Discussion on the Future of Heavy Ion Physics

Moderator/Provocateur: Miklos Gyulassy

My talk invitation email from one of the organizers:

“BTW, having a talk about future of Heavy Ion Physics may not be a bad idea

.

Many founders of this field, including you, Larry, Edward, Laszlo, Jean-Paul turned 60, recently.

[Al Mueller and Stan Brodsky just turned 70.
TD is over 80. Nick is still in his prime,
but the others...]

So one may even ask if this field has a future.”

The Near 5 Year A+A Theoretical Future just got a *huge boost* : December 14, 2009

Announcement on the Selection of Topical Collaborations in Nuclear Theory

******* Thanks to hard work both CATHIE/Dima et al and TECHQM/XinNian et al to build the compelling physics case *******

The Office of Nuclear Physics (NP), on the basis of a peer review, has selected the following topical collaborations for funding:

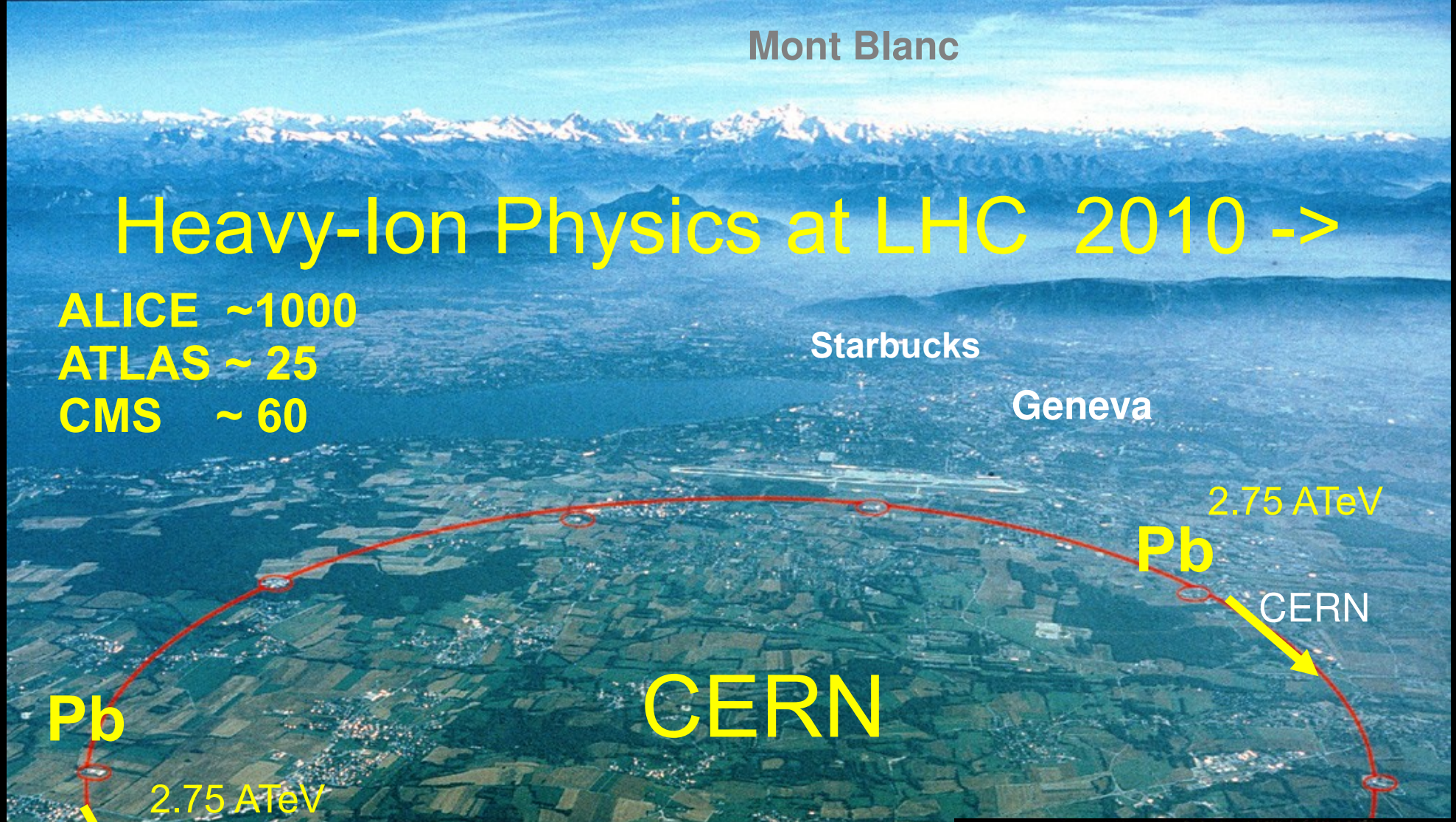
- Jet and Electromagnetic Tomography (JET) in Heavy-Ion Collisions
  Lead Institution: Lawrence Berkeley National Laboratory
  Principal Investigator/Project Director: X-N. Wang
  Participating Institutions: Columbia University, Duke University, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, McGill University, Ohio State University, Purdue University, Texas A & M University

- Advancing the Theory of Nuclear Reactions with Rare Isotopes: From the Laboratory to the Cosmos
  Lead Institution: Lawrence Livermore National Laboratory
  Principal Investigator/Project Director: I. Thompson
  Participating Institutions: Michigan State University, Oak Ridge National Laboratory, Ohio University, Texas A & M University

- Neutrinos and Nucleosynthesis in Hot and Dense Matter
  Lead Institution: Los Alamos National Laboratory
  Principal Investigator/Project Director: S. Reddy

Heavy-Ion Physics at LHC 2010 ->

ALICE ~1000
ATLAS ~ 25
CMS ~ 60



The Experimental Future has already begun

So much for the good news.

Now Back to the Present!

Both theory and experiment

face formidable challenges

worthy of the new physics at stake

TECHQM/CATHIE Workshop
Dec 14-18

Systematic Cleaning up of the
Theoretical and Experimental
"Dirty" Laundry

on the road toward more
<u>quantitative physics</u>
from the first decade of
RHIC data

Is this the near future of A+A?

Have all the big discoveries been made?

Will we just toil in the trenches?

Immediate urgent challenges

1) Control fluctuations distortions

2) Build better Fluid to Hadron Gas hybrid bridges

3) Improve CGC phenomenology and prefluid GLASMA interface

4) Converge *at least* on perturbative QCD and AdS holographic Jet Quenching theory

5) Need more quantitative falsifiable predictions to discriminate pQCD from AdS holography models

Fluctuations are our current most troublesome albatross

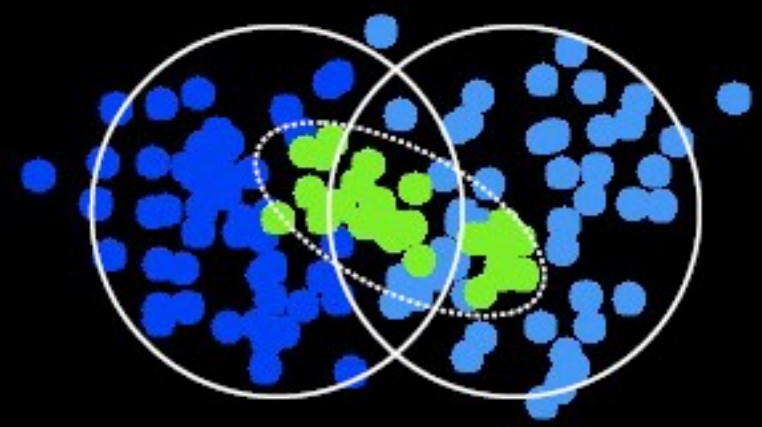
Real world
A+A pest

Need a
theory
that can
eliminate
this pest

P.Steinberg

Cu+Cu

Principal axes make sense if v_2 depends on shape of produced matter (in SLP), not the reaction plane



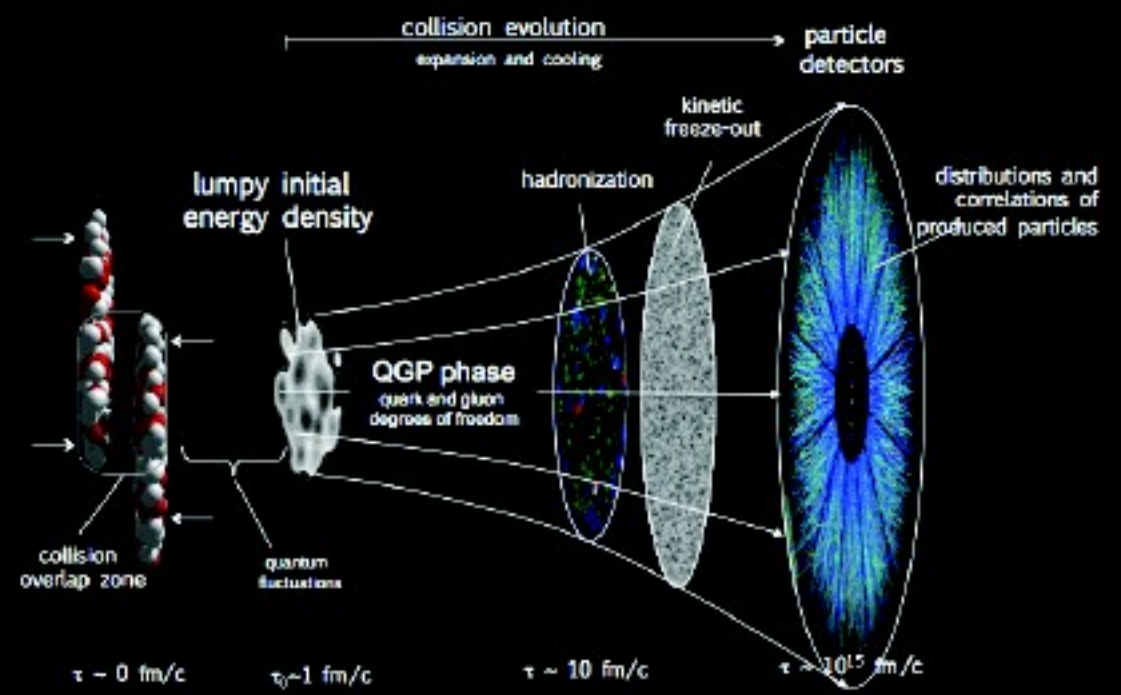
$$\epsilon_{part} = \frac{\sigma_y'^2 - \sigma_x'^2}{\sigma_y'^2 + \sigma_x'^2} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4(\sigma_{xy}^2)^2}}{\sigma_y^2 + \sigma_x^2}$$

"Participant eccentricity"

Non-flow and Fluctuations: A Systematic Error or a Killer Measurement?

