Sensitivity to new high-mass particles decaying to $t\bar{t}$ in fully boosted regime at a 100 TeV collider

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ANL

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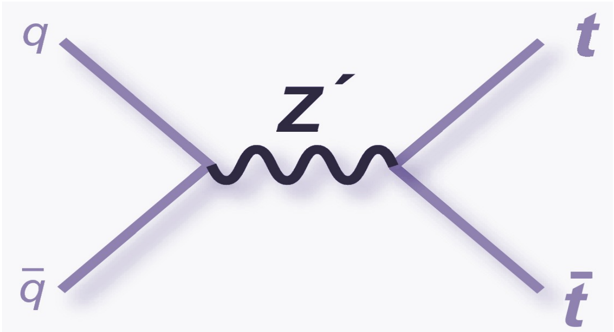
IAS program on the Future of High-Energy Physics

Not a summary talk! A summary of several studies!
In collaboration with B.Auerbach, J.Love, A.V. Kotwal, J.Proudfoot

Heavy particles decaying to $t\bar{t}$



- **Extensions of the SM predict the existence of heavy particles**
- **Decays to $t\bar{t}$ is one of the promising channels**
  - Top is heaviest known particle! A window to new physics
- **Decays to “golden" channels (leptons, photons) can be suppressed**

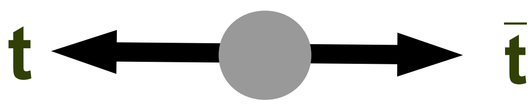
100 TeV collider & BSM models with top decays

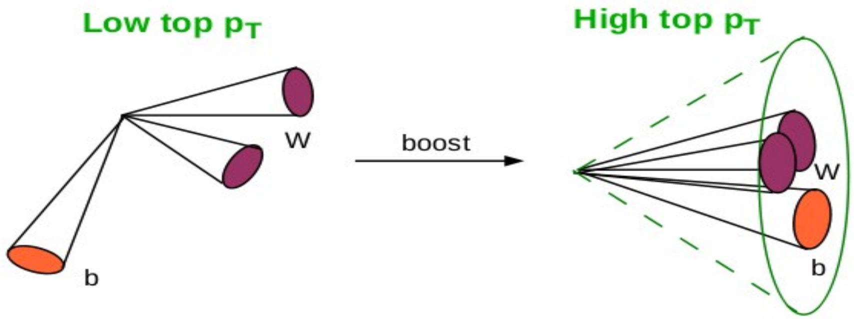
- 100 TeV collider can study physics beyond 10 TeV
- Most interesting mass range is > 5 TeV
- Such masses lead to highly boosted top decays pT(t) > 2-3 TeV

Questions:

- How to measure $t\bar{t}$ resonances at the 10 TeV mass scale?:
  - separate decay particles cannot be “resolved”
  - how to use “traditional” calorimetry measurements?
- What are sensitivity limits for a “generic” $t\bar{t}$ resonance using boosted techniques?

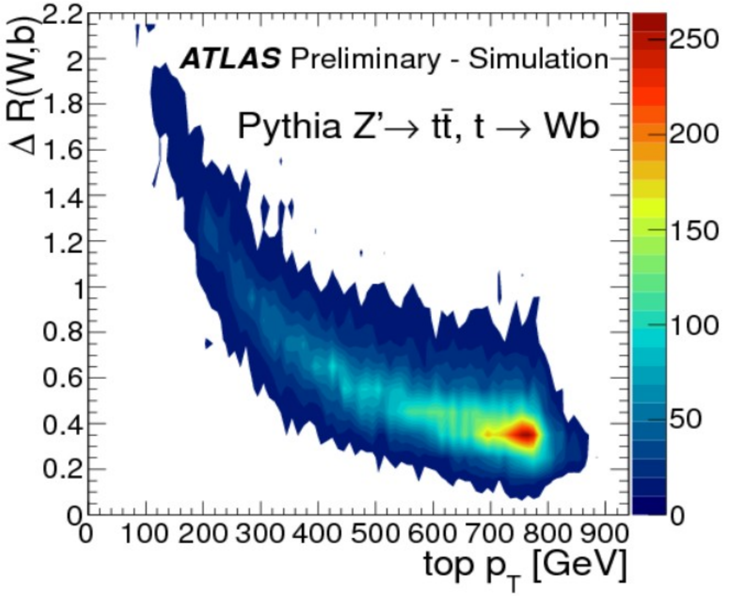
Boosted top from high-mass particles





www.quantumdiaries.org

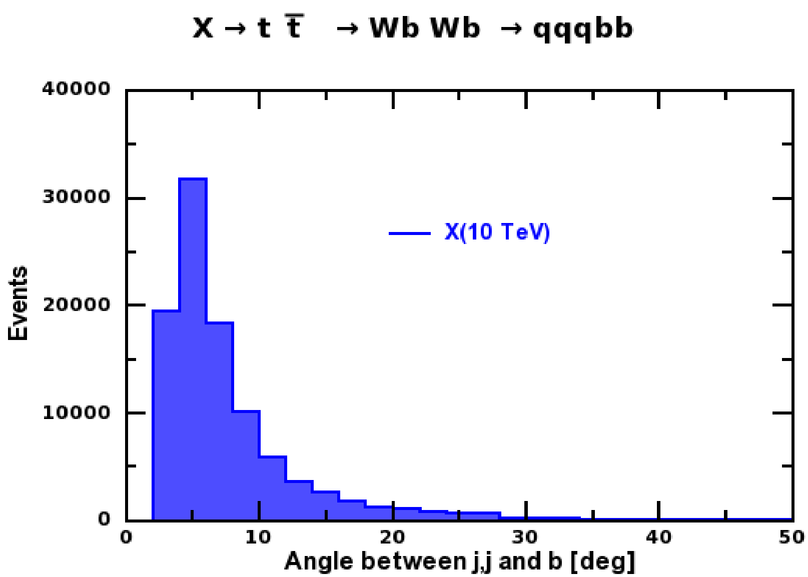
- M ~ 10 TeV generates top quarks with pT > 3-5 TeV
- ΔR distance between 2 particles (W,b) from top decay
- ΔR ~ 2* pT / m(top)

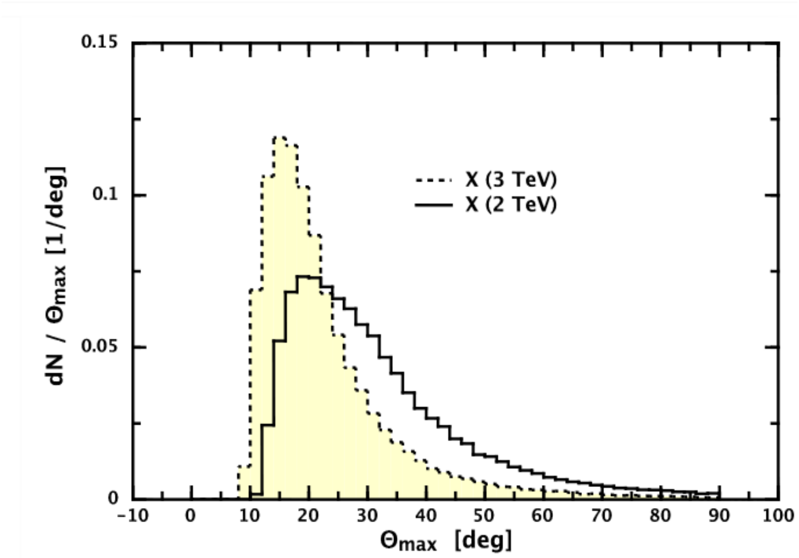


We use $t\bar{t}$ as an example!
There are many similar decays (W' → tW) with boosted topologies!

Separation of top decay products for X (10 TeV)→ $t\bar{t}$

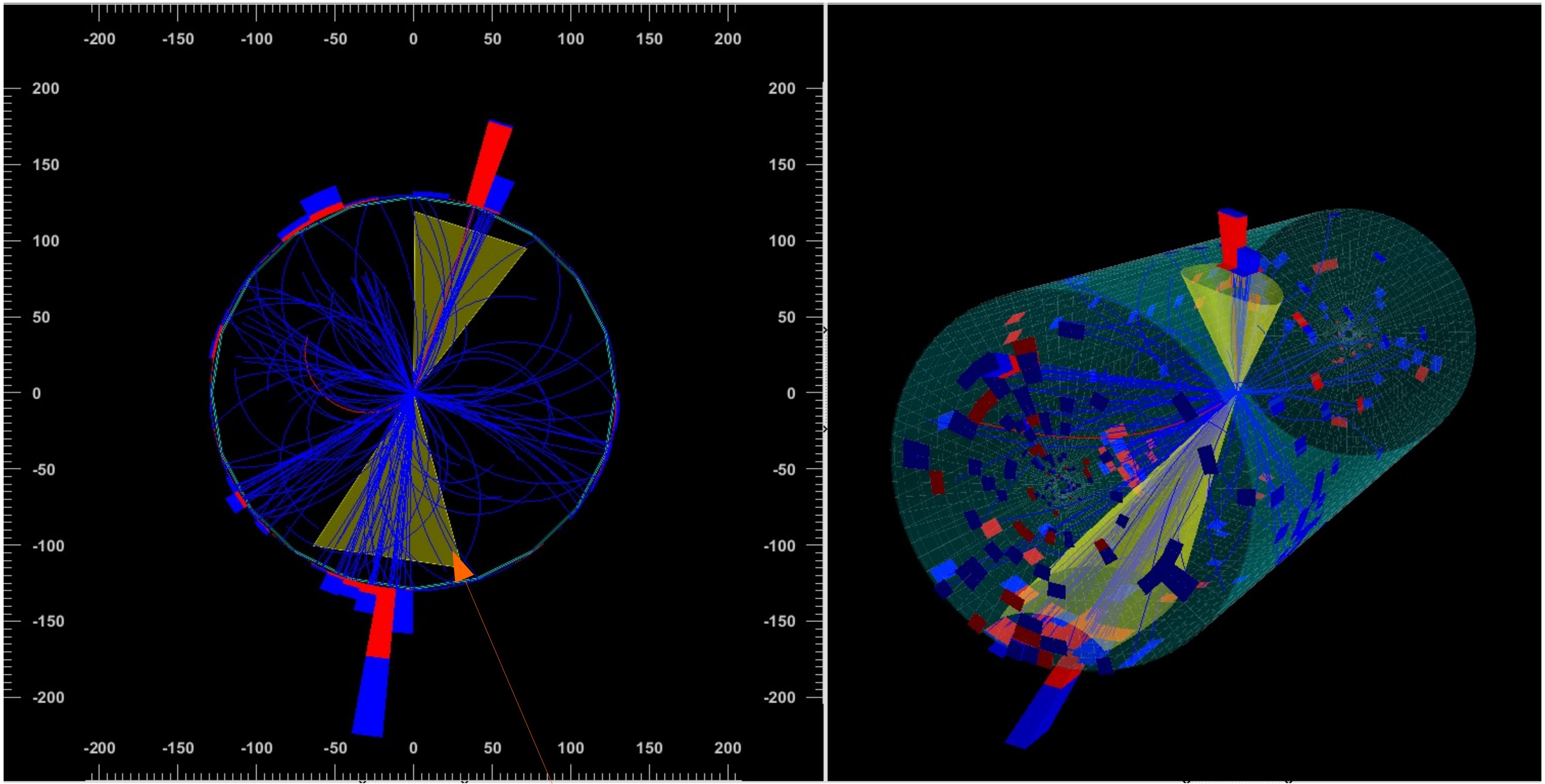
Phys. Rev. D81 (2010) 114038 S.C. J.Proudfoot





- For ~10 TeV object, typical opening angle between q, $\bar{q}$ and b from t ($\bar{t}$) is 5 degree
- "Highly boosted" regime: decay products are inside "standard" jets with R=0.5
- Event kinematics → "back-to-back" jets
  - top decays form a narrow "core"
  - large final-state gluon radiation introduces extra smearing (Snowmass13, arXiv:1307.6908)

Zprime (10 TeV)→ $t\bar{t}$. Fast detector simulation using Delphes



anti-kT jets with R=0.5

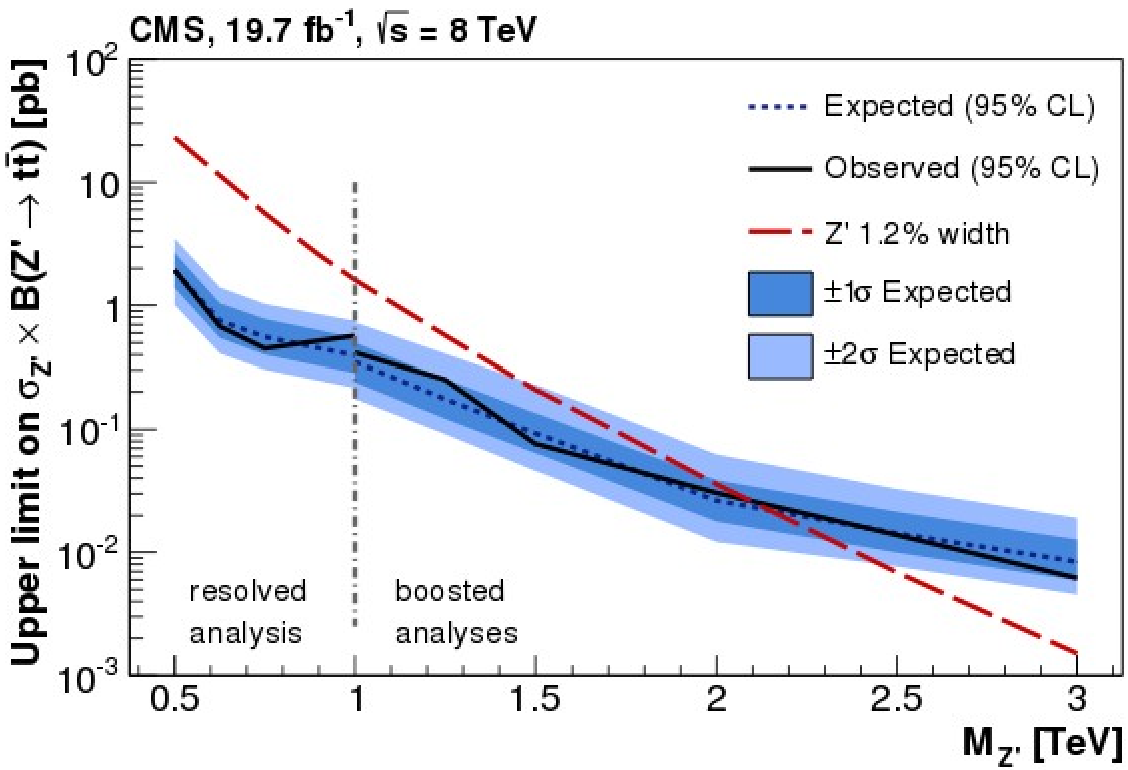
Current landscape of experimental searches

- **8 TeV: ATLAS & CMS** (CERN-PH-EP-2013-032, Phys.Rev.Lett. 111 (2013) 211804)
  - ATLAS:
    - A narrow leptophobic (narrow) Z' is excluded for M<1.7 TeV
    - KK excitation is excluded up to M=2.1 TeV
    - Upper limits: 0.03 pb up to 3 TeV
  - CMS:
    - Z' is excluded up to 2 TeV
    - KK excitation up to 2.5 TeV
  - → Methods: lepton+jets channel:
    - resolved+ some boosted technique (HepTopTagger)

- **14 TeV** for pp with 3 ab^{-1} (Snowmass13, K.Agashe et al, arXiv:1309.7847)
  - Masses < 4-5 TeV can be excluded (depends on reconstruction scenario)

