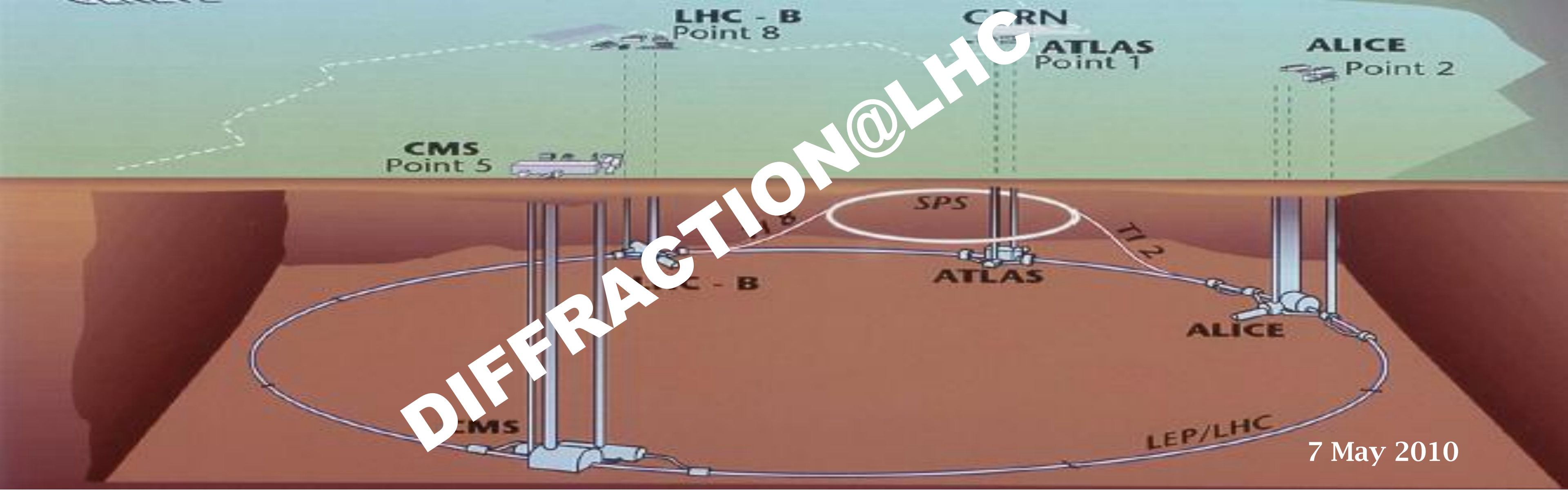


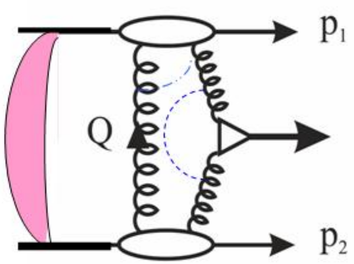
7 May 2010

Outlook on Central Diffractive Processes at the Tevaron , LHC and RHIC

V.A. Khoze (IPPP, Durham)

(In collaboration with L. Harland-Lang, M. Ryskin and W.J. Stirling)

CDP



χ_c, χ_b

Outline

- Introduction.
- Central exclusive production (CEP) of $\chi_{c0,1,2}$ states at the **Tevatron, LHC and RHIC.**
- Overview of $\gamma\gamma$ and χ_b CEP results and ongoing studies.
- **Forward proton distributions and correlations.**
- Conclusion.

Preprint typeset in JHEP style - PAPER VERSION

IPPP/10/32
DCPT/10/64
Cavendish-HEP-10/08

Standard Candle Central Exclusive Processes at the Tevatron and LHC

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Abstract: Central exclusive production (CEP) processes in high-energy proton – (anti)proton collisions offer a very promising framework within which to study both novel aspects of QCD and new physics signals. Among the many interesting processes that can be studied in this way, those involving the production of heavy (c, b) quarkonia and $\gamma\gamma$ states have sufficiently well understood theoretical properties and sufficiently large cross sections that they can serve as 'standard candle' processes with which we can benchmark predictions for new physics CEP at the CERN Large Hadron Collider. Motivated by the broad agreement with theoretical predictions of recent CEP measurements at the Fermilab Tevatron, we perform a detailed quantitative study of heavy quarkonia (χ and η) and $\gamma\gamma$ production at the Tevatron, RHIC and LHC, paying particular attention to the various uncertainties in the calculations. Our results confirm the rich phenomenology that these production processes offer at present and future high-energy colliders.

Introduction

Why are we interested in central exclusive χ_c (χ_b, $\gamma\gamma$, jj) production?

- Driven by same mechanism as Higgs (or other new object) CEP at the LHC.
- χ_c, jj and $\gamma\gamma$ CEP has been observed by CDF.

D0, RHIC data to come soon

$\rightarrow$ Can serve as 'Standard Candle' processes, which allow us to check the theoretical predictions for central exclusive new physics signals at the LHC.

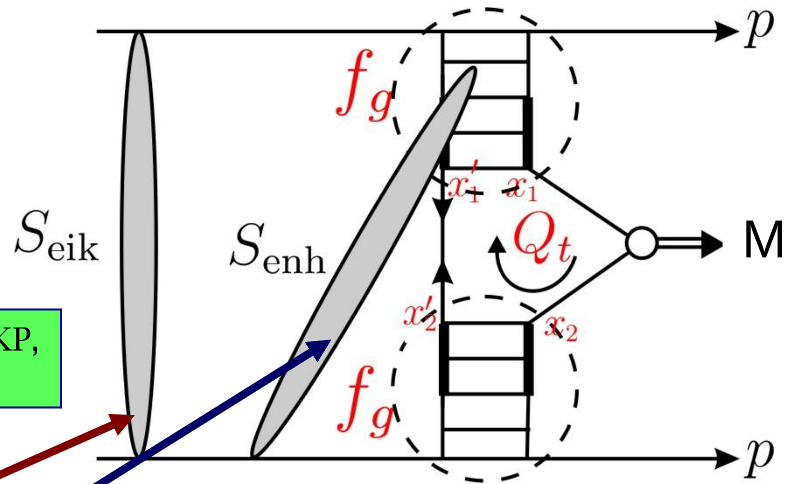
- $\chi_{c,b}$ production is of special interest: (star reactions!)
  - Heavy quarkonium production can shed light on the physics of bound states (lattice, NRQCD$\cdots$).
  - Potential to produce different J^P states, which exhibit characteristic features (e.g. angular distributions of forward protons).
  - Could perhaps shed light on the various 'exotic' charmonium states observed recently.

