2018 RHIC & AGS Annual Users' Meeting

Jet Reconstruction in Au+Au Collisions at RHIC

Ph.D. Thesis Overview

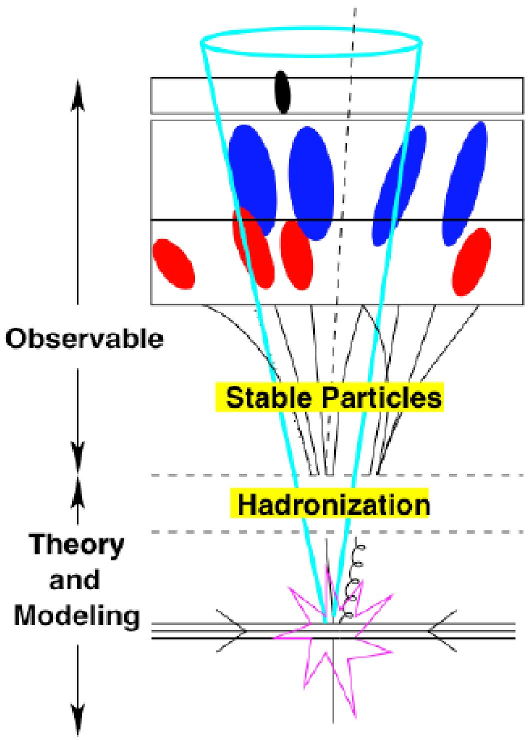
Jan Rusnak

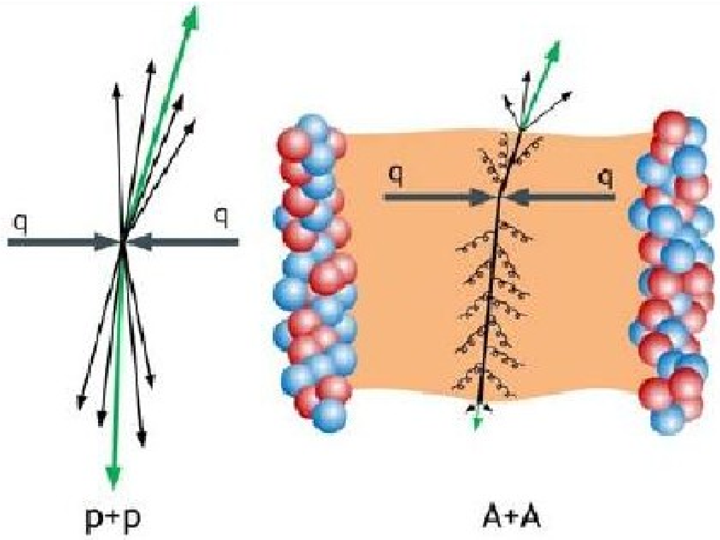
NPI, Czech Academy of Sciences

Jets: Probe of the Quark Gluon Plasma

Jets:

- collimated sprays of hadrons created by fragmentation and hadronization of hard-scattered partons
- partonic, hadronic and detector level
- p+p collisions: test of pQCD
- Au+Au collisions: probe of the medium





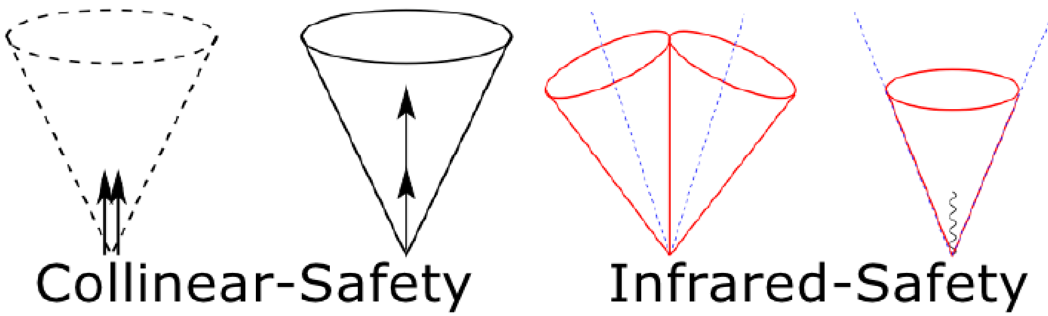
different fragmentation in medium
=> jet quenching

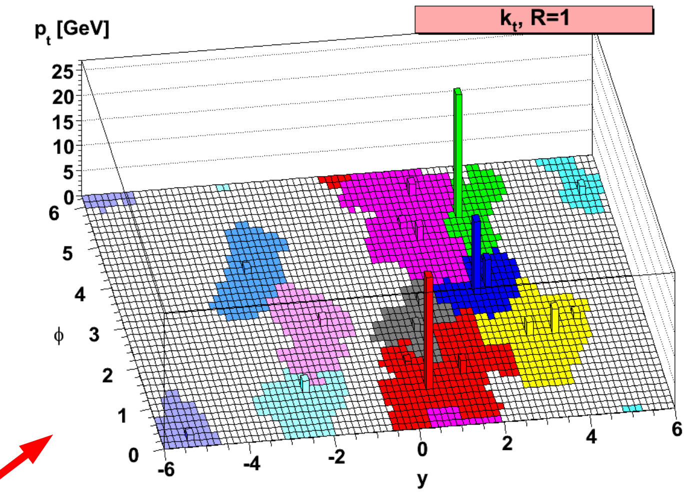
- Jet reconstruction in heavy-ion collisions is very challenging
  - high multiplicity of particles
  - large background with local fluctuations comparable to signal

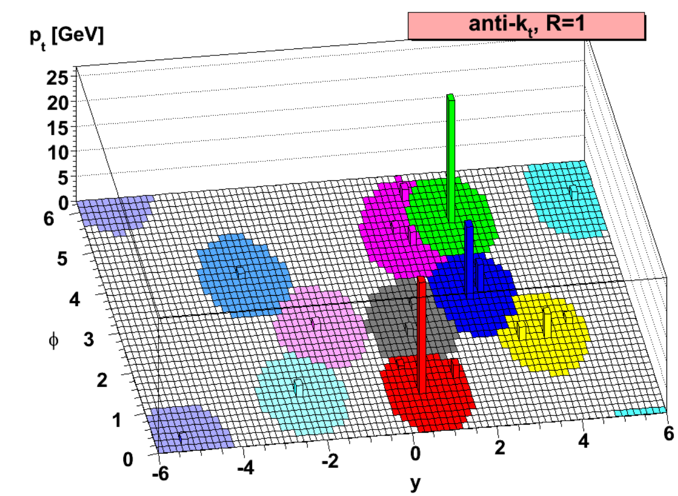
Jet Reconstruction Algorithms

Requirements:

- infrared and collinear safety
- low computational demands







[Cacciari, Salam, Soyez: Eur.Phys.J. C72 (2012) 1896]

Sequential recombination algorithms

- k_T – starts with low p_T particles
- anti-k_T – starts with high p_T particles
- jet size limited by the jet resolution parameter *R*

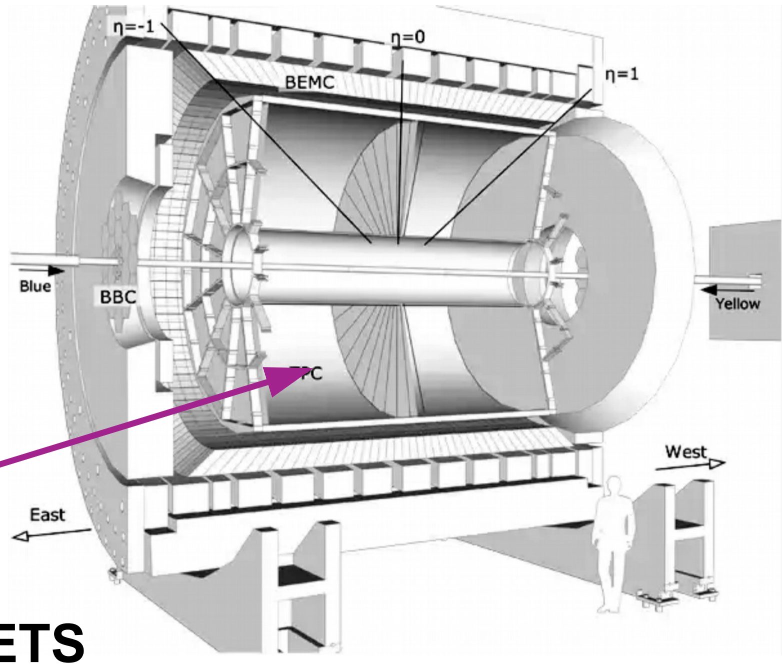
=> implemented in **FASTJET** [Cacciari, Salam, Soyez: Eur.Phys.J. C72 (2012) 1896]

