Universiteit Utrecht

Comparing energy loss phenomenology in a hot dense medium

Marta Verweij
Utrecht University
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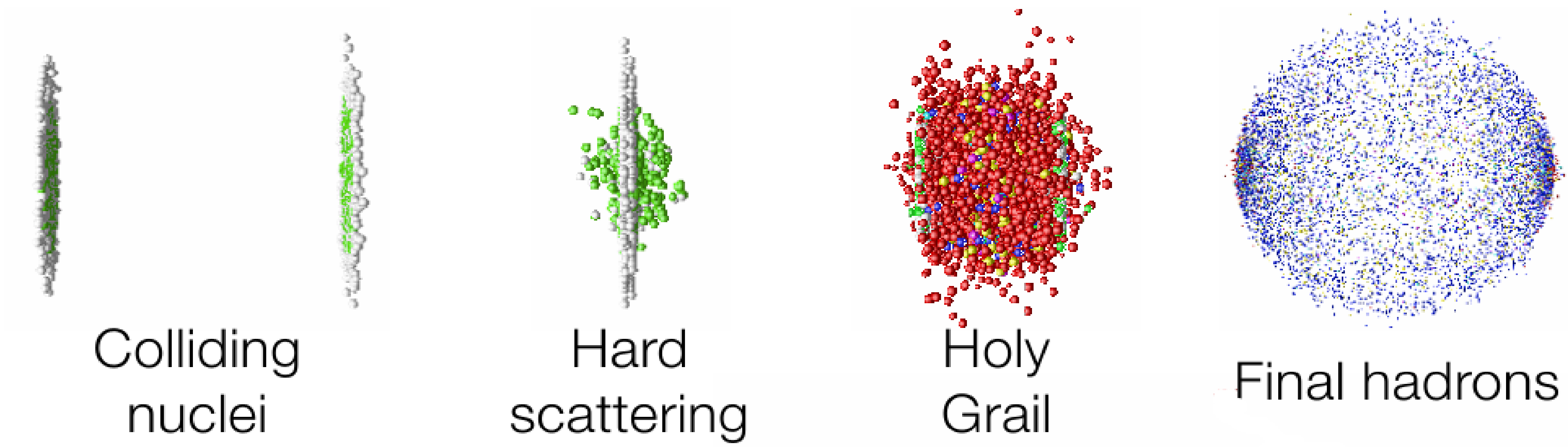
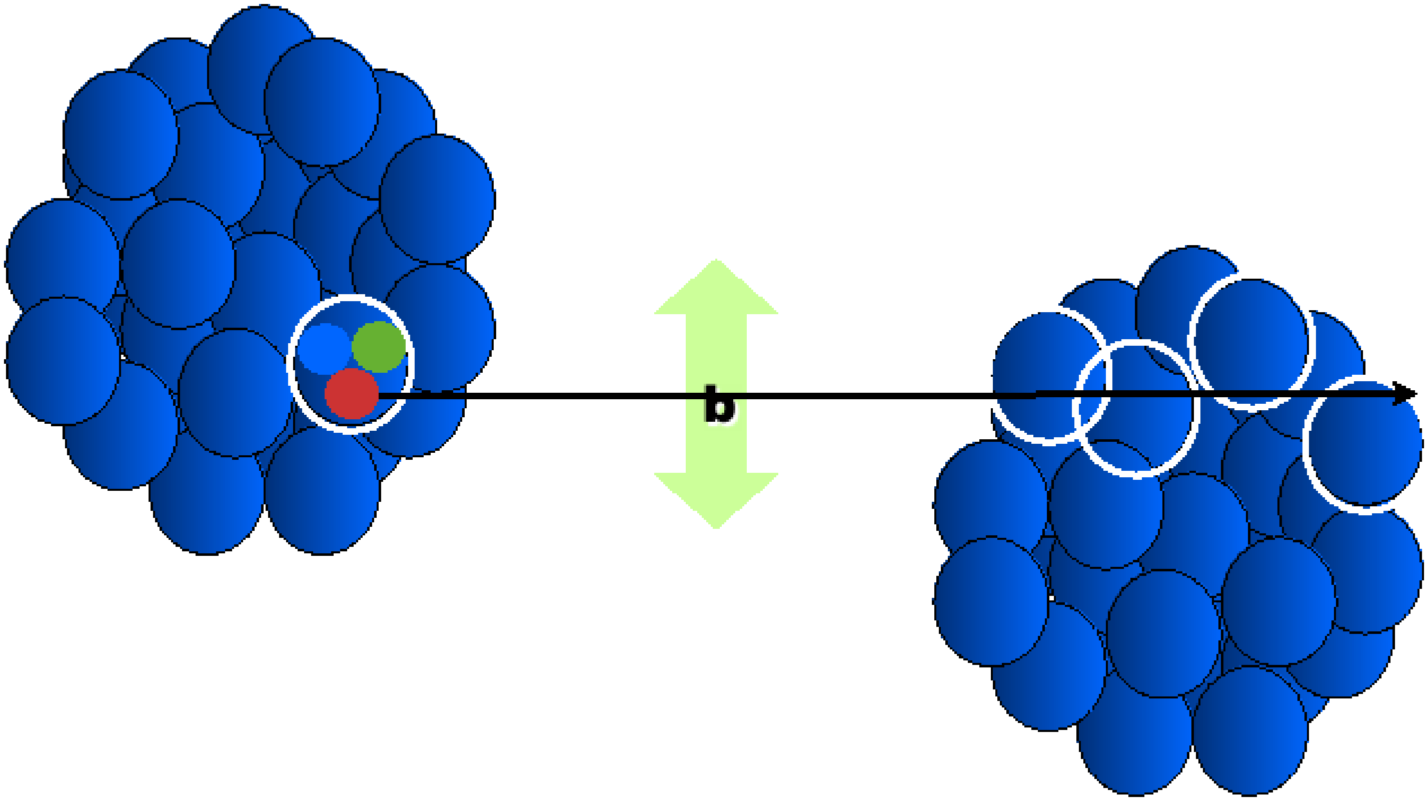
Heavy ion collision



