Summary of WG5 – Heavy Flavors

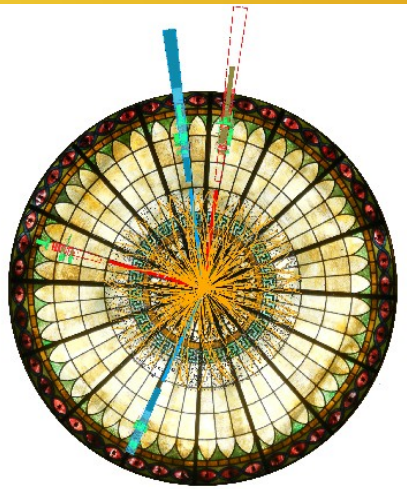
Conveners:

- ***Marco Guzzi***
- ***Achim Geiser***
- ***Flera Rizatdinova***

DIS 2015

XXIII International Workshop on Deep-Inelastic Scattering and Related Subjects

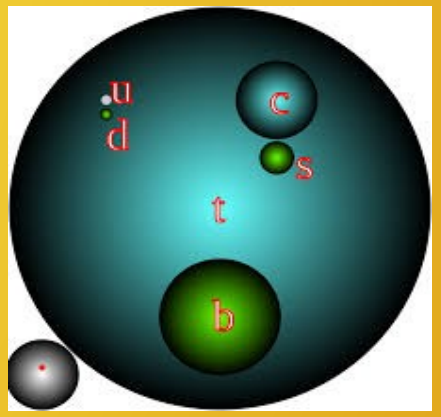
Dallas, Texas
April 27 – May 1, 2015



SMU®

Heavy-flavor physics: leading role in many areas of collider phenomenology

- **Perturbative and non-perturbative aspects of QCD**
- **Extremely important for the structure of the proton in various kinematic regimes.**
- **Investigate and constrain fundamental parameters of SM: quark masses, couplings,..**
- **BSM Physics: search for new signals and test new models in rare decays, B-physics, CP-violations.**
- **Probe state of QCD matter at high density: collisions nucleous-nuclous and proton-nucleous**



Heavy Flavor Physics WG5 PROGRAM:

8 sessions, 4 of which where combined with WG1, WG3, WG4.
Totally 31 Talks:

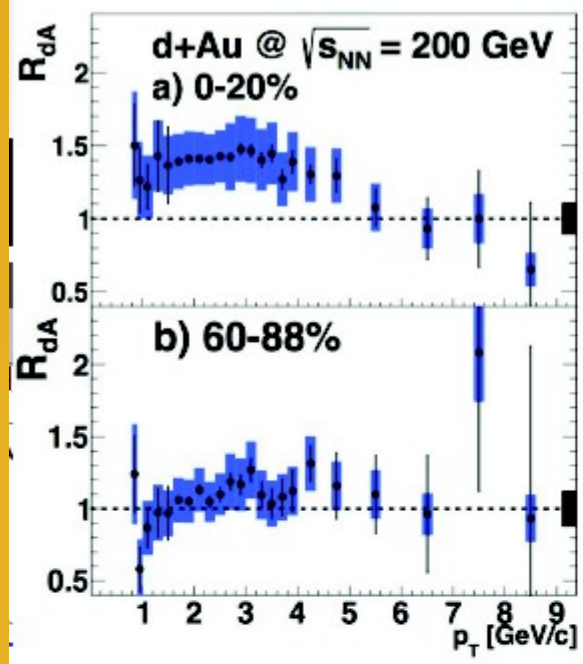
- Top-quark pair and single-top production, inclusive and differential measurements at LHC and Tevatron
- Top-quark mass measurements
- Updates from the theory side: QCD calculations at Higher orders
- New results for heavy-flavors in QCD global analyses of PDFs
- New results from ALICE, STAR and PHENIX experiments
- B-physics and rare bottom- and charm-quark decays at LHC
- D* Differential measurements at HERA
- New results from BaBar
- New results for Top-quark FB asymmetries at Tevatron
- New results for heavy-flavor jets at the LHC

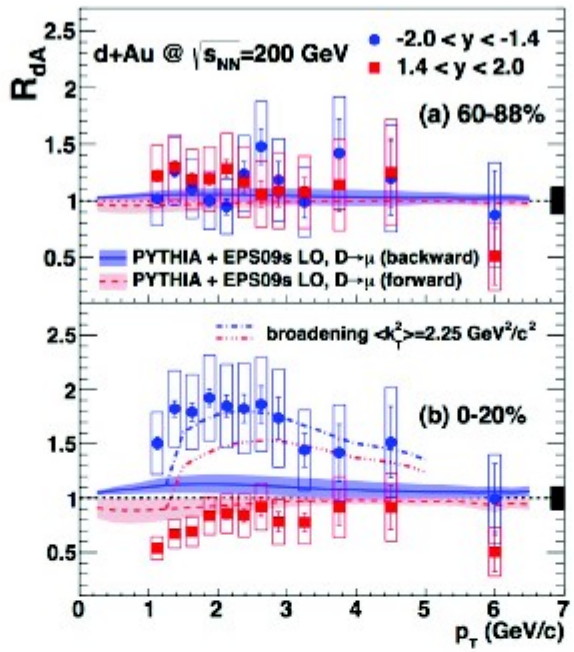
We apologize in advance if some of your results are not be covered here! Too little time!

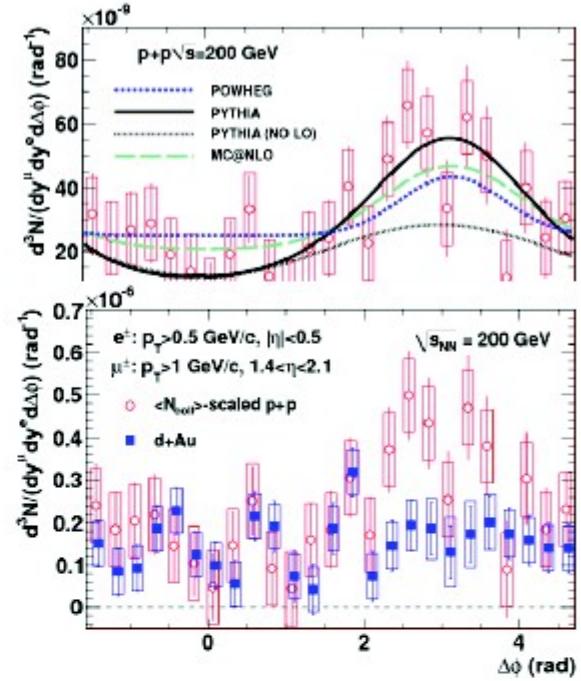
News results from ALICE, STAR and PHENIX experiments

S. Lim

Heavy-flavor in d+Au collisions at PHENIX





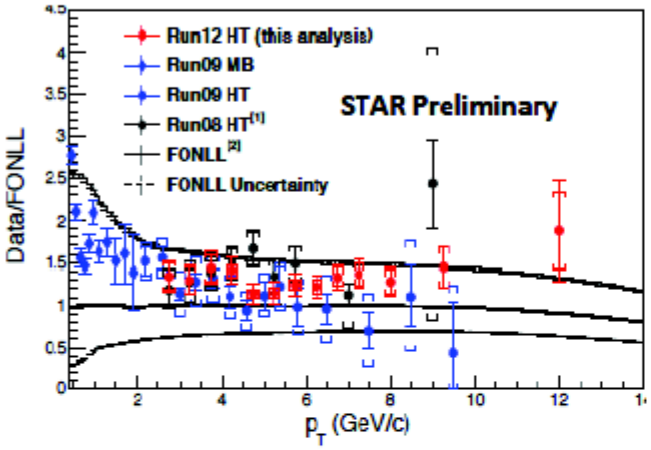


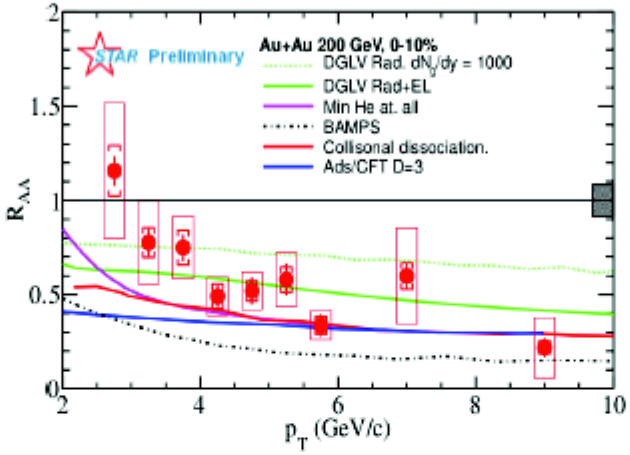
- PHENIX has measured leptons from open heavy-flavor in d+Au collisions at wide rapidity range
  - consistent with the scaled p+p results in peripheral collisions
  - suppression at forward rapidity, whereas enhancement at mid and backward rapidity in central collisions
  - suppression of HF pair production at forward rapidity
- Enhancement in d+Au collisions
  - qualitatively agreements with the model calculations considering final-state interaction or radial flow of heavy quarks

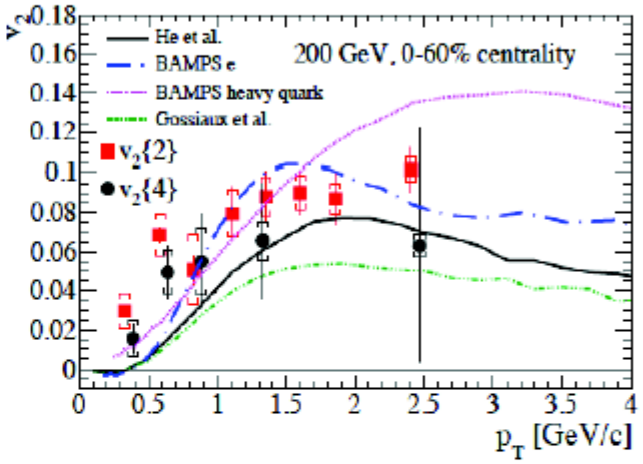
Z. Ye

Open Heavy Flavor in Semi-Leptonic Channel at STAR

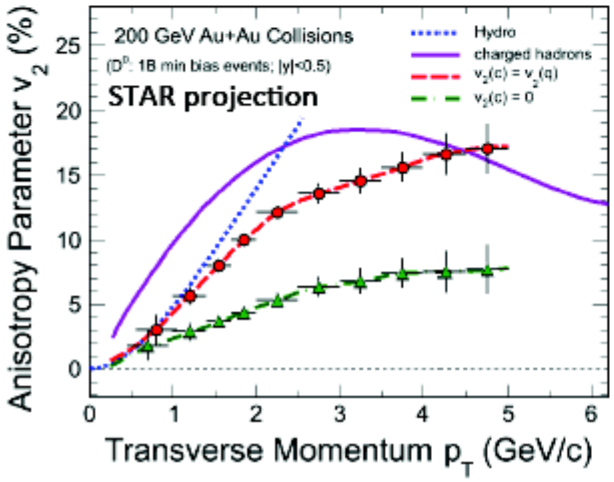
Results in p+p collisions have better uncertainties than pQCD calculations. Results in Au+Au collisions also place strong constraints on model calculations for HF-QGP interactions.

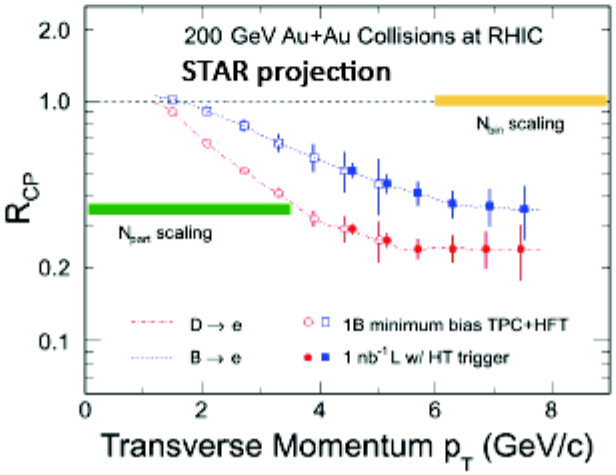


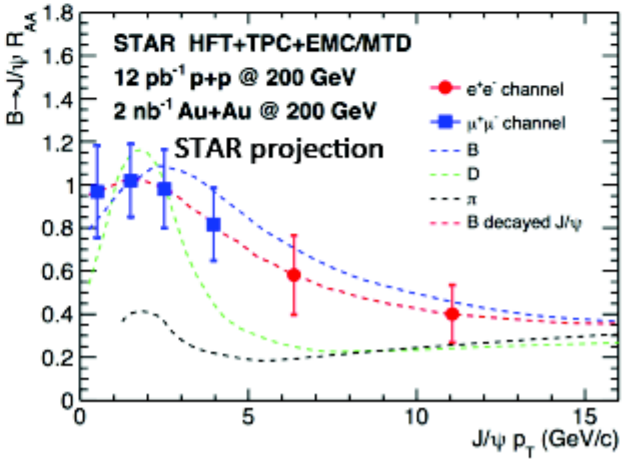




Silicon vertex and Muon detectors installed in 2014 will provide precise results on heavy flavor production in p+p, p+A, and A+A collisions. New era of HF physics at STAR just start!

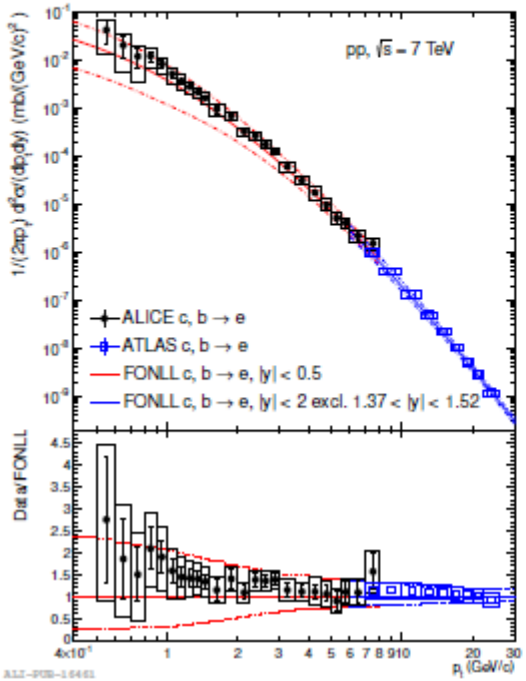






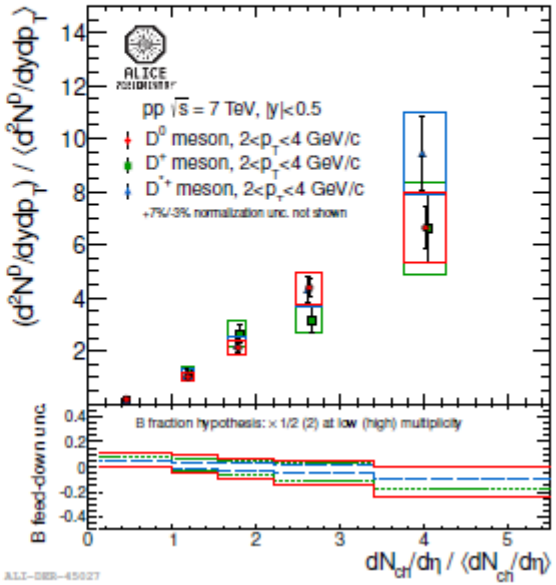
DIS2015, Zhenyu Ye

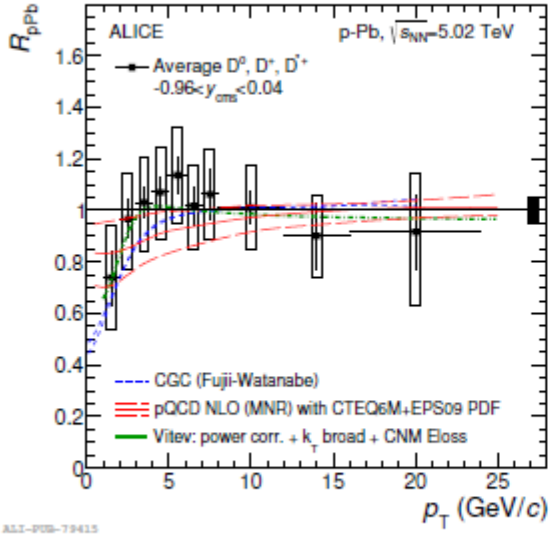
Summary of open Heavy-flavour measurements in pp and p-Pb collisions with ALICE



pp collisions:

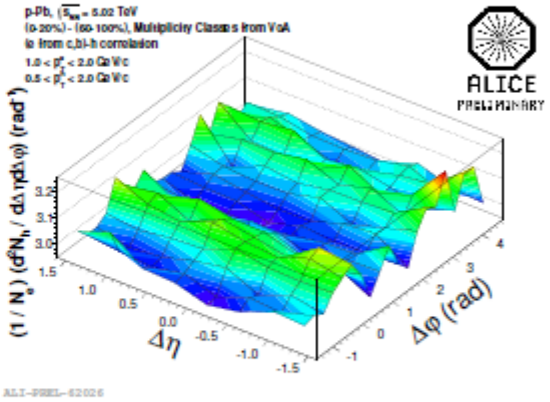
- p_T differential cross-sections are measured for different heavy flavour (HF) mesons at √s = 2.76 and 7 TeV.
- Measurements are consistent with different pQCD calculations.
- Increase of D-meson yields with increasing charged particle multiplicity of the event → suggesting multi-parton interactions at LHC energies.





p-Pb collisions:

- Nuclear modification factor for different HF mesons are well described by models which include cold nuclear matter effects.
- No large suppression observed for HF yields at high p_T.
- Double-ridge structure observed in HF-decay electron angular correlations with charged hadrons at low electron p_T and in high multiplicity events.



