Summary talk WG4: Diffraction and Small x

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On behalf of the WG4 conveners: Deniz Sunar Cerci, MH

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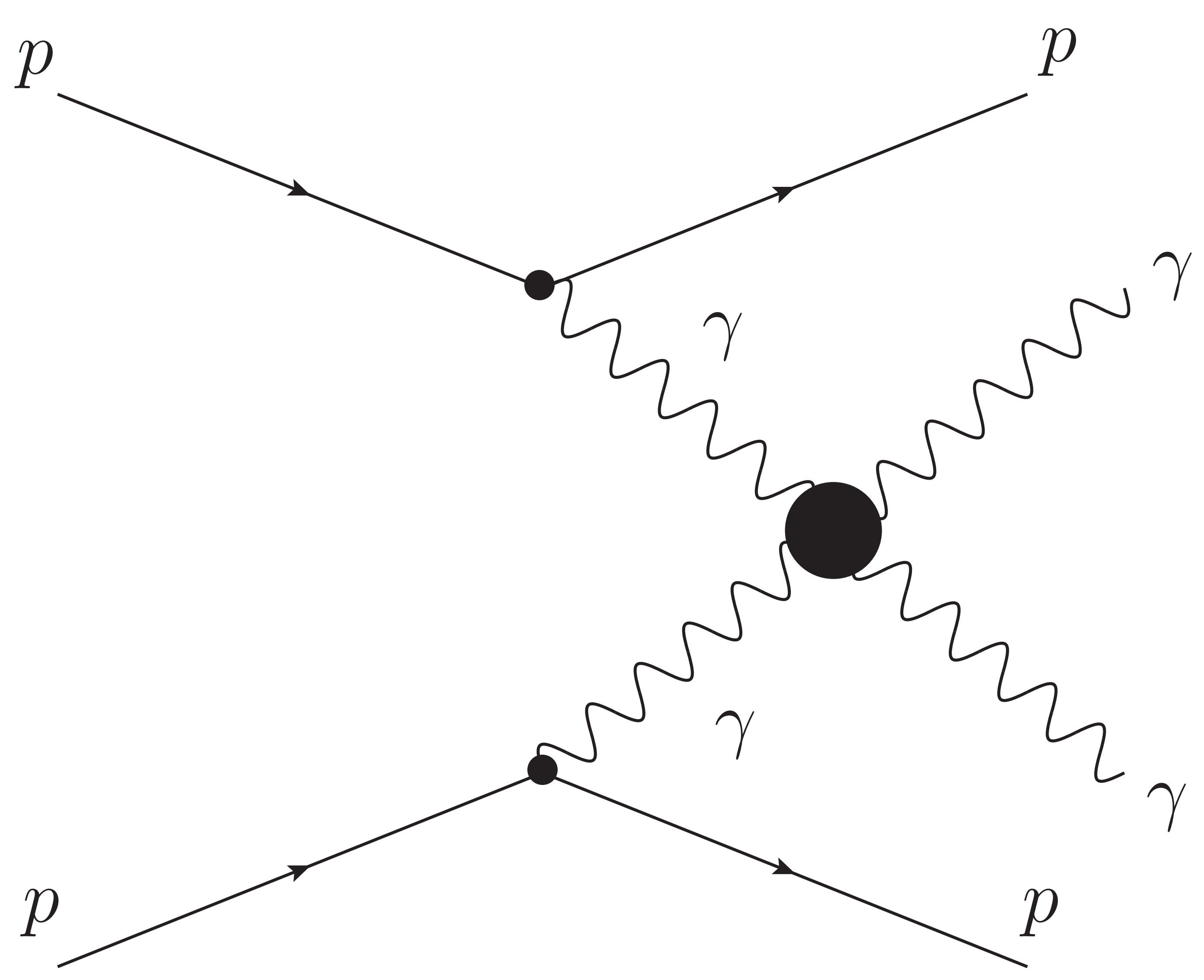
ATLAS and CMS results

Christophe Royon: CMS and TOTEM results on diffraction and low x



- many interesting results; please see original talks for details
- Here: tests of anomalous couplings

- Consider the LHC as a $\gamma\gamma$ collider: leads to very clean events (like at LEP) where we measure intact protons and produced particles in CMS/ATLAS
- Search for exclusive $\gamma\gamma$, ZZ, WW, $t\bar{t}$ at high luminosity at the LHC: Leads to best sensitivities to quartic anomalous couplings to date and also to the productions of axion-like particles at high mass

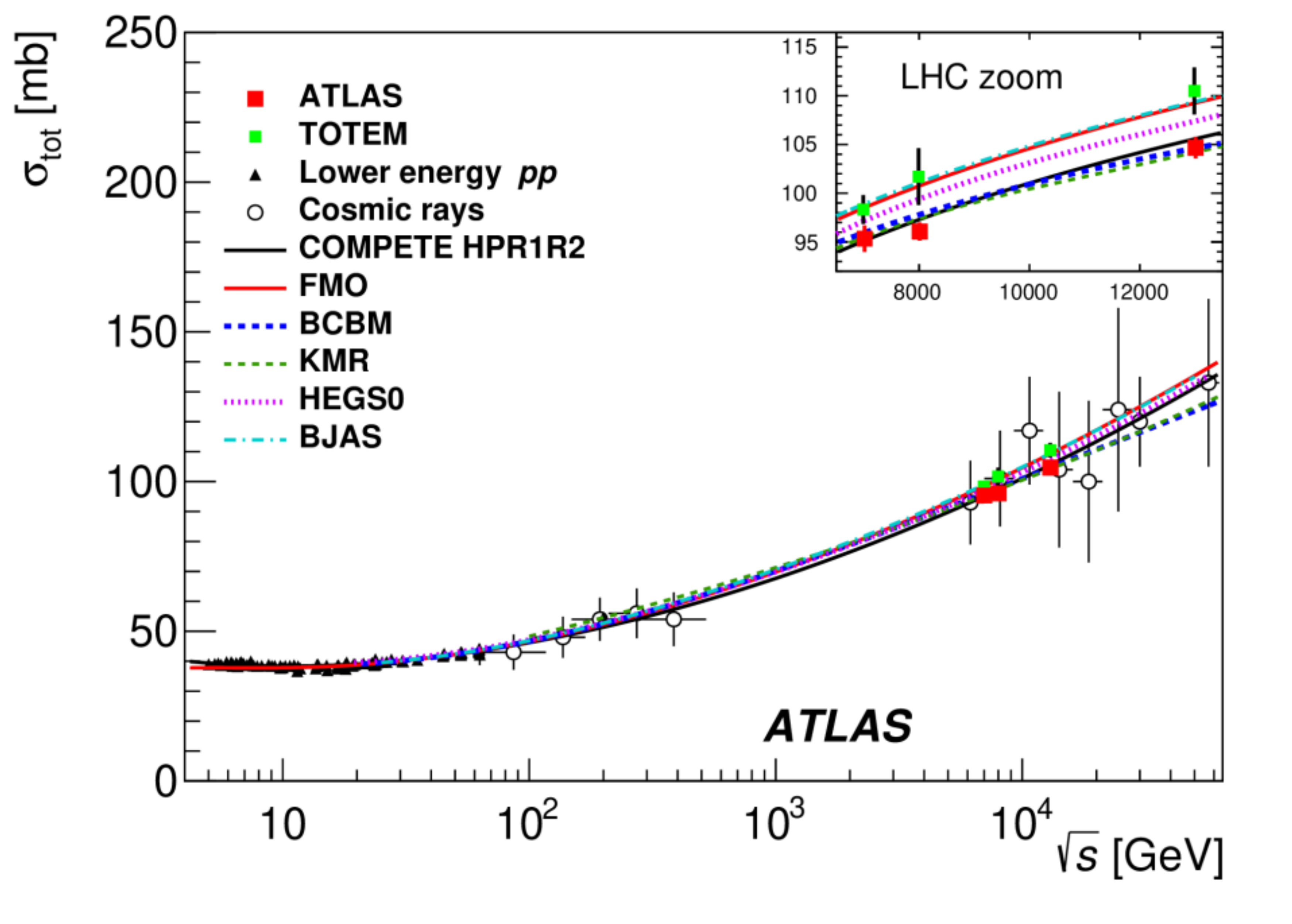
Peter Bussey: Elastic and exclusive forward proton measurements with ATLAS

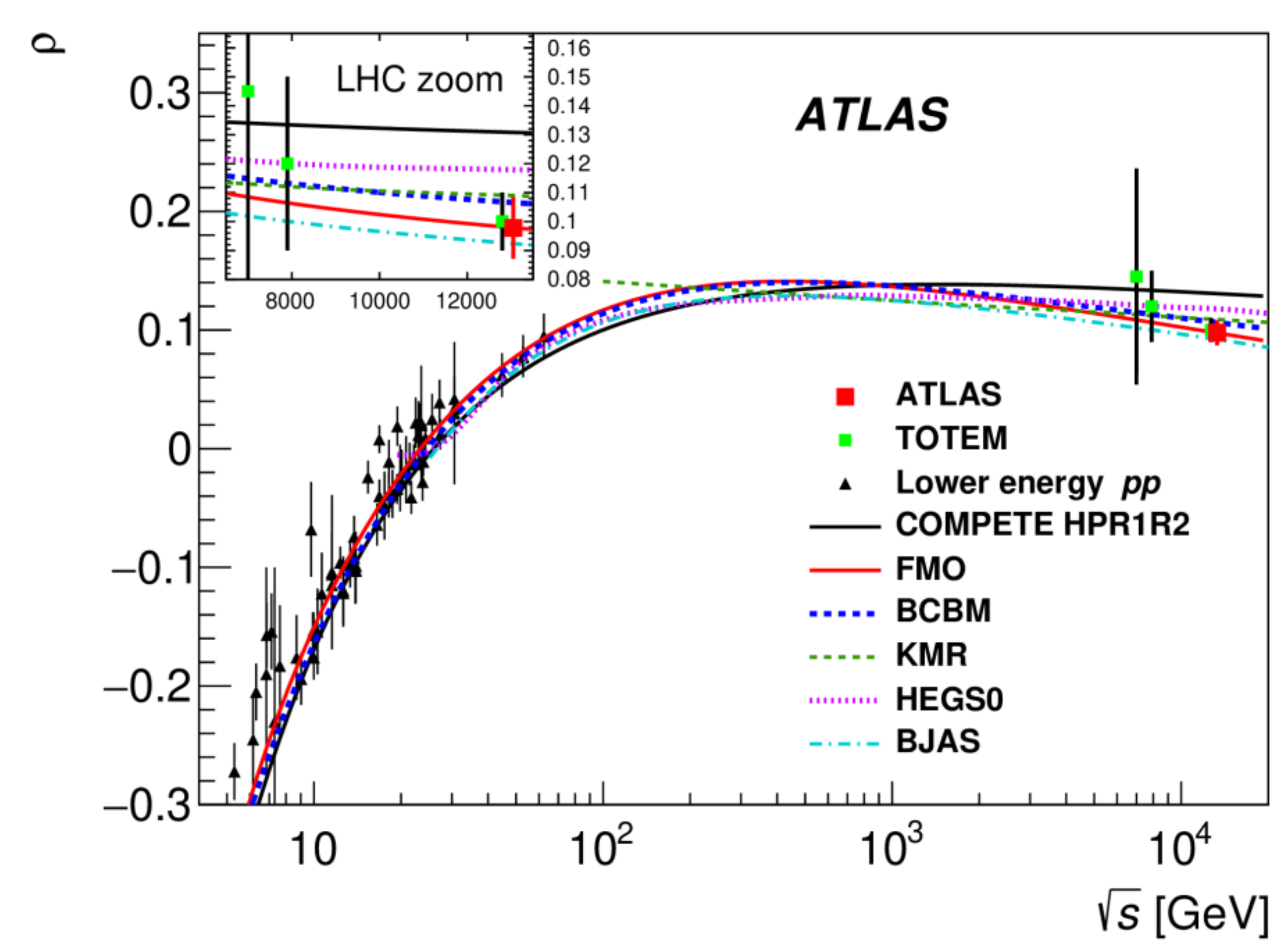
Finally we can get the **total cross section** using the Optical theorem:

$$\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \cdot \frac{d\sigma_{el}}{dt}\bigg|_{t\to 0}$$

where

$$\rho = \frac{\mathrm{Re}(f_{el}(t))}{\mathrm{Im}(f_{el}(t))}\bigg|_{t\to 0}$$

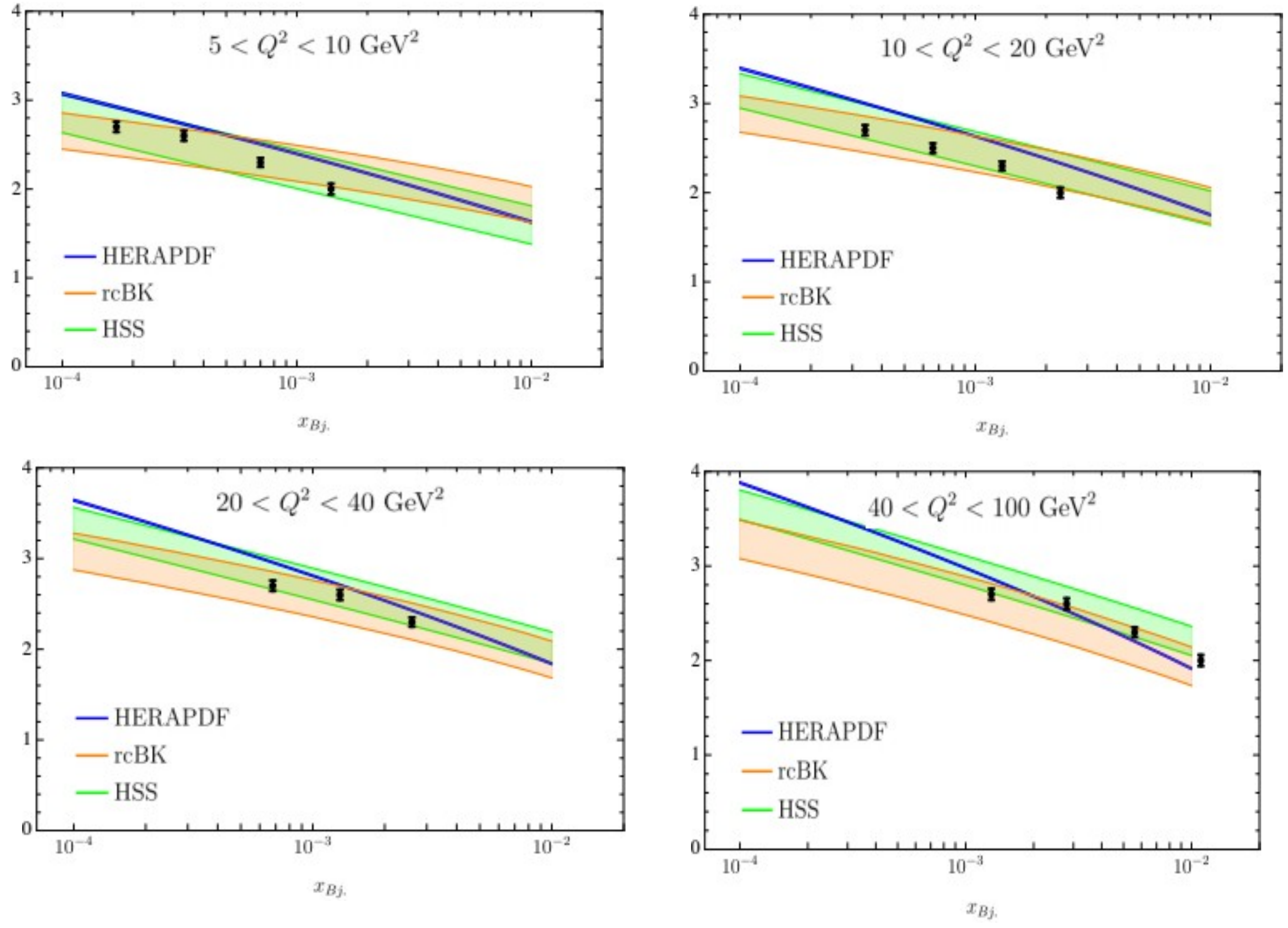




- The widely used model COMPETE is in poor agreement with above (predicts $\rho = 0.13$)
- It is a model with Odderon exchange tuned to TOTEM
- ALFA and TOTEM disagree at 2.2 σ level (similar trend at 7, 8 GeV)
- σ_{tot} somewhat lower than TOTEM, largely due to normalisation

