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Top quark pair cross section measurements in ATLAS

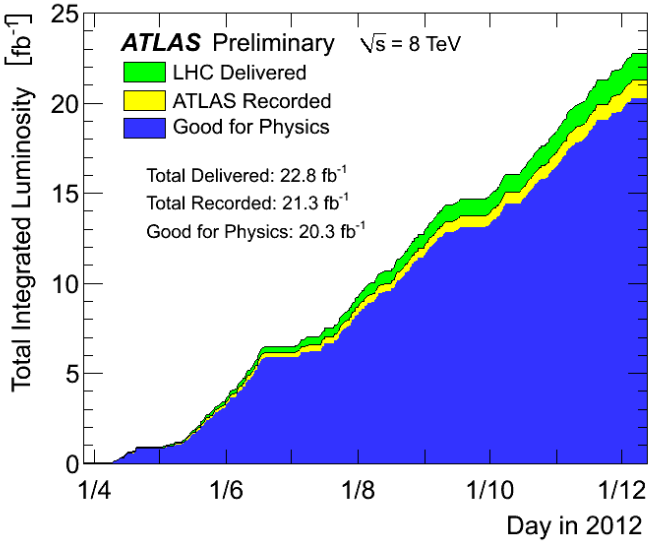
Michele Faucci Giannelli

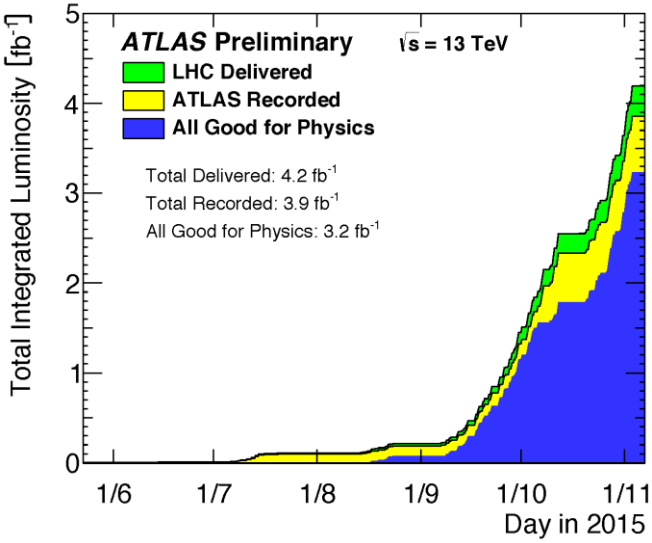
On behalf of the ATLAS collaboration

ROYAL HOLLOWAY UNIVERSITY OF LONDON

ATLAS

- ATLAS performed very well both in Run 1 and in Run 2
  - 20.3 fb^{-1} at $\sqrt{s}$=8 TeV
  - 3.2 fb^{-1} at $\sqrt{s}$=13 TeV
- Top quarks are produced in large numbers
  - 5.3M recorded at $\sqrt{s}$=8 TeV
  - 2.3M recorded at $\sqrt{s}$=13 TeV
- Such numbers allow for an incredibly rich research programme
  - Differential measurements
  - We can focus on leptonic decays to reduce uncertainties





7/8 TeV results: differential measurements

Resolved l+jet analysis at 8 TeV (Accepted by EPJC, arXiv:1511.04716)

Resolved di-leton analysis at 7 and 8 TeV (arXiv:1511.04716)

Boosted l+jet analysis at 8 TeV (*Phys. Rev. D93 (2016) 032009*, arXiv:1510.03818)

Motivations for differential measurements

- Probe several variables and compare with predictions
  - New physics can be strongly constrained using top
  - Non resonant, model independent search
  - Improve PDFs prediction in extreme regions
- Unfolded results at parton level
  - Comparison with NNLO predictions
- Unfolded distributions at particle level
  - Closest to detector and not dependent on generator
  - Provides top modelling for next generation of MC generators
  - It is a legacy measurements independent of generators available today

Resolved l+jet analysis: topology and selection

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Resolved l+jet analysis: topology and selection

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Resolved l+jet analysis: topology and selection

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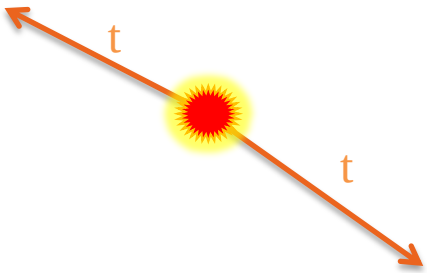

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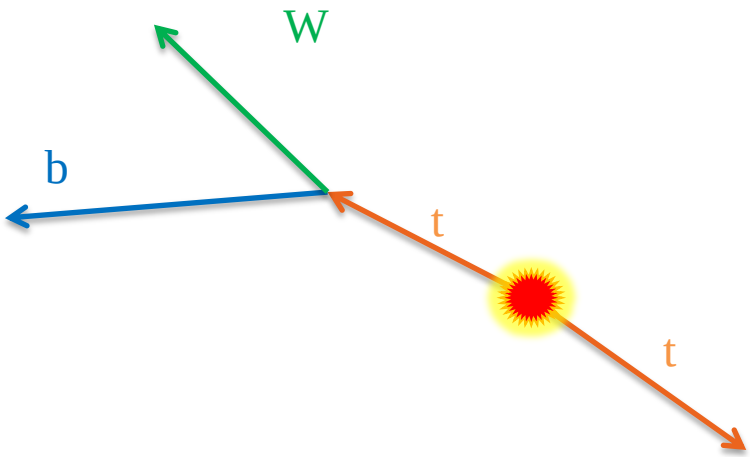

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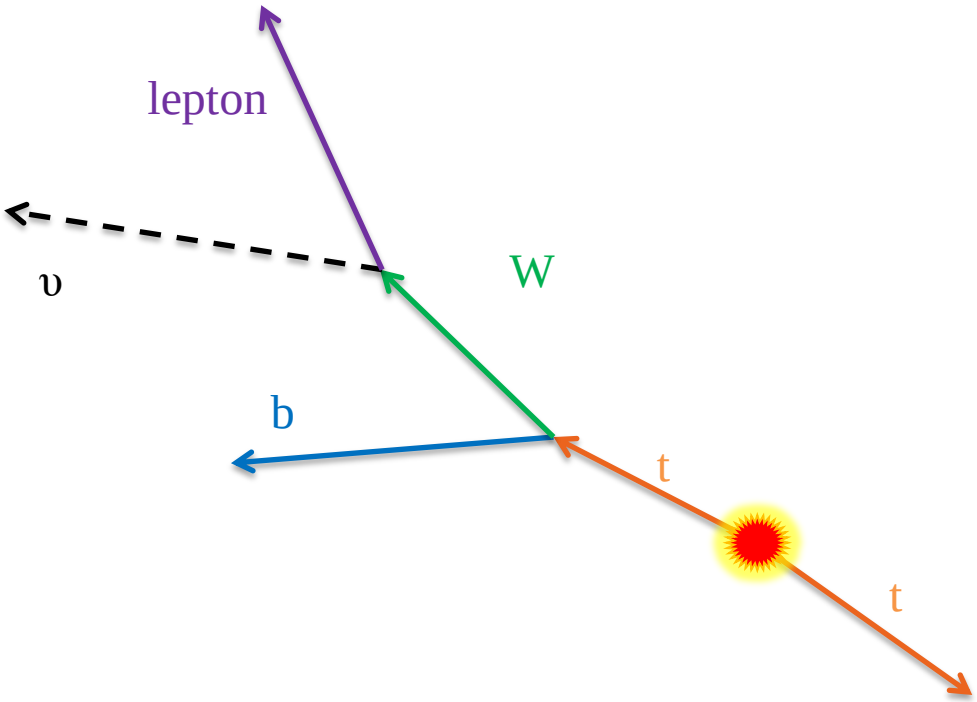

Resolved l+jet analysis: topology and selection

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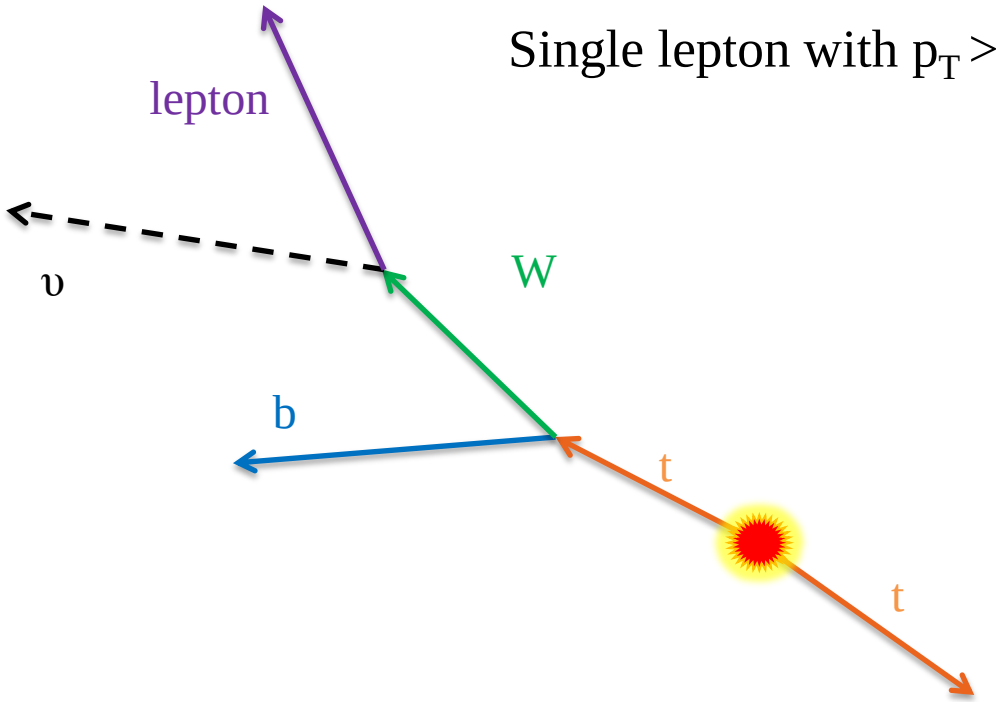
Single lepton with $p_T > 25$ GeV



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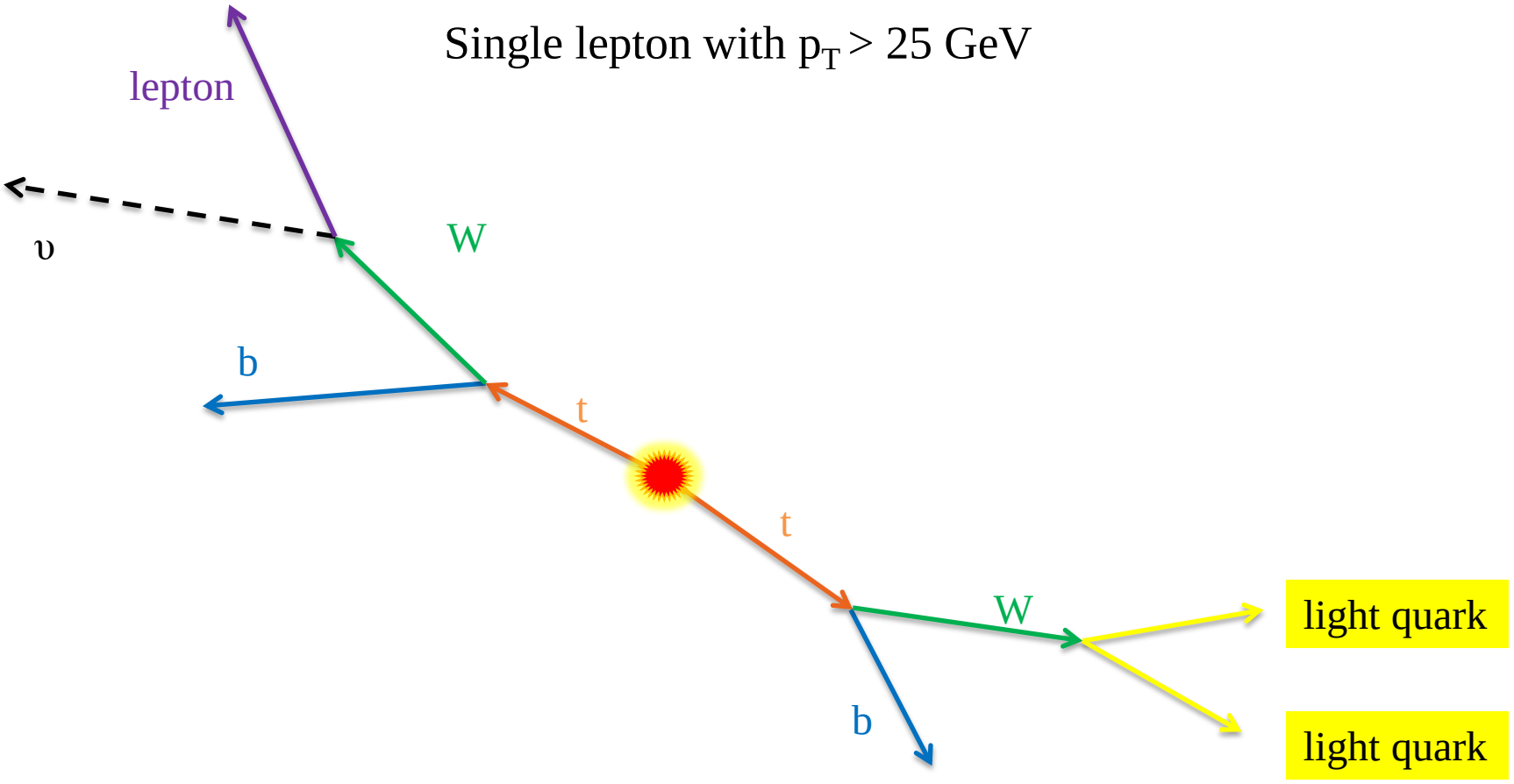

Resolved l+jet analysis: topology and selection

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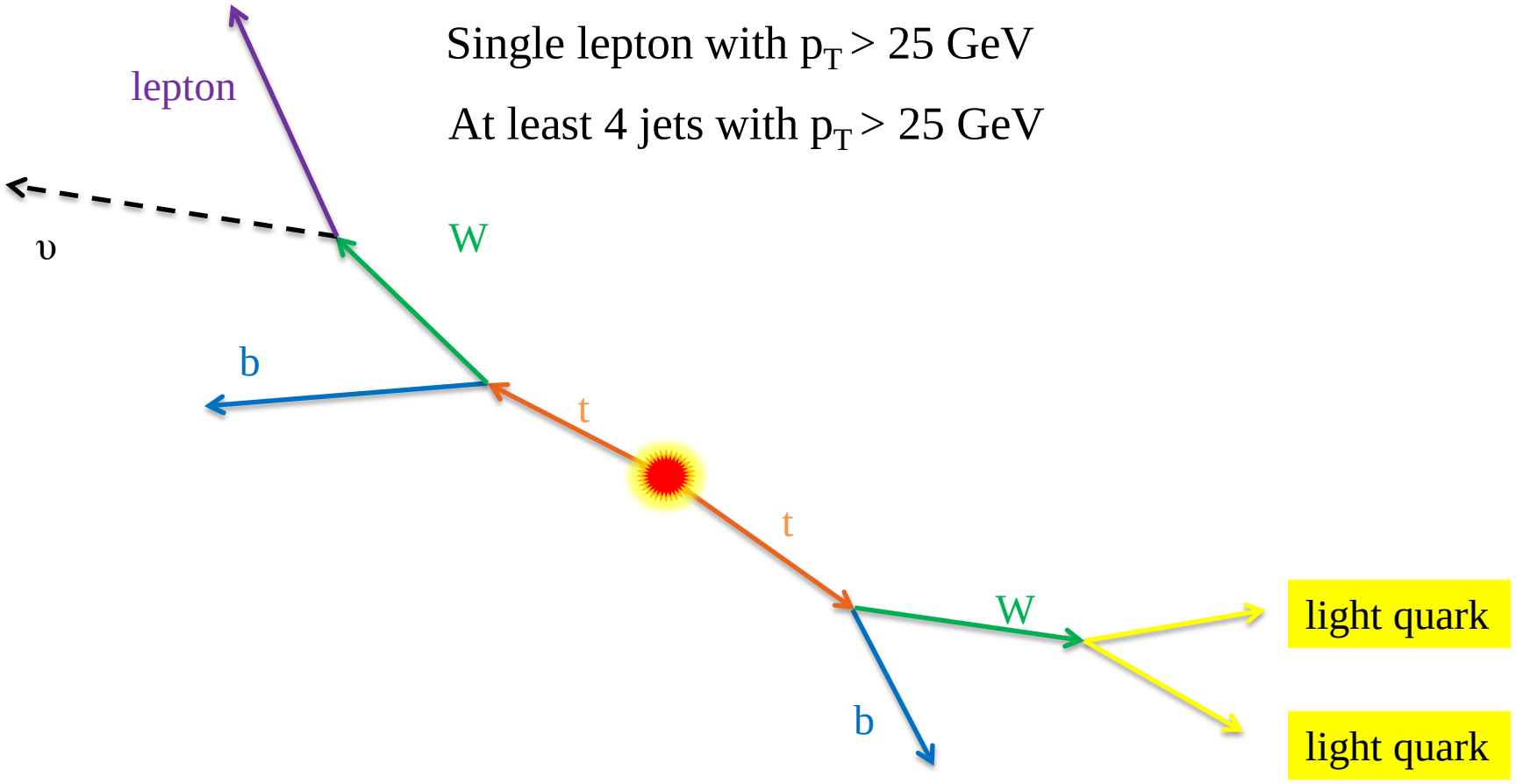
Single lepton with $p_T > 25$ GeV

At least 4 jets with $p_T > 25$ GeV



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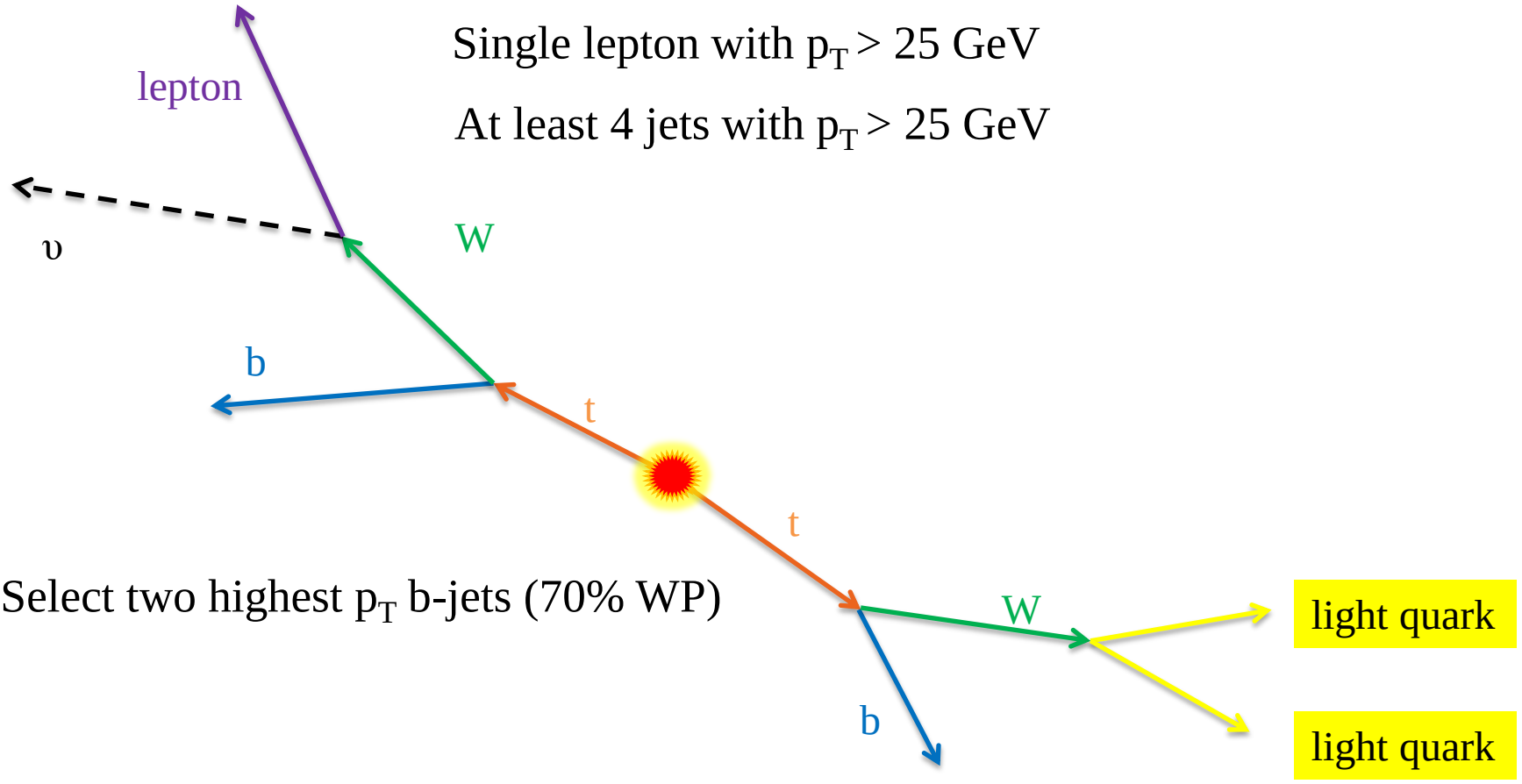

Select two highest p_T b-jets (70% WP)

