# Searching for invisible particles with forward proton detectors

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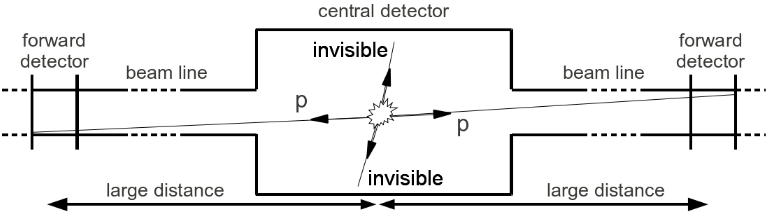
# Introduction






- Invisible particles: forward protons (missing mass) + nothing
- Possible scenarios:
  - magnetic monopoles (trapped)
  - very massive, slow particles (miss trigger window)
  - other models?
- Work in progress:
  - Done: background for different measurement scenarios
  - To do: possible reach of the method

# Motivation – magnetic monopoles



$$\nabla \cdot \mathbf{E} = 4\pi\rho_{\mathrm{e}} \qquad \nabla \cdot \mathbf{B} = 4\pi\rho_{\mathrm{m}}$$

$$-\nabla \times \mathbf{E} = \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_{\mathrm{m}} \qquad \nabla \times \mathbf{B} = \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_{\mathrm{e}}$$

- Symmetry between electric and magnetic quantities
- Dirac quantisation: $q_m q_e = \frac{1}{2}\hbar c n$
- Dirac quantisation $\rightarrow$ quantisation of electric charge
- Predicted by BSM theories (GUT, string theories)

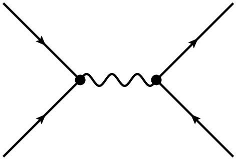
- $\alpha = 1/137 \quad \rightarrow \quad q_{\mathsf{m}}/q_e = 68.5$
- Large charge $\rightarrow$ large coupling to photons
- Possible to produce in two-photon exchange
- Perturbative calculations not valid

# Magnetic monopoles at a hadron collider

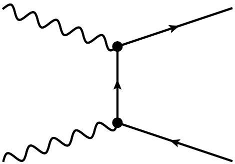


**Production mechanisms**

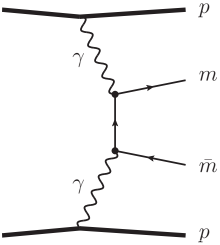
Drell-Yan



Photon fusion



**Elastic photon fusion**

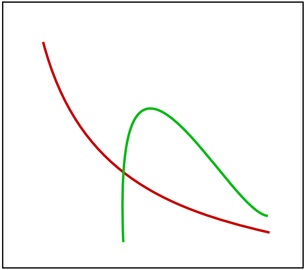



- Possible final state:
    - free monopoles
    - trapped in beam pipe material
    - annihilation to $2\gamma$
    - bound state (monopolium)
- Monopoles can be invisible
- Slow monopoles can miss trigger window

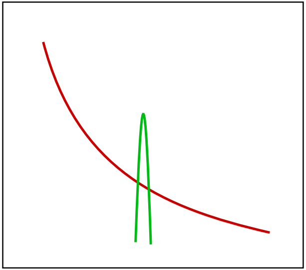
# Non-resonant vs resonant production



Continuum



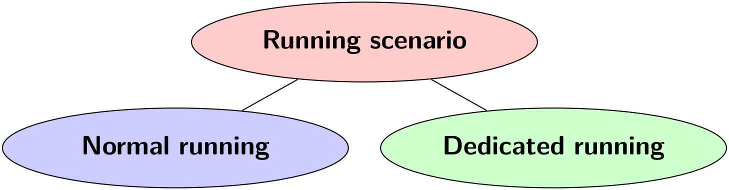
Resonance



Requires good understanding of the background

Narrow resonance can be visible even without good understanding of the background

# Experimental conditions



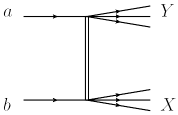

- Long running time
- Very high integrated luminosity
- High pile-up: many $pp$ interaction in event
- Central detector never empty

- Short running time ($\sim$ 1 week)
- Conditions as requested
- Low pile-up possible
- Low integrated luminosity

