Systematic Monte-Carlo studies of dijets at RHIC
using the VNI/BMS Parton Cascade

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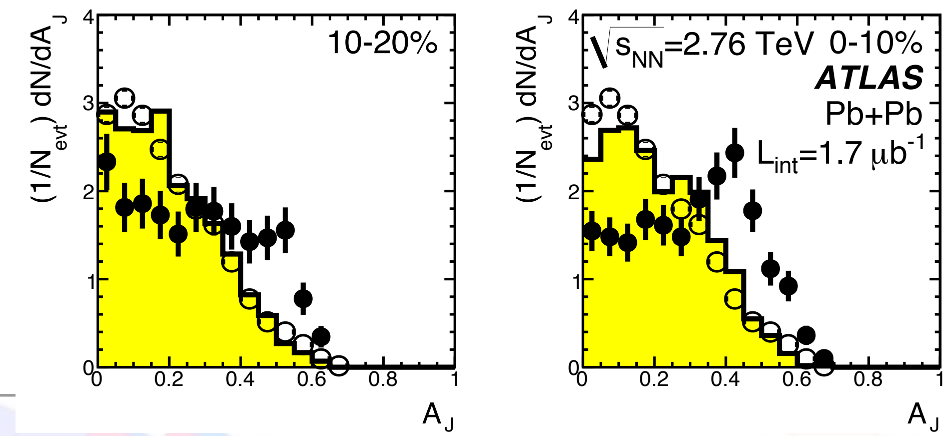
QuarkMatter - 2012

Introduction

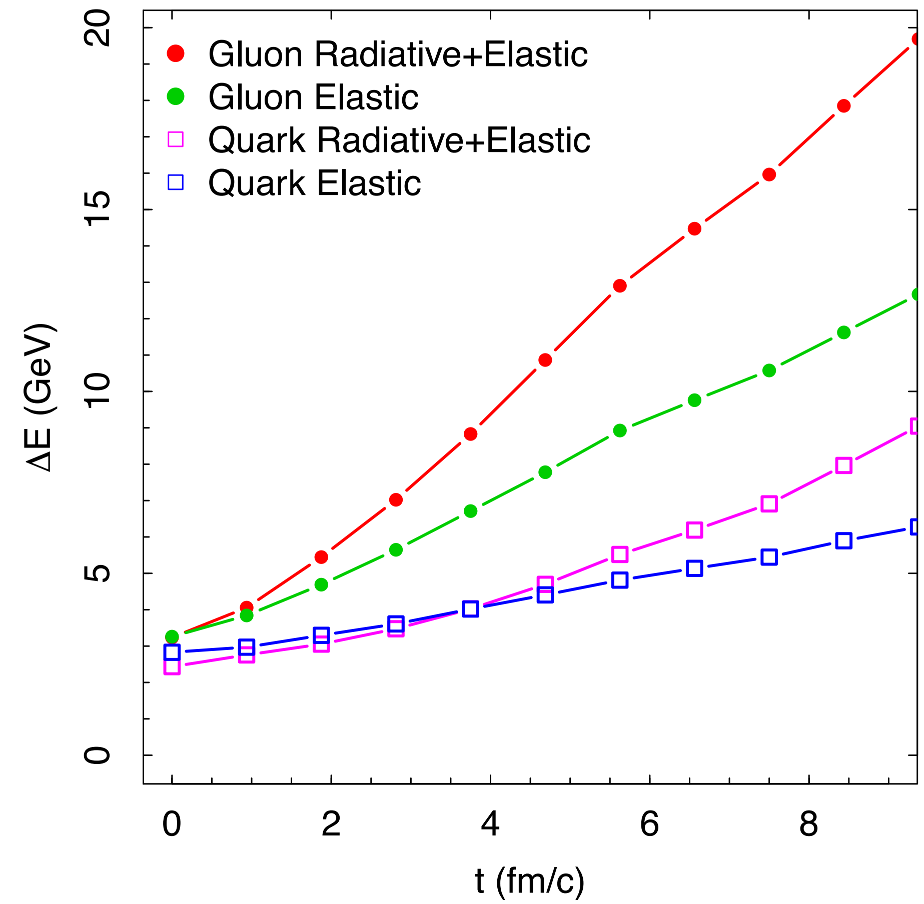


- Dijets provide a strong signal for the modification of hard probes at the LHC
- What are the shapes of these jets, and how does medium evolution change them?
- Explore dijets and gamma-jets at RHIC scales:
  - Understand the sensitivity of dijet observables to medium properties, strong coupling, path length, jet definition...
  - Which observables provide the most physics resolution?
  - What role does hadronization play in these processes and observables?
- Use the VNI/BMS model of jets and their transport to gain a schematic understanding

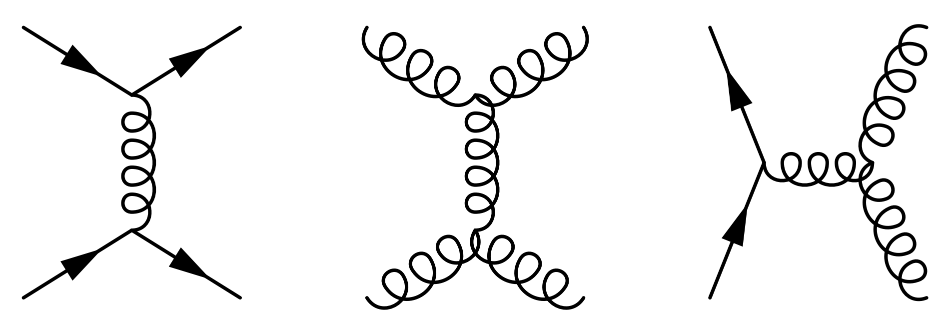
VNI/BMS, a simple-enough transport model

- VNI/BMS models partonic transport via the Boltzmann equation. Treats medium and jet on an equal footing.
- Interactions are tree level 2->2 scatterings and final-state radiation. Radiation includes leading order (BDMPS-Z) LPM effect.
- Medium is a box of thermal partonic QGP at a fixed temperature. No expansion!
- A generated jet is injected, cascade of interacting partons are tracked. Evolution of entire jet is recorded.
- Color flow is tracked, hadronization is handled by the Lund string model in Pythia 8.
- A Jet-finder is applied in post-processing stage, jet development can be extracted for varying jet-definitions.

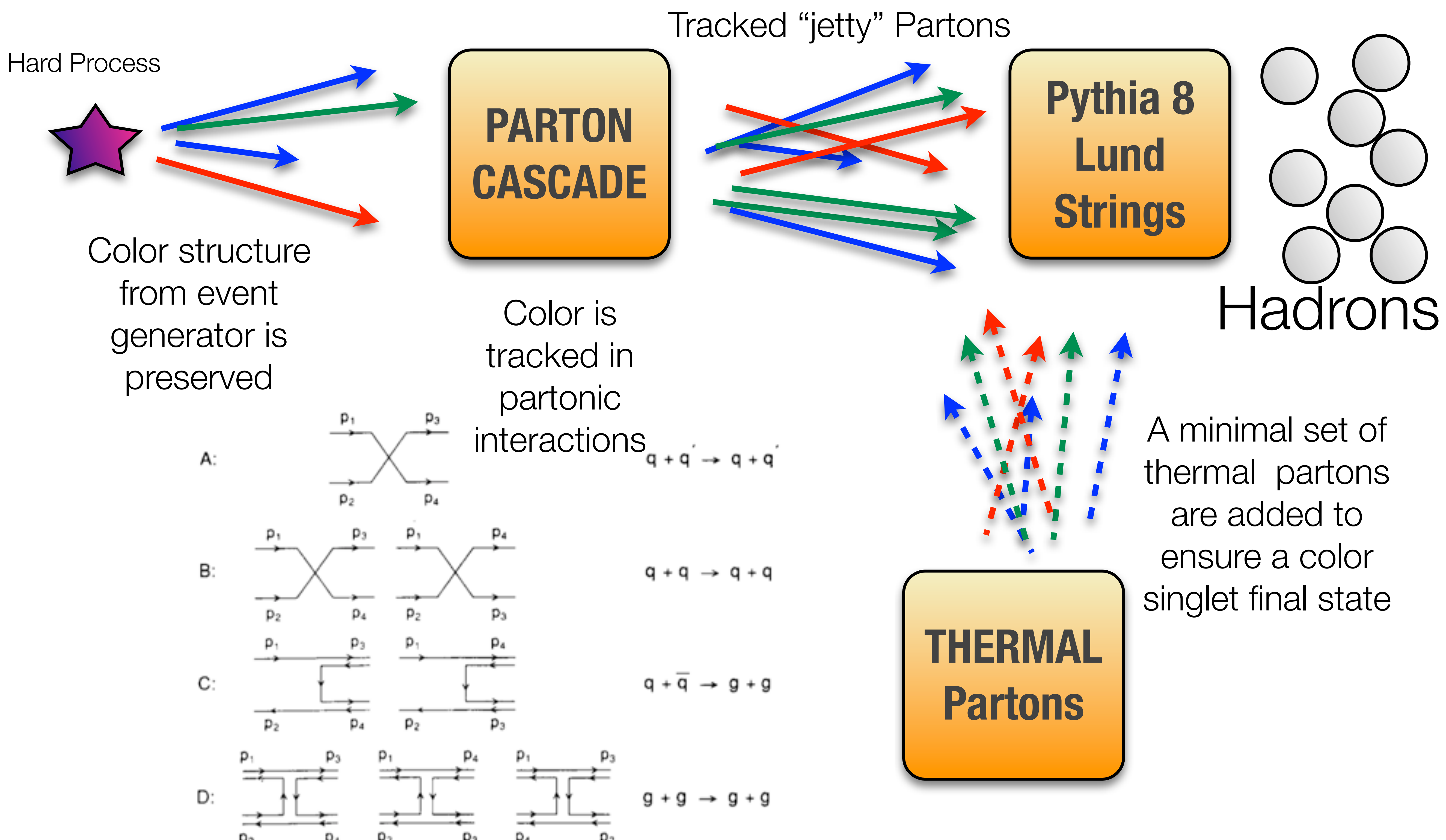
$$p^{\mu}\frac{\partial}{\partial x^{\mu}}F_k(x,\mathbf{p}) = \sum_{processes} \mathcal{C}_i F.$$



$$-\Delta E_{\rm BDMPS} = \frac{\alpha_s C_R}{8}\frac{\mu^2}{\lambda_g}L^2\log\frac{L}{\lambda_g}.$$



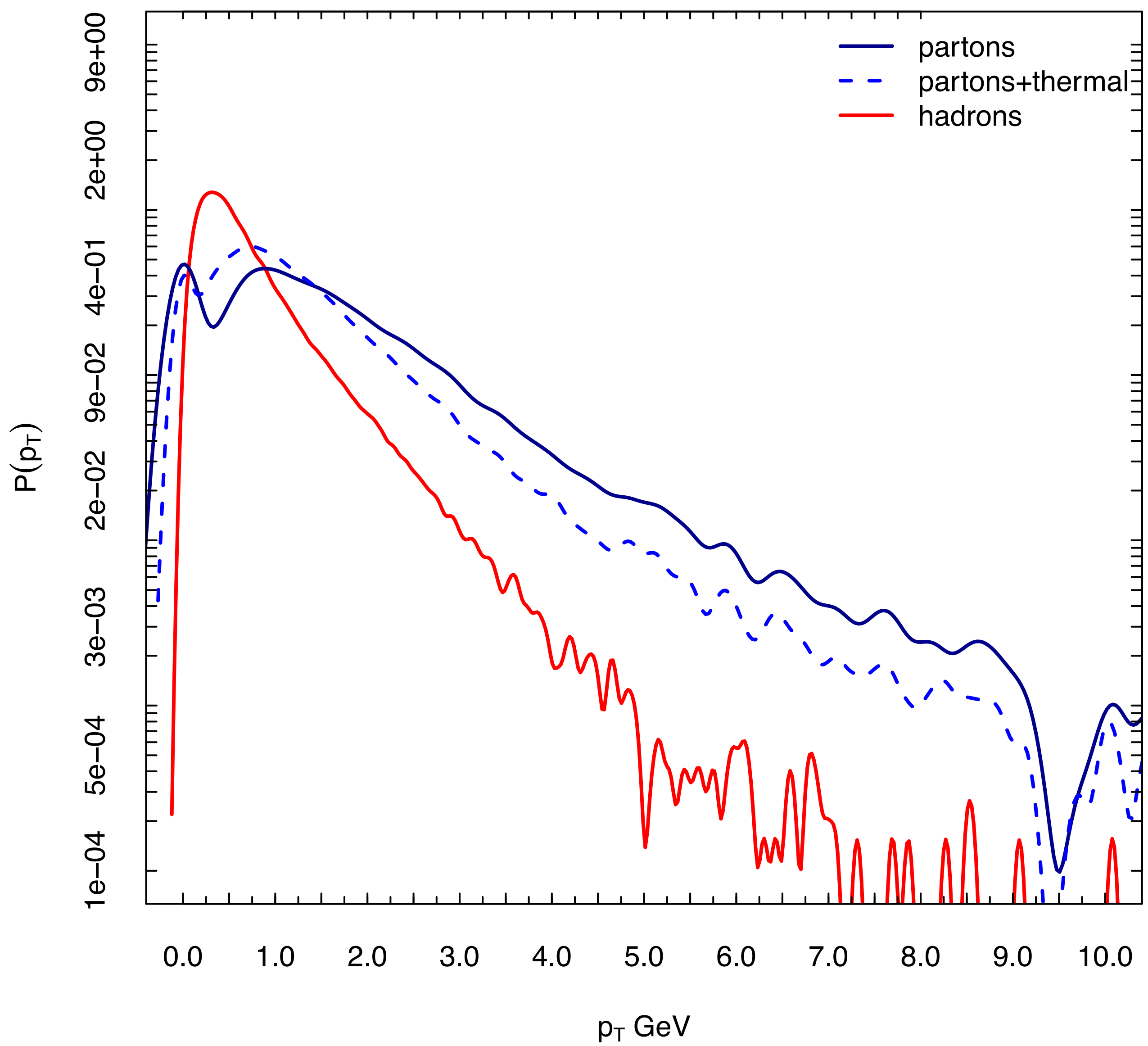
Hadronization In VNI/BMS



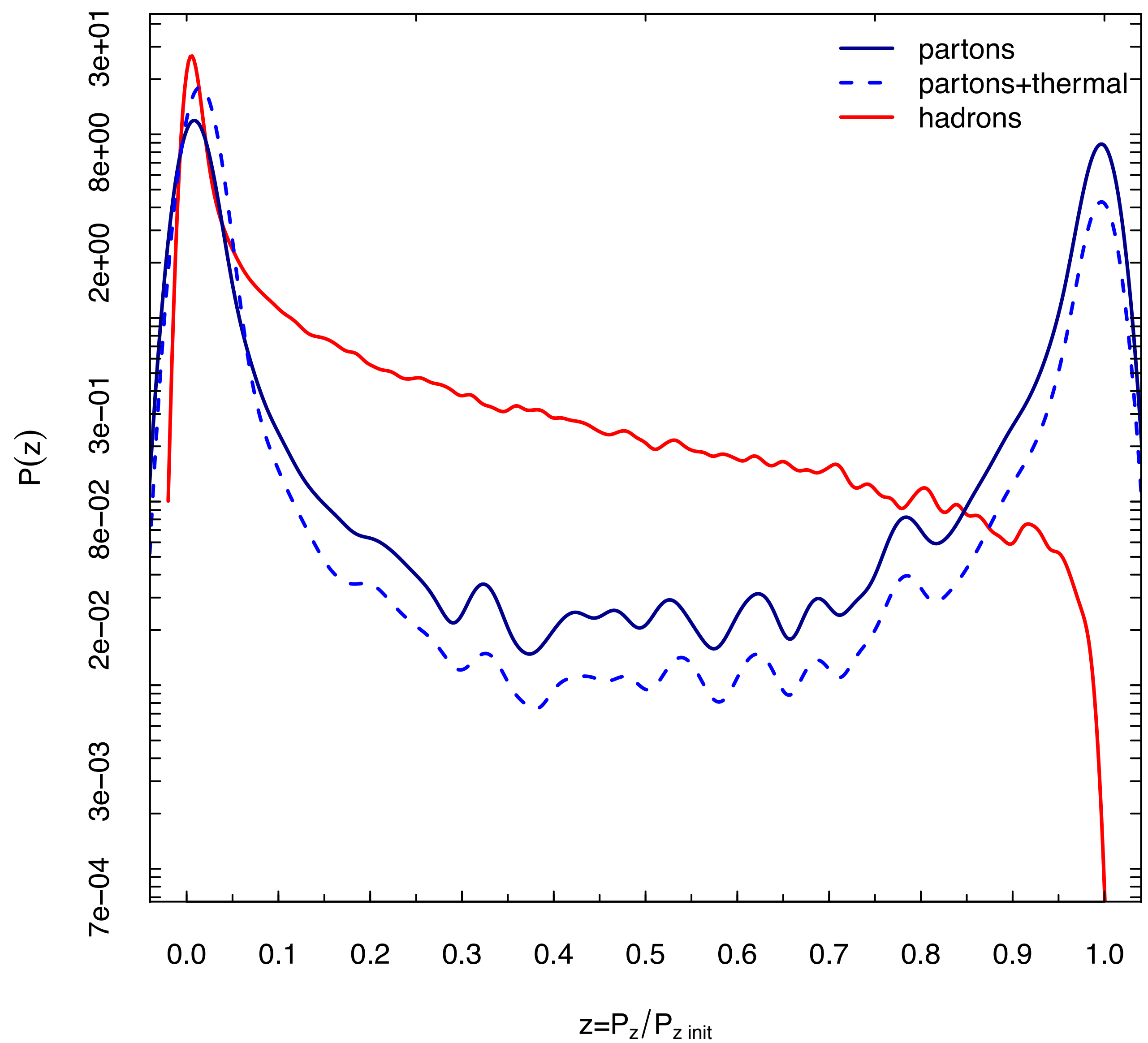
Color labeling follows the Les Houches Accord