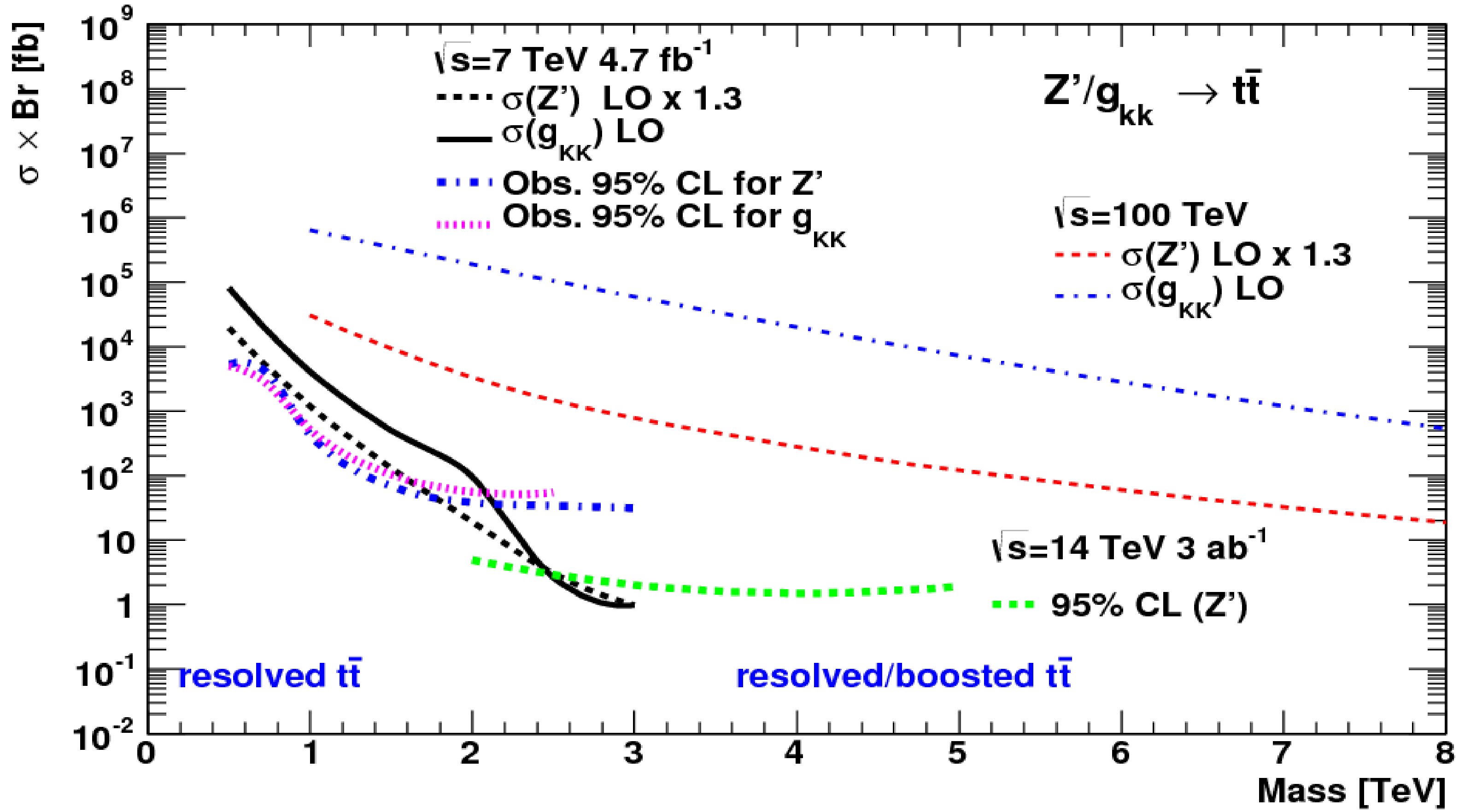
- Region with M(X)>5 TeV is new territory for such searches
- Lepton+jets reconstruction will be very difficult due to large overlap of decay products (especially for e+/e-)

Current landscape of experimental searches



Isolated lepton (muon or electron) is required

Current landscape of experimental searches



- **Exclusion limits for Z' up to 5 TeV using:**
  - HL-LHC (3 ab-1)
  - a mix of "resolved" and "boosted" techniques (typically requires isolated μ/e)

Goals and analysis plan for 100 TeV collider studies

- **Exploring the unexplored. Use ~10-20 TeV mass range**
- **Using MC simulations, set model-independent sensitivity limits for observation of a "generic" $t\bar{t}$ resonance assuming 10 ab^{-1} (10,000 fb^{-1})**
- **Use Z' and g_{KK} simulations as examples of expected "signal"**
  - Z' is narrow (Γ/M ~ 3%) while g_{KK} is broad (Γ/M ~ 16%)
- **Use basic substructure techniques to deal with background**
  - irreducible $t\bar{t}$ background and QCD dijet background
- **Use a b-tagging with reasonable assumption on efficiency and fake rates**
- **No detector simulation**
  - Our limits are for the best-possible scenarios for $X \to t\bar{t}$ reconstruction
  - Be careful in extracting limits on the production of Z'/g_{KK}
    - Leptonic decays may have better chances for detection!
    - See, for example D.Hayden, R.Brock, C.Willis (2013) arXiv:1308.5874

MC simulation

- **Signal (LO QCD). PYTHIA8**
  - $f\bar{f} \rightarrow Z0'$ with M=8,10,12,14,16,18,20 TeV. Code 3001. Pure Z' contribution. Γ/M=3%
    - cross section scaled by the k-factor 1.3 (careful here → using 8 TeV CM energy!)
  - $q\bar{q} \rightarrow g_{KK}$ with M=8,10,12,14,16,18,20 TeV. Code 5006. Pure g_{KK} contribution. Γ/M=16%
    - cross section is at LO

- **Background processes:**
  - PYTHIA8 for QCD backgrounds
    - NLOjet++ (NLO) to extract the k-factor (MSTW2008nlo68cl for PDF)
  - HERWIG++ x k-factor as alternative (contain W/Z brem. events)
  - SM $t\bar{t}$ process was generated with Madgraph (MSTW2008nlo68cl for PDF)
    - NLO QCD+ HERWIG6
  - PYTHIA8 for all SM boson processes (like Z/W+jets)
    - Not too realistic, but the usage of “realistic” ALPGEN should not change conclusions

Software Monte Carlo toolkit for this study

- **Monte Carlo samples from the HepSim repository:**
  - http://atlaswww.hep.anl.gov/hepsim/
  - Select p → ← p then 100 TeV

hep-ph > arXiv:1403.1886

Show all

p →← p
7 TeV
8 TeV
13 TeV
14 TeV
33 TeV
100 TeV

e →← e
500 GeV

e →← p
920 GeV

HepSim

Repository with predictions for HEP experiments

Selected: pp collisions, 100000 GeV energy, all type

This is a new HepSim database. For more datasets use the Old HepSim repository

Show 25 entries

Previous 1 2 Next Search:

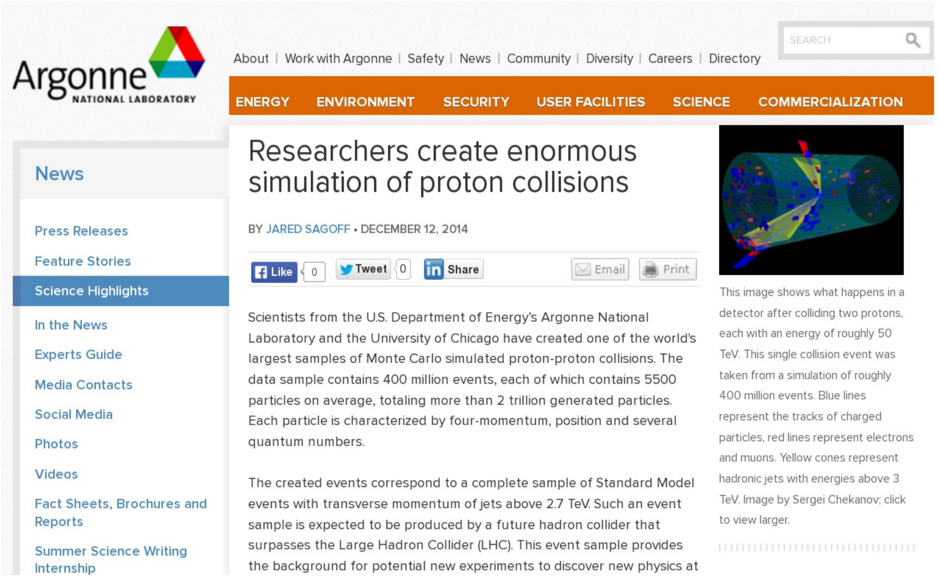
Id	→←	E (GeV)	Name	Generator	Process	Topic	Info	Url
1	pp	100000.0	higgs_pythia8_100tev	PYTHIA8	gg2Httbar and qqbar2Httbar	Higgs	Info	URL link
2	pp	100000.0	higgs_ttbar_mg5	MADGRAPH+HERWIG6	Higgs+ttbar (NLO+PS)	Higgs	Info	URL link
3	pp	100000.0	kkgluon_ttbar_1tev_pythia8	PYTHIA8	KKgluon (1 TeV) to ttbar	Exotic	Info	URL link
4	pp	100000.0	kkgluon_ttbar_4tev_pythia8	PYTHIA8	KKgluon (4 TeV) to ttbar	Exotic	Info	URL link
7	pp	100000.0	qcd_herwigpp_pt2700	HERWIG++	All dijet QCD events	SM	Info	URL link
8	pp	100000.0	kkgluon_ttbar_8tev_pythia8	PYTHIA8	KKgluon(8 TeV) to ttbar	Exotic	Info	URL link
9	pp	100000.0	kkgluon_ttbar_16tev_pythia8	PYTHIA8	KKgluon (16 TeV) to ttbar	Exotic	Info	URL link
10	pp	100000.0	kkgluon_ttbar_20tev_pythia8	PYTHIA8	KKgluon (20 TeV) to ttbar	Exotic	Info	URL link
11	pp	100000.0	qcd_pythia8_pt300	PYTHIA8	All dijet QCD events	SM	Info	URL link
12	pp	100000.0	qcd_pythia8_pt900	PYTHIA8	All dijet QCD events	SM	Info	URL link
13	pp	100000.0	qcd_pythia8_pt2700	PYTHIA8	All dijet QCD events	SM	Info	URL link
14	pp	100000.0	qcd_pythia8_pt8000	PYTHIA8	All dijet QCD events	SM	Info	URL link
15	pp	100000.0	ttbar_mg5	MADGRAPH+HERWIG6	p p > t t~ [QCD] (ttbar at NLO)	Top	Info	URL link
16	pp	100000.0	ttbar_pt2500_mg5_lo	MADGRAPH+HERWIG6	p p > t t~ (ttbar at LO)	Top	Info	URL link
20	pp	100000.0	ttbar_pythia8_pt900	PYTHIA8	g g -> t tbar, q qbar -> t tbar	Top	Info	URL link
21	pp	100000.0	ttbar_pythia8_pt300	PYTHIA8	g g -> t tbar, q qbar -> t tbar	Top	Info	URL link
22	pp	100000.0	ttbar_pythia8_pt2700	PYTHIA8	g g -> t tbar, q qbar -> t tbar	Top	Info	URL link
23	pp	100000.0	ttbar_pythia8_pt8000	PYTHIA8	g g -> t tbar, q qbar -> t tbar	Top	Info	URL link
24	pp	100000.0	ttbar_mcfm_100tev	MCFM	ttbar production at NLO	Top	Info	URL link

Data samples & analysis program are public

MC samples for this study

- http://atlaswww.hep.anl.gov/hepsim/

World's largest public MC sample hosted by HepSim used in this study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Researchers create enormous simulation of proton collisions

BY JARED SAGOFF • DECEMBER 12, 2014

Scientists from the U.S. Department of Energy's Argonne National Laboratory and the University of Chicago have created one of the world's largest samples of Monte Carlo simulated proton-proton collisions. The data sample contains 400 million events, each of which contains 5500 particles on average, totaling more than 2 trillion generated particles. Each particle is characterized by four-momentum, position and several quantum numbers.

The created events correspond to a complete sample of Standard Model events with transverse momentum of jets above 2.7 TeV. Such an event sample is expected to be produced by a future hadron collider that surpasses the Large Hadron Collider (LHC). This event sample provides the background for potential new experiments to discover new physics at

This image shows what happens in a detector after colliding two protons, each with an energy of roughly 50 TeV. This single collision event was taken from a simulation of roughly 400 million events. Blue lines represent the tracks of charged particles, red lines represent electrons and muons. Yellow cones represent hadronic jets with energies above 3 TeV. Image by Sergei Chekanov; click to view larger.

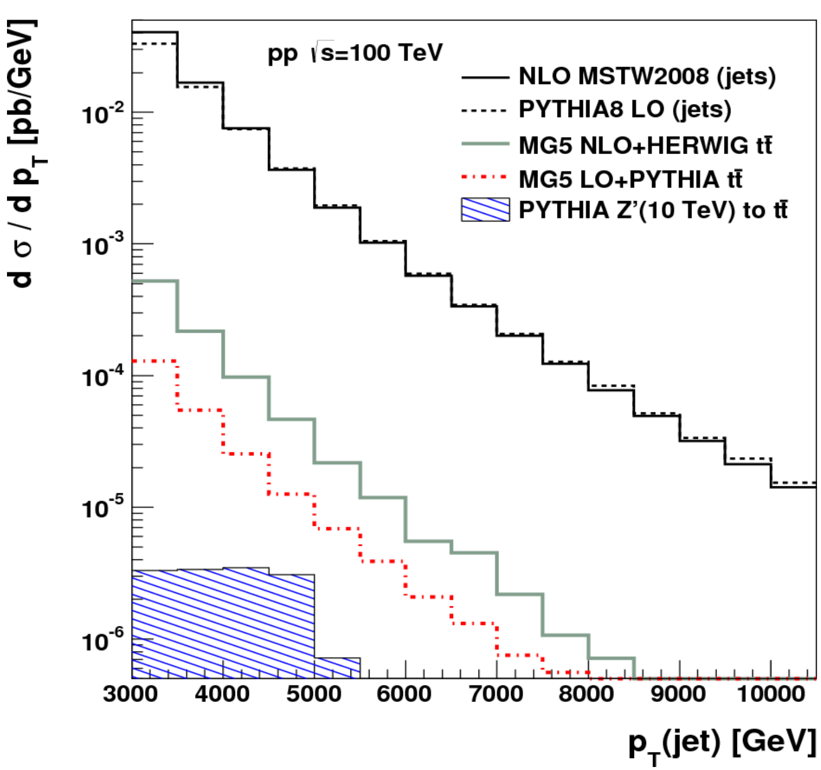
MC event samples for Z' / g_{KK} studies:

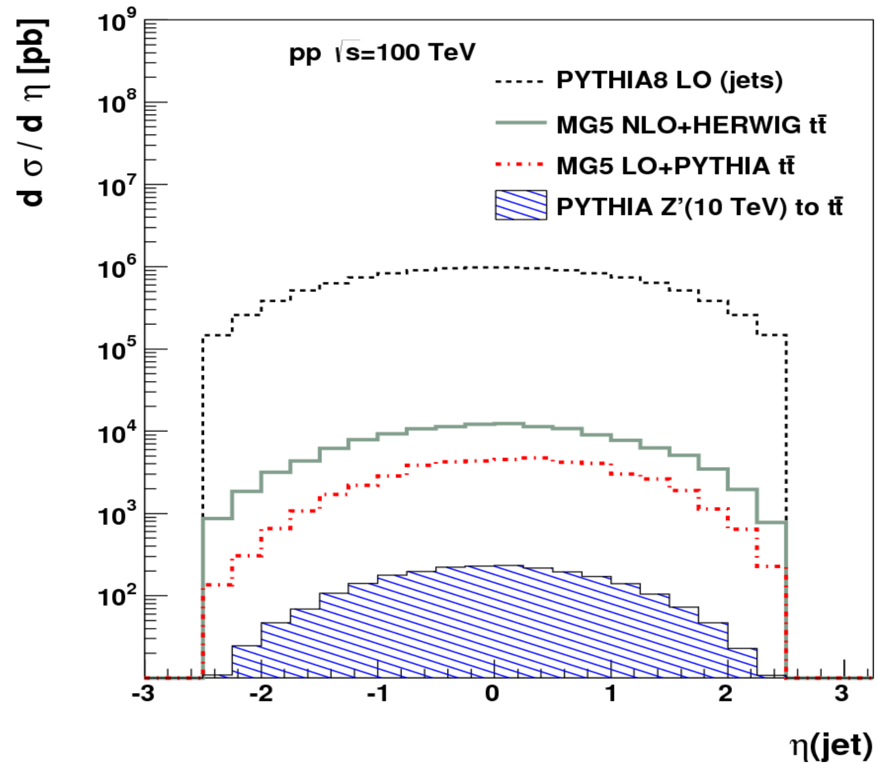
- qcd_herwigpp_pt2700
- qcd_pythia8_pt2700
- ttbar_pythia8_pt2700
- pythia10tev_wjet2700
- ttbar_pt2500_mg5
- ttbar_pt2500_mg5_lo
- zprime*_pythia8
- kkgluon_ttbar*_pythia8

Includes the description of how to:
- download samples
- build an analysis program
- run fast detector simulation (Delphes)

Pythia8 dijets. Int. luminosity ~10 ab^{-1}
0.4 billion pp events at 100 TeV

Kinematic distributions



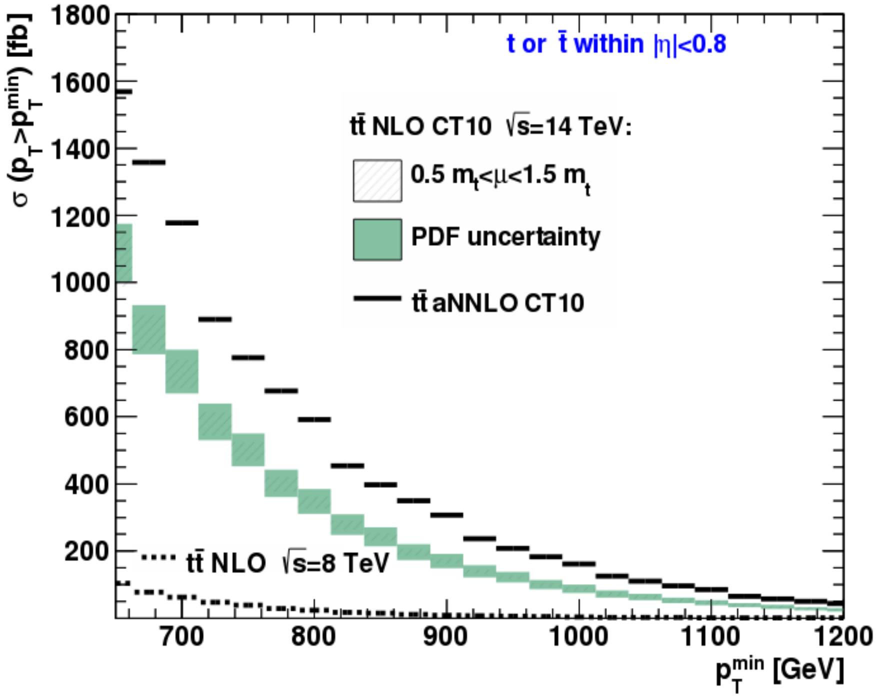


- Jets reconstructed using antiKT5 (R=0.5) from FastJet
- pT(jet)>2.7 TeV and |eta|<2.5
- The k-factor for dijets is ~10%, but large for $t\bar{t}$ (~3!)
- The distributions look as expected, with a harder pT spectrum for Z'(10 TeV)

Do we understand $t\bar{t}$ at large pT?

