Experimental Summary and Outlook

H. Jung (DESY, University Antwerp)
hannes.jung@desy.de

How to prepare a good summary talk ?

Look at previous summary talks

- Too many individual talks, so cannot cover everything !
  - Make selection ?
    - what should be left out ?
    - instead of covering everything, I'll ask what I do not understand

Soft QCD and Multiparton Dynamics

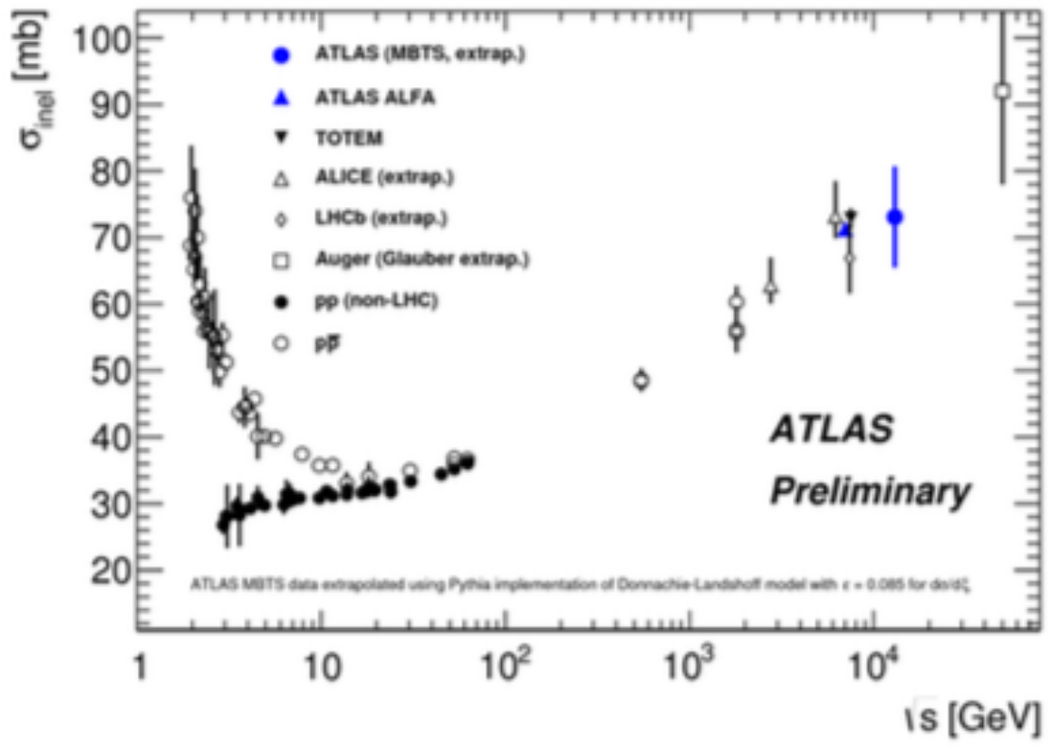
Contributions

- Soft QCD and multi-parton interactions, FIELD, Richard Dryden
- Soft QCD measurements from the LHC, BRUNI, Alessia
- Overview of MC tuning to LHC data, SIEGERT, Frank
- QCD in Heavy Ion Collisions, MORSCH, Andreas
- Hard Diffraction at HERA, BRITZGER, Daniel
- Results on total pp cross sections, diffractive and exclusive final states from ATLAS, ARRATIA MUNOZ, Miguel Ignacio
- Results on minimum bias interactions, underlying event and particle production from ATLAS, CAIRO, Valentina
- Associated quarkonium production at ATLAS as a new probe of QCD, BERTSCHE, David Edwin
- Exclusive processes at HERA, BRUNI, Alessia
- Small-x Physics at the LHeC, ARMESTO PEREZ, Nestor
- Di-photon and photon-hadron correlations at the LHC, REZAEIAN, Amir
- Data-driven approaches to pile-up treatment at the LHC, VAN HAEVERMAET, Hans
- Searches for resonant and non-resonant new phenomena in CMS, YOO, Hwi Dong
- Searches for resonant and non-resonant new phenomena from ATLAS, ELLIOT, Alison
- Precision calculations for squark and gluino production at threshold, BORSCHENSKY, Christoph
- Hadronization processes in neutrino interactions for oscillation physics, KATORI, Teppei

Total x-section in pp

J. Butterworth, Overview, plenary
A. Bruni, Soft QCD, plenary
M. Arratia (ATLAS), Total pp xsections
Multiparton Dynamics

Results: Total cross-section

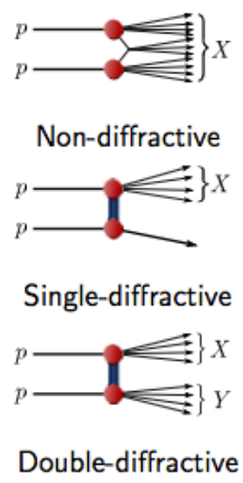


$\sigma = 73.1 \pm 0.9(\text{exp.}) \pm 6.6(\text{lumi}) \pm 3.8(\text{extrapol.})$ mb

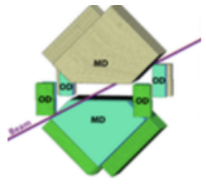
28 / 29

- First measurement of σ_{pp} at $\sqrt{s} = 13\ TeV$
- Important consistency check, needed for all calculations and simulations, also for pile-up !

- Measurement with different methods:
  - at 13 TeV: detecting final states

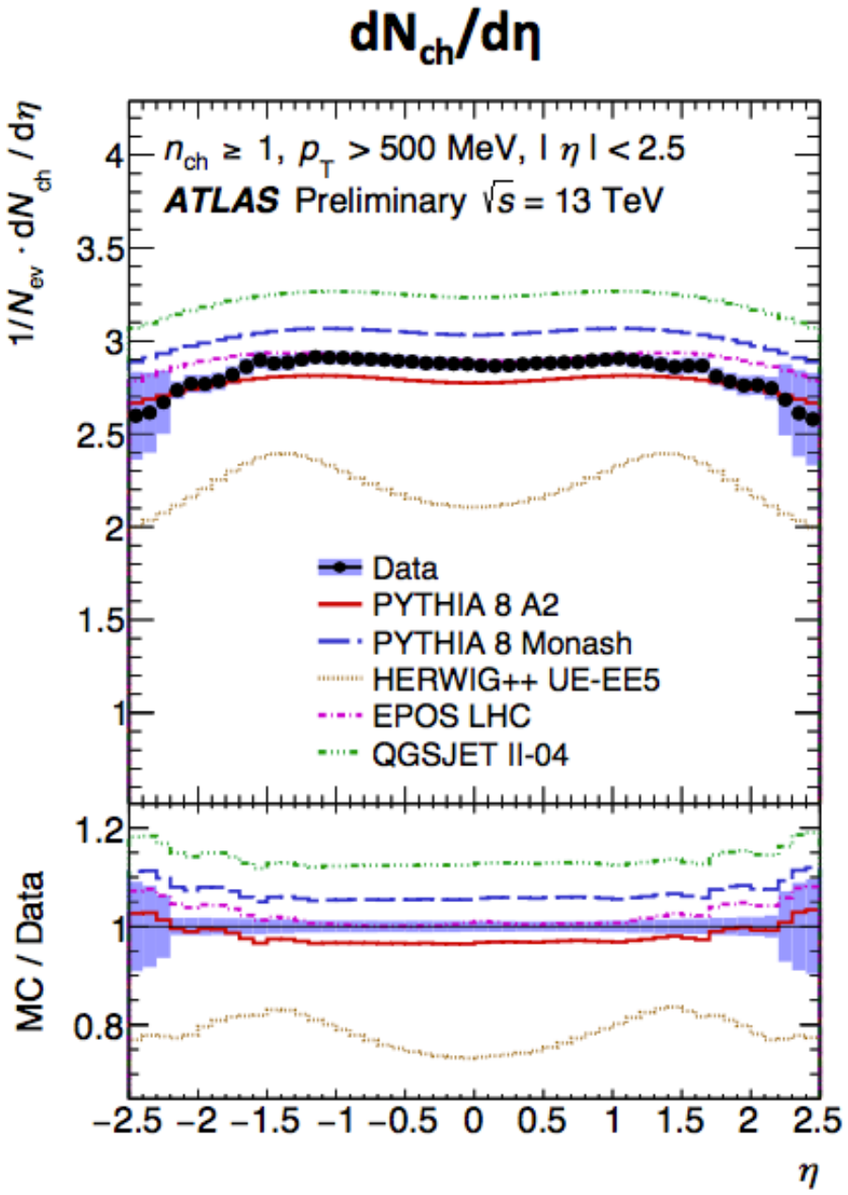


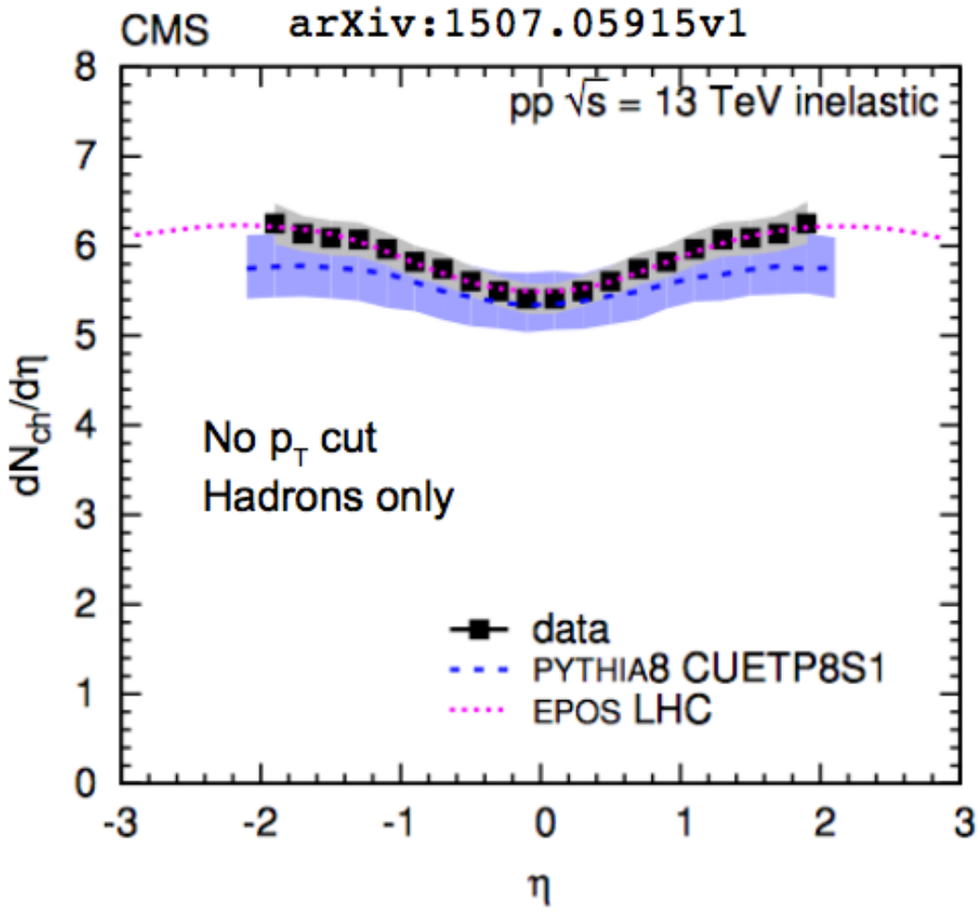
  - at 8 TeV: using ALPFA and elastic slope



Minimum Bias measurements

V. Cairo (ATLAS), Min Bias & UE
Multiparton Dynamics
J. Butterworth, LHC overview, plenary
A. Bruni, Soft QCD, plenary
R. Field, Soft QCD, plenary





- Very essential measurements for experiments
  - basic x-check of MC prediction needed for pileup simulation
  - big success of MC tuning: no extra tune needed for Min Bias !

Apropos pileup ….

H. Van Haevermaet
Data-driven approaches to pile-up treatment
Multi Parton Dynamics

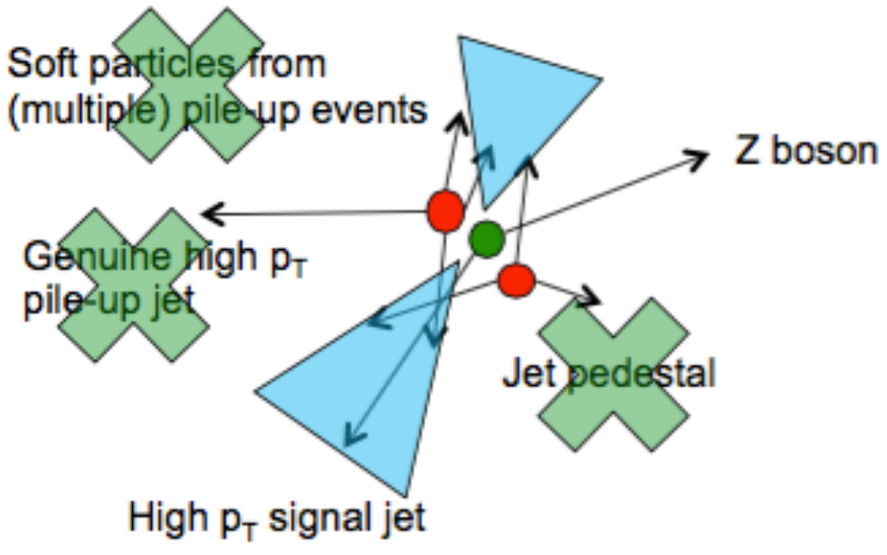
- Many QCD processes are distorted by high pileup at high luminosity

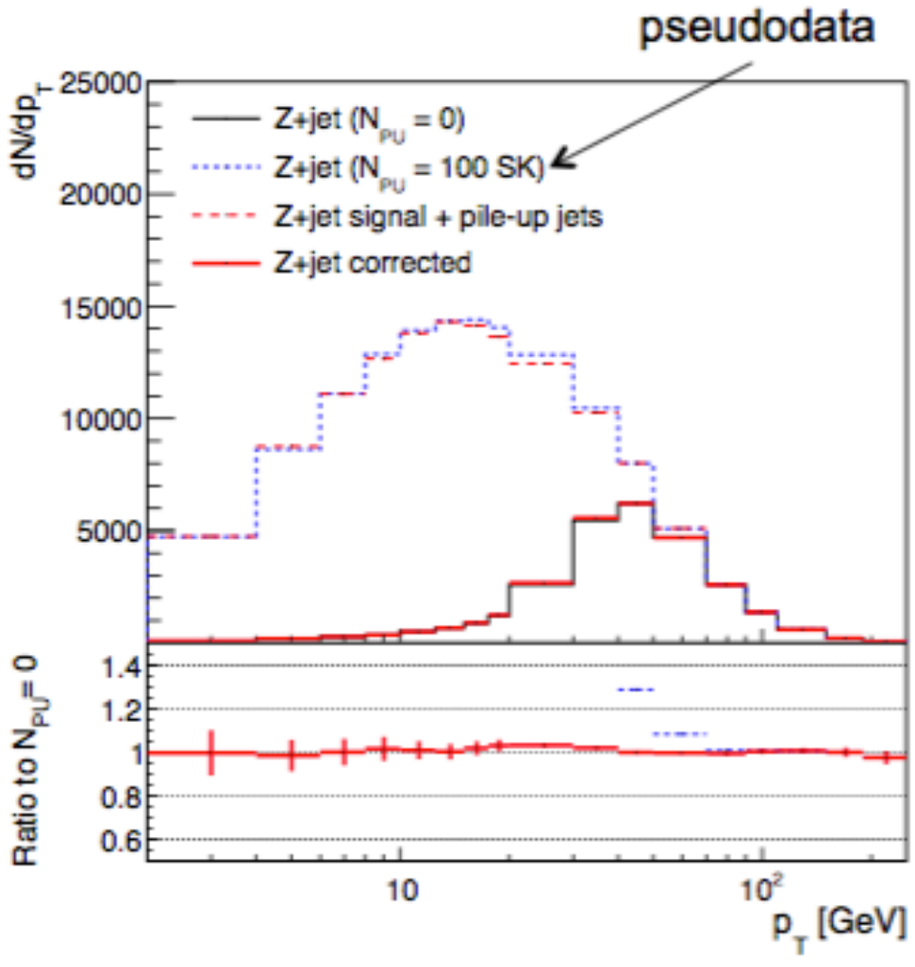
arXiv 1508.07811

> Extract signal without relying on Monte Carlos

> From mixed sample can extract true signal succesfully

> Advantages:
➔ works in high N_{PU} regime
➔ no data at low pile-up needed
➔ no Monte Carlo needed





$N_{PU} = 100$

H. Van Haevermaet | QCD@LHC 02/09/2015 | Page 9

Parton Density Functions

Contributions

- Status of PDFs, ALEKHIN, Sergey
- Proton structure and hard QCD at HERA, SARKAR, Amanda
- QCD at the LHeC, NEWMAN, Paul Richard
- MMHT14 PDFs: updates and outlook, HARLAND-LANG, Lucian
- The CT14 Global Analysis of QCD, STUMP, Daniel
- On the impact of lepton PDFs, CARRAZZA, Stefano
- Self Organizing Maps Parameterization of Parton Distribution Functions, SIMONETTA, Iiuti
- Measurements of W charge asymmetry, PENNING, Bjoern
- HERAFitter project and its related studies, SAPRONOV, Andrey
- Studies of PDF sensitivity relevant for ATLAS measurements, HANNA, Remie
- Jet measurements, alpha_s and PDF results from CMS, RABBERTZ, Klaus
- Recent developments in the fast reproduction of QCD calculations with the APPLgrid project, SUTTON, Mark
- fastNLO v2 Developments, RABBERTZ, Klaus
- Nuclear PDFs in eA collisions at the LHeC, ARMESTO PEREZ, Nestor
- Proton PDFs at the LHeC, GWENLAN, Claire
- Parton Distributions for the LHC Run II, ROTTOLI, Luca
- Reduction strategies for the combination of PDF sets, ROJO CHACON, Juan
- New PDF4LHC recommendations for parton distribution uncertainties for the LHC run-II era, DE ROECK, Albert
- New CTEQ-Jefferson Lab (CJ15) analysis of parton distributions, MELNITCHOUK, Wally
- Impact of heavy-flavour production cross sections measured by the LHCb experiment on parton distribution functions at low x, SARKAR, Amanda
- Forward charm production and the small-x gluon PDF, GAULD, Rhorry
- A Variable Flavour Number Scheme with Intrinsic Charm, BONVINI, Marco

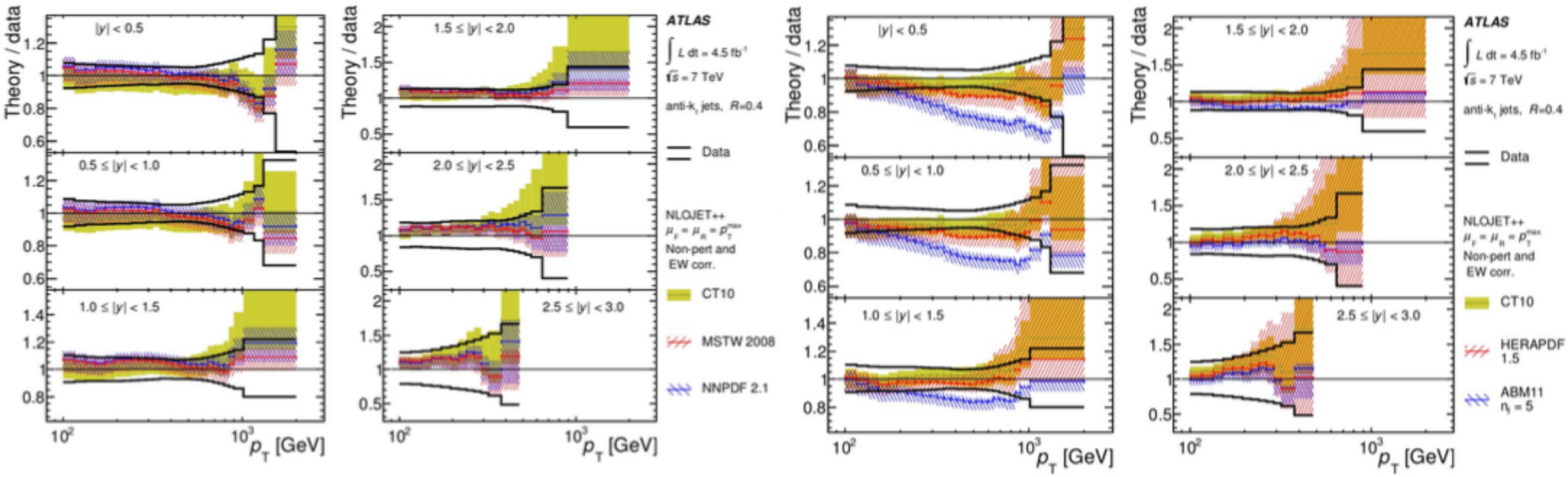
Jet measurements: constrain PDFs

R. Hanna (ATLAS),PDF sensitivity
Hard QCD

6) *Incl. jet, di-jet and 3-jet cross-sections*

JHEP 02 (2015) 153 - JHEP05(2014)059
- Eur. Phys. J. C (2015) 75

4.5 fb^{-1} of 7 TeV data



- **Inclusive jet cross section** : the predictions CT10, MSTW2008, NNPDF 2.1 (left), HERA1.5, ABM11 (right) are generally consistent with the measured cross-sections, except in a few bins (HERA, ABM at low rapidity).