Data Analysis

- RHIC Run11 data, Au+Au $\sqrt{s_{NN}}$=200 GeV
- Minimum Bias (MB) trigger

centrality bin	0-10%	60-80%
# of accepted events [M]	~40	~80

STAR experiment



Jet Reconstruction:

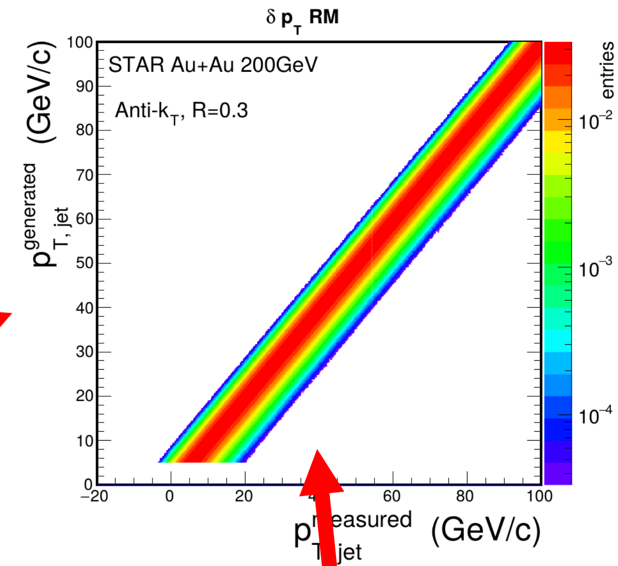
- only charged tracks from TPC => **CHARGED JETS**
- *R*=0.2, 0.3, 0.4
- anti-k_T
- |η|<1-R
- constituents: p_T>0.2 GeV/c → very low p_T wrt. ATLAS or CMS

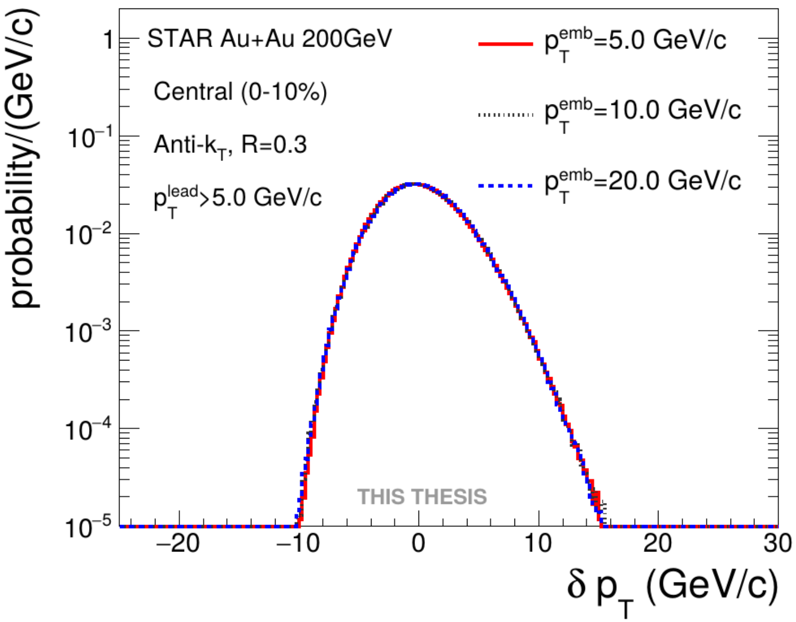
Effect of Background Fluctuations: δp_T distribution

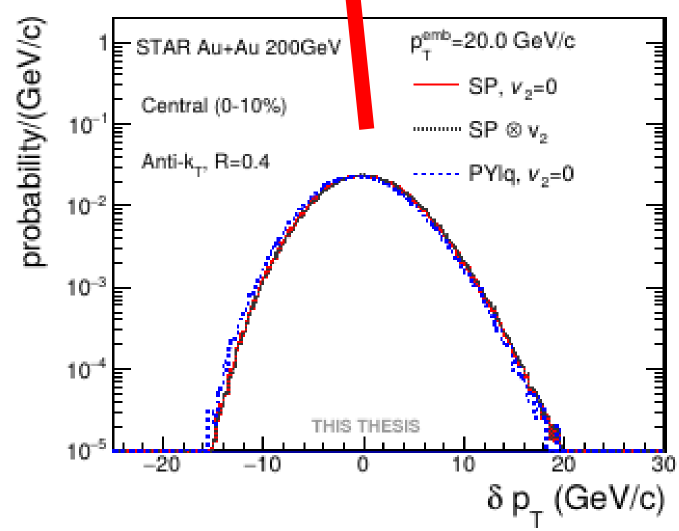
- a simulated jet is embedded into real events and is reconstructed

$$\delta p_T = p_{T,reco} - p_{T,emb} = p_T - A_{jet} \times \rho - p_{T,emb}$$

- different values of $p_{T,emb}$ => response matrix $\mathbf{R}_{\delta pT}$





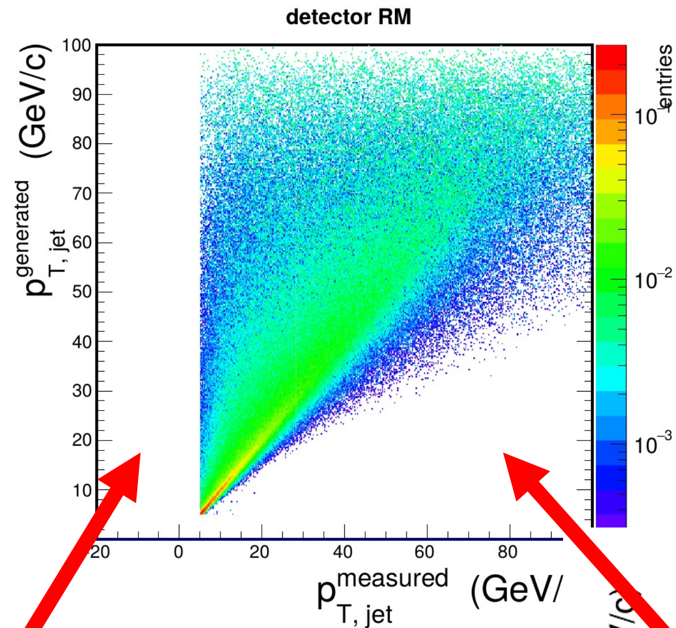


- δp_T – distribution does not depend significantly neither on $p_{T,emb}$, nor on jet fragmentation

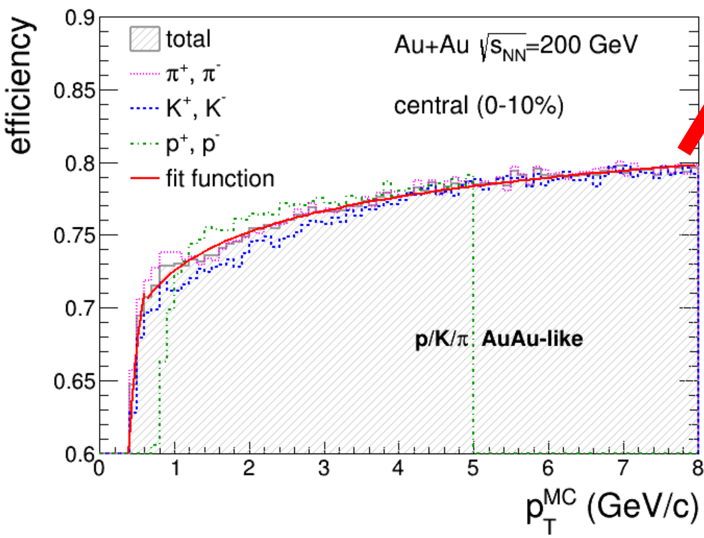
Detector Effects

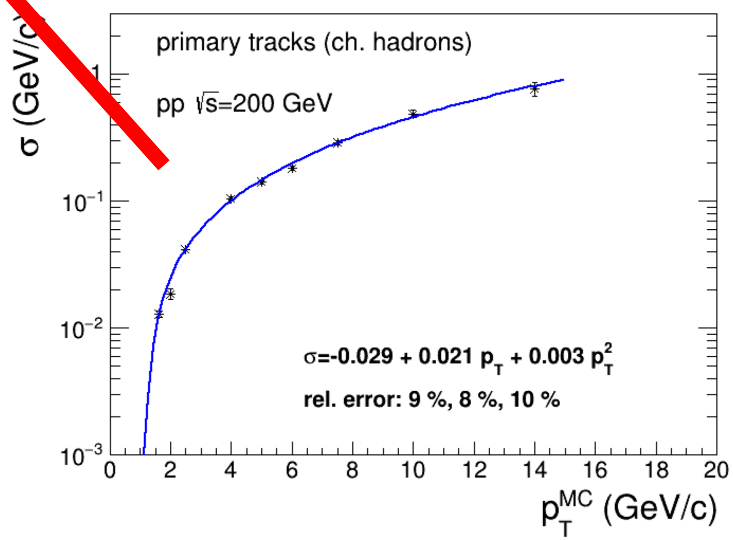
- instead of MC simulation we parametrize 2 main effects
- effects applied on PYTHIA jets (*u-quark* and *gluon*)

