Central exclusive quarkonium production at LHCb

Ronan McNulty (UCD Dublin)
on behalf of the LHCb collaboration

CERN-LHC Seminar. 4th February 2013

Outline

- Theoretical background and motivation
  - Generally for Central Exclusive Production (CEP),
  - Particularly for J/ψ and ψ(2S)
- Experimental signatures
- Selection of Central Exclusive Produced J/ψ and ψ(2S)
- Results and Discussion
- Future Prospects

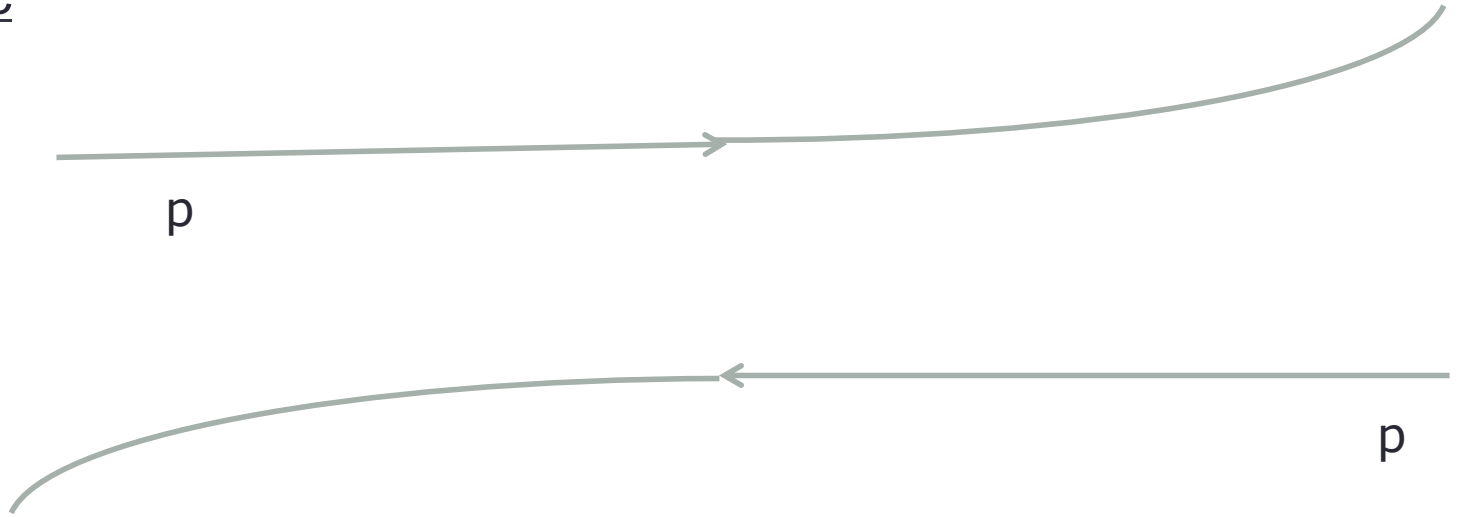
Theoretical background and motivation

Understanding QCD

- At hard scales
  - theory perturbative and thus predictive
  - key features well tested by experiment
- At soft scales
  - non-perturbative – precise predictions generally not possible
  - yet this is where most physics happens
    - bound hadrons and nature of vacuum
  - choose your experimental environment carefully and challenge theory
- Open questions
  - colourless objects (pomeron, reggeon, odderon)
  - glueballs
  - QCD behaviour may change at very soft scales
    - inexorable rise of gluon PDF as x->0?
    - new phenomenology like saturation?

Physics of the Vacuum

Elastic

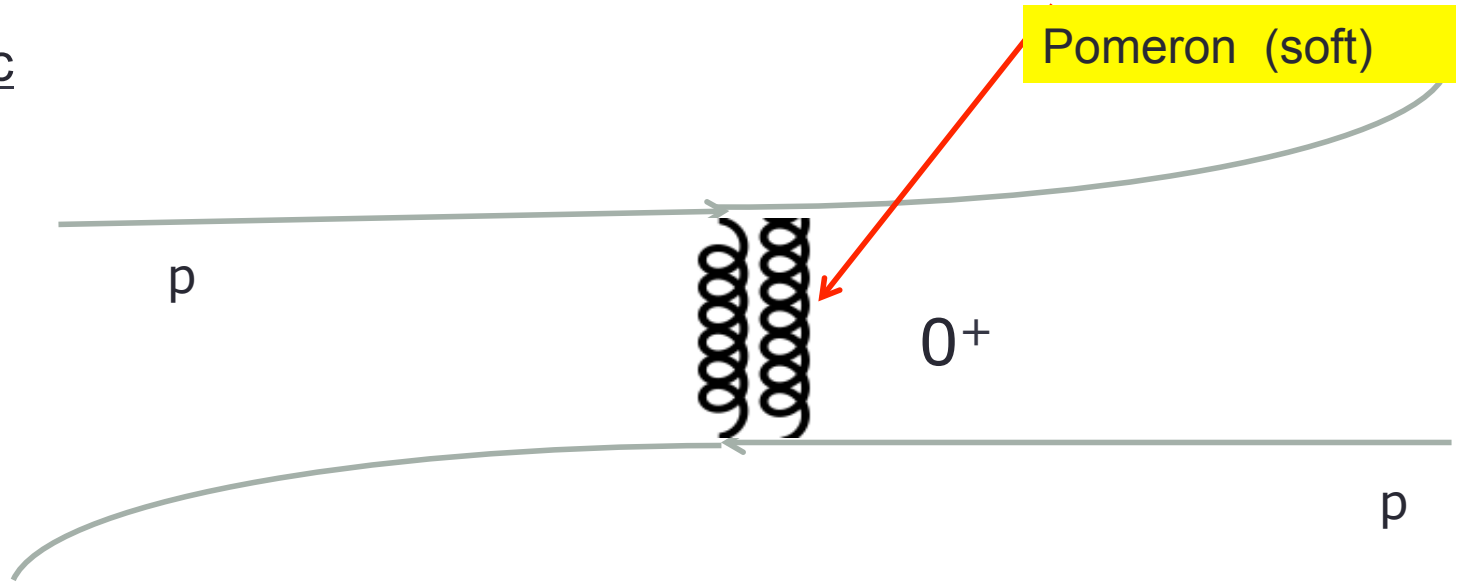


It's QCD – but not as we normally see it. It's colour-free

$\sigma_{elastic}$ ≈ 40mb
$\sigma_{diffractive}$ ≈ 10mb
$\sigma_{inelastic}$ ≈ 60mb

Physics of the Vacuum

Elastic



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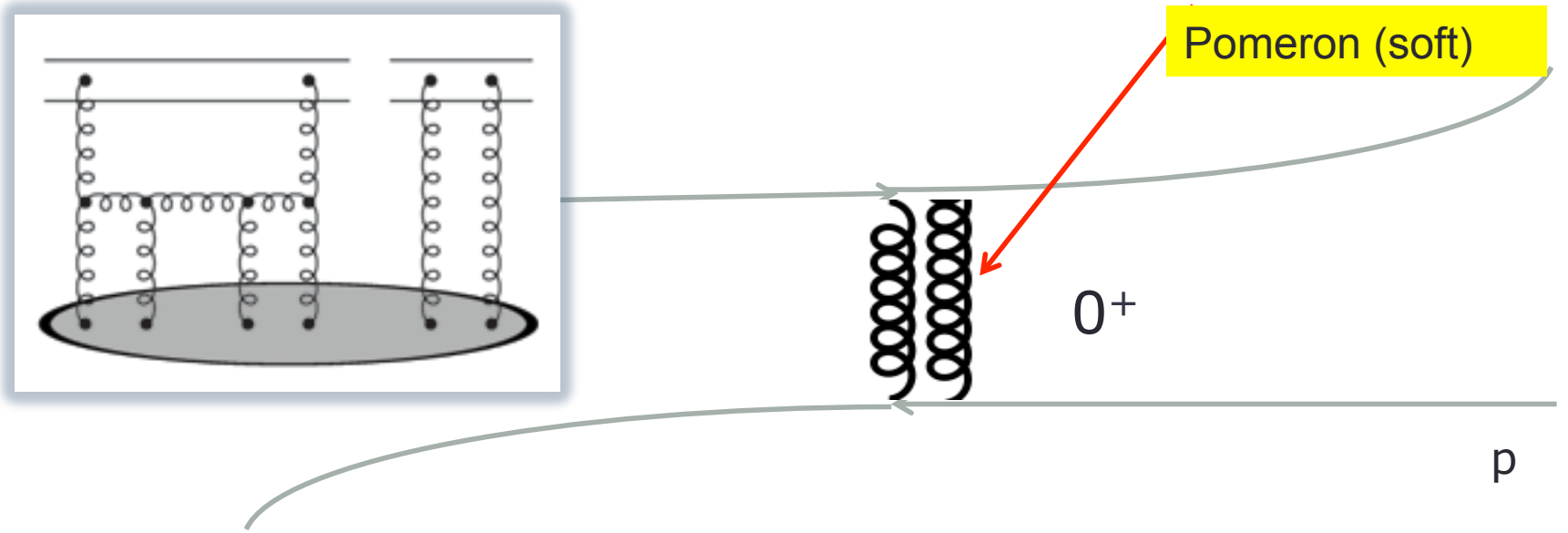
Physics of the Vacuum



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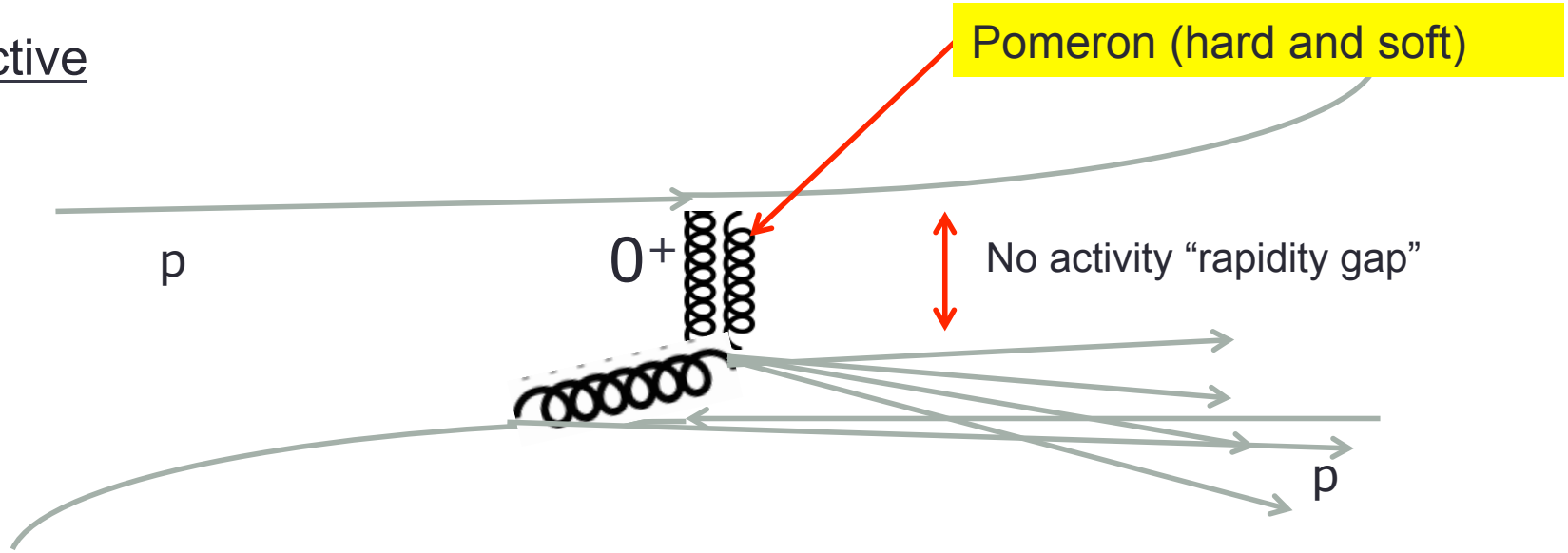
Physics of the Vacuum

Diffractive



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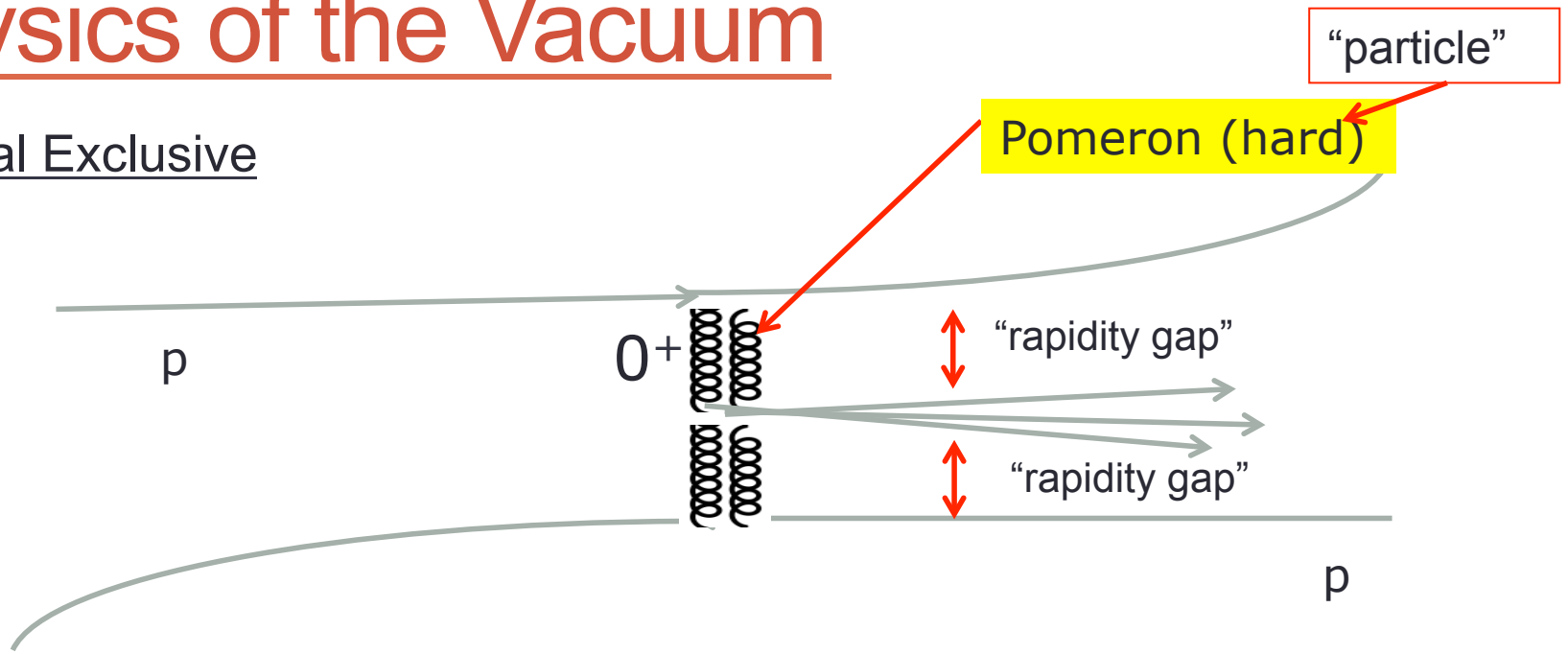
Physics of the Vacuum

Central Exclusive



Elastic diffractive: clean environment to study vacuum, and in particular, transition between soft and hard pomeron.

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Physics of the Vacuum

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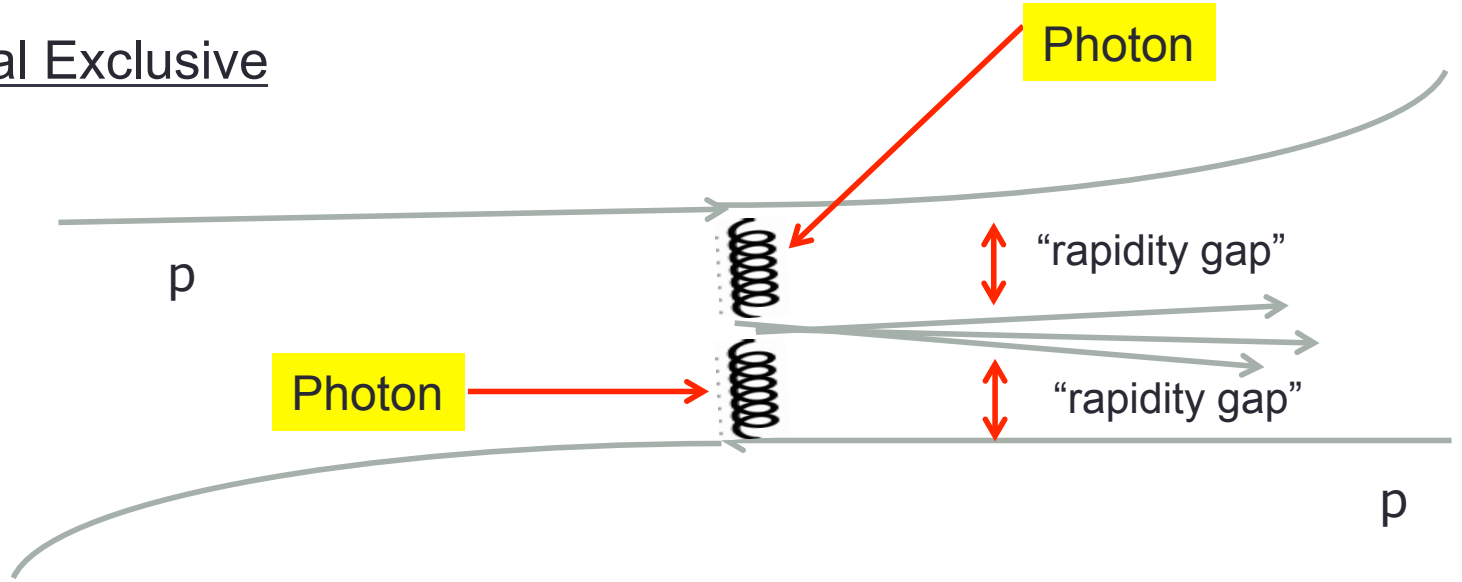

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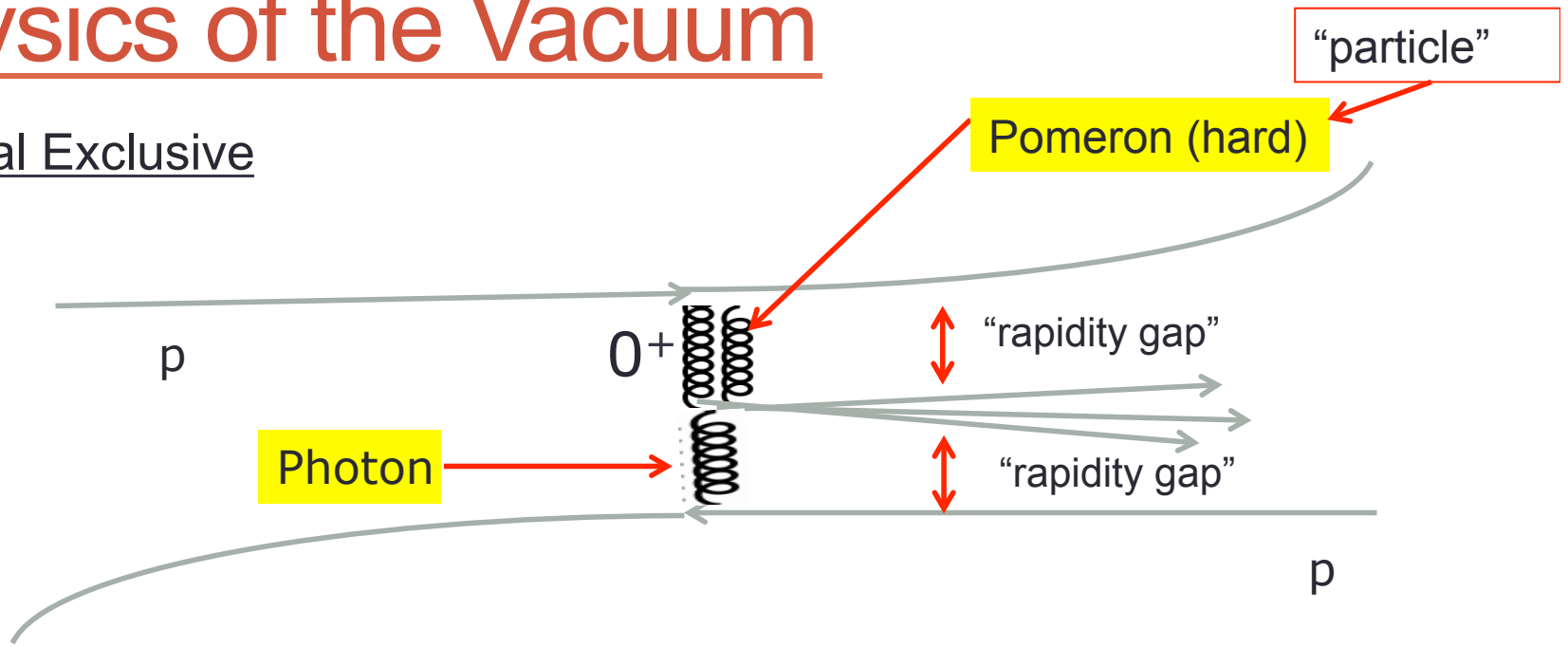

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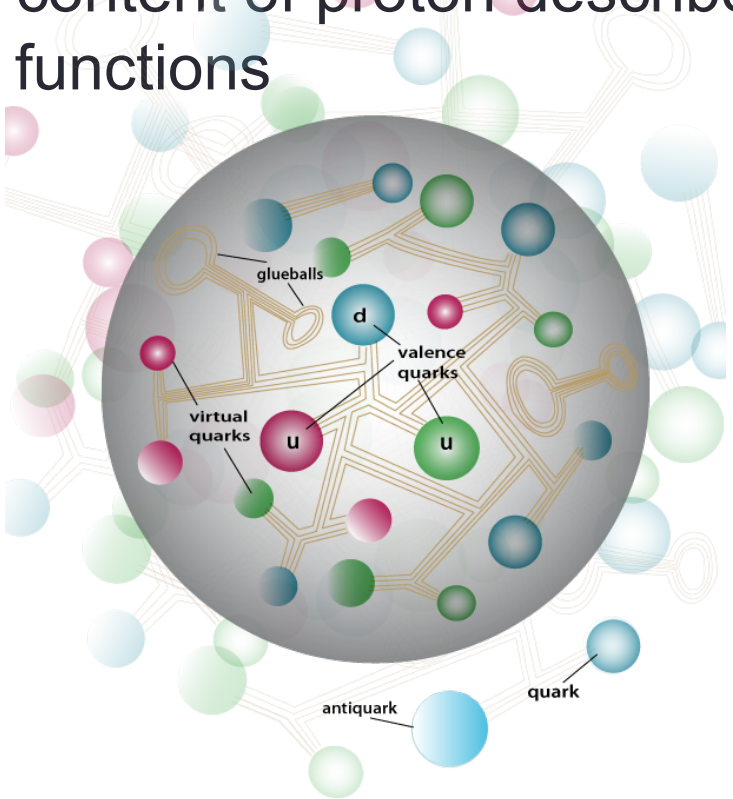
Pragmatic reasons to understand gluon

- If you want to describe gg->X, gg->H
- if you want to describe the underlying event

- content of proton described in terms of parton distribution functions



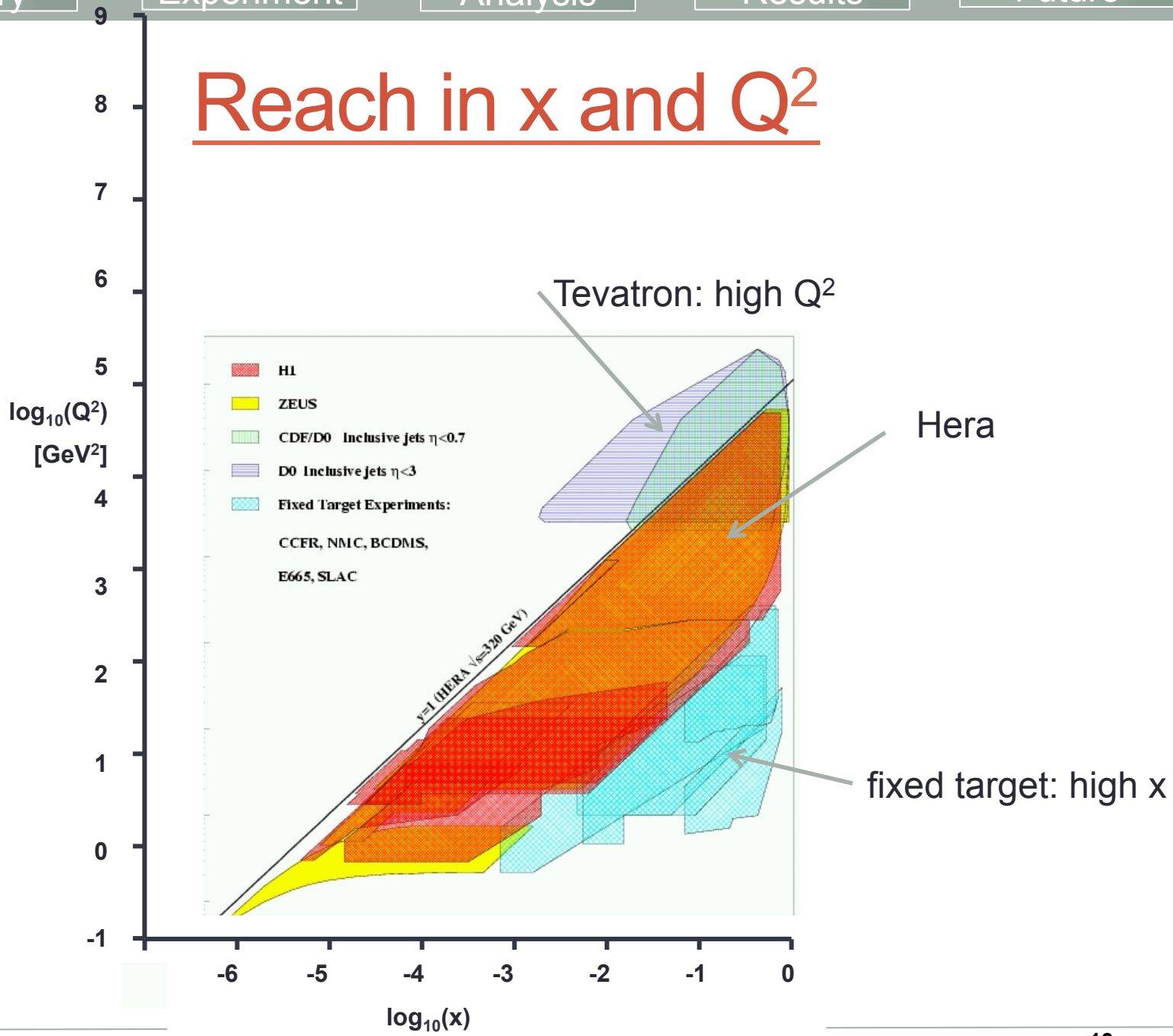
$f_q(x,Q^2)$

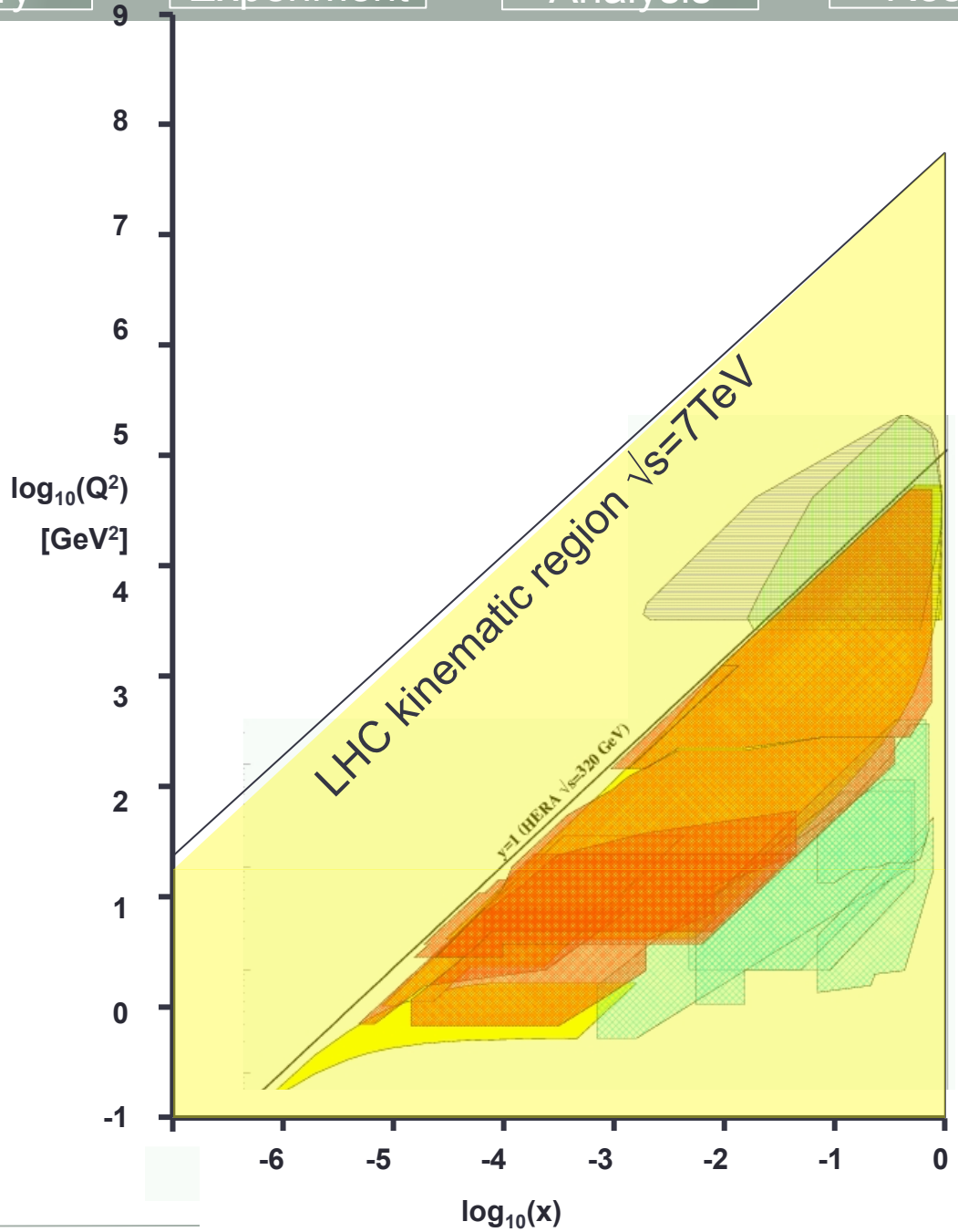
Probability that proton contains this parton with this momentum fraction

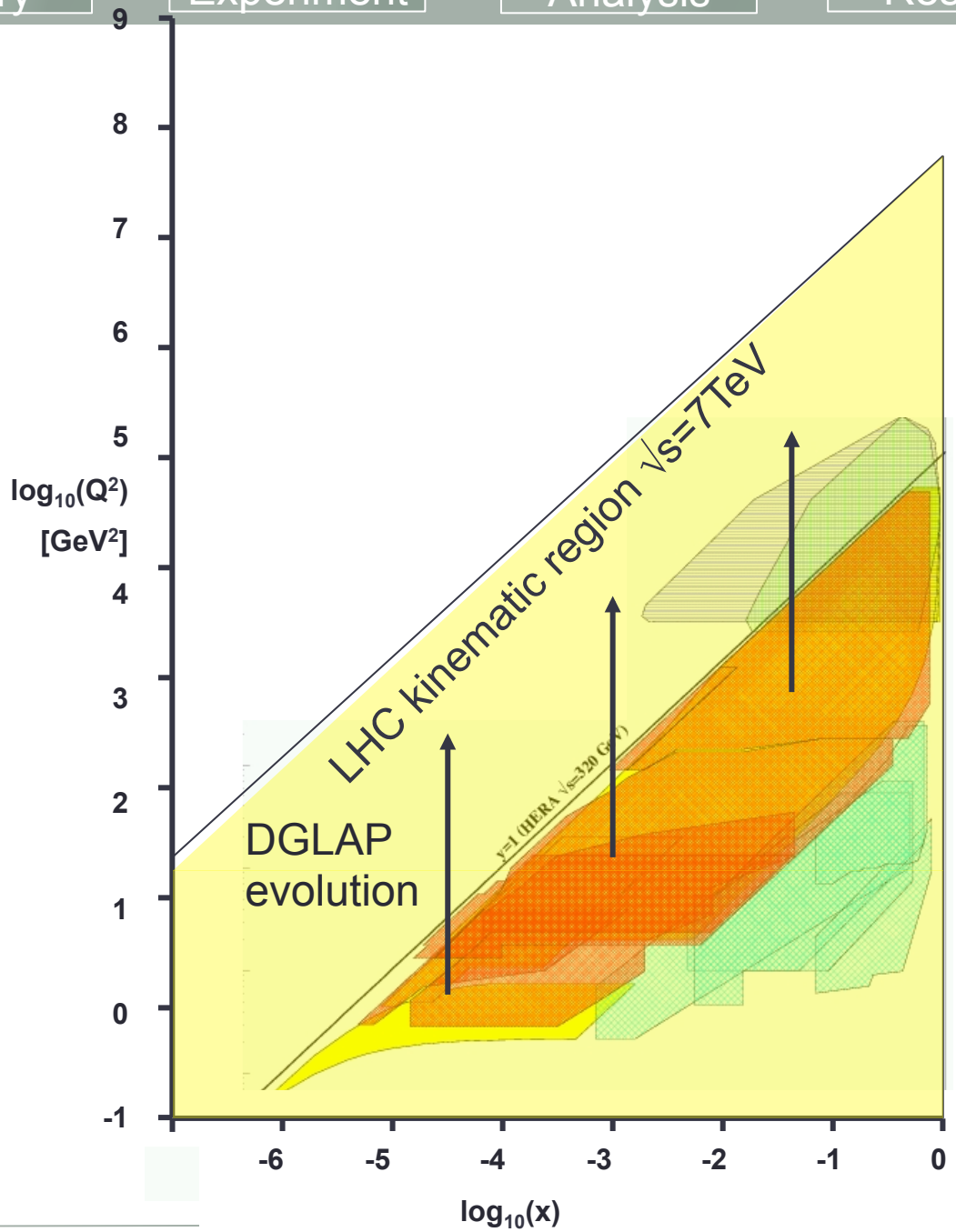
Q = Invariant mass of parton interaction