Charged hadron multiplicity and hadronic entropy in DIS

K. Kutak: Maximally entangled proton and charged hadron multiplicity in DIS

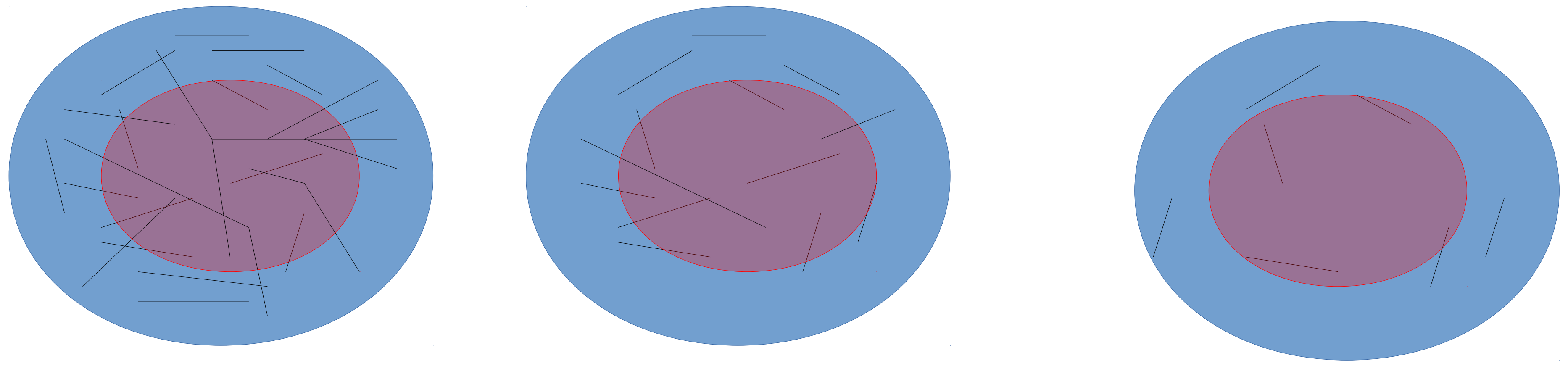


Possible to describe H1 data, using a proposal by Kharzeev and Levin (even though uncertainties remain)

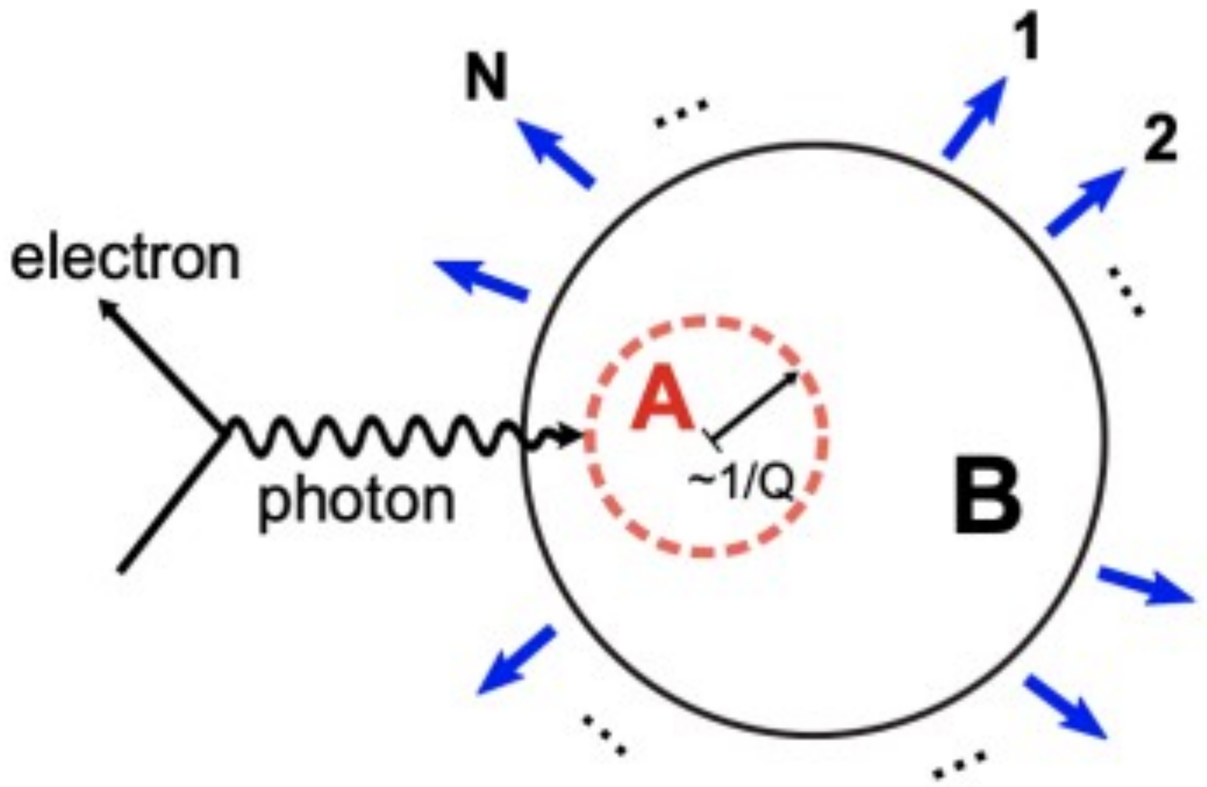
$$S_{hadron} = \sum P(N) \ln P(N)$$

$P(N)$ = # hadrons in bin/total #

E. Schrödinger: "*Entanglement of predictions arises from the fact that two bodies at earlier times … were interacting and left behind choices onto each other*"



In DIS at low x: the color dipole as a useful degree of freedom → naturally entangled



Virtual photon: observe only subset of size $1/Q^2$→ entanglement entropy

Kharzeev, Levin, 2017:

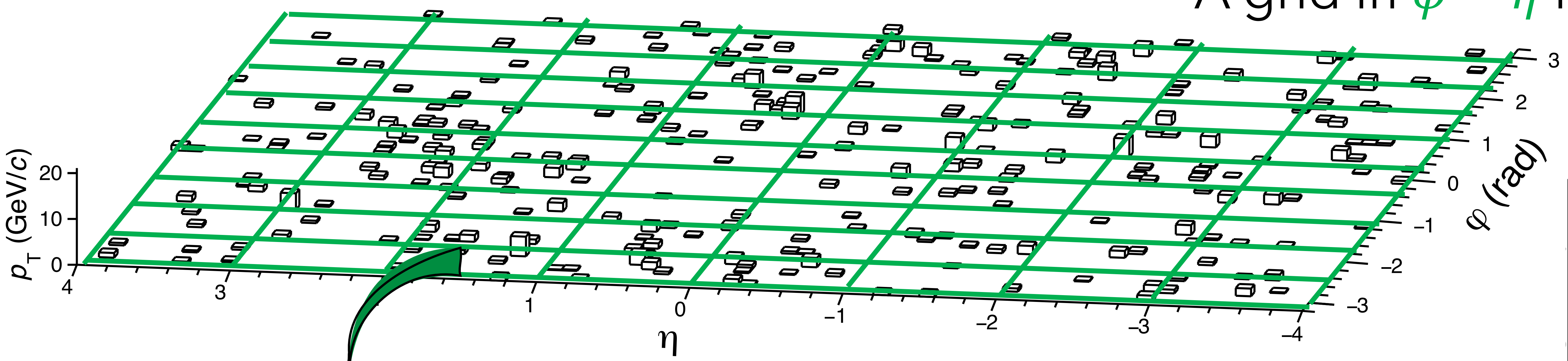
At low x, this entanglement entropy can be estimated using

$$S(x, Q) = \ln(xg(x, Q))$$

+ can be obtained experimentally from hadronic entropy (from multiplicity distribution of produced hadrons)

Antonio Ortiz: Multi-parton interactions at LHC run 3 and beyond

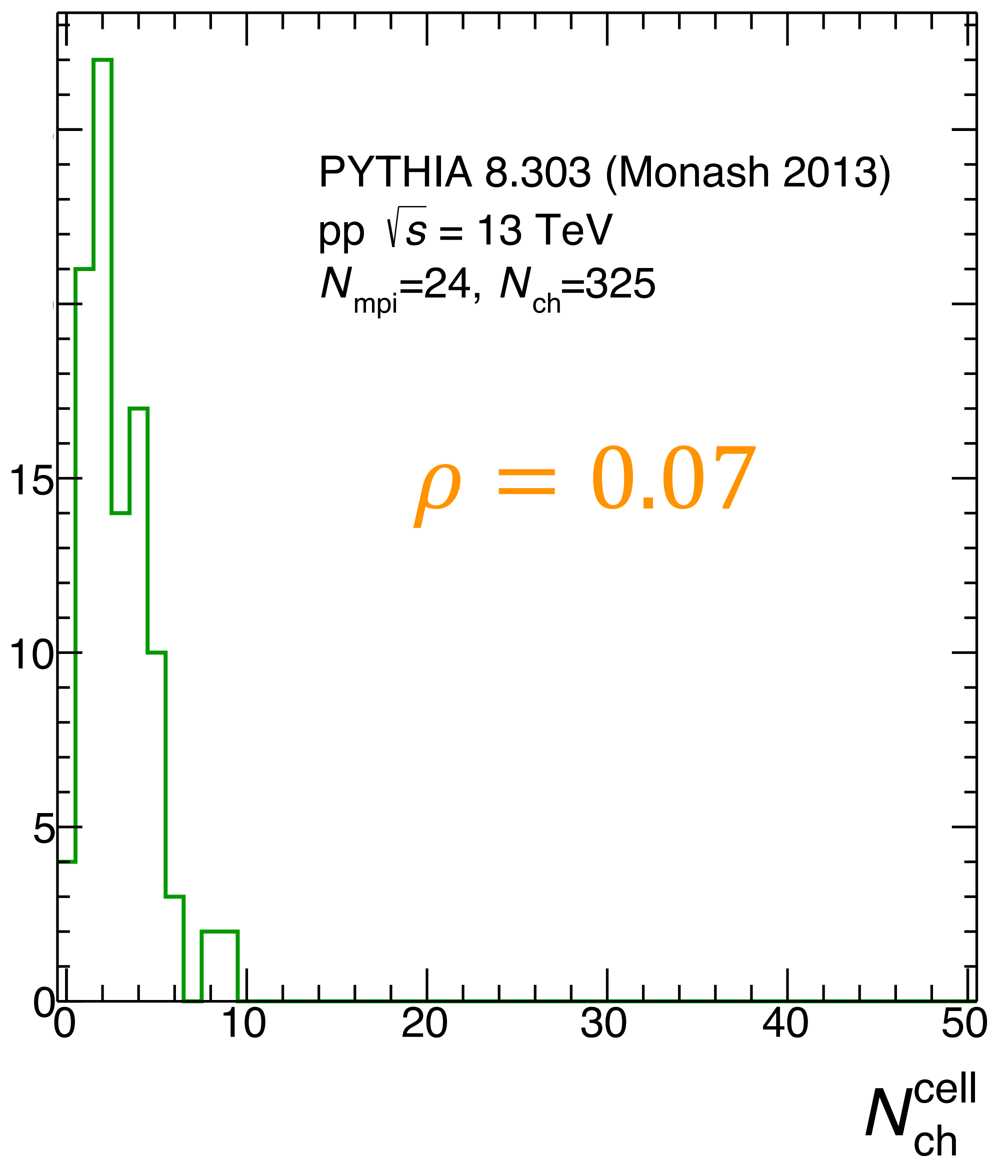
Flattenicity



A grid in $\varphi - \eta$ is built: $N_{\rm cell} = 10 \times 8$

EbE the $N_{\rm ch}^{\rm cell}$ distribution is obtained

In the cell i, the charged particle multiplicity is computed: $N_{\rm ch}^{{\rm cell},i}$



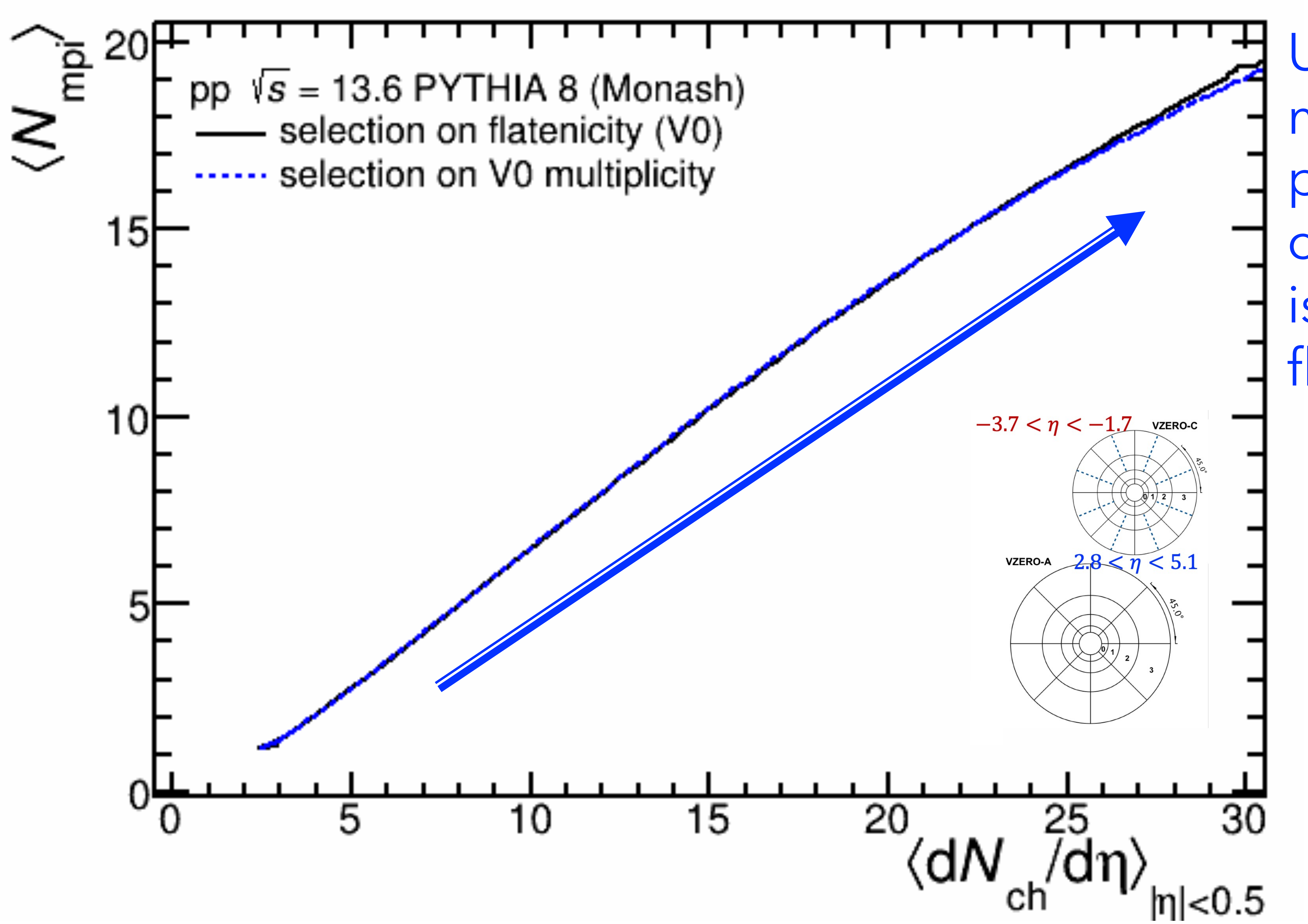
A. Ortiz et al, arXiv:2204.13733
A. Ortiz, A. Khuntia, O. Vázquez et al, arXiv:2211.06093

$$\rho = \frac{\sqrt{\sum_i (N_{\rm ch}^{{\rm cell},i} - \langle N_{\rm ch}^{\rm cell}\rangle)^2 / N_{\rm cell}^2}}{\langle N_{\rm ch}^{\rm cell}\rangle}$$

Events with isotropic distribution of particles (very active MPI) are expected to have small ρ values

Events with jet structures are expected to have large ρ values

Flattenicity vs MPI and "hardness" of the coll



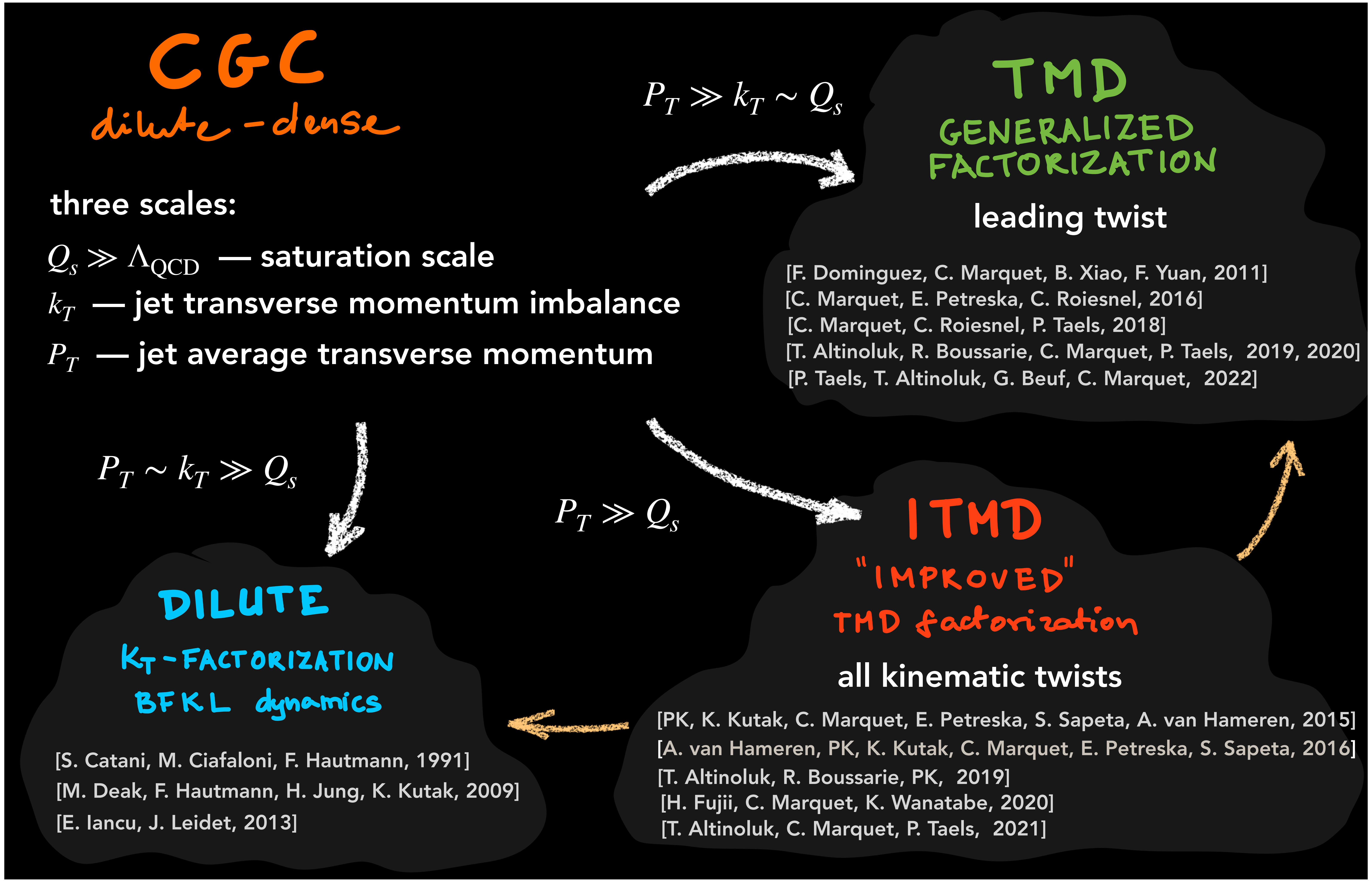
UE as a function of the average midpseudorapidity charged-particle density. Very similar correlation if the event selection is done either in multiplicity or flattenicity in the V0 region

