中國科學院高能物理研究所
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Search for heavy resonances in $H\gamma$ channel with the ATLAS detector

- The 6th CLHCP Conference 06/11/2020-09/11/2020

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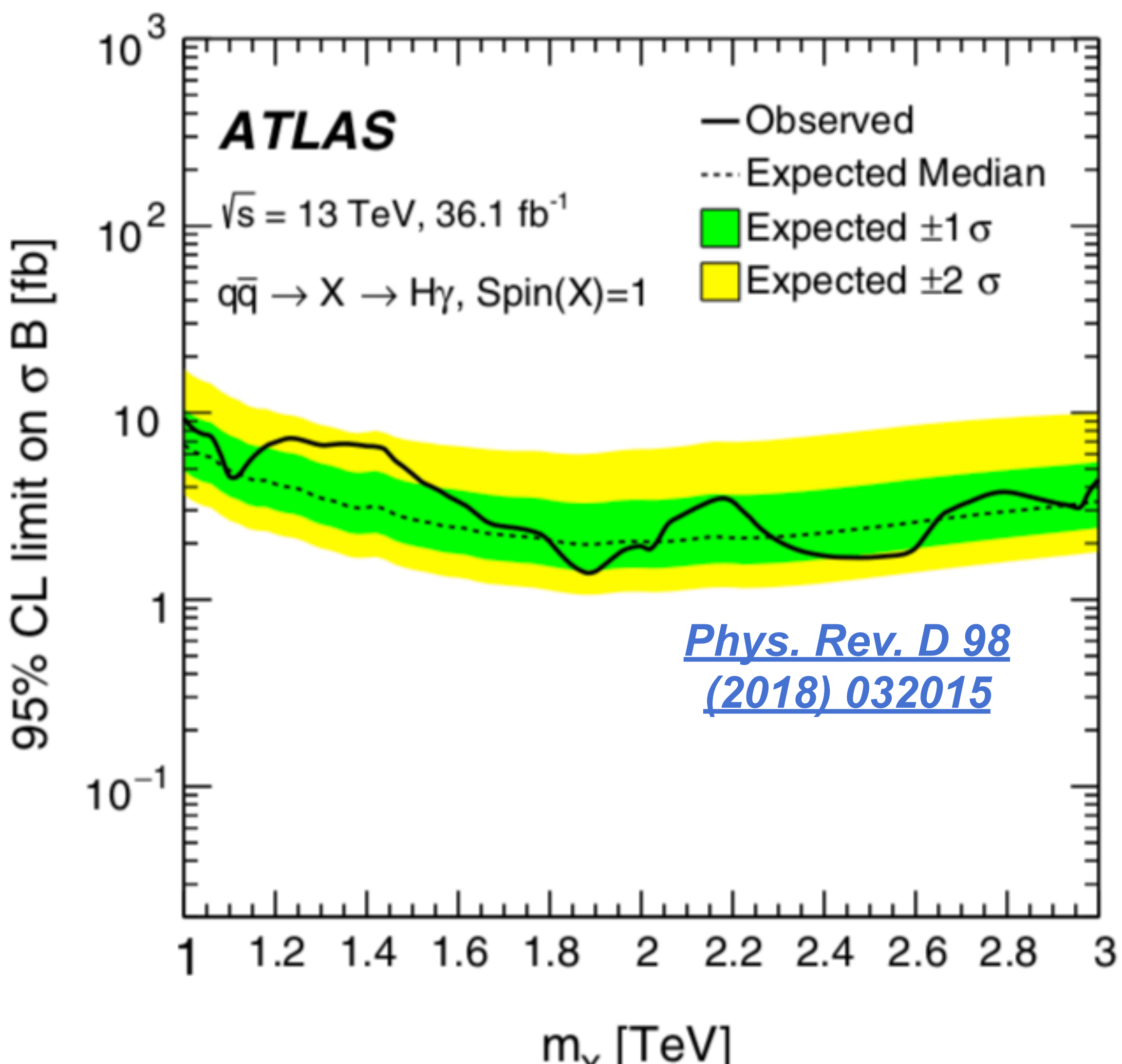
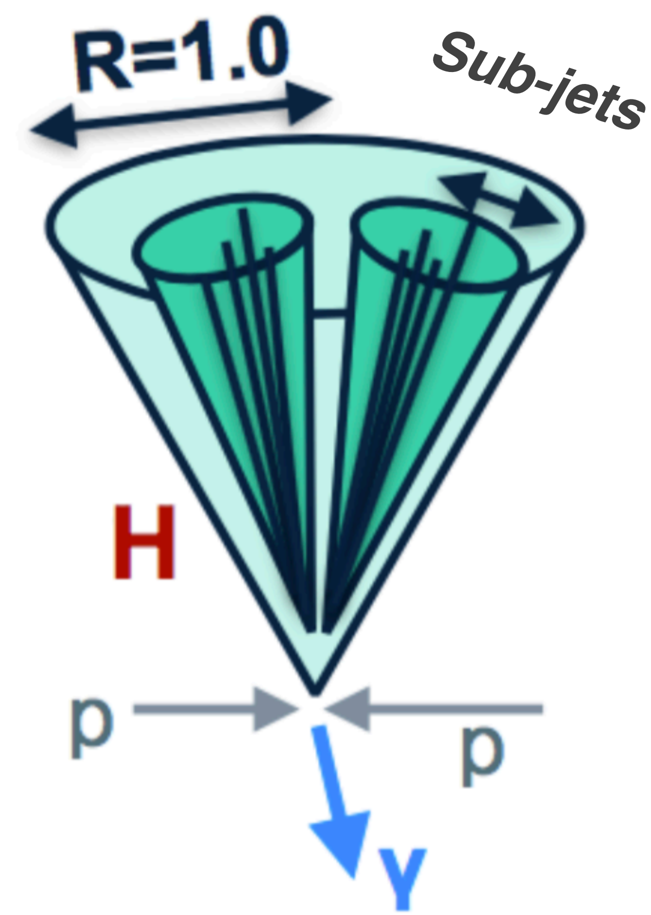
- arXiv:2008.05928

Introduction

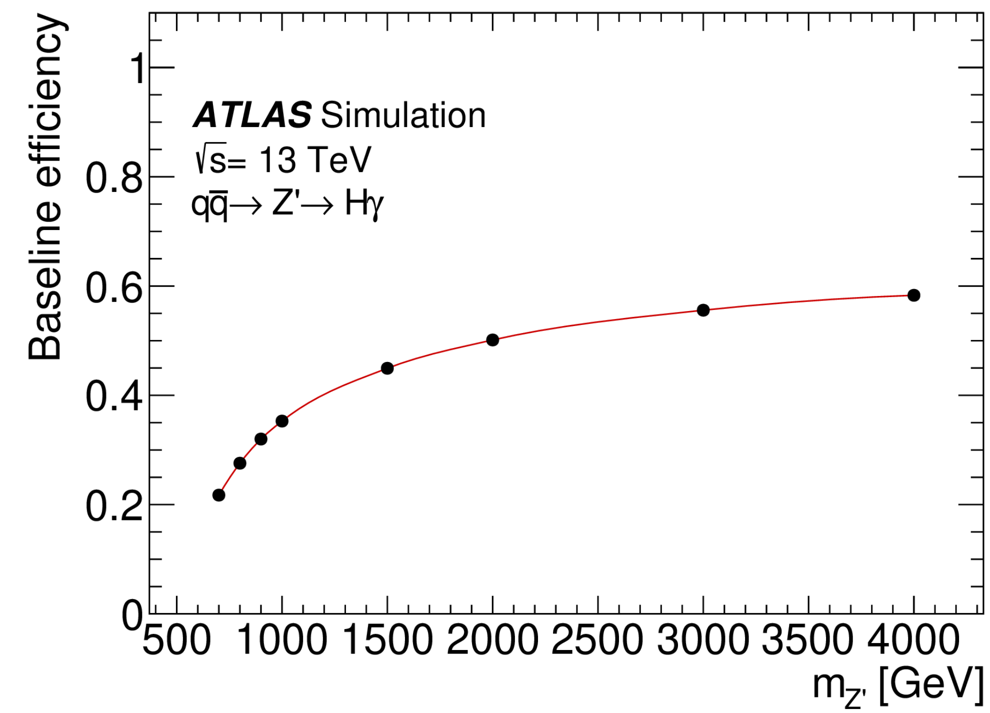
- spin=1, neutral narrow resonance search: qq->Z'->Hy
  - Much larger dataset: Full run-II data 139/fb vs. 36/fb
  - Much Wider search range: 0.7-4 TeV vs. 1-3 TeV
  - New categorization strategy applied
  - New sub-jets reconstruction algorithm applied
- Submitted to **PRL** (arXiv:2008.05928)
- China ATLAS team(IHEP, TDLI) is playing a leading role



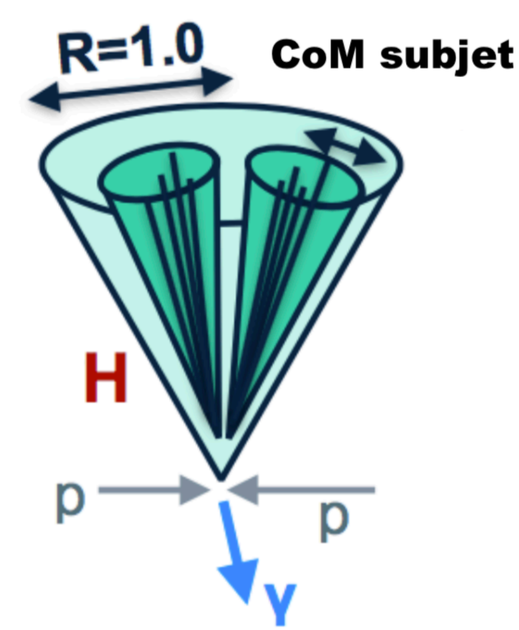


Baseline Event Selection

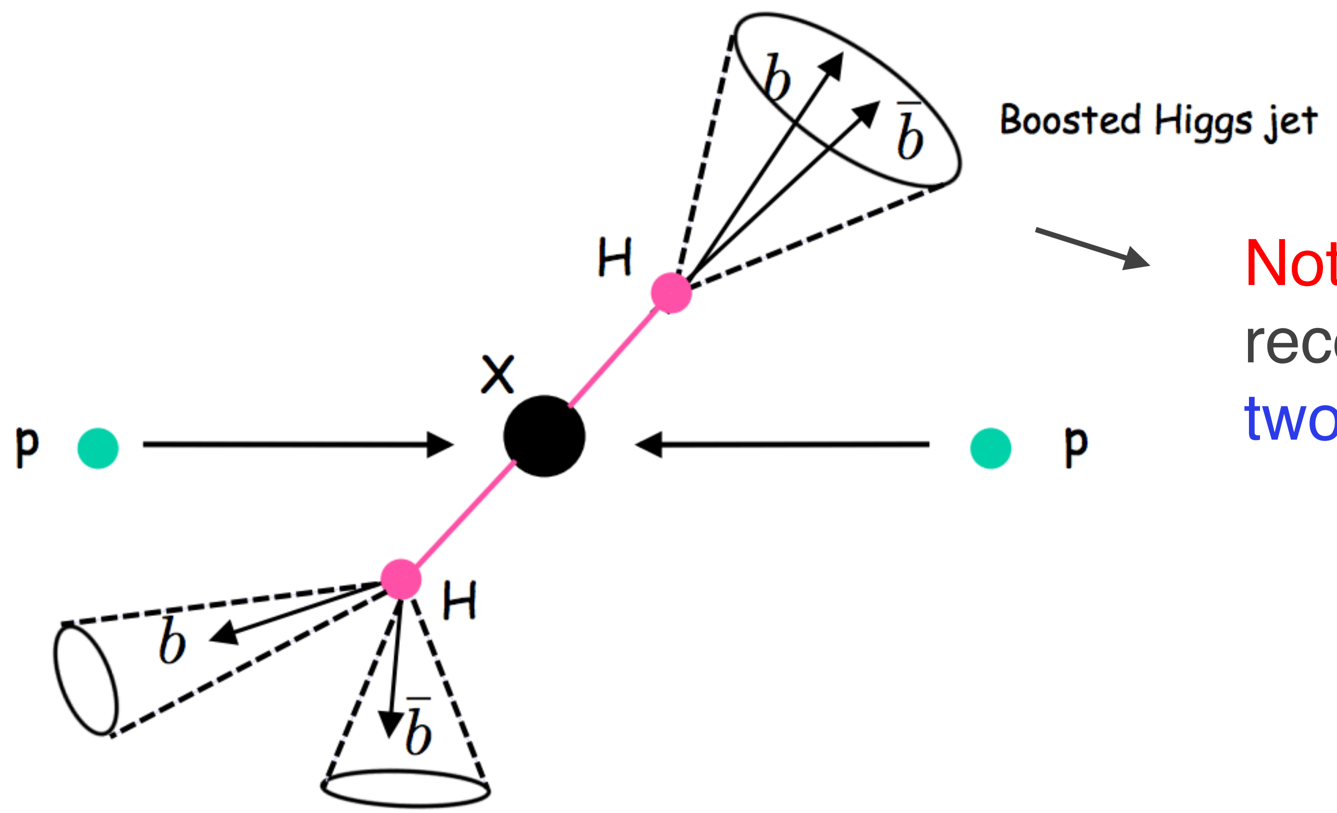
- **spin=1 qq->X->Hγ**
  - hadronic decay mode(H->bb ~58%)
  - merge/boosted regime is considered



