भारतीय प्रौद्योगिकी संस्थान दिल्ली
Indian Institute of Technology Delhi

Diffractive Vector Meson Production Using Sartre With Machine Learning

QCD with Electron Ion Collider (QEIC) II

Jaswant Singh and **Tobias Toll**

December 19, 2022

Indian Institute of Technology, New Delhi

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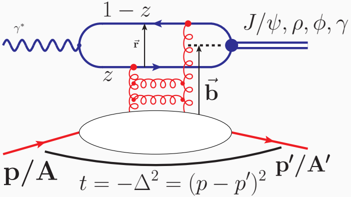
Electron-proton Scattering

Diffractive Vector Meson Production



- Exclusive measurement :

  $e + p \rightarrow e + \mathrm{VM}/\gamma + p$

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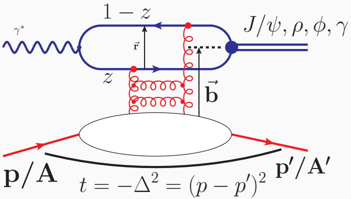

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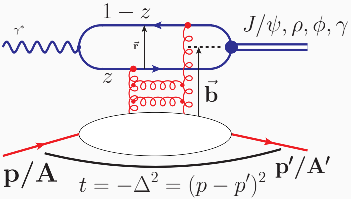

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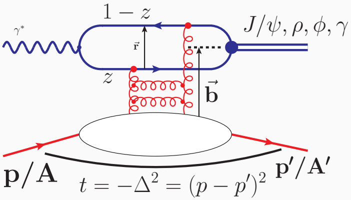

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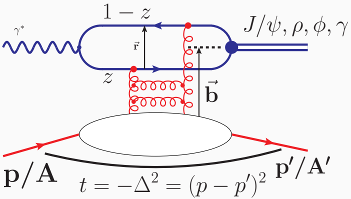

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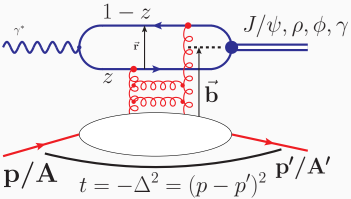

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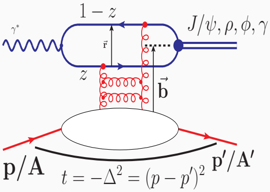
- Sensitive to high gluon densities

Diffractive Vector Meson Production....



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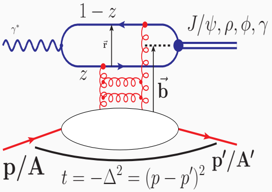

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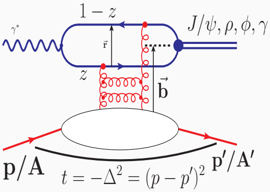

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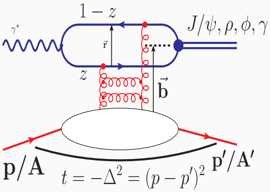

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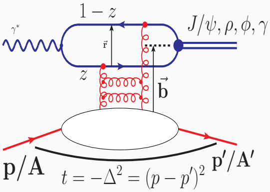

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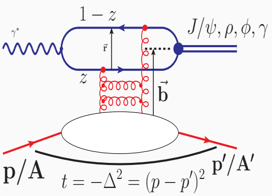

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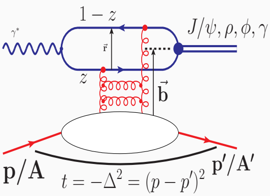

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- a sensitive probe to high gluon density and transverse spatial profile.

