Emerging Jets Update

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Carleton University

ATLAS UEH Meeting - 02 July 2020

Outline

- Analysis Reminder
- Studies on detector acceptance
- Vertex reconstruction efficiency
    - Core efficiency
    - Algorithm efficiency
    - Seed efficiency
    - Total efficiency
- Studies on split rate
- Summary

Analysis Reminder

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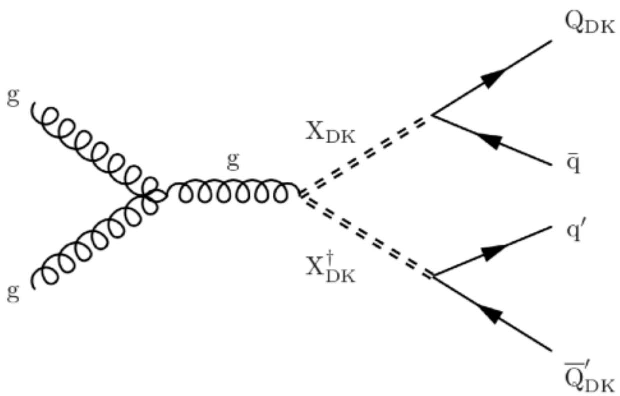

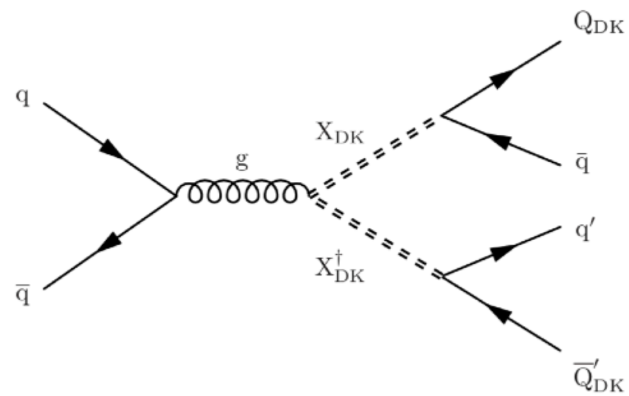

	Model A	Model B	Model C	Model D	Model E
Λ_d [GeV]	10	4	20	40	1.6
m_{ρ_d} [GeV]	20	8	40	80	3.2
m_{π_d} [GeV]	5	2	10	20	0.8
m_{X_d} [GeV]	1400 | 1000 | 600				
$c\tau_{\pi_d}$ [mm]	300, 150, 75, 20, 5, 2 | 300, 150, 75, 5, 2, 1 | 300, 150, 20, 2, 1, 0.5				

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Searching for evidence of QCD-like BSM dark sector:

- Pair production of QCD-colored mediators via quark-antiquark or gluon fusion, each of which promptly decays to a dark quark and a light QCD quark
- With a certain combination of dark sector parameters, dark quarks can hadronize in the dark sector first, leading to long-lived dark mesons that eventually decay to SM particles
- This results in a final state with two SM jets and two objects called "emerging jets" which can have multiple displaced vertices within the jet cone

-- NB: With different dark sector parameters can result in a more homogeneously-distributed phenomenology of soft, unclustered energy patterns, or SUEP (also here in UEH)

ModelA	ModelB	ModelC	ModelD	ModelE
ModelA_1400_20	**ModelB_1400_20**	**ModelC_1400_75**	**ModelD_1400_2**	**ModelE_1400_75**
ModelA_1000_150	**ModelB_1000_5**	**ModelC_1000_5**	**ModelD_1000_1**	**ModelE_1000_150**
ModelA_600_1	**ModelB_600_300**	**ModelC_600_2**	**ModelD_600_300**	**ModelE_600_0.5**

The results are presented based on 15 signal points, defined by scalar mediator mass[GeV] and dark pion life time[mm].

Analysis strategy

- DRAW_RPVLL filter selected two separate data streams, defined by triggers:
  - **search region;** 4-jet trigger
  - **validation region;** prescaled single-jet trigger, expected no contribution from signal events
- Search region further refined by offline selection:
  - **4 pT-120 jets;** HT > 1000 GeV , $|\eta| < 2.5$
- Search-minus-one region; 4 pT-120 jets with no HT cut
- Material map veto applied to all DVs
- Signal Region being defined within search region
  - further refinement of signal region selection is ongoing by including NDV and NJetHT cuts.
- Background estimate for analysis will be fully data-driven.
  - estimated with ABCD method in the search region after applying the relevant cuts.
  - tested with multijet MC (JZ4W slice)
- MC being validated in various regions; proved to be reasonable compared to data
  - need to repeat the consistency checks with all background slices

Last update from G. Gonella ☞

Analysis status

- Ongoing **DV/jet** studies on “good DV” and “emerging-like jet” cuts for signal DVs and signal jets - tentative selection sets defined for DVs to significantly reduce background DVs; jet selections still being investigated to target events with 1-2 emerging-like jets

- **ABCD** method being optimized - ready to test multitude of potential (good) DV, jet variables to determine Signal Region A with optimal signal efficiency and background rejection

- Jet background MC will be useful for further studying secondary vertices and large-radius tracking and to further validate data-driven ABCD method for background estimate

  - JZ4W is for jets with 400 GeV < pT < 800 GeV

  - Analysis uses jets with pT > 120 GeV; necessarily limits the usefulness of JZ4W by itself

  - Submitted a JIRA ticket for processing of all JZXWithSW slices; https://its.cern.ch/jira/browse/ATLMCPROD-8633 (currently in "submitted" status)

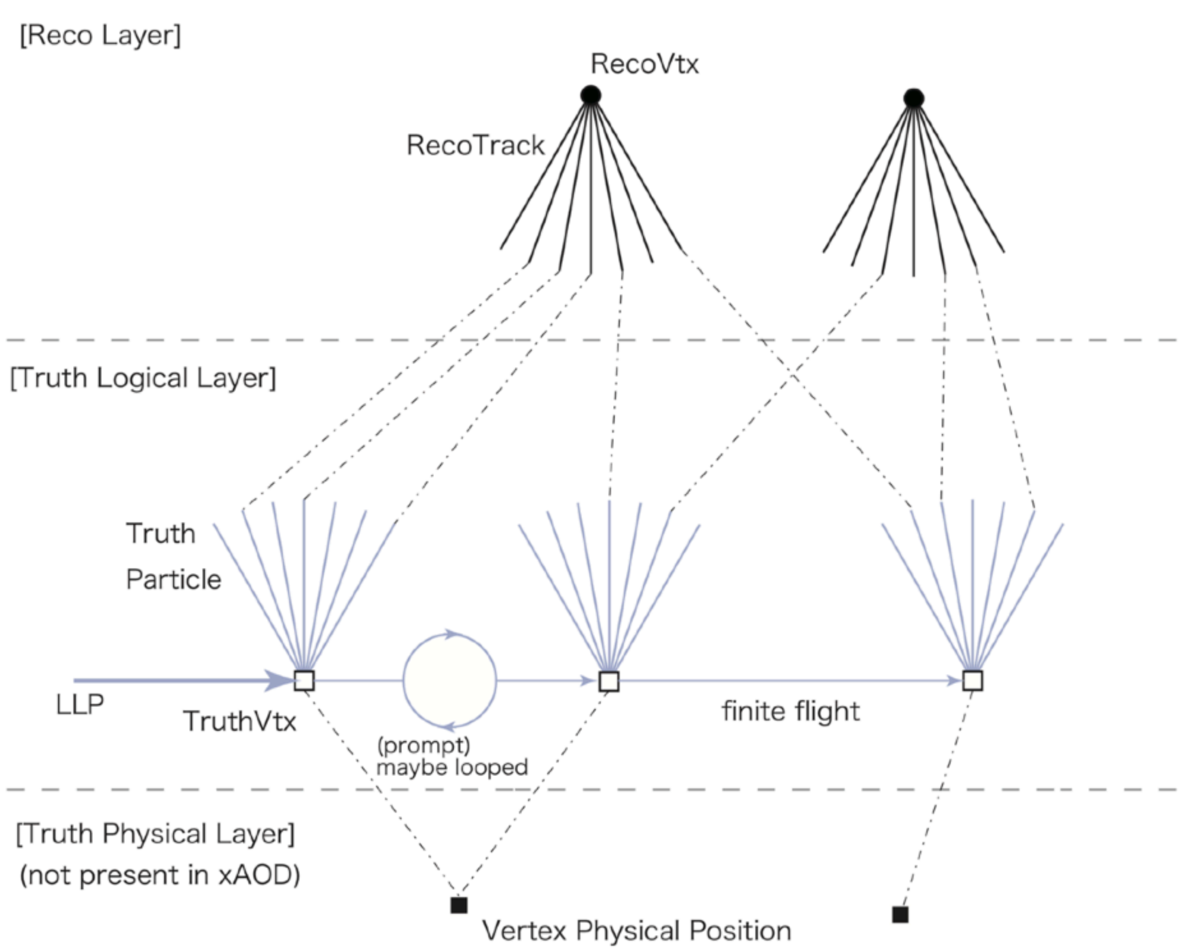
- New Ntuples in production with bug fix, material veto off (for testing), no pflow jets (for space) for original 15 and subsequent 21 signal points

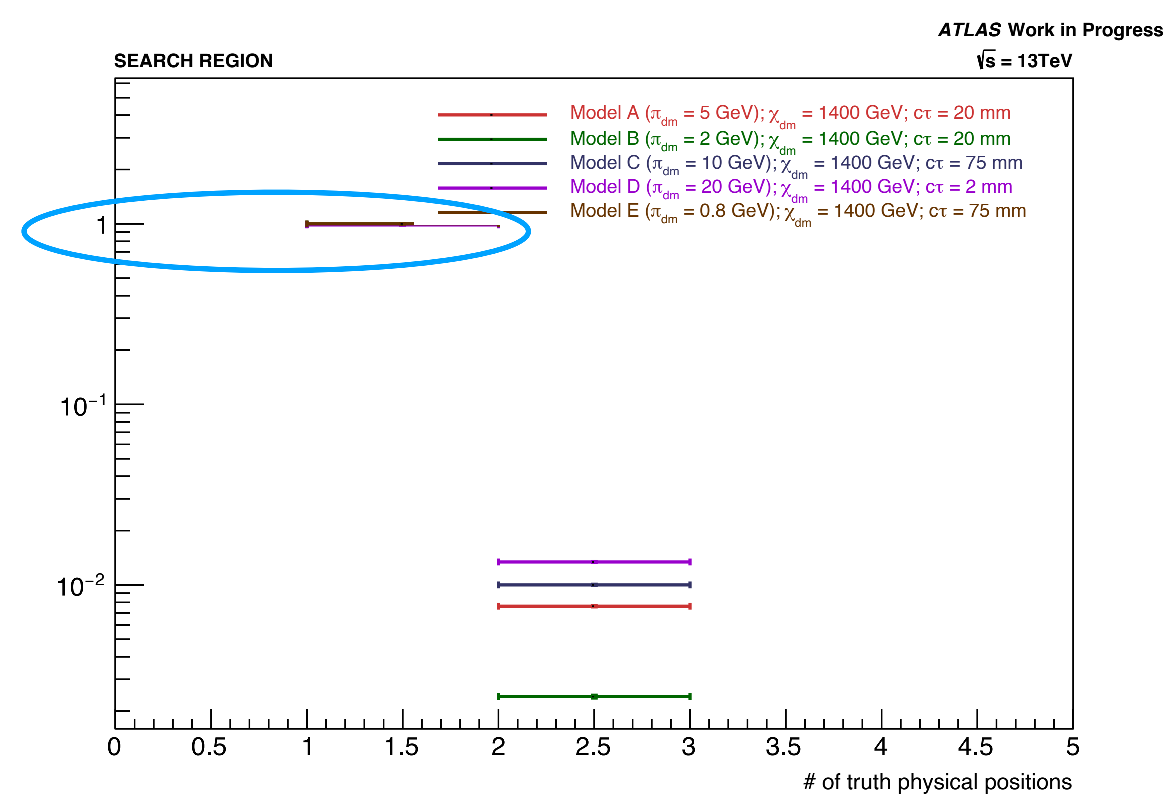
- Performing vertex (underway) and track (TBD) reconstruction efficiency studies

- Beginning to implement statistical machinery / systematics

The topology of the decay chain can be potentially different depending on the LLP signatures:

- In case of hadronization, the decay tree involves many intermediate virtual particles.
- Some hadrons (excited states or strongly-decaying hadrons) have very short lifetime, and their decay position is effectively the same as the LLP decay position.
- Heavy flavor hadrons fly a short distance and then decay.
- One should also include the effect of conversions or hadronic interactions at the material by the outgoing hadrons in the downstream.





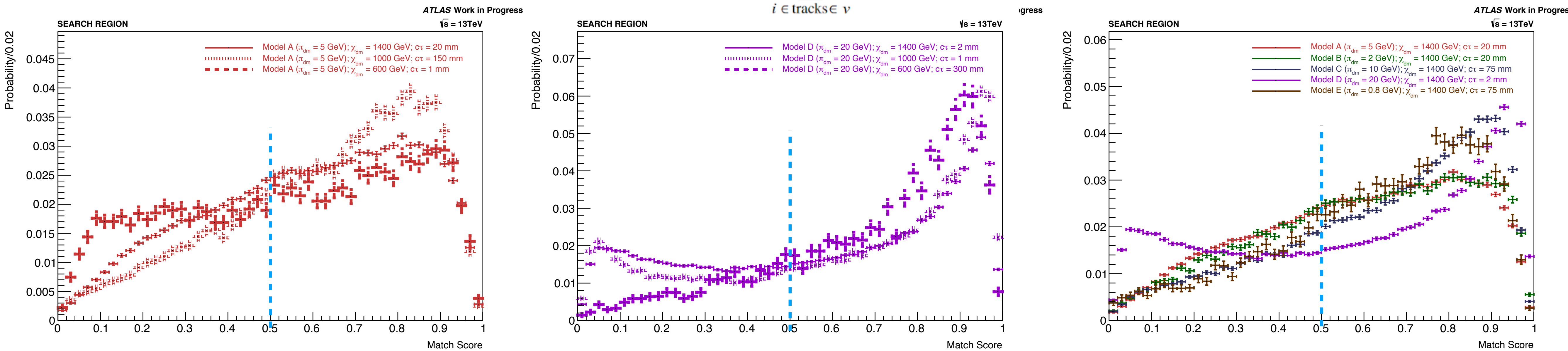
Secondary vertex reconstruction efficiency

The total efficiency is calculated as:

The ratio of the number of LLP decays with at least one matched reconstructed vertex (with a match score> 0.5) to the number of reconstructible LLP decays.

Match score is extracted as the ratio of sum pT of the representative truth vertex position to the sum pT of tracks in reco vertex, ranges in [0, 1].

$$s(v, l) \equiv \frac{\sum_{i \in \text{tracks} \in v} \left(p_{\mathrm{T}}^{(i)} \mid \text{descendent of LLP decay } l \right)}{\sum_{i \in \text{tracks} \in v} p_{\mathrm{T}}^{(i)}}$$



A **reconstructible LLP decay** is required to satisfy the following set of fiducial criteria:

- At least two charged particles with pT > 1 GeV; produced in the posterity of the LLP decay.
  - the production position within r<300mm and |z|<1500mm.
  - the decay position must be outside SCT or stable particle.

We skip truth vertices outside fiducial volume(SCT):

- the transverse distance from the origin must be r < 563 mm.
- the z-position must be |z| < 2720 mm.

Calculation of reconstruction efficiency

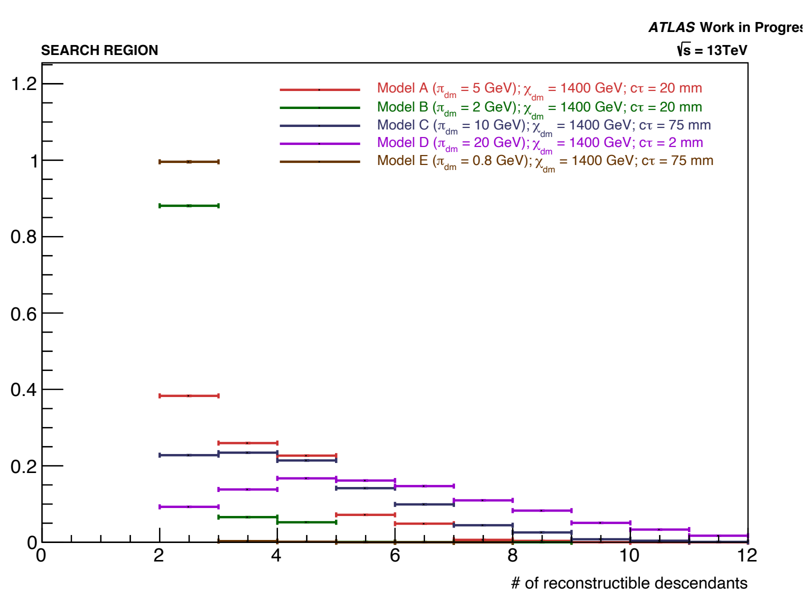
$\varepsilon^{\mathrm{tot}}_{\vec{x}} = \mathcal{A}_{\vec{x}} \cdot \varepsilon^{\mathrm{alg}}_{\vec{x}} = \mathcal{A}_{\vec{x}} \cdot \varepsilon^{\mathrm{seed}}_{\vec{x}} \cdot \varepsilon^{\mathrm{core}}_{\vec{x}}$ **=** Number of llp decays with match score>0.5 / Number of **reconstructible** llp decays

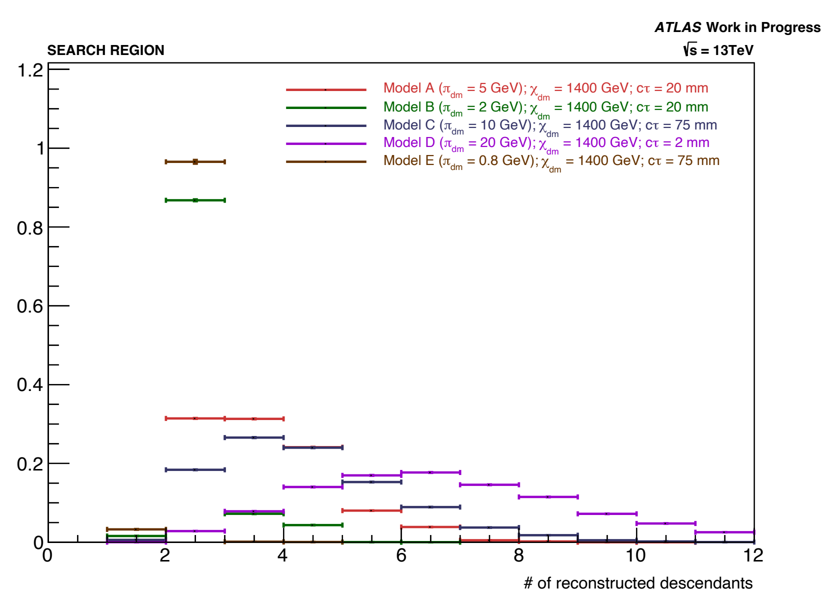
$\mathcal{A}_{\vec{x}}$ **=** Number of llp decays with at least 2 **reconstructed** tracks / Number of **reconstructible** llp decays

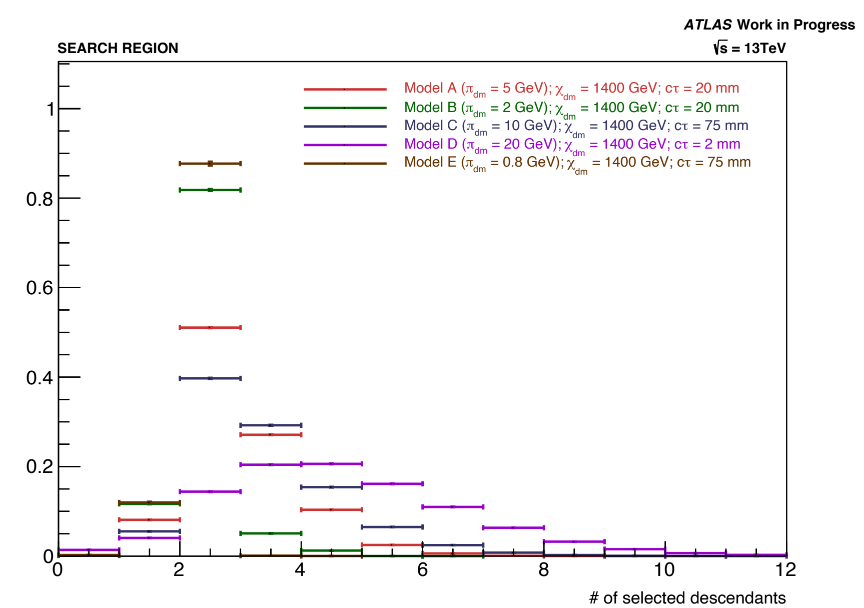
$\varepsilon^{\mathrm{alg}}_{\vec{x}} = \varepsilon^{\mathrm{tot}}_{\vec{x}} / \mathcal{A}_{\vec{x}}$ **=** Number of llp decays with match score>0.5 / Number of llp decays with at least 2 **reconstructed** tracks

$\varepsilon^{\mathrm{seed}}_{\vec{x}}$ **=** Number of llp decays with at least 2 **selected** tracks/Number of llp decays with at least 2 **reconstructed** tracks

$\varepsilon^{\mathrm{core}}_{\vec{x}} = \varepsilon^{\mathrm{alg}}_{\vec{x}} / \varepsilon^{\mathrm{seed}}_{\vec{x}}$ **=** Number of llp decays with match score>0.5 / Number of llp decays with at least 2 **selected** tracks







What will be shown in the next slides

ModelD_1400_2
ModelD_1000_1
ModelD_600_300

ModelE_1400_75
ModelE_1000_150
ModelE_600_0.5

Efficiency vs. pileup

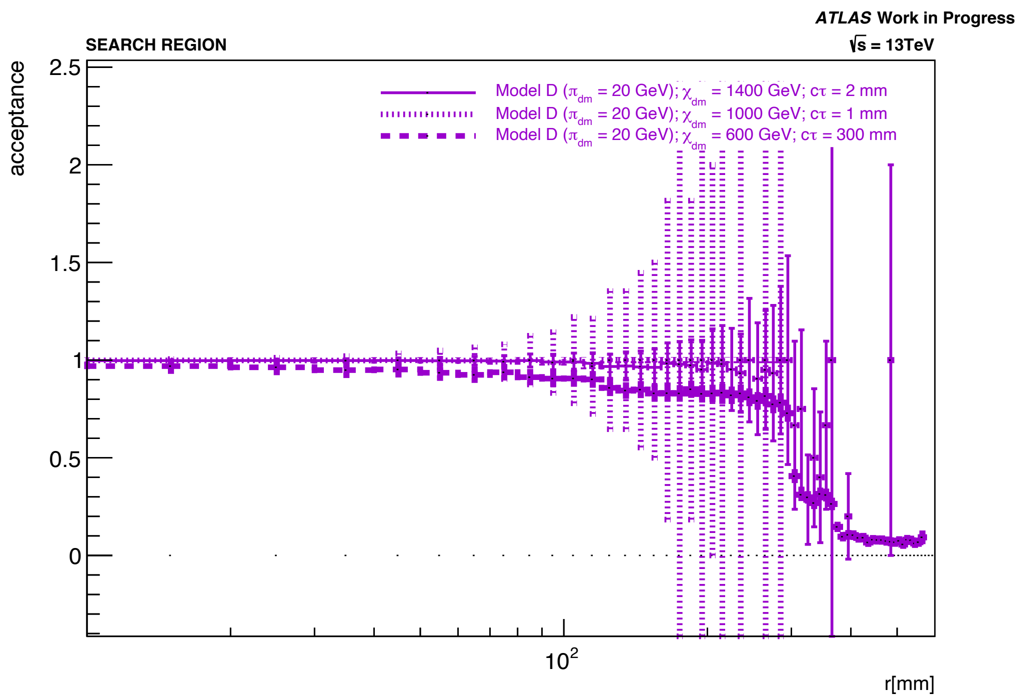
Efficiency vs. transverse decay position

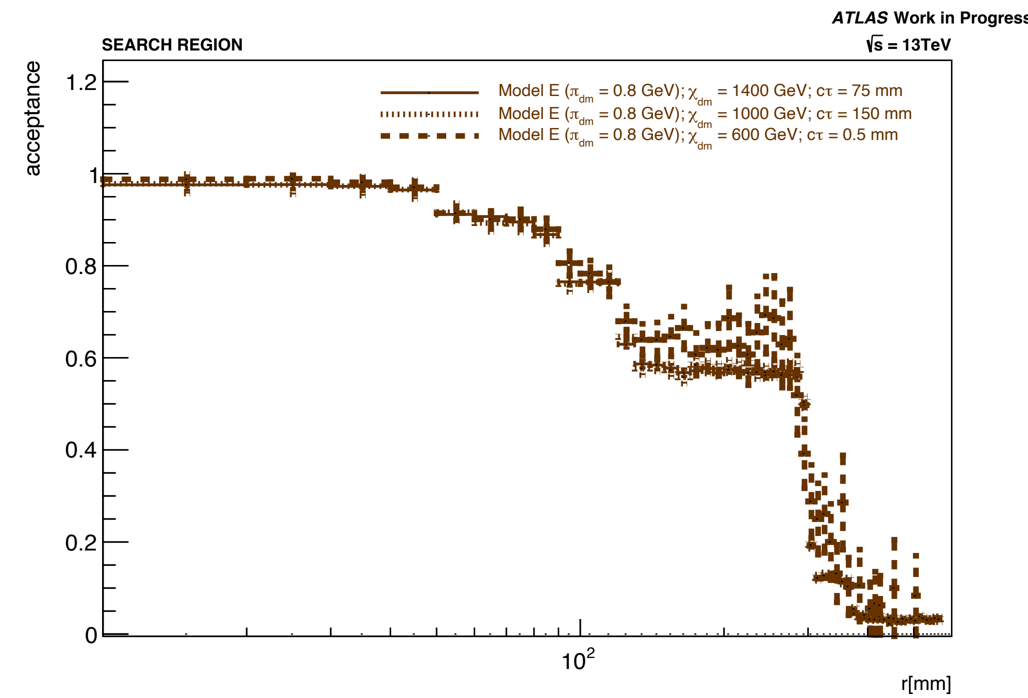
Comparing models with same
Mediator mass and dark pion life time

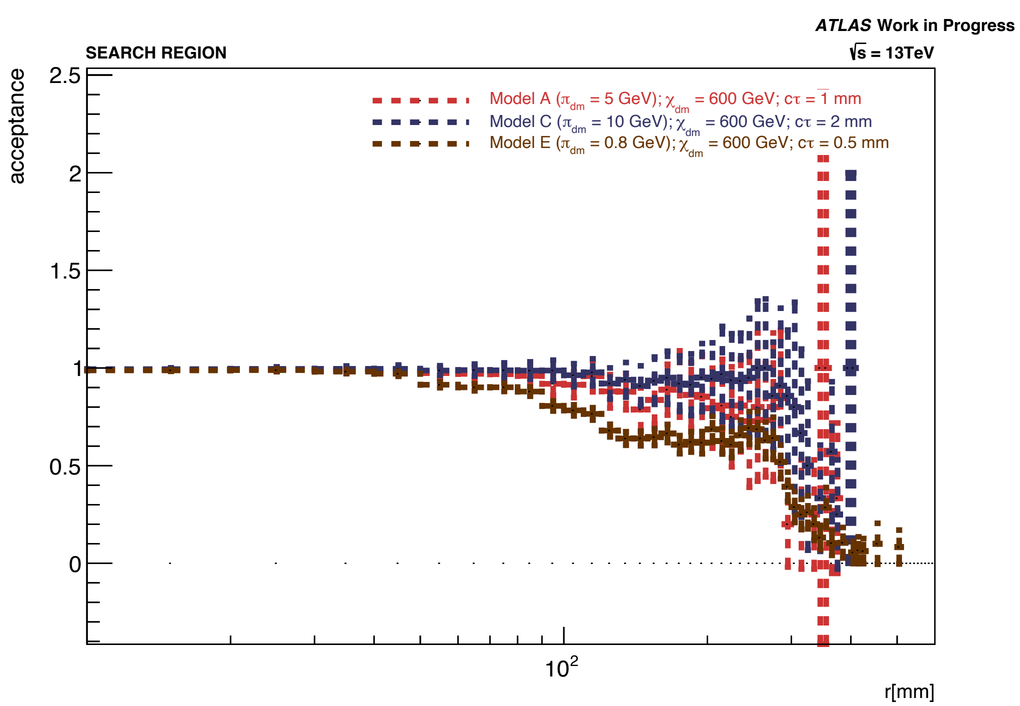
Comparing models with same
mediator mass and different dark pion life time

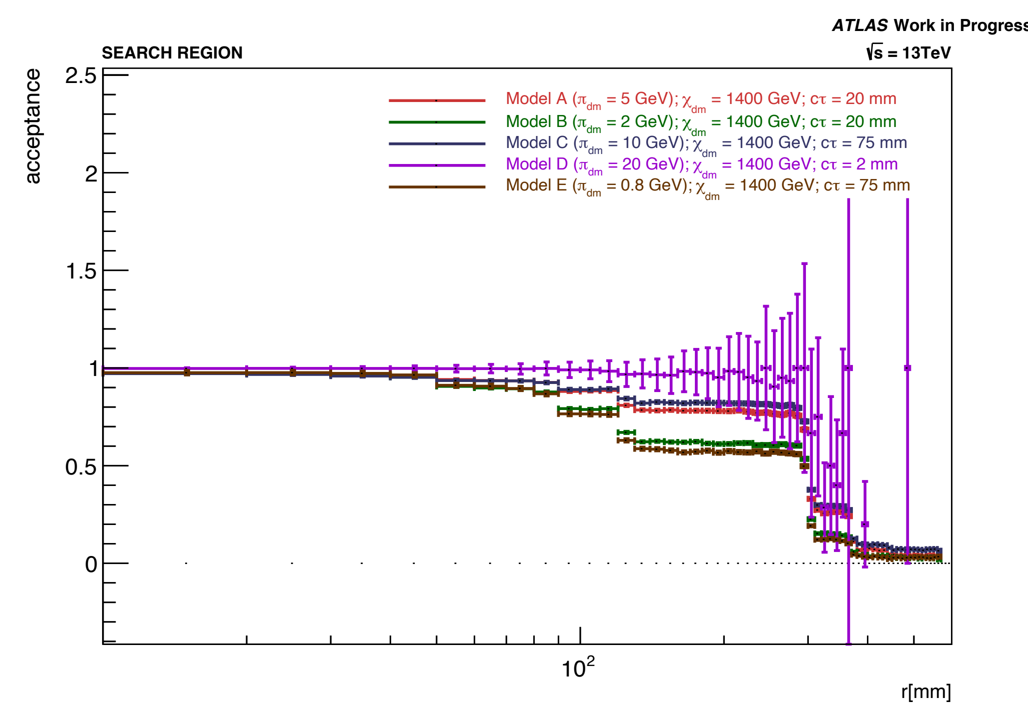
Acceptance vs. transverse decay position

The acceptance is defined as the ratio of LLP decays having at least two reconstructed tracks of outgoing charged particles of pT>1 GeV to the number of reconstructible LLP decays in the fiducial volume.

