SuperChic v2 : a new Monte Carlo for central exclusive production

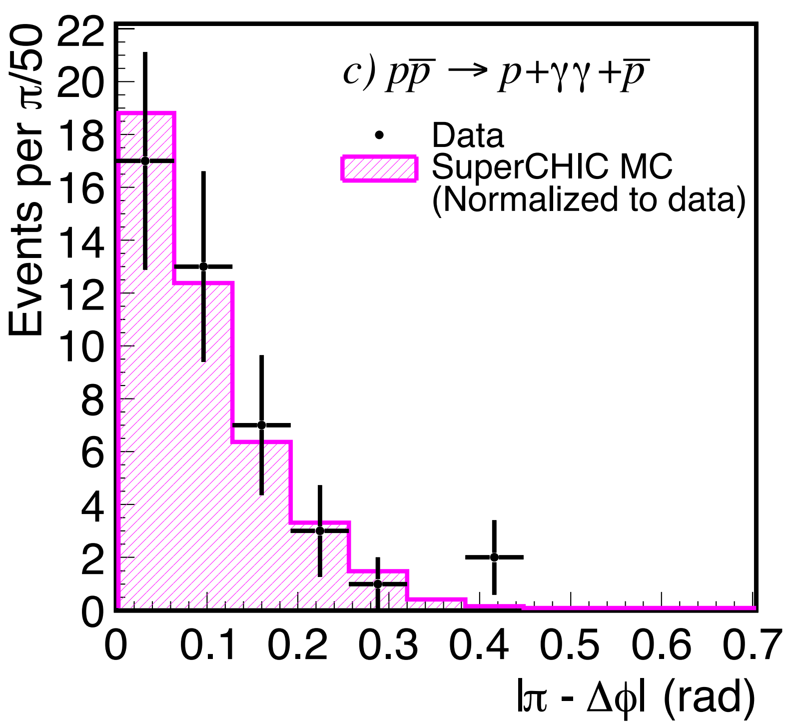
Lucian Harland-Lang (UCL)

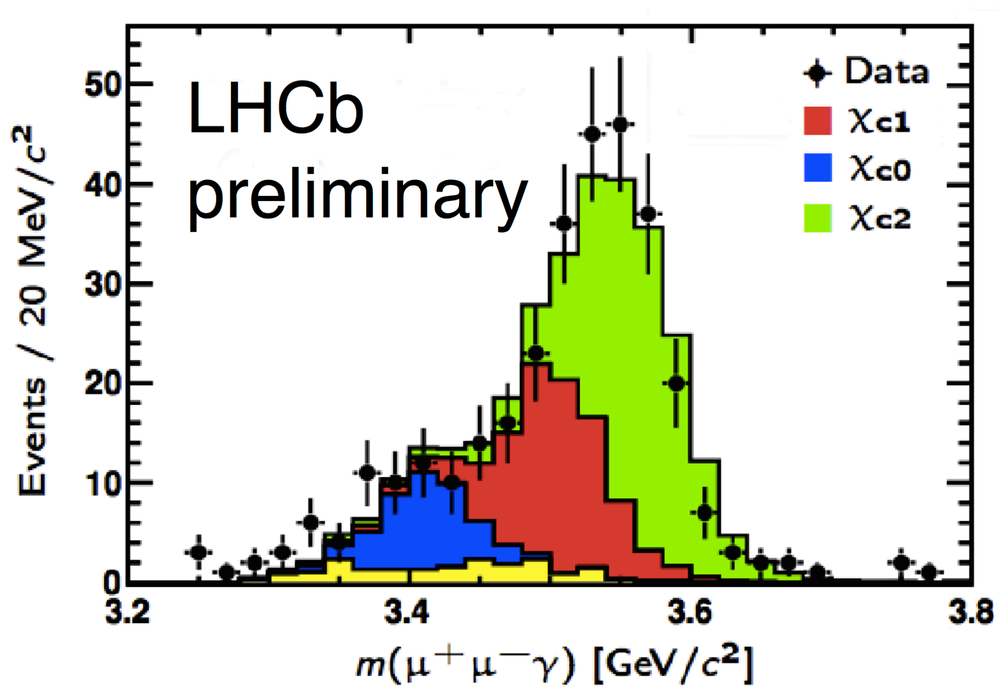
EDS Blois
Borgo, Corsica, 30 June 2015

In collaboration with Valery Khoze and Misha Ryskin

Outline

- CEP: brief introduction.
- SuperChic 2: what's new.
- Present results for three specific processes:
    - J/ψ photoproduction
    - Two-photon induced production
    - Jet production

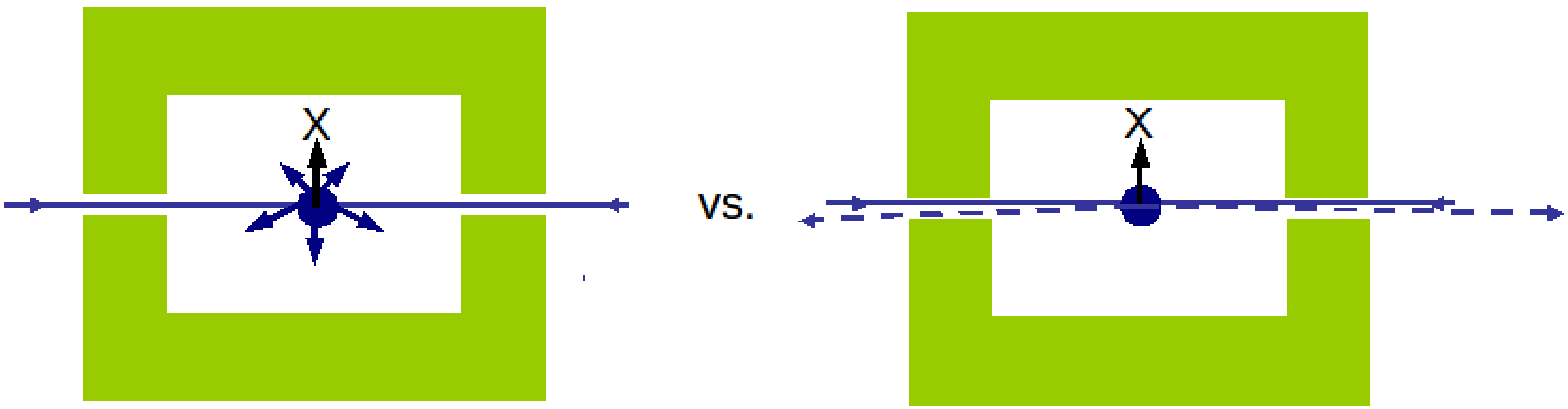




Central exclusive production (CEP) is the interaction

$$pp(\bar{p}) \to p + X + p(\bar{p})$$

- Protons remain intact after collision. Only object of interest X is produced ($X =$ jets, $J/\psi, \pi^+\pi^-, W^+W^-$...) :
  - Clean experimental environment (in absence of pile-up).
  - Can measure outgoing protons - reconstruct X 4-momentum, proton distributions...



Also: Odderon

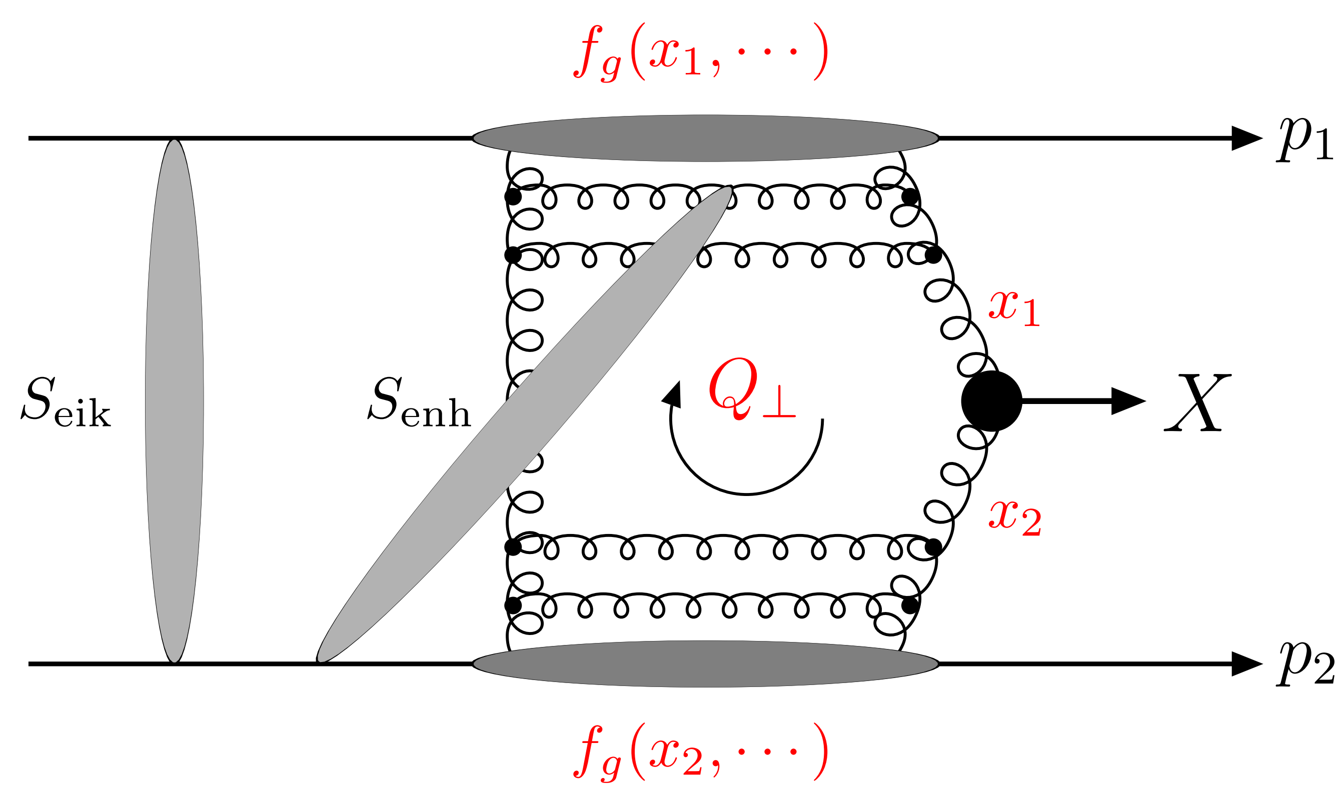
Can (principally) occur through $I\!P I\!P$, $I\!P\gamma$ and $\gamma\gamma$ interactions

‘Durham Model’ of Central Exclusive Production

(QCD mediated)

- The generic process $pp \to p + X + p$ is modeled perturbatively by the exchange of two t-channel gluons.
- The use of pQCD is justified by the presence of a hard scale $\sim M_X/2$. This ensures an infrared stable result via the Sudakov factor: the probability of no additional perturbative emission from the hard process.

