Signatures for AdS/CFT using the CMS experiment at the LHC

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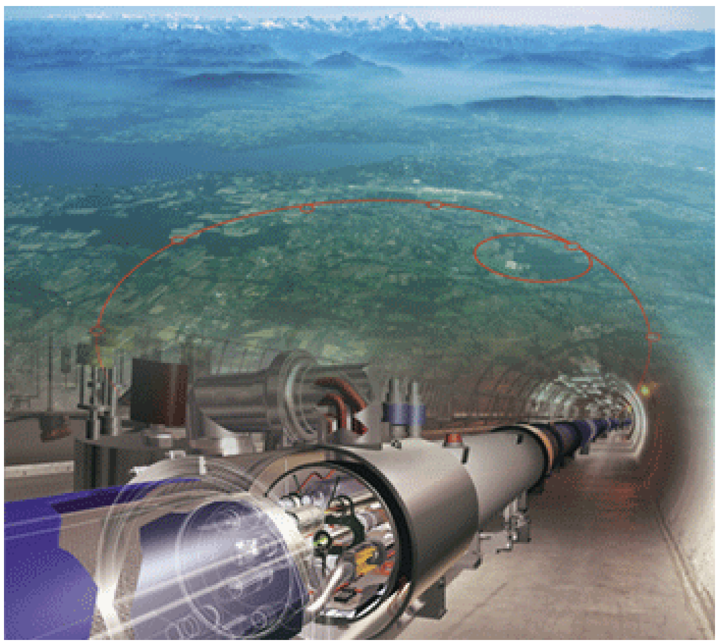
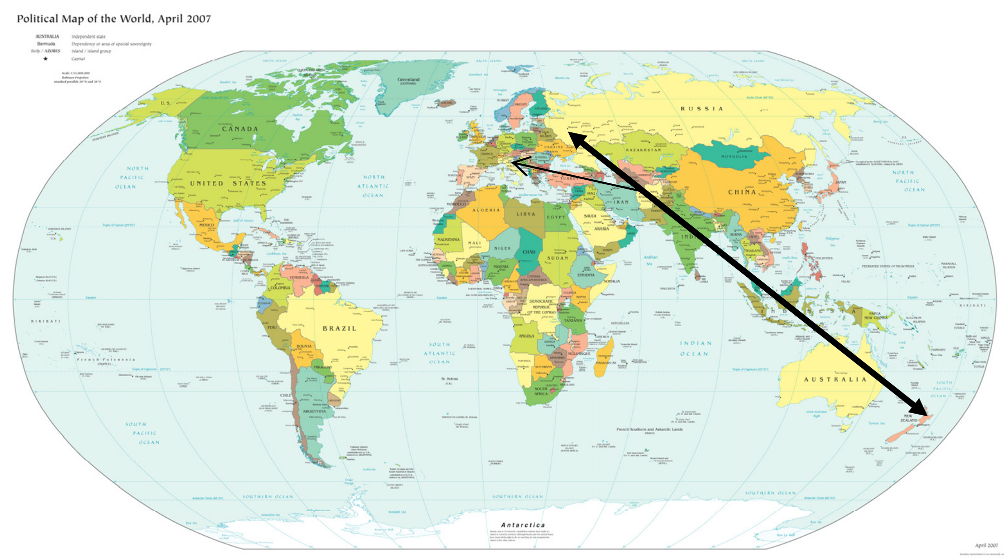
The University of Auckland
(For the CMS Collaboration)





New Zealand in the CMS collaboration: a long distance collaboration with Moscow

Further CMS talks in this session:

Ilina - *Study of Jet Transverse Structure with the CMS experiment at* $\sqrt{S} = 10\ \mathrm{TeV}$

Petrushanko – *Elliptic Flow Studies in heavy-ion collisions using the CMS detector at the LHC*

Sarycheva – *Ion Studies in CMS experiment at LHC*

2007 Annual Meeting of the Division of Nuclear Physics
Wednesday–Saturday, October 10–13, 2007; Newport News, Virginia

Session HA: AdS/CFT - Applications of String Theory to Nuclear Physics

Chair: Alice Mignerey, University of Maryland
Newport News Marriott at City Center - Grand Salon I

Saturday, October 13, 2007 9:00AM - 9:36AM	HA.00001: Bulk Properties and Collective Flow of Quark Gluon Plasma Invited Speaker: Joseph Kapusta
Saturday, October 13, 2007 9:36AM - 10:12AM	HA.00002: Quark Gluon Plasma: Experiments With Strings Attached? Invited Speaker: Barbara Jacak
Saturday, October 13, 2007 10:12AM - 10:48AM	HA.00003: Understanding the Quark-gluon Plasma via String Theory Invited Speaker: Hong Liu
Saturday, October 13, 2007 10:48AM - 11:24AM	HA.00004: A few comparisons between string theory and heavy-ion physics Invited Speaker: Steven Gubser

Recall: string theory started out as a theory of the strong nuclear force

[1] G. Veneziano, *"Construction of a Crossing-Symmetric , Regge-Behaved amplitude for Linearly rising trajectories"*, Nuovo Cimento **A57** (1968) 190.

[2] L. Susskind, *"Dual-symmetric theory of hadrons"*, Nuovo Cimento A69 (1970) 457

[3] G. Veneziano, *"An introduction to dual models of strong interactions and their physical motivations"*, Physics Reports **9** (1974) 199-242.

What is AdS/CFT – not QCD!

For large N_C and $\lambda = g_{YM} N_C$: t'Hooft coupling

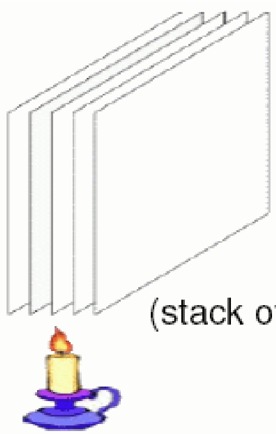
- Certain gauge-theories in Minkowski space can be obtained as limits in the 4-D boundary of simpler 5-D string dual theories:

$$\mathcal{L} = \frac{1}{2g_{\mathrm{YM}}^2}\mathrm{Tr}(F_{\mu\nu}F^{\mu\nu}) + i\mathrm{Tr}(\bar{\psi}\gamma^\mu D_\mu \psi) \longleftrightarrow ds^2 = \frac{r^2}{R^2}(-dt^2 + d\vec{x}^2) + \frac{R^2}{r^2}d\Omega_5^2$$

(Conformal gauge theory) (Anti-de-Sitter curved space)

- "Easy" case: strongly-coupled QFT ↔ classical gravity

$\mathcal{N}$= 4 SYM plasma in 4-dimensions



(stack of 4 branes)

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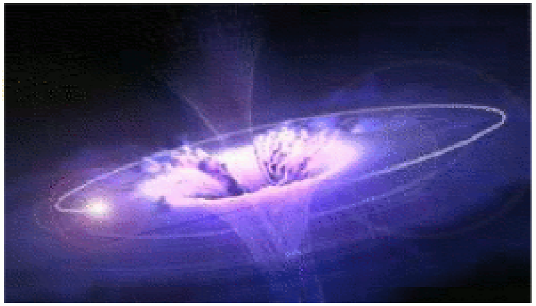


Black-Hole in $AdS_5 \times S^5$

- **High Temperature HI collisions** – deconfined (sQGP?), no supersymmetry

Use AdS/CFT to calculate dynamical properties of the QGP analog

Heavy Ion Collision Probes to study strongly interacting matter at the LHC

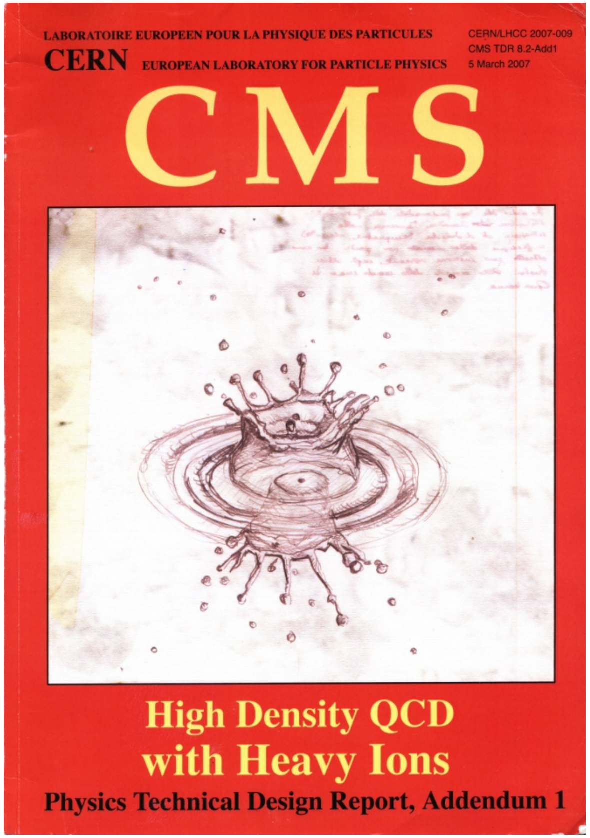
(a) **Elliptic flow** at low P_T (STAR/PHENIX at RHIC)

(b) **Gauge Boson Jet Tagging** γ^*- jet, Z^0-jet

(c) **Jet Effects** – Mach Cones, Diffusion, Energy Loss

(d) **Quarkonia Melting** - velocity scaling of the screening length

(e) **Nuclear Modification factors** - strong coupling deviation from pQCD predictions



J. Phys. G: Nucl. Part. Phys. **34** (2007) 2307–2455.

“Soft” physics – flow of nuclear matter

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T\,dp_T\,dy}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Phi_R)]\right)$$

