Precise determination of Pomeron intercept via scaling entropy

XXXVII International Workshop on High Energy Physics “Diffraction of hadrons: Experiment, Theory, Phenomenology”

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Scaling entropy phenomenology

A Universal Framework for Initial-State Dynamics in High-Energy Collisions

1. Motivation Puzzle with LHC high multiplicity data
2. Experiments: What experiments on multiplicity shows
3. Theory: Model of interaction
4. Phenomenology of DIS
5. Phenomenology of LHC (pp)

Motivation

Charged hadron multiplicity distributions offer a window into partonic dynamics.

Disentangling initial-state effects from final-state interactions is essential for interpreting signals of QCD matter

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Do we truly understand gluon dynamics in the high-multiplicity regime?

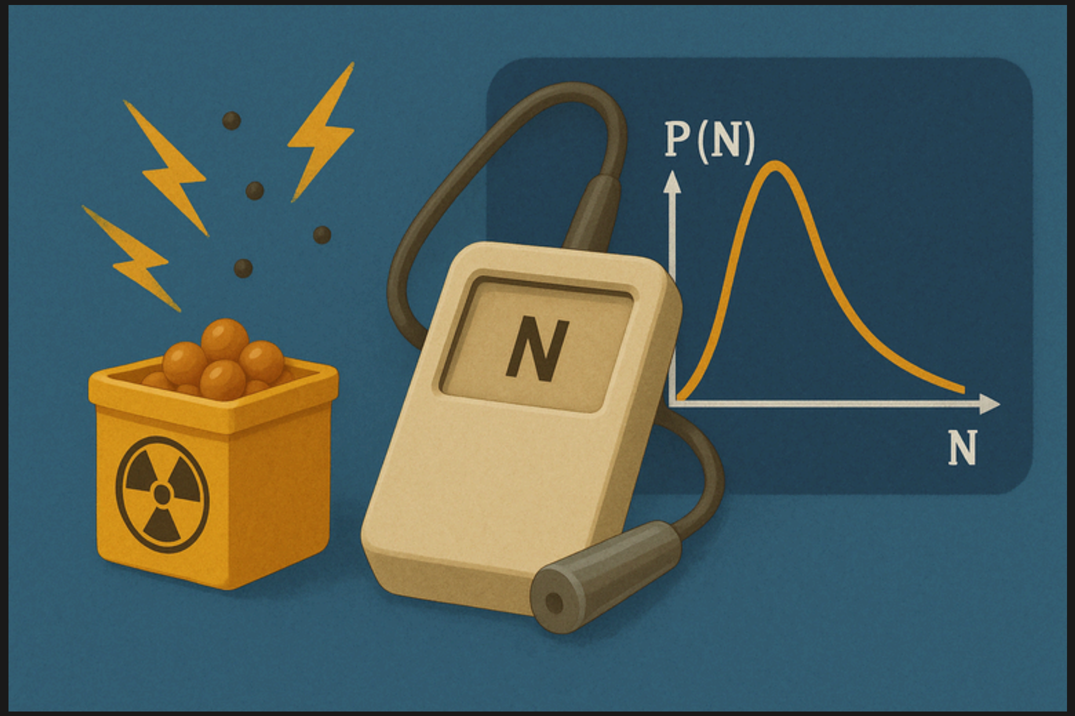
Can scaling entropy reveal universal features across different collision systems?

Are QGP-like signatures in small systems driven by initial-state dynamics?

Experimental data on multiplicity

Entropy in Counting Experiments

N Particles produced with probability P(N)



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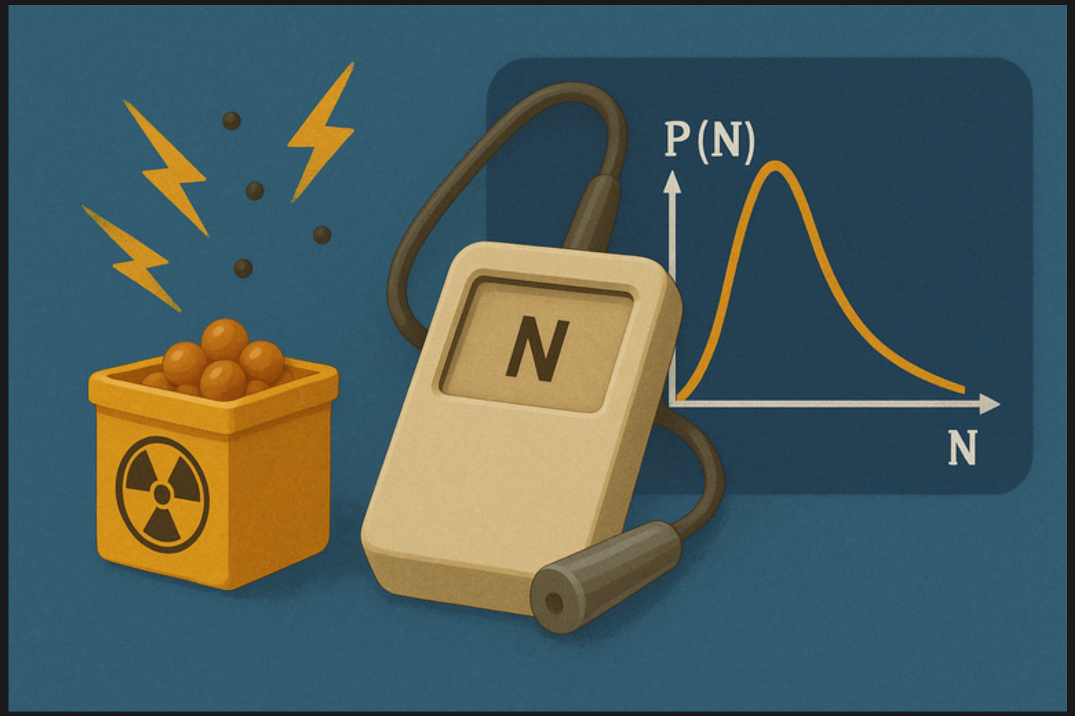