1) track reconstruction efficiency



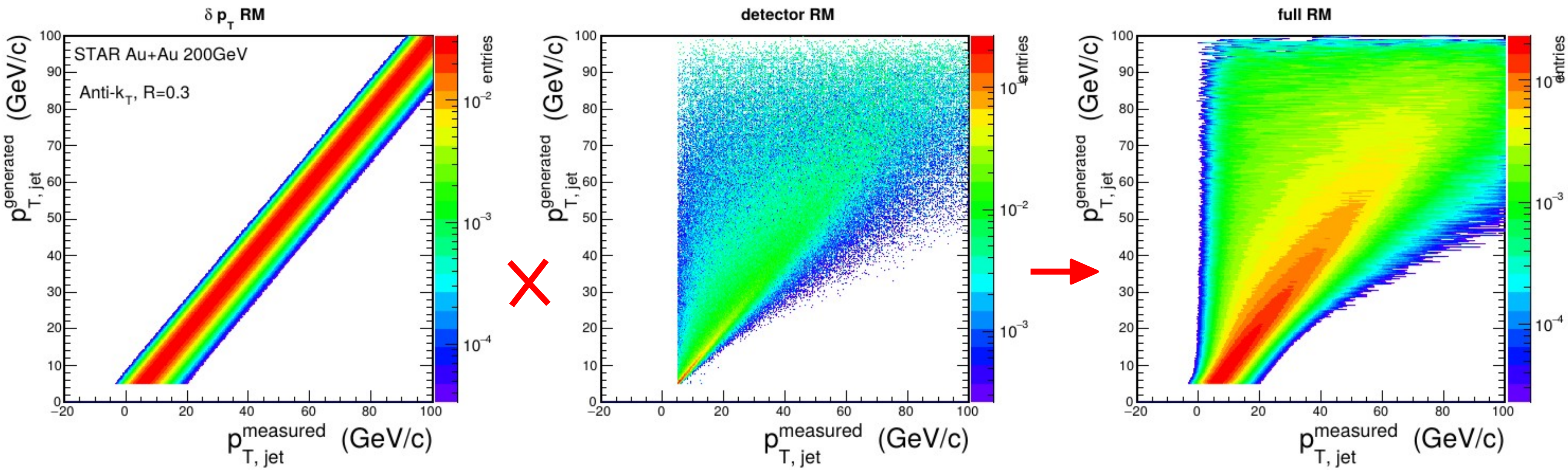
2) momentum resolution





Full Response Matrix

- we assume background fluctuations and detector effects are independent
- full response matrix is obtained by multiplying the two response matrices

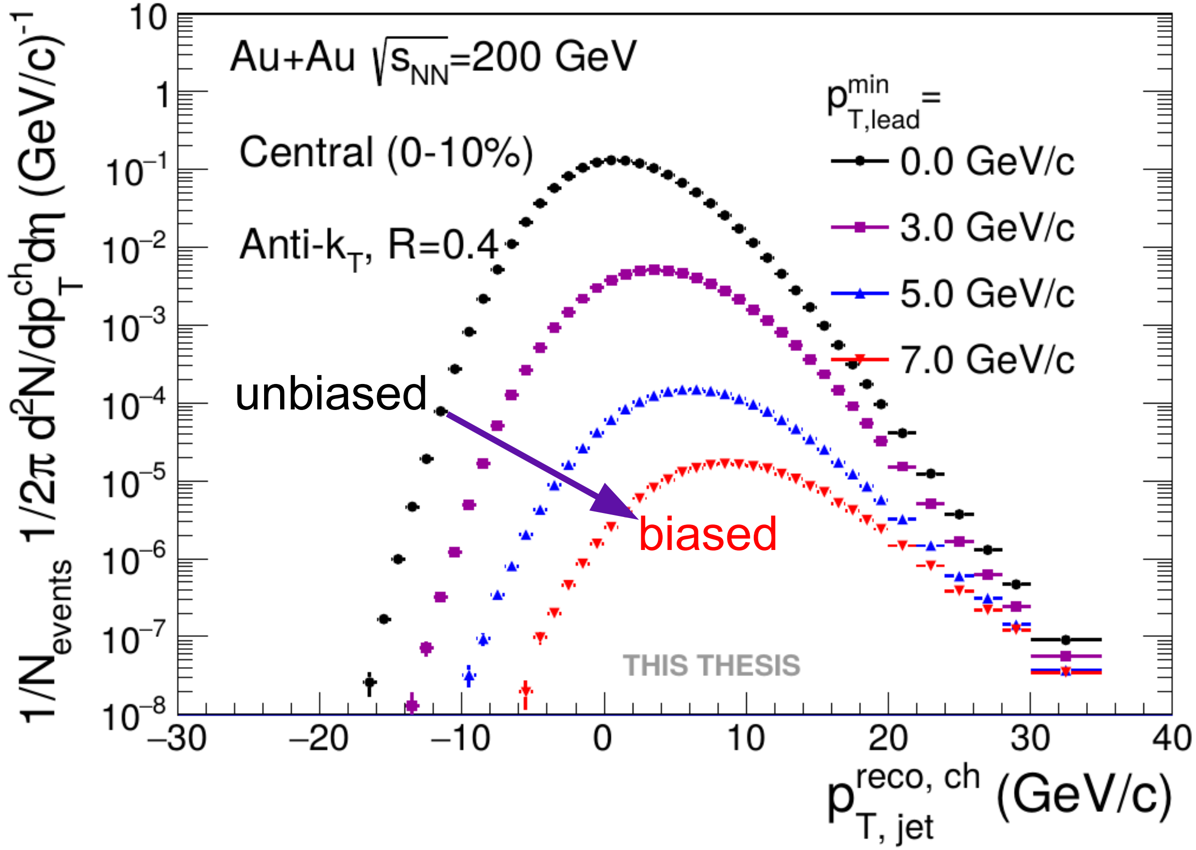


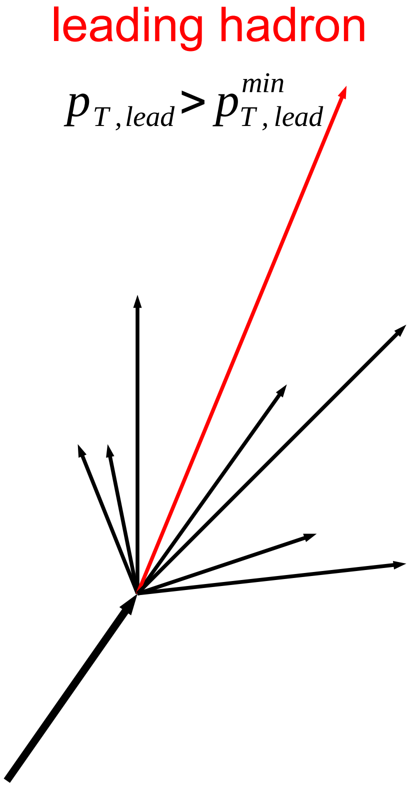
- the response matrix is used to correct the spectra for the background fluctuations and detector effects by the means of **unfolding**
- two unfolding methods used
  - SVD unfolding [1]
  - Bayesian unfolding [2]

[1] Hocker and V. Kartvelishvili, Nucl.Instrum.Meth. **A372**, 469 (1996)
[2] D'Agostini, ArXiv e-prints (2010), arXiv:1010.0632

