

Snowmass 2021: EF06 Hadronic Structure and Forward QCD

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May 21 2020

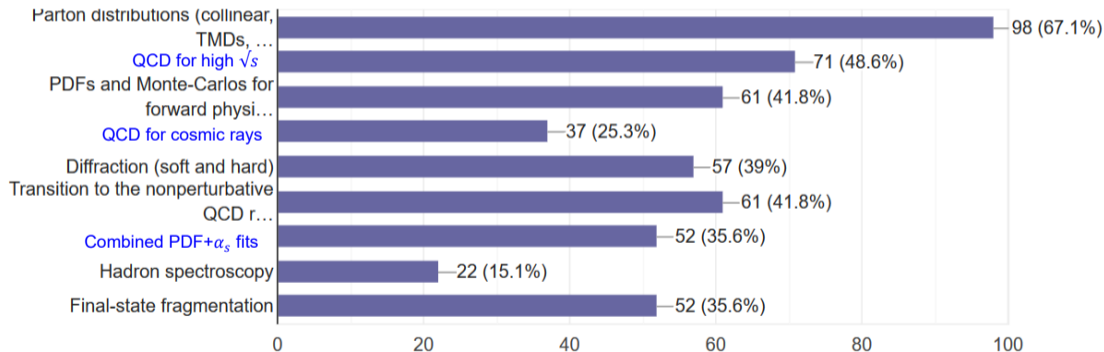
- EF06 organization and meetings
- Physics topics
- Goals and timescale

Energy Frontier Topical Group 06: Topics

- PDFs in proton and nuclei (collinear, TMDs, GPDs, (un)polarized, with EW contributions, nucleus, pion, kaon, photon?)
- Computations on the lattice
- QCD for high \sqrt{s} and forward physics: BFKL, saturation, color glass condensate, ...
- PDFs and Monte-Carlos for forward physics
- QCD predictions for cosmic ray physics
- Diffraction (soft and hard)
- Transition to the nonperturbative QCD region at low Q
- Combined measurements of PDFs and SM parameters (alphas, quark masses, M_W , ...)
- Hadron spectroscopy
- Final-state fragmentation
- Machine learning applications

Repartition of different topics

Percentages of EF06 participants who expressed interest in the indicated topics in our initial survey



EF06 organization and meetings

- EF06 meetings - every Wednesday at 9:00 am (US central time) for 1 to 2 hours
 - Meetings organized in 3-week cycles according to the following topics:
 - PDFs, GPDs, TMDs
 - Forward physics and diffraction
 - Other topics including Monte Carlo, non-perturbative physics, soft physics lattice QCD, hadron spectroscopy, fragmentation
 - In addition, common sessions with EF05 (QCD and strong interactions) and EF07 (Heavy ions) - dates and times of joint meetings to be defined
- Common topics with other frontiers: Cosmic frontier (understanding of cosmic rays and interactions with atmosphere, related to forward physics), theory frontier (NNNLO calculations, BFKL NLL developments, lattice QCD), computational frontier (advanced methods such as machine learning techniques, new methods to fit PDFs at high order...)

EF06 kick-off meeting

- EF06 kick-off meeting: May 20 2020, <https://indico.fnal.gov/event/43267/>
- More than 70 people connected, 50% from outside US
- 14 talks on many different topics
- These short talks will lead to LOIs and ultimately publications

9:00 AM	→ 9:20 AM	EF06: Organization and working plans	10m
		Speaker: Christophe Boyen	
		snowmass_202020...	
9:20 AM	→ 9:30 AM	Small- x limit and diffraction	10m
		Speaker: Cristian Balonegno	
		Balonegno_EFKL.pdf	
9:30 AM	→ 9:40 AM	3D tomography of the proton TMD gluon distribution	10m
		Speaker: Francesco Cellerno	
		Cellerno_gluon_TM...	
9:40 AM	→ 9:50 AM	Summary of proposed Belle II activities: Charmonium, Bottomium and XYZ states	10m
		Speaker: Bryan Fulson	
		Fulson_BelleII.pdf	
9:50 AM	→ 10:00 AM	Far forward neutrinos at the LHC as an opportunity to study various QCD aspects	10m
		Speaker: Mats Garzella	
		Garzella_ForwardNe...	
10:00 AM	→ 10:10 AM	Connections between the upcoming EIC program and hadron collider (LHC) phenomenology	10m
		Speaker: Tim Hobbs	
		Hobbs_EIC-LHC.pdf	
10:10 AM	→ 10:20 AM	Plans for potential contributions for Snowmass 2020-2021	10m
		Speaker: Kozyski Kizak	
		Kizak_ForwardQCD...	
10:20 AM	→ 10:30 AM	The spectrum of heavy quark exotics	10m
		Speaker: Richard Lebed	
		Lebed_SpectrumExp...	

