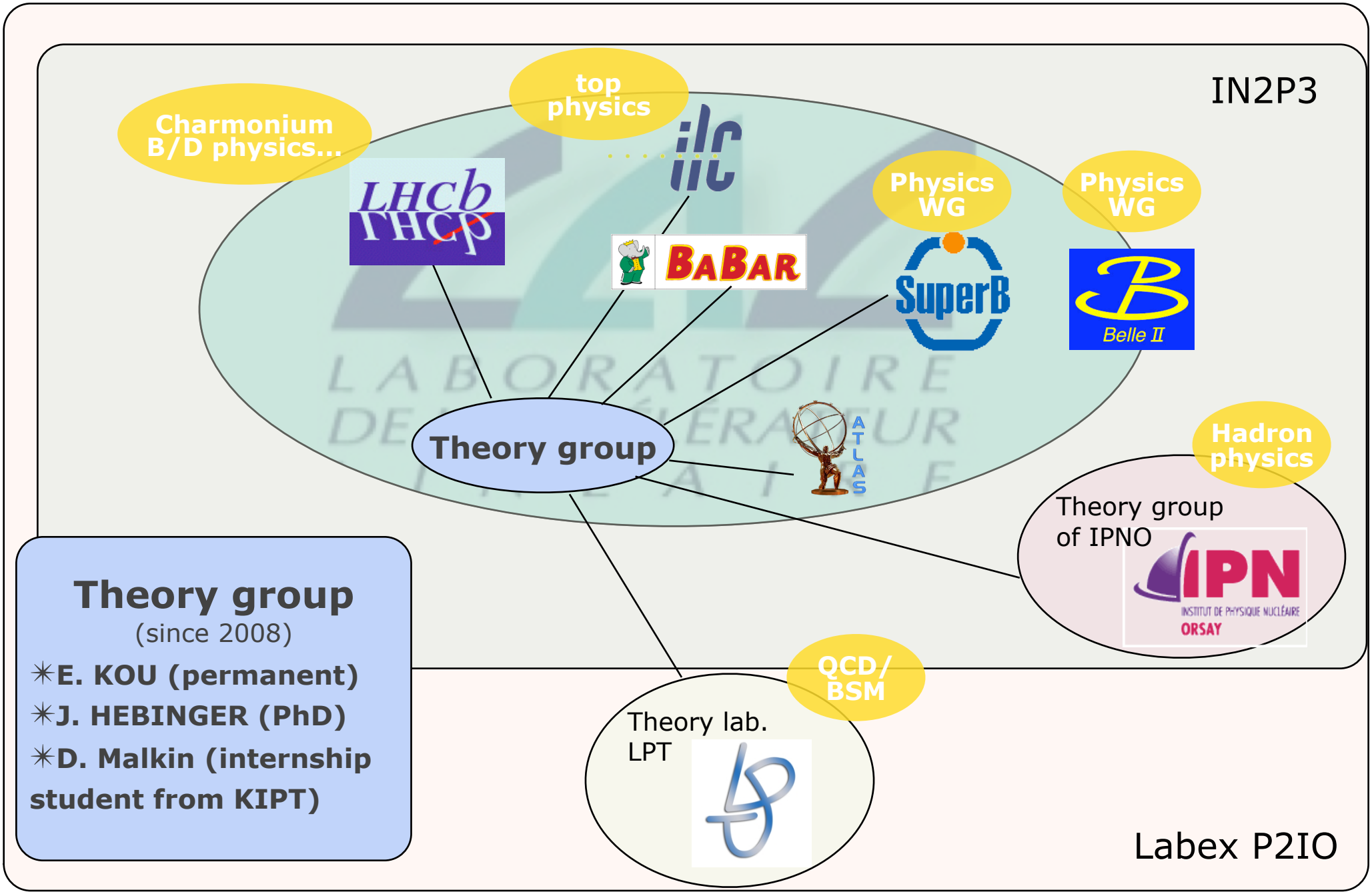
Works of LAL theory group and French-Ukrainian collaborations