B. Auerbach, S.C., N. Kidonakis
SNOW13-00027 Snowmass2013 (arXiv:1301.5810)

N. Kidonakis,
Phys. Rev. D 82, 114030



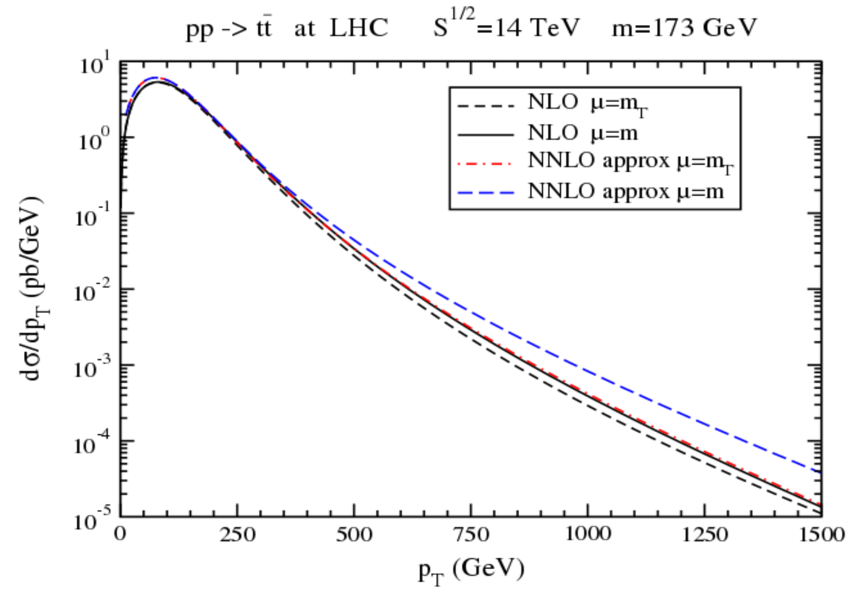
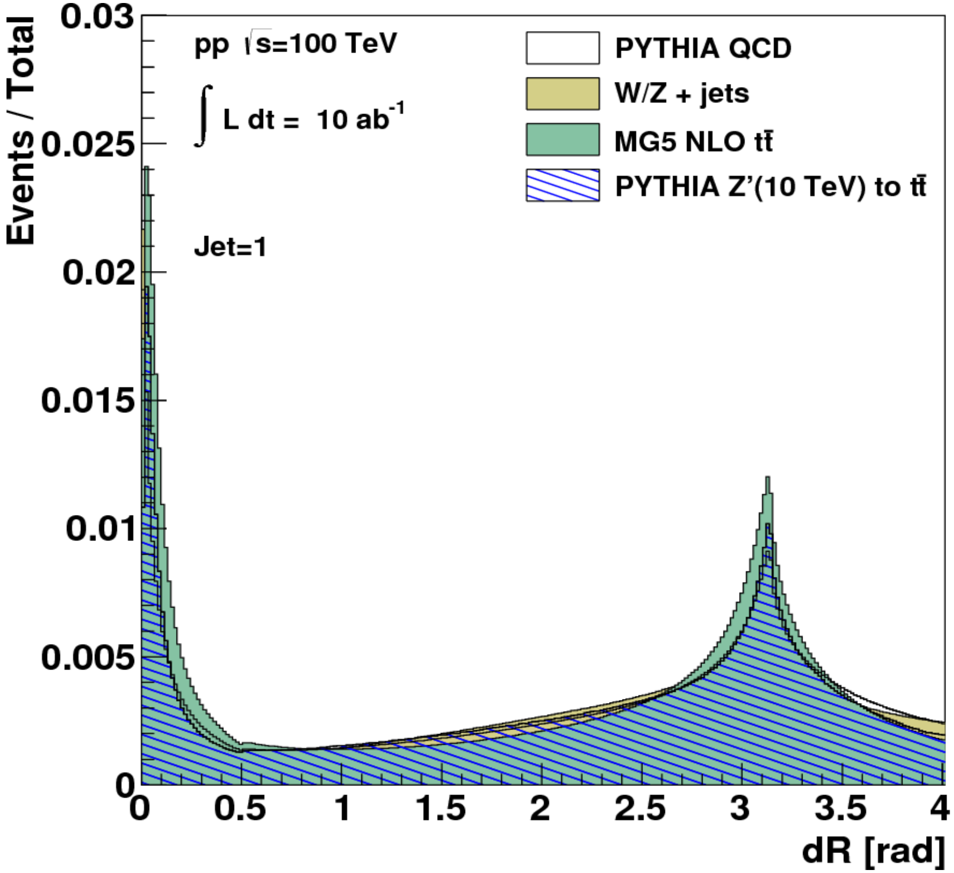


FIG. 14 (color online). The top quark p_T distribution at the LHC with $\sqrt{S} = 14$ TeV, $m = 173$ GeV, and $\mu = m$ or $\mu = m_T$ in a logarithmic plot.

- Warning: background estimates are based on NLO..
- but aNNLO corrections can large at large pT(top)

Particle distribution inside jets

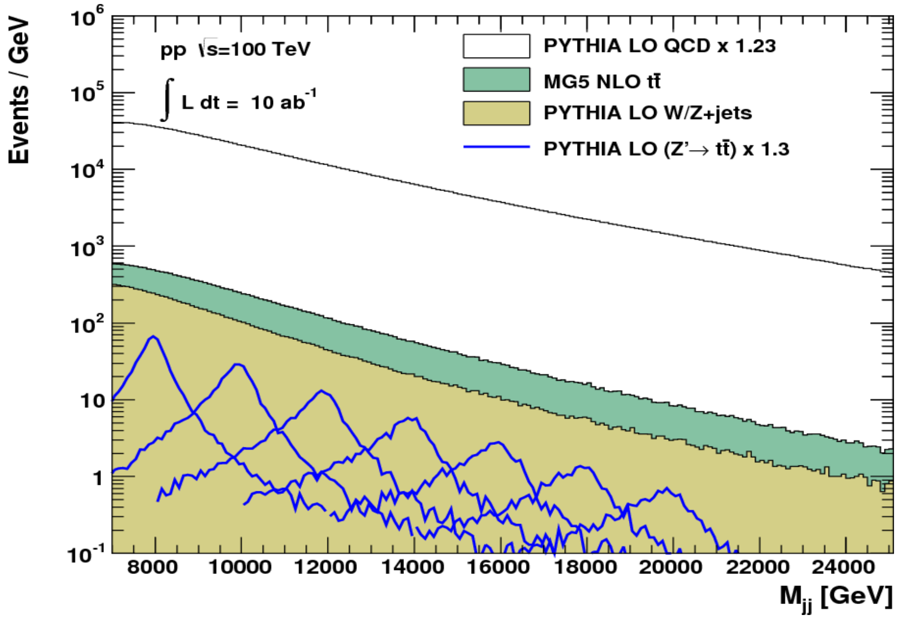


- dR – distance in φ and η between any final state particle and jet center for leading jets

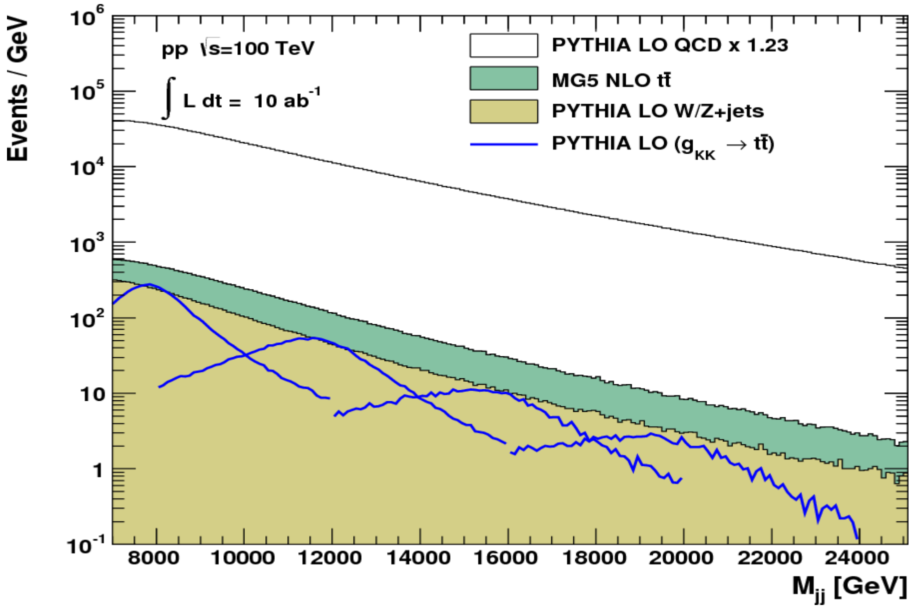
- $t\bar{t}$ jets are broader than jets from light-flavor dijets ("QCD")
- Also broader than $t\bar{t}$ from Z' (harder momentum spectrum)
- Jet size (R=0.5) is adequate for all processes

Dijet invariant mass for 10 ab^{-1}

$Z' \rightarrow t\bar{t}$



$g_{KK} \rightarrow t\bar{t}$



- Look at 2 leading jets above pT>2.7 TeV.
  - all decay channels. Semileptonic decays are included
  - add missing ET for lowest-ET jet
- Z' model leads to narrow signal (Γ/M ~ 3%)
- g_{KK} is wider (Γ/M ~ 16%) and has larger cross section

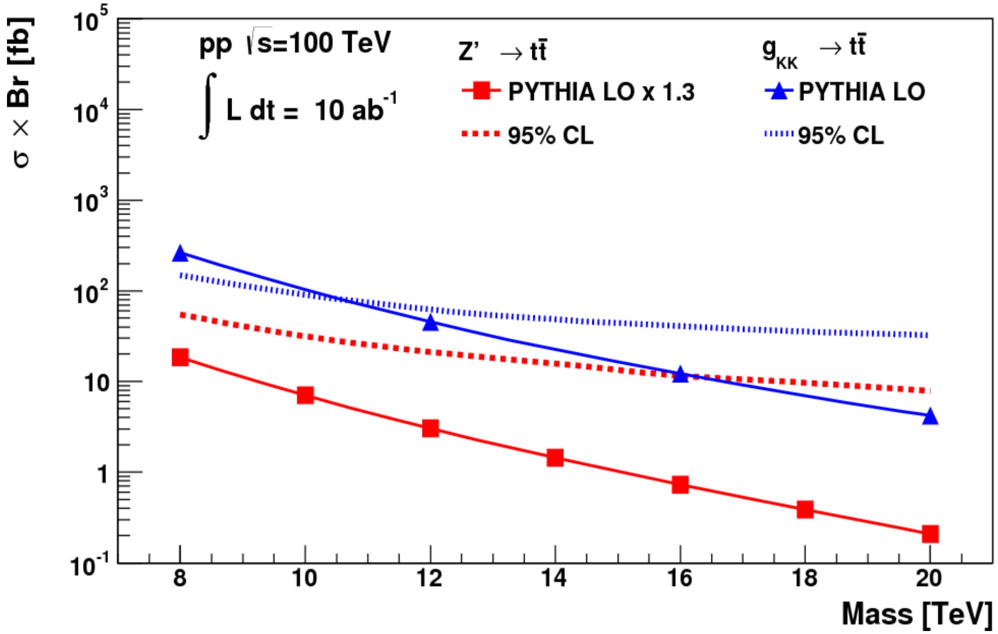
Signal(Z')/Bkg ~ 0.0007

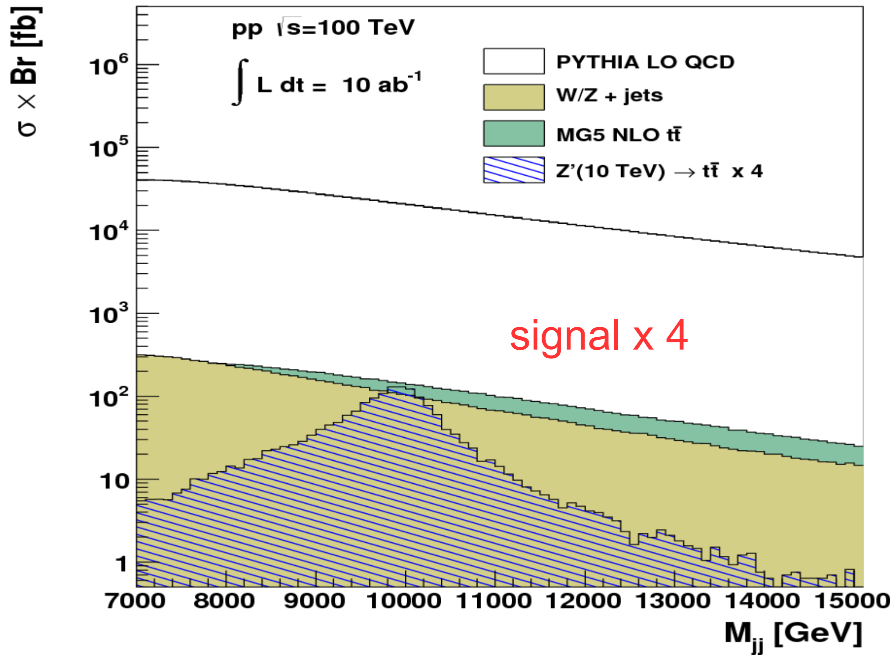
Not That Obvious:

How to reduce QCD (reducible) and $t\bar{t}$ (irreducible) background for back-to-back jet events?

Sensitivity limits (no cuts)

Example: Scale Z' cross section scaled until we see it with 95% confidence





CL_b method with treatment of statistical uncertainties to extract "sensitivity" at 95% CL ("2 σ" discovery)

→ 95% CL sensitivity is far away from the predicted cross sections for Z'!

