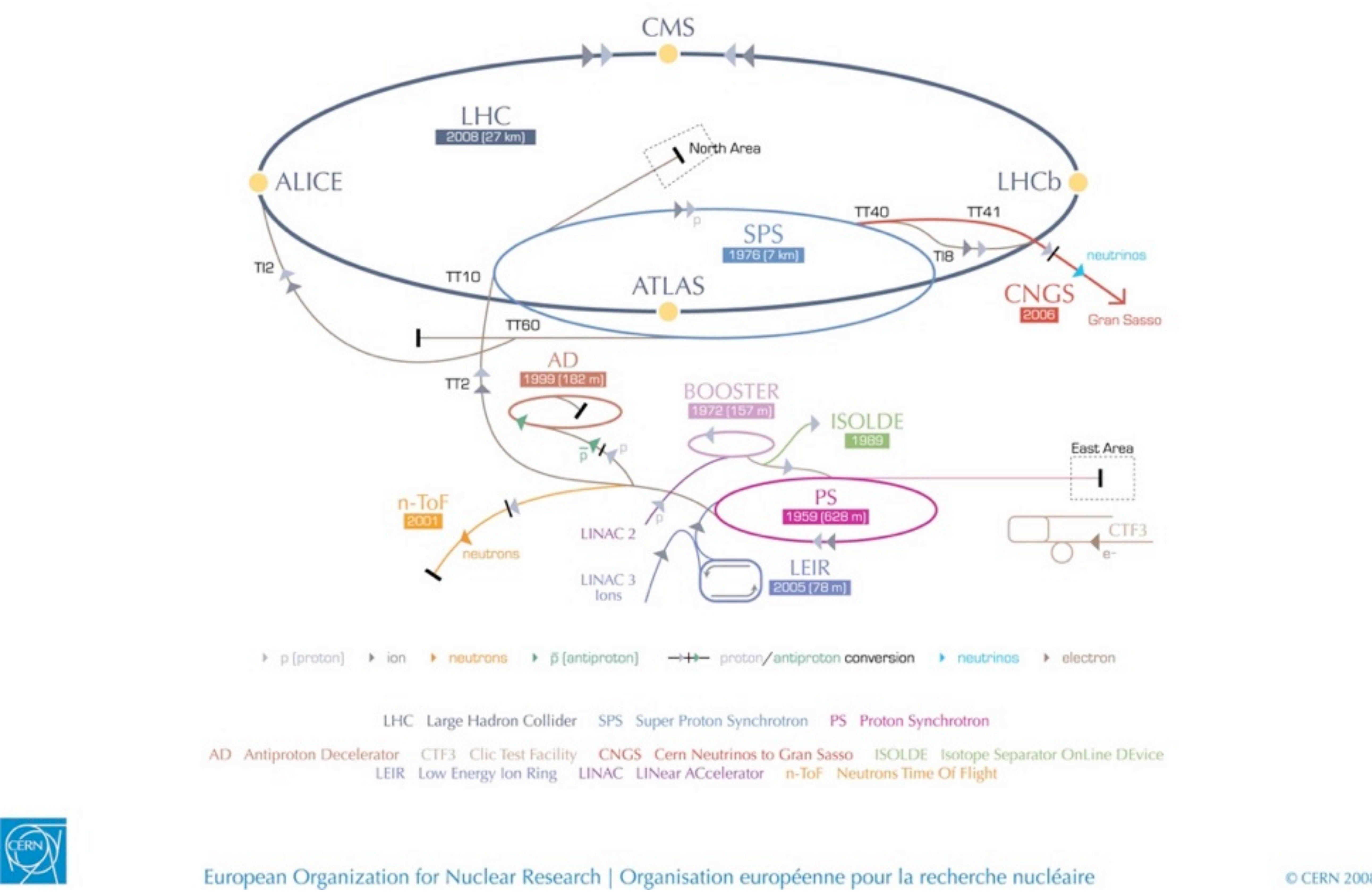
ATLAS-PHYS-PUB-2010-008

Conclusion

- Top quarks have finally visited Europe! Signal is now established at the LHC.
- ATLAS cross section measurements in single and di-lepton channel are in good agreement with standard model expectations. **Systematics dominated: 180±18 pb. Improvements will need to focus on reduction of systematics uncertainties.**
- ATLAS **Top mass is 169 ±4(stat)±4.9 (syst)**
- If O(300) to 500 pb for summer and few fb^{-1} in 2011 → **exciting prospects for new physics searches with top, *for instance top resonances***

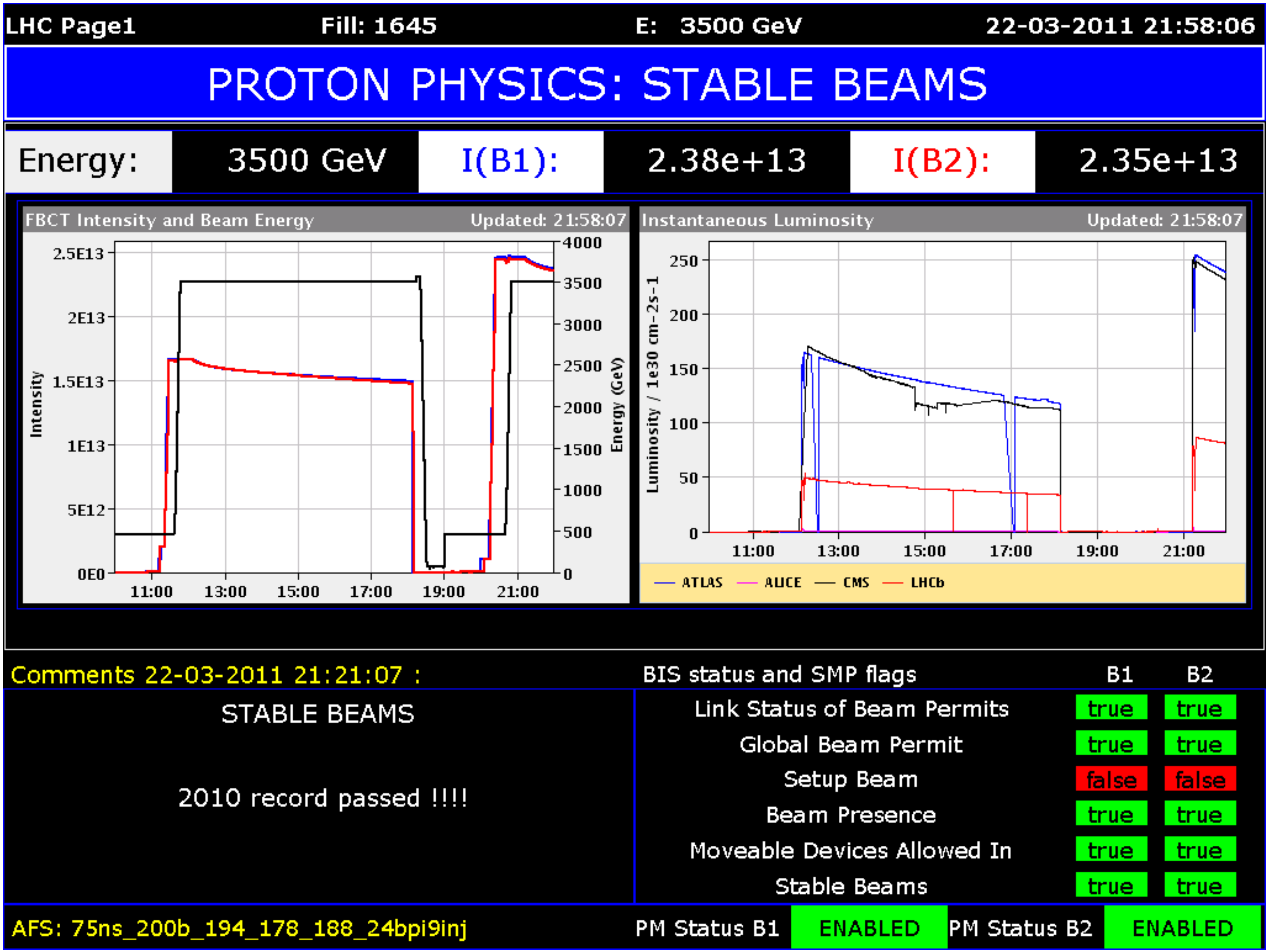
BACK-UP

CERN's accelerator complex



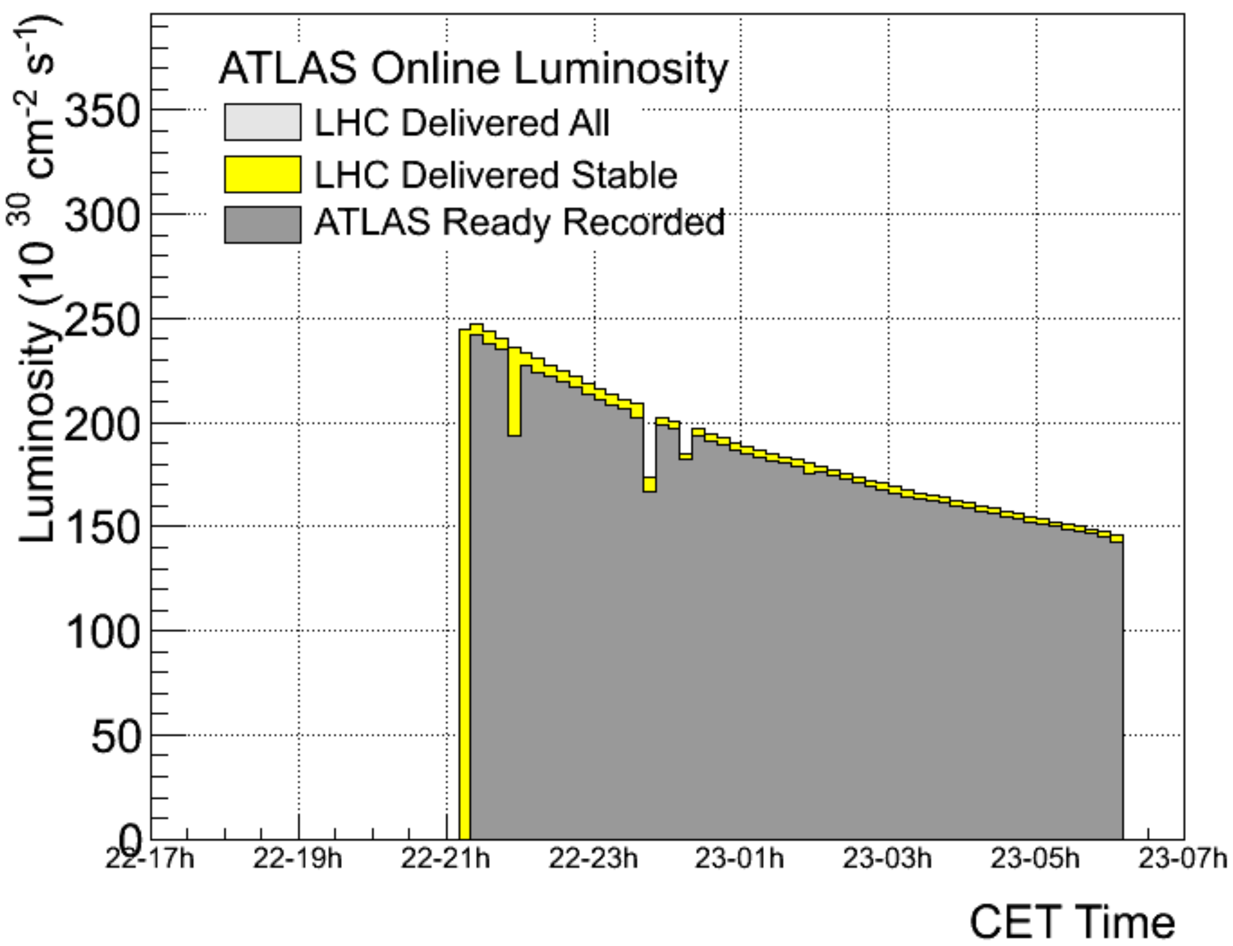
LHC record: 22nd March 2010

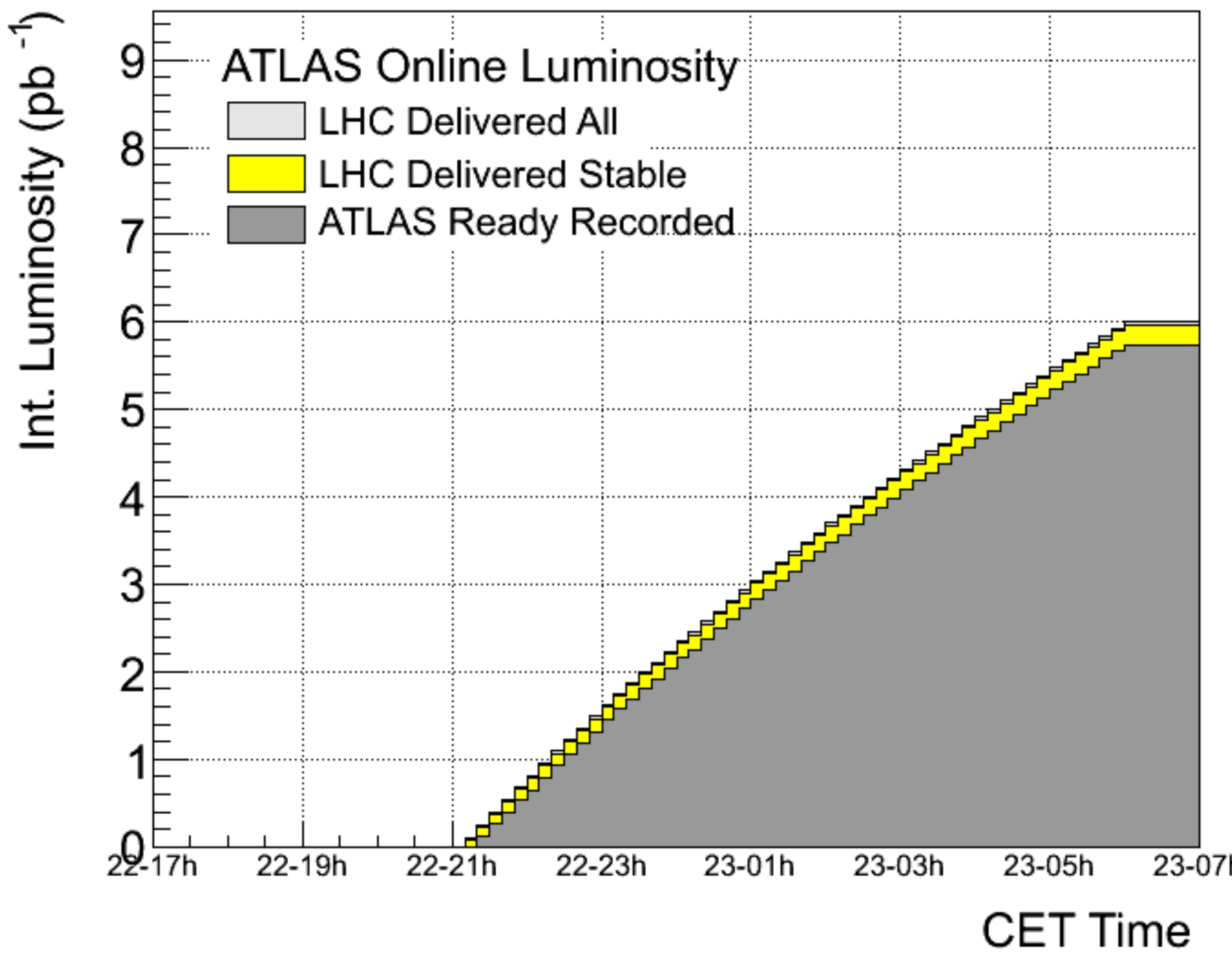
- S Meyers, 105th LHCC open Session, 23rd March 2011