Emi Kou (LAL/IN2P3)

French-Ukrainian Workshop 2014
1st October @LAL-Orsay

LAL Theory group

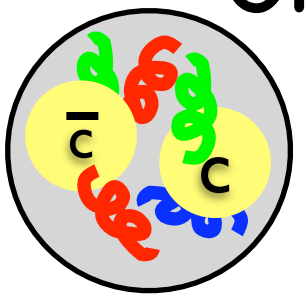


Theory group

(since 2008)

- **E. KOU (permanent)**
- **J. HEBINGER (PhD)**
- **D. Malkin (internship student from KIPT)**

Works done:
Charmonium production at LHCb



S. Barsuk, J. He, E.K., M. Teklishyn, B.Viaud

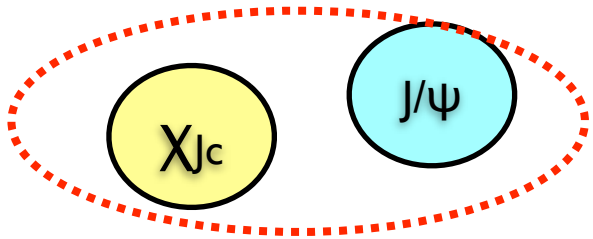
- Studying quarkonium is very important to have a deep understanding of QCD.

		$n\ ^{2s+1}l_J$	J^{PC}	mass MeV	width MeV	discovery
η_c	pseudoscalar	$1\ ^1S_0$	0^{-+}	2980	25.5	1980 ←
J/ψ	vector	$1\ ^3S_1$	1^{--}	3097	0.093	1974
h_c	axial vector	$1\ ^1P_1$	1^{+-}	3524		2005 ←
χ_{c0}	scalar	$1\ ^3P_0$	0^{++}	3415	10.4	1975
χ_{c1}	axial vector	$1\ ^3P_1$	1^{++}	3511	0.89	1975
χ_{c2}	tensor	$1\ ^3P_2$	2^{++}	3556	2.06	1975
$\psi(3770)$	vector	$1\ ^3D_1$	1^{--}	3771	23.0	1977
$\eta_c(2S)$	pseudoscalar	$2\ ^1S_0$	0^{-+}	3637	< 55	2002 ←
$\psi(2S)$	vector	$2\ ^3S_1$	1^{--}	3686	0.337	1974

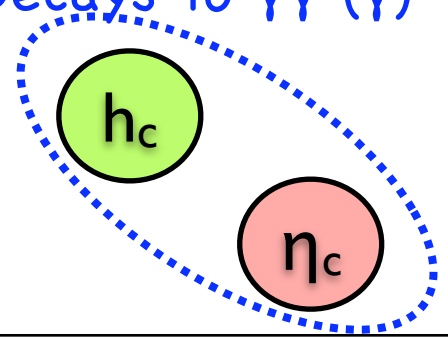
- Tevatron anomaly since 1995 on J/ψ and χ_{cJ}.
- Investigating η_c, h_c is important. However, hadron machines had never seen these states!

