QCD EXOTICA: FROM LHC TO EIC

LHC
High Energy
Medium/High Luminosity
High Backgrounds

→

EIC
Low Energy
High Luminosity
Low Backgrounds
(detector design)

Ronan McNulty (UCD)

ECT* Workshop, Trento, 19-21 Dec 2018.

QCD: Great Expectations

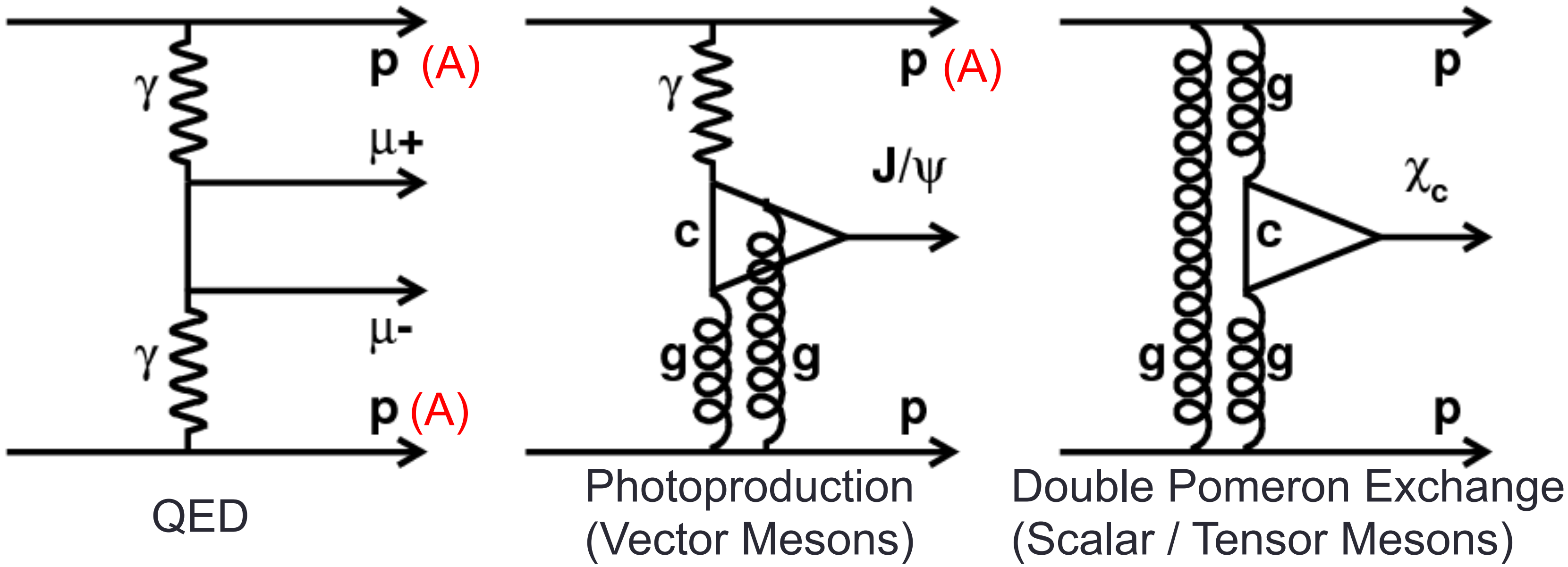
- Extensions to the quarks model
  - Tetraquarks
  - Hybrids
  - Glueballs
- Odderon
- Saturation
- Dark photons

“Take nothing on its looks; take everything on evidence. There's no better rule.”
Charles Dickens, Great Expectations.

LHC

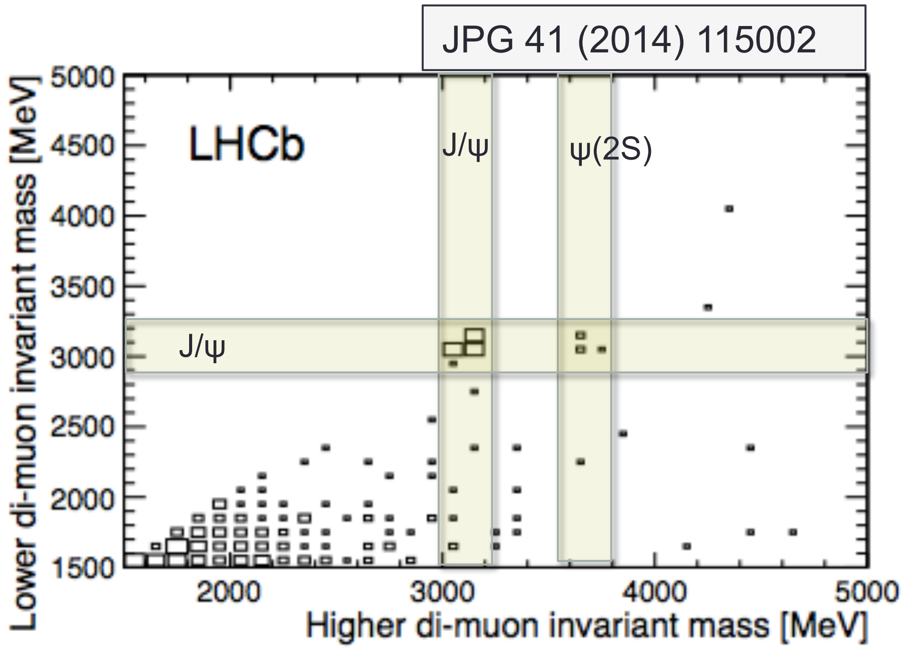
- CMS and ATLAS are designed for high-Pt physics.
  - Trigger bandwidth dedicated to supersymmetry etc not forward physics
  - Low-pt objects often absorbed or scattered
  - Multiple pp interactions 10-50.
  - However, some dedicated low-lumi runs and proton tagging
- LHCb designed for low-Pt physics in forward region
  - Huge samples of low multiplicity events (<10 tracks)
  - Good pion, kaon, photon, electron identification for pT>~200 MeV
  - Typical pile-up of ~1.
  - But no proton-tagging....

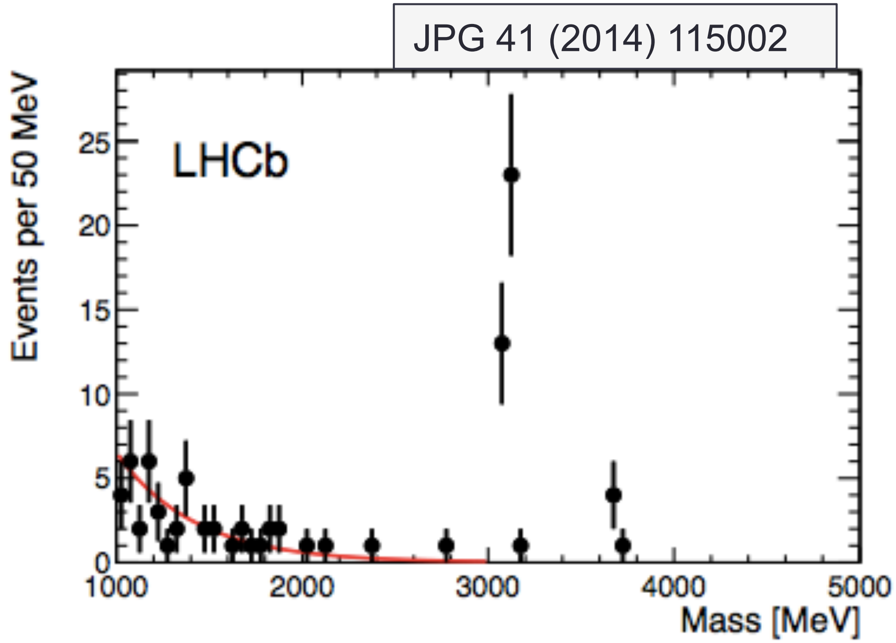
CEP: Colourless propagators



- Signal: central system with rapidity gaps down to proton
- Background: proton dissociation & finite detector acceptance.
- pp running: generally $\sigma_{PP} > \sigma_{P\gamma} > \sigma_{\gamma\gamma}$
- pA running
  - $\sigma_{P\gamma}$ enhanced by Z^2 in UPC, σ_{PP} enhanced by $A^{1/3}$
- AA running
  - $\sigma_{\gamma\gamma}$ enhanced by Z^4 in UPC

