# The dihadron fragmentation function

# &

# hadron hadron correlations

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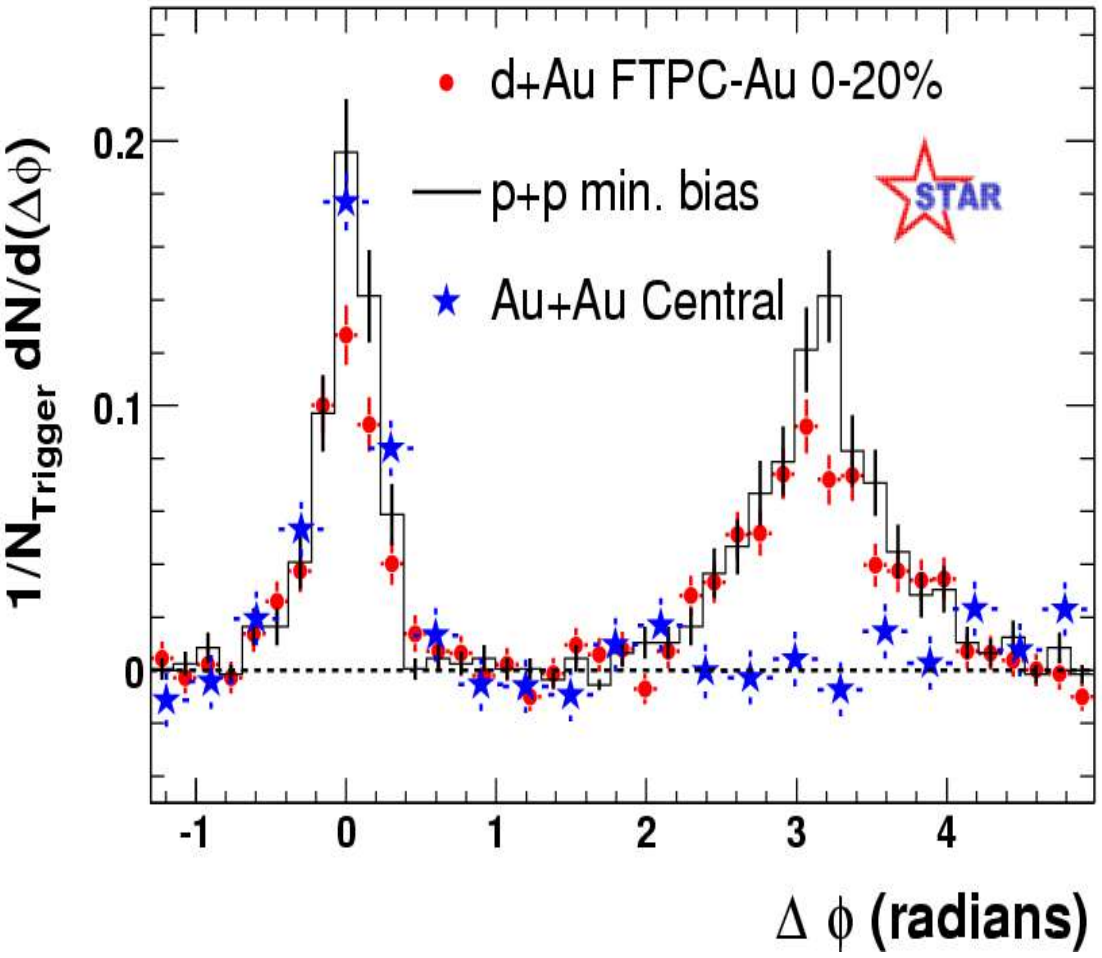
# *OUTLINE*

- *HEAVY-ION COLLISIONS, MOTIVATIONS*
- *HIGH $P_T$ JETS, TWO PARTICLE CORRELATIONS*
- *VARIOUS APPROACHES: PARTONIC INTERACTION!*
- *FACTORIZATION: NAILING IT DOWN IN* $e^+ e^-$
- *DGLAP EVOLUTION: NON-SINGLET, SINGLET,GLUONS*
- *COMPARISONS WITH JETSET !*
- *IN-MEDIUM MODIFICATIONS* **PRELIMINARY !!**

# *RESULTS FROM STAR @ QM2004*

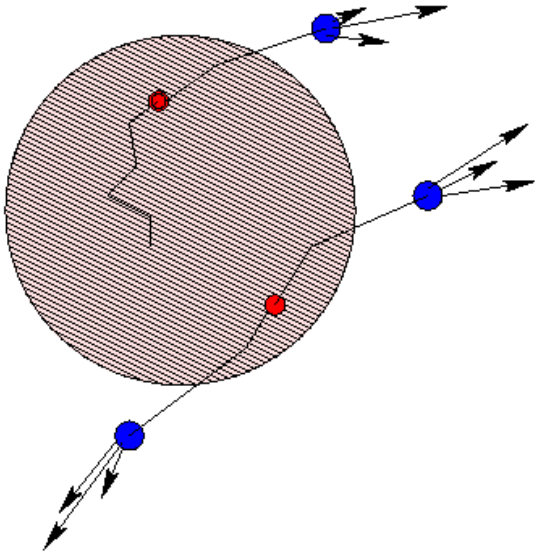


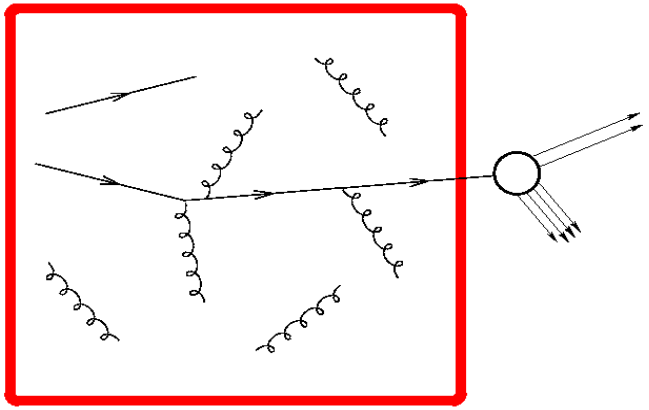

- *d+Au central very similar to p+p*
- *Away side, central Au+Au suppressed*
- *Near side, central Au+Au unchanged*
- *Why? → simple pictures!*