Poisson process

$$P(N) = \frac{\langle N \rangle^N}{N!} e^{-\langle N \rangle}$$

Events are independent and random → no correlation between detections

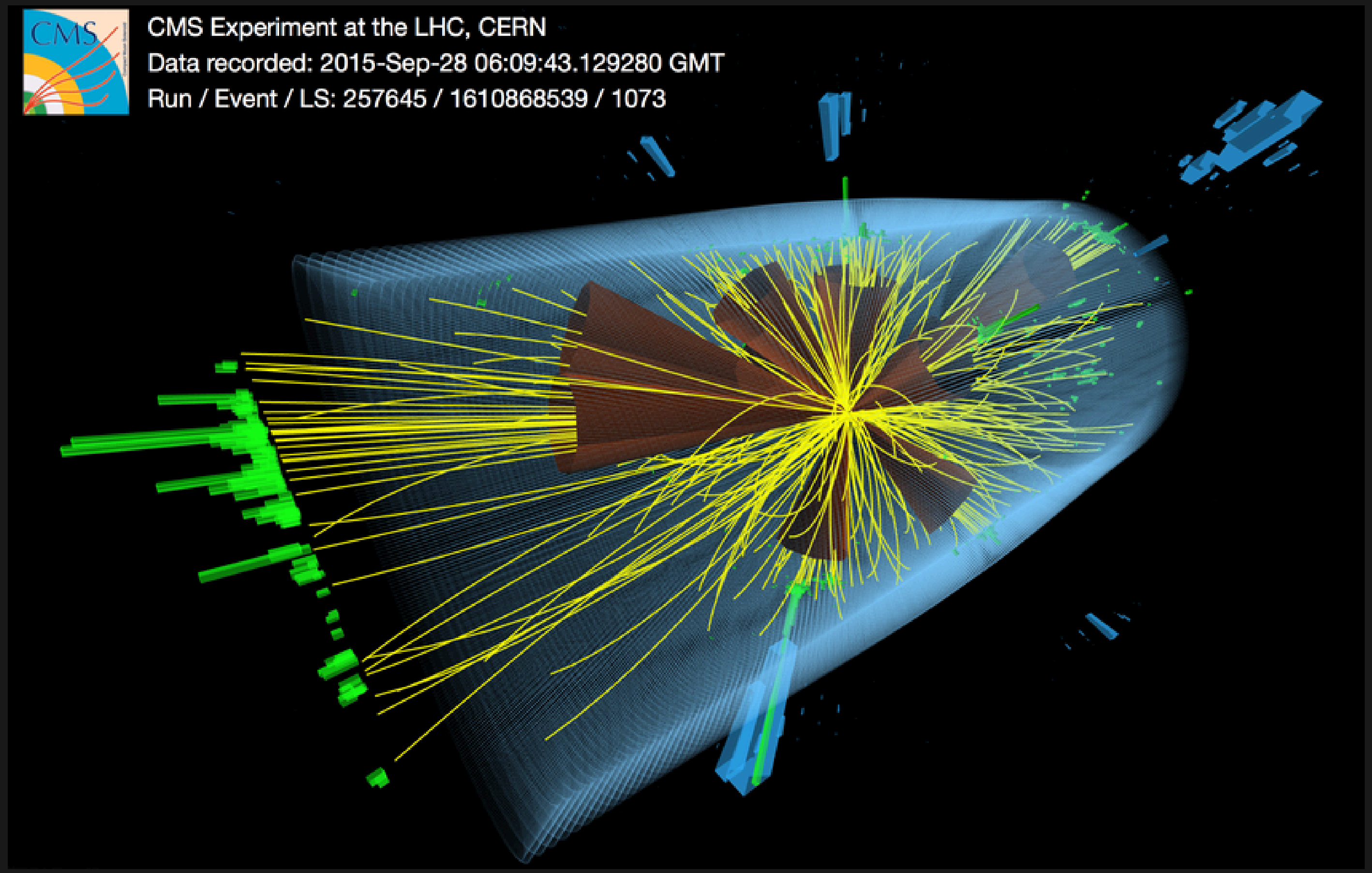
$$Var(N) = \langle N \rangle$$

Ideal baseline for fluctuation analysis

The experimental data on multiplicieties

Entropy in Counting Experiments : high energy case

Experimental multiplicity distributions exhibit
large fluctuations



The experimental data on multiplicieties

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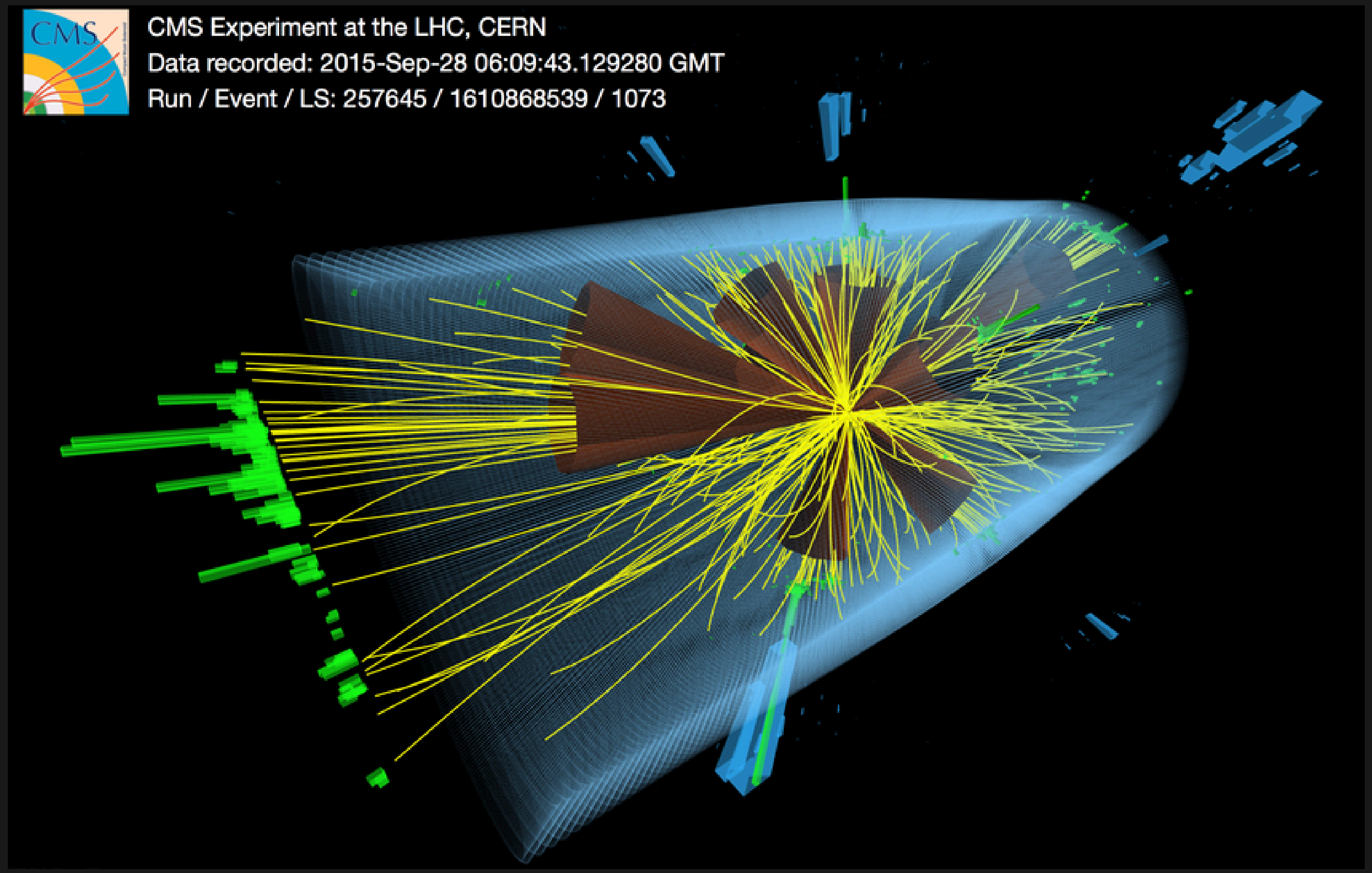


Negative Binomial process

$$P(N) = \frac{\Gamma(N+k)}{\Gamma(k)\,N!}\left(\frac{\langle N\rangle}{\langle N\rangle + k}\right)^N\left(\frac{k}{\langle N\rangle + k}\right)^k$$

Evidence of clustering and correlations points to non-trivial partonic dynamics

$$Var(N) = \langle N\rangle + \langle N\rangle^2/k$$

overdispersion growth with energy

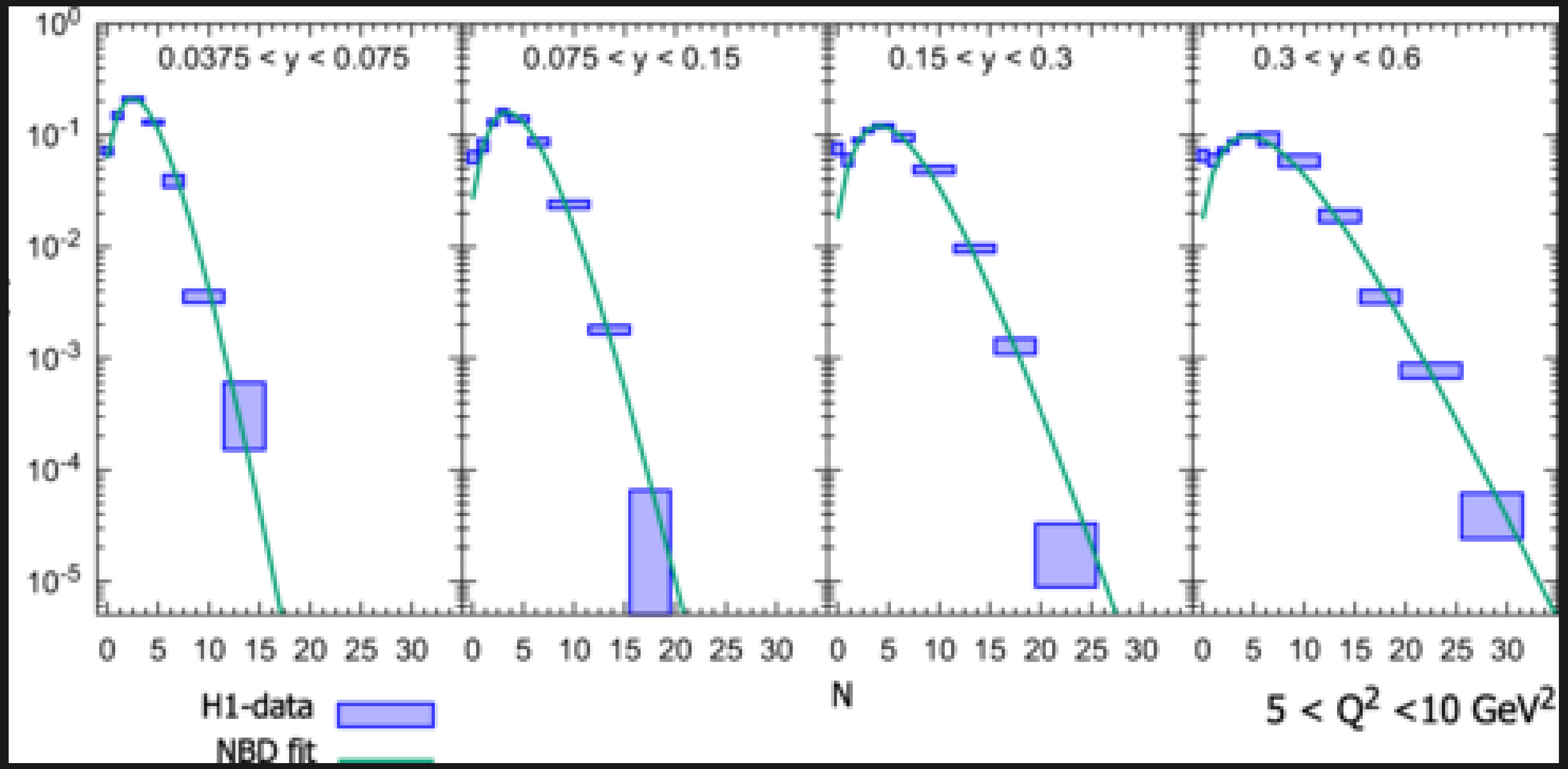
The key challenge: understanding the origin of overdispersion in particle production.

The experimental data on multiplicieties

Deep Inelastic Scattering (DIS)

We begin with DIS , where the initial state is better controlled.

$P(N)$



N

Negative Binomial Distribution Fits data

The experimental data on multiplicieties

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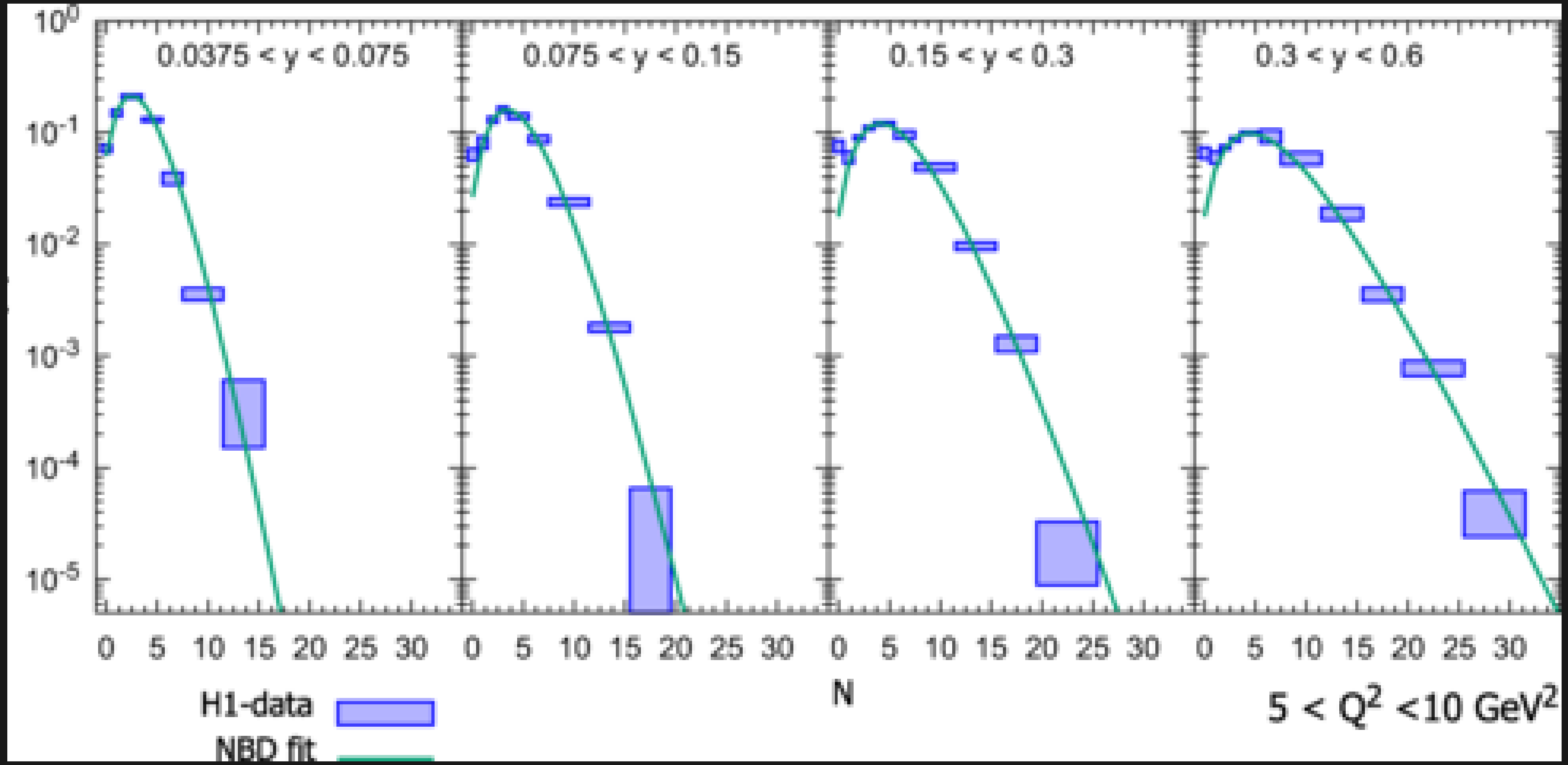