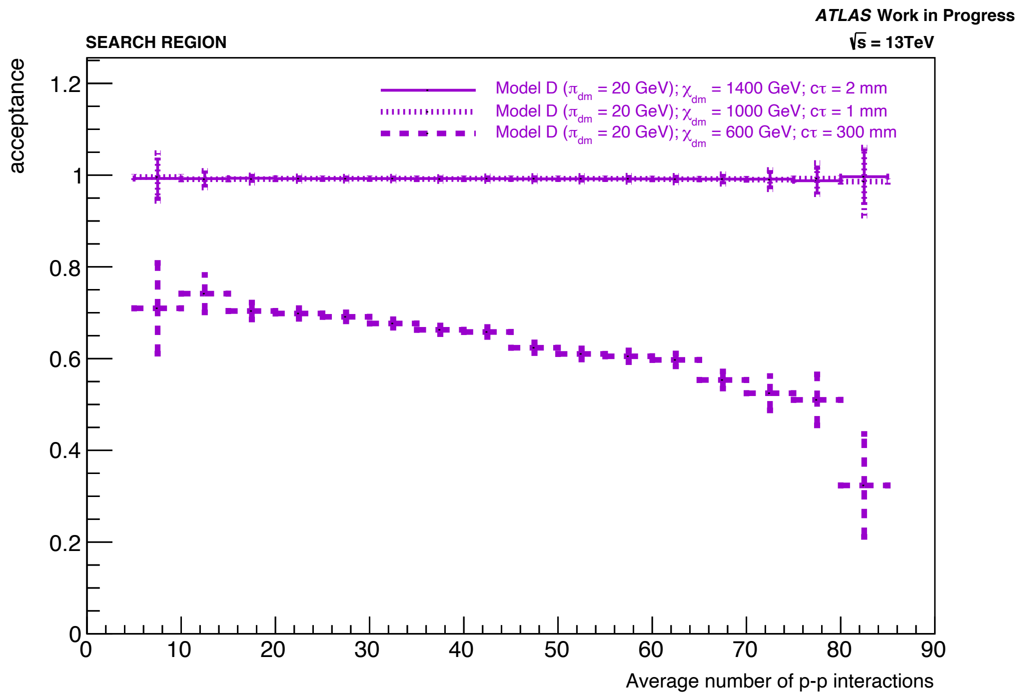


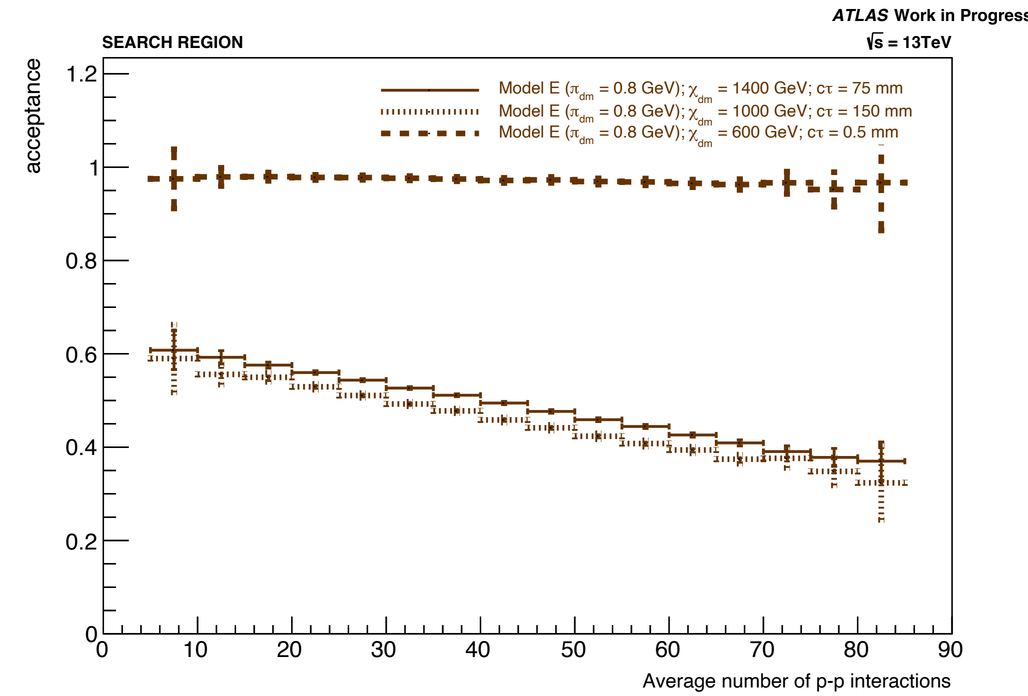


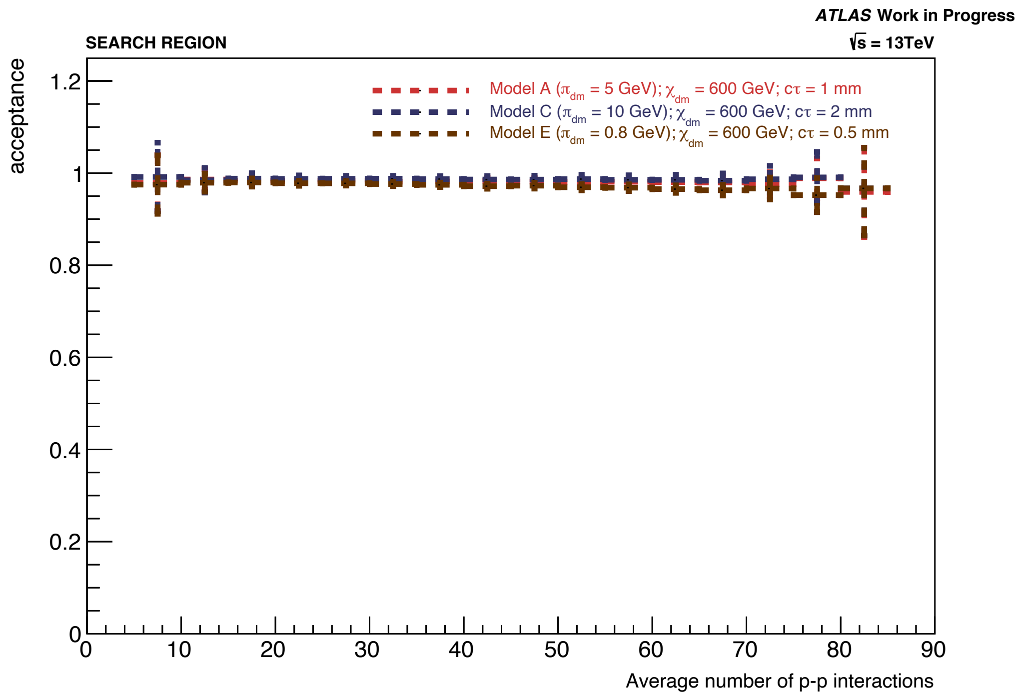


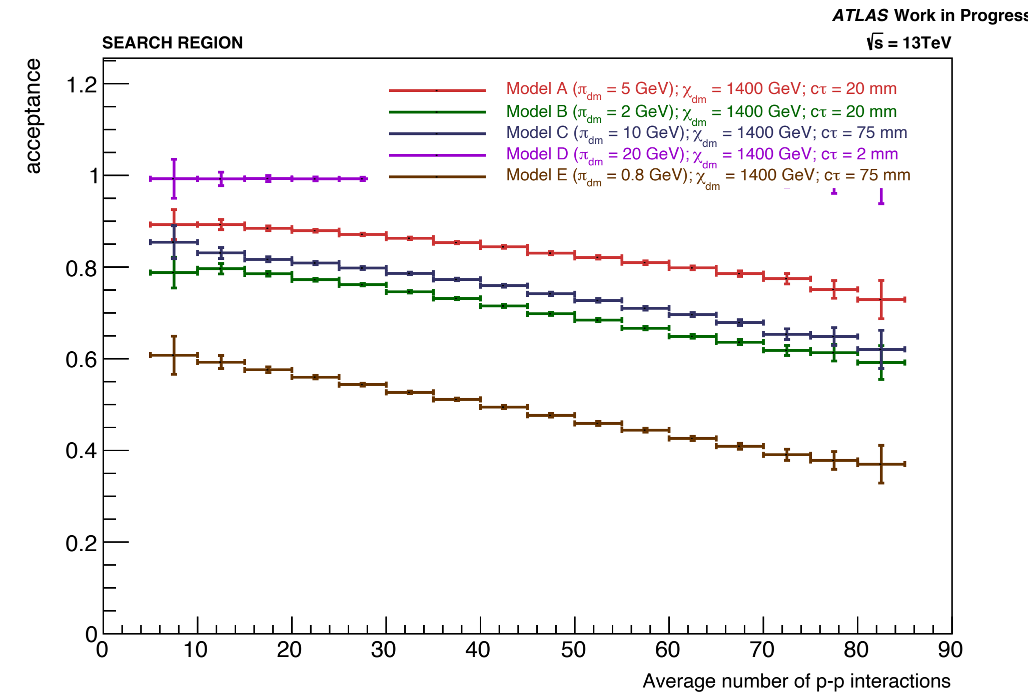


Acceptance efficiency vs. pileup



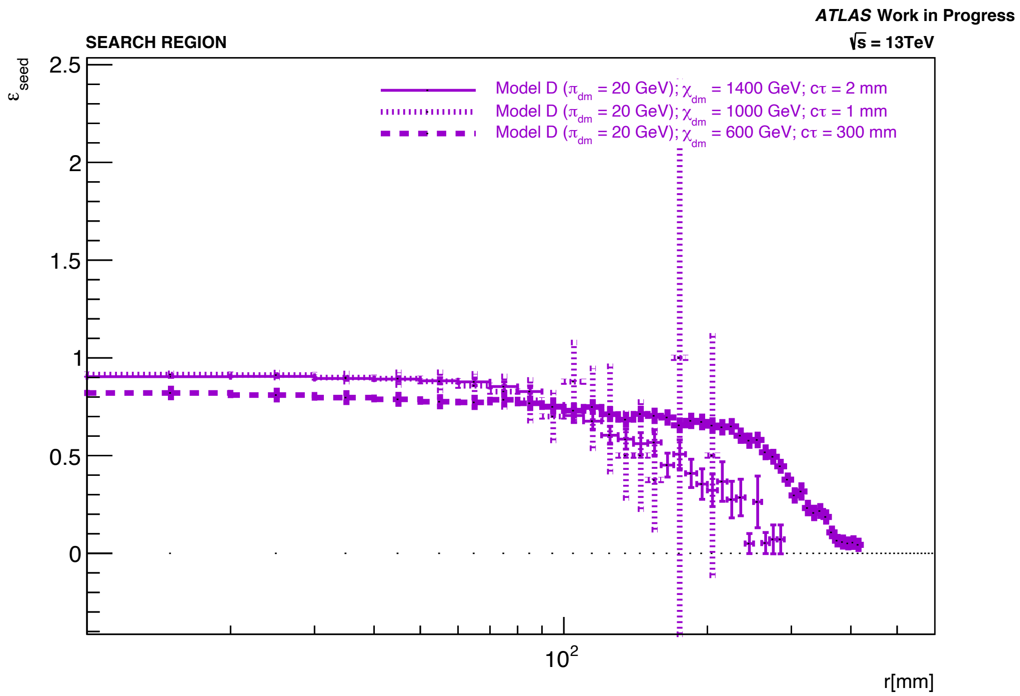


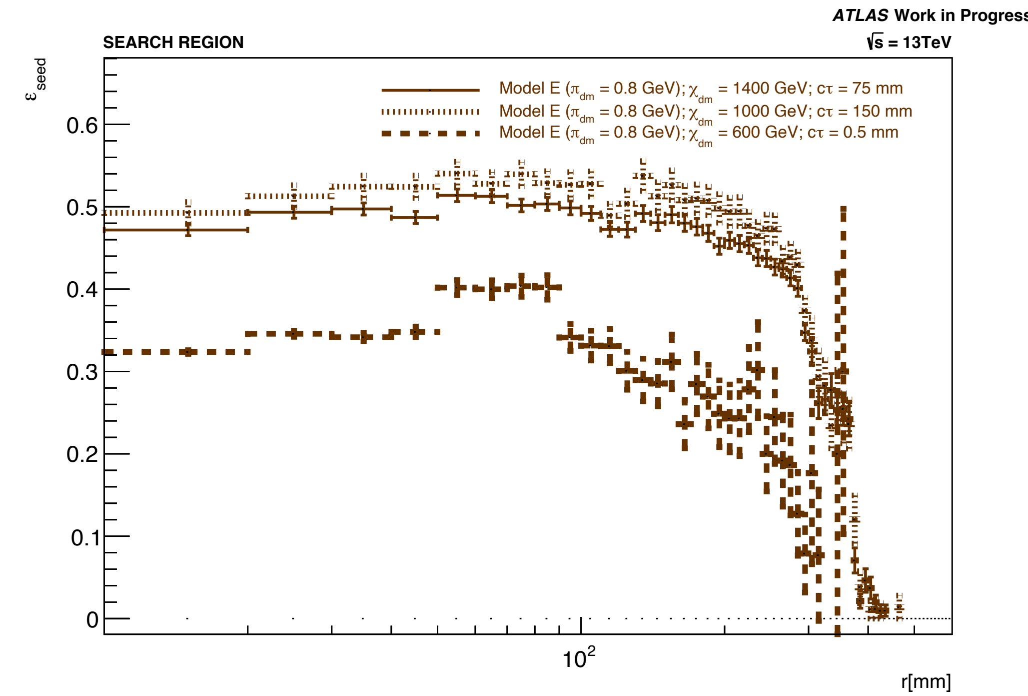


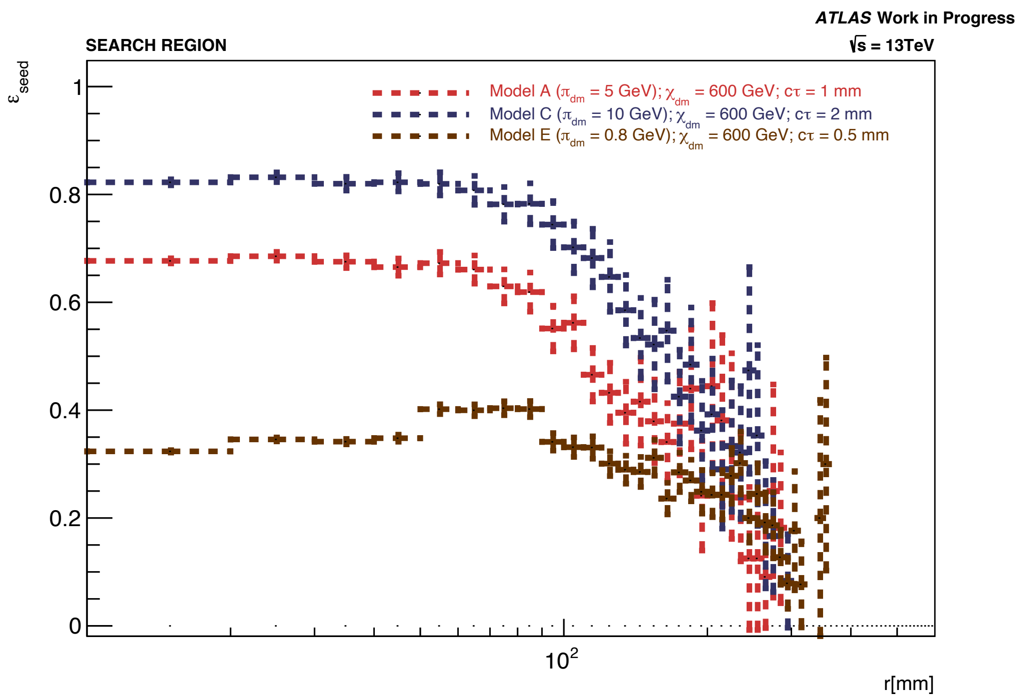


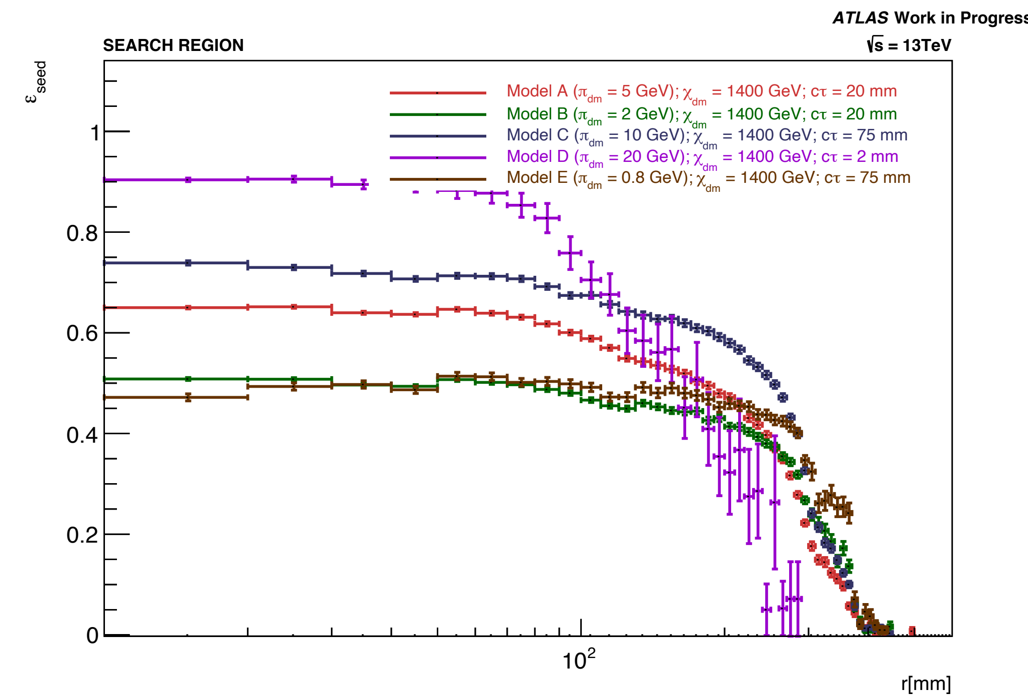
Seed efficiency vs. transverse decay position

$\varepsilon^{seed}_{\vec{x}} \rightarrow$ is defined as the ratio of the number of LLP decays with at least two selected tracks passing the requiren
.. to the number of LLP decays passing the acceptance criteria.









Seed efficiency vs. pileup

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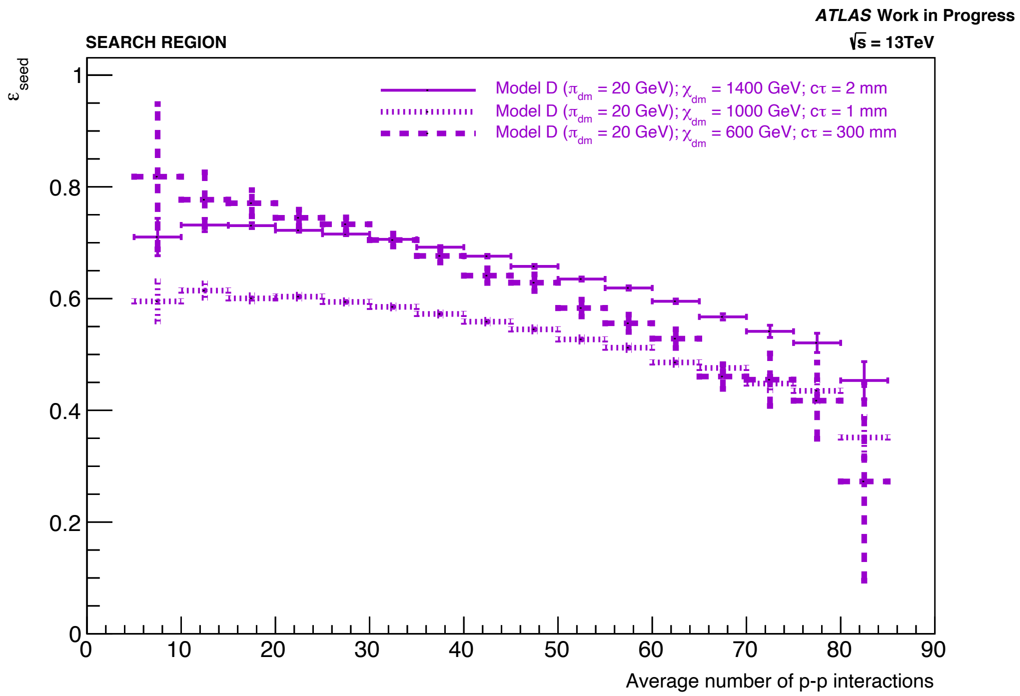
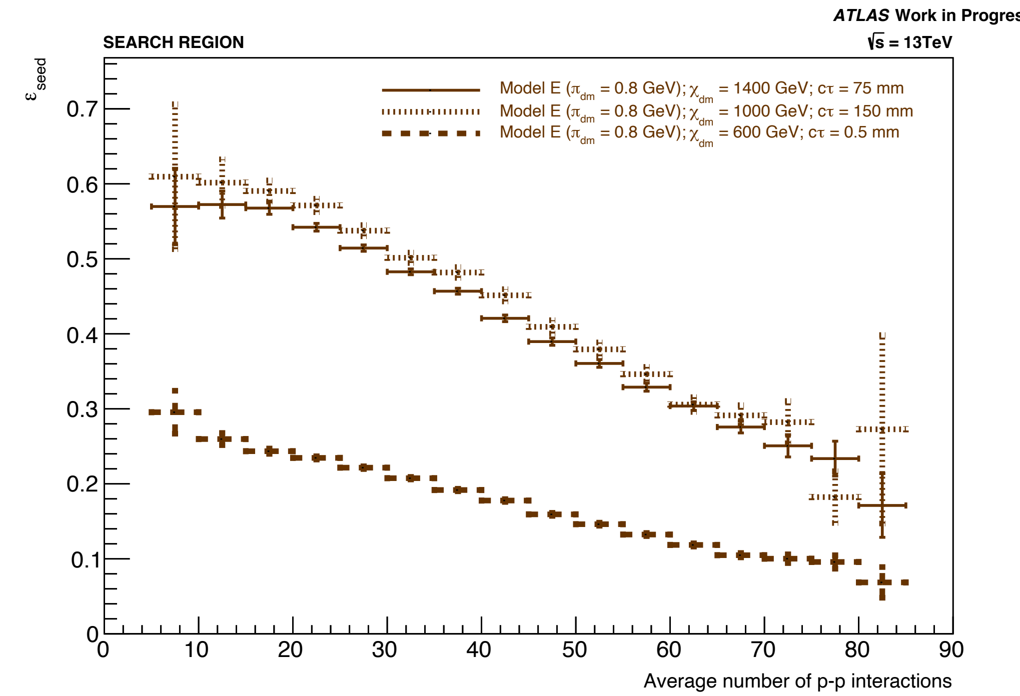
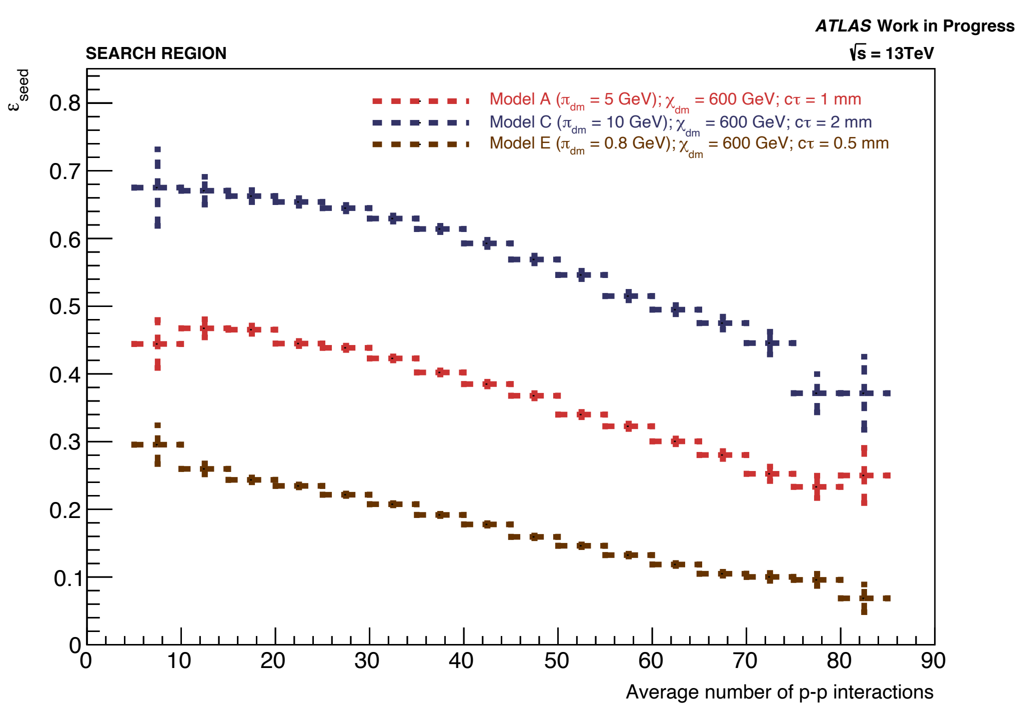
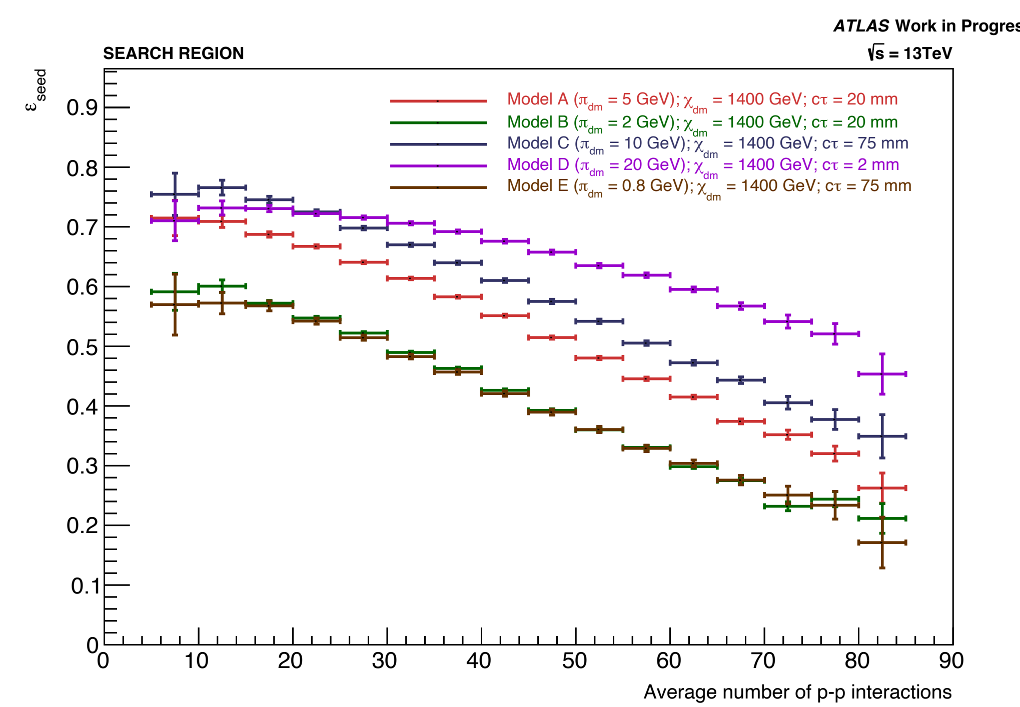


