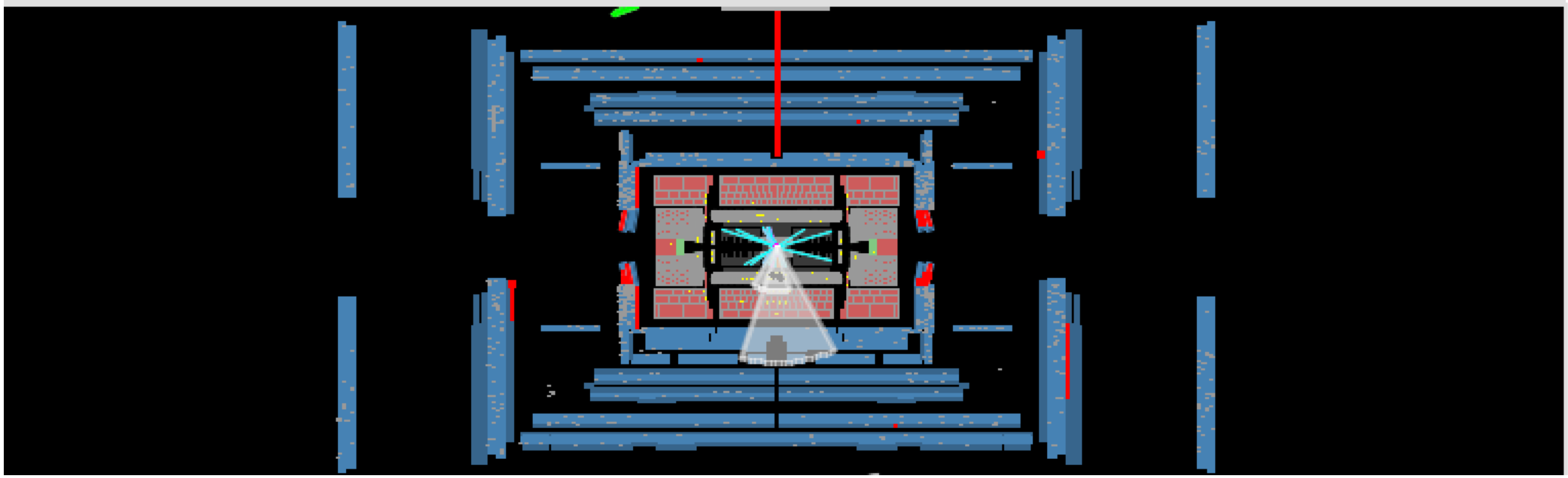
Tracking to the Dark Side at ATLAS: the Present and the Potential



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University of Chicago

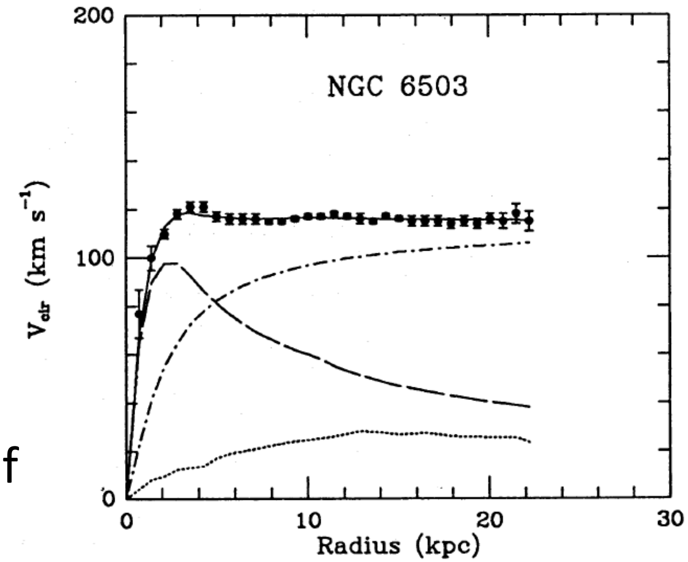
LEPP Journal Club, 11/06/2015

Outline

- **Introduction**
- **Dark Matter Searches at ATLAS**
  - mono-jet
  - mono-b(b)/ top
  - mono-Higgs(→bb)
- **Tracking**: the importance and challenge
- **FastTracKer (FTK) trigger upgrade at ATLAS**
  - Concept
  - Hardware Implementation
  - Physics Performance
- **Conclusions and Outlook**

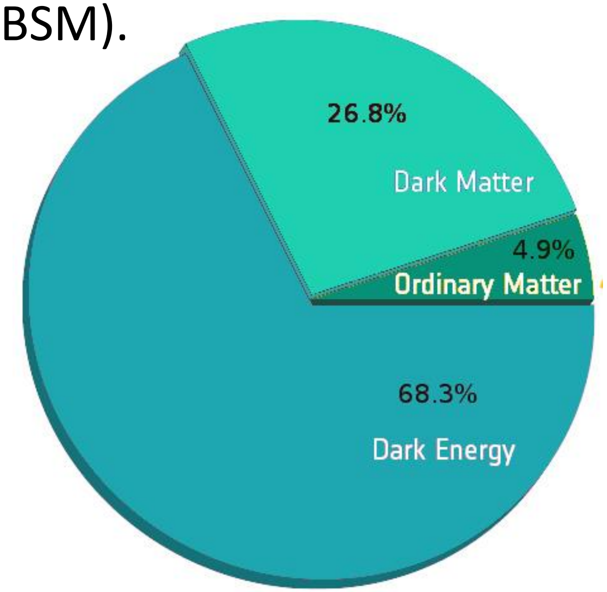
Why Dark Matter?

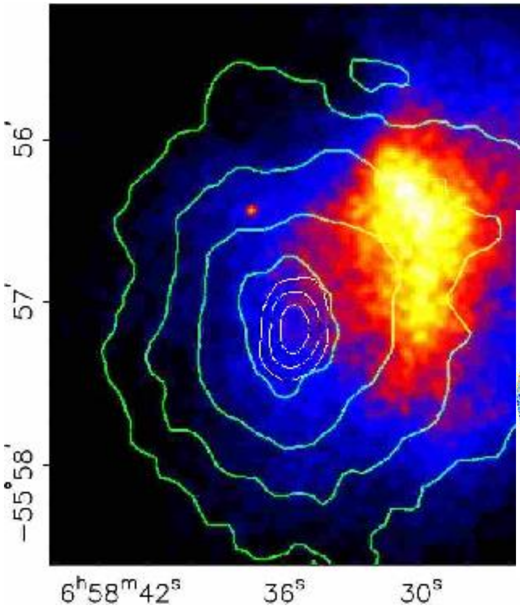
- Plethora of evidence from independent observations on different astrophysical scales: compelling proof for the existence of dark matter (DM)



Galactic Scale (rotation curves of galaxies)

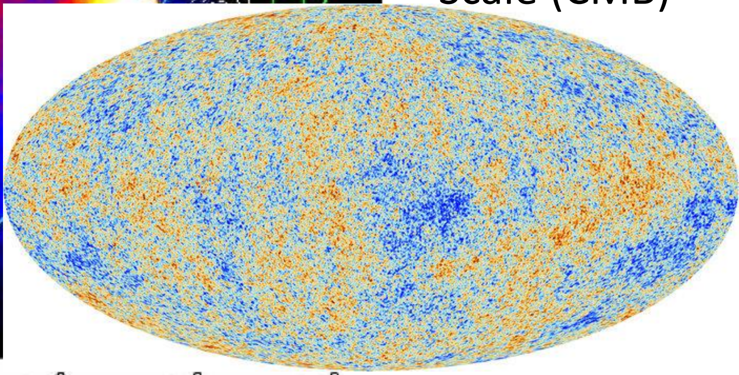
- One of the most striking evidence of physics beyond the Standard Model (BSM).



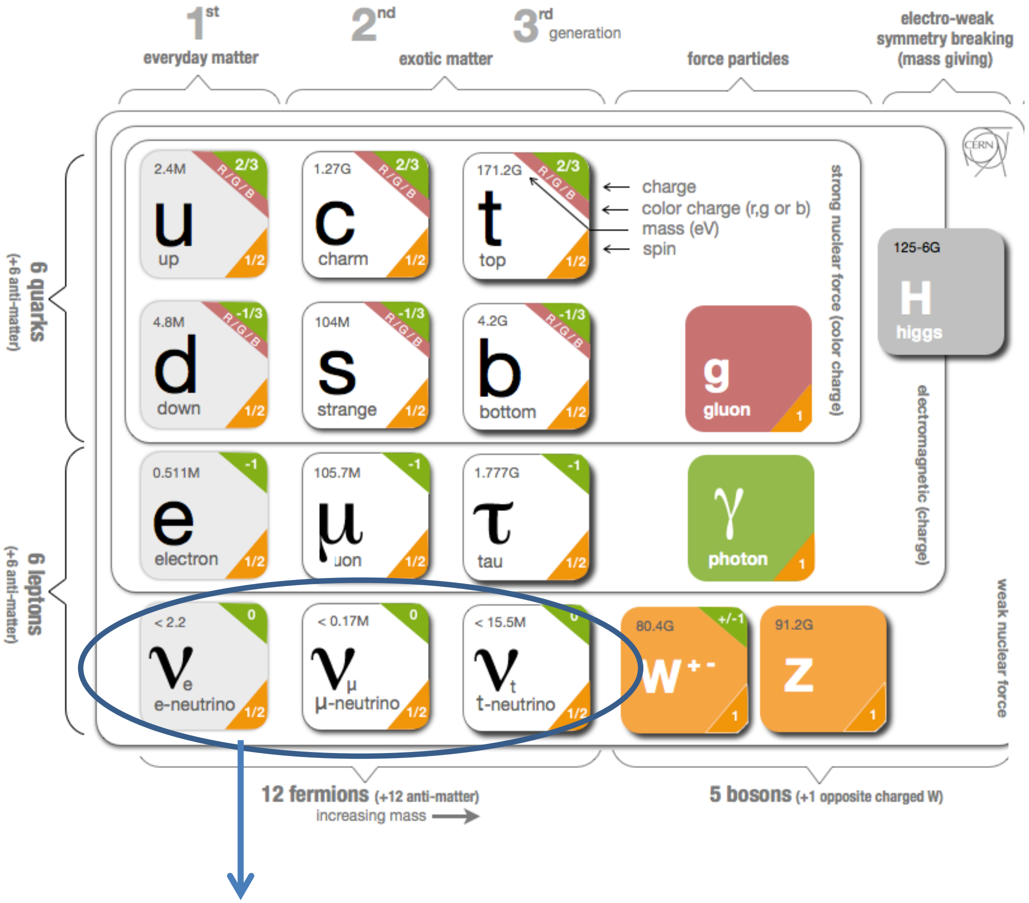


Galactic Cluster Scale (gravitational lensing)

Cosmological Scale (CMB)



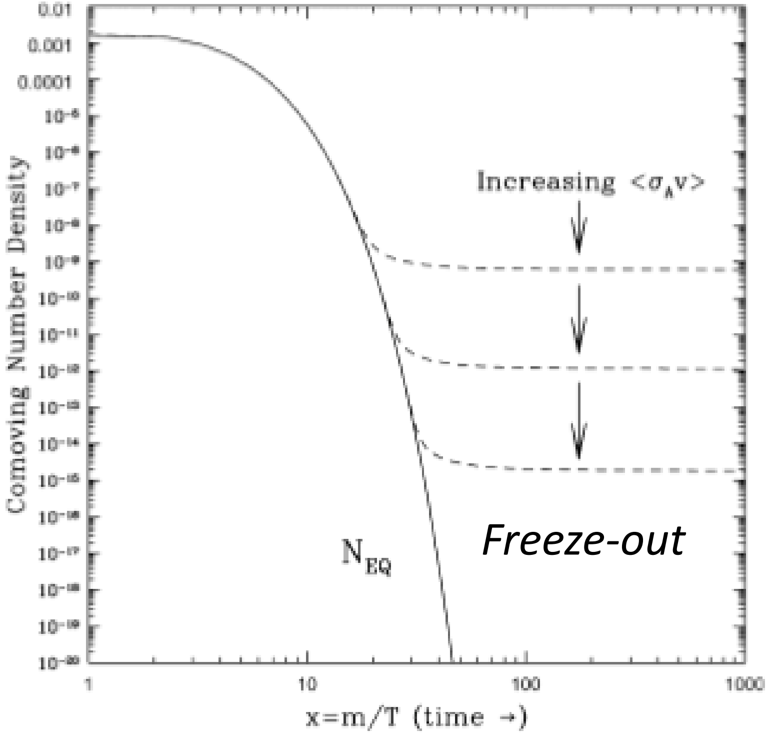
What is Dark Matter?



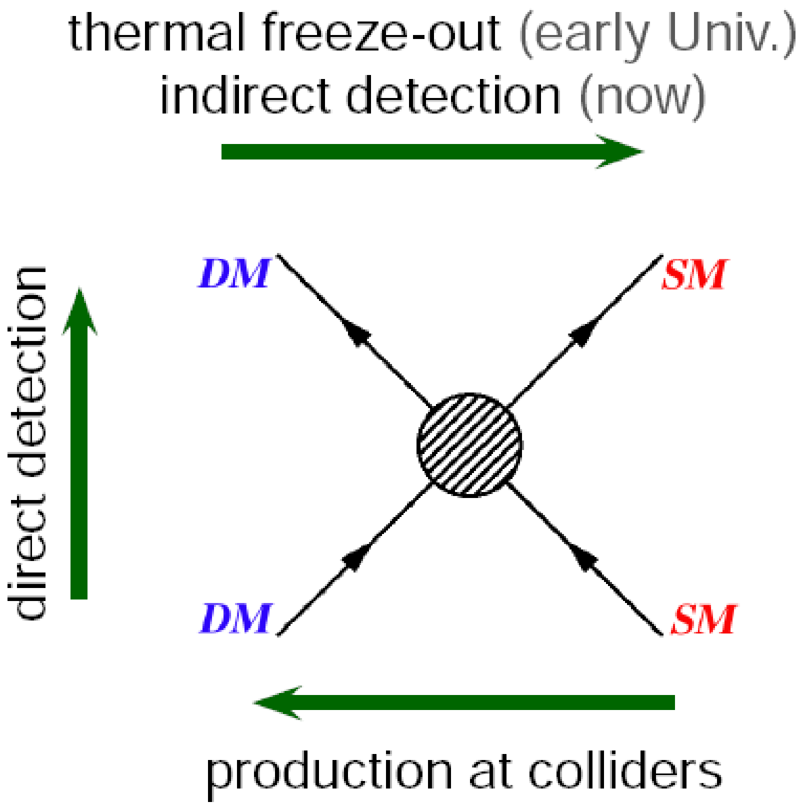
- Not nearly abundant enough to be the dominant source of dark matter!
- Not cold: neutrinos are ~relativistic

If DM is made of particles

- SIMPs? Axions? …
- **WIMP Miracle**
    - fits relic density (cold DM)
    - BSM theories offer viable candidates (SUSY, extra-dim…)



How to look for Dark Matter?

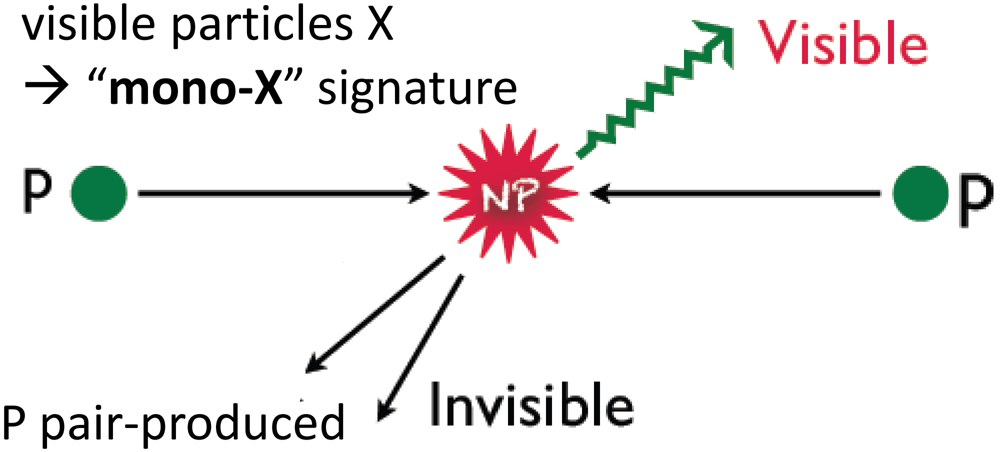

thermal freeze-out (early Univ.)
indirect detection (now)

direct detection

production at colliders

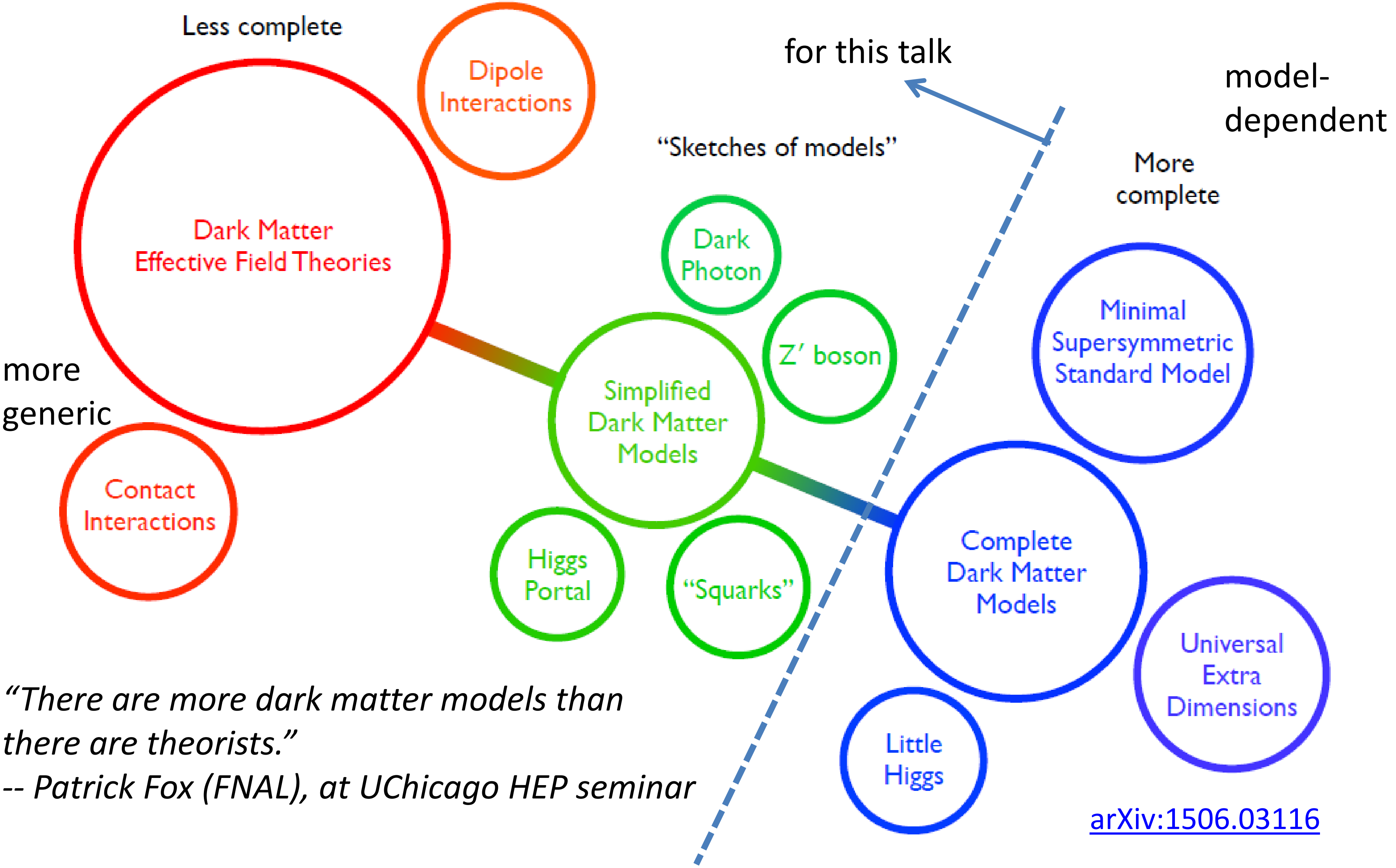
Three
COMPLEMENTARY
experimental methods

Recoiling against one or more visible particles X
→ "**mono-X**" signature



WIMP pair-produced
→ large E_T^{miss}

DM Models for Collider Searches



Less complete

Dipole Interactions

Dark Matter Effective Field Theories

more generic

Contact Interactions

"Sketches of models"

Dark Photon

Z′ boson

Simplified Dark Matter Models

Higgs Portal

"Squarks"

for this talk

model-dependent

More complete

Minimal Supersymmetric Standard Model

Complete Dark Matter Models

Universal Extra Dimensions

Little Higgs

"There are more dark matter models than there are theorists."
-- Patrick Fox (FNAL), at UChicago HEP seminar

arXiv:1506.03116

DM Models: EFT VS Simplified

Effective Field Theory (EFT)

- Heavy mediator not directly produced at collider energy

  → contact interaction
- Various operators (dim.; SI & SD)
- Most-generic, minimal parameters of interest:
  - DM mass & suppression scale
- Validity constraints:
  - momentum transfer *below* mediator mass
  - crucial when comparing with direct & indirect detection

Simplified Models

- Complete enough:
  - explicitly include mediators
- Simple enough:
  - minimal number of renormalizable interactions
- Valid enough:
  - satisfy all non-high pT constraints within parameter space

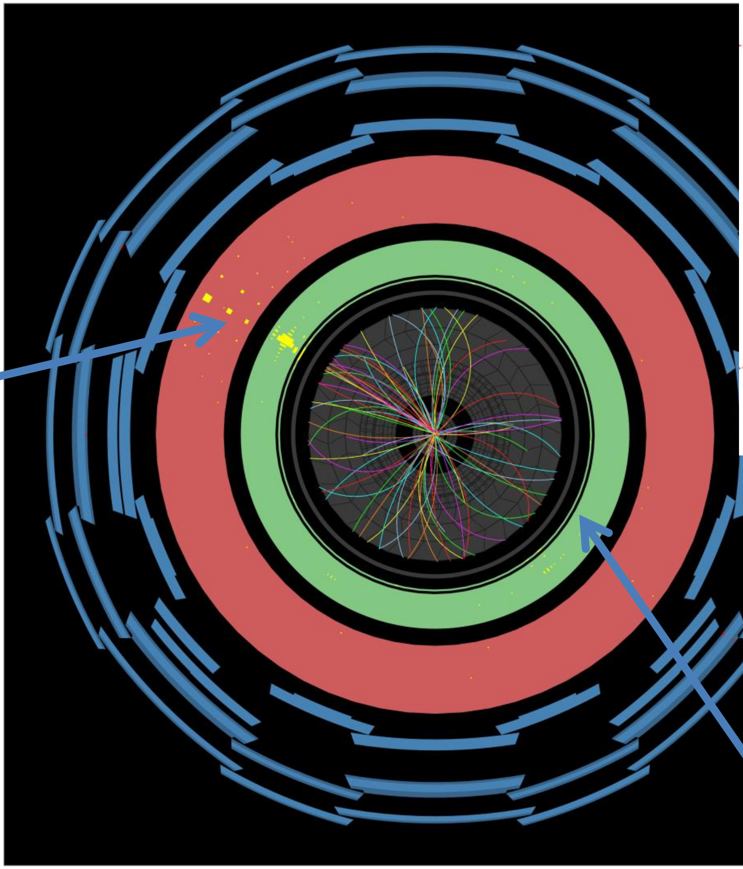
→ may be seen as a simplified version of a complete BSM theory containing only lightest dark-sector state

Collider Signature: E_T^{miss} + "X"

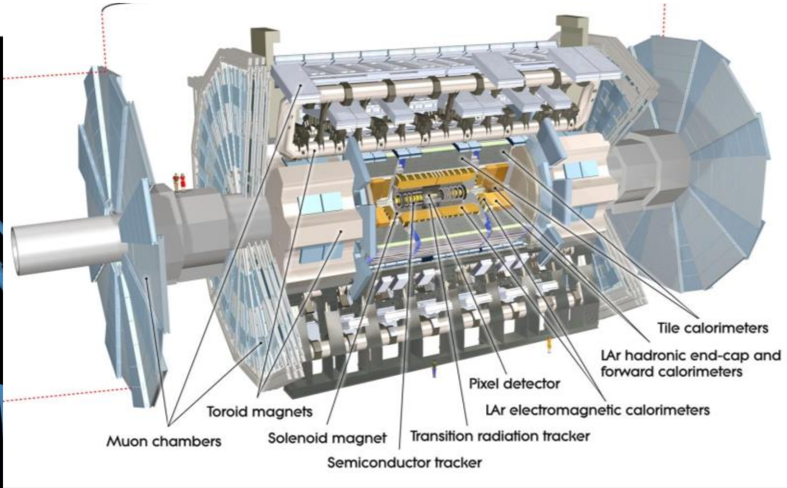
Event display for "**mono-jet**" candidate in the 7TeV collision data.

Final state:

- jet pT = 602 GeV
- E_T^{miss} = 523 GeV
- no additional jet with pT > 30 GeV



E_t^{miss} : what could have escaped?



ATLAS Detector:

- **Inner Detector (tracking)**
  - PIX + SCT + TRT
- **Calorimeter (energy + location)**
  - LAr + Tile
- **Muon Spectrometer**

Physics Object of Interest: E_T^{miss}

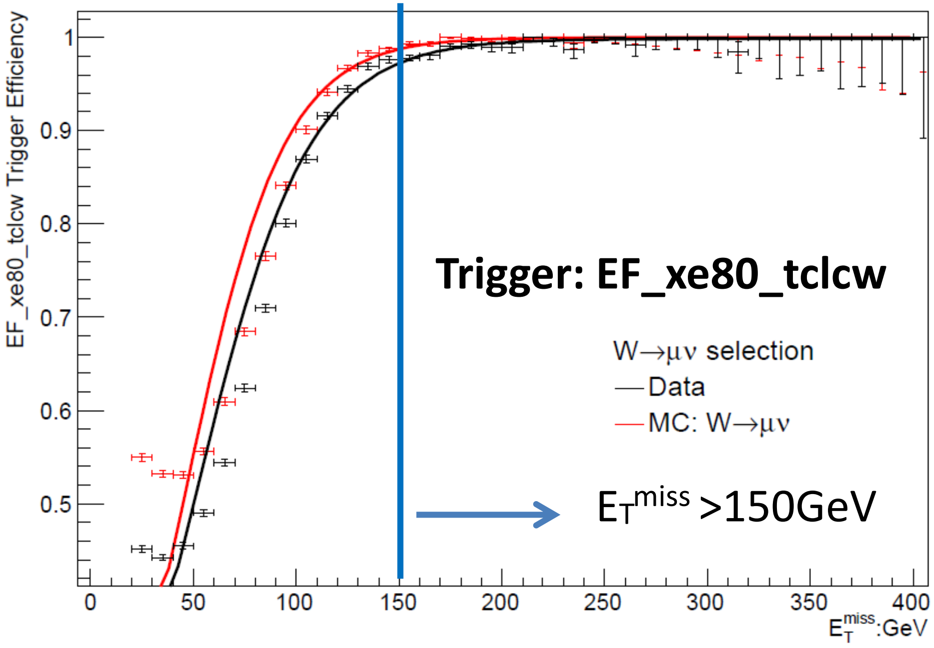
Reconstruction: $E_{x(y)}^{\text{miss}} = E_{x(y)}^{\text{miss,Hard Term}} + E_{x(y)}^{\text{miss,Soft Term}}$

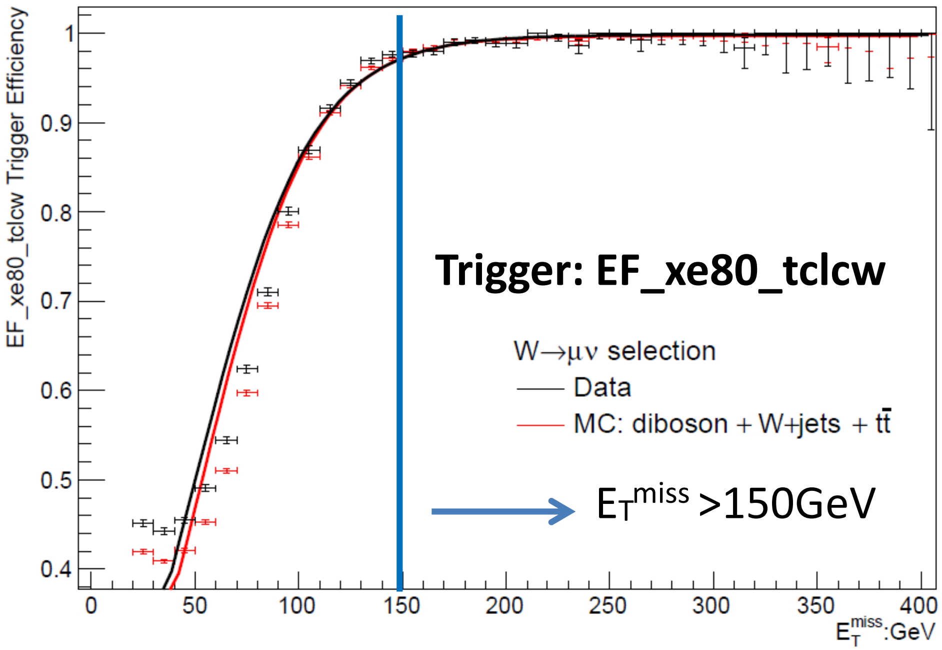
$\rightarrow$ reconstructed event objects (e, μ, γ, jets …)

Trigger selection:

- L1 $E_T^{\text{miss}} > 60$ GeV   Calorimeter info
- L2 $E_T^{\text{miss}} > 65$ GeV   L1 + muon chambers
- EF $E_T^{\text{miss}} > 80$ GeV   Calibration: Local Cluster Reweighting (LCW)

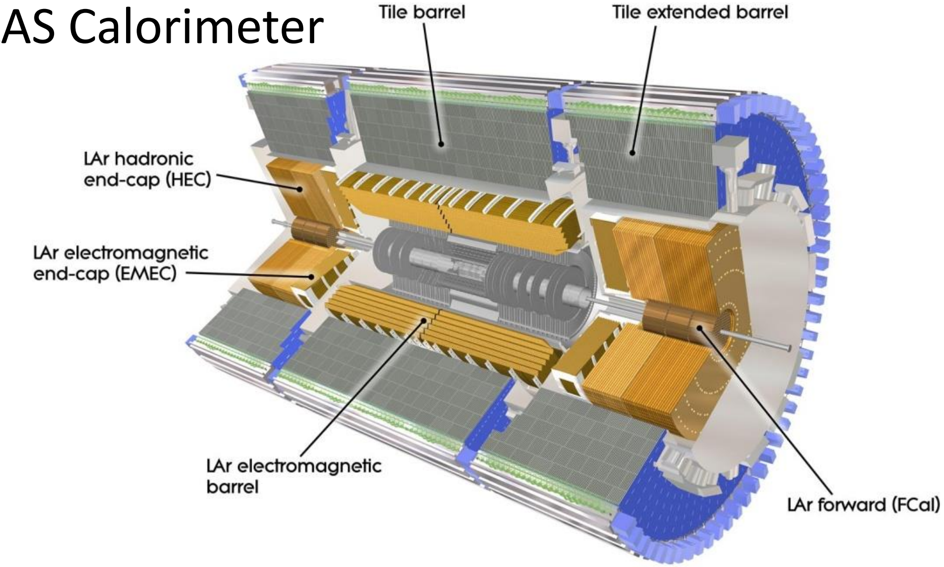
Trigger performance:

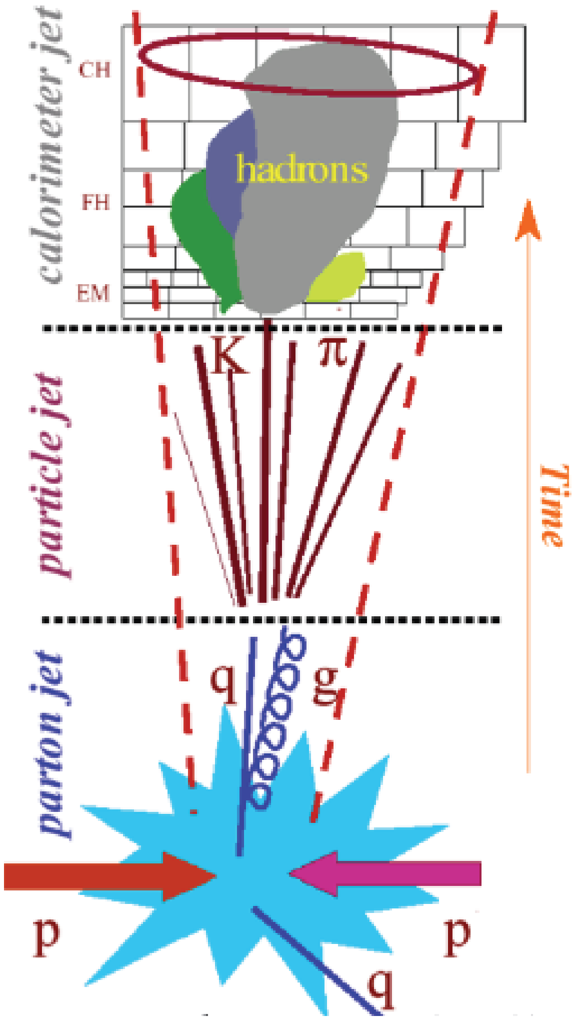




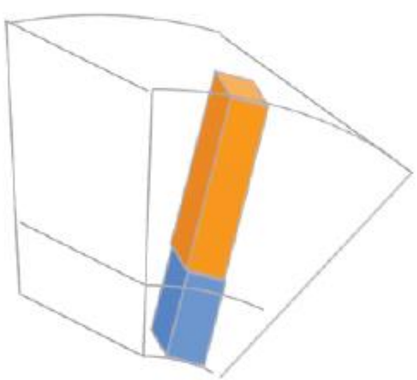
Physics Object of Interest: Jets

ATLAS Calorimeter

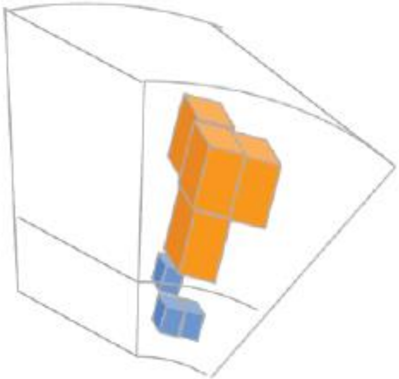




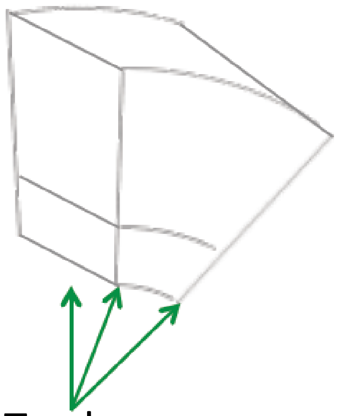
Inputs to jets



Towers
(trigger-only)

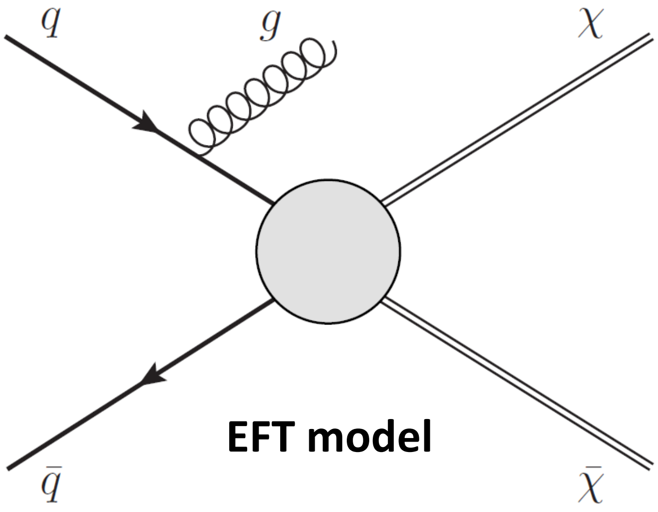


Topoclusters
(energy deposits in calo.)



