Summary of Experimental Talks of Heavy Flavour Working Group (WG5)

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DIS 2013, XXI. International Workshop on Deep-Inelastic Scattering and Related Subjects
April 22th to 26th 2013, Marseille, France

- A lot of experimental results on heavy flavours this year!
- This summary obviously is a selection and does not cover everything, apologies for contributions not shown.

Huge amount of new results on various topics:

- Charm and Beauty Production
- Top-quark physics
- Quarkonium
- Heavy Flavour in Heavy Ion Collisions
- Heavy flavours at B-factories
- CP-Violation, Spectroscopy and B-decays

- Combined session with WG1 (Structure Functions)
- Combined session with WG4 (QCD and Hadronic Final States)

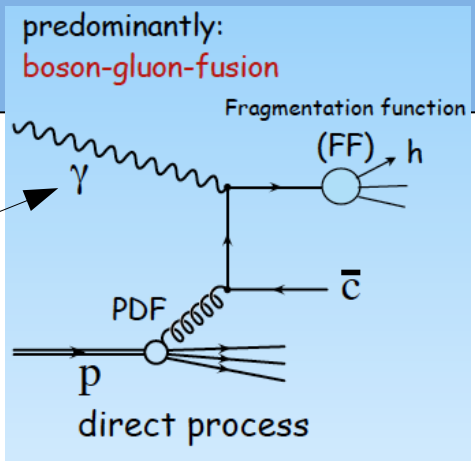
Charm and Beauty Production

- HERA:
  - Charm and beauty Photoproduction (DAUM)
  - Charm in DIS (GEISER, ZENAIEV, BACHYNSKA)
- LHC:
  - Beauty production in ATLAS (ROSSI)
  - Beauty production in CMS (GALANTI)
  - Charm and beauty in LHCb (KOZLINSKIY)

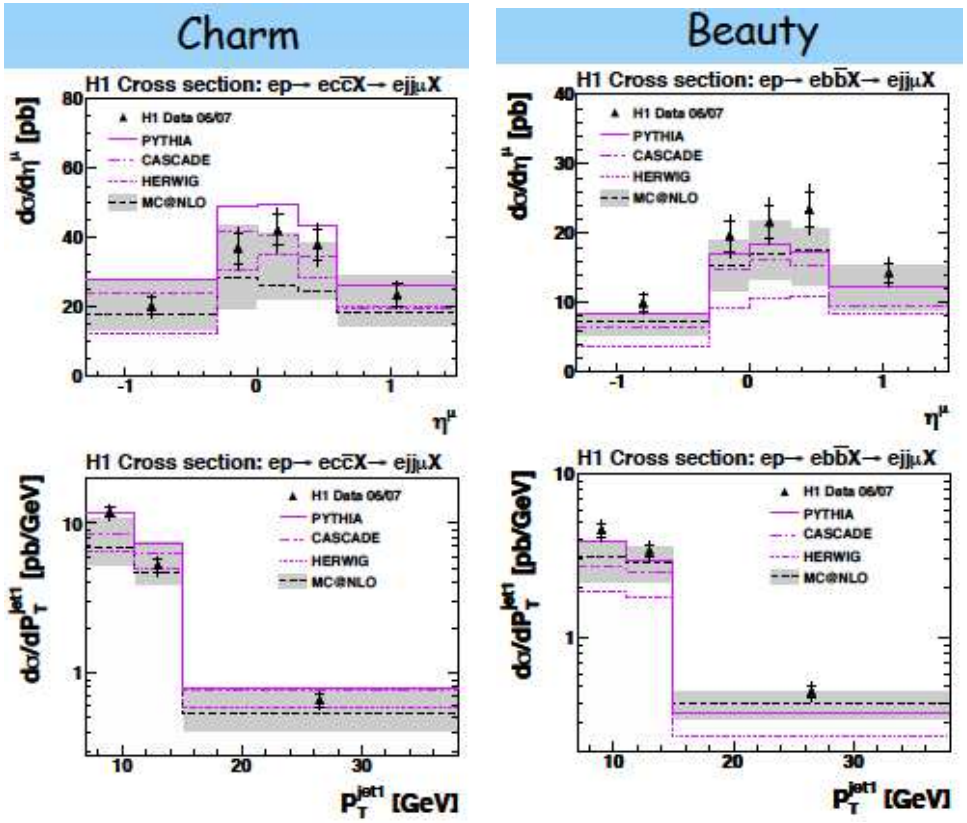
Charm and Beauty Photoproduction at HERA

- Two new measurements using electrons or muons:

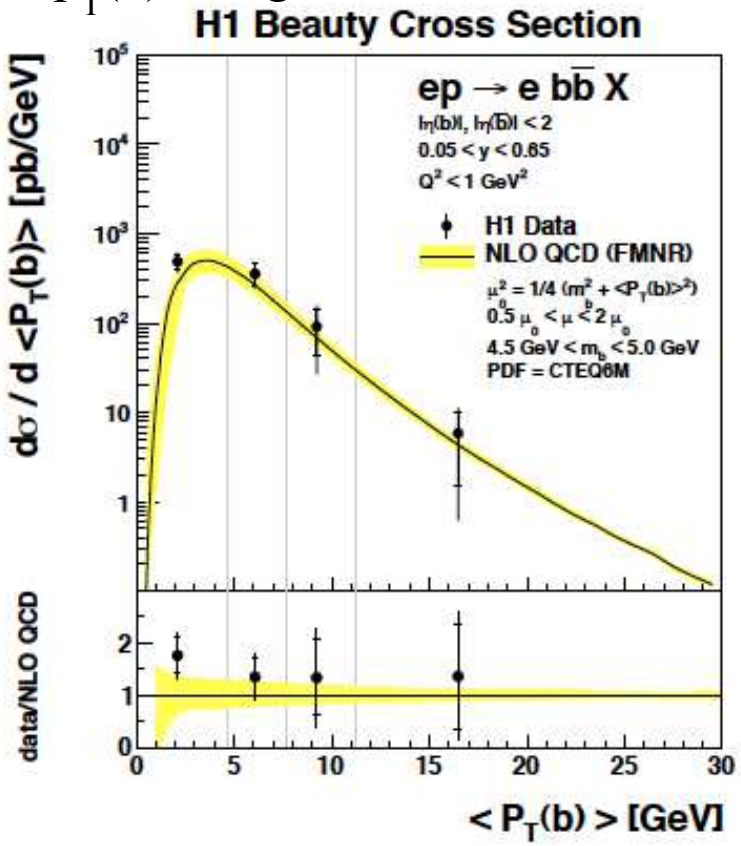
$Q^2 \sim 0$ GeV^2
Quasi real photon.



- Charm and Beauty production with muons.

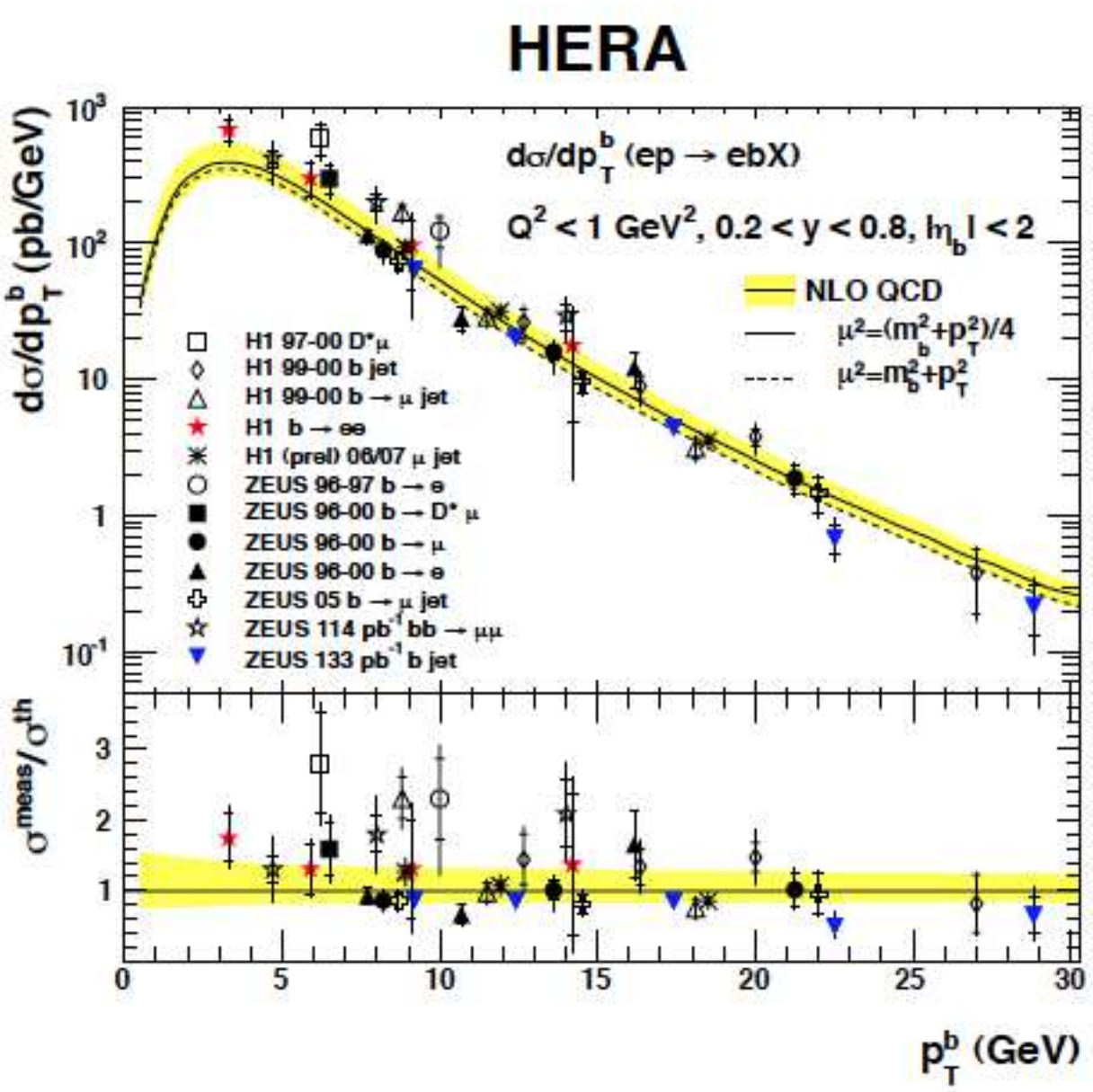


- Beauty production at low $p_T(b)$ using electrons:



(DAUM)

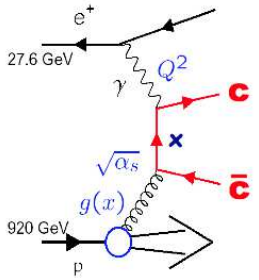
Beauty Photoproduction at HERA as a function of $p_T(b)$



- NLO QCD in good agreement with data

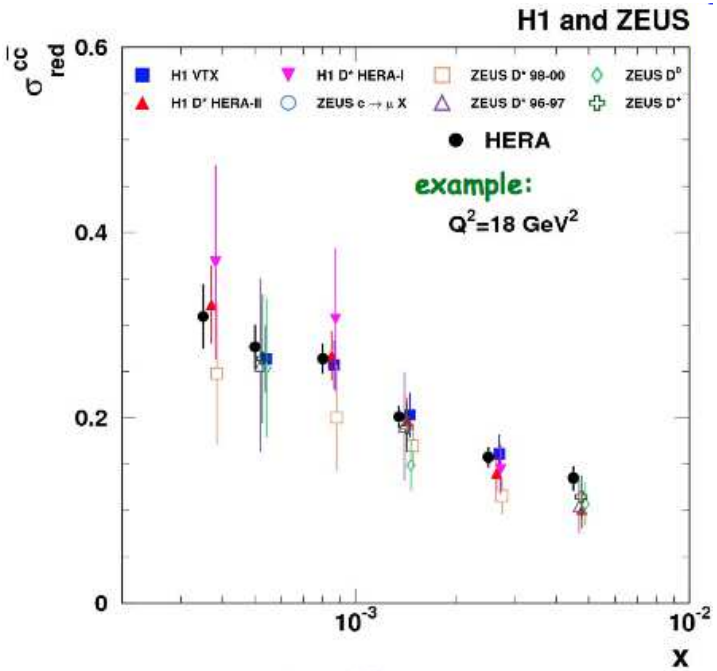
(DAUM)

F_2^{cc} at HERA from data combination and new D^*, D^+ data



$Q^2 >> 0 GeV^2$, DIS up to 30% of the cross section

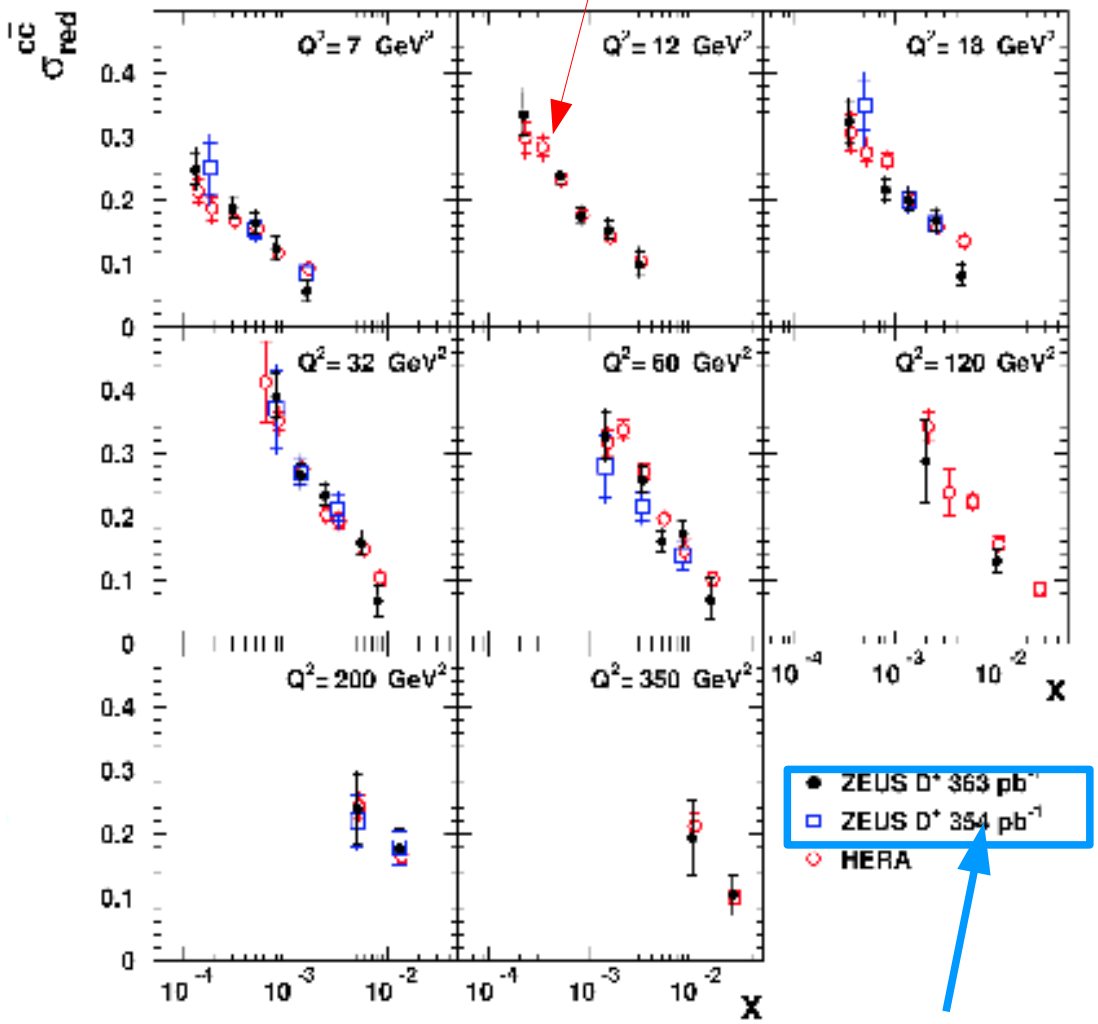
- Combination of charm data from H1 and ZEUS leads to a huge reduction of the errors:



- Data shows sensitivity to charm mass (see PDF summary talk by WG1)

(GEISER)

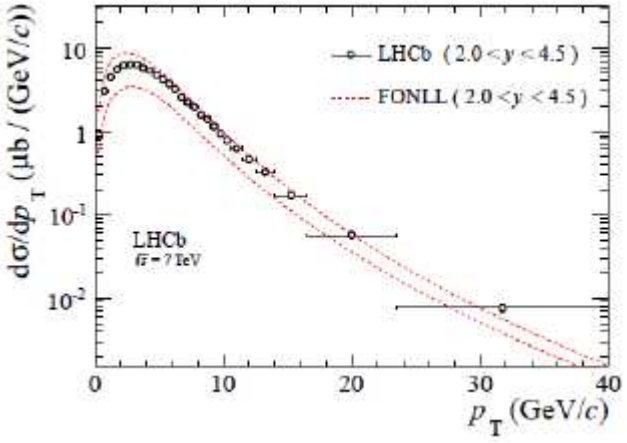
Combined HERA data



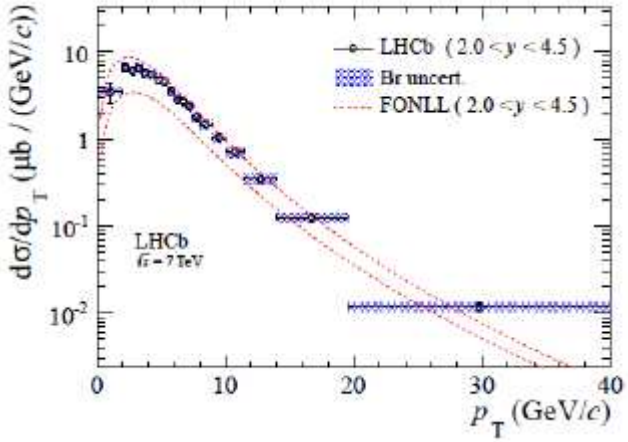
New precise F_2^{CC}, from D* and D+ not yet contained in the combination, (ZENAIEV, BACHYNSKA)

- Measured cross sections:
  - Charm: D^0, $D^{*\pm}$, D^+, D_s^+, Λ_c^+.
  - B mesons: B^+, B^0, B_s^+.
  - $b\bar{b}$ production.
  - $b\bar{b}$ forward-central asymmetry.
- Good agreement with theoretical predictions.

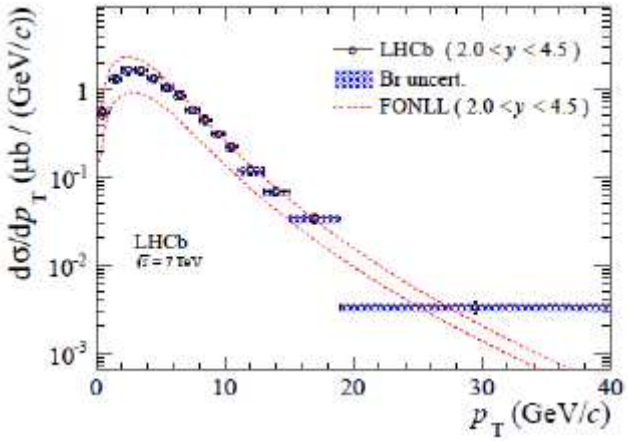
B^+



B^0



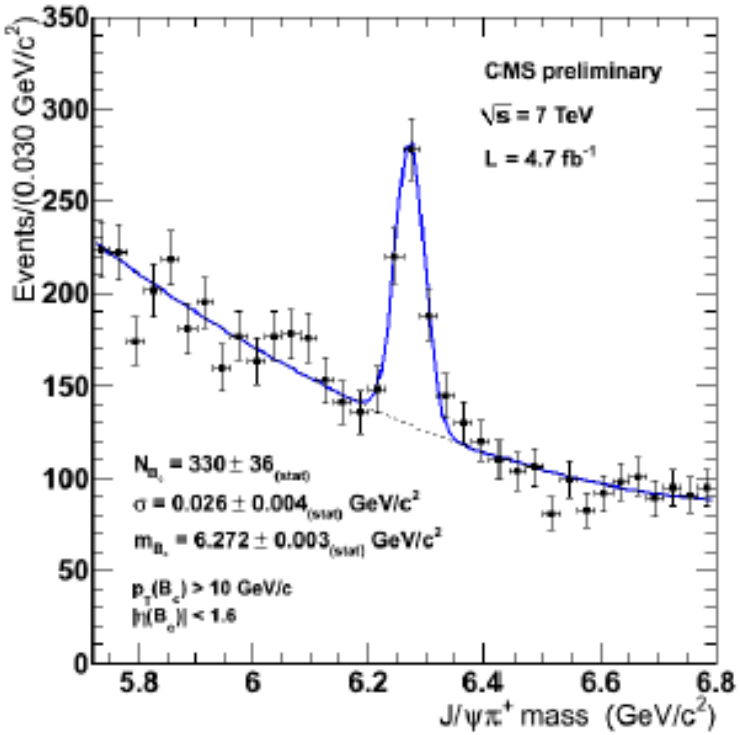
B^+_s

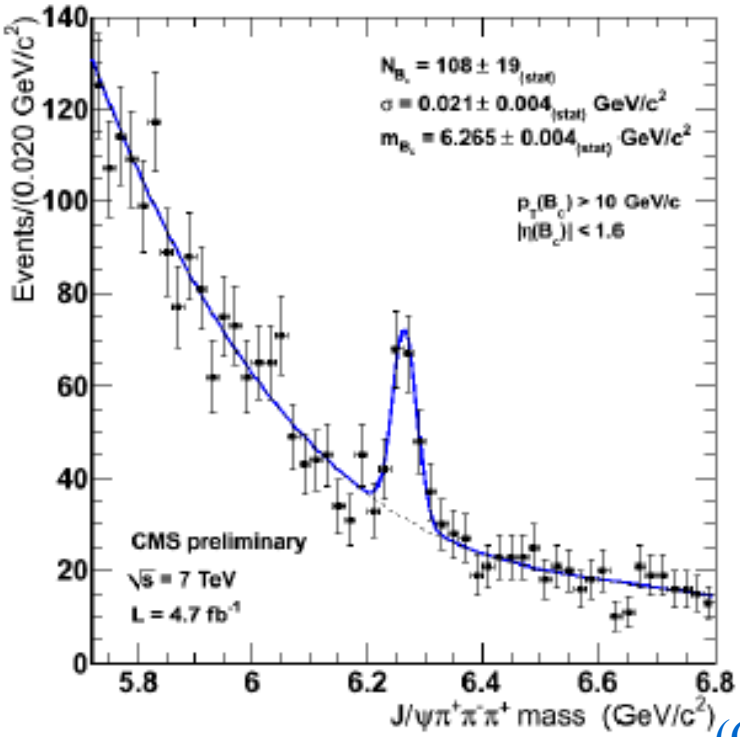


(KOZLINSKIY)

Heavy Flavour results of CMS

- A new measurement of $b\bar{b}$ **angular correlations** complementing previous CMS results
- Several results in the Λ_b^0 **sector:**
  - Differential $\Lambda_b^0 \rightarrow J/\psi\Lambda$ cross section
  - Particle/antiparticle asymmetry
  - Mean lifetime
- Measurement of the B_s **lifetime difference** $\Delta\Gamma_s$
- Observation of $B_c \rightarrow J/\psi\pi$ **and** $B_c \rightarrow J/\psi\pi\pi\pi$ **decays**

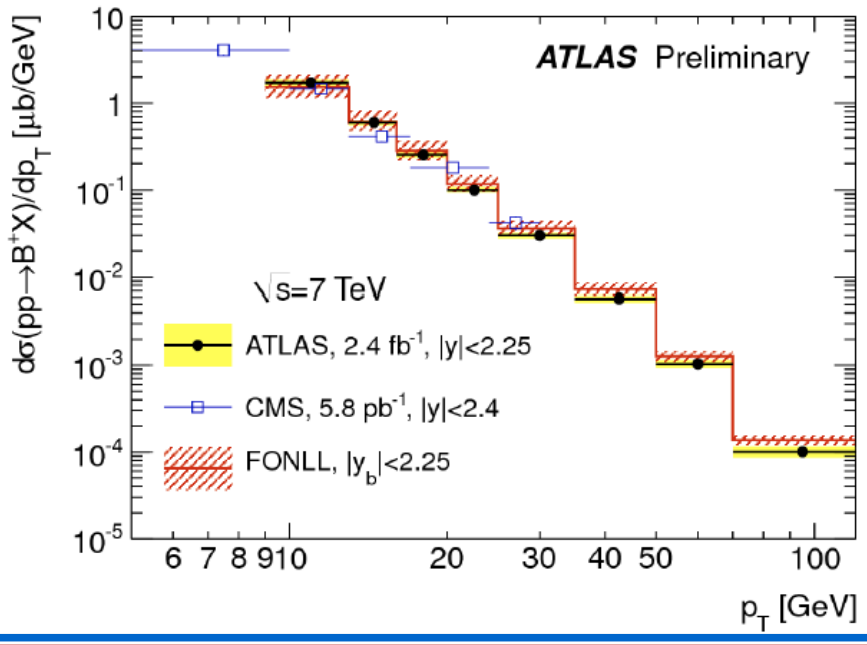




(GALANTI)

- **b-hadron production cross-section from D*μX final states 3.3 pb^{-1} (Nucl. Phys. B864 (2012) 341-381):** Differential cross sections as functions of p_T and |y| are produced for both H_b and $H_b \rightarrow D^*\mu X$ production. These measurements are found to be higher than the NLO QCD predictions, but consistent within the experimental and theoretical uncertainties.
- **Production cross section of B^+ at $\sqrt{s}$ = 7TeV ($B^\pm \rightarrow J/\psi K^\pm$) (ATLAS-CONF-2013-008):** The measured differential cross section is in agreement with the predictions of next-to-leading order and a FONLL QCD computations within the experimental and theoretical uncertainties

$B^\pm \rightarrow J/\psi K^\pm$: cross-section measurement



Fixed-Order-Next-to-Leading Logarithm (FONLL) (with $f_b \rightarrow B^+ = (0.401 \pm 0.008)$) is in good agreement with the measured $d\sigma/dp_T$.

(ROSSI)

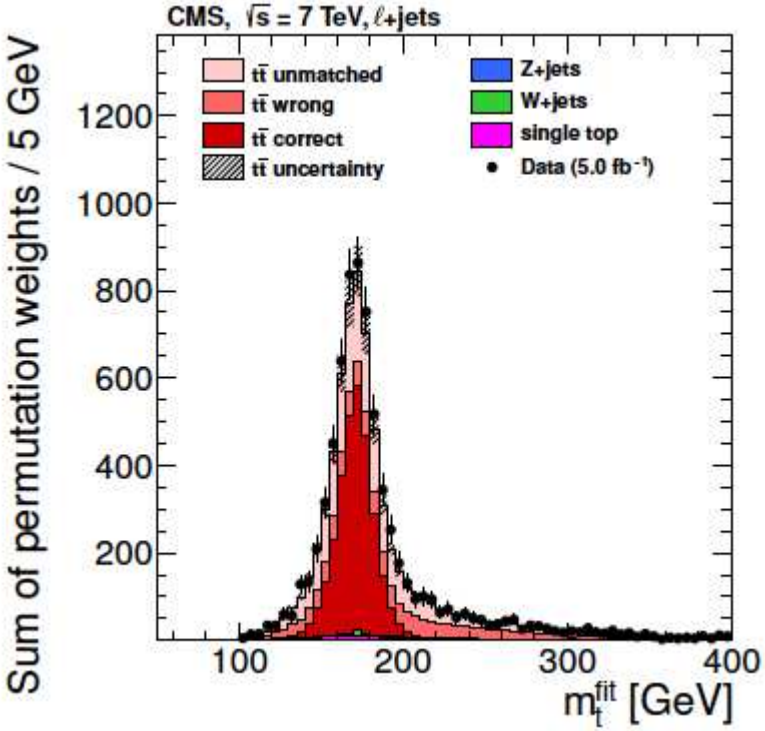
Top

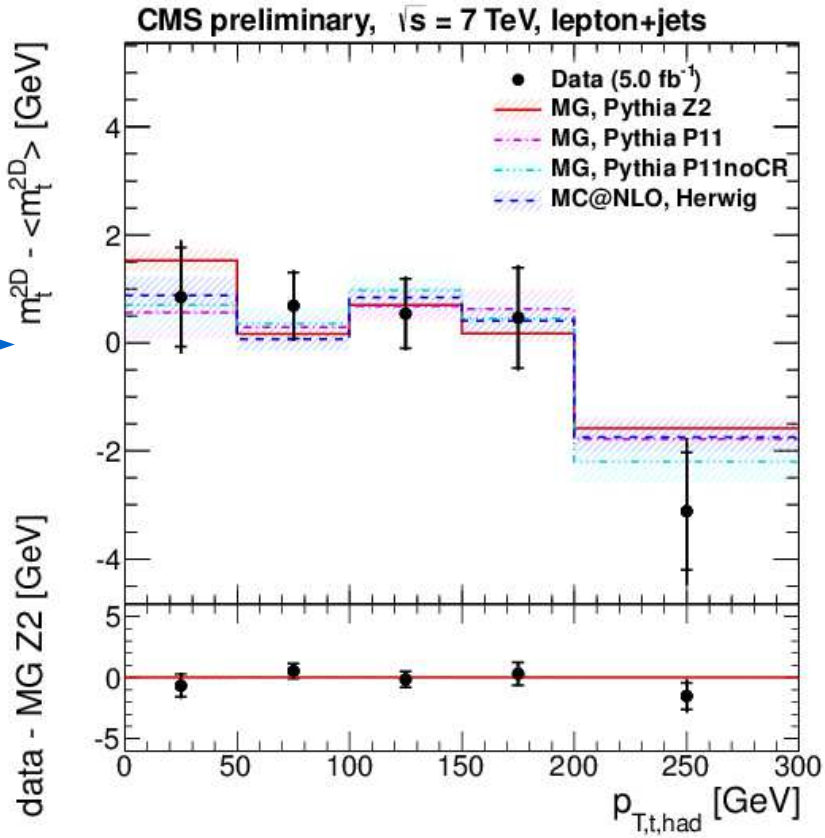
- … in CMS (BROCHERO, RÖCKER, YAZGAN)
- … in ATLAS (FRANCHINI, HOWARTH)

Top mass measurements

- Precision of "direct" m(top) measurements at LHC already competitive with Tevatron, using various decay channels
- Now investigating new, alternative techniques and starting differential mass studies to test systematics and gain better understanding of m(top)

