

Monte Carlo Modeling of Hard Processes

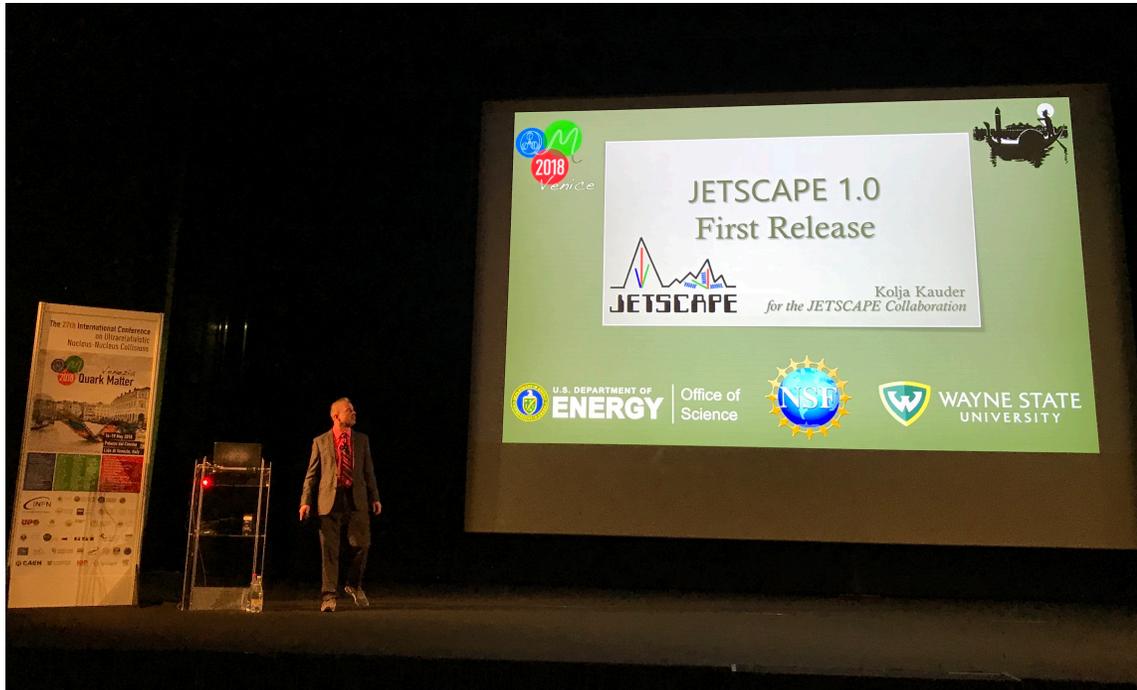
in $p+p$, $p+A$, $A+A$, and beyond

Kolja Kauder



Disclaimer: I am not a Theorist, or MC expert

... but I play one on TV!



KK [nucl-th]
[arXiv:1807.09615](https://arxiv.org/abs/1807.09615)



... and now streaming live!



Thanks to many people for
their input and feedback

*All errors and omissions
are my own*

Monte Carlo Methods

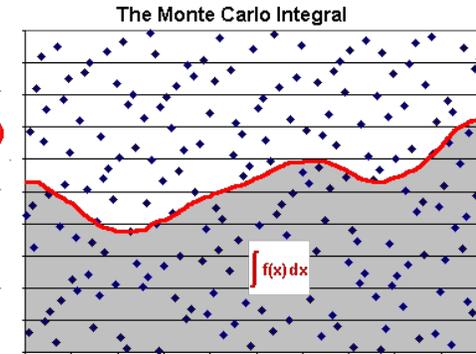
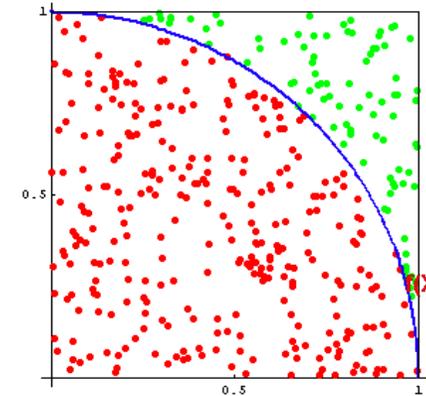


Monte Carlo: **Randomly sample a distribution**

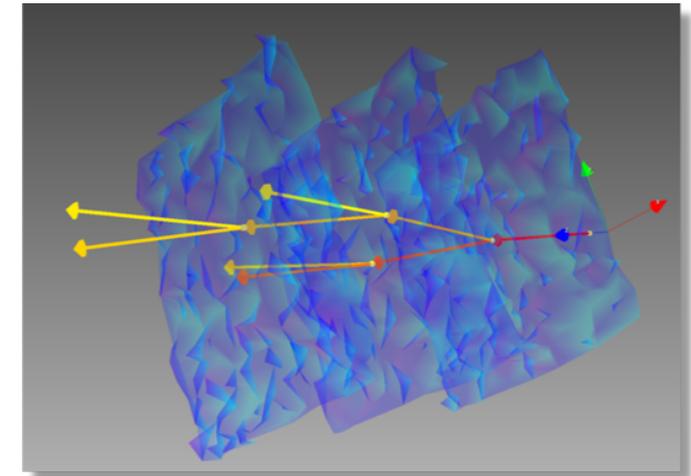
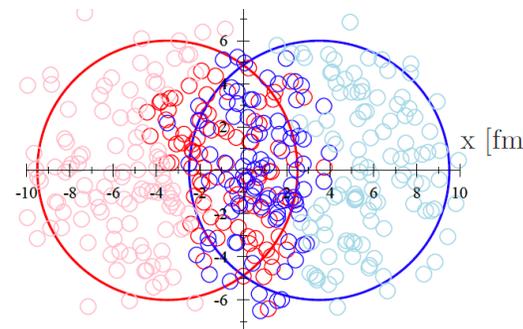
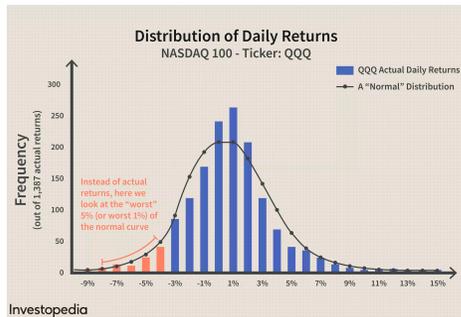
- Constraints are important – don't throw away too much

1. Solve an integral that has a **unique solution**

- Very important **tool**, e.g. for high dimensionality, not a **model**



2. Describe **intrinsically stochastic** processes with average and moments difficult or impossible to integrate out



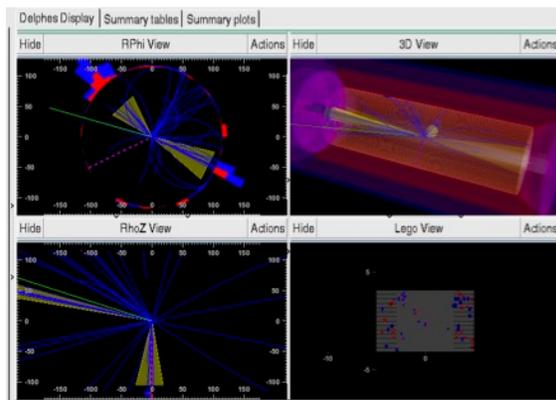
Monte Carlo Use Cases

Black Box

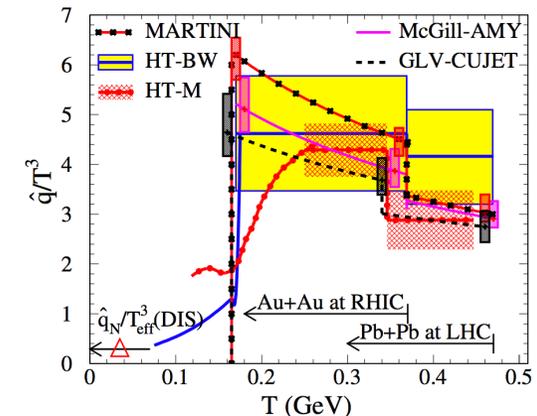
- **Toy**
E.g. quickly test sensitivity to HI BG by drawing from an exponential
- Sophisticated, **focus on reproducing data** regardless on mechanism
 - GEANT or fast simulation
 - Train a response matrix

