Hadronic tau decays in ATLAS

a review of the tau object reconstructed and supported by ATLAS and its current status

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Outline

Hadronic tau decays in ATLAS...

1. Introduction
   motivation, dataset, *pile-up*
2. Reconstruction
   seeding, vertex choice, track selection
3. Identification
   jet and electron discriminants, performance
4. Triggering
   tau chain, VBF triggers
5. Systematic uncertainties
   efficiency and energy scale measurements

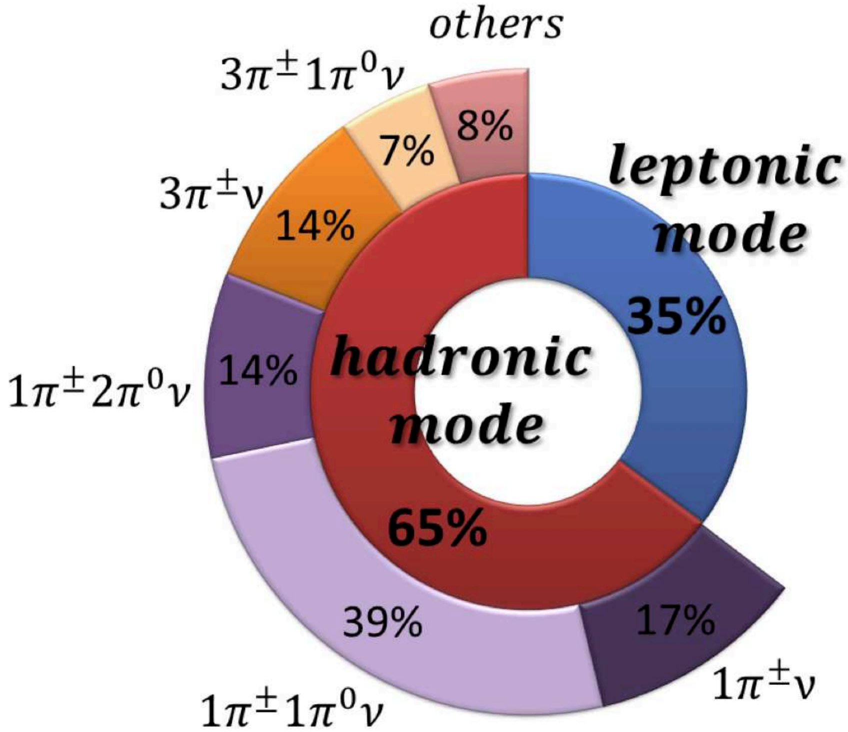
Themes:

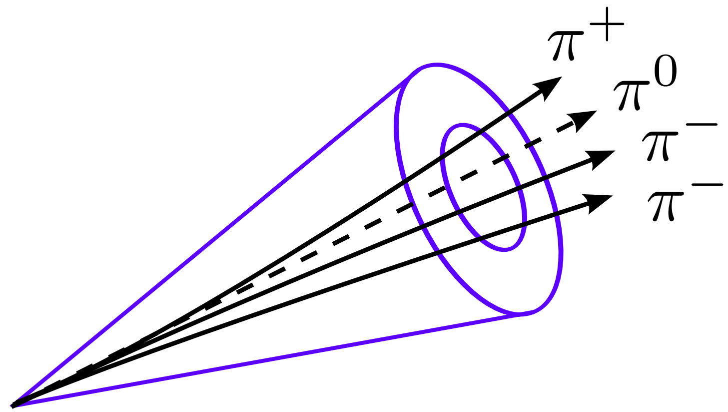
- Focus on current issues
- Adapting to luminosity increases
- Pile-up robustness
- Improving systematics with additional data

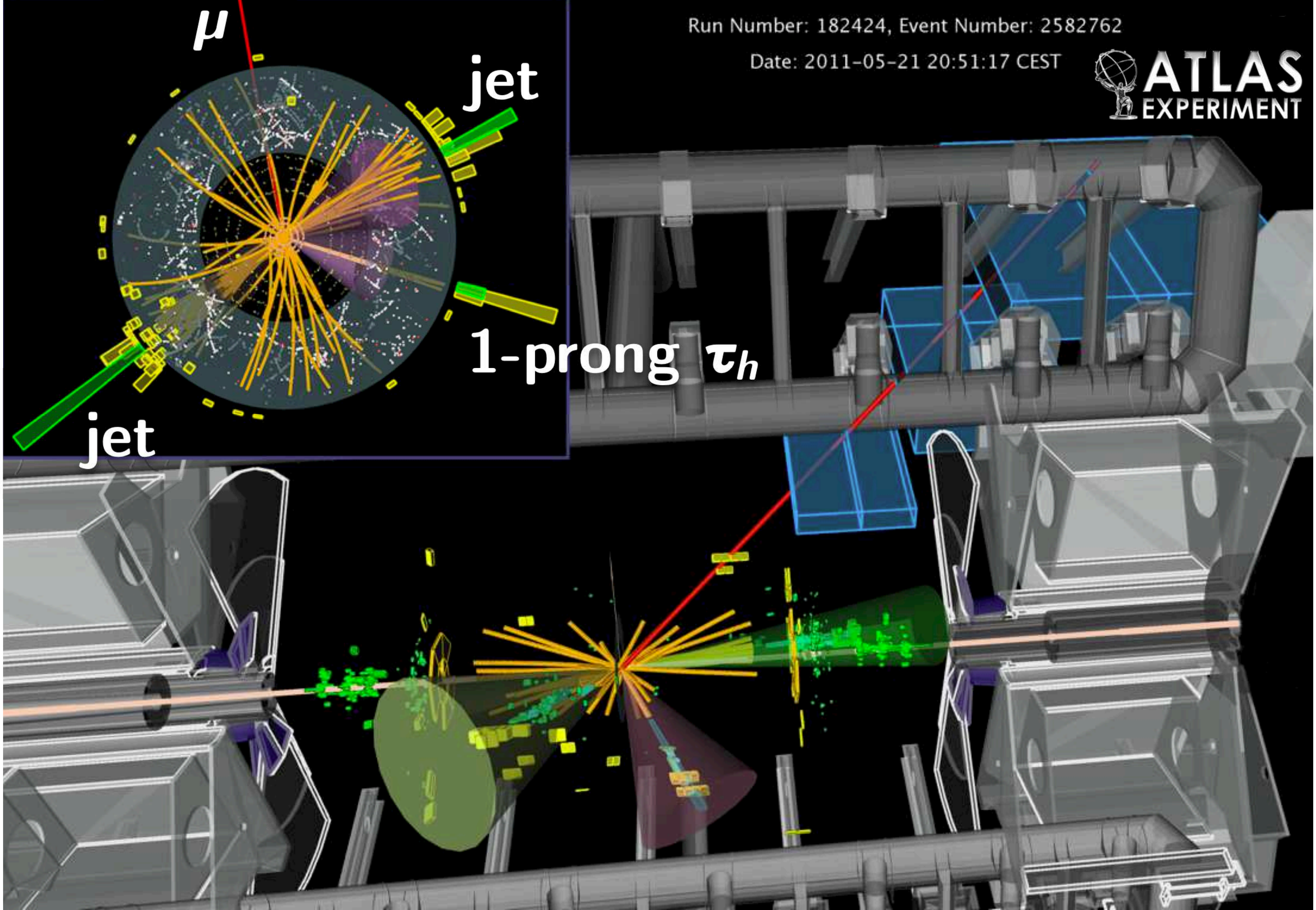
Introduction

What's a tau?

- Only lepton massive enough to decay hadronically.
- Decay in beam pipe: $c\tau \approx 87$ μm
- 65% hadronic
  50% 1-prong, 15% 3-prong.
- **Signature:** narrow jet with 1 or 3 tracks, possibly additional EM clusters.
- **Challenge:** large multijet background at hadron colliders.
- **Importance:** often preferred coupling to new physics
  (SM $H\to\tau\tau$, $H^+\to\tau^+\nu$, $Z'\to\tau\tau$, high-tanβ SUSY...)



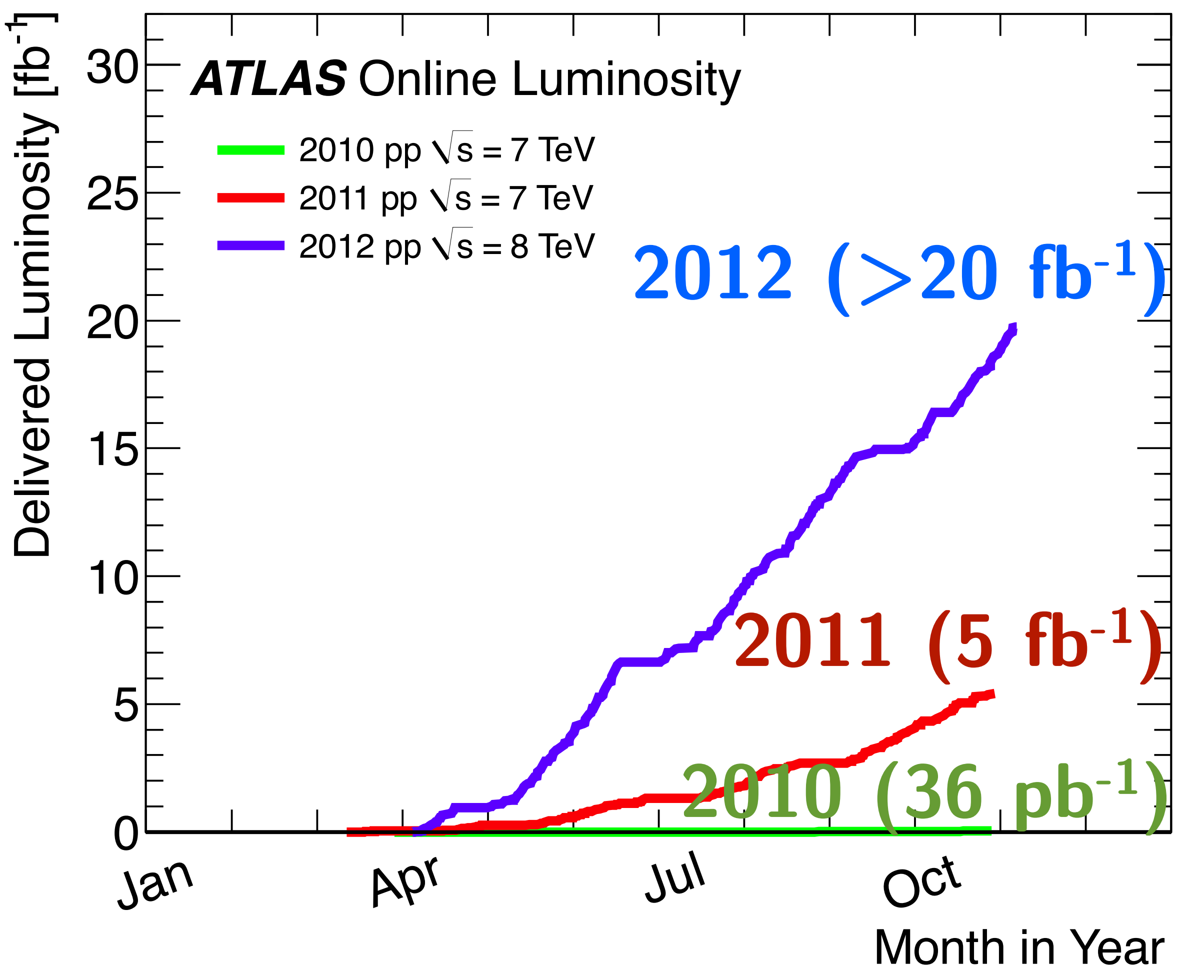




$t\bar{t} \to b\bar{b}(\mu\nu)(\tau_{\mathrm{h}}\nu)$ candidate

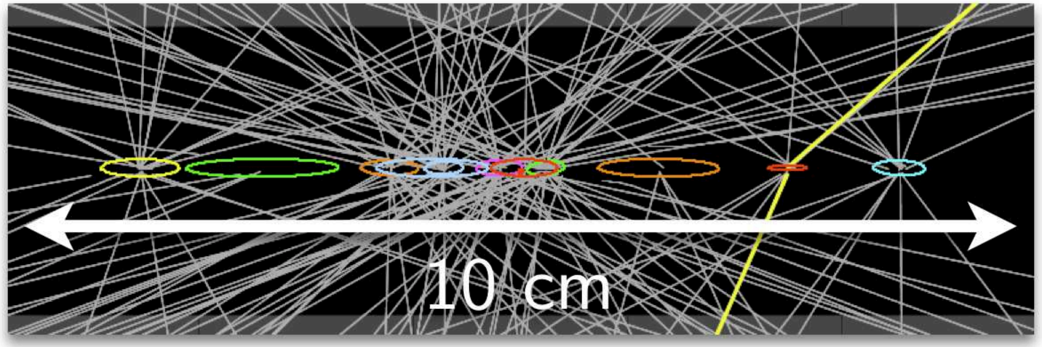
Timeline of taus at ATLAS

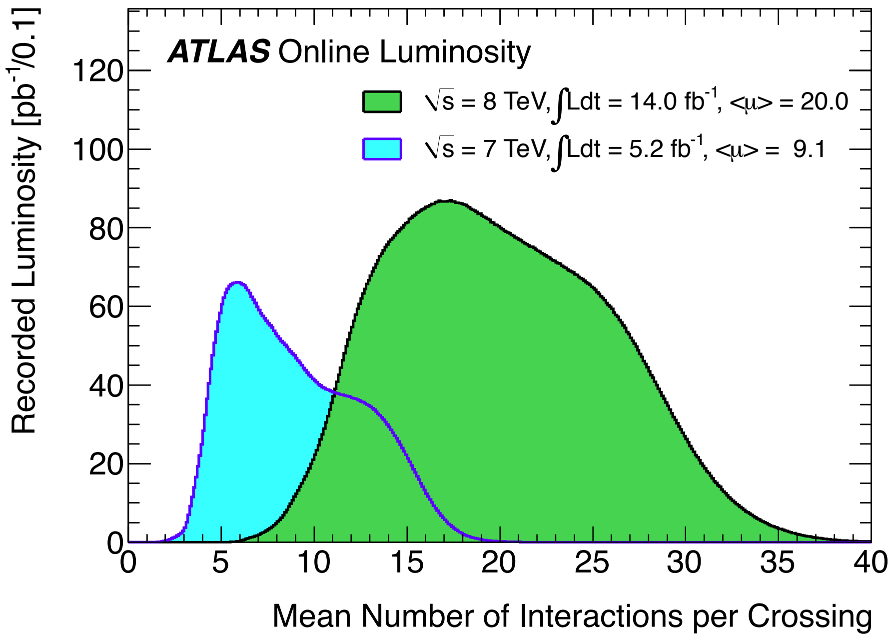
- Nov 2010: Obs. of $W\rightarrow\tau\nu$
- Feb 2011: Obs. of $Z\rightarrow\tau\tau$
- July 2011: $W\rightarrow\tau\nu$ and $Z\rightarrow\tau\tau$ cross section measurements
- Feb 2012: $Z\rightarrow\tau\tau$ cross section with 1.5 fb^{-1}.
- June 2012: SM $H\rightarrow\tau\tau$ excluded 3-4$\times$SM at $m_H\approx$125 GeV [arXiv:1206.5971]
- Several other analyses: MSSM $H\rightarrow\tau\tau$, $t\bar{t}$ with τ, $H^+\rightarrow\tau\nu$, $Z'\rightarrow\tau\tau$, SUSY τ+MET, ...



- Now eagerly waiting to see if $H\rightarrow\tau\tau$ will be excluded at 1$\times$SM this year?

Pile-up

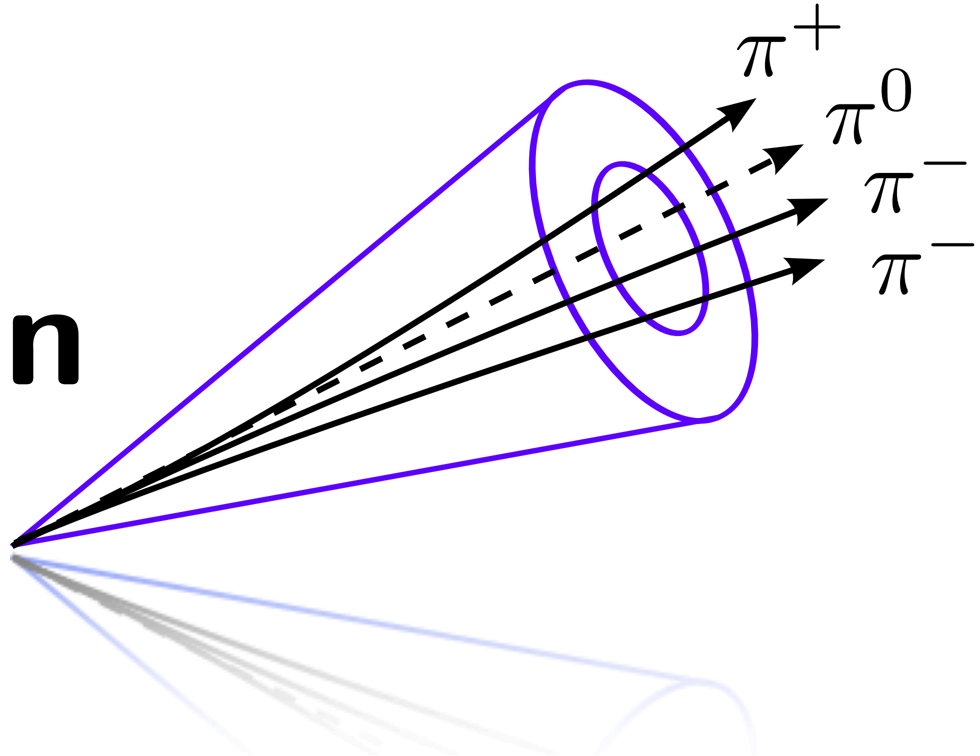




- 1-40 pile-up interactions / crossing
- The additional tracks and clusters from pile-up are especially challenging for tau identification, which discriminates hadronic tau decays from jets with isolation-related track and calorimeter quantities.
- Efforts in 2011→2012 involved re-defining or adding corrections to identification variables to be more robust against the increasing pile-up.

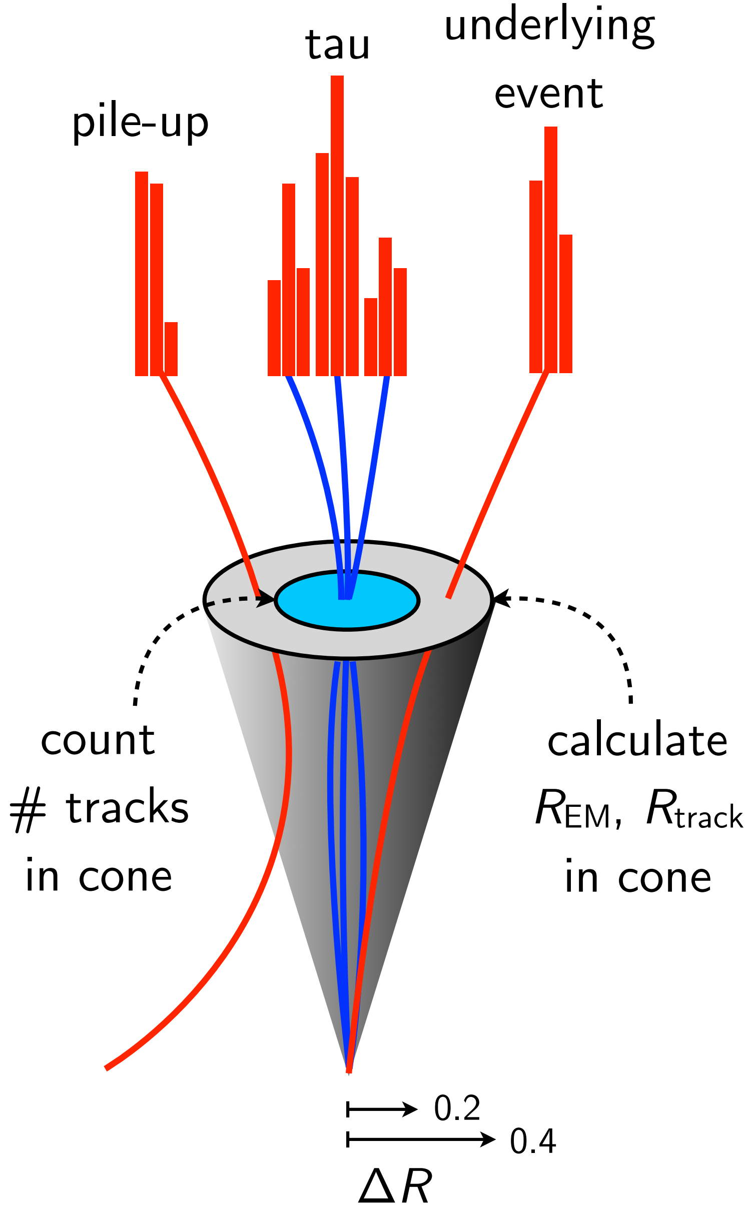
[https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResults]

Reconstruction



Reconstruction

1. **Seeded by anti-k_t jets** (R=0.4) of 3-D topological calorimeter clusters.
2. **Define the four-momentum** as the jet-axis with a tau-specific calibration.
3. **Associate tracks** with the jet that are consistent with the chosen vertex.
4. **Calculate discriminating variables** from the combined calorimeter and tracking information, later used to identify hadronic tau decays with BDT and likelihood based discriminants.