→ Some sensitivity to g_{KK} near M=10 TeV, **S/B~0.001 → to small for realistic observation!**

Note:

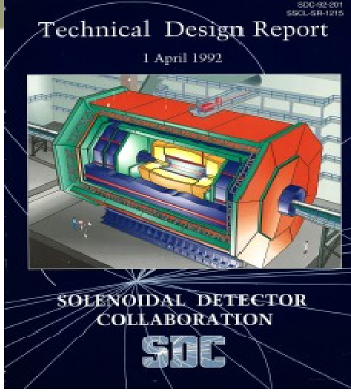
→ g_{KK} cross sections are at LO

→ assume 1.3 correction for Z'

→ **But NLO corrections can be large!** ⟶

Jun Gao, Chong Sheng Li, Bo Hua Li, Hua Xing Zhu, and C.-P. Yuan, **Phys. Rev. D 82, 014020**

Discriminating variables

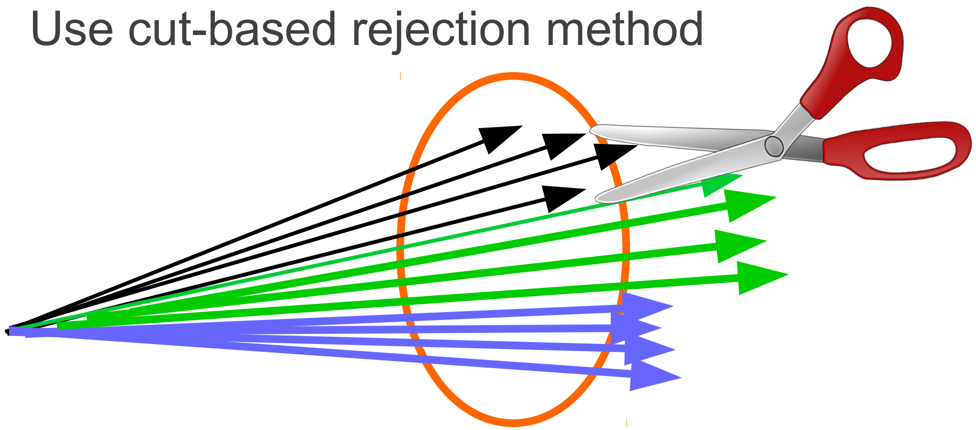


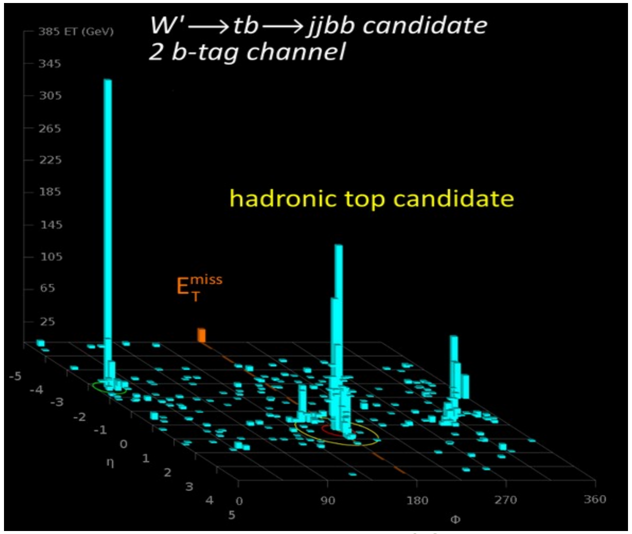
- Use jet substructure signatures (SSC-SR-1217 TDR 1992 p 3-26)
- Tremendous recent progress in advancing such approach
- Most basic variables used in this study:
  - Jet mass
  - τ_{32} and τ_{21} (N-subjettiness jet characteristics)
  - Jet shapes (eccentricity)
  - $\sqrt{d_{12}}$ splitting scale
  - R^{eff} effective jet radius (weighted with energy radial distance to jet center)
  - b-tagging assuming ~70 efficiency
  - high-pT muons
- Use cut-based rejection method

J.Thaler, K. Van Tilburg, JHEP 1103:015, 2011

S.C., J.Proudfoot, Phys. Rev. D81 (2010) 114038

J. M. Butterworth, B. E. Cox, and J. R. Forshaw, Phys. Rev. D65 (2002) 96014



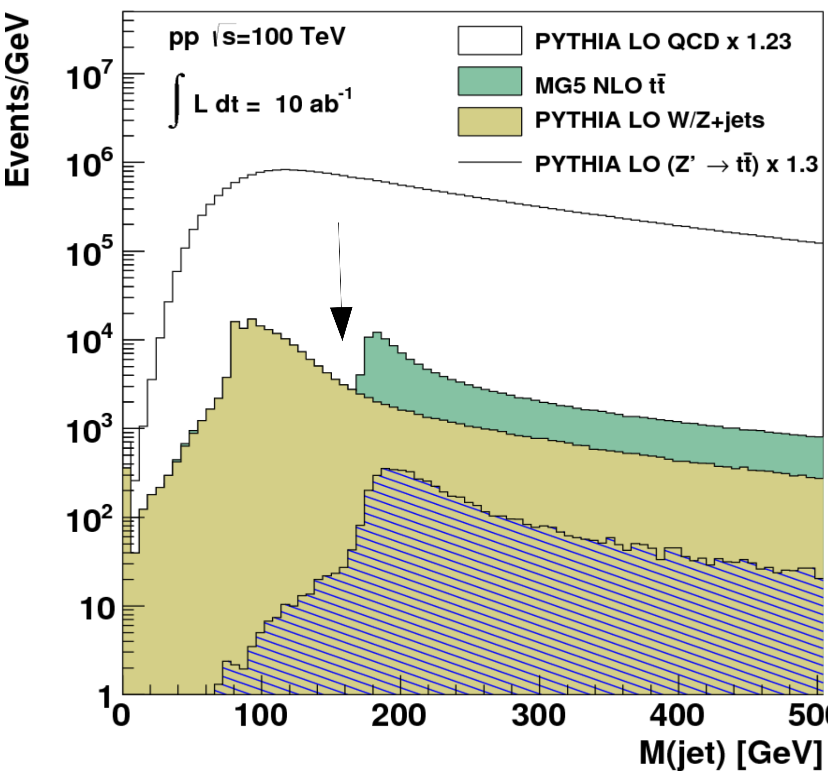


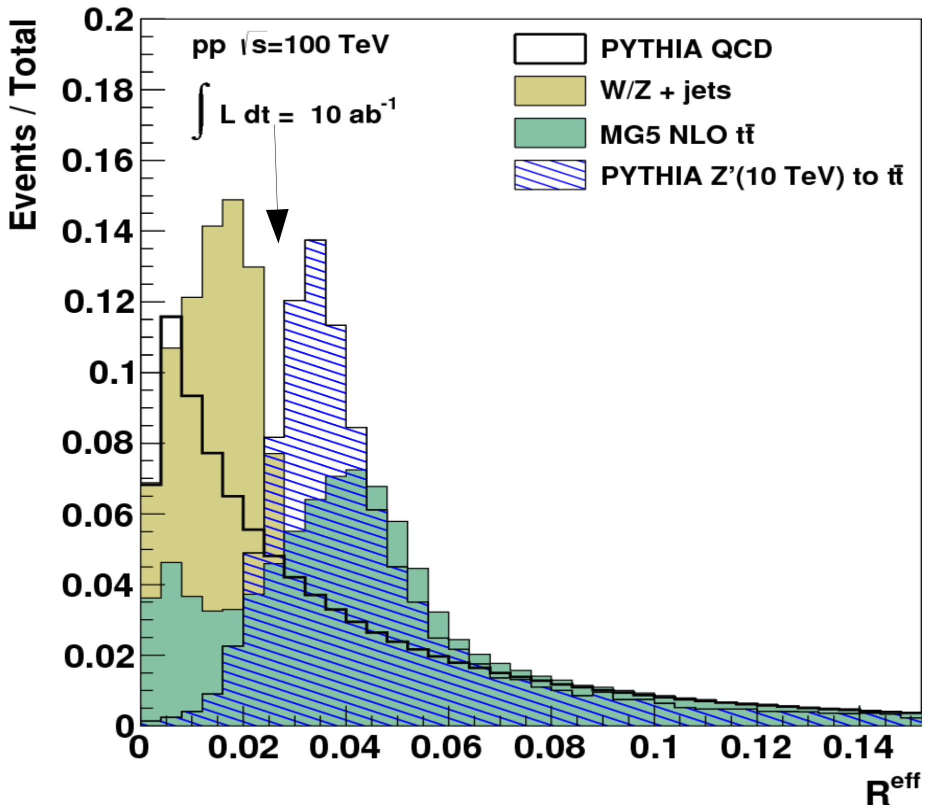
Jet mass & effective jet radius

Example of possible cuts:

- Look at jet mass of a leading in pT jet. M(jet)>140 GeV rejects:
  - boosted W/Z(+jets)
  - low mass QCD events below the Sudakov mass peak
- Effective jet radius is larger for top-initiated jets

$R_{eff} = \sum R_i \, E / E_i$

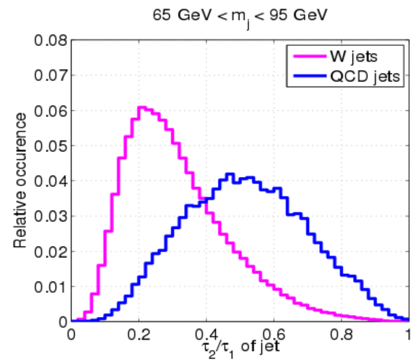


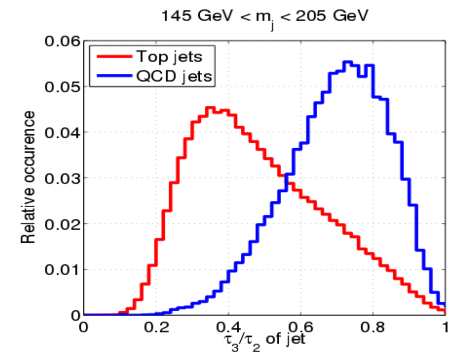


Substructure variables

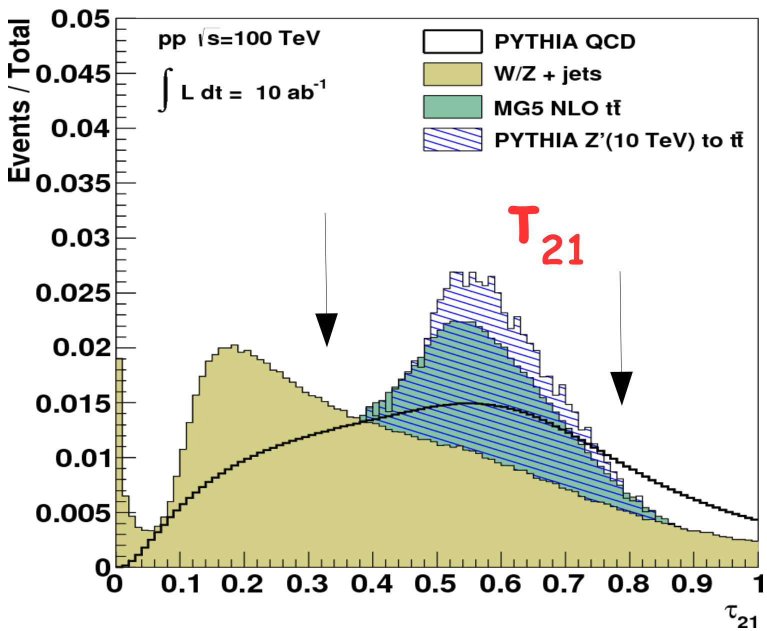
J.Thaler and K. Van Tilburg, JHEP 1103 (2011) 015

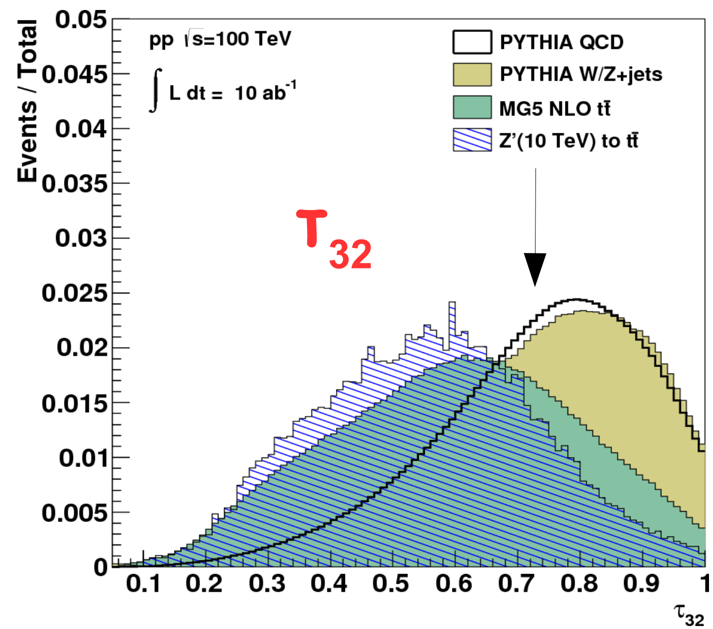
- τ_N-subjettiness - measure of the degree to which a jet can be considered as being composed of N-subjets
- $\tau_{32} = \tau_3 / \tau_2$ and $\tau_{21} = \tau_2 / \tau_1$



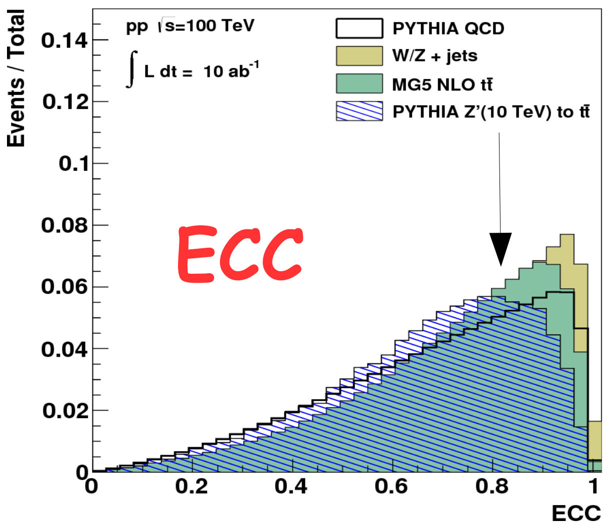


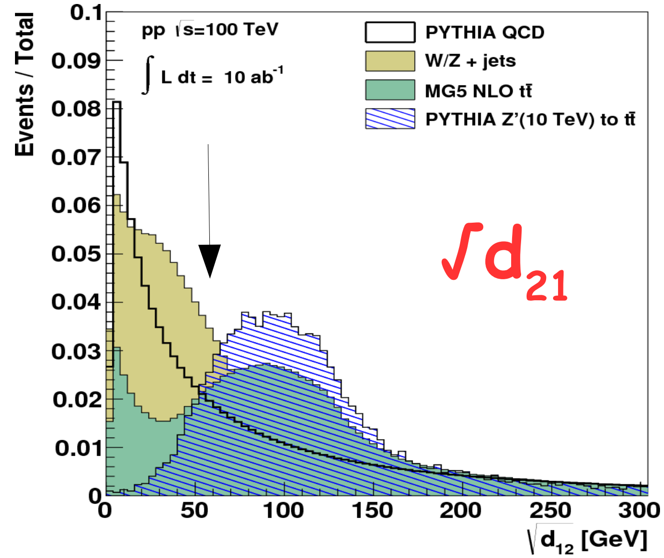
- τ_{32} >0.75 reduces QCD and boosted W/Z
- τ_{21}<0.3 reduces W/Z
- τ_{21}>0.8 reduces QCD background





Discriminating variables (lead. jet)





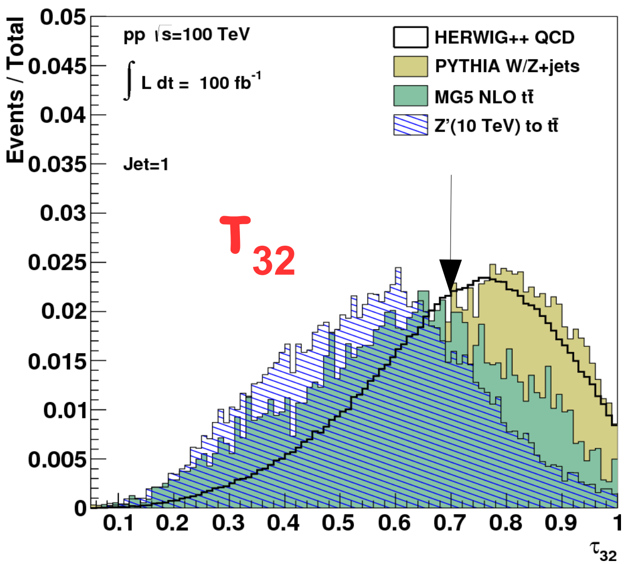
- jet eccentricity (**ECC**)- degree of elongation of jet shape
  - **ECC>0.9** rejects background
- **$\sqrt{d_{12}}$ = min (pT$_1$, pT$_2$) x dR$_{12}$** - jet splitting scale
  - **$\sqrt{d_{12}}$> 50 GeV** reduces QCD,W/Z, some $t\bar{t}$