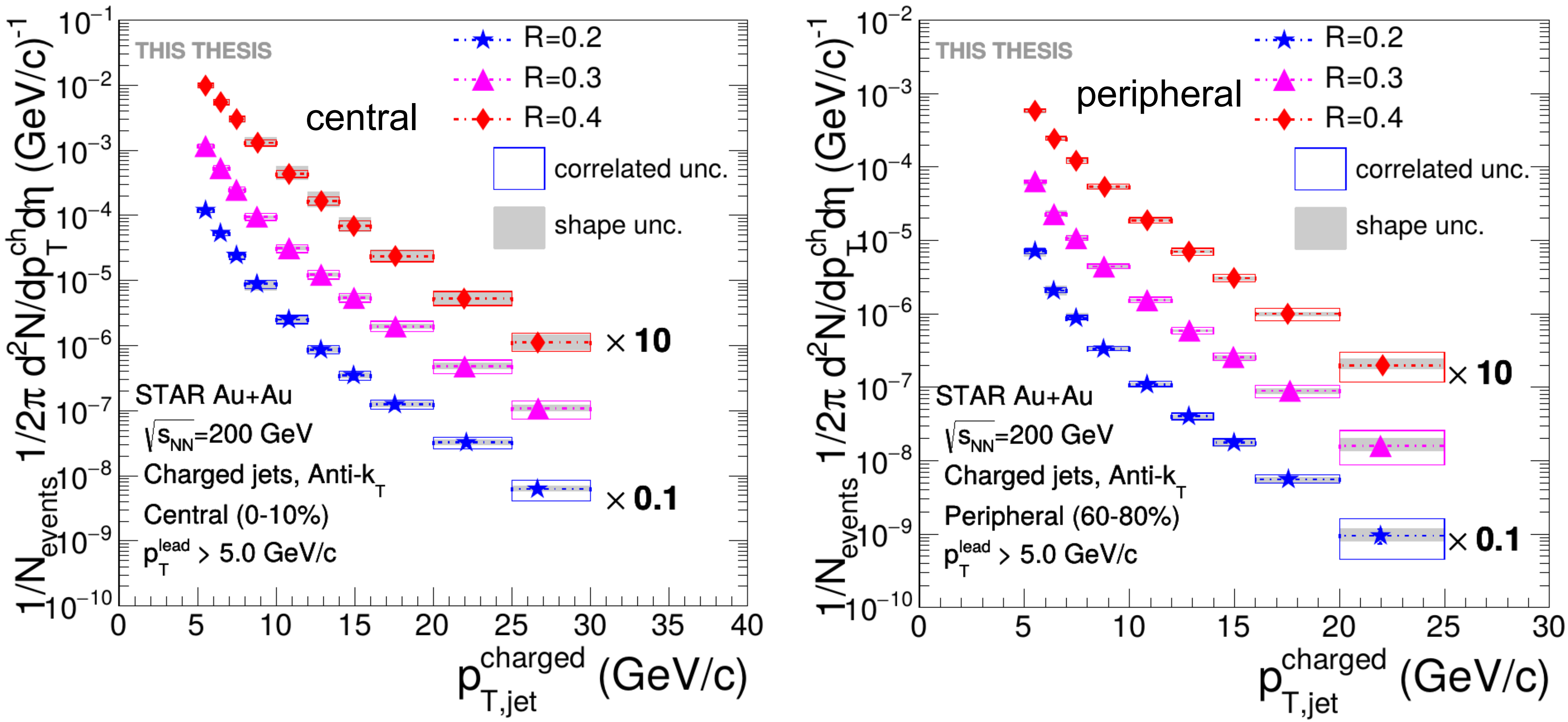
Combinatoric Background Suppression

- unfolding deals only with momentum smearing, not with jet reconstruction inefficiency and fake combinatoric jets
- combinatoric jets suppressed by imposing a cut on leading hadron momentum
- imposes a bias on jet fragmentation and breaks collinear safety
  - this bias needs to be explored





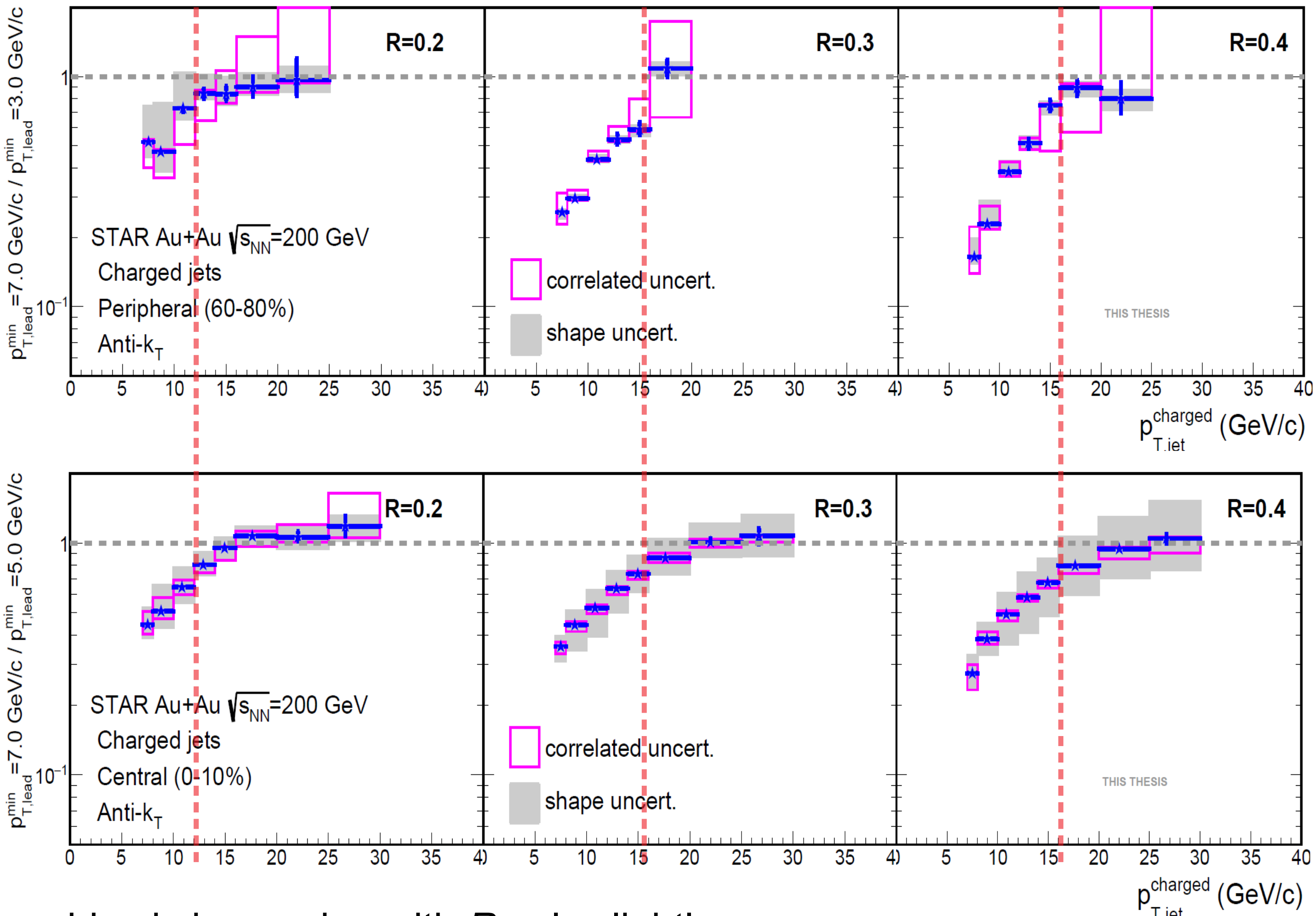
Fully Corrected Spectra



- systematic study of charged jet spectra as a function of R, centrality and p_T^{lead} performed