Modelling Physics

- Quickest, best, or maybe only way to generate predictions for a proposed **physical mechanism**
- Reject or **sharpen parameters** by comparison to data

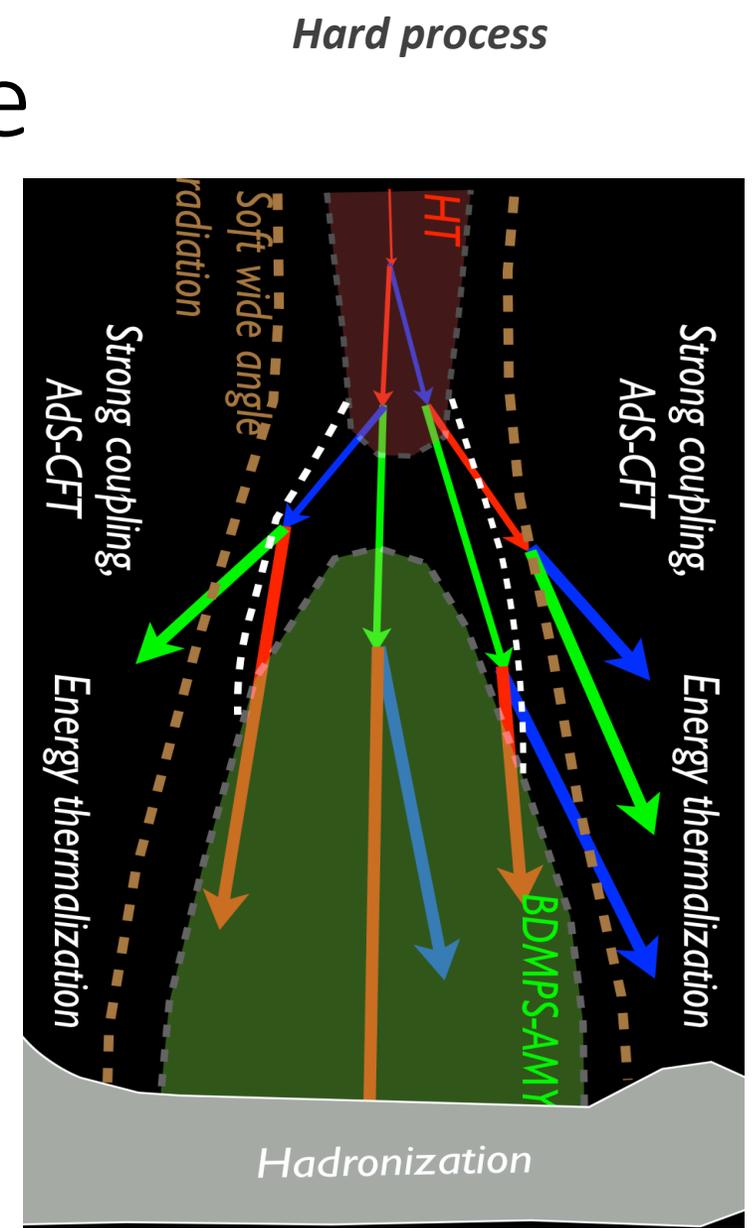
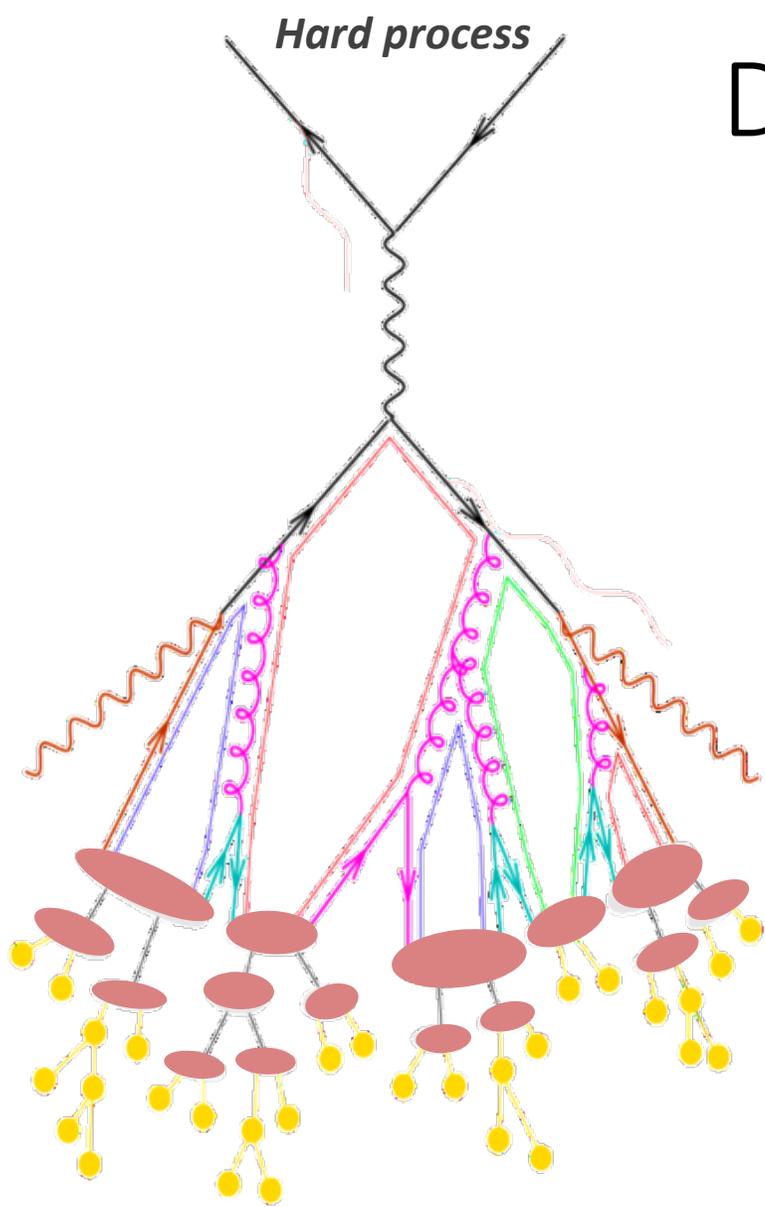


- **All MC models (strive to) live here**
- **All MC models have aspects from here**
- **All MC models will be used for this**