Jet measurements: constrain PDFs

K. Rabbertz (CMS), Jets
Hard QCD & PDFs

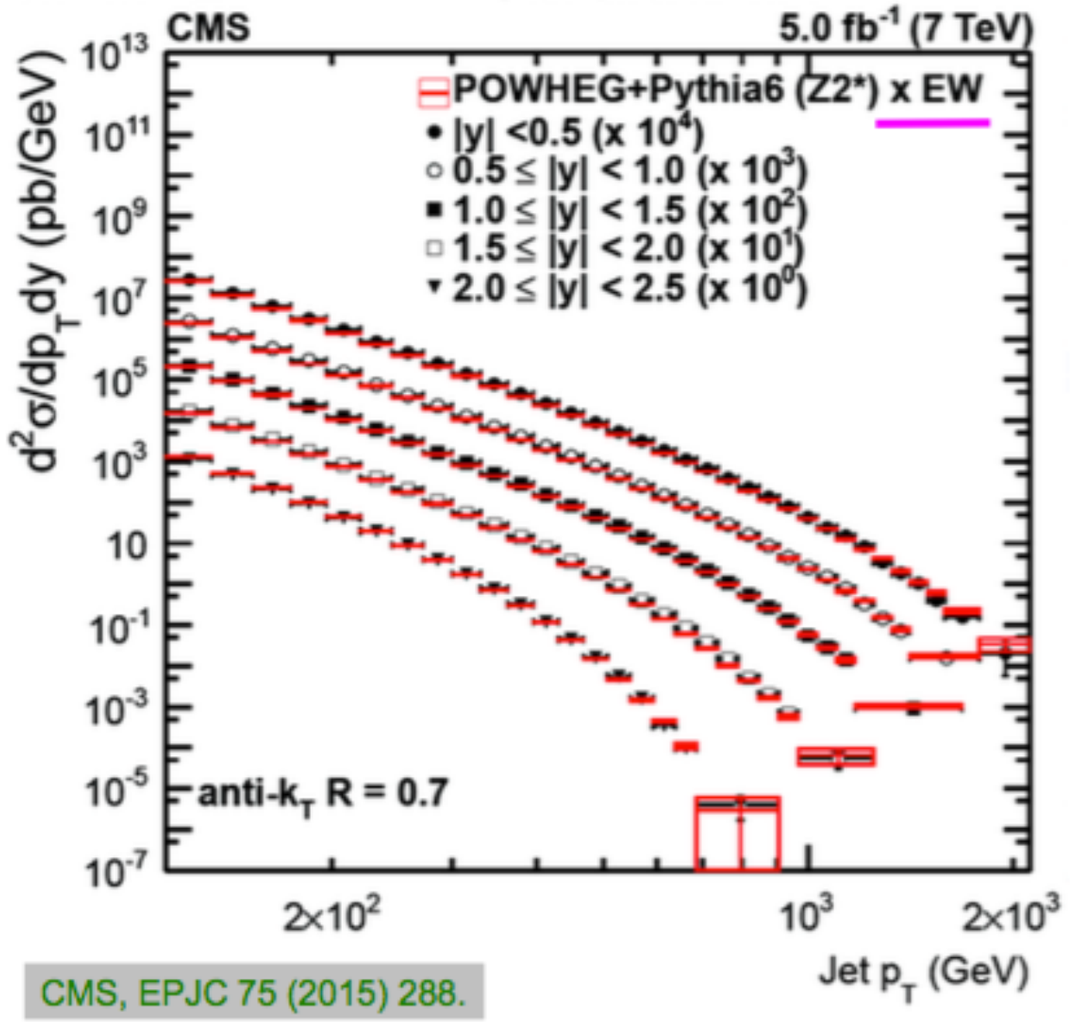
Agreement with predictions of QCD over many orders of magnitude in cross section and beyond 2 TeV in jet p_T

Constrains PDFs
"Harder" gluon at high x compared to DIS

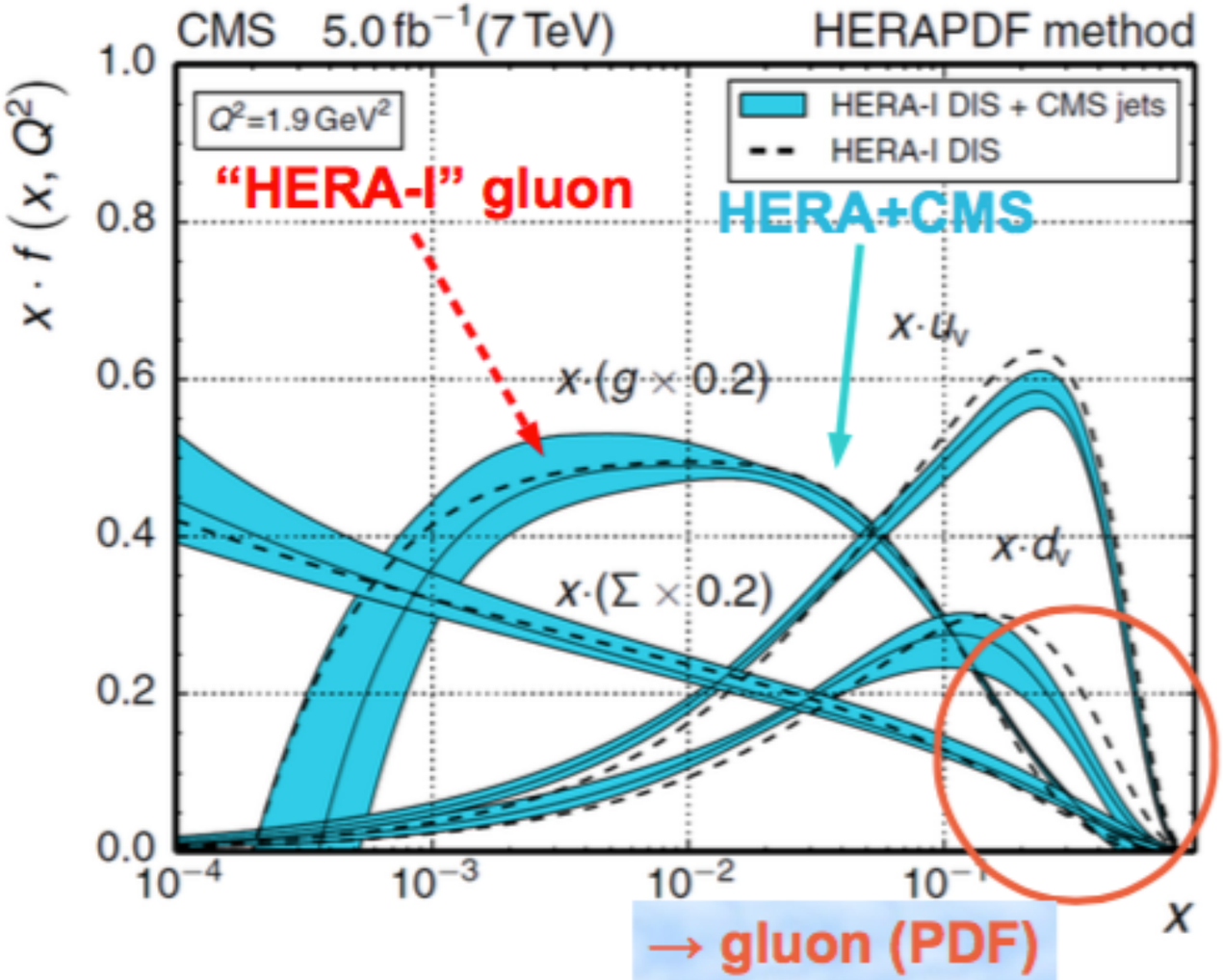
$$\frac{d^2\sigma}{dp_T dy} \propto \alpha_s^2$$

Data vs. NLO+PS ⊗ EW corrections
→ impact visible in dijet angular obs.

anti-kT, R=0.7, 7 TeV, 2011



CMS, EPJC 75 (2015) 288.

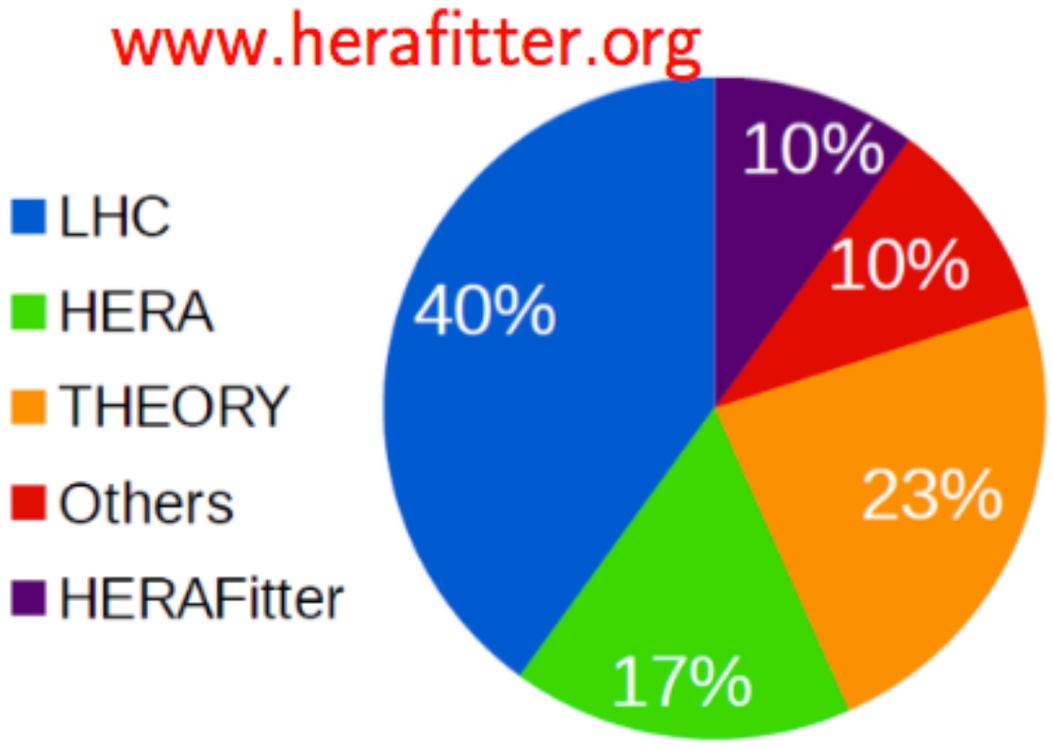


→ gluon (PDF)

Tools for calculations: **herafitter**, applgrid, fastnlo, …

- HERAfitter is a open-source tool for QCD analyses in lepton-hadron and hadron-hadron

A. Sapronov HERAFitter PDF



30 public results obtained using HERAFitter from the beginning of the project

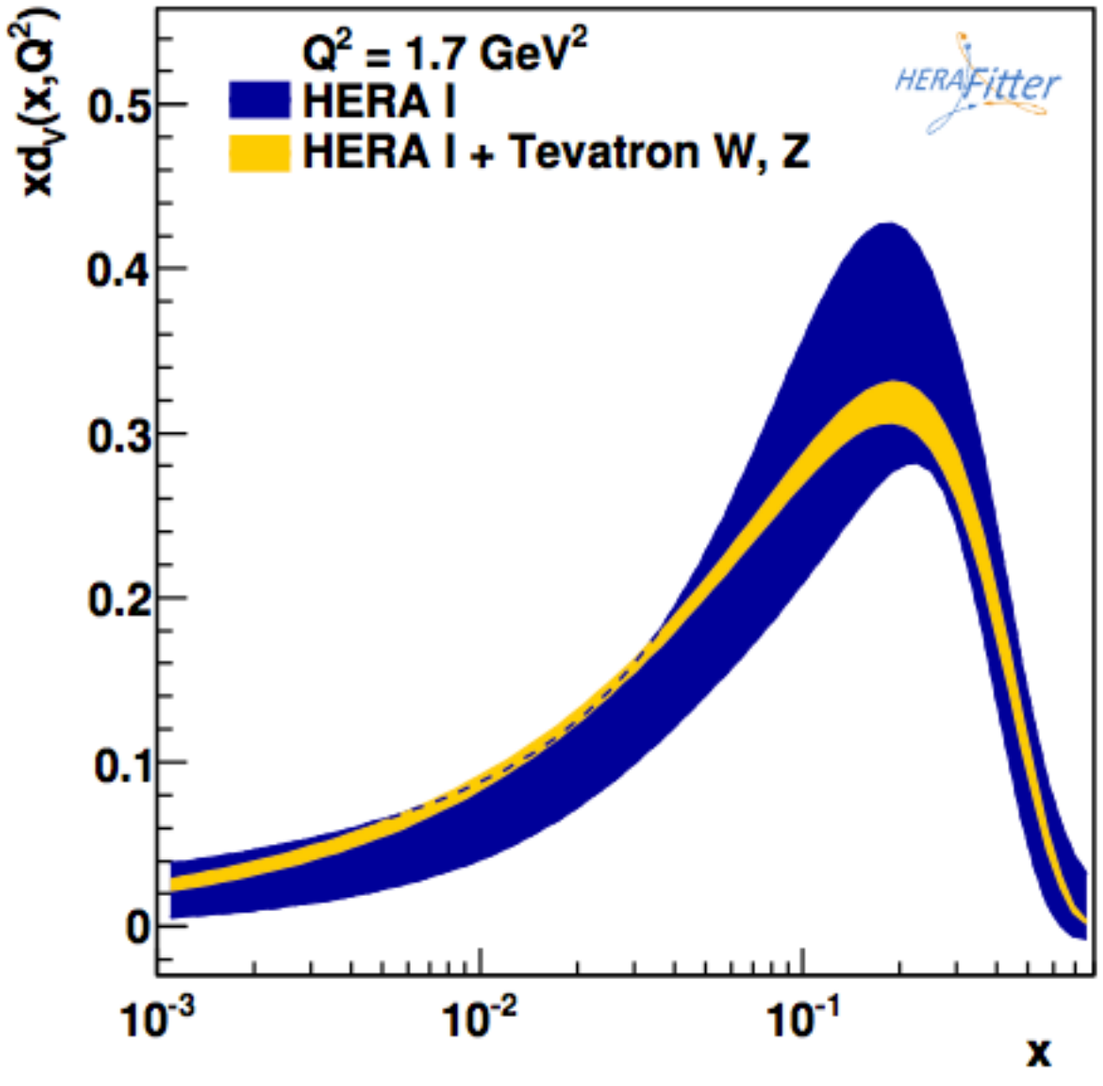
- Perform QCD analysis of proton structure using experimental data
- Extract and improve precision of the PDFs
- Assess impact of the new data on PDF determination
- Check experimental data consistency
- Test different theoretical approaches to the proton structure description.

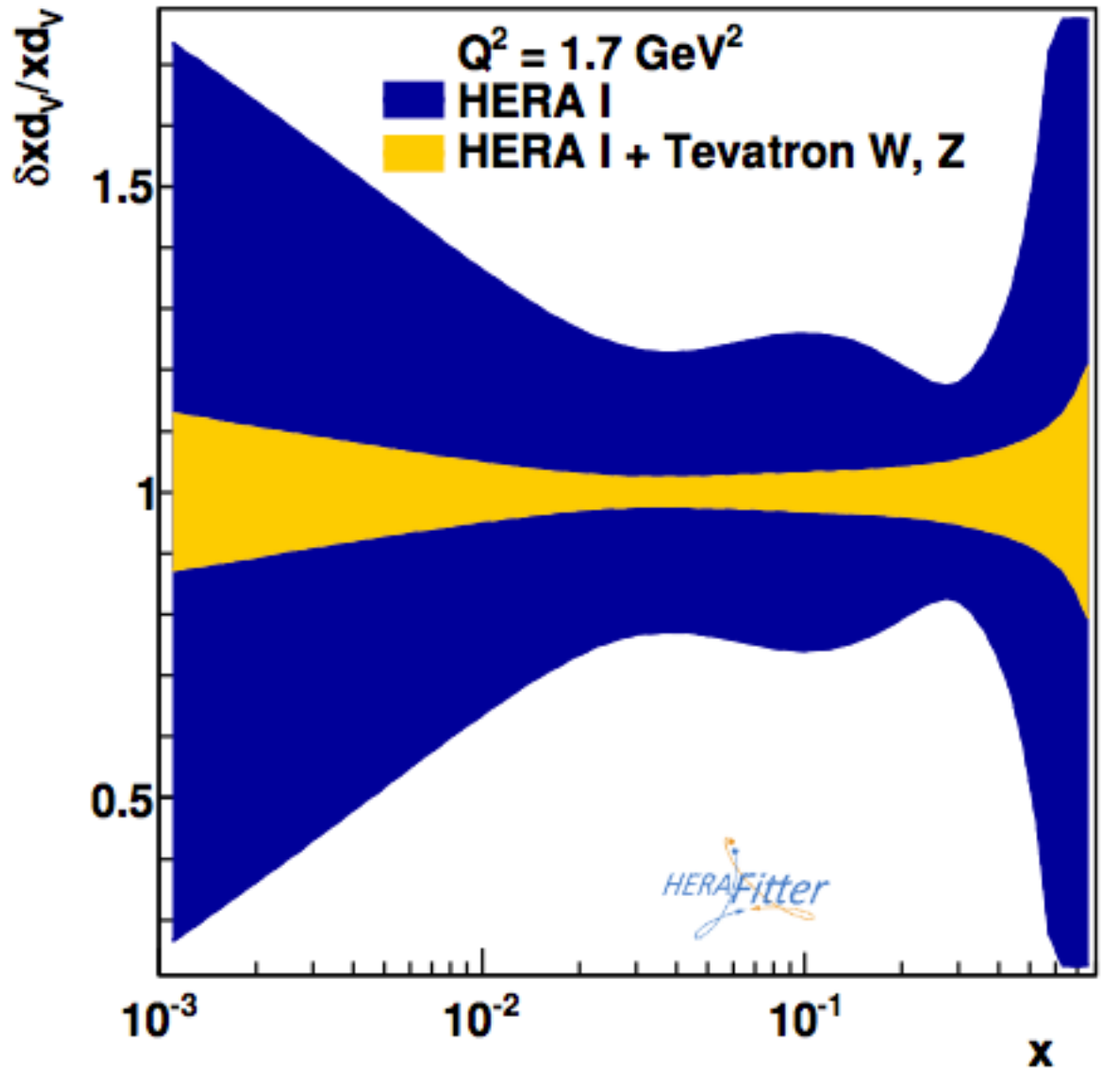
Tools for calculations: **herafitter**, applgrid, fastnlo, …

- HERAfitter is a open-source tool for QCD analyses in lepton-hadron and hadron-hadron

A. Sapronov HERAFitter PDF

The Tevatron W and Z data exhibit significant impact on valence quarks relative to HERA-I data alone. Especially on d-quark.

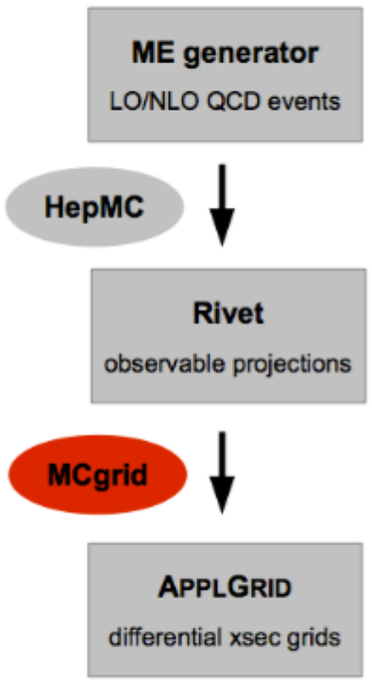




Tools for calculations: herafitter, **applgrid**, fastnlo, …

- Applgrid is a **fully open source package** to build a library of C++ utility classes for performing fast (N)NLO convolutions with PDFs
- includes now:
  - MCFM, NLOjet++ for jet prod.
  - All fixed order NLO processes in aMC@NLO, using the aMCfast interface, arXiv:1406.7693
  - Sherpa for fixed NLO processes using MCgrid, arxiv:1312.4460
  - Sherpa interface is available

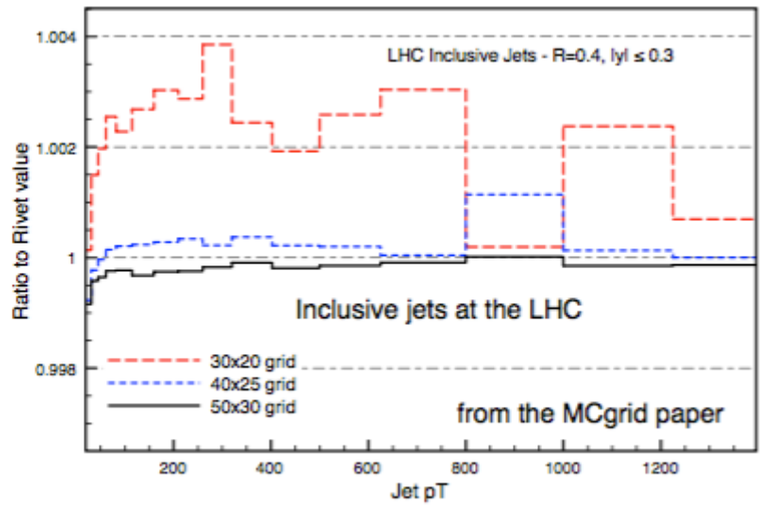
- Written by Del Debbio, Hartland and Schumann arXiv:1312.4460. http://mcgrid.hepforge.org
- Available for all fixed order NLO processes using the generic PDF decomposition

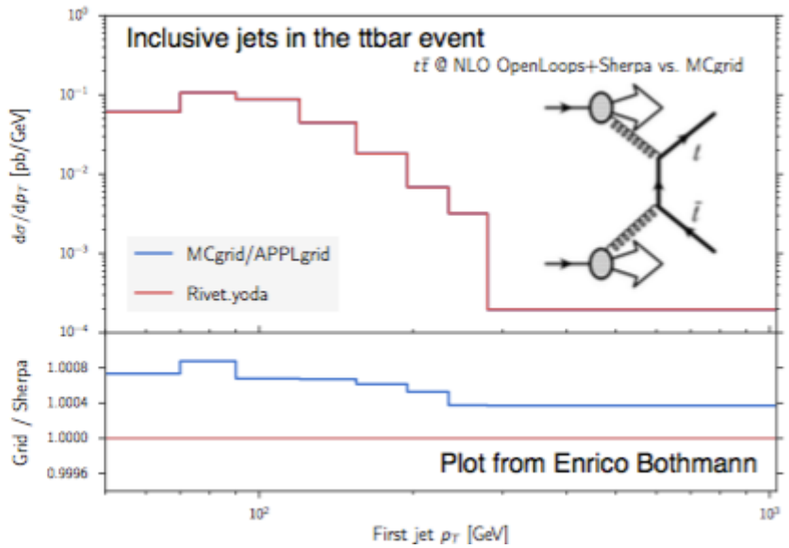


- MCgrid works as a Rivet plugin using the HepMC event record

M Sutton - Recent developments with APPLgrid

M. Sutton (ATLAS), applgrid, Hard QCD & PDF

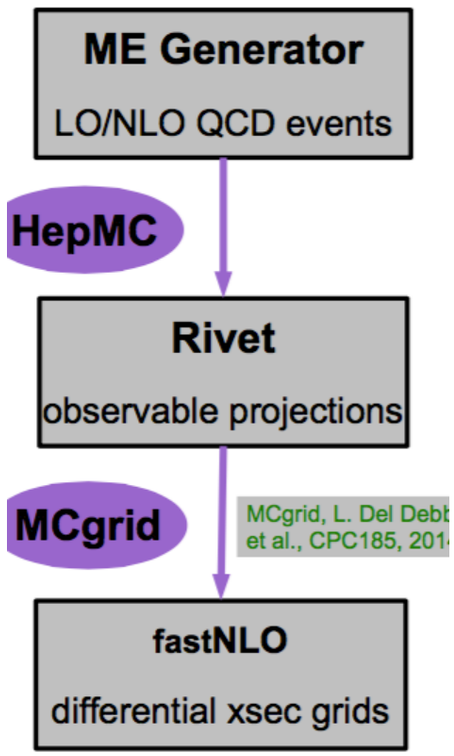


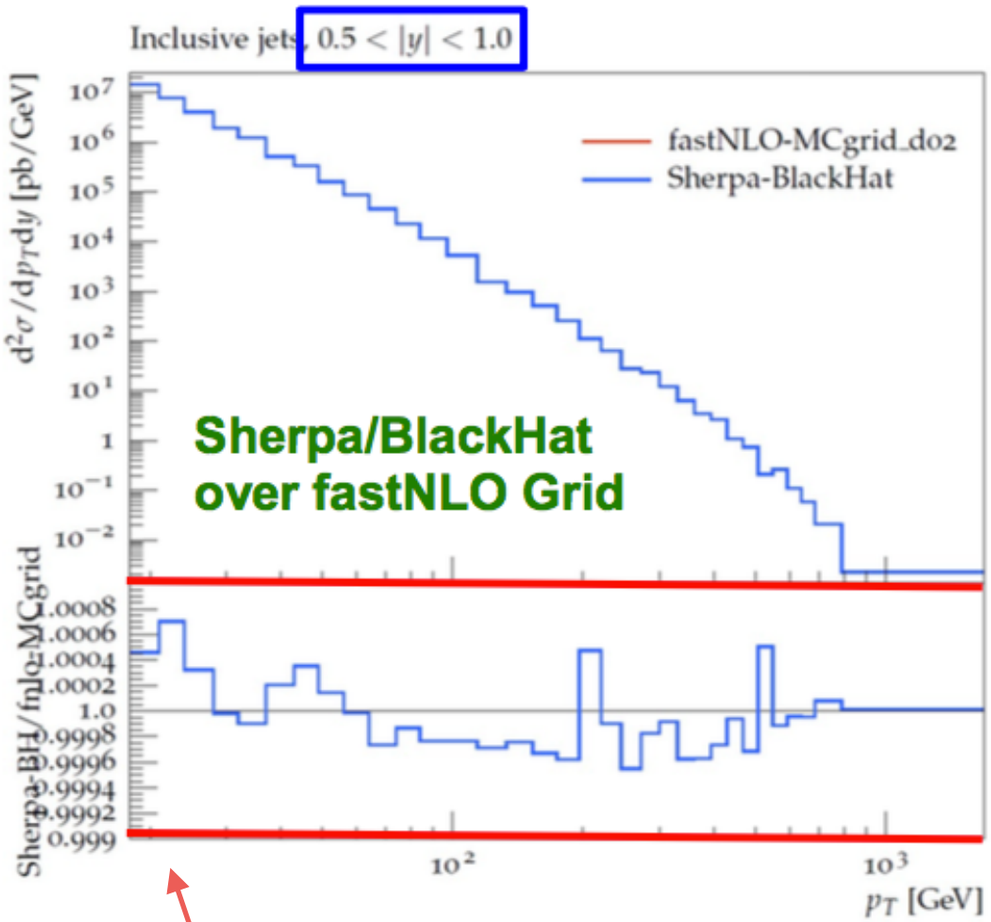


Tools for calculations: herafitter, applgrid, **fastnlo**, …

- fastNLO is a **fully open source package** to build a library of C++ utility classes for performing fast (N)NLO convolutions with PDFs
  - includes now: NLOjet++ for jet production, DIFFTop, BlackHat
  - Sherpa for fixed NLO processes using MCgrid2

K. Rabbertz (CMS), fastNLO
Hard QCD & PDFS





0.1%

Move towards a common interface for both applgrid and fastNLO with the different QCD calculations !