Deepa Thomas

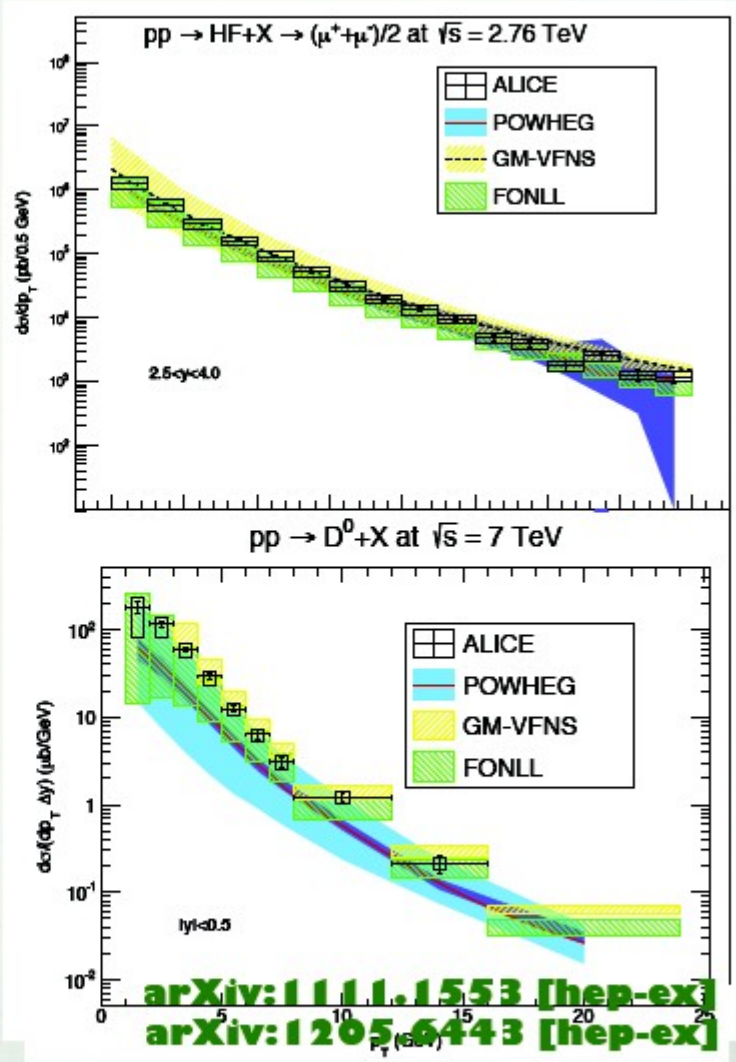
K. Kovarik

- **FONLL & GM-VFNS**
  - NLO and NLL order the same in both
  - difference in treatment of fragmentation functions

	LL	NLL	NNLL	...
LO	l m≠0			
NLO	aL m≠0	a m≠0		
NNLO	$(aL)^2$ m=0	a(aL) m=0	a^2	
...	... m=0	... m=0	...	...

- **POWHEG**
  - NLO and LL accuracy through shower resummation

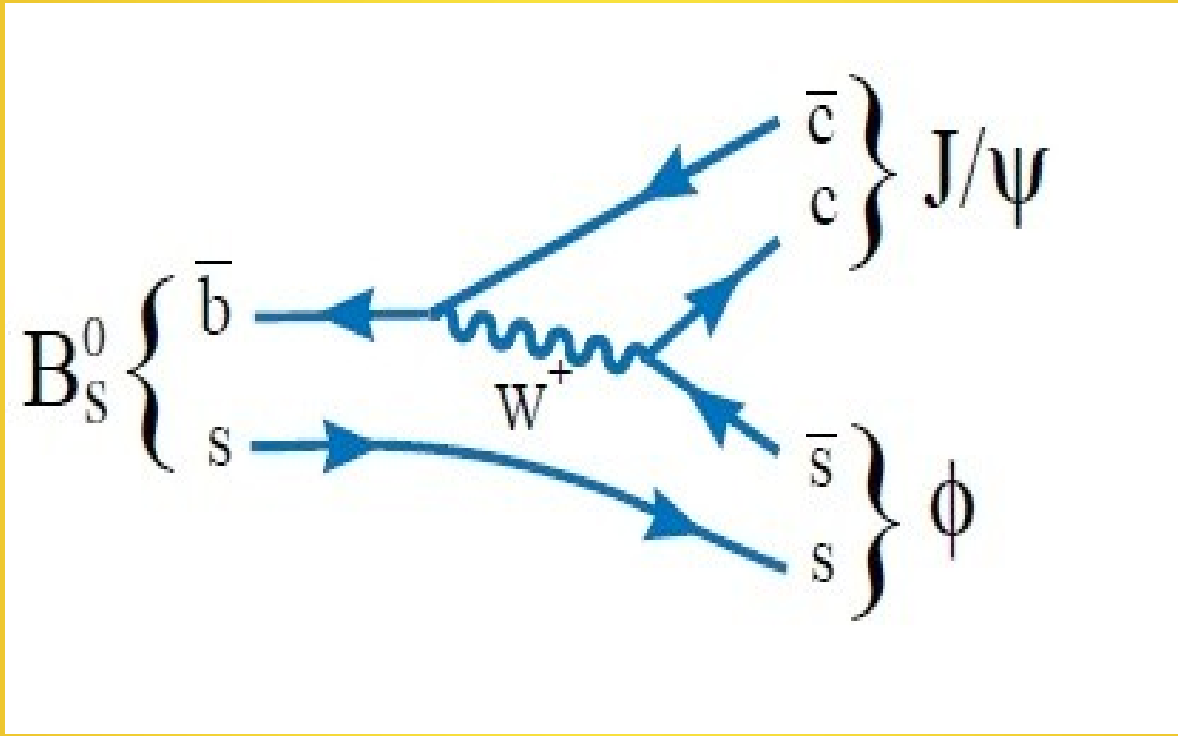
- PDF uncertainty relevant for large rapidity
  e.g. leptonic decays of B,D-mesons



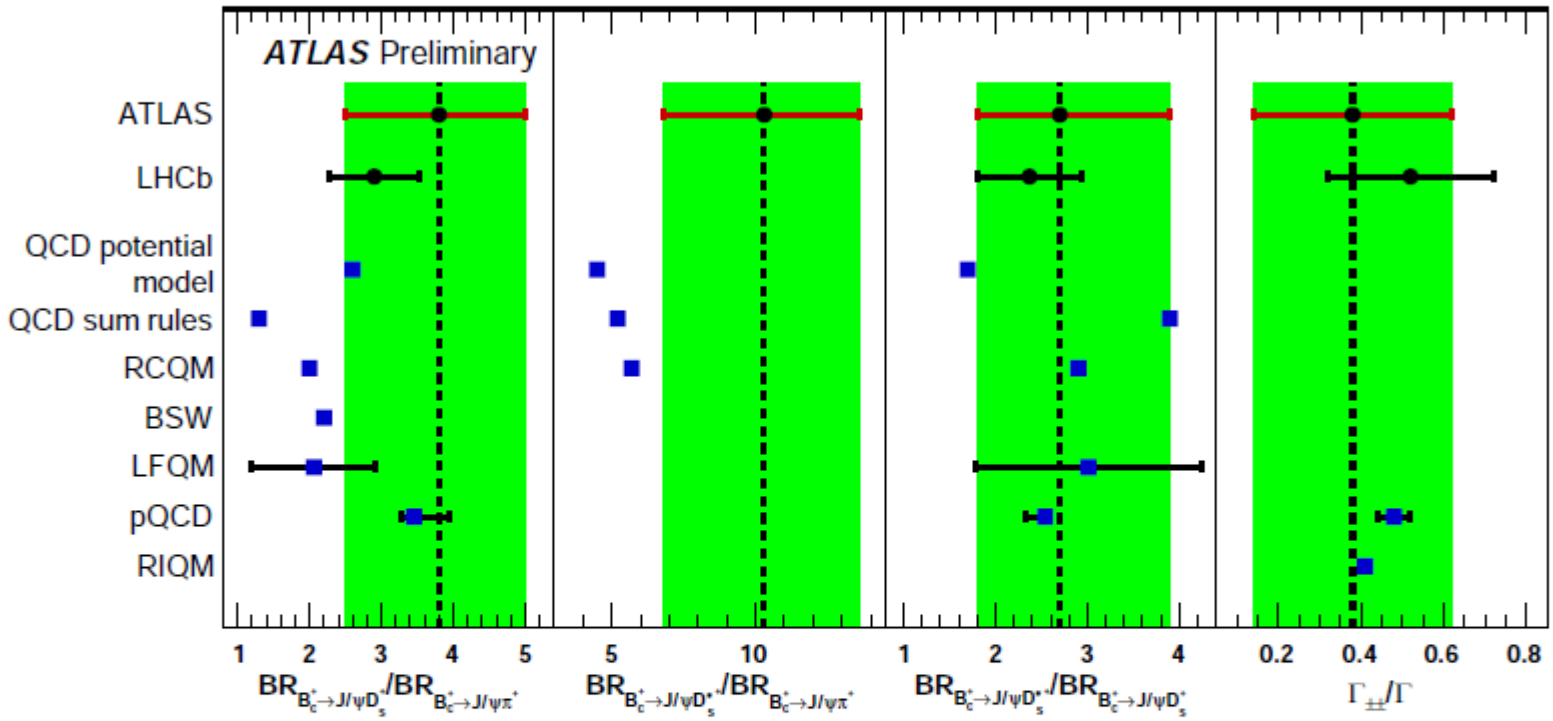
based on JHEP 1408 (2014) 109

Westfälische Wilhelms-Universität Münster

B-Physics



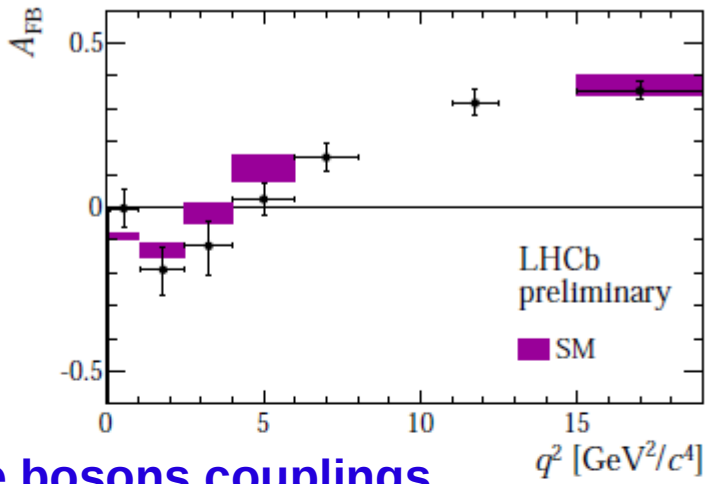
Study of the $B_c^+ \to J/\psi D_s^{(*)+}$ - Results



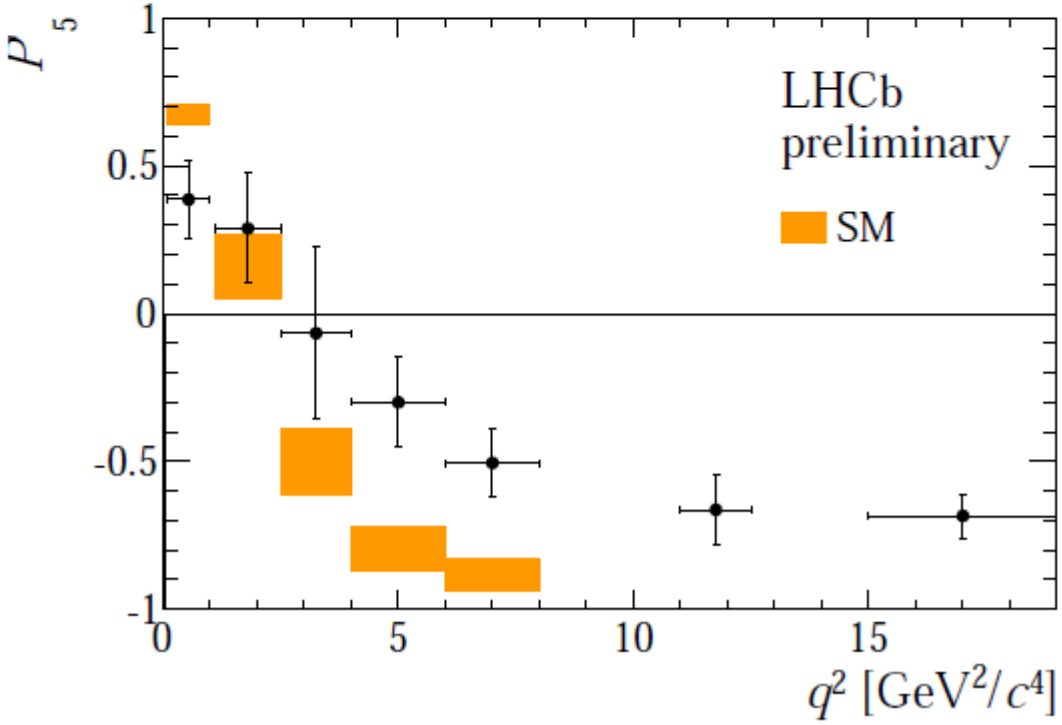
- Generally well described by perturbative QCD, consistent with other models
- Underestimation of $B_c^+ \to J/\psi D_s^{(*)+}$ decay rates by some models
- Results consistent with LHCb measurement (Phys. Rev. D 87 (2013) 112012)

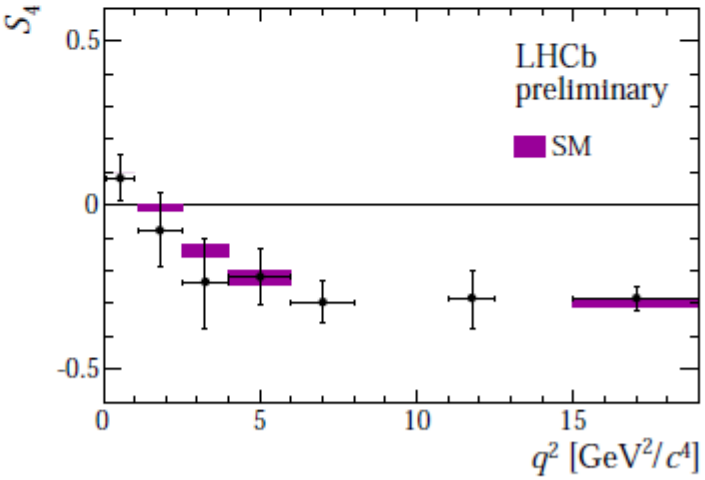
$B^0 \to K^* \mu\mu$ update with 3 fb^{-1}

- Recently we release a preliminary result with 3 fb^{-1} [LHCb-CONF-2015-002]
- Anomaly stays at 3.7 σ.
- Soon a full result with finer bins!