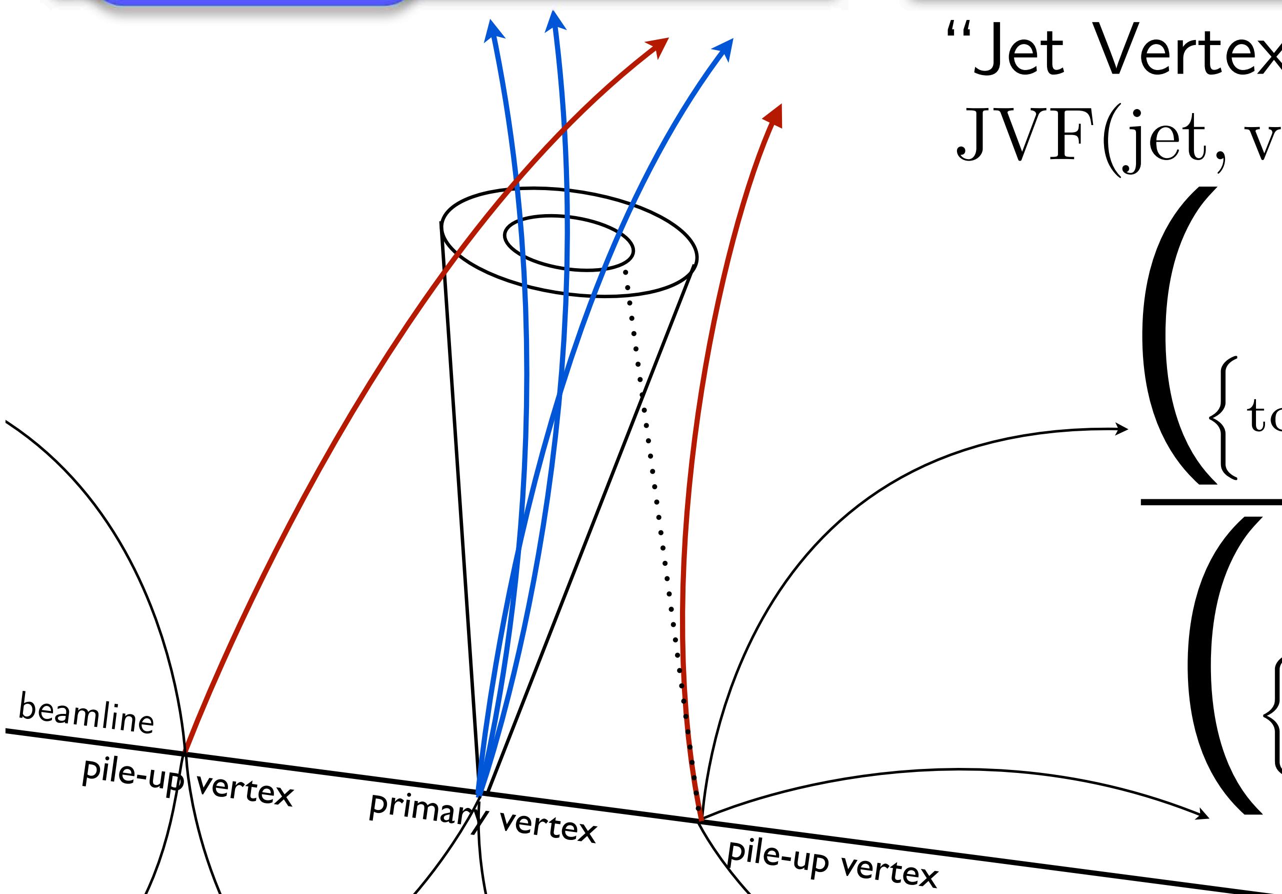


Tau vertex association

Tau track selection

- $p_T > 1$ GeV,
- Number of pixel hits ≥ 2,
- Number of pixel hits + number of SCT hits ≥ 7,
- $\boxed{|d_0| < 1.0 \text{ mm},}$
- $\boxed{|z_0 \sin\theta| < 1.5 \text{ mm},}$

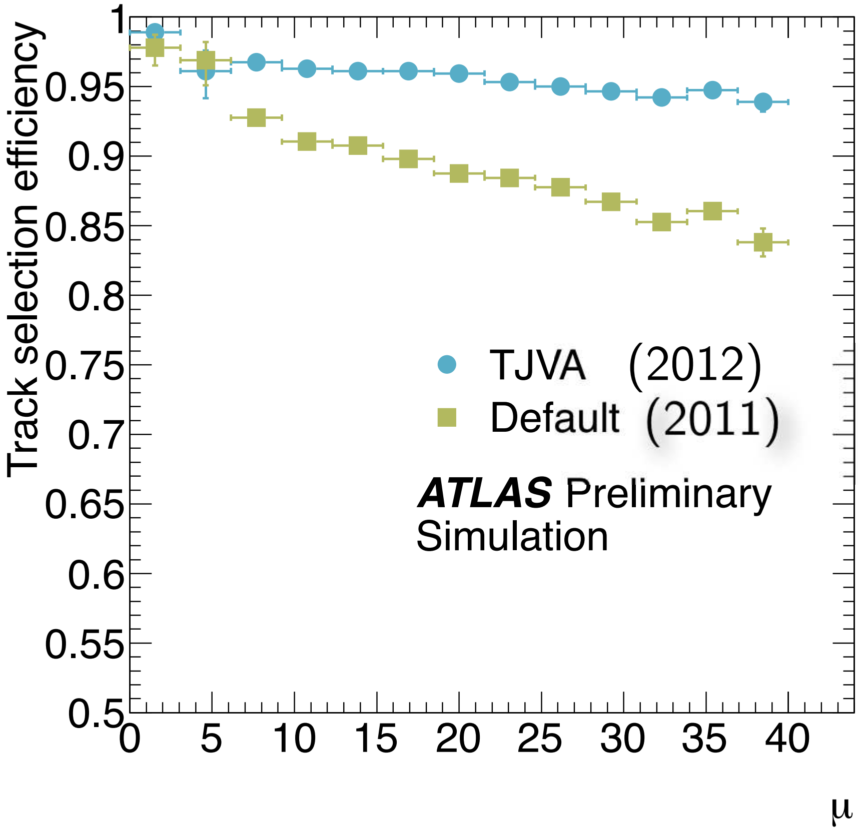
- The d_0 and z_0 requirements depend on the choice of vertex.
- Beginning in 2012, choose the vertex with the highest JVF for that tau candidate.

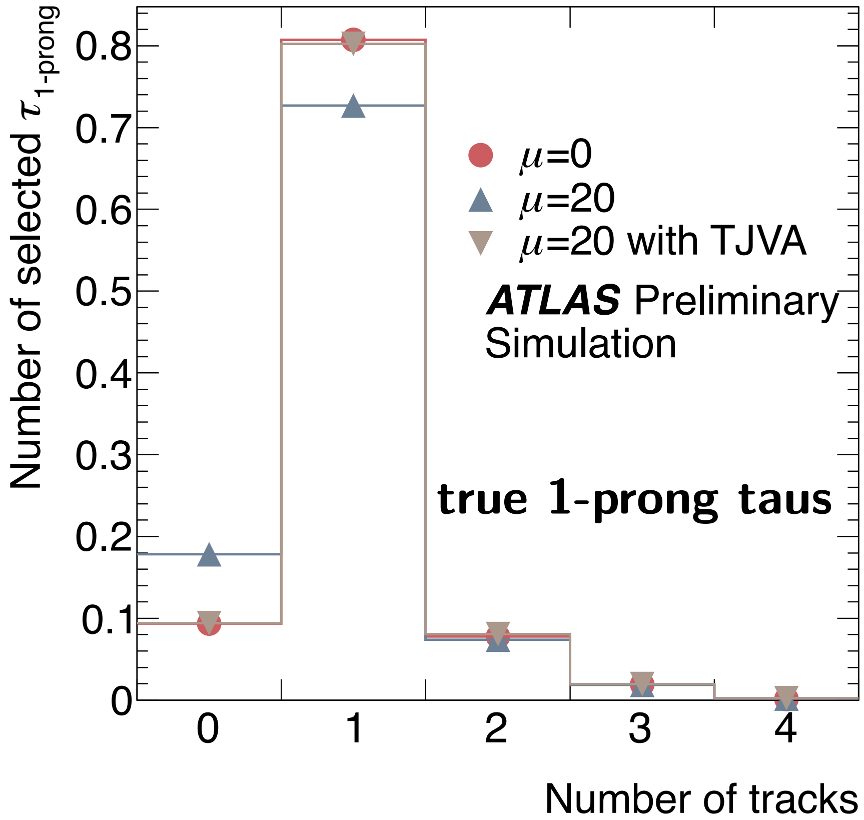


"Jet Vertex Fraction"

$$\mathrm{JVF}(\mathrm{jet},\mathrm{vertex}) = \frac{\left(\sum_{\left\{\substack{\text{tracks matched}\\ \text{to jet and vertex}}\right\}} p_T(\text{track})\right)}{\left(\sum_{\left\{\substack{\text{tracks matched}\\ \text{to jet}}\right\}} p_T(\text{track})\right)}$$

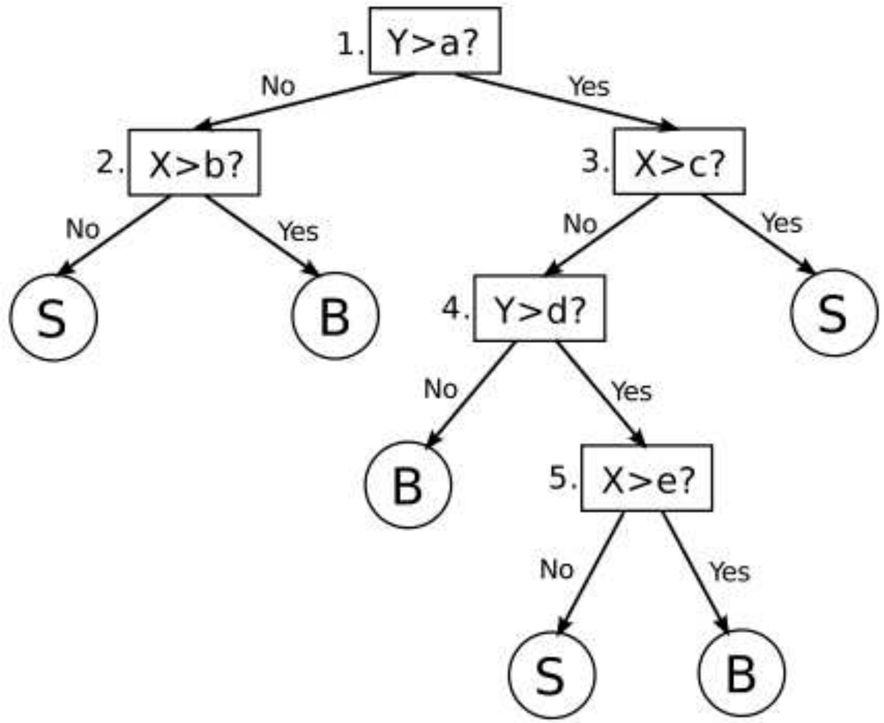
Track selection efficiency



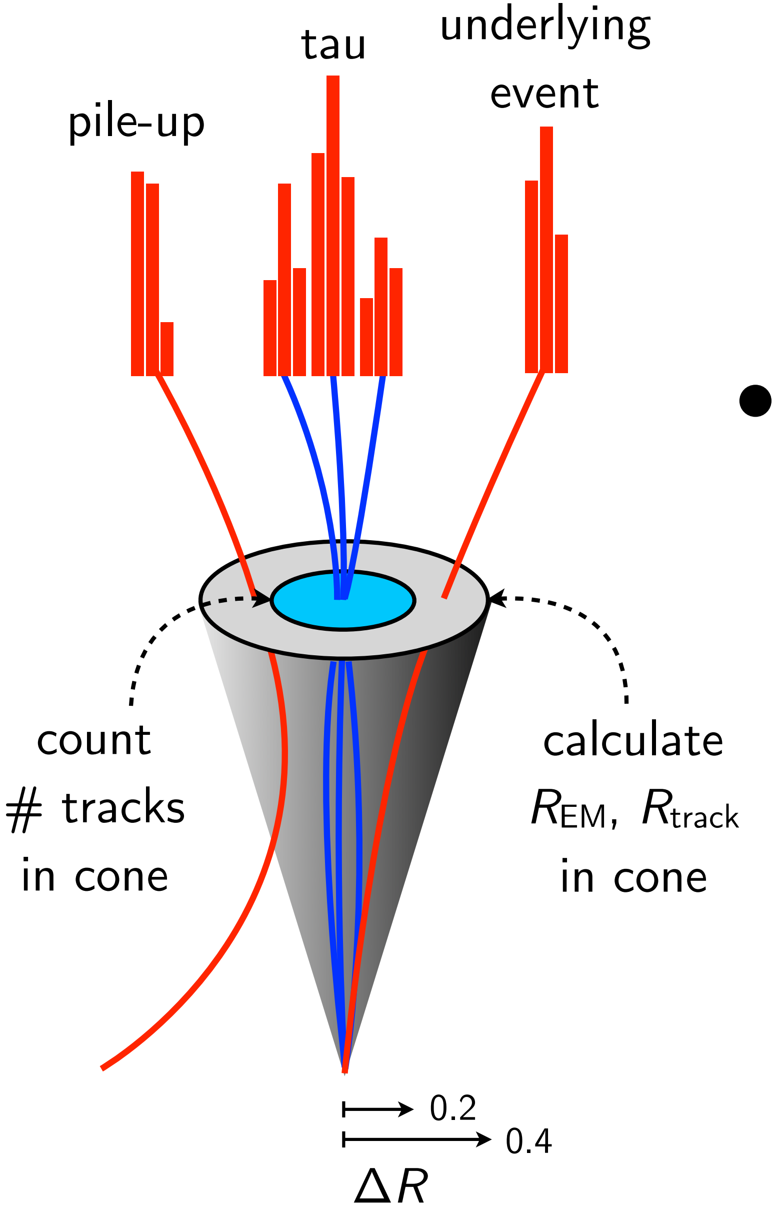


- In 2011, the track selection for tau candidates cut on the d_0 and z_0 with respect to the vertex with the highest $\sum p_{\mathrm{T}}{}^2$.
- Selecting the vertex with the highest JVF recovers efficiency in high pile-up (Tau Jet Vertex Association).

Identification



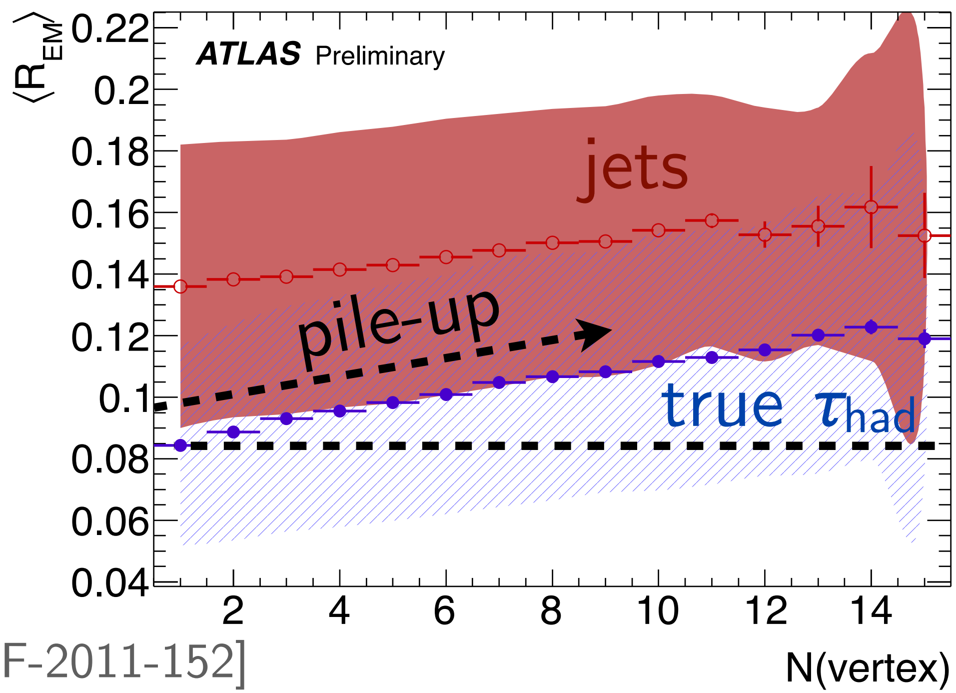
Identification and pile-up



- Important offline variable in 2010-2011: ***EM radius*** - "width of jet in calorimeter"

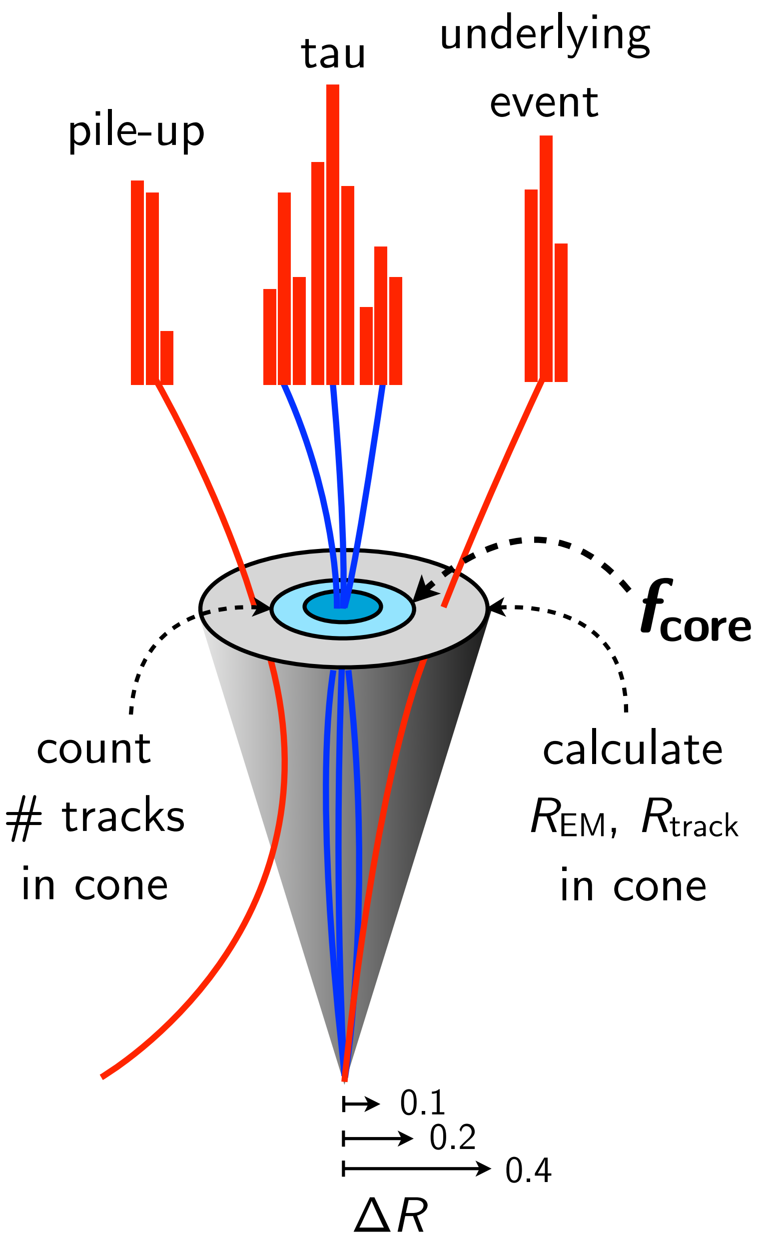
$$R_{\mathrm{EM}} = \frac{\sum_{\{\Delta R<0.4\}} E_{\mathrm{T}}^{\mathrm{EM}}(\mathrm{cell})\, \Delta R(\mathrm{cell},\, \mathrm{jet})}{\sum_{\{\Delta R<0.4\}} E_{\mathrm{T}}^{\mathrm{EM}}(\mathrm{cell})}$$

- ***Strong pile-up dependence*** due to using calorimeter deposits in the wide cone: $\Delta R < 0.4$.



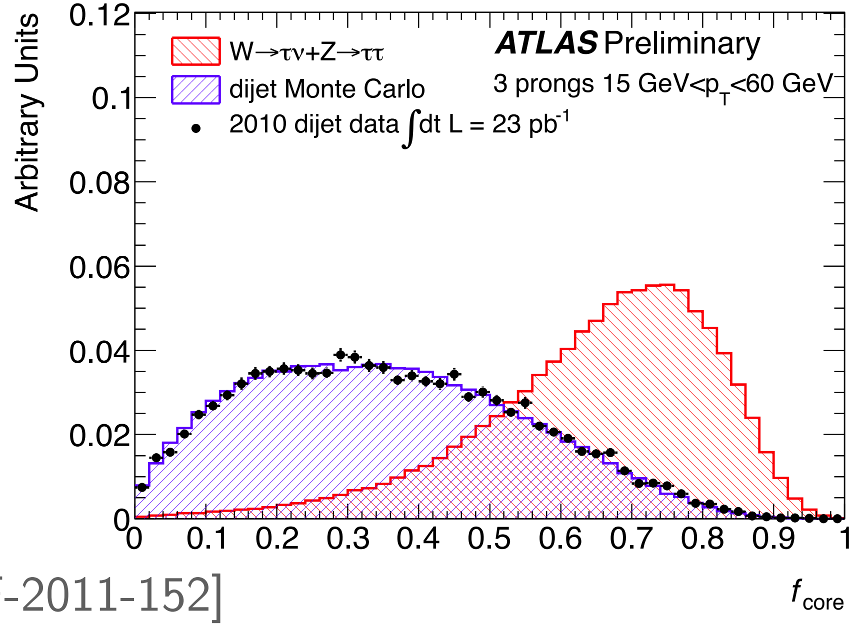
[ATLAS-CONF-2011-152]

Pile-up robust variables



- Beginning in 2012, the core energy fraction is used instead of R_{EM}, which has less pile-up dependence by using the ratio of energies in smaller ΔR cones of 0.1 and 0.2.

$$f_{\rm core} = \frac{\sum_{\{\Delta R<0.1\}} E_{\rm T}^{\rm EM}(\rm cell)}{\sum_{\{\Delta R<0.2\}} E_{\rm T}^{\rm EM}(\rm cell)}$$

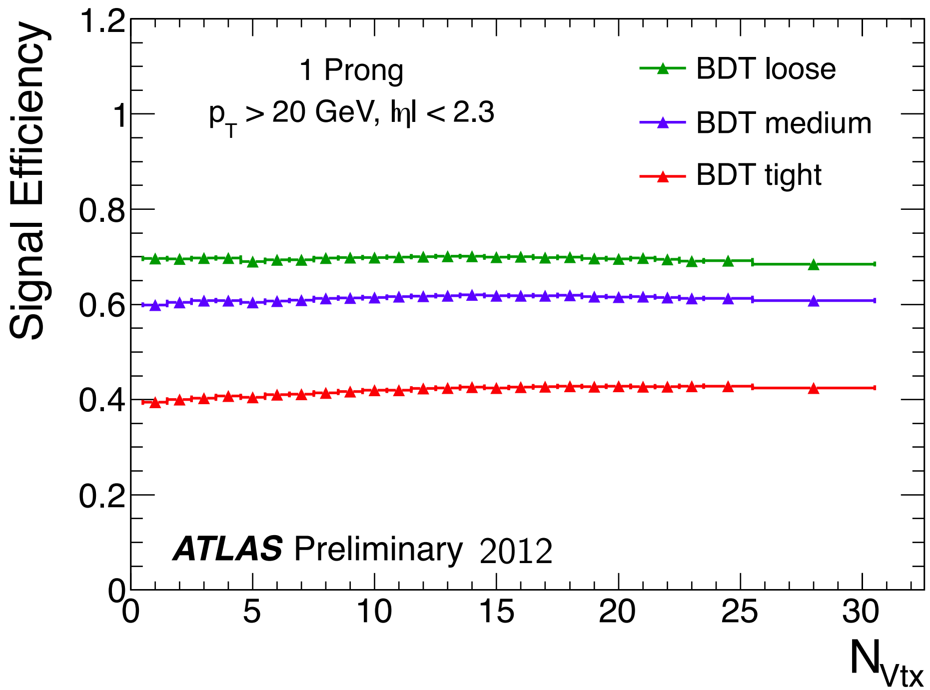


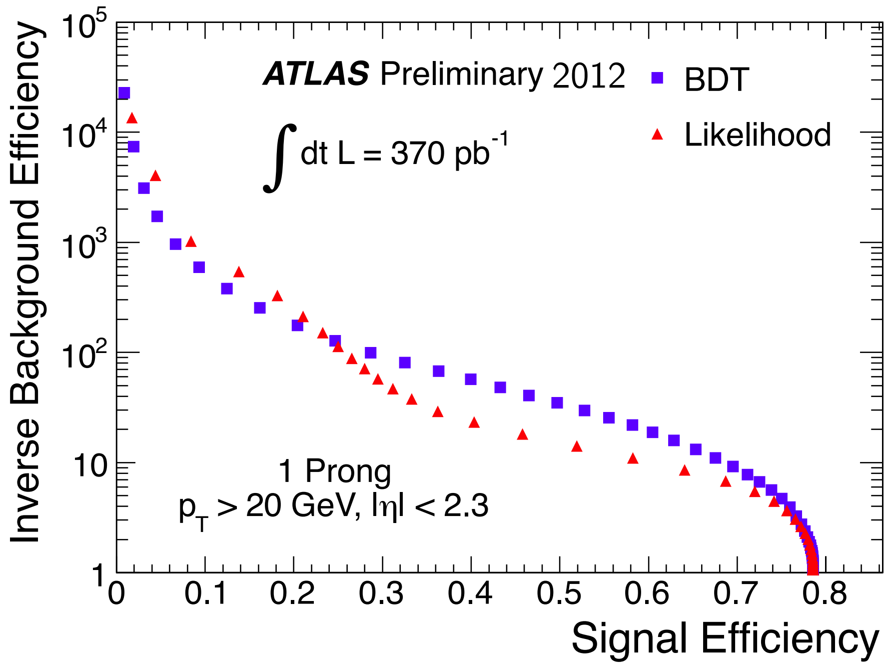
Pile-up corrections

- Also beginning in 2012, the variables with the largest pile-up dependence (f_{core} and f_{track}) are corrected with terms that are linear in the number of reconstructed vertices.

$$f_{\mathrm{core}} = \frac{\sum_{\{\Delta R<0.1\}} E_{\mathrm{T}}^{\mathrm{EM}}(\mathrm{cell})}{\sum_{\{\Delta R<0.2\}} E_{\mathrm{T}}^{\mathrm{EM}}(\mathrm{cell})} \quad + \ (0.3\%/\mathrm{vertex}) \times N(\mathrm{vertex})$$

- Tight/Medium/Loose working points of the BDT and LLH are defined (≈40%, 60%, 70% efficient), optimized as function of p_{T} and in separate N(vertex) categories.

