Diffraction and saturation at the LHC

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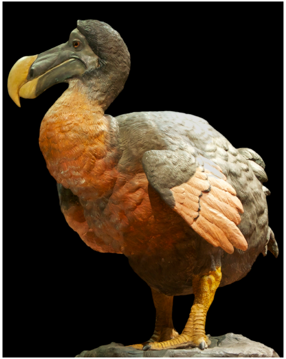
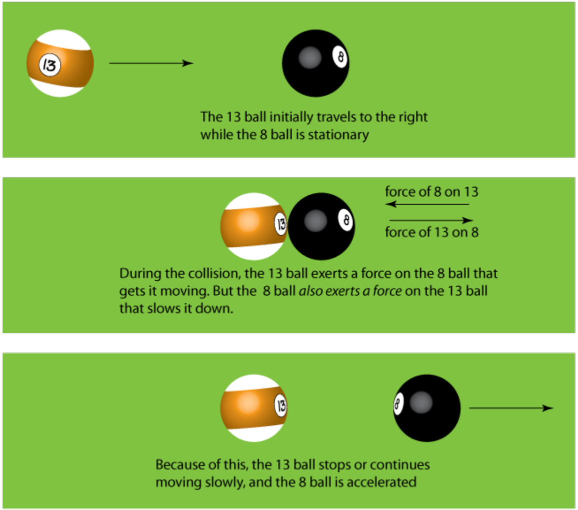


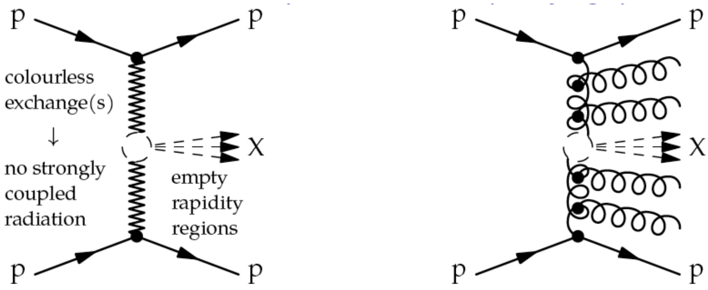
- Elastic interactions and the Odderon discovery
- Inclusive diffraction: Pomeron structure and BFKL studies
- Looking for saturation at the LHC
- Photon-exchange processes

What is elastic scattering? The pool game...



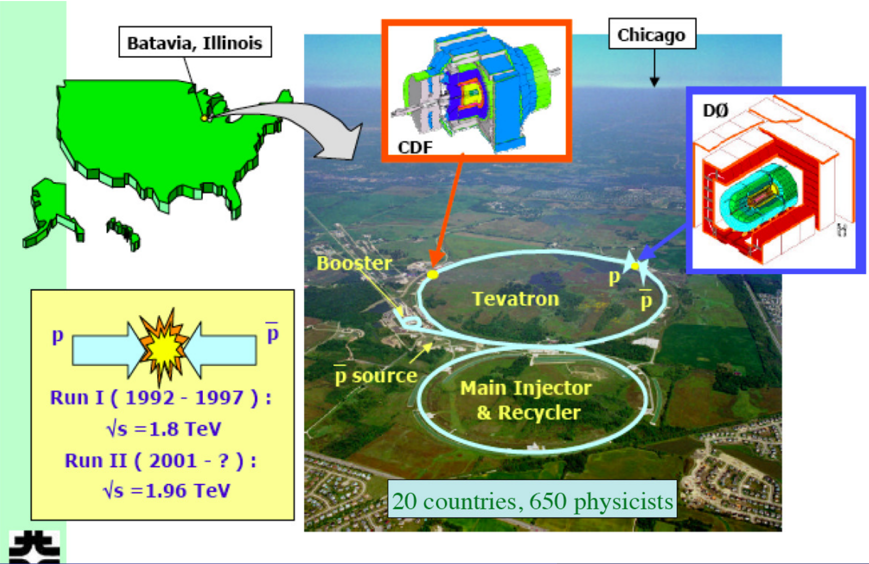
- We want to study "elastic" collisions between protons and proton-antiprotons
- In high energy physics: $pp \to pp$ and $p\bar{p} \to p\bar{p}$
- In these interactions, each proton/antiproton remains intact after interaction but are scattered at some angles and can lose/gain some momentum as in the pool game

How to explain the fact that protons can be intact?



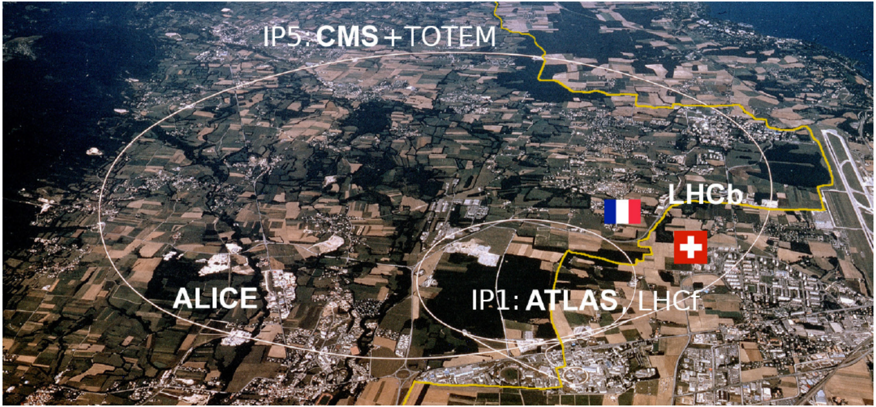
- Quarks/gluons radiate lots of gluons when one tries to separate them (confinement)
- Gluons exchange color, interact with other gluons in the proton and in that case protons are destroyed in the final state
- In order to explain how protons can remain intact: we need colorless exchanges, or at least 2 gluons to be exchanged

$p\bar{p}$ interactions: the Tevatron

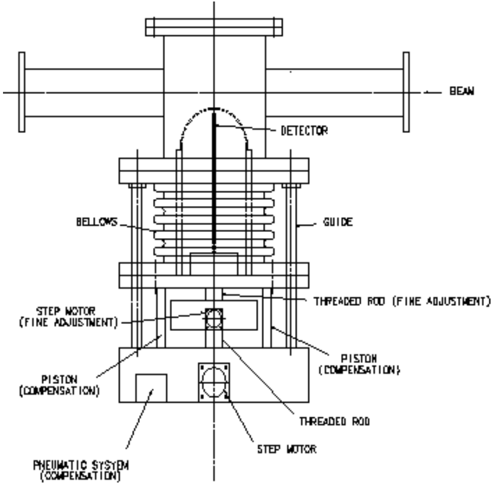


pp interactions: The Large Hadron Collider at CERN

- Large Hadron Collider at CERN: proton proton collider with 2.76, 7, 8 and 13 TeV center-of-mass energy
- Circonference: 27 km; Underground: 50-100 m

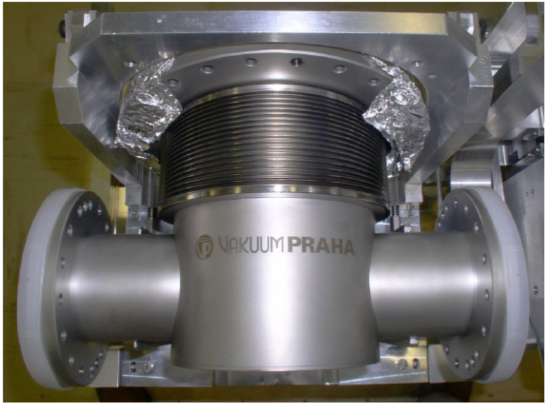


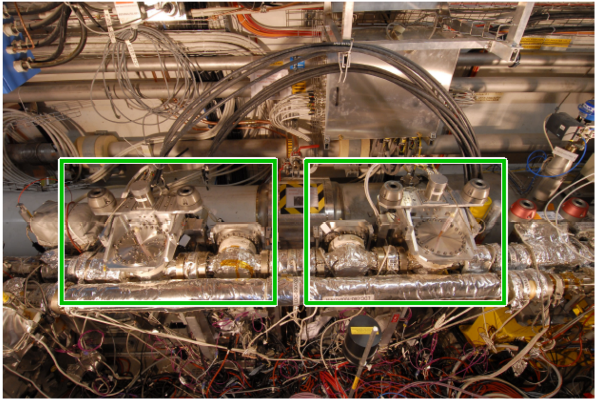
Which tools do we have? Roman Pot detectors