Dramatis Personae

- Hard parton
- Partonic shower
- *Hadronization*
- Hadrons

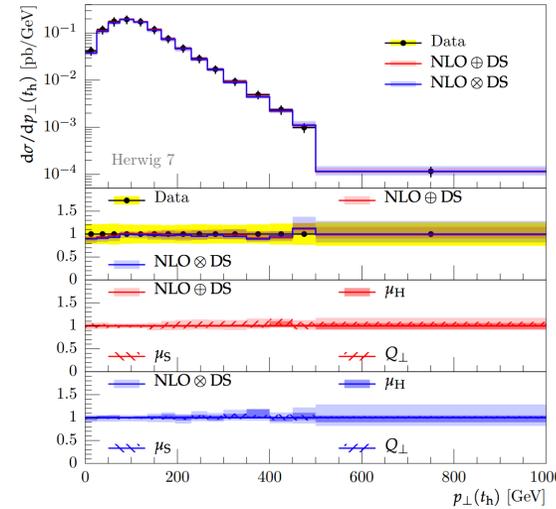


Hard Process Creation

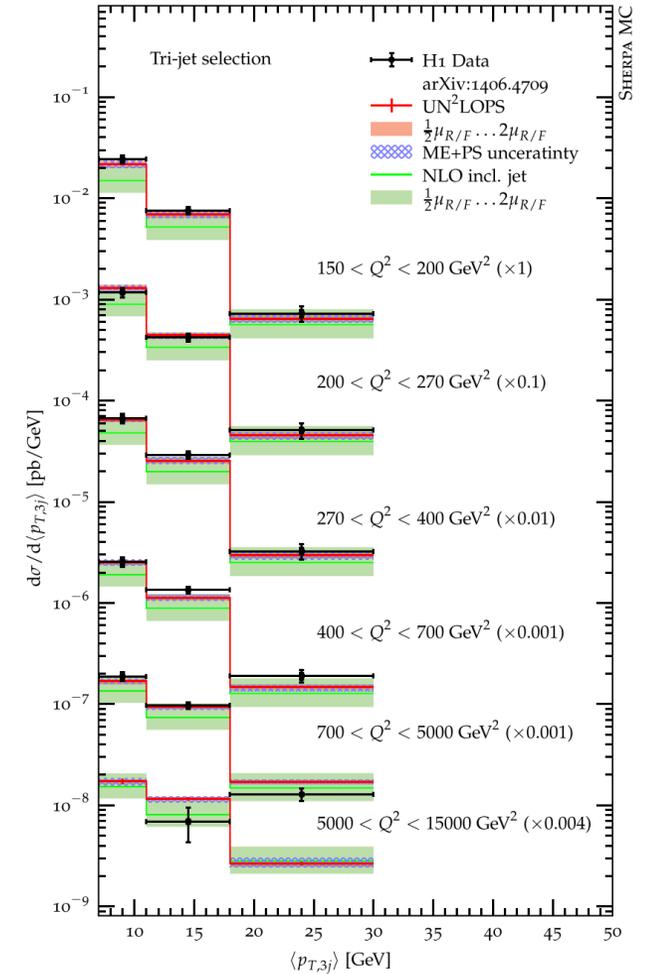


	NLO Matching	Multijet Merging
Herwig 7	Internally automated	Internally automated
Pythia 8	External	Internal, ME via event files
Sherpa 2	Internally automated	Internally automated

- NLO QCD corrections: **“Off the shelf”**
- NNLO starts to become available for more and more processes

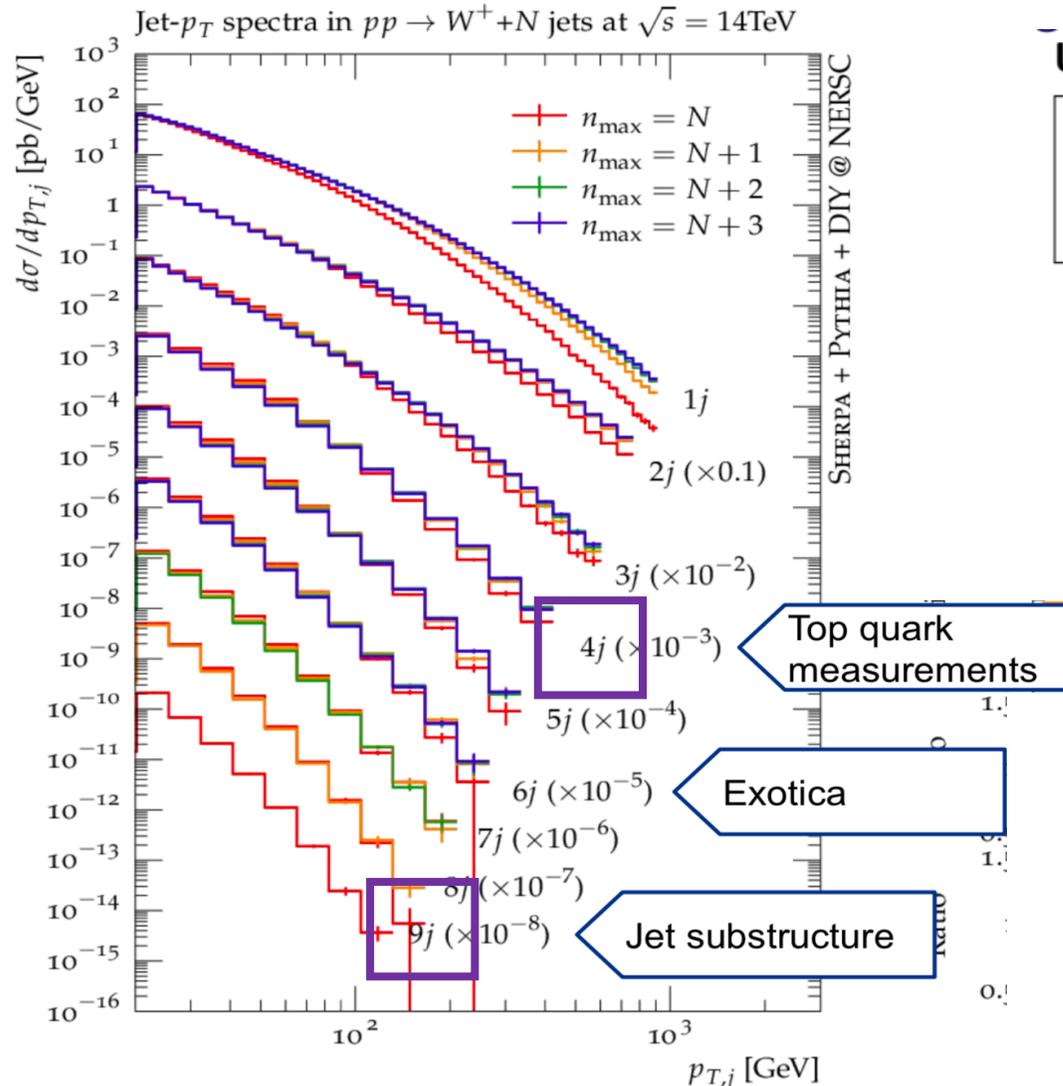


Cormier, Plätzer,
Reuschle,
Richardson, Webster
EPJC C79 (2019) 915
pp → tt (ATLAS)
H7 using POWHEG
and MC@NLO



Kuttimalai, Li, Höche
PRD 98 (2018) 114013
DIS at NNLO with SHERPA

The Price of Precision



Unweighted $W^+ \leq 0.4j @ \text{LO}$



W+0 jets

LO Matrix Element (ME) Generation



W+4 jets

Timing distribution: LO merging example

- For multijet events, ME currently **dominates the computational cost**
- Idea: NN with Normalizing Flows
- Promising, but there's no free lunch

unweighting efficiency		LO QCD				
		$n = 0$	$n = 1$	$n = 2$	$n = 3$	$n = 4$
$W^+ + n$ jets	Sherpa	$2.5 \cdot 10^{-1}$	$3.4 \cdot 10^{-2}$	$6.7 \cdot 10^{-3}$	$1.7 \cdot 10^{-3}$	$6.6 \cdot 10^{-4}$
	NN+NF	$5.8 \cdot 10^{-1}$	$1.2 \cdot 10^{-1}$	$8.8 \cdot 10^{-3}$	$1.6 \cdot 10^{-3}$	$8.9 \cdot 10^{-4}$
	Gain	2.3	3.6	1.3	0.99	1.4

Stefan Höche

EICUG Round Table 2020

Kolja Kauder, MC Modeling - HP 2020

Gao, Isaacson, Krause, Schulz, Höche

PRD **101**, 076002

Hard Process in pA, AA

	Hard Process Generation
JEWEL	PYTHIA6
Q-PYTHIA	PYTHIA6
PyQuen	PYTHIA6
AMPT	PYTHIA6
BAMPS	PYTHIA6
HYDJET++	PYTHIA (6?)
CUJET3	embedded pp baseline
EPOS LHC / 3 / HQ	Gribov-Regge
DREENA	NLO spectra (not an EG)

	Hard Process Generation
JETSCAPE	PYTHIA8 (but flexible)
• MATTER	
• Martini	
• (Co-)LBT	
• AdS/CFT	
• (LIDO)	
Hybrid strong/weak coupling	PYTHIA8
HIJING++	PYTHIA8

- A common theme
- Geometry: Glauber, TRENTO, ...
- What about (n)PDF's?

