

Contact info: <u>bingxuan.liu@cern.ch</u> Skype: prbbing Nordita Workshop: Is There Still Room For Naturalness (April 18-29th 2022, Stockholm)

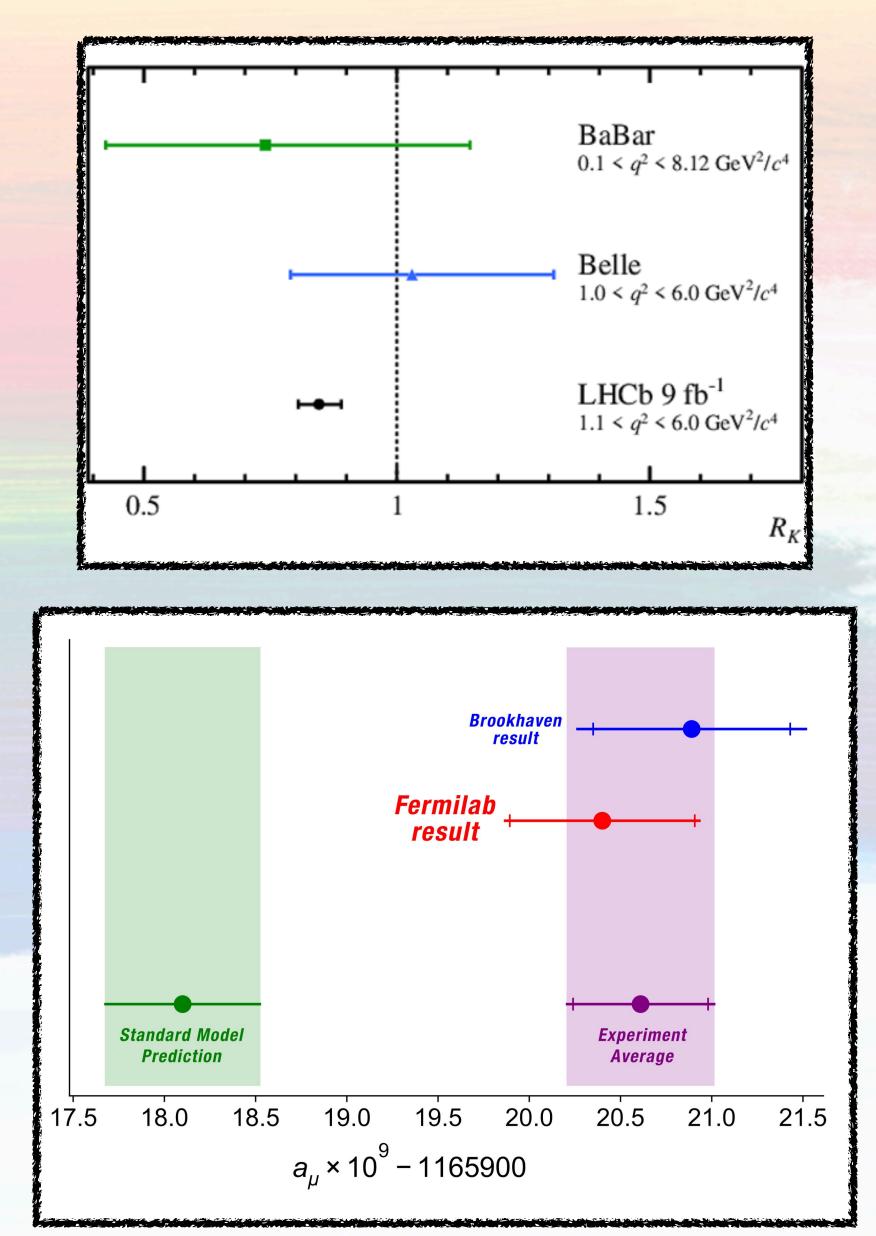
# **Non-natural Signatures in the Pursuit of Naturalness**

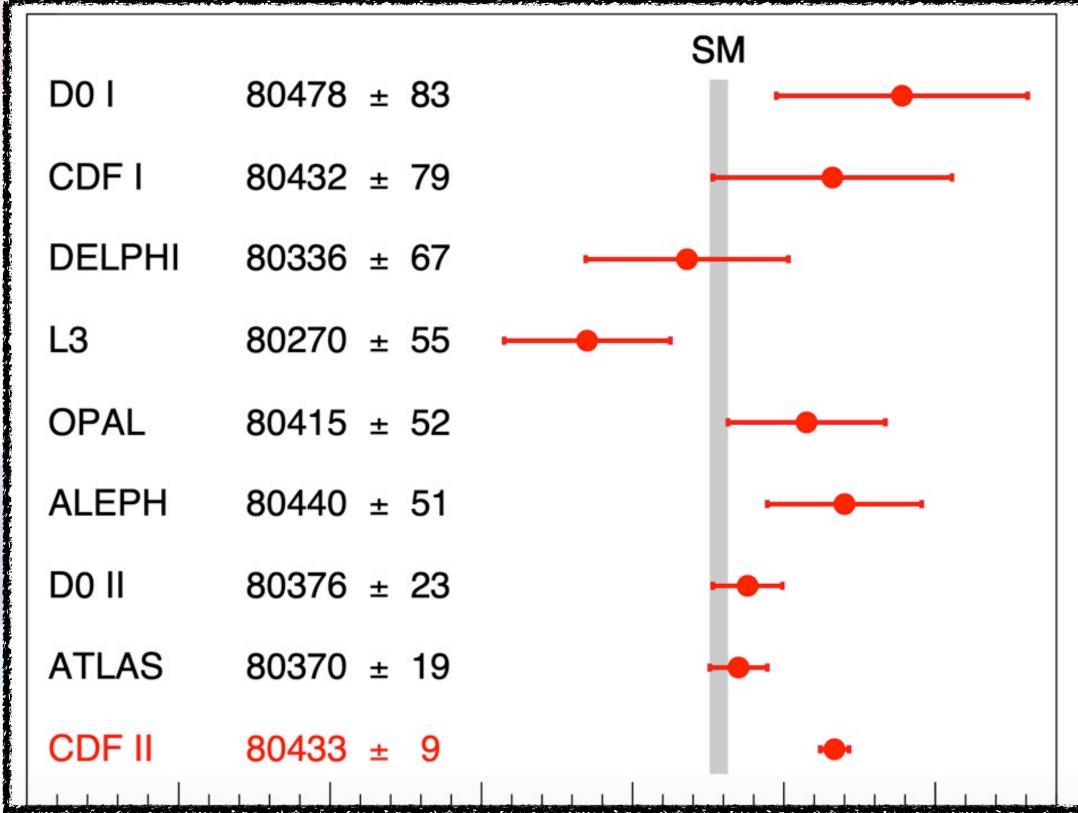
Bingxuan Liu Simon Fraser University

SFU



### **Exciting Time!**





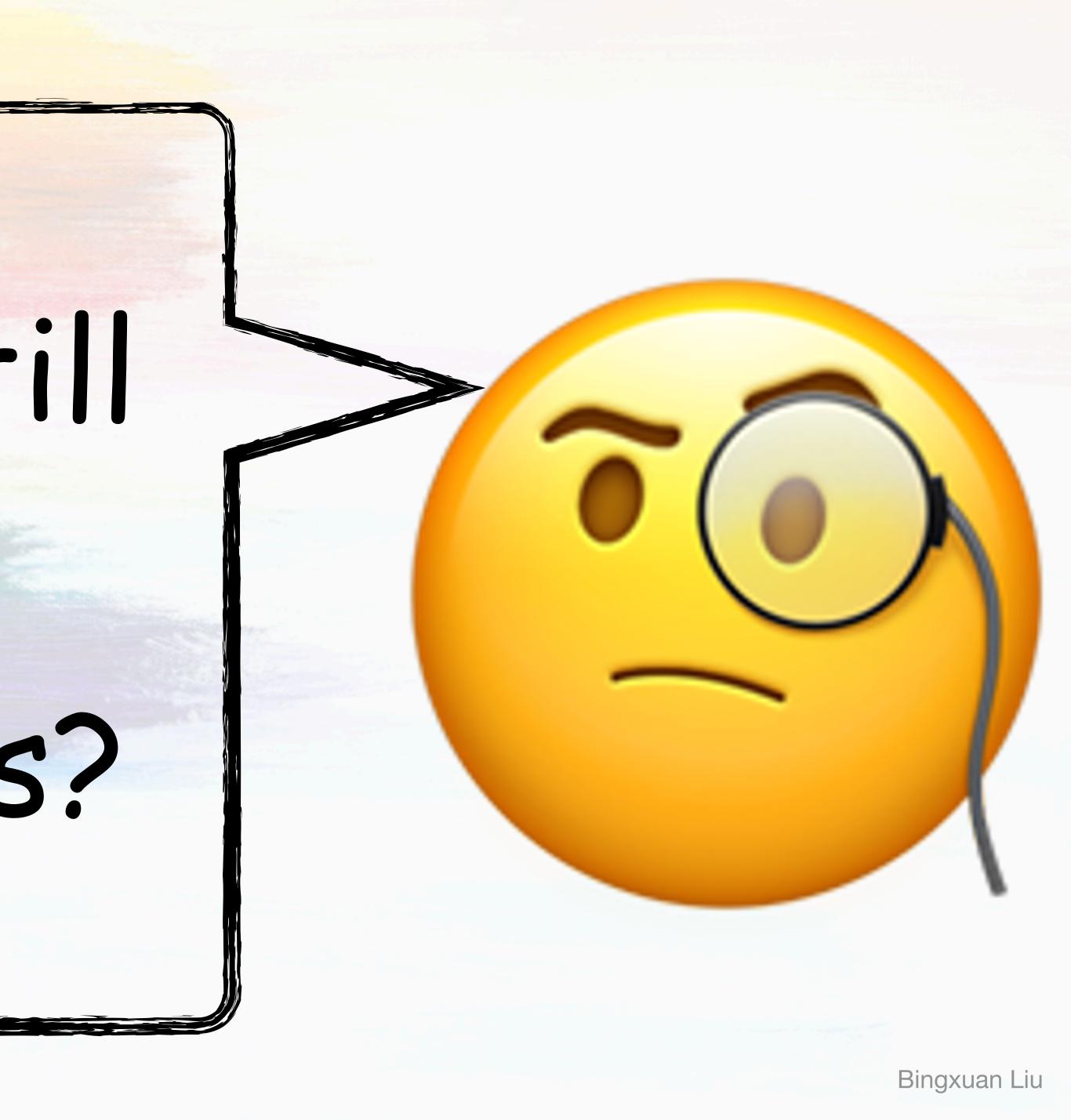


Hmmm..Ok what do these tell me. It looks like searches involving third generation is important, precision measurement is also vital and maybe something a bit more crazy???? So ....





# Is there still room for naturalness?



### **Definition of Naturalness...A Different Point of View**

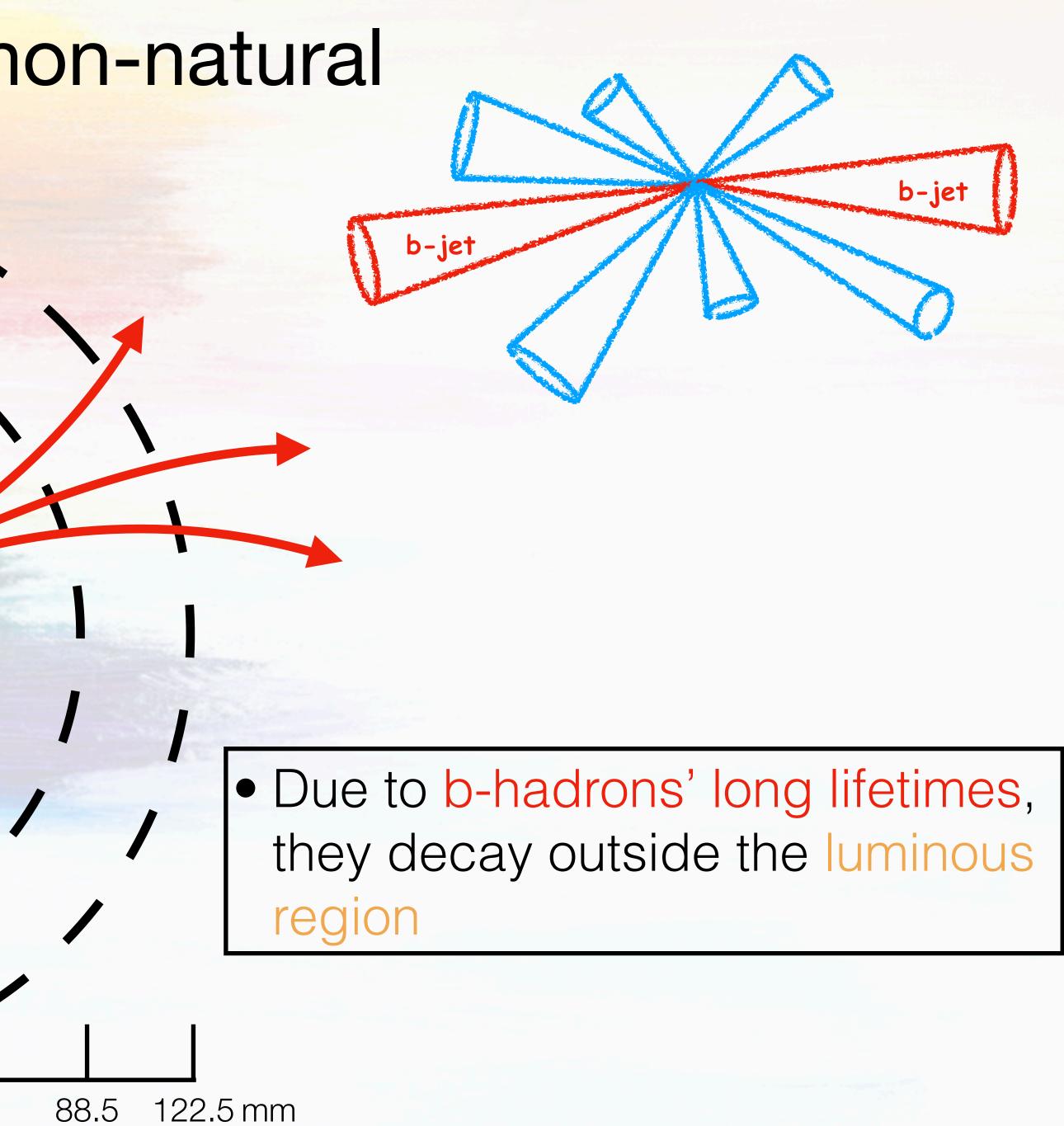
**Inner Tracker** Layers

- The detectors are cylindrically symmetric
  - A natural physics object is originated from the luminous region



### B-hadron Decay: A bit non-natural

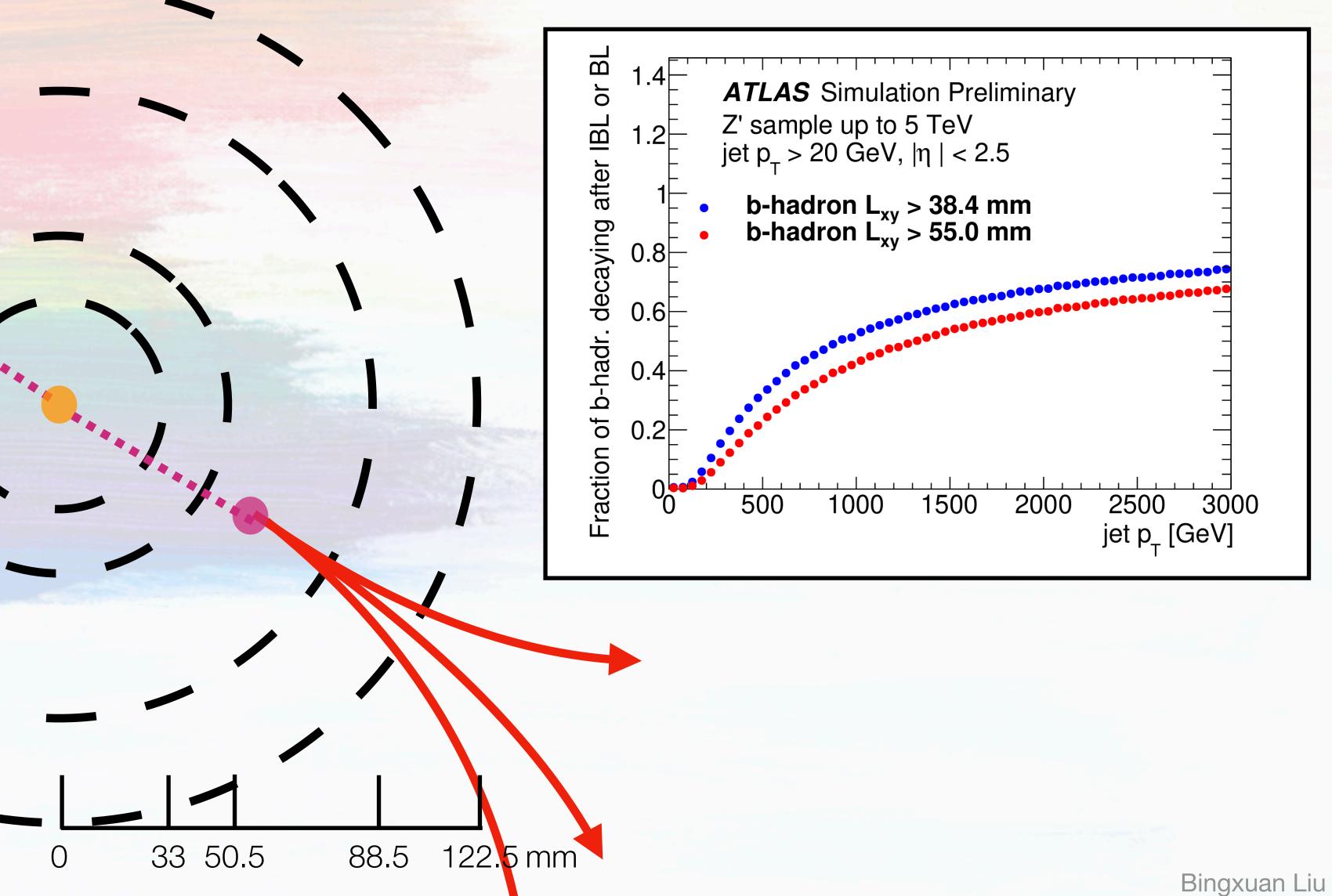
Inner Tracker Layers



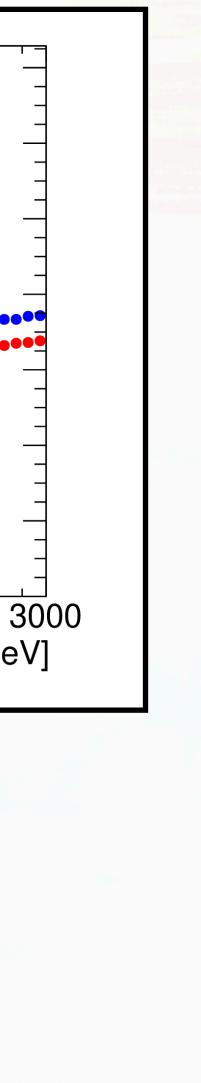


# B-hadron Decay: A bit non-natural

**Inner Tracker** Layers



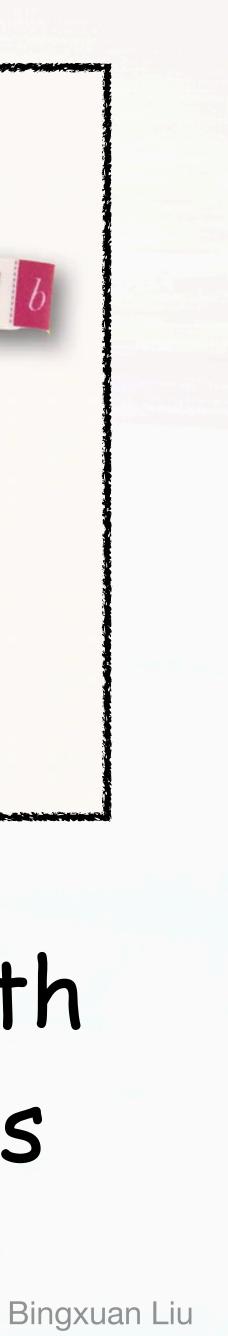




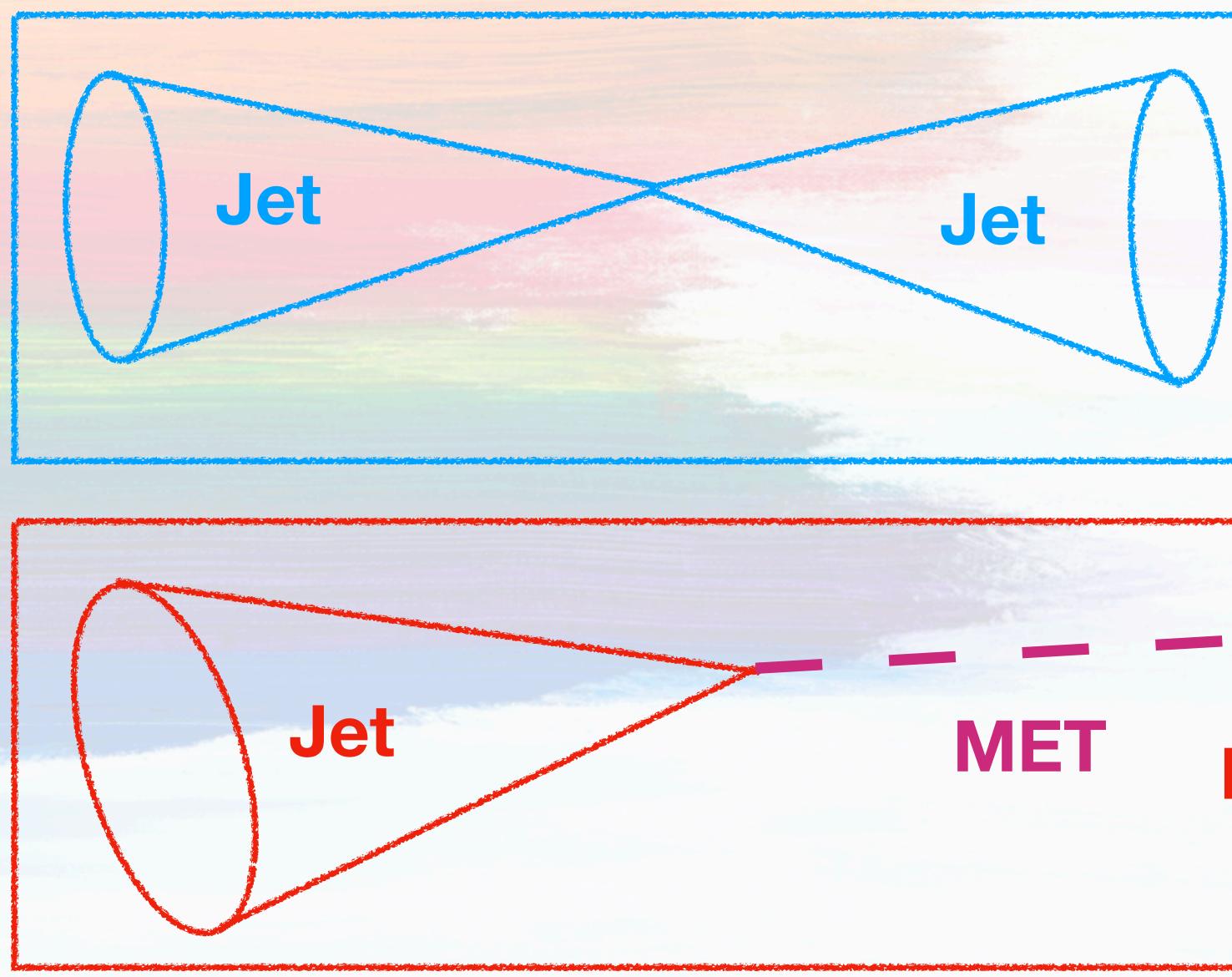




# Inclusive search with heavy flavor quarks



### **Flagship Inclusive Searches**



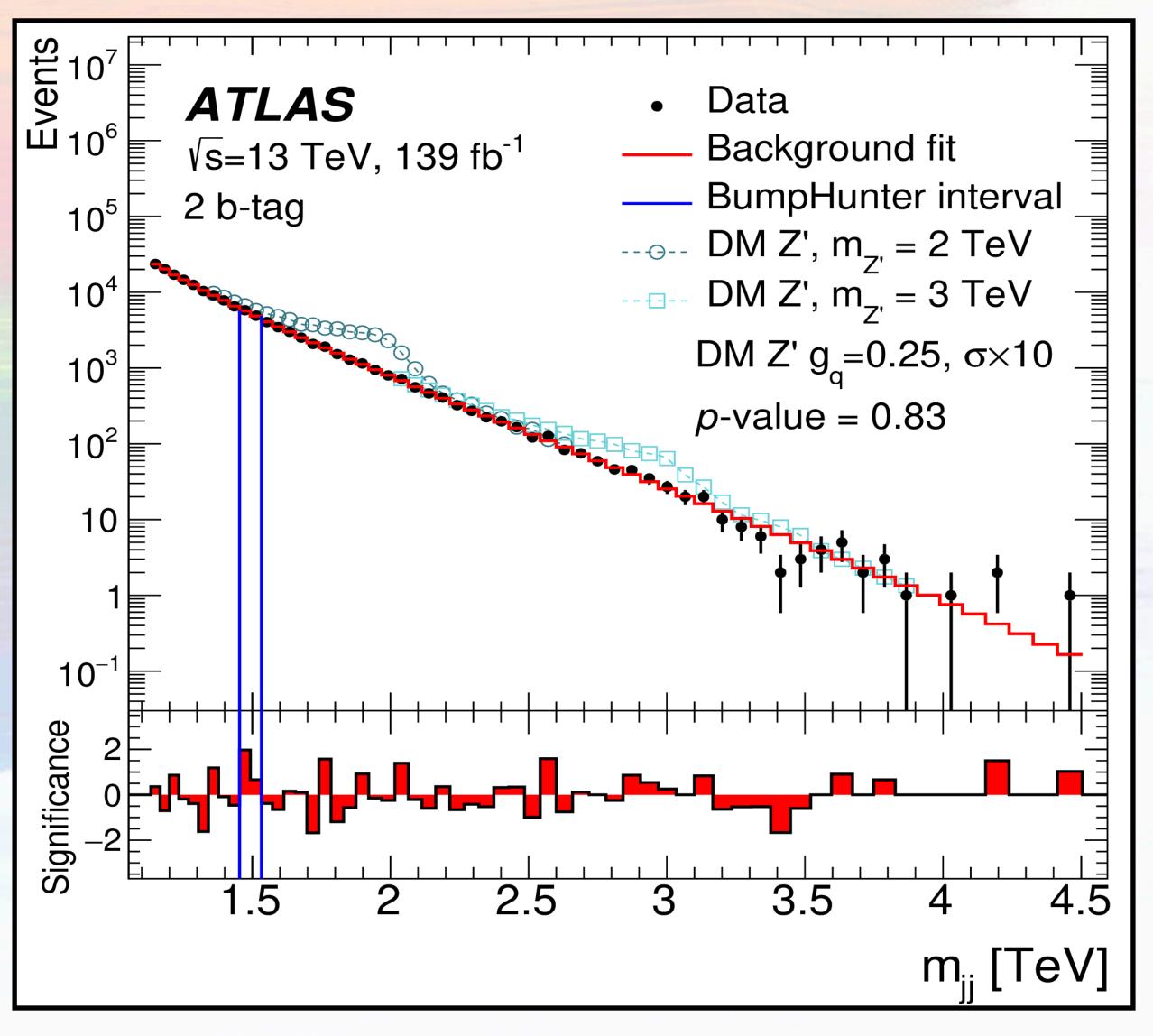
### **Dijet searches Heavy particle**

### **Mono-jet searches** Dark matter

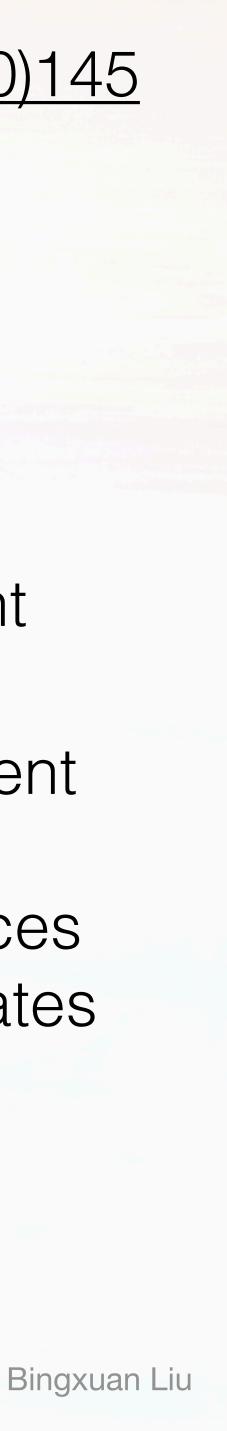


### Inclusive Di-(b)-jet Search

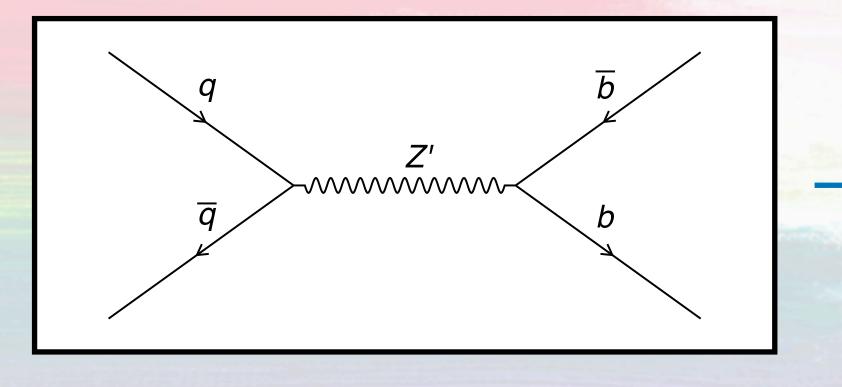
• ATLAS has published the full Run 2 inclusive di-(b)-jet search