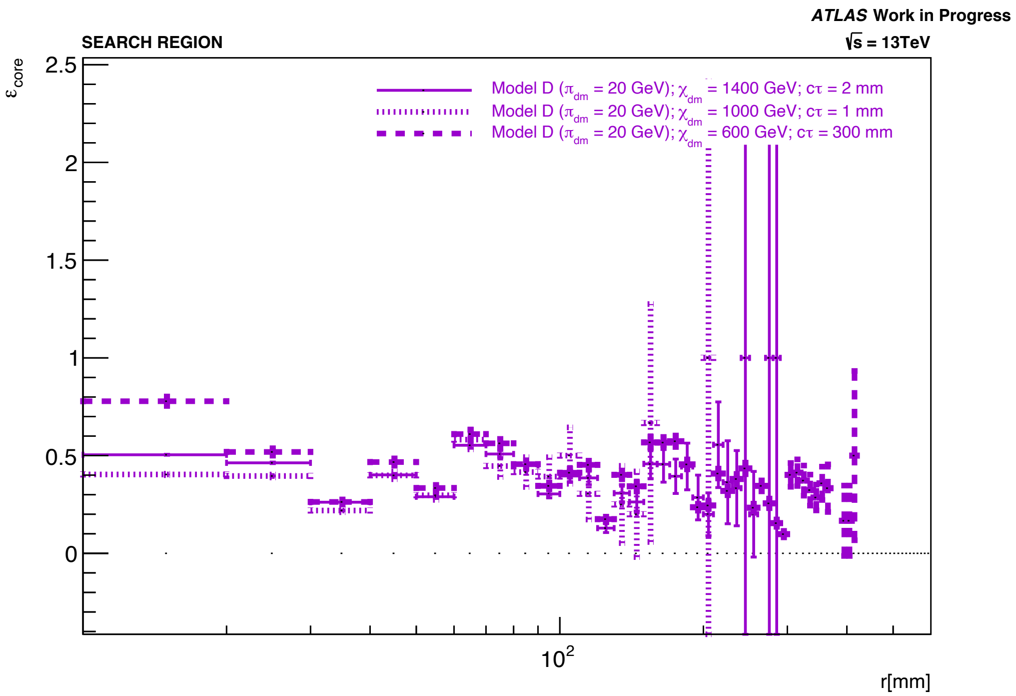


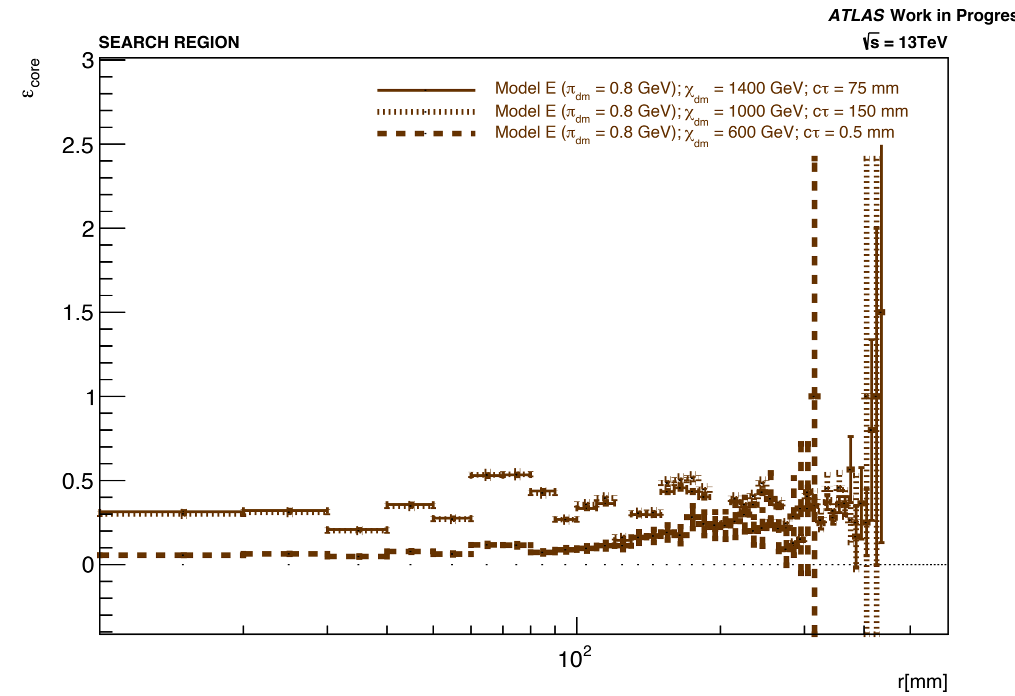


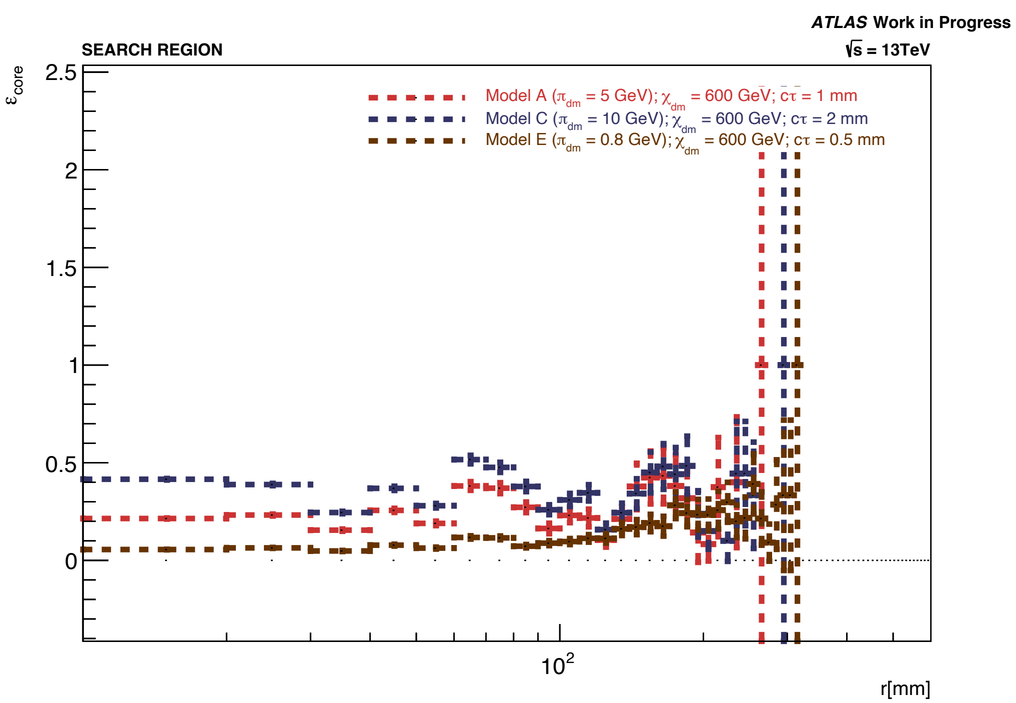


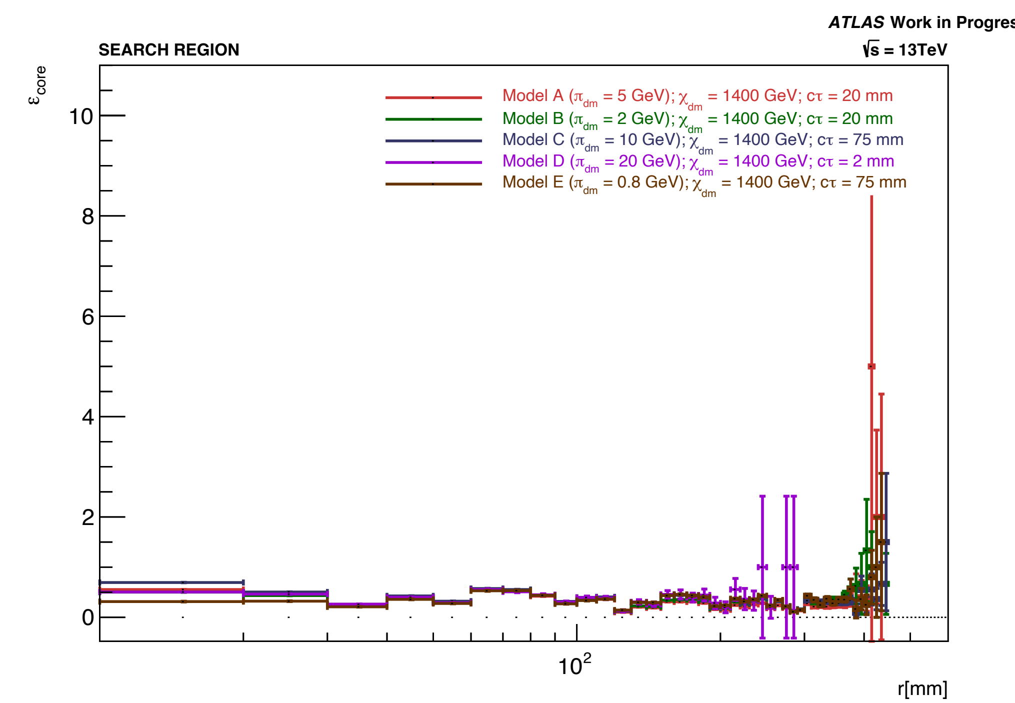
Core efficiency vs. transverse decay position

$\varepsilon^{\text{core}}_{\vec{x}} = \varepsilon^{\text{alg}}_{\vec{x}} / \varepsilon^{\text{seed}}_{\vec{x}}$ → It probes the pure vertex reconstruction efficiency.

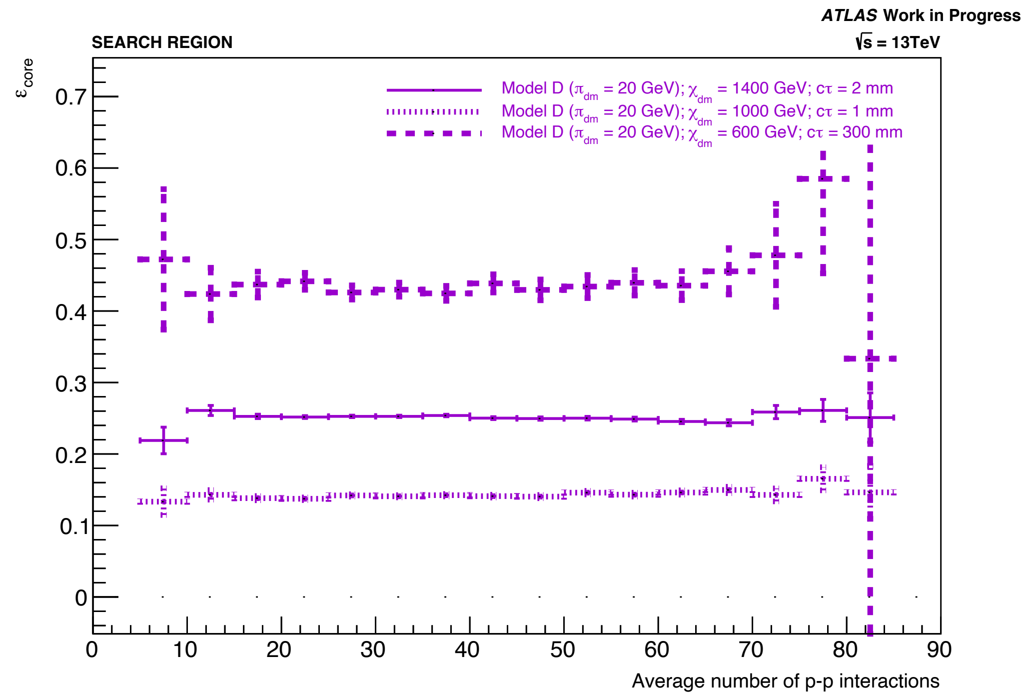


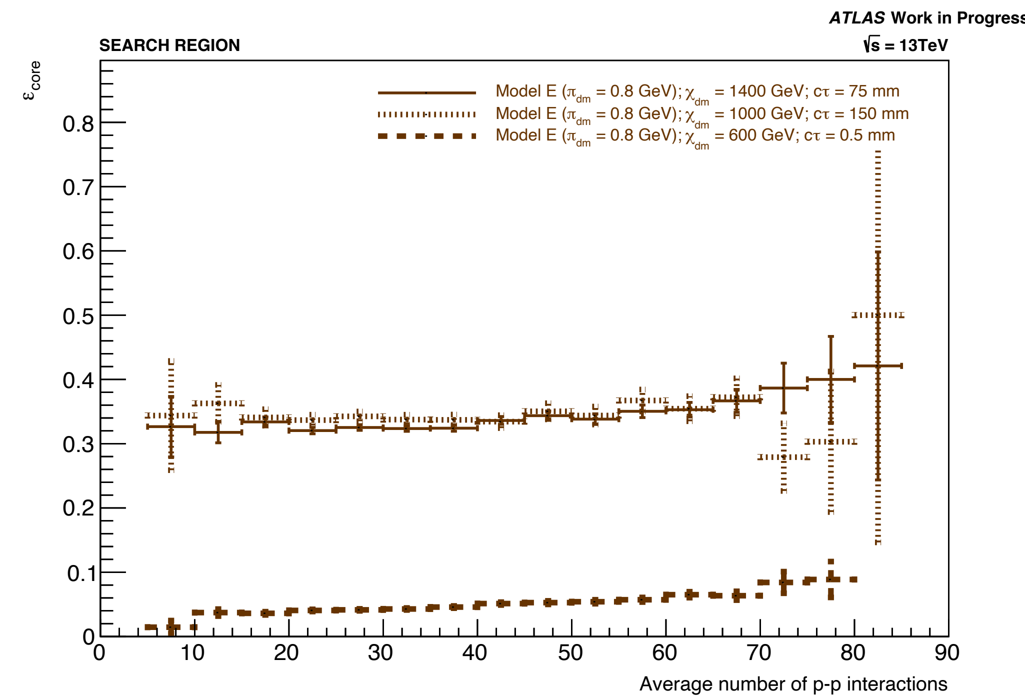


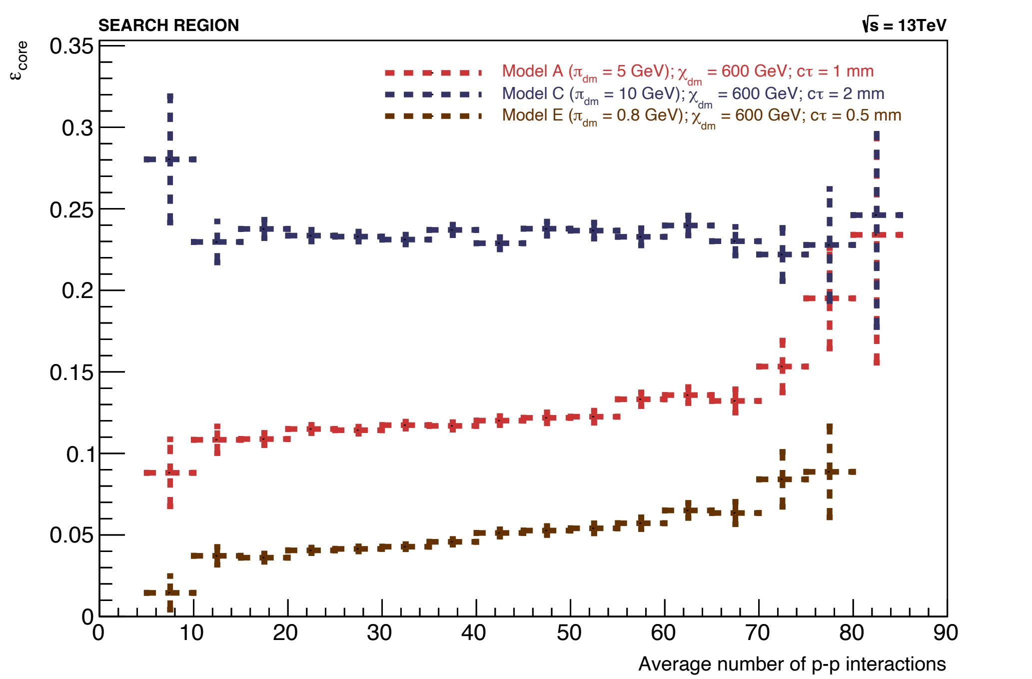


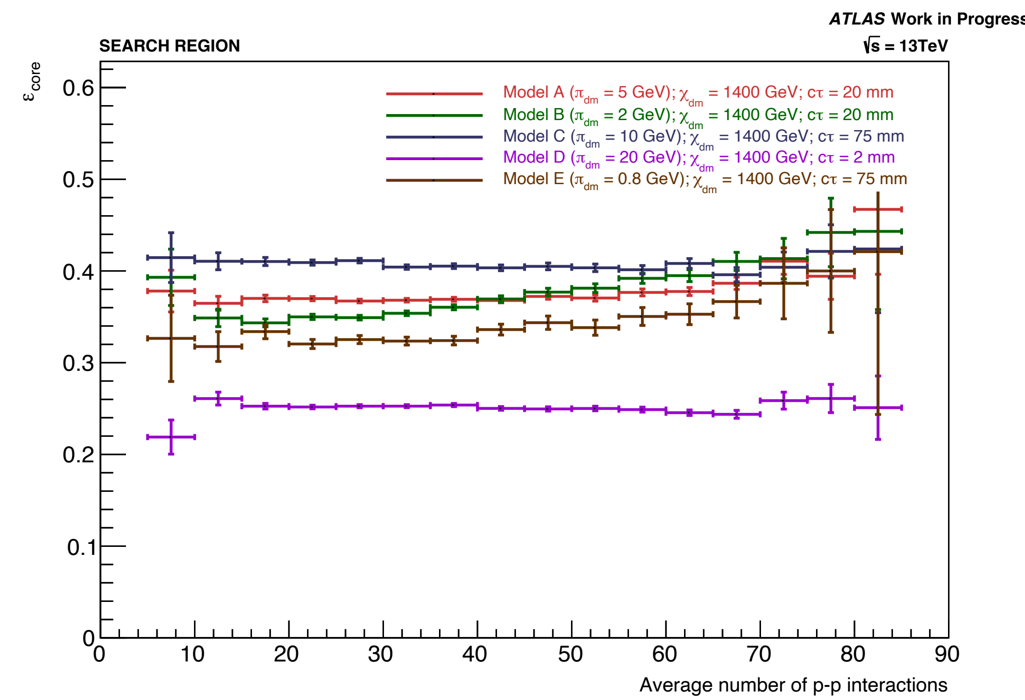


Core efficiency vs. pileup



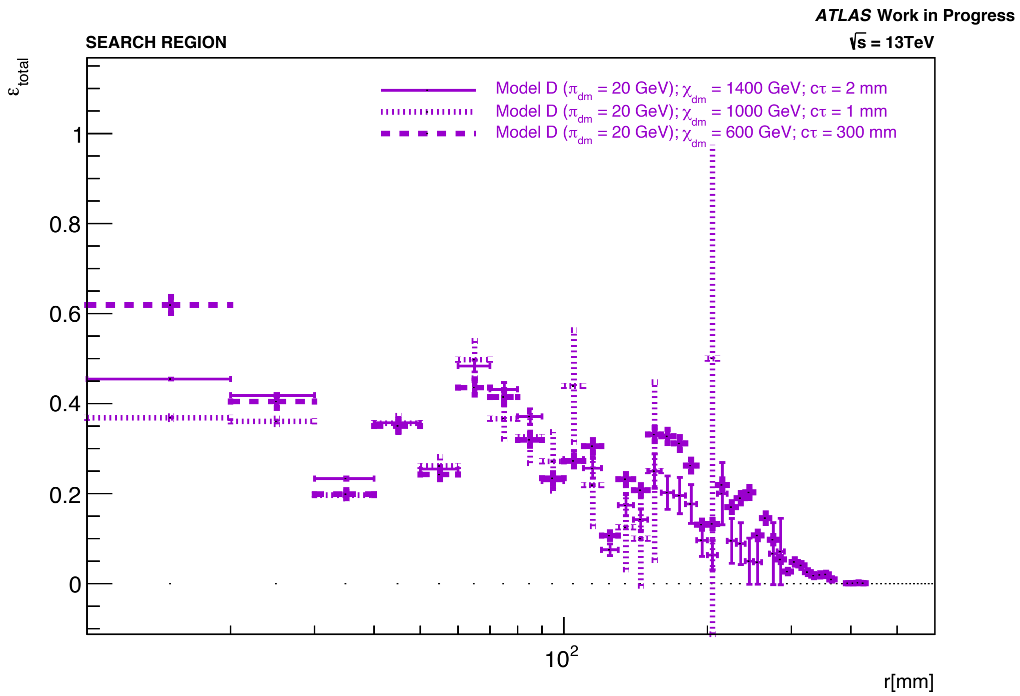


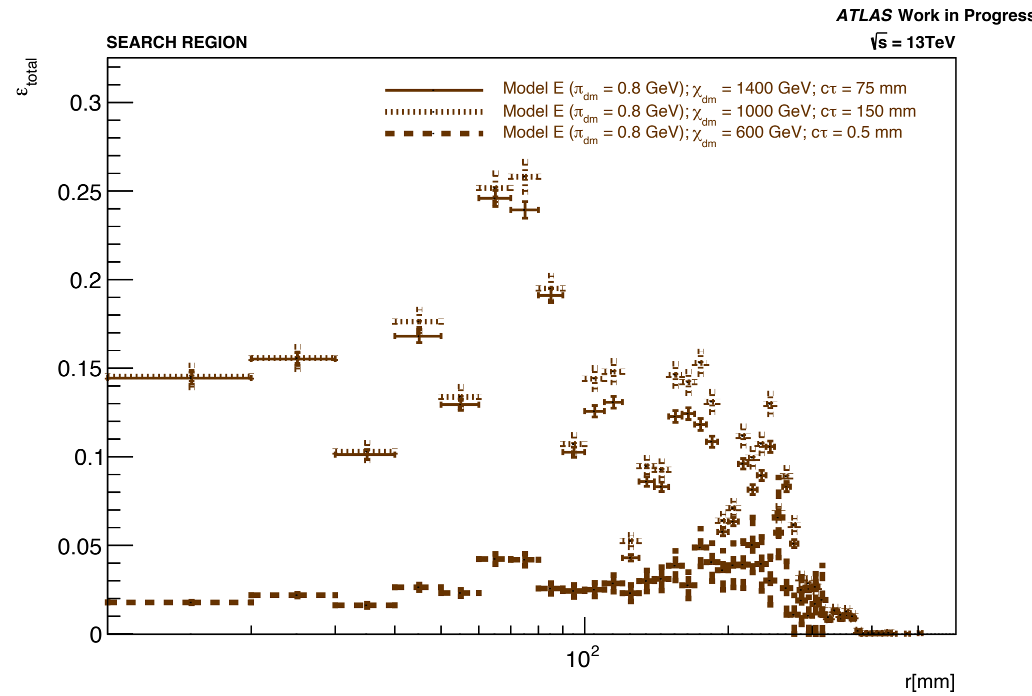


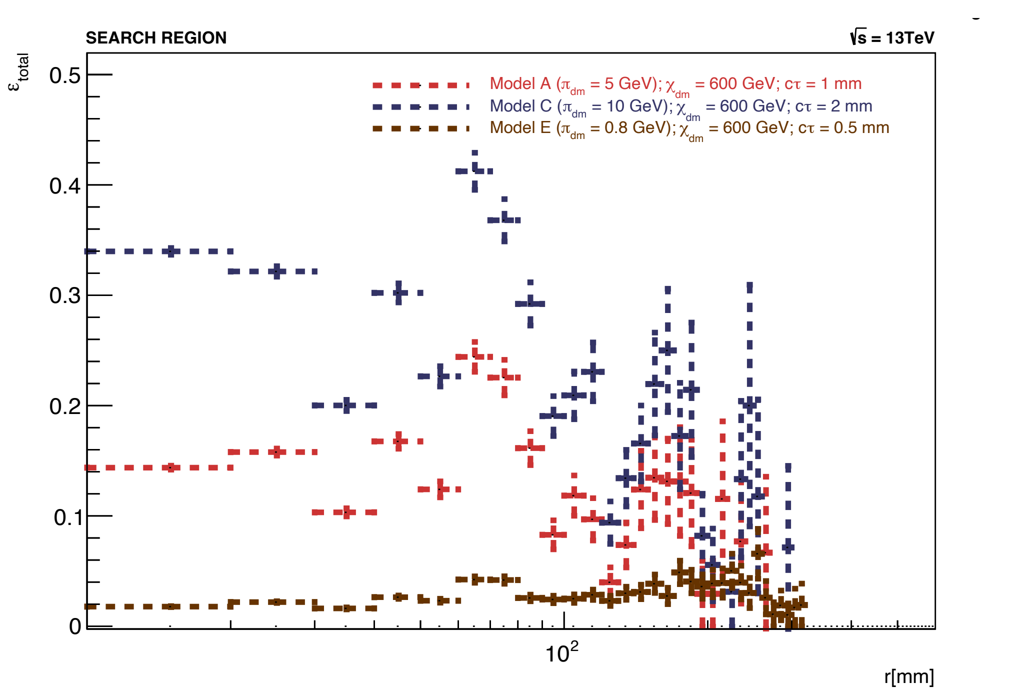


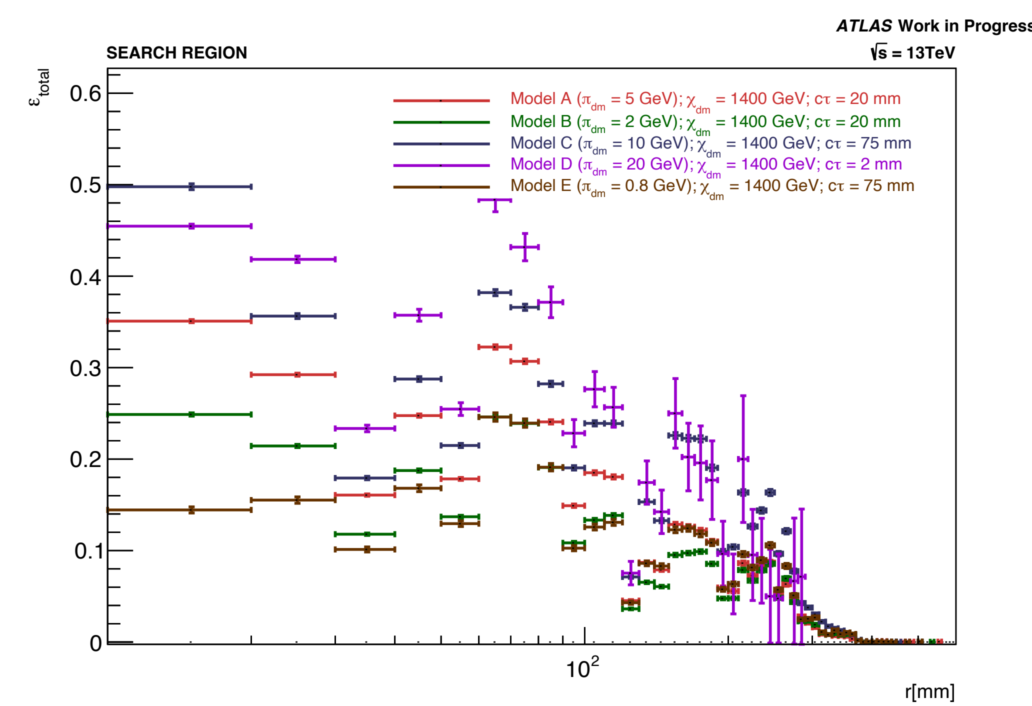
Total efficiency vs. transverse decay position

$\varepsilon^{tot}_{\vec{x}} \rightarrow$ is defined as the ratio of the number of LLP decays with a corresponding reconstructed vertex (with a match score of at least 0.5) to the number of reconstructible LLP decays.