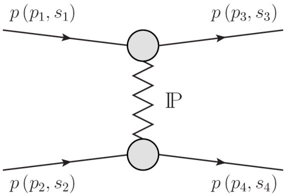
- We use special detectors to detect intact protons/ anti-protons called Roman Pots
- These detectors can move very close to the beam (up to 3σ) when beam are stable so that protons scattered at very small angles can be measured

Roman Pot detectors at the LHC





The odderon in a nutshell

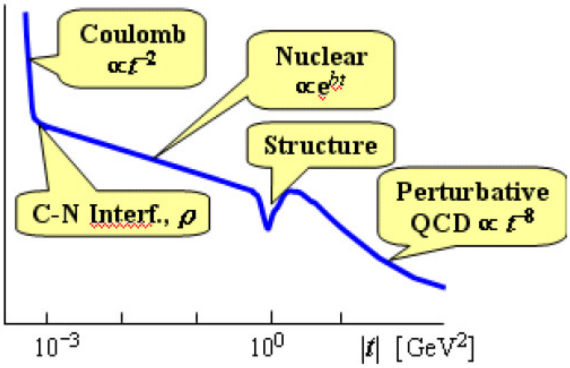


- Let us assume that elastic scattering can be due to exchange of colorless objects: Pomeron and Odderon
- Charge parity C: Charge conjugation changes the sign of all quantum charges
- Pomeron and Odderon correspond to positive and negative C parity: Pomeron is made of two gluons which leads to a $+1$ parity whereas the odderon is made of 3 gluons corresponding to a -1 parity
- Scattering amplitudes can be written as:

$$A_{pp} = Even + Odd$$
$$A_{p\bar{p}} = Even - Odd$$

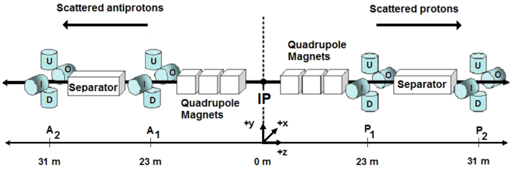
- From the equations above, it is clear that observing a difference between pp and $p\bar{p}$ interactions would be a clear way to observe the odderon

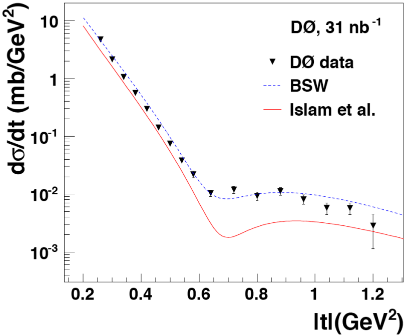
Measurement of elastic scattering at Tevatron and LHC



- Study of elastic $pp \to pp$ reaction: exchange of momentum between the two protons which remain intact
- Measure intact protons scattered close to the beam using Roman Pots installed both by D0 and TOTEM collaborations
- From counting the number of events as a function of $|t|$ (4-momentum transferred square at the proton vertex measured by tracking the protons), we get $d\sigma/dt$

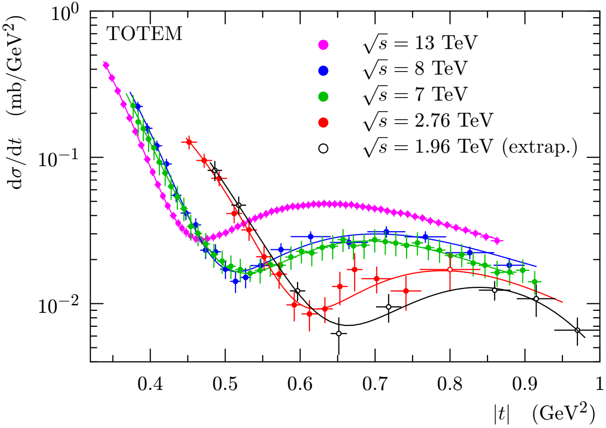
D0 elastic $p\bar{p}$ $d\sigma/dt$ cross section measurements





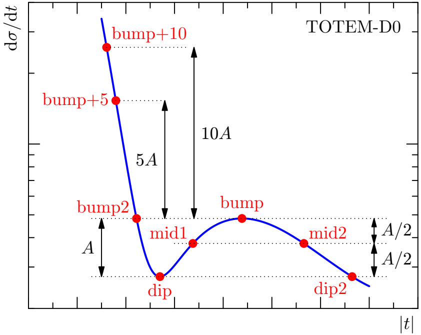
- D0 collected elastic $p\bar{p}$ data with intact p and $\bar{p}$ detected in the Forward Proton Detector with 31 nb^{-1} Phys. Rev. D 86 (2012) 012009
- Measurement of elastic $p\bar{p}$ $d\sigma/dt$ at 1.96 TeV for $0.26 < |t| < 1.2$ GeV^2

Strategy to compare pp and $p\bar{p}$ data sets



- In order to identify differences between pp and $p\bar{p}$ elastic $d\sigma/dt$ data, we need to compare TOTEM measurements at 2.76, 7, 8, 13 TeV and D0 measurements at 1.96 TeV
- All TOTEM $d\sigma/dt$ measurements show the same features, namely the presence of a dip and a bump in data, whereas D0 data do not show this feature

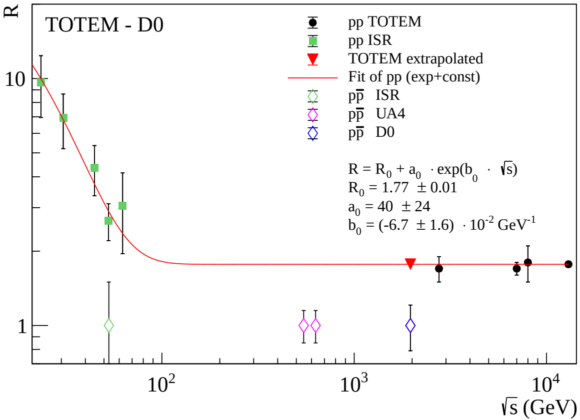
Reference points of elastic $d\sigma/dt$



- Define 8 characteristic points of elastic *pp* $d\sigma/dt$ cross sections (dip, bump...) that are feature of elastic *pp* interactions

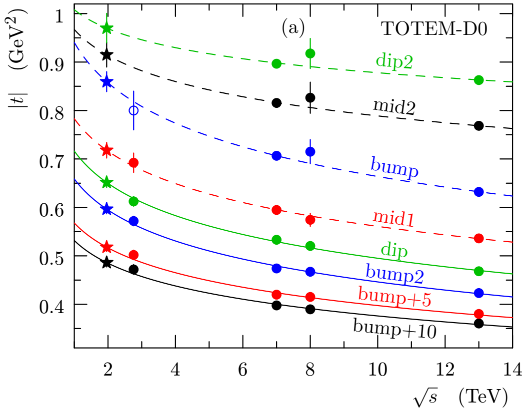
- Determine how the values of $|t|$ and $d\sigma/dt$ of characteristic points vary as a function of $\sqrt{s}$ in order to predict their values at 1.96 TeV
- We use data points closest to those characteristic points (avoiding model-dependent fits)
- Data bins are merged in case there are two adjacent dip or bump points of about equal value
- This gives a distribution of t and $d\sigma/dt$ values as a function of $\sqrt{s}$ for all characteristic points

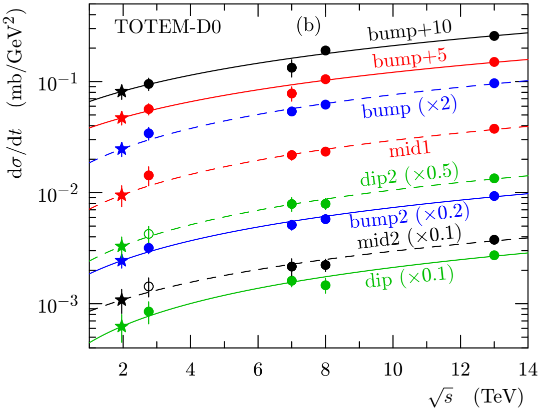
Bump over dip ratio



- Bump over dip ratio measured for *pp* interactions at ISR and LHC energies
- Bump over dip ratio in *pp* elastic collisions: decreasing as a function of $\sqrt{s}$ up to $\sim$ 100 GeV and flat above
- D0 $p\bar{p}$ shows a ratio of 1.00$\pm$0.21 given the fact that no bump/dip is observed in $p\bar{p}$ data within uncertainties: **more than 3σ difference between *pp* and $p\bar{p}$ elastic data** (assuming flat behavior above $\sqrt{s} = 100 GeV$)