Hadronization In VNI/BMS

100 GeV quark evolved for 4fm in a box at T=350 MeV

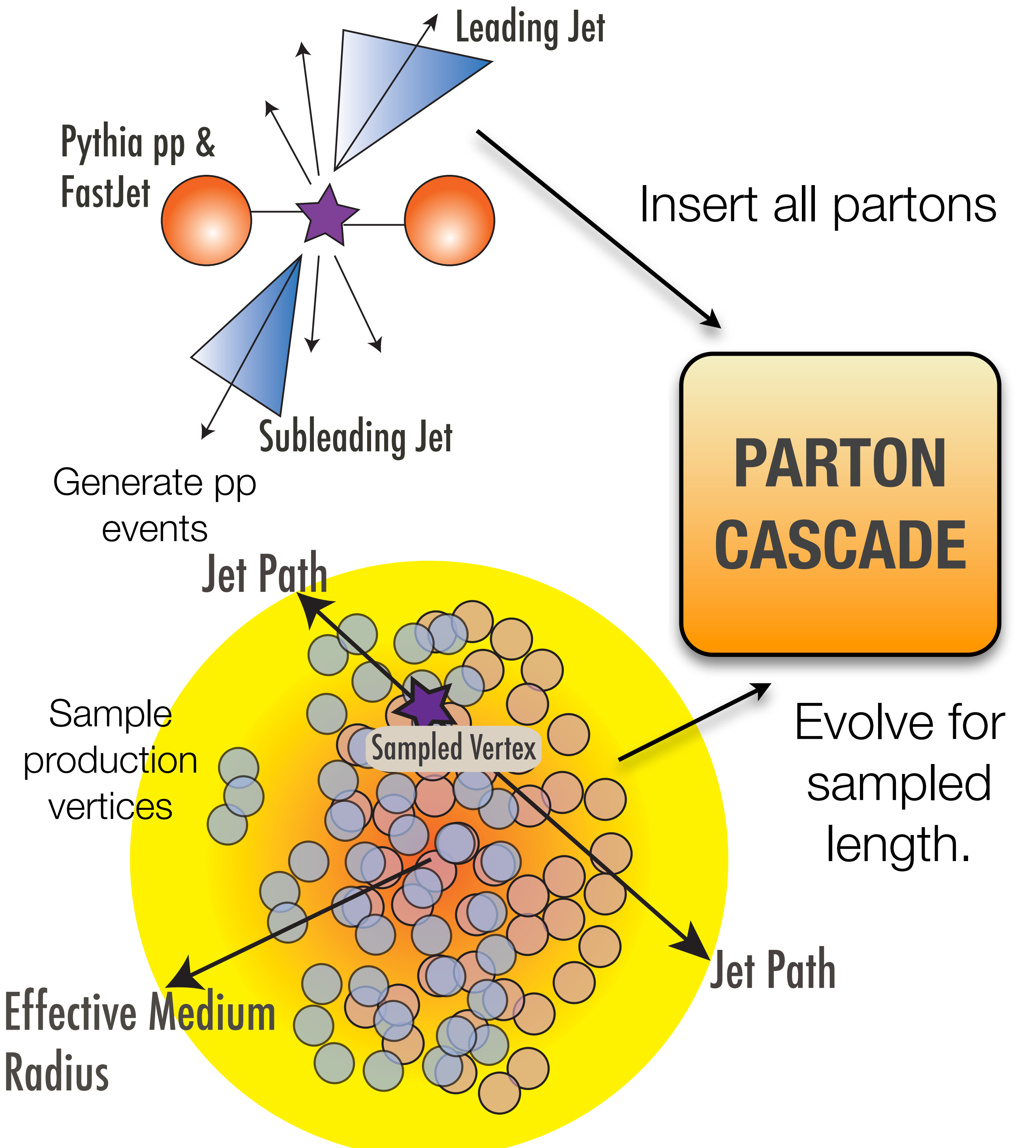


Hadronization contracts the transverse momentum distribution



Hadronization smooths the longitudinal distribution, peak at Z=1 is redistributed

Dijet Simulation Method: Circle Mode

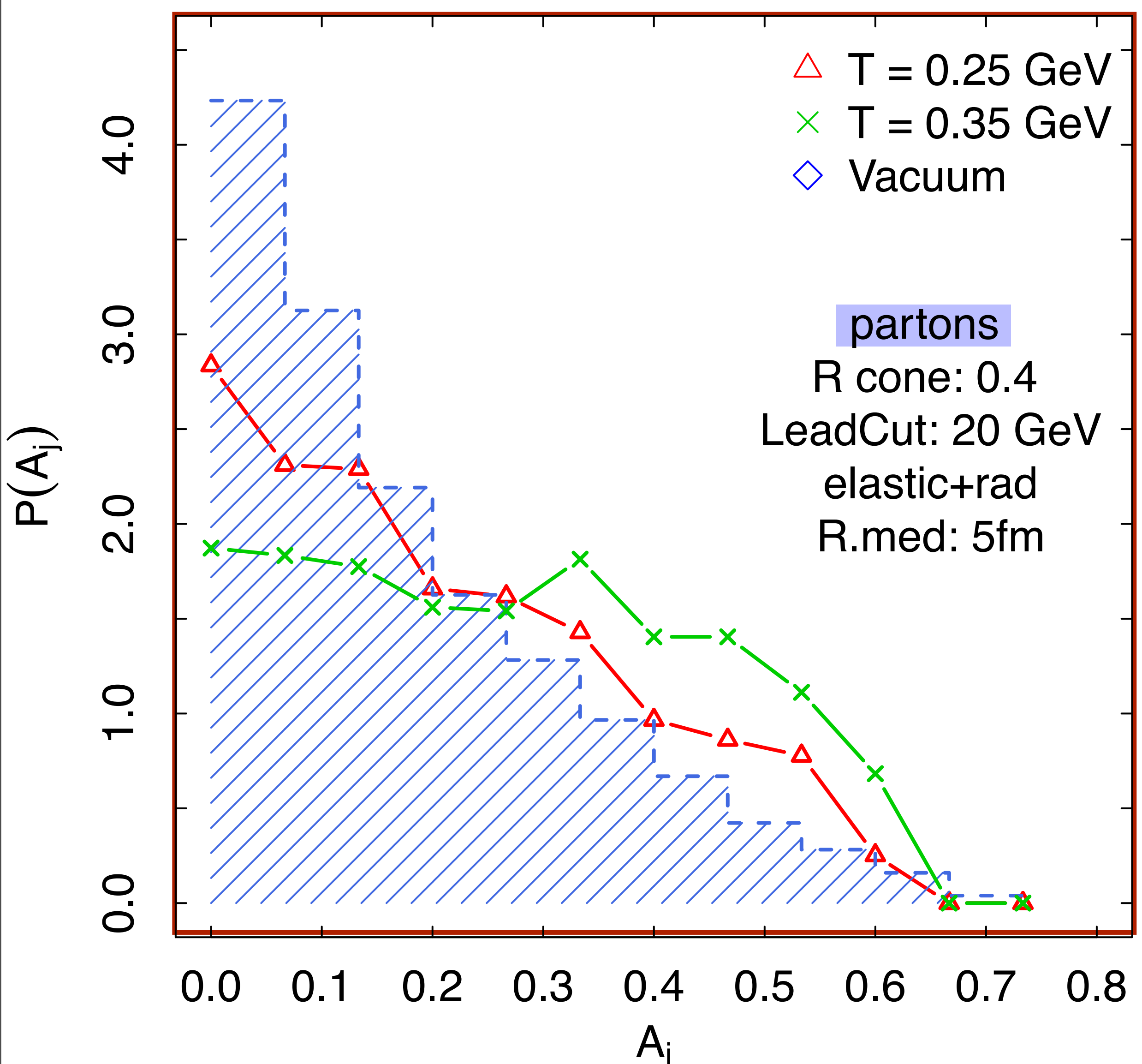


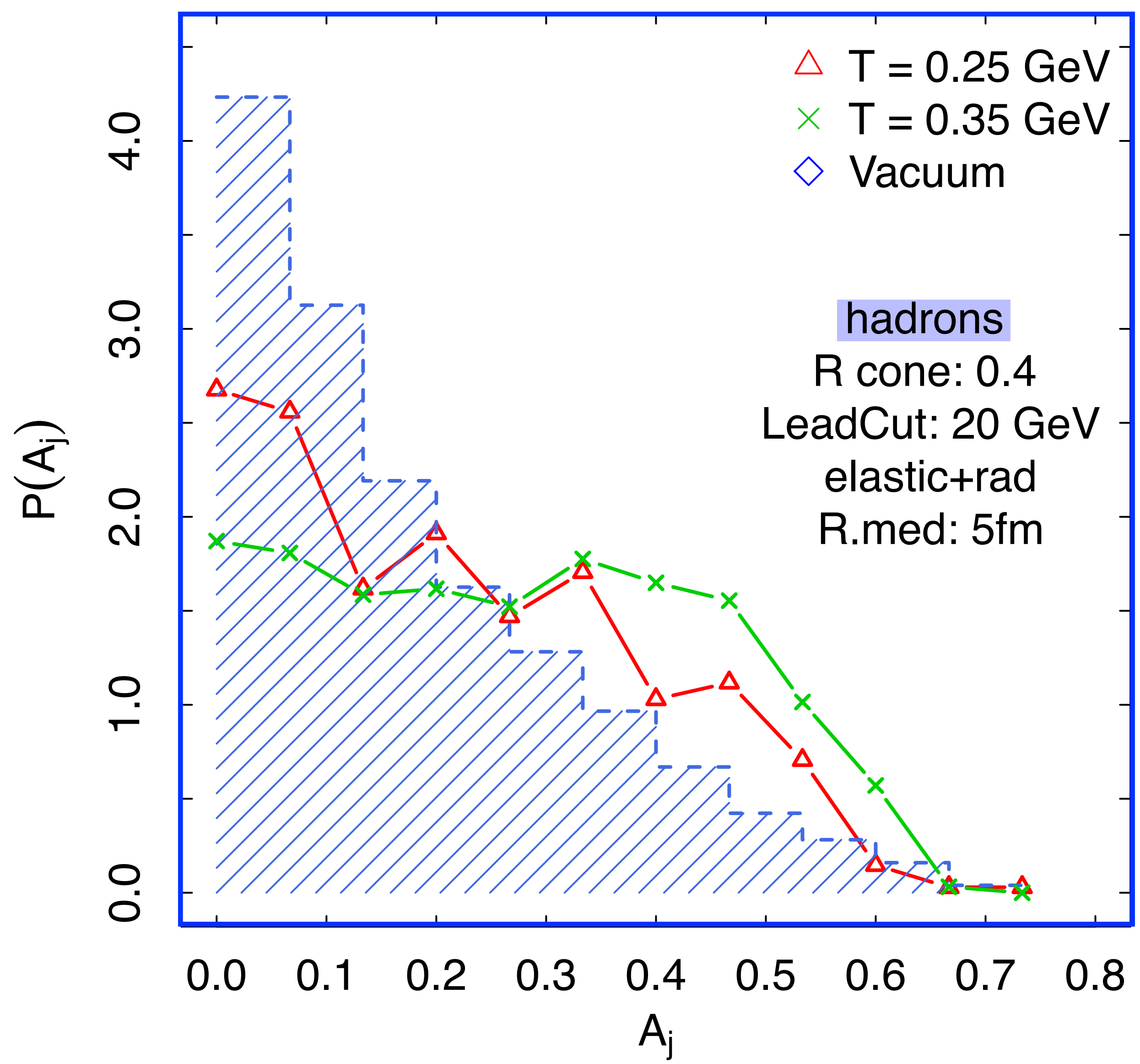
- Generate pp events at 2.76 TeV using pythia 8, extract acceptable dijet pairs using FastJet.
- Vacuum shower evolution takes place in Pythia.
- Sample production vertices uniformly within a circular medium of some radius R. Sample jet paths as length of random chord generated from vertices to edge of medium.
- Insert all partons from each jet into parton cascade box and evolve for sampled path length.
- Medium is partonic and static, temperature is fixed for duration of the evolution.