Paul Sorensen

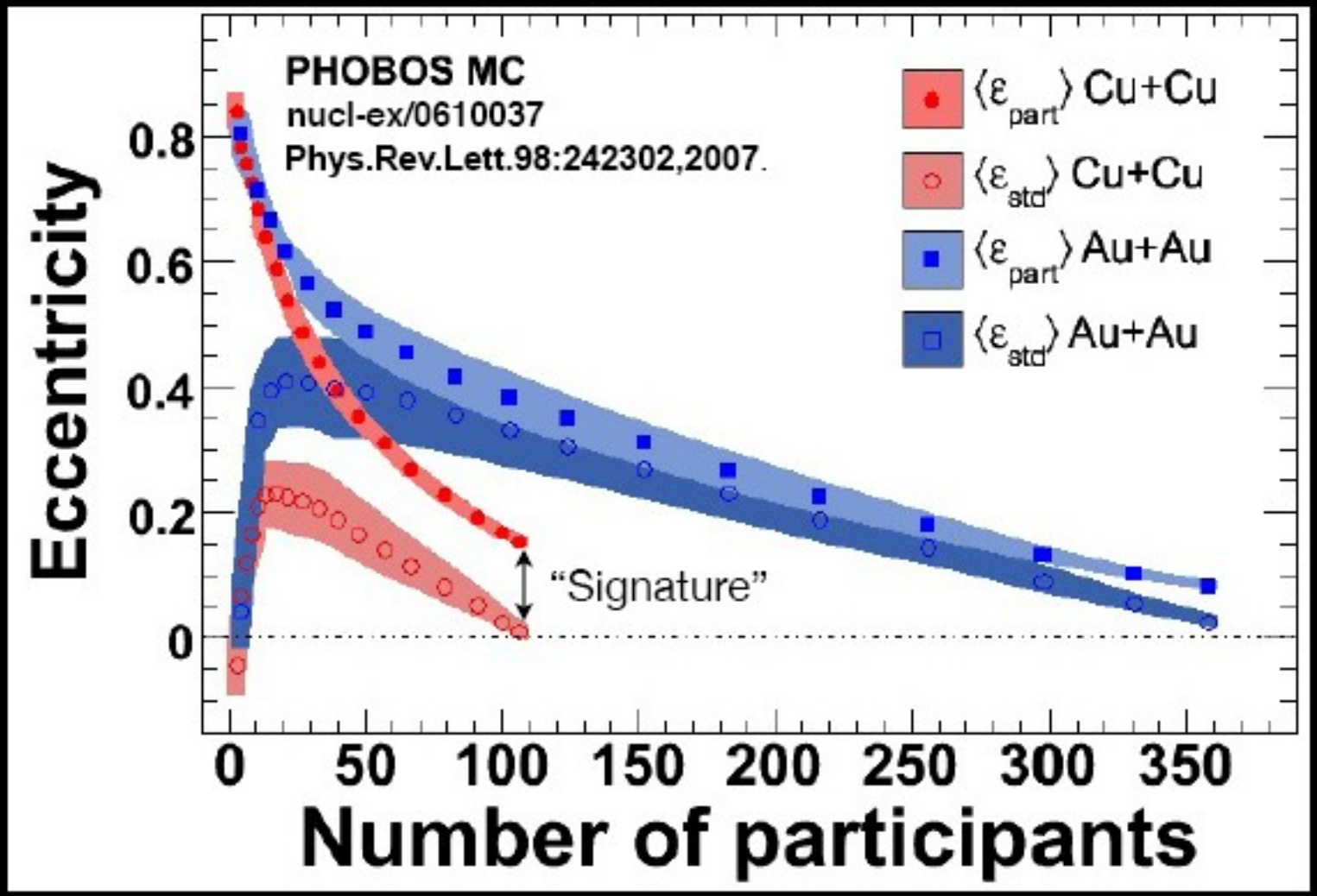
BROOKHAVEN NATIONAL LABORATORY



Elliptic Flow: A Study of Space-Momentum Correlations In Relativistic Nuclear Collisions.
P. Sorensen, Quark Gluon Plasma, Vol. 4, World Scientific, arXiv:0905.0174 [nucl-ex]

P.Steinberg

Participant vs. Standard



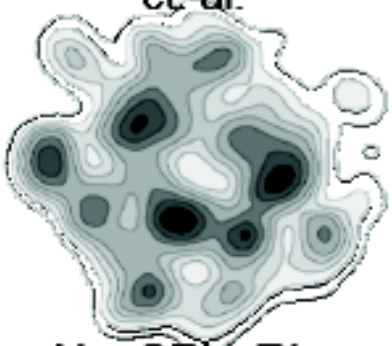
If you see ε~0 in central collisions, then you are using the wrong eccentricity, or not including fluctuations

P. Sorensen

Geometry Fluctuations

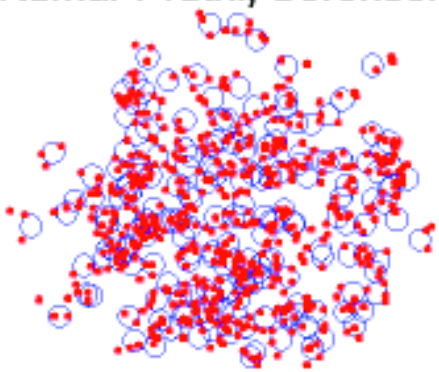
If we have space-momentum correlations, then there should be a lot more to the story than just $\langle v_2 \rangle$

Hama, Grasi, Kodama, et. al.



NexSPheRio

Kumar Pruthi, Sorensen



Additive Quark Model

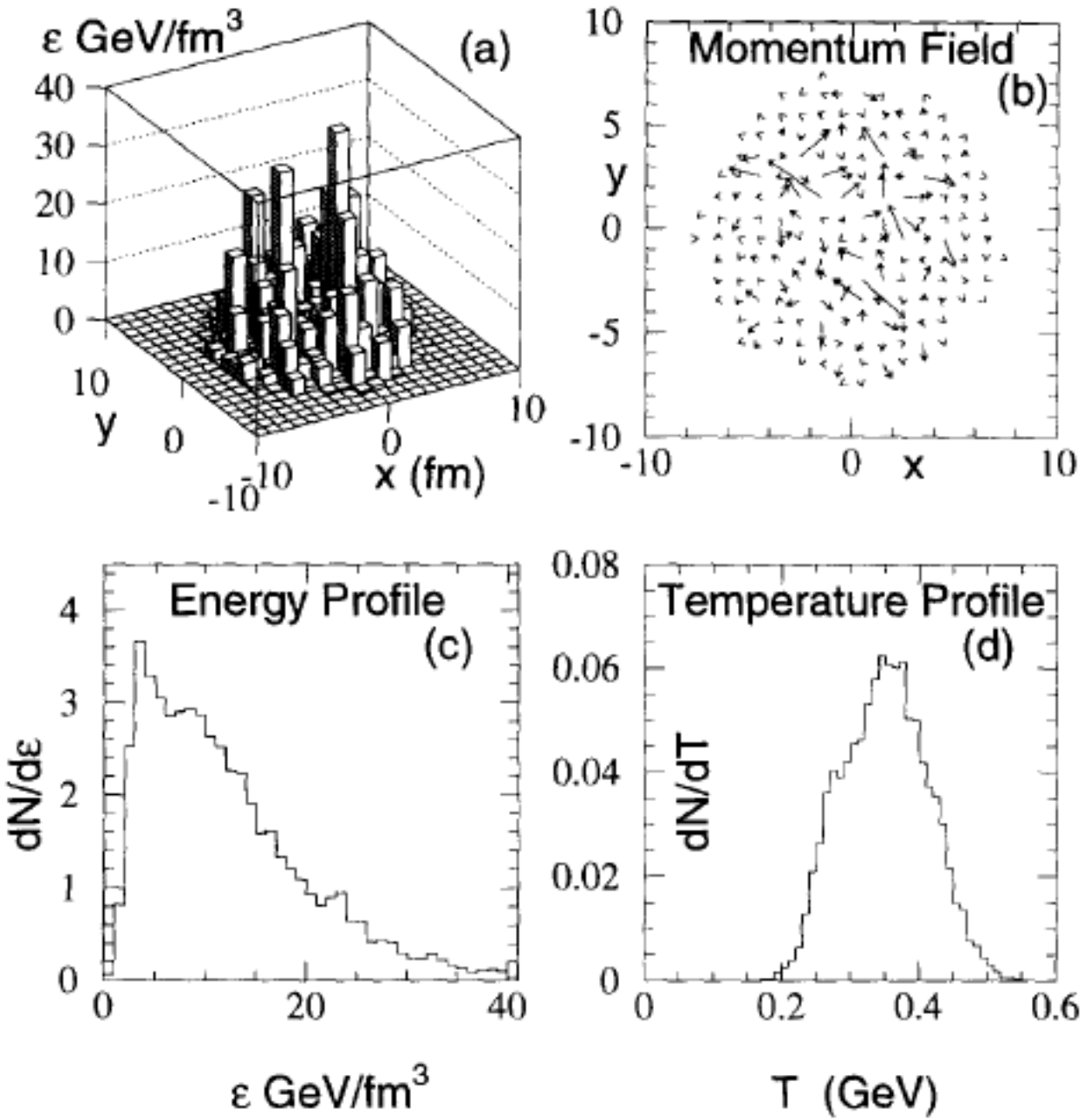
Dumitru, Gelis, McLerran, Venugopalan, Lappi