Spin-Parity Analyzer

- Detailed tests of dynamics of soft diffraction (KMR-02)

"soft" scattering can easily destroy the gaps

S^2 → absorption effects -necessitated by unitarity



gap

gap

Everybody's ~ happy (KMR, GLMM, FHSW, KP, Petrov et al, BH, GGPS, Luna...MCs)

eikonal rescatt: between protons ← soft-hard factoriz^n conserved

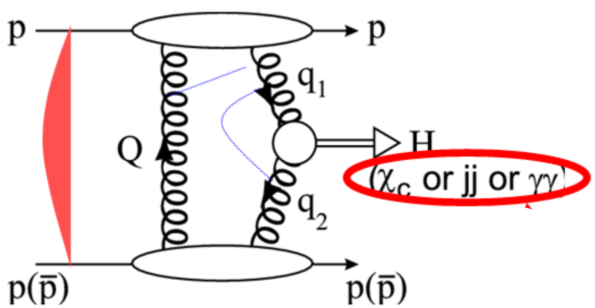
enhanced rescatt: involving intermediate partons ← broken

Subject of hot discussions nowadays : S^2enh

Standard Candle Processes

'Better to light a candle than to rant against darkness'

(Confucius)



孔夫子

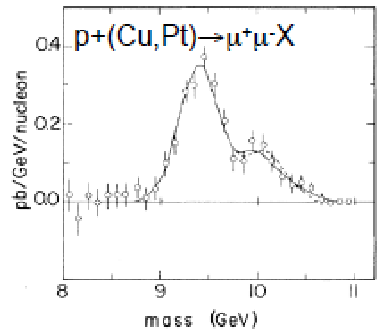
孔丘 *Kong Qiu*

The process p-p→$\gamma\gamma$/χ_c/ χ_b/ j-j are standard candles for the exclusive Higgs

CDF & DO (Christina, Mike)

Bottomonium history started 30 years ago

(PRL 39, 242 (1977) and PRL 39,1240 (1977))



$M(\Upsilon)=9.40\pm0.013$

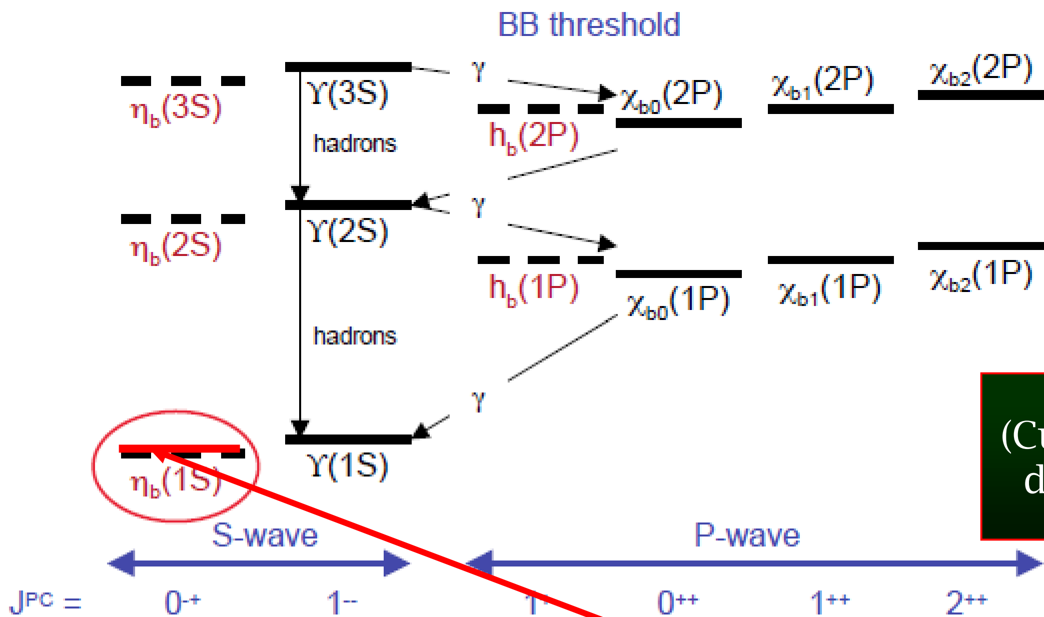
$M(\Upsilon')=10.00\pm0.04$

$M(\Upsilon'')=10.43\pm0.12$

FNAL, E288

30 years later….

(spins- still unconfirmed)



$\Upsilon(nS)$ confirmed and $\chi_{bJ}(1,2P)$ states observed

Below $B\bar{B}$, several states not yet observed: 3 S-wave (η_b), 2 P-wave (h_b), D-wave,etc…

(Currently no complete theoretical description of onium properties.)

(BABAR (2008)

(Still puzzles)

The heaviest and most compact quark–antiquark bound state in nature

(Christina, Mike)

(Cannot detect p/pbar, down beam pipe, but BSC → η = 7.4 empty)

FSC@LHC (Mike)

* $p+\bar{p} \rightarrow p+\gamma\gamma+\bar{p}$
* $p+\bar{p} \rightarrow p+\chi_c+\bar{p}$
$p+\bar{p} \rightarrow p+\chi_b+\bar{p}$
* $p+\bar{p} \rightarrow p+JJ+\bar{p}$

Cleanest (no S.I.) but smallest σ
KMR: 38 pb in our box). 2+1 candidates (more coming soon)

Clean, big σ: $\frac{d\sigma}{dy}(y=0) \sim 100\,\mathrm{nb}$ (KMRS)

but M(c) small (non-pert) & hadron

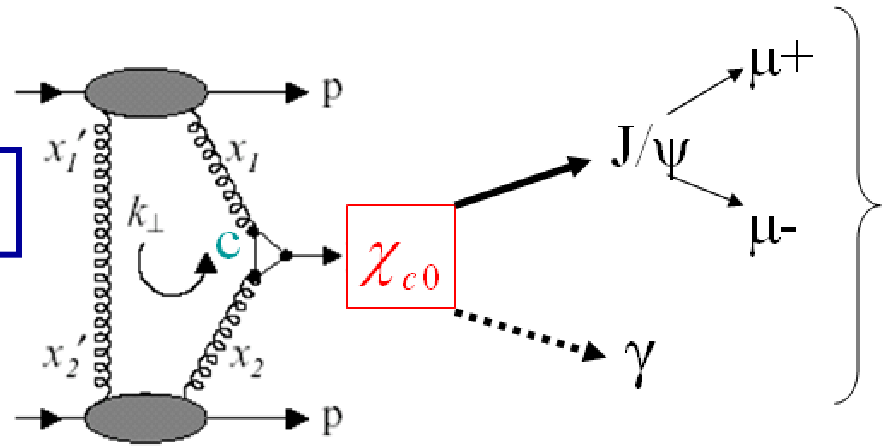
More perturbative, smaller theory uncertainty
But σ ~ 1/500th χc. Also BR's not known!

Prpospects !

Big cross section, but least well defined (jets!)
and largest background. ~ 100 pb for M(JJ) > 30 GeV

Our 3 measurements are all in good agreement (factor "few") with the Durham group predictions.