- Lepton + 4 jet analysis:



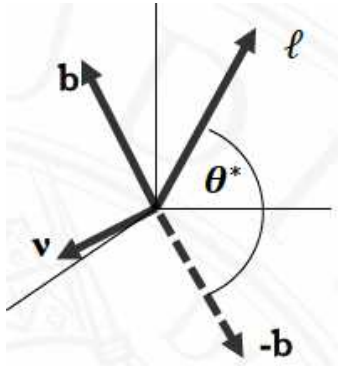


Kinematic dependence of reconstructed m(top) well modeled by MC (BROCHERO)

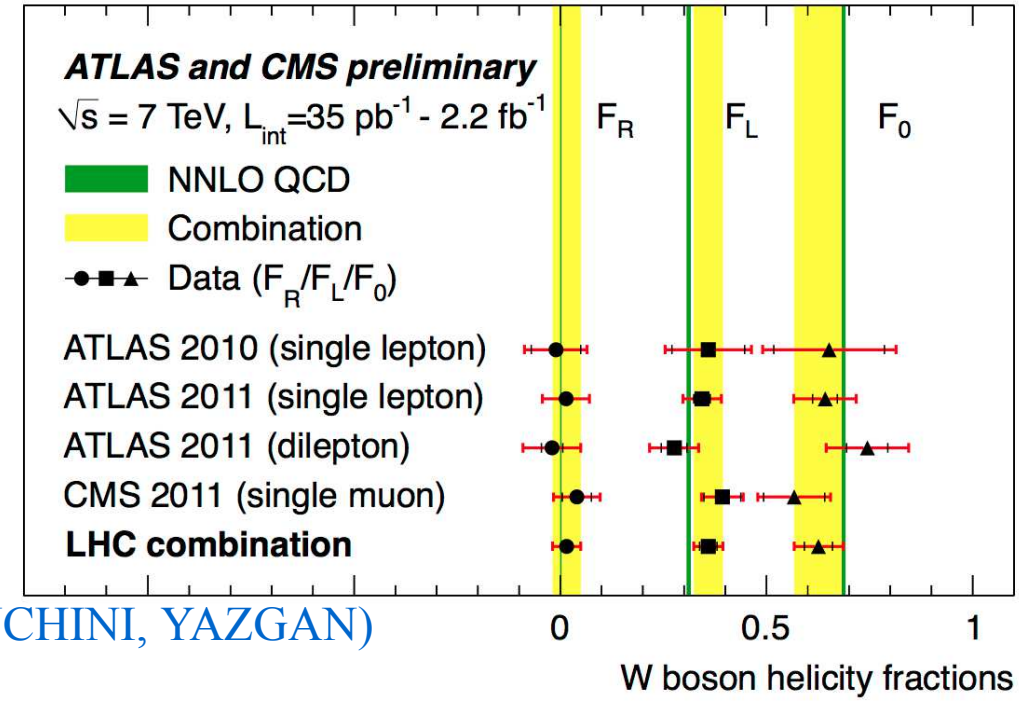
W Helicity fractions in $t\bar{t}$ and single top

- Angular distribution parameterized with 3 variables

$$\frac{1}{\sigma}\frac{d\sigma}{\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)F_0 + \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{8}(1+\cos\theta^*)^2 F_R$$

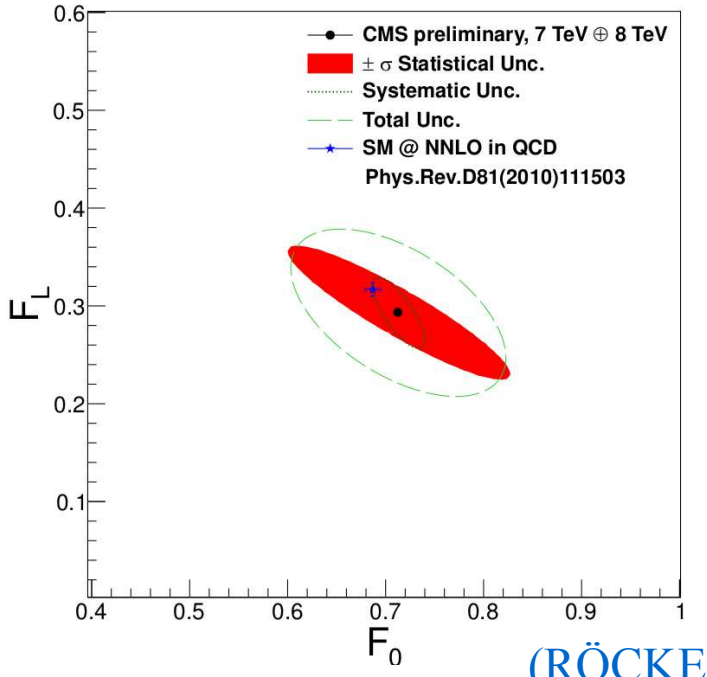


- In $t\bar{t}$ (new: ATLAS-CMS combination)



(FRANCHINI, YAZGAN)

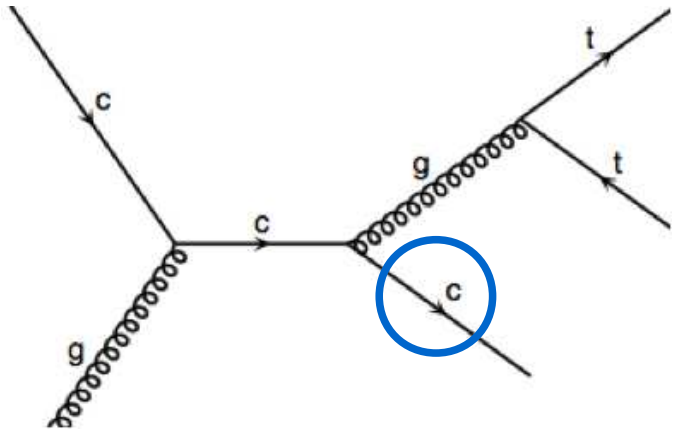
- Now also in single-top:



(RÖCKER, YAZGAN)

- Consistent results, compatible with SM V-A couplings

$t\bar{t}$ + Heavy Flavour



- **$t\bar{t}$ + HF** (HF = bb, cc, b, c)
- Flavour coming from gluon splitting proton
- Main irreducible background to **ttH**
- Many **BSM** models also predict additional HF in **tt** events.

$$R_{\mathrm{HF}} = \frac{\sigma_{\mathrm{fid}}(t\bar{t}+\mathrm{HF})}{\sigma_{\mathrm{fid}}(t\bar{t}+j)}$$

At least 3 b-tagged jets

At least 2 b-tagged jets

RHF = [7.1 ± 1.3 (stat.) +5.3/-2.0 (syst.)] %

RHF (LO) = [3.4 ± 1.1 (syst.)] %
RHF (NLO) = [5.2 ± 1.7 (syst.)] %

- No deviation from SM observed.

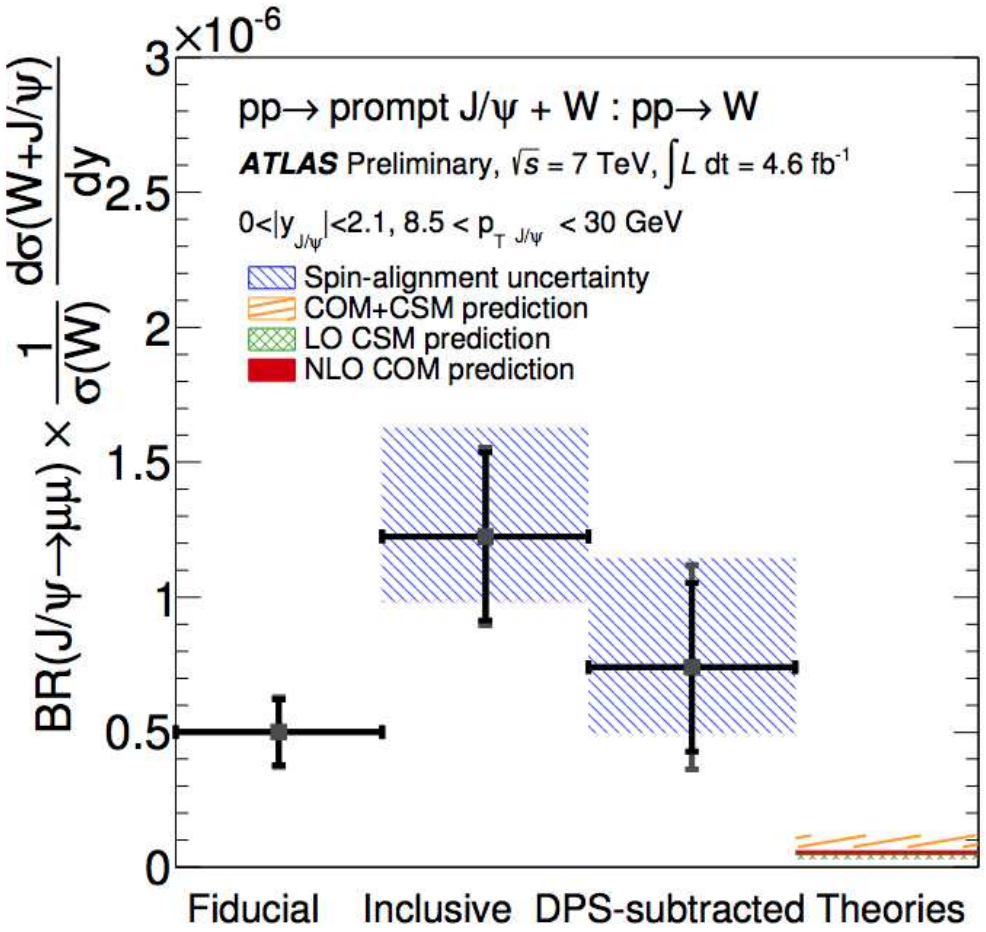
(HOWARTH)

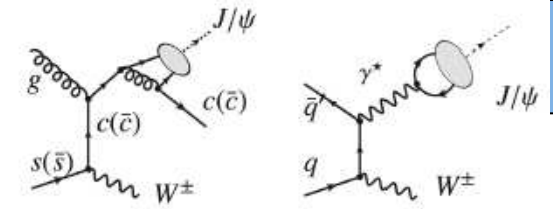
Quarkonium

- Inelastic J/ψ in Photoproduction at HERA (BERTOLIN)
- Production of Quarkonium in ATLAS (PRICE)
- Production of Quarkonium in CMS (SEIXAS)
- Exotic Quarkonium in LHCb (FITZPATRICK)
- Exotic Quarkonium in CMS (YETKIN)

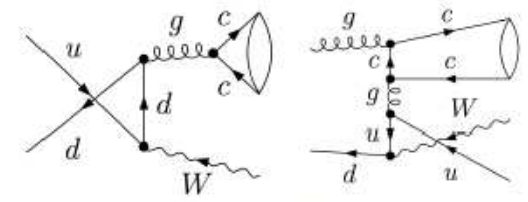
Production of W boson + prompt J/ψ (Atlas)

- Total cross section of inclusive W+prompt J/ψ before and after double parton scattering component:





LO CSM (SINGLET) arXiv:1303.5327



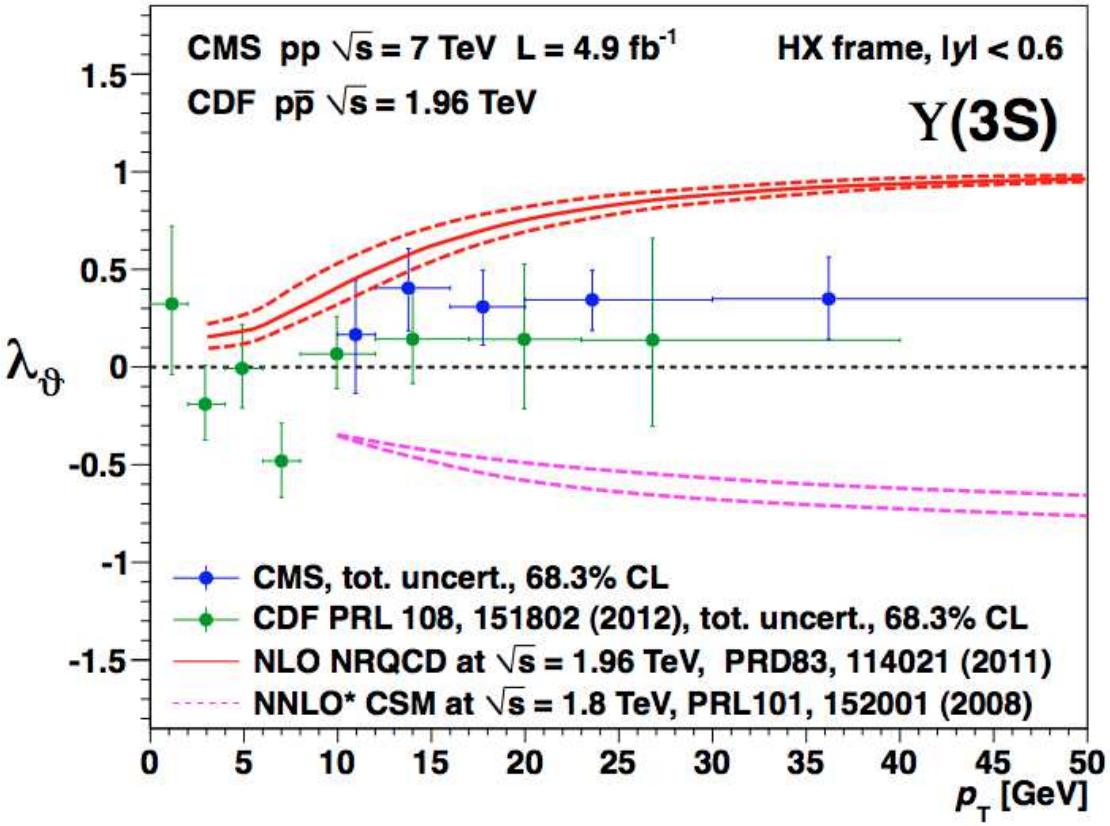
NLO COM (OCTET) arXiv:1304.4670

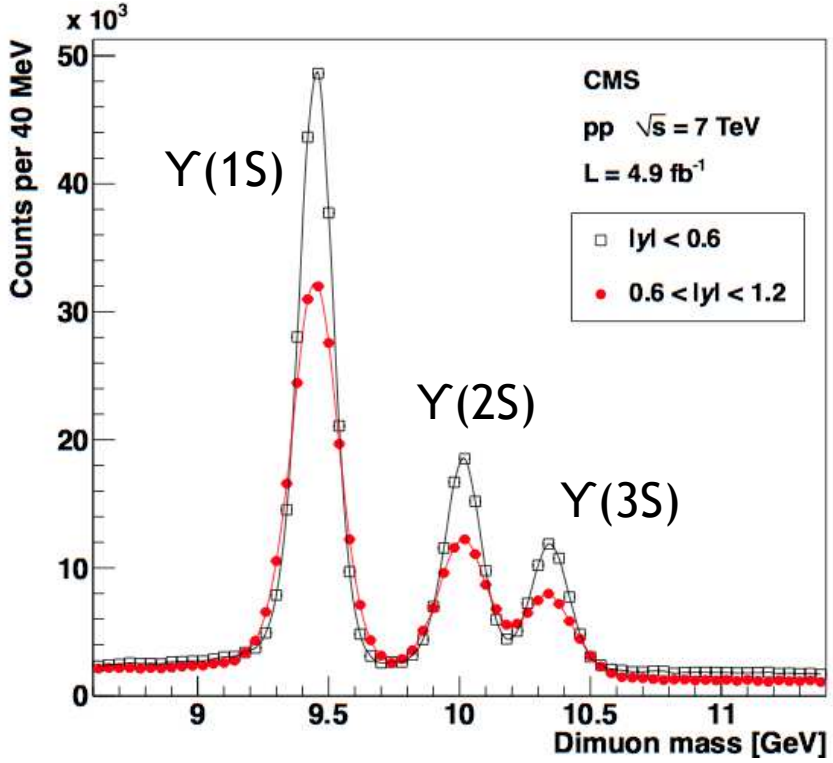
- First observation (5.3 σ) and measurement of associated W+prompt J/ψ.
- Data approximately an order of magnitude above predictions.