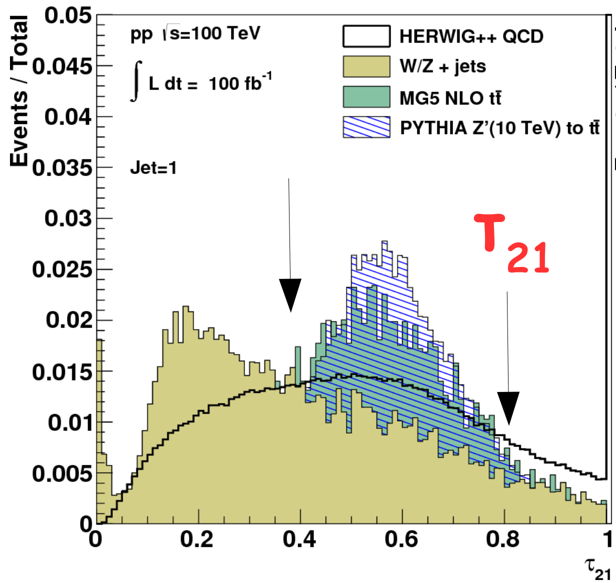
S.C., J.Proudfoot, Phys.Rev.D81:114038 (2010)

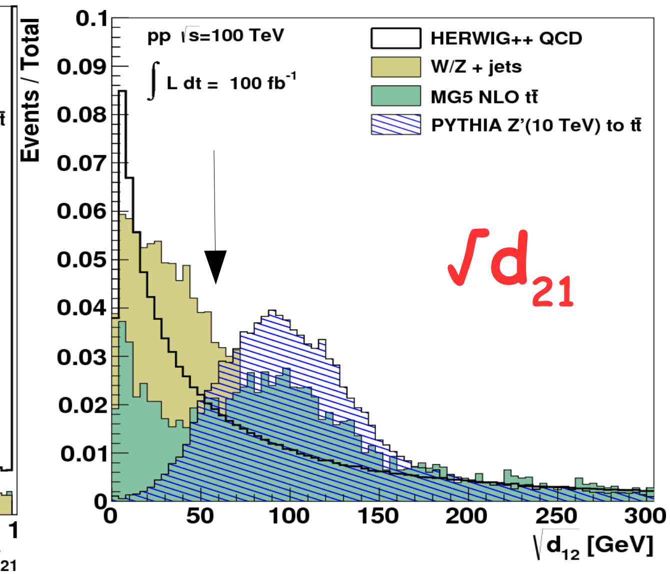
ATLAS Collaboration, JHEP, 1205, 128 (2012)

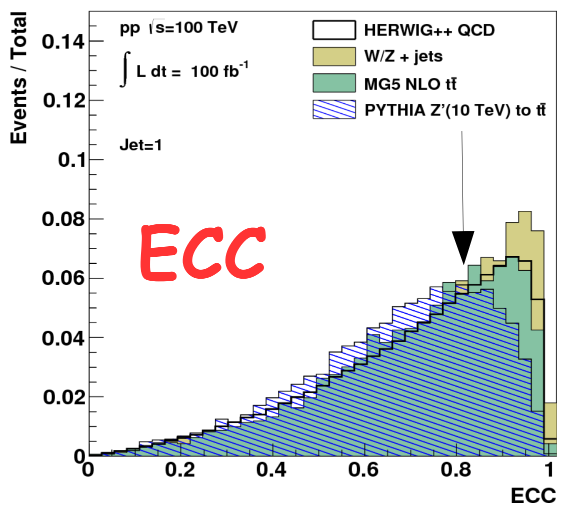
Correlation between variables:
~10% for τ_{32} , τ_{21} , mass
~30% correlation between d_{12} mass, ECC

Discriminating variables (lead. jet) PYTHIA8 → HERWIG++







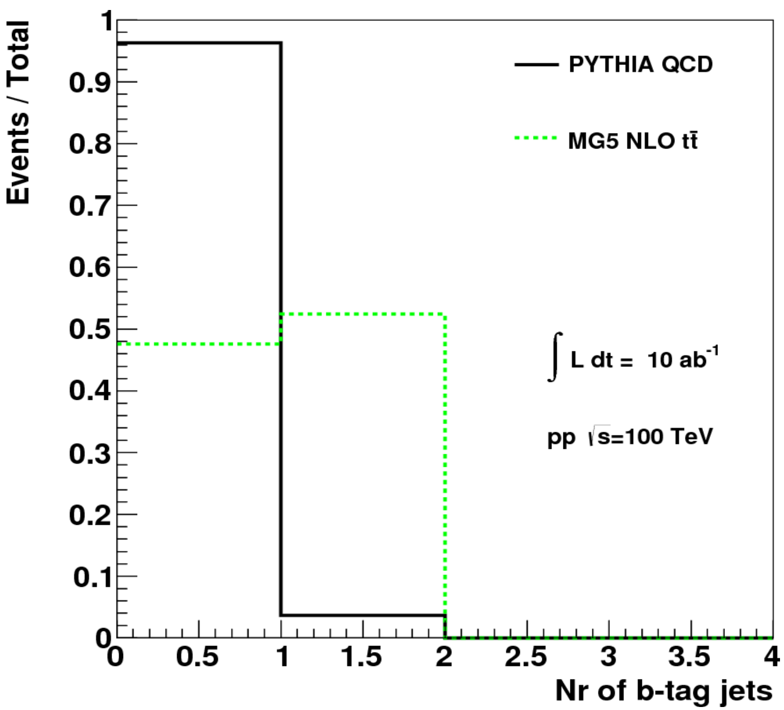


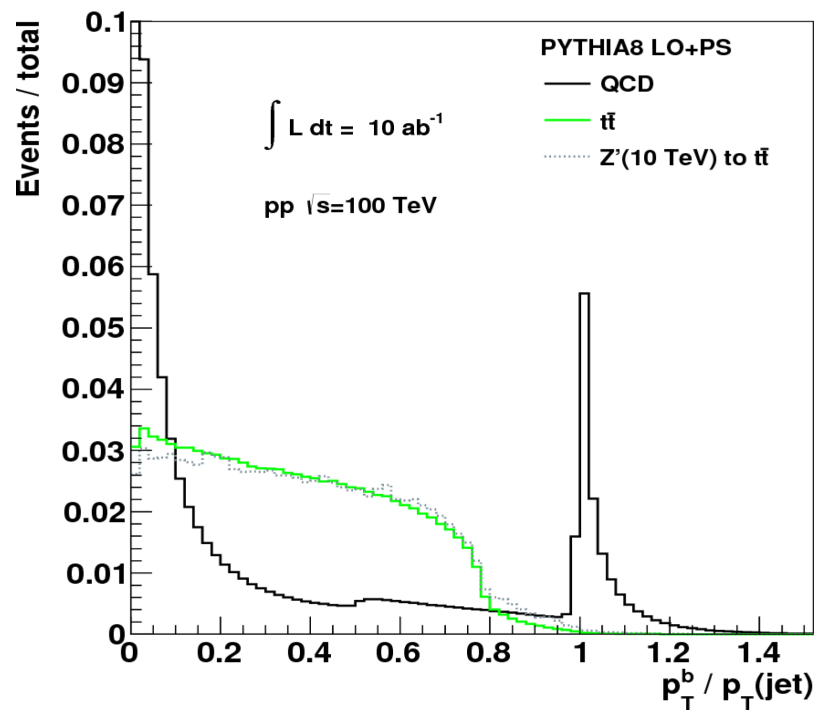
- τ_{32} **>0.75** reduces QCD and boosted W/Z
- τ_{21}**<0.3** reduces W/Z
- τ_{21}**>0.8** reduces QCD background
- $\sqrt{d_{12}}$**> 50 GeV** reduces QCD,W/Z, some $t\bar{t}$

HERWIG++ gives very similar QCD background (contains W/Z brem. events!)

b-tagging and muon pT

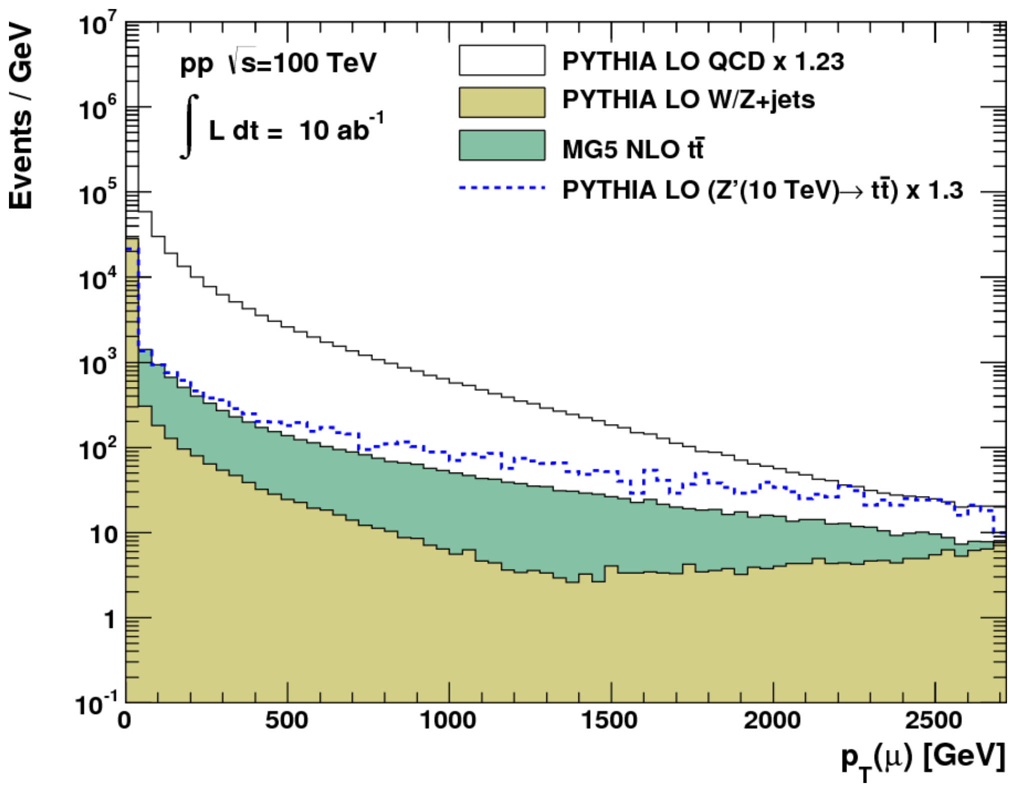
- Match antiKT5 jet with a quark using dR(eta-phi)<0.1
- Assume efficiencies and fake rates:
  - 70% efficiency for b-tagging
  - 10 % fake rate for c-quarks
  - 1% fake rate for light quarks
- b-tagging assumes $p_T^b / p_T > 0.2$





Muon p_T

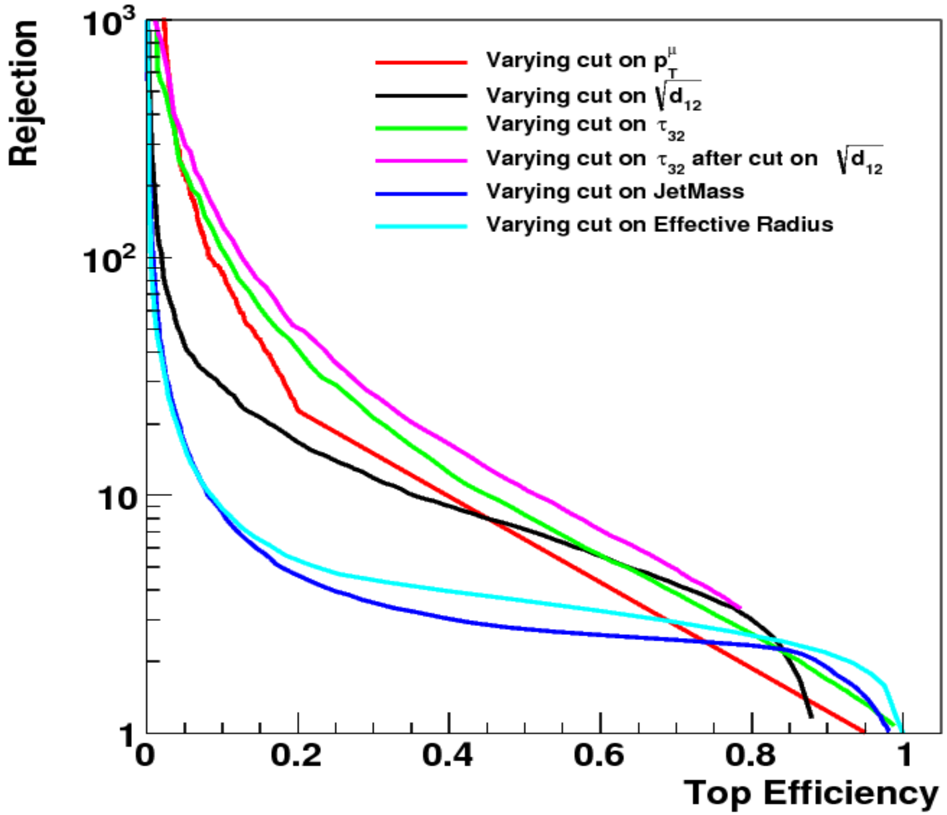
- Can we use muons to reject background?
- We can, but too low statistics for 10 ab^{-1} assuming p_T >1-2 TeV



What is rejection vs efficiency anyway for all selection variables?

Rejection vs efficiency

- Jet-mass rejection is not attractive option compared to N-subjetiness
  - For the same 50% efficiency τ_{32} has a factor of x3 better rejection than jet mass
- N-subjetiness performs better than a cut on muon



S/B ratio after b-tag and jet-shape (JS) requirements

Cuts applied for 1st jet:

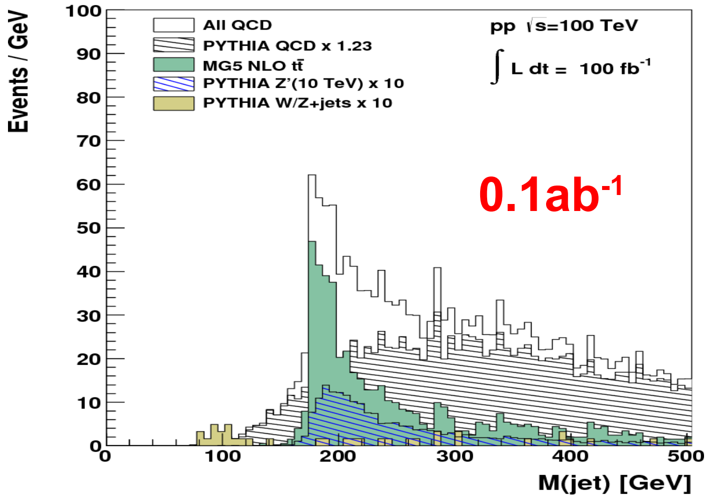
No cuts	JS	b-tag	b-tag+JS	b-tag+JS+μ
0.0007	0.0025	0.013	0.025	0.12

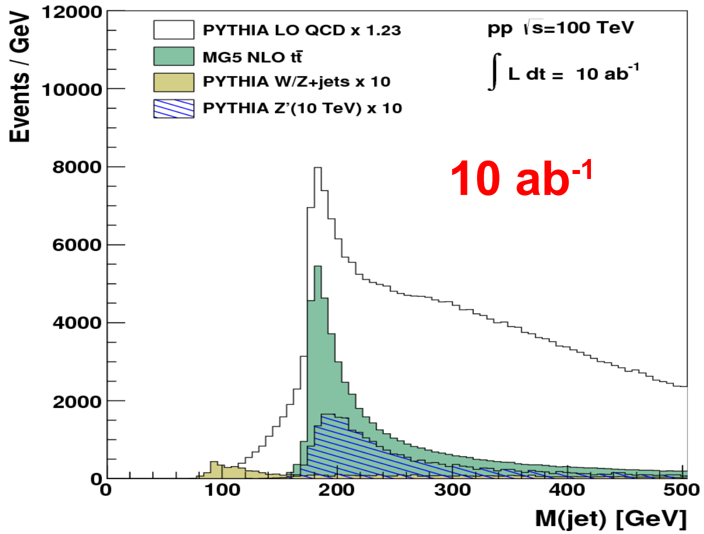
Cuts applied for 1st and 2nd jet:

No cuts	JS2	b-tag	b-tag+JS1	b-tag+JS2	b-tag+JS1+μ
0.0007	0.007	0.16	0.19	0.21	0.36

We can achieve S/B ~ 20-30% using double-b tag + jet shape cuts

Masses of jets after selection cuts





- Consider 2-jet events with pT>2.8 TeV
- "Tag" any jet with the cuts:
  - **b-tagging**
  - **τ_{32}<0.7 and 0.3<τ_{21}<0.8**
  - **$\sqrt{d_{12}}$> 50 GeV**
- Observe a bump in jet mass due to top without using cuts on the opposite jet

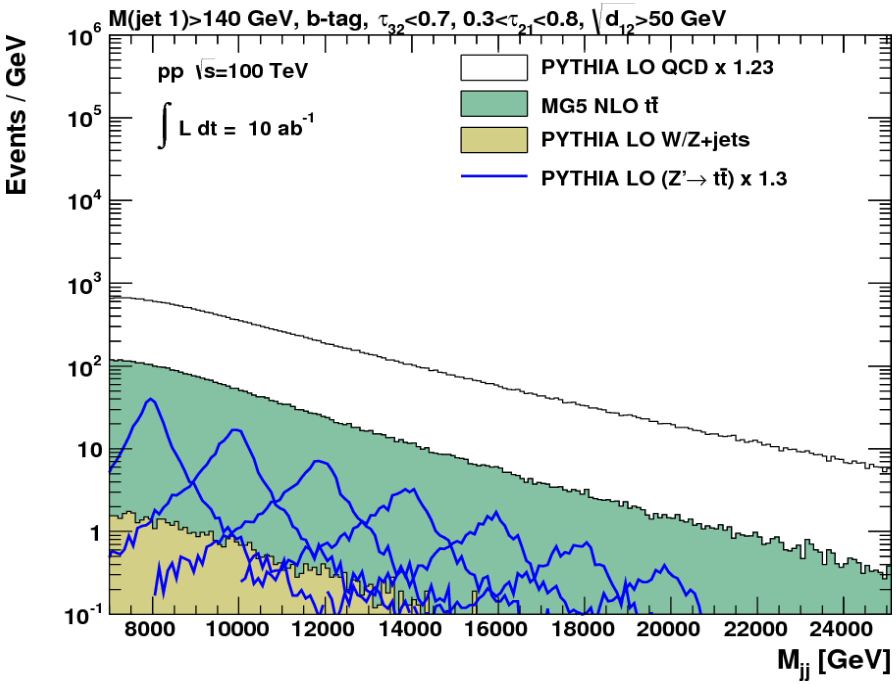
100 fb^{-1} should be enough to observe super-boosted single top quarks in fully inclusive channel t+X !
(can be $t\bar{t}$, single top and exotic decays!)