* with apologies to the γ specialists like STARlight, JETPHOX

** and everyone I missed or misrepresented

Showers in pp



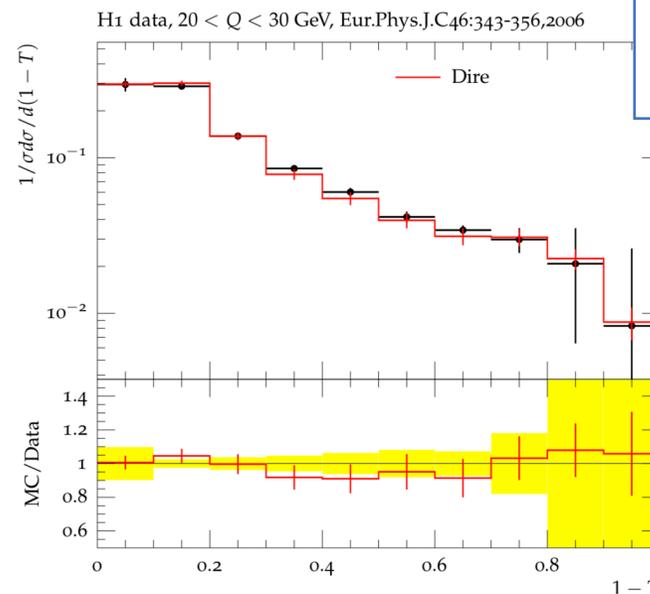
	Shower algorithms
Herwig 7	QTilde, Dipoles
Pythia 8	Pt ordered, DIRE, VINCIA
Sherpa 2	CSShower, DIRE

Spin: [arXiv:1807.01955](https://arxiv.org/abs/1807.01955)

Spin: [arXiv:1708.01736](https://arxiv.org/abs/1708.01736)

- Multiple variants of LO & NLO parton shower, dipole shower, or mix thereof
- Different ordering options

"Parton showers and hadronization have become focus of development again"



Dire plugin → DIS
[arXiv:1506.05057](https://arxiv.org/abs/1506.05057)

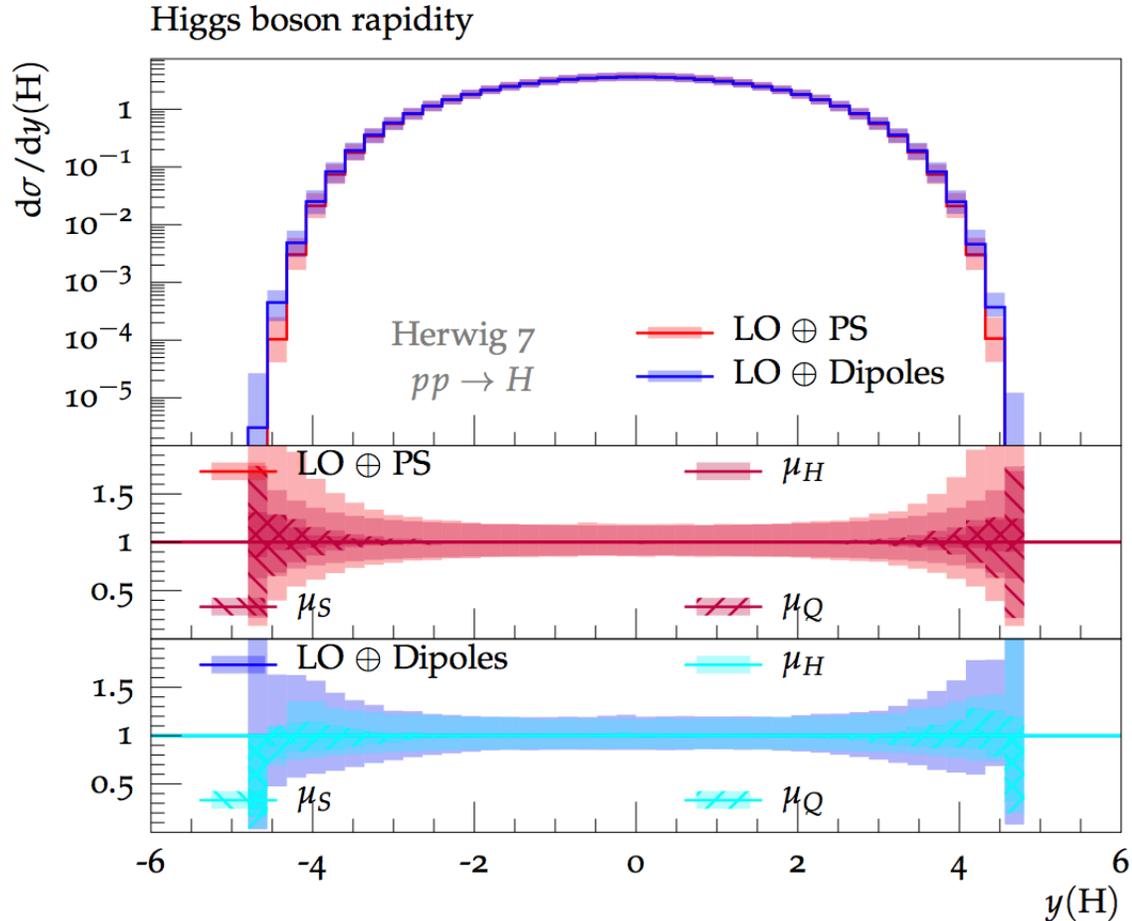
Simon Plätzer

EICUG Round Table 2020

DIS Workshop Torino 2019

Kolja Kauder, MC Modeling - HP 2020

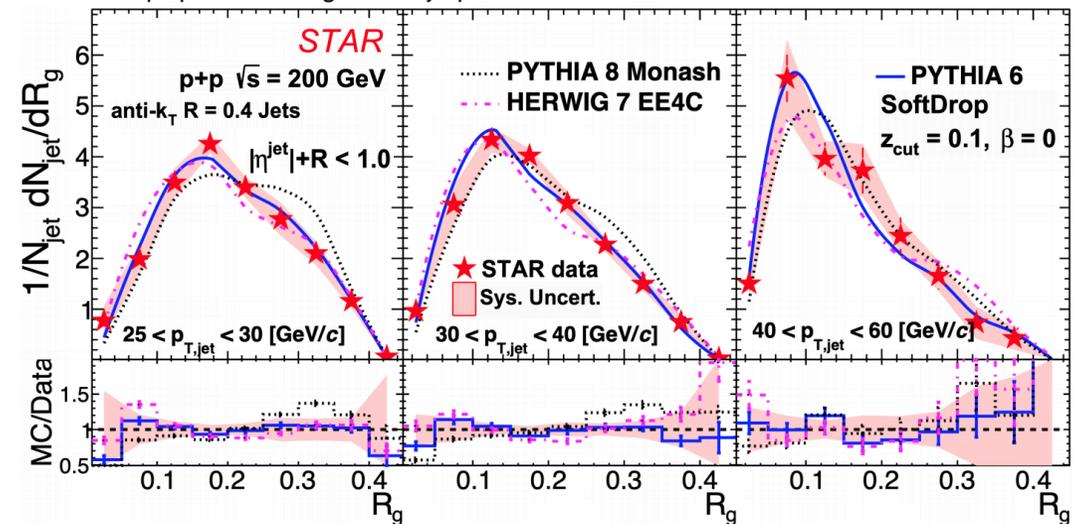
Does the Shower Type Matter?