For a similar fraction of cross section, flattenicity and multiplicity in the V0 select pp collisions with very similar charged particle densities ($|\eta| < 0.5$)

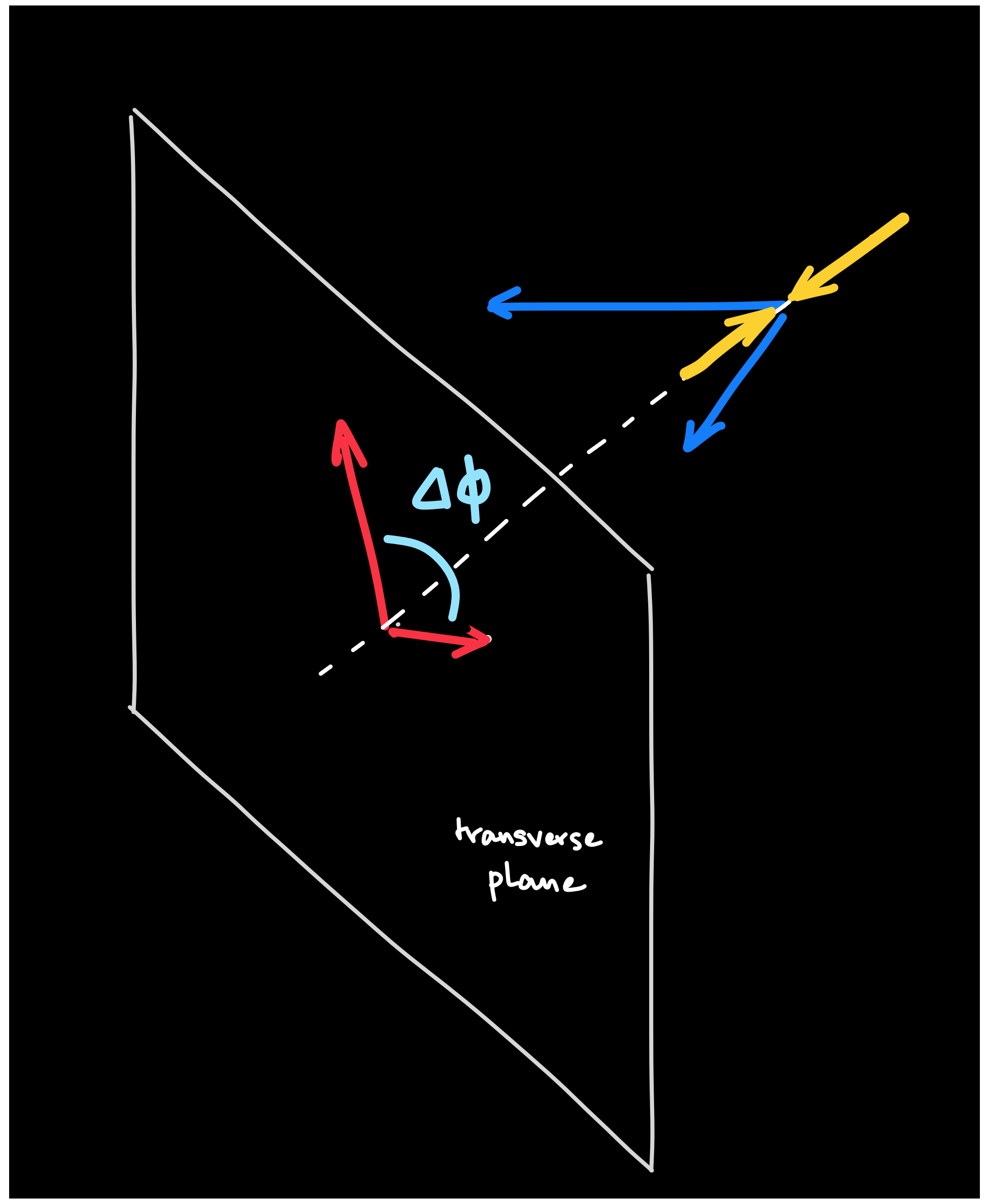
Event class	$1-\rho$	V0M
0-1%	25.0	27.1
1-5%	22.9	23.0
5-10%	18.4	18.7
10-20%	15.6	15.3

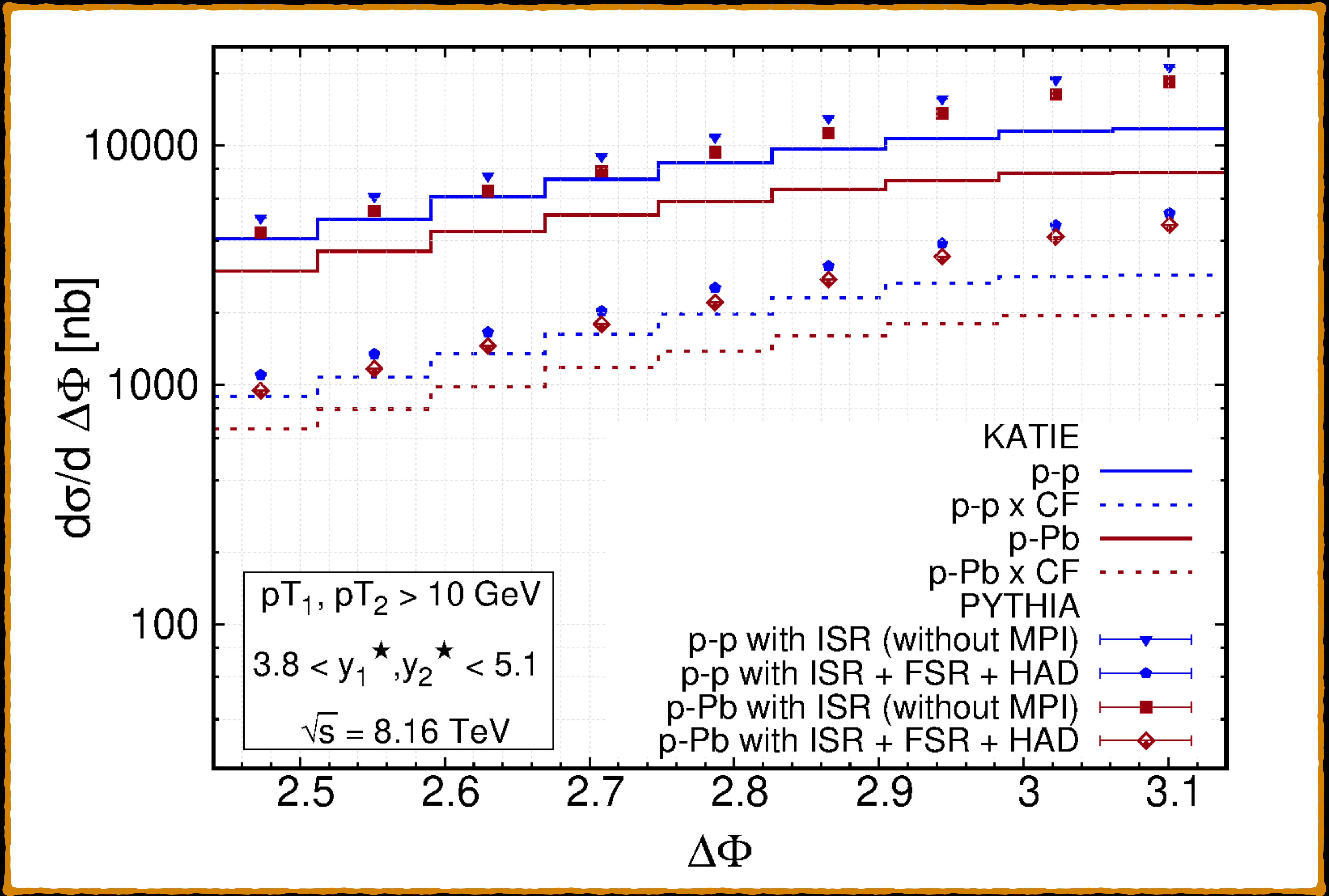
Back-to-back dihadron and jets

Piotro Kotko: Studying saturation effects in dijets production at forward LHC calorimeters



+ Sudakov resummation
+ Pythia initial state and final state shower

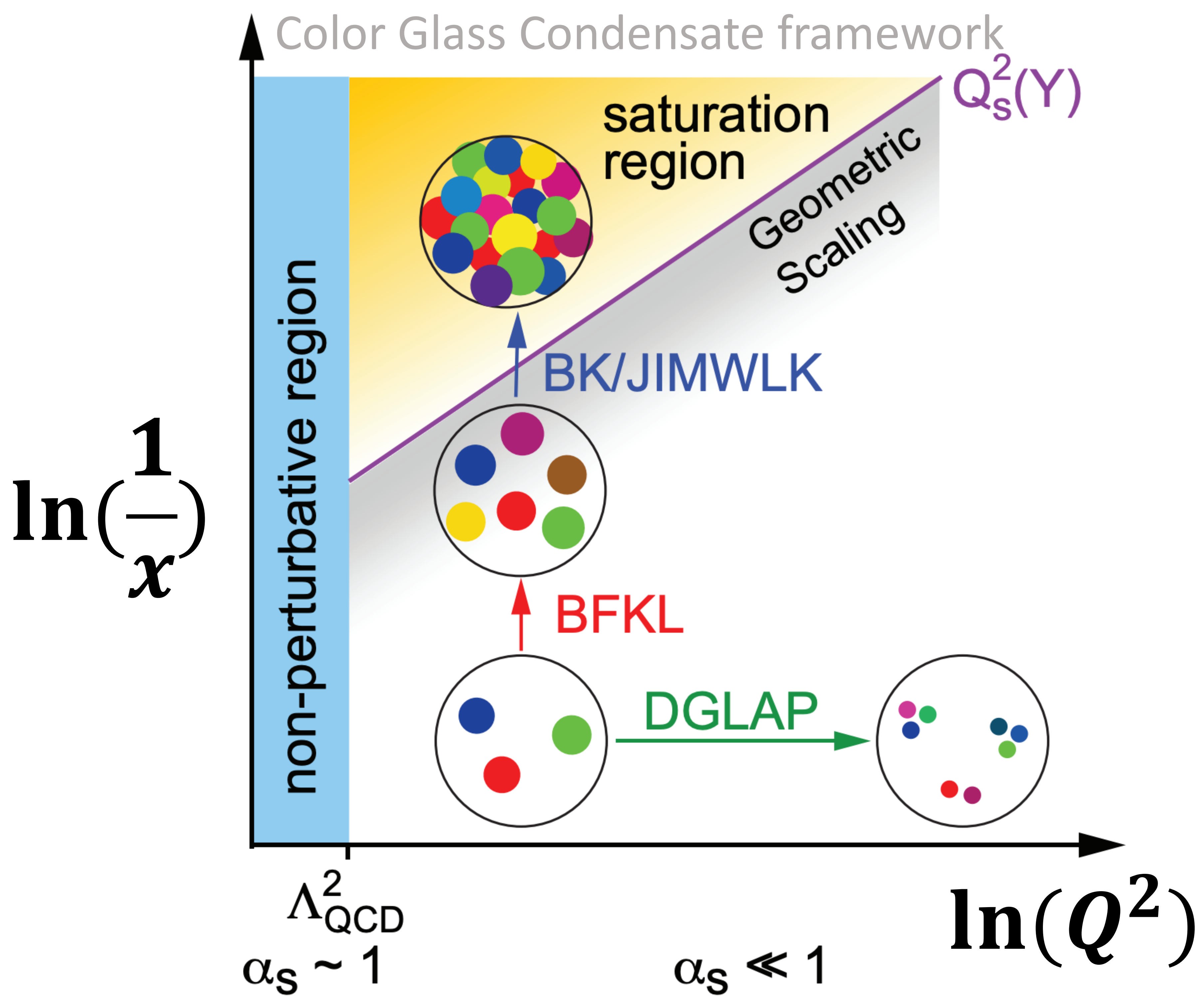




- azimuthal correlations between jets
- p-p and p-Pb cross sections in FoCal and ATLAS setup
- nuclear modification ratios
- ITMD framework with KS TMD gluon distributions using KaTie Monte Carlo
- both the full b-space Sudakov resummation and the approximate MC-convenient approach
- Pythia computations to estimate nonperturbative corrections

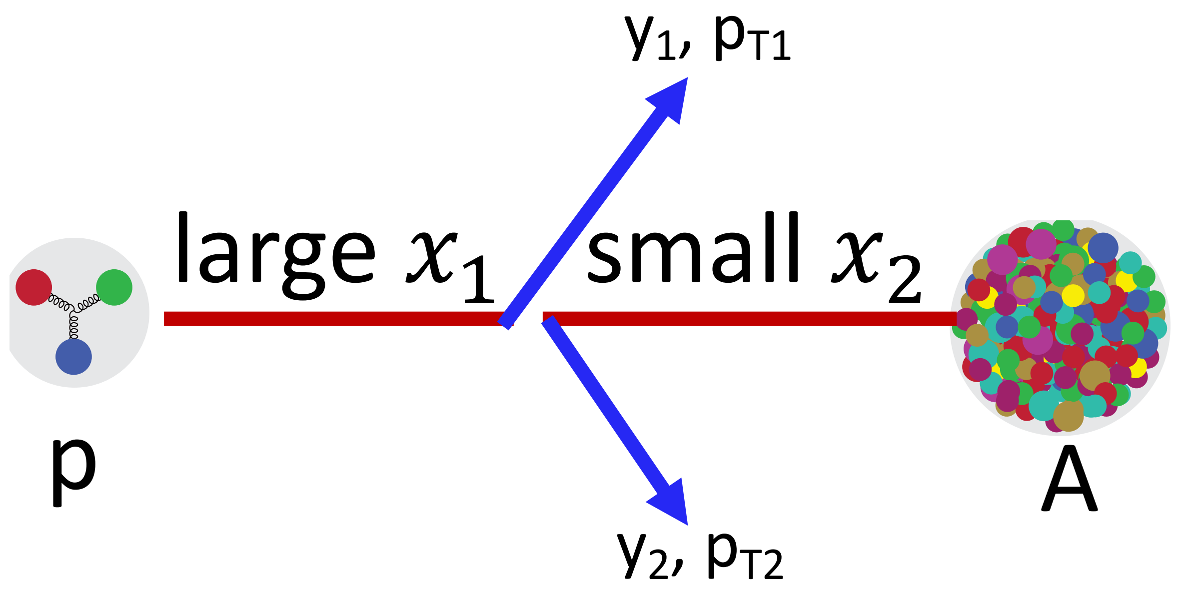
Predictions for FOCAL

Xiaoxuan Chu:Back-to-back di-π^0 azimuthal correlation at forward rapidities at STAR