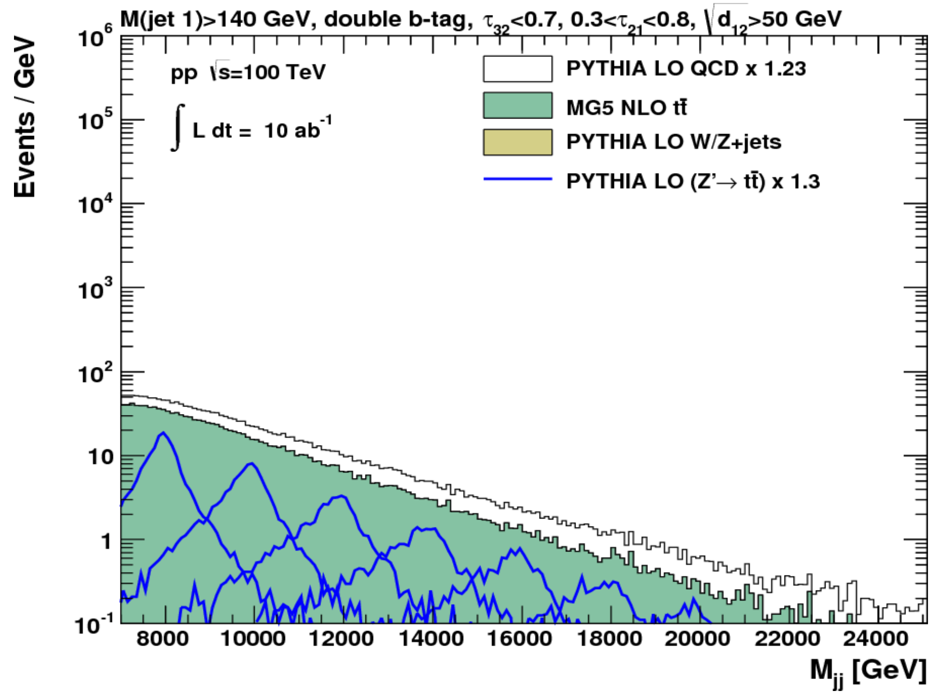
See the 14 TeV case:
B. Auerbach, S. C., N. Kidonakis
arxiv.org:1301.5810 ANL-HEP-13-05. Snowmass

White histogram: all processes (dijet, top, W/Z)

Dijet mass after selection (Z' → $t\bar{t}$)

double b-tag case





- Consider 2-jet events with pT>2.8 TeV
- Apply selection (for any jet):
  - M>140 GeV
  - b-tagging
  - τ_{32}<0.7 and 0.3<τ_{21}<0.8
  - $\sqrt{d_{12}}$ > 50 GeV

before cuts

Sig(Z')/Bkg ~ 0.0007

single-jet tag

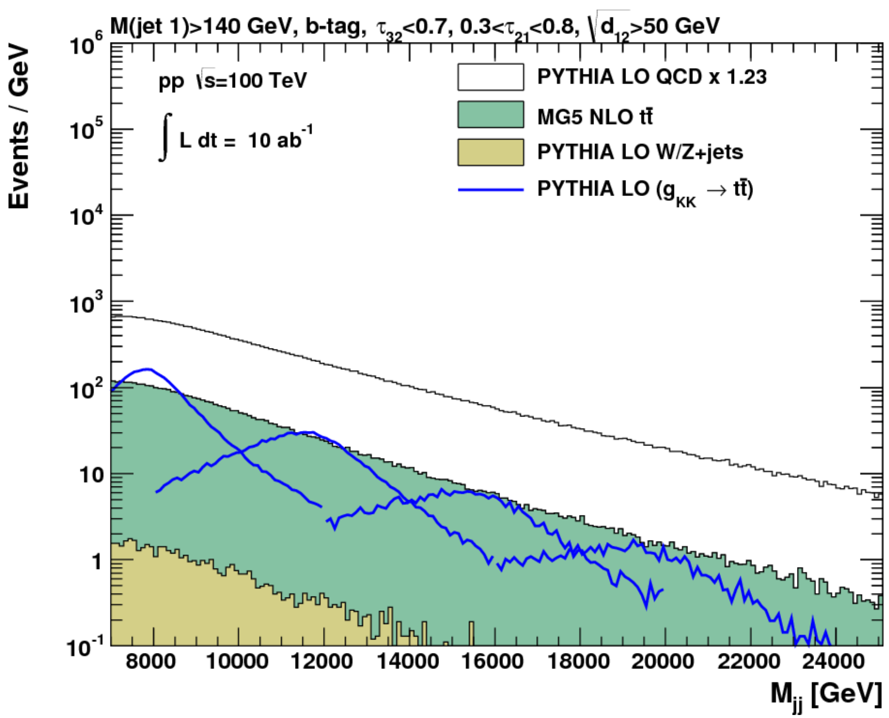
Sig(Z')/Bkg ~0.03

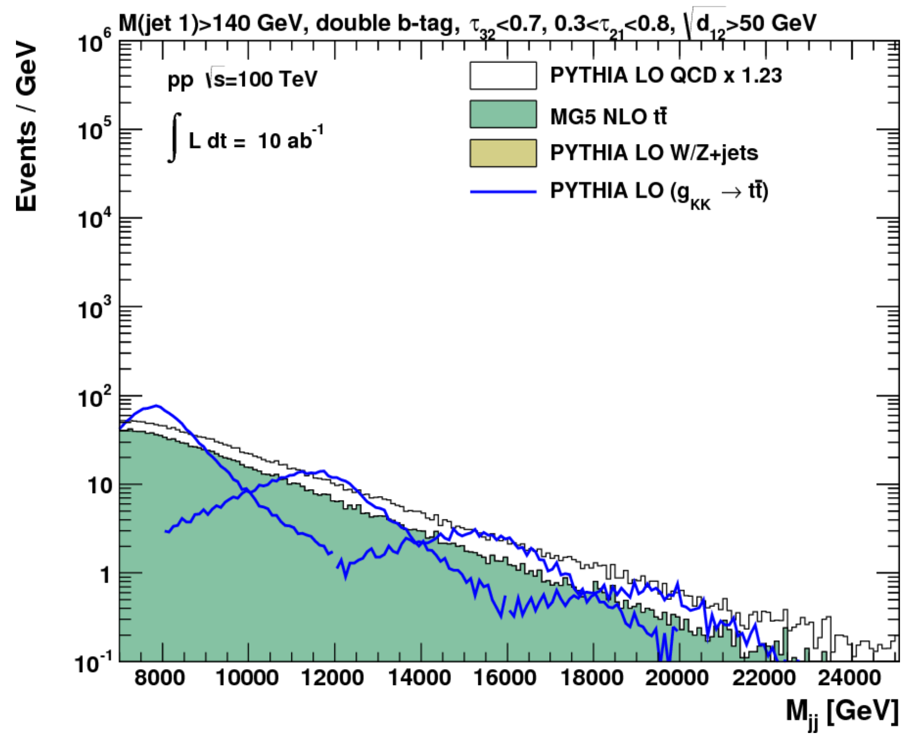
double-jet tag

Sig(Z')/Bkg ~0.2

Dijet mass after selection $(g_{kk} \rightarrow t\bar{t})$

double b-tag case





- Consider 2-jet events with pT>2.8 TeV
- Apply selection (for any jet):
  - M>140 GeV
  - b-tagging
  - τ_{32}<0.7 and 0.3<τ_{21}<0.8
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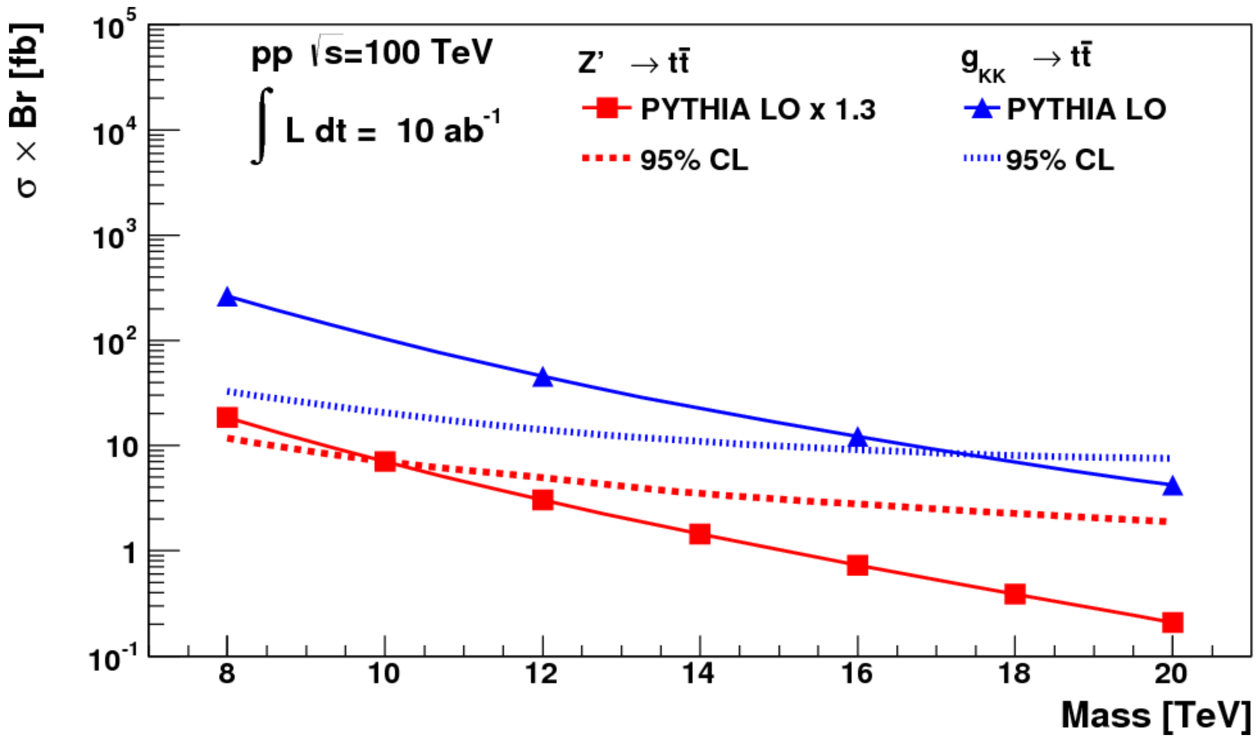
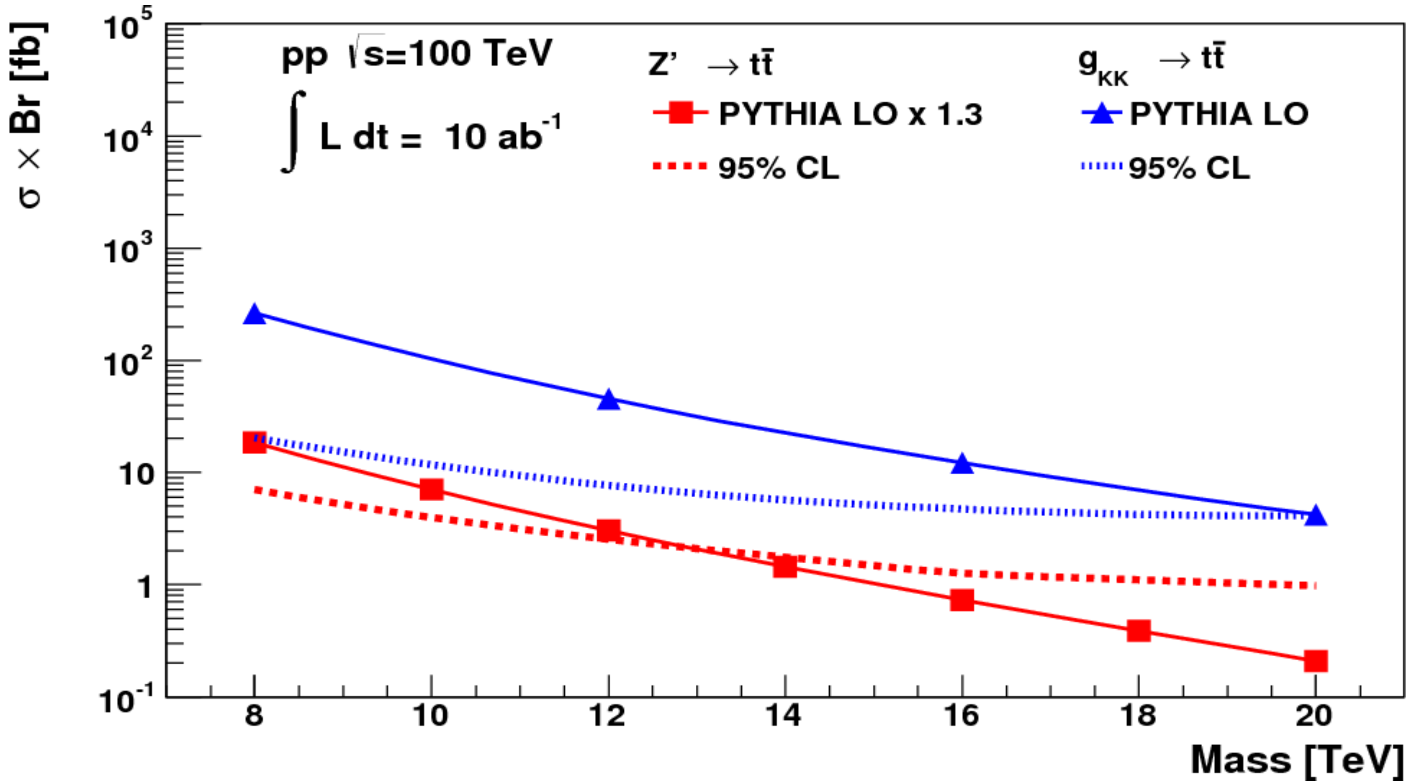
Sensitivity limits using single-jet tagging



- **95% CL sensitivity reach for 10 ab^{-1}:**
  - M~10 TeV for Z'
  - M~17 TeV for g_{KK}
- **σ x Br = 5 (10) fb for Z' (g_{KK})**
- **S/B ~ 3-5% (small!)**