# *TWO POSSIBILITIES !*

***PARTONIC ENERGY LOSS :***

- ***High energy partons are created over the entire collision zone***





- ***Lose energy by partonic interaction, medium may be hadronic or partonic***
- ***Emerge as partons and then fragment***

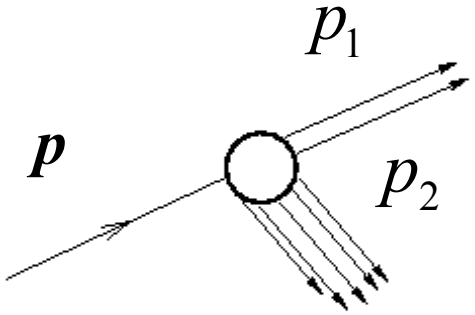
- ***Partonic energy loss models explain single inclusive suppression pretty well !***
  ***(Gyulassy Wang, Gyulassy Levei Vitev, Wang Guo Zhang, Wiedemann Salgado, BDMPS )***

- ***All models depend require a high density of scattering centers***

- ***High density seen as evidence of QGP.***

- ***To explain double inclusive spectra requires a new phenomenological object: Dihadron fragmentation function!***

$$D_{q,g}^{h1h2}(z_1, z_2)$$

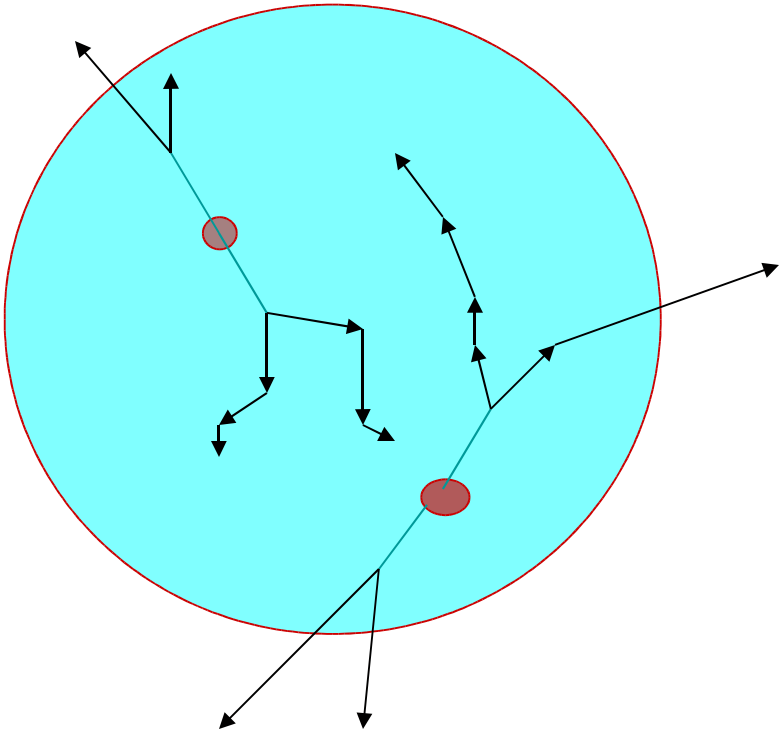



$$z_1 = \frac{p_1^+}{p^+}$$

$$z_2 = \frac{p_2^+}{p^+}$$

## *HADRONIC ENERGY LOSS:*

- *Fragmentation occurs inside the hot medium*
- *Hadrons become independent due to scattering*
- *Each hadron suffers the same Energy Loss on average*



***Hadronic scattering models can explain mean single supp. !***
***C. Greiner et. al. @QM2004, V. Koch (unpublished!)***

- ***Probability of observing two hadrons factorizes  P(1,2) = P(1)P(2)***
- ***Each probability is suppressed compared to p+p: P(h) = s p(h)***

- ***Thus the conditional probability is also suppressed compared to p+p collisions***

$$\frac{P(1,2)}{P(1)} = \frac{P(1)P(2)}{P(1)} = P(2) = sp(2) = s\frac{p(1)p(2)}{p(1)}$$

***P(h) is for A+A;  p(h) is for p+p***

- ***Hadronic absorption models cannot explain the double inclusive spectrum***

# *How does partonic interaction effect dihadrons?*

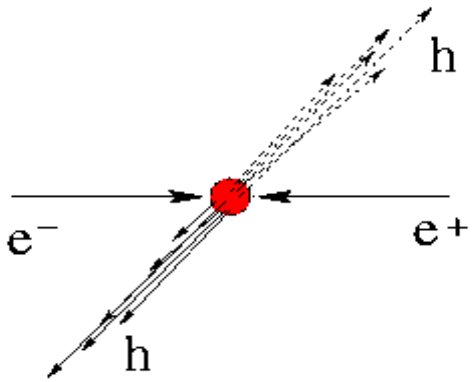
- ***Important to A+A, d+A, DIS and*** $e^+ e^-$ ***experiments.***
- ***To date observations in A+A d+Au and DIS***