Implications on limits on anomalous triple gauge bosons couplings





University of Zurich

AdS/QCD predictions for $B \to \rho \ell \nu$ and $B \to K^* \mu^+ \mu^-$ rare decays

Motivated by its success in explaining experimental data on diffractive ρ production, AdS/QCD light front wavefunction is used to calculate ρ and K^* DAs and $B \to \rho, K^*$ transition form factors.

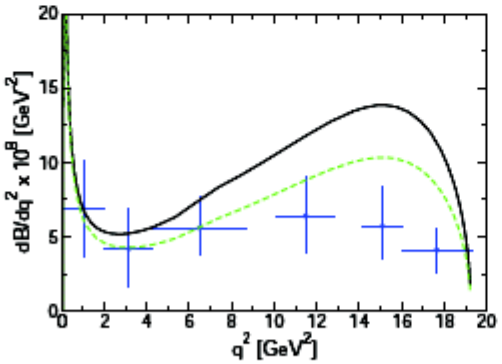
$B \to \rho \ell \nu$ data in three q^2 bins from BABAR: $\Delta B_{\text{a-b}} = \int_a^b \frac{\mathrm{d}B}{\mathrm{d}q^2} \mathrm{d}q^2$

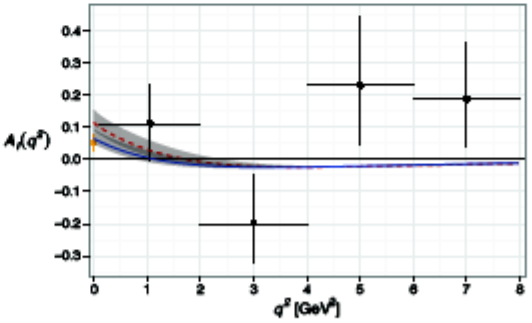
$\Delta B_{0\text{-}8} = (0.564 \pm 0.166)$, $\Delta B_{8\text{-}16} = (0.912 \pm 0.147) \times 10^{-4}$, $\Delta B_{16\text{-}20.3} = (0.268 \pm 0.062) \times 10^{-4}$

V_{ub}-independent data: $R_{\text{low}} = \frac{\Delta B_{0\text{-}8}}{\Delta B_{8\text{-}16}} = 0.618 \pm 0.207$, $R_{16\text{-}20.3} = \frac{\Delta B_{\text{high}}}{\Delta B_{8\text{-}16}} = 0.294 \pm 0.083$

AdS/QCD predictions: $R_{\text{low}} = 0.580, 0.424$ and $R_{\text{high}} = 0.427, 0.503$ for $m_f = 0.14, 0.35$

$B \to K^* \mu^+ \mu^-$ differential branching ratio and isospin asymmetry data from LHCb:





Green-dashed is for assuming $C_9^{\text{NP}} = -1.5$, Red-dashed is the prediction of QCD sum rules.

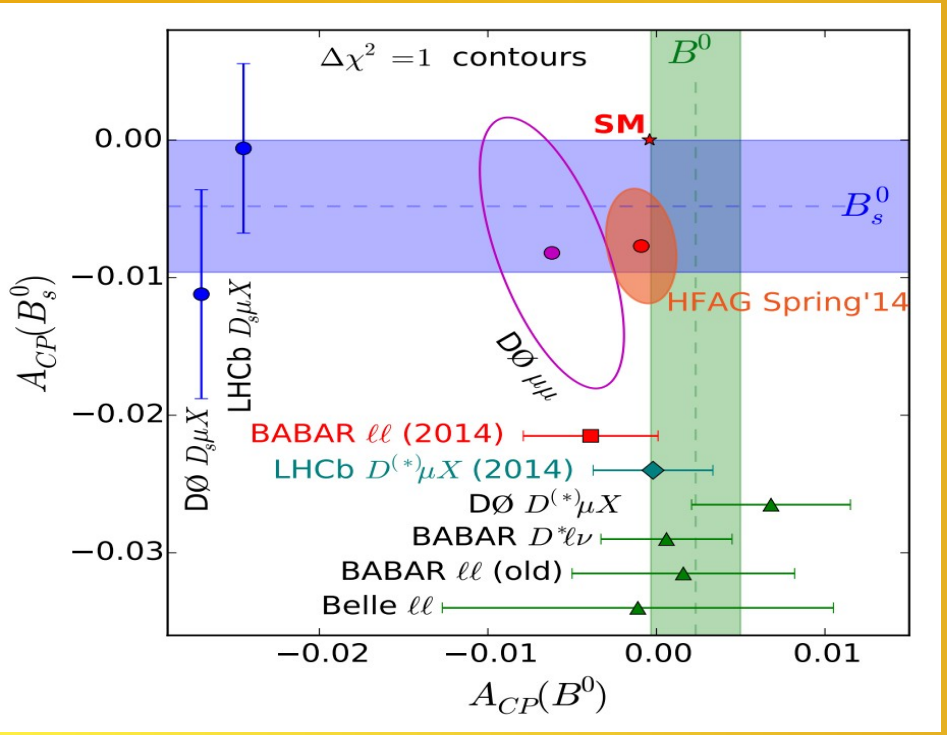
B-meson results from Babar and ATLAS

BABAR measured CP and Br asymmetries in B->$X_s\gamma$ and B-> $X_s l^+ l^-$ decays.

- Acp = (−3.9 ± 3.5 ± 1.9)×10^(−3)

  is in agreement with SM.

Chrzaszcz

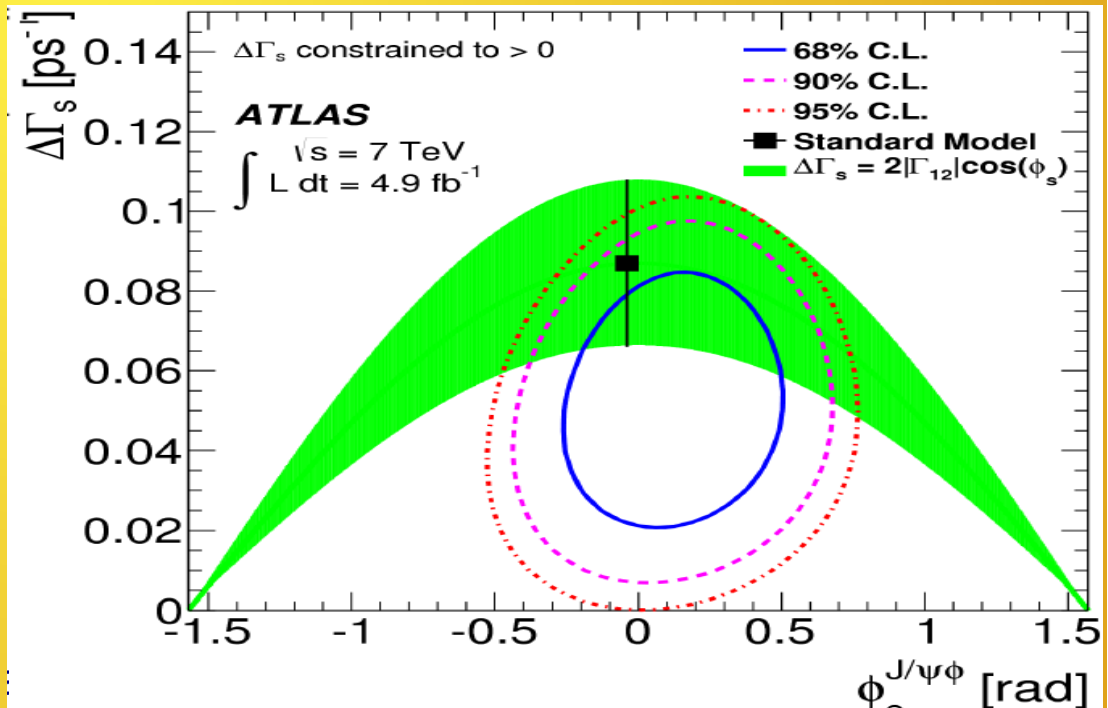


Nooney

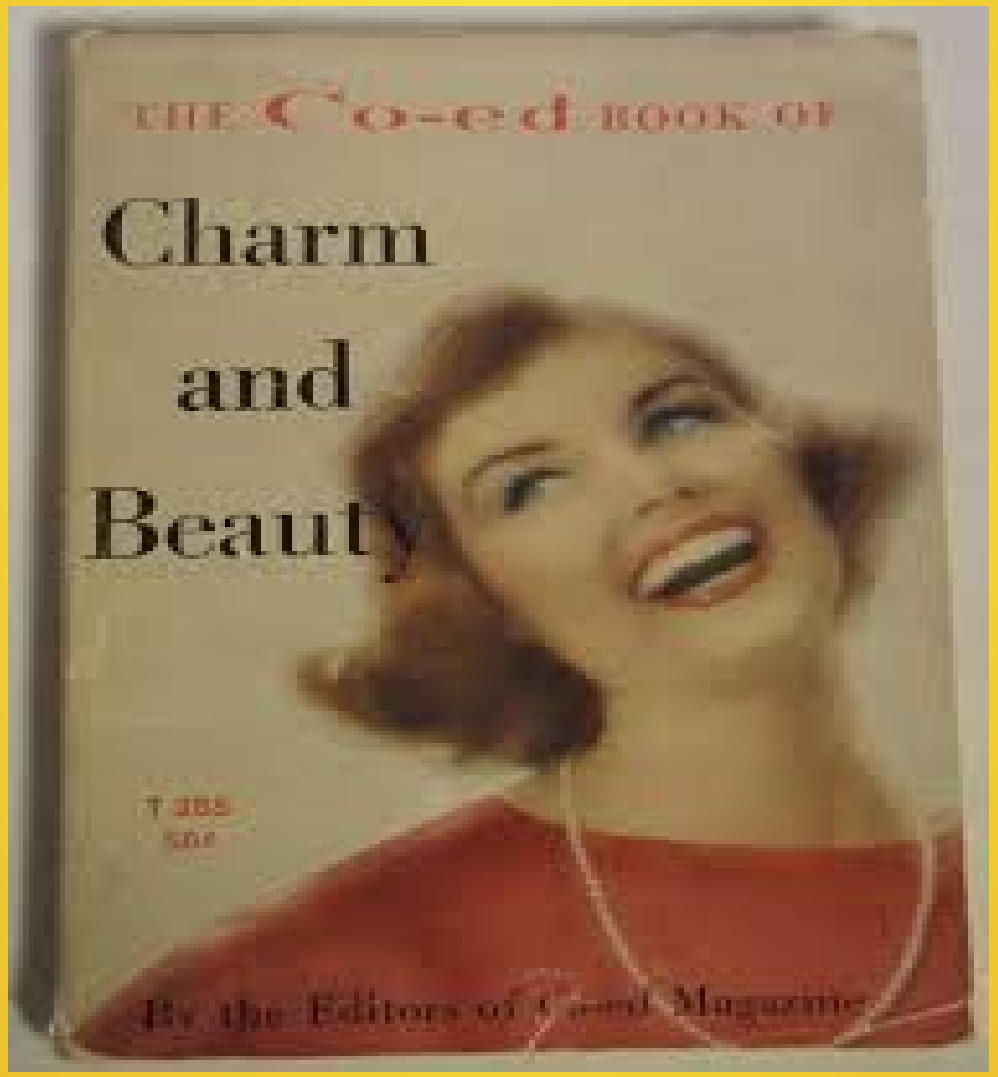
New physics searches with B mesons at ATLAS: decay of Bs --> J/ψ φ

- Consistent with values obtained in untagged analysis.

- Consistent with the values predicted in the SM.