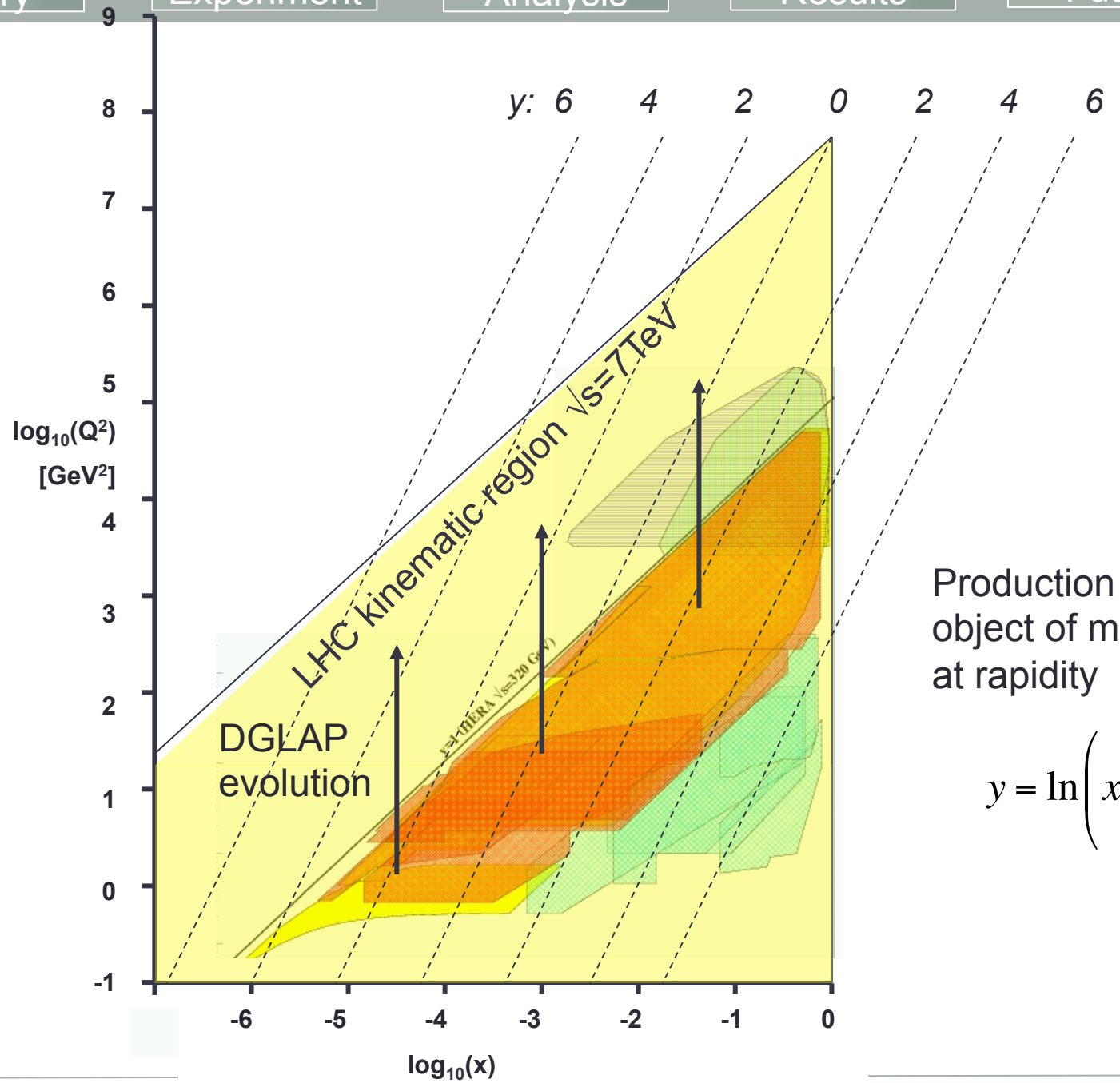
$x = Qe^{\pm y}/\sqrt{s}$ [y is rapidity, $\sqrt{s}$ c.o.m]

Reach in x and Q^2



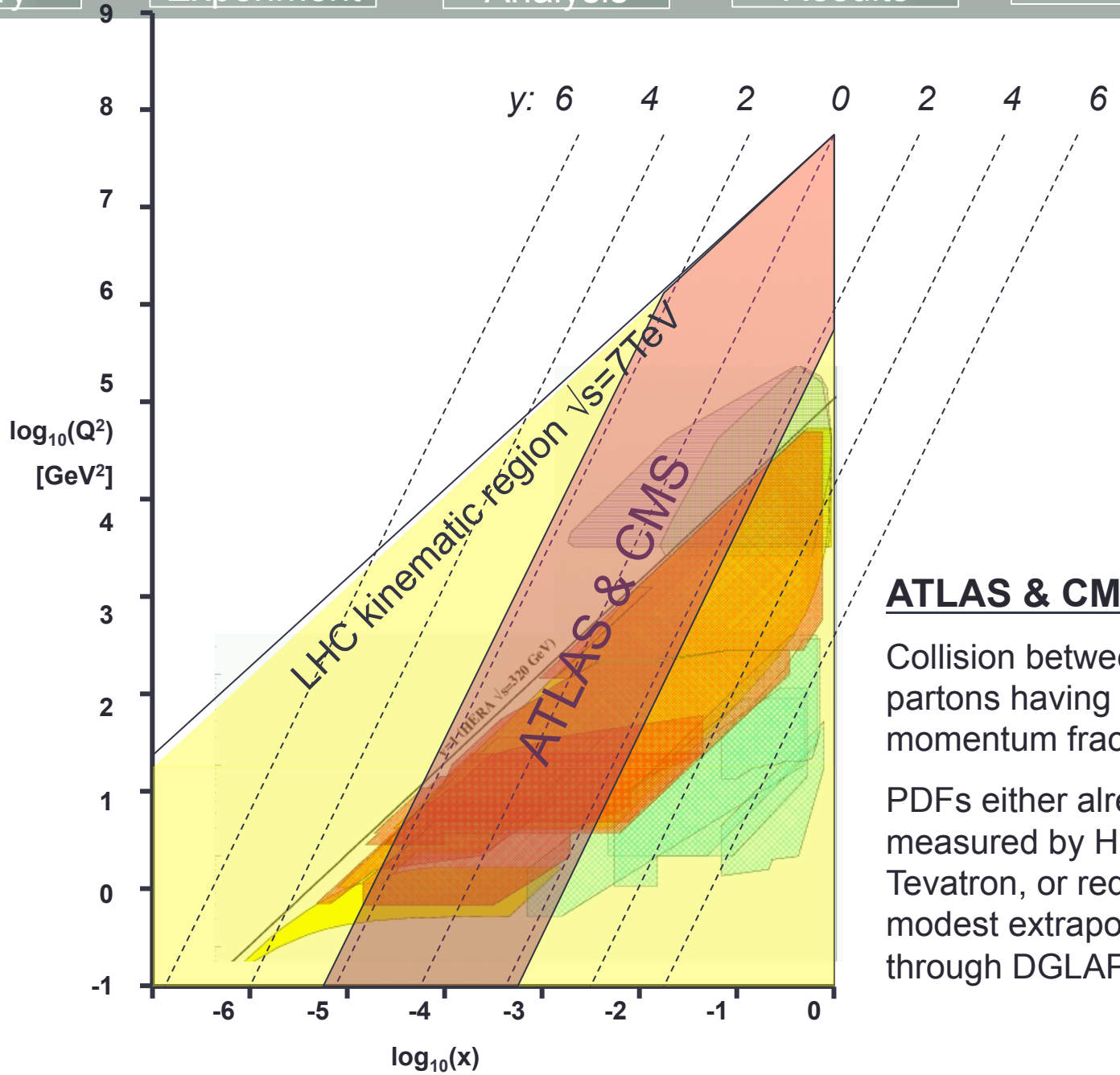

LHC kinematic region √s=7TeV
x=1 (HERA √s=320 GeV)
log10(Q2) [GeV2]
log10(x)
9
8
7
6
5
4
3
2
1
0
-1
-6
-5
-4
-3
-2
-1
0


LHC kinematic region √s=7TeV
DGLAP evolution
log10(Q2) [GeV2]
log10(x)
9
8
7
6
5
4
3
2
1
0
-1
-6
-5
-4
-3
-2
-1
0



Production of object of mass Q at rapidity

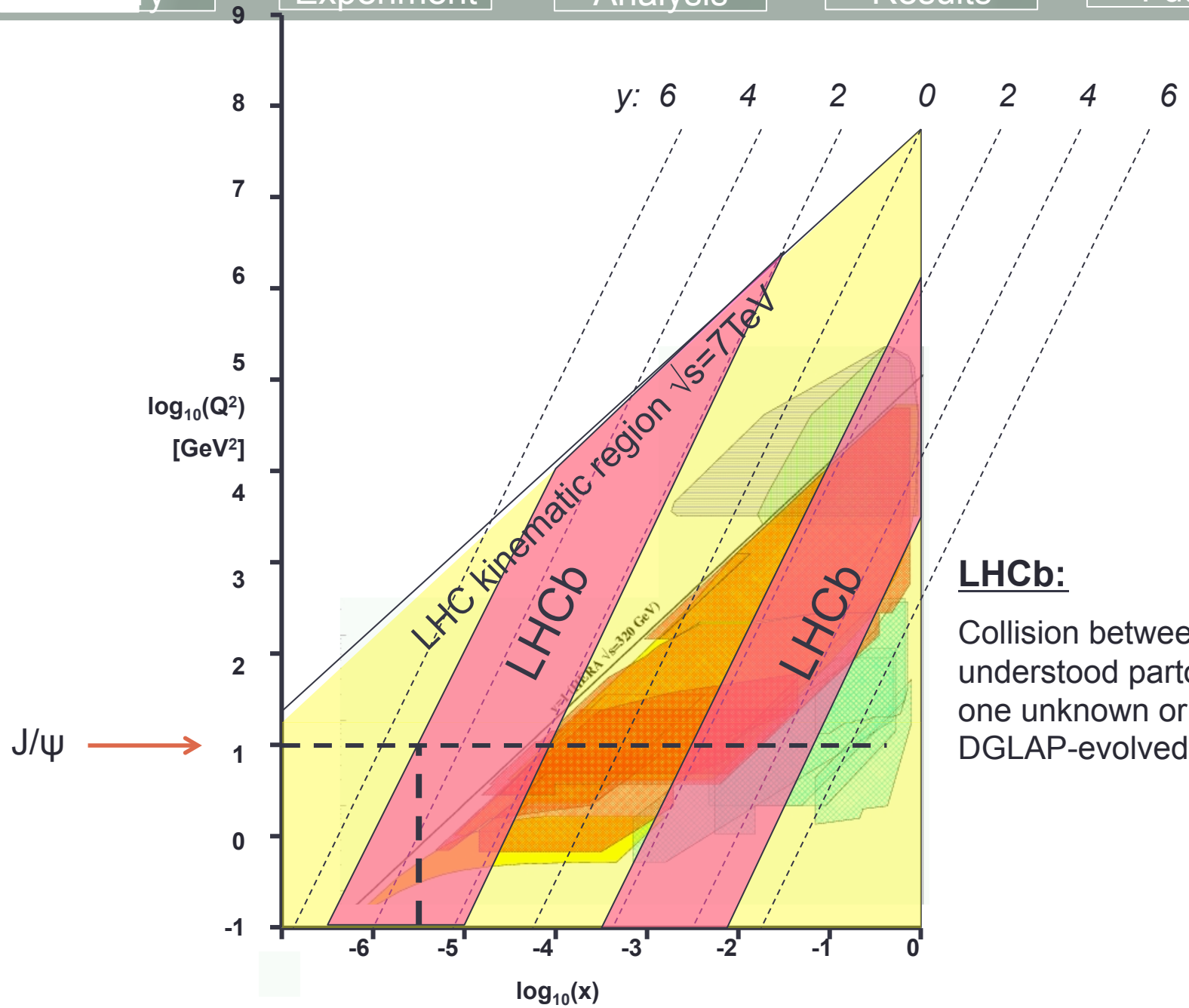
$$y = \ln\left(x\frac{\sqrt{s}}{Q}\right)$$



ATLAS & CMS:

Collision between two partons having similar momentum fractions.

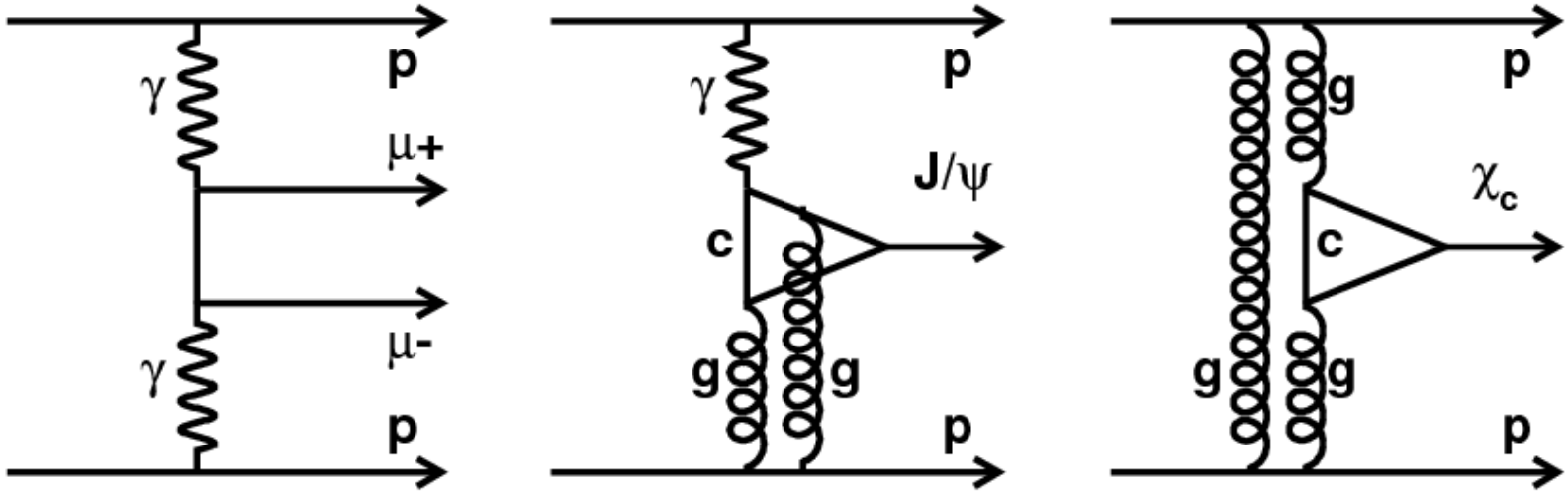
PDFs either already measured by HERA or Tevatron, or requiring modest extrapolation through DGLAP.



LHCb:

Collision between one well understood parton and one unknown or large DGLAP-evolved parton.

Central Exclusive Production with Dimuon final states

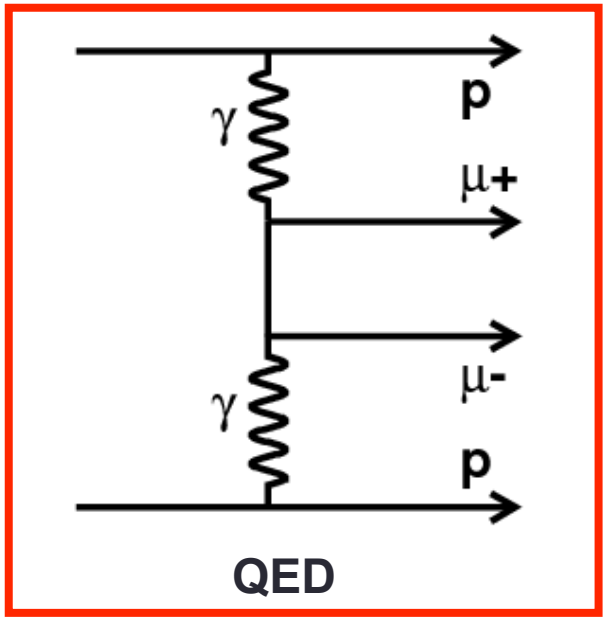


QED | **Photo production** | **Double pomeron exchange**

(Note: $J/\psi \rightarrow \mu\mu$ and $\chi_c \rightarrow J/\psi\gamma$)

Related phenomena where the colourless object creates a particle

Central Exclusive Production with Dimuon final states



QED

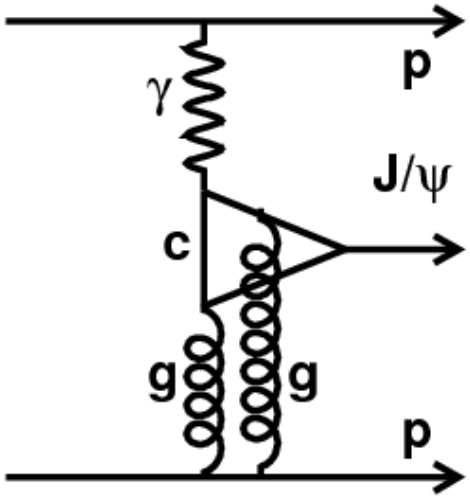
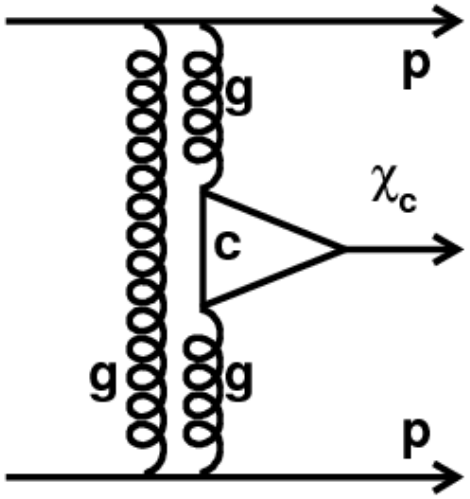


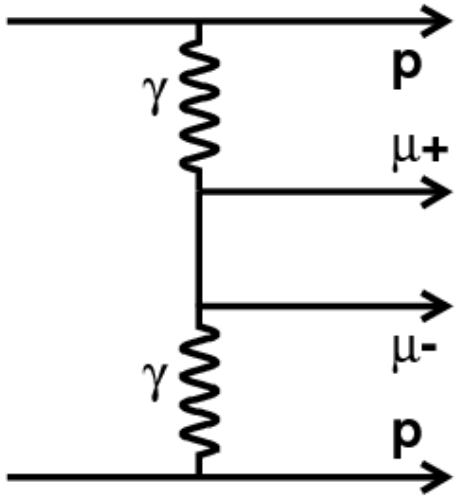
Photo production



Double pomeron exchange

- QED process. Can be predicted with high accuracy (~1%)
- Candidate process for very precise luminosity determination at LHC

Central Exclusive Production with Dimuon final states



QED

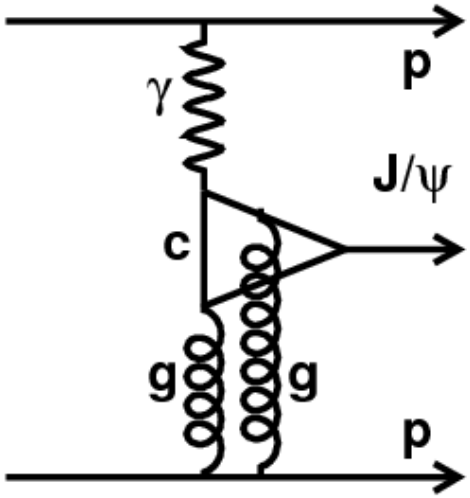
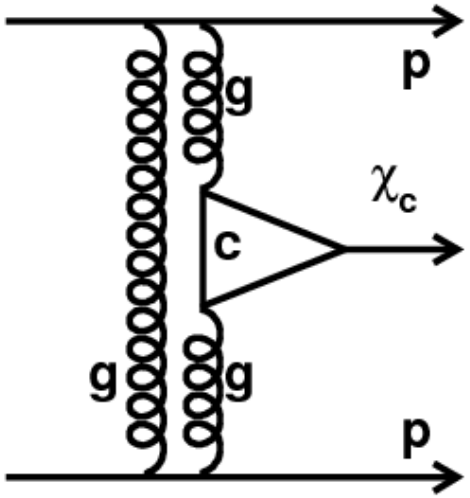


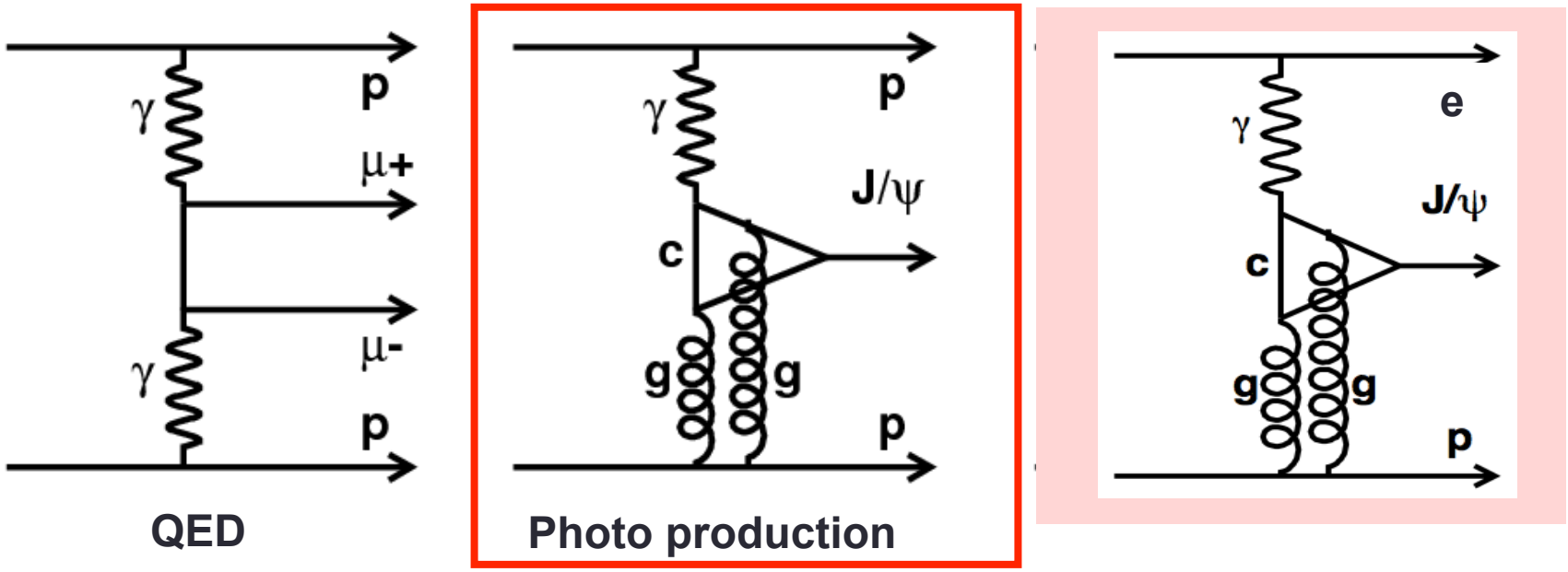
Photo production



Double pomeron exchange

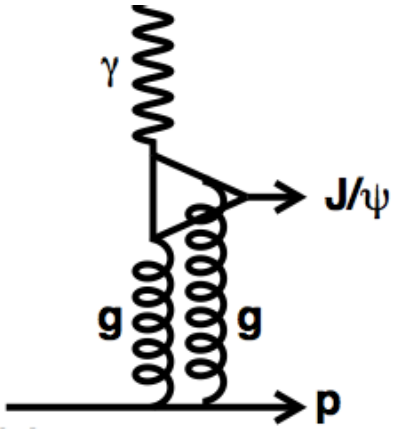
- Double pomeron exchange.
- Unambiguous evidence for pomeron
- 'Standard Candle' for other DPE processes, in particular, Higgs.

Central Exclusive Production with Dimuon final states



- Test of QCD and pomeron in clean environment
- Sensitive to diffractive PDF at very low x (to 5×10^{-6})
- Search for the odderon and saturation effects
- Measured at HERA/Tevatron but at different photon-proton energy, W

Photo-production cross-section

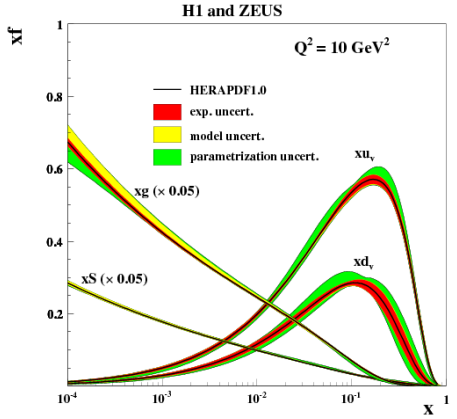


$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}t}(\gamma^* p \to J/\psi\, p)\right|_{t=0} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48\alpha}\left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} x g(x,\bar{Q}^2)\right]^2 \left(1+\frac{Q^2}{M_{J/\psi}^2}\right)$$

$$\bar{Q}^2 = (Q^2 + M_{J/\psi}^2)/4, \qquad x = (Q^2 + M_{J/\psi}^2)/(W^2 + M_{J/\psi}^2).$$

Cross-section proportional to gluon^2 $\sigma \sim (xg)^2$

and so $\sigma \sim x^{\lambda}$



[1] Martin A D, Nockles C, Ryskin M and Teubner T 2008 Small x gluon from exclusive J/ψ production *Phys. Lett.* B **662** 252 (arXiv:0709.4406)

[2] Ryskin M G 1993 J/ψ electroproduction in LLA QCD *Z. Phys.* C **57** 89

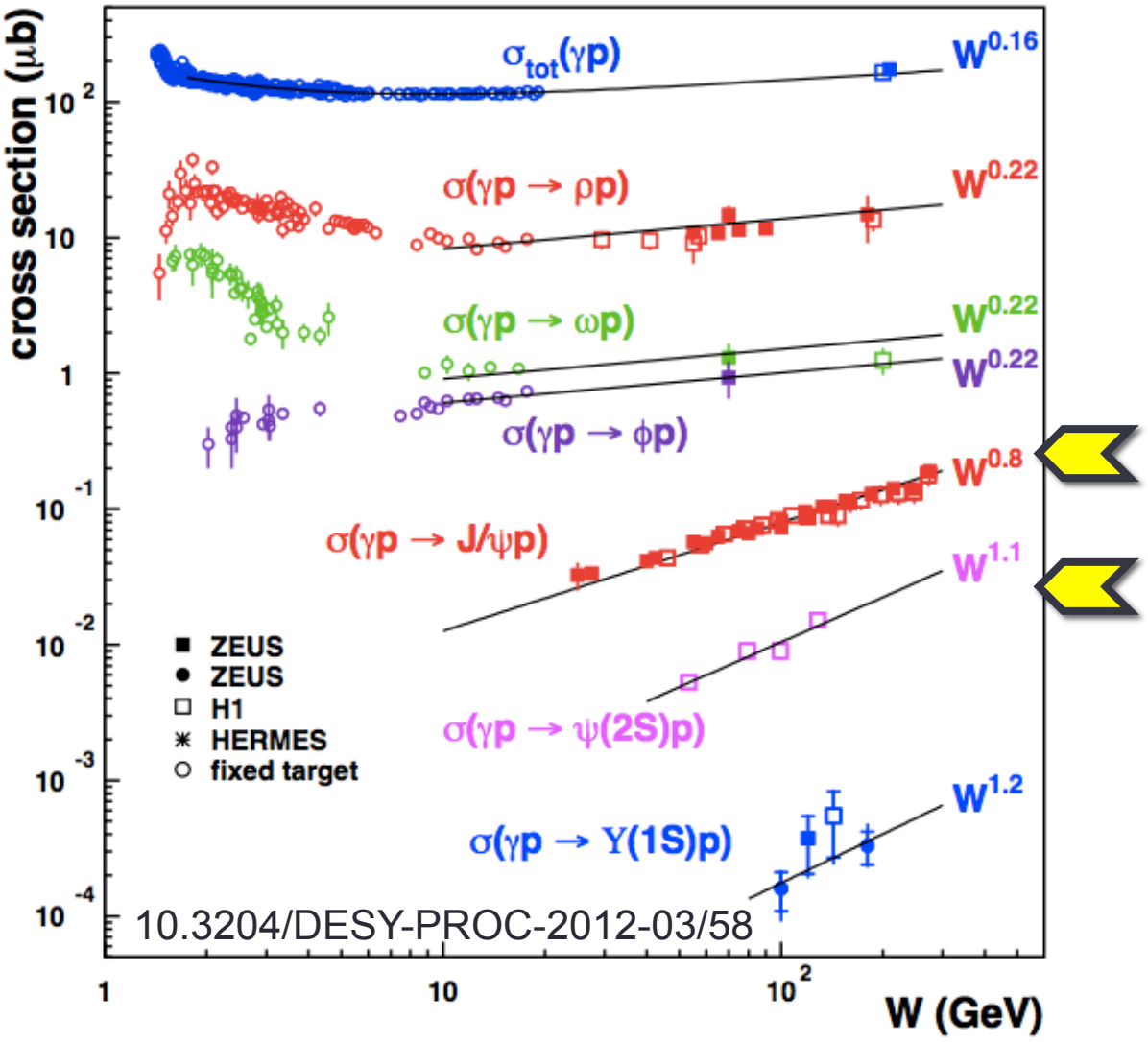
[3] Ryskin M G, Roberts R G, Martin A D and Levin E M 1997 Diffractive J/ψ photoproduction as a probe of the gluon density *Z. Phys.* C **76** 231 (arXiv:hep-ph/9511228)

[4] S. Jones, A. Martin, M. Ryskin, and T. Teubner, *Probes of the small x gluon via exclusive J/ψ and Υ production at HERA and the LHC*, JHEP **1311** (2013) 085, arXiv:1307.7099.

