Diffractive, forward physics and UPC

Workshop on the physics of HL-LHC, and perspectives at HE-LHC

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on behalf of ALICE, ATLAS, CMS, LHCb

10/31/2017

Overview

- Physics topics
  - Central diffraction (pp)
  - Light-by-light scattering (pp and ion-ion)
  - Ultra-peripheral collisions (p-ion and ion-ion)
    - photo-production of vector mesons
    - continuum $\gamma\gamma \to e^+e^-$, $\gamma\gamma \to q\bar{q}$
    - UPC jets (direct access to nPDF)
- Detector upgrades
  - tracker upgrades for LHC run 3 and 4
  - forward detectors, including roman pots

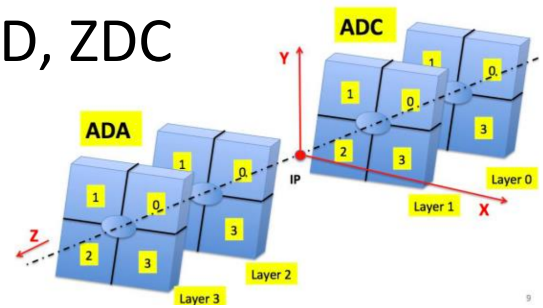
Forward detectors – present situation

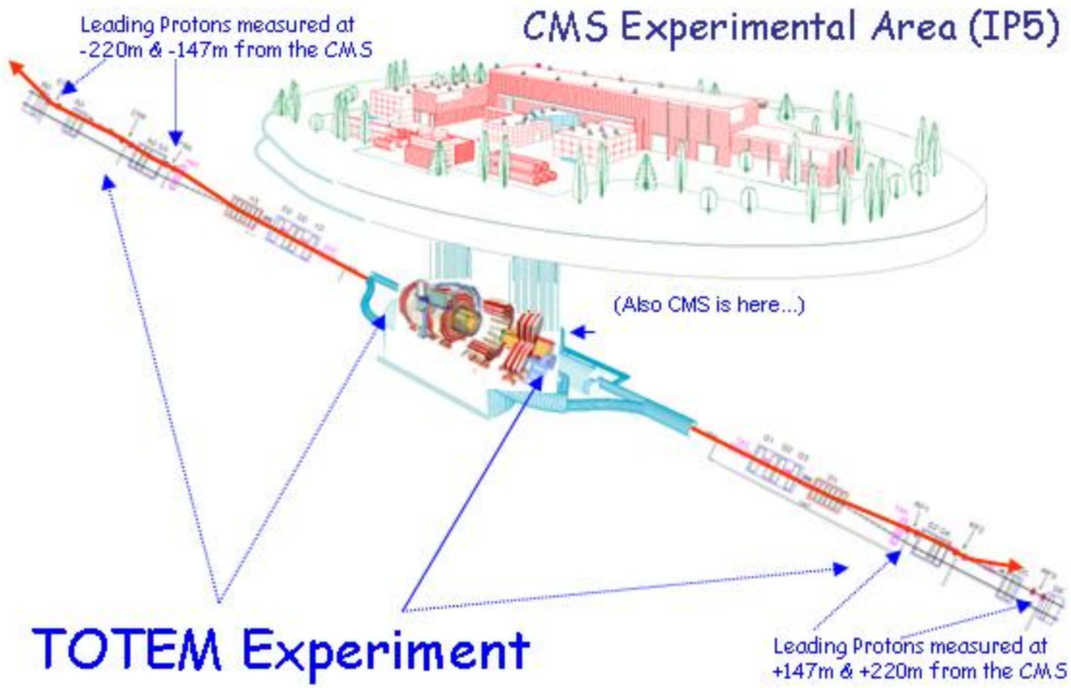
CMS: ZDC, TOTEM

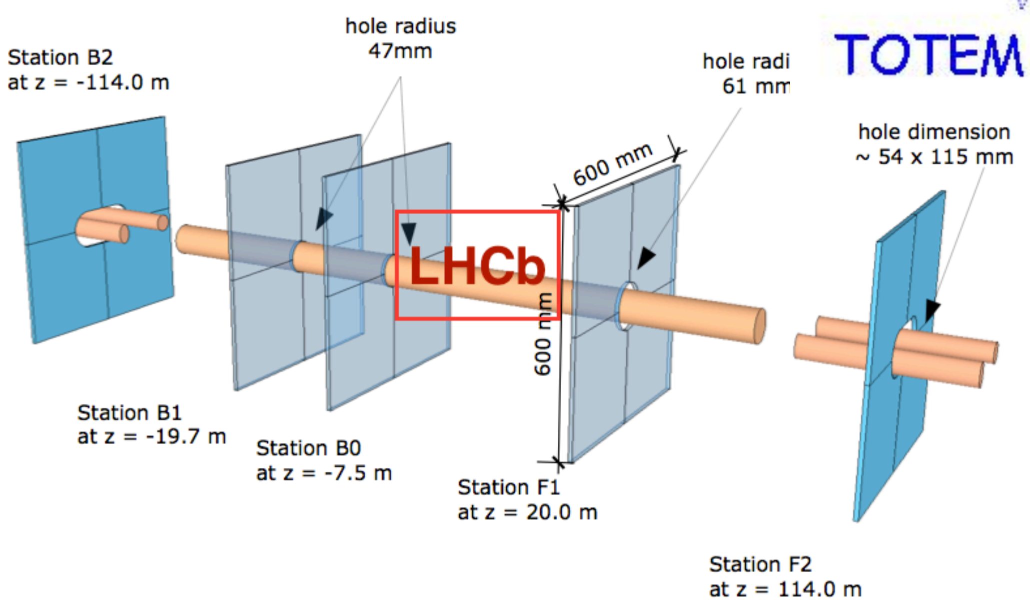
ATLAS: AFP, ALPHA

LHCb: HERSCHEL

ALICE: AD, ZDC

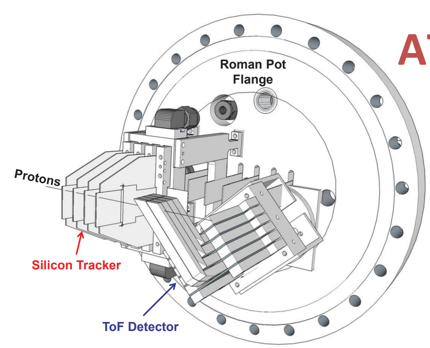


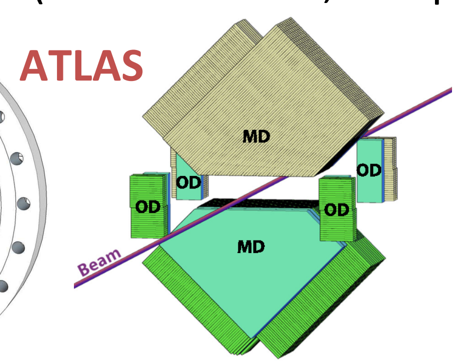




Left: ALFA detectors (vertical RPs, high-β*)

Right: AFP detectors (horizontal RPs, low-β*)



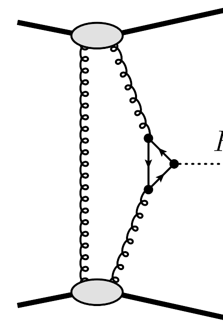


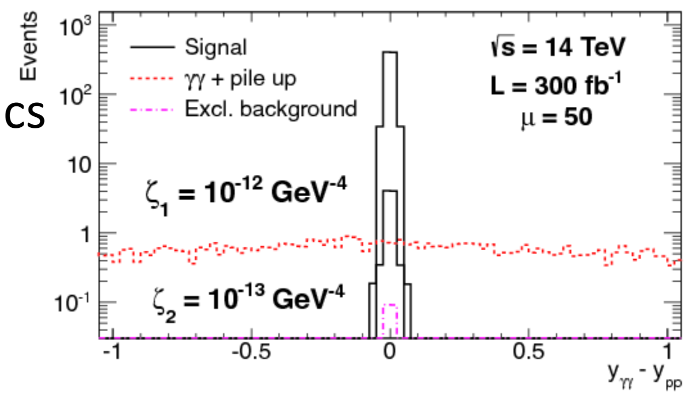
→ poster by J. Chwastowski, R. Staszewski, M. Trzebiński