- **Baseline Selection:**
  - Photons
    - Pt>200GeV, |eta|<1.37
    - Passing tight photon ID and tight calorimeter isolation
    - Leading pT
  - Large-R jet (Ak10 LCTopo Jet)
    - Pt>200GeV, |eta|<2.0, 50GeV<mass<200GeV
  - Jet and photon overlap removal (remove Jet if dR(jet, photon)<1.0)
  - Leading pT Large-R jet & photon to form Jet+gamma(Jg) system



Boosted hadronically decaying Higgs boson



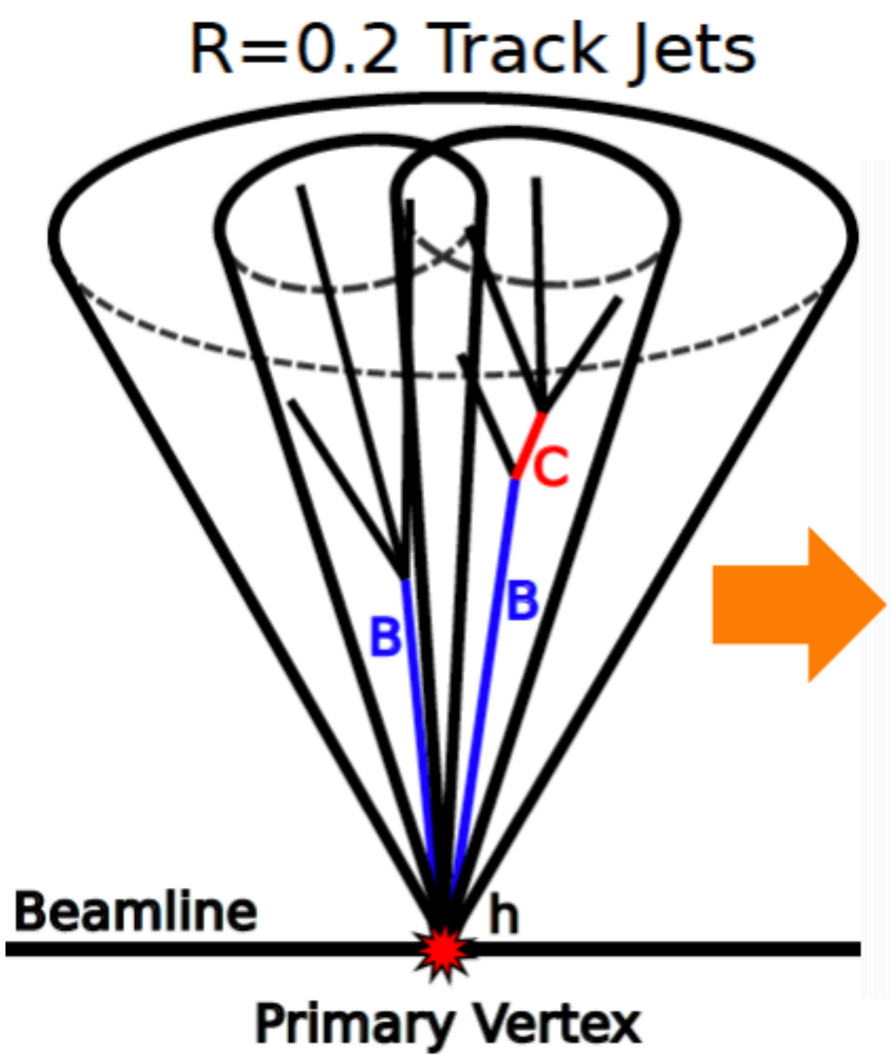
Not efficiently reconstructed as two small R jets

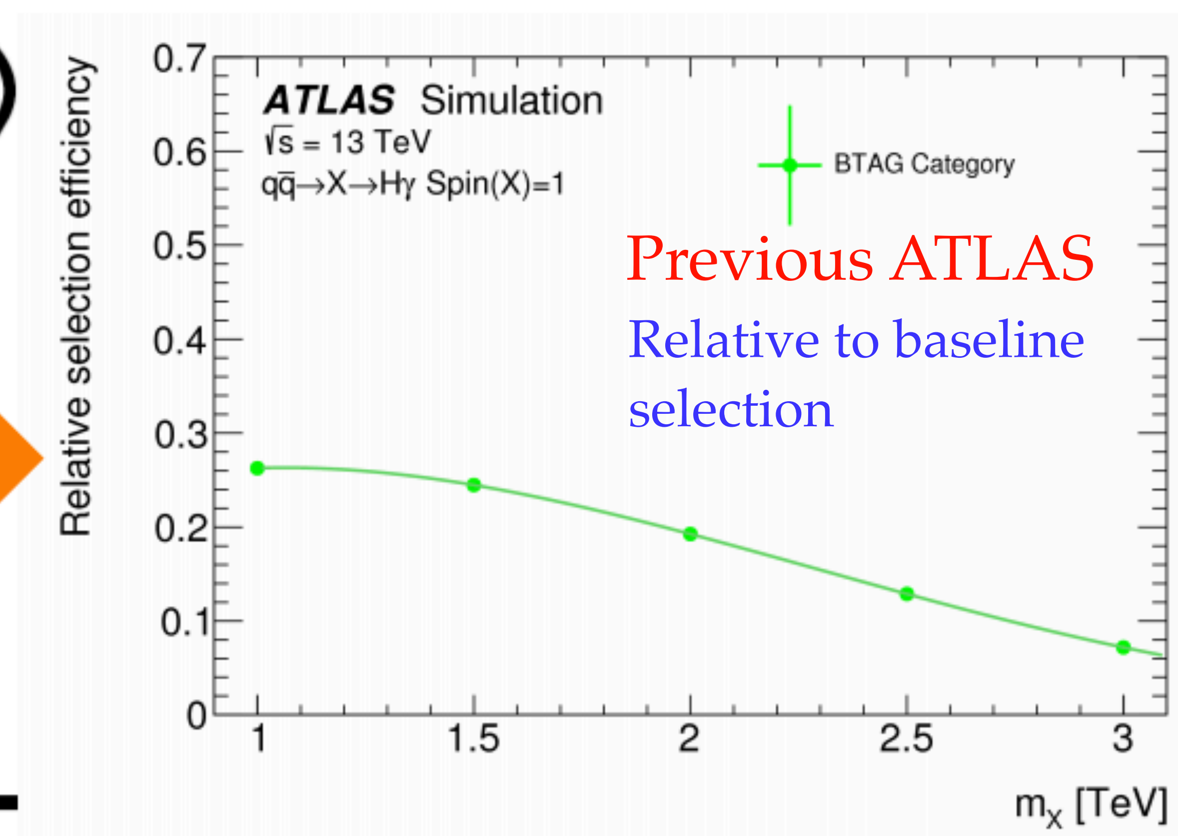
- Strongly boosted Higgs boson
  - Decay products are highly colimated
  - Both quarks reconstructed inside a single jet with large cone size (Large-R jet)

Subjet reconstruction algorithm

Previous analysis sub-jets algorithm

- The fixed-radius R=0.2 track jet approach
  - Works well for low pt Higgs boson
  - Significant efficiency loss due to track jets overlapping for hight pt Higgs boson



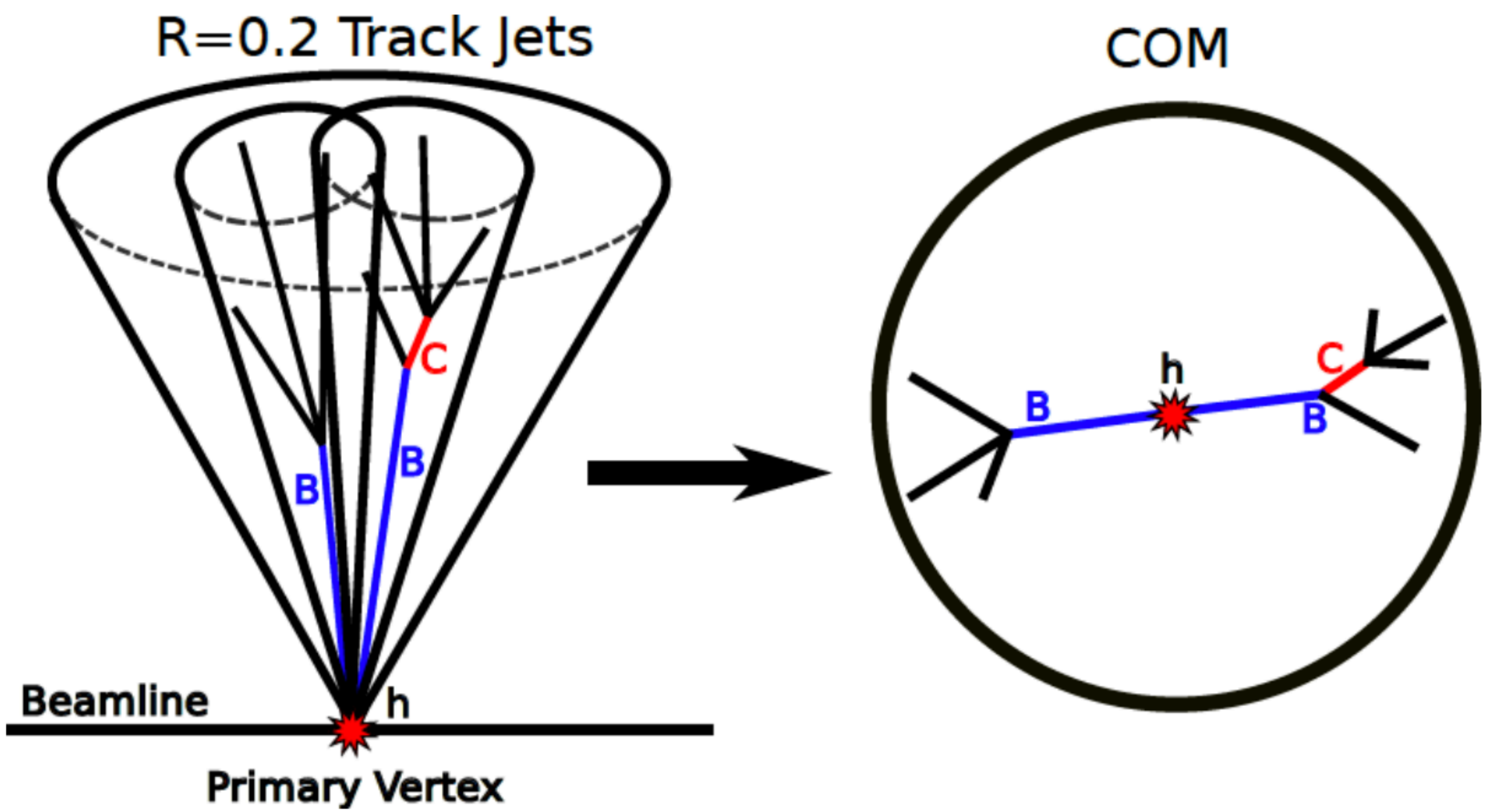


Variable Radius, Exclusive-k_T, and Center-of-Mass Subjet Reconstruction for Higgs($\rightarrow b\bar{b}$) Tagging in ATLAS, ATL-PHYS-PUB-2017-010, 2017

The new subjet algorithm

The center of mass (CoM) sub-jets reconstruction technique

- Performs in the center of mass frame of the large-R jet
- Easily separate final products of Hbb into back-to-back topology