Sensitivity limits using double-jet tagging



- **95% CL sensitivity reach for 10 ab^{-1}:**
  - M~13 TeV for Z'
  - M~20 TeV for g_{KK}
- **σ x Br = 2 (4) fb for Z' (g_{KK})**
- **S/B ~ 20%**

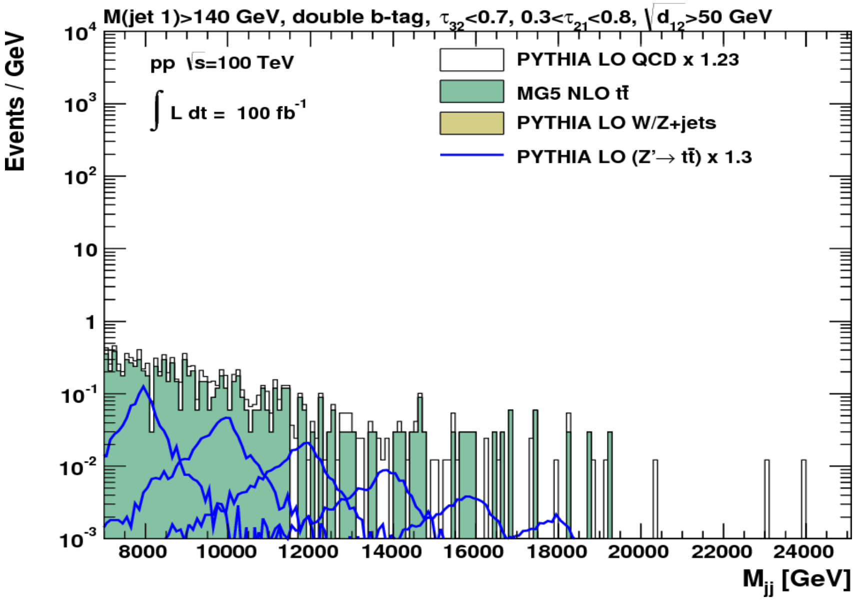
Extrapolating the results to a higher luminosity

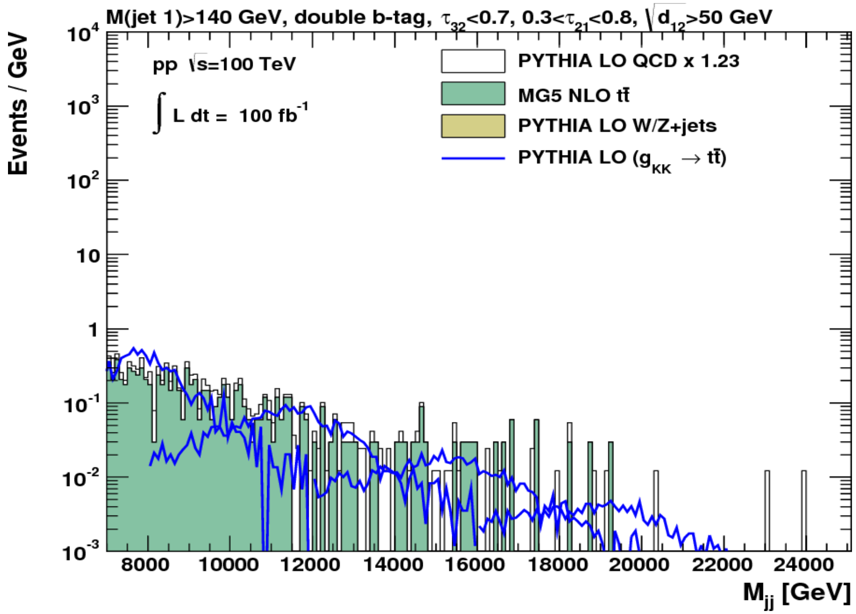
Using L=10 ab^{-1}:

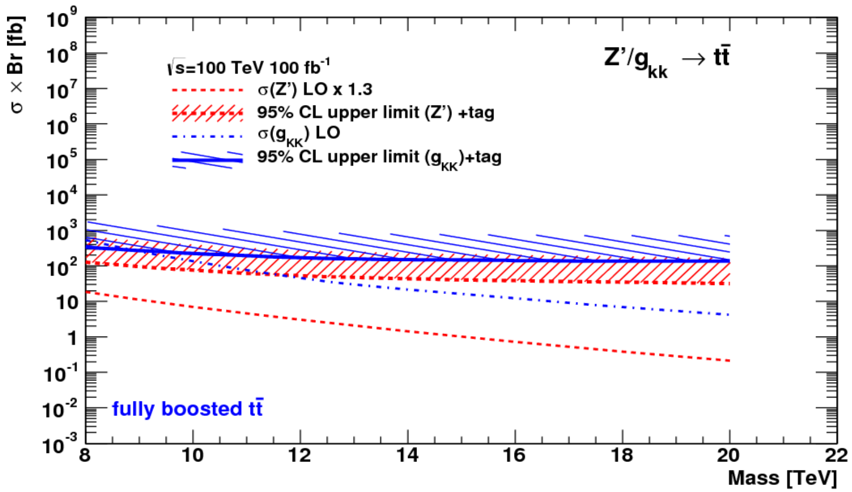
mass		$\sigma\times$Br (fb)		
(TeV)	$Z^{0\prime}$ (th.)	$Z^{0\prime}$ (exp.)	g_{KK} (th.)	g_{KK} (exp.)
8	18.46	7.00	262.3	20.2
10	7.03	3.97		
12	3.02	2.54	45.4	7.7
14	1.44	1.75		
16	0.73	1.27	12.2	4.7
18	0.39	1.10		
20	0.21	0.98	4.2	4.1

- **Use this data to extrapolate to a higher luminosities:**
- **Single jet tag:**
  - Sensitivity reach will increase to 12 TeV (30 ab^{-1}) or 16 TeV (150 ab^{-1})
- **Double jet tag:**
  - Sensitivity reach will increase to 16 TeV (30 ab^{-1}) or 19 TeV (150 ab^{-1})

Sensitivity to $t\bar{t}$ using lower int. luminosity: 0.1 ab^{-1}

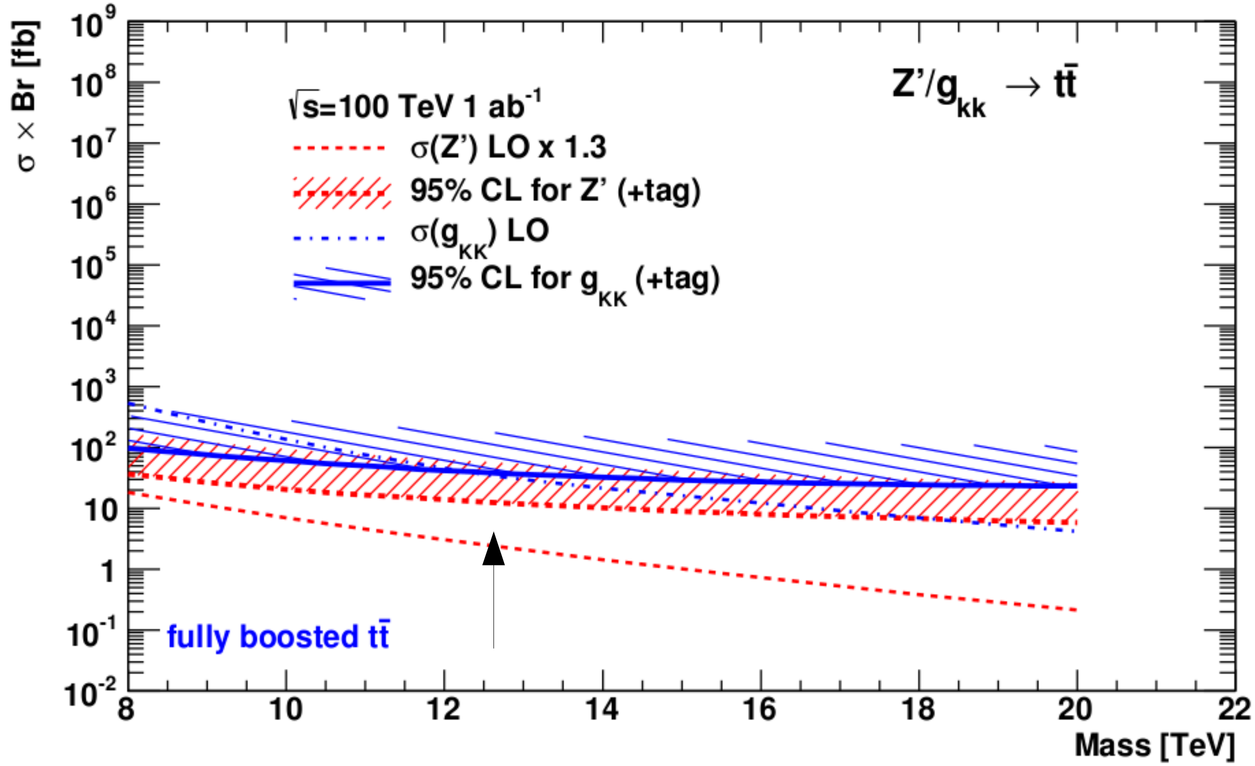






- Sensitivity reach will decrease below 10 TeV using 0.1 ab^{-1}

Sensitivity to $t\bar{t}$ using lower int. luminosity: 1 ab^{-1}



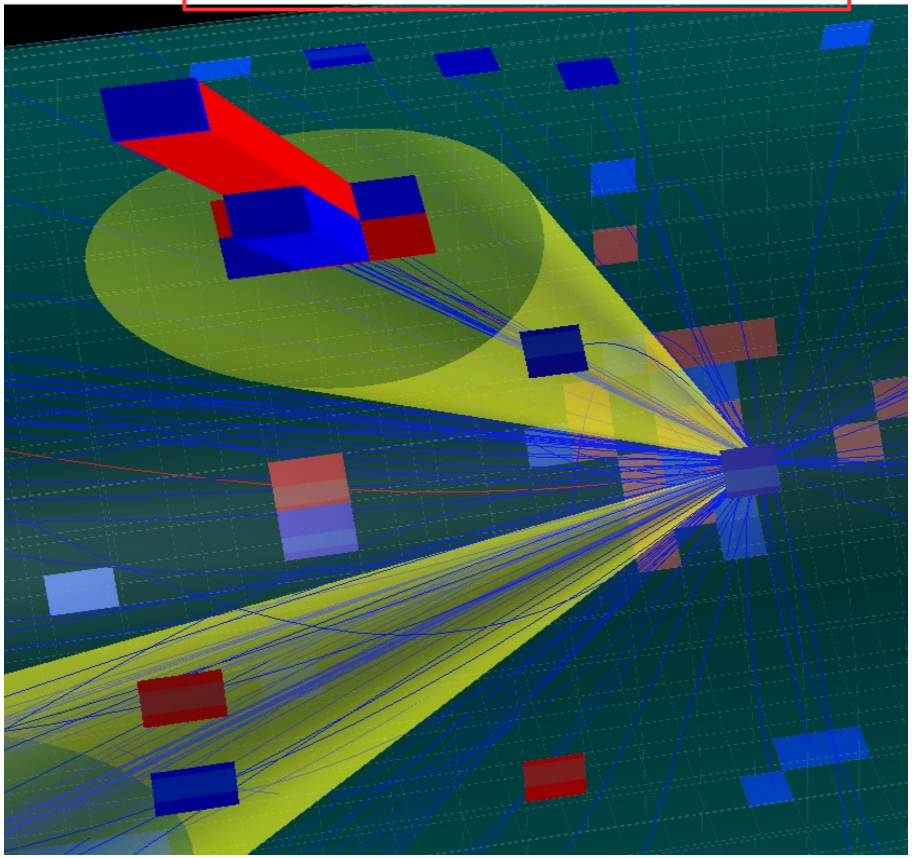
– 1 ab^{-1} is barely enough to reach 12 TeV for g_{KK}

Detector requirements

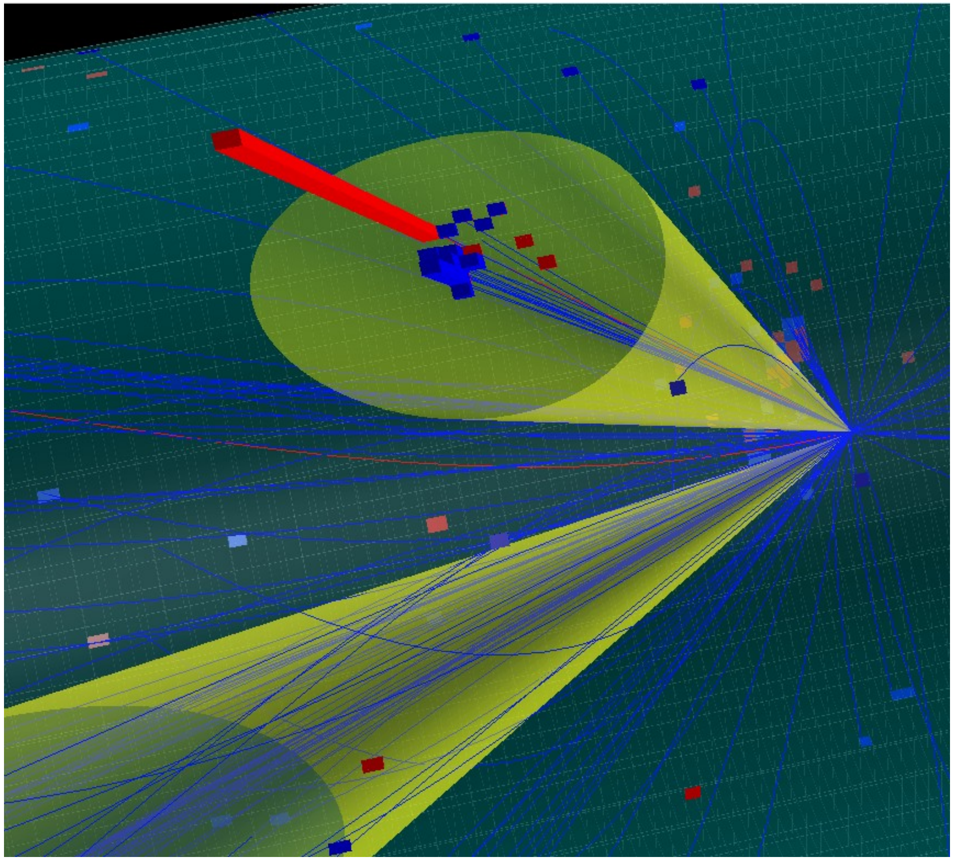
- **High-efficient b-tagging with small fake rate for light-flavor jets**
  - 70% efficiency & 1% fake rate for jets with 2.7<pT<10 TeV assumed in this study
- **High-granular calorimeter**
- **Good jet energy resolution**

Example: Z'(10 TeV) → $t\bar{t}$ → 2 antiKT05 jets (pT> 3 TeV)

Snowmass-like CAL geometry
'ATLAS'-like



x4 smaller CAL cells



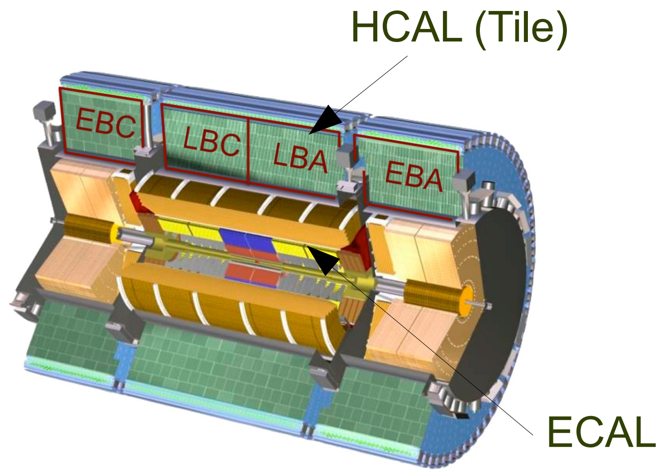
~ 5 deg :
Phi ~ 5 deg, Eta ~ 0.1

x 4 better →

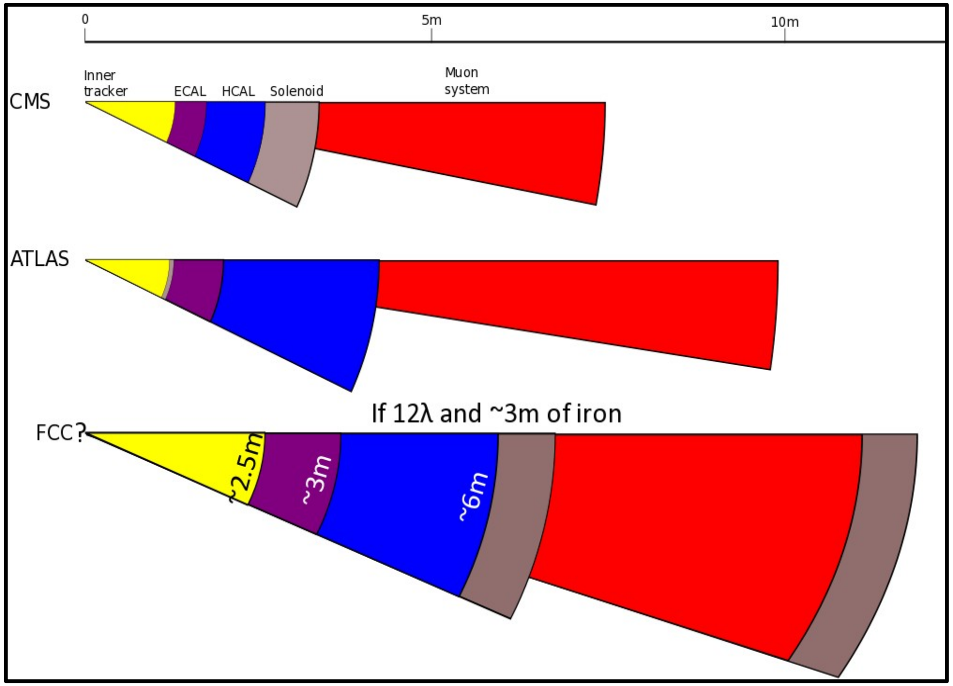
~ 1.25 deg :
Phi ~ 1.25 deg, Eta ~ 0.025

Note: this study uses a fast simulation.
We ignore effects from Molière radius when considering transverse profile of showers!