Tracks
(more on that later!)

Mono-jet: Signal & Background

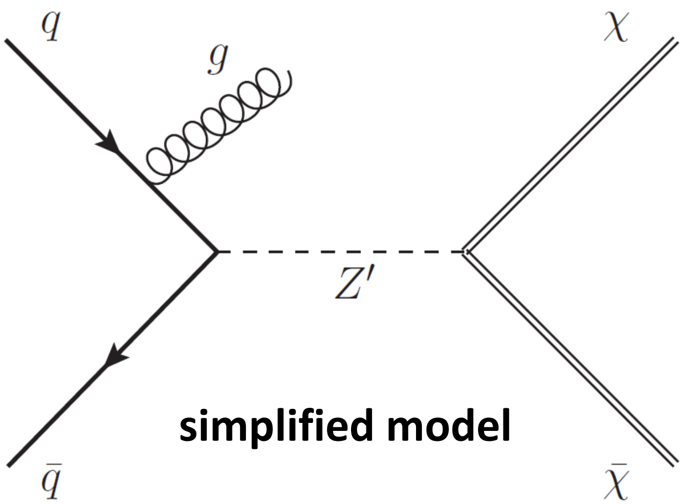


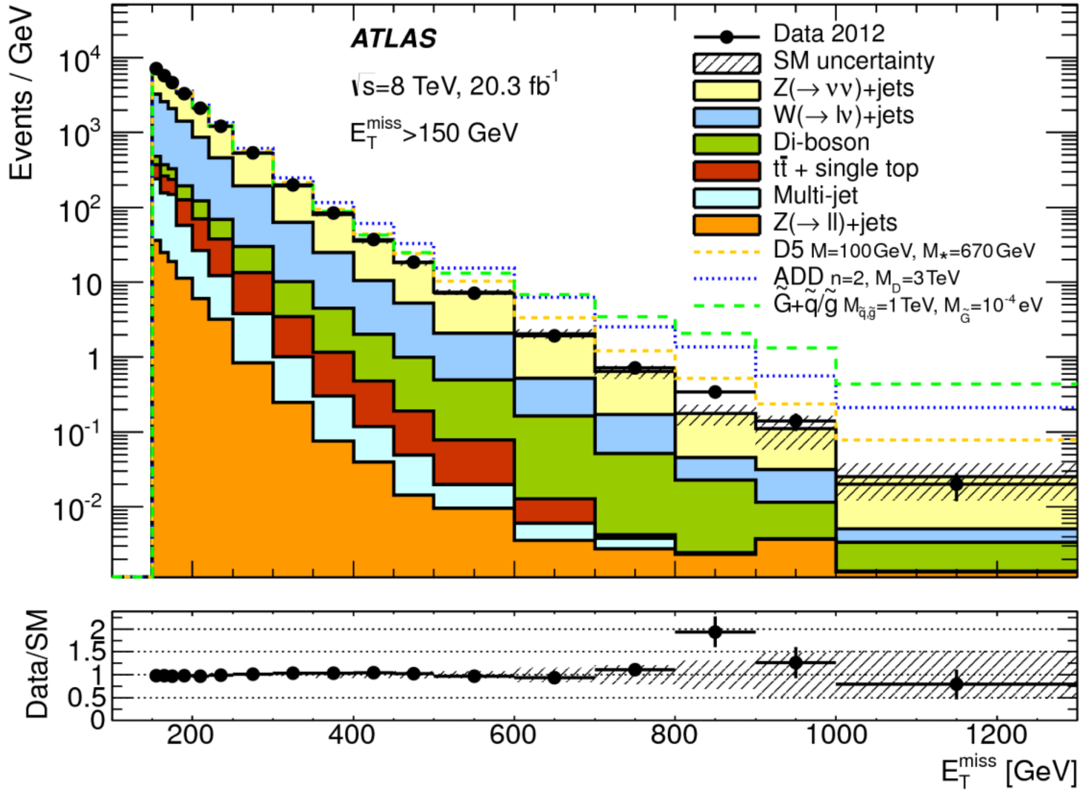
SR1 – SR9: E_T^{miss} threshold 150GeV to 700GeV

Background estimation:

- W+jets & Z(νν)+jets : MC normalized with data
- Top, Z(ll)+jets, diboson: MC
- Multijet: data-driven

arXiv:1502.01518

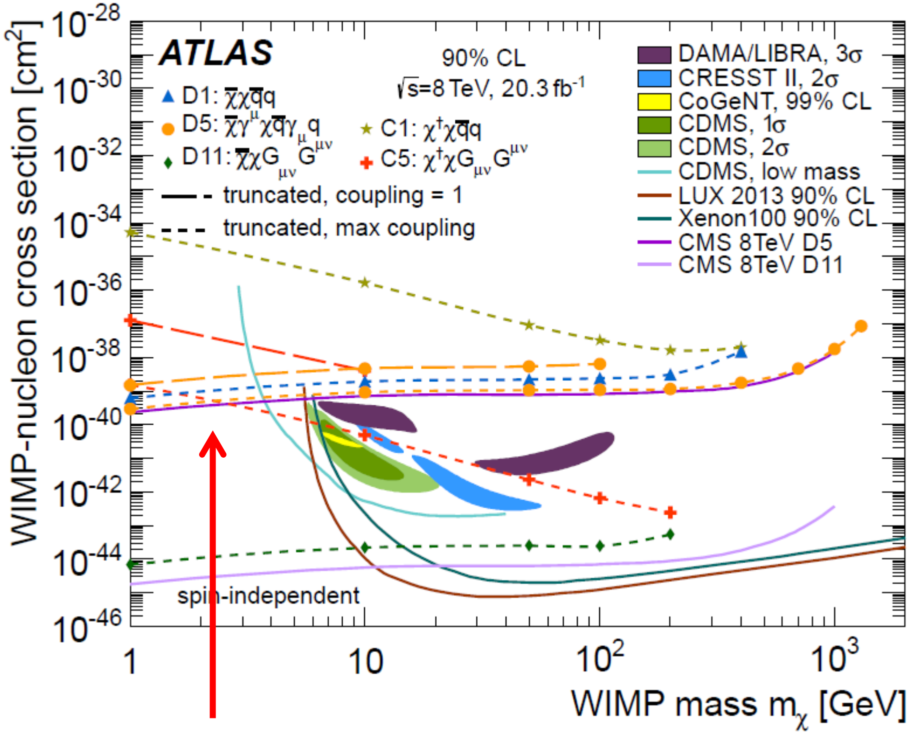




Mono-jet: Result

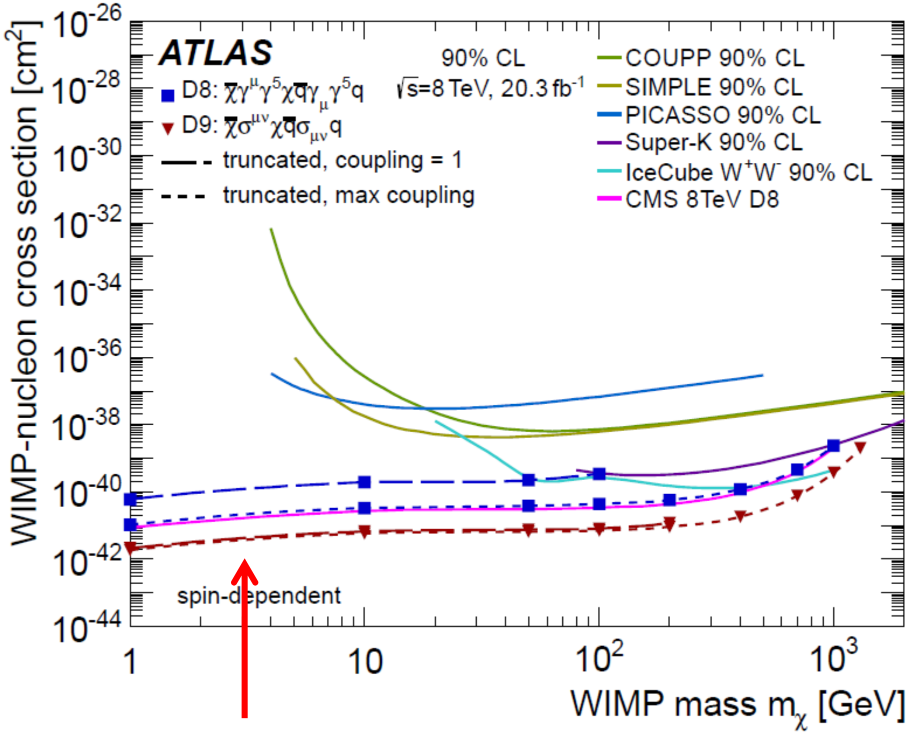
arXiv:1502.01518

Spin-Independent (SI) DM



- Collider limits stronger than direct detection for SI-DM at low mass
  - nuclear recoil energy (~keV) hard to detect with current technology

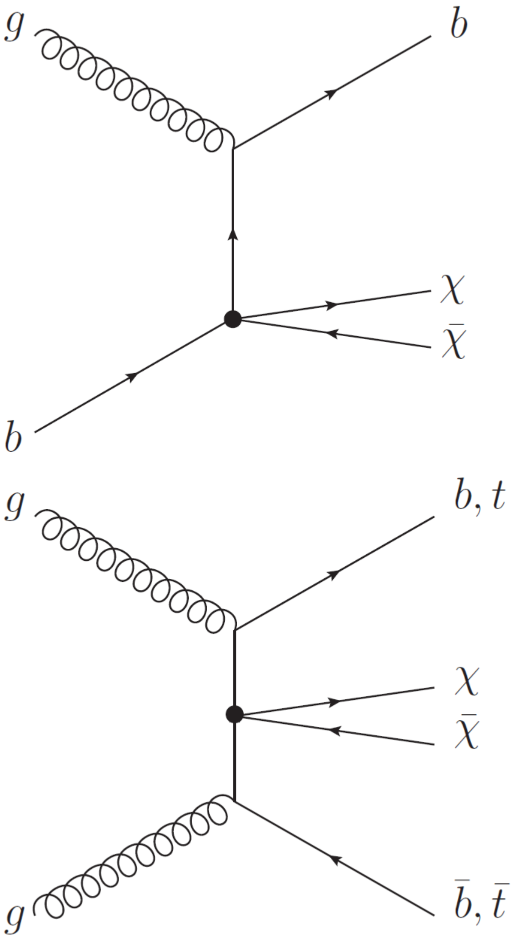
Spin-Dependent (SD) DM



- Collider limits stronger than direct detection for SD-DM for most DM mass range:
  - SD-DM less sensitive at direct detection due to coupling to nuclear spin (vs mass)

DM+Heavy Flavor: Motivation (EFT)

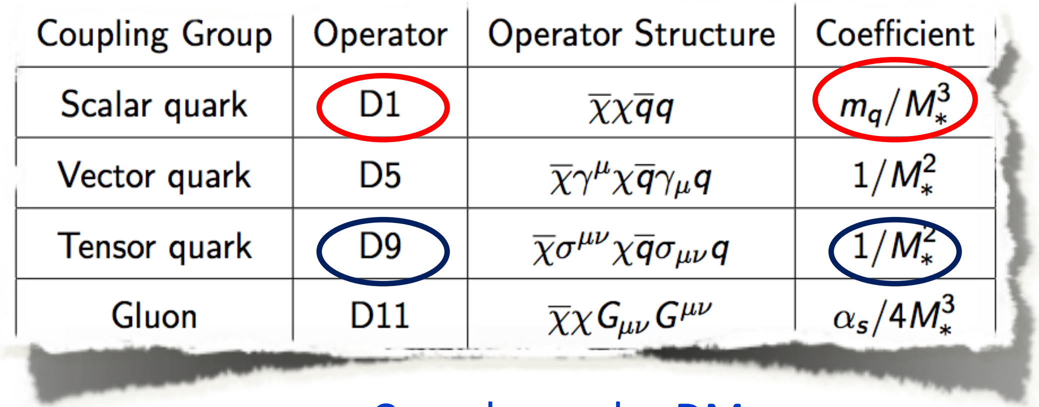
EFT: Diagram



EFT: Operators

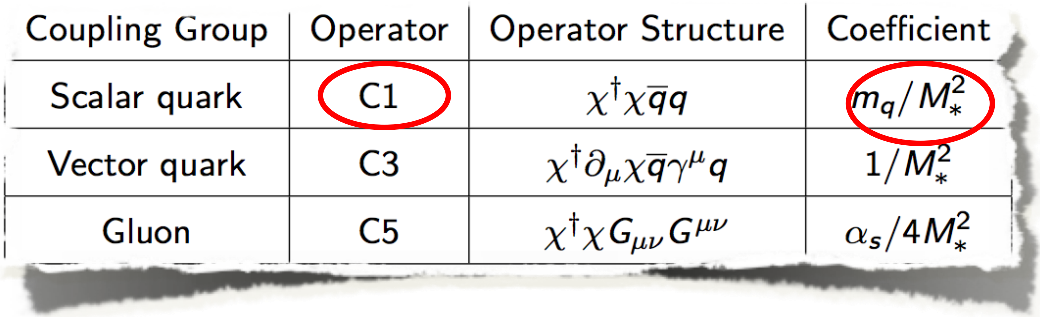
arXiv:
1008.1783
1303.6683

Fermionic DM



Coupling Group	Operator	Operator Structure	Coefficient
Scalar quark	D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
Vector quark	D5	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
Tensor quark	D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
Gluon	D11	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$

Complex scalar DM



Coupling Group	Operator	Operator Structure	Coefficient
Scalar quark	C1	$\chi^\dagger\chi\bar{q}q$	m_q/M_*^2
Vector quark	C3	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu q$	$1/M_*^2$
Gluon	C5	$\chi^\dagger\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^2$

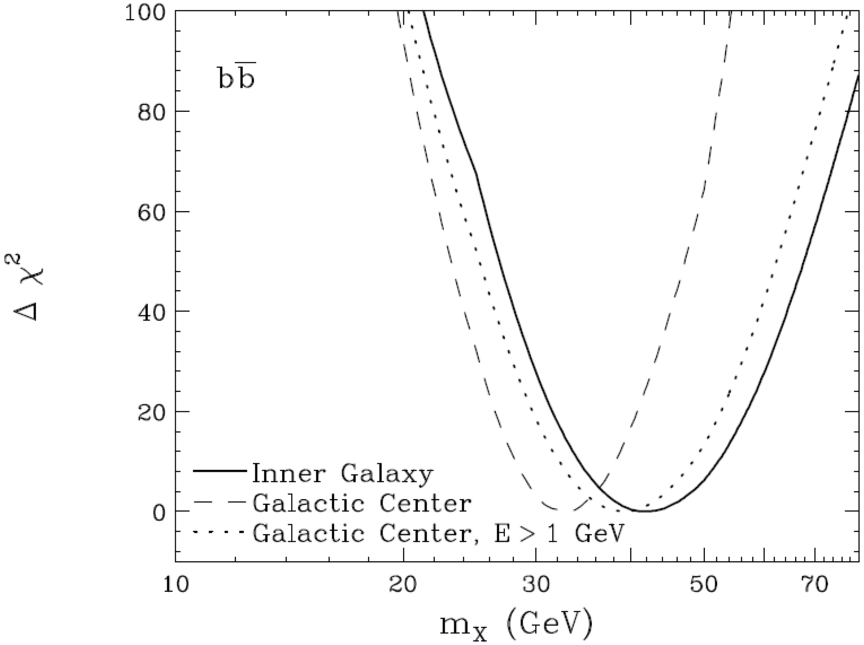
D1, C1: coupling normalized by quark mass

D9: quark mass dependence from Yukawa coupling

DM+Heavy Flavor: Motivation (Simplified)

Fermi-LAT Result Interpretation

arXiv:1402.6703

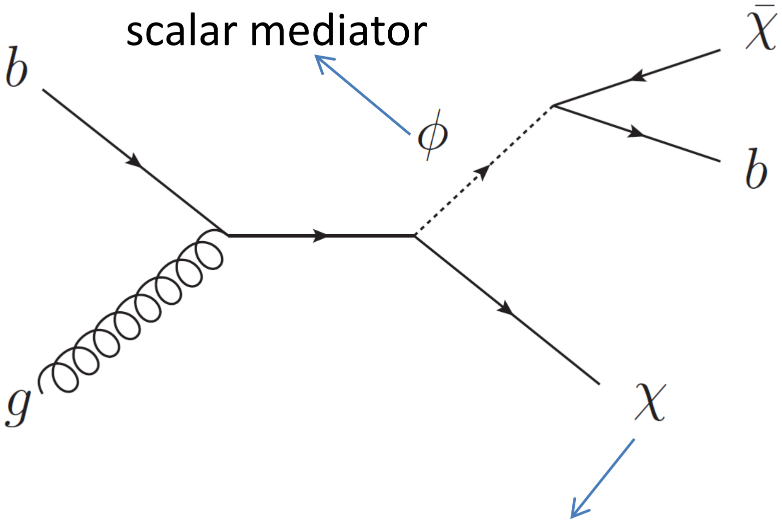


Excess of gamma rays from galactic center can be interpreted as DM annihilation:

- analysis favors DM of ~35GeV annihilating into b-quarks via colored mediator

bottom-Flavored Dark Matter

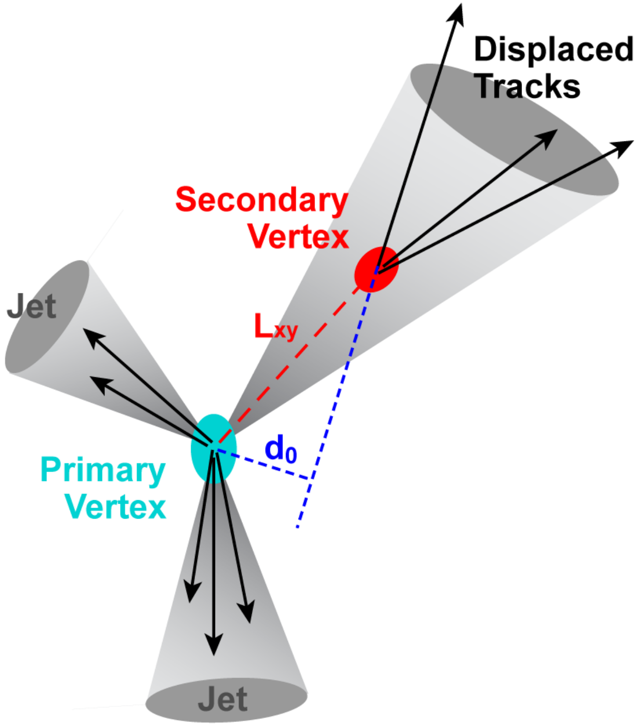
arXiv:1404.1373

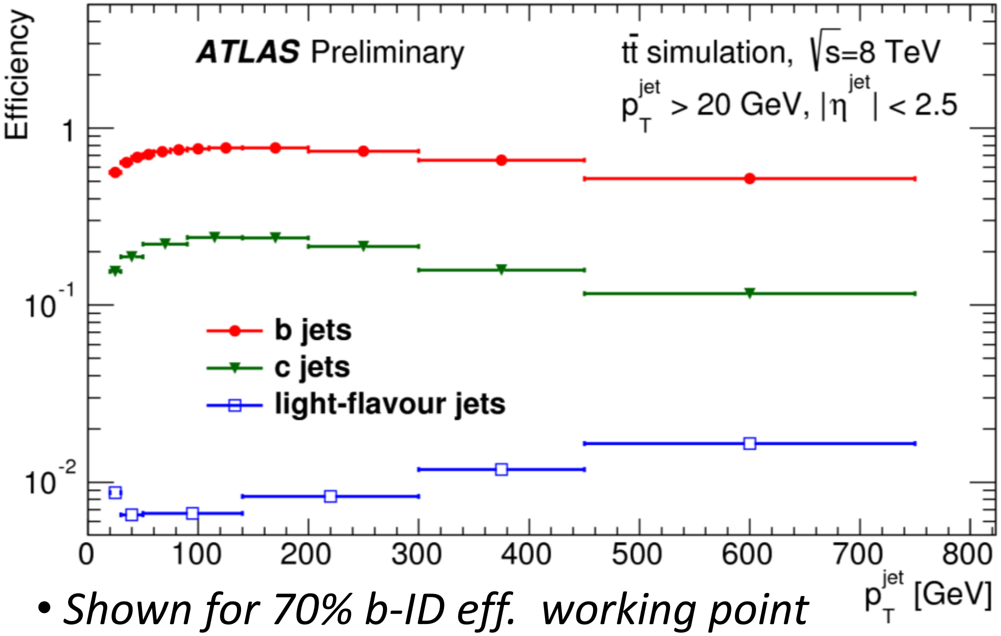


scalar mediator

Dirac fermion DM particle; preferentially couples to b-quarks

Physics Object of Interest: b-jet





- *Shown for 70% b-ID eff. working point*
- *Calibrated to using ttbar dilepton data events*

- b-tagging "MV1" multi-variant algorithm: input from multiple algorithms incl. I3PD (track-based) ; SV1 (secondary-vertex finding); JetFitter (neural network)

→60%* , 70%, 80% b-jet ID efficiency working points

*selected for optimal signal sensitivity: mis-ID rate ~15% for c-jet & <1% for light

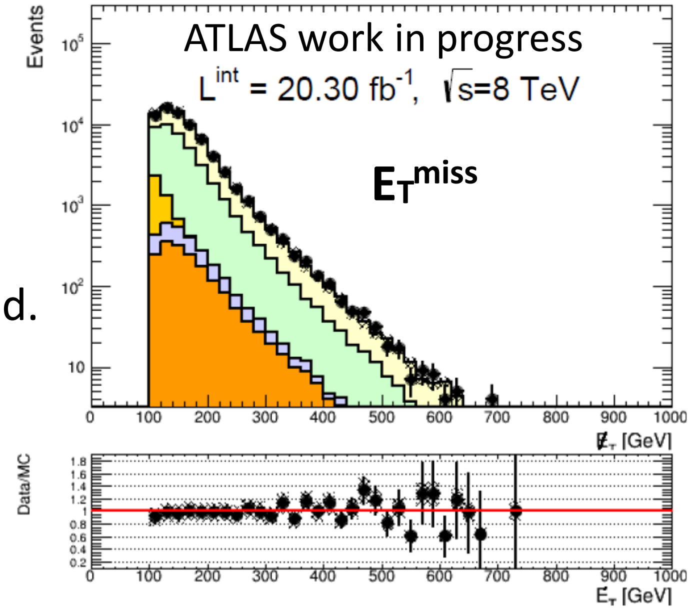
- Jets considered for b-tagging: pT>20GeV, |η|<2.5

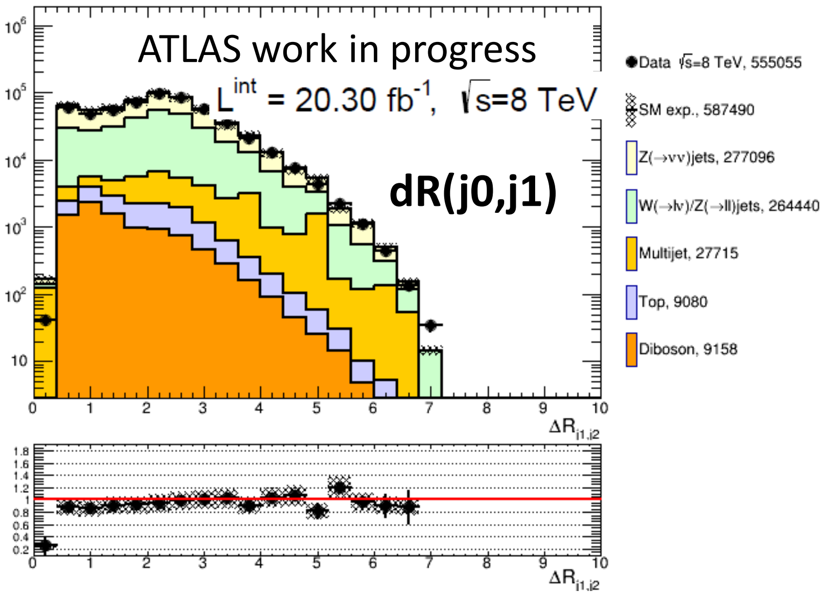
Data-Driven Background: Z(νν)+jets

- Main & irreducible background → data-driven estimation (no good MC at high pT)
- E_T^{miss} <200GeV , reweight from **Z(→μμ)+jets data**
  - Select Z→μμ CR; TF: Z→νν (MC) E_t^{miss} / Z→μμ (MC) (E_T^{miss} + pT of 2μ)
- E_T^{miss} >200GeV, reweight from **γ+jets data** (low stats with Z→μμ)
  - Similar production of Z,γ when pT>>mZ ; select 1 prompt, high pT photon
  - TF: γ+jets(MC) (E_T^{miss} +γ pT) / Z→νν (MC) E_t^{miss}

Z(→νν)+jets CR
0-Lepton,
0-btagged jet

1-bjet also studied. Good agreement across-board.