- The possibility of additional soft rescatterings filling the rapidity gaps is encoded in the ‘eikonal’ and ‘enhanced’ survival factors, $S^2_{\rm eik}$ and $S^2_{\rm enh}$.
- In the limit that the outgoing protons scatter at zero angle, the centrally produced state X must have $J_Z^P = 0^+$ quantum numbers.



SuperChic v1

LHL talk at EDS Blois 2013

A MC event generator including[8]:

- Simulation of different CEP processes, including all spin correlations:
  - $\chi_{c(0,1,2)}$ 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.
  - $\chi_{(b,c)J}$ and $\eta_{(b,c)}$ CEP via general two body decay channels
  - Physical proton kinematics + survival effects for quarkonium CEP at RHIC.
  - Exclusive J/ψ and Υ photoproduction. $+\ \psi(2S)$
  - $\gamma\gamma$ CEP.
  - Meson pair ($\pi\pi$, KK, $\eta\eta$...) CEP.
- More to come (dijets, open heavy quark, Higgs...?).

$\longrightarrow$ Additional processes to add, but also theoretical improvements to be included.

SuperChic v2

New MC for CEP close to release. Based on original SuperCHIC, but with significant extensions.

- Theoretical developments:
  - Correct inclusion of Sudakov factor T.D. Coughlin and J.R. Forshaw, JHEP 1001 (2010) 121
  - Consistent treatment of ‘skewed’ gluon PDFs LHL, Phys. Rev. D88 (2013) 3, 034029
  - Full (differential) treatment of soft survival effects

- LHAPDF interface.

- Complete calculation performed ‘on-line’, and structured so that additional processes can be easily added.

- Processes generated:

New ▸ SM Higgs boson

New ▸ Jets: gg, heavy/massless $q\bar{q}$, ggg, massless $gq\bar{q}$

New ▸ Double quarkonia: $J/\psi J/\psi$, $J/\psi\psi(2S)$ and $\psi(2S)\psi(2S)$

▸ Light meson pairs: $\pi\pi$, KK, $\rho\rho$, $\eta(')\eta(')$, $\phi\phi$

▸ $\chi_{c,b}$: two body and J/ψ, $\Upsilon + \gamma$ channels

▸ $\eta_{c,b}$

▸ Photoproduction: J/ψ, $\psi(2S)$ and Υ HERA fit

New ▸ Two-photon interactions: W^+W^-, $\mu^+\mu^-$ and e^+e^-

Theoretical improvements

- Sudakov factor:

$$T(\boldsymbol{Q}_\perp,\mu)=\exp\left(-\int_{\boldsymbol{Q}_\perp^2}^{\hat{s}/4}\frac{\mathrm{d}k_\perp^2}{k_\perp^2}\frac{\alpha_s(k_\perp^2)}{2\pi}\int_0^{1-\Delta}\mathrm{d}z\,\left[zP_{gg}(z)+\sum_q P_{qg}(z)\right]\right)$$

with $\Delta = k_\perp/M_X$ T.D. Coughlin and J.R. Forshaw, JHEP 1001 (2010) 121

Different value taken in Durham results before the CF paper, but this correct prescription used after. Accounted for in MC.

- Skewed gluon PDF often related to standard unintegrated gluon by

$$f_g(x,x',Q_\perp^2,\mu^2)\approx \tilde{R}_g\frac{\partial}{\partial\ln(Q_\perp^2)}\left[xg(x,Q_\perp^2)\sqrt{T(Q_\perp,\mu^2)}\right]$$

with 'skewness factor' $\tilde{R}_g$. However more exact form can be readily implemented in MC: LHL, Phys. Rev. D88 (2013) 3, 034029

$$f_g(x,x',Q_\perp^2,\mu^2)=\frac{\partial}{\partial\ln(Q_\perp^2)}\left[H_g\left(\frac{x}{2},\frac{x}{2};Q_\perp^2\right)\sqrt{T(Q_\perp,\mu^2)}\right]$$

with $$H_g\left(\frac{x}{2},\frac{x}{2},Q^2\right)=\frac{4x}{\pi}\int_{x/4}^1\mathrm{d}y\,y^{1/2}(1-y)^{1/2}\,g\left(\frac{x}{4y},Q^2\right)$$

Survival factor

- Survival factor, $S^2_{\rm eik}$: probability of no additional soft proton-proton interactions, spoiling exclusivity of final-state.

- Not a constant: depends sensitively on the outgoing proton $\mathbf{p}_\perp$vectors. Physically- survival probability will depend on impact parameter of colliding protons. Further apart $\longrightarrow$ less interaction, and $S^2_{\rm eik} \to 1$.
 b_t and $p_\perp$: Fourier conjugates.

$\longrightarrow$ Need to include survival factor differentially in MC.

• Averaged survival factor given by (in impact parameter space)

Opacity, relates to prob. of no inelastic scattering

$$\langle S^2_{\rm eik} \rangle = \frac{\int {\rm d}^2\mathbf{b}_{1t}\,{\rm d}^2\mathbf{b}_{2t}\,|T(s,\mathbf{b}_{1t},\mathbf{b}_{2t})|^2\exp(-\Omega(s,b_t))}{\int {\rm d}^2\,\mathbf{b}_{1t}{\rm d}^2\mathbf{b}_{2t}\,|T(s,\mathbf{b}_{1t},\mathbf{b}_{2t})|^2}$$

One-channel for illustration

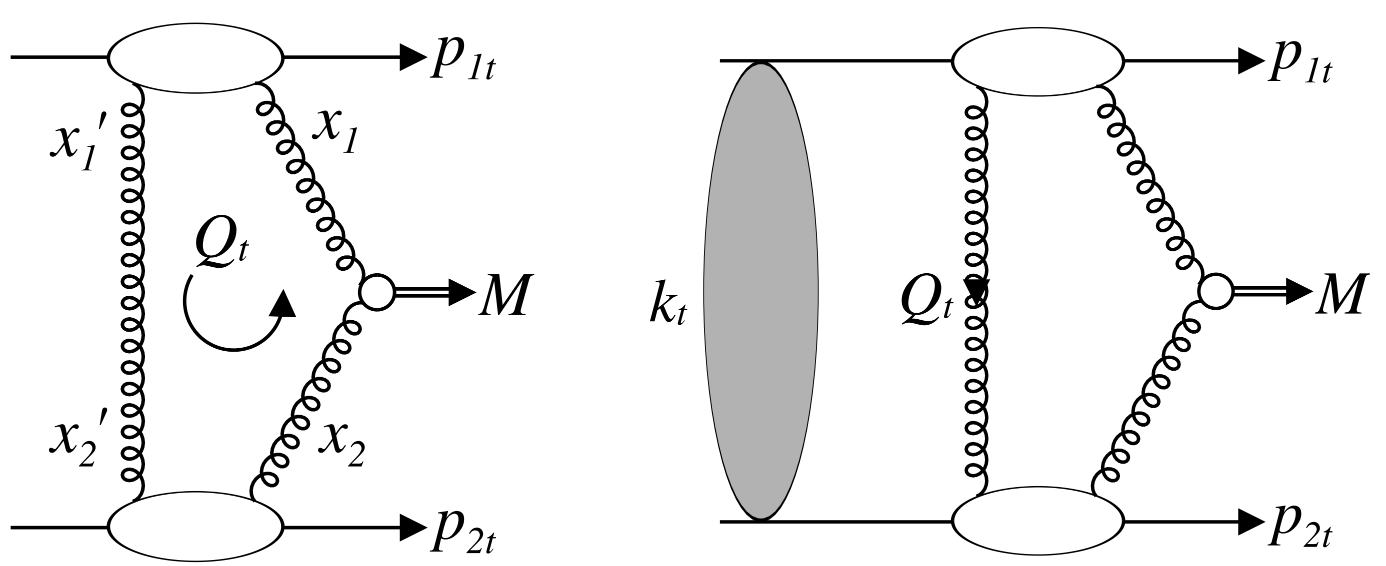
in $p_\perp$ space this is equivalent to

'Bare' amplitude

$$\langle S^2_{\rm eik} \rangle = \frac{\int {\rm d}^2\mathbf{p}_{1_\perp}\,{\rm d}^2\mathbf{p}_{2_\perp}\,|T(s,\mathbf{p}_{1_\perp},\mathbf{p}_{2_\perp})+T^{\rm res}(s,\mathbf{p}_{1_\perp},\mathbf{p}_{2_\perp})|^2}{\int {\rm d}^2\mathbf{p}_{1_\perp}\,{\rm d}^2\mathbf{p}_{2_\perp}\,|T(s,\mathbf{p}_{1_\perp},\mathbf{p}_{2_\perp})|^2}$$

where 'screened' amplitude is given by

$$T^{\rm res}(s,\mathbf{p}_{1_\perp},\mathbf{p}_{2_\perp}) = \frac{i}{s}\int\frac{{\rm d}^2\mathbf{k}_\perp}{8\pi^2}\,T_{\rm el}(s,\mathbf{k}_\perp^2)\,T(s,\mathbf{p'}_{1_\perp},\mathbf{p'}_{2_\perp})$$



'Bare' amplitude

'Screened amplitude'

- In $p_\perp$ space we can therefore write

'Bare' amplitude

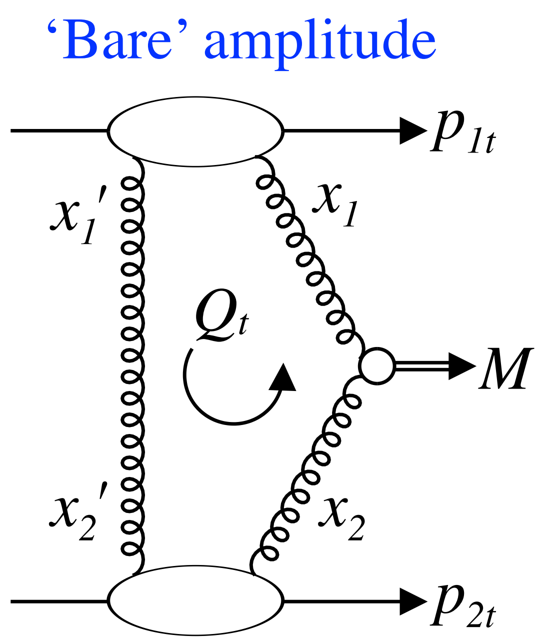
$$\frac{\mathrm{d}\sigma}{\mathrm{d}y_X} = \int \mathrm{d}^2\mathbf{p}_{1_\perp}\mathrm{d}^2\mathbf{p}_{2_\perp}\frac{|T(s,\mathbf{p}_{1_\perp},\mathbf{p}_{2_\perp}))|^2}{16^2\pi^5} S^2_{\mathrm{eik}}(s,\mathbf{p}_{1_\perp},\mathbf{p}_{2_\perp}) \;,$$