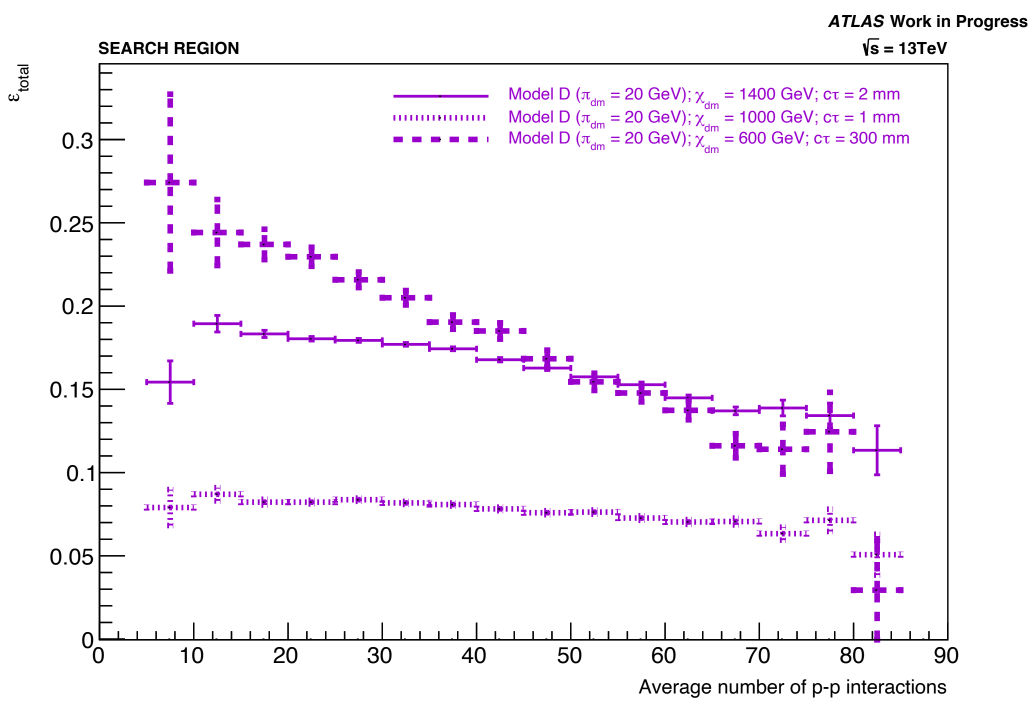


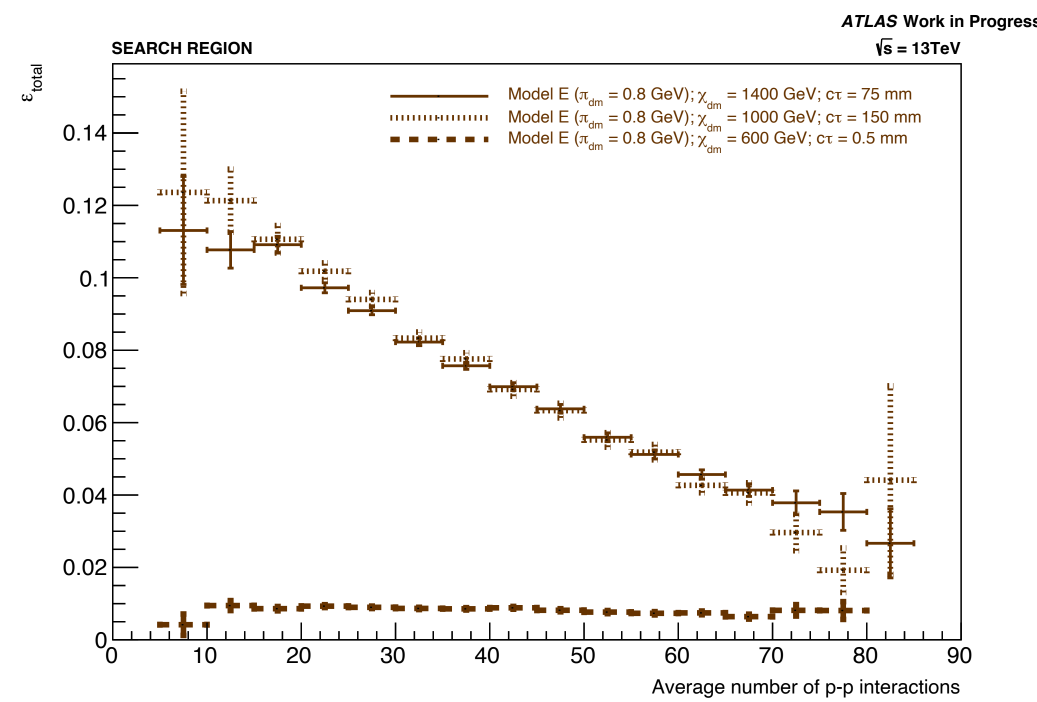


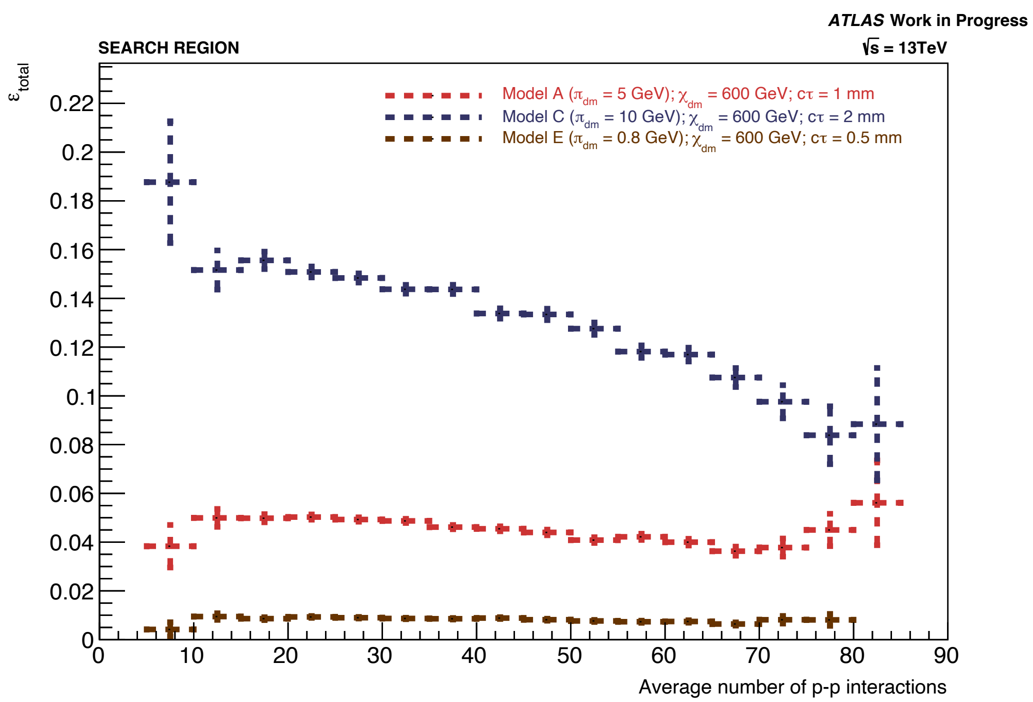


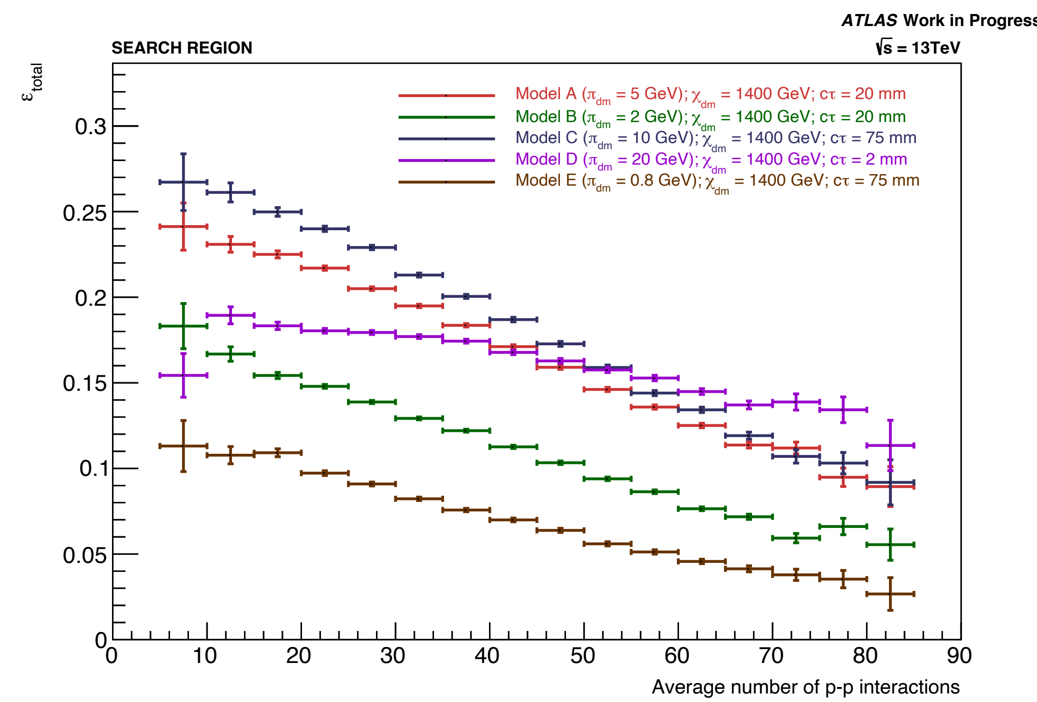
Total efficiency vs. pileup

$$\varepsilon^{\text{tot}}_{\vec{x}} = \mathcal{A}_{\vec{x}} \cdot \varepsilon^{\text{alg}}_{\vec{x}} = \mathcal{A}_{\vec{x}} \cdot \varepsilon^{\text{seed}}_{\vec{x}} \cdot \varepsilon^{\text{core}}_{\vec{x}}$$



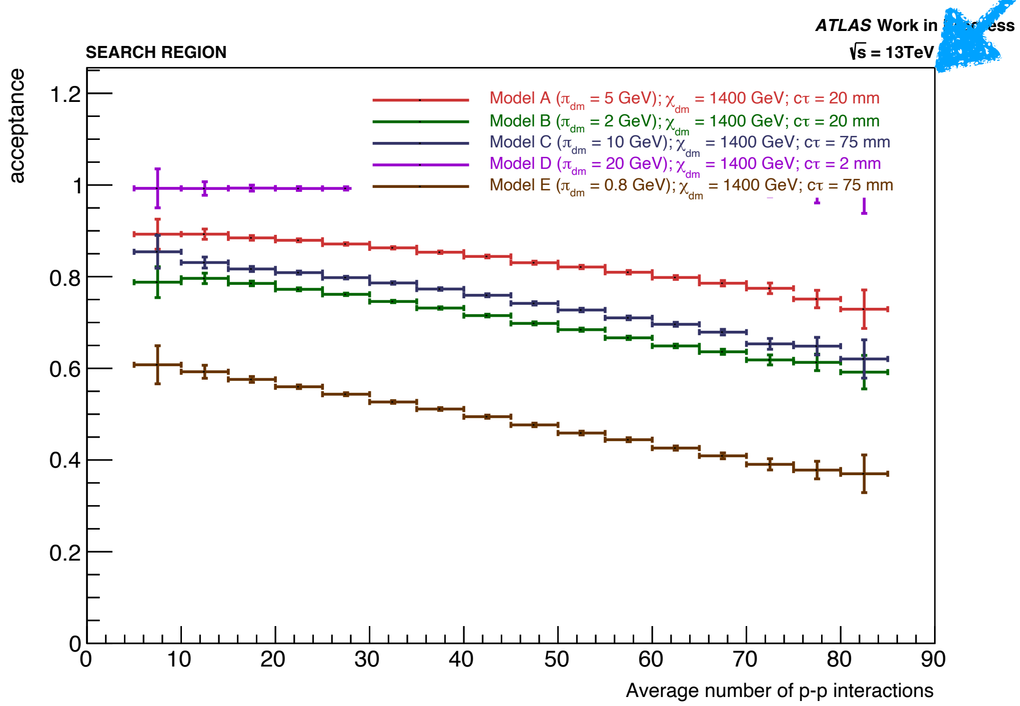


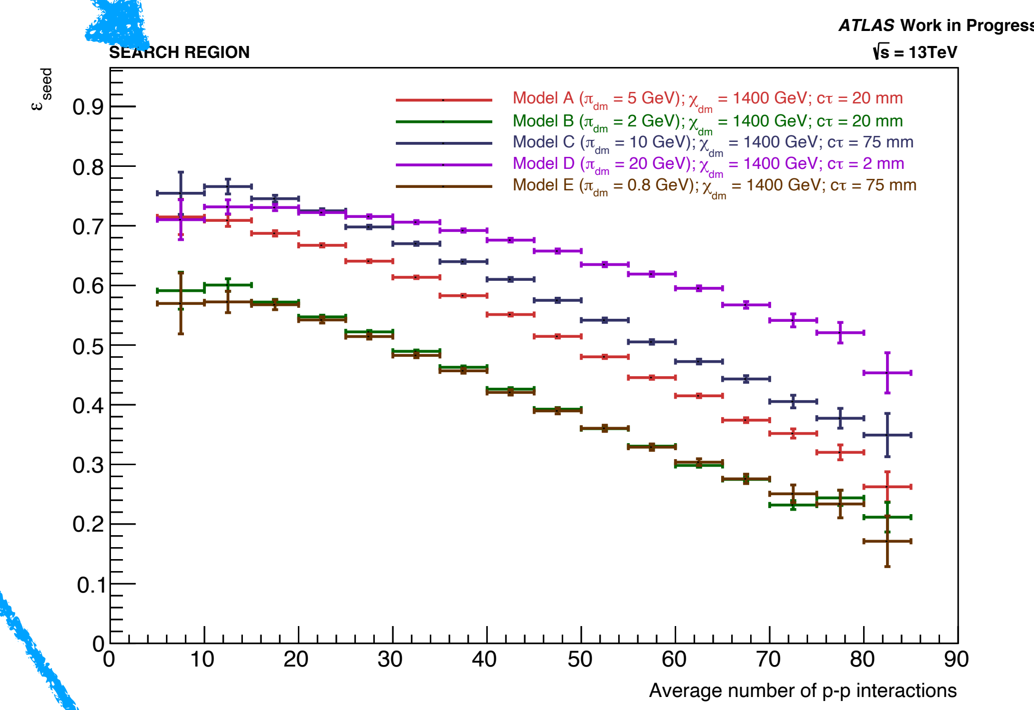


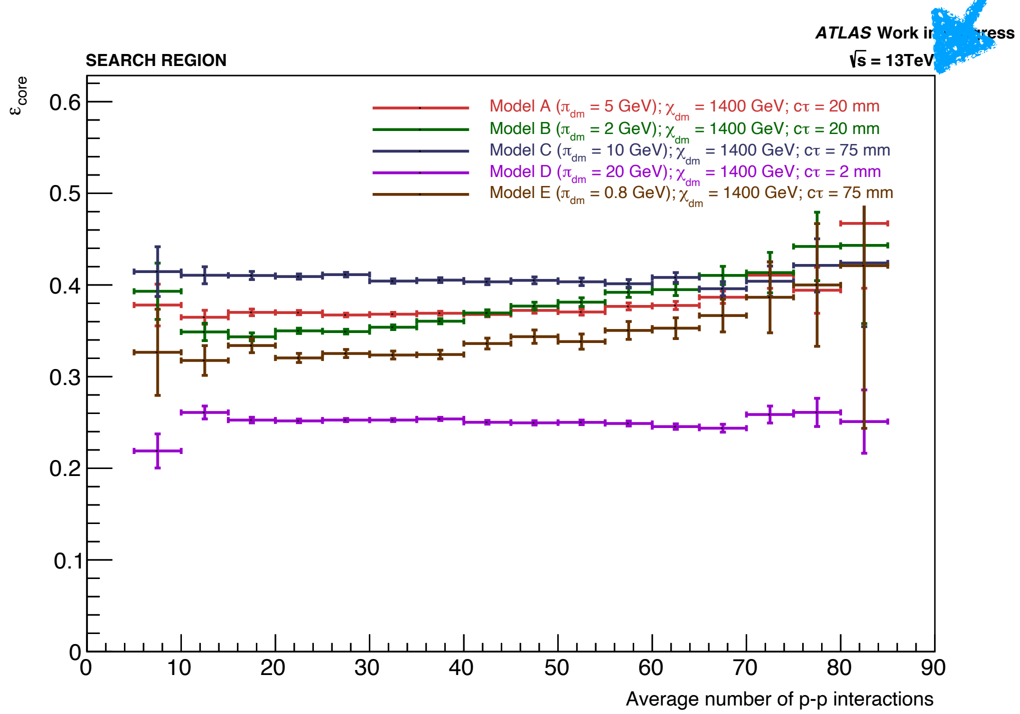


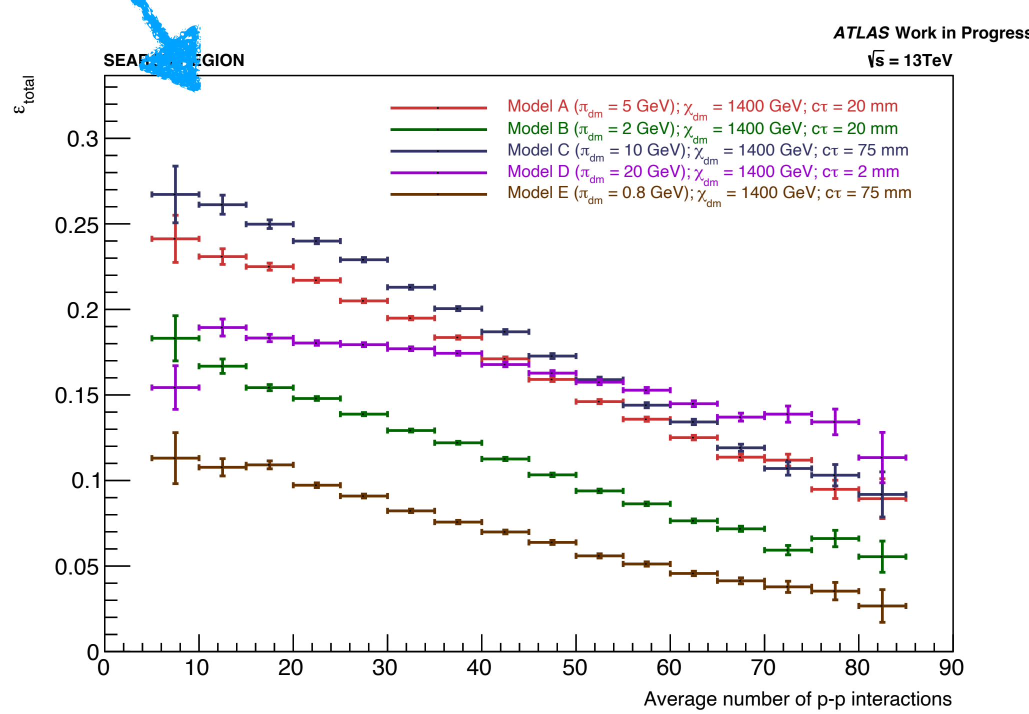
Sv component efficiencies vs. pileup

$$\varepsilon^{tot}_{\vec{x}} = \mathcal{A}_{\vec{x}} \cdot \varepsilon^{alg}_{\vec{x}} = \mathcal{A}_{\vec{x}} \cdot \varepsilon^{seed}_{\vec{x}} \cdot \varepsilon^{core}_{\vec{x}}$$









Split Rate

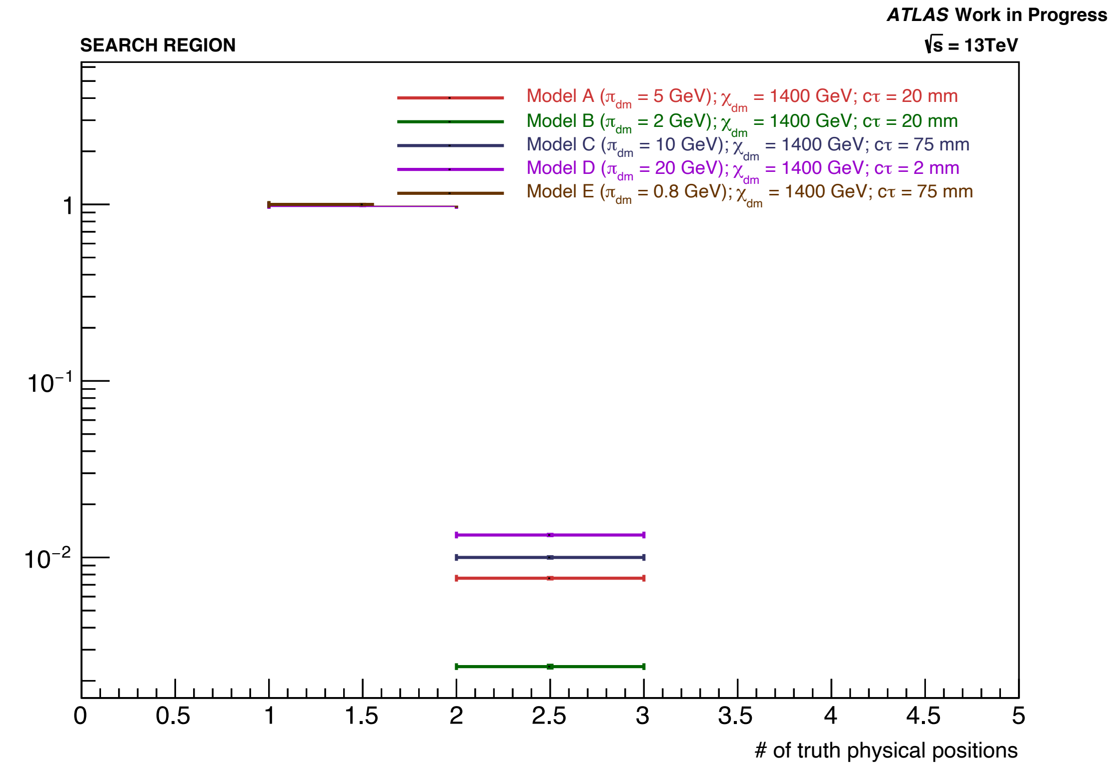
We may potentially expect to have multiple reco-vertices to be around the LLP decay position especially when:

- the track multiplicity of the vertex is large
- the decay of the LLP contains tertiary vertices
- may also be formed due to the long-tails in the position resolution of the vertex

The split rate can be defined in different ways:

- Pure split rate:

  Having multiple reco-vertices matched to the same TruthVertexPos.