We set out to measure exclusive $\chi_c \rightarrow J/\psi + \gamma \rightarrow \mu^+\mu^- \gamma$



BSC very important as rap gap detectors.
All LHC experiments should have them!

(Gap Detectors in no P-U events)

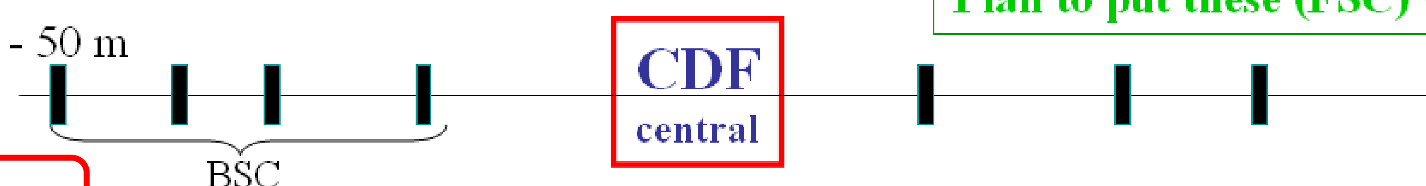
& nothing else
in all CDF
$-7.4 < |\eta| < +7.4$

Beam Shower Counters BSC: $5.2 < |\eta| < 7.4$

If these are all empty, p and $\bar{p}$ did not dissociate

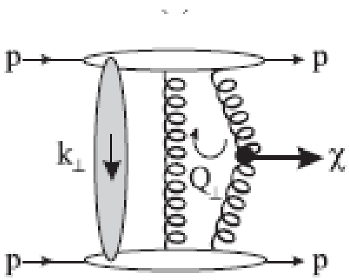
but went down beam pipe with small (<~ 1 GeV/c) transverse momentum.

Plan to put these (FSC) with CMS



What we expect within the framework of the Durham formalism
(KMR-01, KKMR-03, KMRS-04, HKRS-10)

Example, O++ -case



$$T = A\pi^2 \int \frac{d^2 Q_\perp \, P(\chi(0^+))}{Q_\perp^2 (\vec{Q}_\perp - \vec{p}_{1\perp})^2 (\vec{Q}_\perp + \vec{p}_{2\perp})^2} f_g(x_1, x_1', Q_1^2, \mu^2; t_1) f_g(x_2, x_2', Q_2^2, \mu^2; t_2),$$

$$A^2 = 8\pi\Gamma(\chi \to gg)/M_\chi^3 \quad {}^*K_{NLO} \qquad P(\chi(0^+)) = (\vec{Q}_\perp - \vec{p}_{1\perp}) \cdot (\vec{Q}_\perp + \vec{p}_{2\perp}).$$

- **Strong sensitivity to the polarization structure of the vertex in the bare amplitude.**

  Absorption is sizeably distorted by the polarization structure **(affects the b-space distr.)**

  KMR-01

- χ_c, χ_b -production is especially sensitive to the effects of enhanced absorption
  - larger available rapidity interval
  - lower scale ➔ larger dipole size ➔larger absorption

  (Gap size for χ_c at the Tevatron is expected to exceed that for the Higgs at the LHC)

  KMR-02, KKMR-03

- **Forward proton distributions & correlations– possibility to test diffraction dynamics**

  KMR-02

CDF χ_c data

Phys.Rev.Lett.102:242001,2009

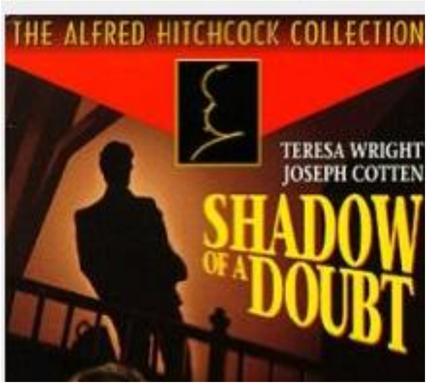
- 65 ± 10 signal χ_c events observed, but with a limited $M(J/\psi\gamma)$ resolution.
- Possible contribution from χ_{c1} and χ_{c2} states assumed, rather than observed, to be negligible.
- Assuming χ_{c0} dominance, CDF found:

$$\left.\frac{\mathrm{d}\sigma(\chi_{c0})}{\mathrm{d}y_\chi}\right|_{y=0} = (76 \pm 14)\,\mathrm{nb}\;,$$

  in good agreement with the previous KMRS value of 90 nb (arXiv:0403218).

Too good to be true ?!

- But can we be sure that χ_{c1} and χ_{c2} events to do not contribute?



SuperCHIC MC (HKRS-09)

- A new MC (available on HepForge) including:
  - Non-forward $p_\perp \neq 0$ protons via the 'effective' slope parameters $b_{\rm eff}$.
  - Full simulation of $\chi_{c(0,1,2)}$ CEP via the $\chi_c \to J/\psi\gamma \to \mu^+\mu^-\gamma$ decay chain.
  - $\chi_{b(0,1,2)}$ CEP via the equivalent $\chi_b \to \Upsilon\gamma \to \mu^+\mu^-\gamma$ decay chain.
  - More to come...
- The angular distributions of the final state particles, modeled in the MC, might help us to distinguish between the different states...
- ...however the severity of current CDF experimental cuts for χ_c CEP ($p_\perp(\mu) > 1.4\,{\rm GeV/c}$, $|\eta_\mu| < 1$) appears to preclude this.
- **Diphoton CEP**

χ_{c1} and χ_{c2}: general considerations

- General considerations tell us that χ_{c1} and χ_{c2} CEP rates are strongly suppressed:
  - χ_{c1}: Landau-Yang theorem forbids decay of a $J = 1$ particle into on-shell gluons.
  - χ_{c2}: Forbidden (in the non-relativistic quarkonium approximation) by $J_z = 0$ selection rule that operates for forward ($p_\perp$=0) outgoing protons. KMR-01 (A. Alekseev-1958-positronium)
- However the experimentally observed decay chain $\chi_c \to J/\psi\gamma \to \mu^+\mu^-\gamma$ strongly favours $\chi_{c(1,2)}$ production, with:

$$\mathrm{Br}(\chi_{c0} \to J/\psi\gamma) = 1.1\% \,,$$
$$\mathrm{Br}(\chi_{c1} \to J/\psi\gamma) = 34\% \,,$$
$$\mathrm{Br}(\chi_{c2} \to J/\psi\gamma) = 19\% \,.$$

- We should therefore seriously consider the possibility of $\chi_{c(1,2)}$

(R.Pasechnik et al, Phys.Lett.B680:62-71,2009; HKRS, Eur.Phys.J.C65:433-448,2010)

Cross section results (1)