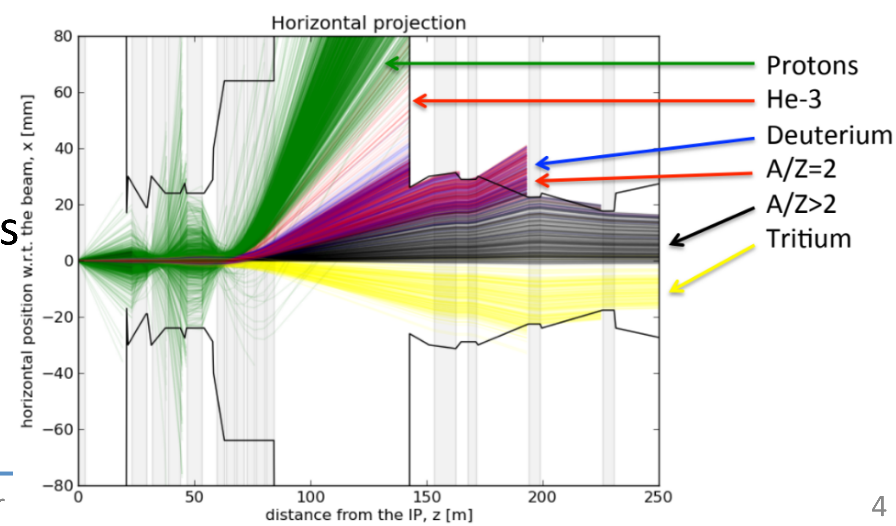
Roman Pots @ High-Luminosity LHC

Possible physics cases for HL-LHC

- Exclusive Higgs
  - quantum numbers are constrained to 0^{++} or 2^{++}
  - produced by gluon fusion, constraints on Hbb
- New physics searches
  - two-photon processes are sensitive to new physics
  - clean exclusive events, pp → pγγp
- Diffraction
  - high β^*: pile-up prevents measurements of soft diffraction
  - low β^*: study hard diffraction
- HI collisions:
  - provides **centrality** based on spectators and not on participants
  - **veto** for γγ (and γ-nucleus) processes



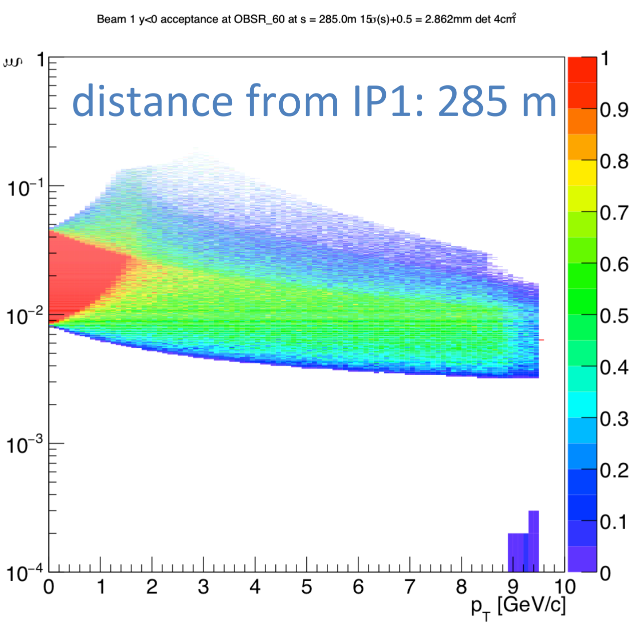


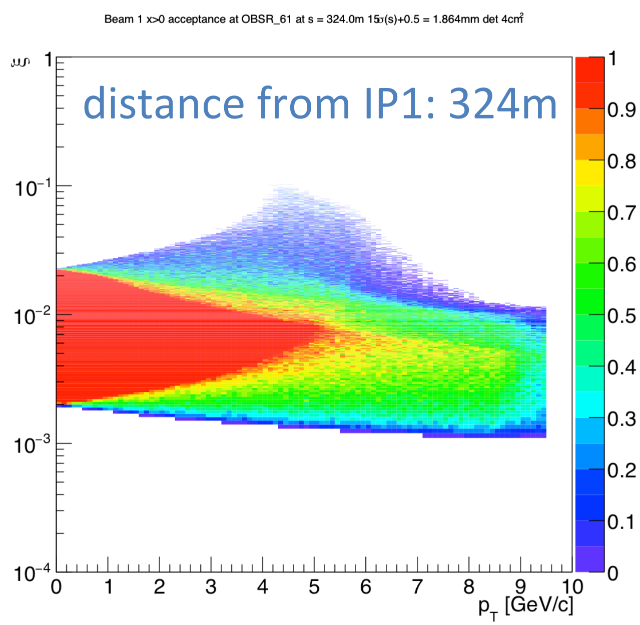


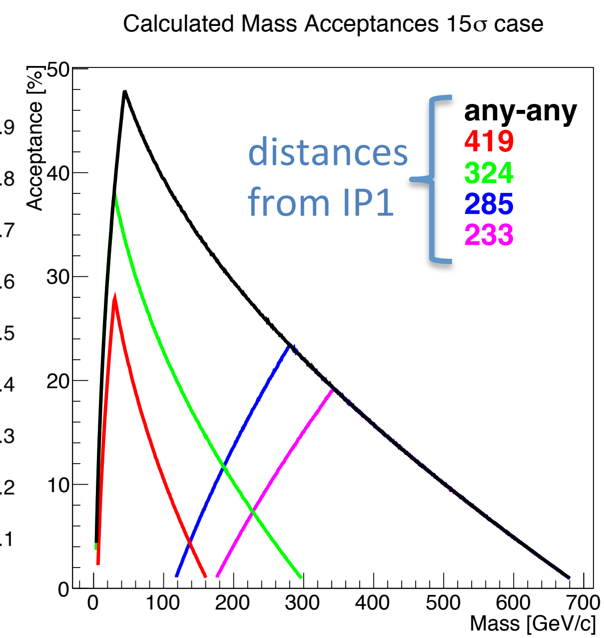
Roman Pots @ High-Luminosity LHC

First feasibility studies with HL-LHC optics v. 1.3

- Detector size: 22 cm^2
- Detector position: 15σ + 500 μm
- Acceptance is studied as a function of proton relative energy loss and proton p_T
- HL-LHC has the potential to observe exclusive Higgs production and perform BSM searches with tagged forward protons





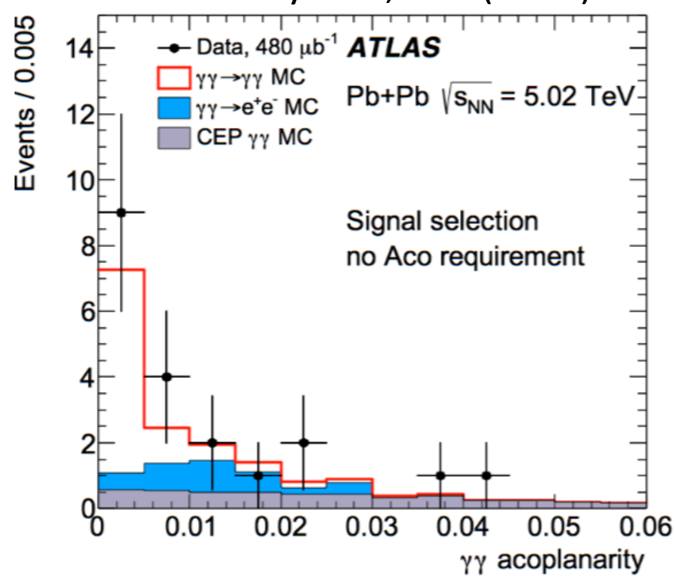


Light-by-light scattering

Pb+Pb collisions

- softer EPA spectrum (ω_{max}≈80 GeV for $\sqrt{s_{NN}}$=5 TeV) → $M(\gamma\gamma)_{max}$≈160 GeV
- AA ($\gamma\gamma$) cross-sections scale as Z^4
- gluonic cross-sections scale with A^2 (lower QCD background w.r.t. pp)
- low pile-up (< 1%)*
- Short LHC Pb-Pb campaigns (cf. pp)
- Proposed as a good channel to study *e.g.*
  - Anomalous gauge couplings
  - Contributions from BSM particles in the loops

Nature Phys. 13, 852 (2017)



pp collisions

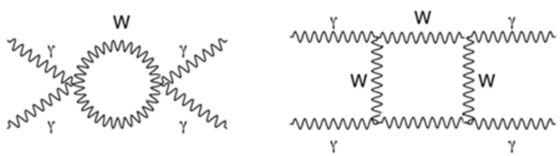
- harder EPA spectrum (ω_{max}≈2 TeV for $\sqrt{s}$=13TeV) → $M(\gamma\gamma)_{max}$≈4 TeV
- large pile-up (multiple interactions per bunch crossing)
- large datasets available, O(10 fb^{-1})
- hard to trigger on low-p_T objects

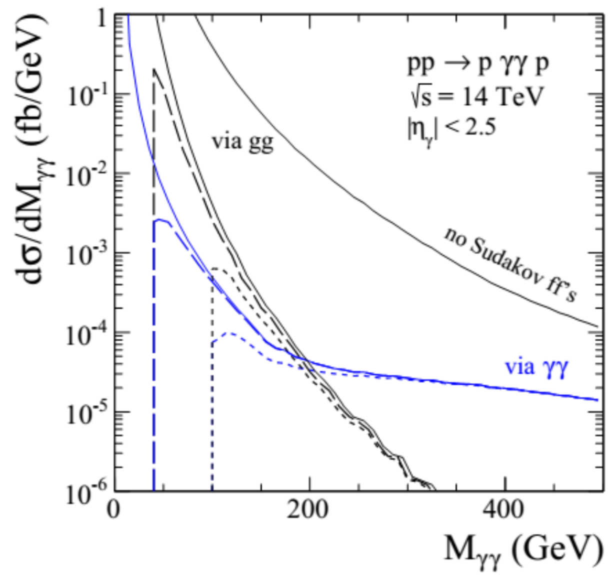
* O(10%) for EM dissociation will be important effect @ HL-LHC