(PRICE)

CMS ϒ(nS) Polarization Analysis

- Analysis done for various, frame-independent polarization parameters λ.
- λ= 0 indicates no polarization.





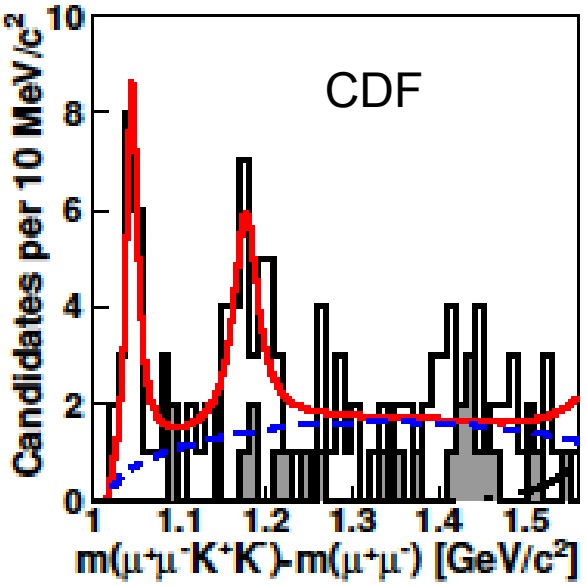
- CDF and CMS are consistent.
- No evidence for strong polarization.
- Totally unexpected, theory predictions do not agree with experimental result.

(SEIXAS)

χ(4140) → J/ψ Φ

- χ(4140) → J/ψ Φ observed by CDF in B → J/ψ ΦK decays:
- Narrow structure considered unusual, almost certain exotic.

- LHCb and CMS reported both on this topic ....



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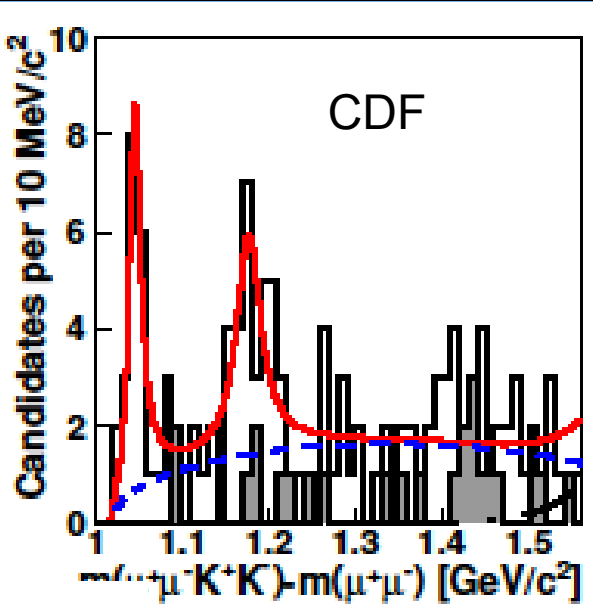
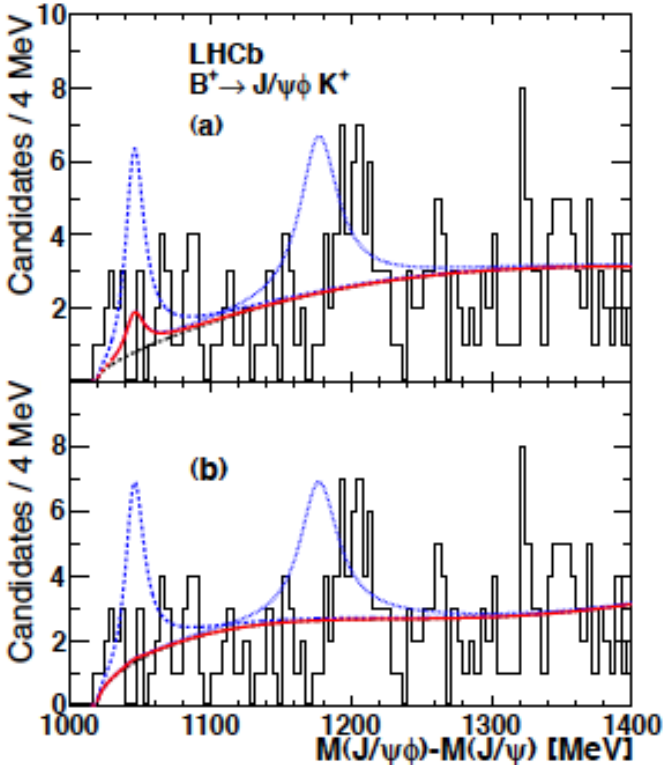


(FITZPATRICK)

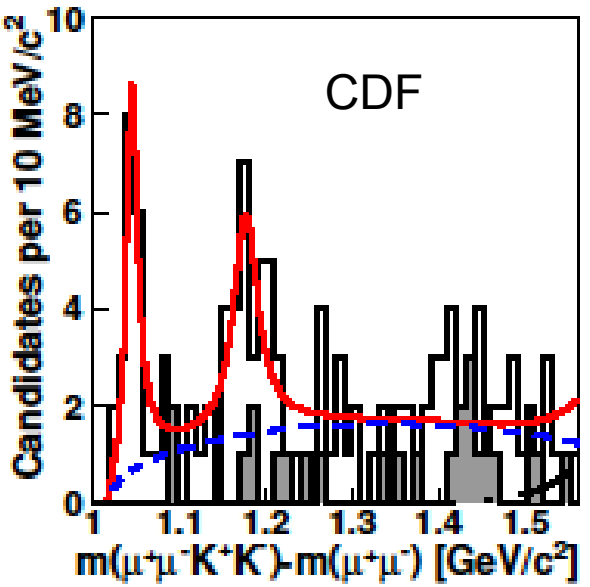


- Top: Fit assuming 3-body phase-space model:
  $N(\mathrm{X}(4140)) = 6.9 \pm 4.9$
  2.4σ disagreement
  $N(\mathrm{X}(4274)) = 3.4^{+6.5}_{-3.4}$
- Bottom: Fit assuming 3-body phase-space × quadratic polynomial
  $N(\mathrm{X}(4140)) = 0.6\ (< 7.1)$
  2.7σ disagreement
  $N(\mathrm{X}(4274)) = 0\ (< 10)$
- LHCb does not confirm narrow structure near threshold

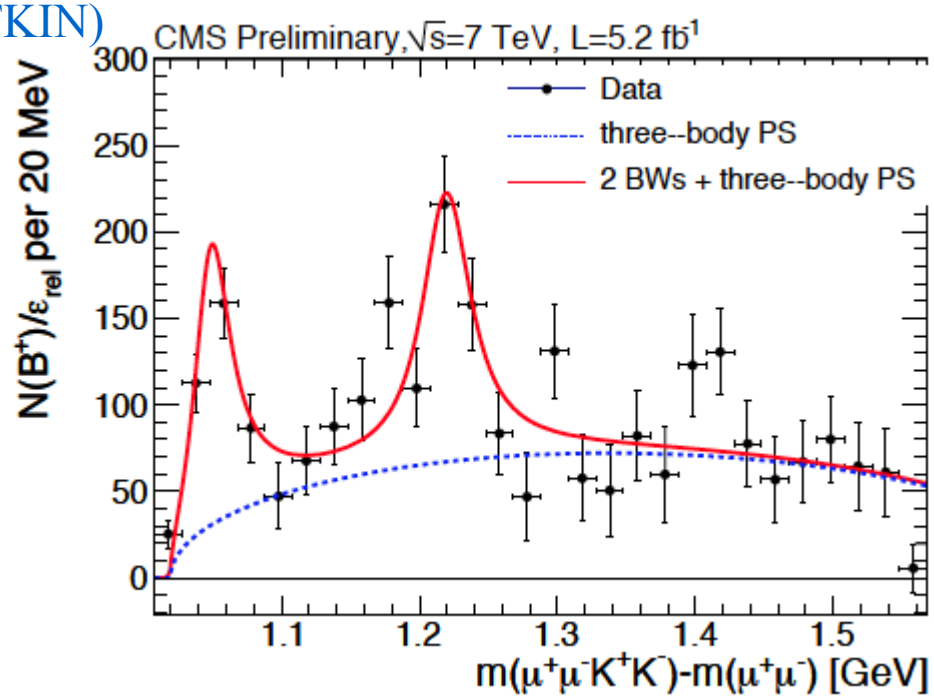
- LHCb: No confirmation of structure.

$\chi(4140) \rightarrow J/\psi\ \phi$

- $\chi(4140) \rightarrow J/\psi\ \phi$ observed by CDF in $B \rightarrow J/\psi\ \phi K$ decays:
- Narrow structure considered unusual, almost certain exotic.



(YETKIN)



*CMS **confirmed** a structure at 4148 MeV with a significance greater than 5σ and **saw an evidence for the second structure** in the same mass spectrum.*

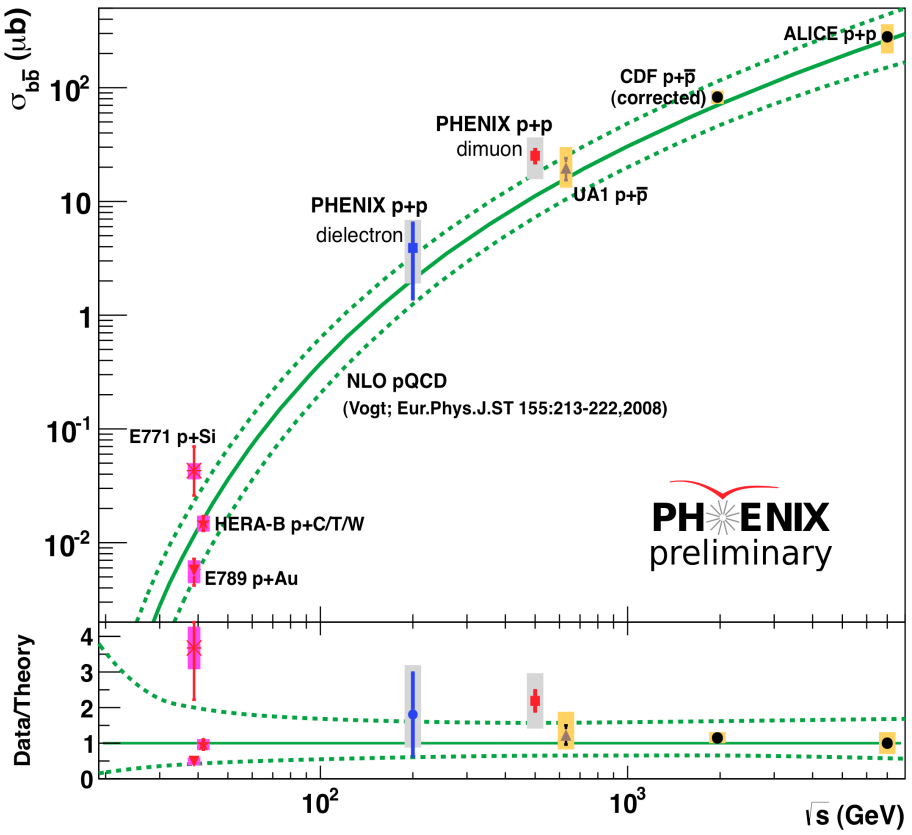
- CMS: Confirmation of structure.

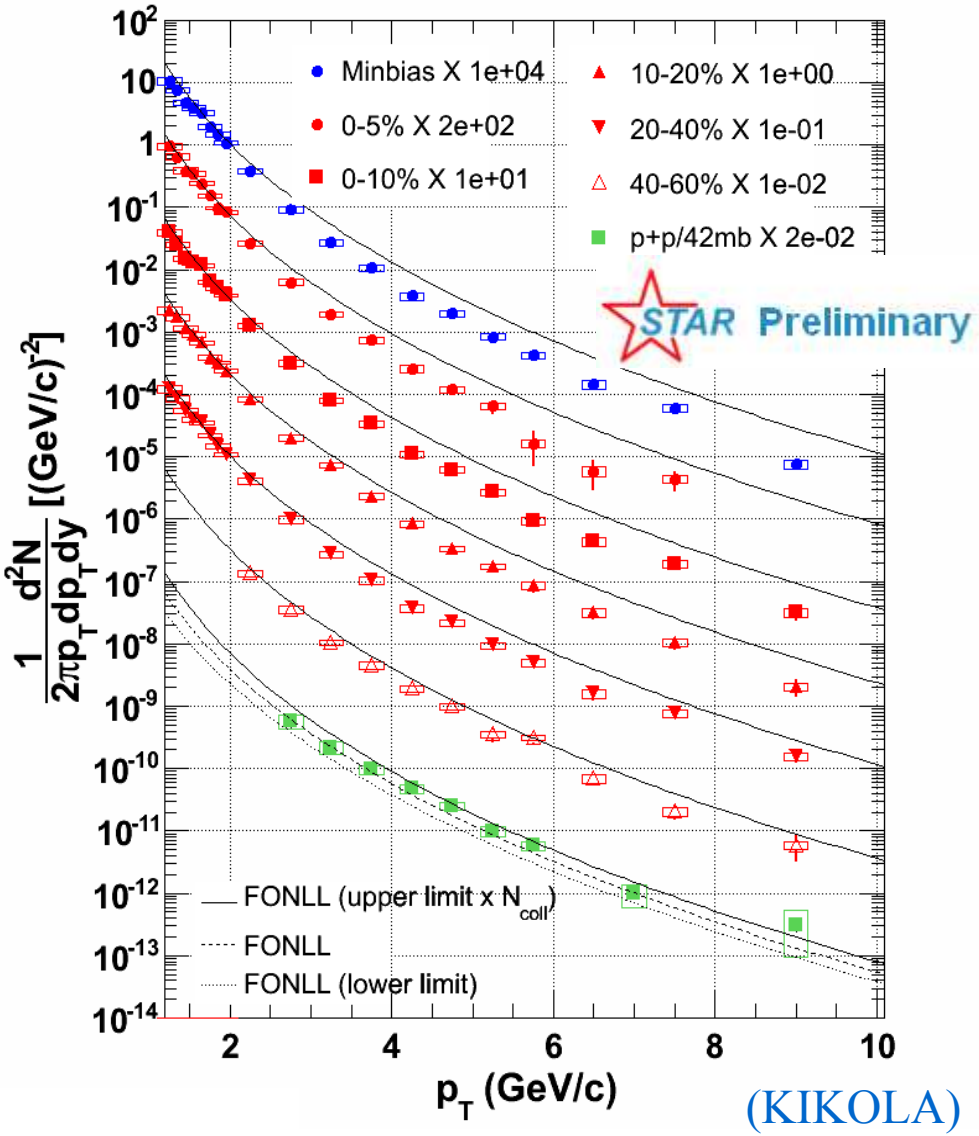
Heavy Flavour in Heavy Ion Collisions

- RHIC
  - Open Heavy Flavor Production at STAR (KIKOLA)
  - Open Heavy Flavor Results from PHENIX (PATEL)
  - Quarkonia results from PHENIX (SEN)
  - Quarkonium measurements at STAR (BIELCIK)
- LHC
  - Studying hot QCD matter at ATLAS, CMS and ALICE (MISCHKE)
  - Open heavy-flavour production with the ALICE (STOCCO)

Charm and Beauty @ RHIC

(PATEL)



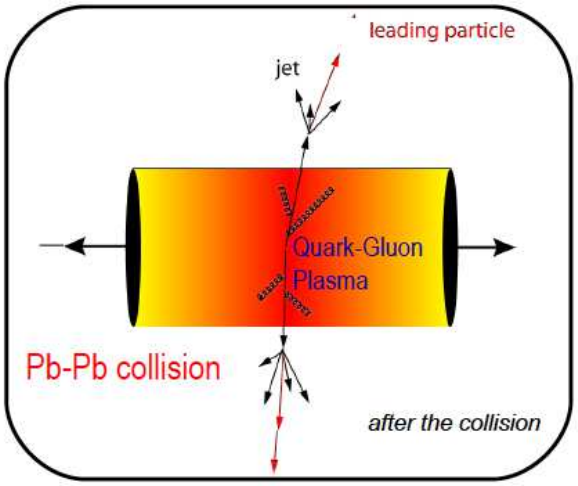


(KIKOLA)

- STAR and PHENIX have multiple measurements for charm and beauty production.
- For pp agreement with pQCD is observed.
- Strong charm suppression at high-p_T in central Au+Au collisions observed.