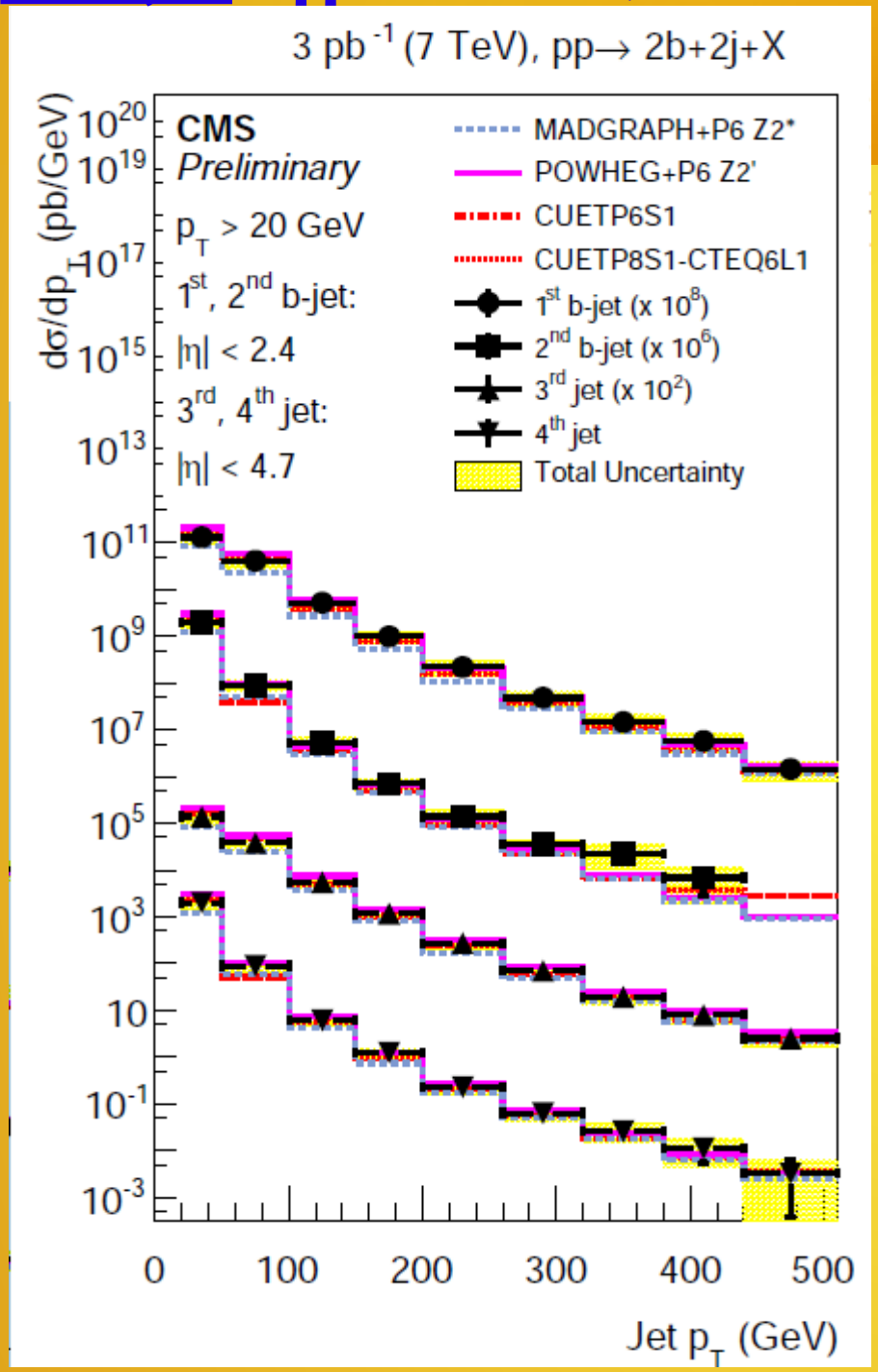
Production of charm and beauty

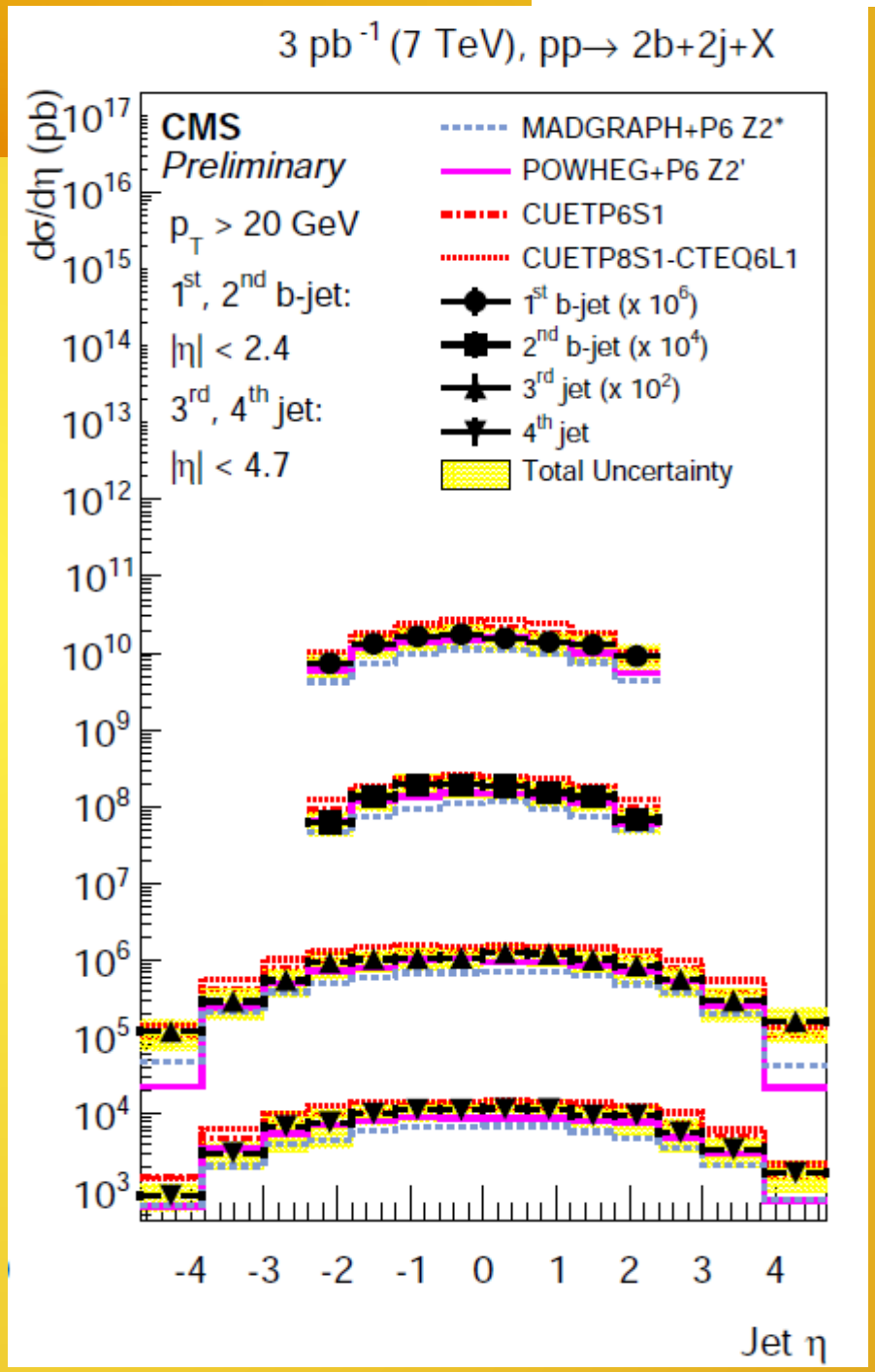


Measurement of four-Jet production including two b-jets in pp collision at 7 TeV at CMS (P.Gunnellini)

CMS-FSQ-13-010

NEW!

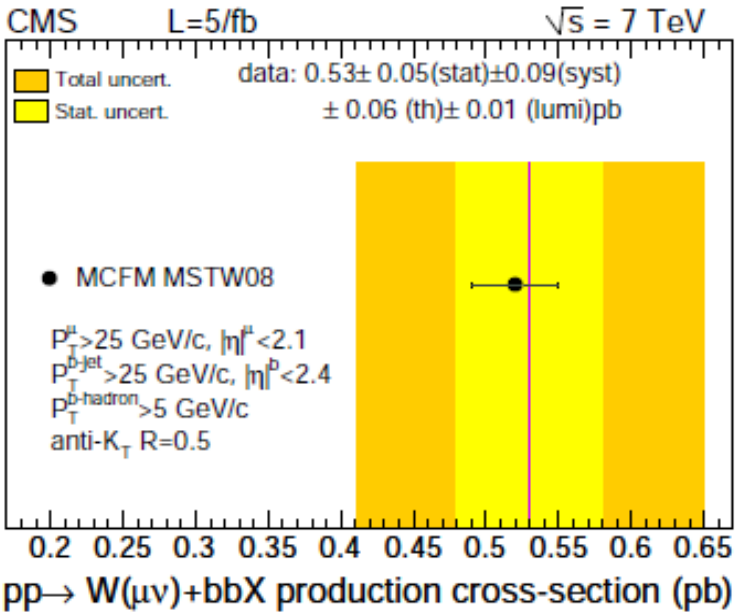


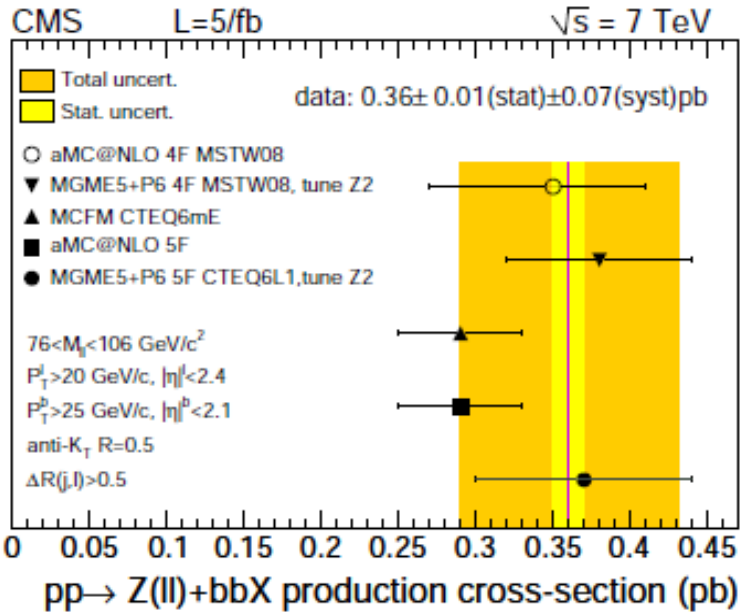


Vector boson + heavy flavor production at CMS (Mastrianni)

V+b(b) Cross Sections at 7 TeV

Z+b(b) arxiv: 1402.1521, W+bb arxiv: 1312.6608, W+c arxiv: 1310.1138





Cross section	Measured	MADGRAPH (5F)	aMC@NLO (5F)	MCFM (parton level)	MADGRAPH (4F)	aMC@NLO (4F)
σ_{Z+1b} (pb)	$3.52 \pm 0.02 \pm 0.20$	3.66 ± 0.22	$3.70^{+0.23}_{-0.26}$	$3.03^{+0.30}_{-0.36}$	$3.11^{+0.47}_{-0.81}$	$2.36^{+0.47}_{-0.37}$
σ_{Z+2b} (pb)	$0.36 \pm 0.01 \pm 0.07$	0.37 ± 0.07	$0.29^{+0.04}_{-0.04}$	$0.29^{+0.04}_{-0.04}$	$0.38^{+0.06}_{-0.10}$	$0.35^{+0.08}_{-0.06}$
σ_{Z+b} (pb)	$3.88 \pm 0.02 \pm 0.22$	4.03 ± 0.24	$3.99^{+0.25}_{-0.29}$	$3.23^{+0.34}_{-0.40}$	$3.49^{+0.52}_{-0.91}$	$2.71^{+0.52}_{-0.41}$
$\sigma_{Z+b/Z+j}$ (%)	$5.15 \pm 0.03 \pm 0.25$	5.35 ± 0.11	$5.38^{+0.34}_{-0.39}$	$4.75^{+0.24}_{-0.27}$	$4.63^{+0.69}_{-1.21}$	$3.65^{+0.70}_{-0.55}$

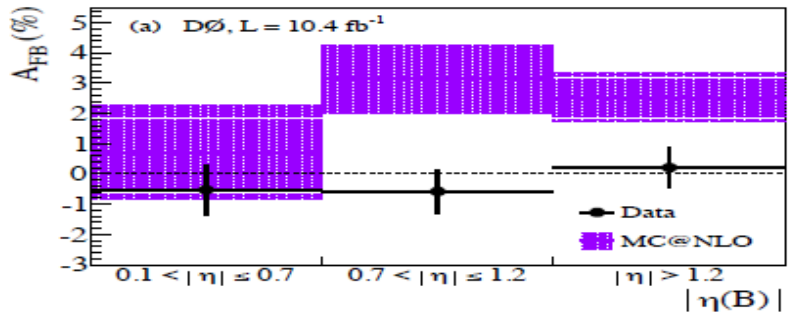
- Uncertainty in Z+Jets is limited by systematics (bTagging)

FB Asymmetries of B+/- at the Tevatron (B. K. Abbott)

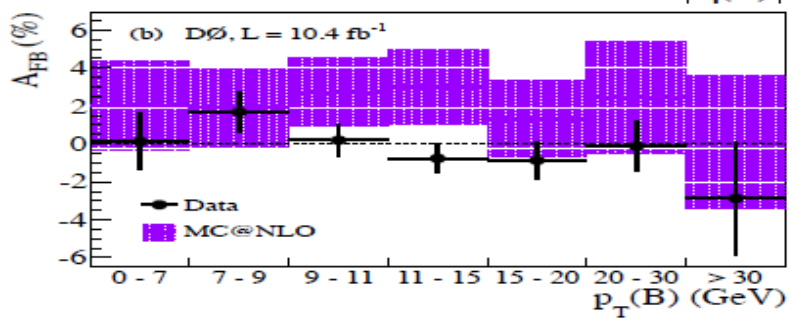
Comparison of $A_{FB}(B^{\pm})$ to MC@NLO

χ^2/dof

10.3/3 correlated sys
11.8/3 uncorrelated sys



6.6/7 correlated sys
7.0/7 uncorrelated sys



Data systematically lower than MC@NLO at all η for P_T=9-30 GeV

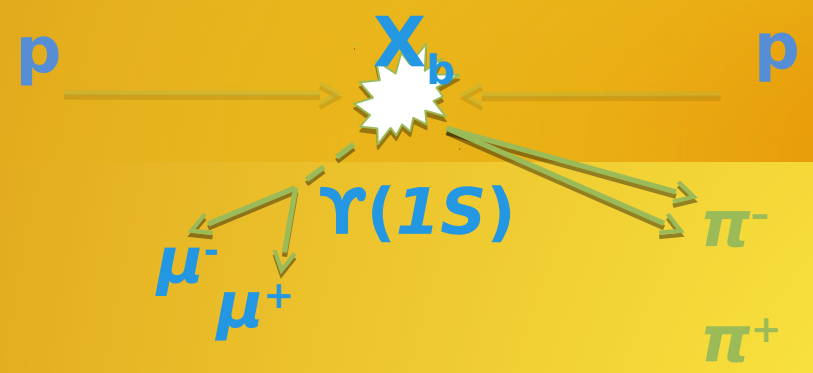
Some tension with data and MC@NLO

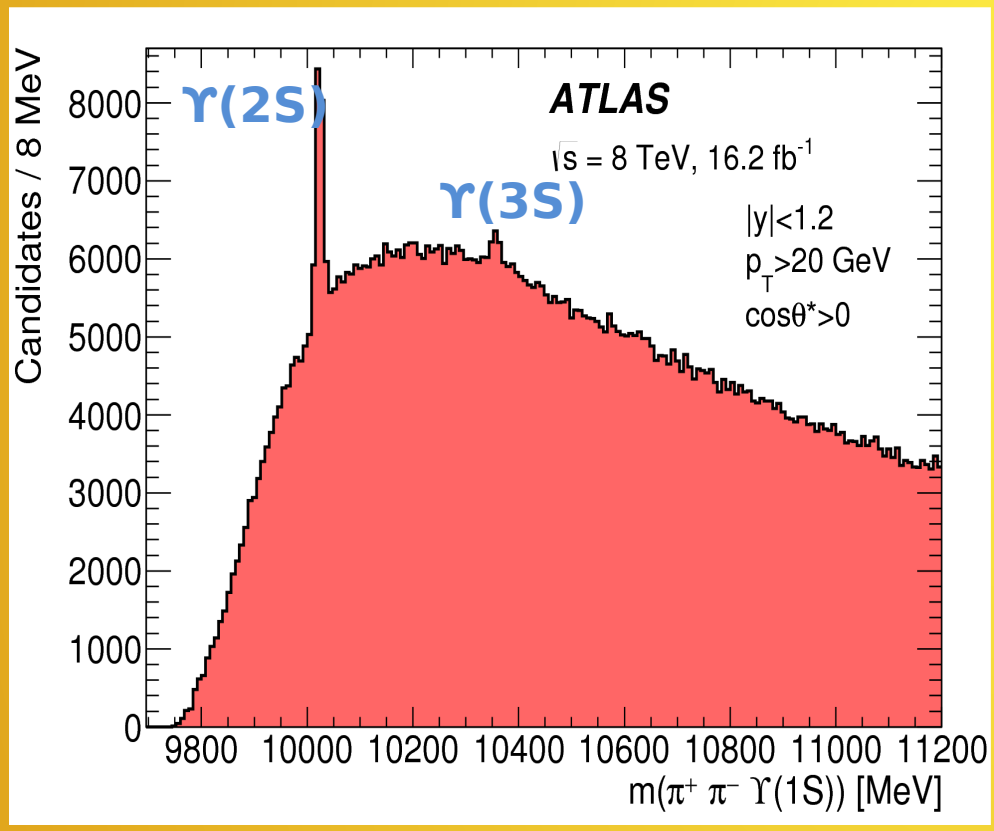
$A_{FB}(B^{\pm}) = -0.0024 \pm 0.0041(\text{stat}) \pm 0.0019(\text{sys})$

We observe no significant forward-backward asymmetry

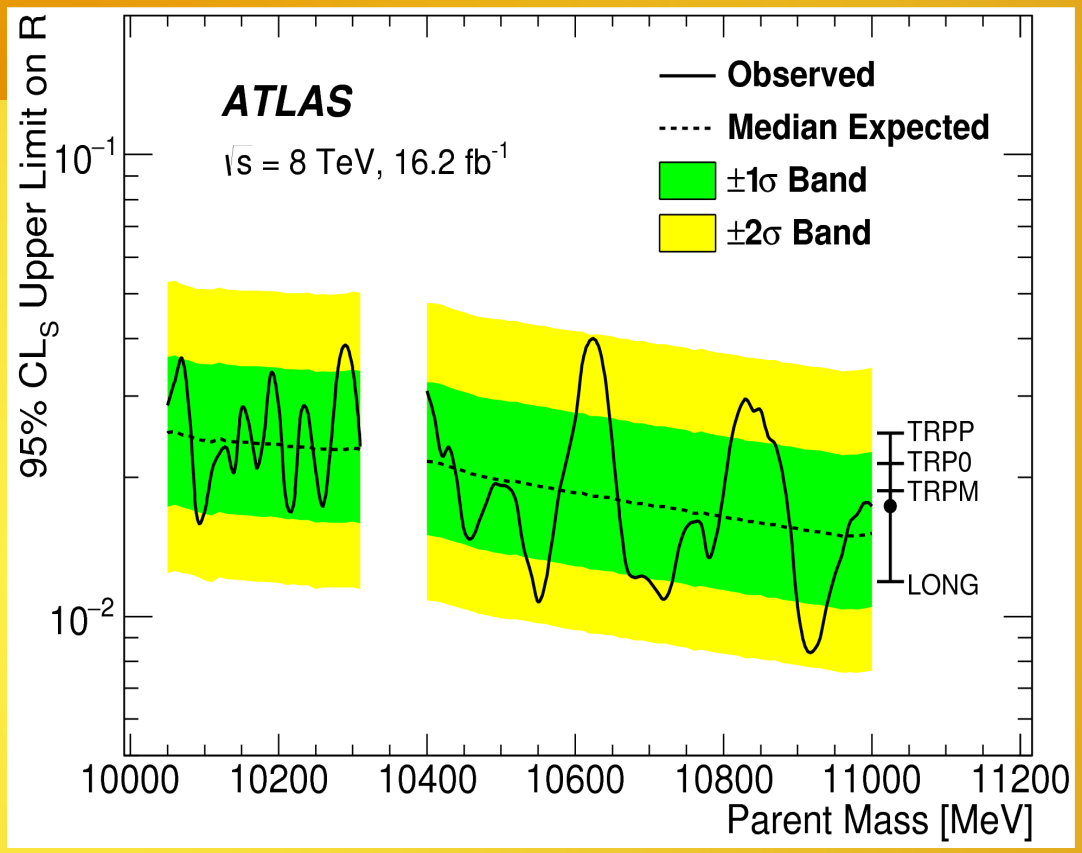
First measurement of this quantity

Search for Xb -->$\pi^+\pi^-\Upsilon(\mu\mu)$ production:





ATLAS: Most sensitive limits on Exotic Xb -->$\pi^+\pi^-\Upsilon(\mu\mu)$ production

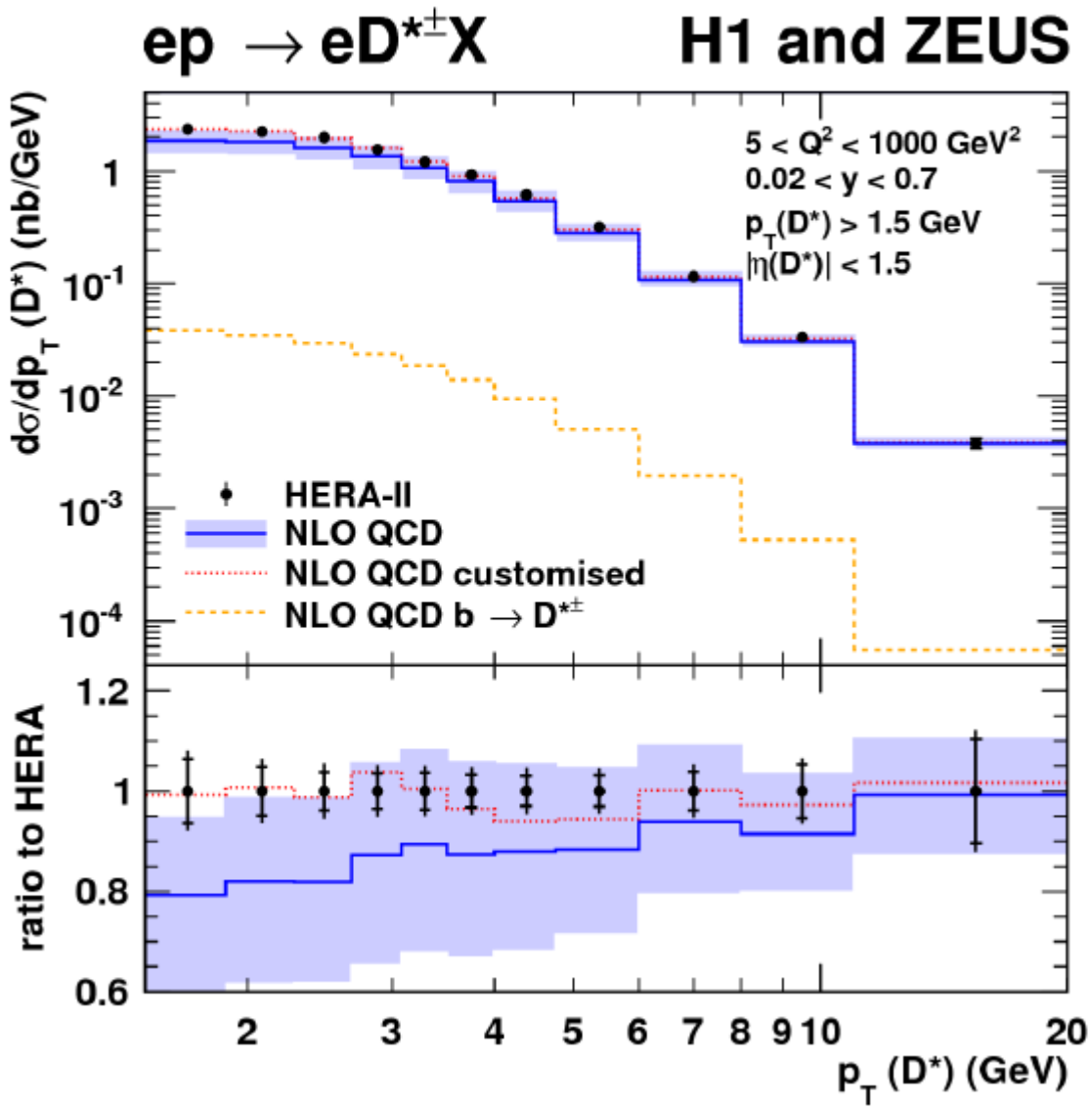


No evidence for “beauty tetra-quark” candidate

Joseph Michael Izen
Talk

Combination of D* differential cross sections measurements in DIS at HERA (O.Behnke)

Results: $p_T(D^*)$

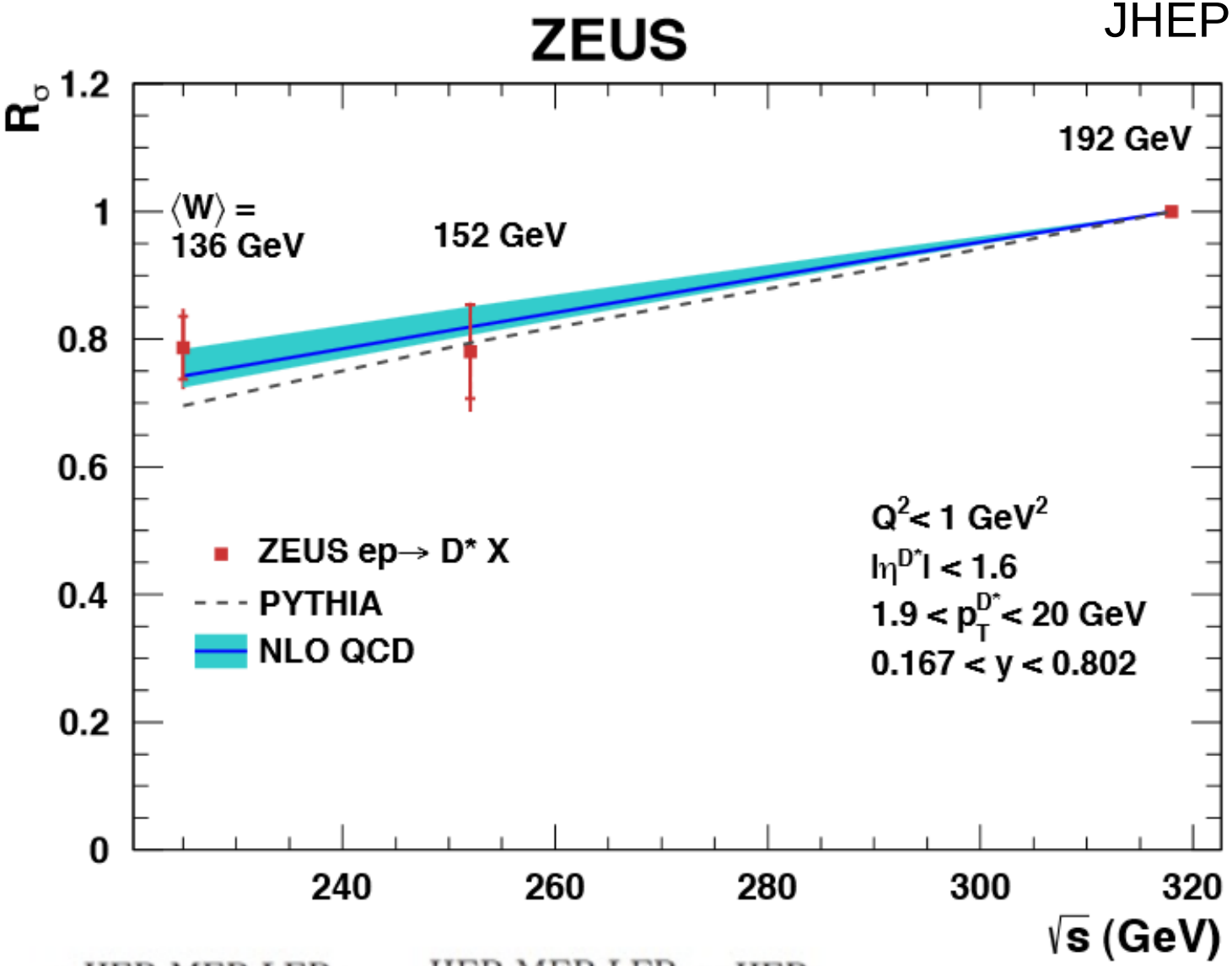


ArXiv:1503.06042

NLO prediction:
- → describes data
- → large uncertainties
- → customised variant: ☺

Energy dependence of *D** cross sections

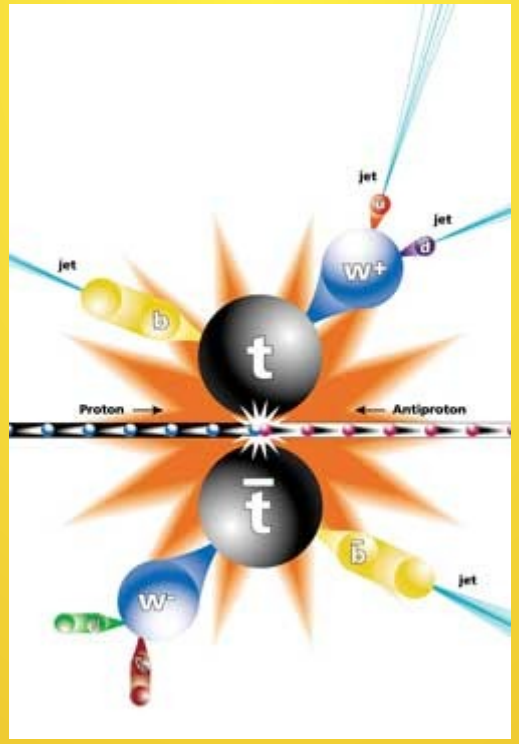
JHEP 10 (2014) 003



- Cross sections for LER and MER are compatible.
- Both are significantly smaller than the HER cross section.
- Behaviour predicted well by PYTHIA and NLO QCD.
- Compatibility of gluon distribution in the proton.
- More confidence in calculations used for e.g. LHeC.

$$R_\sigma^{\mathrm{HER,MER,LER}} = \sigma_{\mathrm{vis}}^{\mathrm{HER,MER,LER}} / \sigma_{\mathrm{vis}}^{\mathrm{HER}}.$$

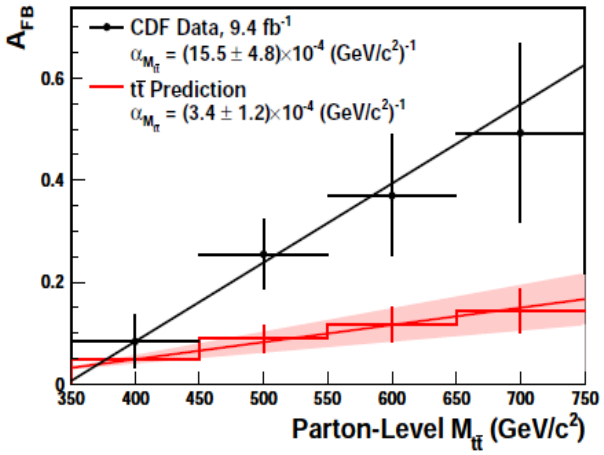
TOP-QUARK PHYSICS

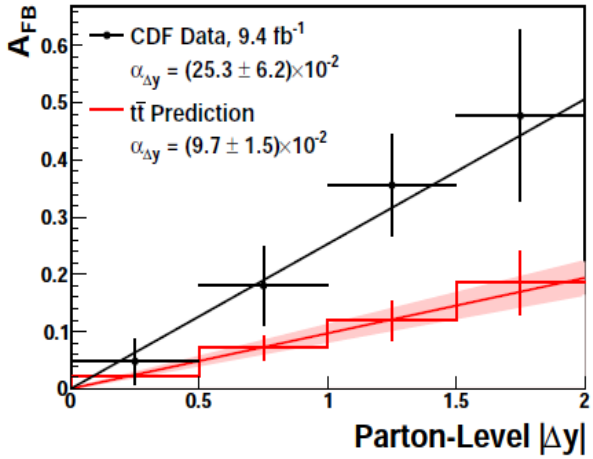


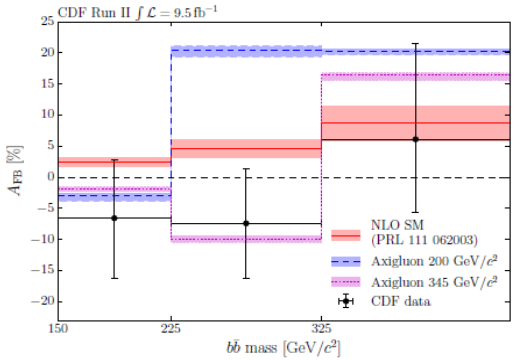
Asymmetries in heavy-quark production at CDF Tevatron

J. Wilson

- In lepton+jets channel, measure top A_{FB} as function of $t\bar{t}$ mass and $|\Delta y|$
- Linear as function of both
- Fit lines to extract slope
- As before, NLO fails to predict data; NNLO does much better