Light-by-light scattering

Background

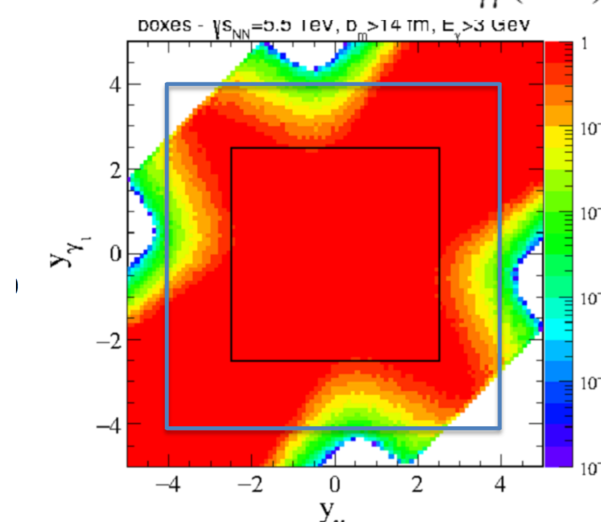
- $M(\gamma\gamma)$ < 200 GeV: diffractive mechanism dominates
- $M(\gamma\gamma)$ > 200 GeV: two-photon production dominates
  - Mainly thanks to W loops
  - Clean channel to study BSM effects at large-mass





Photon pseudorapidity

- Could benefit from the extended tracker range: ($|\eta| < 2.5 \rightarrow |\eta| < 4.0$)
- Increase of $\sigma(\gamma\gamma)$ (ET > 3 GeV, $|\eta|<2.5$)
  - pp@13TeV ≈70% (SuperCHIC2)
  - PbPb@5.02TeV ≈%20
- Difference comes from $Y_{max} = \ln(2\omega_{max}/W)$



[PRC 93 (2016) 4, 044907]

Light-by-light scattering

Measuring LbyL scattering at (future) LHC

- Trade-off between pp and Pb+Pb configurations (*e.g.* Z^4 vs ω_{max} vs CEP background)
- Lighter ions as an option? (*e.g.* Xe-Xe?)

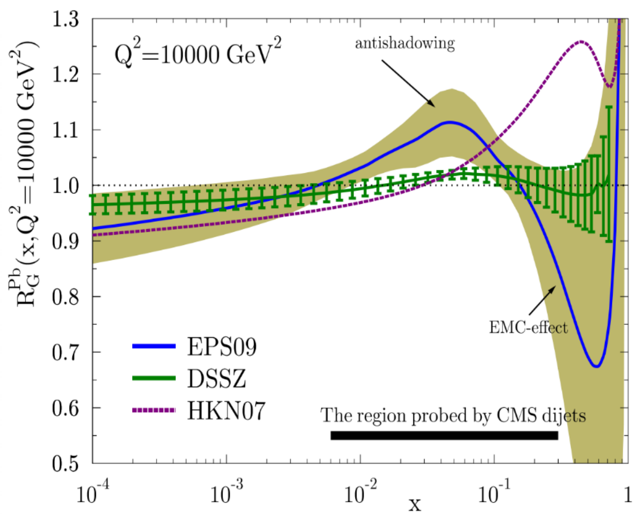
HE-LHC

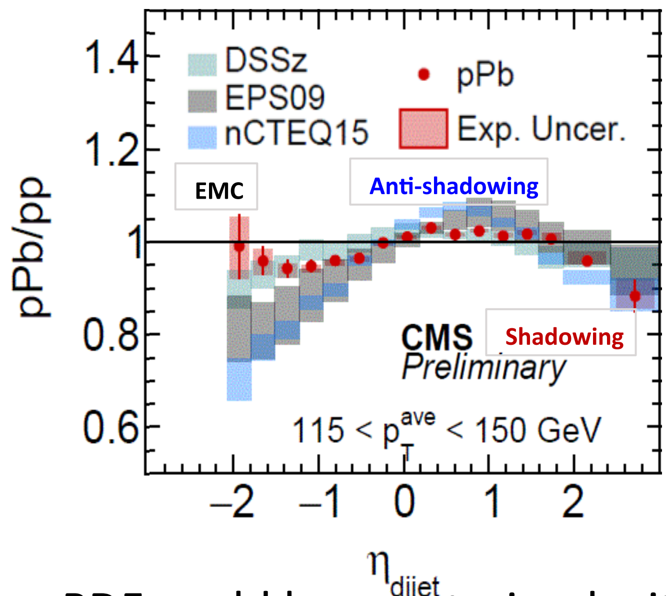
- moderate increase of cross-sections with $\sqrt{s_{NN}}$ [$\approx \ln^3(\sqrt{s_{NN}})$]
- linear increase of ω_{max} → $M(\gamma\gamma)_{max} \approx 320$GeV for $\sqrt{s_{NN}}$=10TeV (Pb+Pb) → possibility to probe W-loop contribution

HL-LHC

- 'EM pileup' can be an issue in Pb+Pb
- Possible benefits from detector upgrades, *e.g.*, extended tracker acceptance

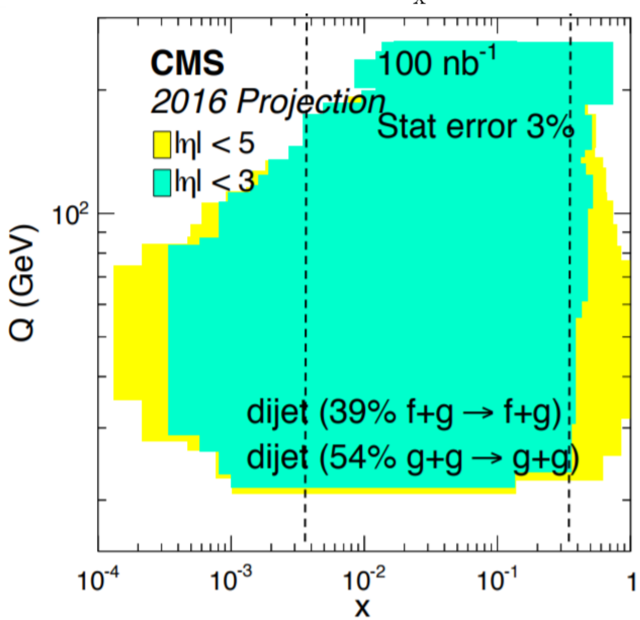
γA collisions – nPDF measurements





EPJC 74 (2014) 2951

CMS-PAS-HIN-16-003



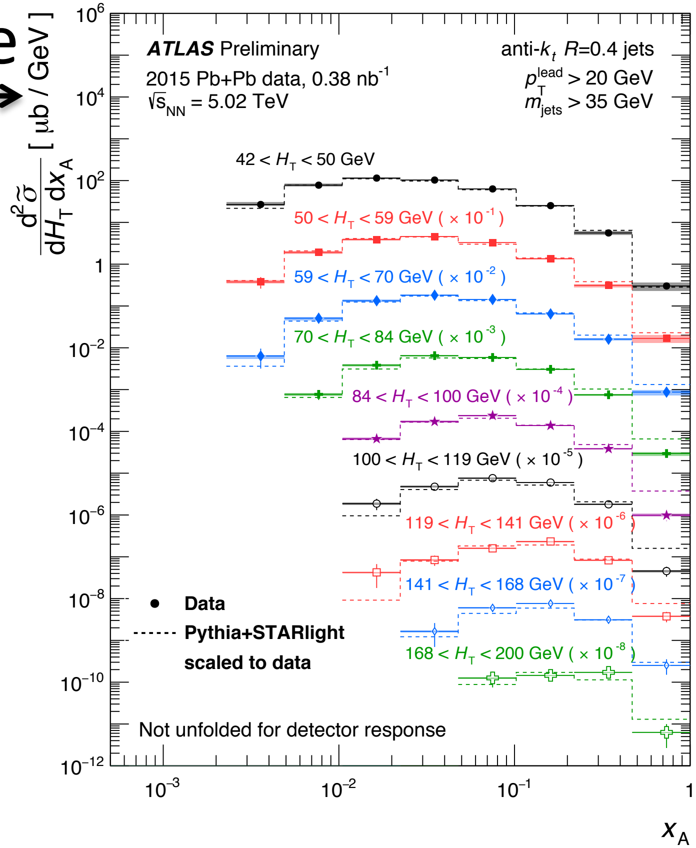
- nPDF could be constrained with high Q^2 dijet data, complementary to low-Q data from hadrons.
- Important test for the factorization assumption
- The first dijet data has already been included in EPPS16 which improved gluon nPDF
- Significantly higher statistics pA data in HL-LHC could further reduce the statistical and systematical uncertainties and cover a wider x and Q phase space
- High precision heavy flavor jet (ex: b-dijet 96% from γγ scattering) will become feasible with HL-LHC data

→ see also Heavy Ions WG: session 4 (Wed 11/1)

γA collisions – nPDF measurements

- Di-jet production as proof of principle
- Diffractive jet production
  - Diffractive PDFs important input to shadowing models
- Heavy flavour (jets): Is there an EMC effect for gluons?
- γ-jet: Provides access to different flavour distributions