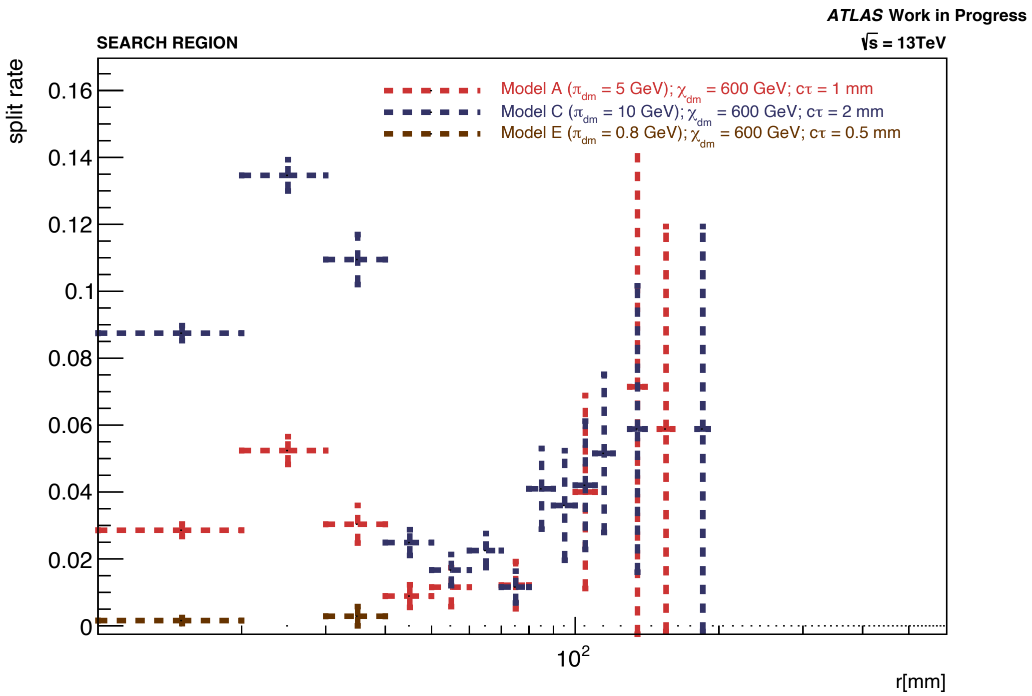


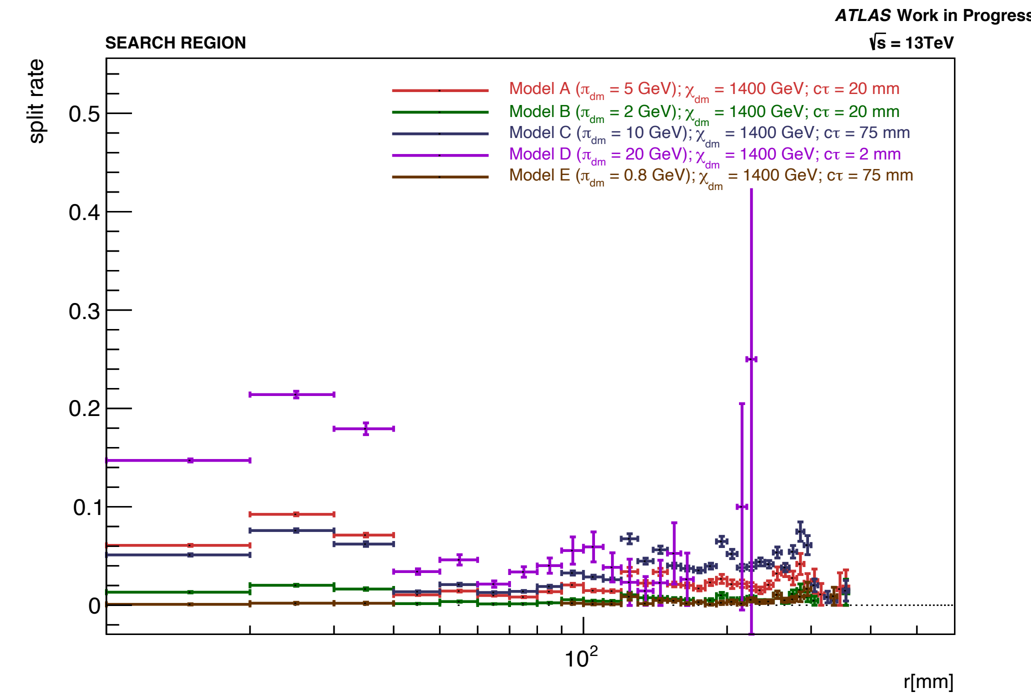
- Effective split rate:

  Having multiple reco-vertices matched to any of the TruthVertexPos listed in the LLP decay.

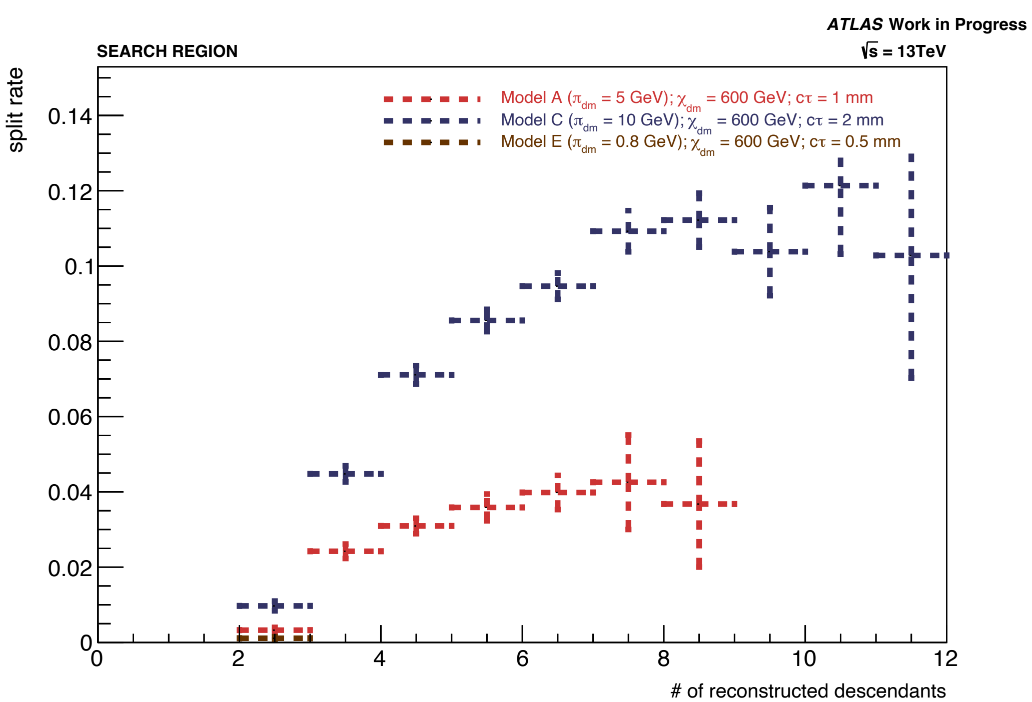
  Some distance regulation can be applied to reject e.g. hadronic interactions in downstream.

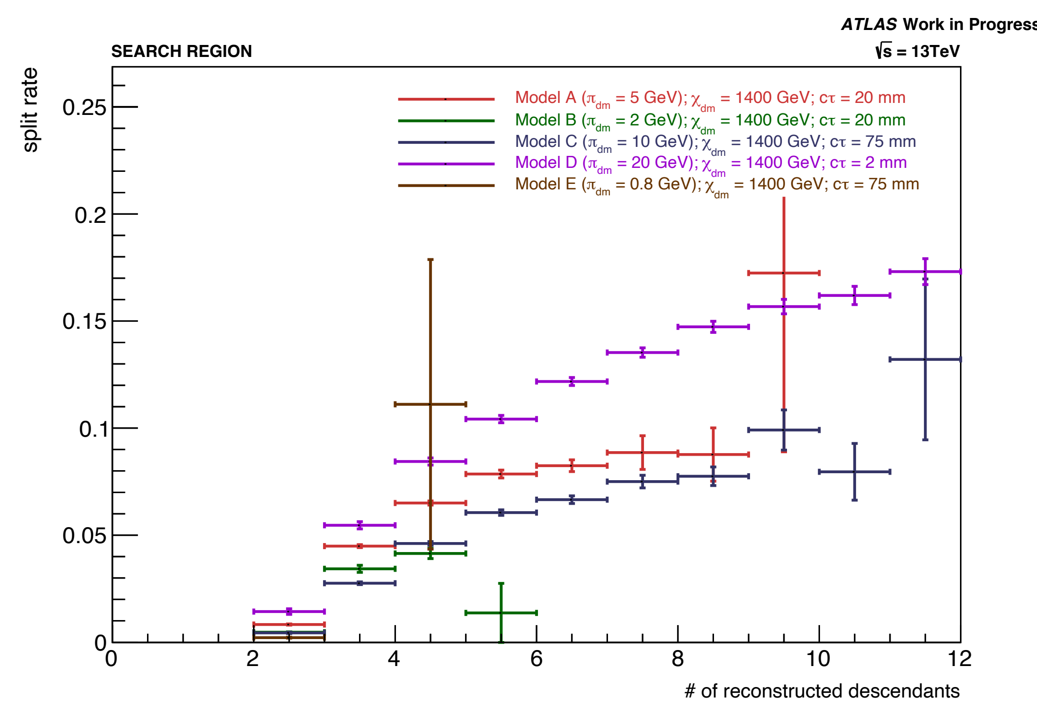
Split rate vs. transverse decay position



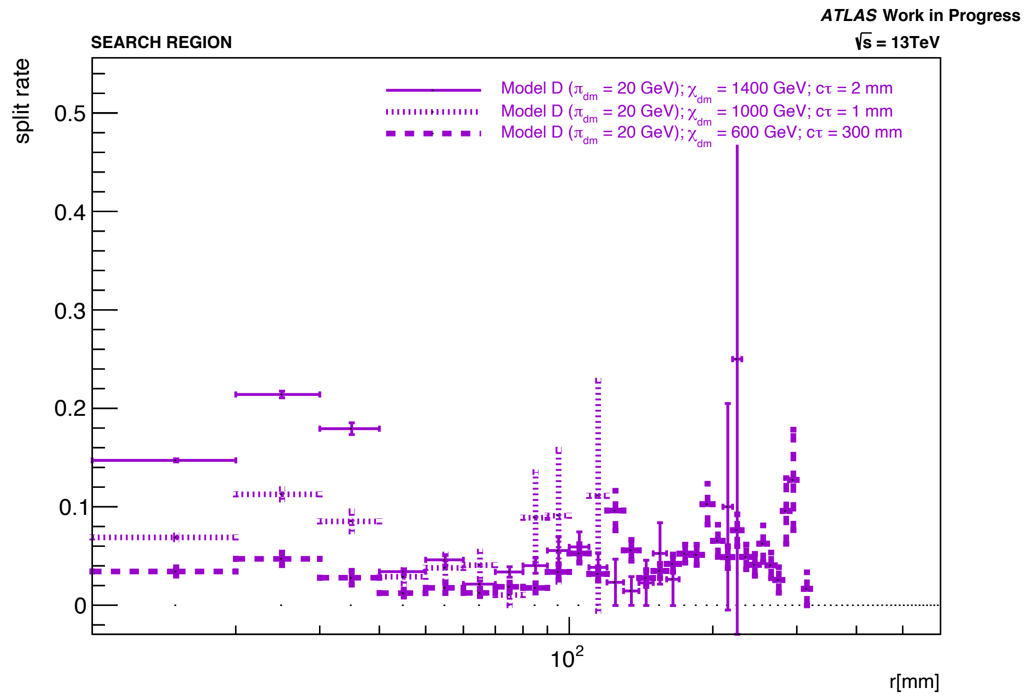


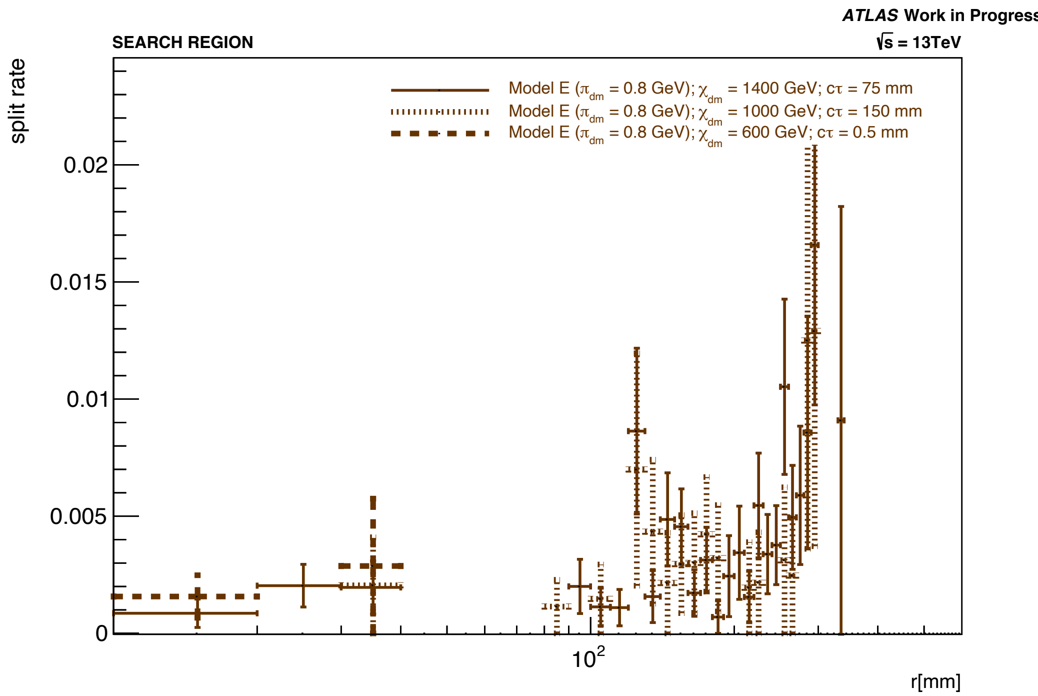
Split rate vs. reconstructed track multiplicity



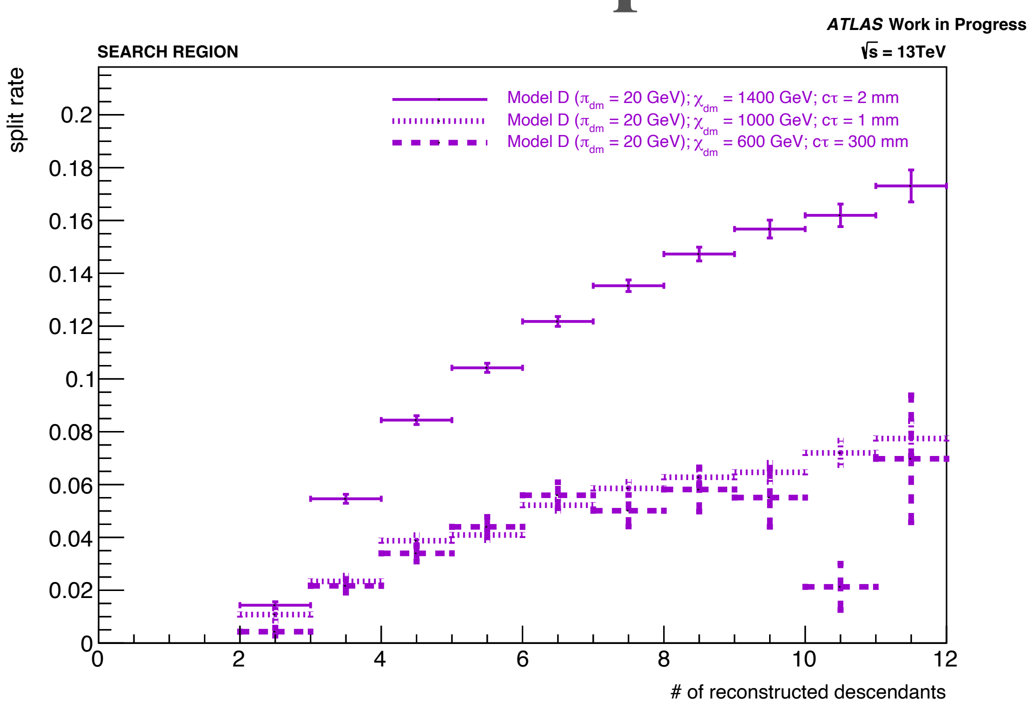


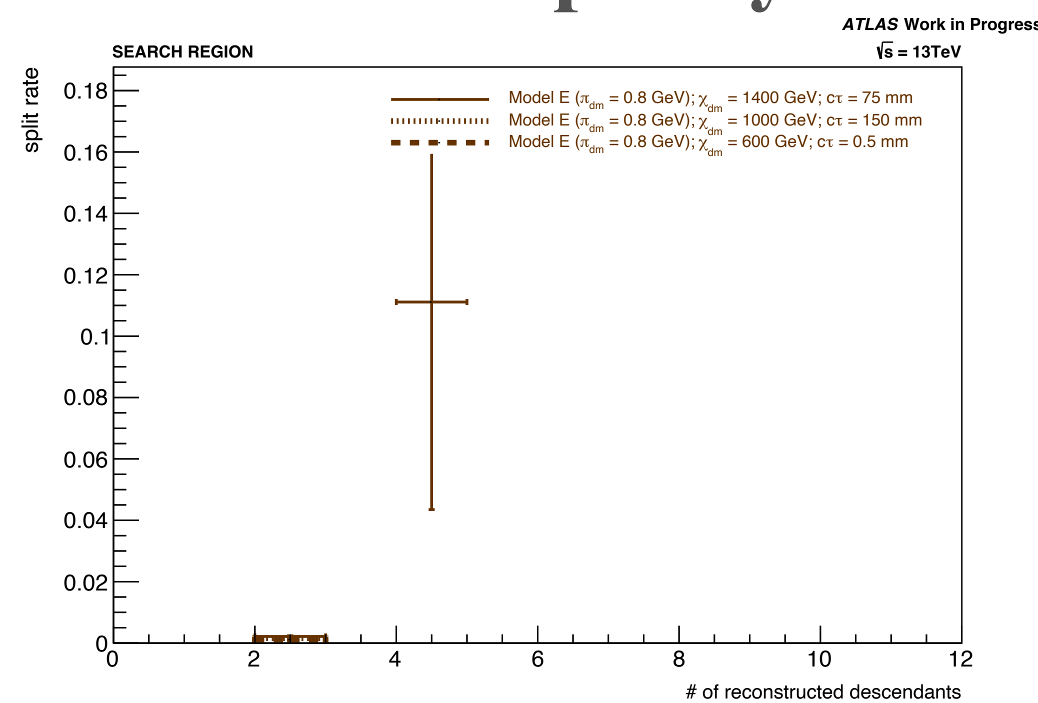
Split rate vs. transverse decay position





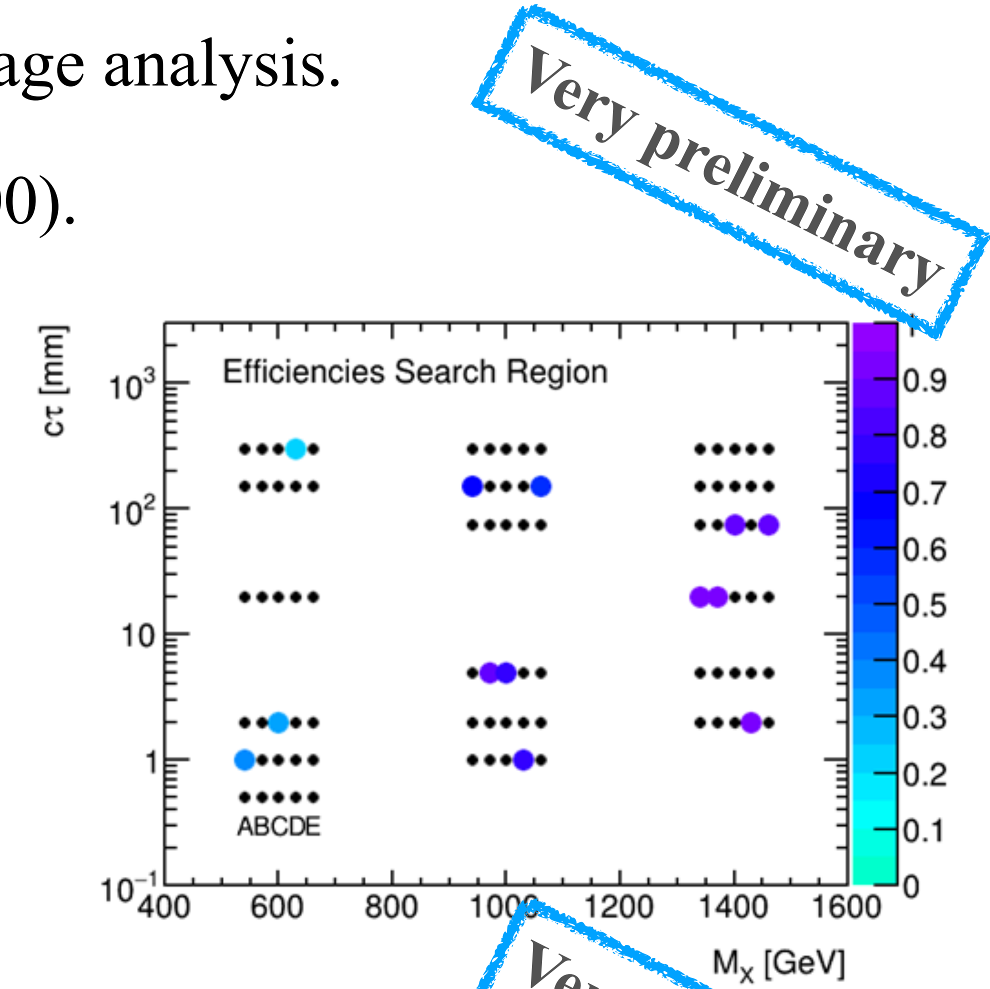
Split rate vs. reconstructed track multiplicity

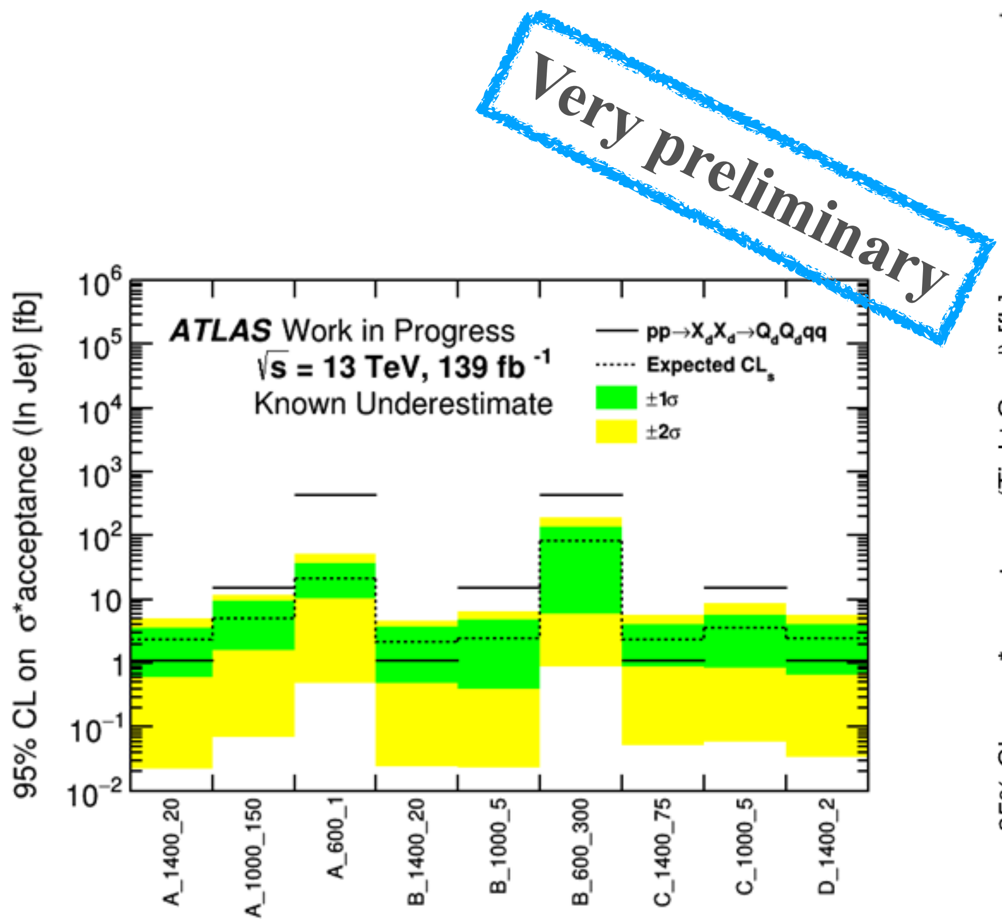


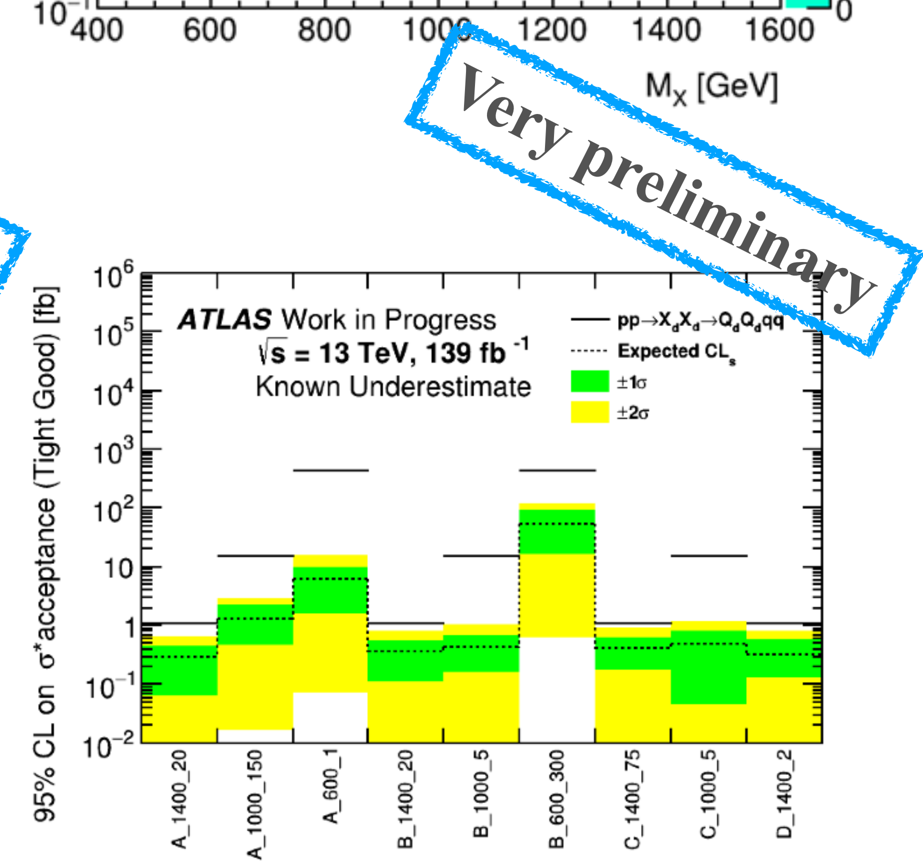


Cross section upper bounds

- We have begun developing statistical machinery as late-stage analysis.
- Search Region: ABCD plane (4 pt-120 jets with HT > 1000).