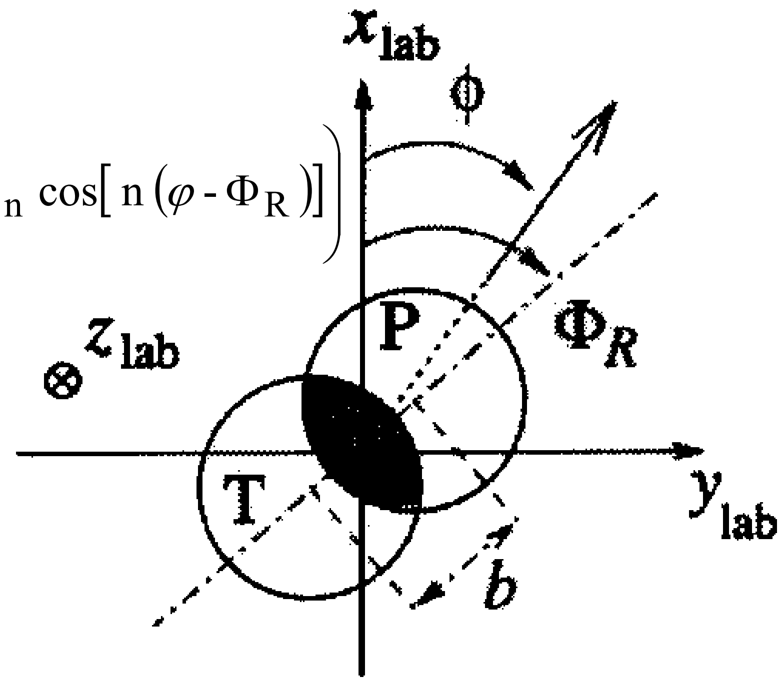
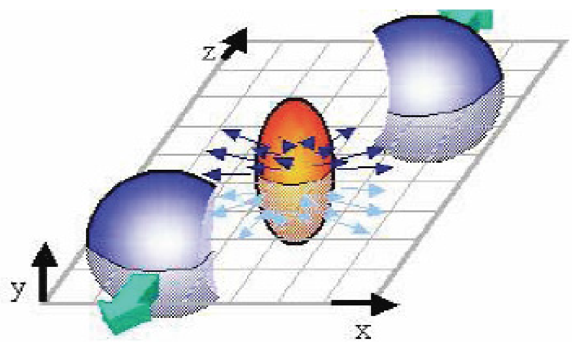
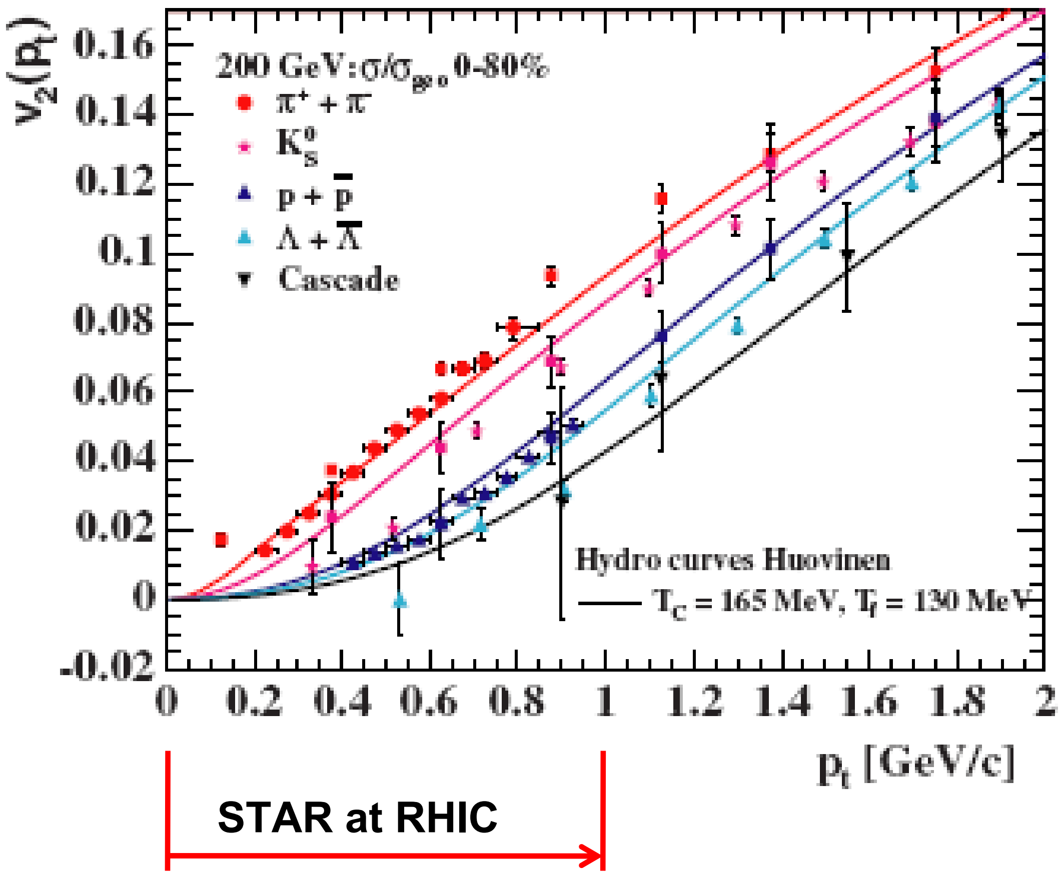


Fig. 1. Schematic picture of a nucleus–nucleus collision viewed in the plane transverse to the collision axis z. b is the impact parameter, Φ_R its azimuthal angle. ϕ is the azimuthal angle of an outgoing particle.

sQGP “Liquid” at RHIC, still true at LHC?



- Elliptic flow (v_2): key parameter
  related to initial partonic pressure
- LHC: null-viscosity fluid (RHIC) ?
  weakly interacting QGP ?

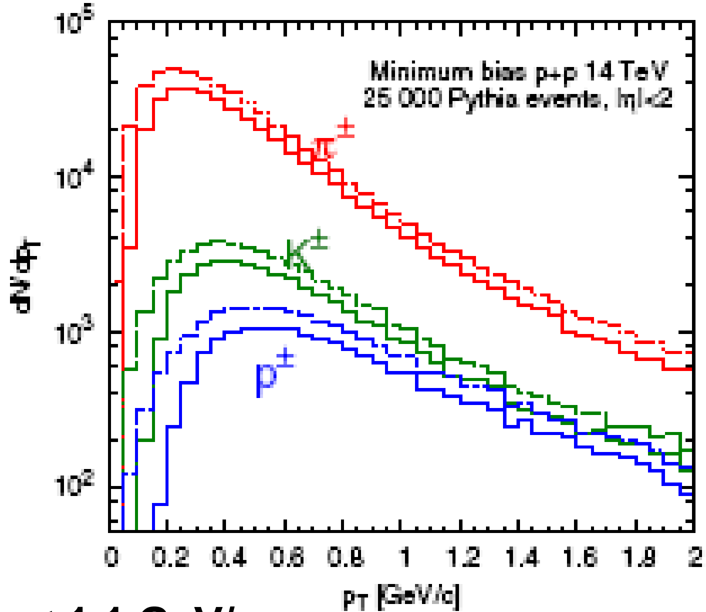


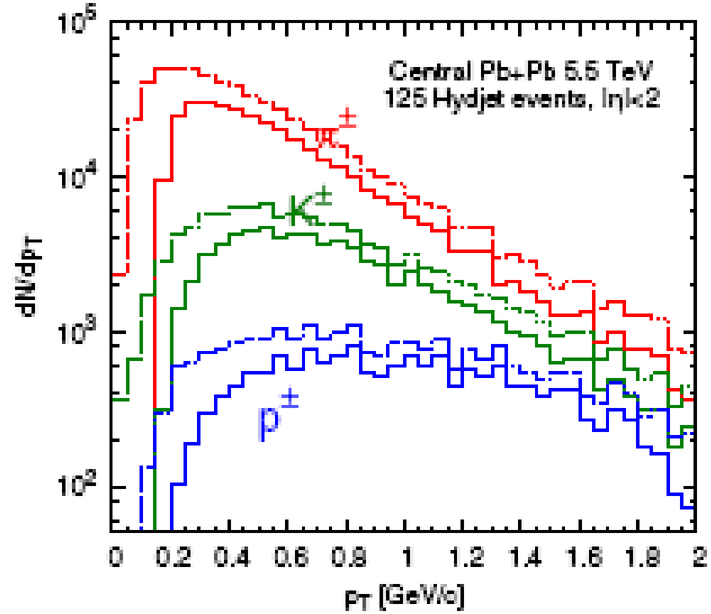
$$\frac{\eta}{s} \geq \frac{1}{4\pi}$$

Kotvun, Son, Starinets, *”Viscosity in Strongly Interacting Quantum Field Theories from Black Hole Physics”* PRL **94** 111601 (2005)