Searching for tetraquarks

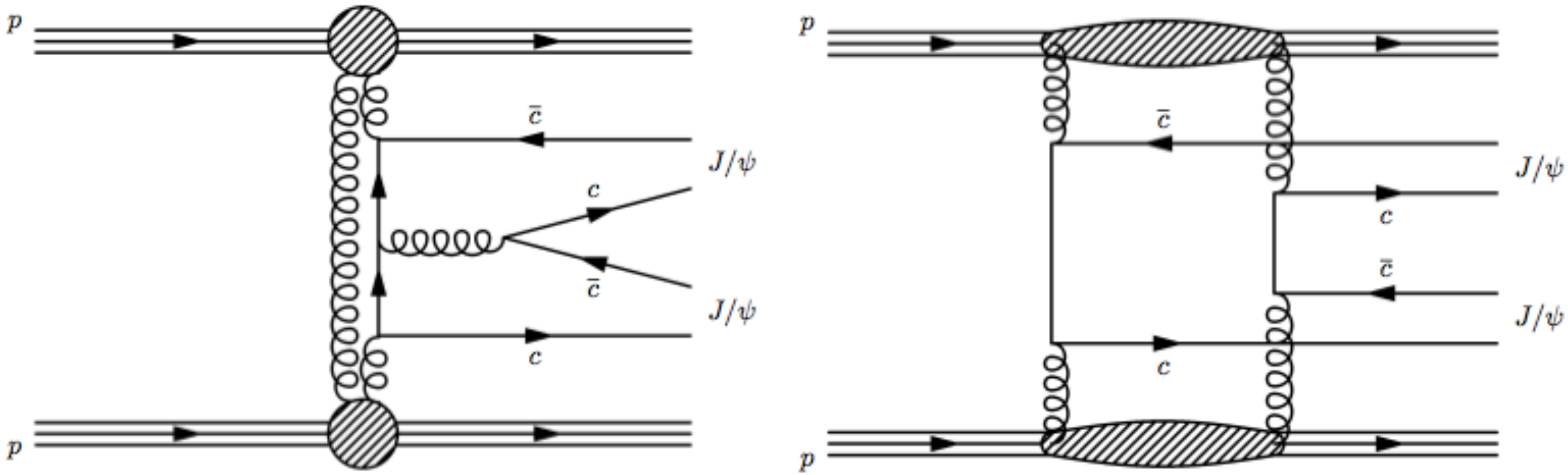




Dimuon spectrum having required other two muons have J/ψ mass

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

Double J/ψ production



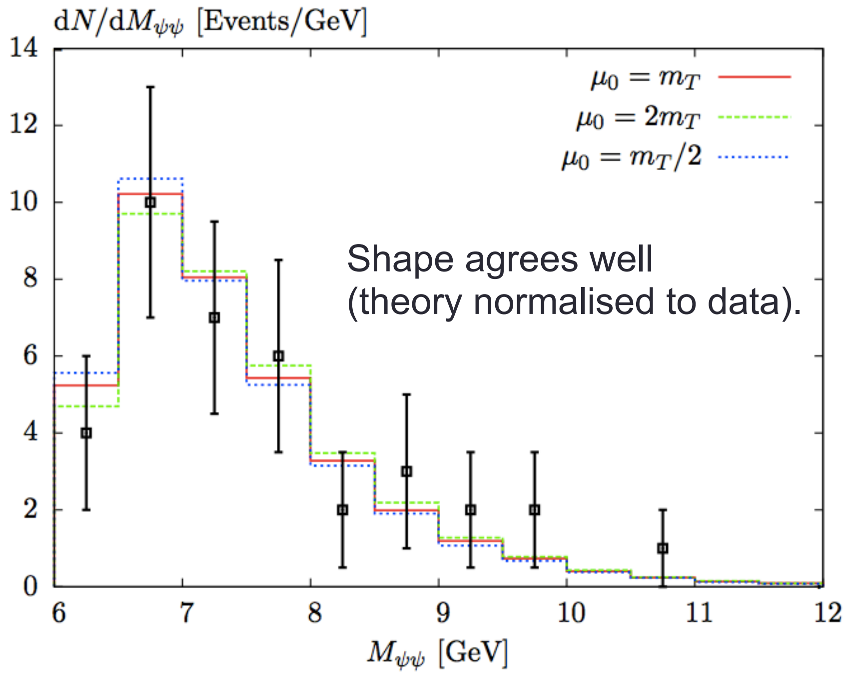
Final state theoretically studied in diphoton production (linear collider) but not through double pomeron exchange (hadron collider)

Sensitivity to higher mass states (tetraquarks, η_b)
Inclusive production has attracted much interest (DPS effects)

Double J/ψ production (Tetraquark candidate)

LHCb estimates exclusive cross-section. **24+-9 pb**

Harland-Lang, Khoze, Ryskin: JPG 42 (2015) 5,055001 **2-7 pb**

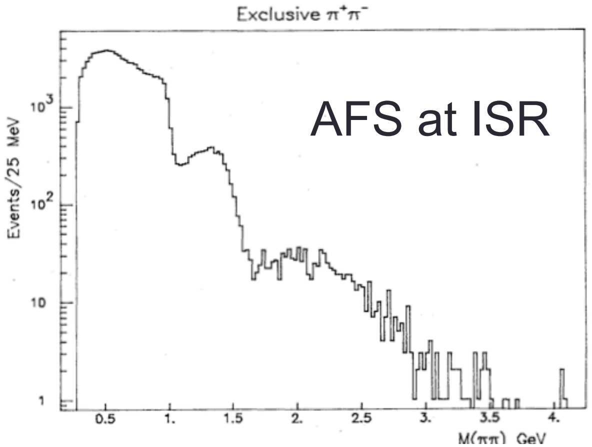


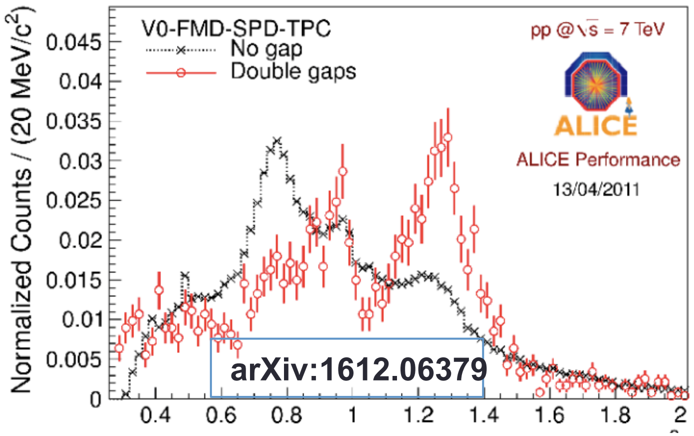
Lessons learnt:
A very distinctive signal (leptons) is clearly observable at hadron colliders.
You don’t know what you find until you look...
Theory may need updating

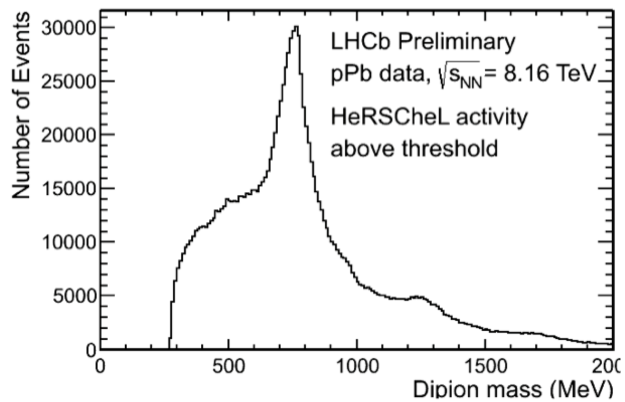
EIC message: Produce such states through gamma-gamma collisions.