- Very powerful/important search
- Setting the most stringent limits on models with narrow heavy resonances in the hadronic final states



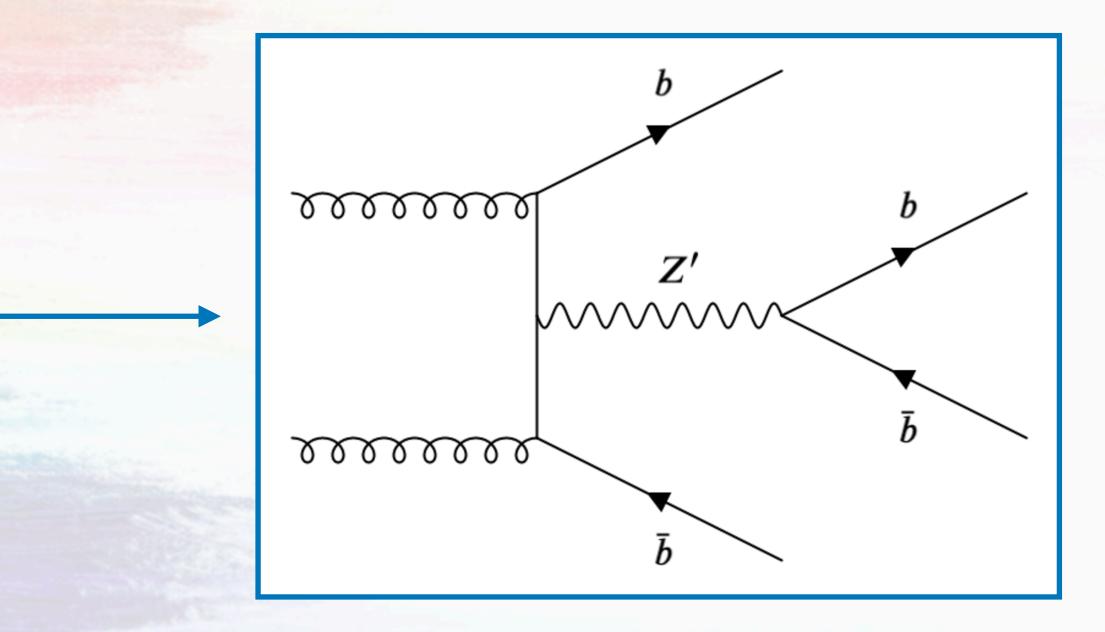
# Heavy Particle Search with Associated b-quarks



• It has to be produced in association with additional b-quarks at the LHC • Multi-b-jet final state, two from the heavy particle decay and two from the

- spectator quarks
- - Lepton Universality Violating Z' [JHEP07(2015)142, Admir, et.al]

### What if the new heavy particle is exclusively coupled to third generation

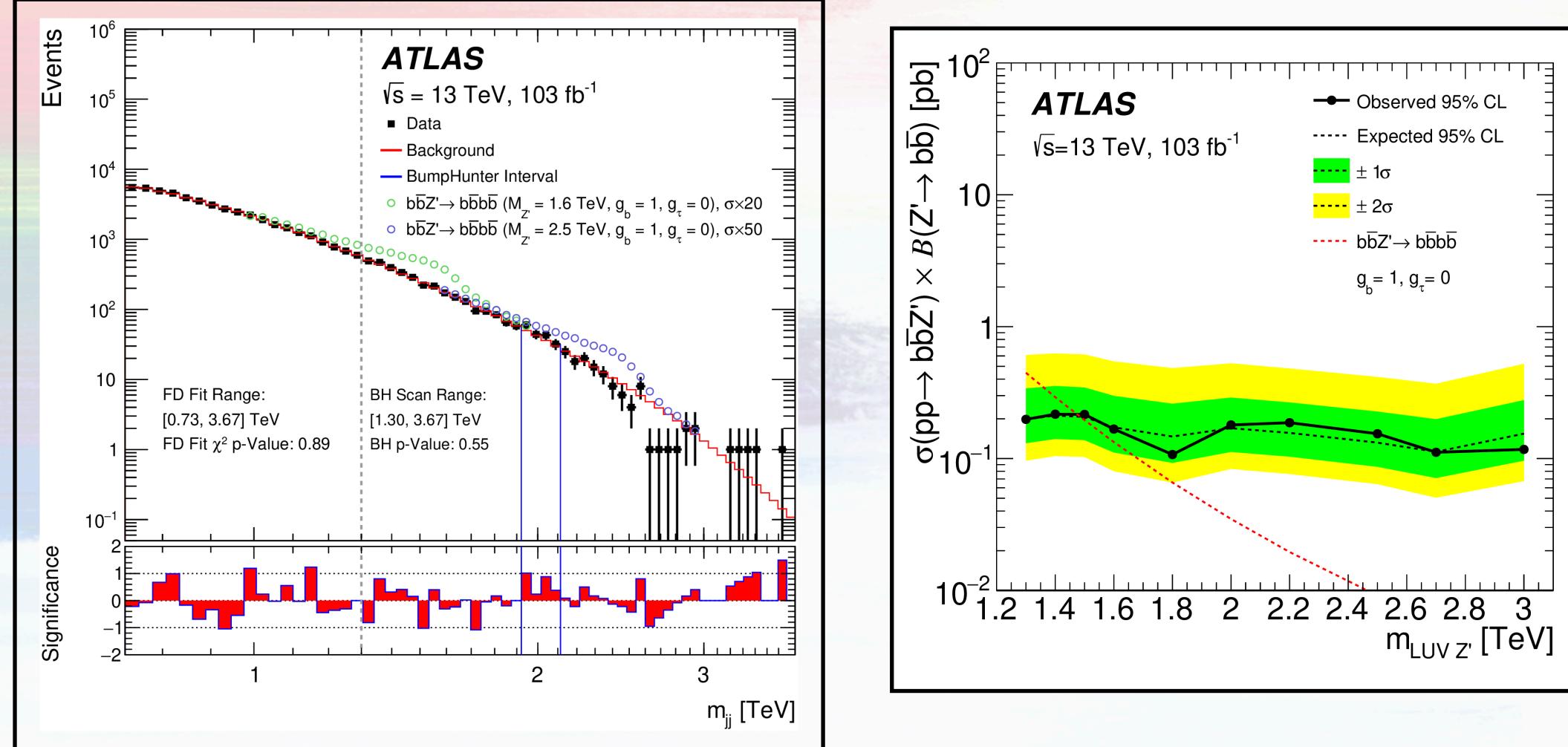


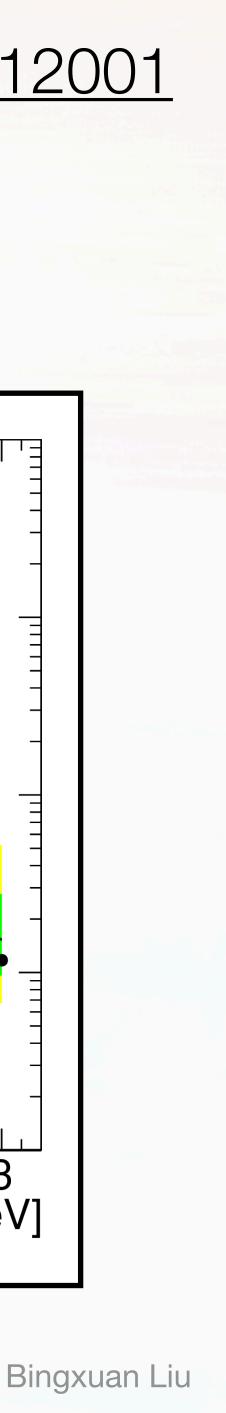
This type of Z' can incorporate the flavor physics anomalies observed in LHCb



### Lepton Universality Violating (LUV) Z' PhysRevD.105.012001

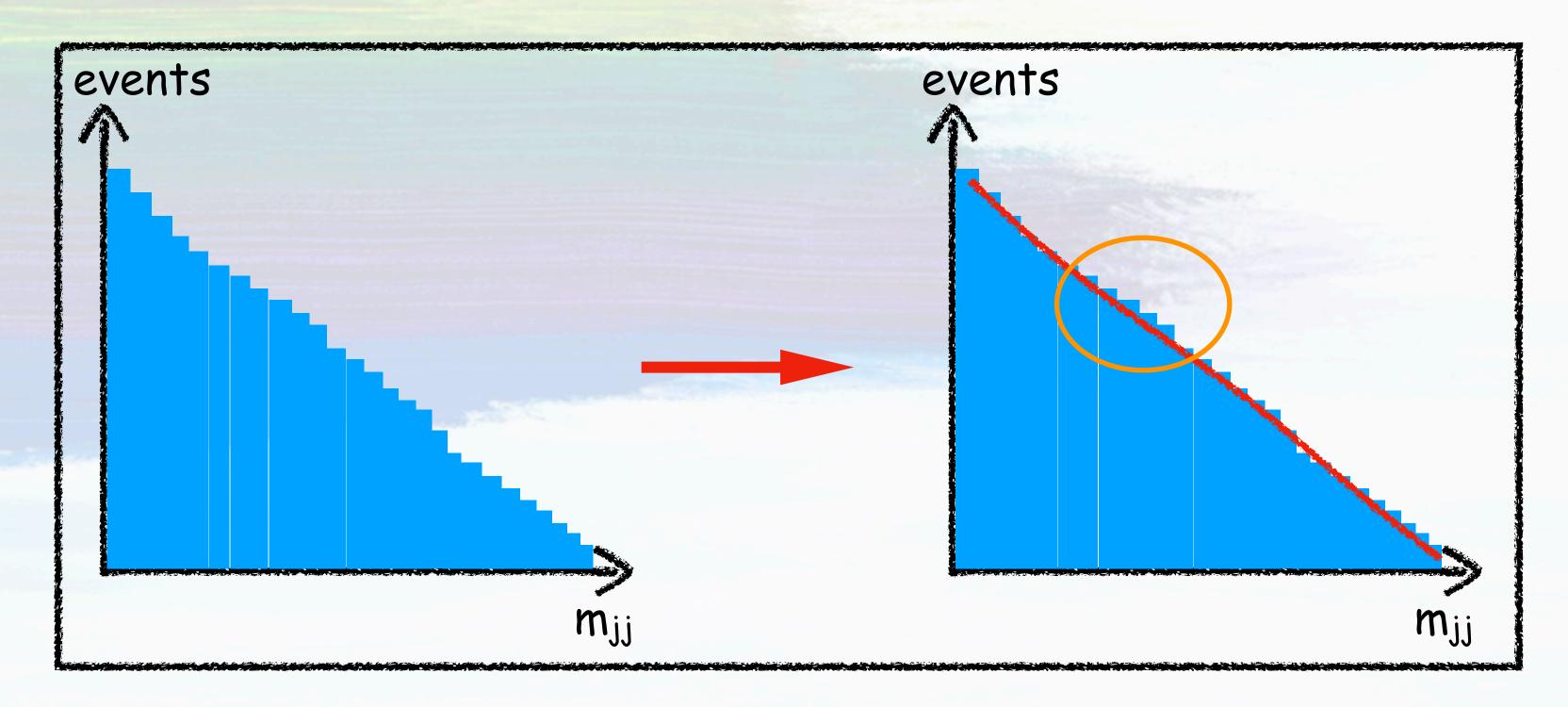
 No significant deviations are observed, limits are set on LUV Z' First coverage up to 3 TeV in this final state





### **Traditional Approach: Functional Fit**

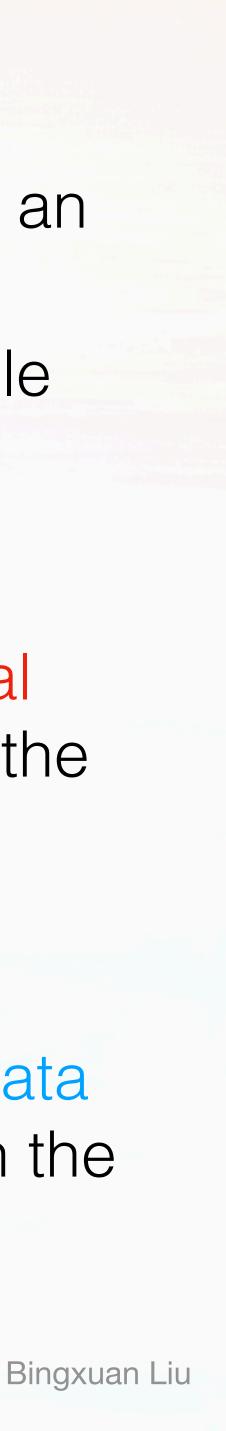
- enormous multi-jet background
  - Size
- Functional fit is widely applied



Heavy particle searches in hadronic final states usually have to deal with an

Multi-jet simulation has large theoretical uncertainties and limited sample

- Apply empirical functions to fit the data spectrum
- And look for significant deviations in data compared with the background fit



### **Traditional Approach: Functional Fit**

- enormous multi-jet background
  - size

# But empirical functions may Is there a more universal approach?

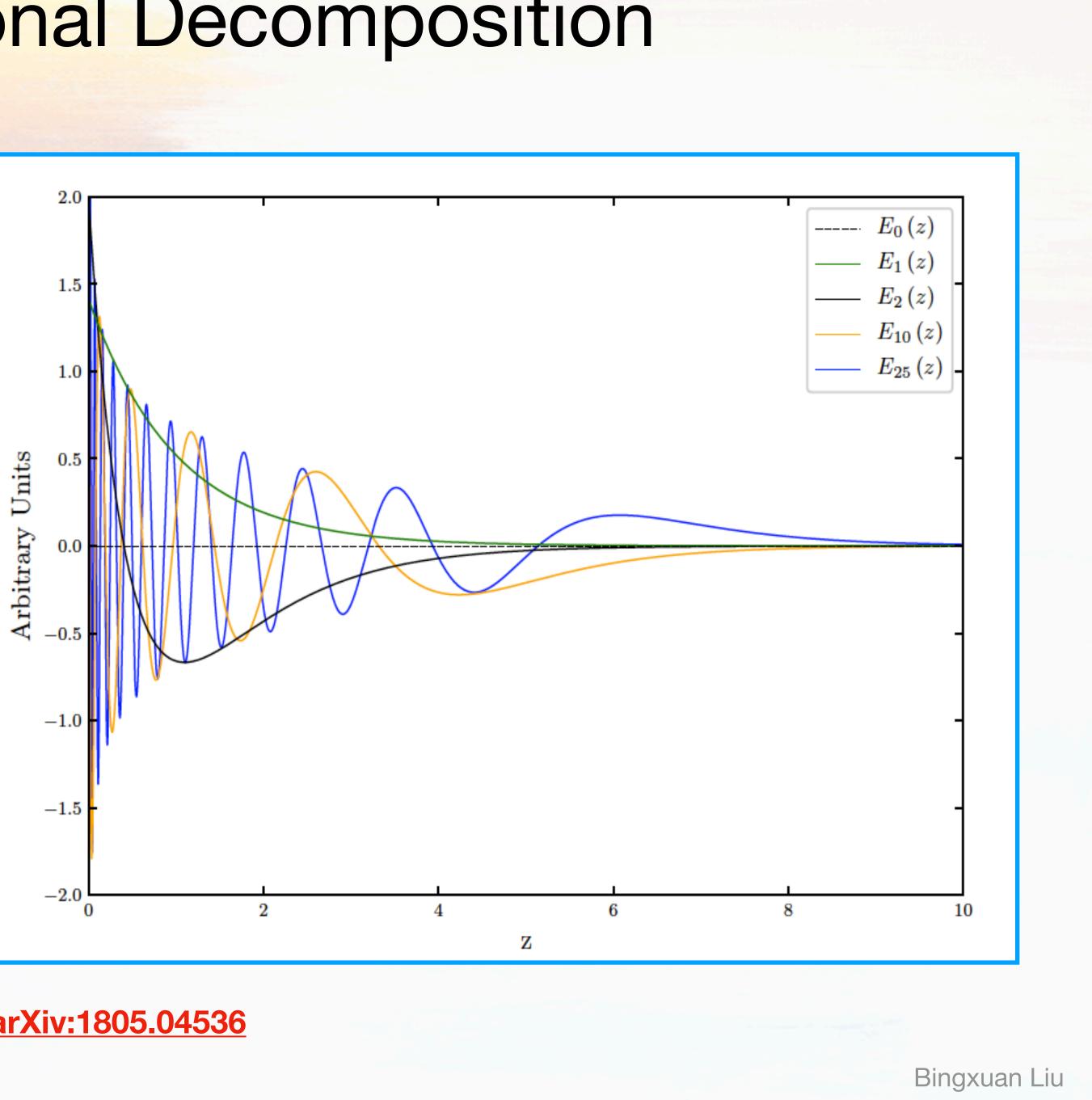
Heavy particle searches in hadronic final states usually have to deal with an

Multi-jet simulation has large theoretical uncertainties and limited sample



## **New Approach: Functional Decomposition**

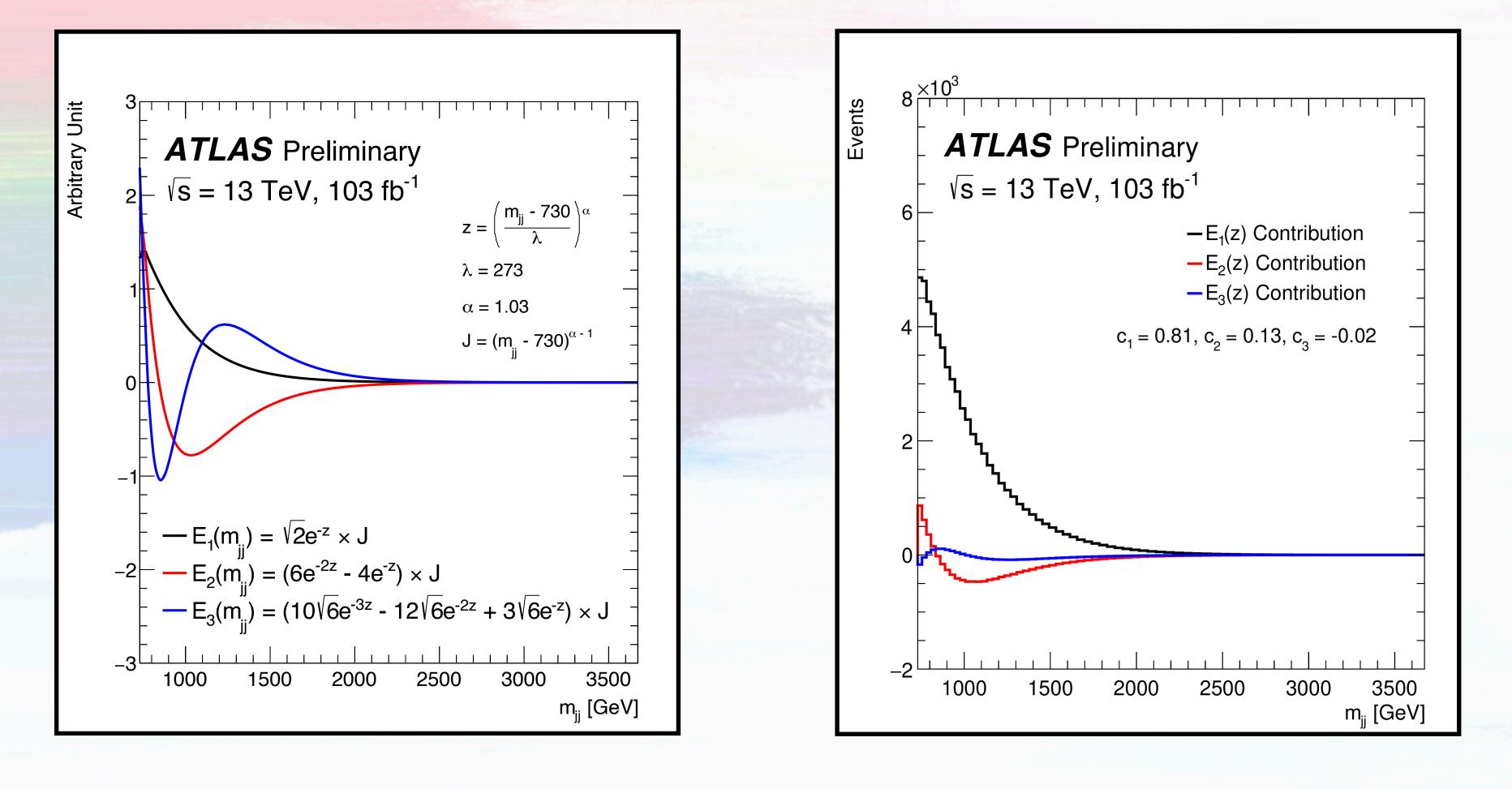
- Functional Decomposition
  - Using orthonormal basis
  - Analogous to Fourier Analysis
- An infinite series can describe any given spectrum
- Truncate the series so that it is sufficient to describe the background not incorporating new physics



arXiv:1805.04536

### **Decomposed Background**

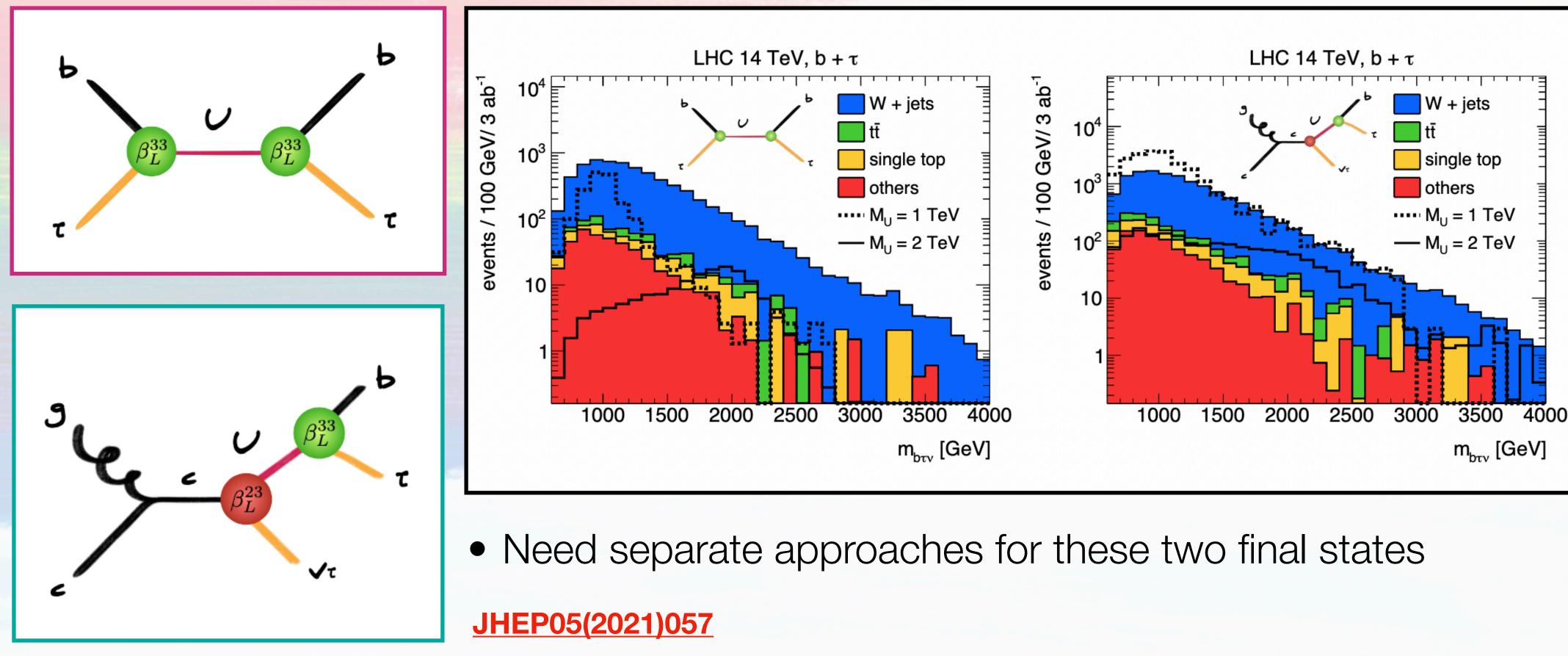
 Using three moments is sufficient to describe the background The background components are not physical as they come from mathematical forms