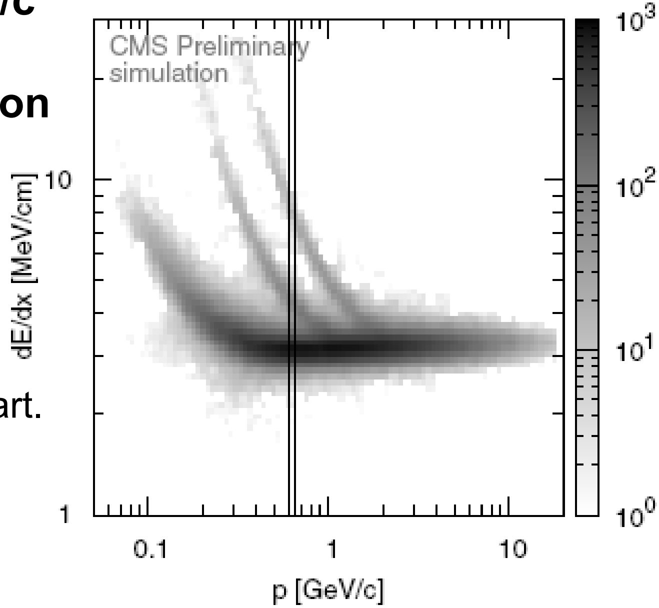
Low P_T particle Identification at CMS

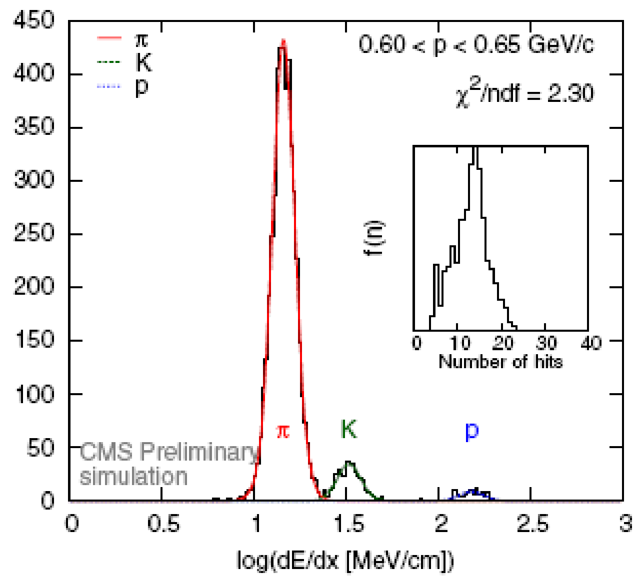
Fit tracks





0.1 GeV/c $< P_T <$ 1.1 GeV/c
STAR at RHIC
Check V_2 in same P_T region for sQGP





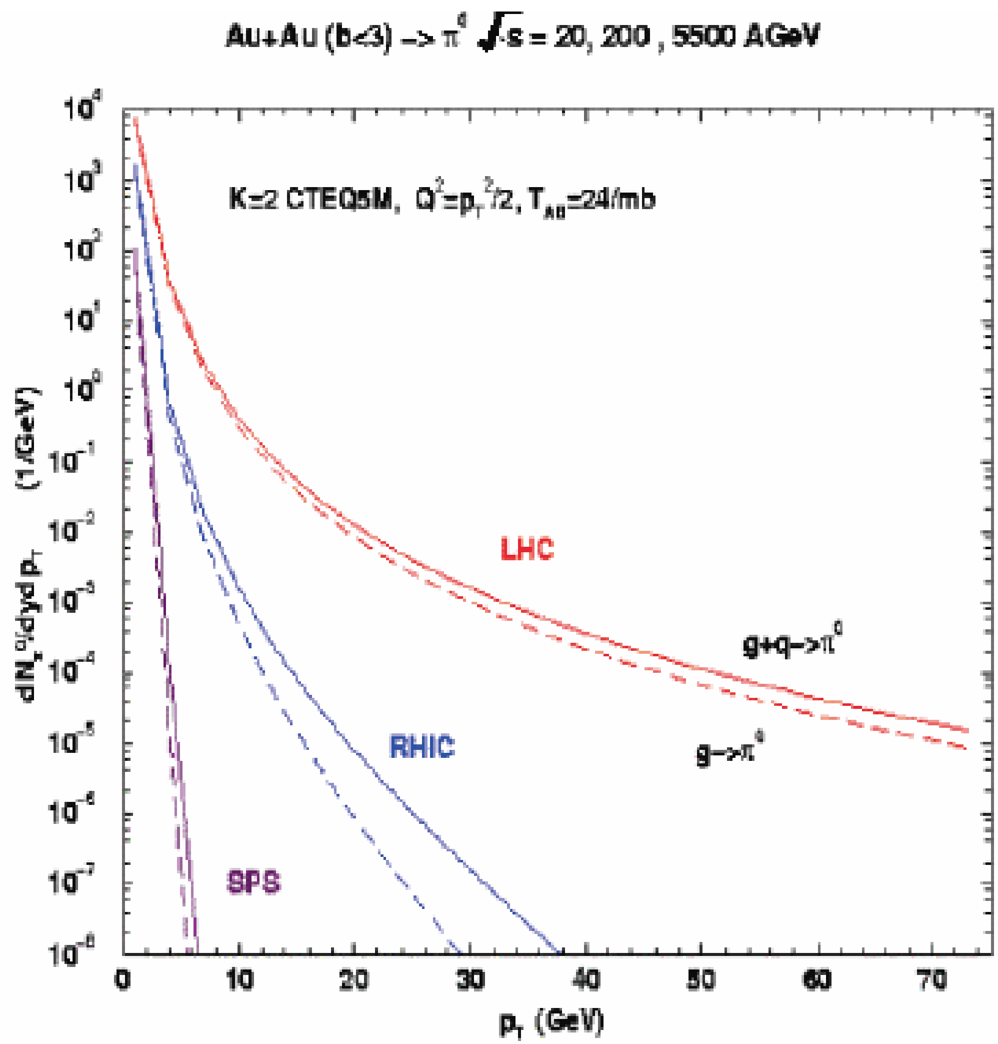
Sikler, J. Phys. G: Nucl. Part. Phys. **35** (2008) 104150

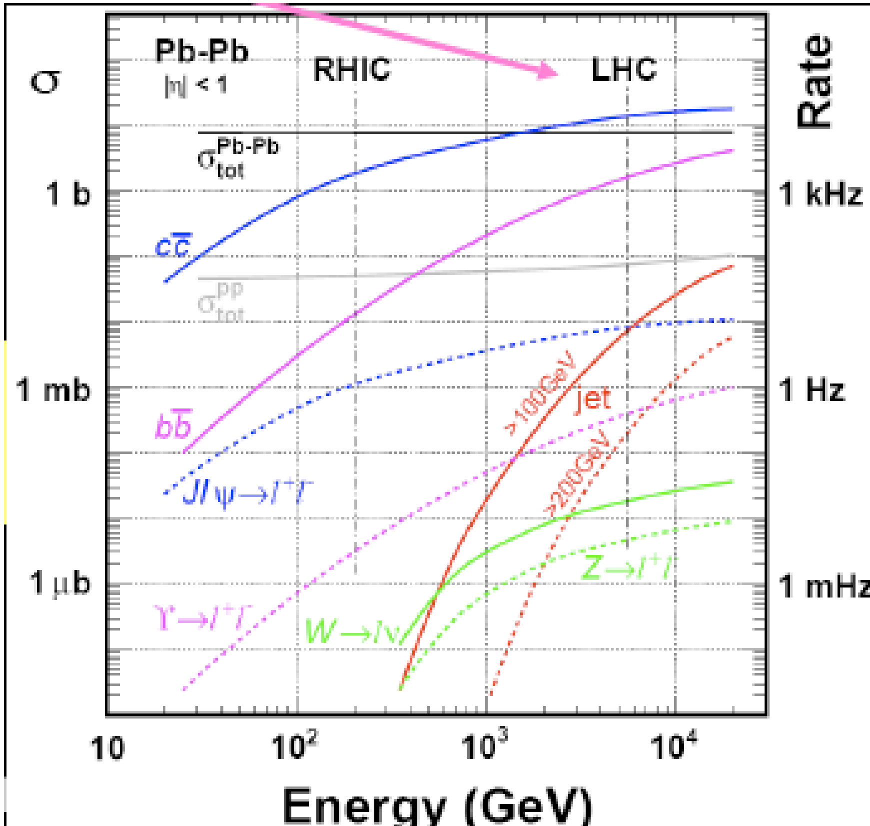
D. Krofcheck

Heavy Ions at the LHC – $b\bar{b}$ $c\bar{c}$
Significant increase in hard processes

σ_{bb} (LHC) ~ 100 σ_{bb} (RHIC)

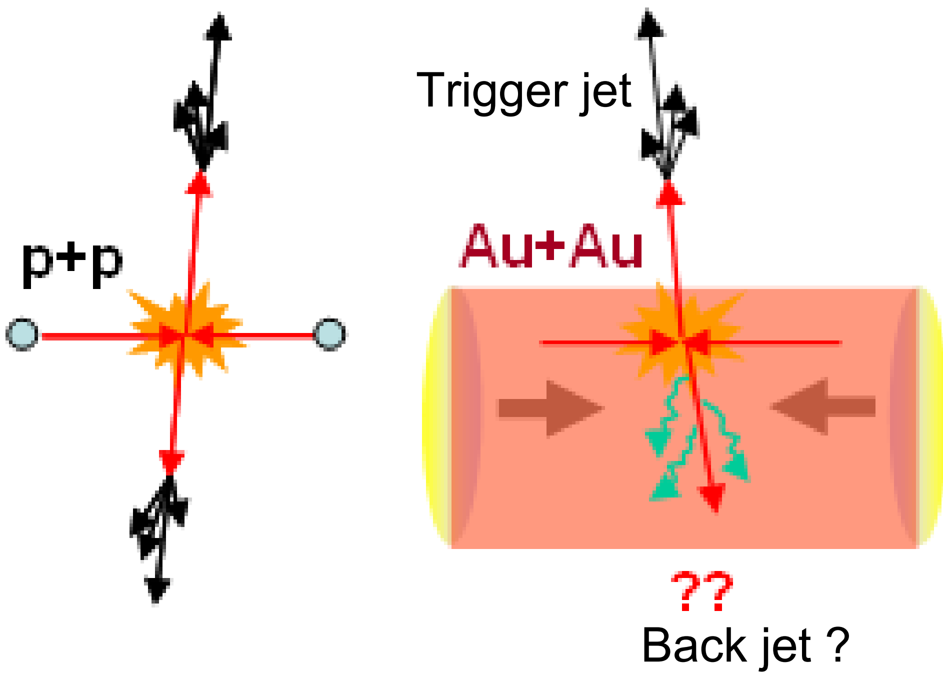
σ_{cc} (LHC) ~ 10 σ_{cc} (RHIC)