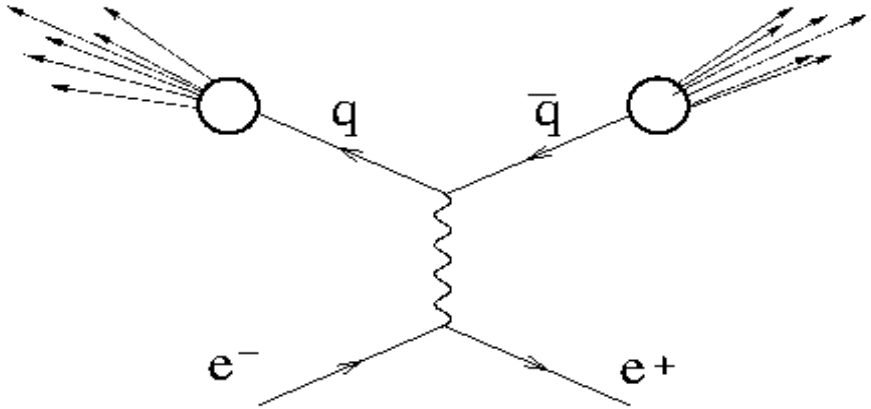
***Wish List!***

- ***Definition and factorization of dihadron fragmentation function***
- ***Calculate the effect of medium modification***
- ***Requires the evaluation of 23 twist-4 diagrams, very difficult!***
- ***But medium modification similar to vacuum evolution***
- ***Calculate and check vacuum evolution first (simpler!)...***

# *Defining the Dihadron fragmentation function!*

- *Fragmentation functions have to be universal*
- *We need a definition in terms of operators*
- *Start with simple system :* $e^+ e^-$ *, demonstrate factorization*
- *Derive evolution (vacuum splitting functions)*
- *Measure at* $\mu$ *and predict its evolution to scale Q*



# Dihadron fragmentation in $e^+e^-$ Collisions

***The basic process may be factorized as:***

$$\frac{d^2\sigma}{dz_1\,dz_2} = \sigma_0\left[D_q(z_1, z_2, \mu) + D_{\bar{q}}(z_1, z_2, \mu)\right]$$

$\sigma_0 = Hard\ Cross\ section$

$D_q(z_1, z_2, \mu) = Dihadron\ fragmentation\ function$

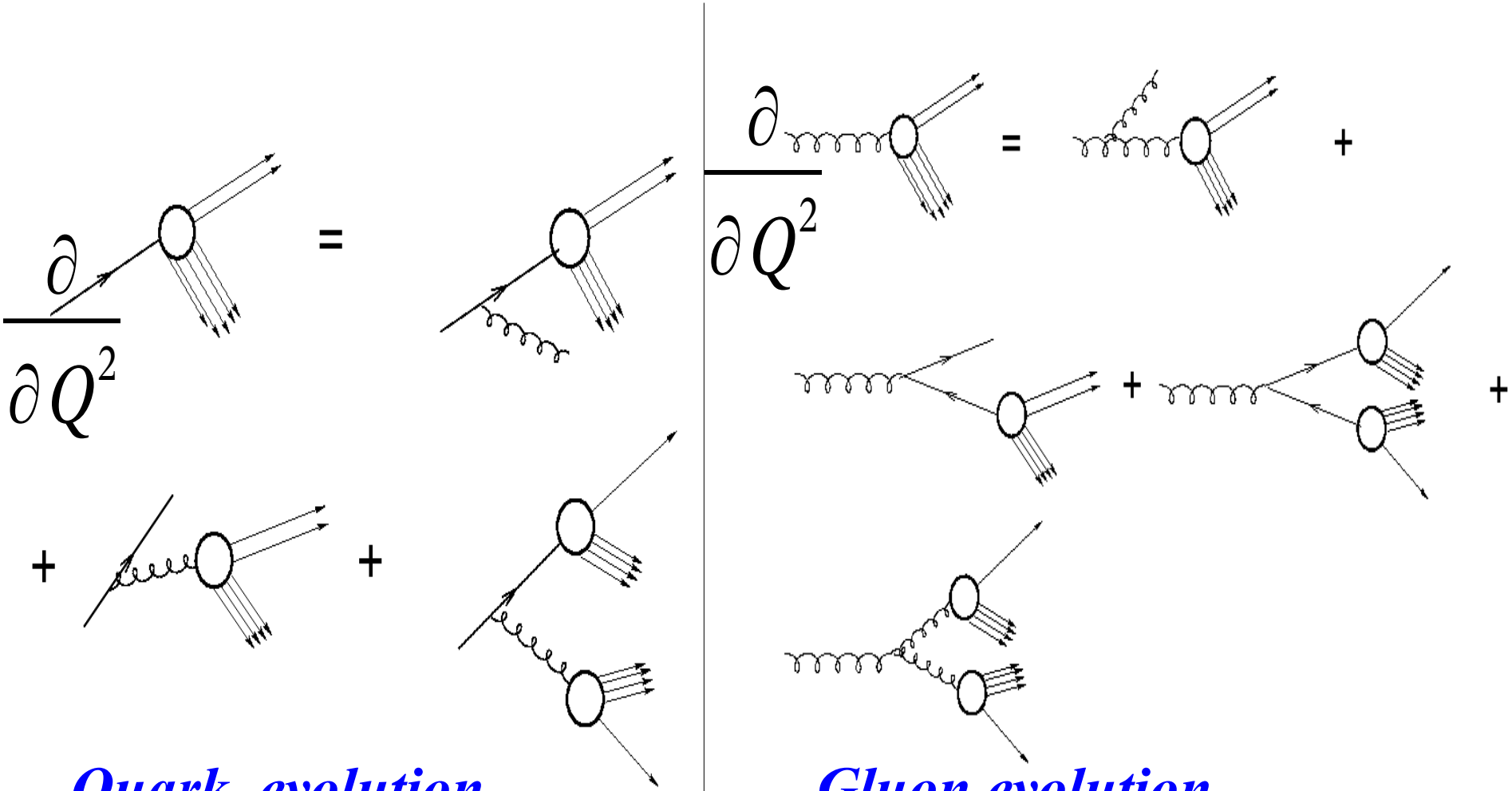
***Can be factorized from hard process if*** $\lambda^2_{QCD} \ll \mu^2 \ll Q^2$