Calorimeter segmentation



- **ATLAS:**
  - HCAL (TileCal) has 64 modules in **φ** and **η=0.1** in the central region
  - ECAL has x4 better segmentation
  - HCAL ~2m away from IP
- **x2 better segmentation for a detector that has x2 larger distance from IP requires same technology as for ATLAS LArg and Tile calorimeter**
- **Increasing segmentation by x4 or x6 may require different technology!**
- **Can be studies using HepSim MC event samples + Delphes fast simulation**



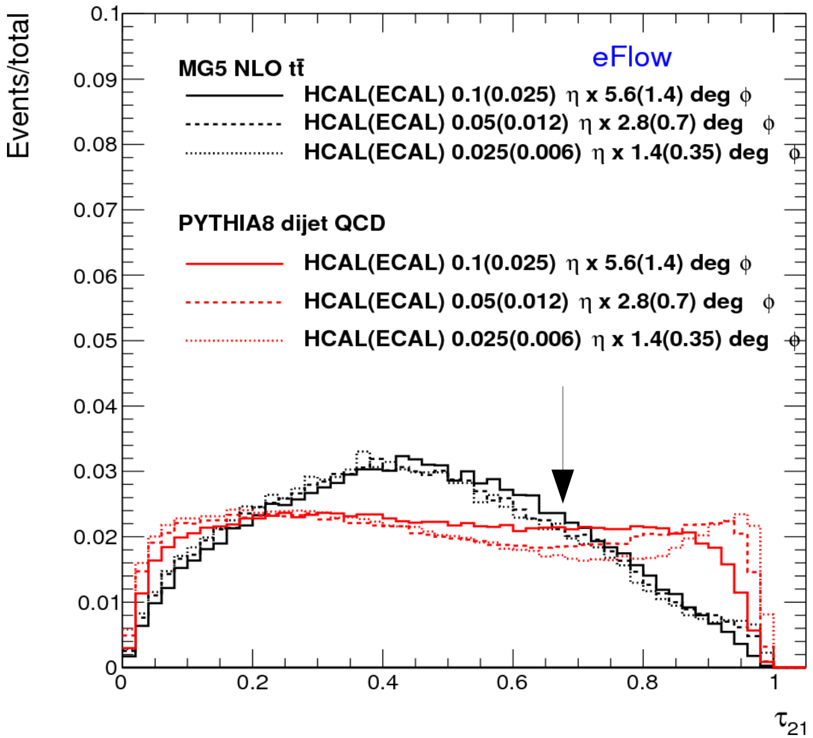
C.Barnet, C.Helsens

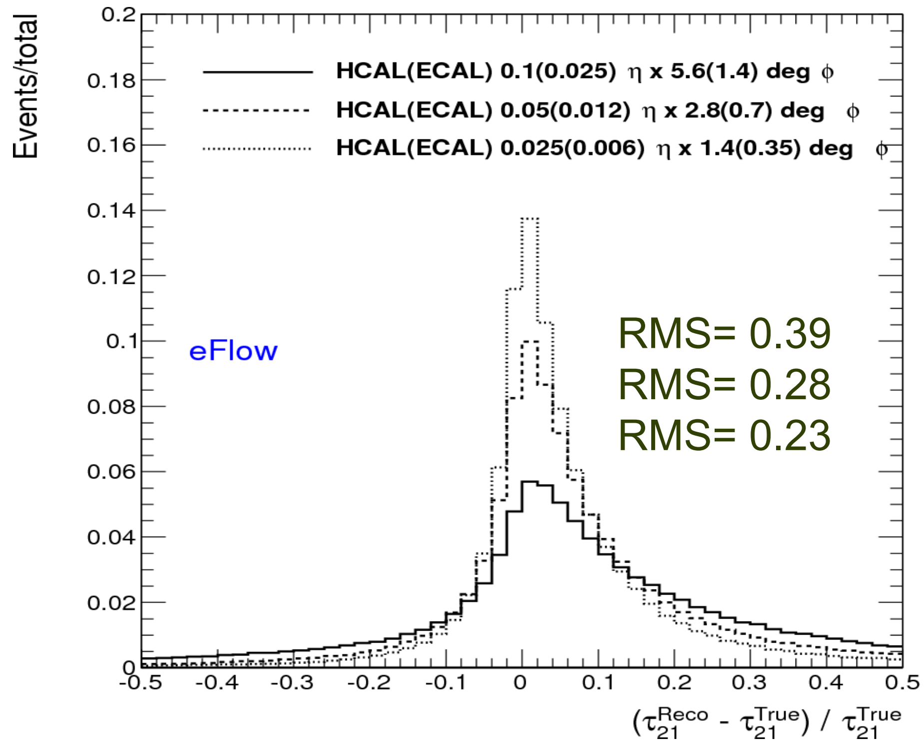
Thanks to A. M. Henriques Correia for discussion

τ_{21}. Finer HCAL & ECAL cells. Delphes fast simulation

- pT(jet)>3 TeV
- Assume x2 and x4 finer granularity of both ECAL and HCAL
- x2 (x4) granularity leads to 36% (67%) improvement in resolution

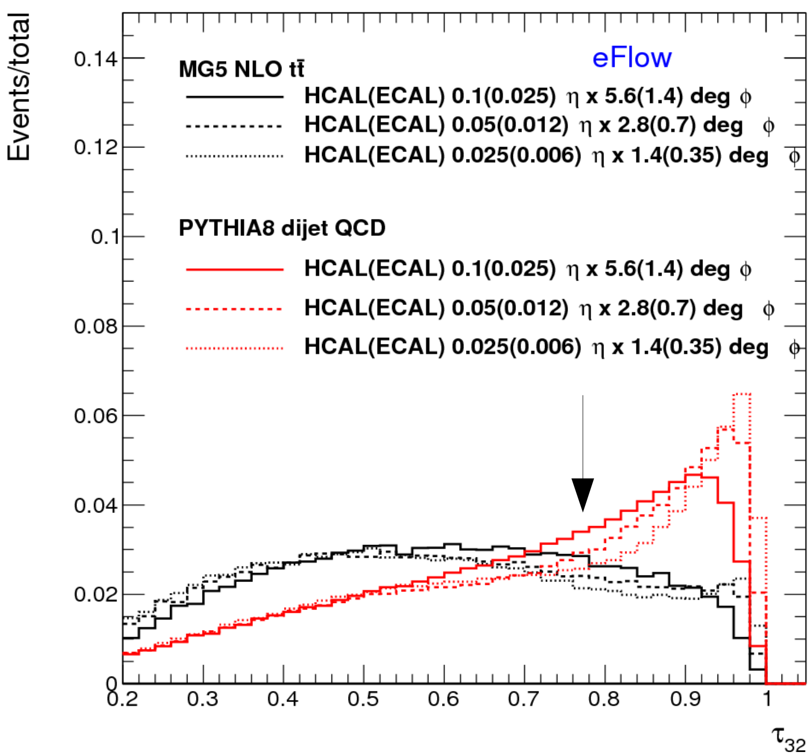
HepSim MC input + Delphes 3.2



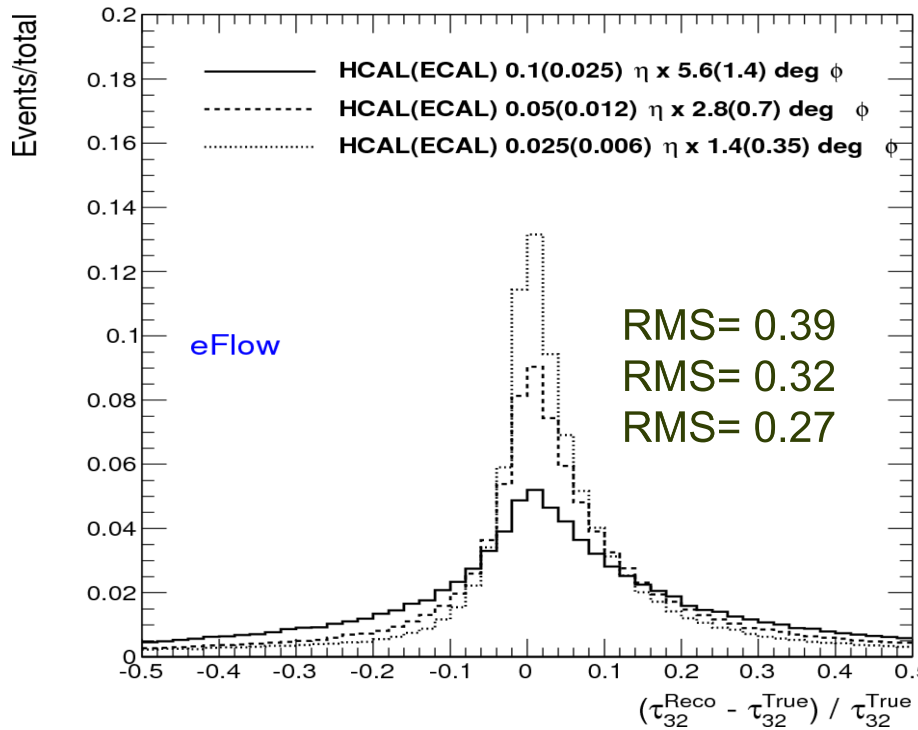


τ_{32}. Finer HCAL & ECAL cells. Delphes fast simulation

- pT(jet)>3 TeV
- Assume x2 and x4 finer granularity of both ECAL and HCAL
- x2 (x4) granularity leads to 20% (40%) improvement in resolution



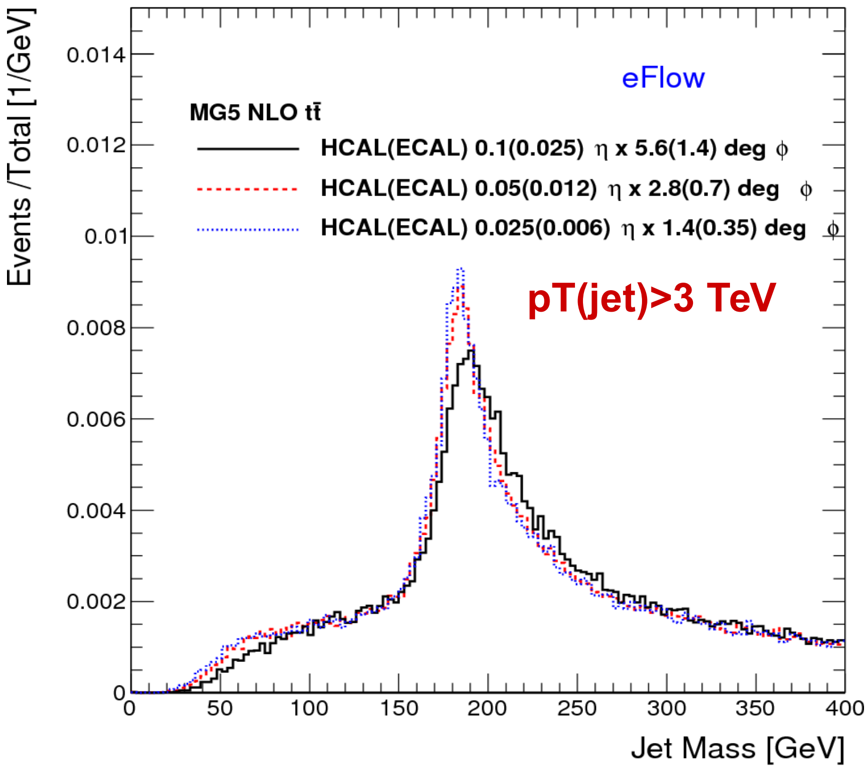
HepSim MC input + Delphes 3.2

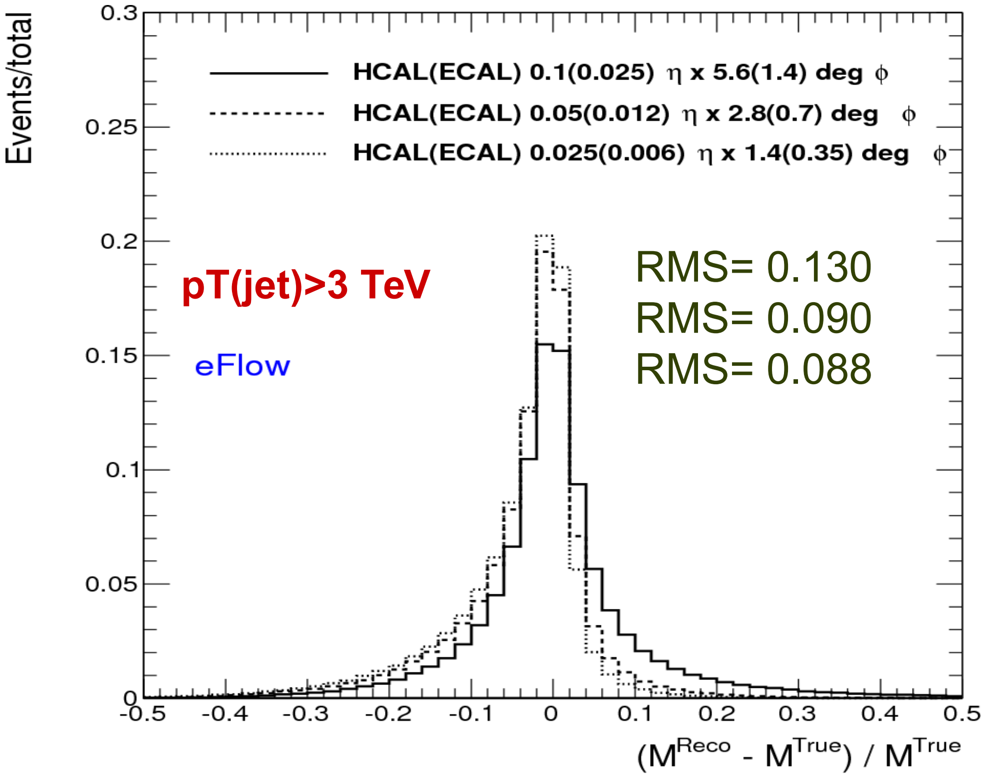


Jet mass. Finer HCAL & ECAL cells

- Assume x2 and x4 finer granularity of both ECAL and HCAL
- x2 (x4) granularity leads to 44% (48%) improvement in resolution

HepSim MC input + Delphes 3.2





Summary

- **Sensitivity limits on $X \rightarrow t\bar{t}$ calculated in the mass range 8-20 TeV**
  - Fully boosted regime (top decays products are not resolved, dijet topology)
  - Technique: b-tagging, substructure variables & jet shapes.
- **Double-tag scenario: sensitivity reach for Z' (g_{KK}) masses is 13 (20) TeV**
- **95% CL for σ x Br = 2 (4) fb for Z' (g_{KK}), with S/B ~ 20%**
- **Interplay between detector design and backg. rejection methods**
- **Requirements for a future experiment:**
  - efficient b-tagging (largest bkg. separation)
  - high-granular calorimeter to use jet substructure techniques for R~0.5 jets
  - > 10 ab^{-1} of int. luminosity
- **More details in arXiv:1412.5951**