Resolved l+jet analysis: topology and selection

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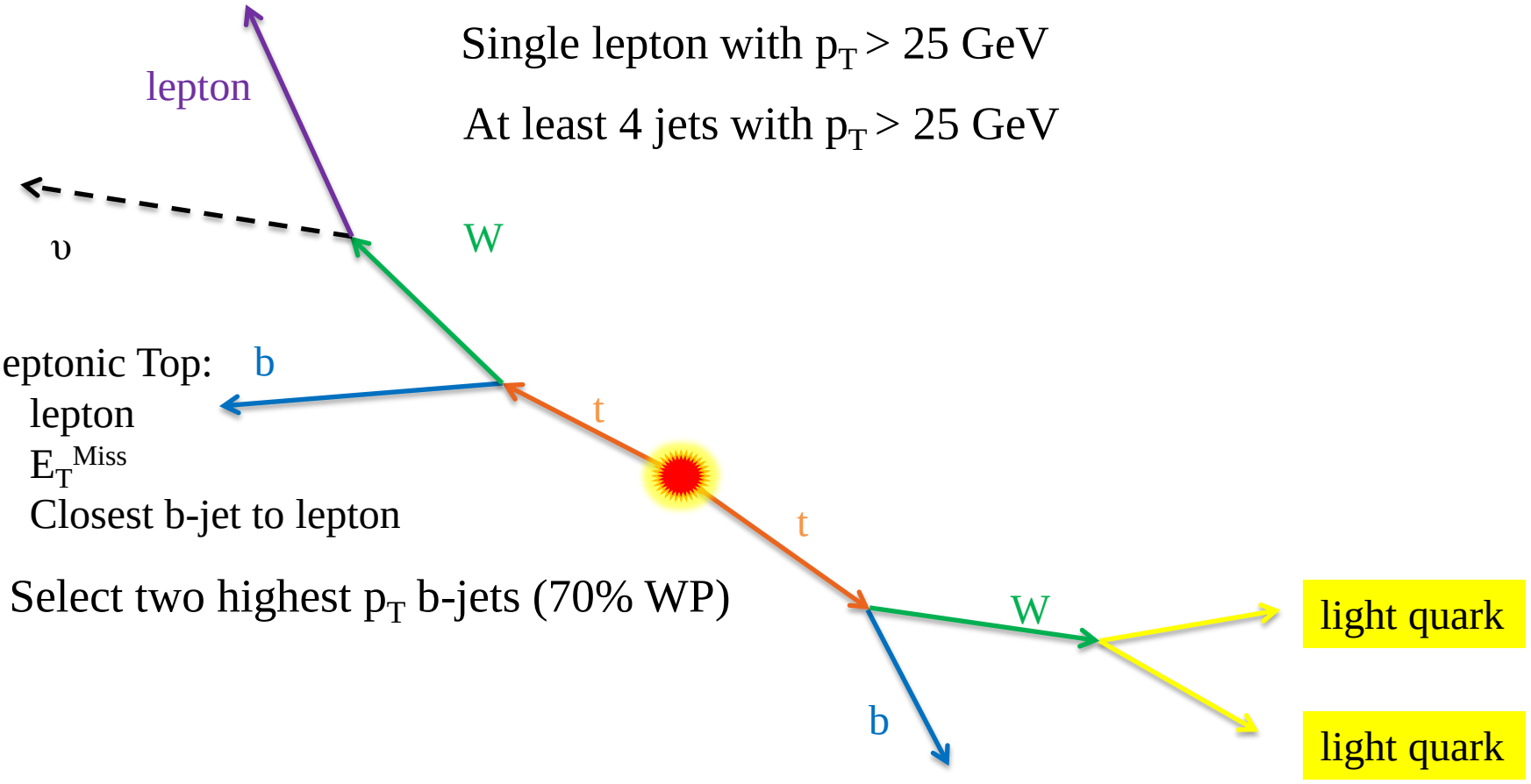

Leptonic Top:
- lepton
- E_T^{Miss}
- Closest b-jet to lepton

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Resolved l+jet analysis: topology and selection

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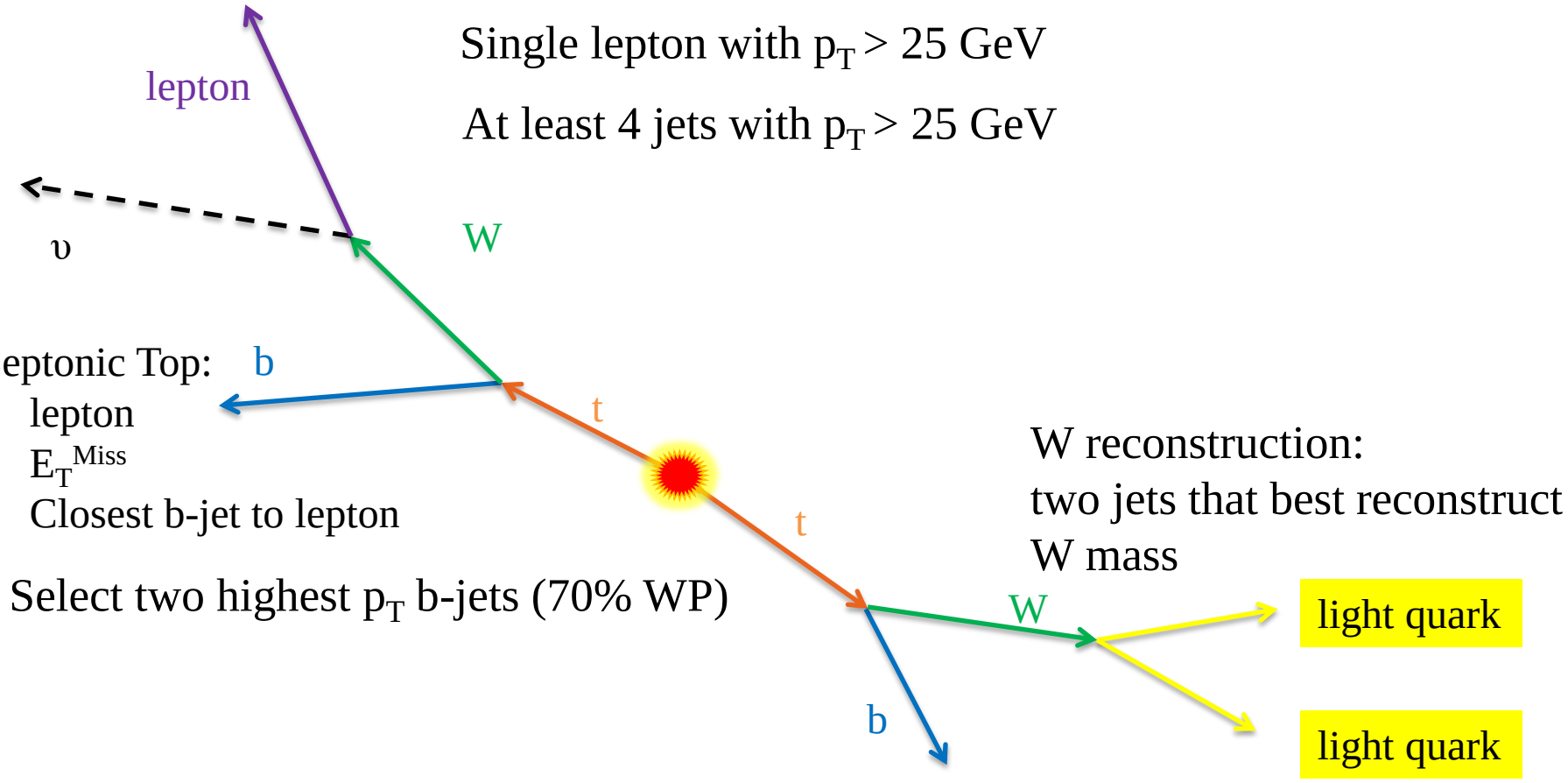

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W reconstruction:
two jets that best reconstruct W mass

Resolved l+jet analysis: topology and selection

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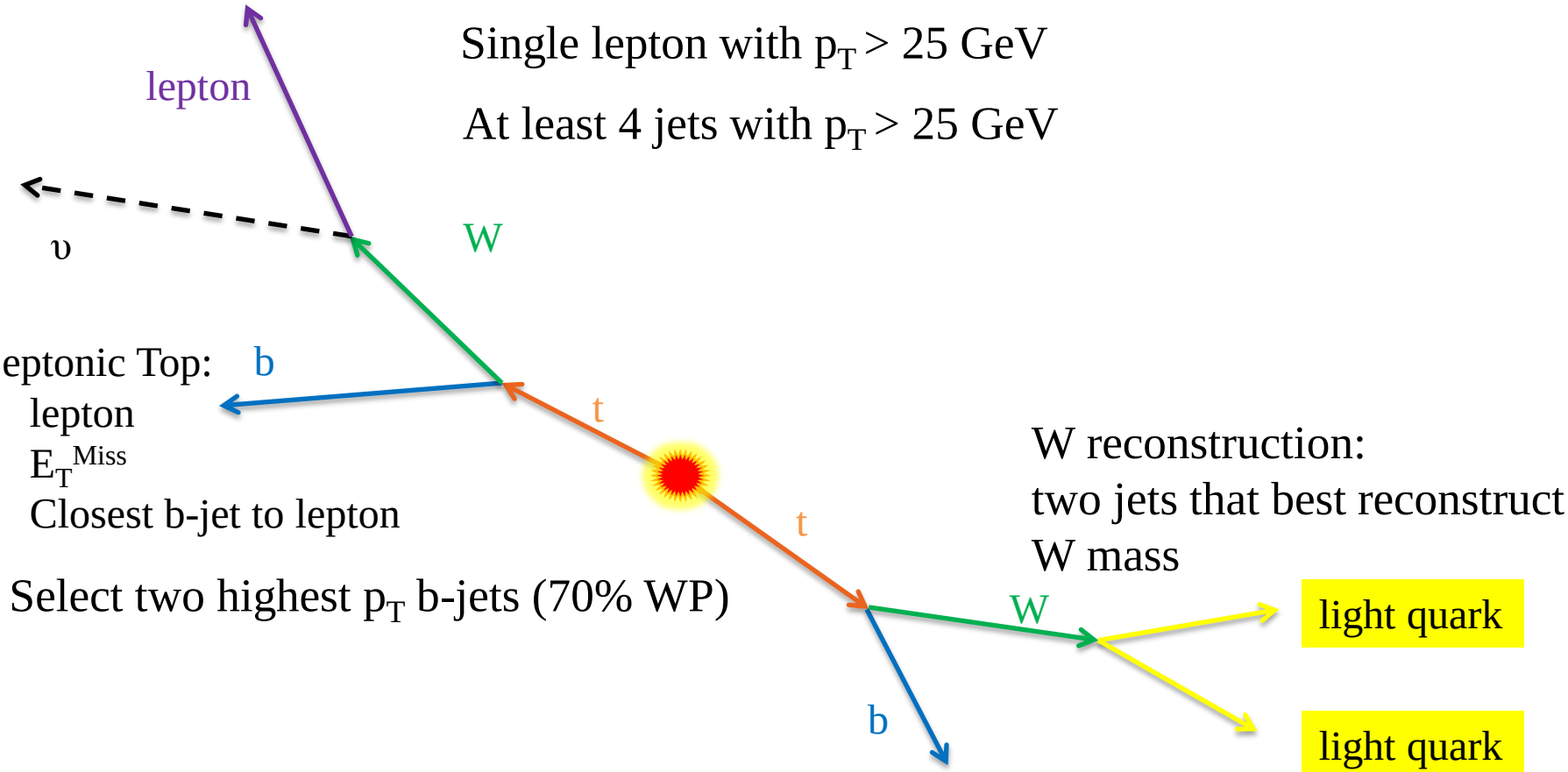

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- two light jets
- other b-jet

Resolved l+jet analysis: topology and selection

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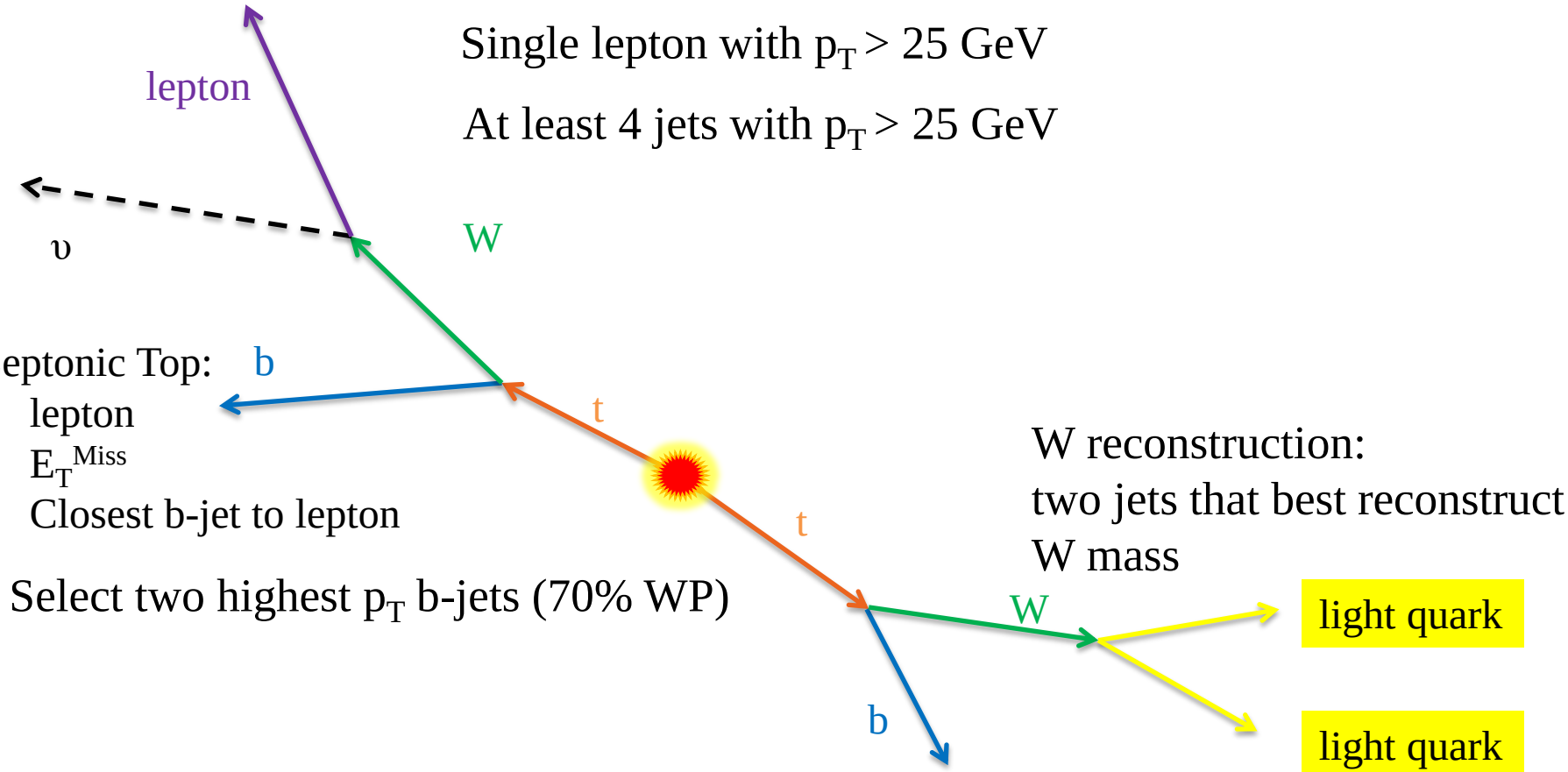

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two jets that best reconstruct W mass

Hadronic Top:
- two light jets
- other b-jet

Top selection is identical at reco and particle level

Results at particle level

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arXiv:1511.04716

11 variables measured

- Hadronic top p_T, $|y|$
- $t\bar{t}$ system mass, p_T, $|y|$
- Production angle ($\chi^{t\bar{t}}$)
- Longitudinal boost ($y^{t\bar{t}}_{boost}$)
- Out of plane momentum ($p^{t\bar{t}}_{out}$)
- Azimuthal angle ($\Delta\phi^{t\bar{t}}$)
- Scalar sum of p_T of all objects ($H_T^{t\bar{t}}$)
- Ratio of p_T of W and top (R_{Wt})

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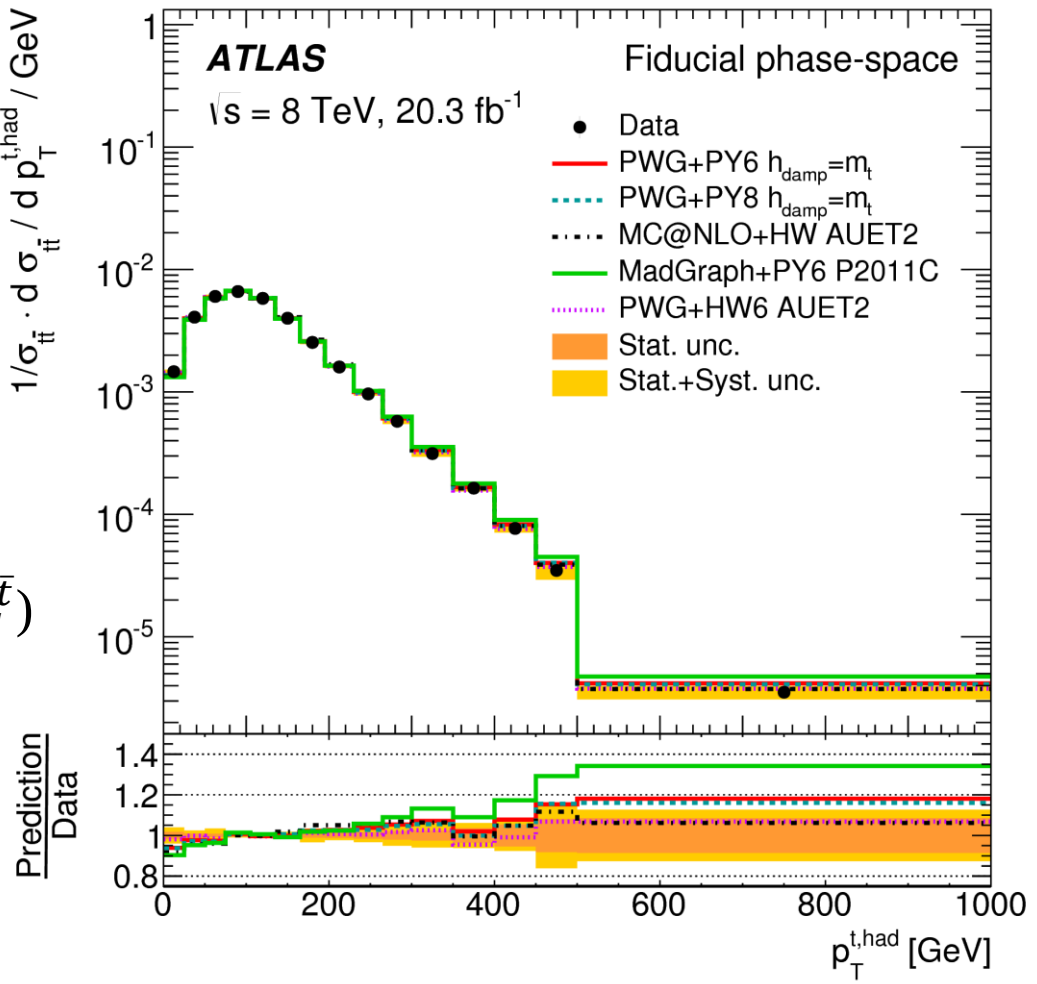

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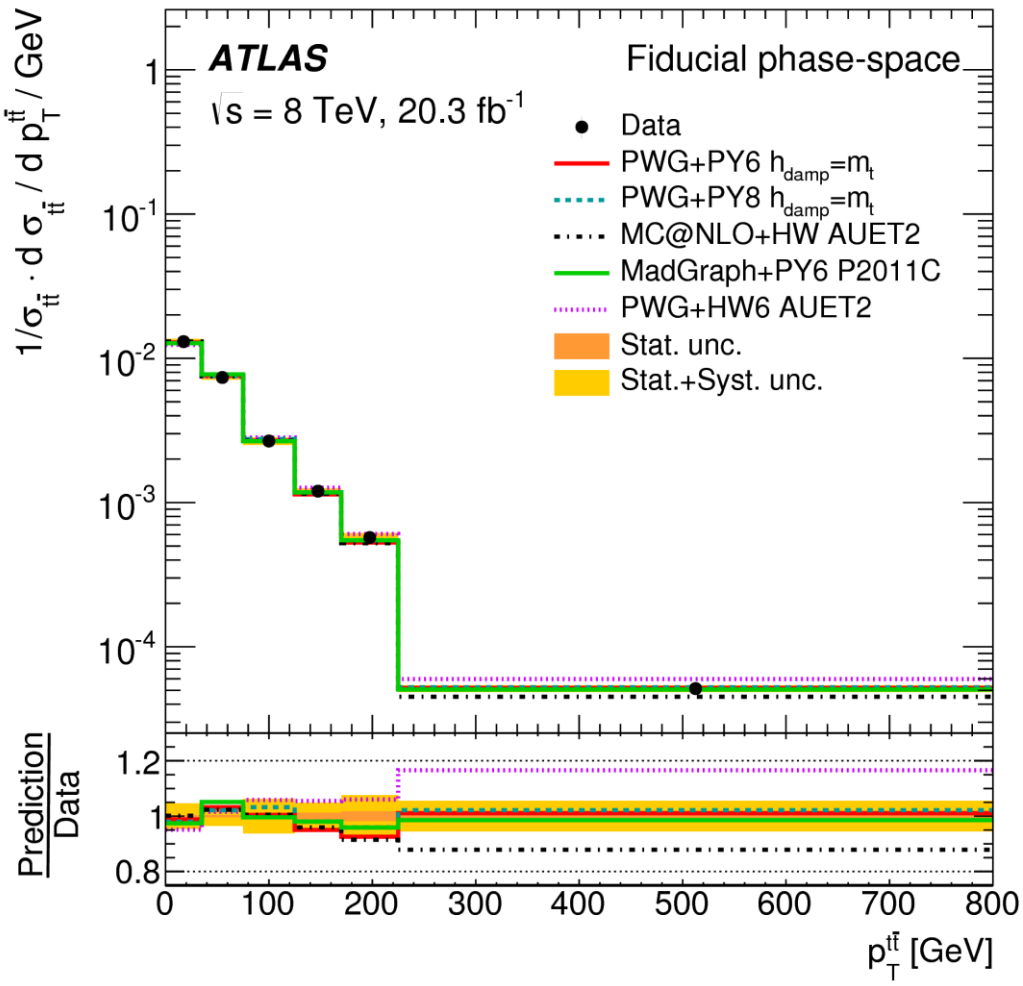

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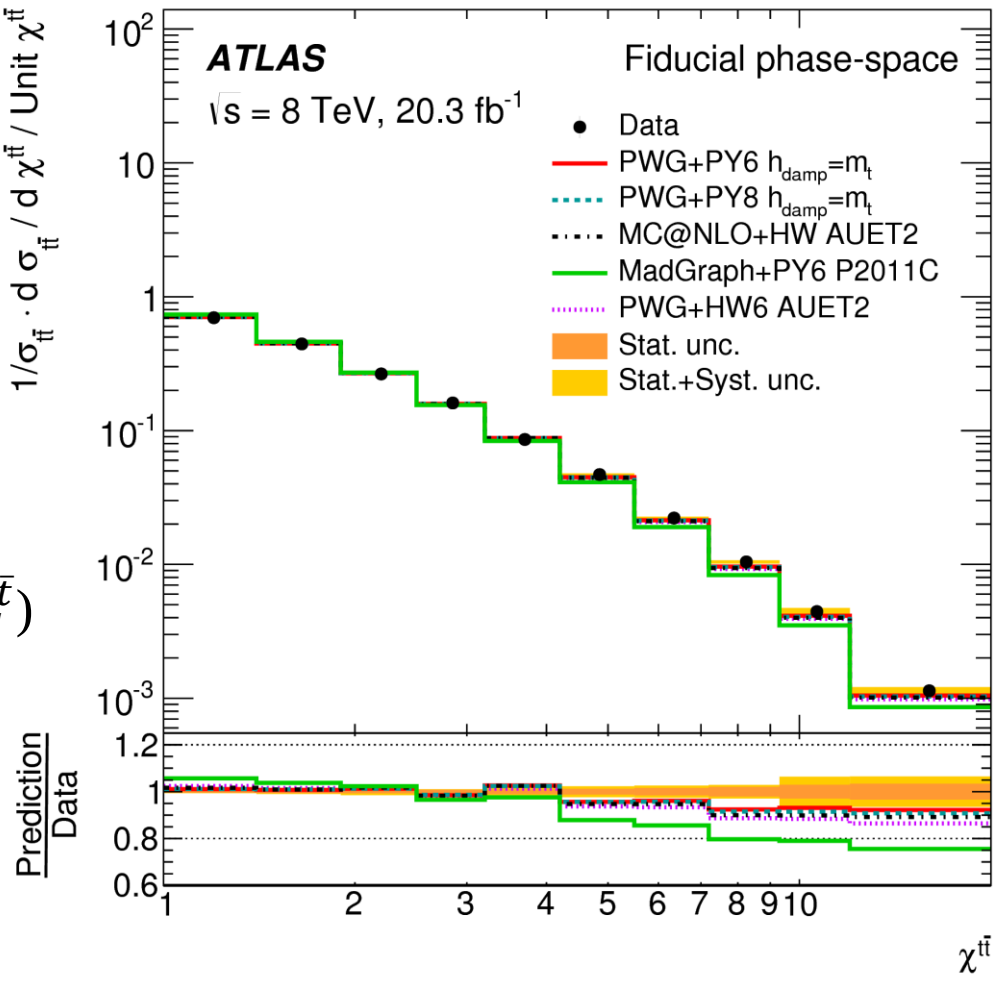