Dipole Model

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Golec-Biernat, Wusthoff 1999,
Kowalski, Teaney 2000

- The bSat dipole model:

$$\frac{d\sigma_{q\bar{q}}}{d^2\mathbf{b}} = 2\left[1 - \exp(-\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) xg(x, \mu^2)\, T_p(\mathbf{b}))\right]$$

Where: $T_p(\mathbf{b}) = \frac{1}{2\pi B_p} \exp(-\mathbf{b}^2/2B_p)$, $xg(x, \mu_0^2) = A_g x^{-\lambda_g}(1-x)^{5.6}$ and $\mu^2 = \mu_0^2 + \frac{C}{r^2}$

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- Momentum transfer (-t) distribution is a Fourier Transform to the spatial distribution of the target
- Fundamental understanding of nucleon structure at high energy

Electron-Ion Scattering

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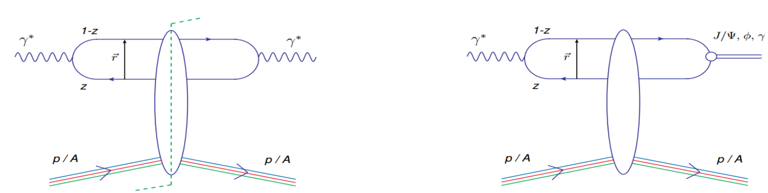

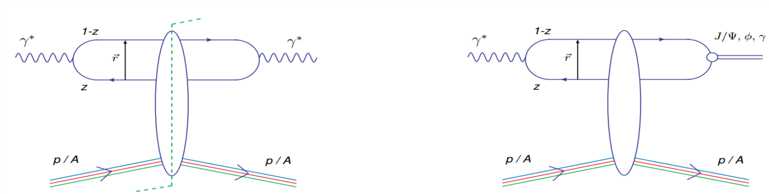

Good-Walker picture:

$$\sigma_{\mathbf{inc}} \propto \sum_{f \neq i} \langle i|\mathcal{A}|f\rangle^\dagger \langle f|\mathcal{A}|i\rangle$$

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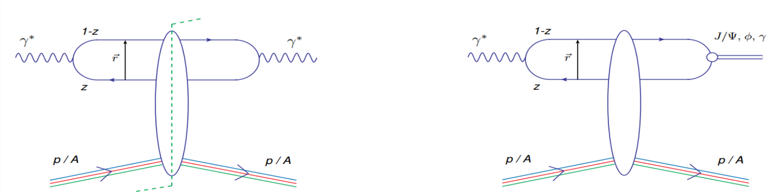

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$$\mathcal{A}(\Omega_j) = \int dr \, \frac{dz}{4\pi} d^2\mathbf{b} (\Psi_V^* \Psi)(r,z) 2\pi r b J_0([1-z] r\Delta)$$
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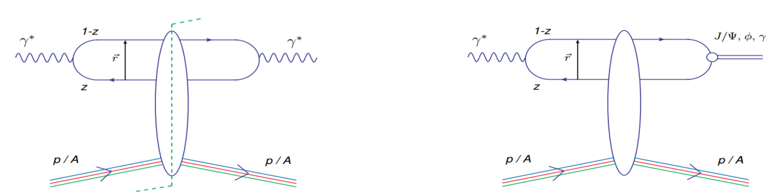

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$$\frac{d\sigma_{tot}}{dt} = \frac{1}{16\pi}\langle |\mathcal{A}|^2\rangle, \quad \frac{d\sigma_{coherent}}{dt} = \frac{1}{16\pi}|\langle \mathcal{A}\rangle|^2$$

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Electron-Ion Scattering ...

ep:

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Using Independent Scattering

Phys. Rev. C 87, 024913 (2013)

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- We don't have analytical solution
- Numerical Methods

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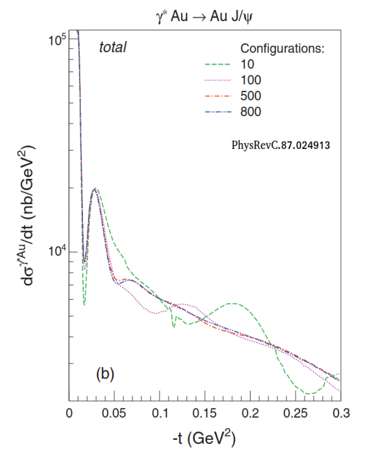
Phys. Rev. C 87, 024913 (2013)