DM+Heavy Flavor: Signal Regions

	SR1	SR2	SR3
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}}$	5 jets || 4jets(1b)
Jet multiplicity n_j	1–2	3–4	$\geq$5
b-jet multiplicity n_b	>0 (60% eff.)	>0 (60% eff.)	>1 (70% eff.)
Lepton multiplicity n_ℓ	0	0	0
$E_{\mathrm{T}}^{\mathrm{miss}}$	>300 GeV	>300 GeV	>200 GeV
Jet kinematics	$p_{\mathrm{T}}^{b_1} > 100$ GeV	$p_{\mathrm{T}}^{b_1} > 100$ GeV $p_{\mathrm{T}}^{j_2} > 100$ (60) GeV	$p_{\mathrm{T}}^{j} > 25$ GeV
Three-jet invariant mass			
$\Delta\ i\left(j_i, E_{\mathrm{T}}^{\mathrm{miss}}\right)$	$> 1.0,\ i = 1, 2$	$> 1.0,\ i = 1 - 4$	-
Angular selections	-	-	$\Delta\ i\left(b_1, E_{\mathrm{T}}^{\mathrm{miss}}\right) \geq 1.6$
Event shape	-	-	Razor R >0.75

SR1: DM+b

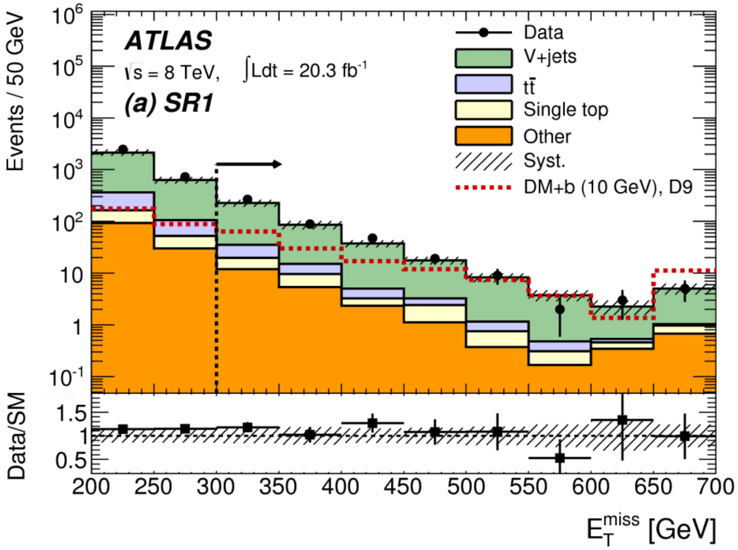
SR2: DM+ bbbar

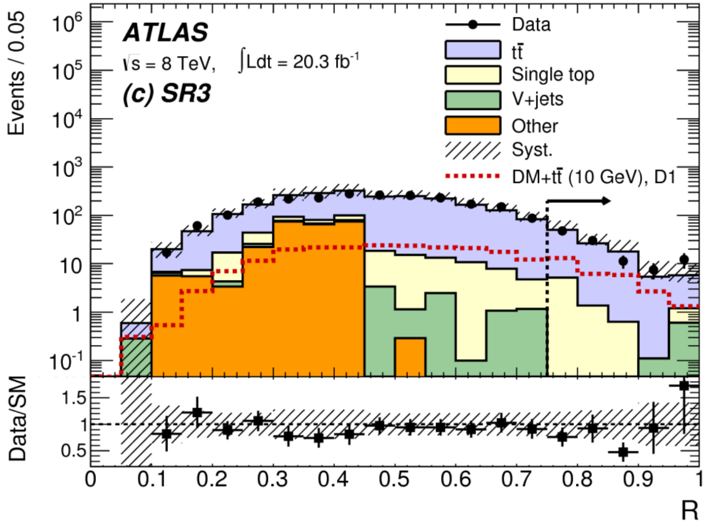
SR3: DM+ ttbar

→

SR1-3 fully hadronic

Additional SR4 using SUSY STop 1Lepton selection for DM+ttbar



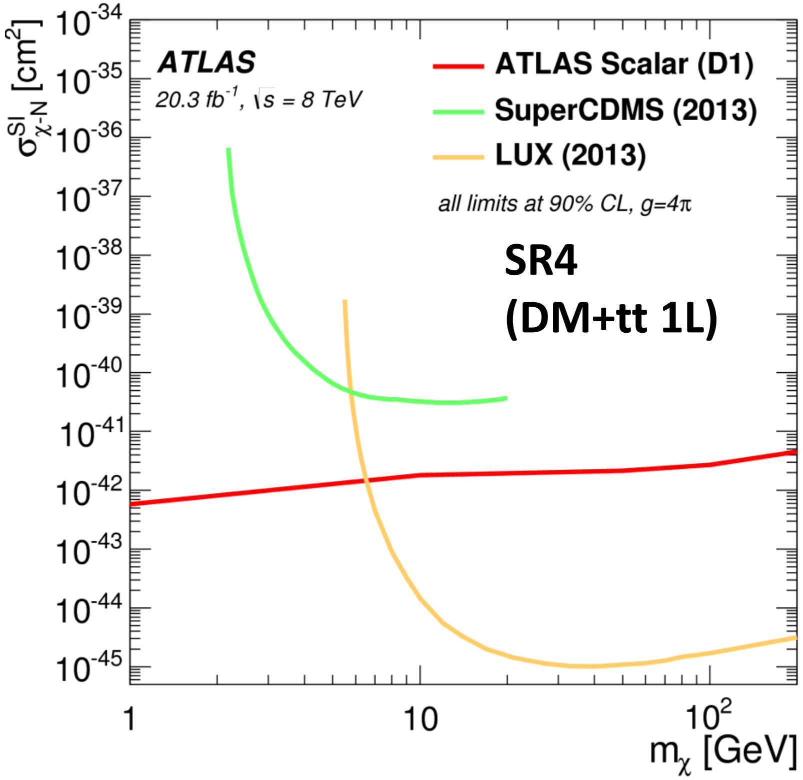


arXiv:1410.4031

DM+Heavy Flavor: mono-b(b) Results

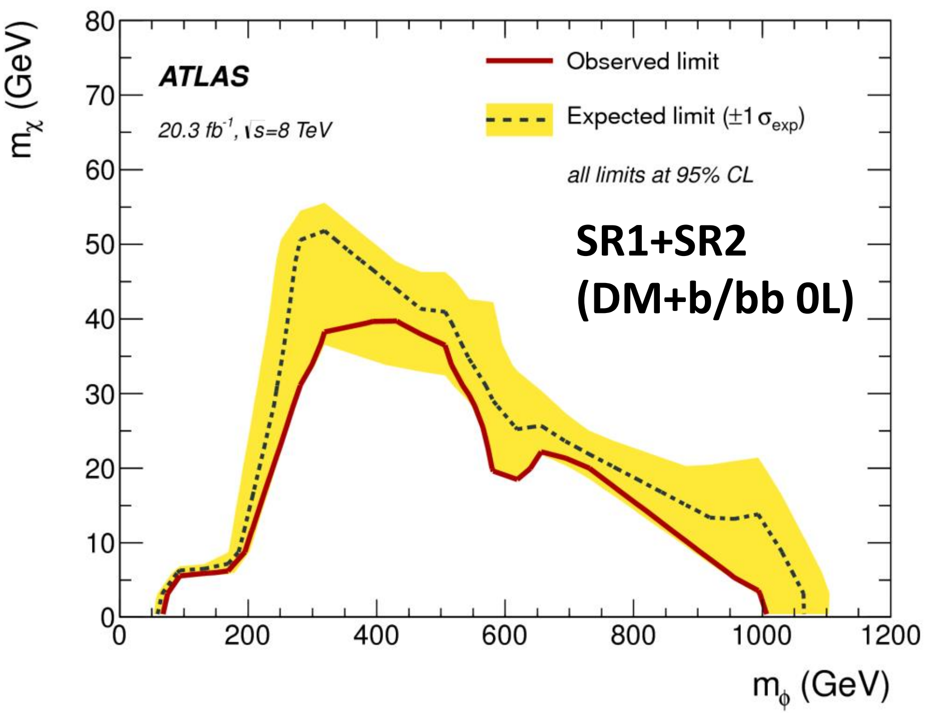
arXiv:1410.4031

EFT Model



SR4
(DM+tt 1L)

Simplified Model (b-FDM)



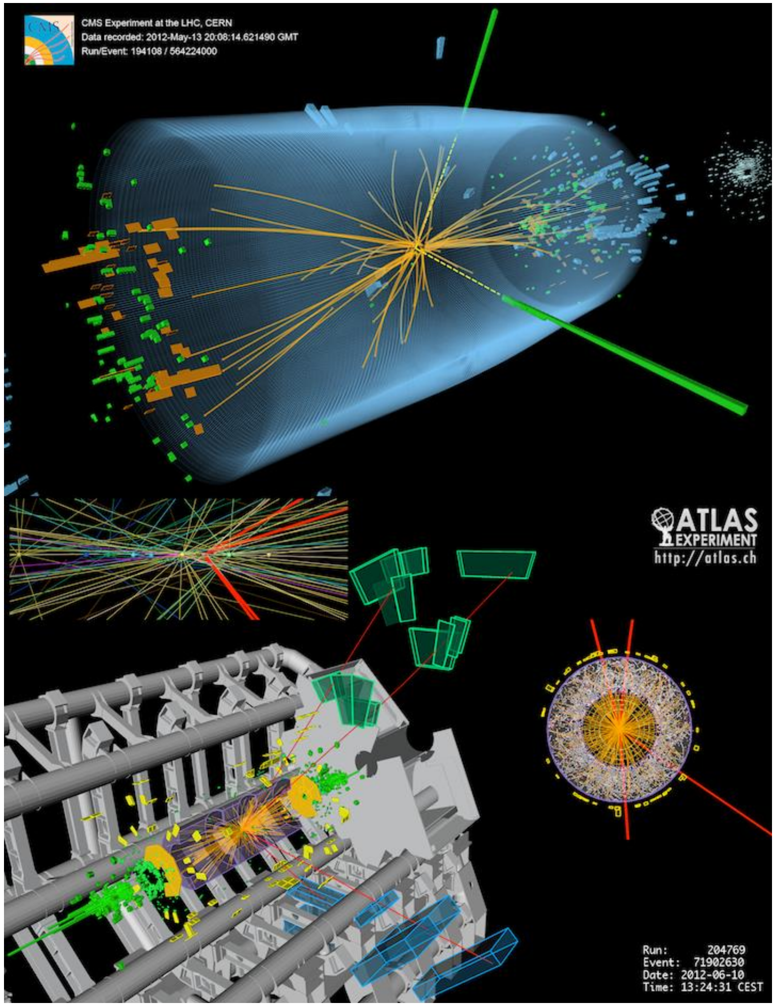
SR1+SR2
(DM+b/bb 0L)

Stronger limit than mono-jet by ~x100!
More sensitive than direct detection for low mass DM (SI-DM) !

First collider limits on b-FDM simplified model!
First ATLAS results for C1 scalar operator set in this search as well!

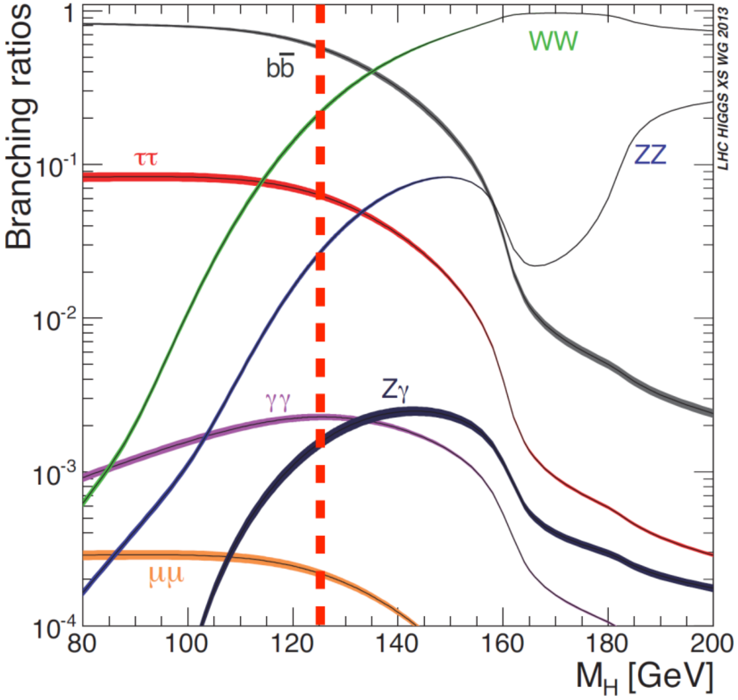
DM+Higgs(→bb): Motivation

We found the (a?) Higgs!



New Probe for DM

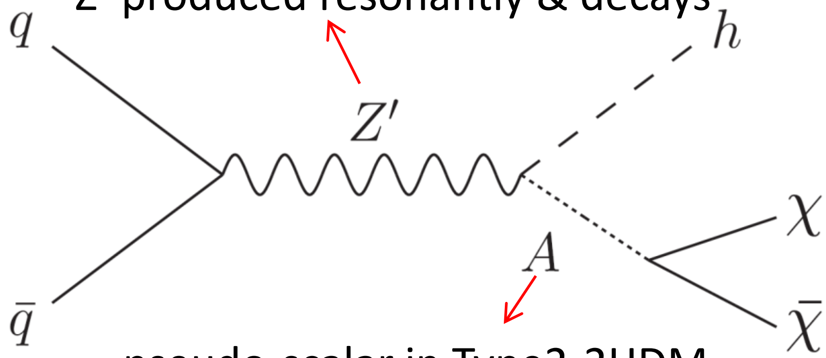
- Higgs unlikely from ISR → DM-SM coupling
- Search in Higgs→bb channel: large BR for 125GeV Higgs



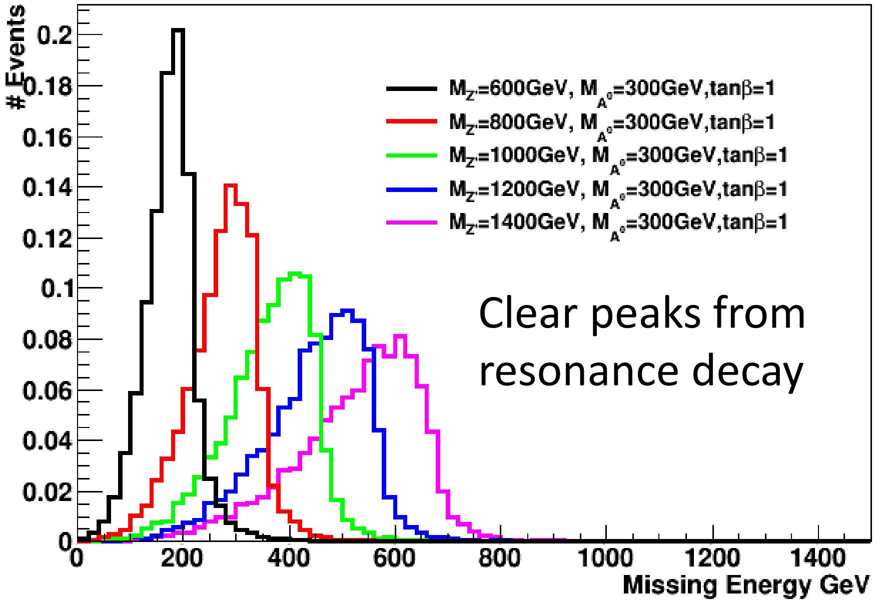
DM+Higgs(→bb): Signal Models

Simplified Model arXiv:1402.7074

Z’ produced resonantly & decays



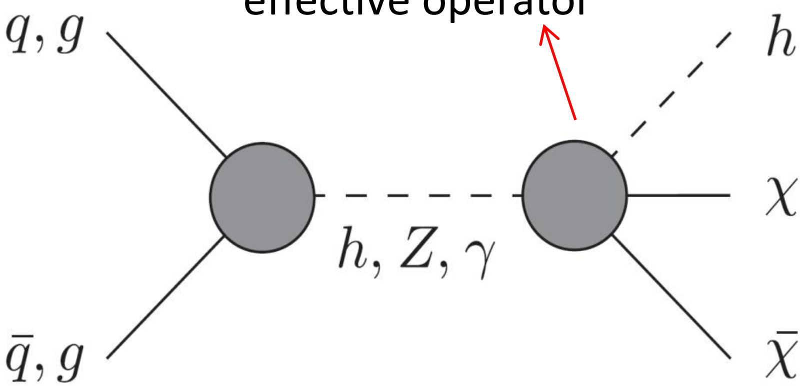
pseudo-scalar in Type2-2HDM

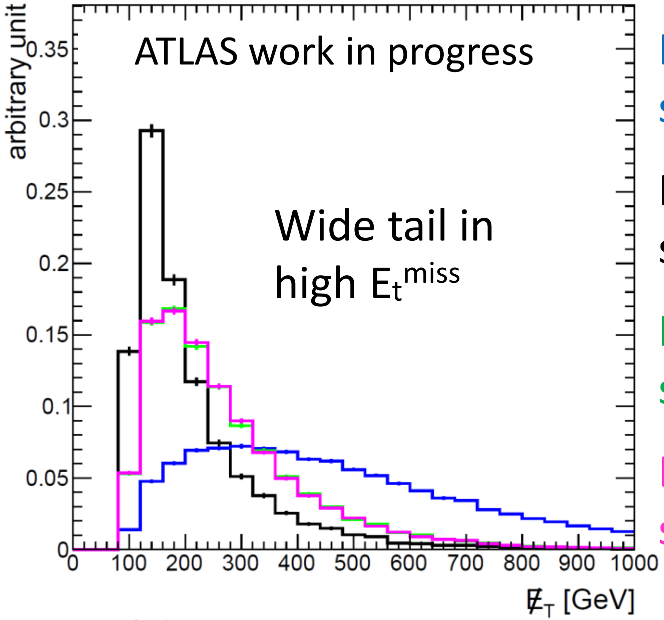


Clear peaks from resonance decay

EFT Model arXiv:1312.2592

effective operator





Wide tail in high E_t^{miss}

Dim.8 spin-1/2 DM

Dim-6 spin-0 DM

Dim-5 spin-1/2 DM

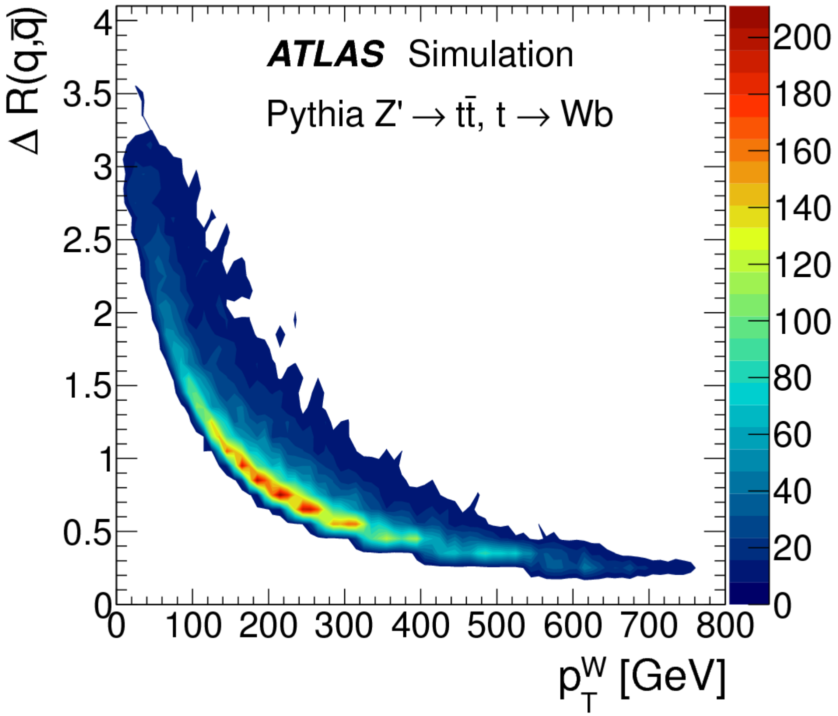
Dim-4 spin-0 DM

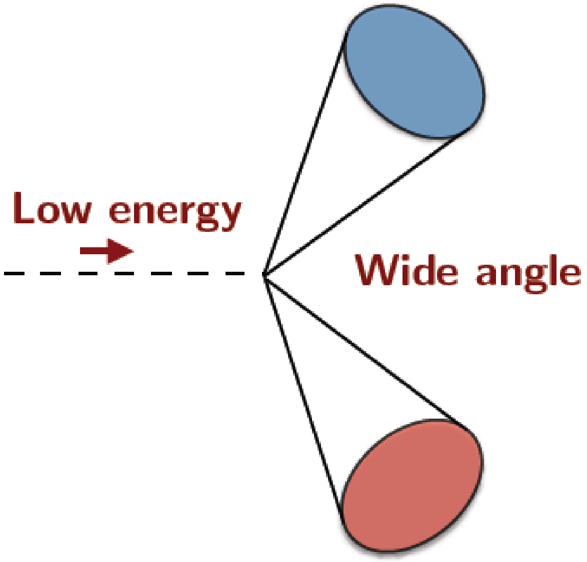
Physics Object of Interest: Boosted Decay

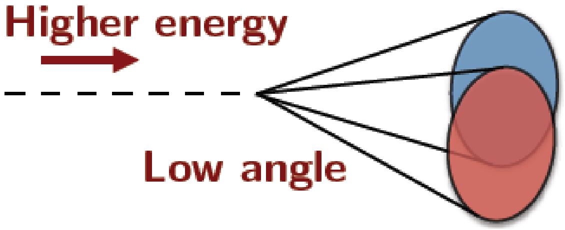
Decay products of high-pT objects highly collimated:

→ difficult to reconstruct as “traditional” jets

“These aren’t your daddy’s jets” – BOOST2010



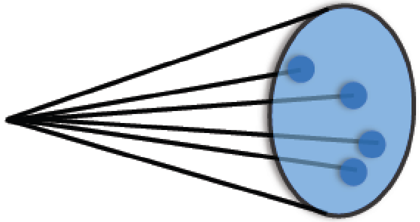




But jets are more than energy & location:

→ multi-prong decays have STRUCTURE

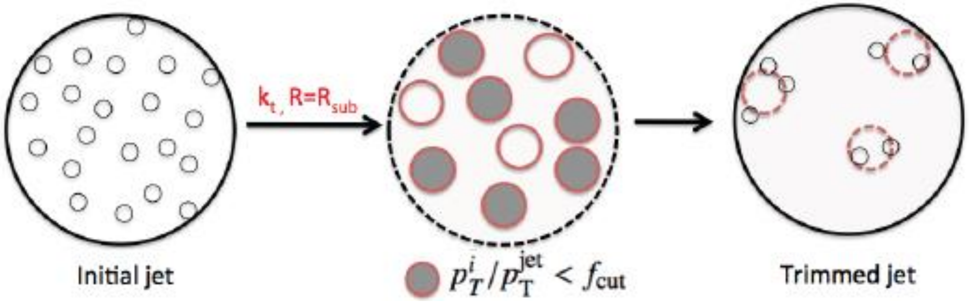
→ important info for reco. & signal vs bkgd



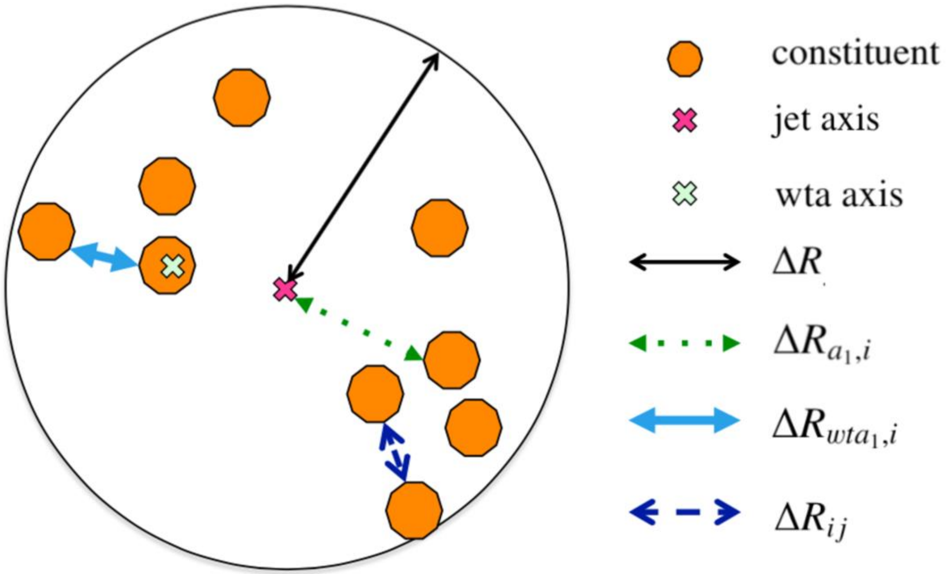
Use larger-radius jet (fat-jet) to contain all relevant decay products

Physics Object of Interest: Jet Substructure

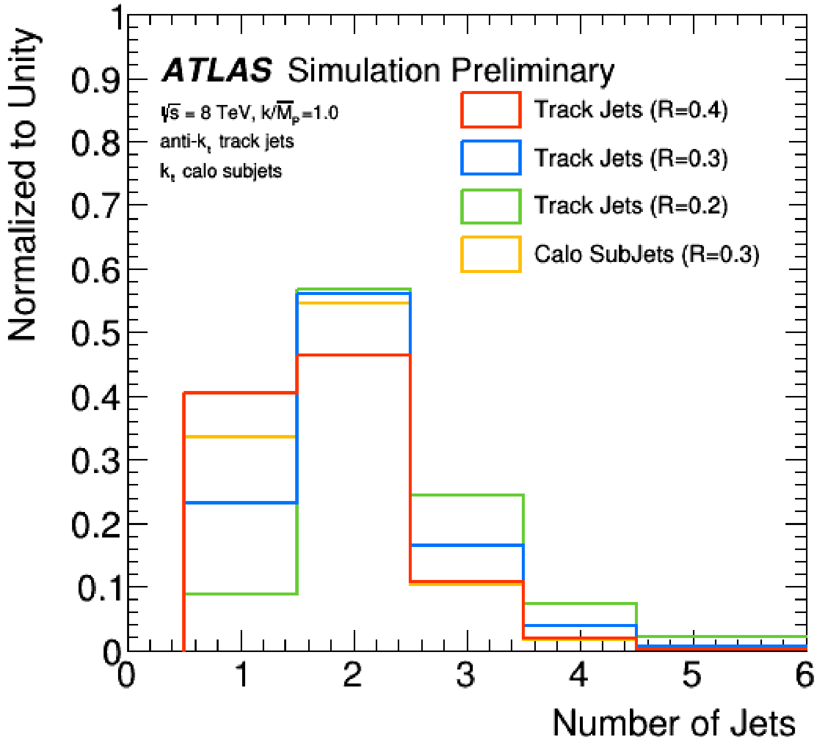
Jet trimming (arXiv: 0912.1342)



(Some) substructure variables



Flavor Tagging with Track Jets in Boosted Topologies

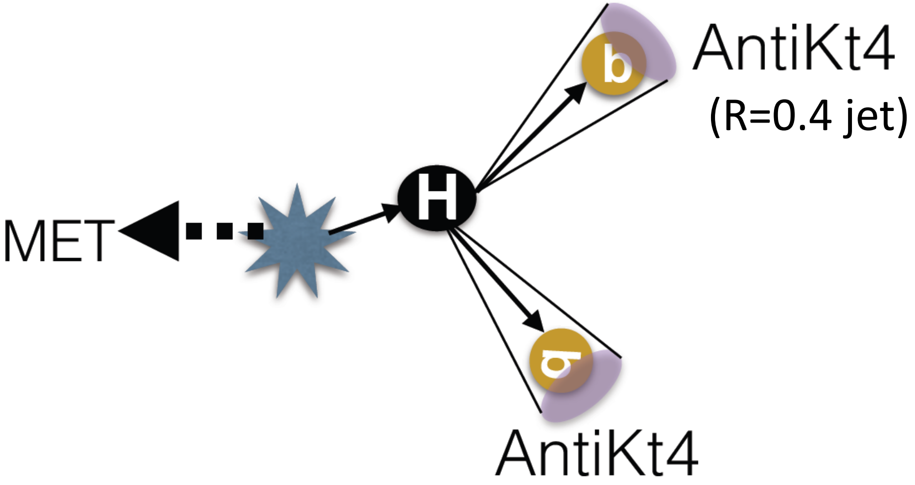


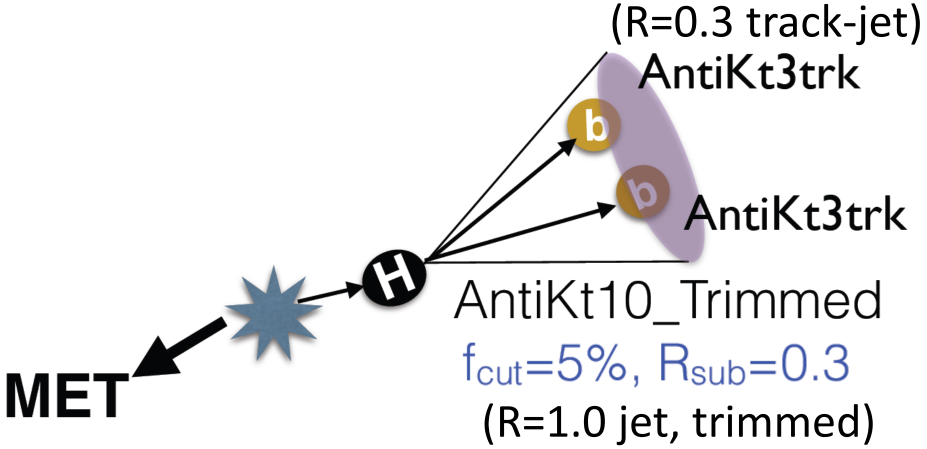
Use R=0.3 track-jets “ghost-associated” with a R=1.0 fat-jet with substructure.

DM+Higgs(→bb): Analysis Strategy

- Resolved channel:
  - Higgs pT 150GeV – 450GeV
  - used for Z'-2HDM simplified model
- Boosted channel:
  - Higgs pT > 450GeV

  →$dR(b_1, b_2)<0.4$
  - used for EFT models





Two complementary channels maintain acceptance for a wide kinematic range.
Select either analysis channel with better sensitivity for either model!

DM+Higgs(→bb): Signal Selection

	Resolved	Boosted
$\Delta\phi_{min}(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, j_i)$	> 1.0	> 1.0
Jet multiplicity	$2 \le n_j \le 3$	$n_J \ge 1$ $n_{j^{\mathrm{trk}}} \ge 2$
b-jet (60% eff.) p_{T}	$p_{\mathrm{T}}^{b_1} > 100$ GeV	-
b-jet multiplicity	$n_b \ge 2$ (60% eff.)	$n_{b^{\mathrm{trk}}} = 2$ (70% eff.)
Jet p_{T}	$p_{\mathrm{T}}^{b_2} > 60$ GeV when $n_j = 3$ $p_{\mathrm{T}}^{j_2} > 100$ GeV when $n_j = 3$	$p_{\mathrm{T}}^{J_1} > 350$ GeV
$\Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	-	$< \pi/2$
Dijet separation	$\Delta R(j_1, j_2) < 1.5$	-
Invariant mass	$90 \text{ GeV} \le m_{b_1 b_2} \le 150 \text{ GeV}$	$90 \text{ GeV} \le m_{J_1} \le 150 \text{ GeV}$
$E_{\mathrm{T}}^{\mathrm{miss}}$	$> 150, 200, 300,$ or 400 GeV	> 300 or 400 GeV

Reject multijet

Reconstruct bb system

Reject top

Higgs mass

(J: R=1.0 jet; j_trk: track-jet; b_trk: b-tagged track-jet)

Sliding E_T^{miss} cut:

E_T^{miss} spectrum shifts with $m_{Z'}$ / m_A in Z'-2HDM model, m_χ / operator in EFT models

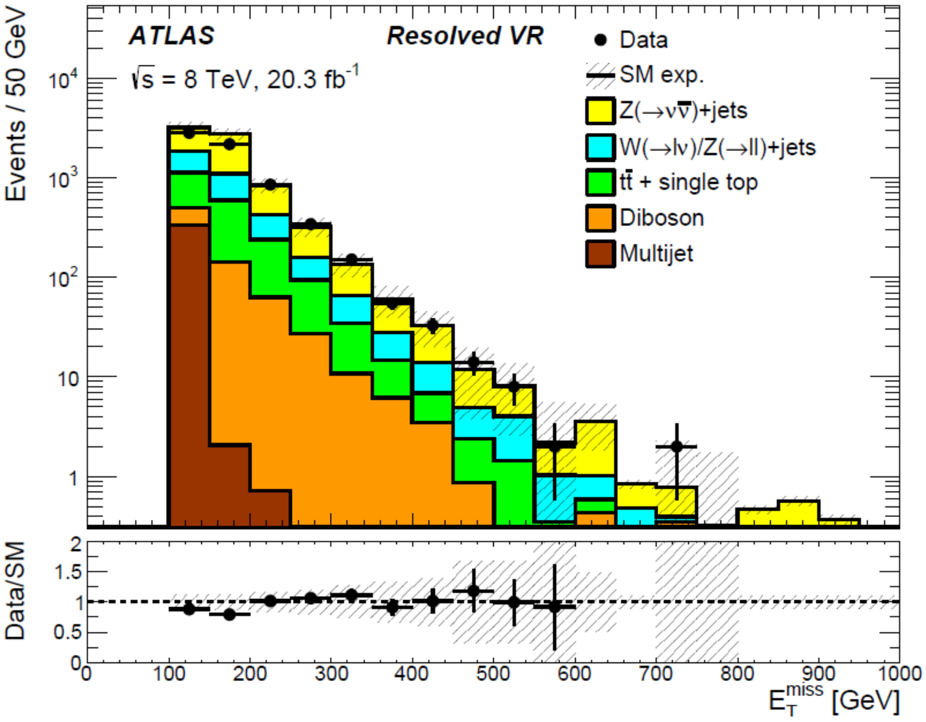
→ optimize for individual signal

DM+Higgs(→bb): Background Overview

- Main backgrounds: **good agreement to data in CRs & VRs**
  - simulated: W(lν)/Z(ll)+jets, top, diboson(well-validated), Vh(bb)
  - data-driven: multijet, **Z(νν)+jets (dominant in most SR)**
- Data-driven background
  - **Z(νν)+jets**: >=2b-tag SR →0b-tag/1b-tag Z→νν CR
    - E_T^{miss} <200GeV, reweight from Z→μμ (only used in resolved channel)
    - E_T^{miss} >200GeV, reweight from γ+jets (used in both channels)
  - multijet: jet-smearing method (resolved) | ABCD method (boosted)
- Simulated background: shape from MC; normalized to data in CR
  - 0-lepton Signal Region (SR) →1-lepton Control Region (CR)
  - N_j=2| no b-tag: W(lν)/Z(ll)+jets
  - N_j=3 | with b-tag: top (ttbar + single top)
- Total background
  - 0lep Validation Region (VR): 2b-tag, inv. mass of bb in Higgs-mass sideband

DM+Higgs(→bb): 0-lepton VR

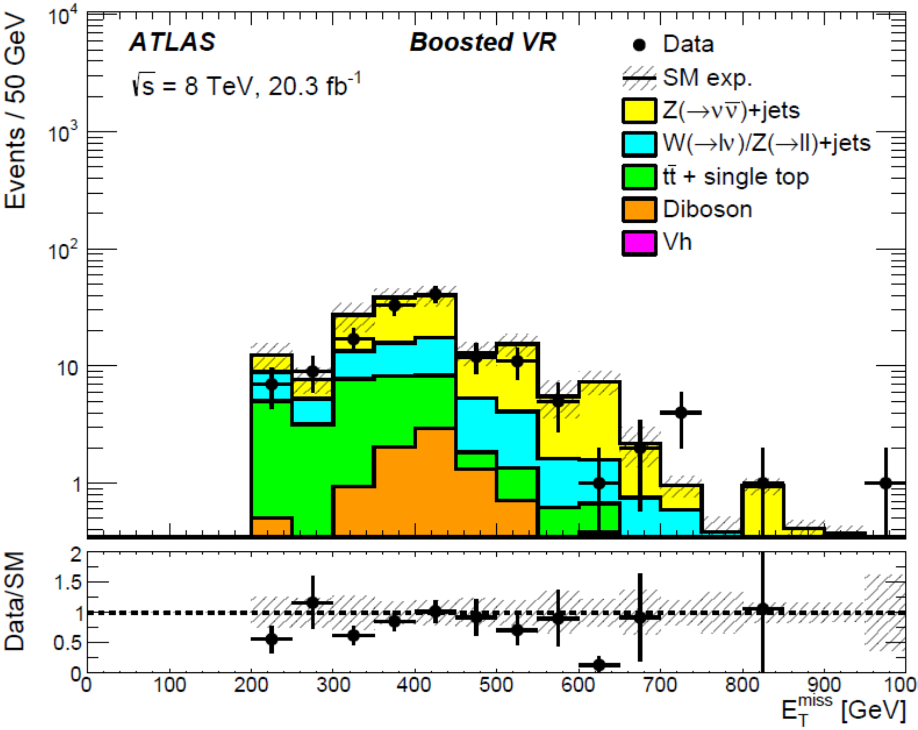
Resolved Channel



Full hadronic, >=1 b-tagged small-R jet

m_{bb} <60GeV || m_{bb} >150GeV

Boosted Channel



Full hadronic, 1 b-tagged track-jet

m_J<90GeV || m_J>150GeV

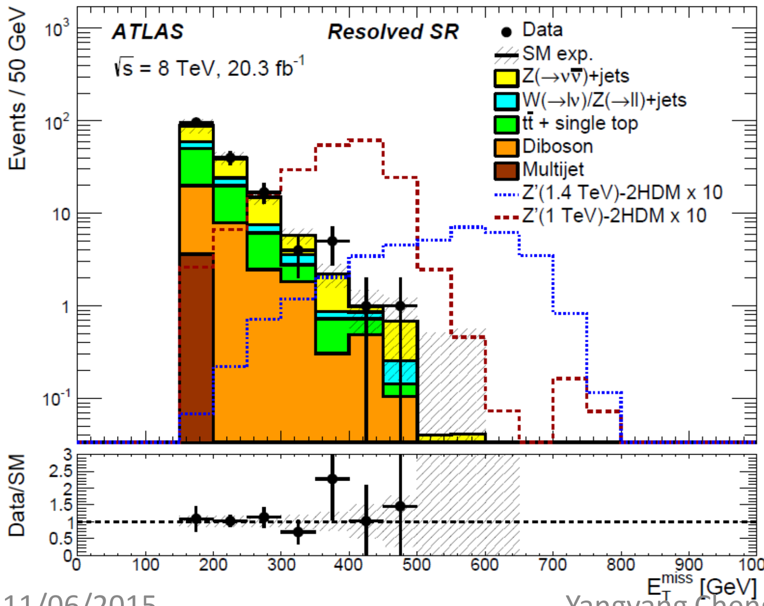
Good agreement achieved in both channels.

