Searches for Dark Matter at the LHC in forward proton mode

Valery Khoze (IPPP, Durham & PNPI, St. Petersburg)

(in collaboration with Marek Tasevsky, Lucian Harland-Lang and Misha Ryskin)
LHC Searches for Dark Matter in Compressed Mass Scenarios: Challenges in the Forward Proton Mode

L. A. Harland-Lang\textsuperscript{1}, V. A. Khoze\textsuperscript{2}, M. G. Ryskin\textsuperscript{1} and M. Tasevsky\textsuperscript{1}

\textsuperscript{1}Rudolf Peierls Centre, Beacroft Building, Parks Road, Oxford, OX1 3PU, UK
\textsuperscript{2}IPPP, Department of Physics, University of Durham, Durham, DH1 3LE, UK
\textsuperscript{3}Petersburg Nuclear Physics Institute, NRC “Kurchatov Institute”, Gatchina, St. Petersburg, 188300, Russia
\textsuperscript{4}Institute of Physics, Czech Academy of Sciences, CS-18221 Prague 8, Czech Republic

Abstract

We analyze in detail the LHC prospects for charged electroweakino searches, decaying to leptons, in compressed supersymmetry scenarios, via exclusive photon-initiated pair production. This provides a potentially increased sensitivity in comparison to inclusive channels, where the background is often overwhelming. We pay particular attention to the challenges that such searches would face in the hostile high pile-up environment of the LHC, giving close consideration to the backgrounds that will be present. The signal we focus on is the exclusive production of same-flavour muon and electron pairs, with missing energy in the final state, and with two outgoing intact protons registered by the dedicated forward proton detectors installed in association with ATLAS and CMS. We present results for slepton masses of 120–300 GeV and slepton–neutralino mass splitting of 10–20 GeV, and find that the relevant backgrounds can be controlled to the level of the expected signal yields. The most significant such backgrounds are due to semi-exclusive lepton pair production at lower masses, with a proton produced in the initial proton dissociation system registering in the forward detectors, and from the coincidence of forward protons produced in pile-up events with an inclusive central event that mimics the signal. We also outline a range of potential methods to further suppress these backgrounds as well as to enlarge the signal yields.
Aim:
- to report current status of our ongoing studies on prospects of searches at the LHC for ELECTROWEAKINO pair production via photon fusion with forward proton detectors (AFP, CT-PPS). To identify & quantify challenges of such searches.
- exemplified within the framework of the compressed mass MSSM (Jesse)


Recently: Lydia Beresford, Jesse Liu, 1811.06465 (Jesse’s talk)
(focused mainly on the WW background)

**SUSY** — solution to various shortcomings of SM (as an example only)
If (it looks like) squarks and gluinos are too heavy, sleptons, charginos, neutralinos - the main target.

(null search result so far)

**MSSM**: charginos $\tilde{\chi}_{1,2}^\pm$, four neutralinos $\tilde{\chi}_{1,2,3,4}^0$

$\tilde{\chi}_{1}^0$, natural candidate for cold Dark Matter – LSP
natural SUSY: existence of light nearly mass-degenerate Higgsinos/charginos
Mass ~ 100-200 GeV
mass splitting ~ 4-20 GeV

Most challenging scenarios: small mass difference between Higgsinos/charginos
Motivated by naturalness, cosmological observations and (g-2) phenomenology.

(Conclusion-Jessse)
Co-annihilation

Dark matter annihilation

\[ \chi \rightarrow g_{DM} \rightarrow \ell \]

- Overproduces dark matter (Unless large couplings)
- We need a mechanism to reduce the DM relic density

Freeze-out temperature \( T_F \sim m_{DM}/25 \)

Boltzmann factor \( \exp \left(-\frac{\Delta M}{T} \right) \)

We need mass splitting of 4% of \( m_{DM} \)

Initially DM in thermal equilibrium with SM, later it freezes out

to bring DM abundance down to the observed value
Mono-Mania (at the LHC)

Searches for Electroweakinos at the LHC

Model dependence
\( \gamma \gamma \) collisions at the LHC

**Extensive Program**
- \( \gamma \gamma \rightarrow \mu \mu, \text{ee} \) QED processes
- \( \gamma \gamma \rightarrow \text{QCD (jets..)} \)
- \( \gamma \gamma \rightarrow WW,...\gamma \gamma \) anomalous couplings
- \( \gamma \gamma \rightarrow \text{squarks, top... pairs} \)
- \( \gamma \gamma \rightarrow \text{Charginos, Sleptons, ALPS} \)
- Other new BSM objects

\[ pp \rightarrow \ell_{L,R}^+ \ell_{L,R}^- \]
\[ \ell \rightarrow \ell \tilde{\chi}_1^0, \ell \in [e, \mu] \]

**Strong advantage**-model independent production mechanism, accurate mass measurement
At large masses $\gamma\gamma$ takes over, KMR-02

$$0.03 < \xi < 0.15$$

$M \sim 200 - 2000 \text{ GeV}$

- Tag and measure protons at $\pm 210 \text{ m}$: AFP (ATLAS Forward Proton), CT-PPS (CMS TOTEM - Precision Proton Spectrometer)

- Sensitivity to high mass central system, $X$, as determined using AFP/CT-PPS: Very powerful for exclusive states: kinematical constraints coming from AFP and CT-PPS proton measurements

(Valentina, Maceij)
Diphoton X-Pair Production

\[ \begin{align*}
pp & \rightarrow p + \gamma \gamma + p, \\
\gamma \gamma & \rightarrow X^+ X^-,
\end{align*} \]

where \( X = \text{W–boson, lepton, slepton, chargino} \ldots \)

- If particle decays semi-invisibly, then additional information from tagged proton momenta can be used to measure masses and discriminate BG.

\[ \begin{align*}
\gamma & \rightarrow \nu \nu' + l^+ l^- + X^0 \ldots
\end{align*} \]

- Consider exclusive production of chargino pair \( \tilde{\chi}_1^+ \tilde{\chi}_1^- \), decaying via

\[ \tilde{\chi}_1^+ (\tilde{\chi}_1^-) \rightarrow l^+ (l^-) + \nu (\bar{\nu}) + \tilde{\chi}_1^0, \]

where the \( \tilde{\chi}_1^0 \) is an LSP neutralino.