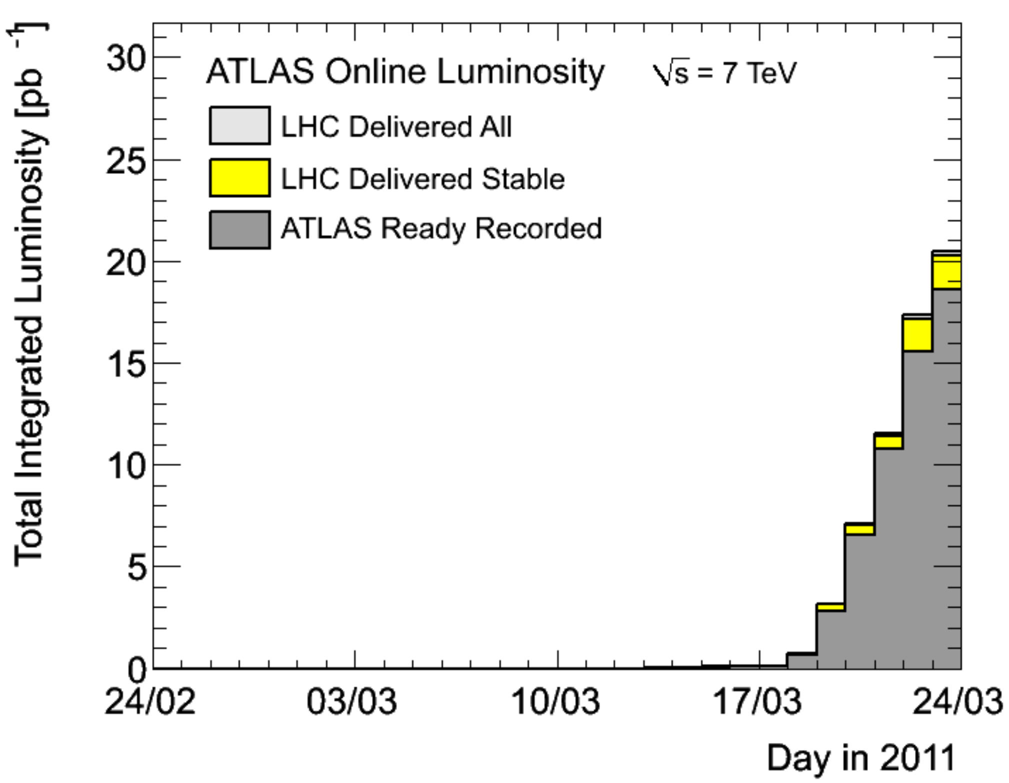


https://indico.cern.ch/conferenceDisplay.py?confId=130457

Best fill 22nd March







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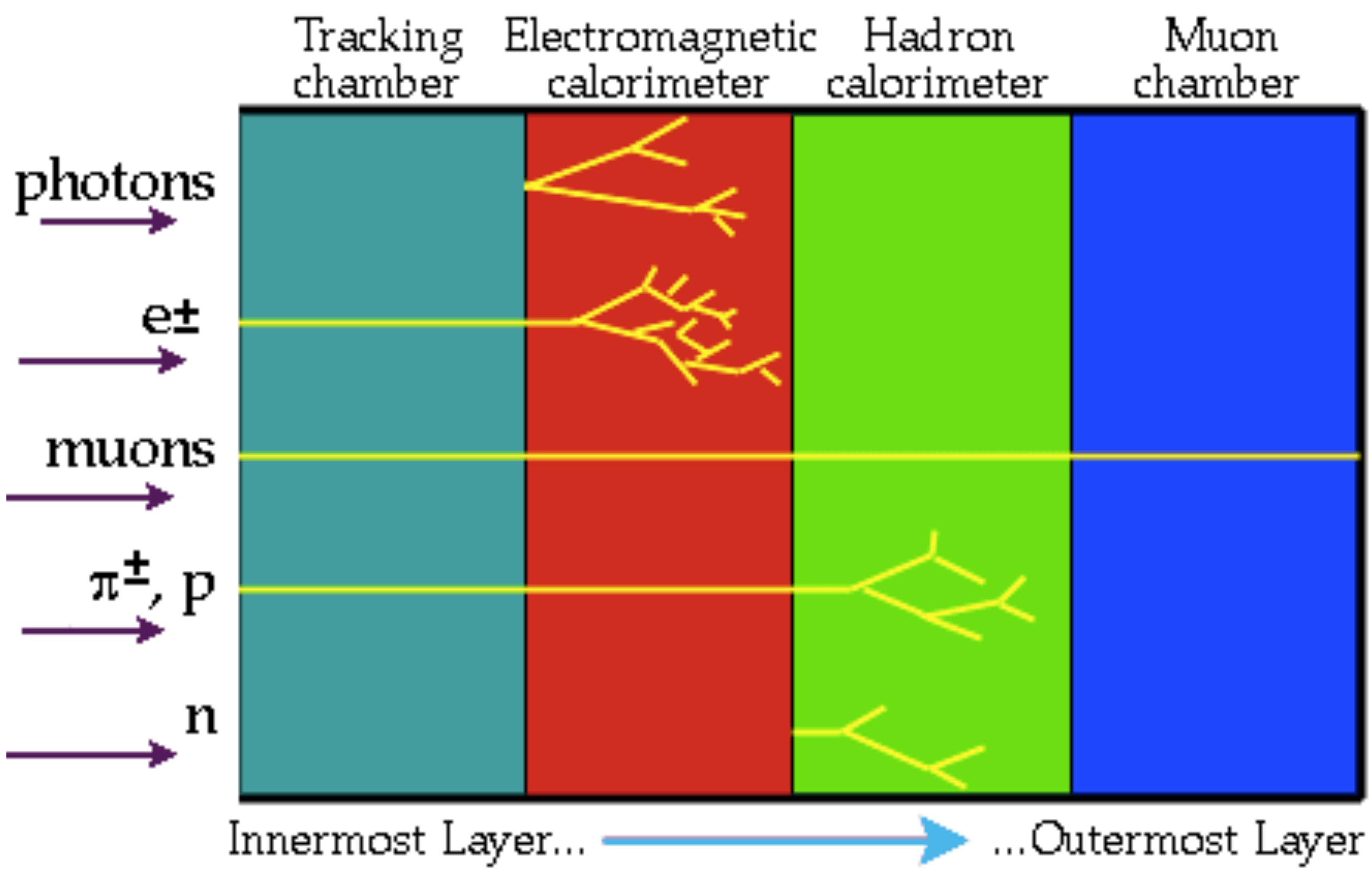
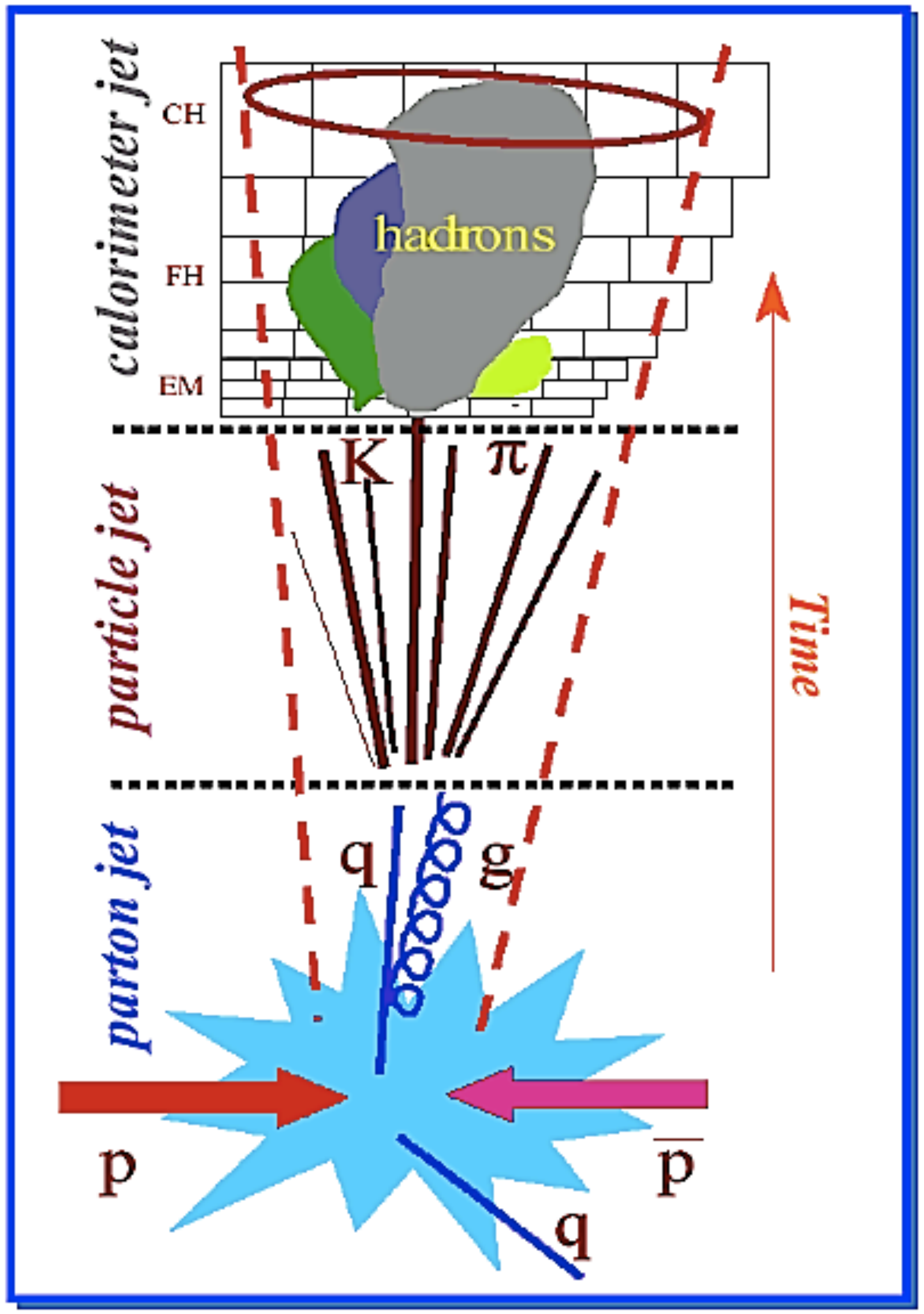
https://indico.cern.ch/conferenceDisplay.py?confId=130457