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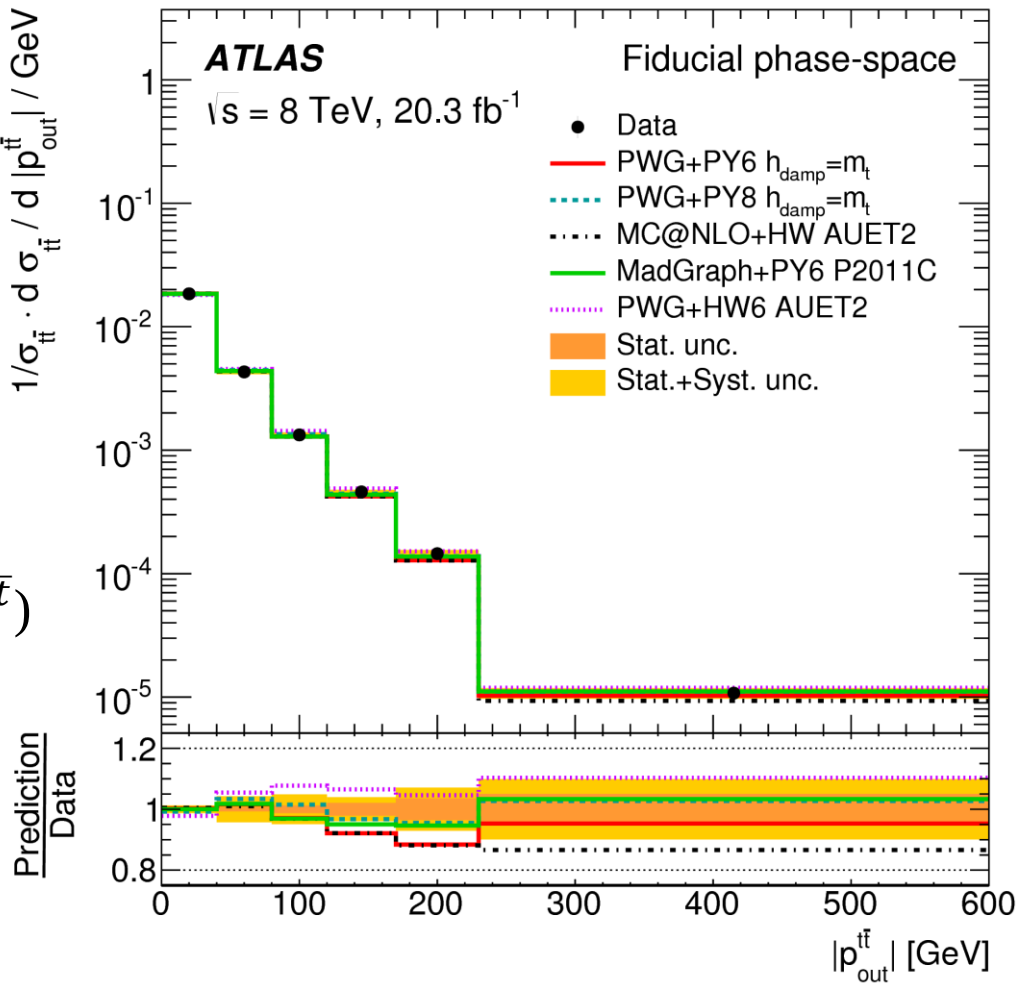

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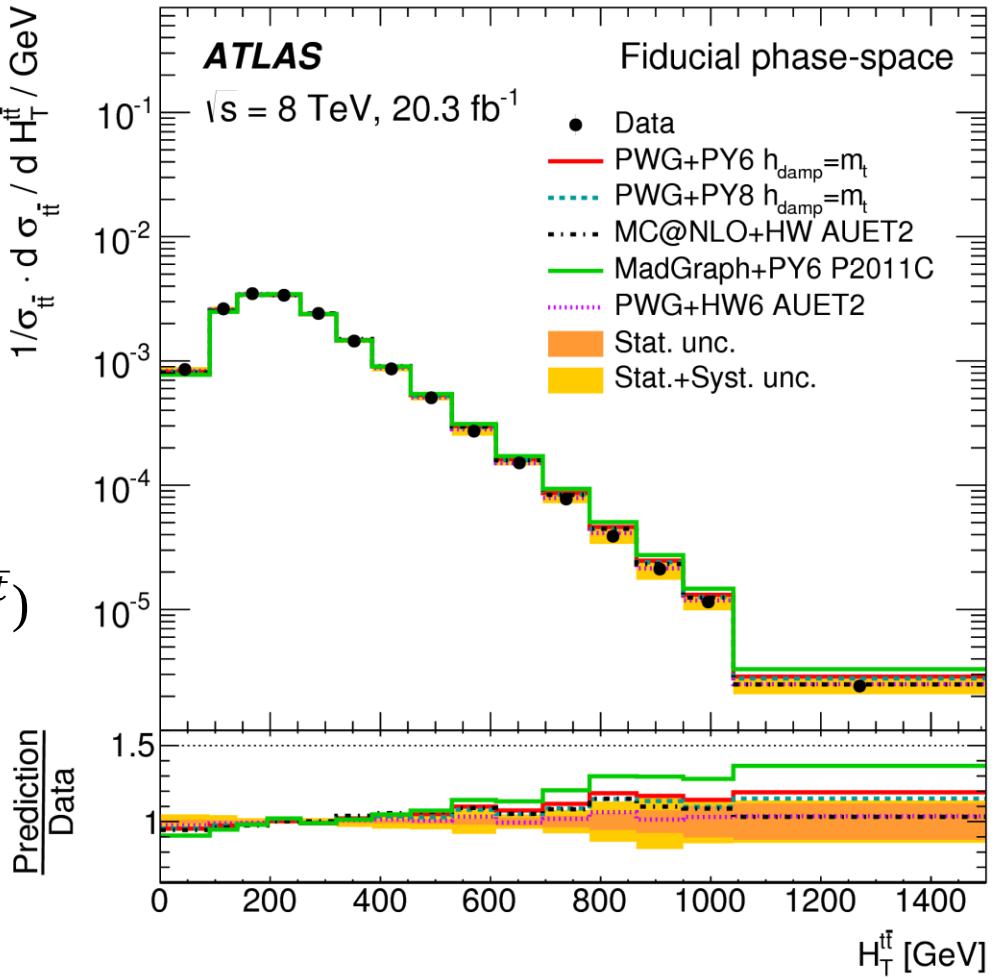

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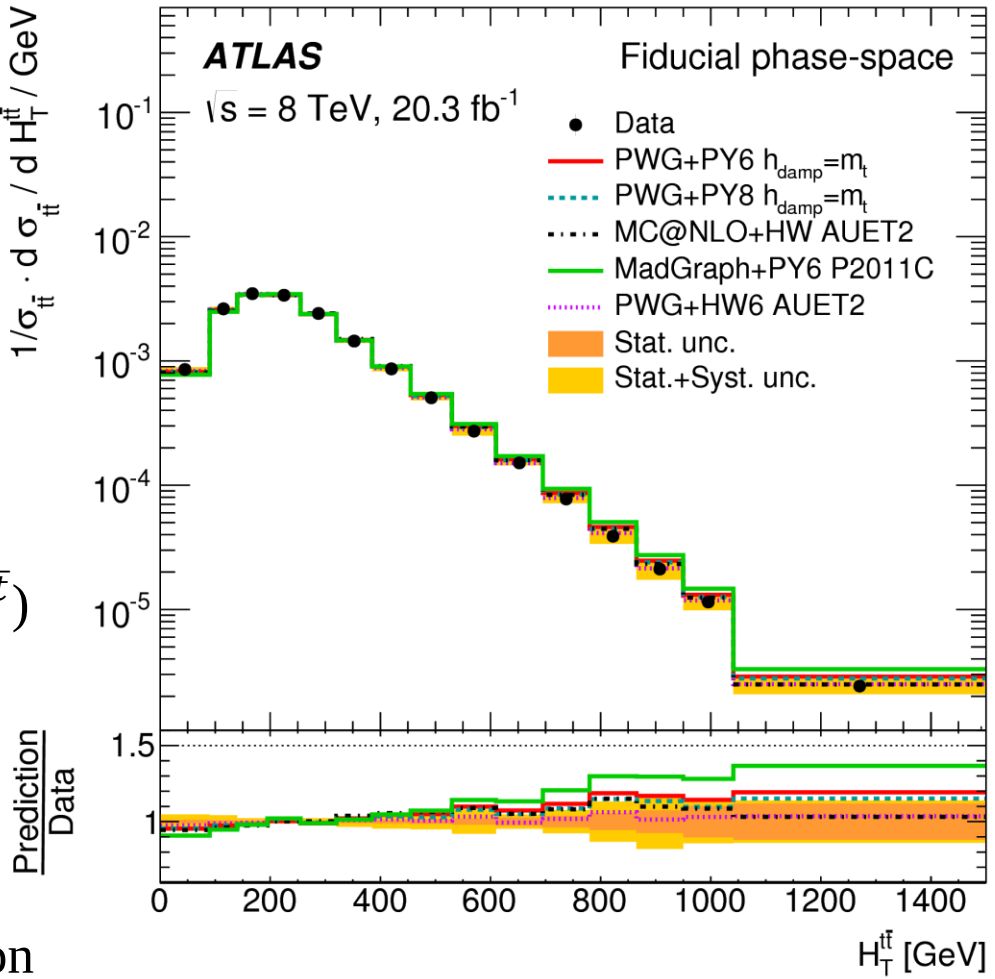

Both absolute and normalised distribution at particle and parton level distributions are available

Constraining PDF

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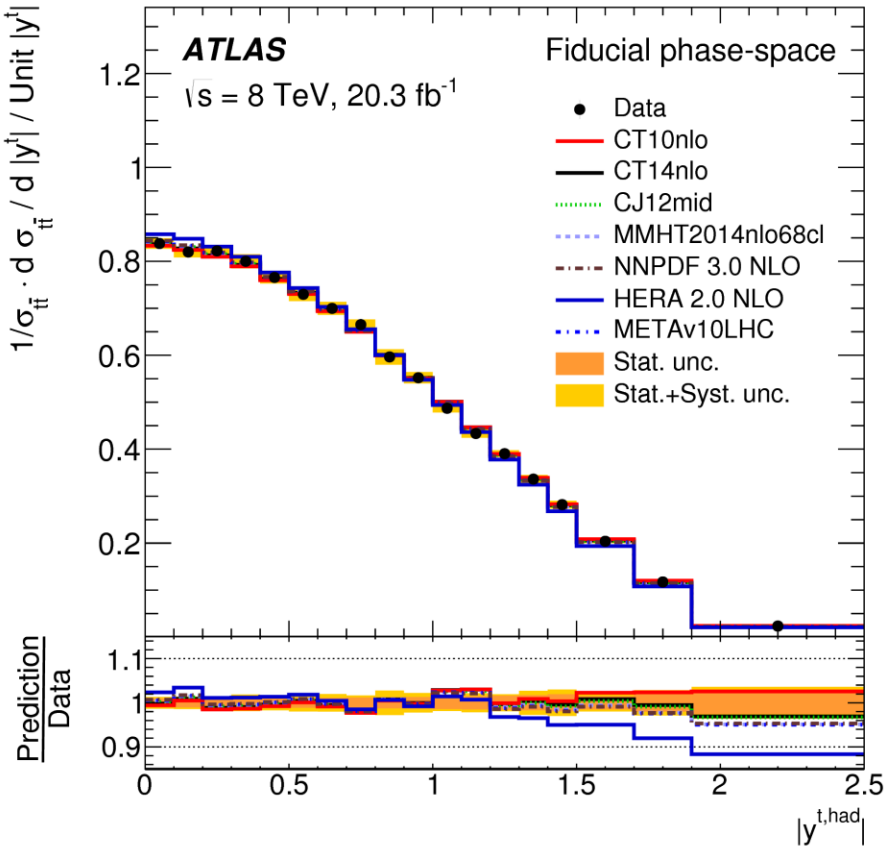
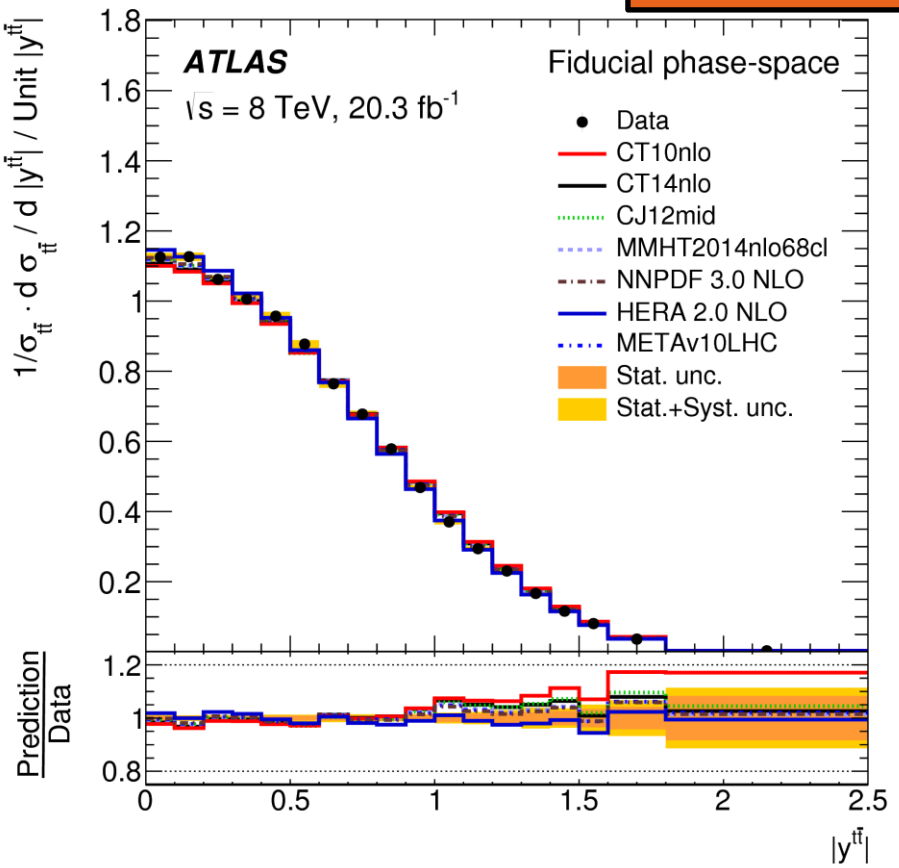
arXiv:1511.04716





Rapidity distributions can be used to constrain PDF

- Some prediction not compatible with data
- Top and $t\bar{t}$ are sensitive to different PDFs

Comparison with NNLO prediction

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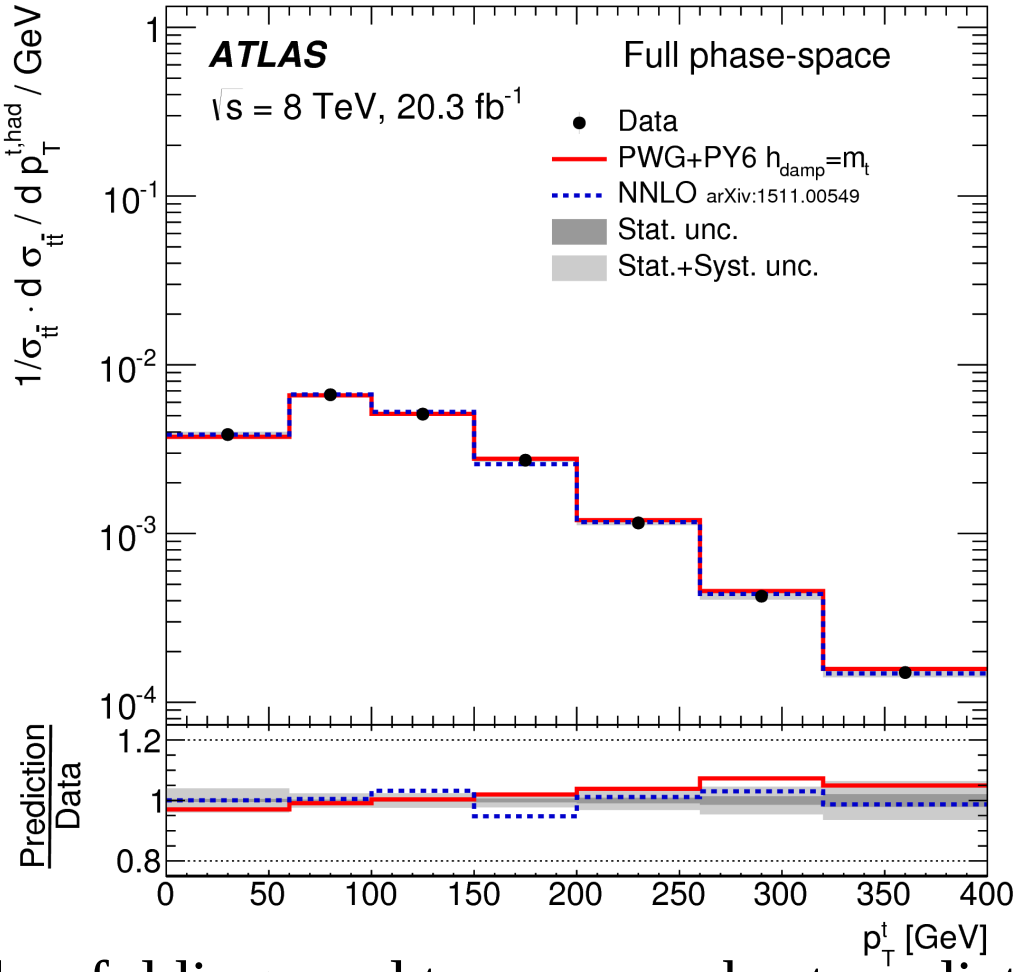
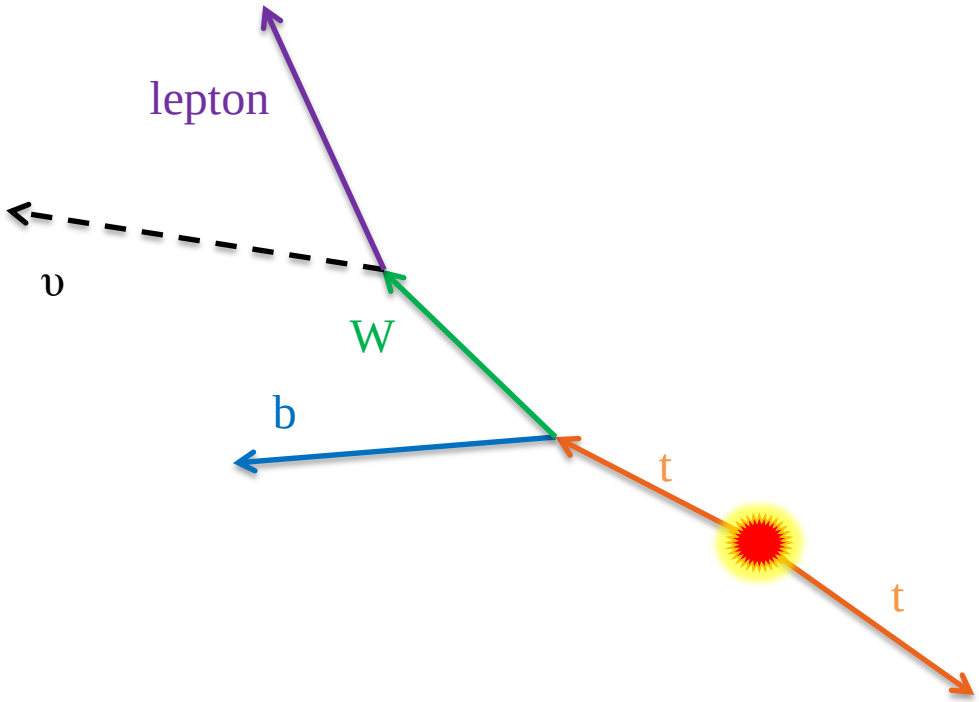
arXiv:1511.04716



Parton level unfolding used to compare best predictions

- NNLO is more compatible with data than NLO prediction

Resolved di-lepton analysis



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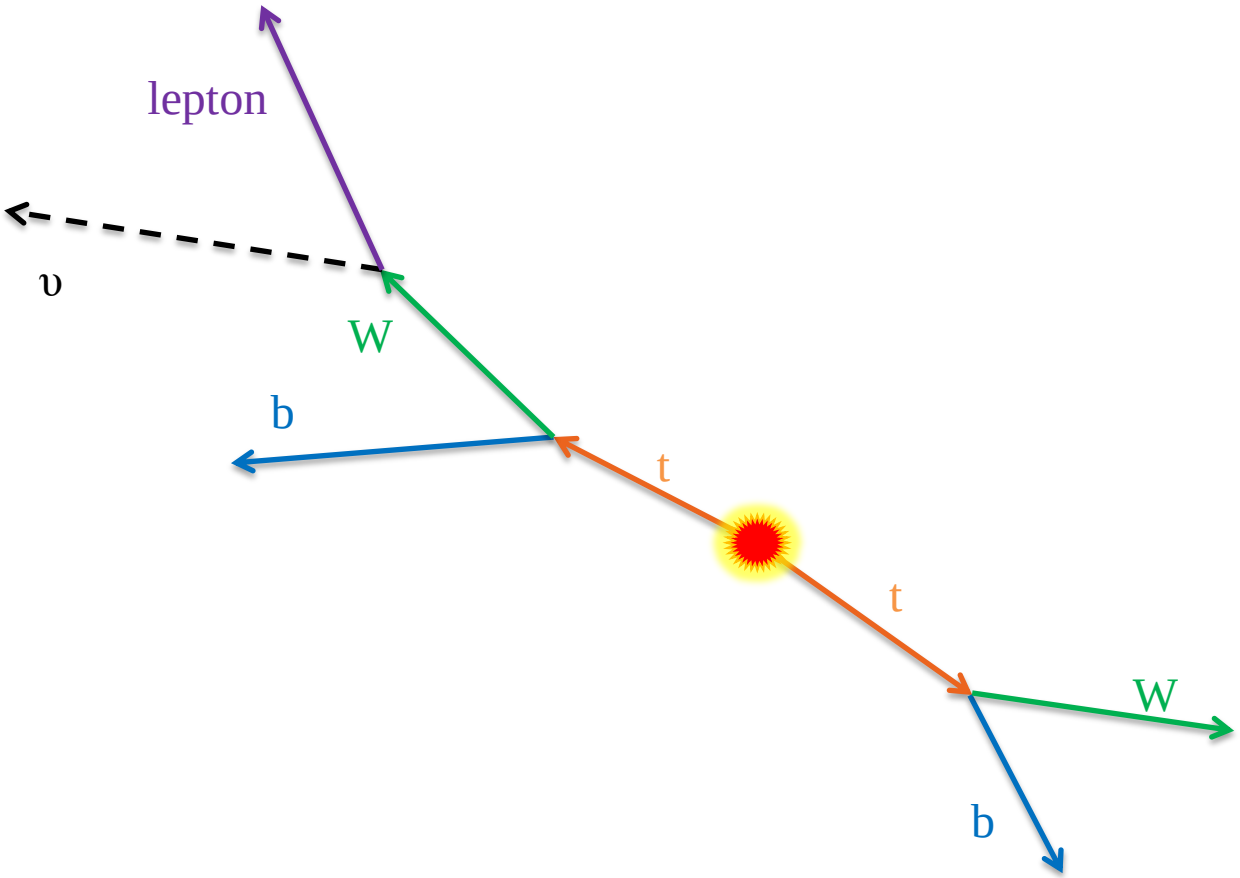