***Measure the function at the scale μ, can be done in 2 ways***

$$Factorized\ Distribution: D(z_1, z_2, \mu) = D(z_1, \mu)\,D(z_2, \mu)$$

$$Event\ generator\ distribution: D(z_1, z_2, \mu) = \frac{1}{N_{events}}\frac{dN}{dz_1\,dz_2}$$

- *Evolving to a higher scale Q ☞ solving DGLAP equations*
- *Set of coupled differential equations containing the following processes:*




***Quark evolution*** ***Gluon evolution***

# *Evolution of Non-singlet quarks*

$$D_{NS} = D_q - D_{\bar{q}}$$

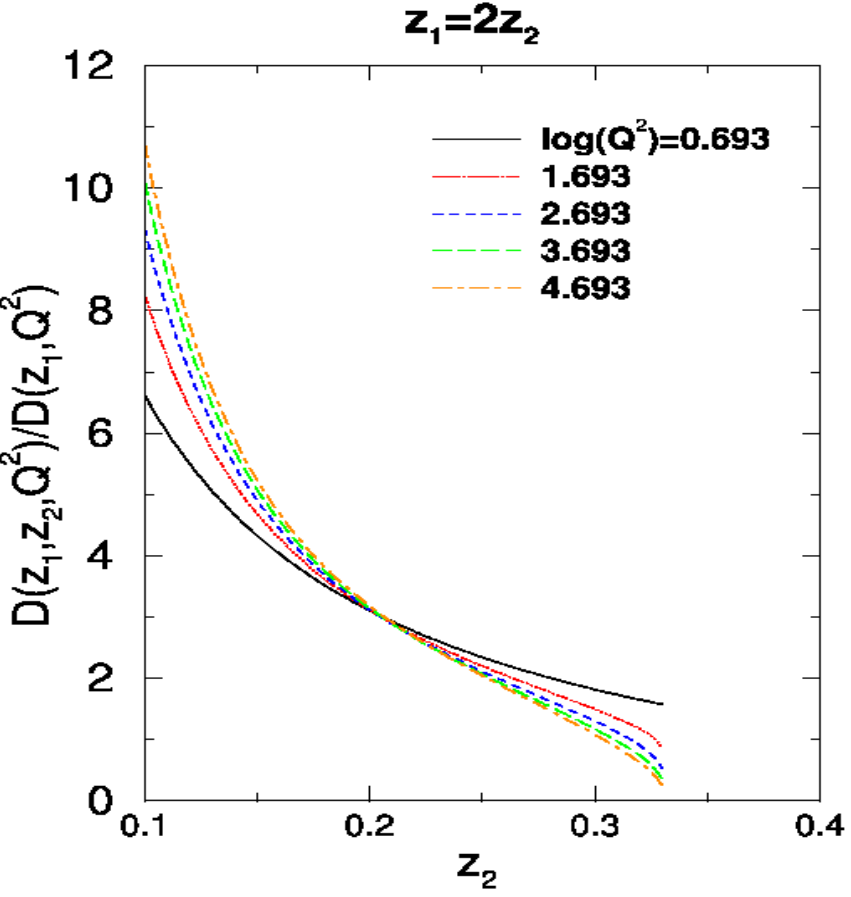
***Simpler: contribution from gluon fragmentation cancels out***

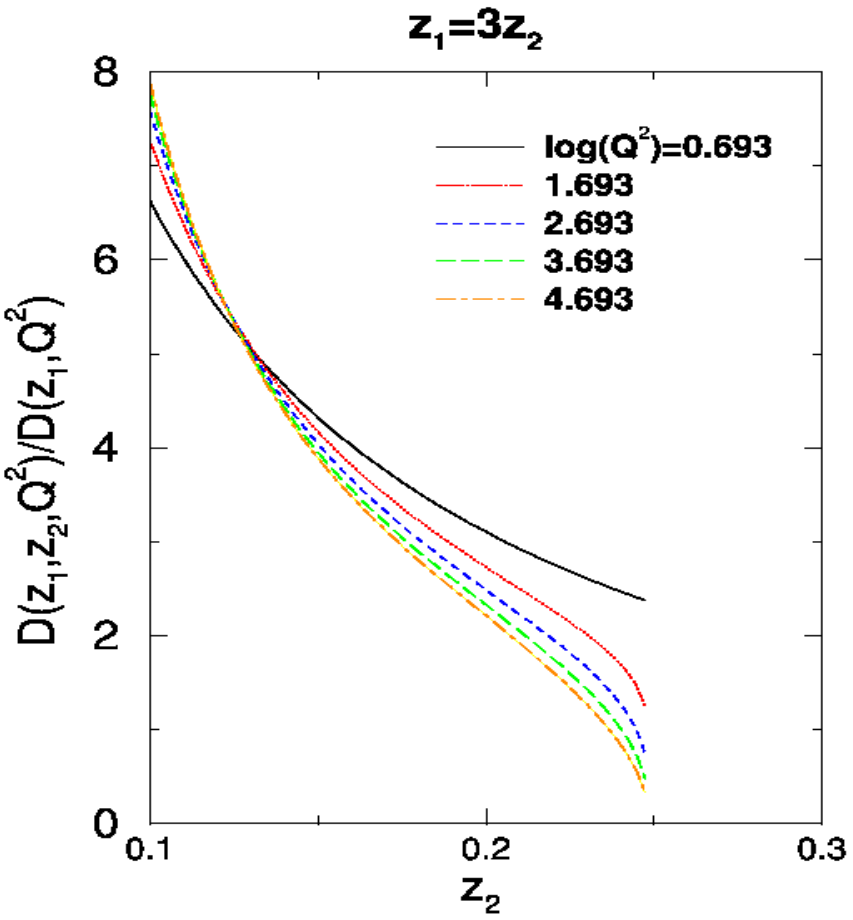
$$Single\ evolution: \frac{\partial D_{NS}(z, Q^2)}{\partial Q^2} = \int_z^1 \frac{dy}{y} P_{q\to qg}(y) D_{NS}(z/y, Q^2)$$