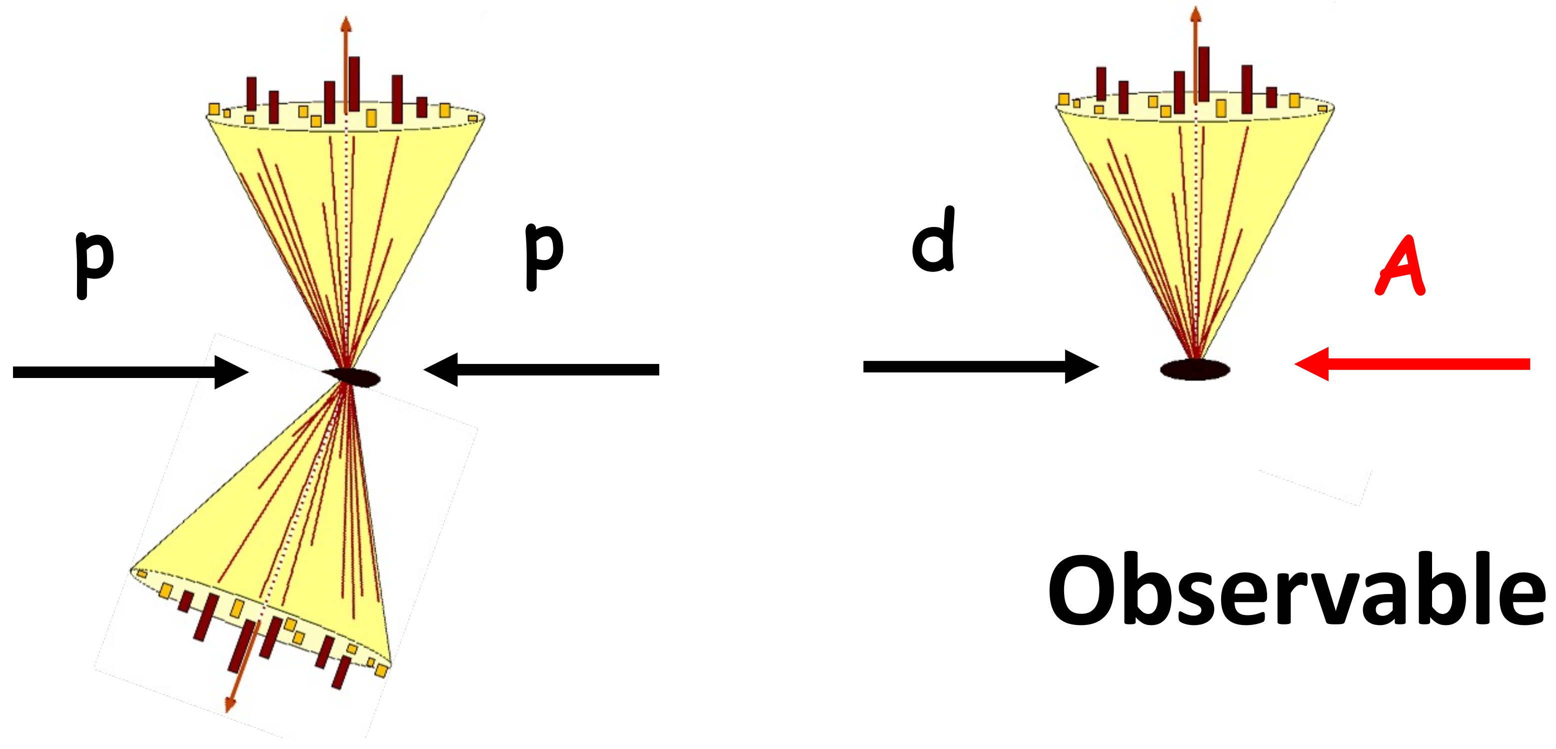
Decrease x, Q^2:

1. More forward direction
2. Lower p_T hadron



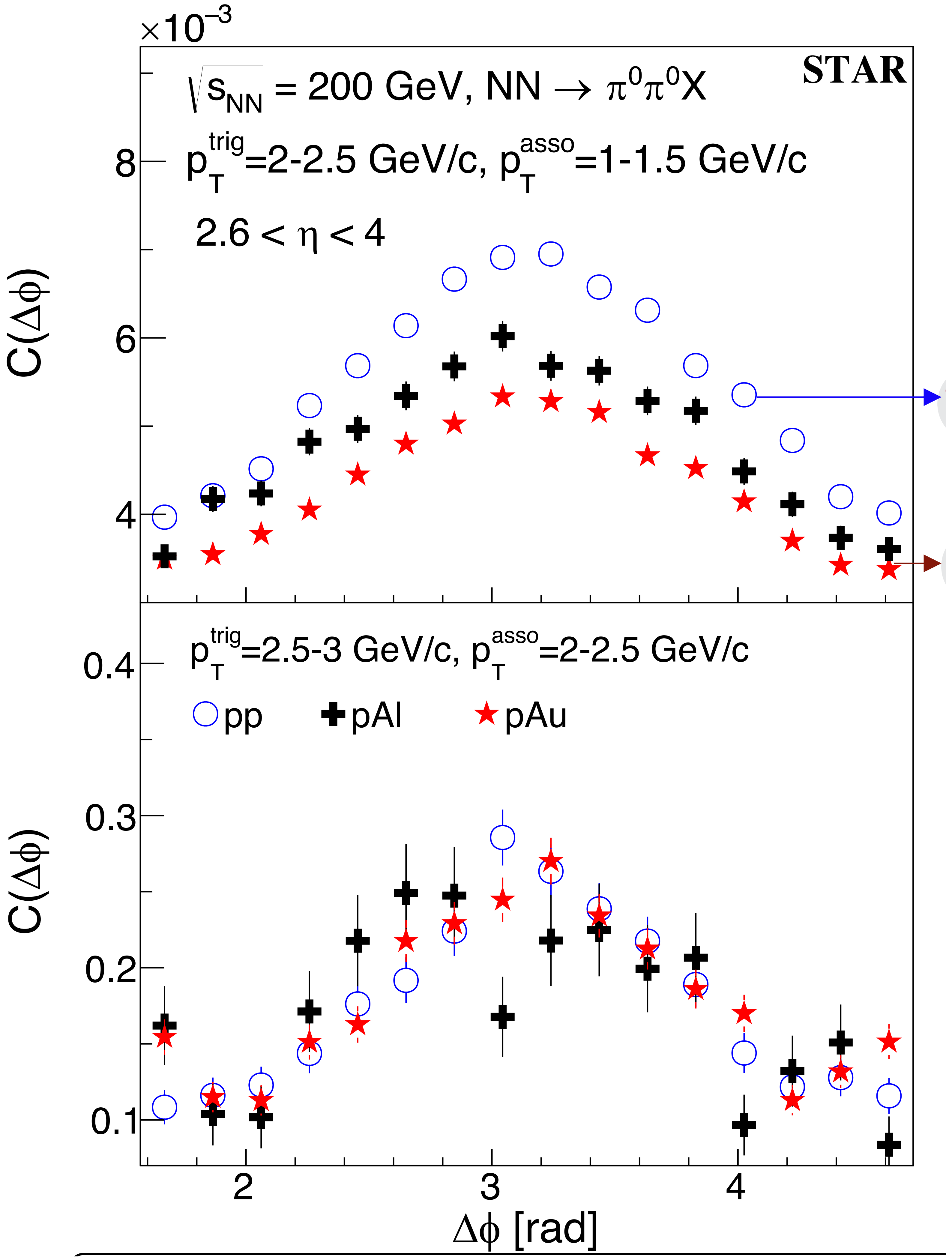
$$x_2 \sim \frac{p_{T1}e^{-y_1} + p_{T2}e^{-y_2}}{\sqrt{s}}$$

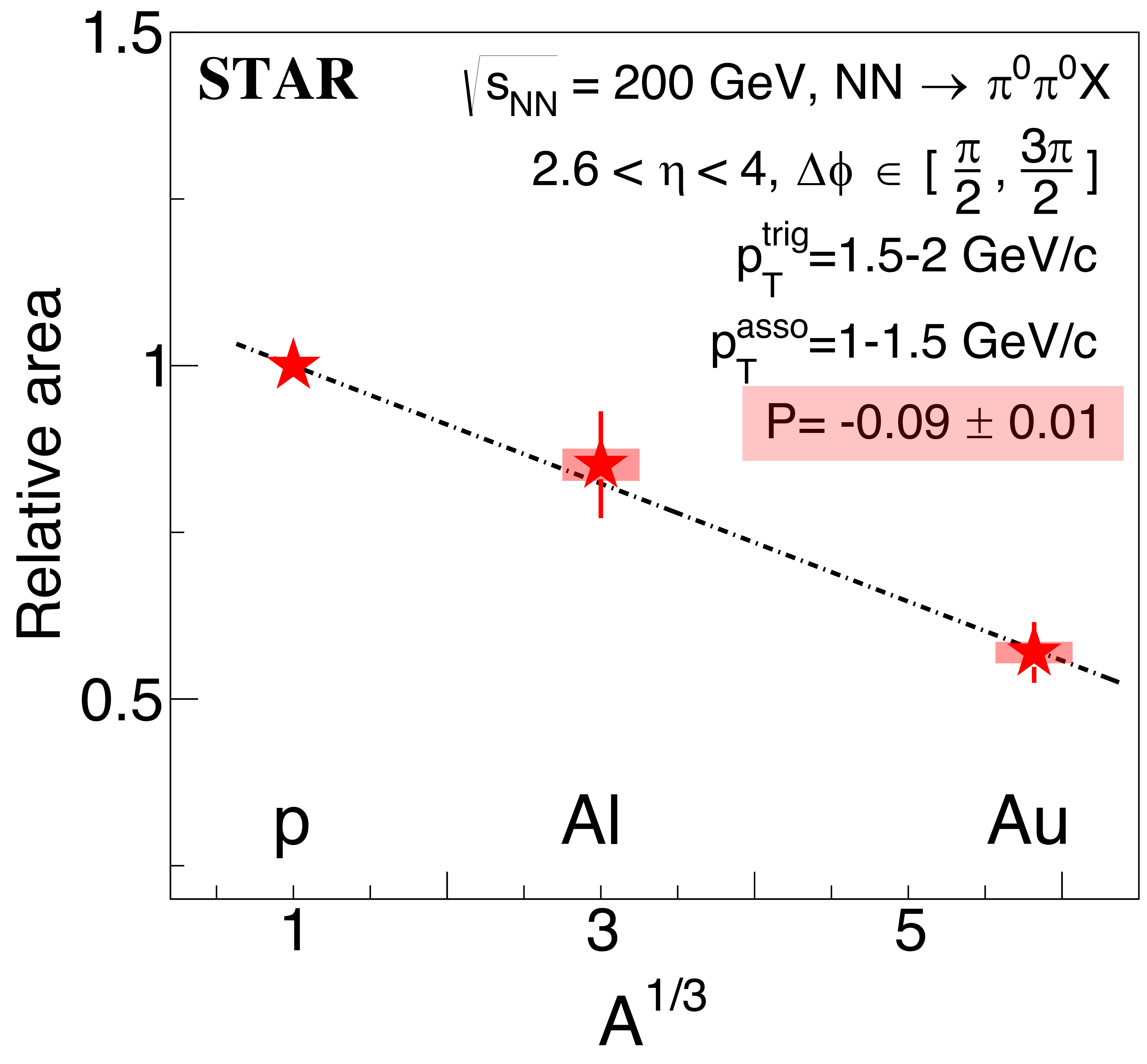
$$Q \sim \frac{p_{T1} + p_{T2}}{2}$$



Search for suppression of the away side peak

Observable: $C(\Delta\phi) = \frac{N_{pair}(\Delta\phi)}{N_{trig} \times \Delta\phi_{bin}}$



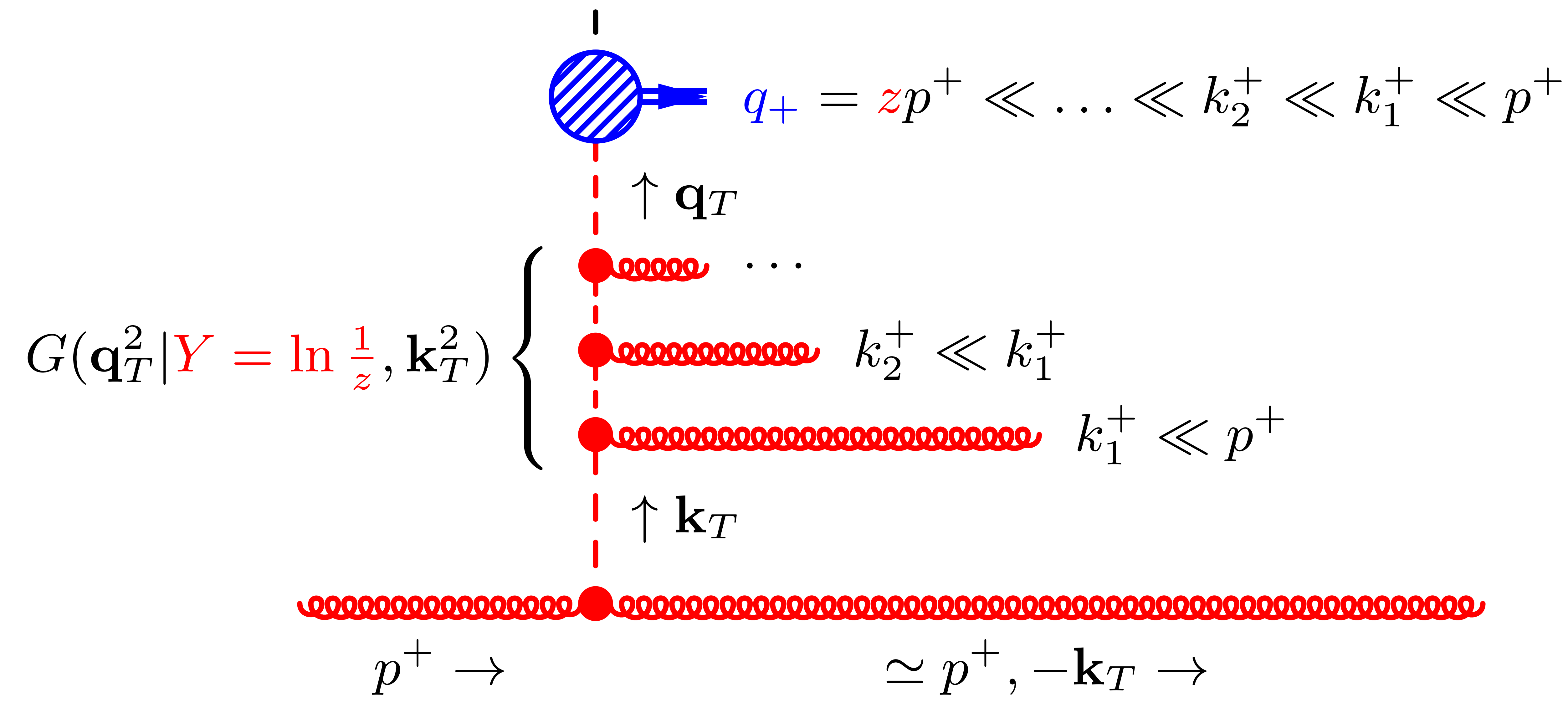


Suppression linearly depends on $A^{\frac{1}{3}}$

$\leftrightarrow$ $Q_s^2 \sim A^{\frac{1}{3}}$ scaling of the saturation scale

Related theory: Low x TMD distributions and double logarithms

M. Nefedov: Two scale evolution from rapidity ordered BFKL cascade



Notice, that k^+-conservation is taken care of by the MRK!

Region of applicability:

$$q_+ \frac{1-z}{z} \lesssim |\mathbf{q}_T| \ll \mu_1,$$

Realized for production of heavy particle (Higgs, quarkonium)

For certain limit: **negative** LO cusp anomalous dimensions

$$\tilde{\mathcal{C}} \propto \exp\left[-\hat{\alpha}_s\left(\ln^2 \frac{\mu_1}{|\mathbf{q}_T|} - 2\ln\frac{\mu_1}{|\mathbf{q}_T|}\left(\ln\frac{\mu_2}{|\mathbf{q}_T|} - \gamma_E\right)\right)\right].$$

Paul Caucal: Back-to-back dijets production in DIS at small x: Sudakov suppression and gluon saturation at NLO

In pure NLO result: soft double log with wrong (positive sign)
Solution:

- Kinematic improvement: impose both k_g^- and k_g^+ ordering (lifetime ordering).

  $\Longrightarrow$ Resum large transverse double logarithms to all orders.

  $\Longrightarrow$ Solve the instability of NLO B-JIMWLK evolution.

  Beuf, 1401.0313, Taels, Altinoluk, Beuf, Marquet, 2204.11650

- In practice, add an additional constraint in the LL evolution kernel

$$k_g^+ \geq k_f^+ \Longrightarrow k_g^- \leq \frac{\boldsymbol{k}_{g\perp}^2}{Q_f^2} k_f^-$$

- With this modification $\mathcal{K}_{\mathrm{LL}} \to \mathcal{K}_{\mathrm{LL,coll}}$, one recovers the expected double logarithm.