DM+Higgs(→bb): Signal Region

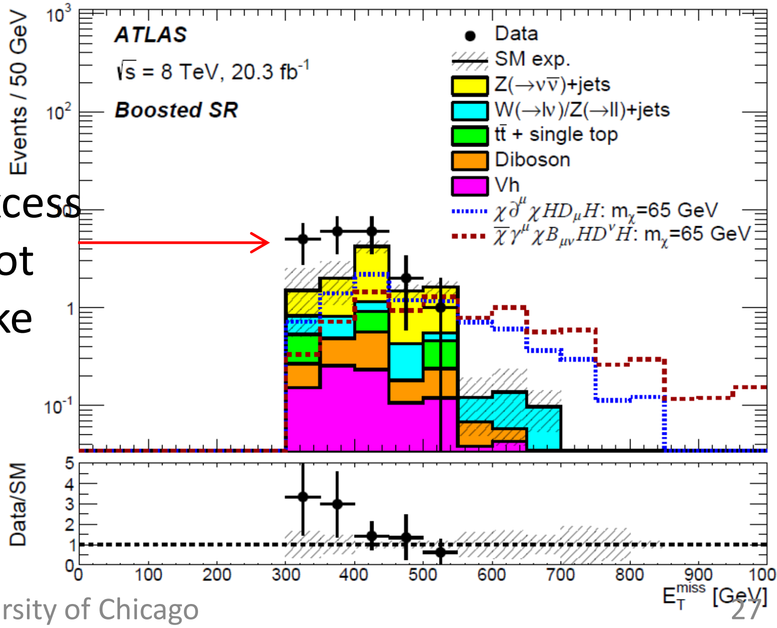
Model-independent upper limit

	E_T^{miss}	N_{obs}	N_{bkgd}	$\langle\sigma_{\text{vis}}\rangle^{95}_{\text{obs}}$ [fb]	$N_{\text{BSM}}{}^{95}_{\text{obs}}$	$N_{\text{BSM}}{}^{95}_{\text{exp}}$	$p(s=0)$
Resolved	> 150 GeV	164	148	3.6	74	63^{+22}_{-14}	0.31
	> 200 GeV	68	62	1.3	27	$21^{+8.4}_{-3.9}$	0.28
	> 300 GeV	11	9.4	0.49	9.9	$8.2^{+3.4}_{-1.9}$	0.31
	> 400 GeV	2	1.7	0.24	4.8	$4.7^{+1.6}_{-1.0}$	0.39
Boosted	> 300 GeV	20	11.2	0.90	18	$9.9^{+4.2}_{-2.9}$	0.03
	> 400 GeV	9	7.7	0.43	8.8	$7.7^{+3.3}_{-2.0}$	0.37

Look-elsewhere effect calculation: ~10% likelihood excess from bkgd statistical fluctuation

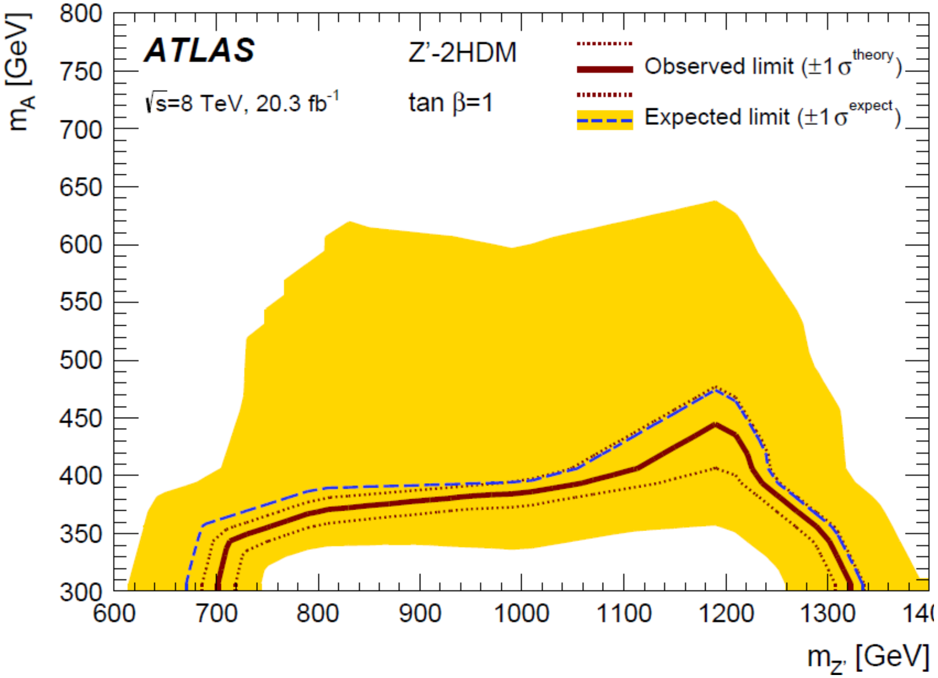


Small excess (2.2σ) not signal-like



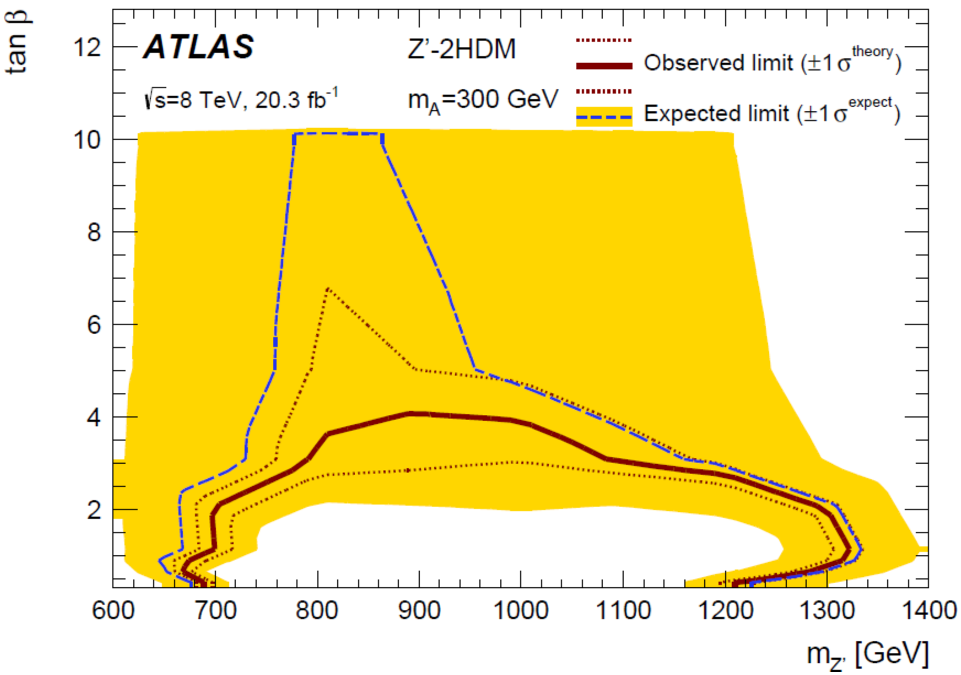
DM+H(→bb) Results: Z'-2HDM (Resolved)

mZ'-mA



mZ'-tanβ

[arXiv:1510.06218](https://arxiv.org/abs/1510.06218)



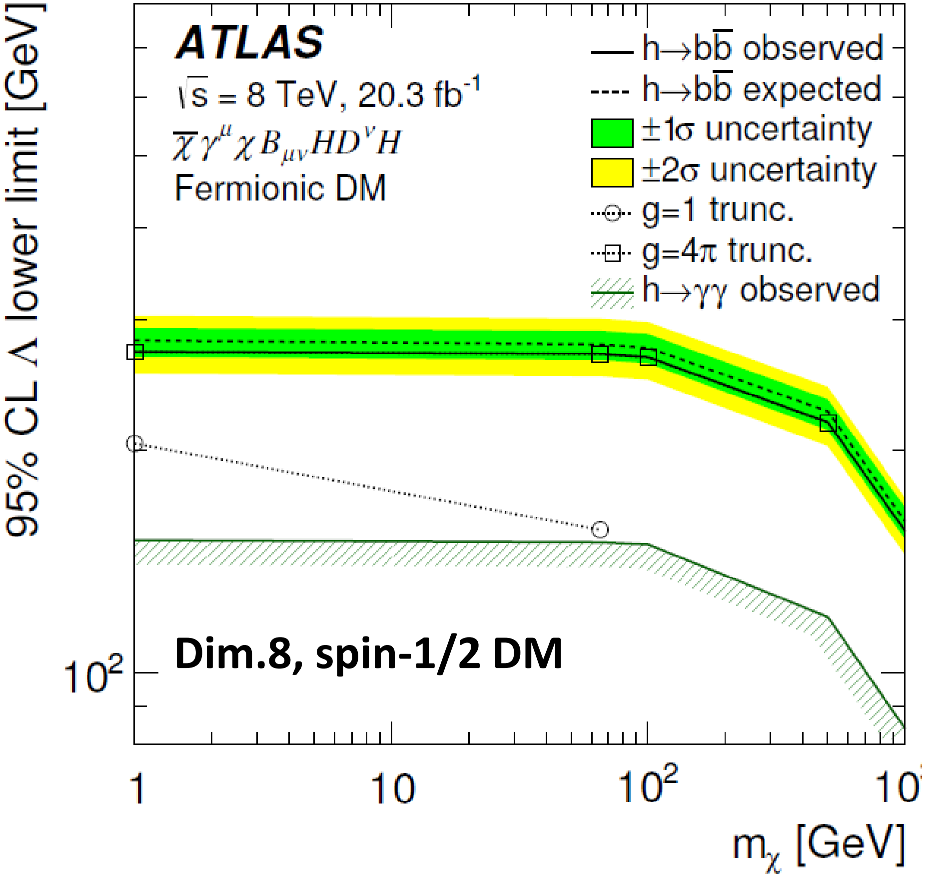
Exclude mZ'=700-1300GeV for mA<350GeV **Exclude mZ'=700-1300GeV for tanβ<2**

First Collider Limits for the Z'-2HDM model!

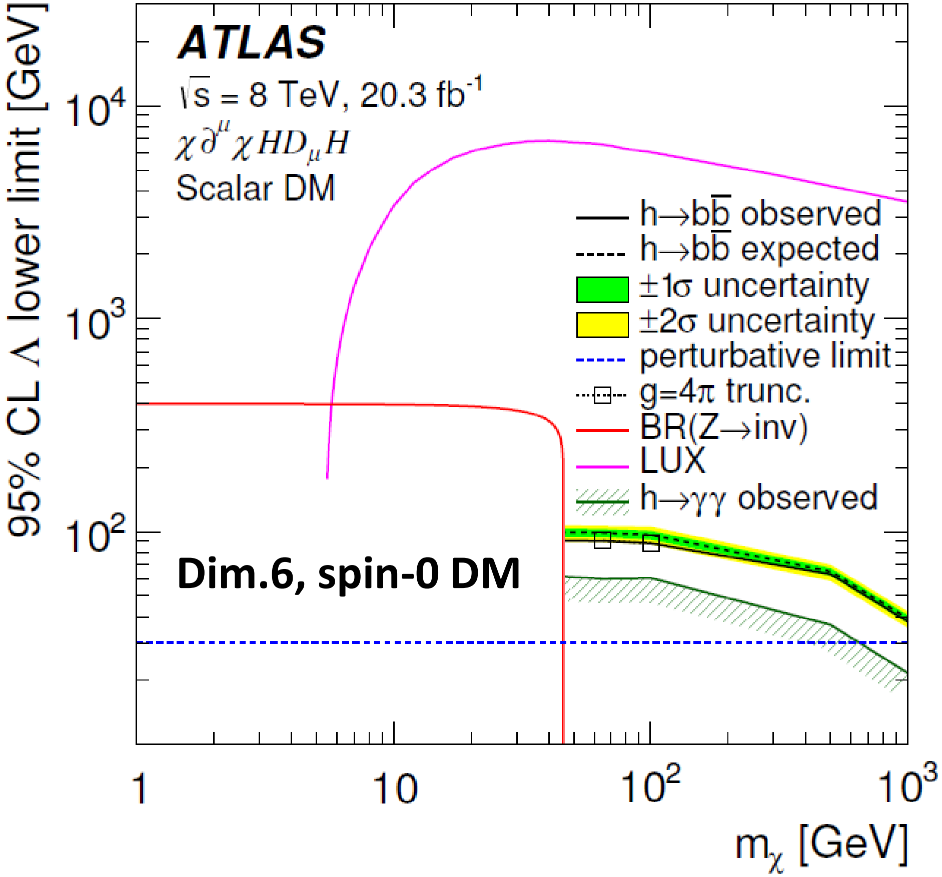
- alignment limit (α=β-π/2) where h is SM-like; avoid constraints from fits to Higgs coupling
- Z' gauge coupling set to 95% CL U.L. from electroweak & dijet search constraints

DM+H(→bb) Results: EFT (Boosted)

arXiv:1510.06218



Exclude Λ up to 270GeV (g=4π)



Exclude Λ up to 91GeV (g=4π)

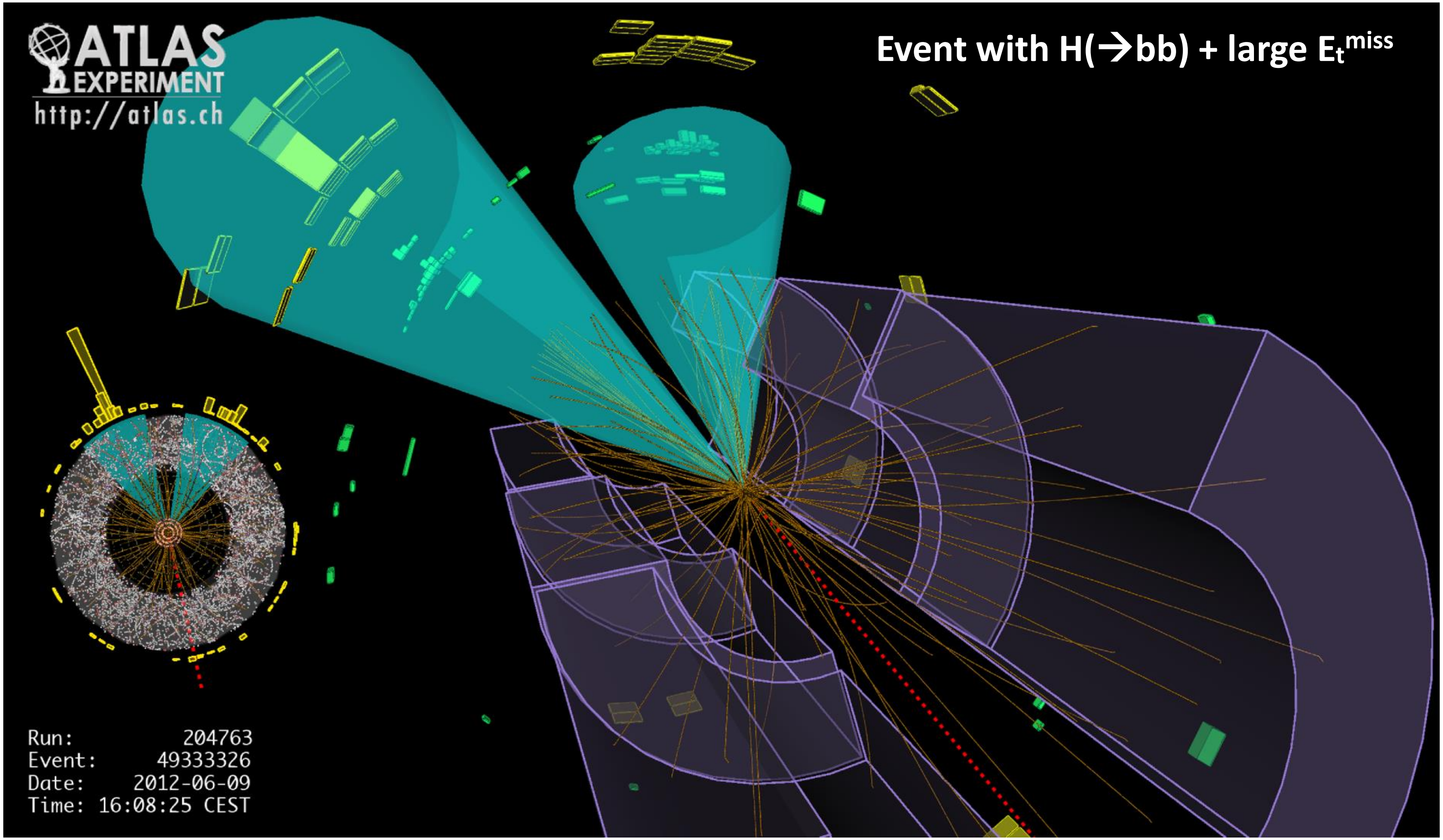
Strongest Collider Limits for these EFT models!

EFT Validity requirement for signal: $Q_{tr} = m_{\chi\chi} < m_V = \Lambda\sqrt{g_q g_x}, g = \sqrt{g_q g_x} \subset (0,4\pi)$

Summary (for the dark stuff)

- Collider searches for DM: large **E_t^{miss} + visible object(s)**
  - Complementary to (in)direct detections; sensitive to both EFT and simplified models
- **Mono-jet**
  - Powerful for many models
  - *Stronger than direct detection* for low mass SI-DM and most SD-DM
- **DM + Heavy Flavor** (mono-b/bb/tt)
  - *First collider search* for DM in these final states
  - *Strongest/First collider limits* for EFT operators with quark-mass dependency (D1/C1)
  - *First collider limits* on b-flavor DM simplified model (→ Fermi-LAT gamma-ray excess)
- **DM+ Higgs (→bb)**
  - *First collider search* for DM in this final state
  - Adopt resolved + boosted topology for Higgs(→bb) reconstruction
  - *First collider limits* for Z'-2HDM simplified model
  - *Strongest collider limits* for various EFT models (a few times better than DM+H(→γγ) !)
  - Model-independent upper limit into high E_T^{miss} region helps guide future search

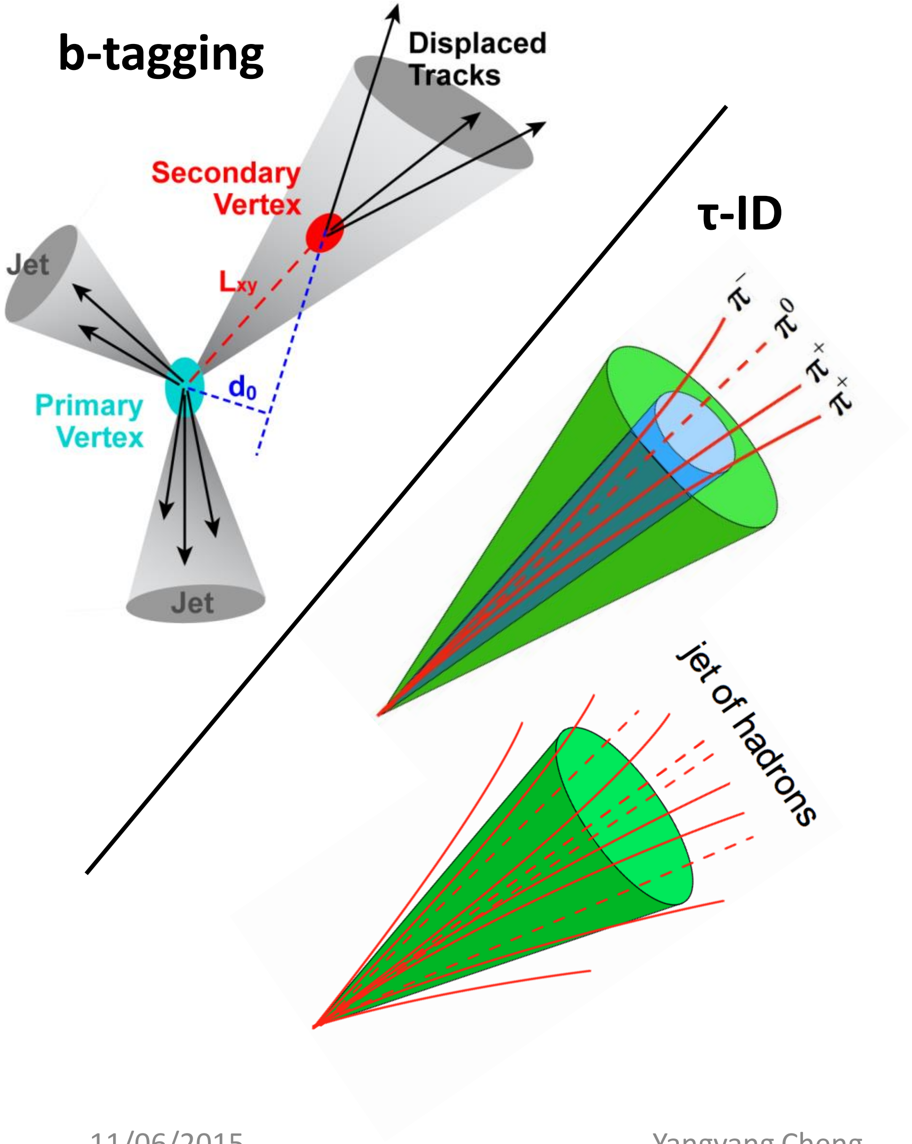
Tracks? Tracks!



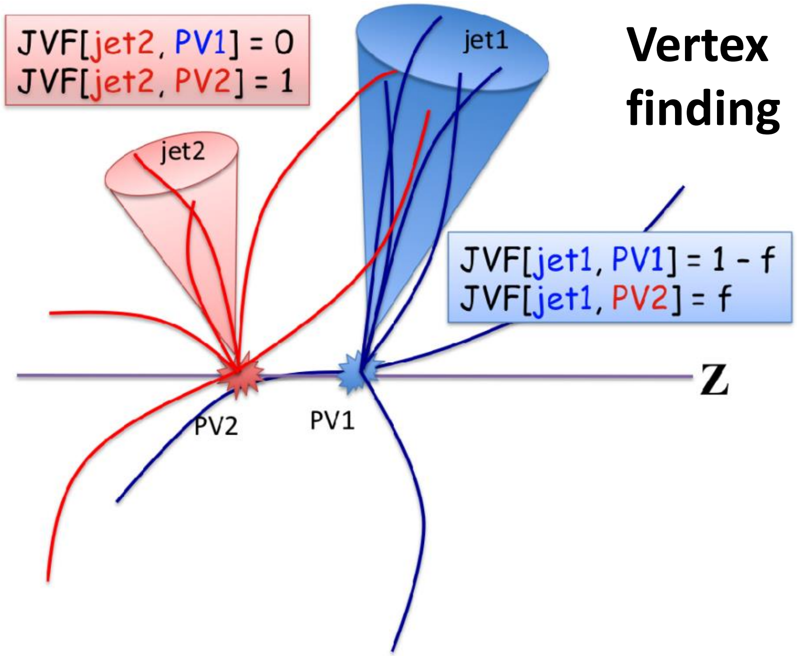
Physics is Exciting! Tracking is Important!

b-tagging

τ-ID



Vertex finding



- Jet reconstruction
- E_T^{miss} reconstruction
- Lepton isolation

…

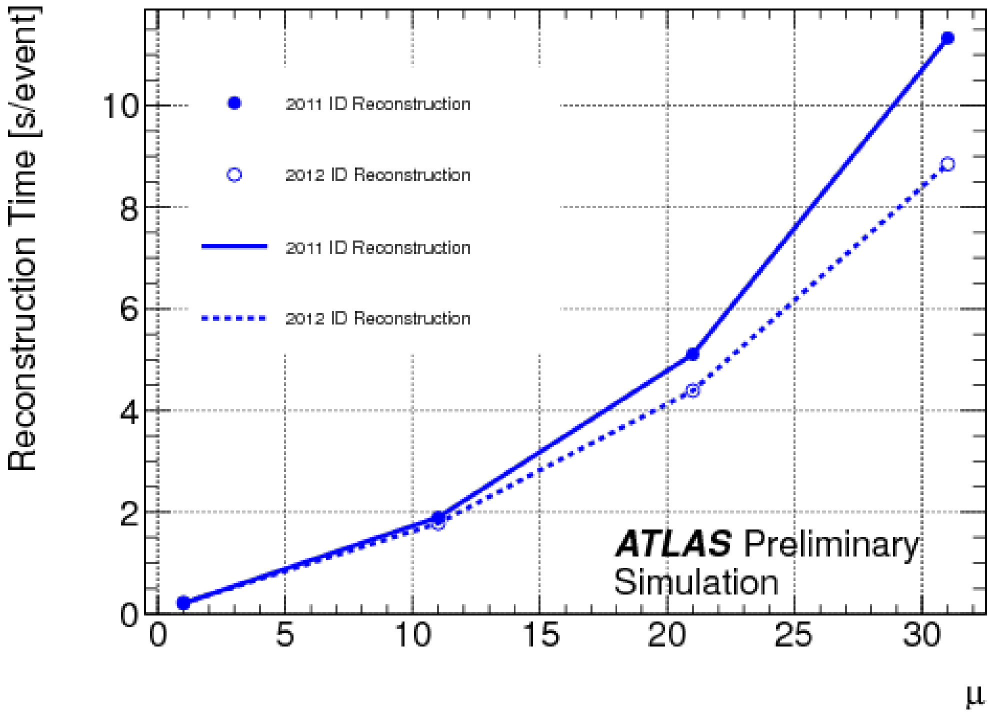
Physics is Exciting! Tracking is Tricky!

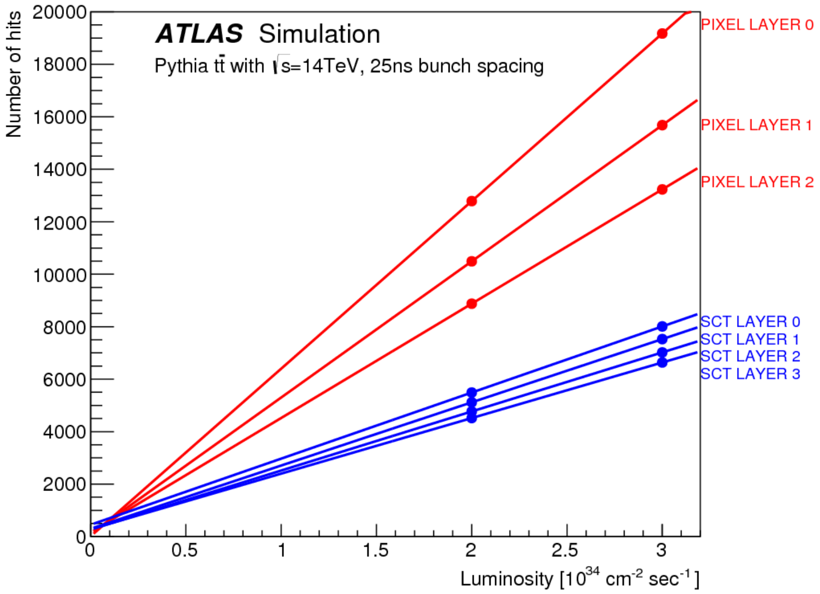
- More particles per collision
- More interactions per bunch

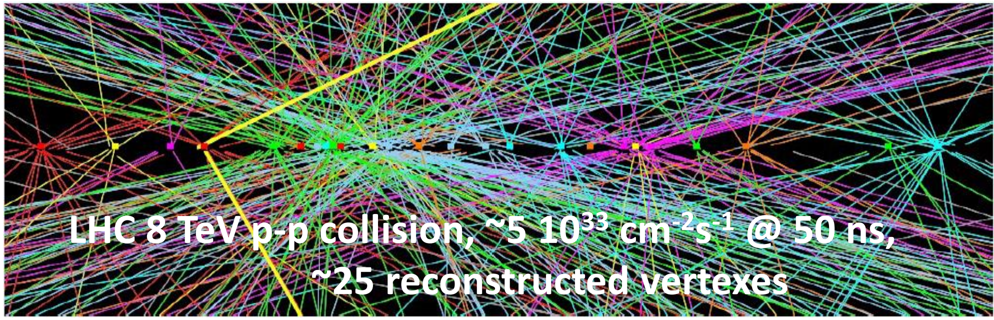
→ complex challenge for tracking

- Ability to reach rare processes crucial

→ importance of trigger



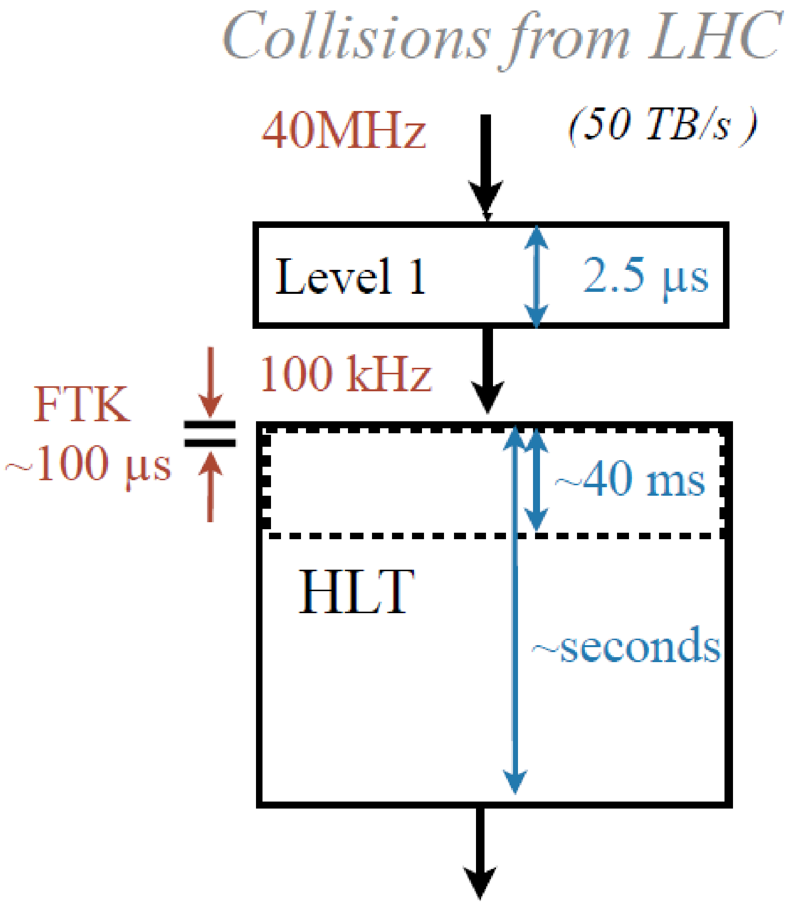




LHC 8 TeV p-p collision, ~5 10^{33} cm^{-2}s^{-1} @ 50 ns, ~25 reconstructed vertexes

ATLAS Trigger Upgrade and the FastTracKer

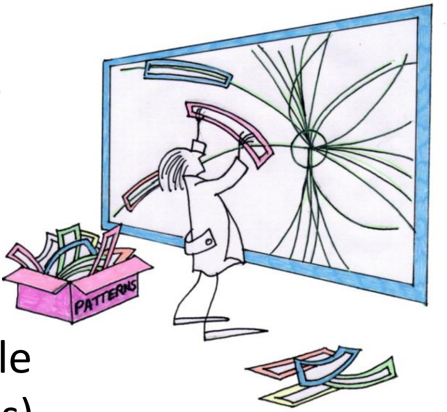
- ATLAS Trigger Upgrades for RunII:
  - removed internal subdivision between Level-2 and HLT
  - improved network infrastructure
- Software-based full tracking still limited by ROIs to a fraction of the Level-1 triggers
- Where **FastTracKer (FTK)** comes in:
  - *Hardware-based*
  - *Full tracking* will be provided for every Level-1 trigger (up to 100 KHz)
  - Any trigger selection will be able to exploit the track information
  - FTK tracks can be used to bootstrap other tracking algorithms



FTK receives data in parallel to HLT
→ *FTK output available at beginning of HLT*

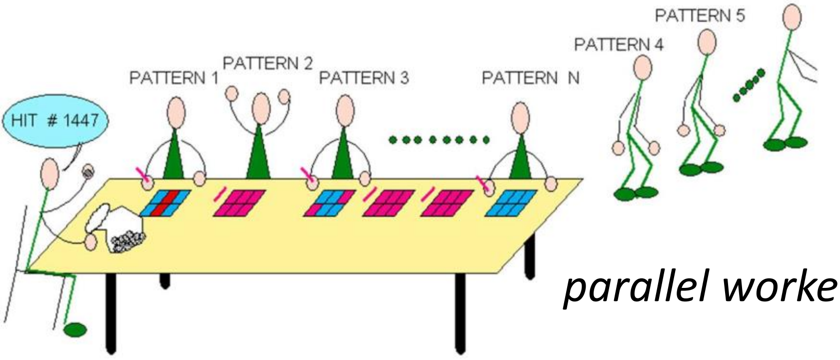
FTK: Core Concept

Pattern Recognition



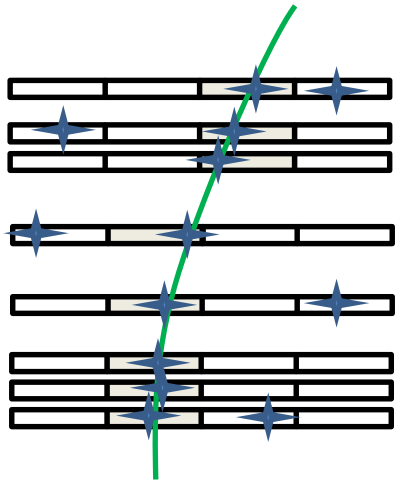
Associative Memory compares coarse detector hits to ~10^9 pre-stored patterns in parallel

- content-addressable memory chips (CAMs)



parallel workers

Track Fitting



- use full resolution hits associated to patterns
- linear approximation in *small* region of detector

Track parameters & χ^2 components

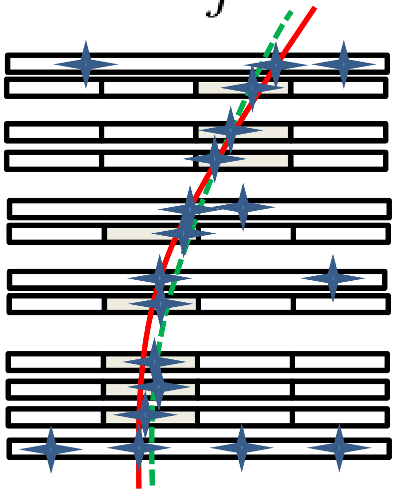
Hit coordinates

$$p_i = \sum_j c_{ij} \cdot x_j + q_i$$

constants

Pattern matching limited to 8 layers: 3 pixels + 5 SCTs.