Probing hot and dense QCD matter

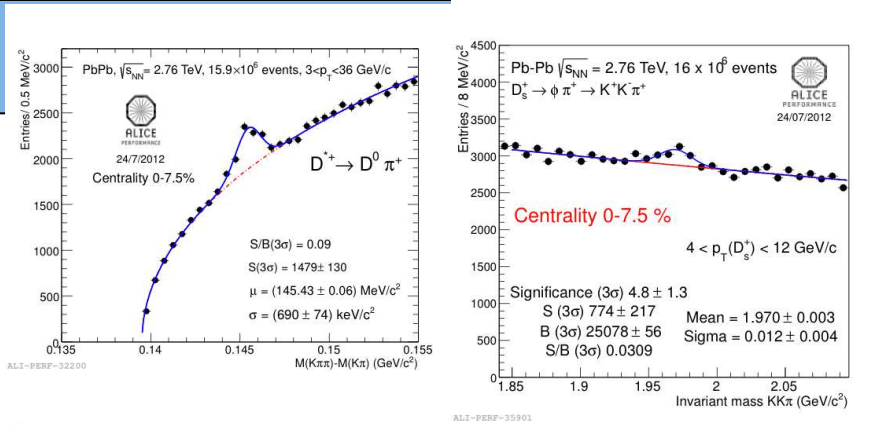
(MISCHKE, STOCCO)

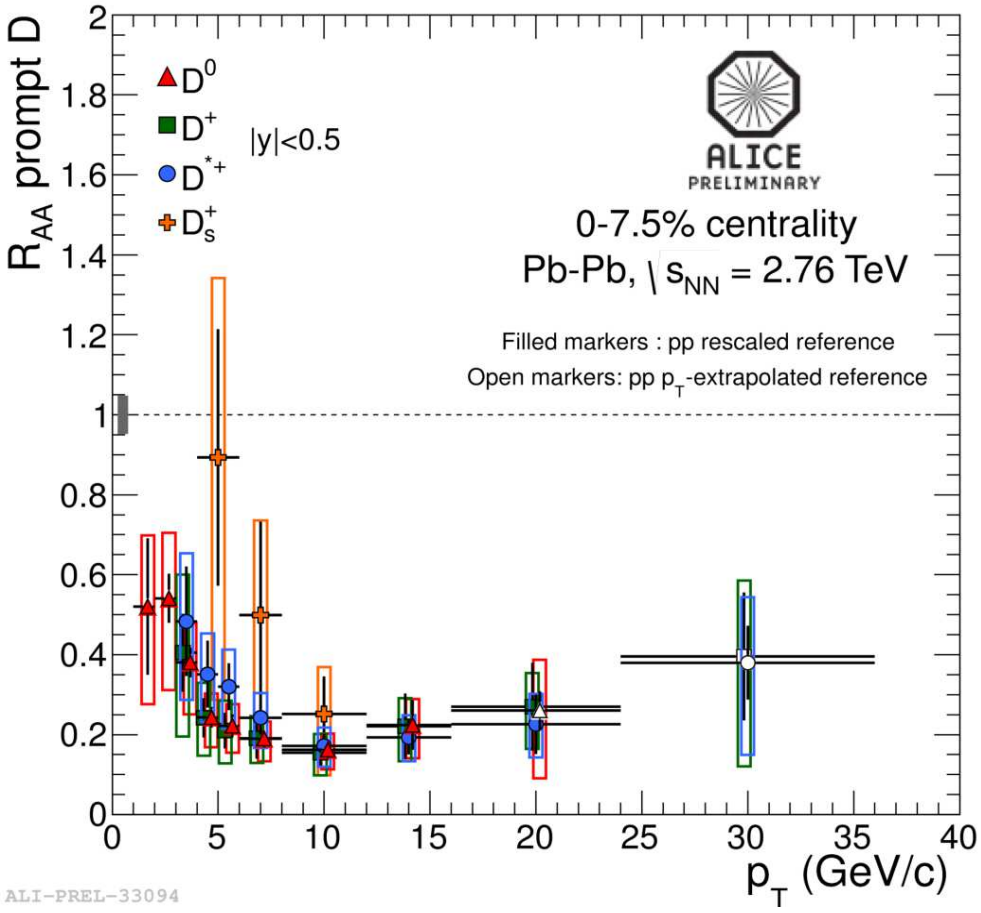


- Quantify medium effects with nuclear modification factor:

$$R_{AA}(p_T) = \frac{\text{Yield}_{AA}(p_T)}{\langle N_{bin} \rangle_{AA} \text{Yield}_{pp}(p_T)}$$

- Suppression provides density measurement of medium.
- No medium effects: production in AA collisions = production in pp collisions ⊗ average number of nucleon collisions
  → $R_{AA} = 1$





- Strong suppression (factor 4-5) above 5 GeV.

Heavy Flavour at B-Factories

- Measurements at BABAR (MULLER, BERNARD, PEREZ)
- CP Violation and polarization in B_s at Belle (ESEN)

CP-Violation, Spectroscopy and B-decays

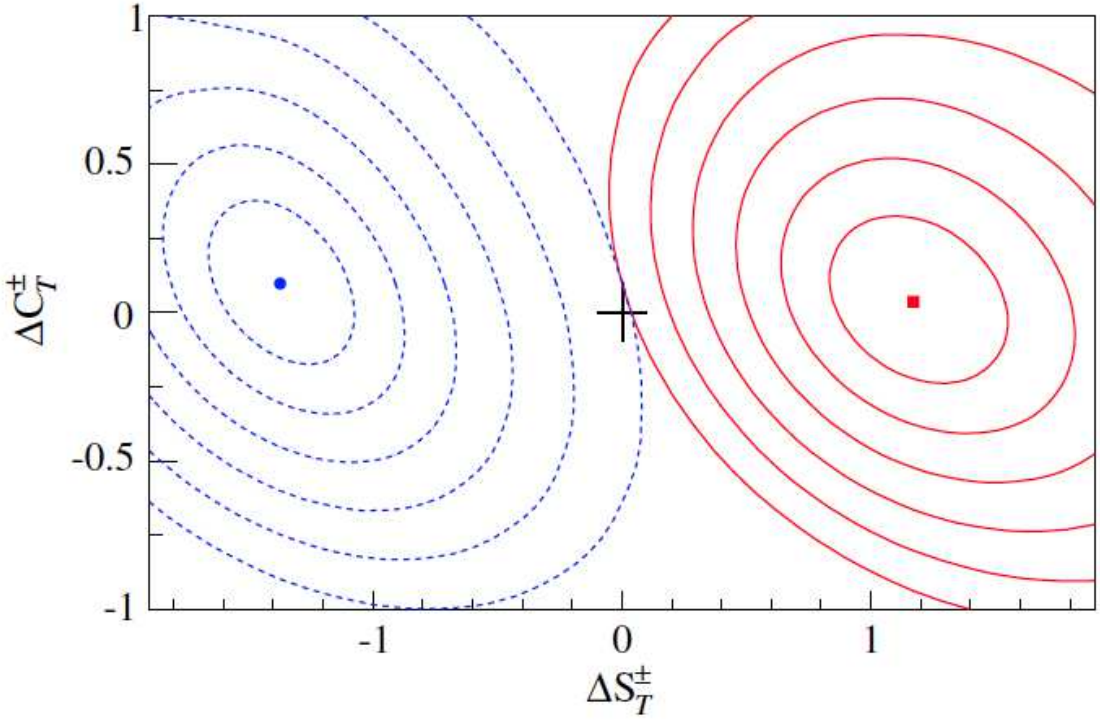
- … with results from D0, ATLAS, CMS, LHCb (BERTRAM, XUHAO, GLIGOROV, SHI, DEWHURST, TURCHIKHIN)

Observation of T-reversal in B^0_d-$\overline{B}^0_d$ system

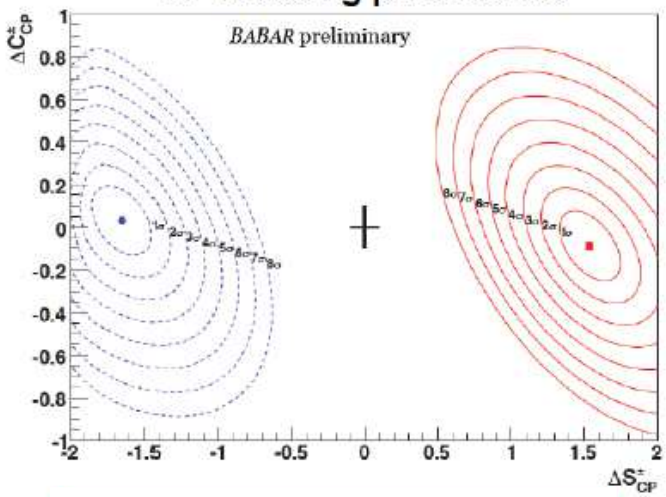
Look for the following transitions

Reference (X,Y) = (tag,CP)		T	T-transformed	
$B^0 \to B_+$	$(\ell^-, J/\psi K^0_L)$	⟷	$B_+ \to B^0$	$(J/\psi K^0_S, \ell^+)$
$B^0 \to B_-$	$(\ell^-, J/\psi K^0_S)$		$B_- \to B^0$	$(J/\psi K^0_L, \ell^+)$
$\overline{B}^0 \to B_+$	$(\ell^+, J/\psi K^0_L)$		$B_+ \to \overline{B}^0$	$(J/\psi K^0_S, \ell^-)$
$\overline{B}^0 \to B_-$	$(\ell^+, J/\psi K^0_S)$		$B_- \to \overline{B}^0$	$(J/\psi K^0_L, \ell^-)$

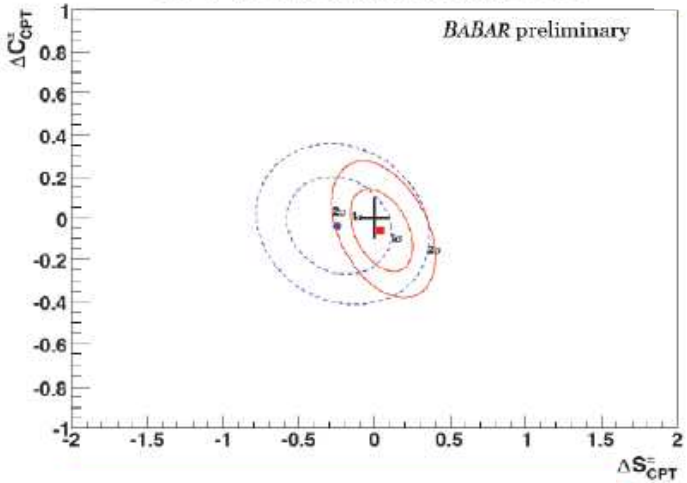
- T-asymmetry:



CP violating parameters



CPT violating parameters



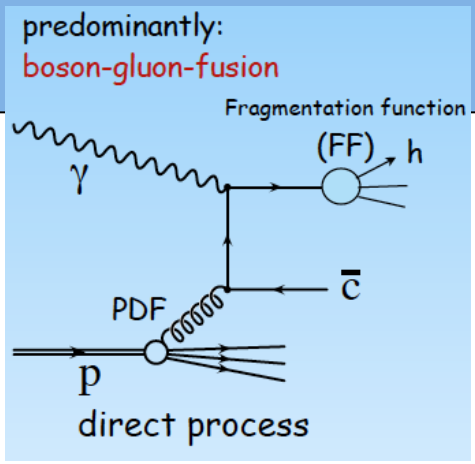
- T reversal in B^0_d-$\overline{B}^0_d$ system is violated, supporting CPT invariance
- 1st observation of T-reversal observation (14 σ).
- Clear evidence for CP violation (16.6 σ) and no evidence of CPT violation.