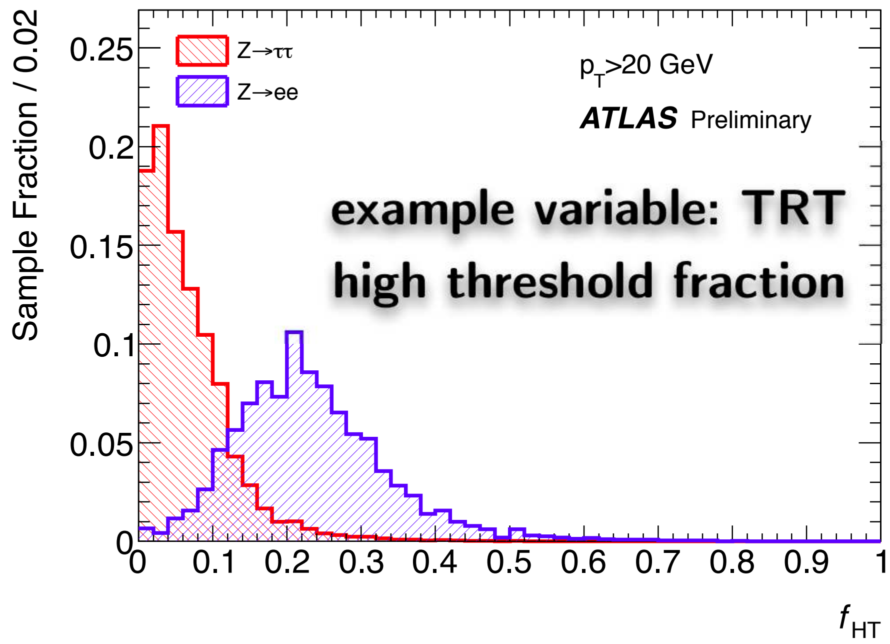


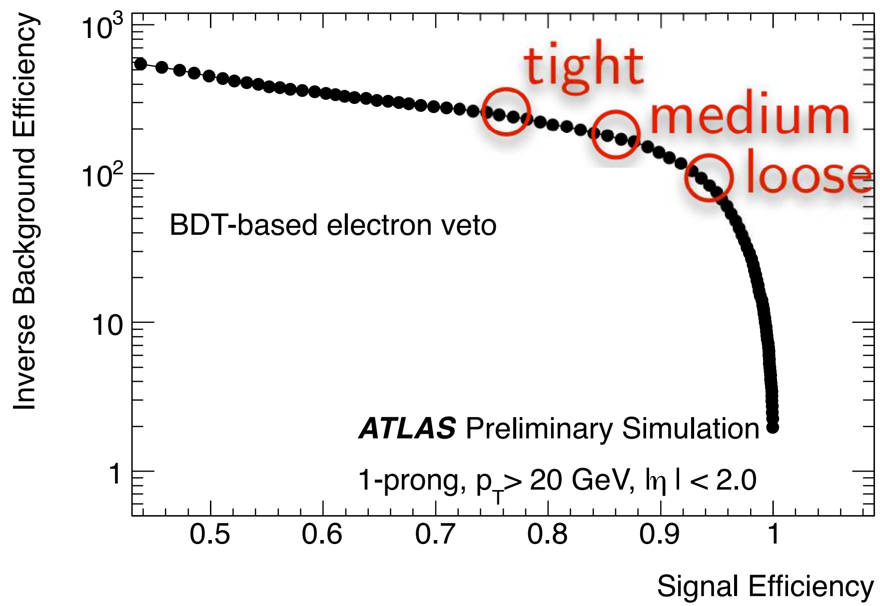


[https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TauPublicCollisionResults]

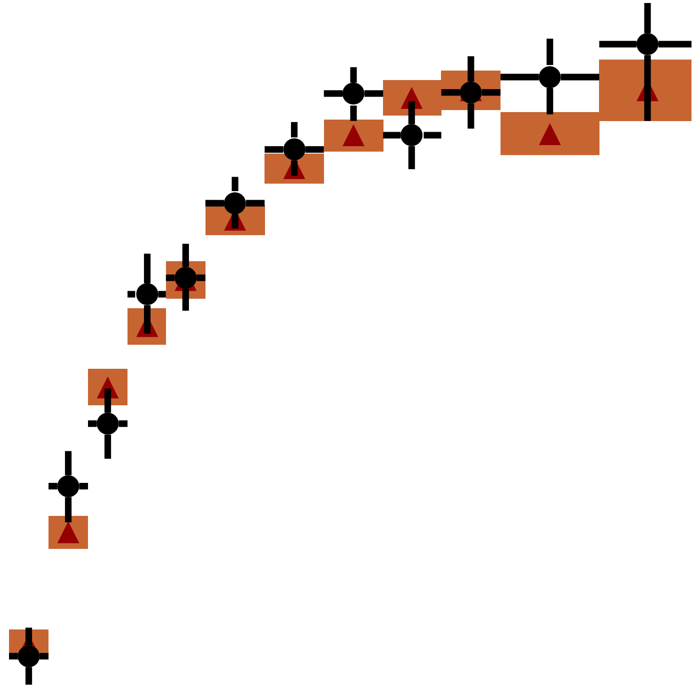
Electron veto

- Electrons provide a track and calorimeter deposit that can fake hadronic tau decay identification.
- ATLAS provides a BDT to discriminate electrons from tau candidates, even after removing overlaps with selected electrons.
- Tight/Medium/Loose working points are defined (≈75%, 85%, 95% efficient).
- In 2012, the BDT is being re-optimized to have better efficiency at high-p_T.





Triggering



Tau triggering

1. **Level 1:** (latency 2.5 μs)

   Coarse EM+Had calorimeter trigger towers $\Delta\eta\times\Delta\phi = 0.1\times0.1$. Candidate passing thresholds on the sum of energies:

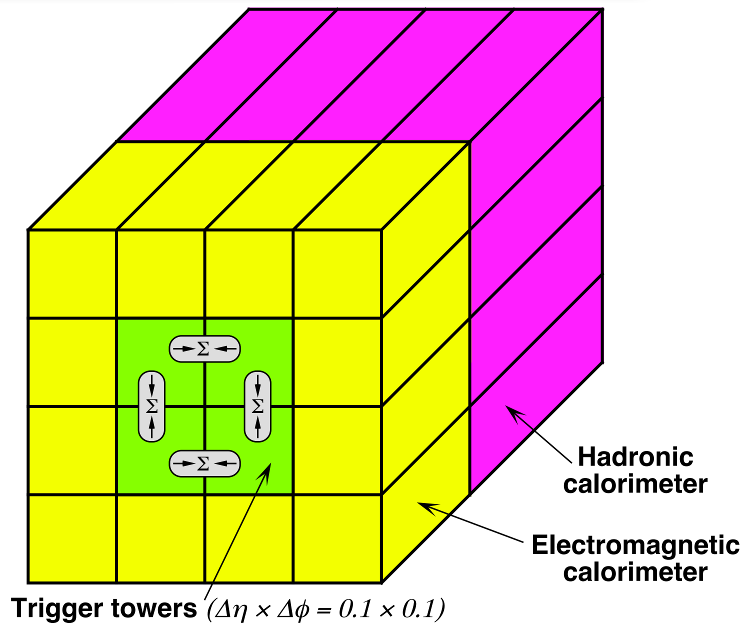
   1. highest 2×1 towers
   2. surrounding 4×4 isolation ring

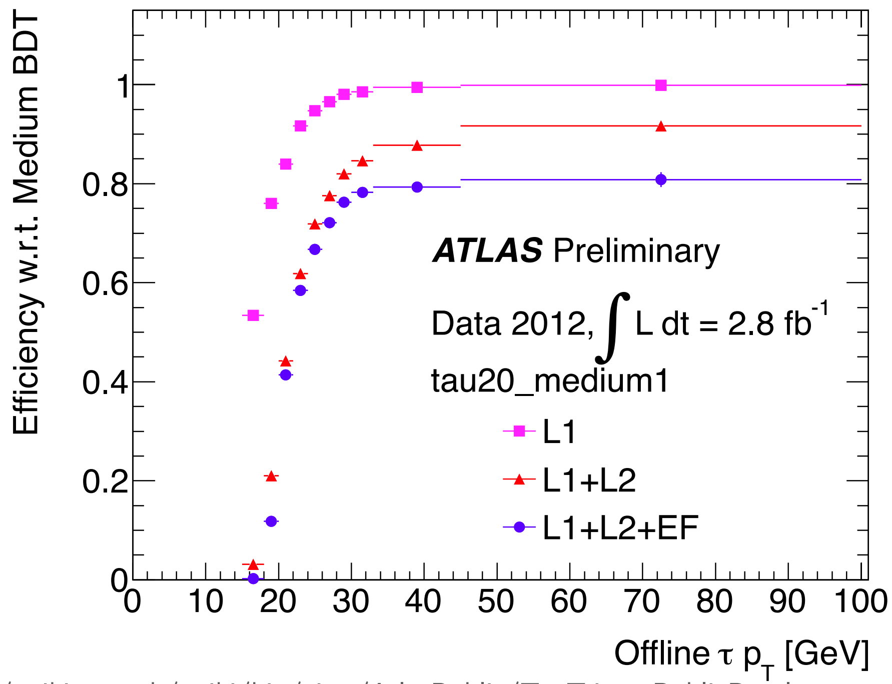
2. **Level 2:** (latency 40 ms)

   Fast tracking. Region-of-interest (RoI) calculation of track- and calorimeter-based ID variables. Similar selection to offline cut-based ID.

3. **Event Filter:** (latency 4 s)

   Beginning in 2012, started using the offline BDT algorithm at the EF trigger.



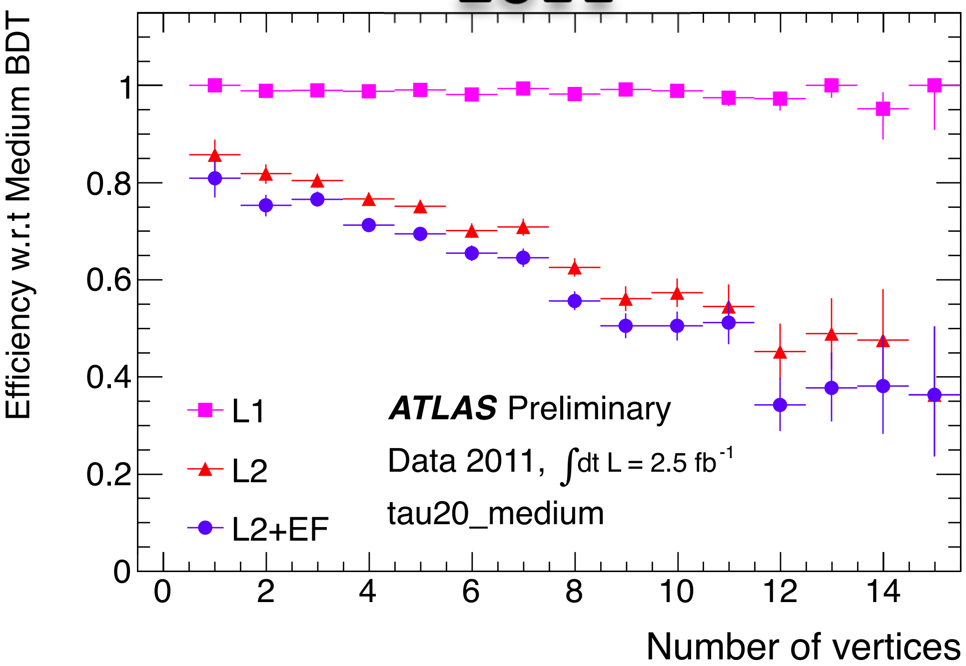


L2 pile-up robustness

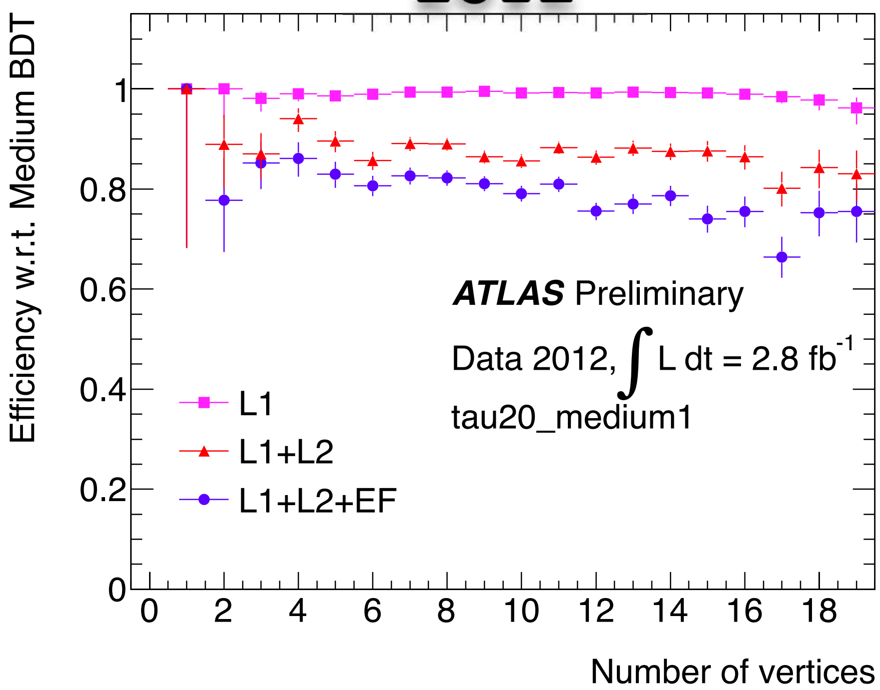
Example improvements to variable definitions to lessen sensitivity to pile-up:

- Smaller ΔR cone for calculating EM radius 0.4→0.2
- Select tracks within $\Delta z < 2$ mm of the highest-p_T track within the RoI (cannot vertex at L2).

2011



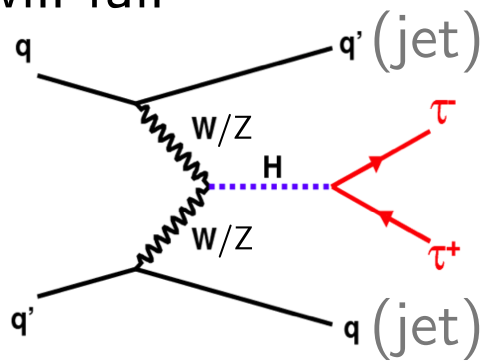
2012

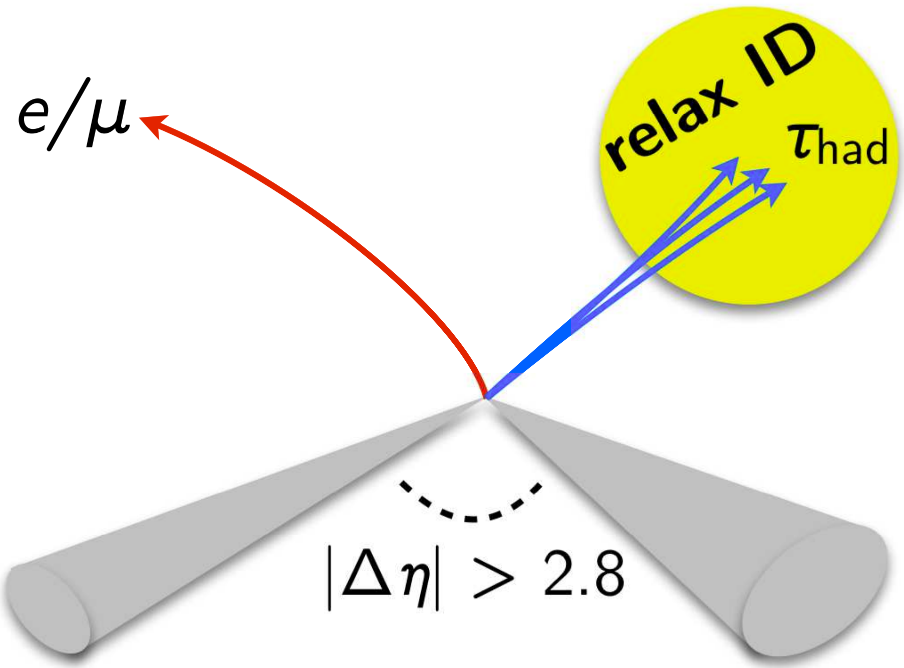


https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TauTriggerPublicResults

VBF triggers

- New VBF triggers *relax tau identification* required at L2 and the EF by adding requirements for forward jets.
- This increases the control sample of tau candidates that will fail identification, used to ***estimate the fake contribution***.
- Being evaluated for the H→ττ→ lep+τ_{had} search.





New as of periods G1, H2

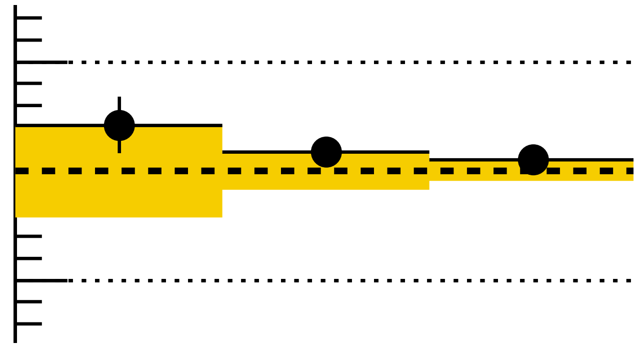
VBF reqs:

- 2 L2 jets $p_{\text{T}} > 15$ GeV, $|\Delta\eta| > 2.5$
- 2 EF jets $p_{\text{T}} > 25$ GeV, $|\Delta\eta| > 2.8$, $M_{\text{jj}} > 400$ GeV

Trigger menu

$\tau_{\text{had}}+\mu$	$\tau_{\text{had}}+e$
tau20_medium1_mu15	tau20Ti_medium1_e18vh_medium1
mu15_vbf_L1TAU8_MU10	e18vh_medium1_vbf_2L1TAU11I_EM14VH

Systematic Uncertainties

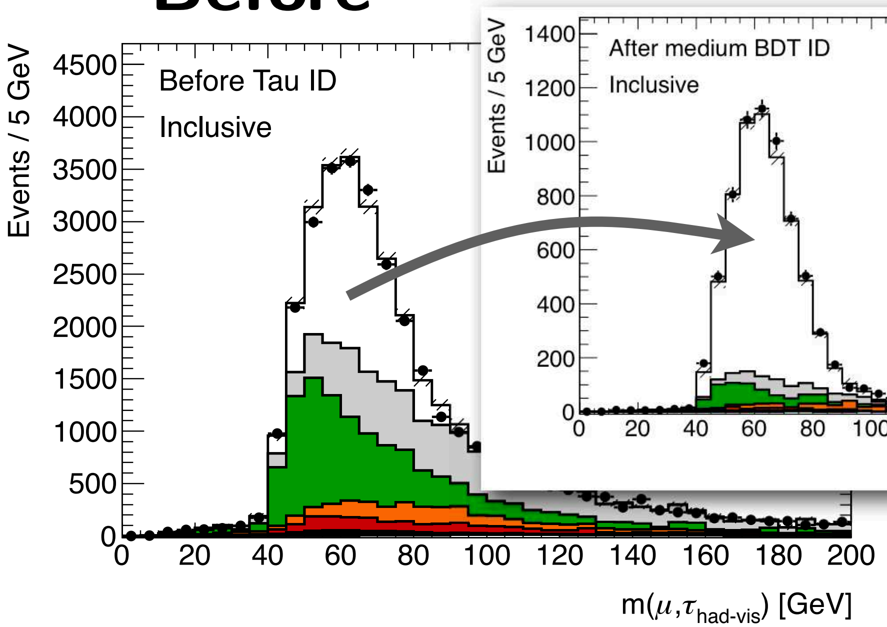


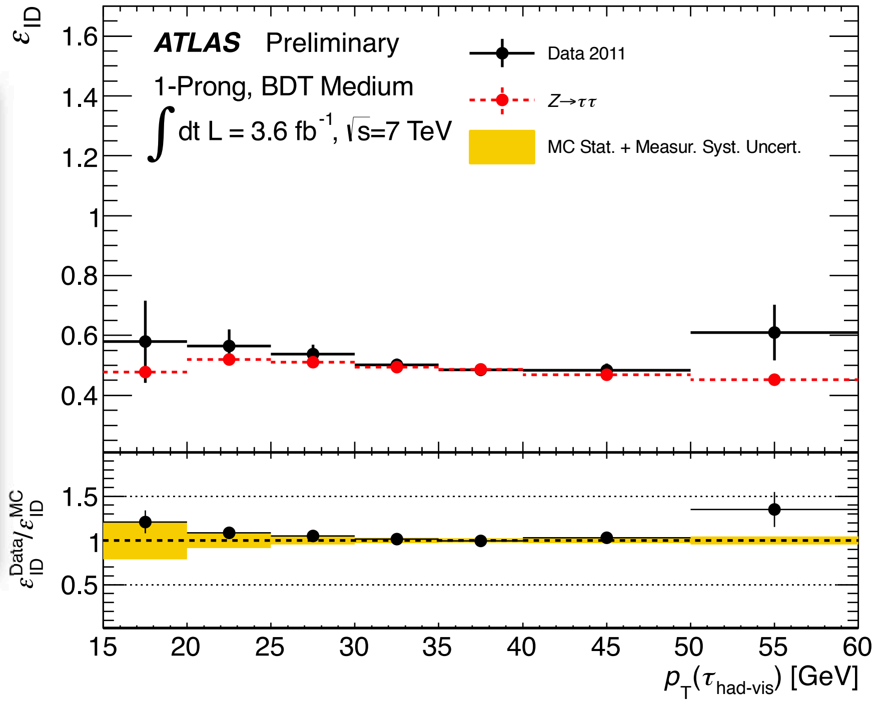
Identification efficiency

- ***Tag-and-probe***: selecting a sample of a known composition without some ID, so one can probe its efficiency.