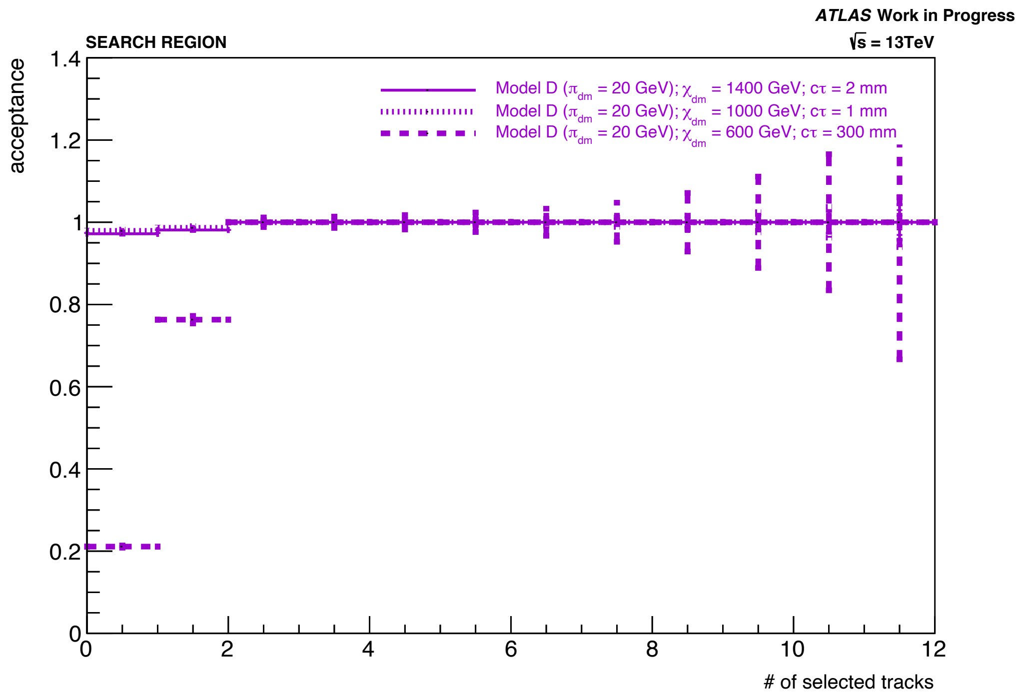


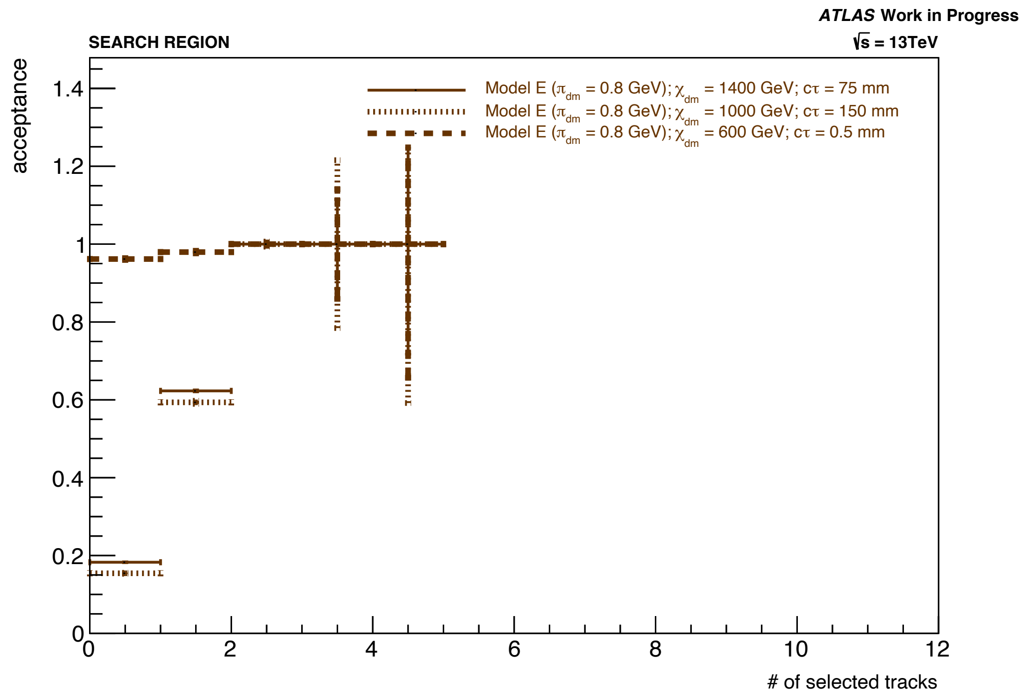
Summary

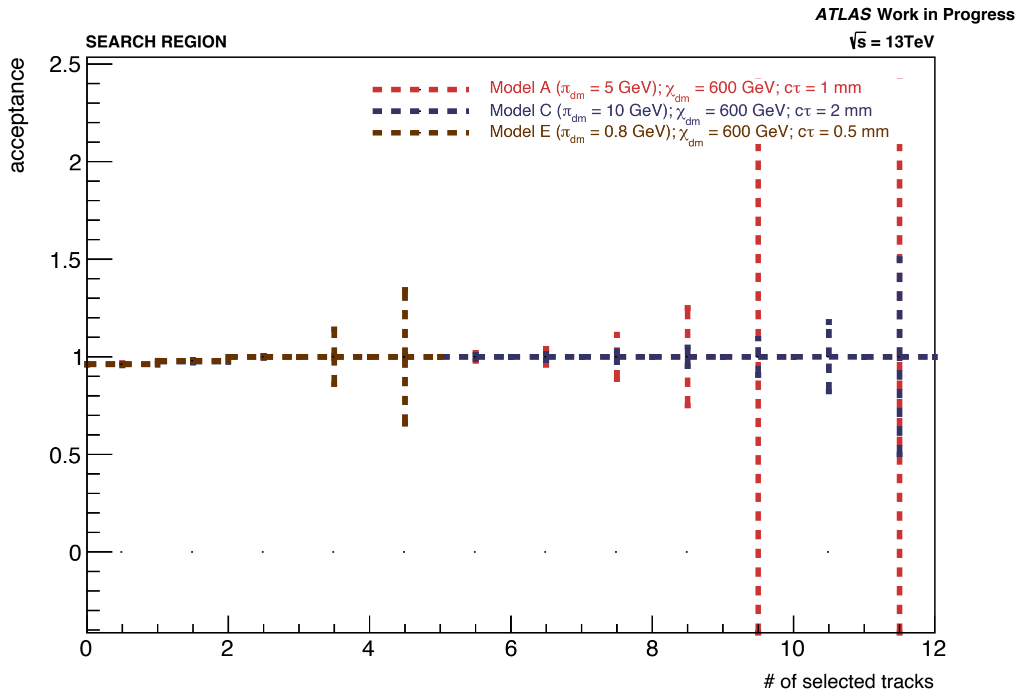
- Secondary vertex reconstruction efficiency and split rate results was estimated for different models
- We've submitted a JIRA ticket for processing of all JZXWithSW slices
  - waiting for all slices to validate background description
- More studies on material veto possible with update ntuples
- Selection of good DVs and emerging-jets-like jets to be incorporated in the ABCD machinery for testing
- Implementation of statistical interpretation work in progress
- We are initiating to implement the systematic uncertainties and estimate their impact.

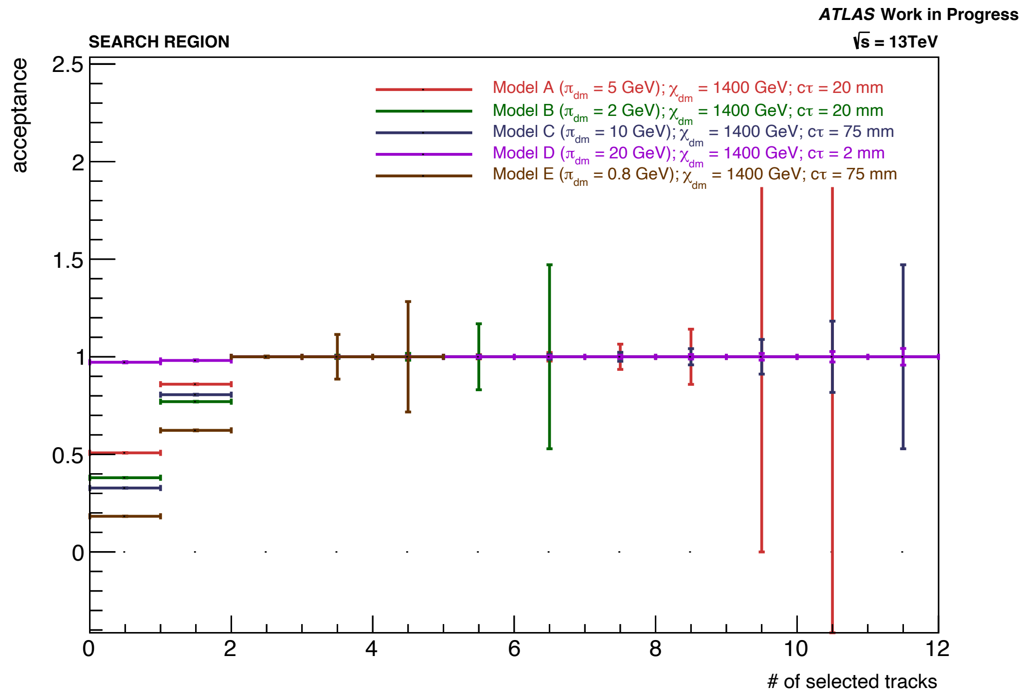
Backup

Acceptance vs. selected track multiplicity

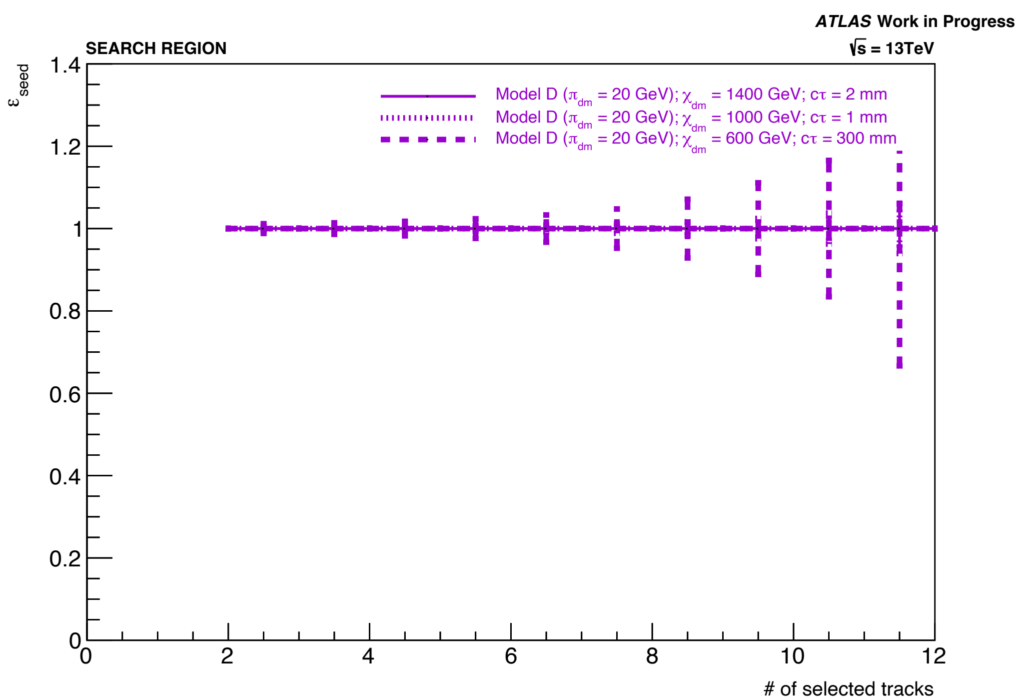


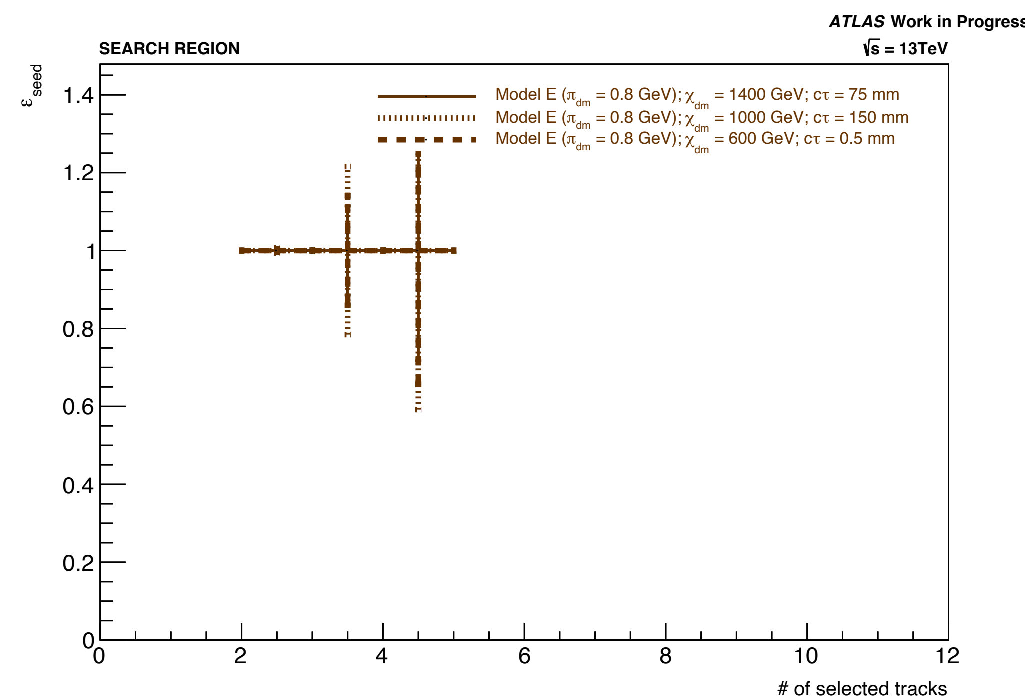


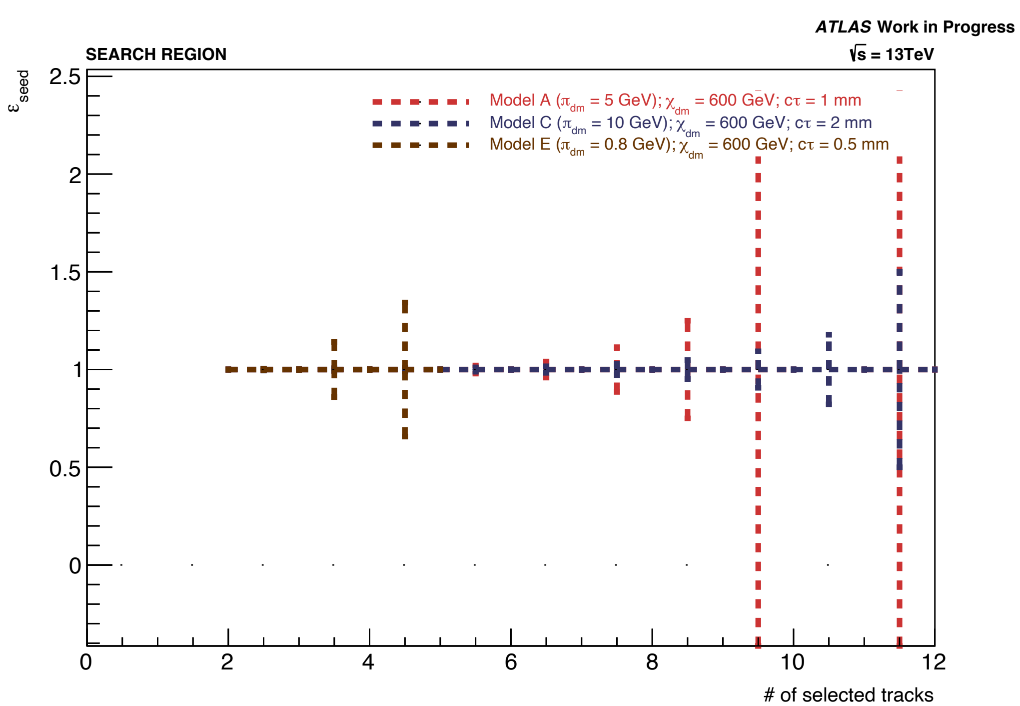


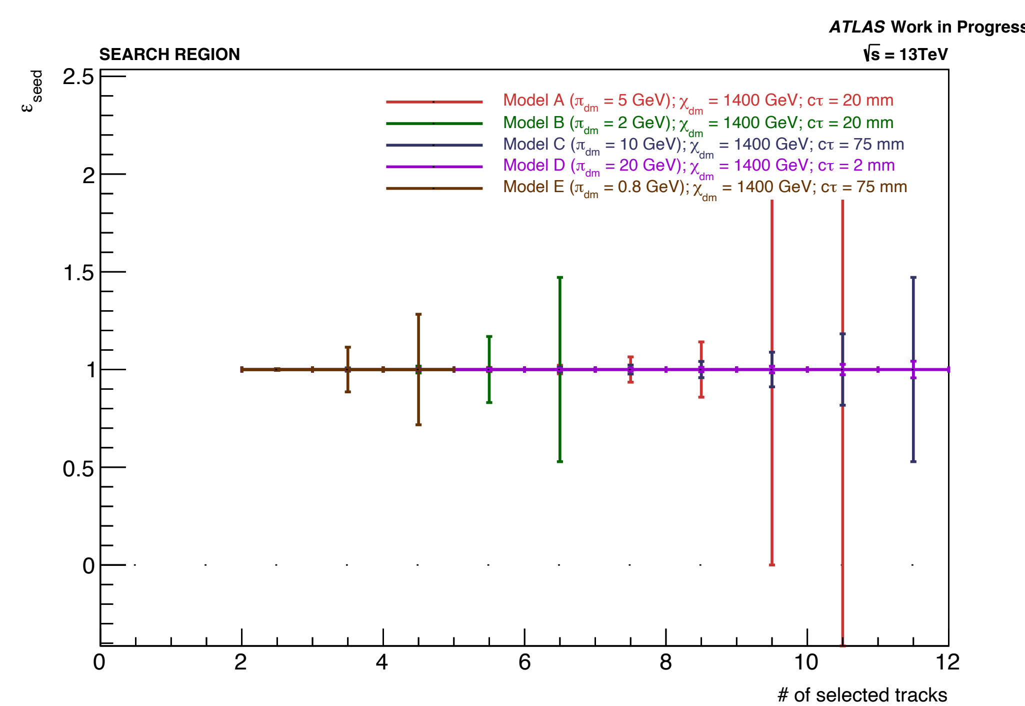


Seed efficiency vs. Selected track multiplicity



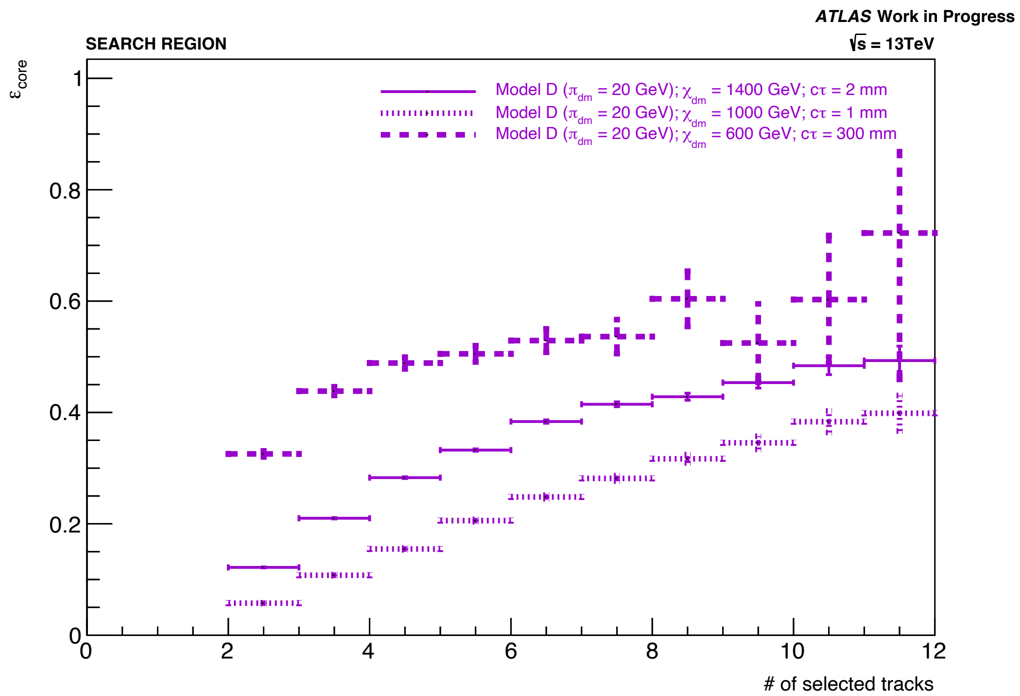


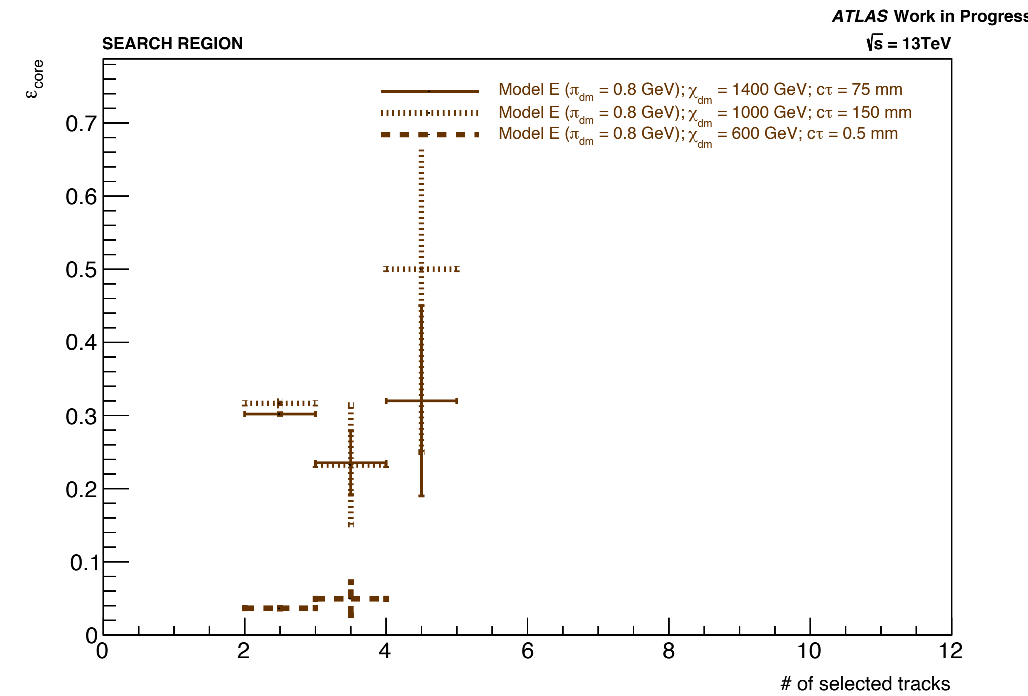


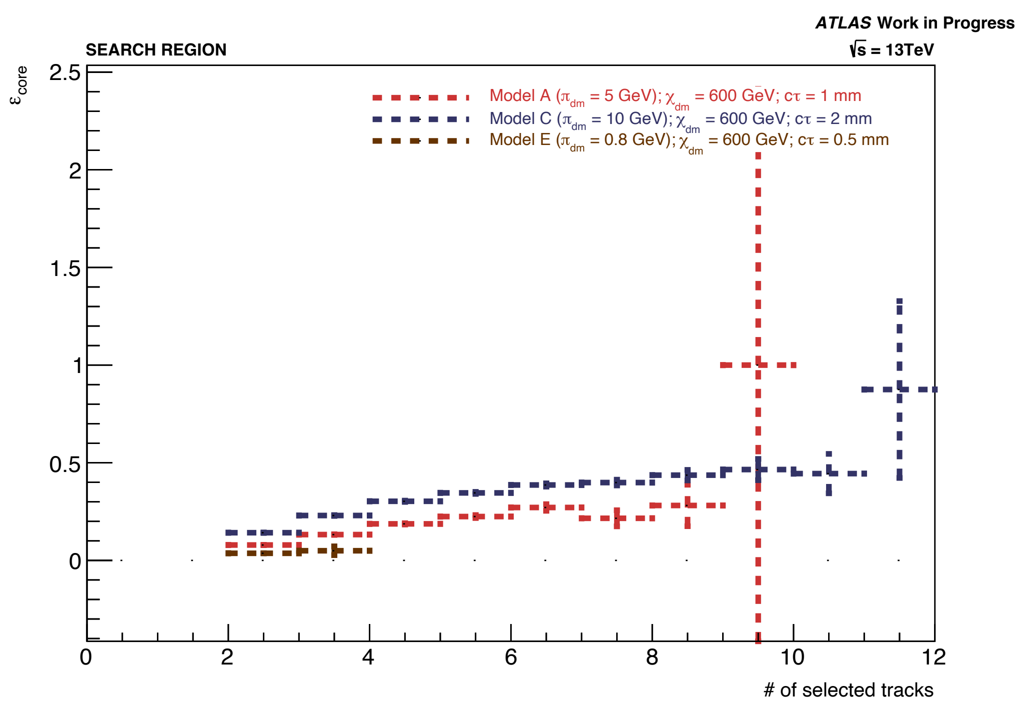


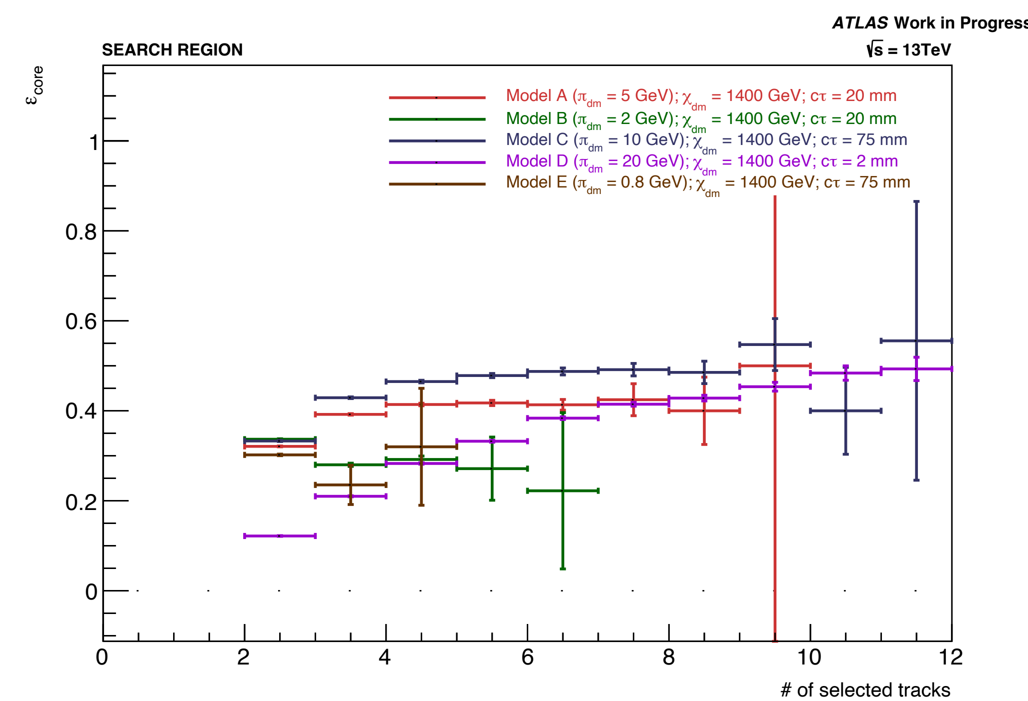
Core efficiency vs. Selected track multiplicity

$$\varepsilon^{\text{core}}_{\vec{x}} = \varepsilon^{\text{alg}}_{\vec{x}} / \varepsilon^{\text{seed}}_{\vec{x}}$$