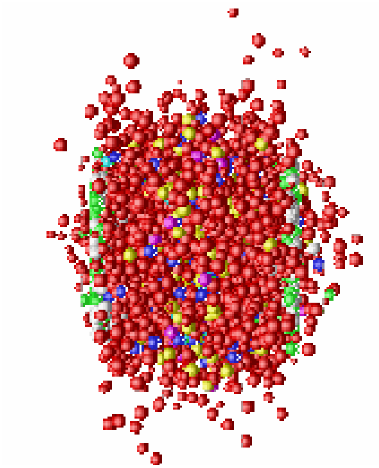
Heavy ion collision

Hard scattering

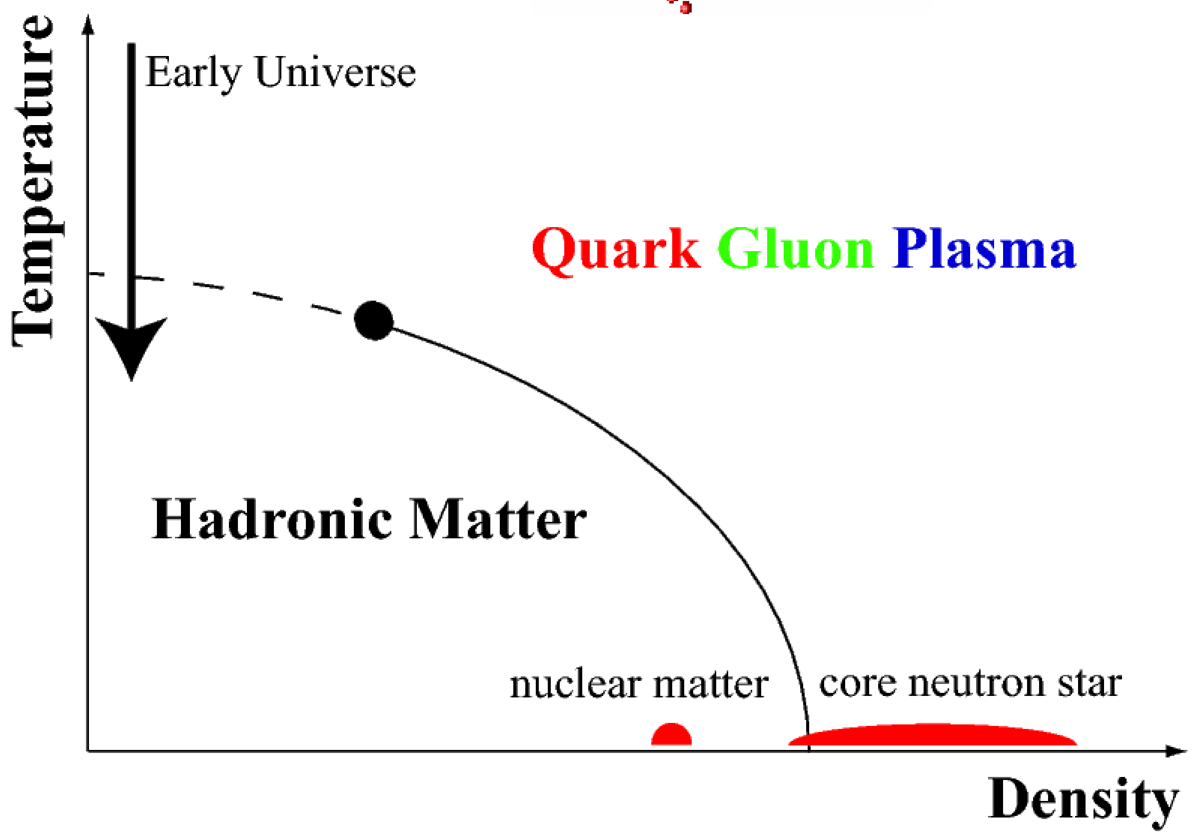


- Many independent hard scatterings.

Hot dense medium

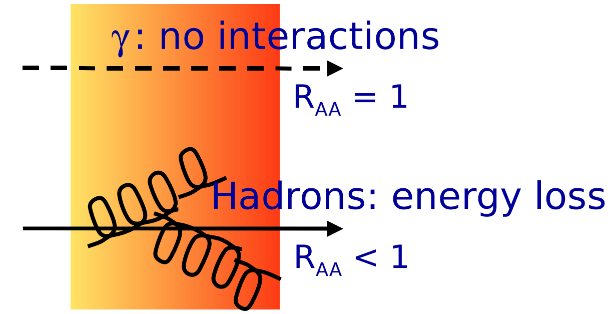


- What is the density of the medium?
- Energy density of the medium?
- Viscosity of the medium?
- Quark Gluon Plasma?
- Phase transition?
- Equation of state?