Ratio of Spectra with Different p_T^{lead}

- gives us information about the size of the bias imposed by the p_T^{lead} cut

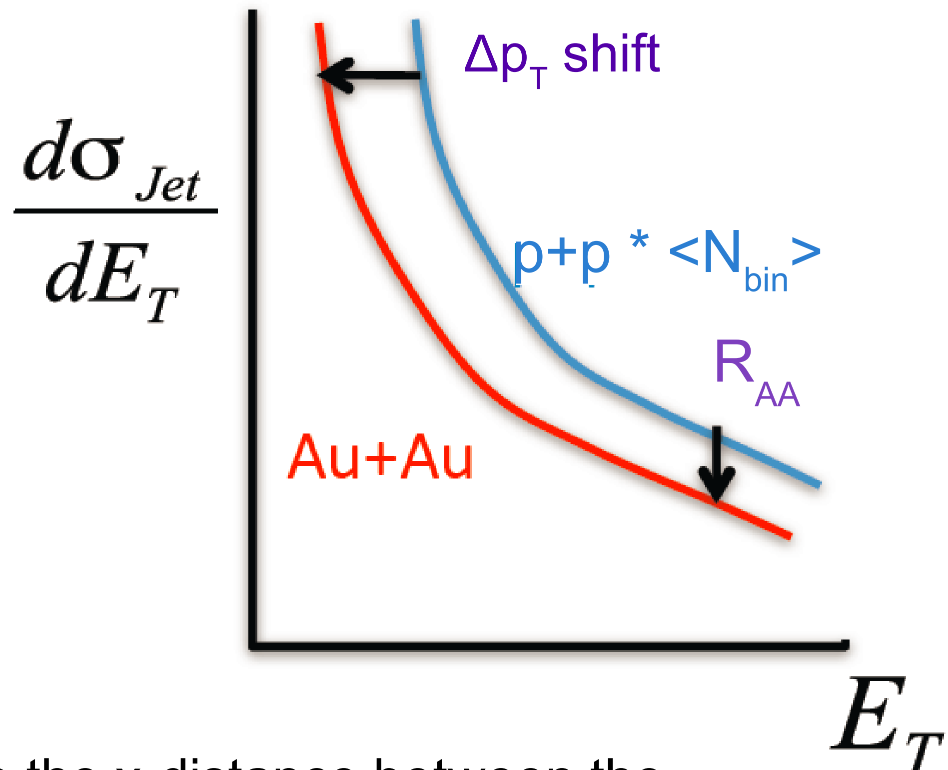


- bias is increasing with *R* only slightly

Jet R_{AA}, R_{CP} and ΔpT Shift

- R_{AA} - nuclear modification factor– ratio of A+A spectrum to p+p spectrum scaled by the mean number of binary collisions
- R_{CP} – similar to R_{AA}, instead of p+p collisions one compares to peripheral A+A collisions

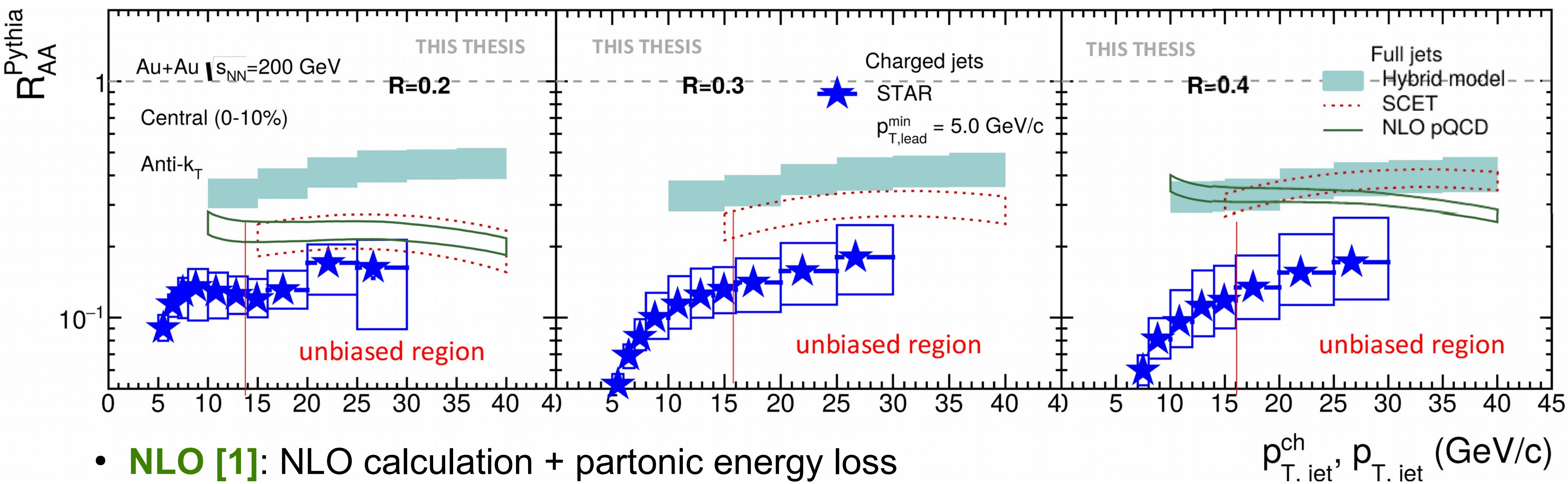
$$R_{AA} = \frac{1/N^{AuAu}_{events}}{1/N^{pp}_{events}} \cdot \frac{\frac{d^2 N_{AuAu}}{dp_T\, d\eta}}{\langle N_{bin} \rangle \frac{d^2 N_{pp}}{dp_T\, d\eta}}$$



- alternatively, one can measure the x-distance between the distributions - **Δp_T shift**

Jet R_{AA} and Comparison to Models

- p+p baseline: PYTHIA 6

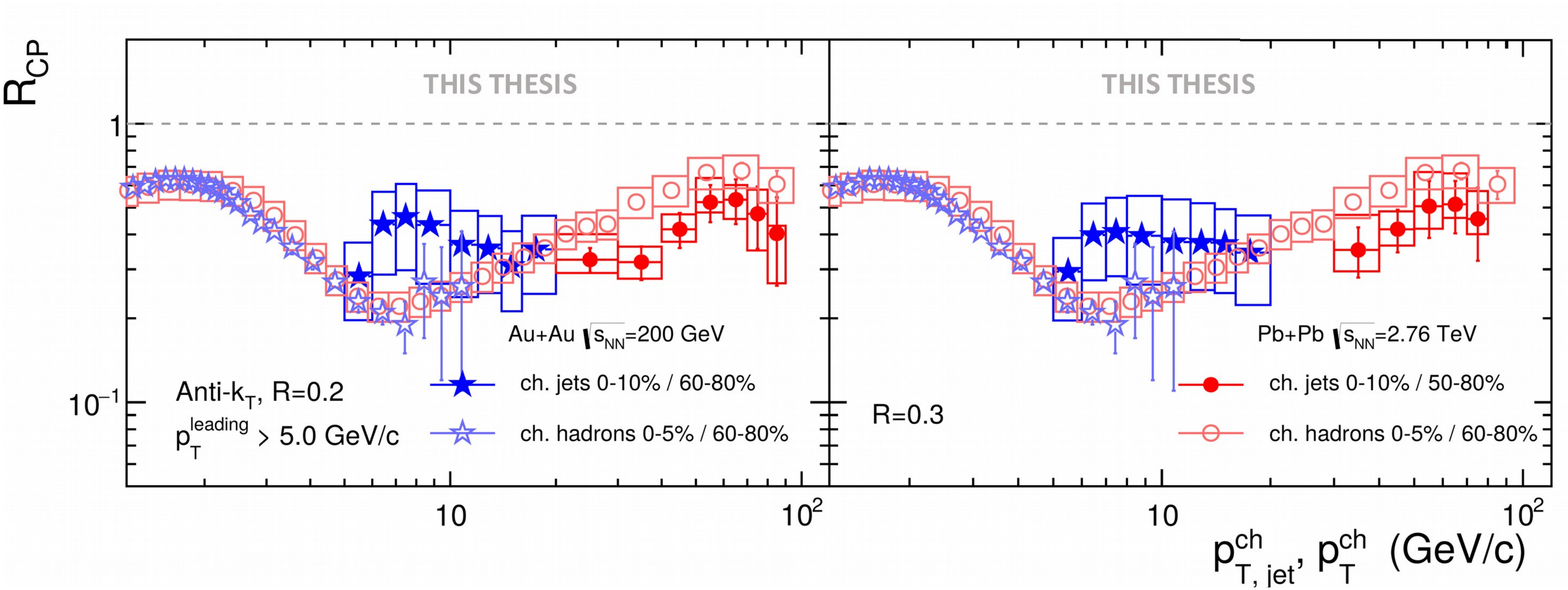


- **NLO [1]**: NLO calculation + partonic energy loss
- **SCET [2]**: soft-collinear effective theory (SCET) + CNM effects + full medium induced splitting functions
- **Hybrid Model [3]**: DGLAP evolution + hybrid strong/weak coupling approach to jet quenching

- all 3 predictions overestimate the R_{AA}
  - however the calculations were made for full jets, not charged jets
- data and Hybrid Model show no *R* dependency