- We find the following approximate hierarchy for the spin-summed amplitudes squared

$$|V_0|^2 : |V_1|^2 : |V_2|^2 \sim 1 : \frac{\langle \mathbf{p}_\perp^2 \rangle}{M_\chi^2} : \frac{\langle \mathbf{p}_\perp^2 \rangle^2}{\langle \mathbf{Q}_\perp^2 \rangle^2} \,. \tag{2}$$

- This $\sim 1/40$ suppression for the $\chi_{c1,2}$ states will be compensated by the larger $\chi_c \to J/\psi\gamma$ branching ratios, as well as by the larger survival factors $S^2_{\rm eik}$ for the more peripheral reactions.
- An explicit calculation gives (for the perturbative contribution):

$$\frac{\Gamma^{\chi_0}_{J/\psi+\gamma}}{\Gamma^{\chi_0}_{\rm tot}} \frac{{\rm d}\sigma^{\rm pert}_{\chi_{c0}}}{{\rm d}y} : \frac{\Gamma^{\chi_1}_{J/\psi+\gamma}}{\Gamma^{\chi_1}_{\rm tot}} \frac{{\rm d}\sigma^{\rm pert}_{\chi_{c1}}}{{\rm d}y} : \frac{\Gamma^{\chi_2}_{J/\psi+\gamma}}{\Gamma^{\chi_2}_{\rm tot}} \frac{{\rm d}\sigma^{\rm pert}_{\chi_{c2}}}{{\rm d}y} \approx \quad 1 : 0.6 : 0.22$$

- Note: these approximate values carry a factor of $\sim \overset{\times}{\div}\, 2$ uncertainty.

Cross section results

- As the cms energy increases we have:
  - Larger gluon density at smaller x values.
  - Smaller $S^2_{\rm eik}$ survival factor.
  - Smaller $S^2_{\rm enh}$ due to increase in size of rapidity gaps ($\sim s/m_\chi^2$) available for 'enhanced' absorptive effects.

$\rightarrow$ The combined result of these different effects is that the χ_c CEP rate has only a very weak energy dependence going from the Tevatron to the LHC.

- $S^2_{\rm eik}$ and $S^2_{\rm enh}$ accounted for in the integrand

$\sqrt{s}$ (TeV)	0.5	1.96	7	10	14
$\frac{d\sigma}{dy_{\chi_c}}(pp \to pp(J/\psi + \gamma))$	0.57	0.73	0.89	0.92	1.0
$\frac{d\sigma(1^+)}{d\sigma(0^+)}$	0.59	0.61	0.69	0.67	0.71
$\frac{d\sigma(2^+)}{d\sigma(0^+)}$	0.21	0.22	0.23	0.23	0.23

(76 ± 14) nb **CDF**

Differential cross section (in nb) at rapidity $y_\chi = 0$ for central exclusive χ_{cJ} production via the $\chi_{cJ} \to J/\psi\gamma$ decay chain, summed over the $J = 0, 1, 2$ contributions, at RHIC, Tevatron and LHC energies, and calculated using GRV94HO partons,

$\chi_c \to \pi\pi$, $\chi_c \to K\overline{K}$ Spin-parity Analyzer

Central Diffractive Production of χ_b

$\mathrm{BR}(\chi_{b1} \to \Upsilon\gamma) = (35 \pm 8)\%$
$\mathrm{BR}(\chi_{b2} \to \Upsilon\gamma) = (22 \pm 4)\%$

- Calculation exactly analagous to χ_c case with same hierarchy. However we have a stronger supression in the χ_{b1} and χ_{b2} rates than for the χ_c case.
- Larger $\langle Q_\perp^2 \rangle$ scale gives smaller b_{eff} values, i.e. non-forward effects are less strong, but still important.
- Significant uncertainties in input parameters:
  - Only have $\mathrm{Br}(\chi_{b0} \to \Upsilon\gamma) < 6\%$ from experiment (Crystal Ball -1986)
  - $\Gamma_{\text{tot}}(\chi_{b0})$ experimentally undetermined.
- Consistently with the results of NRQCD, as well as the existing experimental data, we can take the values[3] $\Gamma(\chi_{b0} \to gg) = 0.8$ MeV and $\mathrm{Br}(\chi_{b0} \to \Upsilon\gamma) = 3\,\%$.
- $\chi_b(nP) \to DX$ (about 0.25 of all hadronic decays (CLEO-2009)

  $\chi_{b1} \to c\bar{c}X$ (Barbieri et al (1979), NRQCD)

FSC@LHCb ?

Suppressed non-resonant background $\sim m_c^2/M_{\chi_b}^2$

χ_b CEP (2)

$$\frac{\Gamma^{\chi 0}_{\Upsilon+\gamma}}{\Gamma^{\chi 0}_{\rm tot}}\frac{d\sigma^{\rm pert}_{\chi_{b0}}}{dy} : \frac{\Gamma^{\chi 1}_{\Upsilon+\gamma}}{\Gamma^{\chi 1}_{\rm tot}}\frac{d\sigma^{\rm pert}_{\chi_{b1}}}{dy} : \frac{\Gamma^{\chi 2}_{\Upsilon+\gamma}}{\Gamma^{\chi 2}_{\rm tot}}\frac{d\sigma^{\rm pert}_{\chi_{b2}}}{dy} \approx \quad \mathbf{1 : 0.03 : 0.08}$$

$\sqrt{s}$ (TeV)	0.5	1.96	7	10	14
$\frac{d\sigma}{dy_\chi}(\chi_{c0})$	27	35	42	43	45
$\frac{d\sigma}{dy_\chi}(\chi_{b0})$	–	0.017	0.021	0.022	0.022

Table 4: Differential cross section (in nb) at rapidity $y_\chi = 0$ for central exclusive $\chi_{(b,c)0}$ production at RHIC, Tevatron and LHC energies, and calculated using GRV94HO partons, as explained in the text.

$\sqrt{s}$ (TeV)	1.96	7	10	14
$\frac{d\sigma}{dy_{\chi_b}}(pp \to pp(\Upsilon + \gamma))$	0.56	0.70	0.73	0.74
$\frac{d\sigma(1^+)}{d\sigma(0^+)}$	0.029	0.032	0.032	0.034
$\frac{d\sigma(2^+)}{d\sigma(0^+)}$	0.077	0.081	0.081	0.083

Table 5: Differential cross section (in pb) at rapidity $y_\chi = 0$ for central exclusive χ_{bJ} production via the $\chi_{bJ} \to \Upsilon\gamma$ decay chain, summed over the $J = 0, 1, 2$ contributions, at Tevatron and LHC energies, and calculated using GRV94HO partons, as explained in the text.