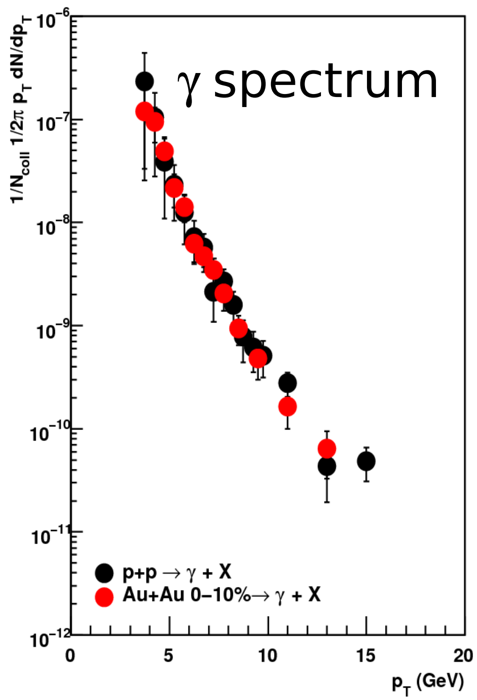


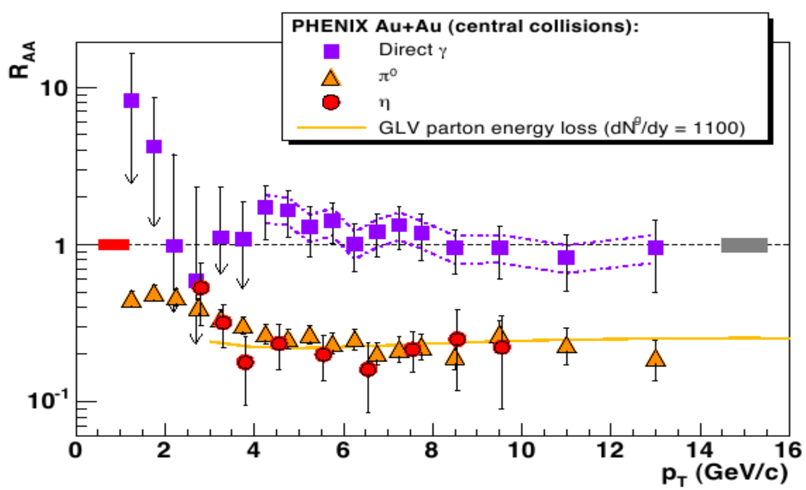
Nuclear Modifaction Factor

$$R_{AA} = \frac{dN/dp_t|_{Au+Au}}{N_{coll} dN/dp_t|_{p+p}}$$



- Yield per collision relative to p-p



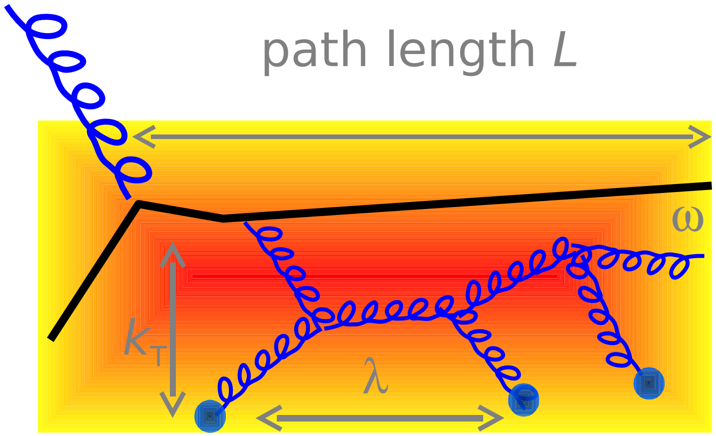


PHENIX, PRL 94, 232301

- High p_t hadrons strongly suppressed.
- Direct photons scale with N_{coll}.
- A+A is superposition of p+p

Energy loss in hot dense medium

- Parton traversing medium radiates gluons.
- Medium characterized by: Transport coefficient $\hat{q} = \frac{\langle k_t^2 \rangle}{\lambda}$



$$\frac{dN}{dp_{t,hadr}} = \frac{dN}{dp_{t,parton}} \circ P(\Delta E) \circ D(p_{t,hadr}/p_{t,parton})$$

Measurement	Input parton spectrum Known LO pQCD	**Energy loss Has to be calculated**	Fragmentation Factor Known from e+e-

Energy loss models

- Multiple Soft Scattering Approximation:
  many interactions
  Input parameters: qhat and L
- Opacity Expansion:
  few hard interactions
  Input parameters: mu and lambda
- Both have an energy loss probability distribution.

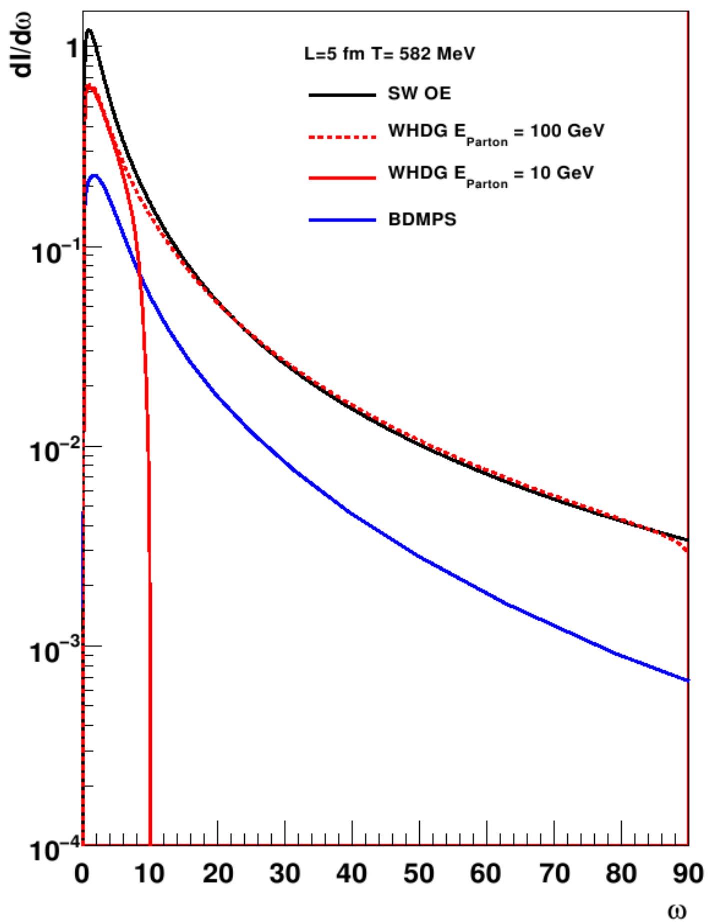
TECHQM Brick Problem

Theory-Experiment Collaboration for Hot QCD Matter

- Brick: fixed length L and temperature T.
- Parton of energy E is shot through brick.
- Apple-to-apple comparison of:
  - Multiple Soft Scattering (ASW-BDMPS) *Phys.Rev.**D68** 014008*
  - Opacity expansion:
    - ASW-SH *Phys.Rev.**D68** 014008*
    - WHDG radiative *Nucl.Phys.**A784** 426*
- Input parameters are calculated from T.