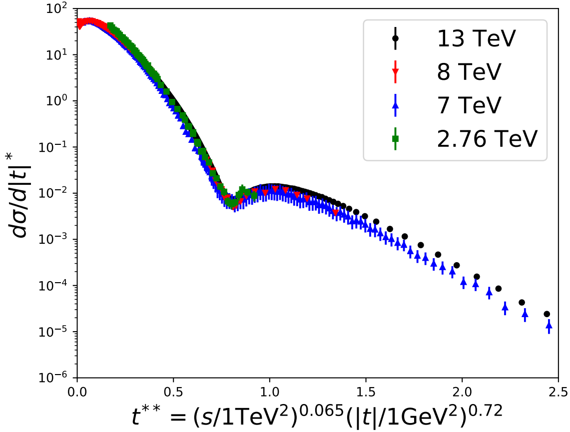
Variation of t and $d\sigma/dt$ values for reference points





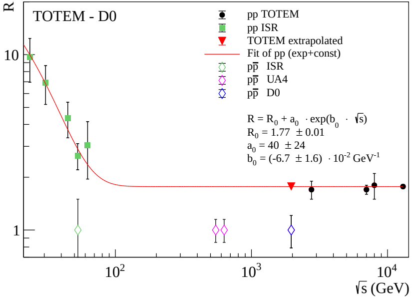
$$|t| = a \log(\sqrt{s}[\text{TeV}]) + b \qquad (d\sigma/dt) = c\sqrt{s}\ [\text{TeV}] + d$$

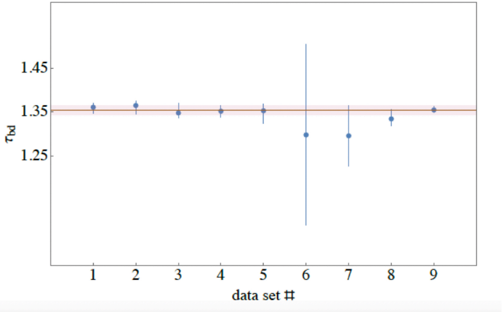
One aside: The first approach of a new scaling in data



- We introduce the variable $t^* = (s/|t|)^A \times |t|$, inspired by geometric scaling in terms of saturation models
- $t^{**} = t^*/s^B$, A and B being parameters to be fitted to data
- $d\sigma/dt^*$ shows scaling as a function of t^{**}
- A and B are correlated: full valley of parameters leading to similar scalings: $B = A - 0.065 \rightarrow 1$ single parameter fit
- $A = 0.28$, C. Baldenegro, C. Royon, A. Stasto, Phys. Lett. B830 (2022) 137141

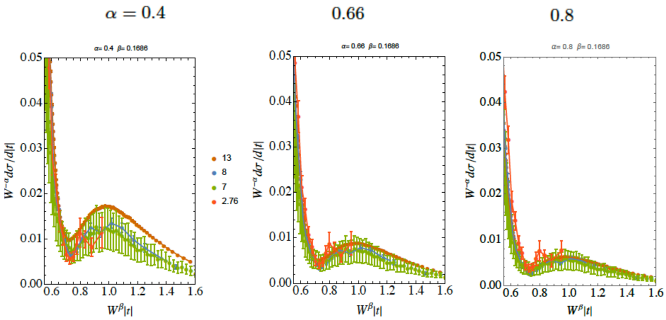
One aside: Scaling of the elastic proton-proton cross section





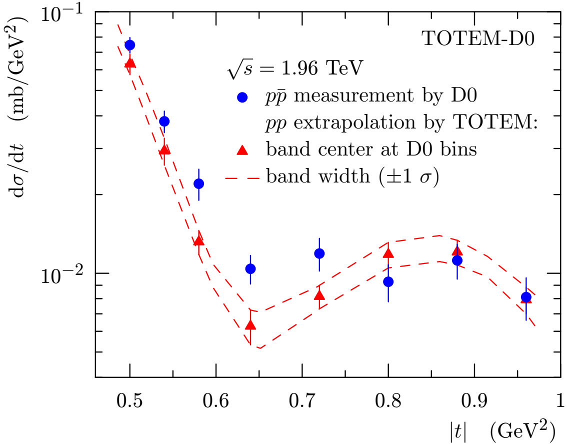
- Bump over dip cross section $d\sigma/dt$ ratio constant at high energies
- The position ratio in $|t|$ between the bump and the dip is also contant between ISR and LHC energies
- C. Baldenegro, M. Praszalowicz, C. Royon, A. Stasto, Phys. Lett. B 856 (2024) 13896

One aside: Scaling of the elastic proton-proton cross section



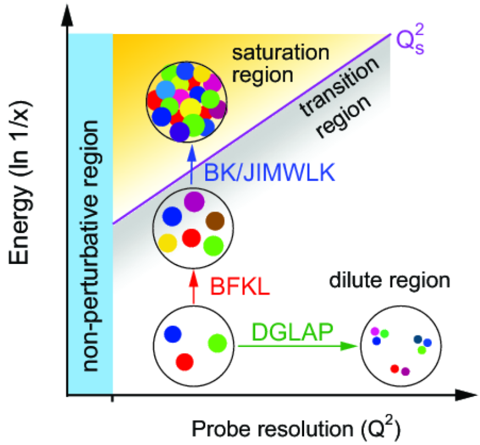
- $|t| \to \tau = W^{\beta}|t|$ with $\beta = 0.1686$
- $\frac{d\sigma_{el}}{dt}(\tau) \to W^{-\alpha}\frac{d\sigma_{el}}{dt}(\tau)$
- A family of scalings exists at high energy

Predictions at $\sqrt{s} = 1.96$ TeV



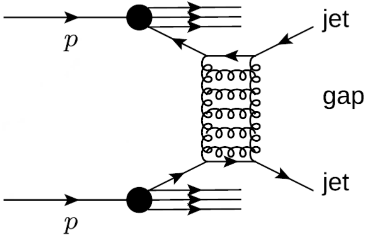
- Reference points at 1.96 TeV (extrapolating TOTEM data) and 1σ uncertainty band
- Comparison with D0 data: the χ^2 test with six degrees of freedom yields the ***p*-value of 0.00061, corresponding to a significance of 3.4σ**
- Combination with the independent evidence of the odderon found by TOTEM using ρ and total cross section measurements at low t leads to a 5.3 to 5.7σ discovery

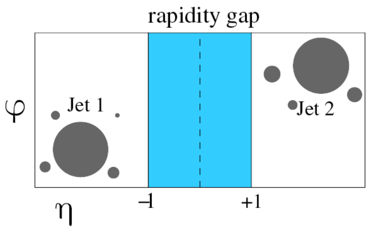
Looking for BFKL resummation /saturation effects



- DGLAP (Dokshitzer Gribov Lipatov Altarelli Parisi): Evolution in resolution Q^2, resums terms in $\alpha_S \log Q^2 \to$ resolving "smaller" partons at high Q
- BFKL (Balitski Fadin Kuraev Lipatov (BFKL): Evolution in energy x, resums terms in $\alpha_S \log 1/x \to$ Large parton densities at small x
- Saturation region at very small x
- Important to understand QCD evolution, parton densities
- EIC: look for saturation effects using HIN

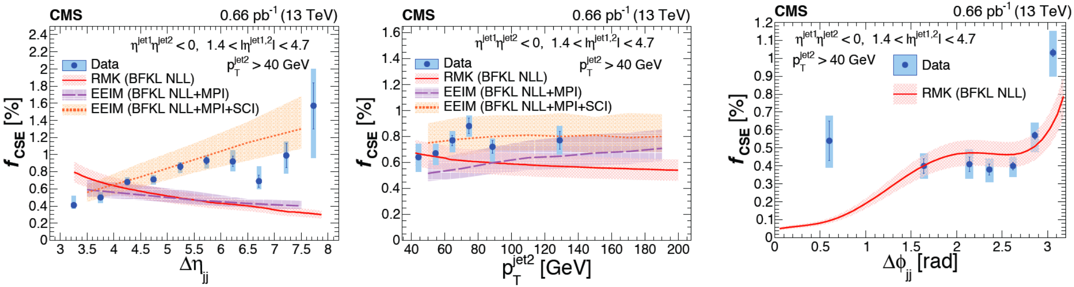
Mueller Tang: Gap between jets at the Tevatron and the LHC