Bellm et al.
arXiv:1605.01338

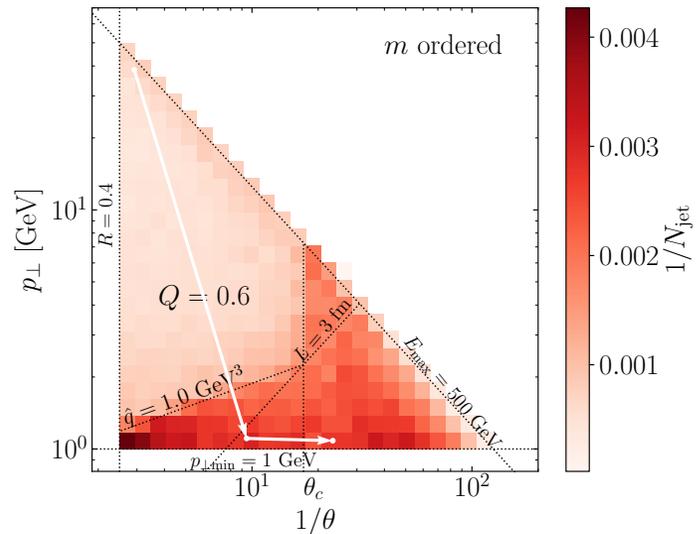
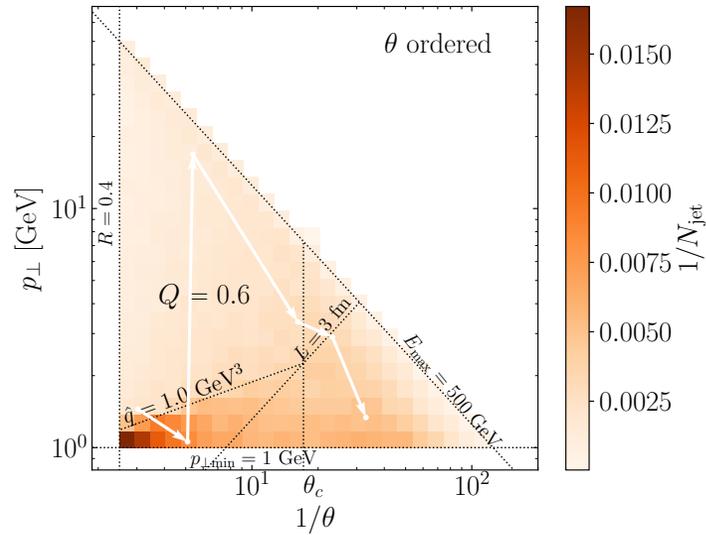
In pp:

- Dipole and PS all but identical (when tuned)
- Even subjet variables competitively described, at low p_T !

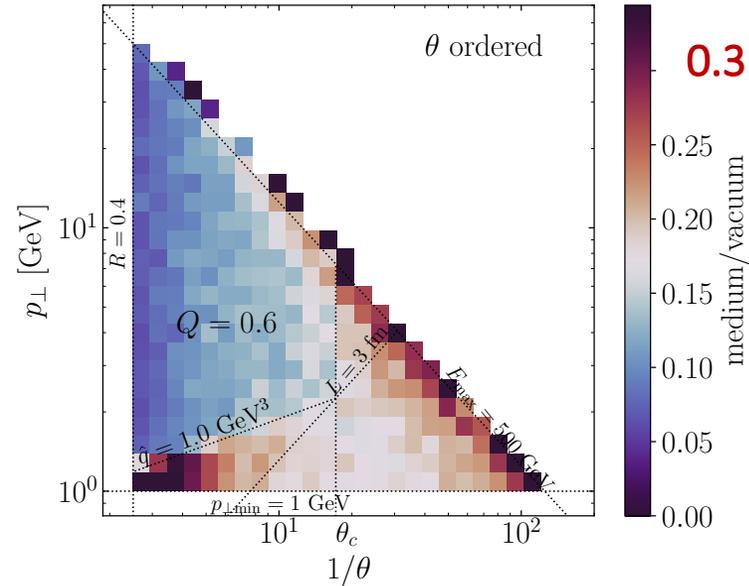


Isaac Mooney - Wed E1
arXiv:2003.02114

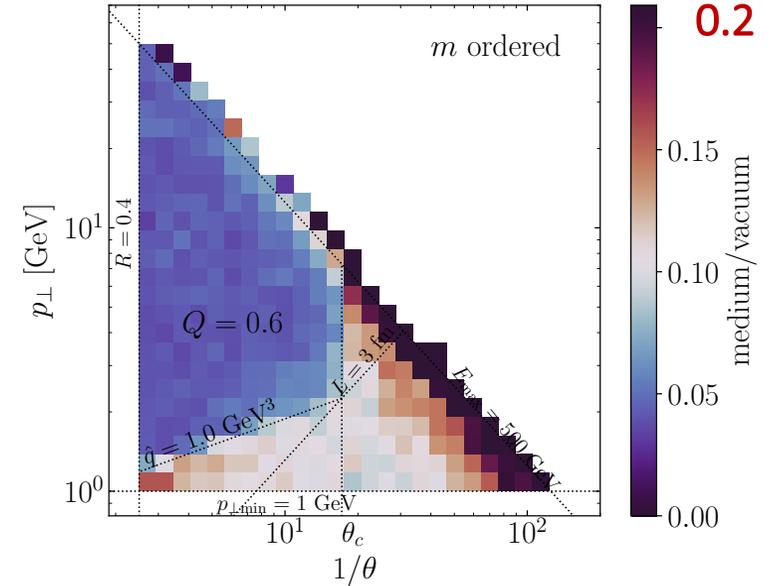
In AA, it May Matter



~ HERWIG



~ Pythia <6.4



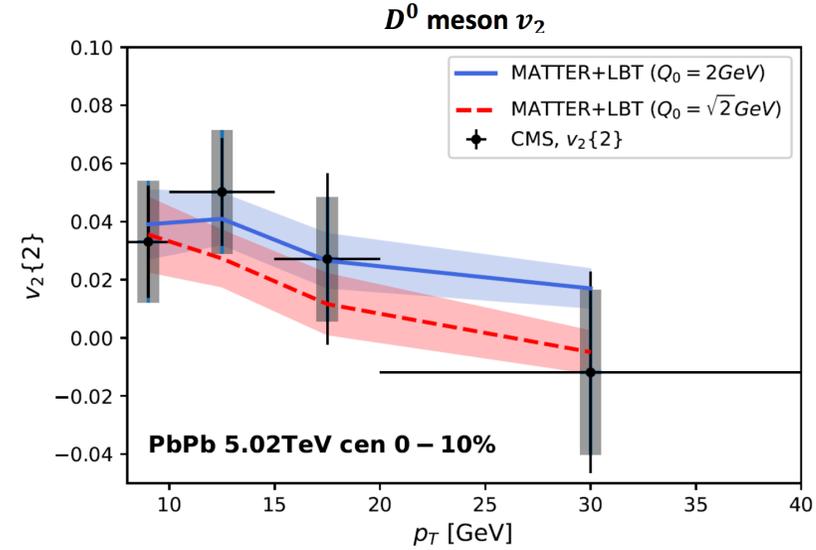
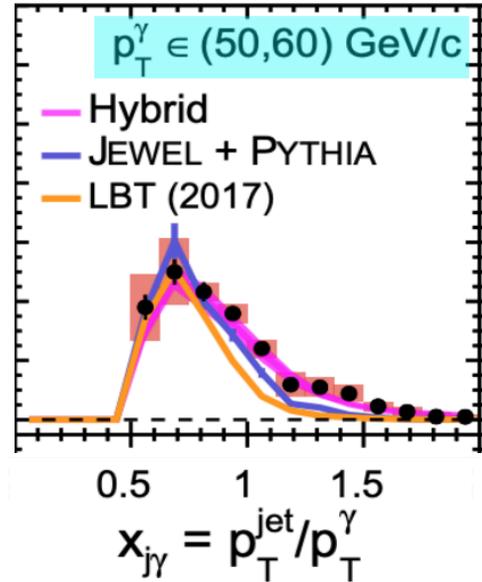
Assumption: Branch gets quenched **only if the medium resolves its color charge**