Works done in collaboration: Charmonium production at LHCb

Decays to $\mu^+\mu^-(\gamma)$



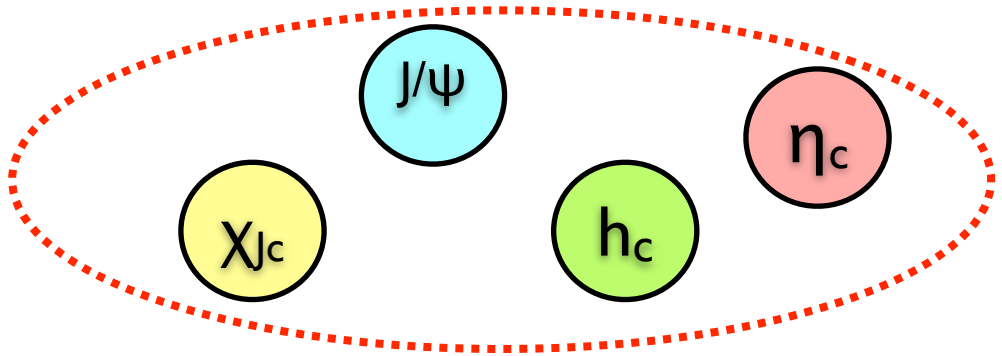
Decays to $\gamma\gamma$ (γ)



S. Barsuk, J. He, E.K. B.Viaud PRD '12

This is why J/ψ and χ_{Jc} have been already seen at hadron machines but not h_c and η_c.

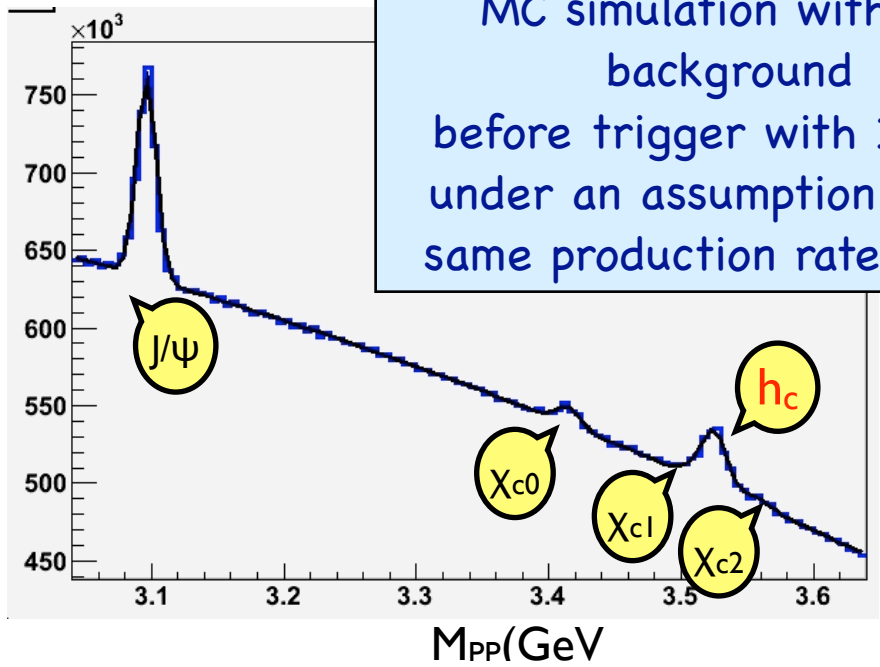
Decays to proton anti-proton!



We can investigate simultaneously all the states using the proton anti-proton final state!

Works done in collaboration: Charmonium production at LHCb

Simulation in 2010...