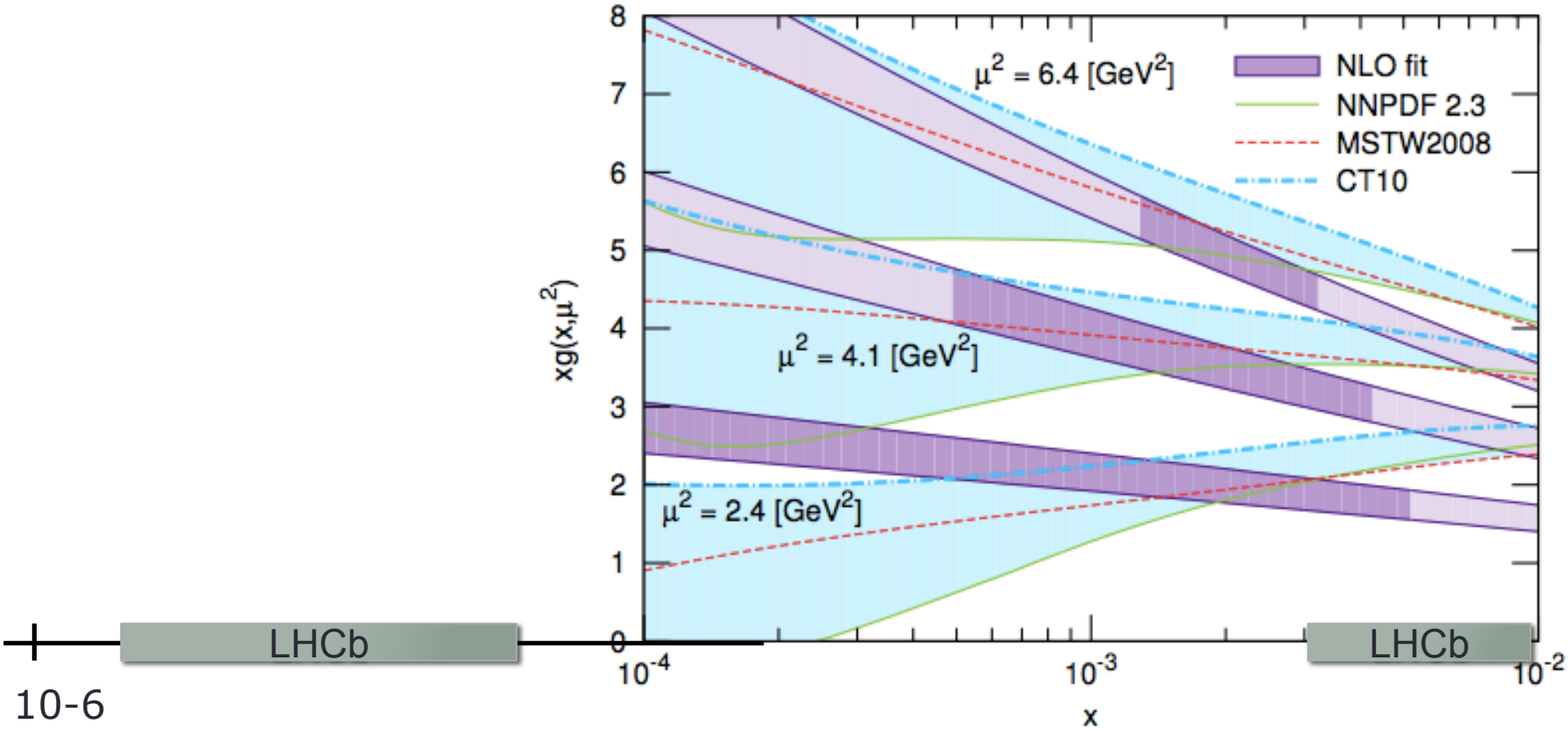
HERA vector meson photo-production results

Note:

- $\sigma \sim x^{\lambda}$
- soft/hard
- g(x,Q^2)



Sensitivity to gluon pdf (arXiv: 1307.7099)



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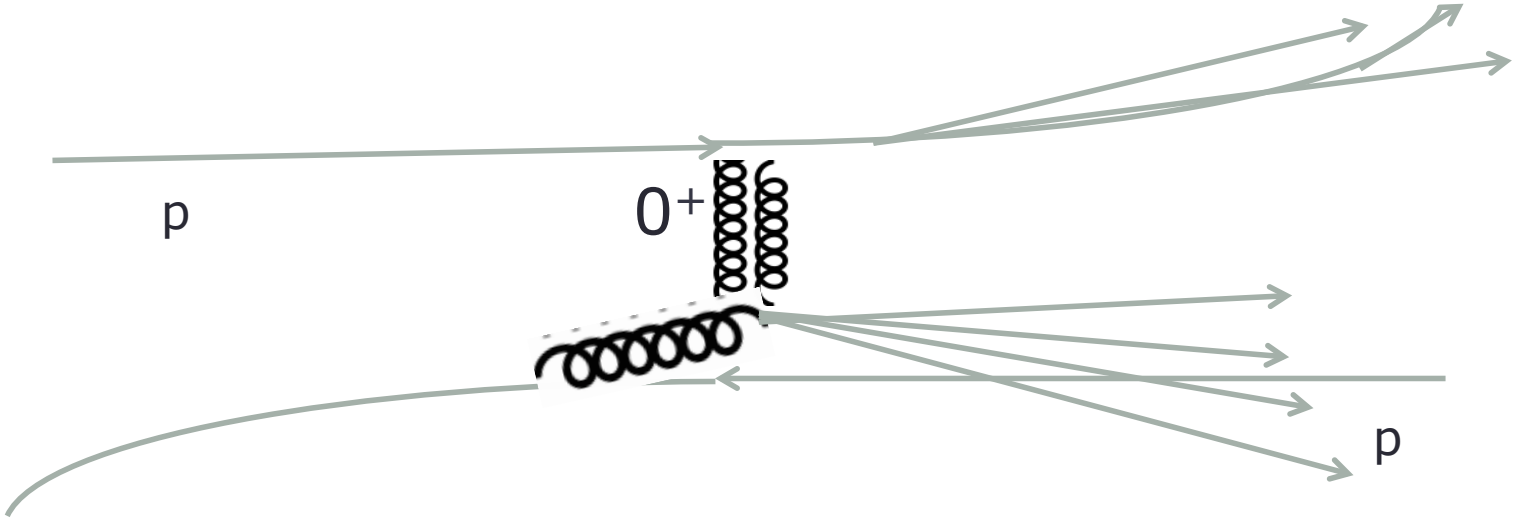
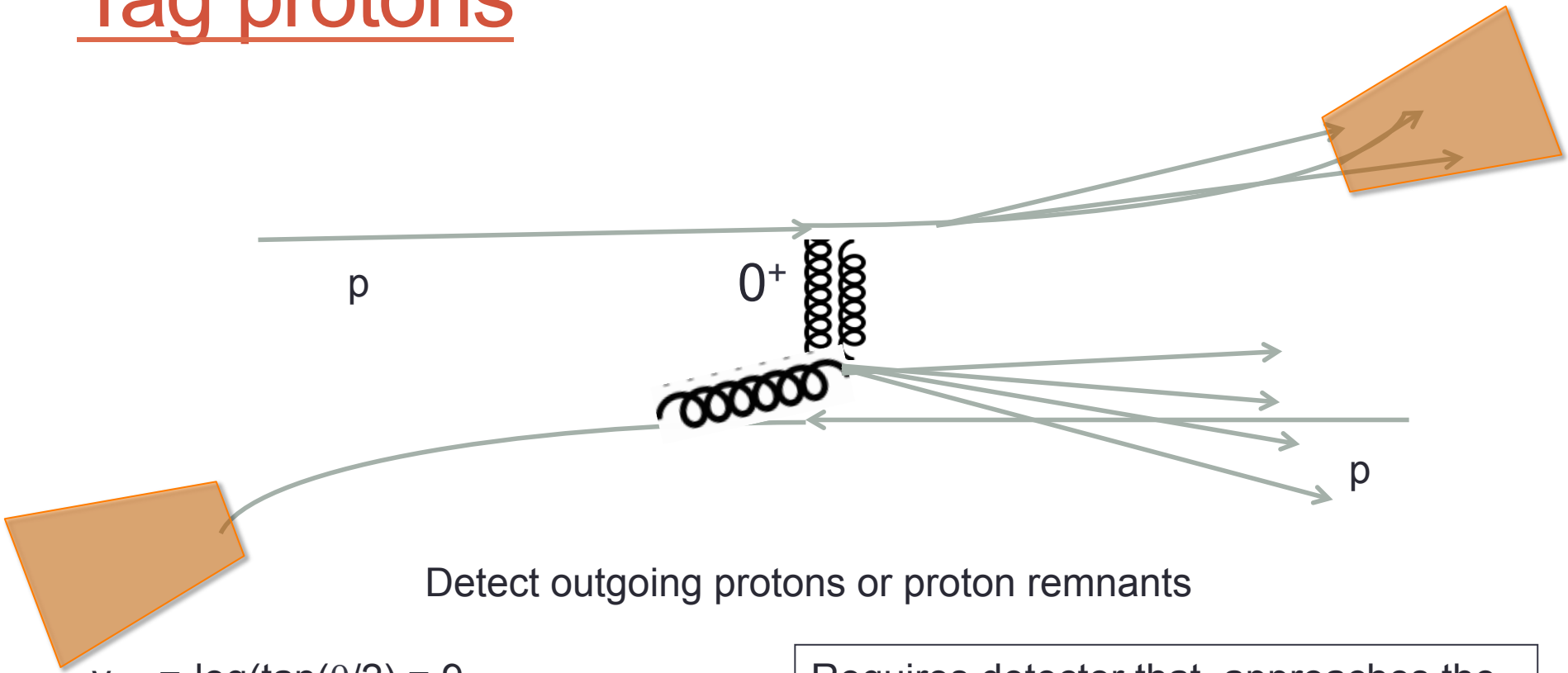
Experimental Signatures

Experimental Signatures:



Tag protons



Detect outgoing protons or proton remnants

$y \sim \eta = -\log(\tan(\theta/2)) = 9$

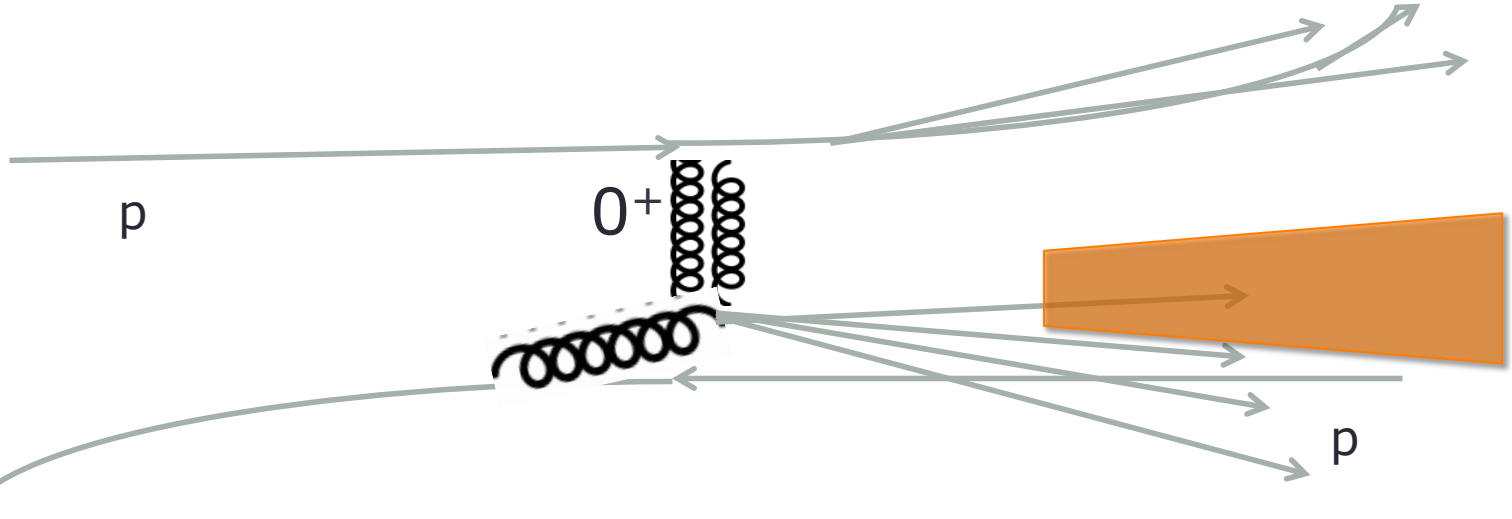
P_T=1 GeV

P_{beam}= 3500 GeV

Requires detector that approaches the beamline

CMS-Totem PPS, ATLAS AFP projects Silicon in roman pots with 10ps timing
See FP LHC WG.

Find rapidity gap

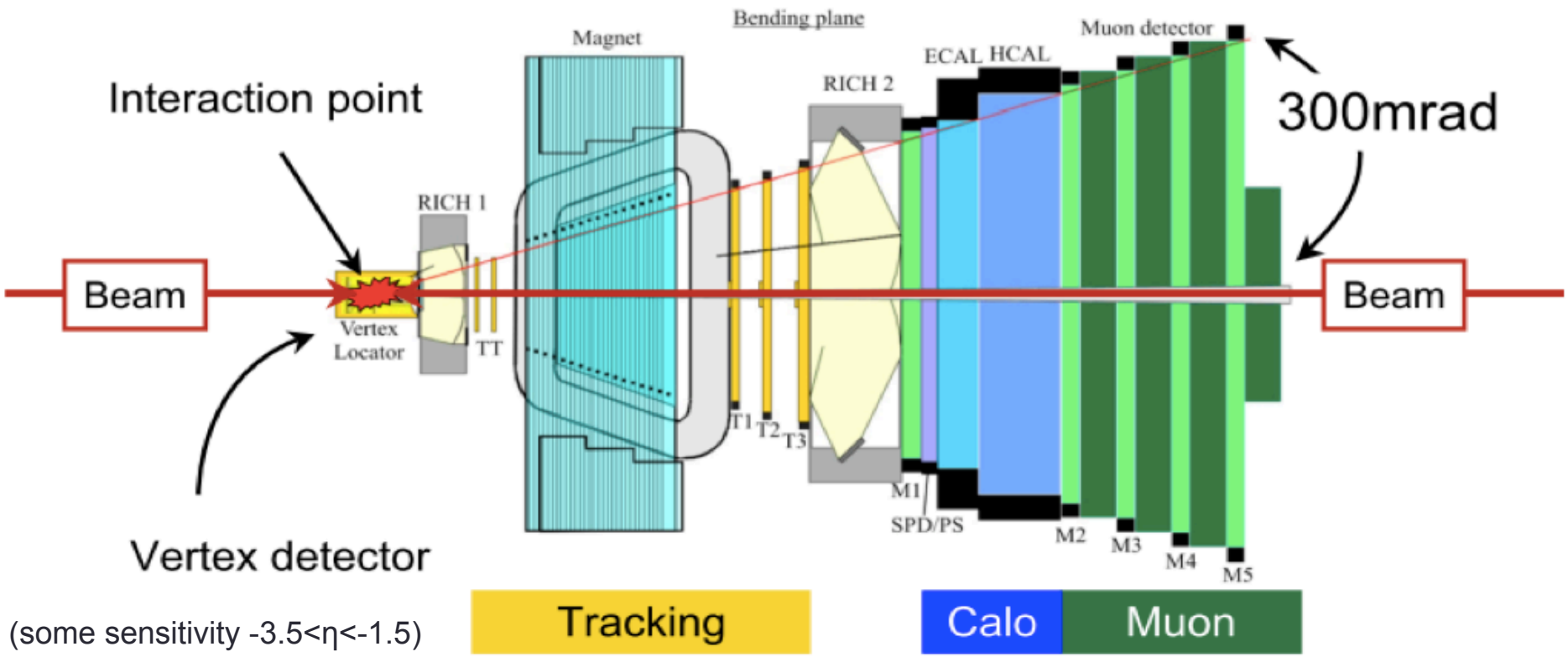


Detect ‘central’ system including presence of **rapidity gap**

Most pp interactions distribute particles throughout 4π (collimated in jets but also with activity between jets)

Size of gap you can detect is critical

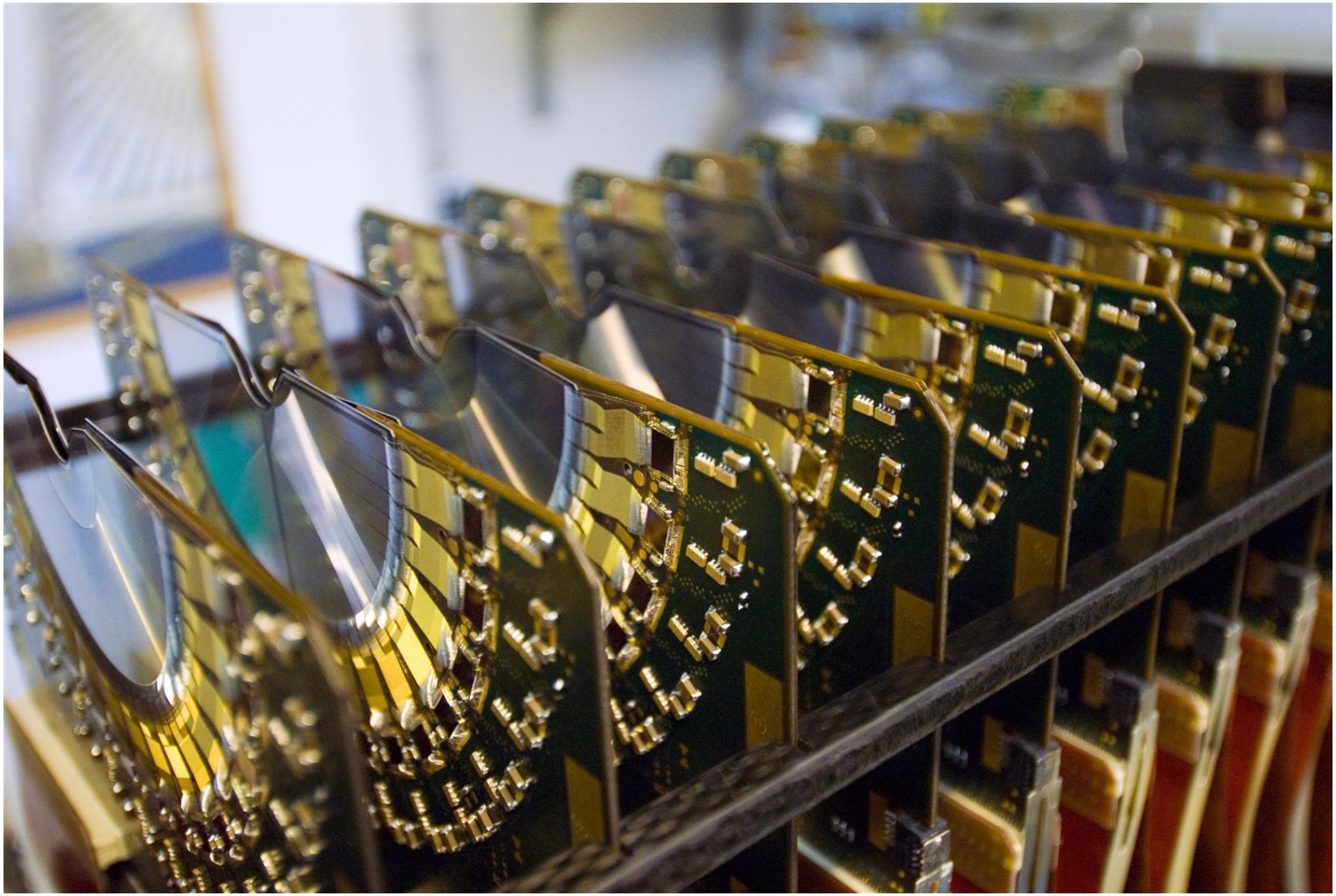
The LHCb detector



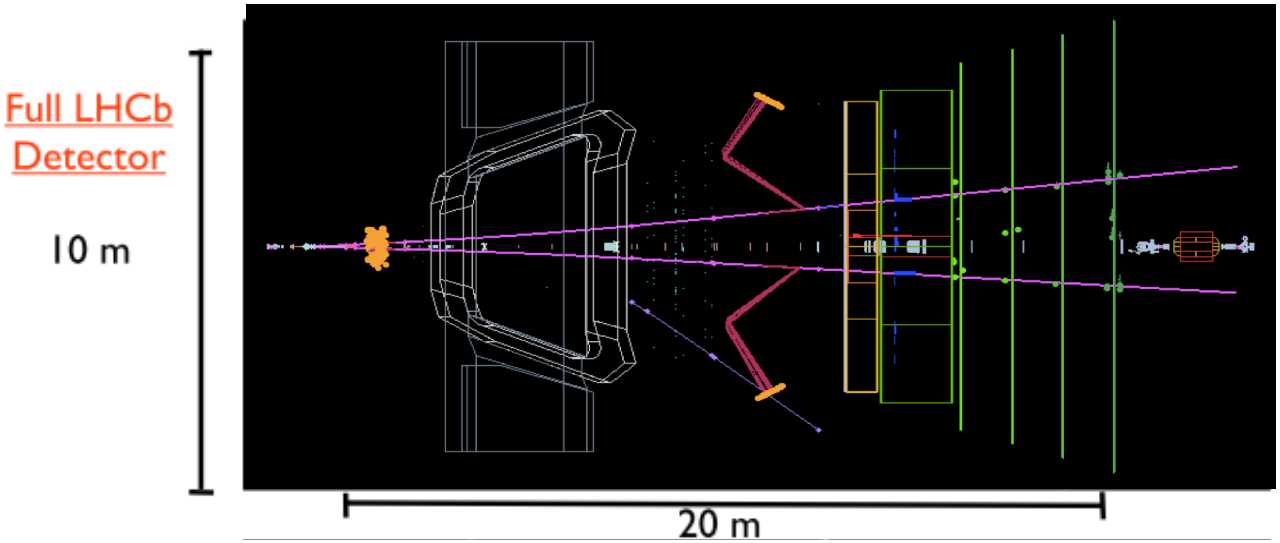
(some sensitivity -3.5<η<-1.5)

Fully instrumented from $2 < \eta < 5$

VELO sub-detector



Use of backwards tracks



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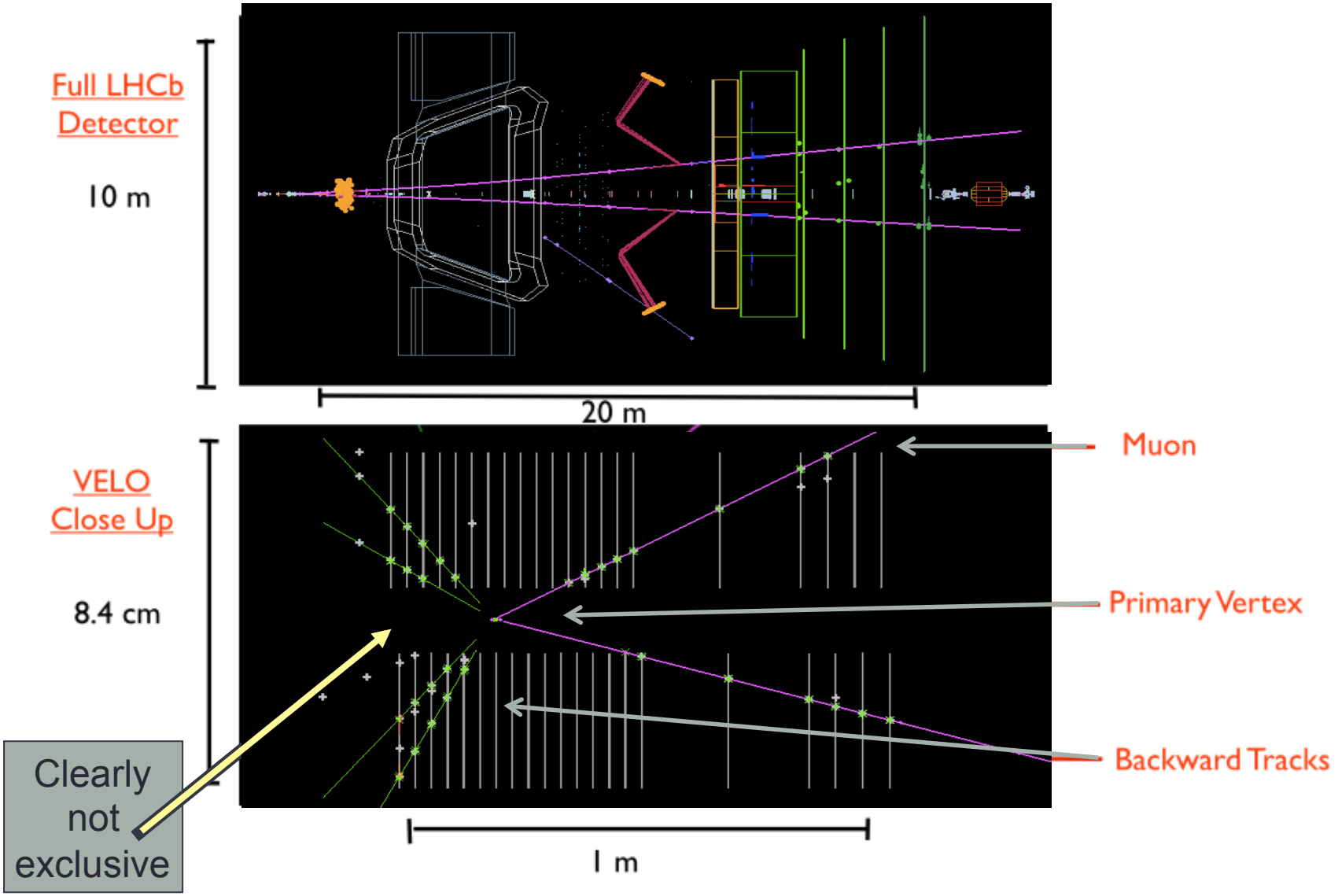
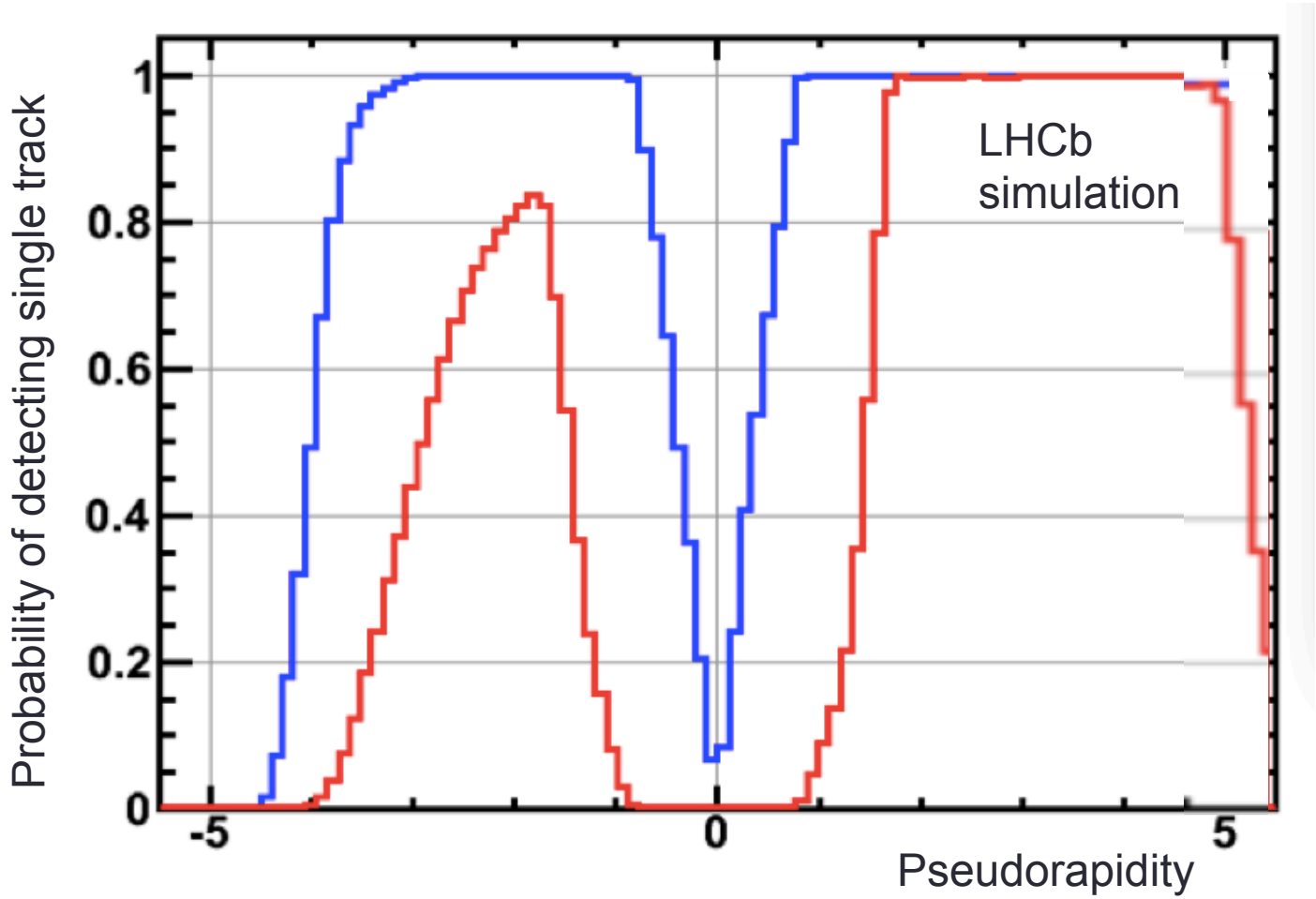
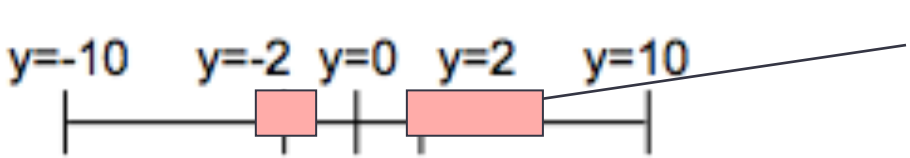


Pseudorapidity veto range

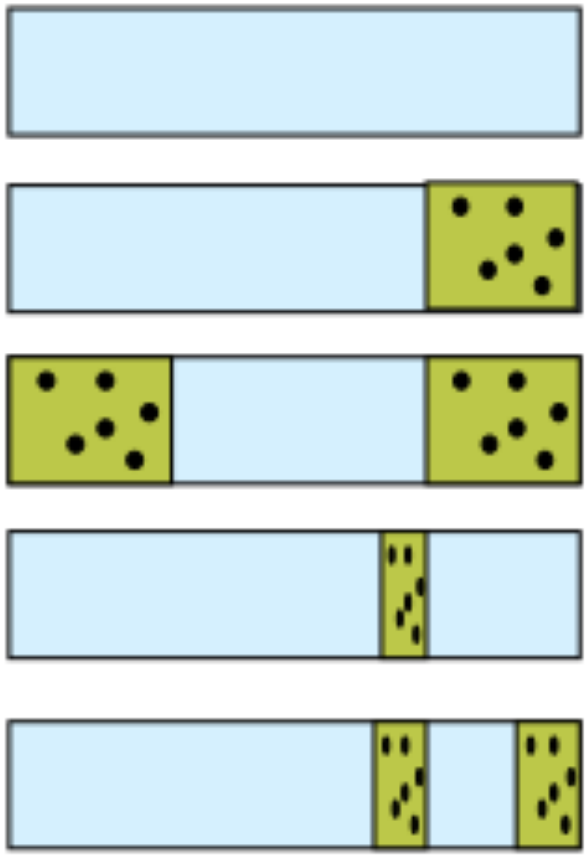


All results I show imply red region void, (except for muons from signal).