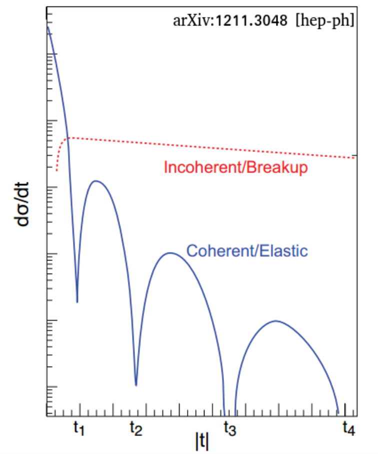
Coherent, Incoherent and Total Cross-section

$$\left\langle \frac{d\sigma_{q\bar{q}}}{d^2b} \right\rangle_\Omega = 2\left[1 - \left(1 - \frac{T_A(b)}{2}\sigma^{\mathrm{p}}_{q\bar{q}}\right)^A\right]$$

$$\frac{d\sigma_{\mathrm{Total}}}{dt} = \frac{d\sigma_{\mathrm{Coherent}}}{dt} + \frac{d\sigma_{\mathrm{Incoherent}}}{dt}$$

$$\sigma_{incoherent} = \langle|\mathcal{A}|^2\rangle - |\langle\mathcal{A}\rangle|^2$$





The Event Generator: Sar$t$re

Sar*t*re

- Dedicated to the Exclusive diffractive vector meson production
- Sar*t*re: Event Generator for **ep** and **eA**
- bSat, bNonSat is basis of Sar*t*re
- Use 3D lookup tables in $(\mathbf{Q^2}, \mathbf{W^2}, \mathbf{t})$ and use the powerful computer to produce the tables
- Hosted at sartre.hepforge.org
- Developer/maintainer : Tobias Toll, Thomas Ullrich

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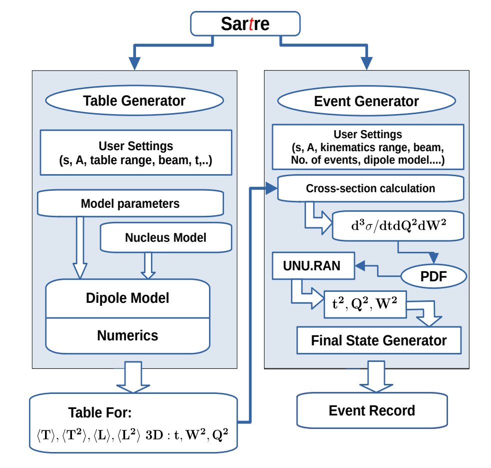
Event generator: Exclusive diffractive vector meson production and DVCS

- For total need $\sim$ 500 configuration
- For each kinematic point(4D integral) we have to average over all number of configurations
- Look-up table: Amplitudes stored in the tables corresponding to (Q^2, W^2, t)



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Look-up Table: Sar$t$re

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- Table range:
  - $0 \leq |t| \leq 0.5$, $384 \leq W^2 \leq 20164$, $0.001 \leq Q^2 \leq 20.0$ GeV^2