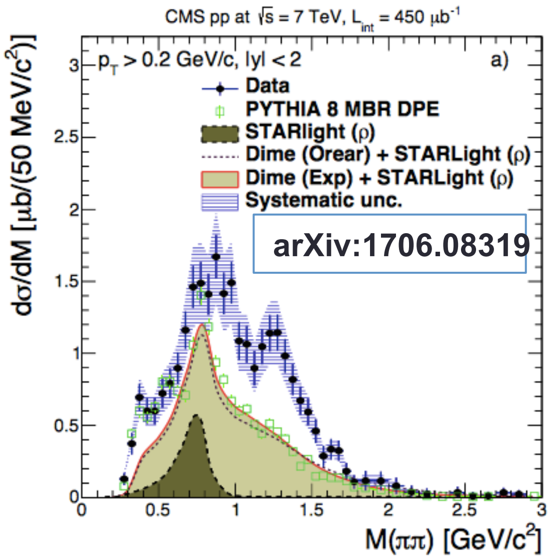
Hybrids

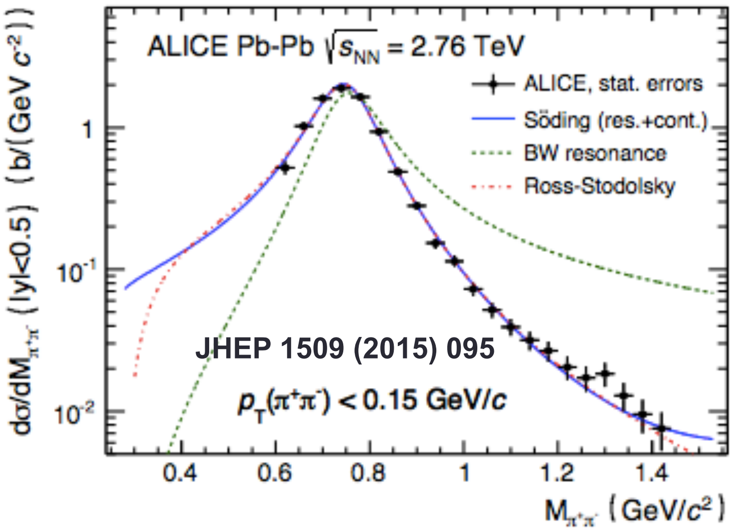
LHC has large samples of Central Exclusive Produced $\pi^+ \pi^0 K^+ K^0 \eta\ \eta'\ \gamma\ e\ \mu$ in pp, pA and AA data.

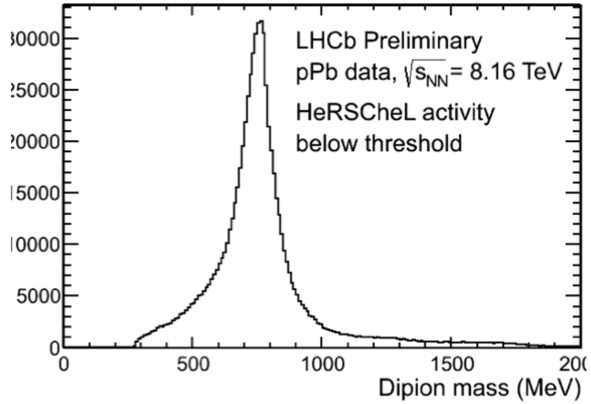










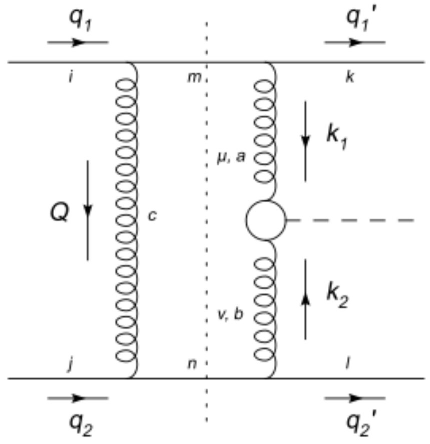


Difficulty separating competing resonances. PWA: Reconstruct cosθ* but not Φ*

EIC message: Proton/Ion tagging

Glueballs

Double-pomeron-exchange processes: Glue Laboratory

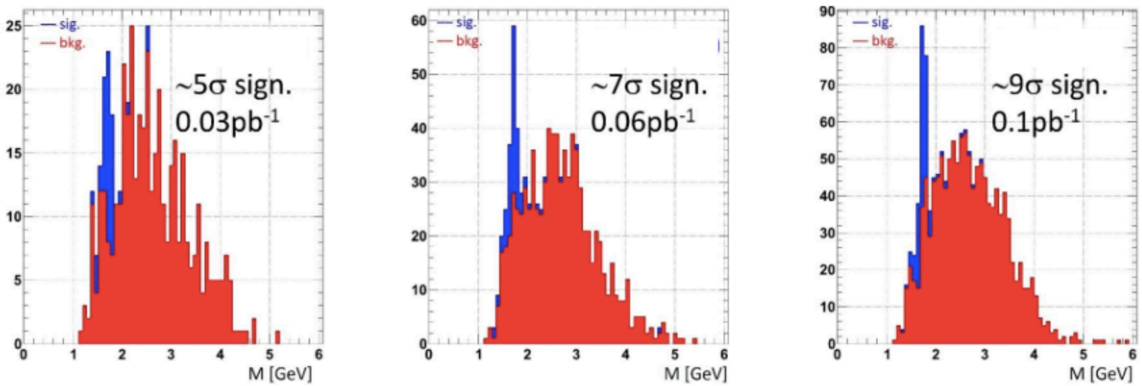


Glueballs: decay characterisation

Analysis of available common CMS-TOTEM data set ($\mathcal{L}$ = 3 nb^{-1} of double arm RP trigger) show sensitivity to $f_0(1710) \rightarrow \rho^0\rho^0$.

Study signal + non-resonant $\rho^0\rho^0$ background (DIME MC[1]) using parametrisation of CMS tracker performance

$\Rightarrow$ **0.06 pb^{-1} needed for $f_0(1710)$ observation**



K. Osterberg
LHC Forward Meeting
7.12.2014

How do we know when we have found it? Democratic final states?