Good 8-layer tracks are extrapolated to additional layers (IBL + 3SCT) , improving the fit

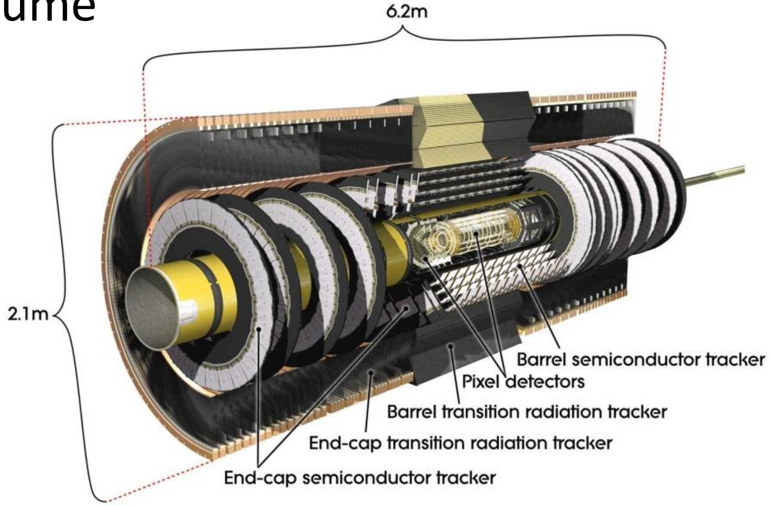


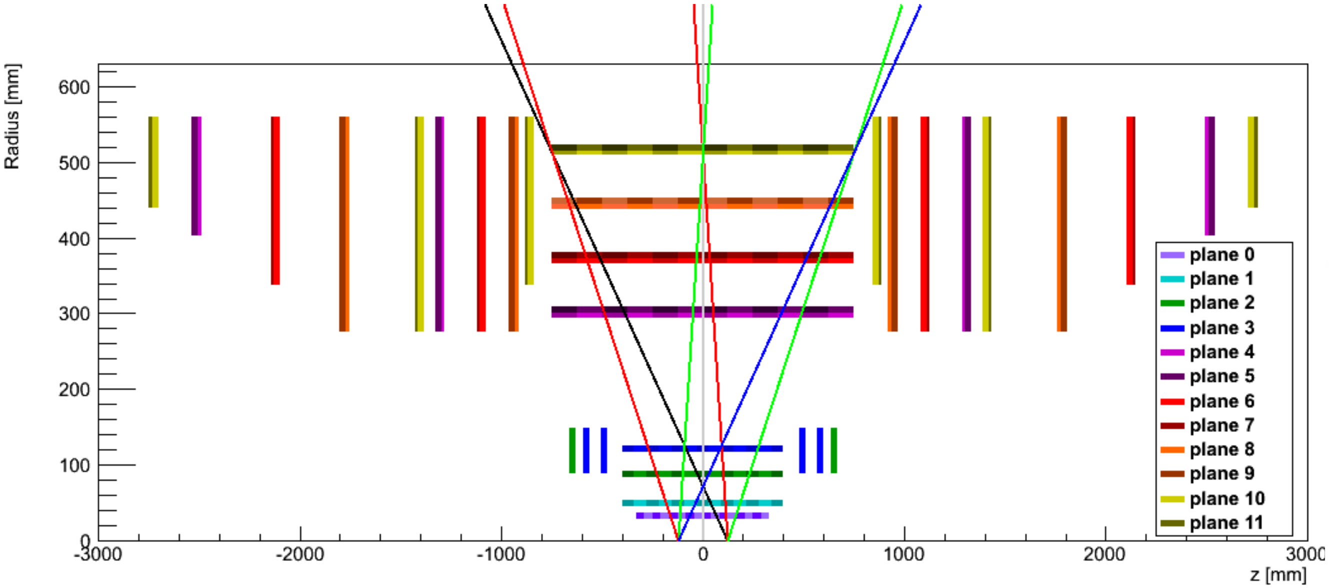
FTK: Parallel Processing

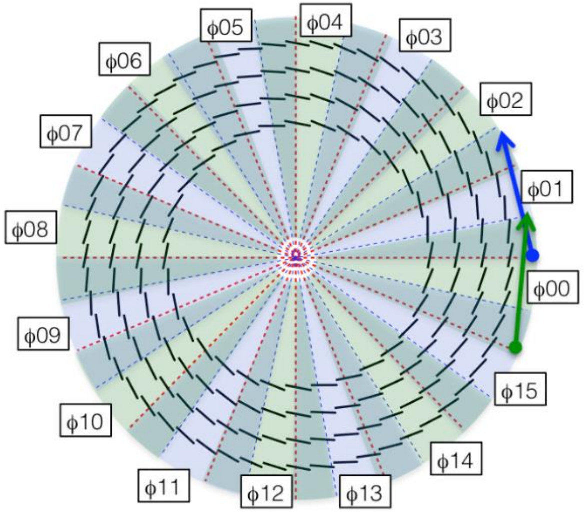
Challenge: complex inner detector; large data volume

- Massive parallel structure
  - Segment inner detector to 64 (4-η X 16-ϕ) independent towers (with small overlap)
  - 8 independent processing unit per tower
- Map detector physical layers to logical layers
  - optimized for performance and efficiency

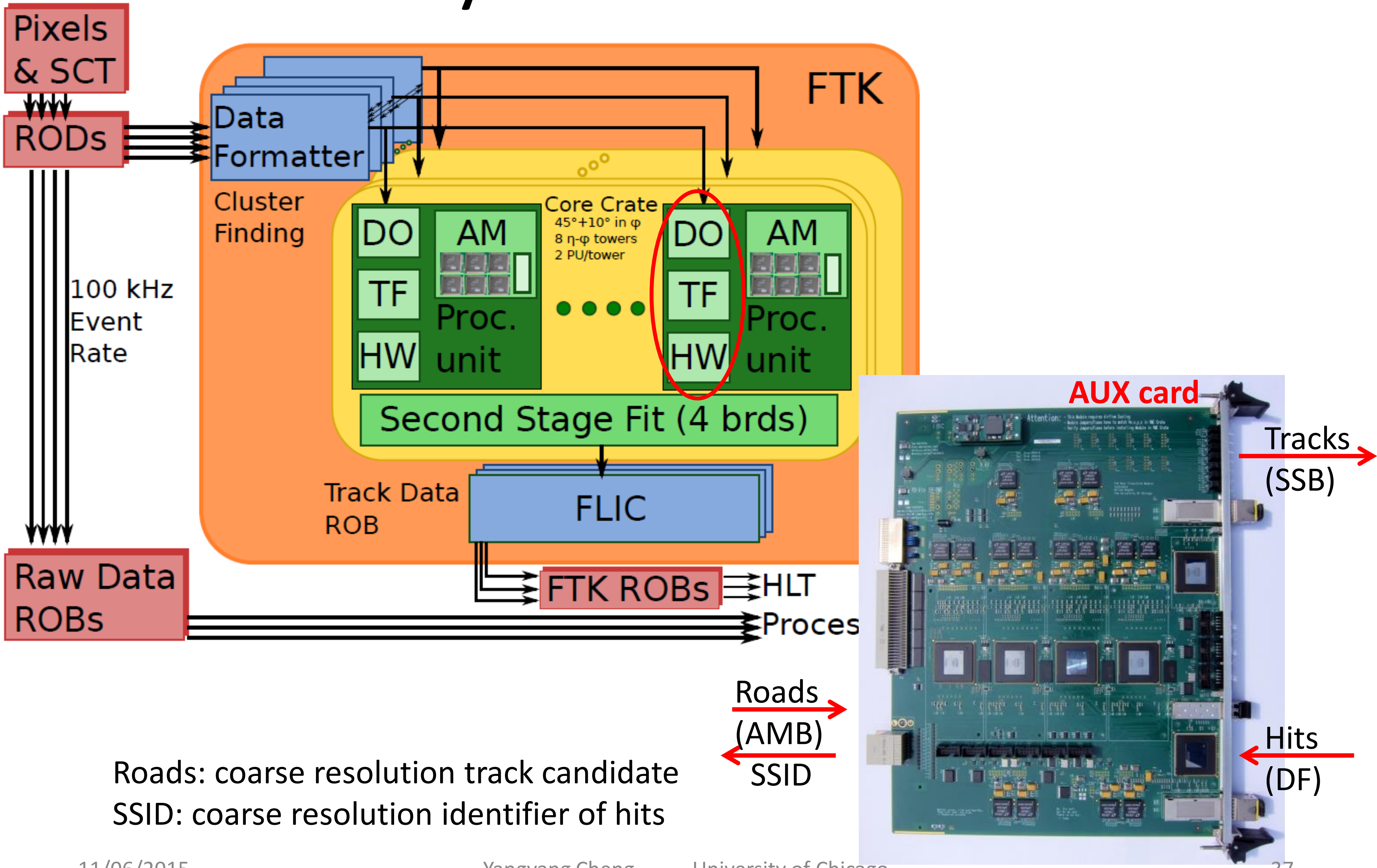
ATLAS inner detector





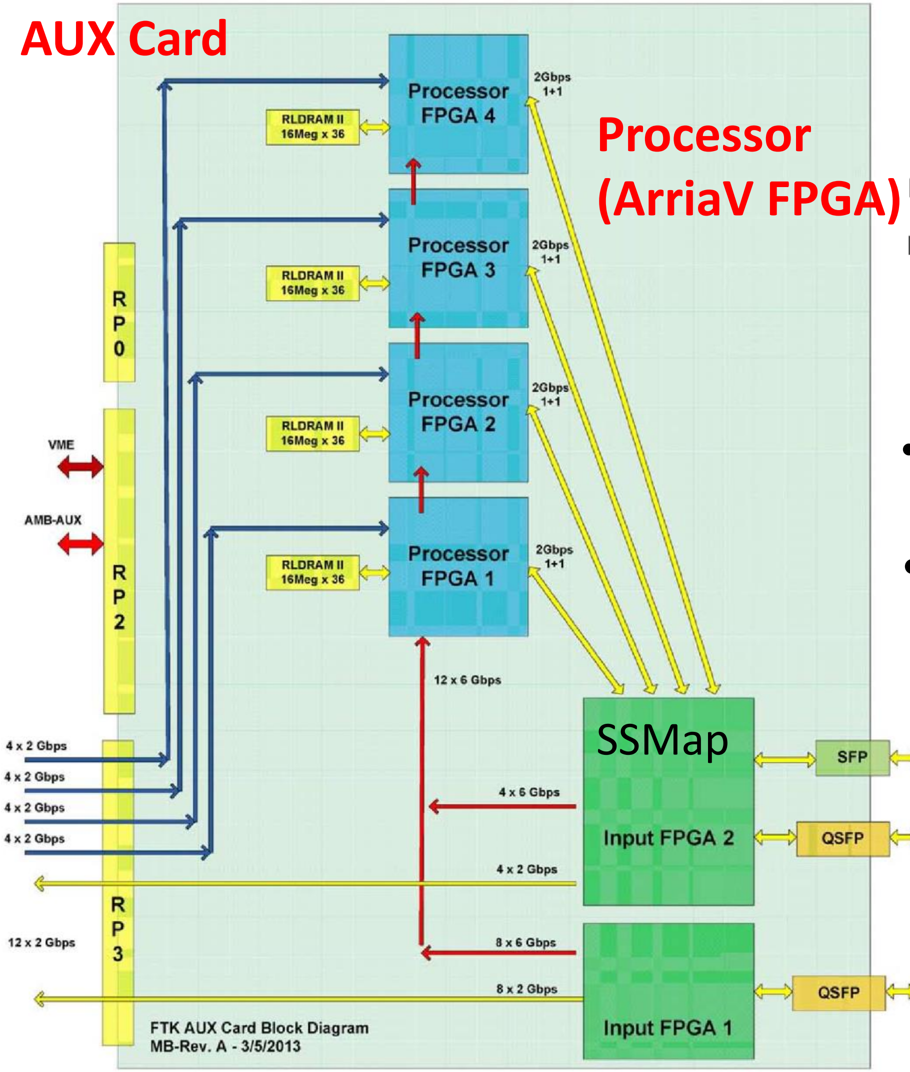


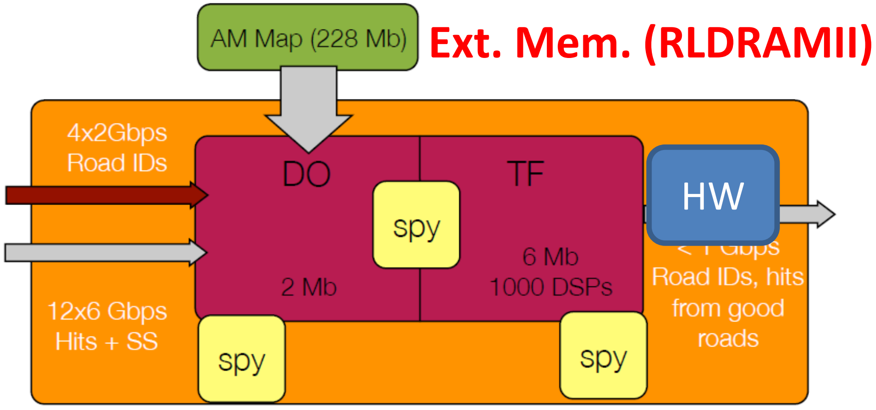
FTK: System Architecture



Roads: coarse resolution track candidate
SSID: coarse resolution identifier of hits

FTK: Auxiliary Card (Processor Unit)

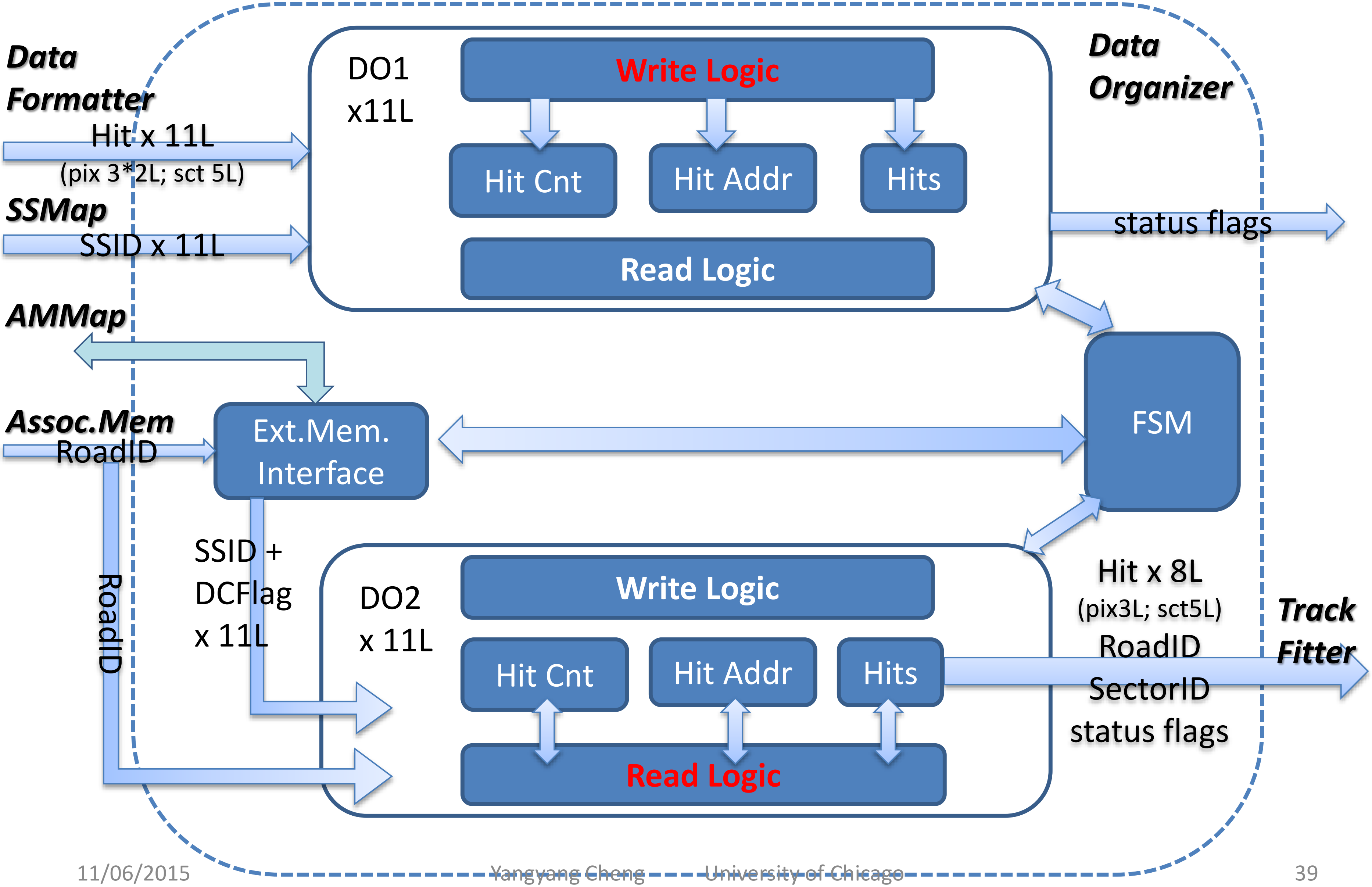




- Input FPGAs:
    - SSMap: converts hit clusters to SSIDs
- Processor FPGAs:
    - **Data Organizer** (DO):
    - →stores full res. hits by their SSID
    - →receives matched road IDs
    - →fetches corresponding hits
    - **Track Fitter** (TF)
    - →Performs 8layer fit to reject fake tracks
    - **Hit Warrior** (HW):
    - →Remove duplicate tracks

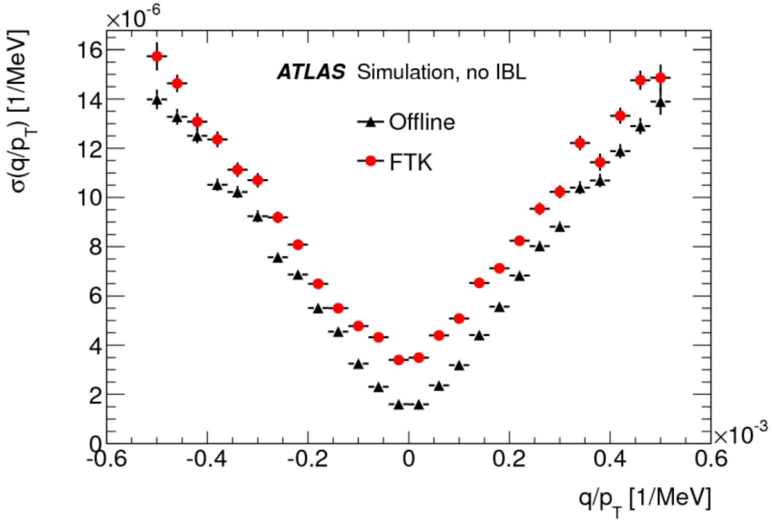
➔ Tracks sent to 2nd-stage for 12-layer fit

FTK: Data Organizer

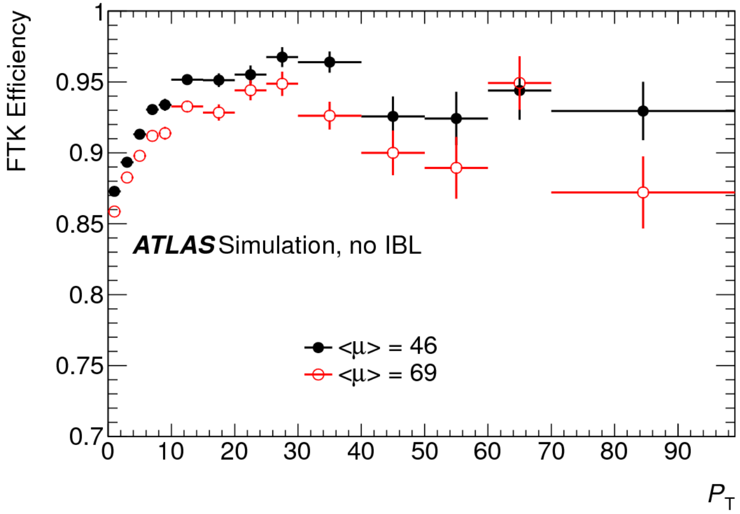


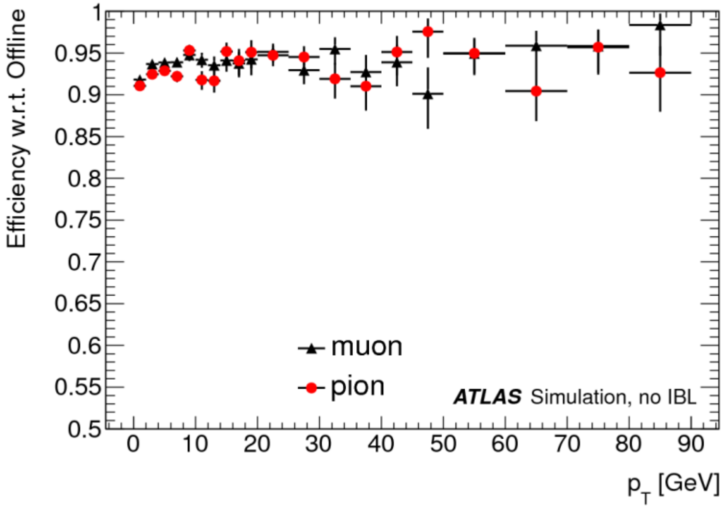
FTK Physics Performance: Track Finding

Close to Offline Performance



Robust with High Pile-up





FTK will provide reconstruction for all tracks with p_T>1 GeV in about 100 μs.

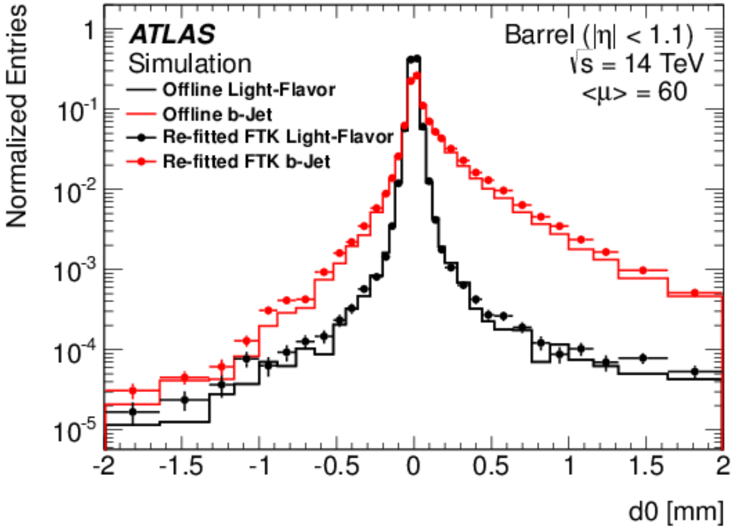
- performance close to those from offline.
- FTK tracks can be refitted using offline

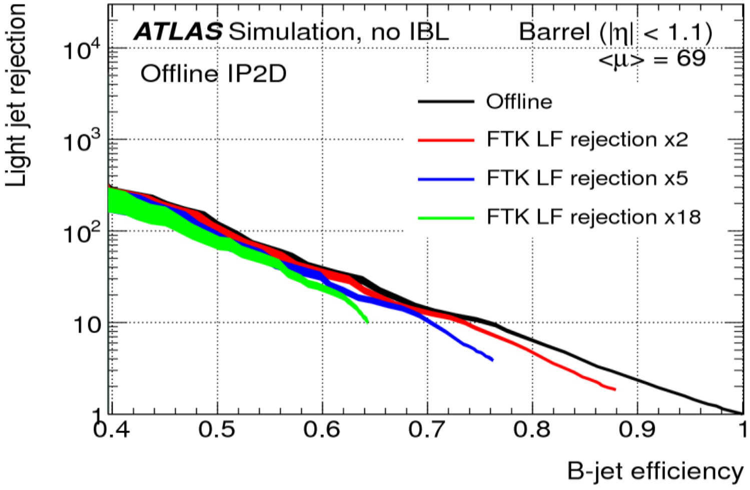
→Allows the HLT to increase the use of selections based on tracks

→ Reduce effects from high pile-up

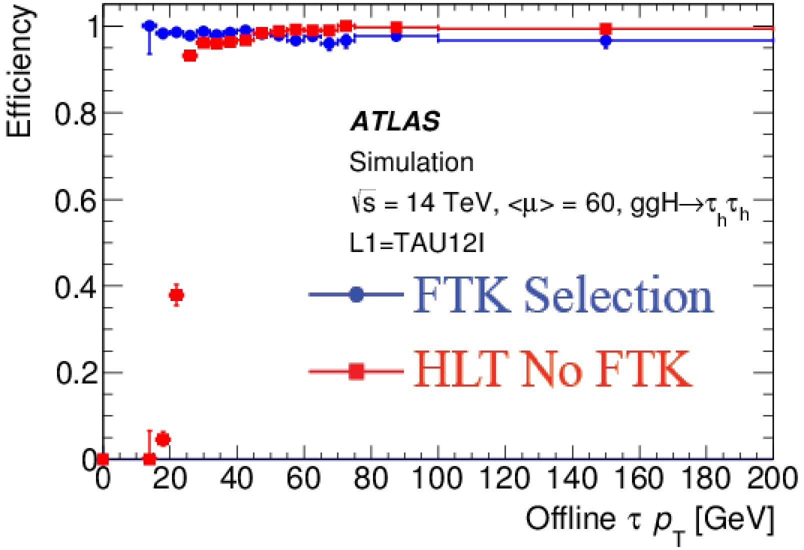
FTK Physics Performance: Event Objects

b-tagging





τ-finding



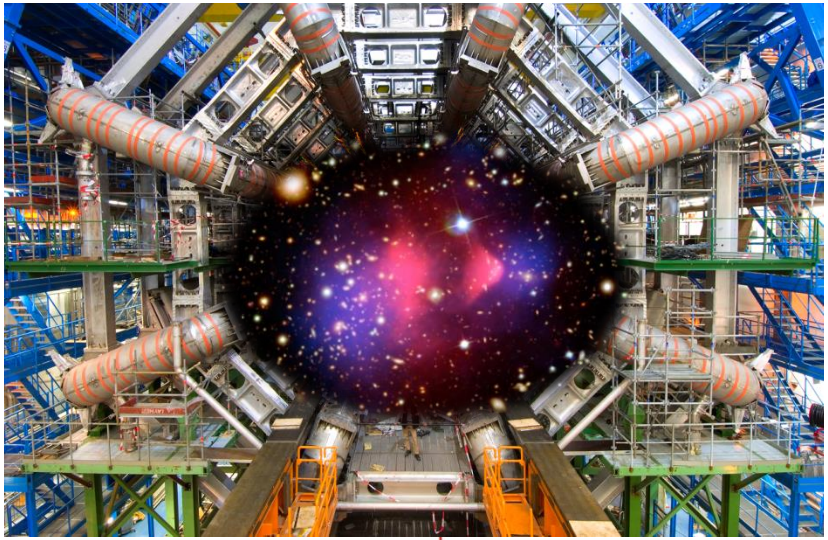
- Significant improvement in complex objects esp. b- or τ-jets
- Improvements to jet/ E_T^{miss} reconstruction, lepton isolation, primary vertex finding, trigger

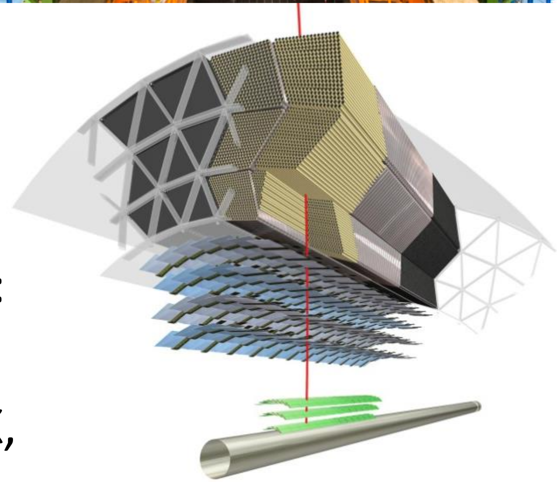
→ Improve tracking in existing ROIs

→ Tracking finding without ROI constraints

Summary

- WIMP Dark Matter may be pair produced at colliders experiments and detected as large E_t^{miss} with visible object(s)
  - Complementary to (in)direct detections
- Many models:
  - **EFT, Simplified,** UV-Complete…
- Many search channels “mono-X”:
  - **mono-jet**: powerful for many models
  - **mono-b(b)**, top: DM-SM flavor dependency
  - **mono-Higgs**: DM-Higgs sector interaction
  - mono-W/Z/γ …
- Significant reliance on track-based event objects: jet, b-jet, track-jet, E_t^{miss} , …
- Improvements to tracking performance, incl. **FTK**, bring exciting prospects in RunII





What Can We Do in RunII?

Same cliff: existing searches

- **Jump higher & further**

→ 13/14TeV; higher lumi; …

- Become a better jumper

→ better detector/trigger/algor.