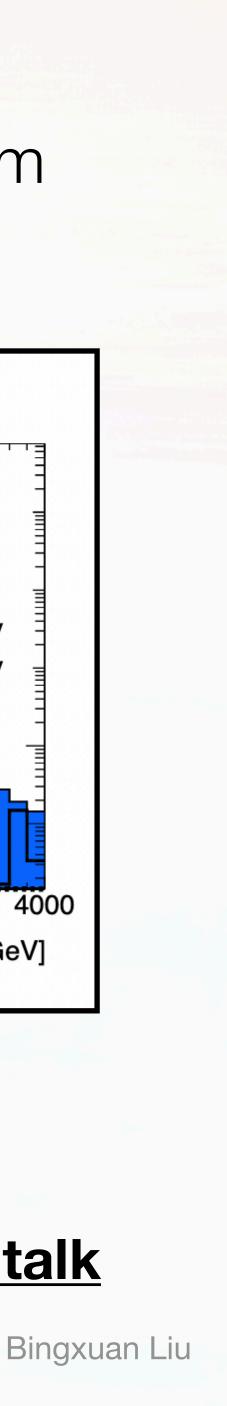
### PhysRevD.105.012001



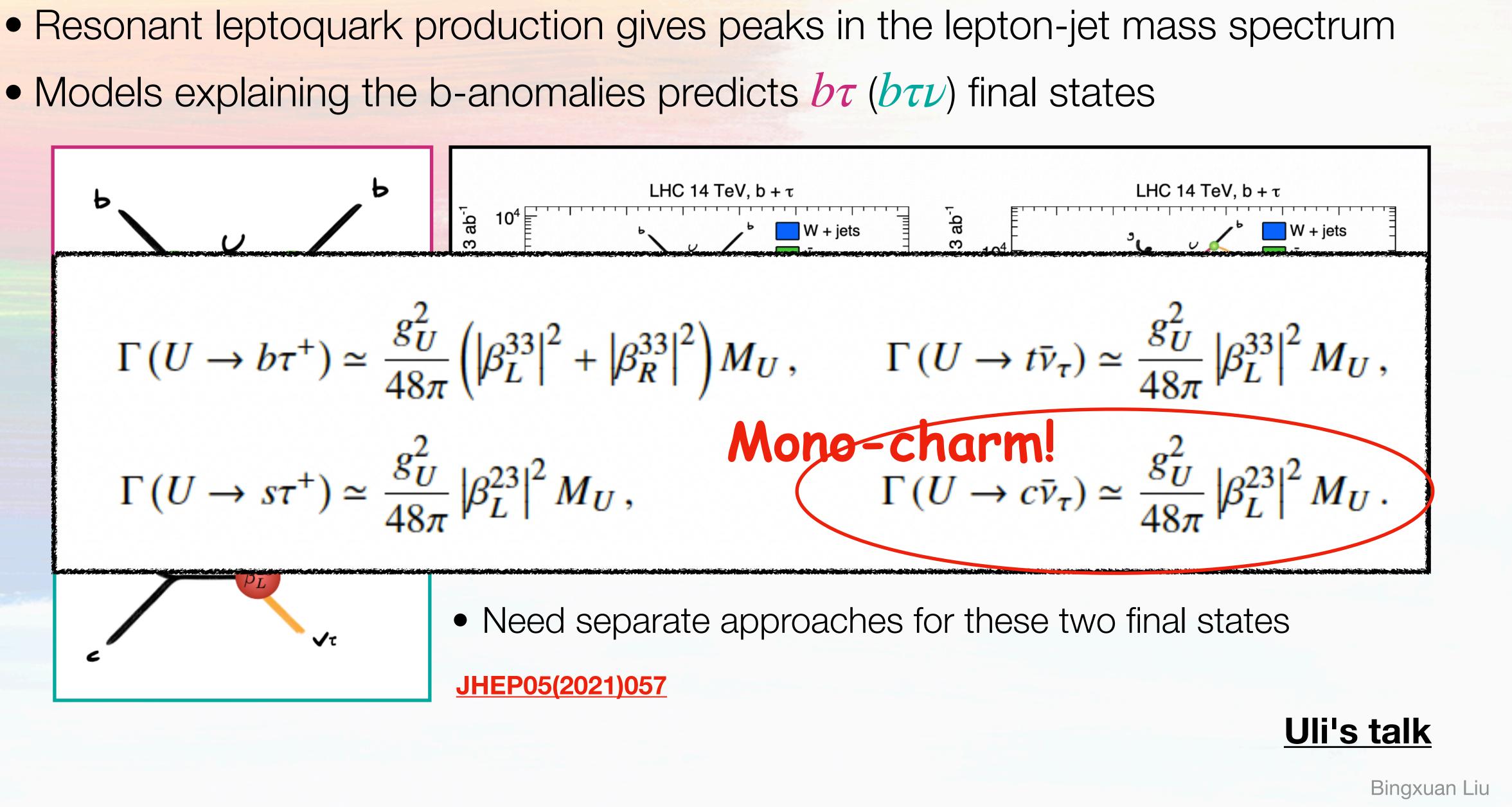
### Lepton Universality Violating Leptoquark Resonant leptoquark production gives peaks in the lepton-jet mass spectrum • Models explaining the *b*-anomalies predicts $b\tau$ ( $b\tau\nu$ ) final states



**Uli's talk** 

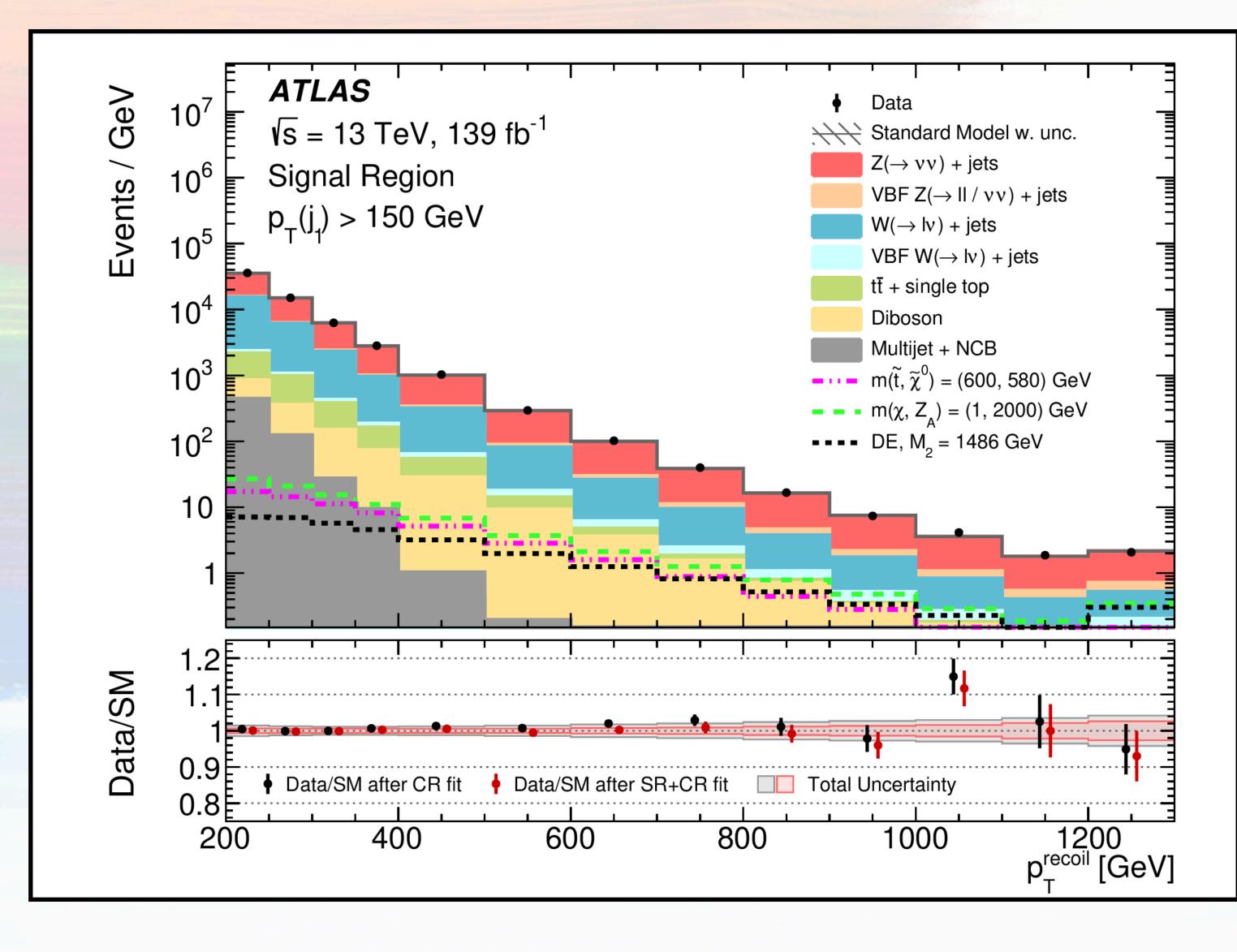


### How About Mono-jet?



### Inclusive Mono-jet

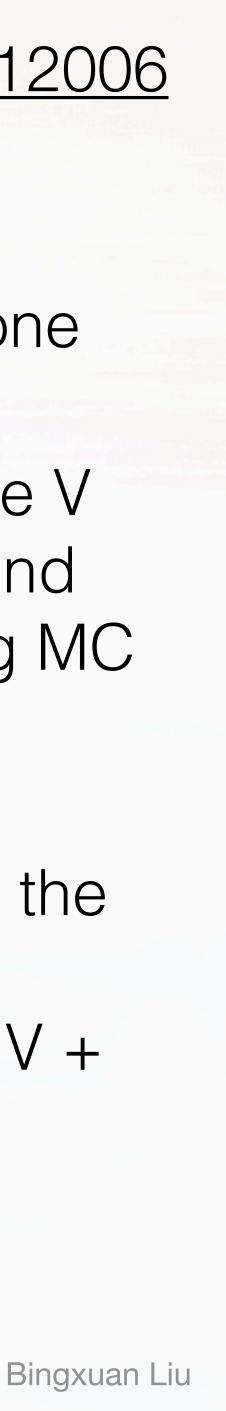
ATLAS has published the full Run 2 inclusive mono-jet search



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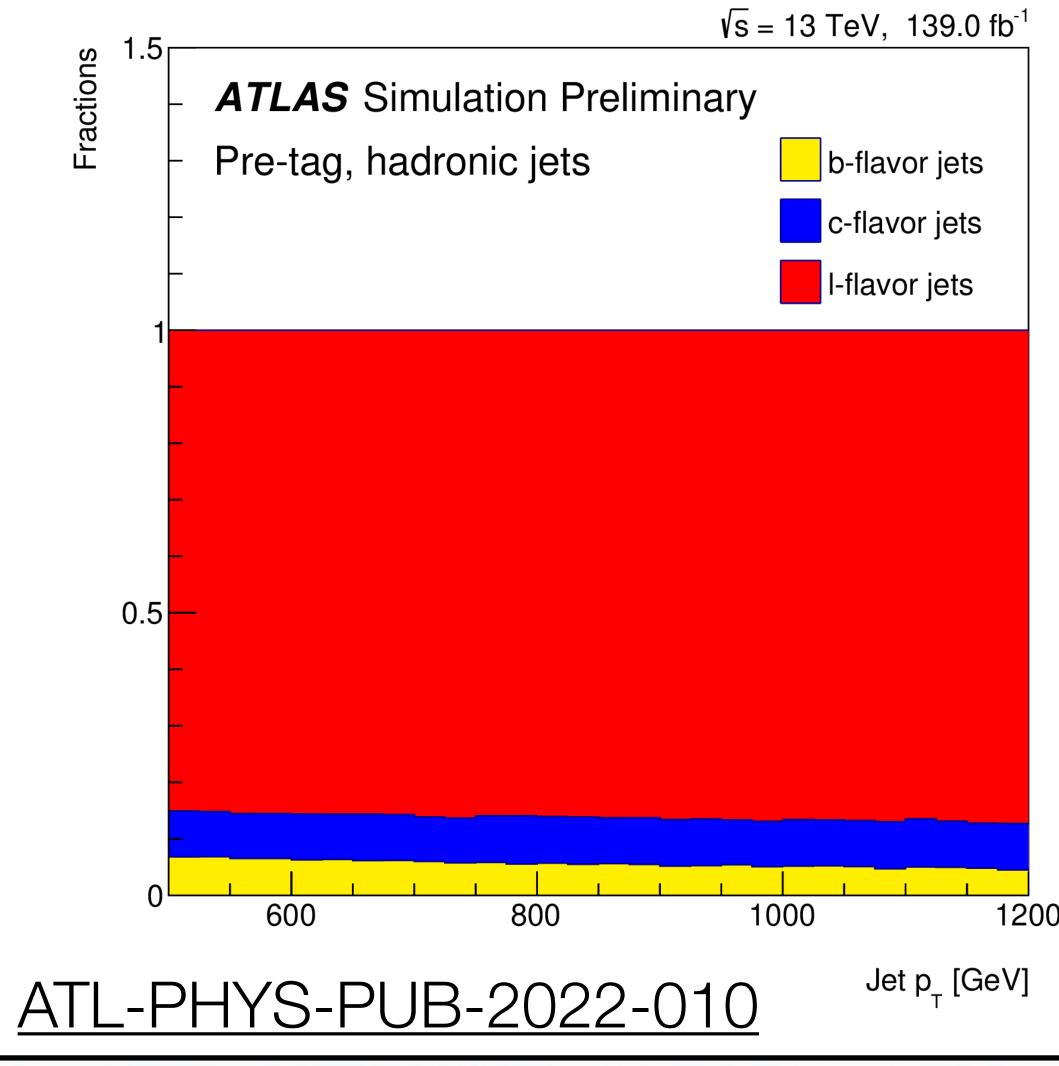
### PhysRevD.103.112006

- Excellent work done by the theorists
  - Amazing precise V + jets background estimation using MC
- Mono-HF (b or c) could have been hiding here given the large light jet contribution from V + jets

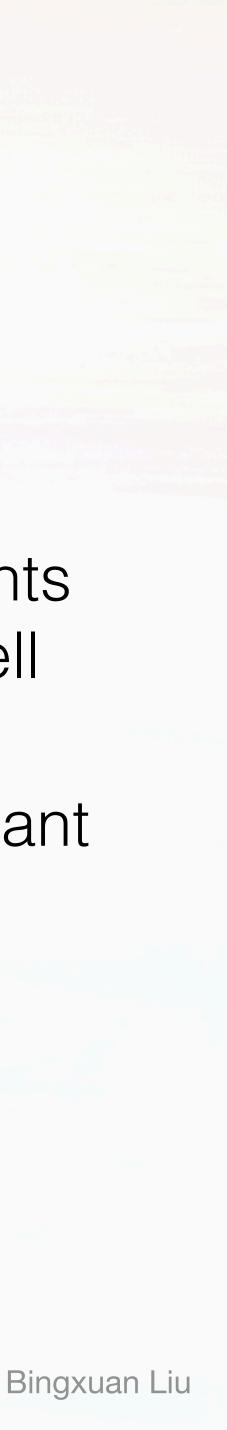


### Inclusive Mono-jet

Multi-jet and V + jets are dominated by light flavor jets

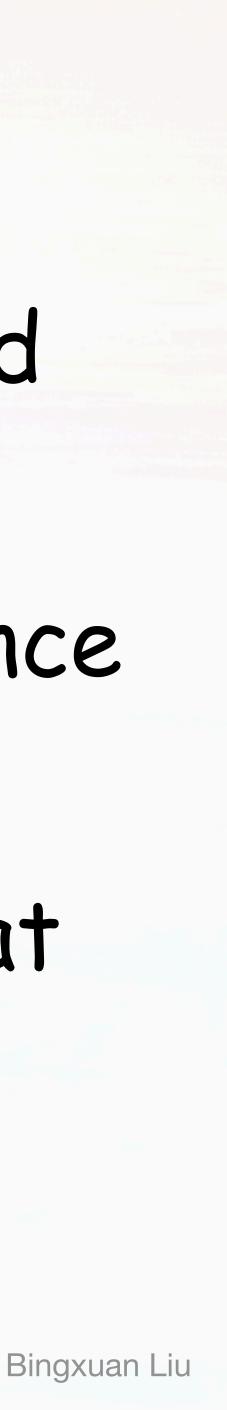


- Better sensitivities can be achieved via bottom/charmtagging
- However V + HF measurements and simulations are not as well studied as the inclusive case
- Theory inputs are very important and good opportunity to collaborate again

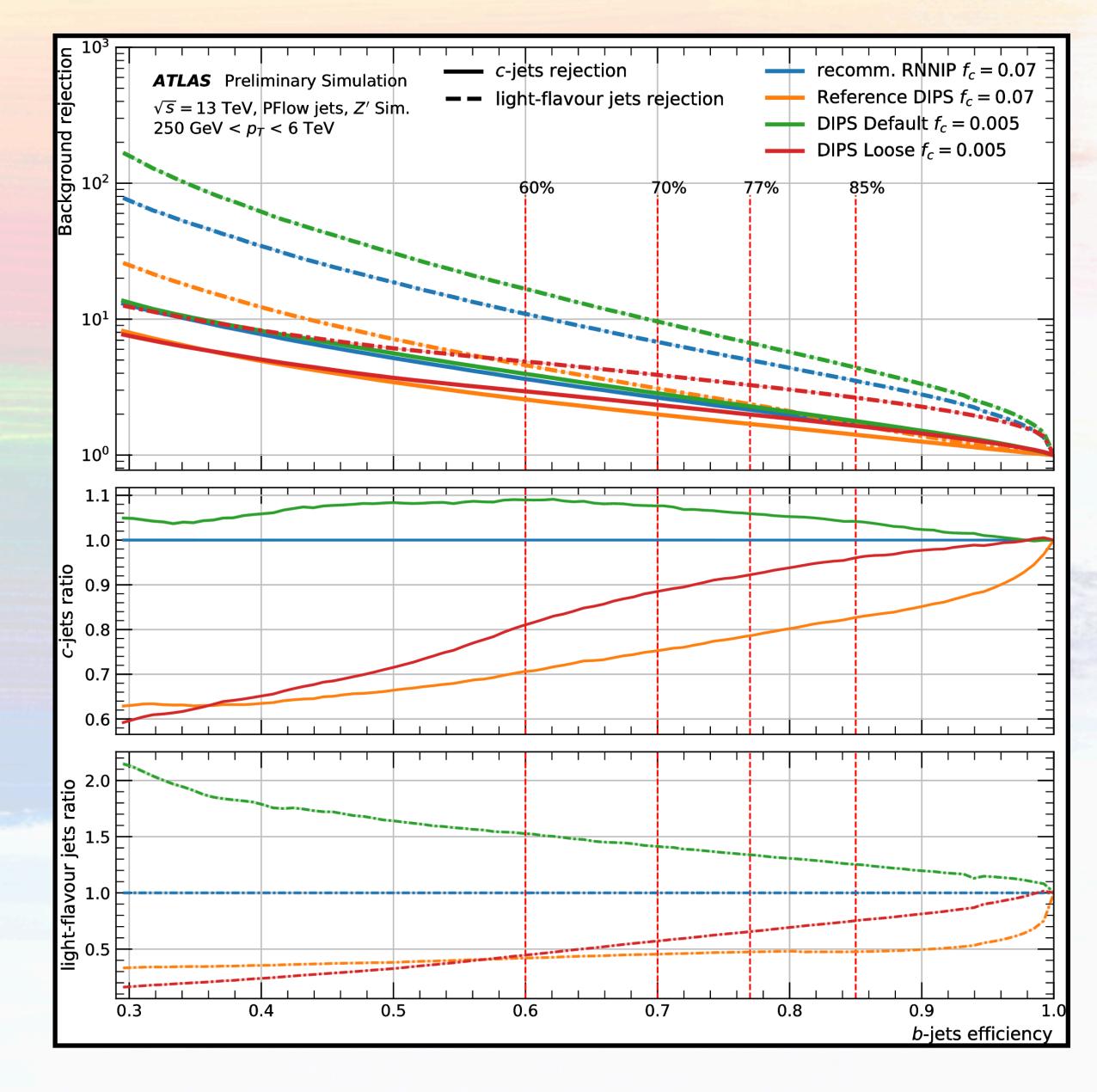




# Heavy flavor associated production mode Flavor tagging performance at high energy scale Heavy flavor modeling at high energy scale



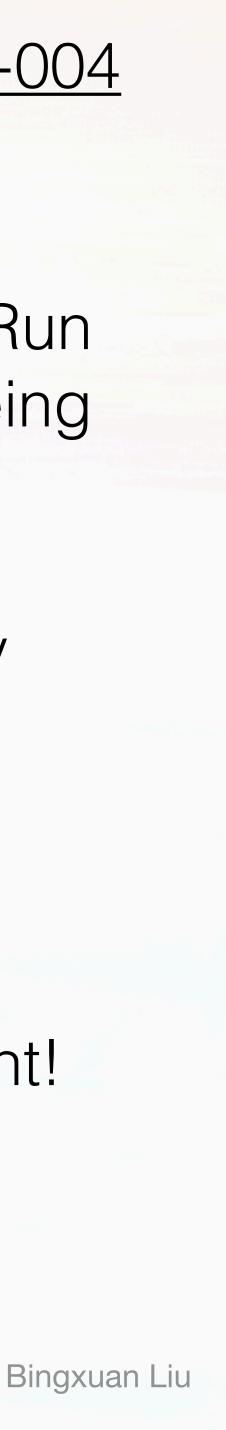
### New b-Tagger For Run 3



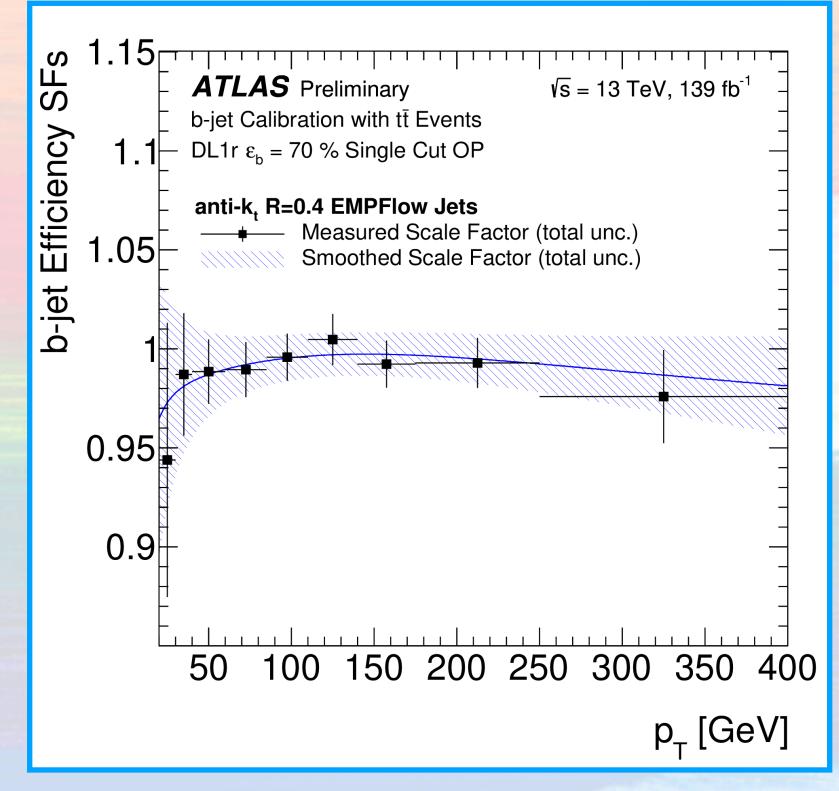
22

### FTAG-2021-004

- New b-taggers for ATLAS Run 3 physics programs are being developed
- Already seen great improvement in preliminary results for high pT jets
- The reason why projected sensitivities are often pessimistic
  - Performance improvement!

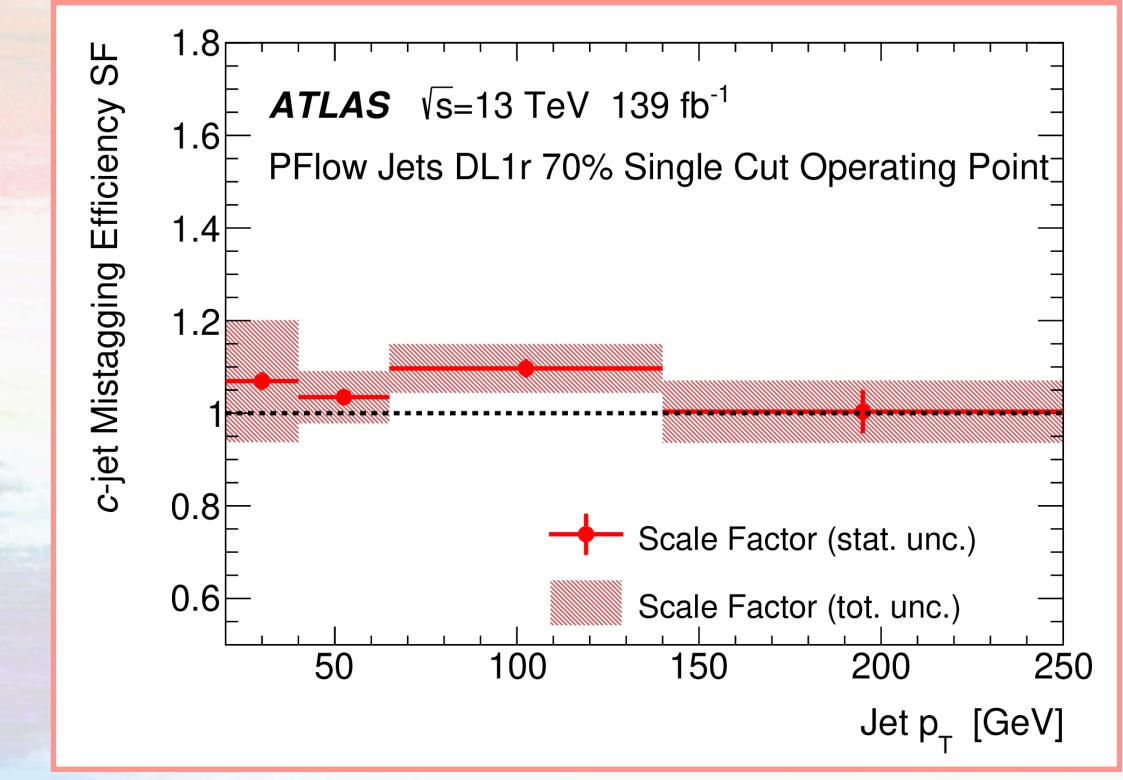


### **Uncovered Phase Space** FTAG-2021-001

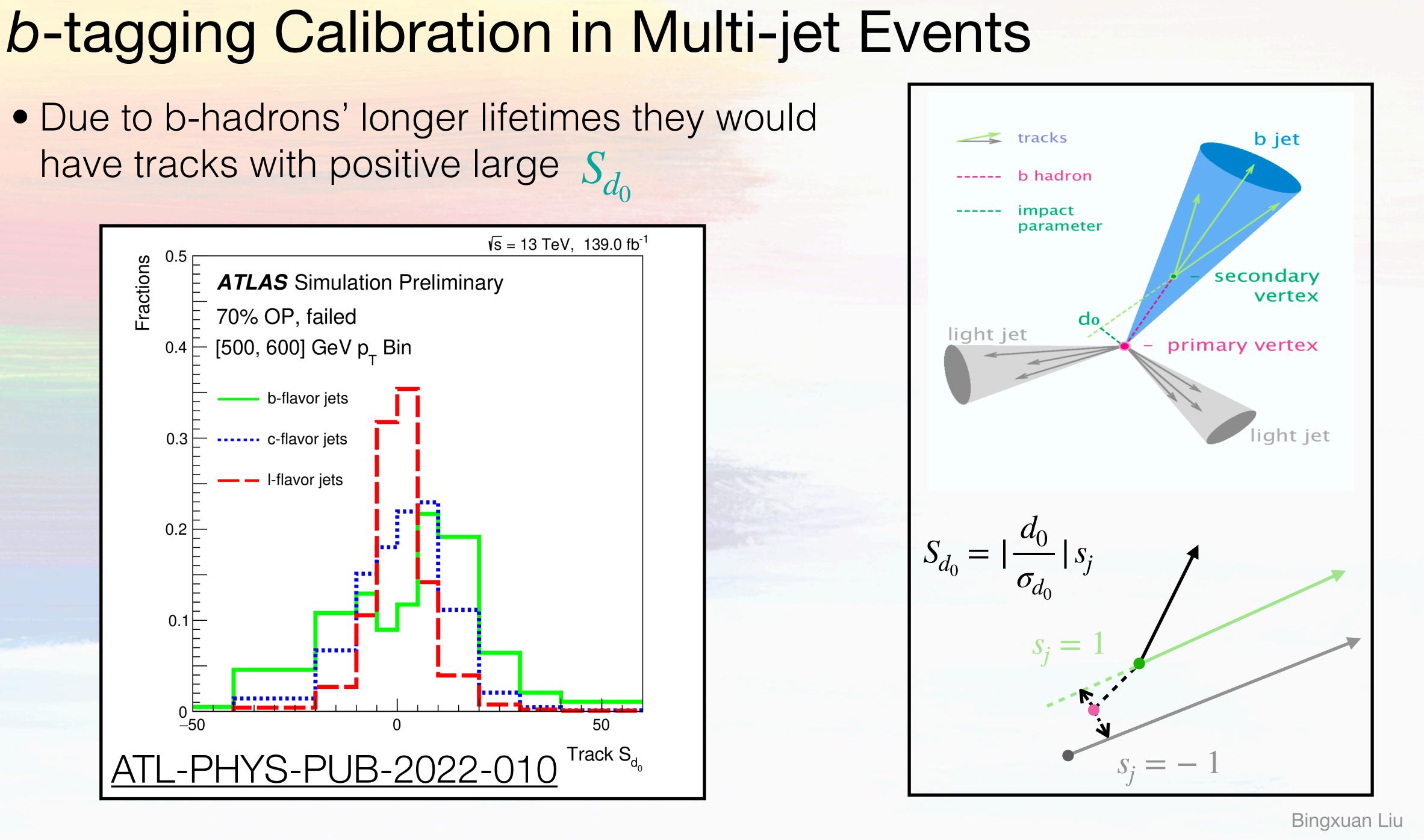


 TeV scale jets are considered in these searches but the tagging performance is only studied up to a few hundreds GeV in data