EIC message: Little sensitivity

Odderon

ELSEVIER

Physics Letters B

Volume 778, 10 March 2018, Pages 414-418

open access

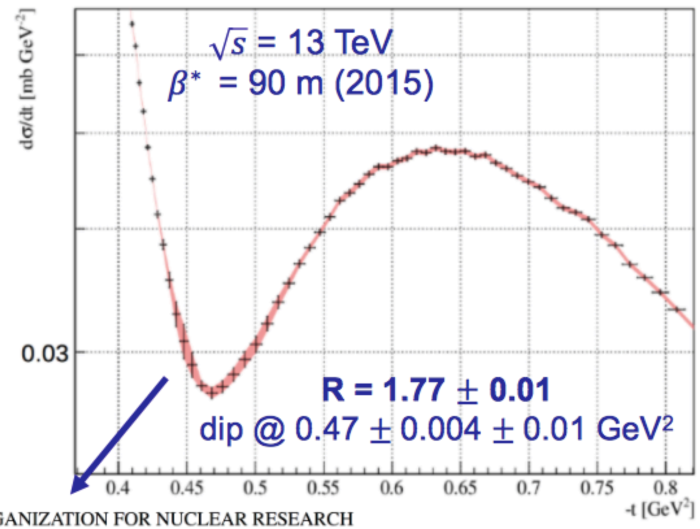
Did TOTEM experiment discover the Odderon?

Evgenij Martynov [a], Basarab Nicolescu [b]

TOTEM

Diffractive dip in pp @ $\sqrt{s}$ = 13 TeV

TOTEM: observation of diffractive dip in $d\sigma_{el}/d|t|$ @ $\sqrt{s}$ = 13 TeV



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

TOTEM 2018-003
December 13, 2018

CERN-PH-EP-2018-?
December 13, 2018

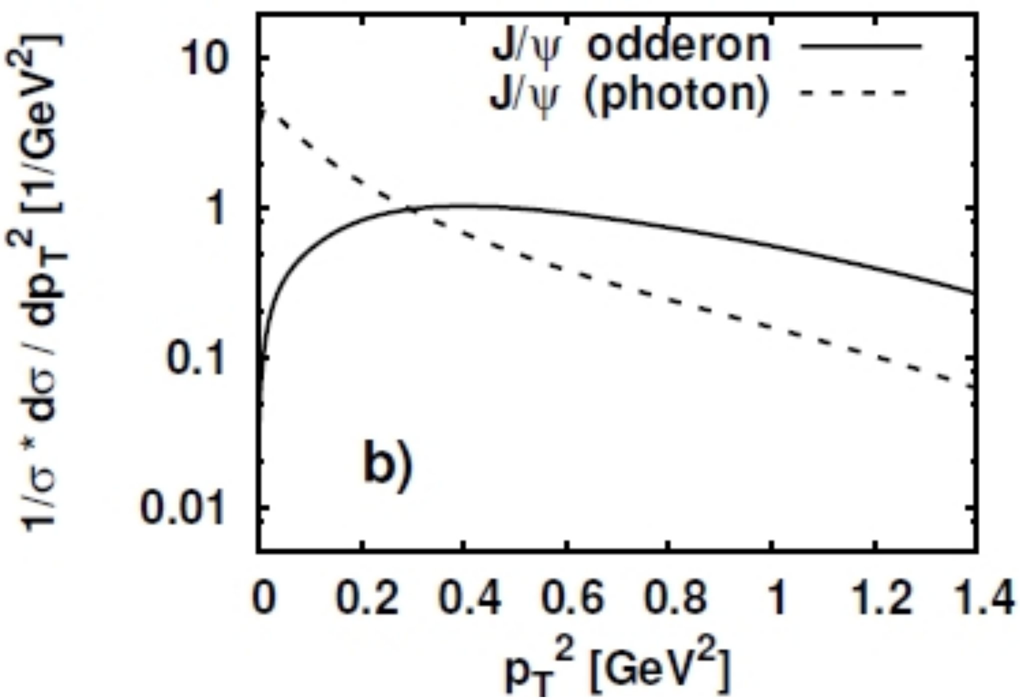
Elastic differential cross-section measurement at $\sqrt{s}$ = 13 TeV by TOTEM

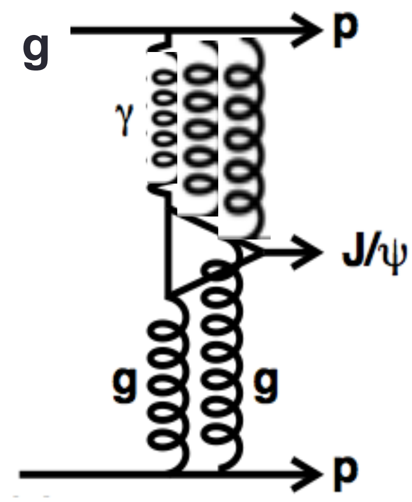
The TOTEM Collaboration

paper approved by CERN-PH, soon in CDS !!

From K.Osterberg yesterday at Forward Meeting CERN.

The odderon (1)



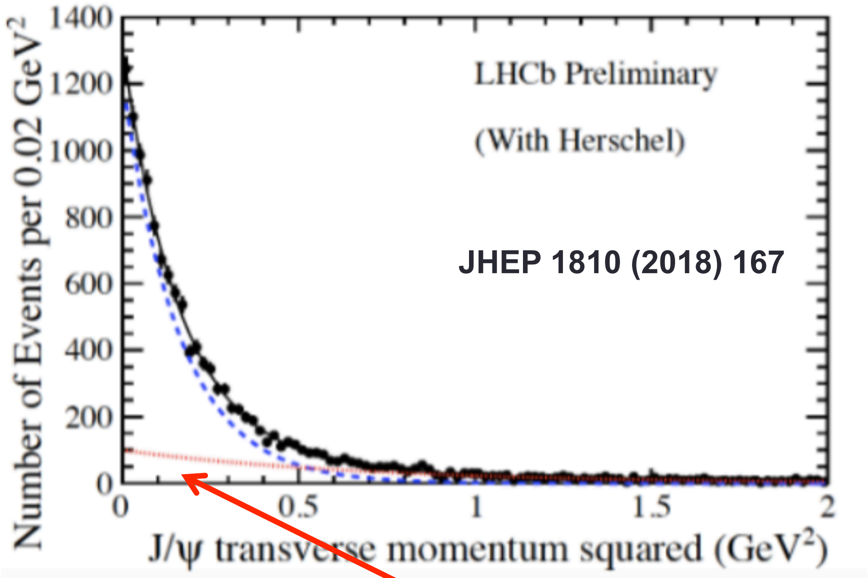


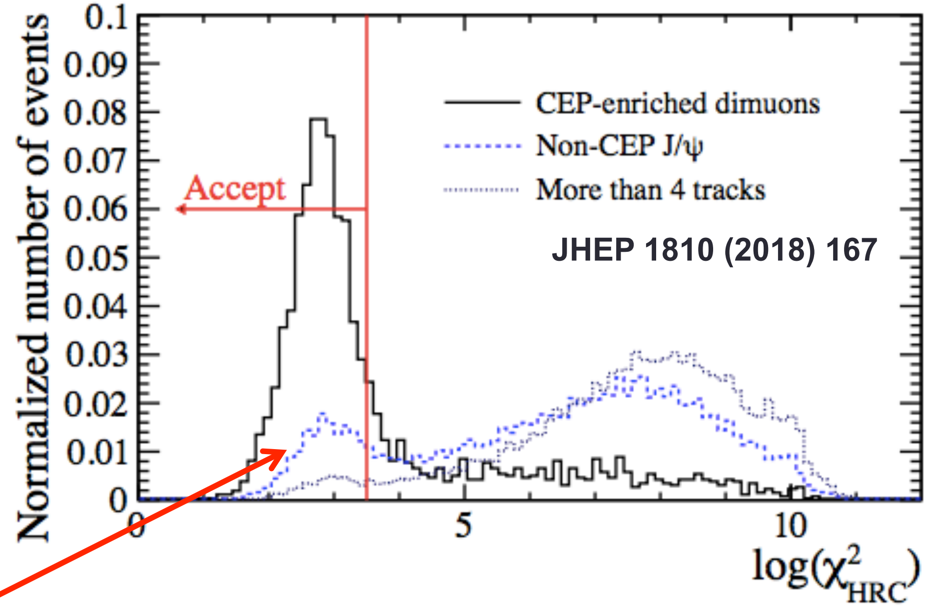
Bzdak, Motyka, Szymanowski, Cudell
PRD 75 (2007) 094023
arXiv:0808.2216