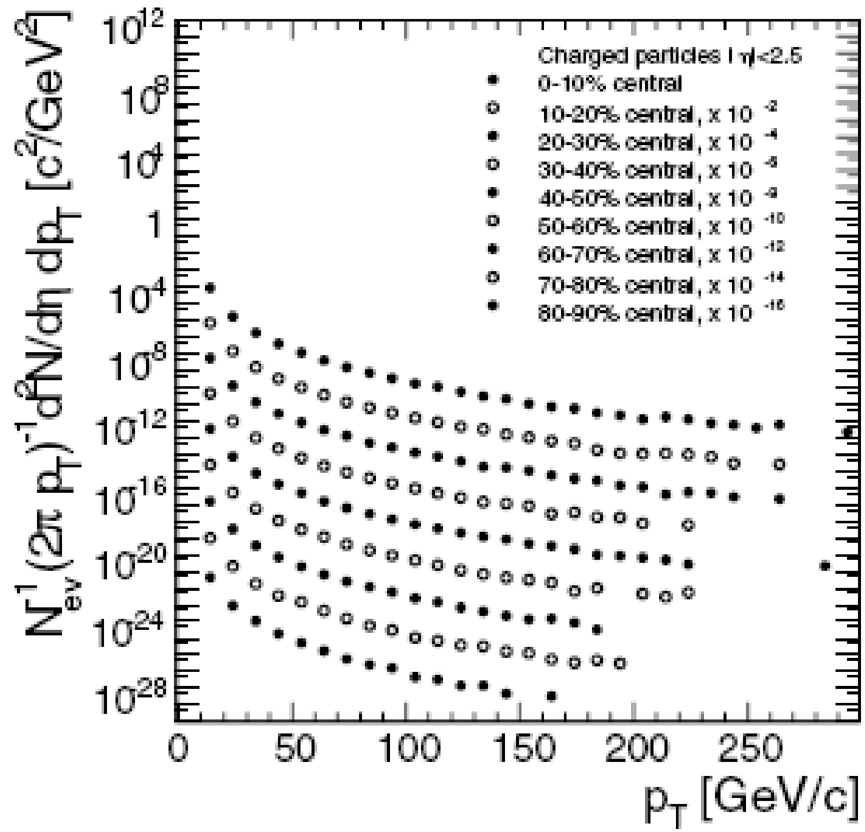


Jet Effects at LHC

"Low" Density QCD **"High" Density QCD**

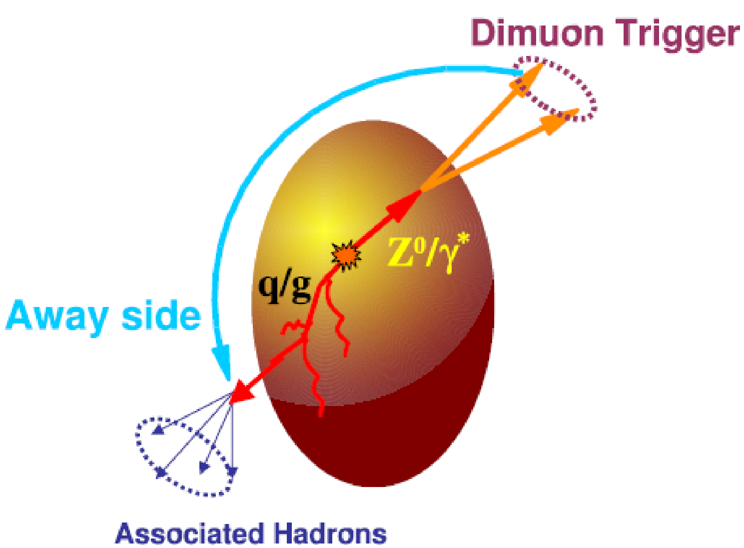


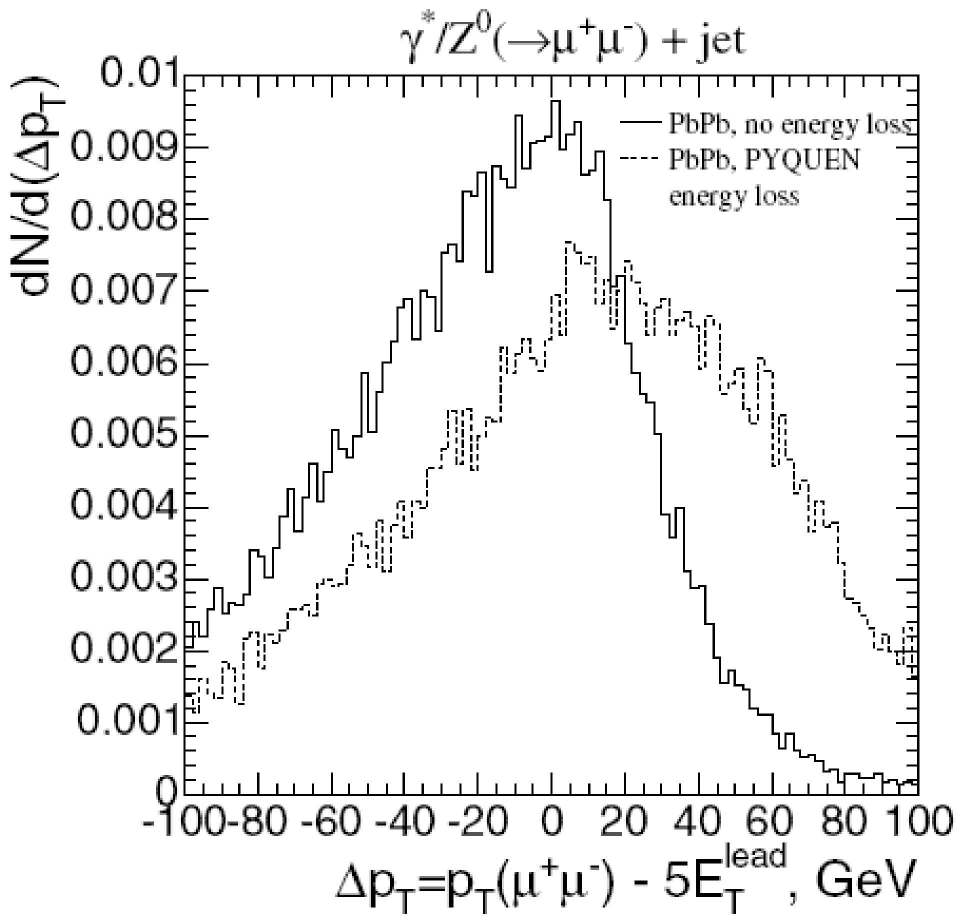
High Level Trigger PbPb



HYDJET Lokhtin, Snigirev, EPJ 45 211,2006

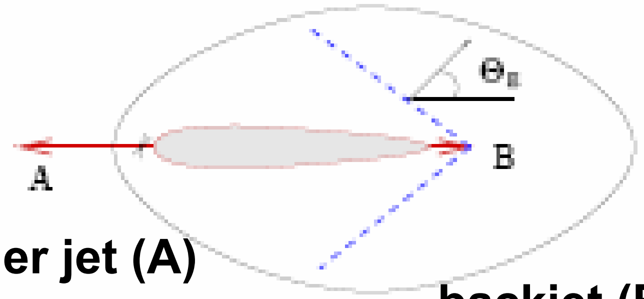
Gauge Boson Jet Tagging





J. Phys. G: Nucl. Part. Phys. **34** (2007) 2307–2455

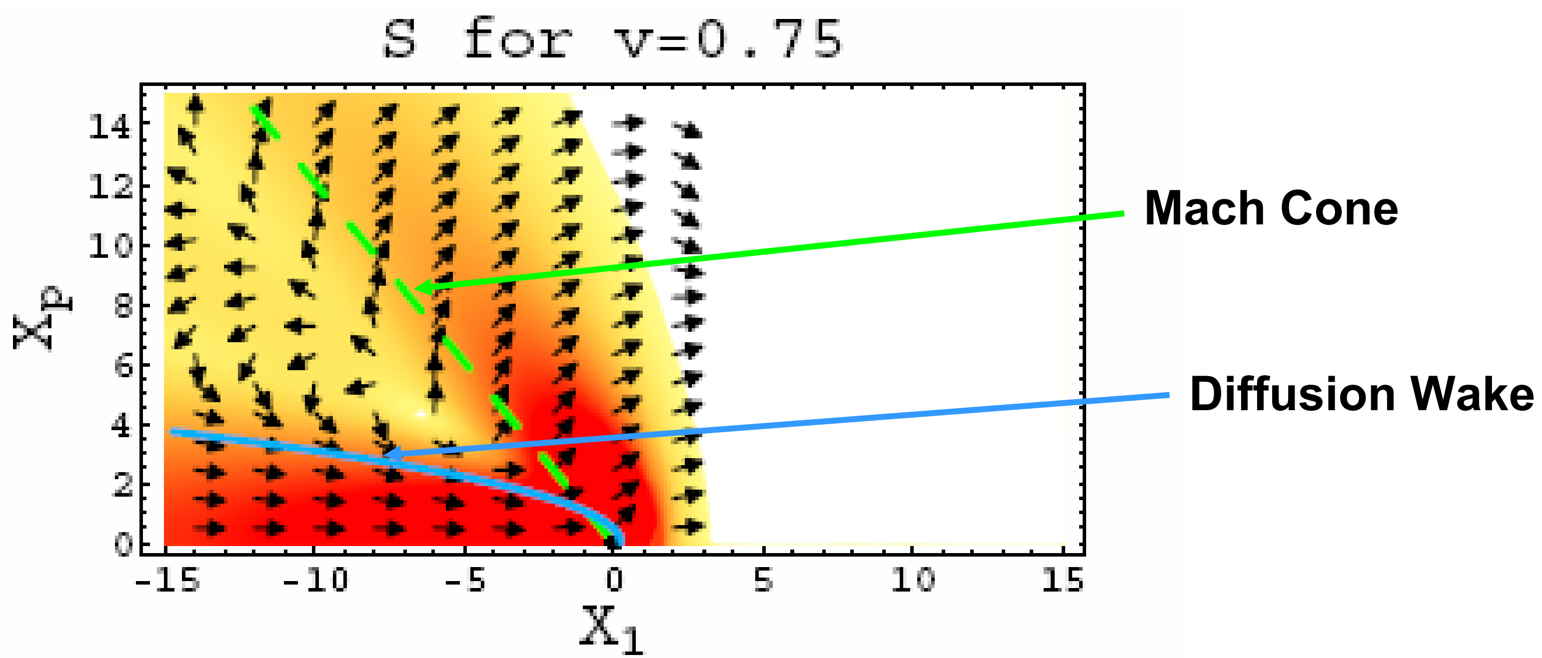
Mach Cones and Diffusion in HI jets



trigger jet (A)

Gubser et al, "*Sonic booms and diffusion wakes generated by a heavy quark in thermal Gauge-String Duality*", Phys. Rev. Lett. **100**, 012301 (2008)

backjet (B) propagates though the entire medium.