ATLAS-CONF-2017-011

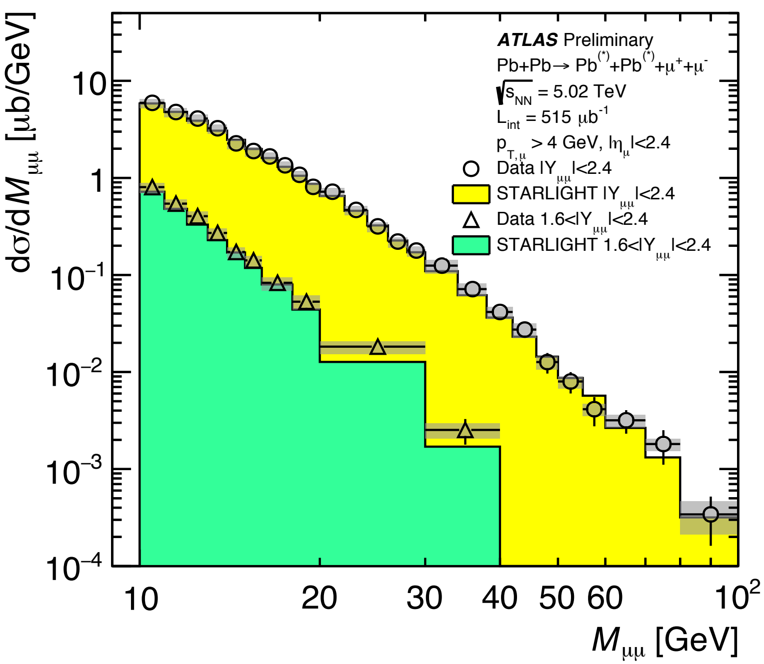


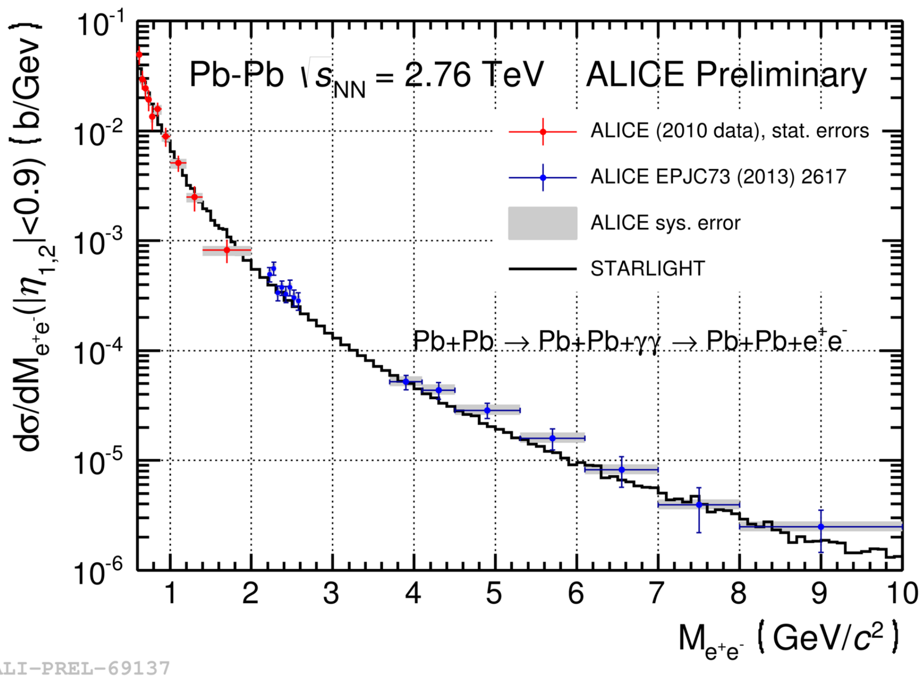
→ see also Heavy Ions WG: session 4 (Wed 1

γγ collisions (QCD)

- The process $\gamma\gamma \to q\bar{q}$ is an elementary QCD process
  - Rates can be calibrated with $\gamma\gamma \to \mu^+\mu^-$
- Can do very clean QCD measurements a la e^+e^-
  - α_S, fragmentation functions, etc.

ATLAS-CONF-2016-025



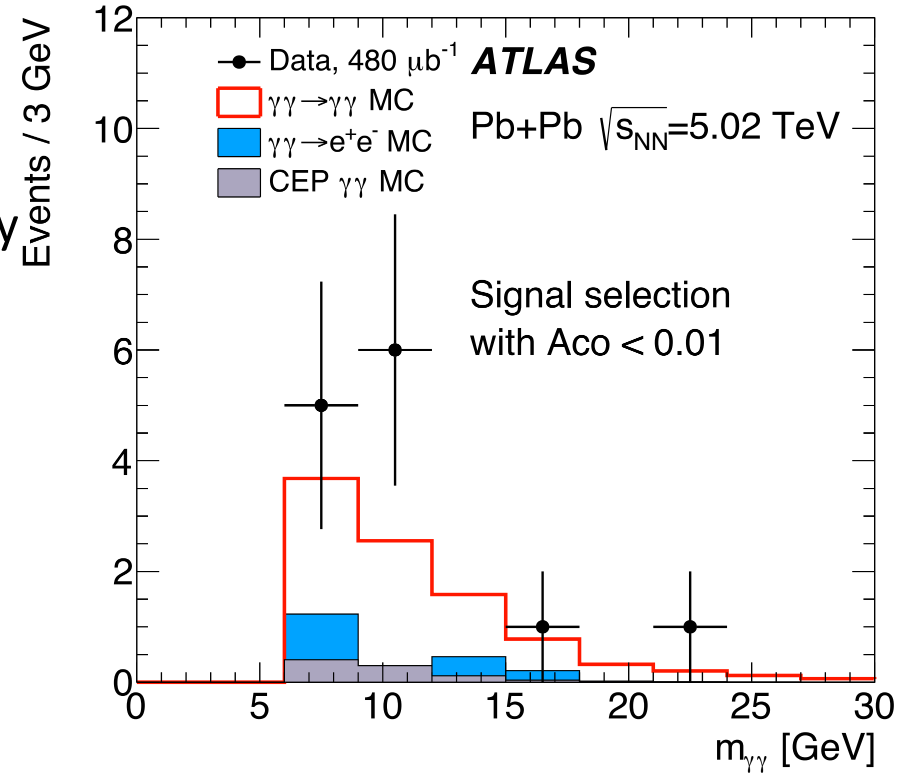


→ see also Heavy Ions WG: session 4 (Wed 11/1)

γγ collisions (rare and BSM)

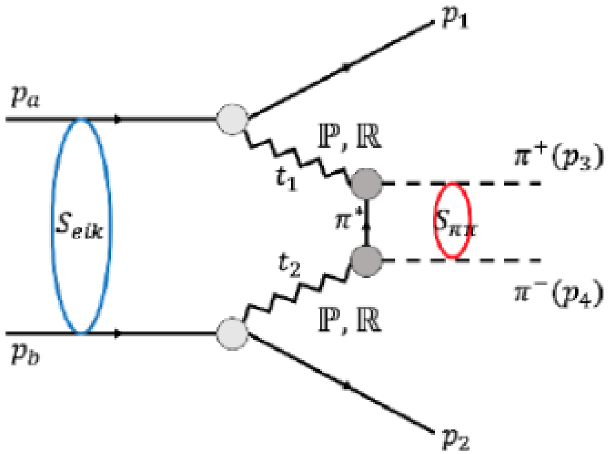
- Improved significance in LbL scattering measurement
  - Currently 4.4 sigma evidence
  - Huge benefit from increased luminosity & increased detector acceptance
- Leads to many exclusive SM processes
  - Exclusive processes non-Abelian gauge couplings, *e.g.,* Diboson production
- Need generators with realistic photon fluxes, calibrated against data.
- Potential for searches
  - BSM, axion-like particles, others?

