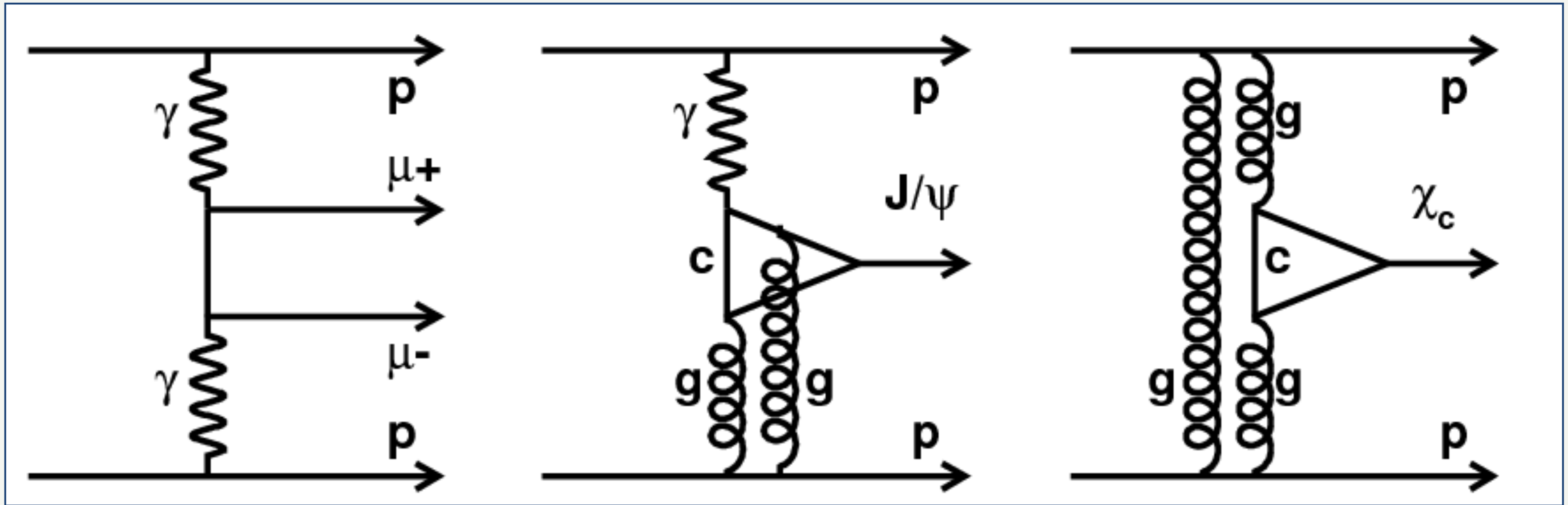
Diffractive physics at LHCb in Central Exclusive Production



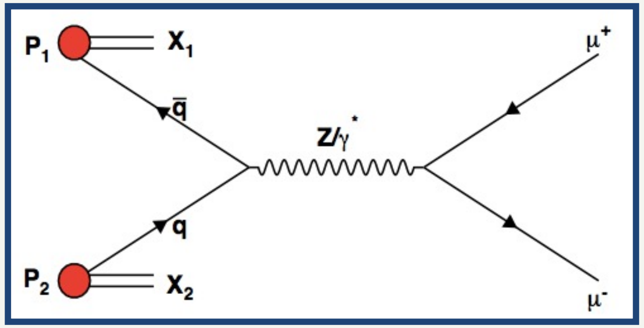
Ronan McNulty
University College Dublin

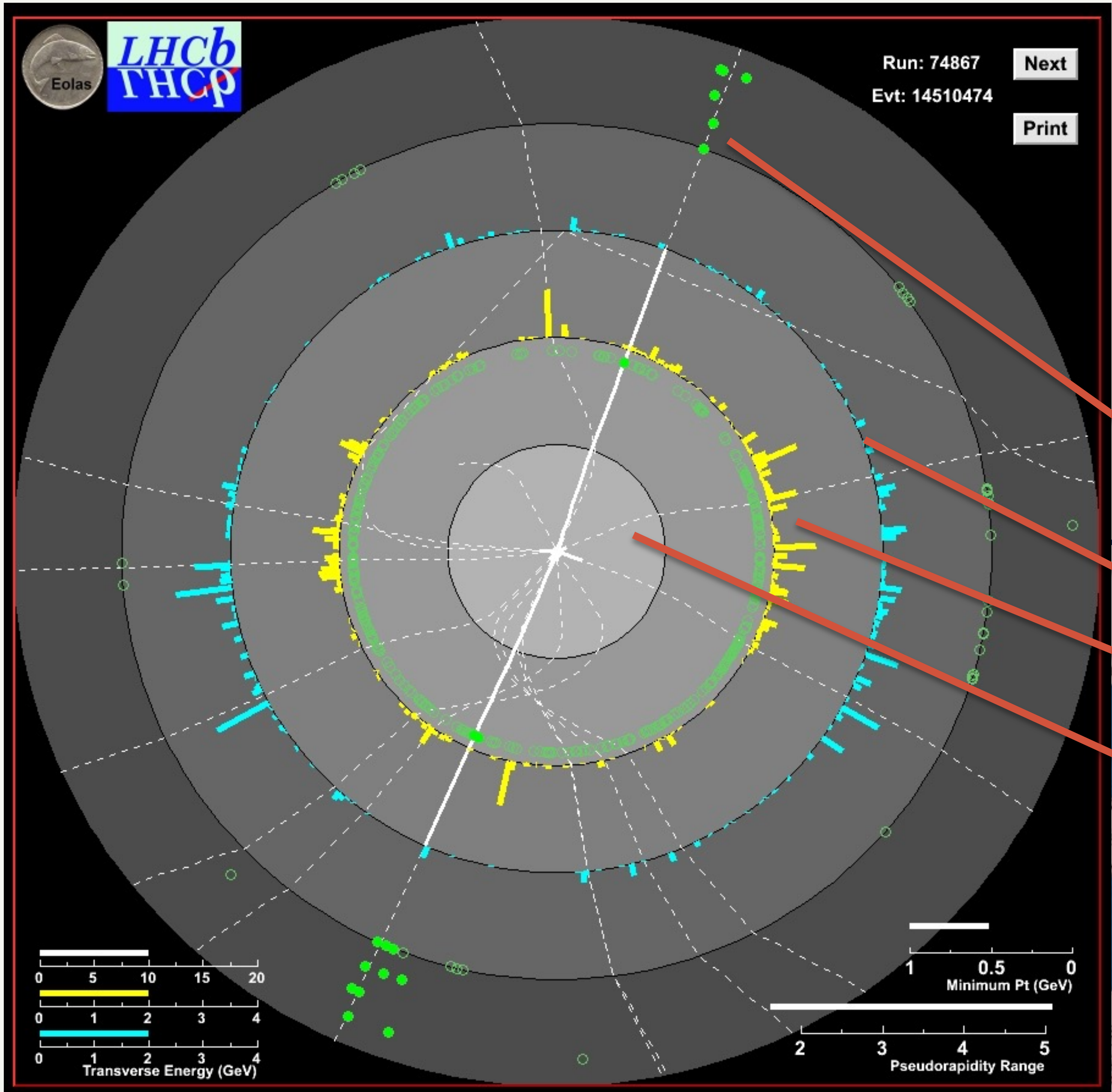
Forward Physics and QCD at the LHC and EIC, WE-Heraeus seminar, Bad Honnef, 25.10.23

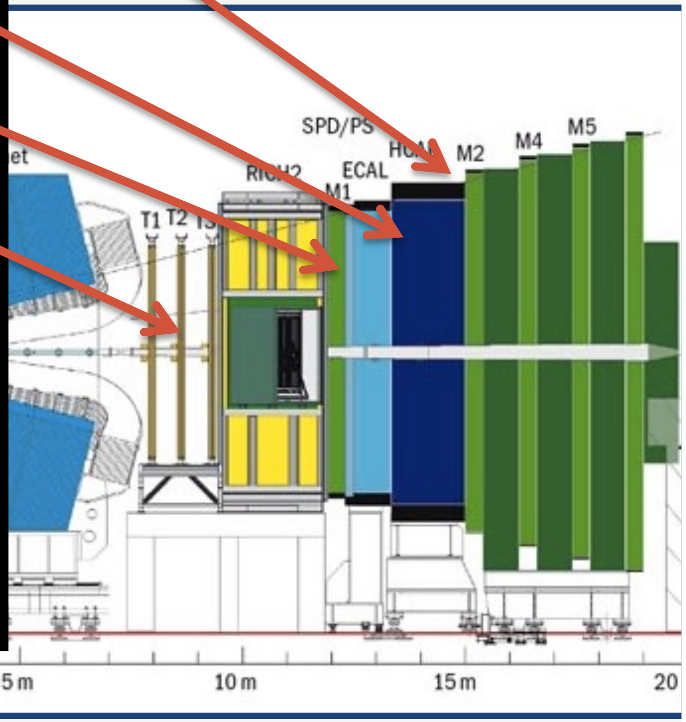
Motivation

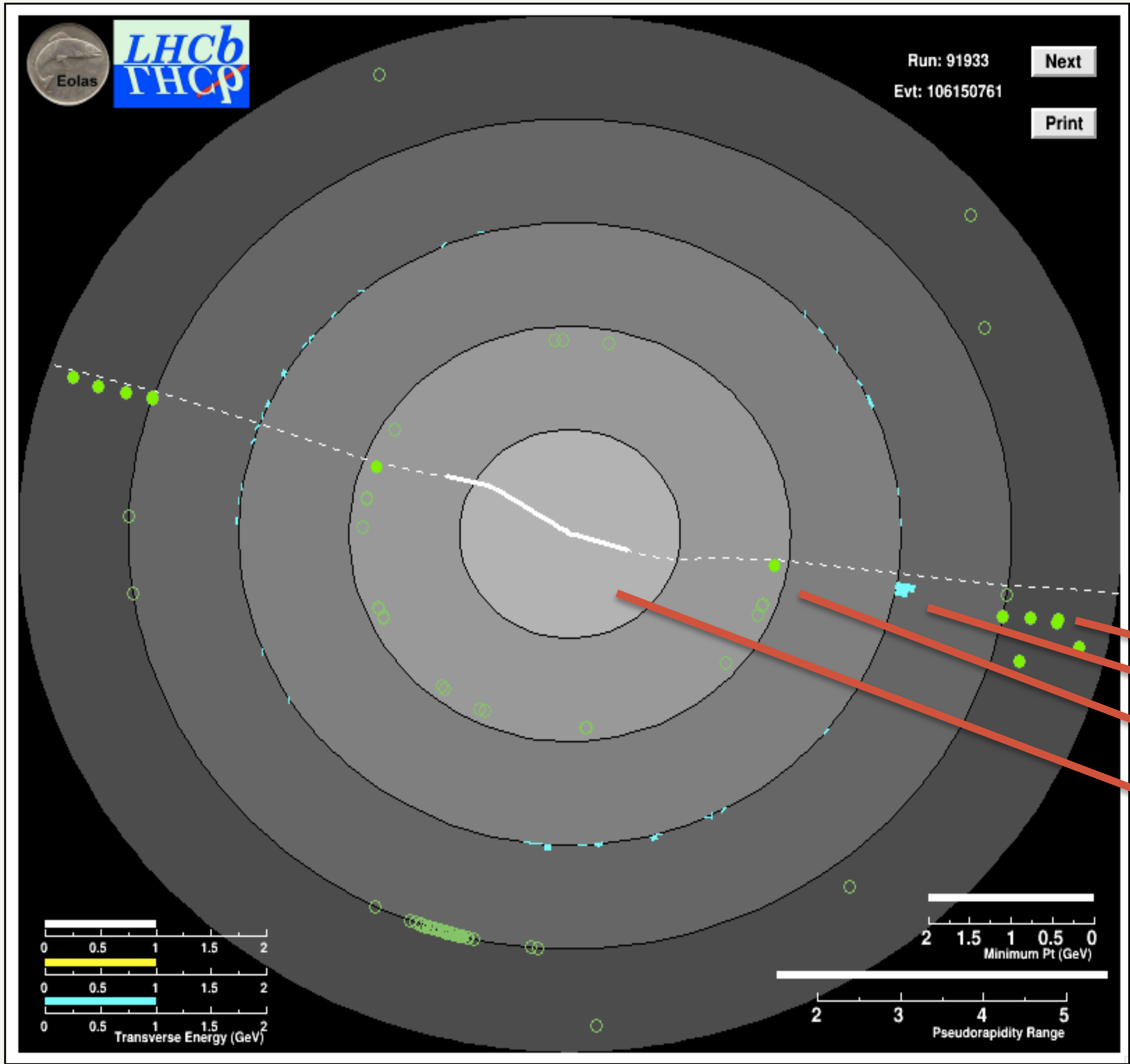
- Much to understand about QCD
  - perturbative / non-perturbative regime
  - proton structure
  - saturation
  - quark model bound states (ρ, ρ', f_0,$f_{2....}$)
  - beyond the naïve quark model (hybrids, tetraquarks, glueballs)
  - colourless propagators: pomerons and odderons.
- Searches for BSM (dark matter)
- CEP: a clean experimental laboratory.

Inclusive pp->ZX

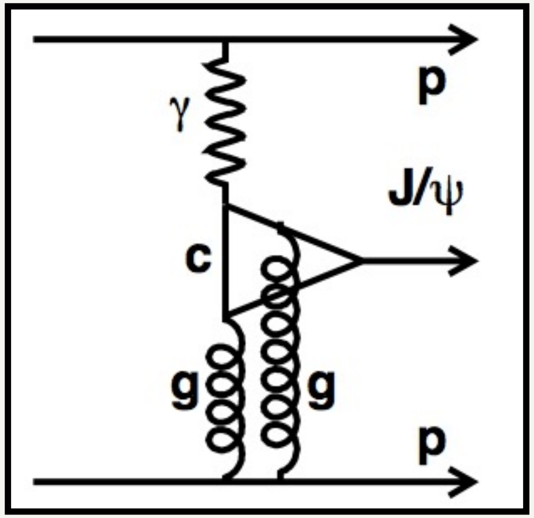


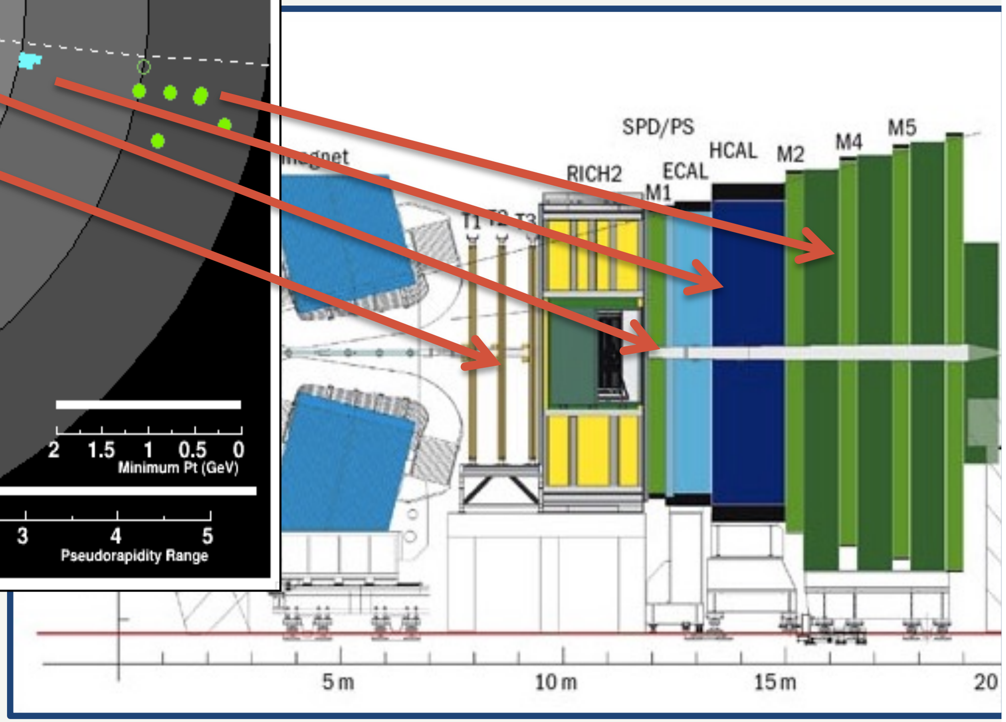





Eolas
LHCb
Run: 91933
Evt: 106150761
Next
Print
0 0.5 1 1.5 2
Transverse Energy (GeV)
2 1.5 1 0.5 0
Minimum Pt (GeV)
2 3 4 5
Pseudorapidity Range

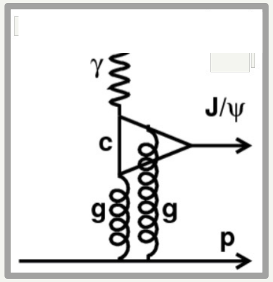
CEP


γ
p
J/ψ
c
g
g
p

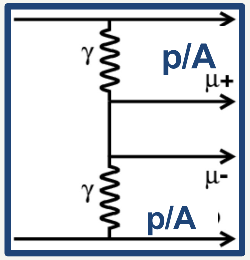

SPD/PS
HCAL
M2
M4
M5
RICH2
ECAL
M1
5 m
10 m
15 m
20

Overview of talk

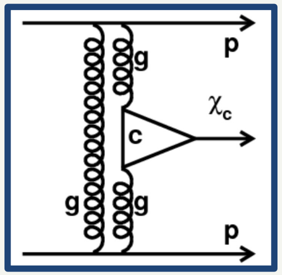
Introduction



γP



γγ

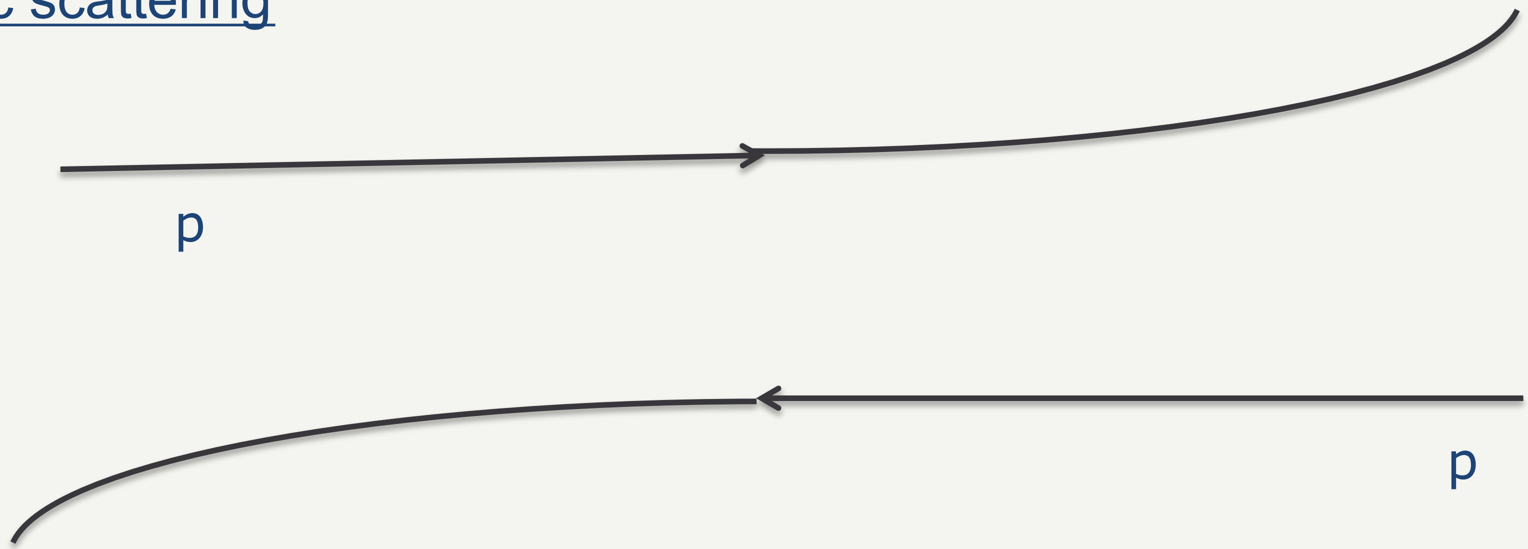


DPE

- ❑ perturbative / non-perturbative
- ❑ saturation
- ❑ proton structure
- ❑ quark model bound states
- ❑ Beyond the quark model
- ❑ Pomerons and odderons
- ❑ Standard Model
- ❑ Beyond the Standard Model

Physics of the Vacuum

Elastic scattering



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

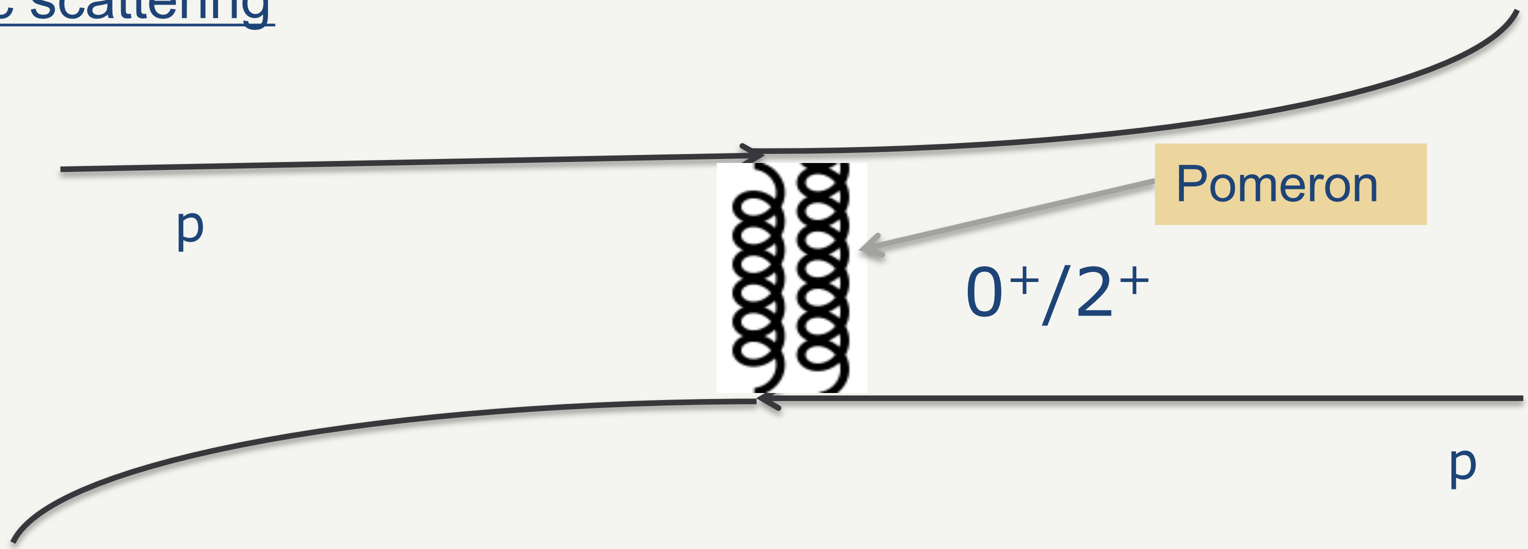
$\sigma_{elastic} \approx 40mb$

$\sigma_{diffractive} \approx 10mb$

$\sigma_{inelastic} \approx 60mb$

Physics of the Vacuum

Elastic scattering



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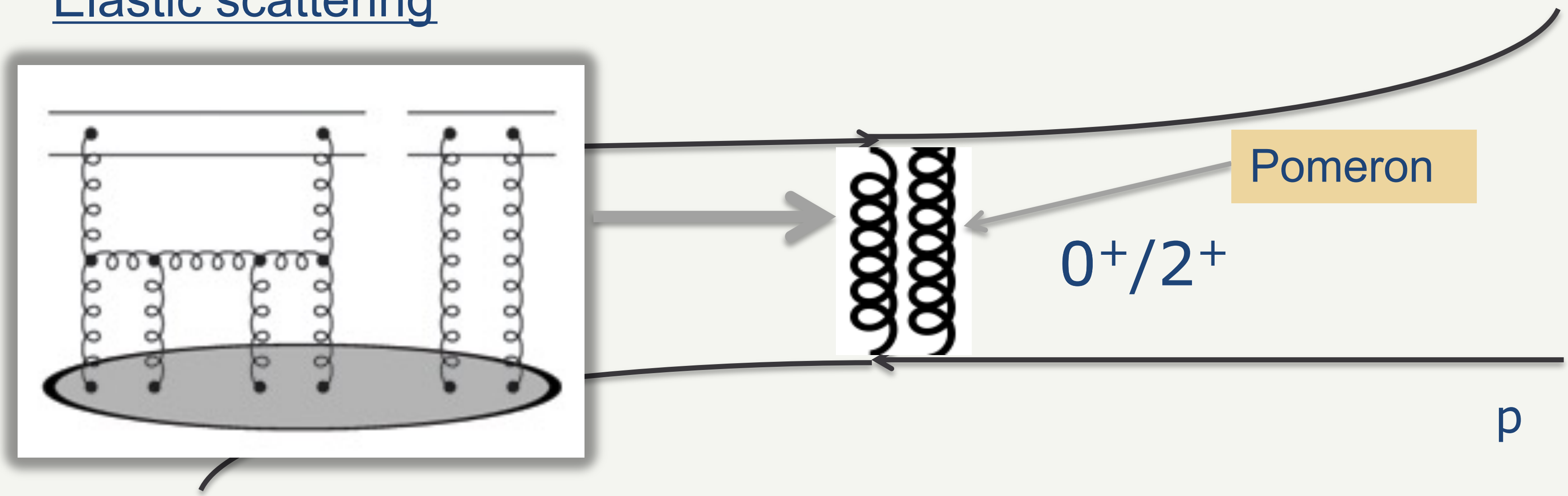
Physics of the Vacuum

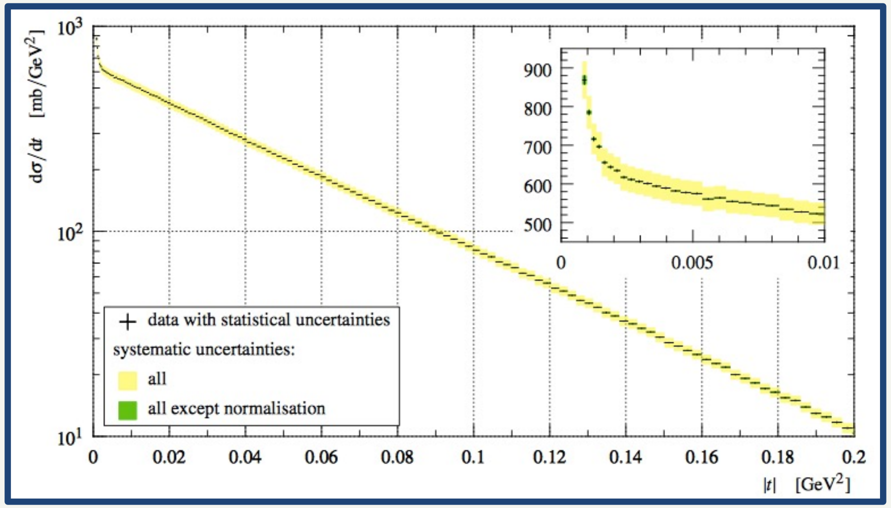
Elastic scattering



At high energy: $A(s,t)=s^{\alpha(t)}$
$\alpha_P(t)=\alpha_P(0)+\alpha' t$

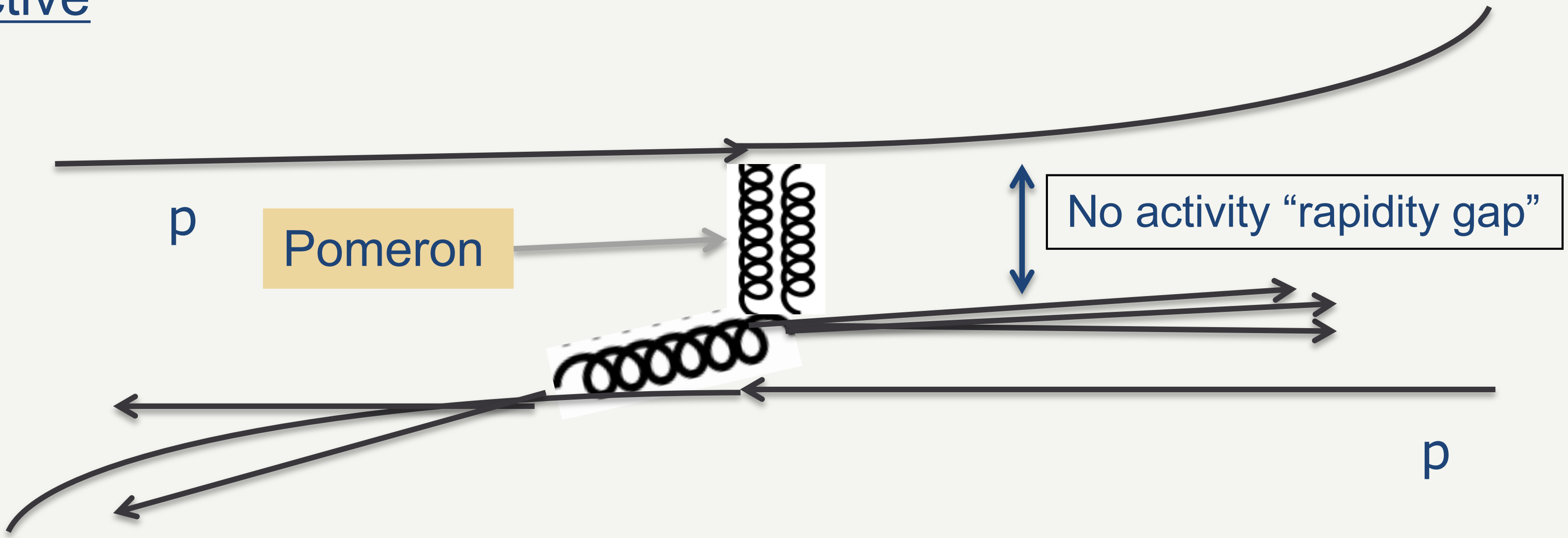
$\sigma_{elastic} \approx 40mb$
$\sigma_{diffractive} \approx 10mb$
$\sigma_{inelastic} \approx 60mb$

