Neutral pion production
in Au+Au collisions at RHIC

PH✳ENIX

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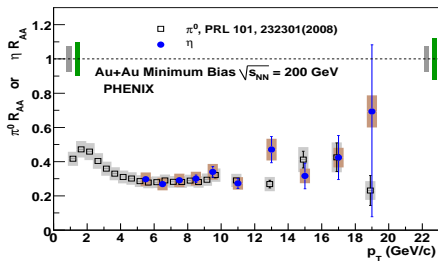
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Hard Probes 2012
27 May – 1 June 2012, Cagliary (Sardinia, Italy)

Jet Quenching

Hadron production sensitive to:

- Initial state interactions
- Hot medium (suppression)
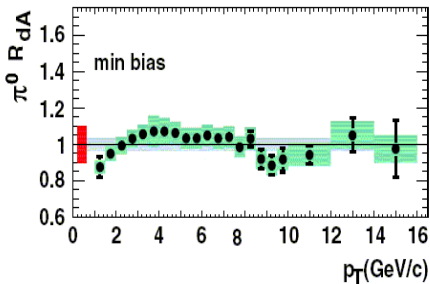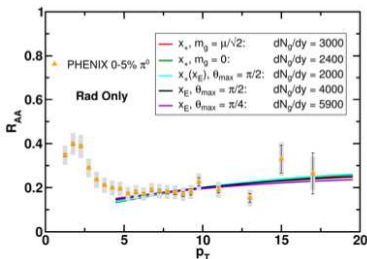- Cronin effect (enhancement)

Comparing Au+Au to p+p:

Nuclear Modification Factor

$$R_{AA}^h(p_T, \eta) = \frac{1}{\langle N_{bin} \rangle} \frac{d^2\sigma_{AA \to h}/dp_T d\eta}{d^2\sigma_{pp \to h}/dp_T d\eta}$$

Central Au+Au: hadrons suppressed

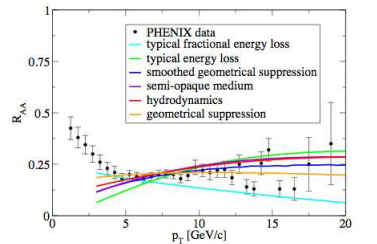- Strong centrality dependence
- Photons: no suppression

- No suppression in **d+Au**

Theoretical motivation

Horowitz, Cole, PRC81, 024909   Renk, PRC79, 054906

R_{AA} **not restrictive enough on models**
Additional input required to discriminate b/w different mechanisms
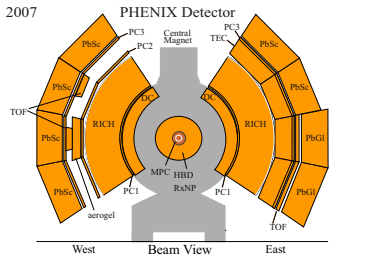
Different model classes on the market

GLV Opacity expansion (Gyulassy, Lévai, Vitev)
BDMPS-Z-ASW Multiple soft scattering (Wiedemann, NPB588)
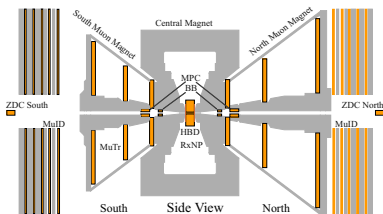HT Higher-twist (Guo, Wang, Majumder)
AMY Thermal field theory (Arnold, Moore, Yaffe)

The PHENIX experiment (2007)

Reconstruction of $\pi^0 \to \gamma\gamma$

- Calorimeter: **PbSc** and PbGl $|\eta| \leq 0.35$
- photons detected
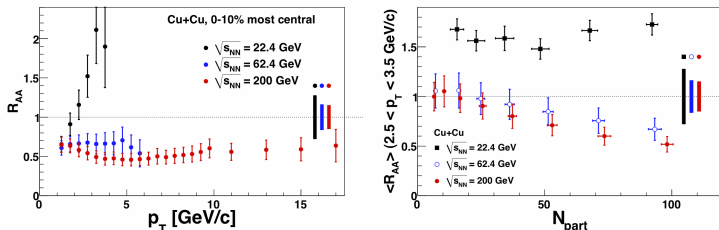- cluster merging negligible below $p_T < 12$ GeV