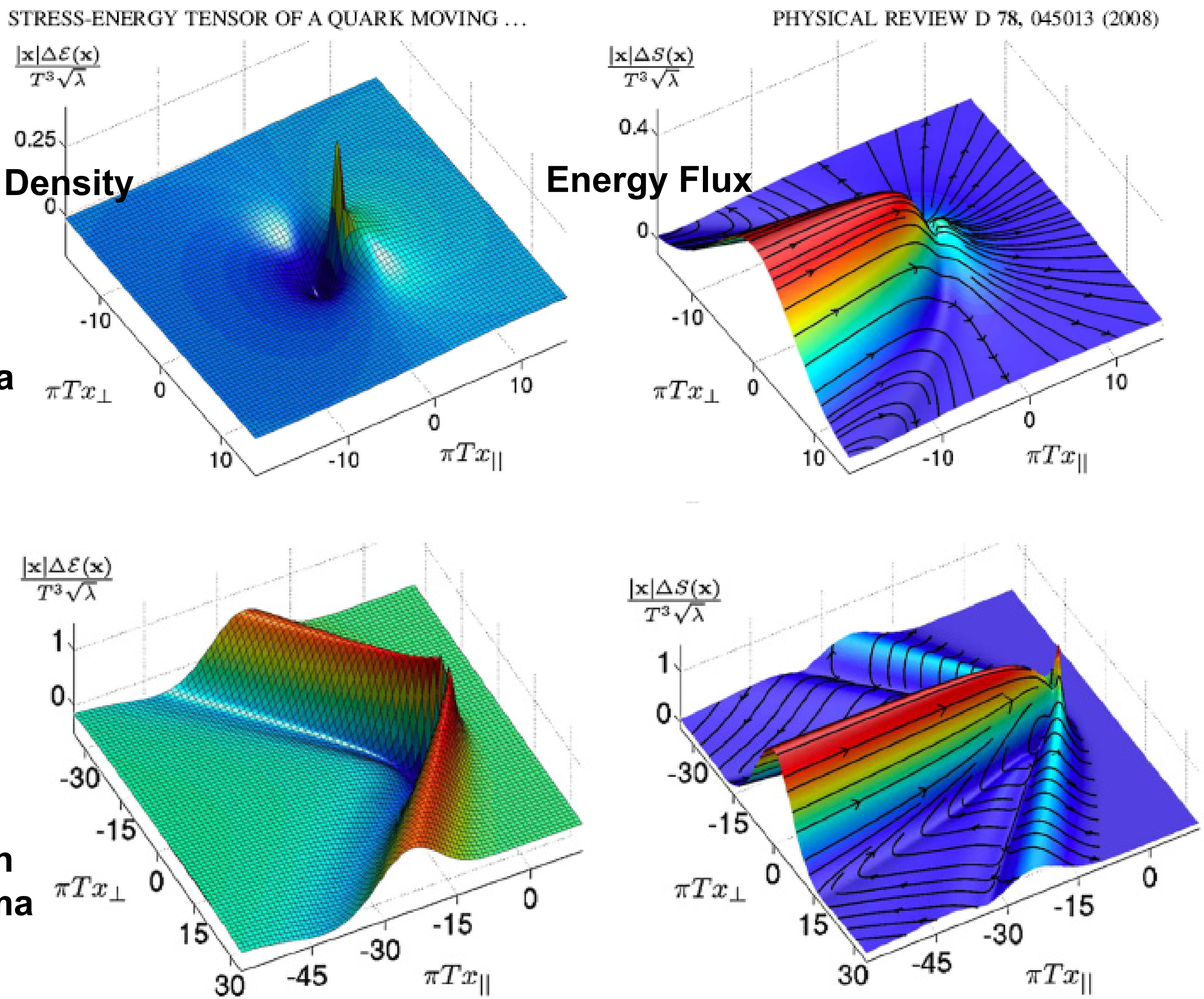


Energy lost by heavy quark Mach Cone ~ $1+v^2$ larger than energy in via wake

Energy Density **Energy Flux**

Sub-sonic motion through SYM plasma

Super-sonic motion through SYM plasma



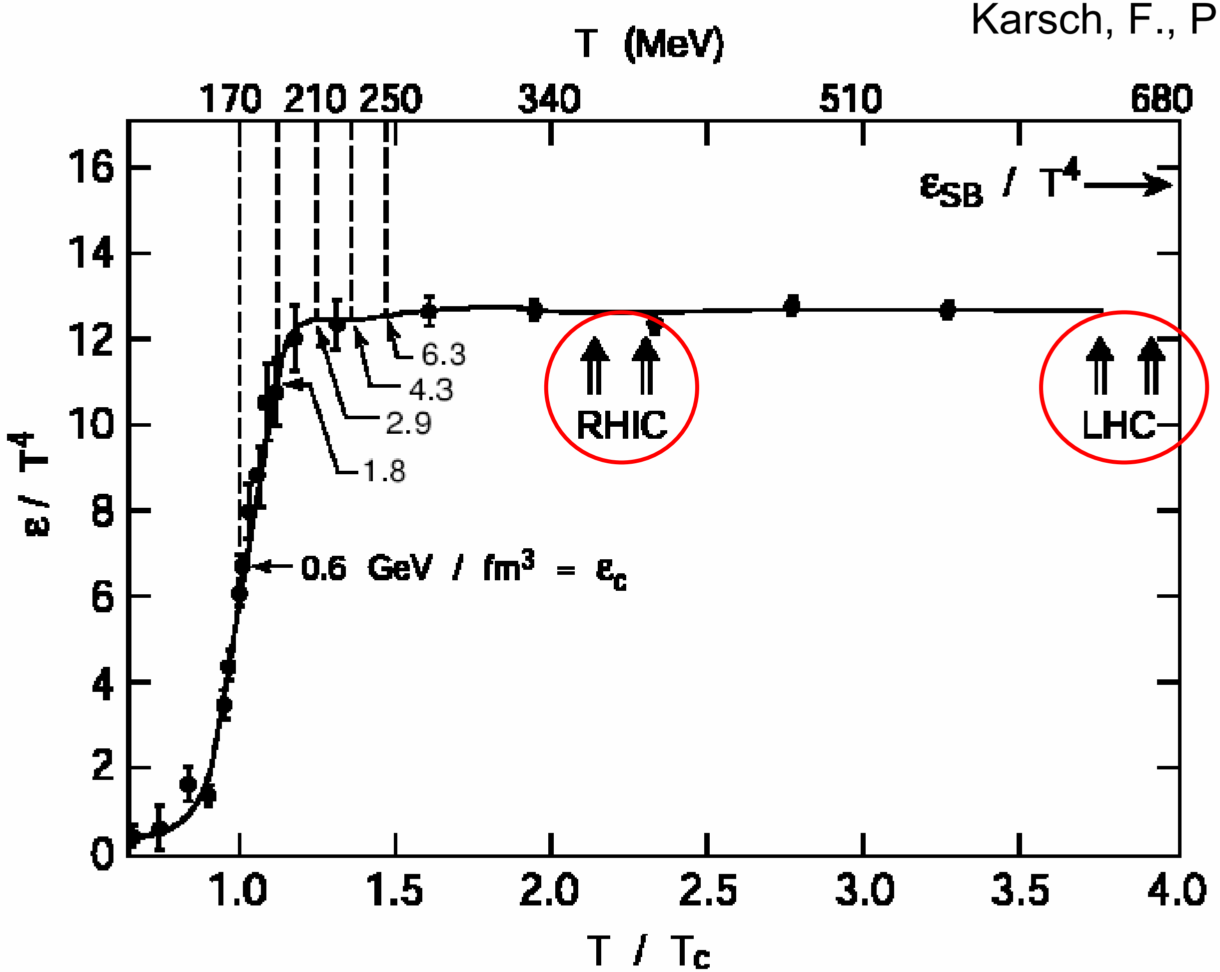
Chesler & Yaffee , PRD **78**, 045013 (2008)

Quarkonia Melting

High T at LHC energy

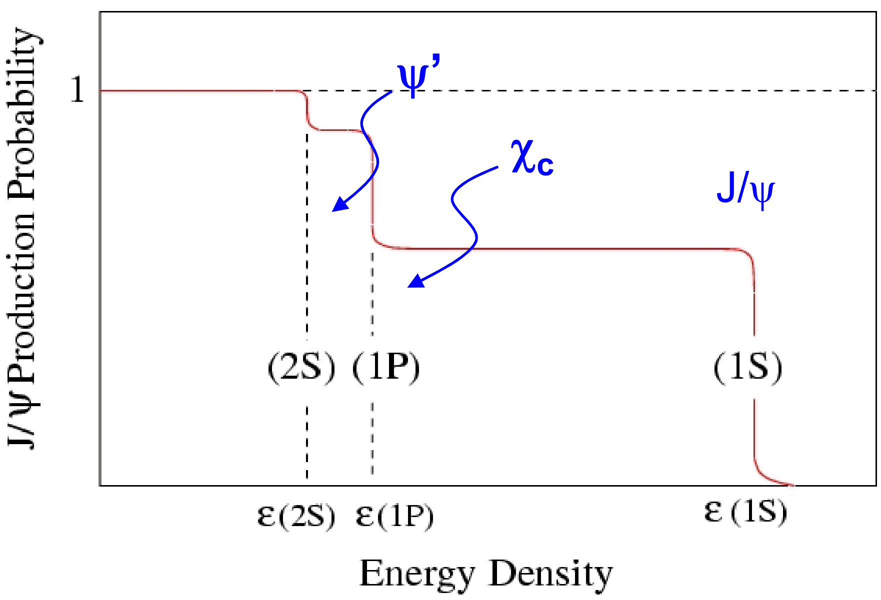
Karsch, F., Phys. Lett., **B478**, (2000), 447.

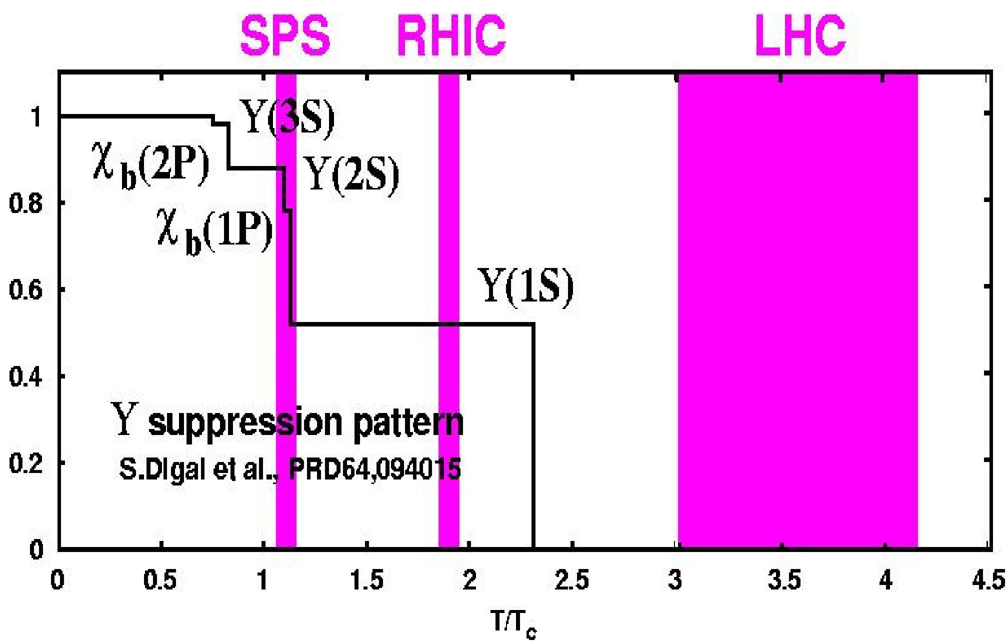
Preprint hep-lat/0305025



Quarkonia Melting

The feed-down from higher states leads to "step-wise" J/y and Υ suppression patterns.