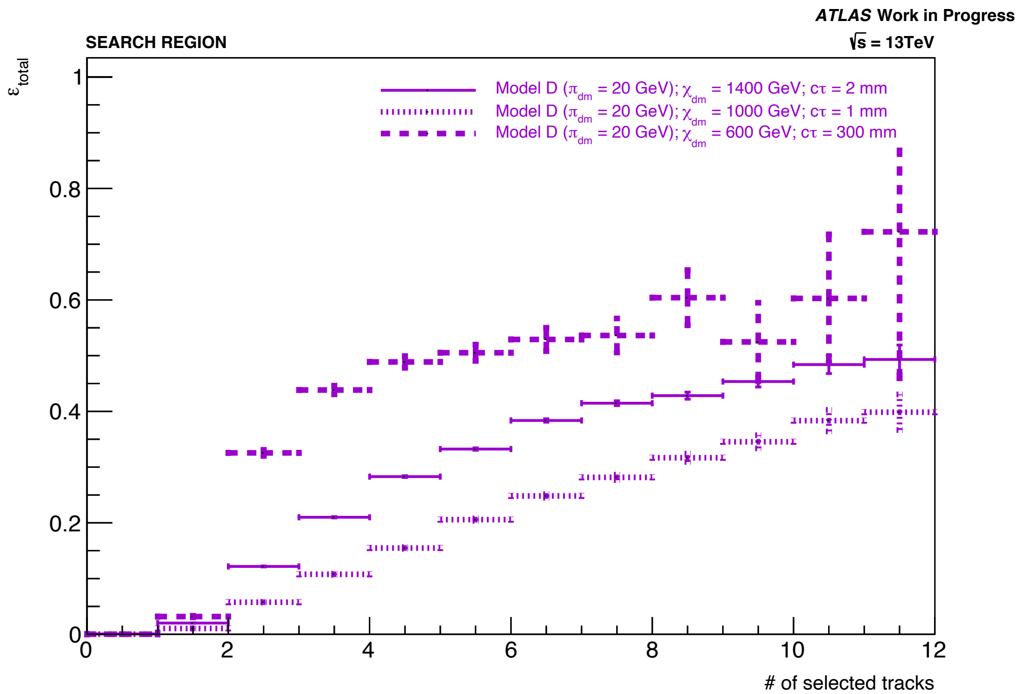


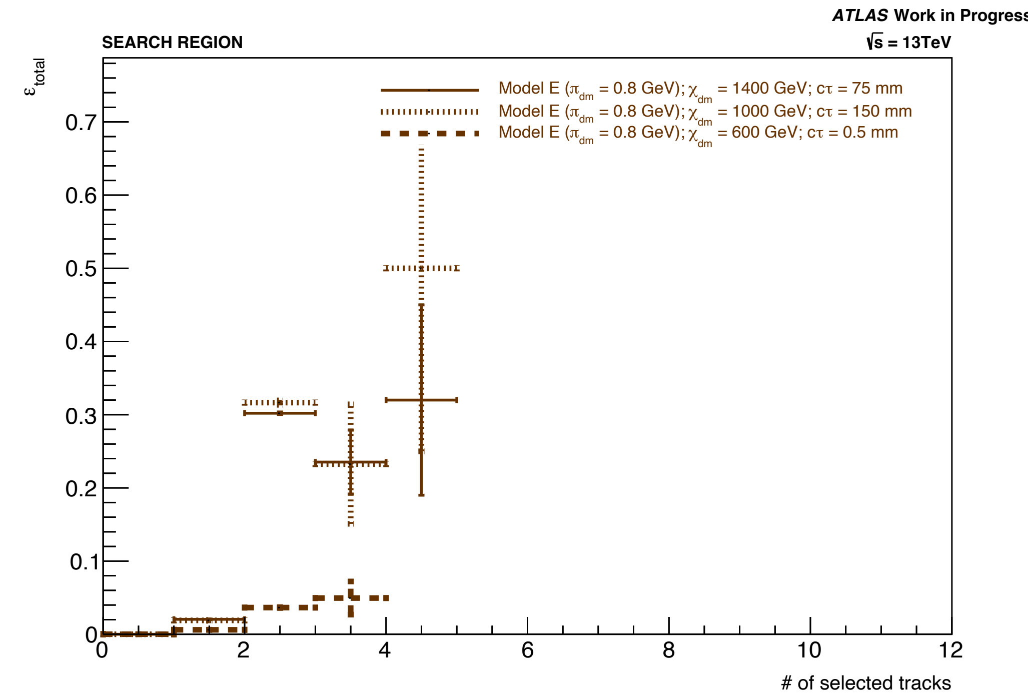


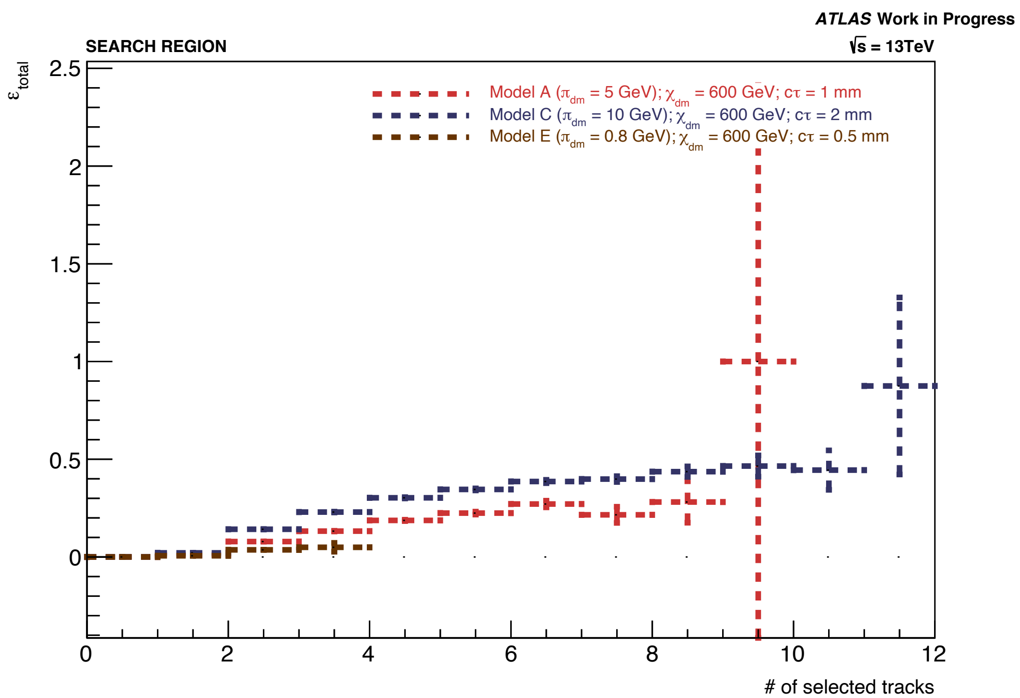


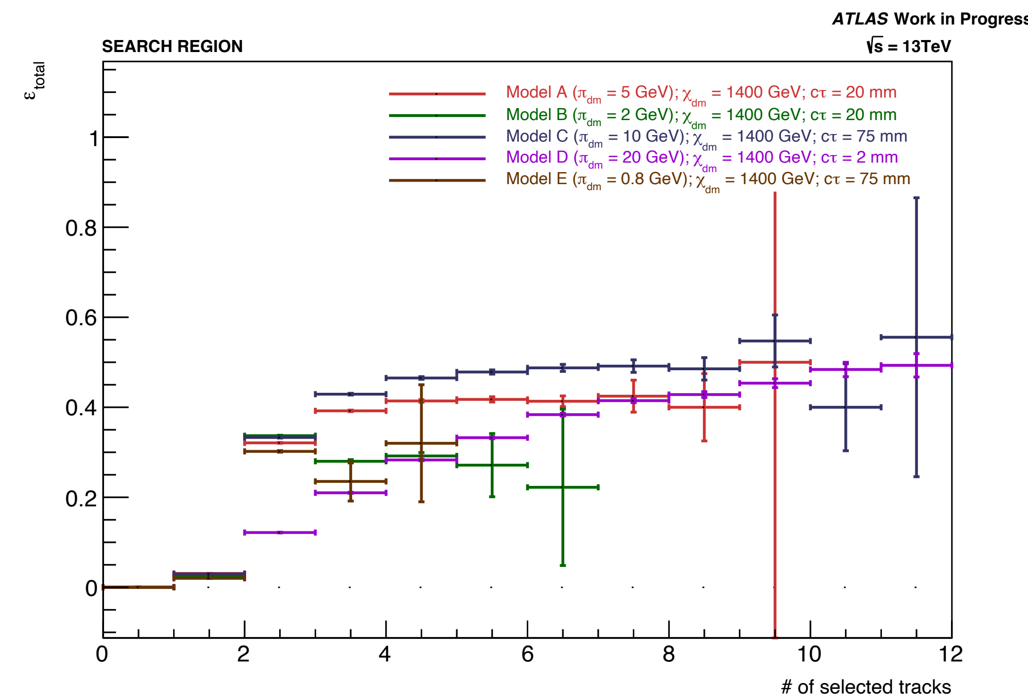
Total efficiency vs. Selected track multiplicity

$$\varepsilon^{\mathrm{tot}}_{\vec{x}} = \mathcal{A}_{\vec{x}} \cdot \varepsilon^{\mathrm{alg}}_{\vec{x}} = \mathcal{A}_{\vec{x}} \cdot \varepsilon^{\mathrm{seed}}_{\vec{x}} \cdot \varepsilon^{\mathrm{core}}_{\vec{x}}$$

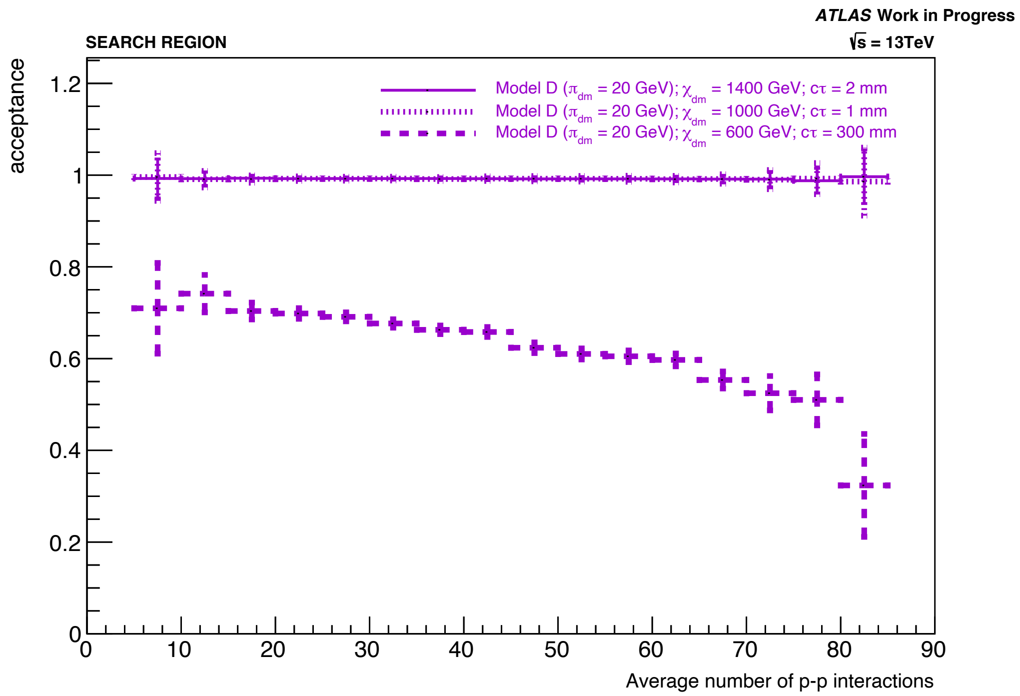


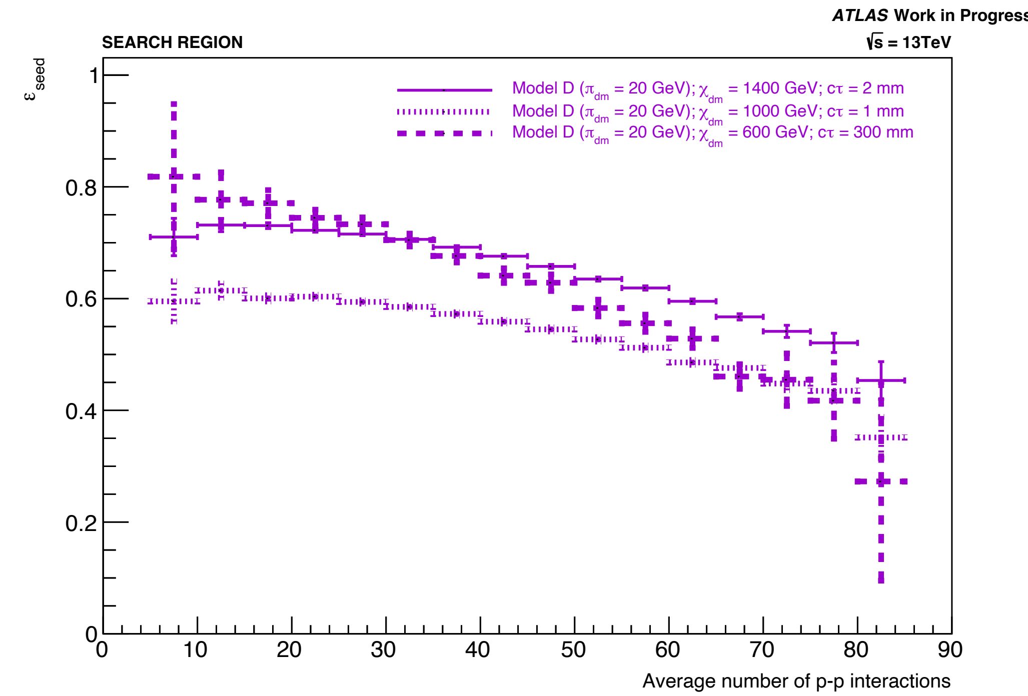


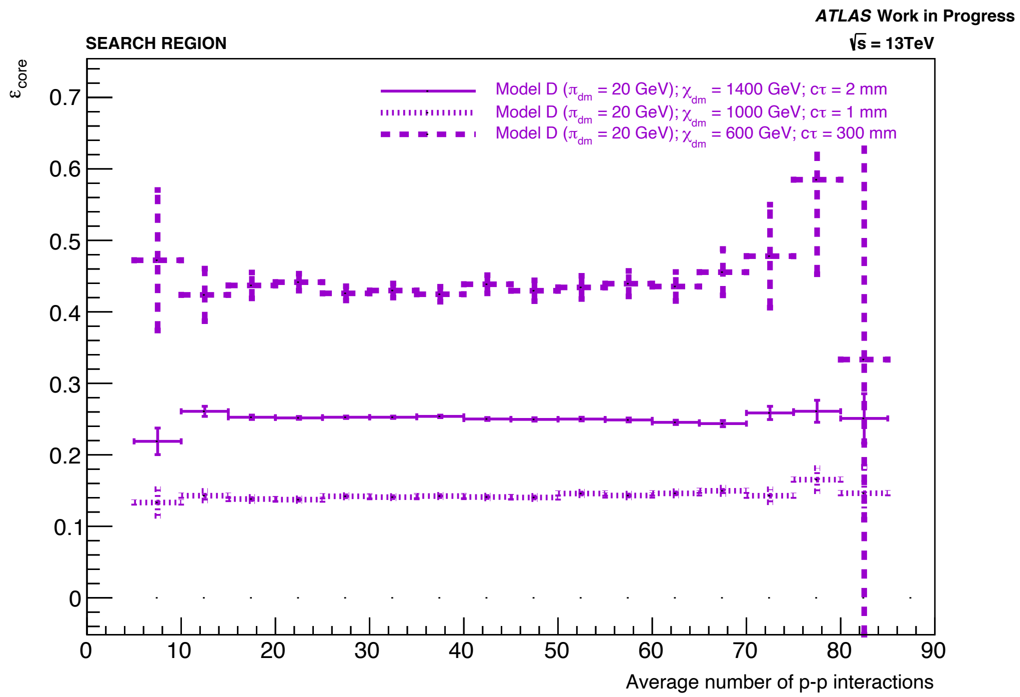


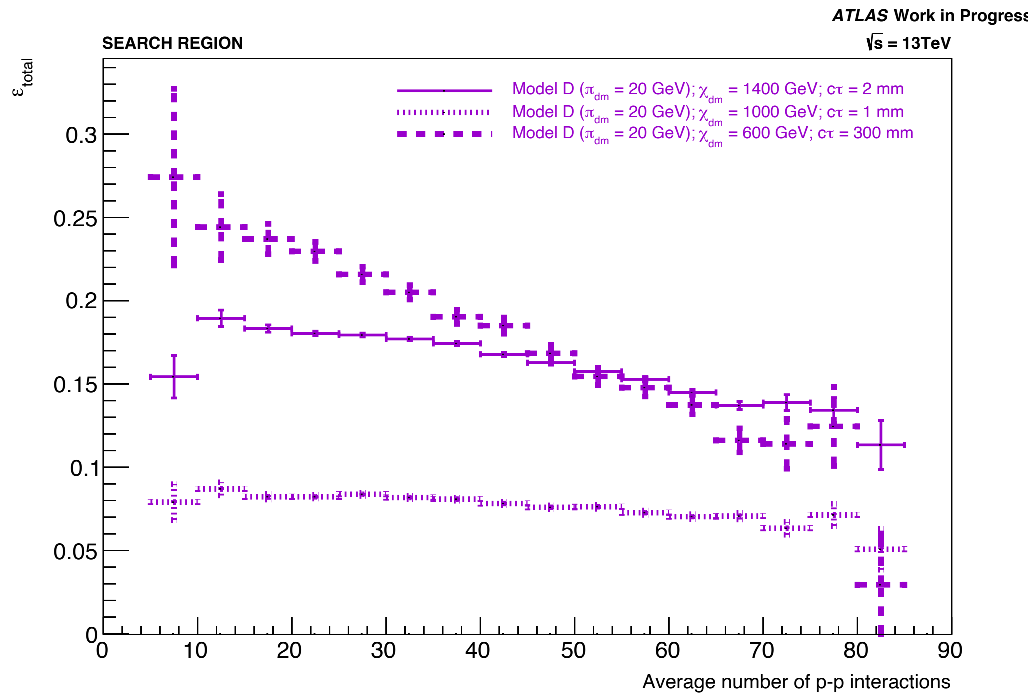


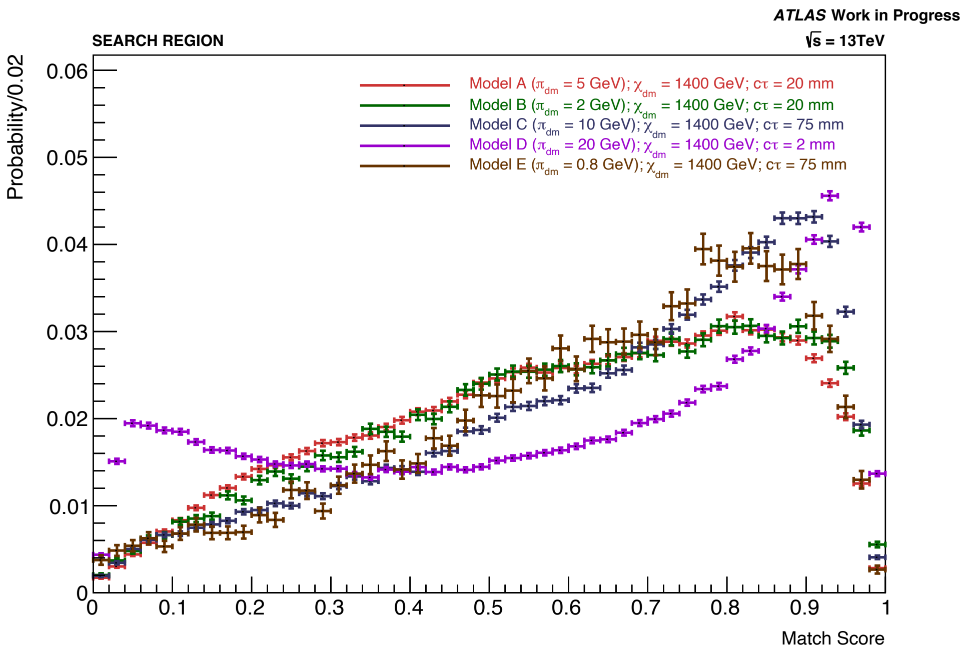
$$\varepsilon_{\vec{x}}^{\mathrm{tot}} = \mathcal{A}_{\vec{x}} \cdot \varepsilon_{\vec{x}}^{\mathrm{alg}} = \mathcal{A}_{\vec{x}} \cdot \varepsilon_{\vec{x}}^{\mathrm{seed}} \cdot \varepsilon_{\vec{x}}^{\mathrm{core}}$$

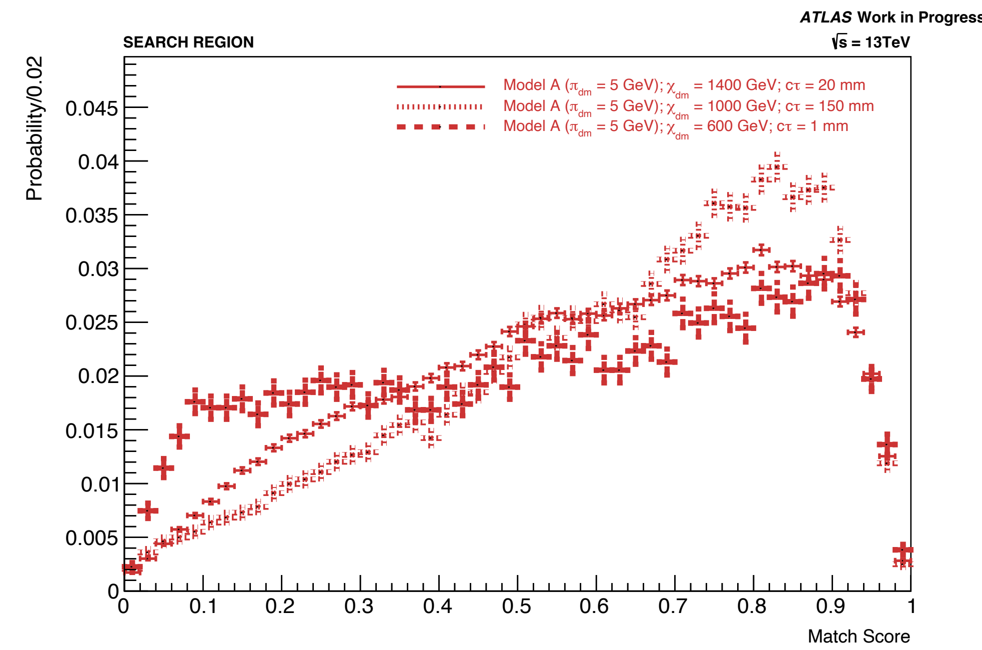


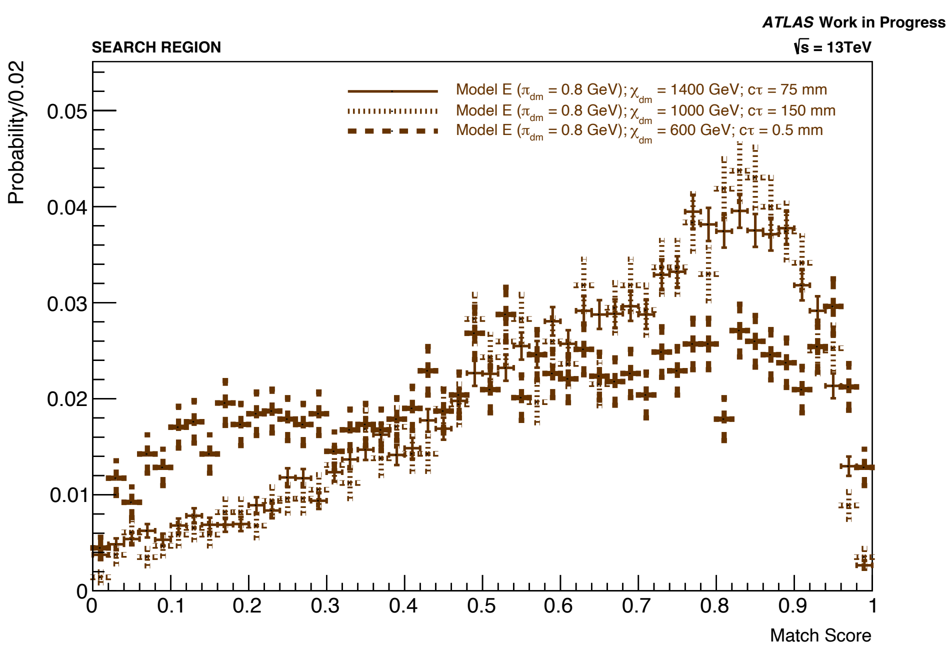


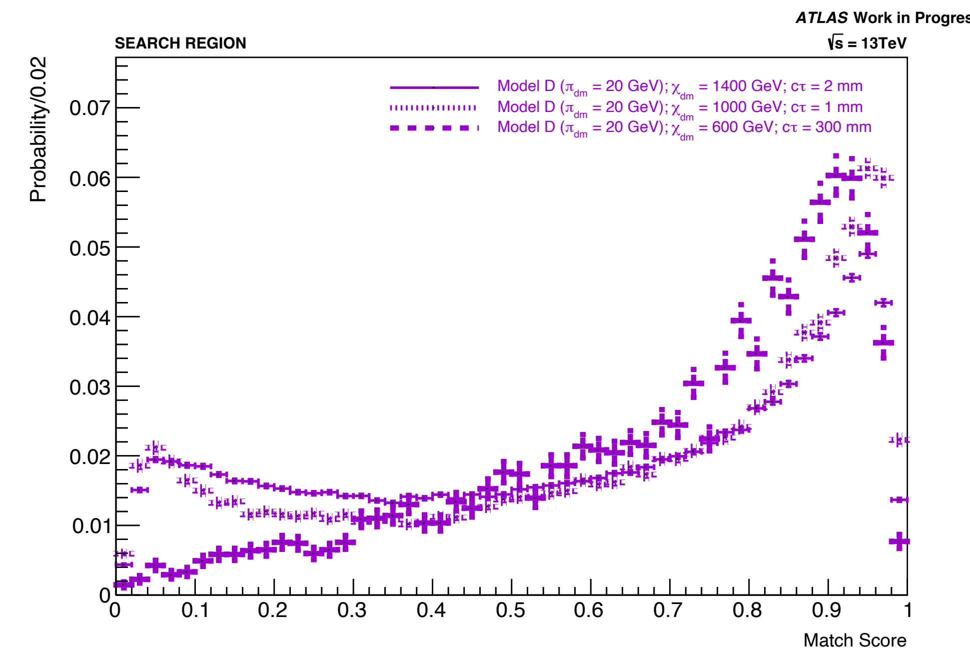


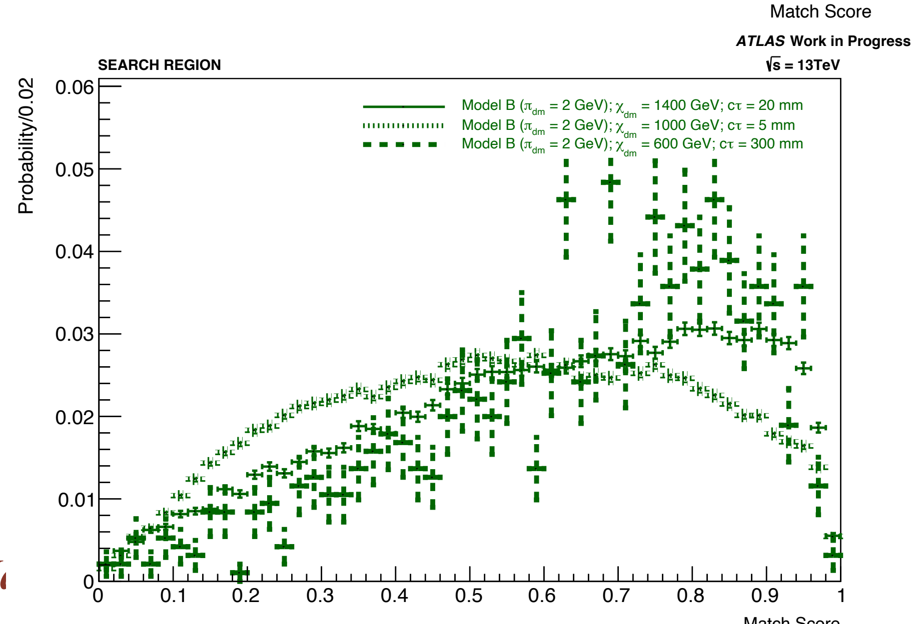


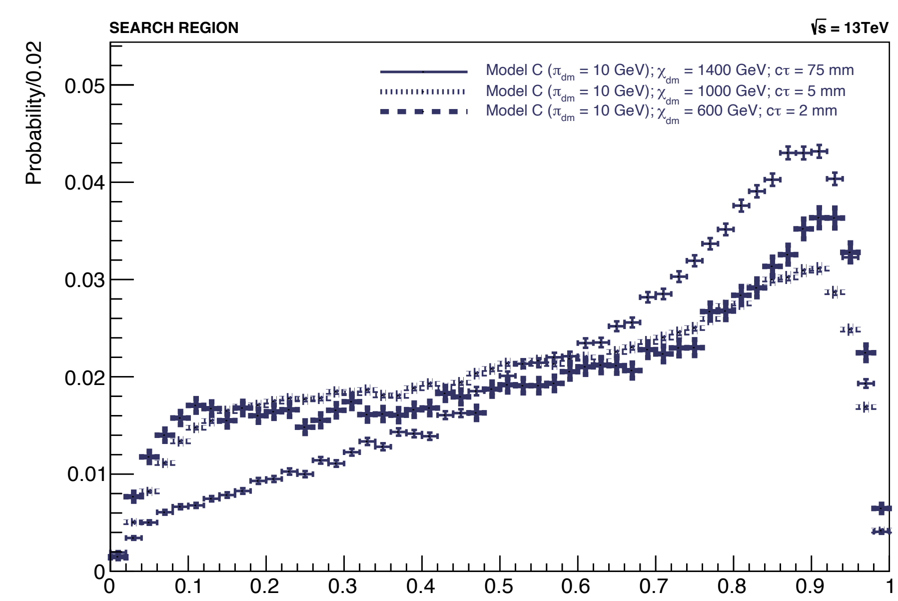

ATLAS Work in Progress
SEARCH REGION
√s = 13TeV
Model A (π_{dm} = 5 GeV); χ_{dm} = 1400 GeV; cτ = 20 mm
Model B (π_{dm} = 2 GeV); χ_{dm} = 1400 GeV; cτ = 20 mm
Model C (π_{dm} = 10 GeV); χ_{dm} = 1400 GeV; cτ = 75 mm
Model D (π_{dm} = 20 GeV); χ_{dm} = 1400 GeV; cτ = 2 mm
Model E (π_{dm} = 0.8 GeV); χ_{dm} = 1400 GeV; cτ = 75 mm
Probability/0.02
Match Score