Reaction plane determination

- **RxNP** (Plastic Scintillator) $1.5 \leq |\eta| \leq 2.8$
- **MPC** (PbWO4 Crystals) $3.1 \leq |\eta| \leq 3.7$
- Improved v_2 determination

Evolution of suppression w.r.t. system size, energy

Phys. Rev. Lett. **101**, 162301 (2008) [arXiv:0801.4555 [nucl-ex]].
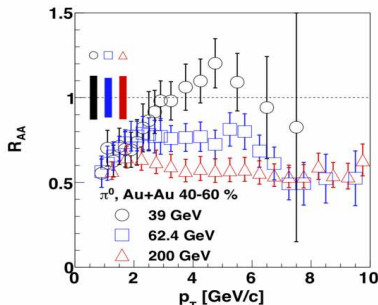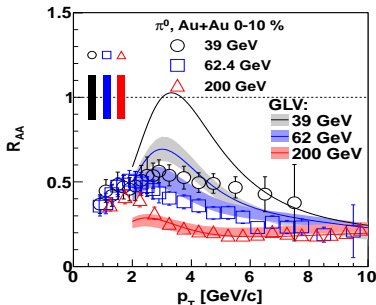

Energy dependence in Cu+Cu (smaller system)

- Suppression in central 62.4 GeV and 200 GeV
- No suppression in peripheral
- Enhancement at 22.4 GeV ($\sim$constant)

# Au+Au central R_{AA} from 32 to 200 GeV (2010 data)

[arXiv:1204.1526]

- Strong suppression in central collisions even at 39 GeV
- 62.4 and 200 GeV R_{AA} is similar at higher p_T
- No suppression at 39 GeV at lower centralities
- Central data comparable with GLV model
  Solid curves represent 30% higher initial-state parton mean free paths
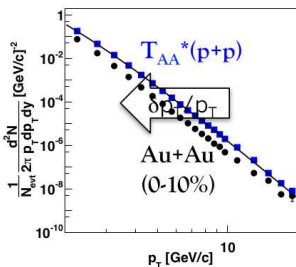 corresponding to a larger Cronin effect)

Integrated R_{AA}

[arXiv:1204.1526]
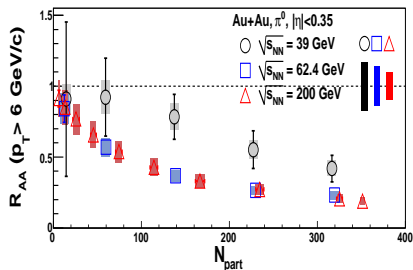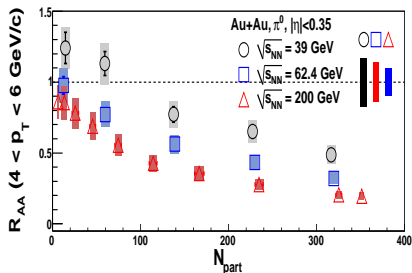
- 62.4 and 200 GeV data shows strong suppresion even in more peripheral collisions
- 39 GeV is only suppressed at higher centralities
- No significant difference between 62.4 and 200 GeV data points if $p_T > 6 \; \mathrm{GeV}/c$
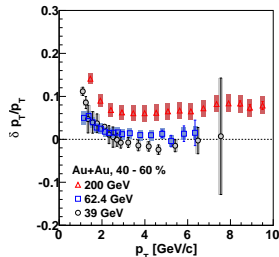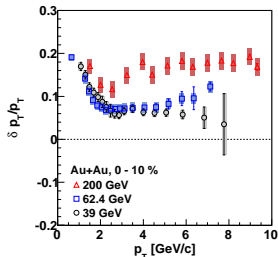
Fractional energy loss

Horizontal shift of Au+Au spectrum from properly scaled p+p

- Largest energy loss in 200 GeV
- 62.4 GeV and 39 GeV agree at lower p_T
- 39 GeV not suppressed at higher p_T
  $S(p_T) < 0$ corresponds to $R_{AA} > 1$
- Larger energy loss in central collisions