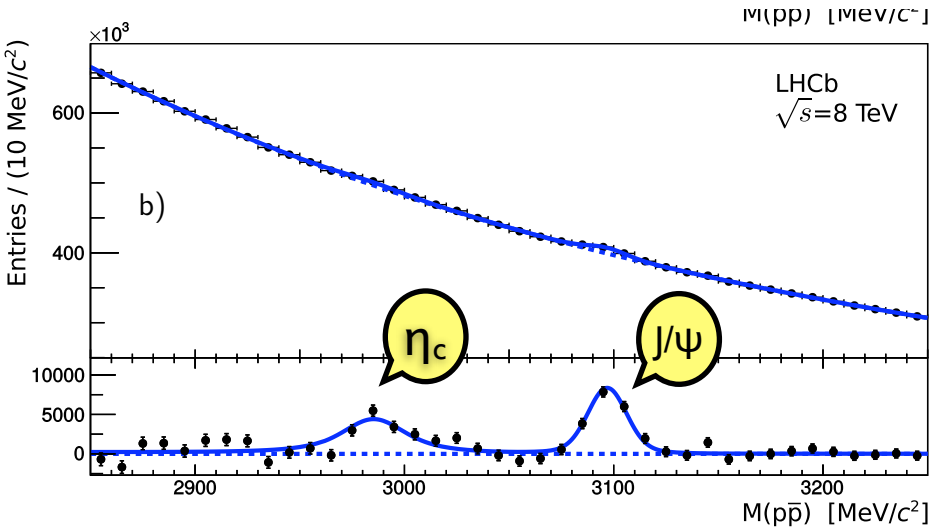


Barsku, He, E.K. and Viaud '10

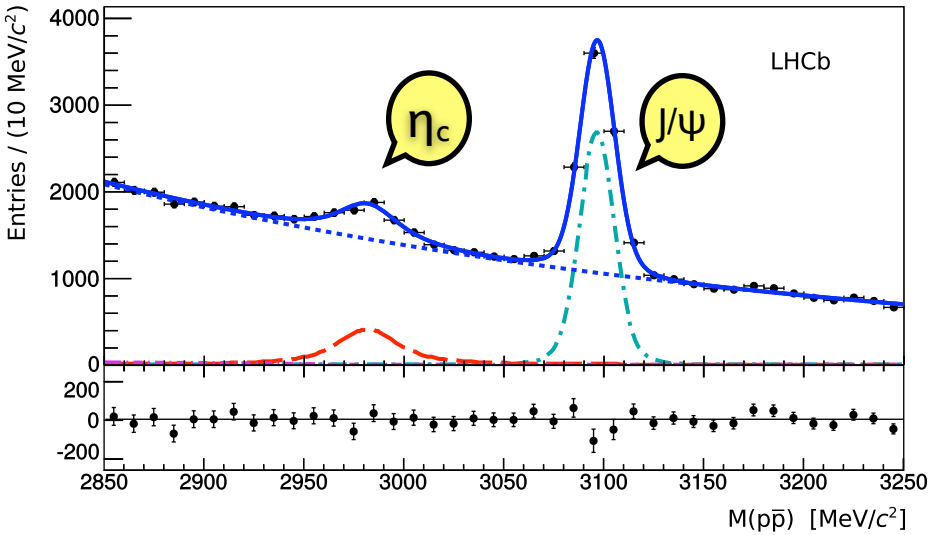
Works done in collaboration: Charmonium production at LHCb

LHCb result 2014 !!

η_c and J/ψ from prompt production



η_c and J/ψ from b quark decay



First observation of η_c at hadron machine!

Thesis of Maksym Teklishyn 2014,
LHCb publication
arXive:1409.3612

Works possible in the future I?
Theoretical interpretation of the LHCb result

Slide from M.Teklishyn thesis defense

Process dependent: calculable in perturbation theory

Hadronic parameters: Non-perturbative but extractable from experiments

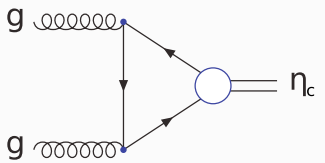
Spin symmetry

$$\langle \mathcal{O}_8^{\eta_c}(^1S_0)\rangle = \frac{1}{3}\langle \mathcal{O}_8^{J/\psi}(^3S_1)\rangle,$$
$$\langle \mathcal{O}_8^{\eta_c}(^3S_1)\rangle = \langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle,$$
$$\langle \mathcal{O}_8^{\eta_c}(^1P_1)\rangle = 3\,\langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle.$$