New PDF4LHC recommendations

A. DeRoeck, PDF4LHC, PDF
J. Rojo, Reduction Strategies, PDF

Basically two kinds of usage:

- For assessment of PDF uncertainties in comparing predictions to theory (top xsection, jets, W/Z xsections)

  Use individual PDF sets (CT, NNPDF, MMHT, HERAPDF,ABM, JR, CJ …)

- For assessment of PDF uncertainties as in searches, discoveries, acceptance measurements (e.g. Higgs, SUSY, …)

  Use PDF4LHC prescription

  - PDF4LHC15_mc: a Monte Carlo PDF set with $N_{\rm rep} = 100$ replicas
  - PDF4LHC15_30: a symmetric Hessian PDF set with $N_{\rm eig} = 30$ eigenvectors
  - PDF4LHC15_100: a symmetric Hessian PDF set with $N_{\rm eig} = 100$ eigenvectors

- These are available at NLO and NNLO and for standard $\alpha_s = 0.118$ and $\delta\alpha_s = \pm 0.0015$ variations
- Available in LHAPDF repository

- Which ones to use when: Part of the recommendation being documented eg
  - _MC set: contains also non-gaussian effects. Important for searches at high masses. ..
  - _30 set: very good precision and probably usable for most experimental needs
  - _100 superior precision, eg for TH Higgs cross section uncertainty determinations...

Hard QCD

Contributions

- LHC Experimental Overview and Prospects, BUTTERWORTH, Jonathan
- Theoretical Developments in Hard QCD, Predictions GLOVER, Nigel
- Recent QCD results from the LHC, ARCIDIACONO, Roberta
- Frontiers of QCD: new insights from SCE WAALEWIJN, Wouter
- Recent developments in QCD MCs SOPER, Davison
- Multiboson production at the LHC (theory) VON MANTEUFFEL, Andreas
- Multiboson production at the LHC ROVELLI, Chiara Ilaria
- EW corrections at high energy, DENNER, Ansgar
- Developments in QCD analytic resummation, LAENEN, Eric
- QCD in Higgs and BSM, TOMPKINS, Lauren Alexandra
- Measurements of jet and photon production in pp collisions with the ATLAS detector, DE LA TORRE, Hector
- Measurement of the Inclusive Isolated Prompt Photon production cross section in ppbar collisions at \sqrt{s}=1.96TeV using the full CDF dataset, LUCA, Alessandra
- Numerical multi-loop calculations based on the program SecDec, HEINRICH, Gudrun
- Five-point two-loop master integrals in QCD, LO PRESTI, Nicola Adriano
- Color and Kinematic Decomposition for QCD Amplitudes, OCHIROV, Alexander
- Studies of PDF sensitivity relevant for ATLAS measurements, HANNA, Remie
- Jet measurements, alpha_s and PDF results from CMS, RABBERTZ, Klaus
- Subleading Logarithms in High Energy Jets, BROOKS, Helen
- Recent developments in the fast reproduction of QCD calculations with the APPLgrid project, SUTTON, Mark
- fastNLO v2 Developments, RABBERTZ, Klaus

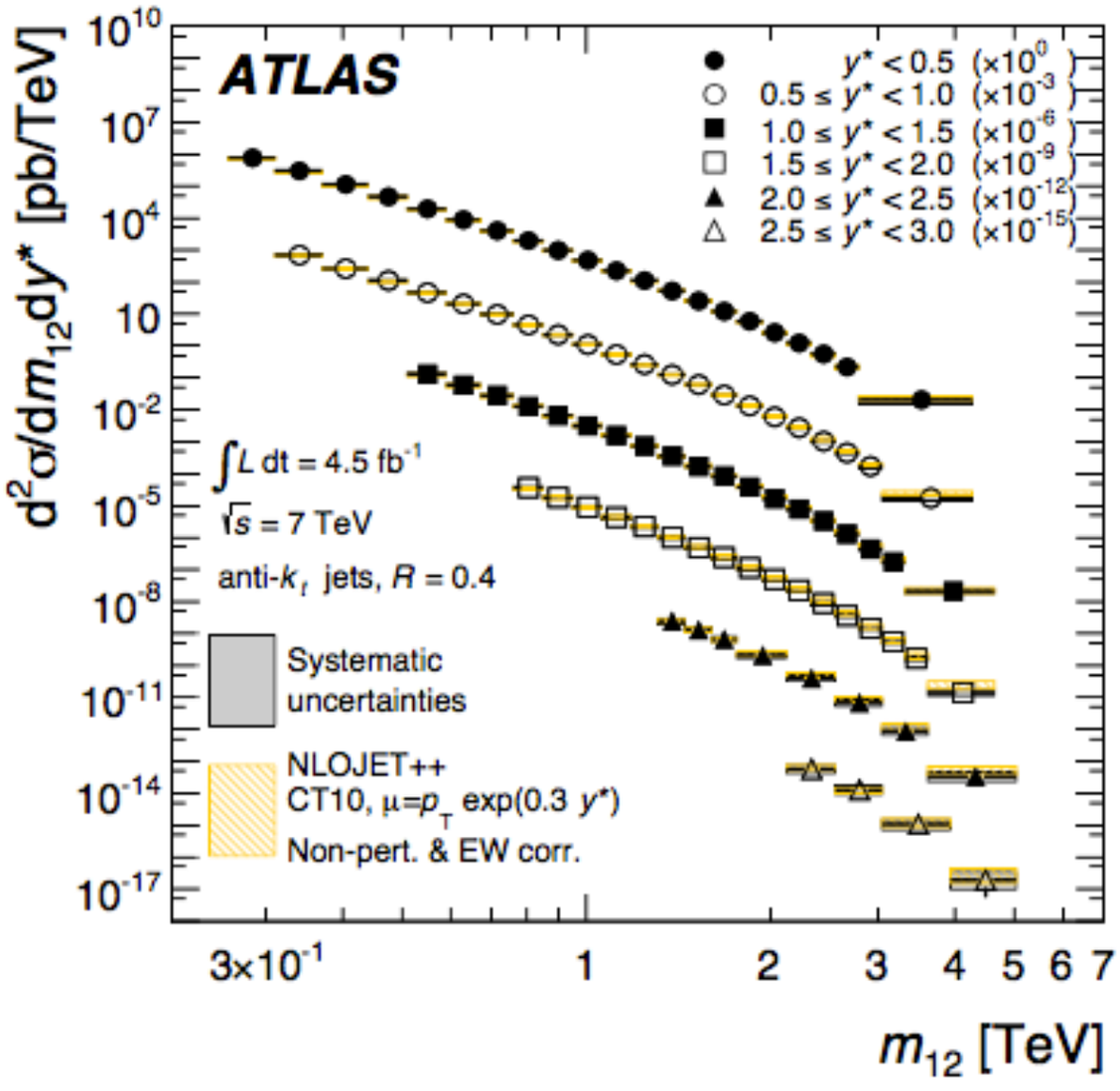
Contributions

- Higgs measurements from CMS, ZGHICHE, Amina
- Higgs measurements from ATLAS, LIU, Bo
- NNLO cross sections using the jettiness method, GIELE, Walter
- Higgs + jet at NNLO QCD: Fiducial cross sections, SCHULZE, Markus Christian
- Approximate N3LO: Higgs and more, BONVINI, Marco
- Analytic NNNLO corrections to the total Higgs production cross section in the qq'-Channel, HASSELHUHN, Alexander
- Fully differential decay rate of a standard model Higgs boson into a b-quark pair at NNLO accuracy, TROCSANYI, Zoltan Laszlo
- Fully differential VBF Higgs production at NNLO, DREYER, Frederic Alexandre
- Higgs production in gluon fusion in association with jets, GREINER, Nicolas
- Electroweak and QCD corrections with MadGraph5_aMC@NLO: top quark pair production in association with heavy bosons, SHAO, Huasheng
- Vector boson plus jets measurements with the ATLAS detector, TANNENWALD, Benjamin
- Automated NLO QCD+EW corrections for V+multijet production, LINDERT, Jonas
- Z boson production in association with a jet at NNLO QCD, MORGAN, Thomas
- Loop-tree duality and its application to NLO computations, SBORLINI, German
- Measurements of Drell--Yan transverse momentum, lepton azimuthal decorrelation and angular distributions with the ATLAS detector, LIN, Tai-Hua
- W/Z results from CMS, LAWHORN, Jay
- NNLOPS Simulations of Higgs and Vector Boson Production, HAMILTON, Keith
- Combining parton showers with NNLO matrix elements, LI, Ye
- Recent electroweak results from ATLAS, BAAS, Alessandra
- Diboson production at NNLO, GRAZZINI, Massimiliano
- Automated NNLL+NLO Resummation for Jet-Veto Cross Sections, ROTHEN, Lorena

Jet measurements

J. Butterworth, Overview, pleanry
R. Arcidiacono, Recent results, plenary
H. de la Torre (ATLAS),Measurements of jets
Hard QCD

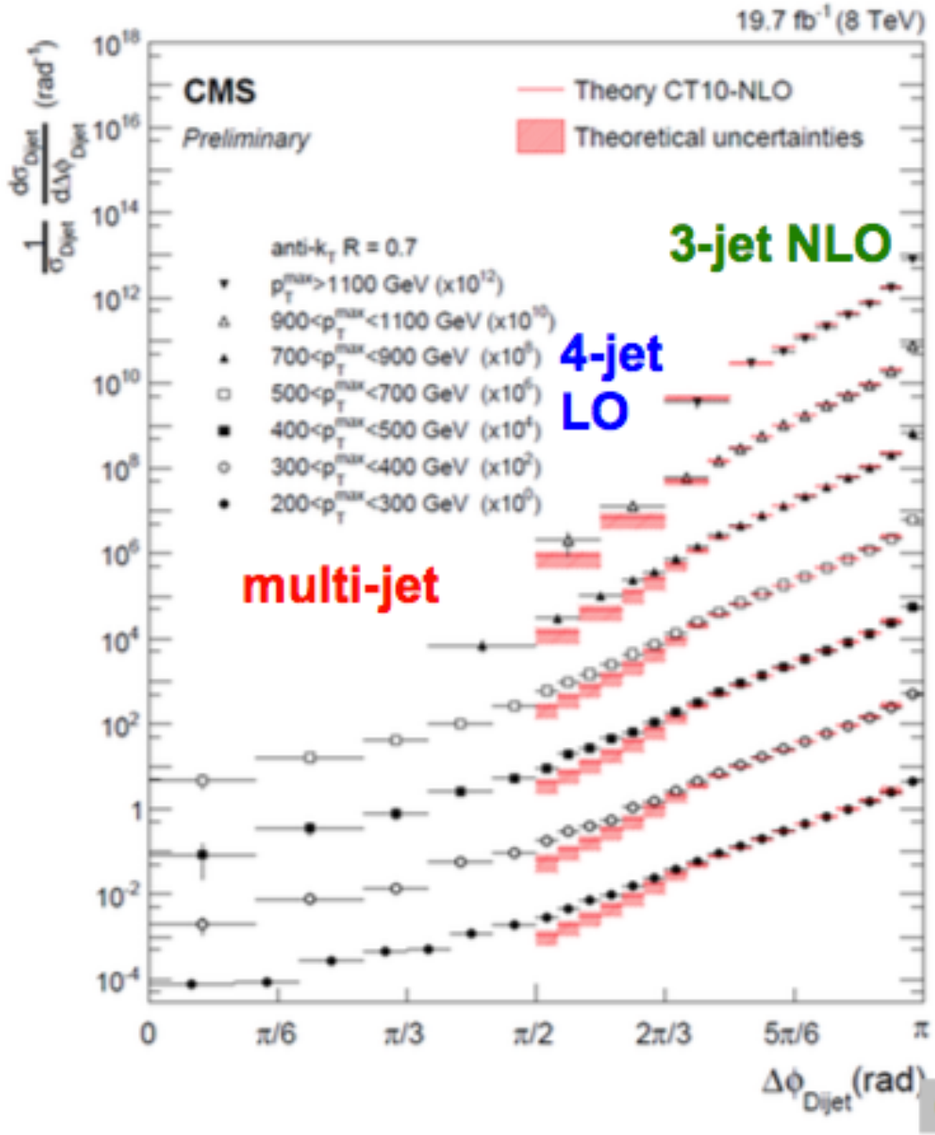
- Sensitivity to resonances (as a function of dijet mass) decaying into two jets.
- High dijet-mass region constrains gluon PDF.
- $P_T^{jet1} \geq 100$ GeV, $P_T^{jet2} \geq 50$ GeV
- $|y^{jet}| < 3.0$ and $|y^*| < 3.0$
- $y^* = |y^{jet1} - y^{jet2}|/2$
- NLO pQCD: NLOJET++.
- Several PDF sets.
- NLO is corrected for non-perturbative and EW effects.
  - NPC obtained with PYTHIA/HERWIG with various tunes.
- Data unfolded to particle-level using an IDS method.



Dijet measurements: azimuthal correlations

R. Arcidicaono, Recent results, plenary
K. Rabbertz (CMS), Jet measurements
Hard QCD

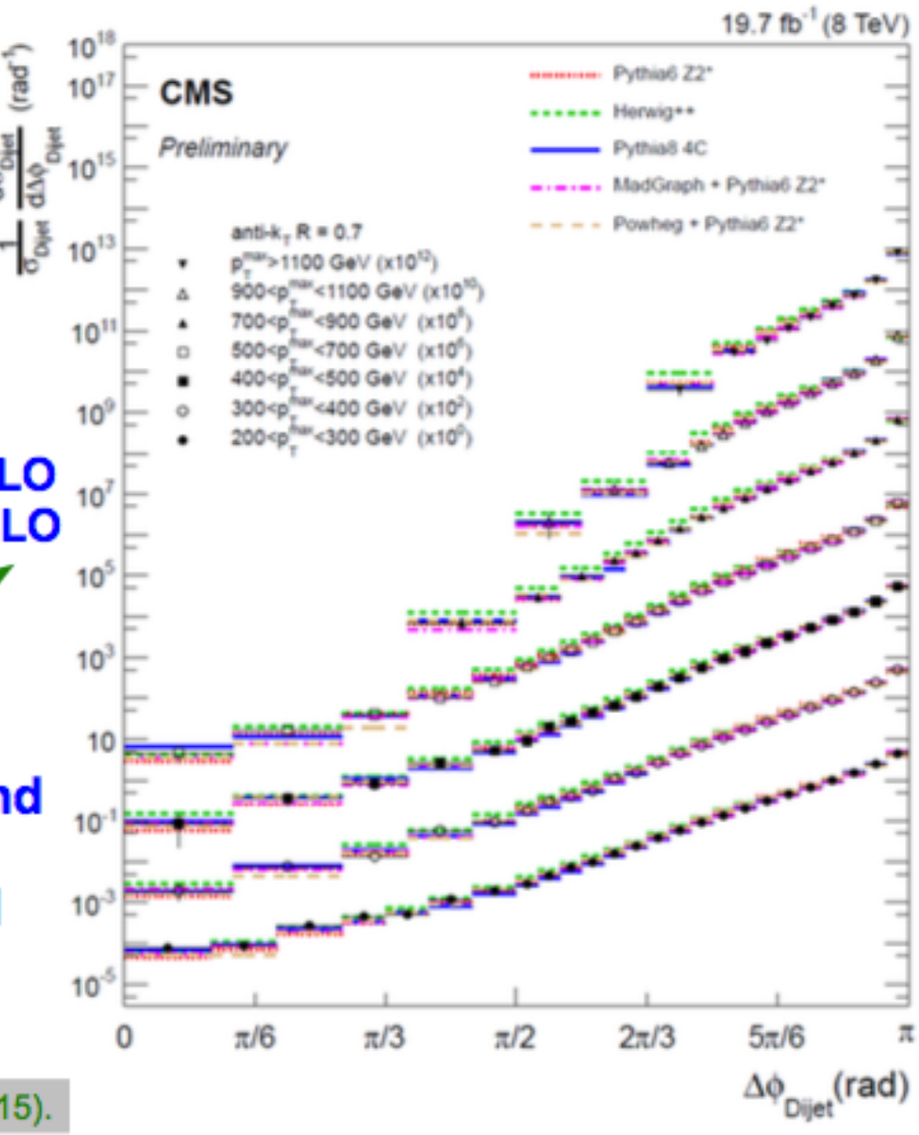
$\Delta\varphi_{jj}$ in bins of p_{T1} for p_T > 100 GeV, p_{T1} > 200 GeV, $|y_1|$, $|y_2|$ < 2.5
- dijet LO configuration is always $\Delta\varphi_{jj} = \pi$
- deviations through multijet production



Comparison to fixed-order PQCD
→ need multijet NLO

Sherpa + BlackHat → 4-jet NLO
Njet → 5-jet NLO
to be checked

Comparison to LO ME+PS and multijet ME+PS
→ good general description

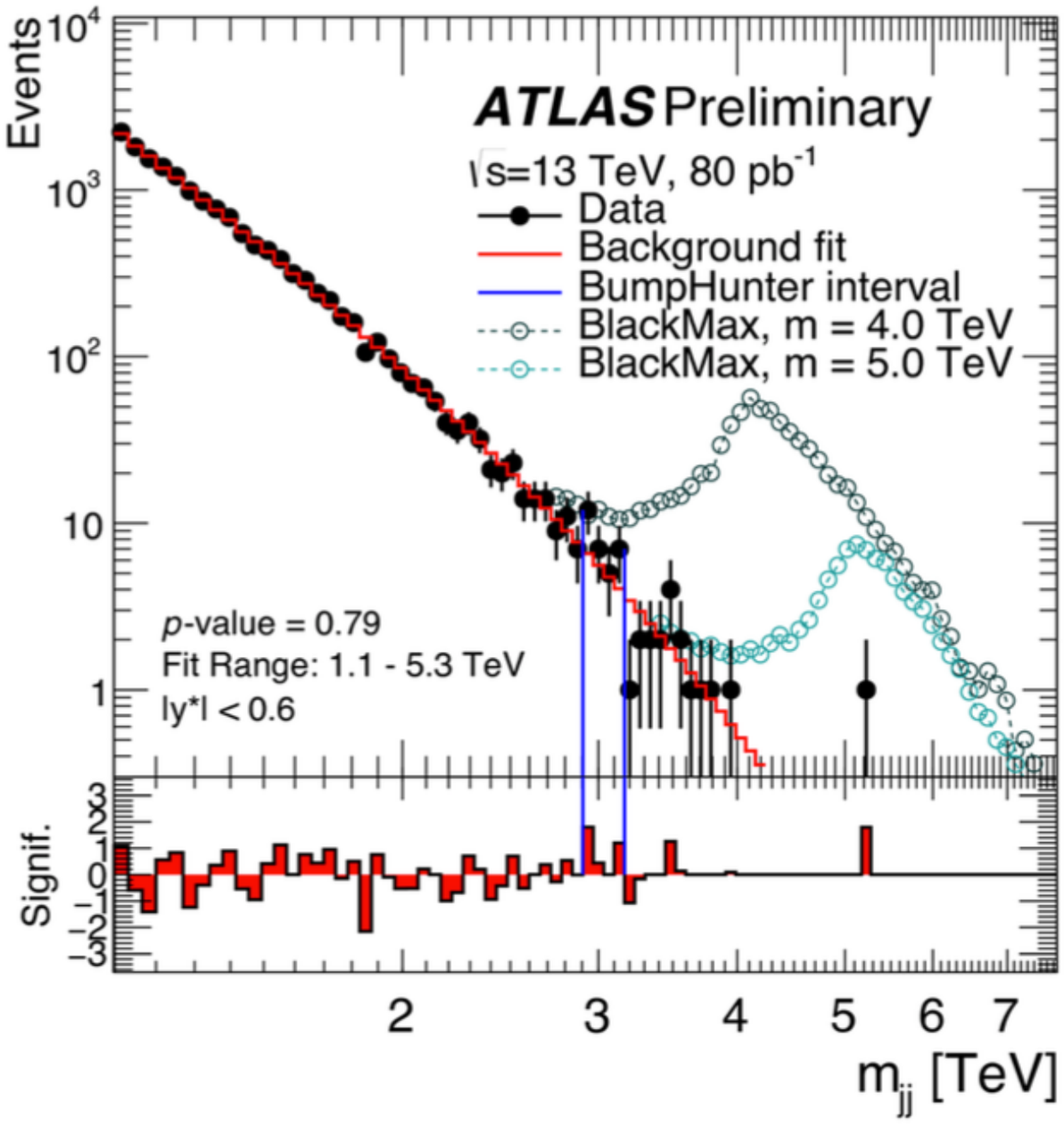


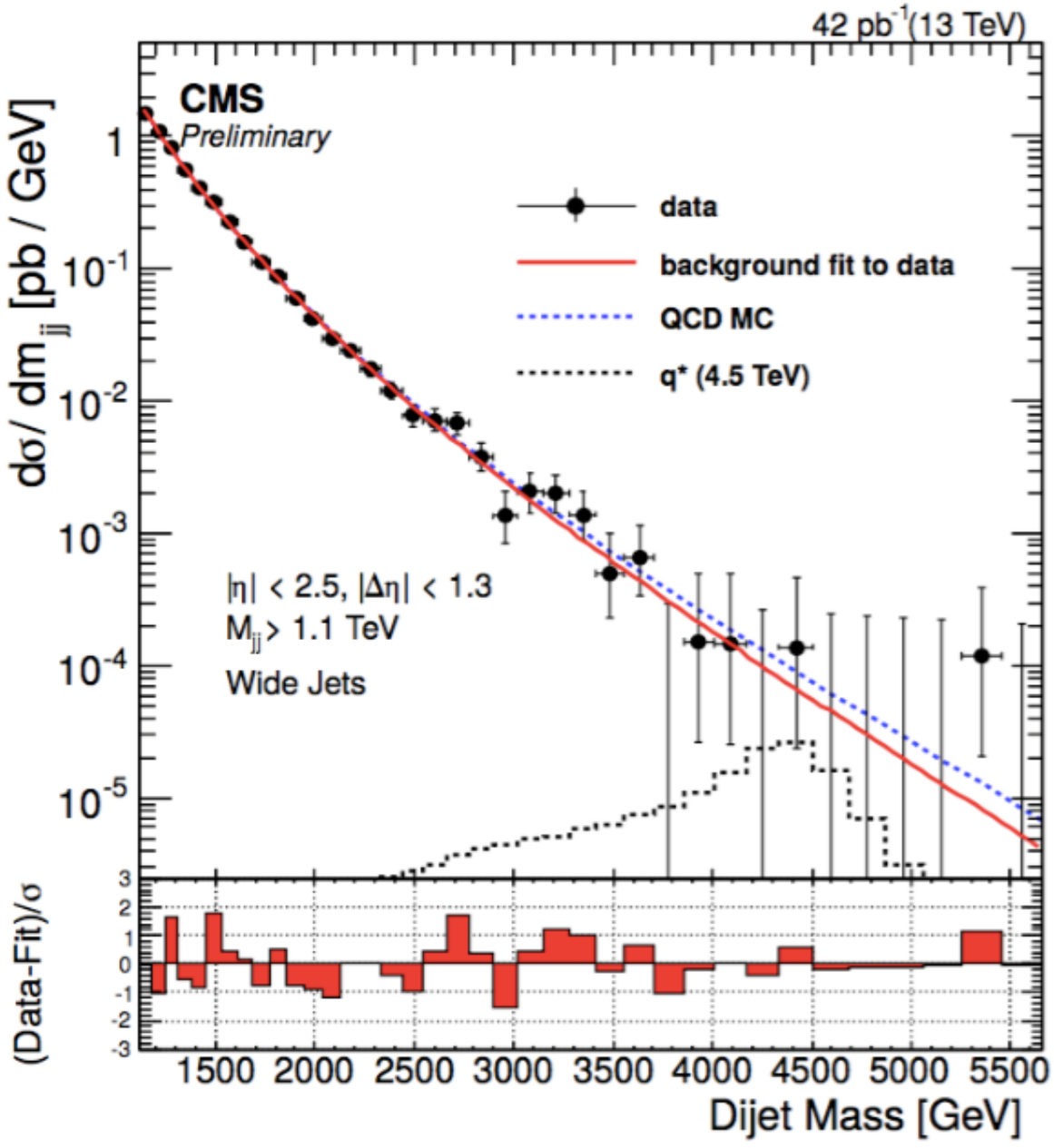
CMS-PAS-SMP-14-015 (2015).