Note: Cronin-effect is $\sqrt{s}$-dependent and it is negligible at $\sqrt{s_{NN}} = 200$ GeV (see d+Au)

Fractional energy loss

$S(p_T) = \delta p_T / p_T$

x_T-scaling

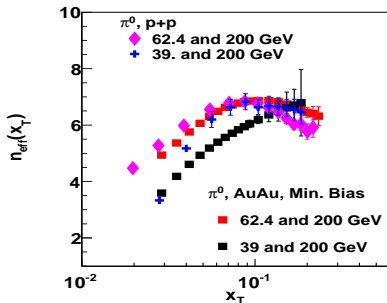### x_T scaling in hard scattering

$$x_T = 2p_T/\sqrt{s}$$

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{\sqrt{s}^{n(x_T, \sqrt{s})}} G(x_T)$$

LO QCD $n(x_T) = 4$

Obtaining the power between different $\sqrt{s_{NN}}$ values by linear approximation on the log scale
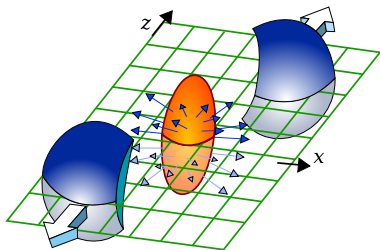
Effective power

$$n_{eff}(x_T) = \frac{log\left(\frac{Yield(x_T, \sqrt{s_1})}{Yield(x_T, \sqrt{s_2})}\right)}{log(\sqrt{s_2}/\sqrt{s_1})}$$
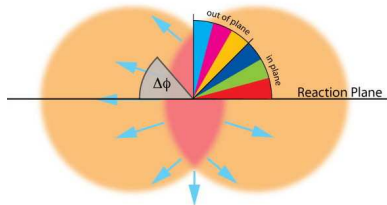

- p+p values & trend comparable
- 62.4 vs. 200 GeV Au+Au shows similar trend to p+p
- 39 vs. 200 GeV Au+Au radically different – NO scaling for $x_T<0.2$

Geometry

Flow: Initial spatial anisotropy converts to momentum anisotropy (v_2)
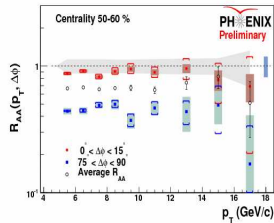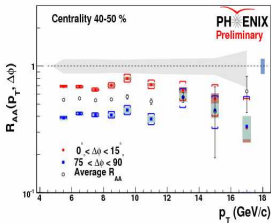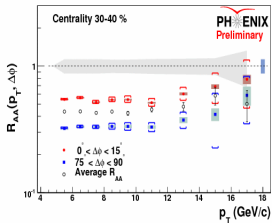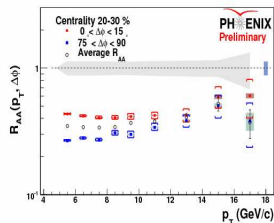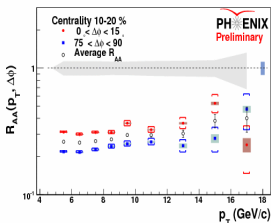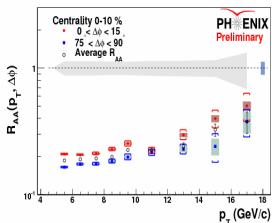

Red initial short pathlength
Cyan long pathlength

R_{AA} wrt. reaction plane $\sim R_{AA}$ wrt. path length

$$R_{AA}(p_T, \Delta\Phi) \approx R_{AA}(p_T) \times \frac{N(p_T, \Delta\Phi)}{\sum_i N(p_T, \Delta\Phi_i)}$$