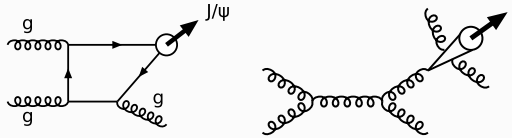
Quarkonium production mechanism

- The effective Lagrangian of NRQCD
  - expansion in $1/m$ and $\alpha_s(m)$
  - $\mathcal{L}_{\mathrm{NRQCD}} = \sum_n \frac{c_n(\alpha_s(m),\mu)}{m^n} \times O_n(\mu, mv, mv^2, \ldots)$
- Factorisation assumption
  - $c\bar{c}$ pair production at $E \sim m_Q$
  - independent hadronisation at $E \sim m_Q v$
- Two production mechanisms:
  - colour-singlet (CS)
  - colour-octet (CO)
- Very few theory predictions for η_c
  - no NLO calculations
  - LO colour-singlet and colour-octet differs by two orders of magnitude

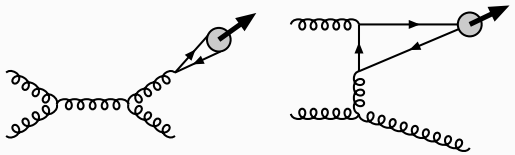
- η_c hadroproduction at LO
  [F. Maltoni and A. D. Polosa, Phys. Rev. D **70** (2004) 054014]



- J/ψ colour-singlet [M. Kramer, 1, Prog. Part. Nucl. Phys. **47** (2001) 141]



- J/ψ colour-octet



Works possible in the future I?
Theoretical interpretation of the LHCb result

Slide from M.Teklishyn thesis defense

Quarkonium production mechanism

- The effective Lagrangian of NRQCD
  - expansion in $1/m$ and $\alpha_s(m)$
  - $\mathcal{L}_{\mathrm{NRQCD}} = \sum_n \frac{c_n(\alpha_s(m),\mu)}{m^n} \times O_n(\mu, mv, mv^2, \ldots)$
  - Factorization assumption

Process dependent: calculable in perturbation theory

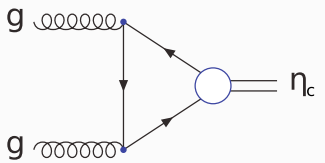
We can obtain a new information about J/ψ production mechanism by investigating the η_c production:
To do so, we need NLO computation of the η_c production

$\langle \mathcal{O}_8^{\eta_c}(^3S_1)\rangle = \langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle,$

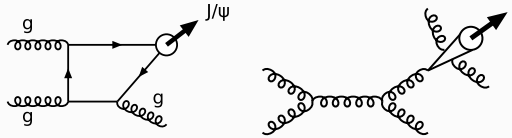
$\langle \mathcal{O}_8^{\eta_c}(^1P_1)\rangle = 3\,\langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle.$

- no NLO calculations
- LO colour-singlet and colour-octet differs by two orders of magnitude

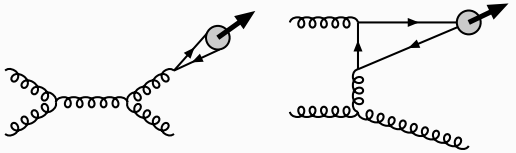
- η_c hadroproduction at LO
  [F. Maltoni and A. D. Polosa, Phys. Rev. D **70** (2004) 054014]



- J/ψ colour-singlet [M. Kramer, 1, Prog. Part. Nucl. Phys. **47** (2001) 141]



- J/ψ colour-octet



Works possible in the future I?
Theoretical interpretation of the LHCb result

Slide from M.Teklishyn thesis defense

Quarkonium production mechanism

- The effective Lagrangian of NRQCD
  - expansion in $1/m$ and $\alpha_s(m)$
  - $\mathcal{L}_{\mathrm{NRQCD}} = \sum_n \frac{c_n(\alpha_s(m),\mu)}{m^n} \times$
  - $O_n(\mu, mv, mv^2, \ldots)$