$d\sigma^{corr}/dy$	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

Requires understanding p_T^2 spectrum for proton dissociation (or rejection of it)

Odderoproduction





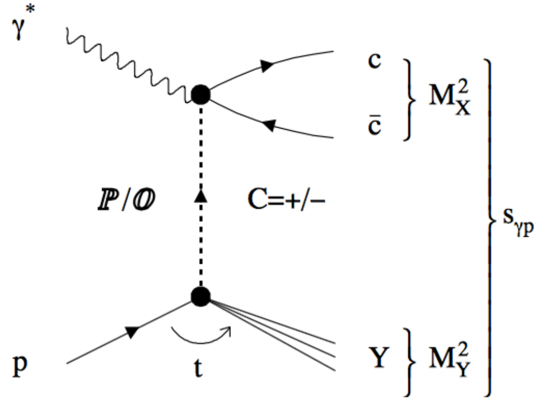
Activity at very low pseudorapidity

Proton dissociation or Odderoproduction ? !

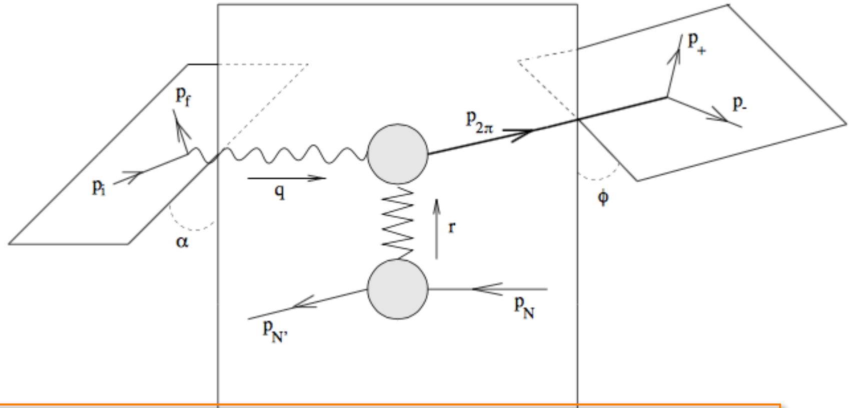
EIC message: Proton tagging

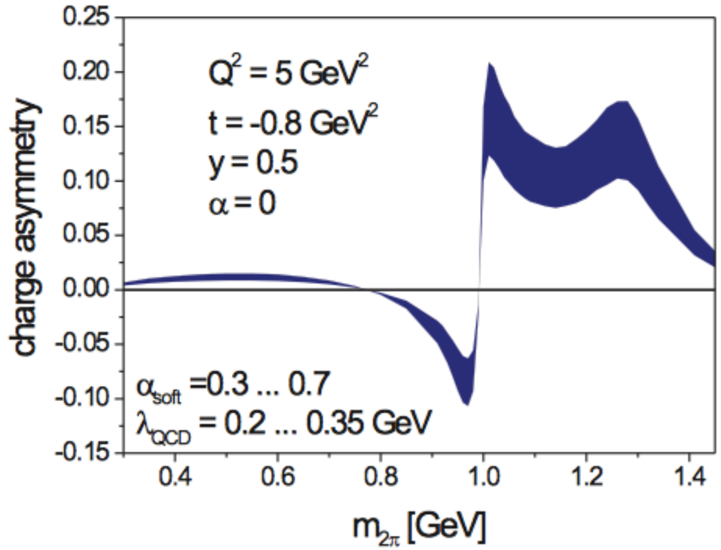
Open questions in QCD: The odderon (2)

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



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

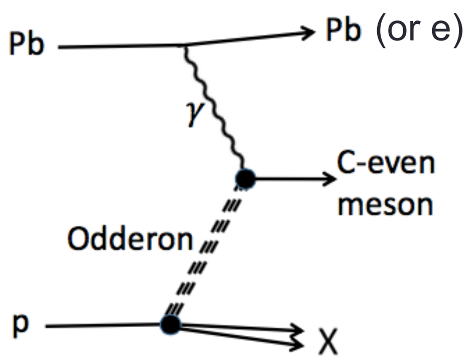




EIC message: Detect outgoing proton

Open questions in QCD: The odderon (3)

$\gamma p \to \eta p$, $\gamma p \to \pi^0 p$, $\gamma p \to f_2 p$, $\gamma\gamma \to \pi^0\pi^0$