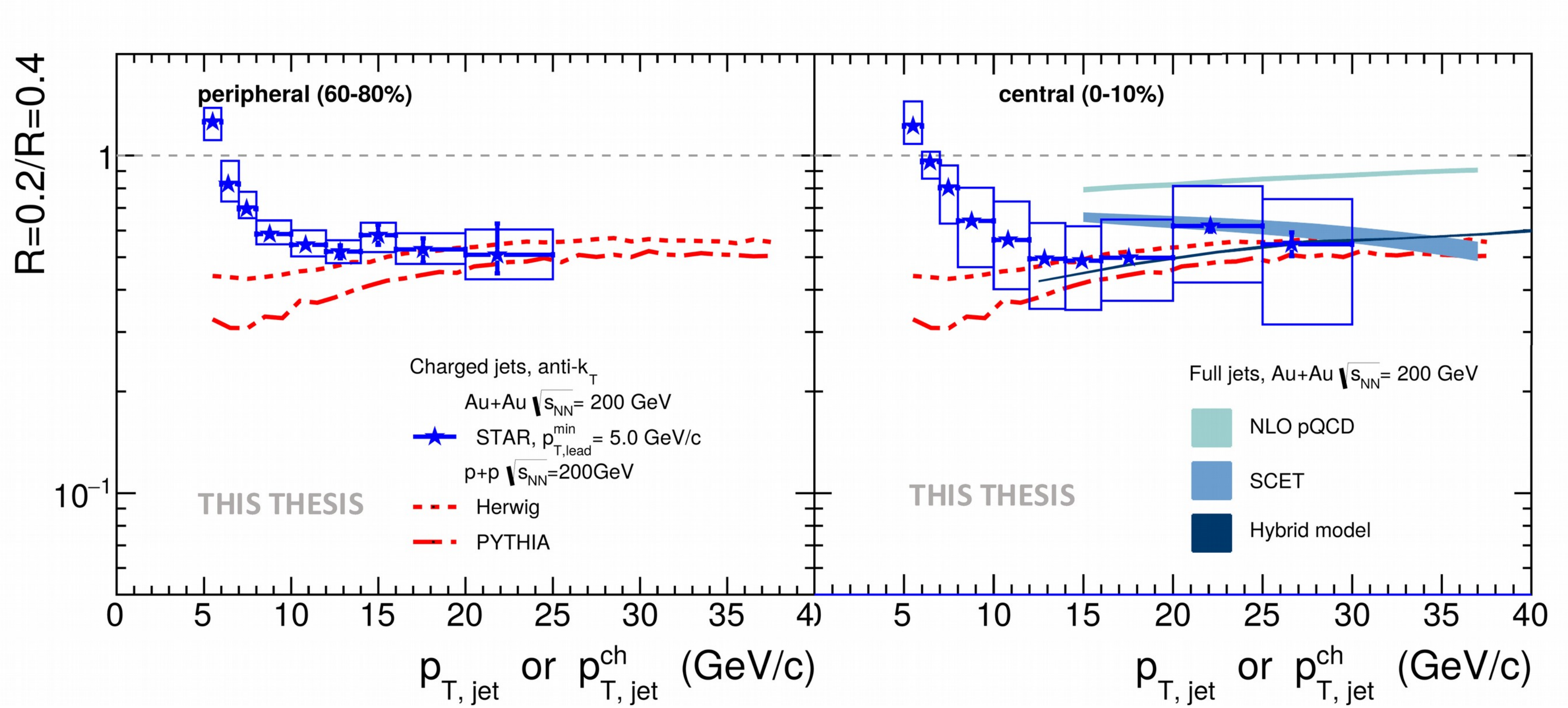
[1] arXiv:0910.1090 [2] arXiv:1509.02936 [3] arXiv:1405.3864

Jet R_{CP} and Comparison to LHC



- R_{CP} comparable to LHC (ALICE) results
- significantly higher than charged hadron R_{CP} at the same p_T, but comparable with lower p_T hadrons

Jet Shape: Ratio of Different *R*s



- no p_T^{lead} cut used in theoretical models
- ratios consistent in Au+Au central, peripheral and p+p collisions
  → small jets modified by the medium in a similar way as the large jets
- theoretical models, which were unable to describe the R_{AA}, describe the spectra ratios of different radii well

Conclusions and Outlook

- performed the first measurement of inclusive spectrum of reconstructed charged jets in Au+Au collisions at RHIC

- nuclear modification factors show strong suppression of jet production in central Au+Au collisions with respect to p+p and peripheral Au+Au collisions
- available model calculations significantly overestimate the R_{AA} value

- jet inner structure was explored by measuring ratios of jet yields for different jet radii

- an advanced paper draft ready for STAR internal publication committee

THANK YOU!

BACKUP

Systematic Uncertainties

two types of uncertainties:

correlated

- affect all bins in the same direction
- do not change shape of the spectrum

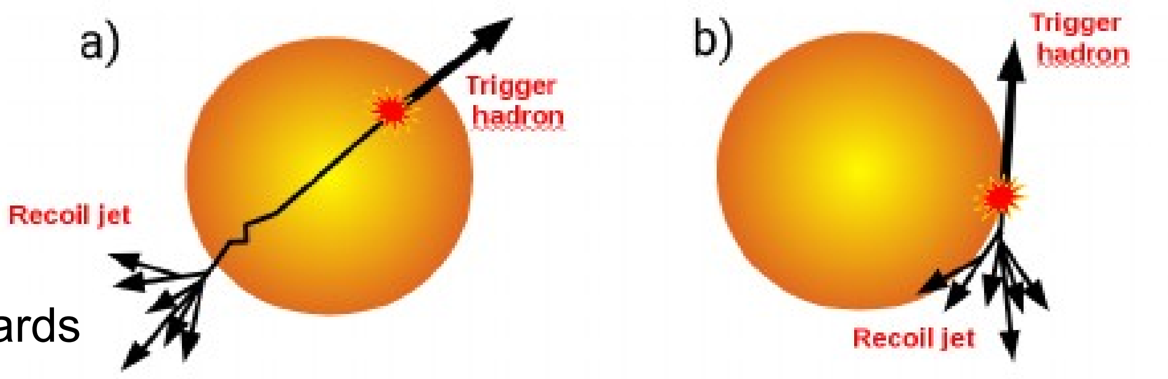
shape

- can change shape of the spectrum
- from unfolding

Systematic uncertainty (%)									
		central Au+Au				peripheral Au+Au			
	R	0.2		0.4		0.2		0.4	
	$p_{\mathrm{T,jet}}^{\mathrm{ch}}$ [GeV/c]	[14,16]	[20,25]	[14,16]	[20,25]	[14,16]	[20,25]	[14,16]	[20,25]
correlated	tracking	13	24	13	17	10	15	13	20
	δp_{T} shape	13	15	6	21	10	13	7	11
	jet fragmentation	6	3	8	9	3	1	1	2
	ρ calculation	5	7	3	3	4	7	10	25
	total correlated	19	25	16	28	14	21	18	33
shape	unfolding	9	15	34	32	5	11	3	5

Δ*p*T Shift: Inclusive and Recoil Jets

- average p_T distance between central and peripheral spectrum
- similar calculation was done for recoil jets at STAR
- recoil jets exhibit ~2x higher p_T shift → recoil jets biased towards maximum path length



Au+Au collisions, $\sqrt{s_{NN}}$=200 GeV $10 < p^{ch}_{T,jet} < 20$ GeV/c		
R	p_T-shift peripheral→central (GeV/c)	
	inclusive jets	h+jet [1]
0.2	$-2.2 \pm 0.1_{stat} \pm 0.5_{sys}$	$-4.4 \pm 0.2_{stat} \pm 1.2_{sys}$
0.3	$-2.3 \pm 0.1_{stat} \pm 0.5_{sys}$	$-5.0 \pm 0.5_{stat} \pm 1.2_{sys}$
0.4	$-2.1 \pm 0.1_{stat} \pm 0.6_{sys}$	$-5.1 \pm 0.5_{stat} \pm 1.2_{sys}$