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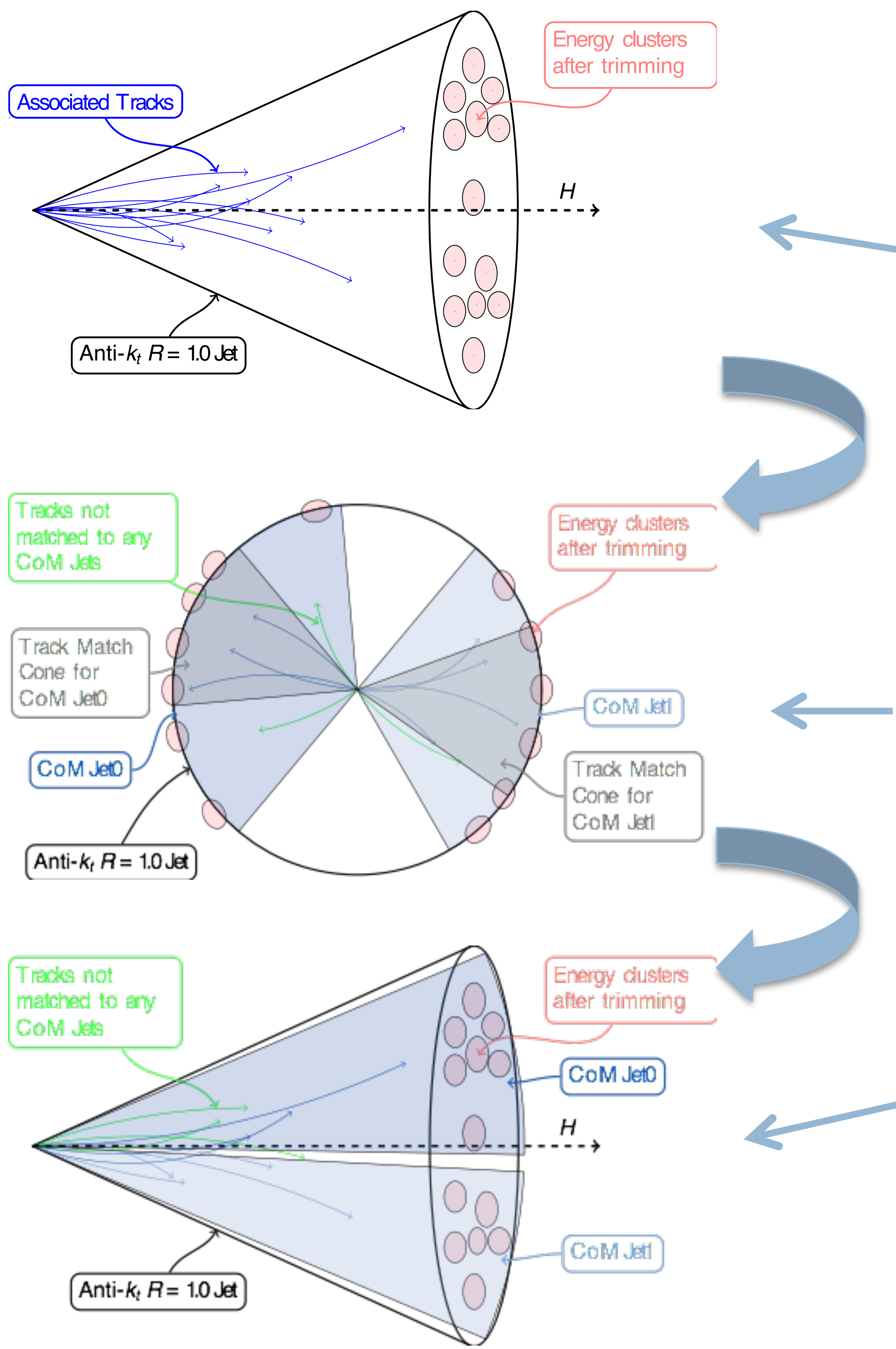
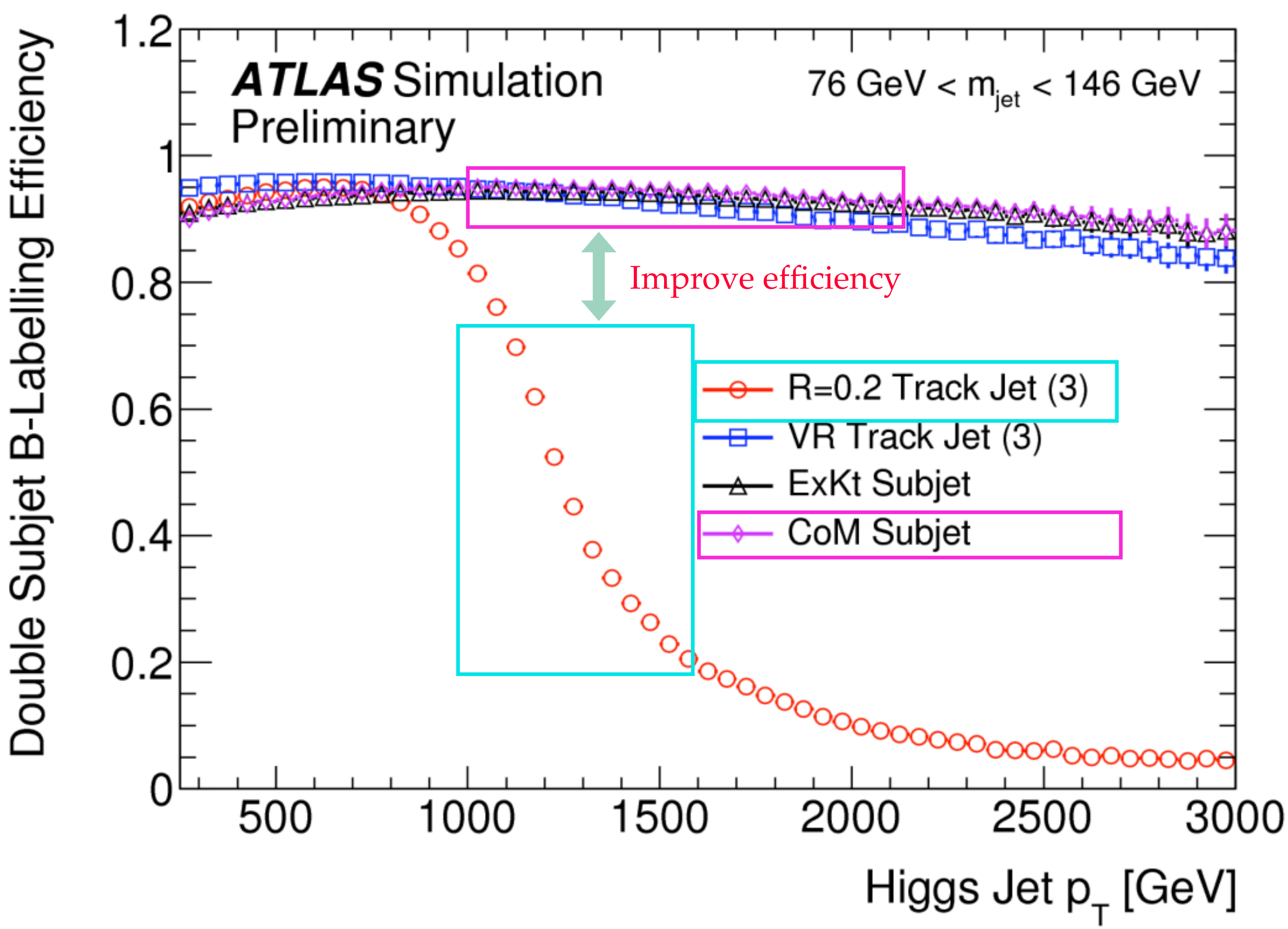
Center of mass (CoM) subjets



- Center-of-Mass(CoM):
  - Collect Large-R jet information
  - Boost to Higgs(Large-R jet) frame
  - Reconstruct two subjets
  - Associate track to subjet
  - Boost back to lab frame

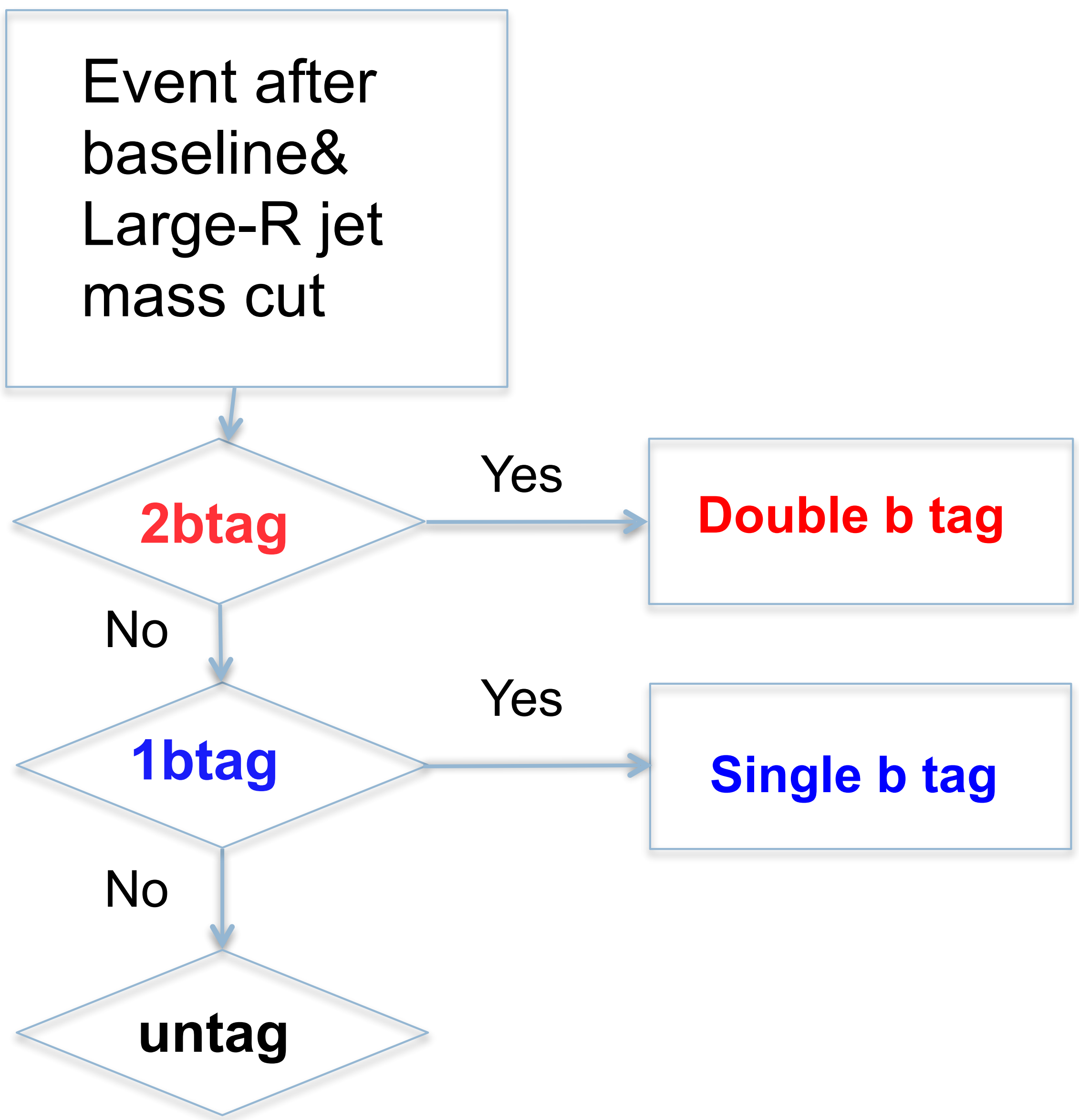
Reconstruction efficiencies



The **efficiency** of **CoM jet** is much better than the **R=0.2 track jet** for **high Jet pT** (**pT>1000GeV**)