Dijets for searches

H. Yoo, Searches in CMS
A. Elliot Searches from ATLAS
Multiparton Dynamics

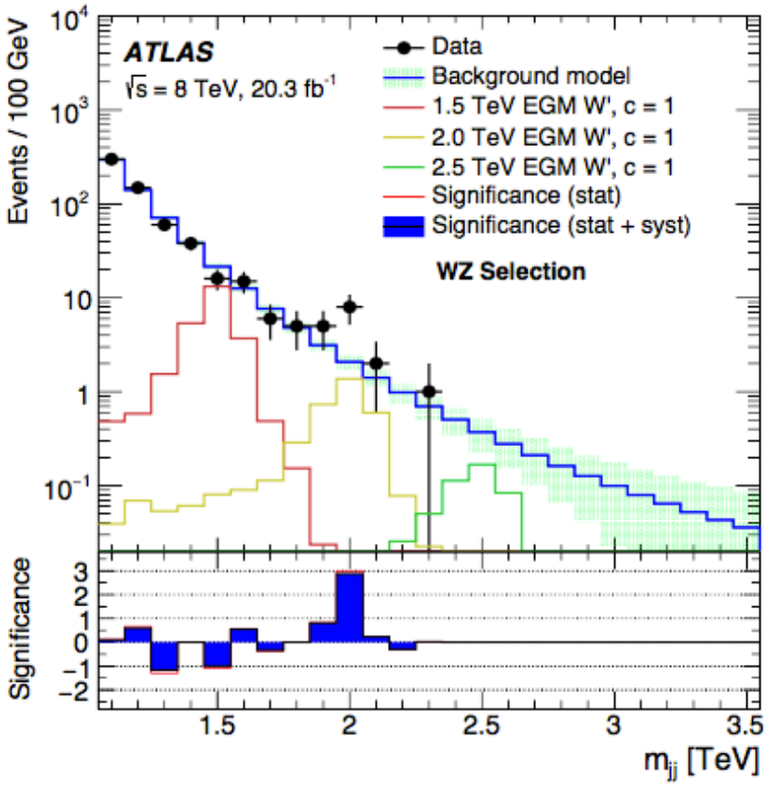
- 13 TeV data are already analyzed

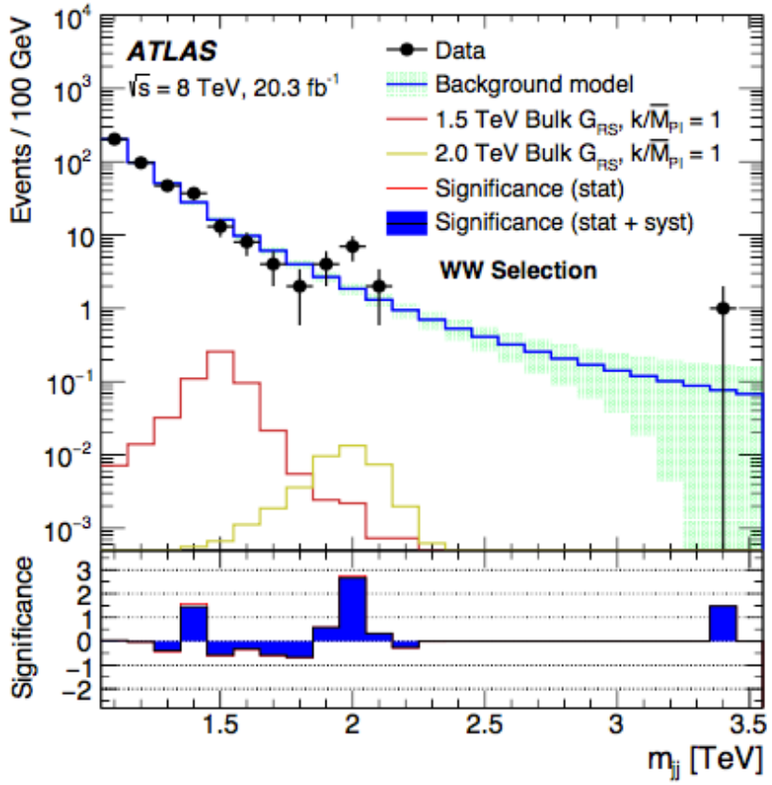


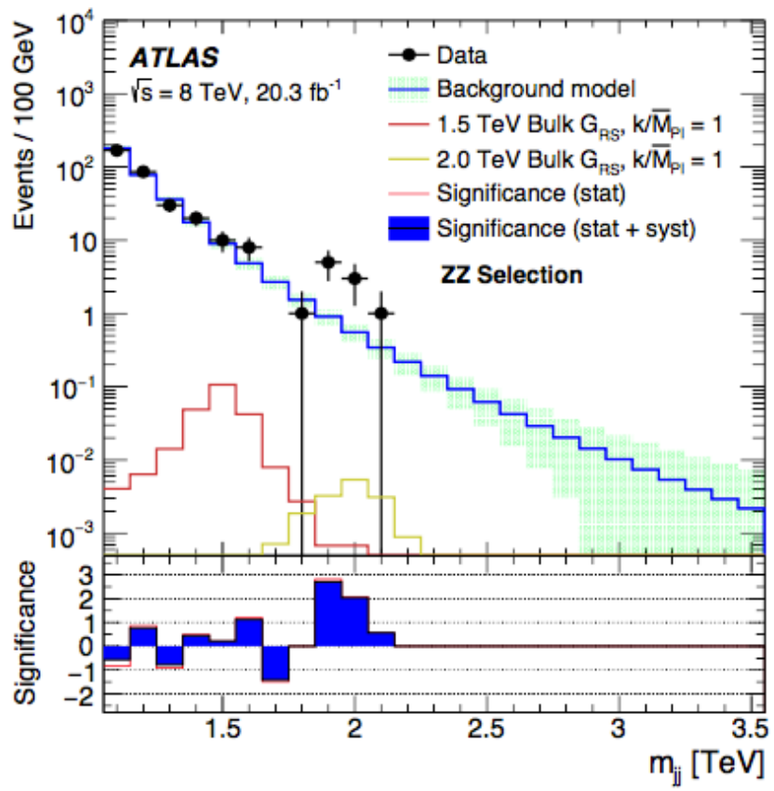


Diboson production

H. Yoo, Searches in CMS
A. Elliot Searches from ATLAS
Multiparton Dynamics

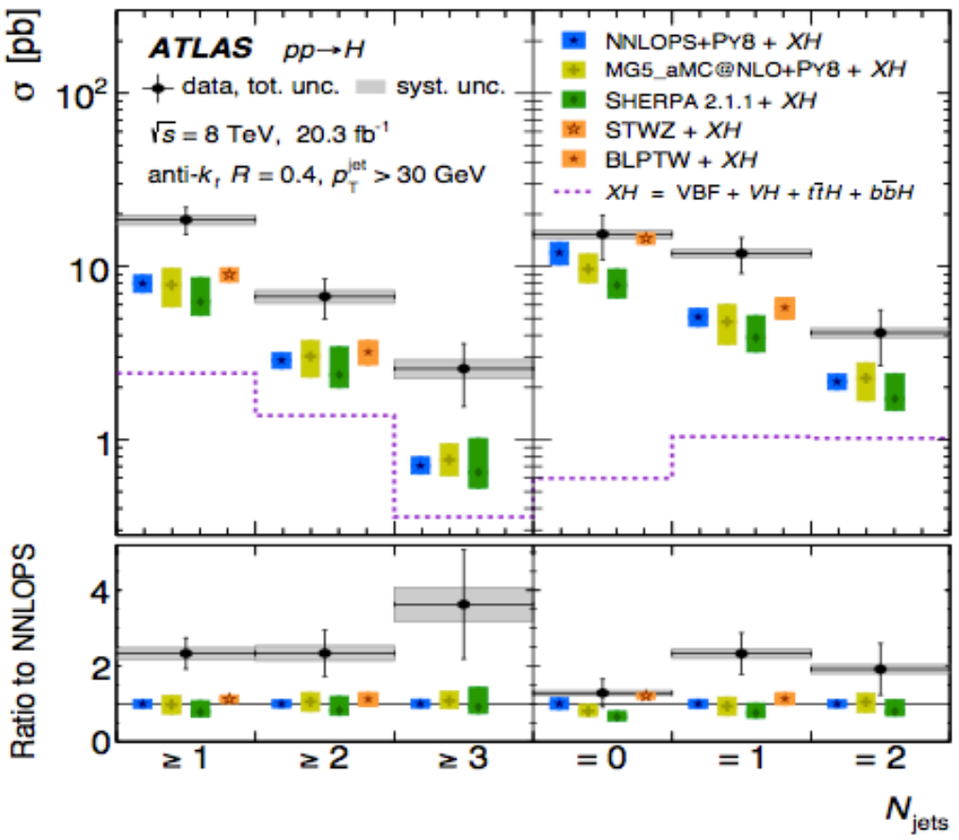


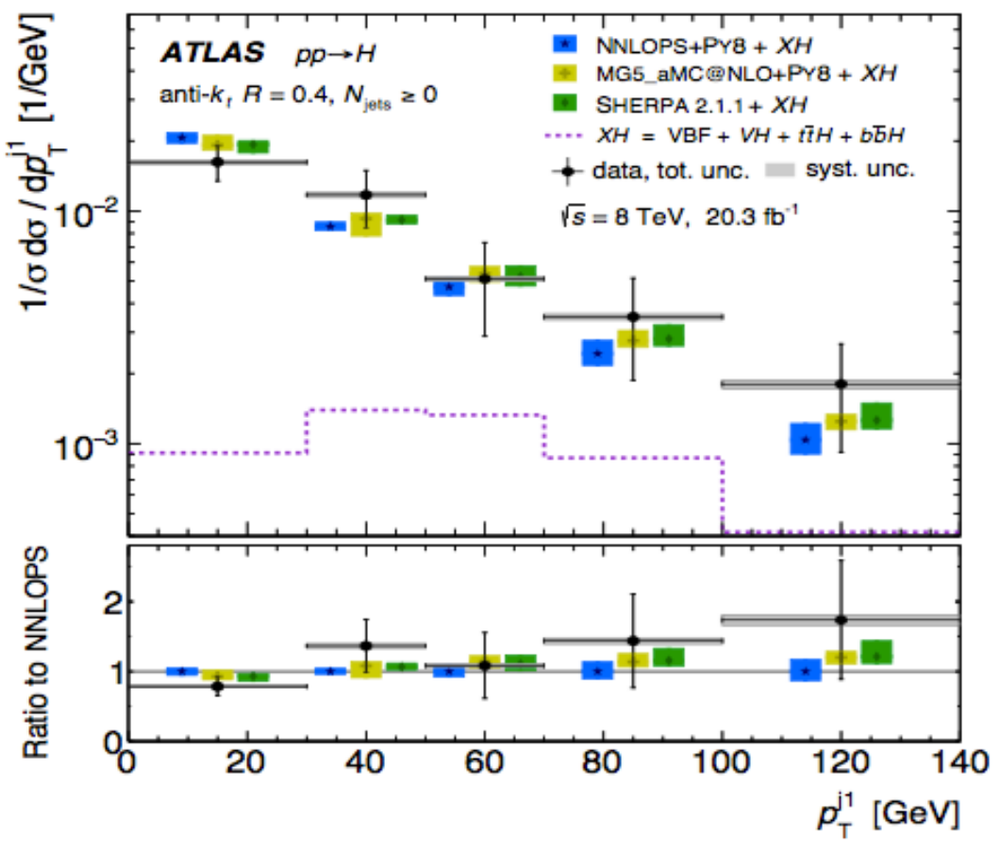




Higgs +jet measurements

L. Tompkins, QCD in Higgs and BSM, plenary
A.Zghiche,Higgs from CMS, Hard QCD
B.Liu Higgs from ATLAS, Hard QCD
K.Hamilton, NNLOPS, Hard QCD





- Jet bins low for all MCs ; HNNLOPS expectedly better in 0-jet bin
- " ... poorest agreement with data ... in the inclusive and exclusive 1-jet bins, with p-values ranging between 0.1% and 3.6%."
- Normalised lead jet p_T agreeing well between data & all MCs

Heavy Quarks

Contributions

- Heavy flavour theory developments, DE FREITAS, Abilio
- Heavy quark production results, NEEDHAM, Matthew David
- Top quark production at the LHC, CUEVAS MAESTRO, Javier
- Heavy flavour production with the ATLAS experiment, BJERGAARD, David Martin
- Quarkonia results in heavy ions from CMS, KAMIN, Jason Adrian
- Heavy quark spectroscopy, PAPPAGALLO, Marco
- Spectroscopy and decay properties with b-hadrons at the ATLAS experiment, TOMS, Konstantin
- LHCb early measurements focusing on B and Charm production, NEEDHAM, Matthew David
- t tbar + isolated photon production at NLO accuracy matched with parton shower, TROCSANYI, Zoltan Laszlo
- On NLL soft gluon corrections to the t-tbar-Higgs boson production at the LHC, MOTYKA, Leszek
- Top quark pair production measurements using the ATLAS detector at the LHC, YAMAUCHI, Katsuya
- Top quark pair properties using the ATLAS detector at the LHC, LEVY, Mark
- Measurement of t-channel single top quark production in pp collisions, ROCKER, Steffen
- 3-loop heavy flavor non-singlet contributions to different observables, BLUEMLEIN, Johannes
- Decay rate of the SM Higgs boson to bottom quarks at O(alpha alphas), MIHAILA, Luminita
- Heavy quark production asymmetries at LHCb, GAULD, Rhorry Graham
- Searches for top/bottom partners and new phenomena in top/bottom quark pair signatures in CMS, MARGAROLI, Fabrizio
- Single Top quark production cross section and properties using the ATLAS detector at the LHC, PEDRAZA LOPEZ, Sebastian
- Heavy flavour theory developments, DE FREITAS, Abilio
- Heavy quark production results, NEEDHAM, Matthew David

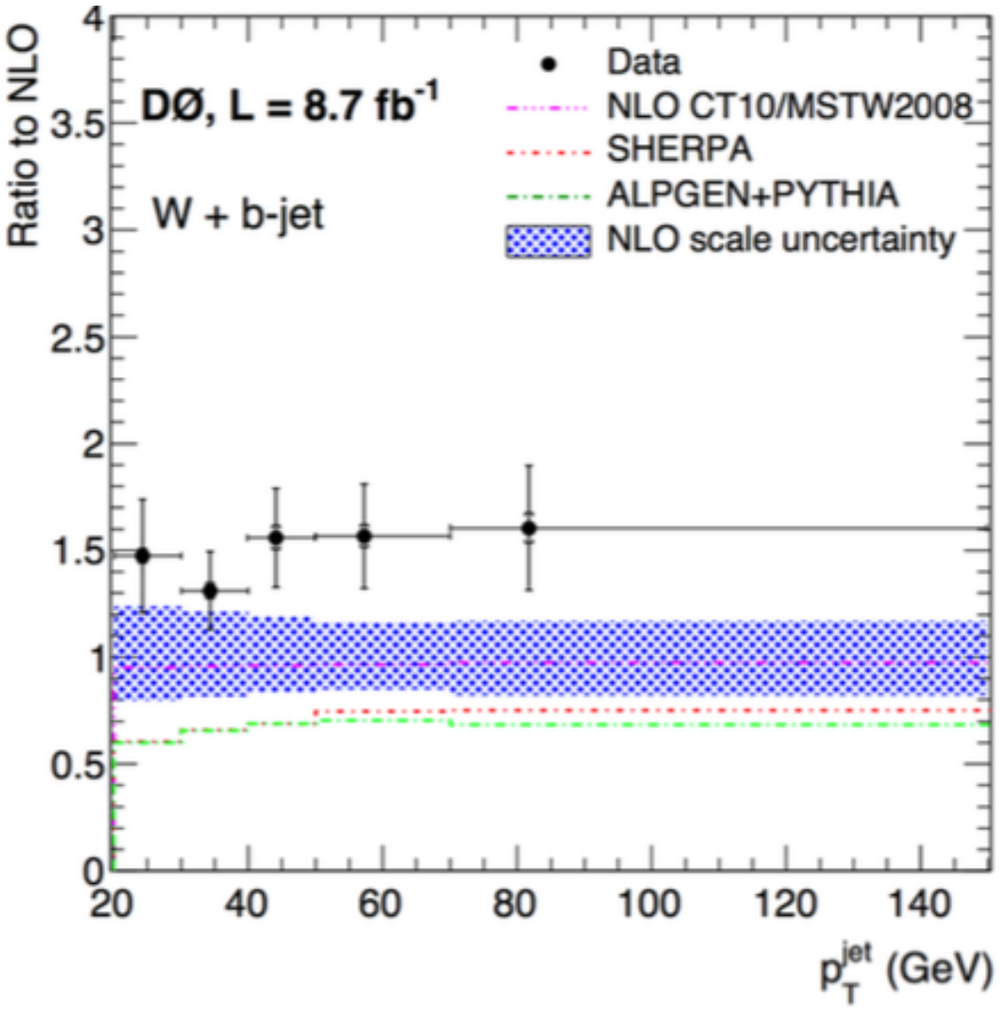
Contributions

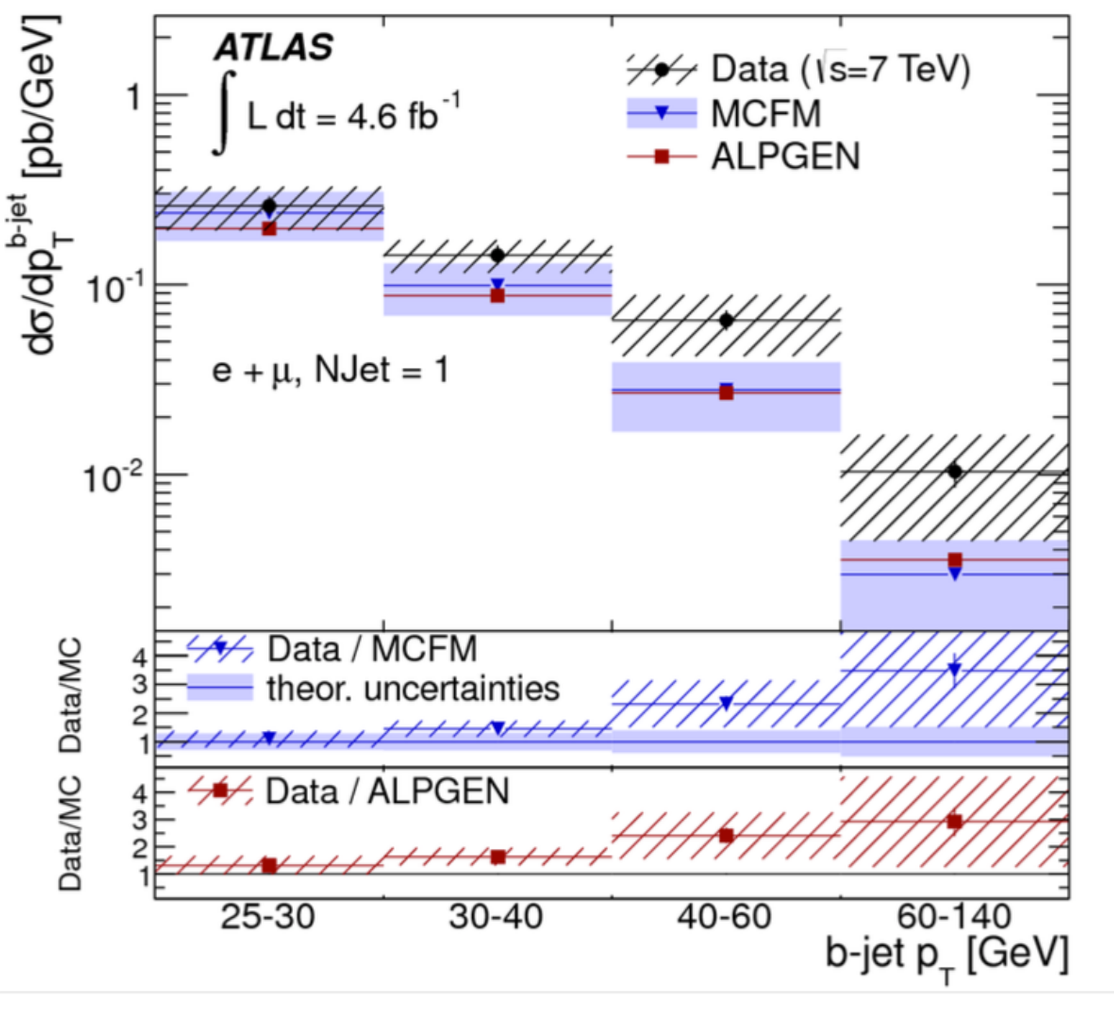
- LHCb CP Violation in B decays, GRILLO, Lucia
- LHCb rare decays, CLIFF, Harry Victor
- LHCb exotics, PAPPAGALLO, Marco
- Measurements of heavy-flavour production in pp and p-Pb collisions with ALICE at the LHC, KIM, Minjung
- Higgs production in association with top quarks in CMS, MARGAROLI, Fabrizio
- Recent V+charm/beauty jets measurements from DZero, PRICE, Darren
- Measurements of heavy flavour production in association with W and Z bosons with the ATLAS detector, LAW, Alexander
- Vector boson production in association with jets and heavy flavor quarks from CMS, LUETIC, Jelena

W+heavy quarks

A. Law, heavy flavor with W/Z ATLAS
J. Luetic, Vector boson + jets, CMS
D. Price, V+charm/bottom D0
Heavy Quarks

- W+b





- Even larger difference observed in W+c in D0

Rare decays

H. Cliff, Rare decays LHCb
Heavy Quarks

FCNC decays proceed via loops in the SM

- Highly suppressed (hence rare)
- Can receive significant modifications from NP

In this talk:

<u>b → s transitions</u>

$B^0 \to K^{*0}\mu^+\mu^-$ LHCb-CONF-2015-002

$B_s^0 \to \phi^0\mu^+\mu^-$ arXiv:1506.08777

$\Lambda_b^0 \to \Lambda^0\mu^+\mu^-$ JHEP 06 (2015) 115

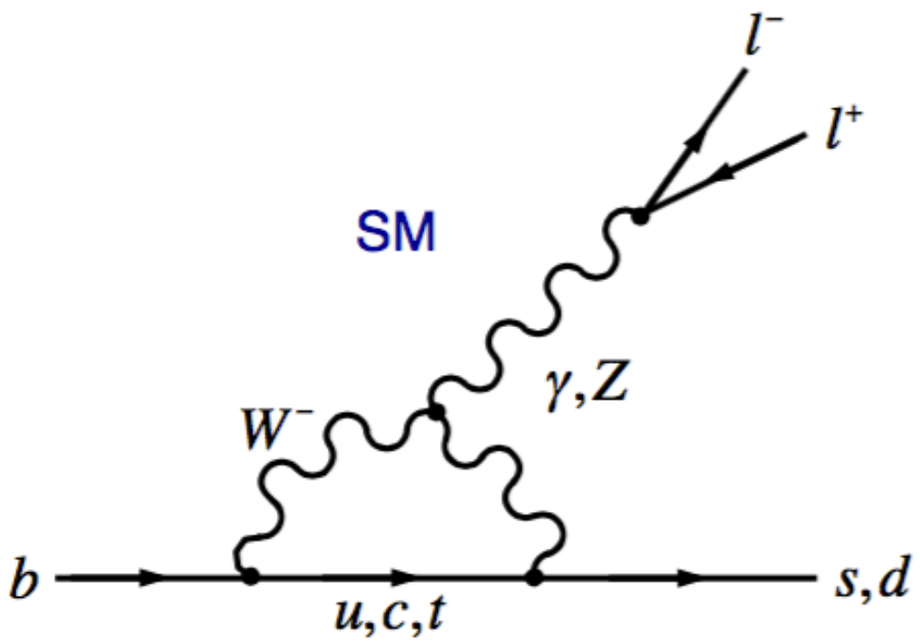
<u>b → d transition</u>

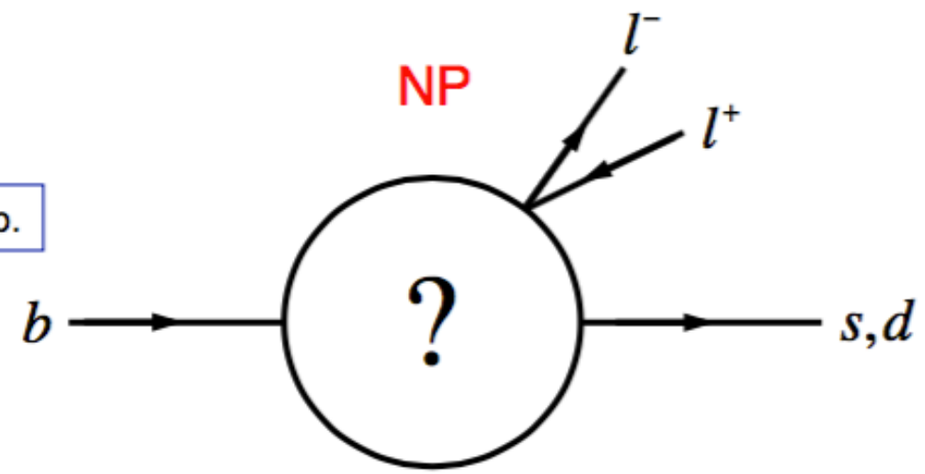
$B^+ \to \pi^+\mu^+\mu^-$ Preliminary, LHCb-PAPER-2015-035 in prep.