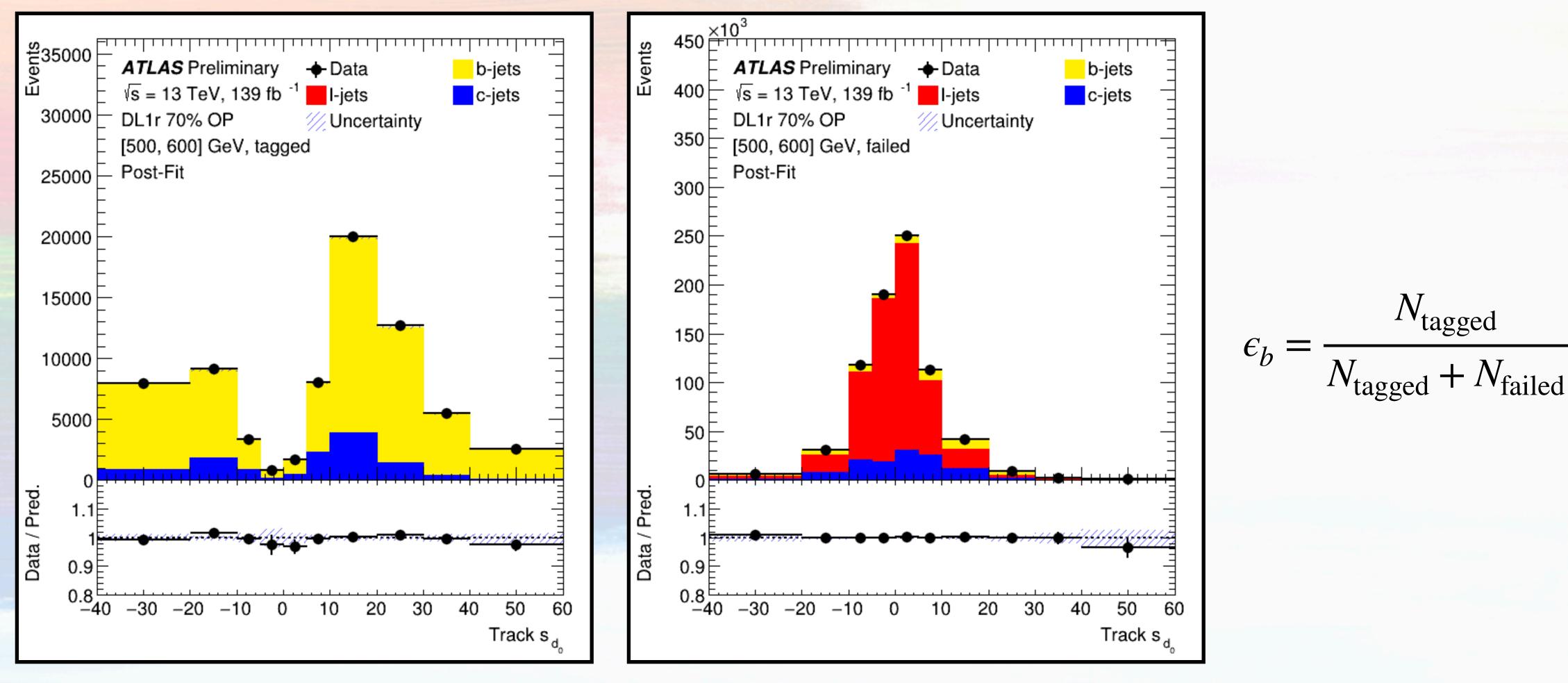
### Eur. Phys. J. C (2022) 82:95



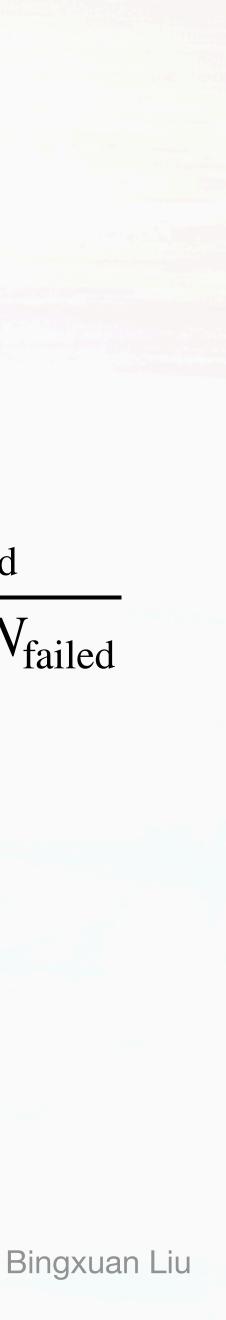




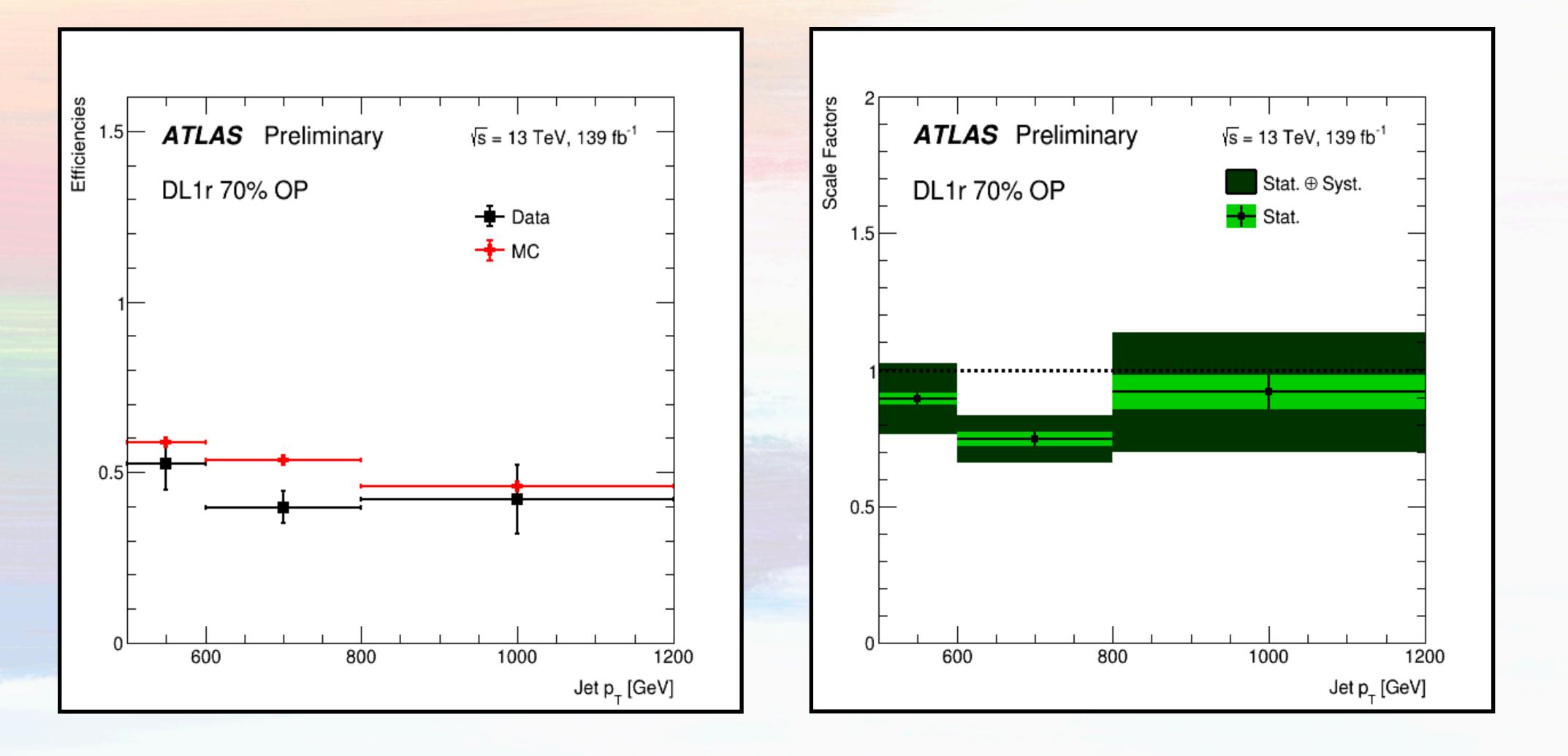
### **b-tagging Calibration in Multi-jet Events**



### ATL-PHYS-PUB-2022-010



### **b-tagging Calibration in Multi-jet Events**

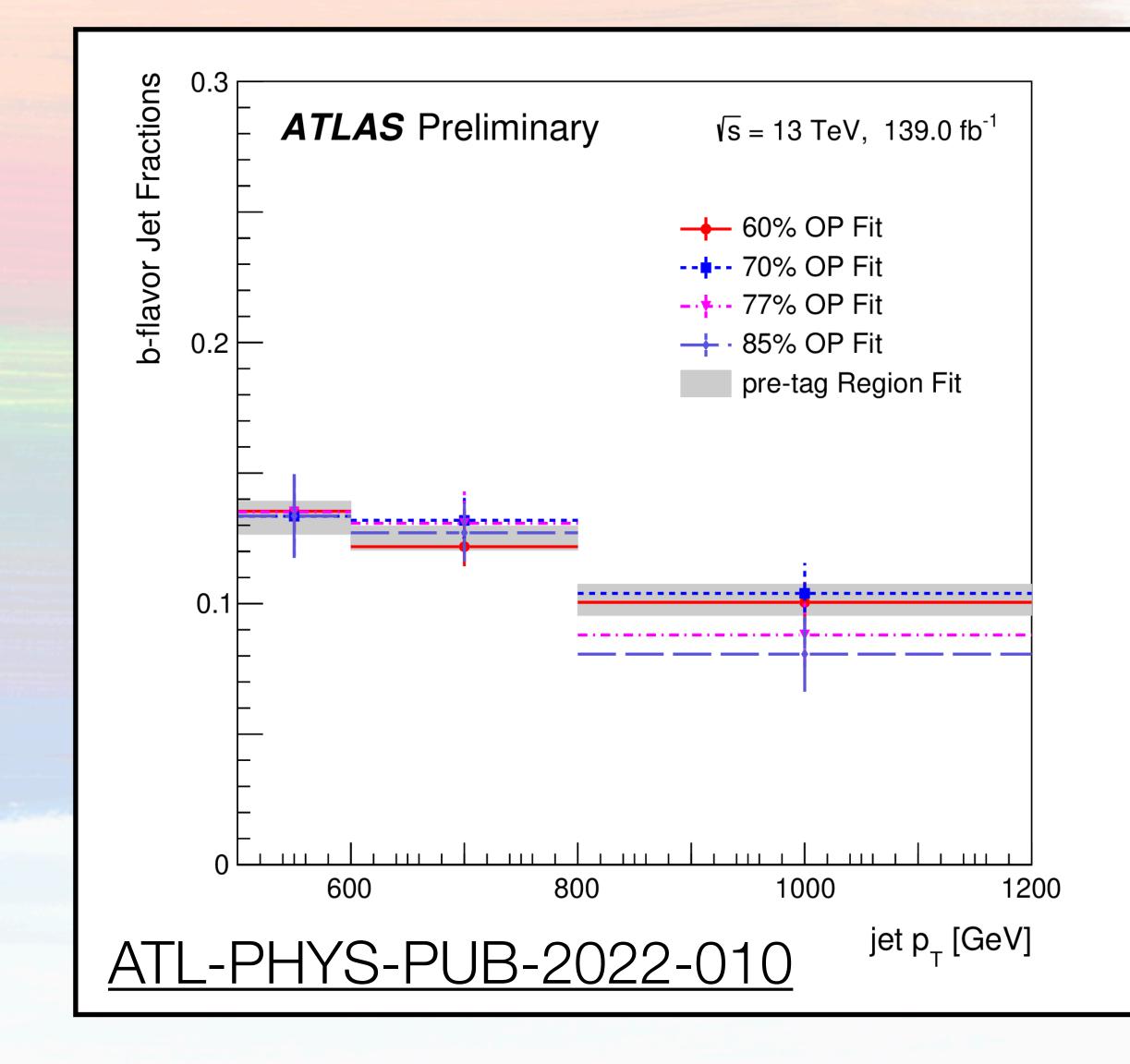


ATL-PHYS-PUB-2022-010

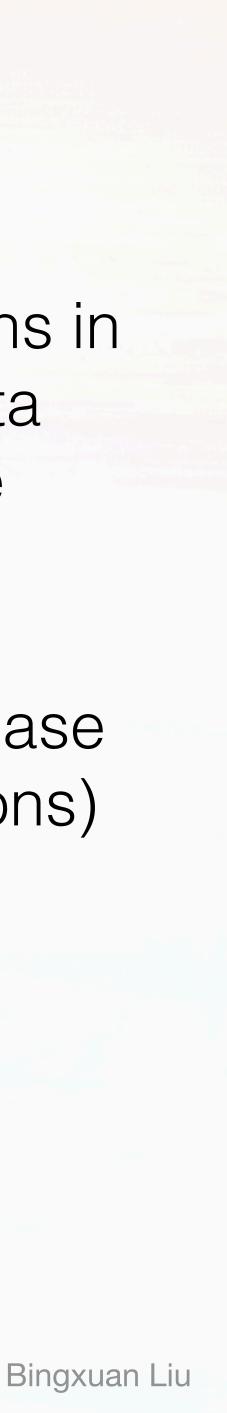
• The performance at TeV scale is not optimal. Need to improve



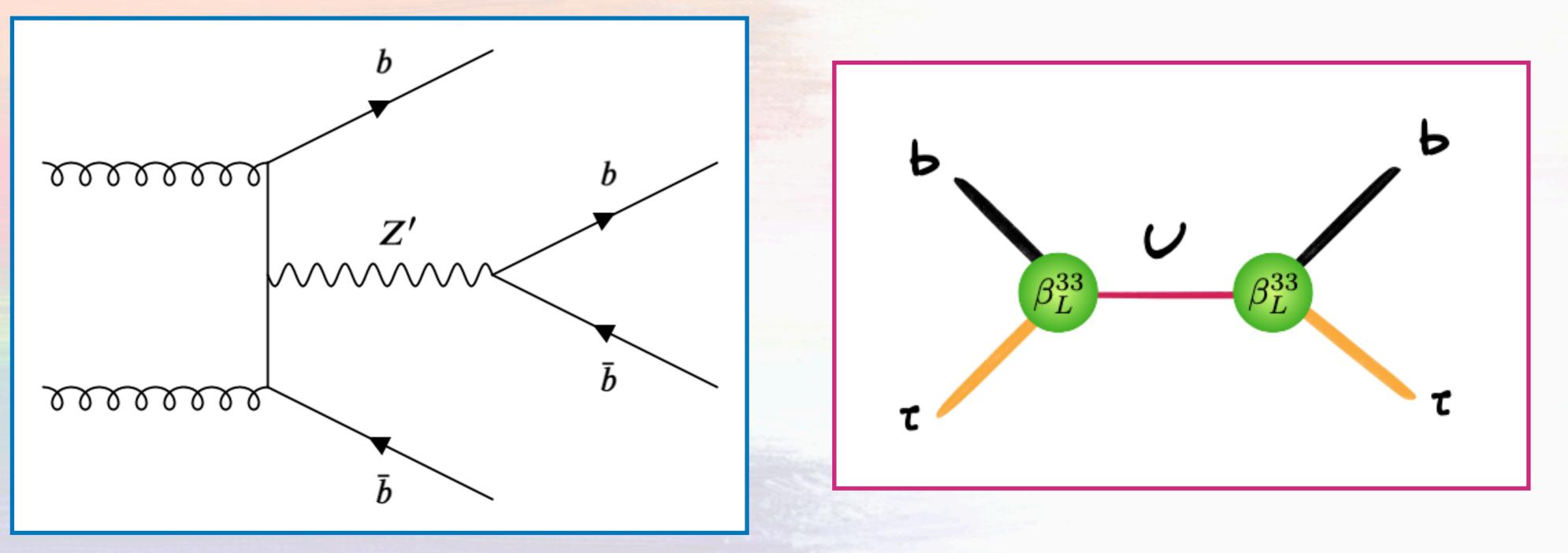
## HF Measurement at High Energy Scale



- Tuning the jet flavor fractions in simulation to match the data will significantly reduce the background estimate uncertainties
- Had a look at a specific phase space (jets containing muons) in this calibration work
- A thorough measurement would be ideal

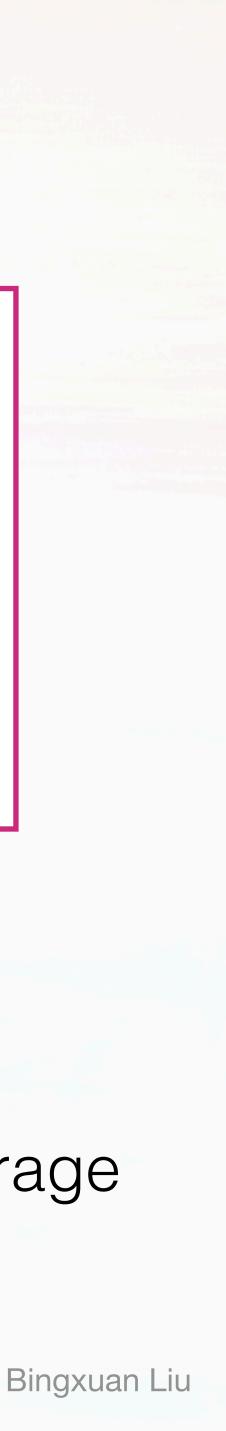


### **HF Flavor Associated Production**

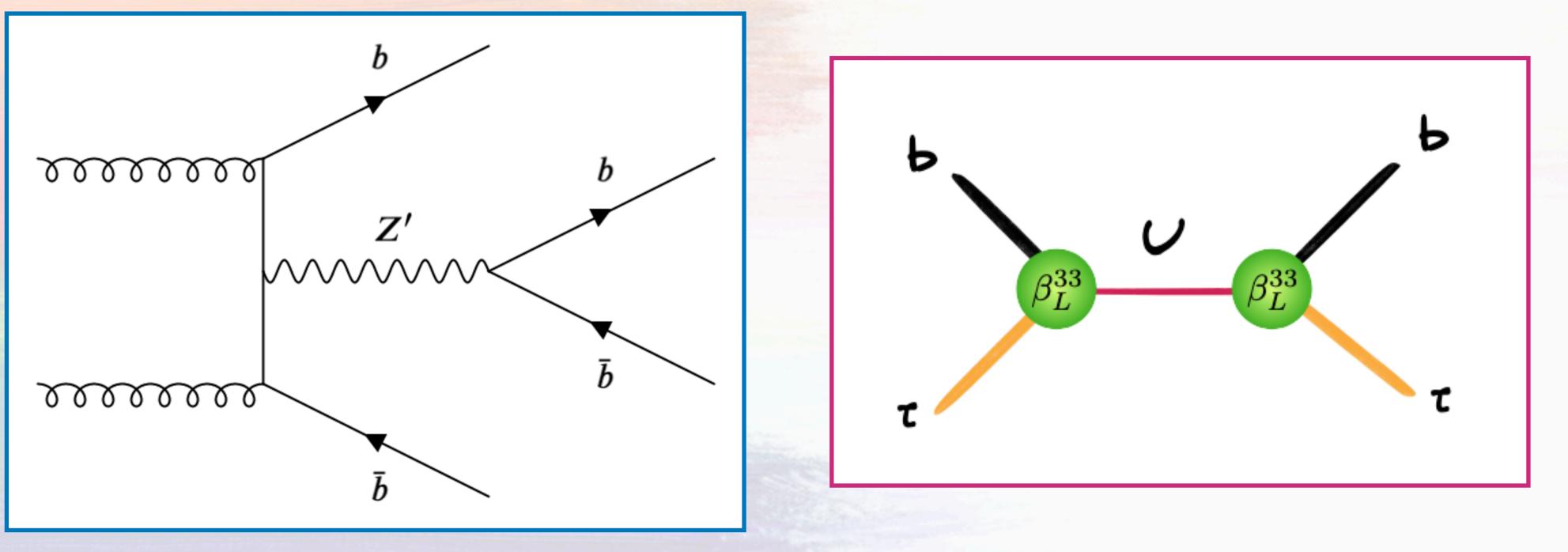


- Due to LHC PDF, soft additional heavy flavor quarks are produced
  - Extra objects to trigger on
  - - Tracker Upgrade (ITK) and forward flavor tagging

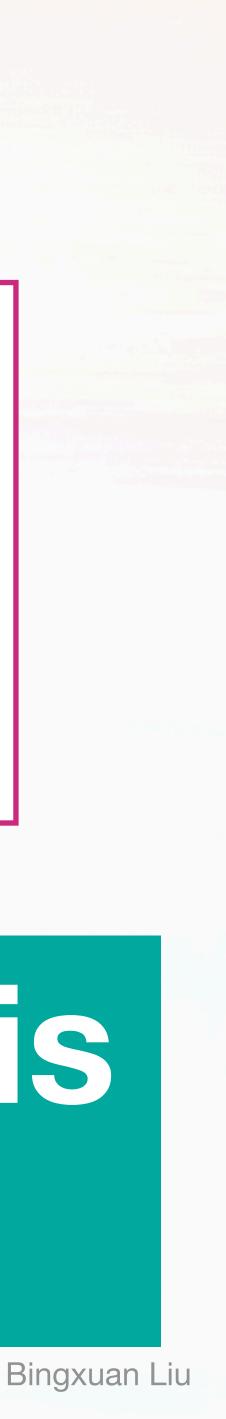
Additional heavy flavor quarks can go beyond the current tracker coverage



### **HF Flavor Associated Production**



# Plenty room to optimize this scenaro



### **BSM Long-lived Particles (LLPs) Decay**

**Inner Tracker** Layers



- New physics can have particles with significantly longer life-time compared with the b-hadrons
  - They decay further away from the luminous region

122.5 mm 88.5



### Long-lived Particle Search

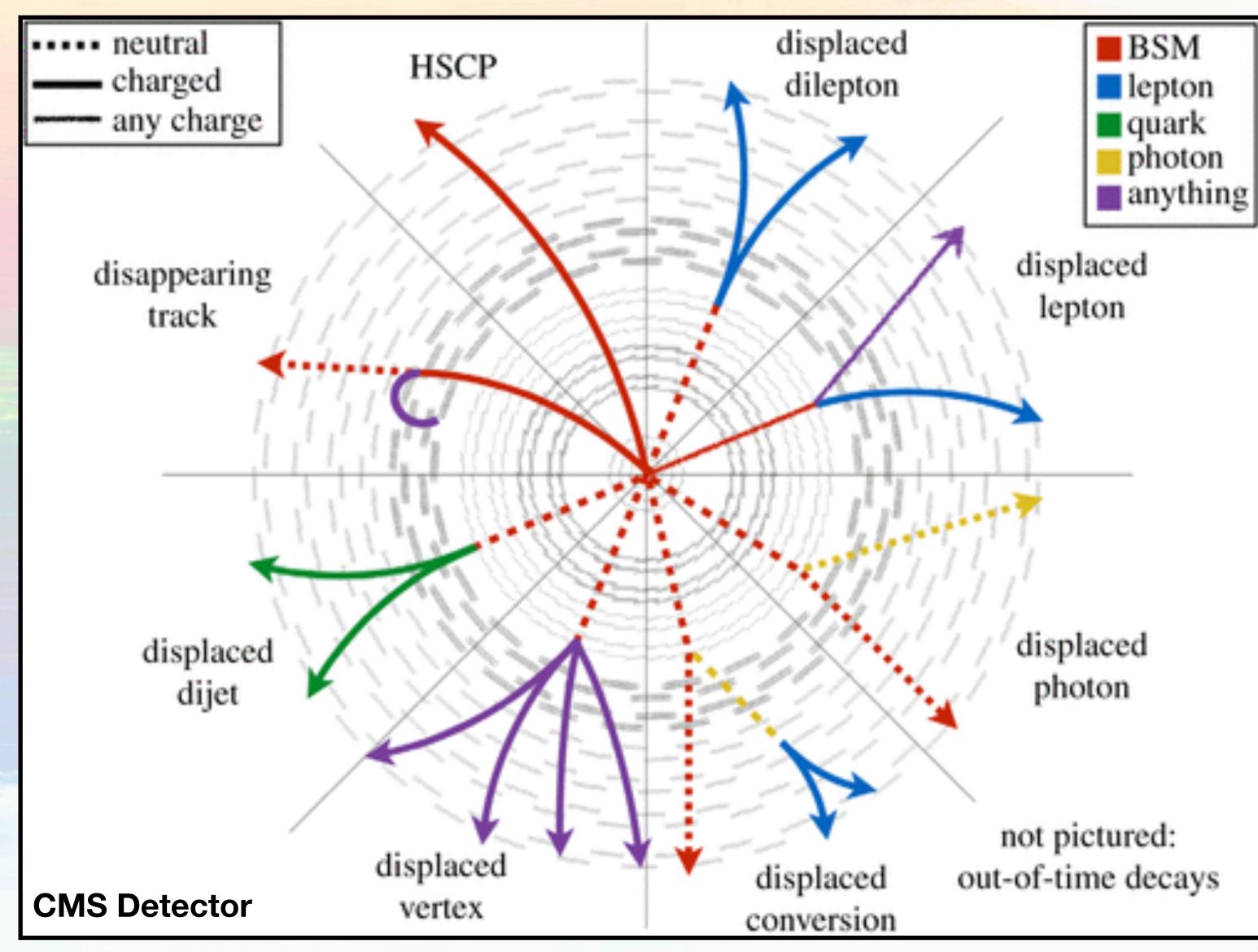
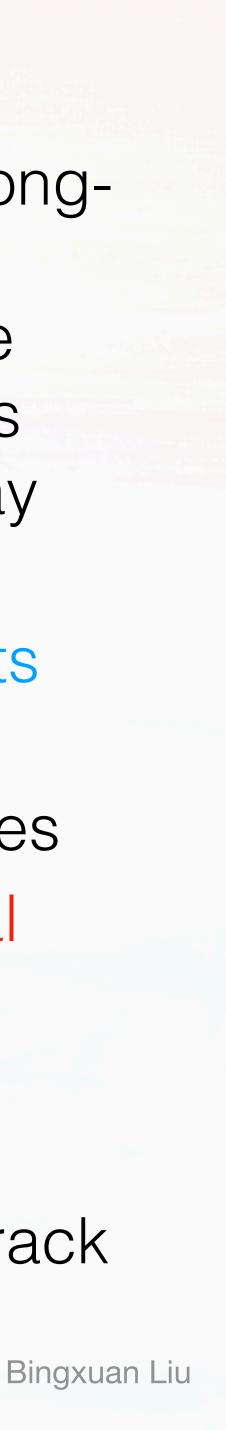