IPsat GCG, Glasma

H. Kowalski, T. Lappi and R. Venugopalan, Phys. Rev. Lett. 100, 022303 [arXiv:0705.3047 [hep-ph]].

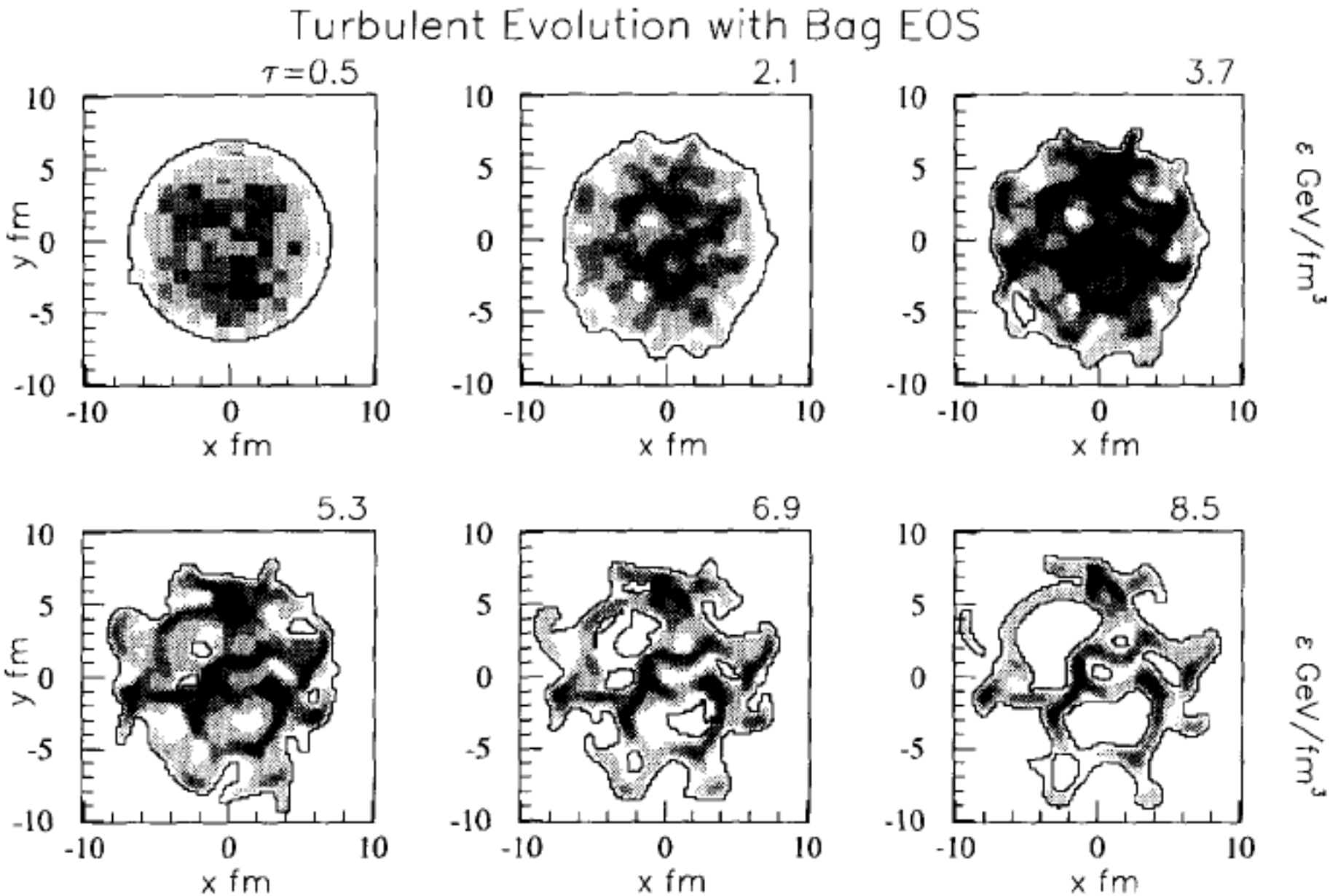
Can we get away with ignoring the rest? At what cost?
Can we take advantage of the initial geometry fluctuations?

Hot Spots and Turbulent Minijet Initial Conditions t=0.5 fm/c

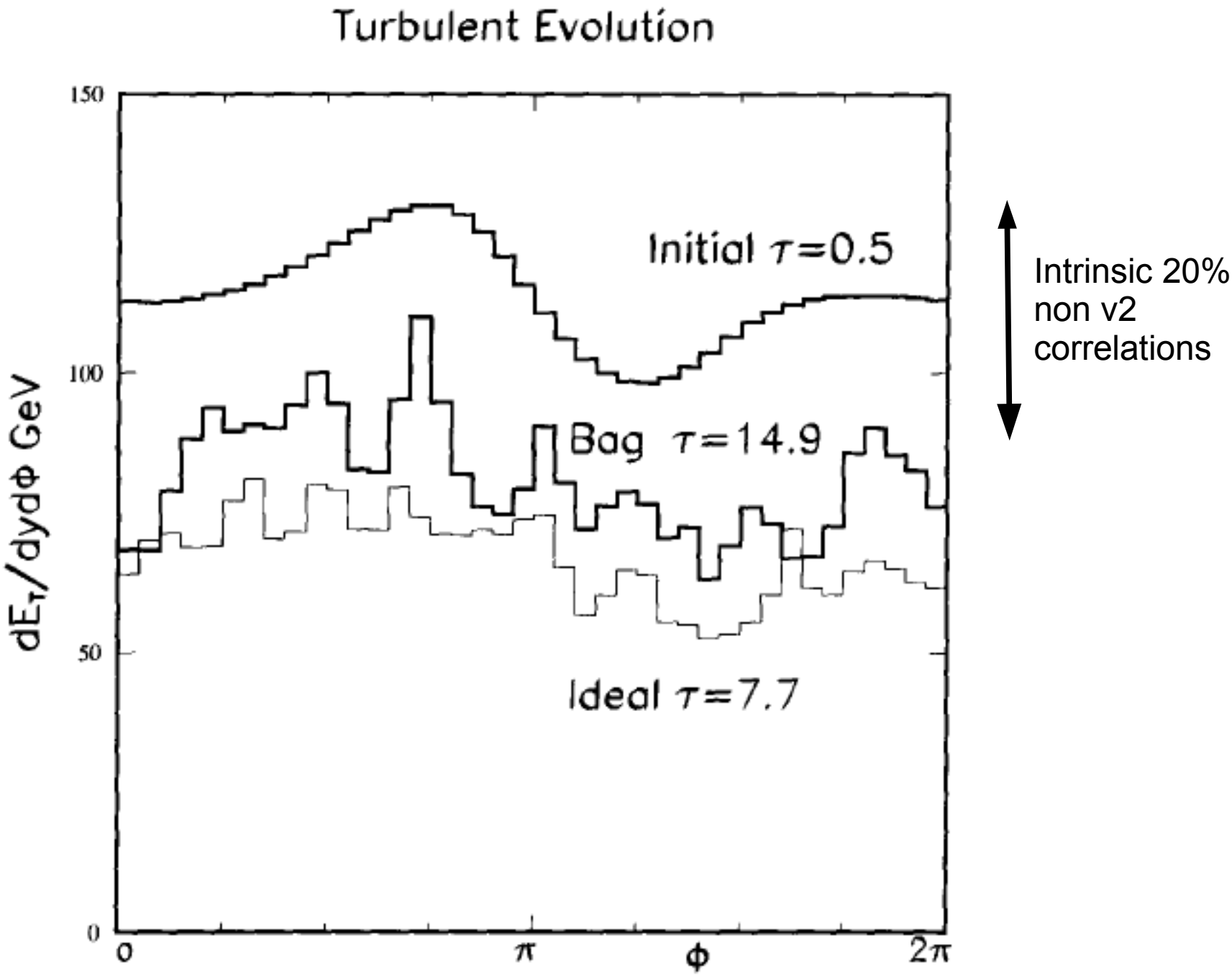


Hydrodynamic evolution of Albatross dropping w/turbulent initial conditions

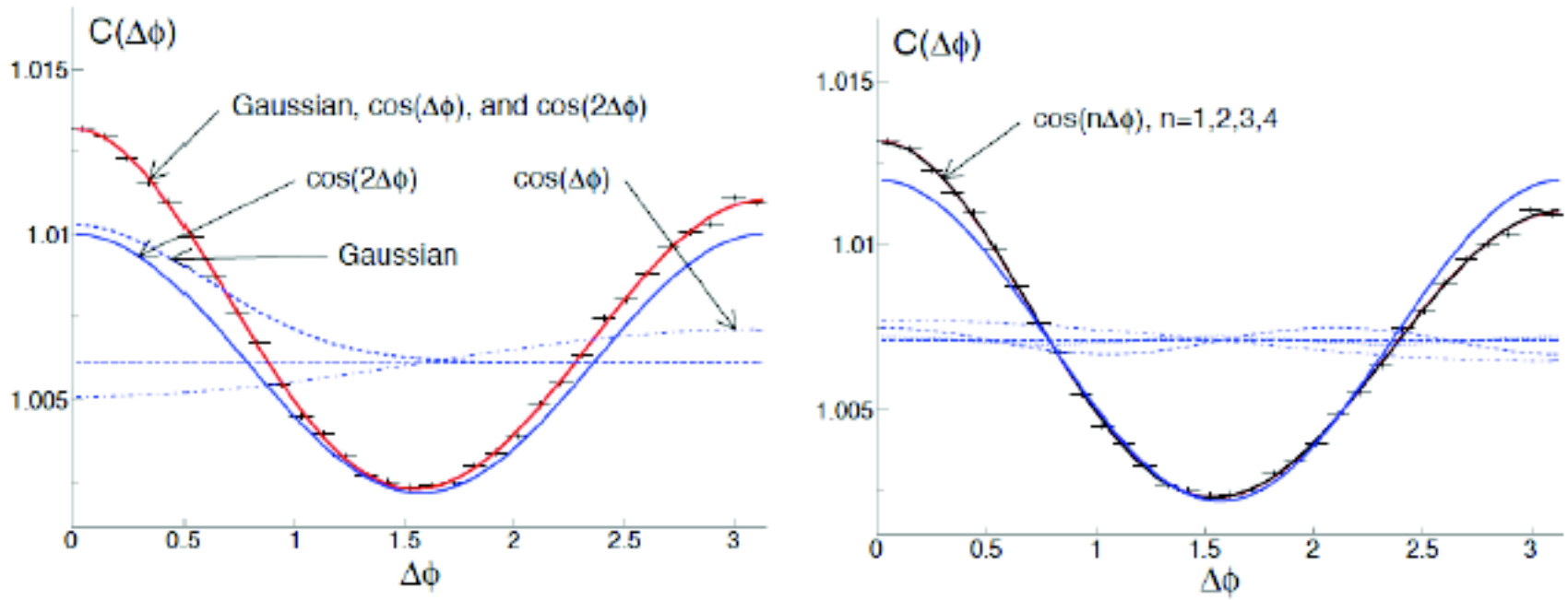
420 M. Gyulassy et al./Nuclear Physics A 613 (1997) 397–434



M. Gyulassy et al./Nuclear Physics A 613 (1997) 397–434



Implies non-trivial 2-particle correlations



We can fit with ZYAM + jet ***or*** just cos(n) terms

Allowing odd n terms in ZYAM will make it possible to fit the whole signal -> no jets or cones required

Control of initial state fluctuations will be critical for quantitative physics conclusions on bulk properties of sQGP from AA data

1) How do eccentricity fluc from the CGC->GLASMA -> Perfect Fluid distort the final v2 -> eta/s mapping?