Dijets at RHIC

Dijet Asymmetry - Varying Medium Temperature

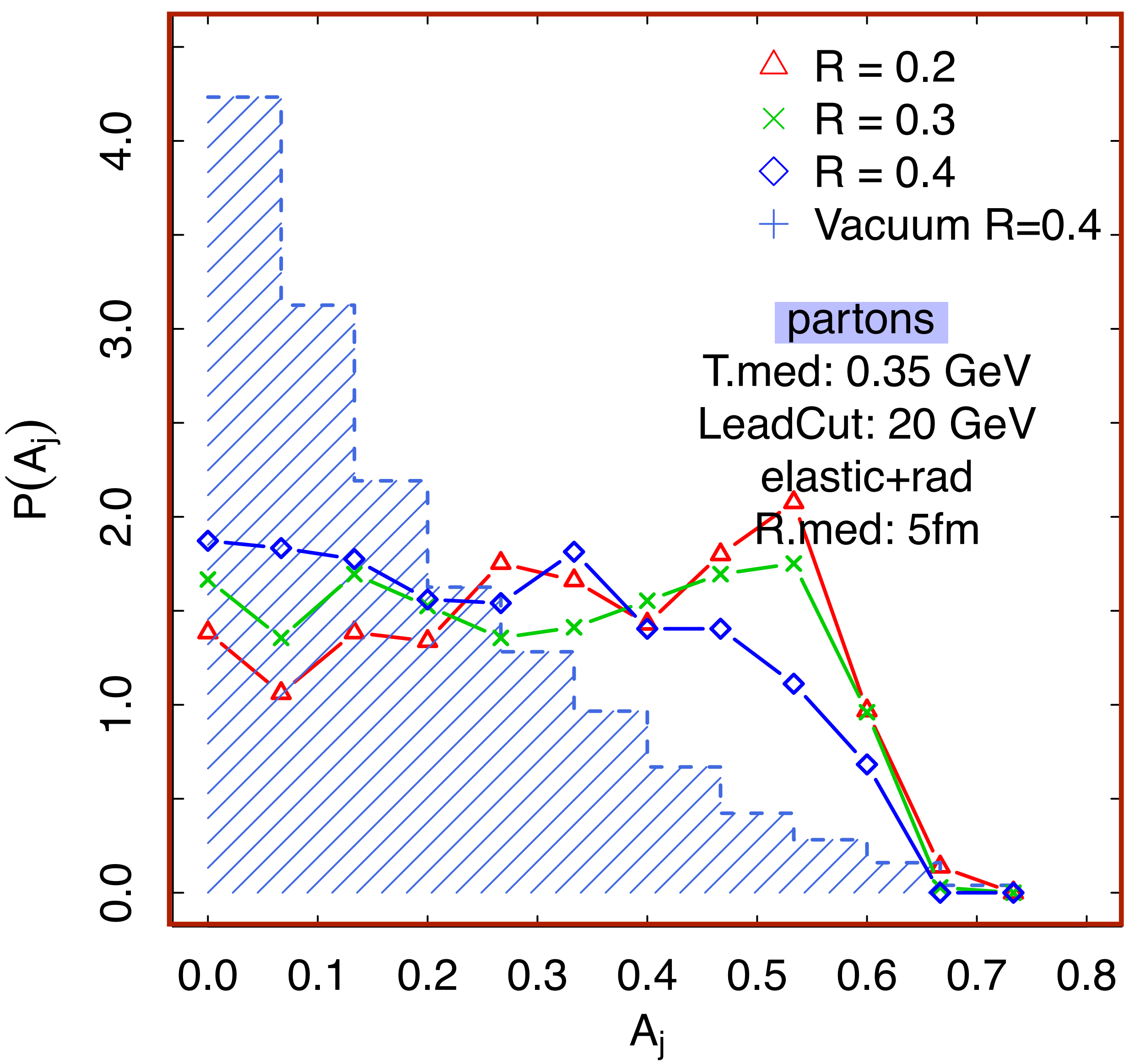
Increasing medium temperature increases asymmetry.

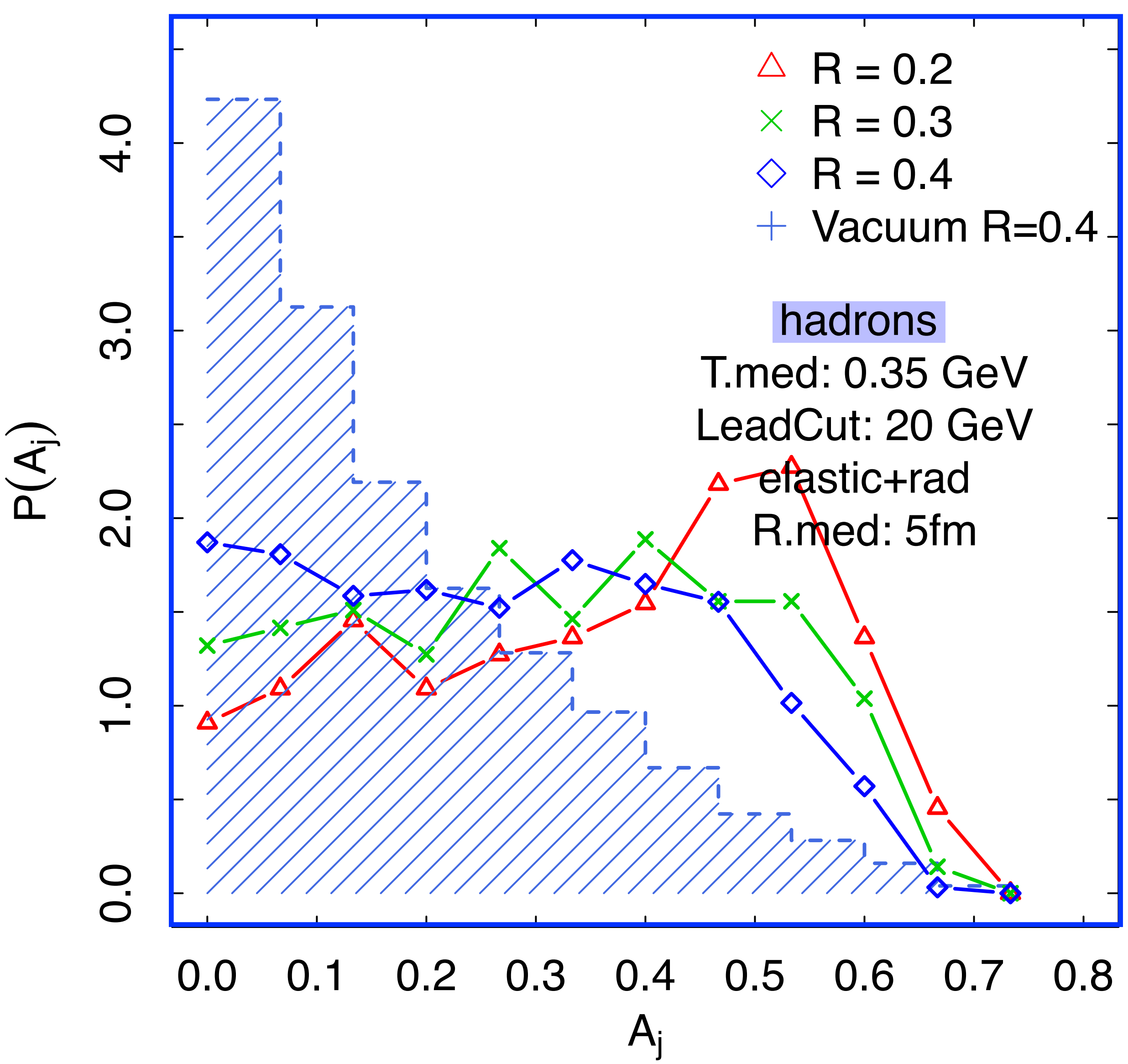




Dijet Asymmetry is similar for partonic and hadronic jets

Dijet Asymmetry - Varying Jet Cone Radius

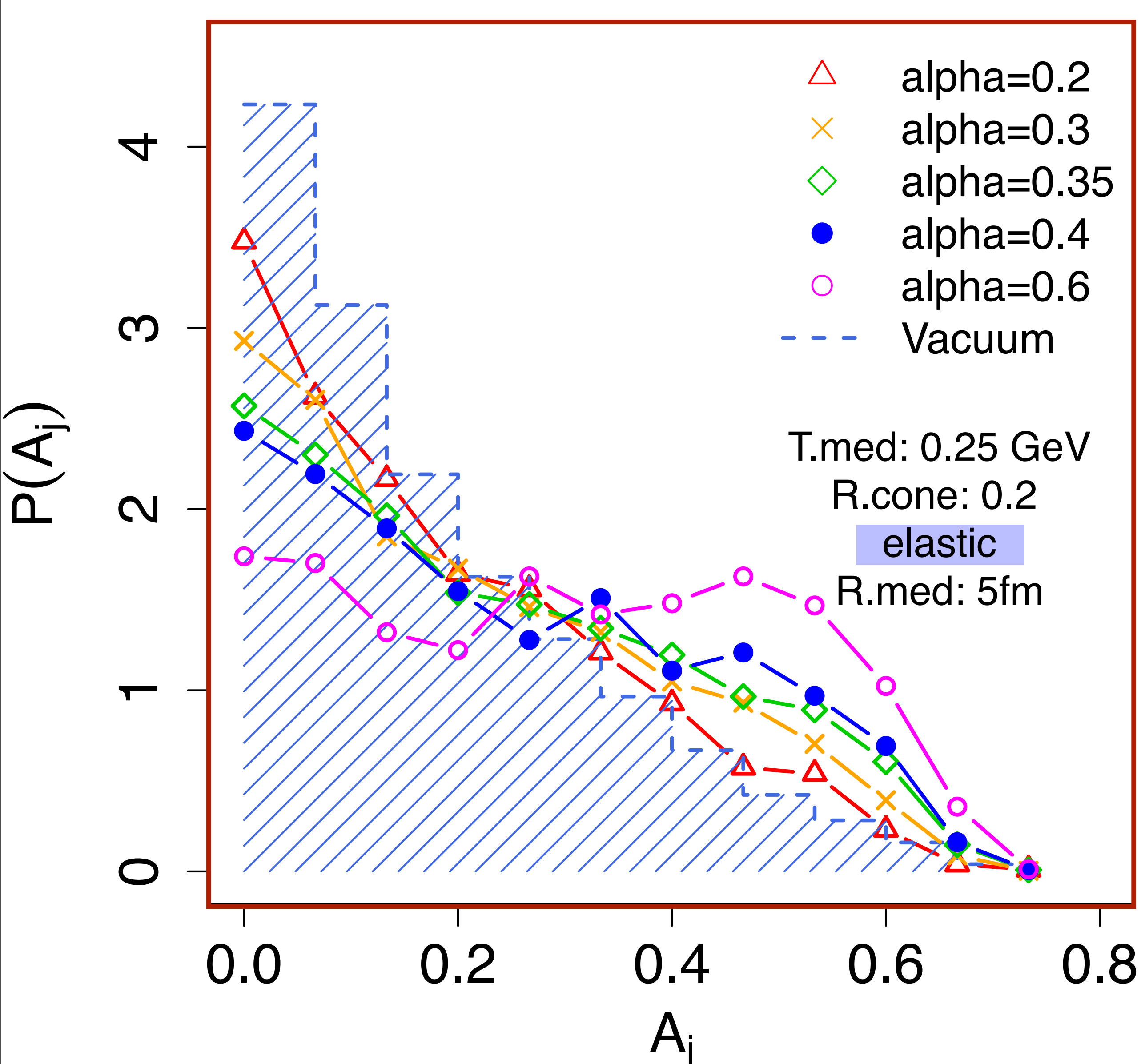




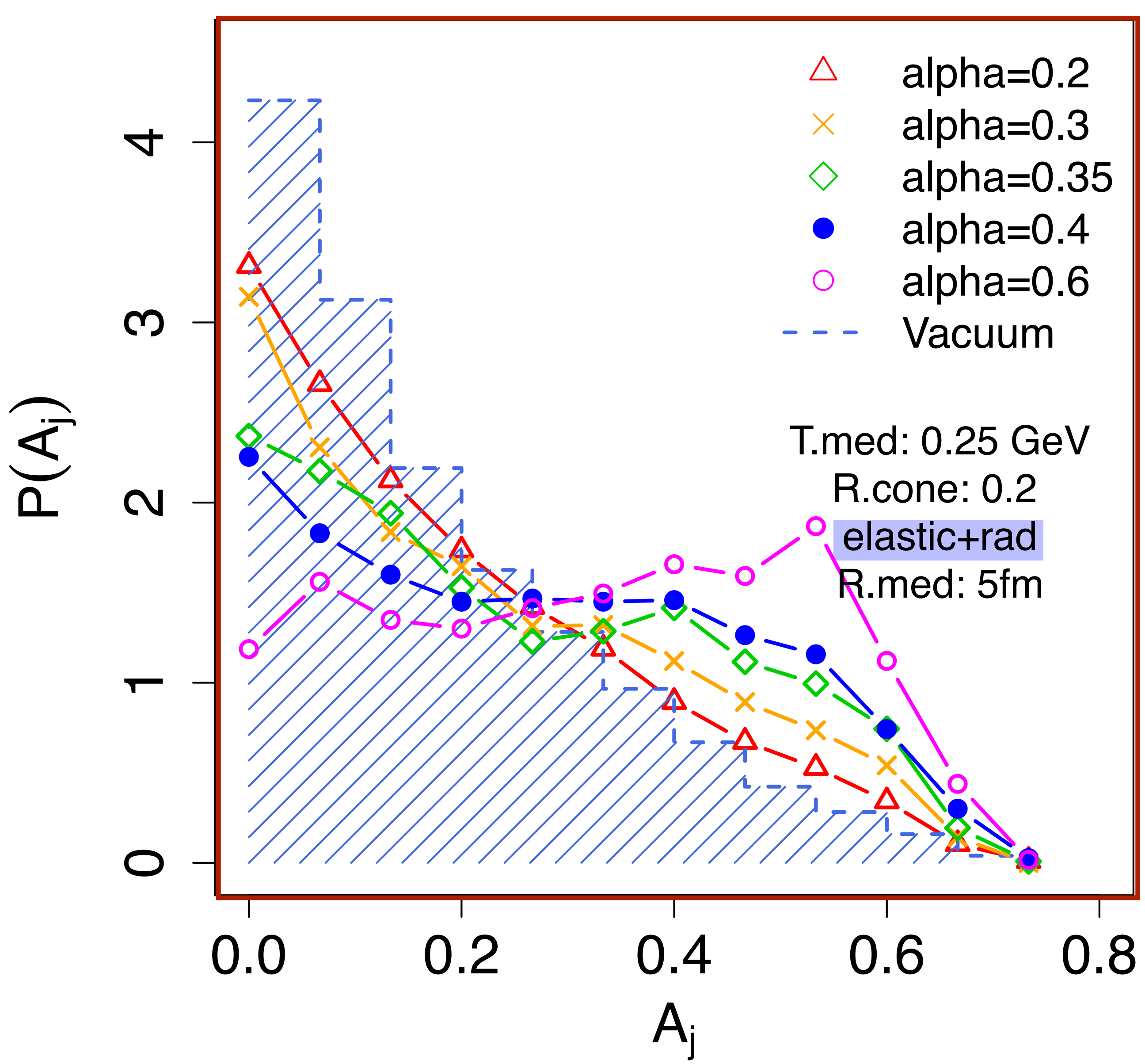
Increased Cone Radius reduces asymmetry,
captures more of the modified jet