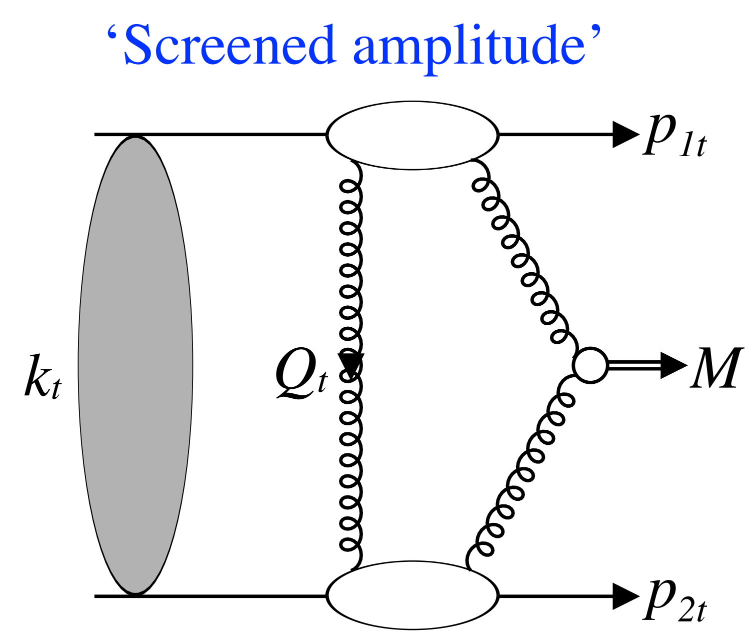
Not a constant!

with

$$S^2_{\mathrm{eik}}(s,\mathbf{p}_{1_\perp},\mathbf{p}_{2_\perp}) \equiv \frac{|T(s,\mathbf{p}_{1_\perp},\mathbf{p}_{2_\perp}) + T^{\mathrm{res}}(s,\mathbf{p}_{1_\perp},\mathbf{p}_{2_\perp})|^2}{|T(s,\mathbf{p}_{1_\perp},\mathbf{p}_{2_\perp})|^2} \;,$$

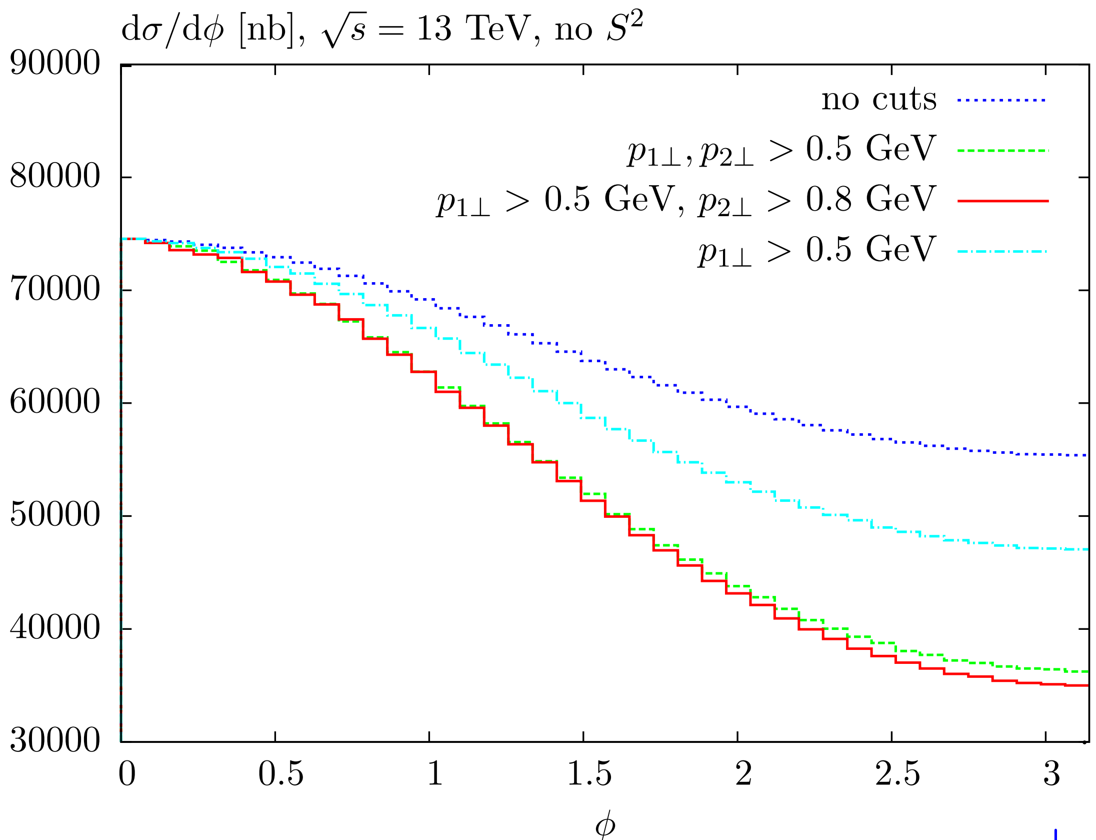
These expressions, suitably generalised to multi-channel case, are used in the MC to give the correct differential treatment of S^2_{eik}. KMR, Eur. Phys. J. C73 (2013) 2503



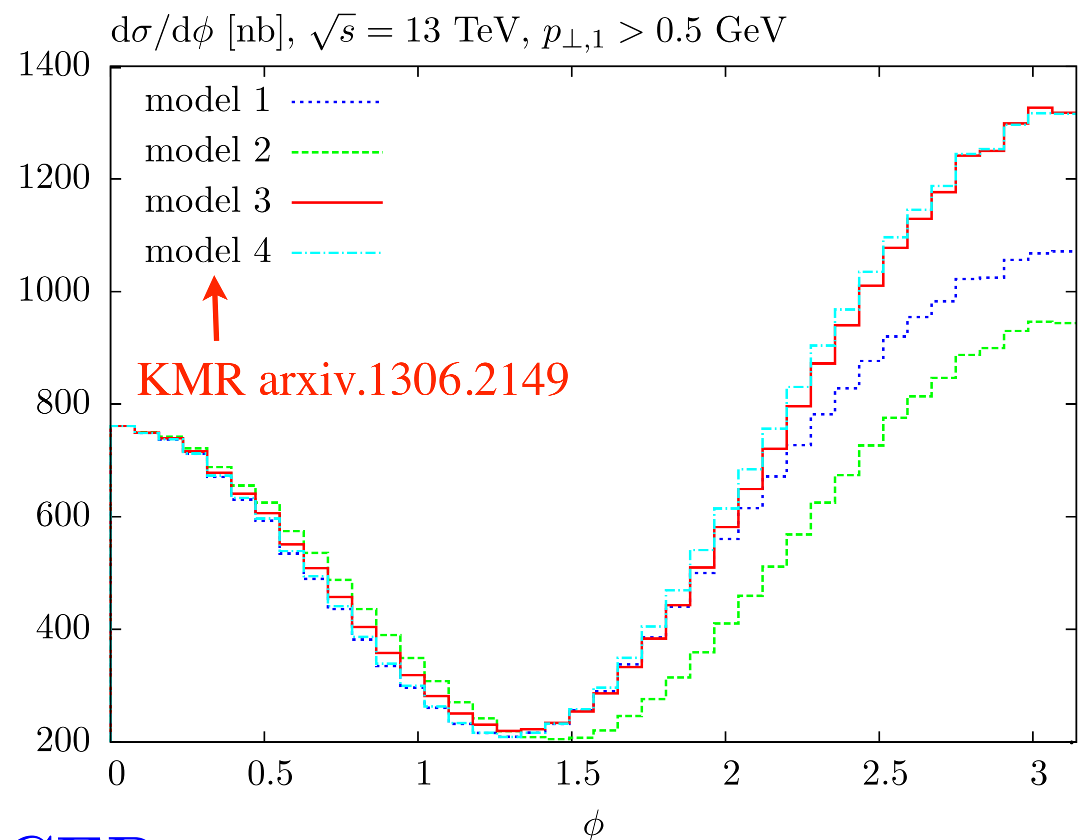


• The observation of CEP with tagged protons also provides additional information about survival factors...

S^2 off



S^2 on



$\pi^+\pi^-$ CEP

LHL, V.A. Khoze and M.G. Ryskin, arXiv:1312.4553

• Distribution in angle ϕ between outgoing protons strongly effected, in model dependent way.

• In particular true when larger values of proton $p_\perp$ are selected. Cancellation between screened and unscreened amplitudes leads to characteristic 'diffractive dip' structure

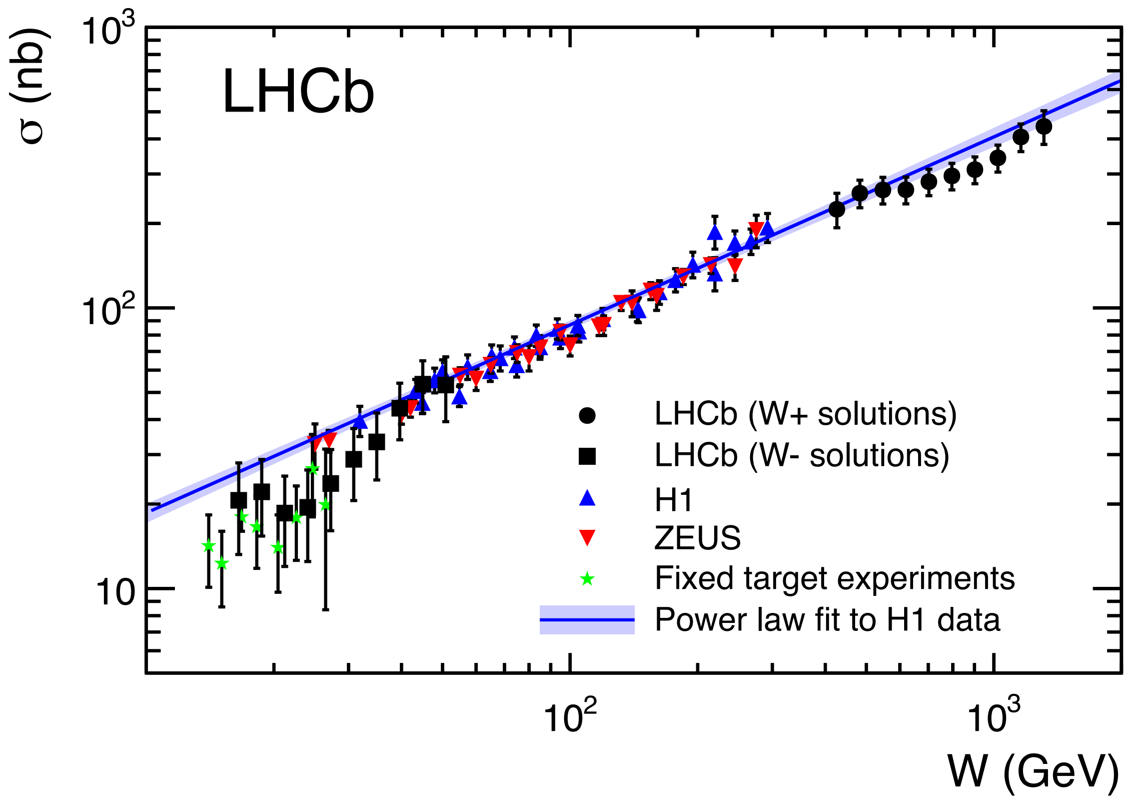
V. A. Khoze, A.D. Martin and M.G. Ryskin, hep-ph/0203122
LHL, V.A. Khoze, M.G. Ryskin and W.J. Stirling, arXiv:1011.0