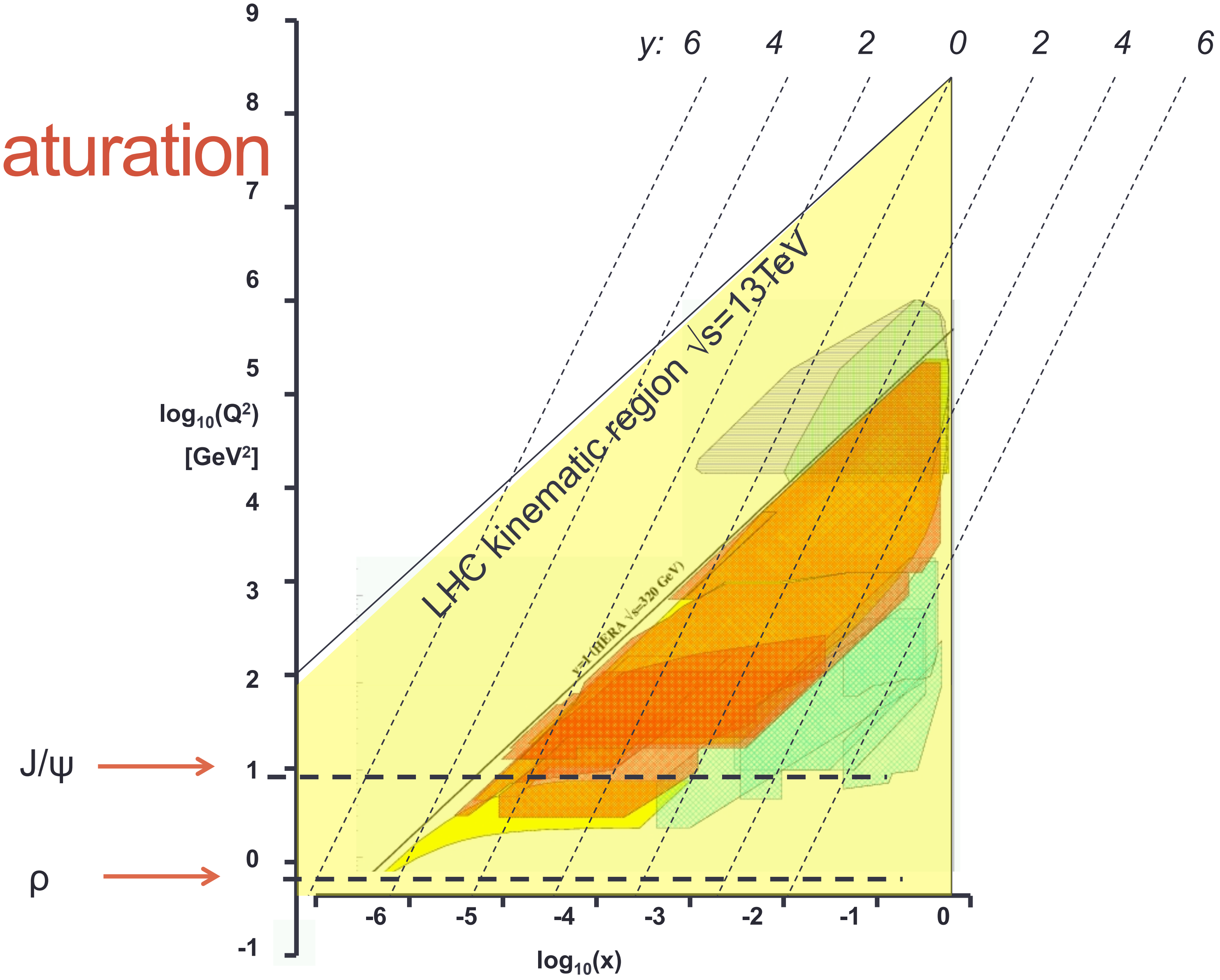


Czyzewski et al., PLB398 (1997) 400.
Berger et al., EPJ C9 (1999) 491.
M.G. Ryskin EPJ C2 (1998) 339.
Kilian & Nachtmann, EPJ C5 (1998) 317.
Harland-Lang et al. arXiv:1811.12705

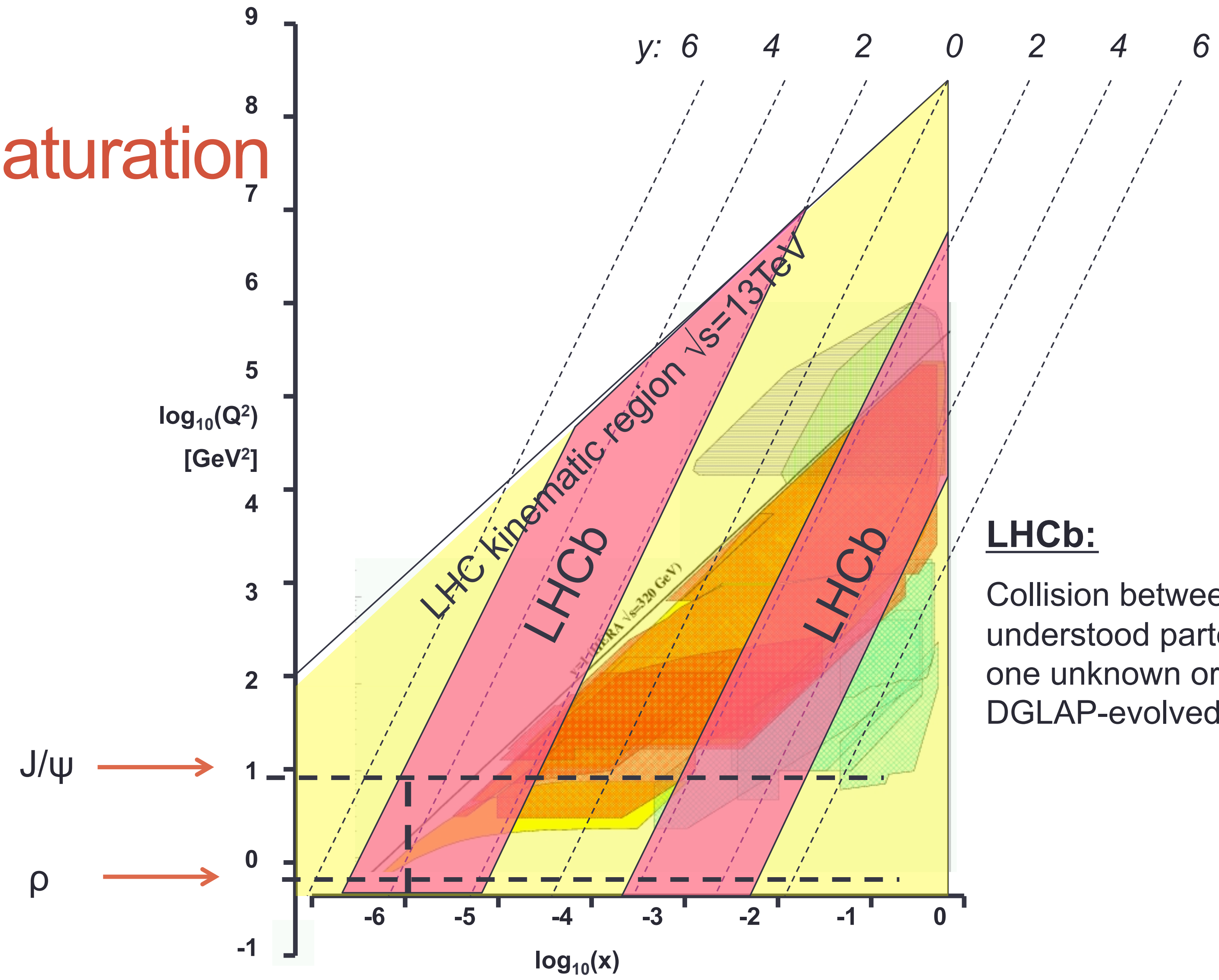
C-even meson (M)	Odderon Signal		Backgrounds		
	Upper Limit	QCD Prediction	$\gamma\gamma$	Pomeron-Pomeron	$V \to M + \gamma$
π^0	7.4	0.1 - 1	0.044	–	30
$f_2(1270)$	3	0.05 - 0.5	0.020	3 - 4.5	0.02
$\eta(548)$	3.4	0.05 - 0.5	0.042	negligible	3
η_c	–	$(0.1 - 0.5) \cdot 10^{-3}$	0.0025	$\sim 10^{-5}$	0.012

EIC message: Perfect use-case. Comparison of ep and e-ion in high luminosity environment should find these if they exist

Saturation


y: 6 4 2 0 2 4 6
LHC kinematic region √s=13TeV
y=1 (HERA √s=320 GeV)
log10(Q2) [GeV2]
9
8
7
6
5
4
3
2
1
0
-1
-6 -5 -4 -3 -2 -1 0
log10(x)
J/ψ
ρ