Totem: Eur.Phys.J. C79 (2019) no.9, 785



Physics of the Vacuum

Diffractive



$\sigma_{elastic}$ ≈ 40mb
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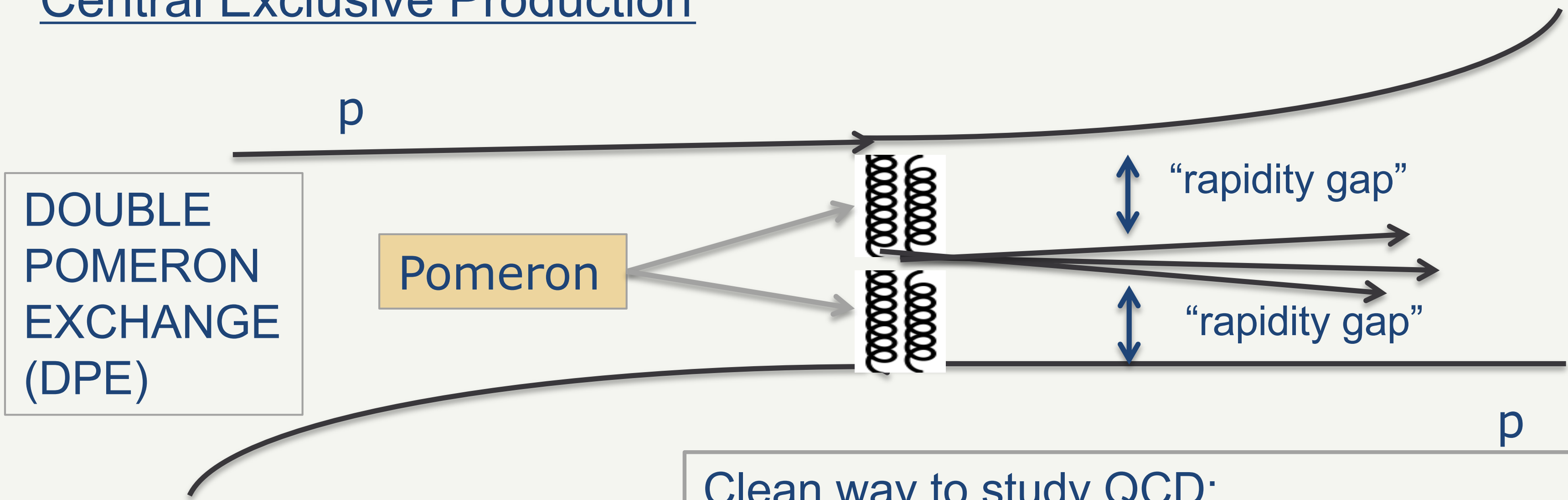
Physics of the Vacuum

Central Exclusive Production



Clean way to study QCD:

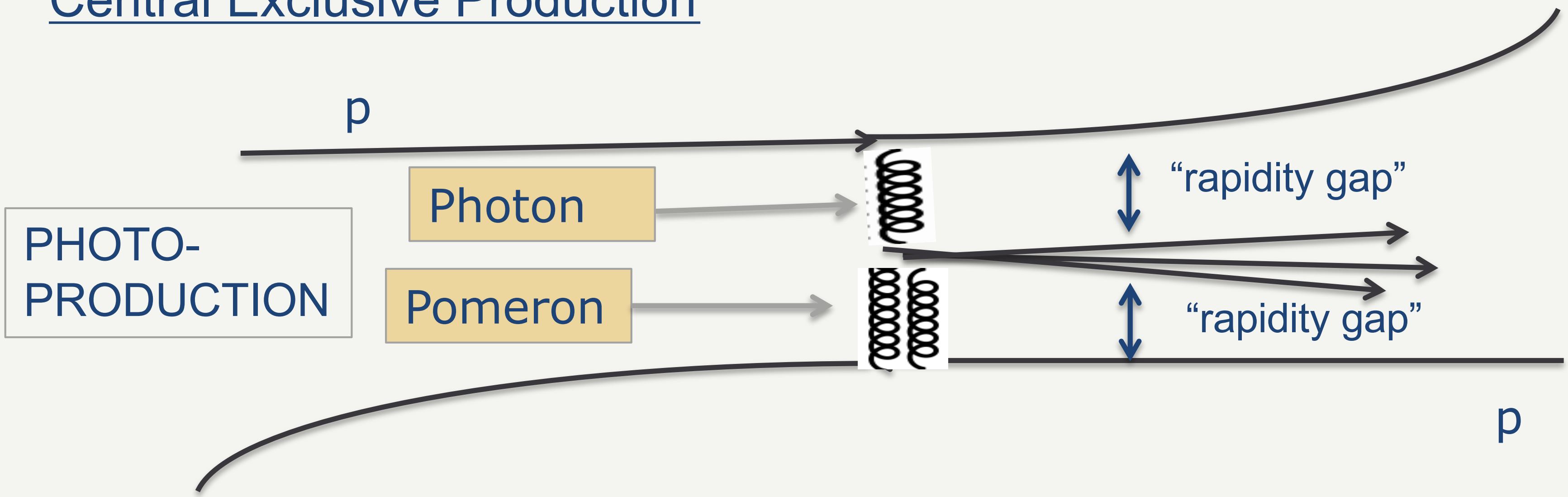
- structure of projectiles
- nature of colour-free propagators
- structure of what is produced out of vacuum

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

100 μb

Physics of the Vacuum

Central Exclusive Production



$\sigma_{elastic} \approx 40mb$

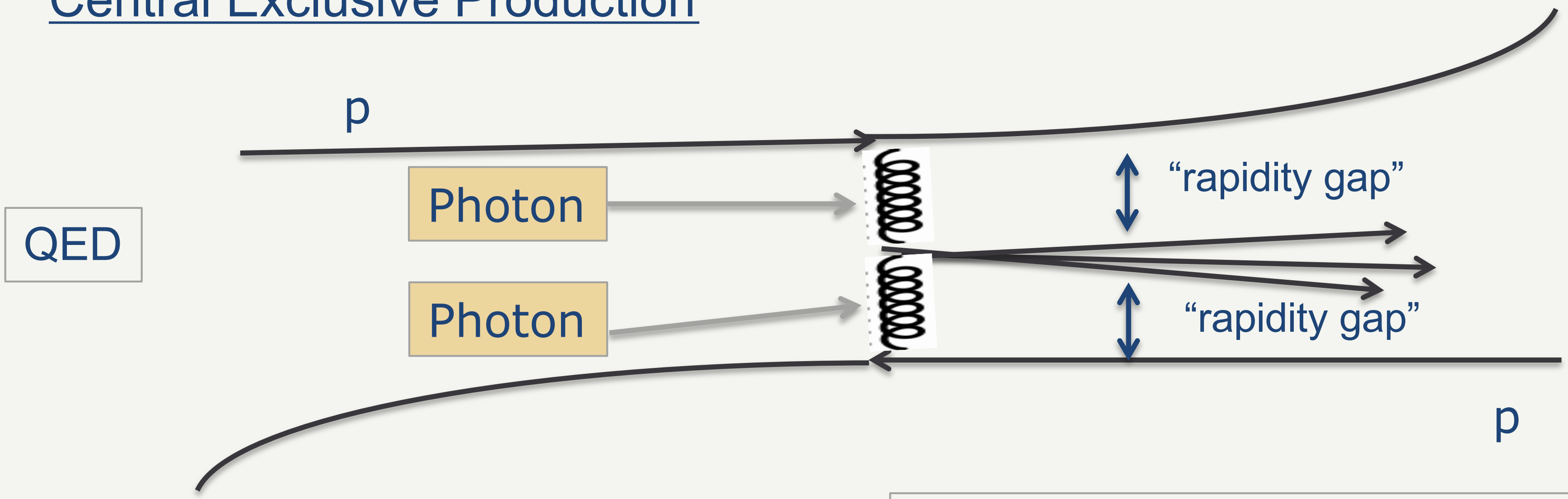
$\sigma_{diffractive} \approx 10mb$

$\sigma_{inelastic} \approx 60mb$

100 μb

Physics of the Vacuum

Central Exclusive Production



CEP is characterised by a rapidity gap all the way to the proton

Detect as large a gap as possible...

$\sigma_{elastic} \approx 40mb$

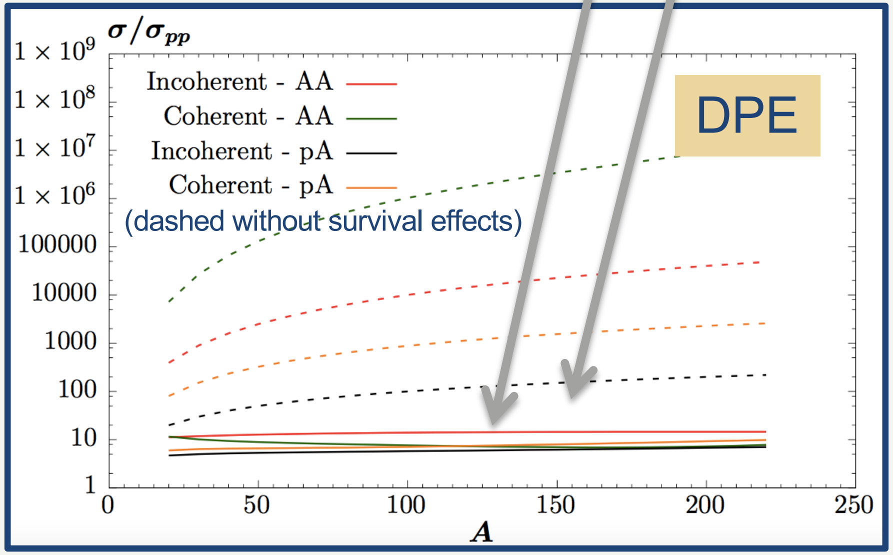
$\sigma_{diffractive} \approx 10mb$

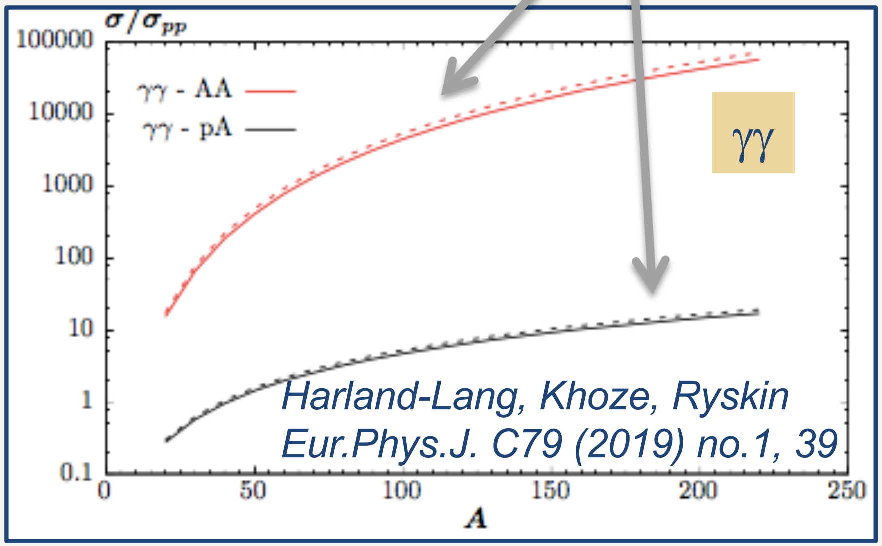
$\sigma_{inelastic} \approx 60mb$

100 pb

Complementarity of collisions

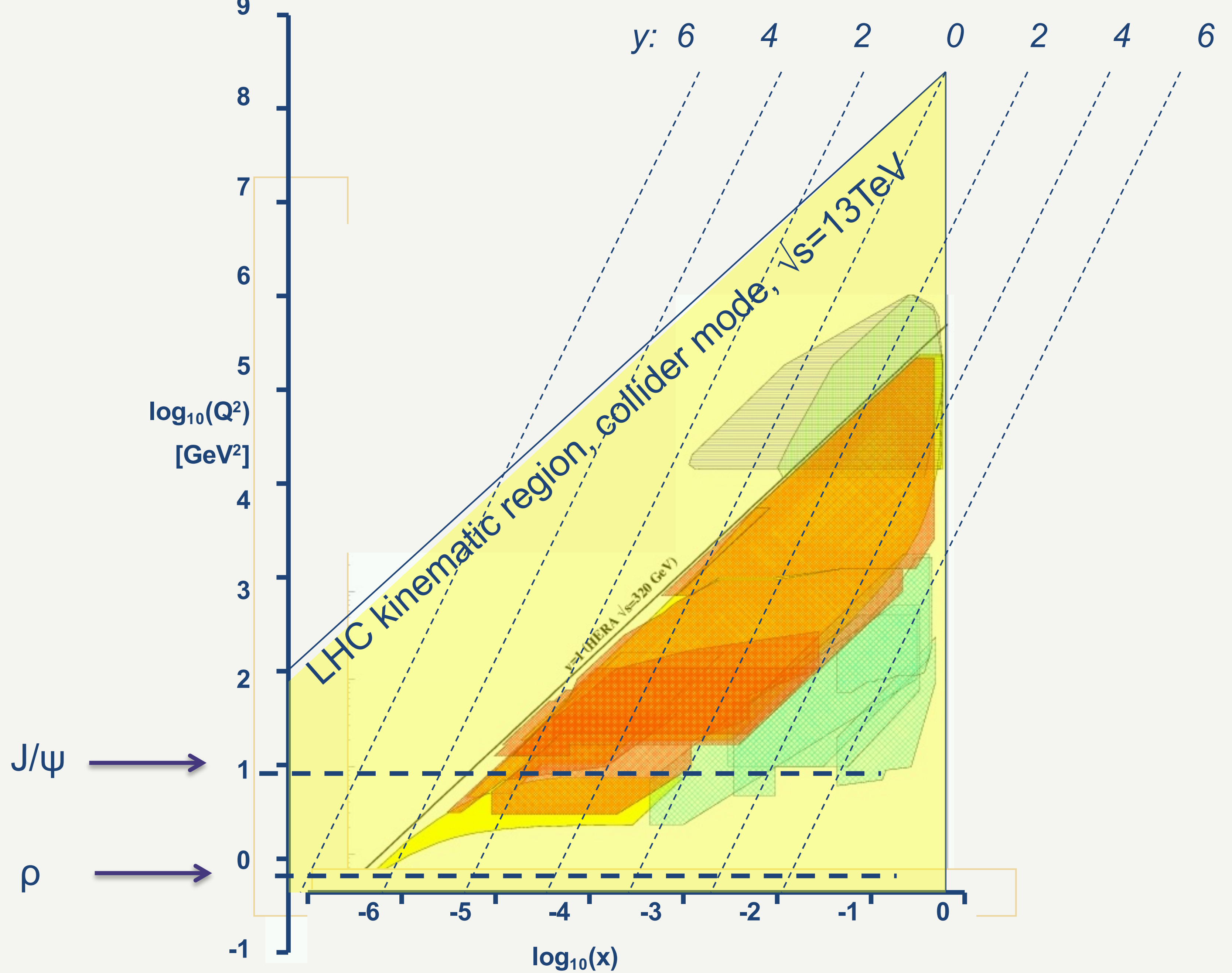
Coherent	DPE (PP)	γP	γγ
pp	~100μb	~100μb	~0.0001μb
pA	x $A^{1/3}$	x Z^2	x Z^2
AA	x $A^{1/6}$	x AZ^2	x Z^4



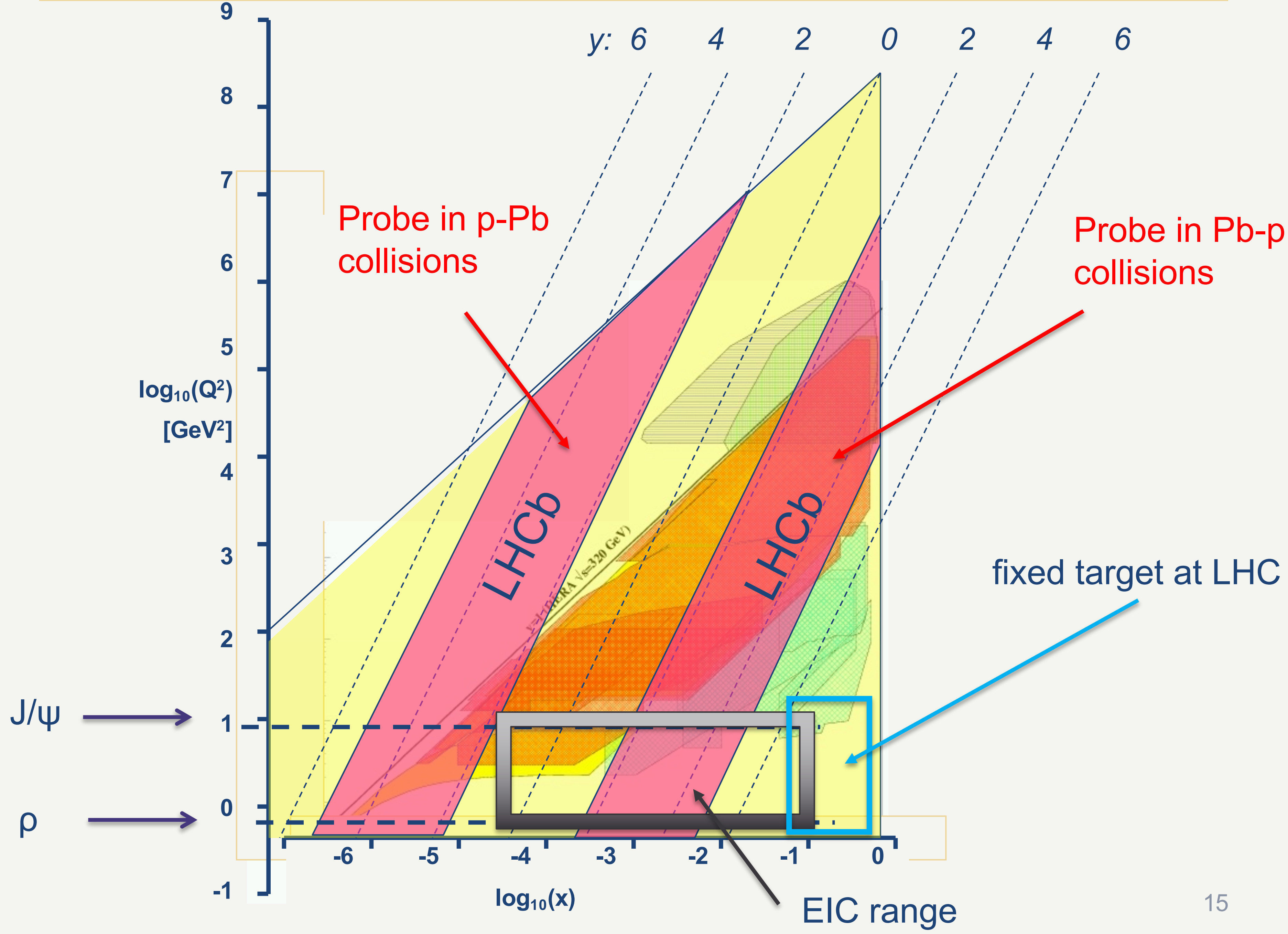


Harland-Lang, Khoze, Ryskin
Eur.Phys.J. C79 (2019) no.1, 39

x-Q² values probed at LHC



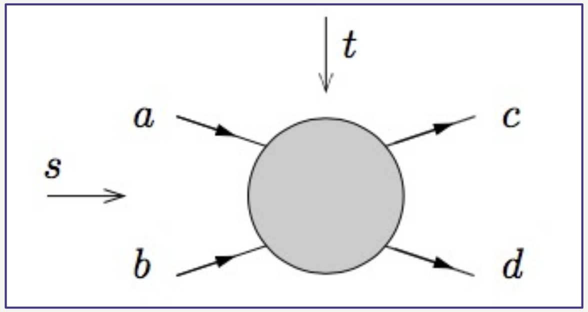
Complementarity of experiments/projectiles



Regge Theory

Predates QCD. Uses simple robust ideas of unitarity, analycity, crossing symmetry.

Regge theory describes scattering processes with *s*>>|*t*|

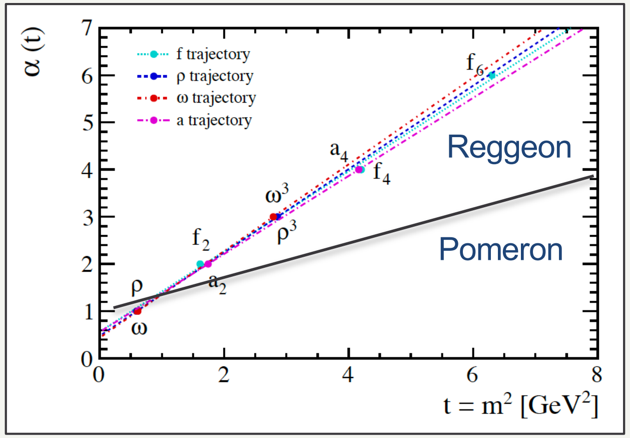


Particles exchanged in the t-channel lead to power growth in s-channel.

$$A(s,t) \sim s^{\alpha(t)}$$

where $\alpha(t)$ is the Regge trajectory for the exchanged particle

e.g. Pomeron trajectory $\alpha_{\wp}(t) = \alpha_{\wp}(0) + \alpha'_{\wp} t$



For processes mediated by a single Pomeron

$$\sigma_T = \frac{1}{s}\,\mathrm{Im}\,A_{\mathrm{el}}(s, t=0)$$ so $$\sigma_T \sim s^{\alpha(0)-1}$$ gives intercept

$$\frac{d\sigma}{dt} = \frac{1}{16\pi s^2}\,|A(s,t)|^2$$ so $$\frac{d\sigma}{dt} \sim s^{2\alpha(t)-2}$$ gives slope

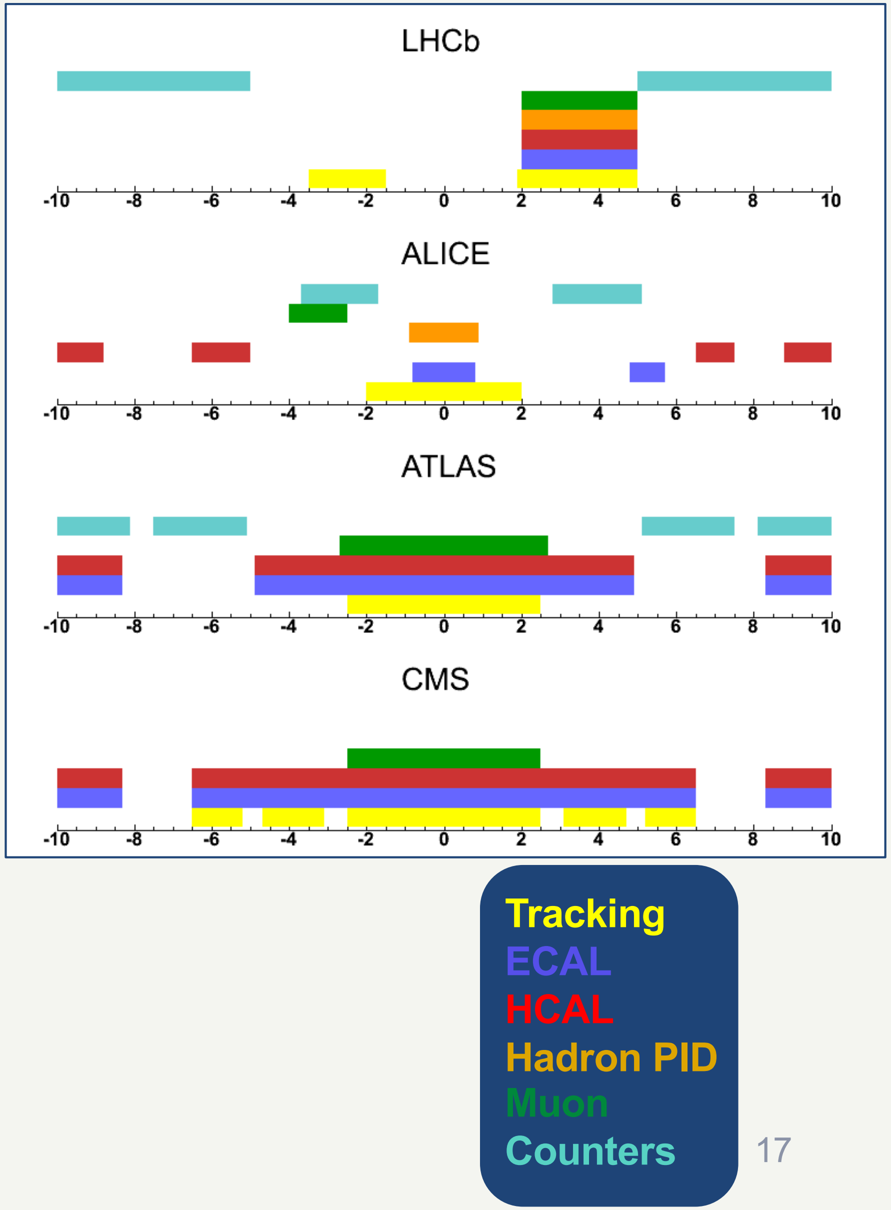
LHC and the detectors

- LHC collides pp, pPb and PbPb
- Also possible is **fixed target** mode of p or Pb on gas

ATLAS, CMS	High Lumi	High pT
ALICE, LHCb	Low Lumi	Low pT

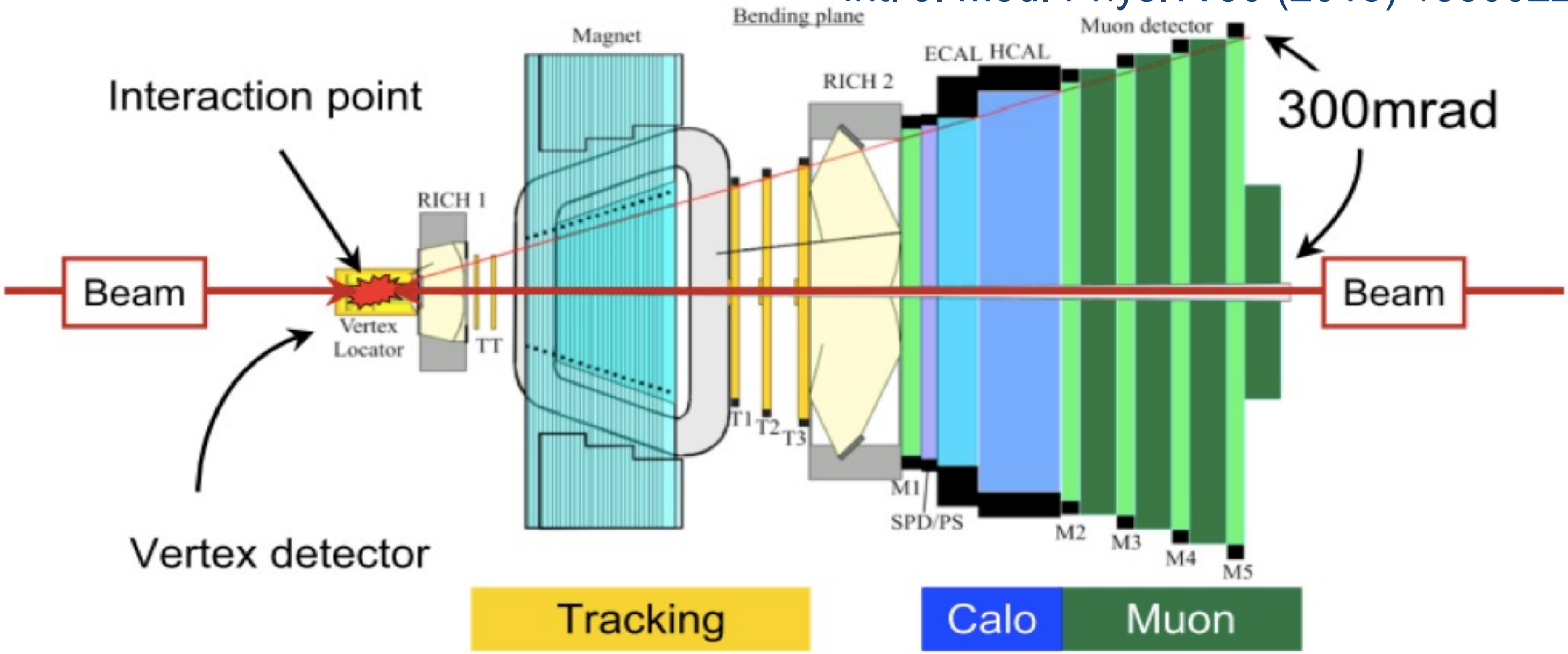
- LHCb: full reconstruction $2<\eta<5$
- ATLAS, CMS, ALICE: $5<\eta<5$