Machine Learning

Machine Learning in Sar*t*re:Neural Network

- Fit to the data (3D tables) generated using the dipole model

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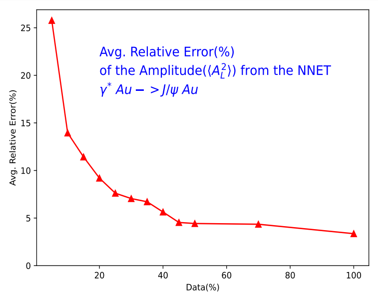
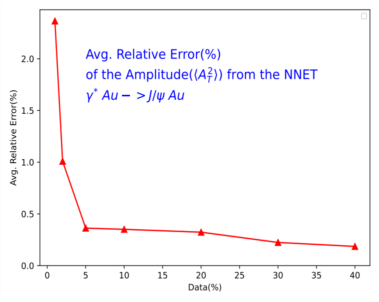
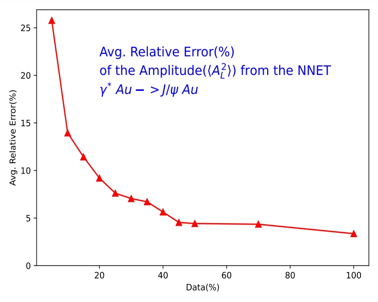
- A nice computation tool to reduce CPU hours
  - With current framework in Sartre it take months to generate tables in all kinematic region
  - Any new physics input, produce all tables again from beginning
- Way out : Produce tables with few bins and train NN to produce to tables in all kinematic region
  - Long-term, Use NN architecture with all parameters of dipole model as input

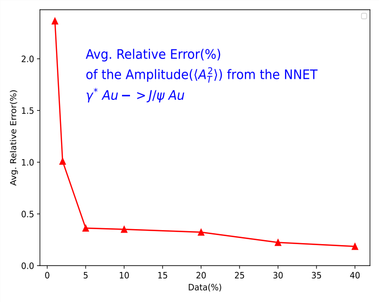
Avg. Relative Error(%) vs Data





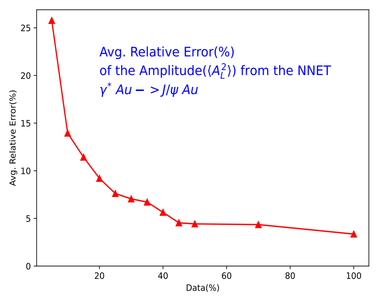
Avg. Relative Error(%) vs Data

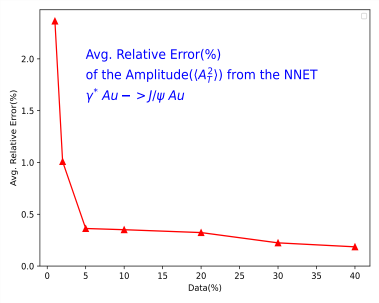




- Needs $\sim$ 40%(of $\sim$ 20000) data to train the neural network with in the error(5%) cut-off for Longitudinal case