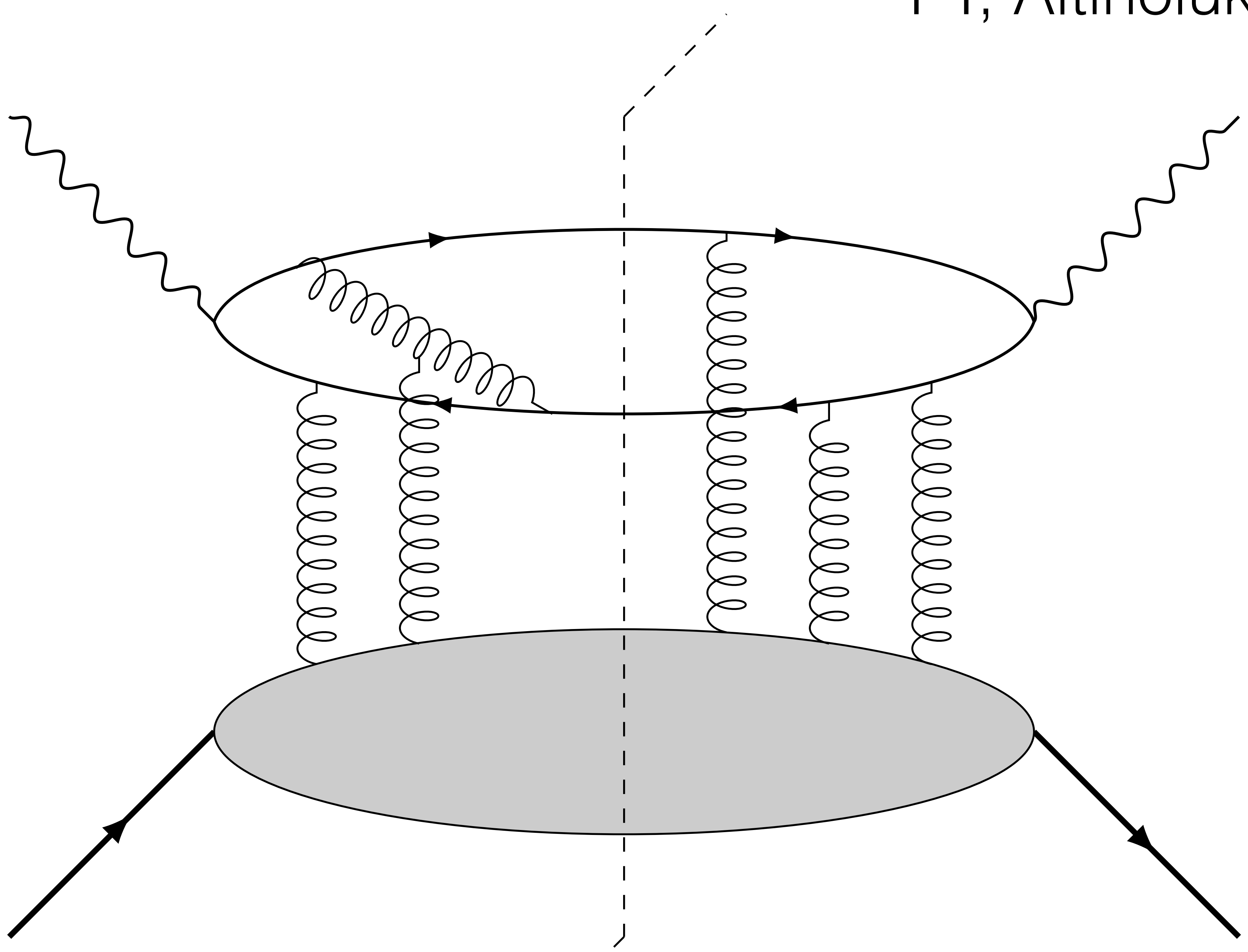
Comment: this is a great and useful observation, but we should also sort this out in a systematic way
Within high energy factorization

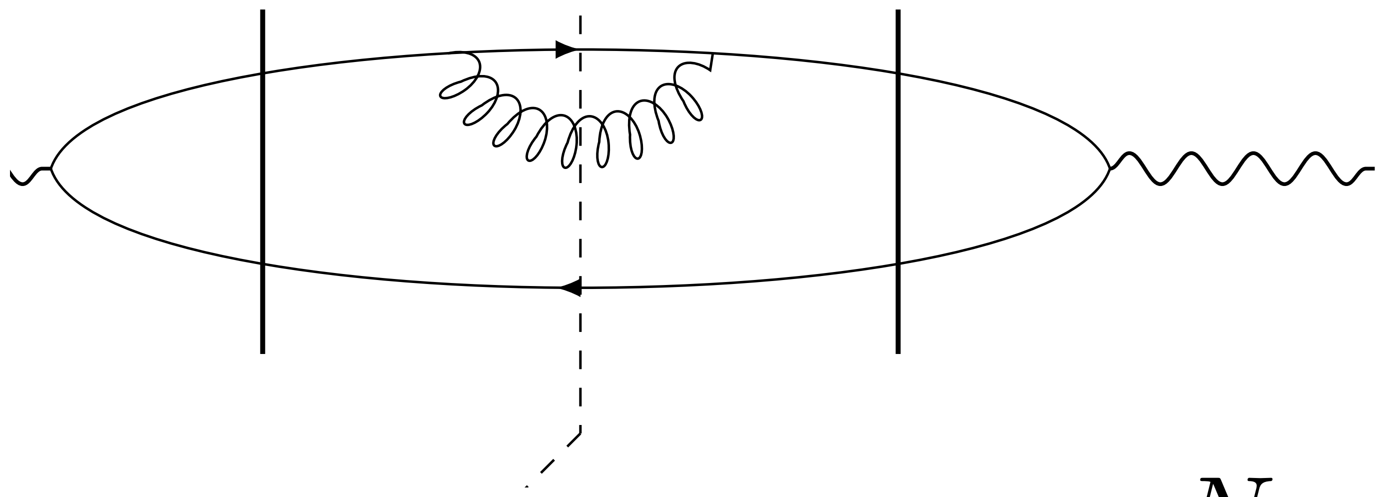
+ interesting results on TMD limit at NLO

P. Taels: Gluon transverse momentum distributions and saturation

Dijet photoproduction at NLO in the CGC

PT, Altinoluk, Beuf, Marquet (2022)





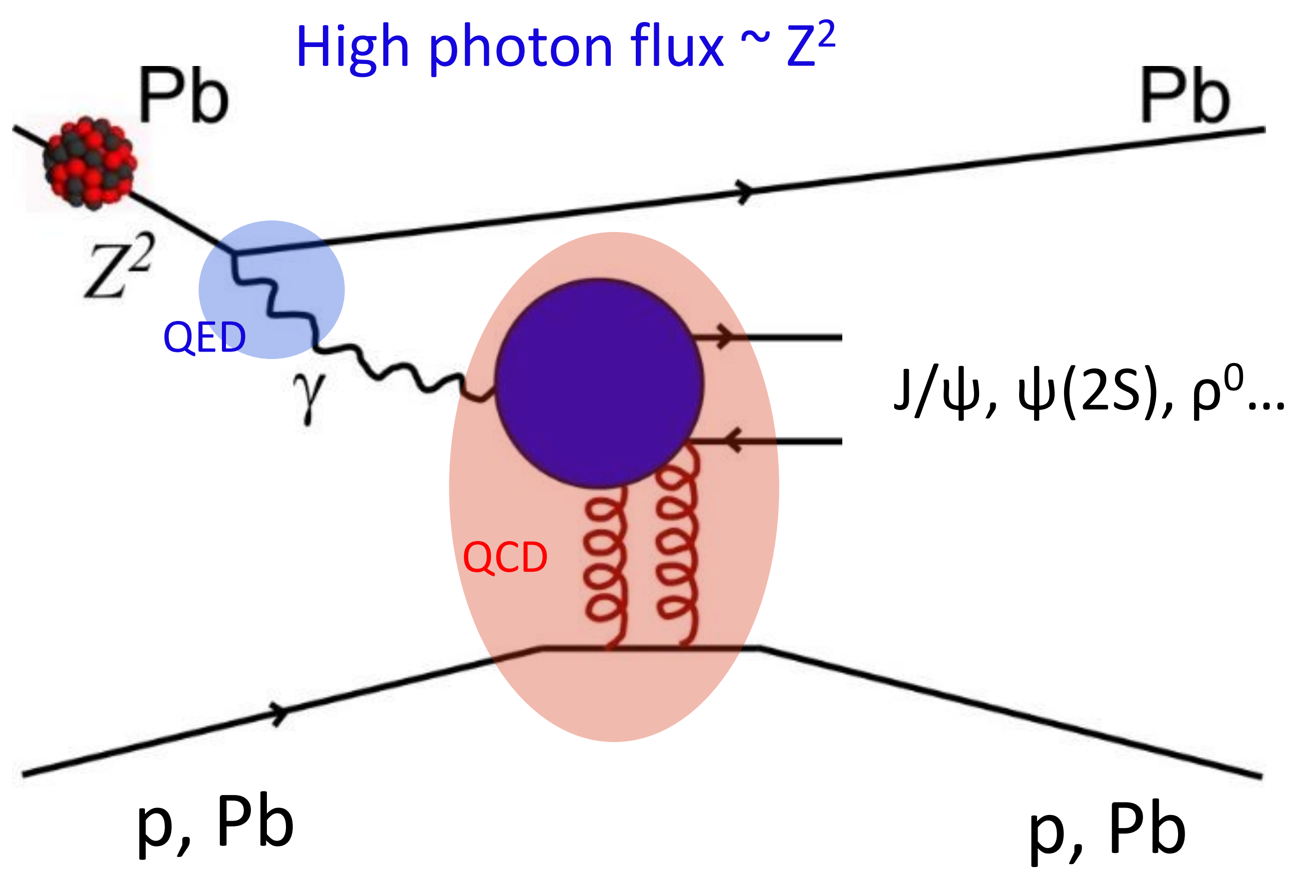
Final-state radiation leads to large Sudakov logarithms which drive TMD evolution:

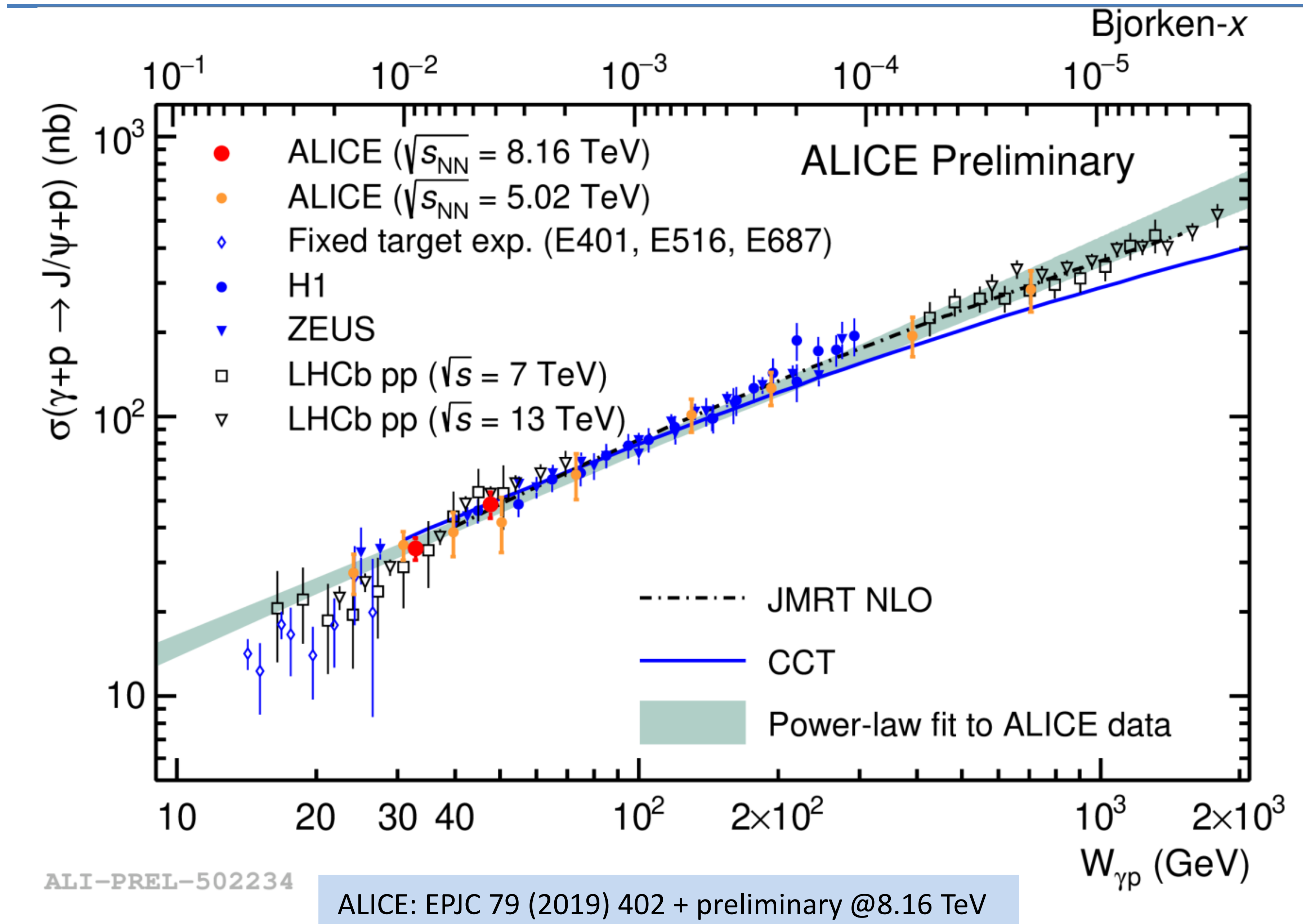
$$\mathrm{d}\sigma_{\mathrm{NLO}}^{\mathrm{TMD}} = \mathrm{d}\sigma_{\mathrm{LO}}^{\mathrm{TMD}} \times -\frac{\alpha_s N_c}{4\pi} \ln\left(\frac{\mathbf{P}_\perp^2(\mathbf{b}-\mathbf{b}')^2}{c_0^2}\right)^2 + \mathrm{fact.\ breaking}$$

Rigorous inclusion of Sudakov resummation becomes closer provided kinematically improved high-energy evolution

Exclusive photo production of vector mesons

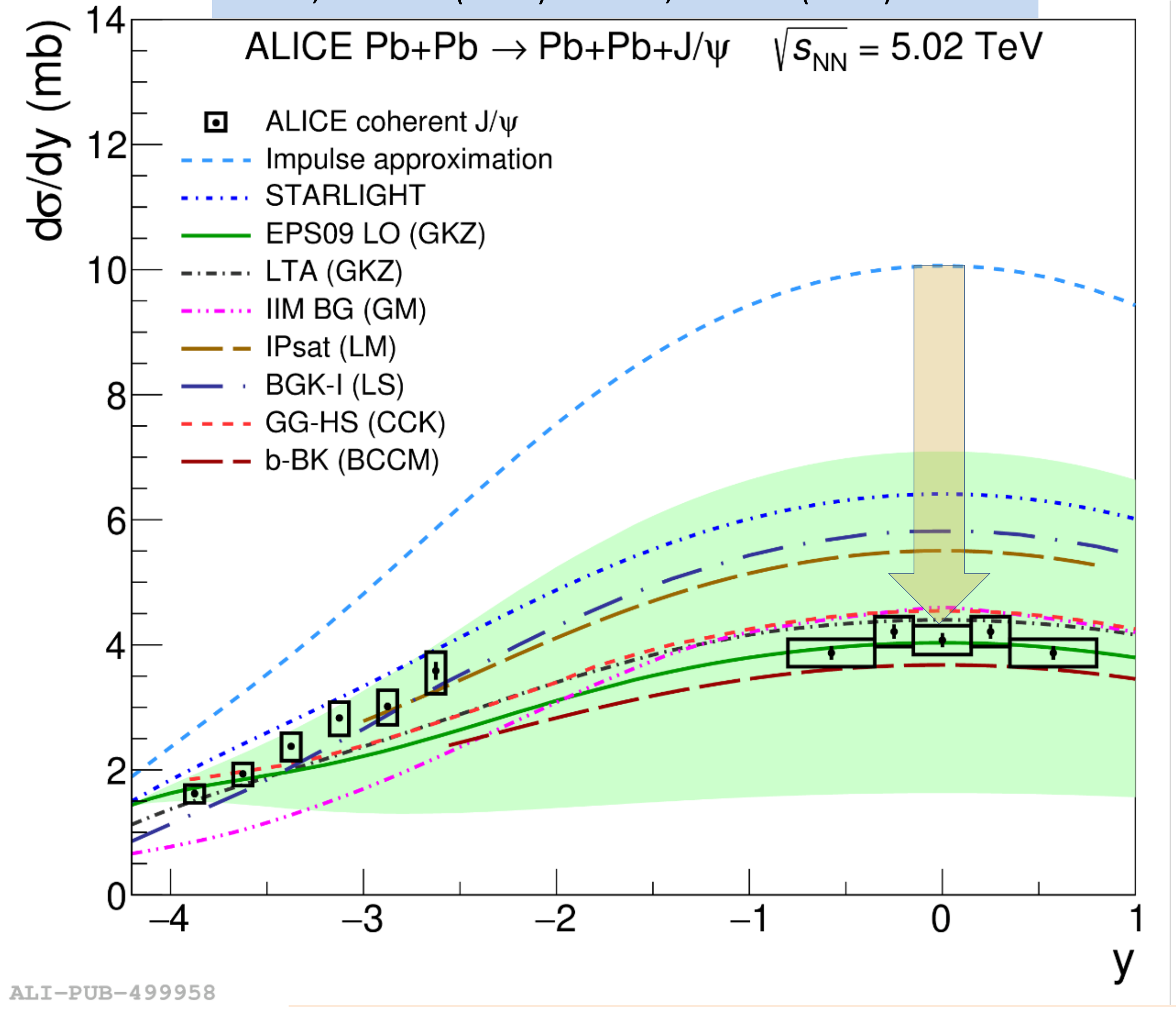
Evgeny Kryshen: Recent ALICE results on photon-induced interactions