- Quenching depends on path through the Lund plane
- Fewer branches in quenching region \rightarrow θ -ordered shower shows least suppression

Adam Takacs- Thu G1

Many Successful Medium Interaction Models

γ +jet Mon B4
Molly Taylor

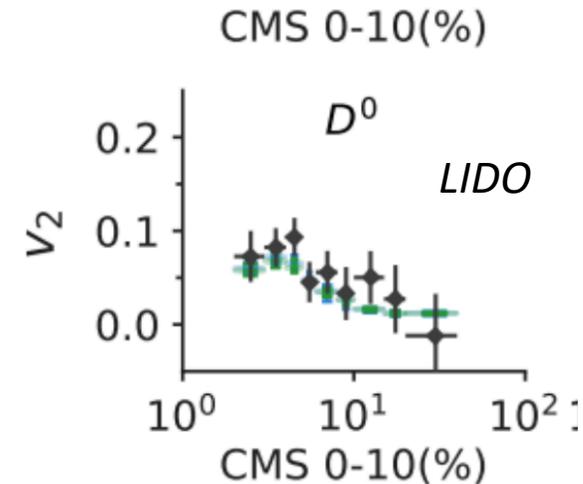
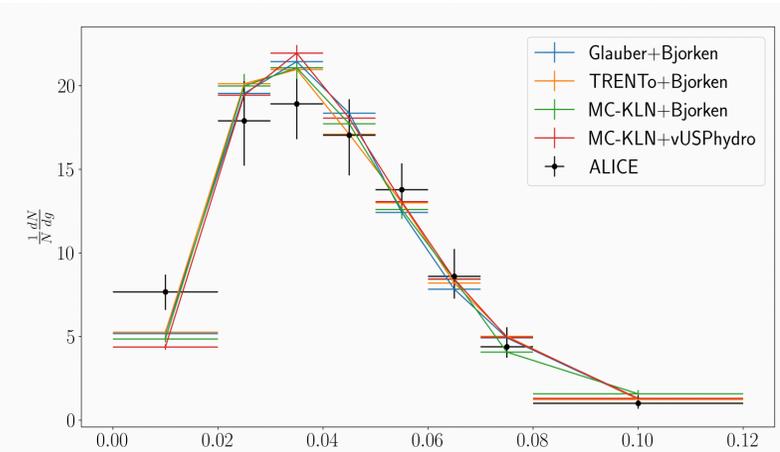
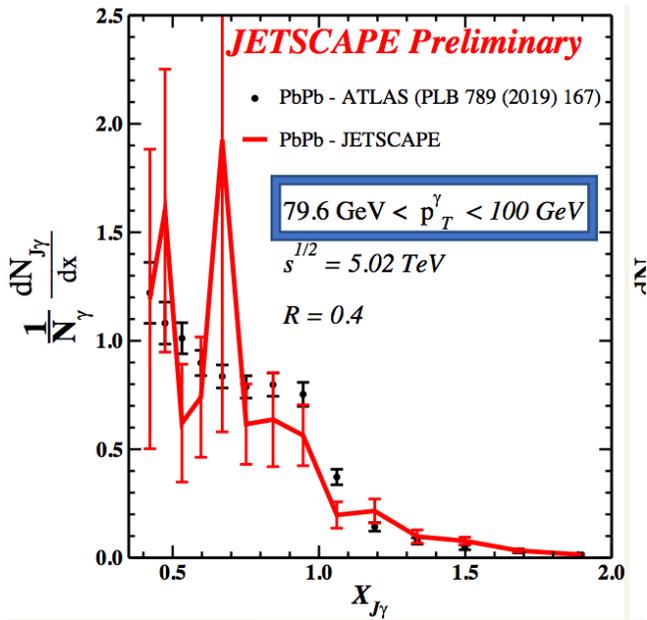


D0 Tue C3
Wenkai Fan

γ +jet Tue C2
Chathuranga Sirimanna

In JETSCAPE:

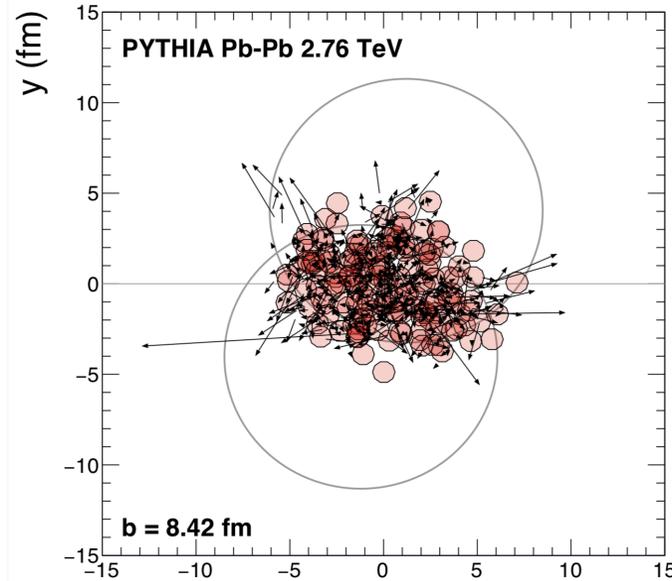
MATTER+LBT
LIDO



JEWEL Tue D1
Fabio Canedo

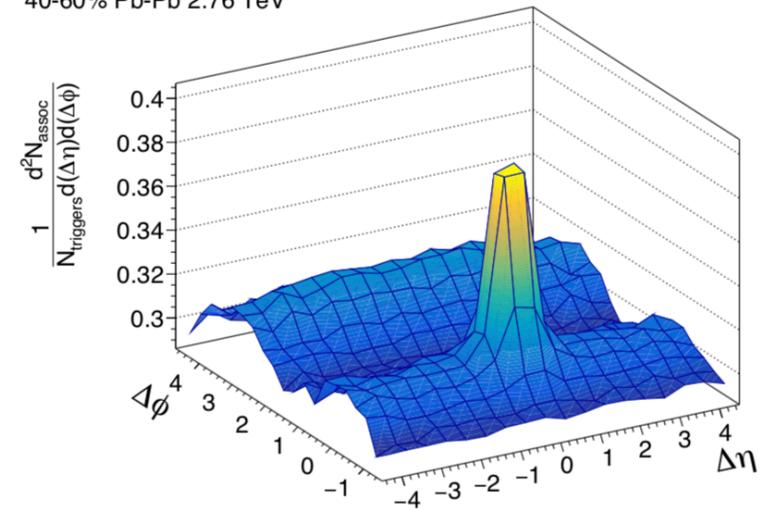
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The New Kid



PYTHIA Angantyr + UrQMD
Decays and Interactions
40-60% Pb-Pb 2.76 TeV

$2.0 < p_T^{\text{trigger}} \text{ (GeV/c)}$
 $2.0 < p_T^{\text{assoc}} \text{ (GeV/c)} < 4.0$



PYTHIA+ANGANTYR How far can you push the "baseline"?