Dijet Asymmetry - Varying Strong Coupling

medium temperature T = 250 MeV



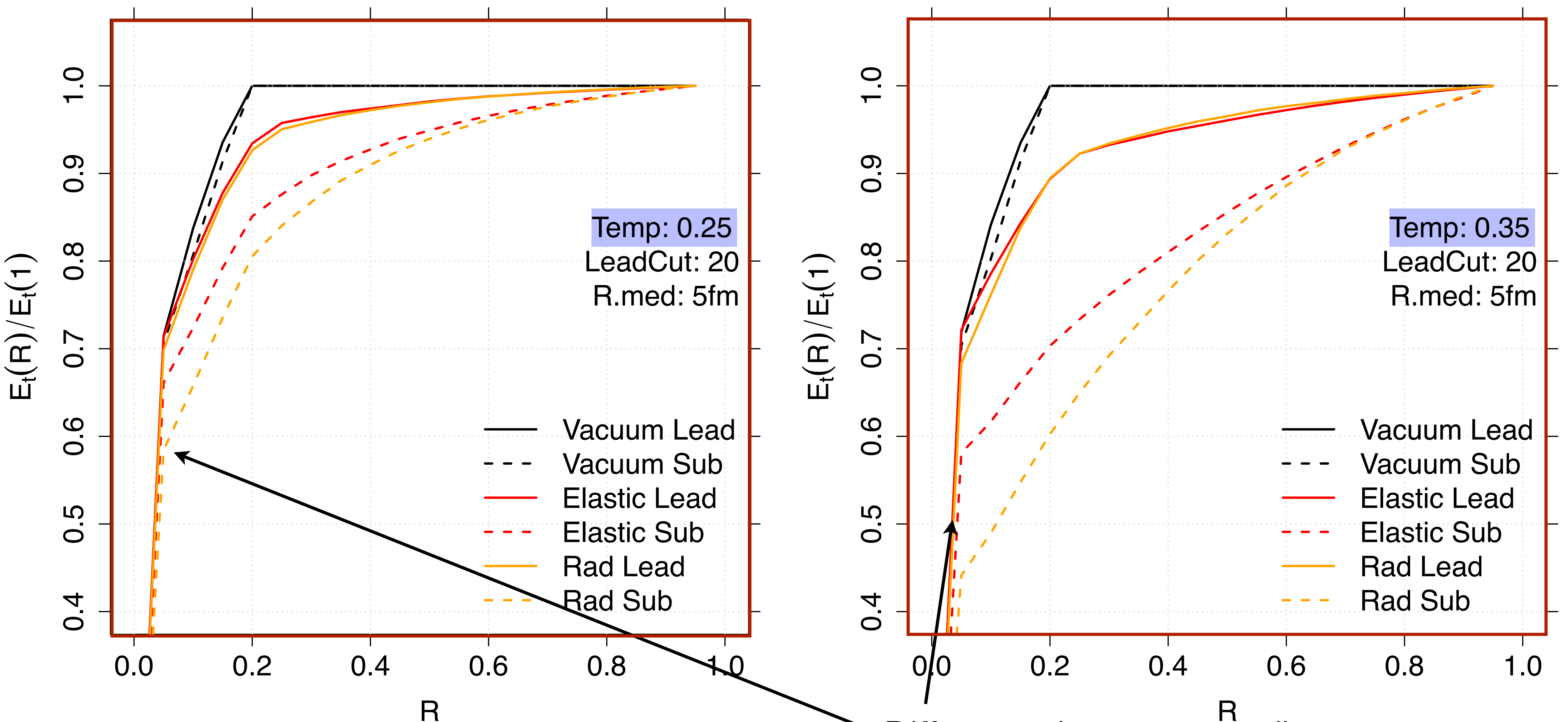
medium radius fixed at 5fm



Increasing Strong Coupling increases asymmetry

Jet Shape

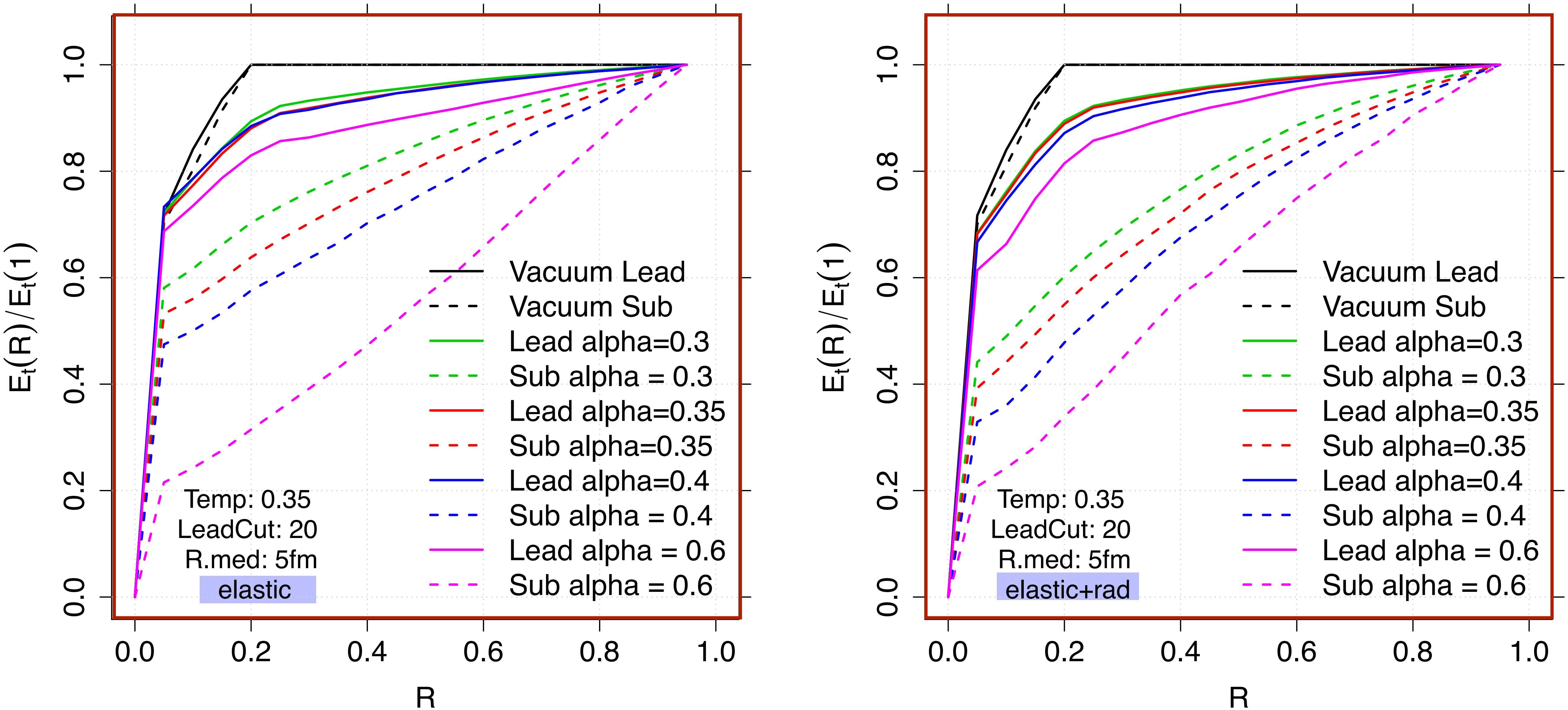
Reconstruct jets with Anti-Kt at successively larger cone radii



Clear separation between elastic (red) and radiative (orange) modes

Difference between medium temperatures is very strong, note values as R->0

Jet Shape - 2, varying strong coupling



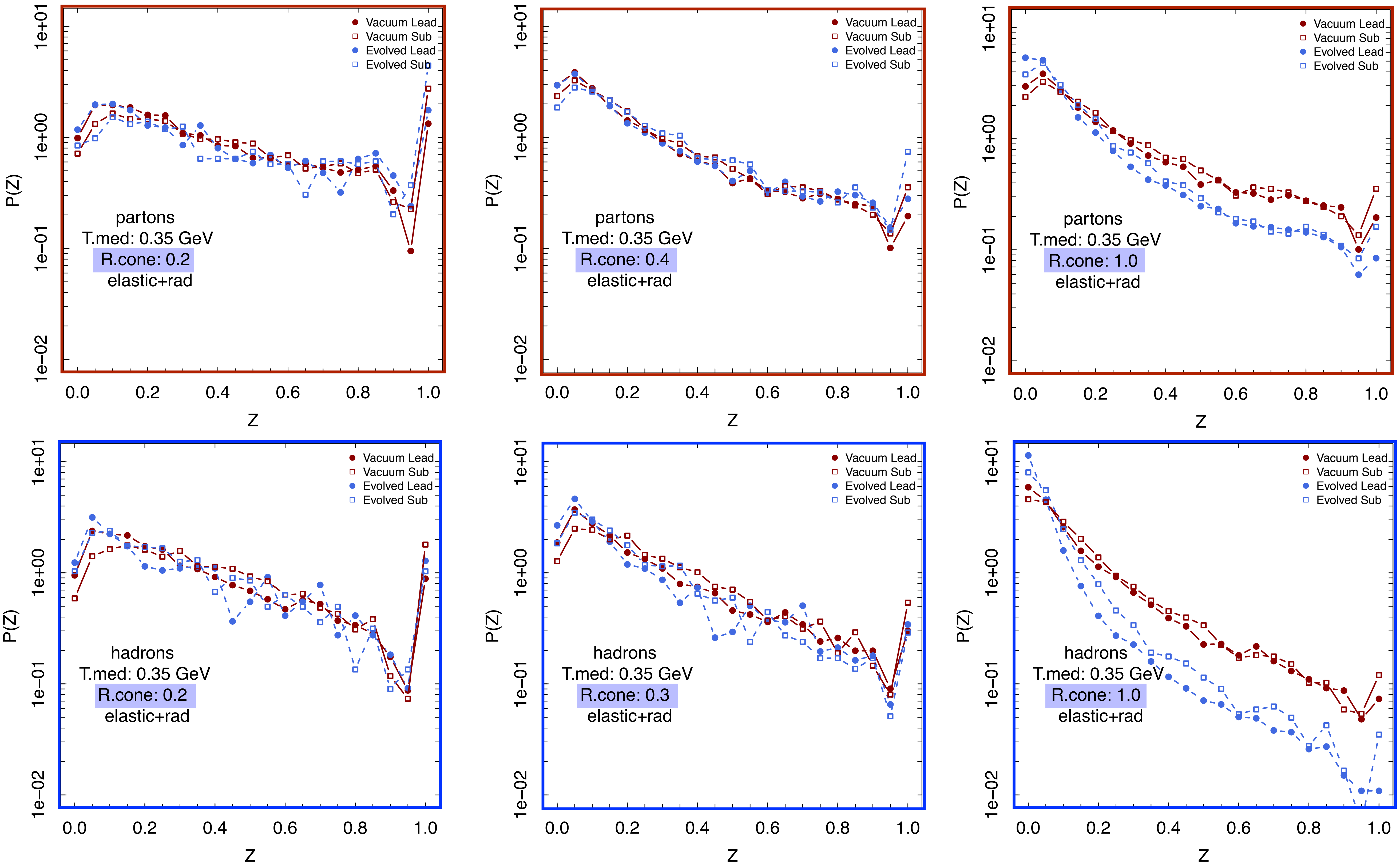
elastic interactions only

elastic+radiative

Elastic and Radiative modes show strong response to variation in alpha, profile shapes are qualitatively different

Jet Fragmentation - Longitudinal

$$z = E_T / E_{T,Jet} \cos \Delta R$$



Jet Fragmentation - Longitudinal

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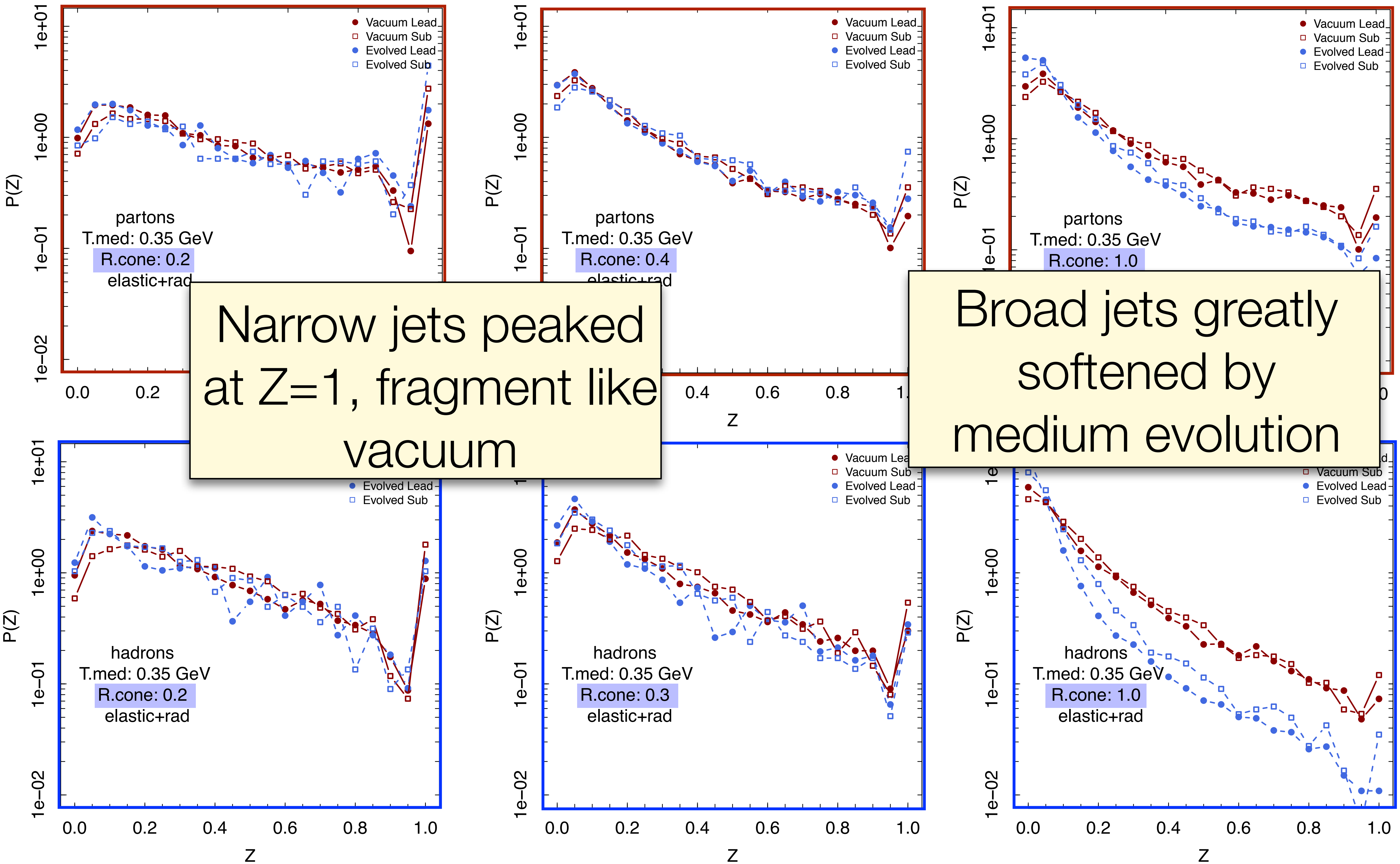
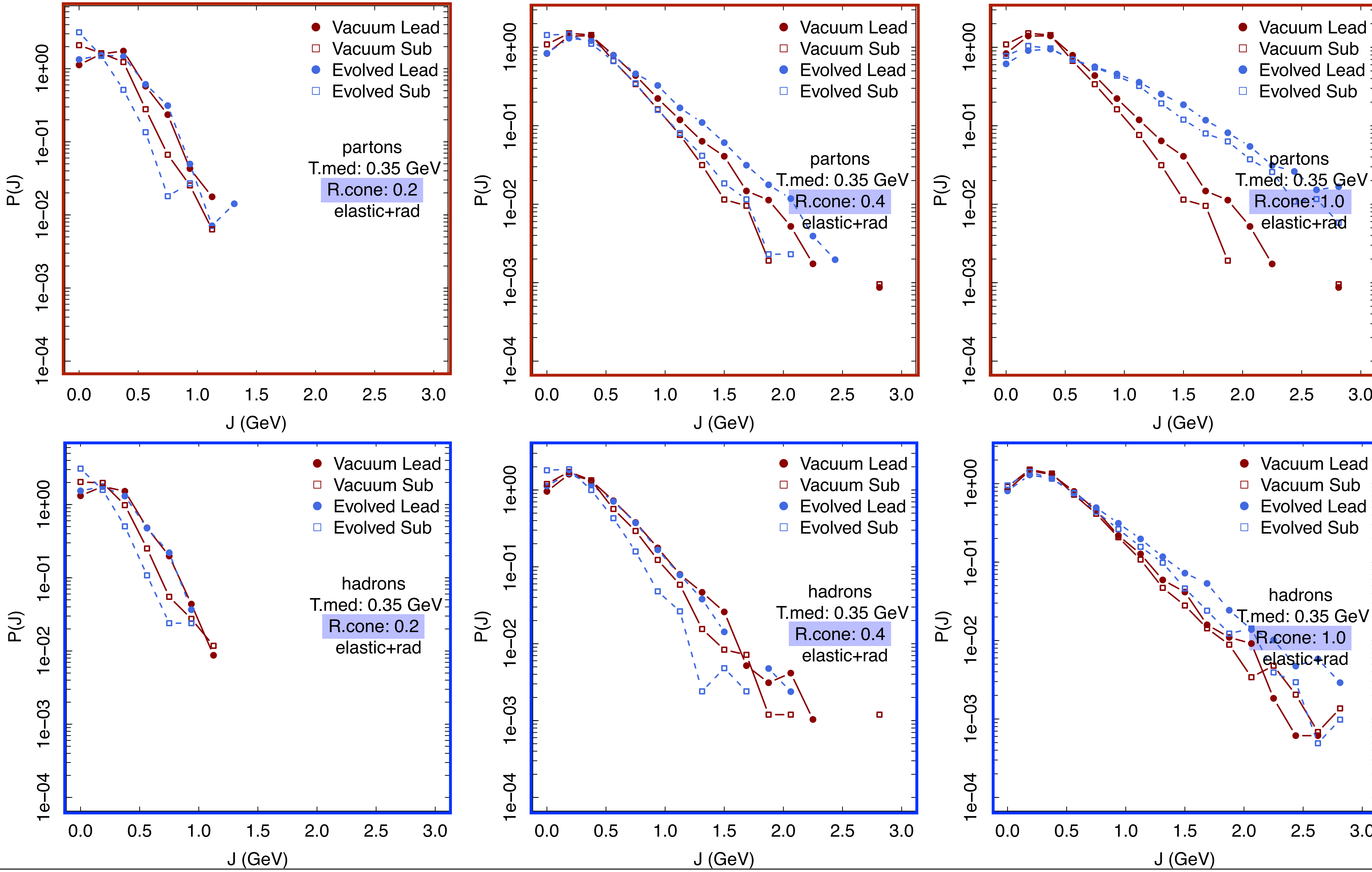