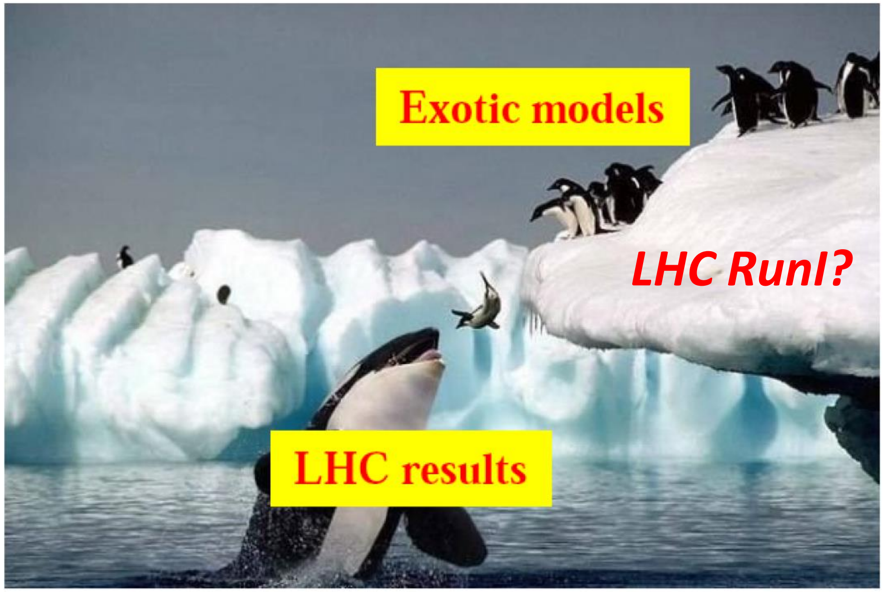
→ (boosted) top/W/Z/H tagging

→ high-pT b-tagging

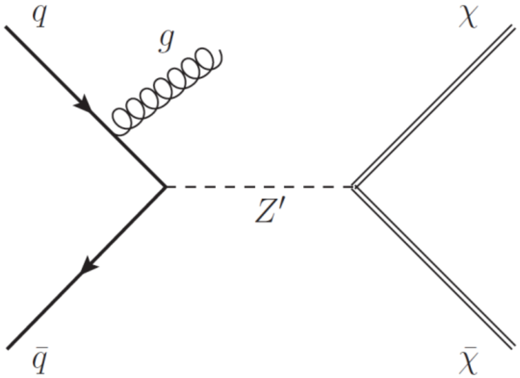
→ combination of channels

→ search for mediators too!

Good tracking crucial for many of these!



(graphics c/o Henri Bachacou)



Direct searches in dilepton/dijet channels: complementary!

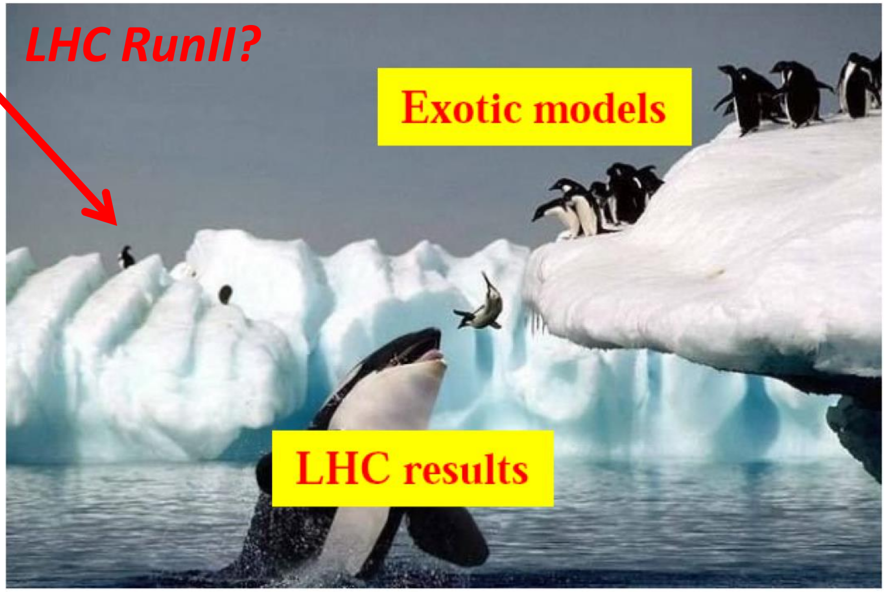
What Can We Do in RunII?

Find a new cliff: new searches

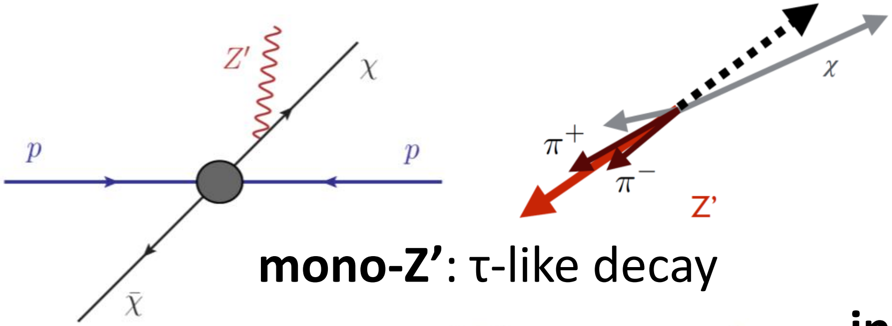
→more inclusive final states

e.g. mono-jet → multi-jet

→ new final states

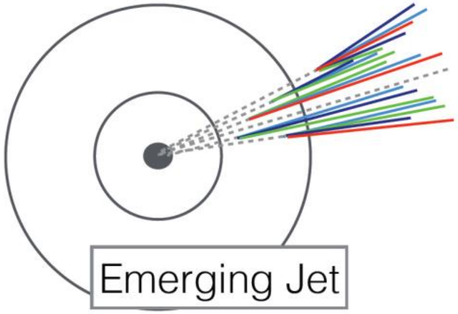


(graphics c/o Henri Bachacou)

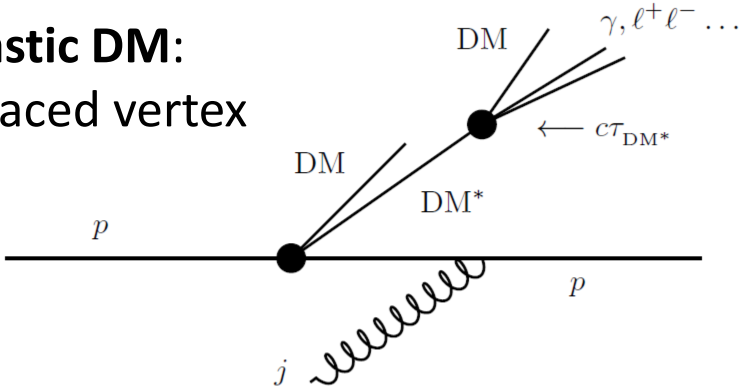


mono-Z': τ-like decay

composite dark sector

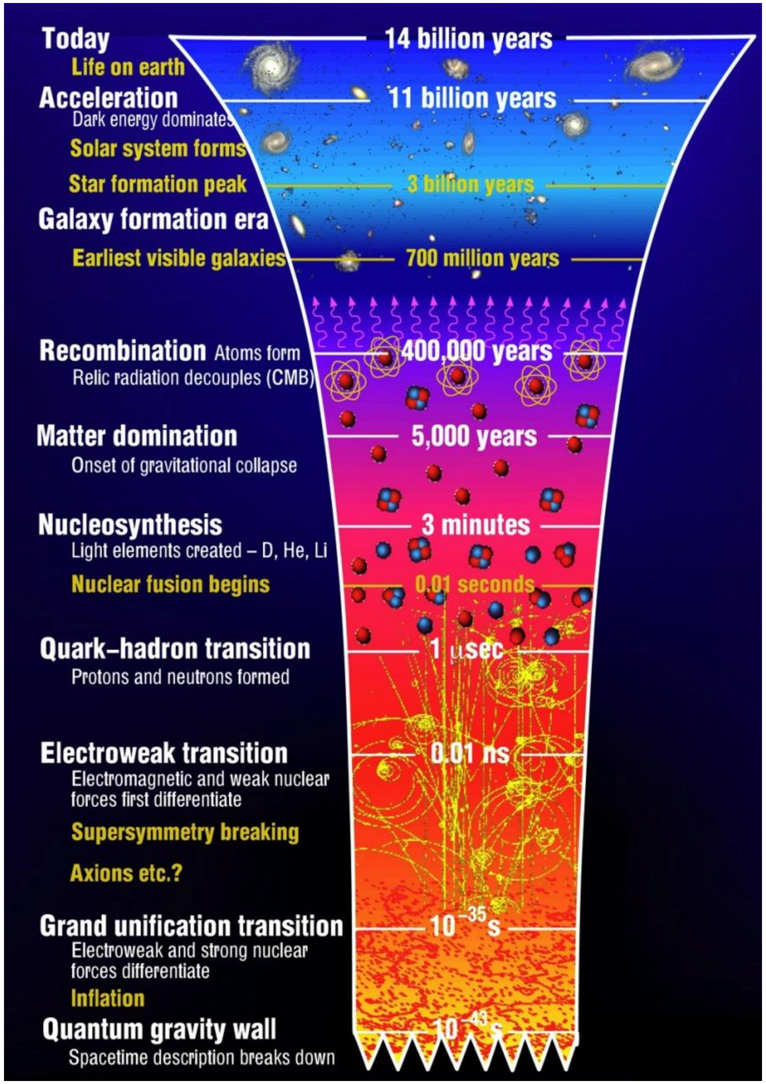


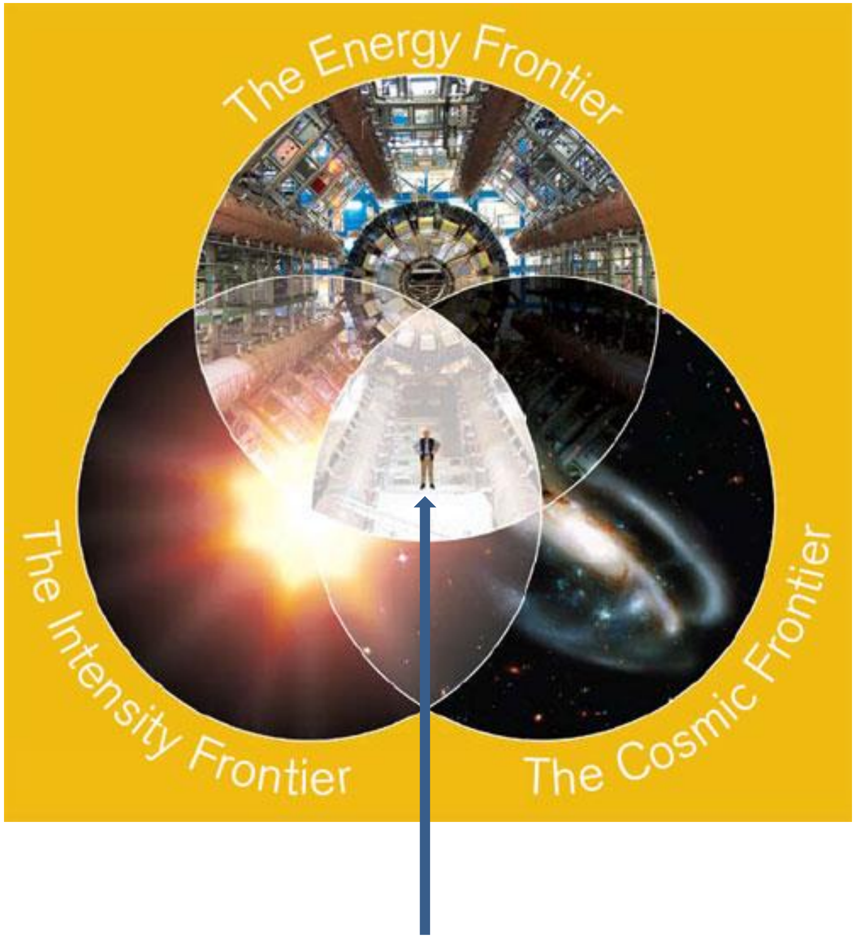
inelastic DM: displaced vertex



Good tracking critical for many of these!

Thank You!

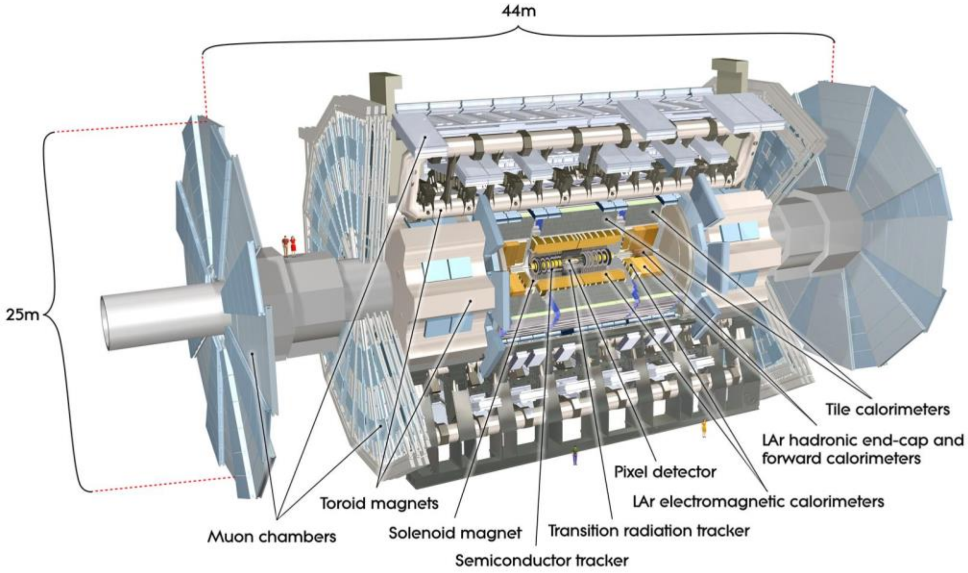


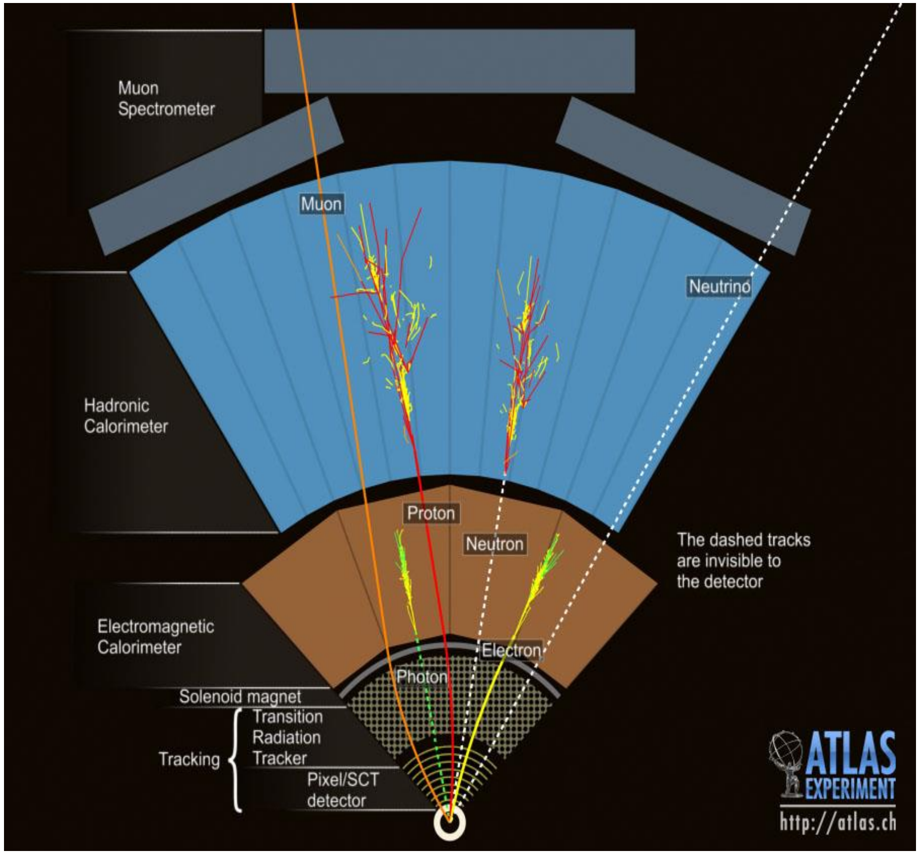


WE ARE HERE.

BACKUP

The ATLAS Detector



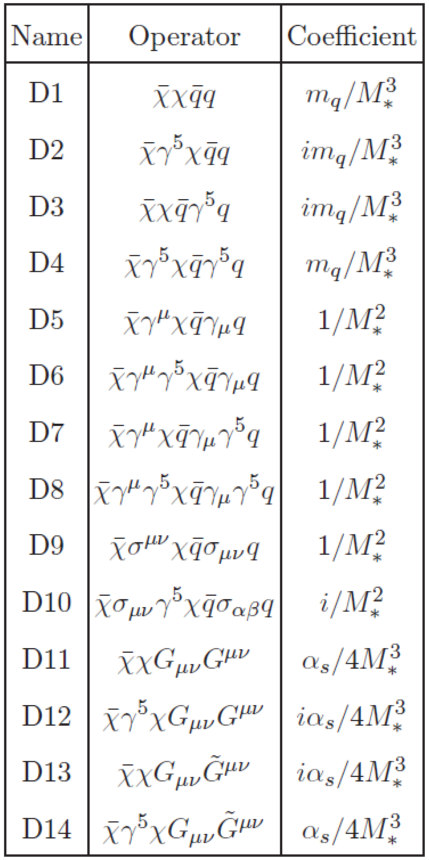


- **Inner Detector (tracking)**
  - Pixel Detector (PIX)
  - Semiconductor Tracker (SCT)
  - Transition Radiation Tracker (TRT)
- **Calorimeter (energy + location)**
  - LAr + Tile
- **Muon Spectrometer**

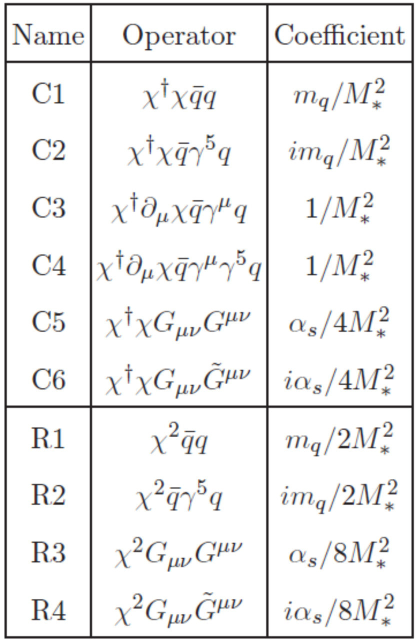
Limit Interpretation: Collider->Direct Detection

EFT operators

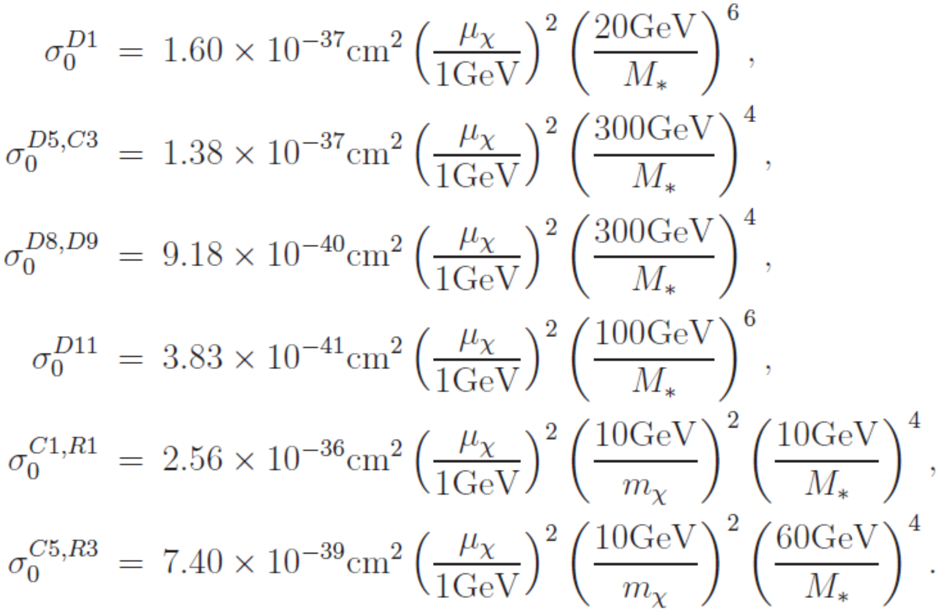
WIMP-Nucleon Xsec



Name	Operator	Coefficient
D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
D2	$\bar{\chi}\gamma^5\chi\bar{q}q$	im_q/M_*^3
D3	$\bar{\chi}\chi\bar{q}\gamma^5 q$	im_q/M_*^3
D4	$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	m_q/M_*^3
D5	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D6	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D7	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D8	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\alpha\beta}q$	i/M_*^2
D11	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
D12	$\bar{\chi}\gamma^5\chi G_{\mu\nu}G^{\mu\nu}$	$i\alpha_s/4M_*^3$
D13	$\bar{\chi}\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^3$
D14	$\bar{\chi}\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$\alpha_s/4M_*^3$



Name	Operator	Coefficient
C1	$\chi^\dagger\chi\bar{q}q$	m_q/M_*^2
C2	$\chi^\dagger\chi\bar{q}\gamma^5 q$	im_q/M_*^2
C3	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu q$	$1/M_*^2$
C4	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu\gamma^5 q$	$1/M_*^2$
C5	$\chi^\dagger\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^2$
C6	$\chi^\dagger\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^2$
R1	$\chi^2\bar{q}q$	$m_q/2M_*^2$
R2	$\chi^2\bar{q}\gamma^5 q$	$im_q/2M_*^2$
R3	$\chi^2 G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/8M_*^2$
R4	$\chi^2 G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/8M_*^2$

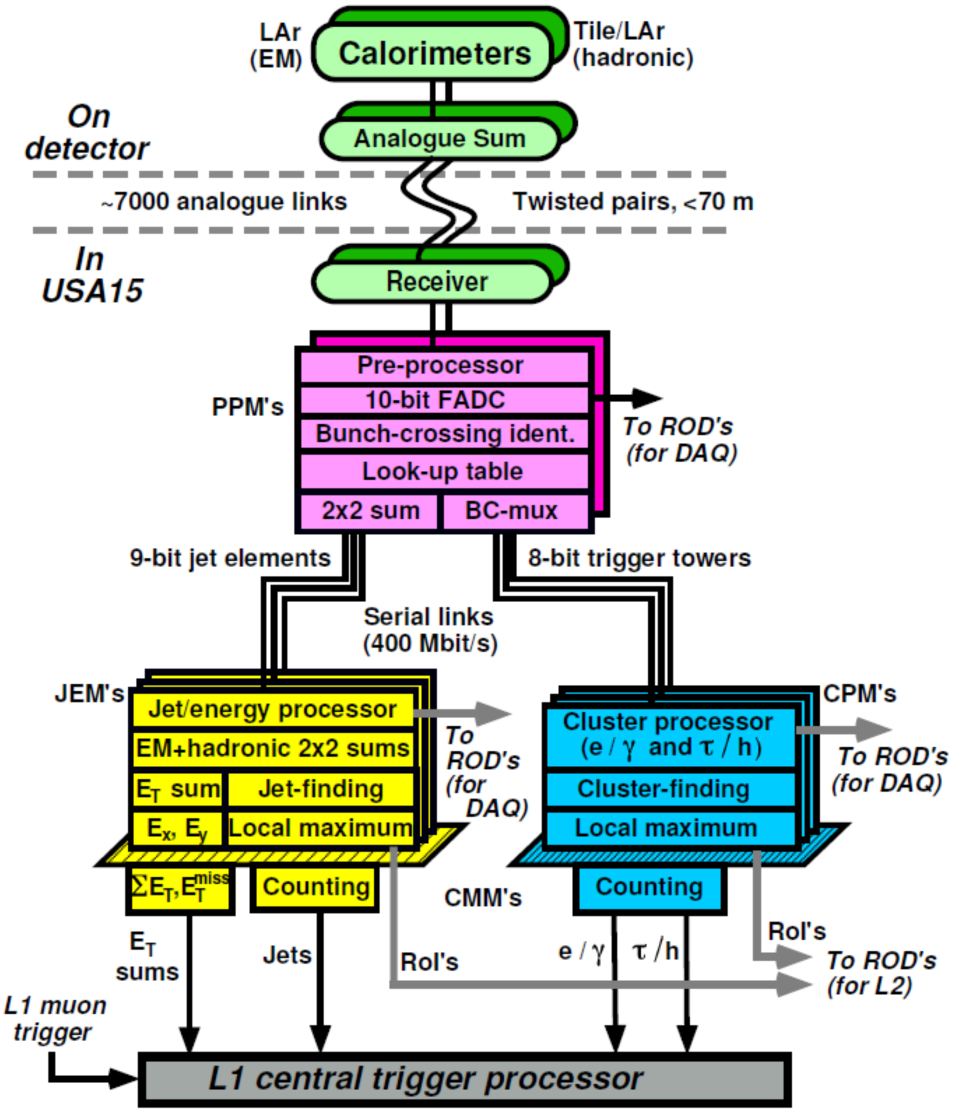


$$
\begin{aligned}
\sigma_0^{D1} &= 1.60\times10^{-37}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{20\mathrm{GeV}}{M_*}\right)^6, \\
\sigma_0^{D5,C3} &= 1.38\times10^{-37}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{300\mathrm{GeV}}{M_*}\right)^4, \\
\sigma_0^{D8,D9} &= 9.18\times10^{-40}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{300\mathrm{GeV}}{M_*}\right)^4, \\
\sigma_0^{D11} &= 3.83\times10^{-41}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{100\mathrm{GeV}}{M_*}\right)^6, \\
\sigma_0^{C1,R1} &= 2.56\times10^{-36}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{10\mathrm{GeV}}{m_\chi}\right)^2\left(\frac{10\mathrm{GeV}}{M_*}\right)^4, \\
\sigma_0^{C5,R3} &= 7.40\times10^{-39}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{10\mathrm{GeV}}{m_\chi}\right)^2\left(\frac{60\mathrm{GeV}}{M_*}\right)^4.
\end{aligned}
$$

μ_χ : reduced WIMP-nucleon mass

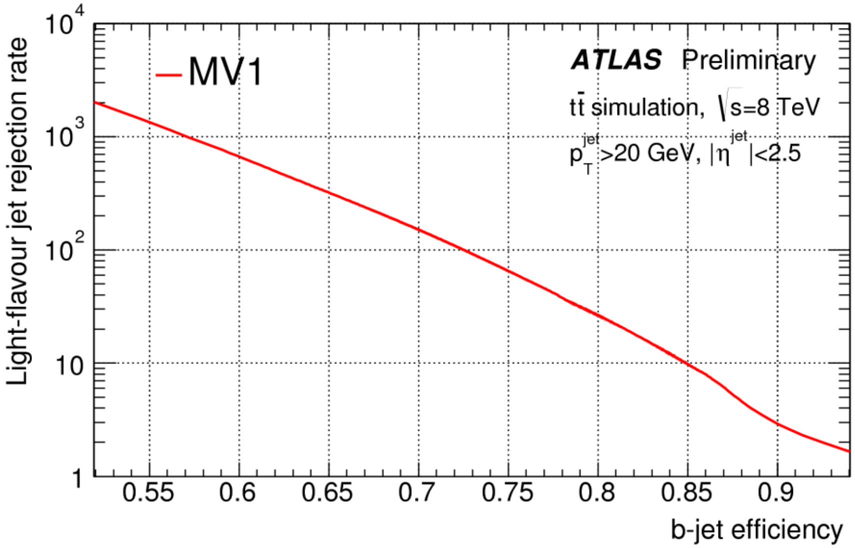
M_*: suppression scale (also noted as Λ)

ATLAS L1 Calorimeter Trigger System

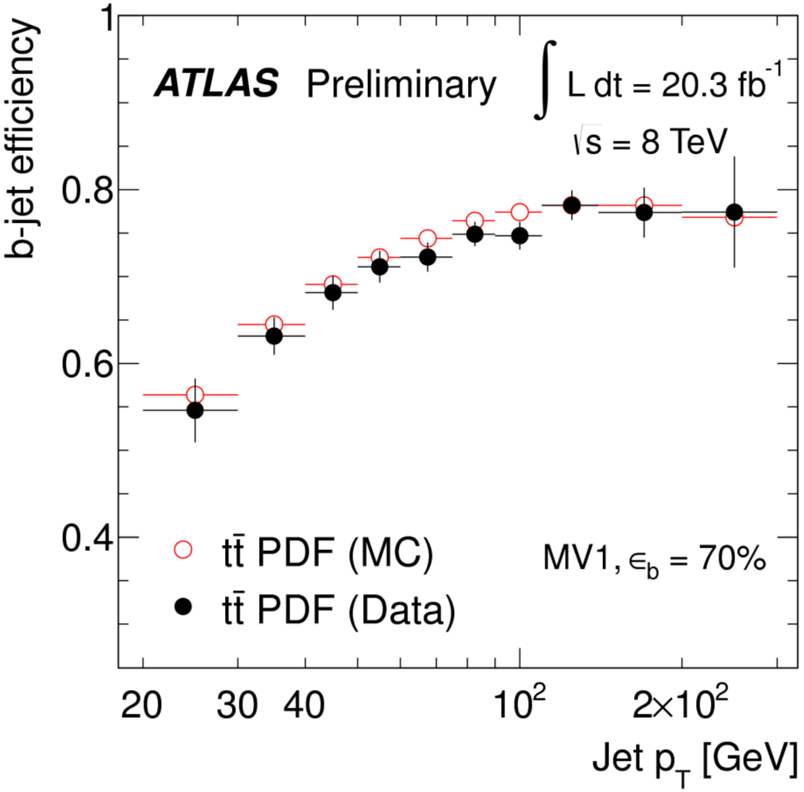


b-tagging

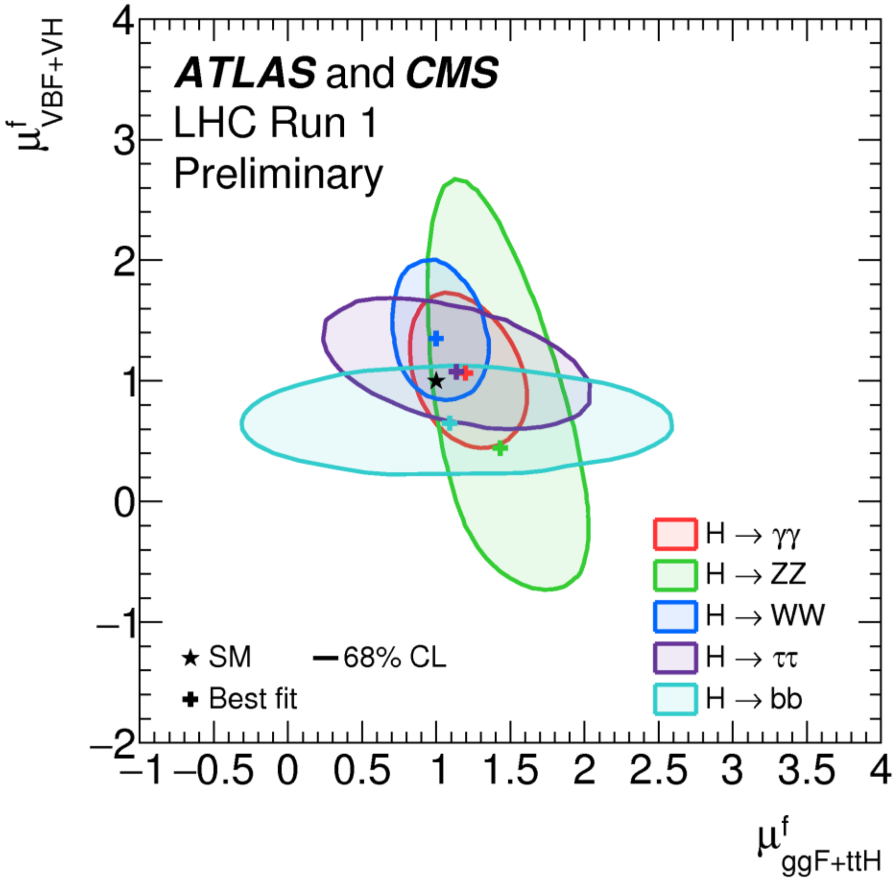
b-tagging eff. vs l-jet rejection

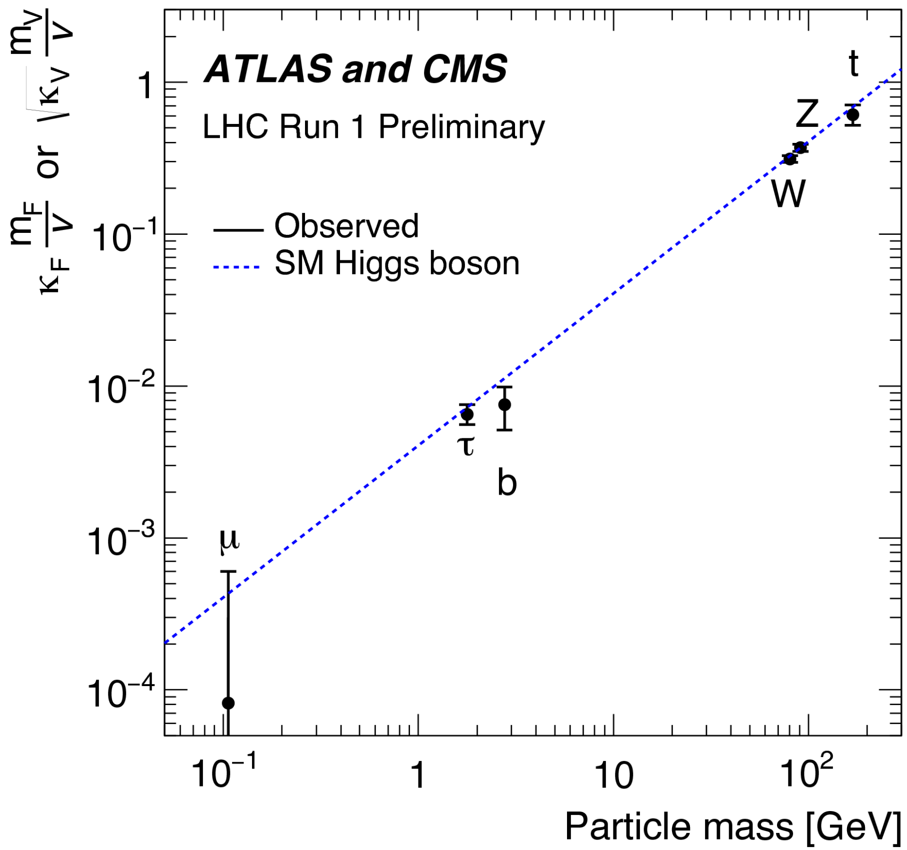


btagging calibration w/ ttbar



ATLAS/CMS Higgs Coupling Combination





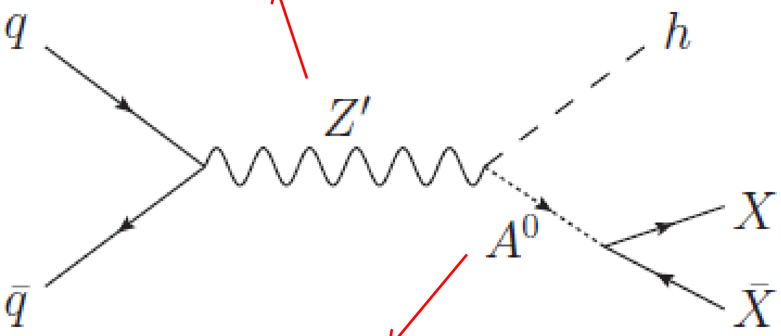
“The combined signal yield relative to the Standard Model expectation is measured to be 1.09 +- 0.11… **The data are consistent with the Standard Model predictions** for all parameterisations considered.”