Graphical Representation



Rough LHCb coverage



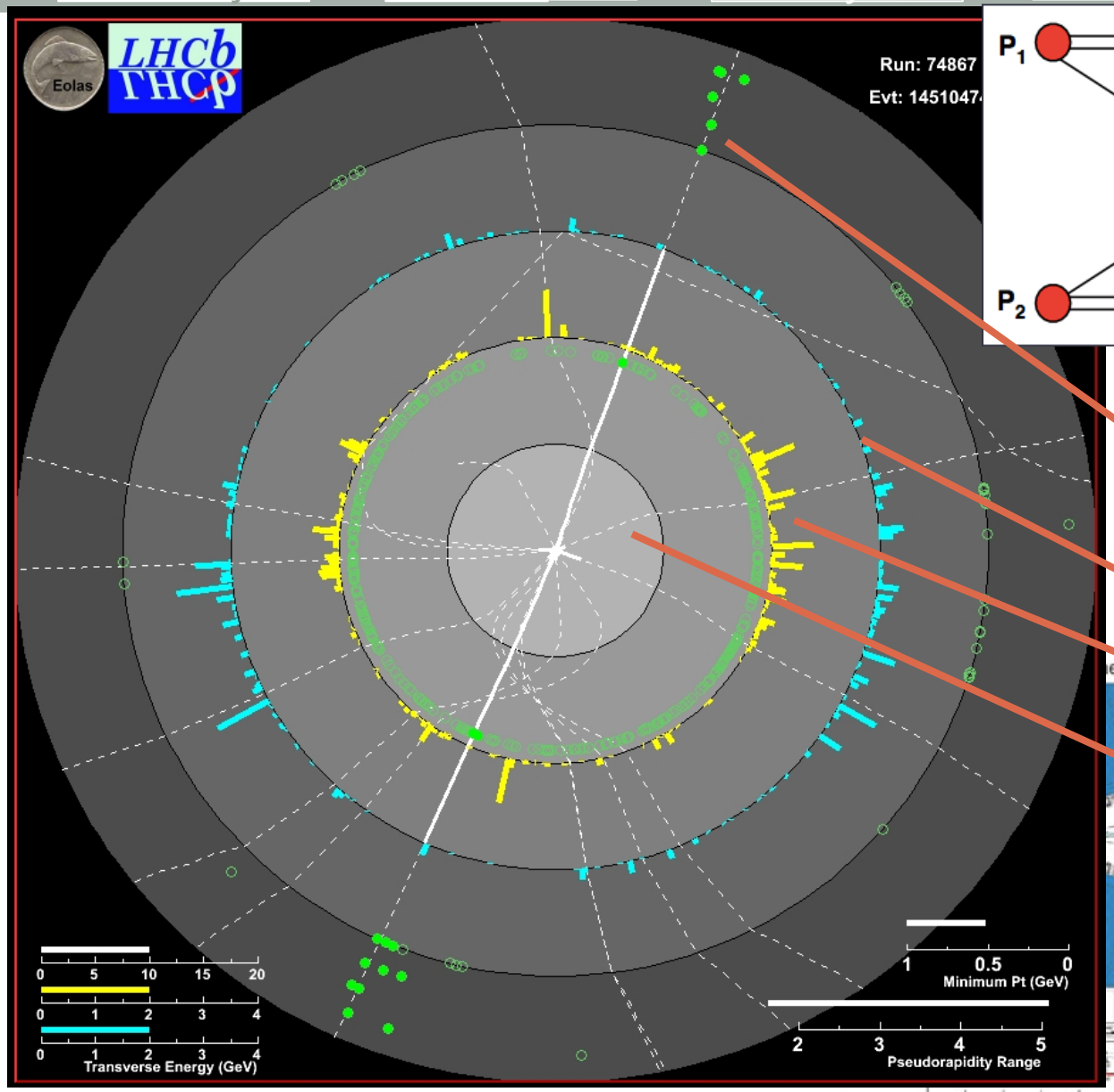
Elastic Scattering

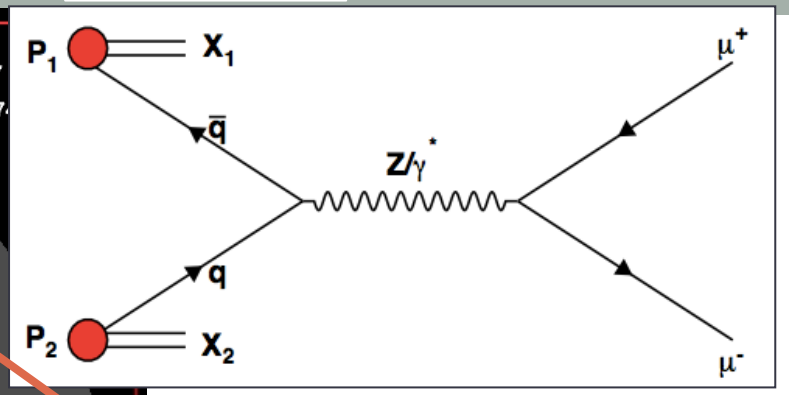
Single Diffraction

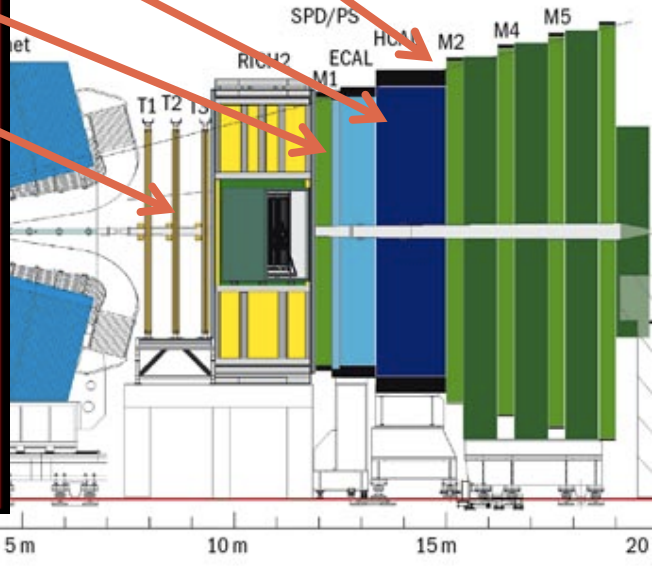
Double Diffraction

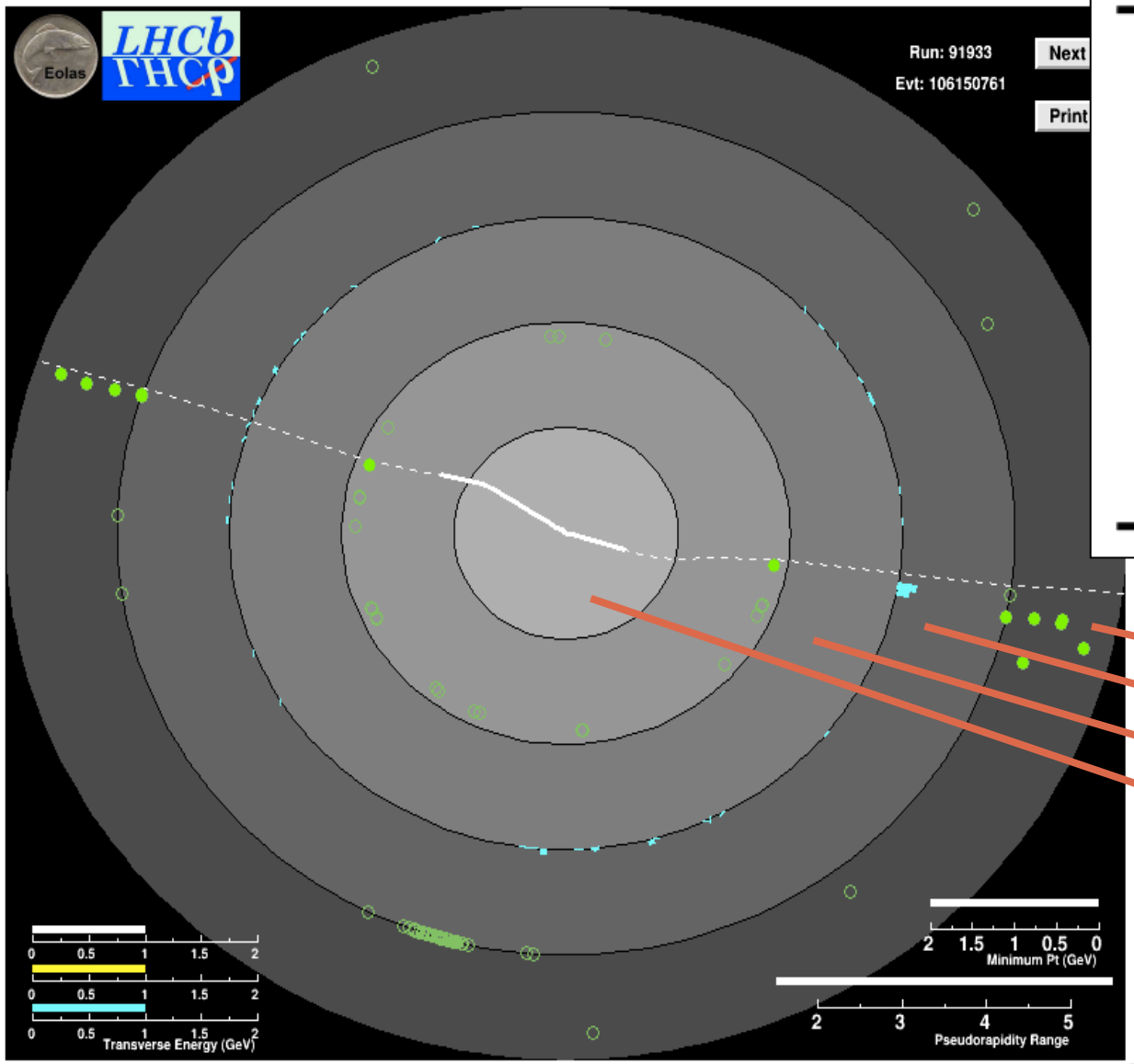
Central Exclusive Production (elastic)

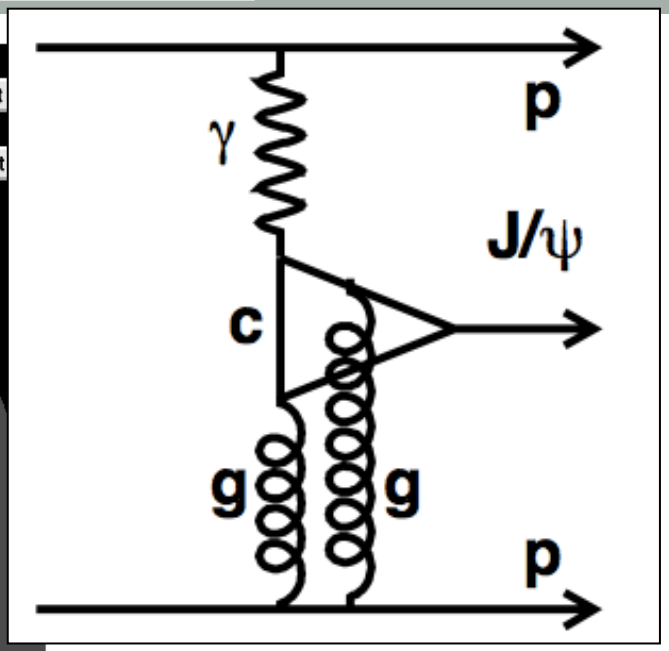
Central Exclusive Production (inelastic)

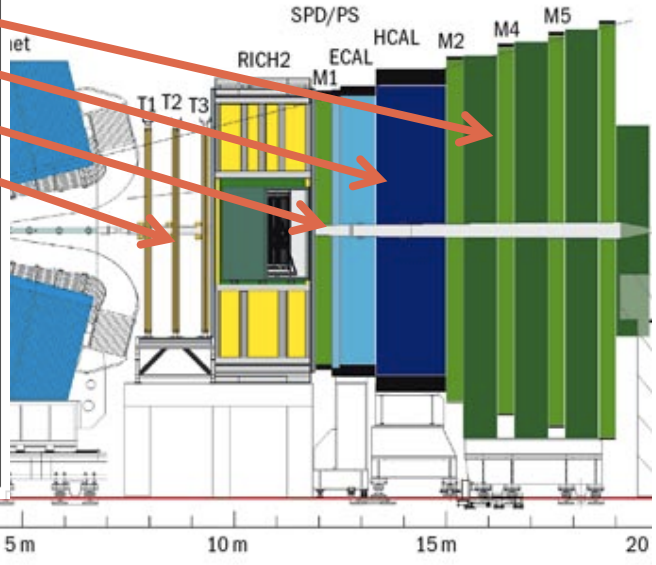

LHCb
Eolas
Run: 74867
Evt: 1451047
0 5 10 15 20
0 1 2 3 4
0 1 2 3 4
Transverse Energy (GeV)
1 0.5 0
Minimum Pt (GeV)
2 3 4 5
Pseudorapidity Range


P1
X1
q̄
Z/γ*
q
P2
X2
μ+
μ-

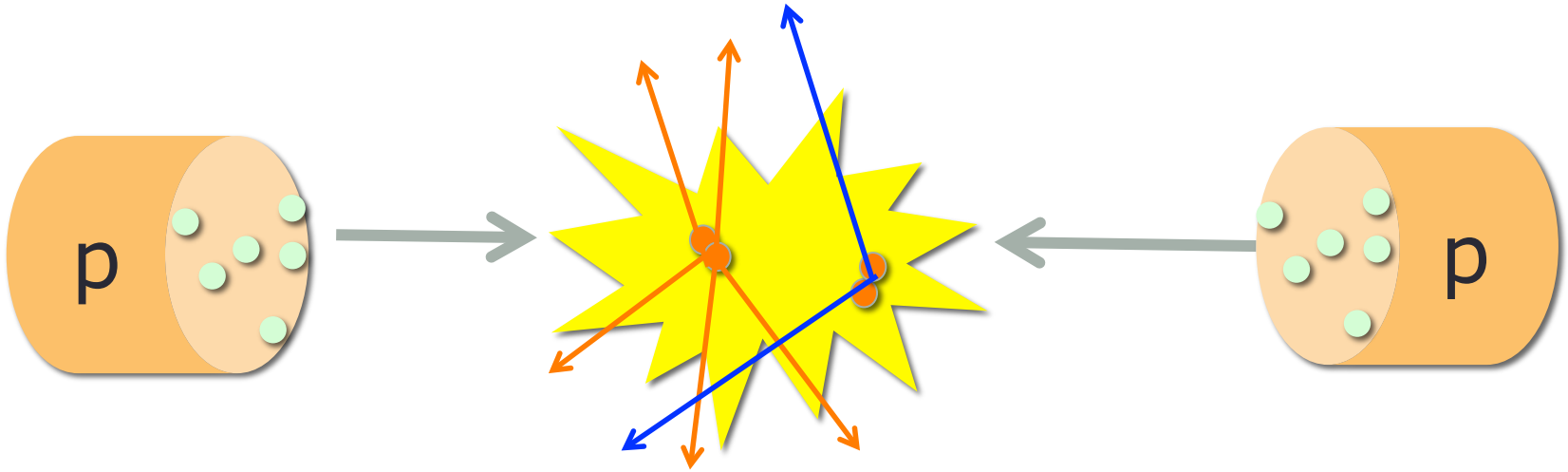

SPD/PS
M2
M4
M5
ECAL
M1
T1 T2
5 m
10 m
15 m
20


LHCb
Eolas
Run: 91933
Evt: 106150761
Next
Print
Transverse Energy (GeV)
Minimum Pt (GeV)
Pseudorapidity Range


γ
p
J/ψ
c
g
g
p


SPD/PS
HCAL
M2
M4
M5
RICH2
ECAL
M1
T1 T2 T3
5 m
10 m
15 m
20

Beam pile-up

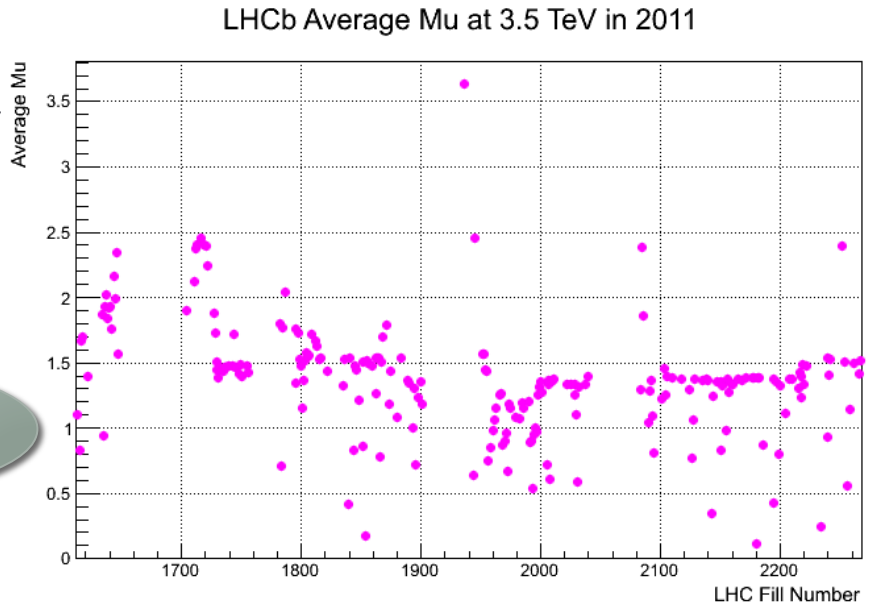


High luminosity requires multiple proton interactions per beam-crossing.

Number of interactions (N) /crossings, distributed

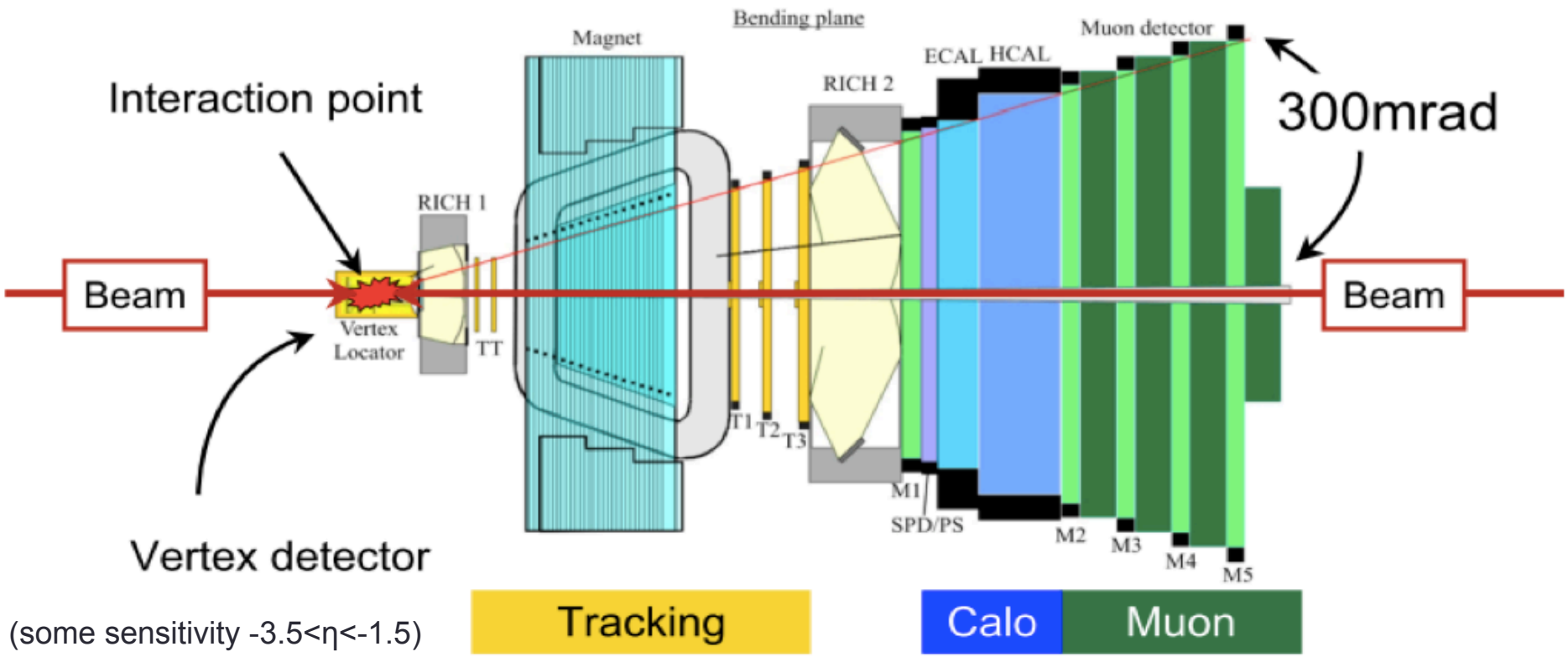
Average #interactions

$$f(N) = \frac{e^{\mu}\mu^{N}}{N!}$$



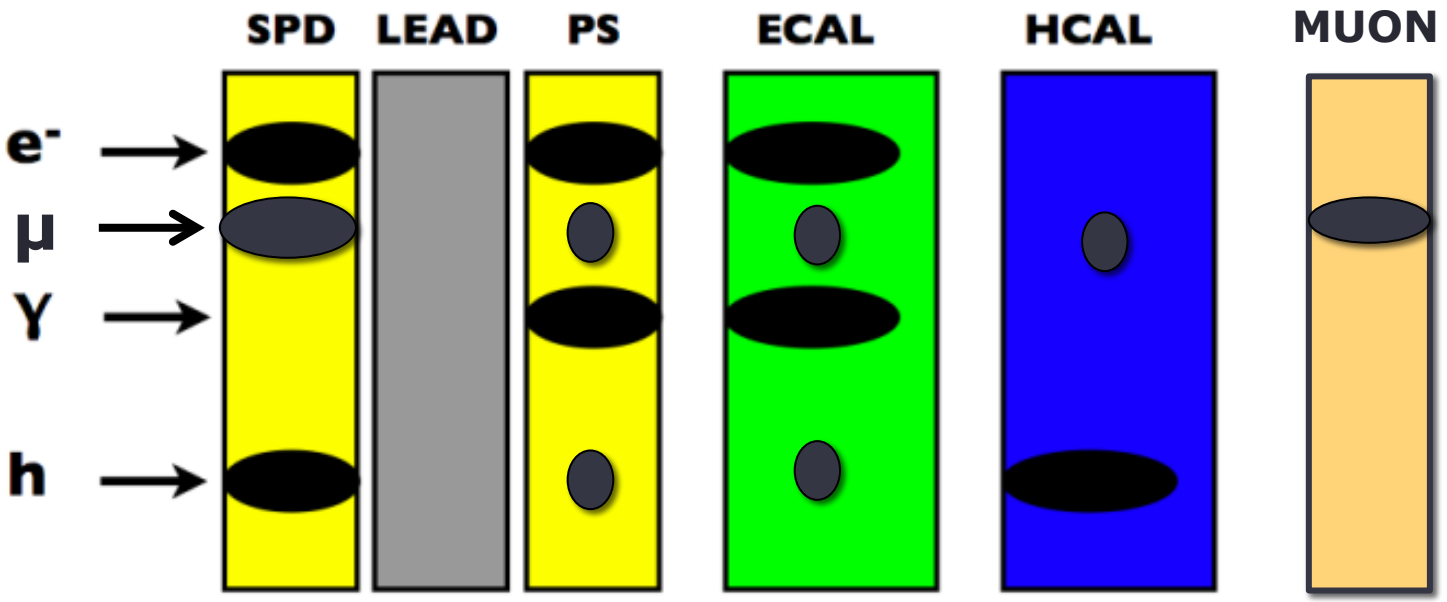
For LHCb in 2011, $\bar{\mu}$=1.4

The LHCb detector



(some sensitivity -3.5<η<-1.5)

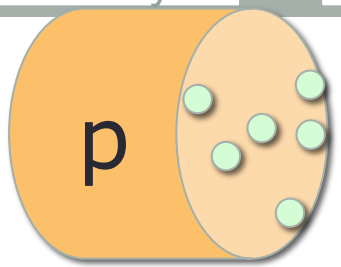
Calorimeter System in LHCb



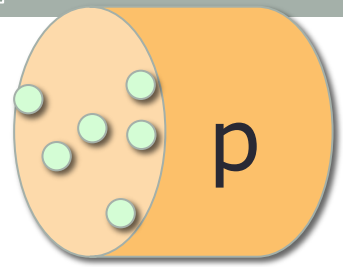
Scintillation Pad Detector.
If a charged particle goes through, we get a signal.
Rough count of number of charged particles.

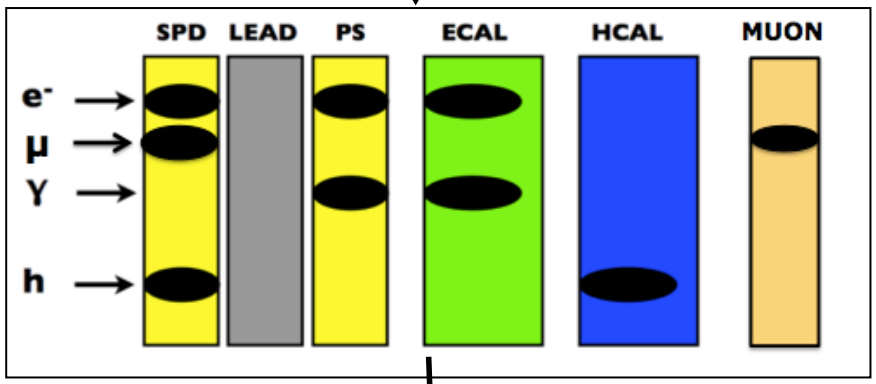
Use in trigger to select **low multiplicity** events for CEP. <10 hits

Triggering



40 MHz





L0 Trigger:

p_T^{μ}>400 MeV
#SPD<10

Hardware:
Fast electronics

~1 MHz

HLT Trigger:

Two muons
with p_T > 400 MeV

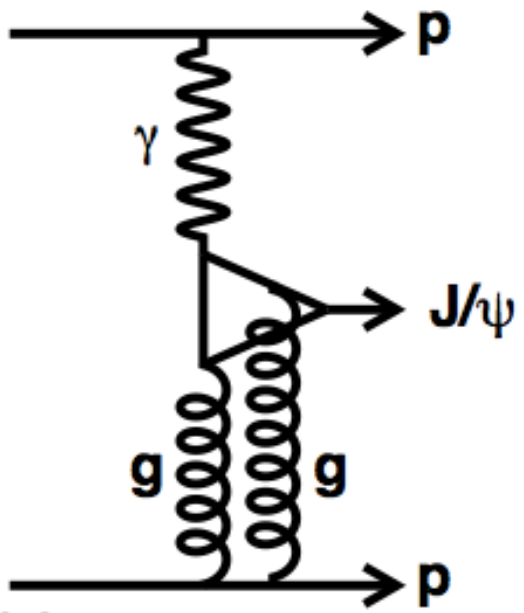
Software:
Parallel processing

~2 kHz

Central Exclusive Production of J/ψ and ψ(2S) mesons

Data-taking year	Energy	Integrated Luminosity	Paper
2010	7 TeV	$37pb^{-1}$	JPG 40 (2013) 045001
2011	7 TeV	$930pb^{-1}$	arXiv: 1401.3288 (accepted by JPG)

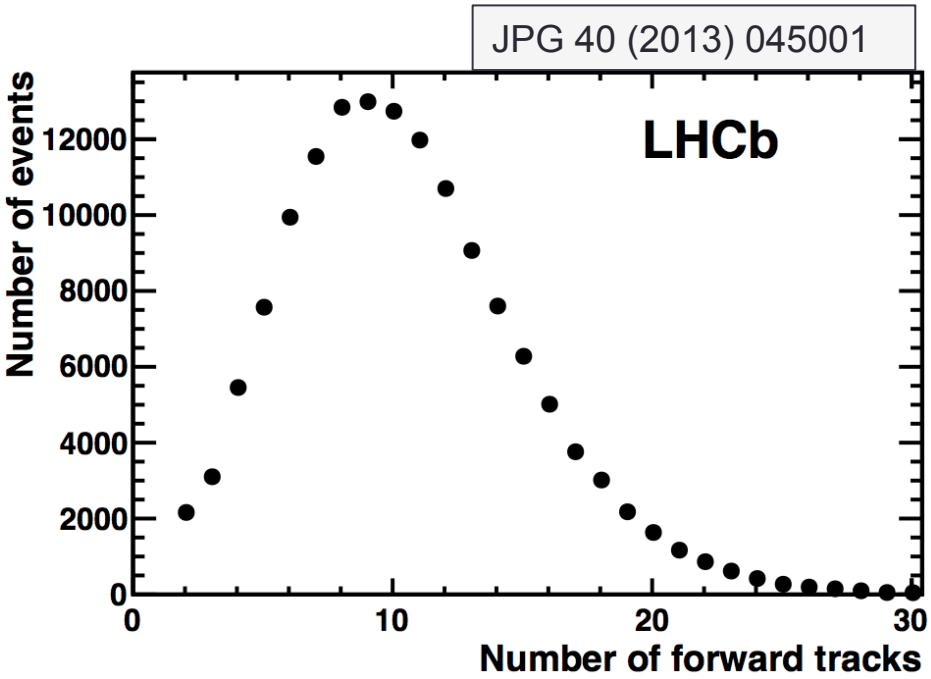
Simple Selection Criteria



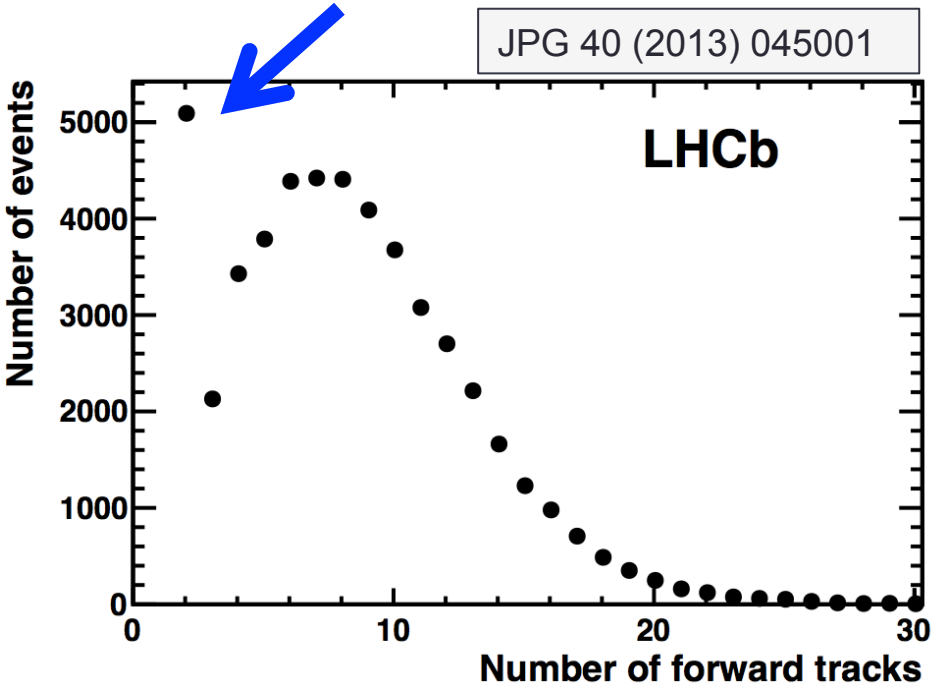
- **Precisely two forward muons**
- **No backward tracks**
- No photons
- p_T^2 of dimuon < 0.8 GeV^2
- Mass of dimuon within 65 MeV of J/ψ or ψ(2S)

2 forward gaps that sum to 3.5 units of rapidity + a backward <gap> of 1.7

Effect of rapidity gap requirement on low multiplicity muon triggered events

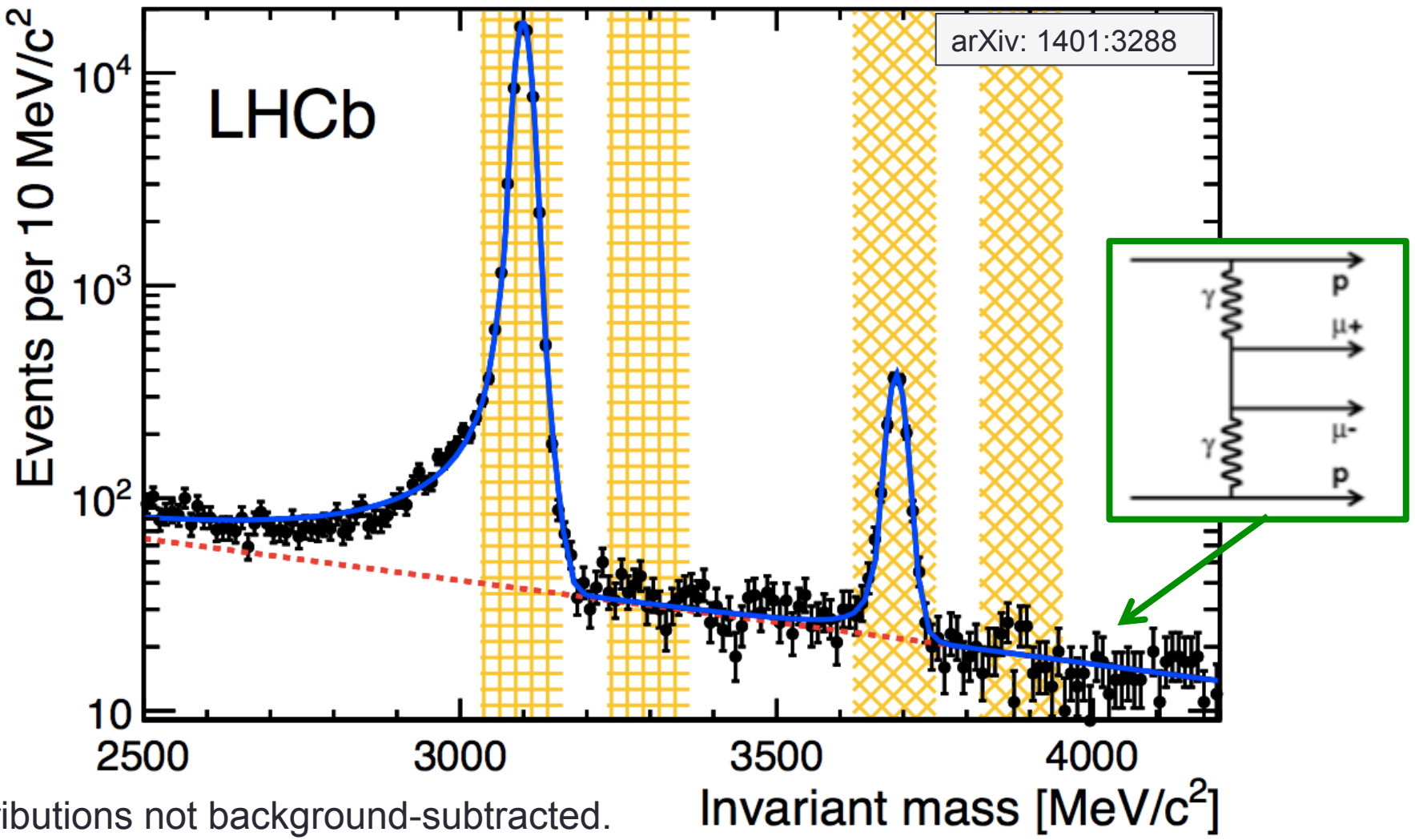


All triggered events



With veto on backward tracks

Non-resonant background very small

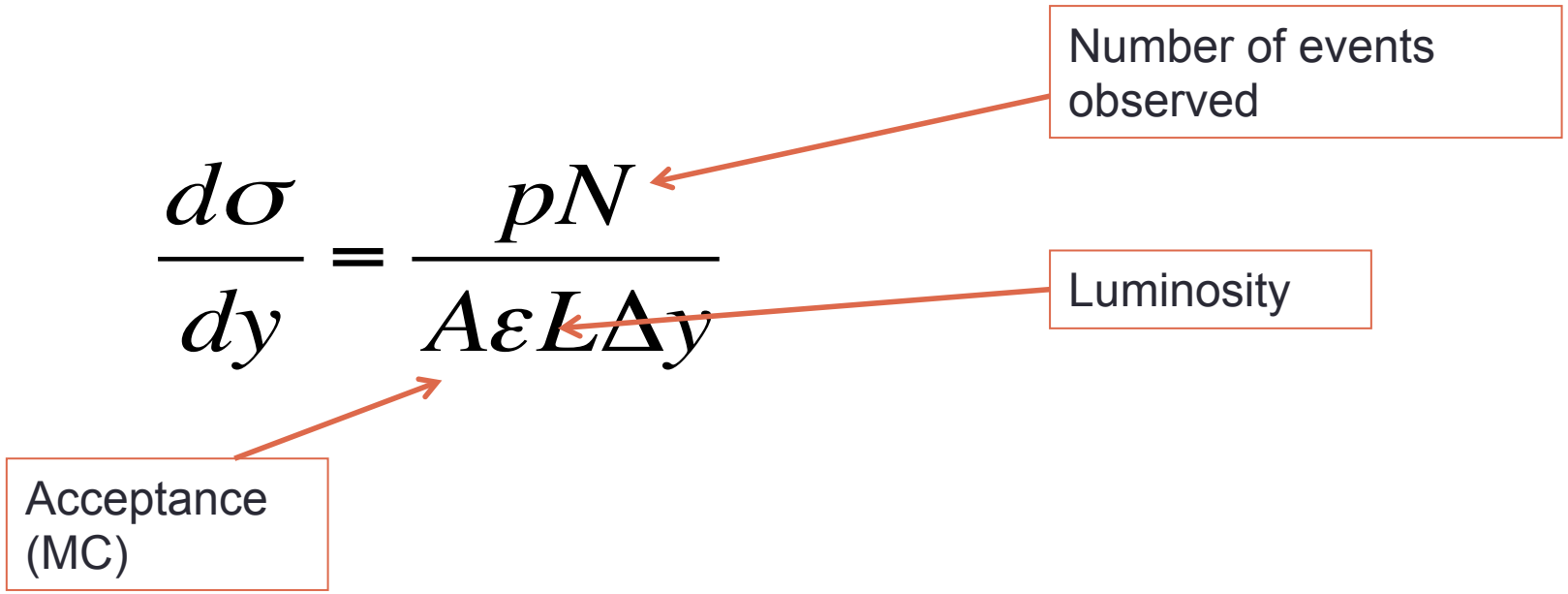


Distributions not background-subtracted.
55985 J/ψ and 1565 ψ(2s)