Jet Fragmentation - Transverse

$$J_T = E_T \sin \Delta R$$



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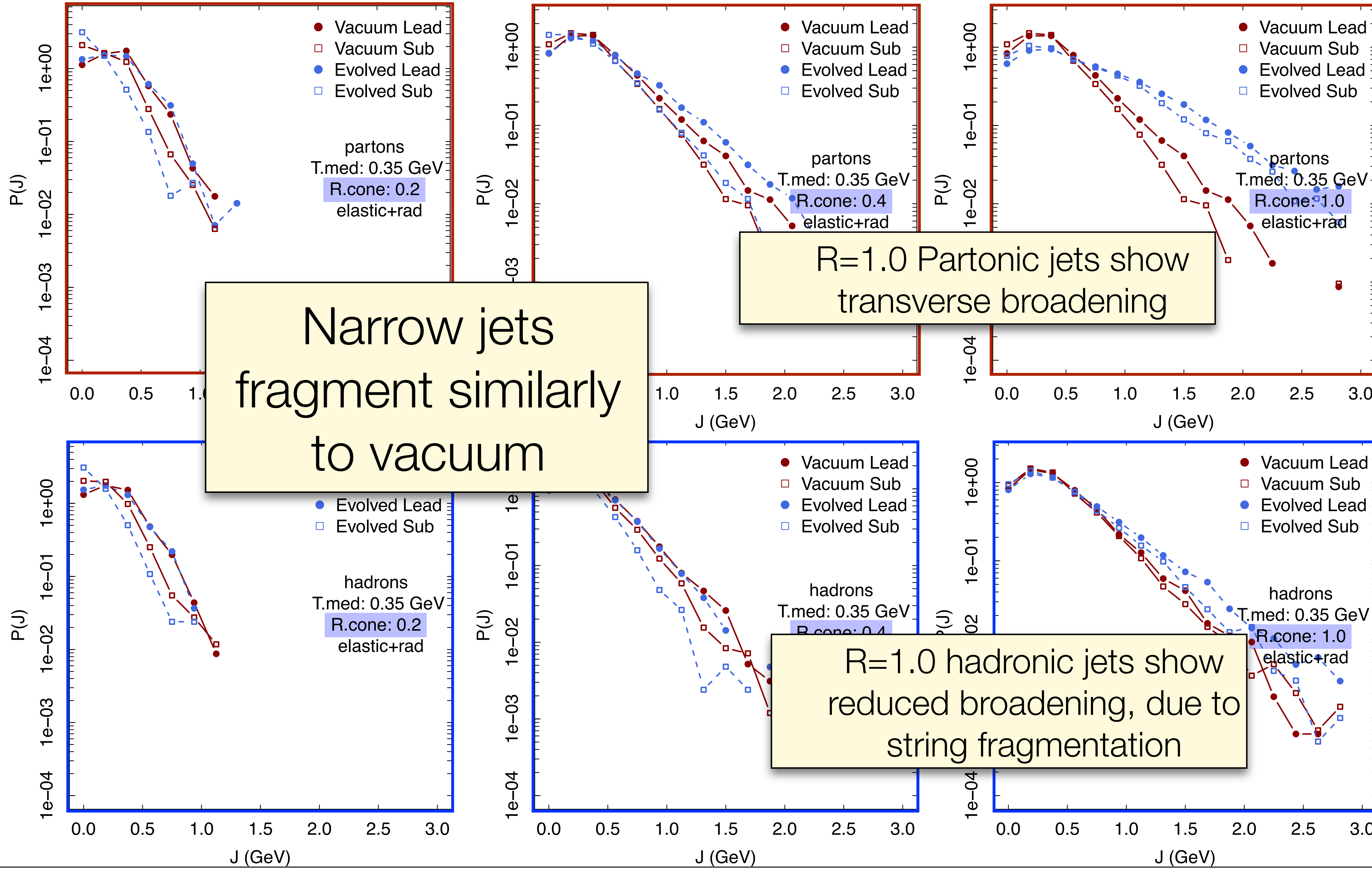
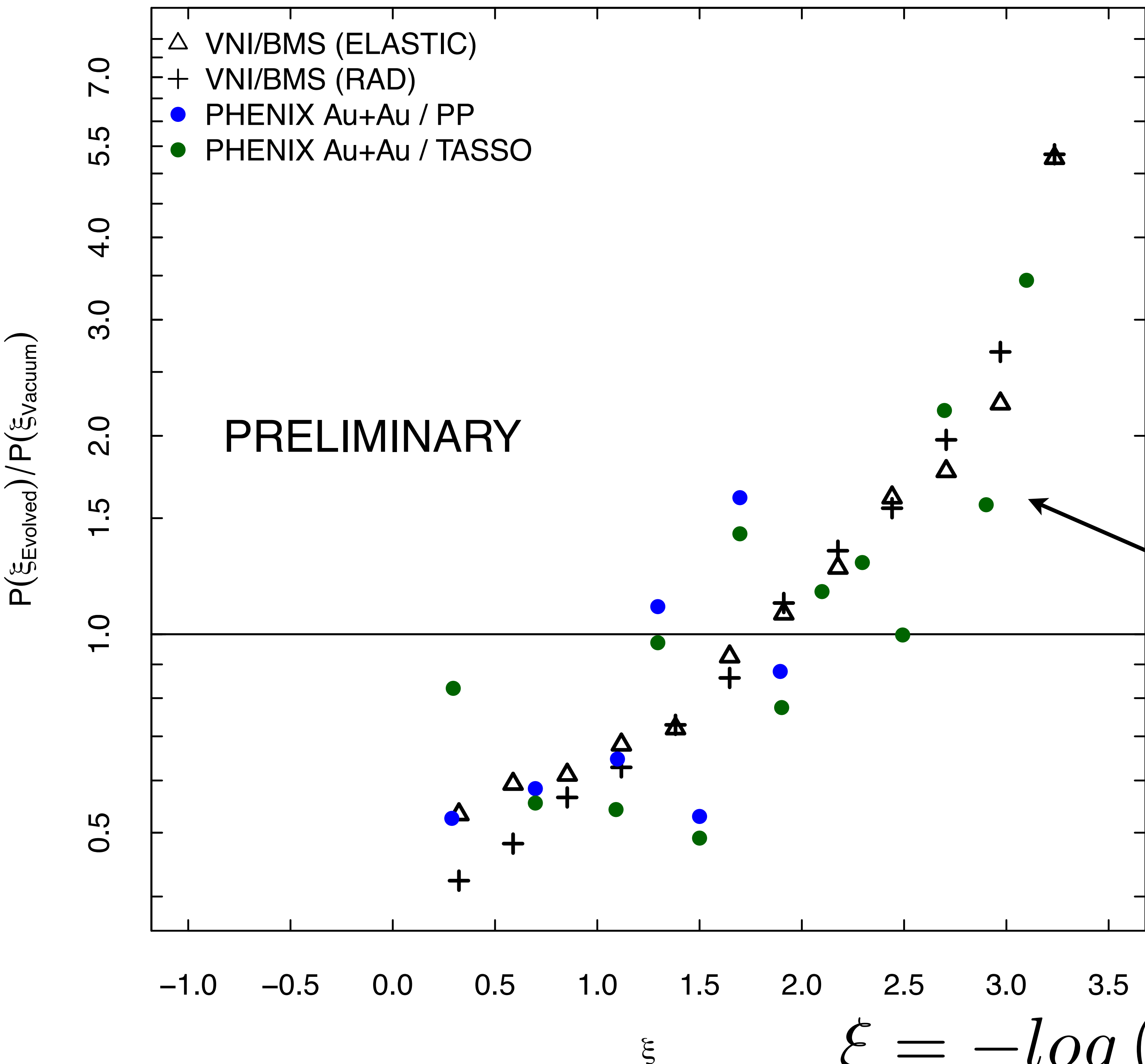
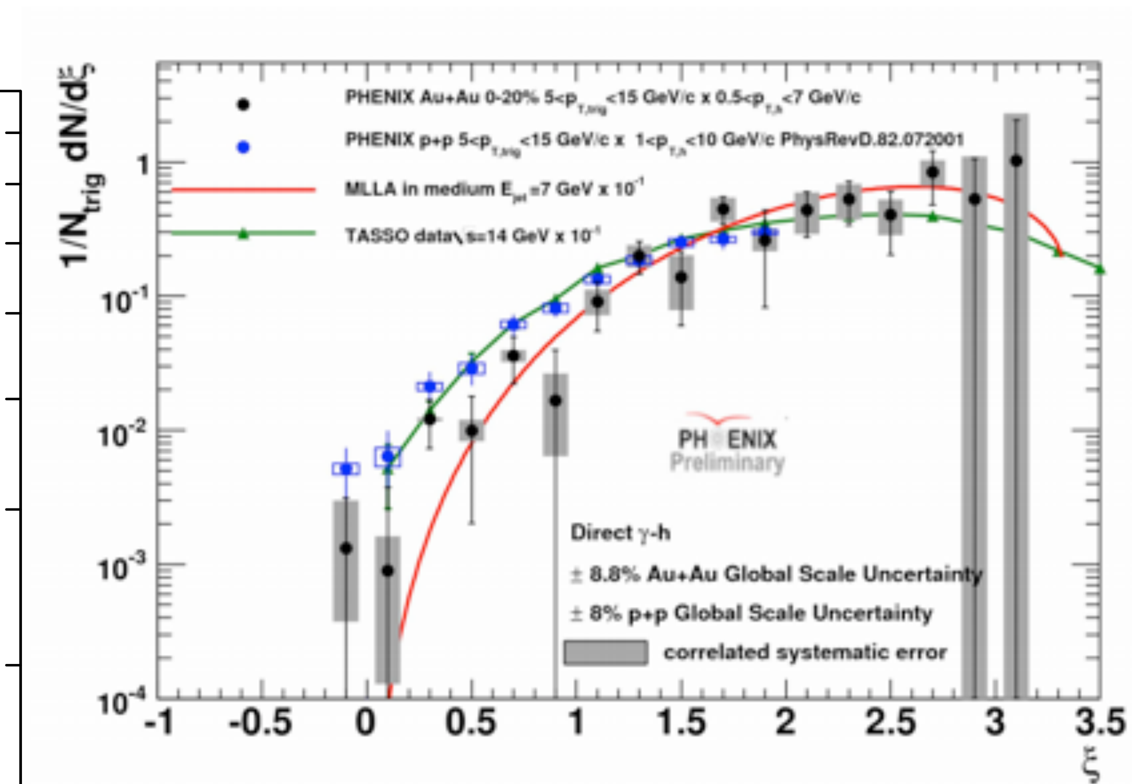


Photon-Hadron Correlations at PHENIX





Soft region of the Fragmentation function is enhanced by medium evolution

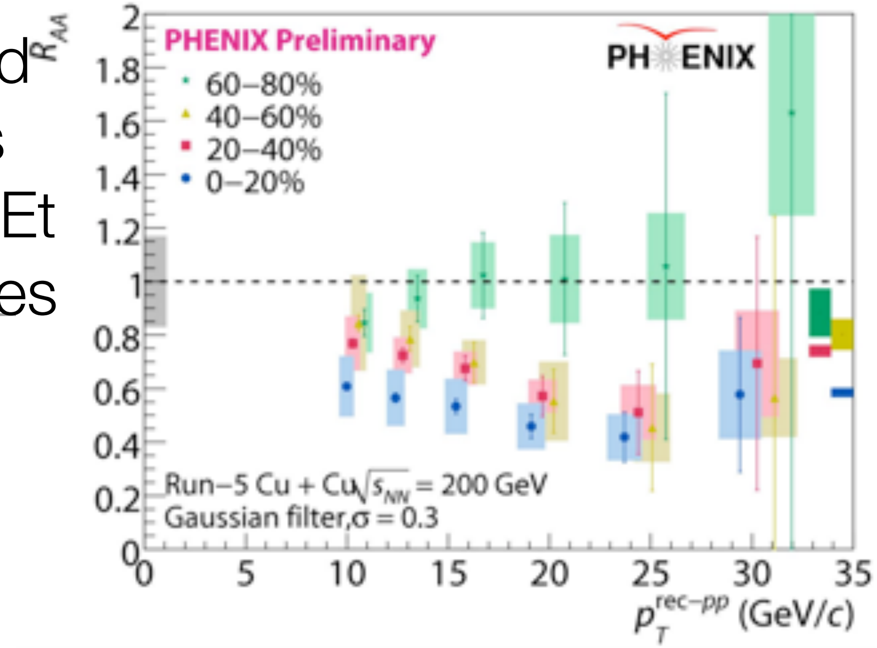
$$0.5 < E_{T,H} < 7\text{GeV}$$

$$10 < E_{T,\gamma} < 15\text{GeV}$$

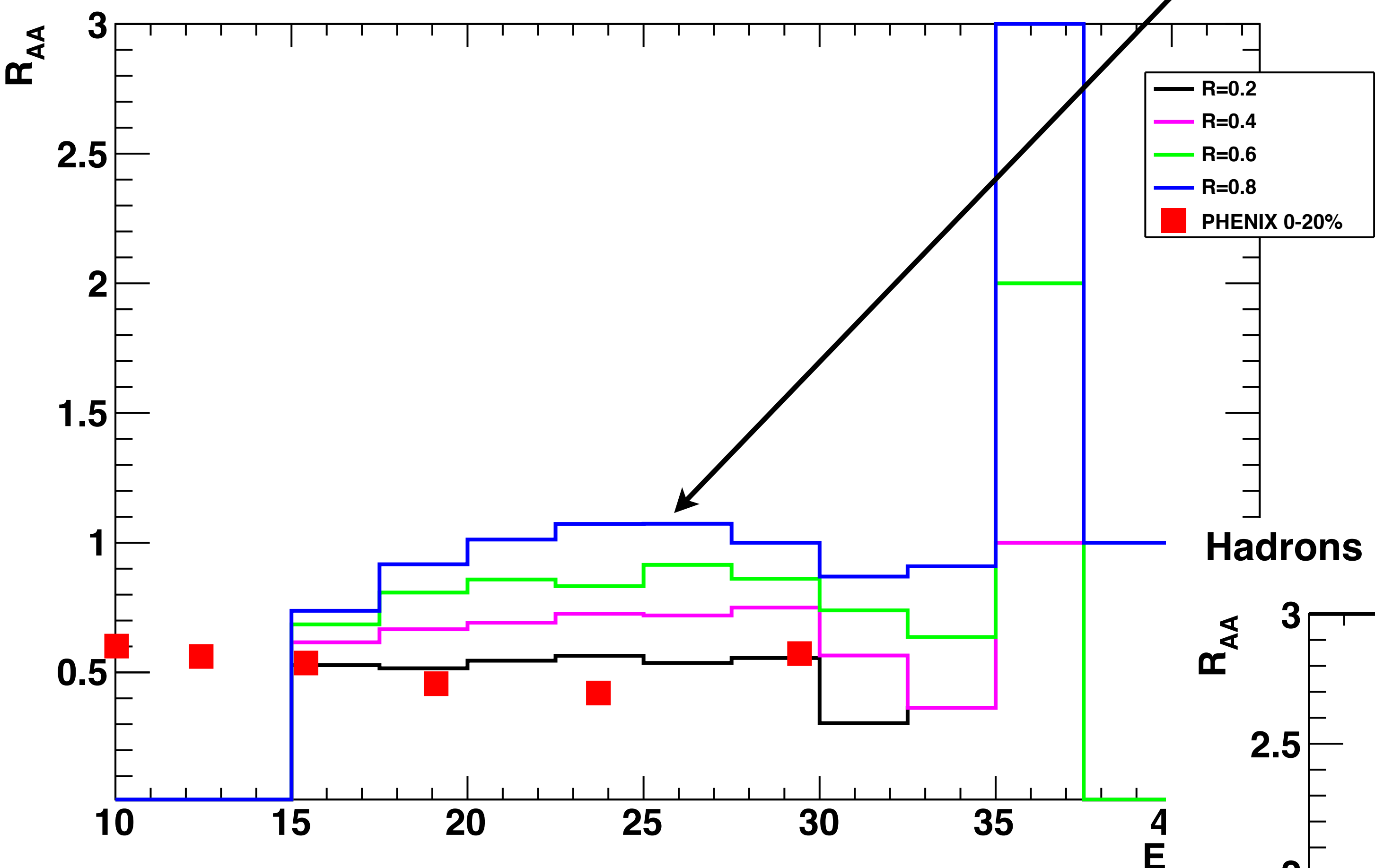
$$\xi = -log\left(E_{T,H}/E_{T,\gamma}\cos(\Delta\phi)\right)$$