# Measurements at low luminosity

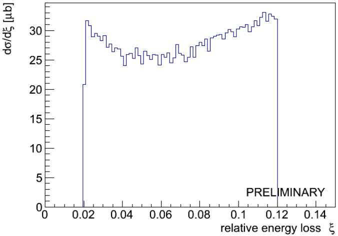
**Signature:**

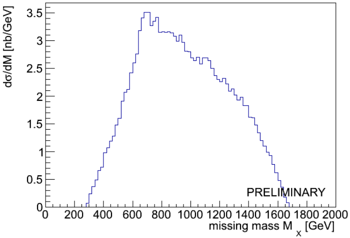
- One proton tagged at each side (low $\beta^*$: $0.02 < \xi < 0.12$)
- No activity in central detector ($|\eta| < 5$, $p_T > 200$ MeV)



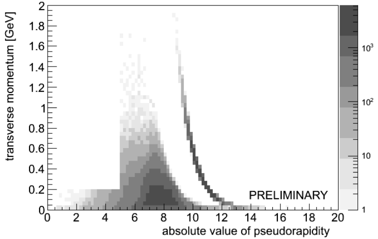

**Background:**

- Double diffraction:
  - large rapidity gap
  - sometimes protons present in dissociated states
- Large visible cross section: few µb
- Large MC uncertainty

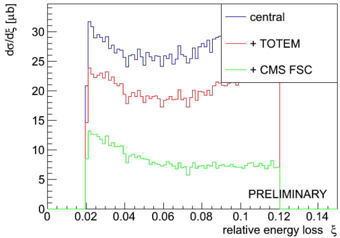


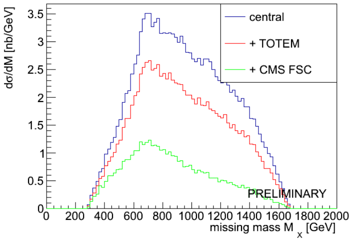



# Possible background reduction




- Large visible cross section
- Particles produced at $6 < |\eta| < 9$
- Background can be reduced with veto on forward detectors
- A lot still remains



# Measurement at high luminosity

- High luminosity $\rightarrow$ pile-up
- Central detector is never empty
- Multiple forward protons
- Possible background reduction with timing detectors
- No hard object $\rightarrow$ trigger problem
- Standalone readout possible (w/o central detectors)
- Without information from central detector cannot use timing

# Effective cross section



- Two protons from two independent SD interactions
- Left and right side independent → possible data-driven background estimate
- Effective cross section:

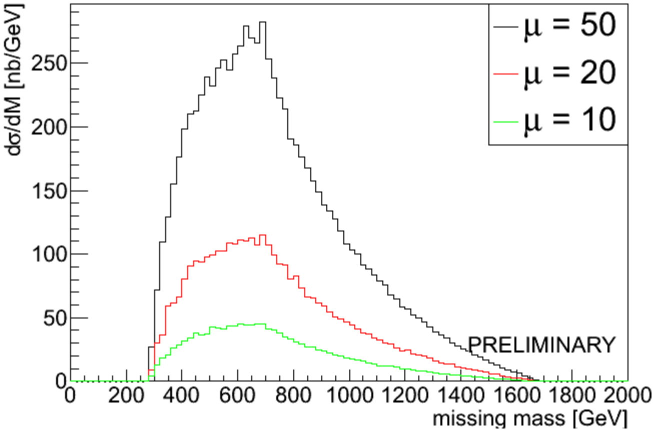
$$\sigma_{\text{eff}} = \frac{\langle N_{\text{BX}} \rangle}{L_{\text{BX}}}$$

$$\left\langle N_{\text{BX}} \right\rangle = \left\langle N^{\text{left}}_{\text{protons}} \right\rangle \cdot \left\langle N^{\text{right}}_{\text{protons}} \right\rangle$$

- Dependence on pile-up multiplicity
- Simple SD model:

$$\frac{\mathrm{d}\sigma_{\text{SD}}}{\mathrm{d}\xi} \sim \frac{1}{\xi}$$

# High luminosity – results




- High background, but large integrated luminosity
- Large statistics → small fluctuations

# Summary



- Feasibility study of searches for invisible particles with forward proton detectors
- Aim: estimate the possible reach of the method for different experimental scenarios
- Dedicated LHC running
  - forward protons + nothing
  - background from DD (few μb)
- Standard LHC running
  - Effective cross section depends on pile-up
  - Much larger statistics possible
  - Only information about protons
  - Data-driven background estimates possible