10:30 AM	→ 10:40 AM	Towards N ³ LO accuracy of collinear nucleon PDFs	10m
		Speaker: Pavel Nadolsky	
		Nadolsky_PDFs.pdf	
10:40 AM	→ 10:50 AM	nCTEQ wish list	10m
		Speaker: Fried Oelms	
		Oelms_nCTEQ.pdf	
10:50 AM	→ 11:00 AM	High energy inclusive processes with forward/backward or single forward production	10m
		Speaker: Alessandro Papa	
		Papa_ForwardProd...	
11:00 AM	→ 11:10 AM	Forward physics at proton collider	10m
		Speaker: Michael Pitt	
		Pitt_ForwardPhysic...	
11:10 AM	→ 11:20 AM	Minijets	10m
		Speaker: Mark Strikman	
		Strikman_minijets.p...	
11:20 AM	→ 11:30 AM	Anomalous coupling with forward protons	10m
		Speaker: Justin Williams	
		Williams_ForwardPr...	
11:30 AM	→ 11:40 AM	Precision determination of nucleon PDFs	10m
		Speaker: Keqiang Xie	
		Xie_PDFs.pdf	
11:40 AM	→ 12:10 PM	Discussion	30m

Nucleon collinear PDFs @ Snowmass: from 2013 to 2021

Topic	Status, Snowmass 2013 [arXiv:1310.5189]	Status and plans, Snowmass 2021
Benchmarking of PDFs for the LHC	Before PDF4LHC'2015 recommendation	In progress toward PDF4LHC'2X recommendation
PDFs with NLO EW contributions	MSTW'04 QED, NNPDF2.3 QED	Needs an update using LuXQED and other photon PDFs; PDFs with leptons and massive bosons
PDFs with resummations	Small x (in progress)	Needs an update using existing PDFs with small-x and threshold resummations
Parton luminosities at 14, 33, 100 TeV	CT10, MSTW2008, NNPDF2.3 Update at 100 in CERN YR (1607.01831)	Needs an update based on the latest PDFs
LHC processes to measure PDFs	W/Z , single-incl. jet, high- p_T Z , $t\bar{t}$, $W + c$ production	updates on these processes + $Q\bar{Q}$, dijet, $\gamma/W/Z$ +jet, low-Q DY, ...
Future experiments to probe PDFs	LHC Run-2 DIS: LHeC	LHC Run-3 DIS: EIC, LHeC, ...

NEW TASKS in THE HL-LHC ERA:

Obtain complete NNLO and N3LO predictions for PDF-sensitive processes	Reconcile experimental measurements; improve models for correlated systematic errors	Find ways to constrain large-x PDFs without relying on nuclear targets or fixed-target experiments
Develop and benchmark fast NNLO interfaces	Estimate NNLO theory uncertainties	Develop a community recommendation on comparing and combining PDF fits