ALICE: EPJC 79 (2019) 402 + preliminary @8.16 TeV

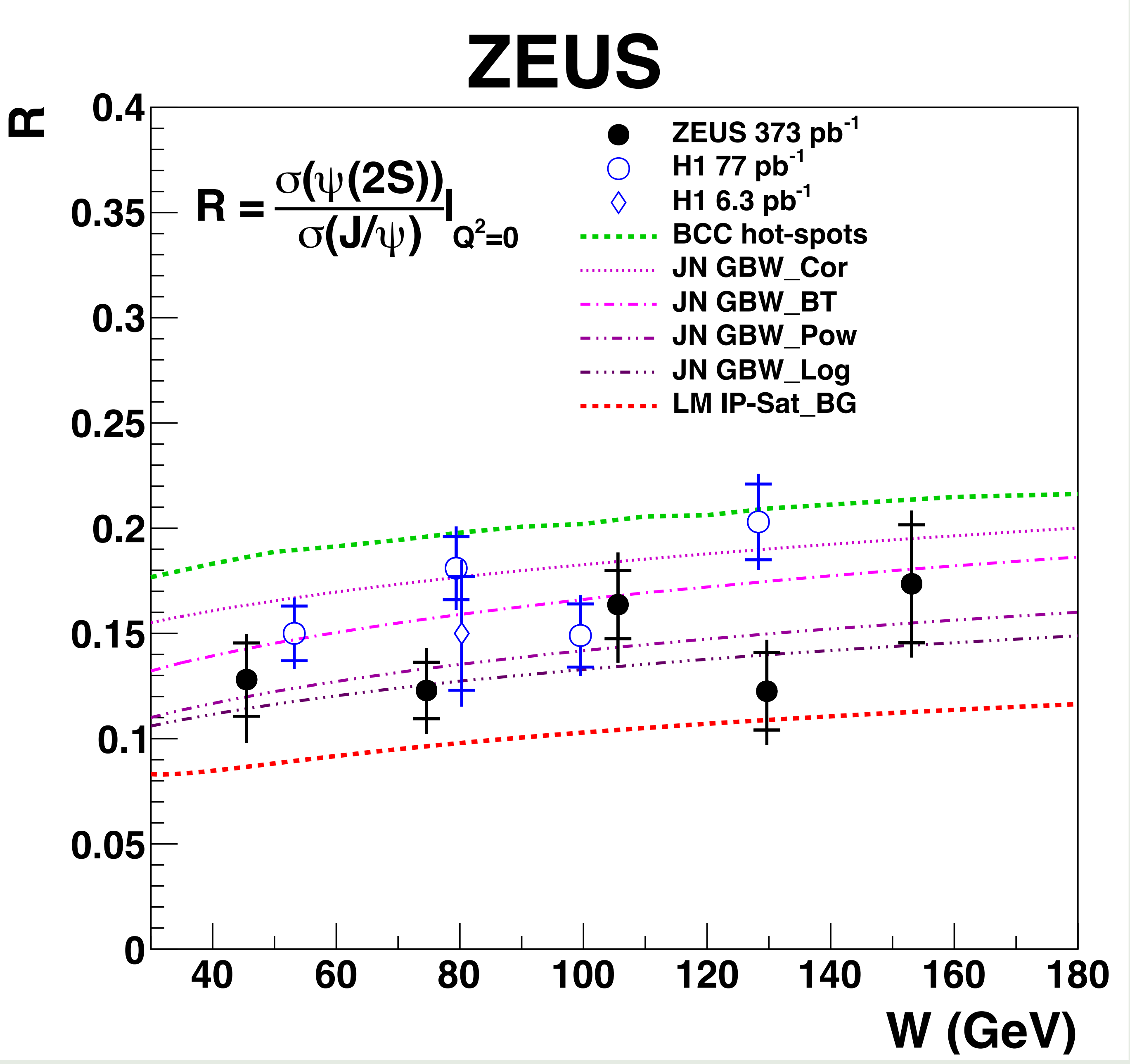
ALICE, PLB 798 (2019) 134926,PLB 817 (2021) 136280



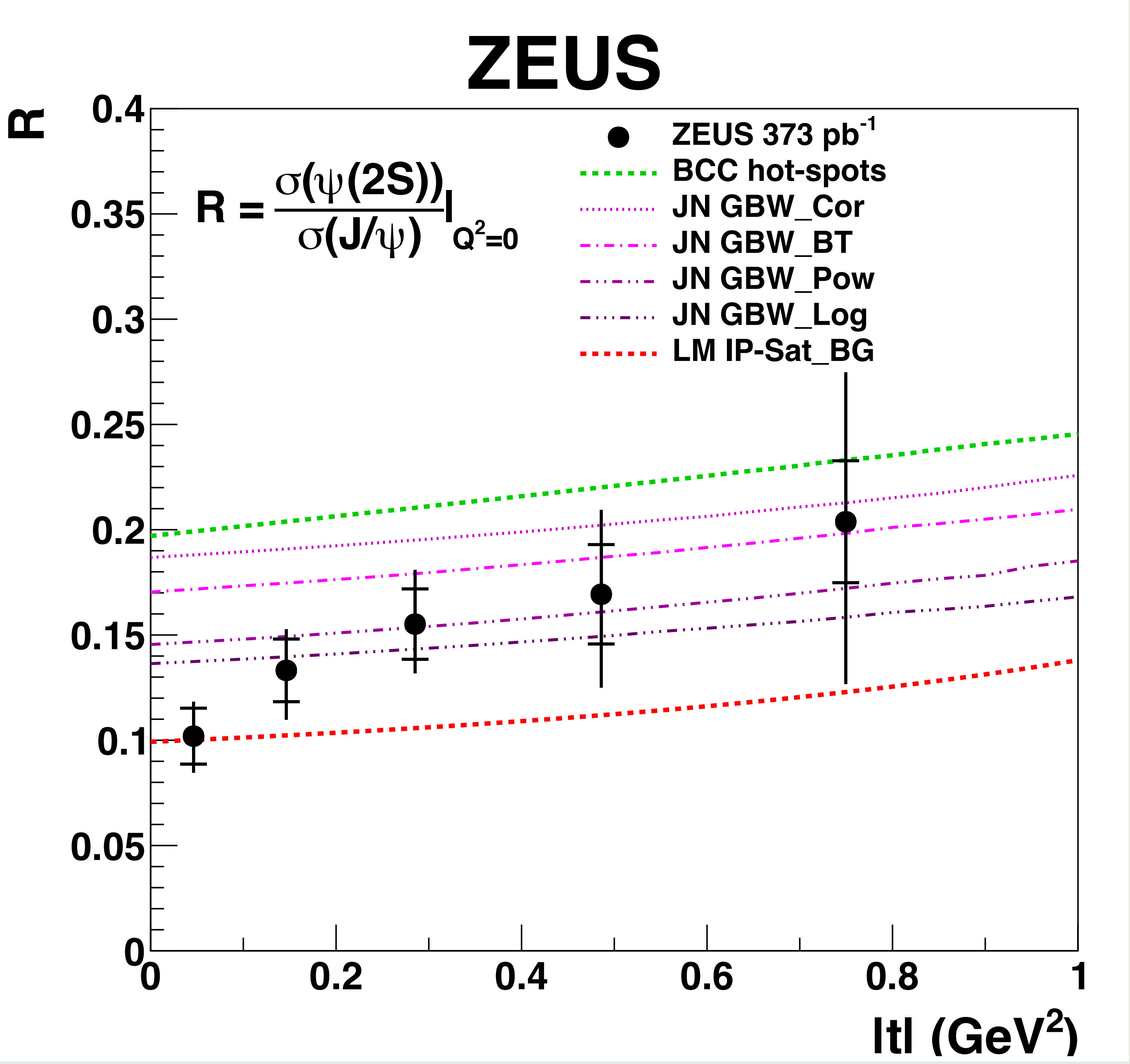
- Strong suppression wrt impulse approximation
- No models describing all data

Grzegorz Grzelak: $\psi(2s)$ over J/ψ ratio with ZEUS

R vs. W



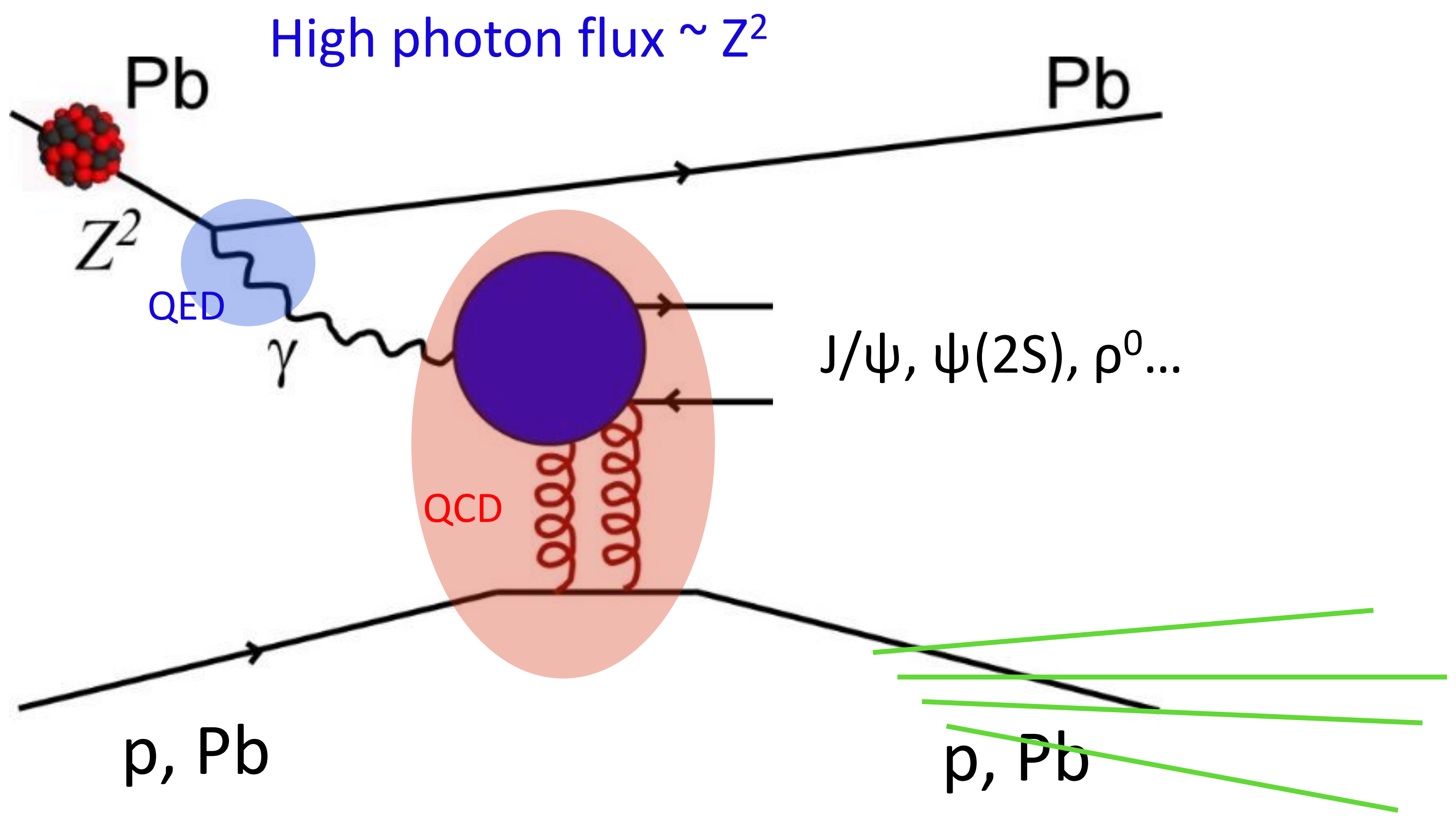
R vs. $|t|$



Personal comment:

- Rise vs. constant with W can give hints on the size of non-linear dynamics (different wave function)
- What about the rise with $|t|$?
- Relative normalization of the $\psi(2s)$ and J/ψ wave function?

Mark Strikman: rapidity gap dynamics - color fluctuations vs knockout mechanism



Diffractive: proton/Pb breaks up

Main message: description of soft diffraction by Good and Walker requires t=0:

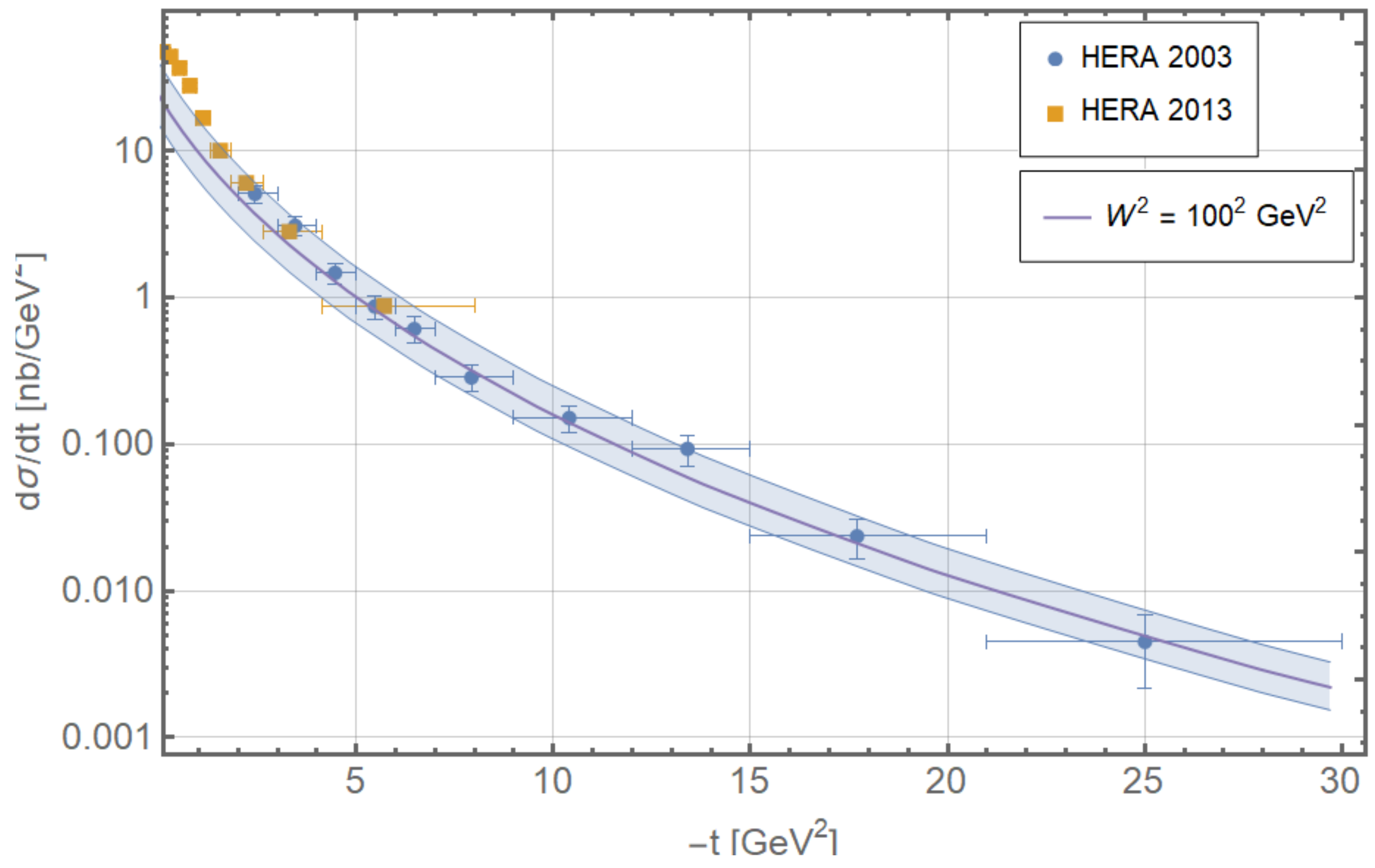
$$\left.\frac{d\sigma_{diffractive}}{dt}\right|_{t=0} \propto \langle G^2 \rangle$$

$$\left.\frac{d\sigma_{elastic}}{dt}\right|_{t=0} \propto \langle G \rangle^2$$

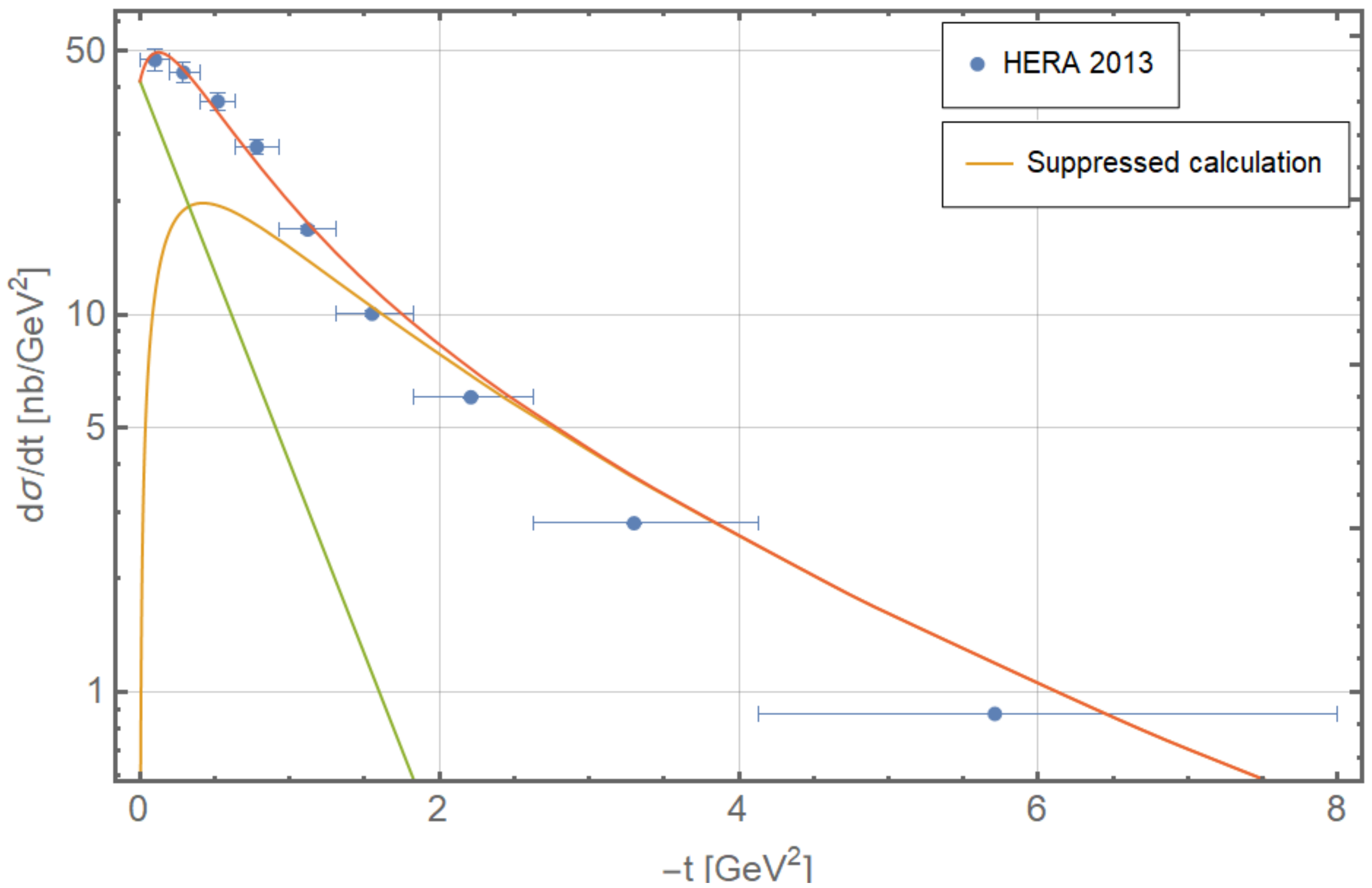
Incoherent reaction = fluctuations:

$$\left.\frac{d\sigma_{diffractive}}{dt}\right|_{t=0} - \left.\frac{d\sigma_{elastic}}{dt}\right|_{t=0} \propto \langle G^2 \rangle - \langle G \rangle^2 = \langle \Delta G^2 \rangle$$

Can in general not be extended to $t \neq 0$



Large t calculation extrapolated to small t



Suppression included.