Avg. Relative Error(%) vs Data

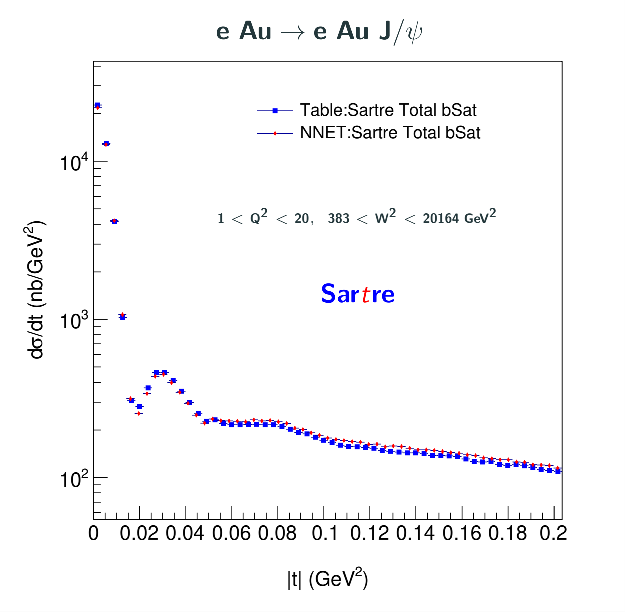




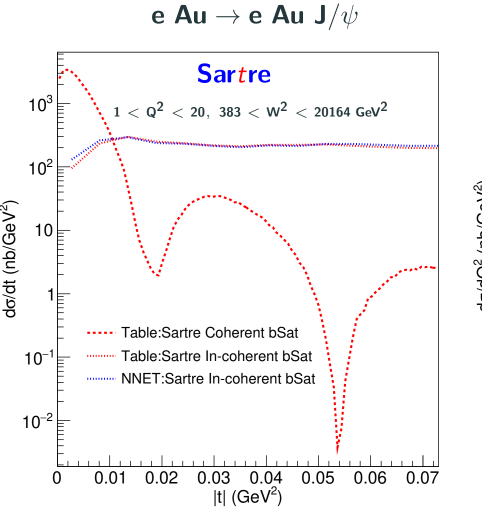
- Needs $\sim 40\%$(of ~ 20000) data to train the neural network with in the error(5%) cut-off for Longitudinal case
- Needs $\sim 5\%$ (of ~ 20000)data to train the neural network with in the error(5%) cut-off for Transverse case

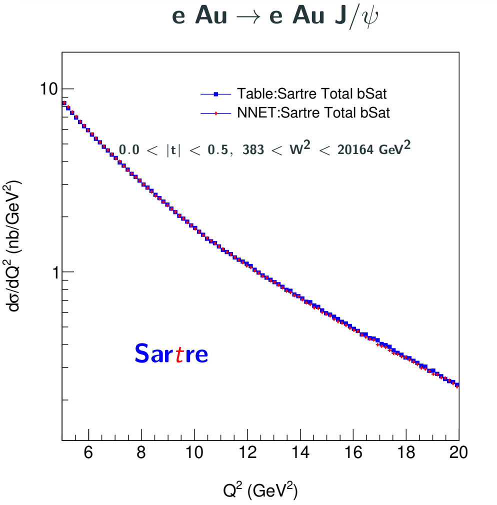
Results

Results


e Au → e Au J/ψ
Table:Sartre Total bSat
NNET:Sartre Total bSat
1 < Q² < 20,   383 < W² < 20164 GeV²
Sartre
dσ/dt (nb/GeV²)
|t| (GeV²)
10⁴
10³
10²
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2

Results...


e Au → e Au J/ψ
Sartre
1 < Q2 < 20, 383 < W2 < 20164 GeV2
Table:Sartre Coherent bSat
Table:Sartre In-coherent bSat
NNET:Sartre In-coherent bSat
dσ/dt (nb/GeV2)
|t| (GeV2)


e Au → e Au J/ψ
Table:Sartre Total bSat
NNET:Sartre Total bSat
0.0 < |t| < 0.5, 383 < W2 < 20164 GeV2
Sartre
dσ/dQ2 (nb/GeV2)
Q2 (GeV2)

Conclusions

Conclusions: Neural Network

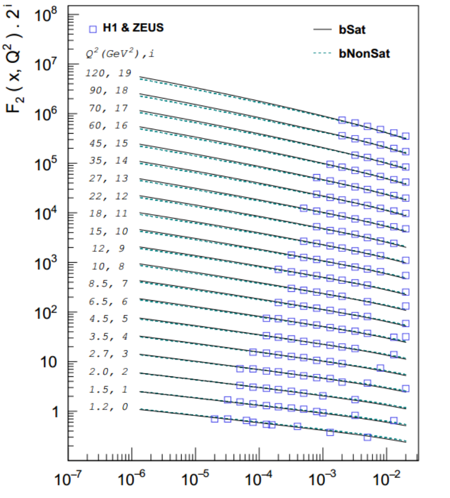
- We need 10% of the bins for Transverse and 40-50% for Longitudinal amplitude square tables.
- In total we need to generate $\sim$25% of the table points.
- We can produce the tables(NN) much faster than using model.
- Work in progress to reduce the error for longitudinal amplitude