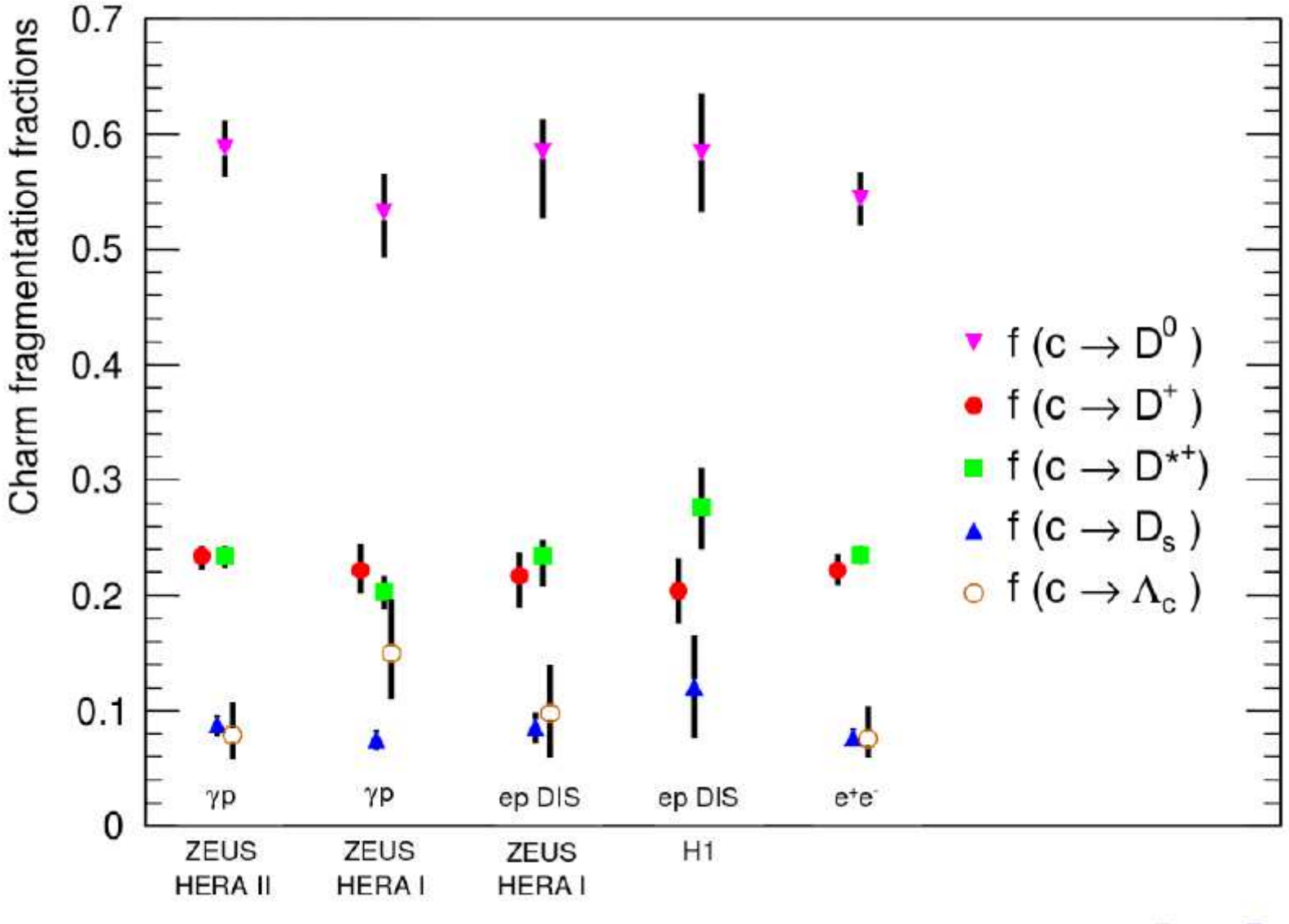
(PEREZ)

Heavy Flavours, QCD and Hadronic Final States
(combined session with WG 4)

- Excited charm and Charm Fragmentation with ZEUS at HERA (VERBYTSKYI, PAUL)
- Flavour composition of di-jets in ATLAS (SHIMIZU)
- Quarkonium Production with CMS (YORK)

Charm fragmentation fractions at HERA





(PAUL)

- Charm fragmentation fractions γp, ep and e^+e^- data consistent.
- Supports hypothesis of heavy-quark fragmentation universality.

Summary

- In our working group we had: Beautiful data, top talks and charming discussions.

- Impressive performance of the experiments, plenty of beautiful new results.
- Models generally describe data remarkably well, but theory challenged in some cases.

Summary of the theory part of Heavy Flavour Session

Antoni Szczurek

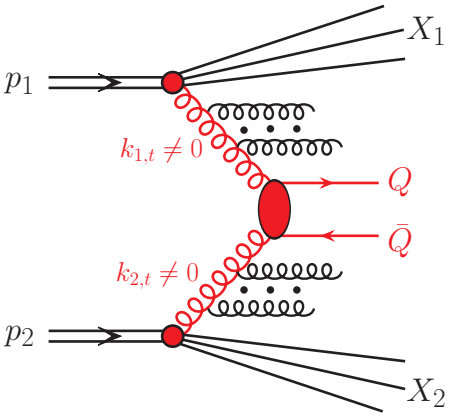
Institute of Nuclear Physics (PAN), Cracow, Poland

Rzeszow University, Rzeszow, Poland

DIS2013

Marseille, France, April 22 - 27, 2017

Charmed mesons and nonphotonic leptons at the LHC



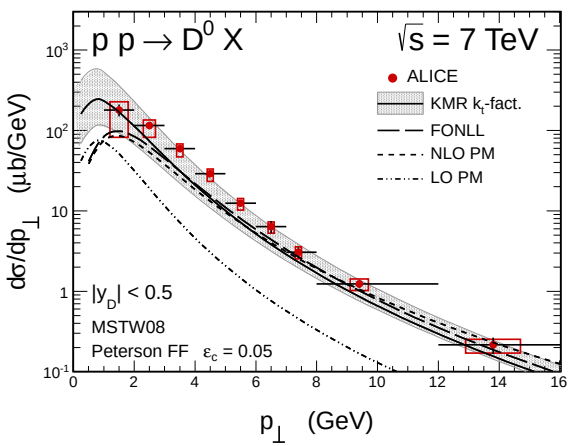
R. Maciula and A. Szczurek, arXiv:1301.3033 (hep-ph)

k_t-factorization approach $\longrightarrow \kappa_{1,t},\ \kappa_{2,t} \neq 0$

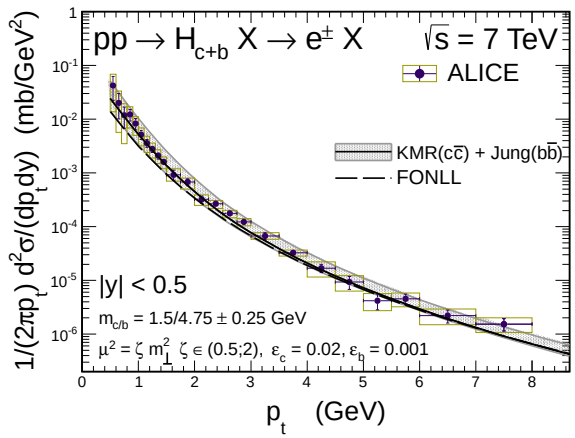
$\Rightarrow$ efficient for $Q\bar{Q}$ correlations

- gluon-gluon fusion $\longrightarrow$ charm and bottom quarks production at high energies
- charm cross section at the LHC $\rightarrow$ small-x region (up to 10^{-5})
  great test of existing unintegrated gluon distribution functions!
- several models of UGDFs: Jung (CCFM, wide x-range), KMS, Kutak-Stašto (small-x, saturation effects), Kimber-Martin-Ryskin (larger x-values)

most of the LHC inclusive D mesons data reasonably described only within KMR UGDFs and only with upper limits of theoretical uncertainties



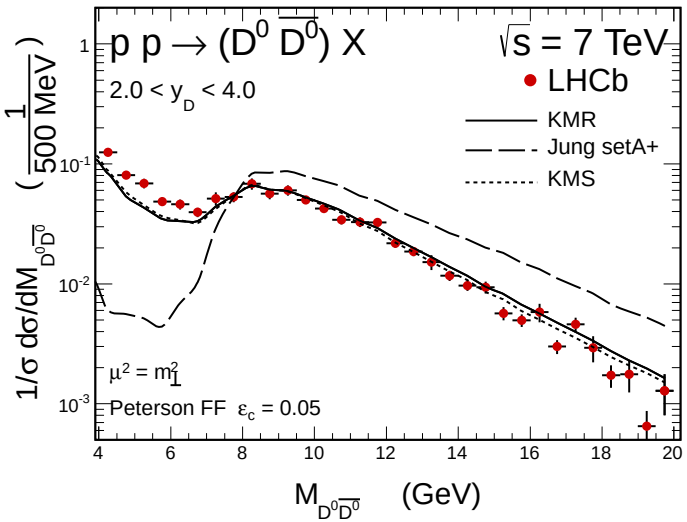
spectra of leptons from semileptonic decays very well described, using KMR and Jung set$A+$ UGDFs, respectively for charm and bottom components

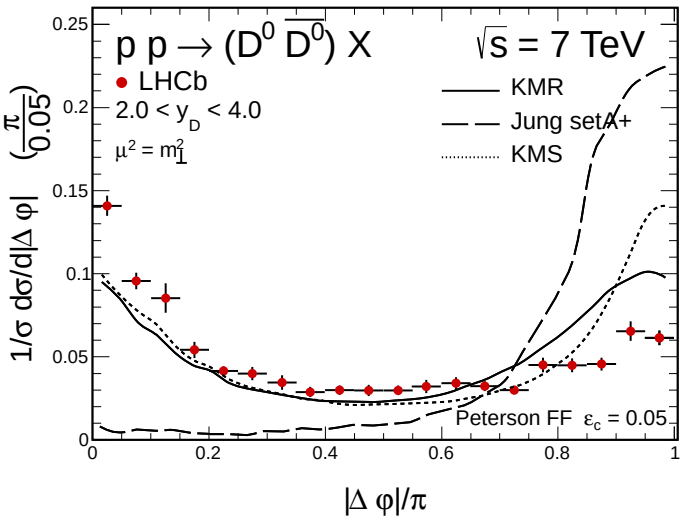


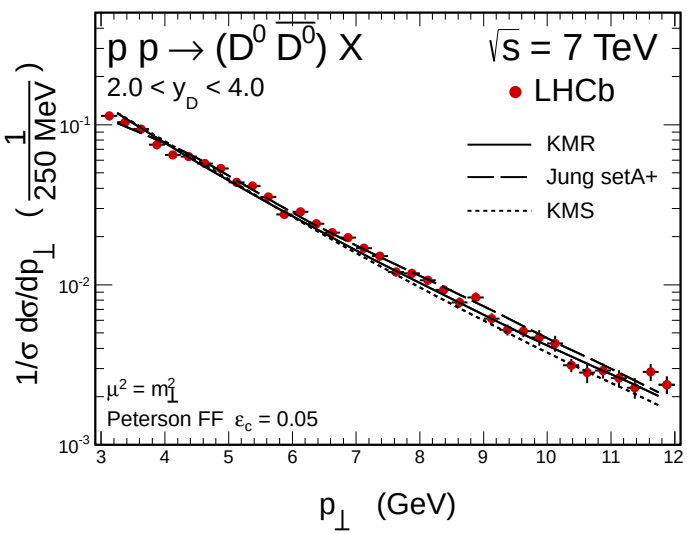
inclusive distributions consistent with FONLL predictions

Kinematical correlations between D and $\overline{D}$ at the LHCb

R. Maciula and A. Szczurek, arXiv:1301.3033 (hep-ph)





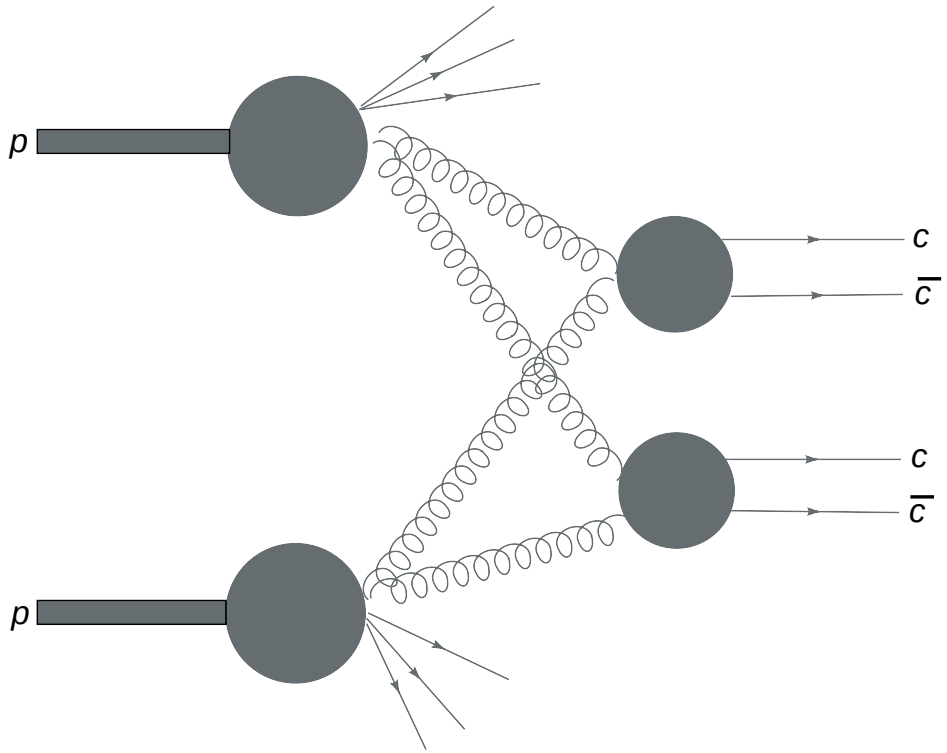


- first theoretical predictions!
- LHCb $D\overline{D}$ data out of reach in the case of FONLL and GM-VFNS approaches
- very good description of shapes of the differential $M_{D^0\bar{D}^0}$, $\varphi_{D^0\bar{D}^0}$ and $p_\perp$ distributions as well as of integrated cross sections for different $D_i\overline{D_j}$ modes within KMR UGDFs

Double parton contribution

A. Szczurek

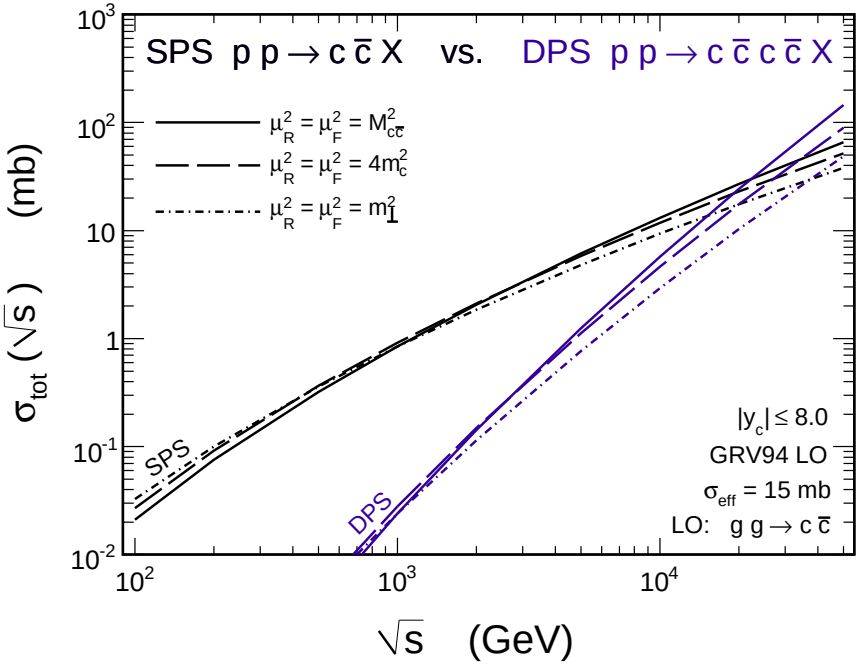
Two hard (parton) scatterings



Luszczak, Maciula, A.S., arXiv:1111.3255,
Phys.Rev. **D85** (2012) 094034,
Maciula, A.S., arXiv:1301.4469, in print in Phys. Rev. D