The ATLAS detector

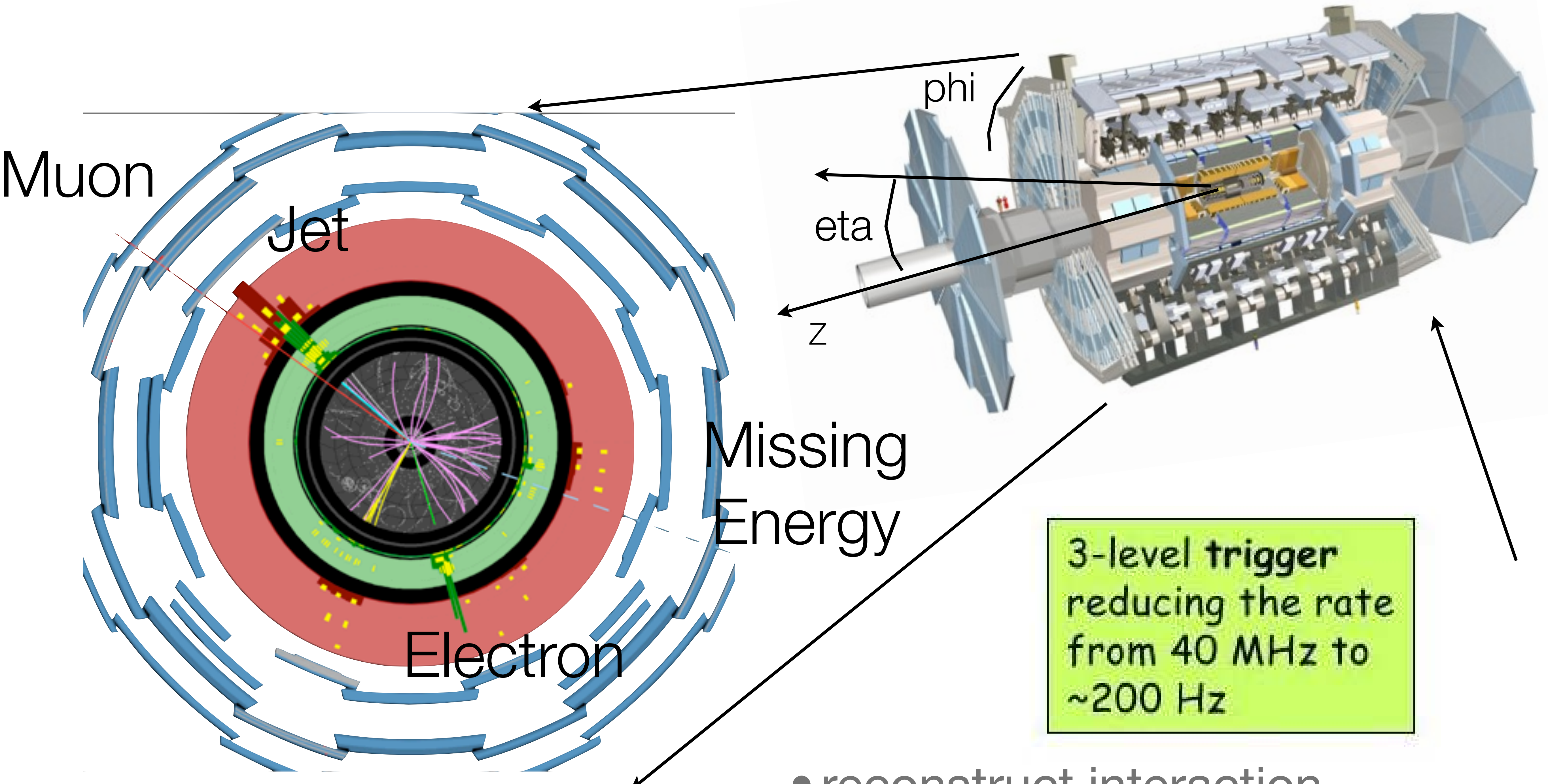
- Onion-like structure





ATLAS : a *Top* observer

Top is a real commissiong tool: full detector at play

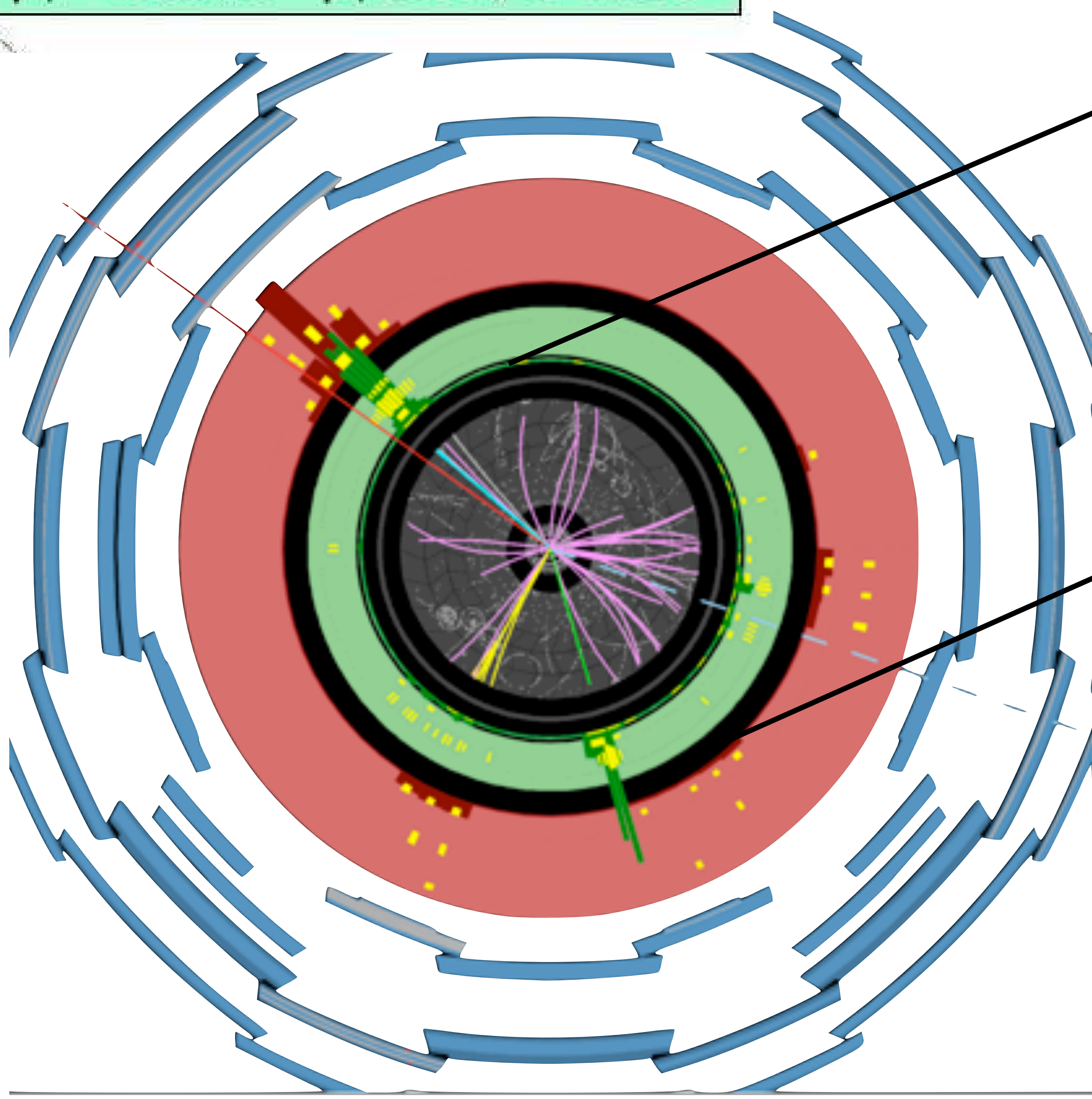


3-level trigger reducing the rate from 40 MHz to ~200 Hz

- reconstruct interaction vertex, electrons, muons, jets and missing energy

ATLAS : a *Top* observer

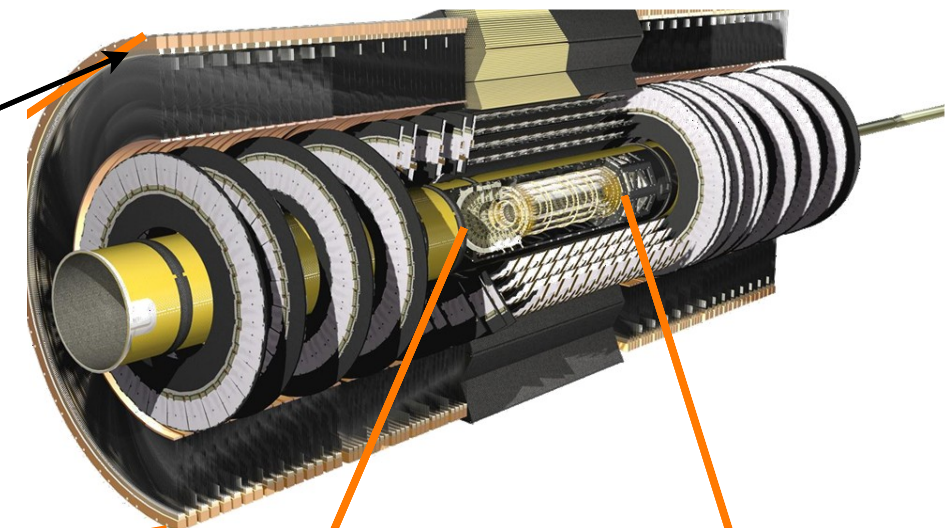
Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition
Radiation detector (straws)
Precise tracking and vertexing,
e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T\,(\mathrm{GeV}) \oplus 0.015$