- For the case of tau ID, select $Z \to \tau\tau \to \mu\tau_h 3\nu$ by triggering on the muon and selecting events with muon + tau candidate.

Before **After Tau ID**

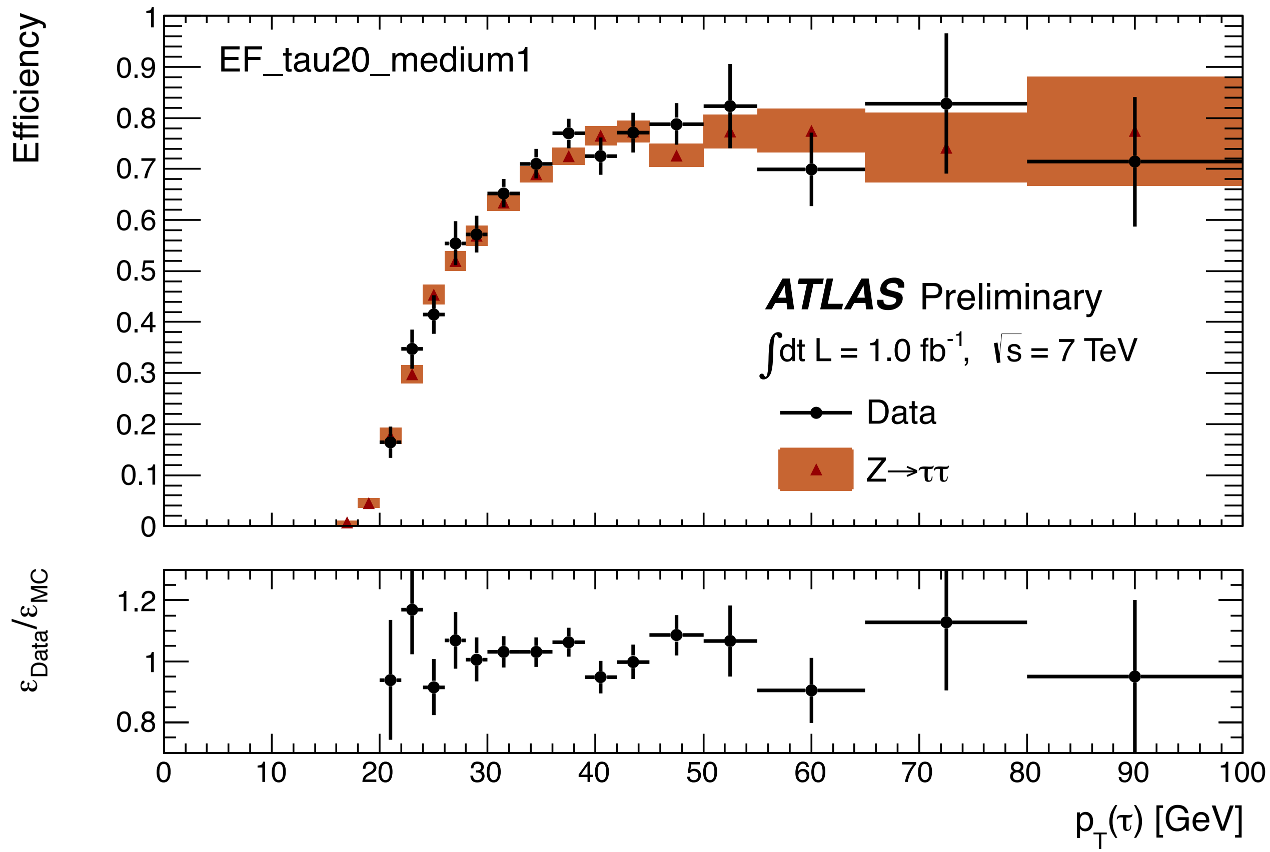




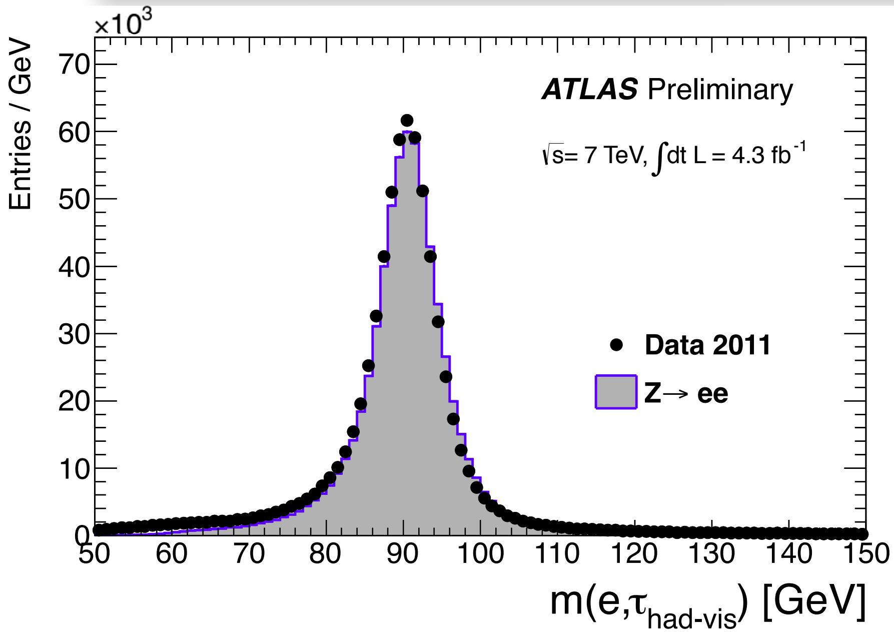
- Scale factor ≈ 1, known to a few percent, 2-3% (1-prong), 5-6% multi-prong.

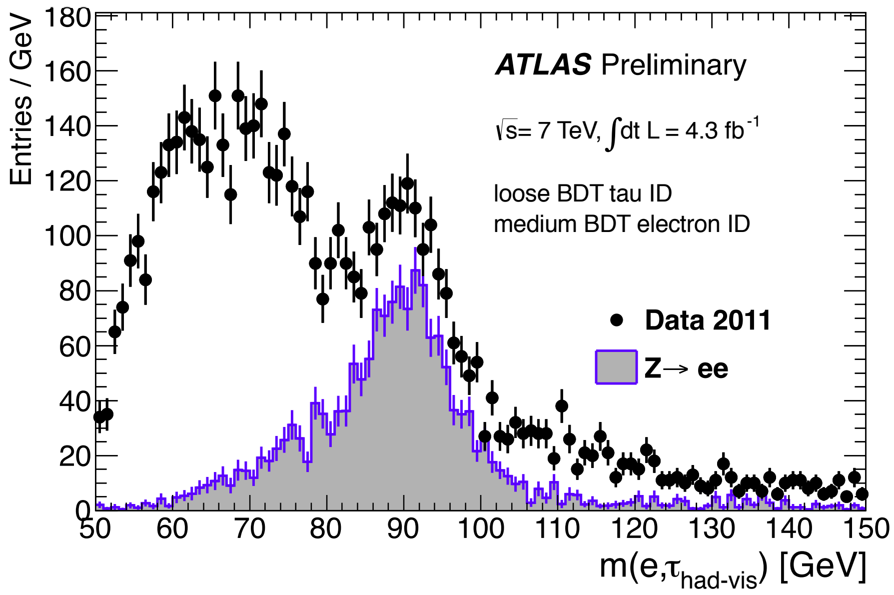
Trigger efficiency

- The same $Z \to \tau\tau \to \mu\tau_{\mathrm{h}} 3\nu$ tag-and-probe sample is used to measure the efficiency of the tau triggers.
- Known to $O(5\%)$ in the turn-on.
- Improving with statistics in 2012.



Electron veto fake rate





- Tag e + tau candidates
- Probe the e-veto efficiency after removing overlap with selected electrons.

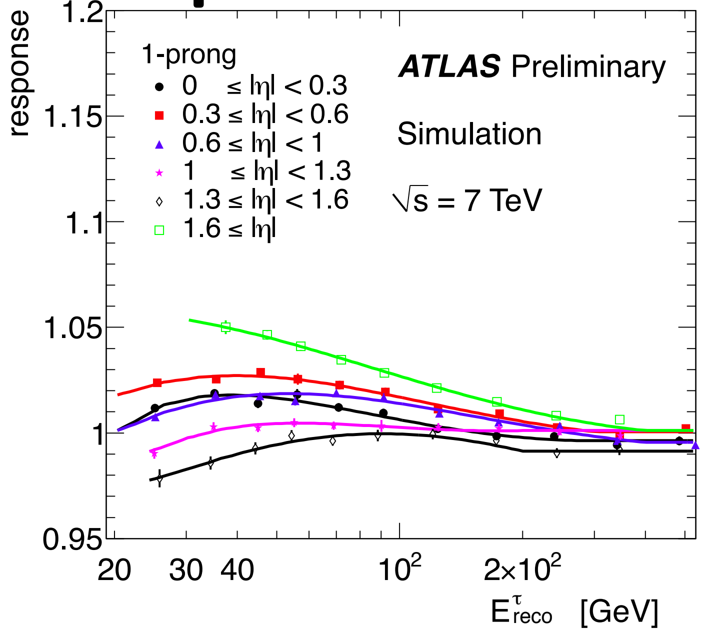
data/MC scale factor and uncertainty
from Z→ee tag-and-probe with 2.6/fb from 2011

electron BDT veto	$\lvert\eta_{\rm trk}\rvert < 1.37$	$1.37 < \lvert\eta_{\rm trk}\rvert < 1.52$	$1.52 < \lvert\eta_{\rm trk}\rvert < 2.00$	$\lvert\eta_{\rm trk}\rvert > 2.00$
loose	0.96±0.22	0.8±0.3	0.47±0.14	1.7 ±0.4
medium	1.3 ±0.5	-	0.5 ±0.4	2.8 ±1.3

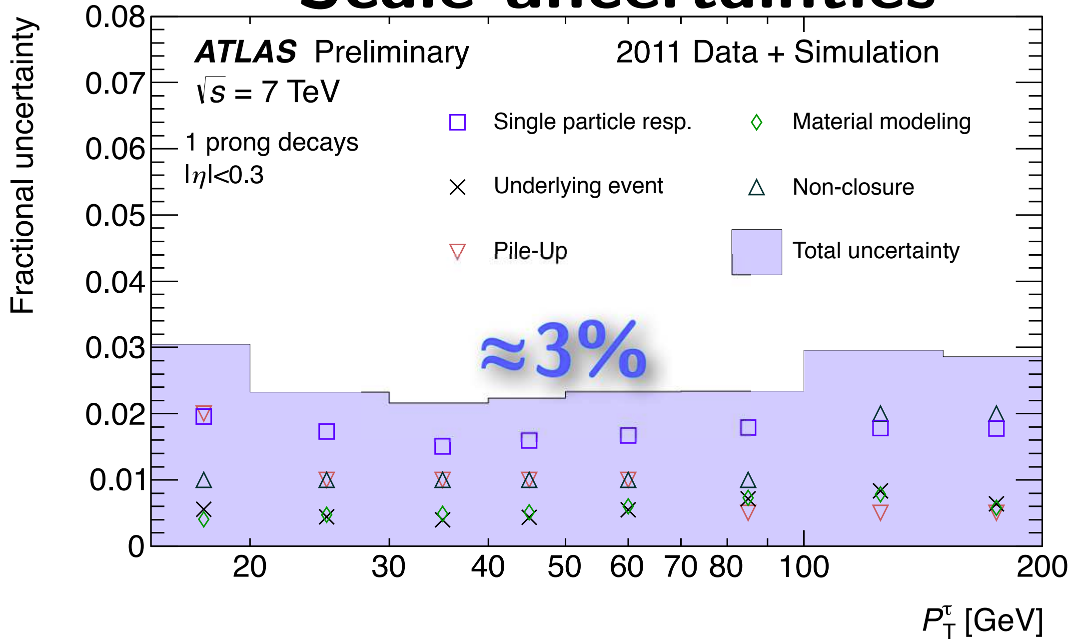
- Statistically limited by the sample that pass the veto, giving uncertainties ≈ 50-100%.
- Improving with the data added in 2012.

Energy scale

Response functions



Scale uncertainties



- Tau candidates are first brought from the EM to the Jet Energy Scale with LC calibration of the clusters within $\Delta R < 0.2$ (from 0.4 to be pile-up robust).
- Then response functions are calibrated with tau Monte Carlo to make final corrections of a few percent.
- Uncertainties are determined by smearing the Monte Carlo truth according the tau decays true composition, using uncertainties constrained by single particle response measurements (CTB, E/p, $Z \rightarrow ee/\pi^0$-resp.)

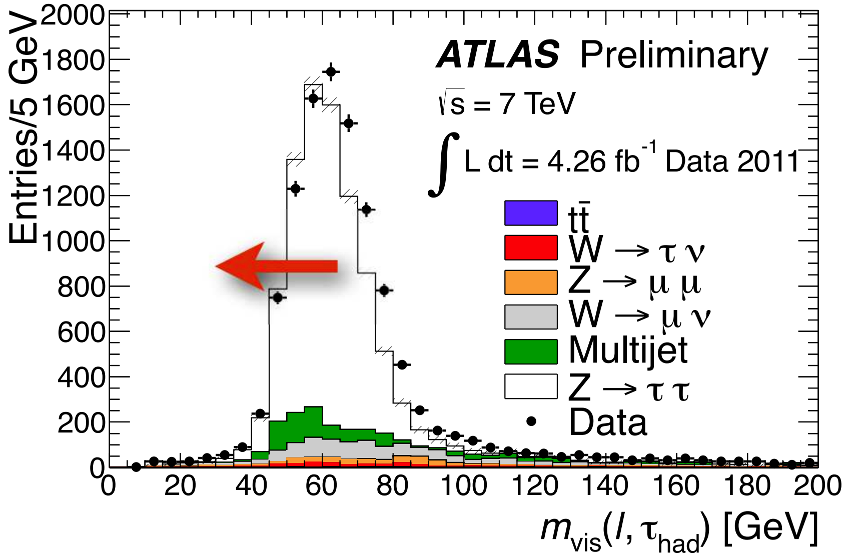
Energy scale cross check

- Tau energy scale is manually shifted in the modeling.
- Median of the visible mass peak is used to decide which scale matches the data.
- Toy experiments are used to estimate the uncertainty.

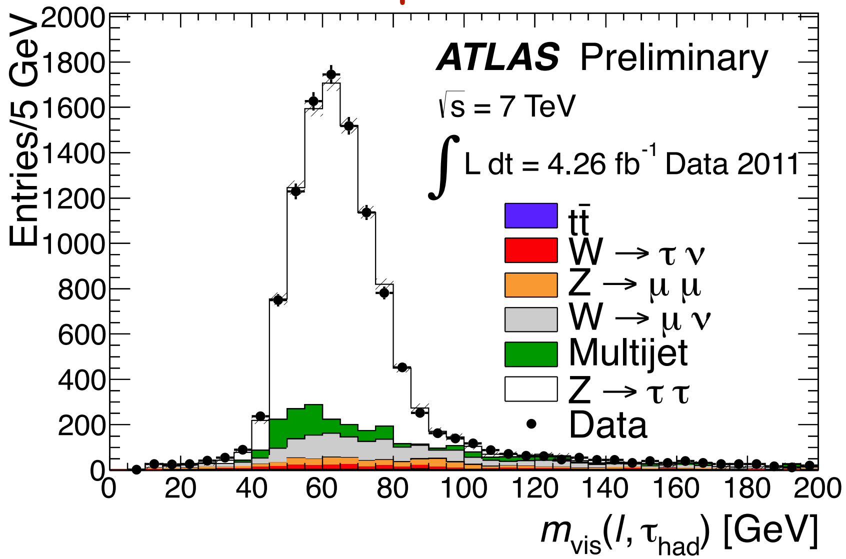
$\|\eta\|$	best scale	uncert.
0.0-0.8	-1.5%	3.3%
0.8-2.5	+1.5%	2.8%

- Scale consistent with 1 within single-particle-response uncertainties ≈ 3%.
- May become primary method with more data.

scale shifted -10%



best fit +1.5%



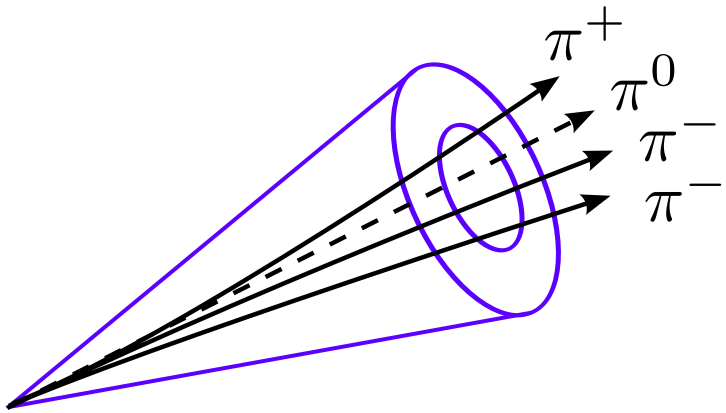
Conclusions

- The rise of pile-up in 2011 challenged the performance of tau identification and triggering.
- Efforts in multiple areas (identification, triggering, energy calibration) have mitigated the effects of pile-up with better design choices or corrections.
- The future will bring opportunities to further shrink our scale factor uncertainties with additionally analyzed 2012 data.
- It is an exciting time to analyze tau final states at ATLAS.

Back up

Phenomenology of tau decays

$\tau^- \to$			
	$e^- \, \bar{\nu}_e \, \nu_\tau$	17.8%	leptonic 35.2%
	$\mu^- \, \bar{\nu}_\mu \, \nu_\tau$	17.4%	
	$\pi^- \, \pi^0 \, \nu_\tau$	25.5%	1 prong 49.5%
	$\pi^- \, \nu_\tau$	10.9%	
	$\pi^- \, 2\pi^0 \, \nu_\tau$	9.3%	
	$K^- \, (N\pi^0) \, (NK^0) \, \nu_\tau$	1.5%	
	$\pi^- \, 3\pi^0 \, \nu_\tau$	1.0%	
	$\pi^- \, \pi^- \, \pi^+ \, \nu_\tau$	9.0%	3 prong 15.2%
	$\pi^- \, \pi^- \, \pi^+ \, \pi^0 \, \nu_\tau$	4.6%	

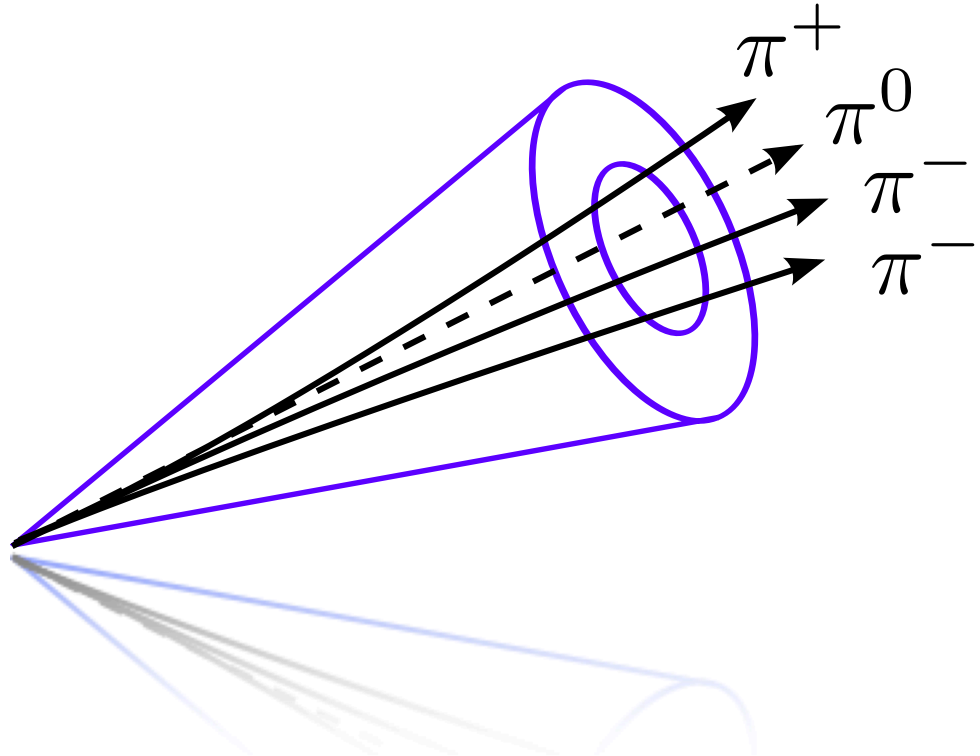


Current tau identification variables

1. Core energy fraction*
$$f_{\text{core}} = \frac{\sum_{\{\Delta R<0.1\}} E_{\mathrm{T}}^{\mathrm{EM}}(\text{cell})}{\sum_{\{\Delta R<0.2\}} E_{\mathrm{T}}^{\mathrm{EM}}(\text{cell})}$$
2. Leading track momentum fraction*
3. Track radius $R_{\text{track}} = \frac{\sum_{\{\Delta R<0.4\}} p_{\mathrm{T}}(\text{track})\, \Delta R(\text{track, jet})}{\sum_{\{\Delta R<0.4\}} p_{\mathrm{T}}(\text{track})}$
4. Number of isolation tracks $N_{\text{trk}}^{0.2<\Delta R<0.4}$
5. Leading track impact parameter significance $S_{\text{lead track}} = \frac{d_0}{\sigma_{d_0}}$
6. Transverse flight path significance $S_{\mathrm{T}}^{\text{flight}} = \frac{L_{\mathrm{T}}^{\text{flight}}}{\sigma_{L_{\mathrm{T}}^{\text{flight}}}}$
7. Mass of track system
8. Maximum ΔR between jet-axis and core tracks