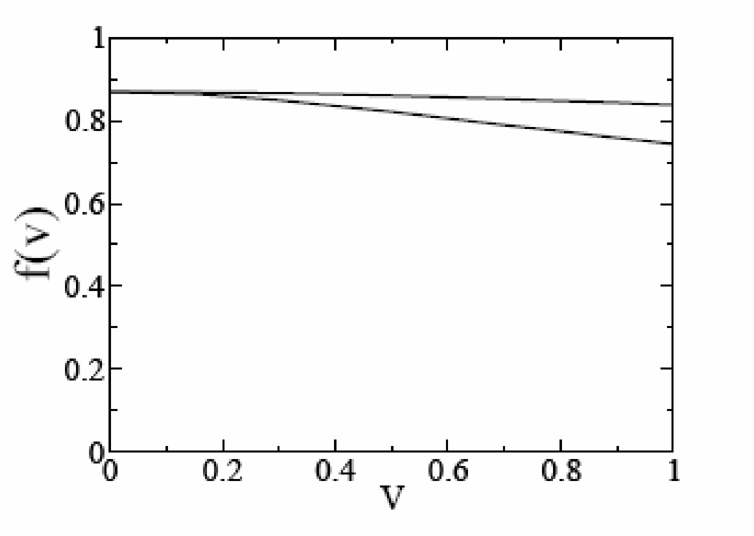




Quarkonium melting in moving medium calculated using AdS/CFT

Screening Length changes due to moving quarks in the medium

$$L_{MAX} = \frac{f(v)}{\pi T}\left(1 - v^2\right)^{1/4}$$



…so Melting Temperature changes

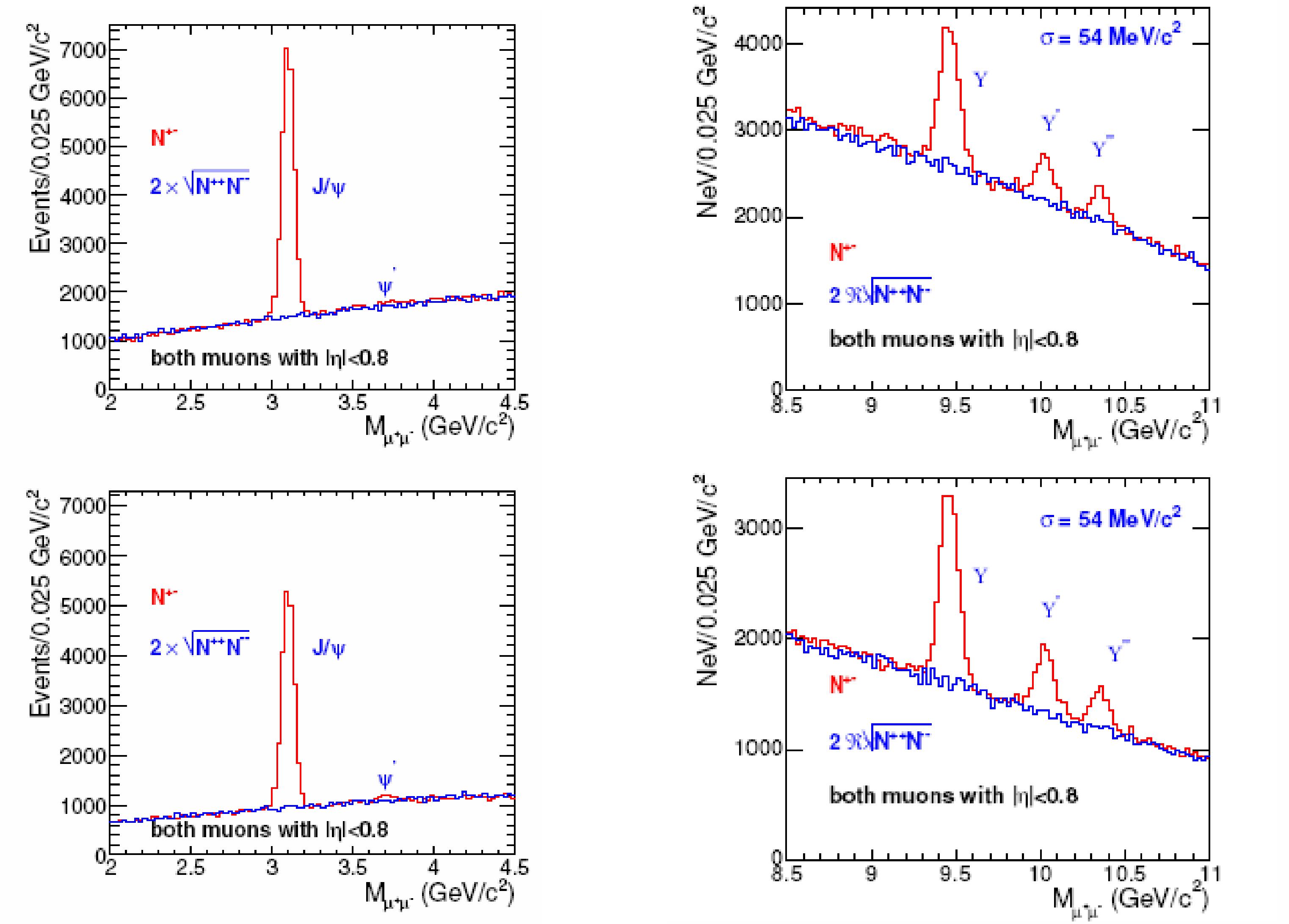
$$T_{MELT}(v) \sim T_{MELT}(v=0)\left(1 - v^2\right)^{1/4}$$

P_T dependent Dissociation Temperature

Hong Liu, *"Heavy Ion Collisions and AdS/CFT"*, J.Phys.G**34**:S361-368 (2007)

Liu et al., *"An AdS/CFT calculation of screening in a hot wind"*, Phys.Rev.Lett.**98**:182301,2007

CMS reconstructs J/Ψ and Υ from di-muons



Define R_{AA} – nuclear matter "modification factor"

1. Compare Pb+Pb to nucleon-nucleon cross sections

2. Compare Pb+Pb, central / peripheral collisions

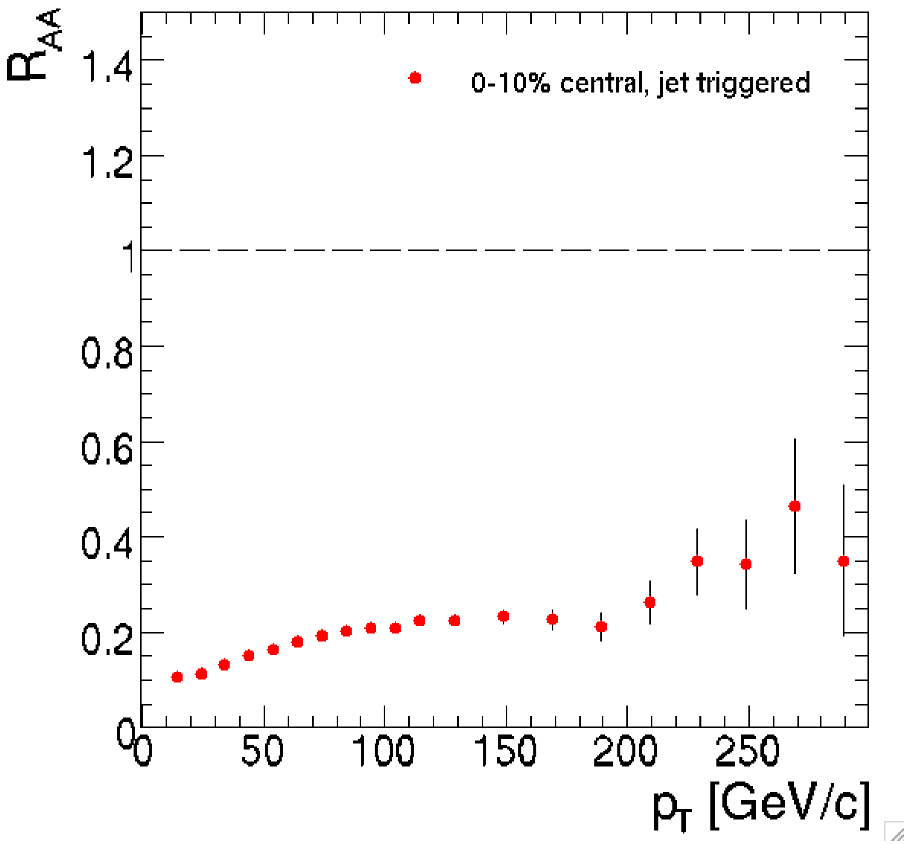
$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA}\, d^2\sigma^{NN}/dp_T d\eta}$$

nucleon-nucleon cross section

$\langle N_{binary}\rangle / \sigma_{inel}^{p+p}$

$$R_{AA}(p_T) \sim \frac{\text{"Hot Dense QCD matter"}}{\text{"QCD vacuum"}}$$

Define R_{AA} – nuclear matter "modification factor"