- Looking for a gap between two jets: Region in rapidity devoid of any particle production, energy in detector
- Exchange of a BFKL Pomeron between the two jets: two-gluon exchange in order to neutralize color flow
- Method to test BFKL resummation: Implementation of BFKL NLL formalism in HERWIG/PYTHIA Monte Carlo

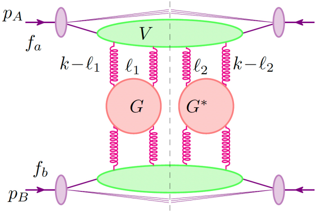
LHC: Measurement of jet gap jet fraction (CMS)



- Measurement of fraction of jet gap jet events as a function of jet $\Delta\eta$, p_T, $\Delta\Phi$ (Phys.Rev.D 104 (2021) 032009)
- Comparison with NLL BFKL (with LO impact factors) as implemented in PYTHIA, and soft color interaction based models (Ingelman et al.)
- Disagreement between BFKL and measurements ($\Delta\eta$ dependence): What is going on?

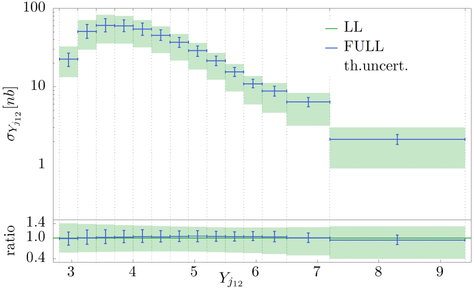
Jet gap jet: Full NLO BFKL calculation including NLO impact factor

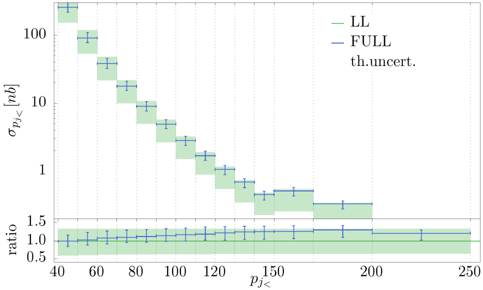
- Combine NLL kernel with NLO impact factors (Hentschinski, Madrigal, Murdaca, Sabio Vera 2014)



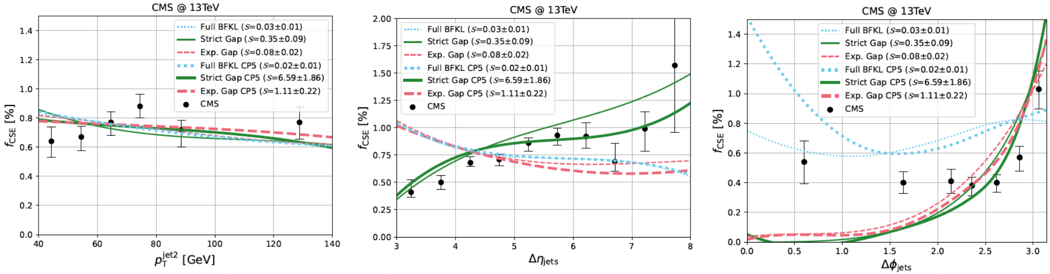
- Gluon Green functions in red
- Impact factors in green
- Will lead to an improved parametrisation to be implemented in HERWIG/PYTHIA
- D. Colferai, F. Deganutti, T. Raben, C. Royon, JHEP 06 (2023) 091

Effect of NLO impact factor on jet gap jet cross section: final results



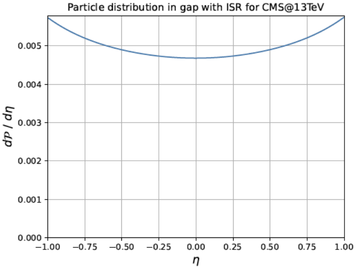


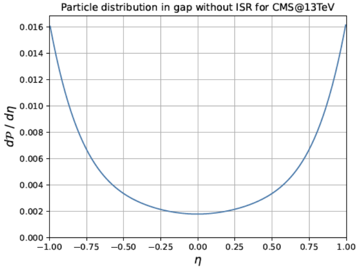
- Higher cross section by 20% at high p_T and small effect on the y dependence
- Total uncertainties are much smaller at NLO: 15-20%



- Implementation of BFKL NLL formalism in Pythia and compute jet gap jet fraction
- Dijet cross section computed using POWHEG and PYTHIA8
- Three definitions of gap: theory (pure BFKL), experimental (no charged particle above 200 MeV in the gap $-1 < \eta < 1$) and strict gap (no particle above 1 MeV in the gap region) (C. Baldenegro, P. Gonzalez Duran, M. Klasen, C. Royon, J. Salomon, JHEP 08 (2022) 250)
- Two different CMS tunes: CP1 without MPI, CP5 with MPI

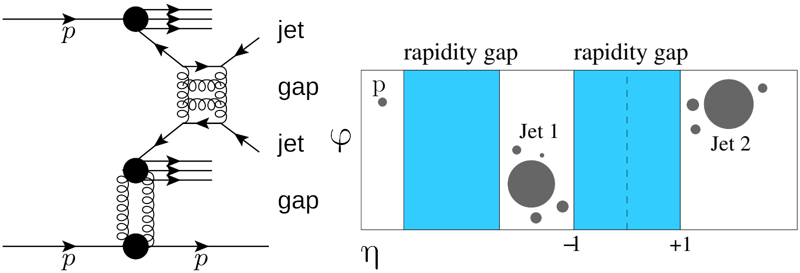
Charged particle distribution





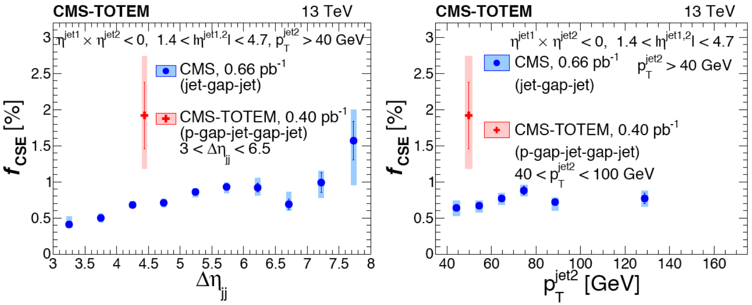
- Disitribution of charged particles from PYTHIA in the gap region $-1 < \eta < 1$ with ISR ON (left) and OFF (right)
- Particles emitted at large angle with $p_T > 200$ MeV from initial state radiation have large influence on the gap presence or not, and this on the gap definition (experimental or strict)

Jet gap jet events in diffraction (CMS/TOTEM)



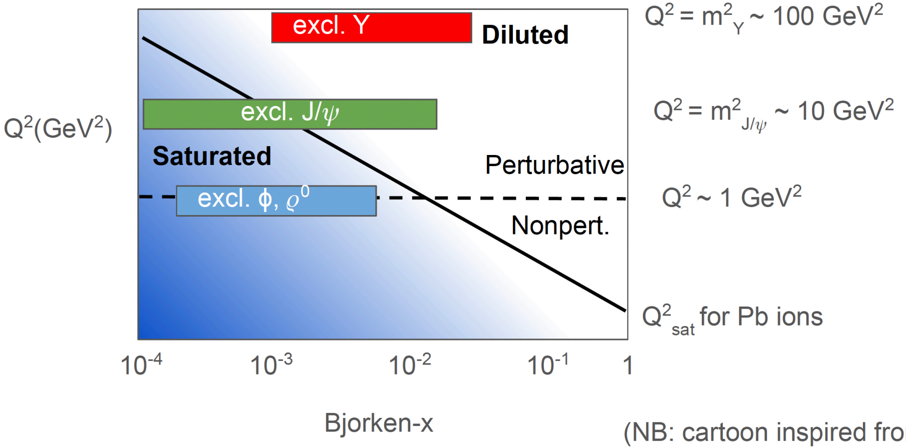
- Jet gap jet events: powerful test of BFKL resummation C. Marquet, C. Royon, M. Trzebinski, R. Zlebcík, Phys. Rev. D 87 (2013) 3, 034010
- Subsample of gap between jets events requesting in addition at least one intact proton on either side of CMS
- **Jet gap jet events were observed for the 1st time by CMS!** (Phys.Rev.D 104 (2021) 032009)