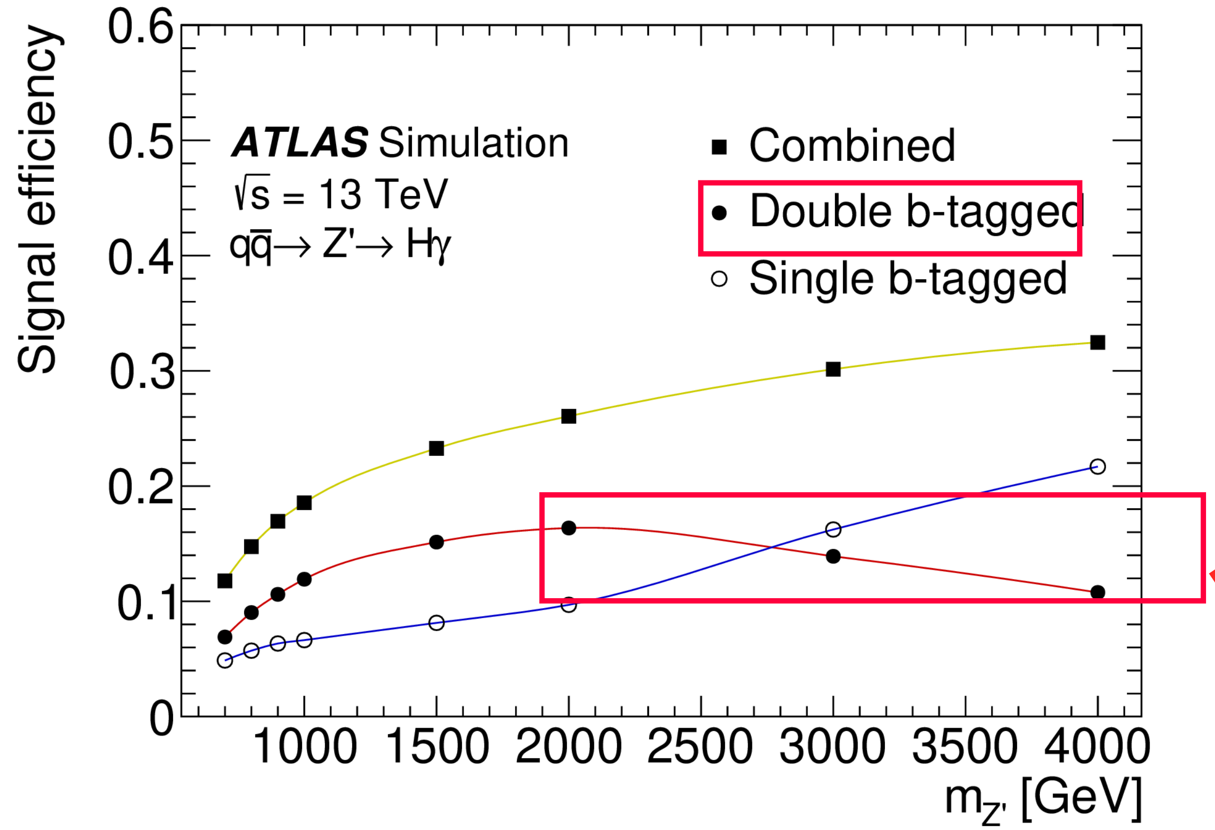
Categorization

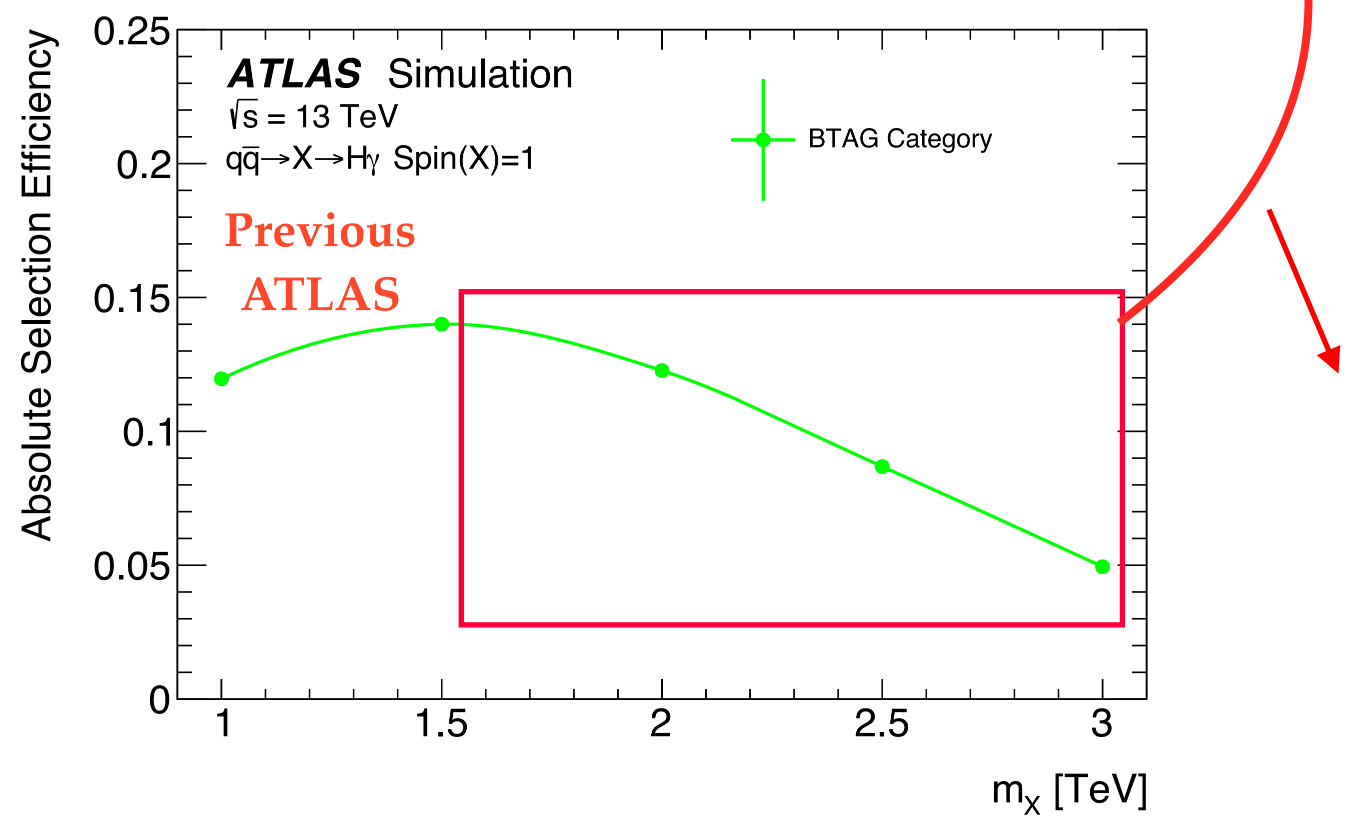
- Subjets are reconstructed by using CoM techniques and tagged with MV2c10 tagging algorithm
- Btag: MV2c10 fix @77% efficiency working point

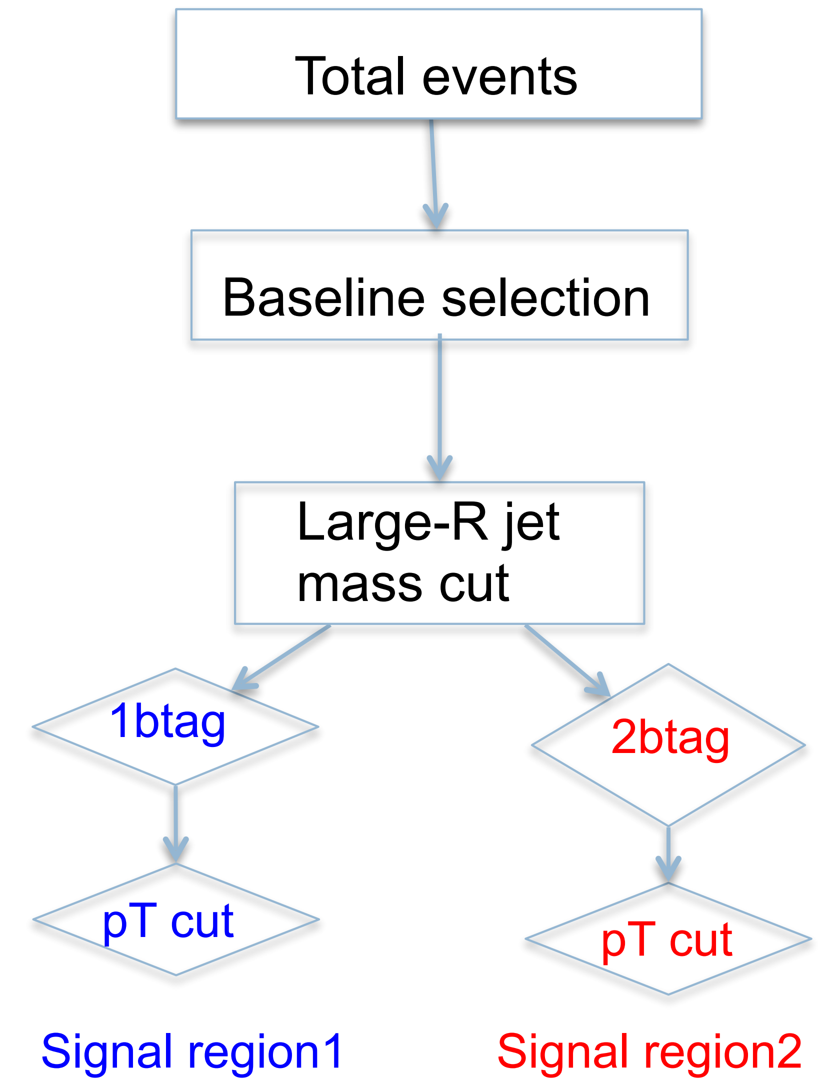


Add 1 btagged comparing to previous ATLAS

Overall signal efficiency



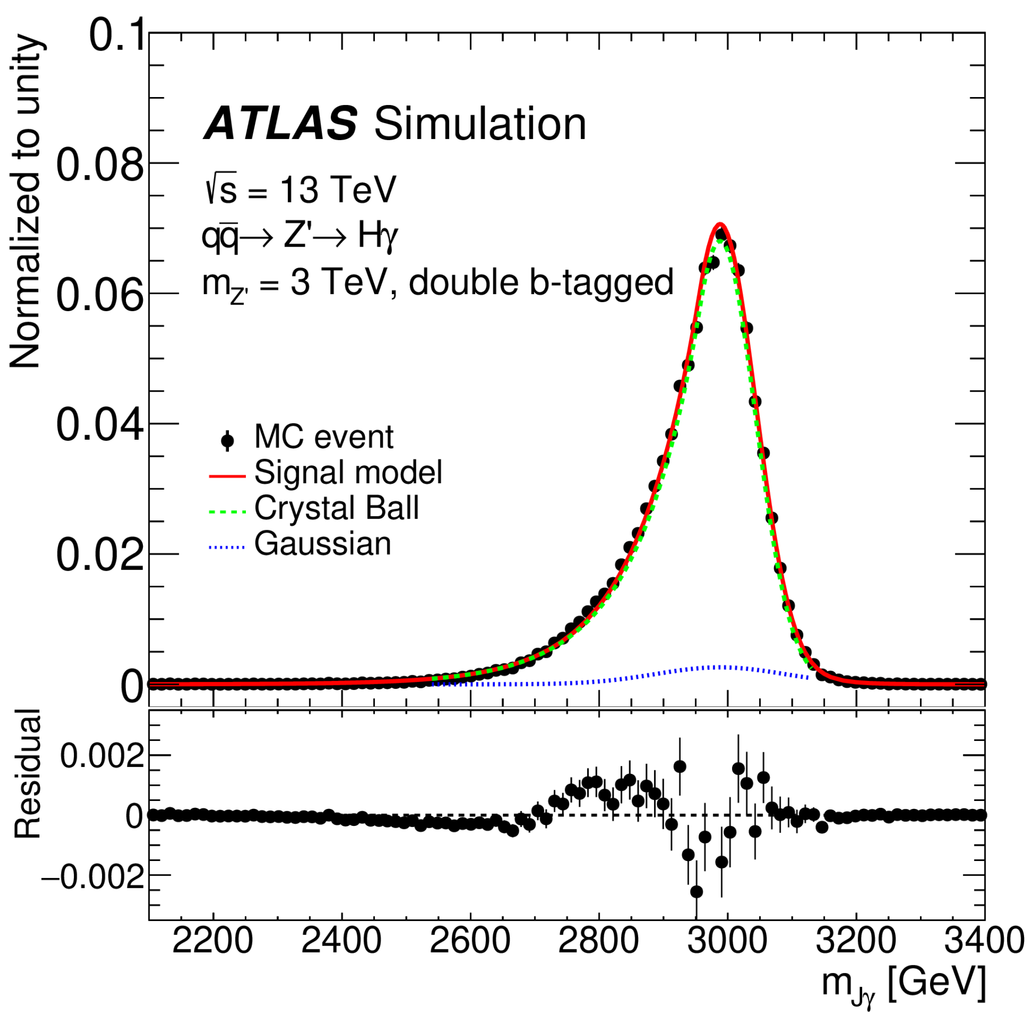




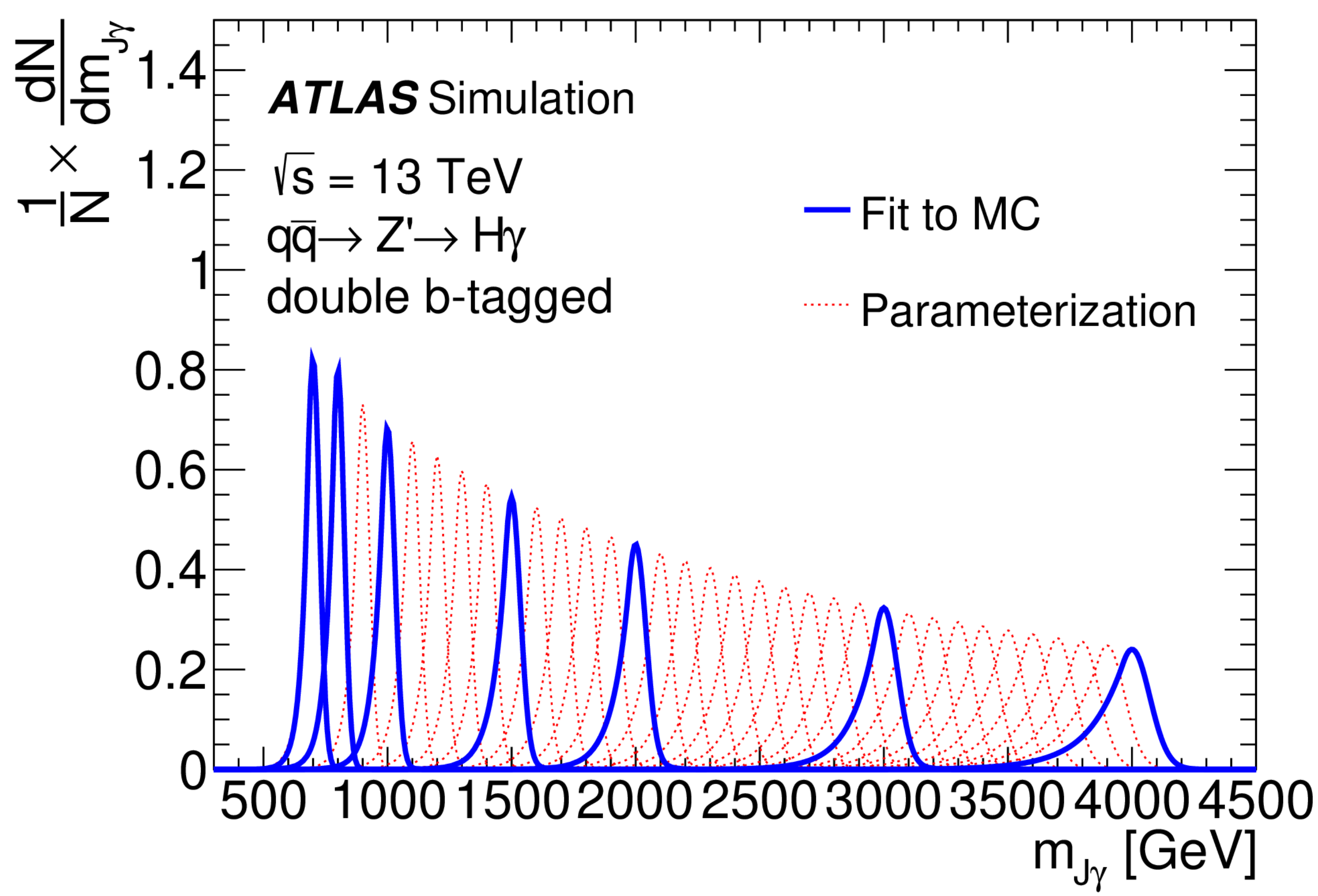
Improve the signal efficiency comparing to the previous one for the high resonance mass region ($m>1.5$TeV)

Signal Modelling

- $f_{signal}(m_{\gamma J}) = f_{CB} \bullet CB(m_{\gamma J}; \mu, \alpha_{CB}, \sigma_{CB}, n_{CB}) + (1 - f_{CB}) \bullet Gauss(m_{\gamma J}; \mu, \sigma_{Gauss})$