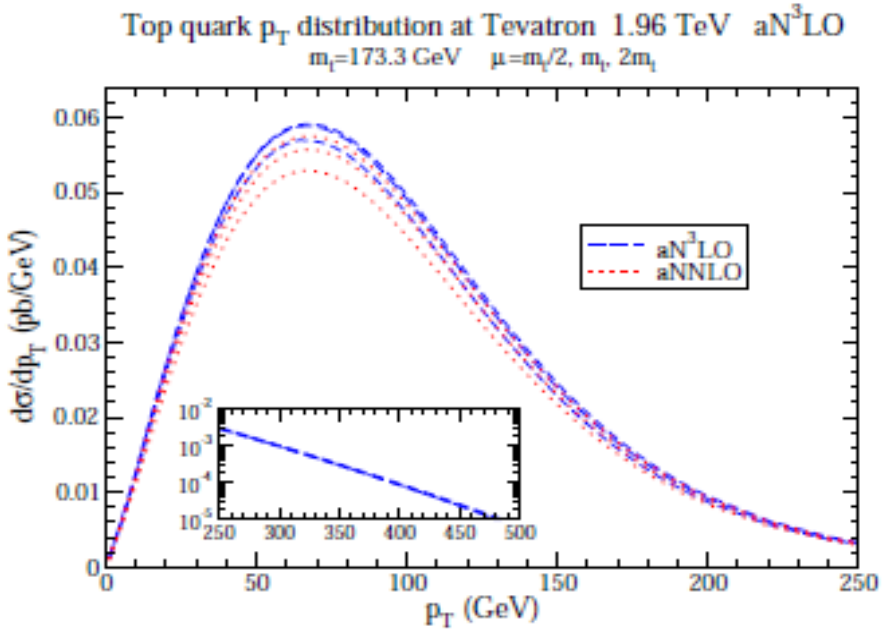


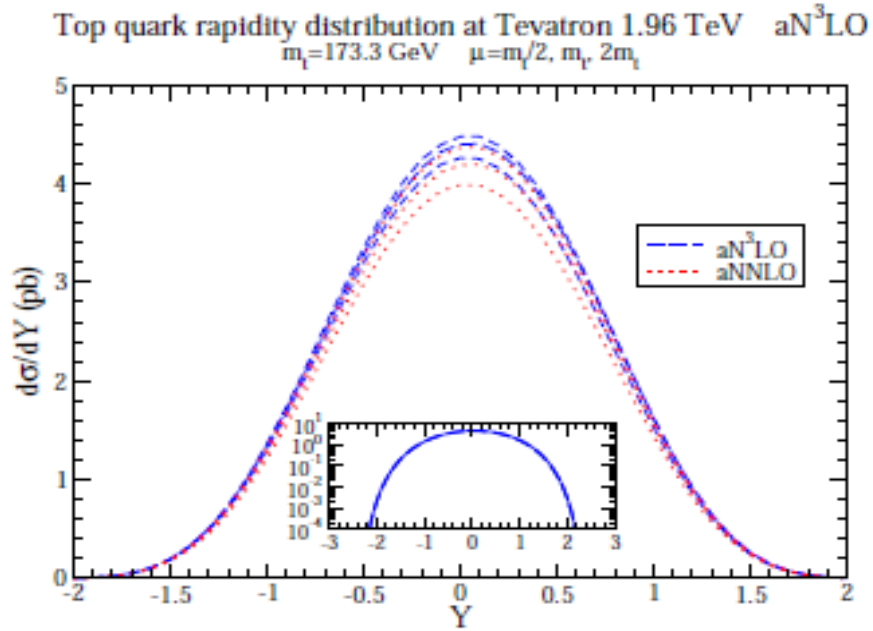


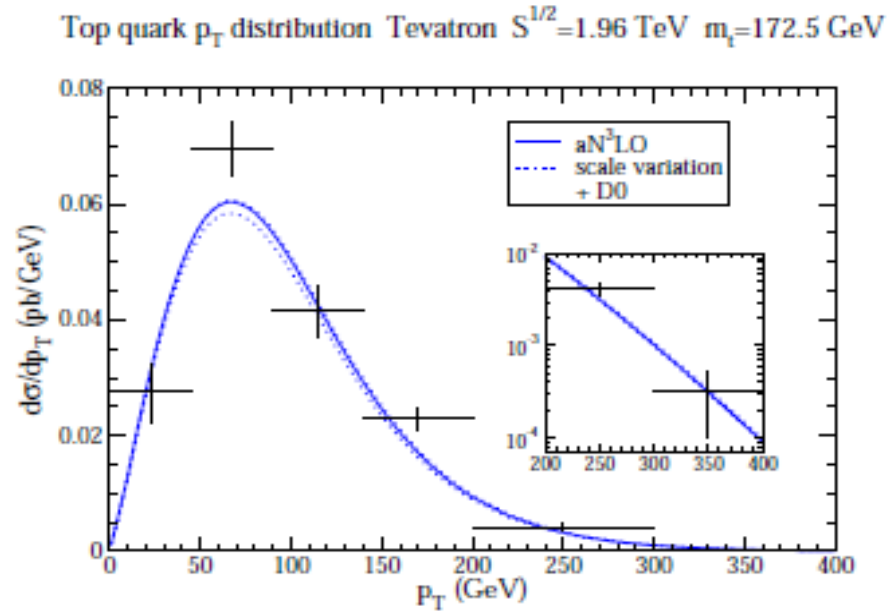
- A_{FB} consistent with NLO SM and with zero
- No indications of new physics
- Able to start ruling out some models
- Axigluon with mass 200 GeV/c^2 and width 50 GeV excluded at 95 % level
- Similar axigluon with mass 345 GeV/c^2 and width 80 GeV not excluded

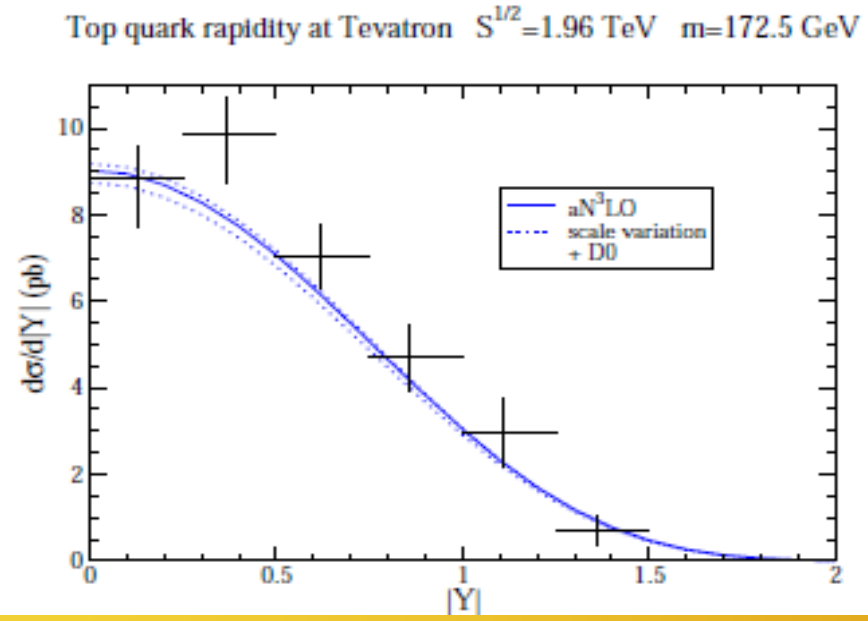
Approx. NNNLO theory predictions for top-pair and single top production: N.Kidonakis

Top quark p_T and rapidity distributions at the Tevatron



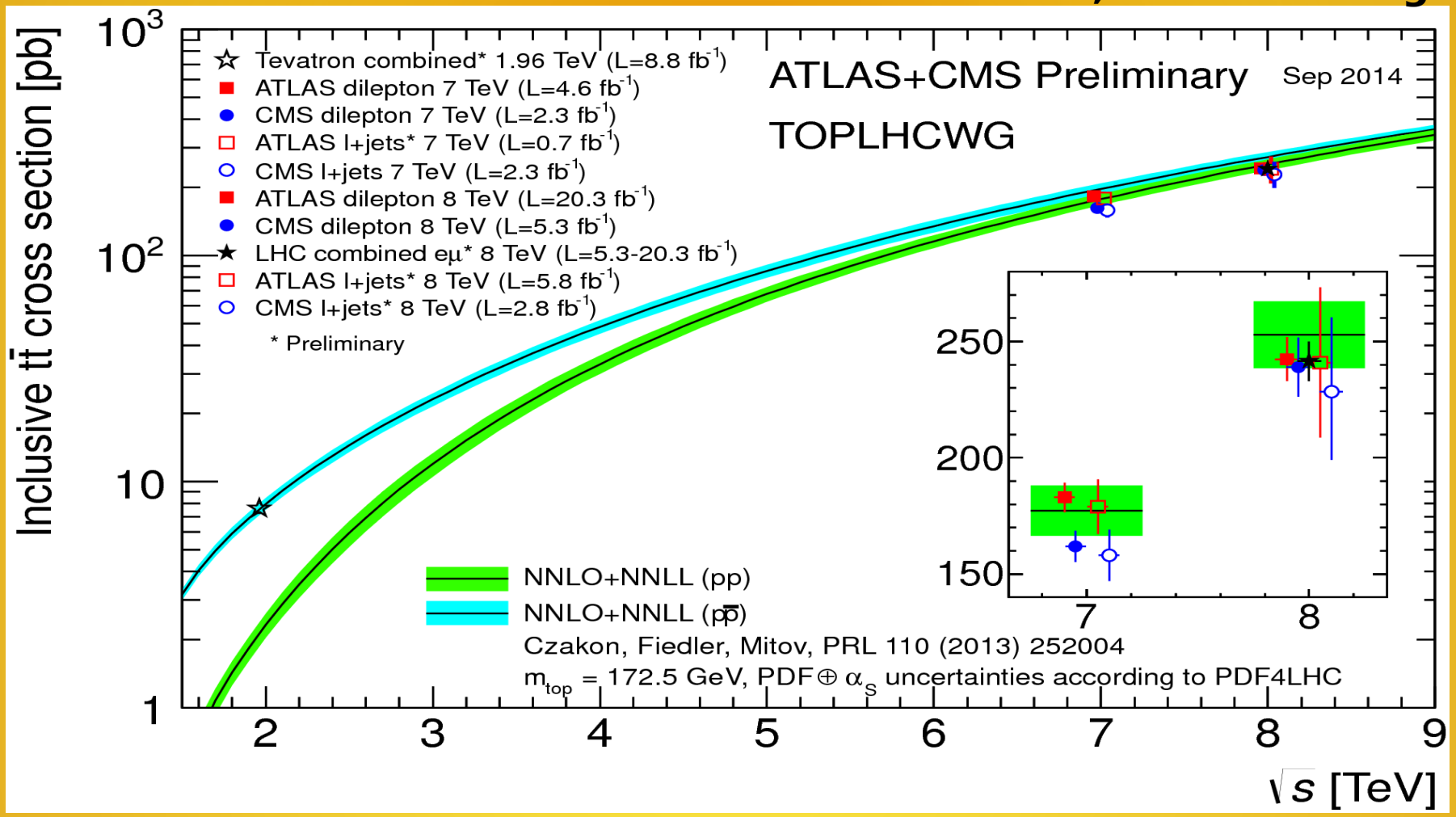






Inclusive top-quark pair production cross sections

Protopopesku, Garay
Garcia,Schwanenberger,Jung

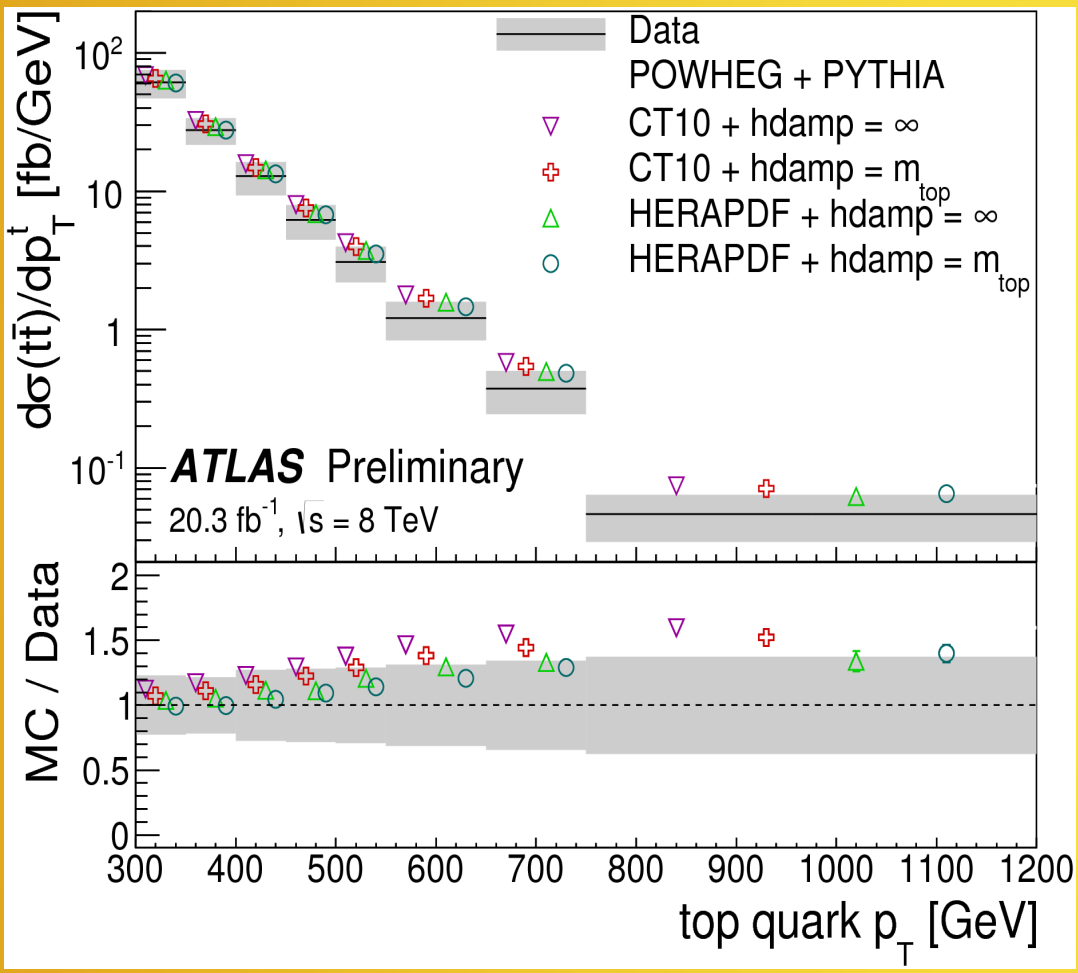


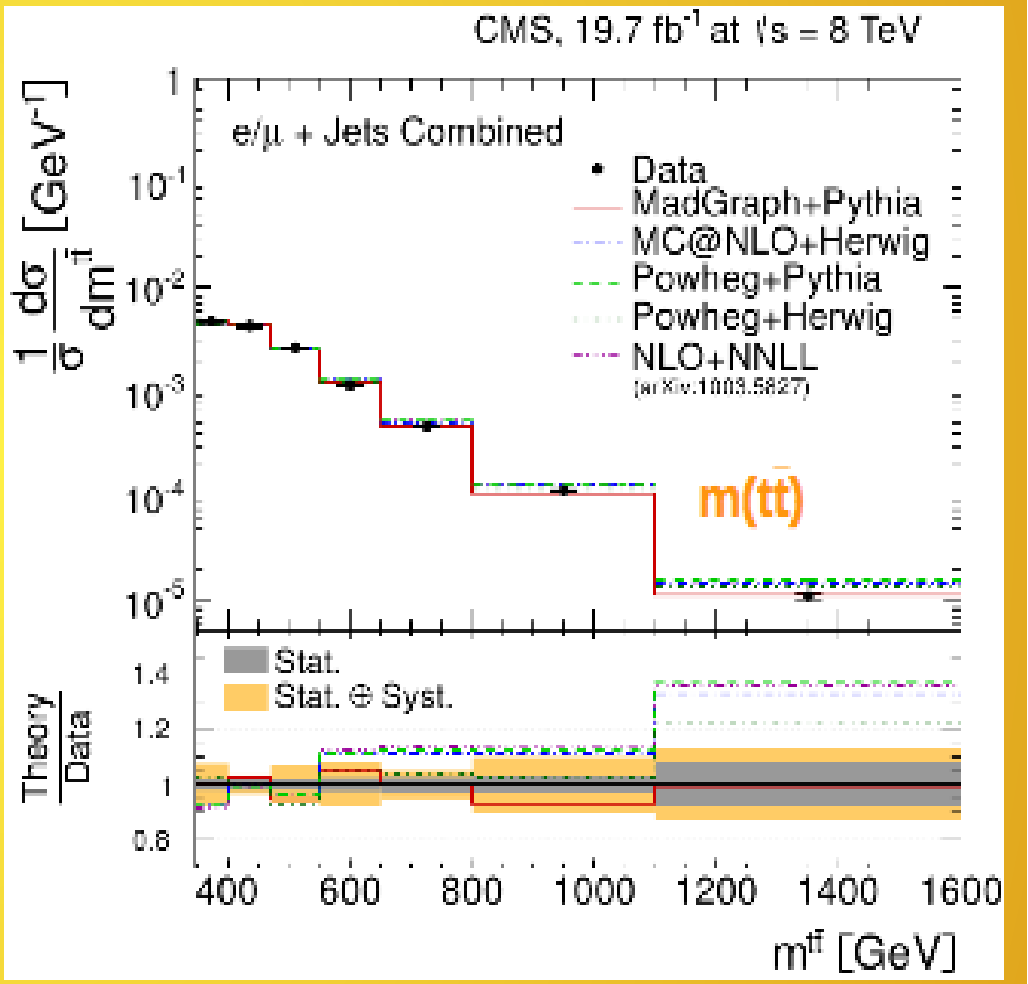
Process	Cross section	Sign.
$t\bar{t}Z$	150^{+55}_{-50} (stat.) ± 21 (syst.) fb	3.1σ
$t\bar{t}W$	300^{+120}_{-100} (stat.) $^{+70}_{-80}$ (syst.) fb	3.1σ

Process	Cross section	Significance
$t\bar{t}W$	170^{+90}_{-80}(stat.)$^{+70}_{-70}$(syst.) fb	1.6 σ
$t\bar{t}Z$	200^{+80}_{-70}(stat.)$^{+40}_{-30}$(syst.) fb	3.1 σ
$t\bar{t}W + t\bar{t}Z$	380^{+100}_{-90}(stat.)$^{+80}_{-70}$(syst.) fb	3.7 σ