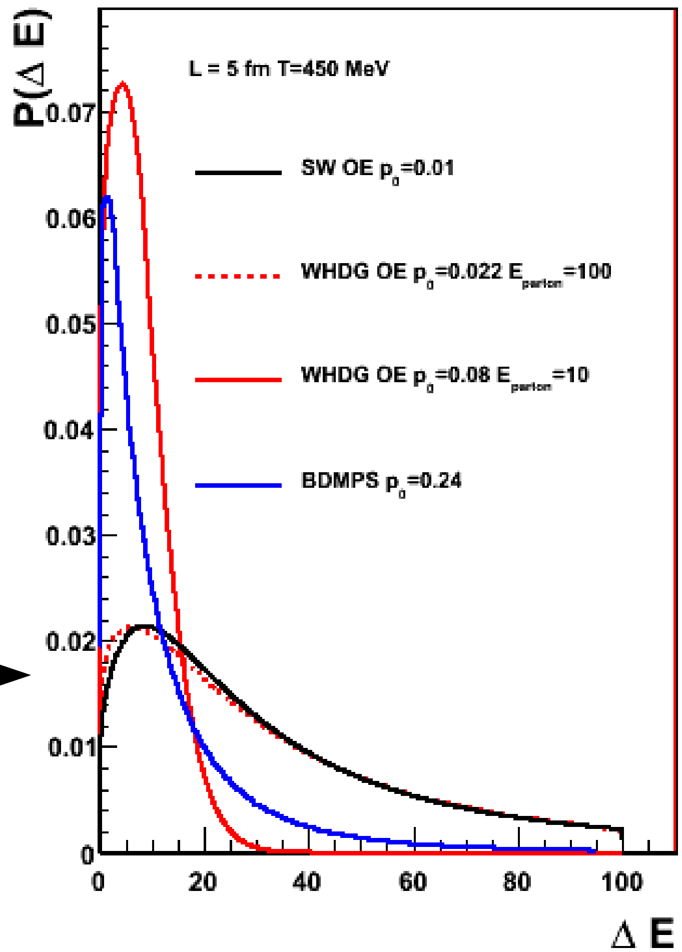
Brick examples

- Single gluon emission spectrum



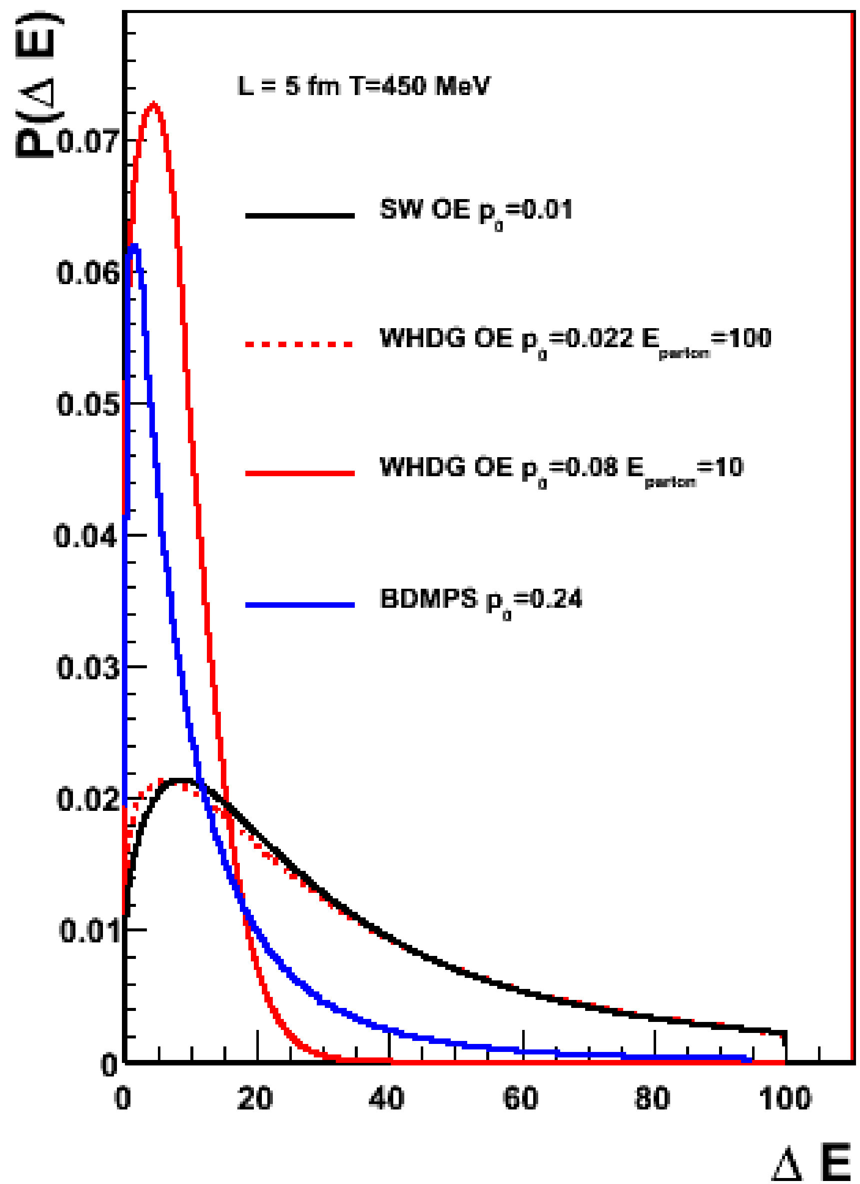
Poisson convolution gives multiple gluon spectrum →

- Energy loss distribution



Energy loss probability distribution

- P(ΔE):
  - Continuous part
  - Discrete part
- Large differences between models under same medium conditions.

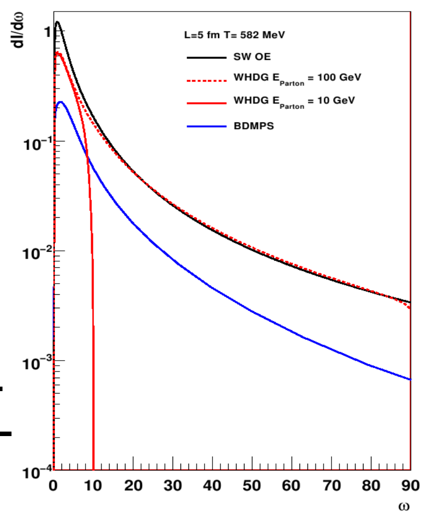


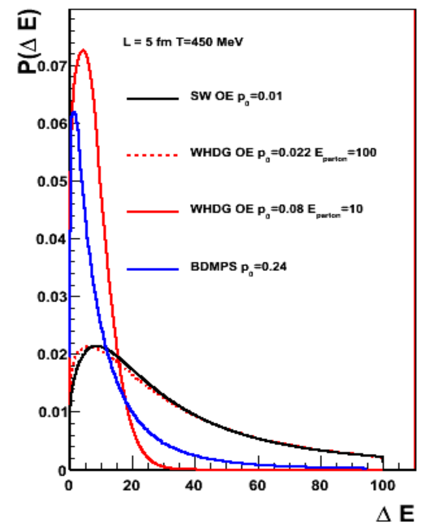
How much energy do we lose?

- Single gluon spectrum
- Energy loss distribution

$$\langle N_{gl} \rangle = \int d\omega \frac{dI}{d\omega}$$

$$\langle \omega \rangle = \frac{\int d\omega\, \omega \frac{dI}{d\omega}}{\langle N_{gl} \rangle}$$





	$\langle N_{gl} \rangle$	$\langle \omega \rangle$ (GeV)	$\langle \Delta E \rangle$ (GeV)
BDMPS	2.0	13	3.4
WHDG (E=10 GeV)	3.0	3.2	5.4
WHDG (E=100 GeV)	5.3	12	8.1
SWOE	7.2	9.8	9.0