Measuring forward proton angular distributions

KKMR-03

- For low proton transverse momenta $p_{1,2_\perp}$ we have:

$\boxed{p_\perp^2 \ll Q_\perp^2}$

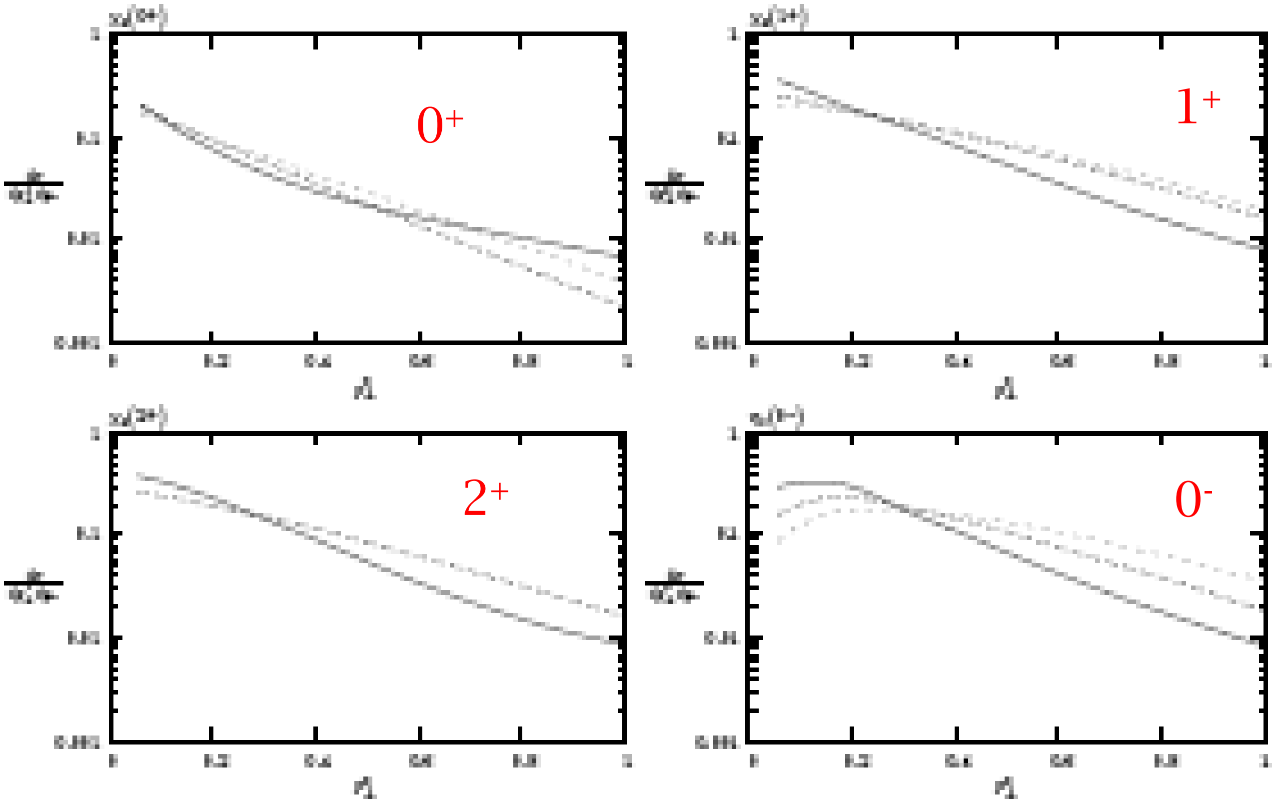
$$d\sigma(0^+)/d\phi \approx \text{const.} \,,$$
$$d\sigma(1^+)/d\phi \approx (p_{1_\perp} - p_{2_\perp})^2 \,,$$

$$d\sigma(0^-)/d\phi \approx \; p_{1\perp}^2 p_{2\perp}^2 \sin^2\phi \,,$$

while there does not exist a simple closed form for the χ_2 case.

- Note these will receive corrections of $O(p_\perp^2/\langle Q_\perp^2\rangle)$.
- These distributions are strongly affected by absorptive corrections, through their dependence on the proton distribution in impact parameter b space.
- Forward proton detection would allow a clear discrimination between the different J states.

Very topical for STAR@RHIC forthcoming measurements with tagged forward protons (HKRS results soon to come).



Distribution (in arbitrary units) within the perturbative framework of the outgoing proton $p_{1\perp}^2$, integrated over the second proton $p_{2\perp}$, for the CEP of different J^P $c\bar{c}$ states at $\sqrt{s} = 14$ TeV. The solid (dotted) line shows the distribution including (excluding) the survival factor, calculated using the two channel eikonal model of Ref. [74], while the dashed line shows the distribution in the small $p_\perp$ limit, using the vertices of Eqs. (3.16)–(3.18) and excluding the survival factor.

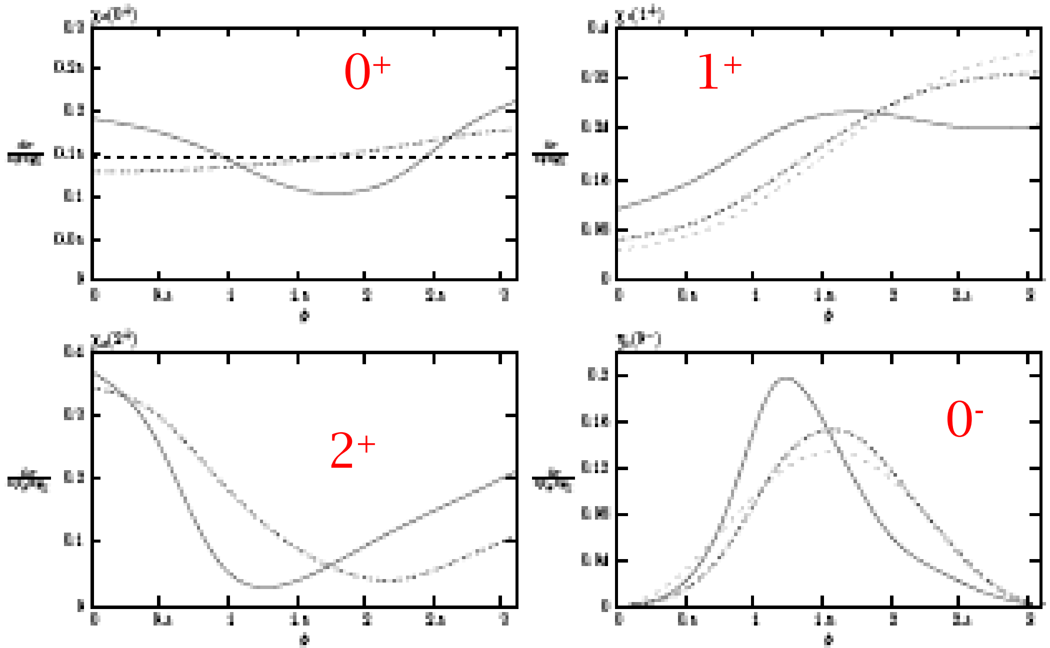
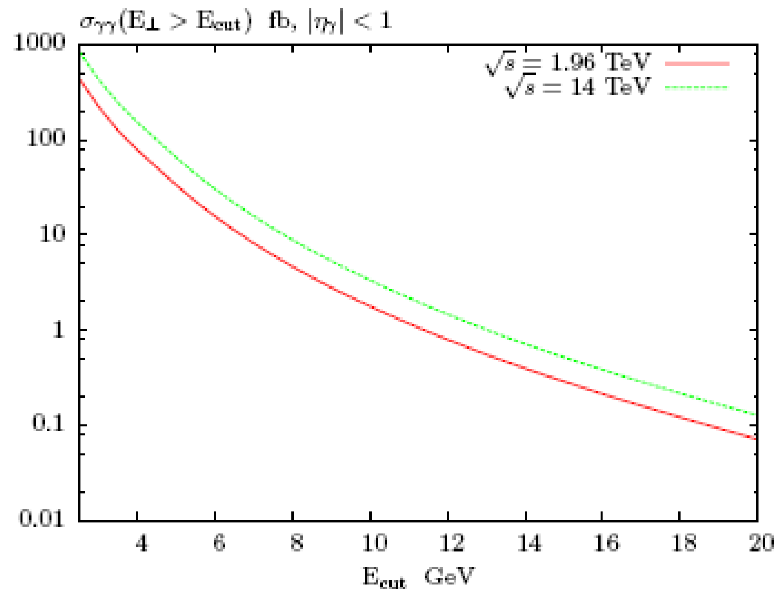