First observation of jet gap jet events in diffraction (CMS/TOTEM)



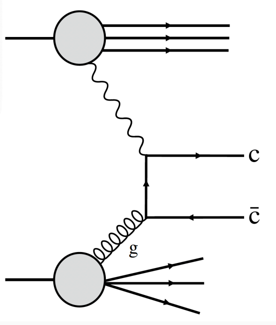
- First observation: 11 events observed with a gap between jets and at least one proton tagged with ~ 0.7 pb^{-1}
- Leads to very clean events for jet gap jets since MPI are suppressed and might be the "ideal" way to probe BFKL
- Would benefit from more stats $>$10 pb^{-1} needed, 100 for DPE

Looking for saturation effects: vector meson channel



(NB: cartoon inspired from Wei's plot)

Forward jets, J/Ψ, c and b productions: observables for saturation



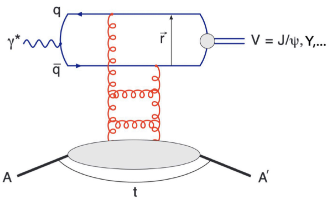
- What do we need to see saturation at the LHC?
- γPb c, b, J/Ψ are ideal probes for low-x physics

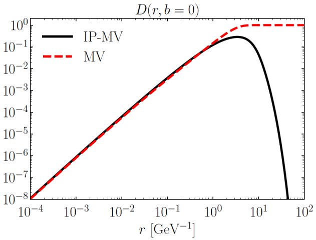
$$x = \frac{m_{c\bar{c}}}{\sqrt{s_{NN}}} \exp(-y_c)$$

- We can reach low x values of 10^{-4} or smaller
- We need a low scale (to be below Q_S), and this is why c or b where one can go to very low p_T or J/Ψ (low mass vector mesons) are ideal while still being in the perturbative region
- $d\sigma/dW$ is the best observable while $d\sigma/dy$ presents the difficulties to mix up low and high x

Looking for saturation: vector meson production

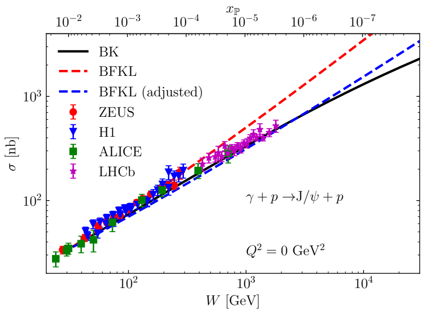
$$\partial_Y D(\mathbf{x}_0,\mathbf{x}_1,Y) = \int \mathrm{d}^2\mathbf{x}_2\, K_{BK}(\mathbf{x}_0,\mathbf{x}_1,\mathbf{x}_2)\Big[D(\mathbf{x}_0,\mathbf{x}_2,Y) + D(\mathbf{x}_2,\mathbf{x}_1,Y) - D(\mathbf{x}_0,\mathbf{x}_1,Y) - D(\mathbf{x}_0,\mathbf{x}_2,Y)D(\mathbf{x}_2,\mathbf{x}_1,Y)\Big]$$

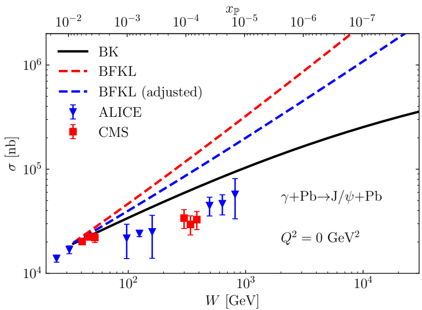




- Compute exclusive vector meson production in γp (HERA, EIC and pPb LHC) and γPb (EIC and Pb Pb LHC) where we probe the gluon density in p or Pb
- Saturation effects are expected to happen in Pb Pb, not in p Pb
- Computation: Factorize the $\gamma \to q\bar{q}$ part from the coupling to the proton: cross section proportional to $(xG)^2$ at LO

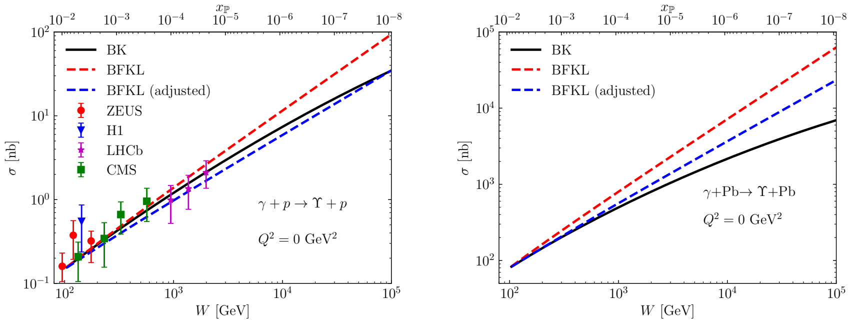
Looking for saturation: J/Ψ vector meson production





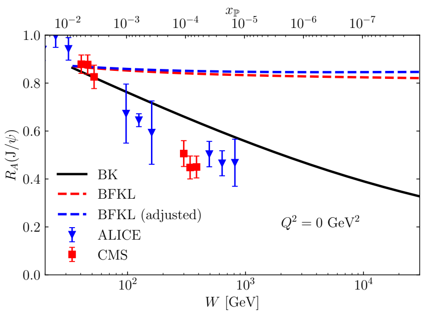
- BFKL and BK CGC predictions after taking into account b-dependence (J. Penttala, C. R.)
- J/Ψ production in pPb: small differences between BK and BFKL, BK slightly favored
- Large differences between BK and BFKL in PbPb collisions

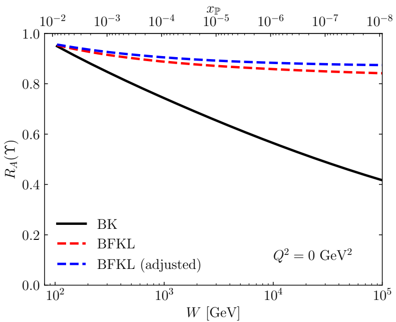
Looking for saturation: Υ vector meson production



- Υ vector meson production: smaller differences between BFKL and BK in pPb or PbPb collisions
- Looking for additional observables: charm, etc

Looking for saturation: J/Ψ and Υ nuclear suppression factor

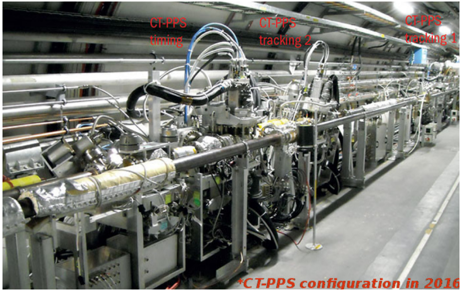




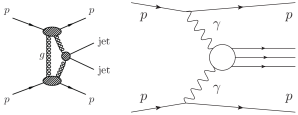
- Large nuclear suppression factor for J/Ψ in PbPb collisions
- Have we seen saturation in Pb Pb?
- Importance to have precise measurements of pp interactions as a reference at the same $\sqrt{s}$

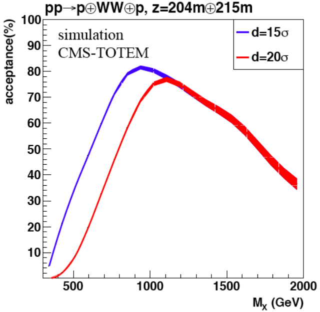
Searching for beyond standard model physics using intact protons

Roman pot detectors from PPS installed in the tunnel

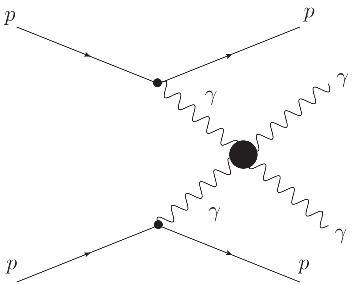


- Good acceptance at high mass in standard runs (PPS in CMS, AFP in ATLAS)
- >100 fb^{-1} collected in Run II