► for E_{max} = 10 GeV

- **Large difference between BDMPS and OEs!**

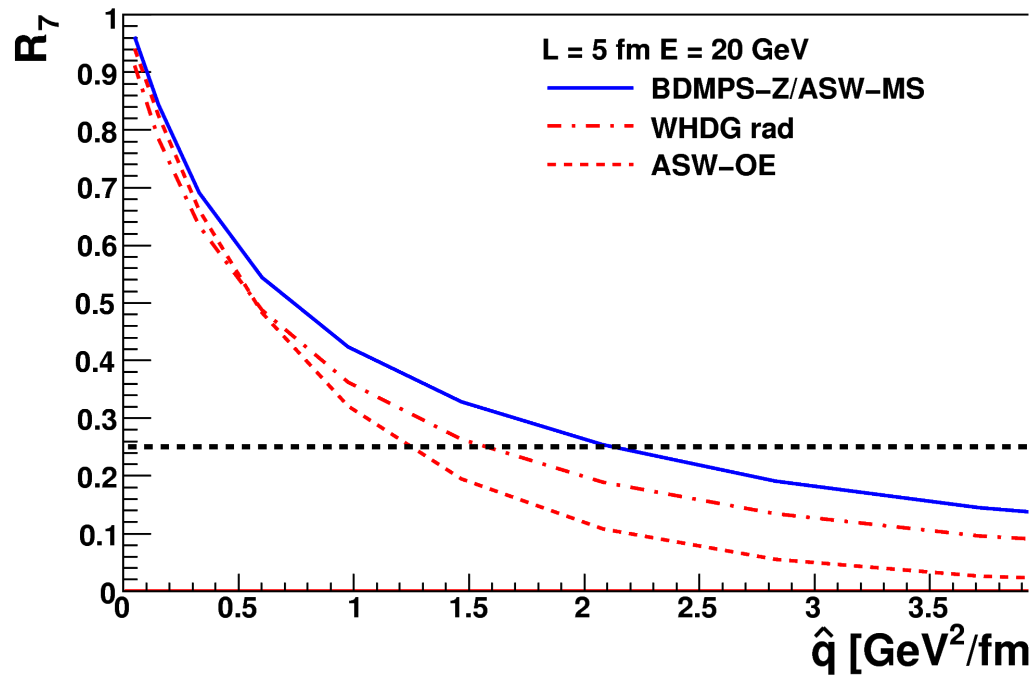
Suppression in a brick

- R_7 is an approximation for R_{AA}.

$$R_n = \int_0^1 d\epsilon(1-\epsilon)^{n-1}P(\epsilon)$$

$$\epsilon = \Delta E/E$$

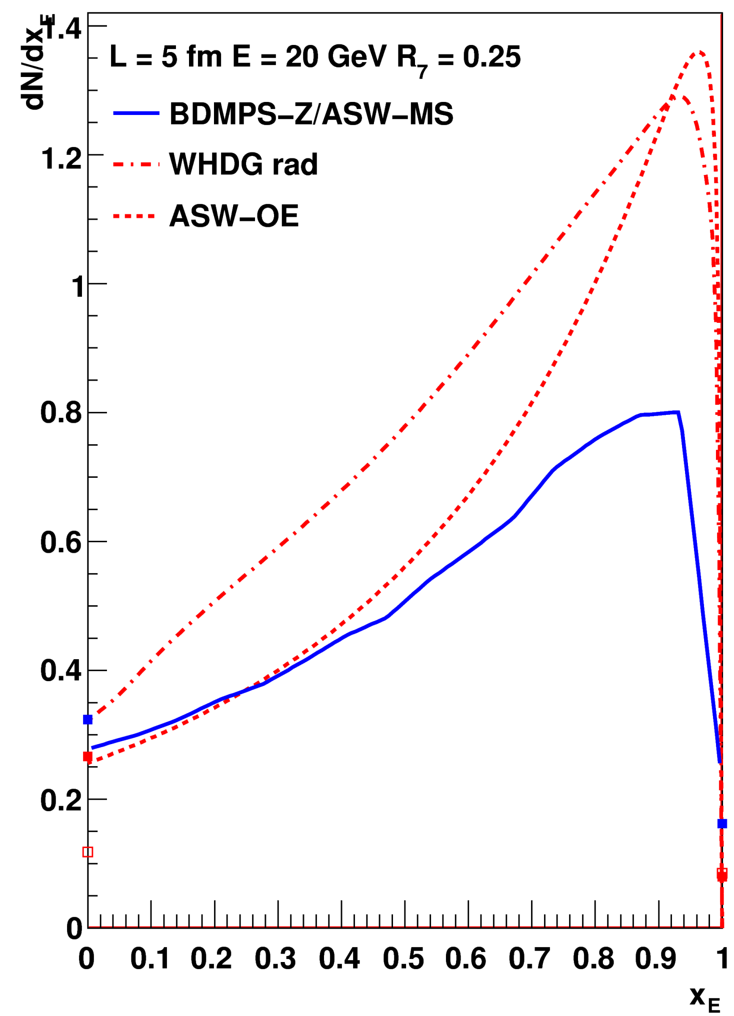
- Roughly factor 2 difference in qhat for same suppression.



R7=0.25	qhat (GeV^2/fm)	T (MeV)
BDMPS	2.13	400
ASW-OE	1.25	360
WHDG	1.58	330

Outgoing quark spectrum

- $x_E = 1 - \Delta E/E$
- $x_E = 0$: Absorbed quarks
- $x_E = 1$: No energy loss
- *Black-white* scenario for BDMPS



“Realistic” Geometry

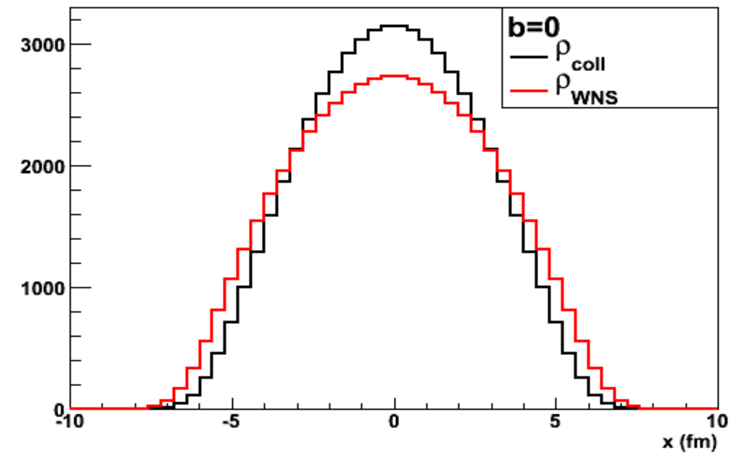
- Parton spectrum: LO pQCD T. Renk
- Energy loss: BDMPS and WHDG