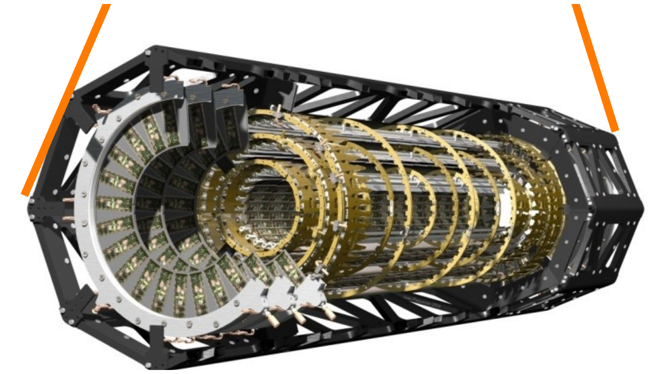
Inner detector

Transition radiation tracker

Semi conductor tracker



track, particle identifcation,
pt measurement



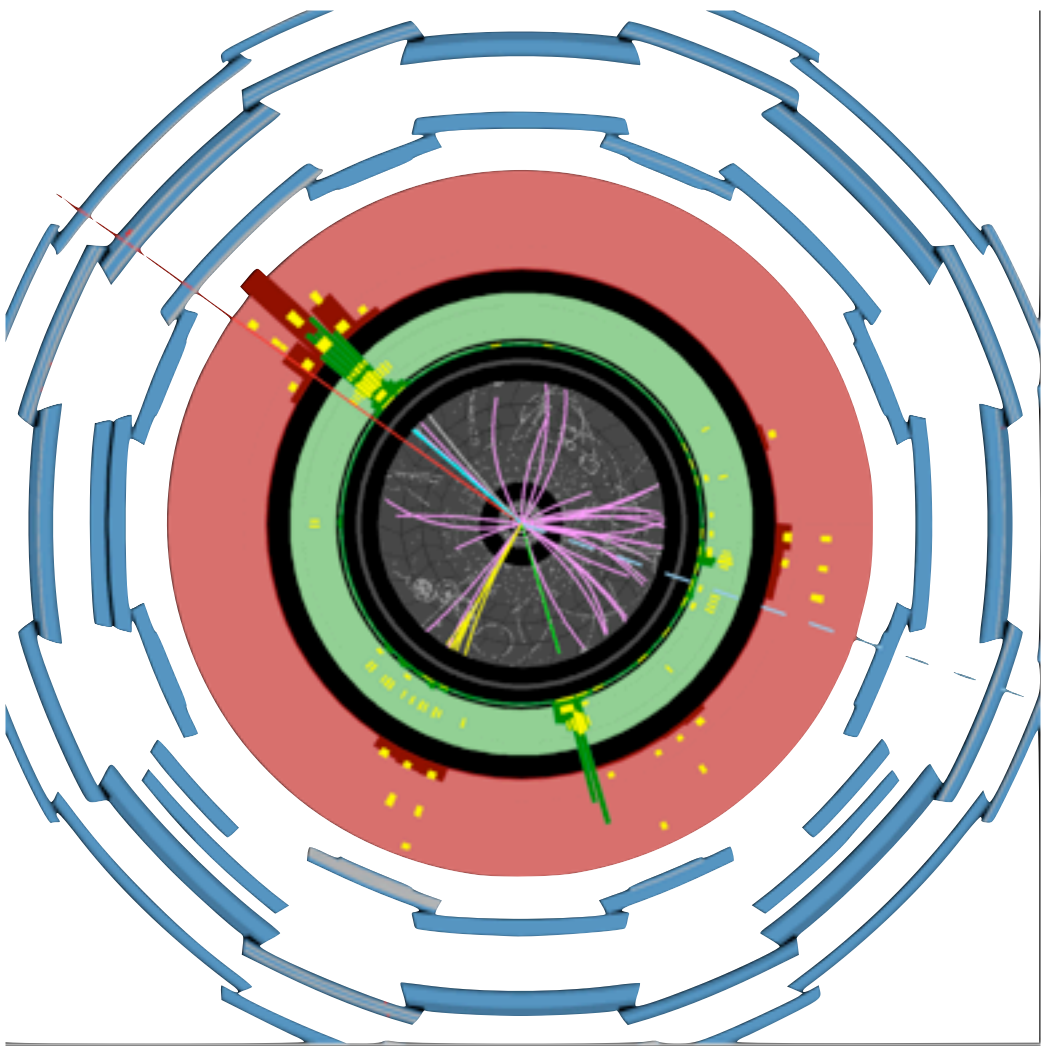
Pixel detec tor

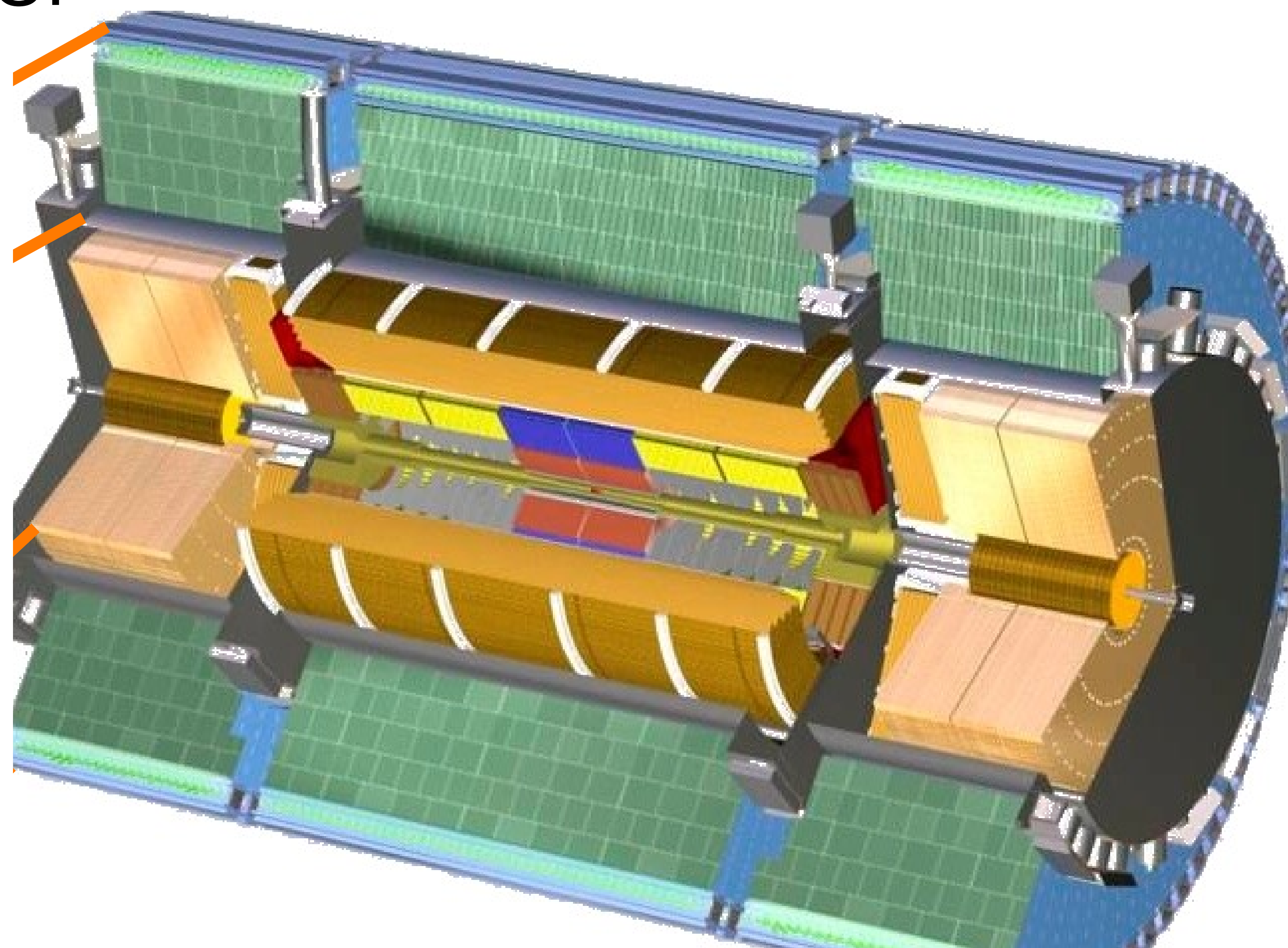
b-tagging

ATLAS **:** a *Top* observer

Calorimeters

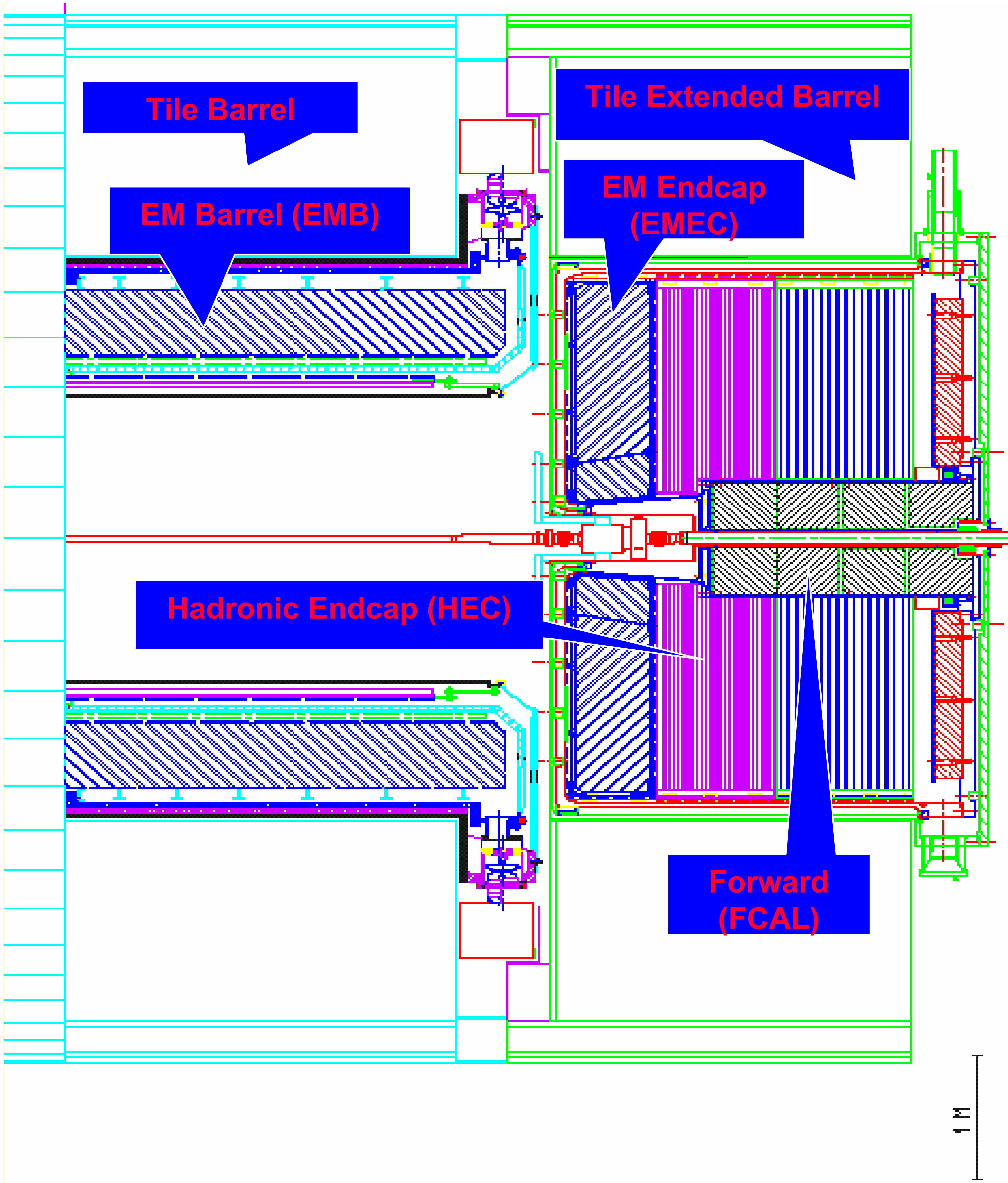
electron and jets reconstruction
Missing transverse energy





EM calorimeter: Pb-LAr Accordion
e/γ trigger, ID and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$



ATLAS Calorimetry

2

- EM LAr-Pb :
  - Barrel (EMB): |η| < 1.5
  - EndCap (EMEC): 1.4<|η|<3.2
- Hadron Calorimeters
  - Barrel (Tile) Scintil.-Steel: |η|<1.7
  - End-Cap (HEC): LAr-Cu 1.5<|η|<3.2
- Forward Calorimeter 3.2 <|η|< 5.0
  - Fcal1: LAr-Cu
  - Fcal2&3: LAr-W

Variety of materials, techniques, granularity, different performances

↓

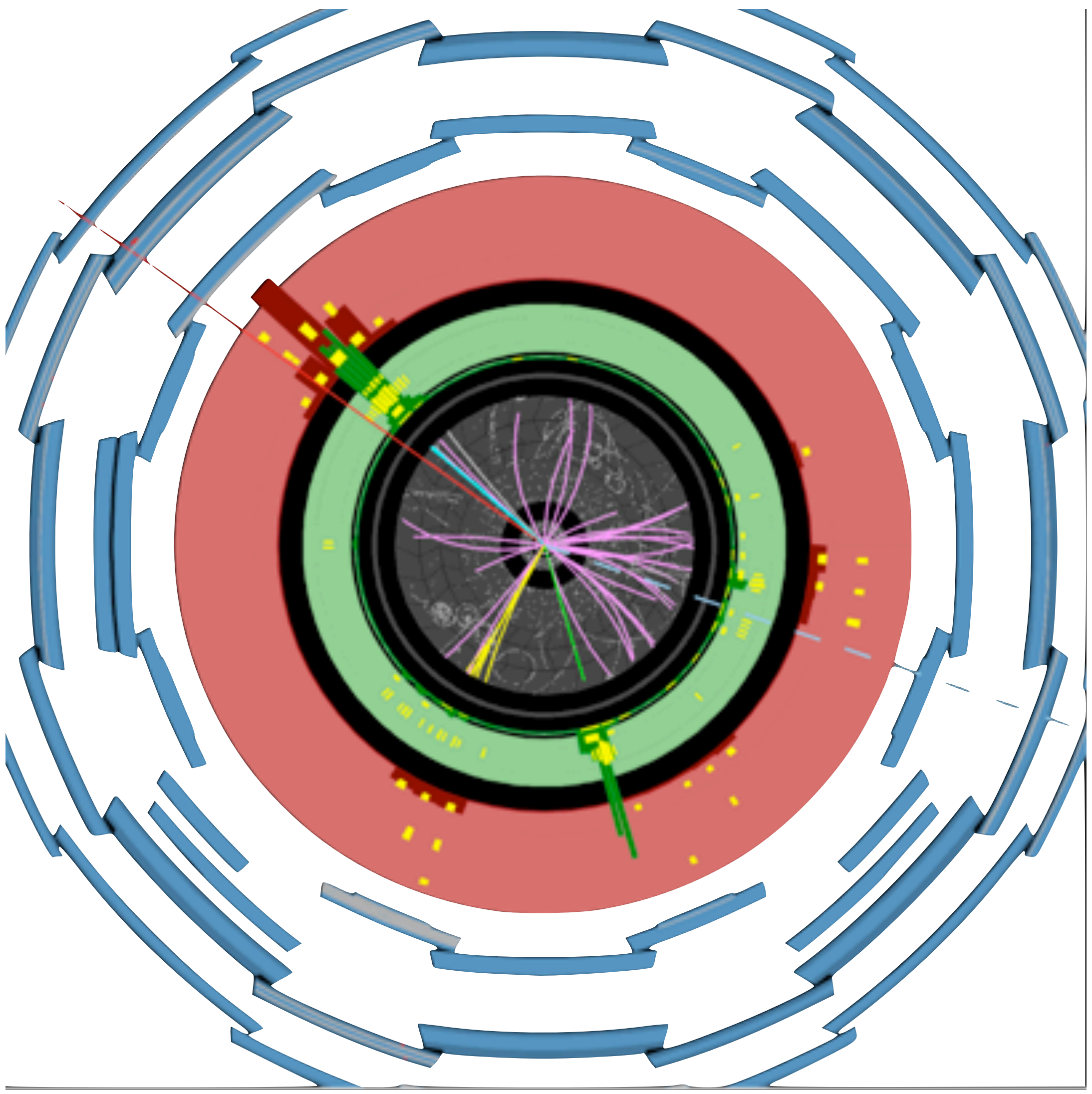
Need coherent view!

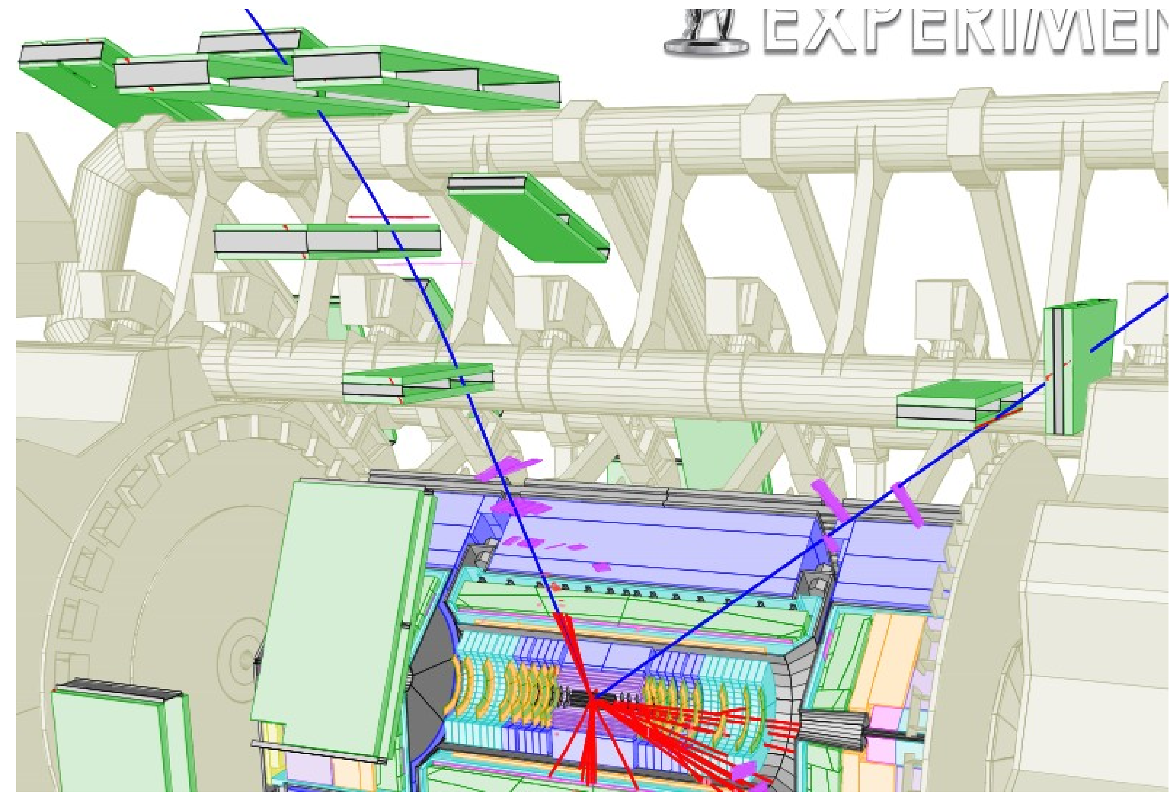
Physics Workshop - Roma - 8th June 2005

F Spanò, Local Hadron calibration, Atlas Physics Workshop Rome 2005

ATLAS **:** a *Top* observer

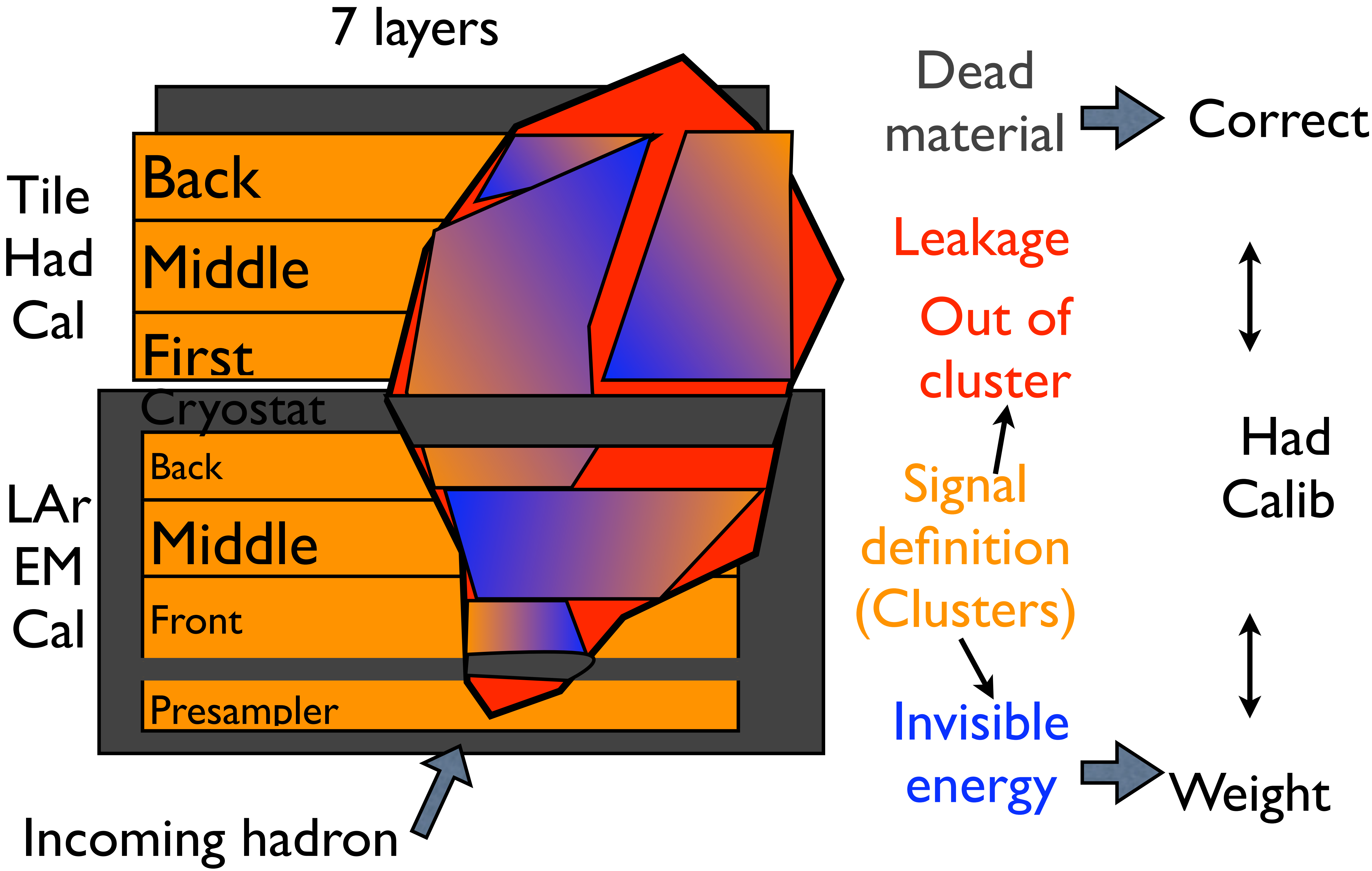
Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to $E_\mu \sim 1$ TeV