- Extended MPI, introducing **space-time** via interacting Lund strings and wounded nuclei, hadronic interaction with UrQMD
- Can capture many HI phenomena rather well – without a QGP
- QGP won't go away, but what does this say about current models?

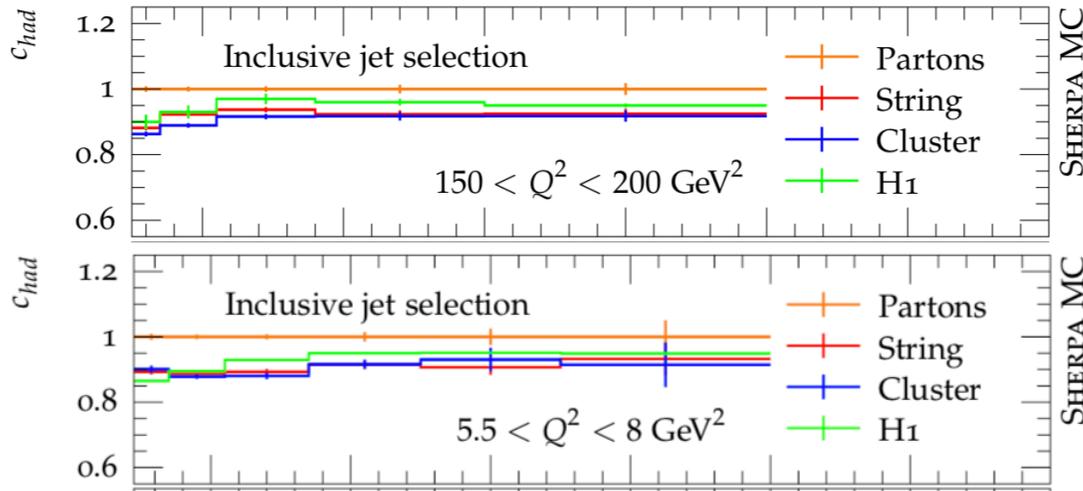
Stay online for
Christian Bierlich

Also activity in HERWIG

Hadronization



Hadronization corrections comparable between cluster and string model

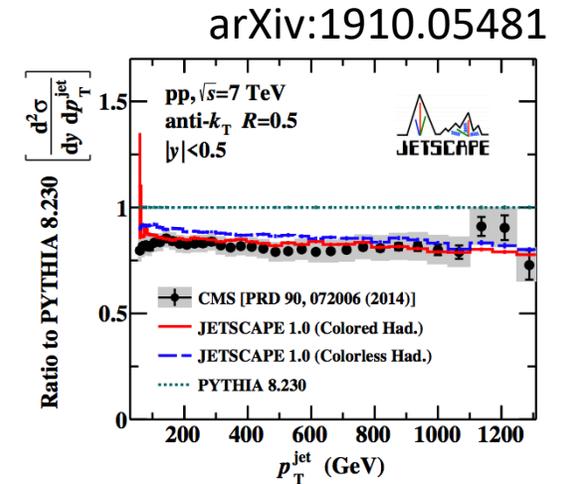


Heavy Ions add freezeout + coalescence

How to make an event "white" to hand over to hadronization?

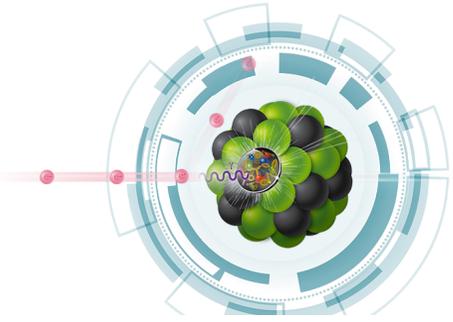
JETSCAPE: Add parton(s) down the beam pipe.

Works well for mid-rapidity LHC jets!



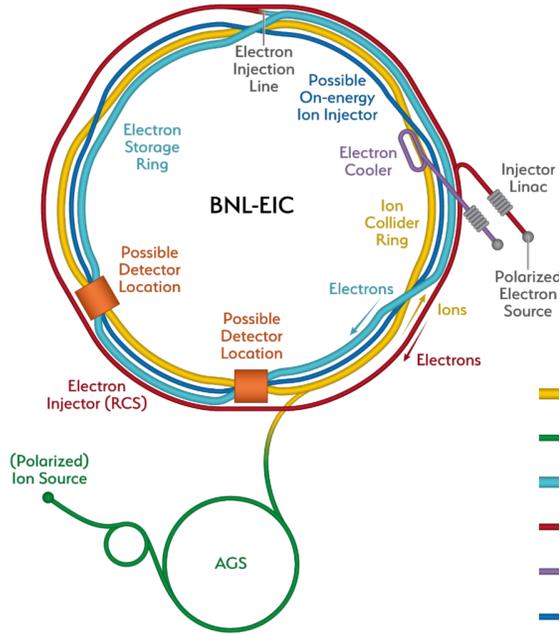
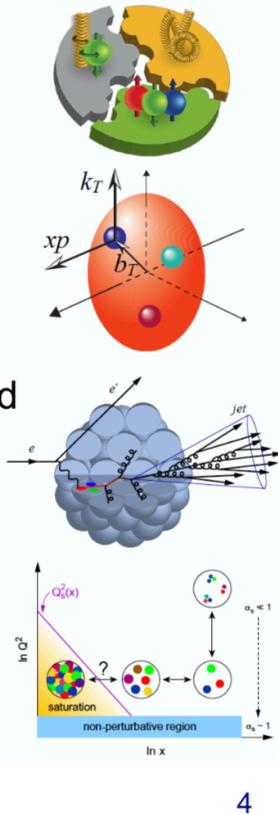
But will need significant fine-tuning for sparse, forward, high-precision data such as pA or ...

EIC - A Different Hard Probe



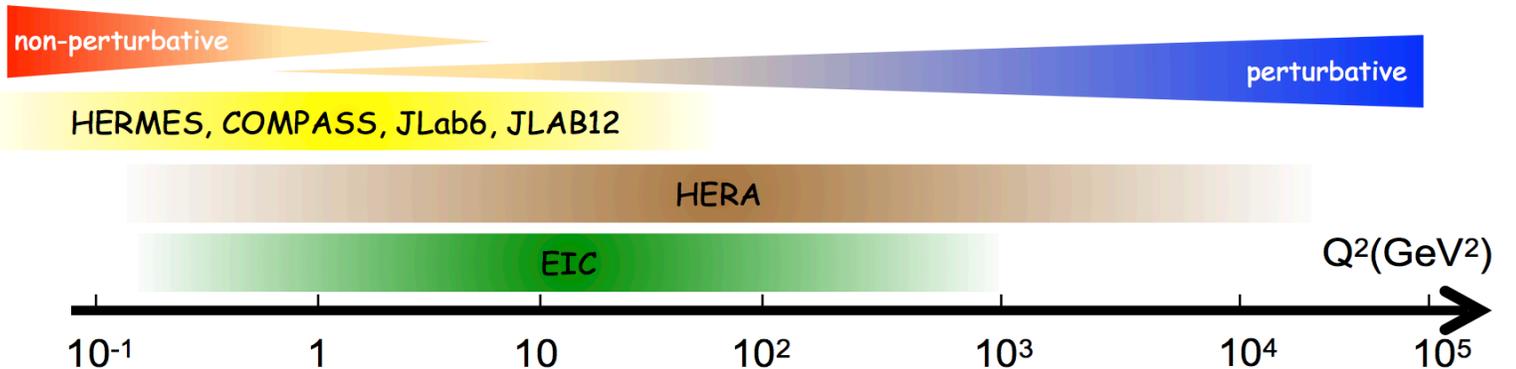
Key questions:

- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
- How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?
- Where does the saturation of gluon densities set in? Does this saturation produce matter with universal properties?