$$Double\ evolution: \frac{\partial D_{NS}(z_1, z_2, Q^2)}{\partial Q^2} = \int_{z_1, z_2}^1 \frac{dy}{y^2} P_{q\to qg}(y) D_{NS}(z_1/y, z_2/y, Q^2)$$

$$+ \int_{z_1}^{1-z_2} \frac{dy}{y(1-y)} \hat{P}_{q\to qg}(y) D_q(z_1/y, Q^2) D_g(z_2/(1-y), Q^2)$$

$$\hat{P} = P - virtual\ corrections$$




***Note: ratio double/single shows little change at intermediate z. Why ?***

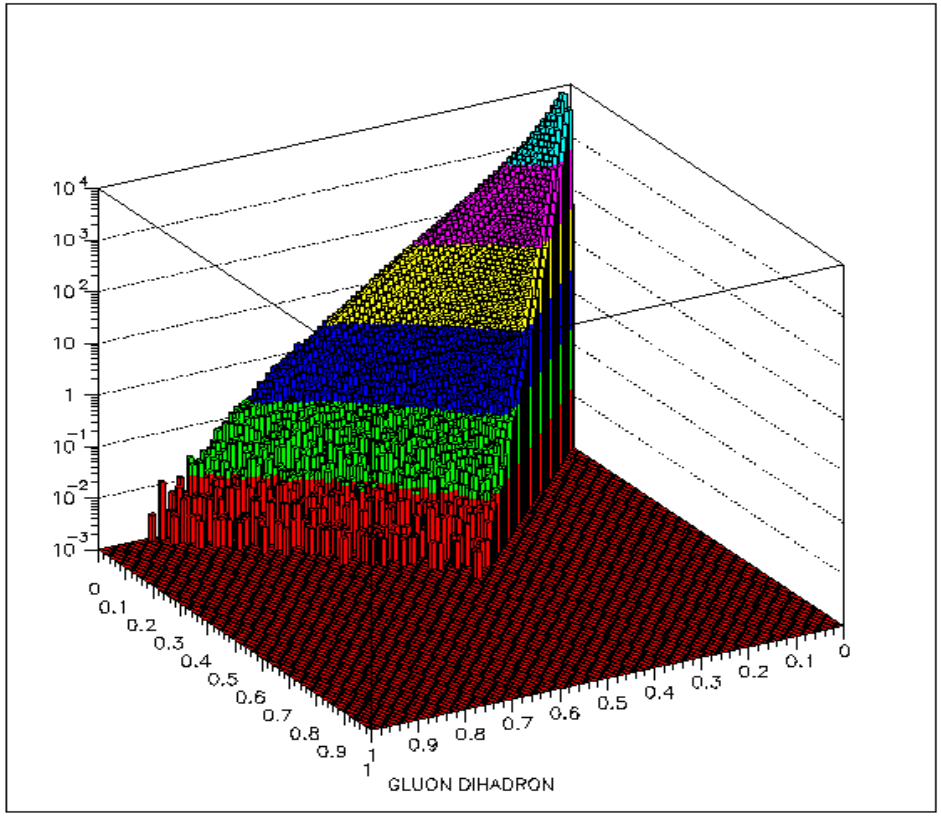
***Ratio is the number of associated particles for given trigger !***

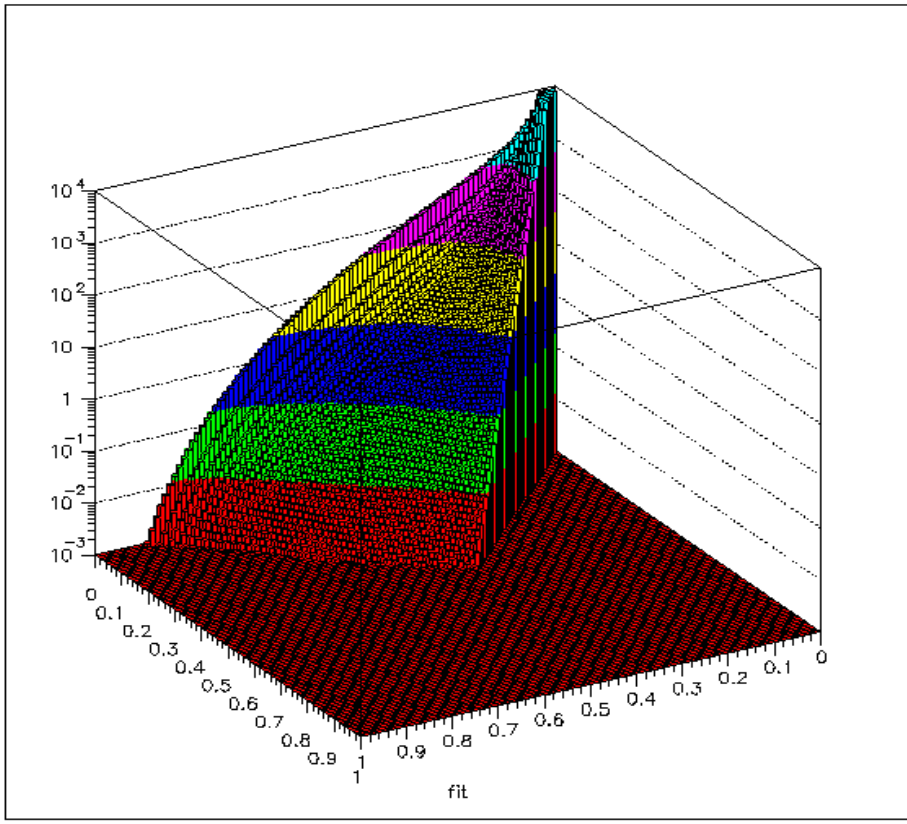
***Regular evolution softens the spectrum: as for single hadrons***