Probing gluon TMD PDFs in DGLAP and BFKL regions

Francesco Celiberto

Status

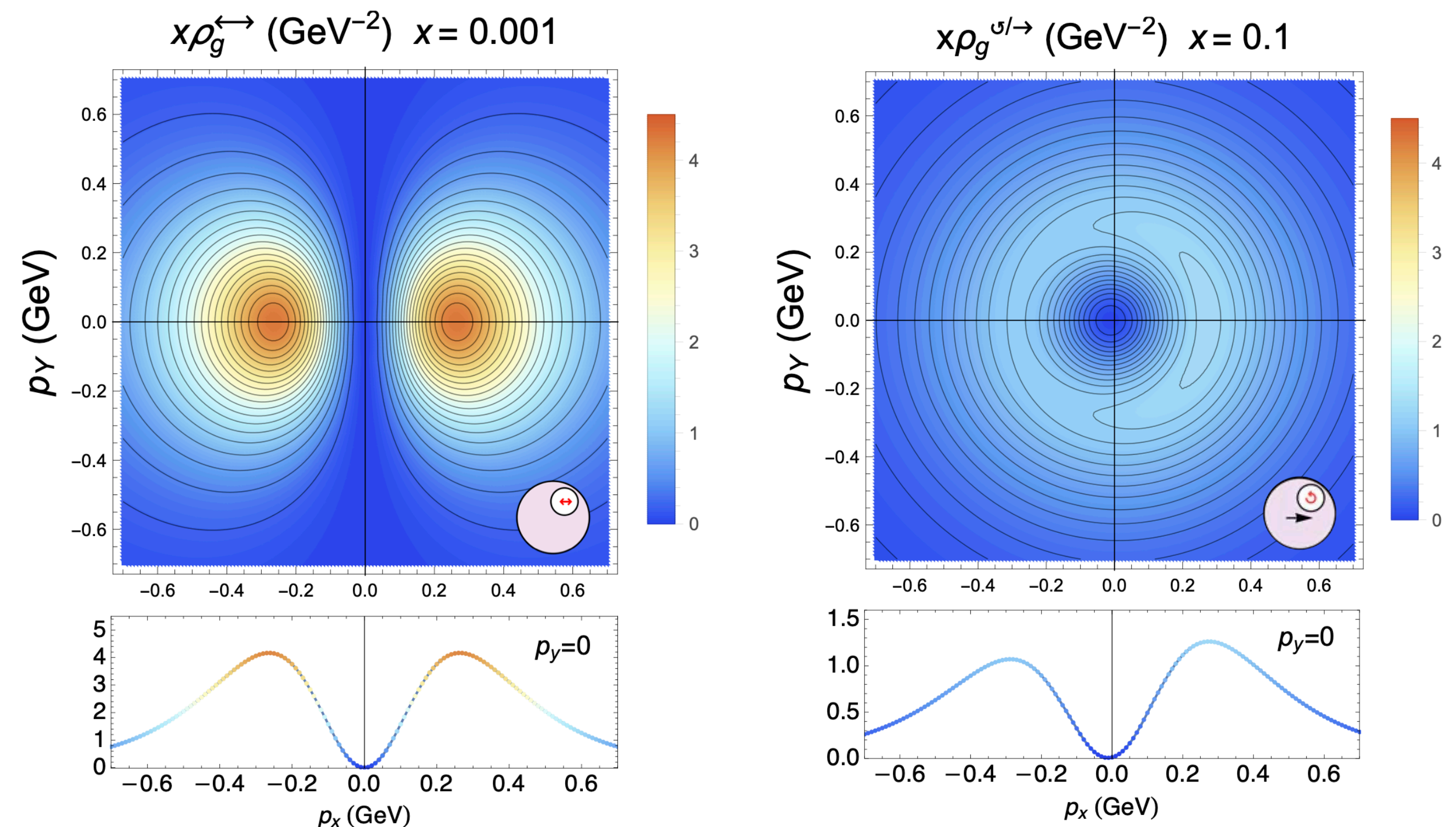
- * Gluon-TMD PDFs: *core* sector of **EIC** studies
- * Need for a *flexible* model, suited to *pheno*
- * **Unpolarized** and **polarized gluon TMDs**
- * *Consistent* framework for quark TMDs

- Calculation of all twist-2 *T*-even gluon TMDs
- Inclusion of small- and moderate-*x* effects
- Simultaneous fit** of f_1 and g_1 PDFs

 [A. Bacchetta, F.G.C., M. Radici, P. Taelis [[arXiv:2005.02288](https://arxiv.org/abs/2005.02288)]]

Prospects

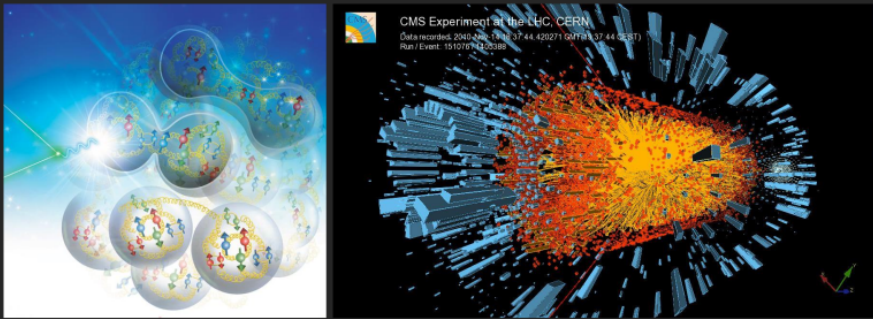
- Twist-2 *T*-odd TMDs (**Sivers**, etc.)
- Relevant **spin asymmetries** to be identified
- Predictions** as inputs for **pseudodata**
- Pheno support to small-*x* physics
- Towards a small-*x* gluon TMD?