*has pile-up correction term linear in N(vertex)

tauRec

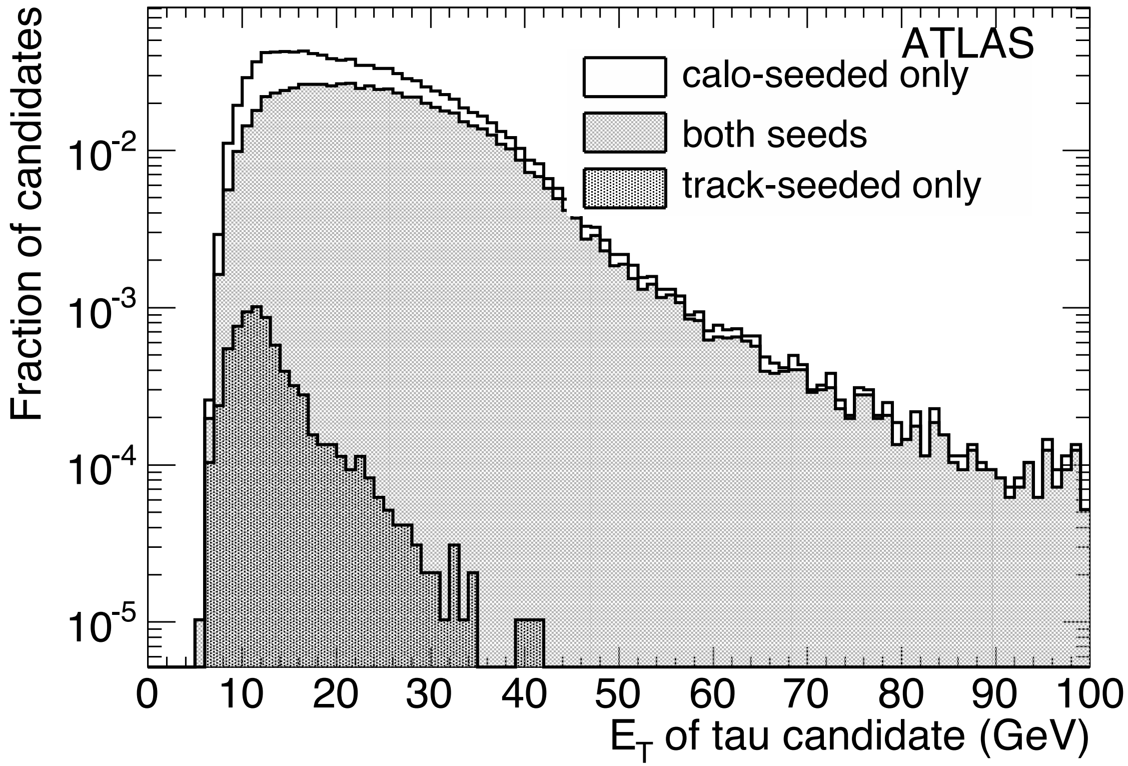


Seeds of reconstruction

Once upon a time, there were two tau reconstruction algorithms. 2009

1. **tauRec** - seeded by $p_{\mathrm{T}} > 10$ GeV anti-k_{T} 0.4 topo-jets. "calo-seeded"

2. **tau1p3p** - seeded by $p_{\mathrm{T}} > 6$ GeV inner detector tracks. "track-seeded"



Since virtually all candidates have a calo-seed, we effectively merged the variable calculation of both algorithms, using only calo-seeds.

"Performance of the tau reconstruction and identification algorithm with 14.2.20 and mc08"
[ATL-COM-PHYS-2009-229]

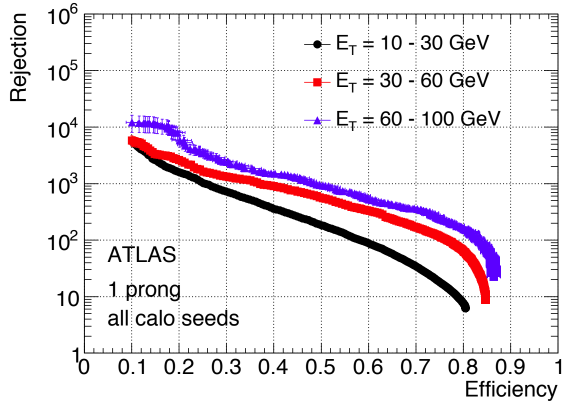
Early MV identification

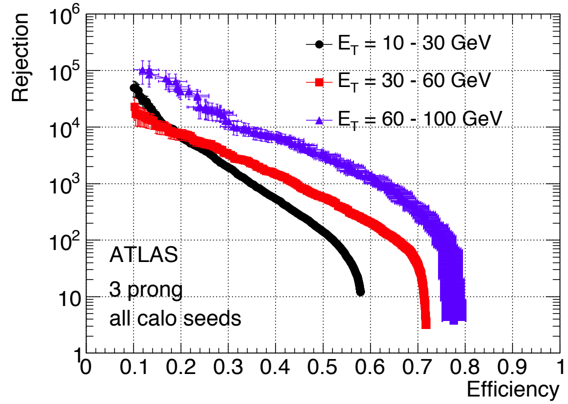
2009

- **Jet-tau discrimination**

  Prefers narrow calorimeter jets, likelihood-based discriminant.

$$R_{\mathrm{EM}} = \frac{\sum_i^{\Delta R_i<0.4} E_{\mathrm{T},i}^{\mathrm{EM}} \Delta R_i}{\sum_i^{\Delta R_i<0.4} E_{\mathrm{T},i}^{\mathrm{EM}}},$$



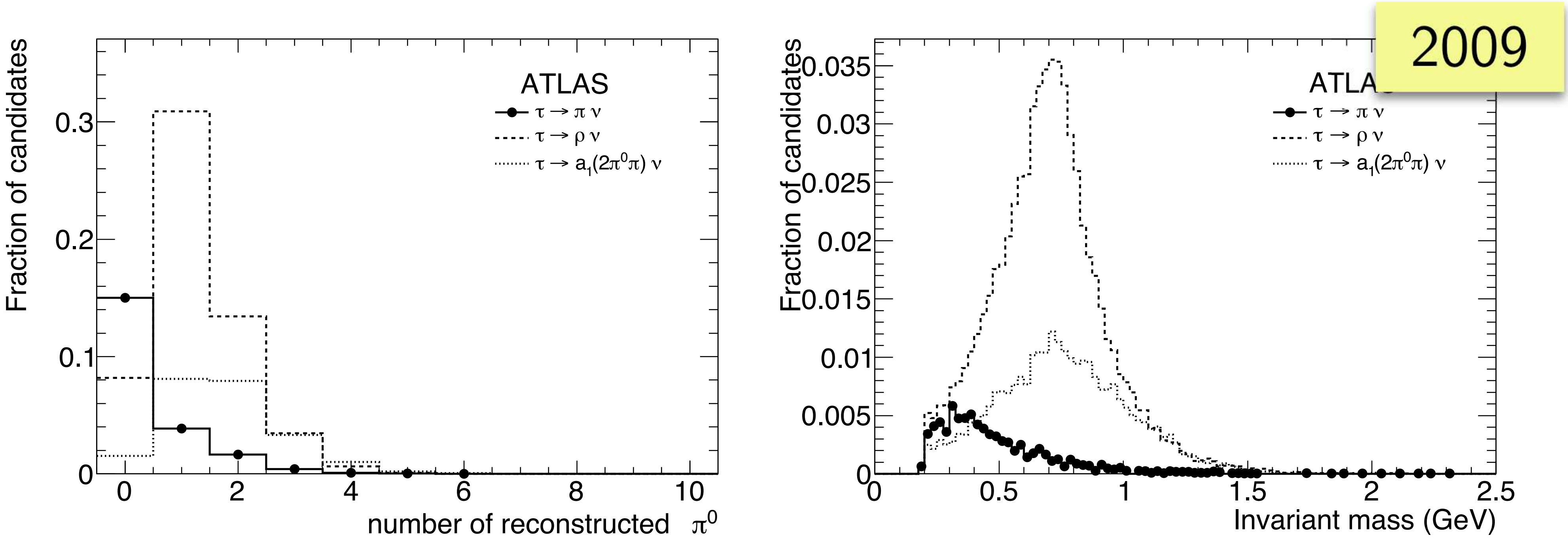


- **Electron-tau discrimination**

	IsEle(%)			IsEle_eg(%)		
Candidate	Overall	1P	3P	Overall	1P	3P
τ from W$\rightarrow \tau\nu$	93.2	92.7	95.3	99.8	99.8	99.8
τ form A$\rightarrow \tau\tau$	93.3	92.5	96.3	99.9	98.8	99.5
Electron form W$\rightarrow e\nu$	2.8	2.4	0.1	14.8	13.4	0.3
Electron form A$\rightarrow \tau\tau$	5.9	4.5	0.5	18.0	15.8	0.8

[ATL-COM-PHYS-2009-229]

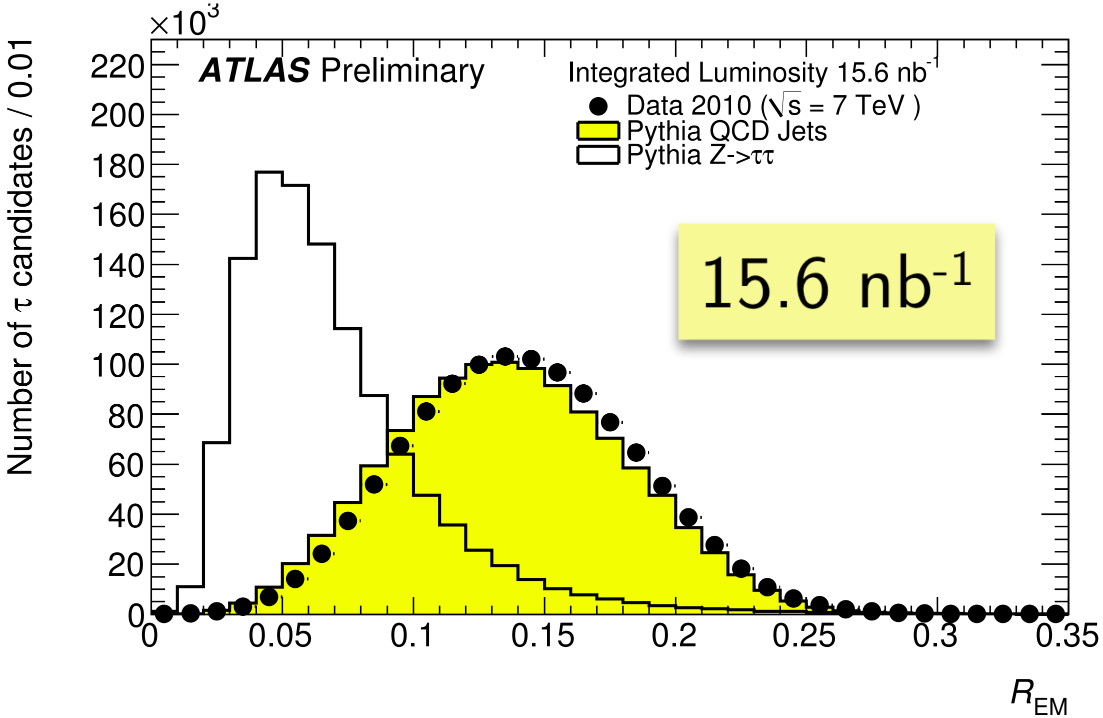
Early sub-structure studies

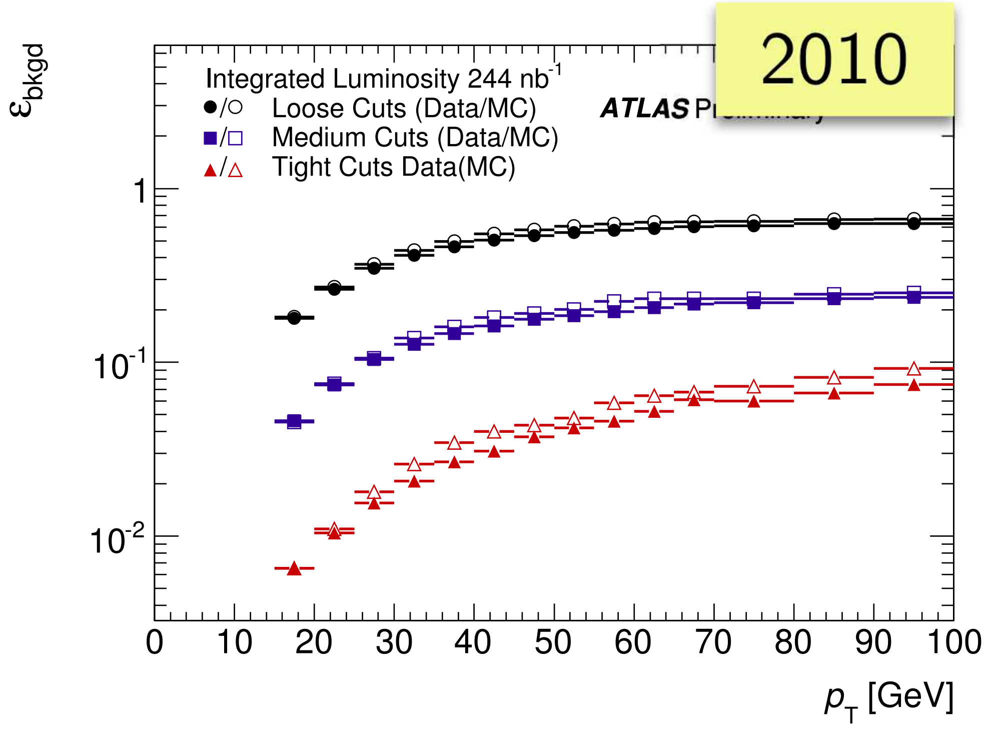


- Monte Carlo based substructure studies
- Cell-based shower-shape subtraction π^0 reconstruction.
- Still unvalidated with data.

[ATL-COM-PHYS-2009-229]

First data





- First comparisons of background distributions and the QCD fake-rate between data and Monte Carlo.

- Already see that MC over-estimates the jet fake-rate. $\Rightarrow k_W \approx 0.5$

"Reconstruction of hadronic tau candidates in QCD events at ATLAS with 7 TeV pp collisions" [ATLAS-CONF-2010-059]

"Tau Reconstruction and Identification Performance in ATLAS" [ATLAS-CONF-2010-086]

Tau discriminants

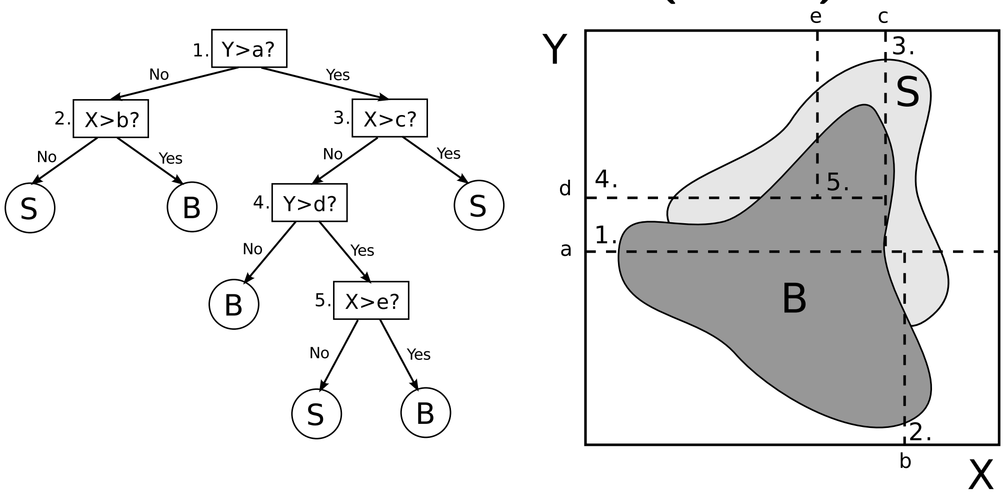
- **Cuts**

  p_{T}-parametrized cuts on R_{EM} and R_{track}, and a cut on f_{track}.

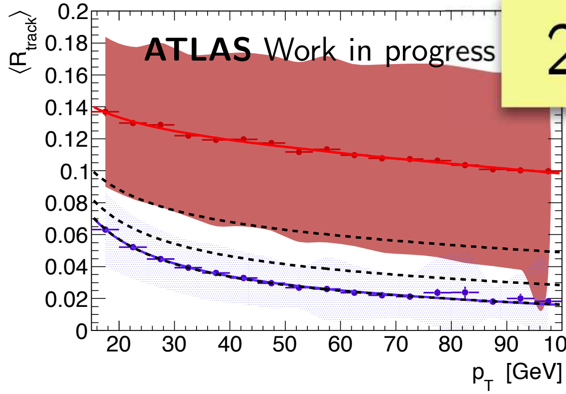
- **Projective likelihood**

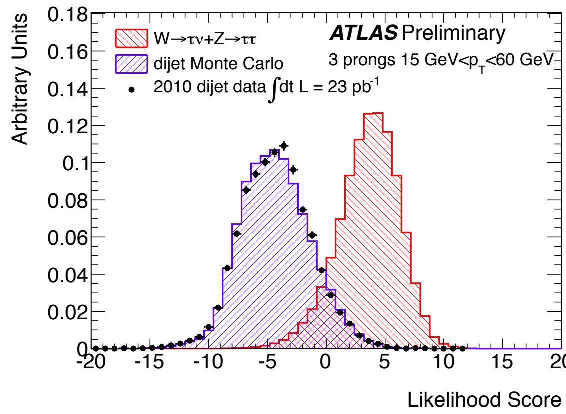
  $$d = \ln\left(\frac{L_S}{L_B}\right) = \sum_{i=1}^{N} \ln\left(\frac{p_i^S(x_i)}{p_i^B(x_i)}\right)$$

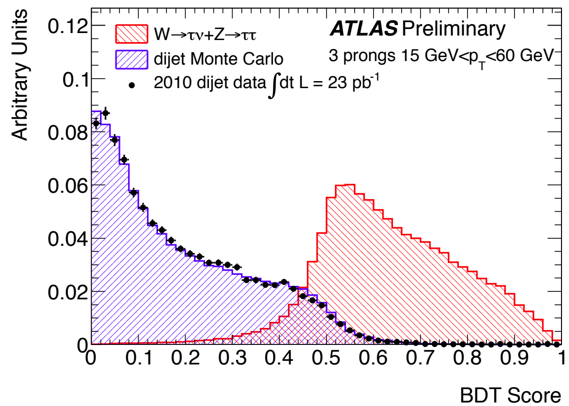
- **Boosted decision trees (BDT)**



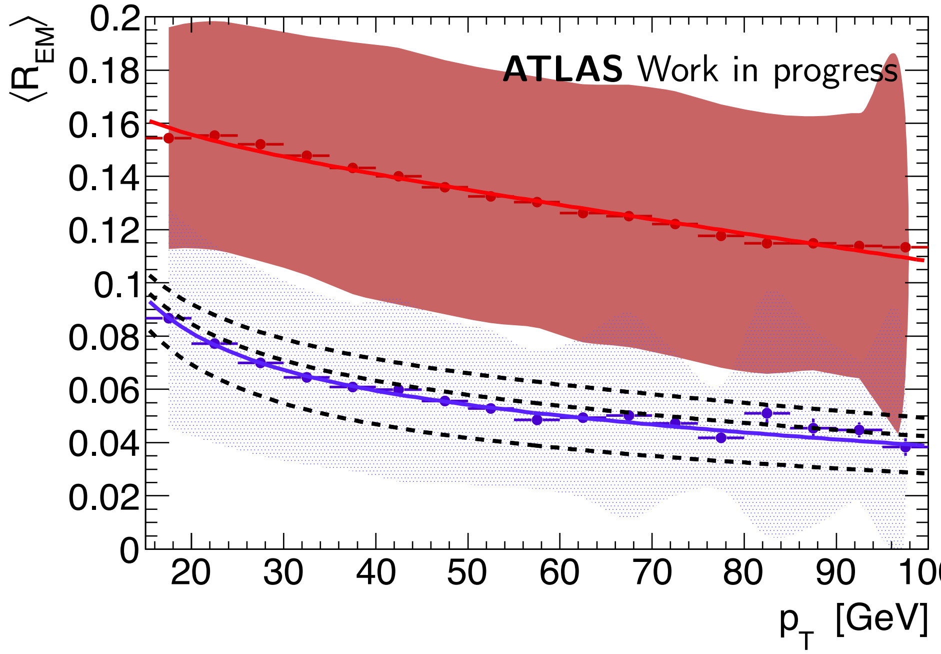
2010

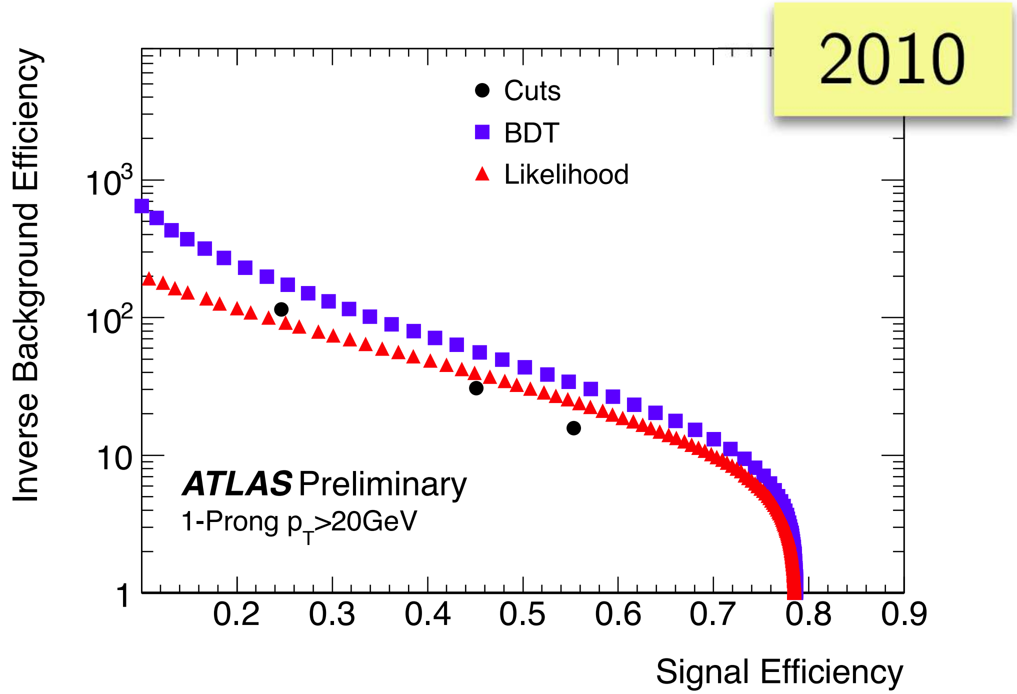






Maturing of discriminants



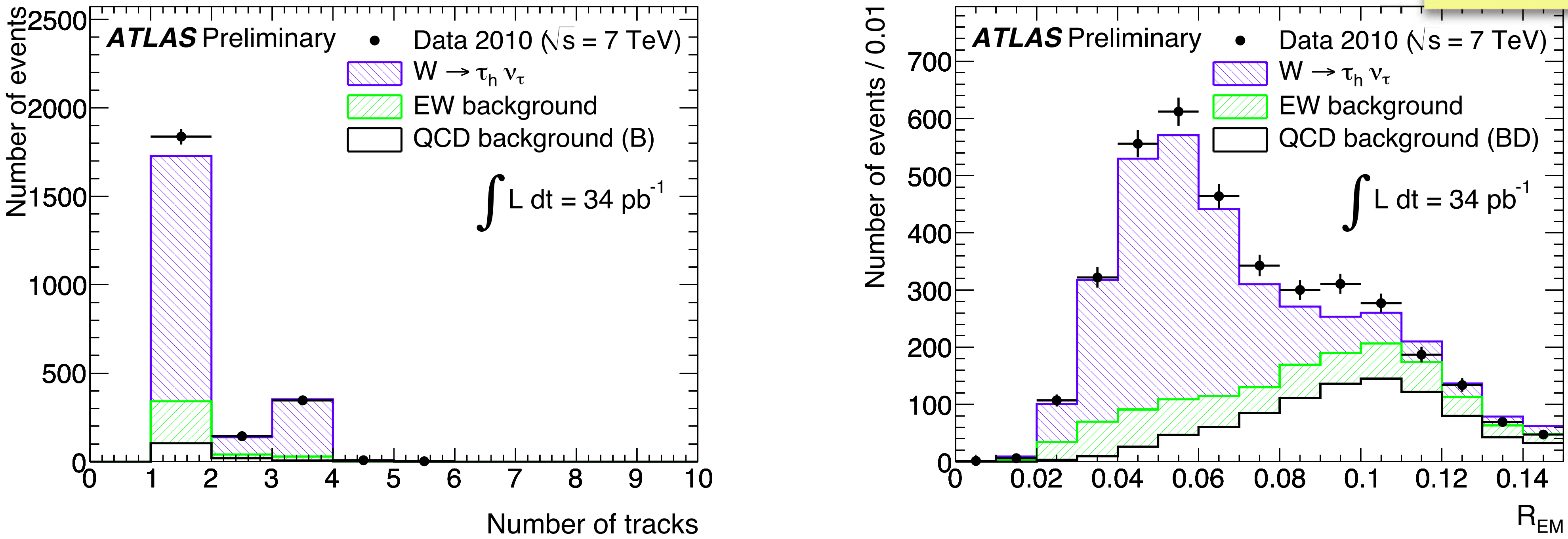


- Cuts are pt-parametrized to account for the Lorentz collimation of boosted taus.
- Experience grows with LLH and BDT discriminants, which become the preferred discriminants in 2011.