2) Do conical correlations still exist? (or are Mach cones and ZYAM dead due to odd moment fluctuations?)

3) Is Photon radiance thermometer (Ed's dream) broken by huge local temperature fluctuations?

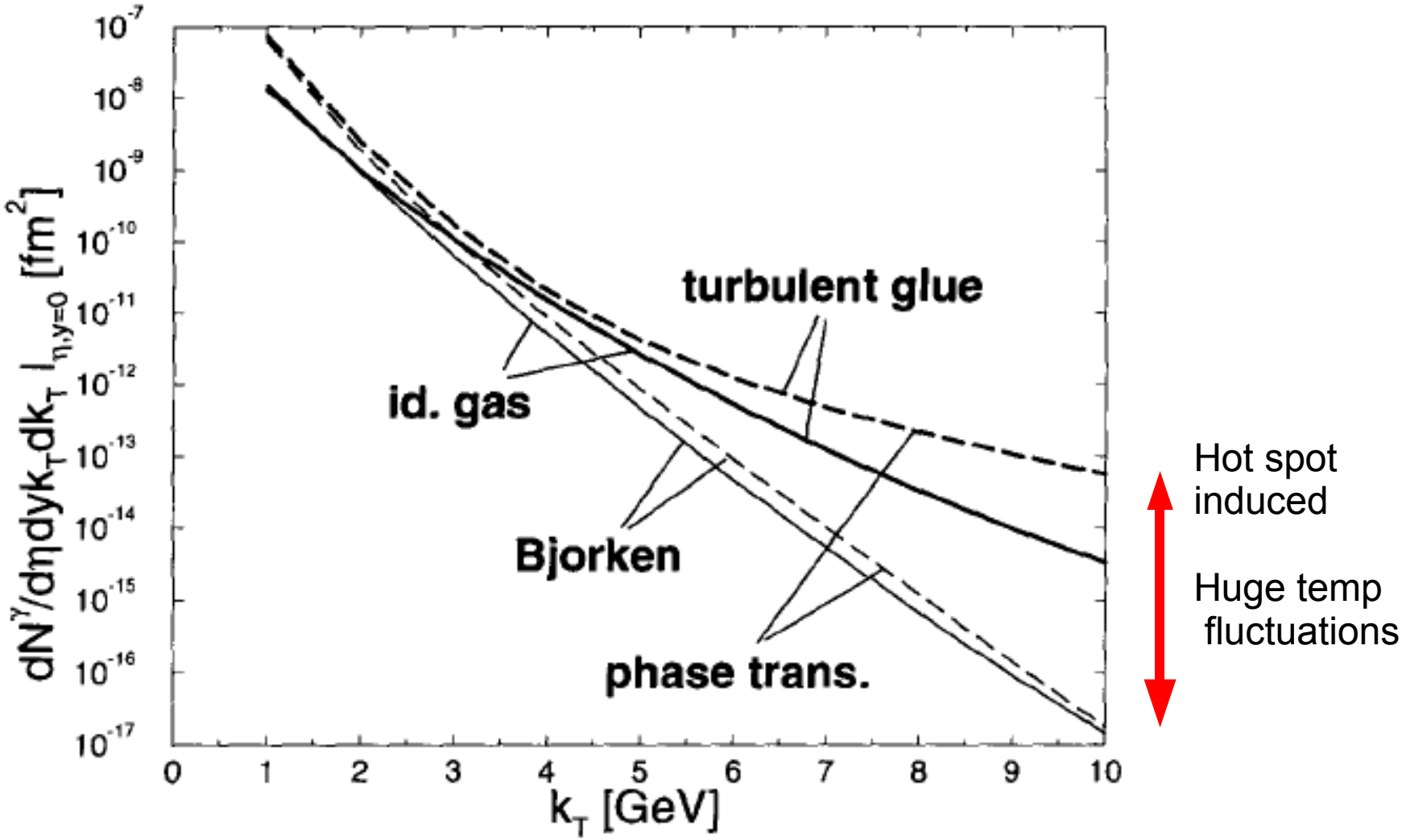


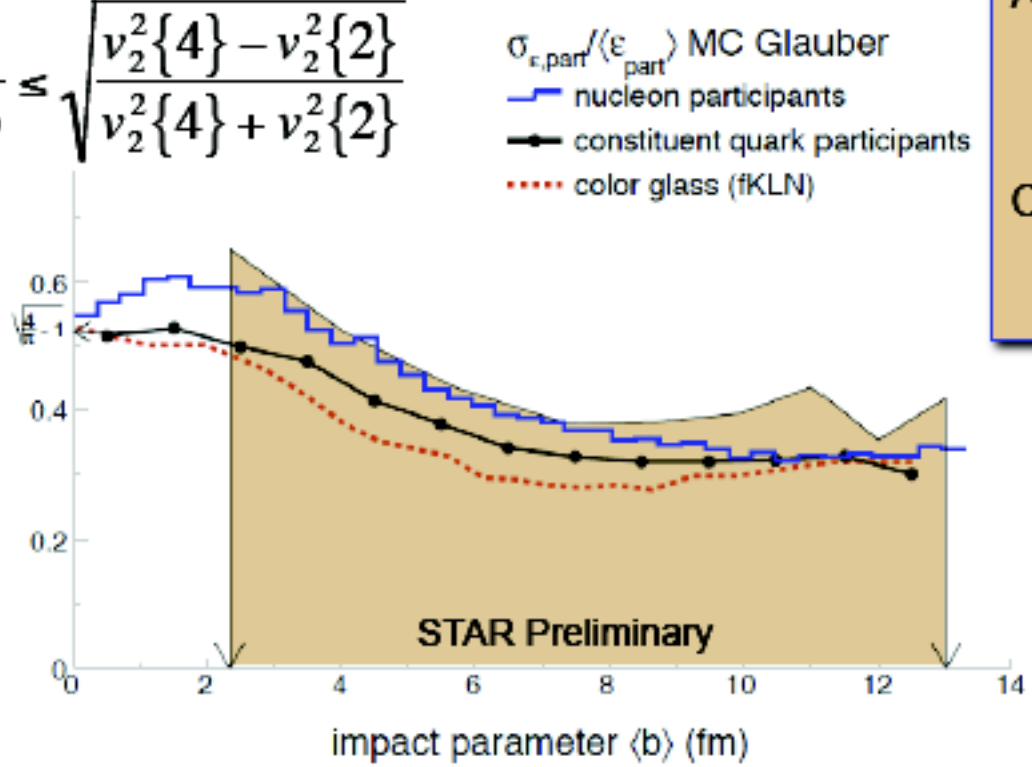
Fig. 20. Photon transverse momentum spectra at $y = \eta = 0$. Thick lines are the average spectra calculated from the hydrodynamical evolution of 10 (turbulent) HIJING events, thin lines are for the evolution of a homogeneous Bjorken cylinder of radius $R = 4$ fm with the same initial energy content. Dashed lines are obtained assuming the equation of state with phase transition, full lines are for the ideal gas equation of state.

5. Enhanced radiance of hot spots

Comparison to Models

Upper limit challenges models: MC Glauber already exhausts entire width with participant fluctuations

$$\frac{\sigma_{v_2}}{\langle v_2 \rangle} \leq \sqrt{\frac{v_2^2\{4\} - v_2^2\{2\}}{v_2^2\{4\} + v_2^2\{2\}}}$$



Additive Quark MC:
- treats confined constituent quarks as the participants
- decreases eccen. fluctuations

Color Glass MC:
- includes effects of saturation
- increases the mean eccentricity

comparison to hydro (NexSPheRio): *Hama et.al. arXiv:0711.4544*

eccentricity fluctuations from CGC: *Drescher, Nara. Phys.Rev.C76:041903,2007*

extraction of Knudsen number: *Vogel, Torrieri, Bleicher. nucl-th/0703031*

fluctuating initial conditions: *Broniowski, Bozek, Rybczynski. Phys.Rev.C76:054905,2007*

first disagreement with $\varepsilon_{standard}$ and use of quark MC: *Miller, Snellings. nucl-ex/0312008*

Does this disprove CGC MC models?

In near future there is a great deal of detailed work needed to gain quantitative control over fluctuations to access bulk sQGP

TECHQM / CATHIE must provide the disciplined focus needed to get the job done

PART II: Hard Probes have become Harder at this workshop

What steps are needed?