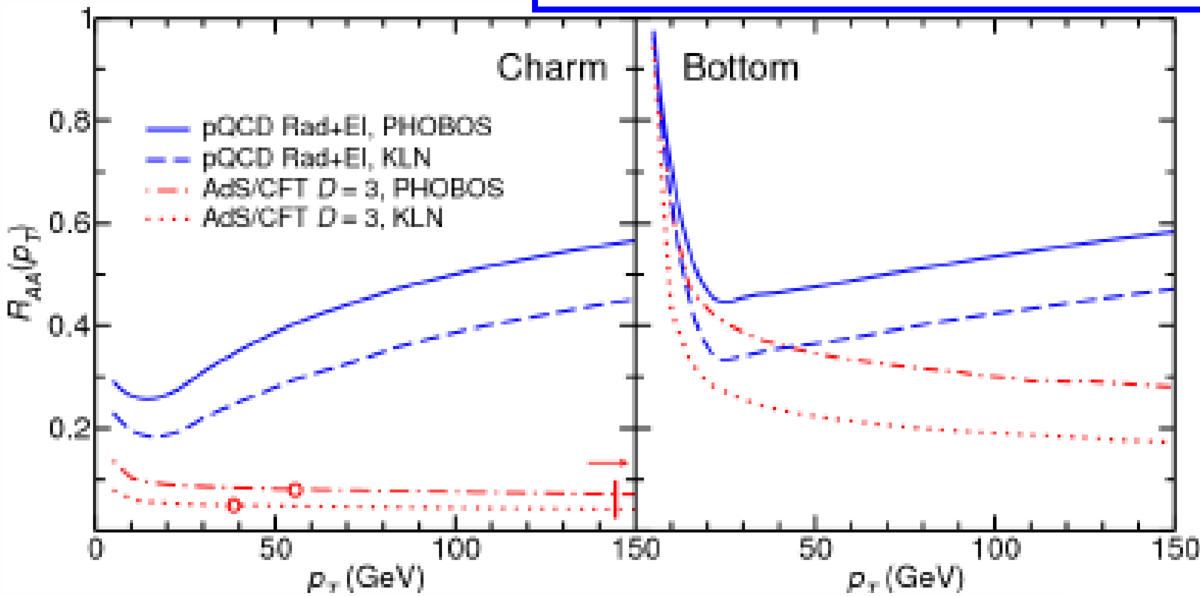


HYDJET for charged hadrons, Triggered on high $E_{T\ jets}$

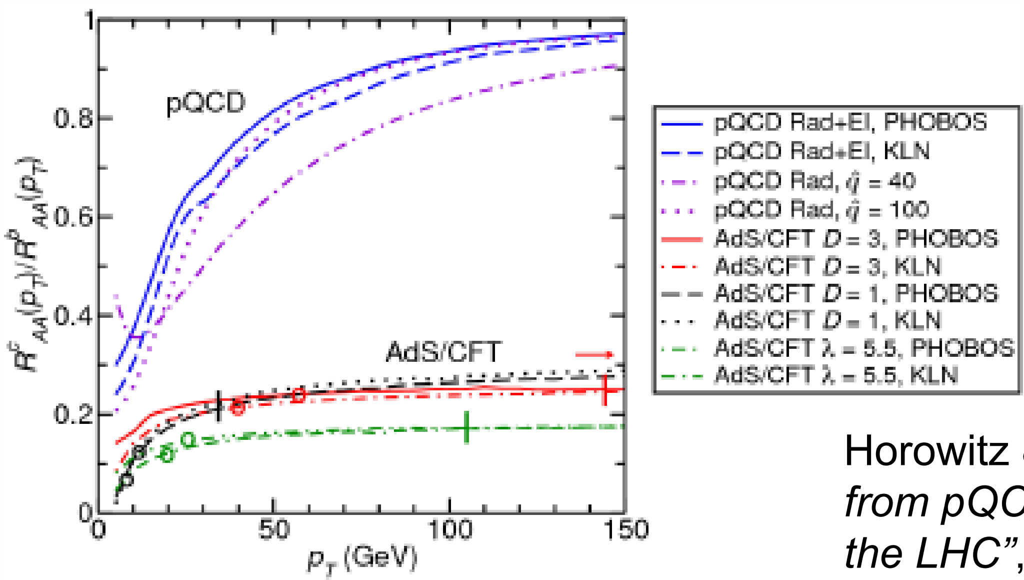
Studies of the identification in CMS of open charm and beauty mesons (e.g. via their D→*Kπ and B→J/ Ψ, μ⁺μ⁻*) produced in heavy-ion collisions are *a* priority.

UNDER CONSTRUCTION

R_{AA} for c and b quarks



Very high $P_T \rightarrow$ LHC, CMS



Double Ratio: $$\frac{R^{c}_{AA}(P_T)}{R^{b}_{AA}(P_T)}$$

Horowitz & Gyulassy, *"Testing AdS/CFT Deviations from pQCD Heavy Quark Energy Loss with Pb+Pb at the LHC"*, Phys.Lett.B**666**:320-323 (2008)

Summary

- LHC will extend energy range and in particular high P_T reach of High Density QCD physics

- new qualitative and quantitative aspects of AdS/CFT

- CMS is preparing to take advantage of the LHC capabilities
  - Particle ID for Elliptic flow reaching very low P_T (RHIC)

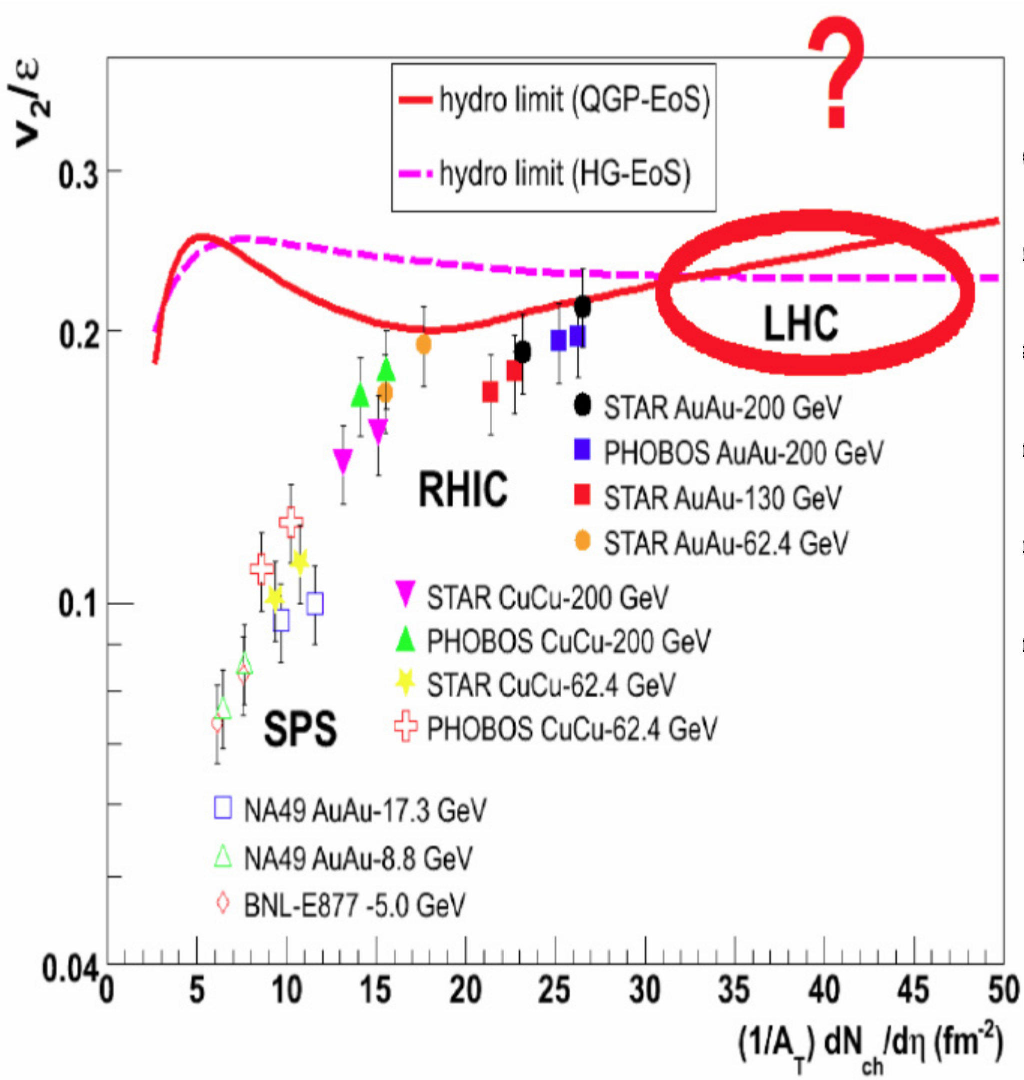
    Null viscosity nuclear fluid persists?
  - CMS excellent hermetic coverage and resolution

    Heavy Quarkonia Melting - J/Ψ and Y mesons

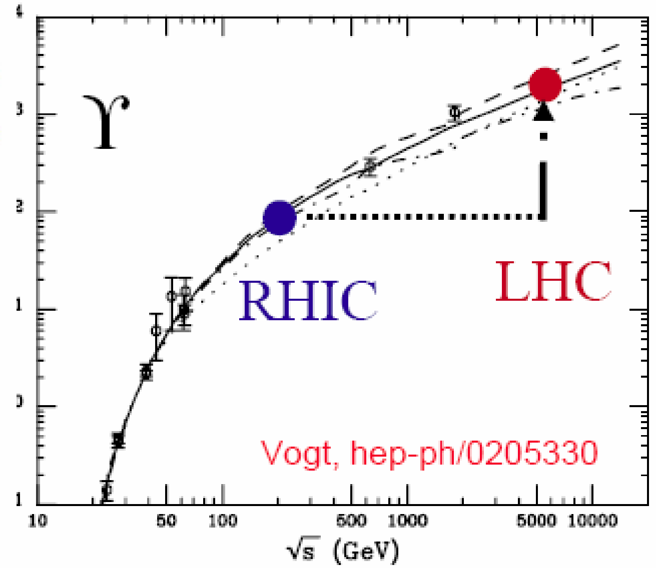
    Jet Effects – heavy quark energy loss with tagged jets

    R_{AA} Factors – pQCD and AdS/CFT for heavy quarks
  - Need baseline pp data…starting in 2009, PbPb 2010