"Reconstruction, Energy Calibration, and Identification of Hadronically Decaying Tau Leptons in the ATLAS Experiment" [ATLAS-CONF-2011-077, ATL-PHYS-INT-2011-068]

Seeing first hadronic taus

2010



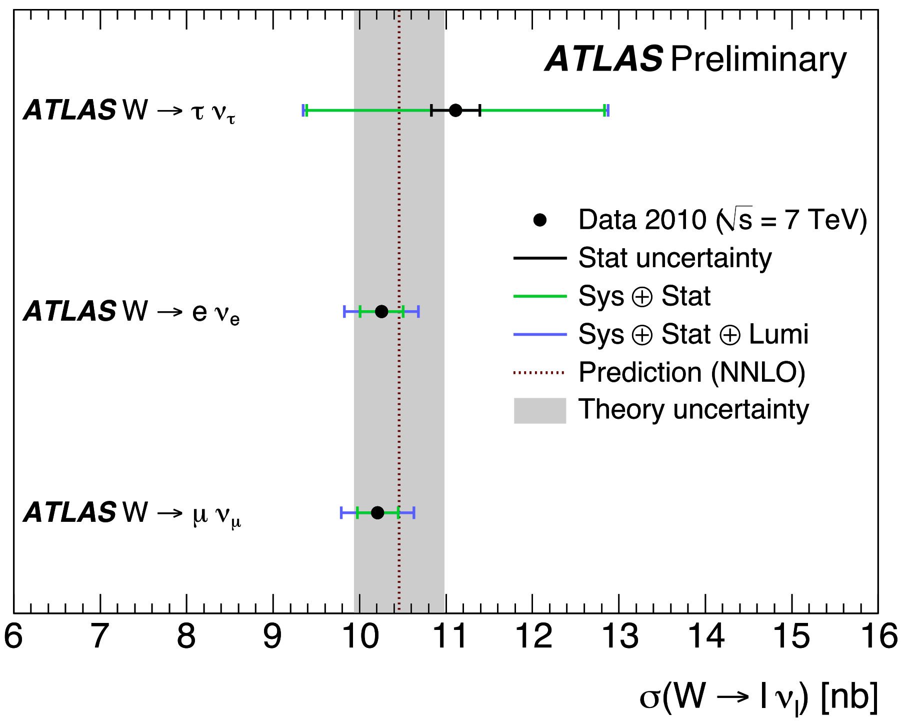
- Nov 2010: Observation of $W \rightarrow \tau_h \nu$ [ATLAS-CONF-2010-097]
- Feb 2011: Observation of $Z \rightarrow \tau_h \tau_l$ [ATLAS-CONF-2011-010]

$W \to \tau\nu$ cross section

2010

$$\sigma(W \to \tau\nu) = 11.1 \pm 0.3(\text{stat.}) \pm 1.7(\text{sys.}) \pm 0.4(\text{lumi.})\ \text{nb}$$

$$\sigma_{\text{theory}} = 10.46 \pm 0.52\ \text{nb at NNLO}$$



Dominant systematics

- τ_{h} efficiency 10.3%
- τ_{h} energy scale 8.0%
- τ_{h} + MET trigger efficiency 7.0%
- luminosity 3.4%
- acceptance 2.3%

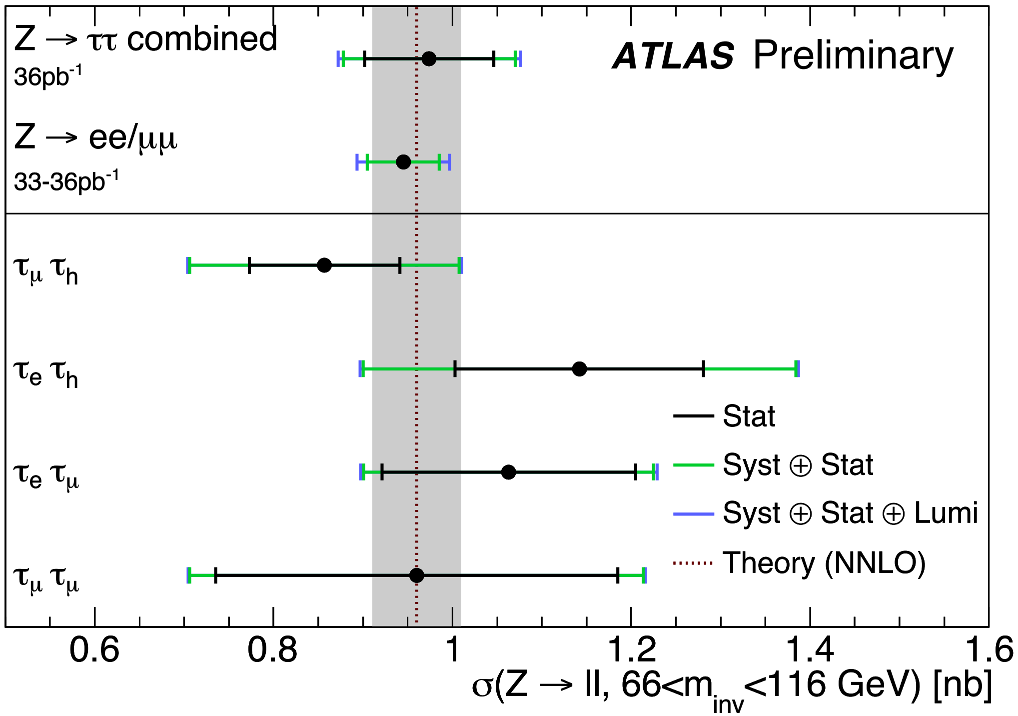
"Measurement of the $W \to \tau\nu$ cross section in pp collisions at sqrt(s)= 7 TeV with the ATLAS experiment" [arXiv:1108.4101]

$Z\rightarrow\tau\tau$ cross section

2011

$$\sigma_{\text{combined}} = 0.97 \pm 0.07(\text{stat.}) \pm 0.07(\text{sys.}) \pm 0.03(\text{lumi.})\ \text{nb}$$

$$\sigma_{\text{theory}} = 0.96 \pm 0.05\ \text{nb at NNLO}$$

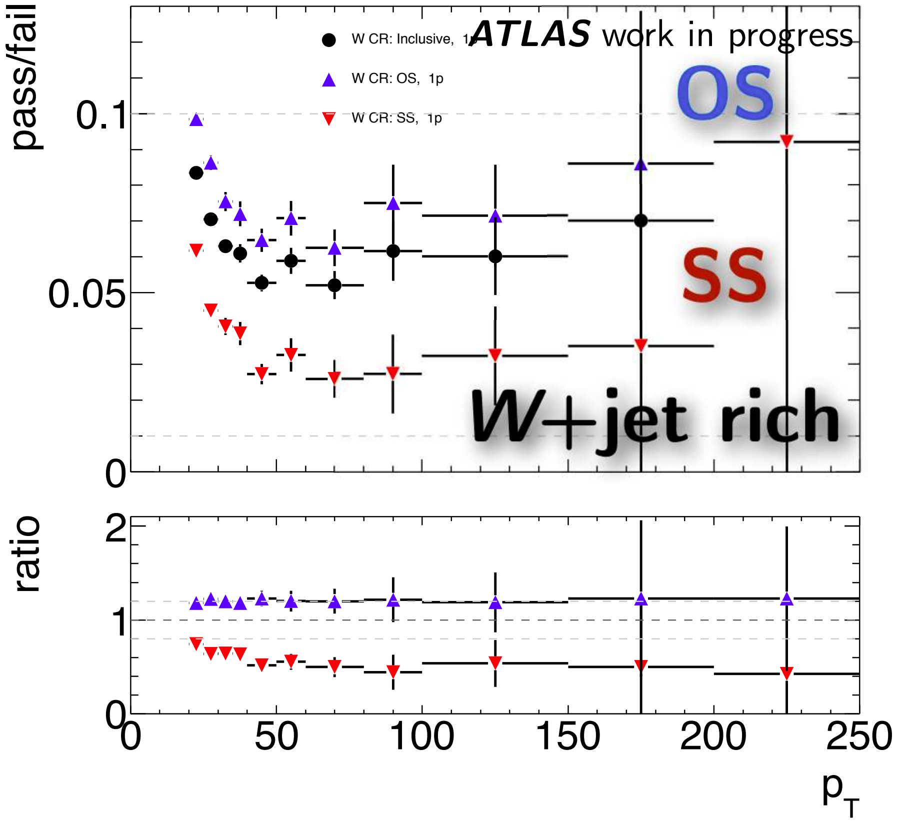


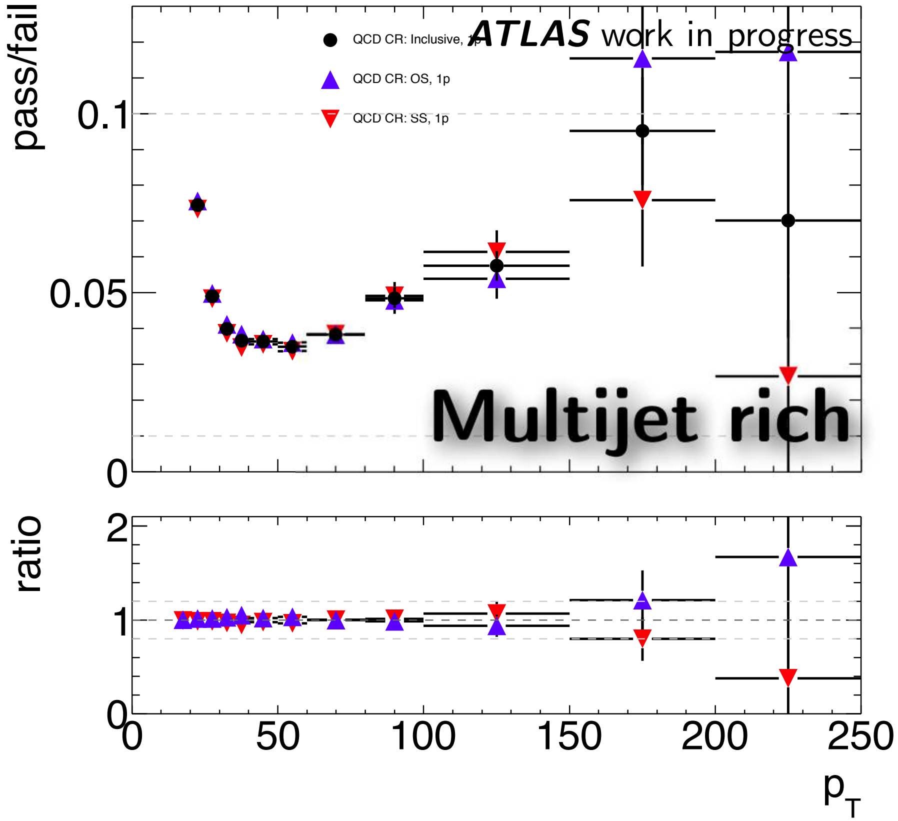
Dominant systematics

- $\tau_{\rm h}$ energy scale 11%
- $\tau_{\rm h}$ efficiency 8.6%
- μ efficiency 8.6%
- e efficiency 3-10%
- acceptance 3%
- luminosity 3.4%

"Measurement of the $Z\rightarrow\tau\tau$ cross section in pp collisions at sqrt(s)= 7 TeV with the ATLAS detector"
[arXiv:1108.2016]

Observed variance in fake-rates





(BDTMedium)

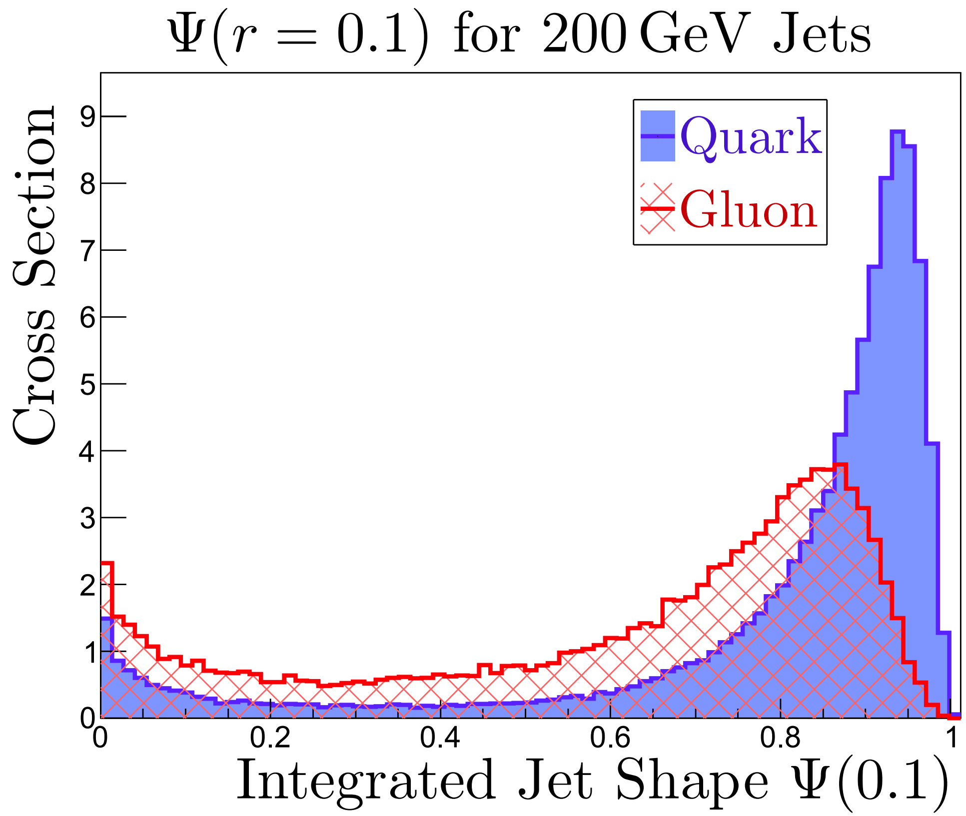
- Hypothesis: quarks vs gluons
- Divide the issue into two questions:

  1. *Why do quarks and gluons have different tau fake-rates?*
  2. *How does the quark/gluon fraction vary among samples?*

Jet width for quark/gluons

Why do quarks and gluons have different tau fake-rates?

- $\Psi(r)$ = fraction of jet energy within $\Delta R < r$.
- Quark jets are more narrow than gluon jets of the same energy.
- Tau identification prefers narrow candidates.



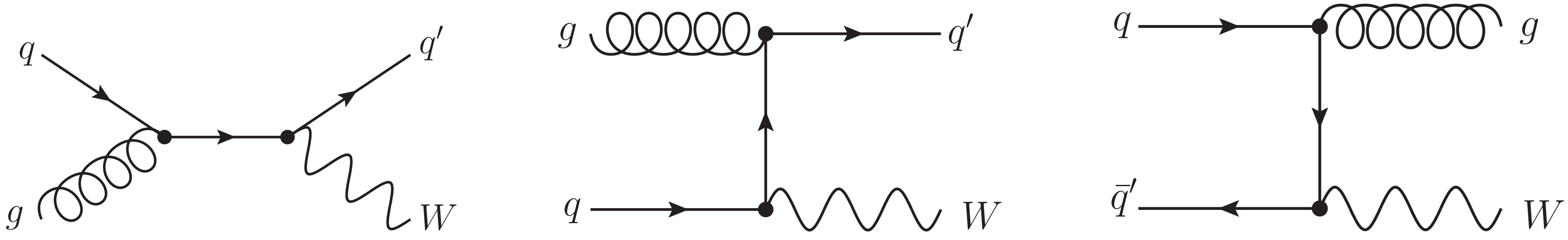
- This is consistent with samples of quark-enriched jets, like W+jet, having higher fake-rates.

J. Gallicchio, M. Schwartz. “Quark and Gluon Tagging at the LHC”. arXiv:1106.3076.

OS vs SS *W*+jet

How does the quark/gluon fraction vary among samples?

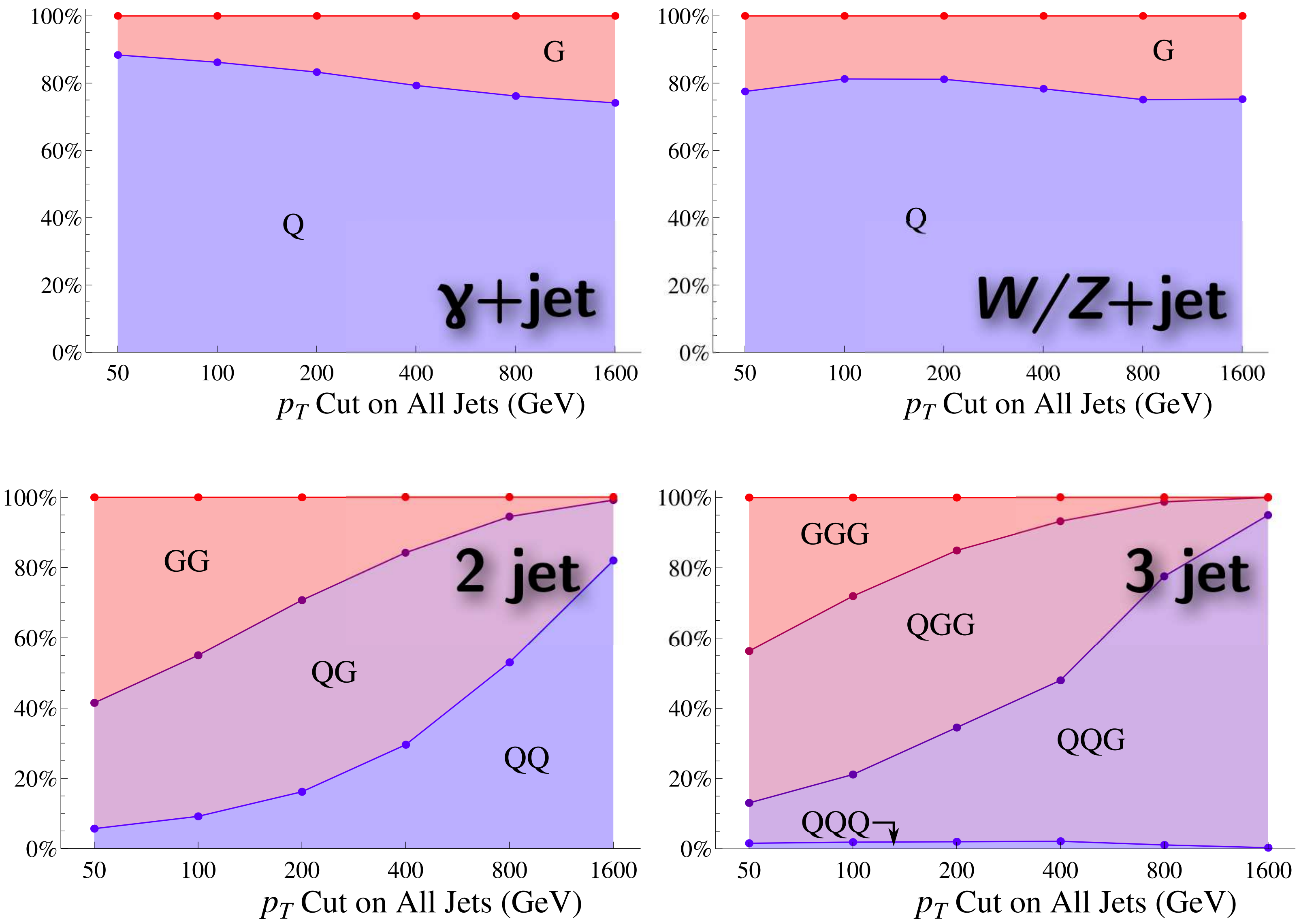
Leading order *W*+jet production:



(a) (b) (c)

- The charge of the quark should correlate with the reconstructed charge of the tau candidate, therefore (a) and (b) preferably produce opposite sign W+jet events.
- OS and SS will have different quark/gluon fractions.