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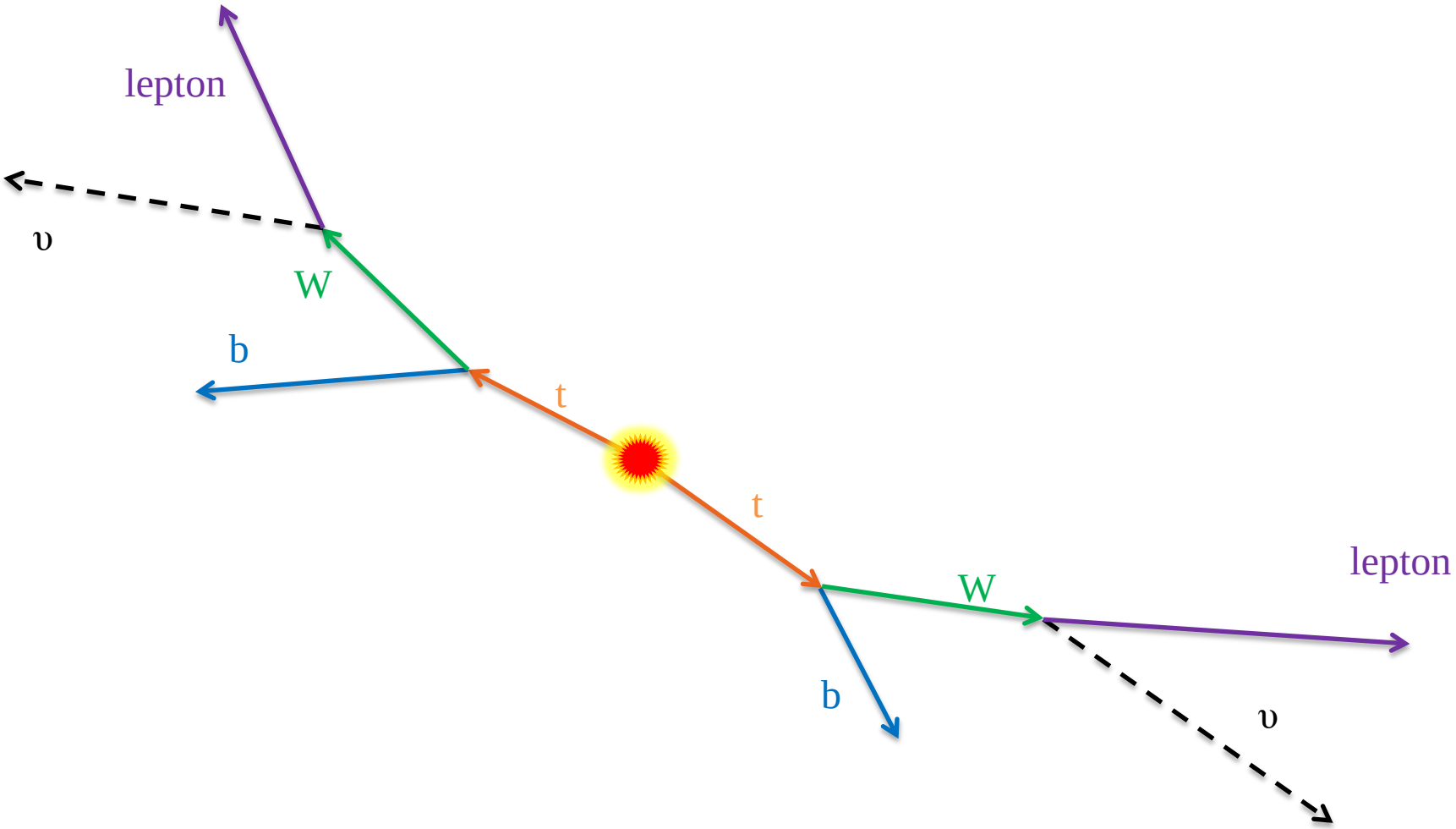

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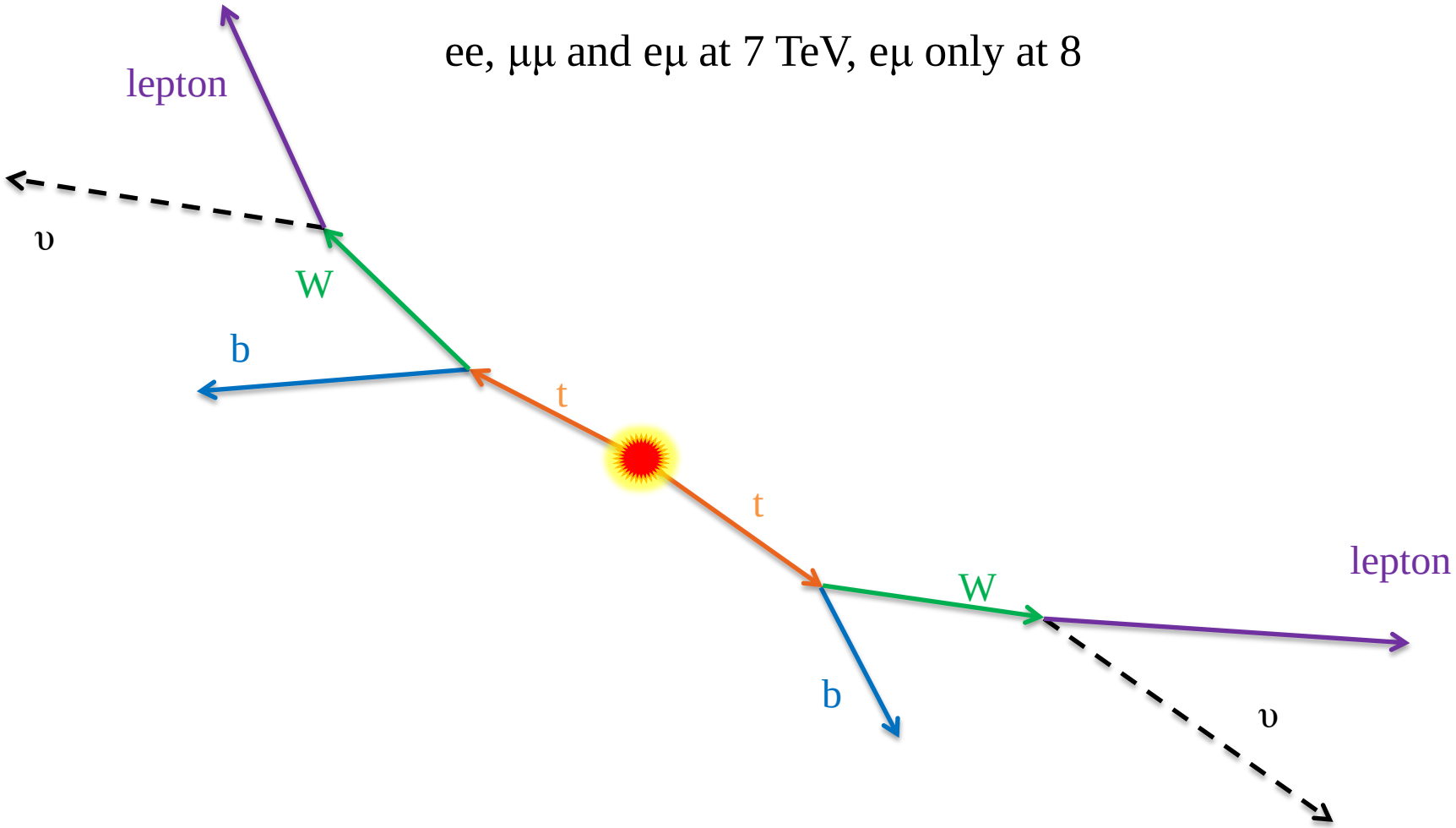

Resolved di-lepton analysis

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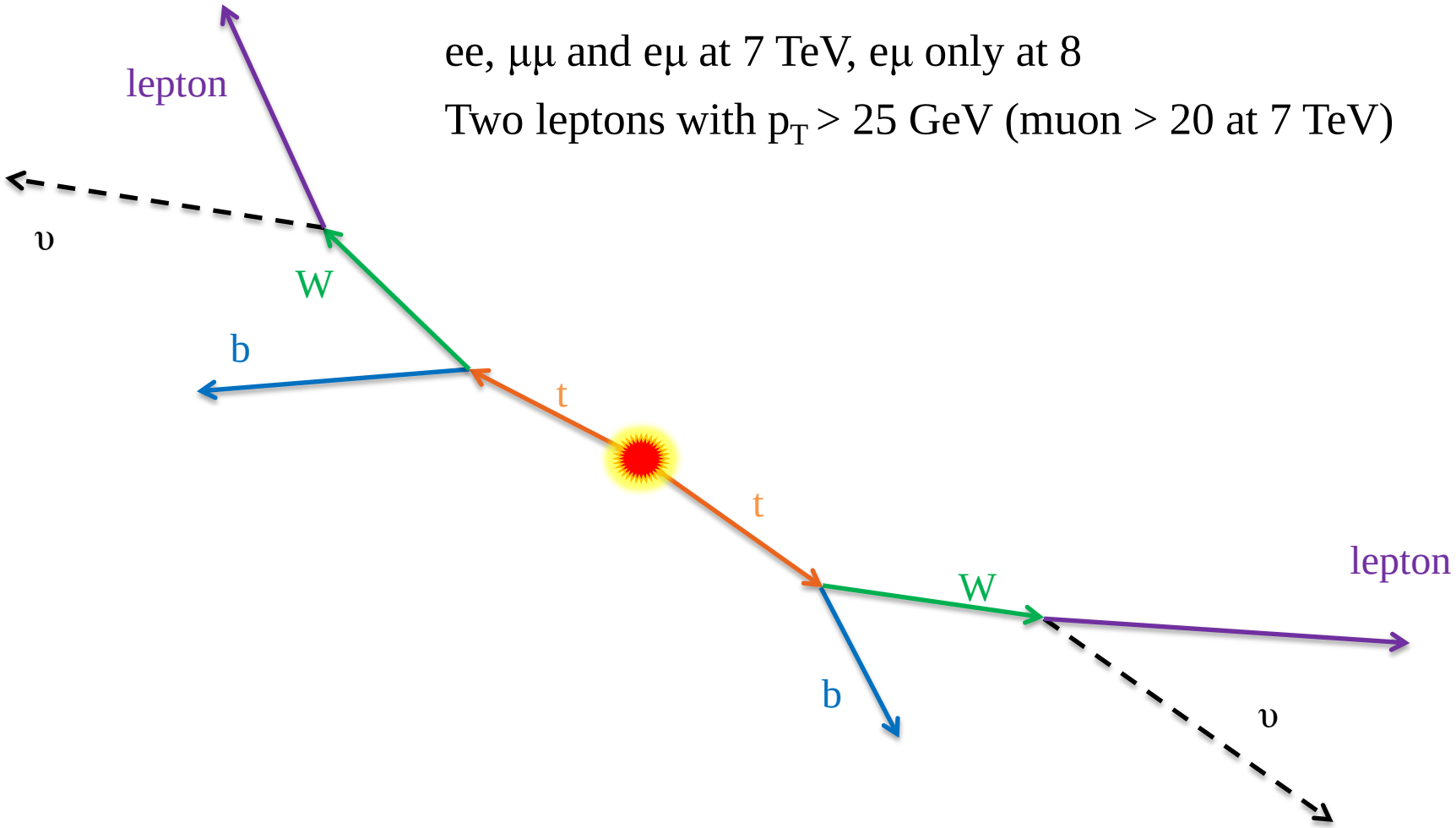
ee, μμ and eμ at 7 TeV, eμ only at 8

Two leptons with $p_T > 25$ GeV (muon > 20 at 7 TeV)



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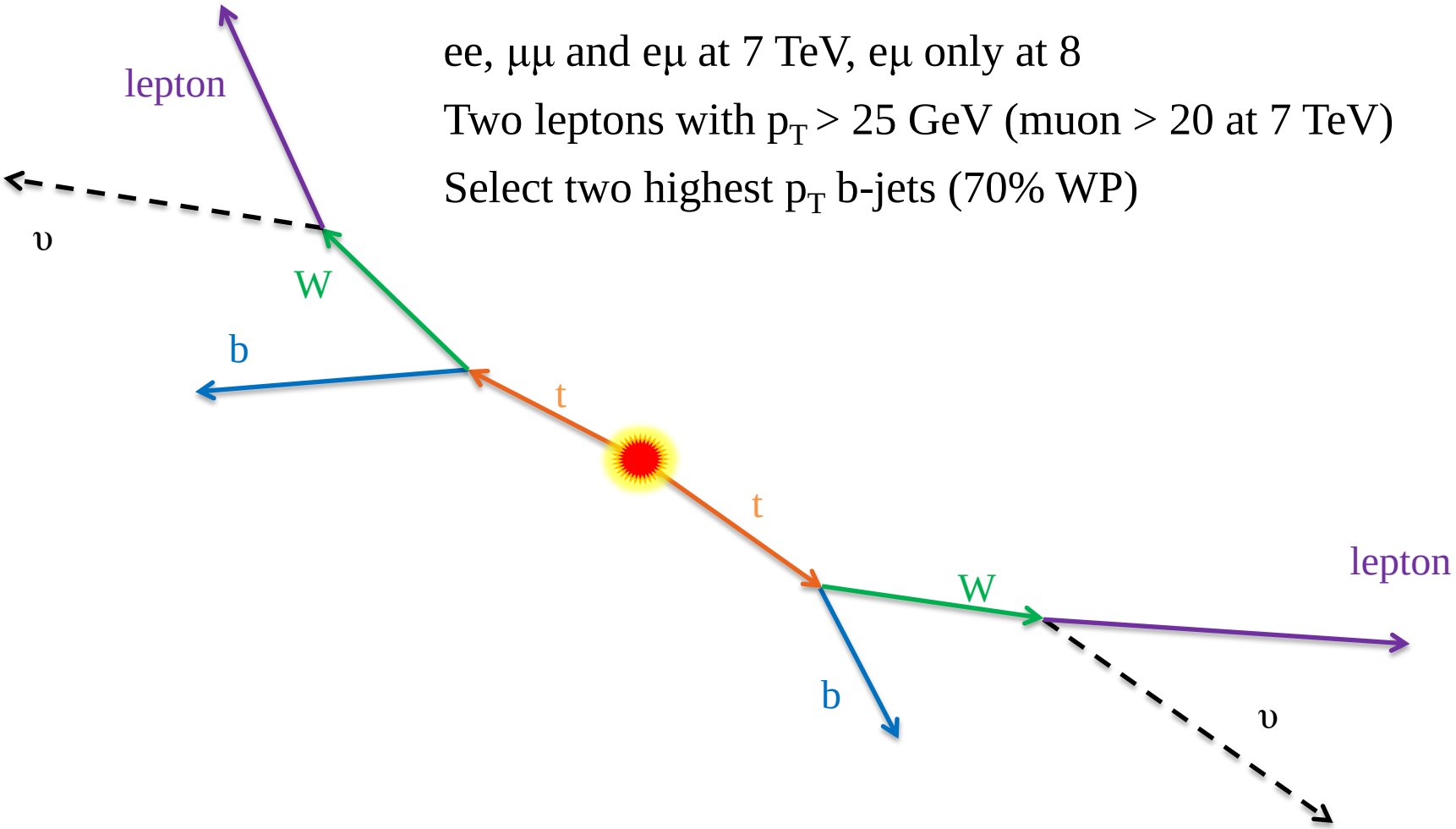

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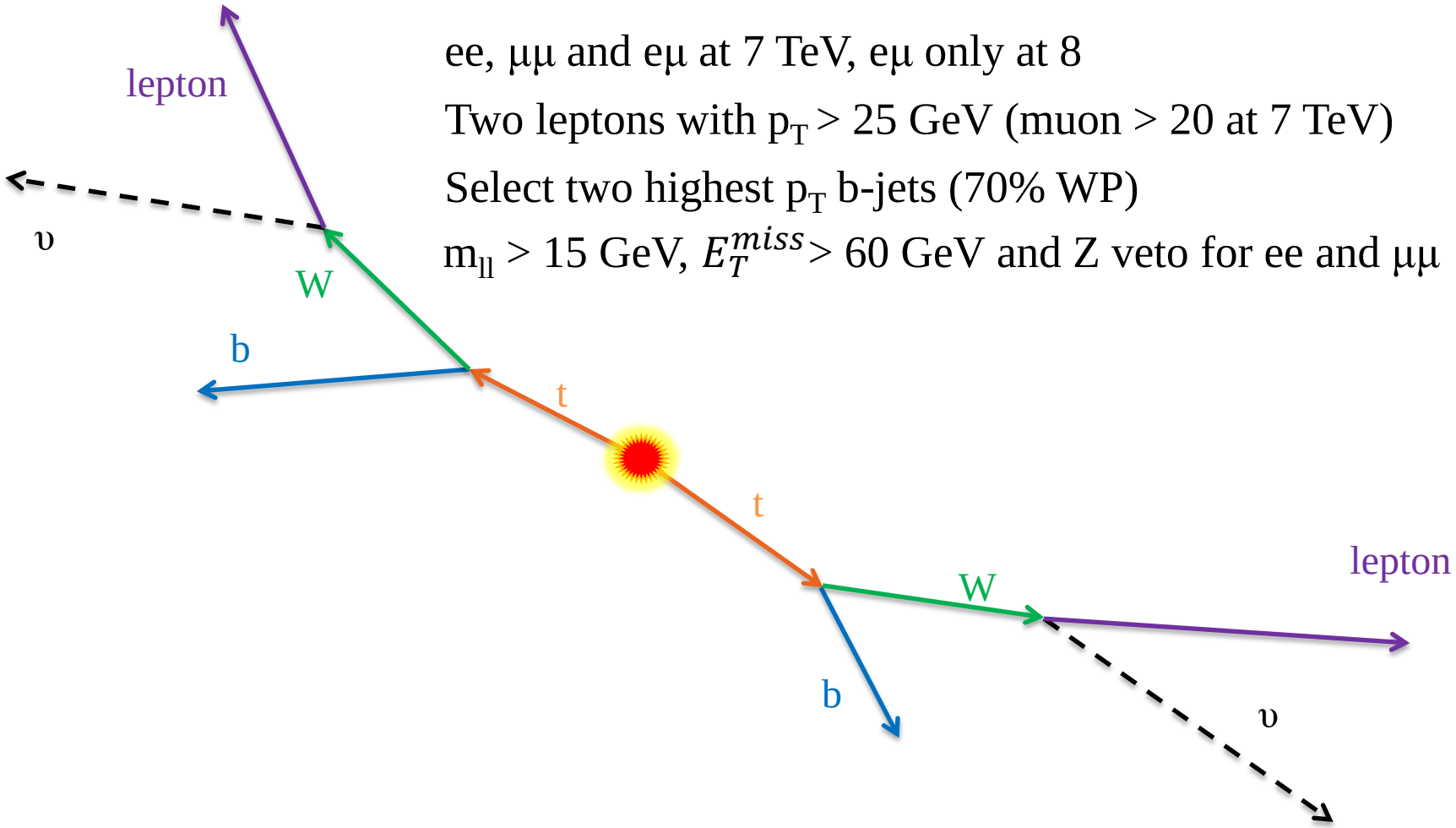

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m_{ll} > 15 GeV, E_T^{miss} > 60 GeV and Z veto for ee and μμ

Resolved di-lepton analysis

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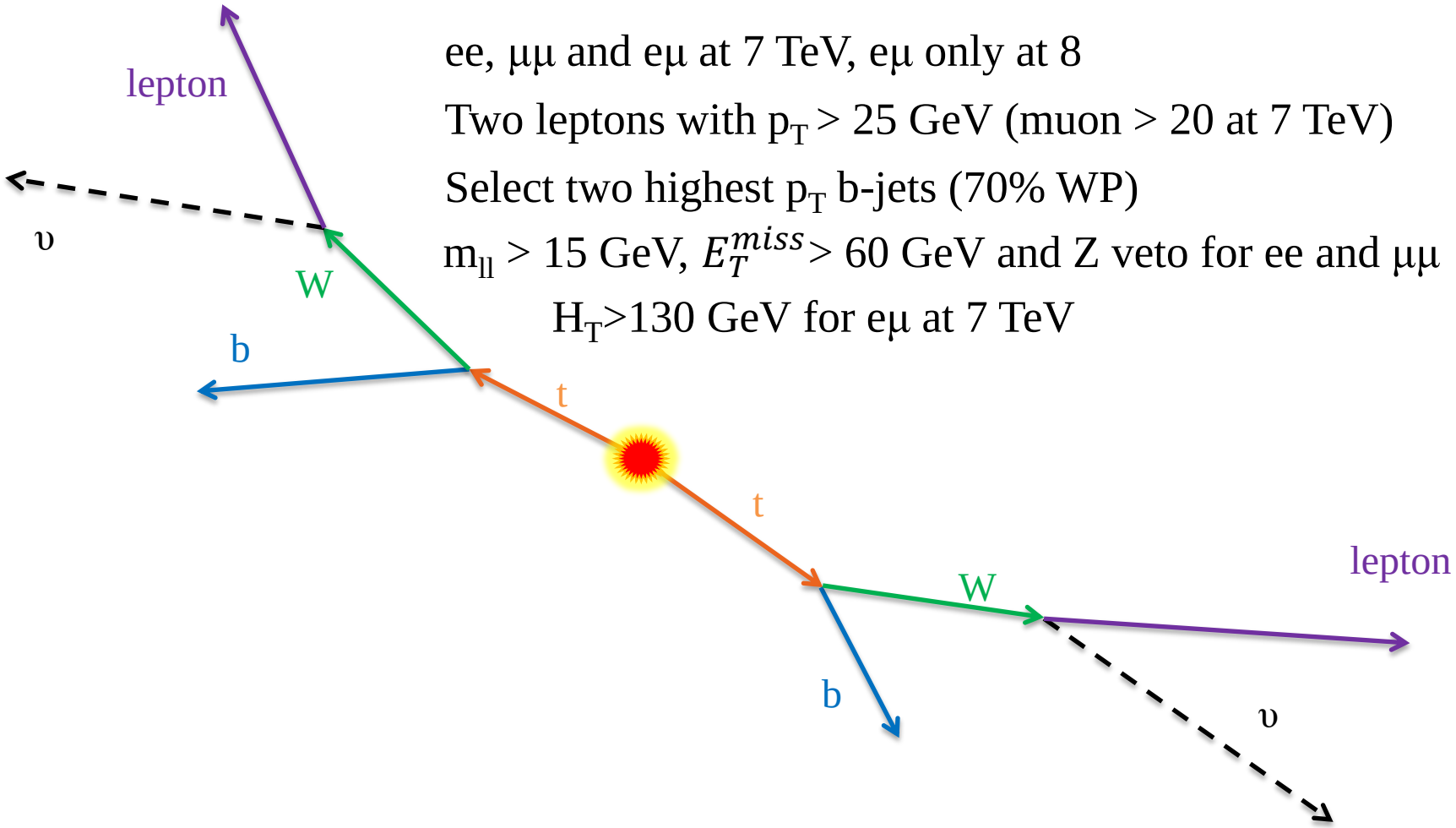