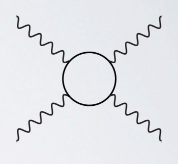
Search for quartic $\gamma\gamma\gamma\gamma$ anomalous coupling

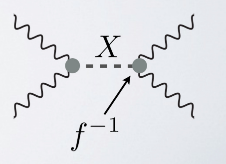


- Search for production of two photons and two intact protons in the final state: $pp \to p\gamma\gamma p$

- Additional channels: WW, ZZ, γZ, $t\bar{t}$
- Possible larger number of events than expected in SM due to extra-dimensions, composite Higgs models, axion-like particles
- Anomalous couplings can appear via loops of new particles coupling to photons or via resonances decaying into two photons
- JHEP 1806 (2018) 131; JHEP 1502 (2015) 165; Phys.Rev. D89 (2014) 114004; Phys.Rev. D81 (2010) 074003; Phys.Rev. D78 (2008) 073005

Motivations to look for quartic $\gamma\gamma$ anomalous couplings



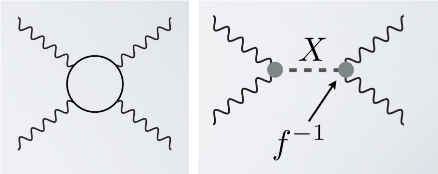


- Two effective operators and two different couplings at low energies ζ
- $\gamma\gamma\gamma\gamma$ couplings can be modified in a model independent way by loops of heavy charge particles

$$\zeta_1 = \alpha_{em}^2 Q^4 m^{-4} N c_{1,s}$$

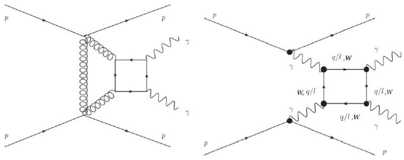
where the coupling depends only on $Q^4 m^{-4}$ (charge and mass of the charged particle) and on spin, $c_{1,s}$ depends on the spin of the particle This leads to ζ_1 of the order of 10^{-14}-10^{-13}

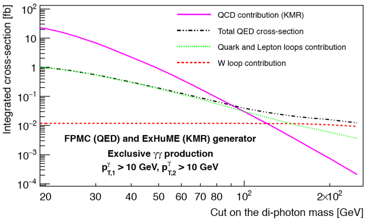
Motivations to look for quartic $\gamma\gamma$ anomalous couplings



- Two effective operators at low energies
- ζ_1 can also be modified by neutral particles at tree level (extensions of the SM including scalar, pseudo-scalar, and spin-2 resonances that couple to the photon) $\zeta_1 = (f_s m)^{-2} d_{1,s}$ where f_s is the $\gamma\gamma X$ coupling of the new particle to the photon, and $d_{1,s}$ depends on the spin of the particle; for instance, 2 TeV dilatons lead to $\zeta_1 \sim 10^{-13}$

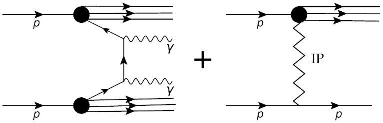
$\gamma\gamma$ exclusive production: SM contribution

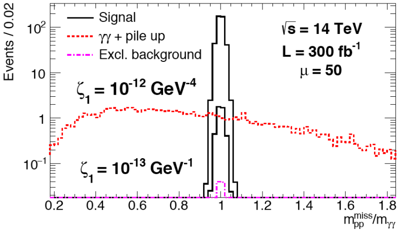


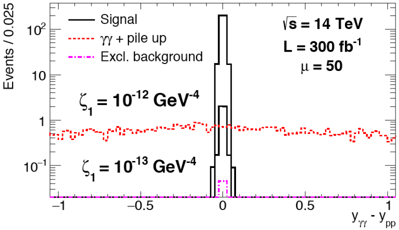


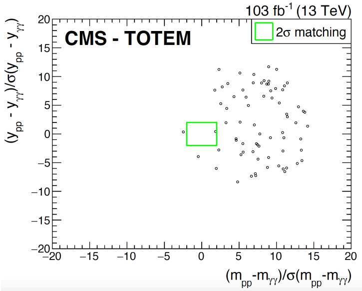
- QCD production dominates at low $m_{\gamma\gamma}$, QED at high $m_{\gamma\gamma}$
- Important to consider W loops at high $m_{\gamma\gamma}$
- At high masses ($>$ 200 GeV), the photon induced processes are dominant
- **Conclusion: Two photons and two tagged protons means photon-induced process**

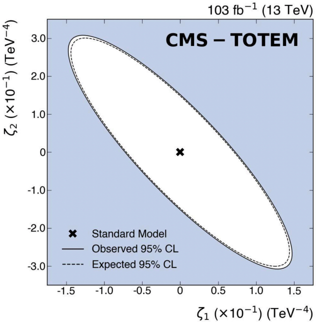
- Advantage of tagging protons: negligible background after matching mass/rapidity of photon and proton systems (JHEP 1502 (2015) 165; Phys.Rev. D89 (2014) 114004)
- Possibility to use fast timing detectors to measure proton time of flights





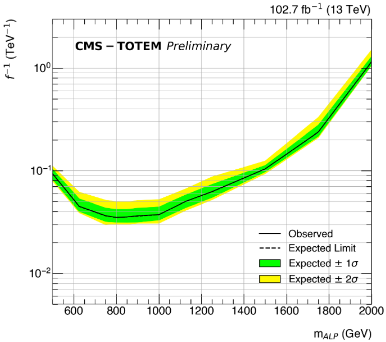


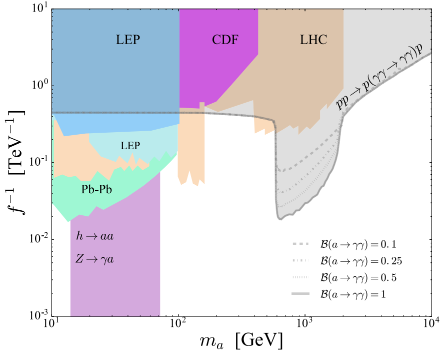


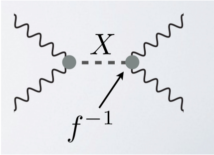


- Search for exclusive diphoton production: back-to-back, high diphoton mass ($m_{\gamma\gamma} > 350$ GeV), matching in rapidity and mass between diphoton and proton information
- 1st limits on $|\zeta_1| < 2.9\ 10^{-13}$ GeV^{-4}, $|\zeta_2| < 6.\ 10^{-13}$ GeV^{-4} ($\sim$10 fb^{-1}), PRL 129 (2022) 1, 011801
- Limit updates with 102.7 fb^{-1}: $|\zeta_1| < 7.3\ 10^{-14}$ GeV^{-4}, $|\zeta_2| < 1.5\ 10^{-13}$ GeV^{-4} (Phys. Rev. D 110 (2024) 1, 012010)

First search for high mass production of axion-like particles (CMS/TOTEM)

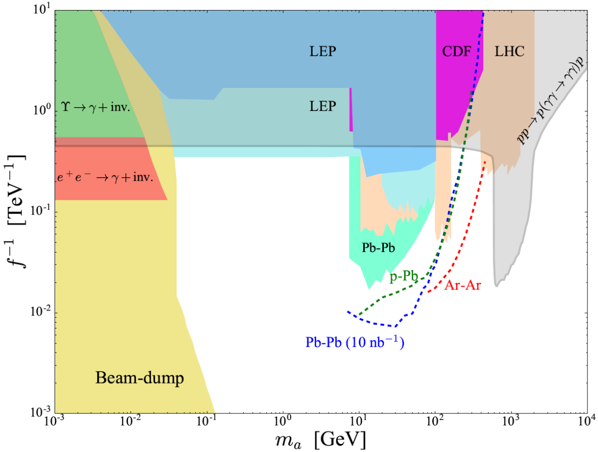




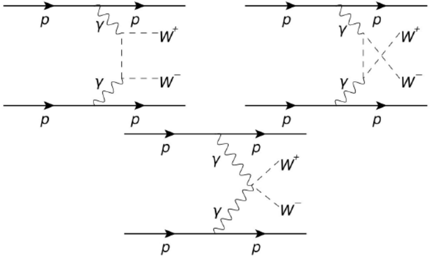


- First limits on ALPs at high mass (CMS-PAS-EXO-21-007)
- Sensitivities projected with 300 fb^{-1} (C. Baldenegro, S. Fichet, G. von Gersdorff, C. Royon, JHEP 1806 (2018) 13)