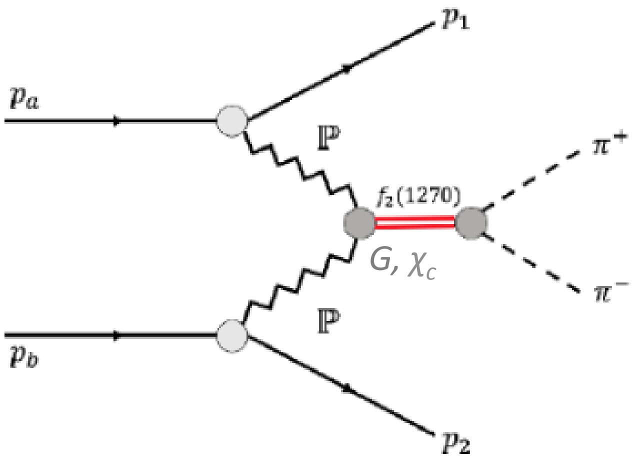
Nature Physics 13 (2017) 852



Diffractive physics in Run 3 and 4

- Expected integrated luminosities:
  - pp @5.5 TeV: 6 /pb
  - pp @14 TeV
    - pp data taking @14 TeV still to be defined within ALICE
    - For the following estimates we used 200/pb (×10 more than in run 2)
- Benchmark analyses (central diffraction):
  - Precision scalar and tensor meson spectroscopy including strangeonia and charmonia states (ππ,KK,4π,2π2K, etc.), partial wave analysis
  - Gluonic jets, two particle correlations and femtoscopy in CEP (→Appendix)
  - Glueball searches (including exotics like 0-- and 0+- at high masses)
  - Magnetic monopole and monopolium searches (→ Appendix)



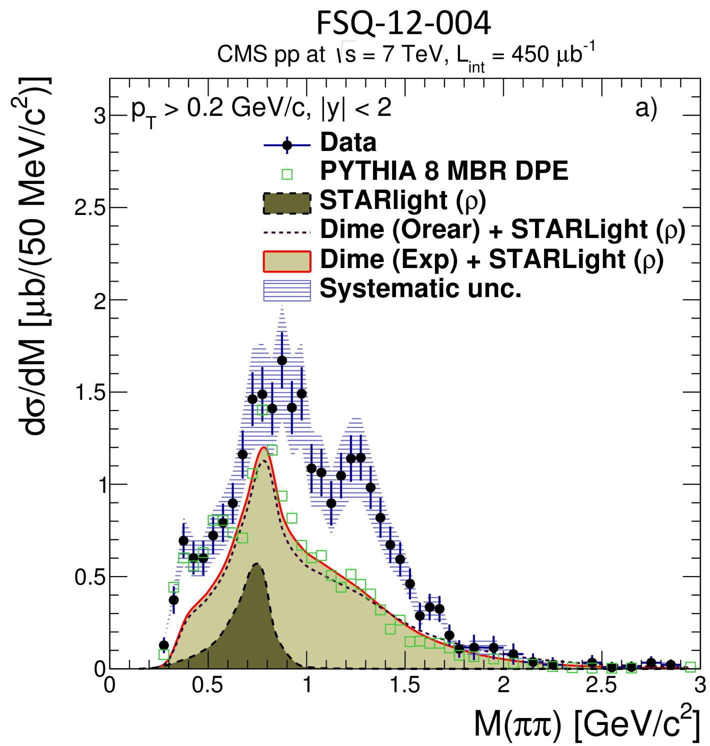


Hadron spectroscopy

- precision hadron spectroscopy and glueball searches
- see M.Albrow, arXiv:1701.09092 for a short and comprehensive summary of the field

TABLE I: Light meson states allowed in DIPE . Branching fractions are in %. (PDG 2016)

Name	M(MeV)	Γ(MeV)	$I^G J^{PC}$	$\pi\pi$	$K\bar{K}$	Other modes
$f_0(500)/\sigma$	400-550	400-700	0^+0^{++}	~100	-	-
$f_0(980)$	990±20	10-100	0^+0^{++}	dominant	seen	$\gamma\gamma$ seen
$f_2(1270)$	1275.5±0.8	$186.7^{+2.2}_{-2.5}$3	0^+2^{++}	$84.2^{+2.9}_{-0.9}$	$4.6^{+0.5}_{-0.4}$	$4\pi \sim 10\%$
$f_0(1370)$	1200-1500	200-500	0^+0^{++}	seen	seen	$\rho\rho$ dominant
$f_0(1500)$	1504±6	109±7	0^+0^{++}	34.9±2.3	8.6±1.0	4π 49.5±3.3
$f_2'(1525)$	1525±5	73^{+6}_{-5}	0^+2^{++}	0.8±0.2	88.7±2.2	$\eta\eta$ 10.4±2.2
$f_0(1710)$	1723^{+6}_{-5}	139±8	0^+0^{++}	seen	seen	$\eta\eta$ seen
$f_2(1950)$	1944±12	472±18	0^+2^{++}	seen	seen	$\eta\eta$ seen
$f_2(2010)$	2011^{+60}_{-80}	202±60	0^+2^{++}	-	seen	$\phi\phi$ seen
$f_4(2050)$	2018±11	237±18	0^+4^{++}	17%	~0.7%	$\eta\eta$ 0.2%
$f_2(2300)$	2297±28	149±40	0^+2^{++}	-	seen	$\phi\phi$ seen
$f_2(2340)$	2345^{+50}_{-40}	322^{+70}_{-60}	0^+2^{++}	-	-	$\phi\phi$, $\eta\eta$ seen



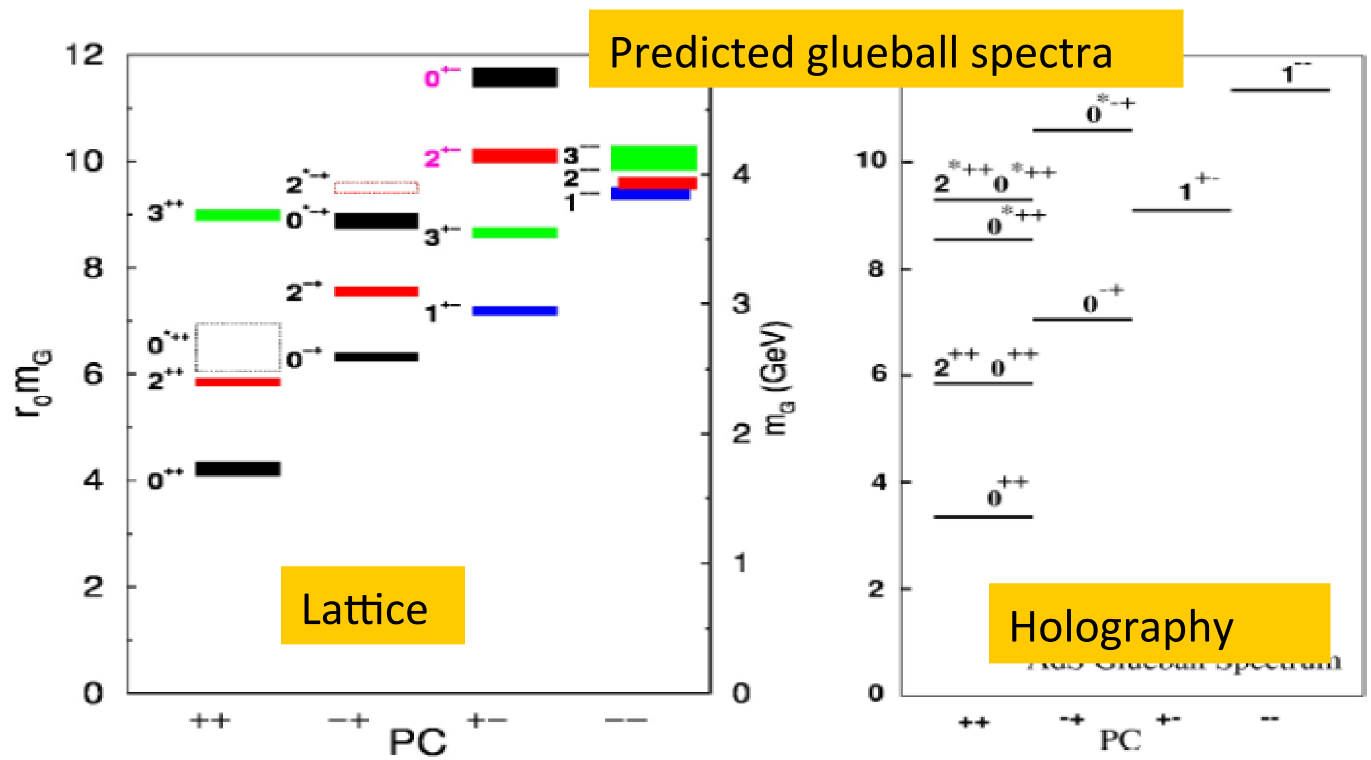
High potential to contribute to PDG.

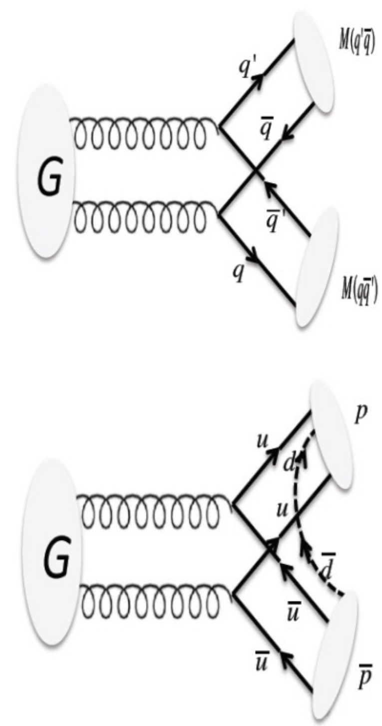
High discovery potential

It is a challenge to measure all these (sometimes overlapping) states with their decay modes, and partial wave analysis to distinguish $J = 0$ and $J = 2$. The most favored states for the lightest glueball, albeit mixed with $q\bar{q}$ states, are the scalar $f_0(1500)$ [14] and $f_0(1710)$ [15]