Process dependent: calculable in perturbation theory

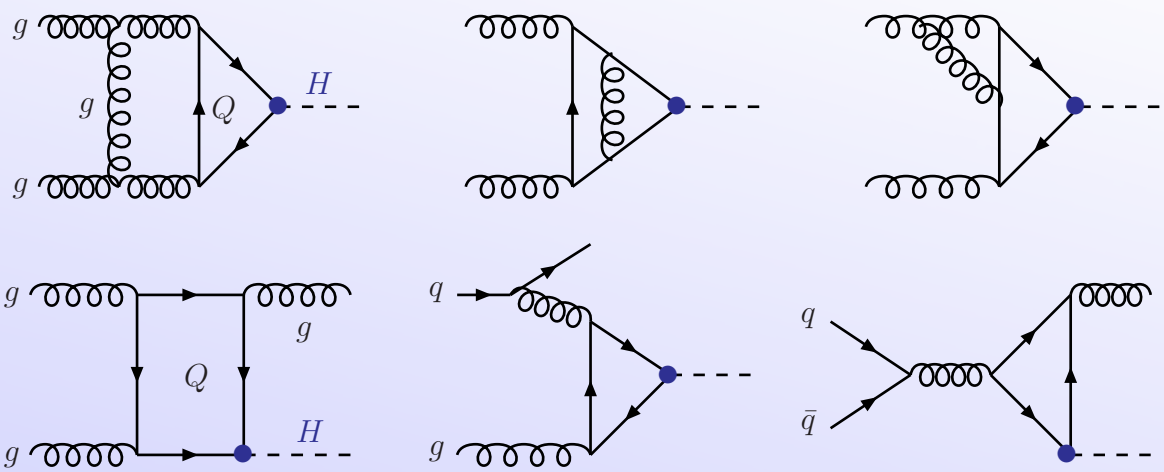
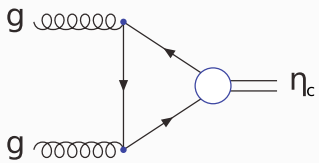
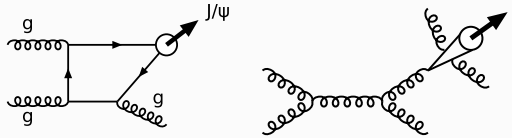


Figure 3.19: Typical diagrams for the virtual and real QCD corrections to $gg \to H$.

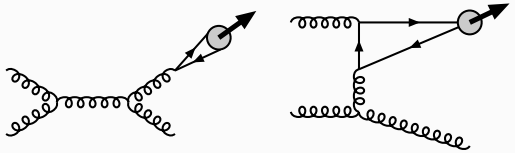
- η_c hadroproduction at LO
  [F. Maltoni and A. D. Polosa, Phys. Rev. D **70** (2004) 054014]



- J/ψ colour-singlet [M. Kramer, 1, Prog. Part. Nucl. Phys. **47** (2001) 141]



- J/ψ colour-octet



Works possible in the future II?
Various topics on B physics

- Advance of the LHCb analysis and strategies for the next run
  - ☑ Constraining new physics with full data analysis of LHCb (7, 8 TeV run)
  - ☑ Determining the new benchmark points
- Belle II Theory-Experiment Working Group
  - ☑ What could we learn with the first 10/ab's data?

Focus of our group

Many collaborations possible!
*continuation of the work on B->K*e+e- or Bs->ΦΦ (SM, and BSM) etc etc*

Contribution of low-lying vector resonances to polarization observables in $\bar{B}_d^0 \to \bar{K}^{*0} e^+ e^-$ decay

Alexander Yu. Korchin[1,*] and Vladimir A. Kovalchuk[1,†]

[1] *NSC 'Kharkov Institute of Physics and Technology', 61108 Kharkov, Ukraine*

Conclusions

- Our group has been having very nice collaborations and research exchanges with professor and student from Ukraine.
- LIA will certainly help us to further increase the interactions with our Ukrainian colleagues.
- Short term visiting will be quite useful for our collaborations in the future.