Search for axion like particles: complementarity with heavy ion runs

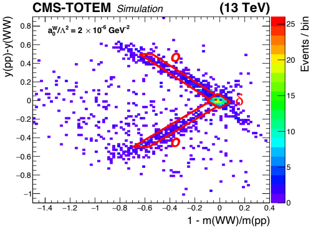


- Production of ALPs via photon exchanges in heavy ion runs: Complementarity to *pp* running
- Sensitivity to low mass ALPs: low luminosity but cross section increased by Z^4, C. Baldenegro, S. Hassani, C.R., L. Schoeffel, ArXiv:1903.04151
- Similar gain of three orders of magnitude on sensitivity for $\gamma\gamma\gamma Z$ couplings in *pp* collisions: C. Baldenegro, S. Fichet, G. von Gersdorff, C. R., JHEP 1706 (2017) 142

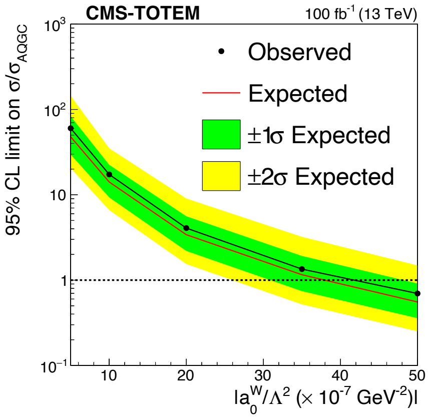


- Search with fully hadronic decays of W bosons: anomalous production of WW events dominates at high mass with a rather low cross section

- 2 "fat" jets (radius 0.8), jet $p_T > 200$ GeV, 1126< m_{jj} <2500 GeV, jets back-to-back ($|1 - \phi_{jj}/\pi| < 0.01$)
- Signal region defined by the correlation between central WW system and proton information

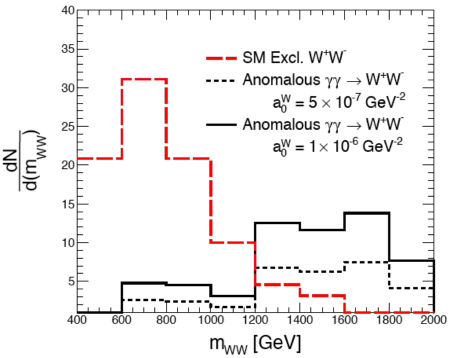


WW and ZZ exclusive productions



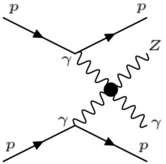
- Searches performed in full hadronic decays of W bosons (high cross section) with AK8 jets
- SM cross section is low
- Limits on SM cross section $\sigma_{WW} < 67$fb, $\sigma_{ZZ} < 43$fb for $0.04 < \xi < 0.2$ (JHEP 07 (2023) 229)
- New limits on quartic anomalous couplings (events violating unitarity removed) : $a_0^W/\Lambda^2 < 4.3\ 10^{-6}$ GeV^{-2}, $a_C^W/\Lambda^2 < 1.6\ 10^{-5}$ GeV^{-2}, $a_0^Z/\Lambda^2 < 0.9\ 10^{-5}$ GeV^{-2}, $a_C^Z/\Lambda^2 < 4.\ 10^{-5}$ GeV^{-2} with 52.9 fb^{-1}

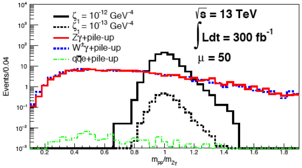
The future: Observation of exclusive WW production

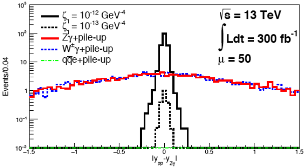


- SM contributions appears at lower WW masses compared to anomalous couplings
- Use purely leptonic channels for W decays (the dijet background is too high at low masses for hadronic channels)
- SM prediction on exclusive WW (leptonic decays) after selection: about 50 events for 300 fb^{-1} (2 background)
- JHEP 2012 (2020) 165, C. Baldenegro, G. Biagi, G. Legras, C.R.

$\gamma\gamma\gamma Z$ quartic anomalous coupling: leptonic and hadronic decays of Z boson



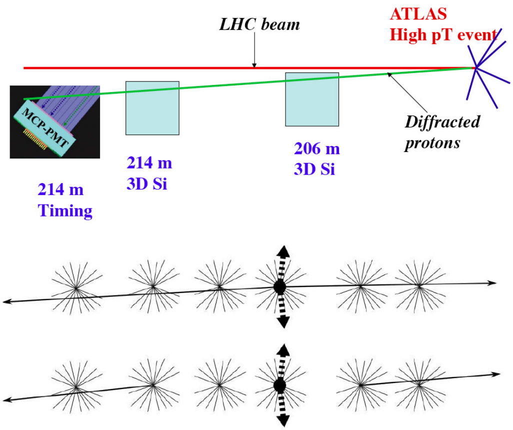




Coupling (GeV^{-4})	ζ ($\tilde{\zeta}=0$)		$\zeta=\tilde{\zeta}$	
Luminosity	300 fb^{-1}		300 fb^{-1}	
Pile-up (μ)	50		50	
Channels	5 σ	95% CL	5 σ	95% CL
$\ell\bar{\ell}\gamma$	$2.8\cdot10^{-13}$	$1.8\cdot10^{-13}$	$2.5\cdot10^{-13}$	$1.5\cdot10^{-13}$
$jj\gamma$	$2.3\cdot10^{-13}$	$1.5\cdot10^{-13}$	$2\cdot10^{-13}$	$1.3\cdot10^{-13}$
$jj\gamma \bigoplus \ell\bar{\ell}\gamma$	$1.93\cdot10^{-13}$	$1.2\cdot10^{-13}$	$1.7\cdot10^{-13}$	$1\cdot10^{-13}$

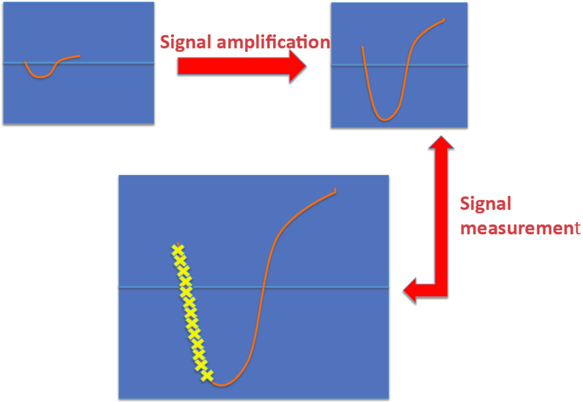
- C. Baldenegro, S. Fichet, G. von Gersdorff, C. Royon, JHEP 1706 (2017) 142
- Best expected reach at the LHC by about three orders of magnitude
- Sensitivity to wide/narrow resonances, loops of new particles

Additional method to remove pile up: Measuring proton time-of-flight



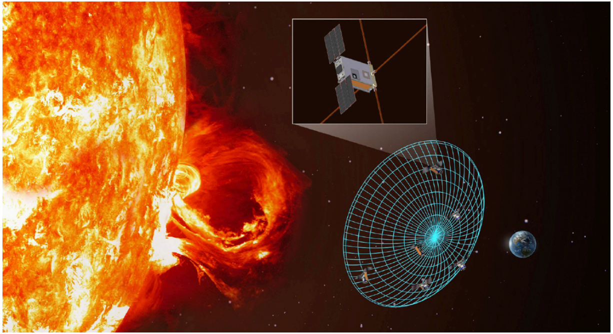
- Measure the proton time-of-flight in order to determine if they originate from the same interaction as the selected photon
- Typical precision: 10 ps means 2.1 mm
- Idea: use ultra-fast Si Low Gain Avalanche Detectors (signal duration of ∼few ns and possibility to use fast sampling to reconstruct full signal)

Signal amplification and measurement



- Signal originating from a Si detector: signal duration of a few nanoseconds (fast detector)
- 1st step: Amplify the signal using an amplifier designed at KU using standard components (price: a few 10's of Euros per channel)
- 2nd step: Very fast digitization of the signal: measure many points on the fast increasing signal as an example
- Allows to measure simultanously time-of-flight, pulse amplitude and shape