Glueball searches

- $f_0(1710)$ and f2(2300) are most promising 0^{++}, 2^{++} glueball candidates
- 0^{++}, 2^{++} glueballs mix with $q\bar{q}$ mesons with similar quantum numbers
  - precise determination of branching ratios needed to determine gluonic content
- Pseudoscalar glueball (0^{-+}) expected ~2.6 GeV:
  - BR(G→KKπ)=49% according to PRD95 (2017), 014028
  - $K_sK^+\pi^-$ and $K_sK^-\pi^+$ might be promising in ALICE: Axε(|y|<1) is about 10%
- $K_sK^+\pi^-$ and $K_sK^-\pi^+$ also promising for 0^{--} oddball searches (2.8 GeV in JHEP 1510 (2015) 137)





Charm sector in central exclusive production (pp)

ALICE

Channel	BR	A x ε	σ(5.5 TeV) pb	Y (5.5 TeV) 1 /pb	Y(5.5 TeV) 6 /pb	σ(14 TeV) pb	Y (14 TeV) 1 /pb	Y(14 TeV) 200 /pb
$\chi_{c0} \rightarrow \pi\pi$	0.83%	25.2%	97933	205	1229	118120	247	49412
$\chi_{c0} \rightarrow KK$	0.59%	20.5%	97933	118	711	118120	143	28573
$\chi_{c0} \rightarrow 4\pi$	2.24%	9.40%	97933	206	1237	118120	249	49743
$\chi_{c0} \rightarrow 2\pi 2K$	1.75%	1.70%	97933	29	175	118120	35	7028
$\chi_{c1} \rightarrow \pi\pi$	<0.10%	25.2%	968	0	<1	1009	0.3	<51
$\chi_{c1} \rightarrow KK$	<0.10%	20.5%	968	0	<1	1009	0.2	<41
$\chi_{c1} \rightarrow 4\pi$	0.76%	9.40%	968	1	4	1009	0.7	144
$\chi_{c1} \rightarrow 2\pi 2K$	0.45%	1.70%	968	0	0	1009	0.1	15
$\chi_{c2} \rightarrow \pi\pi$	0.23%	25.2%	5779	4	22	7634	4.4	885
$\chi_{c2} \rightarrow KK$	0.11%	20.5%	5779	1	9	7634	1.7	344
$\chi_{c2} \rightarrow 4\pi$	1.07%	9.40%	5779	6	38	7634	7.7	1536
$\chi_{c2} \rightarrow 2\pi 2K$	0.89%	1.70%	5779	1	6	7634	1.2	231

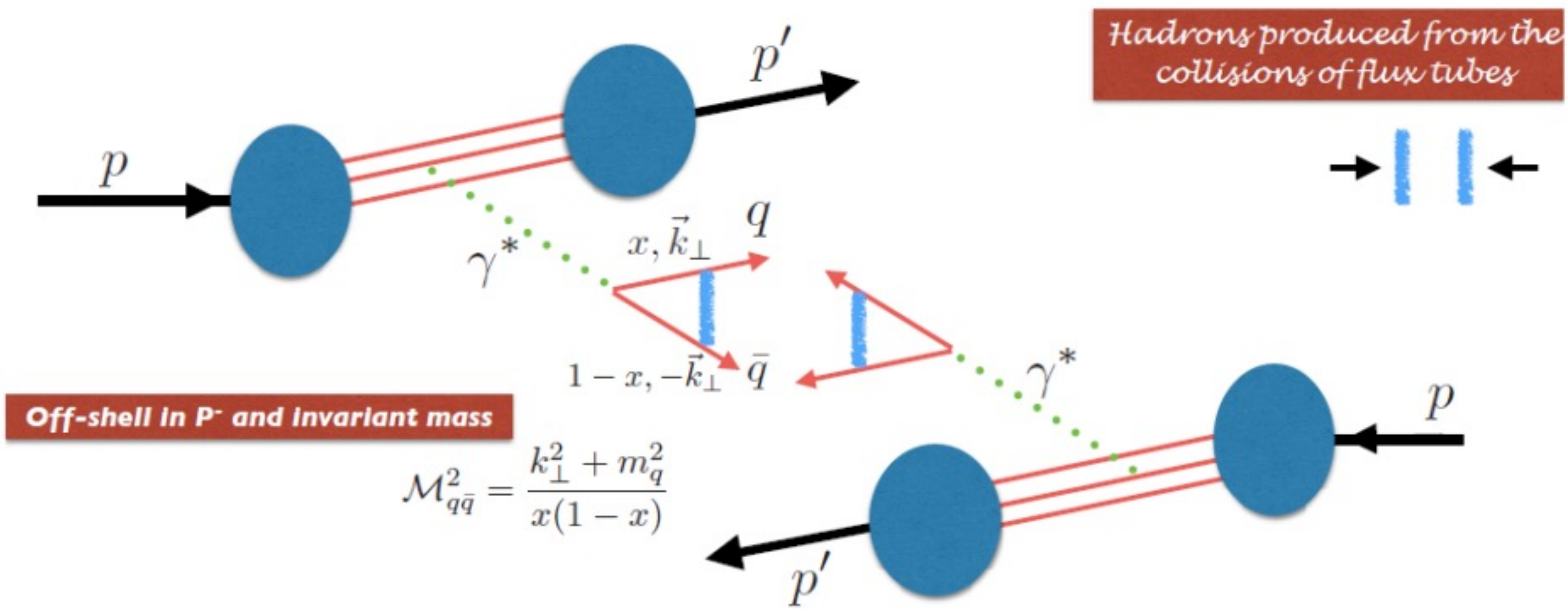
Cross sections were estimated with the SuperChic2 generator

- Using lowest prediction with NNPDF3.0 and model 1 for the gap survival prob.
- Caveat: Superchic2 predicts at least ×3 higher cross section w.r.t. LHCb preliminary

Only χ_{c0} channel is feasible in the baseline plan: $O(10^3)$ expected.

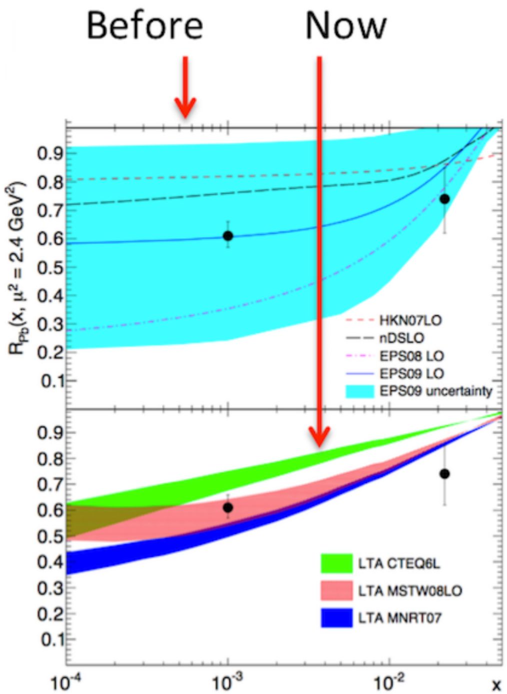
Two-particle correlations in γγ interactions in pp

- Idea is to study the origin of long range correlations (ridges) in photon-photon collisions: https://arxiv.org/abs/1708.07173
- pp CEP is dominated by gluonic jets. Study h-pi, h-K, h-p correlation shapes and pi,K and p associated particle yields in CEP, compare with min bias shapes/yields? Might be more promising then full jet reconstruction analysis.



UPC measurements in Run1 and in Run2

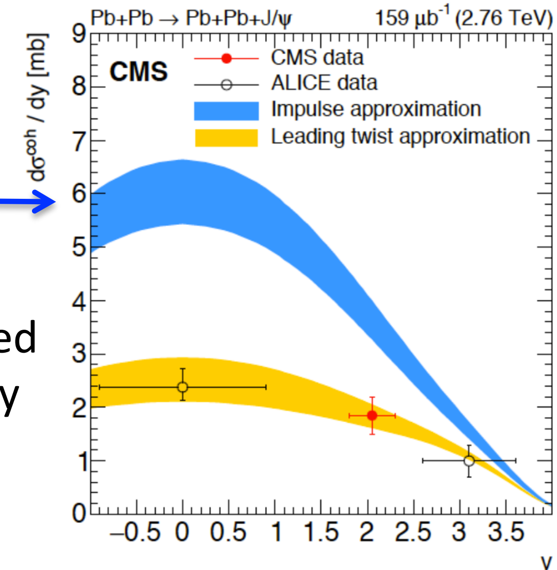
V. Guzey, *et al.* Phys. Lett. B726 (2013) 290-295



UPC J/Ψ in Pb-Pb

Impulse approximation (no nuclear effects)

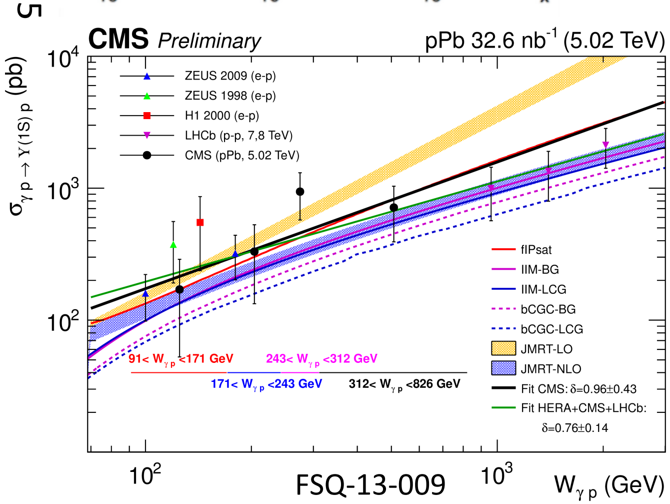
UPC measurements are being used to constrain nuclear gluon density functions