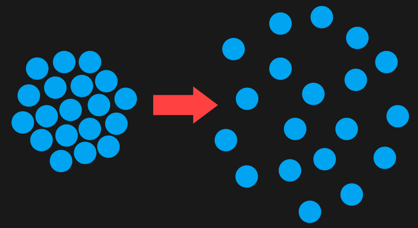
N

Negative Binomial Distribution Fits data

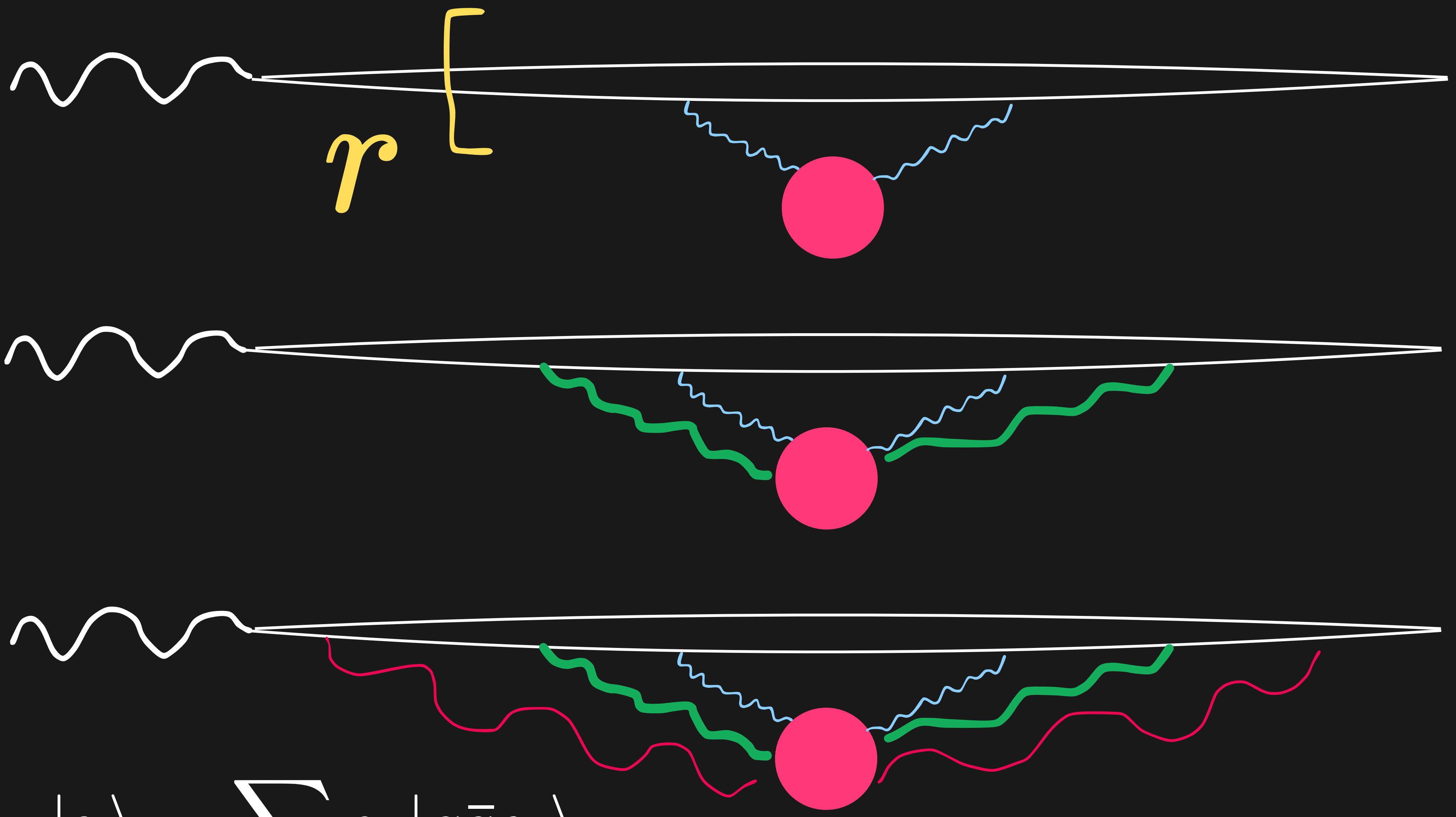
Energy incresces (small -x)

$$x_{bj} = \frac{Q^2}{sy}$$

The dispersion of multiplicity distributions grows with decreasing x, indicating diffusive gluon dynamics.



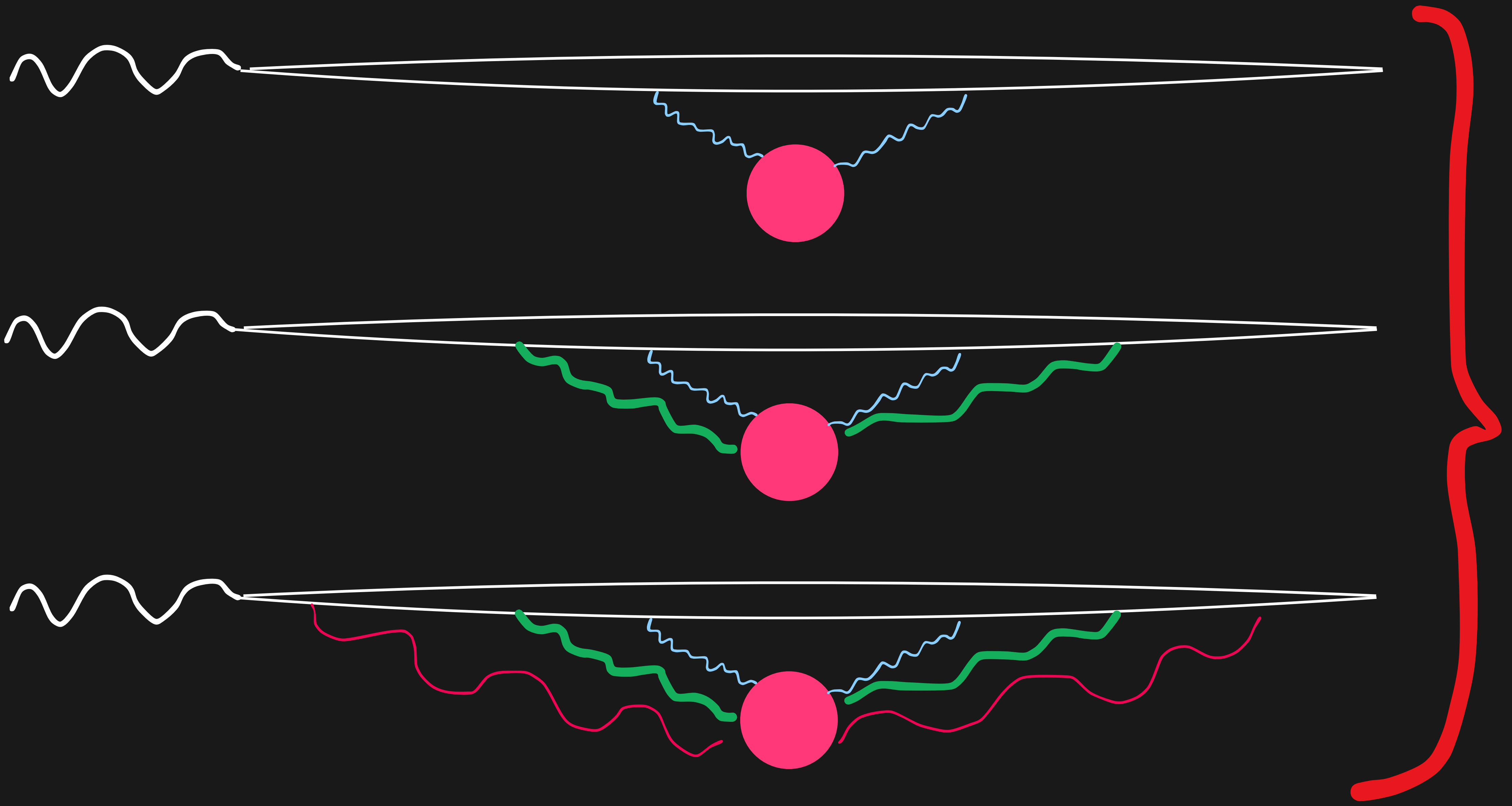
Dipole scattering with different gluons wave-length