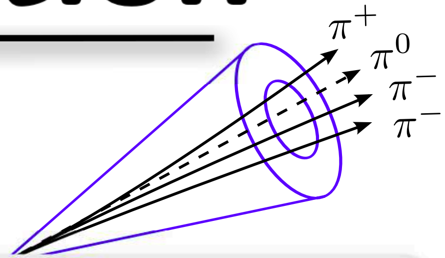
Madgraph predicted Quark/Gluon



J. Gallicchio, M. Schwartz. "Pure Samples of Quark and Gluon Jets at the LHC". arXiv:1104.1175

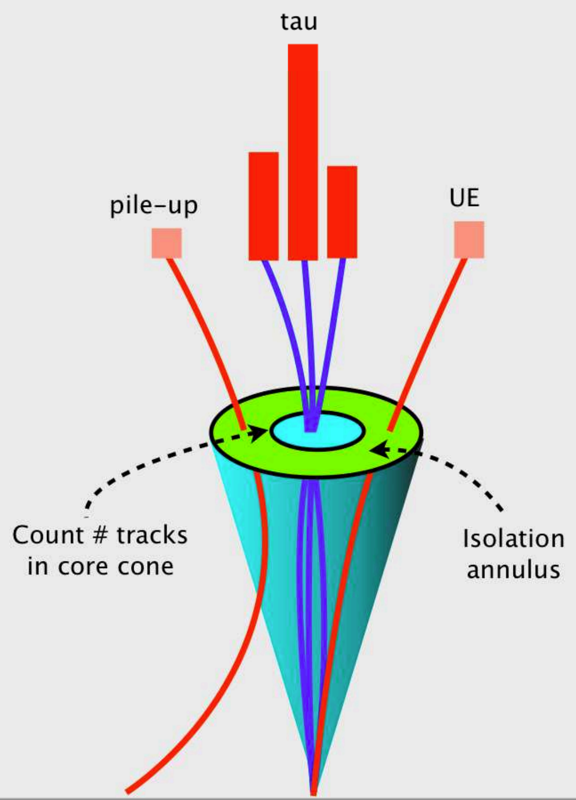
CMS Tau ID

High-p_T τ_h reconstruction



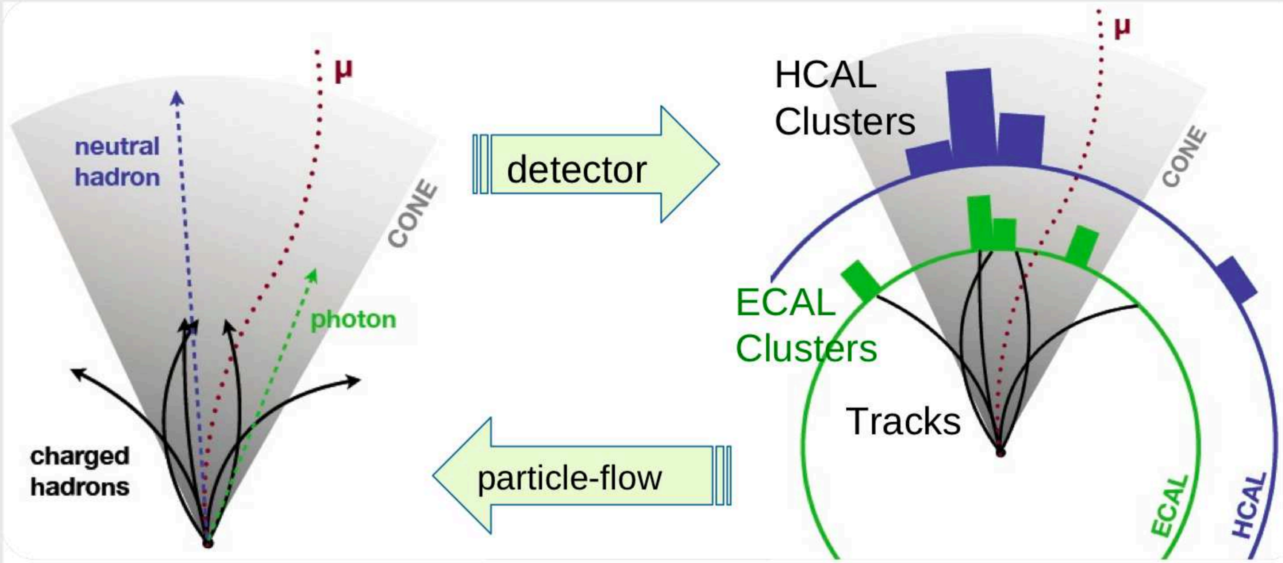
- Hadronic decays dominantly to 1 or 3 $\pi^\pm$ and possibly a few additional π^0s
- Decay in beam-pipe: $c\tau \approx 87$ μm

ATLAS



- τ_h reco seeded by calorimeter jets
- associate tracks in $\Delta R < 0.2$, select 1 or 3
- combine calorimeter and tracking information in a BDT or likelihood discriminant, preferring narrow clustering, hadronic activity

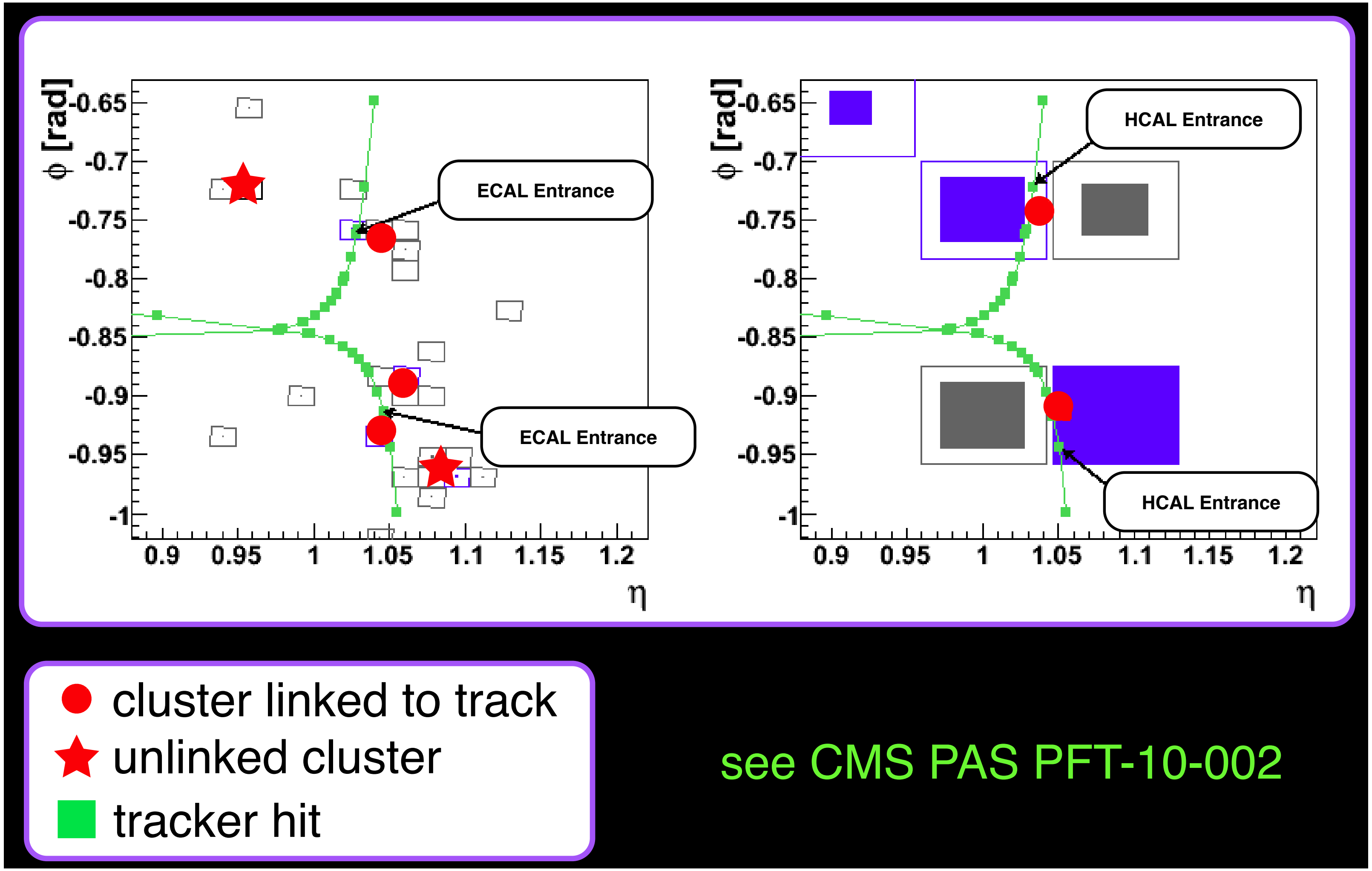
CMS



- particle-flow reconstructs constituent 4-vectors
- τ_h reco seeded by particle-flow hadrons
- Hadron Plus Strip (HPS) algorithm for counting π^0s
- isolation cone for rejecting QCD jets

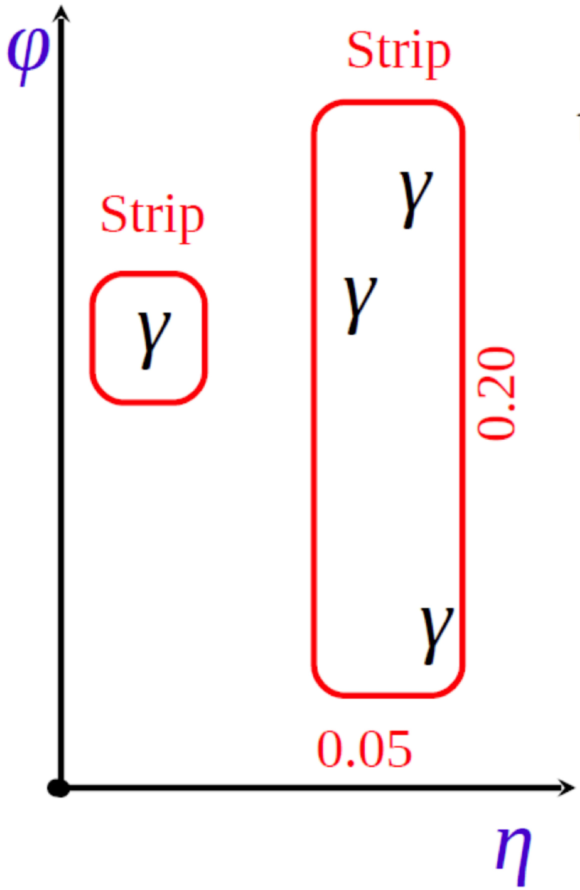
[ATLAS-CONF-2011-152, CMS PAS TAU-11-001]

CMS Particle Flow



- Matches track to clusters to form charged and neutral PF objects.
- PF objects are used as input for all CMS tau reconstruction.

CMS: Hadron Plus Strip (HPS)



Build all possible taus
that have a 'tau-like'multiplicity
from the seed jet

π^+

$\pi^+ \pi^0$

$\pi^+ \pi^+ \pi^-$

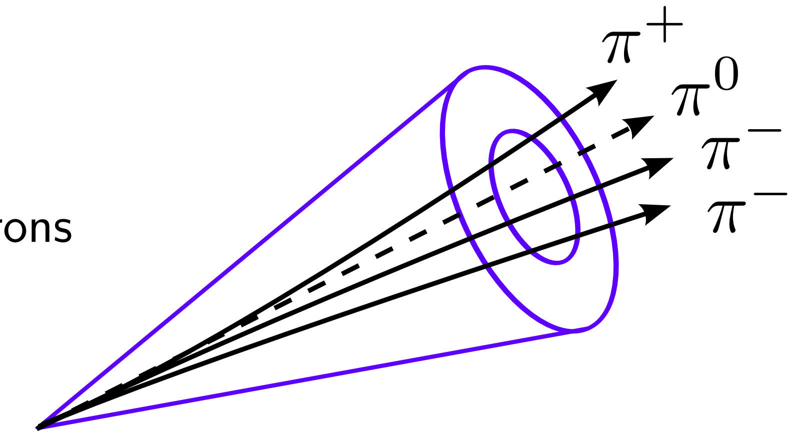
tau that is 'most isolated'
with compatible m_{vis}
is the final tau candidate
associated to the seed jet

Discrimination with calorimeter based isolation $\Delta R < 0.5$.

[CMS PAS TAU-11-001]

CMS: Tau Neural Classifier (TaNC)

- Uses a ***shrinking core-cone***:
  - ΔR(photons) < 0.15 for photons
  - ΔR(charged) $< (5\ \text{GeV})/E_{\text{T}}$ for charged hadrons
  - ΔR(charged) $< \Delta R$(isolation) < 0.5



- Immediately discarded if the candidate doesn't match an expected tau decay mode.

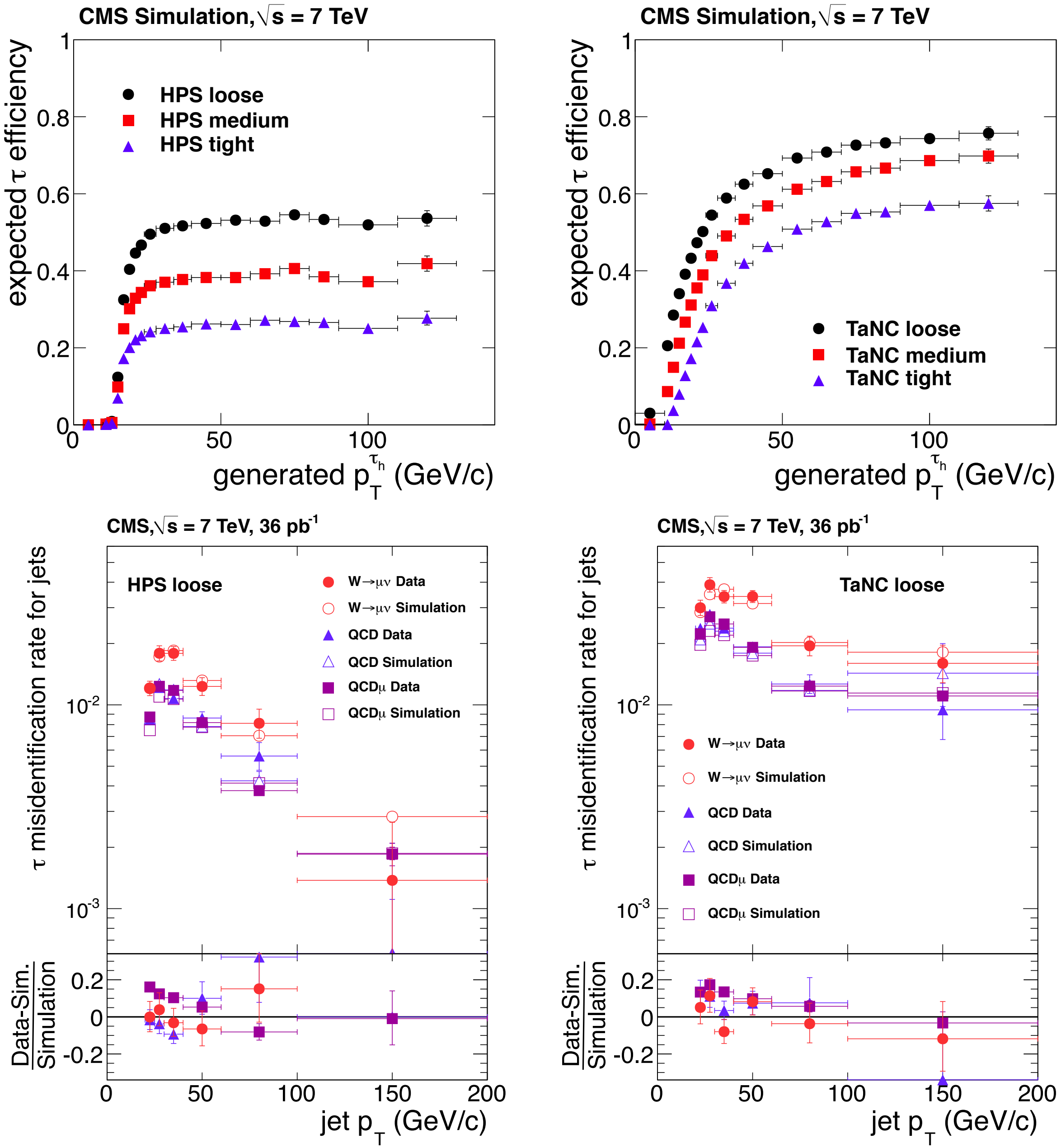
Decay mode	Resonance	Mass (MeV/c^2)	Branching fraction (%)
$\tau^- \to h^- \nu_\tau$			11.6%
$\tau^- \to h^- \pi^0 \nu_\tau$	ρ^-	770	26.0%
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	a_1^-	1200	9.5%
$\tau^- \to h^- h^+ h^- \nu_\tau$	a_1^-	1200	9.8%
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$			4.8%

- Dedicated Neural-net classifier for each decay mode

[CMS PAS TAU-11-001]

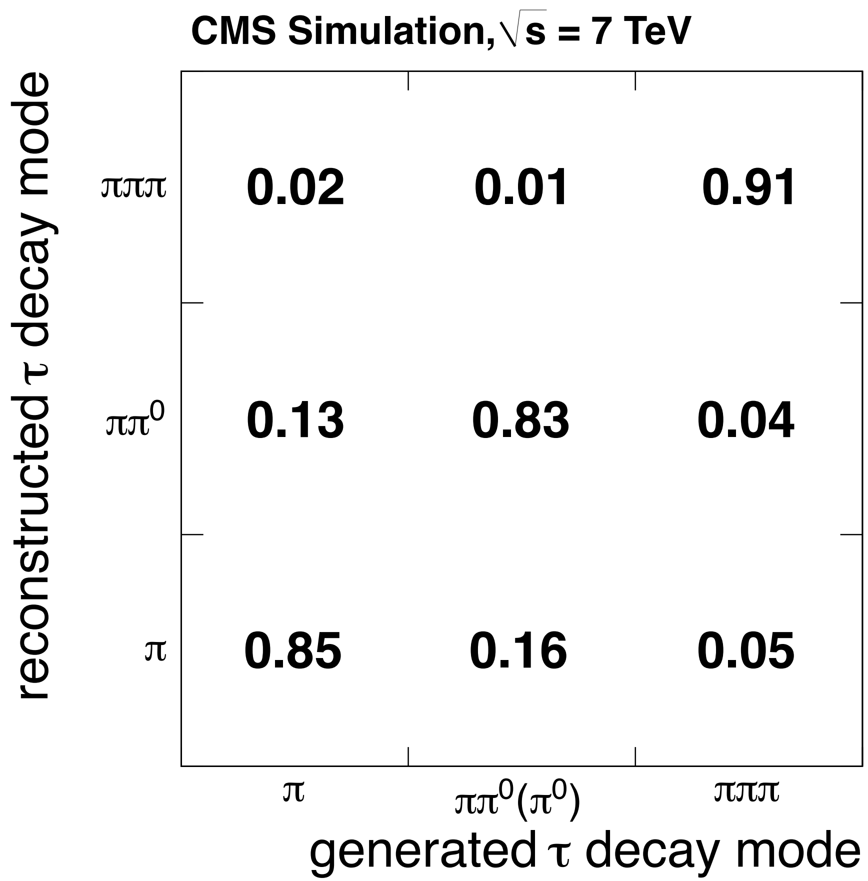
CMS Performance

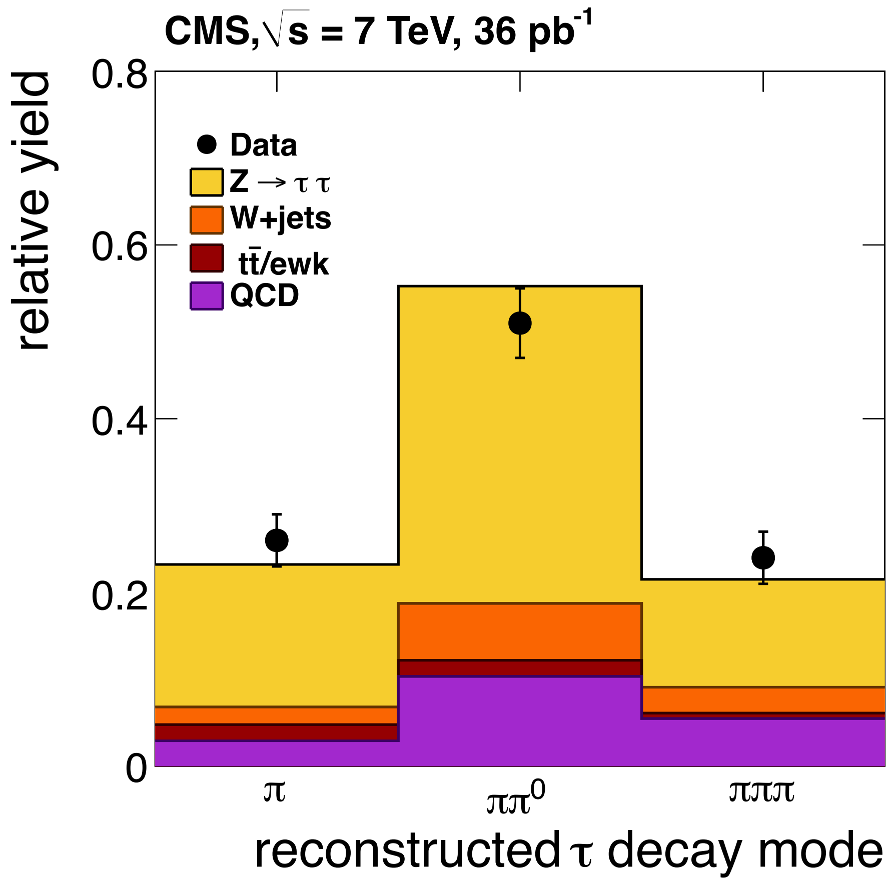
- Not trivial to compare ATLAS and CMS tau performance because we bin fake-rates in N(track) instead of categorizing the decay mode.