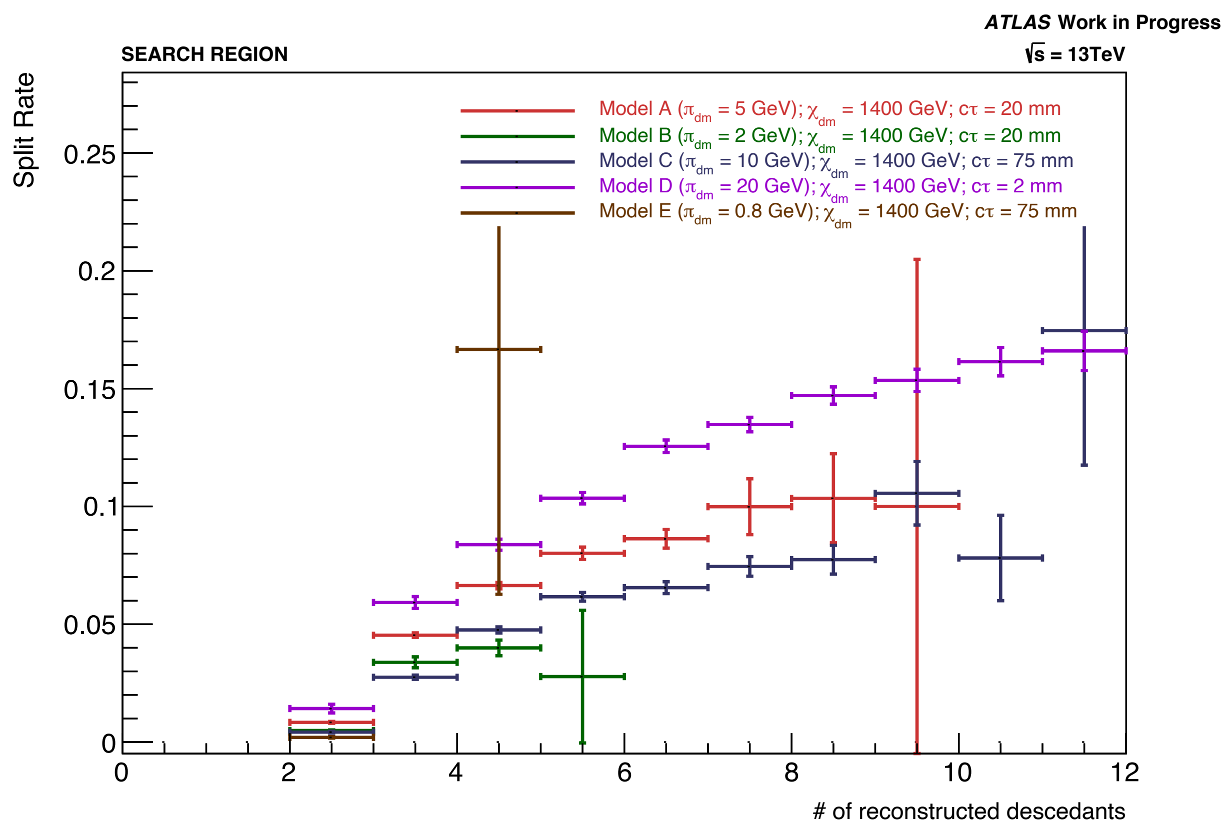

ATLAS Work in Progress
SEARCH REGION
√s = 13TeV
Model A (π_{dm} = 5 GeV); χ_{dm} = 1400 GeV; cτ = 20 mm
Model A (π_{dm} = 5 GeV); χ_{dm} = 1000 GeV; cτ = 150 mm
Model A (π_{dm} = 5 GeV); χ_{dm} = 600 GeV; cτ = 1 mm
Probability/0.02
Match Score

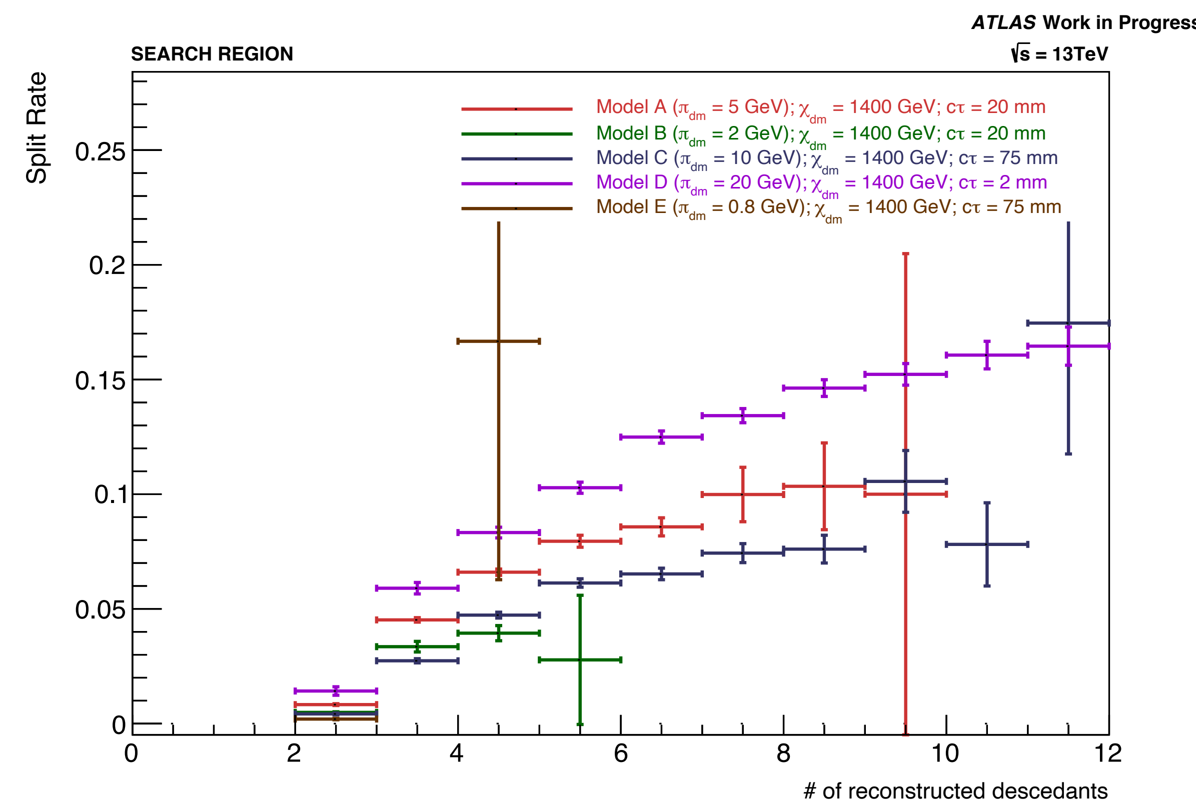

ATLAS Work in Progress
SEARCH REGION
√s = 13TeV
Model E (π_{dm} = 0.8 GeV); χ_{dm} = 1400 GeV; cτ = 75 mm
Model E (π_{dm} = 0.8 GeV); χ_{dm} = 1000 GeV; cτ = 150 mm
Model E (π_{dm} = 0.8 GeV); χ_{dm} = 600 GeV; cτ = 0.5 mm
Probability/0.02
Match Score

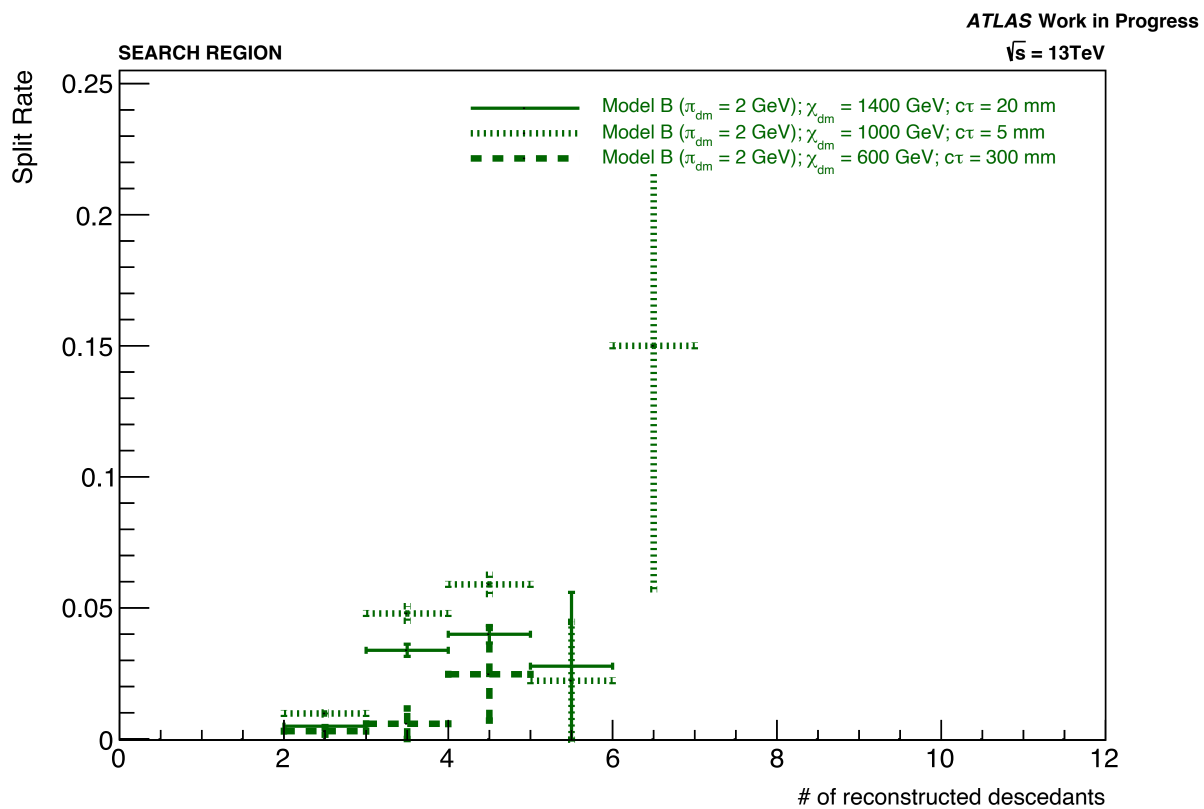

ATLAS Work in Progress
SEARCH REGION
√s = 13TeV
Model D (π_{dm} = 20 GeV); χ_{dm} = 1400 GeV; cτ = 2 mm
Model D (π_{dm} = 20 GeV); χ_{dm} = 1000 GeV; cτ = 1 mm
Model D (π_{dm} = 20 GeV); χ_{dm} = 600 GeV; cτ = 300 mm
Probability/0.02
Match Score

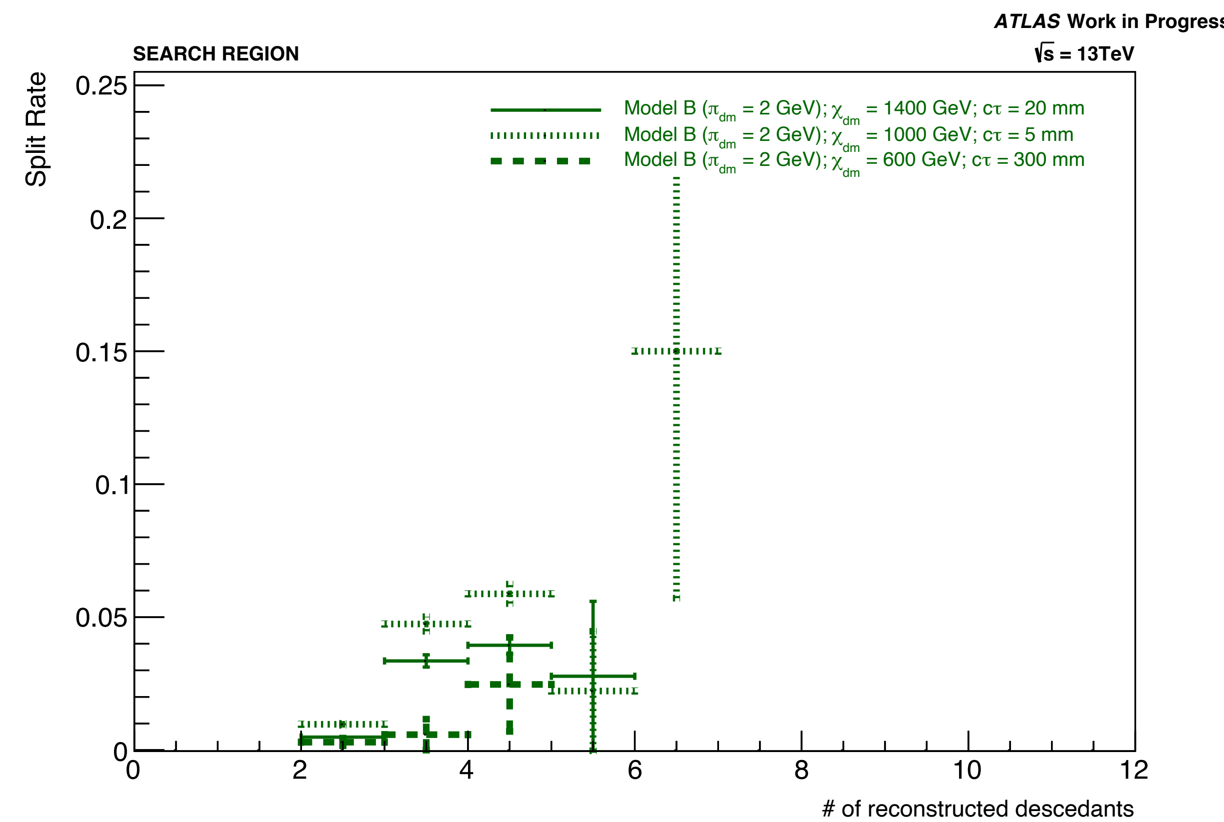

ATLAS Work in Progress
SEARCH REGION
√s = 13TeV
Model B (π_{dm} = 2 GeV); χ_{dm} = 1400 GeV; cτ = 20 mm
Model B (π_{dm} = 2 GeV); χ_{dm} = 1000 GeV; cτ = 5 mm
Model B (π_{dm} = 2 GeV); χ_{dm} = 600 GeV; cτ = 300 mm
Probability/0.02

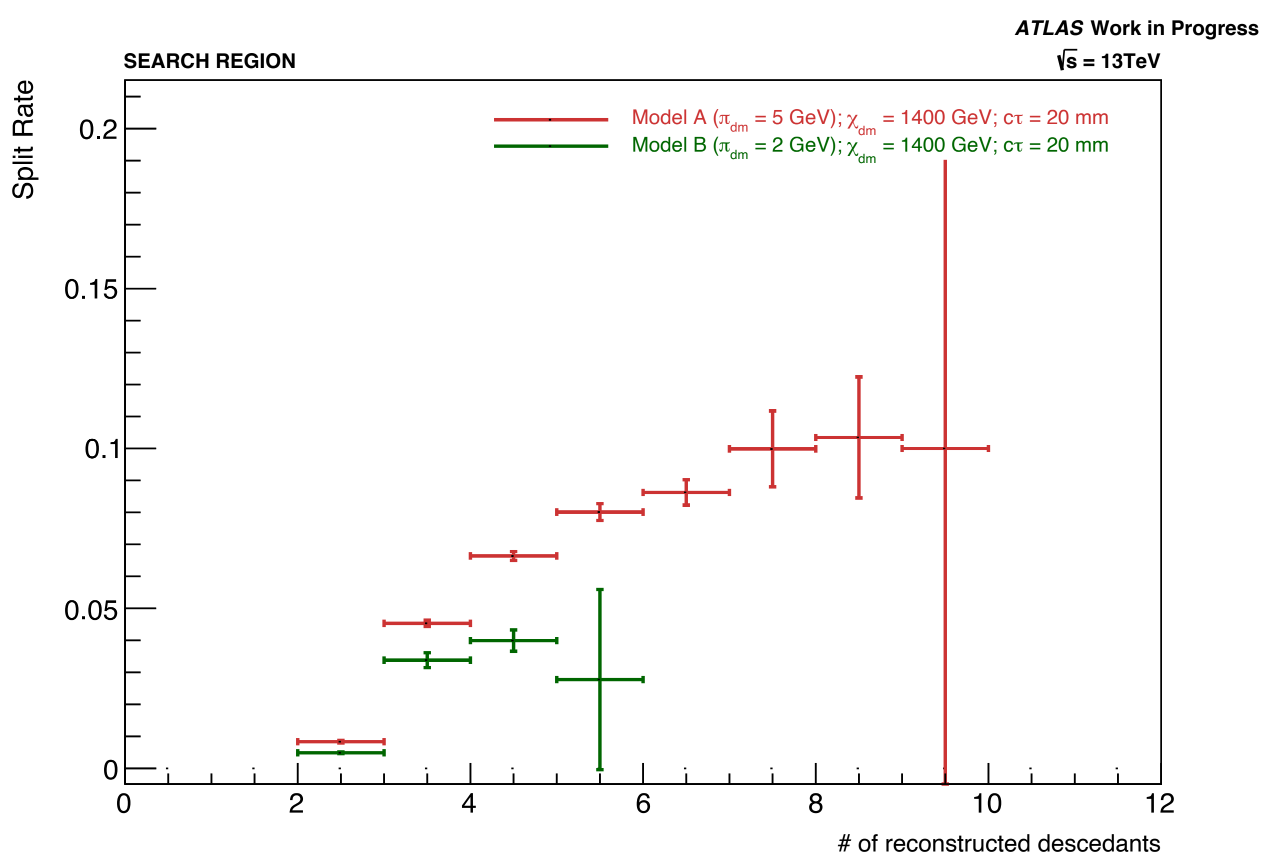

SEARCH REGION
√s = 13TeV
Model C (π_{dm} = 10 GeV); χ_{dm} = 1400 GeV; cτ = 75 mm
Model C (π_{dm} = 10 GeV); χ_{dm} = 1000 GeV; cτ = 5 mm
Model C (π_{dm} = 10 GeV); χ_{dm} = 600 GeV; cτ = 2 mm
Probability/0.02

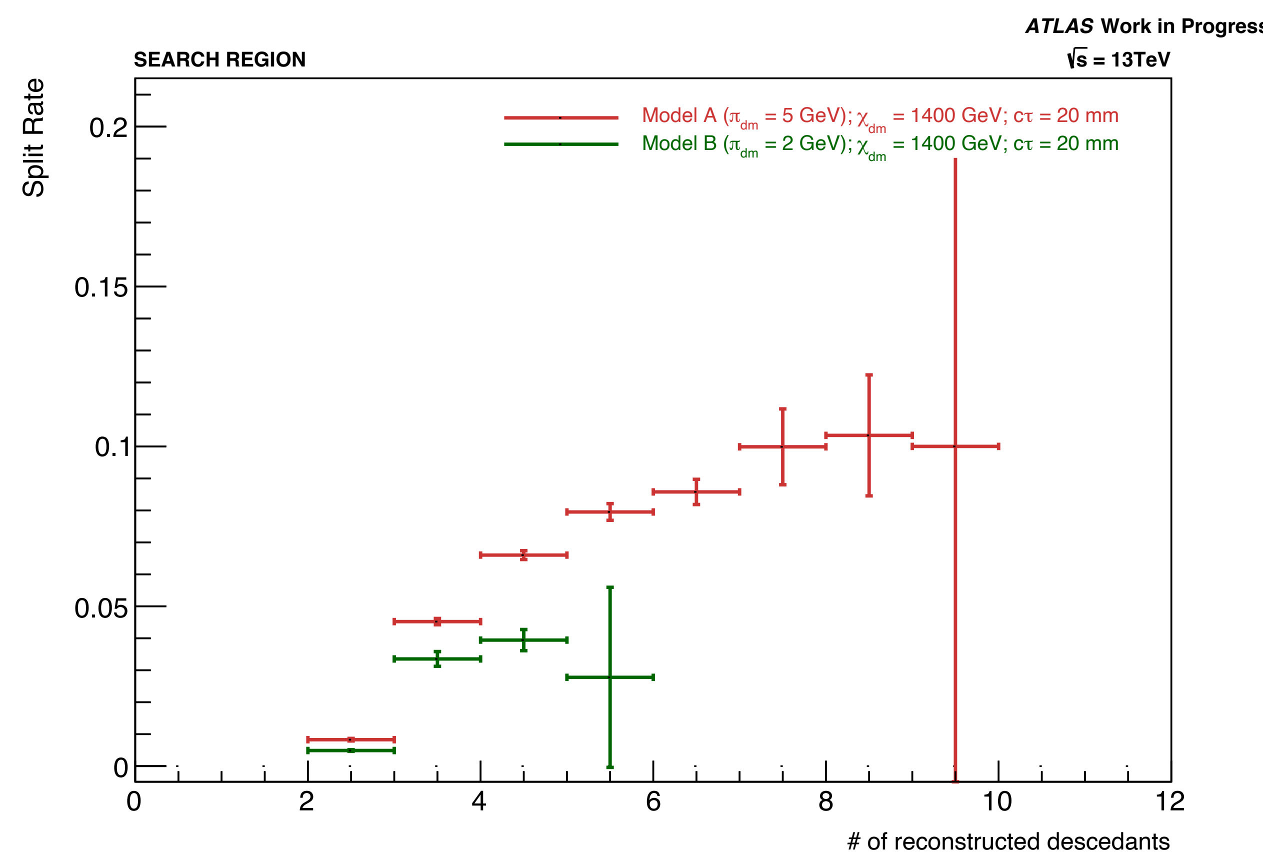

ATLAS Work in Progress
SEARCH REGION
√s = 13TeV
Split Rate
# of reconstructed descedants
Model A (π_{dm} = 5 GeV); χ_{dm} = 1400 GeV; cτ = 20 mm
Model B (π_{dm} = 2 GeV); χ_{dm} = 1400 GeV; cτ = 20 mm
Model C (π_{dm} = 10 GeV); χ_{dm} = 1400 GeV; cτ = 75 mm
Model D (π_{dm} = 20 GeV); χ_{dm} = 1400 GeV; cτ = 2 mm
Model E (π_{dm} = 0.8 GeV); χ_{dm} = 1400 GeV; cτ = 75 mm


ATLAS Work in Progress
SEARCH REGION
√s = 13TeV
Split Rate
# of reconstructed descedants
Model A (π_{dm} = 5 GeV); χ_{dm} = 1400 GeV; cτ = 20 mm
Model B (π_{dm} = 2 GeV); χ_{dm} = 1400 GeV; cτ = 20 mm
Model C (π_{dm} = 10 GeV); χ_{dm} = 1400 GeV; cτ = 75 mm
Model D (π_{dm} = 20 GeV); χ_{dm} = 1400 GeV; cτ = 2 mm
Model E (π_{dm} = 0.8 GeV); χ_{dm} = 1400 GeV; cτ = 75 mm


ATLAS Work in Progress
√s = 13TeV
SEARCH REGION
Split Rate
Model B (π_dm = 2 GeV); χ_dm = 1400 GeV; cτ = 20 mm
Model B (π_dm = 2 GeV); χ_dm = 1000 GeV; cτ = 5 mm
Model B (π_dm = 2 GeV); χ_dm = 600 GeV; cτ = 300 mm
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
# of reconstructed descedants


ATLAS Work in Progress
√s = 13TeV
SEARCH REGION
Split Rate
Model B (π_dm = 2 GeV); χ_dm = 1400 GeV; cτ = 20 mm
Model B (π_dm = 2 GeV); χ_dm = 1000 GeV; cτ = 5 mm
Model B (π_dm = 2 GeV); χ_dm = 600 GeV; cτ = 300 mm
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
# of reconstructed descedants


ATLAS Work in Progress
√s = 13TeV
SEARCH REGION
Split Rate
Model A (π_dm = 5 GeV); χ_dm = 1400 GeV; cτ = 20 mm
Model B (π_dm = 2 GeV); χ_dm = 1400 GeV; cτ = 20 mm
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
# of reconstructed descedants


ATLAS Work in Progress
√s = 13TeV
SEARCH REGION
Split Rate
Model A (π_dm = 5 GeV); χ_dm = 1400 GeV; cτ = 20 mm
Model B (π_dm = 2 GeV); χ_dm = 1400 GeV; cτ = 20 mm
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
# of reconstructed descedants