Figure credit: J. Antonelli

- Often categorize longlived particle searches by where the particle decays and what the decay products are
  - Displaced objects
    - Jets, leptons, photons, vertices
  - Non conventional objects
    - Highly ionizing track, disappearing track



### Long-lived Particle Search

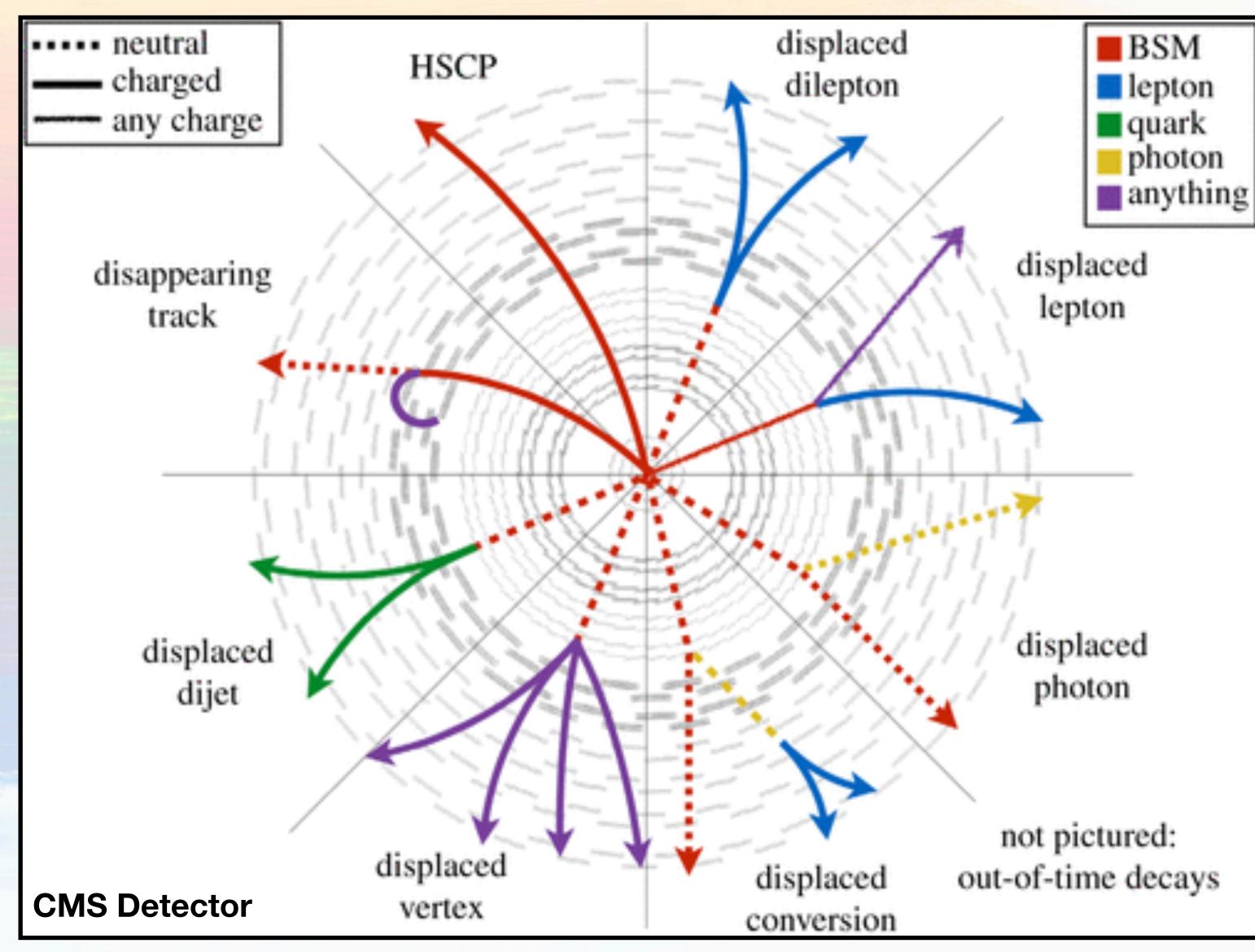


Figure credit: J. Antonelli

Signature Drivent Look for special signatures in the detector that have not been searched before

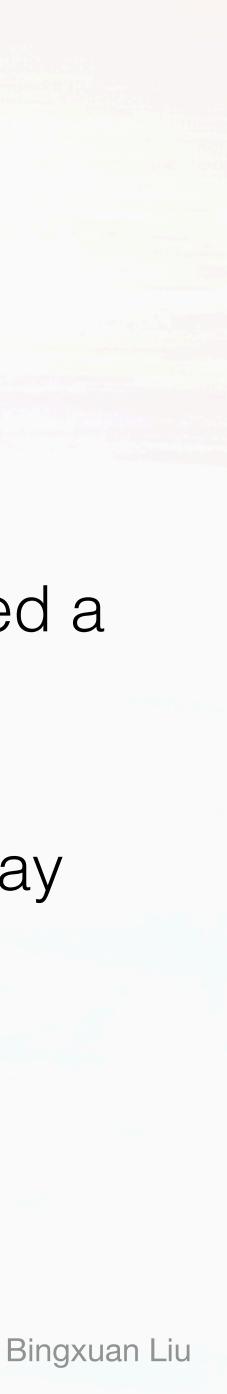


## Long-lived Particle Search

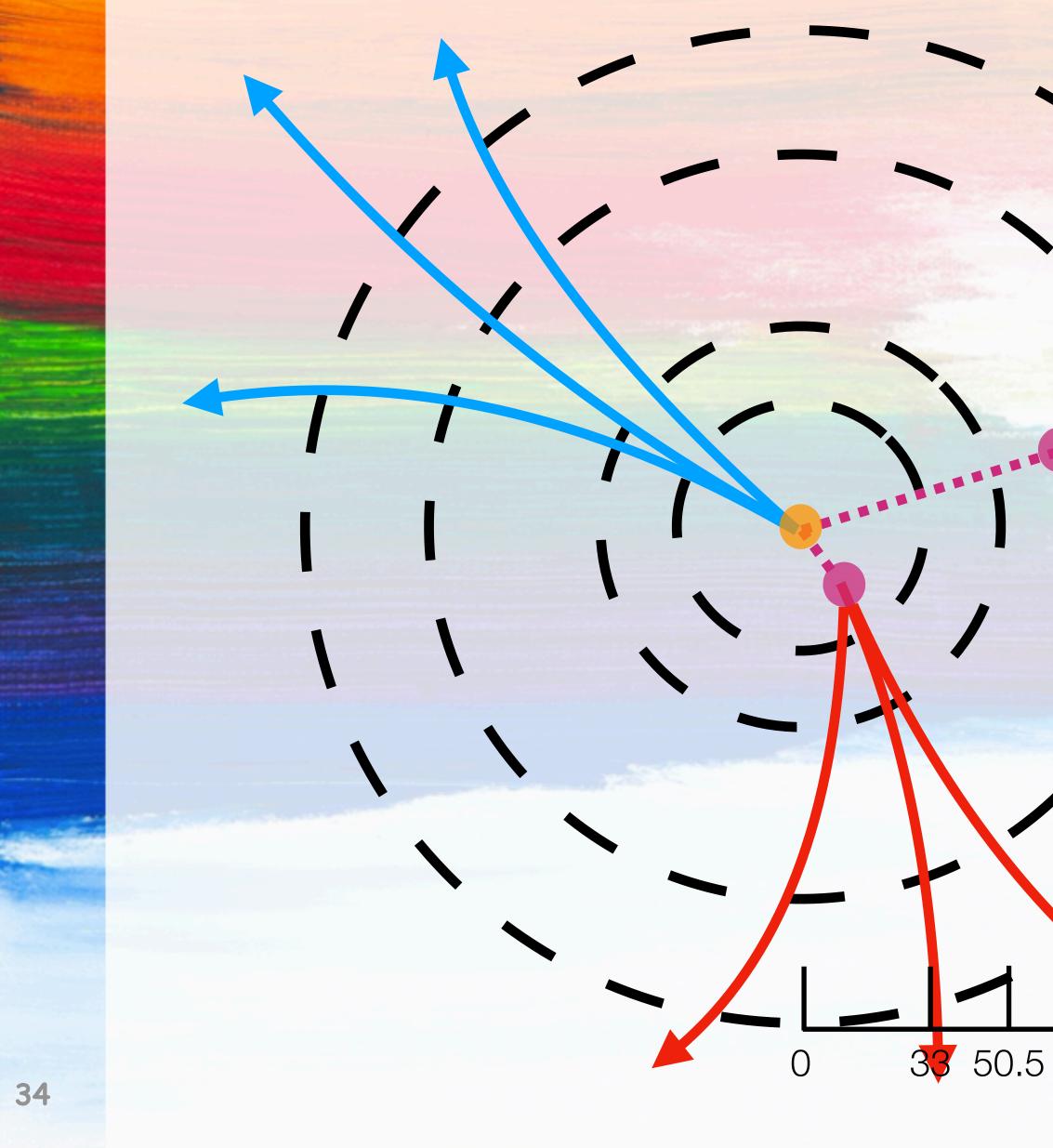
- They are also well motivated theoretically Predicted in many scenarios
- R-parity violated Supersymmetry
  - whose mean lifetimes are free parameters
    - large parameter space
- Hidden valley scenarios
  - chain can have long lifetimes
    - Higgs is very sensitive to this scenario
- Many other models as well
  - Anomaly Mediated SUSY Breaking (AMSB), etc.

 The lightest supersymmetric particles (LSP) can decay to SM particles Becoming more important as traditional SUSY searches have excluded a

A hidden sector is connected with SM and the new particles in the decay

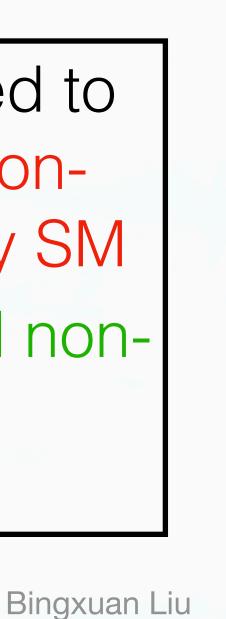


### Challenging!



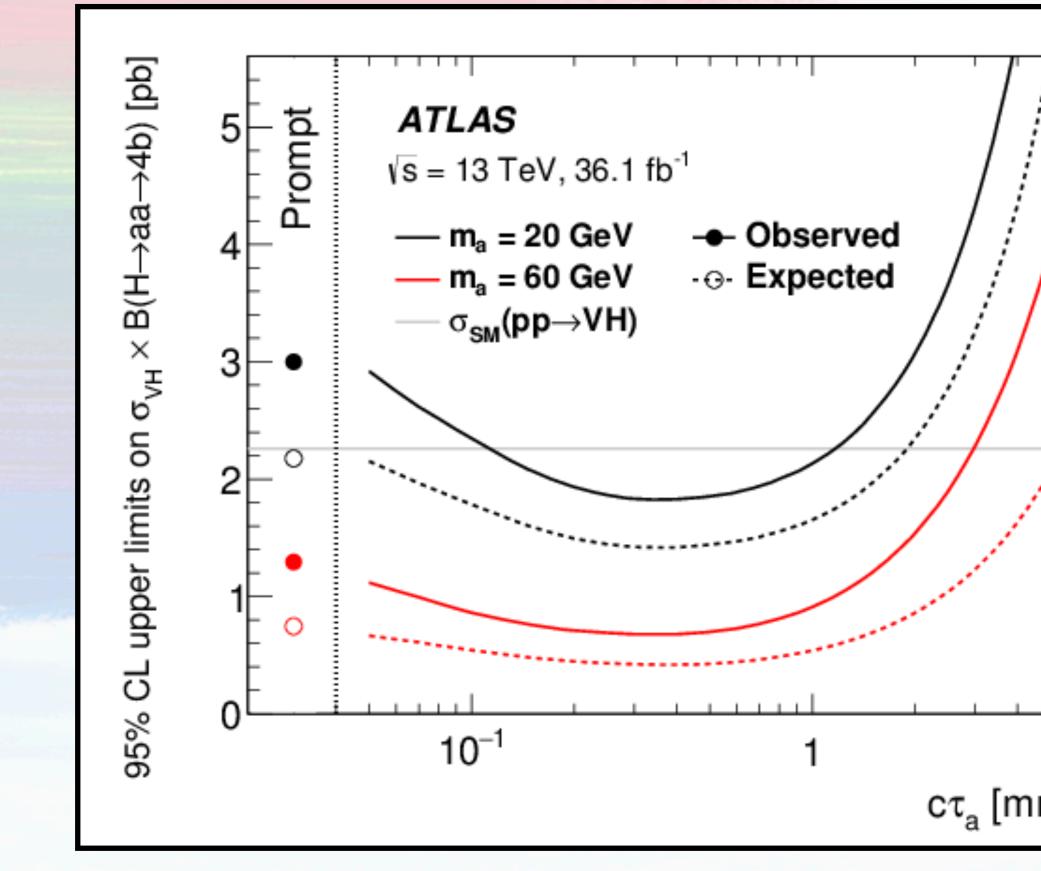
- The detectors were designed to look for prompt decays or nonprompt decays expected by SM
- Performance on exotic BSM nonprompt decays were not optimized

122.5 mm 88.5



## b-tagging Long-lived Particles

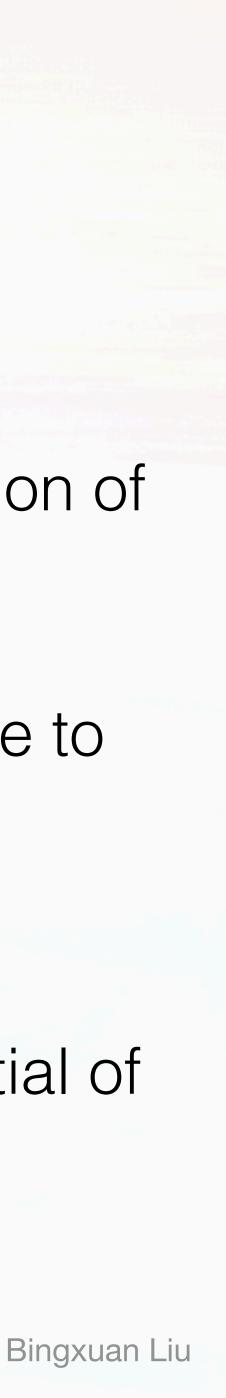
- Long-lived particles can have lifetimes similar as b-hadrons
  - Can be b-tagged

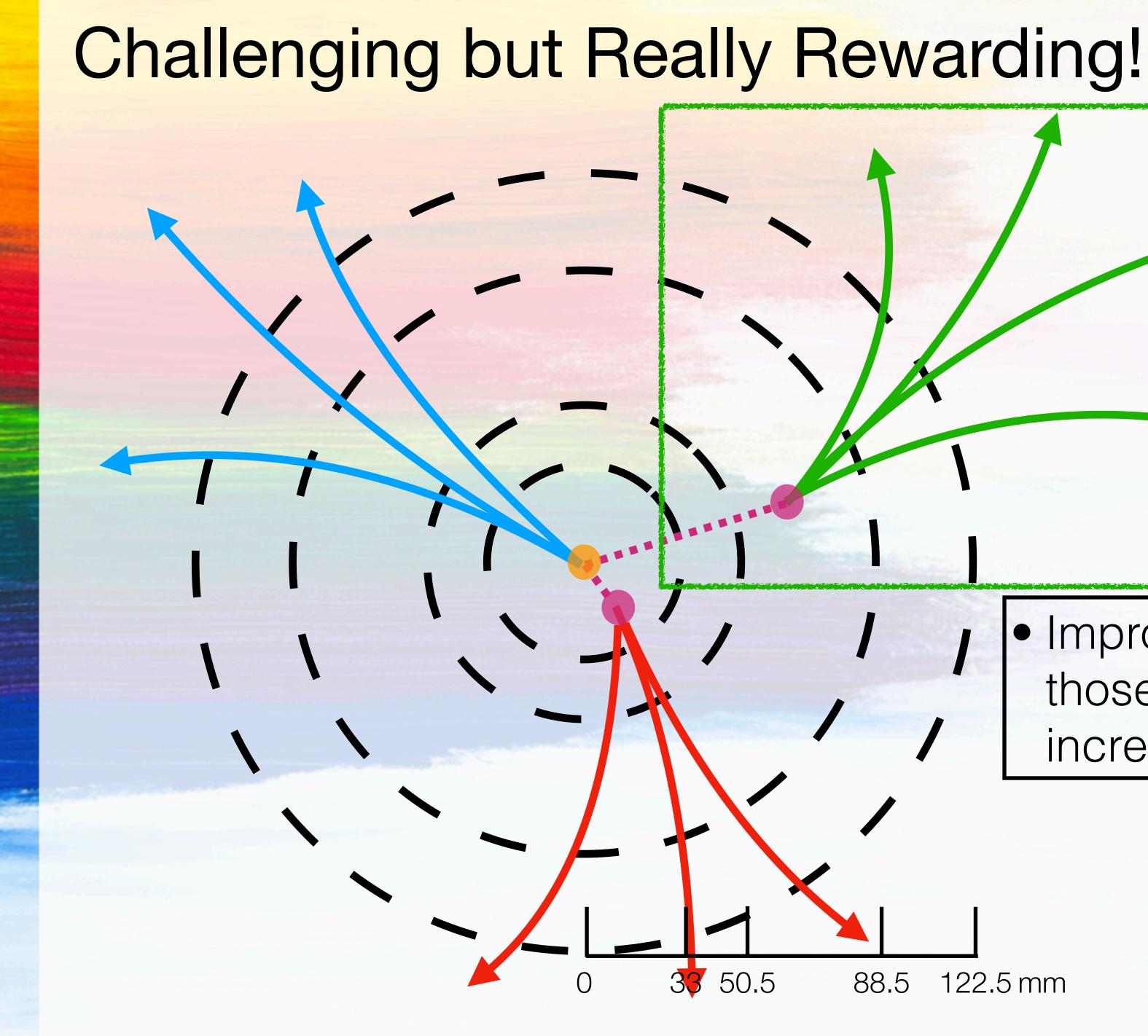


JHEP (2018) 31

Standard searches with b-tagging have sensitivities to such LLPs

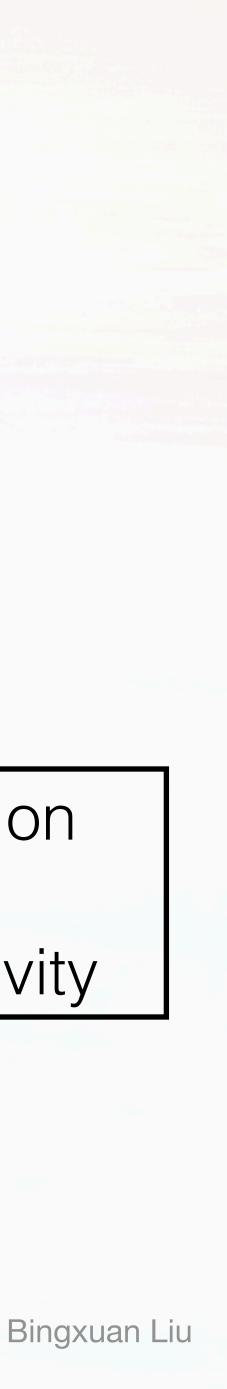
	• We performed a re-interpretation the $VH(H \rightarrow aa \rightarrow b\overline{b}b\overline{b})$ search
	• Without changing analysis strategy, the search is sensitive to $c\tau_a$ up to 1mm
	• Usually consider $c\tau$ as a parameter of the signal
m]	<ul> <li>Very exciting to see the potential dedicated taggers targeting intermediate lifetimes</li> </ul>





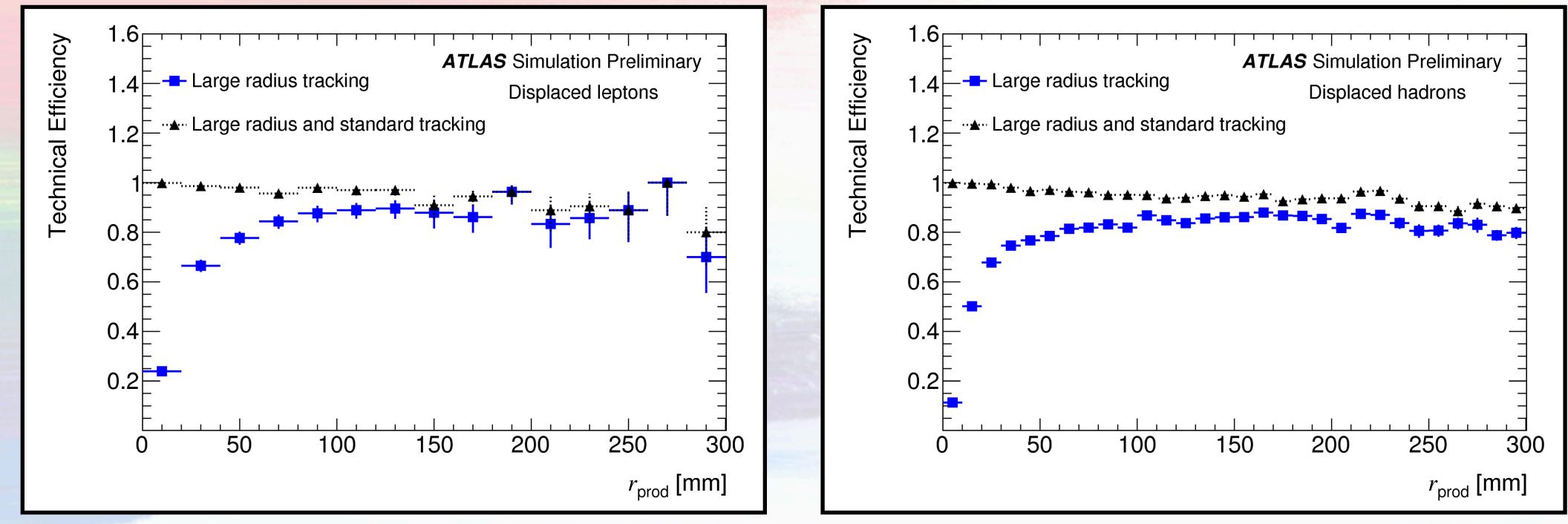
 Improving the performance on those displaced signature increases the search sensitivity

88.5 122.5 mm



### Large Radius Tracking in ATLAS

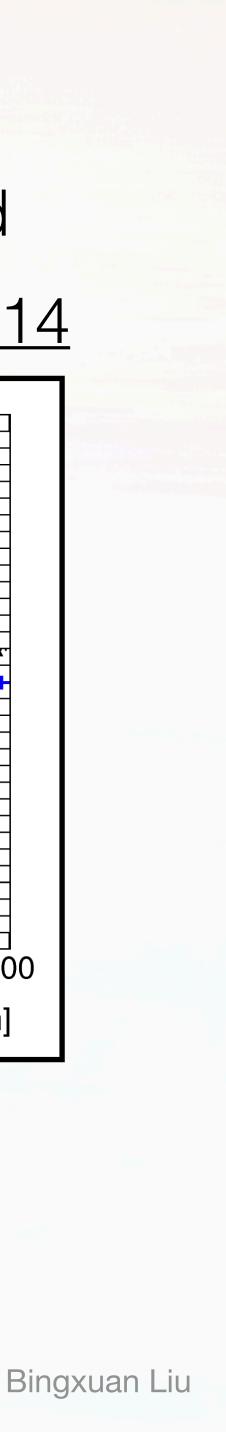
particle (LLP) searches



 It has been applied in many Run2 LLP searches Good efficiency up to production radius ~ 300 mm!