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H_T>130 GeV for eμ at 7 TeV

Resolved di-lepton analysis

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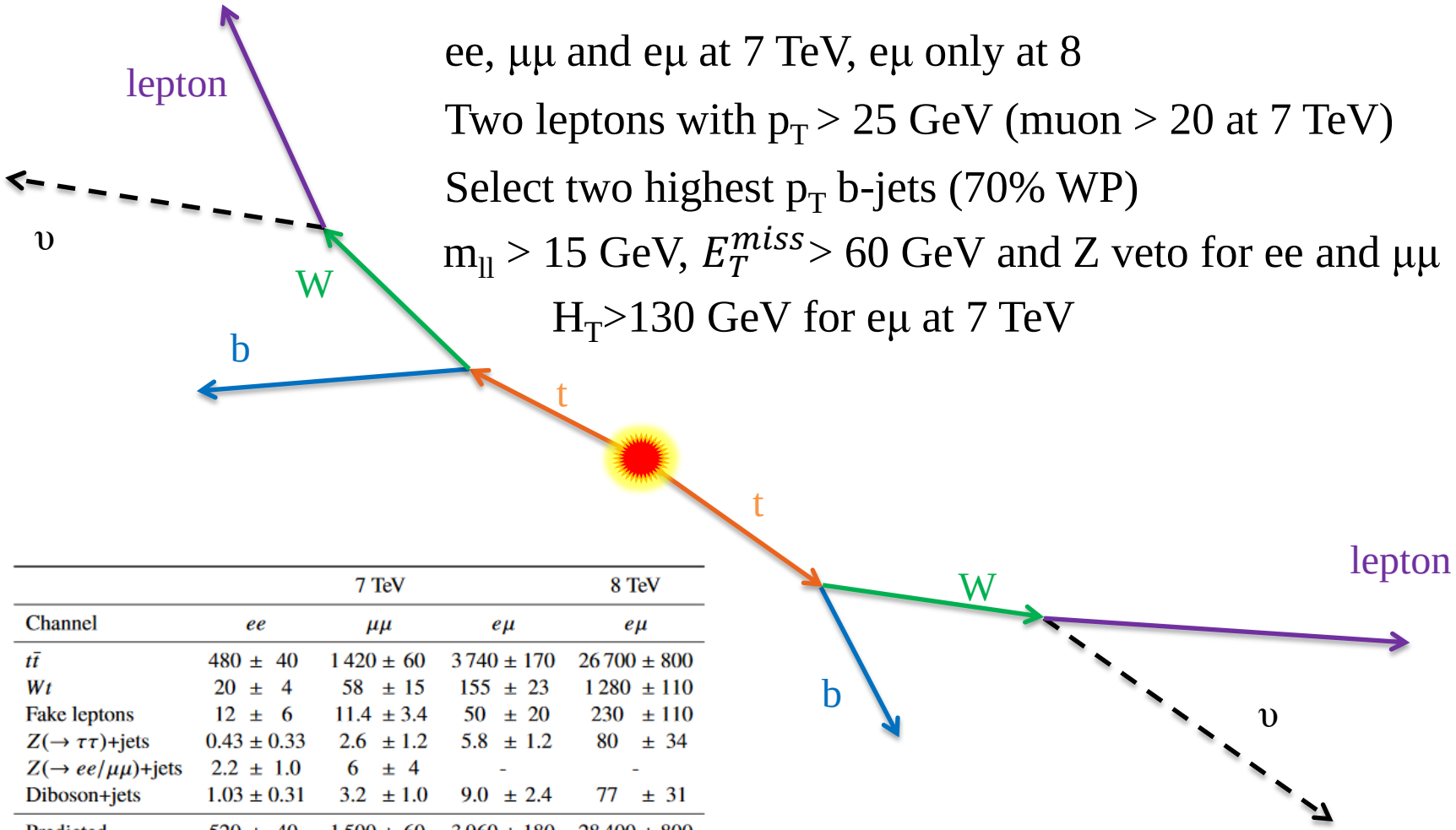

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H_T>130 GeV for eμ at 7 TeV

	7 TeV			8 TeV
Channel	ee	$\mu\mu$	$e\mu$	$e\mu$
$t\bar{t}$	480 ± 40	1 420 ± 60	3 740 ± 170	26 700 ± 800
Wt	20 ± 4	58 ± 15	155 ± 23	1 280 ± 110
Fake leptons	12 ± 6	11.4 ± 3.4	50 ± 20	230 ± 110
$Z(\rightarrow \tau\tau)$+jets	0.43 ± 0.33	2.6 ± 1.2	5.8 ± 1.2	80 ± 34
$Z(\rightarrow ee/\mu\mu)$+jets	2.2 ± 1.0	6 ± 4	-	-
Diboson+jets	1.03 ± 0.31	3.2 ± 1.0	9.0 ± 2.4	77 ± 31
Predicted	520 ± 40	1 500 ± 60	3 960 ± 180	28 400 ± 800
Observed	532	1509	4038	28772

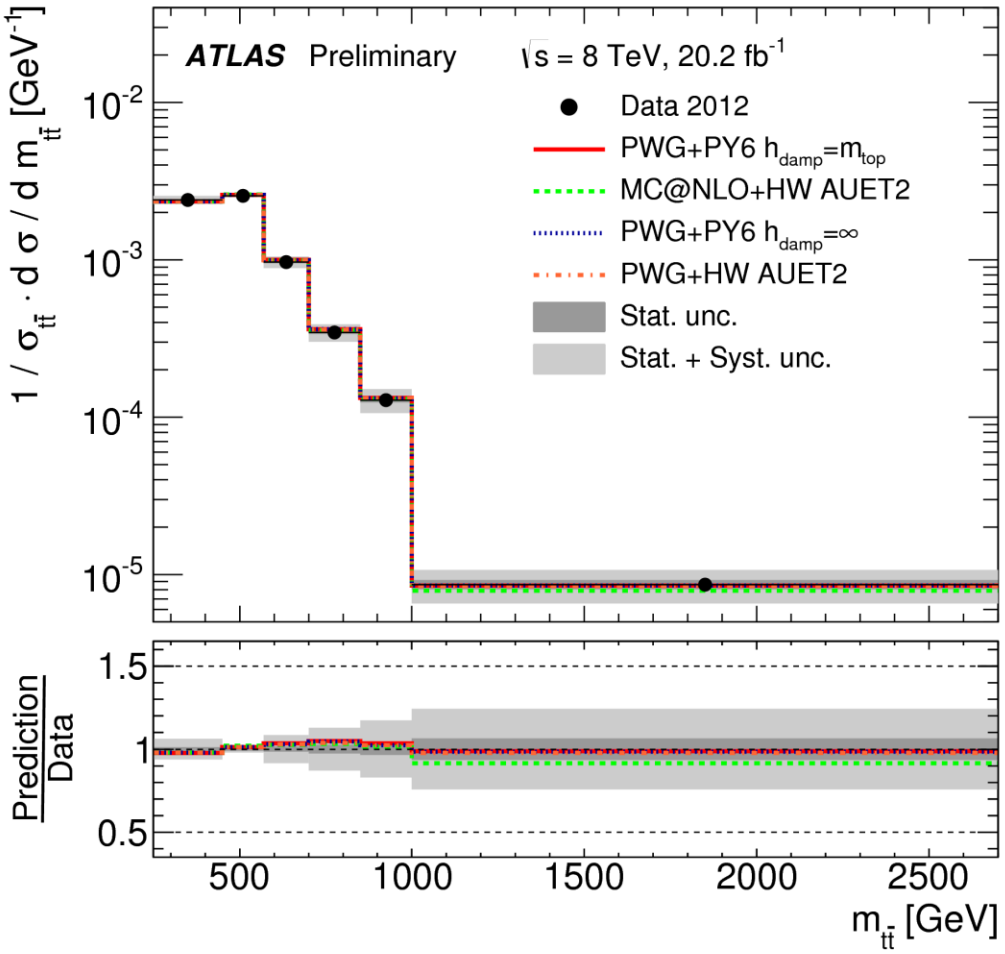
Results at parton level

Three distributions of the $t\bar{t}$ system are unfolded:

Results at parton level

Three distributions of the $t\bar{t}$ system are unfolded:

- mass



Results at parton level

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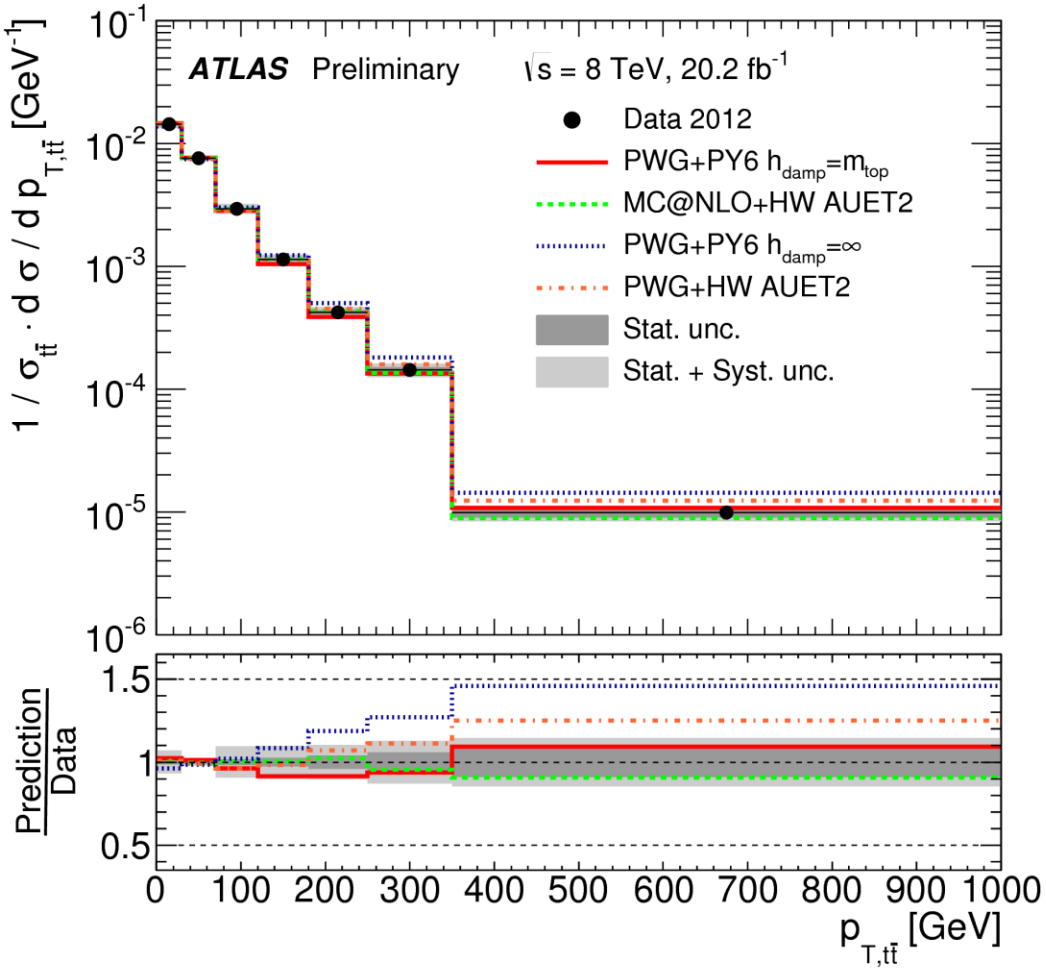
- p_T



Results at parton level

Three distributions of the $t\bar{t}$ system are unfolded:

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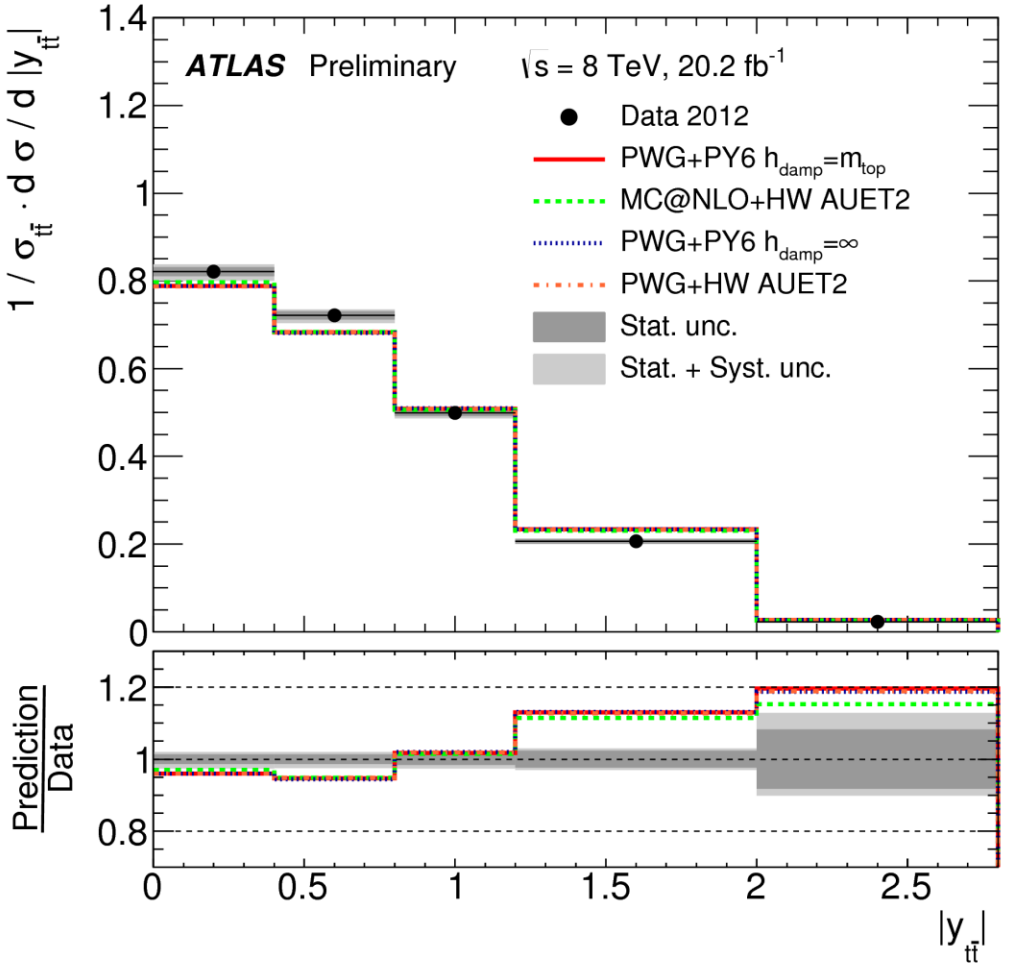
- y



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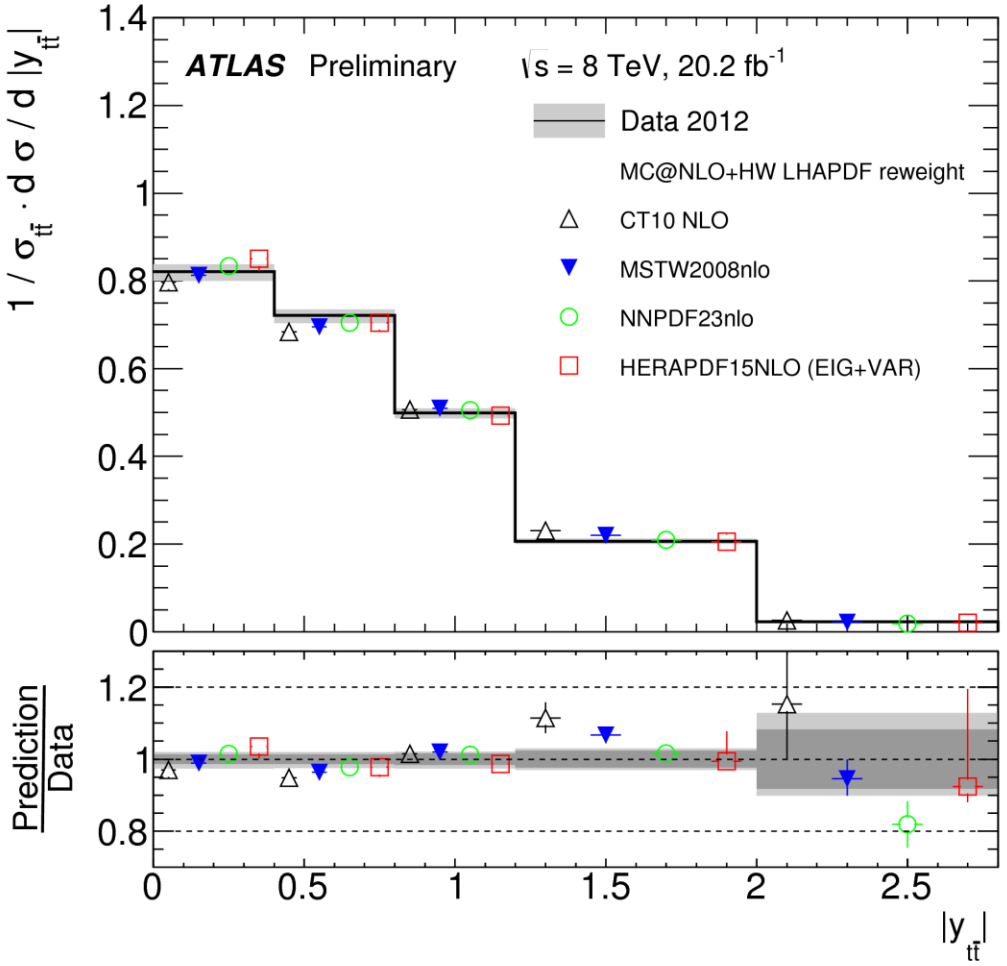
Effect of PDF



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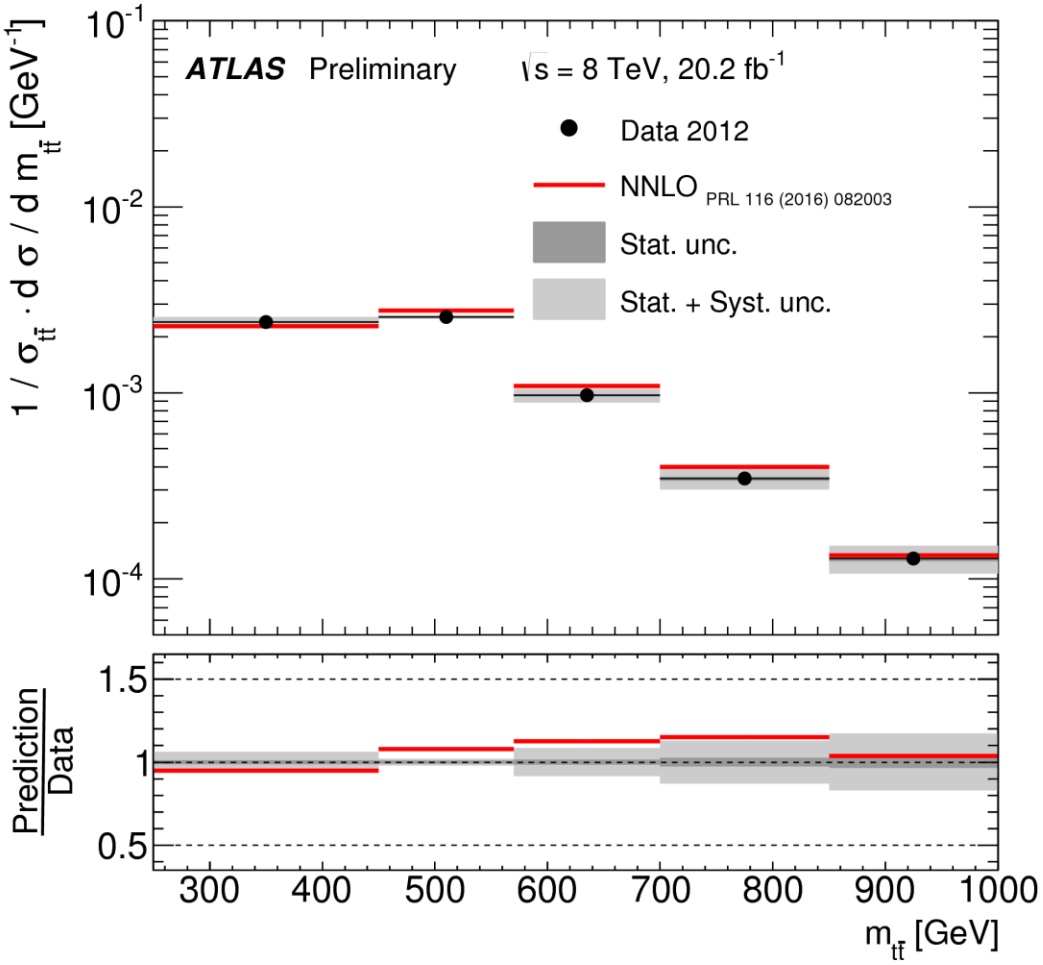
Effect of PDF