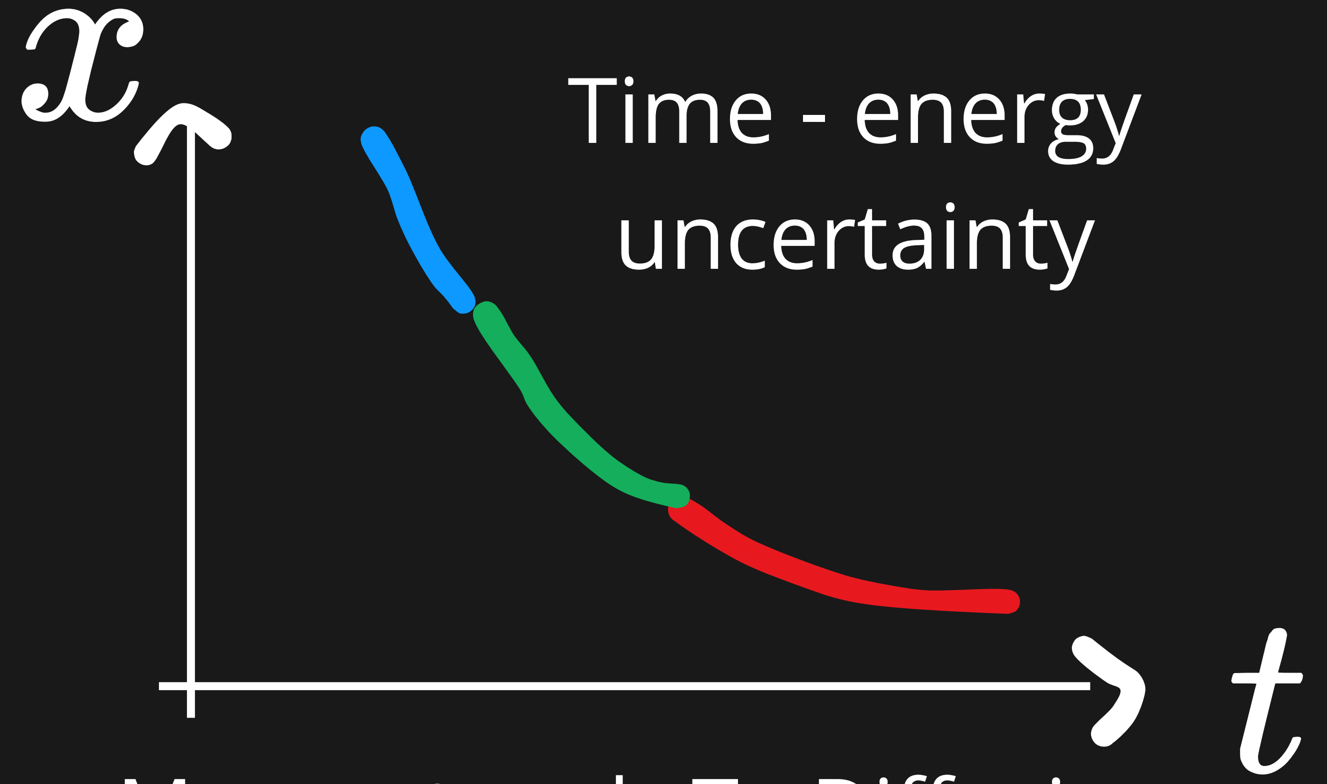


$$|\gamma\rangle = \sum_i a_i |q\bar{q}g_i\rangle$$

Dipole The Dipole Picture and Small-x Evolution

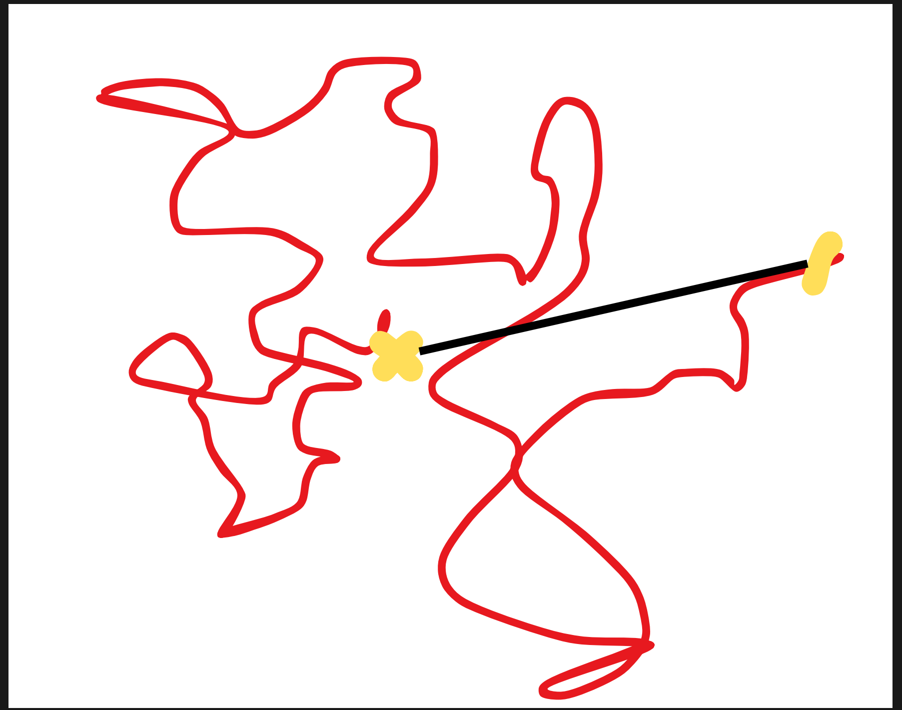
Dipole scattering with different gluons wave-length





Time - energy uncertainty

Momentum k_T - Diffusion



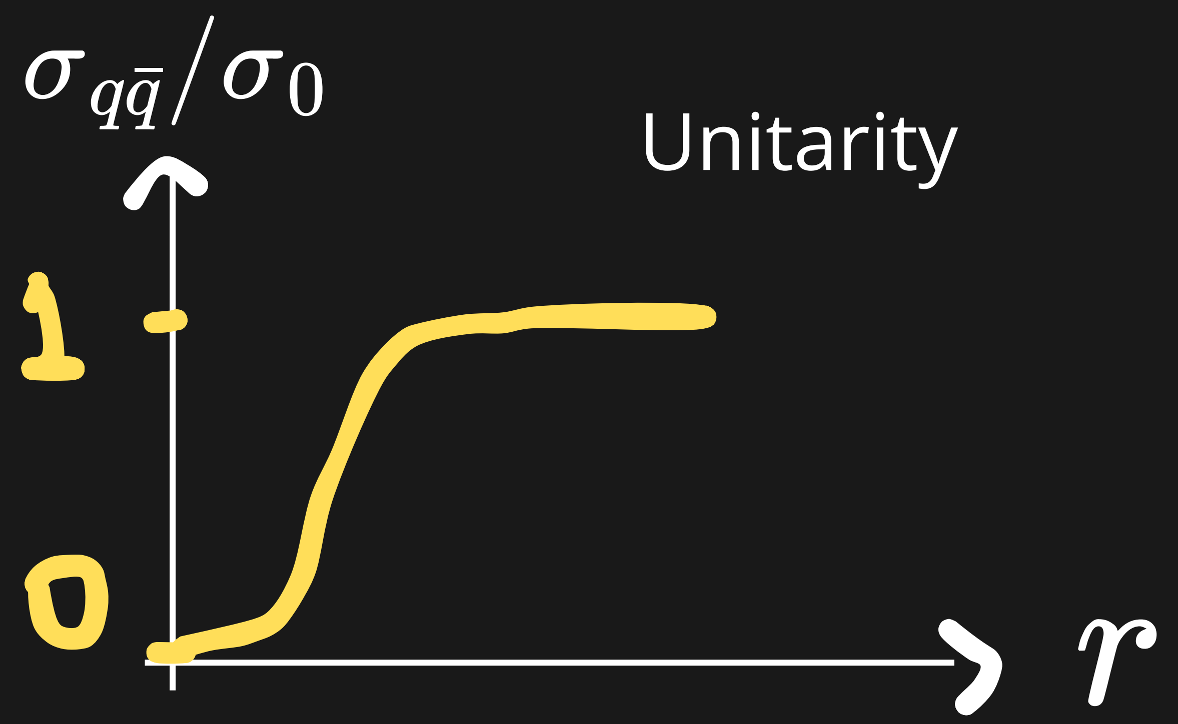
Theoretical Description of DIS

Unitarity and saturation scale

Position

Inclusive cross section

$$\sigma_{\gamma^* p}(x) = \int \sigma_{q\bar{q}}(r) \times |\psi_\gamma(r)|^2 \, d^2 r$$



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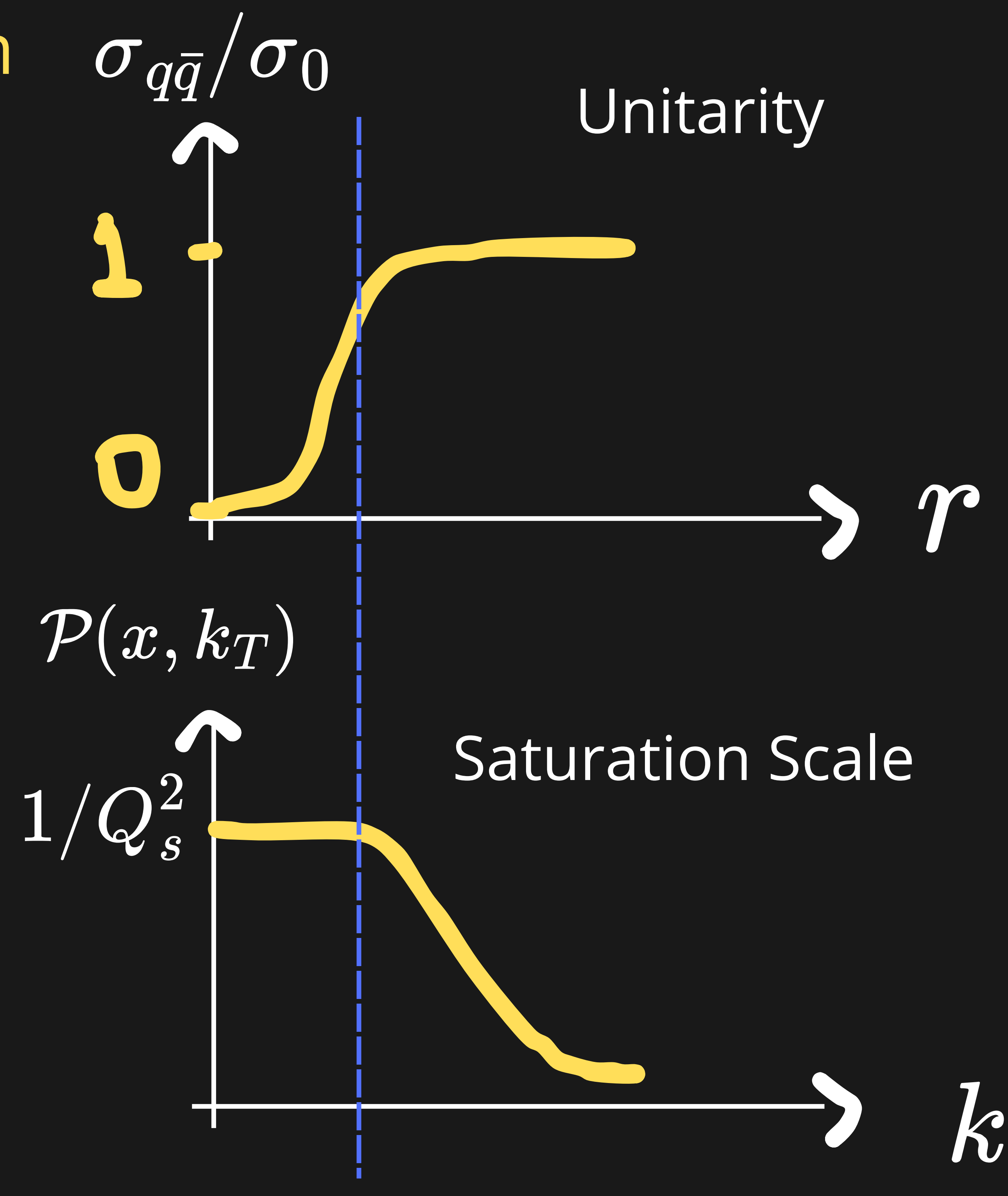
$$\sigma_{\gamma^* p}(x) = \int \sigma_{q\bar{q}}(r) \times |\psi_\gamma(r)|^2 \, d^2 r$$

Momentum

$$\sigma_{\gamma^* p}(x) = \int \mathcal{P}(k_T) \times |\psi_\gamma(k_T)|^2 \, d^2 k_T$$