[1] Phys. Rev. C 96, 024905 (2017), arXiv:1702.01108

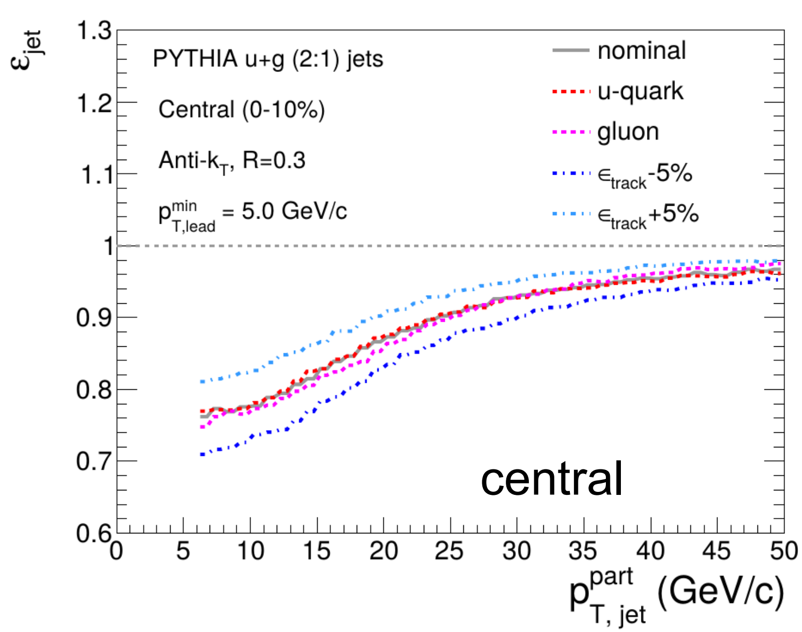
Jet Reconstruction Efficiency

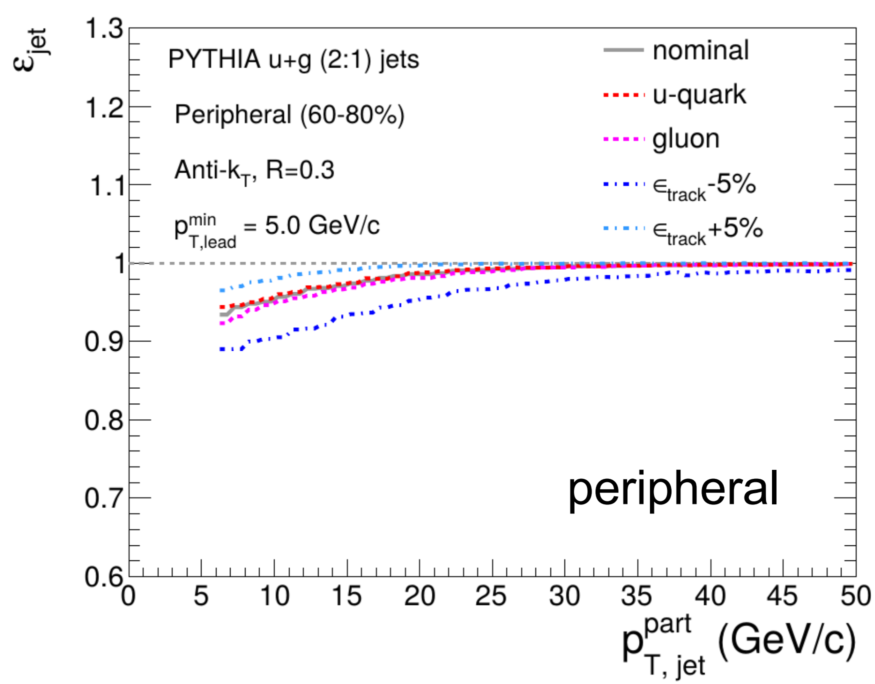
- jet reconstruction efficiency ε<100%
- generated sample of PYTHIA jets – particle level
- detector effects applied – detector level

} 1 to 1 matching

- detector level spectrum is unfolded
- efficiency calculated as ratio of unfolded detector level spectrum to particle level spectrum

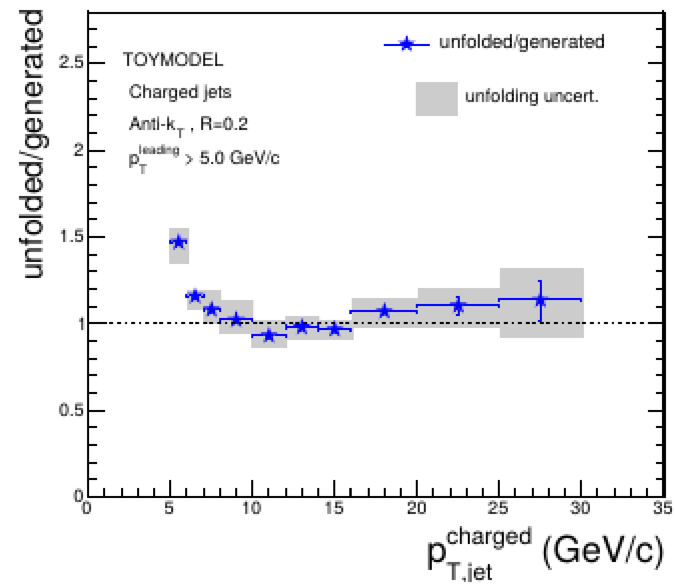
$$\varepsilon(p_{\mathrm{T,jet}}^{\mathrm{part}}) = \frac{\frac{\mathrm{dN_{jet}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{det}}} \otimes \widetilde{\mathbf{R}^{-1}}\left[p_{\mathrm{T,jet}}^{\mathrm{part}} \rightarrow p_{\mathrm{T,jet}}^{\mathrm{det}}\right]}{\frac{\mathrm{dN_{jet}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{part}}}}$$

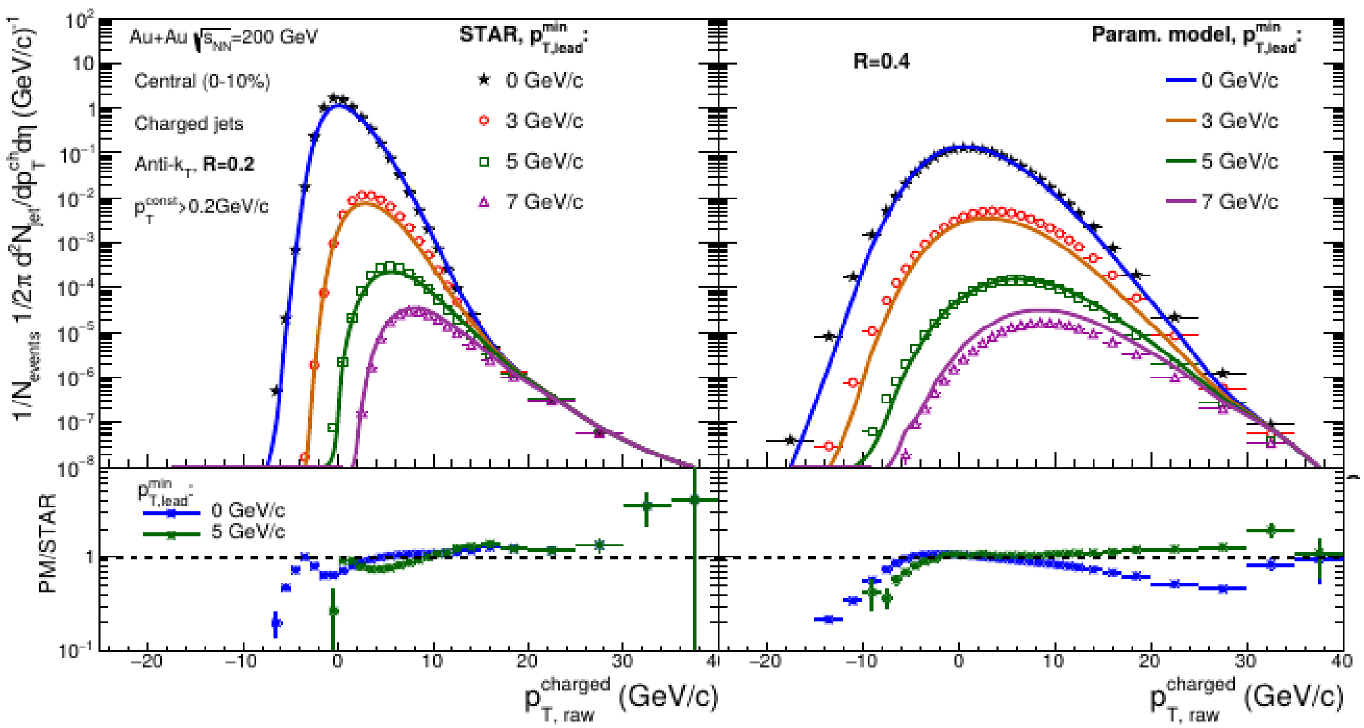


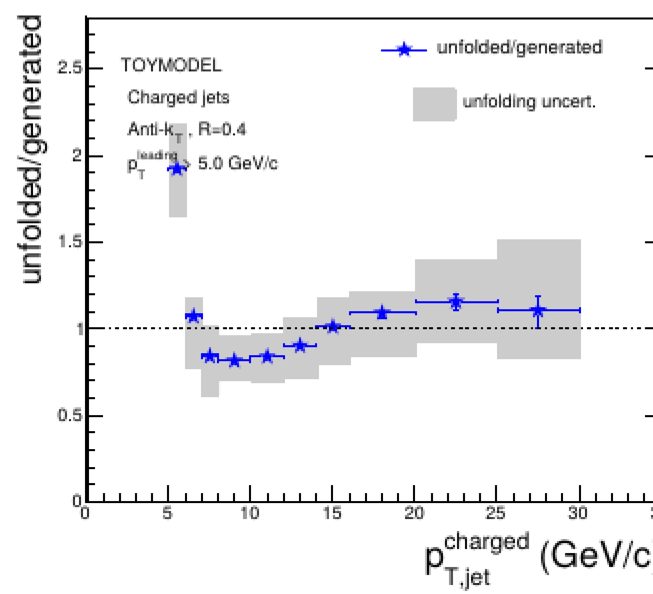


Parametrized Model

- test bench for study of systematic effects
- unfolding closure test
- 2 components: hard distribution + thermal background
- describes STAR data reasonably well