	FY19	FY20	FY21	FY22
Critical Decisions	CD-0 Dec 2019	★	★	CD-1 March 2021
Research & Development		Research & Dev		

Time is ticking!



Accardi, A., et al.

[Eur. Phys. J. A 52, 268 \(2016\)](#)

Event Generators for e+P



Herwig

Traditional focus on showers, Qtilde and Dipoles shower, cluster hadronization model, NLO matching and merging.



Pythia

Sophisticated soft physics, pt-ordered, DIRE and Vincia shower, string hadronization, NLO merging using event files.



Sherpa

Focus on perturbative improvements, CS and DIRE shower, cluster or string hadronization, NLO matching and merging.

- Tremendous development in recent years
- Thriving community beyond the Big Three

- DIS
- Some photoproduction

Currently Missing:

- Radiative corrections
- DVCS
- Full MinBias

Also, LHAPDF6 is missing crucial PDF's

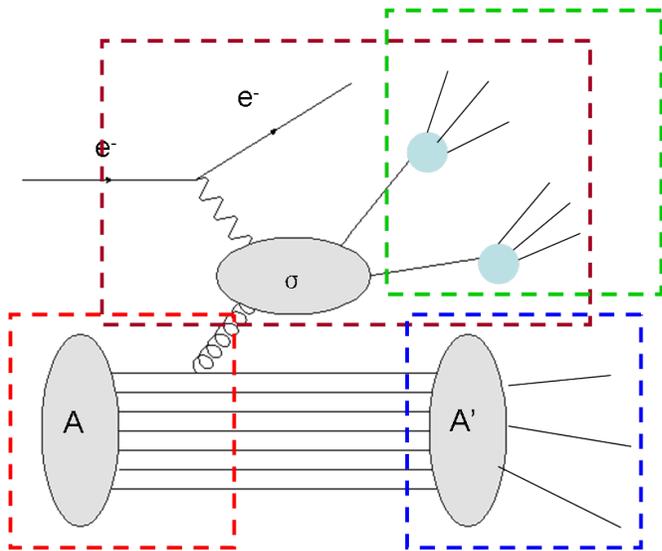
Relying on PYTHIA6, DJANGO, MILOU, and other fortran tools

Extension: Conversion from HOLLERITH to INTEGER

Event Generators for e+A

Excepting specialists (Sartre, eSTARLIGHT):

- **Currently only BeAGLE**



A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

Nuclear geometry by DPMJet and nPDF provided by EPS09.

Parton level interaction and jet fragmentation completed in PYTHIA.

Nuclear evaporation (gamma dexcitation/nuclear fission/fermi break up) treated by DPMJet

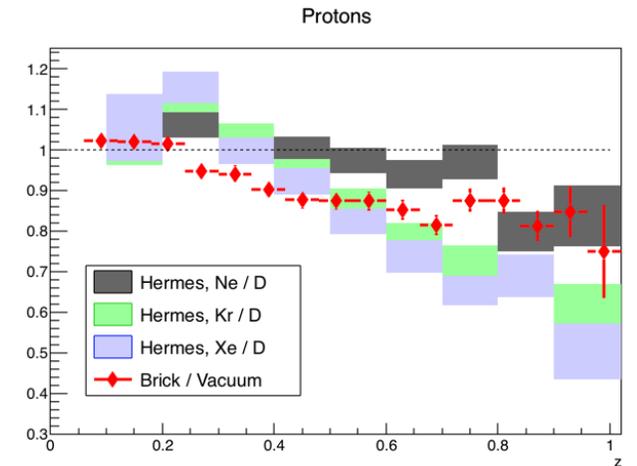
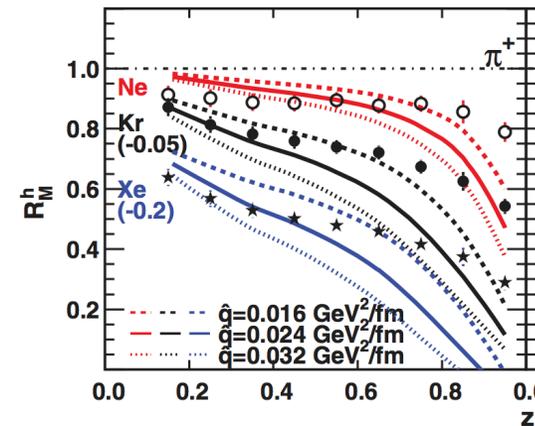
Energy loss effect from routine by Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter

- Pythia+Angantyr?

An attempt in JETSCAPE (from public branch)

- ❖ Use MATTER to describe HERMES
- ❖ **Proof of concept works!**
- ❖ **Now need help with hadronization**

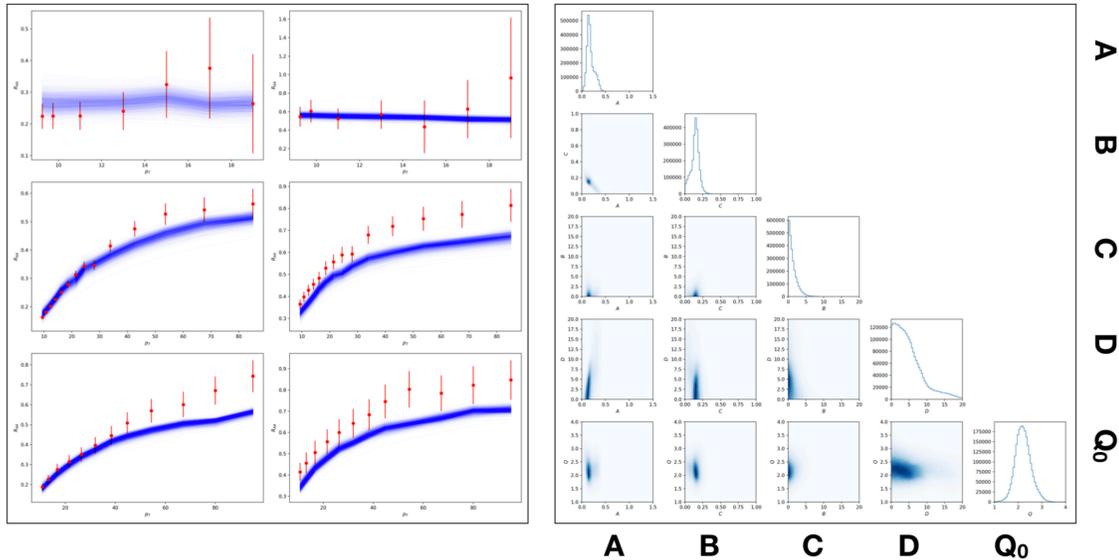
$\hat{q} = 0.02 \text{ GeV}^2 / \text{fm}$
 $L = 5 \text{ fm}$
 FXT, 27.6 GeV e on X



Some Parting Thoughts

Need to avoid Black Box Mentality

- Document switches, parameters
- Compare and challenge models!



- Can we unite further on interfaces?
Fortran etc?

"Rivet is working! We should use it!"

There is an effort going on to make Rivet fully ep aware, and to wrap HZTOOL into it. Please donate your analysis!

- <https://rivet.hepforge.org/z>