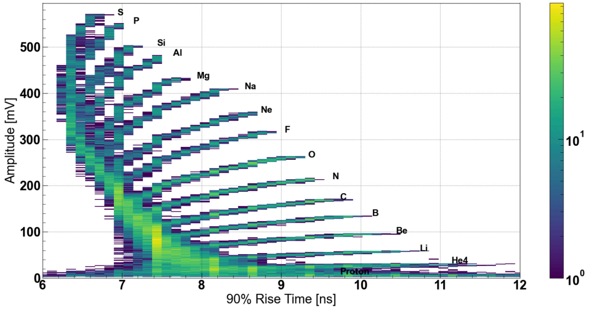
Goals of AGILE (Advanced Energetic Ion Electron Telescope)



- Build a compact low power and low cost instrument for characterization of solar energetic (SEP) and anomalous cosmic ray (ACR) particles

- Focus on Ions (H-Fe), $E = (1- 100)$ MeV/nucl, Electrons, $E = (1 - 10)$MeV, upgradable to higher energy ranges
- AGILE will perform robust real-time particle identification and energy measurement in space
- Solution: use multiple layers of fast Si detector (with or without absorbers) and measure the signal in stopping layer using the fast sampling technique
- Characteristics aspects of the signal (amplitude and duration) allow particle Id and energy measurement

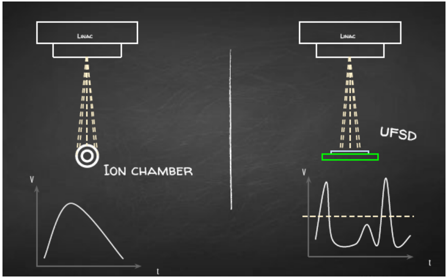
Particle identification with AGILE



- Maximum amplitude vs time needed to reach 90% of maximum of amplitude (rise time) for p-Fe ions stopping in the detector
- Allows to obtain Particle Id since curves do not overlap for many values of rise time
- Allows even to distinguish between ^{3}He, and ^{4}He!
- Launch is foreseen by the end of this year

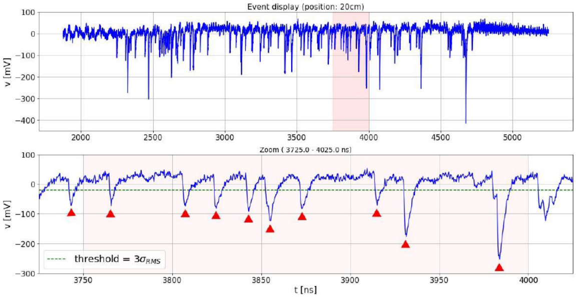
Measuring radiation in cancer treatment

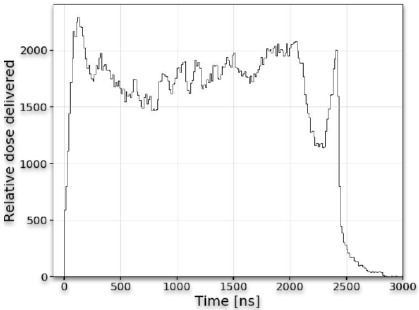
- Ultra fast silicon detectors and readout system were put in an electron beam used in the past for photon therapy at St Luke Hospital, Dublin, Ireland
- Precise and instantaneous measurements of dose during cancer treatment (especially for flash proton beam treatment)
- Develop a fast and efficient detector to count the particles up to a high rate: very precise instantaneous dose measurement, no need of calibration, high granularity (mm^2)



What Si detector can do better: Single particle Id in Dublin hospital

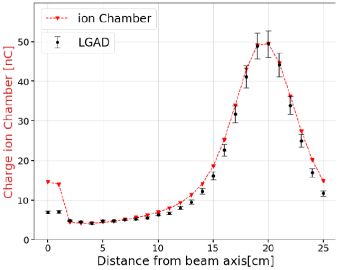
- Use UFSD and their fast signal in order to identify and measure spikes in signal due to particles passing by
- Allows measuring doses almost instantaneously

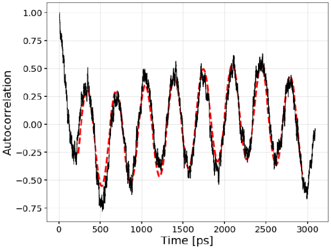




- Very precise dose measurement allowing to adapt better treatment to patients especially for flash dose treatments (brain cancer for instance)

Tests performed at St Luke hospital, University of Dublin, Ireland





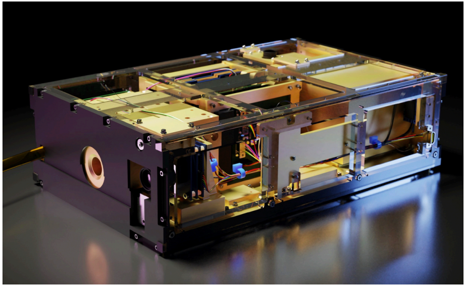
- Measurement of charge deposited in Si detector compared to standard measurement using an ion chamber: good correlation
- Our detectors see in addition the beam structure (periodicity of the beam of ∼330 ps, contrary to a few seconds for the ion chamber): measure single particles from the beam
- Fundamental to measure instantaneous doses for high intensity proton therapy as example
- For more details: Arxiv 2101.07134, Phys. Med. Biol. 66 (2021) 135002

Conclusion

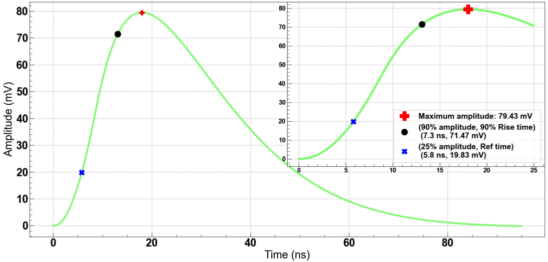
- Detailed comparison between $p\bar{p}$ (1.96 TeV from D0) and pp (2.76, 7, 8, 13 TeV from TOTEM) elastic $d\sigma/dt$ data: odderon discovery
- Study of BFKL dynamics and saturation at the LHC
- PPS allows probing quartic anomalous couplings with unprecedented precision: sensitivity to composite Higgs, extra-dimension models, axion-like particles
- Development of fast timing detectors for HEP and applications in medicine, cosmic-ray physics

We need to look everywhere! For instance using intact protons...

Method developed for AGILE: signal measurement

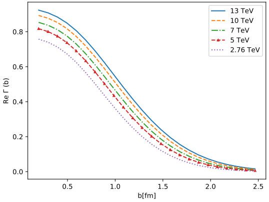


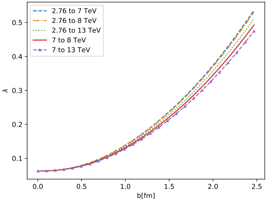
- 3 layers of fast Si detectors as a prototype
- Identification of ion type (*p*, *He*, *Au*, *Pb*, etc) and energy measurement by measuring the signal amplitude and duration



- Simulated signals of a 14 MeV/n oxygen ion that stopped in 2nd layer of AGILE
- Key characteristics: Maximum Amplitude and time to reach 90% of maximum

One aside: Going to the impact parameter space: The profile function





- Relation between the profile function Γ and the amplitude A: $\mathrm{Re}(\Gamma(s,b)) = \frac{1}{4\pi i s}\int_0^\infty dq\, q\, J_0(qb)\, A(s,t=-q^2)$
- We define λ as $\lambda = \frac{1}{\ln(s_1/s_2)} \ln\left(\frac{\mathrm{Re}\Gamma(s_1,b)}{\mathrm{Re}\Gamma(s_2,b)}\right)$
- $\lambda = (\alpha - \gamma)/2+$term vanishing when $b \to 0$, $\lambda = 0.06$ which means that scaling predicts a universal behavior of λ at small b
- Scaling together with the value of λ at low b, could be interpreted as having a large density of gluons inside colorless gluonic compounds (responsible for diffraction) that reach the black disc limit at small b. At higher b, the density of gluons is smaller and in principle describable by BFKL dynamics (C. Baldenegro, C. Royon, A. Stasto, Phys. Lett. B830 (2022) 137141