Outlook and Summary

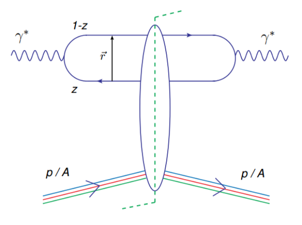
- Need to reduce the error of outcome of the Neural Network(For longitudinal case)
- Produce the more tables for the other species(pb, Zr,...).
- We generated the events using the 3D table produced from the neural network in Sar$t$re
- Dipole Scattering amplitude:
$\mathcal{A}_{T,L}^{\gamma^* p \rightarrow V\ p}(x, Q, \Delta) = i \int d^2\mathbf{r} \int_0^1 \frac{dz}{4\pi} \int d^2\mathbf{b}\ (\Psi_V^* \Psi)_{T,L} e^{-i\ \mathbf{b}\cdot\Delta}\ \frac{d\sigma_{q\bar{q}}}{d^2\mathbf{b}}$
- Scattering amplitude(NNET):
$\mathcal{A}_{T,L}^{\gamma^* p \rightarrow V\ p}(x, Q, \Delta) = i \int d^2\mathbf{r} \int_0^1 \frac{dz}{4\pi} \int d^2\mathbf{b}\ (\Psi_V^* \Psi)_{T,L} e^{-i\ \mathbf{b}\cdot\Delta}\ \frac{d\sigma_{q\bar{q}}}{d^2\mathbf{b}}(NNT)$
- we are working on the inclusive diffractive deep inelastic scattering(DDIS)
- Upgrade Sartre to inclusive diffraction.
  - We need 4D tables
  - Need to include t-dependence

Thank You!

Back-up Slides

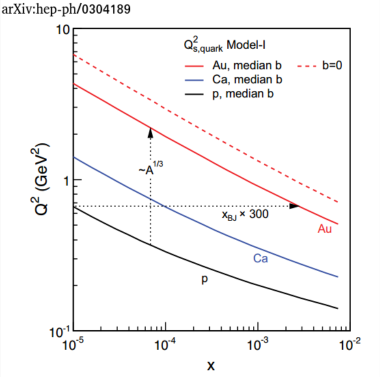


*Arjun Kumar



- ❖ No indication of saturation
- ❖ Well explanation by bSat & bNonSat dipole model
- ❖ No saturation even in LHeC kinematic regime($x = 10^{-7}$)

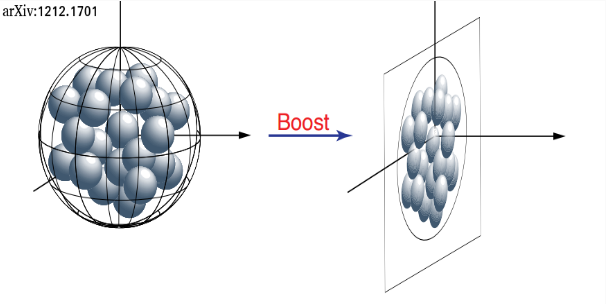
saturation scale



Proton : $Q^2(x) = \left(\frac{x_0}{x}\right)^{\lambda} \quad \lambda \sim 0.2 - 0.3$

- Q_x^2 value large at low-x
  - treat as perturbative scale
- Two way to increase the saturation scale:
  - Increase the c.o.m energy in ep collisions to probe small x values ($x \sim \frac{Q^2}{W^2}$)
  - Change the target particle from proton to nucleus
- Use heavy ion geometry to enhance saturation scale

scale ...



Nucleus:

$$Q_s^2(x,A) \sim A^{\frac{1}{3}} \left(\frac{1}{x}\right)^{\lambda} \sim \left(\frac{A}{x}\right)^{1/3}$$

$$x \sim \frac{Q^2}{W^2} \qquad W^2 = M_A^2 + Q^2 \frac{(1-x)}{x}$$