Cross-section measurement J/ψ / ψ(2S)

$$\frac{d\sigma}{dy} = \frac{pN}{A\varepsilon L \Delta y}$$

Cross-section measurement J/ψ / ψ(2S)



Cross-section measurement J/ψ / ψ(2S)

$$\frac{d\sigma}{dy} = \frac{pN}{A\varepsilon L \Delta y}$$

Number of events observed

Luminosity

Acceptance (MC)

Efficiency: (found from data)
1. Trigger
2. Muon identification
3. Single interaction beam-crossing

$$P(1) = \mu^1 e^{-\mu} / 1!$$

Cross-section measurement J/ψ / ψ(2S)

Purity: (found from data)
1. non-resonant bkg (1% / 17%)
2. Feeddown (10% / 2%)
3. Inelastic Jpsi production (40% / 40%)

Number of events observed

$$\frac{d\sigma}{dy} = \frac{pN}{A\varepsilon L \Delta y}$$

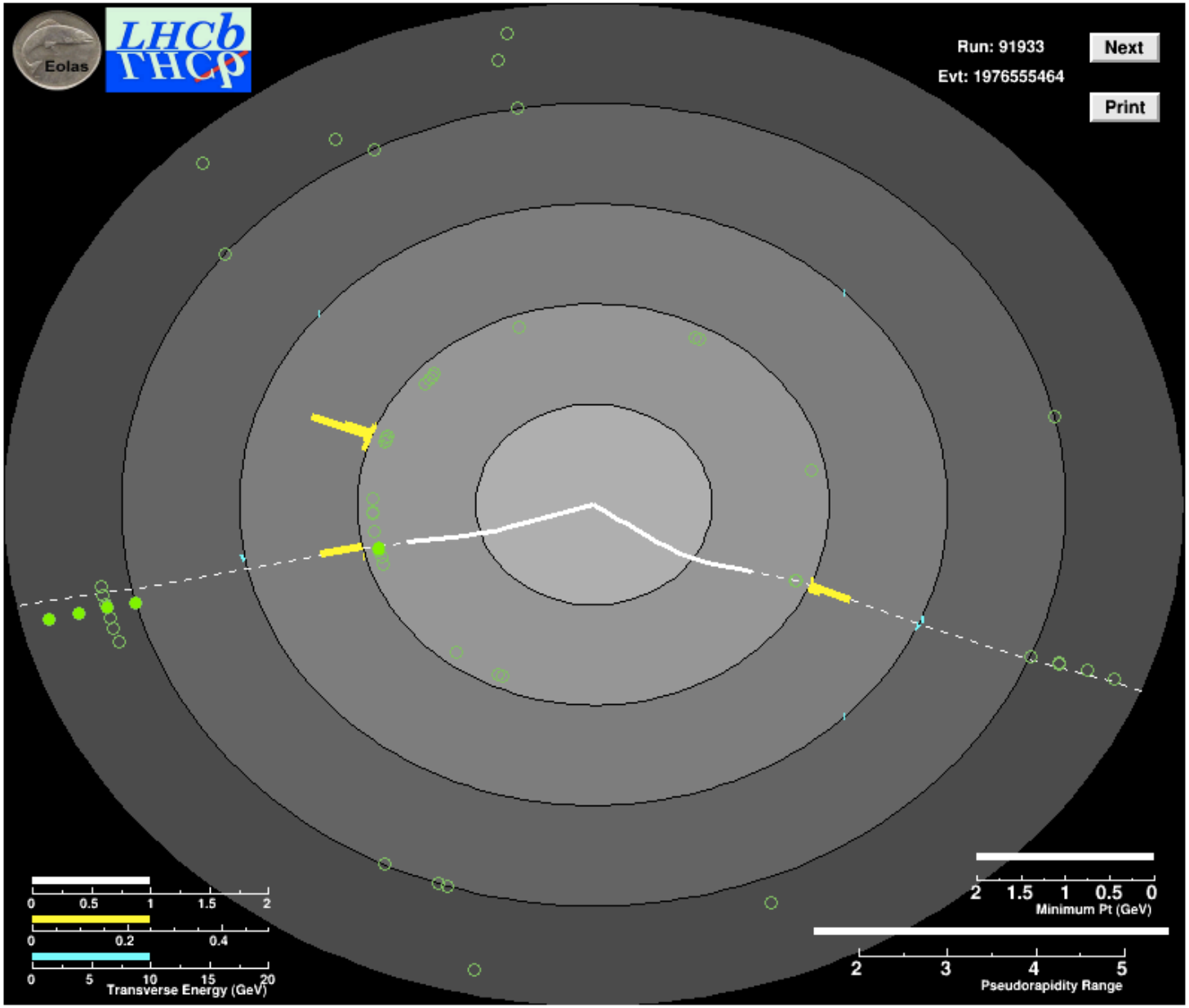
Luminosity

Acceptance (MC)

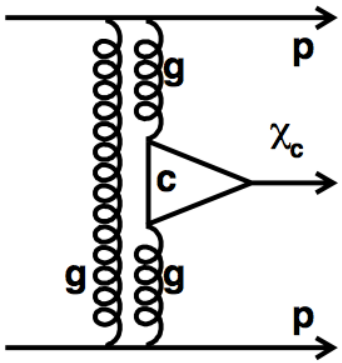
Efficiency: (found from data)
1. Trigger
2. Tracking & muon id.
3. Single interaction beam-crossing

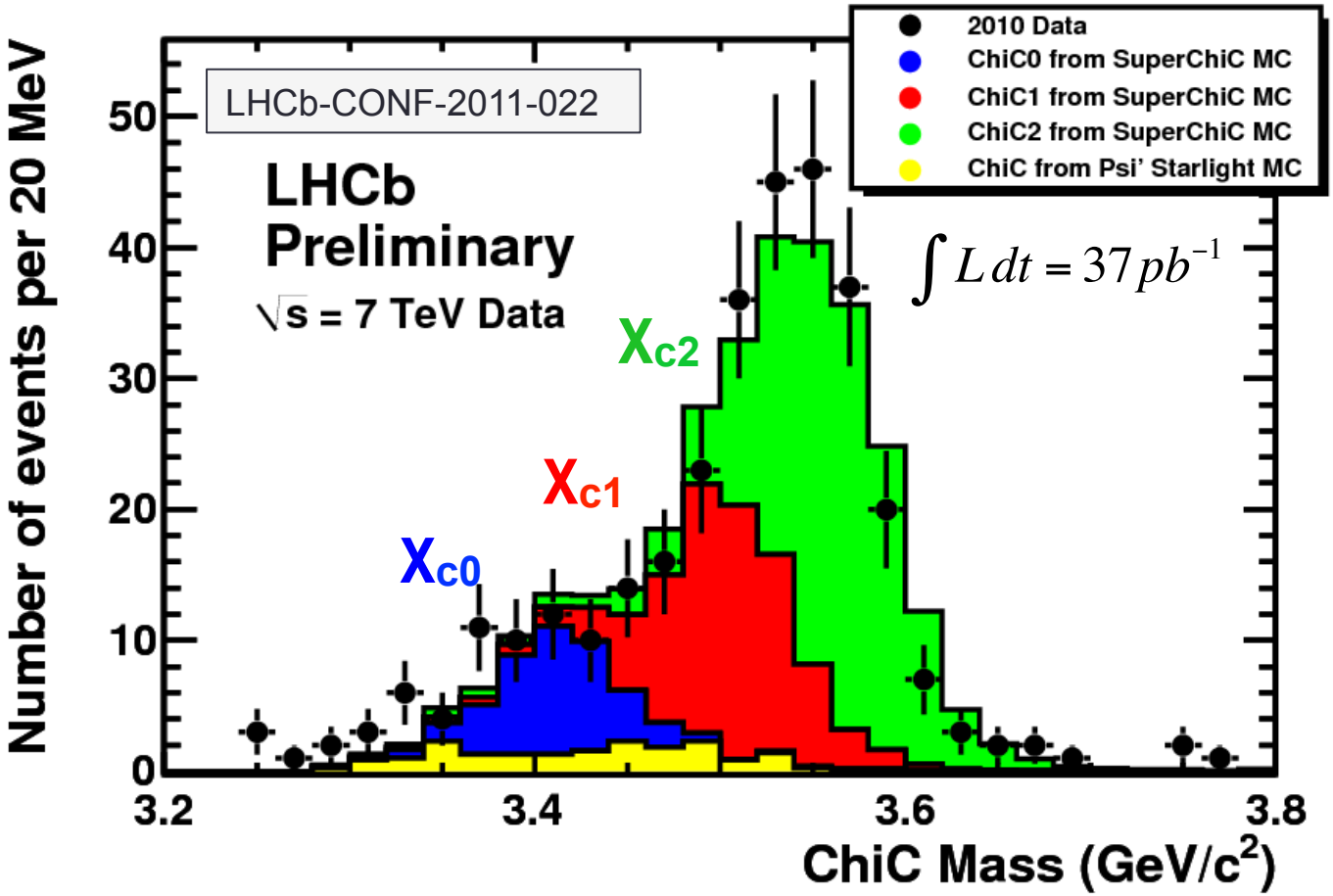
$$P(n) = \mu^n e^{-\mu} / n!$$

Candidate for χ_c decay to J/ψ+γ

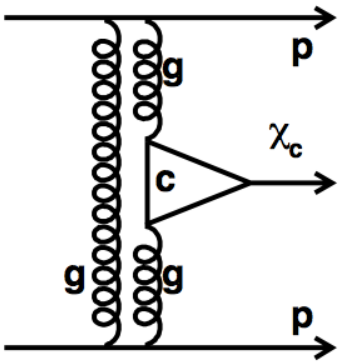


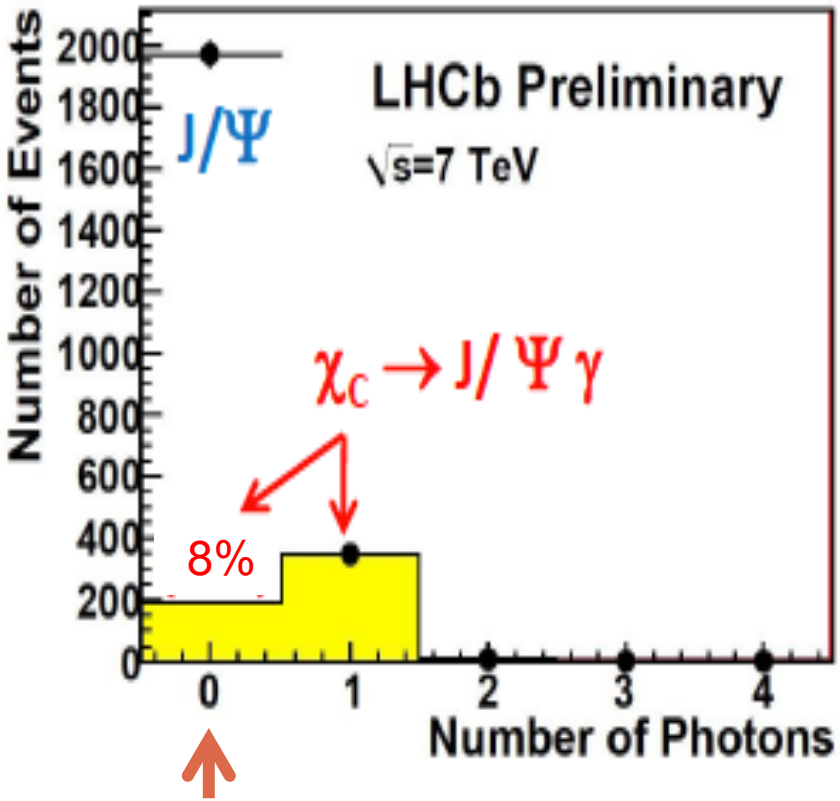
Selected $\chi_{c0,1,2}$ candidates



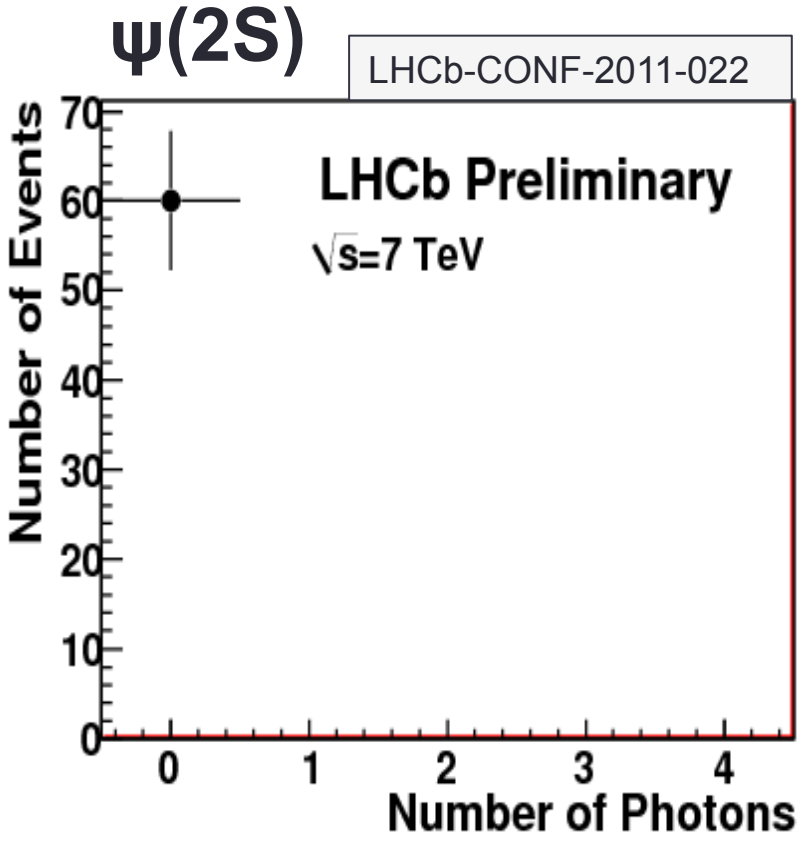


Feed-down background

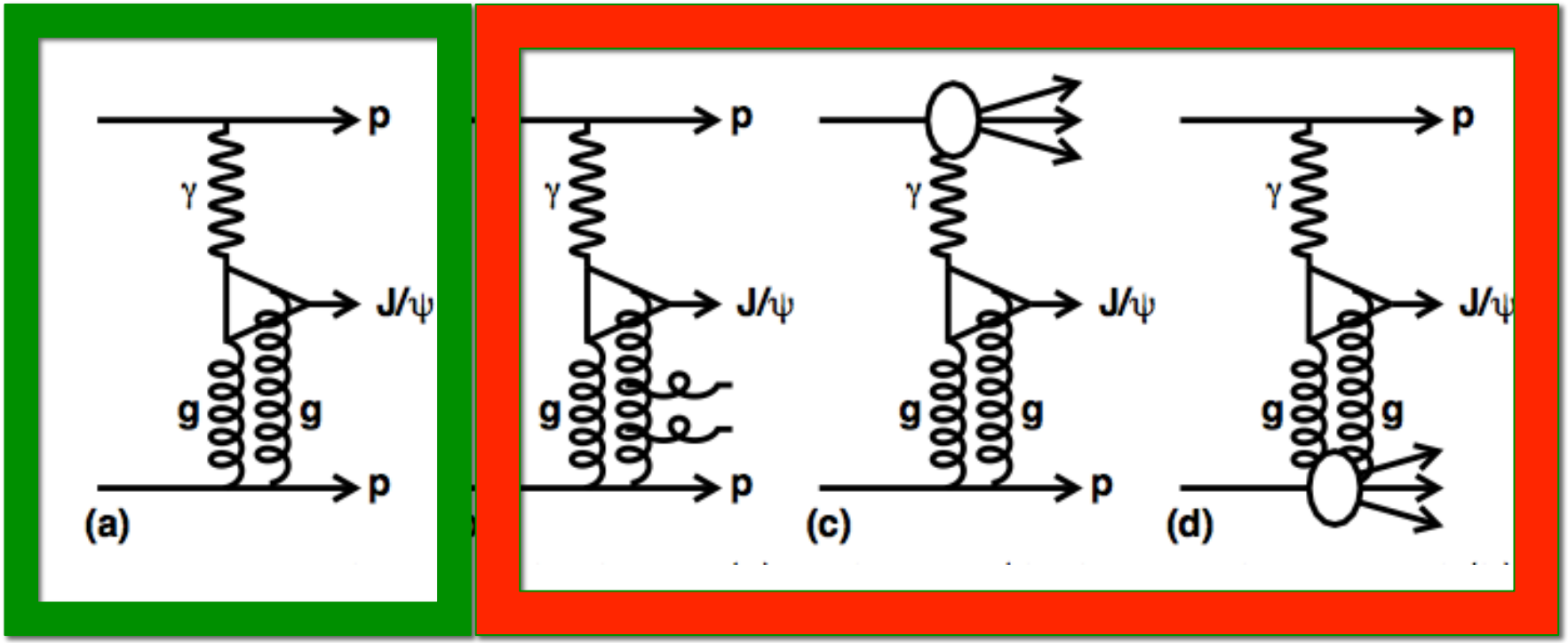




Estimated feeddown

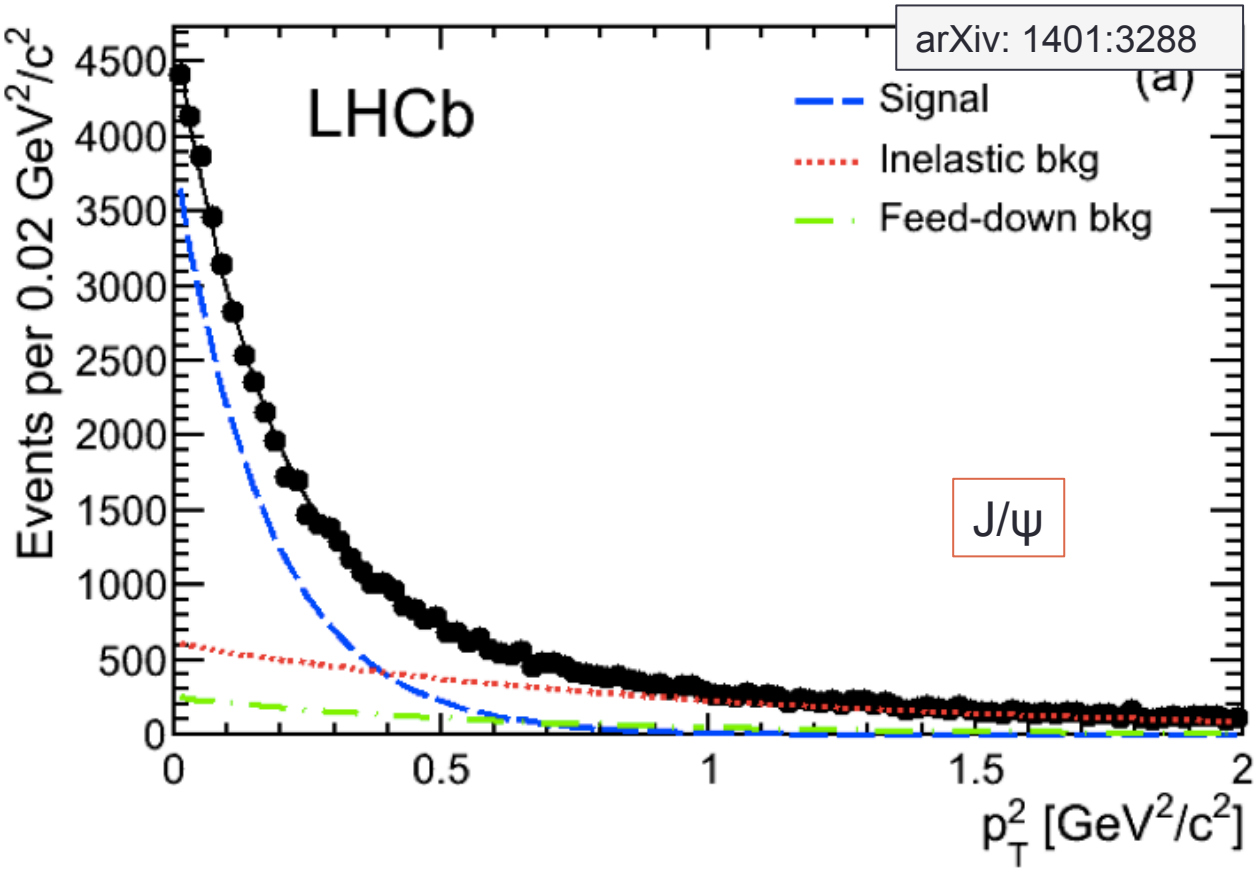


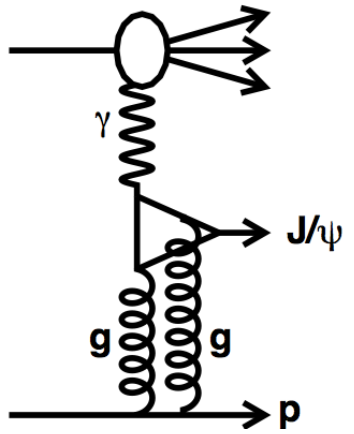
Inelastic background



Signal Background

Inelastic background J/ψ





Regge theory: $\frac{d\sigma}{dt} \sim e^{bt}$

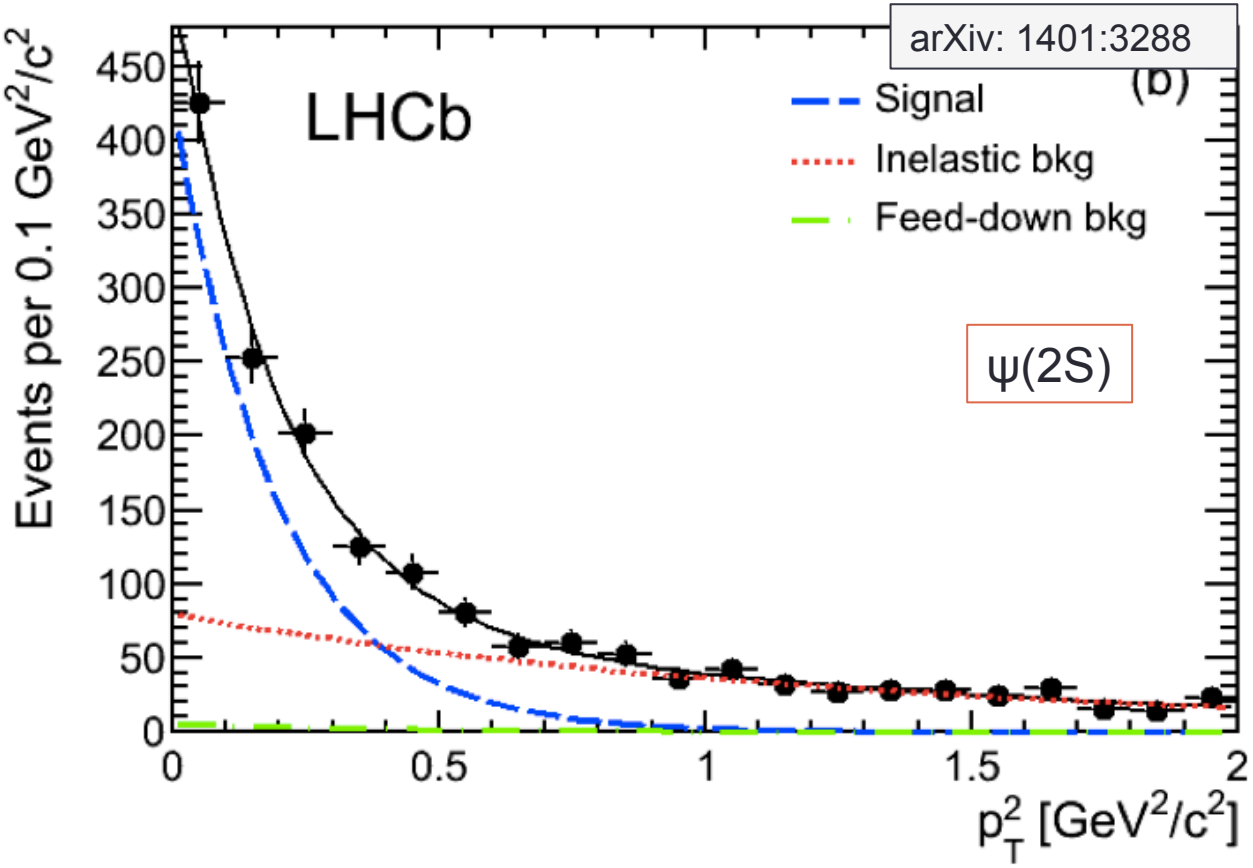
HERA measured:
b_s=4.9 GeV^{-2}
b_{pd}=1.1 GeV^{-2}

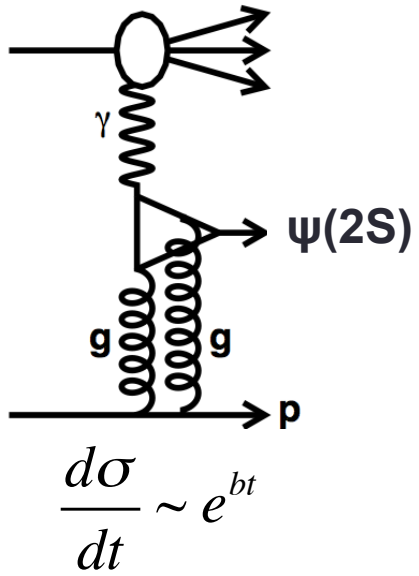
LHCb Expect:
b_s ~ 6 GeV^{-2}
b_{pd}~ 1 GeV^{-2}

LHCb Fit:
b_s=5.70±0.11 GeV^{-2}
b_{pd}=0.97±0.04 GeV^{-2}

Systematic: Change signal to $(1 + b_{\mathrm{pd}} p_{\mathrm{T}}^2/n)^{-n}$

Inelastic background ψ(2S)





HERA measured:
b_s=4.2 GeV^{-2}
b_{pd}=0.6 GeV^{-2}

LHCb Expect:
b_s ~ 5.5 GeV^{-2}
b_{pd}~ 0.6 GeV^{-2}

LHCb Fit:
b_s=5.1±0.7 GeV^{-2}
b_{pd}=0.8±0.2 GeV^{-2}

Numbers entering calculation

Table 1: Quantities entering the cross-section calculations as a function of meson rapidity.

y range (J/ψ)	[2.00, 2.25]	[2.25,2.50]	[2.50,2.75]	[2.75,3.00]	[3.00,3.25]
# Events	798	3911	6632	8600	9987
Acceptance	0.467 ± 0.009	0.653 ± 0.013	0.719 ± 0.014	0.718 ± 0.014	0.713 ± 0.014
$\epsilon^{\psi}_{\rm id} \times \epsilon^{\psi}_{\rm trig}$	0.71 ± 0.03	0.78 ± 0.02	0.81 ± 0.01	0.84 ± 0.01	0.85 ± 0.01
Purity	$0.592 \pm 0.012 \pm 0.030$				

y range (J/ψ)	[3.25, 3.50]	[3.50,3.75]	[3.75,4.00]	[4.00,4.25]	[4.25,4.50]
# Events	9877	7907	5181	2496	596
Acceptance	0.739 ± 0.015	0.734 ± 0.015	0.674 ± 0.014	0.566 ± 0.011	0.401 ± 0.008
$\epsilon^{\psi}_{\rm id} \times \epsilon^{\psi}_{\rm trig}$	0.87 ± 0.01	0.88 ± 0.01	0.87 ± 0.01	0.83 ± 0.02	0.81 ± 0.03
Purity	$0.592 \pm 0.012 \pm 0.030$				

y range ($\psi(2S)$)	[2.00, 2.25]	[2.25,2.50]	[2.50,2.75]	[2.75,3.00]	[3.00,3.25]
# Events	31	111	208	1287	268
Acceptance	0.678 ± 0.013	0.800 ± 0.016	0.834 ± 0.017	0.787 ± 0.016	0.755 ± 0.015
$\epsilon^{\psi}_{\rm id} \times \epsilon^{\psi}_{\rm trig}$	0.80 ± 0.03	0.83 ± 0.02	0.86 ± 0.01	0.88 ± 0.01	0.88 ± 0.01
Purity ($\psi(2S)$)	$0.52 \pm 0.07 \pm 0.03$				

y range($\psi(2S)$)	[3.25, 3.50]	[3.50,3.75]	[3.75,4.00]	[4.00,4.25]	[4.25,4.50]
# Events	282	201	105	61	11
Acceptance	0.748 ± 0.015	0.702 ± 0.014	0.628 ± 0.013	0.524 ± 0.010	0.384 ± 0.008
$\epsilon^{\psi}_{\rm id} \times \epsilon^{\psi}_{\rm trig}$	0.90 ± 0.01	0.89 ± 0.01	0.87 ± 0.01	0.84 ± 0.02	0.77 ± 0.03
Purity ($\psi(2S)$)	$0.52 \pm 0.07 \pm 0.03$				

y range (J/ψ and $\psi(2S)$)	[2.00, 4.50]
$\epsilon_{\rm sel}$	0.87 ± 0.01
$\epsilon_{\rm single}$	0.241 ± 0.003
L ($\rm pb^{-1}$)	929 ± 33

Results and Discussion

Cross-sections and systematics

Cross-section*BR for both muons in pseudorapidity range 2<η<4.5:

y range	[2.00, 2.25]	[2.25,2.50]	[2.50,2.75]	[2.75,3.00]	[3.00,3.25]
$\frac{d\sigma}{dy}$ J/ψ	29.3 ± 1.7	92.5 ± 2.4	137.8 ± 2.4	173.1 ± 2.6	198.0 ± 2.7
$\frac{d\sigma}{dy}$ $\psi(2S)$	0.56 ± 0.11	1.75 ± 0.17	3.06 ± 0.22	4.41 ± 0.26	4.24 ± 0.26

y range	[3.25, 3.50]	[3.50,3.75]	[3.75,4.00]	[4.00,4.25]	[4.25,4.50]
$\frac{d\sigma}{dy}$ J/ψ	187.6 ± 2.6	148.9 ± 2.4	107.4 ± 2.1	65.3 ± 2.0	21.9 ± 1.3
$\frac{d\sigma}{dy}$ $\psi(2S)$	4.51 ± 0.27	3.43 ± 0.25	2.05 ± 0.20	1.47 ± 0.19	0.36 ± 0.11

Correlated uncertainties expressed as a percentage of the final result	
ϵ_{sel}	1.4%
Purity determination (J/ψ)	2.0%
Purity determination $(\psi(2S))$	13.0%
$^*\epsilon_{\text{single}}$	1.0%
*Acceptance	2.0%
*Shape of the inelastic background	5.0%
*Luminosity	3.5%
Total correlated statistical uncertainty (J/ψ)	2.4%
Total correlated statistical uncertainty $(\psi(2S))$	13.0%
Total correlated systematic uncertainty	6.5%

ψ(2S)

J/ψ

Comparison to theory

V. P. Gonçalves and M. V. T. Machado, *Vector meson production in coherent hadronic interactions: an update on predictions for RHIC and LHC*, Phys. Rev. **C84** (2011) 011902, arXiv:1106.3036.

S. Jones, A. Martin, M. Ryskin, and T. Teubner, *Probes of the small x gluon via exclusive J/ψ and Υ production at HERA and the LHC*, JHEP **1311** (2013) 085, arXiv:1307.7099.

L. Motyka and G. Watt, *Exclusive photoproduction at the Fermilab Tevatron and CERN LHC within the dipole picture*, Phys. Rev. **D78** (2008) 014023, arXiv:0805.2113.