Double parton scattering

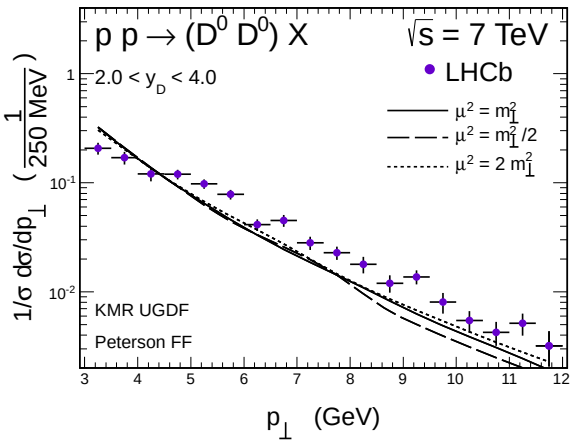
LO collinear calculation

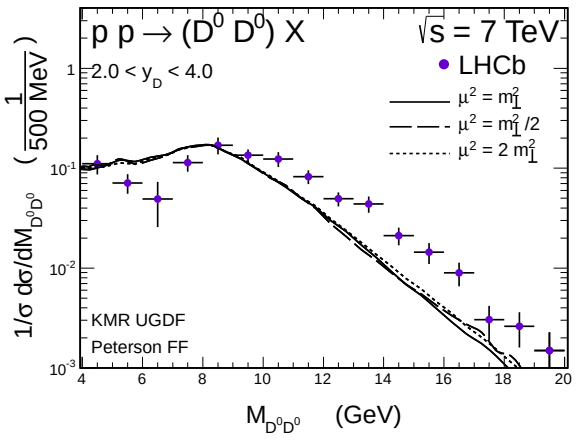


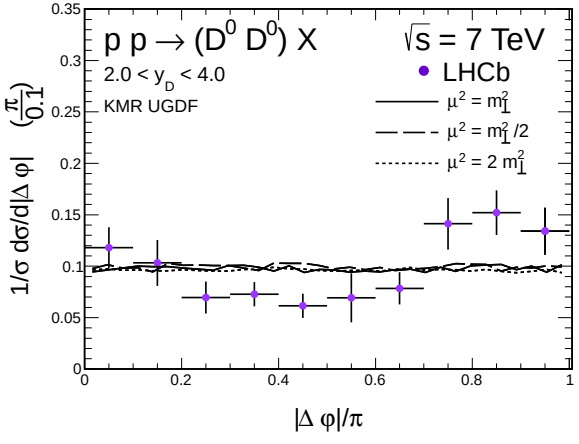
different energy behaviour of $c\bar{c}$ and $c\bar{c}c\bar{c}$ production

Double parton scattering

Production of two $D^0 D^0$ mesons







LHCb data

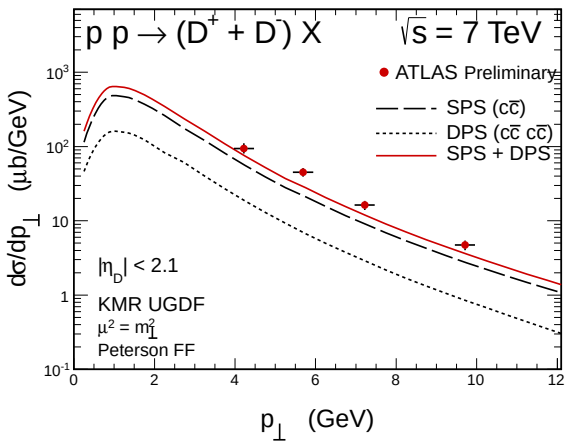
each step within k_t-factorization

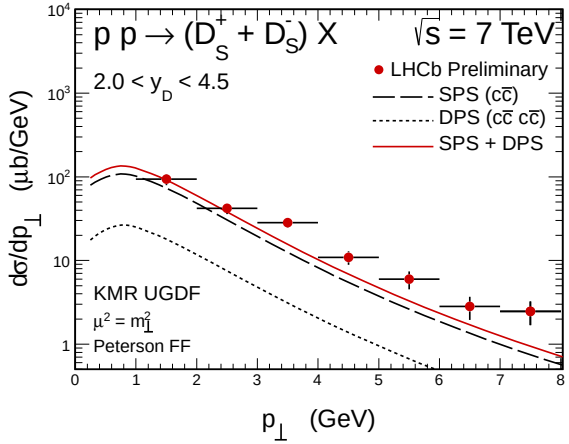
the main tendency is reproduced

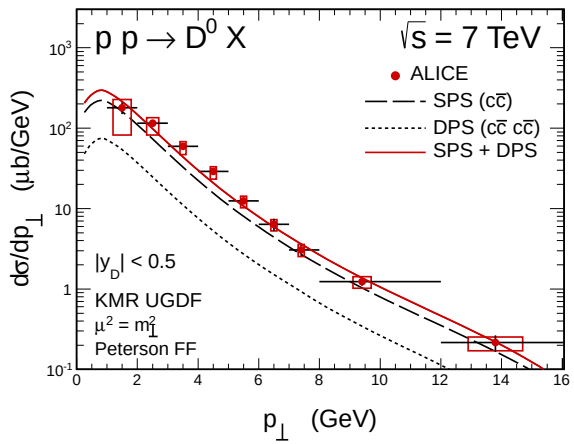
normalizatio roughly OK

Double parton scattering

DPS contribution to inclusive D meson distributions





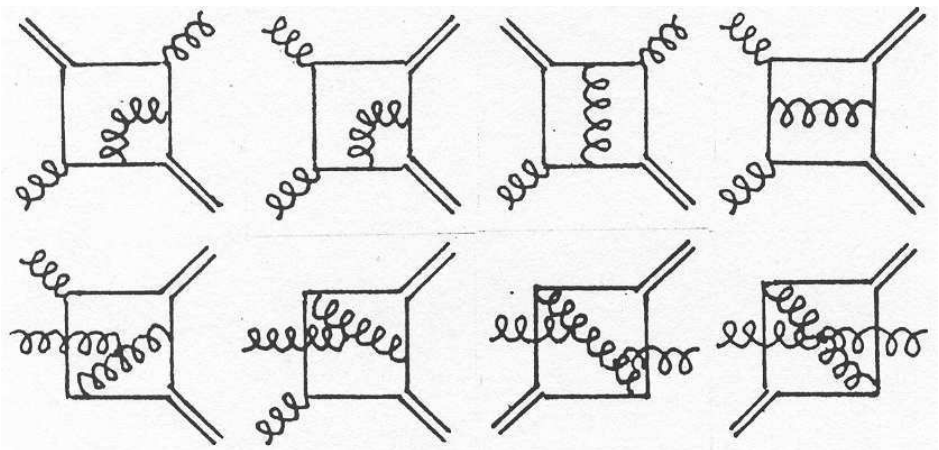


Huge contribution

$pp \to J/\psi J/\psi X$

Nikolai Zotov

single parton mechanisms



$pp \to J/\psi J/\psi X$

LHCb experiment:
$\sigma^{J/\psi J/\psi} = 5.6 \pm 1.1 \pm 1.2$ nb with
$2 < y^{J/\psi} < 4.5$ at 7 GeV.

The single inclusive J/ψ production:
$\sigma^{J/\psi} = 7.65 \pm 0.19 \pm 1.1\ \mu$b

The simple estimate of DPS:
$$\sigma_{DPS}^{J/\psi J/\psi} = \frac{1}{2}\frac{\sigma_{SPS}^{J/\psi}\,\sigma_{SPS}^{J/\psi}}{\sigma_{eff}} \approx 2 \text{ nb}$$

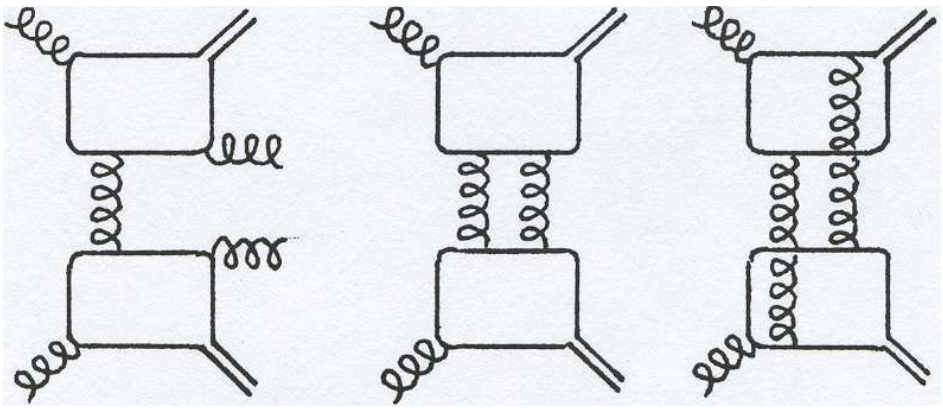
The results of the calculation for SPS contribution:
$\sigma_{SPS}(J/\psi + J/\psi) = 4$ nb

$pp \to J/\Psi J/\psi X$

box single parton processes were estimated

comparable cross section as estimated DPS

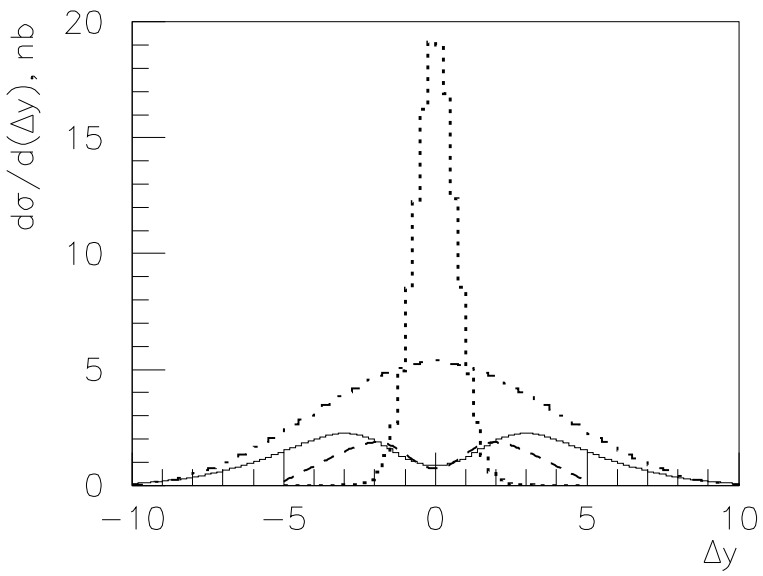
New higher-order mechanisms were identified:



Could be potentially a competition for DPS

$pp \to J/\Psi J/\Psi X$

How to distinguish DPS and SPS processes?

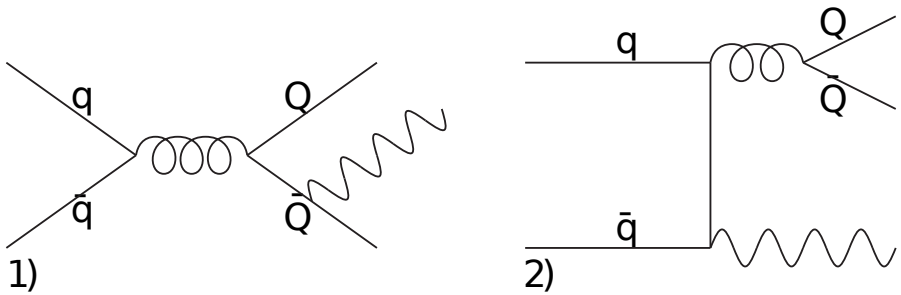


To identify DPS look at large rapidity difference between two J/ψ.
fredContribution of new SPS mechanisms small.

Intrinsic charm/bottom in proton

Tzvetalina Stavreva

Typical diagrams

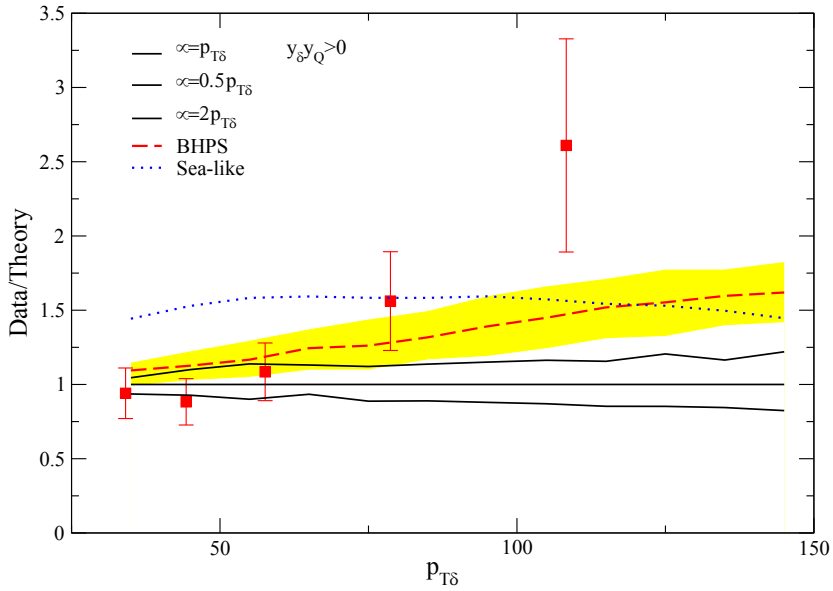


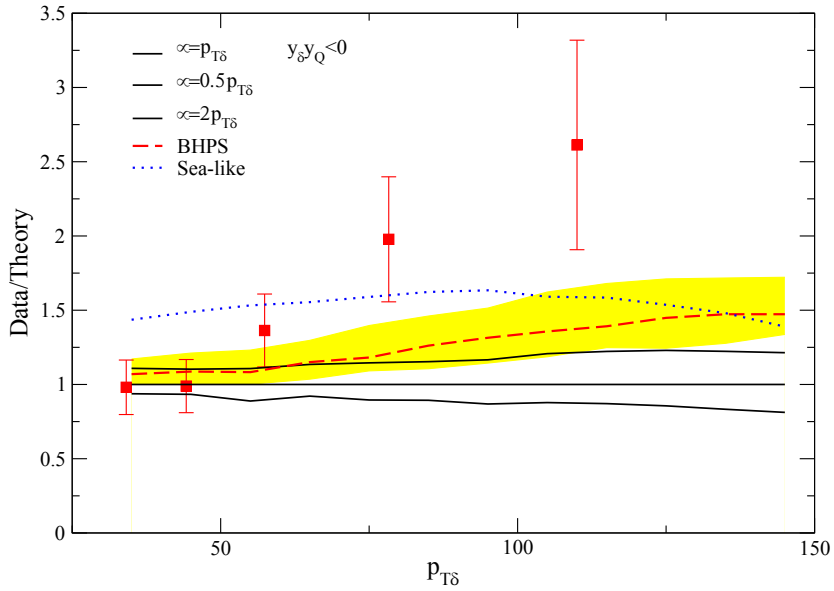
- Next-to-Leading Order - $\mathcal{O}(aa_s^2)$
  - Real Corrections - $2 \to 3$ body scattering subprocesses

$$g + g \to Q + \bar{Q} + \gamma \qquad Q + Q \to Q + Q + \gamma$$
$$g + Q \to g + Q + \gamma \qquad Q + \bar{Q} \to Q + \bar{Q} + \gamma$$
$$Q + q \to q + Q + \gamma \qquad q + \bar{q} \to Q + \bar{Q} + \gamma$$
$$Q + \bar{q} \to Q + \bar{q} + \gamma$$

  - Virtual Corrections - interference between LO Born diagram and virtual diagrams