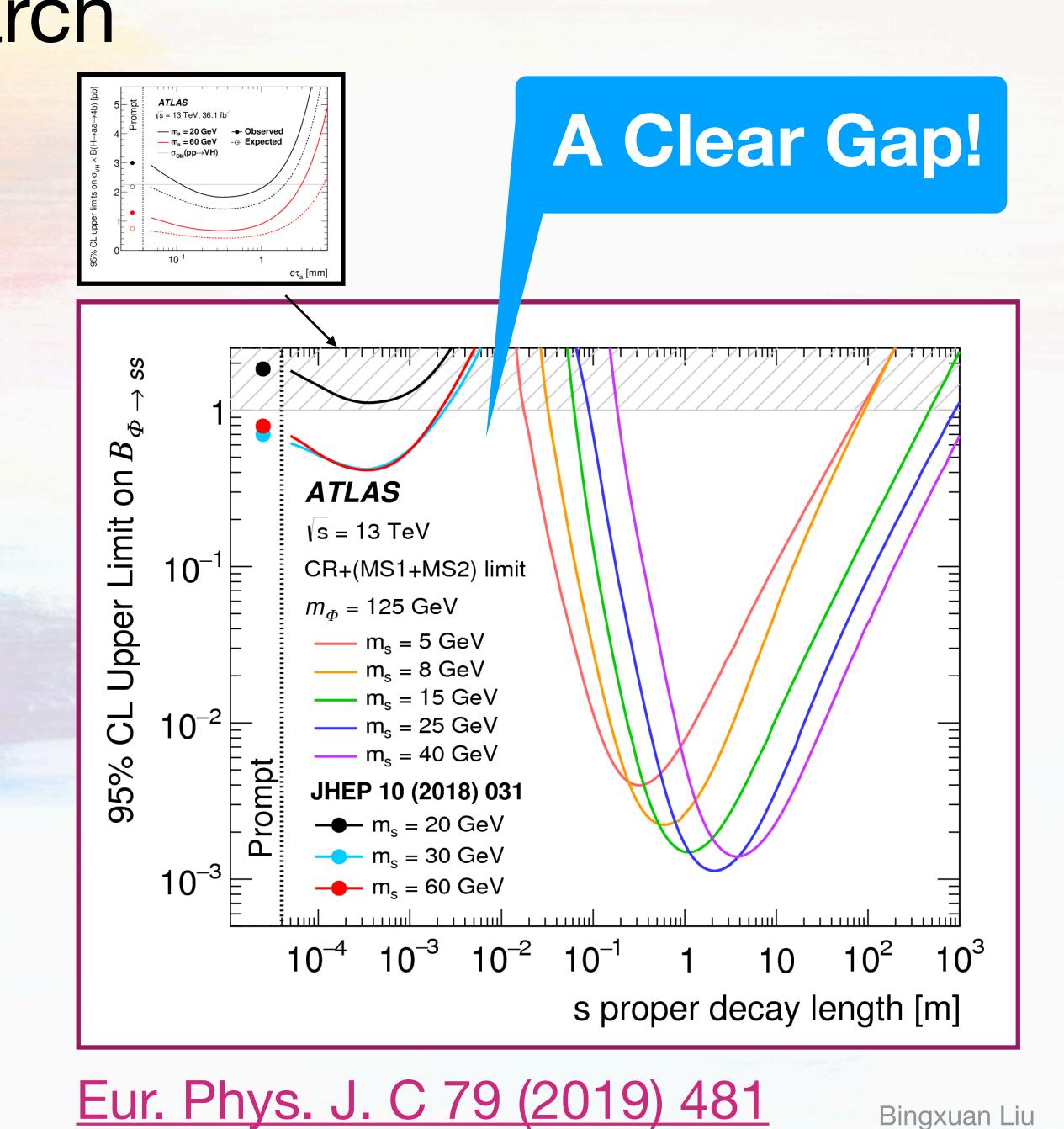
#### Large Radius Tracking (LRT) is a special tracking algorithm for long-lived

#### ATL-PHYS-PUB-2017-014



#### VH4b Dedicated LLP Search

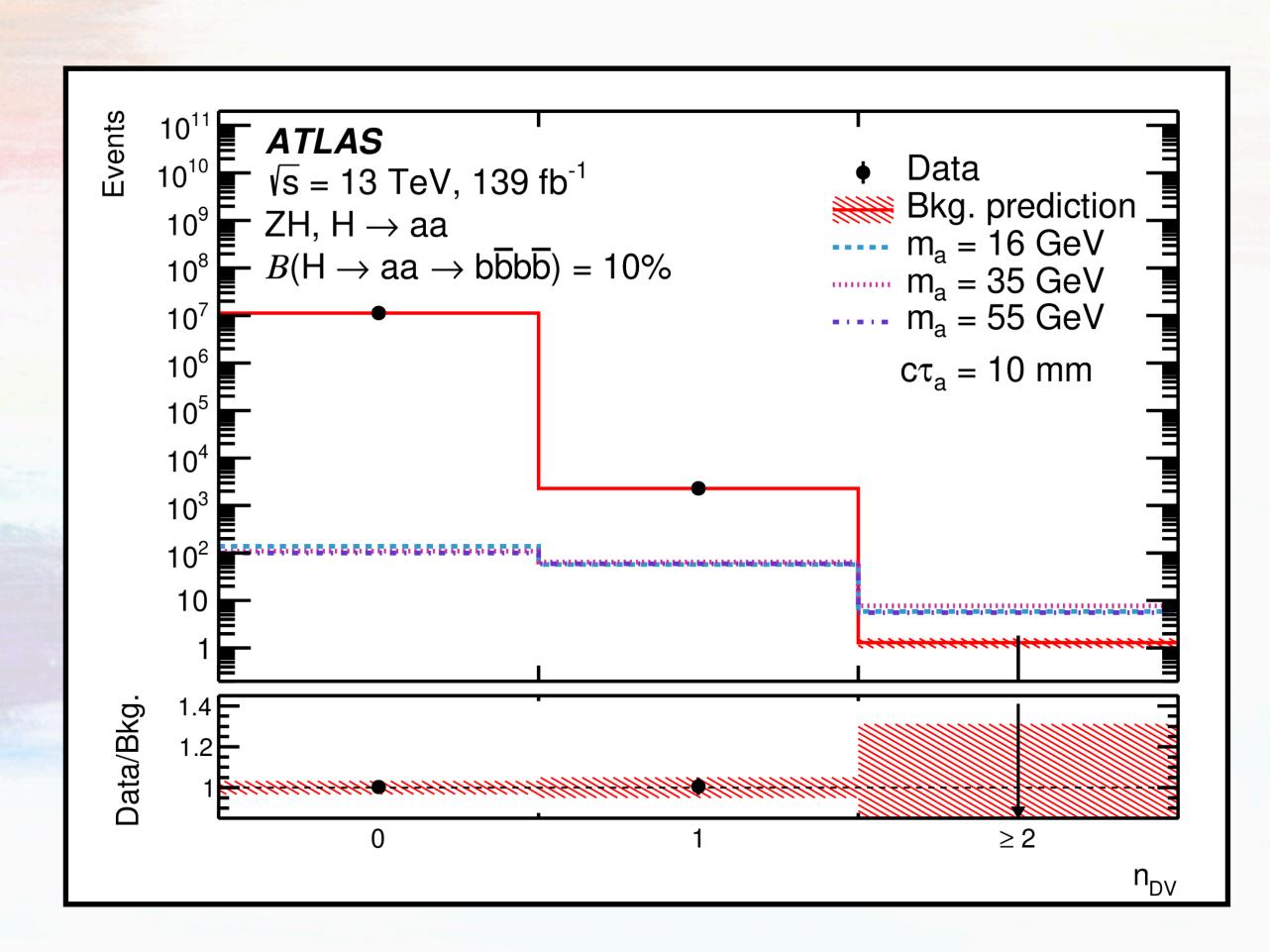
- Intermediate lifetime region has not been covered well
  - Displaced decays within the tracker volume
- We did a dedicated search using LRT to cover this gap
  - Searching for V+Higgs -> aa (long-lived) -> 4 b-quarks via displaced vertices (DV) reconstructed using LRT



Bingxuan Liu

#### VH4b Dedicated LLP Search

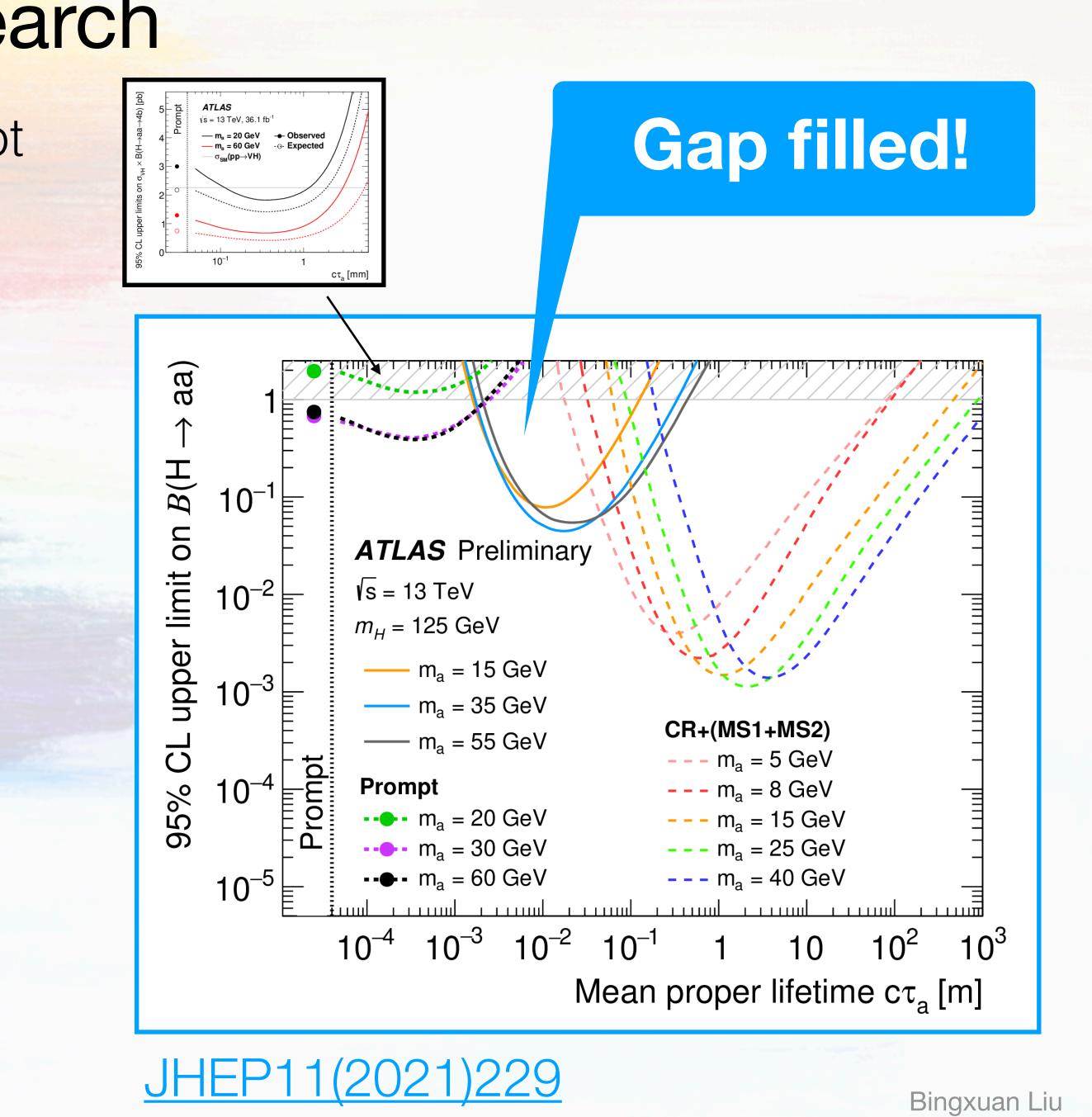
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  - Signal region requires at least two DVs



#### JHEP11(2021)229

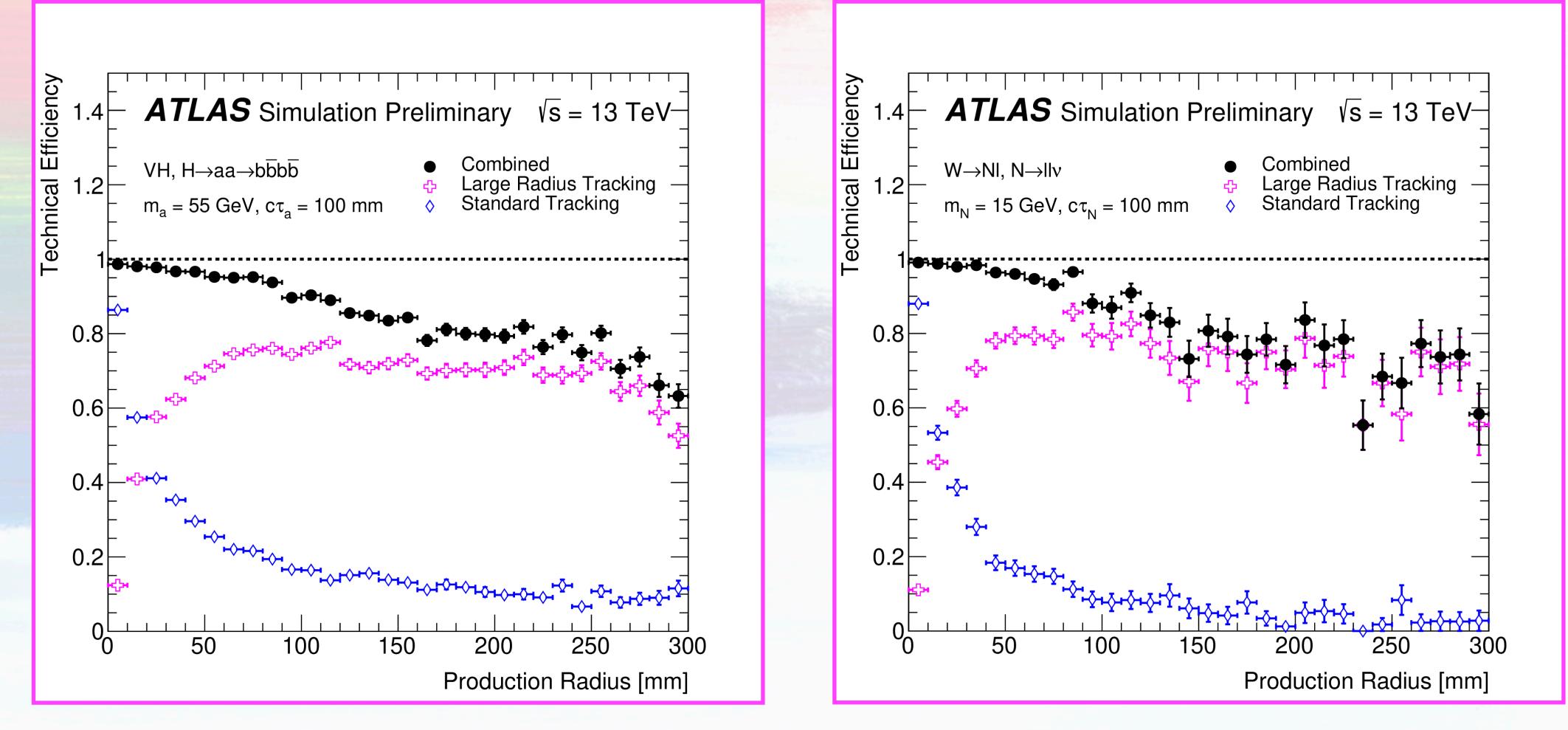
#### VH4b Dedicated LLP Search

- Intermediate lifetime region has not been covered well
  - Displaced decays within the tracker volume
- We did a dedicated search using LRT to cover this gap
  - Searching for V+Higgs -> aa (long-lived) -> 4 b-quarks via displaced vertices (DV) reconstructed using LRT
- Aiming at filling this gap
- And it did fill this gap



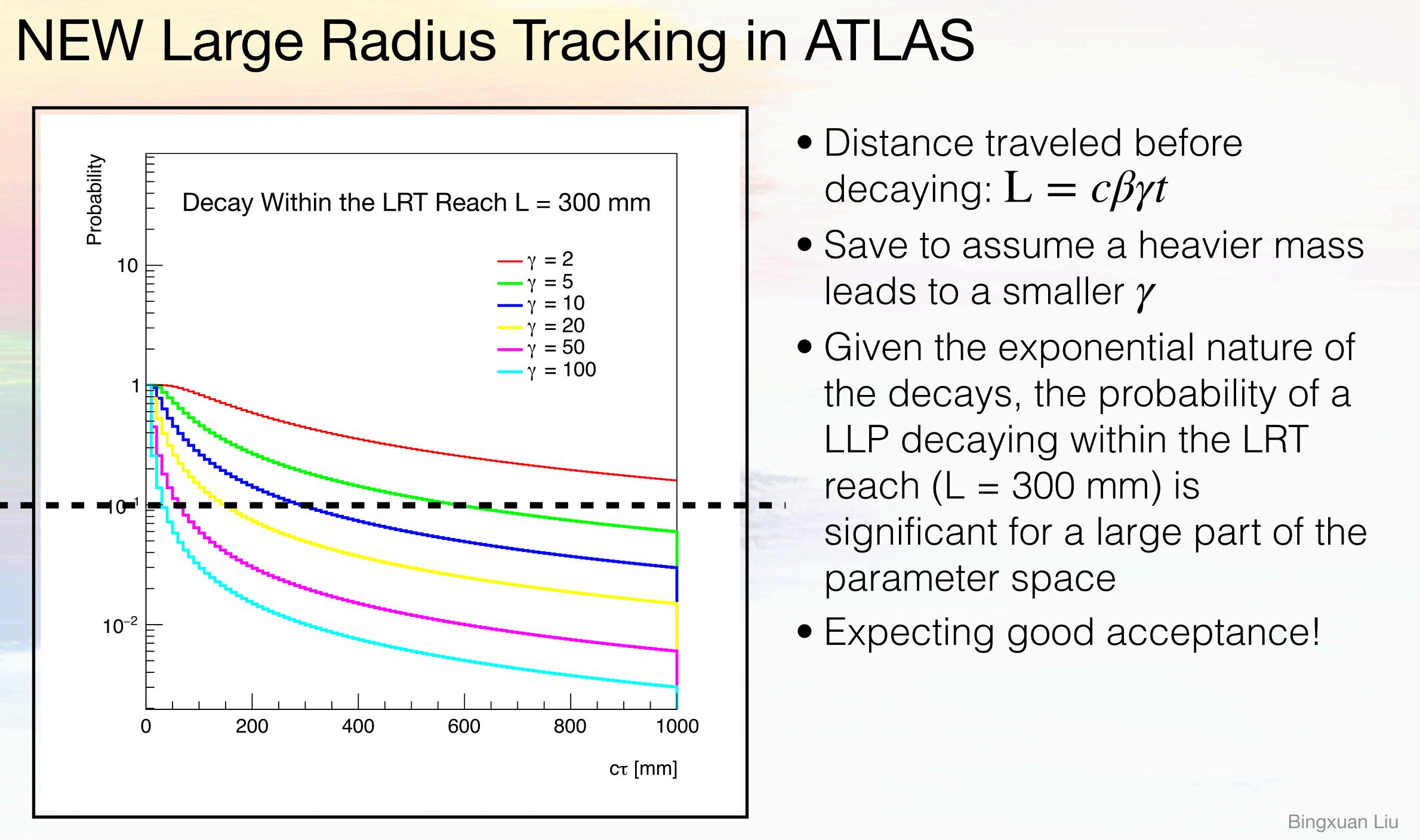
## **NEW Large Radius Tracking in ATLAS**

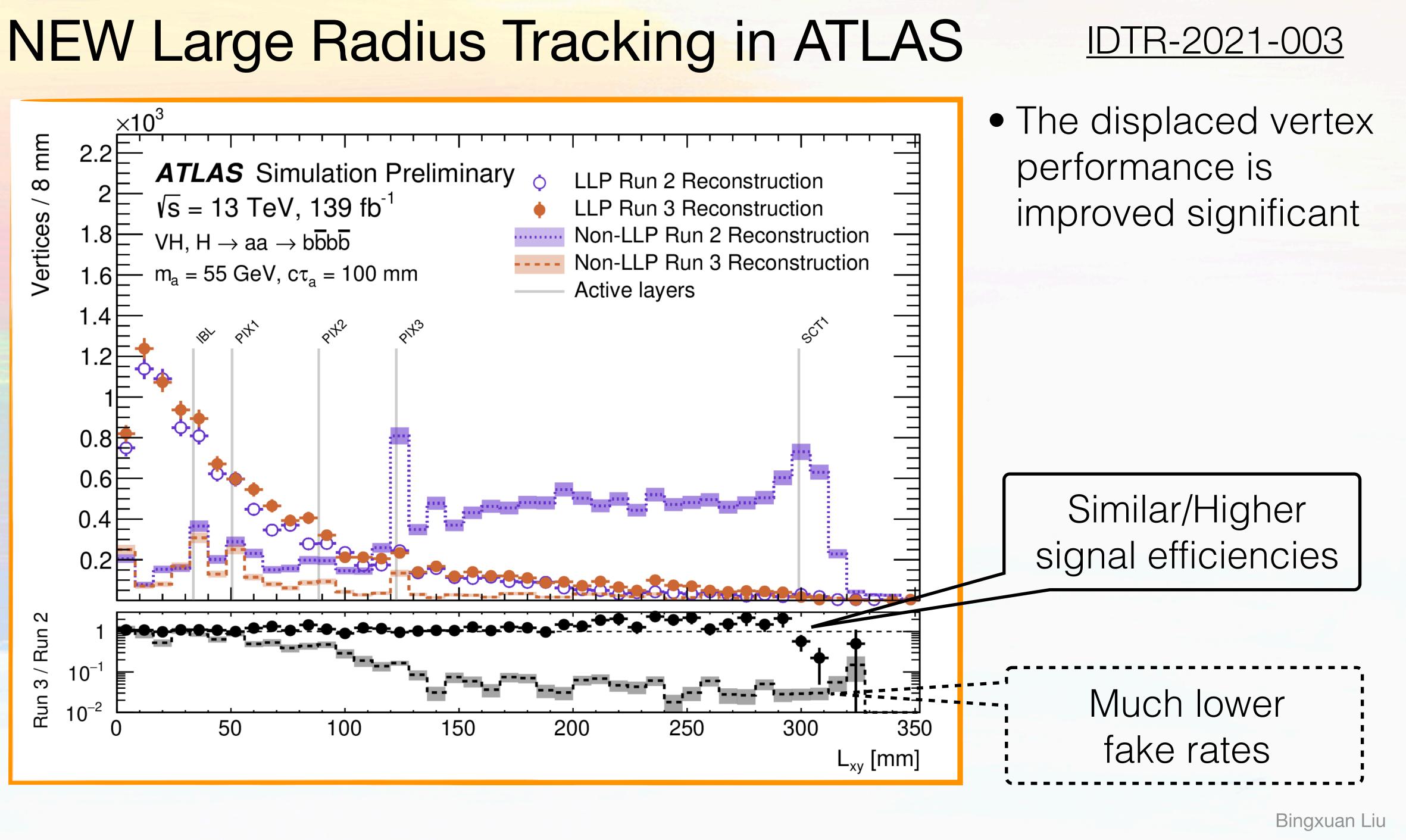
 LRT has been significant updated/improved for Run3! Run2 LLP program can also benefit it from reprocessing



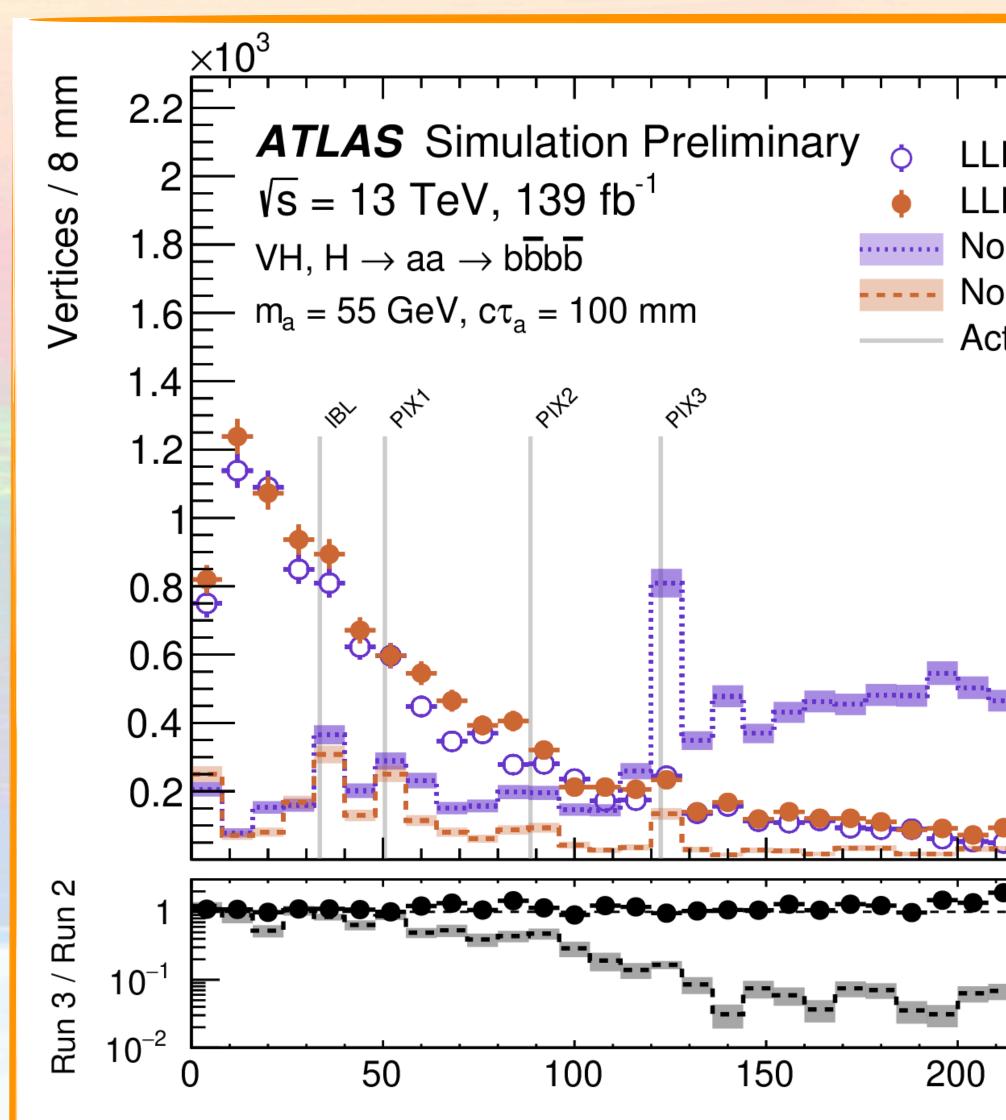
#### IDTR-2021-003







## **NEW Large Radius Tracking in ATLAS**



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LLP Run 2 Reconstruction LLP Run 3 Reconstruction Non-LLP Run 2 Reconstruction Non-LLP Run 3 Reconstruction Active layers

250

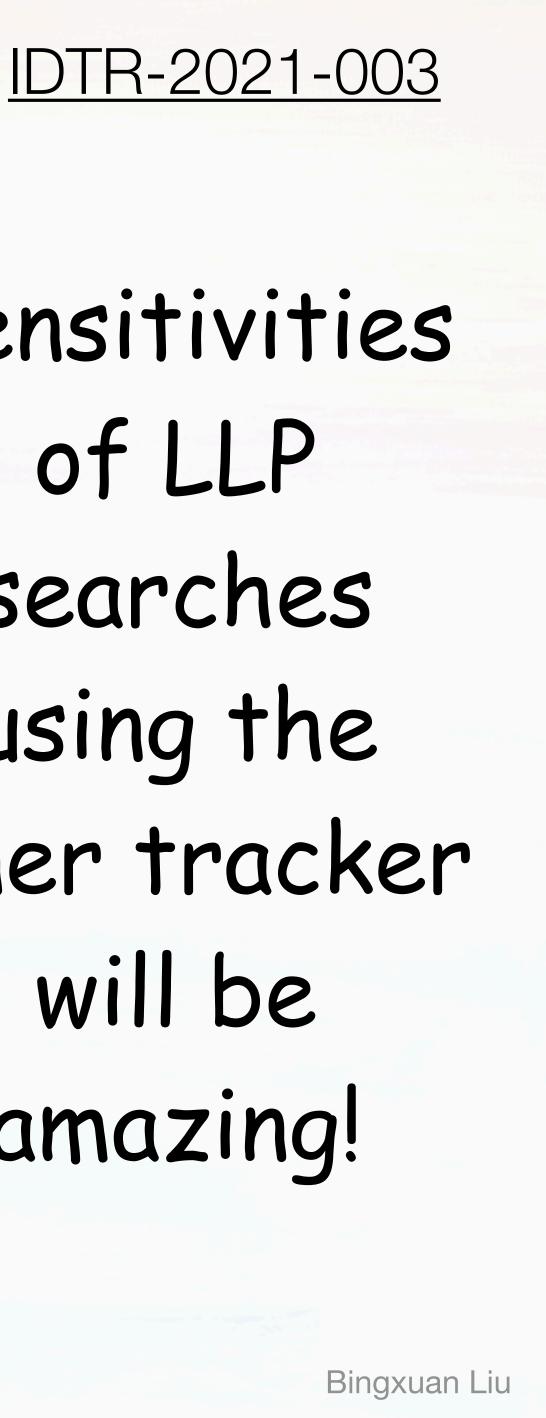
300

350

L<sub>xy</sub> [mm]

Sensitivities of LLP searches using the

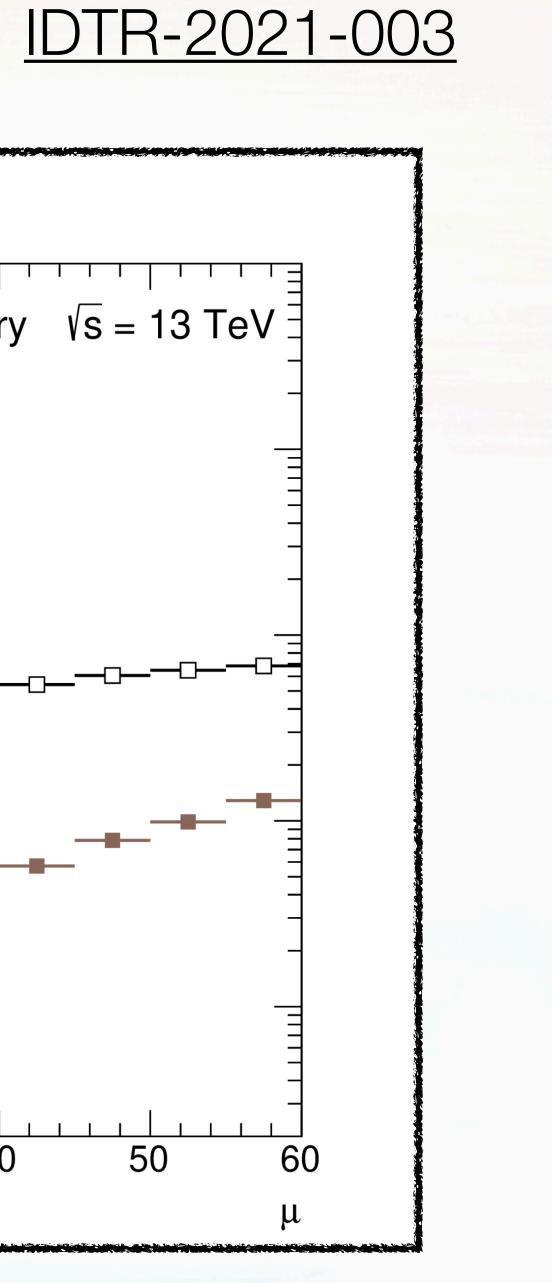
inner tracker will be amazing!