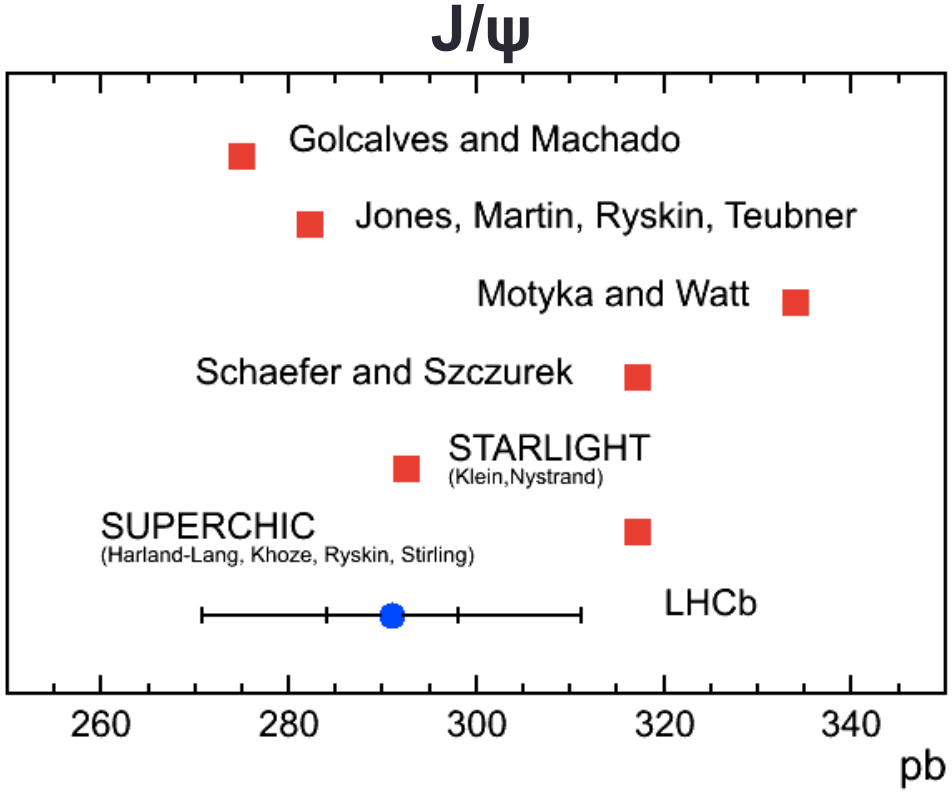
W. Schäfer and A. Szczurek, *Exclusive photoproduction of J/ψ in proton-proton and proton-antiproton scattering*, Phys. Rev. **D76** (2007) 094014, arXiv:0705.2887.

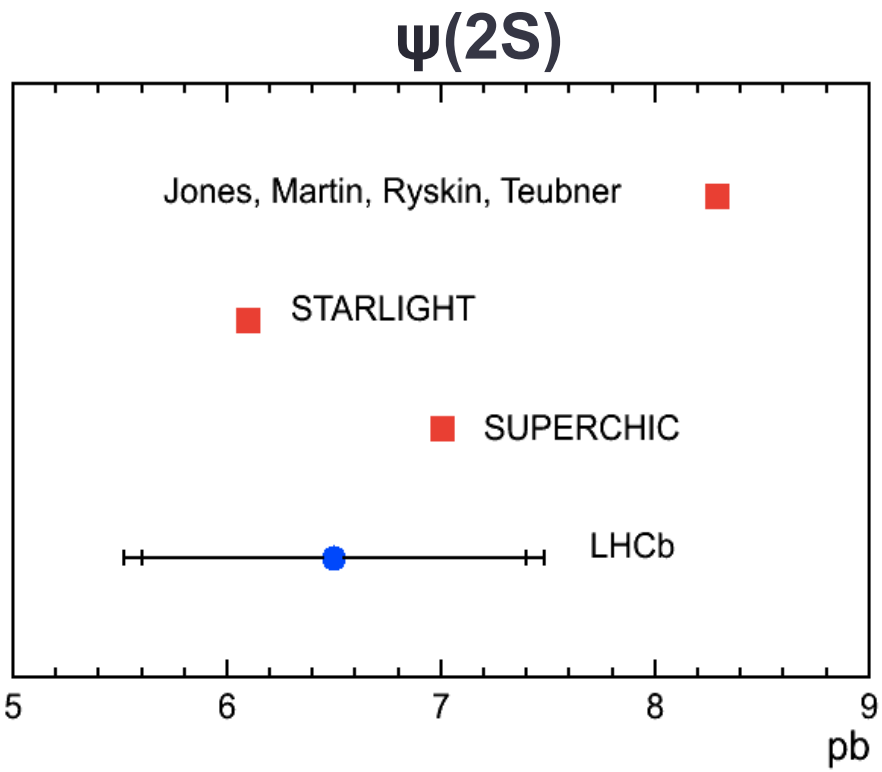
S. R. Klein and J. Nystrand, *Photoproduction of quarkonium in proton proton and nucleus nucleus collisions*, Phys. Rev. Lett. **92** (2004) 142003, arXiv:hep-ph/0311164.

L. A. Harland-Lang, V. A. Khoze, M. G. Ryskin, and W. J. Stirling, *Central exclusive χ_c meson production at the Tevatron revisited*, Eur. Phys. J. **C65** (2010) 433, arXiv:0909.4748.

Integrated Cross-sections

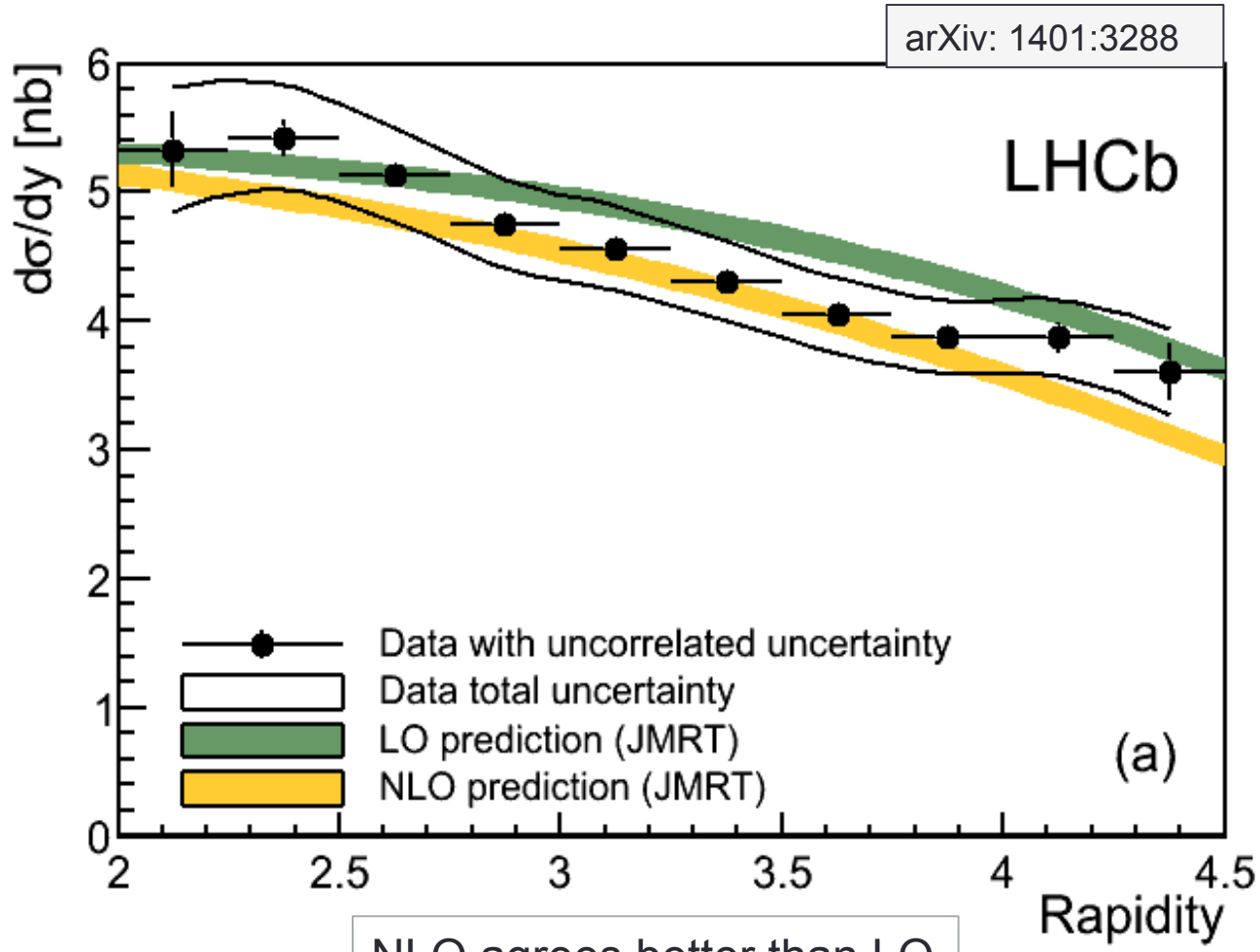
Cross-section*BR for both muons in pseudorapidity range 2<η<4.5:





Good agreement with all theory estimates

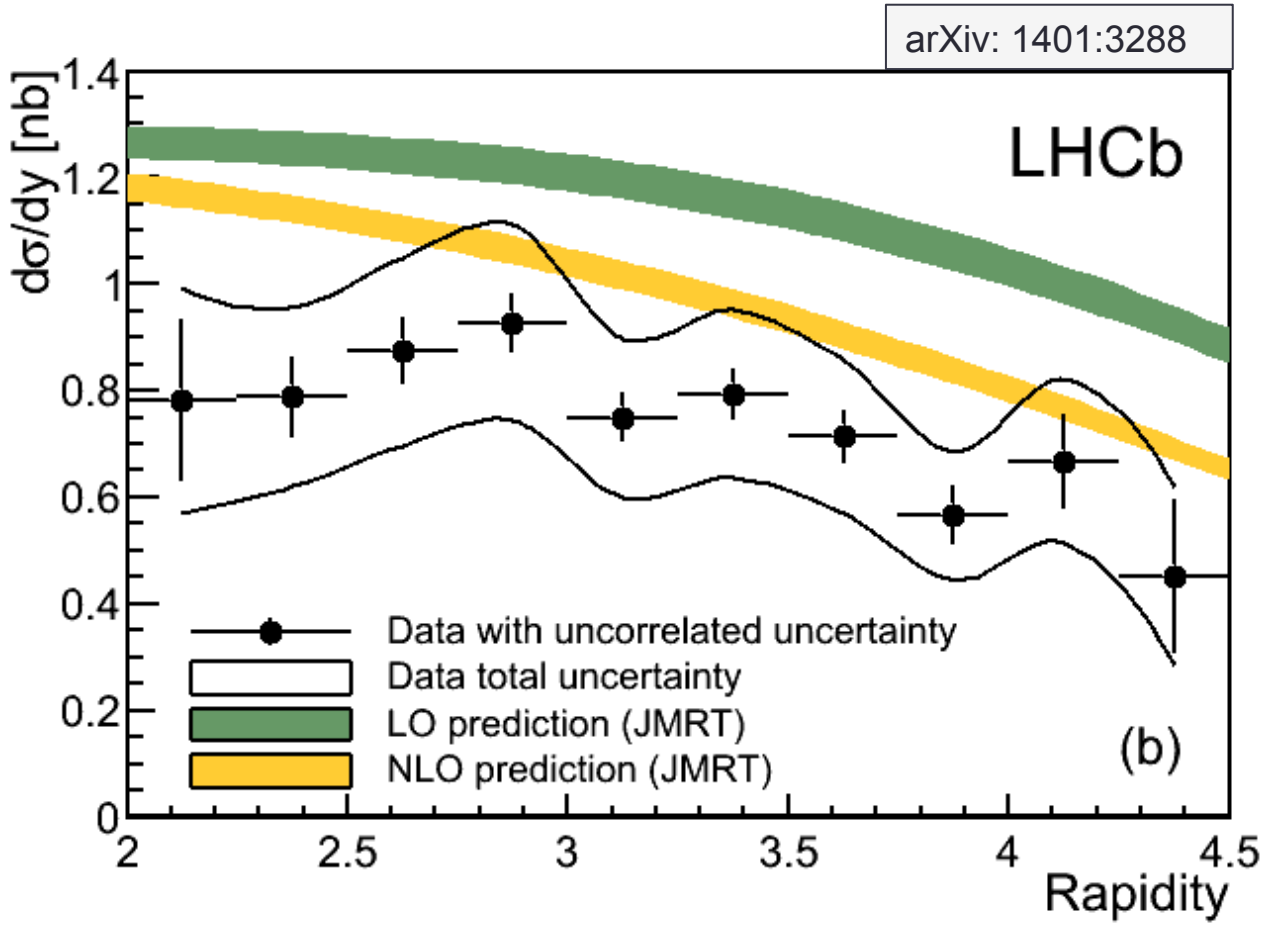
Differential cross-sections J/ψ



NLO agrees better than LO

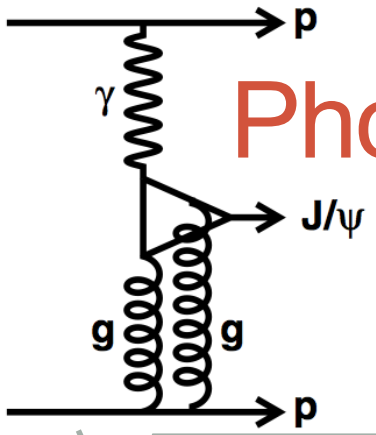
S. Jones, A. Martin, M. Ryskin, and T. Teubner, *Probes of the small x gluon via exclusive J/ψ and ϒ production at HERA and the LHC*, JHEP **1311** (2013) 085, arXiv:1307.7099.

Differential cross-sections ψ(2S)



NLO agrees better than LO

Photo-production cross-section



LHCb measure

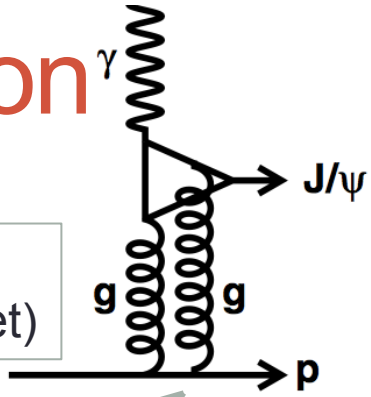


Photo-production
(HERA / fixed target)

$$\frac{d\sigma}{dy}_{pp\to pJ/\psi p} = r_+ k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to J/\psi p}(W_+) + r_- k_- \frac{dn}{dk_-}\sigma_{\gamma p\to J/\psi p}(W_-)$$

Gap Survival

Photon Flux

HERA measured power-law: $\sigma_{\gamma p\to J/\psi p}(W) = 81(W/90\,\mathrm{GeV})^{0.67}\,\mathrm{nb}$

Use this for one cross-section on RHS – LHCb measure the other solution

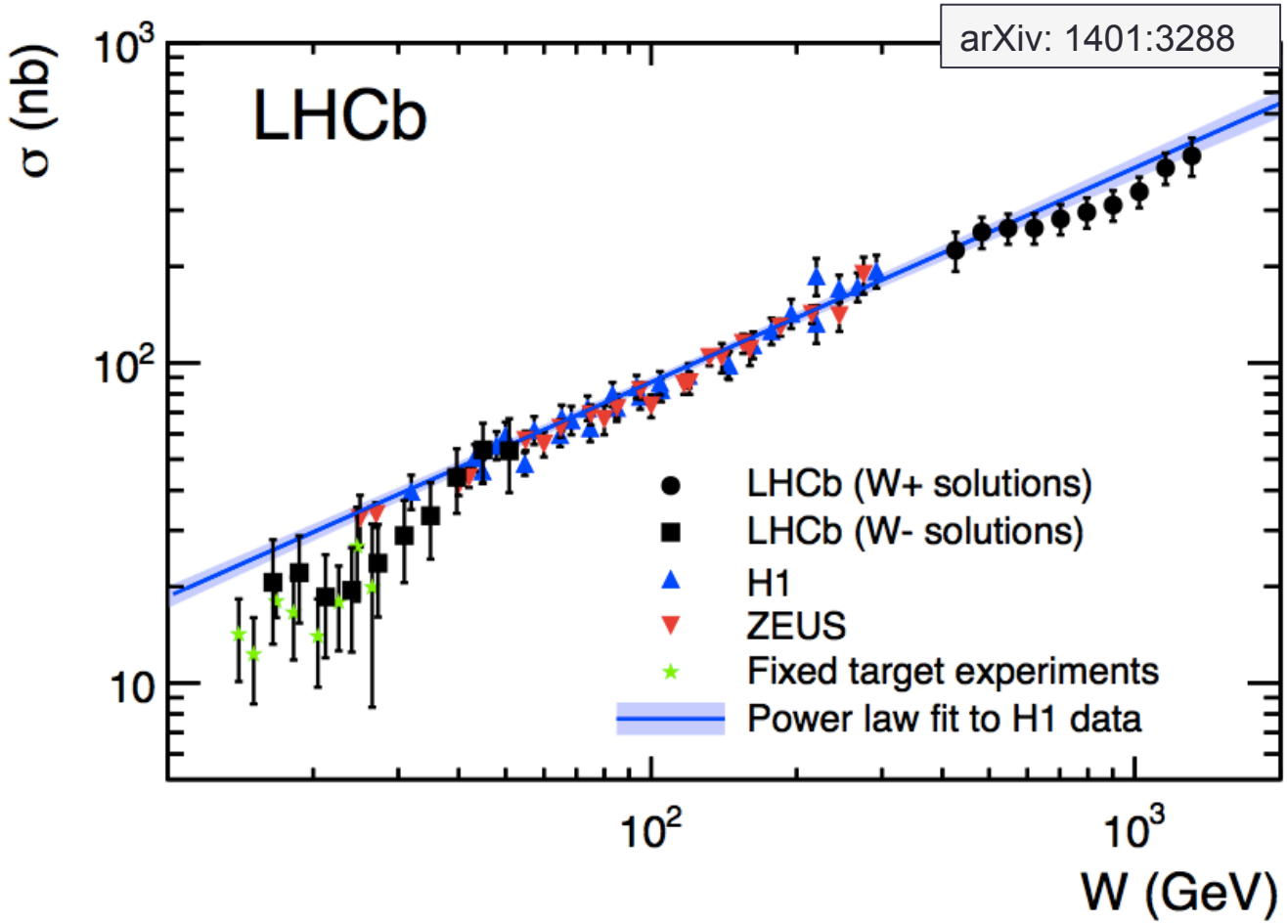
Photo-production cross-section

Measure

Plot

HERA

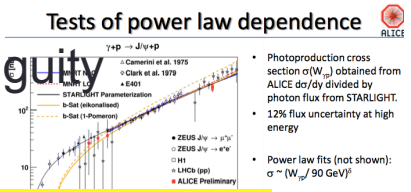
$$\frac{d\sigma}{dy}_{pp\to pJ/\psi p} = r_+ k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to J/\psi p}(W_+) + r_- k_- \frac{dn}{dk_-}\sigma_{\gamma p\to J/\psi p}(W_-)$$



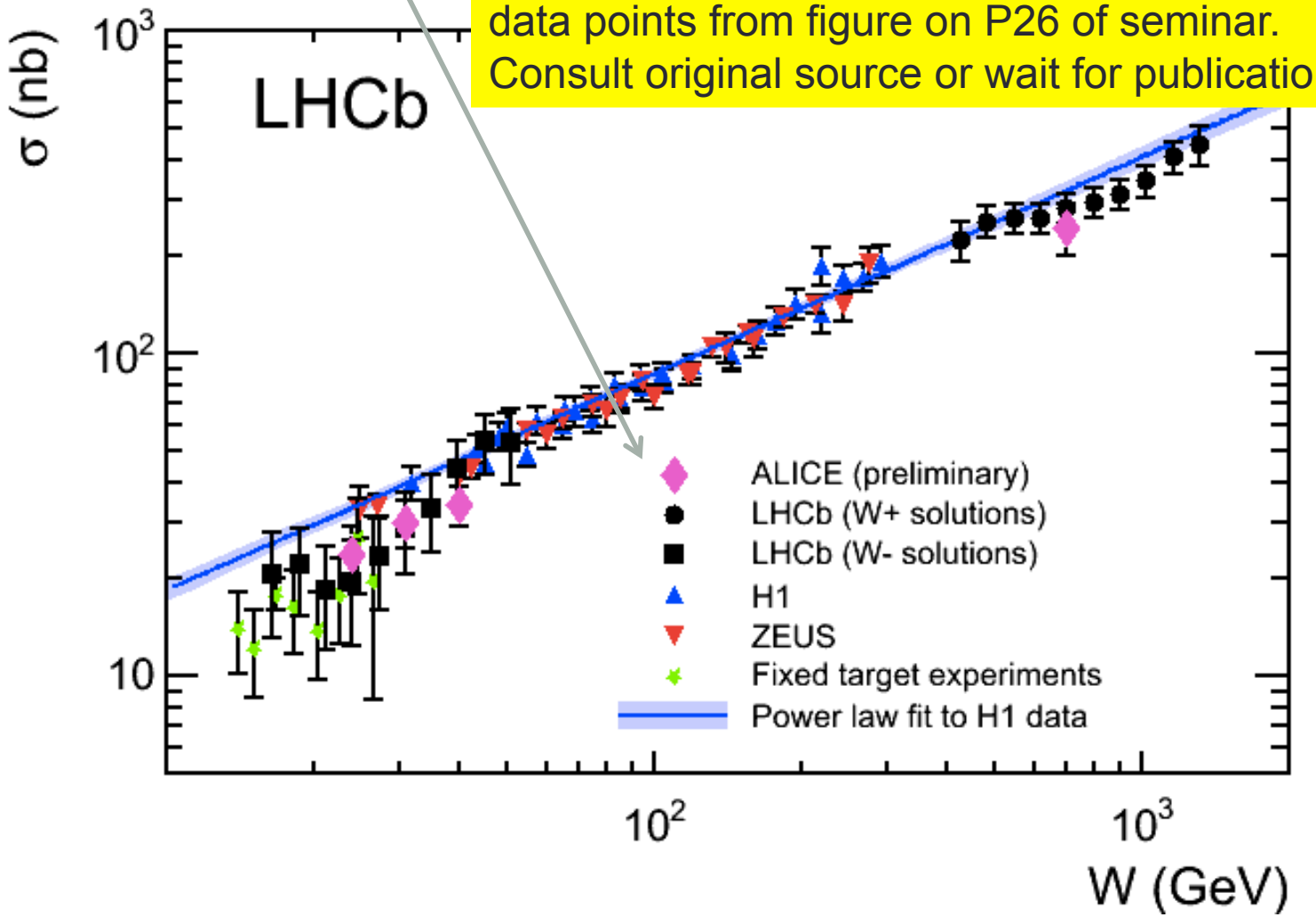
Deviation from pure power-law. i.e. NLO required or only power-law for $W>W_0$

Photo-production cross-section

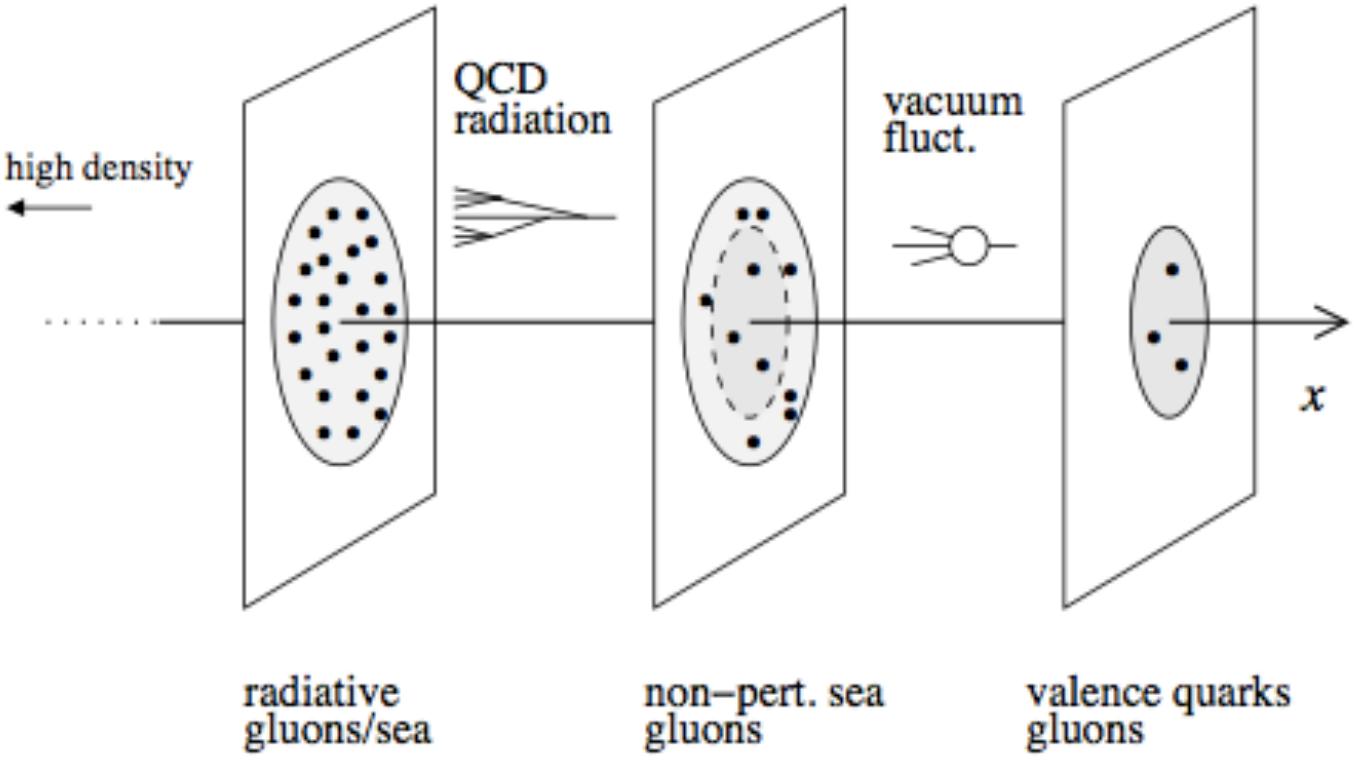
Add ALICE pPb perliminary data which does NOT have ambiguity
See: Evgeny Kryshen, LHC seminar, 17.12.2013.



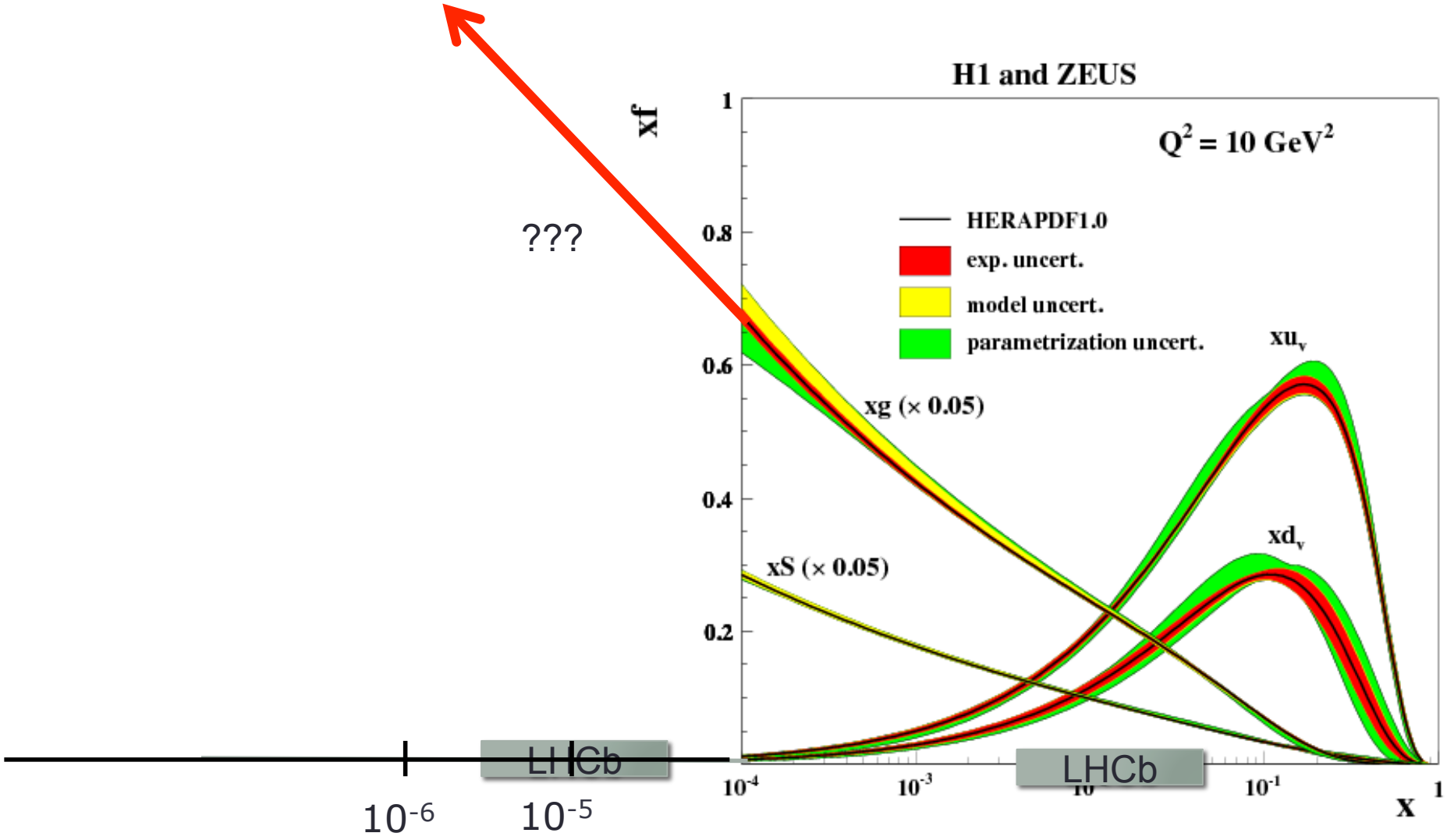
Health warning: This is my attempt to read data points from figure on P26 of seminar. Consult original source or wait for publication.