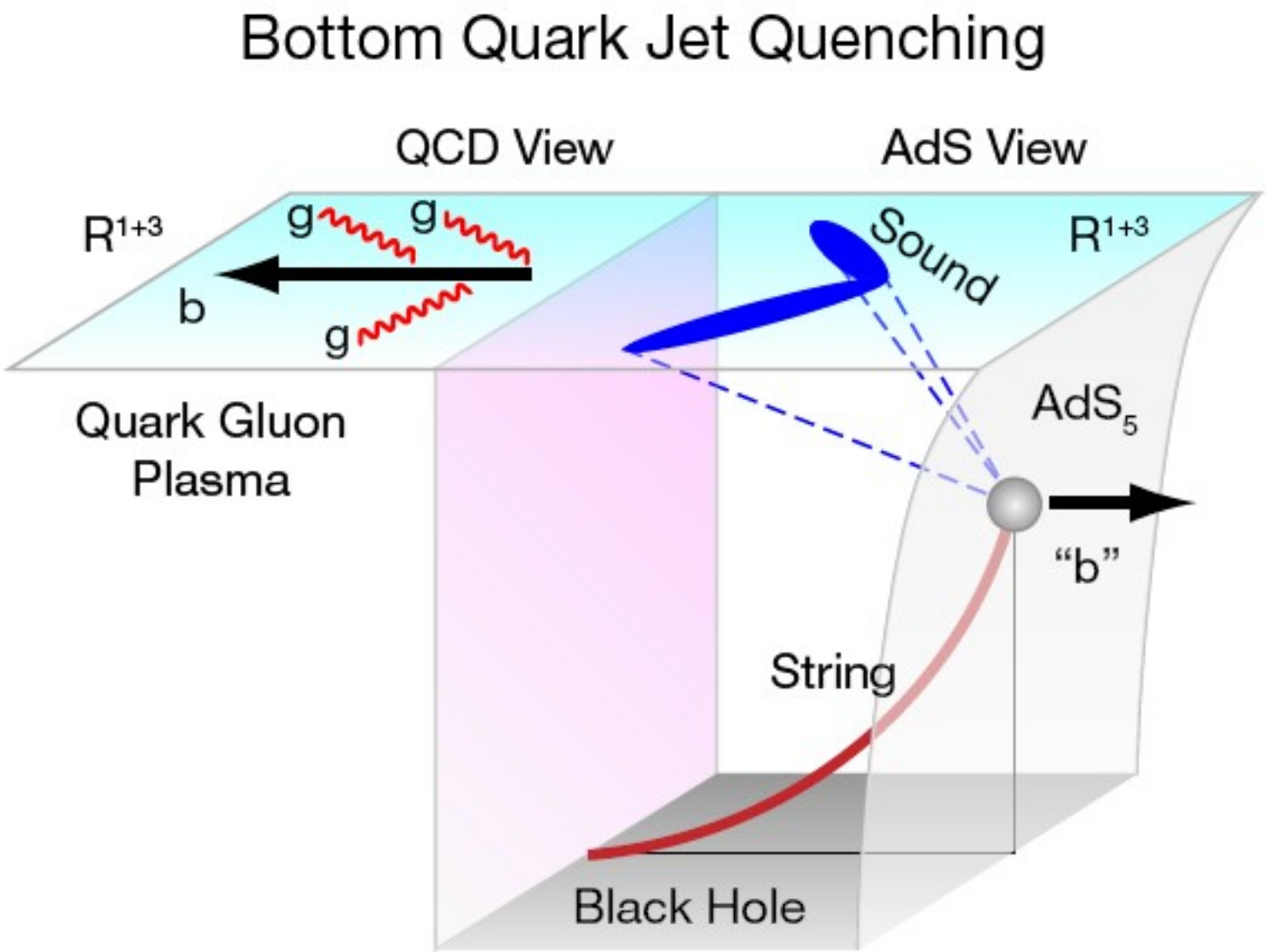
1) Hybrid hard + Eikonal to control large angles

2) Monte-Carlo finite opacity matrix elements

3) Simplifying N=1 or N=infinite opacity models must give way to N~ 10 numerical calculations

4) We must insist on consistency with both light and heavy quark quenching simultaneously or/and be ready to abandon pQCD approach.

To me, the Bottom Quark Quenching Puzzle is the most pressing open problem in the field

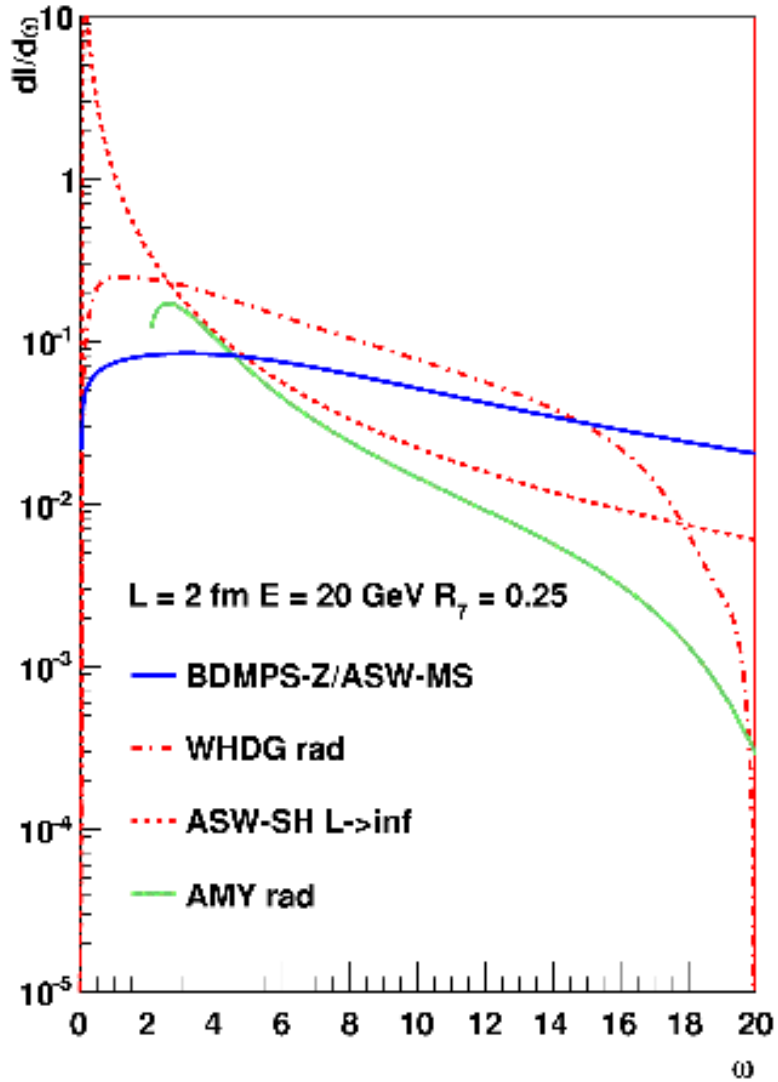


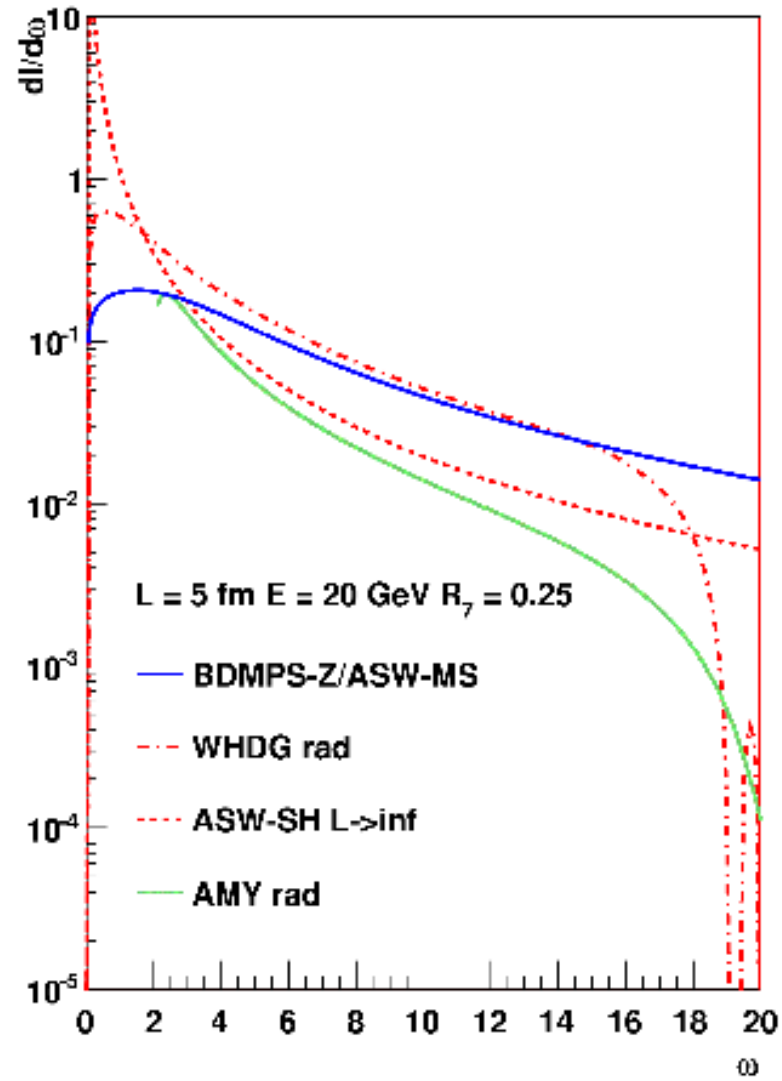
In near term the light quark/glue jet dE/dx
also needs to be cleaned up to converge on and
realize the tomographic power of jet quenching

Energy Loss in the Hot QCD Brick I

W. A. Horowitz
The Ohio State University
December 16, 2009

(Single) Gluon Spectra



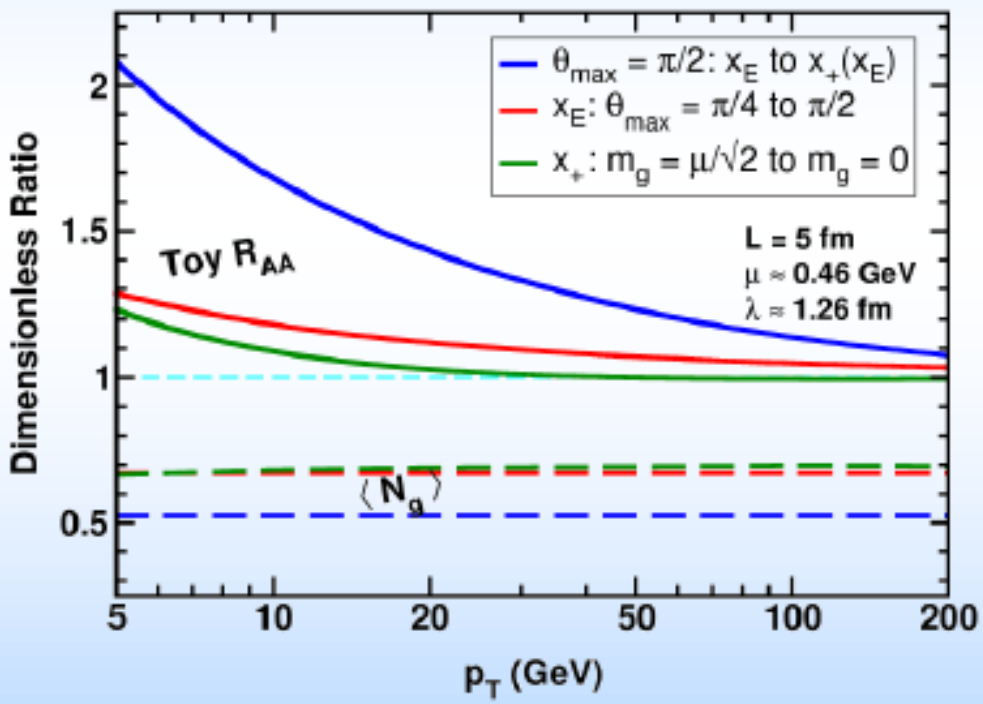


Gluon spectrum BDMPS-Z/ASW-MS for small L limit.