<u>Search for dark bosons using</u>

$B^0 \to K^{*0}\chi^0\left(\to \mu^+\mu^-\right)$ arXiv:1508.04094

All use Run I 3fb^{-1} data set.

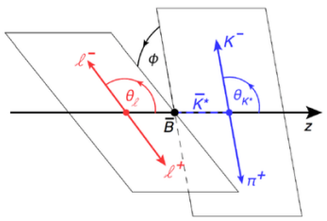




Rare decays

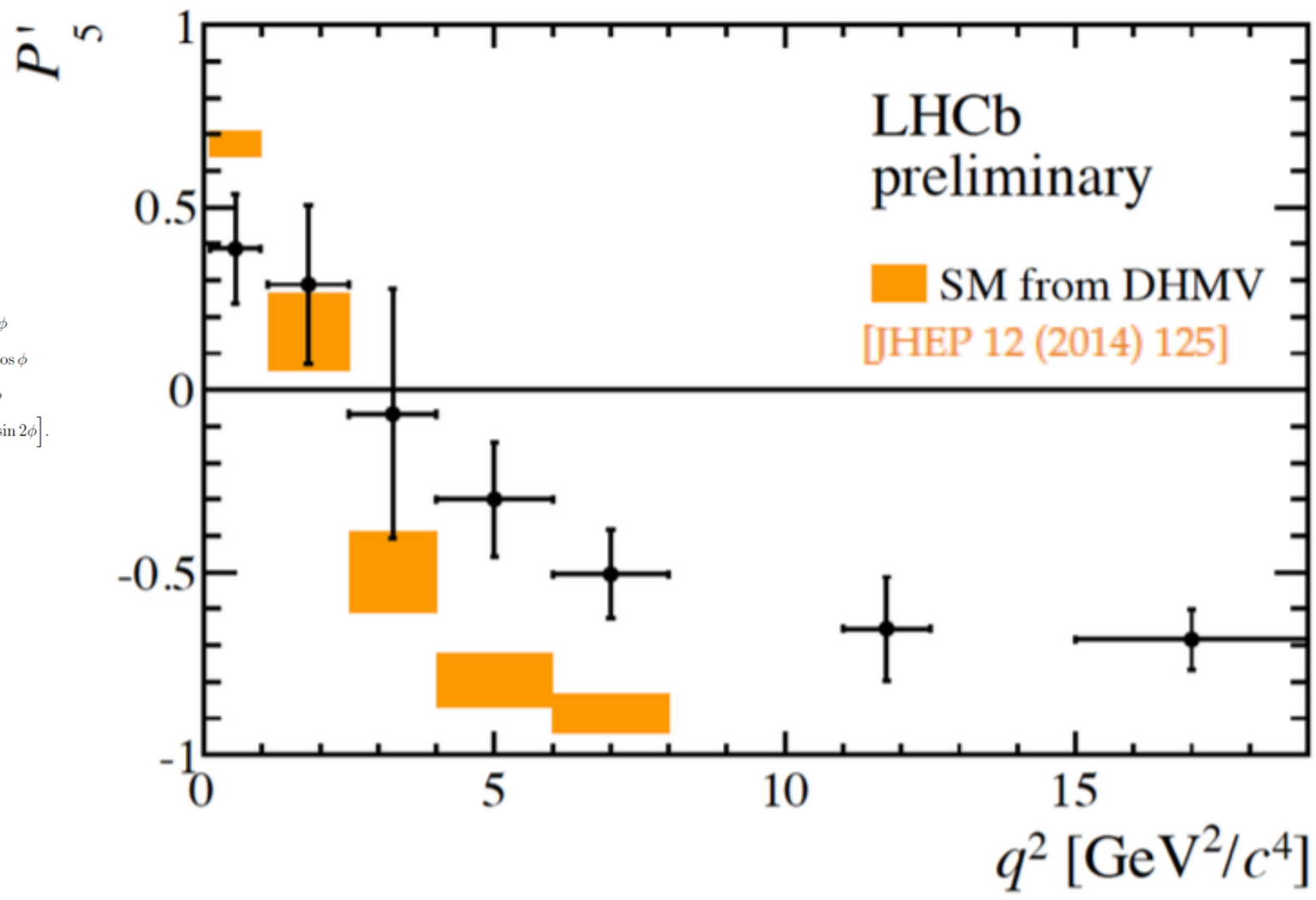
Parameterise the decay in terms of three angles (θ_l, θ_k, ϕ) and $q^2 = m_{\mu\mu}$.

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\bigg|_{\mathrm{P}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_{\mathrm{L}})\sin^2\theta_K + F_{\mathrm{L}}\cos^2\theta_K$$
$$+\tfrac{1}{4}(1-F_{\mathrm{L}})\sin^2\theta_K\cos 2\theta_l$$
$$-F_{\mathrm{L}}\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$+S_4\sin 2\theta_K\sin 2\theta_l\cos\phi + S_5\sin 2\theta_K\sin\theta_l\cos\phi$$
$$+\tfrac{4}{3}A_{\mathrm{FB}}\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big].$$



Can also calculate observables that have less form factor dependence e.g.

$$P'_{4,5} = S_{4,5}/\sqrt{F_{\mathrm{L}}(1-F_{\mathrm{L}})} \qquad A_{\mathrm{T}}^{(2)} = S_3/(1-F_{\mathrm{L}})$$



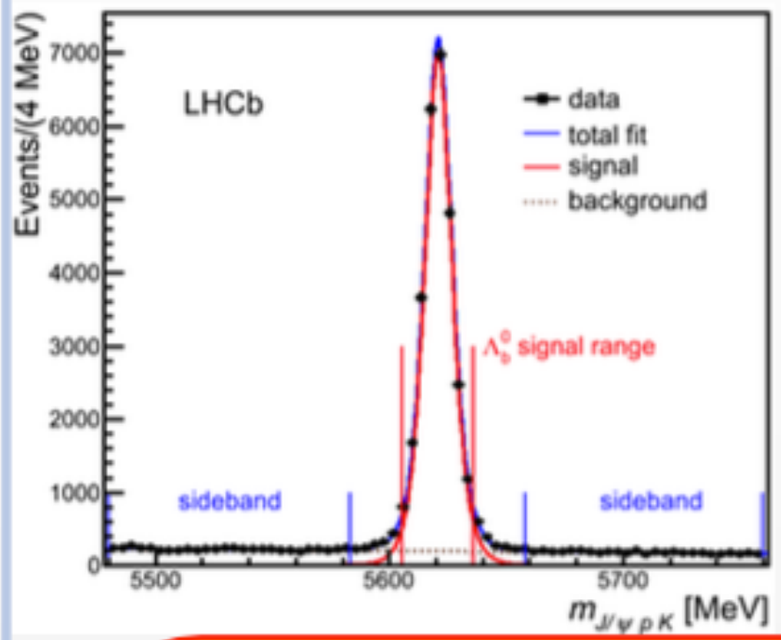
- Deviation from SM at 2.9σ in [4.0-6.0] and [6.0-8.0] GeV^2
- Tension with SM at 3.7σ
- Possible explanations: Z', leptoquark or charm-loops.

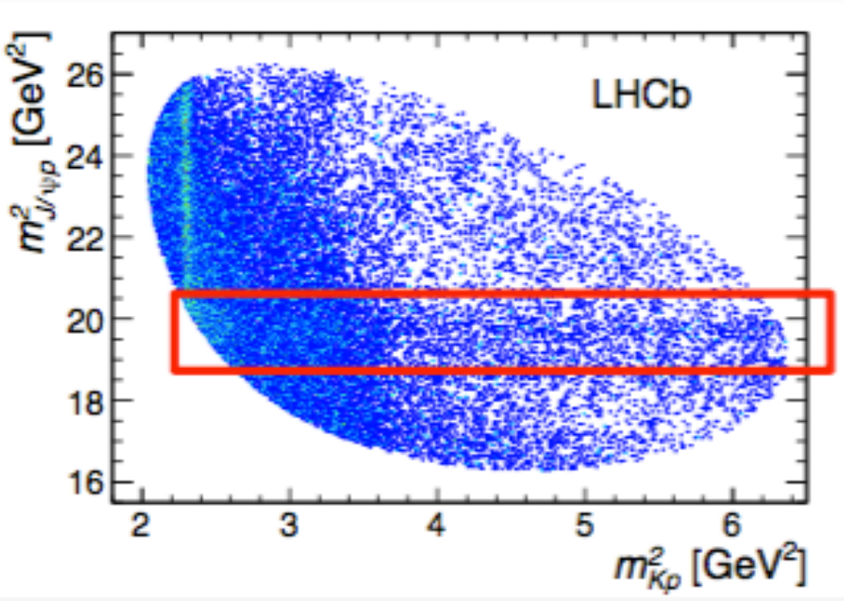
Charmed Pentaquarks

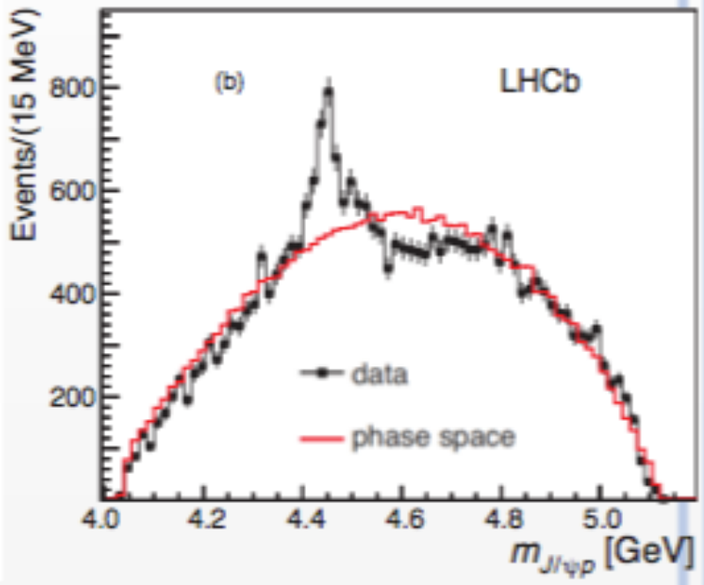
AMPLITUDE ANALYSIS OF $\Lambda_b \rightarrow J/\psi$ Kp

[LHCb: PRL 115, 07201 (2015)]

26k Λ_b^0 candidates
Background ~ 5.4%







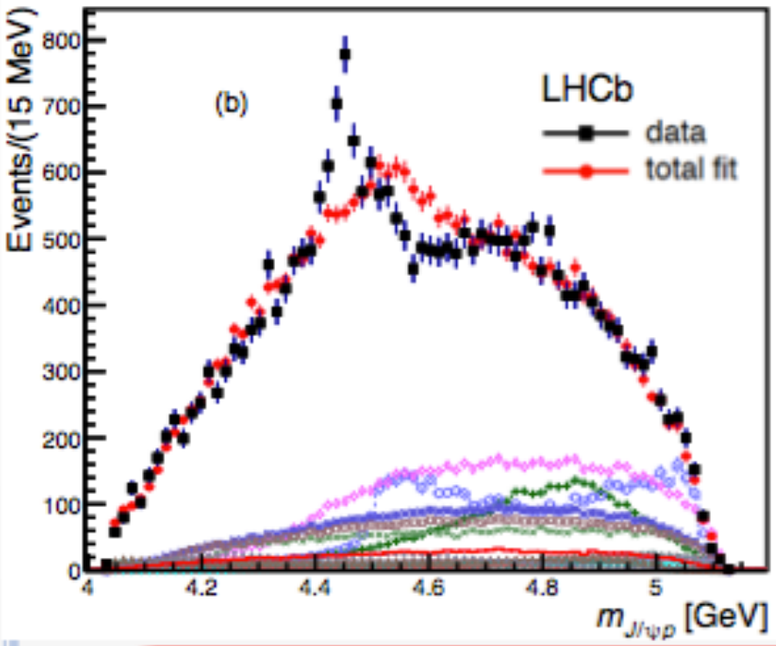
Unexpected narrow peak in m(J/ψ p)!

- Efficiency flat over the "Dalitz" plot
- Cross checks:
  - ✓ Veto $B_s \rightarrow J/\psi KK$ & $B^0 \rightarrow J/\psi K\pi$ after swapping the mass hypothesis of the Λ_b daughters: p ←→K or K ←→ π
  - ✓ Clone and ghost tracks carefully removed
  - ✓ Exclude Ξ_b decays
- Could it be a reflection of the interfering Λ^*'s→ pK^-
  - ✓ 6D unbinned maximum likelihood fit (m_{Kp}, $\theta_{\Lambda b}$, θ_{Λ^*}, ϕ_K, θ_ψ, ϕ_μ)

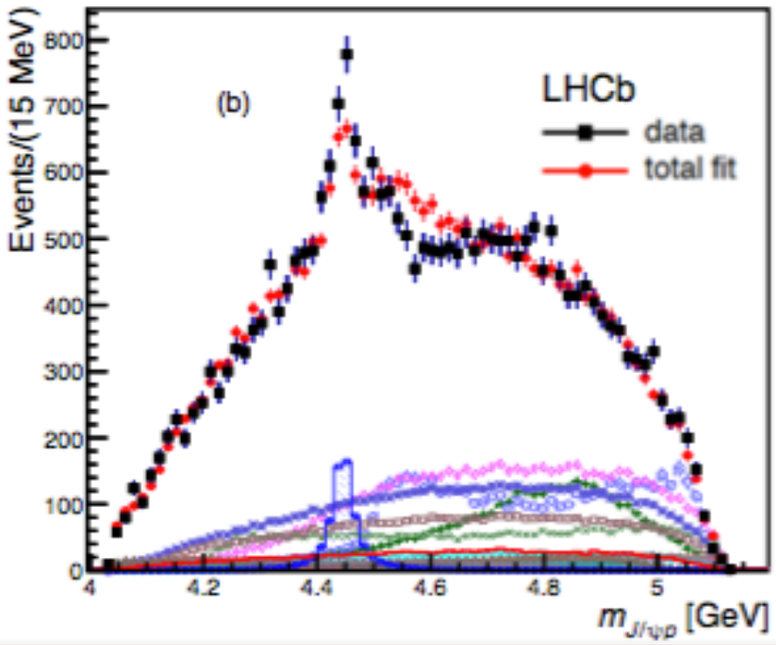
ADDING $P_c \rightarrow J/\psi\, p$ AMPLITUDES

[LHCb: PRL 115, 07201 (2015)]

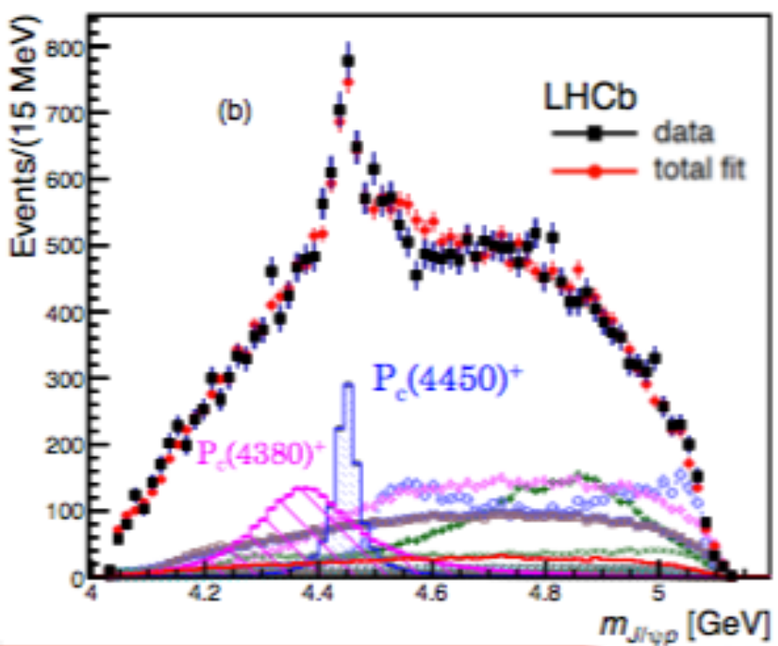
Extended Λ^* model



Extended Λ^* model + 1 P_c^+



Reduced Λ^* model + 2 P_c^+'s



Extended Λ^* model:

- ...the fit projection can reproduce the peaking structure in J/psi p
- Additing non-resonant term, Σ^*'s or extra unknown Λ^*'s doesn't help

Extended Λ^* model + 1 Pentaquark decaying to J/ψ p

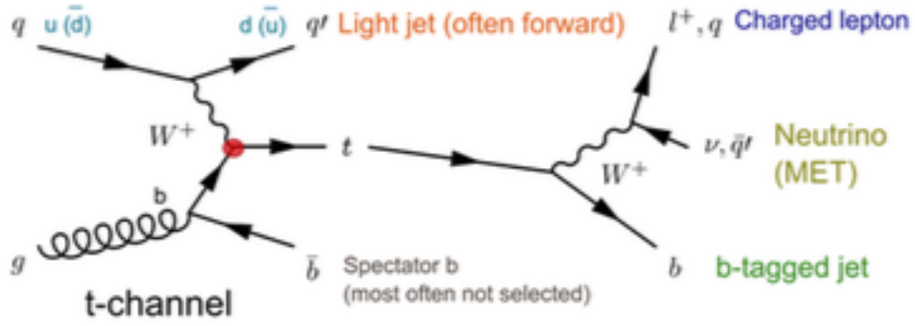
- Try all J^P of P_c^+ up to $7/2^{\pm}$
- Best fit has $J^P = 5/2^{\pm}$. Still not a good fit

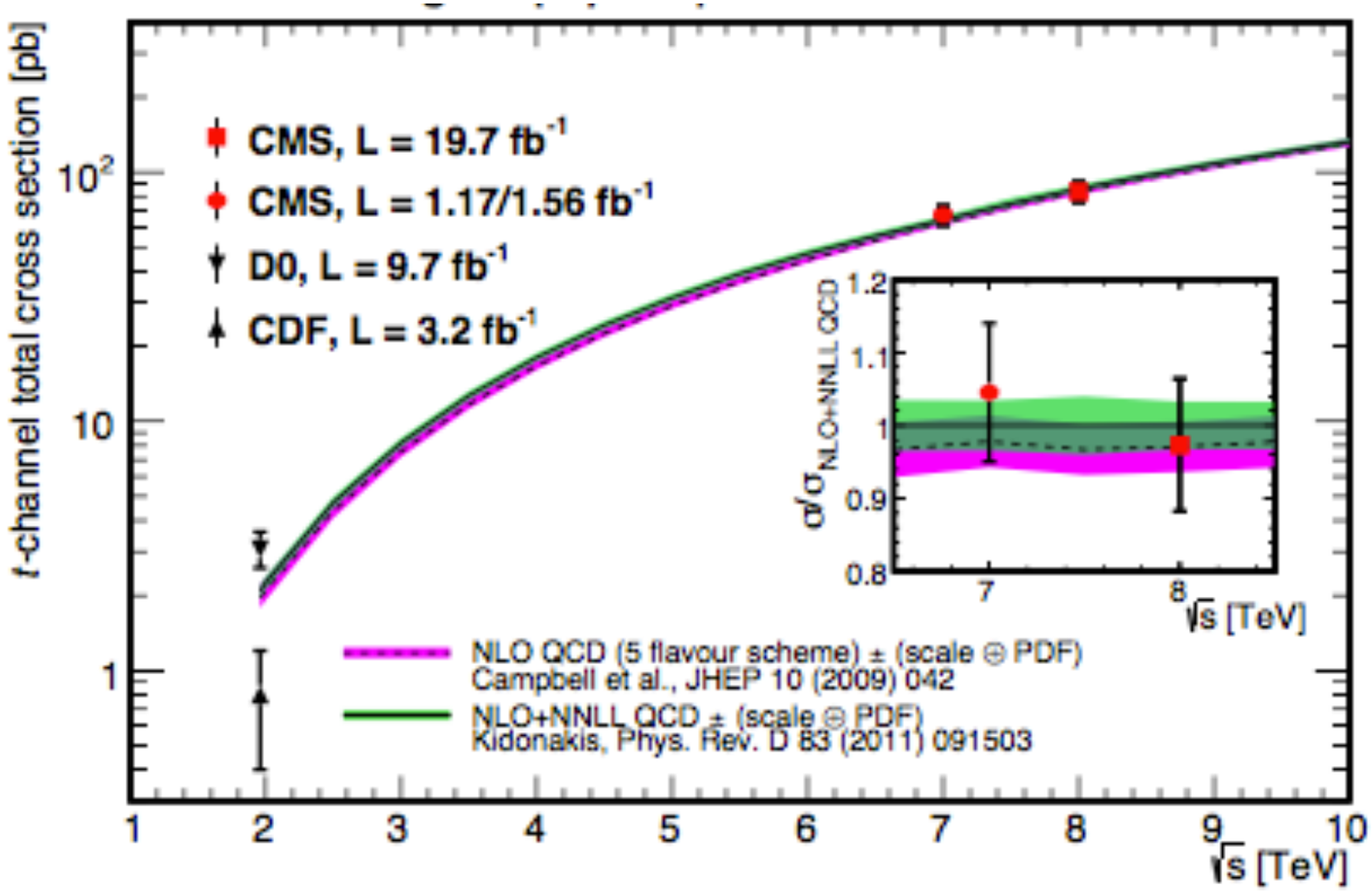
Reduced Λ^* model + 2 Pentaquarks decaying to J/ψ p

- Obtain good fits even with the reduced Λ^* model
- Best fit has $J^P = (3/2^-, 5/2^+)$, also $(3/2^+, 5/2^-)$ & $(5/2^+, 3/2^-)$ are preferred

Top measurements: single top

J. Maestro, Top quark, plenary
K. Yamauchi Top quark pair ATLAS
M. Levy Top quark pair ATLAS detector
S. Rocker Measurement of single top
Heavy Quarks





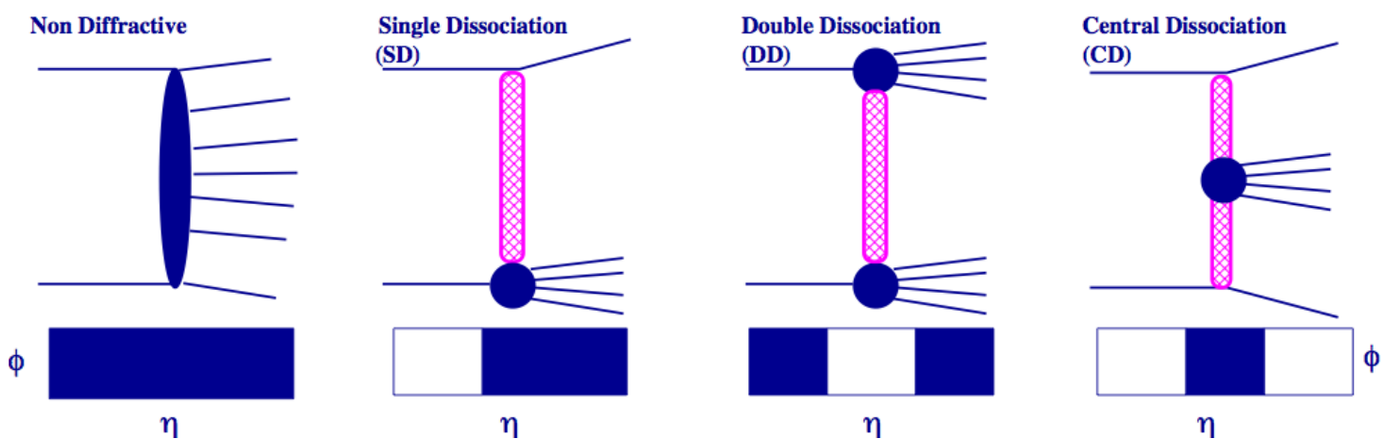
Questions …

Questions …

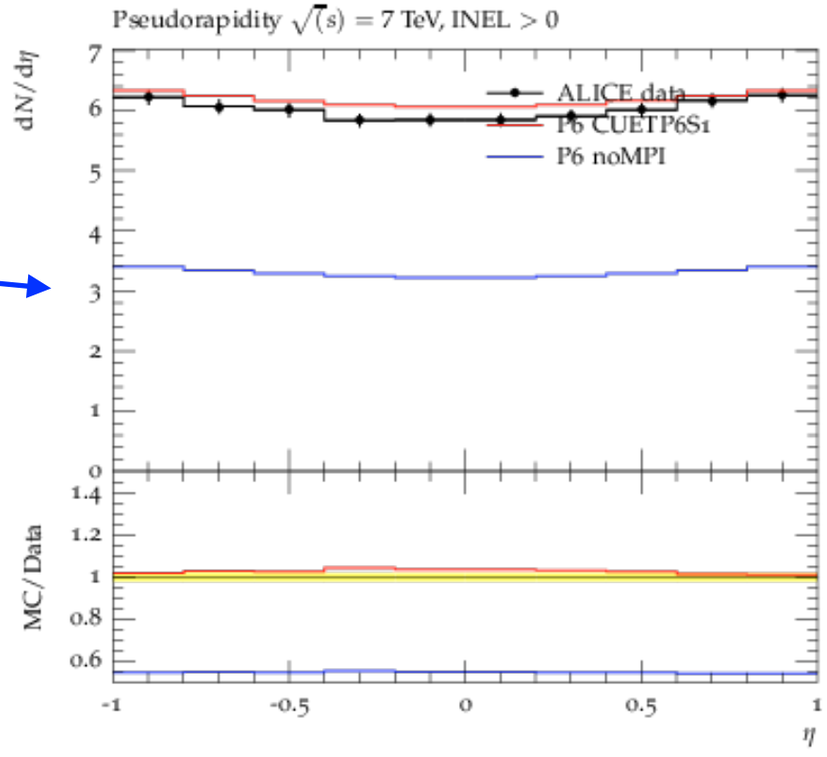
Multiparton Dynamics

What goes into description of $dn/d\eta$?