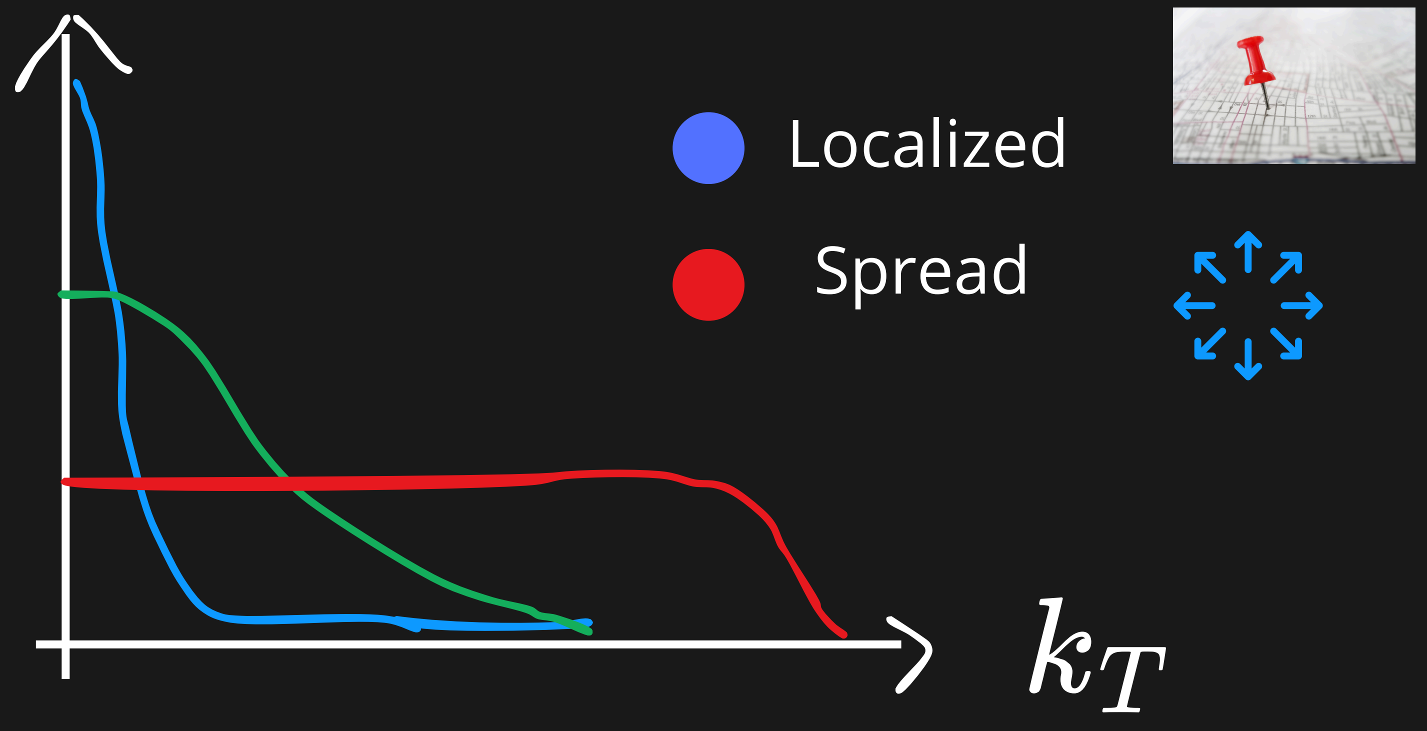


Theoretical Description of DIS

Scaling entropy

Scaling of probability

$$\mathcal{P}(x, k_T) = x^{-\lambda} F(k_T^2 / x^{-\lambda})$$



Einstein Relation (anomalous diffusion)

$$\langle k_T(t) \rangle \sim t^{\lambda} \sim x^{-\lambda}$$

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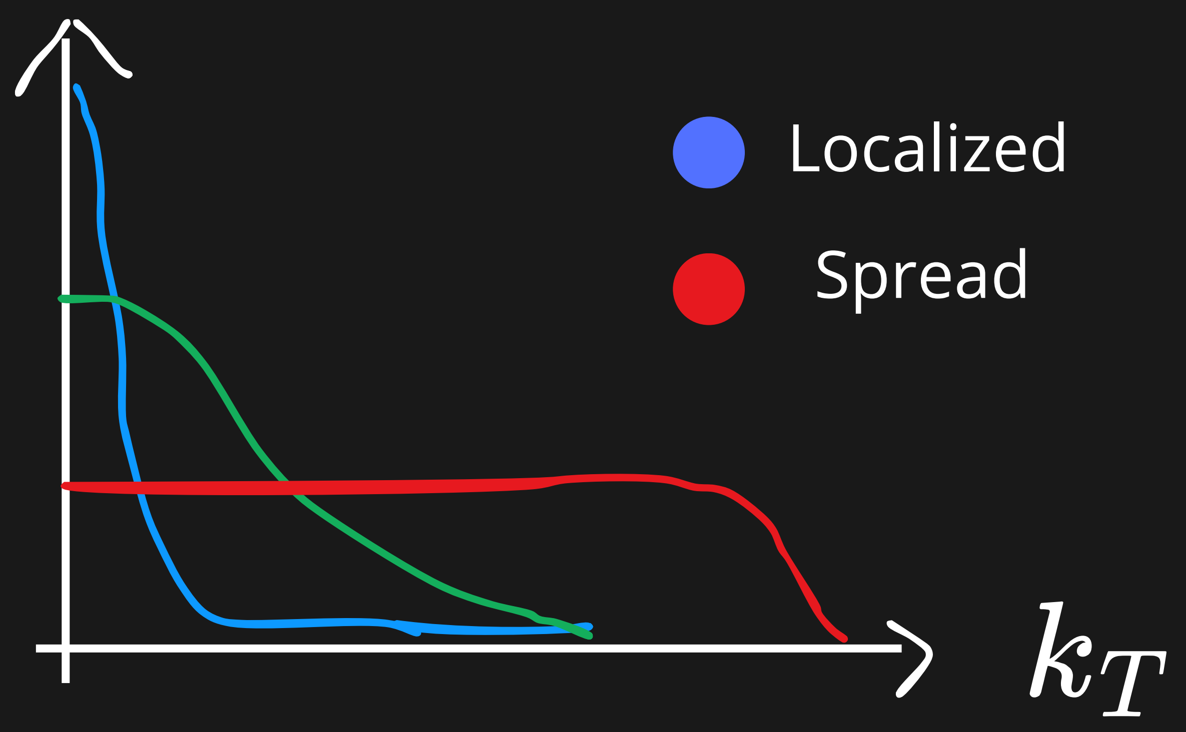

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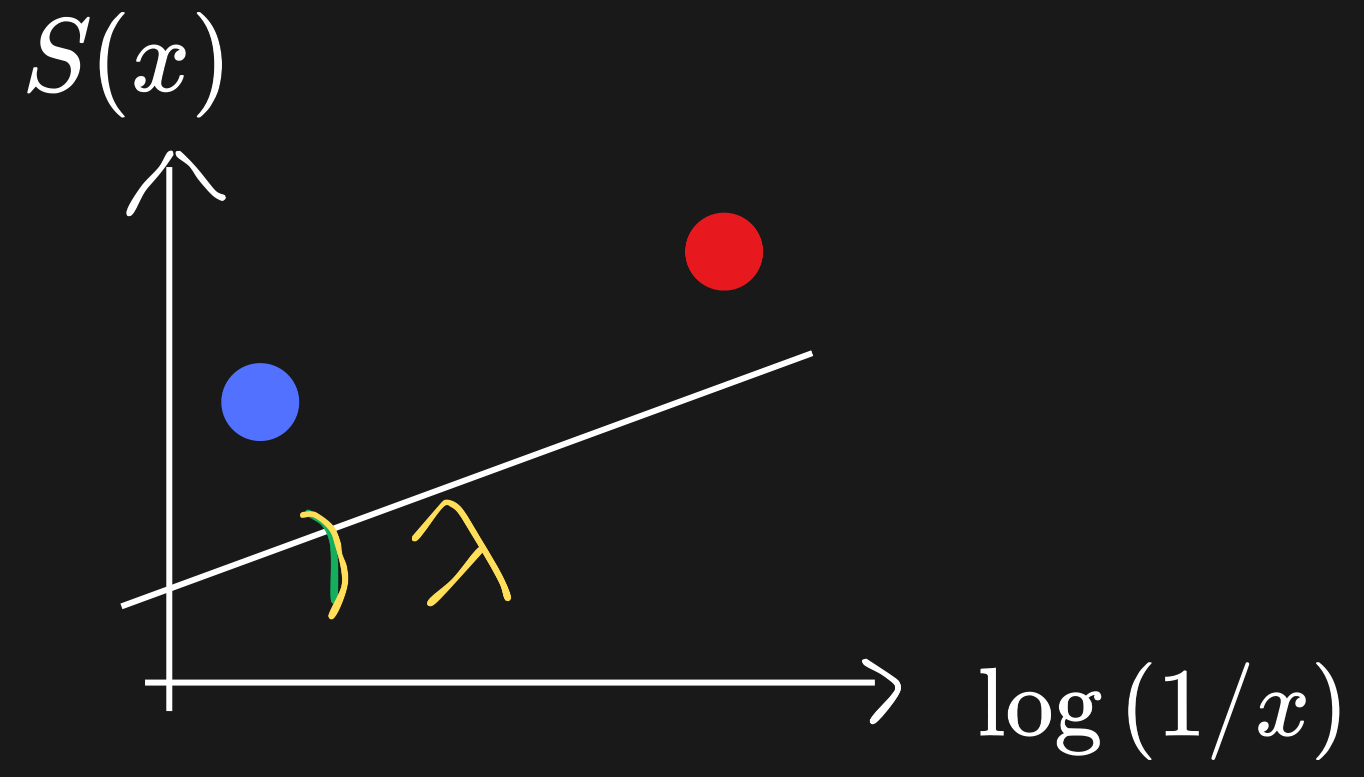
Scaling Entropy



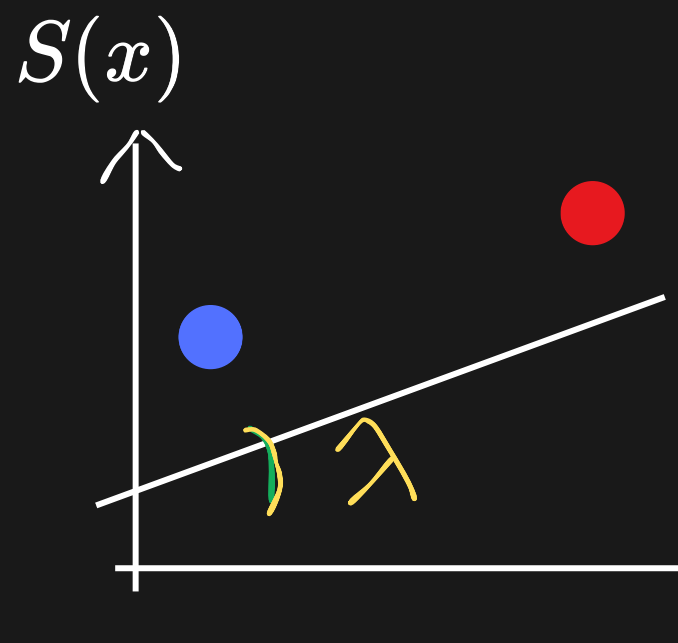
Only the constant C is model dependent

$$S(x) = \lambda \log(1/x) + C$$

Scaling entropy

Linear growth

key message



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THEORETICAL DESCRIPTION OF DIS