DM+H(→bb): Z‘-2HDM Simplified Model

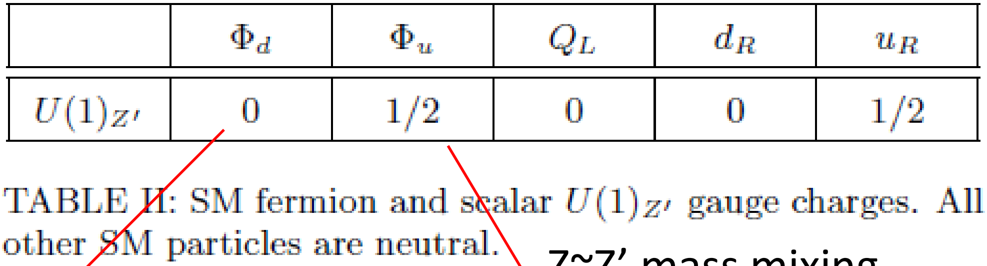
- A simplified model of dark matter production via Zp decay
  - model from http://arxiv.org/abs/1402.7074
    - “Higgs-portal” DM constrained by h→inv at low m_DM
    - precision electroweak constraints on Z, W mass constrain the amount of mixing and is imposed

Z’ produced resonantly

h ~ observed higgs at 125GeV



A0: pseudo-scalar in Type2-2HDM model



	Φ_d	Φ_u	Q_L	d_R	u_R
$U(1)_{Z'}$	0	1/2	0	0	1/2

TABLE II: SM fermion and scalar $U(1)_{Z'}$ gauge charges. All other SM particles are neutral.

Z~Z’ mass mixing

Avoid dilepton constraints: Z’ does not couple to leptons

$$M_{Z'}^2 \approx (M_{Z'}^0)^2 + \epsilon^2 \left[(M_{Z'}^0)^2 - (M_Z^0)^2\right]$$

$$\rho_0 = 1 + \epsilon^2 \left(\frac{M_{Z'}^2 - M_Z^2}{M_Z^2}\right)$$

$$\rho_0 \leq 1.0009$$

DM+H(→bb): Z’ decay and Signal Process

Z’→hA0, h→bb, A0→χχ → DM production signal process

$$\Gamma_{Z'\to hA^0} = (g_z \cos\alpha \cos\beta)^2 \frac{|p|}{24\pi} \frac{|p|^2}{M_{Z'}^2}$$

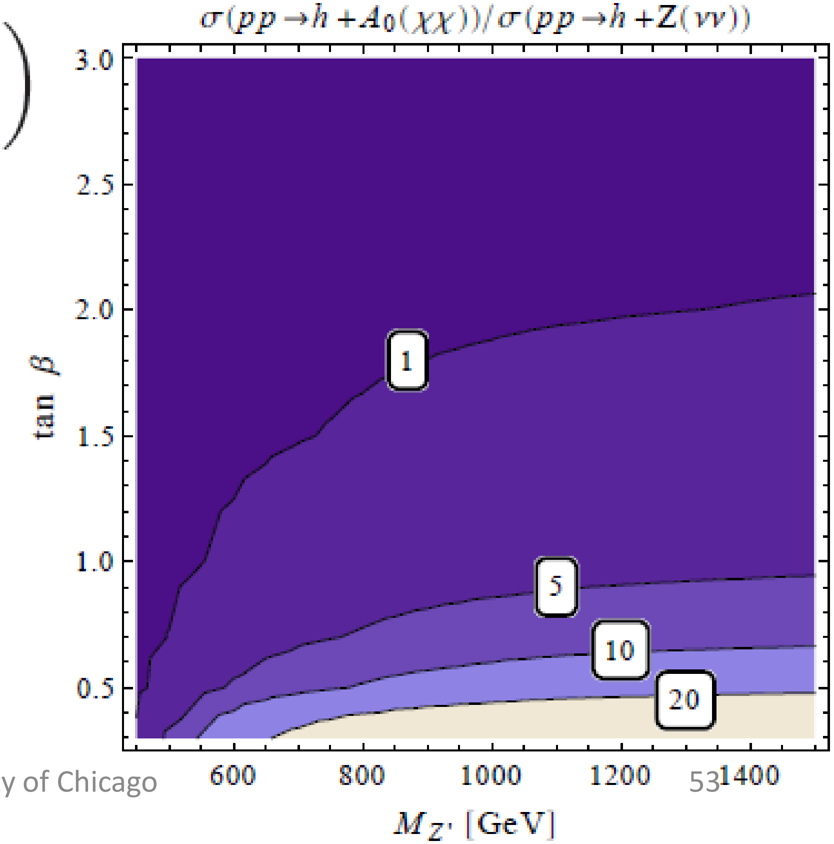
Very similar kinematics

Z’→hZ, h→bb, Z→νν → Additional source of h(bb)+MET

$$\Gamma_{Z'\to hZ} = (g_z \cos\alpha \sin\beta)^2 \frac{|p|}{24\pi} \left(\frac{|p|^2}{M_{Z'}^2} + 3\frac{M_Z^2}{M_{Z'}^2} \right)$$

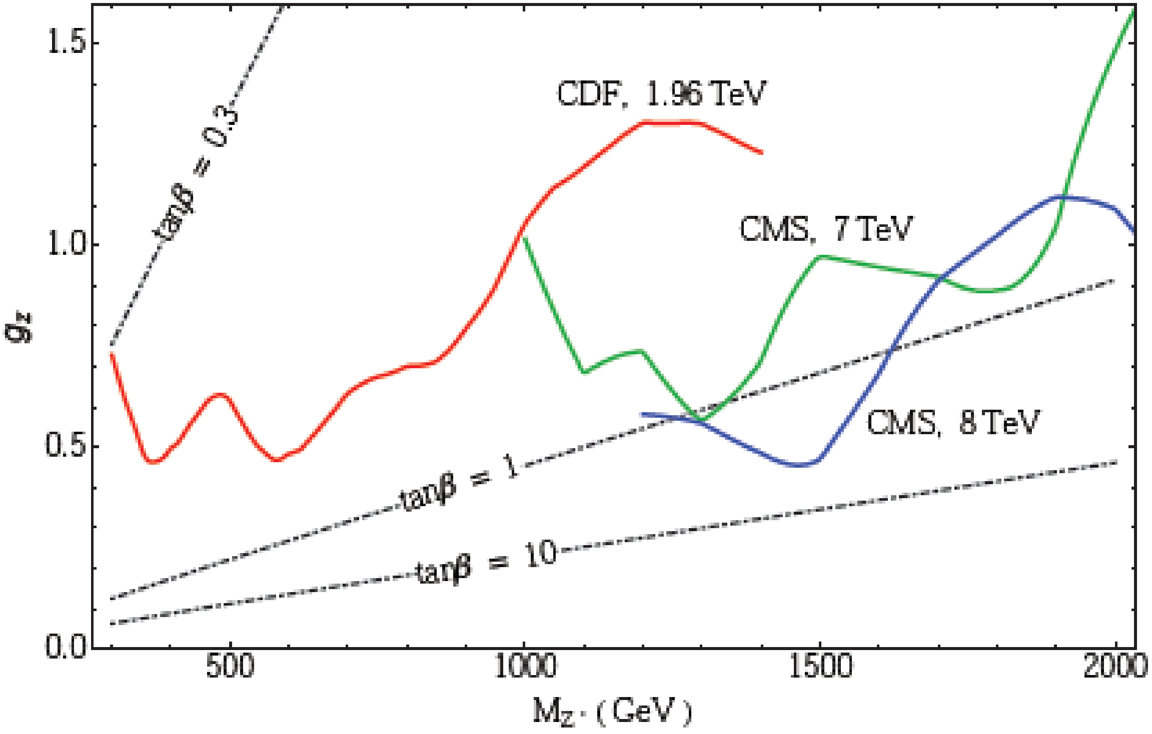
mA0=300GeV: largest DM production xsec
α = β- π/2 : alignment limit
gz = 95% C.L. upper limit on eletroweak (ρ0) and dijet constraints

for most of the parameter space,
Z’→hA0 is dominant process
adding Z’→hZ : ability to probe larger regions



Z’-2HDM Parameter Space and Production: g_z

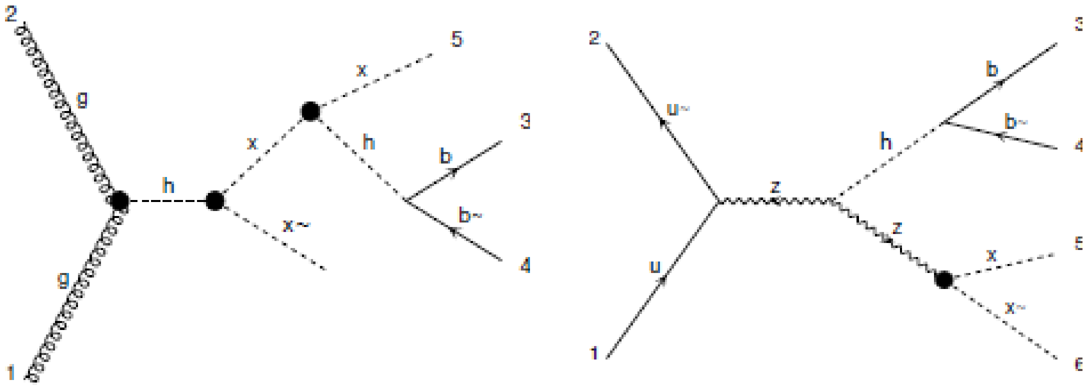
- Signal xsec scales by gz^2; kinematics not affected by gz
- For sensitivity projections, signal xsec are scaled by gz^2 taking the maximum allowed gz value for given m_Zp & tanβ
  - gz < 0.03 * (g/cos θ_w sinβ^2) * sqrt(MZp^2 - MZ^2)/MZ
  - additional constraints from dijet searches of Z’→qq



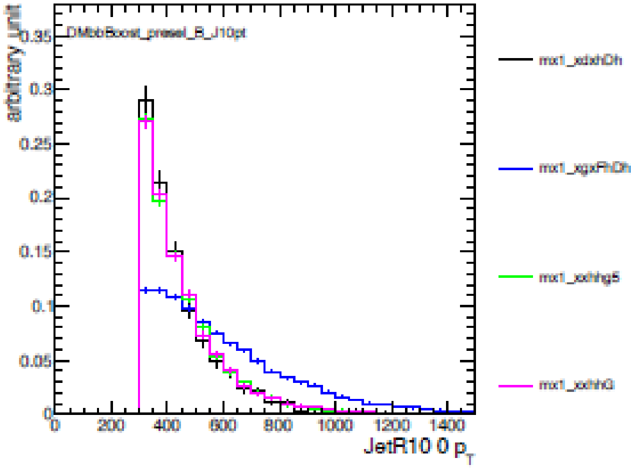
DM+H(→bb) : EFT Models

(c/o S.C.Hsu)

Focus on EFT model for boosted channel



arXiv:1312.2592



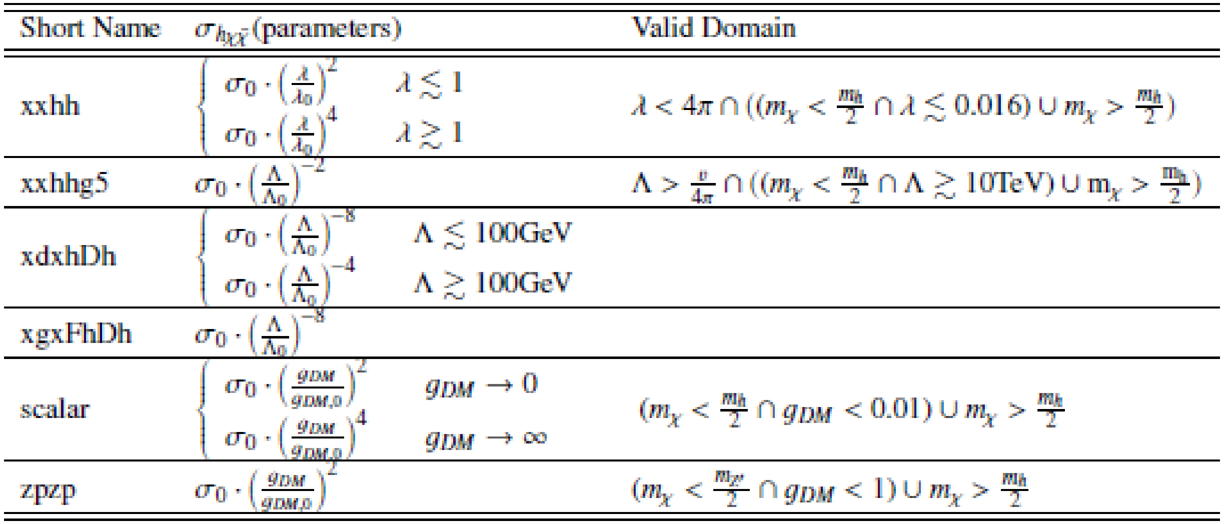
Model Name	EFT Operator	Dim	Dark Matter	Perturb. Req.	$\mathcal{BR}_{\text{inv}}$ Req.
xxhh	$\chi\chi HH$	4	Scalar	$\lambda < 4\pi$	$m_\chi < \frac{m_h}{2} \rightarrow \lambda \lesssim 0.016$
xxhhg5	$\bar{\chi} i\gamma_5 \chi HH$	5	Fermion	$\Lambda < \frac{v}{4\pi}$	$m_\chi < \frac{m_h}{2} \rightarrow \Lambda \gtrsim 10\text{TeV}$
xdxhDh	$\chi^\dagger \partial^\mu \chi H^\dagger D_\mu H$	6	Scalar	$g_{Z_{\text{eff}}} < 4\pi$ ($\Lambda \gtrsim 30\text{GeV}$)	$m_\chi < \frac{m_Z}{2} \rightarrow \Lambda \gtrsim 400\text{GeV}$
xgxFhDh	$\bar{\chi}\gamma^\mu \chi B_{\mu\nu} H^\dagger D^\nu H$	8	Fermion	Use Truncation	N/A

EFT models has been constraint by monoHgamgam (arXiv:1506.01081) from ATLAS

DM+H(→bb) : EFT Models

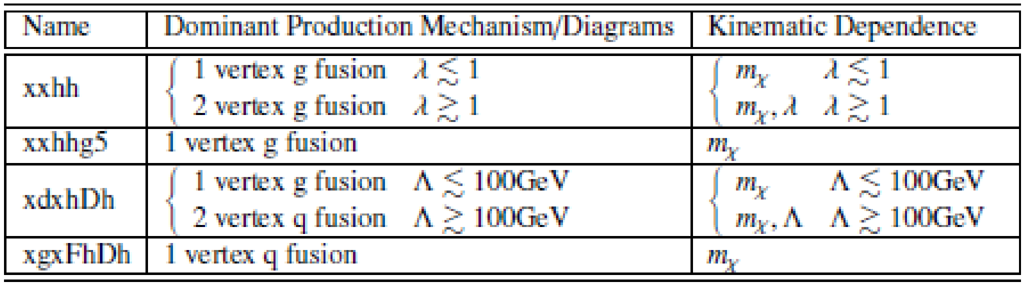
Cross-section scaling

(c/o S.C.Hsu)

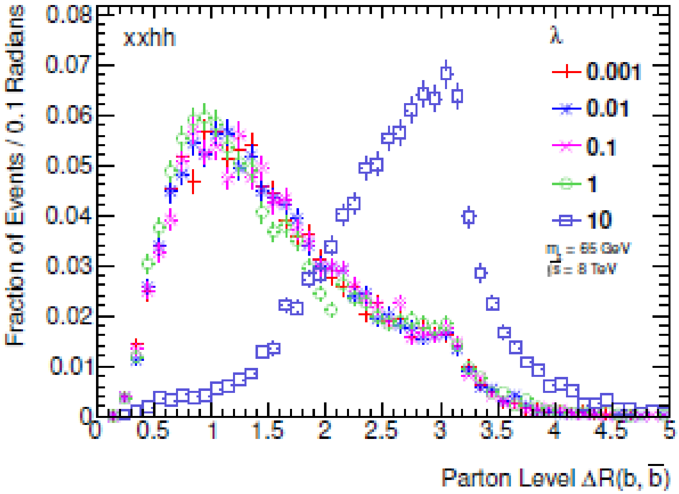


Short Name	$\sigma_{h\chi\bar{\chi}}$(parameters)	Valid Domain
xxhh	$\begin{cases} \sigma_0 \cdot \left(\frac{\lambda}{\lambda_0}\right)^2 & \lambda \lesssim 1 \\ \sigma_0 \cdot \left(\frac{\lambda}{\lambda_0}\right)^4 & \lambda \gtrsim 1 \end{cases}$	$\lambda < 4\pi \cap ((m_\chi < \frac{m_h}{2} \cap \lambda \lesssim 0.016) \cup m_\chi > \frac{m_h}{2})$
xxhhg5	$\sigma_0 \cdot \left(\frac{\Lambda}{\Lambda_0}\right)^{-2}$	$\Lambda > \frac{v}{4\pi} \cap ((m_\chi < \frac{m_h}{2} \cap \Lambda \gtrsim 10\text{TeV}) \cup \text{m}_\chi > \frac{m_h}{2})$
xdxhDh	$\begin{cases} \sigma_0 \cdot \left(\frac{\Lambda}{\Lambda_0}\right)^{-8} & \Lambda \lesssim 100\text{GeV} \\ \sigma_0 \cdot \left(\frac{\Lambda}{\Lambda_0}\right)^{-4} & \Lambda \gtrsim 100\text{GeV} \end{cases}$	
xgxFhDh	$\sigma_0 \cdot \left(\frac{\Lambda}{\Lambda_0}\right)^{-8}$	
scalar	$\begin{cases} \sigma_0 \cdot \left(\frac{g_{DM}}{g_{DM,0}}\right)^2 & g_{DM} \to 0 \\ \sigma_0 \cdot \left(\frac{g_{DM}}{g_{DM,0}}\right)^4 & g_{DM} \to \infty \end{cases}$	$(m_\chi < \frac{m_h}{2} \cap g_{DM} < 0.01) \cup m_\chi > \frac{m_h}{2}$
zpzp	$\sigma_0 \cdot \left(\frac{g_{DM}}{g_{DM,0}}\right)^2$	$(m_\chi < \frac{m_{Z'}}{2} \cap g_{DM} < 1) \cup m_\chi > \frac{m_h}{2}$

Kinematic dependences

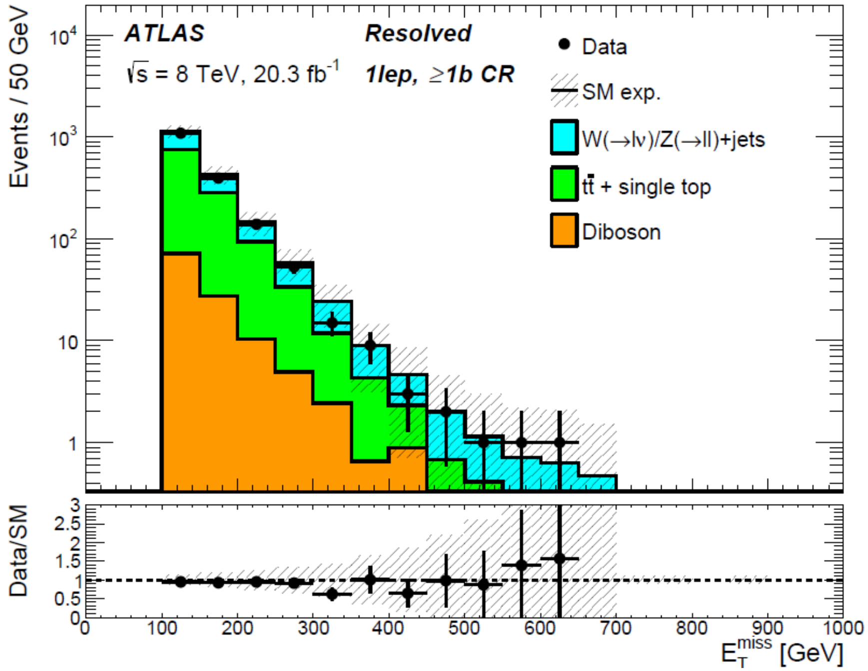


Name	Dominant Production Mechanism/Diagrams	Kinematic Dependence
xxhh	1 vertex g fusion $\lambda \lesssim 1$ 2 vertex g fusion $\lambda \gtrsim 1$	m_χ $\lambda \lesssim 1$ m_χ, λ $\lambda \gtrsim 1$
xxhhg5	1 vertex g fusion	m_χ
xdxhDh	1 vertex g fusion $\Lambda \lesssim 100\text{GeV}$ 2 vertex q fusion $\Lambda \gtrsim 100\text{GeV}$	m_χ $\Lambda \lesssim 100\text{GeV}$ m_χ, Λ $\Lambda \gtrsim 100\text{GeV}$
xgxFhDh	1 vertex q fusion	m_χ



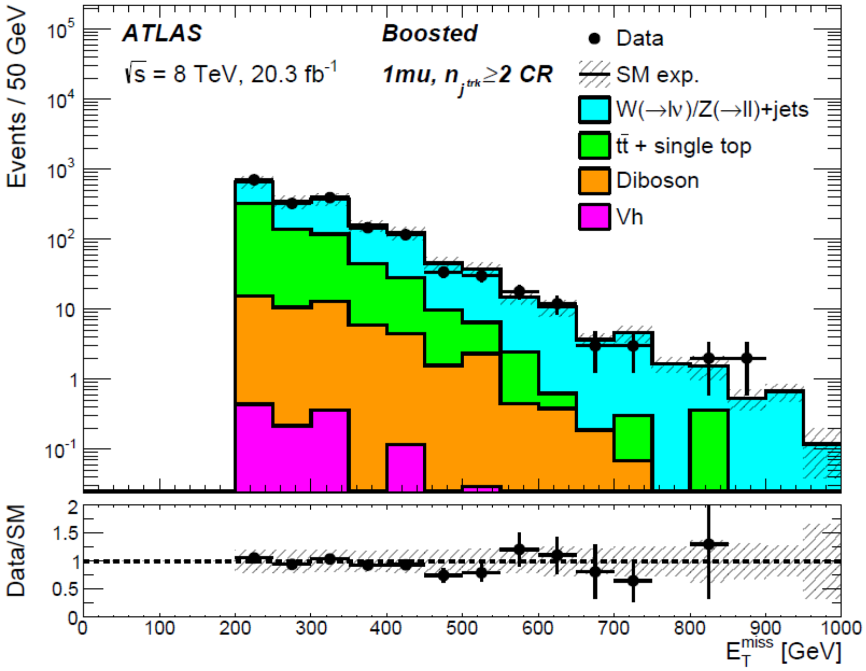
DM+H(→bb) Simulated Bkgd: W+jets & Top

Resolved Channel



- Derive SF=0.92 on Wjets bkgd
- No additional SF for top bkgd
  - top pT rw. has minor effect
    - not applied; considered as sys.

Boosted Channel



- Derive SF=0.82 on Wjets bkgd
- Derive SF=0.89 on top bkgd
  - top pT rw correct high pT tail
    - applied at generator level

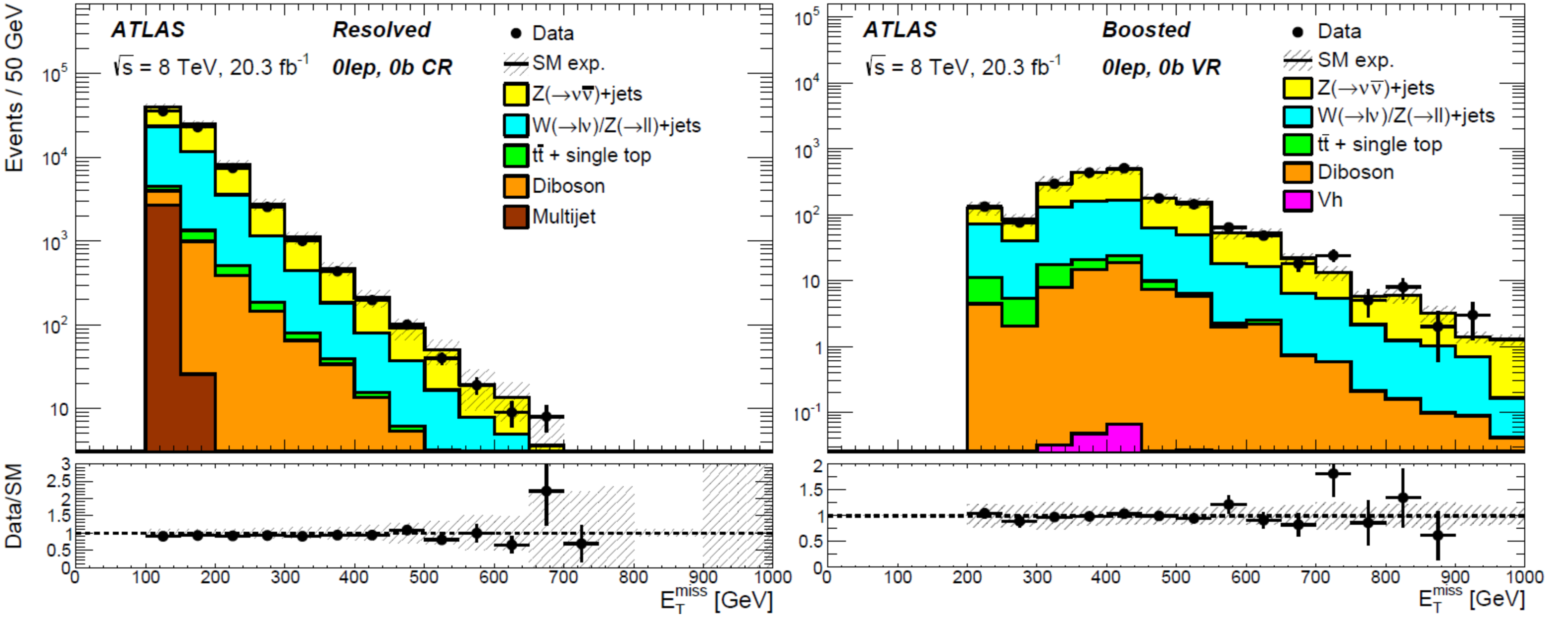
Good agreement achieved in both channels for Wjets, top, and 1lep_combined CRs.

Data-Driven Background: Z(→νν)+jets

- Main & irreducible background → use data-driven estimation (no good MC)
- E_T^{miss} <200GeV , reweight from **Z(→μμ)+jets data**
  - Select Z→μμ CR; TF: Z→νν (MC) E_t^{miss} / Z→μμ (MC) E_T^{miss} + pT of 2μ
- E_T^{miss} >200GeV, reweight from **γ+jets data** (low stats with Z→μμ)
  - γ pT>>mZ; TF: γ+jets(MC) E_T^{miss} +γ pT / Z→νν (MC) E_t^{miss}

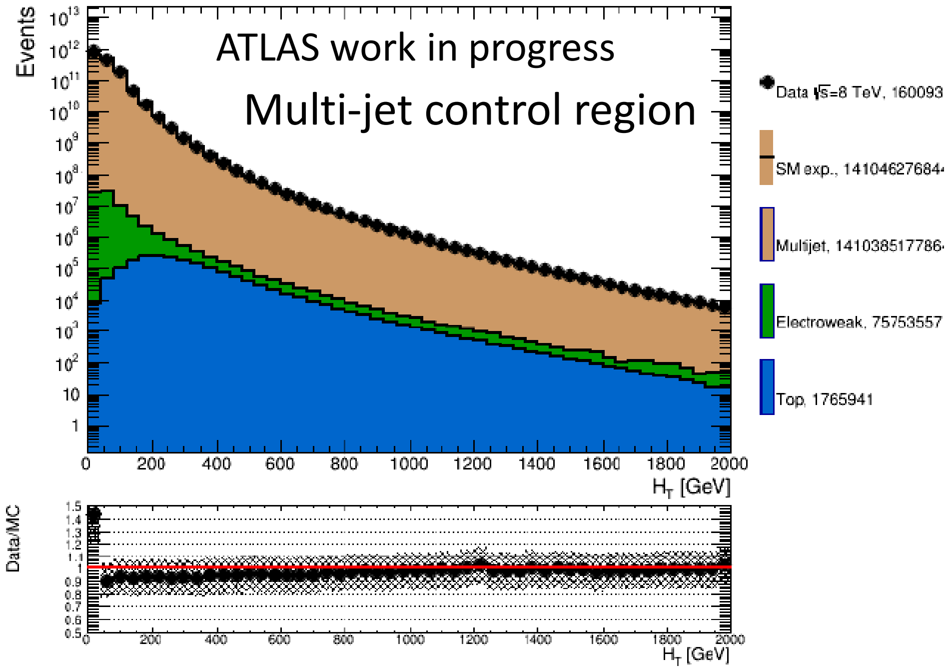
Z(→νν)+jets CR
0Lepton,
==0b
(SF=0.9, applied)

1b | 2b CRs also studied. Good agreement across-board.