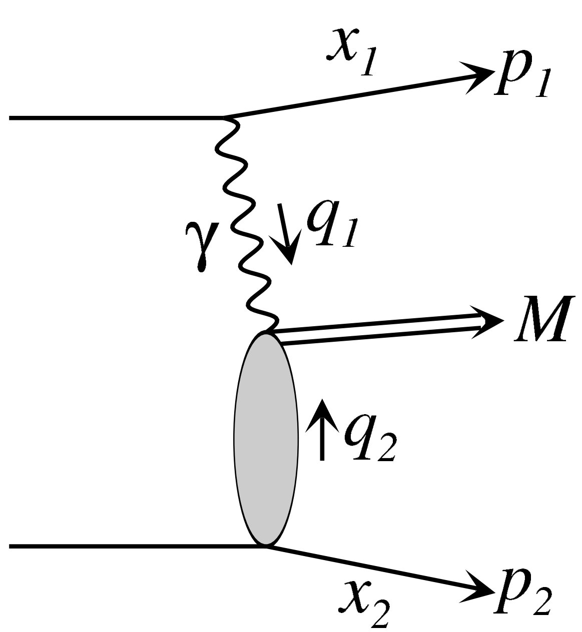
Example process: J/ψ photoproduction

- C-odd J/ψ : produced exclusively through $\gamma I\!P$ fusion.
- Observed by LHCb and ALICE at the LHC.

LHCb collab., J. Phys. G41 (2014) 055002 ALICE collab., Phys. Rev. Lett. 113 (2014) 23, 232504

- Survival effects less important compared to pure QCD CEP, but not negligible, in particular for precise comparisons.





J/ψ photoproduction: theory

- Different approaches to modeling J/ψ photoproduction available.

S.P Jones et al., J. Phys. G41 (2014) 055009

L. Motyka, G. Watt, Phys. Rev. D78 (2008) 0124023

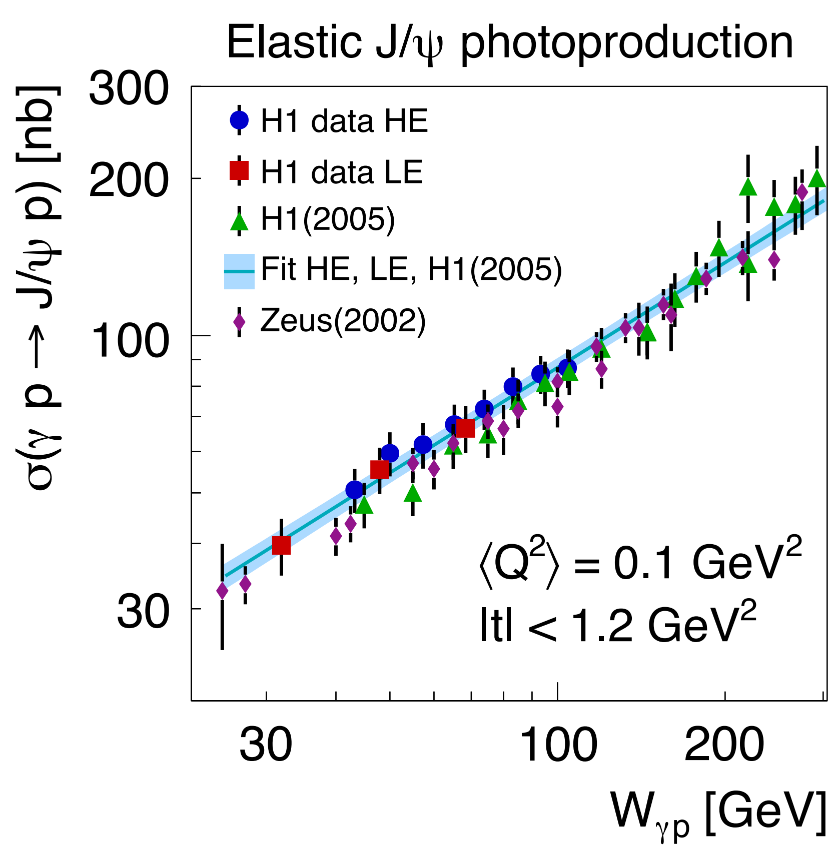
- In Superchic, take simple fit to HERA data:

$$\frac{d\sigma^{\gamma p\to Vp}}{dq_{2\perp}^2} = N_V \left(\frac{W_{\gamma p}}{90\,\text{GeV}}\right)^{\delta_V} b_V e^{-b_V q_{2\perp}^2} \qquad b_V = b_0 + 4\alpha' \log\left(\frac{W_{\gamma p}}{90\,\text{GeV}}\right)$$

$V = \psi$

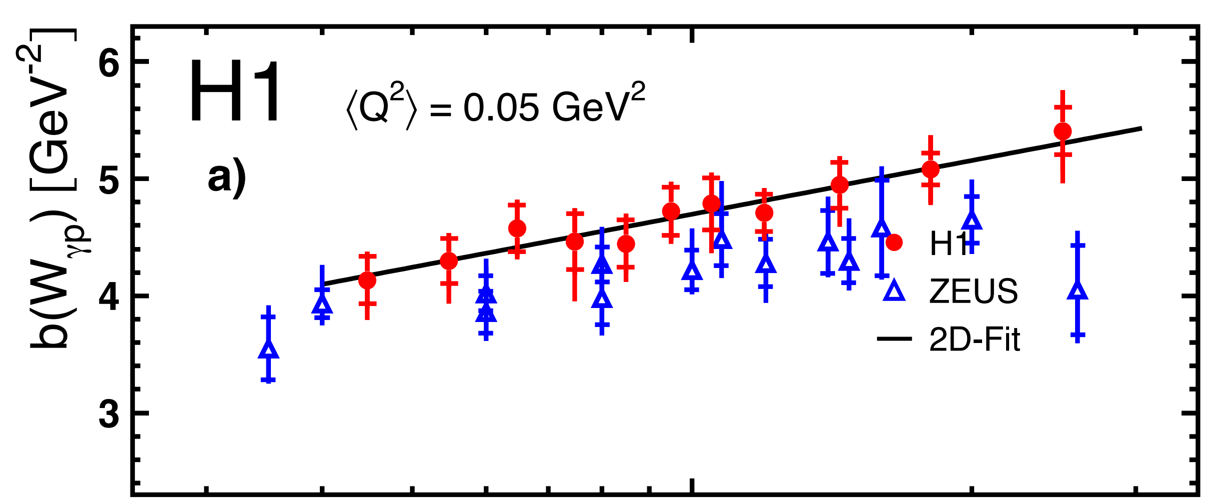
H1 find: $\delta_\psi = 0.67 \pm 0.03$ $\quad N_\psi = 81 \pm 3\,\text{nb}$ Anti-correlated

In what follows we take $\delta_\psi = 0.64\,\text{GeV}^2$ $\quad N_\psi = 81\,\text{nb}$



H1 collab., Eur. Phys. J. C73 (2013) 6, 2466

$\longrightarrow$ Lower end of cross sections allowed by fit



H1 collab., Eur. Phys. J. C46 (2006) 585-603

J/ψ photoproduction: results

- We find:

LHCb acceptance, $\mu^+\mu^-$decay including spin corr.

		$2 < \eta^\mu < 4.5$	
		$\sqrt{s} = 7$ TeV	$\sqrt{s} = 13$ TeV
σ [pb]	$\sigma^\psi_{\rm bare}$	360	512
	$\sigma^\psi_{\rm sc.}$	278	405
	$\langle S^2_{\rm eik}\rangle$	0.77	0.79

- LHCb measure:

$$\sigma^{J/\psi\to\mu^+\mu^-}(2 < \eta^\mu < 4.5) = 291 \pm 7 \pm 19\,{\rm pb}$$

recall these predictions are (roughly) the lowest values in good agreement with the H1 fit (can be up to ~ 40% higher).

$\longrightarrow$ Predictions with screening effects favoured.

What about differential tests?