Figure 4: Distribution (in arbitrary units) within the perturbative framework of the difference in azimuthal angle of the outgoing protons for the CEP of different J^P $c\bar{c}$ states at $\sqrt{s} = 14$ TeV. The solid (dotted) line shows the distribution including (excluding) the survival factor, calculated using the two channel eikonal model of Ref. [74], while the dashed line shows the distribution in the small $p_\perp$ limit, using the vertices of Eqs. (3.16)–(3.18) and excluding the survival factor.

$\gamma\gamma$ CEP

(KMRS, arXiv:0409037)

- 3 candidate events observed by CDF (arXiv:0707.237), with more to come.
- More events would allow us to probe scaling of σ with $E_{\rm cut}$.
- Similar uncertainties to χ_c case for low $E_{\rm cut}$ scale.
- Potential $|J_z| = 2$ contribution found to be unimportant.
- New encouraging results for $gg \to \pi^0\pi^0$ background.
- $\gamma\gamma$ CEP now included in SuperCHIC.

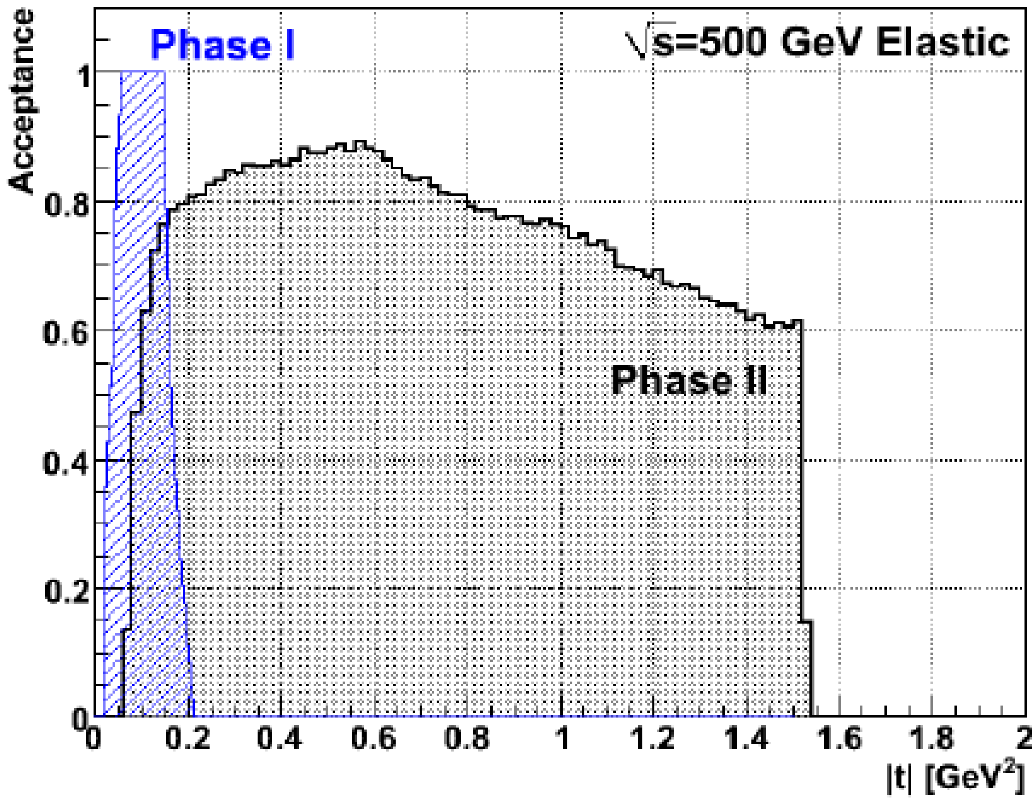


(HKRS-2010)

(Leading term QCD expectations)

- HKRS-results at different energies, $E_\perp$ and η_γ cuts are now available.

t-Acceptance of Roman Pots



Central production with RPs @STAR is taking of.
First pp→pXp data.
Partial wave analysis- soon.

- Phase I set-up focuses on low-*t* (installed)
- Phase II covers higher-*t* range (planned to be installed in 2013)