- basic process: $gg \to gg$ .....
- parton densities at small x and small scales
- non-diffractive, diffractive processes (single diffractive, double diffractive dissociation)



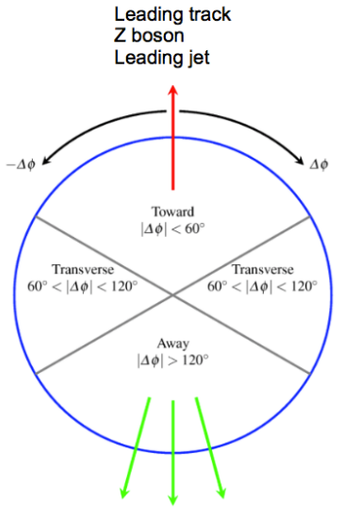
- multiparton interactions:
  - w/o MPI $dn/d\eta$ NOT described !

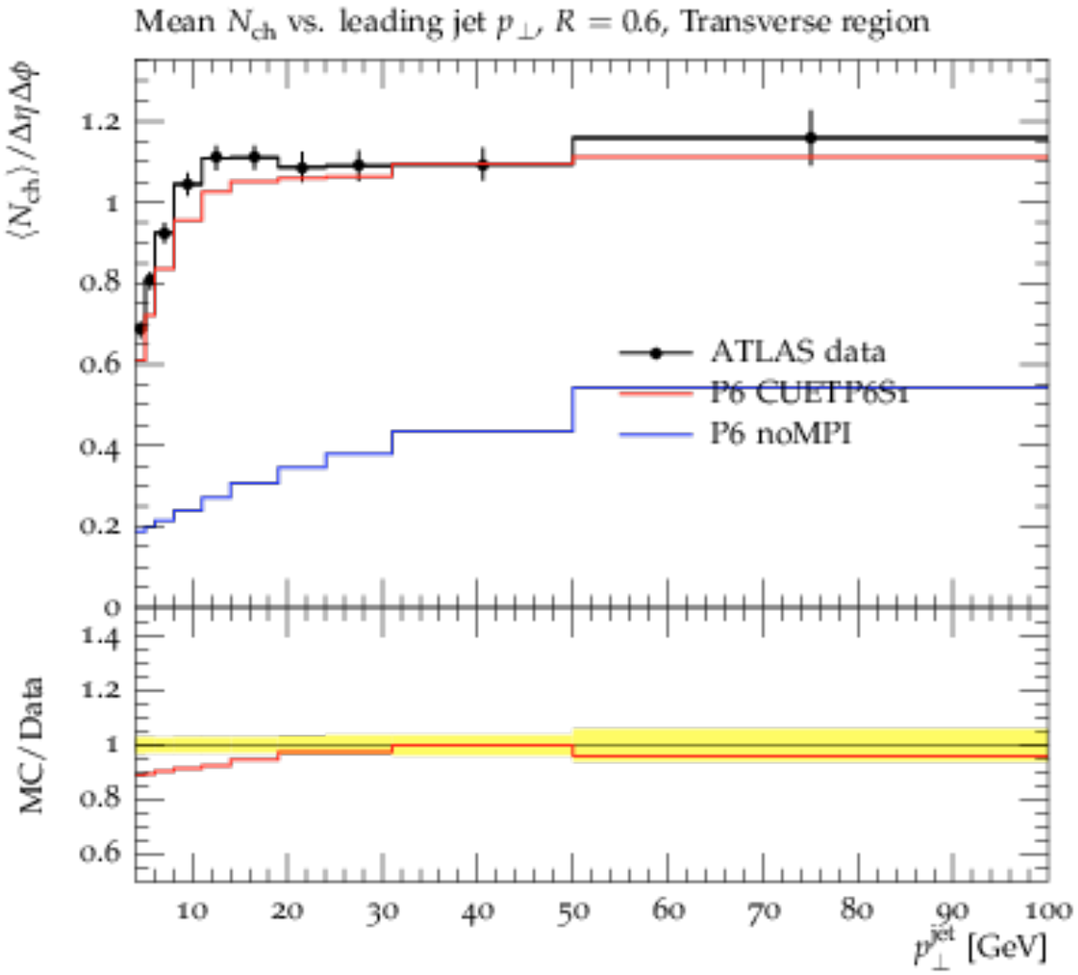


The underlying event

- Measure particle density and average pt in region transverse to trigger object (jet, Z…)

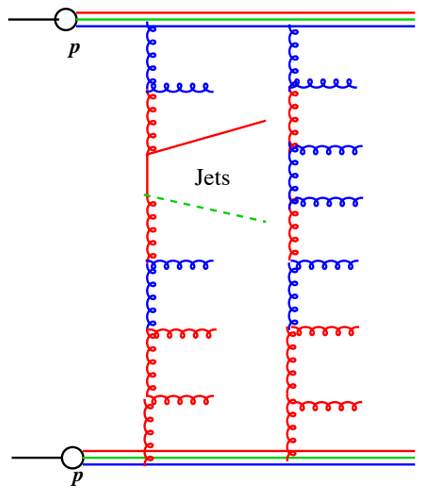
V. Cairo (ATLAS), Min Bias & UE
A. Bruni, Soft QCD, plenary
R. Field, Soft QCD, plenary





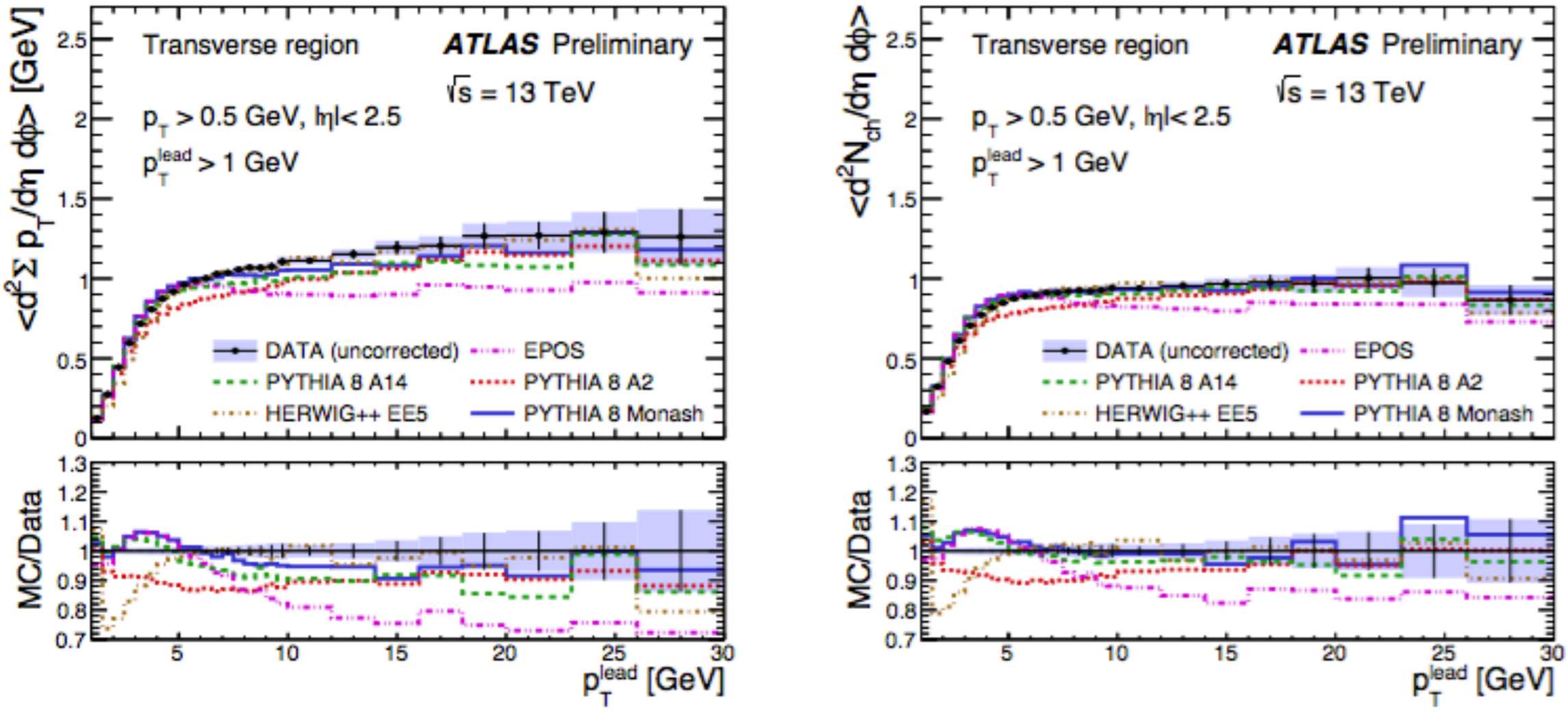
- more activity than predicted from parton shower (higher orders) and hadronization observed

➡ introduce MPI:



Underlying event measurements at 13 TeV

V. Cairo (ATLAS), Min Bias & UE



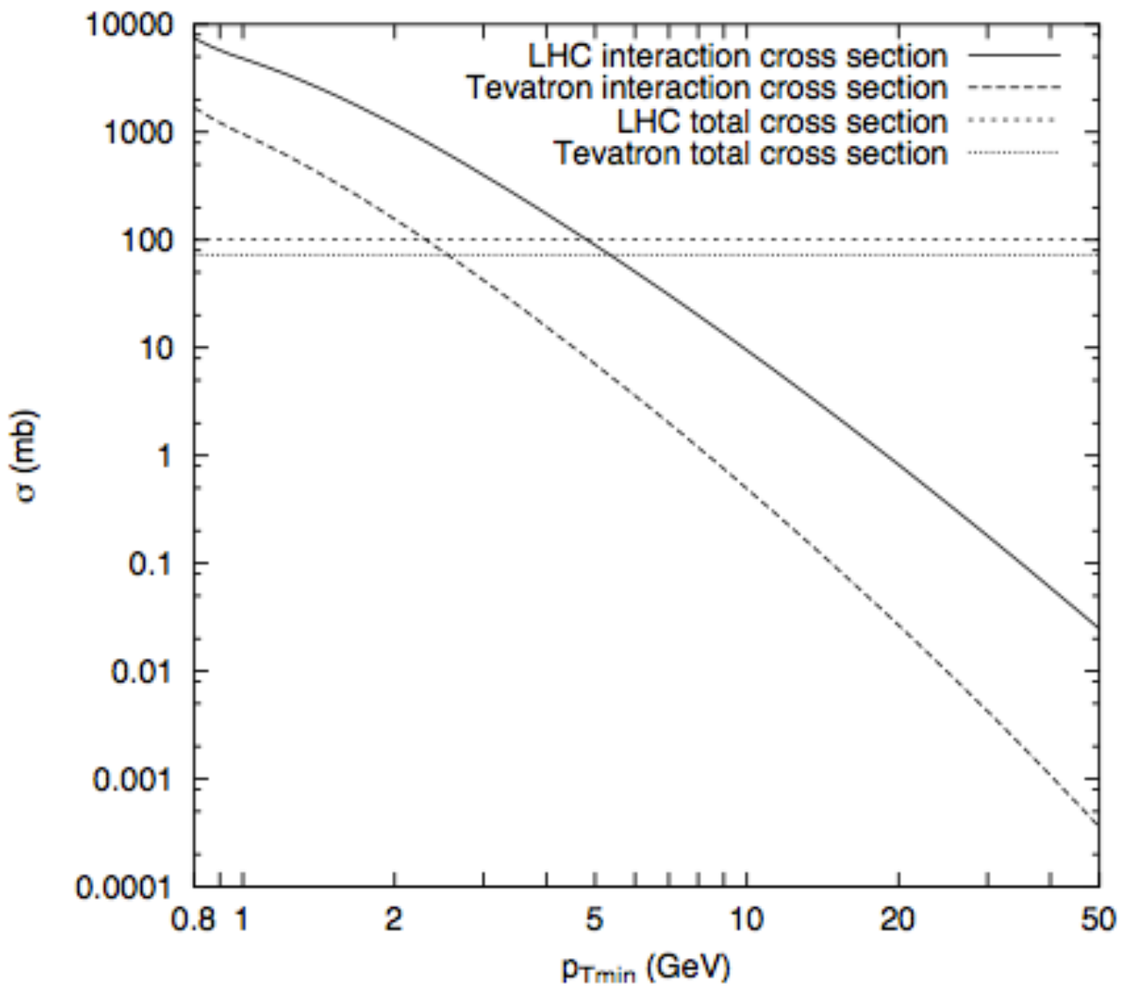
- None of the models describes the initial rise well
- From 10 GeV quite good description for the UE Tunes
- EPOS 15% off in the plateau

September 1-5, 2015 V. Cairo 17

Multi-parton interaction — why ?

- The basic problem for $p_t \to 0$

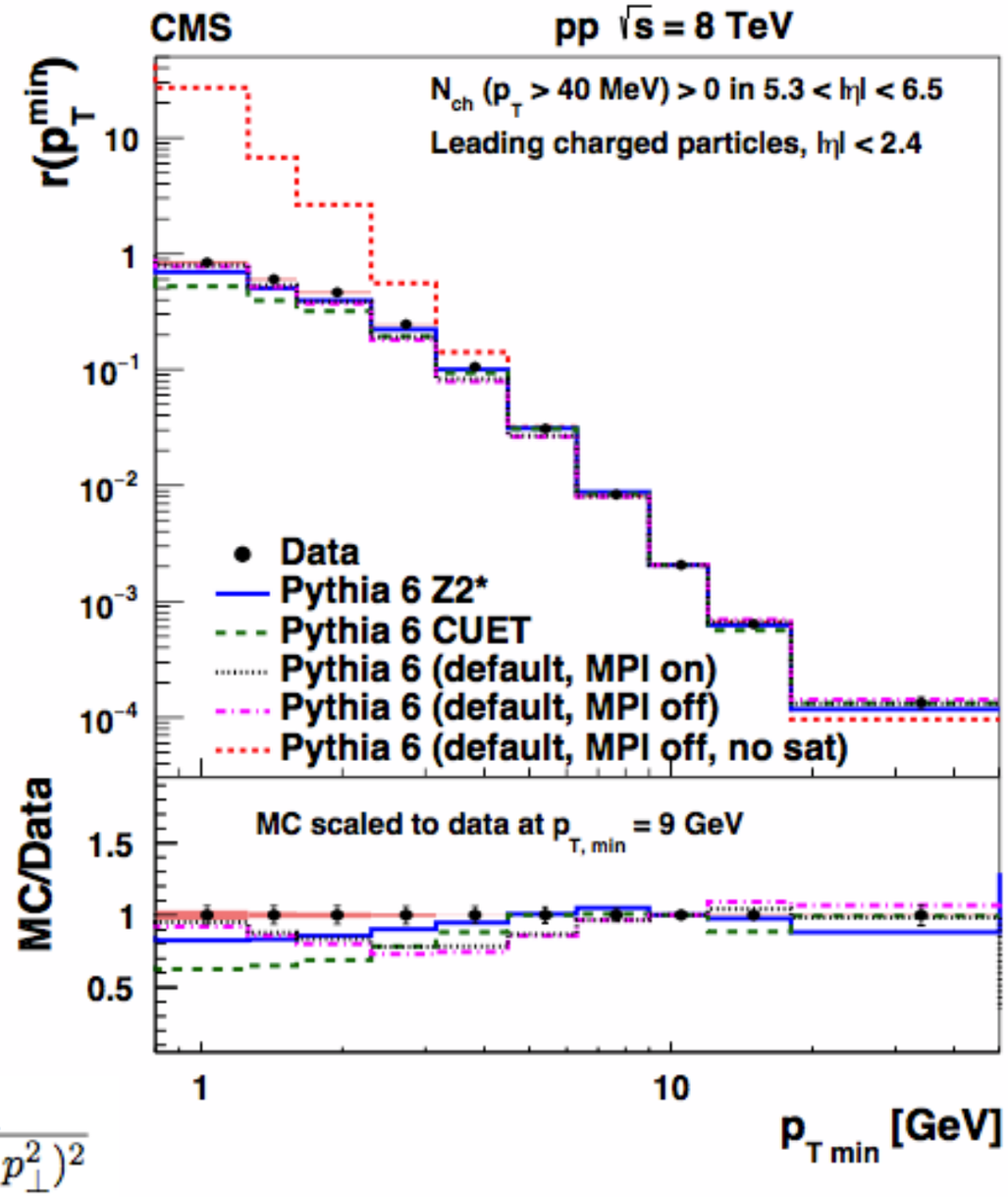
T. Sj¨ostrand and P. Skands. Multiple interactions and the structure of beam remnants. JHEP, 03:053, 2004.



- Taming of x-section with: $\frac{\alpha_s^2(p_{\perp 0}^2 + p_\perp^2)}{\alpha_s^2(p_\perp^2)} \frac{p_\perp^4}{(p_{\perp 0}^2 + p_\perp^2)^2}$
- determine $p_{t\,0}$ from tunes

- Can we measure this ?

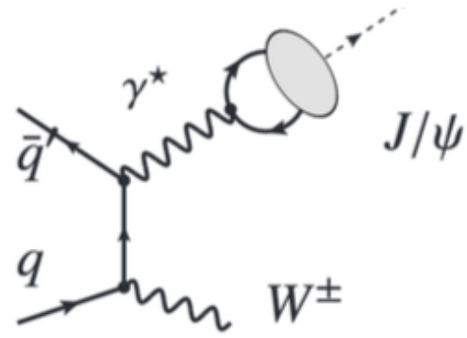
arXiv:1507.00233



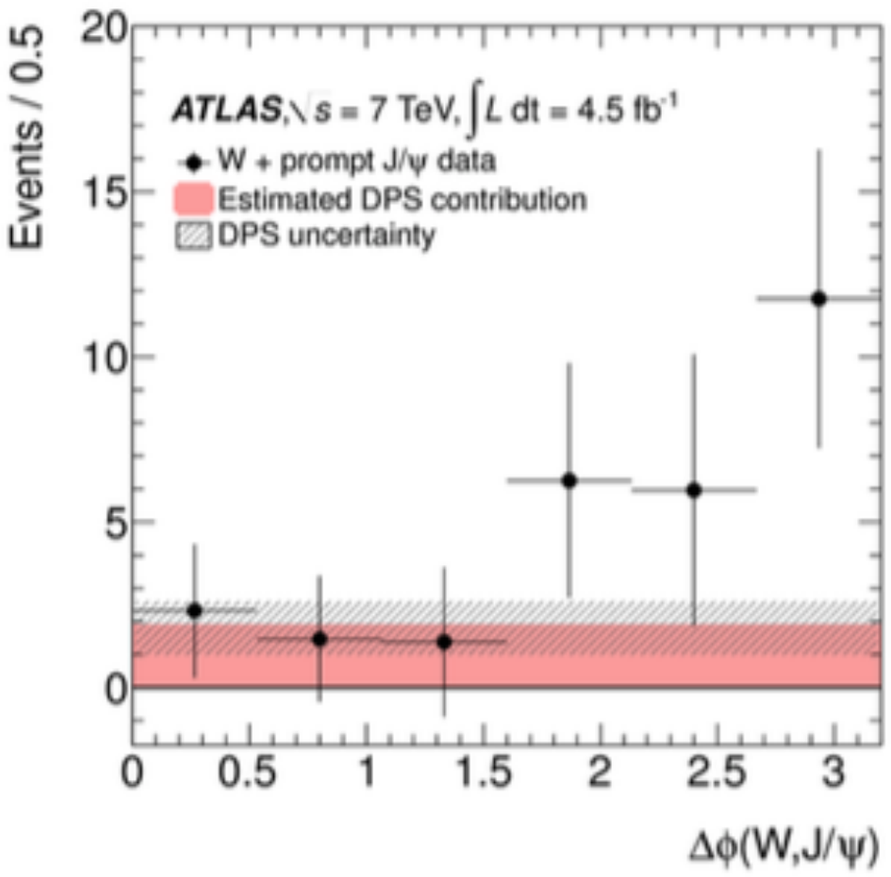
Multiparton interactions - double parton scattering

- Quarkonium+W as a clean probe for DPS

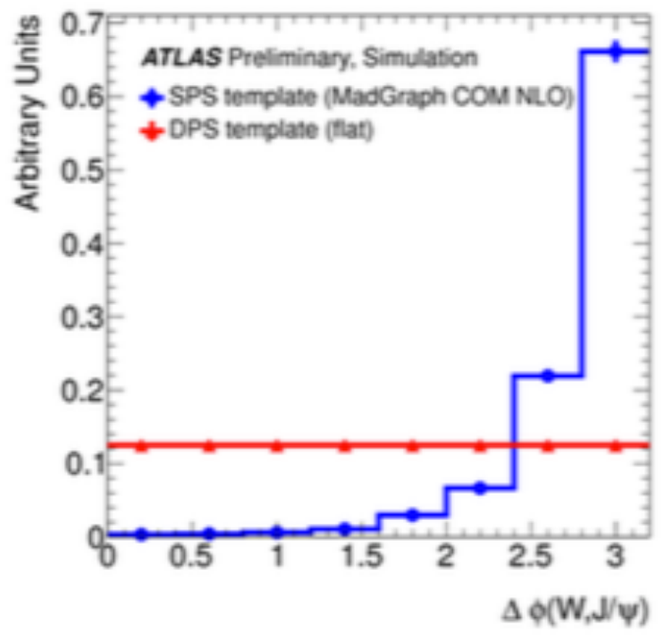
D. Bertsche (ATLAS), Associated quarkonium Multiparton Dynamics



J/ψ+W results: azimuthal opening angle



DPS processes are expected to give a flat azimuthal opening angle (Δφ) distribution



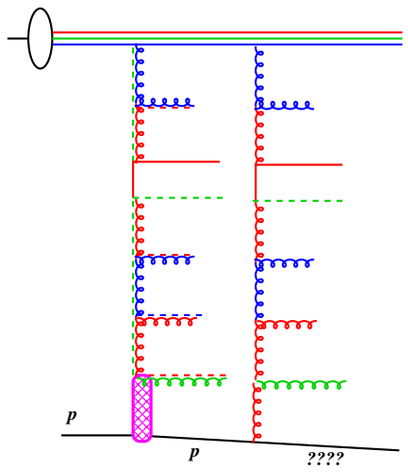
Possible indication of DPS and SPS J/ψ+W production.

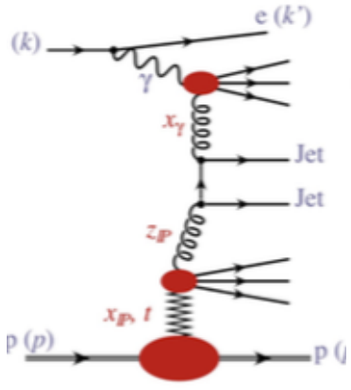
- Very clean process for DPS (in principle)
- What about theory predictions for
  - SinglePartonScattering, DoublePartonScattering ?