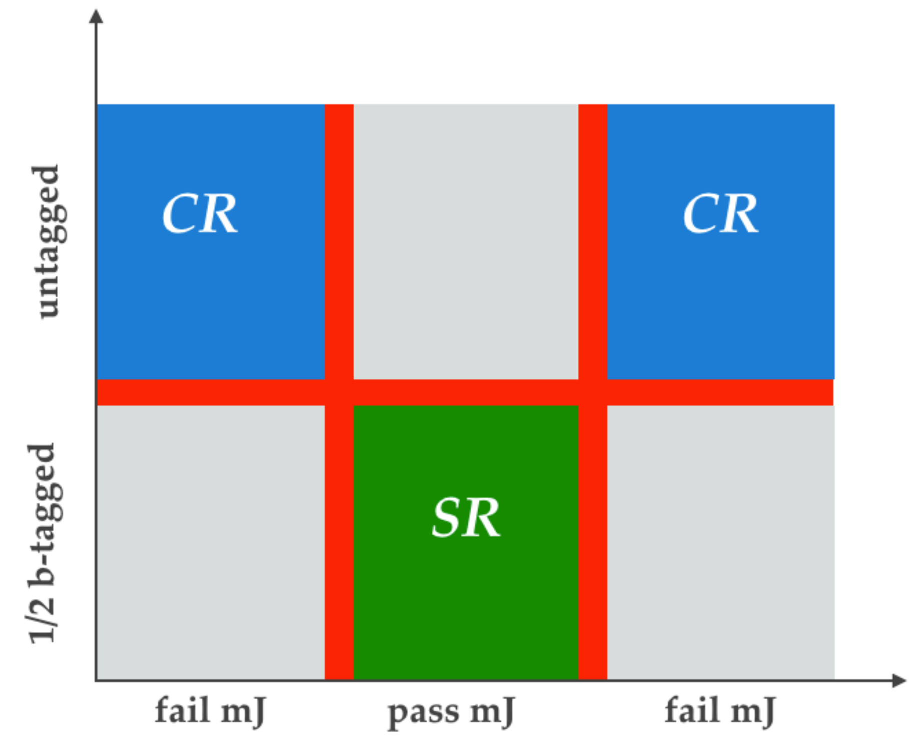
Parameters are parametrized with polynomial function

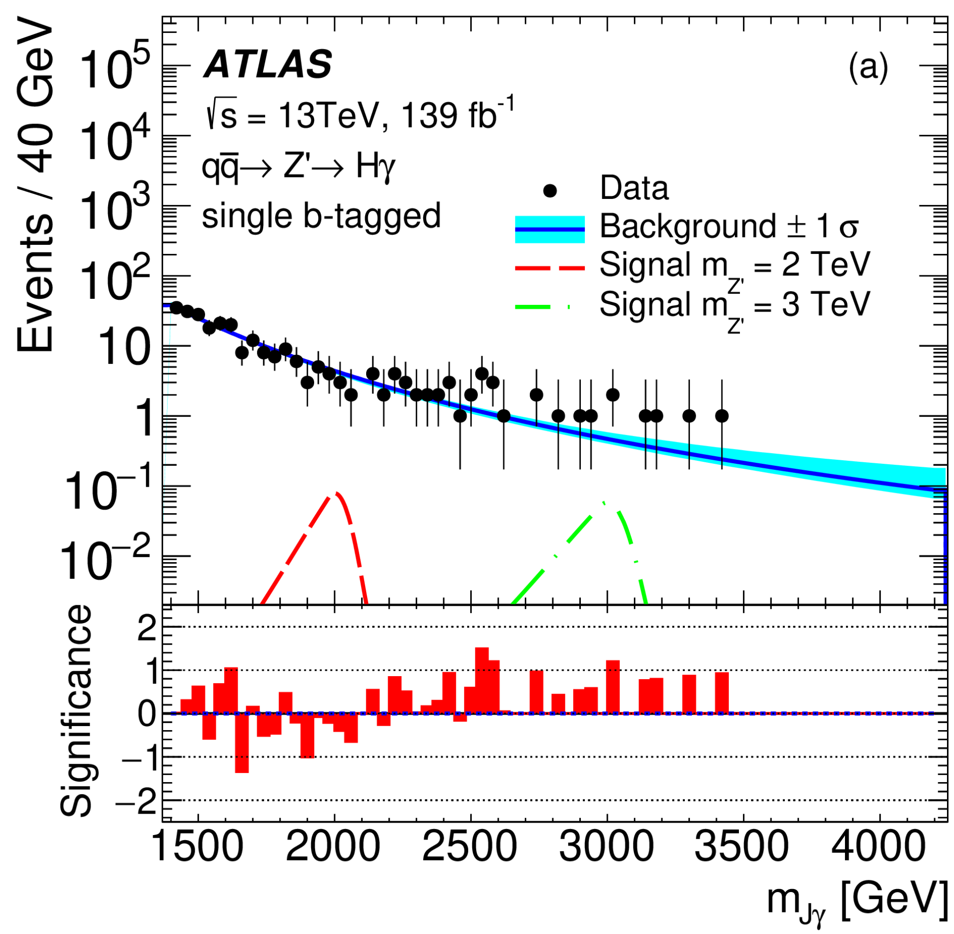


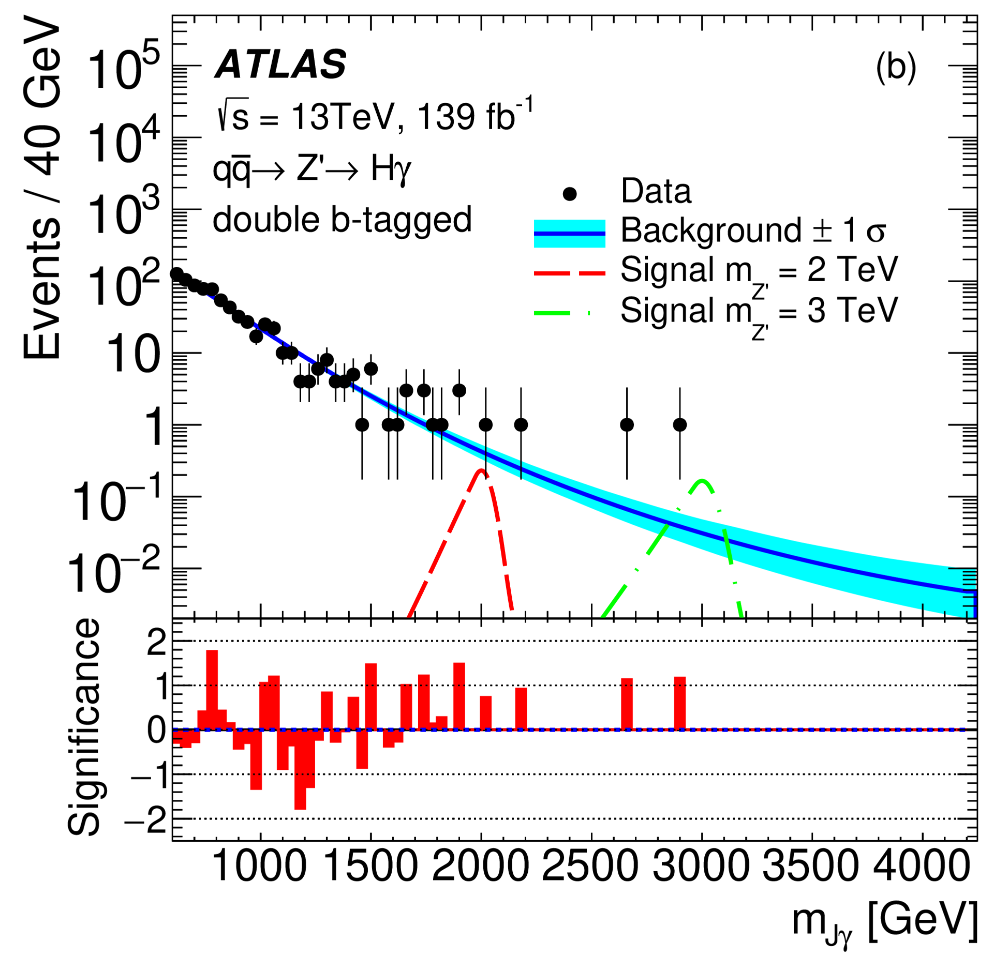
Blue for generated mass points, red for parametrised mass points

Background Fitting

- Background function: with a suitable parametric form based on di-jet family of functions:
  - $B(m_{J\gamma}; p_i) = (1 - x)^{p_1} x^{p_2 + p_3 log(x) + p_4 log^2(x) + p_5 log^3(x) + \ldots}$, $x = m_{J\gamma}/\sqrt{s}$, p_i are dimensionless parameters (Decide number of pi by F-test)
  - Search range:
    - 2btag: 700~4000GeV; 1btag: 1500~4000GeV
  - Fit range:
    - 2btag: 600~4200GeV; 1btag: 1400~4200GeV