Comparison with NNLO



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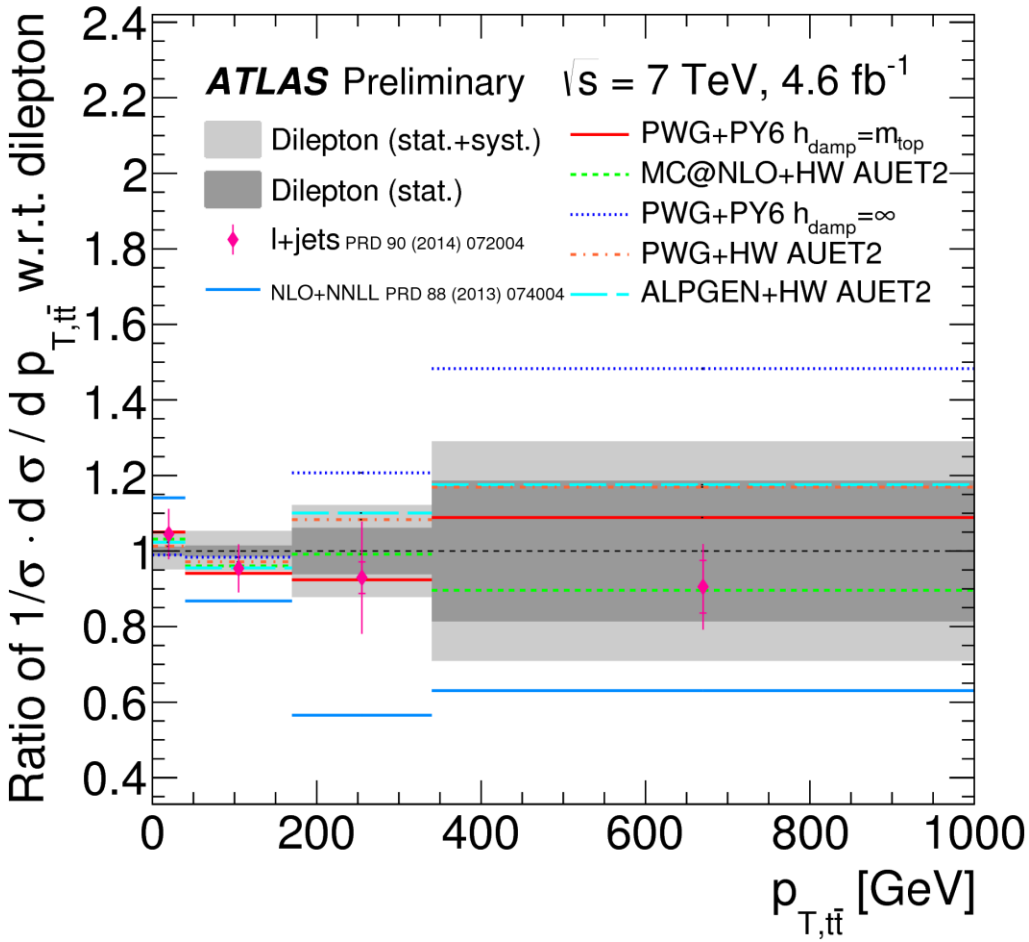
Effect of PDF

Comparison with NNLO

7 TeV distributions



Boosted analysis: topology and selection

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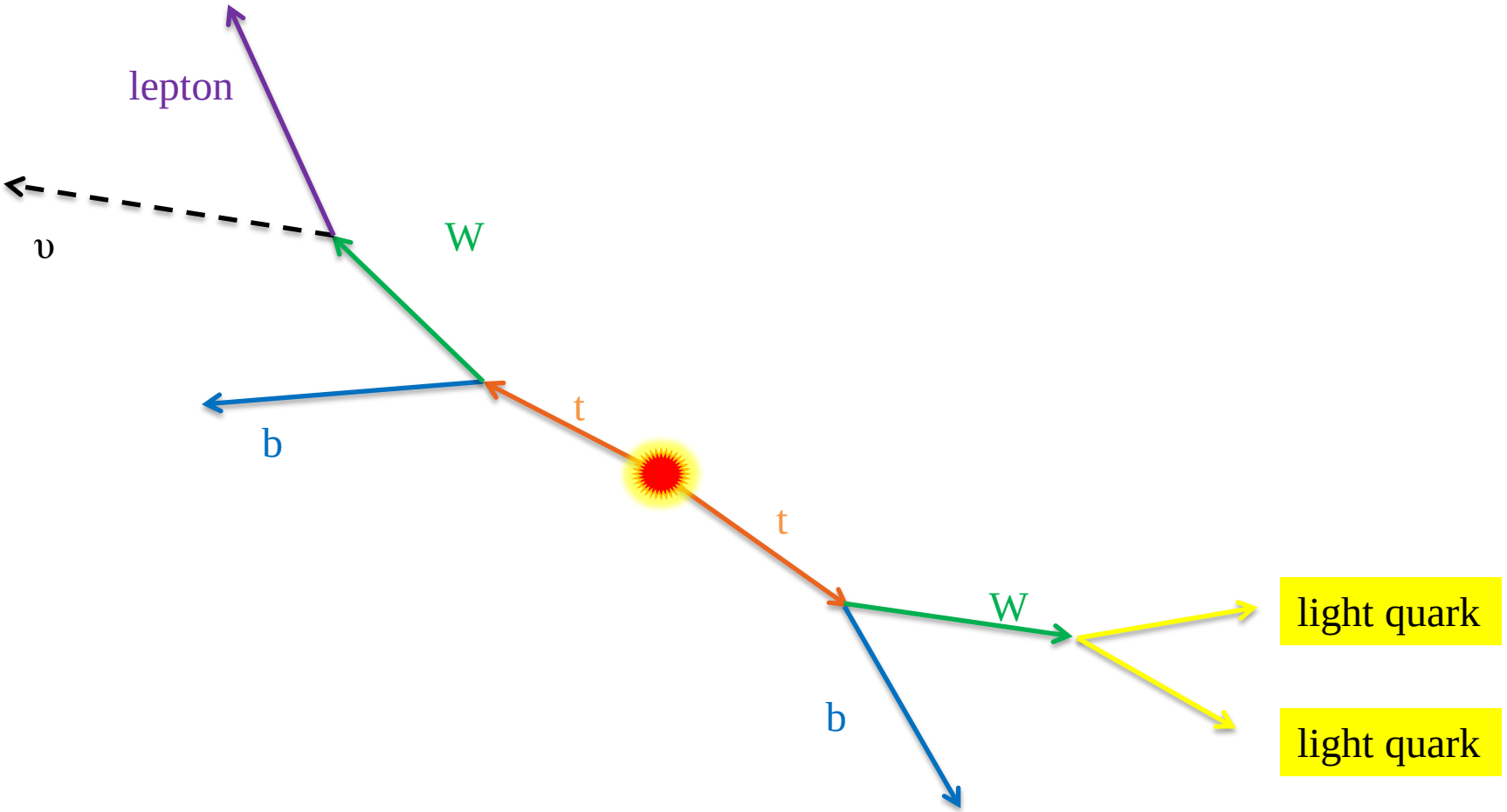

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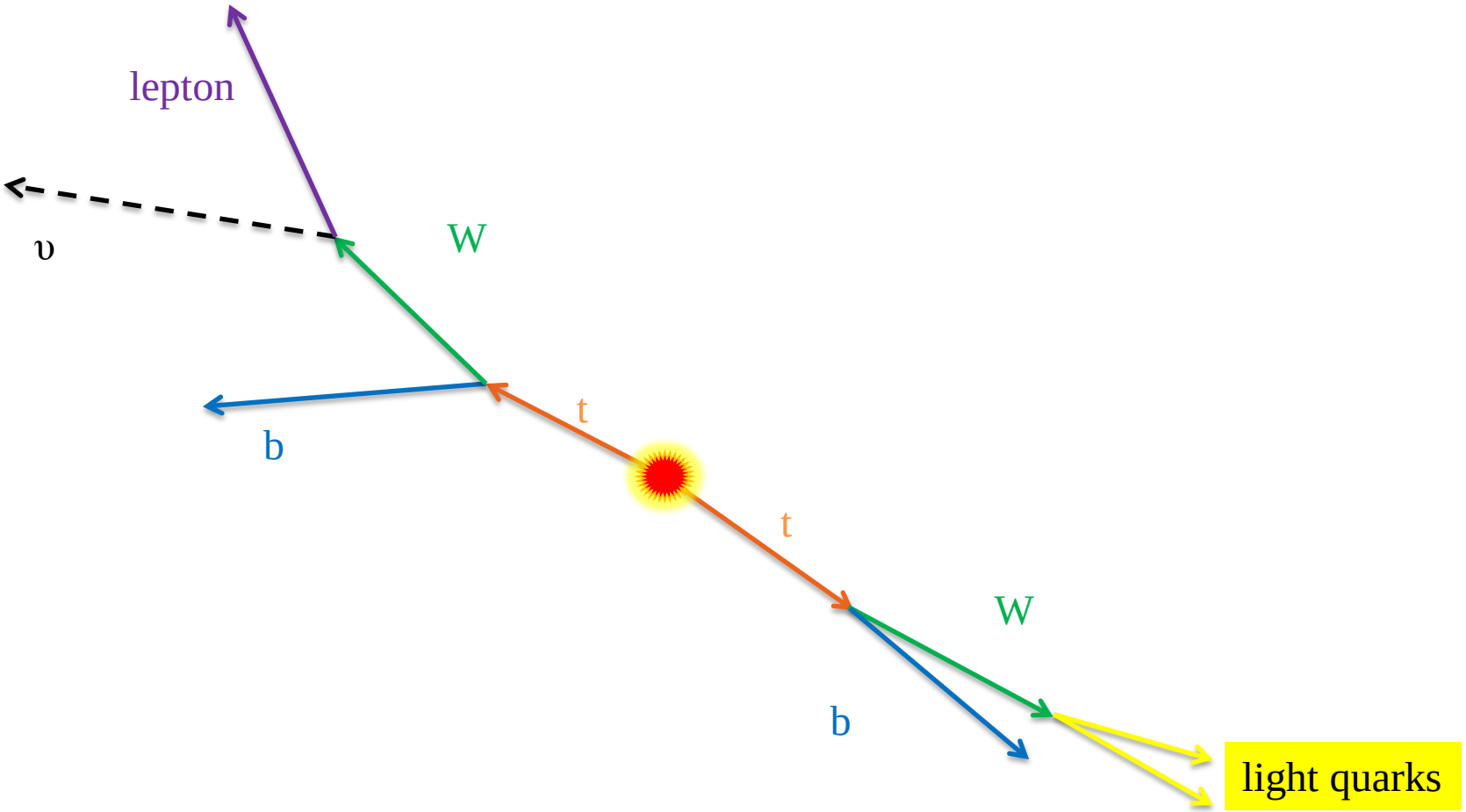

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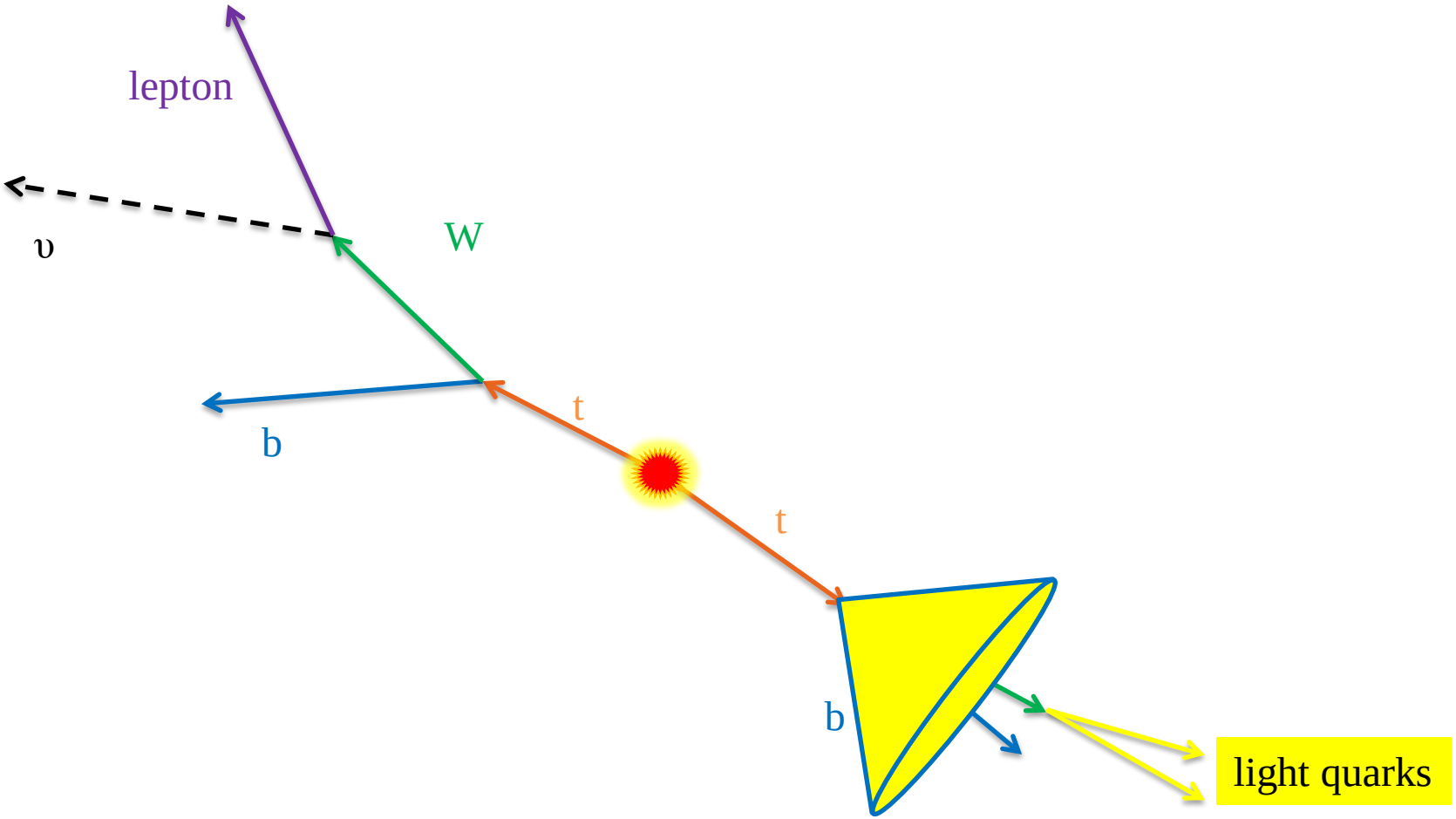

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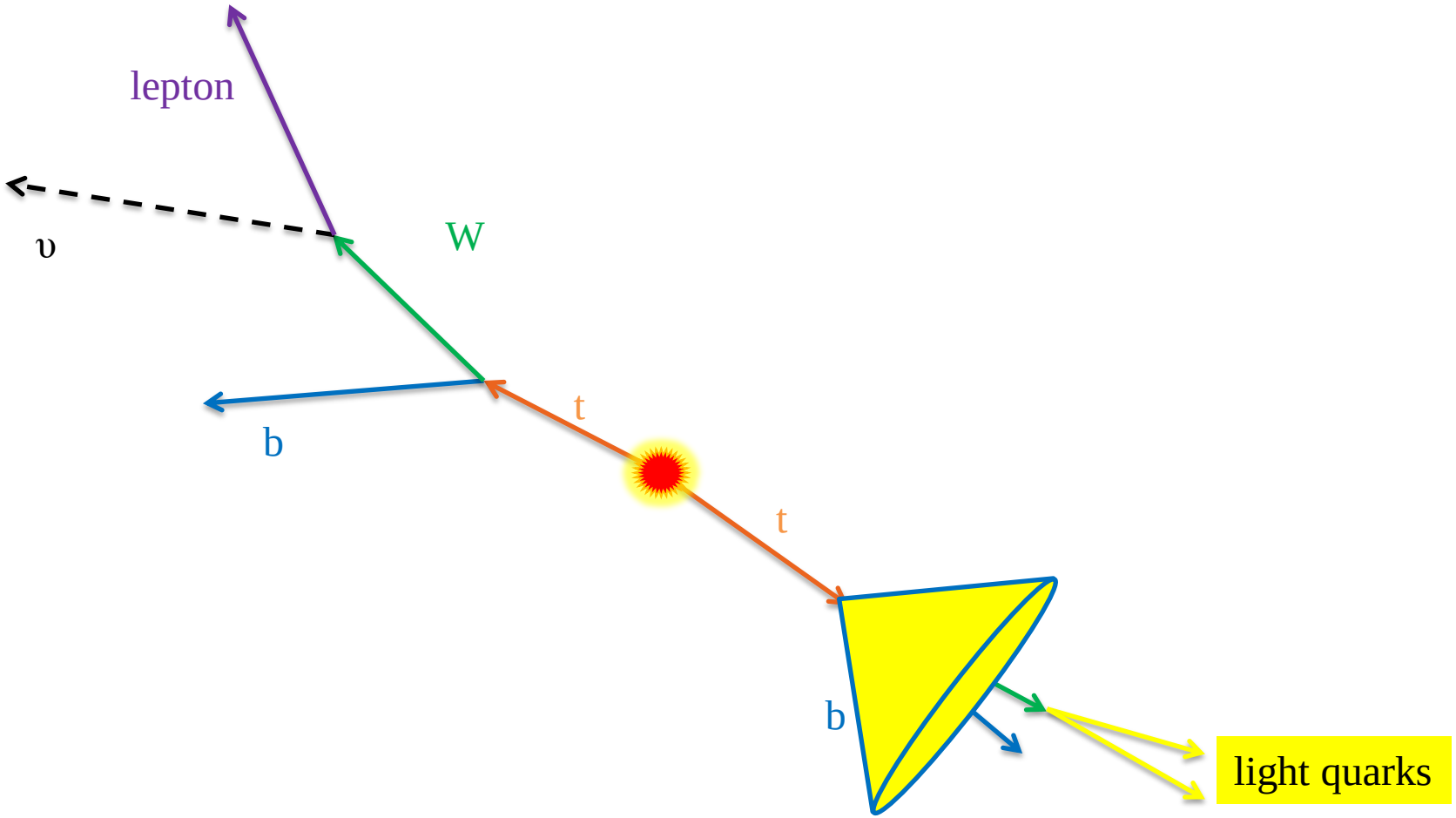

Large jet R=1: p_T>300GeV, mass> 100 GeV

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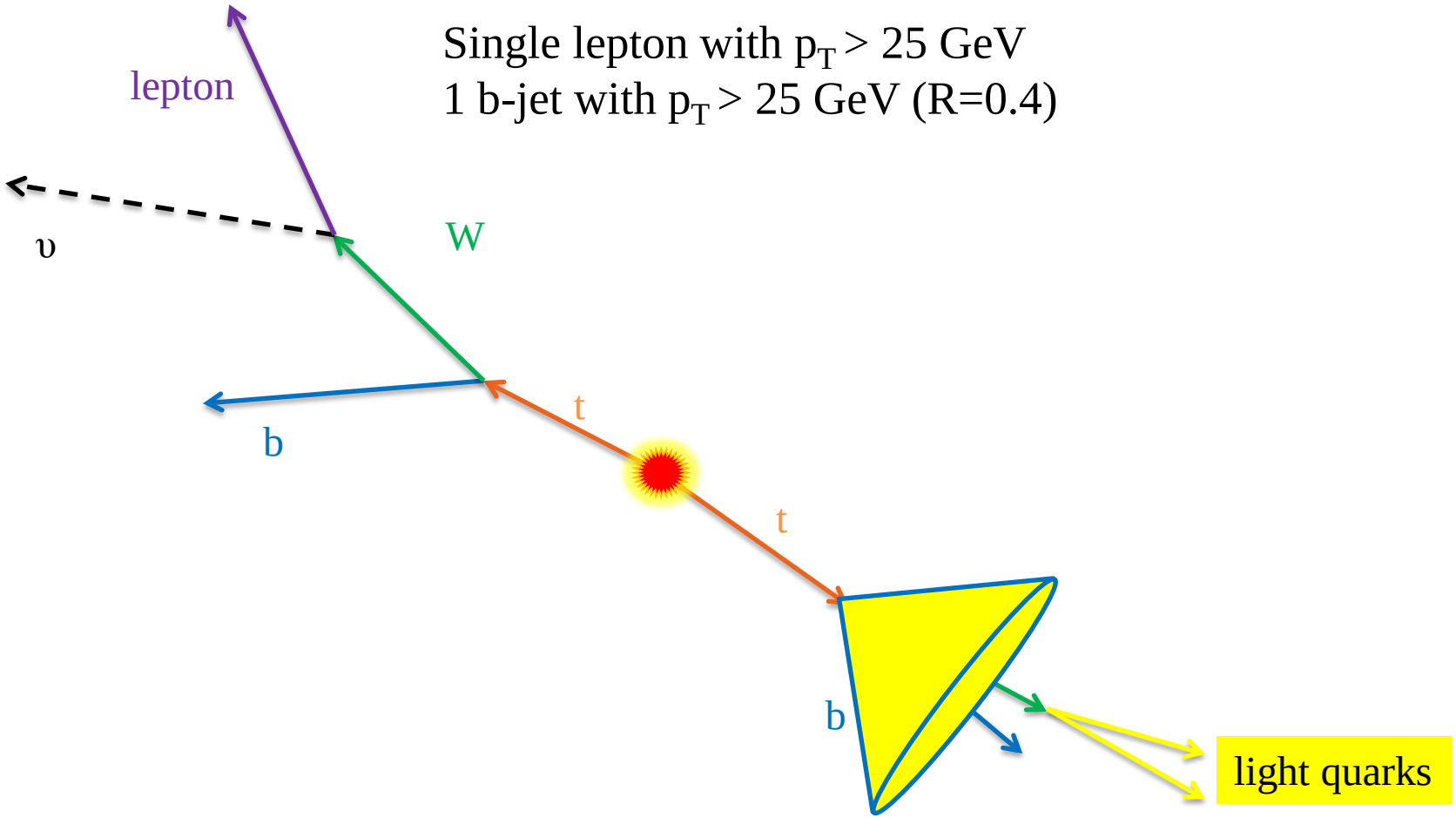
Single lepton with $p_T > 25$ GeV
1 b-jet with $p_T > 25$ GeV (R=0.4)