Rich diffractive structure of the cross sections as a function of proton momenta

KMR-02

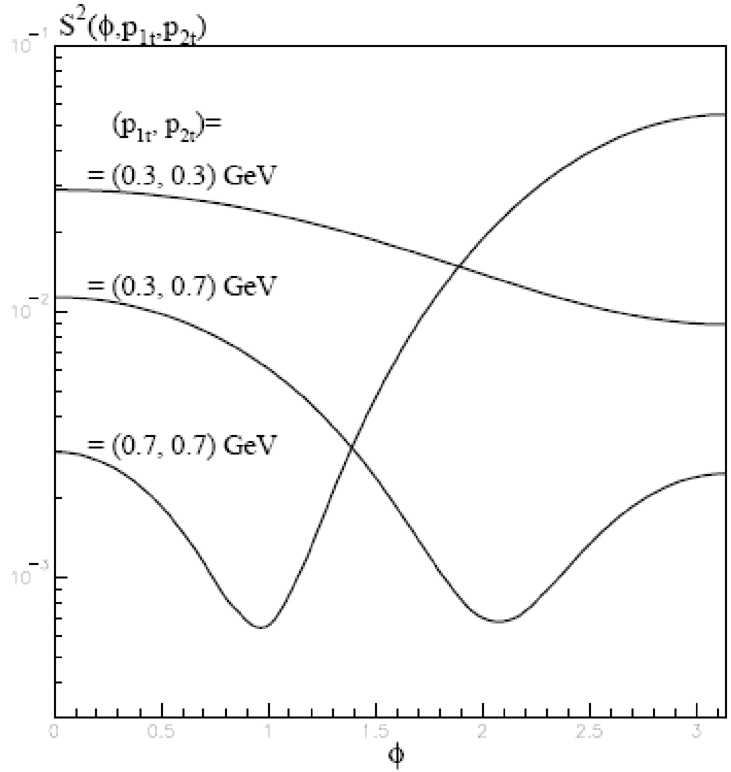


Figure 3: The dependence of the survival probability, S^2, of the rapidity gaps on the azimuthal angle ϕ between the transverse momenta $\vec{p}_{it}$ of the forward going protons in the process $pp \to p + M + p$, for typical values of p_{1t} and p_{2t}.

Ongoing HKRS studies for RHIC energies and kinematics.
Correlations between transverse momenta of outgoing protons

Interesting to compare the results for different $\chi_{c0,1,2}$ states.

Potentially rich program of CDP studies with the LHCb

CENTRAL DIFFRACTION AT THE LHCb

LHCb IS IDEAL FOR DETECTING AND ANALYSING LOW MASS CENTRAL DIFFRACTIVE PRODUCTION OF EXCLUSIVE $\pi^+\pi^-/K^+K^-$ STATES IN:

$$pp \to p + M + p$$

glueballs, hybrids, heavy quarkonia: χ_c, χ_b
exotic states….

$\pi^+\pi^-/K^+K^-$ STATES AS SPIN-PARITY ANALYZERs.

HOW TO FACILITATE THIS?

LHCb
Excellent particle ID (pion/Kaon separation), vertex and proper time resolution

Jerry W. Lämsä and Risto Orava

JINST 4:P11019,2009.

(CDP background to the luminometer)

Jerry W. Lämsä and Risto Orava JINST 4:P11019,2009.

THE PROPOSED LHCb FSC LAY-OUT

ADD FSCs AT **20 – 100 METERS** ON BOTH SIDES OF IP8 – THE FSCs DETECT SHOWERS FROM THE VERY FORWARD PARTICLES.

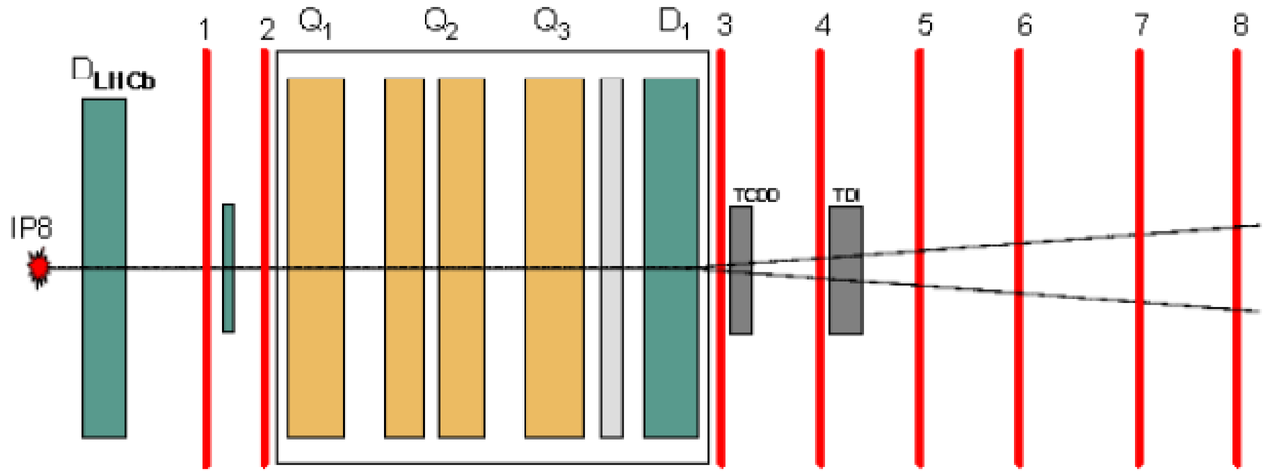


Figure 1. *The layout of LHCb detectors at the LHC Interaction Point (IP8). The proposed Forward Shower Counters (FSCs) are shown as vertical lines (1 to 8). The locations of the dipole (D) and quadrupole (Q) magnet elements are shown as green (dark) and yellow (light) boxes.*

Disclaimer : up to the experts to deliver a verdict

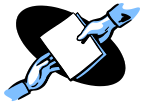
Conclusion

- CEP processes observed at the Tevatron can serve as 'standard candles' for new physics CEP at the LHC.
- Possibility that χ_{c1} and χ_{c2} CEP may contribute to CDF χ_c events.
- Cannot currently distinguish states, but may be possible with:
  - More detailed analysis and/or higher statistics.
  - Forward proton detection.
  - Different decay modes, $\chi_c \to \pi\pi, KK, \overline{p}p, \Lambda\overline{\Lambda}$.

- χ_b , dijet, diphton CEP- rich program of studies at the LHC; promising potential of LHCb.
- New STAR@RHIC results on CEP with tagged forward protons soon to come. 

  Prospects of CDP studies at ALICE (Rainer)

Currently active studies are in progress (both in theory and experiment).



Thank You

BACKUP

UNCERTAINTIES

Known Unknowns

- N(N)LO- radiative effects (K-factors etc..)
  '…possible inadequancy of PT theory in α_{s} …' R.Barbieri et al-1980
- ' 'Right' choice of gluon densities, in particular at so low scales as in the χ_c case (potentiality of a factor of ~3 rise for the H-case) .
- Complete model for calculation of enhanced absorption.
- χ_b -experimental widths, decays…

Unknown Unknowns

- Non- pQCD effects in the meson characteristics.
  Currently no complete description of heavy quarkonium characteristics.
  'Two gluon width does not tell the whole story.'
- Gluons at so low scales, surprises are not excluded at all.

Factor of 5 up or down
(at best)

What we know from Regge theory (KKMR-2003)

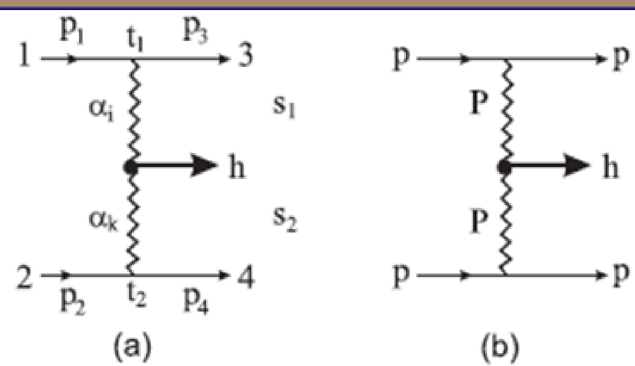


Figure 1: (a) The central production of a state h by double-Reggeon exchange. (b) The double-Pomeron exchange contribution to $pp \to p + h + p$, which dominates at high energies, where the + signs are used to indicate the presence of Pomeron-induced rapidity gaps.