- All have vetos towards beam axis
- ATLAS, CMS, ALICE have ZDCs for neutrons
- ATLAS, CMS(+TOTEM) have roman pots close to beam (but generally do not detect recoil protons for low-mass objects)



The LHCb detector

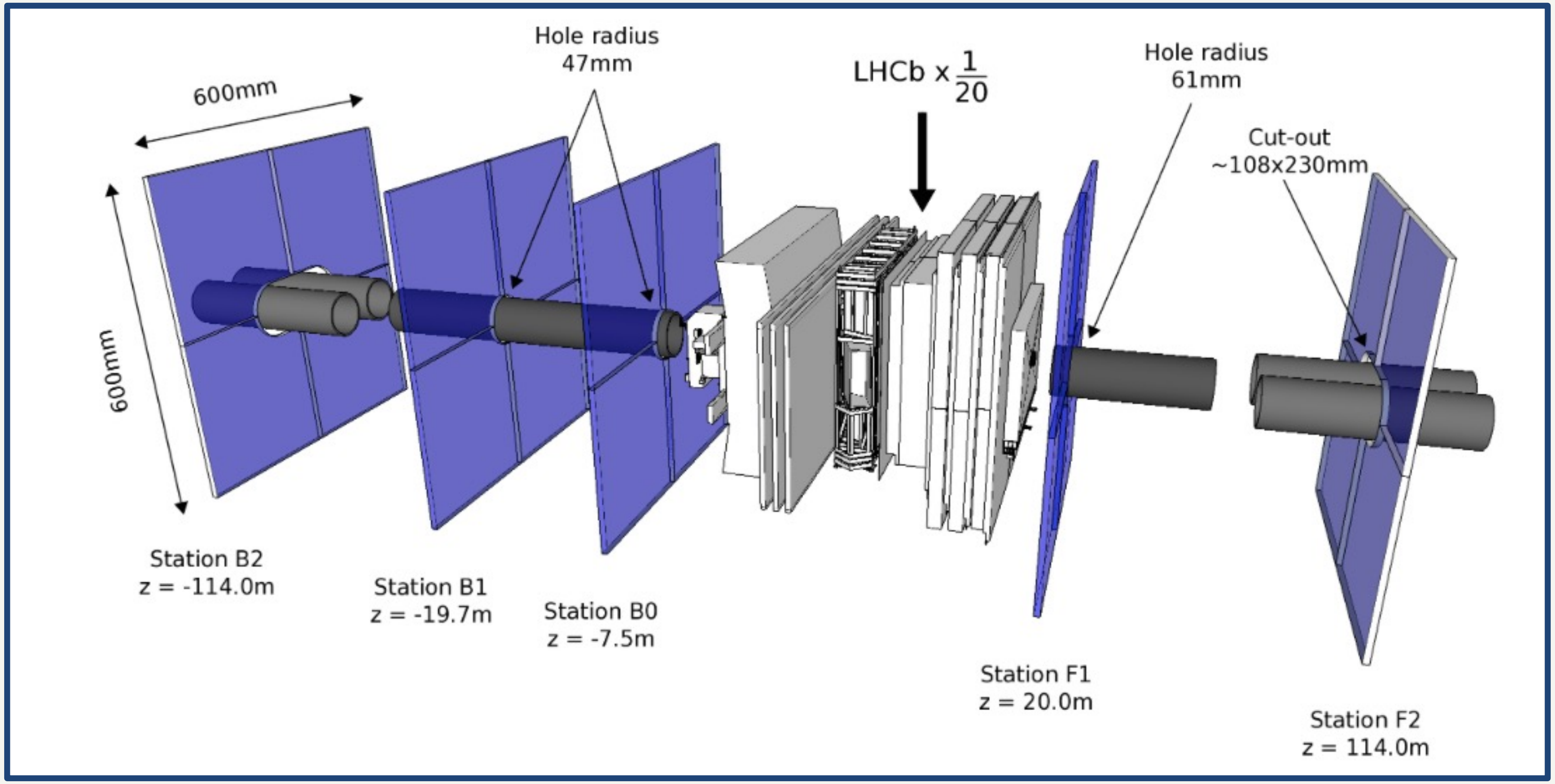
Int. J. Mod. Phys. A 30 (2015) 1530022



Fully instrumented: $2 < \eta < 5$
Veto region (Run 1): $-3.5 < \eta < -1.5$
Veto region (Run 2): $-10 < \eta < -5$, $5 < \eta < 10$

The LHCb detector

JINST 13 (2018) no.04, P04017



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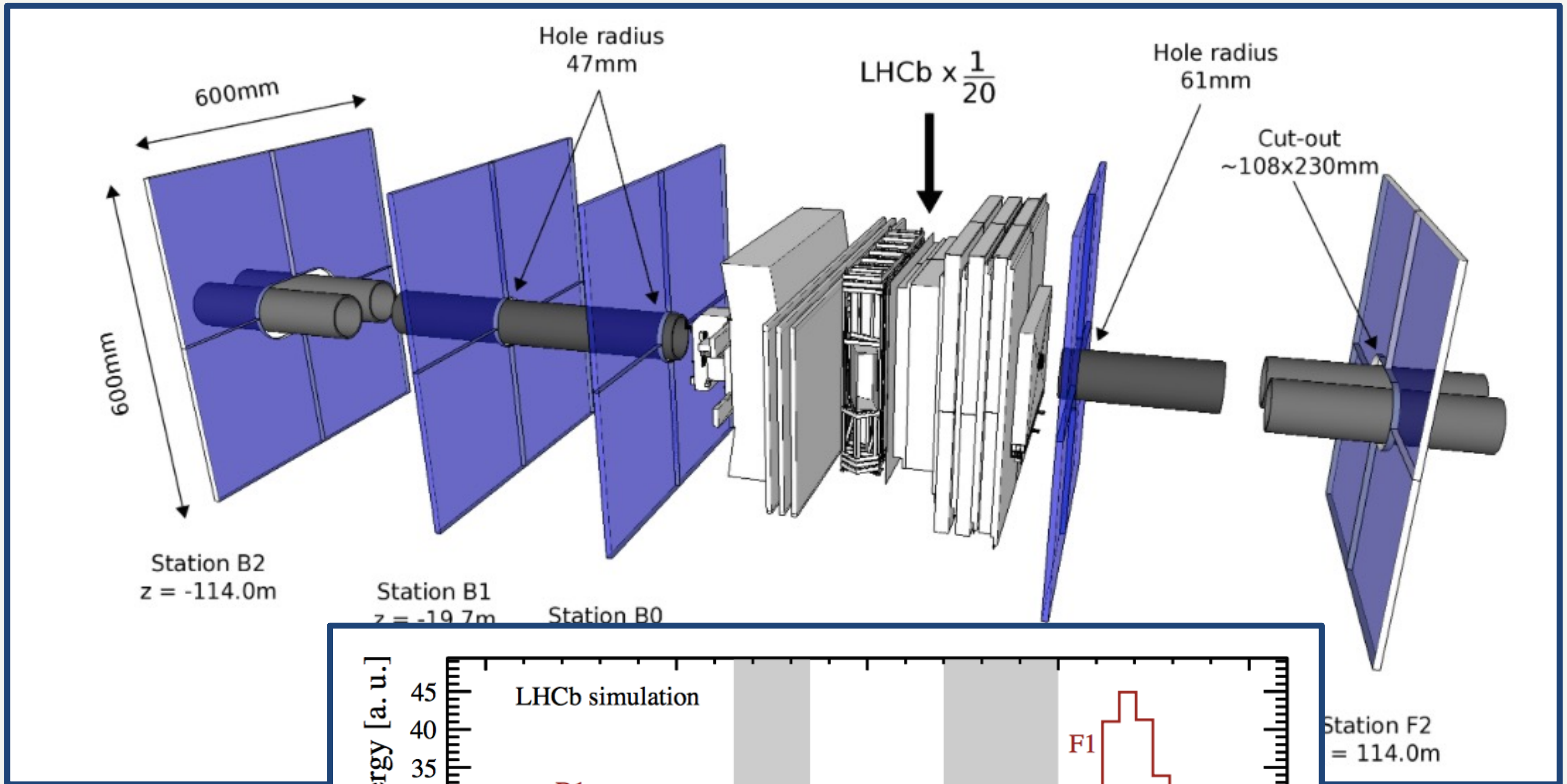
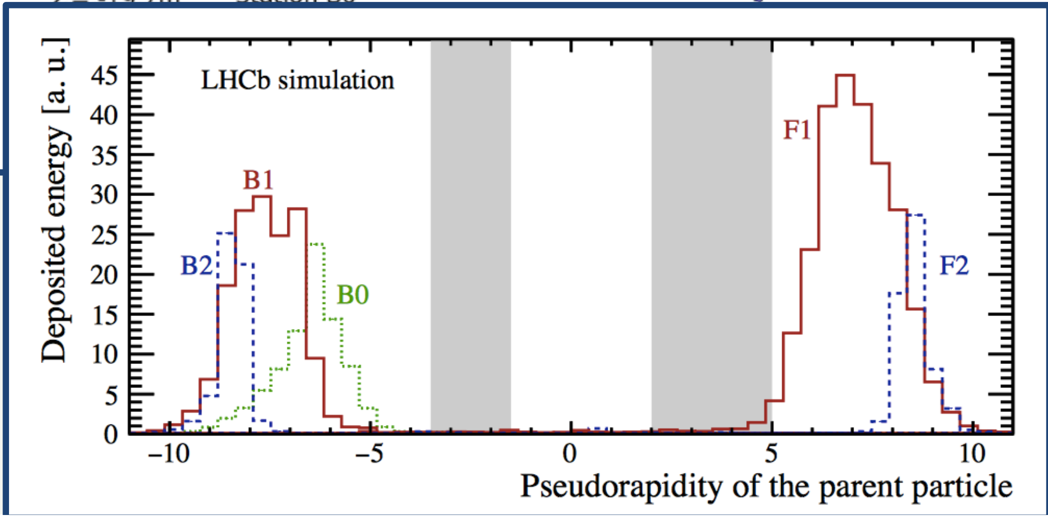
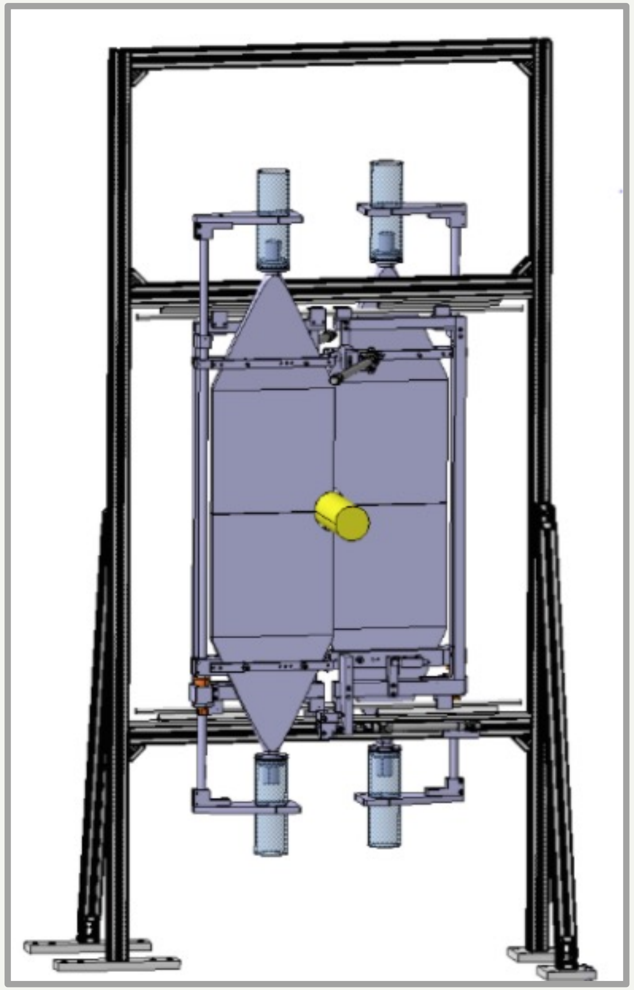
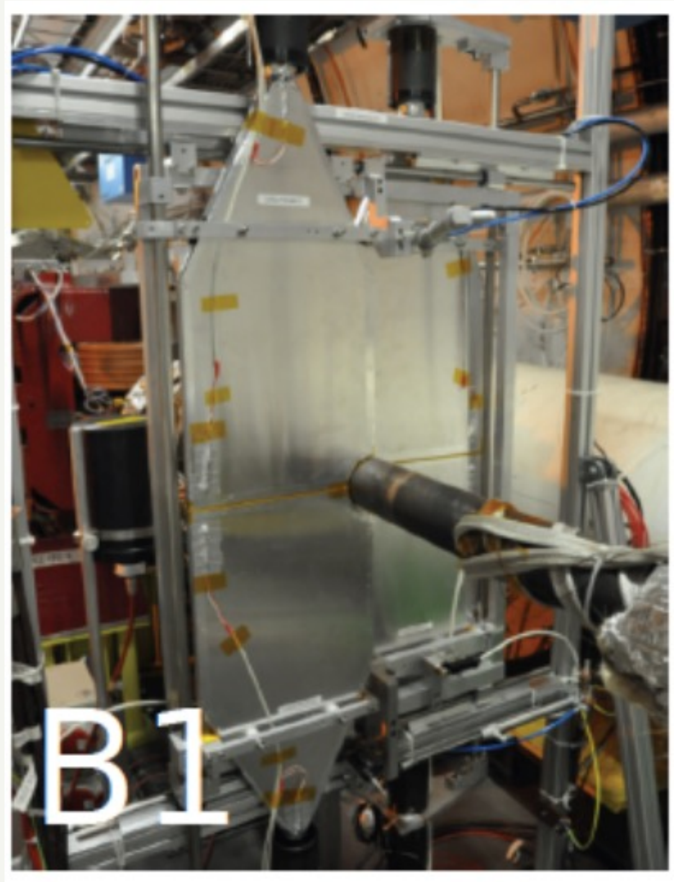




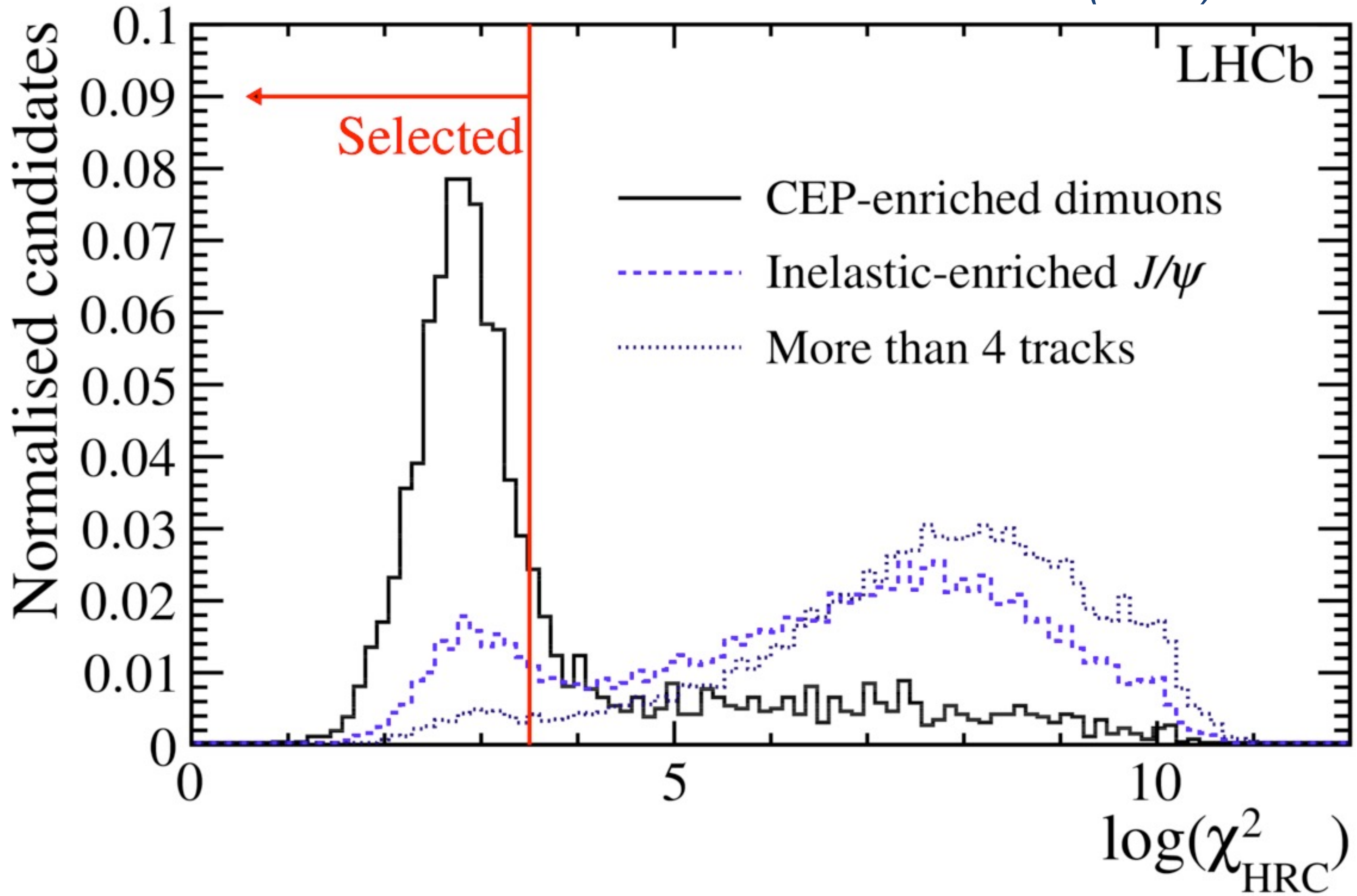
The LHCb detector



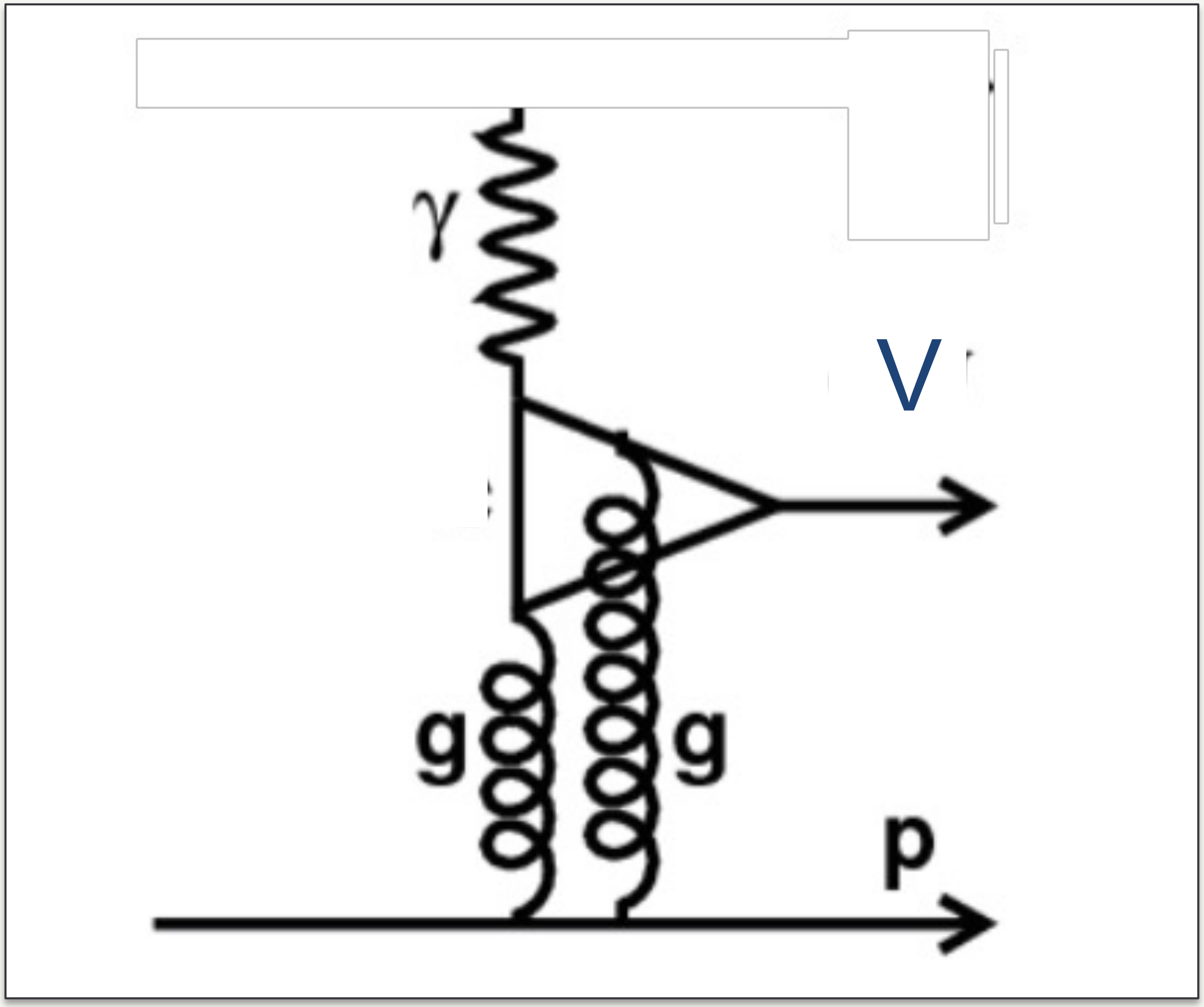


Discrimination power of Herschel

JHEP 1810 (2018) 167

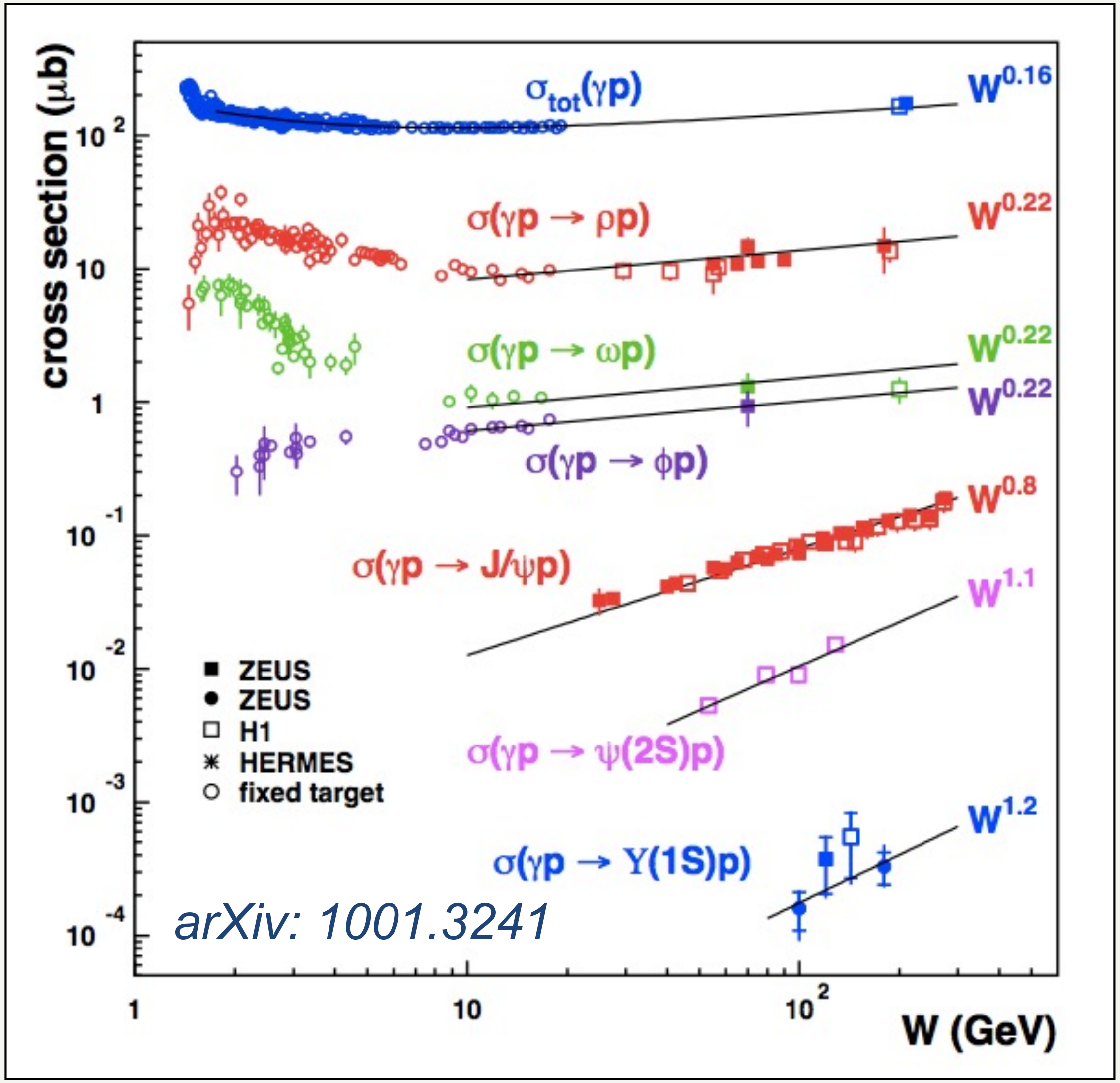


Photoproduction

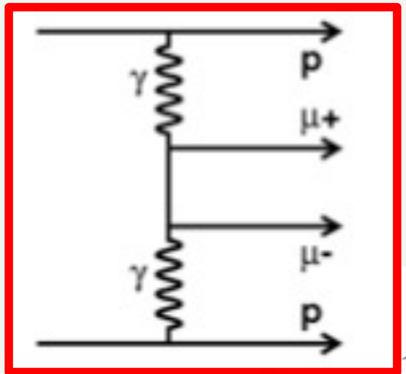


Photoproduction

- Rise in σ related to Pomeron intercept
  - $\sigma \sim W^{\delta}$
  - $\delta=4(\alpha_P(t)-1)$
  - $\alpha_P(t)=\alpha_P(0)+\alpha' t$
- Compare slopes ρ,ω,ϕ to J/ψ,ψ',Υ
- Extract $g(x,Q^2)$