Overall no need for gluon hot spots.
Fluctuation cross section t-slope is comparable soft physics, in particular spin flip contribution

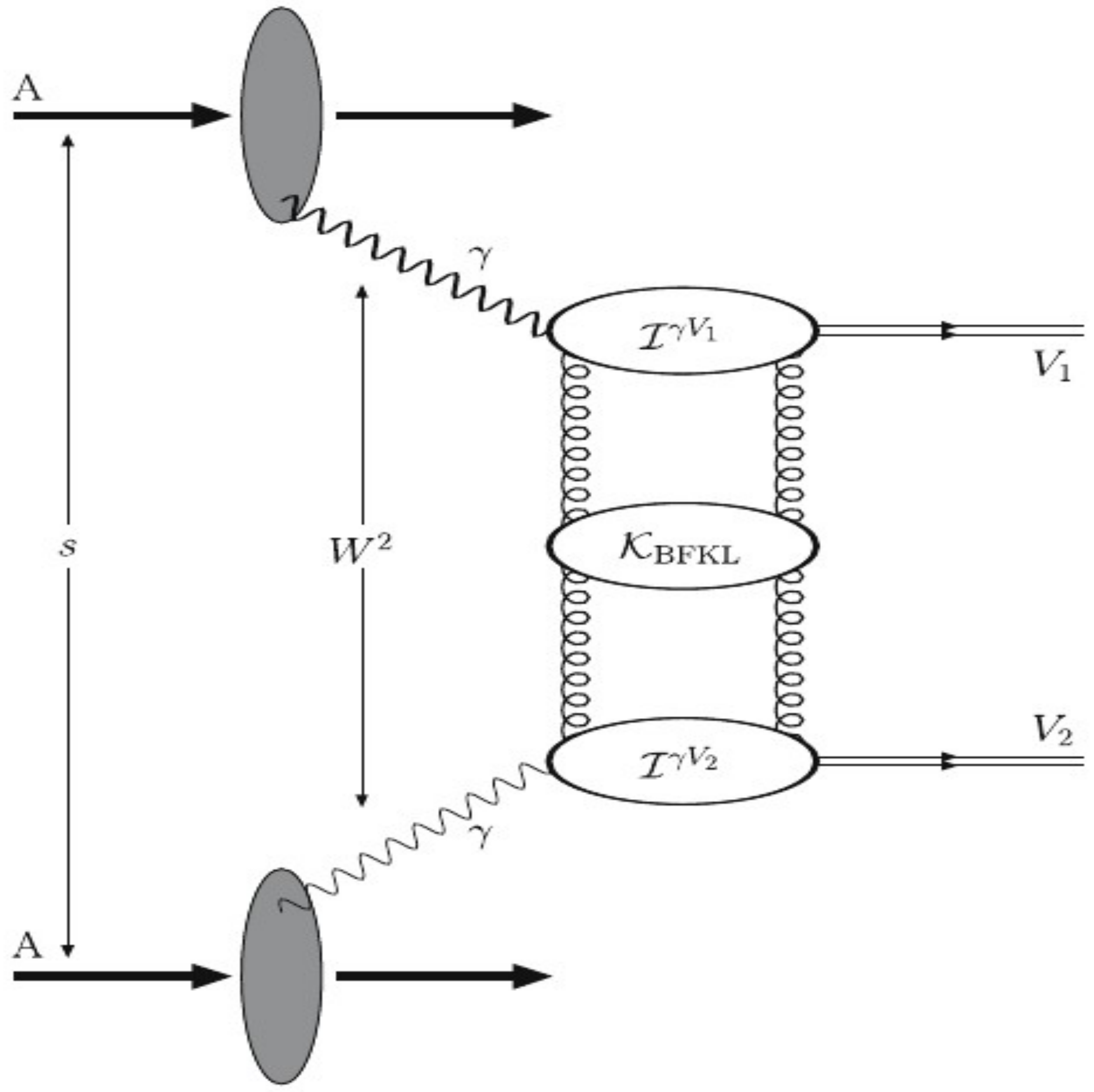
Good Walker model is justified (as a useful model for t close to 0)

Interesting nuclear effects

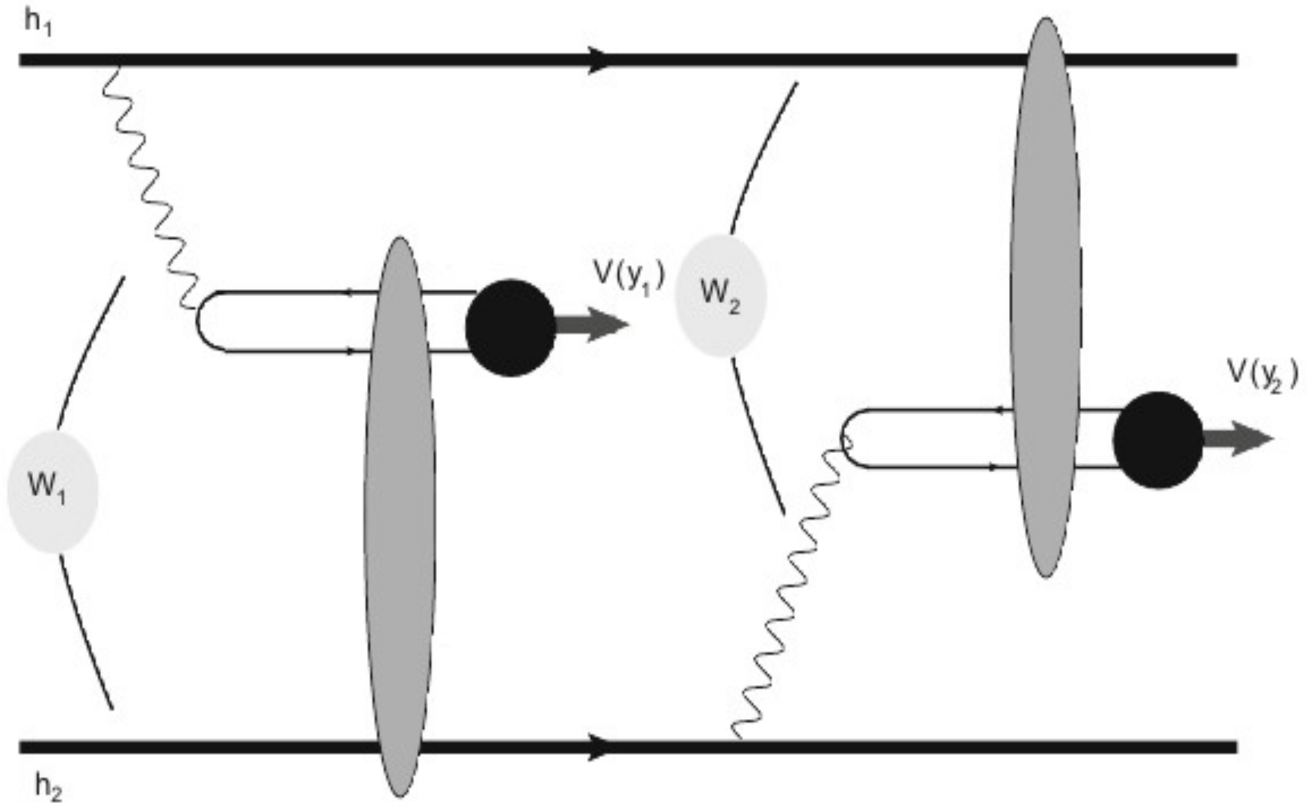
Easier to measure with improved rapidity acceptance of the LHC detectors

Victor P. Goncalves: Double Vector Meson in photon induced reactions at the LHC

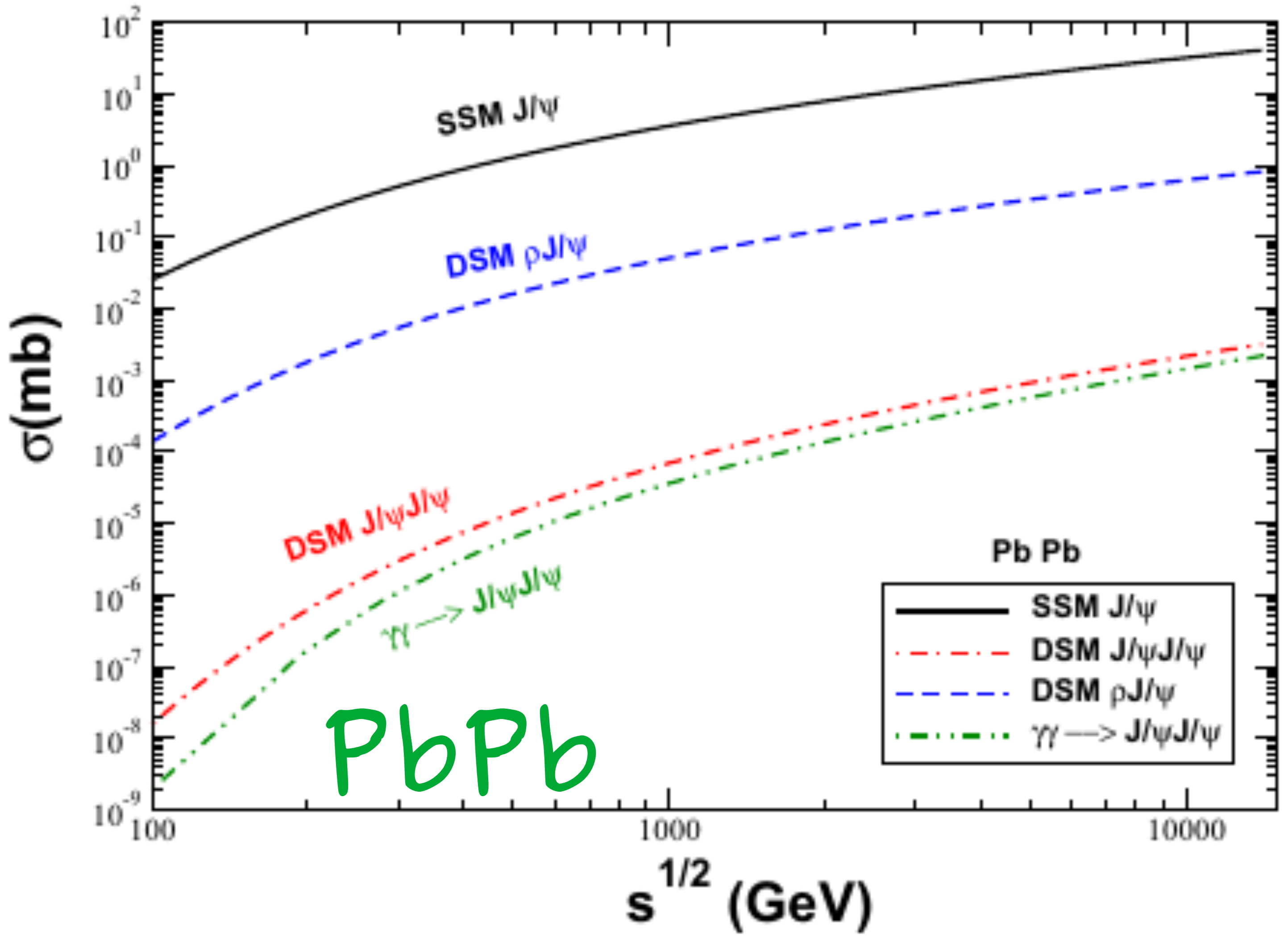
Maybe a very promising channel to explore the non-forward BFKL Pomeron