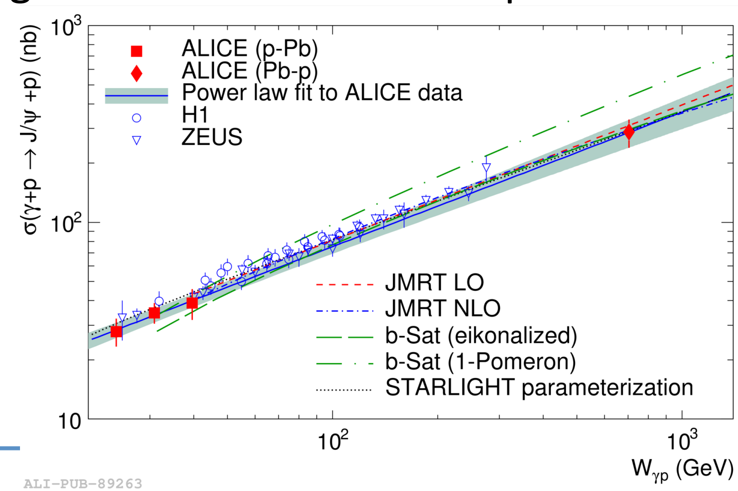


Phys. Lett. B718 (2013) 1273-1283
Eur. J. Phys. C73, 2617 (2013)
Phys. Lett. B772 (2017) 489-511

UPC J/Ψ, Υ in p-Pb

- Cross section is proportional to the square of the nuclear gluon distribution
- Higher $W_{\gamma p}$ energies than at HERA can be probed at the LHC





UPC measurements in Run3 and Run4

Physics processes:

- Multi-differential studies for J/ψ and Ψ(2S) production
  - b-slope dependence → transverse gluon distributions (1611.05471)
  - ZDC → disentangle low-x and high-x contributions
- High-mass vector mesons:
  - Ψ(3S) → DDbar (not measured at HERA)
  - ϒ production
- Inclusive photonuclear charm production
  - σ (γ gluon → c cbar) ≈ 1b
  - Pb+Pb → Pb+c+cbar+X

Expected integrated luminosities:

PbPb: 10/nb @0.5T, 3/nb @0.2T
pPb: 50/nb (ALICE LoI baseline)

- γγ processes:
  - η_C (χ_{C0}, χ_{C2}) production
  - γγ → 4μ: double-VM production, *e.g.* γγ → J/ψ J/ψ , ρ^0 J/Ψ
  - γγ → ppbar (η_C → ppbar), γγ → γγ
- Jet photoproduction
  - direct access to the gluon distribution (ATLAS-CONF-2017-011)
- coherent UPC Φ production

Expected number of events for L^{int} = 10/nb in Pb-Pb

process	central barrel	muon arm	Comments
$J/\psi \rightarrow l^+l^-$	4.1M	620k	STARLIGHT
Ψ(2S)	109k	15k	STARLIGHT
ϒ	5,260	430	STARLIGHT
Ψ(3S)→DDbar	(acc×eff) × 5,900	---	Ψ(3S) → DDbar → $K^+\pi^- K^-\pi^+$ https://indico.cern.ch/event/347071/
$\eta_C \rightarrow 2\pi\ 2K$	(acc×eff) × 49k	---	σ = 490 μb (STARLIGHT), $BR(\eta_C \rightarrow 2\pi 2K) \approx 0.01$
γγ → 4μ (VV)	(acc×eff) × 310	---	$p_T > 0.5$ GeV, $\|y\| < 0.9$: σ ≈ 31 nb (Sczcurek et al. 1708.07742)
γγ → ppbar	(acc×eff) × 350k	---	$p_T > 1$ GeV, $\|y\| < 0.9$: σ ≈ 35 μb (Szczurek et al. 1708.09836)
γγ → γγ	240 (E_T>3 GeV, $\|\eta\|$ <2.4)	---	ATLAS: 0.45/nb 13 ev → 10/nb 240 ev (DOI: 10.1038/NPHYS4208); ALICE/ATLAS acc ≈ 7%
UPC jets	(acc×eff) × O(4M)	----	ATLAS-CONF-2017-011: 110k events with 0.3/nb in $\|\eta\|$<3.2 → 3.7M events with 10/nb

Summary

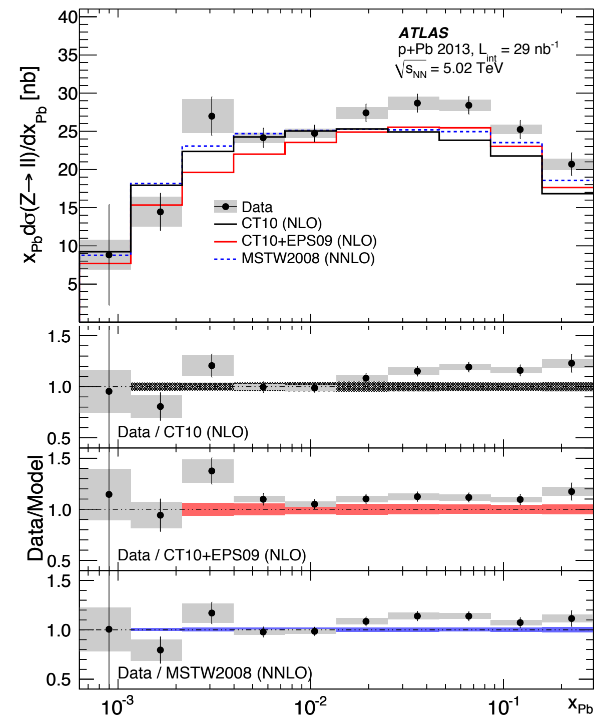
- Many physics topics
  - Central diffraction (pp)
  - Light-by-light scattering (pp and ion-ion)
  - Ultra-peripheral collisions (p-ion and ion-ion)
- Detector upgrades for LHC run 3 and 4
  - tracker upgrades
  - forward detectors, including roman pots
- More ideas, suggestions?

Appendix

Digression: pA collisions for nPDF measurements

- Asymmetry of pA makes it more sensitive to nPDF effects than AA
- Existing EW boson results show evidence of nuclear modification to PDF
- Results are still statistics limited;
  more luminosity—> better constraints on nPDF

Phys. Rev. C 92, 044915 (2015)



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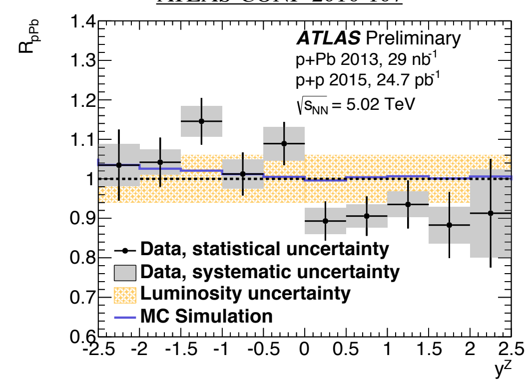


Quarkonia in PbPb at 5.5 TeV

J/Ψ, Ψ(2S), Upsilon:

- Efficiency = tracking efficiency using current AliRoot (no trigger)
- MUON arm: acc($-4.0 < y < -2.5$) × eff for $\mu^+\mu^-$: 22%
- Central barrel: acc($|y|<1$) × eff for e^+e^-: 25%, $\mu^+\mu^-$: 27%

	σ (μb) STARLIGHT	Acceptance		BR→$\mu^+\mu^-$	BR→e^+e^-	Yield per 1/nb		
						central barrel		muon arm
		$\|y\|<1$	$-4.0<y<-2.5$			$\mu^+\mu^-$	e^+e^-	$\mu^+\mu^-$
Y(1S)	103.74	40.2%	7.67%	2.48%	2.38%	279	247	43
Ψ(2S)	8110	32.7%	10.9%	7.9×10^{-3}	7.9×10^{-3}	5660	5240	1536
J/Ψ	41620	31.5%	11.3%	5.96%	5.97%	211k	196k	62k

Ψ(3S):

- Cross section ≈ 0.0179 × σ(J/Ψ) = 745 μb (https://indico.cern.ch/event/347071/)
- BR Ψ(2S) → DDbar → $\pi^+K^-\pi^-K^+$ = 52.4% × $(3.89\%)^2$ = 7.93×10^{-4}
- Yield per 1/nb: 590 events (without acc × eff)