[CMS PAS TAU-11-001]

CMS decay mode ID





[CMS PAS TAU-11-001]

Calorimeter granularity

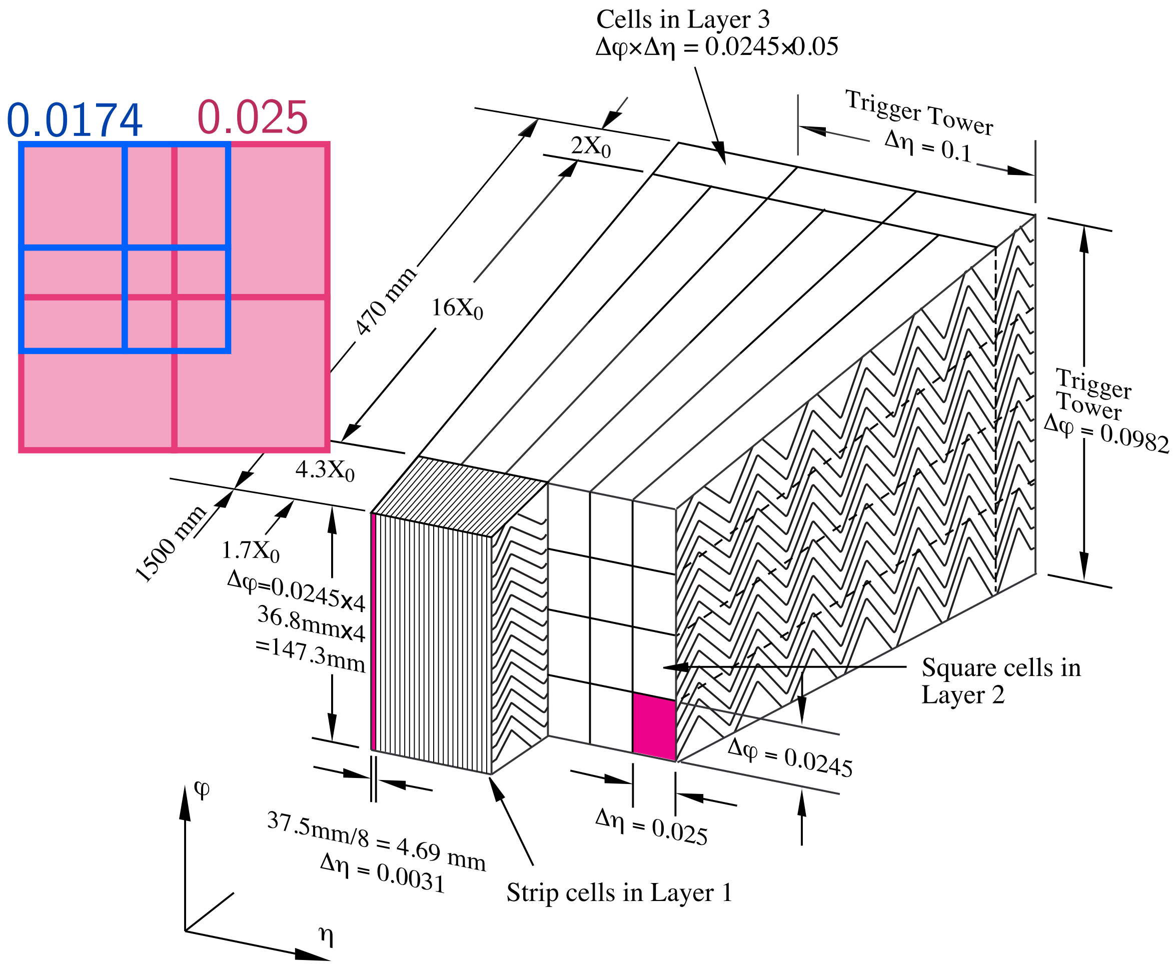
ATLAS

- $B = 2.0$ T
- $\Delta\eta \times \Delta\phi =$ 0.025×0.0245
- R = 0.4 anti-k_T topo-jets

CMS

- $B = 3.8$ T
- $\Delta\eta \times \Delta\phi =$ 0.0174×0.0174
- R = 0.5 anti-k_T PF-jets

ATLAS Barrel EM Calorimeter

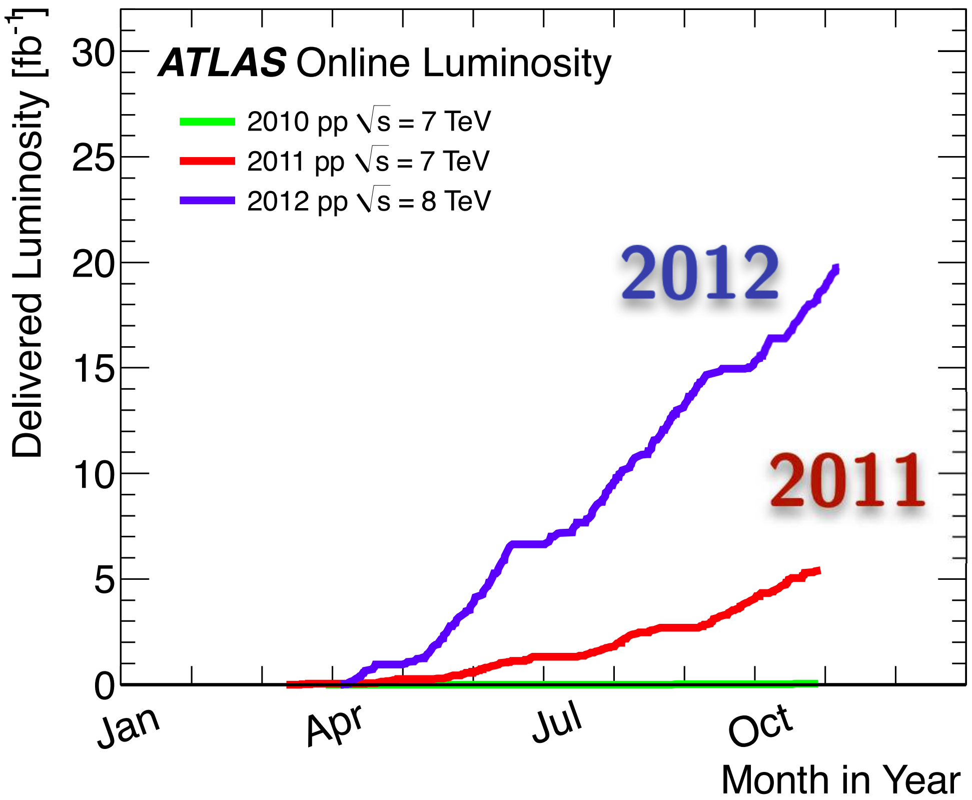


Granularity could fundamentally limit our capacity to reconstruct sub-structure / π^0s.

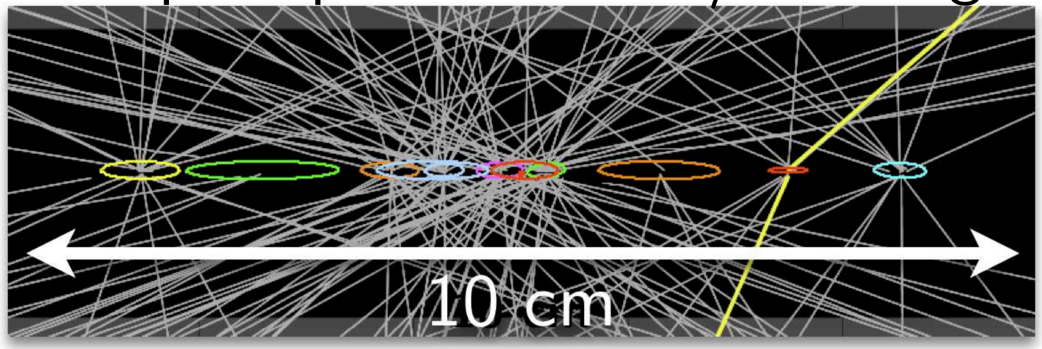
The LHC,
ATLAS, and CMS

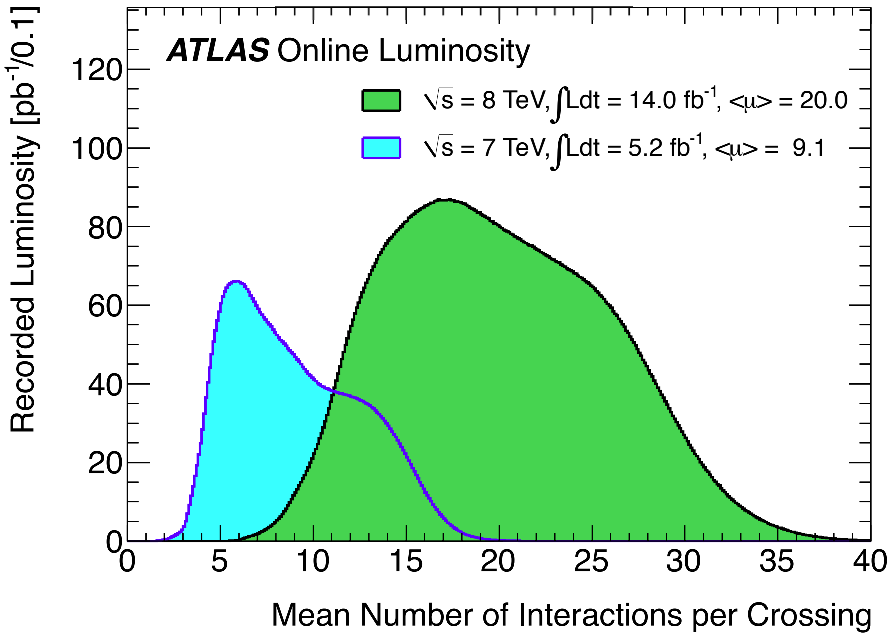
Datasets

Integrated luminosity by year



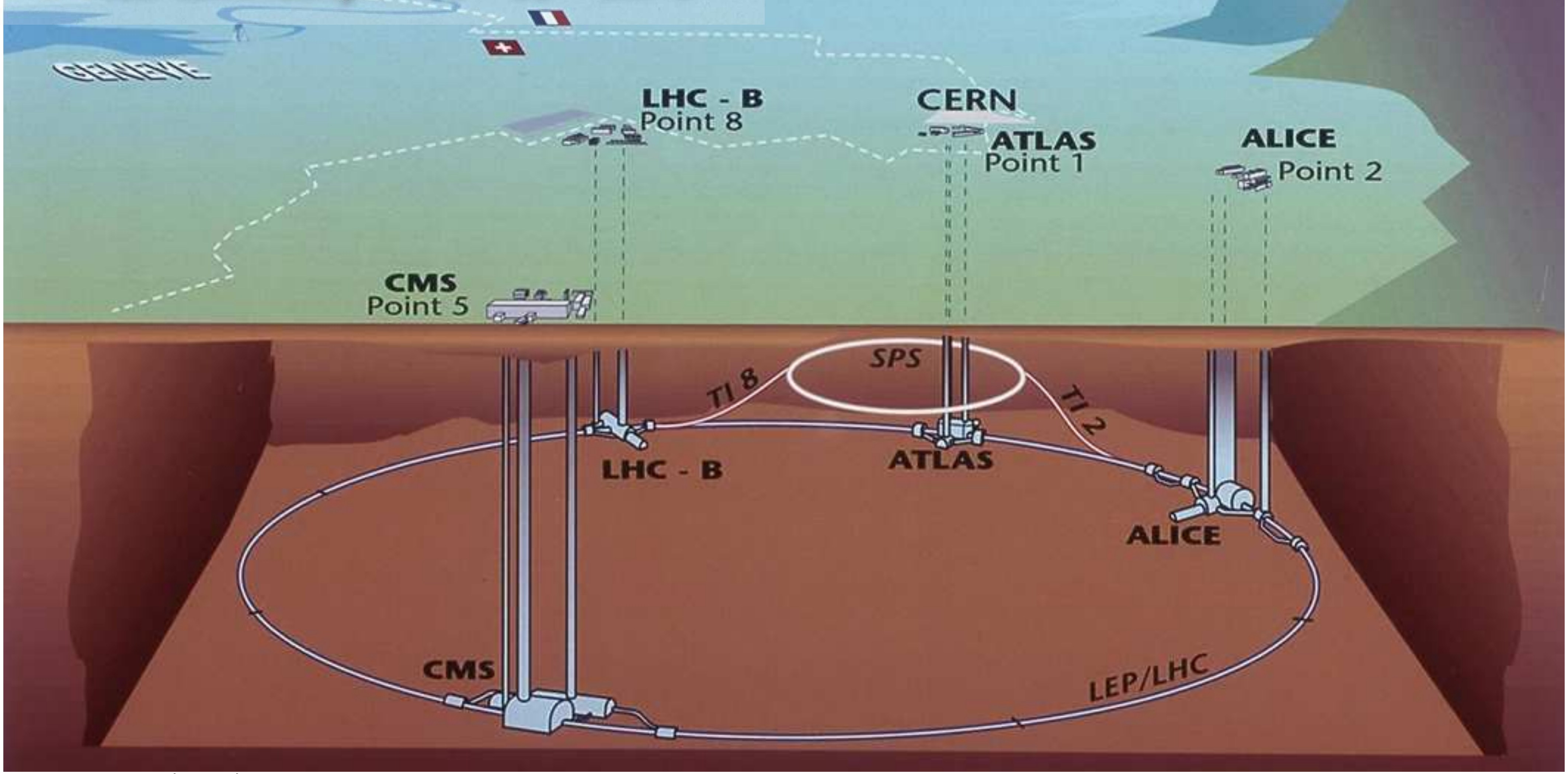
1-40 pile-up interactions / crossing





Overall view of the LHC experiments.

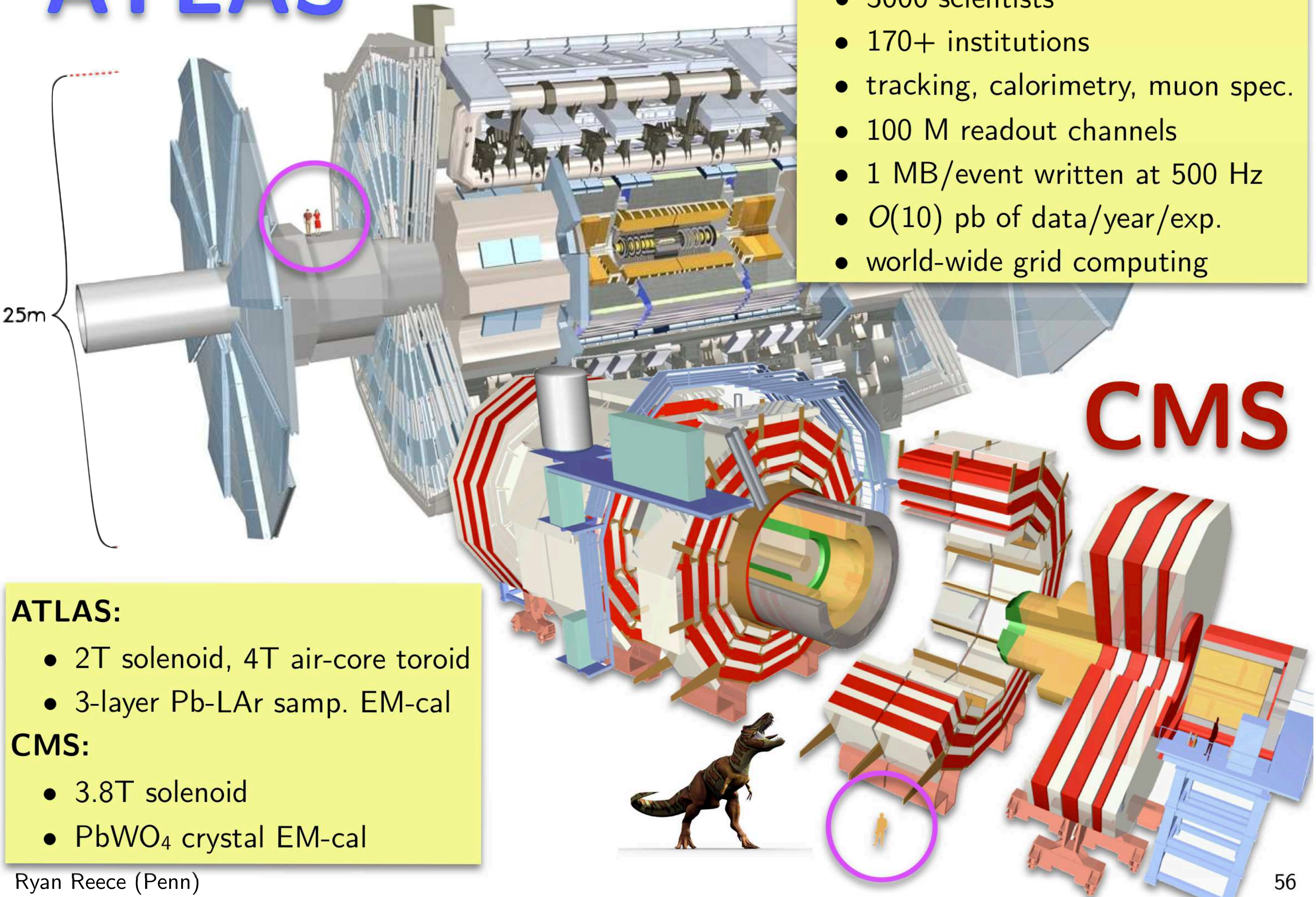
- 27 km circumference
- 1232 dipoles: 15 m , 8.3 T
- 96 tonnes liquid He, 1.9 K
- p-p collisions at $\sqrt{s} = 7\text{-}8$ TeV
- inst. luminosity = 10^{32}-10^{34} cm^{-2}s^{-1}
- 10^{11} protons / bunch $\times$ 1000 bunches
- 20 MHz , 50 ns bunch spacing
- 1-30 interactions / crossing
- 0.5×10^{9} interactions / sec



ATLAS

Each experiment has:

- 3000 scientists
- 170+ institutions
- tracking, calorimetry, muon spec.
- 100 M readout channels
- 1 MB/event written at 500 Hz
- $\mathcal{O}(10)$ pb of data/year/exp.
- world-wide grid computing



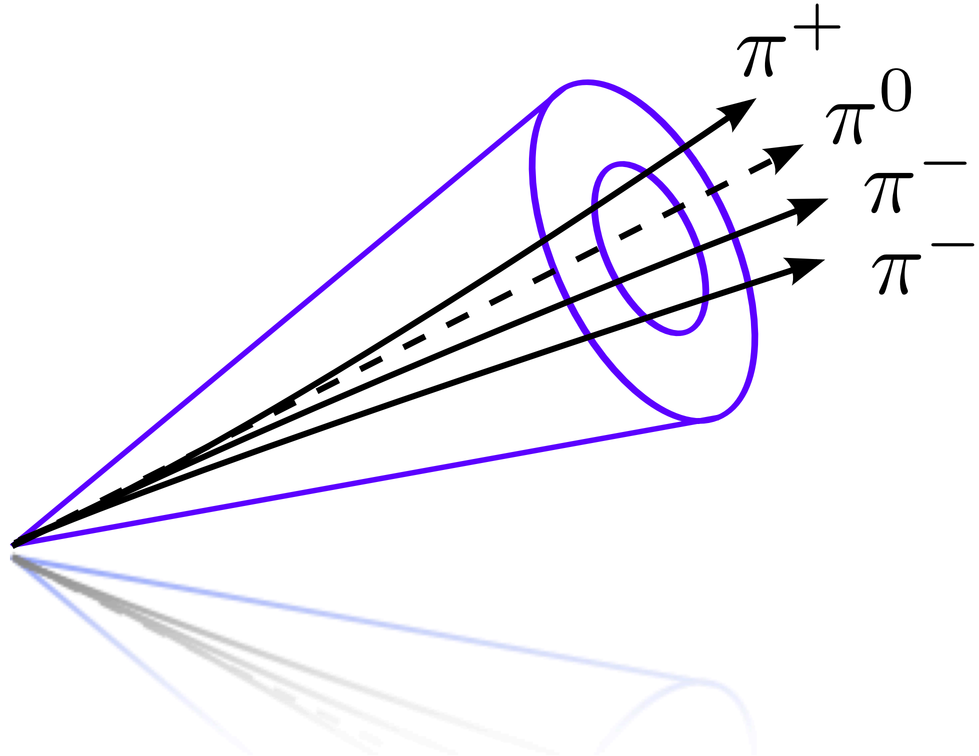
ATLAS:

- 2T solenoid, 4T air-core toroid
- 3-layer Pb-LAr samp. EM-cal

CMS:

- 3.8T solenoid
- $PbWO_4$ crystal EM-cal

References



Charged Higgs

- ATLAS
  - "Search for charged Higgs bosons decaying via $H^{\pm} \rightarrow \tau^{\pm}\nu$ in $t\bar{t}$ events using pp collision data at $\sqrt{s} = 7$ TeV with the ATLAS detector" [arxiv:1204.2760]
- CMS
  - "Search for a light charged Higgs boson in top quark decays in pp collisions at $\sqrt{s} = 7$ TeV" [arvix:1205.5736]

SUSY

- ATLAS
  - "Search for events with large missing transverse momentum, jets, and at least two tau leptons in 7 TeV proton-proton collision data with the ATLAS detector" [arxiv: 1203.6580]
  - "Search for supersymmetry with jets, missing transverse momentum and at least one hadronically decaying τ lepton in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector" [arxiv:1204.3852]
- CMS
  - "Search for anomalous production of multilepton events in pp collisions at $\sqrt{s} = 7$ TeV" [arvix:1204.5341]
  - "Search for new physics with same-sign isolated dilepton events with jets and missing transverse energy" [arxiv:1205.6615]
  - "Search for new physics in events with opposite-sign leptons, jets, and missing transverse energy in pp collisions at $\sqrt{s} = 7$ TeV" [arxiv:1206.3949]

Exotics

- ATLAS
  - "A search for high-mass resonances decaying to $\tau^+\tau^-$ in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector" [ATLAS-CONF-2012-067]
- CMS
  - "Search for high-mass resonances decaying into τ-lepton pairs in pp collisions at $\sqrt{s} = 7$ TeV" [arvix:1206.1725]
  - "Search for pair production of third generation leptoquarks and stops that decay to a tau and a b quark" [CMS PAS EXO-12-002]

Tau performance

- ATLAS
  - “Reconstruction, Energy Calibration, and Identification of Hadronically Decaying Tau Leptons” [ATLAS-CONF-2011-077]
  - “Performance of the Reconstruction and Identification of Hadronic Tau Decays with ATLAS” [ATLAS-CONF-2011-152]
  - “$Z \rightarrow \tau\tau$ cross section measurement in proton-proton collisions at 7 TeV with the ATLAS experiment” [ATLAS-CONF-2012-006]
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TauPublicCollisionResults
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TauTriggerPublicResults

Tau performance

- CMS
  - "Performance of τ-lepton reconstruction and identification in CMS" [arvix:1109.6034, CMS PAS TAU-11-001]
  - "CMS Strategies for tau reconstruction and identification using particle-flow techniques" [CMS PAS PFT-08-001]
  - "Particle–Flow Event Reconstruction in CMS and Performance for Jets, Taus, and E_{T}^{miss}" [CMS PAS PFT-09-001]
  - "Commissioning of the Particle-Flow Reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV" [CMS PAS PFT-10-002]
  - "Commissioning of the particle-flow event reconstruction with leptons from J/Psi and W decays at 7 TeV" [CMS PAS PFT-10-003]
  - "Study of tau reconstruction algorithms using pp collisions data collected at $\sqrt{s} = 7$ TeV" [CMS PAS PFT-10-004]