Muon spectrometer
particle identification
pt measurement

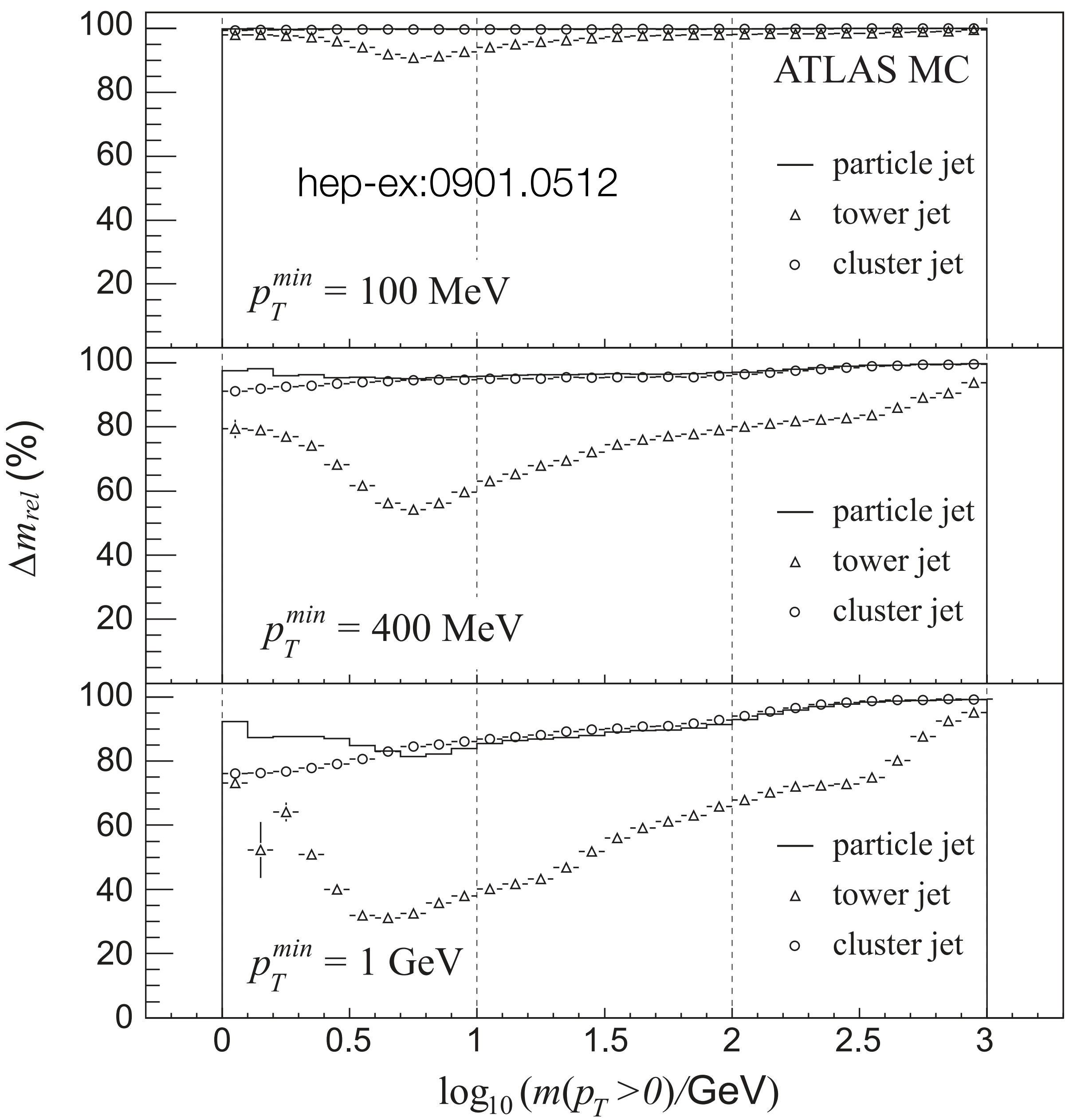
Pion in ATLAS Calo

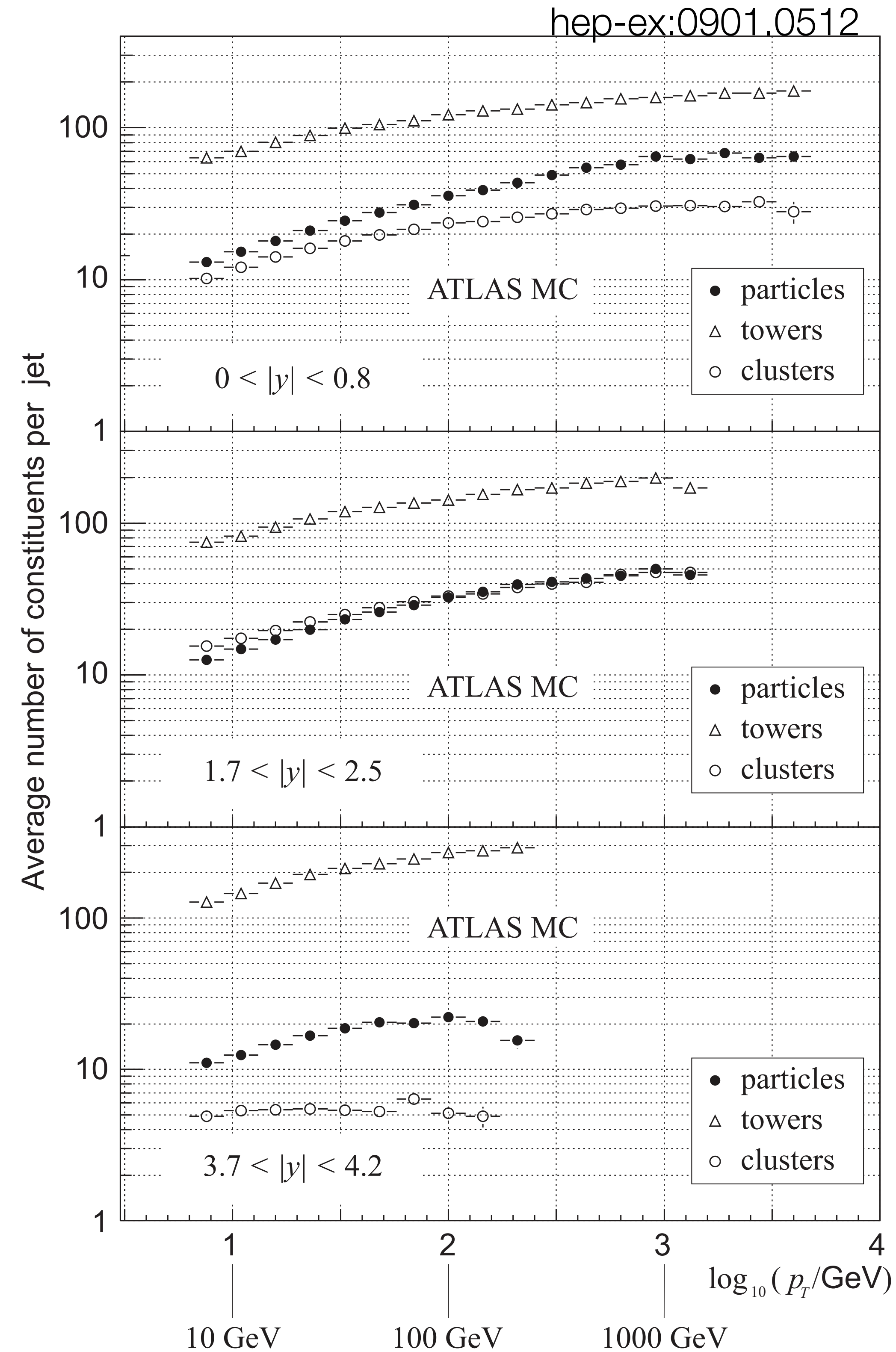


Calorimeter Clustering

di-jet simulated events, anti-k_T R=0.6

- Keep particle picture, capture shower, suppress noise
- Number of constituents per jet and jet mass closest to “true” stable particle jets





Monte Carlo used in top analyses

Generation

- Top quark : MC@NLO
  - xsec is normalized to NNLO effects
- Single top : MC@NLO
  - t, Wt and s channels
  - normalized to MC@NLO, remove Wt overlaps wih tt final state
- Z/gamma+jets : PYTHIA for Z_tautau, ALPGEN (MLM matching for) Zto ee and Z ti mumu NLO factor of 125
- Di-boson : WW, ZZ: ALPGEN normalized to NLO from MCFM
- W+jets: ALPGEN
  - W+n light partons
  - W+bb
  - W+cc
  - W+c

Hadronization

- HERWIG + JIMMY for underlying event modelling

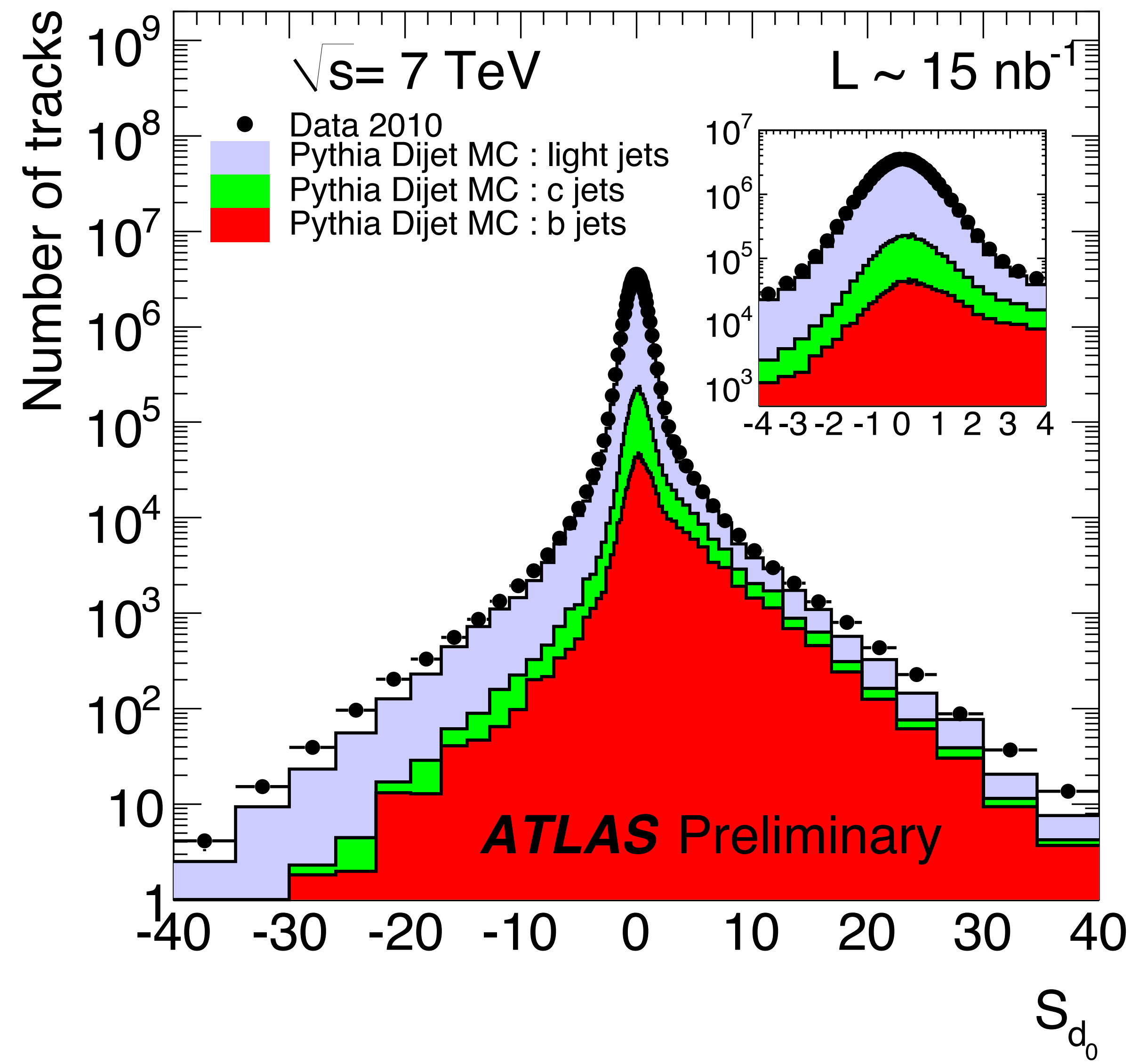
B-tagging : Jet prob algorithm

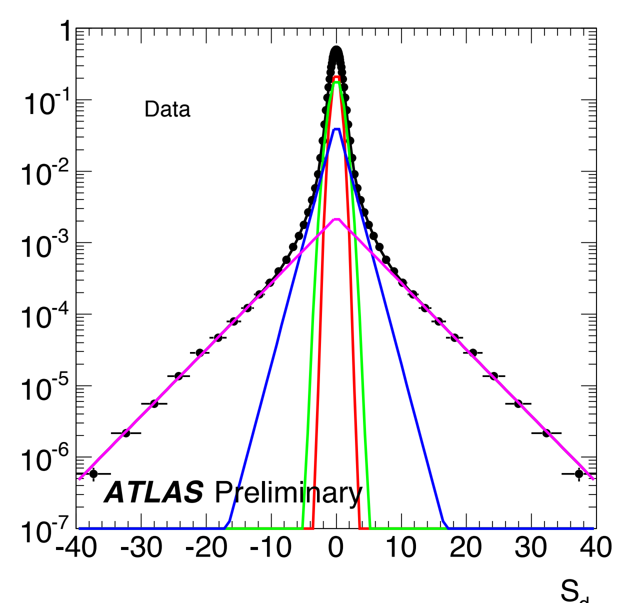
$$S_{d_0} \equiv d_0/\sigma_{d_0}$$

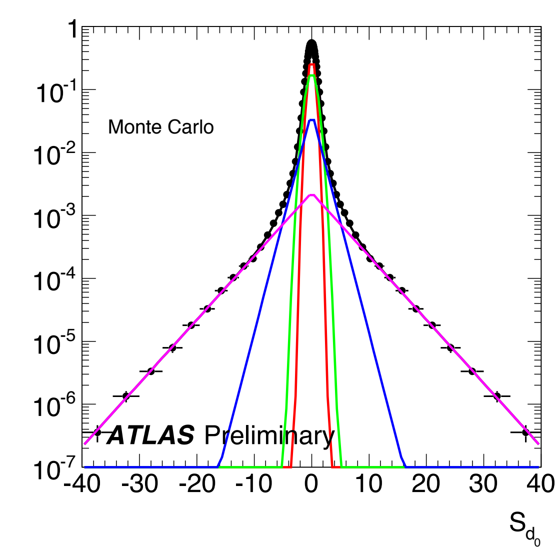
- Compare signed impact parameter significance for each track in jet to resolution function to find track prob. to originate