***Single gluon fragmentation increases multiplicity!***

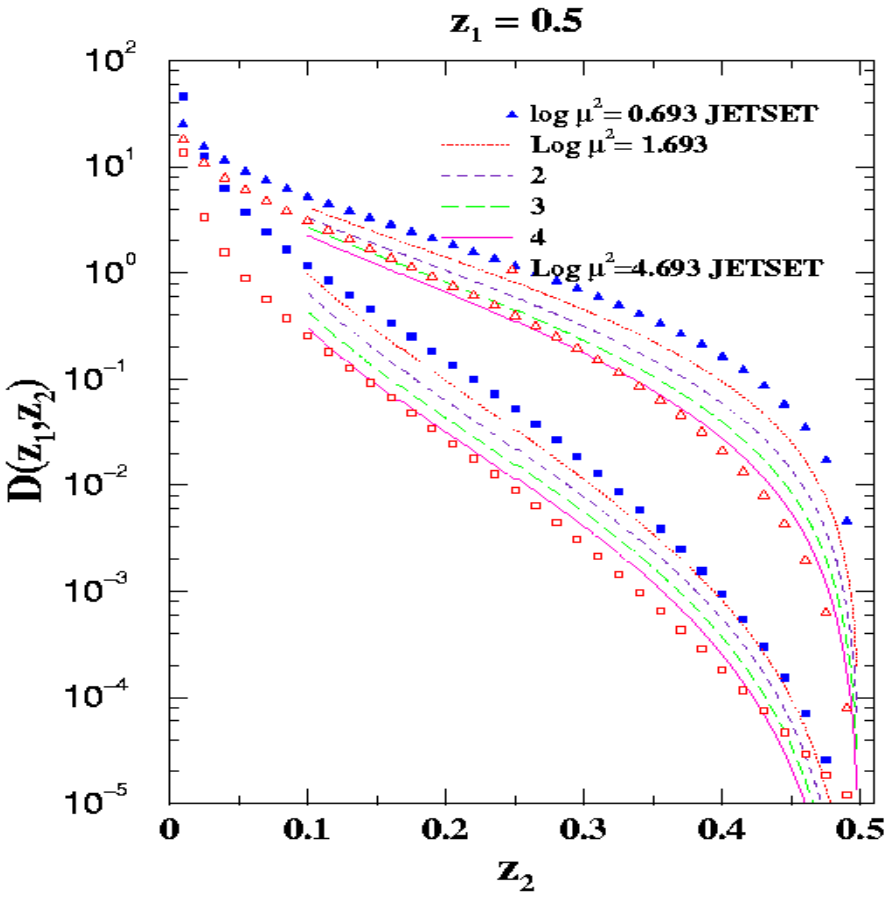
# *Results from Event generators:*

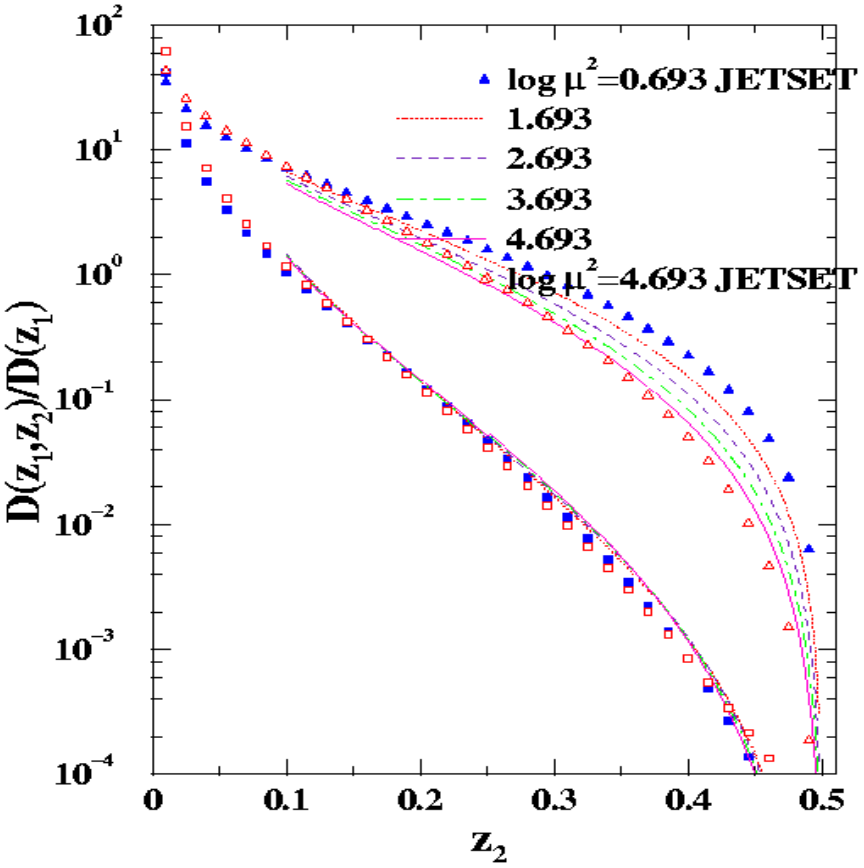
## *a bit ragged (Monte Carlo), fit a function to it !*




$$D(z_{1,}z_2)= N z_1^{\alpha_1} z_2^{\alpha_2} (z_1+z_2)^{\alpha_3} (1-z_1)^{\beta_1} (1-z_2)^{\beta_2} (1-z_1-z_2)^{\beta_3}$$