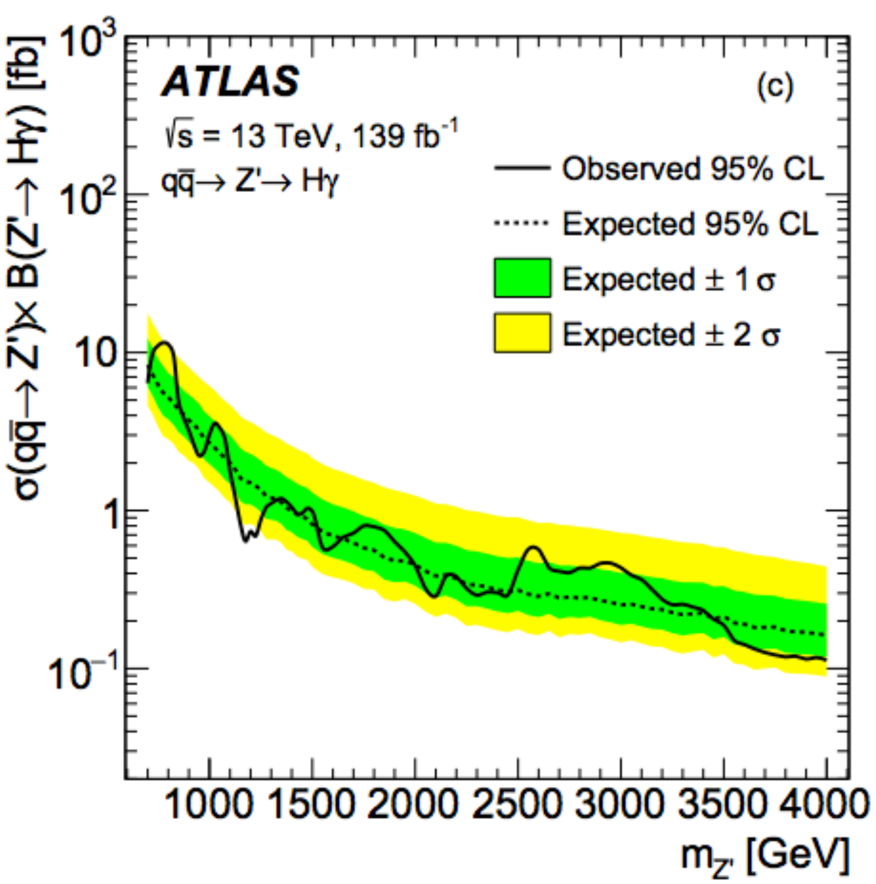


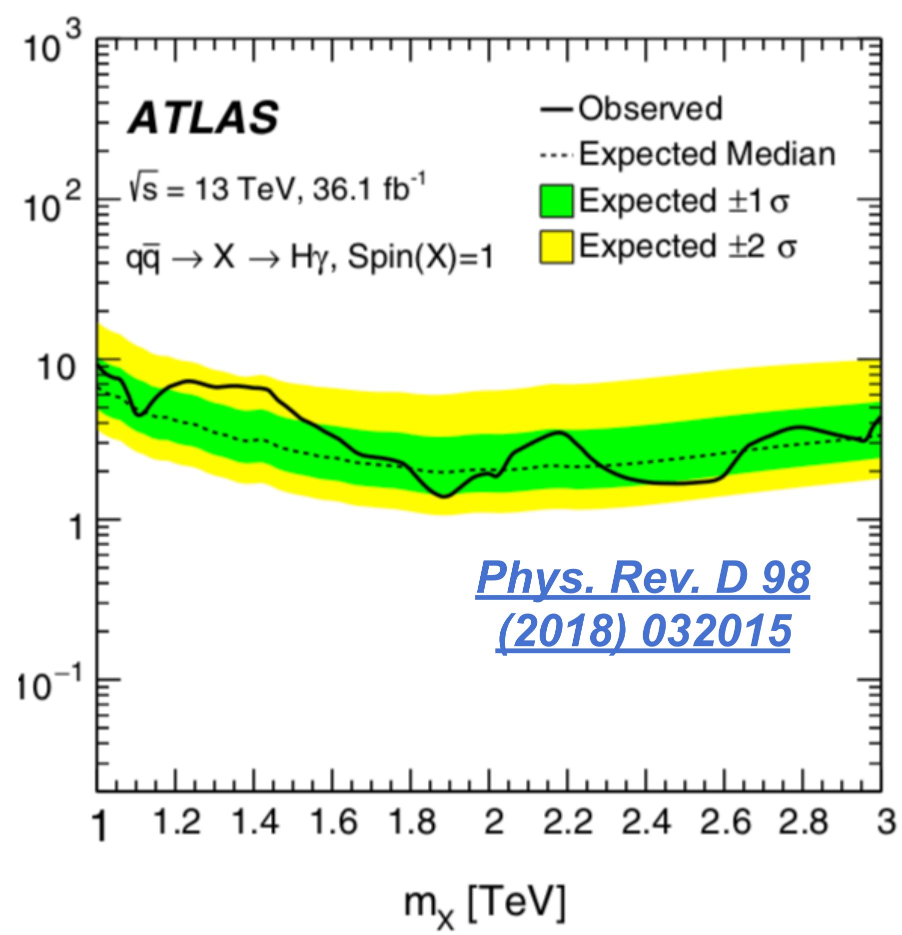


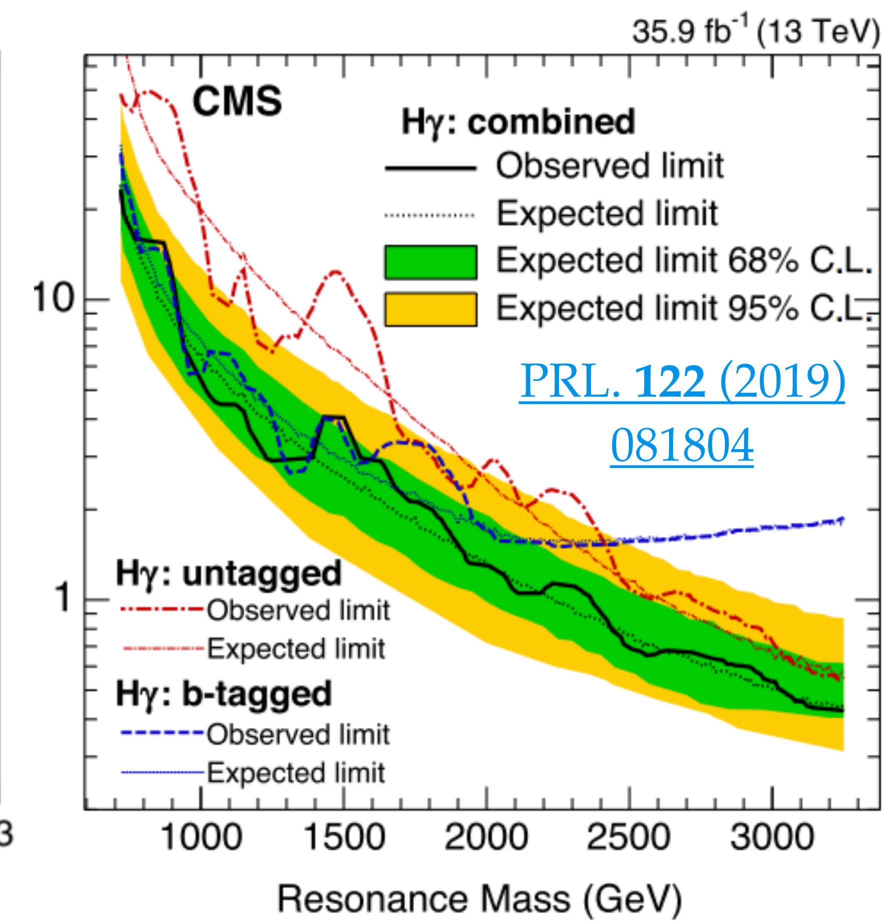


Results

- No significant signal-like excess is observed
- Upper limit on $\sigma \times B$:$m_{Z'}$: 0.7-4 TeV
  - Much better results
    - To previous ATLAS(36.1/fb): 3 times better limit for $m_{Z'} < 1.2TeV$, 15 times better limit for $m_{Z'} > 2.5TeV$
    - To CMS(35.9/fb): 2.5~3 times better limit for $m_{Z'} < 2.5TeV$







Summary

- Search for heavy resonance decaying to H+γ with full run-II data is presented
- No significant signal-like excess is observed
  - Much better limit results to the previous ATLAS and CMS
- Involving some new techniques compare to previous analysis
  - CoM tagger is used to improve the overall performance
- China ATLAS team(IHEP, TDLI) is playing a leading role

MC Study

- Full run-II Data: year 2015~2018, 139fb^{-1}
- All with EXOT3 derivation
- Signal MC, mass point(GeV): 600, 700, 800, 1000, 2000, 3000, 4000

Channel	Generator	Width	Spin	Production
X->Hγ	MadGraph+Pythia8	Narrow-width approximation	1	qq

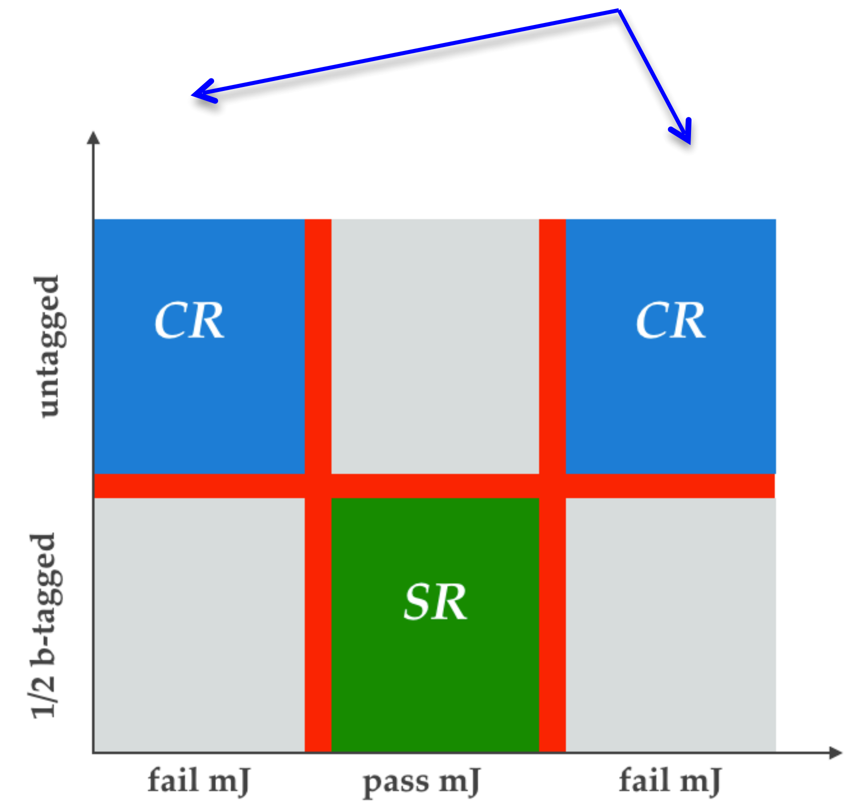
- Background MC (used for validation only)

	Generator
SM γ+jet next-to-leading-order	Sherpa NLO
SM Z+γ	Sherpa
SM W+γ	Sherpa
SM tt+γ	MadGraph+Pythia8

Control region & Background Fit

- CR: **Large R jet mass side-band** + **btag untag**
  - Large R jet mass side-band
  - Untag defintion: In order to define a CR with a small enough potential signal contamination, we tighten the untag region definition by requiring both CoM jets fail 85% efficiency working point selection
- Data driven strategy in CR to determine background fit functional form

CR: on top of Large-R jet side-band, revert btag

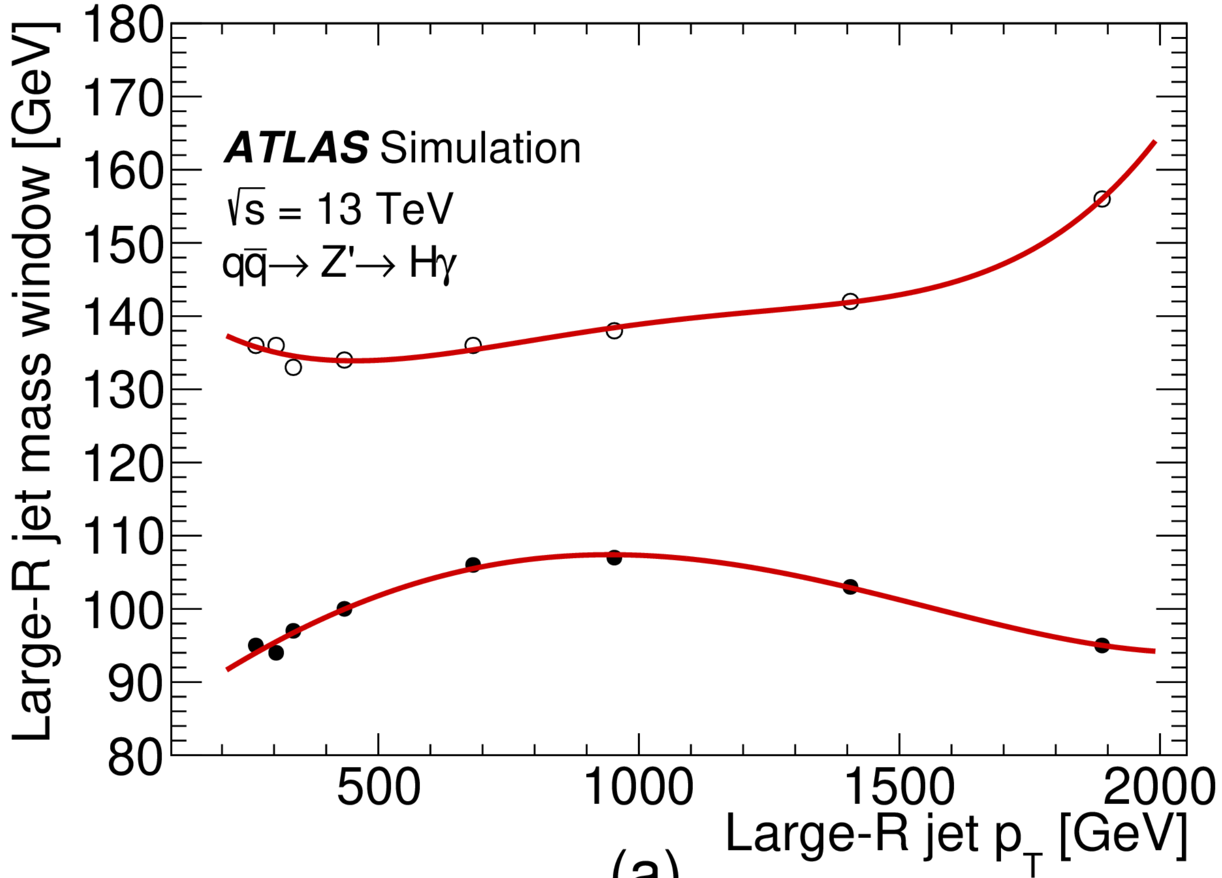


Other selection, baseline selection, Large-R jet pT…, are the same as SR

pT selection for 1btag(SR1b) and 2btag(SR2b) are different. Apply corresponding pT cut, and define CR1b and CR2b.

Large-R jet mass cut optimization

- m_J consistent with Higgs mass m_H: $m_H - \Delta_{m,L} < m_J < m_H + \Delta_{m,R}$
  - two sides mass cut as functions of Large-R jet pT



(a)

- Maximize significance:

$$\frac{\varepsilon}{\frac{a}{2}+\sqrt{B}},\ a = 3 \qquad *$$

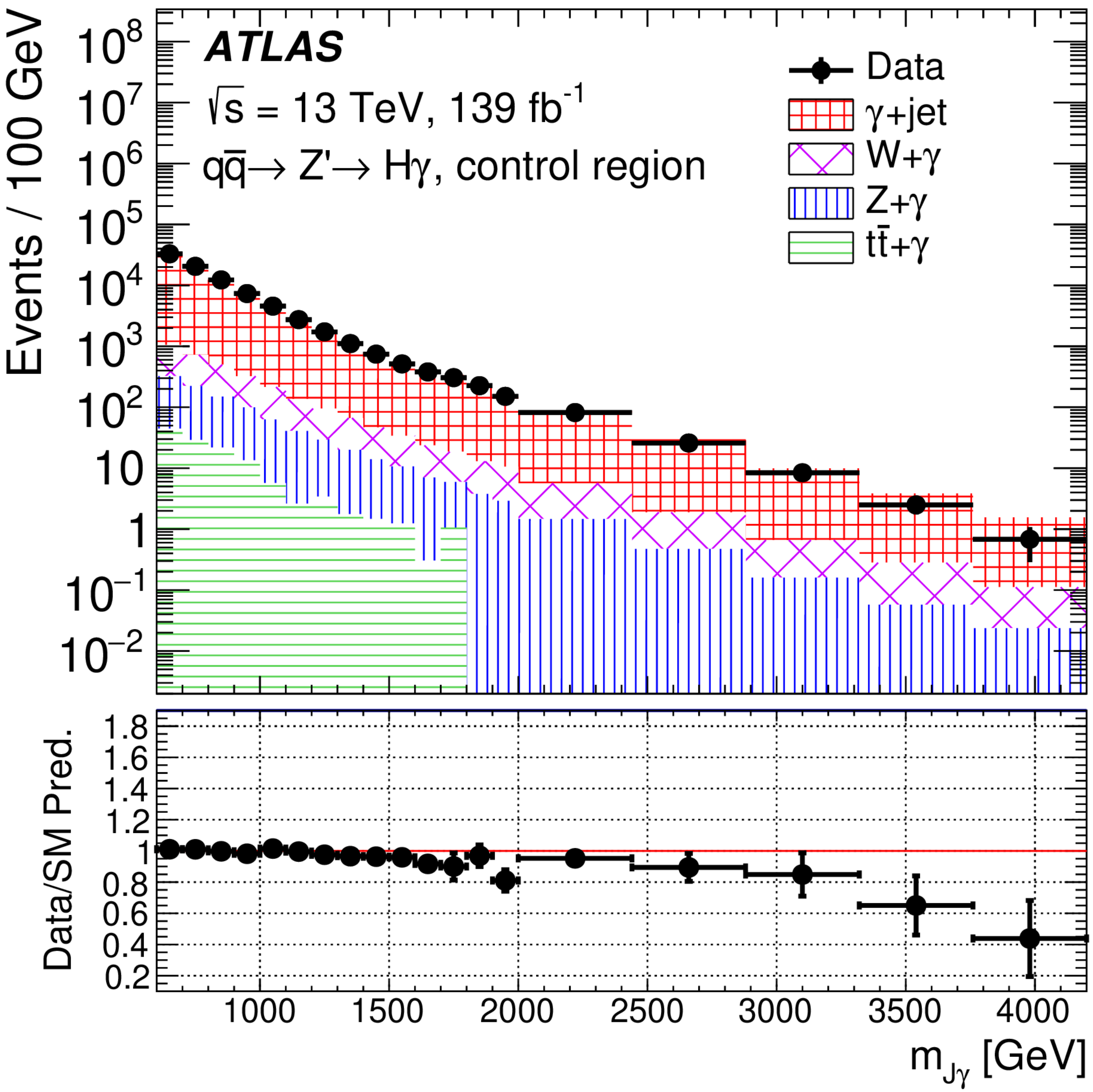
- Large-R jet mass selections are parametrized as functions of large-R jet pT with 4th-order polynomial.