$$\mathscr{P}_{\mathrm{trk}\,i} = \int_{-\infty}^{-|d_0^i/\sigma_{d_0}^i|} \mathscr{R}(x)dx.$$

$$\mathscr{P}_{\mathrm{jet}} = \mathscr{P}_0 \sum_{k=0}^{N-1} \frac{(-ln\mathscr{P}_0)^k}{k!},$$







Jet calibration : top Specific effects

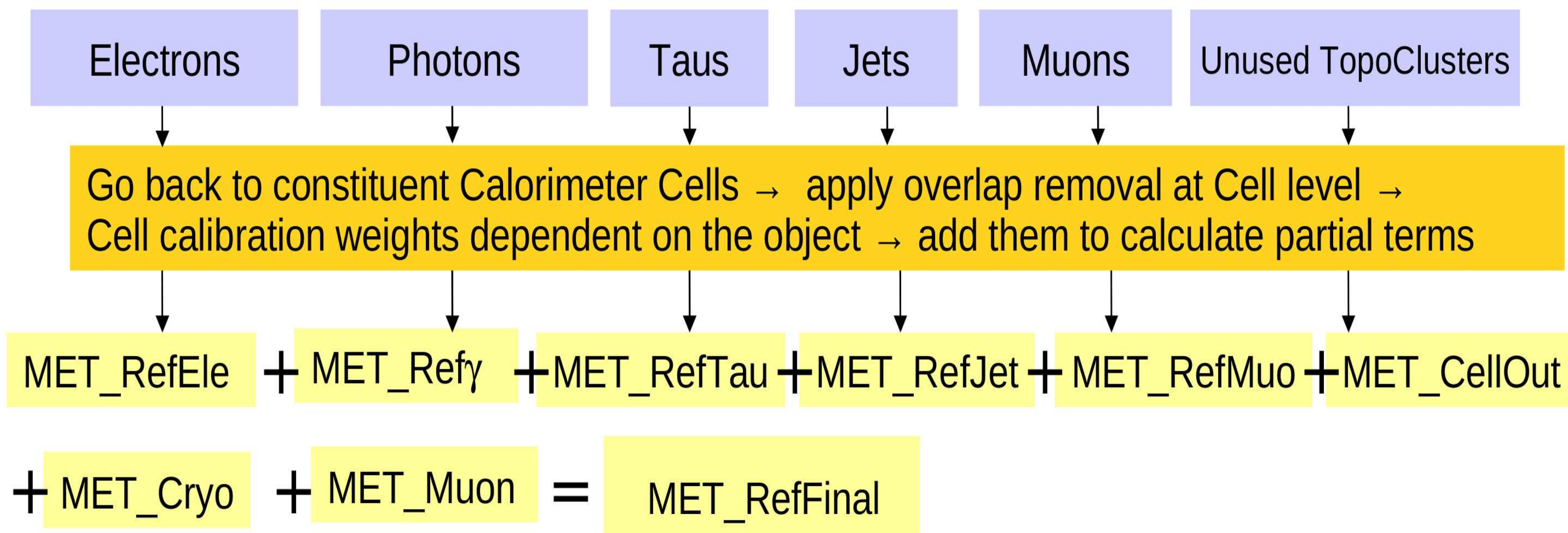
- Close by jet
  - jet splitting can bias scale
  - recover by monte carlo baed correction as a fucntion of isolation

- Gluon vs quark jets
  - differentresponse in gluon initiated and uqark initiated jets
  - validation in di-jet (gluon) and gamma-jet (quark) samples

- B-jet
  - tag and probe method in data-MC in di-jet
  - comparison to track jets (data/MC)

MIssing transverse energy (I)

$$E_{x(y)}^{\text{miss}} = E_{x(y)}^{\text{miss,calo}} + E_{x(y)}^{\text{miss,cryo}} + E_{x(y)}^{\text{miss,muon}}$$



- overlap removal order is
  - electron, photon, hadronic taus, jets, muons

MIssing transverse energy (II)

- The three terms are, muons

$$E_{x(y)}^{\mathrm{miss}} = E_{x(y)}^{\mathrm{miss,calo}} + E_{x(y)}^{\mathrm{miss,cryo}} + E_{x(y)}^{\mathrm{miss,muon}}$$

$$E_{x(y)}^{\mathrm{miss,calo,calib}} = E_{x(y)}^{\mathrm{miss},e} + E_{x(y)}^{\mathrm{miss},\gamma} + E_{x(y)}^{\mathrm{miss},\tau} + E_{x(y)}^{\mathrm{miss,jets}} + E_{x(y)}^{\mathrm{miss,calo},\mu} + \boxed{E_{x(y)}^{\mathrm{miss,CellOut}}}$$

$$E_{x(y)}^{\mathrm{miss},\mu} = -\sum_{\mathrm{selected\ muons}} E_{x(y)}^{\mu}$$

isolated muons

non-isolated muons

$$E_{x(y)}^{\mathrm{miss,cryo}} = -\sum_{\mathrm{jets}} E_{x(y)}^{\mathrm{jet,cryo}}$$

$$E_{x}^{\mathrm{jet,cryo}} = w^{\mathrm{cryo}} \sqrt{E_{\mathrm{EM3}}^{\mathrm{jet}} \times E_{\mathrm{HAD1}}^{\mathrm{jet}}} \frac{\cos\phi_{\mathrm{jet}}}{\cosh\eta_{\mathrm{jet}}}$$

$$E_{y}^{\mathrm{jet,cryo}} = w^{\mathrm{cryo}} \sqrt{E_{\mathrm{EM3}}^{\mathrm{jet}} \times E_{\mathrm{HAD1}}^{\mathrm{jet}}} \frac{\sin\phi_{\mathrm{jet}}}{\cosh\eta_{\mathrm{jet}}}$$

W+jets estimate with ratio method

Estimate pre-tagged amount of W+jets in 4-jet bin then **correct it** to tagged sample

$$W^{\geq 4\text{-jet}}_{\text{tagged}} = W^{\geq 4\text{-jet}}_{\text{pre-tag}} \cdot f^{\geq 4\text{-jet}}_{\text{tagged}}$$

- Assume W+jets amounts in jet bin multiplicity are such that

$W^{n+1\text{-jets}}/W^{n\text{-jets}} \sim \text{constant}$ (Berends ,Giele)

$W^{n\text{-jets}}/W^{2\text{-jets}} = W^{n\text{-jets}}/W^{n-1\text{je}}$ * $(W^{n\text{-jets}}/W^{n-1\text{jet}}$....

$$W^{\geq 4\text{-jet}}_{\text{pre-tag}} = W^{2\text{-jet}}_{\text{pre-tag}} \cdot \sum_{n=2}^{\infty} (W^{2\text{-jet}}_{\text{pre-tag}} / W^{1\text{-jet}}_{\text{pre-tag}})^n,$$

Measured by subtracting simulated nonW bkg in 1,2 jet bin, before b-tagging

good agreement data/MC in control region

$$f^{\geq 4\text{-jet}}_{\text{tagged}} = f^{2\text{-jet}}_{\text{tagged}} \cdot f^{\text{corr}}_{2\to\geq 4};$$

Subtract MC in content of 2jet bin bef and after tagging. Take ratio (only in mu, less QCD)

$$f^{\text{corr}}_{2\to\geq 4} = f^{\geq 4\text{-jet}}_{\text{tagged}} / f^{2\text{-jet}}_{\text{tagged}}$$

from simulation

Systematic uncertainties : single lepton with b-tagging

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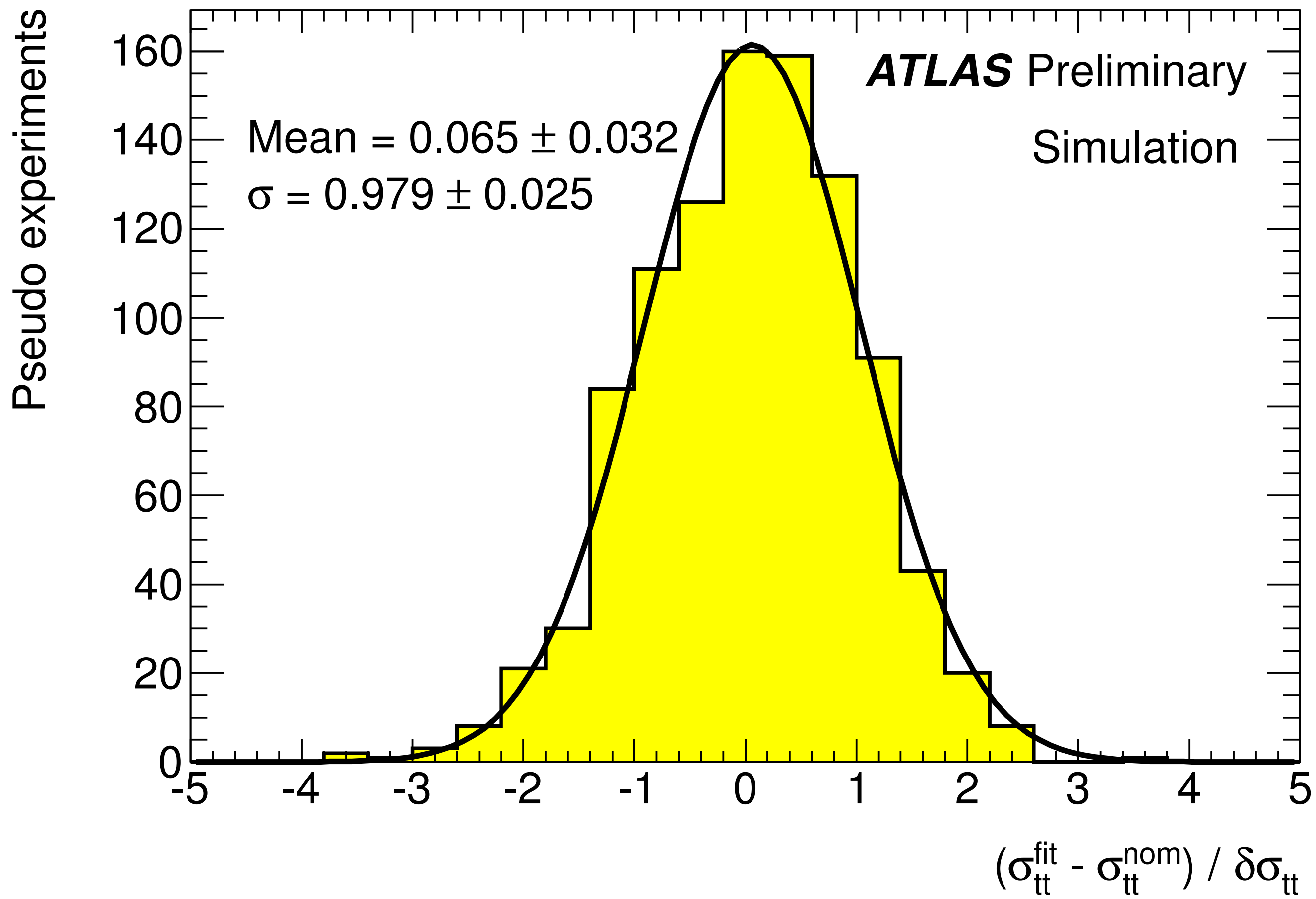
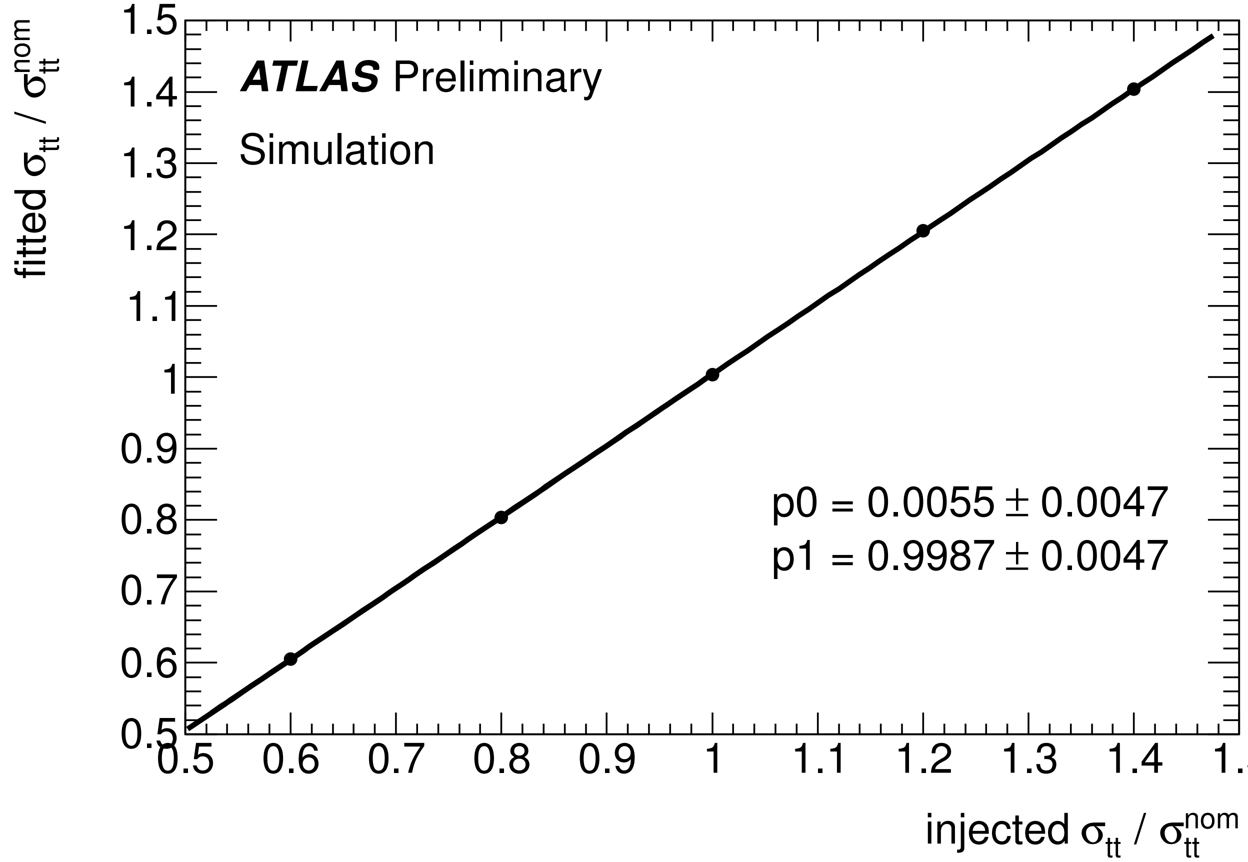
- b-tagging efficiency jet properties (scale, multiplicity) and heavy flavour contents are the dominant contributors