Top-quark differential cross sections at ATLAS and CMS

Protopopesku, Garay Garcia, Schwanenberger,Jung

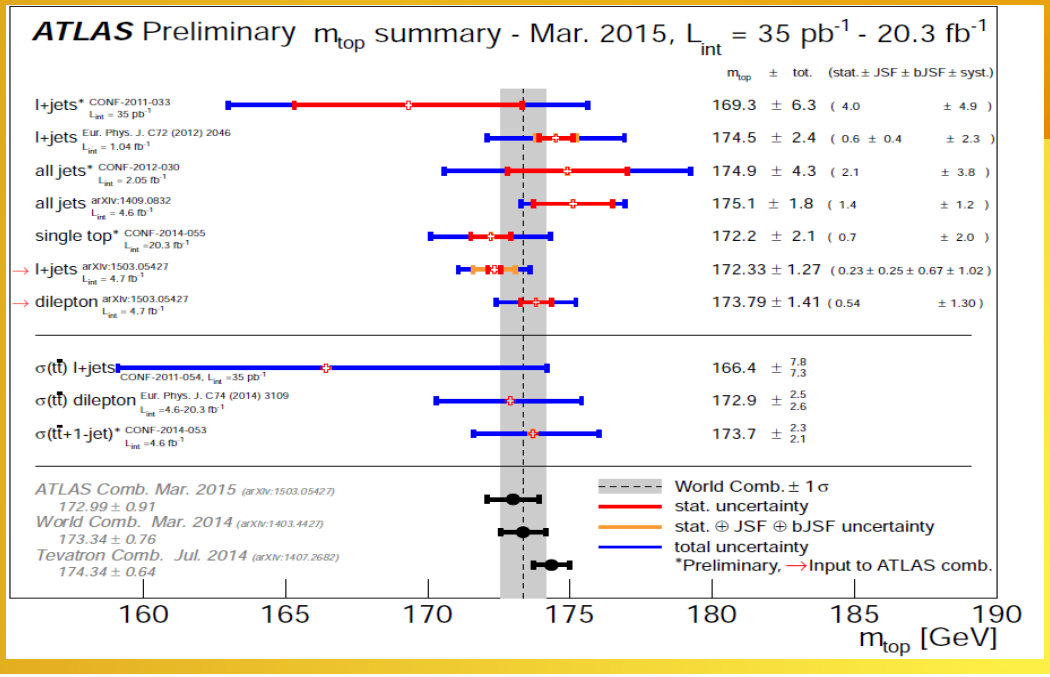


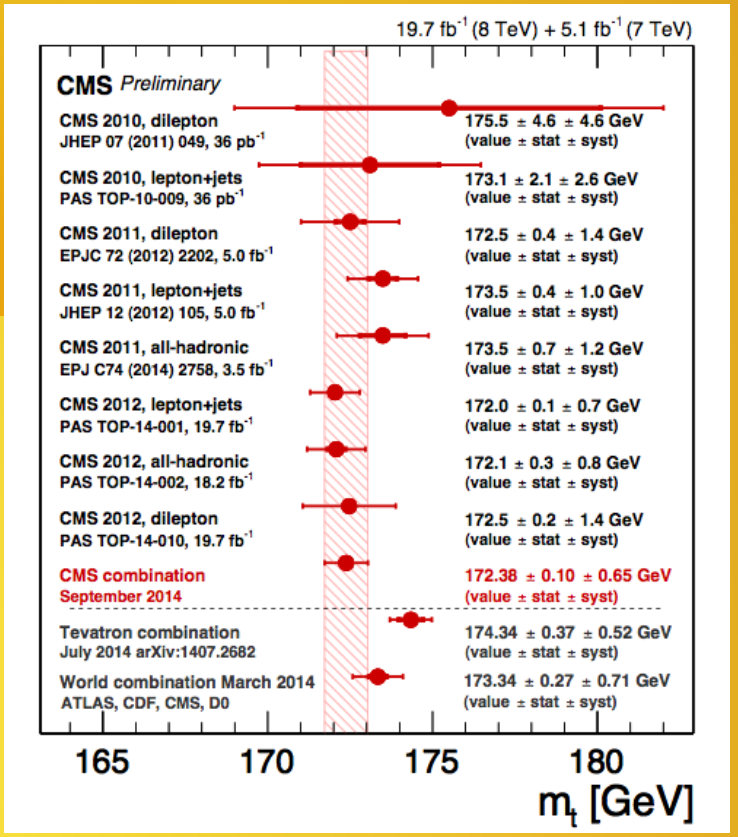


Top quark mass

Menke, Liu

Measured by LHC and TeVatron experiments:





	World comb.	Tevatron comb.	CMS comb.
m_t [GeV]	173.34 ± 0.76	174.34 ± 0.64	172.38 ± 0.66
Precision	0.44 %	0.37 %	0.38 %

D0 single-channel
174.98 ± 0.76
0.43%

New methods developed for the pole-mass measurements

- Extracted from the total ttbar cross section measurement in dilepton channel

$$m^{pole}_{top,7\,TeV} = 171.4 \pm 0.6_{stat} \pm 2.5_{sys+theo}($$
$$m^{pole}_{top,8\,TeV} = 174.1 \pm 0.3_{stat} \pm 2.6_{sys+theo}$$

Top-quark properties: report from ATLAS and CMS

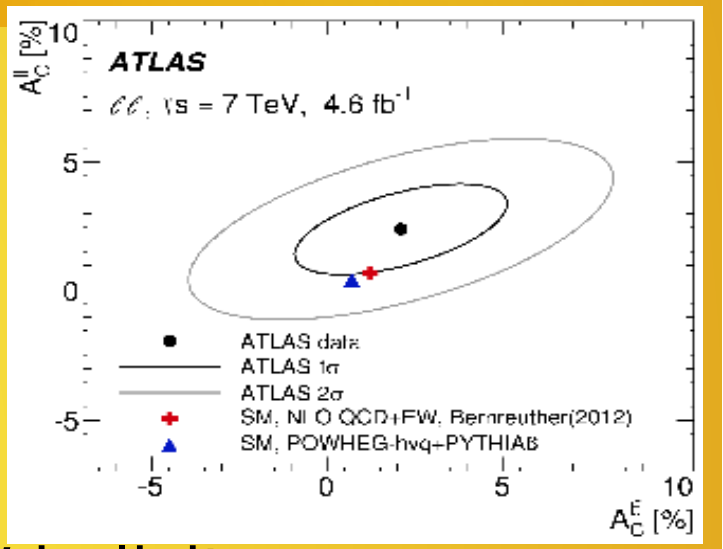
A.Jung

- Charge asymmetries in agreement with theory
  - CMS :

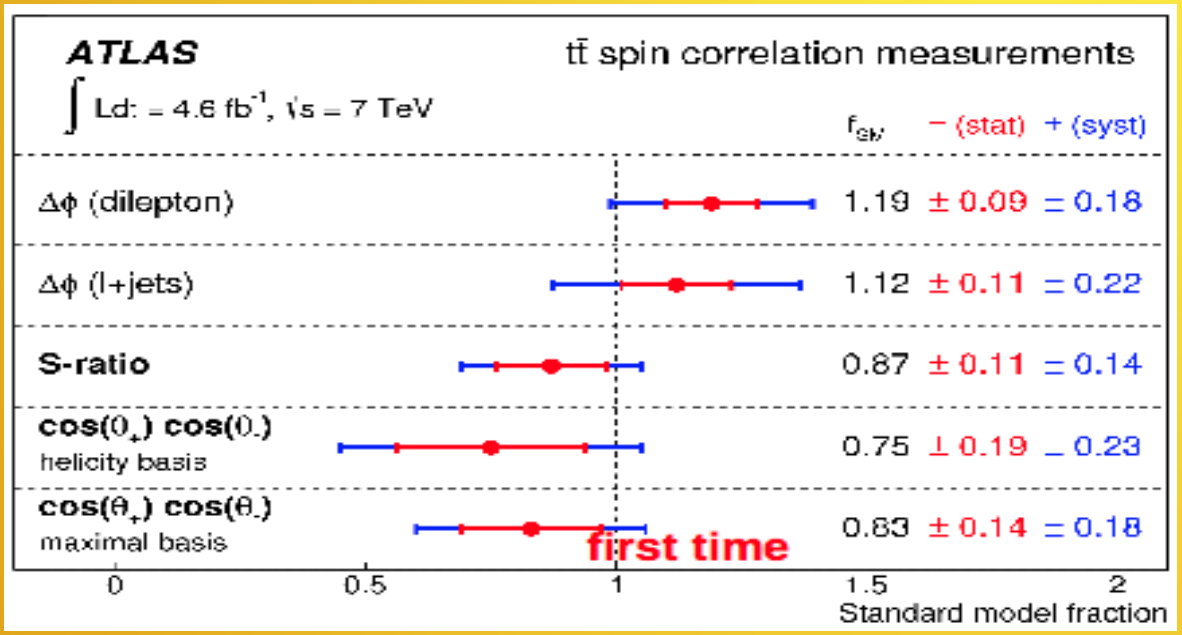
Variable	Data (unfolded)	NLO theory
A_C	$-0.010 \pm 0.017 \pm 0.008$	0.0123 ± 0.0005
A_C^{lep}	$0.009 \pm 0.010 \pm 0.006$	0.0070 ± 0.0003

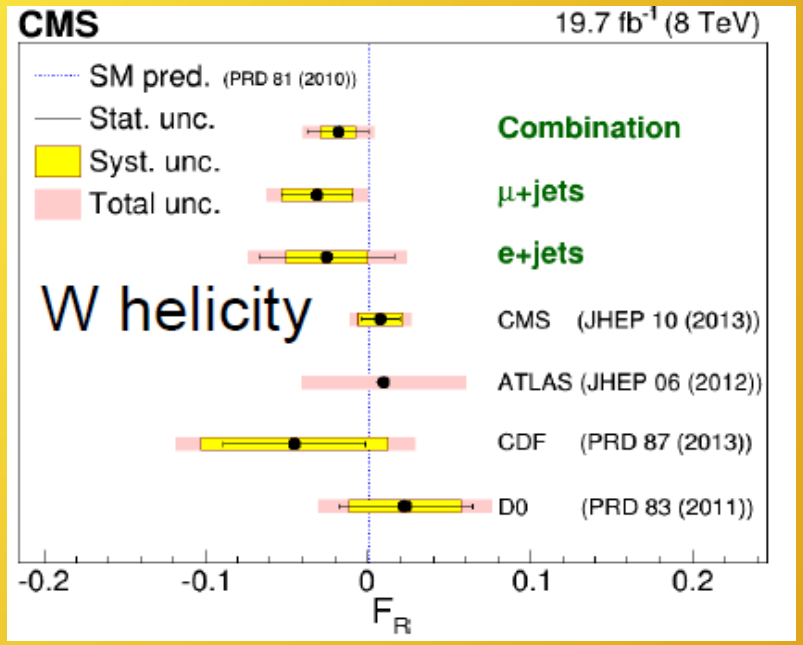
  - in agreement with NLO QCD

ATLAS:



W helicity

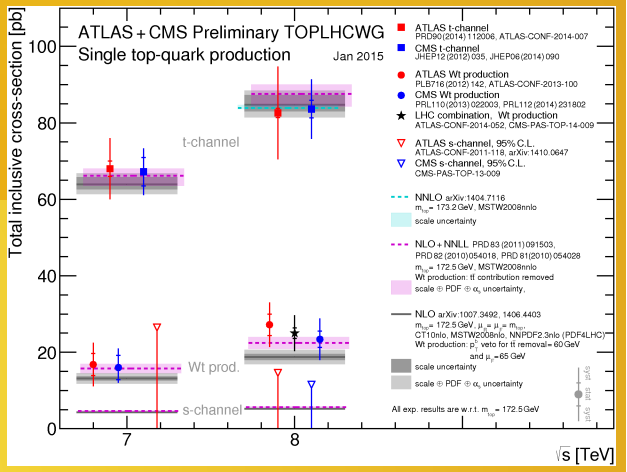




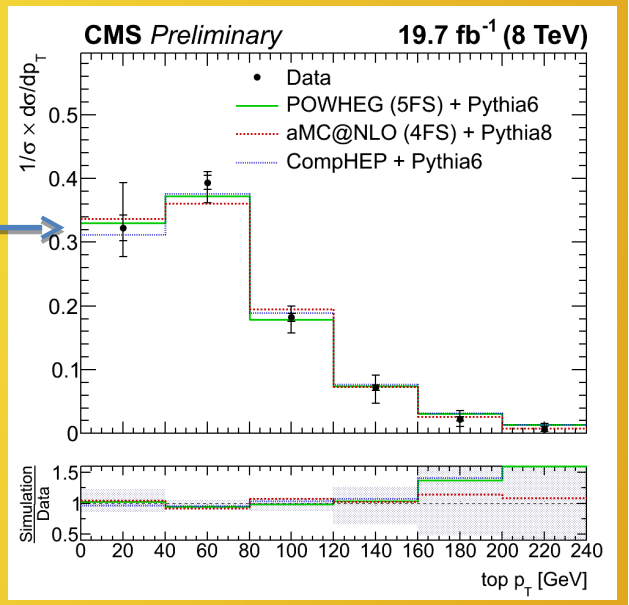
Single top results from ATLAS and CMS

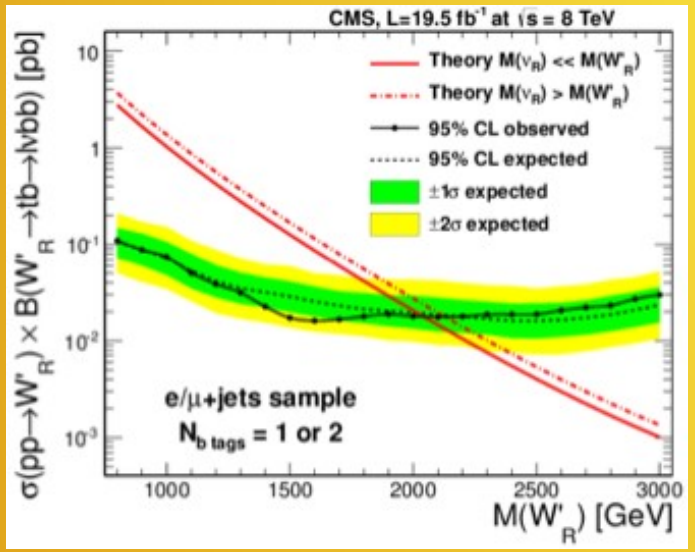
Finelli

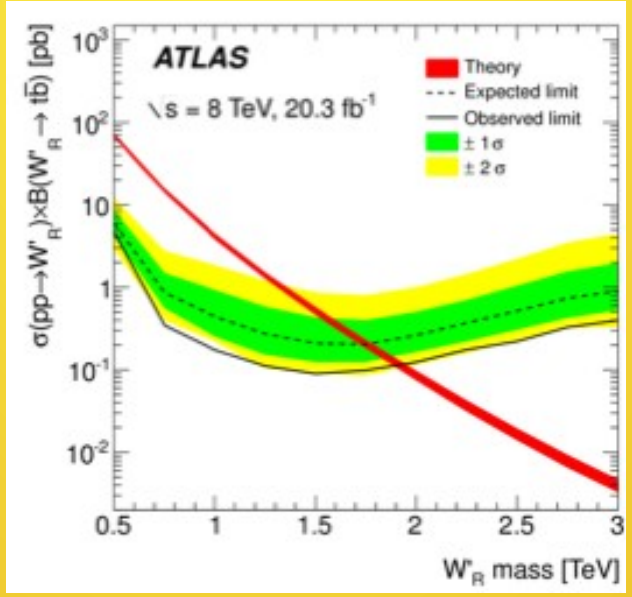
- Inclusive cross section measured in all channels – in a good agreement with current theory
- Differential cross sections:



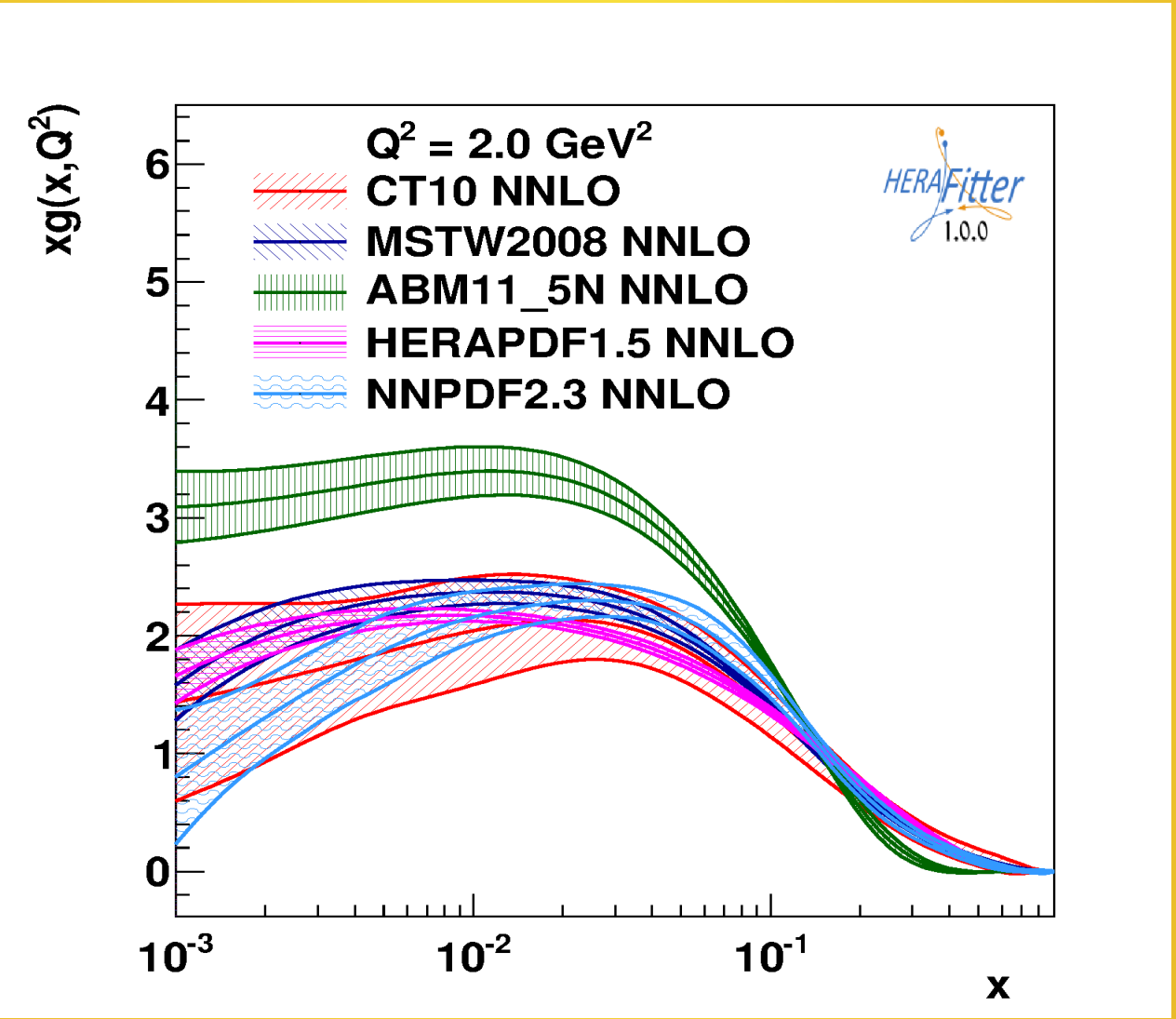
- Single top physics became a probe for BSM physics. Example: Limits on W'->tb



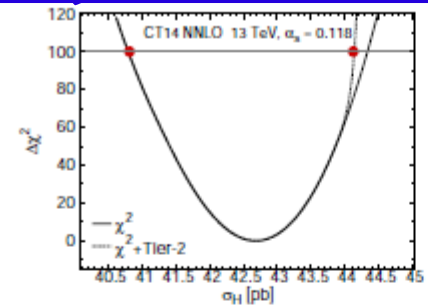


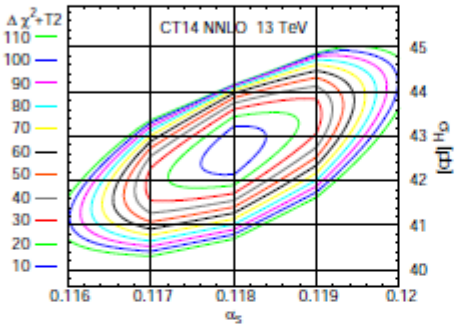


Heavy flavors in global QCD analyses of PDFs



Heavy flavors in the CT14 global PDF analysis: (T.-J. Hou)

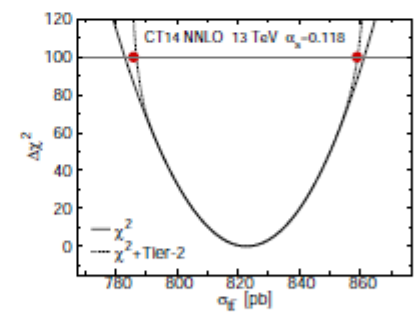


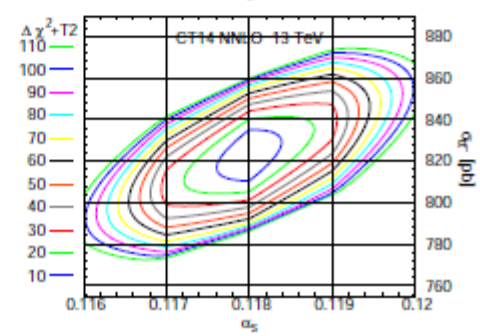


	$gg \to H$ (pb), 13 TeV, 90% C.L.
HM, PDF ($\alpha_s = 0.118$)	$42.68 + 3.32\% - 3.88\%$
LM, PDF ($\alpha_s = 0.118$)	$42.68 + 3.42\% - 3.80\%$
HM, PDF+α_s	$42.68 + 4.94\% - 5.28\%$
LM, PDF+α_s	$42.68 + 5.19\% - 5.96\%$

Consistency check between LM and Hessian methods

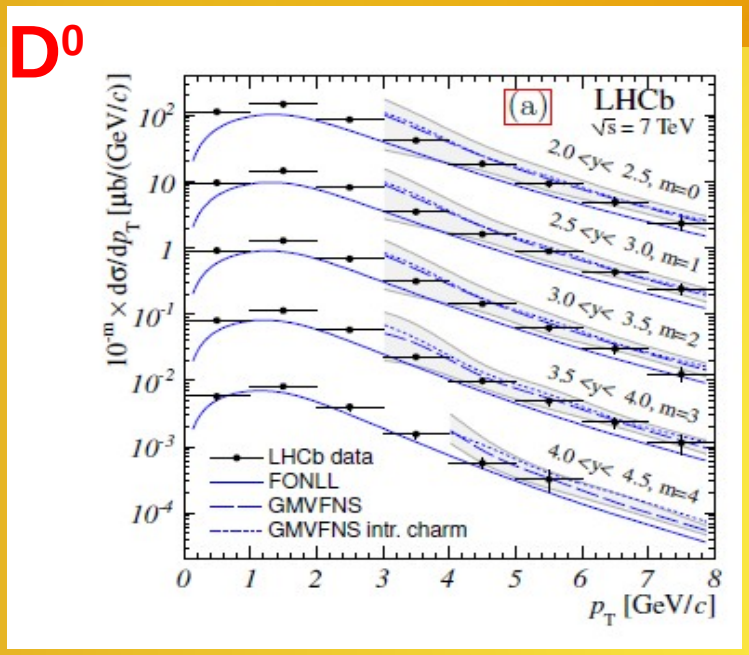
	$pp \to t\bar{t}$ (pb), 13 TeV, 90% C.L.
HM, PDF ($\alpha_s = 0.118$)	$822.64 + 4.41\% - 4.47\%$
LM, PDF ($\alpha_s = 0.118$)	$822.84 + 4.41\% - 4.37\%$
HM, PDF+α_s	$822.64 + 5.84\% - 5.70\%$
LM, PDF+α_s	$822.84 + 5.98\% - 5.89\%$

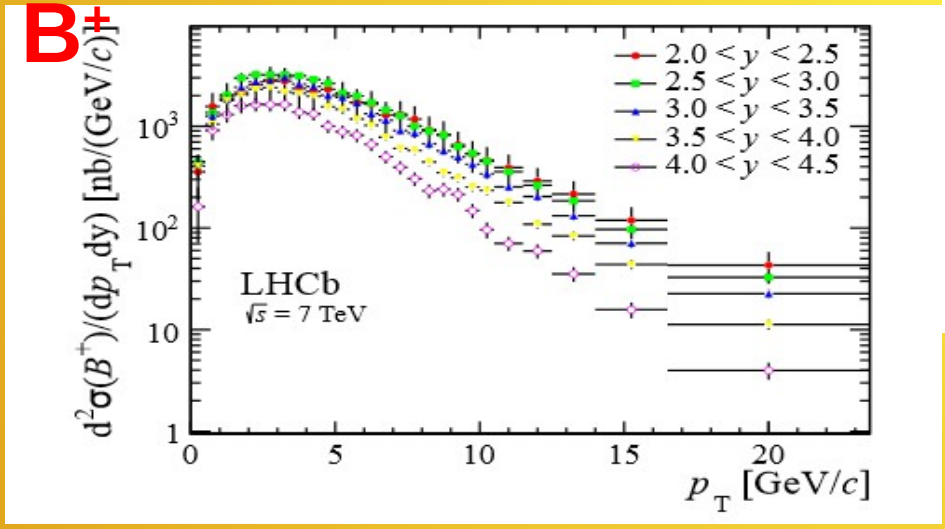


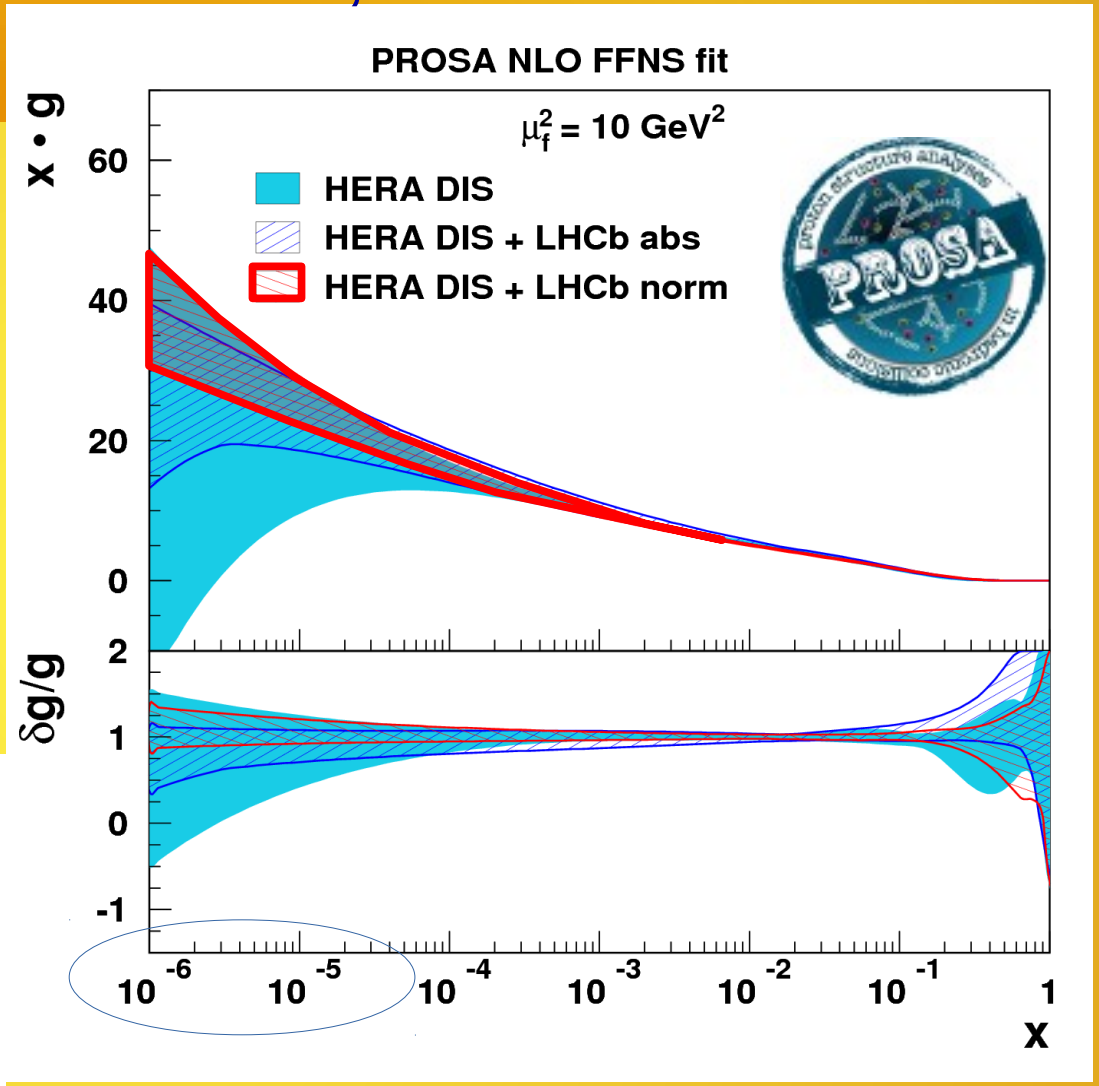


Constraint on low x gluon from LHCb data (A. Geiser)

DESY-15-034, arXiv 1503.04581







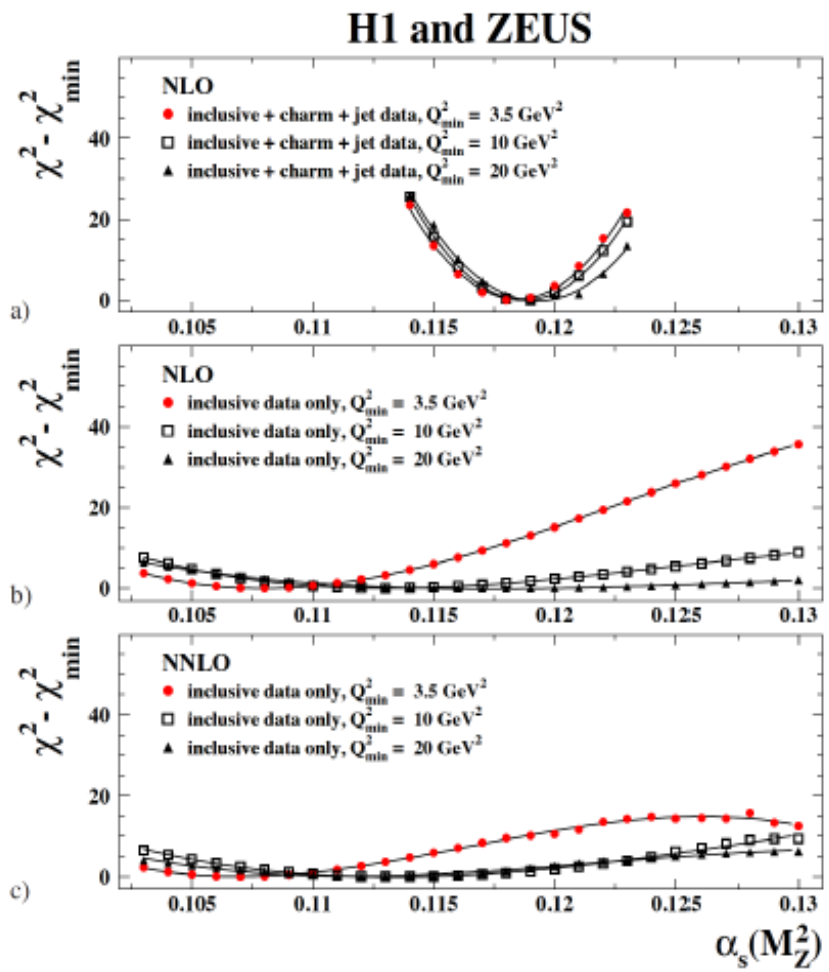
gluon positive and well constrained down to x ~ 10^{-6}

HERAPDF2.0Jets (G. Brandt)

α_s Choice in Fit and Validation

DESY-15-039

$$\alpha_s(M_Z^2) = 0.1183 \pm 0.0009(\text{exp}) \pm 0.0005(\text{model/parameterisation}) \pm 0.0012(\text{hadronisation}) \; ^{+0.0037}_{-0.0030}(\text{scale}) \; .$$



Inclusive, charm and jet data at NLO

- Fit arrives at $\alpha_s(M_Z) = 0.118$
- Largely independent of Q^2_{min}
- Due to inclusion of jet data in fit

- Inclusive only fits at NLO and NNLO cannot constrain $\alpha_s(M_Z)$ very well
- Strong dependence on Q^2_{min}

Summary

Heavy Flavour production is a powerful tool to probe many features of QCD

Crucial for searches of New Physics

Many interesting new results presented

Impressive amount of work already done,

a lot of work to be done, but a lot of fun!