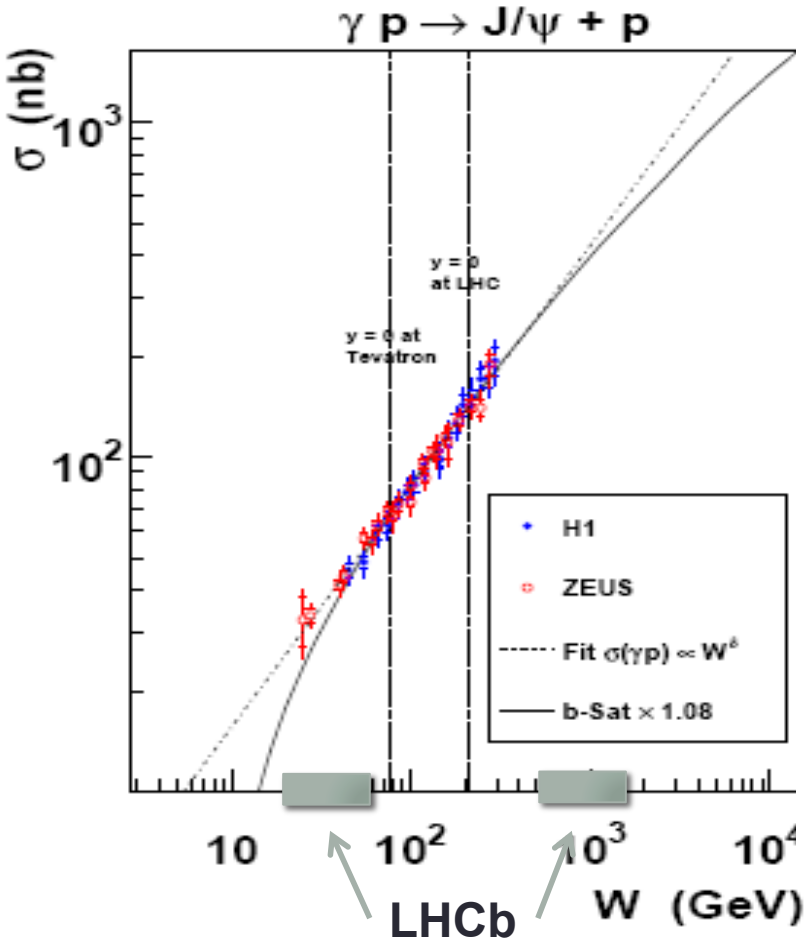
Sensitivity to saturation effects



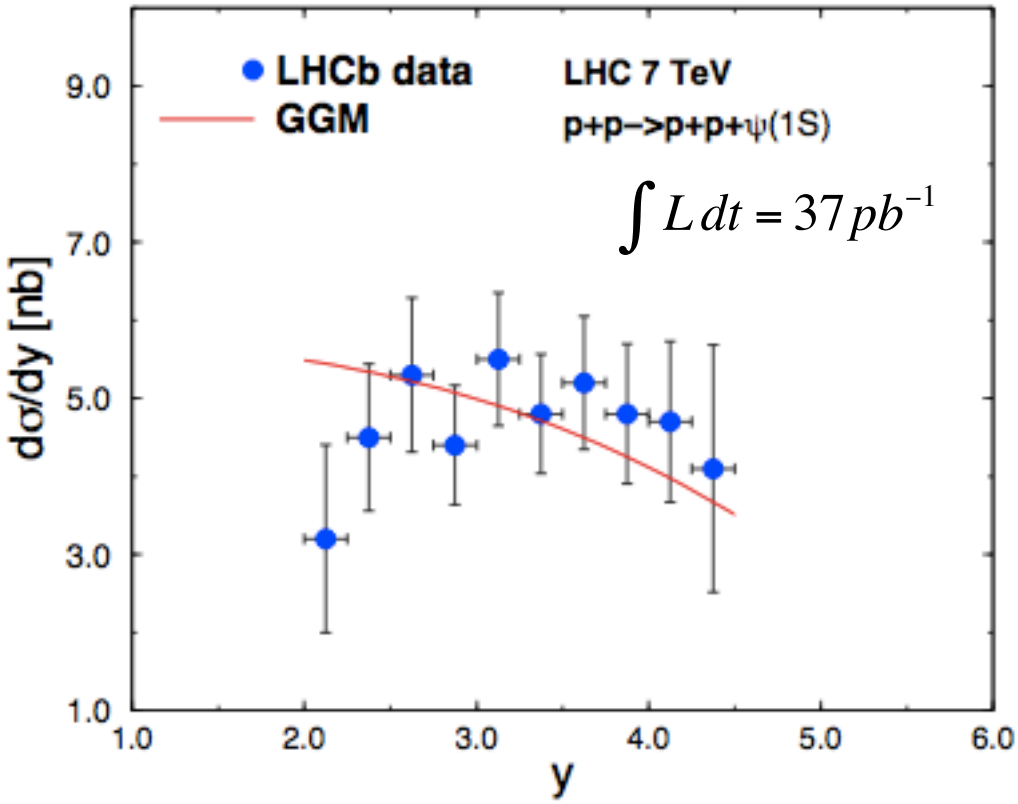
Sensitivity to saturation effects



Sensitivity to saturation effects

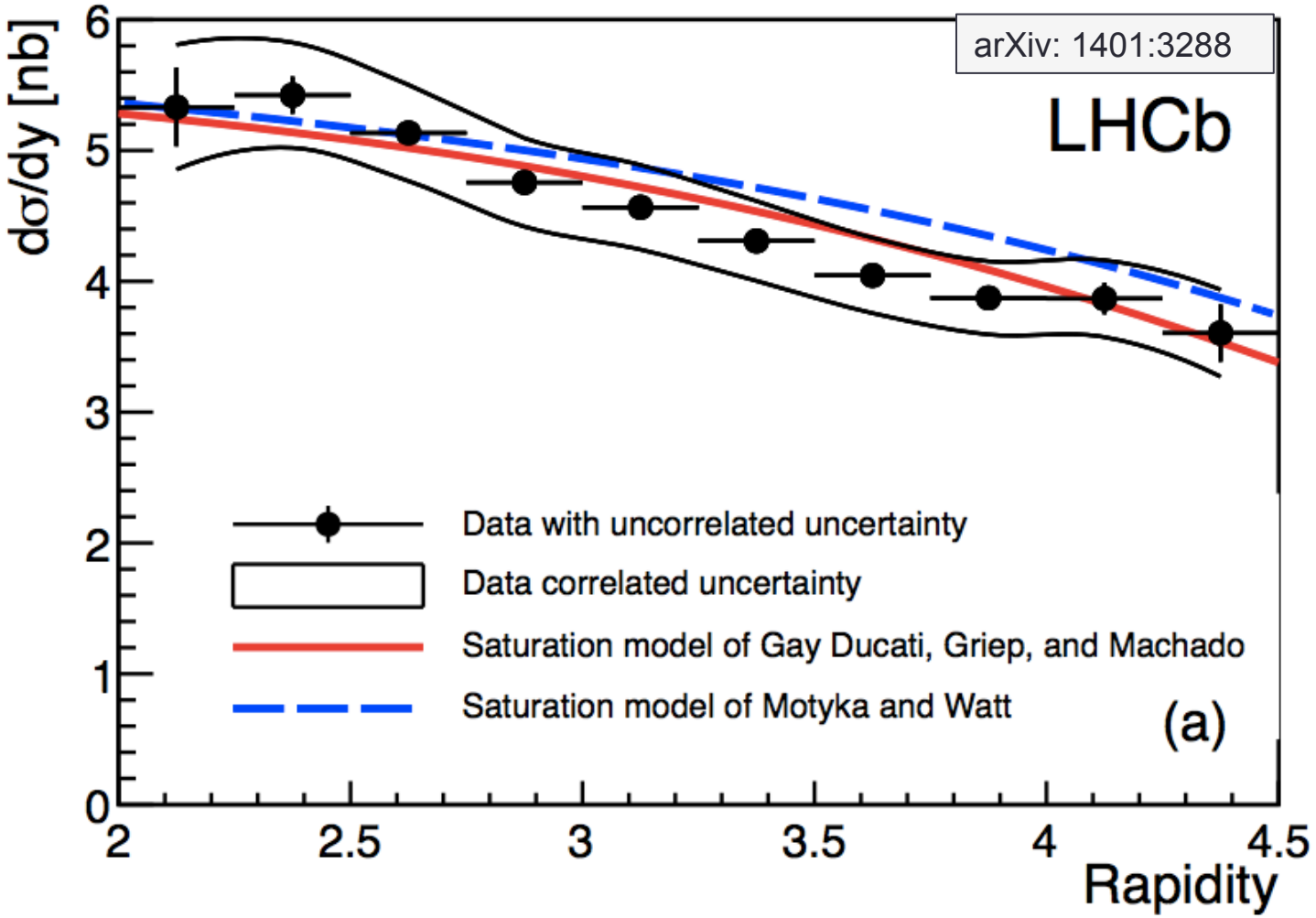


Motyka, Watt: PRD 78, 014023 (2008)



Gay Ducati et al., arXiv: 1305.4611

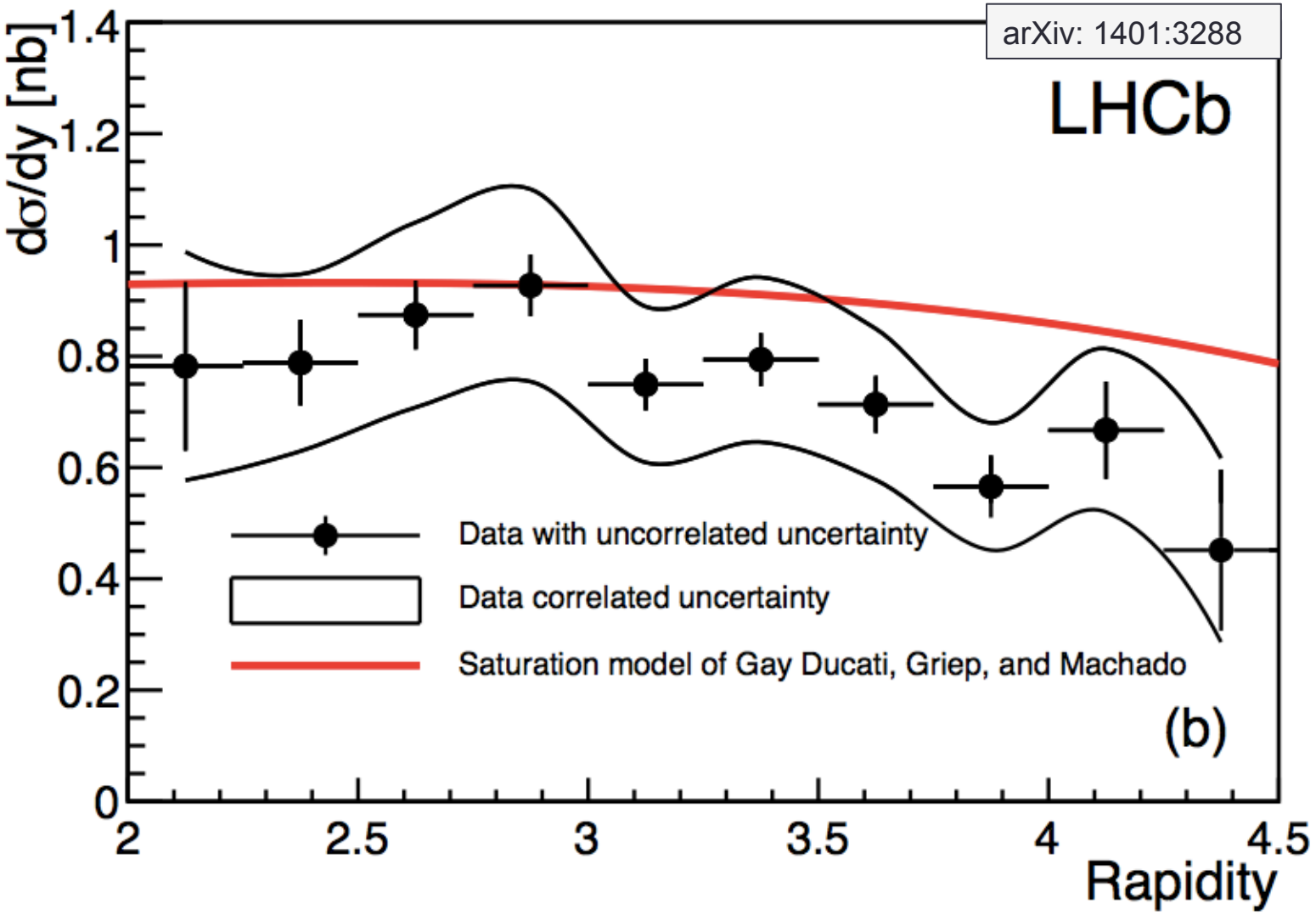
Sensitivity to saturation effects: J/ψ



L. Motyka and G. Watt, *Exclusive photoproduction at the Fermilab Tevatron and CERN LHC within the dipole picture*, Phys. Rev. **D78** (2008) 014023, arXiv:0805.2113.

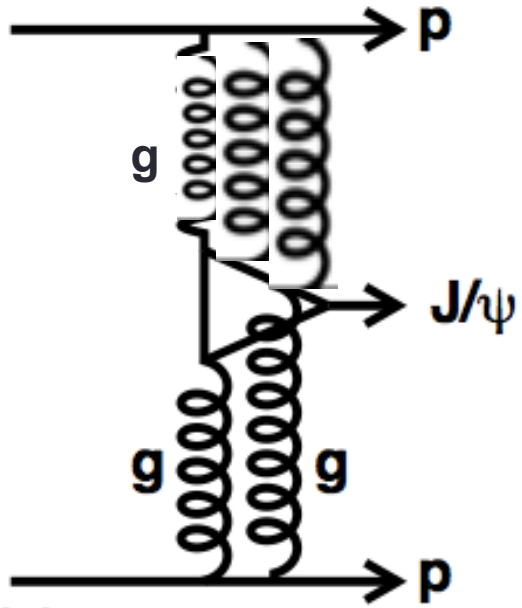
M. B. Gay Ducati, M. T. Griep, and M. V. T. Machado, *Exclusive photoproduction of J/ψ and ψ(2S) states in proton-proton collisions at the CERN LHC*, arXiv:1305.4611.

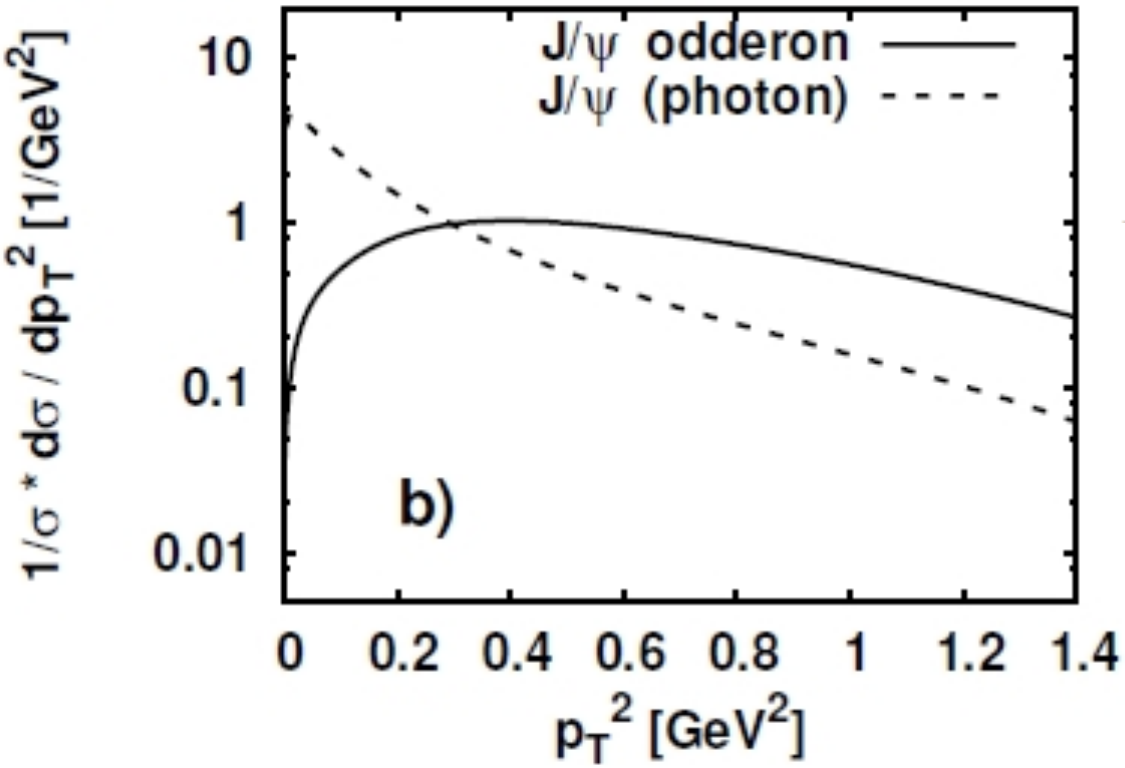
Sensitivity to saturation effects: ψ(2S)



Search for odderon

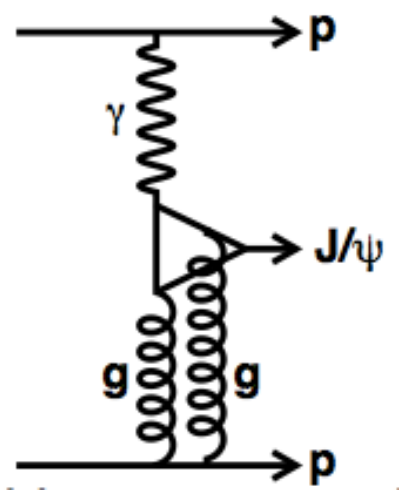
- Motyka, DIS 2008.



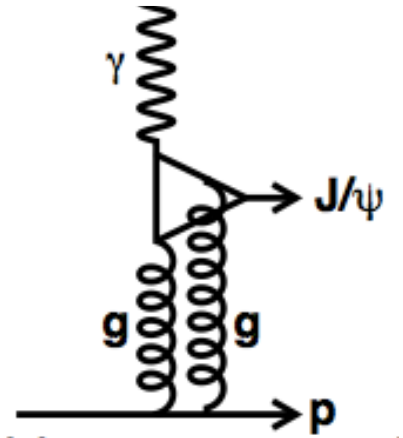


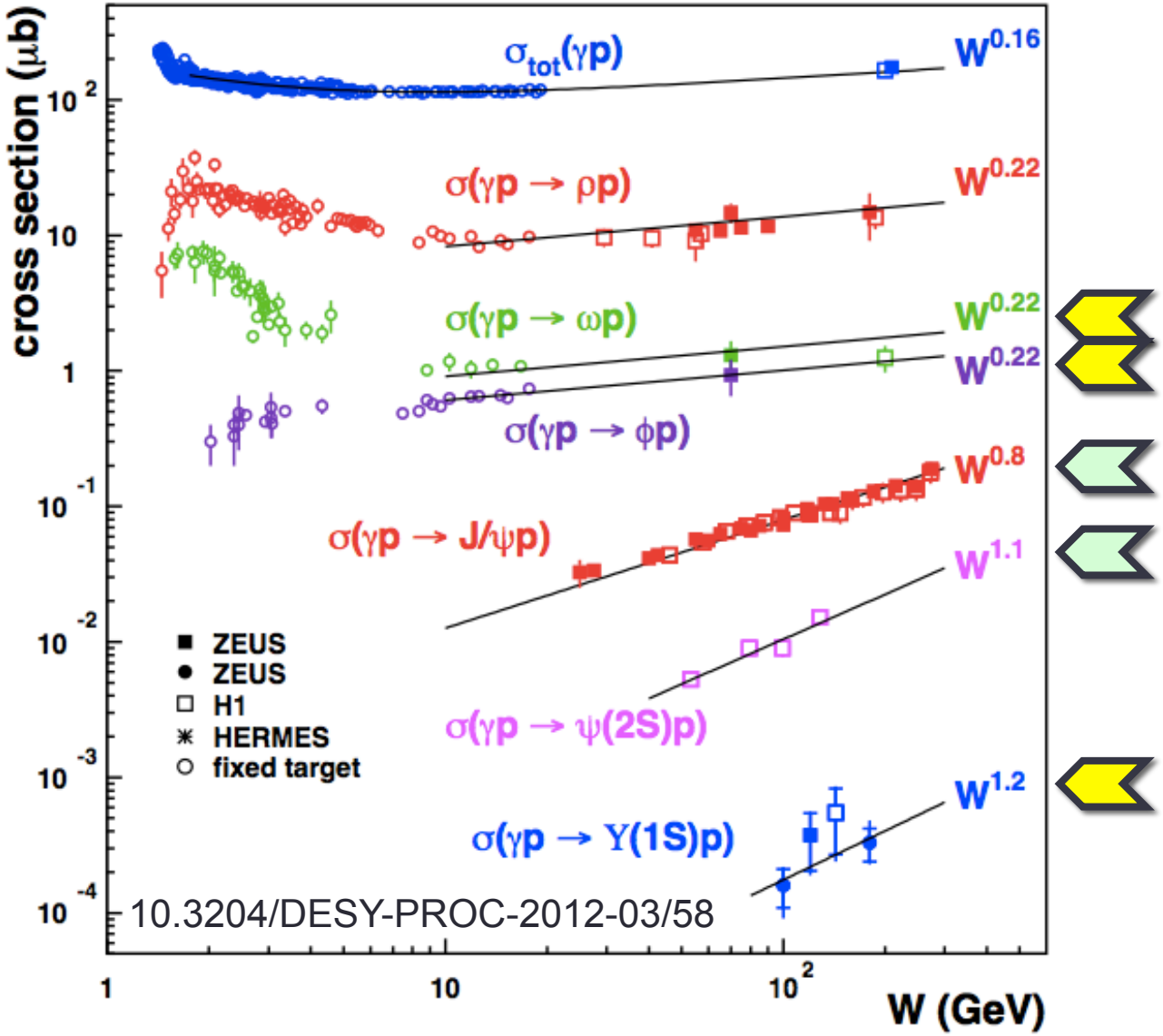
Future Prospects

Investigate other vector mesons

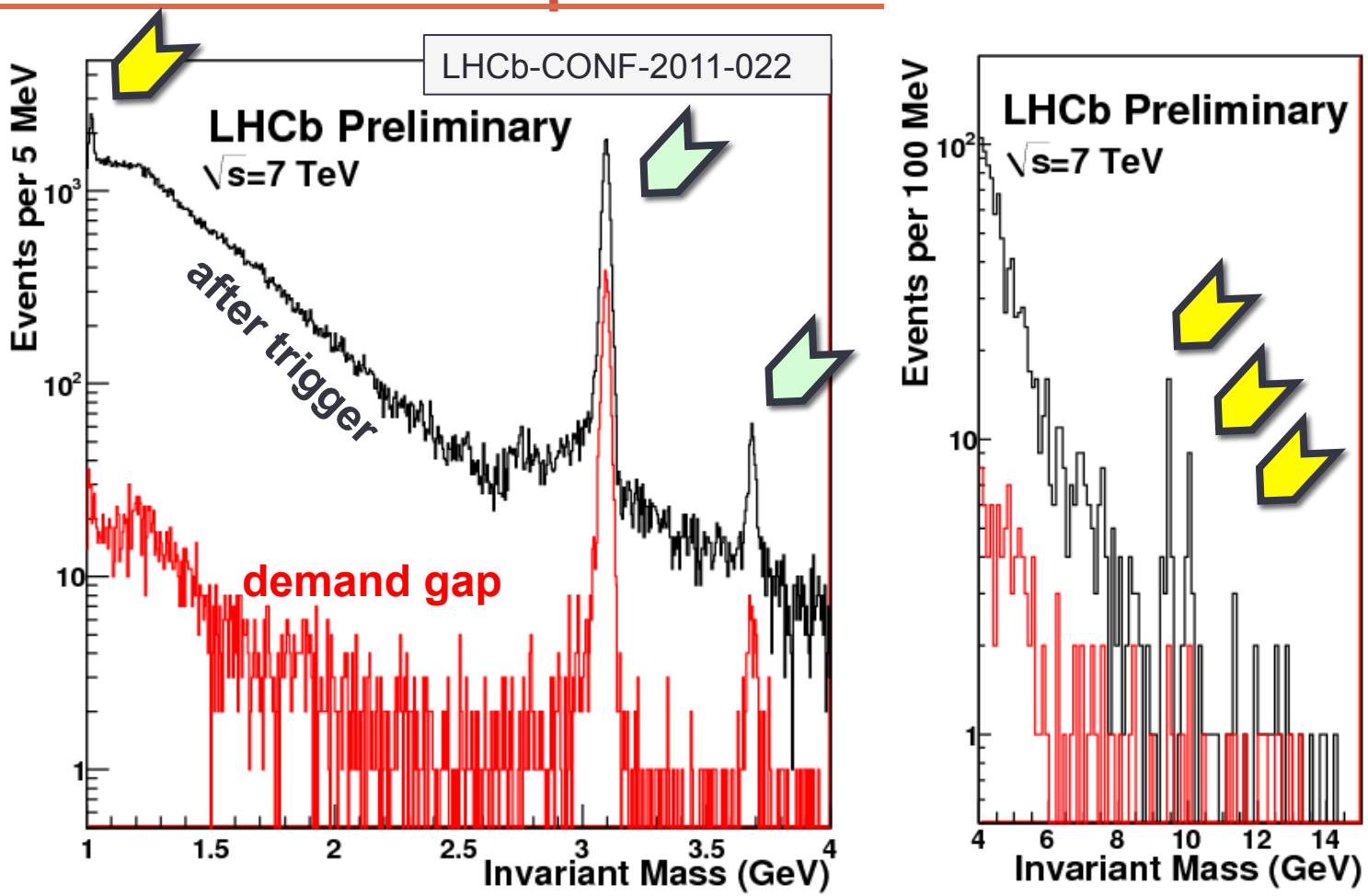


looks very like





Dimuon Mass Spectrum

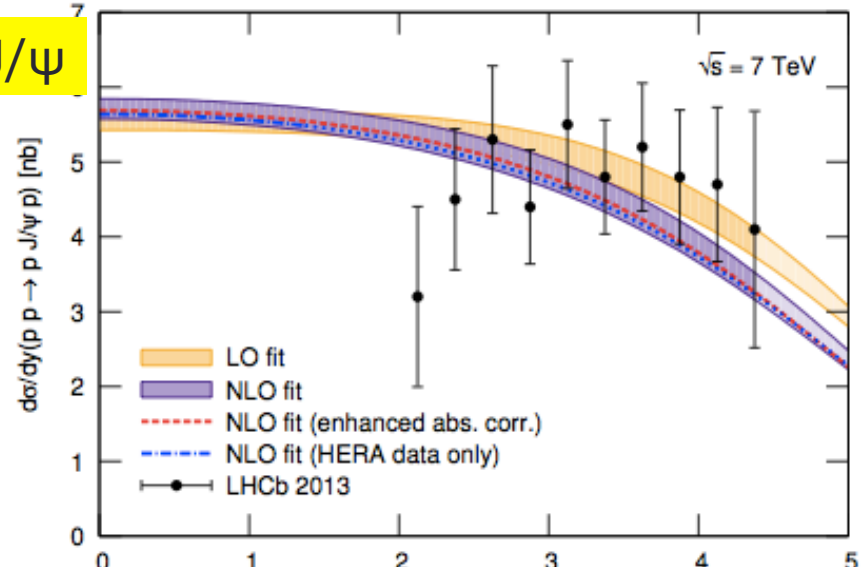


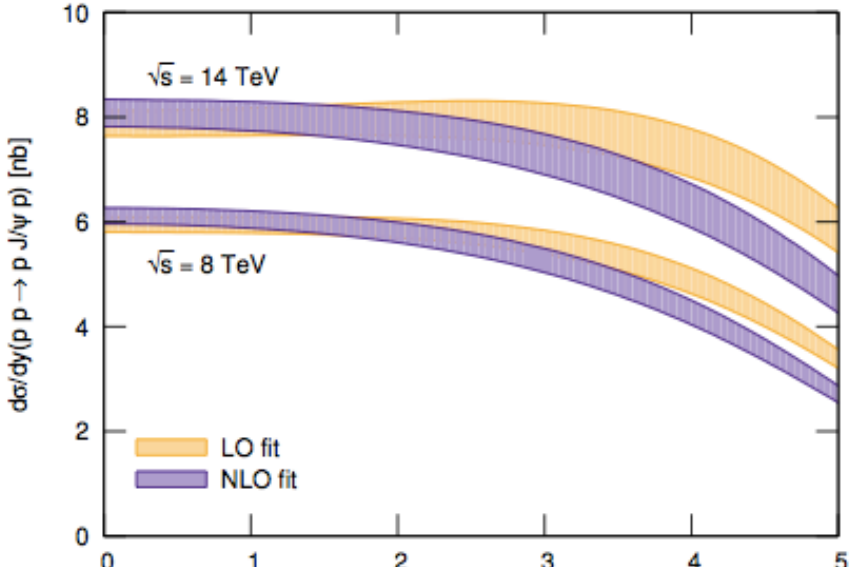
Factor ~ *100 data now available with 2011+2012 (~3fb^{-1})

Predictions (arXiv: 1307.7099)

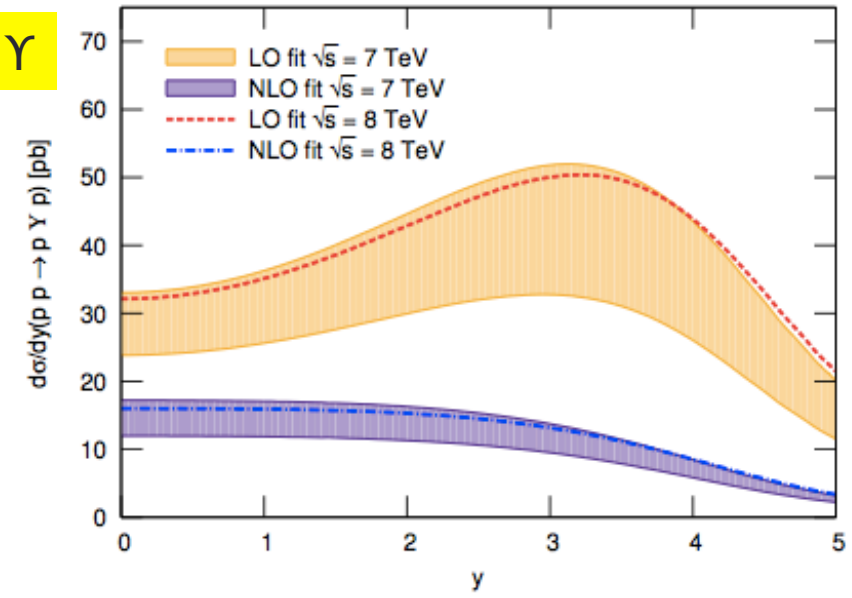
(Jones, Martin, Ryskin, Teubner)

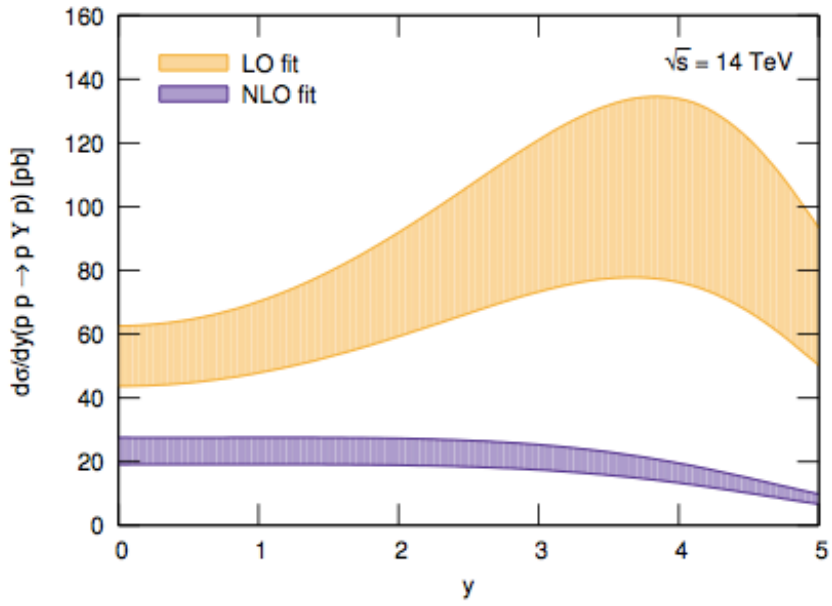
J/ψ



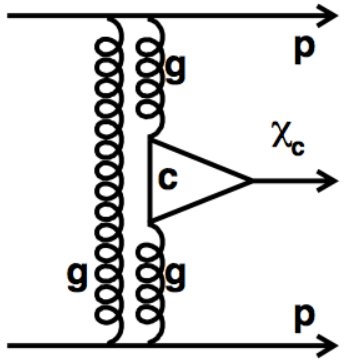


ϒ



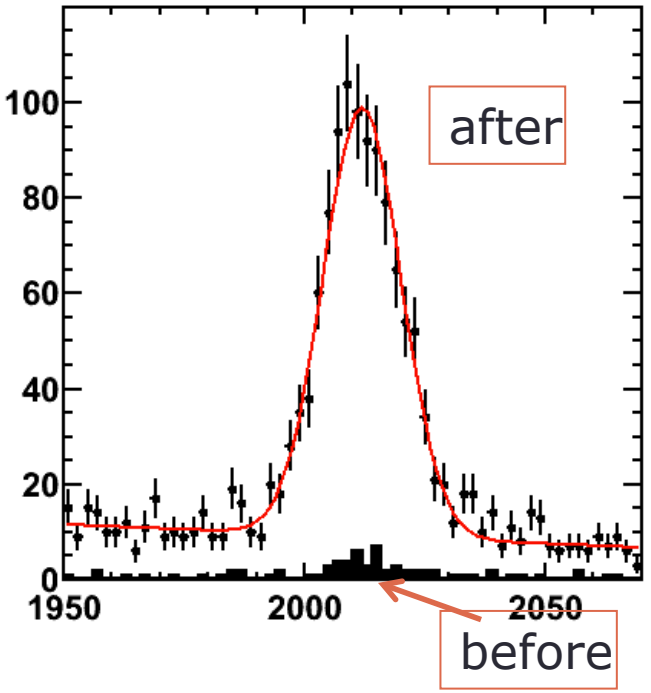


χ_c meson



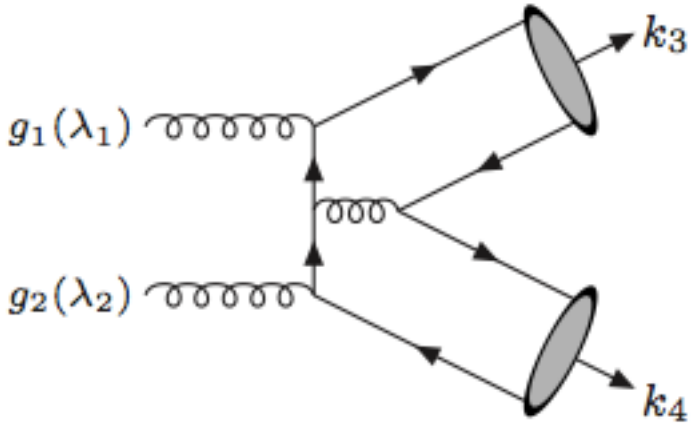
- Observation in J/ψ+γ suffers
  - Large proton-dissociation background
  - Poor resolution to distinguish χ_{c0} χ_{c1} χ_{c2}
- To see χ_{c0}, choose more favourable decay:
  - χ_{c0}->ππ / KK ~1% while χ_{c2}->ππ / KK ~0.1%
  - Backgrounds ok? (arXiv: 1105.1626)
- New low pt trigger for 2012 to access hadronic modes

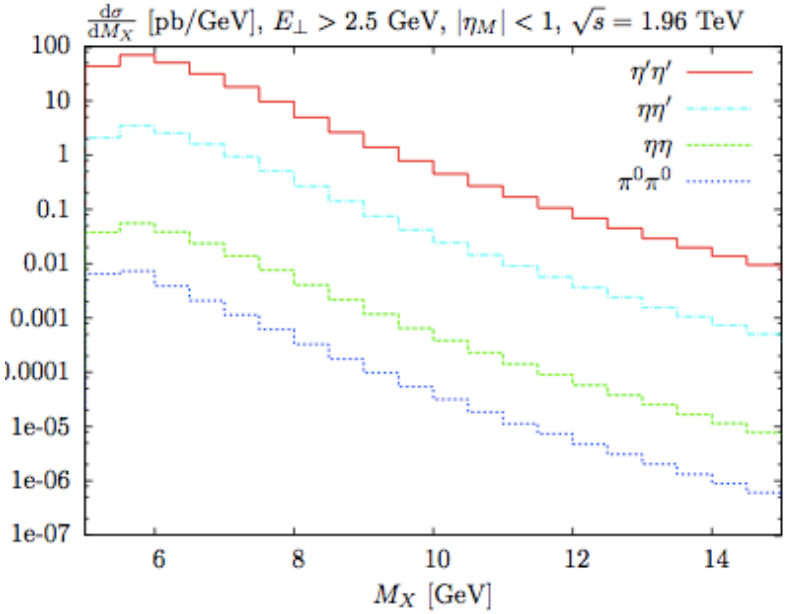
Example of D*->Kππ reconstruction in low multiplicity events



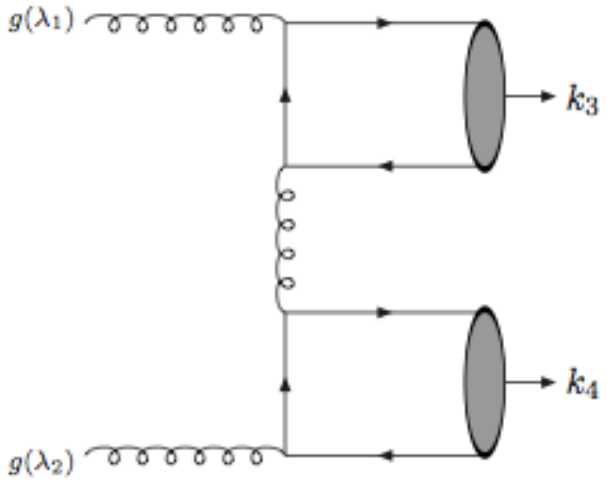
(Harland-Lang, Khoze, Ryskin, Stirling)

CEP meson-meson production arXiv:1105.1626

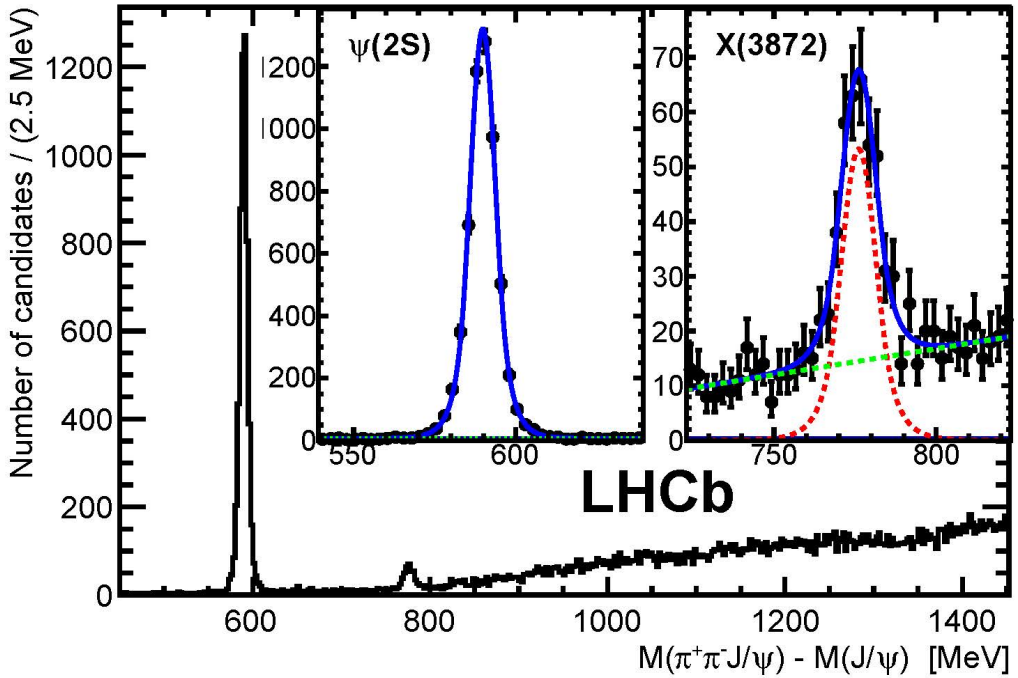




- Vanishing cs when gluons in J_z=0
- Flavour non-singlet mesons suppressed (thus ππ/KK small)
- Flavour singlet (e.g. η'η' production) can proceed via



X(3872)

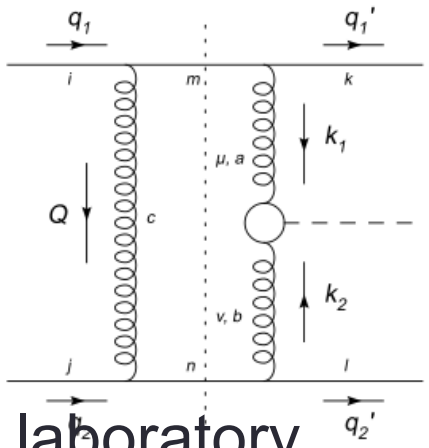


X(3872) observed inclusively. (arXiv:1112.5310) Could it be produced exclusively?