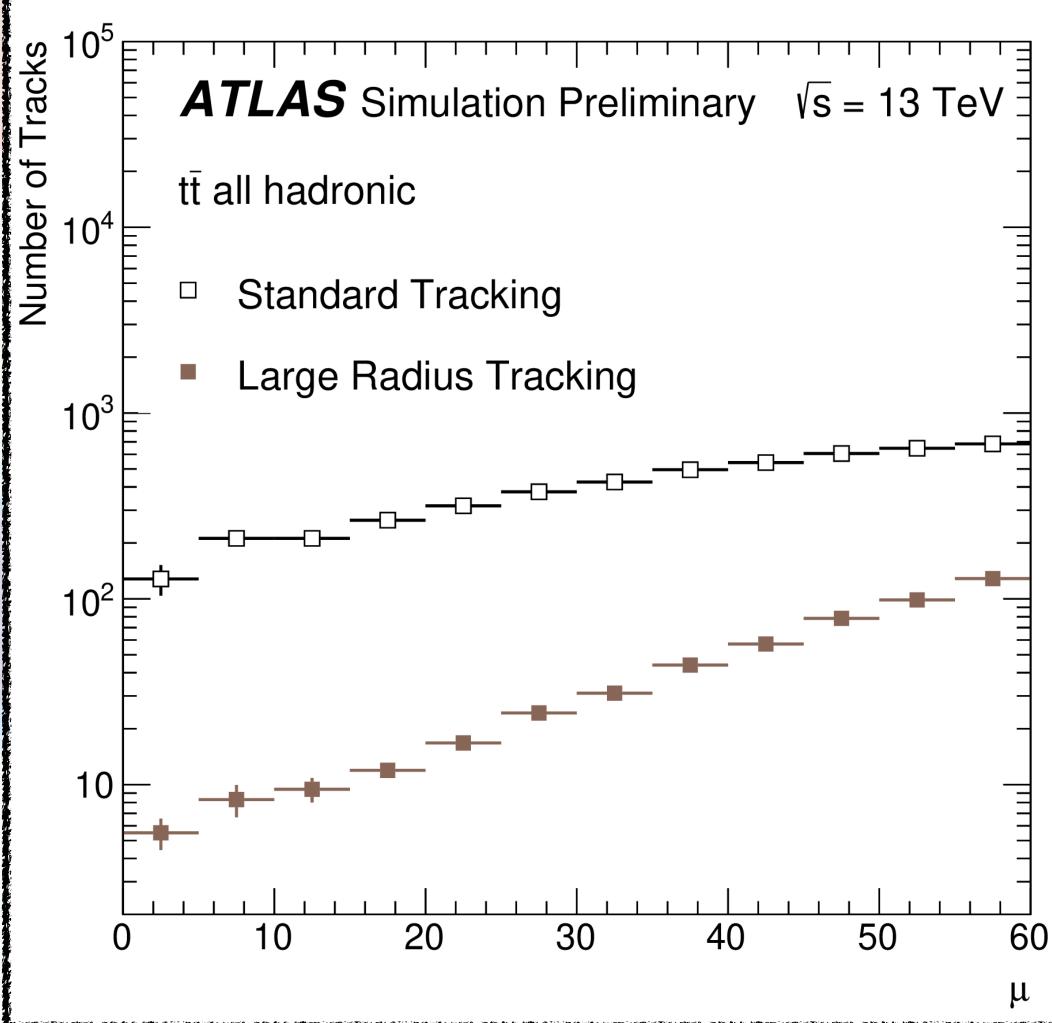


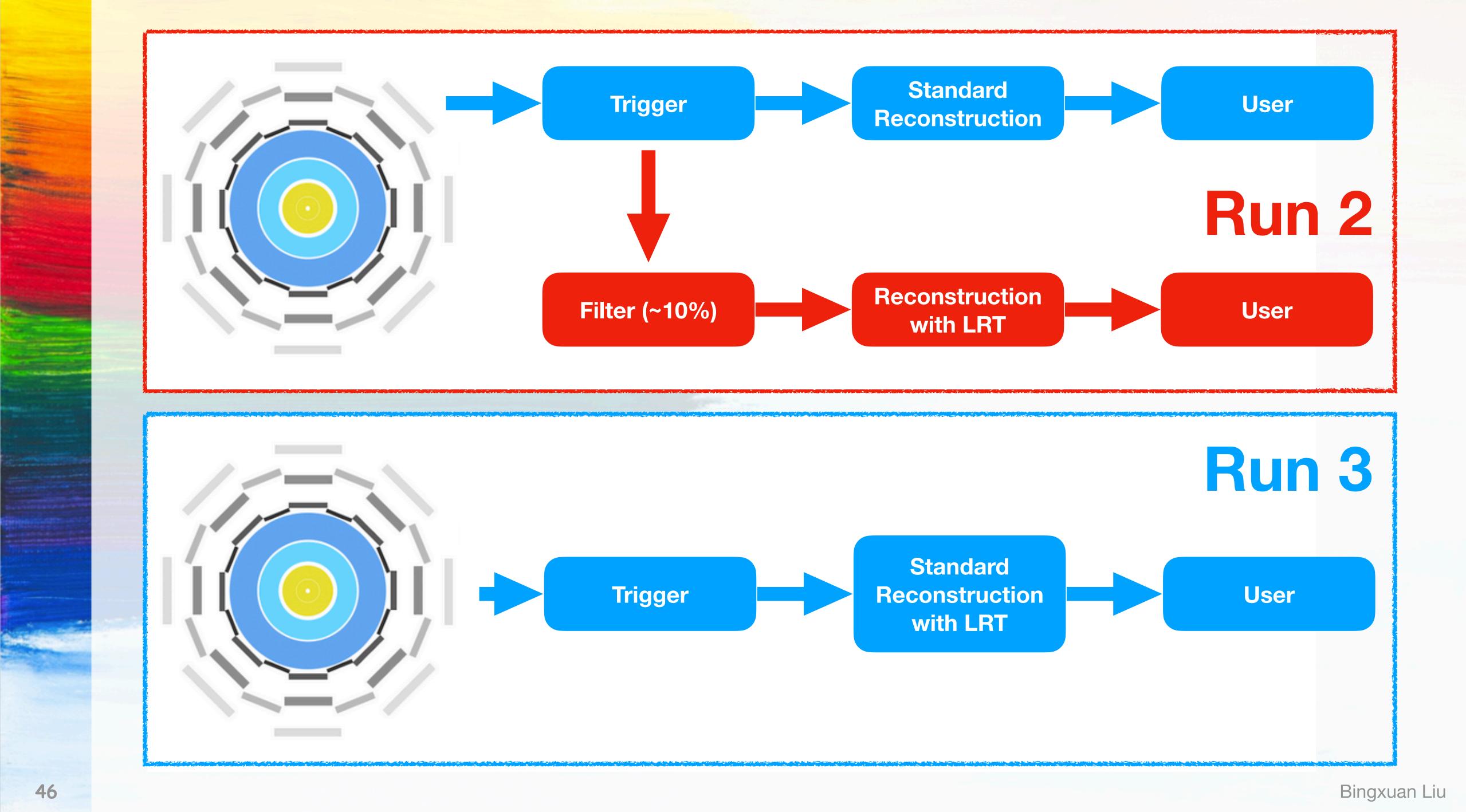
#### NEW Large Radius Tracking in ATLAS

- The new algorithm only adds ~10% more tracks on average in each event
- It is enabled for every single event collected by ATLAS
  - No additional filtering or processing is needed
  - Save computational resource and person power

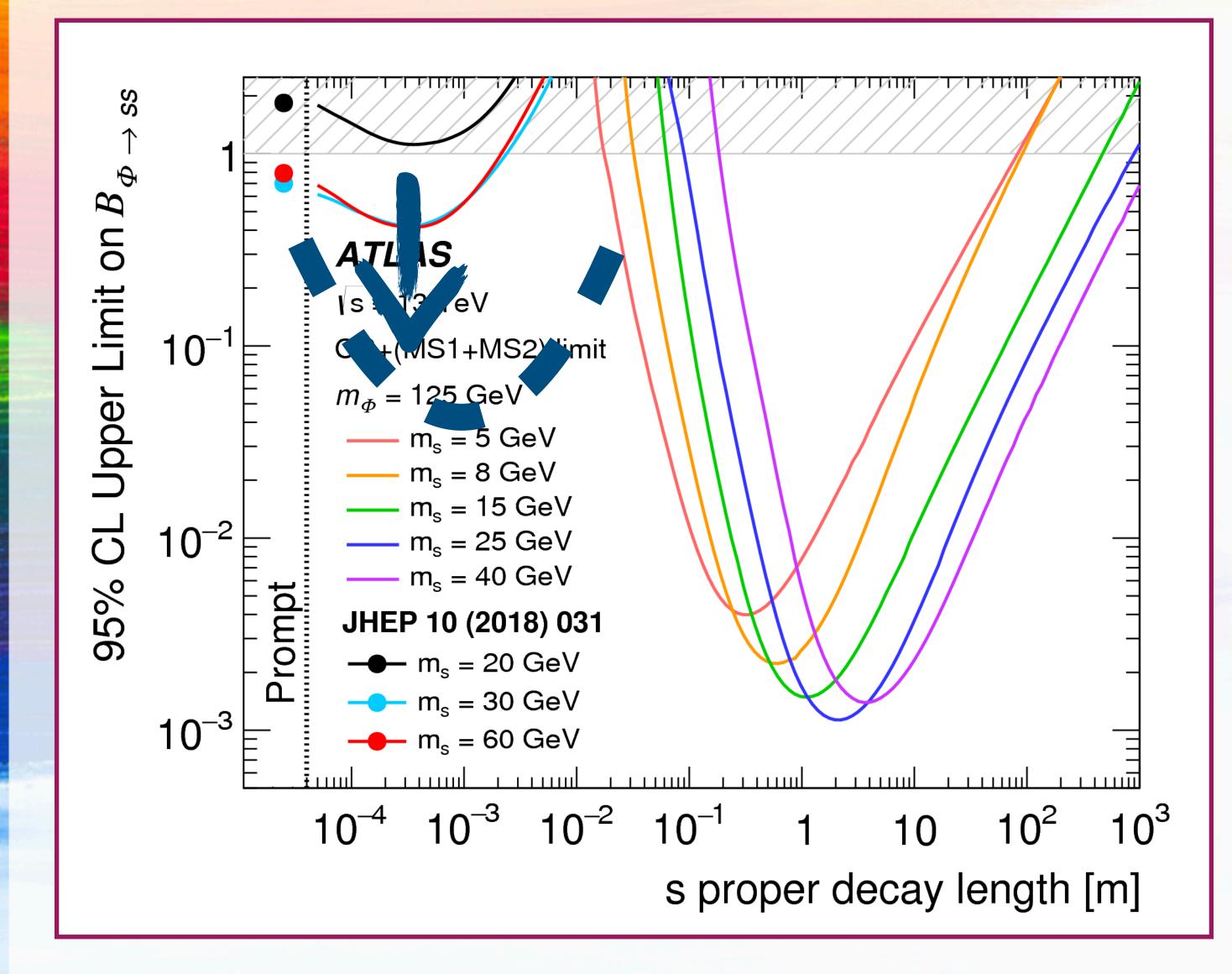
 Previously LRT was only applied to ~10% of the events collected by ATLAS







#### Make Traditional Searches More Sensitive to LLP



- Standard *b*-tagging is clearly already sensitive to LLP in a given phase space
- With the new LRT, we could make it more sensitive!
- A simultaneous coverage extension!



#### Greatly Extend the Parameter Space

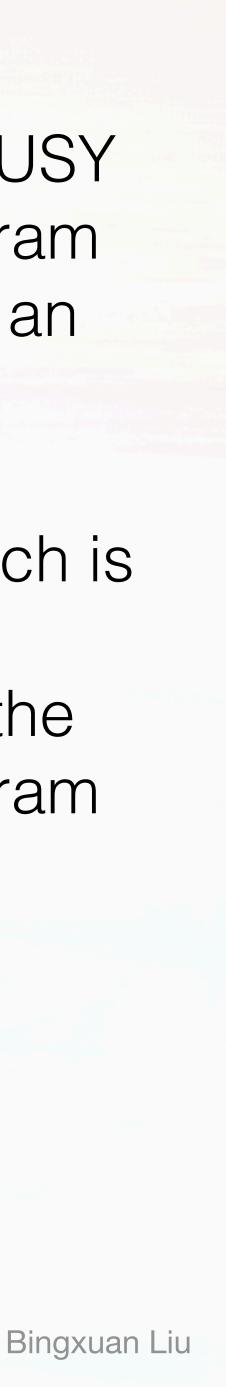
	TLAS SUSY Sea arch 2022 Model		ignatur		` <i>L dt</i> [fb <sup>−</sup>		ss limit					<b>ATLAS</b> Preliminary $\sqrt{s} = 13 \text{ TeV}$ <b>Reference</b>
S	$\tilde{q}\tilde{q},\tilde{q}{ ightarrow}q\tilde{\chi}_1^0$	0 <i>e</i> ,μ mono-jet	2-6 jets 1-3 jets	$E_T^{ m miss}$ $E_T^{ m miss}$	139 139	<ul> <li><i>q</i> [1×, 8× Degen.]</li> <li><i>q</i> [8× Degen.]</li> </ul>	1 1	1.0 0.9		1.85	$m( ilde{\chi}^0_1){<}400\mathrm{GeV}\ m( ilde{q}){=}5\mathrm{GeV}$	2010.14293 2102.10874
Inclusive Searches	$\tilde{g}\tilde{g},  \tilde{g} \rightarrow q \bar{q} \tilde{\chi}_1^0$	0 <i>e</i> , <i>µ</i>	2-6 jets	$E_T^{\text{miss}}$	139	ğ ğ		Forbidden		2.3 1.15-1.95	$m(\tilde{\chi}_1^0)=0 \text{ GeV}$ $m(\tilde{\chi}_1^0)=1000 \text{ GeV}$	2010.14293 2010.14293
	$ \begin{array}{l} \tilde{g}\tilde{g},  \tilde{g} \rightarrow q\bar{q}W\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g},  \tilde{g} \rightarrow q\bar{q}(\ell\ell)\tilde{\chi}_{1}^{0} \end{array} $	1 e,μ ee,μμ	2-6 jets 2 jets	$E_T^{ m miss}$	139 139	δ δ φ				2.2	${ m m}({ ilde { ilde t}}^1)$ <600 GeV ${ m m}({ ilde { ilde t}}^0)$ <700 GeV	2101.01629 CERN-EP-2022-014
usiv	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_1^0$	0 <i>e</i> ,μ SS <i>e</i> ,μ	7-11 jets 6 jets	$E_T^{\text{miss}}$	139 139	o g g g		1	1.15	1.97	$m(\tilde{x}_{1}^{0}) < 600 \text{ GeV}$ $m(\tilde{x}_{1}^{0}) < 600 \text{ GeV}$ $m(\tilde{x}) = 200 \text{ GeV}$	2008.06032 1909.08457
Inc	$\tilde{g}\tilde{g},  \tilde{g} \rightarrow t t \tilde{\chi}_1^0$	0-1 <i>e</i> ,μ SS <i>e</i> ,μ	3 <i>b</i> 6 jets	$E_T^{\rm miss}$	79.8 139	õğ <u>o</u> ğ			1.25	2.25	$m( ilde{\chi}^0_1){<}200~GeV$ $m( ilde{g}){-}m( ilde{\chi}^0_1){=}300~GeV$	ATLAS-CONF-2018-041 1909.08457
	$ ilde{b}_1 ilde{b}_1$	0 <i>e</i> , <i>µ</i>	2 <i>b</i>	$E_T^{\rm miss}$	139	$\tilde{b}_1$ $\tilde{b}_1$		0.68	1.255		$m(\tilde{x}_1^0) < 400  GeV$ 10 $GeV < \Delta m(\tilde{b}_1, \tilde{x}_1^0) < 20  GeV$	2101.12527 2101.12527
rks 'ion	$\tilde{b}_1 \tilde{b}_1,  \tilde{b}_1 {\rightarrow} b \tilde{\chi}_2^0 {\rightarrow} b h \tilde{\chi}_1^0$	0 <i>e</i> ,μ 2 τ	6 <i>b</i> 2 <i>b</i>	$E_T^{ m miss} \ E_T^{ m miss}$	139 139	$\tilde{b}_1$ Forbidden $\tilde{b}_1$			).23-1.35	Δm Δ	$(\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{0}) = 130 \text{ GeV}, \text{m}(\tilde{\chi}_{1}^{0}) = 100 \text{ GeV}$ m $(\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{0}) = 130 \text{ GeV}, \text{m}(\tilde{\chi}_{1}^{0}) = 0 \text{ GeV}$	1908.03122 2103.08189
3 <sup>rd</sup> gen. squarks direct production	$ \tilde{t}_1 \tilde{t}_1,  \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0  \tilde{t}_1 \tilde{t}_1,  \tilde{t}_1 \rightarrow W b \tilde{\chi}_1^0 $	0-1 e,μ 1 e,μ	$\geq 1$ jet 3 jets/1 b	$E_T^{\rm miss}$	139 139	$\tilde{t}_1$	Forbidden	0.65	1.25		$m({ ilde \chi}^0_1)$ =1 GeV $m({ ilde \chi}^0_1)$ =500 GeV	2004.14060,2012.03799 2012.03799
' gen. 'ect pi	$ \begin{split} \tilde{t}_{1}\tilde{t}_{1}, \tilde{t}_{1} \rightarrow \tilde{\tau}_{1}bv, \tilde{\tau}_{1} \rightarrow \tau \tilde{G} \\ \tilde{t}_{1}\tilde{t}_{1}, \tilde{t}_{1} \rightarrow c\tilde{\chi}_{1}^{0} / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_{1}^{0} \end{split} $	1-2 τ 0 <i>e</i> ,μ	2 jets/1 <i>b</i> 2 <i>c</i>	$E_T^{\rm miss}$	139 36.1	$\tilde{t}_1$	roibiddon	Forbidden 0.85	1.4	I.	$m(\tilde{\tau}_1)=800 \text{ GeV}$ $m(\tilde{\tau}_1)=800 \text{ GeV}$ $m(\tilde{\chi}_1)=0 \text{ GeV}$	2108.07665 1805.01649
di. Gi	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	0 e,μ 1-2 e,μ	mono-jet 1-4 <i>b</i>	$E_T^{ m miss}$ $E_T^{ m miss}$ $E_T^{ m miss}$	139 139	$\tilde{t}_1$	0.55	0.067-	1 18		$m(\tilde{t}_1,\tilde{c})-m(\tilde{\chi}_1^0)=5 \text{ GeV}$ $m(\tilde{\chi}_2^0)=500 \text{ GeV}$	2102.10874 2006.05880
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 <i>e</i> , <i>µ</i>	1 <i>b</i>	$E_T^{\rm miss}$	139	$\tilde{t}_2$	Forbidden	0.86		m( $ ilde{\chi}$	$m_{(\ell_2)} = 360 \text{ GeV}, m(\tilde{t}_1) - m(\tilde{t}_1^0) = 40 \text{ GeV}$	2006.05880
	${ ilde \chi}_1^\pm { ilde \chi}_2^0$ via $WZ$	Multiple $\ell$ /jet $ee, \mu\mu$	s $\geq 1$ jet	$E_T^{ m miss} \ E_T^{ m miss}$	139 139	$ \tilde{\chi}_{1}^{\pm}/\tilde{\chi}_{0}^{0} \\ \tilde{\chi}_{1}^{\pm}/\tilde{\chi}_{2}^{0}  $ 0.205		0.96			m( $ ilde{\chi}_1^0$ )=0, wino-bino m( $ ilde{\chi}_1^{\pm}$ )-m( $ ilde{\chi}_1^0$ )=5 GeV, wino-bino	2106.01676, 2108.07586 1911.12606
	$ ilde{\chi}_1^{\pm}  ilde{\chi}_1^{\mp}$ via $WW$ $ ilde{\chi}_1^{\pm}  ilde{\chi}_2^0$ via $Wh$	2 $e, \mu$ Multiple $\ell/jet$	S	$E_T^{ m miss} \ E_T^{ m miss}$	139 139	$\tilde{\chi}_1^{\pm}$ $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ Forbidden	0.42	1.0	6		m( $\tilde{\chi}_{1}^{0}$ )=0, wino-bino m( $\tilde{\chi}_{1}^{0}$ )=70 GeV, wino-bino	1908.08215 2004.10894, 2108.07586
EW direct	$\tilde{\chi}_{1}^{\pm}\tilde{\chi}_{1}^{\pm} \text{ via } \tilde{\ell}_{L}/\tilde{\nu}$ $\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau \tilde{\chi}_{1}^{0}$ $\tilde{\ell}_{L} p \tilde{\ell}_{L} p \tilde{\ell} \rightarrow \ell \tilde{\chi}_{1}^{0}$	2 e,μ 2 τ		$E_T^{\text{miss}}$ $E_T^{\text{miss}}$	139 139	$\tilde{\chi}_{1}^{\pm}$ $\tilde{\tau} = [\tilde{\tau}_{L}, \tilde{\tau}_{R,L}]$ 0.16-0.3	0.12-0.39	1.0			$ m(\tilde{\ell}, \tilde{\nu}) = 0.5(m(\tilde{\chi}_1^{\pm}) + m(\tilde{\chi}_1^0)) \\ m(\tilde{\chi}_1^0) = 0 $	1908.08215 1911.06660
	$\tilde{\ell}_{\mathrm{L,R}} \tilde{\ell}_{\mathrm{L,R}}, \tilde{\ell} \rightarrow \ell \tilde{\chi}_1^0$	2 e,μ ee,μμ	0 jets $\geq 1$ jet	$E_T^{miss}$ $E_T^{miss}$	139 139	<i>ℓ̃</i> 0.256		0.7			$m(\tilde{\ell})=0$ $m(\tilde{\ell})-m(\tilde{\chi}_1^0)=10 \text{ GeV}$	1908.08215 1911.12606
	$\tilde{H}\tilde{H},\tilde{H}{ ightarrow}h\tilde{G}/Z\tilde{G}$	0 <i>e</i> , <i>µ</i> 4 <i>e</i> , <i>µ</i>	$\geq 3 b$ 0 jets $\geq 2$ large jet	$E_T^{\mathrm{miss}}$ $E_T^{\mathrm{miss}}$	36.1 139	<i>Н</i> 0.13-0.23 <i>Н</i>	0.55				$BR(\tilde{\chi}^0_1 \to h\tilde{G}) = 1$ $BR(\tilde{\chi}^0_1 \to Z\tilde{G}) = 1$	1806.04030 2103.11684
		0 e,µ	≥ 2 large jet	$S E_T^{\text{mass}}$	139	Ĥ		0.45-0.93	State - Marcado	the interest of the second	$BR(\widetilde{\chi}^0_1  o Z\widetilde{G})=1$	2108.07586
Long-lived particles	Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	$E_T^{\rm miss}$	139	$ ilde{\chi}_1^{\pm}$ $ ilde{\chi}_1^{\pm}$ <b>0.21</b>		0.66			Pure Wino Pure higgsino	2201.02472 2201.02472
	Stable $\tilde{g}$ R-hadron	pixel dE/dx		$E_T^{ m miss} \ E_T^{ m miss} \ E_T^{ m miss} \ E_T^{ m miss}$	139	<i>ĝ</i>				2.05	~0	CERN-EP-2022-029
arti	Metastable $\tilde{g}$ R-hadron, $\tilde{g} \rightarrow qq \tilde{\chi}_1^0$ $\tilde{\ell}\tilde{\ell}, \tilde{\ell} \rightarrow \ell \tilde{G}$	pixel dE/dx Displ. lep		$E_T^{\text{miss}}$	139 139	$ ilde{g}  [ au( ilde{g}) = 10 \text{ ns}] \\  ilde{e},  ilde{\mu}$		0.7		2.2	$m( ilde{\chi}_1^0)$ =100 GeV $ au( ilde{\ell})$ = 0.1 ns	CERN-EP-2022-029 2011.07812
ЪГ		pixel dE/dx		$E_T^{miss}$	139	$\tilde{ au}$ 0.3 $\tilde{ au}$ 0	34 9.36	0.7			$ au( ilde{\ell}) = 0.1 \text{ ns}$ $ au( ilde{\ell}) = 0.1 \text{ ns}$ $ au( ilde{\ell}) = 10 \text{ ns}$	2011.07812 CERN-EP-2022-029
	$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\pm} / \tilde{\chi}_1^0, \tilde{\chi}_1^{\pm} \rightarrow Z \ell \rightarrow \ell \ell \ell$	<b>3</b> <i>e</i> ,μ			139	$\chi_{1}^{+}/\chi_{1}^{-}$ [BR( $Z\tau$ )=1, BR( $Ze$ )=1]	0.0	6 <b>25</b> 1.0	5		Pure Wino	2011.10543
	$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp} / \tilde{\chi}_2^0 \to WW / Z\ell\ell\ell\ell\nu\nu$	$4 e, \mu$		$E_T^{\rm miss}$	139	$\tilde{\chi}_{1}^{\pm}/\tilde{\chi}_{2}^{0}  [\lambda_{i33} \neq 0, \lambda_{12k} \neq 0]$		0.95		.55	$m(\tilde{\chi}_1^0)$ =200 GeV	2103.11684
	$\tilde{g}\tilde{g},  \tilde{g} \rightarrow qq \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow qqq$		4-5 large jet	S	36.1	$ ilde{g} = [m( ilde{\mathcal{X}}_1^0) = 200 \;  ext{GeV}, \; 1100 \;  ext{GeV}]$			1.3	1.9	Large $\lambda_{112}^{\prime\prime}$	1804.03568
RPV	$\widetilde{t}\widetilde{t}, \ \widetilde{t} \to t \widetilde{\chi}_1^0, \ \widetilde{\chi}_1^0 \to t bs$		Multiple		36.1	$\tilde{t} = [\lambda''_{323} = 2e-4, 1e-2]$	0.55		5		$m(\tilde{\chi}_1^0)$ =200 GeV, bino-like	ATLAS-CONF-2018-003
RF	$ \widetilde{t}\widetilde{t}, \ \widetilde{t} \to b\widetilde{\chi}_1^{\pm}, \ \widetilde{\chi}_1^{\pm} \to bbs \\ \widetilde{t}_1\widetilde{t}_1, \ \widetilde{t}_1 \to bs $		$\geq 4b$ 2 jets + 2 b		139 36.7	t $\tilde{t}_1  [qq, bs]$	Forbidden 0.42 0.	0.95 61			$m(\tilde{\chi}_1^{\pm})$ =500 GeV	2010.01015 1710.07171
	$ \tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow 0 S $ $ \tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow q \ell $	2 <i>e</i> , <i>µ</i>	2 jets + 2 <i>b</i>		36.1	$\tilde{t}_1$			0.4-1.45	5	$BR(\tilde{t}_1 \rightarrow be/b\mu) > 20\%$	1710.05544
		$1 \mu$	DV		136	$\tilde{t}_1$ [1e-10< $\lambda'_{23k}$ <1e-8, 3e-10< $\lambda'_{23k}$	<3e-9]	1.0		1.6	$BR(\tilde{t}_1 \to q\mu) = 100\%,  \cos\theta_t = 1$	2003.11956
	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0/\tilde{\chi}_1^0, \tilde{\chi}_{1,2}^0 \rightarrow tbs, \tilde{\chi}_1^+ \rightarrow bbs$	1-2 <i>e</i> , µ										