RHIC Inclusive Jet RAA

Forward scattered Medium partons enhance partonic Et at large cone angles

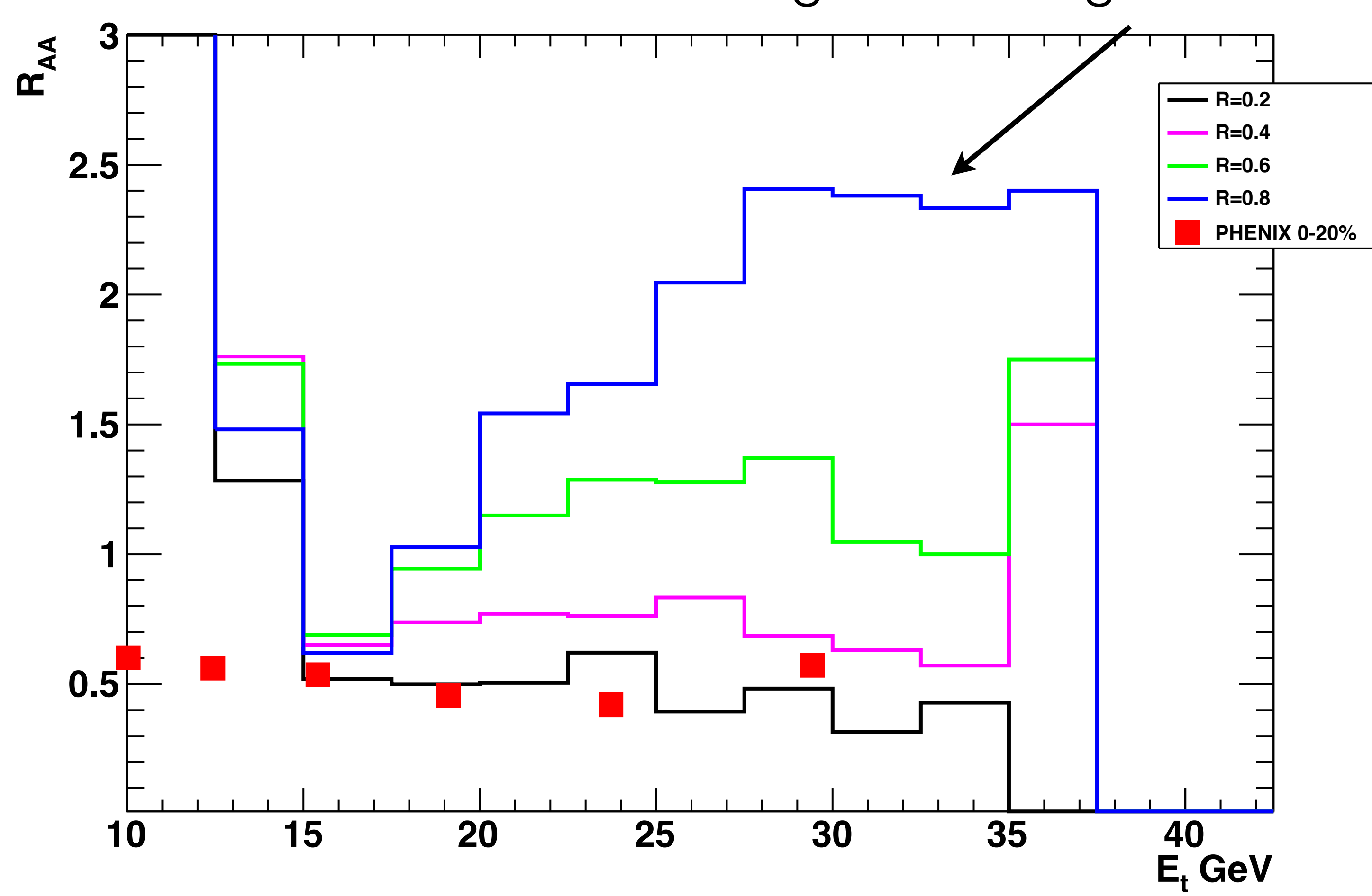


Partons



Thermal partons introduced by color decoherence lead to enhancement of hadronic Et at large cone angles

Hadrons



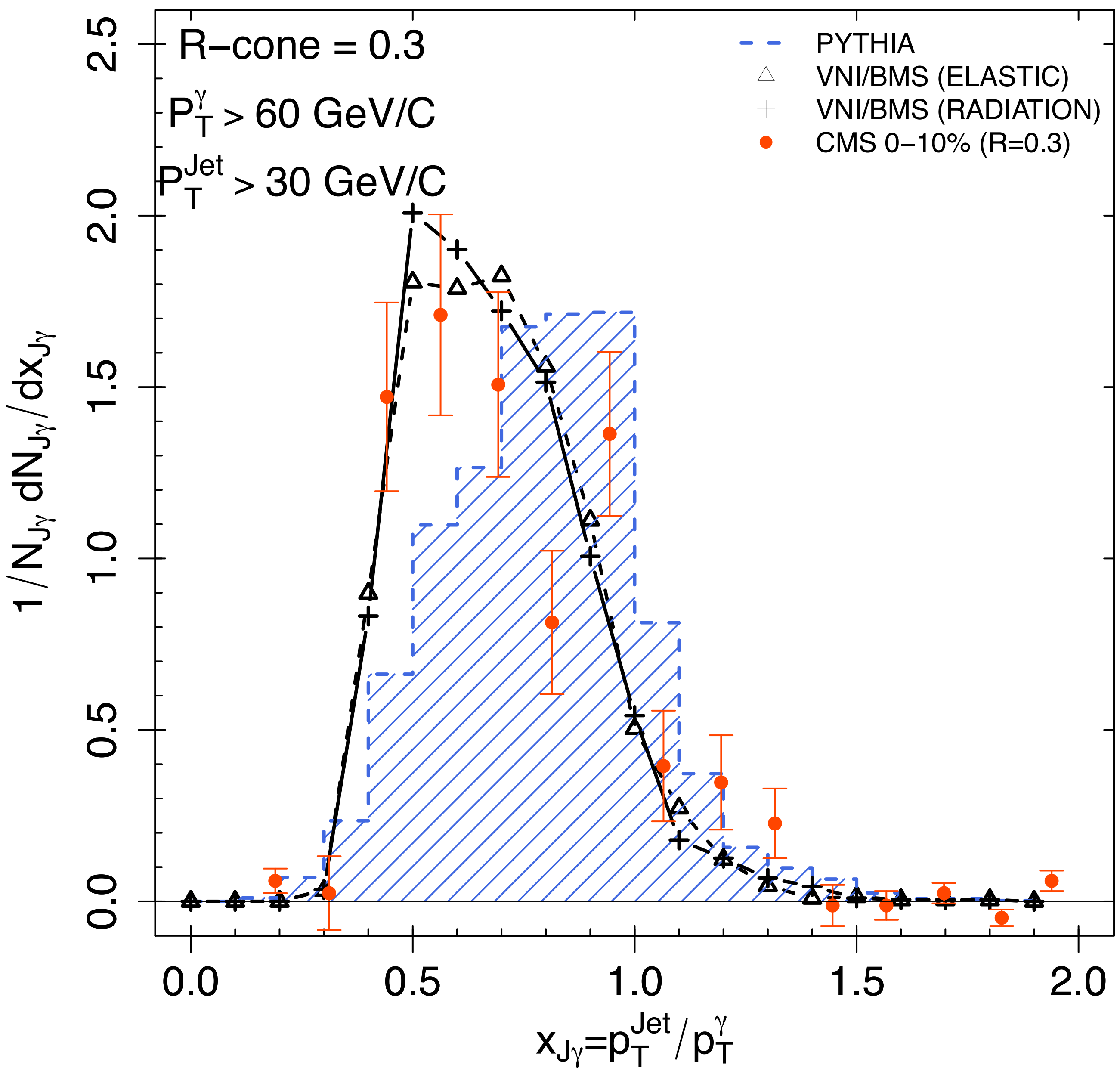
Fragmentation looks like vacuum at R=0.2, 0.4. R_AA & Aj show that these jets are modified

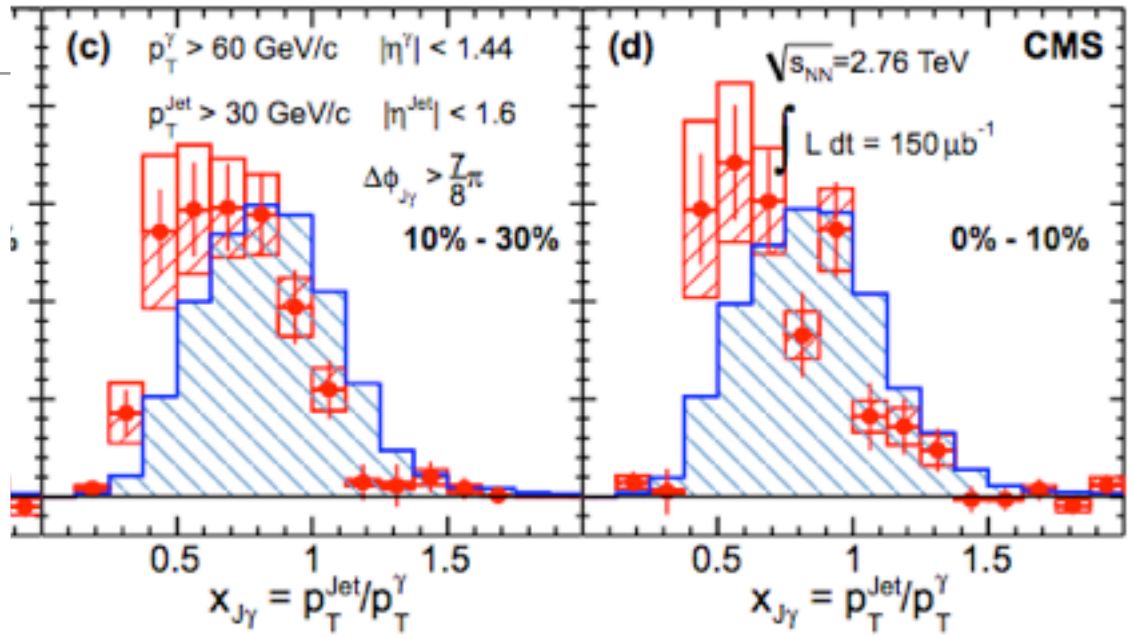
Conclusions

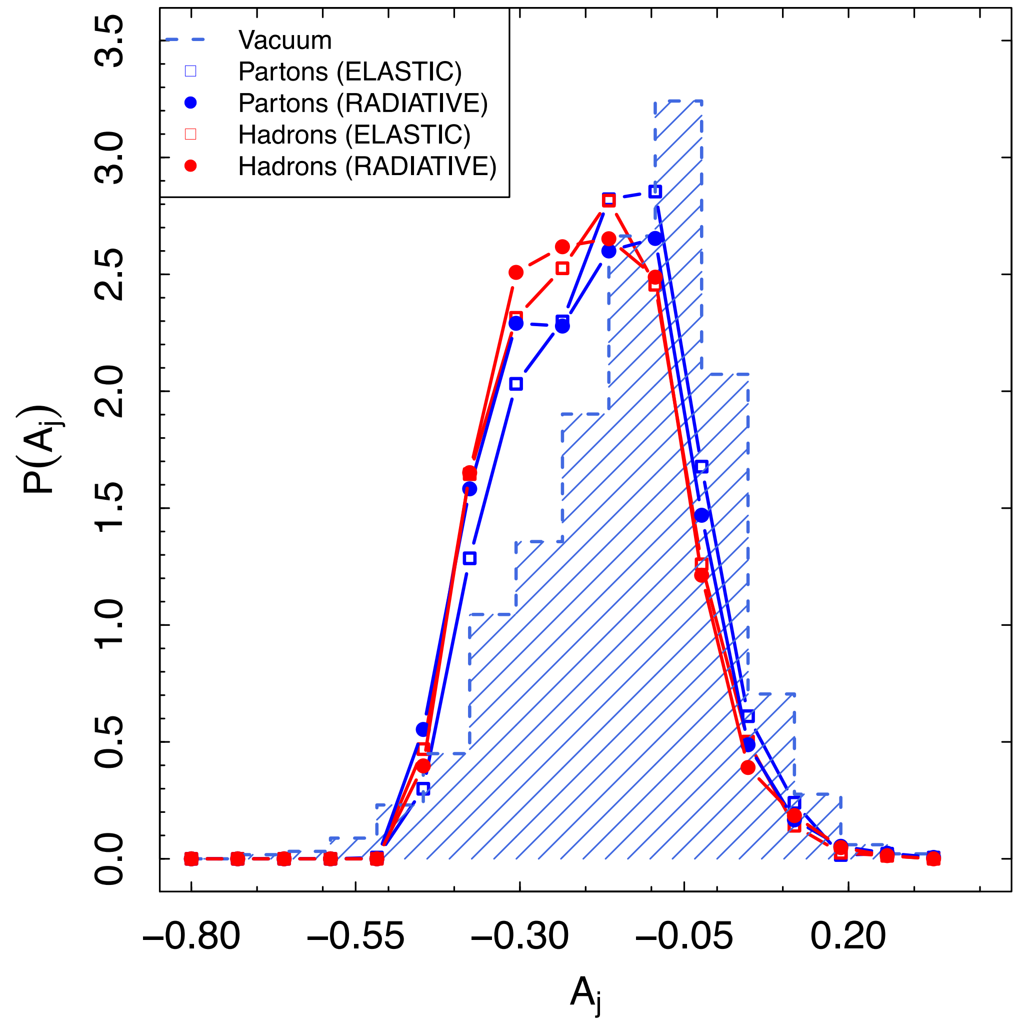
- RHIC Dijet Asymmetry is sensitive to: strong coupling, medium radius, medium temperature and cone radius. Sometimes this is subtle.
- Many jets are not modified, leading jets are strongly surface biased
- Modified jets have a softened radial profile (jet shape), partons are scattered transverse to the jet axis, transverse fragmentation profile softened.
- Fragmentation distributions look similar to vacuum for narrow jets, these jets are still strongly modified as shown by R_AA and Aj
- Fragmentation of broad jets shows strong modifications over vacuum
- Modified jets retain a hard core that looks like a vacuum jet, surrounded by a soft cloud of radiated and liberated particles.