Extras



v_2/ε
hydro limit (QGP-EoS)
hydro limit (HG-EoS)
?
LHC
RHIC
SPS
STAR AuAu-200 GeV
PHOBOS AuAu-200 GeV
STAR AuAu-130 GeV
STAR AuAu-62.4 GeV
STAR CuCu-200 GeV
PHOBOS CuCu-200 GeV
STAR CuCu-62.4 GeV
PHOBOS CuCu-62.4 GeV
NA49 AuAu-17.3 GeV
NA49 AuAu-8.8 GeV
BNL-E877 -5.0 GeV
0.3
0.2
0.1
0.04
0 5 10 15 20 25 30 35 40 45 50
$(1/A_T)\, dN_{ch}/d\eta\ (fm^{-2})$



ϒ
RHIC
LHC
Vogt, hep-ph/0205330
10 50 100 500 1000 5000 10000
$\sqrt{s}$ (GeV)

What is measured in relativistic HI Collisions

- Particle Tracks and energy through detector layers

    Number of charged particles, total energy deposited

- Rapidity (y) → related to "velocity"
- Pseudo-Rapidity (η) → polar angle (θ), azimuthal angle (φ)

    Transverse energy (E_T) to beam direction

    Transverse momentum (P_T)

- Particle Identification (PID)

    Low energy - $p^{\pm}$, $\pi^{\pm}$, $k^{\pm}$, and all $h^{\pm}$

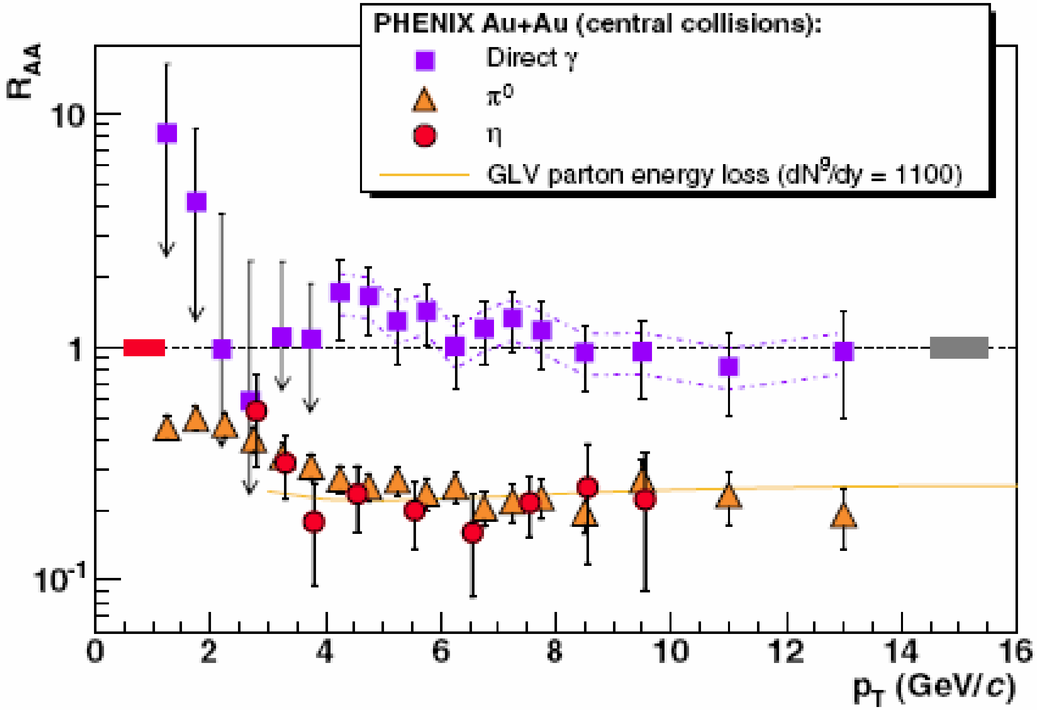
    High energy - $\mu^{\pm}$

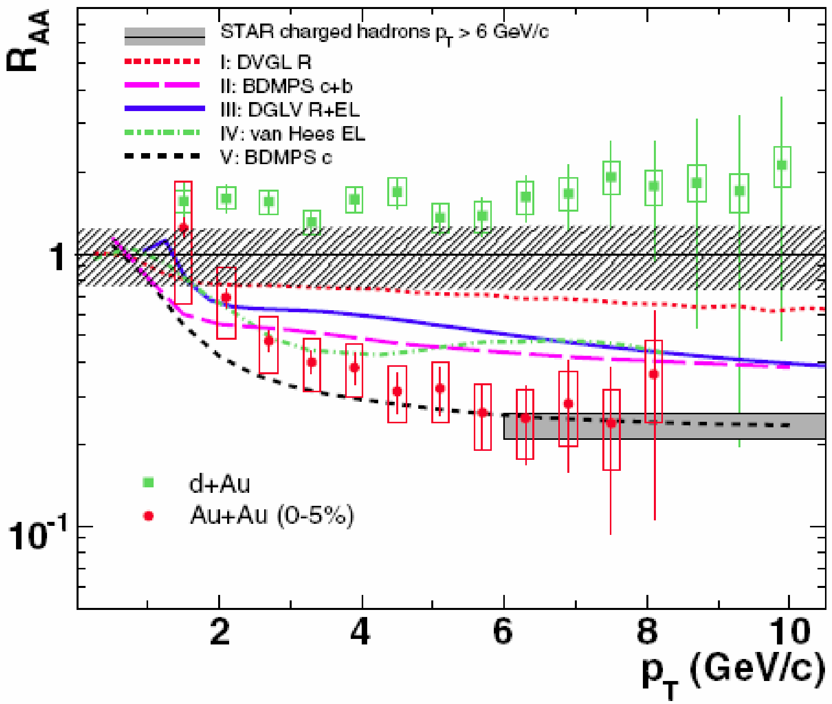
    Reconstruct from tracking – π^0, k^0, Quarkonia Families,

    …and all $h^{\pm}$, $e^{\pm}$

- High Energy Jets (E, φ, θ)

R_{AA} – nuclear matter "modification factor"





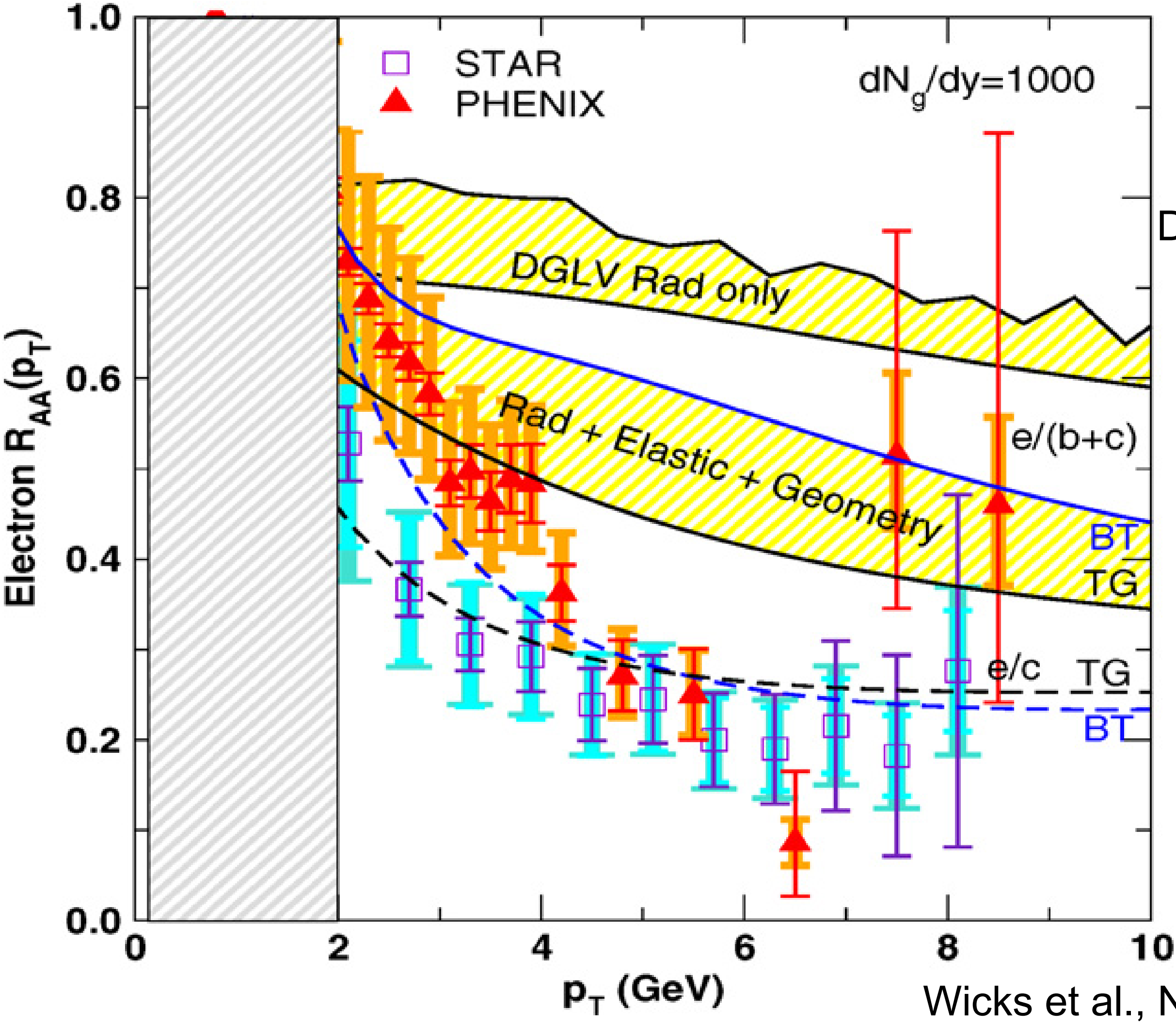
Adler et al. PHENIX, Phys. Rev. Lett. **96** (2006) 202301

Abelev et al. STAR, Phys. Rev. Lett **98**, (2007) 192301

pQCD ok!

Radiative and Collisional energy loss fails for non-photonic e-

R_{AA} for non-photon e- (from c and b jets)



pQCD misses high P_T

Djordjevic et al., PLB **632** (2006) 81

Consider:

non-perturbative contributions

Wicks et al., Nucl. Phys **A784** (2007) 426.