- Background related and PDF uncertainty relative importance is reduced w.r.t to no b-tagging

Statistical Error (%)	**+5.3**	**-5.2**
Object selection (%)		
Jet energy scale	+3.8	-2.8
Jet reconstruction efficiency	+4.2	-4.2
Jet energy resolution	+0.8	-0.2
Electron scale factor	+1.2	-0.8
Muon scale factor	+0.5	-0.6
Electron smearing	+0.3	-0.2
Muon smearing	+0.6	-0.4
Background modeling (%)		
Wjets HF content	+7.2	-6.3
Wjets shape	+1.5	-1.5
QCD shape	+1.0	-1.0
$t\bar{t}$ signal modeling (%)		
ISR/FSR	+4.0	-4.0
NLO generator	+0.5	-0.7
Hadronisation	+0.0	-0.6
PDF	+1.7	-1.7
Others (%)		
b-tagging calibration	+7.5	-6.3
Simulation of pile-up	+1.5	-0.6
Templates statistics	+1.6	-1.5
Total Systematic (%)	**+11.5**	**-10.5**

Extracting cross section - single lepton

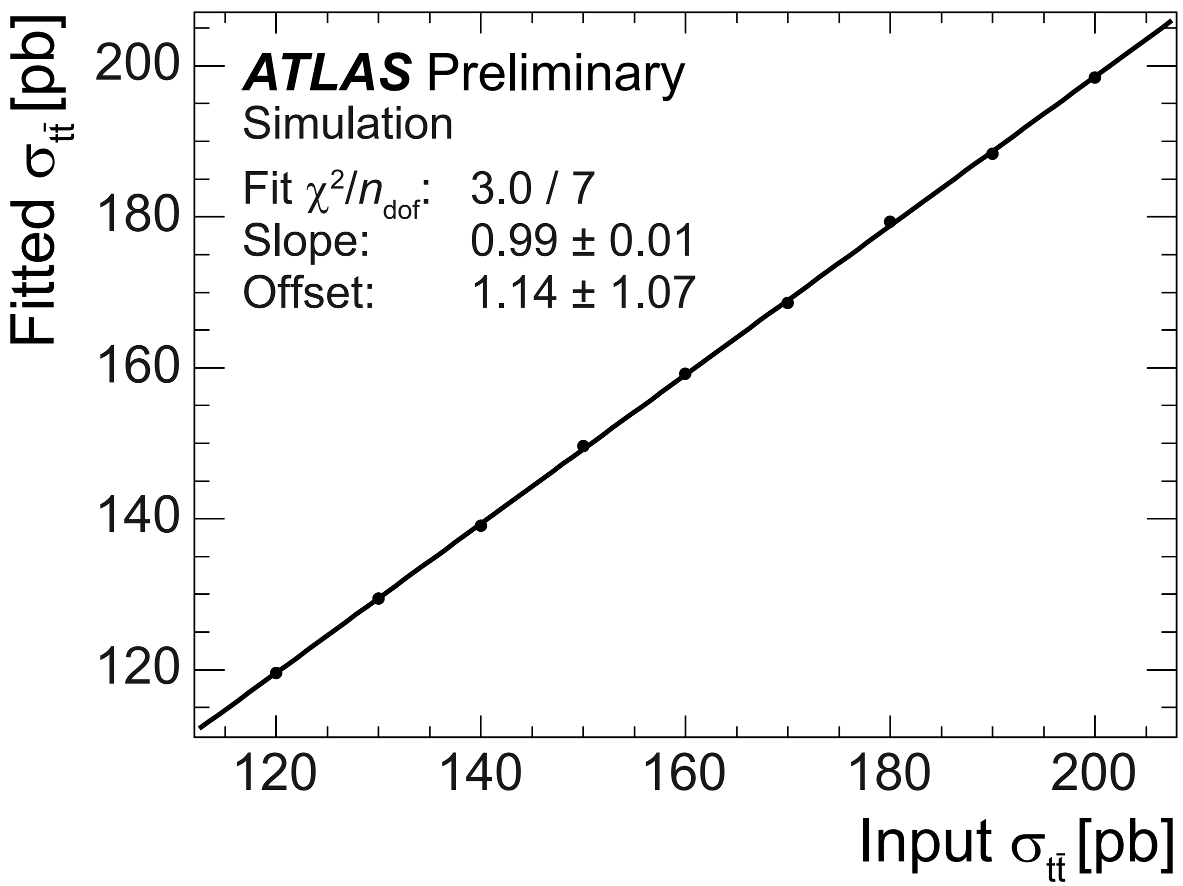


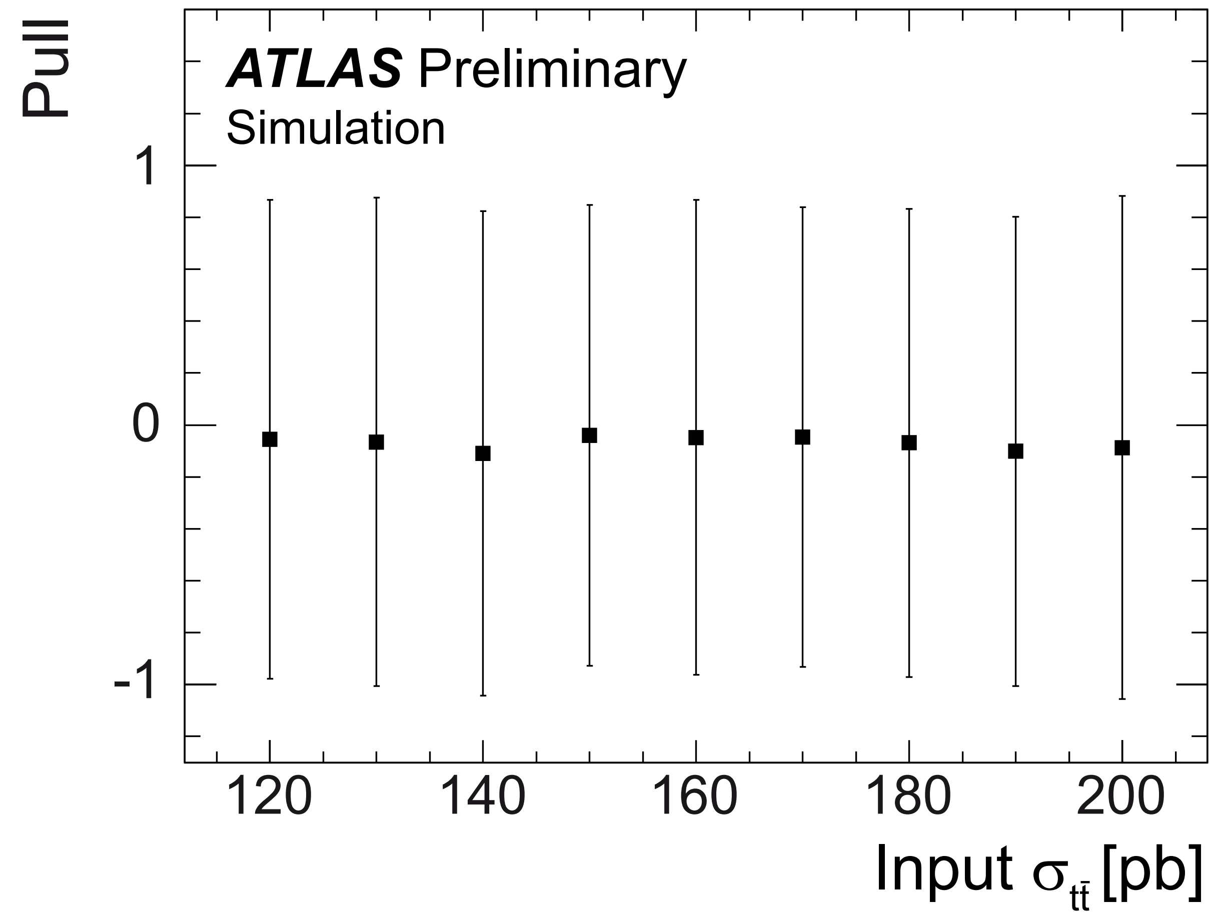


- Pseudo experiments used to test bias and uncertainty
- Bias and pull consistent with zero and 1

expected stat uncertainty is 9.7%

Extracting cross section - single lepton *with b-tagging*





- Simulated Pseudo experiments used to test bias and uncertainty
- Bias and pull consistent with zero and 1

Selecting top pairs : di-lepton

Common

- **Trigger on** high p_T **single lepton**
- Good collision and good quality for jets
- **exactly two opposite sign** high p_T central **leptons (ee, e,mumu)** *matching the trigger object*
- **≥ 2 central** high p_T **jet**

  p_T> 20 GeV
- **M_{ll} >15 GeV** against b-decays and vector mesons
- **exclude cosmic rays candidates** ***mu pairs*** *with large opposite sign impact par + back to back in r/phi*
- **reject** events with **overlapping muon and electron** tracks

ee, mumu

- **$|M_{ll}$ -$M_Z|$<10 GeV** *against Z/gamma*
- **high E_T^{miss}** *> 40 GeV against QCD*

+

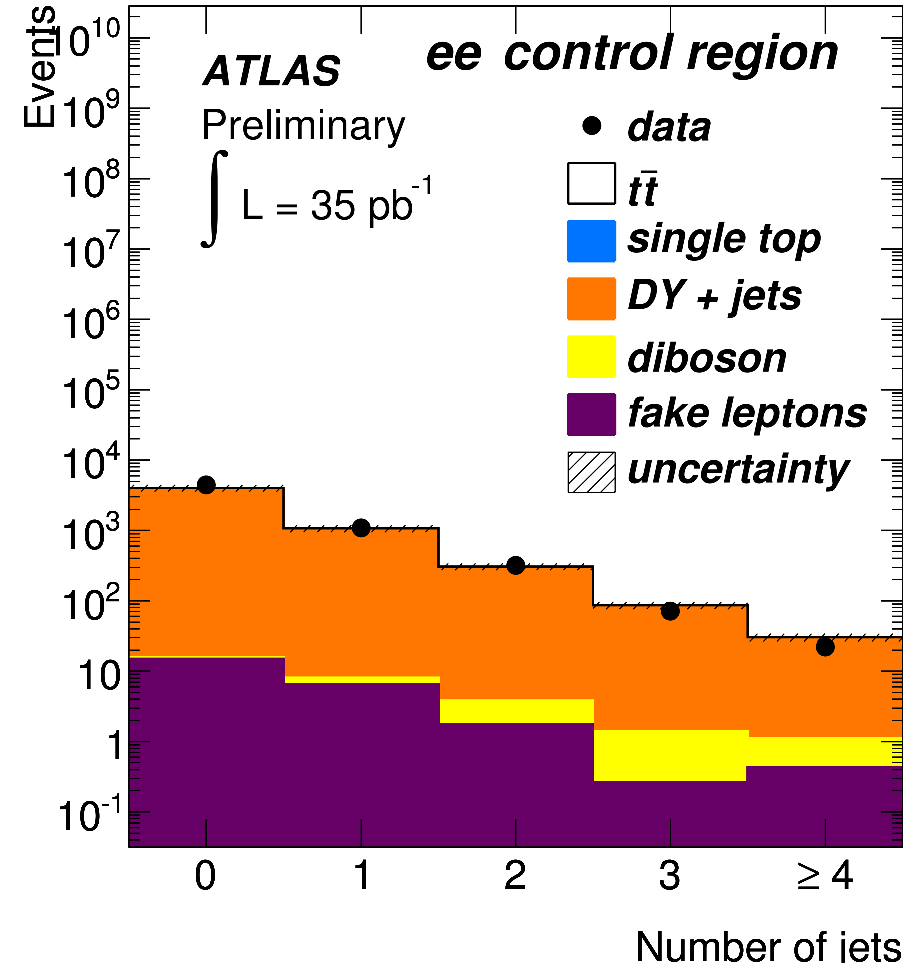
e,mu

- **H_T >130 GeV** *, H_T is sum of all transverse momenta*

Cuts optimized for significance of signal over bkg

Data Driven estimate of Non-Z bkg - di-lepton

- Define tight (standard) and loose lepton samples relaxing
  - calo and track isolation for μ
  - calo isolation, TRT hits, E/p cuts for **e**
- Express measured (tight,loose) samples in terms of unknown (**real**, ***fake***) and estimated probabilities **r** (***f***): for **real** (***fake***) leptons passing loose also to pass tight cuts
- Extract ***fake*** content by matrix inversion