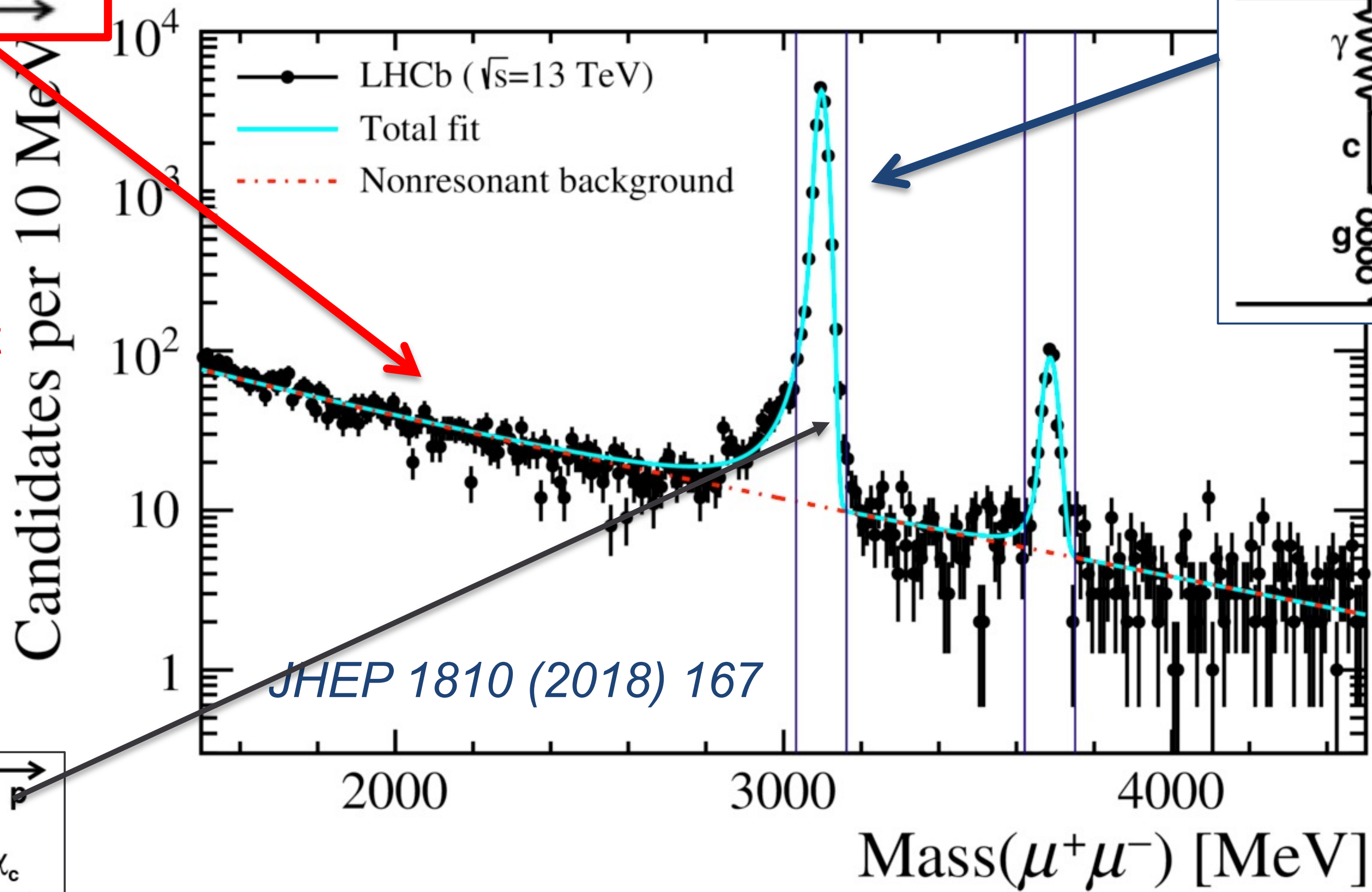


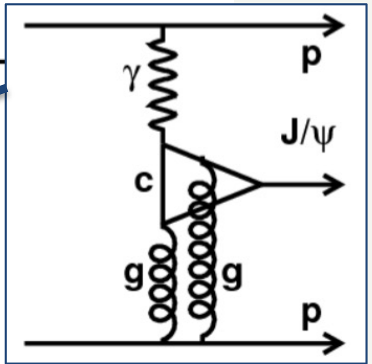
Dimuons in pp collisions



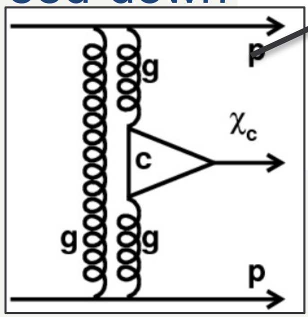
$\gamma\gamma$ events continue to detection threshold at ~ 600 MeV

(electrons down to ~200MeV)





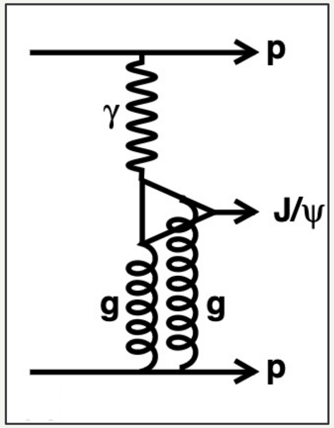
Feed-down

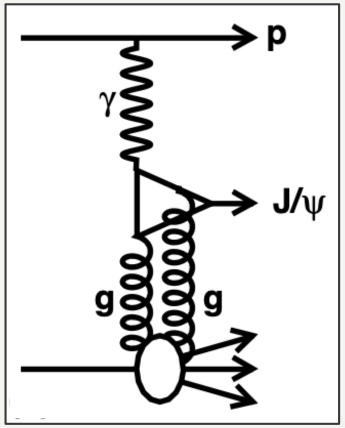


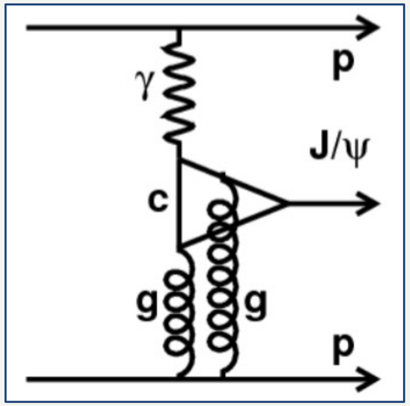
Two muons and nothing else in the LHCb detector

Coherent/Incoherent

- Experimental definitions:
  - **Coherent** interaction where
    - no break-up is observed
    - pt distribution follows exp(bt) b large
      - Does this include nuclear excitation ?
      - Does this include coherent breakup
  - **Incoherent** is where:
    - break-up is observed
    - neutrons are observed
    - pt distribution follows exp(bt) b small
- The translation between the theory and (variable) experimental definitions requires clear definitions, and modelling of theory and detectors



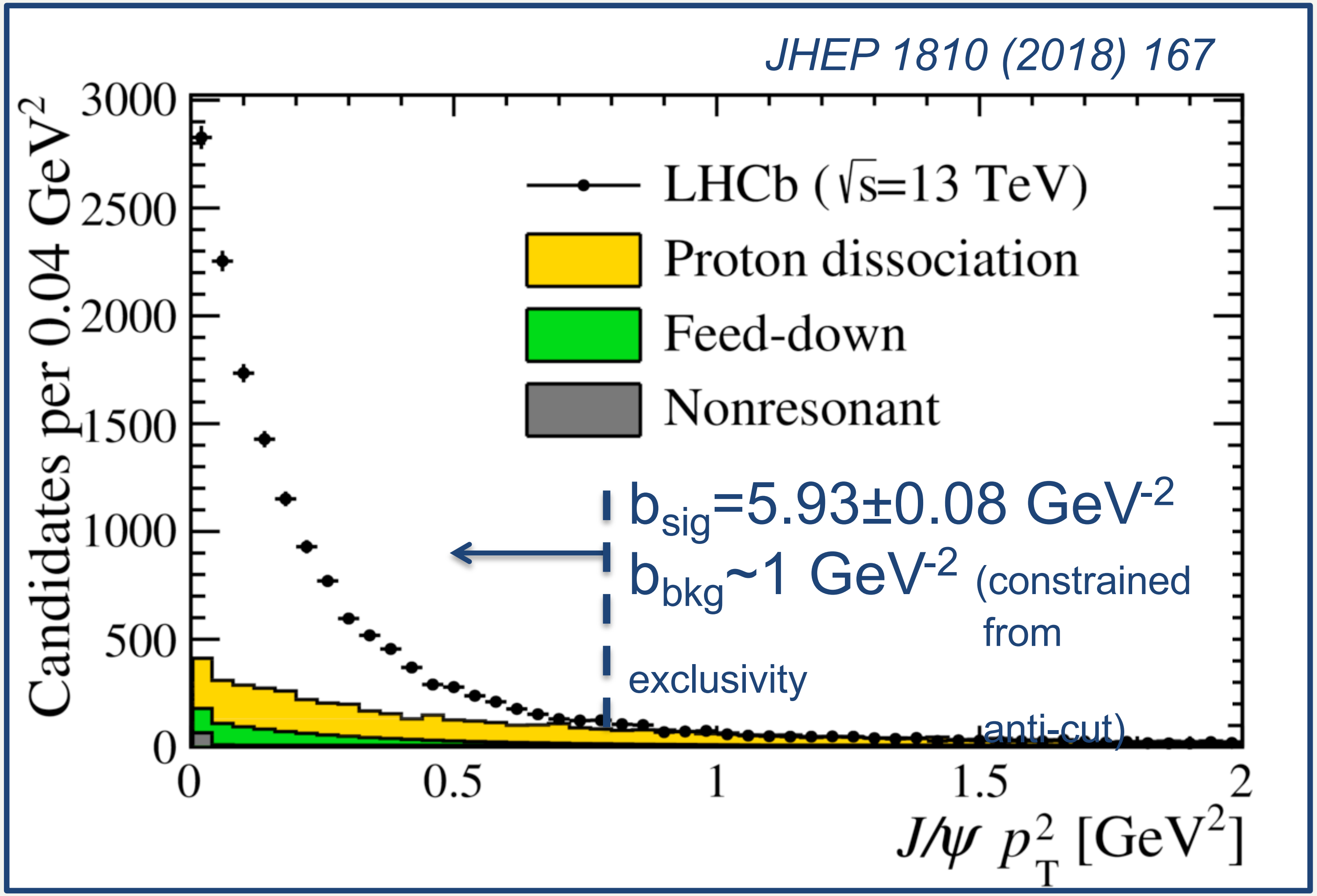




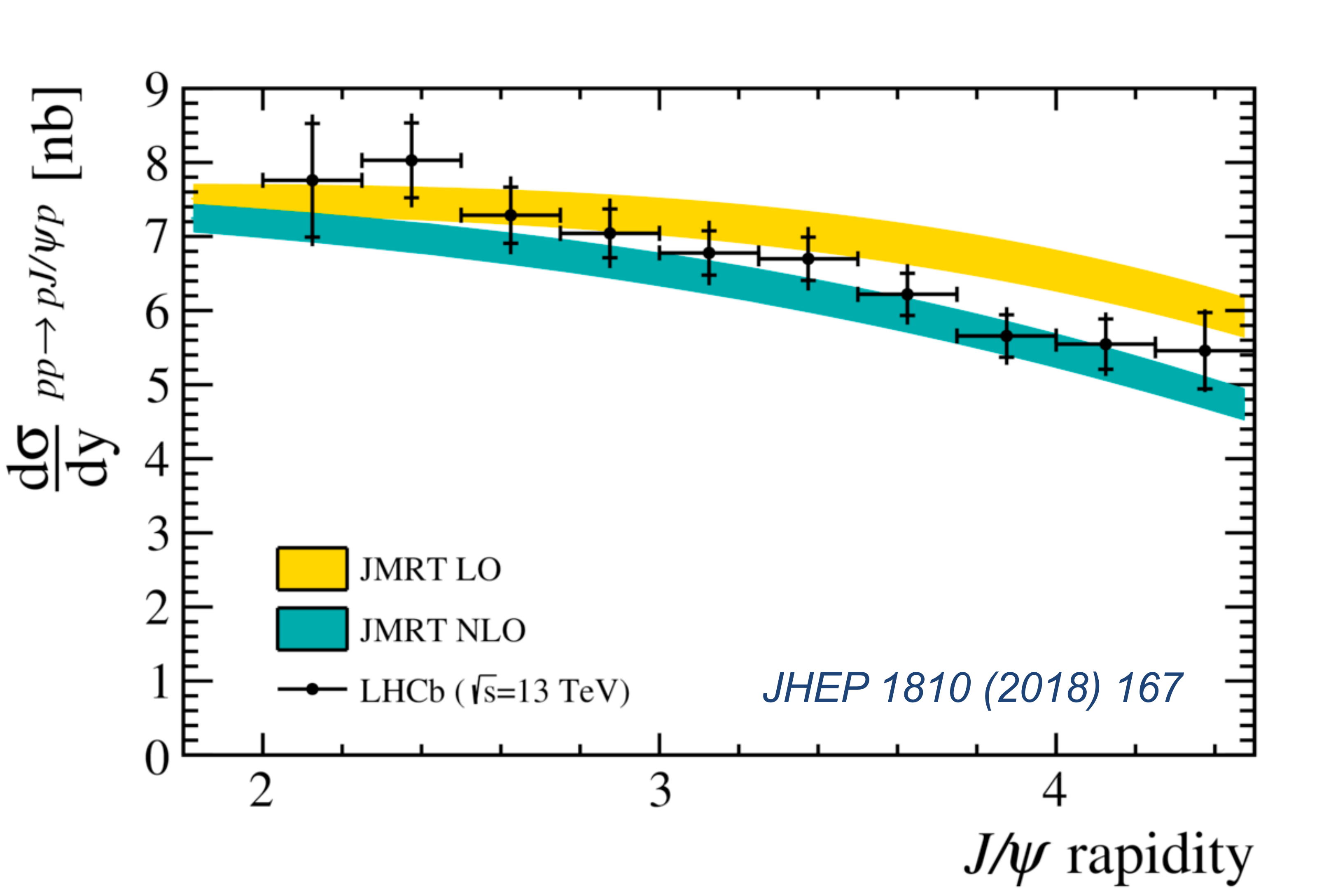
Purity for CEP of J/ψ

Assume Signal and Background

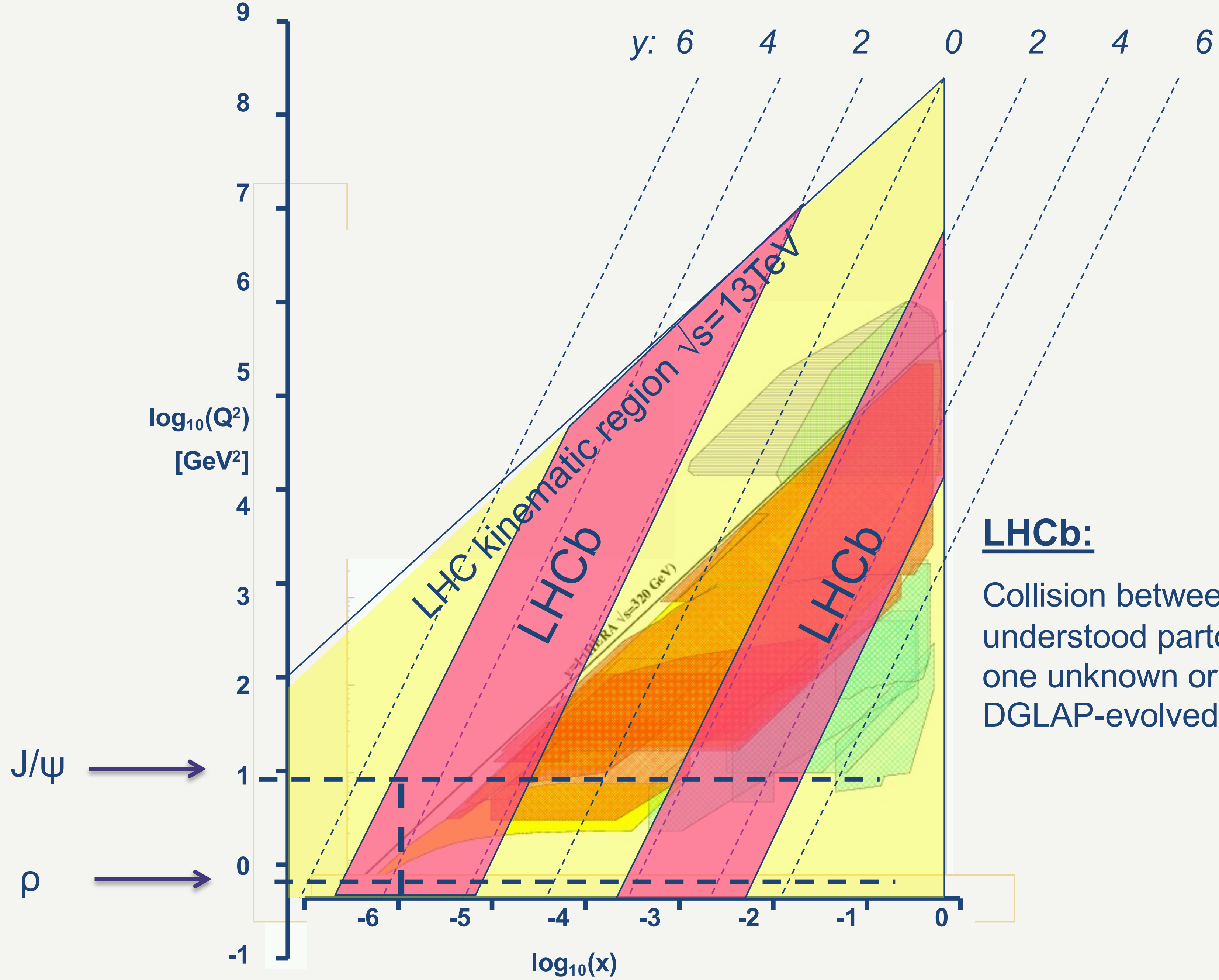
$$\frac{d\sigma}{dt} \sim e^{bt}$$



Differential cross-section pp→pJ/ψp



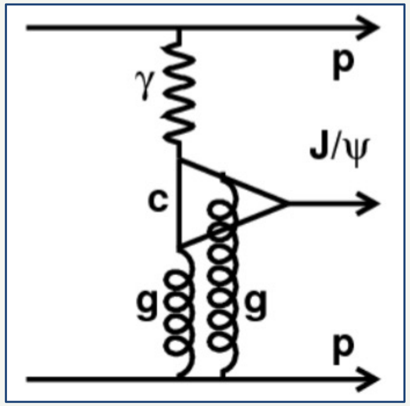
x-values probed at LHC



LHCb:

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

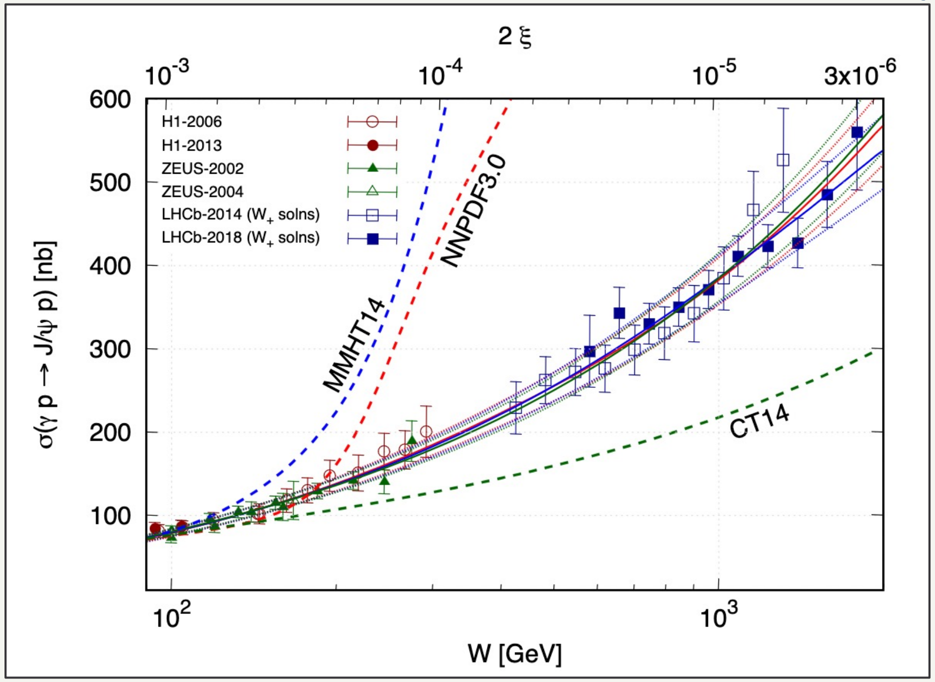
Implications: gluon PDF

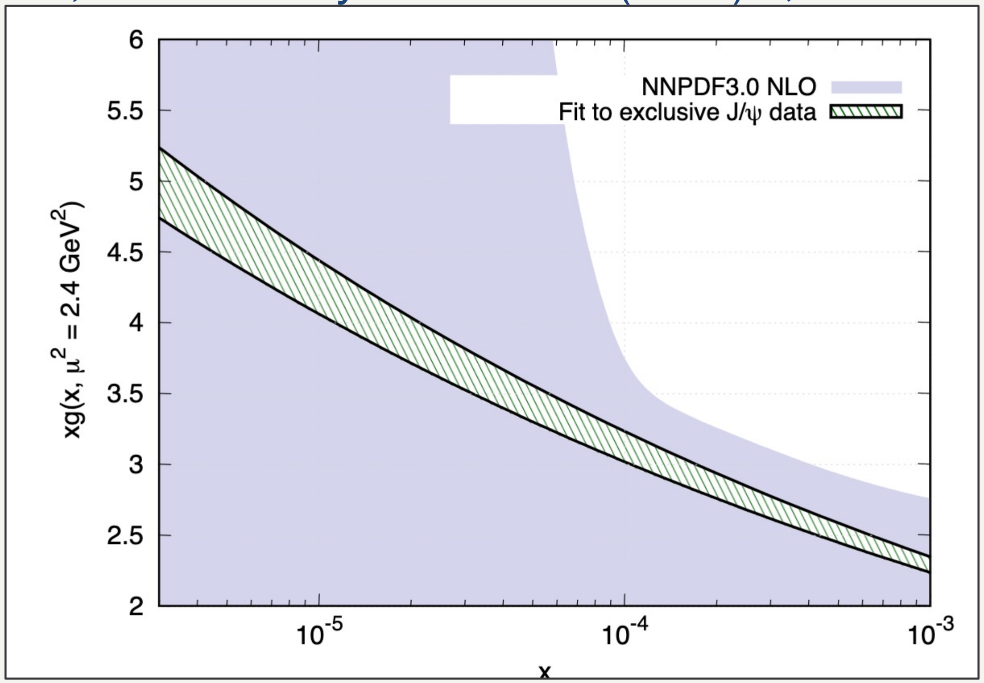


Ryskin, Z. Phys. C 57 (1993) 89

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

Flett, Martin, Ryskin, Teubner. Phys.Rev.D 102 (2020) 114021
Flett, Jones, Martin, Ryskin, Teubner. Phys.Rev.D 101 (2020) 9, 094011





makes use of Shuvaev transform to relate GPDs and PDFs

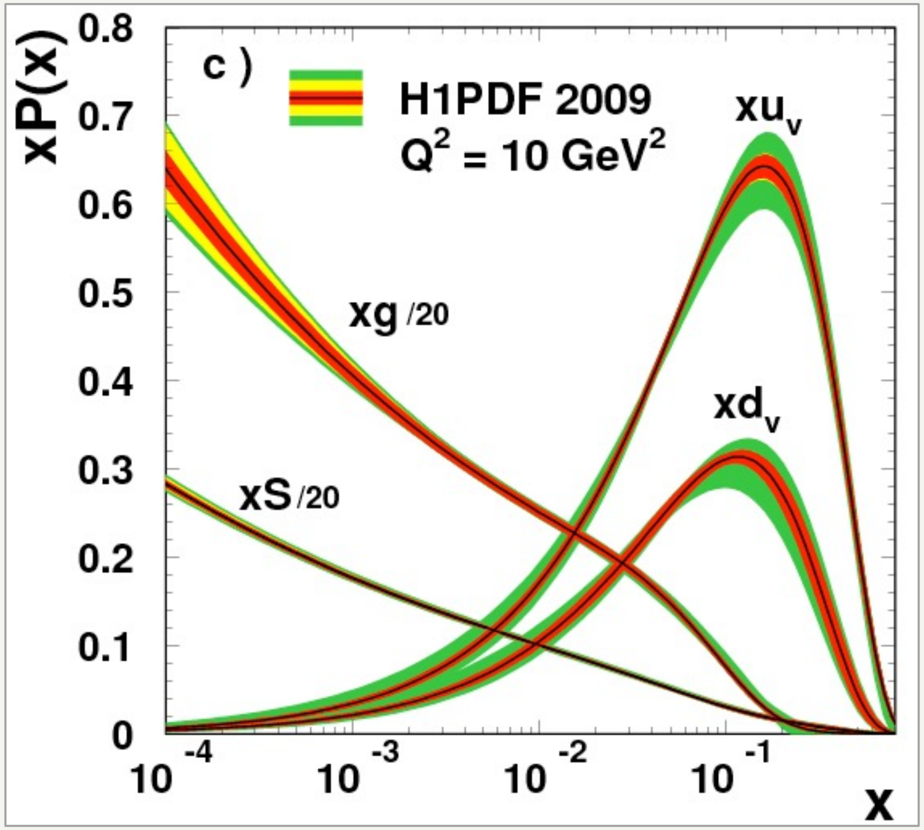
$$H_q(X,\xi) = \int_{-1}^{1} dx' \left[\frac{2}{\pi}\mathrm{Im}\int_0^1 \frac{ds}{y(s)\sqrt{1-y(s)x'}}\right]\frac{d}{dx'}\left(\frac{q(x')}{|x'|}\right),$$

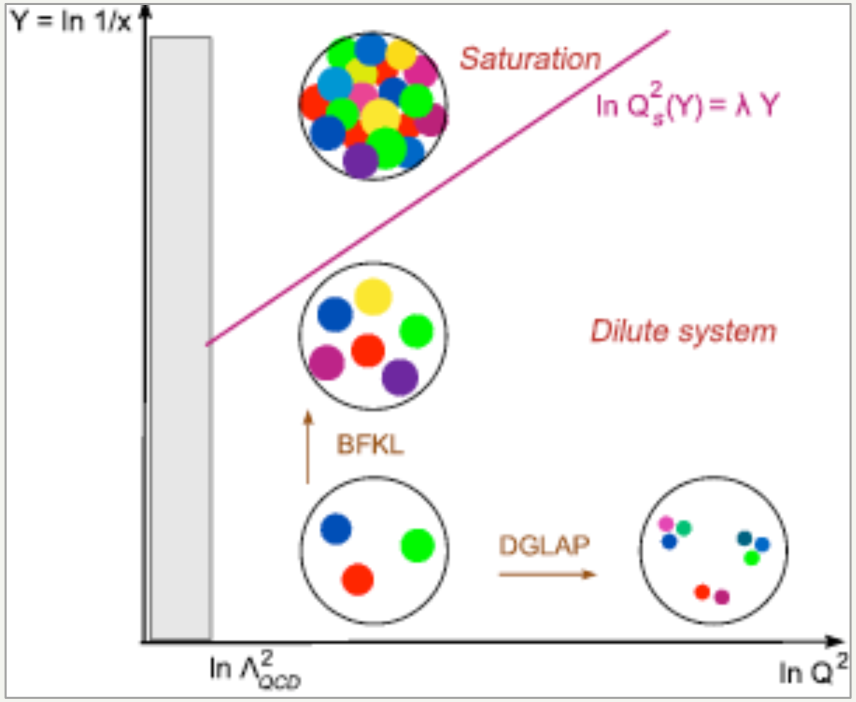
$$H_g(X,\xi) = \int_{-1}^{1} dx' \left[\frac{2}{\pi}\mathrm{Im}\int_0^1 \frac{ds\ (X+\xi(1-2s))}{y(s)\sqrt{1-y(s)x'}}\right]\frac{d}{dx'}\left(\frac{g(x')}{|x'|}\right),$$

where the transform kernel,

$$y(s) = \frac{4s(1-s)}{(X+\xi(1-2s))}.$$

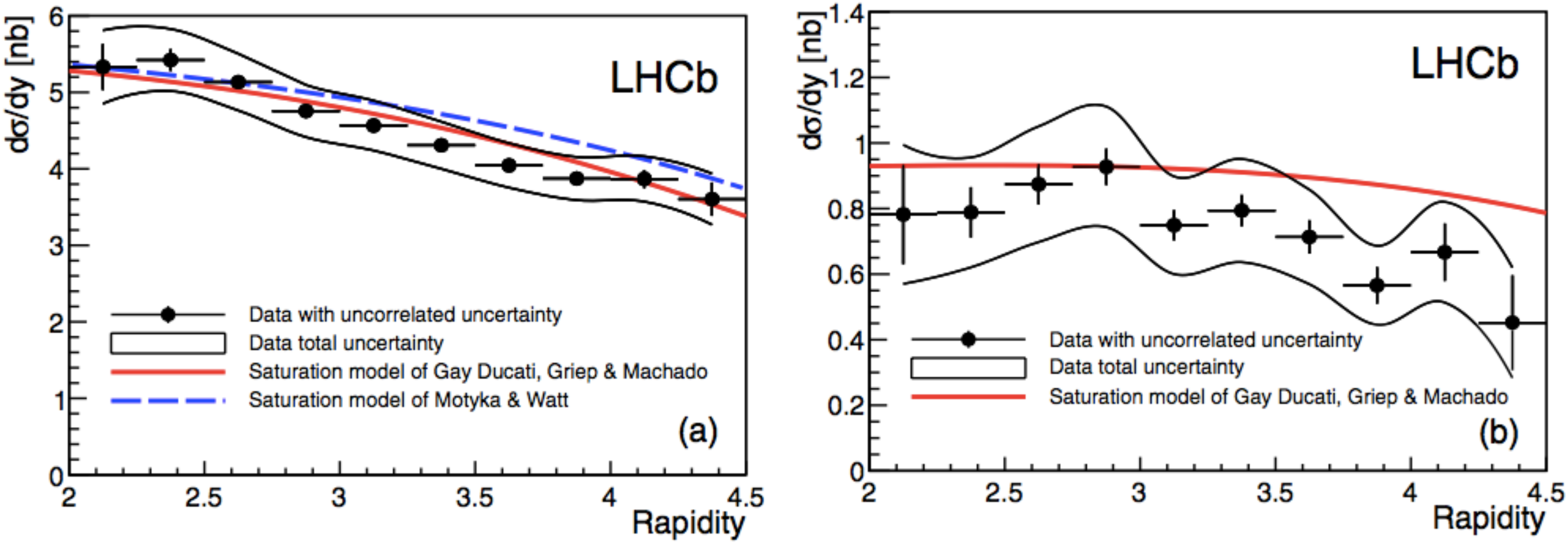
Implications: Saturation





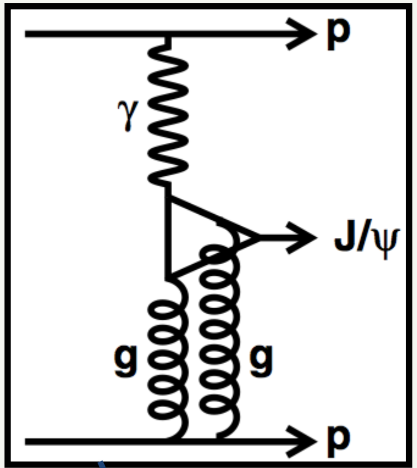
Implications: Saturation?