\*Only a selection of the available mass limits on new states or phénomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

 $10^{-1}$ 

Mass scale [TeV]

- Taking the SUSY search program at ATLAS as an example
- Long-lived particle search is only a small category of the search program



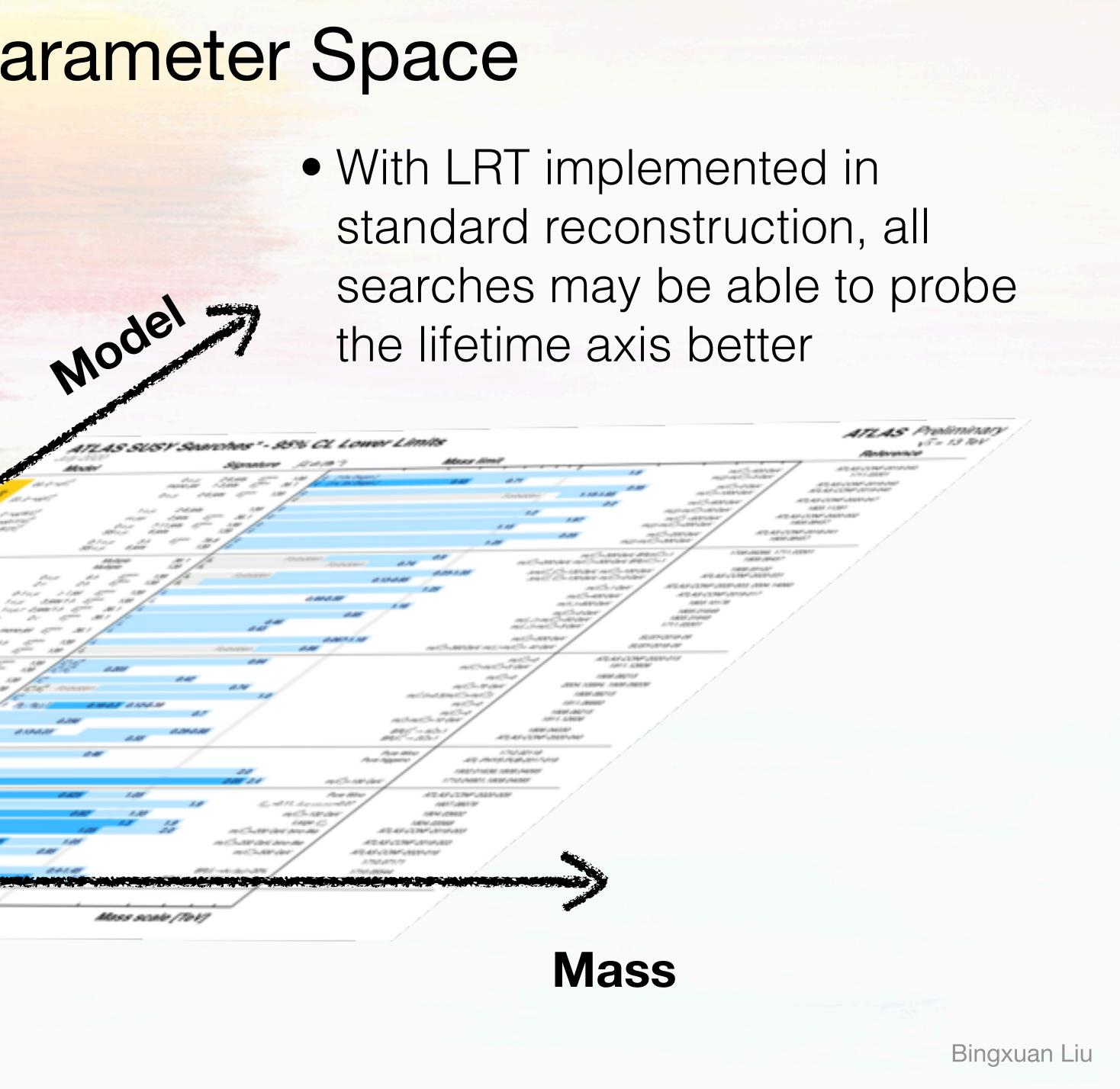
#### Greatly Extend the Parameter Space



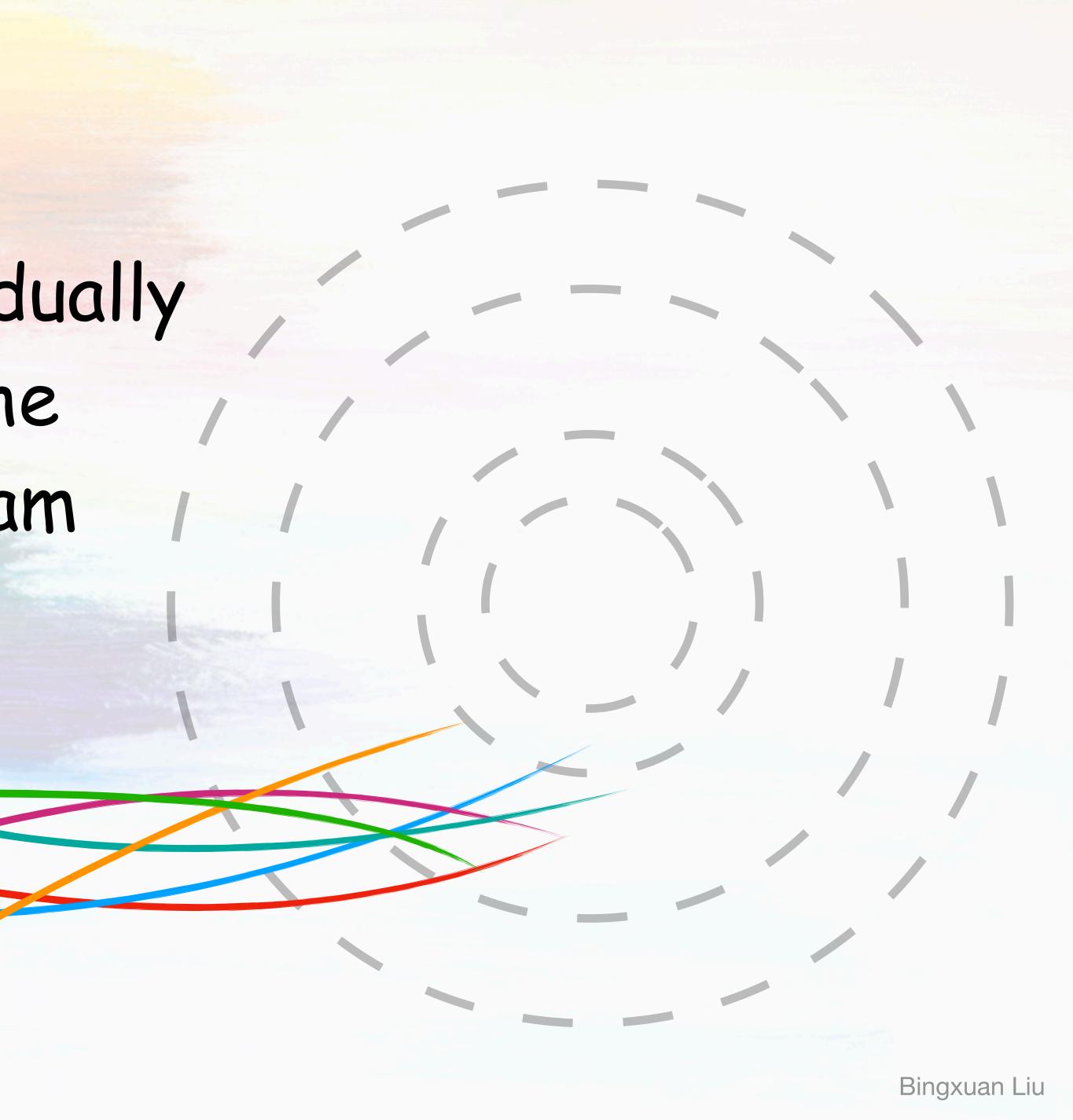
Anderson and a second and a second s second seco

#### What I am excited about!

standard reconstruction, all the lifetime axis better



LLP searches will gradually become part of the mainstream program



## Which means...we can consider

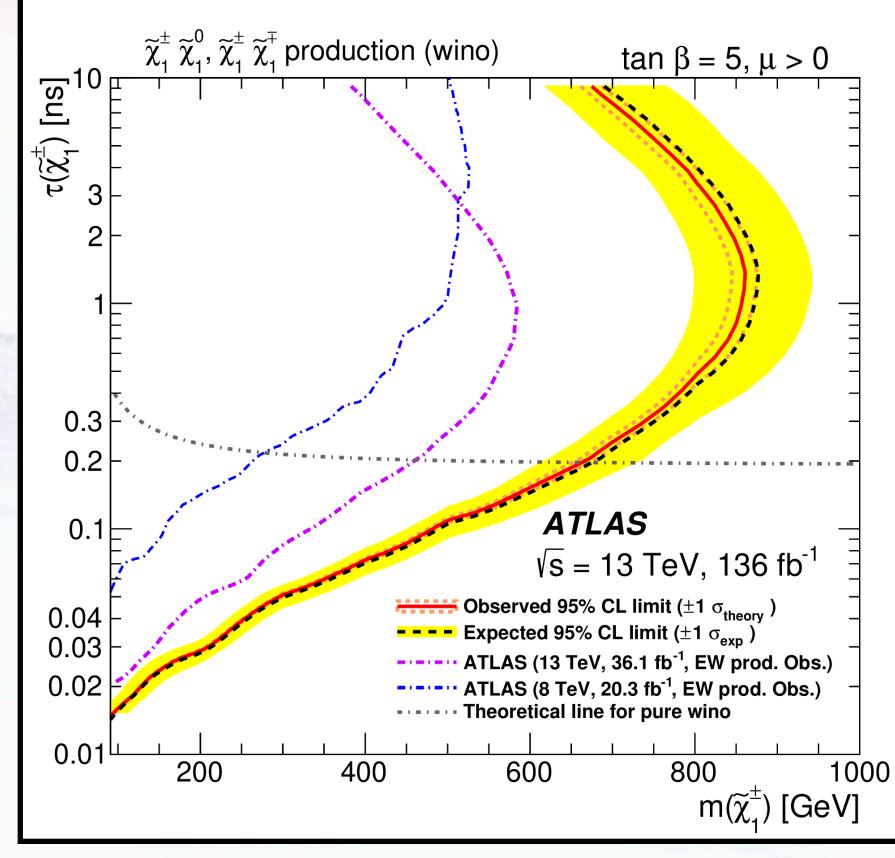
#### more

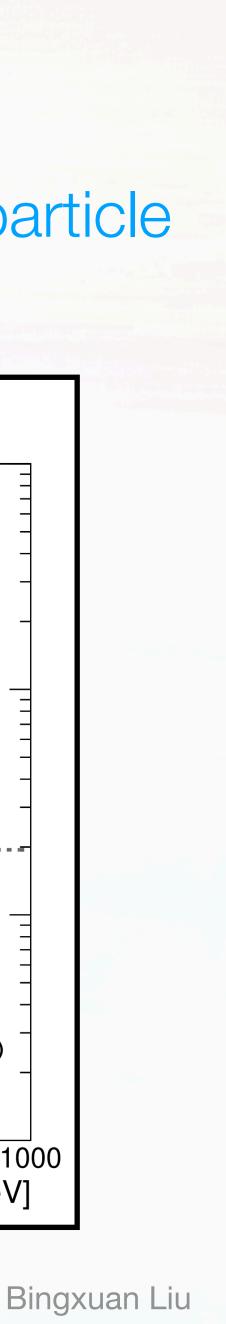




#### Strange Things We Have Probed

• Disappearing Track: Charged LLP decays to a neutral particle + soft charged particle





#### Exotic Tracks: Appearing/Kinked Tracks

- Appearing Track:
  - Neutral LLP decays to a charged particle + soft charged particle: not able to form a displaced vertex
- Kinked Track:
  - A charged LLP decays to a neutral particle and a charged particle



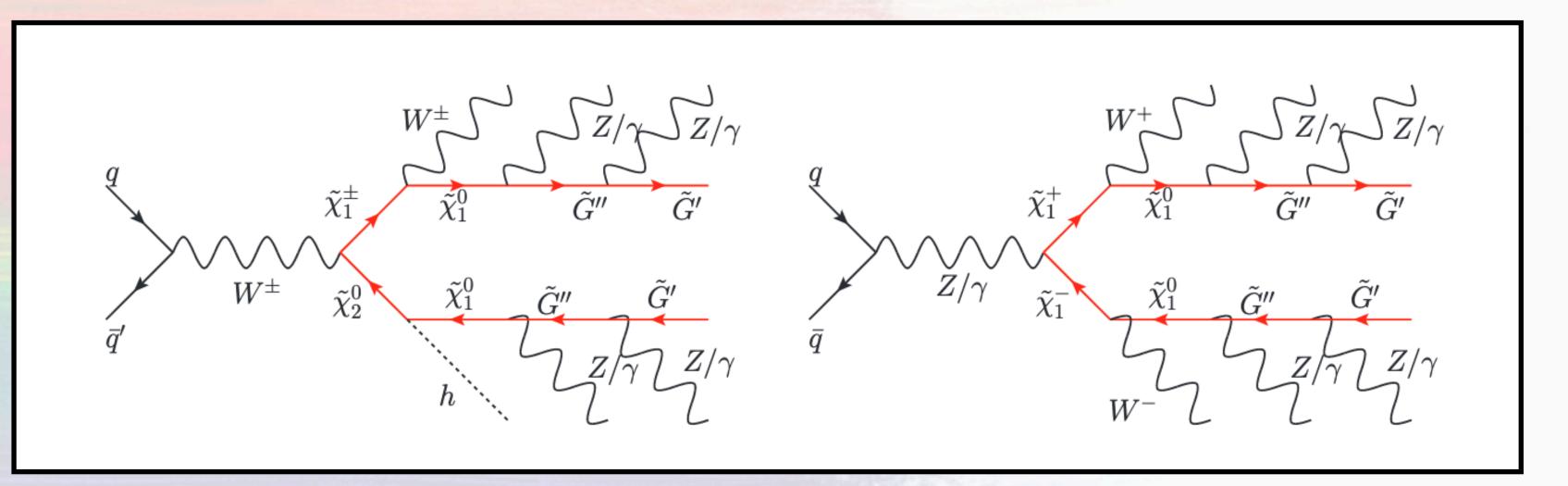
#### More Exotic: Dashed Tracks

Oscillation between charge and neutral particles with measurable lifetimes

- A unique signature rises
  - Disappearing-reappearingdisappearing patterns
- Track characteristics:
  - Missing inner hits along the tracks or holes on tracks in general
    - If they are reconstructed as one single track
  - Track pairs with the same trajectory separated by a few tracker layers
    - If they are reconstructed as various tracks

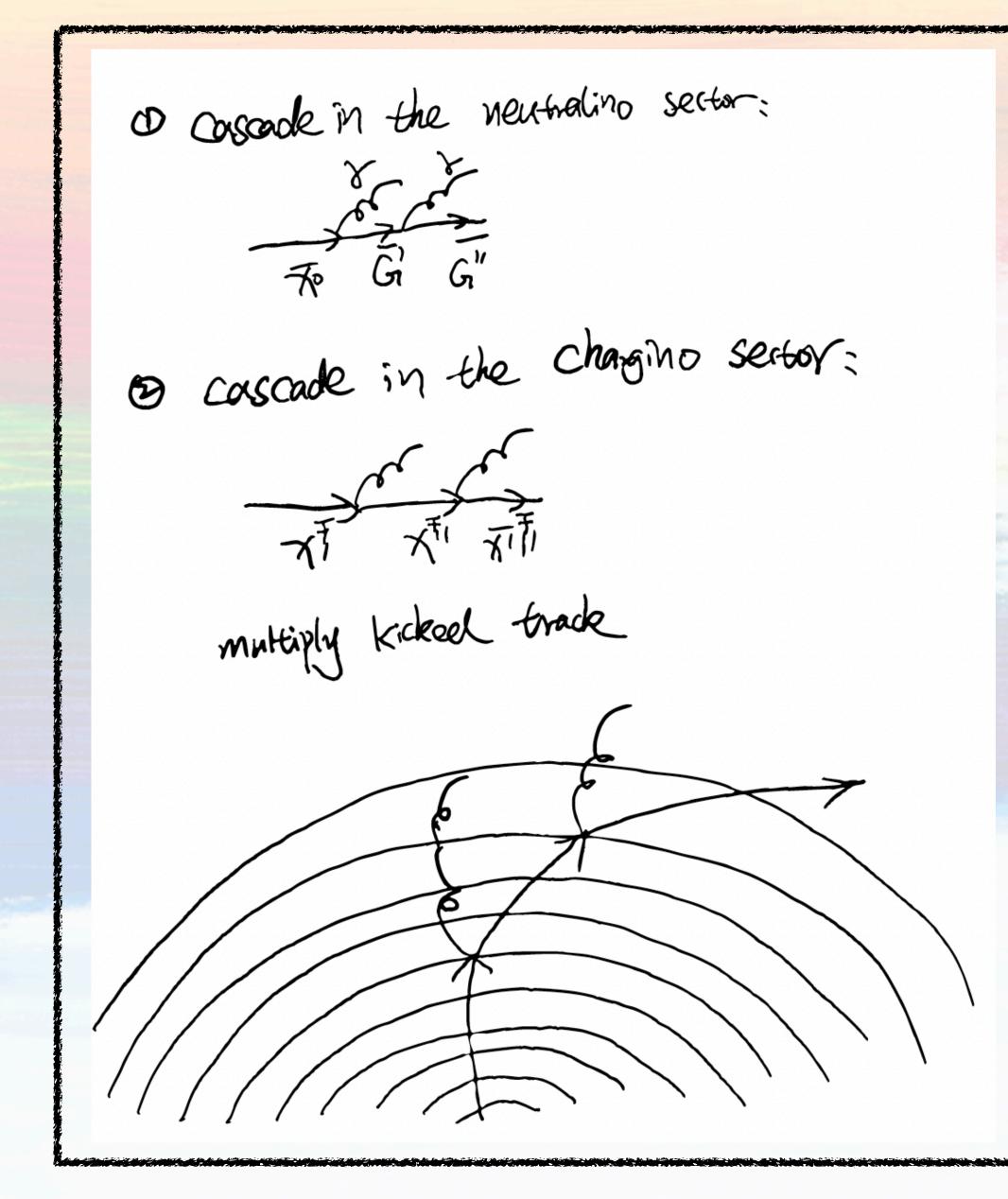


 Diogo, Gabriele, Ellen and Sara investigated similar structures in the neutral sector [arxiv:2111.04775]

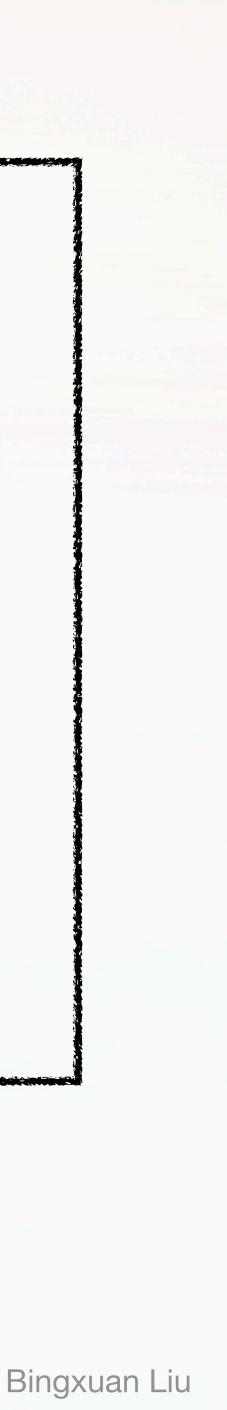


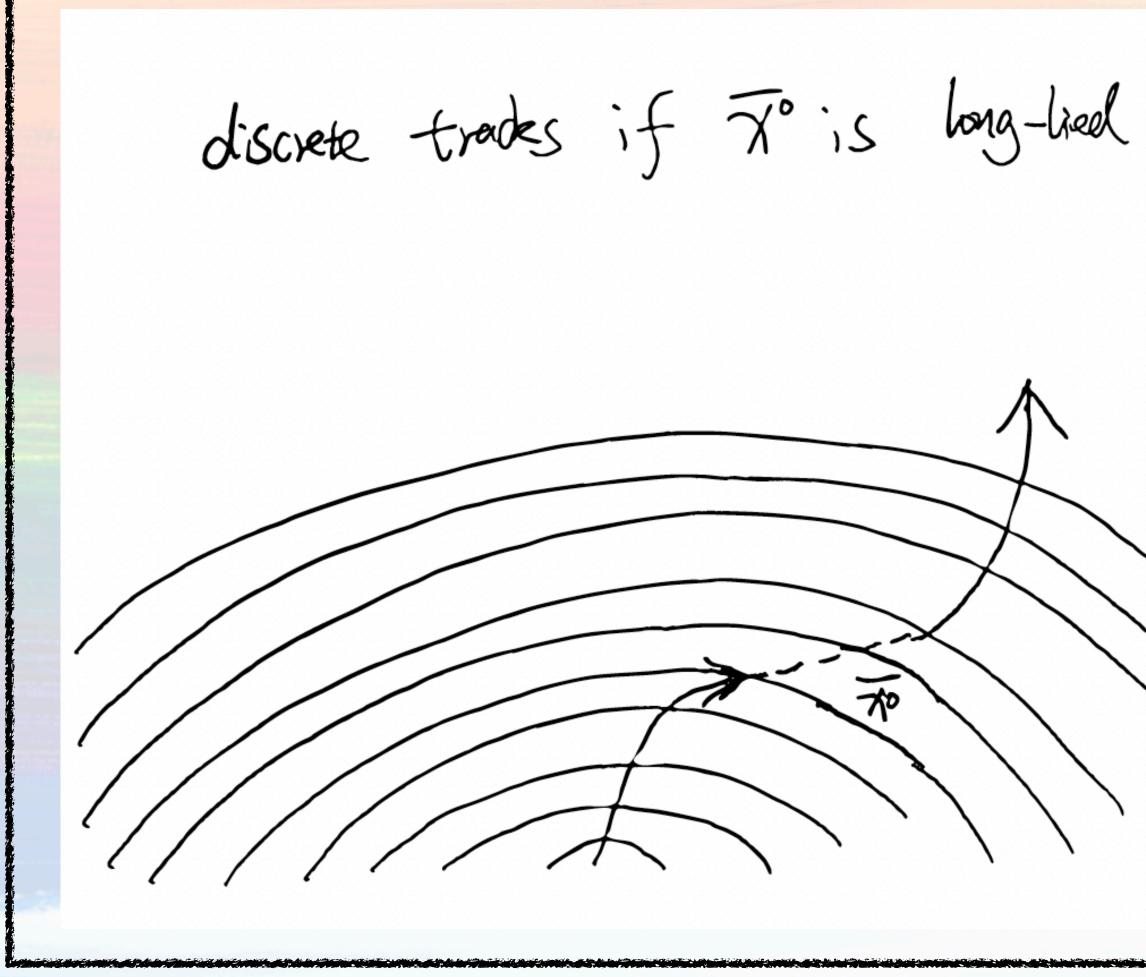
• I read this paper and wondered whether the model can have a similar charged sector





3 cascade in both Sectors with mixing Xt Xo KE Curly Grades = if To is short liked

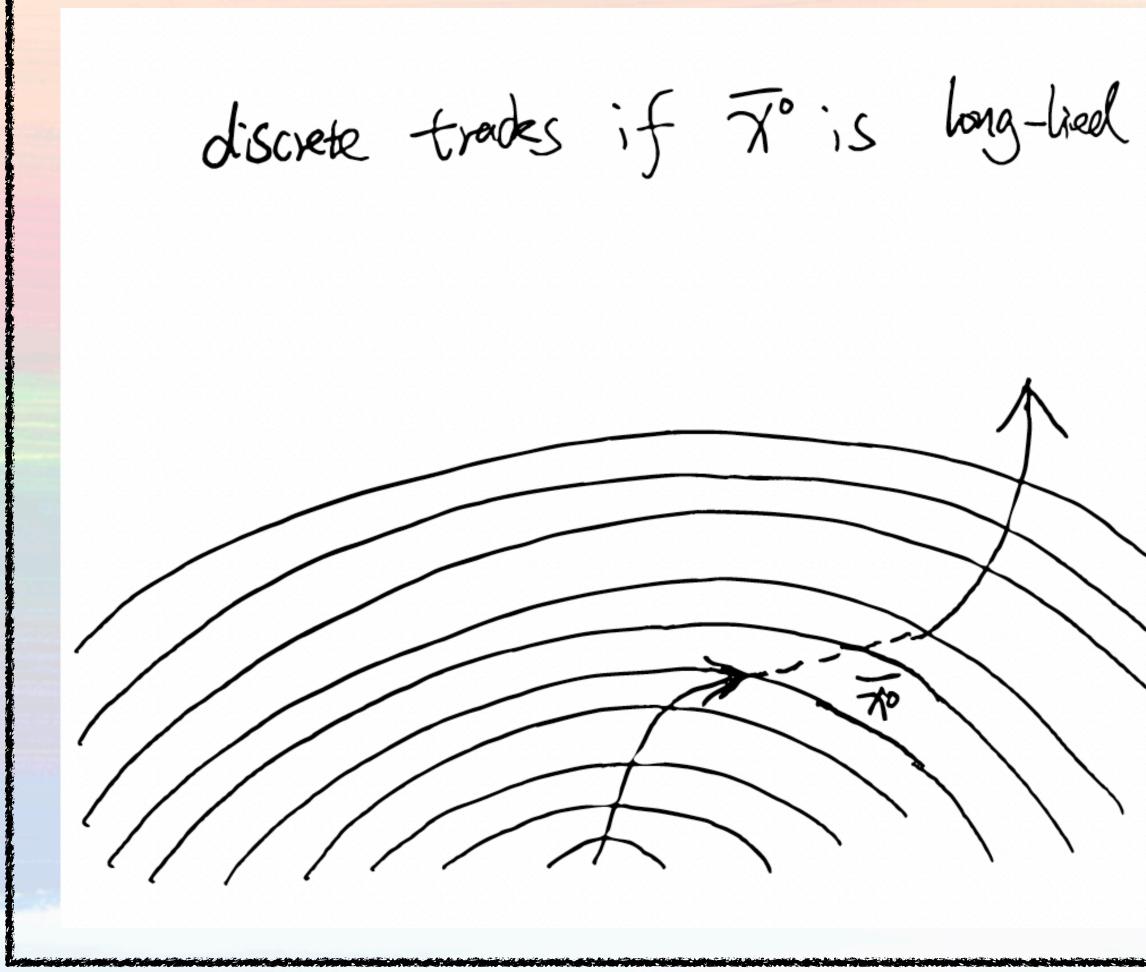




 Hard to be realized in arxiv:2111.04775

• Other possible candidate: baryon genesis ....and maybe your model?





 Hard to be realized in arxiv:2111.04775

• Other possible candidate: baryon genesis ....and maybe your model?

# WEDAVERADED memegenerator.n



#### You are so non-natural!

## But naturalness needs me!

#### Bold Claims





Bingxuan Liu

## There is definitely room for non-natural signatures!



# Searching for them is a natural choice!