Electron-Ion Collider and LHC phenomenology

Tim Hobbs

→ the only new accelerator planned for construction in the US in the coming decades (CD-0, Jan 2020), the Electron-Ion Collider (EIC) will be a high-luminosity DIS collider



LPC Workshop on PHYSICS CONNECTIONS BETWEEN THE LHC AND EIC

Fermilab LHC Physics Center (LPC)
November 13-15, 2019

Exploring physics intersections between LHC
phenomenology and a future
Electron-Ion Collider (EIC) program via:



- Precision QCD
- Monte Carlo Event Generators
- Lattice QCD
- Electroweak/neutrino phenomenology
- BSM physics searches
- Machine learning & computation

Organizing Committee	Local Organizing Committee	LPC Events Committee
Tim Hobbs (Chair, SMU)	Radja Boughezal (ANL/Northwestern)	Gabriele Benelli (Brown)
Abhay Deshpande (BNL)	John Campbell (FNAL)	Kevin Pedro (FNAL)
Jianwei Qiu (JLab)	Olga Evdokimov (UIC)	LPC Coordinators
Rik Yoshida (ANL)	Stefan Hoeche (FNAL)	Cecilia Gerber (UIC)
	Frank Petriello (ANL/Northwestern)	Sergo Jindariani (FNAL)

<https://indico.cern.ch/e/LHCEICPhysics>

* QCD structure of nucleon
and nuclear targets
≤ nCTEQ, talk by F. Olness

* 3-dim Hadron Tomography,
transition to nonperturbative
QCD

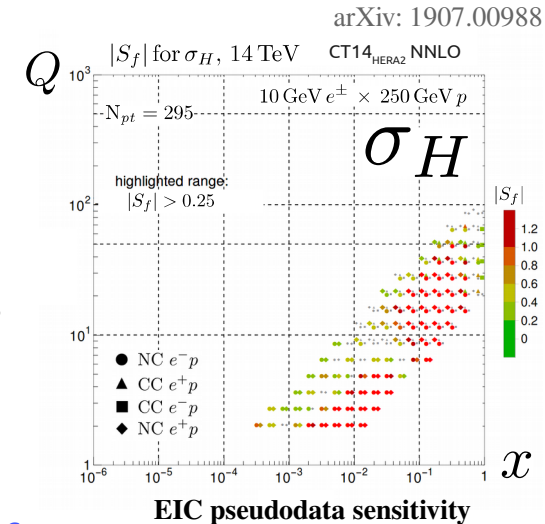
=> collinear, TMD PDFs,
GPDs, fragmentation functions

* Will directly measure large-x nucleon PDFs in the regions
relevant to BSM searches at the HL-LHC

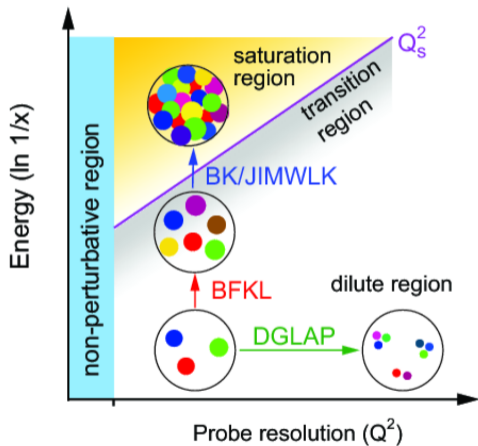
* Will replace **fixed nuclear target** DIS data in global fits of
nucleon PDFs

* Is complementary to HERA DIS and HL-LHC
measurements to the PDFs, is essential for reducing PDF
uncertainties in precision Higgs/EW measurements at the
HL-LHC