JPG 41 (2014) 055002

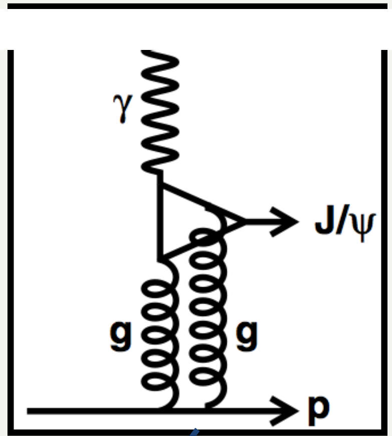


LO doesn't fit data
NLO does
Various saturation models do

Convert to photo-production cross-section



LHCb measures



HERA measured

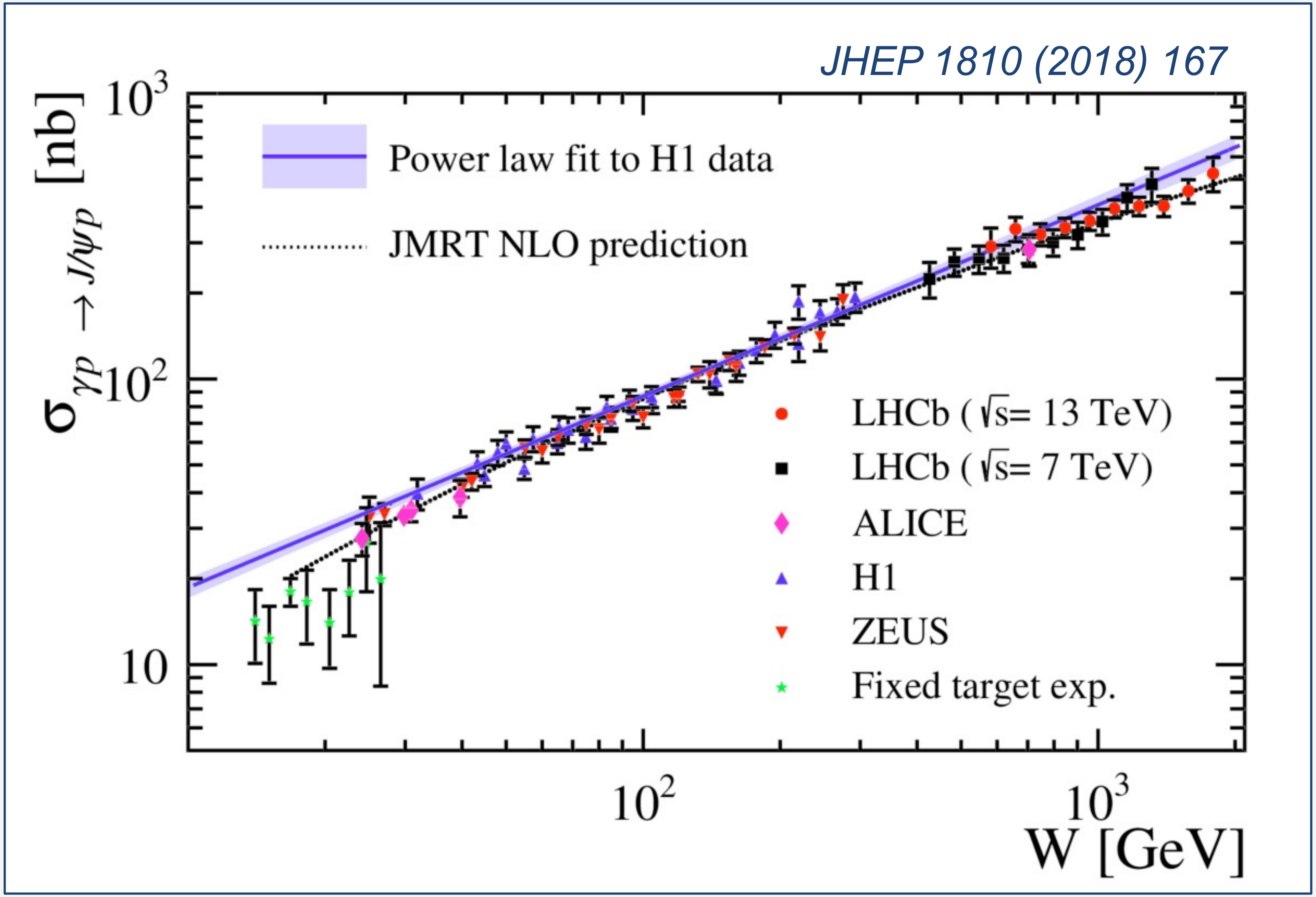
Photon Flux

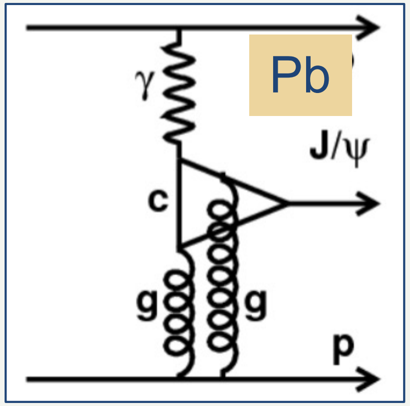
$$\left.\frac{d\sigma}{dy}\right._{pp\to pJ/\psi p} = r_+ k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to J/\psi p}(W_+) + r_- k_- \frac{dn}{dk_-}\sigma_{\gamma p\to J/\psi p}(W_-)$$

Gap Survival

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

Photoproduction cross-section



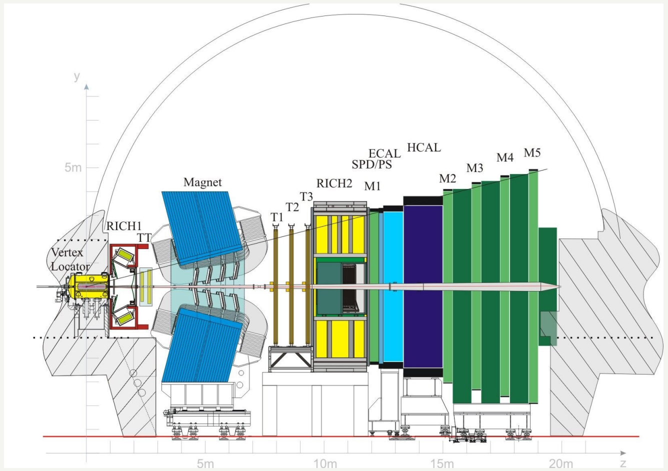


Which projectile produced the photon?

pomeron

Photon

pPb collisions



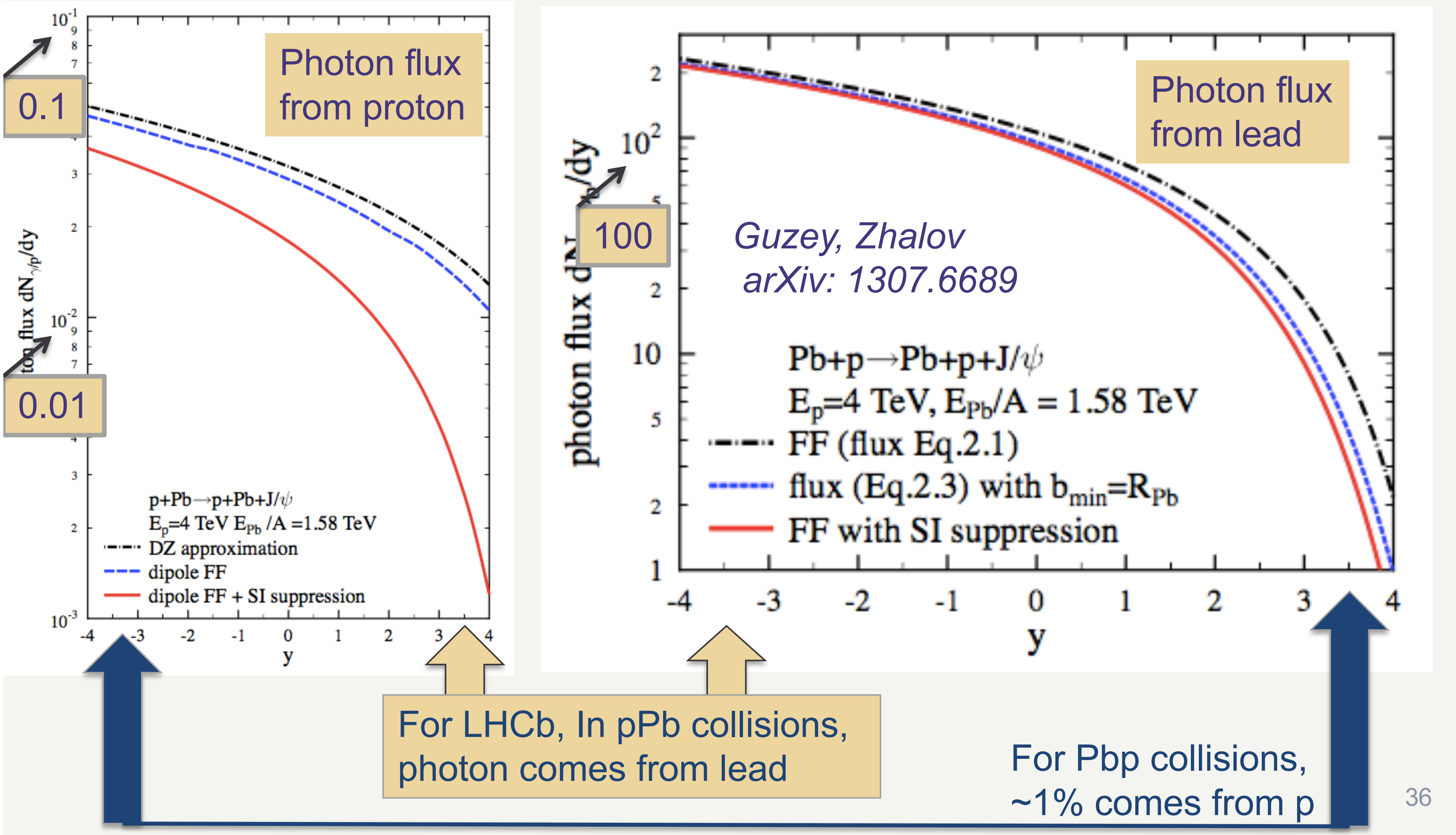
pomeron

Photon

Pbp collisions

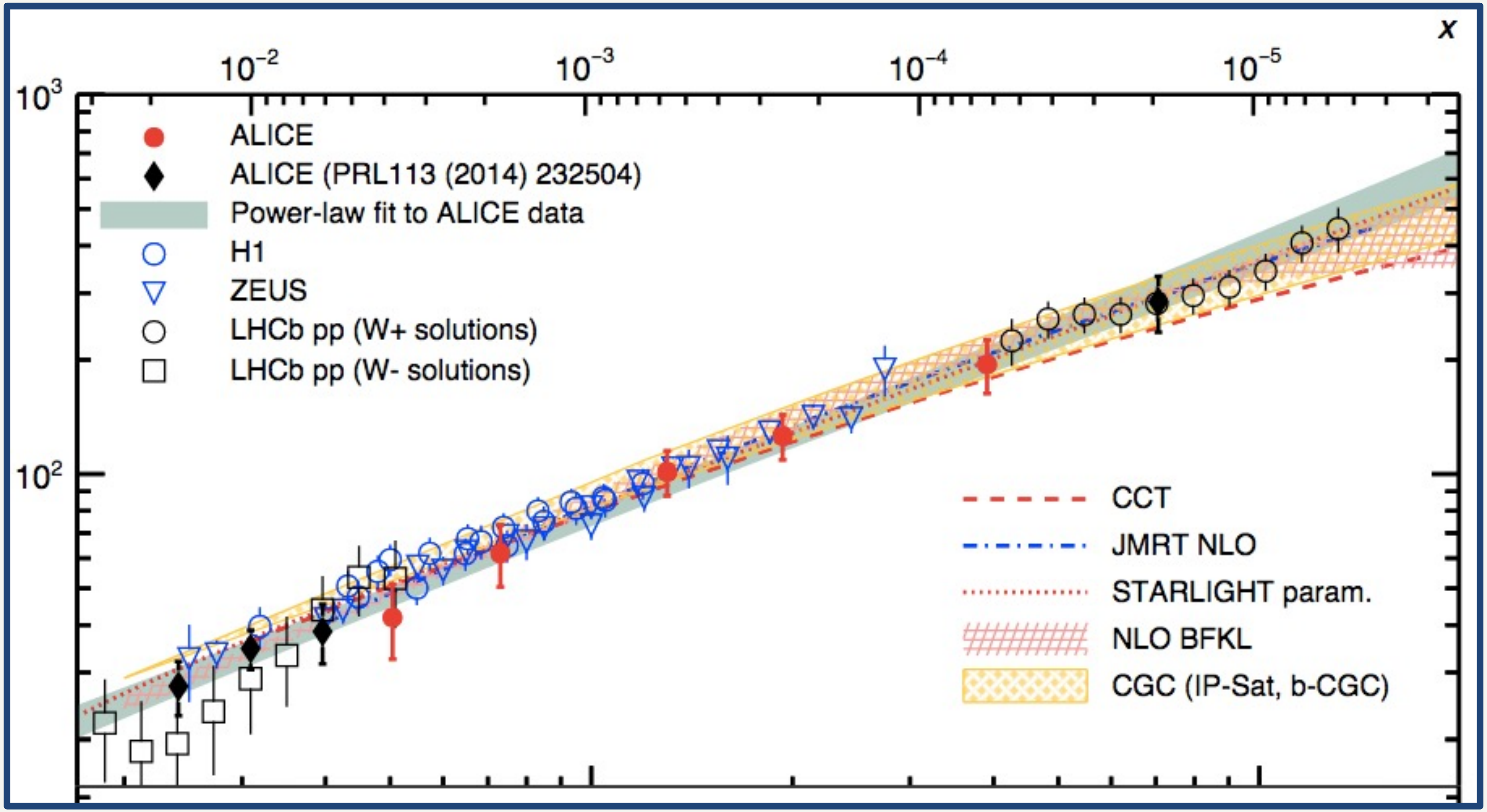
Which projectile produced the photon?

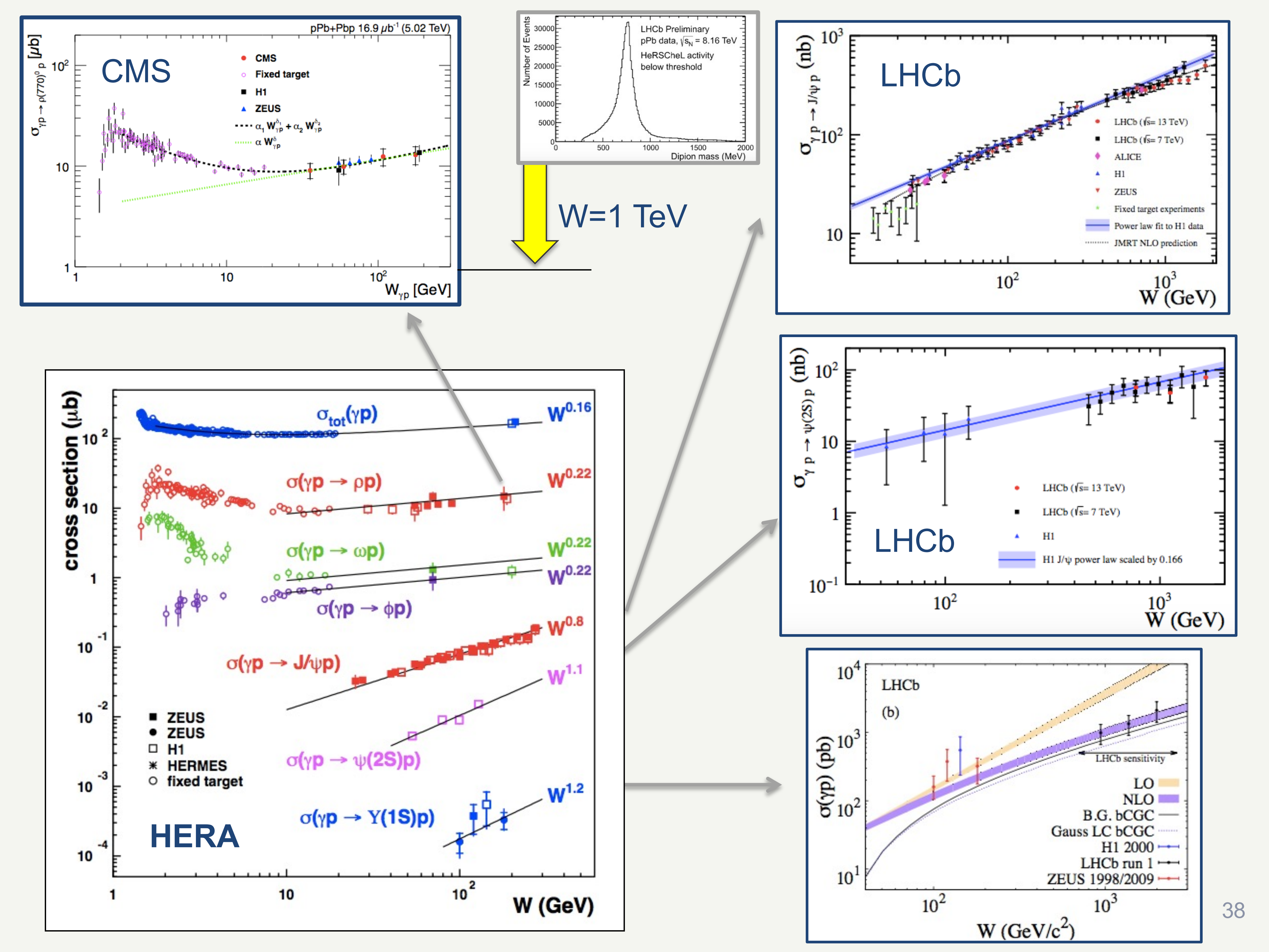
At y~0, photon comes from lead (Z^2 enhancement)



J/ψ production in pPb and Pbp

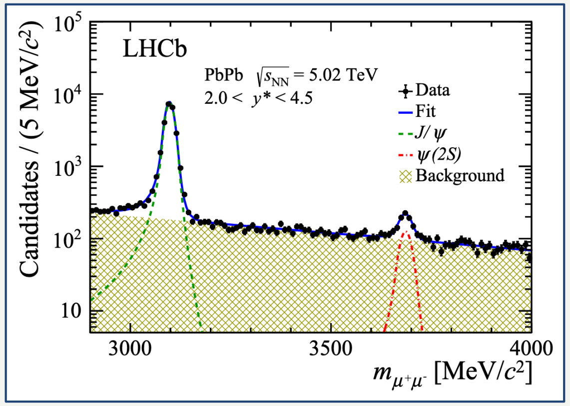
Eur.Phys.J. C79 (2019) no.5, 402

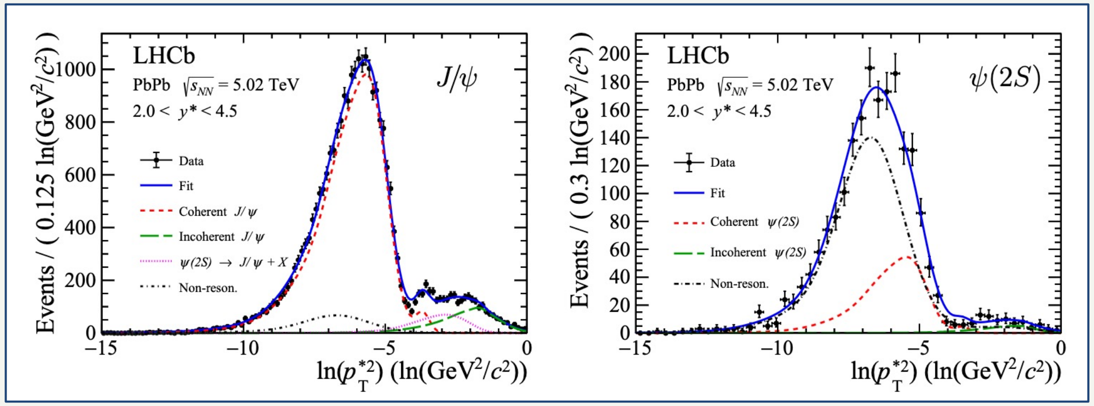


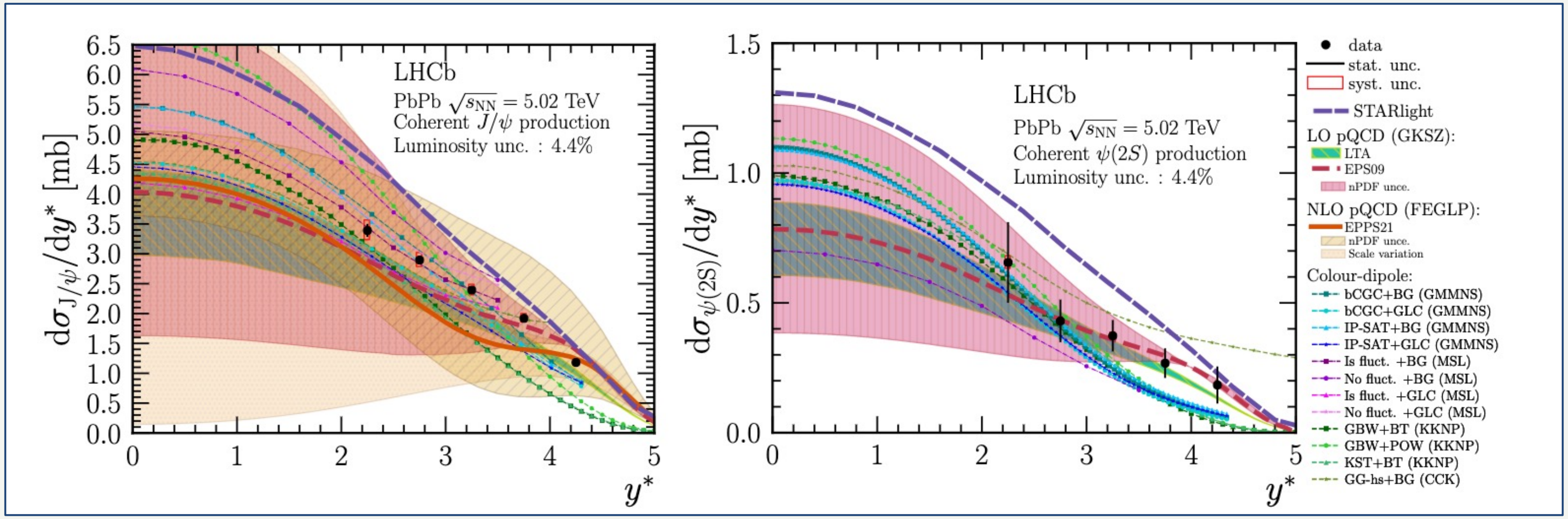

CMS
pPb+Pbp 16.9 μb⁻¹ (5.02 TeV)
CMS
Fixed target
H1
ZEUS
W_γp [GeV]
LHCb Preliminary
pPb data, √s_N = 8.16 TeV
HeRSChel activity
below threshold
Number of Events
Dipion mass (MeV)
W=1 TeV
LHCb
LHCb (√s= 13 TeV)
LHCb (√s= 7 TeV)
ALICE
H1
ZEUS
Fixed target experiments
Power law fit to H1 data
JMRT NLO prediction
W (GeV)
LHCb
LHCb (√s= 13 TeV)
LHCb (√s= 7 TeV)
H1
H1 J/ψ power law scaled by 0.166
W (GeV)
LHCb
(b)
LHCb sensitivity
LO
NLO
B.G. bCGC
Gauss LC bCGC
H1 2000
LHCb run 1
ZEUS 1998/2009
σ(γp) (pb)
W (GeV/c²)
cross section (μb)
σ_tot(γp)
W^0.16
σ(γp → ρp)
W^0.22
σ(γp → ωp)
W^0.22
W^0.22
σ(γp → φp)
W^0.8
σ(γp → J/ψp)
W^1.1
σ(γp → ψ(2S)p)
W^1.2
σ(γp → Υ(1S)p)
ZEUS
ZEUS
H1
HERMES
fixed target
HERA
W (GeV)

J/ψ production in PbPb

JHEP 06 (2023) 146







Description of ρ meson

Ross and Stodolsky Phys. Rev. **149** (1966) 1172

$$\frac{d\sigma}{dM_{\pi\pi}} = f\left|\frac{\sqrt{M_{\pi\pi}M_{\rho^0}\Gamma(M_{\pi\pi})}}{M_{\pi\pi}^2 - M_{\rho^0}^2 + iM_{\rho^0}\Gamma(M_{\pi\pi})}\right|^2 \left(\frac{M_{\rho^0}}{M_{\pi\pi}}\right)^k$$

Söding Phys. Lett.19(1966) 702.