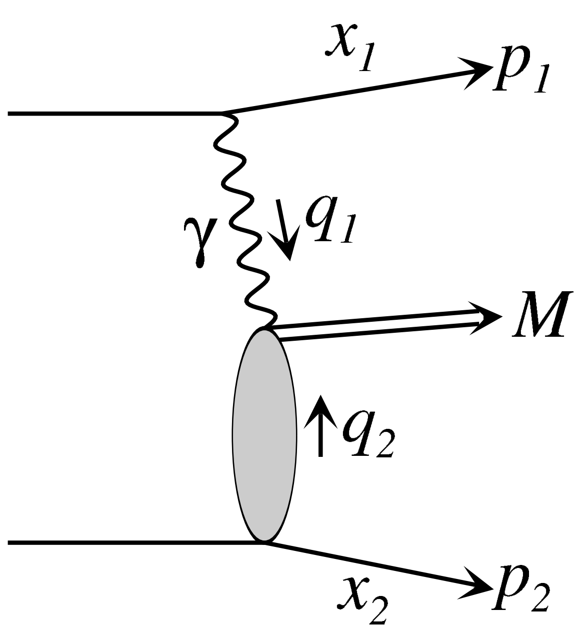
Rapidity distribution

- Photon virtuality has kinematic minimum $Q^2_{1,\mathrm{min}} = \dfrac{\xi_1^2 m_p^2}{1-\xi_1}$

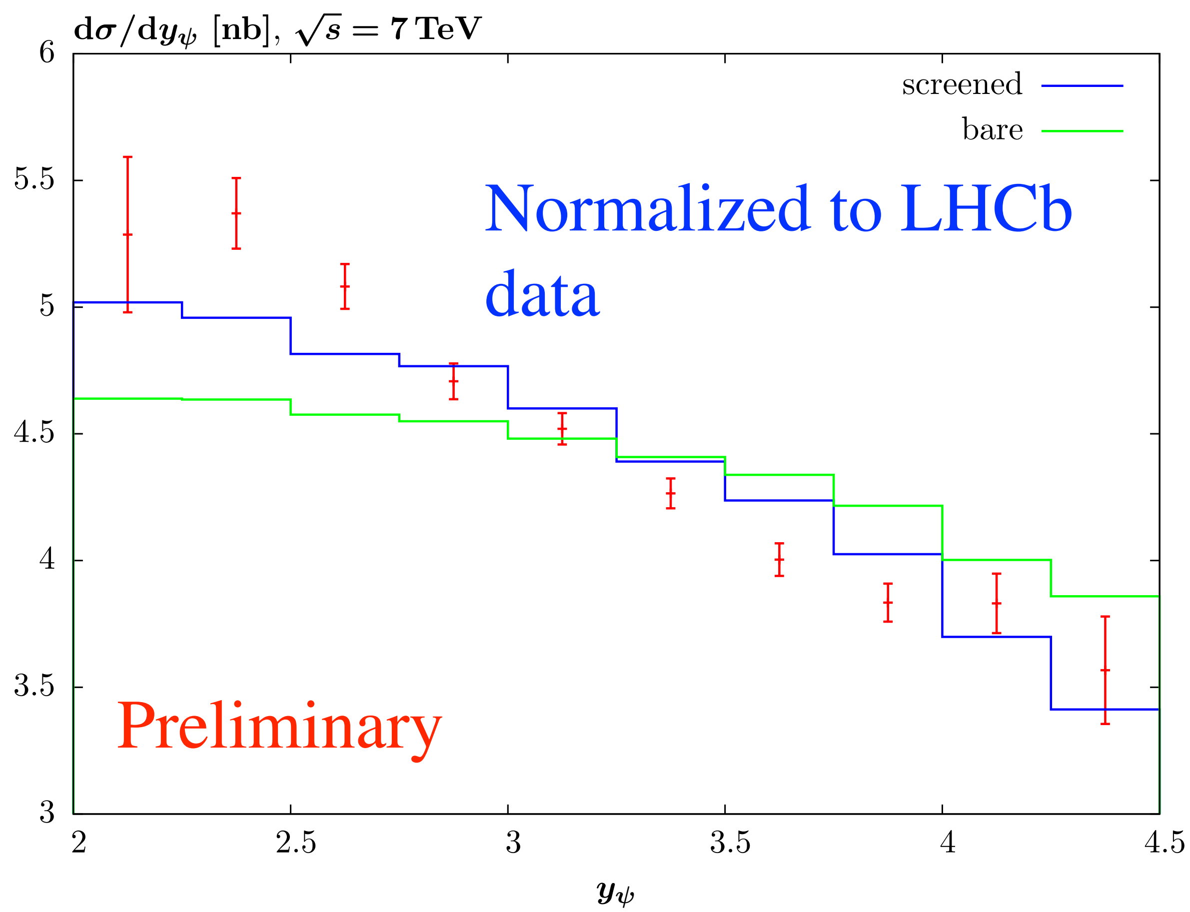
where $\xi_1 \approx \dfrac{M_\psi}{\sqrt{s}} e^{y_\psi}$ assuming photon emitted from proton 1 positive z-direction

$\longrightarrow$ Forward production $\Rightarrow$ higher photon Q^2 and less peripheral interaction

$\Rightarrow$ Smaller S^2_{eik}



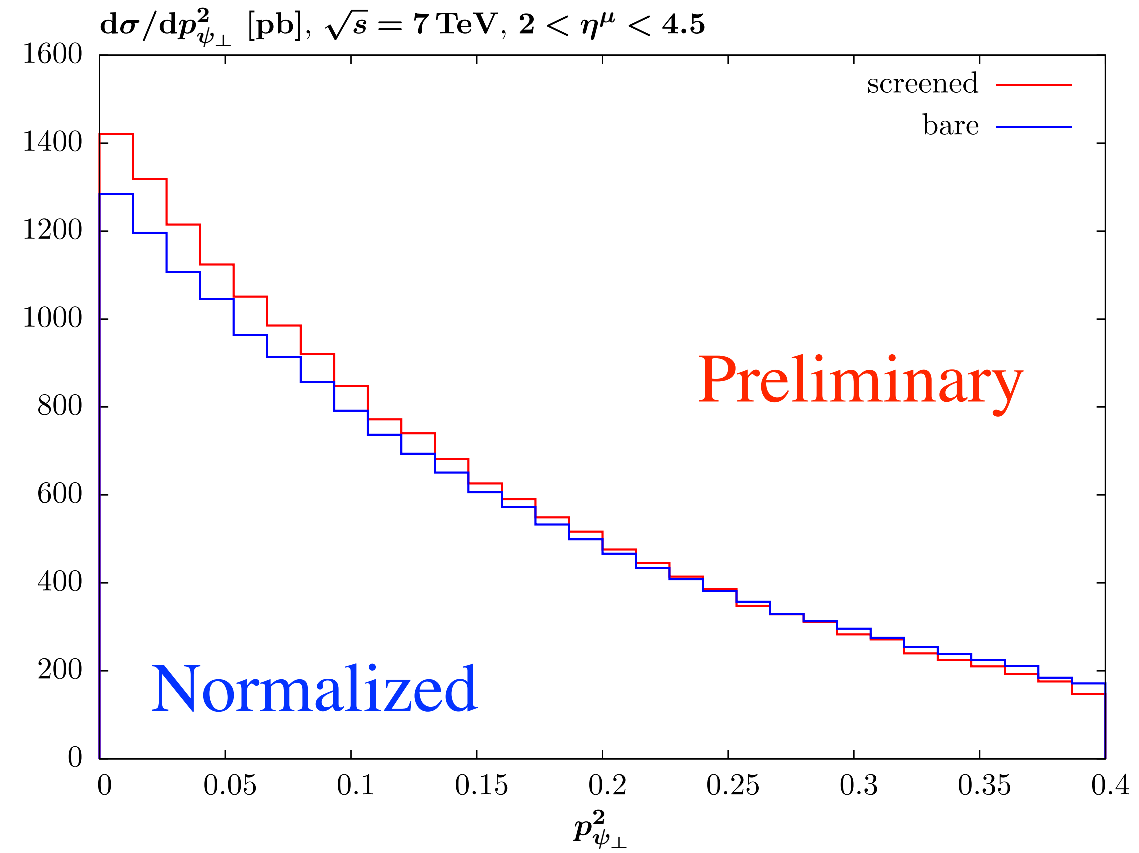
- Predicted rapidity distribution steeper due to survival effects:



- Screened prediction gives better description. Somewhat model dependent (don't have to assume HERA fit)...

$p_\perp$ distribution

- Proton $p_\perp$ transferred directly to J/ψ. Higher $p_{\psi_\perp}$ $\Rightarrow$ less peripheral, and stronger screening. $\Rightarrow$ Survival effects will steepen $p_{\psi_\perp}$ distribution.



- Fit as an exponential $\sim \exp(-bp^2_{\psi_\perp})$ with

$$b_{\rm el}^{\rm bare} = 5.0\,{\rm GeV}^{-2} \qquad b_{\rm el}^{\rm sc.} = 5.5\,{\rm GeV}^{-2}$$

with $\sim \pm 0.1\,{\rm GeV}^{-2}$ error from parameter uncertainty in HERA fit to $\gamma I\!\!P$ vertex.

$$b_V = b_0 + 4\alpha' \log\left(\frac{W_{\gamma p}}{90\,{\rm GeV}}\right)$$

- LHCb have measured this quite precisely:

$$b_{\rm el}^{\psi} = 5.70 \pm 0.11\,{\rm GeV}^{-2}$$

$\longrightarrow$ Survival effects again greatly improve description. Arguably less model-dependent. Crucial to include in any precise phenomenological predictions.

Two-photon initiated processes

- Two-photon initiated exclusive processes are in principle very well understood (standard equiv. photon approx.). Proposed as luminosity test and probe of anomalous gauge couplings.

EPA luminosity

$$\frac{\mathrm{d}\sigma_{pp\to pXp}}{\mathrm{d}\Omega} = \int \frac{\mathrm{d}\sigma_{\gamma\gamma\to X}(W_{\gamma\gamma})}{\mathrm{d}\Omega} \frac{\mathrm{d}L^{\gamma\gamma}}{\mathrm{d}W_{\gamma\gamma}} \mathrm{dW}_{\gamma\gamma} \ ,$$

- However: in proton-proton collisions a correct inclusion of S^2 essential.

- General considerations: the EPA flux prefers small photon virtualities

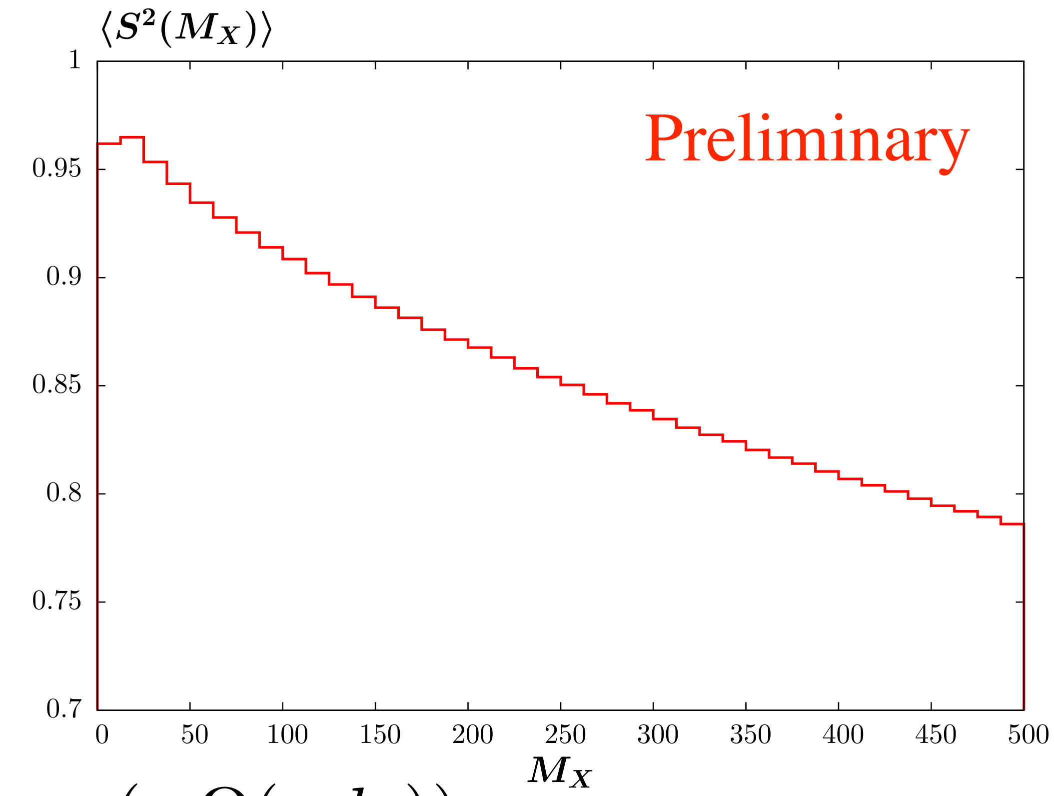
$$Q^2_{i,\min} = \xi_i^2 m_p^2/(1-\xi_i) \qquad \xi \sim \frac{W_{\gamma\gamma}}{\sqrt{s}} e^{\pm y_X}$$

and therefore interaction highly peripheral $\longrightarrow \langle S^2 \rangle \sim 1$

- But still important for precise treatment, and as before if $W_{\gamma\gamma}$ large or for forward production, then $\langle S^2 \rangle$ is smaller.