Theory Dirty Laundry that will soon be cleaned up ! {MG}

Parton Energy Dependence

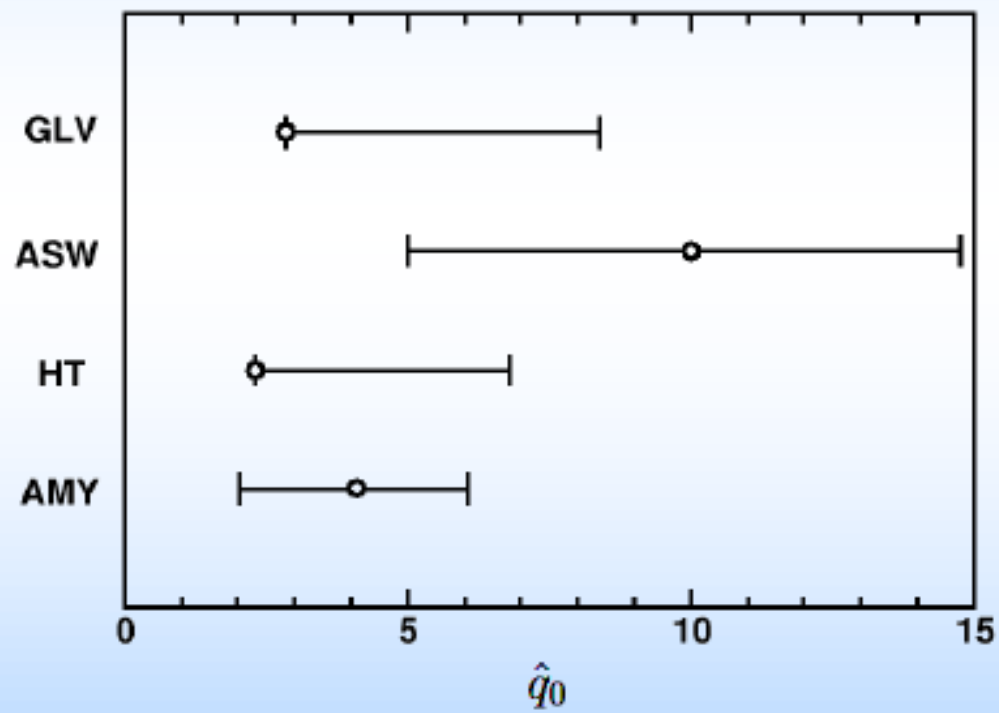
- Dependence on parton energy



WAH and B Cole, arXiv:0910.1823

- Uncertainty on qhat

IS HUGE



– Assume all formalisms equally affected

Conclusions

- Use different physics, expect different parameters
- $dN_g/dxdk_T$ drastically violates collinear approx.
  - Large angle radiation is important
    - Not under theoretical control
  - Leads to ~200% systematic theoretical uncertainty in extracted medium density at RHIC
  - Extracted parameters from pQCD formalisms likely consistent within uncertainty
- Thermal gluon mass effects small
- LHC
  - R_{AA} insensitive to collinear approx. at ultra-high-p_T
  - $\langle N_g \rangle$ uncertainty E-independent
    - Large cone jets not under theoretical control

What do we learn from this?

- BDMPS loses less energy than opacity expansions and AMY at same medium density.
- AMY requires 2.5 times (for L=2 fm) smaller temperature than BDMPS to reach same suppression.
- WHDG rad loses less energy than ASW-SH.

Gluon gas:

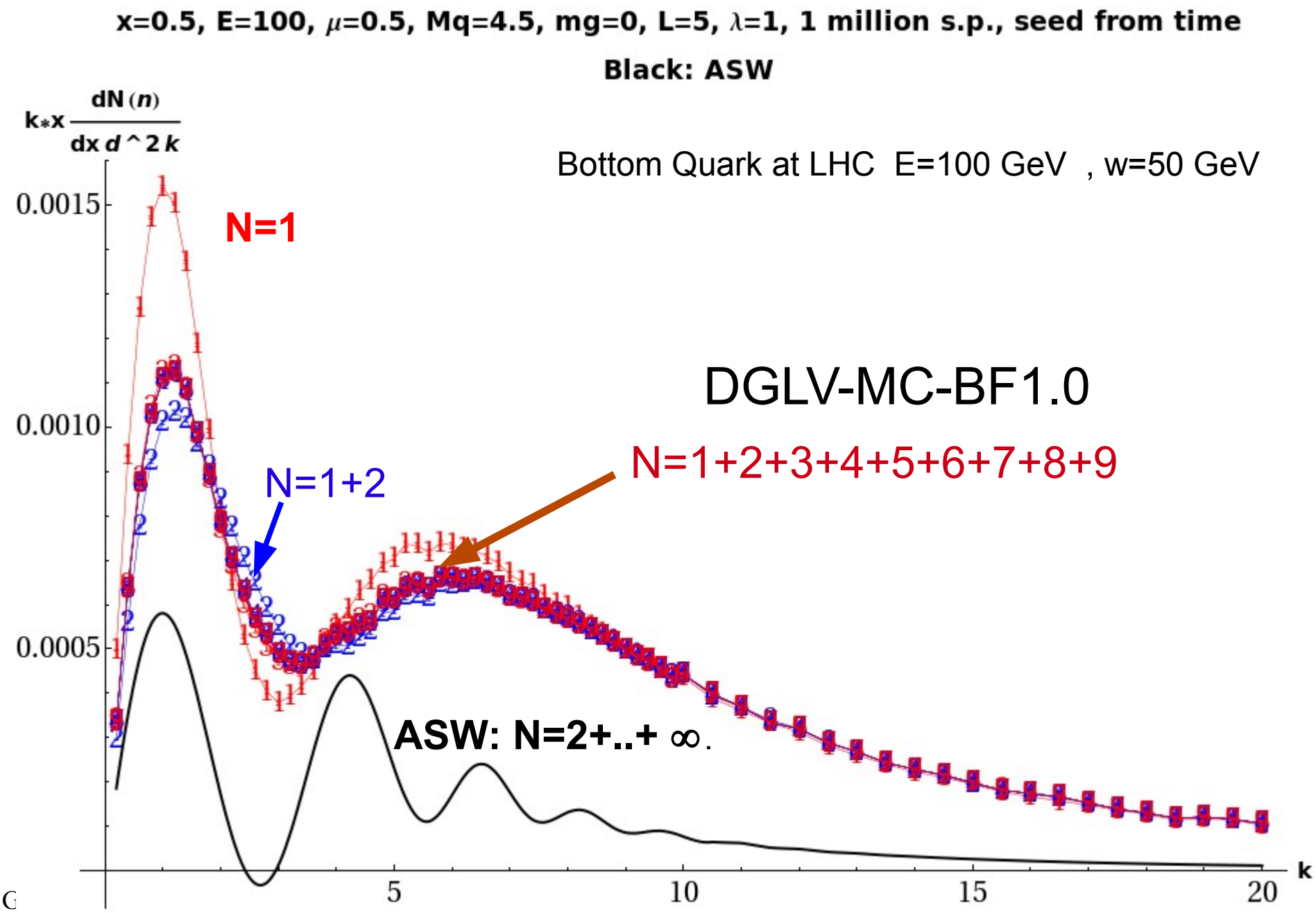
R7=0.25	T (MeV)			
	BDMPS	WHDG rad	ASW-SH	AMY
L = 2 fm	1040	940	730	480
L = 5 fm	440	360	330	235

The clean up crew is already working
to clean the broken pipes

at TECHQM and soon Jet Collab

Monte Carlo Tools finally bypassed the N=1 vs N=infinity impass:

A.Buzzatti
A. Ficnar
S. Wicks , MG



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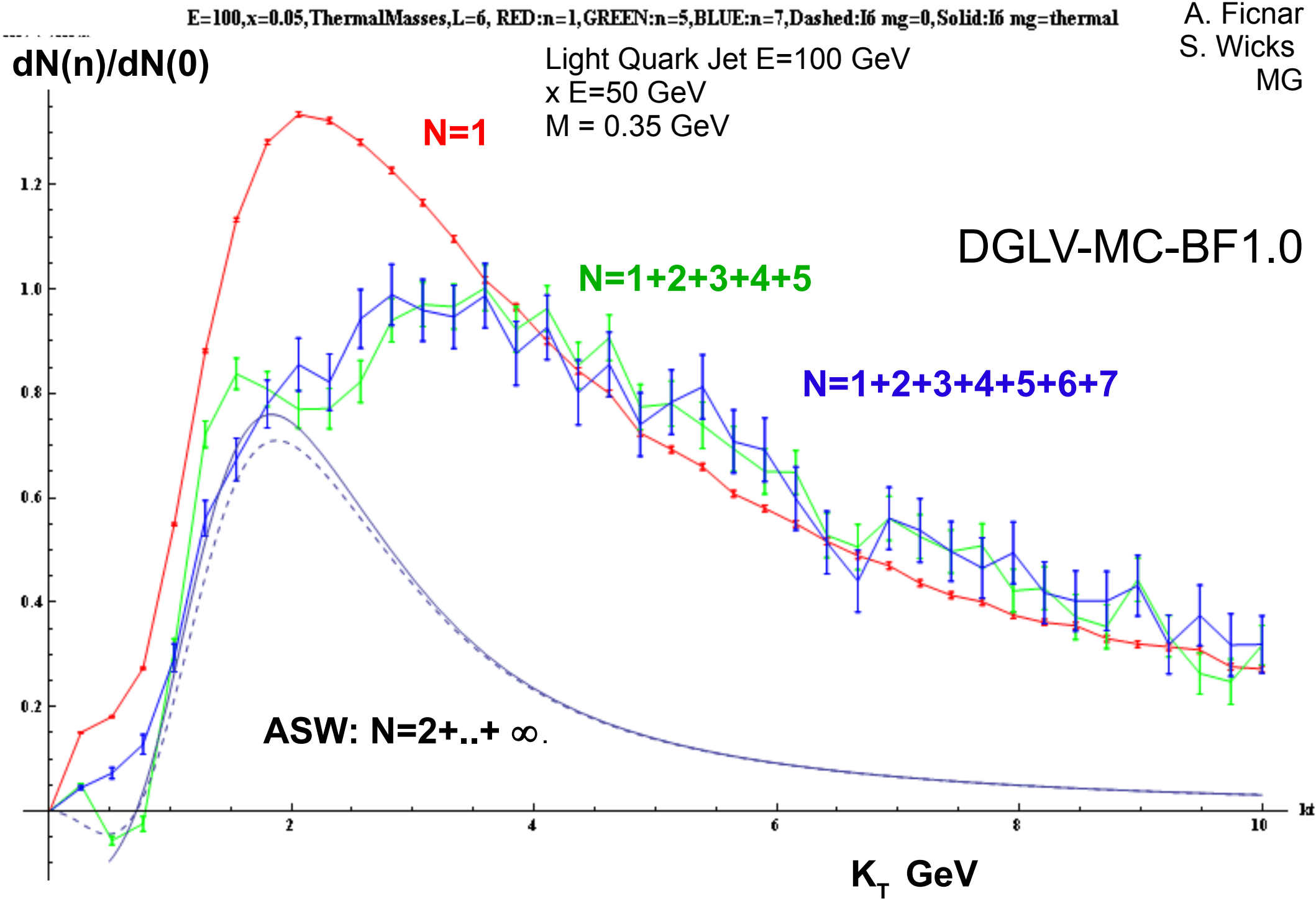
S. Wicks
MG



Is the large angle radiation out of control as William and Brian suggest?

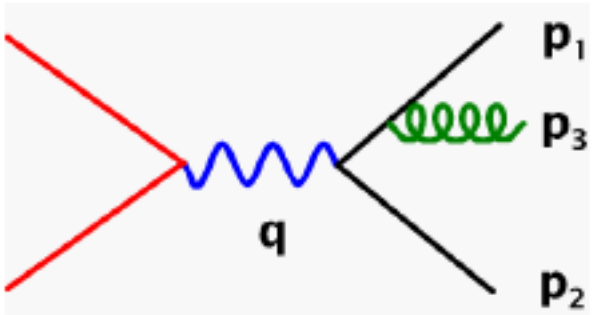
1) Lessons from e+e- -> Q+$\underline{Q}$+g
suggest not if light cone eikonal is used

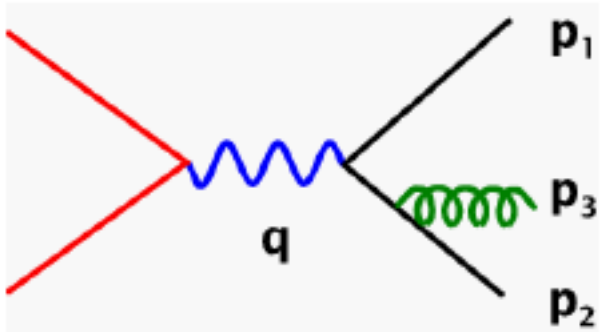
2) Hybrid 1 hard + 2 opacity series
will solve problem in near future

P Arnold proposed using 2 ASW legs.
But for finite L~5 fm the MC opacity series converges well and interpolates between the idealized N=1 and N=2+... ASW multi soft approximations.

Lessons from Exact result on three body final state e+e- -> Q+ Q + G

Revisit e^+e^- scattering (massless partons!) – real emission





$X_1 = 2\ E_Q / Q_0$

$X_3 = 2\ E_g / Q_0$

$X_3 = 2 - X_1 - X_3$

Define handy variables ($q^2 = Q^2 = s$)

$$x_i = \frac{2E_i}{\sqrt{q^2}} = \frac{2p_i \cdot q}{q^2} \Rightarrow x_i \geq 0 \Rightarrow \sum_{i=1}^{3} x_i = 2$$

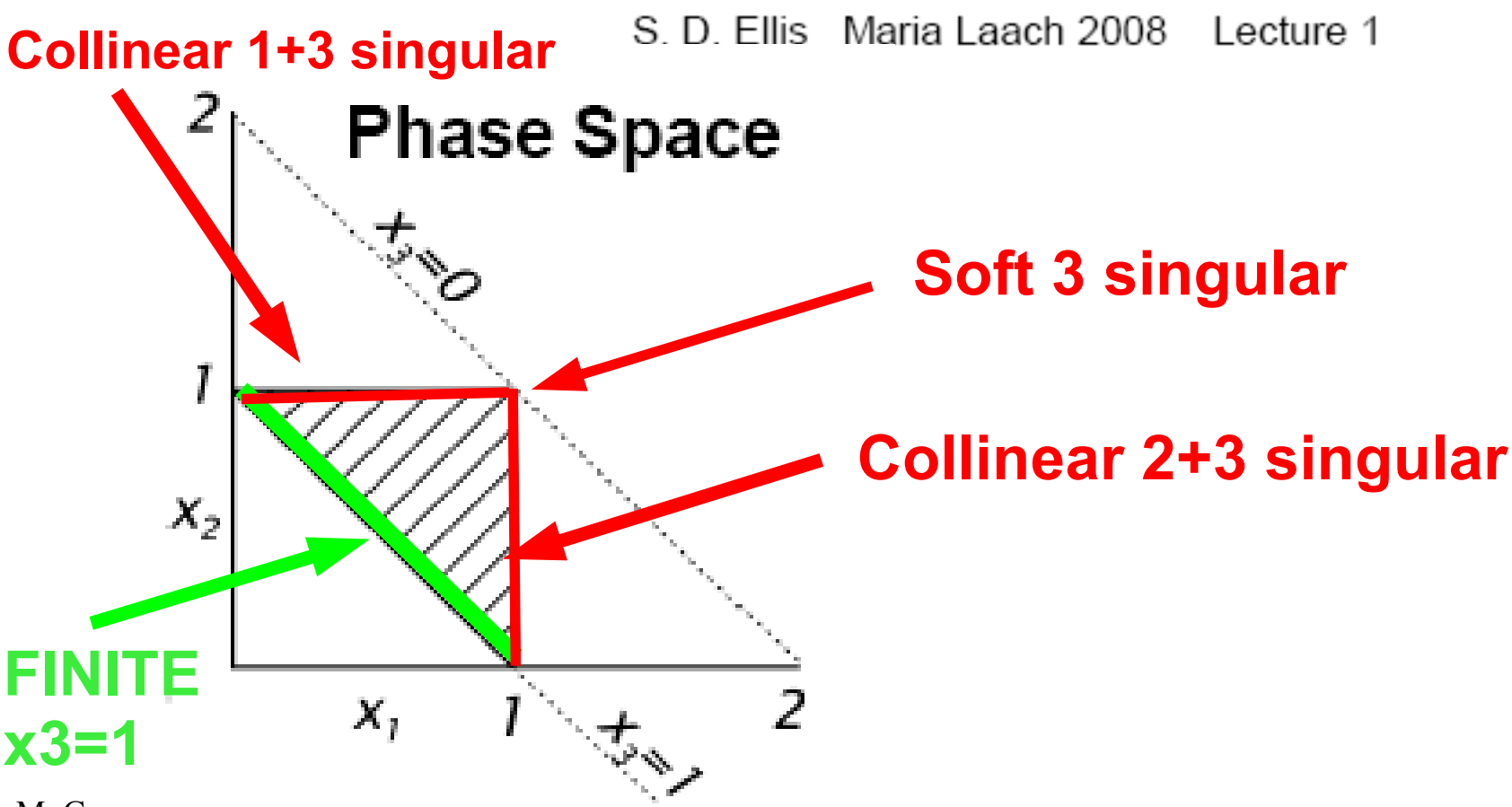
$$1 - \cos\theta_{ij} = \frac{p_i \cdot p_j}{E_i E_j} = \frac{(q - p_k)^2}{2E_i E_j} = \frac{2(1 - x_k)}{x_i x_j}$$

S. D. Ellis Maria Laach 2008 Lecture 1 40

$$\frac{d\sigma}{dx_1 dx_2} = \sigma_0 \frac{\alpha_s}{2\pi} C_F s \frac{E_1^2 + E_2^2}{(p_2 \cdot p_3)(p_1 \cdot p_3)}$$

$$= \sigma_0 \frac{\alpha_s}{2\pi} C_F \frac{x_1^2 + x_2^2}{(1-x_1)(1-x_2)} \qquad \left[\sigma_0 = \frac{4\pi\alpha^2}{3s} \cdot 3 \sum_f e_f^2 \right]$$