CMS Photon - Jet Correlation

CMS hep-ex/1205.0206







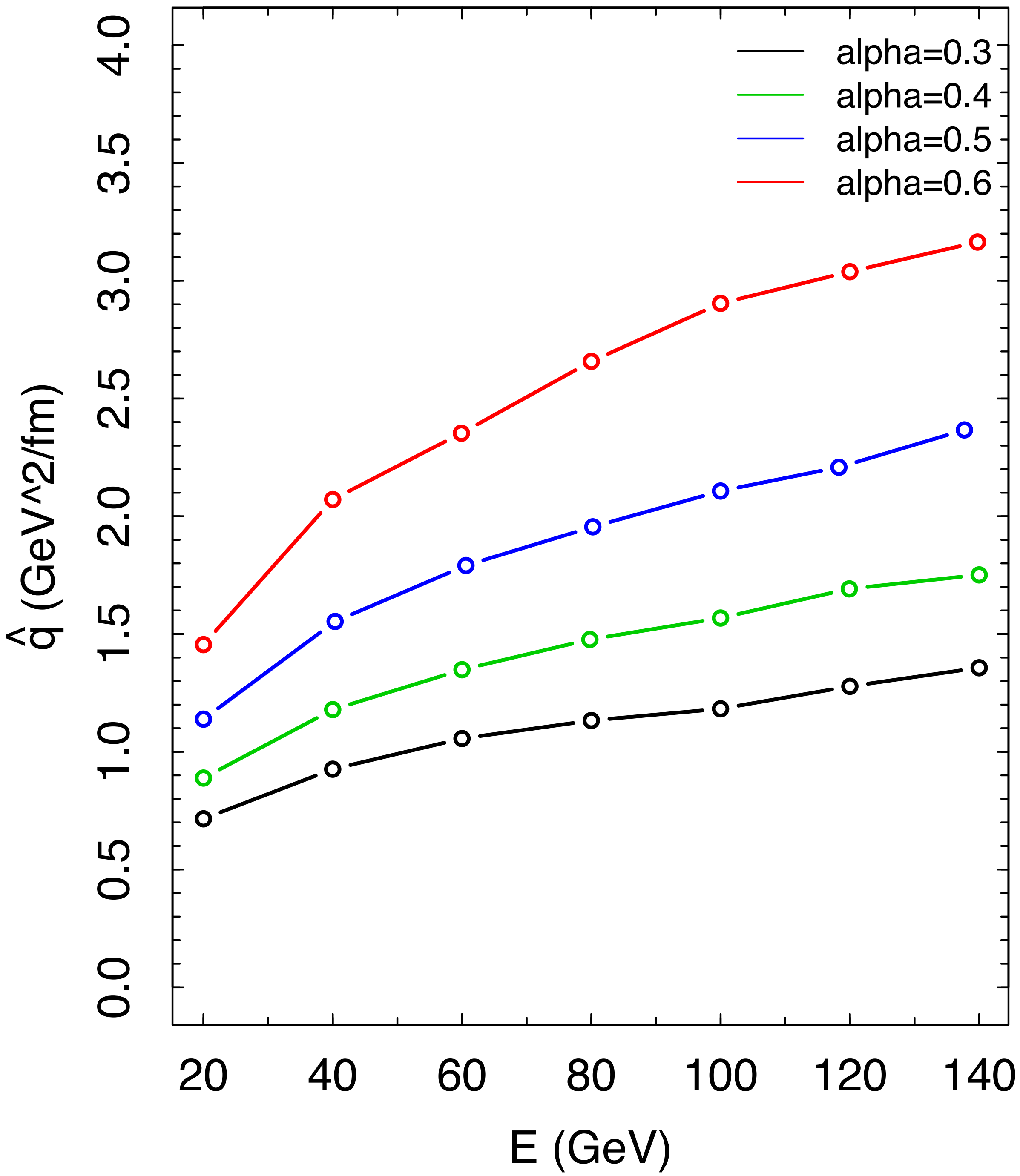
$$E_{T,\gamma} > 60\text{GeV}$$
$$E_{T,\text{Jet}} > 30\text{GeV}$$

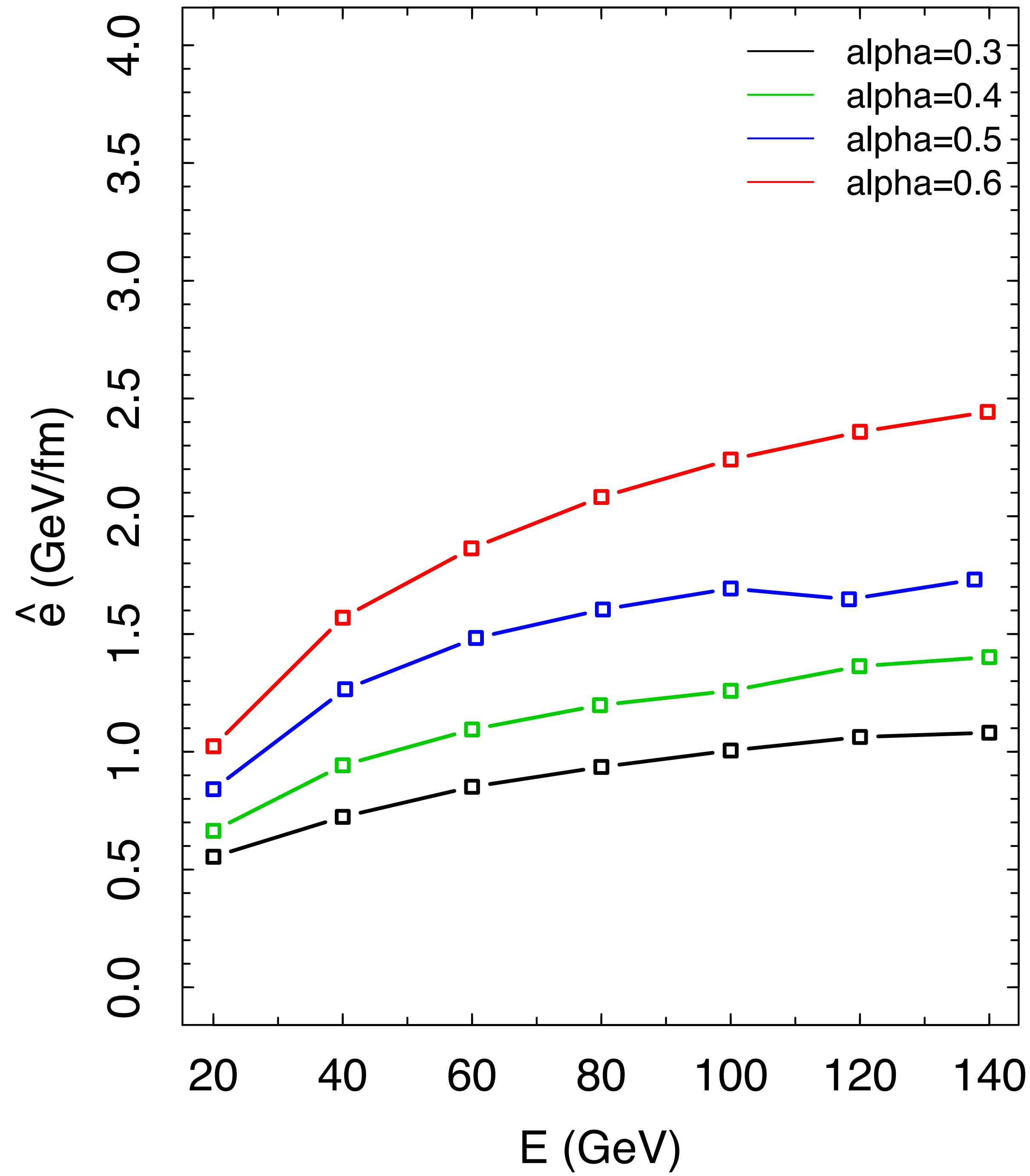
$$A_j = \frac{E_{T,jet} - E_{T,\gamma}}{E_{T,jet} + E_{T,\gamma}}$$