$M_X = W_{\gamma\gamma}$

- Consider $\langle S^2(M_X)\rangle$ for W^+W^- production: clear drop with M_X seen.



- Recall expression for survival factor:

$\gamma\gamma \to X$

$$\langle S^2_{\rm eik}\rangle = \frac{\int {\rm d}^2\mathbf{b}_{1t}\,{\rm d}^2\mathbf{b}_{2t}\,|T(s,\mathbf{b}_{1t},\mathbf{b}_{2t})|^2\,\exp(-\Omega(s,b_t))}{\int {\rm d}^2\,\mathbf{b}_{1t}{\rm d}^2\mathbf{b}_{2t}\,|T(s,\mathbf{b}_{1t},\mathbf{b}_{2t})|^2}$$

$\longrightarrow$ Important to correctly include b_t dependence of subprocess amplitude

(massless leptons)

- l^+l^- production: the $\gamma\gamma \to l^+l^-$ amplitudes vanish for $J_z = 0$ initial state photons. It turns out this leads to less absorption than naive expectations.

- In particular, this leads to dependence on event selection: by demanding small $p_\perp(l^+l^-)$, get $\langle S^2\rangle$ very close to 1.

V.A. Khoze, A.D. Martin, R.Orava, M.G. Ryskin, Eur. Phys. J. C19 (2001) 313-322

	$\mu^+\mu^-$	$\mu^+\mu^-$, $M_{\mu\mu} > 2M_W$	$\mu^+\mu^-$, $p_\perp^{\rm prot.} < 0.1$ GeV	W^+W^-
$\sigma_{\rm bare}$	6240	11.2	3170	87.5
$\sigma_{\rm sc.}$	5990	9.58	3150	71.9
$\langle S^2_{\rm eik}\rangle$	0.96	0.86	0.994	0.82

Preliminary

- New ATLAS data on exclusive $\mu^+\mu^-$and e^+e^- production: arXiv:1506.07098.

- Important of including survival effects is discussed, and measurements compared to predictions of Dyndal & Schoeffel- form of one-channel calculation, with specific assumptions about the form of the opacity:

M. Dyndal and L. Schoeffel, Phys. Lett. B741 (2015) 66-70

EPA flux

$$S^2_{\gamma\gamma} = \frac{\int_{b_1>r_p}\int_{b_2>r_p} n(\vec{b}_1,\omega_1)n(\vec{b}_2,\omega_2)P_{non-inel}(|\vec{b}_1-\vec{b}_2|)d^2\vec{b}_1 d^2\vec{b}_2}{\int_{b_1>0}\int_{b_2>0} n(\vec{b}_1,\omega_1)n(\vec{b}_2,\omega_2)d^2\vec{b}_1 d^2\vec{b}_2} \qquad P_{non-inel}(b) = |1-\exp(-b^2/(2B))|^2,$$

does not include b_t dependence of $\gamma\gamma \to l^+l^-$amplitude.

$\longrightarrow$ Misses important physics, may overestimate suppression due to S^2 .

- ATLAS measure:

$$\sigma^{\text{excl.}}_{\gamma\gamma\to\mu^+\mu^-} = 0.628 \pm 0.032\,(\text{stat.}) \pm 0.021\,(\text{syst.})\text{ pb},$$

$$\sigma^{\text{excl.}}_{\gamma\gamma\to e^+e^-} = 0.428 \pm 0.035\,(\text{stat.}) \pm 0.018\,(\text{syst.})\text{ pb}.$$

Preliminary

- Superchic 2 predictions: $\sigma(\mu^+\mu^-) = 0.74\,\text{pb} \quad \sigma(e^+e^-) = 0.46\,\text{pb} \qquad \langle S^2_{\text{eik}}\rangle \sim 0.94$

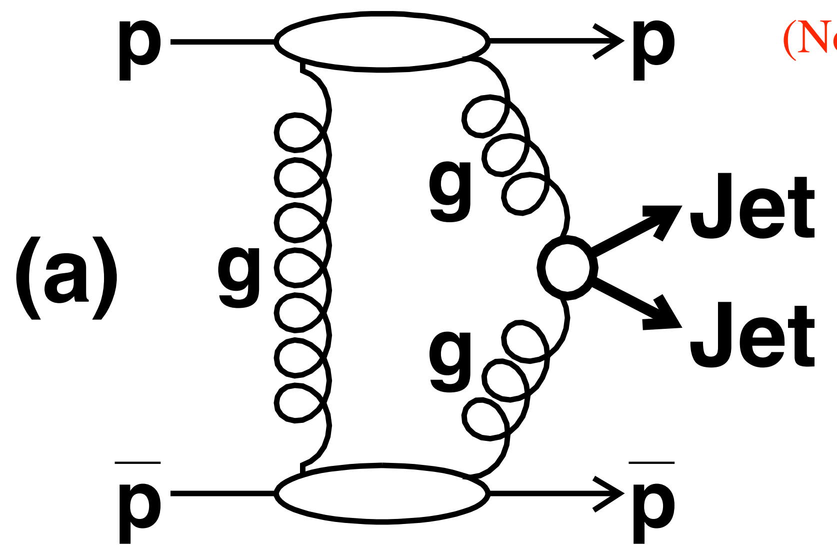
$\longrightarrow$ Good agreement for e^+e^-, some tension with $\mu^+\mu^-$. Higher precision and more differential (in e.g. $p_\perp(\mu^+\mu^-)$) data will shed more light on this. Tagged protons: eliminate dissociative BG.

Example process: Jet production

- We are interested in the exclusive signal, in which case we have

For inelastic DPE: e.g. POMWIG, B.E. Cox and J.R. Forshaw, Comput.Phys.Commun. 144 (2002) 104-110

(Note does not include survival factor)



- The parton-level dijet amplitude is given by the usual Durham expression:

$$T = \pi^2 \int \frac{d^2\mathbf{Q}_\perp \, \mathcal{M}(gg \to X)}{\mathbf{Q}_\perp^2 (\mathbf{Q}_\perp - \mathbf{p}_{1_\perp})^2 (\mathbf{Q}_\perp + \mathbf{p}_{2_\perp})^2} \, f_g(x_1, x_1', Q_1^2, \mu^2; t_1) f_g(x_2, x_2', Q_2^2, \mu^2; t_2)$$

Where $X = gg, q\bar{q}, ggg, q\bar{q}g$

Dijet production

- We need the amplitudes for

$$gg \to gg \quad \text{and} \quad gg \to q\bar{q}$$

For colour singlet gluons. $J_z = 0$ selection rule $\Rightarrow$ dominant contribution will come from amplitude for incoming gluons with $(++,--)$ helicities. These are given by

$$\mathcal{M}\left(g(\pm)g(\pm) \to g(\pm)g(\pm)\right) = \delta^{CD}\frac{N_c}{N_c^2-1}\frac{32\pi\alpha_s}{(1-\cos^2\theta)}$$

Other final state helicities give vanishing amplitudes

$$\mathcal{M}\left(g(\pm)g(\pm) \to q_h\overline{q}_{\overline{h}}\right) = \frac{\delta^{cd}}{2N_c}\frac{16\pi\alpha_s}{(1-\beta^2\cos^2\theta)}\frac{m_q}{M_X}(\beta h \pm 1)\,\delta_{h,\overline{h}}$$

For massless quarks this vanishes!

Helicity non-conservation along quark line

$\longrightarrow$ Quark jets dynamically suppressed by selection rule

Production subprocess

- If we consider the exclusive cross section ratio, we find

$$\frac{\mathrm{d}\sigma(q\overline{q})/\mathrm{d}t}{\mathrm{d}\sigma(gg)/\mathrm{d}t} \approx \frac{N_c^2-1}{4N_c^3}\frac{m_q^2}{M_X^2} = \frac{2}{27}\frac{m_q^2}{M_X^2}$$

Additional suppression from colour and spin 1/2 quarks

- Taking e.g. $m_b = 4.5$ GeV and $M_X = 40$ GeV we then get

$$\frac{\mathrm{d}\sigma(b\overline{b})/\mathrm{d}t}{\mathrm{d}\sigma(gg)/\mathrm{d}t} \approx 10^{-3}$$

Huge suppression in b quark jets (increasing with M_X). Completely unlike inclusive case. See also: $H \to b\overline{b}$

$\longrightarrow$ What about light quark jets?