- Fragmentation: KKP

"Realistic" Geometry

- Parton spectrum: LO pQCD T. Renk
- Energy loss: BDMPS and WHDG
  - Optical Glauber:
    - Density profile of medium
      - Collisional scaling:

$$\rho_{coll} = k_{coll} \times T_A T_B$$



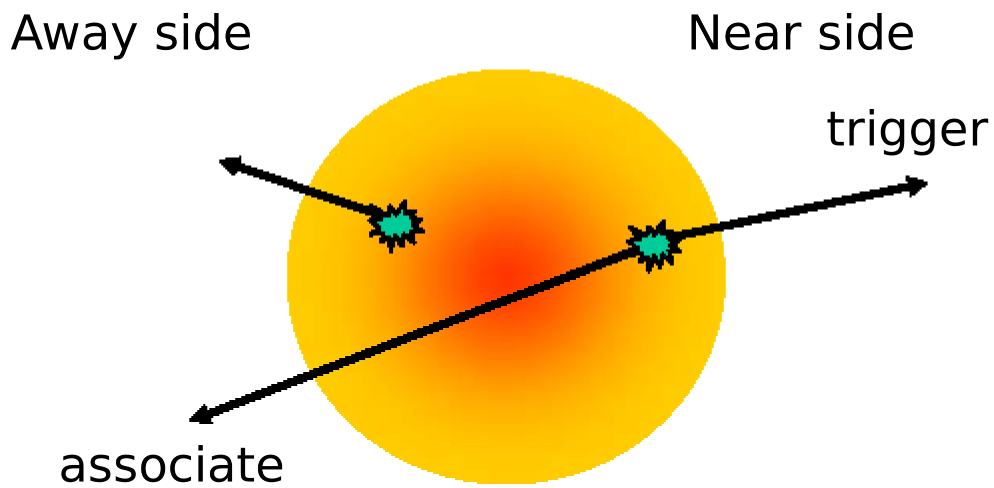
      - Participant scaling:

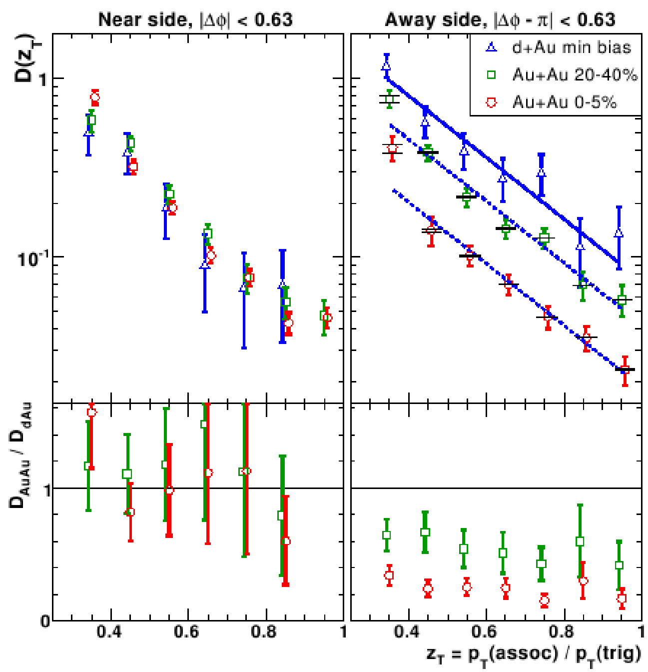
$$\rho_{WNS} = k_{WNS} \times \left(T_A \left(1 - e^{-T_B \sigma_{NN}}\right) + T_B \left(1 - e^{-T_A \sigma_{NN}}\right)\right)$$

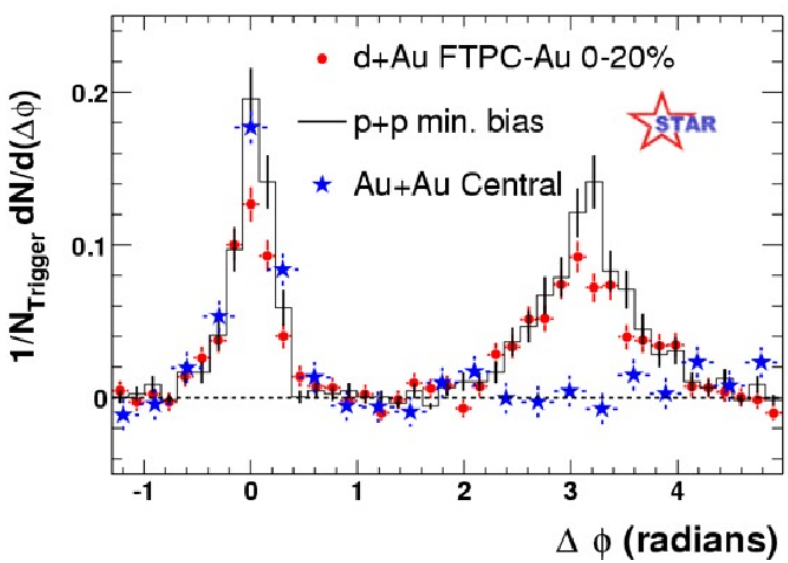
- Fragmentation: KKP

Di-hadron suppression

- I_{AA}: suppression of away side (associate hadrons)

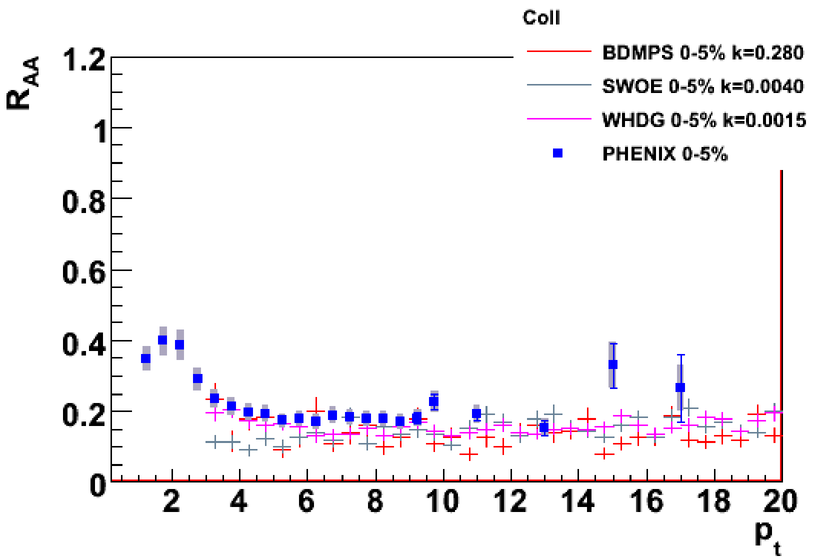






R_{AA} and I_{AA}
Glauber geometry

- All models can always be fitted to R_{AA}.