***Quark and Gluon evolution fits event generator data very well!***

***Thus we can understand evolution of FF from QCD.***

***Once again the double to single ratio shows little change***

# Medium modification

- *Apply to DIS of Nuclei (HERMES expt. at DESY)*
- *A parton in a nucleon is struck by EM probe*
- *Parton traverses cold medium and then fragments*
- *Fragmentation function is medium modified.*

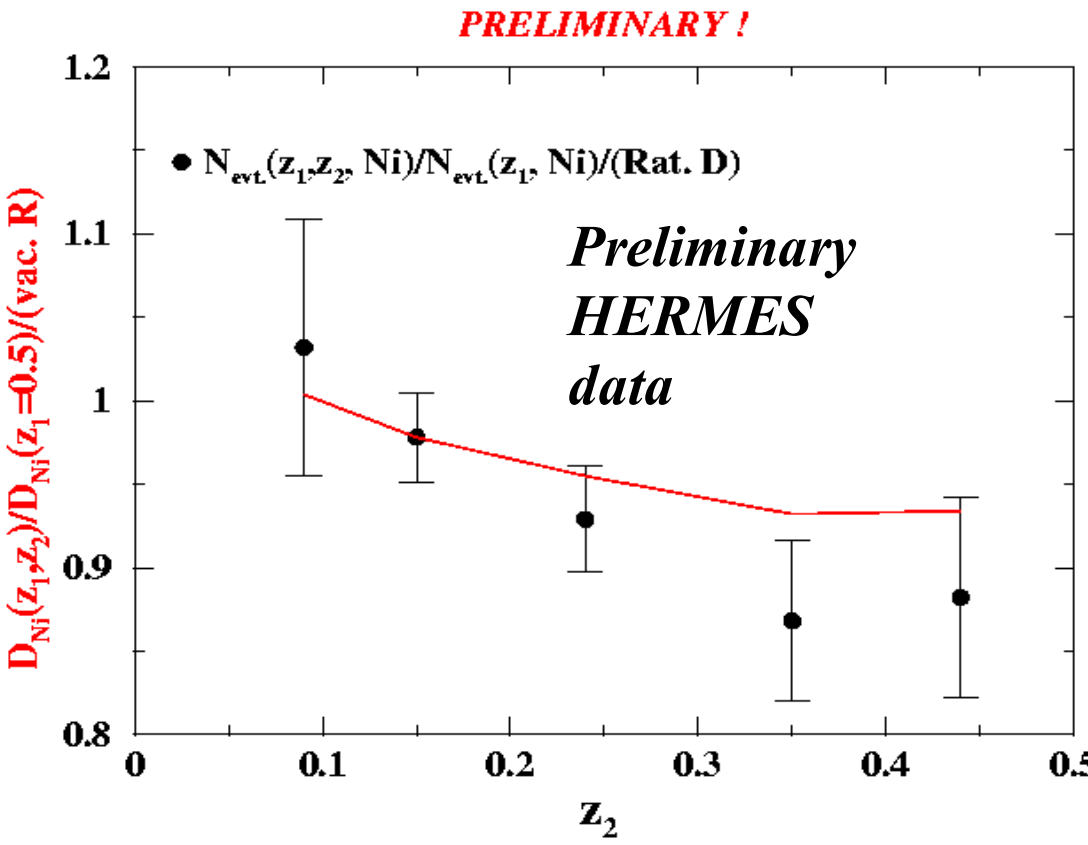
***The medium modification equation looks very similar to the vacuum evolution equation...***

$$\tilde{D}_q(z_1, z_2, \mu^2) = D_q(z_1, z_2, \mu^2) + \int dl_T \int_{z_1+z_2}^{1} \frac{dy}{y^2} \tilde{P}_{q\to qg}(y) D(z_1/y, z_2/y, \mu^2)$$

$$+ \int dl_T \int_{z_1}^{1-z_2} \frac{dy}{y(1-y)} \hat{\tilde{P}}_{q\to qg}(y) D(z_1/y, \mu^2) D(z_2/(1-y), \mu^2)$$

$$\tilde{D} = \text{medium modified fragmentation function}$$

$$\tilde{P} = \text{medium modified splitting function}$$




***The theory curve is the number of pairs with one hadron at $z_1 = 0.5$ and one at $z_2$.***

***The expt. curve is the number of events with a subleading hadron at $z_2$, and $z_1 > 0.5$.***

***Gaussian approx. for nuclear density used!***

***Theory curve: (FF(2h)/FF(1h) in A) / (FF(2h)/FF(1h) in vac.)***

$$\textbf{Expt ratio} = \frac{\dfrac{\text{No. of events with at least 2 hadrons with } z_1 > 0.5}{\text{No. of events with at least one hadron with } z > 0.5}}{\text{same ratio on deuterium}}$$