Scaling entropy

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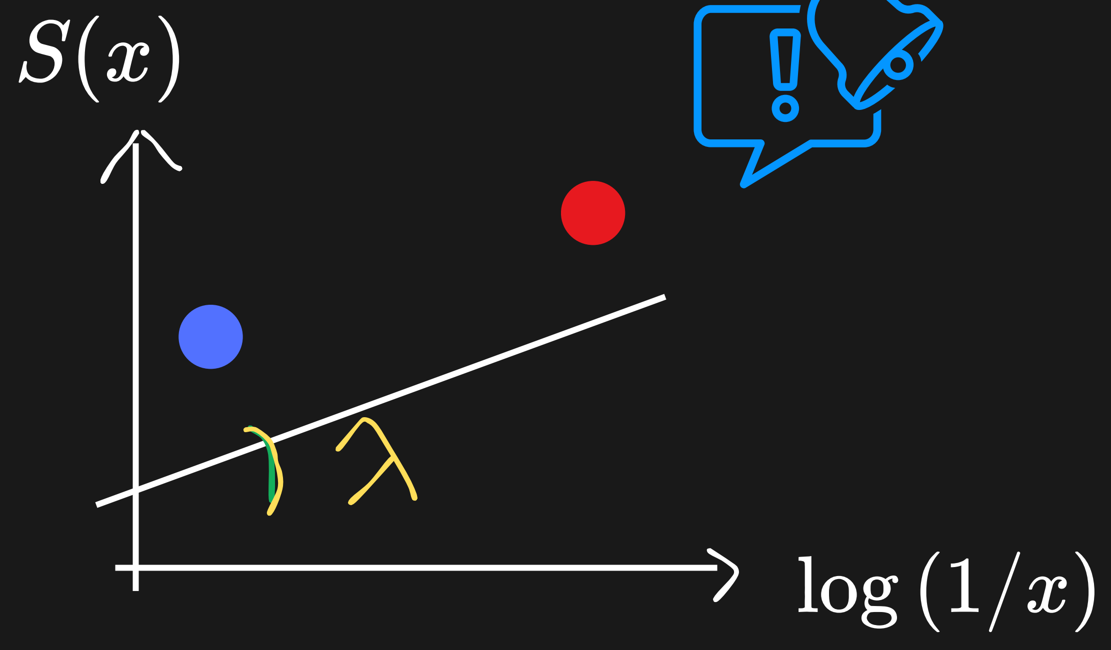


$$S(x) = \lambda \log(1/x) + C$$

Detect scaling in experimental data

Initial state growth of entropy (x - dependent)

Hard pomeron intercept

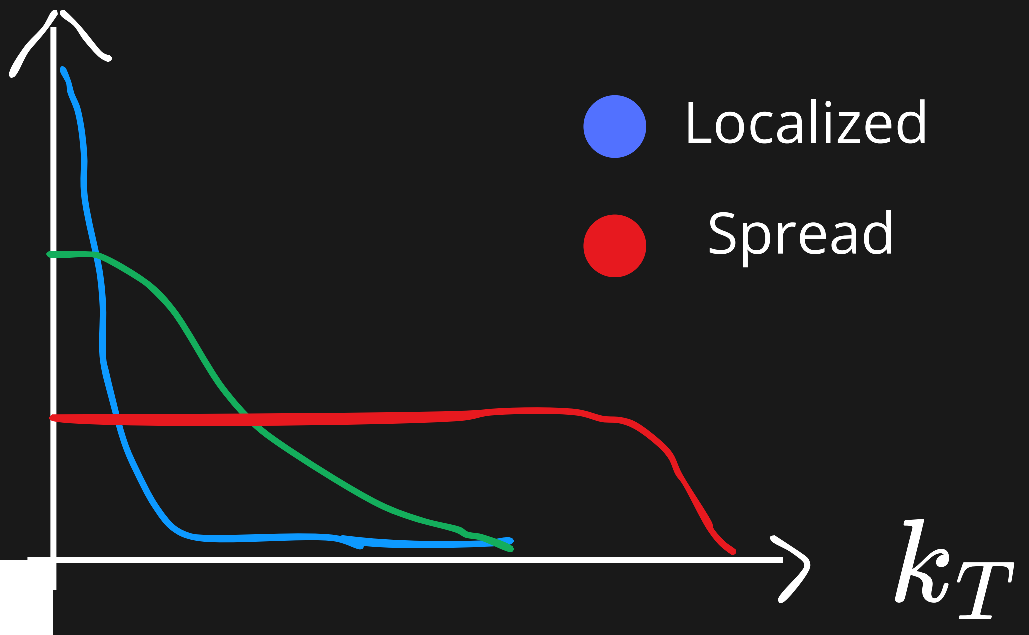
$$\alpha_p = \lambda + 1$$

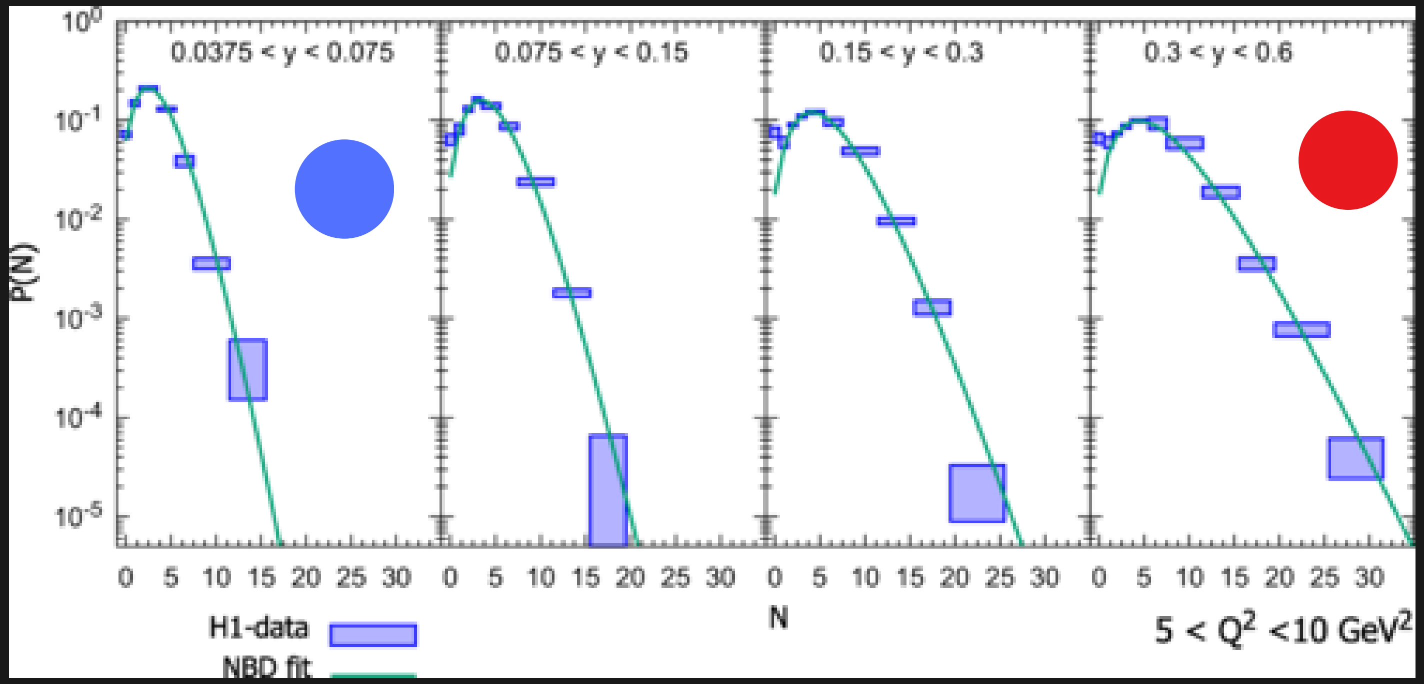
Confront with experiments

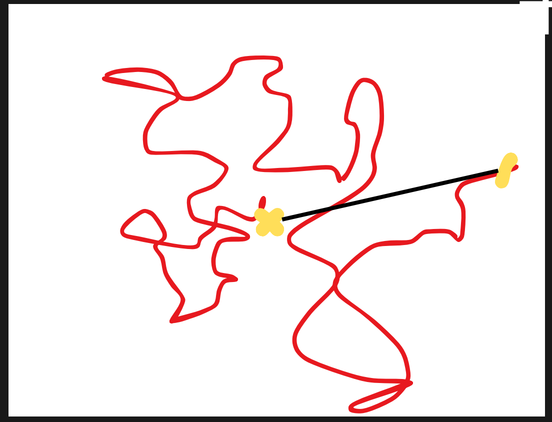
Connection to experimental data

Same entropy growth rate ?

$$\mathcal{P}(x, k_T) = x^{-\lambda} F(k_T^2 / x^{-\lambda})$$







Momentum diffusion = hadron number diffusion ?