Light quark jets

- For light quark jets ($m_q \to 0$) the leading order $J_z = 0$ production amplitude (dominant for CEP) will vanish. $\Rightarrow$ Must consider sub-leading $|J_z| = 2$ contribution. Find that:

$$\mathcal{M}(g(\pm)g(\mp) \to q_h \overline{q}_{\bar{h}}) = \frac{\delta^{cd}}{2N_c} 8\pi\alpha_s \left(\frac{1 \pm h\cos\theta}{1 \mp h\cos\theta} \right)^{1/2} \delta_{h,-\bar{h}}$$

- In general such a $|J_z| = 2$ contribution is suppressed in CEP by

$$\frac{\sigma(|J_z| = 2)}{\sigma(J_z = 0)} \sim \frac{\langle p_\perp^2 \rangle^2}{\langle Q_\perp^2 \rangle^2} \sim 10^{-2}$$

Average outgoing proton transverse momentum (sub-GeV^2)

Average gluon transverse momentum in loop $\sim$ several GeV^2

- Combining these we have

$$\frac{\mathrm{d}\sigma^{J_z=\pm 2}(q\overline{q})/\mathrm{d}t}{\mathrm{d}\sigma(gg)/\mathrm{d}t} \approx \frac{N_c^2 - 1}{16 N_c^3} \frac{\langle p_\perp^2 \rangle^2}{\langle Q_\perp^2 \rangle^2} \sim 10^{-4}$$

For one flavour $\Rightarrow$ multiply by $n_f = 4$

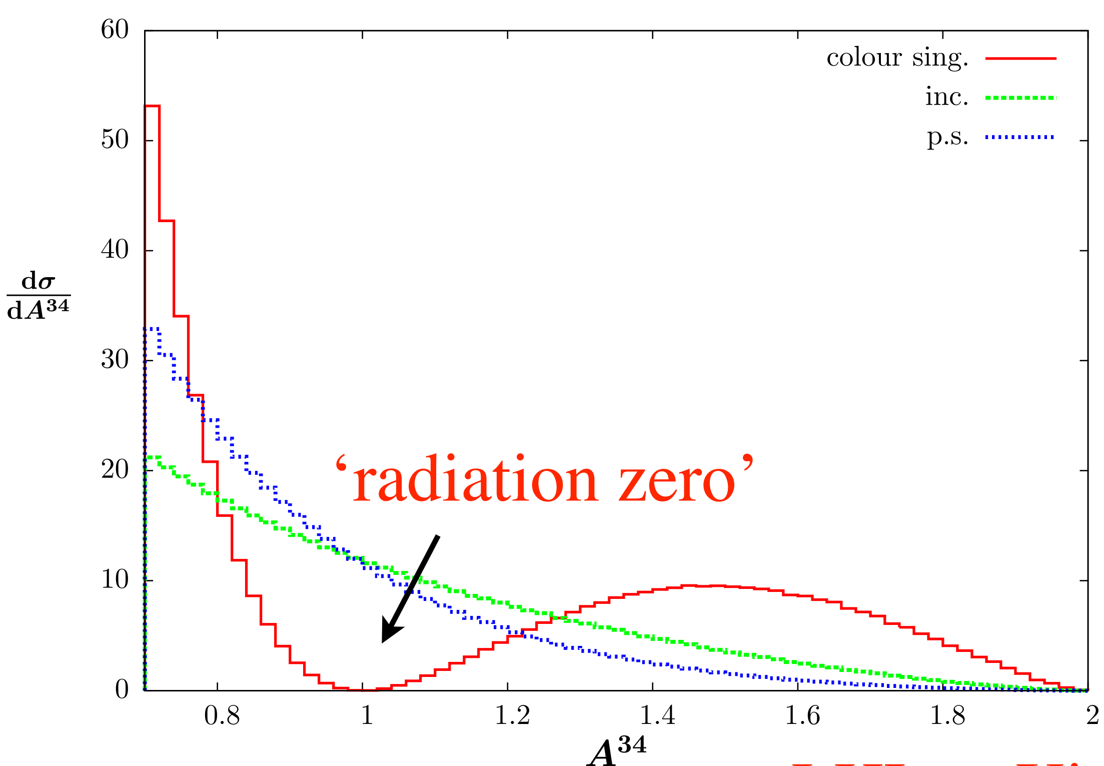
$\longrightarrow$ Huge suppression in light quark jets

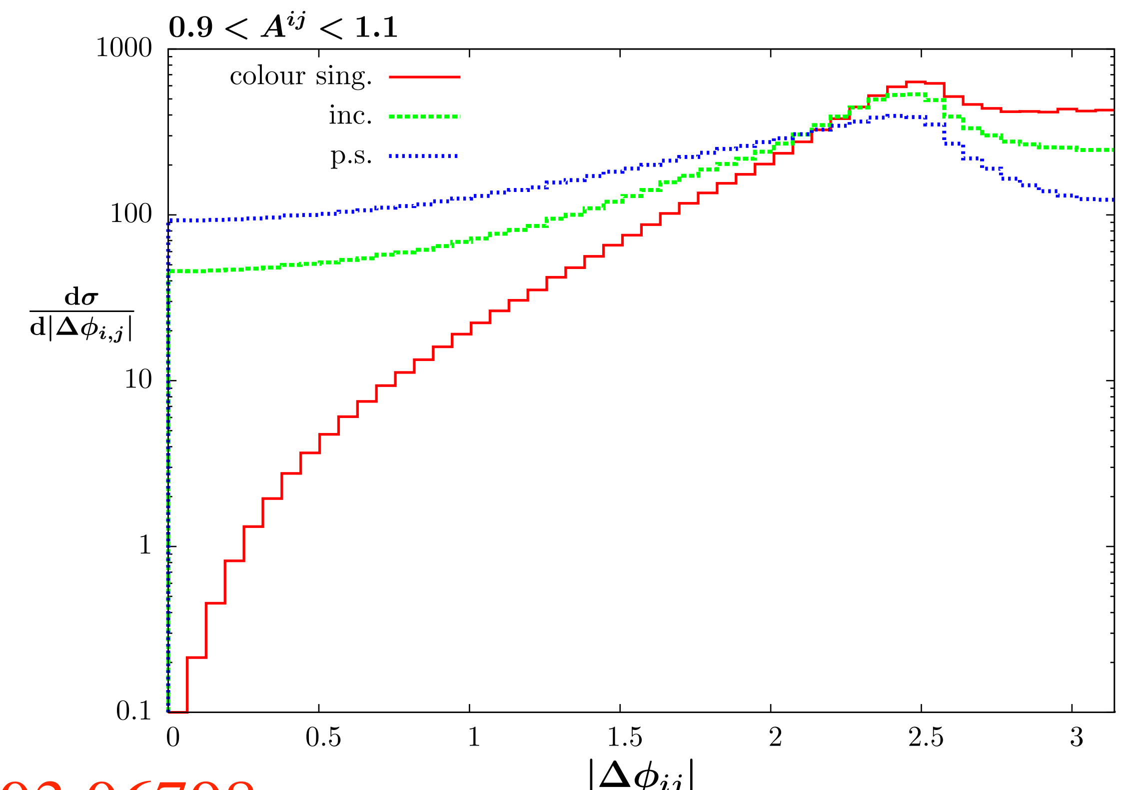
Trijet production

- Consider three-jet production, proceeds via $gg \to ggg$ and $gg \to q\bar{q}g$
- $q\bar{q}g$: configuration with g becoming soft/collinear to $q/\bar{q}$ driven by two-jet $q\bar{q}$ amplitude, which vanishes for $J_z = 0$ gluons and $m_q = 0$.

$\longrightarrow$ Expect relative enhancement of 'Mercedes-like' configuration for $q\bar{q}g$ events.

- In addition, new result: both ggg and $q\bar{q}g$ amplitudes for c.s. initial gluons completely vanish for certain configurations, if all particle momenta lie in a plane ($\Delta\phi_{ij} = 0, \pi$ for final--state particles).





LHL, arXiv:1503.06798

LHC cross sections

- Predictions for $\sqrt{s} = 13\,\text{TeV}$:

σ [pb] $\qquad |\eta_j| < 2.5$ anti–k_t, $R = 0.6$

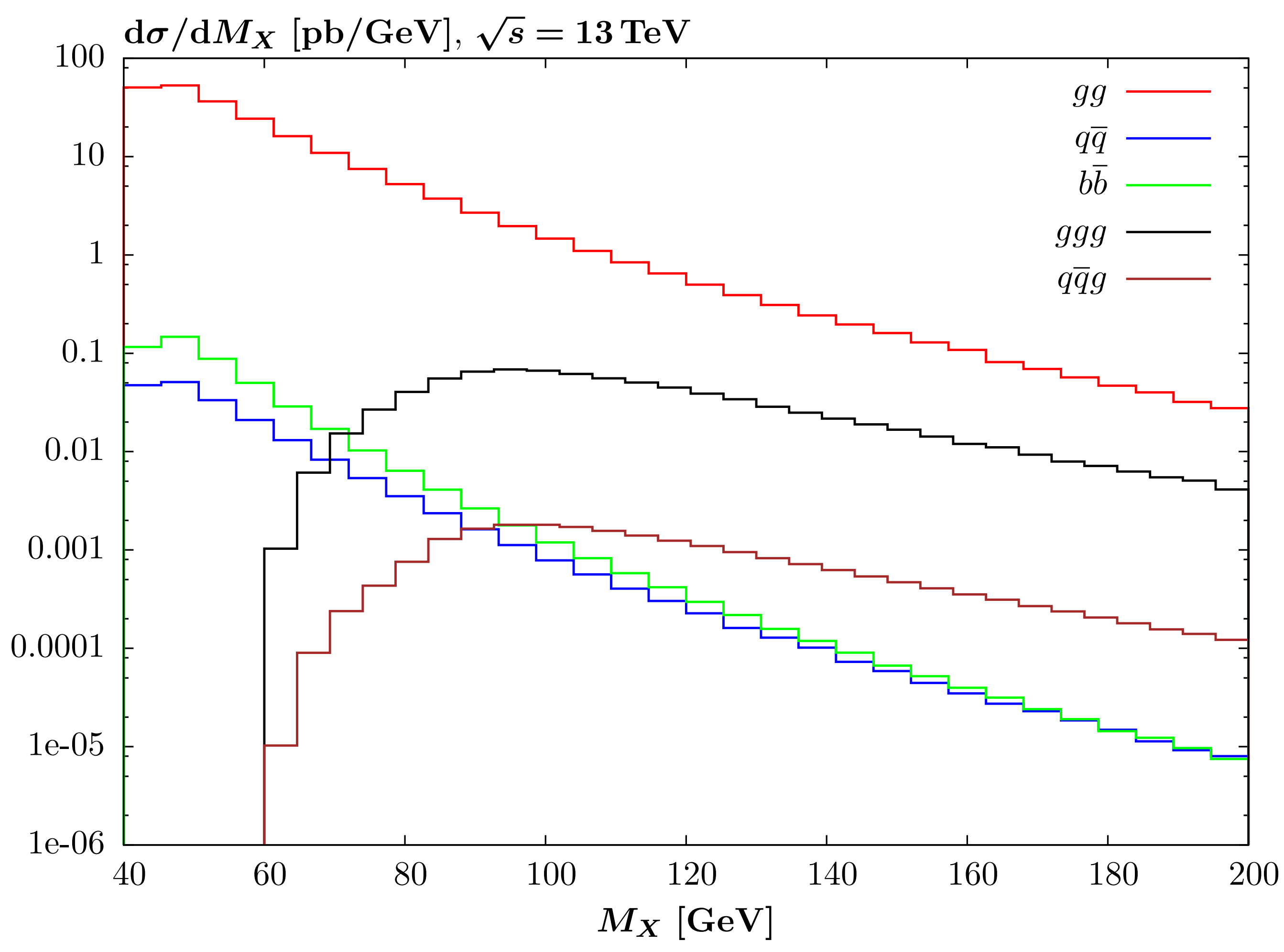
M_X(min)	gg	$q\bar{q}$	$b\bar{b}$	ggg	$gq\bar{q}$
75	120	0.073	0.12	6.0	0.14
150	4.0	1.4×10^{-3}	1.7×10^{-3}	0.78	0.02
250	0.13	5.2×10^{-5}	5.2×10^{-5}	0.018	5.0×10^{-4}

$|p_{\perp,j}| > 20\,\text{GeV}$ → 75, 150

$|p_{\perp,j}| > 40\ \text{GeV}$ → 250

one flavour

MMHT14 LO PDFs



Summary and outlook

- Have discussed new 'SuperChic 2' MC. Builds on previous MC, but with significant changes/extensions:
  - Theoretical improvements, most important a fully differential treatment of survival effects. Crucial to have this in many cases.
  - Completely re-structured: LHAPDF interface, and complete calculation performed 'on-line', structured so that additional processes can be easily added.
  - New processes added: jets, Higgs, two-photon interactions, double quarkonia...
  - In the immediate future: $D\overline{D}$ production will be included. Other processes?
- Release planned for next week, with accompanying paper.