=> Joint studies with EF05 and EF07



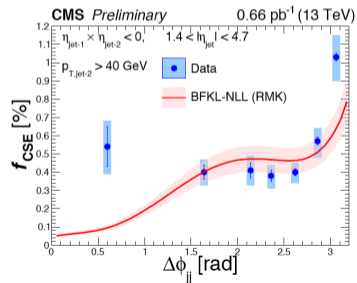
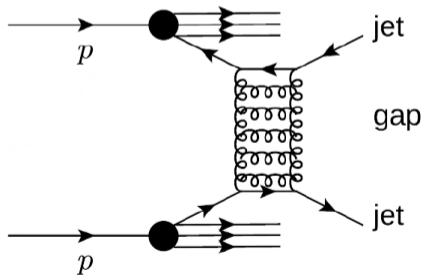
A new regime of QCD: Low x , BFKL resummation effects and saturation



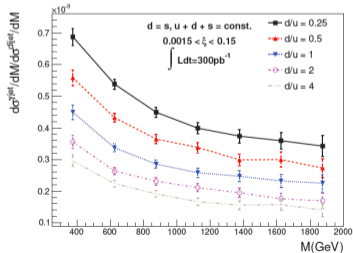
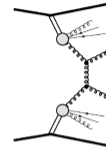
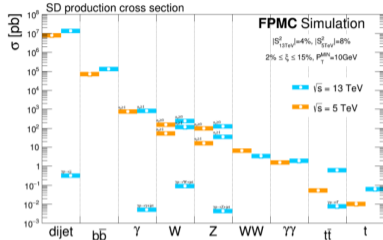
- Define observables that will be sensitive to low x resummation effects and saturation
- Measurement of Mueller-Navelet jets, heavy quark, hadron-hadron, Higgs-jet, vector meson (Papa)
- Measurement of mini-jets:
 - Define more exclusive variables: mini-jets
 - In addition minijets can be used to probe long-range correlations (Strikman)
- 3 jet and 2 jet production especially in forward region: looking for high gluon density regime of QCD (saturation) in heavy ions (Kutak)
- Understanding particle/energy emission in the very forward direction crucial for cosmic ray physics to understand interactions with Oxygen/Nitrogen

Gap between jets

- Looking for BFKL dynamics: Jet gap jet events (Mueller-Tang processes) (Baldenegro)
- New measurements at the LHC and new theoretical calculations in progress
- Low x resummation effects implemented in PDFs: important effects to be quantified at the LHC/EIC also to look for saturation effects

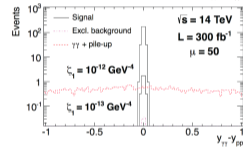
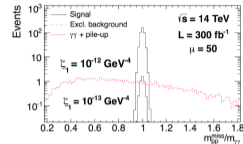
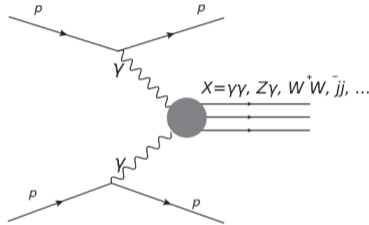


Hard and soft diffraction



- Proton(s) intact after interaction and can be measured in roman pot detectors
- Is it the same kind of process between ep and pp colliders?
- Better understanding of Pomeron structure in terms of quarks and gluons
- Many diffractive channels at the LHC/EIC (Baldenegro/Pitt)

Exclusive diffraction



Phys. Rev. D 89, 114004

- Exclusive production at the LHC of $\gamma\gamma$, WW , ZZ , $t\bar{t}$, γZ (Pitt/Williams)
- We detect all particles in the final state: no background for 300 fb^{-1} (matching in kinematical observables)
- Reach on anomalous coupling 3 to 4 orders of magnitude better than standard methods at the LHC

Conclusion

- We had a very productive kick-off meeting with many exchanges/ideas
- Of course many additional topics still to be added and discussed
- Will lead to many LOIs and papers
- Our next meeting will be on June 3 and will be every week after that
- Meetings organized in 3-week cycles according to the following topics:
 - PDFs, GPDs, TMDs
 - Forward physics and diffraction
 - Other topics including Monte Carlo, non-perturbative physics, soft physics lattice QCD, hadron spectroscopy, fragmentation
- Thank you very much to all participants/contributors!