Broader P(N) → higher uncertainty → higher entropy

Phenomenology of DIS

Extracting the pomeron intercerp

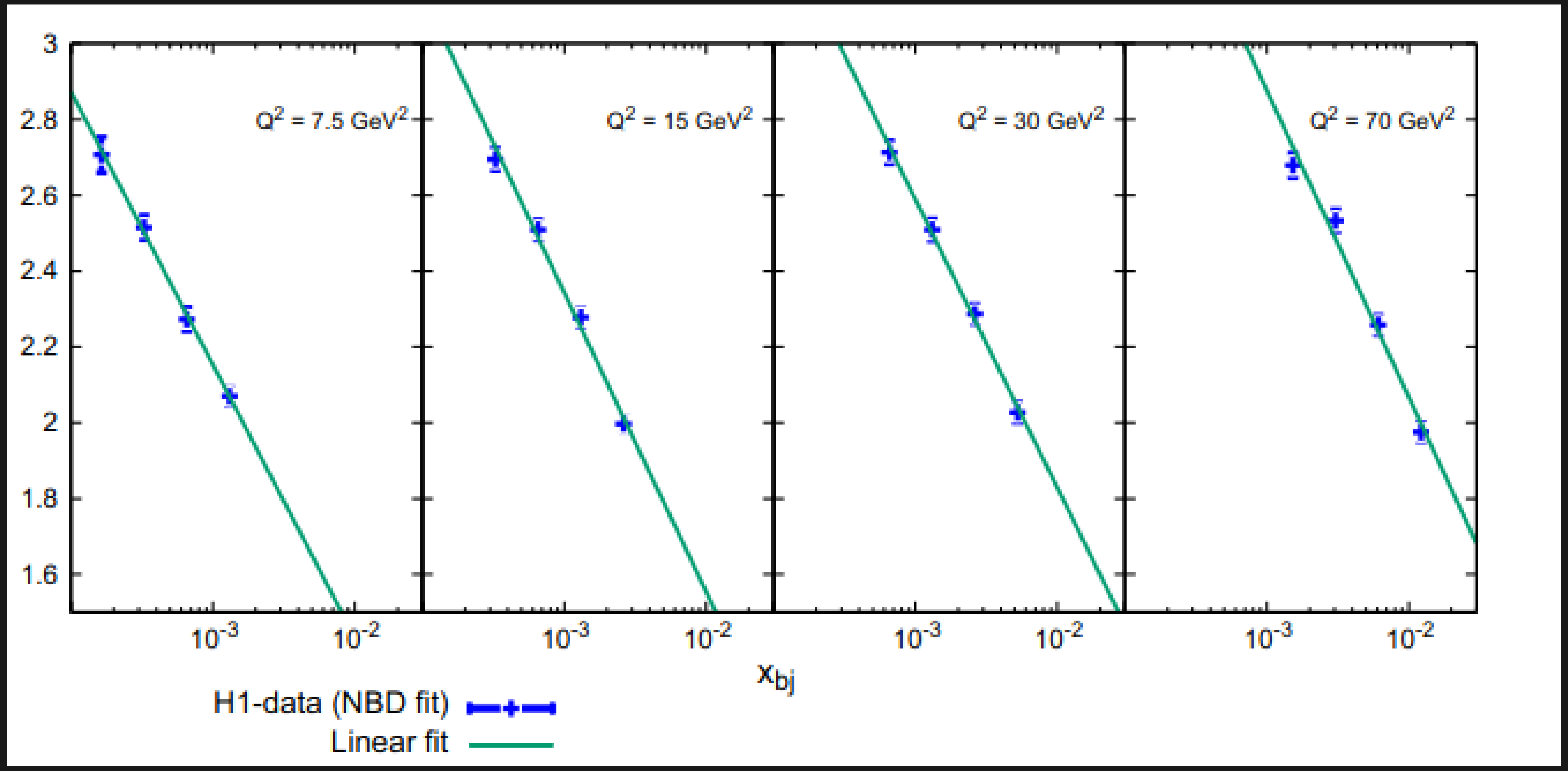
DIS experimental entropy (H1 - data)

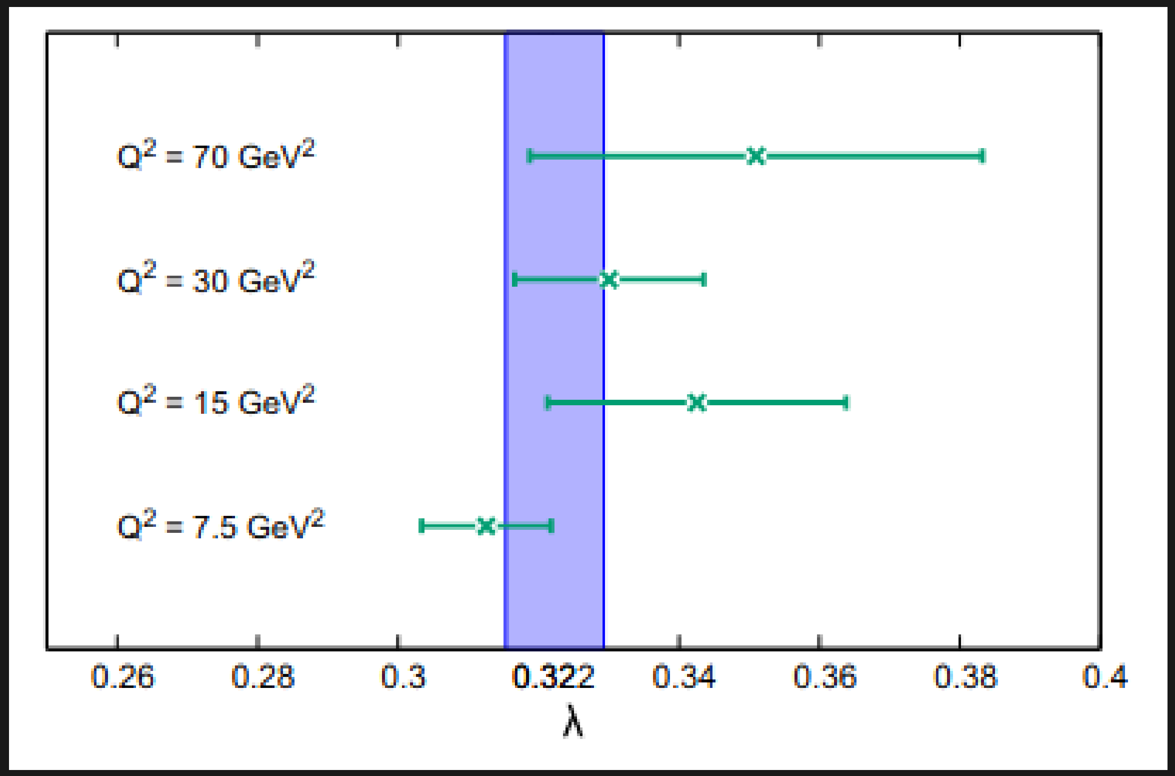
$$S^{H1}(x) = \sum_N P(N)\log(P(N))$$

hypothesis

$$\simeq \quad S(x) = \lambda \log(1/x) + f(Q^2)$$

S(x)





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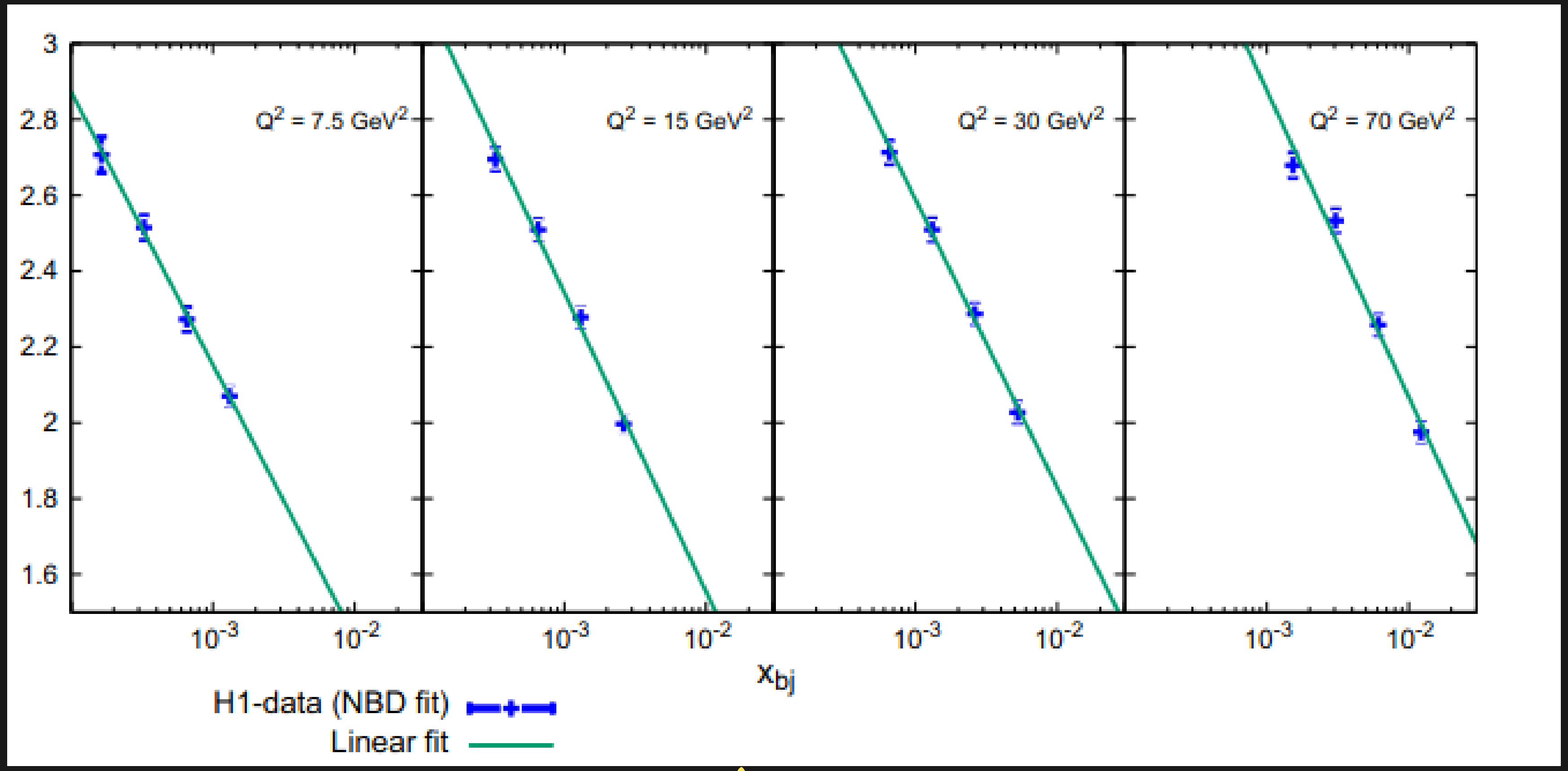

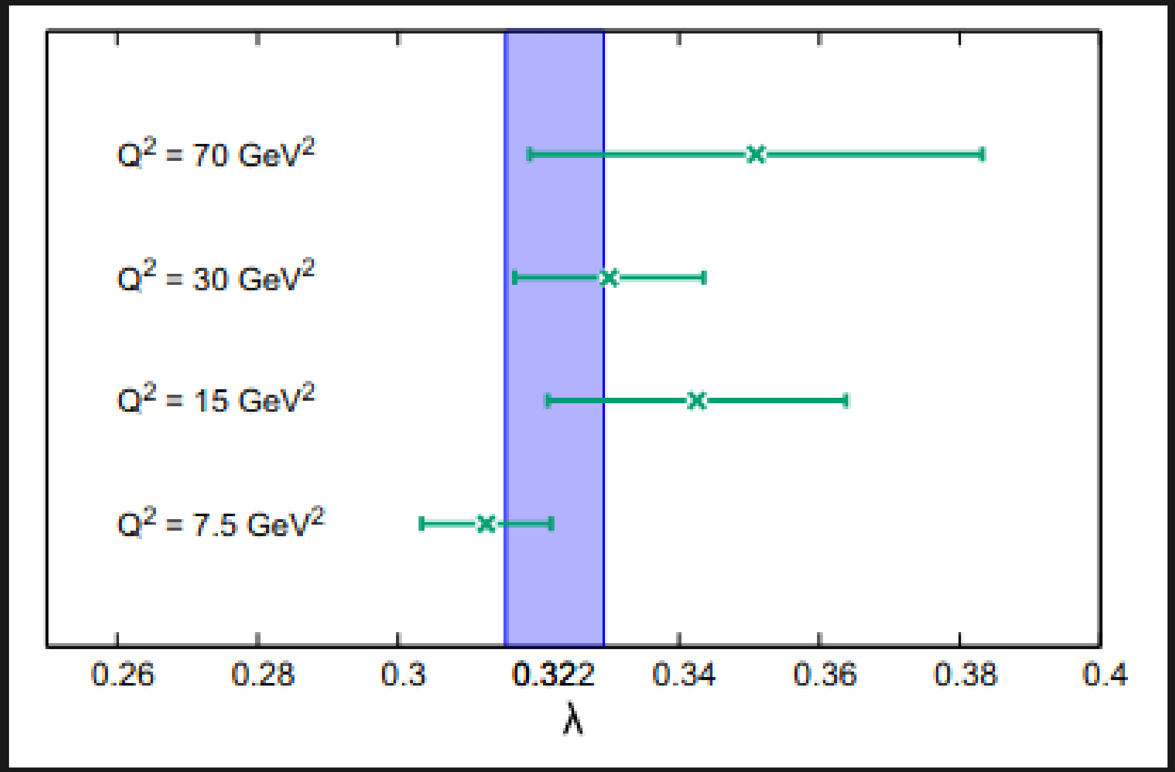

$$\lambda = 0.322 \pm 0.07$$

Agrees with the data at all Q² values

Phenomenology - LHC

Can we do the same as in DIS?