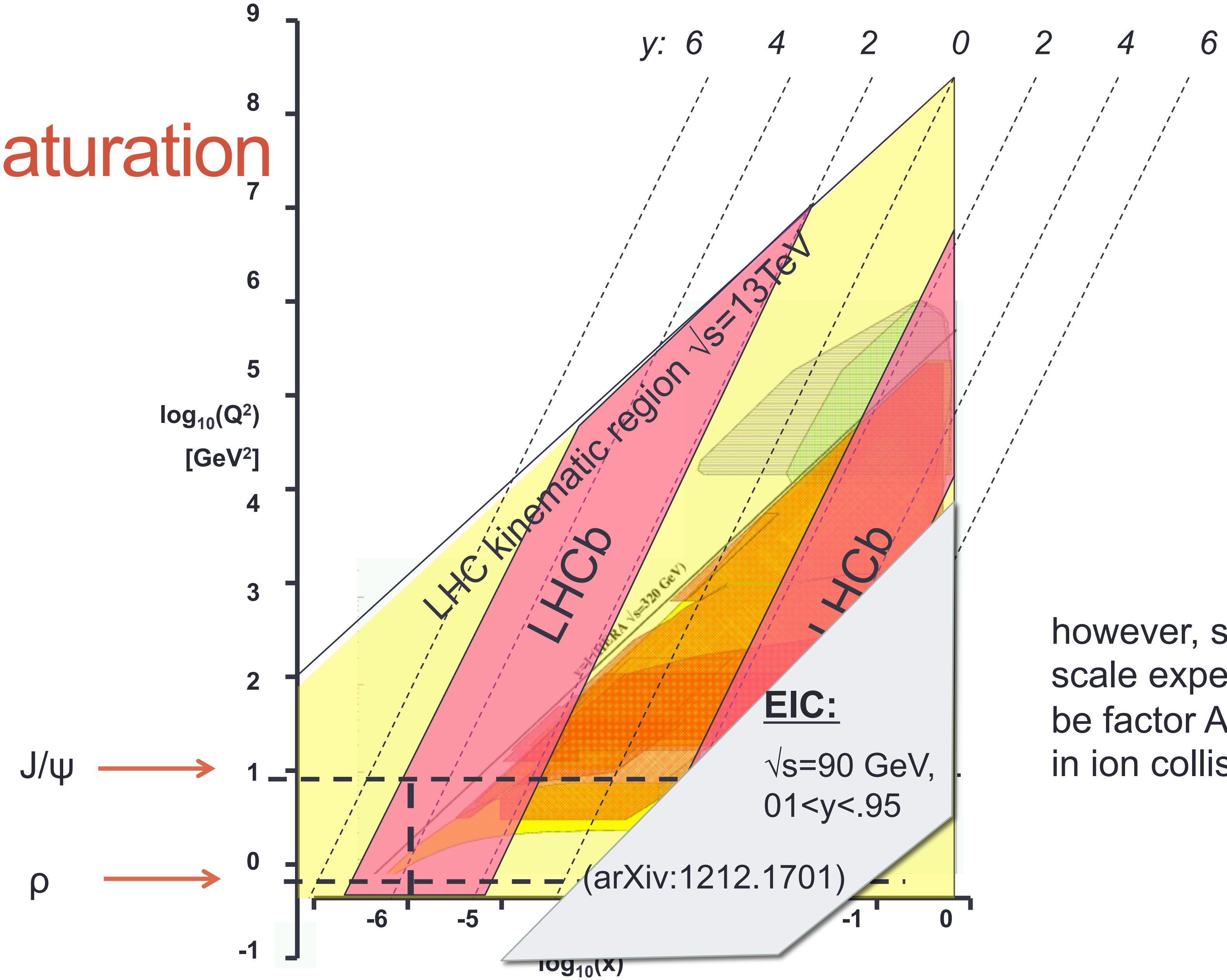
Saturation



LHCb:

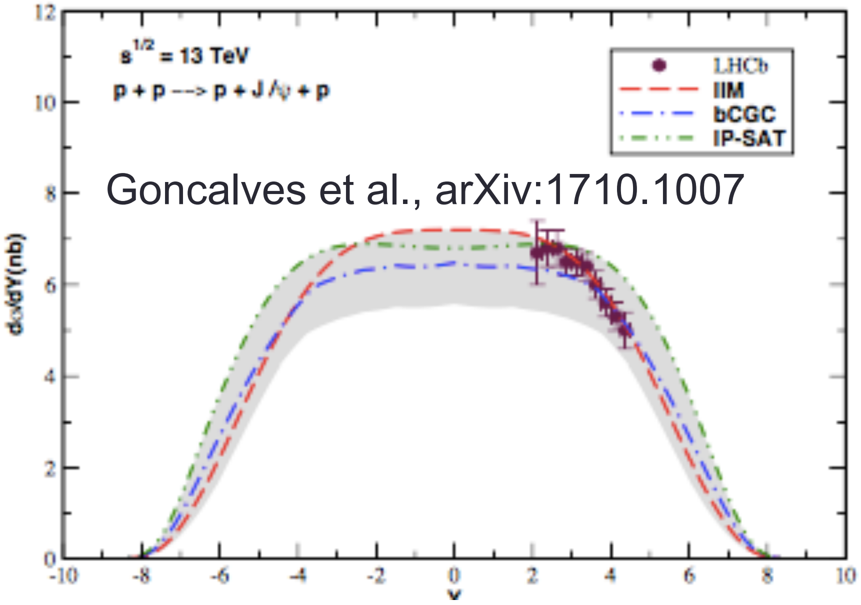
Collision between one well understood parton and one unknown or large DGLAP-evolved parton.

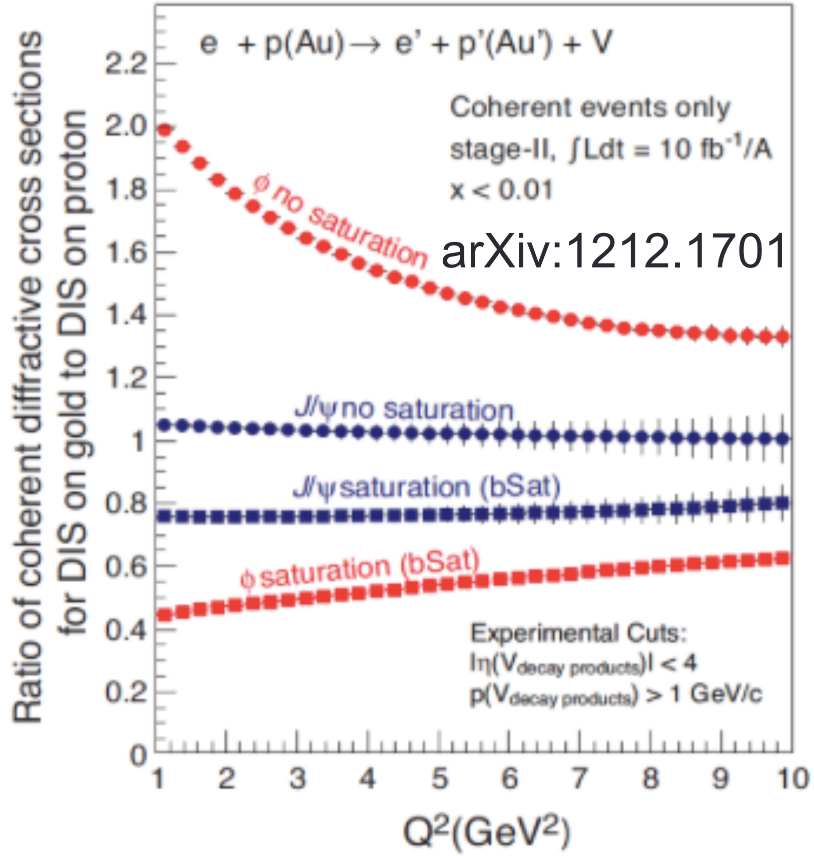
Saturation



however, saturation scale expected to be factor $A^{1/3}$ larger in ion collisions