- ε=signal efficnecy, B= background number, Sensitivity of searches for new signals and its optimization
- https://arxiv.org/abs/physics/0308063

pT optimization(Large-R jet & photon)

- To maximize Significance: $\frac{\varepsilon}{\frac{a}{2}+\sqrt{B}}, a = 3$
  - A varied pt cut applied on different $m_{J\gamma}$
- pT cut(Large-R jet) = 0.8 • pT cut(photon)
- Apply to both single & double btagged category

Comparisons

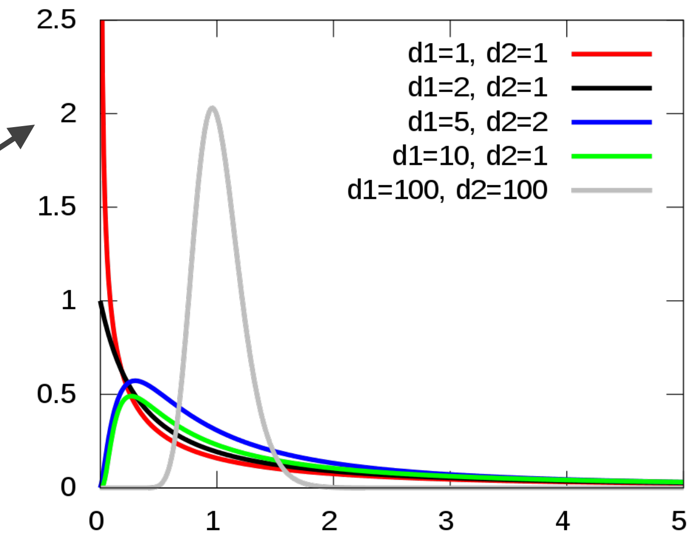


Data/MC comparison in CR

In general, the data distributions are in good agreement with the ones from the MC simulation

Background Fitting

- F - test:
  - Determine number of parameters in bkg function
    - Test statistics $F_{1,2} = \dfrac{(\chi_1^2 - \chi_2^2)/(p_2 - p_1)}{\chi_2^2/(N_{bin} - p_2)}$ follows a fisher distribution
    - Whether a function fits the data significantly better than the other one(different number of parameters)



	2-para. vs 3-para.	3-para, vs 4-para.
control region single b-tagged F value	3.24	0.12
control region single b-tagged P value	0.086	0.728
control region double b-tagged F value	19.05	-1.91
control region double b-tagged P value	$3 \cdot 10^{-4}$	1

- P value would be very small if F has significantly improvement
- With SR/CR ratio correction: 3par for both 1btag/2btag

Systematic uncertainty

Systematic uncertainty:
large-R jet; photon;
b-tag; pile-up;
spurious signal； PDFs; Parton shower; Luminosity
….

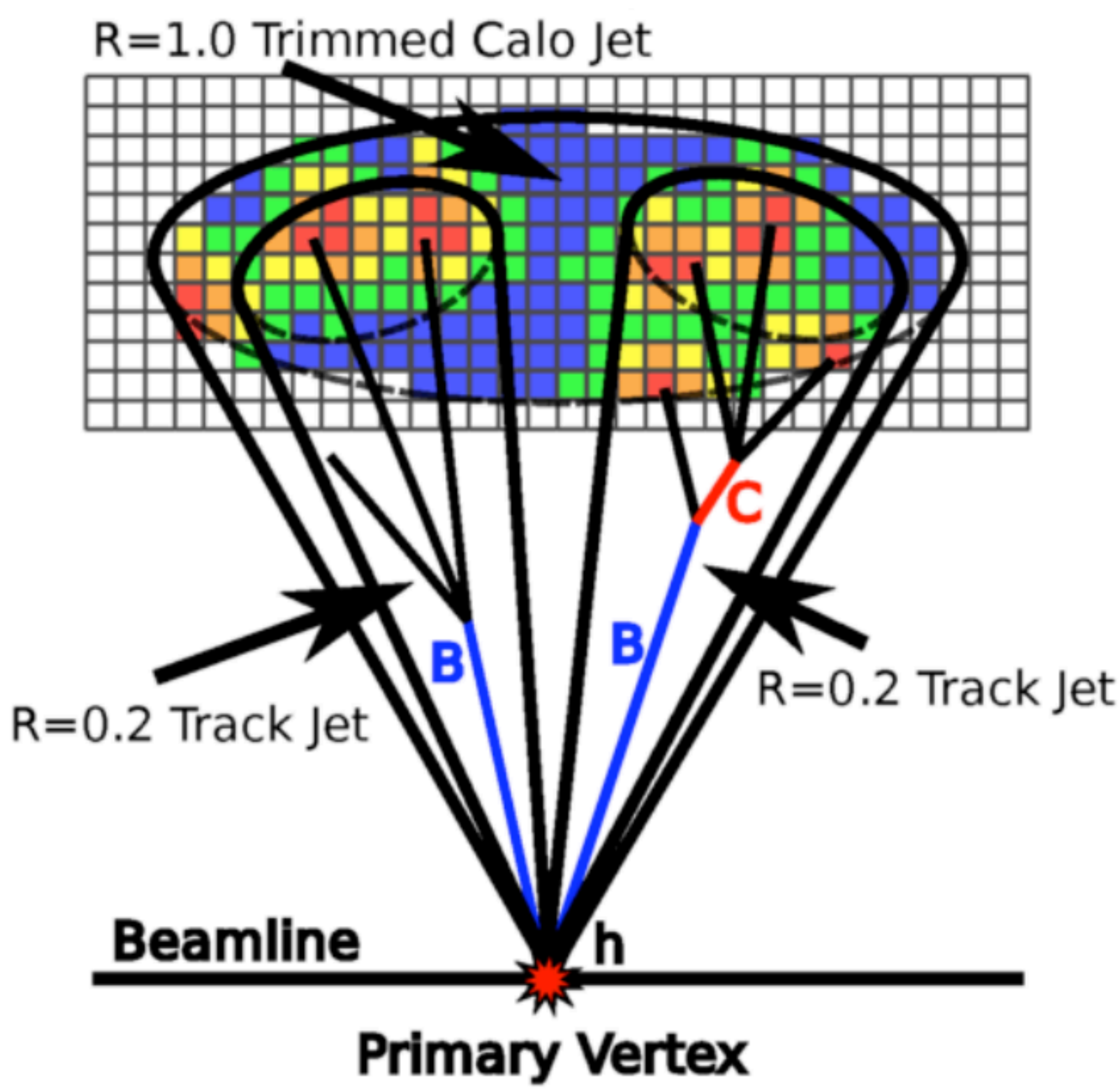
Small effect for most systematic
Three leading systematic uncertainty:
FATJET_JMR （large-R jet mass resolution）
& EFF_Eigen_B_0 (B-tagging)
& FATJET_Medium_JET_Comb_Modelling_Kin(large-R jet pt scale and mass scale)

Systematic from Spurious signal(SS)

- Describe the possible bias between the background **model** and the background **shape**
- Fit **control region data** with bkg+sig model, get number of spurious signal
- parameterization of nSS is used in statistical analysis for results.

R=0.2 track jet

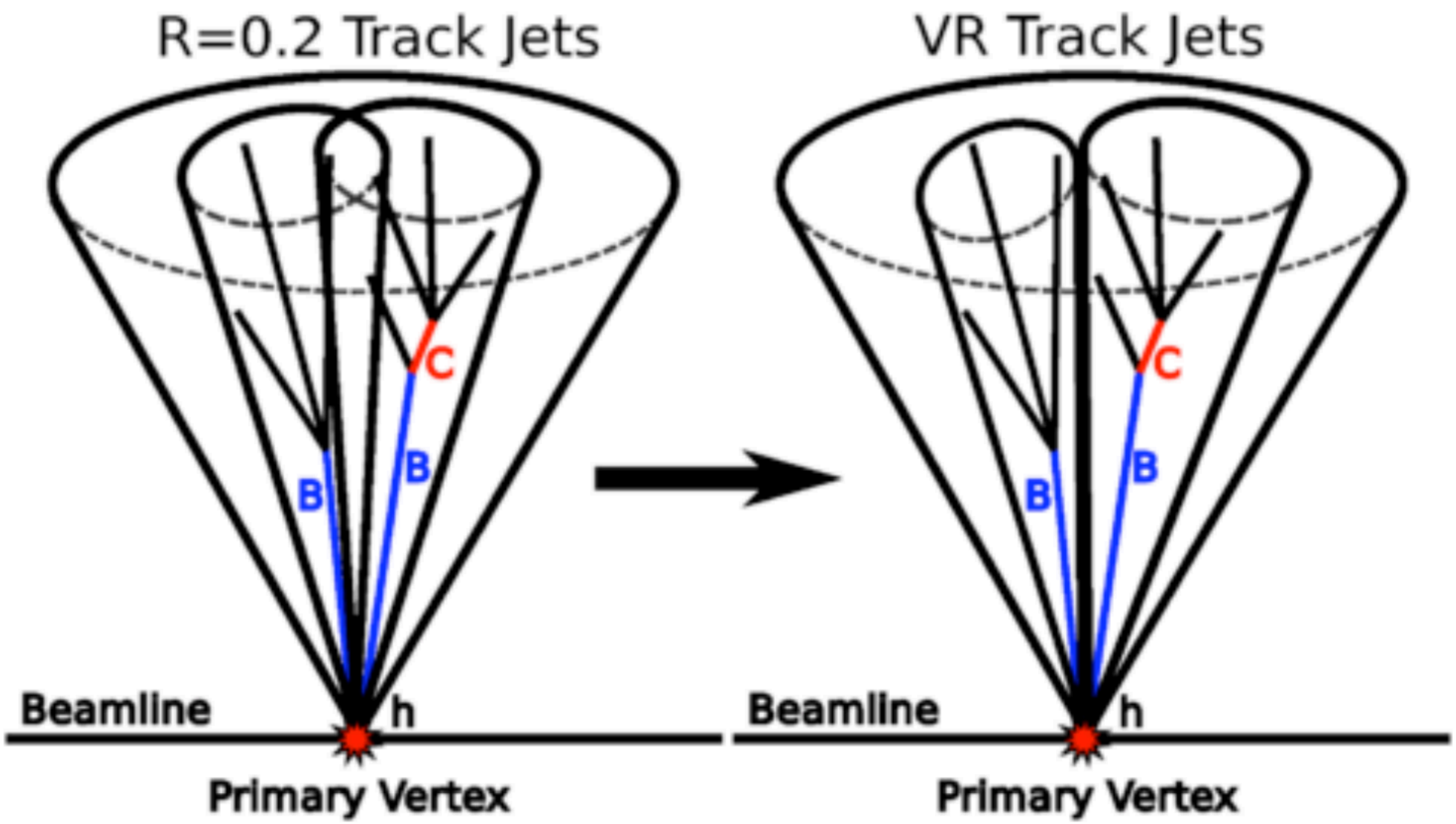
- The fixed-radius R=0.2 track jet approach   Previous



Variable Radius, Exclusive-k_T, and Center-of-Mass Subjet Reconstruction for Higgs($\rightarrow b\bar{b}$) Tagging in ATLAS, ATL-PHYS-PUB-2017-010, 2017

Variable Radius (VR) Track Jets

Cluster anti-k$_T$ track jets using $R_{\rm eff} = \max(R_{\min}, \min(R_{\max}, \rho/\rho_T))$