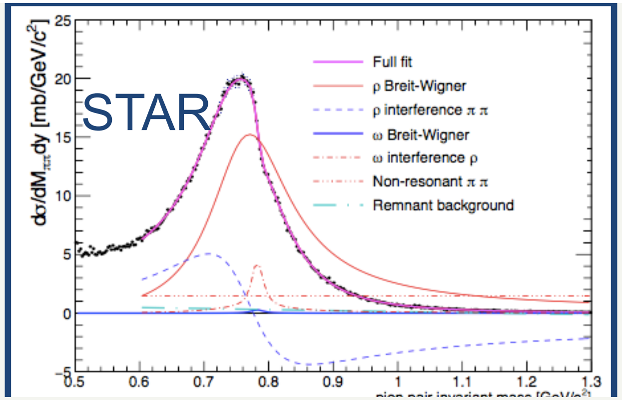
$$\frac{d\sigma}{dM_{\pi\pi}} = \left|A\frac{\sqrt{M_{\pi\pi}M_{\rho^0}\Gamma(M_{\pi\pi})}}{M_{\pi\pi}^2 - M_{\rho^0}^2 + iM_{\rho^0}\Gamma(M_{\pi\pi})} + B\right|^2$$

Söding + ω resonance (note flat continuum is unphysical)

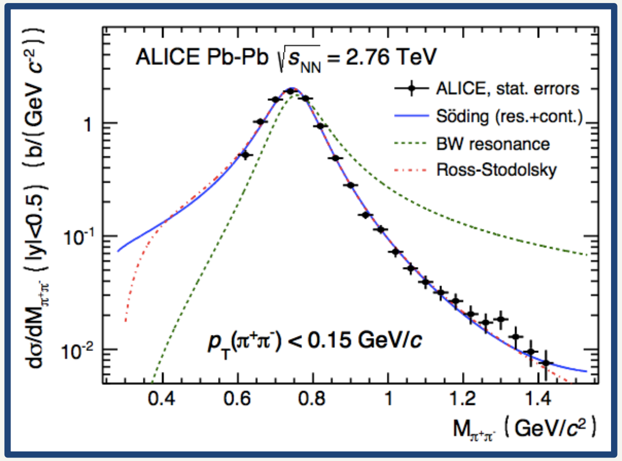
$$\frac{dN_{\pi^+\pi^-}}{dM_{\pi^+\pi^-}} = \left|A\frac{\sqrt{M_{\pi^+\pi^-}M_{\rho(770)}\Gamma_{\rho(770)}}}{M_{\pi^+\pi^-}^2 - M_{\rho(770)^0}^2 + iM_{\rho(770)^0}\Gamma_{\rho(770)}} + B + Ce^{i\phi_\omega}\frac{\sqrt{M_{\pi^+\pi^-}M_{\omega(783)}\Gamma_{\omega(783)\to\pi\pi}}}{M_{\pi^+\pi^-}^2 - M_{\omega(783)}^2 + iM_{\omega(783)^0}\Gamma_{\omega(783)}}\right|^2 .$$

Lebiedowicz, Nachtmann, Szczurek ,Phys.Rev. D91 (2015) no.7, 074023

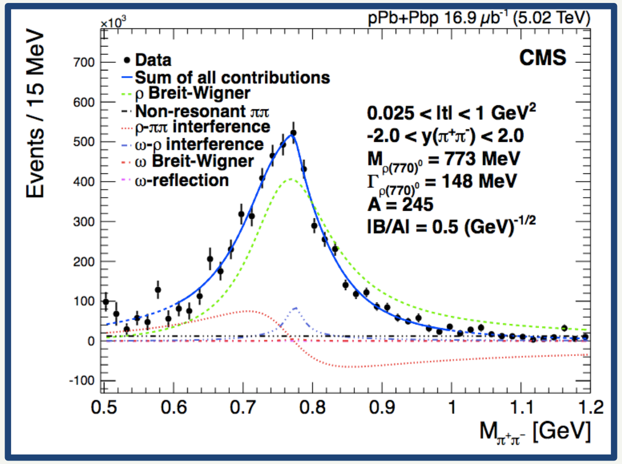
Description of ρ meson



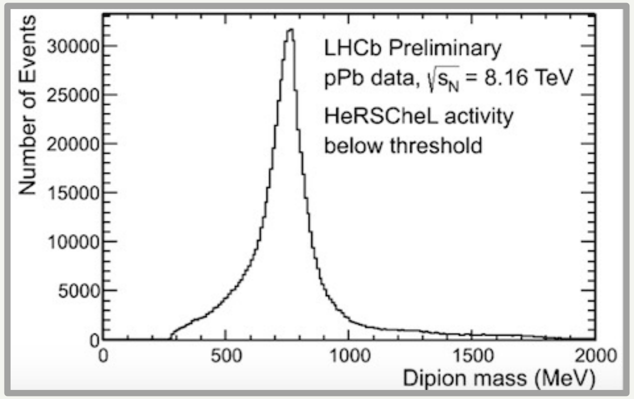
Phys.Rev. C96 (2017) no.5, 054904



JHEP 1509 (2015) 095



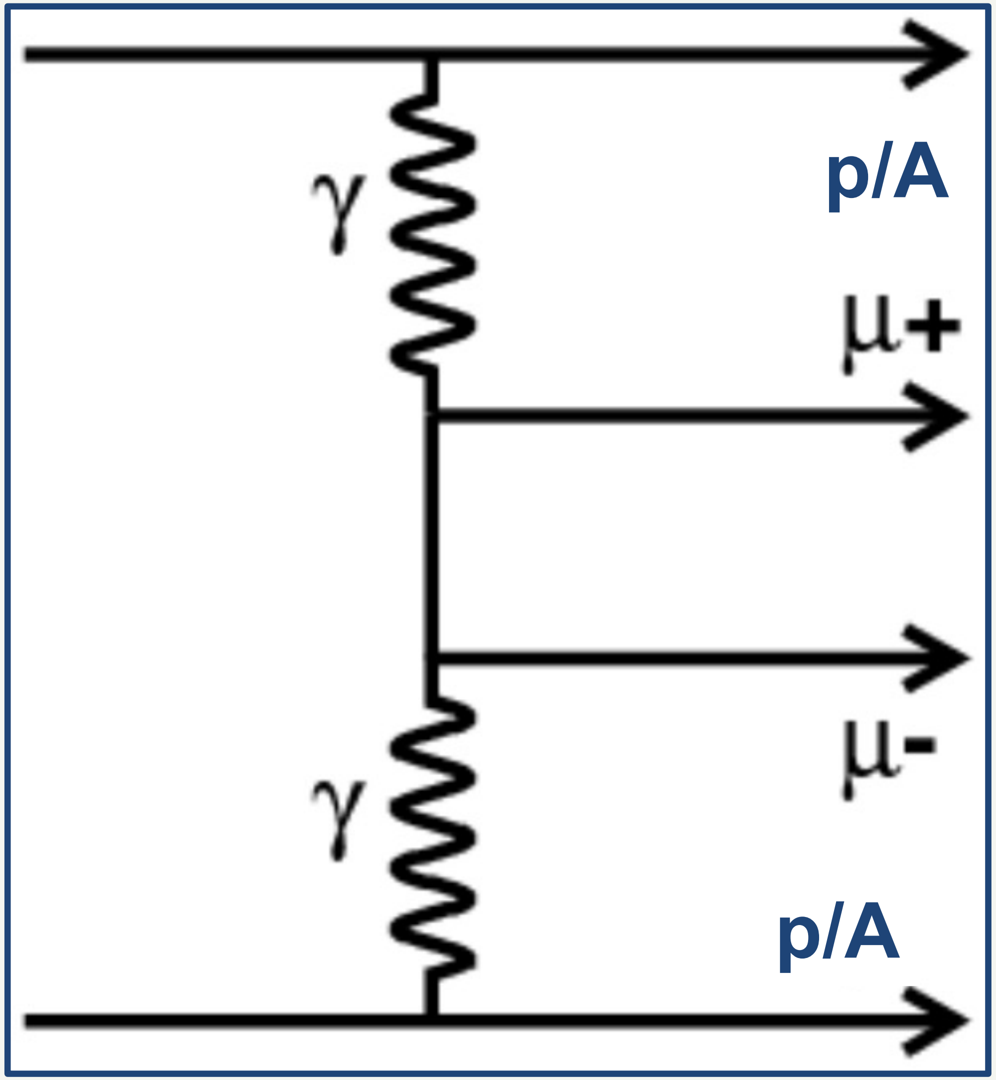
Eur.Phys.J. C79 (2019) no.8, 702



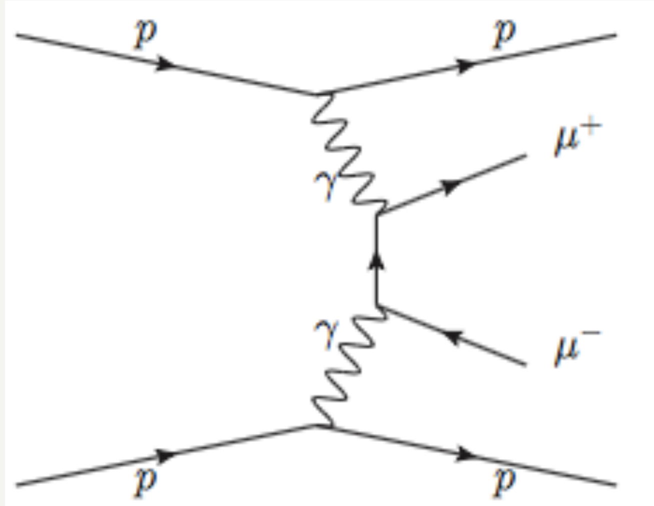
arXiv: 1711.06668

Also: compare $\rho \to \pi\pi, \quad \rho \to \pi\pi\gamma$

Gamma-Gamma collisions

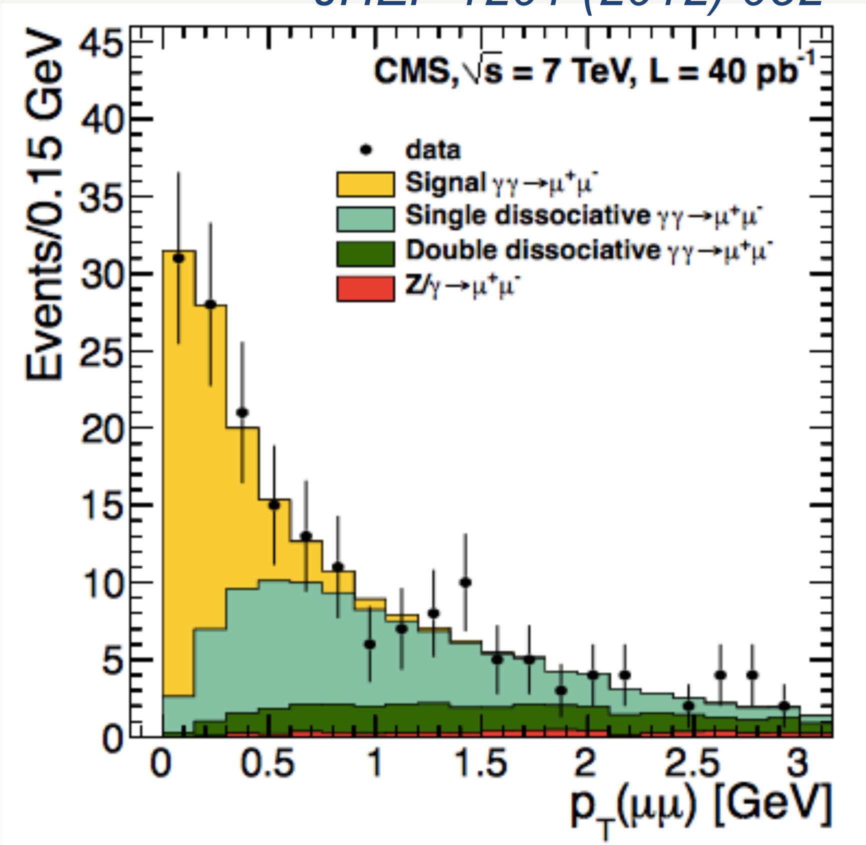


Di-photon fusion (QED)

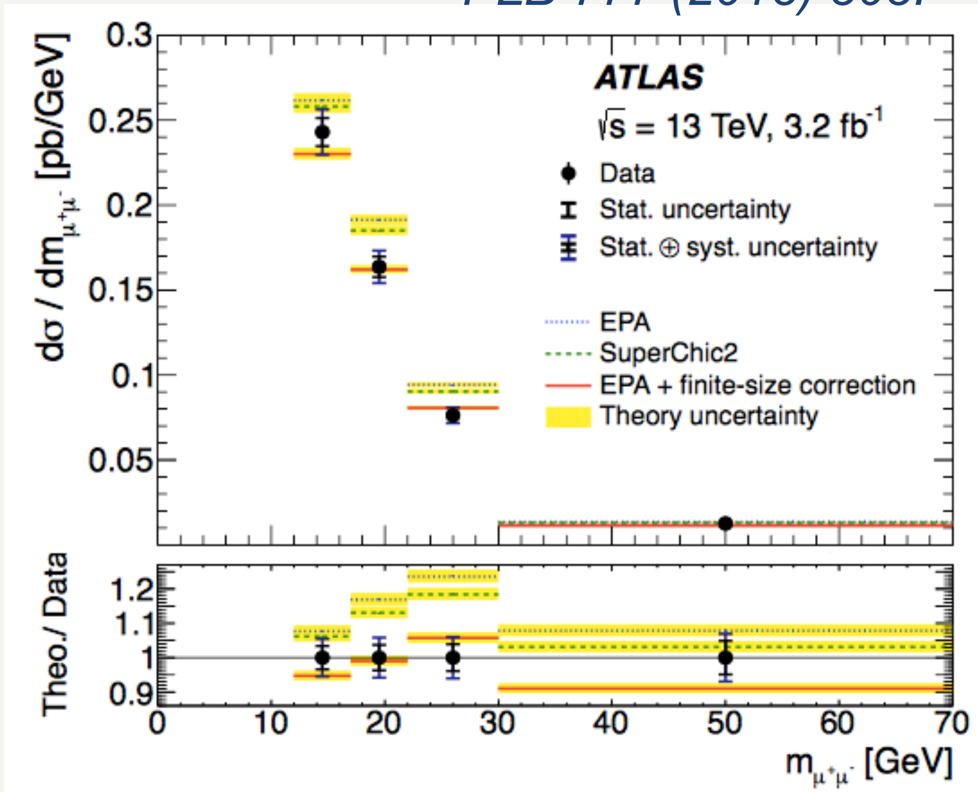


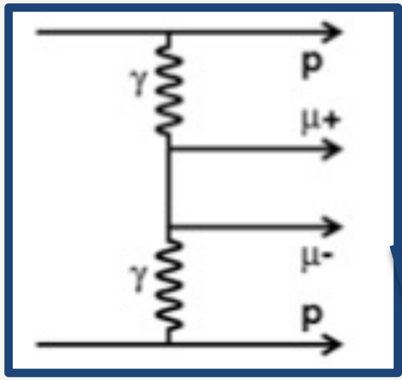
QED CEP process precisely predicted.
Data sensitive to re-scattering corrections

JHEP 1201 (2012) 052

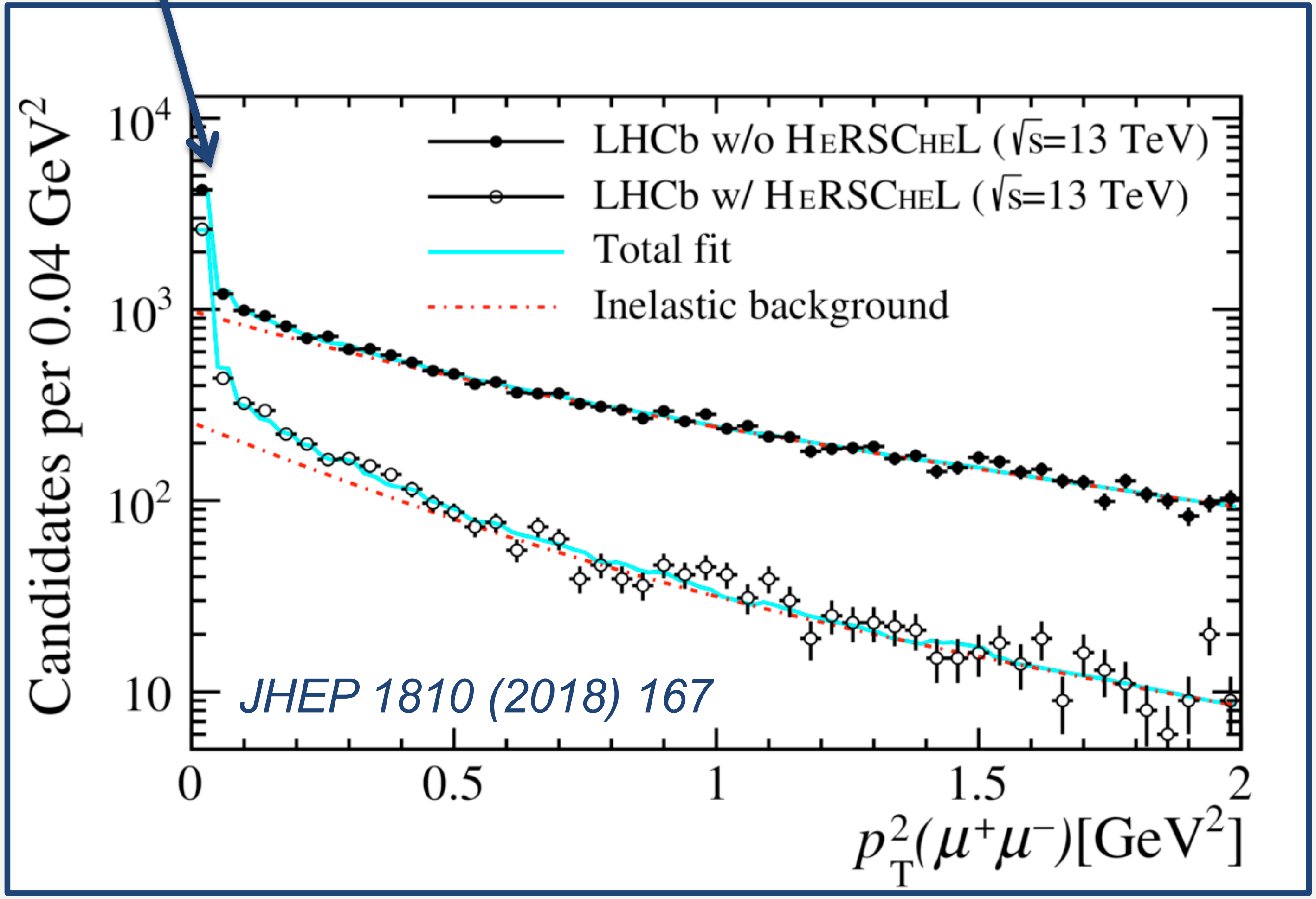


PLB 777 (2018) 303.

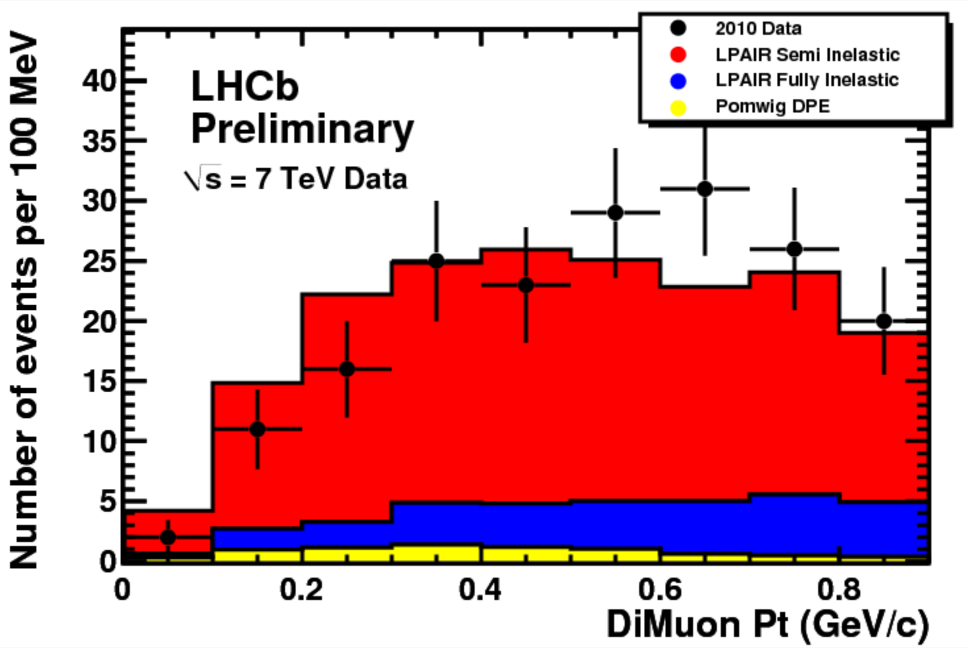


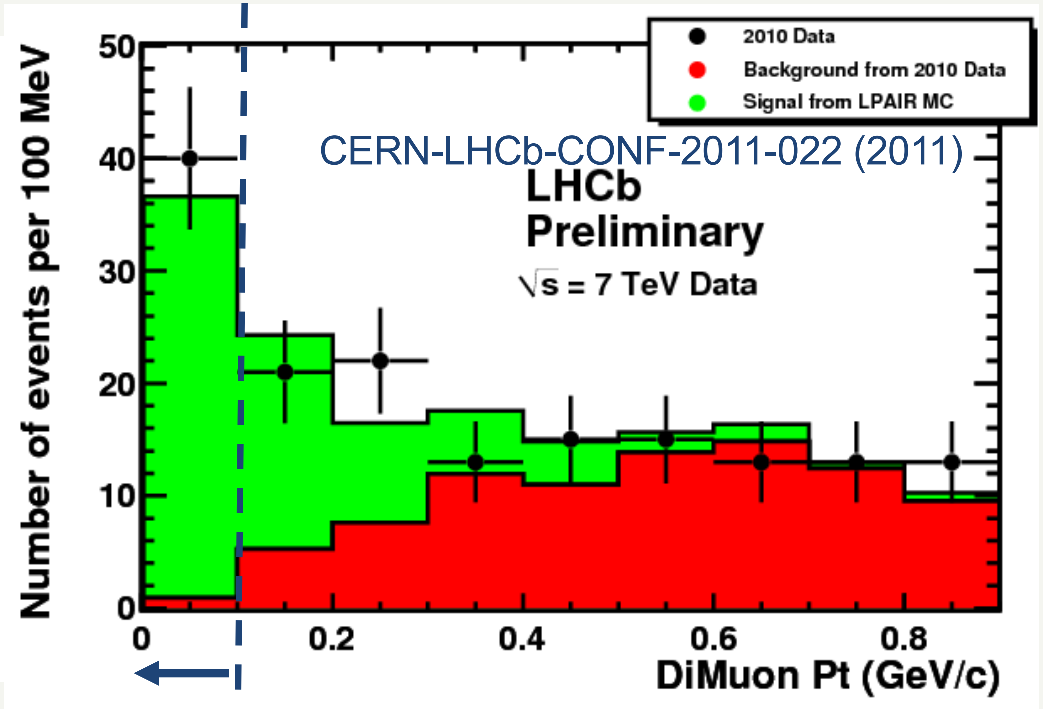


Dimuon continuum



$\gamma\gamma \rightarrow \mu\mu$ ($m_{\mu\mu}$>2.5 GeV)





Shape for inelastic events

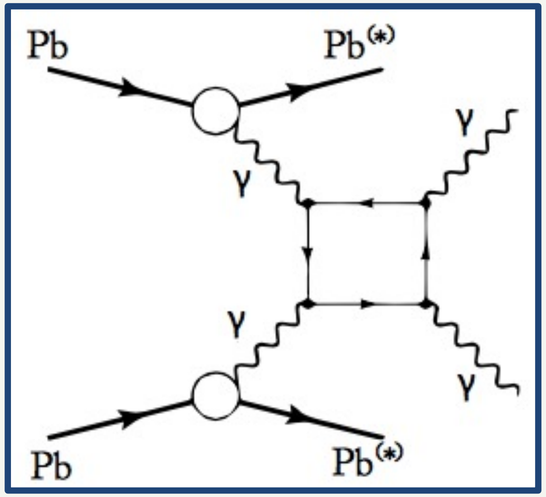
Note: this time we have simulation that predicts the shape for the three contributions.

Fit to signal events

Background shape from data
Signal shape from simulation.