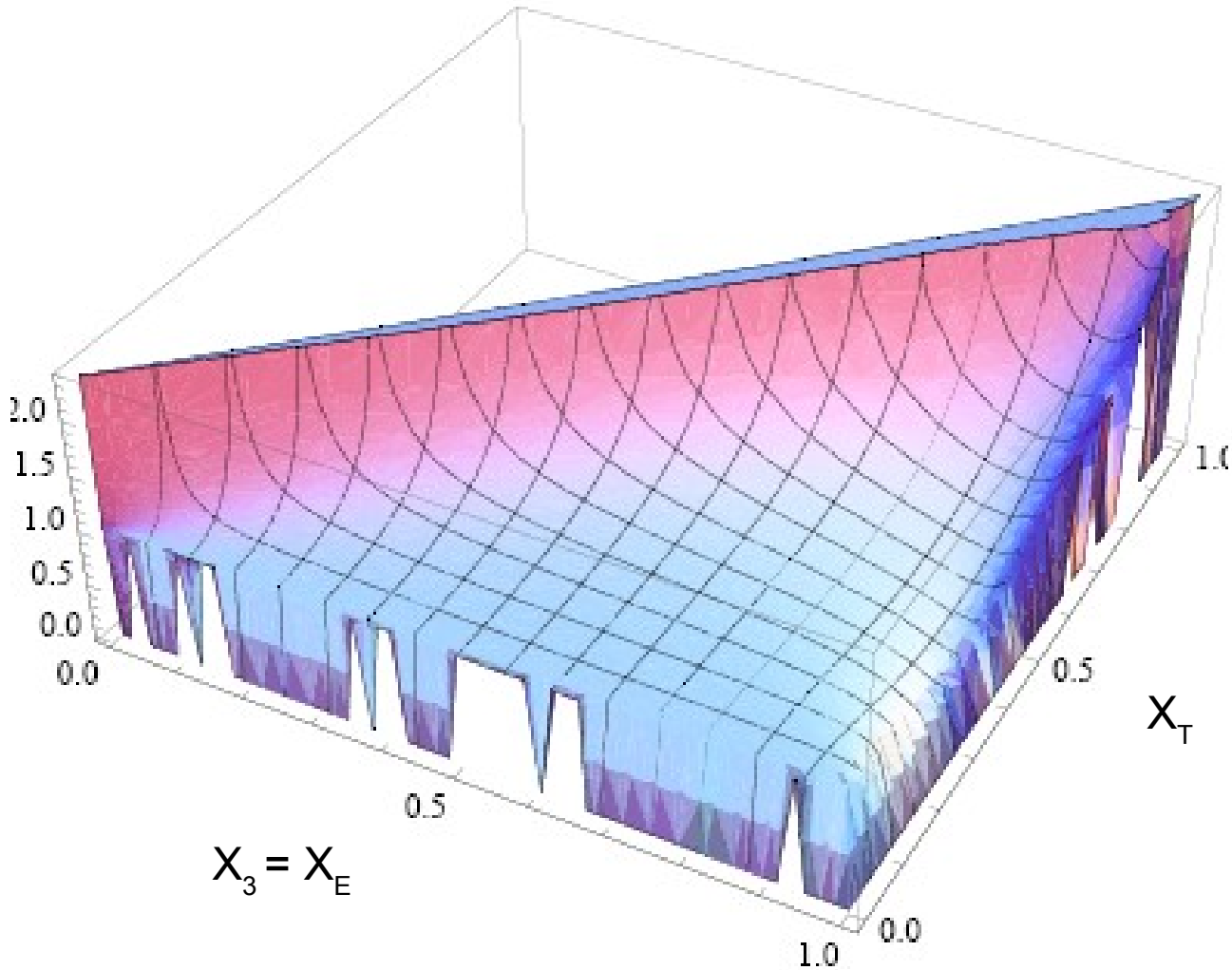
Exact q+q+g
Does NOT vanish at kinematic bounds!!



Ratio of exact $d\sigma/dx_E dx_T$ to Eikonal approximation

$$\frac{2\left(1+(1-x3)^2\right)}{x3\ xt}$$

Exact is much bigger than Eikonal approx with $x_E >> x_T$



Use of $X = X_E$ under estimates the yield near kinematic bounds

Einkonal approx to $d\sigma/dx_+dx_T$ is closer to exact 3 body over whole kinematic range than eikonal approx to $d\sigma/dx_Edx_T$

```
dsdxpdxt[xp_, xt_] := (1 - xt^2/(4 xp^2)) dsdx3dxt[X3p[xp, xt], xt]
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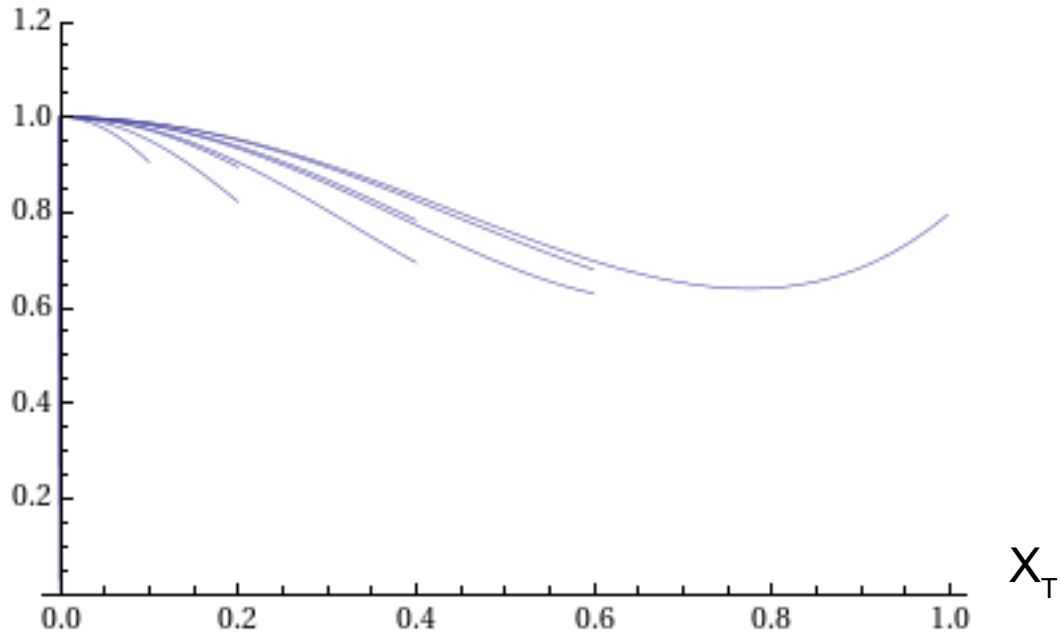


Ratio of exact $d\sigma / dx_+ \, d\, x_T$ to approximate Eikonal for

$x_+ = 0.1, \ldots, 0.9$ vs

x_T in range $0 < x_T < \mathrm{Min}\,(2\, x_+,\ 2\,(1 - x_+))$

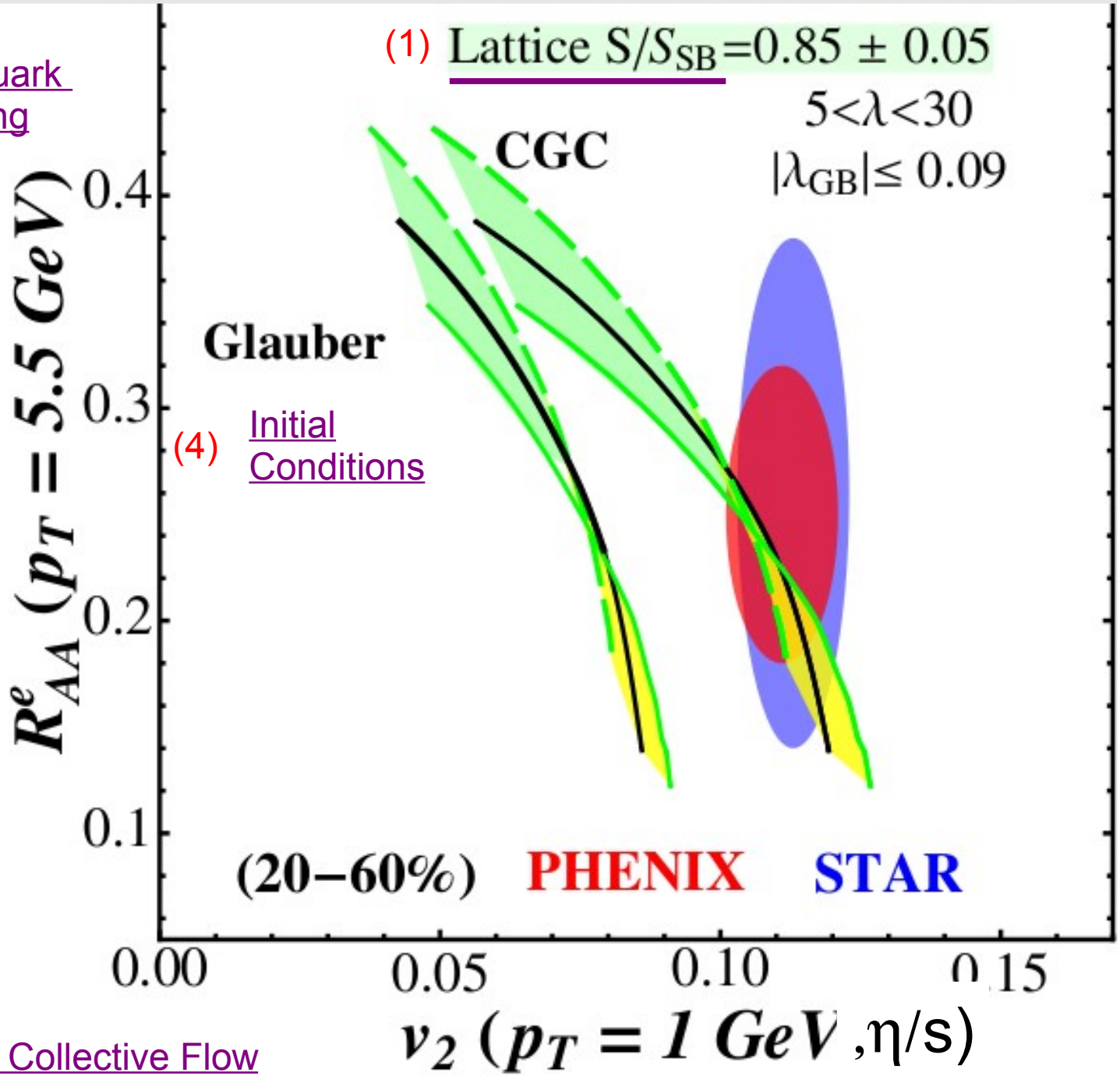
My future wish:

One theoretical framework that explains simultaneously ***both soft and hard*** phenomena and predicts new falsifiable LHC observables within same paradigm and a consistent set of dynamical parameters

5 Fold AA correlations! amazingly well described by sQGP=AdS BH paradigm

J. Noronha, M. Gyulassy, G. Torrieri, hep-ph: 0906.4099

(3) Heavy quark Jet quenching



(5) Heavy quark Jet induced collective flow

The Future

(2) Bulk Collective Flow

The End

Let’s all get back to work

and thank the organizers

BNL hosts and Marcy