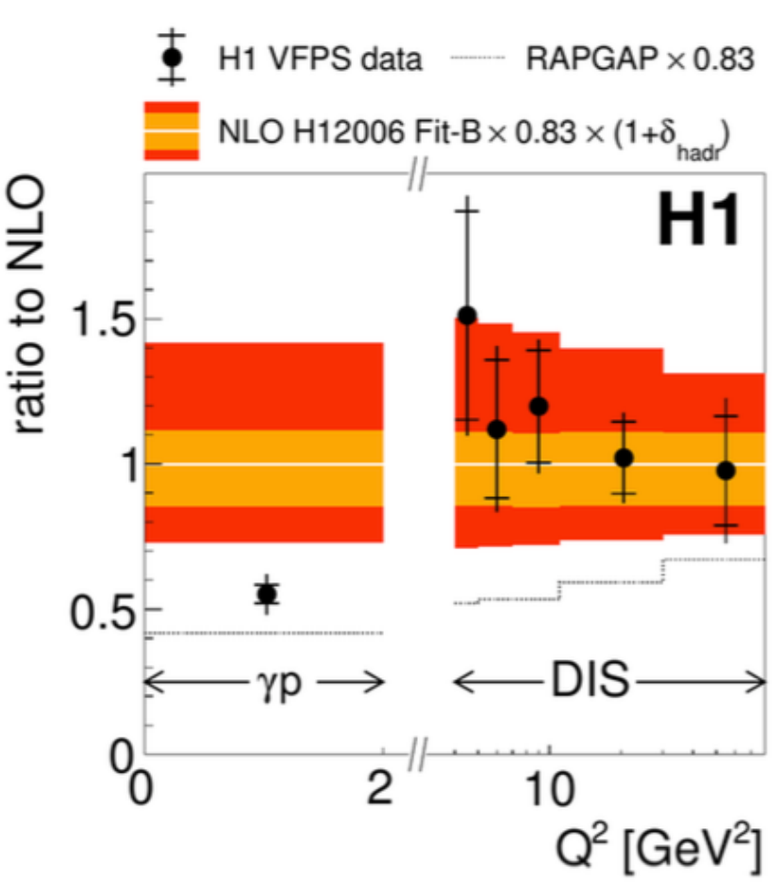
Multiparton interaction and diffraction

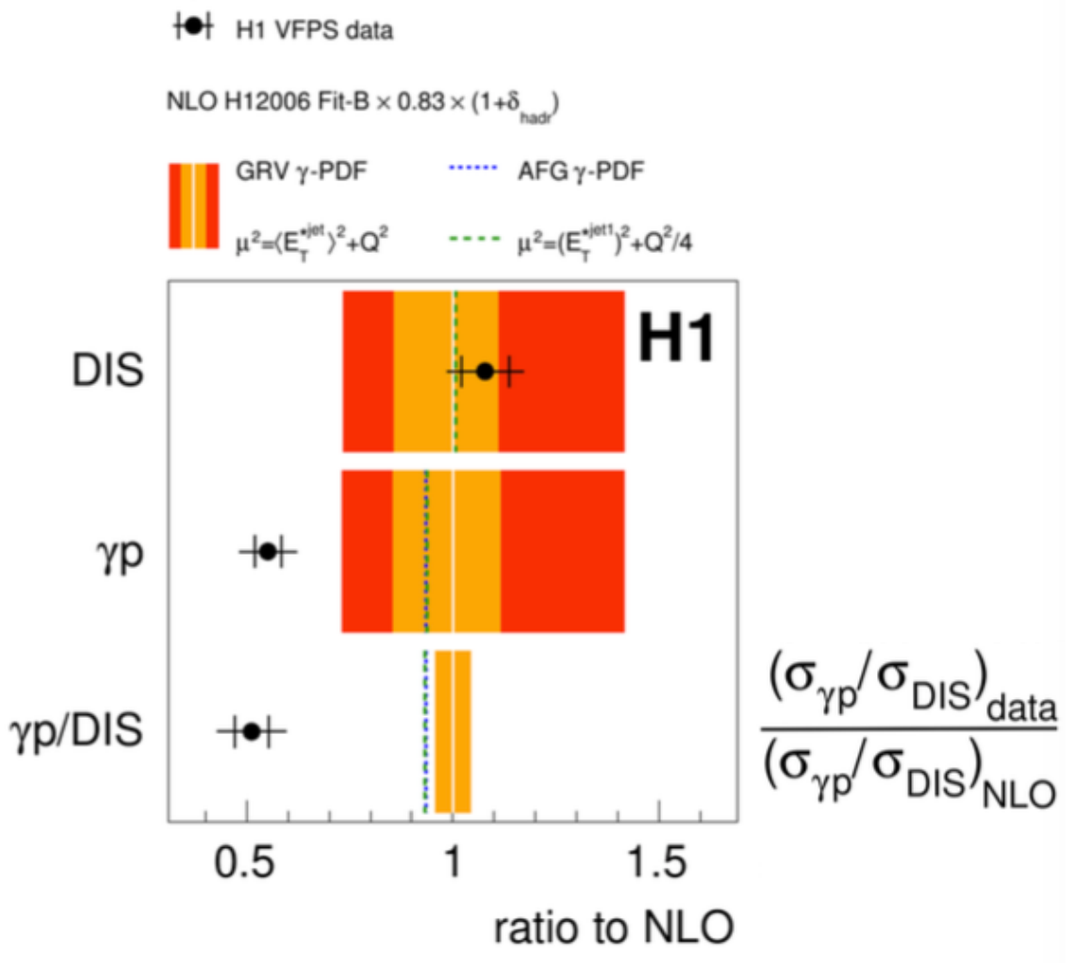
D. Britzger (H1), Hard diffraction at HERA
Multiparton Dynamics

- Hard diffraction and diffractive parton densities measured at HERA, assuming hard scattering factorization in DIS
- Multiparton interaction can destroy diffractive processes
  - gap - survival probability
- Not at all implemented in any MC simulation
- Factorization tests with dijets at HERA in γp and DIS









Questions in Soft QCD & Multiparton Dynamics

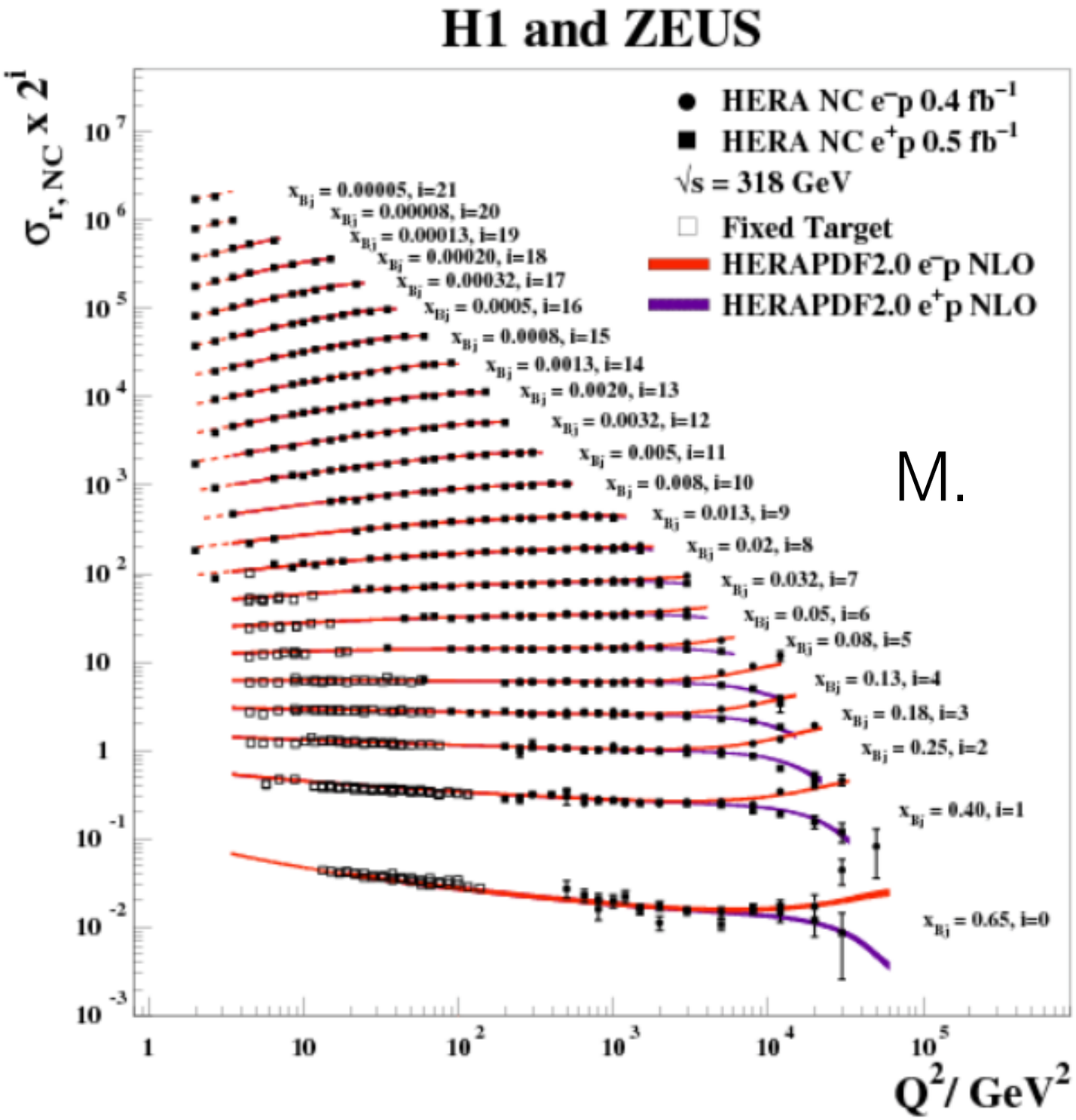
- Do we have really (really !!!) evidence for MPI and/or DPS ?
  - all what we measure is more activity than predicted within a certain framework:
    - collinear factorization and collinear PDFs
- How can diffraction be consistently included into calculations/simulations ?
  - if all comes from high parton densities, they must be directly related
    - could have significant effects on hadronization parameters, tuning etc.
- In UE tuning, a significant fraction of ColorReconnection is needed:
  - how can color-rearrangement be understood if we believe QCD should work down to small scales ?
    - similar issue arises in Quarkonium production.

Questions …

PDFs

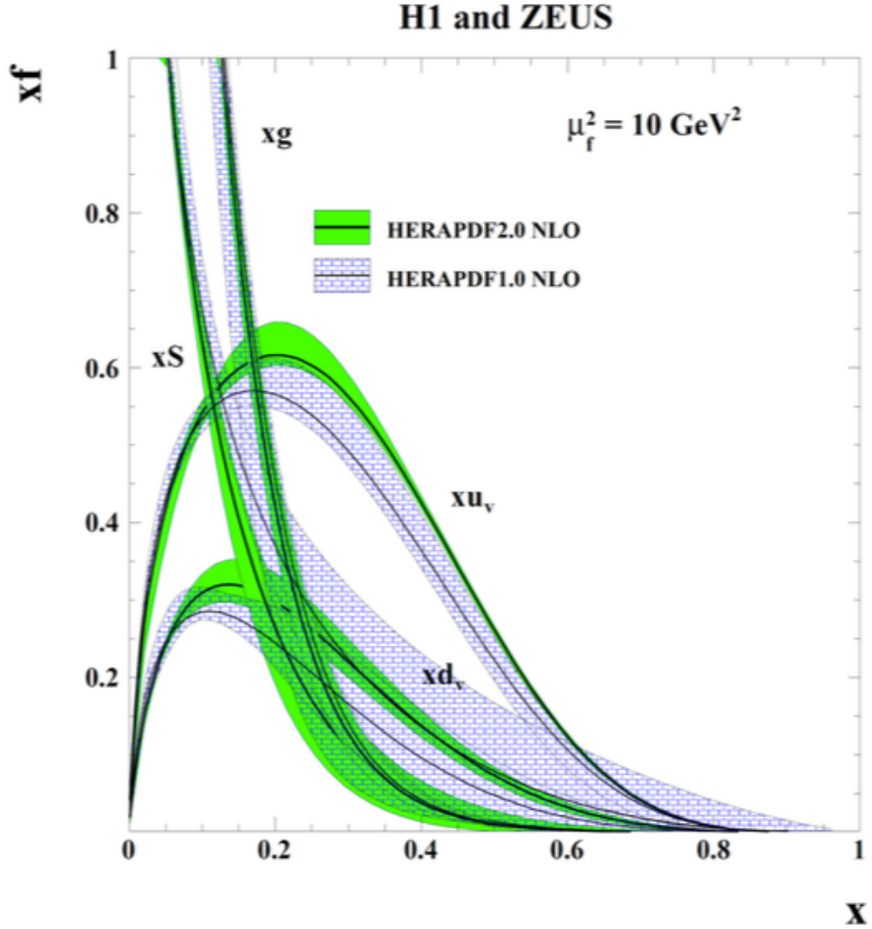
HERA 1 & 2 — combined data

M. Cooper Sakar, Proton structure, plenary



M.

- Combine HERA1 & 2 constrains PDFs at large x

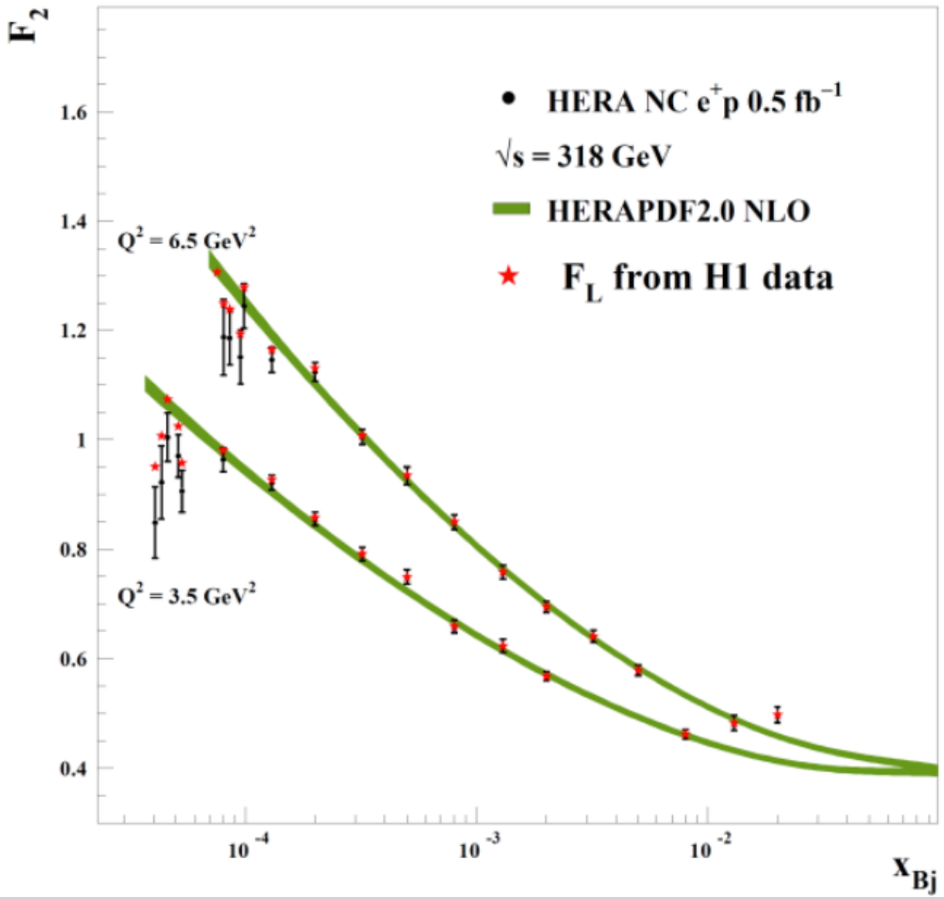


see also parallel talks by:

HARLAND-LANG, Lucian
STUMP, Daniel
MELNITCHOUK, Wally
ISARKAR, Amanda

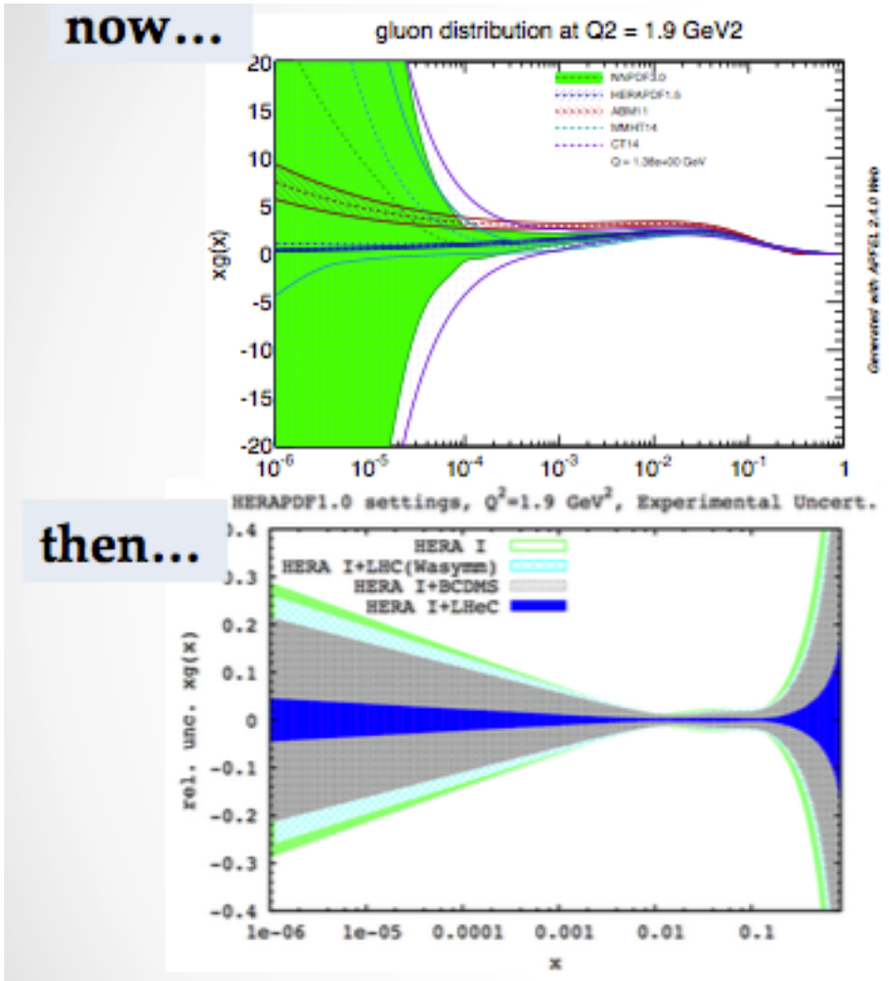
The small x side

- news from precision HERA data fits



M. Cooper Sakar, Proton structure, plenary
P. Newman, LHeC, plenary
C. Gwenlan, PDFs at LHeC, PDF
N. Armesto, smallx physics LHeC, Multiparton
N. Armesto, Nuclear PDFs LHeC, PDF

- how to address the small x side ?
  - LHeC, FCeC ?



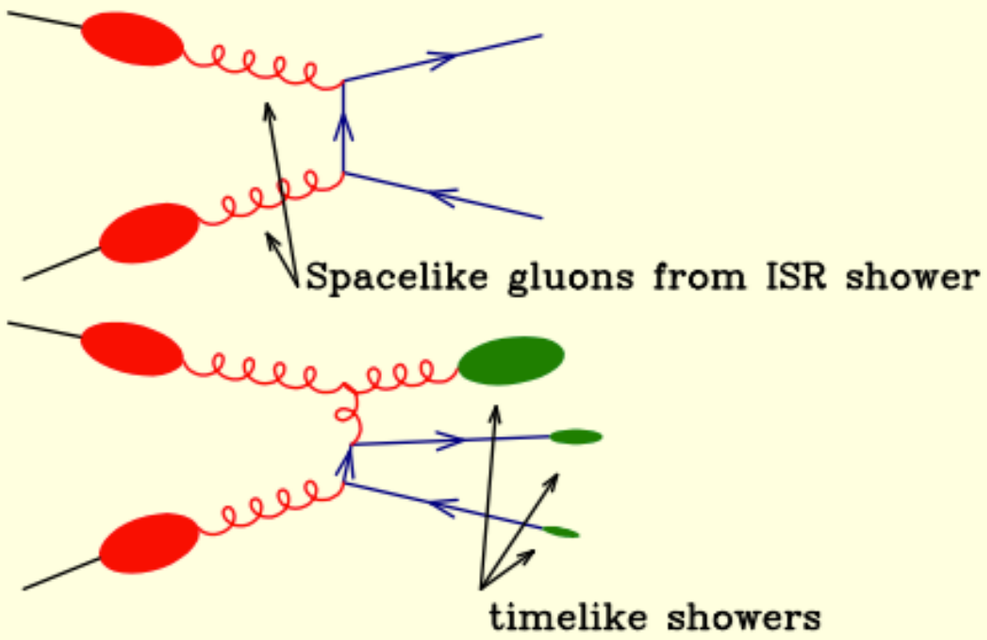
- This has relation to min bias, UE, pileup at LHC

Needs to go beyond collinear PDFs ?

- at small x, transverse momentum dependent (TMD) pdfs are needed, in CCFM etc.
- at larger x, TMD are used & useful to describe DY, Higgs q_T spectrum, for example in SCET and other approaches.
- MC generators with parton showers generate effectively TMDs, even when using in NLO matched calculations.

POWHEG Reshuffling From P.Nason: TOPLHCWG, 22 May 2014, https://indico.cern.ch/event/301787

The cause: MOMENTUM RESHUFFLING



ISR shower throws off shell the incoming gluon. In order to conserve 4-momentum, the final state is boosted. The mass $m_{t\bar{t}}$ is preserved

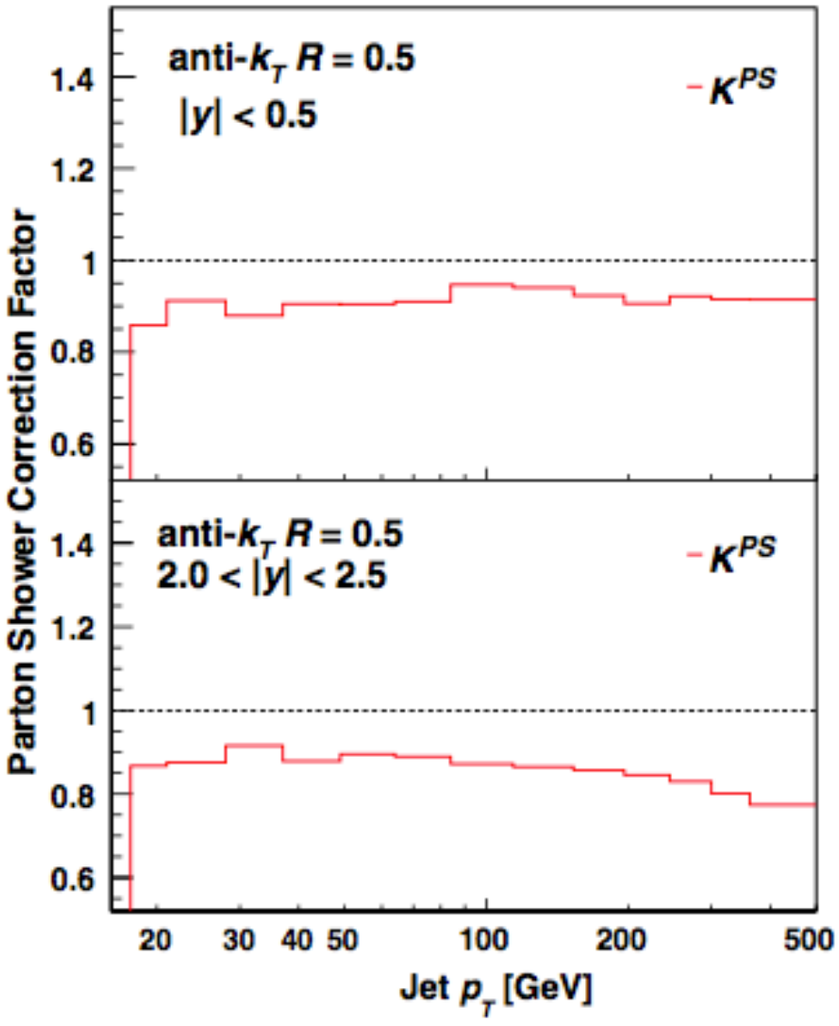
FSR shower changes the mass of final state partons. In order to conserve 4-momentum, the final state momenta are rescaled.