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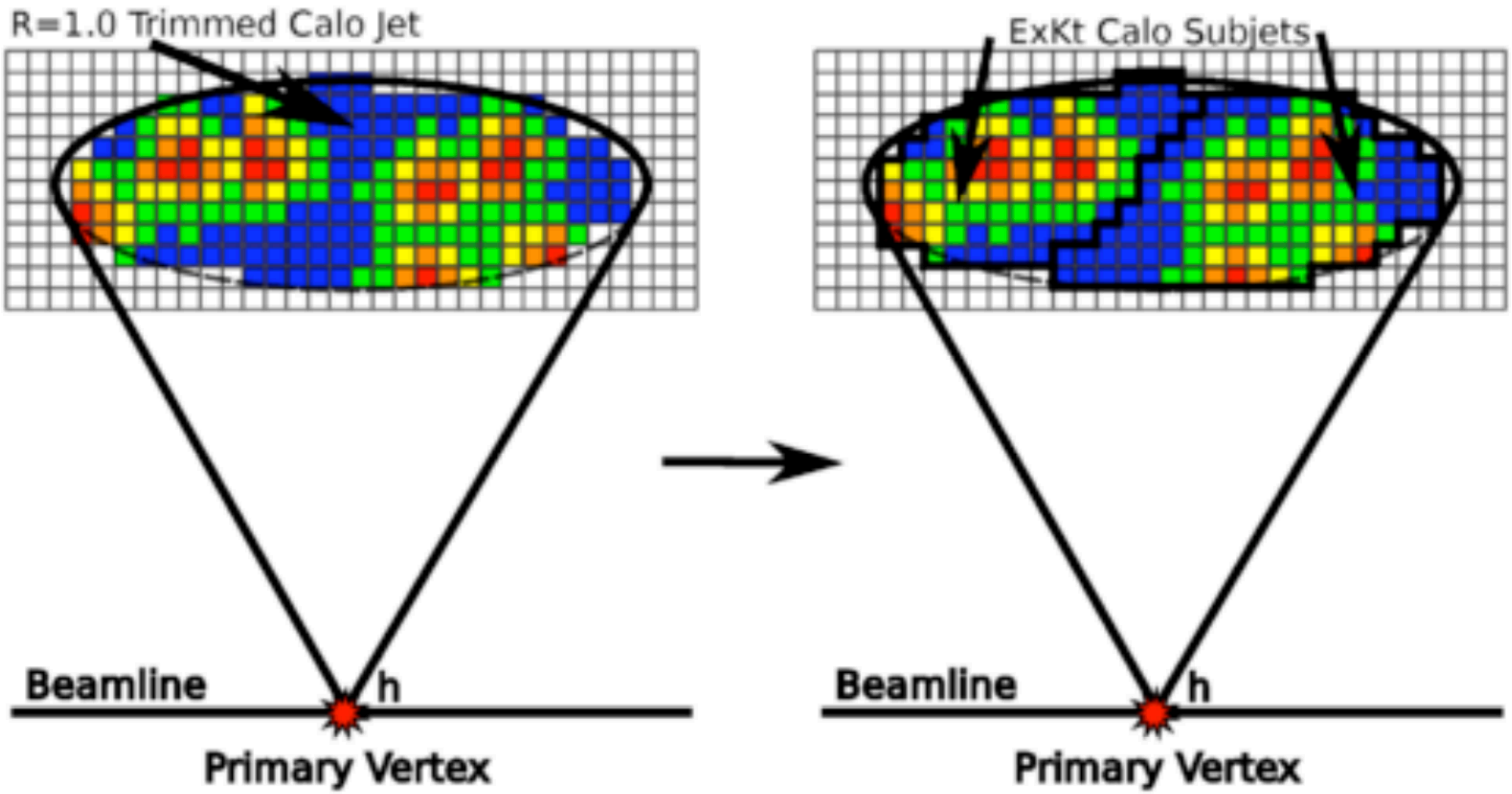
Exclusive k_T Subjets

- Using Higgs jet constituents to cluster k_T jet
- Undo the last clustering step to form exactly 2 subjets



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Signal Modelling

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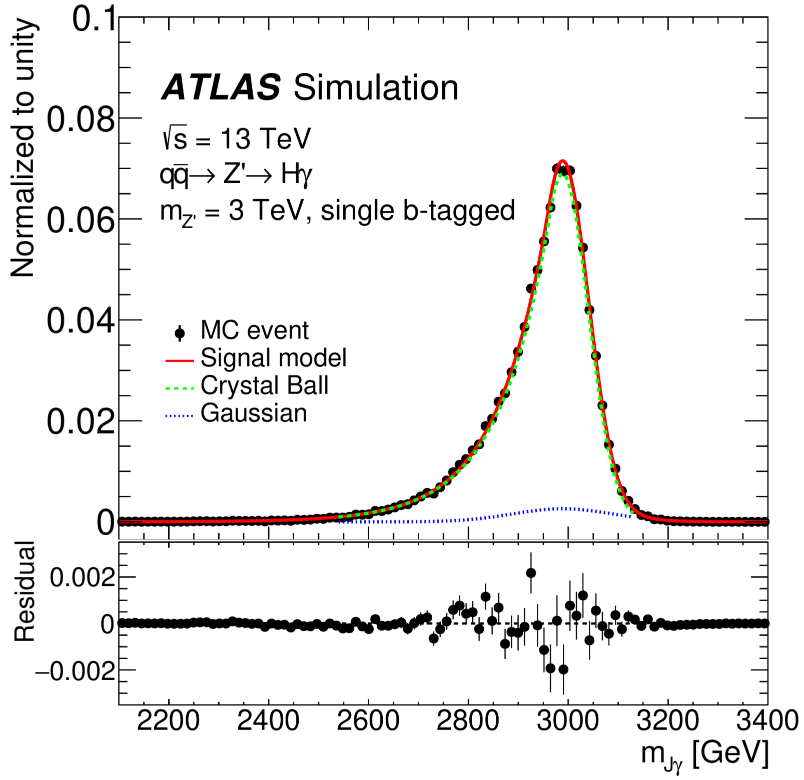
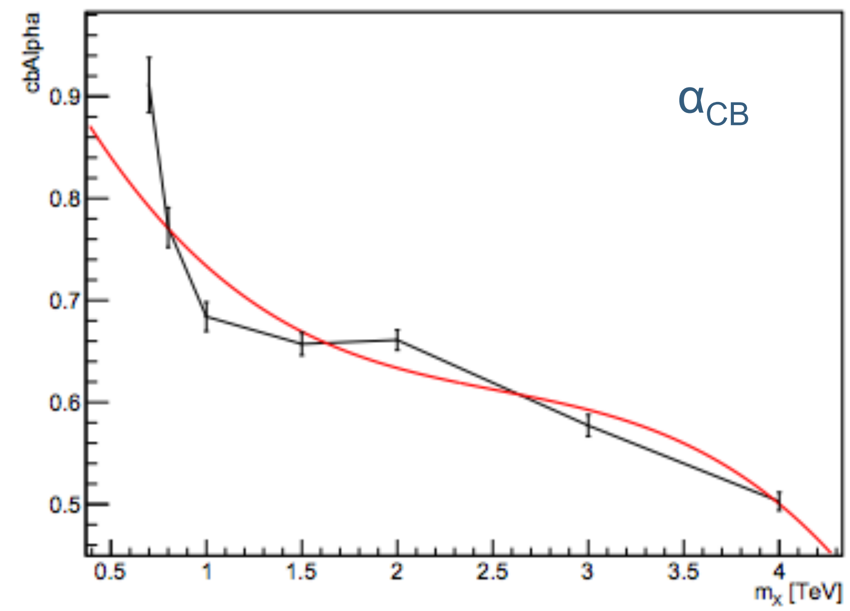
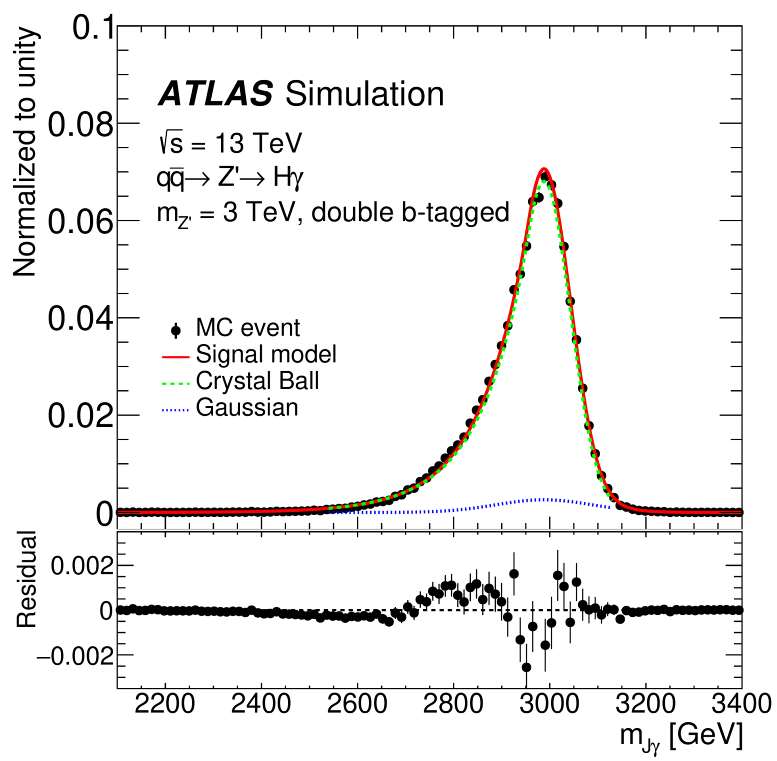
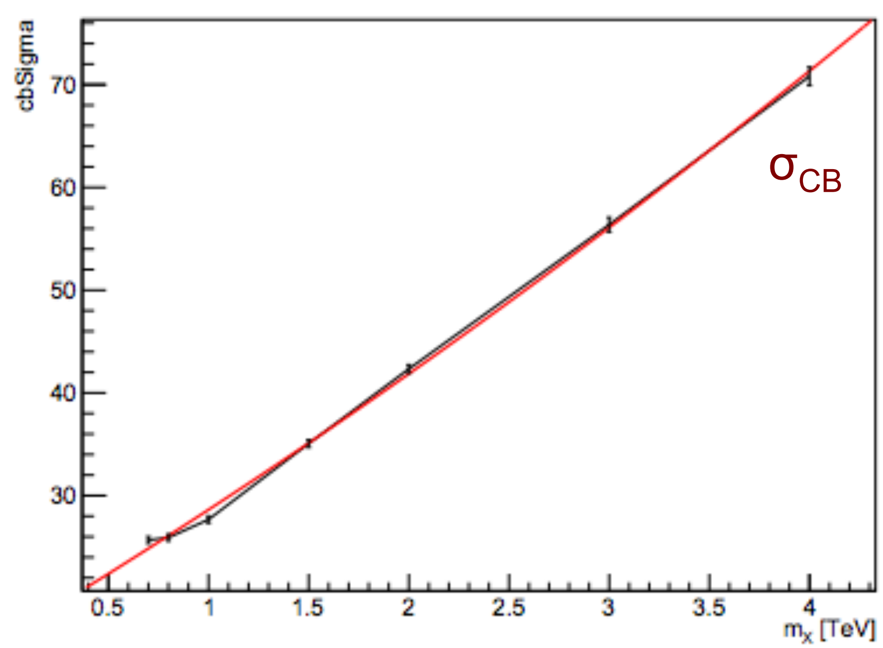


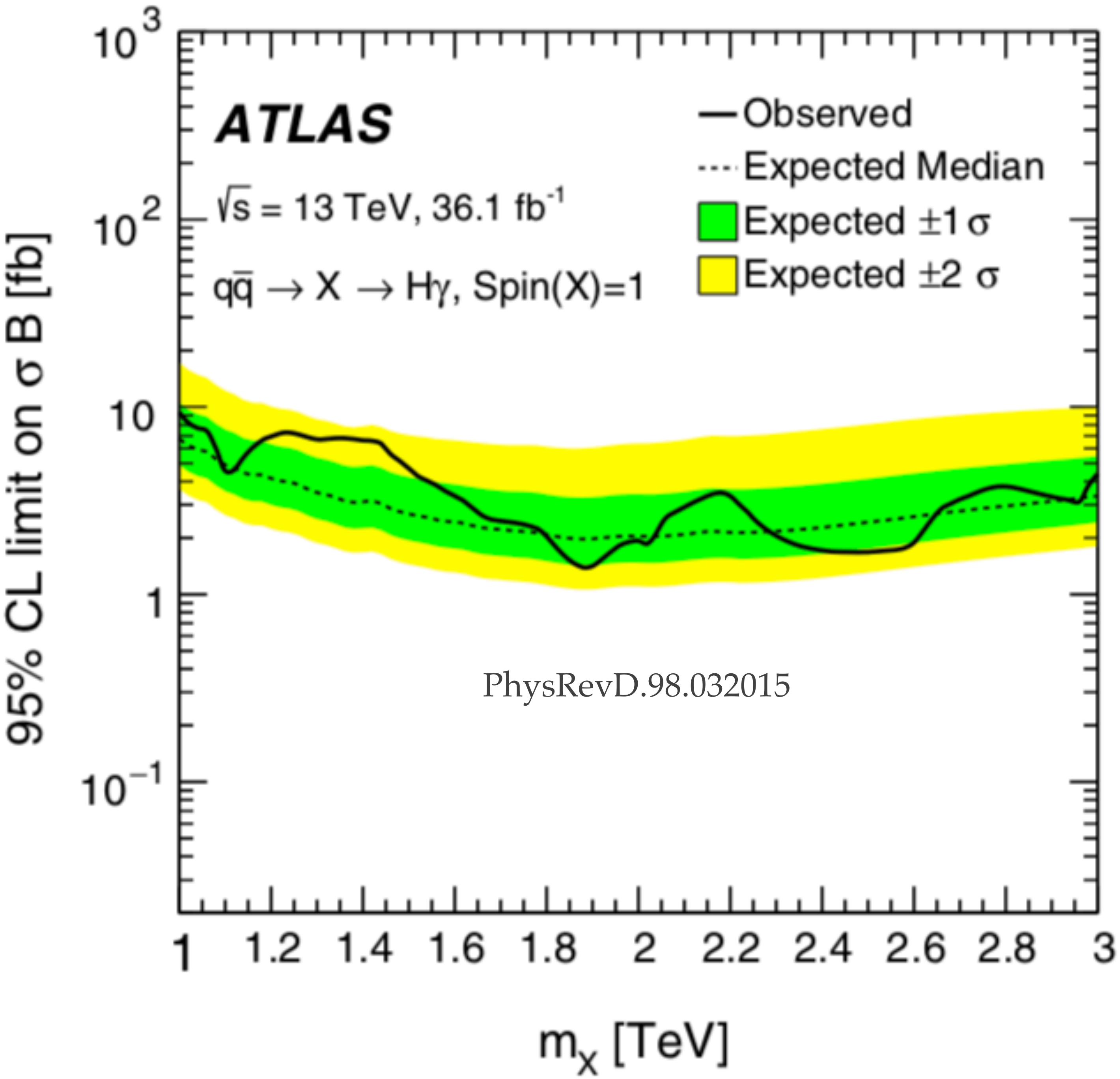


Parameters are parametrized with polynomial function:
2th order for σ_{CB}, σ_{Gauss}, f_{CB}
3th order for α_{CB}

Example of single btag parametrization







PhysRevD.98.032015

Falling signal efficiency lead to a flat limit