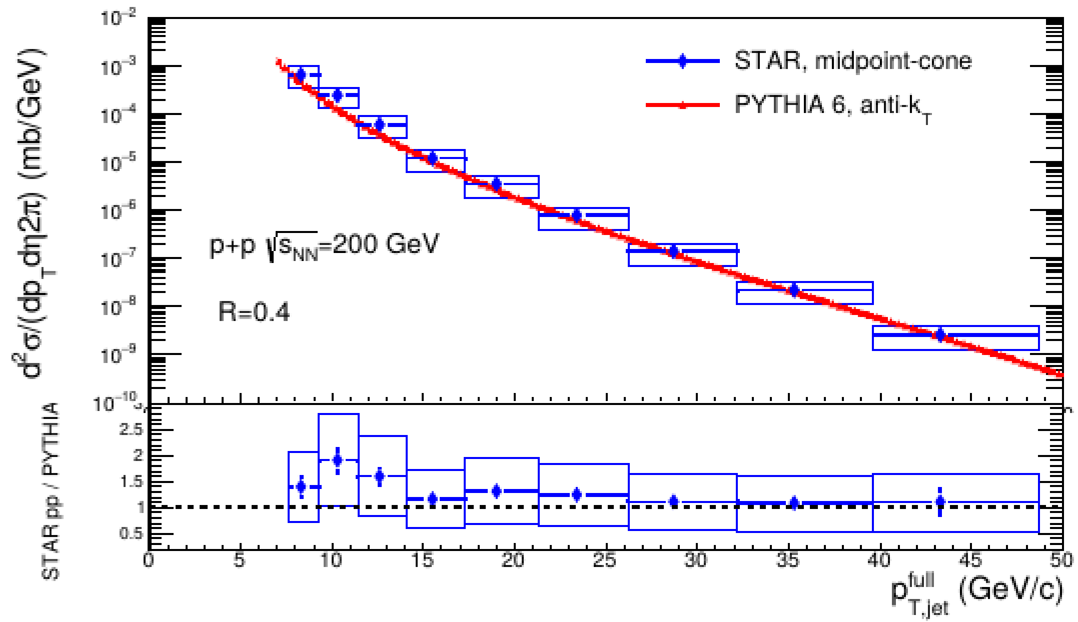


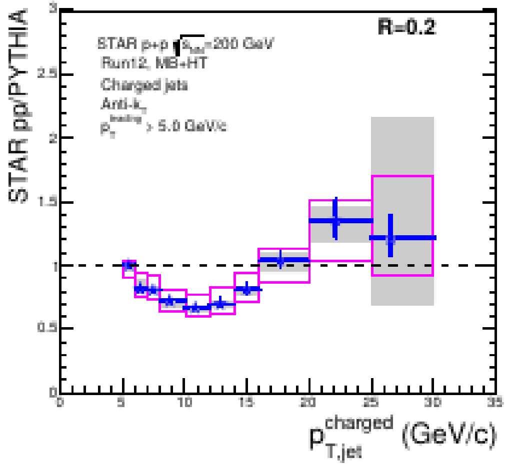


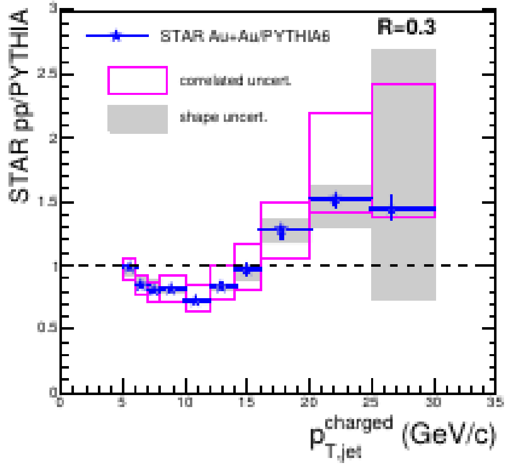


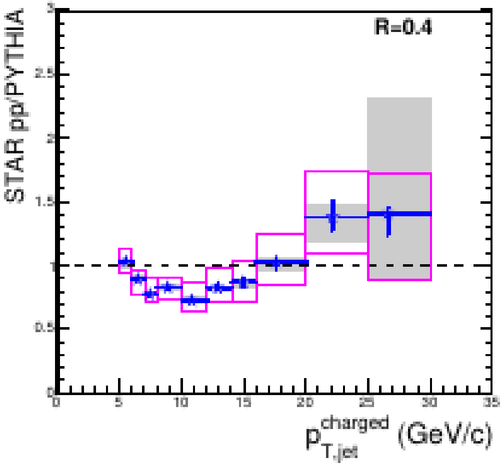
p+p Baseline

- no published STAR p+p charged jet spectra => PYHTIA 6
- validated on published full jet spectra
- a quick and simplified analysis of p+p chared jets as a cross check



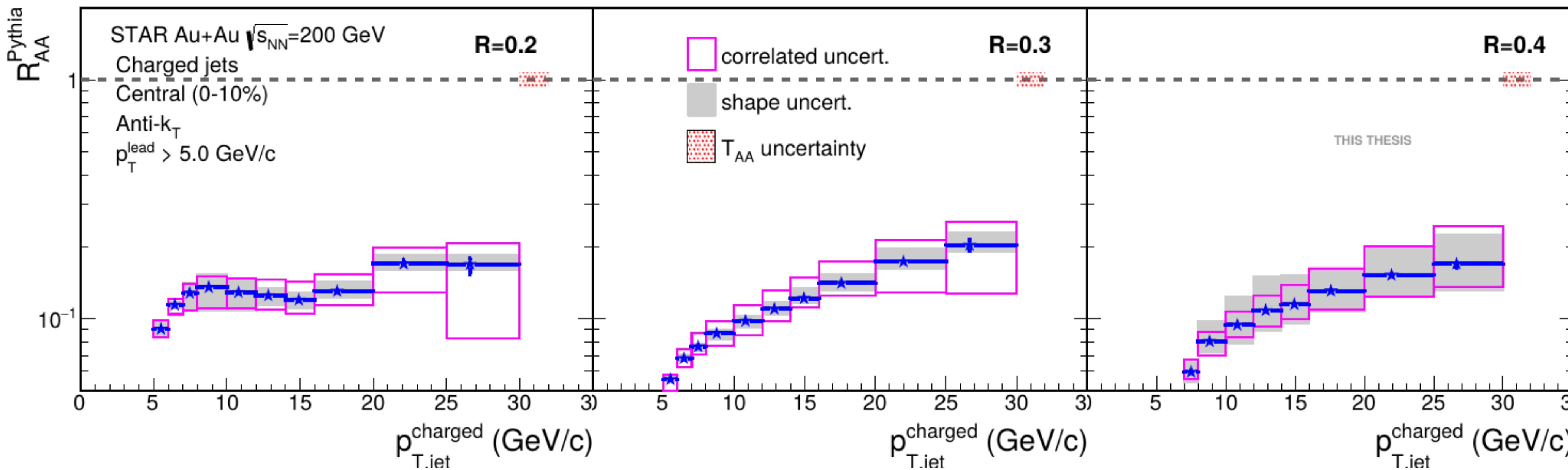






Jet R_{AA} – R Dependency

- baseline: PYTHIA ($p_{T,\,lead}^{min}$ = 0 GeV/c)



- baseline: PYTHIA ($p_{T,\,lead}^{min}$ = 5 GeV/c)