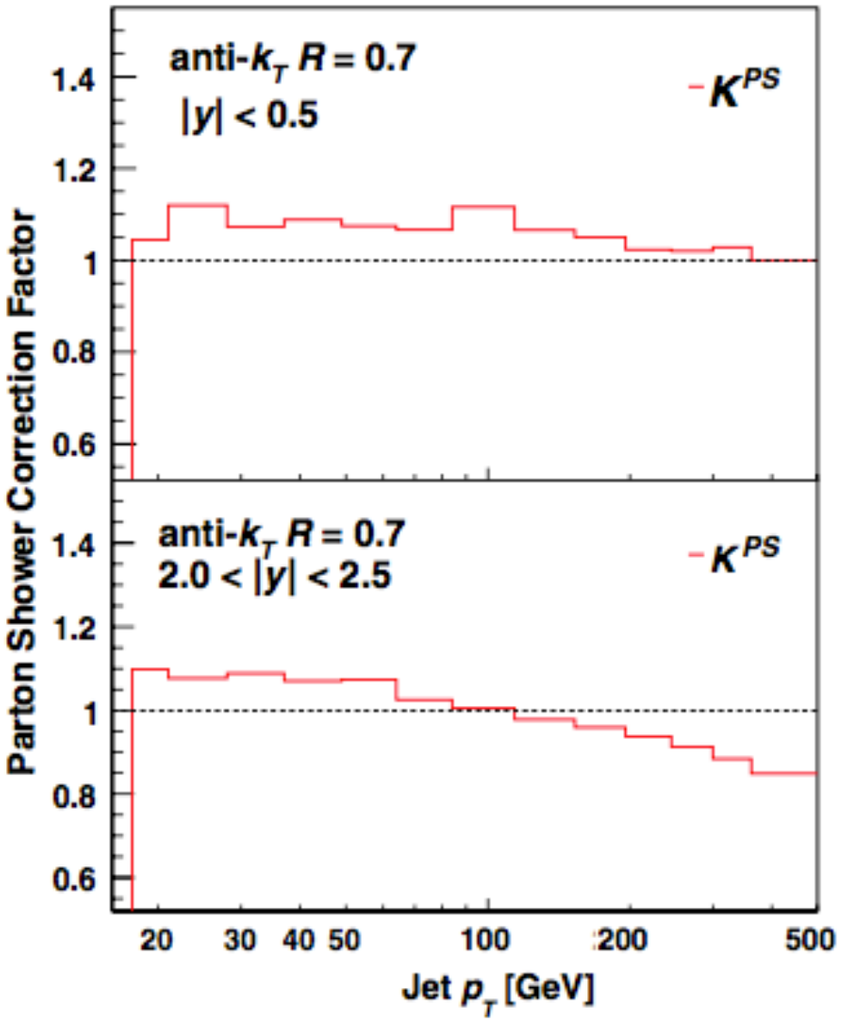
Questions …

hard QCD

Kinematic effects in NLO + PS

- Parton shower effects in Jet distributions





S. Dooling, et al
Phys.Rev., D87:094009, 2013.

$$K^{\mathrm{NP}} = N^{(\mathrm{ps+mpi+had})}_{\mathrm{NLO\text{-}MC}} / N^{(\mathrm{ps})}_{\mathrm{NLO\text{-}MC}},$$

$$K^{\mathrm{PS}} = N^{(\mathrm{ps})}_{\mathrm{NLO\text{-}MC}} / N^{(0)}_{\mathrm{NLO\text{-}MC}},$$

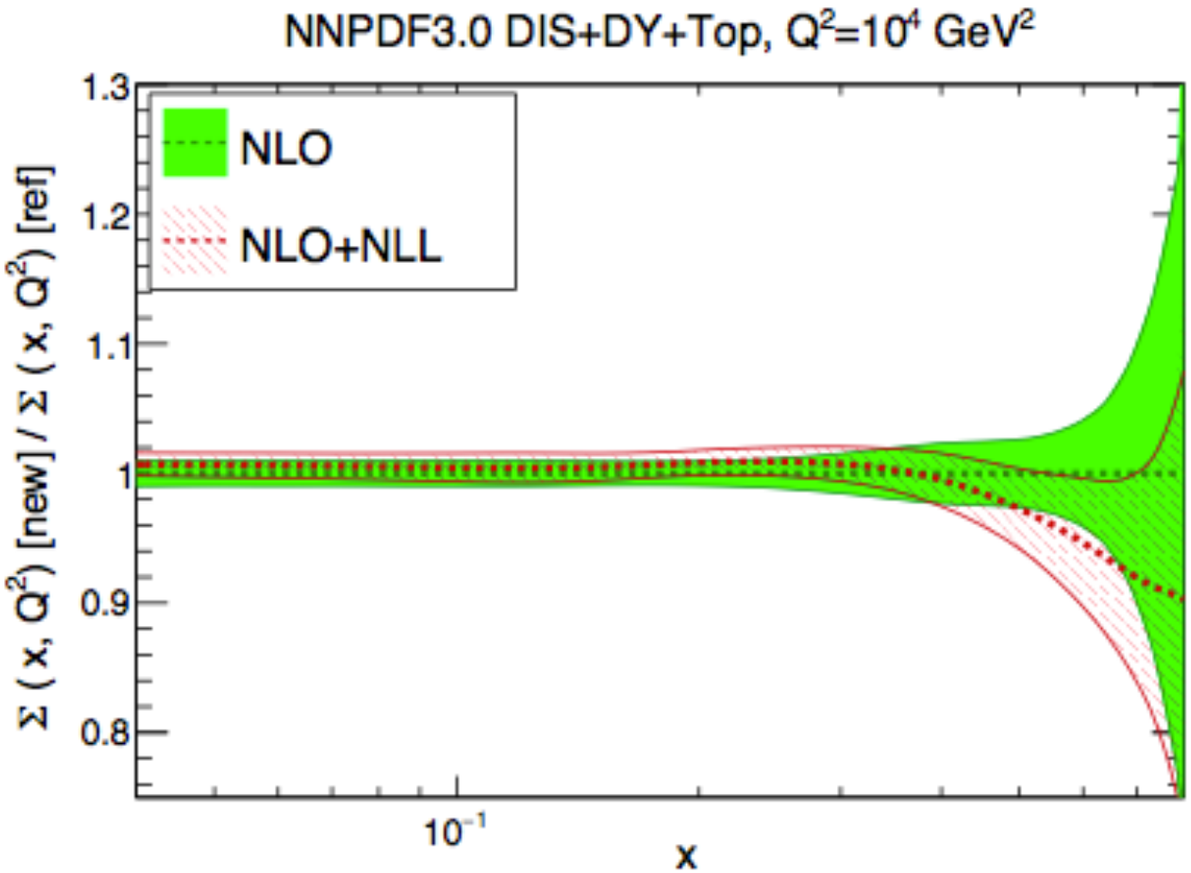
- Sizable effects from Parton Shower
- Not necessarily covered by PDF and scale uncertainties
- How to estimate uncertainties ?

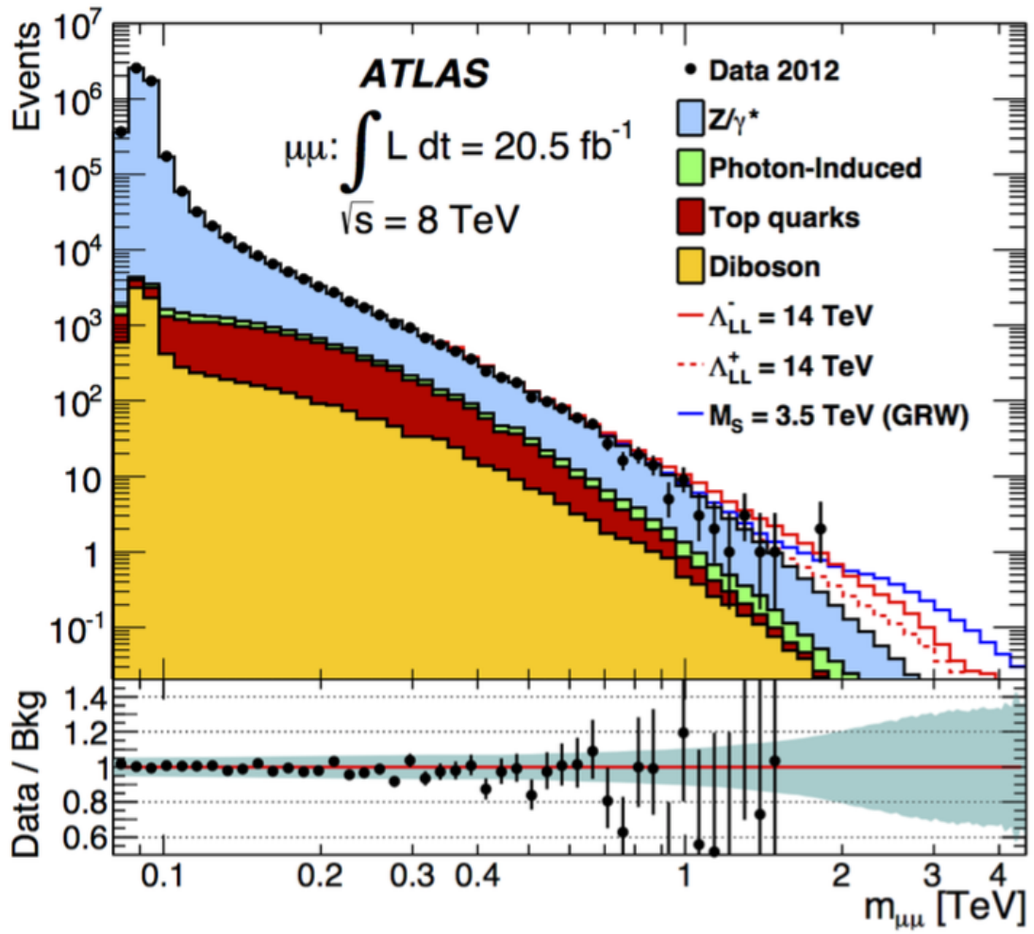
- Top quark pt-spectrum - reweighting
  - most effect comes from parton shower

Threshold resummation

- Activities in large x threshold resummation: $\frac{1}{1-x}$

E. Laenen, Developments, plenary
L. Rottoli, Parton Distributions,PDFs
H. Yoo, Searches CMS
A. Elliot Searches ATLAS
Multiparton Dynamics

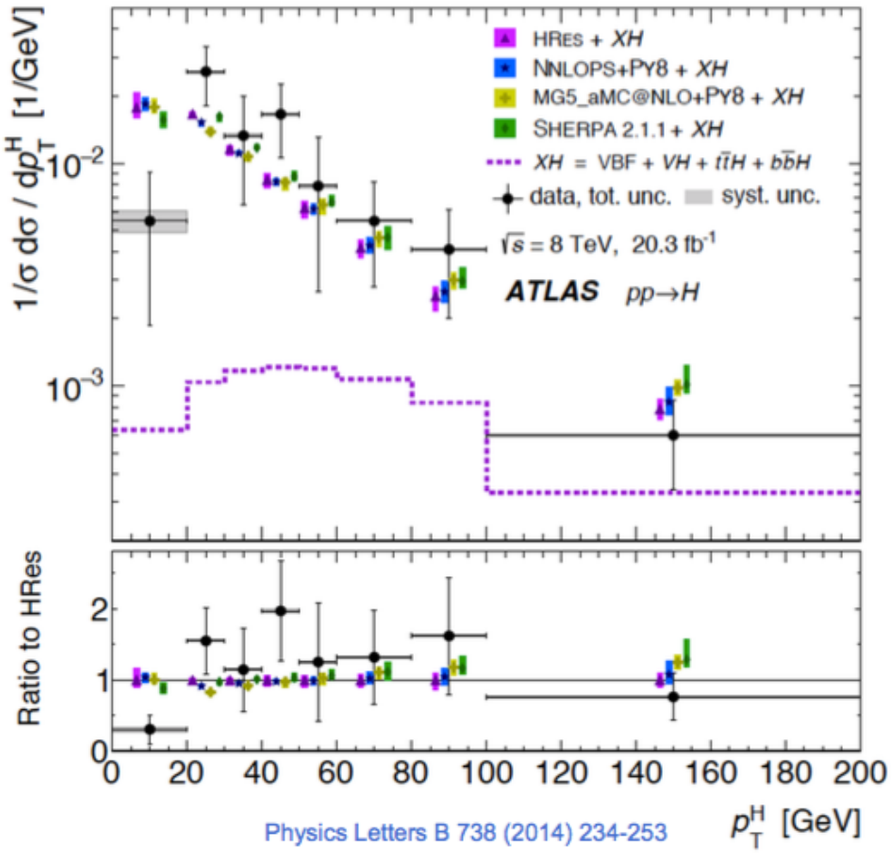


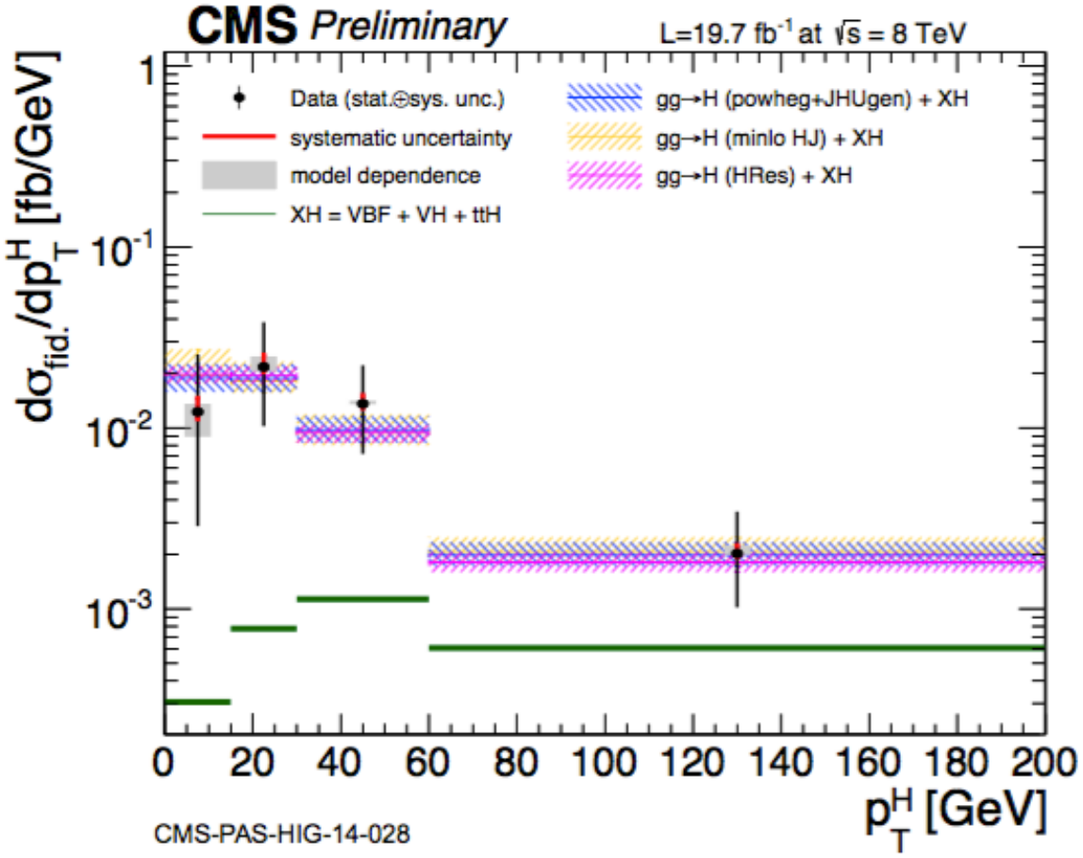


- To observe large x resummation, need a different scenario: define $x' = \frac{m_{\mu\mu}}{m_{vis}}$ with visible mass accessible in detector.
- towards measurements at kinematic limit !

Higgs differential x-section measurements

L. Tompkins, QCD in Higgs and BSM, plenary
A. Zghiche,Higgs from CMS, Hard QCD
B. Liu Higgs from ATLAS, Hard QCD



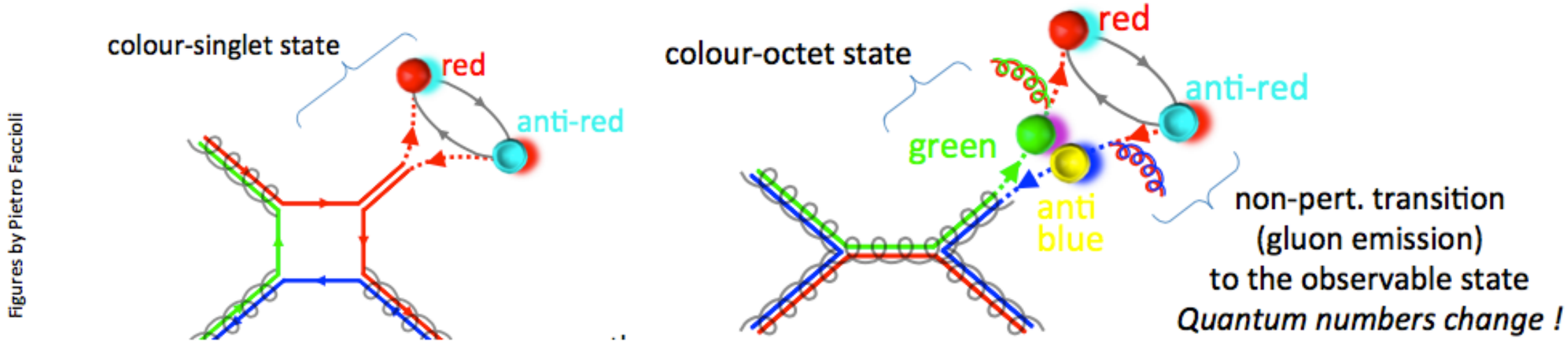


- Naively one would expect to see a maximum at ~ 20 GeV, a drop at small pt.
  - it is hidden in the acceptance cuts … MC describes it, but ?
- Discussion issue: should experimental results be fully corrected, or can they even be at Detector level since we anyway compare to MC-Rivet etc ?
  - provide full resolution matrix, without loss of Infos ? Need discussion in community

Questions …

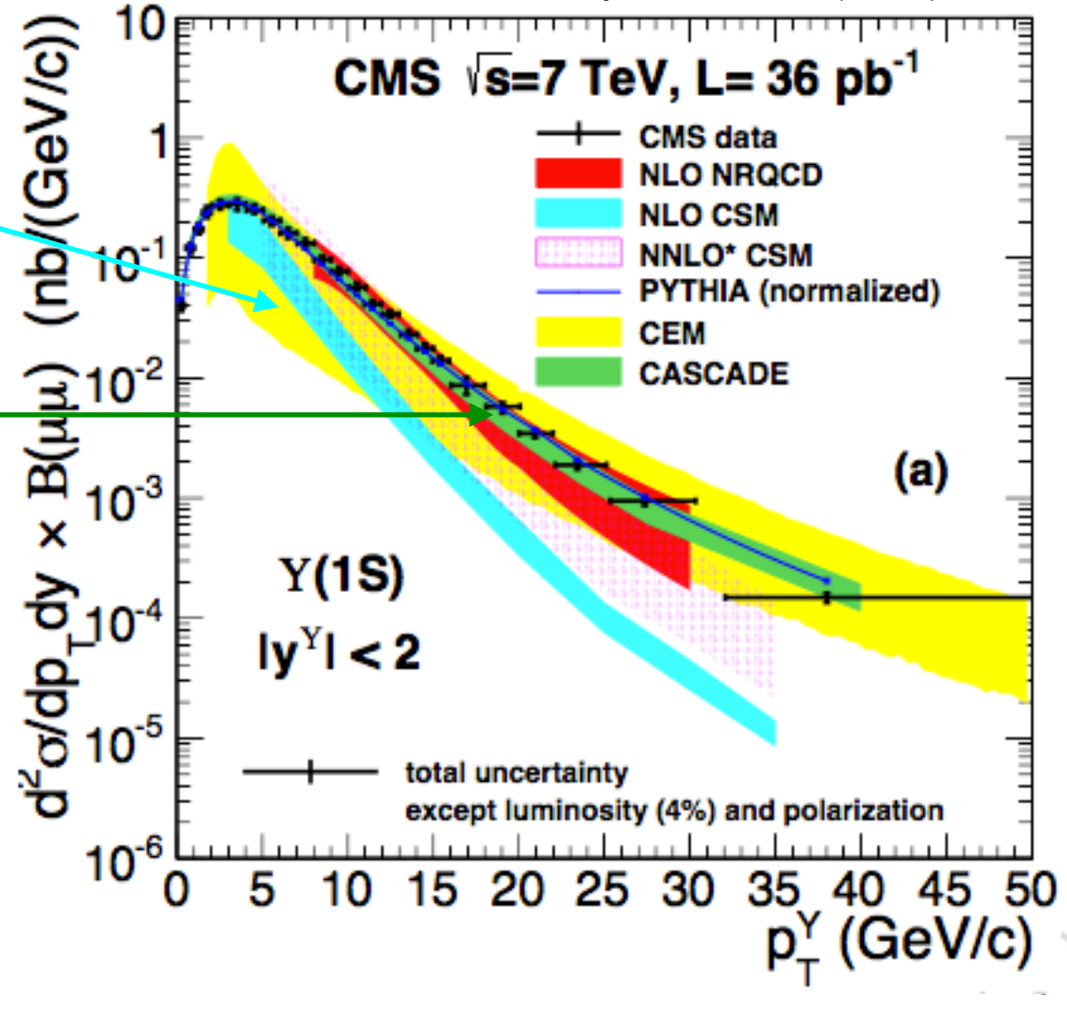
Quarkonium Production

Are color-octed states in Quarkonium needed ?



CMS Phys.Lett. B727 (2013) 101

- color-octed states introduced to describe p_t spectrum in collinear factorization.
- in kt - factorization the contribution from color-octed is much smaller (if needed at all)
- How are color-octed states in Quarkonium production connected to color-reconnection “needed” in UE tunes ?
  - it’s both soft gluons, but …. ?



What can we conclude ?

- Huge progress is made on both experimental and theory/pheno side to understand, what is measured at LHC.
- LHC run 2 has just started, and we already have seen impressive new results, just after a few month of data taking.
- Many very interesting and challenging results will come out in the near future, which will occupy all our resources, from the experimental and theoretical side.

- In a bigger picture, apart from precision measurements and precision calculations, for me, two fundamental questions remain:
  - high energy behavior of QCD
  - color structure of QCD — color confinement

Instead of a summary

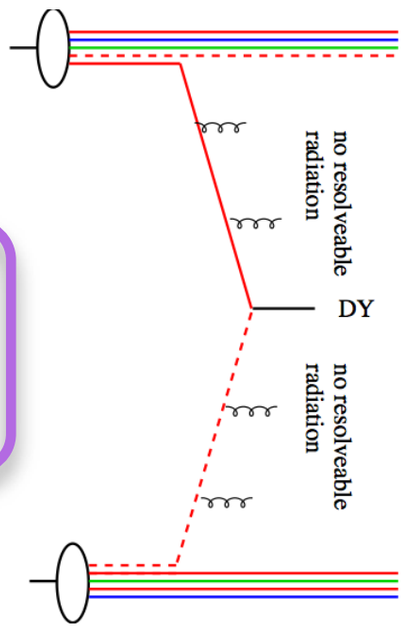
$\log p_T^2$

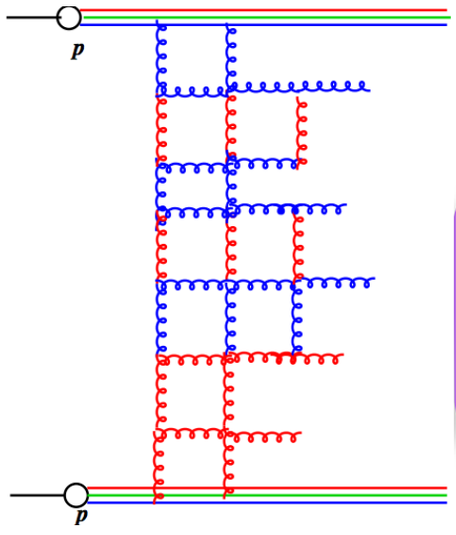
inhibited radiation
nearly empty events

large x resummation

theory
- NLO, NNLO + collinear parton shower
- precision calculations

experiment
- Jets, V-boson, top, Higgs…
- precision measurements





enhanced radiation,
Mulitjets, multiparticles

small x resummation
small pt resummation

$\log 1/x$

A very colorful time

is ahead of us !