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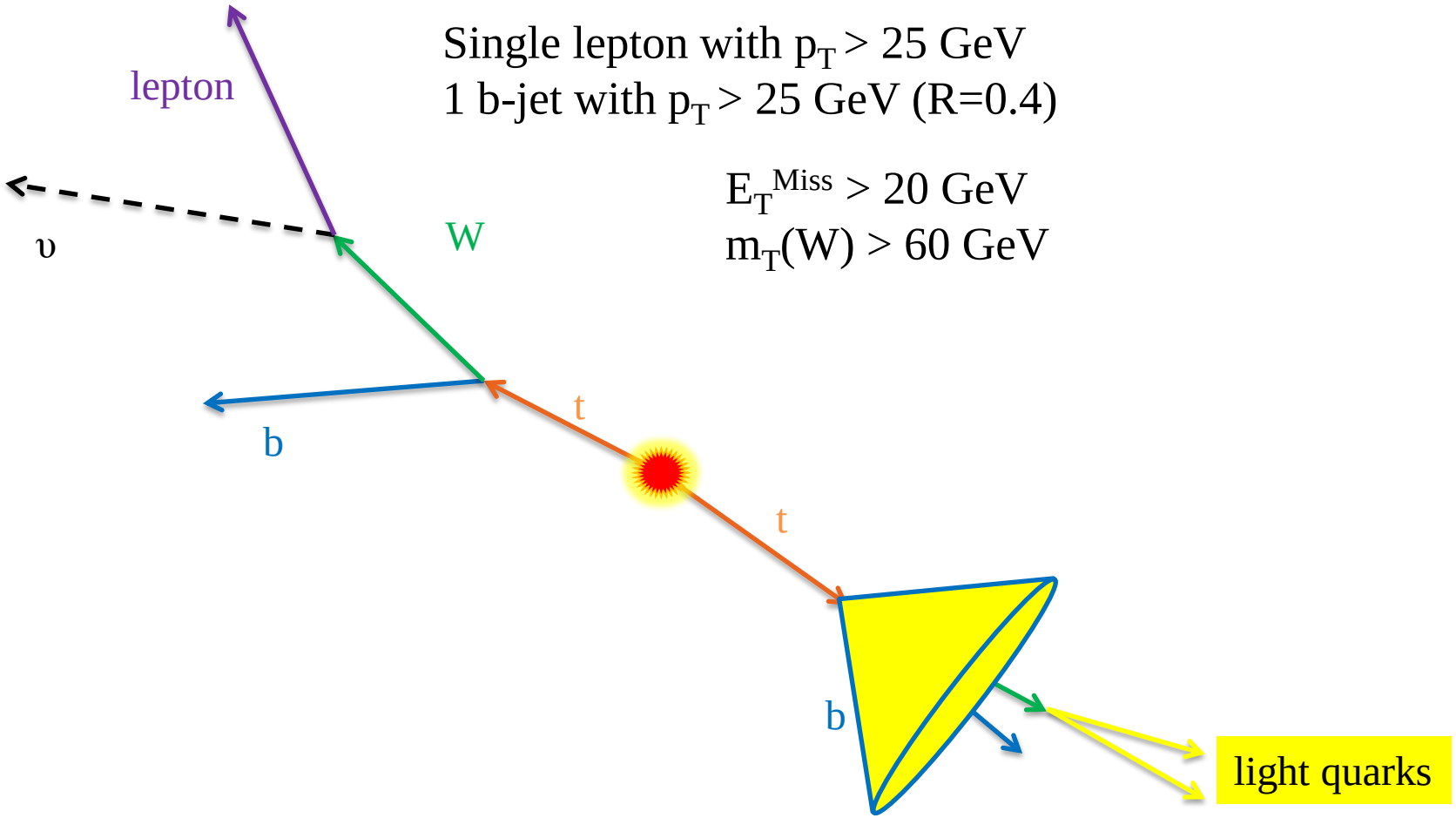

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$E_T^{Miss} > 20$ GeV
$m_T(W) > 60$ GeV

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Boosted analysis: topology and selection

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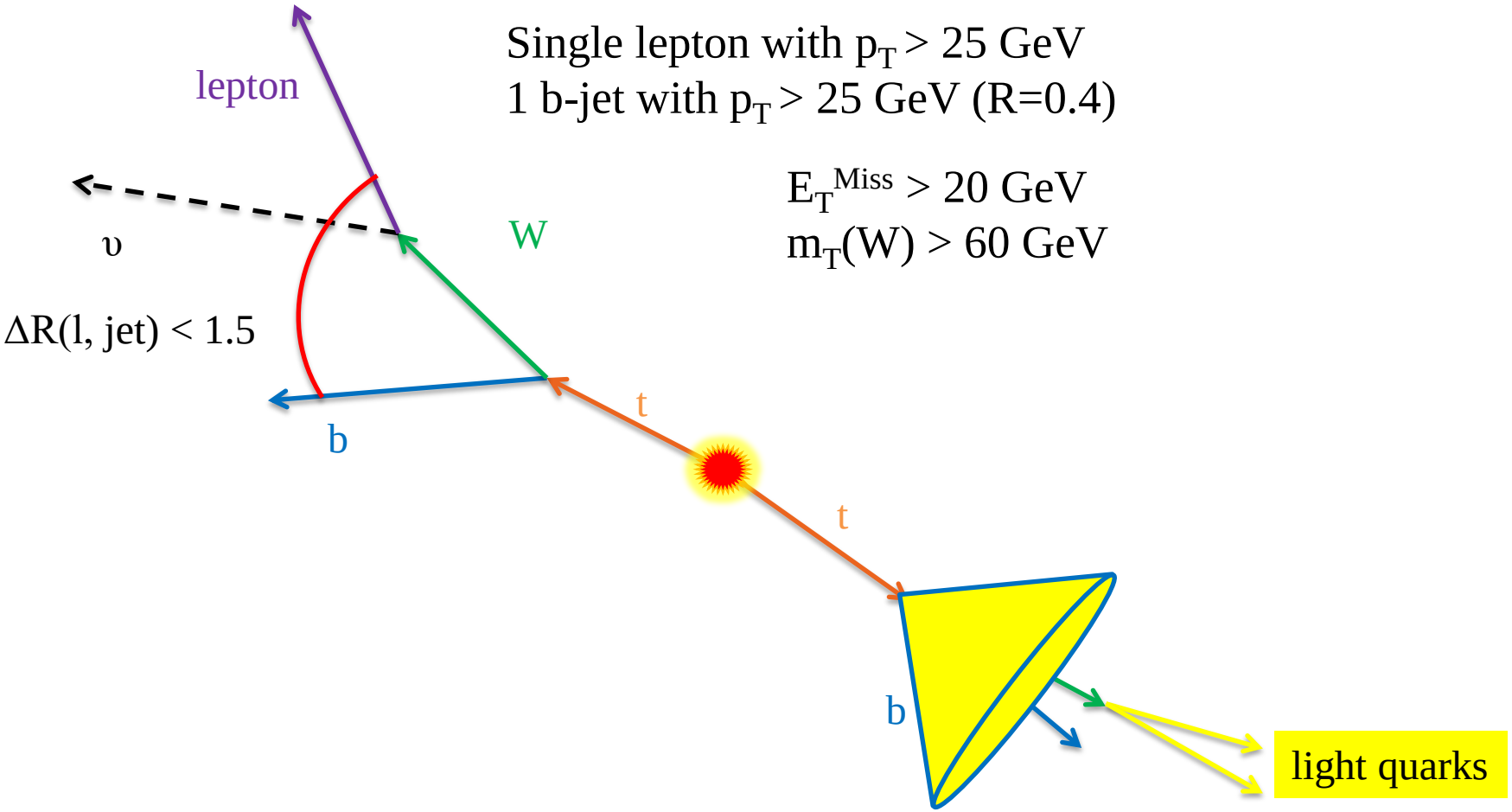

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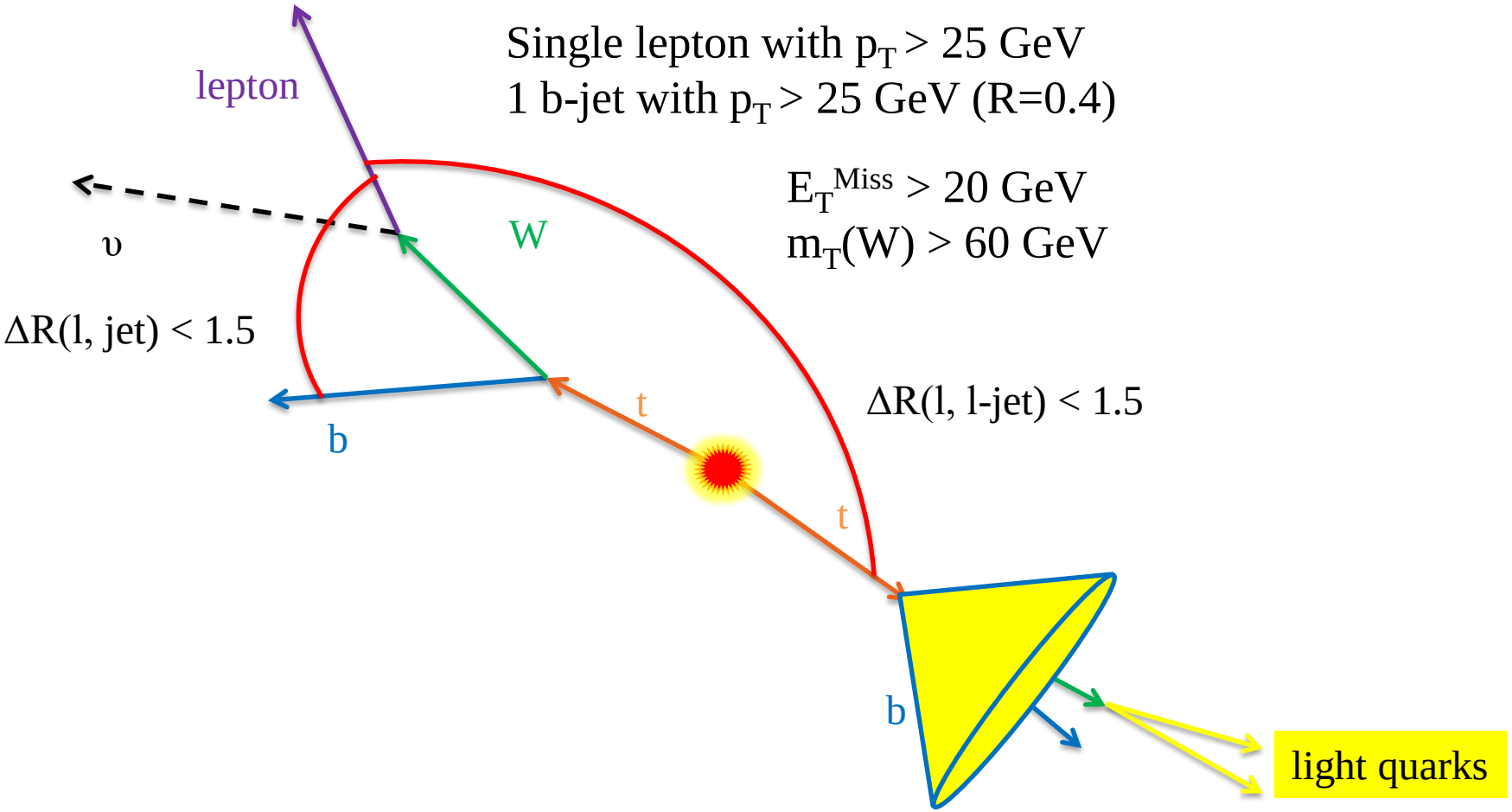

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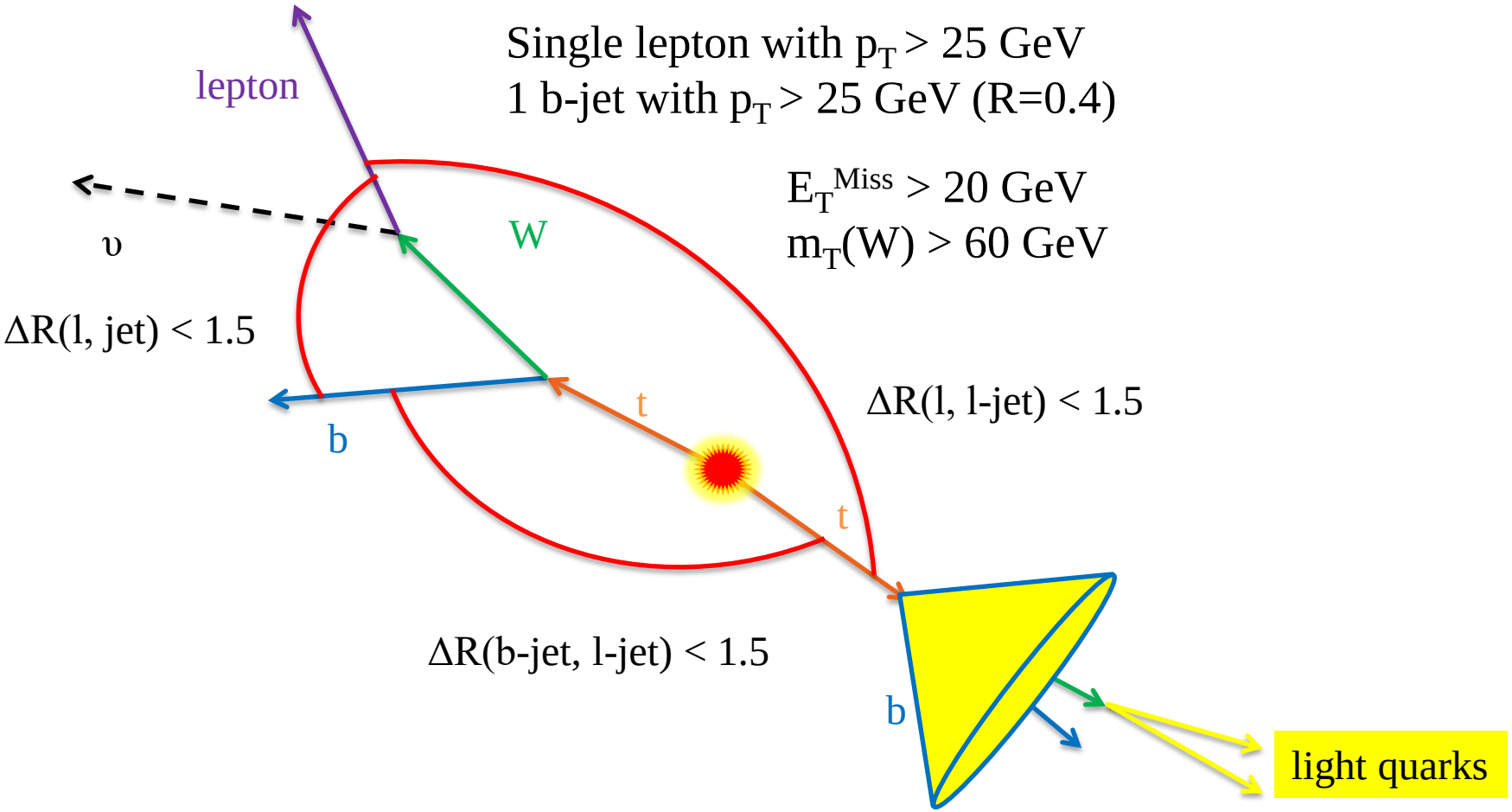

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Boosted p_T distribution

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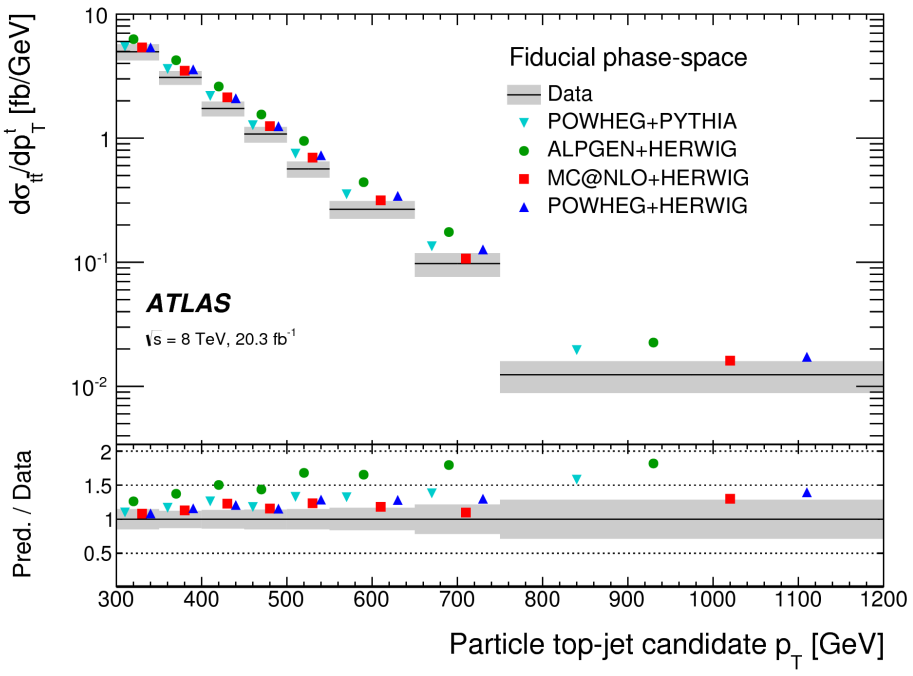

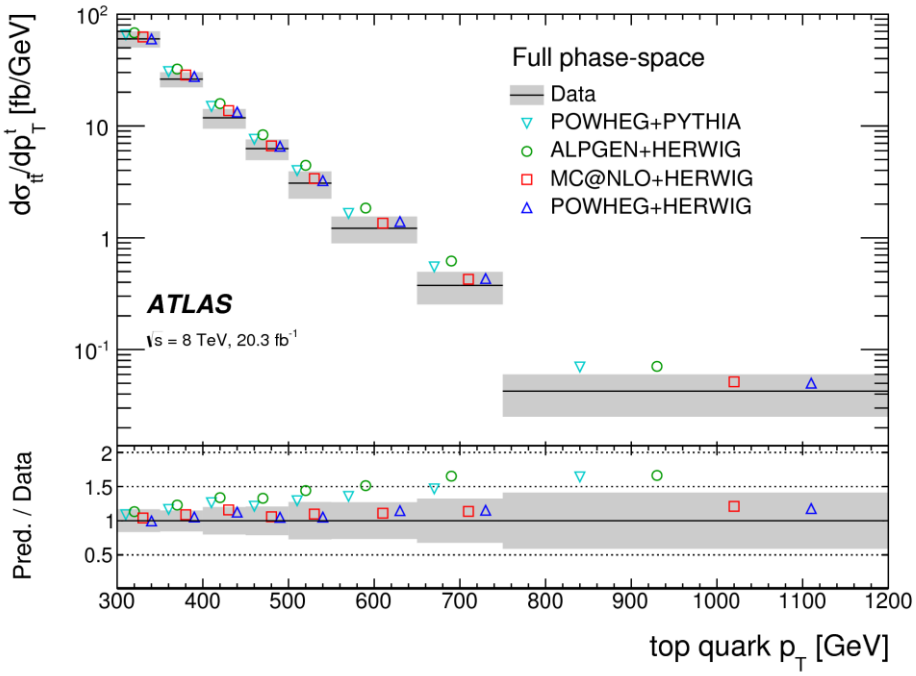

Results between parton and particle level are consistent

Particle level provides smaller uncertainties

Boosted p_T distribution

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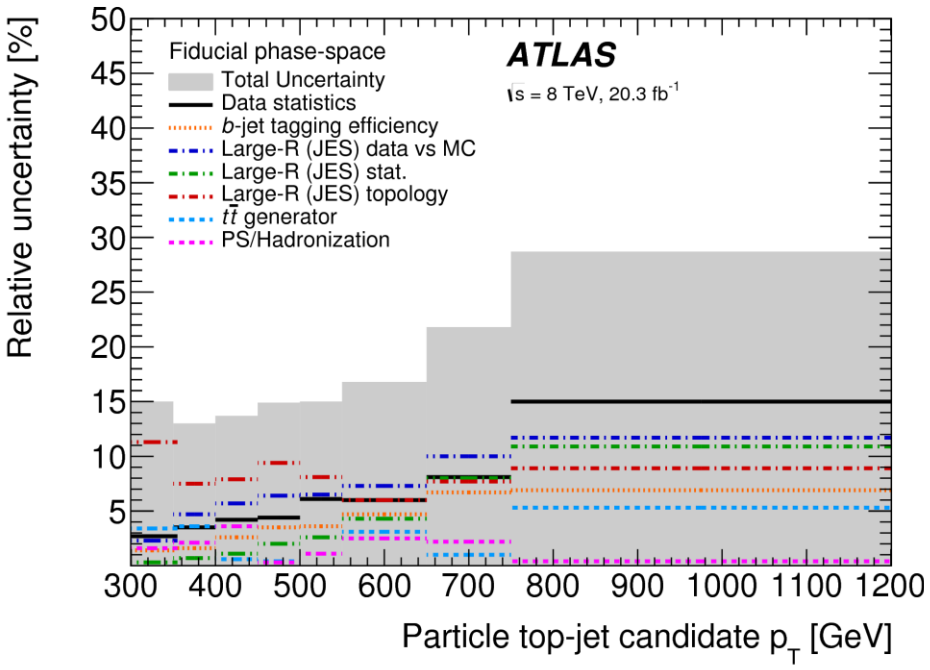
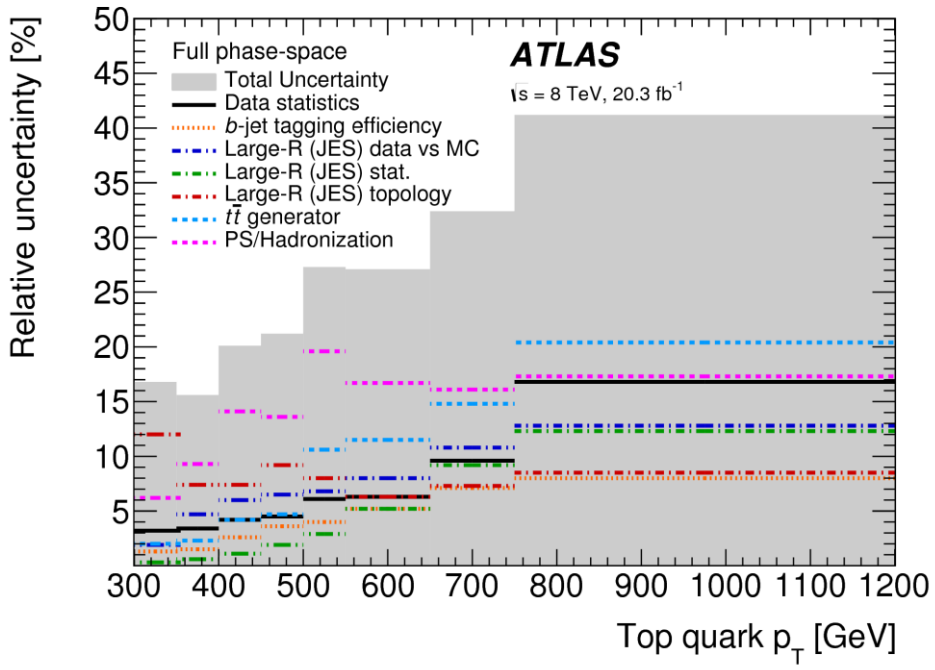




Results between parton and particle level are consistent

Particle level provides smaller uncertainties

Systematic errors smaller at particle level

- Strong reduction in top modelling errors

13 TeV results: inclusive measurement

Cross-section using eμ events using 2015 data (arXiv:1606.02699)

L+jets cross –section using early 2015 data (ATLAS-CONF-2015-049)

Selections

Lepton + jets:

ATLAS-CONF-2015-049

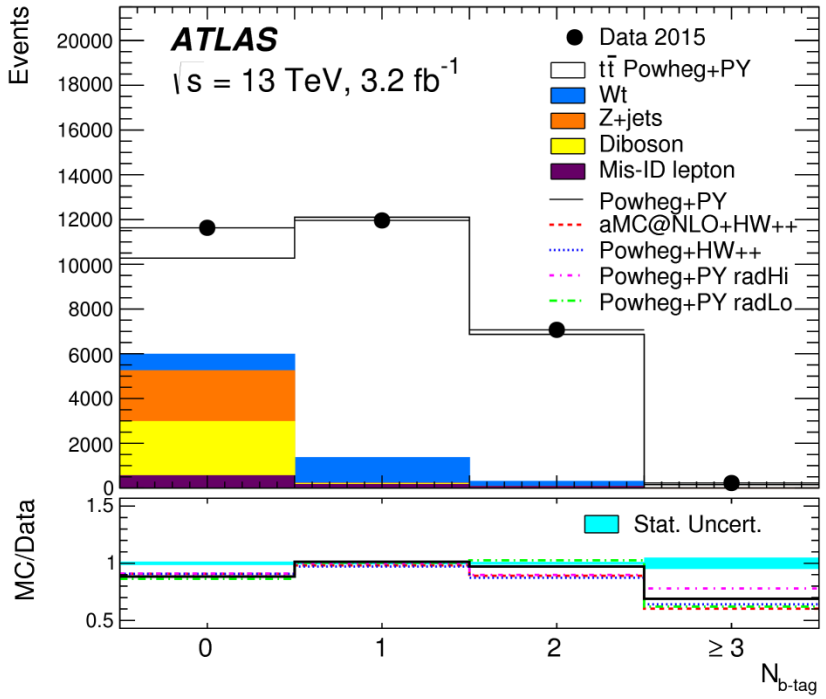
- 1 lepton with > 25 GeV
- 4 jets with p_T > 25 GeV
- 2 b-jets