Backup

Gluon jet dominance

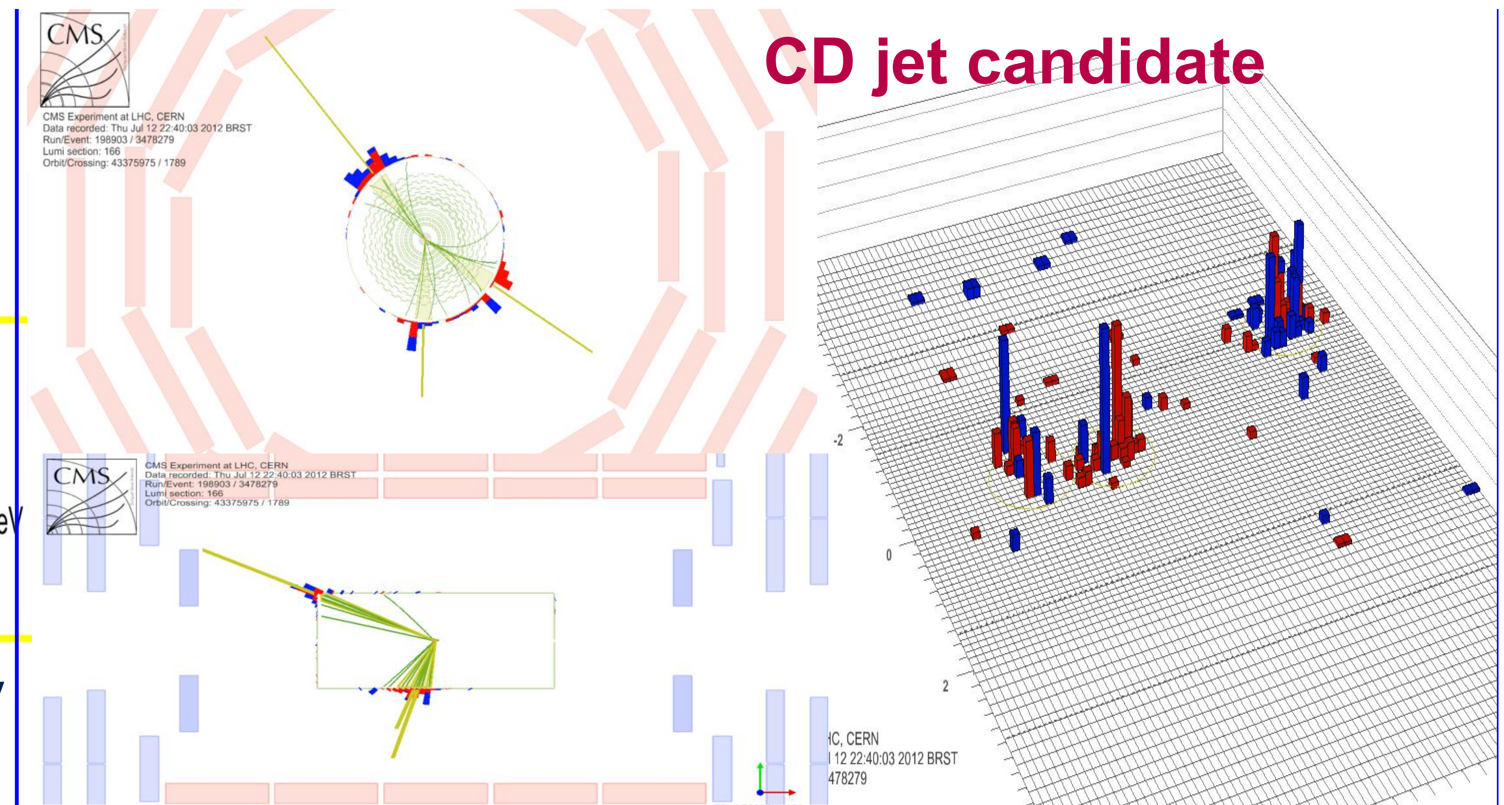
From the above considerations, we expect dijet events to be almost entirely (colour singlet) gg Verified in CDF data sample of $b\bar{b}$ jets

CEP of dijets offers the possibility of observing the isolated production of gluon jets at the LHC.

CMS + TOTEM 90m β*
Run/Event 198903/3478279
Jets E_T = 65,45,27 GeV

MM(pp) = 244 GeV; M(CMS) = 219 GeV
Σp_T(CMS) = 3.4 GeV
FSC empty both sides

M(pp) = 244 GeV ≈ M(central)
ξ_1 = 0.1 ξ_2= 0.01



CMS + TOTEM event displays

Mike Albrow's EDS 2013 summary talk, arXiv:1310.7047 :

> These dijet and trijet events are the cleanest ever seen at a hadron collider, and remind one of LEP events. But these dijets are nearly all gg, while at LEP there were all $q\bar{q}$.

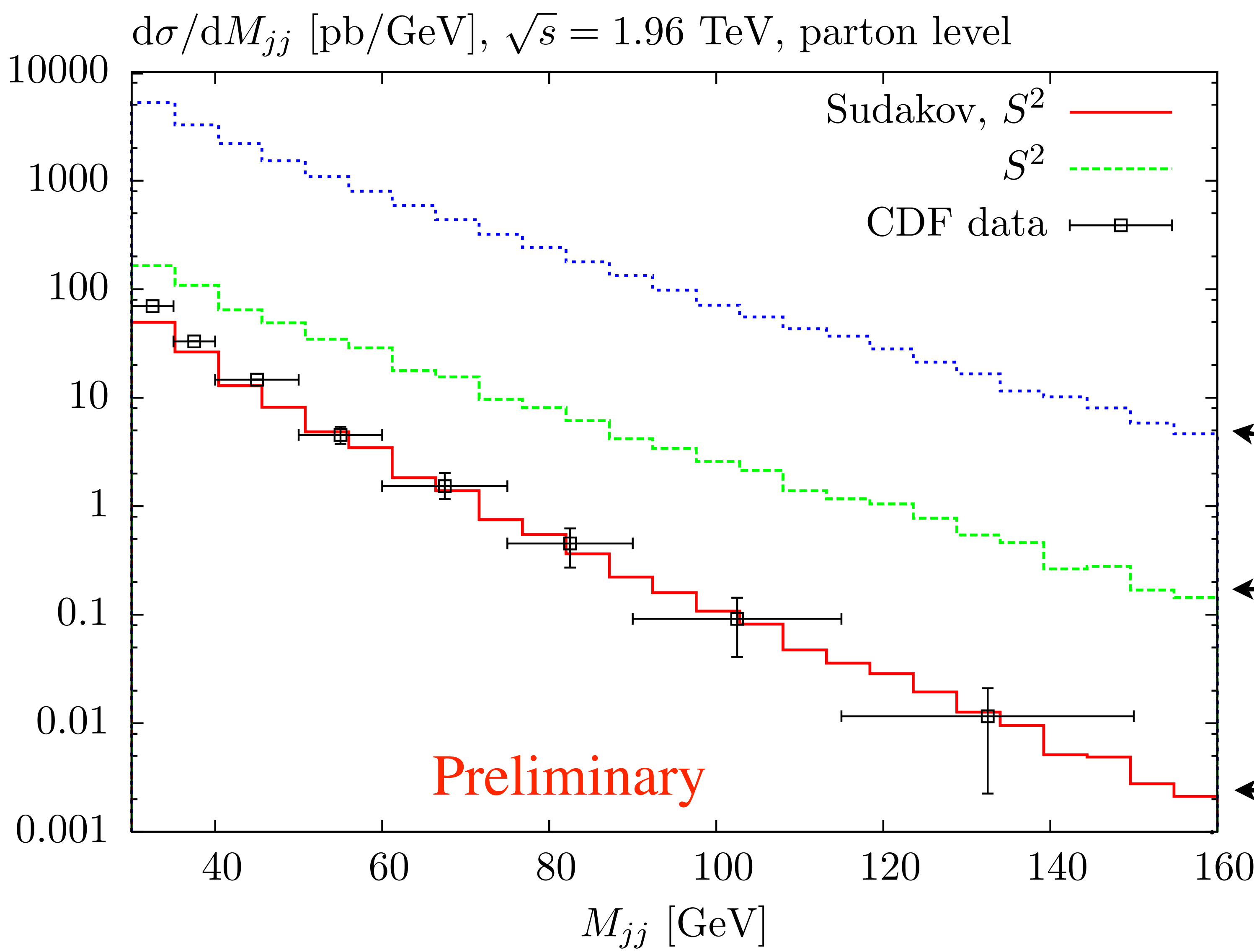
$\longrightarrow$ Clean probe of properties of gluons jets (multiplicity, particle correlations...)

CDF Collab., Phys.Rev.D77:052004,2008

Tevatron cross sections

- Can compare results of the MC with the CDF measurement.
- See clearly how both soft survival effects and Sudakov factor (non-pert. and pert. physics) are crucial to describe data.

Probability to produce colour singlet dijet state drops strongly with M_{jj}



MSTW08LO PDFs, parton level

Soft survival not included, scale of Sudakov factor frozen

Soft survival included, scale of Sudakov factor frozen

Soft survival included, scale of Sudakov factor $\sim M_{jj}$

Made with particular choice of S^2 model and PDFs $\Rightarrow$ more measurements (different $\sqrt{s}$...) needed to test theory further...

Also, caveat: only parton level!