Backup Slides

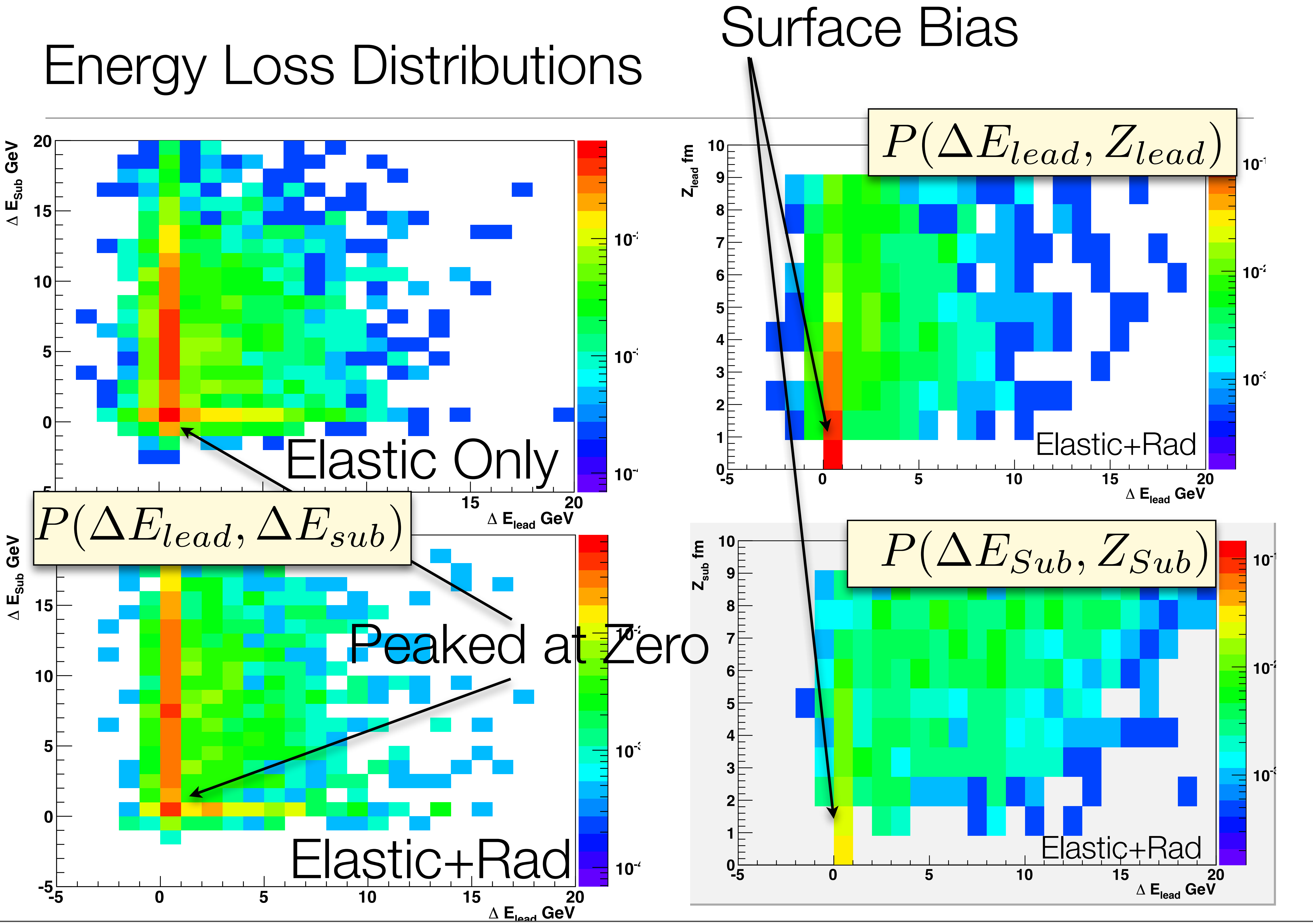
VNI/BMS Transport Coefficients

Quark jets evolved for 4fm in a box at T=350 MeV





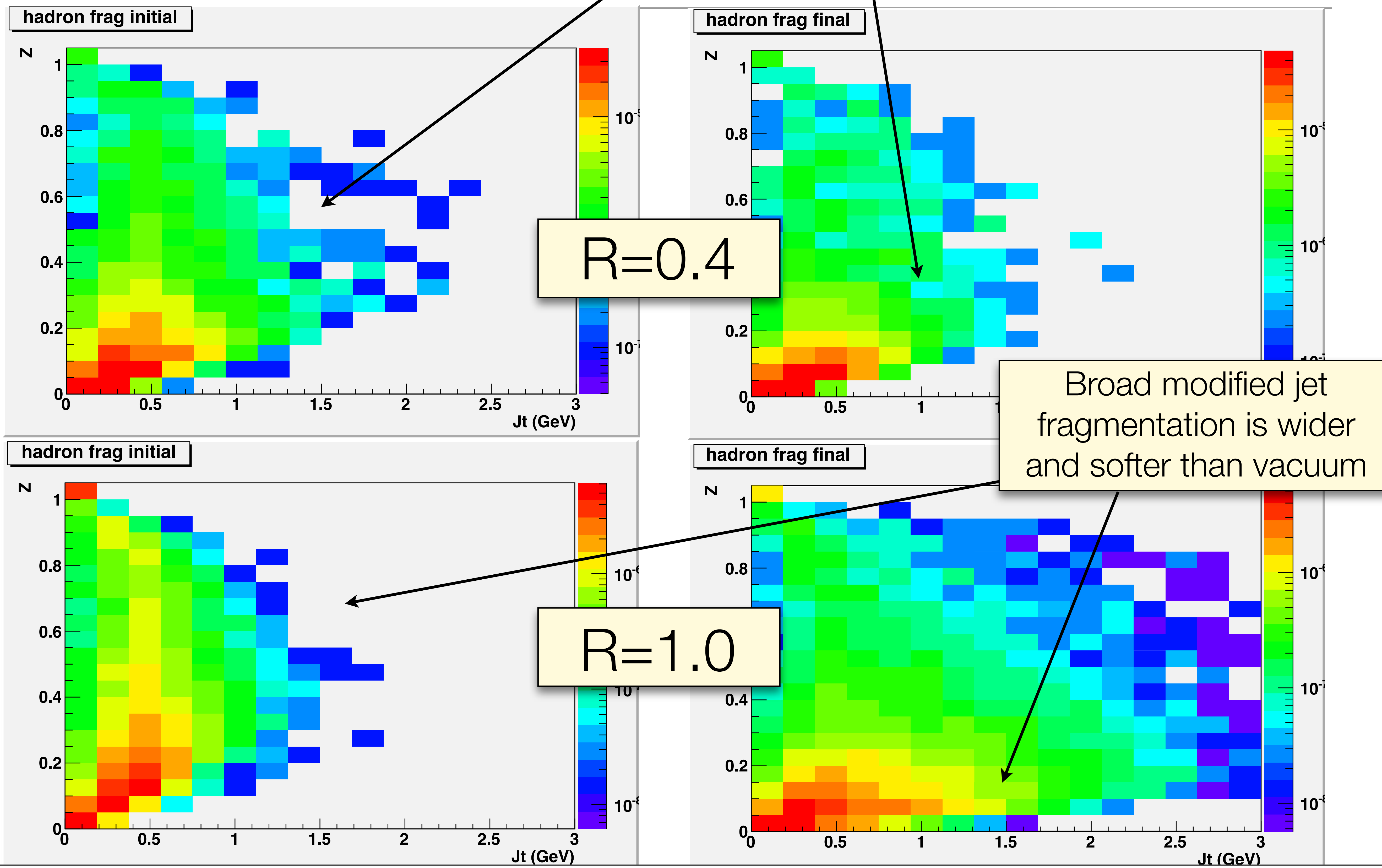
Energy Loss Distributions



2d Fragmentation

$$z = E_T / E_{T,Jet} \cos \Delta R$$
$$J_T = E_T \sin \Delta R$$

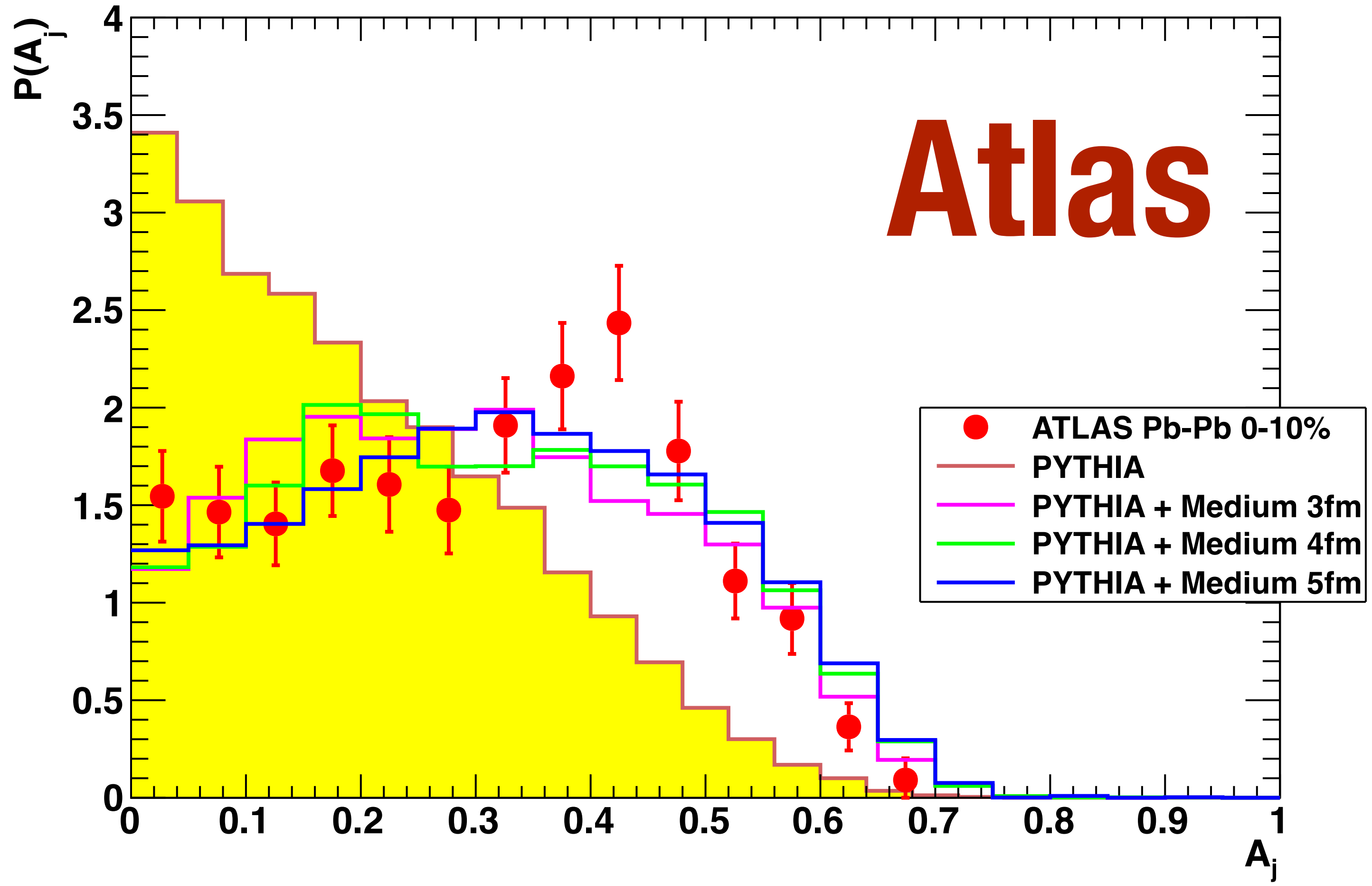
Narrow modified jet
fragmentation similar to vacuum

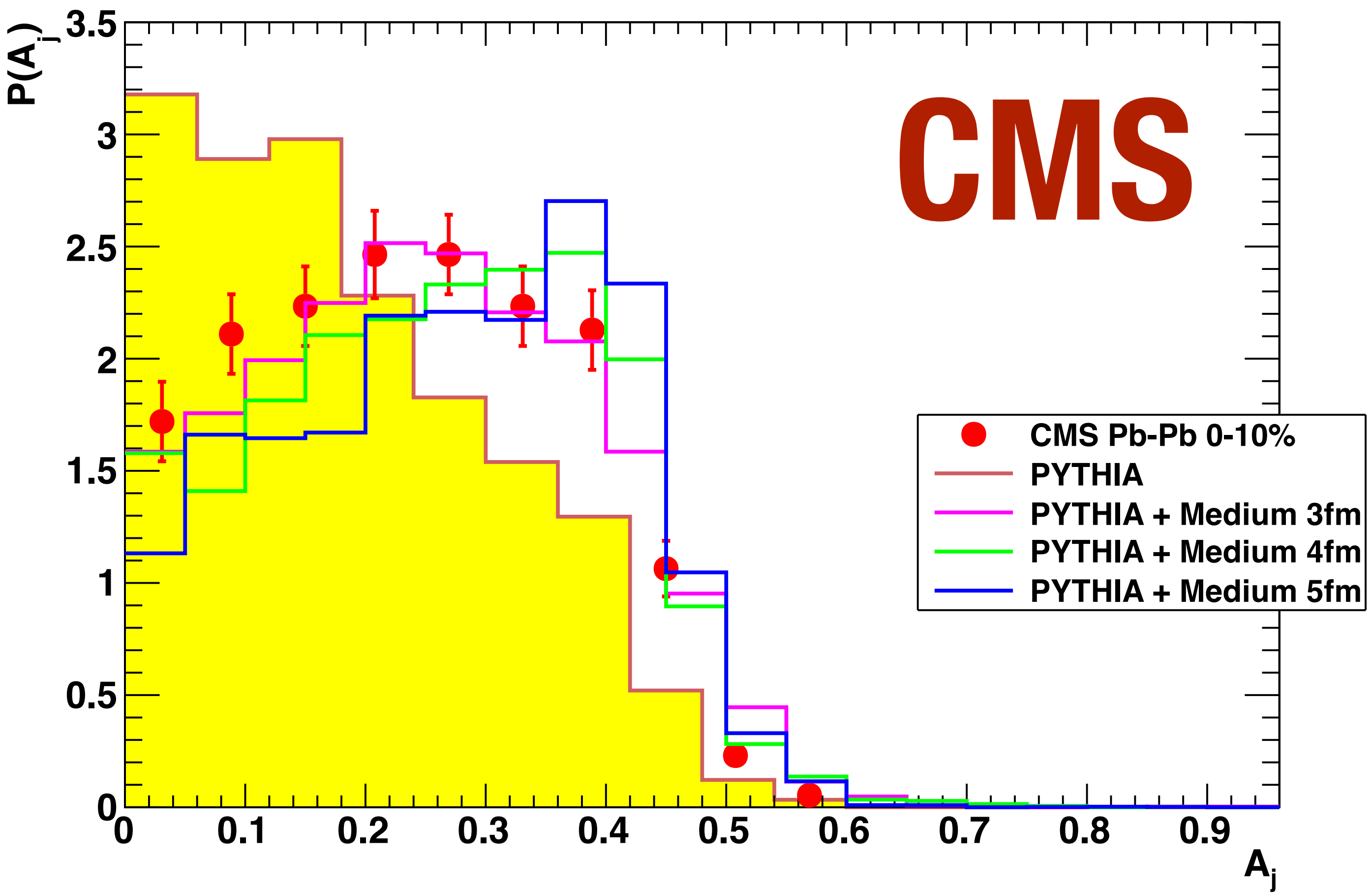


LHC Results

Circle Mode + Glauber Vertices can reproduce LHC data reasonably well.

Central collisions (0-10%)





Both results include detector smearing effect

$$E_t^\star \sim N(E_t, \alpha\sqrt{E_t}), \quad \alpha \simeq 1.2$$

Presented at QM 2011

Coherence Effects in QCD Radiation

- Coherence scales with formation time

$$\tau_f = \frac{2\omega}{q_\perp^2}$$

- Gluon scattering dominates

- Incoherent emission, Bethe-Heitler

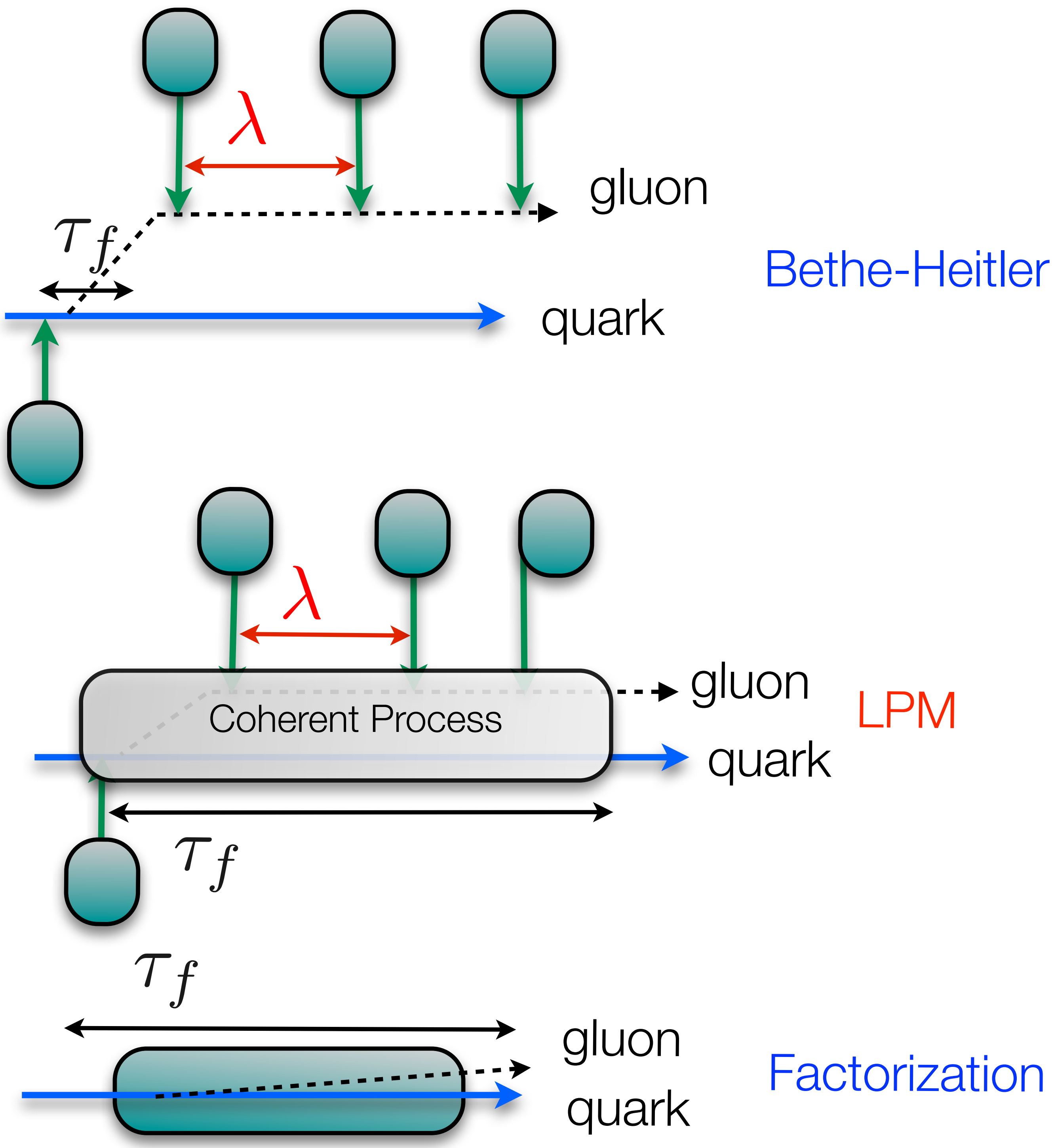
$$\Delta E \propto L$$

- Individual scattering centers not resolved. Coherent radiation. LPM effect

$$\Delta E \propto L^2$$

- Coherence length exceeds medium, Factorization limit.

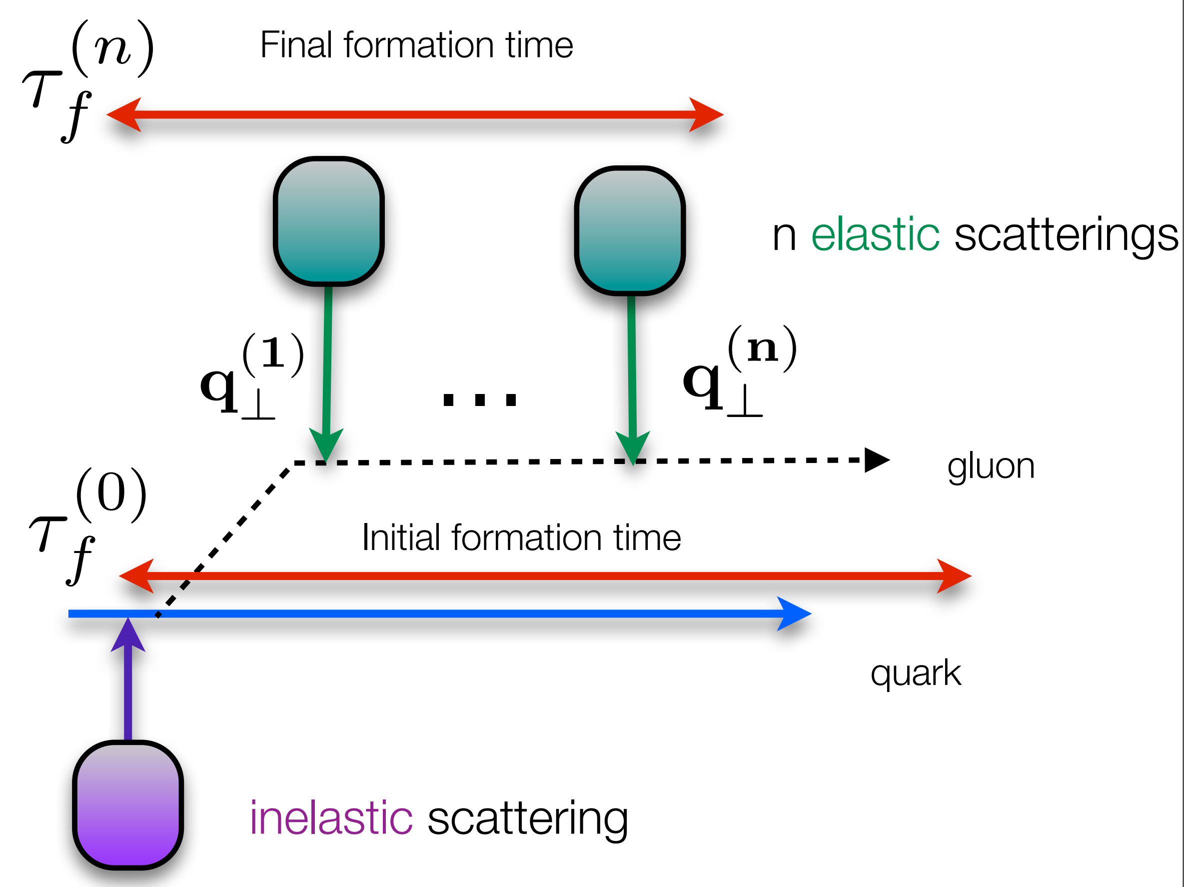
$$\Delta E \propto \sqrt{E}L$$



[9] Landau.L.D, Pomeranchuk.I *Dokl.Akad.Nauk.Ser.Fiz 92 (1953)*, Migdal.A.B *Phys.Rev.103:1881 (1956)*

Zapp and Wiedemann, LPM Algorithm

- Probabilistic local implementation of coherence, gives rise to an L^2 energy loss.
- Post Inelastic scattering, compute formation time of emitted gluon
    - Emitting parton does not interact during this time
    - Radiated gluon rescatters elastically off the medium, recompute modified formation time
    - Repeat until formation time expires
    - Quark and gluon propagate freely
- Simulates coherent emission from multiple centers



$$\tau_f^{(n)} = \frac{2\omega}{\left(\mathbf{k}_\perp + \sum_{i=0}^{n} \mathbf{q}_\perp{}^{(i)}\right)^2}$$

Zapp K, Wiedemann U. *Phys Rev Lett,* 103 (2009) JEWEL
CCS, S.A.Bass, D.K.Srivastava, *hep-ph/1101.4895*

Fully Tracked Evolution