# *Summary & Conclusions!*

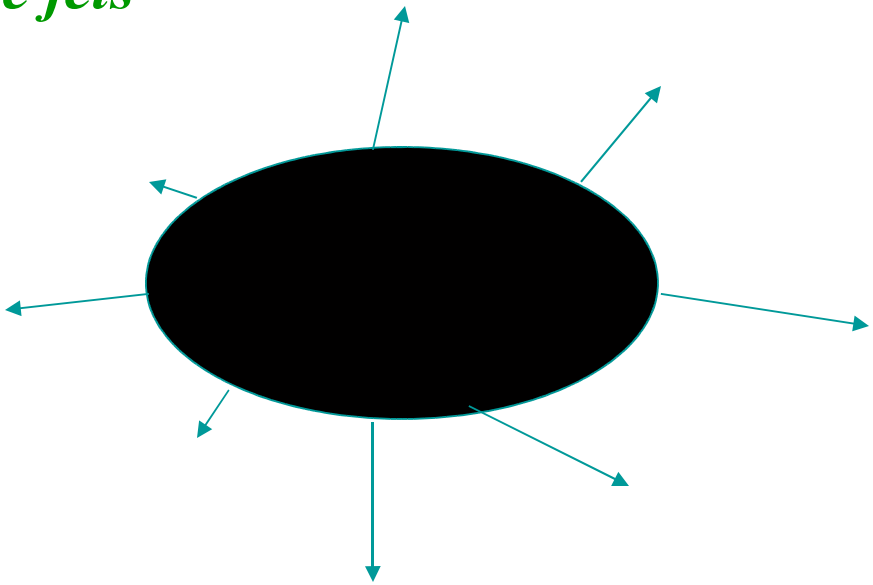
- ***We have defined a new phenomenological object in QCD:***

  ***`` The Dihadron Fragmentation function ''***

- ***Demonstrated its factorization at LO in*** $e^+ e^-$
- ***Derived it evolution equation (has extra components)***
- ***Matched results with JETSET!!***
- ***Allowed a physical understanding of change with scale***
- ***Extended formalism to medium modification in DIS***
- ***Calculation in progress, preliminary results encouraging!***

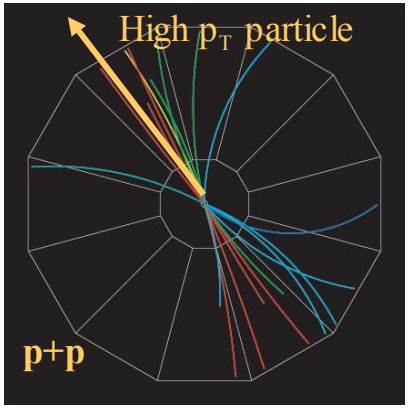
# *SURFACE EMISSION PICTURE*

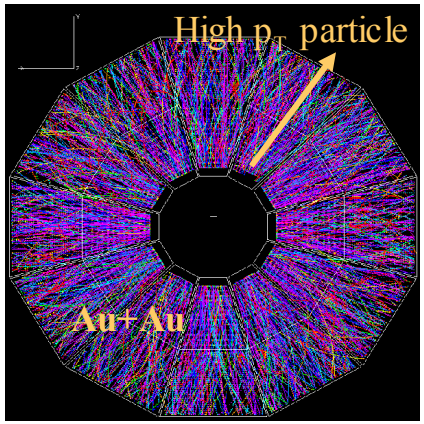
- *Suppose the matter produced is very opaque*
- *Hence only hard collisions on the surface will produce observable jets*

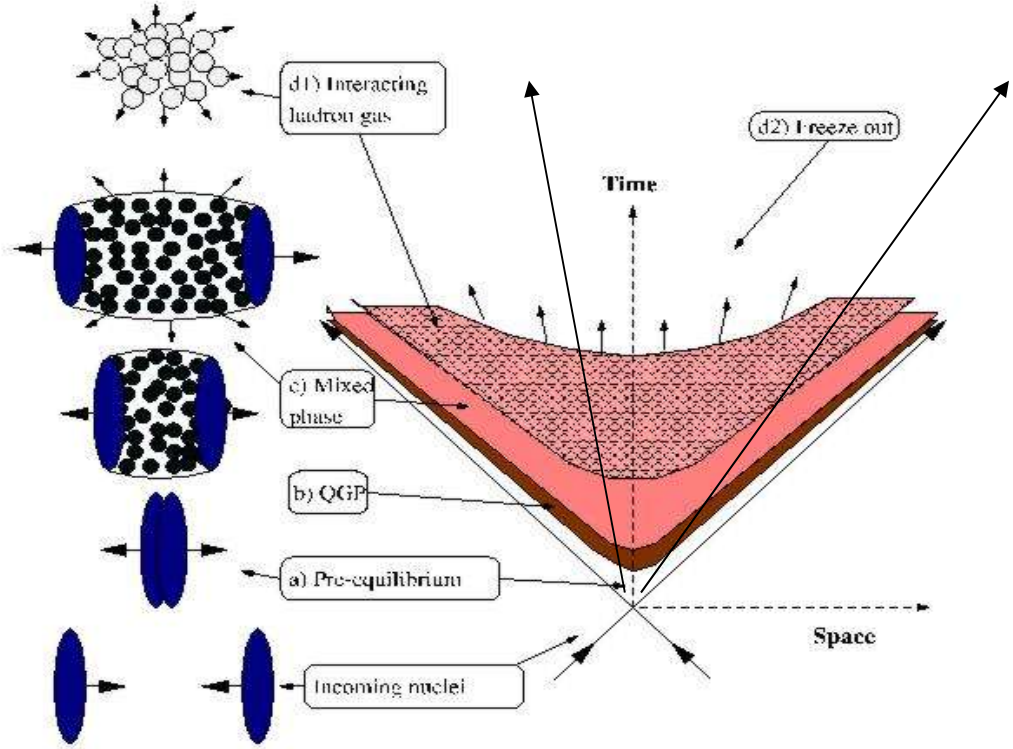


- *Inconsistent with an $R_{AA}$ between participant and binary scaling*
- *Inconsistent with all energy loss models which require bulk emission and fit single inclusive data!*

# *HEAVY-ION COLLISIONS AND JETS*




- ***Select a leading particle $4<p_t<6$ GeV/c, $|\eta|<0.75$***
- ***Associate all other particles ($0.15<p_t<4$ GeV/c, $|\eta|<1.1$) with the leading particle.***