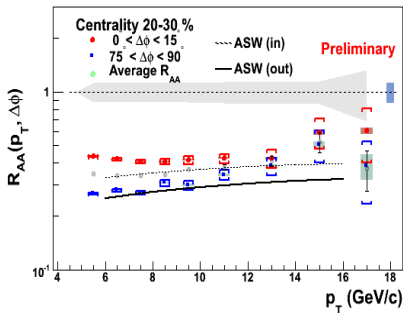$$N(p_T, \Delta\Phi_i) \approx N(1 + 2v_2 \cos(2\Delta\Phi_i))$$
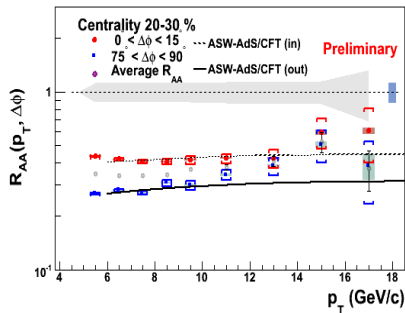
2007 high luminosity, high p_{T} data

- Extends to $p_{\mathrm{T}} = 19 \ \mathrm{GeV}/c$ in several centrality and $\Delta\Phi$ bins
- Centrality-dependent angular behavior seen

Model comparison in $R_{AA}(p_T, \Delta\Phi)$

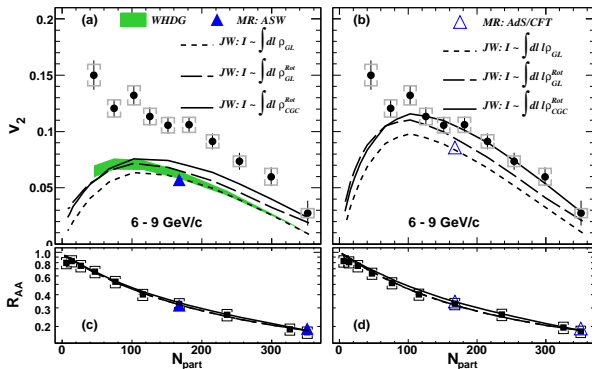

ASW in pQCD
Phys.Rev.C79,024901(2009)

ASW in AdS/CFT
Phys.Lett.B685,270(2010)

$\Delta\Phi$-binned data able to differentiate b/w models

- Out-of-plane R_{AA} (large path length) reproduced by both
- In-plane R_{AA} (small path length) supports AdS/CFT scenario

Model comparison in v_2 and R_{AA} vs. N_{part}

Energy loss models:
- **WHDG** (PQCD)
- **CT** and **JR** (AdS/CFT)
Only radiative processes

Initial geometry in JR:
- CGC (solid)
- Glauber (dotted)
- Glauber with fluctuations (dashed)

3D hydro + pQCD   3D hydro + AdS/CFT

Flow also supports AdS/CFT-like path length dependence over pQCD

Summary

- Evolution of π^0 suppression
  - In central collisions, production suppressed from 39 to 200 GeV
  - An enhancement is present at 39 GeV mid-peripheral collisions
    Indicating a substantial Cronin effect
  - 62.4 GeV and 200 GeV R_{AA} are similar above $p_T < 5 \text{ GeV}$

- Fractional energy loss
  - Largest at 200 GeV and in central collisions

- x_T-scaling
  - $n_{eff}(x_T)$ shows a very different trend when 39 vs. 200 GeV are compared

- Azimuth-dependent $R_{AA}(p_T, \Delta\Phi)$
  - Capable of differentiating between different models
  - In-plane data favors AdS/CFT correspondence over pQCD
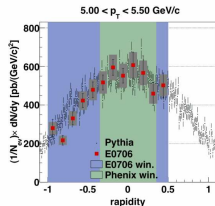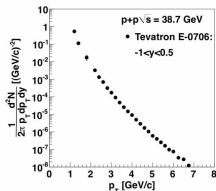
Thank you for your attention!

BACKUP: p+p references for 39 GeV and 62.4 GeV

62 GeV
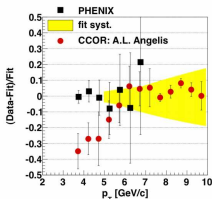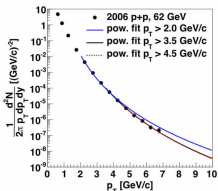
39 GeV

- p+p available up to $p_T < 7\ \mathrm{GeV}$
- extrapolation: power-law function
- systematics on R_{AA}

- p+p reference: Tevatron E0706
  Phys.Rev.D68:052001,2003
- Different rapidity range
- Different acceptance
- Corrections with PYTHIA