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

Measure **r** in Z →ll

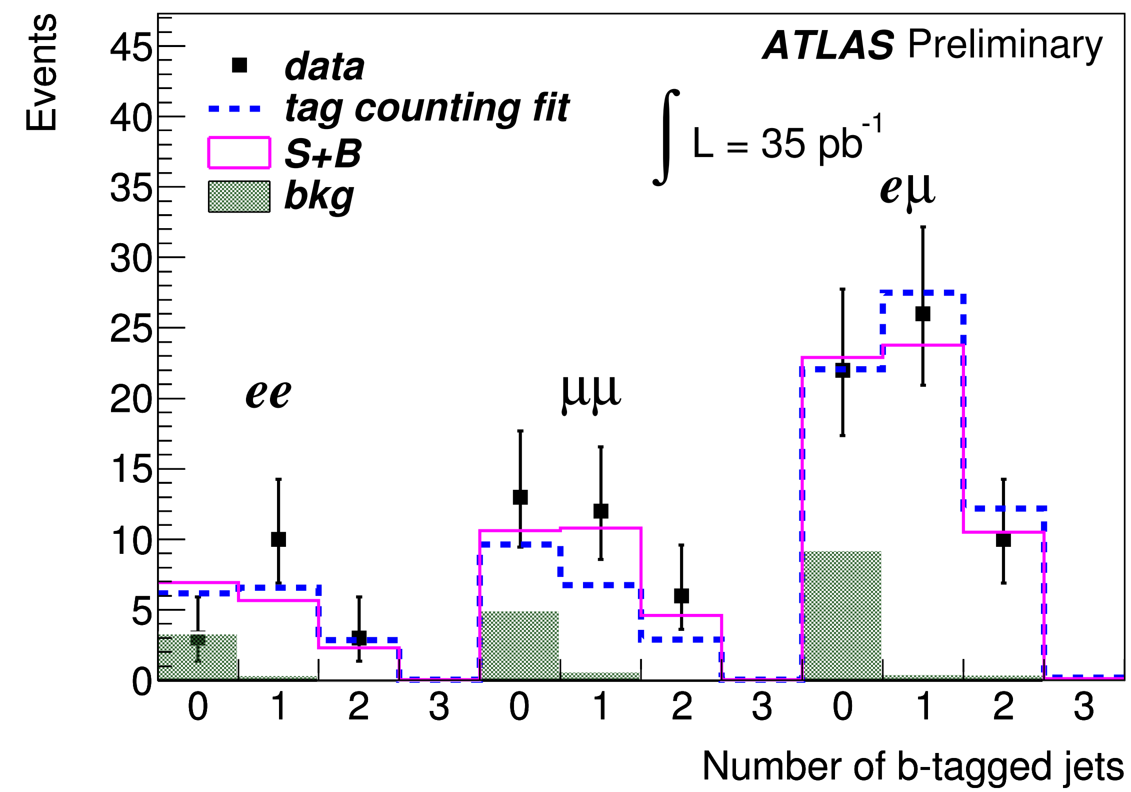
Measure ***f*** in QCD enriched sample: single loose lepton, low E_T^{miss}

(W+jets subtracted using simulation)

Di-lepton cross checks

- Normalize tt signal to measured Z decay rate

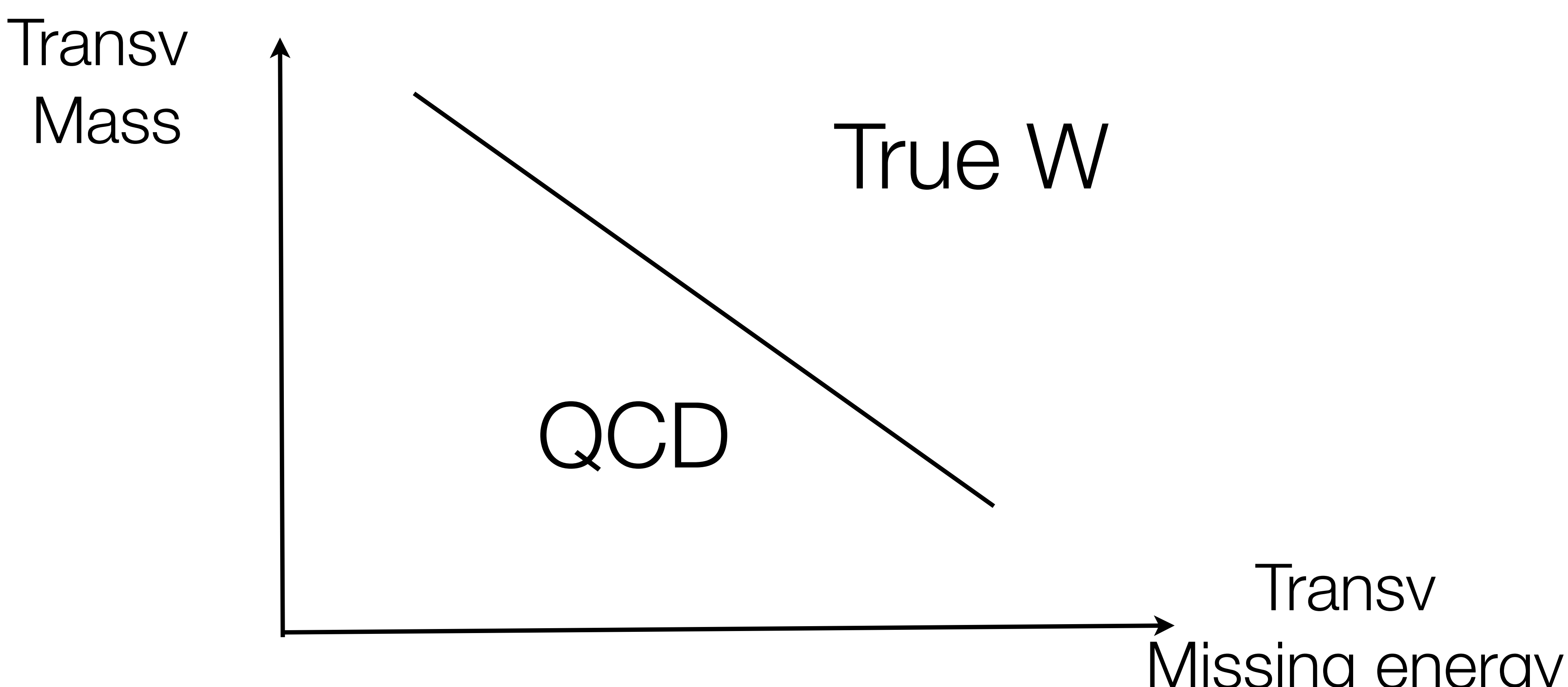
- 2-d template shape fit
  - E_T^{miss} vs N_{Jets}
  - extract cross section for tt, WW and Z tauta
  - relaxed Njets and total transverse energy cuts



- Fit distribution of number of tagged jets to extract tt cross section and b-tagging efficiency

Triangular cut

- True W leptonic decay with large missing transverse energy also have large transverse mass
- Mis-measured jets in QCD may have large missing transverse energy, but small transverse mass
- Requirement on transverse missing energy and transverse mass discriminates the two



Cross checks - single lepton *with b-tagging*

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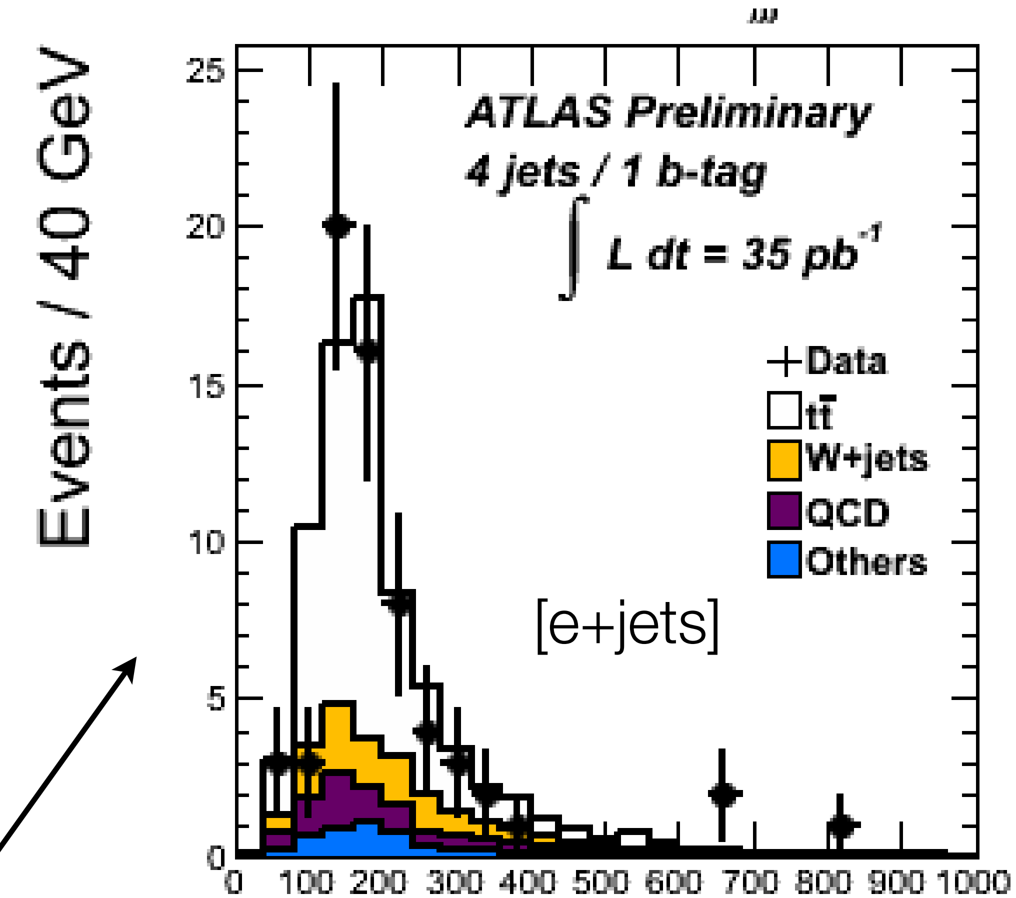
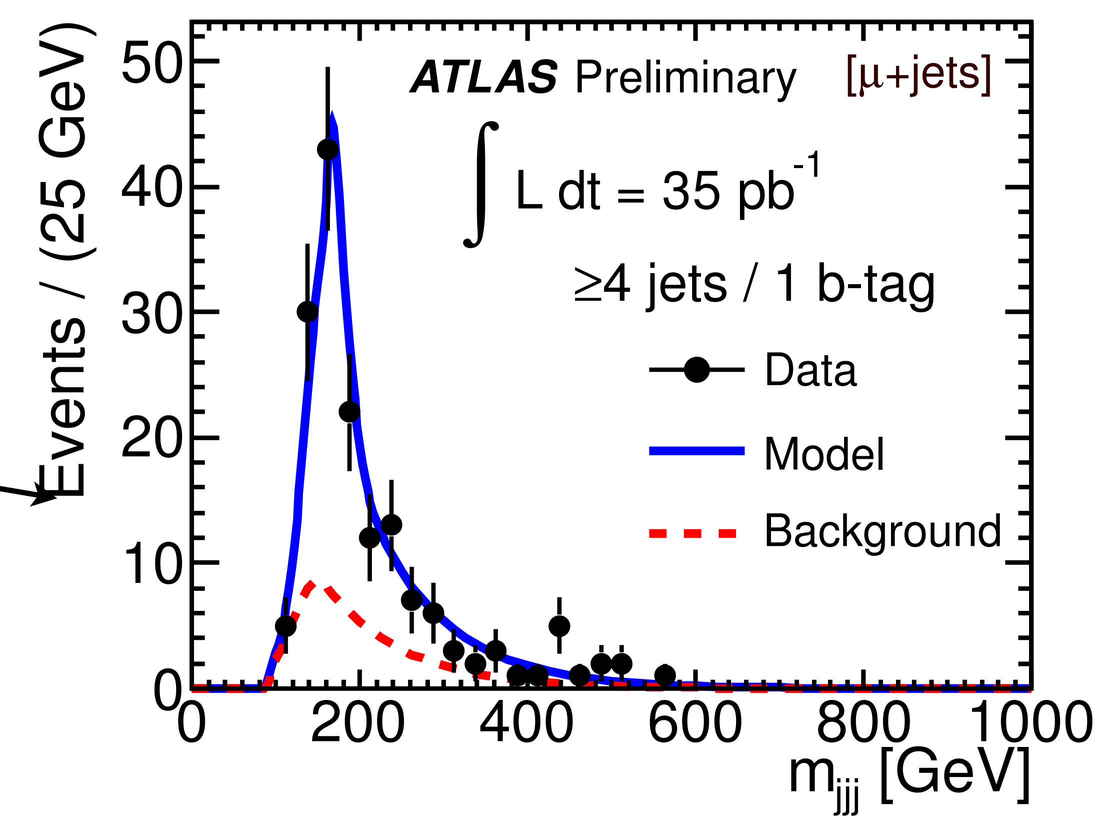
Require >= 1 b-tagged jet

- **Cut and Coun**

$$\sigma(t\bar{t}) = \frac{N_{sig}}{L \times \epsilon} = \frac{N_{obs} - N_{bkg}}{L \times \epsilon}$$

- **Likelihood fit of the 3-jet mass** to weighted sum of templates (in 3, 4, 5 jet bin) **in two ways**
  - ***including systematics*** as nuisance parameters ***in fit***
  - ***standard fit, no nuisance par***; vary parameters to assess systematics





Top mass systematics

	Uncertainty [GeV]	
	Electron channel	Muon channel
Statistical uncertainty	6.7	5.0
Method calibration	0.7	0.5
Signal MC generator(POWHEG VS. MC@NLO)	0.7	0.6
Hadronization POWHEG (PYTHIA VS. HERWIG)	1.0	0.5
Pileup	0.6	0.8
ISR and FSR (signal only)	2.2	2.6
Proton PDF	0.6	0.5
W/Z+jets background normalization (±100%)	1.3	1.7
W/Z+jets background shape	0.6	1.0
QCD background normalization (±100%)	0.8	0.7
QCD background shape	0.6	0.5
Jet energy scale ($\pm 1\sigma$) plus 5% for close by jets	2.3	1.9
b-jet energy scale (±2.5%)	2.5	2.5
b-tagging efficiency and mistag rate	0.6	0.5
Jet energy resolution	0.6	1.1
Jet reconstruction efficiency (±2%)	0.6	0.5
Total systematic uncertainty	4.8	5.0