Sample	e + jets	μ + jets
$t\bar{t}$	2800 ± 400	2620 ± 340
W+jets	340 ± 100	230 ± 60
Single top	192 ± 34	180 ± 30
Z+jets	71 ± 35	45 ± 22
Dibosons	10 ± 5	10 ± 5
Fakes	200 ± 70	130 ± 60
Total background	820 ± 130	600 ± 100
Total expected	3600 ± 500	3220 ± 350
Observed	3439	3314

Di-lepton:

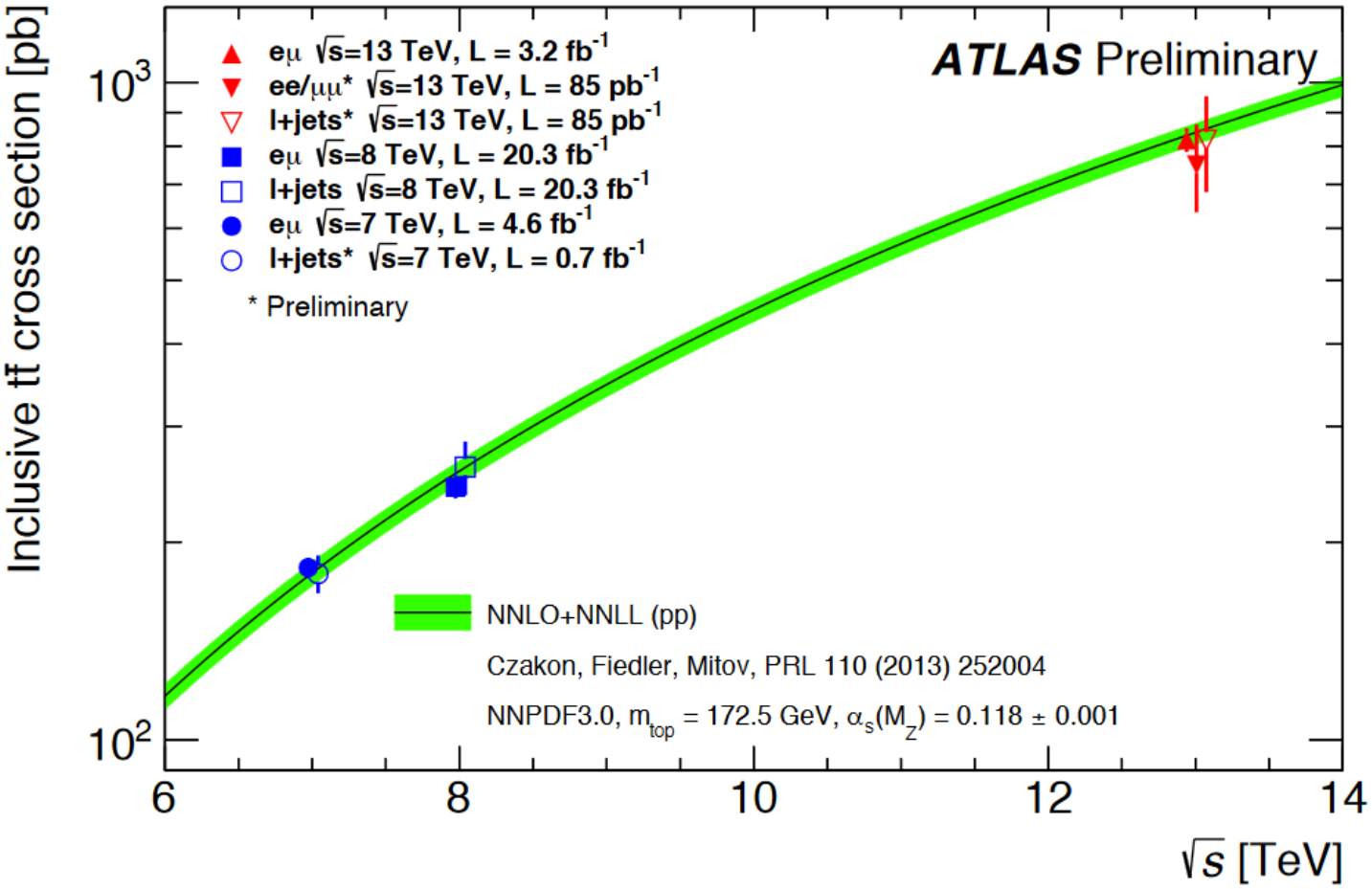
arXiv:1606.02699

- 2 leptons with p_T > 25 GeV
- 1 or 2 b-jets with p_T > 25 GeV



Simultaneous fit of b-tagging efficiency and cross section

Inclusive Cross-section



The cross-section measured in all channels is in good agreement with the best prediction

Effect of PDF on $\sigma_{t\bar{t}}/\sigma_Z$

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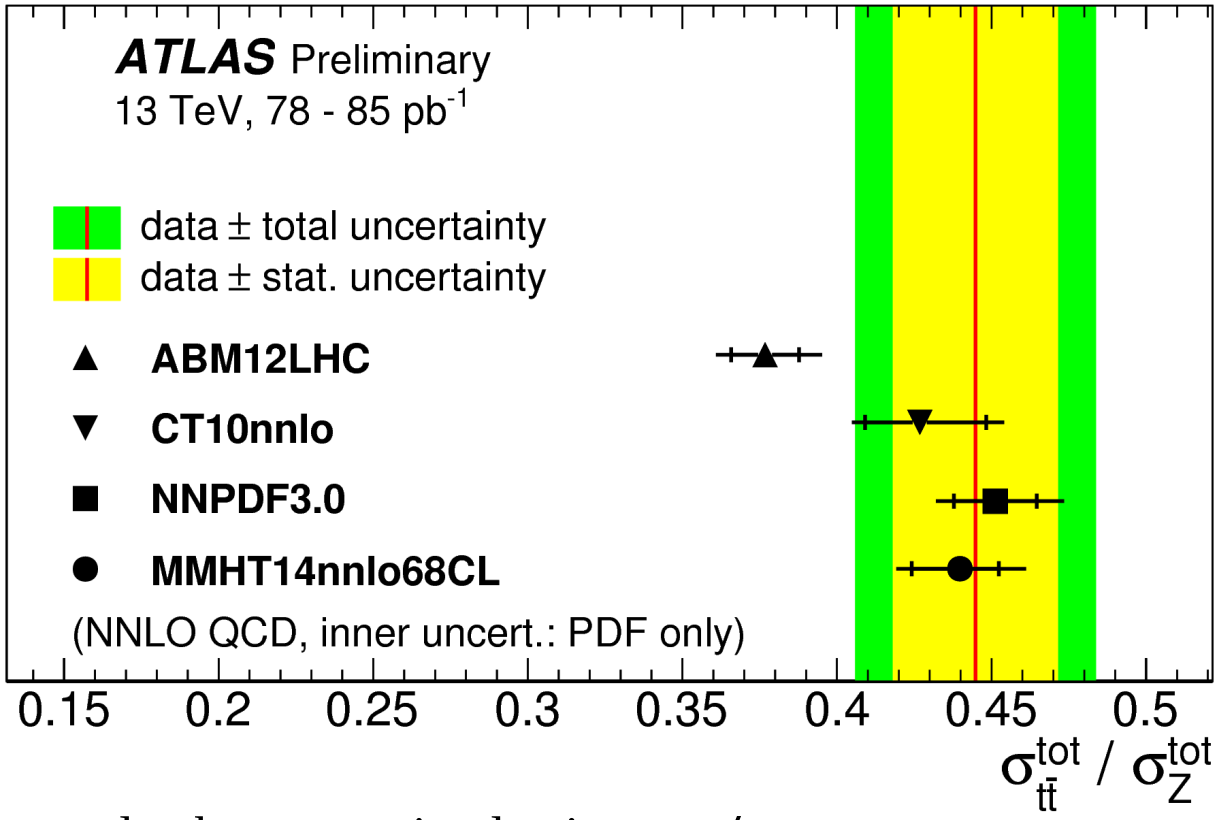
ATLAS-CONF-2015-049



PDF sets can also be constrained using $\sigma_{t\bar{t}}/\sigma_Z$
Some models already show tension with data
Will provide strong constrain more data will be included

Conclusion

- The LHC is a top factory and we are exploiting the large number of top quarks produced
- We published the 7 and 8 TeV legacy differential measurements
  - Some tensions between data and MC
  - But NNLO prediction and new PDF sets are in much better agreement
  - Will be used to improve top modelling
  - Will constrain PDF in extreme regions
- Starting to exploit the 13 TeV events
  - Inclusive cross section in good agreement with NNLO prediction
- 2016 run already undergoing
  - Next year: double differential measurements!

Backup

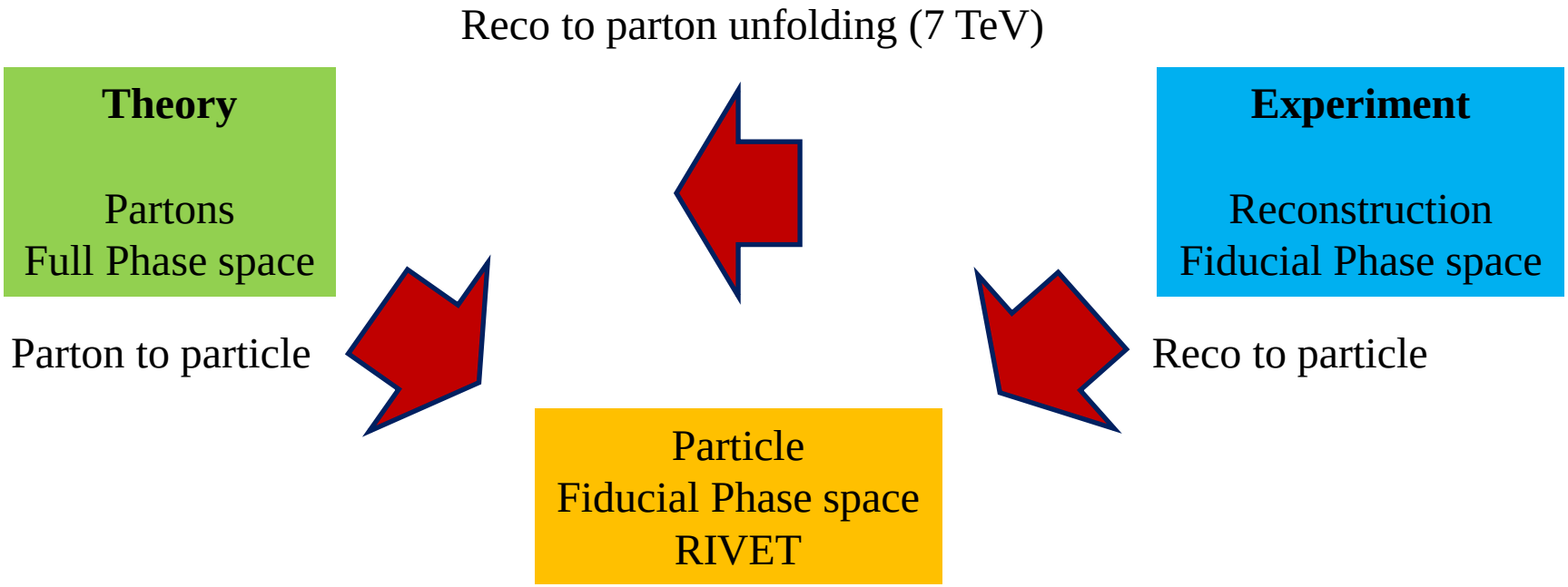
Definition of variables in resolved diffXsec

- Production angle ($\chi_{t\bar{t}} = exp\left[y_{t,had} - y_{t,lep}\right]$)
- Longitudinal boost ($y_{boost}^{t\bar{t}}$)
- Out of plane momentum ($\vec{p}_{out}^{t\bar{t}} = \vec{p}_{t,had} \cdot \frac{\vec{p}_{t,lep} \times \hat{z}}{|\vec{p}_{t,lep} \times \hat{z}|}$)
- Azimuthal angle ($\Delta\phi^{t\bar{t}}$)
- Scalar sum of p_T of all objects ($H_{all}^{t\bar{t}}$)
- Ratio of p_T of W and top ($R_{Wt} = \frac{p_T^W}{p_T^t}$)

Triggers

- 7 TeV
  - muon > 18 GeV
  - electron > 20/22 GeV depending on the period
- 8 TeV
  - muon: > 24 GeV with isolation OR > 36 GeV without isolation
  - electron: > 24 GeV with isolation OR > 60 GeV without isolation
- 13 TeV
  - muon: > 24 GeV with isolation OR > 50 GeV without isolation
  - electron: > 24 GeV with isolation OR > 60 GeV no isolation and tight selection OR > 120 no isolation and loose selection

From experiment to theory



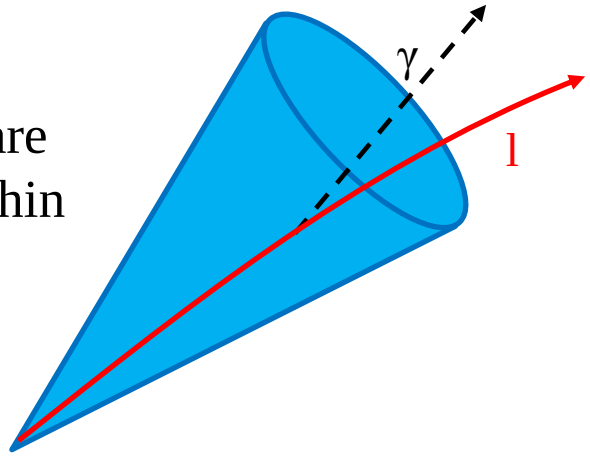
Theorist can compare new models
The results will be relevant for years

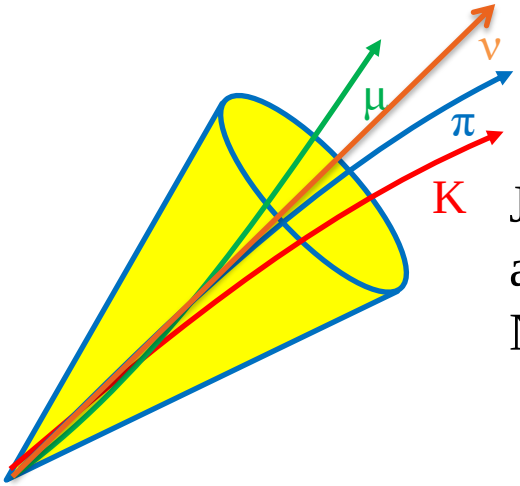
Focus on measurement close to experimental acceptance
Reduce dependency on theory
Migration matrix is more diagonal
Expected reduced systematic uncertainties from modelling

Object Definition

Particle objects

Charged leptons not decaying from a hadrons are "dressed" with the energy from all photons within a R=0.1 cone around the lepton





Jets are clustered from stable MC particles using anti-k_t with R=0.4 (R=1 for boosted objects)
Neutrinos and muons from hadrons are included

E_T^{Miss} defined as sum of all other neutrinos

B tagging defined by matching a jet with a b quark with R<0.35

Reconstructed object use standard definitions (see talk by Chris Pollard)

Effect of PDF and h_{damp}

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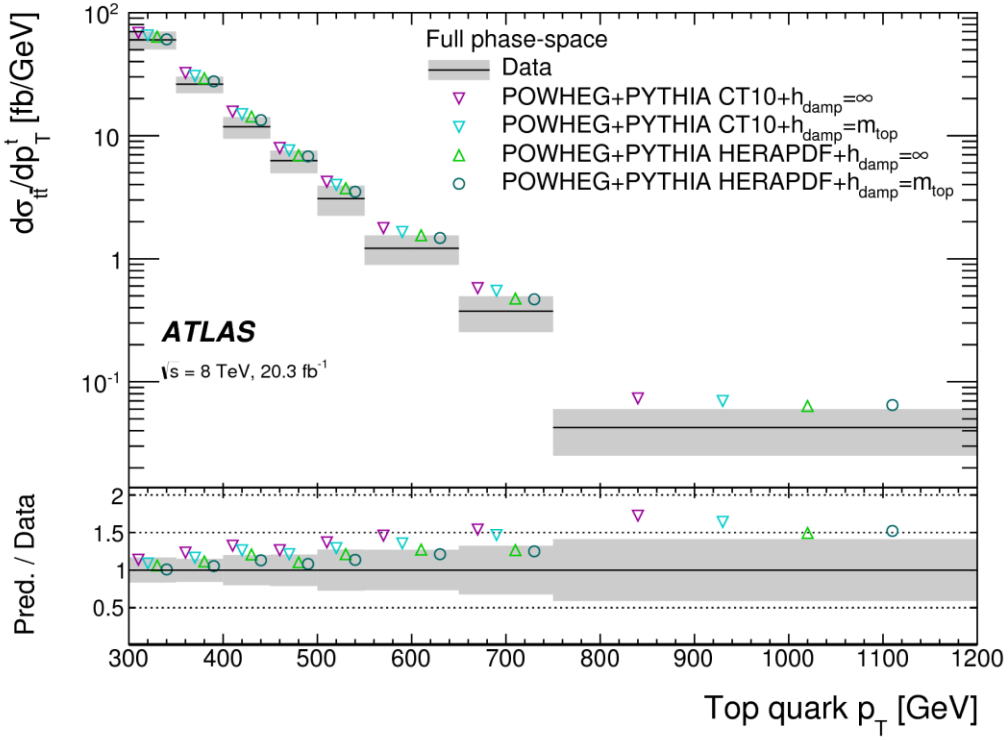

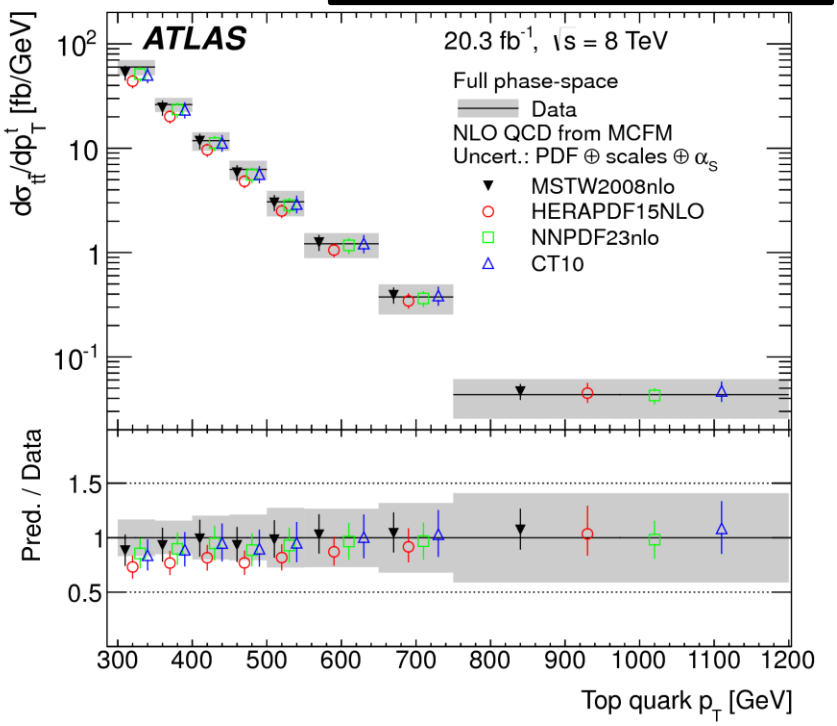

Changing PDF has small impact

Small effect for cut-off of hard radiation in PowHeg (h_{damp})

A slope for PDF with respect to data

Modelling of kinematics

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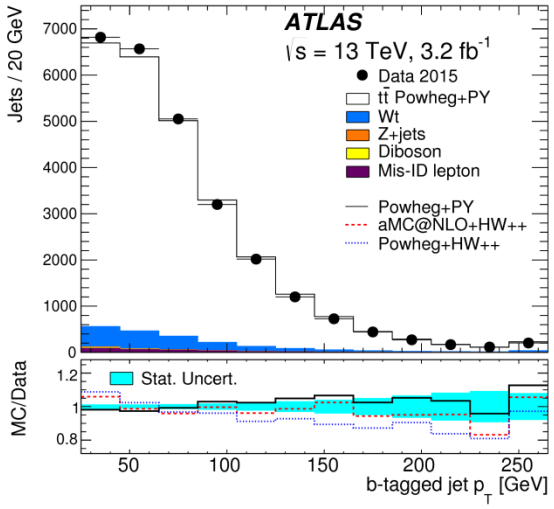
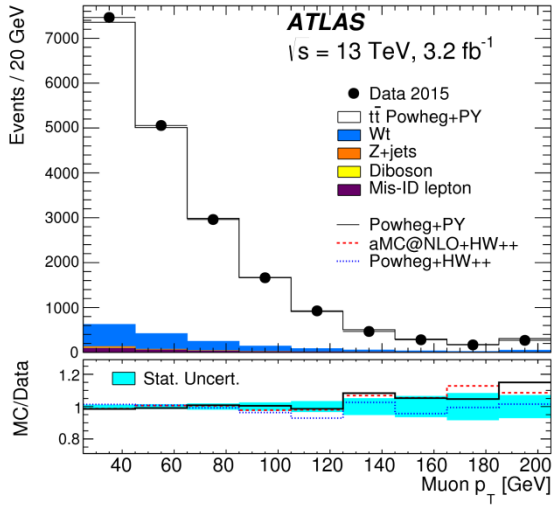
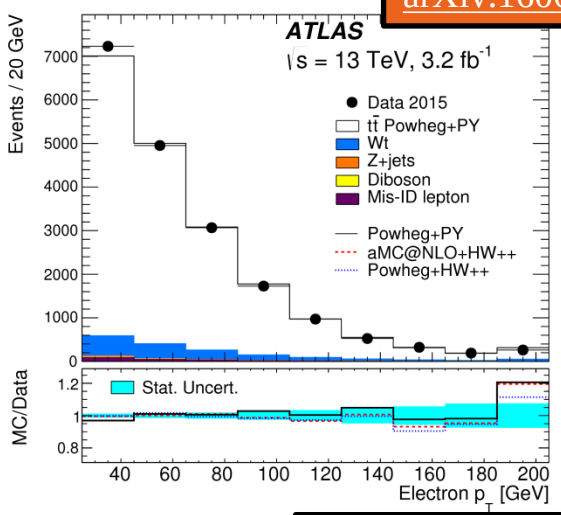
arXiv:1606.02699







ATLAS-CONF-2015-049