R_{AA} and I_{AA}
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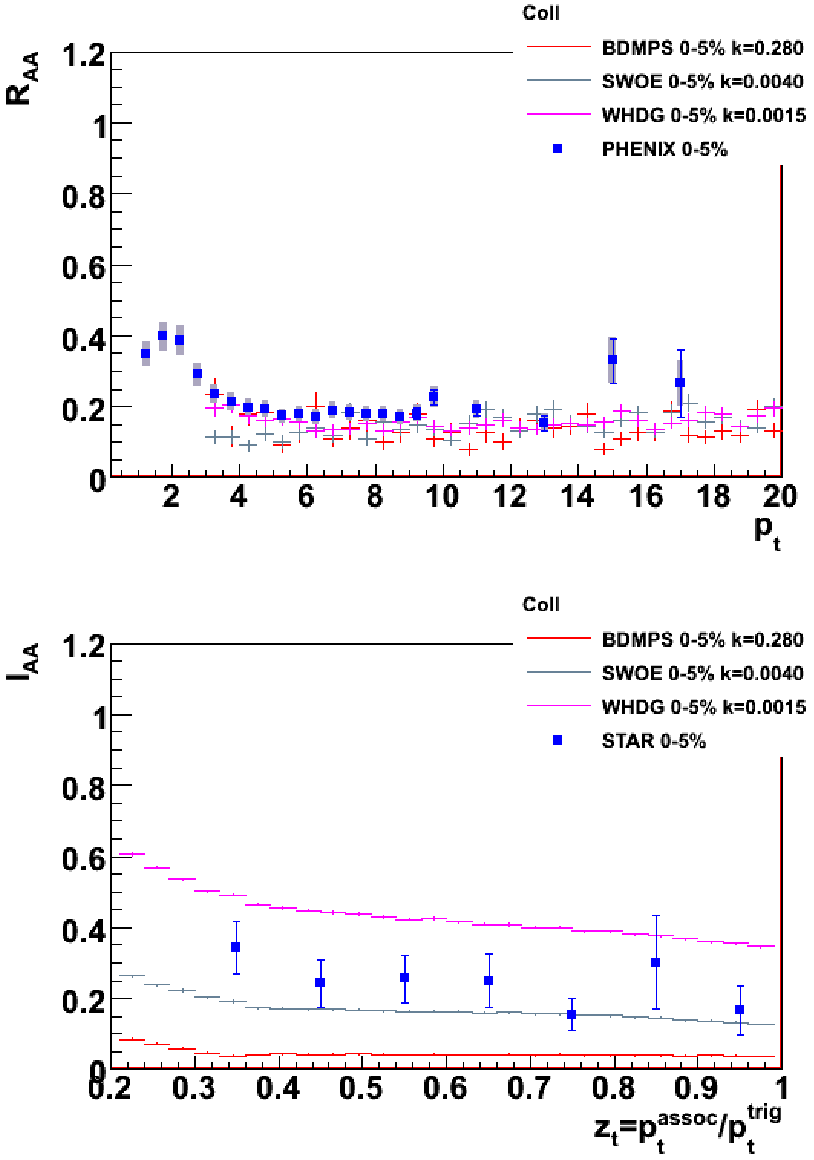
- Using constraint obtained from R_{AA} fit, models do not “predict” I_{AA} measurement.



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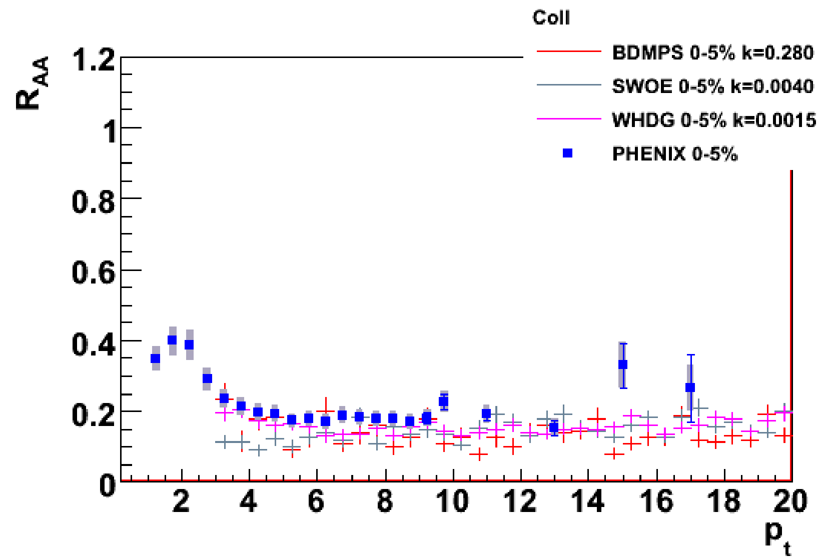
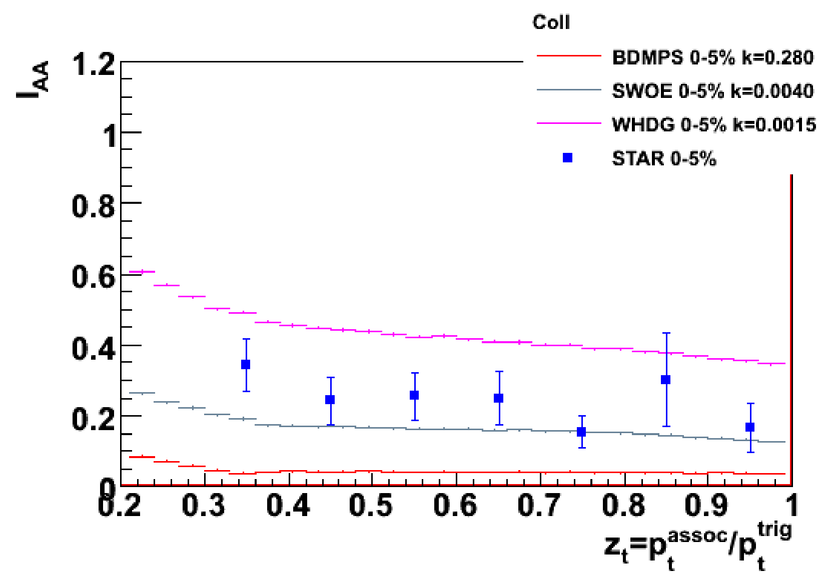
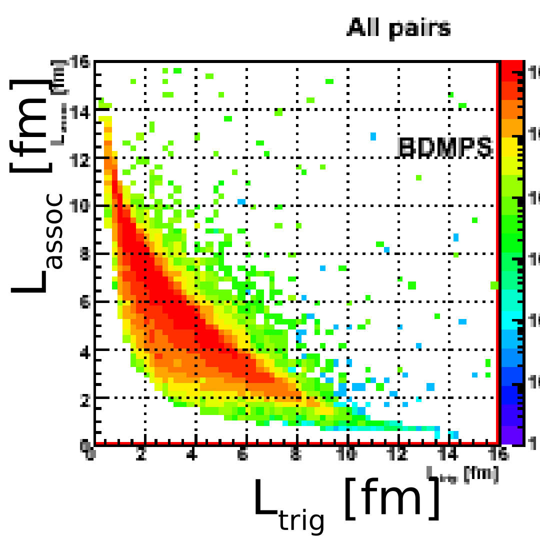
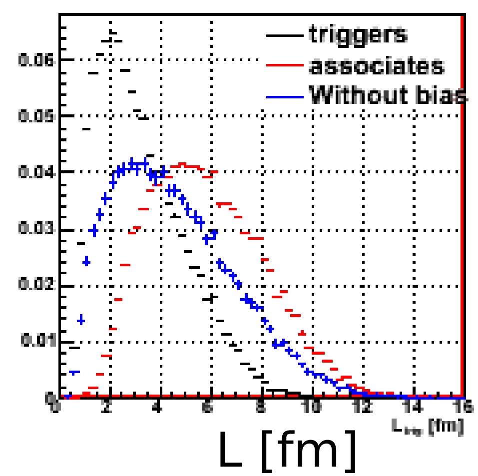