$\boxed{J^P(h) = 0^+}$ Vertex Coupling $g^h_{ik} = f_{0^+}(p^2_{3\perp}, p^2_{4\perp}, \vec{p}_{3\perp}\cdot\vec{p}_{4\perp})$ (depends on dynamics)

$\boxed{J^P(h) = 0^-}$ $\sigma \sim |t_1||t_2| \sin^2\phi$ observed for η,η' by WA102 Group (450 GeV, pp CERN Omega Spectrometer.)

$\boxed{J^P(h) = 1^+}$ For small p_{it}

$$g_{PP} = a_{\lambda=0}(p^2_{3t} - p^2_{4t})/M^2(\vec{p}_{3t}\times\vec{p}_{4t})\vec{e} + f_{\lambda=1}(\vec{K}\times\vec{n})\vec{e}/M\,, \quad \vec{K} = (\vec{p}_3 - \vec{p}_4)$$

- Cross section tends to zero at low K_t
- Dominantly produced in the helicity-one state
- Coincide with the NCVC model expectation by F. Close et al (1999)
- Agree with the WA102 data on f_1 (1420) and f_1(1285)

η_c and η_b

$\sqrt{s}$ (TeV)	1.96	7	10	14
$\frac{d\sigma}{dy_\eta}(\eta_c)$	200	200	190	190
$\frac{d\sigma}{dy_\eta}(\eta_b)$	0.15	0.14	0.14	0.12

Table 6: Differential cross section (in pb) at rapidity $y_\eta = 0$ for central exclusive $\eta_{b,c}$ production at Tevatron and LHC energies, and calculated using GRV94HO partons, as explained in the text.

DIPHOTON CEP

$E_{\rm cut}$	MRST99	MSTW08LO	$M_{\rm min}$	MRST99	MSTW08LO
2	1760	7840	4	3880	18900
5	56.5	162	10	114	345
10	2.89	5.45	20	5.72	11.5

Table 7: Central exclusive $\gamma\gamma$ production cross sections (in fb) at the Tevatron for different values of cuts on the $E_\perp$ ($> E_{\rm cut}$) of the final-state photons and the invariant mass M_X ($> M_{\rm min}$) of the diphoton system, in GeV. The photons are restricted to lie in the centre of mass rapidity interval $|\eta_\gamma| < 1.8$.

- MRST99 and MSTW08LO PDFs provide approximately upper and lower bounds respectively
- Ratios of cross sections at different energies- uncertainties $\lesssim 2$

	E_{cut}	MRST99	MSTW08LO	M_{min}	MRST99	MSTW08LO
$\sqrt{s} = 7$ TeV	5	133	630	10	276	1380
	10	7.32	25.1	20	15.0	53.6
	15	1.15	3.31	30	2.39	7.09
	20	0.274	0.697	40	0.60	1.55
$\sqrt{s} = 10$ TeV	5	156	849	10	322	1860
	10	8.77	35.0	20	17.8	74.4
	15	1.43	4.71	30	2.94	10.0
	20	0.34	1.01	40	0.737	2.23
$\sqrt{s} = 14$ TeV	5	184	1140	10	378	2470
	10	10.8	48.7	20	21.7	102
	15	1.77	6.71	30	3.59	14.1
	20	0.437	1.47	40	0.934	3.21

Table 8: Central exclusive $\gamma\gamma$ production cross sections (in fb) at different LHC c.m.s energies for different values of cuts on the $E_\perp$ ($> E_{\text{cut}}$) of the final-state photons and the invariant mass M_X ($> M_{\text{min}}$) of the diphoton system, in GeV. The photons are restricted to lie in the centre of mass rapidity interval $|\eta_\gamma| < 2$.

PROSPECTIVE MEASUREMENTS

- A clear way to resolve the issue of χ_c spin-parity identification will be be to search for the two-body decays:

$$Br(\chi_{co} \to \pi\pi, K^+K^-) \simeq 1.3\% \qquad \chi_{c1}, \eta_c \not\to \pi\pi, KK \qquad Br(\chi_{c2} \to \pi\pi, K^+K^-) \simeq 0.3\%$$

$$Br(\chi_{c0} \to p\bar{p}) \simeq 2 * 10^{-4} \qquad Br(\chi_{c1} \to p\bar{p}) \simeq 6.6 * 10^{-5} \qquad Br(\chi_{c2} \to p\bar{p}) \simeq 6.7 * 10^{-5}$$

$$Br(\eta_c \to p\bar{p}) \simeq 0.13\%$$

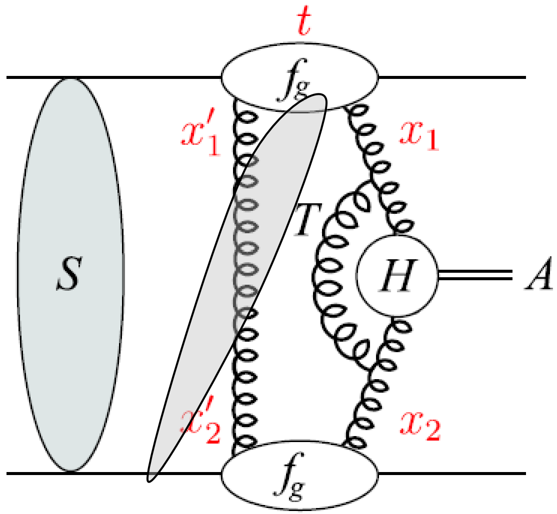
- Tagged forward protons: spin-parity ID of old and new heavy meson states, detailed tests of absorption effects

- With sufficient statistics of $\gamma\gamma$ CEP, the measurement of the ratio

$$\sigma(\chi_b) / \sigma(\gamma\gamma)$$

can be quite instructive (the same mass range, various uncertainties cancel).

Are the early LHC runs,
without proton taggers,
able to check estimates
for pp → p+A+p ?



gap

gap

KMR: 0802.0177

Possible checks of:

(i) survival factor S^2: W+gaps, Z+gaps

(ii) generalised gluon f_g : $\gamma p \to \Upsilon p$

(iii) Sudakov factor T : 3 central jets

(iv) **soft-hard factorisation** **(enhanced absorptive corr^n)**

$$\frac{\#(\text{A+gap}) \text{ evts}}{\#(\text{inclusive A}) \text{ evts}}$$

with A = W, dijet, Υ…

Divide et Impera