Intrinsic charm/bottom in proton

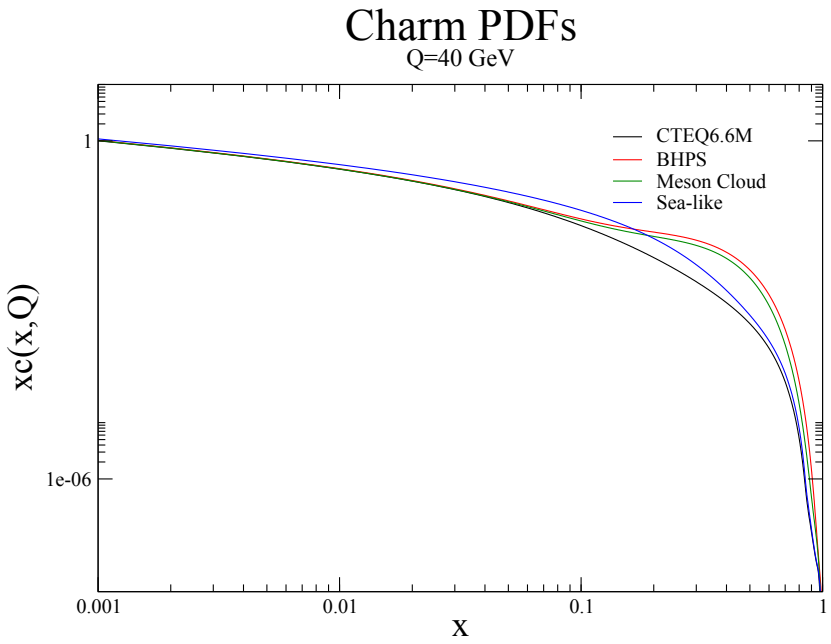




- Sealike - overshoots data at low pT and undershoots at high pT
- BHPS - the cross section grows at large pT, but still below data
- Result inconclusive -
  - New Measurements - Tevatron - CDF & DØ
  - Test at pp Colliders - RHIC & LHC

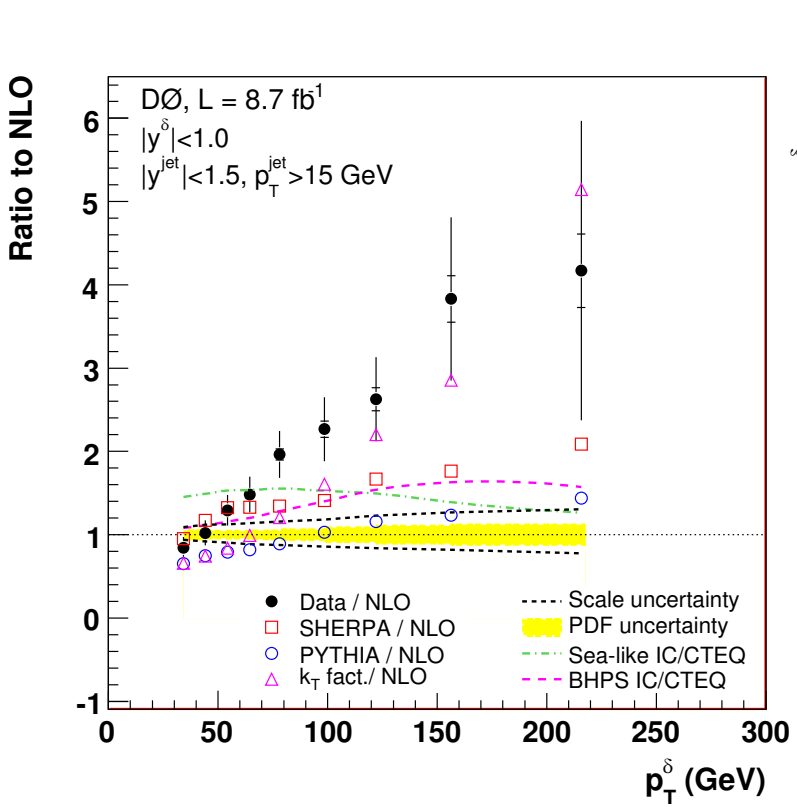
Intrinsic charm/bottom in proton

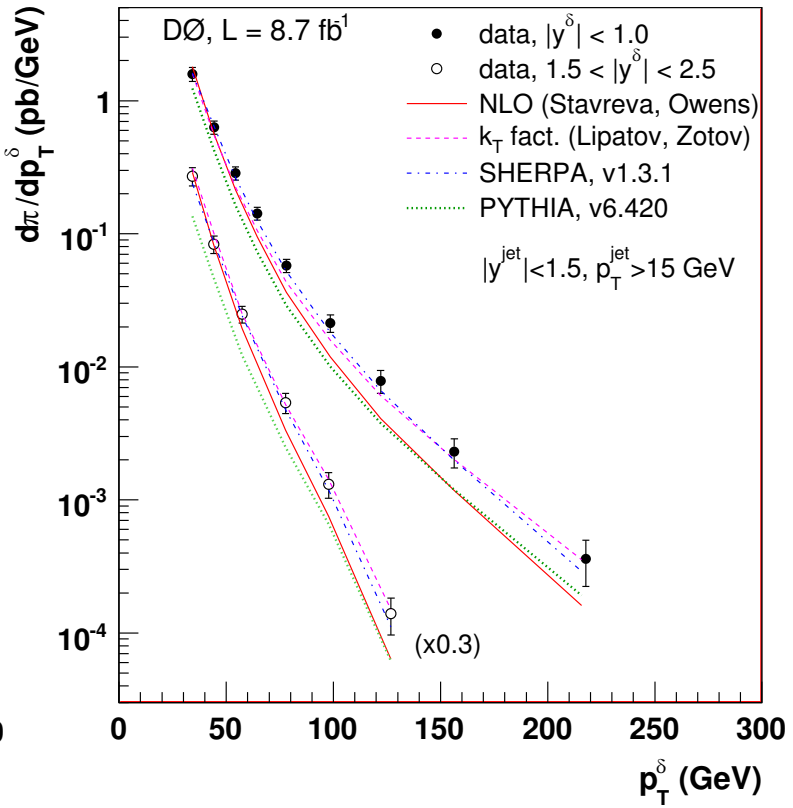
CTEQ has fits with intrinsic charm



large-x effect i.e. potentially important at large transverse momenta

Intrinsic charm/bottom in proton





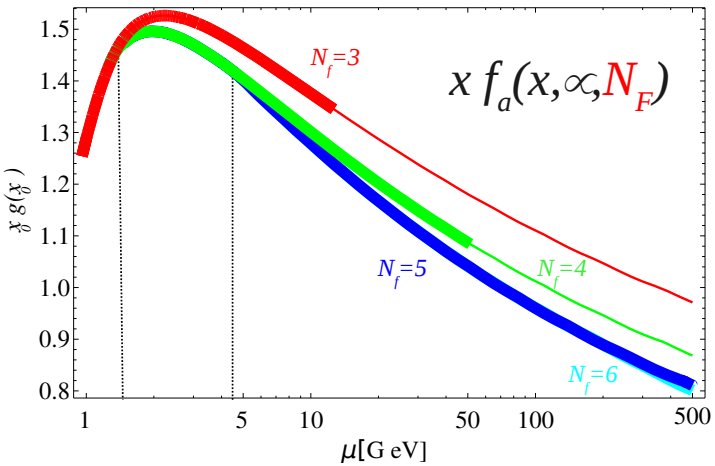
- $\gamma + c$ - left - arXiv:1210.5033
- $\gamma + b$ - right - arXiv:1203.5865

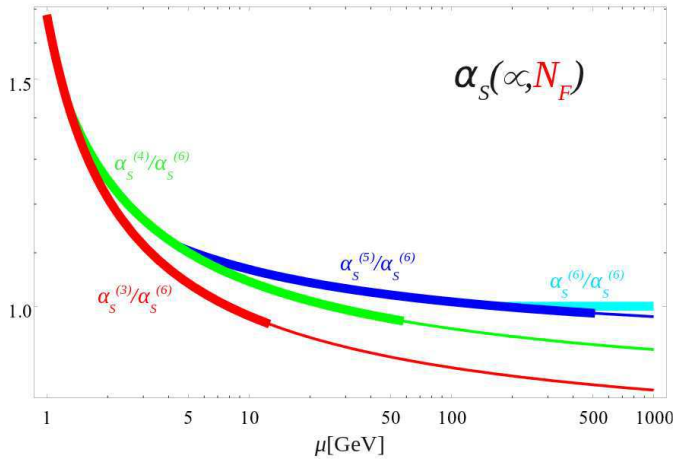
something missing at large transverse momenta?

N_F-Dependent VFNS for Heavy Flavors

Aleksander Kusina

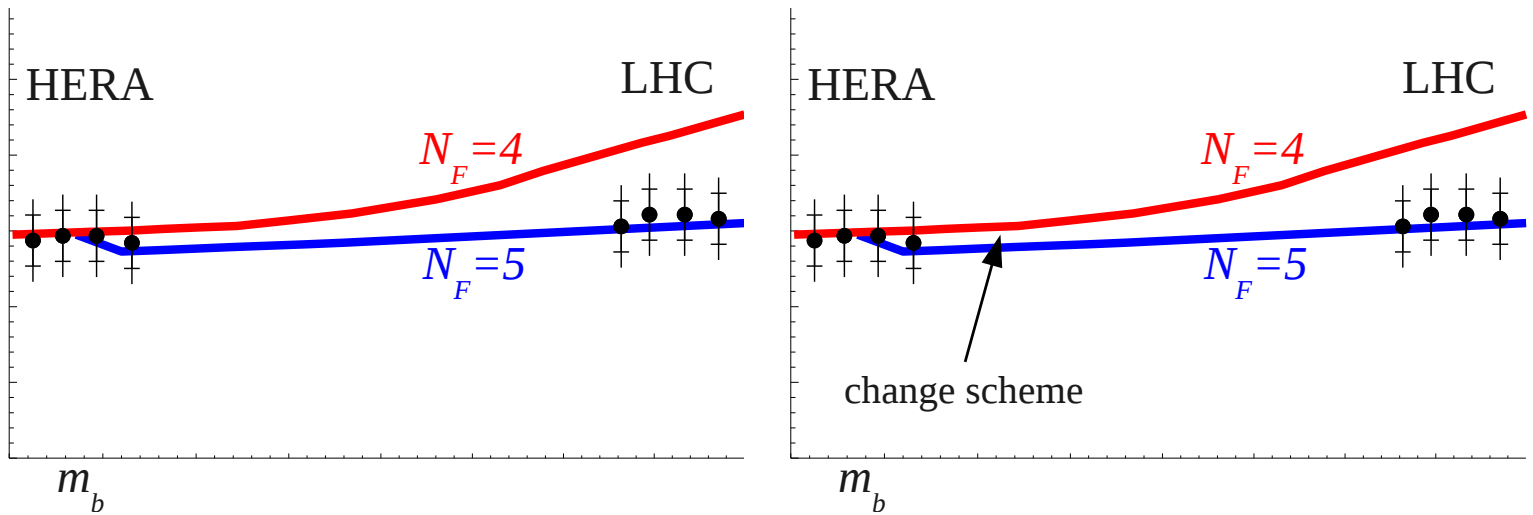
- They proposed a simple generalization of VFNS allowing to take advantage of both FFNS and VFNS.
- Especially interesting for higher order analyses, when PDFs and a_S discontinuous.
- VFNS(N_F) allows to avoid flavors transition if it happens in the middle of a data set.





N_F-Dependent VFNS for Heavy Flavors

Switch between N_F and $N_F + 1$ when convenient



- remember about uncancelled $\log(Q/m_Q)$ in FFNS

Pole vs $\overline{MS}$ mass of top

Mikhail Kalmykov

- Higgs was discovered
- the condition of stability of the SM vacuum ($M_H > 129$ GeV)
- the vaccum stability bound sensitively depends on input parameters -- top quark mass
- pole mass parametrization leads to artificially large perturbative corrections
- $\overline{MS}$ mass is preferable for precision fits

Pole vs $\overline{MS}$ mass of top

Mikhail Kalmykov (Jegerlener+Kniehl)

The full RGE for the mass of top-quark can be written as

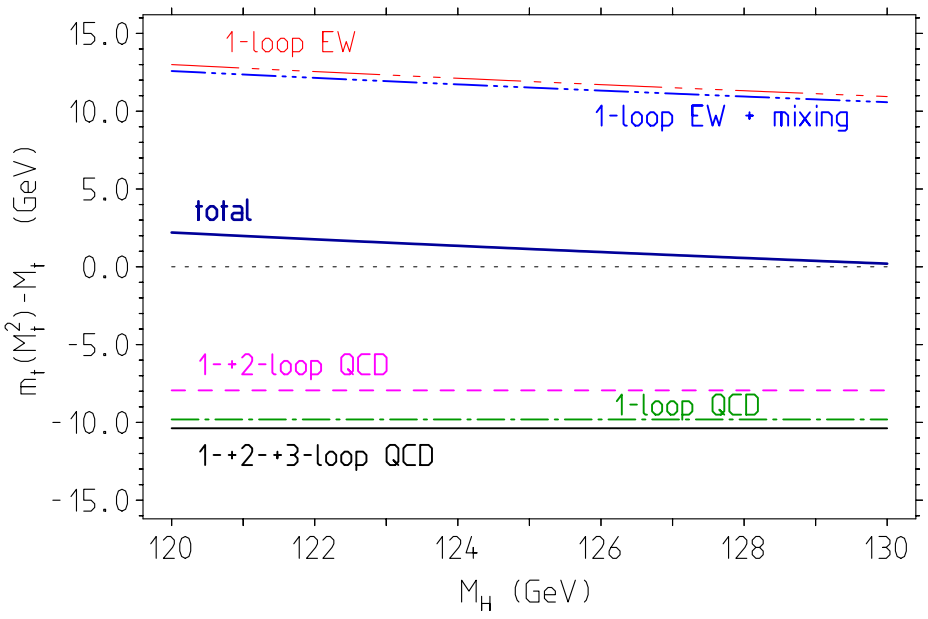
$$\mu^2 \frac{d}{d\mu^2} \ln m_t(\mu^2) = \gamma_t^{QCD} + \frac{1}{y_t}\left(\mu^2 \frac{d}{d\mu^2} y_t\right) + \frac{1}{2}\left(\mu^2 \frac{d}{d\mu^2} \ln m^2\right) - \frac{1}{2}\left(\frac{1}{\lambda}\mu^2 \frac{d}{d\mu^2}\lambda\right),$$

y_t is the Yukawa coupling of quark,

m^2 and λ are the parameters of the scalar potential

$$V = \frac{m^2}{2}\phi^2 + \frac{\lambda}{24}\phi^4$$

High and low energy limits have been discussed.



Almost cancellation of QCD and EW contributions

Radiative decays $B^0 \to V\gamma$ with holographic AdS/QCD DA

Ruben Sandapen

- $b \to (s, d)\gamma$ transition
- Holographic AdS/QCD distribution amplitude for ρ^0 and K^* (from light-front wave function) are used to predict the branching fractions for $\bar{B}^0 \to \rho^0\gamma$, $\bar{B}_s^0 \to K^{*0}\gamma$, beyond leading power accuracy (twist-2 and twist-3).
- No end-point divergences in contrast to the Sum Rule approaches.
- The holographic DA describes ρ^0 electroproduction (a talk at another session).
- The result agree with Babar and Belle data within 10% The branching fraction are of the order $\sim 10^{-6}$ or less.
- Predictions for some other more exotic radiative decays.

Other topics at different sessions

- Sergey Alekhin
  Heavy quark production in DIS
- Johannes Bluemlein
  Three-loop heavy flavour corrections to DIS
- Marco Guzzi
  Charm quark mass dependence in CTEQ NNLO global analysis
- Wolfgang Schäfer
  Exclusive production of one and two heavy quarkonia in nuclear collisions
- Antoni Szczurek
  (Single) Diffractive production of heavy quark-antiquark pairs

Thank You for attention!