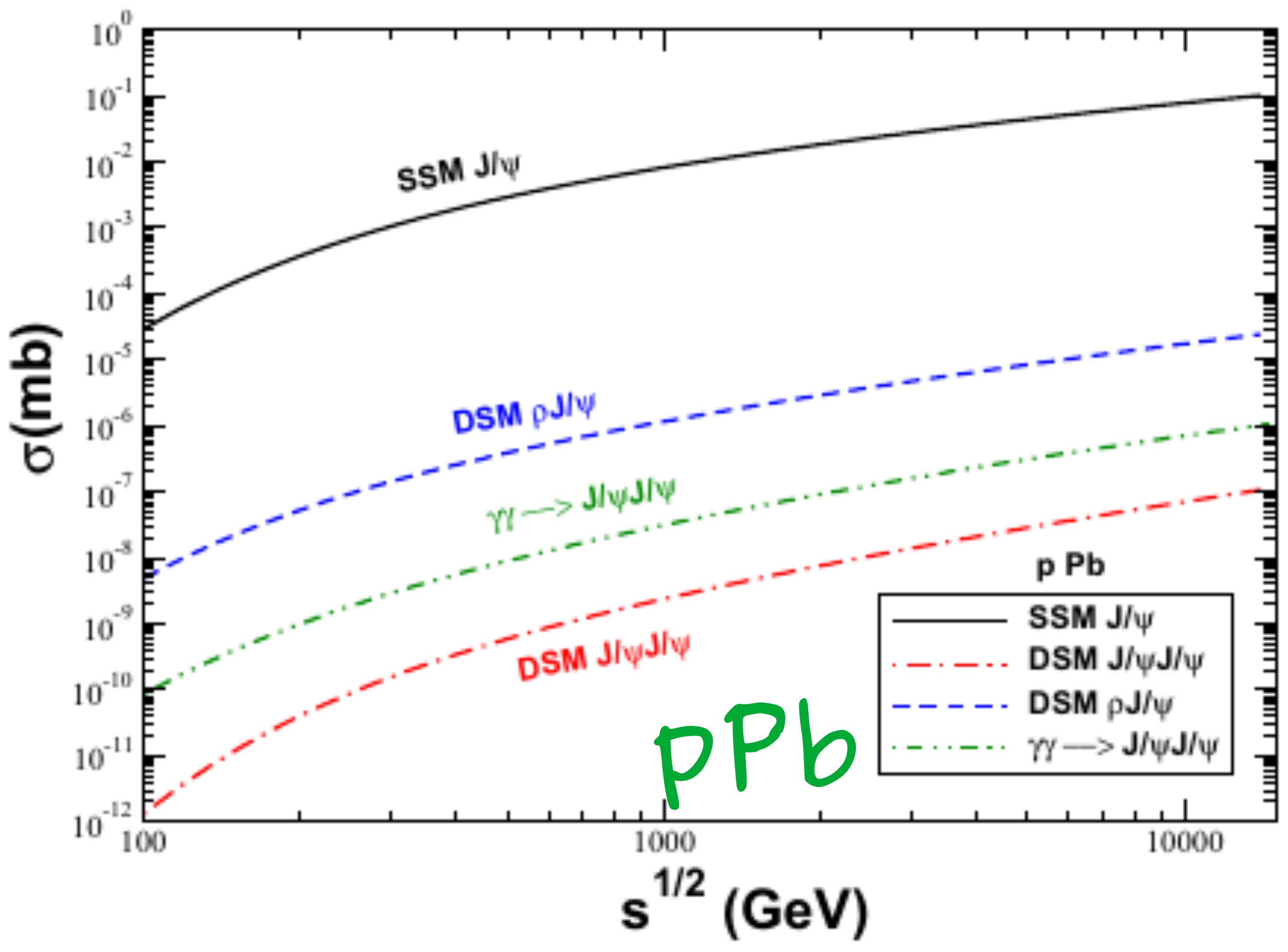


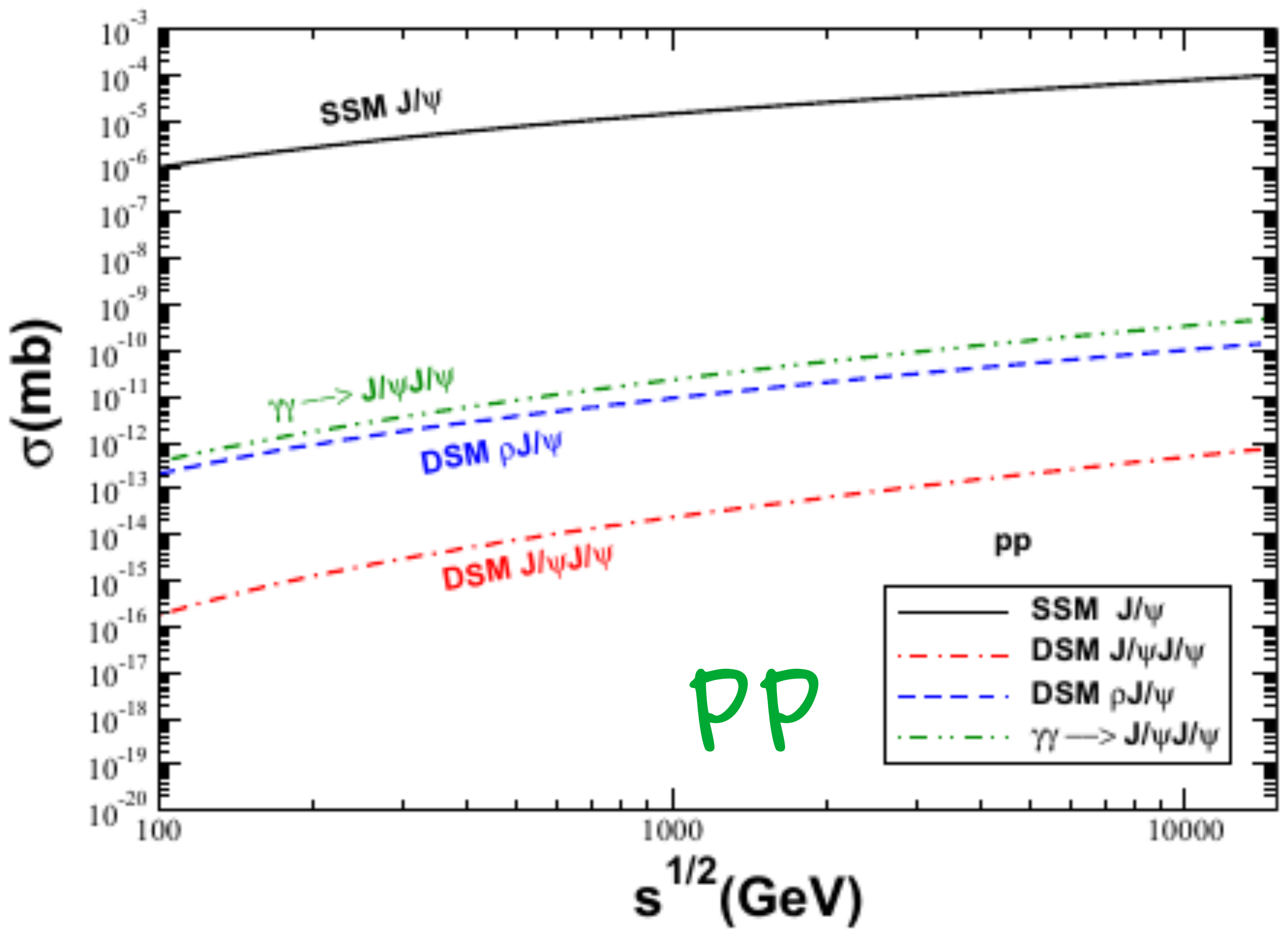
But also requires to estimate the size of background reactions



Double J/Ψ production:

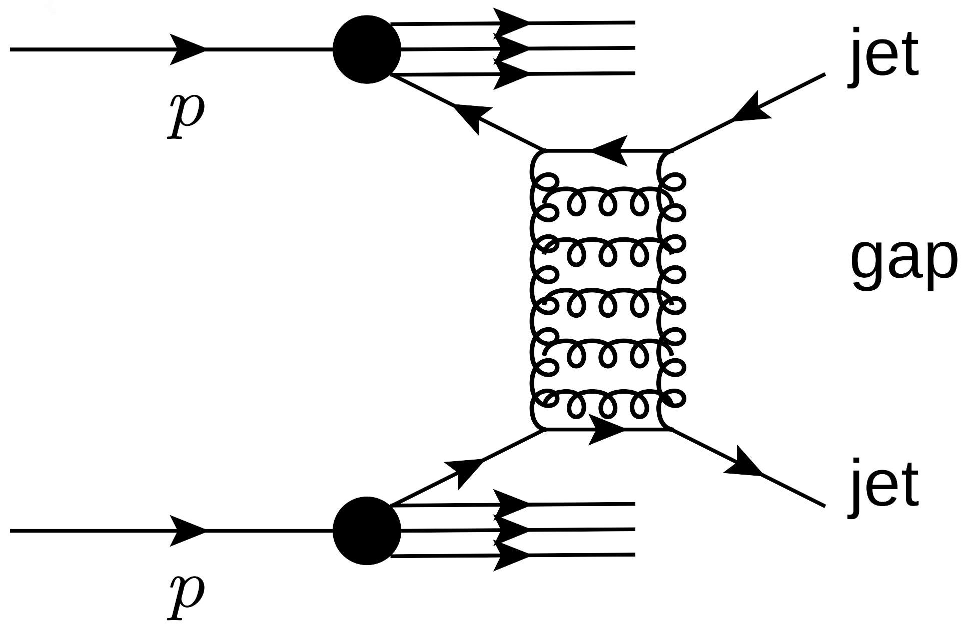


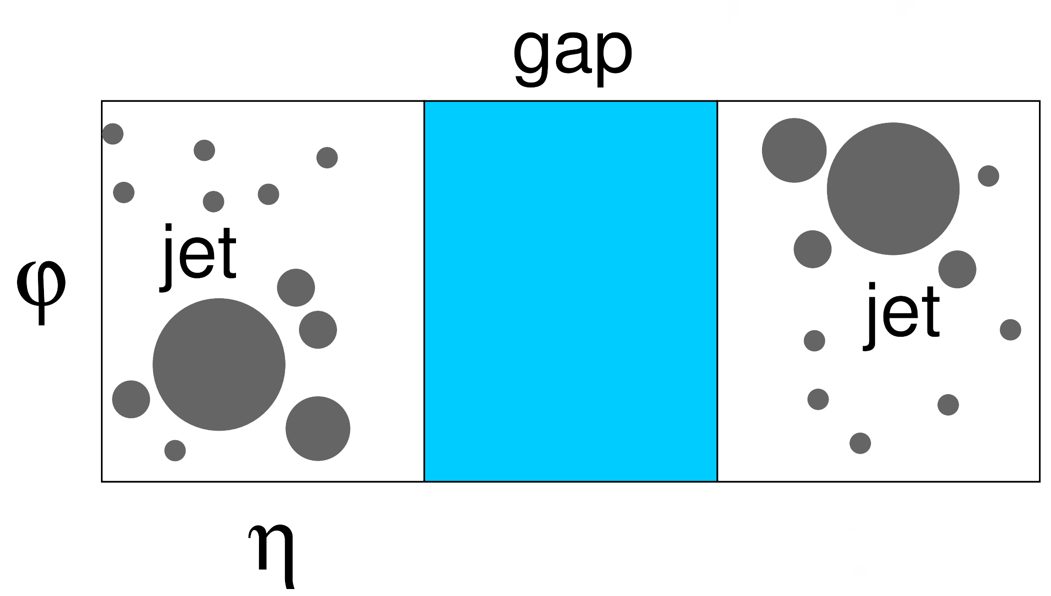




- Double scattering mechanism seems to dominate in $PbPb$ collisions
- What about interference effects? Can one experimentally separate both reactions?

Cristian Baldenegro: Jets separated by a large pseudo rapidity gap at the Tevatron and at the LHC

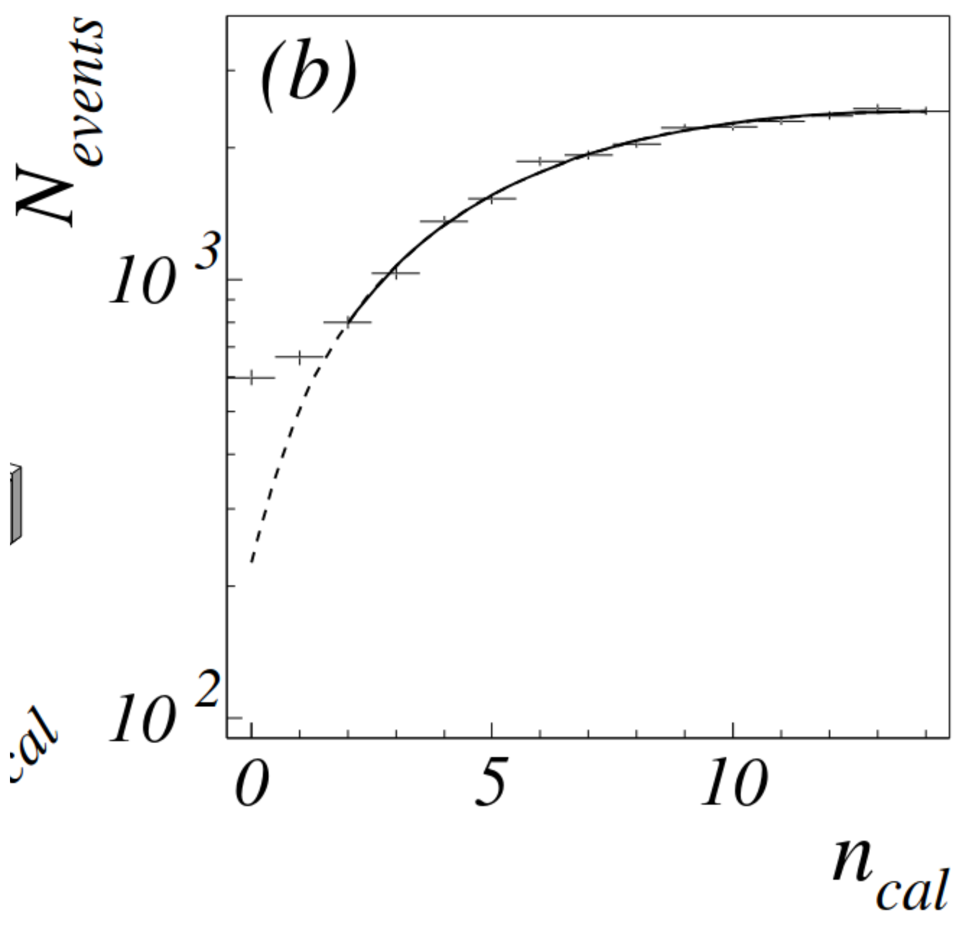


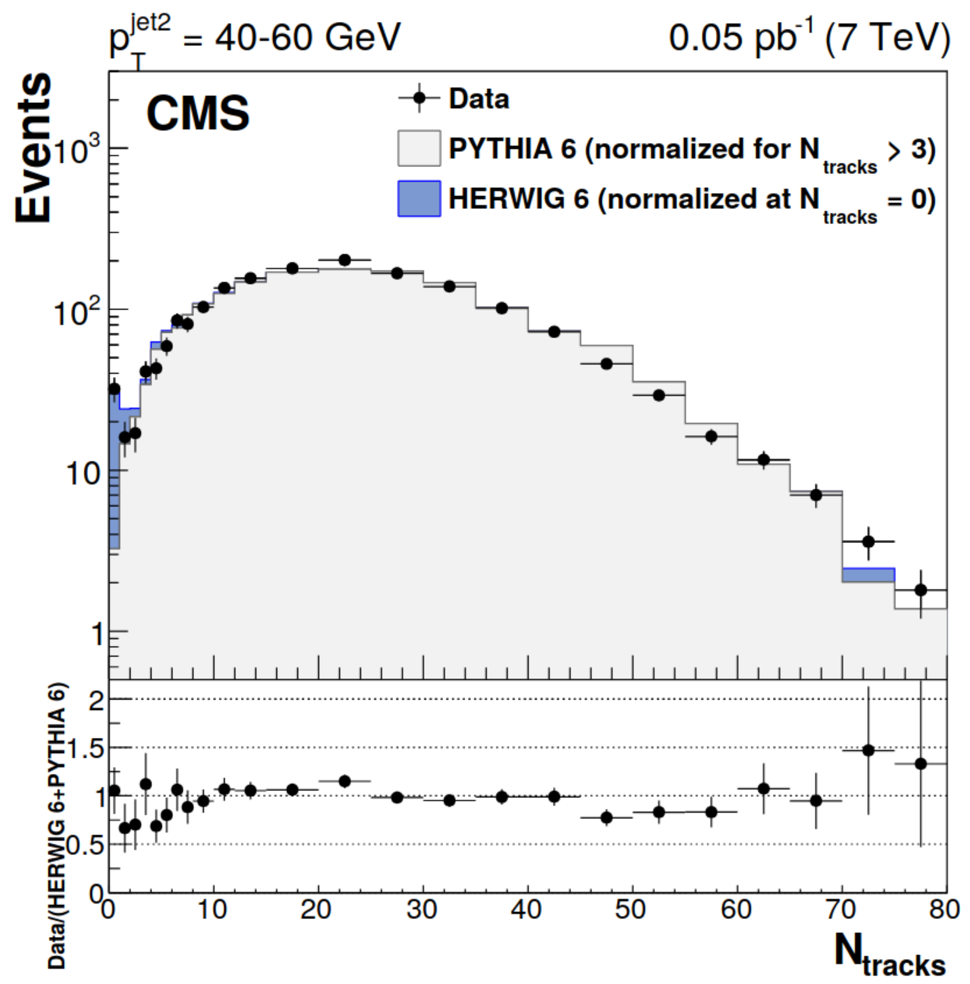


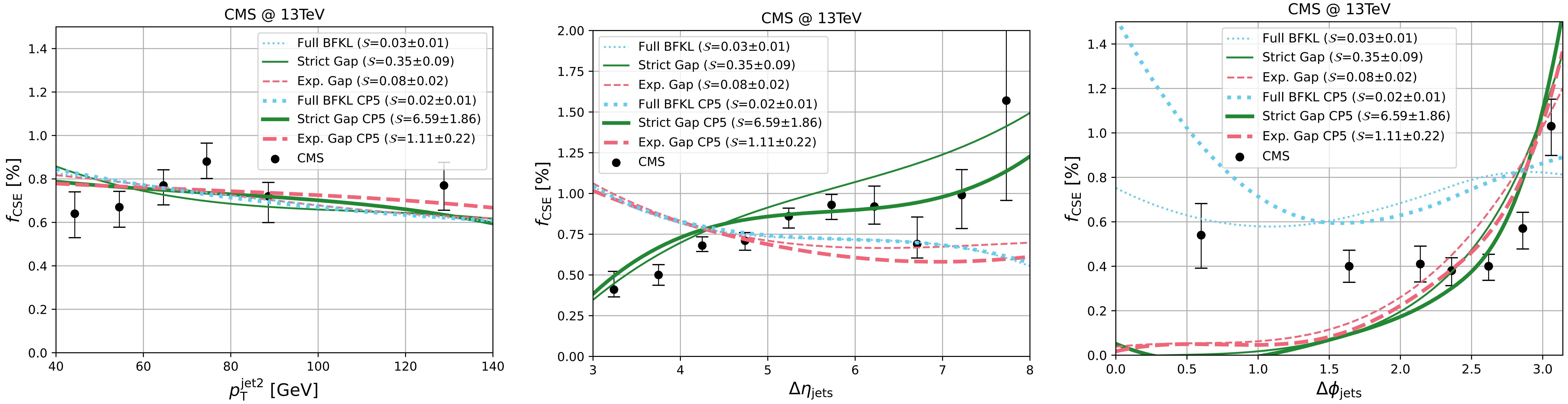
$$f_{\text{CSE}} \equiv \frac{d\sigma_{\text{CSE jets}}}{d\sigma_{\text{inclusive dijet}}}$$

Theoretical description is a challenge (my opinion):

- NLO BFKL evolution + NLO impact factors are complicated (numerical evaluation still in progress)
- Experimental gap ≠ theory gap (color singlet with no emissions);
  → tool: Monte Carlo event generator
- But also: remove colored exchange from data through extrapolation (my understanding)







Data from CMS, 13 TeV PRD 104, 032009 (2021)

- BFKL pomeron exchange in PYTHIA8 (`ISR = on, MPI = off`). Inclusive dijet events with POWHEG+PYTHIA8 (`ISR = on, MPI = on`).
- Full lines: predictions based on theory-like gap definition ($N_{part} = 0$ in $|\eta| < 1$).
- Dashed lines: predictions based on CMS gap definition ($N_{ch} < 3$ with $|\eta| < 1$ with $p_T > 200$ MeV).
- Dotted lines: bare BFKL color-singlet exchange cross section, no rapidity gap requirement.
- **Significant sensitivity to low p_T particle production modeling in MC.**

Considerable progress during the last years, but also many things left to be understood

Thanks a lot!