Saturation

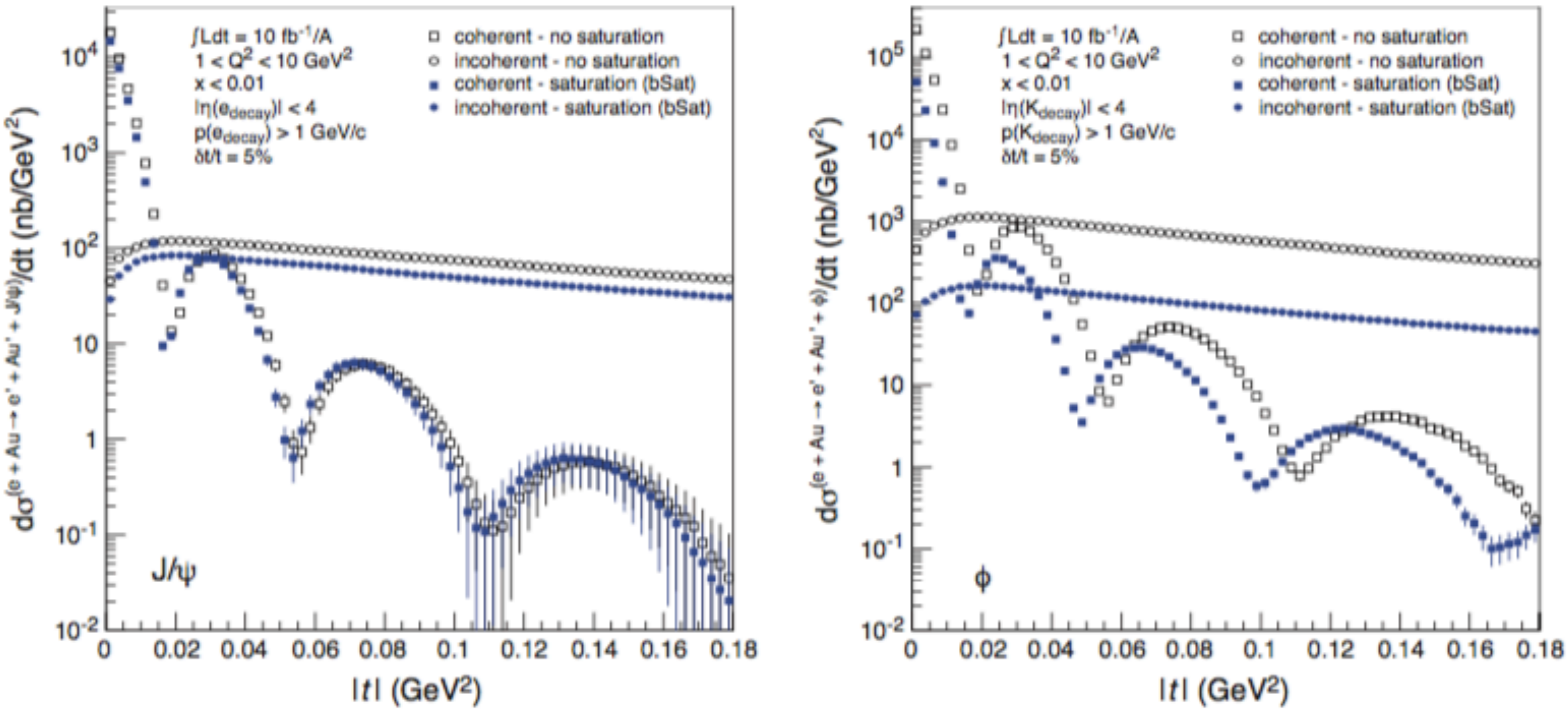




EIC message (slightly provocative): The forward region of the LHC accesses much lower-x than EIC. If saturation is not found in LHC data, it is unlikely to be found in EIC e-p data.

On the other hand, eA data will have much higher luminosity, less backgrounds than in AA or pA LHC data, and $A^{1/3}$ enhancement.

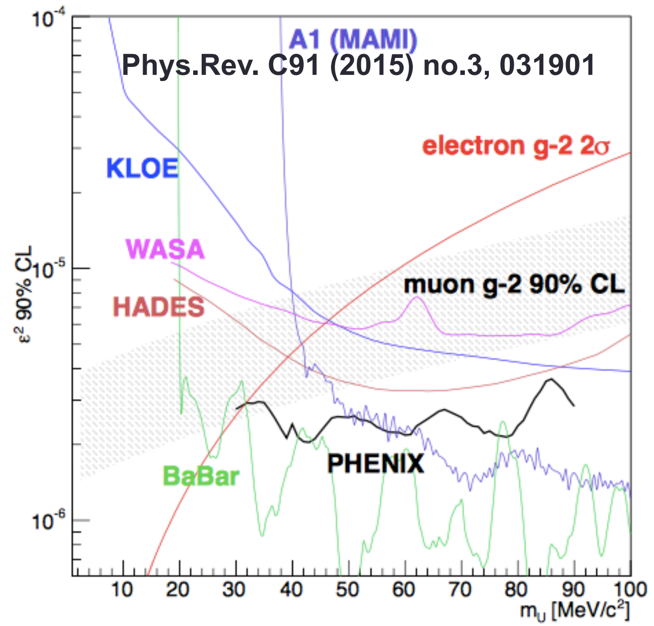
Saturation



Once again, the ‘smoking gun’ is in the non-perturbative plot.....

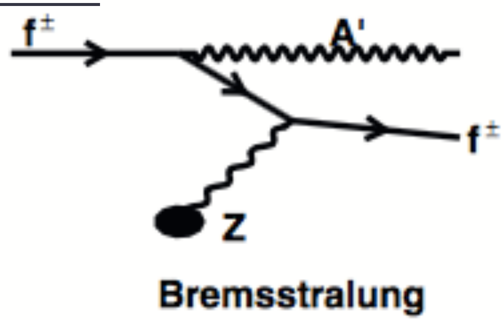
Dark photons.

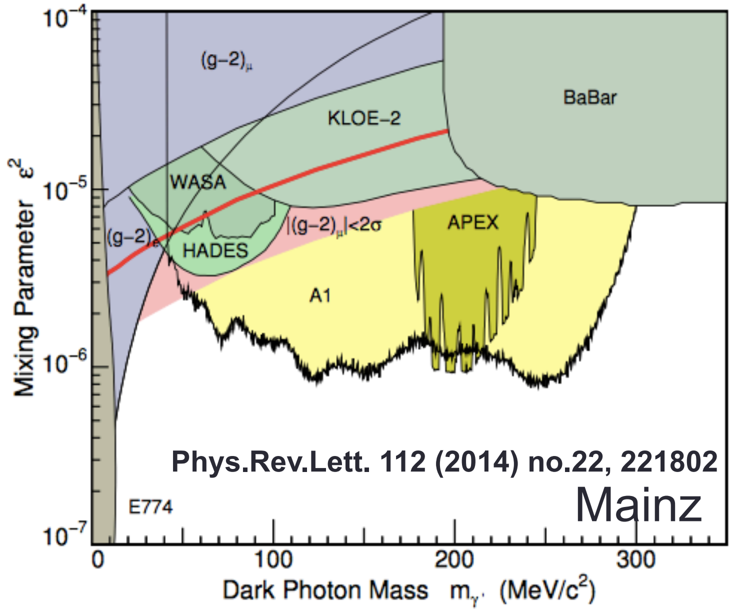
Weakly coupled dark photon requires high stats.
Search in production or decay of photon processes.



Decay:
EIC will have enormous sample of clean π η ω
Look for: π->γU; η->γU μμU, ππU; ω->πU; with U->ee

Production:





EIC message: Develop good electron identification

Conclusion

- LHC and EIC are somewhat complementary.

- Both reconstruct similar low-multiplicity low-mass states and have potential to discover new QCD effects

-

- LHC reaches to lower x but the detectors are not so well suited for this physics.

- EIC may do this better but detector design is critical.