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

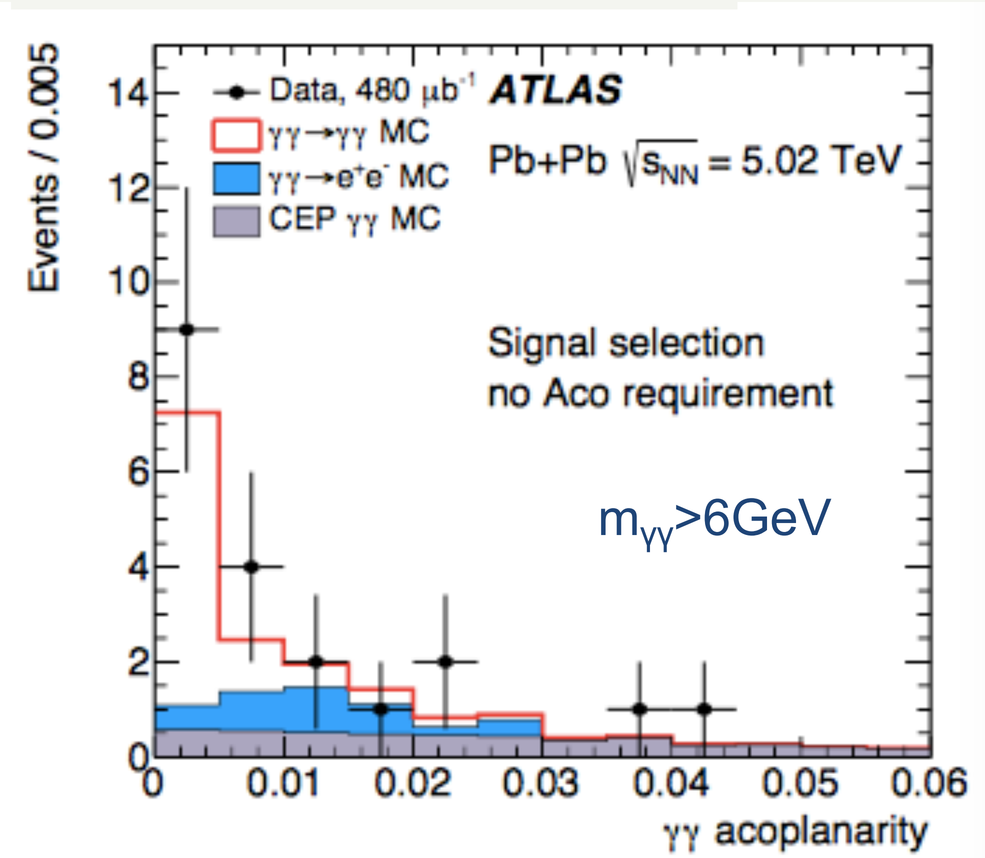
Light-by-light scattering

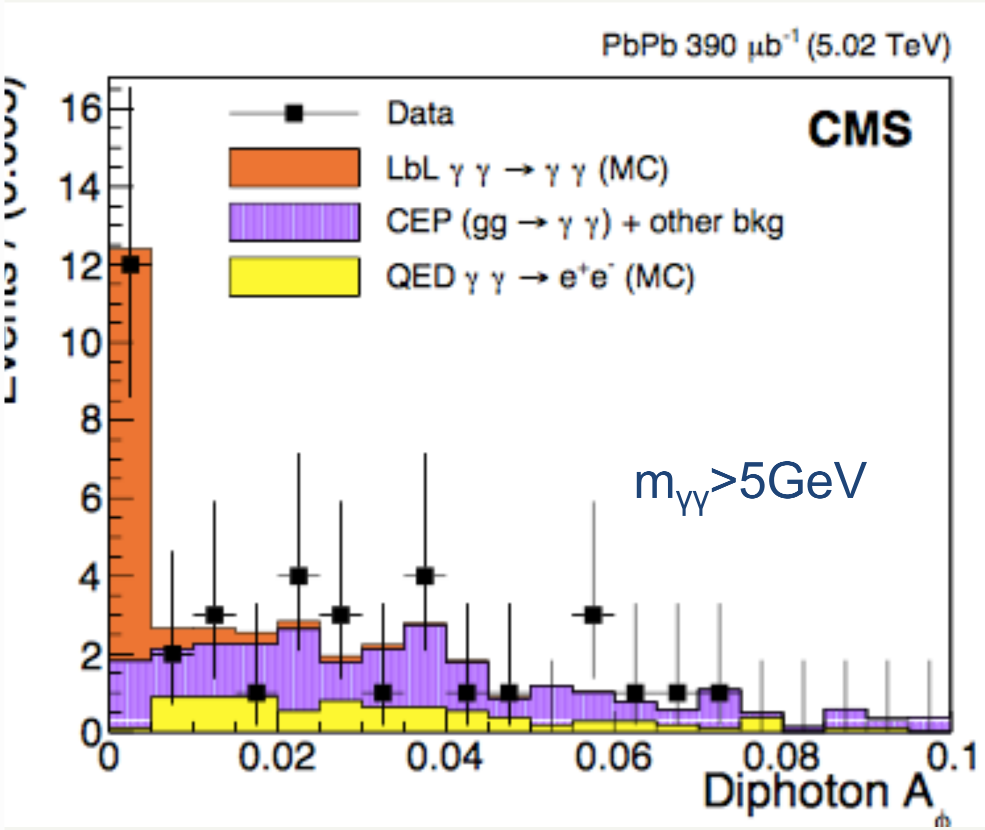


Forbidden in classical EM
Text-book illustration of QM

Nature Physics 13 (2017) 852

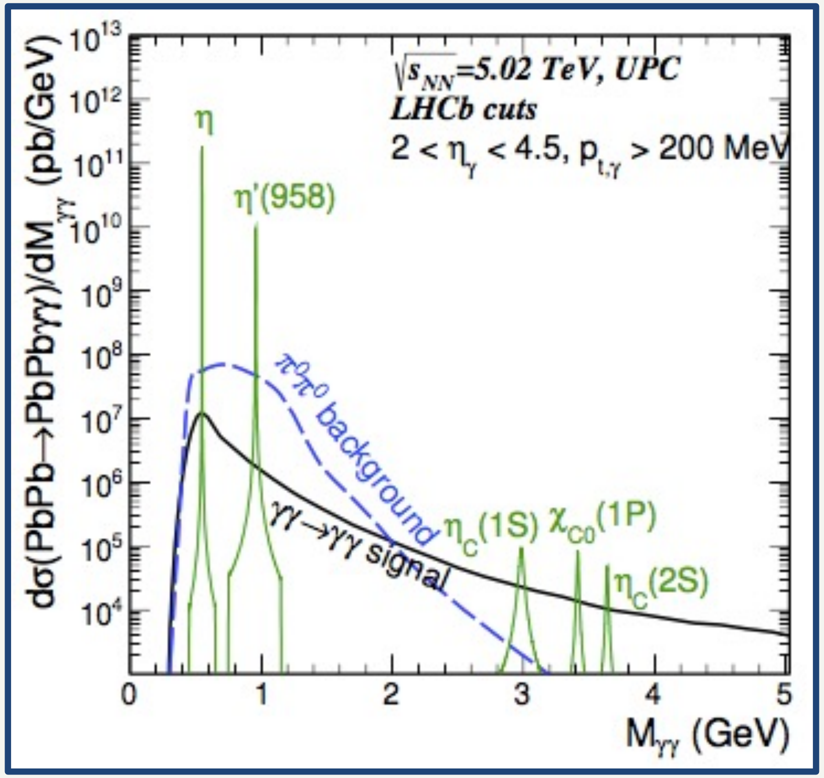
arXiv:1810.04602

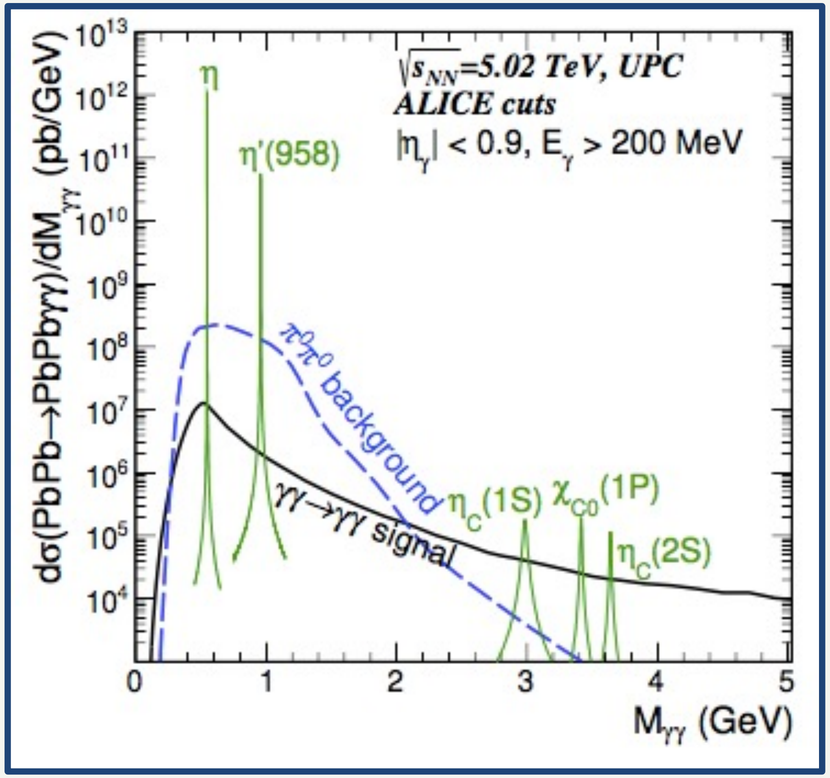




Light-by-light scattering

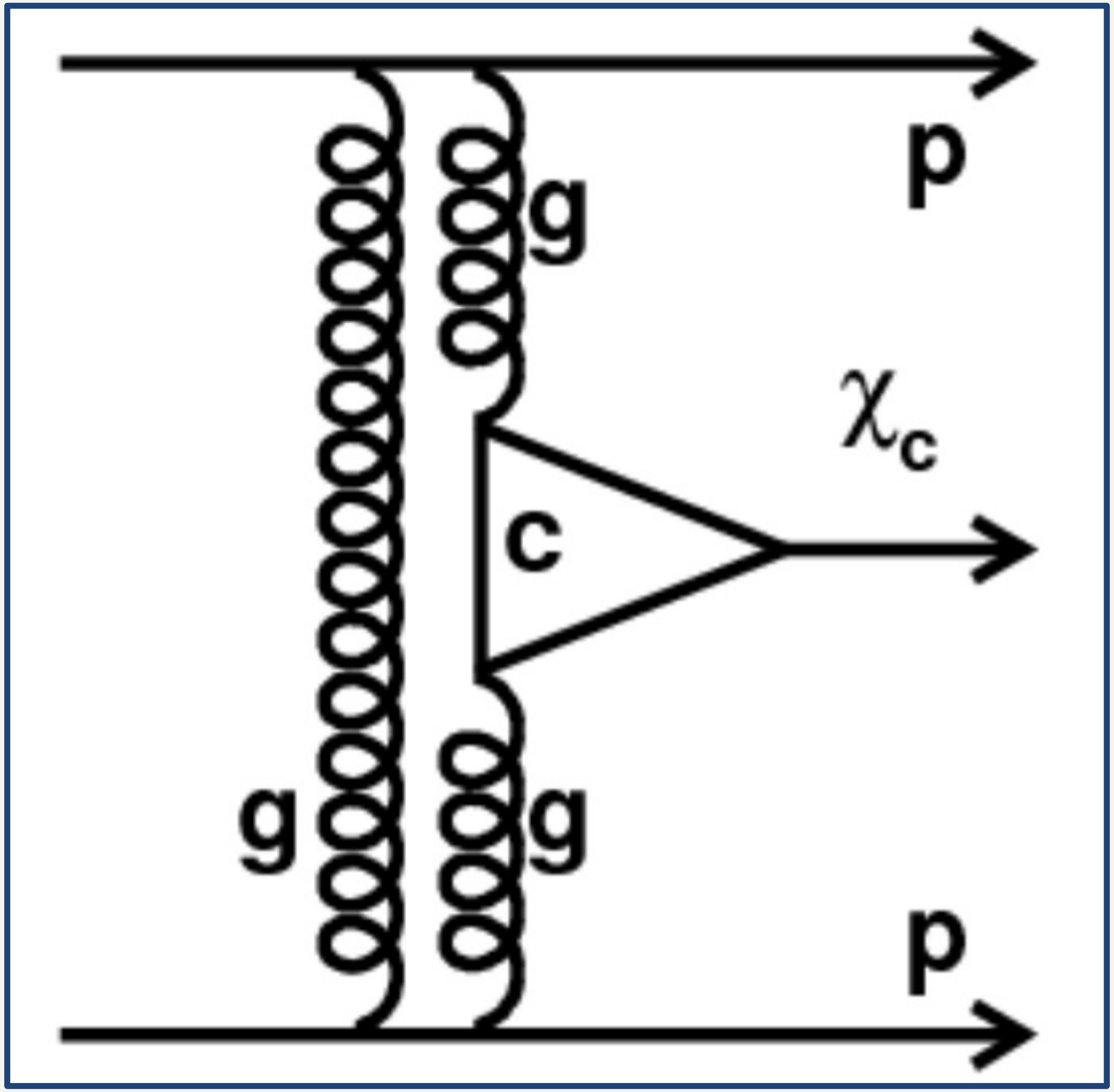
M. Klusek-Gawenda, R. McNulty, R. Schicker, A. Szczurek, Phys.Rev. D99 (2019) no.9, 093013



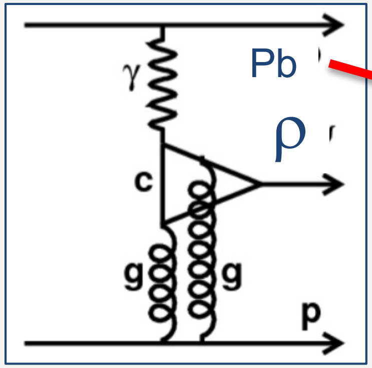


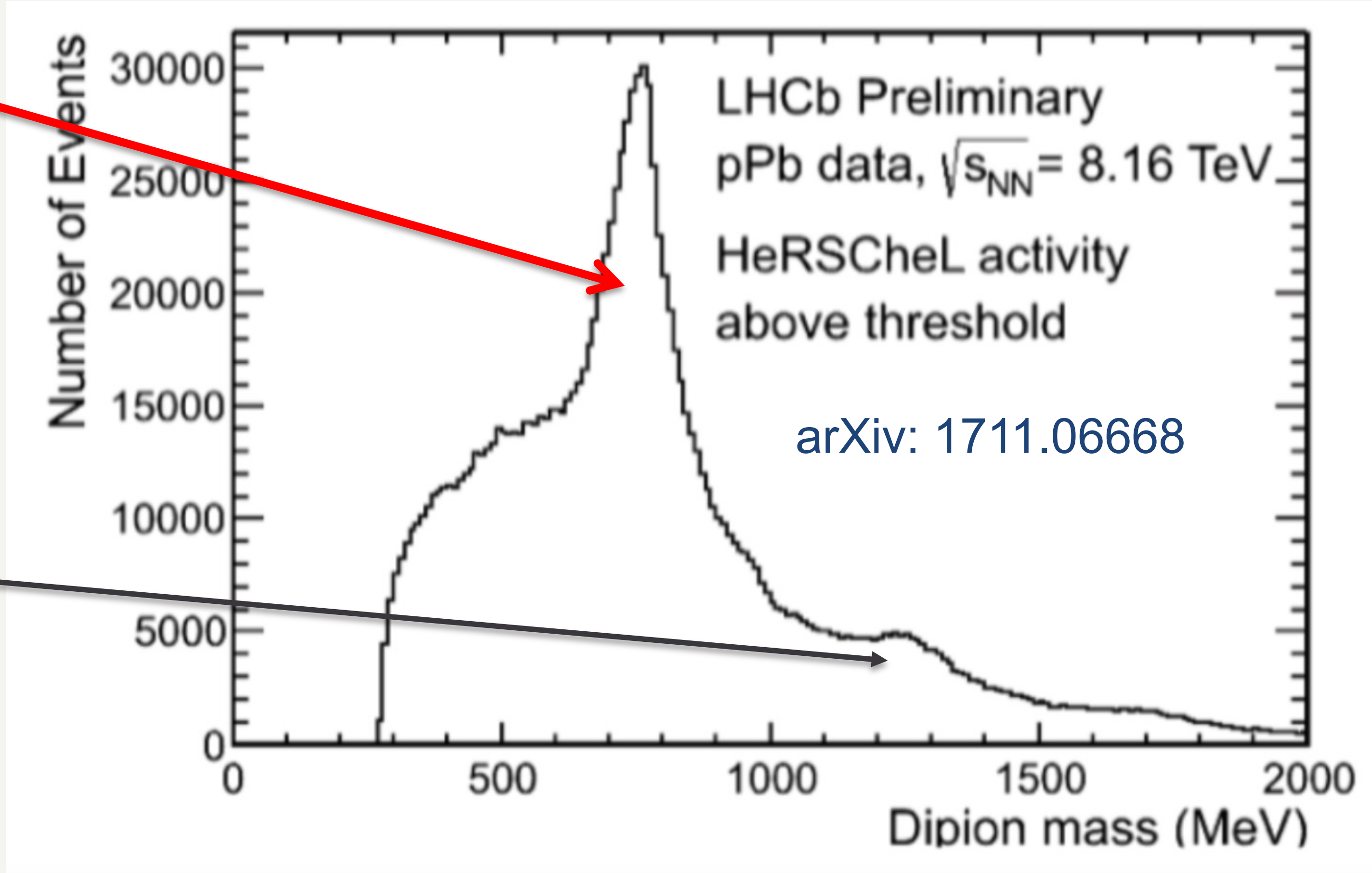
LHCb and ALICE have potential to observe this at low mass.
Important in searches for **new particle decaying to photons** (e.g. ALPs)
Also: Standard candles for η and f_2 production. Are these of interest?

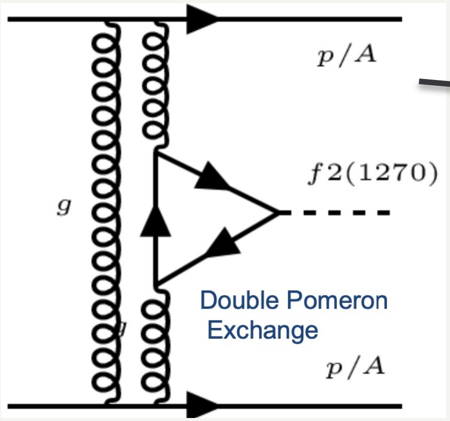
Double Pomeron Exchange



Dipions in pPb collisions





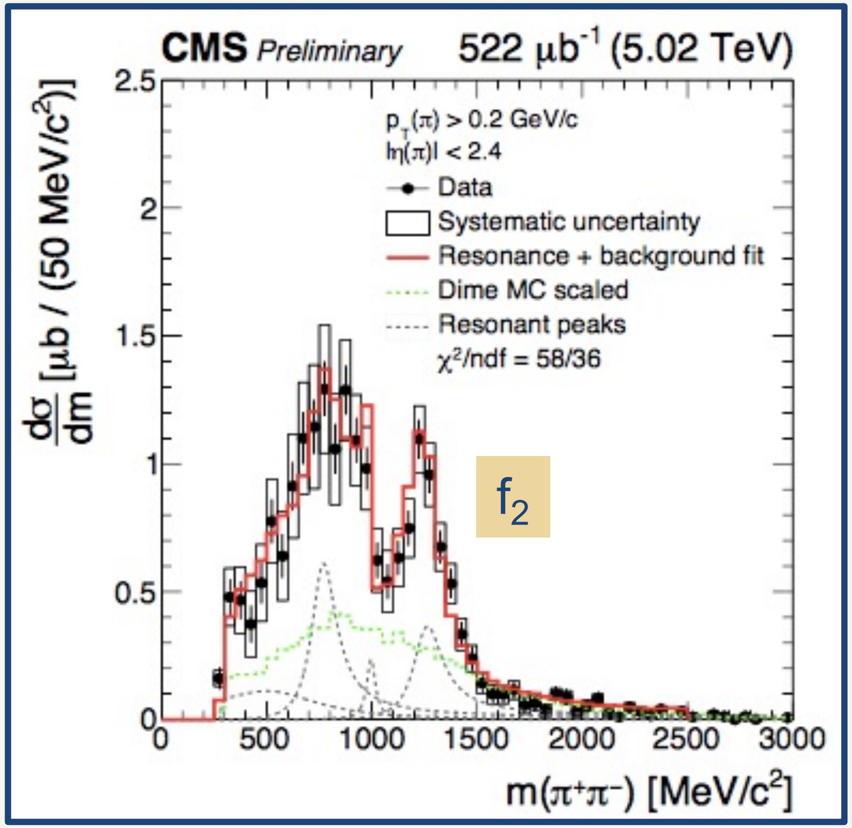


DPE and photoproduction via Reggeons

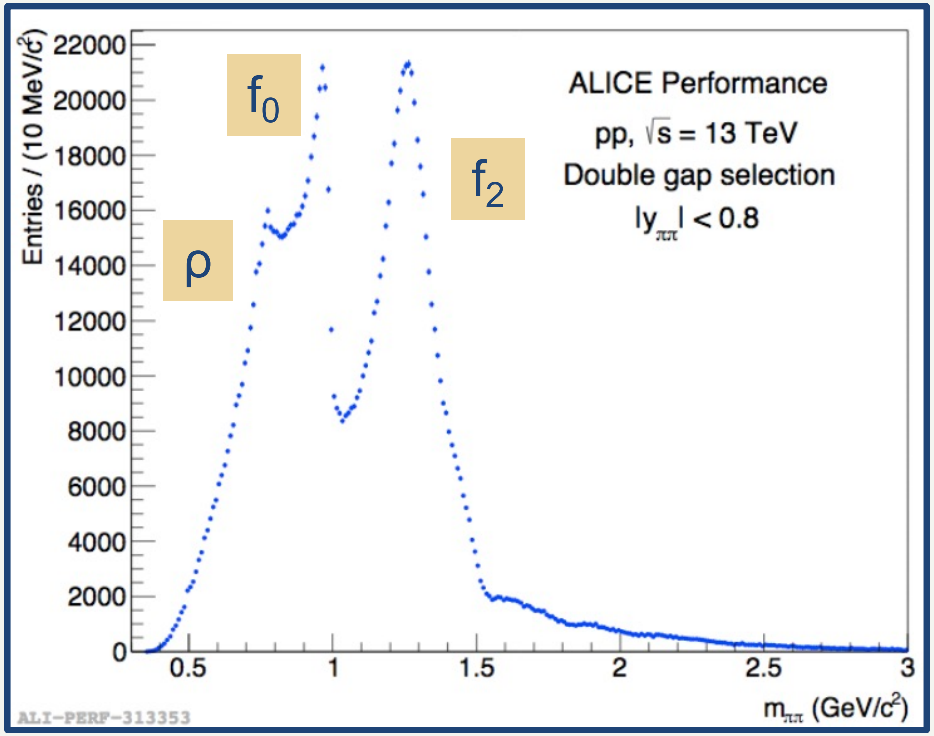
Two pions and nothing else in the LHCb detector

ππ/KK final state

CMS-PAS-FSQ-16-006



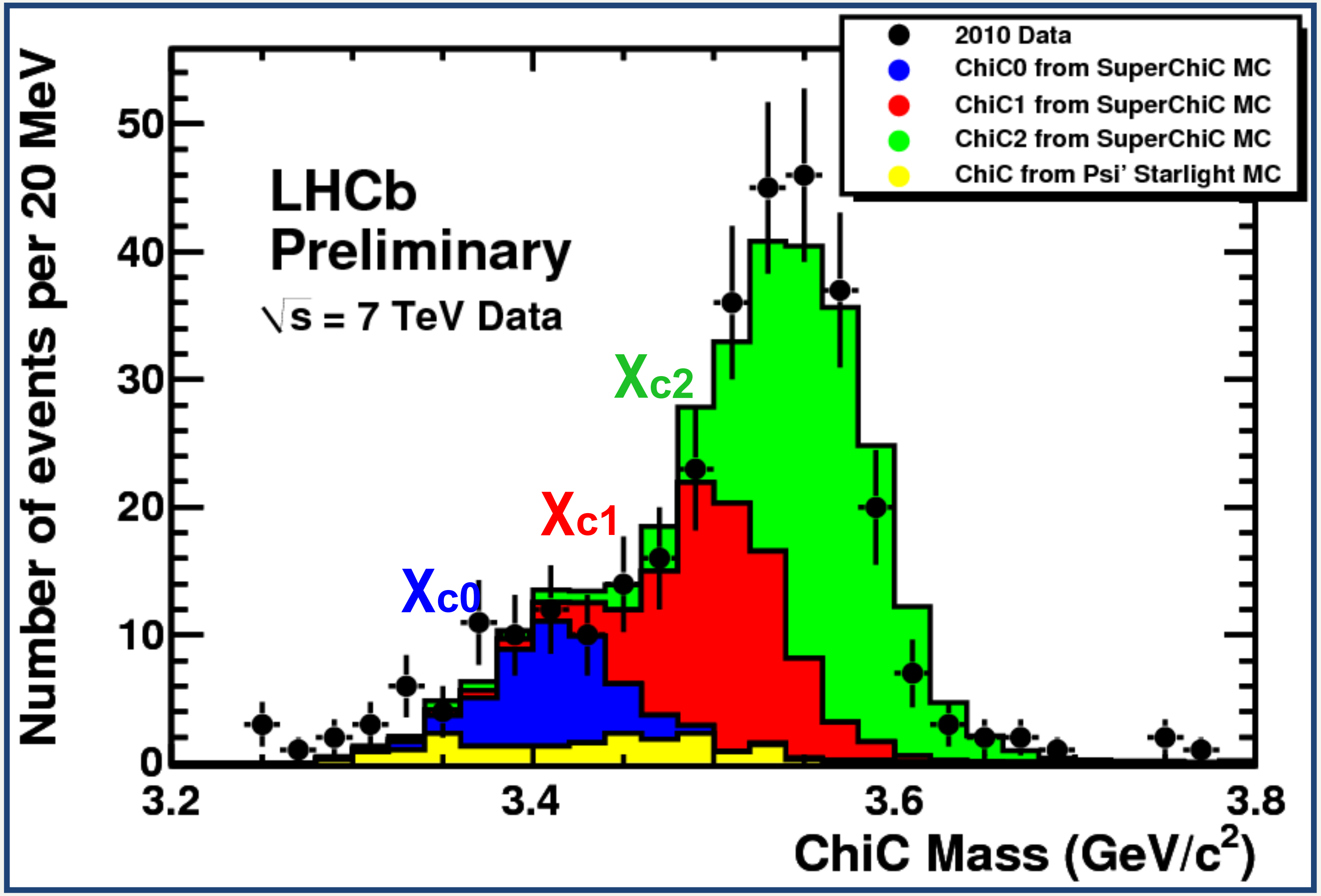
arXiv:1912.00611



LHC sees similar structures.
Note photo-production competes with DPE, especially as you go forward

Double Pomeron Exchange

LHCb-CONF-2011-022

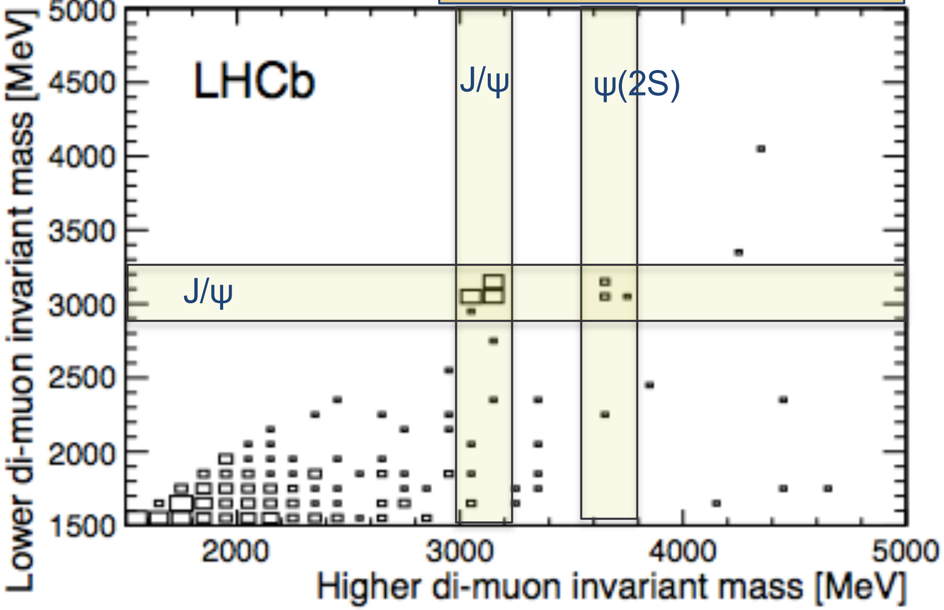


Can only be produced in DPE

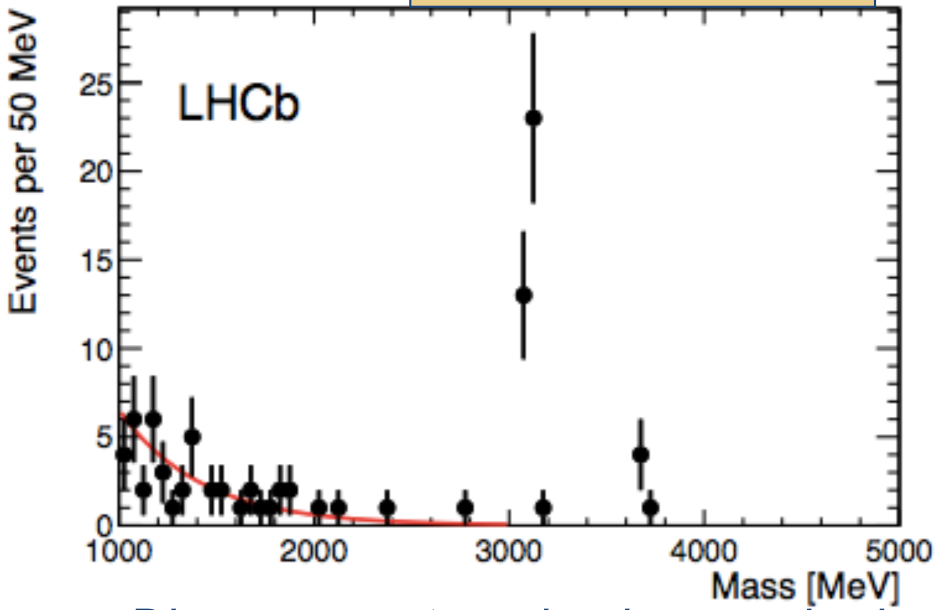
Difficult to separate peaks: work ongoing with photon conversions

Tetraquarks, hybrids, glueballs

JPG 41 (2014) 115002



JPG 41 (2014) 115002



Dimuon spectrum having required other two muons have J/ψ mass

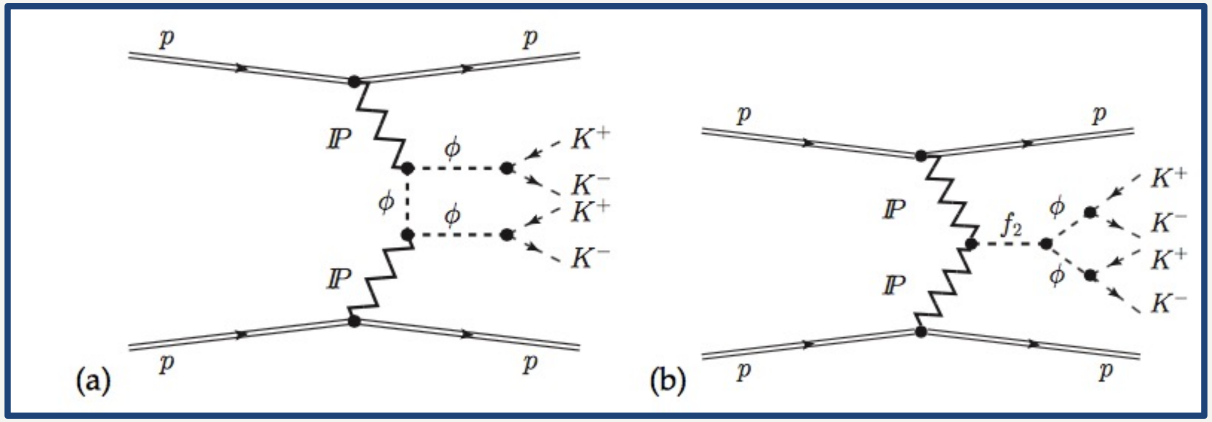
$$
\begin{aligned}
\sigma^{J/\psi\, J/\psi} &= 58 \pm 10(\text{stat}) \pm 6(\text{syst})\ \text{pb},\\
\sigma^{J/\psi\, \psi(2S)} &= 63^{+27}_{-18}(\text{stat}) \pm 10(\text{syst})\ \text{pb},\\
\sigma^{\psi(2S)\psi(2S)} &< 237\ \text{pb},\\
\sigma^{\chi_{c0}\chi_{c0}} &< 69\ \text{nb},\\
\sigma^{\chi_{c1}\chi_{c1}} &< 45\ \text{pb},\\
\sigma^{\chi_{c2}\chi_{c2}} &< 141\ \text{pb},
\end{aligned}
$$

Selection requirement:
Require precisely 4 tracks, at least three identified as muons

DPE: ϕϕ tetraquark/glueball states

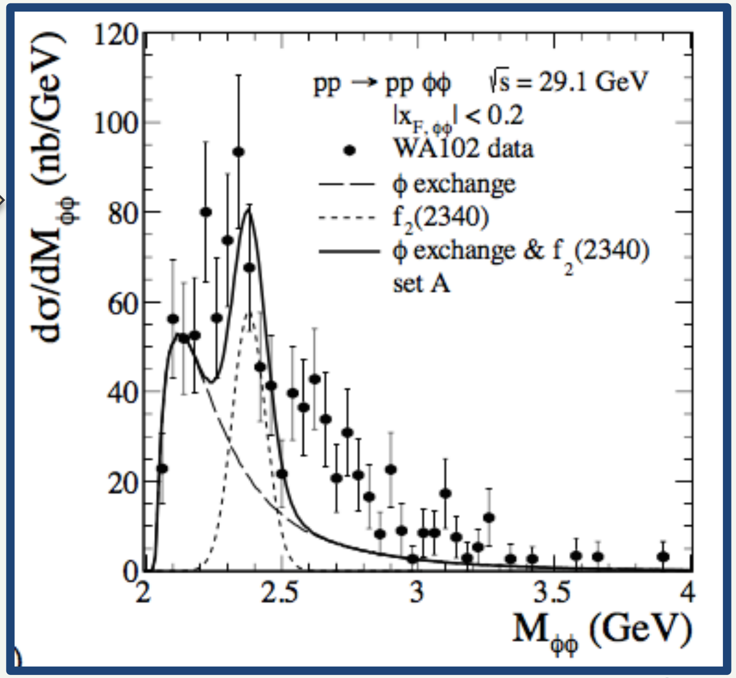
Lebiedowicz, Nachtmann, Szczurek Phys.Rev. D99 (2019) no.9, 094034

Continuum production



Resonance production

- Studied in fixed target and CEP at √s=29.1 GeV (WA102)
- Any resonances are candidates for tetraquarks or glueballs
- LHC should be able to improve on WA102 statistics.



Odderon

Pomeron: C-even colourless gluons.
Odderon: C-odd colourless gluons.
Perturbatively = 2 or 3 correlated gluons.

ELSEVIER

Physics Letters B
Volume 831, 10 August 2022, 137199

Lack of evidence for an odderon at small *t*

A. Donnachie [a], P.V. Landshoff [b]

Springer Link

Regular Article - Theoretical Physics | Open Access | Published: 19 September 2022

The ReBB model and its $H(x)$ scaling version at 8 TeV: Odderon exchange is a certainty

I. Szanyi & T. Csörgő

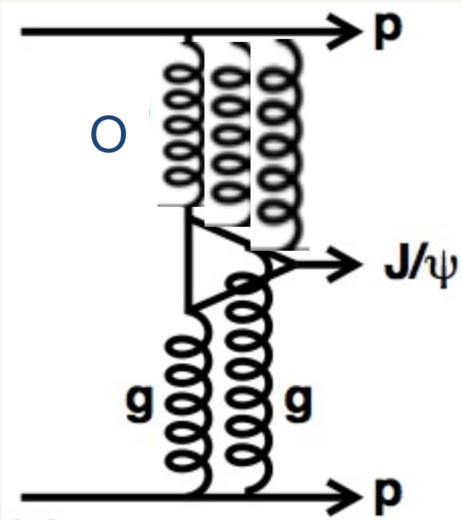
The European Physical Journal C **82**, Article number: 827 (2022) | Cite this article

arXiv:2202.03724

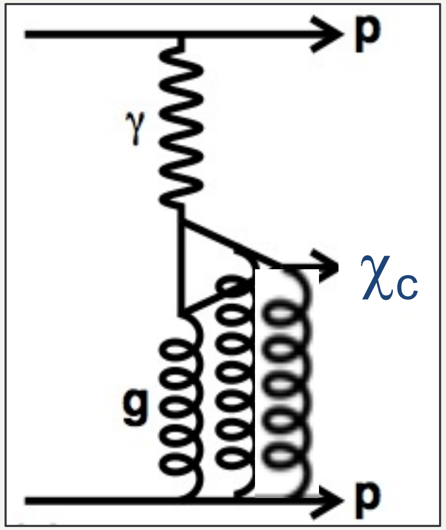
Odderon observation: explanations and answers to questions/objections regarding the PRL publication

Kenneth Österberg on behalf of the D0 and TOTEM collaborations

Odderon search in central production

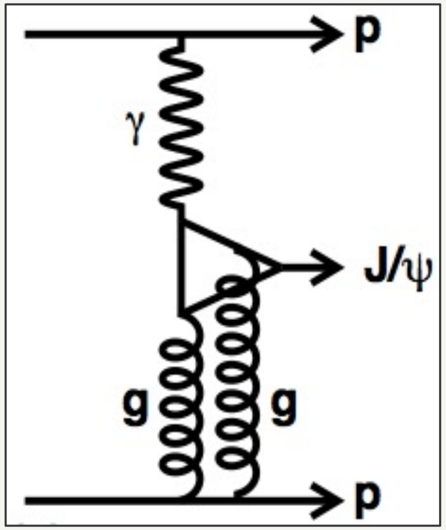


C-odd meson



C-even meson

Method 1: High p_T CEP of vector mesons.