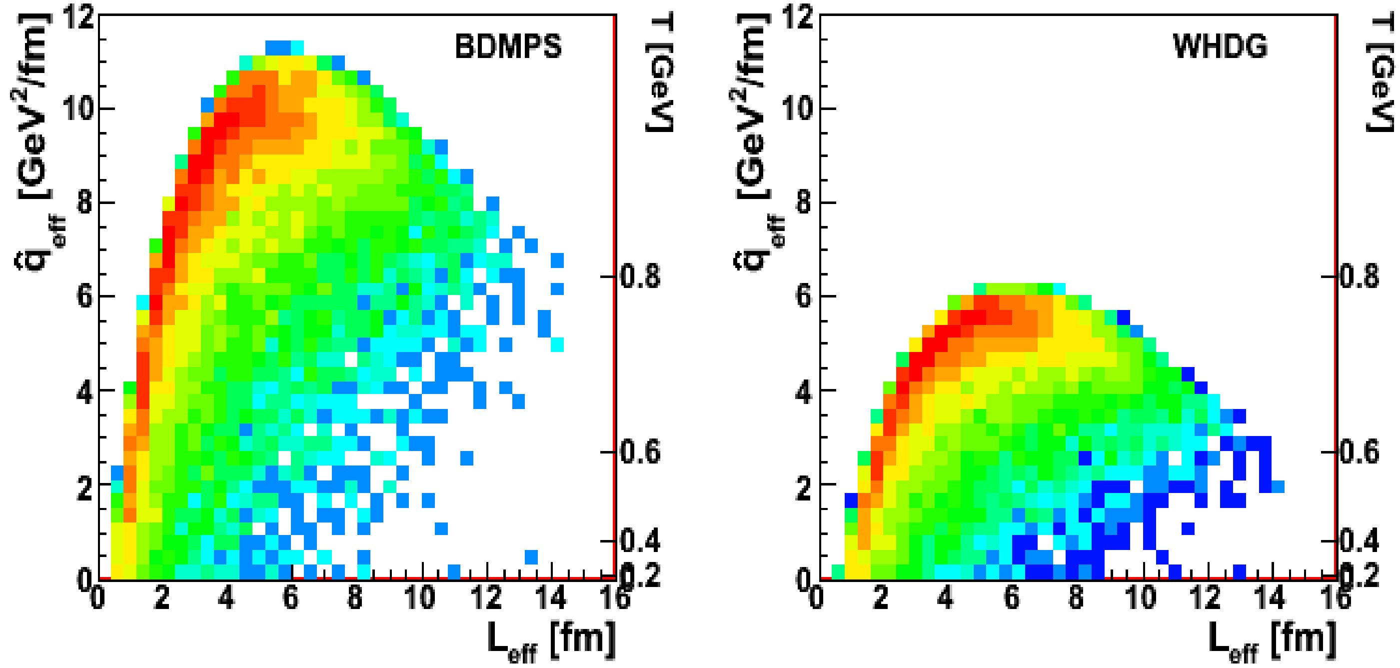


Conclusion

  - All models fit RAA
  - IAA can distinguish between models
- Outlook
  - Typical parton energy at RHIC: 10 GeV
  - At LHC: 100 GeV -> absorption rate lower

Backup

BDMPS vs WHDG (2)



- Scattered background: medium density for best fits collisional scaling in static medium.

Single Gluon Spectra

- BDMPS:

$$\omega \frac{dI}{d\omega} = \frac{\alpha_s C_R}{(2\pi)^2 \omega^2} 2\mathrm{Re} \int_{\xi_0}^{\infty} dy_l \int_{y_l}^{\infty} d\bar{y}_l \int d\mathbf{u} \int_0^{\chi\omega} d\mathbf{k}_\perp \, e^{-i\mathbf{k}_\perp \cdot \mathbf{u}} \, e^{-\frac{1}{2}\int_{\bar{y}_l}^{\infty} d\xi \, n(\xi)\, \sigma(\mathbf{u})}$$
$$\times \frac{\partial}{\partial \mathbf{y}} \cdot \frac{\partial}{\partial \mathbf{u}} \int_{\mathbf{y}=0}^{\mathbf{u}=\mathbf{r}(\bar{y}_l)} \mathcal{D}\mathbf{r} \exp\left[i \int_{y_l}^{\bar{y}_l} d\xi \frac{\omega}{2} \left(\dot{\mathbf{r}}^2 - \frac{n(\xi)\sigma(\mathbf{r})}{i\,\omega} \right) \right]$$

- ASW-SH:

$$\omega \frac{dI}{d\omega} = \frac{4\alpha_s C_R}{\pi} (n_0 L)\gamma \int_0^{\infty} \tilde{q} d\tilde{q} \left[\frac{\tilde{q}^2 - \sin \tilde{q}^2}{\tilde{q}^4} \right] \times \left(\frac{1}{\gamma + \tilde{q}^2} - \frac{1}{\sqrt{(\kappa^2 + \tilde{q}^2 + \gamma^2)^2 - 4\kappa^2 \tilde{q}^2}} \right)$$

- WHDG:

$$x \frac{dN_g}{dx} = \frac{C_R \alpha_s}{\pi} \frac{L}{\lambda} \int_0^{q^2_{\max}} \frac{2q^2 \mu^2 dq^2}{\left(4xE\hbar c/L\right)^2 + \left(q^2 + \beta^2\right)^2}$$

$$\times \int_0^{k^2_{\max}} \frac{dk^2}{k^2 + \beta^2} \frac{k^2\left(k^2 - q^2 + \mu^2\right) - \beta^2\left(k^2 - q^2 - \mu^2\right)}{\left((k-q)^2 + \mu^2\right)^{3/2}\left((k+q)^2 + \mu^2\right)^{3/2}}$$