DM+H(→bb): Data-Driven Multijet Background

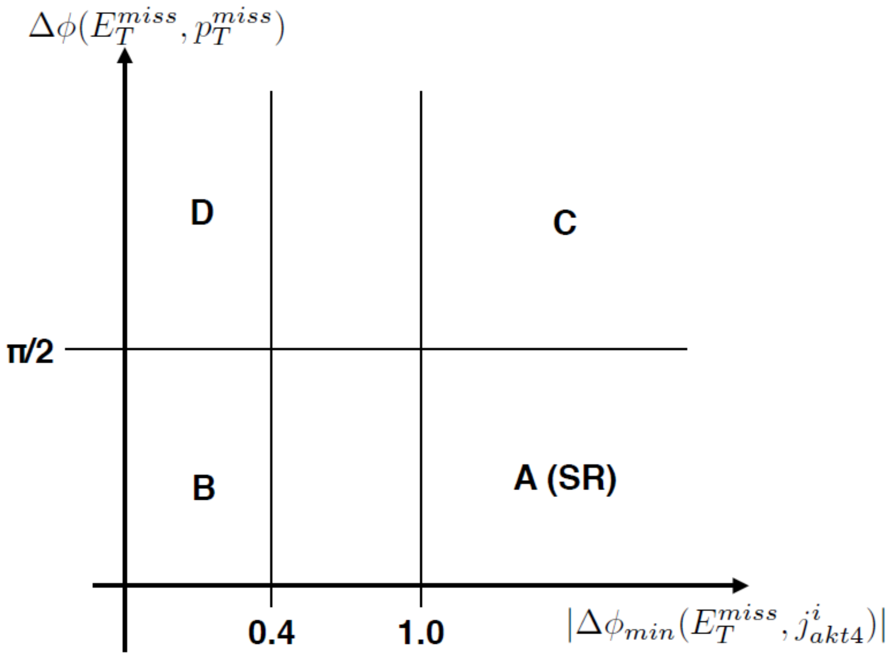
Resolved Channel



jet-smearing method

- good agreement in QCD CR
- minimal in SR

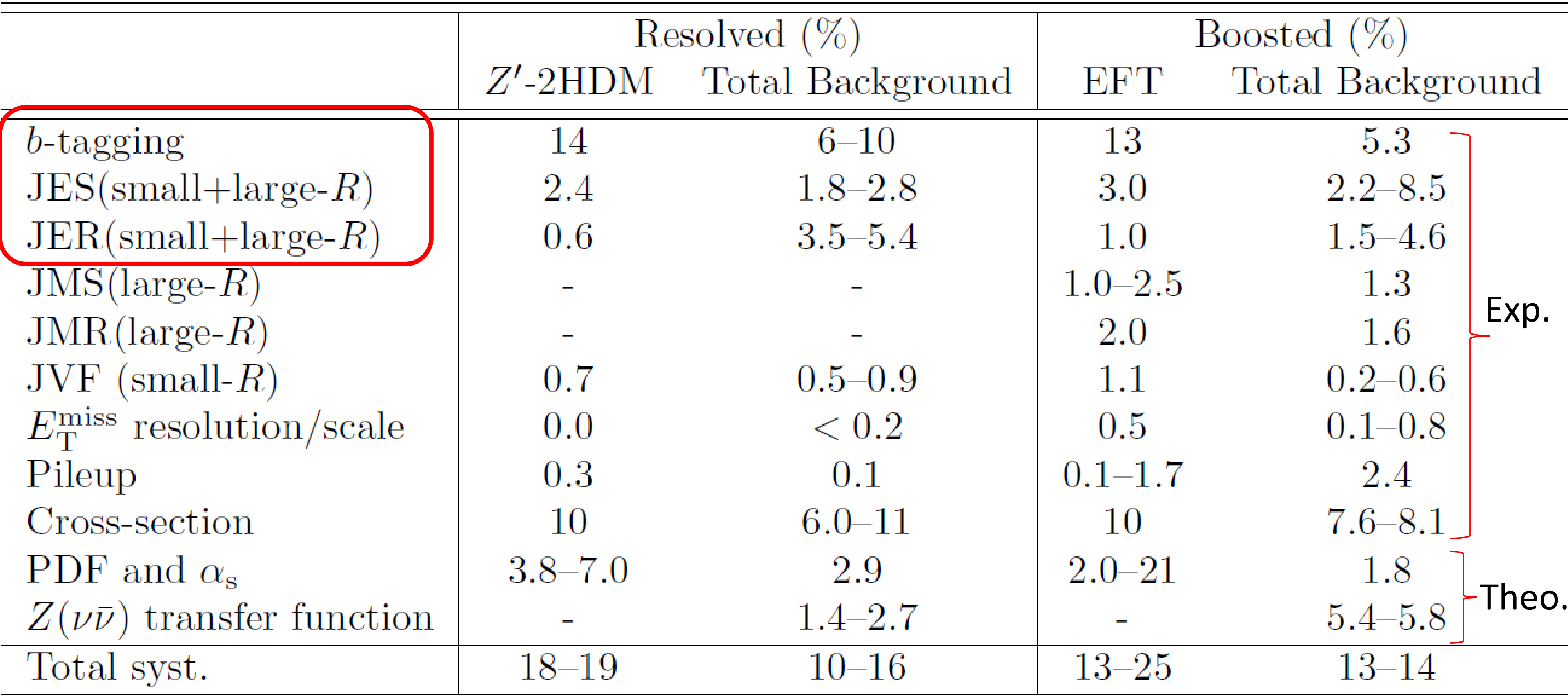
Boosted Channel



ABCD method:

- 68% CL upper limit of 0.1 events in SR

DM+Higgs(→bb): Systematic Uncertainties

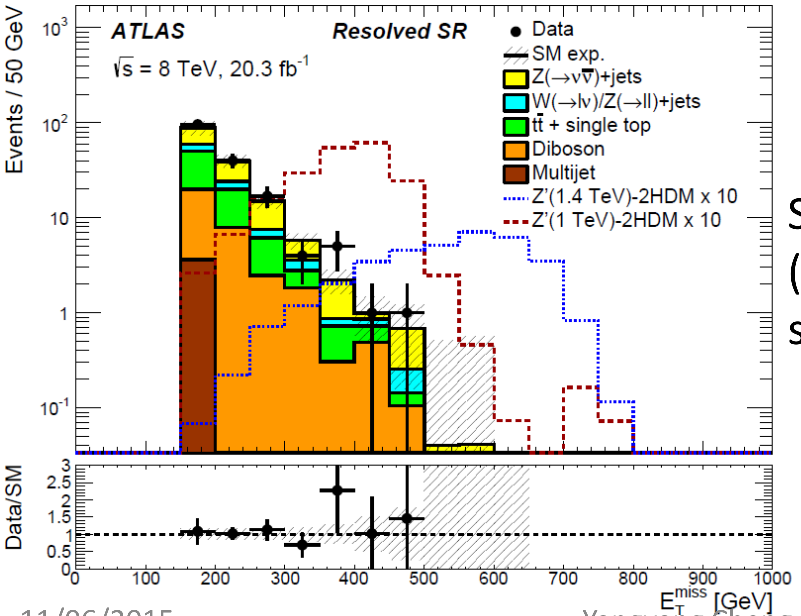


	Resolved (%)		Boosted (%)	
	Z'-2HDM	Total Background	EFT	Total Background
b-tagging	14	6–10	13	5.3
JES(small+large-R)	2.4	1.8–2.8	3.0	2.2–8.5
JER(small+large-R)	0.6	3.5–5.4	1.0	1.5–4.6
JMS(large-R)	-	-	1.0–2.5	1.3
JMR(large-R)	-	-	2.0	1.6
JVF (small-R)	0.7	0.5–0.9	1.1	0.2–0.6
$E_{\mathrm{T}}^{\mathrm{miss}}$ resolution/scale	0.0	< 0.2	0.5	0.1–0.8
Pileup	0.3	0.1	0.1–1.7	2.4
Cross-section	10	6.0–11	10	7.6–8.1
PDF and α_s	3.8–7.0	2.9	2.0–21	1.8
$Z(\nu\bar{\nu})$ transfer function	-	1.4–2.7	-	5.4–5.8
Total syst.	18–19	10–16	13–25	13–14

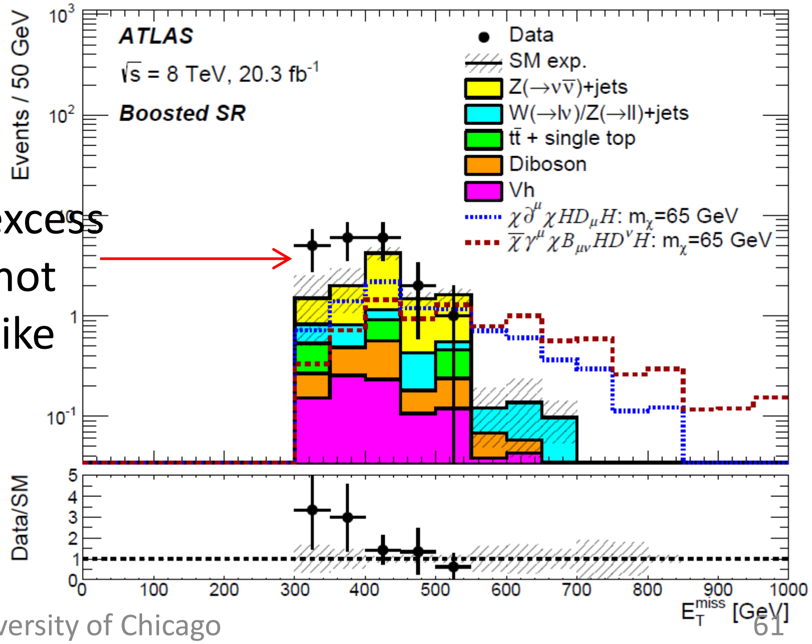
Each source of systematic uncertainty treated as nuisance parameter in limit setting, with correlation between background processes and signal taken into account.

DM+Higgs(→bb): Signal Region

	Resolved				Boosted	
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 150 GeV	> 200 GeV	> 300 GeV	> 400 GeV	> 300 GeV	> 400 GeV
$Z(\rightarrow \nu\bar{\nu})$+jets	48 ± 32	21 ± 5	2.9 ± 1.1	0.3 ± 0.3	7.0 ± 2.0	5.2 ± 1.6
Multijet	3.7 ± 3.1	0.02 ± 0.02	–	–	$< 0.0 \pm 0.1$	$< 0.0 \pm 0.1$
$t\bar{t}$ & single-top	48 ± 10	17 ± 3.8	1.6 ± 0.5	0.3 ± 0.1	0.8 ± 0.5	0.6 ± 0.4
W+jets & Z+jets	15 ± 3.4	6.2 ± 1.5	1.1 ± 0.3	0.3 ± 0.1	1.4 ± 0.7	0.8 ± 0.4
Diboson	29.4 ± 7.5	13.2 ± 3.8	2.8 ± 1.0	0.6 ± 0.3	0.9 ± 0.5	0.6 ± 0.3
$Vh(bb)$	5.0 ± 0.7	4.2 ± 0.6	1.0 ± 0.2	0.3 ± 0.1	1.0 ± 0.2	0.6 ± 0.1
Total background	148 ± 30	62 ± 7.5	9.4 ± 1.8	1.7 ± 0.5	11.2 ± 2.3	7.7 ± 1.7
Data	164	68	11	2	20	9



Small excess (2.2σ) not signal-like



DM+H(→bb): Model-Independent Upper Limit

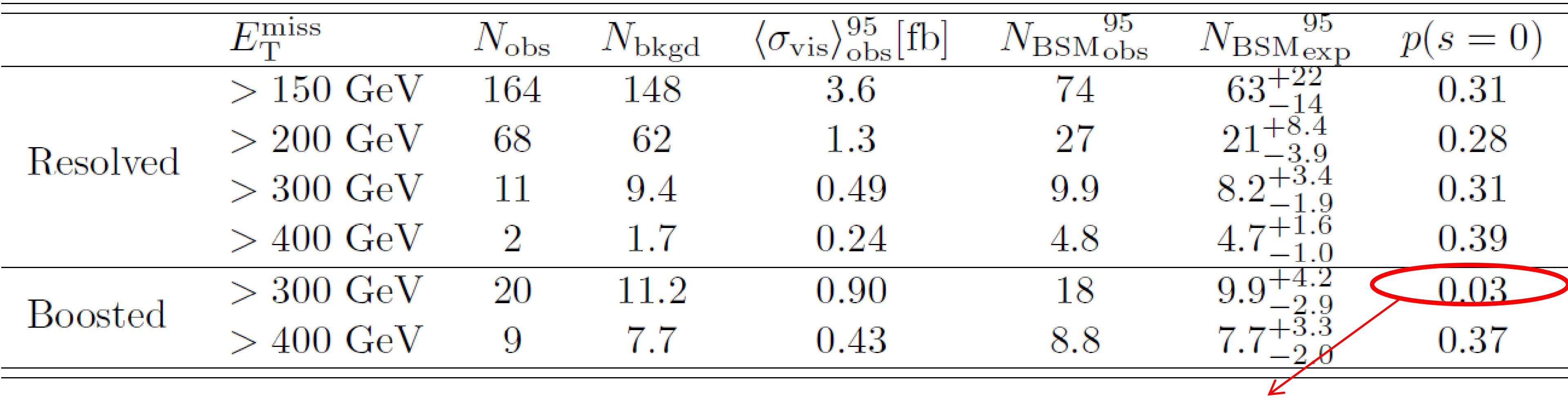
- Profile likelihood method

(with *HistFitter-00-00-47*)

'likelihood assuming background only'

$$\tilde{q}_0 = -2\ln\frac{L(data\,|\,\mu=0,\hat{\hat{\theta}}_0)}{L(data\,|\,\hat{\mu},\hat{\theta})}$$

'likelihood of best fit'



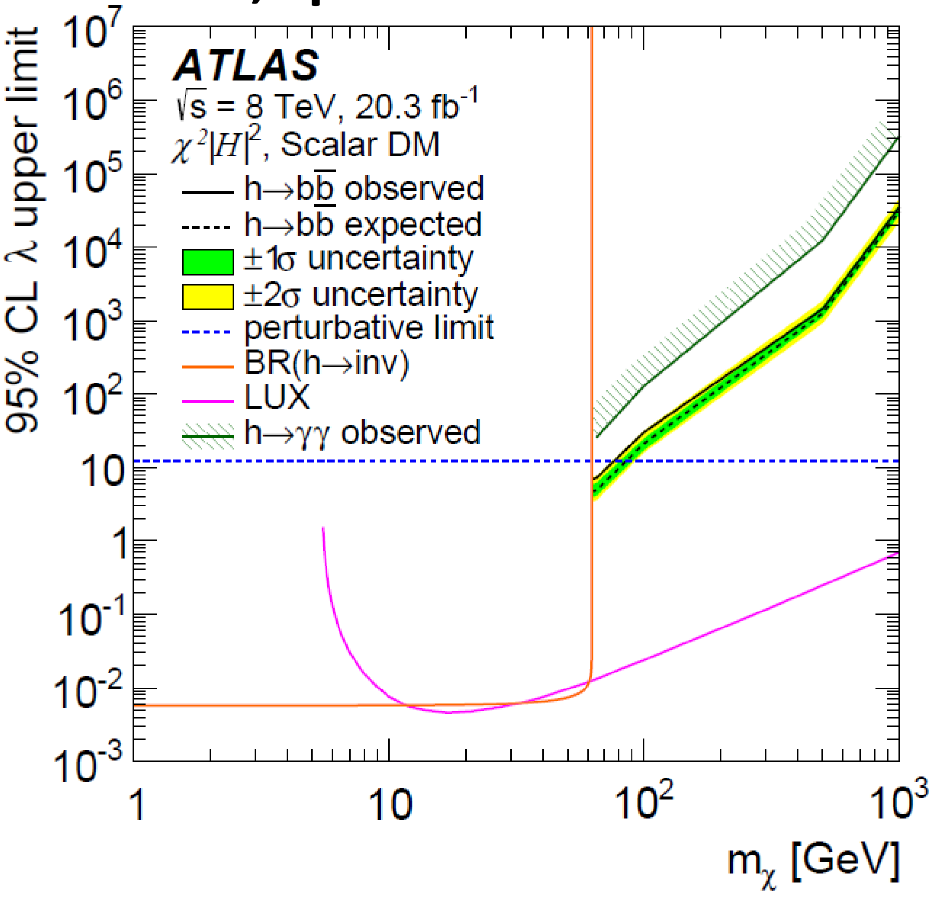
	$E_{\mathrm{T}}^{\mathrm{miss}}$	N_{obs}	N_{bkgd}	$\langle\sigma_{\mathrm{vis}}\rangle^{95}_{\mathrm{obs}}$ [fb]	$N_{\mathrm{BSM}}{}^{95}_{\mathrm{obs}}$	$N_{\mathrm{BSM}}{}^{95}_{\mathrm{exp}}$	$p(s=0)$
Resolved	> 150 GeV	164	148	3.6	74	63^{+22}_{-14}	0.31
	> 200 GeV	68	62	1.3	27	$21^{+8.4}_{-3.9}$	0.28
	> 300 GeV	11	9.4	0.49	9.9	$8.2^{+3.4}_{-1.9}$	0.31
	> 400 GeV	2	1.7	0.24	4.8	$4.7^{+1.6}_{-1.0}$	0.39
Boosted	> 300 GeV	20	11.2	0.90	18	$9.9^{+4.2}_{-2.9}$	0.03
	> 400 GeV	9	7.7	0.43	8.8	$7.7^{+3.3}_{-2.0}$	0.37

Look-elsewhere effect calculation: 10,000 pseudo-experiments in EXCLUSIVE regions
→ trial factor ~ 3 → ~10% likelihood the excess is due to statistical fluctuation in background

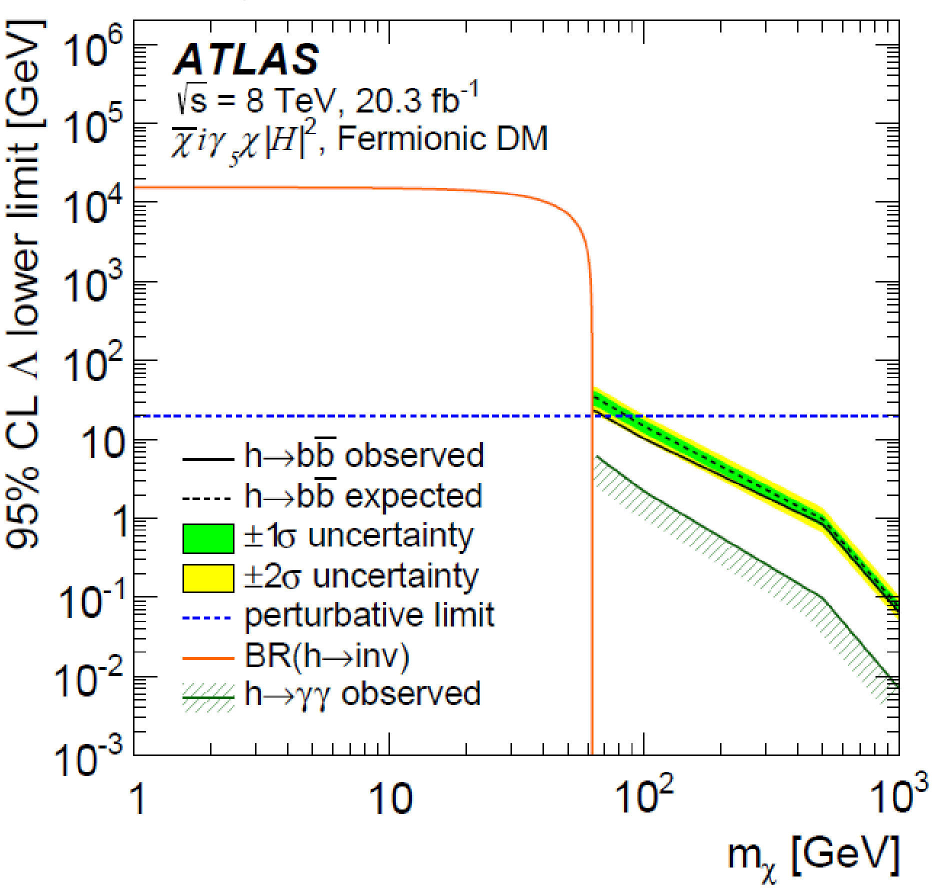
Model-independent upper limit on BSM events/visible xsec for each sliding E_t^{miss} cut (up to high E_t^{miss} region: NEW!) provides useful information for theorists & helps guide future searches.

DM+H(→bb): Additional EFT Limits

Dim.4, spin-0 DM



Dim.5, spin-1/2 DM



DM+H(→bb) Resolved: Systematic Uncertainties

- Signal PDF Uncertainties
  - Signals produced with central value of MSTW2008LO
  - PDF uncertainty calculated for error sets of MSTW2008LO (40sets, asym. Hessian), central value&error sets of NNPDF2.1(100 sets, independent) per PDFLHC4 recommendation; in terms of signal acceptance at >=2btag selection

$$\Delta X_{env} = \frac{1}{2} \cdot [\max(X_0^{NNPDF} + \Delta X, X_0^{MSTW} + \Delta X^+) - \min(X_0^{NNPDF} - \Delta X, X_0^{MSTW} - \Delta X^-)]$$

- Systematic Uncertainty in Z→νν estimation

Theoretical: Uncertainty in calculating TF itself

(numbers in percent)

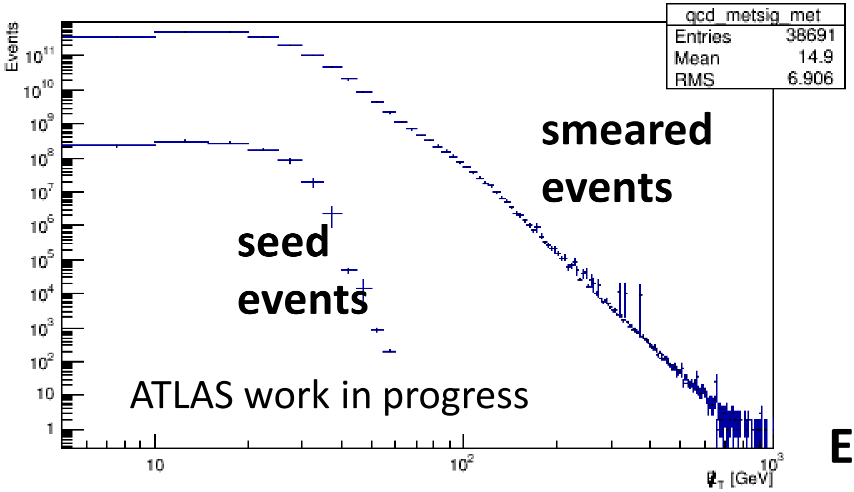
$Z \to \nu\nu$ estimation	fit function	fit error	fit range in E_T^{miss}	fit stage	fit shape	photon-sys	total
$Z \to \mu\mu$ method	0.5	8	0	0.2	1	–	8.1
γ+jets method	0	0.2	0	4.6	2.5	4.0	6.9

Experimental: Detector systematics propagated through TF calculation (from MC samples) and reweighting process

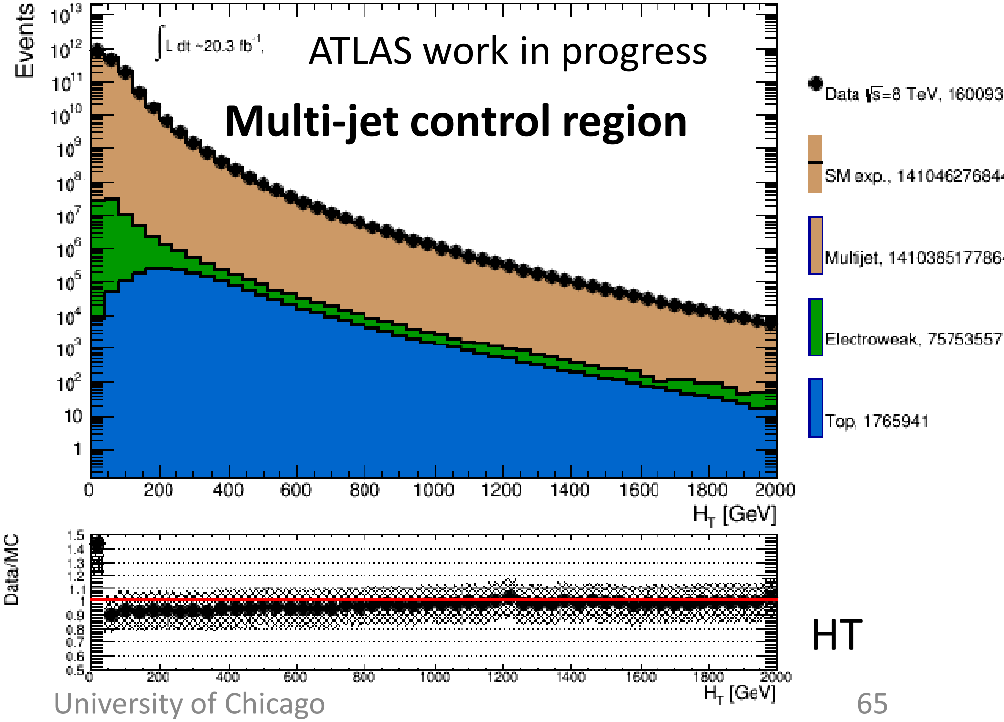
- E_T^{miss} <200GeV, reweight on Z→μμ data (background from MC subtracted)
- E_T^{miss} >200GeV, reweight on γ+jets data only

Data-Driven Background: Multijet

- Select QCD enriched region (seed) using dedicated trigger, low E_T^{miss} and $E_T^{miss,sig}$
- Smear seed data with pre-defined jet response function
- Derive normalization and reweighting from $\Delta\phi_{min}$ (jet, E_T^{miss})<0.7 QCD control region
- Apply analysis selection to smeared and normalized events
- Very good description
- **Multi-jet background negligible after full selection**



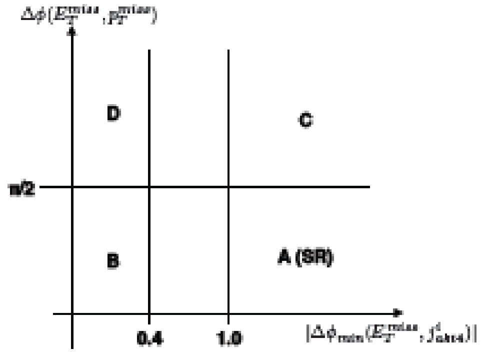
E_T^{miss}



HT

DM+H(→bb) Boosted: Multijet Background

- ABCD method: weakly correlated variables



$$N^{QCD}_{A(SR)} = \frac{N_B}{N_D} \times N_C \times R$$

(c/o S.C.Hsu)

R: 2trk jet to b-tag+mass cut

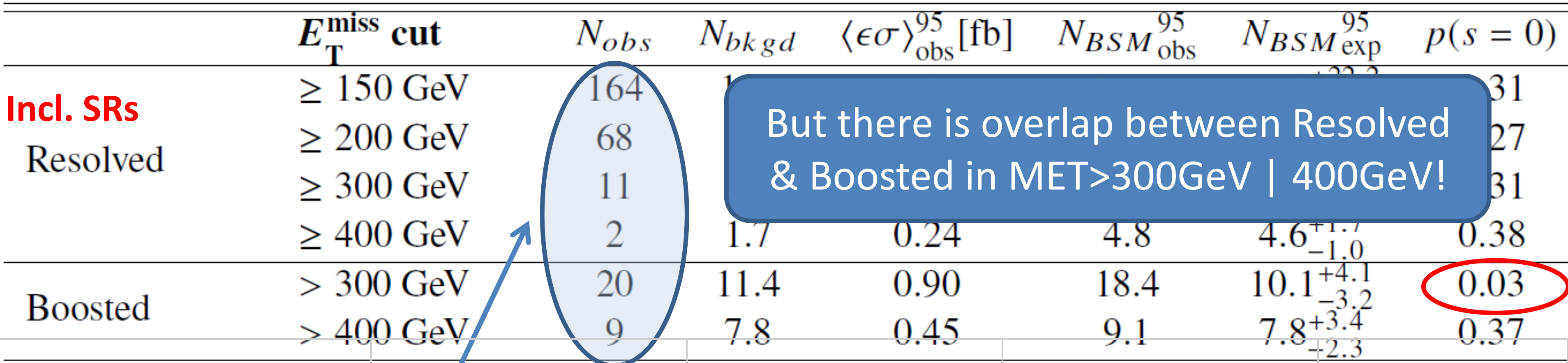
R=0.0072 ± 0.0006

Region		N_B	N_D	N_C
$E_T^{miss} > 200\ GeV$	Diboson	193.64 ± 4.47	21.05 ± 1.59	2.62 ± 0.58
	W+jets	2472.90 ± 14.88	277.33 ± 6.05	39.26 ± 1.64
	$t\bar{t}$	1640.80 ± 17.95	201.16 ± 6.29	3.26 ± 0.74
	$Z\nu\nu$	864.04 ± 7.53	37.25 ± 2.93	1.33 ± 0.33
	Single Top	175.20 ± 10.11	22.95 ± 3.10	1.80 ± 1.02
	Z+jets	145.27 ± 2.21	39.94 ± 1.13	1.61 ± 0.16
	$\gamma + jets$	7.96 ± 3.15	12.89 ± 6.41	0.00 ± 0.00
	Total non-QCD bkg	5499.81 ± 27.16	612.58 ± 11.80	49.89 ± 2.18
	Total Data	8029.00 ± 89.60	1862.00 ± 43.15	45.00 ± 6.71
	Data - $Bkg_{non-QCD}$	$\boxed{2529.19 \pm 93.63}$	1249.42± 44.73	-4.89 ± 7.05

Low purity of multijet in B motivates us to calculate bkg limit

$$N^{QCD}_{A(SR),\ 68\%C.L} = \frac{N_B}{N_D} \times N_{C,\ 68\%C.L} \times R \ = 0.11$$

DM+H(→bb): Look-Elsewhere Effect



	E_T^{miss} cut	N_{obs}	N_{bkgd}	$\langle\epsilon\sigma\rangle_{obs}^{95}$ [fb]	$N_{BSM}{}_{obs}^{95}$	$N_{BSM}{}_{exp}^{95}$	$p(s=0)$
Incl. SRs Resolved	≥ 150 GeV	164	1				31
	≥ 200 GeV	68					27
	≥ 300 GeV	11					31
	≥ 400 GeV	2	1.7	0.24	4.8	$4.6^{+1.7}_{-1.0}$	0.38
Boosted	> 300 GeV	20	11.4	0.90	18.4	$10.1^{+4.1}_{-3.2}$	0.03
	> 400 GeV	9	7.8	0.45	9.1	$7.8^{+3.4}_{-2.3}$	0.37

But there is overlap between Resolved & Boosted in MET>300GeV | 400GeV!

MET range	**(150GeV,200GeV)**	**(200GeV,300GeV)**	**(300GeV,400GeV)**	**>400GeV**
resolved && !boosted	86+/-28.1	52.6+/-6.8	7+/-1.3	0.8+/-0.34
boosted && !resolved			2.7+/-0.9	6.8+/-1.7
resolved && boosted			0.7+/-0.3	0.9+/-0.4

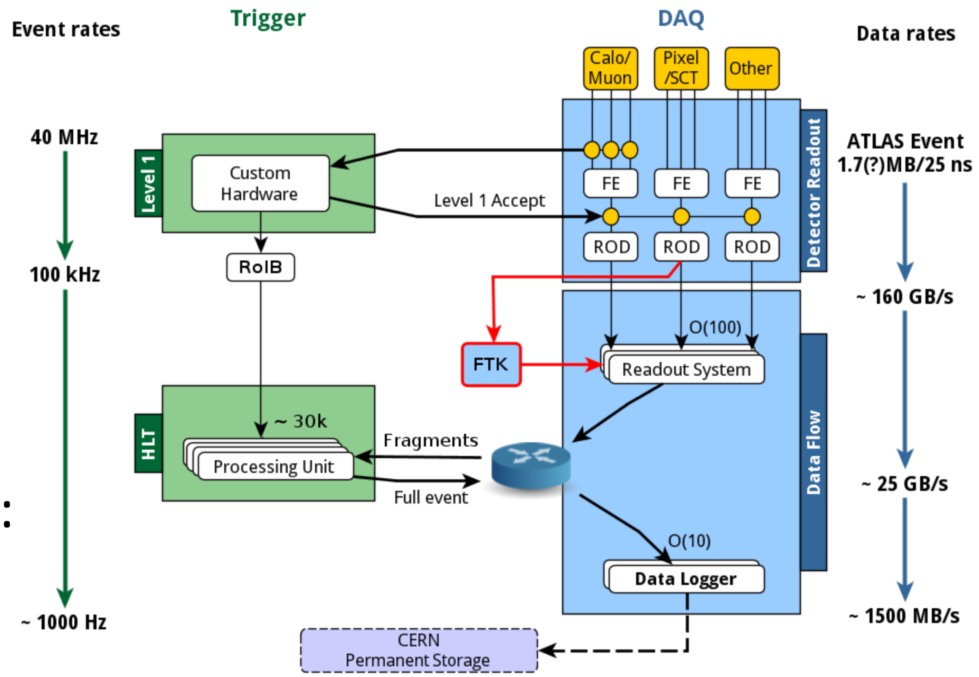
Statistical + systematic errors recalculated correspondingly & combined; for overlap evts, use value from boosted channel (slightly larger; minimal difference)

Find a random number N in a Gaussian dist. with the mean=Nbkgd & sigma for each of the 2+2*3=8 excl. SRs (removed overlap)

Find a random number in a Poisson dist. with mean=N for each of the 8 excl. SR
add them up as toys for Nobs in each of the 6 incl. SRs

ATLAS Trigger Upgrade and the FastTracKer

- ATLAS Trigger Upgrades for RunII:
  - removed internal subdivision between Level-2 and HLT
  - improved network infrastructure
- Software-based full tracking still limited by ROIs to a fraction of the Level-1 triggers
- Where **FastTracKer (FTK)** comes in:
  - *Hardware-based*
  - *Full tracking* will be provided for every Level-1 trigger (up to 100 KHz)
  - Any trigger selection will be able to exploit the track information
  - FTK tracks can be used to bootstrap other tracking algorithms



FTK receives data in parallel to HLT
→ FTK *output available at beginning of HLT*