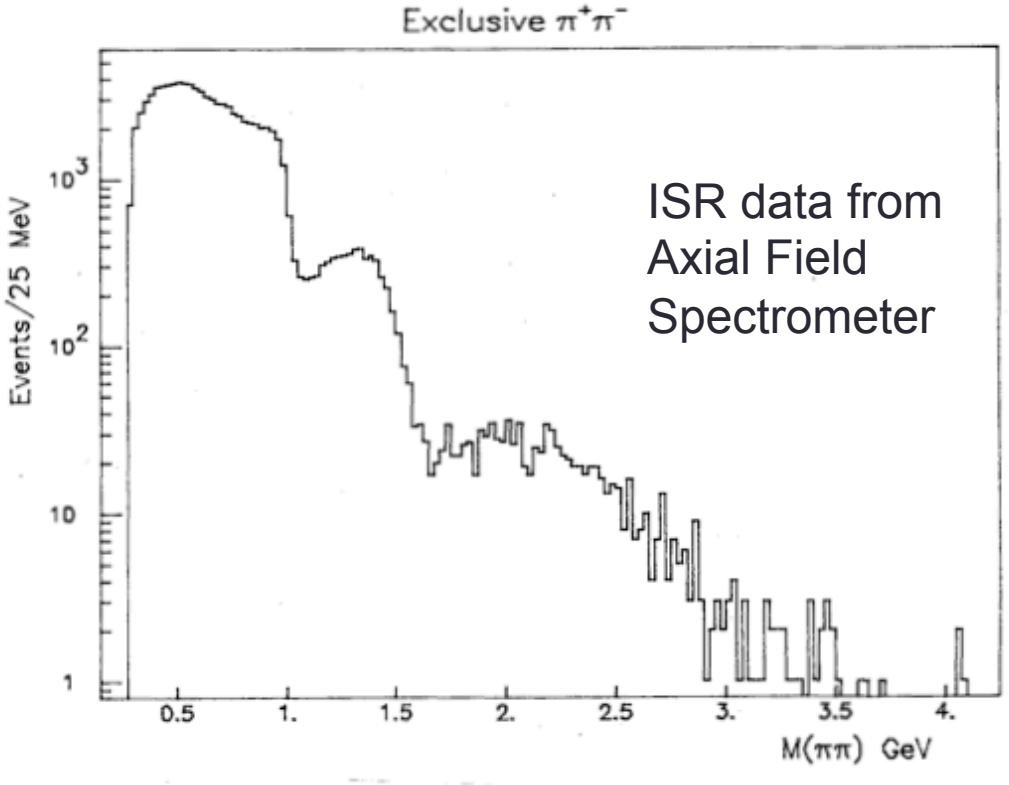
- J^{PC} of X(3872) shown by LHCb to be 1++ (arXiv:1302.6269)
- $\chi_{c(1++)}$ has been observed `exclusively' ?
- If X(3872) is a bound cc state, might expect to observe it in central exclusive production

Low mass spectroscopy + glueballs

- Data from ISR/Tevatron
- Accessible at LHCb
- DPE, probing the nature of the vacuum



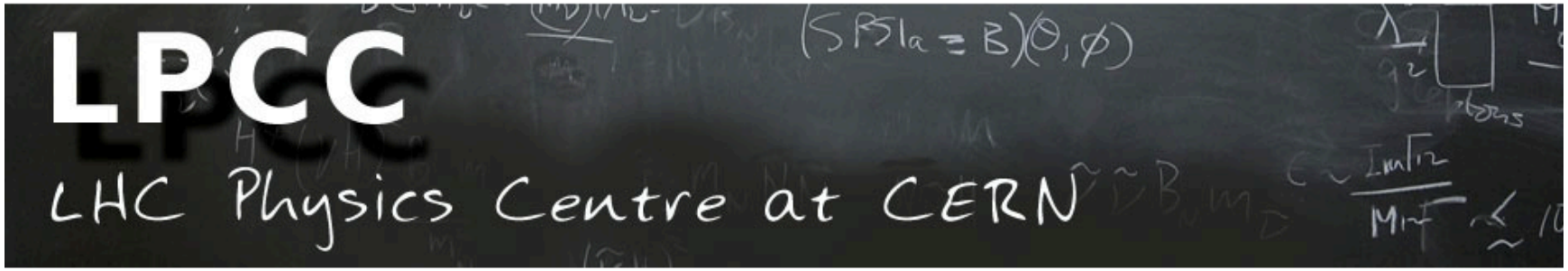
- Glue laboratory



M.G. Albrow, T.D. Coughlin, and J.R. Forshaw, Prog. Part. Nucl. Phys. **65**, 149 (2010). arXiv: 1006.1289

[101] T. Akesson, et al., A search for glueballs and a study of double pomeron exchange at the CERN Intersecting Storage Rings, Nucl. Phys. B264 (1986) 154.

LHC-wide programme of work



LPCC links

- WELCOME
  - About the LPCC
  - Visit the LPCC
  - Subscribe to LPCC News
- LHC WORKING GROUPS
  - MB & UE WG
  - Electroweak WG
  - Rate normalization WG
  - Top WG
  - Forward Physics WG
- EVENTS
  - Forthcoming events
  - Past events
- LHC PUBLICATIONS
- STUDENTS RESOURCES
- MISC

LHC WG on Forward Physics and diffraction

To subscribe to the WG mailing list, go to
http://simba3.web.cern.ch/simba3/SelfSubscription.aspx?groupName=lhc-fwdlhcwg

The WG is a forum for:

- interaction between theorists and experimentalists from the LHC experiments about forward physics
- definition of a physics programme for diffraction either using the rapidity gap method or proton tagging
- definition of a common strategy between the different LHC experiments (special runs...)
- discussion of the different forward detectors (roman pots, movable beam pipes, timing and position detectors)
- application to cosmic ray physics

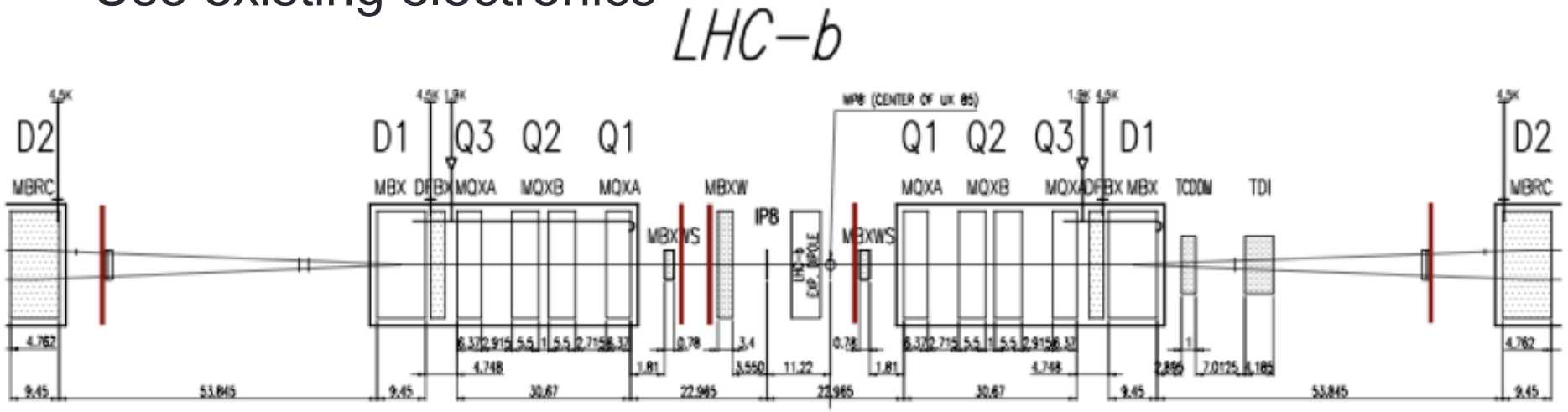
Dedicated subgroup meetings and more general meetings will take place every 5-6 weeks and are opened to everybody.
WG documents and meeting agendas: see links in the right menu

WG links

- WG Twiki page
- WG meetings
- WG documents

High rapidity shower counters for LHCb

- Increase rapidity gap with scintillators in forward region
- Use existing electronics



Left
1. z ~ -7.5 m (after MBXW)
2. z ~ -19m (before MBXWS)
3. z ~ -114m (after BRANS)

Right
1. z ~ 19 m (close to MBXWS)
2. z ~ 114m (after BRANS)

First simulations suggest veto region for charged and neutral particles can be extended to include $5<|\eta|<8$ - an extra 6 units in pseudorapidity.

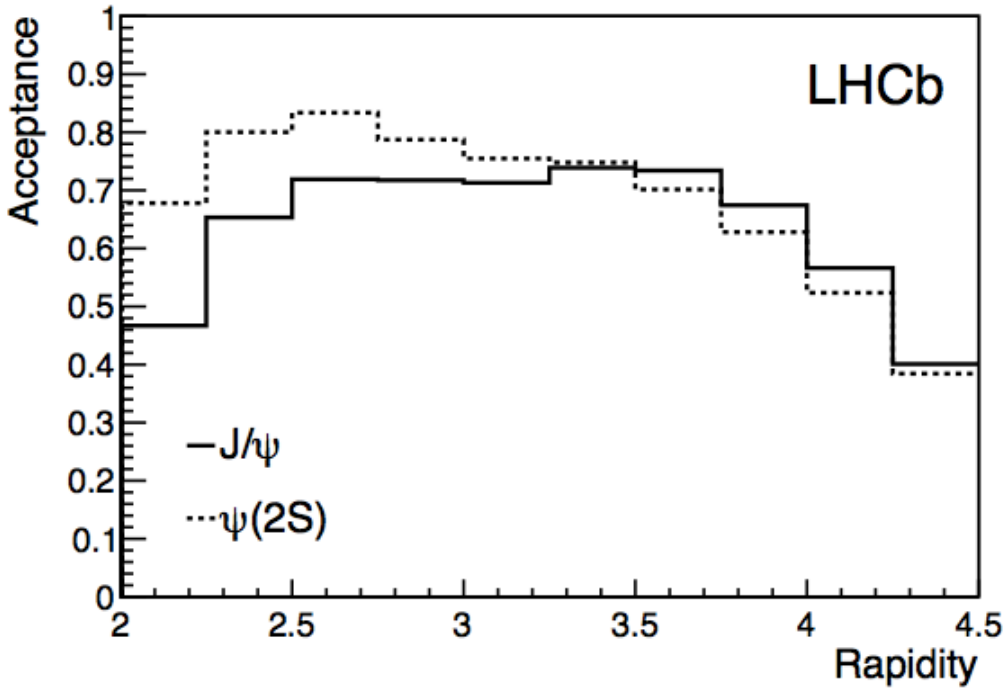
Summary

- Broad range of excellent physics measurements possible through central exclusive production:
  - Testing ground for QCD
  - Understanding the vacuum
  - Glueballs, saturation and other exotic phenomena
- Programme on LHCb underway: first observation of exclusive J/ψ and $\psi(2S)$ in proton-proton collisions:
  - Production compatible with NLO or saturation models
  - Consistent picture in understanding photoproduction coming from many experiments
- Limiting feature of LHCb is our rapidity gap veto capability; addressed in forthcoming run.
- We look forward to many more exclusive results.

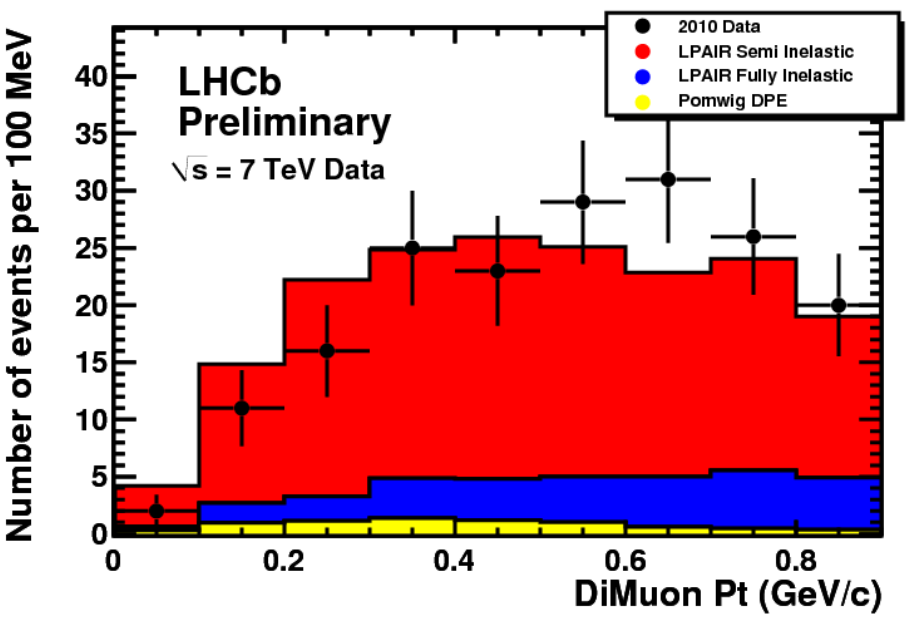
Backups

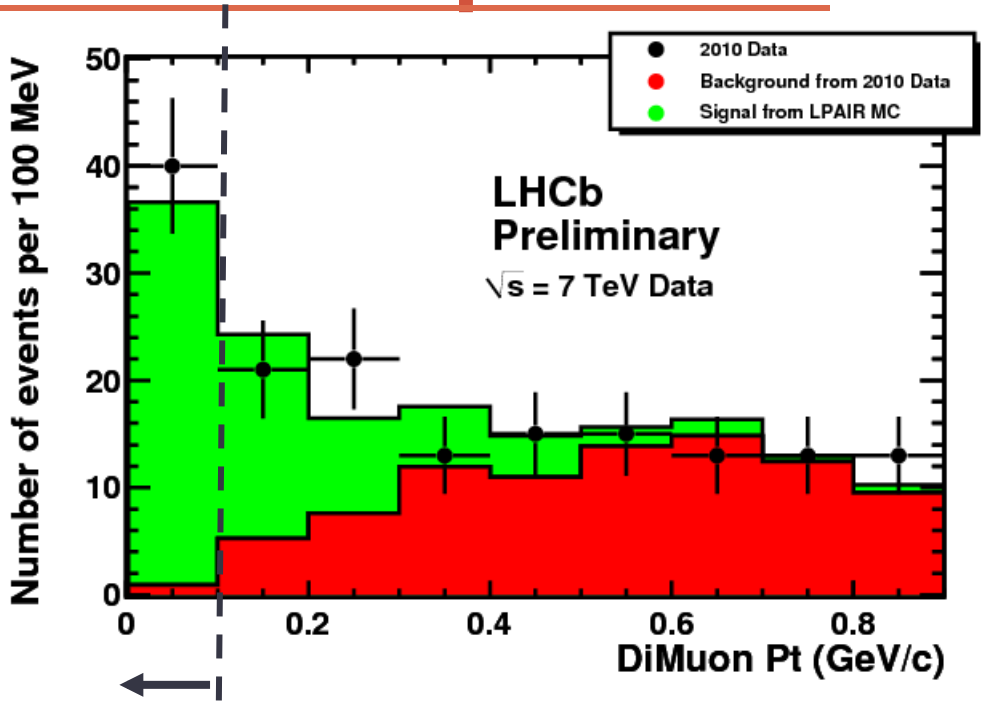
Acceptance and Selection

- Require tracks within muon chamber acceptance
- Precisely two reconstructed muons
- No other activity
  - No other tracks with VELO info
  - No photons
- Mass within 65 MeV of known meson mass
- $p_T^2<0.8$ GeV^2



Fit elastic and inelastic components





Shape for inelastic events

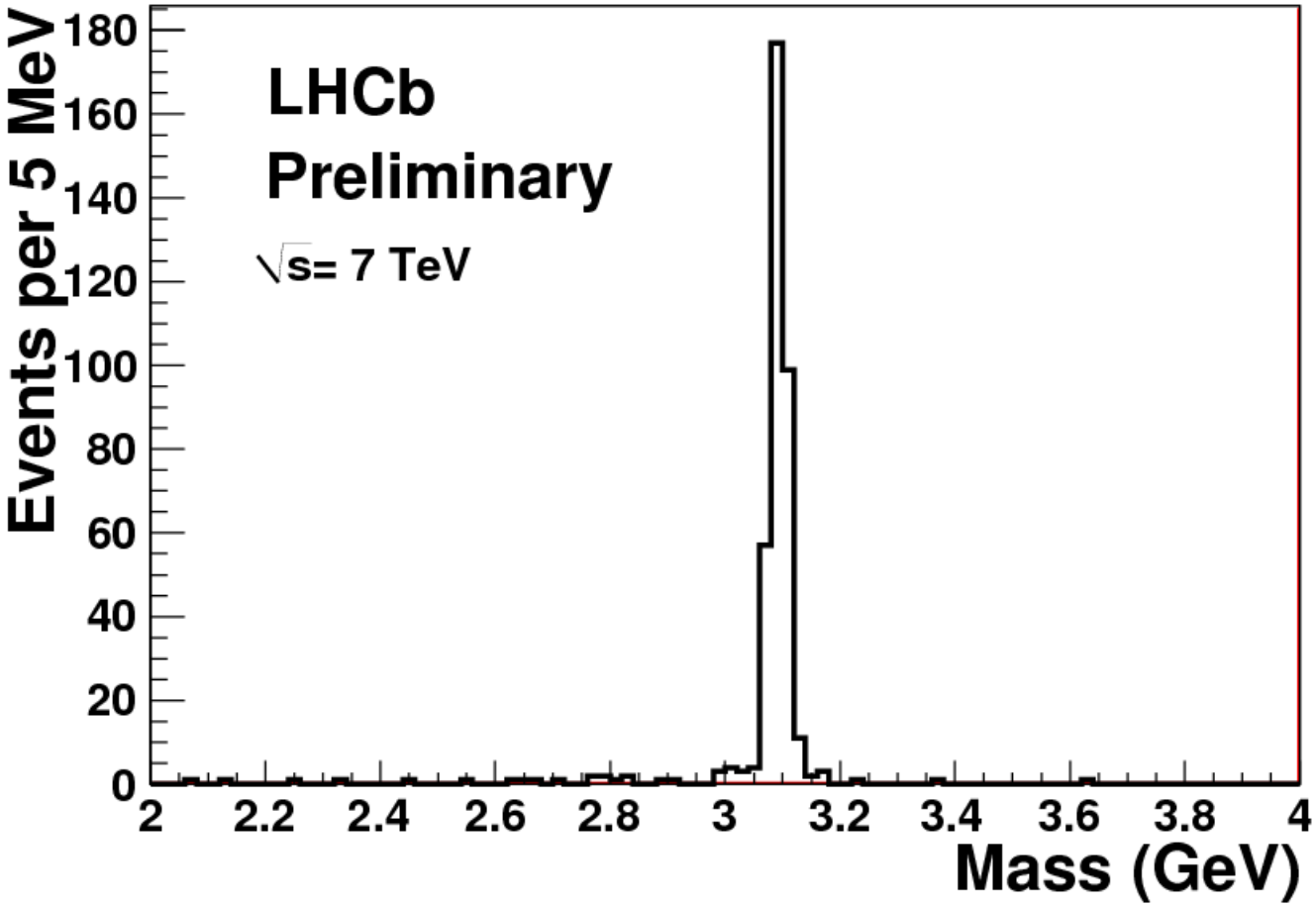
Note: this time we have simulation that predicts the shape for the three contributions.

Fit to signal events

Background shape from data
Signal shape from simulation.

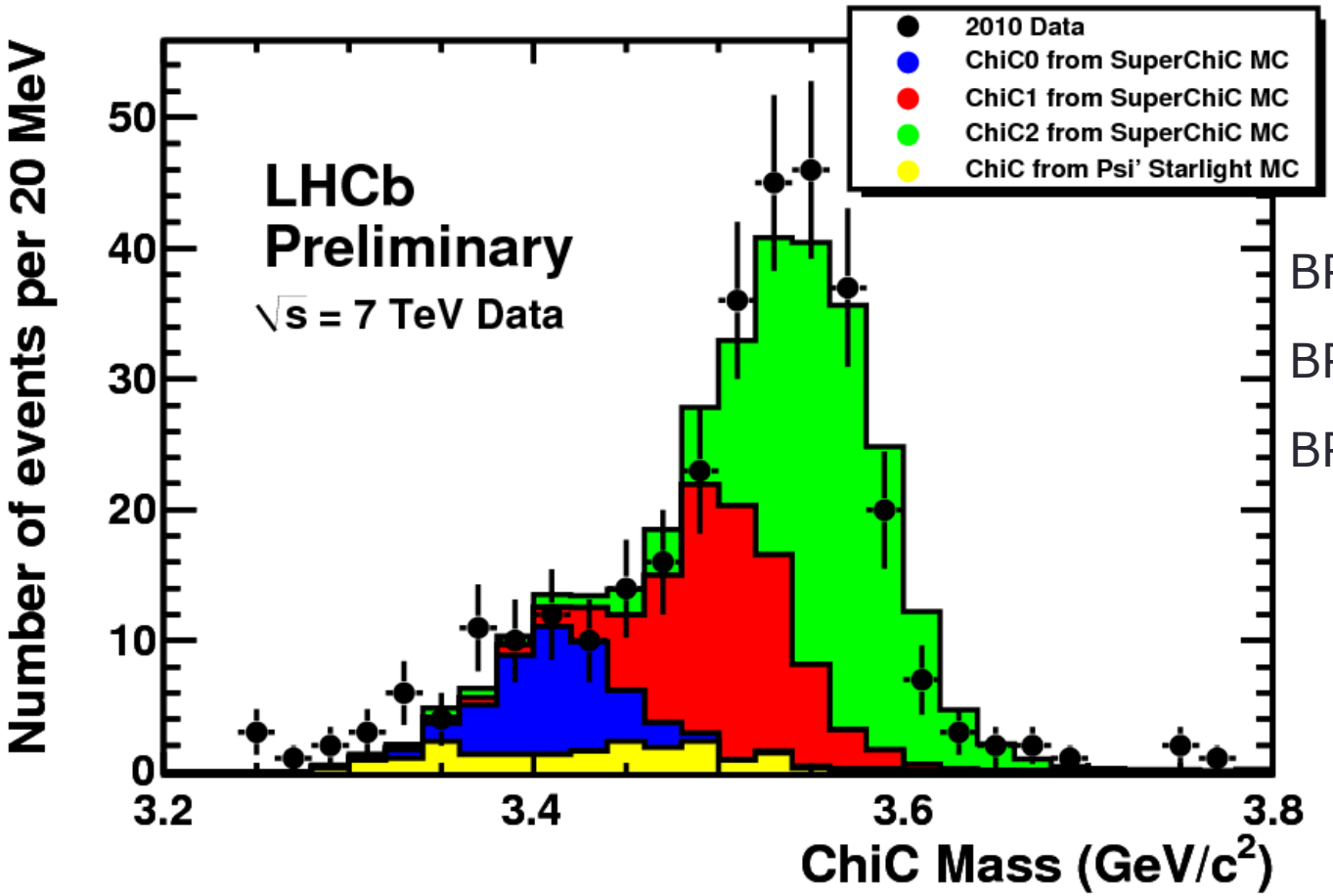
Measured cross-section pμμp: 67 +- 19 pb	LPAIR (J. Vermaseren) 42 pb

χ_c: DiMuon Invariant Mass



About half the background that was observed in the exclusive J/ψ analysis (since no continuum process).

χ_c: DiMuon+Photon Invariant Mass



BR(χc0->J/ψγ)=1.2%

BR(χc1->J/ψγ)=34.4%

BR(χc2->J/ψγ)=19.5%

Inelastic contribution appears to be much larger than for J/ψ.
In a first approximation it should be square of bkg in J/ψ process.

Theory v experiment

$\sigma_{\chi_{c0}\to\mu^+\mu^-\gamma} = 9.3 \pm 2.2 \pm 3.5 \pm 1.8$ pb

$\sigma_{\chi_{c1}\to\mu^+\mu^-\gamma} = 16.4 \pm 5.3 \pm 5.8 \pm 3.2$ pb

$\sigma_{\chi_{c2}\to\mu^+\mu^-\gamma} = 28.0 \pm 5.4 \pm 9.7 \pm 5.4$ pb

LHCb preliminary results with 2010 data

χ_0: 9.3 +- 4.5 pb	χ_1: 16.4 +- 7.1 pb	χ_2: 28.0 +-12.3 pb
SuperChic: 14 pb	10 pb	3 pb

Large contribution due to X_{c0} is confirmed.

χ_{c2} larger than expected but note that non-elastic background has been assumed same for each resonance. More precise data required.

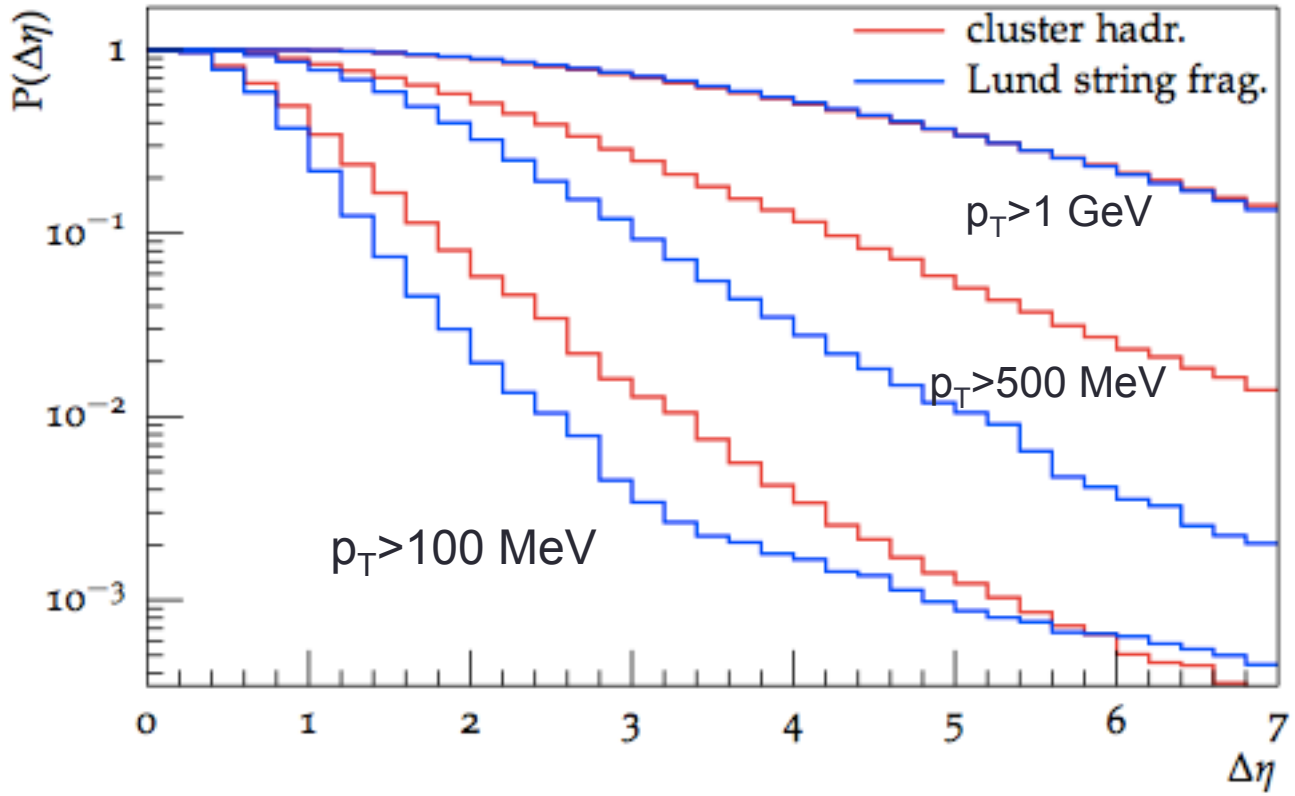
Integrated cross-sections

	J/ψ [pb]	$\psi(2S)$ [pb]
Gonçalves and Machado [29]	275	
JMRT [5]	282	8.3
Motyka and Watt [2]	334	
Schäfer and Szczurek [30]	317	
Starlight [31]	292	6.1
SUPERCHIC [19]	317	7.0
LHCb measured value	$291 \pm 7 \pm 19$	$6.5 \pm 0.9 \pm 0.4$

Good agreement with all theory estimates

What's a large gap?

Probability for finding a rapidity gap>$\Delta\eta$ in inclusive QCD events



- Khoze, Kraus, Martin, Ryskin, Zapp, "Diffraction and correlations at the LHC: definitions and observables", arXiv:1005.4839v2
- Probability for inclusively produced J/ψ to give two muons and nothing else inside LHCb is < ~10^{-5}