Hard central exclusive production

- Light quark production is suppressed
- Clean gluon gets

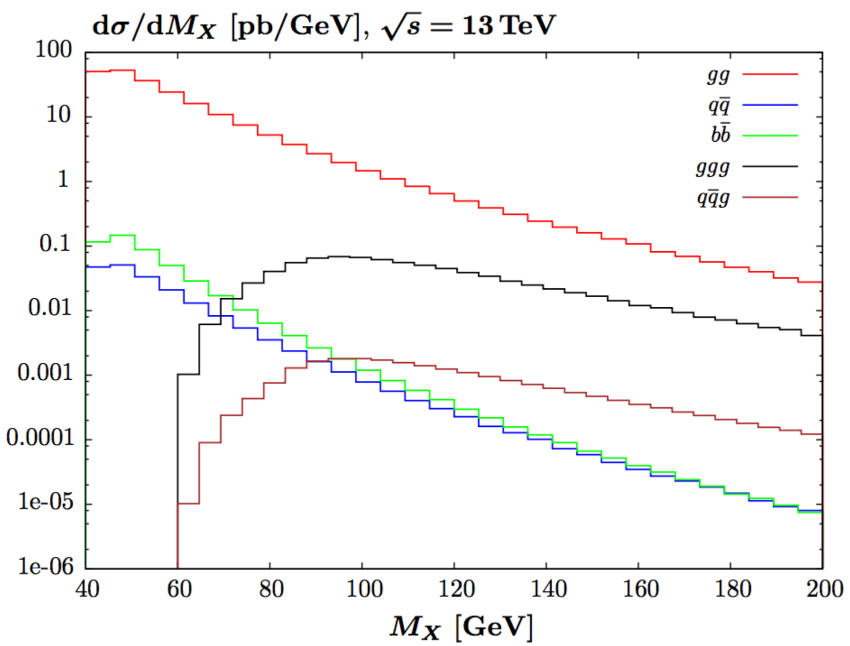


Fig. 3 Parton-level distributions for 2- and 3-jet CEP with respect to the system invariant mass M_X at $\sqrt{s} = 13$ TeV, using MMHT14 LO PDFs [54]. The final-state partons are required to lie in the pseudorapidity region $-2.5 < \eta < 2.5$ and have transverse momentum $p_\perp > 20$ GeV (leading to minimum invariant masses, M_X, of 40 and 60 GeV in the 2- and 3-jet cases, respectively), while the 3-jet events are defined using the anti-k_t algorithm with $R = 0.6$. Distributions are shown for massless quarks, $q\bar{q}$, as well as for $b\bar{b}$ production. Soft survival effects are included using model 4 of [51]

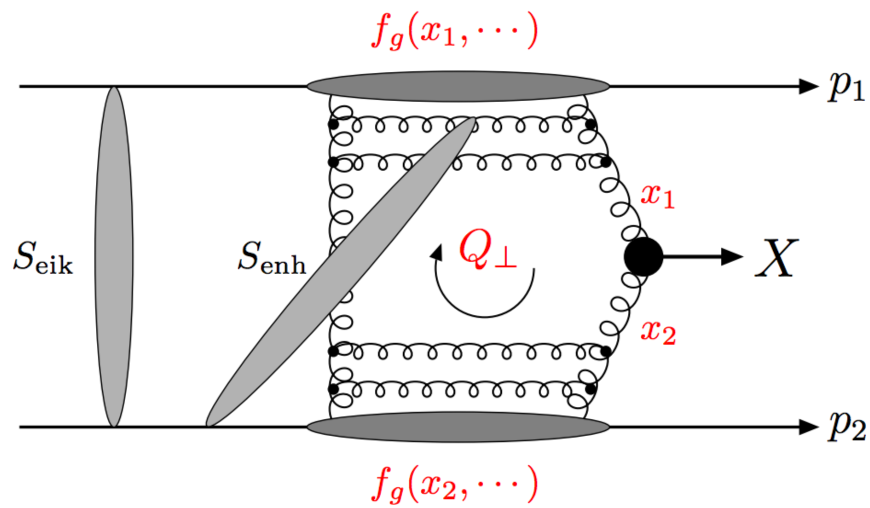


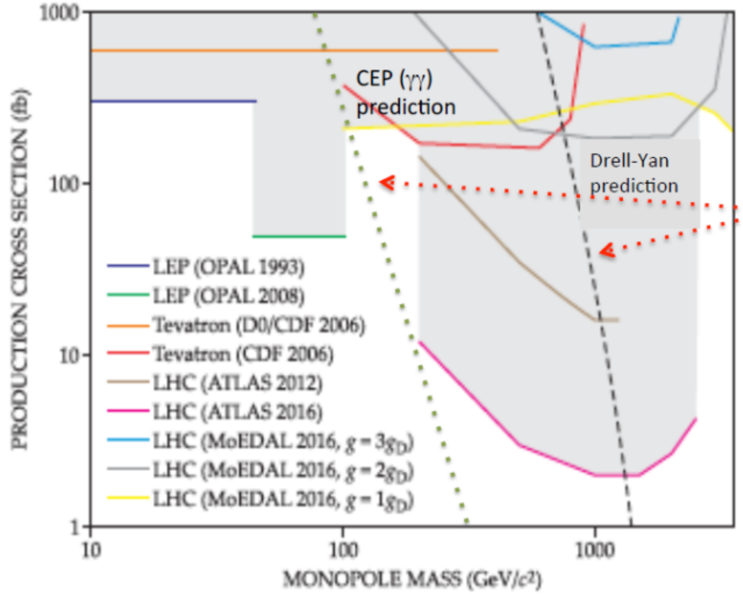
Fig. 1 The perturbative mechanism for the QCD-induced exclusive process $pp \to p + X + p$, with the eikonal and enhanced survival factors shown symbolically

Harland-Lang, L.A., Khoze, V.A. & Ryskin, M.G.
Eur. Phys. J. C (2016) 76: 9

Khoze, V., Ryskin, M. & Stirling, W.
Eur. Phys. J. C (2006) 48: 477

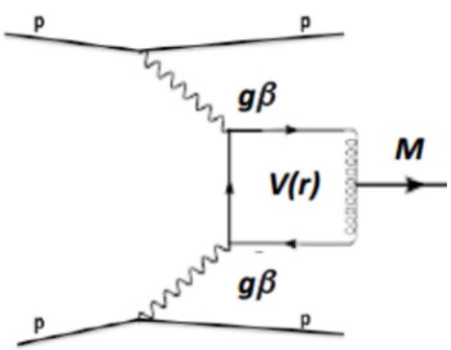
Monopolium searches

Monopole searches via monopole pair decays (or monopolium decays) into photons



usually no production cross sections given
=> no absolute mass limits

CEP and Drell-Yan predictions



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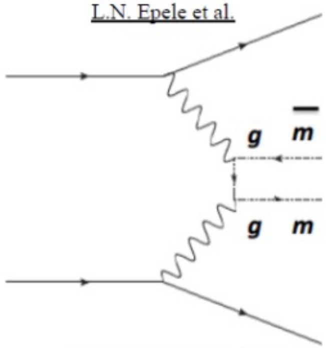
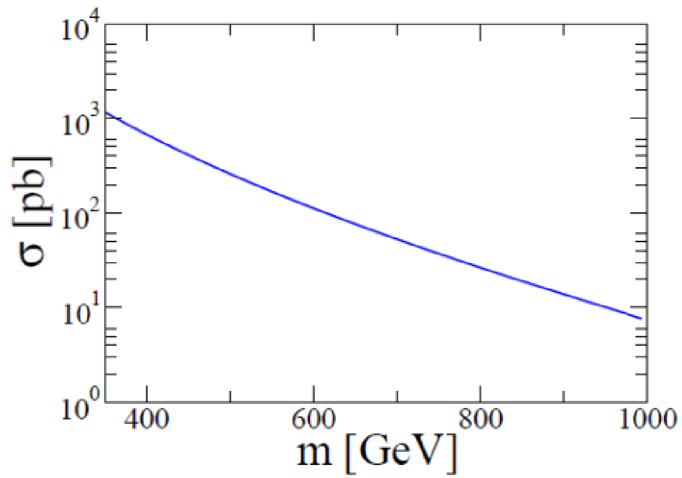
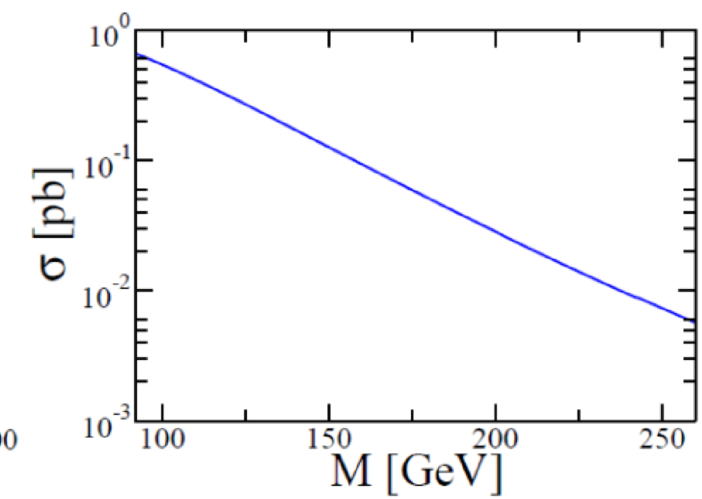


J.T. Reis and W.K. Sauter.





arXiv:1707.04170