Problems

Different experimental methodologies

CMS	ATLAS	ALICE	

x is not observable

Soft contribution (PT ~0)

Phenomenology - LHC

Can we do the same as in DIS?

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CMS	ATLAS	ALICE	

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Soft contribution (PT ~0)

Solutions

Select different data sets

CMS	ATLAS	ALICE	ALICE
1	2	3	4

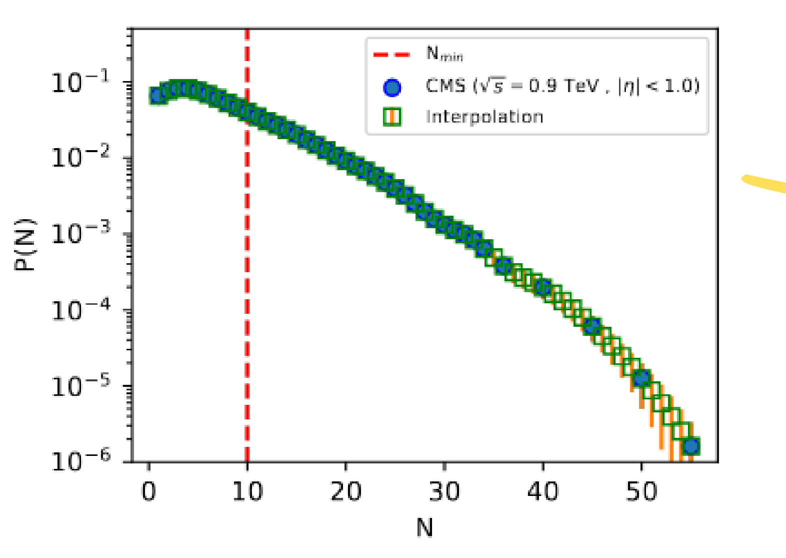
Approximate the minimum value (dominant)

$$x \sim e^{-\eta_{max}} / \sqrt{s}$$

Cut the multiplicity at N_{min}

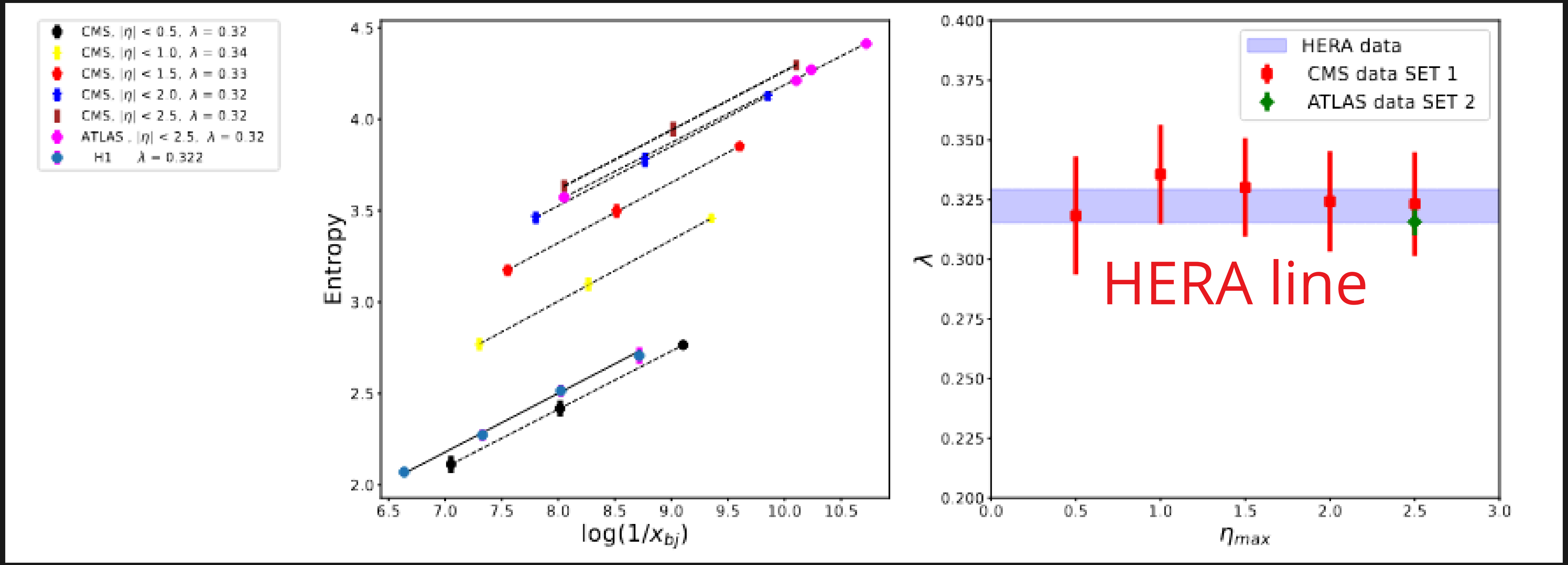
Phenomenology - LHC

Same result as DIS



Cut lower multiplicity N< 10

Experimental entropy



CMS and ATLAS data agrees with HERA

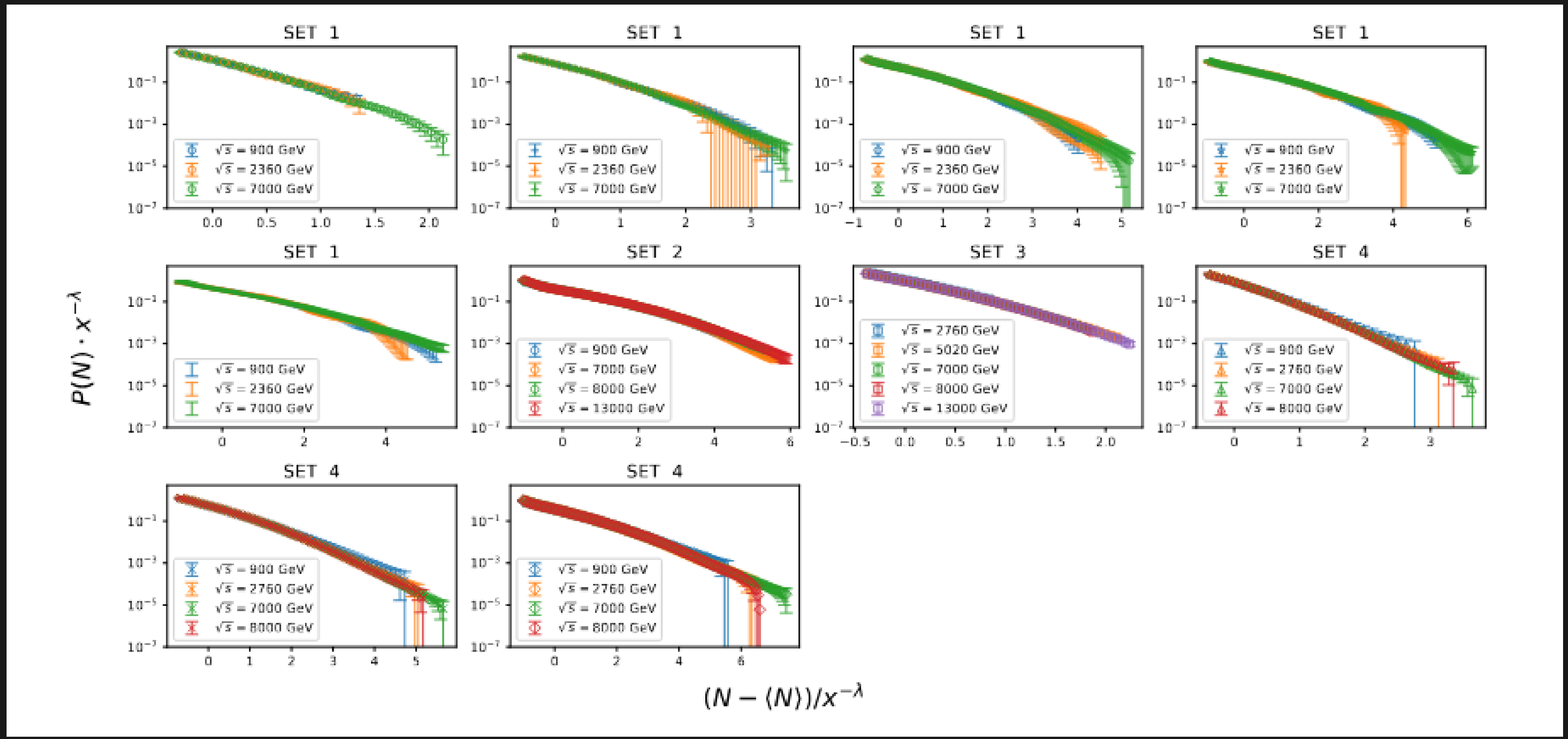
Diffusion of multiplicity is an initial state phenomena !

Phenomenology - LHC

Diffusion Scaling of P(N)

Different energies all collapse to same line

$$P(N) \sim x^{\lambda} F\left(\frac{N-\langle N\rangle}{x^{-\lambda}}\right)$$



Traditional Koba-Nielsen-Olesen (KNO) scaling fails in the high-multiplicity tail of P(N)

This diffusion scaling supports the interpretation of multiplicity fluctuations as an initial-state phenomenon.

Summary

- Universal entropy scaling validated across systems
- Precise determination of **λ** from entropy
- Diffusion scaling replaces KNO at high multiplicities
- Entropy bridges pp and ep phenomenology

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Universal entropy scaling validated across systems

Precise determination of **λ** from entropy

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Future applications

Electron-Ion Collider (EIC): test entropy growth with higher precision

Application to heavy-ion collisions

Heavy-ion collisions: use entropy to distinguish initial-state collectivity from final-state effects.

Thank you for your attention !

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Scaling entropy

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Experimental data

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