Photoproduction of J/ψ has been measured at HERA (γ from e), Tevatron and LHC (γ from p or A)

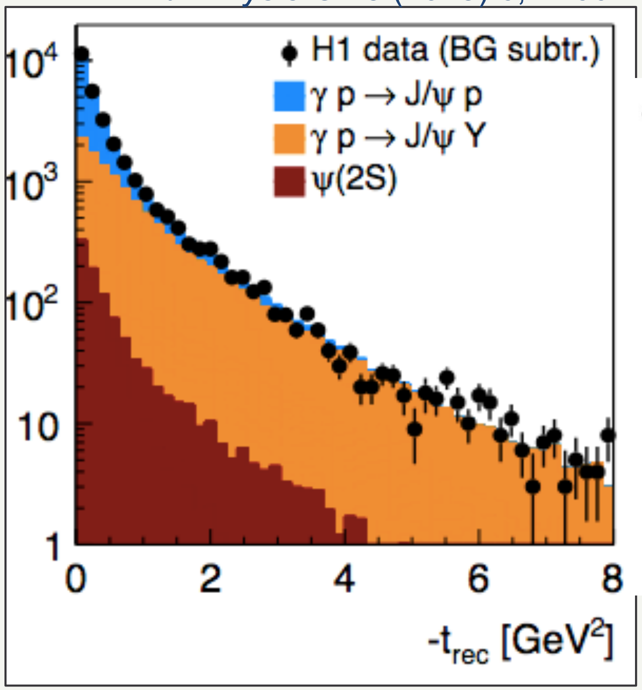
In Regge theory the momentum transfer through the Pomeron is usually modelled and the experimental data broadly supports this

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

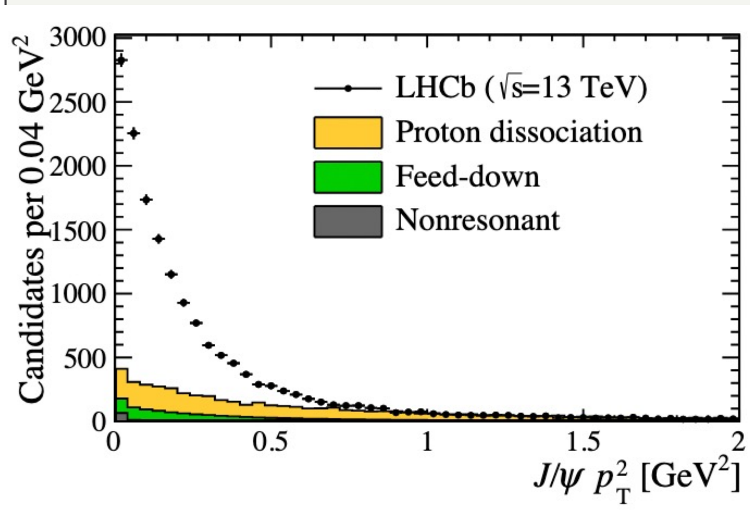
Note:

1. H1 required power-law to fit high p_T tail
2. Backgrounds dominate at high p_T

Eur.Phys.J.C 73 (2013) 6, 2466

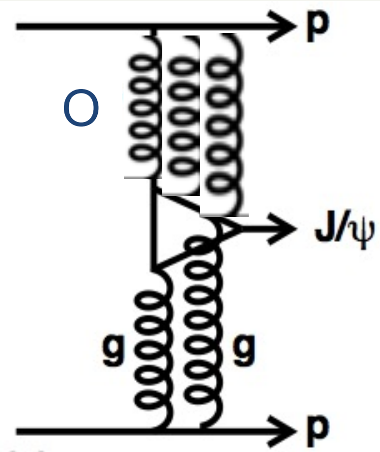


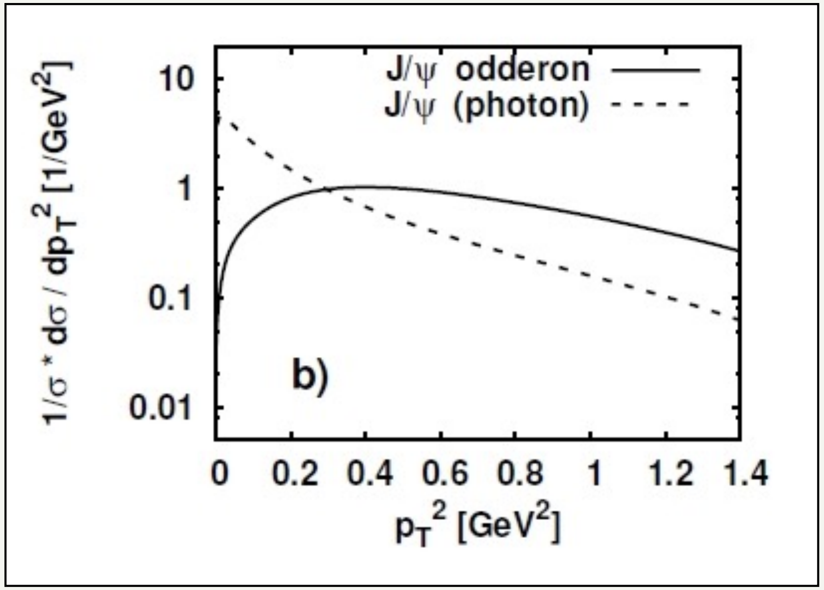
LHCb collaboration JHEP 10 (2018) 167



Method 1: High p_T CEP of vector mesons.

Replace 1^- g with 1^- O





Bzdak, Motyka, Szymanowski, Cudell PRD 75 (2007) 094023

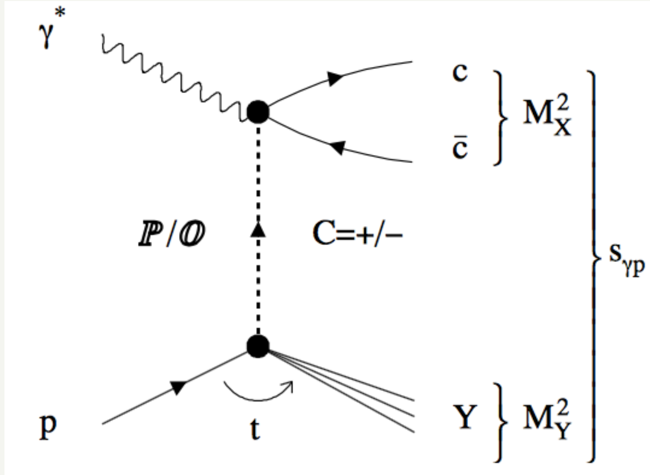
$d\sigma^{corr}/dy$	J/ψ		Υ	
	odderon	photon	odderon	photon
Tevatron	0.3–1.3–5 nb	0.8–5–9 nb	0.7–4–15 pb	0.8–5–9 pb
LHC	0.3–0.9–4 nb	2.4–15–27 nb	1.7–5–21 pb	5–31–55 pb

Odderon contribution might be 1-10% at LHC and would dominate at high p_T

….. but experimentally this is difficult to see

Angular distribution of muons due to polarisation may also differ (R. Schnicker)

Method 2: Interference C+/C-

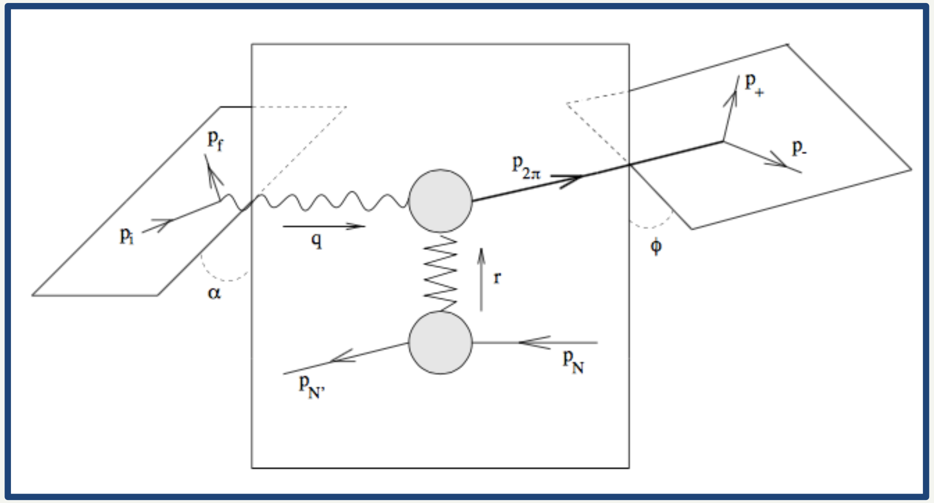


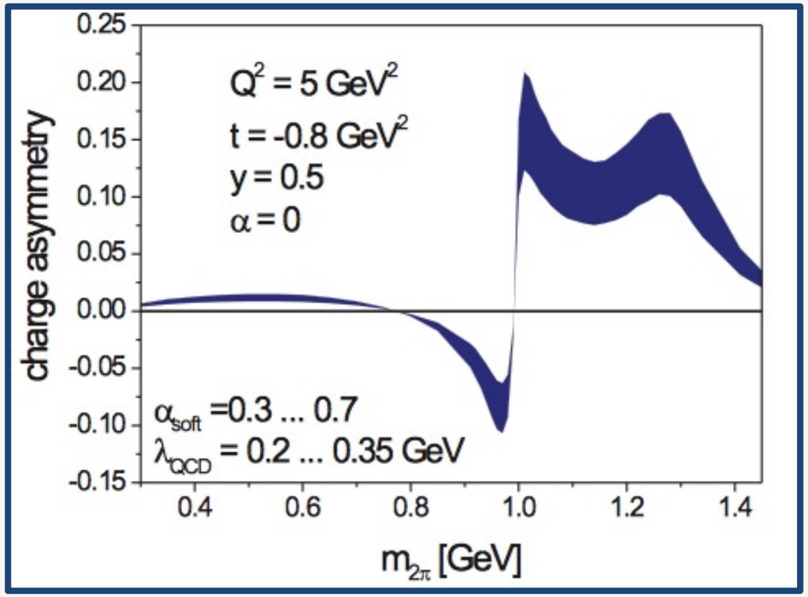
Interference of photoproduction processes

Brodsky, Rathsman, Merino, PLB461 (1998) 114.
Hagler, Pire, Szymanowski, Teryaev, EPJ26 (2002) 261.
Ginzburg, Ivanov, Nikolaev, EPJdirect 1 (2003) 1.
Bolz, Ewerz, Maniatis, Nachtmann, Sauter, Schoening, JHEP 1501 (2015) 151.

$$A(Q^2, t, m^2_{2\pi}, y, \alpha) = \frac{\sum_{\lambda=+,-} \int \cos\theta \, d\sigma(s, Q^2, t, m^2_{2\pi}, y, \alpha, \theta, \lambda)}{\sum_{\lambda=+,-} \int d\sigma(s, Q^2, t, m^2_{2\pi}, y, \alpha, \theta, \lambda)} = \frac{\int d\cos\theta \cos\theta \; N_{charge}}{\int d\cos\theta \; D}$$

N.B. linear with amplitude

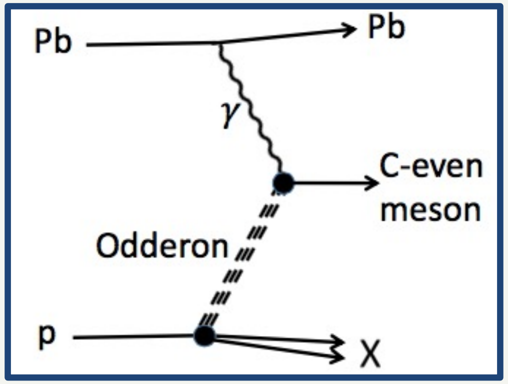




Need to tag outgoing proton to define production plane?

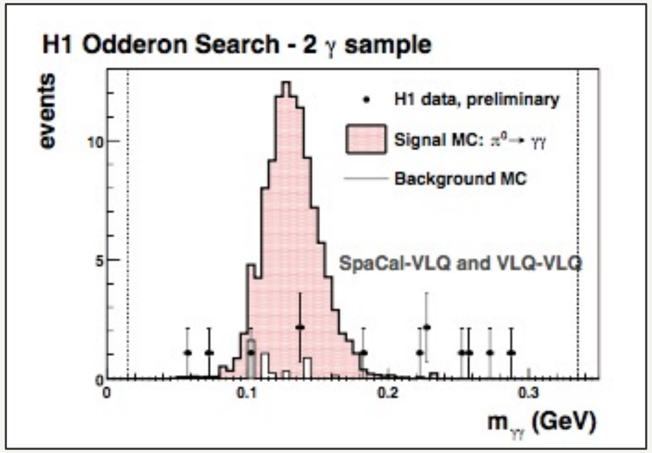
Method 3: Photoproduction of C+

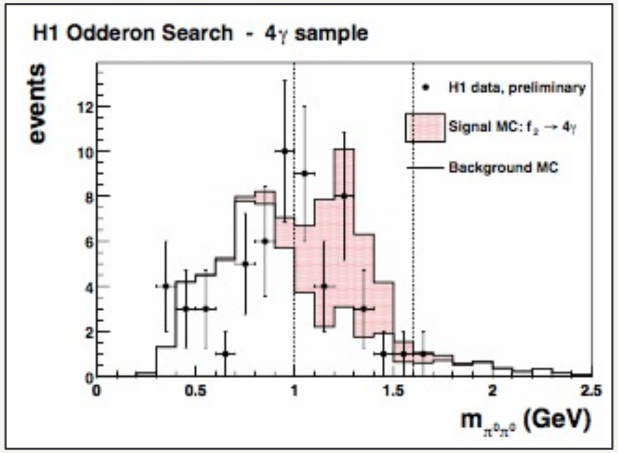
Search in CEP photoproduction where quantum numbers inconsistent with pomeron

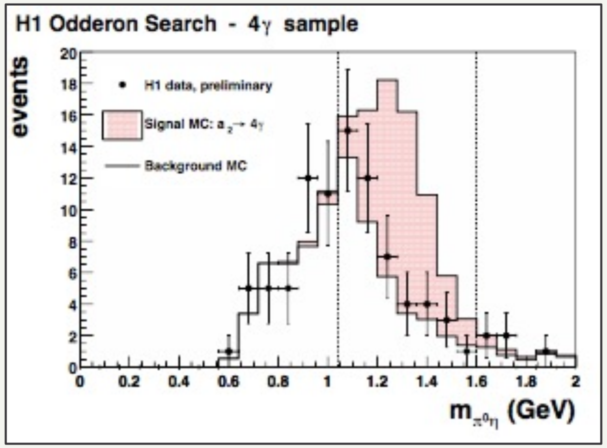


Czyzewski, Kwiecinski, Motyka, PLB398 (1997) 400.
Berger, Donnachie, Dosch, Kilian, Nachtmann, EPJ C9 (1999) 491.
Ryskin EPJ C2 (1998) 339.
Kilian & Nachtmann, EPJ C5 (1998) 317.
Harland-Lang, Khoze, Martin, Ryskin PRD 99 (2019) 3, 034011

Acta Phys. Polon. B33, 3499 (2002). (Conference proceeding.)







Direct observation at LHC?

Harland-Lang, Khoze, Martin, Ryskin PRD 99 (2019) 3, 034011

$d\sigma/dy|_{y=0}$ for Pbp collisions

C-even meson (M)	Odderon Signal		Backgrounds		
	Upper Limit	QCD Prediction	$\gamma\gamma$	Pomeron-Pomeron	$V \to M + \gamma$
π^0	7.4	0.1 - 1	0.044	–	30
$f_2(1270)$	3	0.05 - 0.5	0.020	3 - 4.5	0.02
$\eta(548)$	3.4	0.05 - 0.5	0.042	negligible	3
η_c	–	$(0.1 - 0.5) \cdot 10^{-3}$	0.0025	$\sim 10^{-5}$	0.012

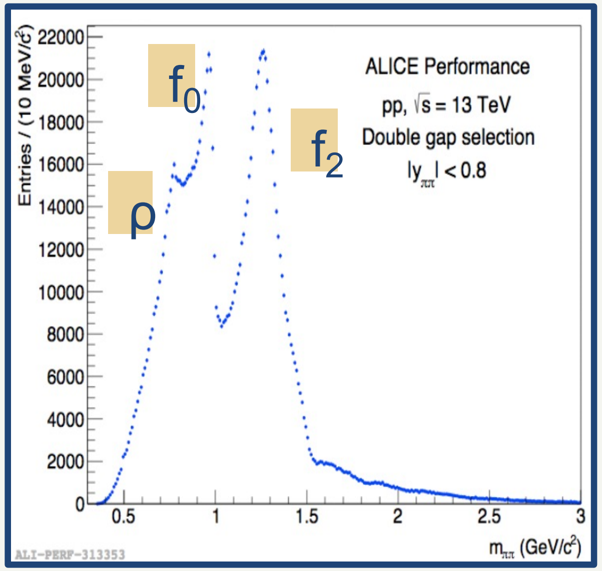
Note: Background processes are always much bigger

Which modes can provide significant signal?
How can you be sure any excess is due to odderon?

Go forward

Photoproduction of C+ meson

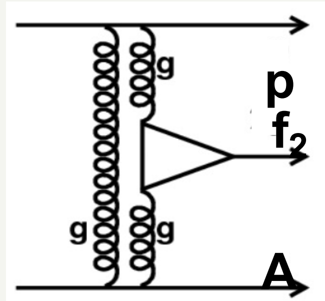
- To enhance the photon flux consider heavy ion collisions
  – Proton-ion (pA)
  – Ion-ion (AA*)
- Compared to pp collisions:
  – SIGNAL: For Pb, photon flux is ~Z^2=6700 greater and strongly peaked to backward rapidities
  – Pomeron-pomeron BKG: cross-section is factor 2-5 greater than for protons
  – $\gamma\gamma$ BKG: Z^2 enhanced in pA. Z^4 in AA! (Z^2 in AA*)



arXiv:1912.00611

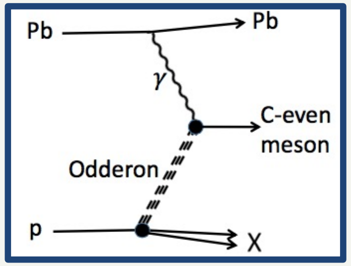
Key idea

C+ mesons dominantly produced by Double Pomeron Exchange: roughly flat with rapidity



SIGNAL PROCESS:

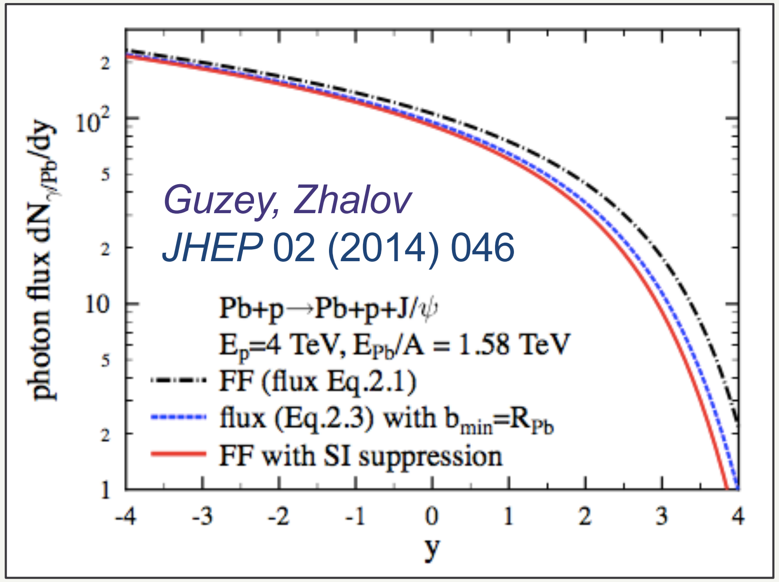
C+ production by photoproduction is peaked towards low rapidities due to energy dependence of photon flux



Ap -> A + f_2 + p
AA* -> A + f_2 + A*

$$\frac{d\sigma_{\rm Odd}}{dy} = \frac{dN}{dy}\,\sigma_{\rm Odd}(\gamma D \to f_2 D)$$

γp -> f_2 + p
γA-> f_2 + A*



$x=M_V e^{-y}$

$$\frac{d^3N_\gamma}{dx\,d^2b_\gamma} = \frac{Z^2\alpha^{\rm QED}}{x\pi^2 b_\gamma^2}\,(x m_n b_\gamma)^2\,K_1^2(x m_n b_\gamma)$$

$b>R_A+R_p$ for pA
$b>2R_A$ for AA

Results for p-Pb collisions

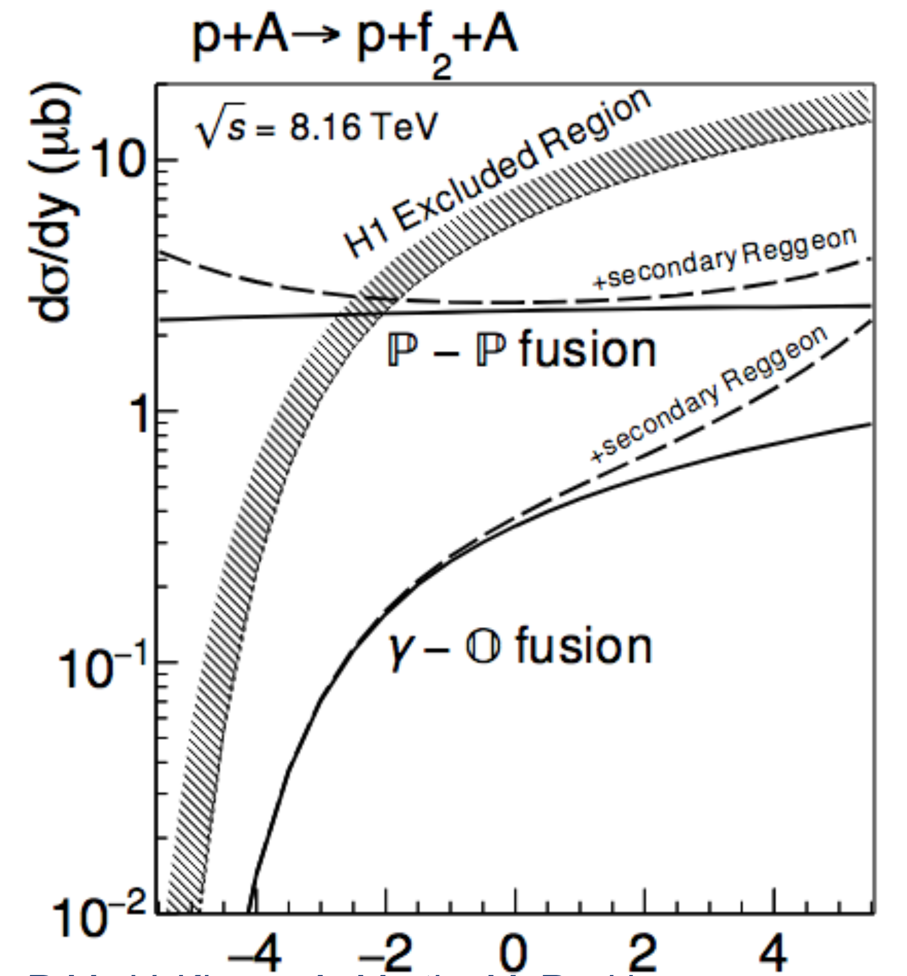
Pomeron-Pomeron production is flat and scaled to p-p results
(CMS arXiv:1706.08310)

Gamma-Odderon is forward peaked. Value unknown. Assume nominal 1nb photoproduction cross-section.

The excluded region comes from preliminary H1 result
(Acta Phys. Polon. B33, 3499 (2002))

Greater sensitivity than previous result.

An excess of events would be seen, but only in the forward region
i.e. for LHCb in pA and not Ap.
Distinctive signature



R.M., V. Khoze, A. Martin, M. Ryskin, Eur.Phys.J.C 80 (2020) 3, 288

Results for (incoherent) AA* collisions

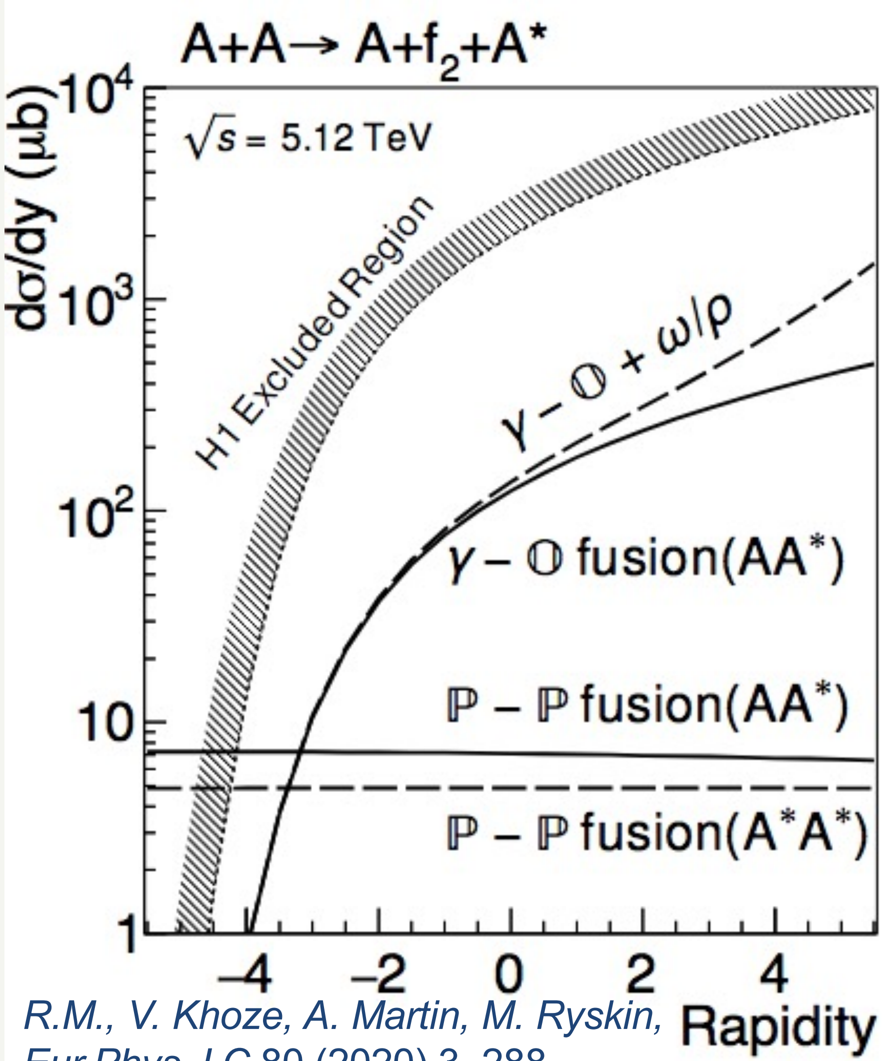
Pomeron-Pomeron production is flat and scaled to p-p results

Gamma-Odderon is forward peaked but **one needs to know which ion emitted the photon.** Detecting break-up allows us do this.

1nb photoproduction cross-section assumed again.

Cross-section is ~ factor 100 greater than in pA. However, luminosity at LHC for AA is ~ factor 100 lower.

Relative background is much lower than in pA collisions.



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Summary

- Rich physics
  - QCD v Regge Theory and transition from perturbative to non-perturbative regimes
  - PDF extraction
  - nuclear suppression
  - meson spectroscopy
  - exotica: tetraquarks, glueballs
  - saturation
  - dark photon searches
  - odderon searches
- CEP provides a clean experimental laboratory, with excellent potential for increasing our understanding, and possibilities for discovery.