- For cases that \( \Delta M = M(\tilde{\chi}_1^0) - M(\tilde{\chi}_1^\pm) \) is relatively small, can be difficult to observe inclusively. (compressed mass BSM scenarios)
Major backgrounds

- \( \gamma \gamma \rightarrow W^+W^- \rightarrow l^+\nu + l^-\bar{\nu} \)  
  (Jesse)

- Low mass \( \gamma \gamma \rightarrow l^+l^- \) production
  Semi-exclusive process with proton from (SD,DD) dissociation detected in the FPD.

- Semi-exclusive QCD-initiated BGs due to low-pt (mainly c-quark) jets, with SD and DD followed by proton hits in the FPD.

- Coincidence of inelastic lepton pair production with two independent SD/DD events from the PU interactions that mimics the signal.
  (danger for other New Physics searches with \( \sigma \leq 1 \) fb)

- \( \tau\tau \), dimeson, vector resonances etc...
Compressed mass scenario → difference between slepton and DM candidate mass, $\Delta M$, is small  
\[<m_{ll}> \sim \Delta M \rightarrow \text{aim is to keep} \quad <m_{ll}> \quad \text{low} \rightarrow \quad 2 < m_{ll} < 40 \text{ GeV}\]

- $|\eta(l)| < 2.5$, cuts on $\eta(l_1) - \eta(l_2)$ (to suppress BG)
- $p_T(l) > 5 \text{ GeV}$ (trigger conditions)
- $p_T(l) < 30 \text{ GeV}$ (in order to suppress the WW BG)
  
  $\gamma\gamma \rightarrow W^+W^- \quad \text{with} \quad W \rightarrow l\nu$

- Requirement of no additional tracks with $p_T > 0.4 \text{ GeV}$ at $|\eta| < 2.5$

- Both protons detected by the proton taggers (with FT)
- Sleptons- quite small cross sections (0.01 - 0.3 fb), +hostile PU environment
- Chargino pair production- extra factor of $\sim 25$ suppression

Calculations: **SuperChic**, analytical, **PYTHIA 8.2, HERWIG 7.1** (quite reasonable agreement)
Can be divided into three cut classes

Forward proton detector acceptance

\[
0.02 < \xi_{1,2} < 0.15 \quad p_{T,\text{proton}} < 0.35 \text{ GeV}
\]

Di-lepton system

| $p_{T,l_1,l_2} > 5 \text{ GeV}$ | $|\eta_{l_1,l_2}| < 2.5 \ (4.0)$ | $\Delta R(l_1, l_2) > 0.3$
|-----------------|-----------------|------------------|
| $A_{\text{co}} \equiv 1 - |\Delta \phi_{l_1,l_2}|/\pi > 0.13 \ (0.095)$ | $2 < m_{l_1,l_2} < 40 \text{ GeV}$ | $|\eta_{l_1} - \eta_{l_2}| < 2.3$
| $\bar{\eta} \equiv (\eta_{l_1} + \eta_{l_2})/2 < 1.0$ | $||p_{T\bar{l}_1}|| - ||p_{T\bar{l}_2}|| > 1.5 \text{ GeV}$ | $W_{\text{miss}} > 200 \text{ GeV}$

No-charged
(No activity around primary vertex)

<table>
<thead>
<tr>
<th>No hadronic activity</th>
<th>$z$-veto</th>
</tr>
</thead>
</table>

Compressed mass scenario → difference between slepton and DM candidate mass, $\Delta M$, is small $<m_{\tilde{l}}> \sim \Delta M$ → aim is to keep $<m_{\tilde{l}}> \text{ low} \rightarrow 2 < m_{\tilde{l}} < 40 \text{ GeV}$

$z$-vertex veto: no vertices/tracks within $\pm 1$ mm of the primary vertex
Procedure

• Cross-section for signal very low -> signal has to be accumulated at high instantaneous luminosities

• Three reference points studied for the average number of PU events per bunch crossing: \( \mu = 0, 10, 50 \)

• Signal as well background events overlaid with PU events (using Delphes)

Track resolutions and reconstruction efficiencies taken into account for the signal (using Delphes).

• Huge suppression factors needed for inclusive backgrounds (~10^{14}) \rightarrow sufficient statistics cannot be generated in reasonable time \rightarrow cuts are factorized into cut classes for the inclusive background

\[ \text{AFP acceptance .AND. Di-lepton system .AND. No-charged} \]

**AFP acceptance**: generator level

**Di-lepton system**: generator level + lepton reconstruction efficiencies

**No-charged**: Factorization to ‘No hadronic activity at \( \mu=0 \)’ times ‘z-veto efficiency for signal at \( \mu=10, 50 \)’

fast simulation **Delphes** software package with ATLAS detector input cards
Processes and MC event generators

- All exclusive processes: **Superchic 2.07**

**QED:** Exclusive sleptons (slepton masses 120-300 GeV, mass splittings 10 and 20 GeV, $\sigma$: 0.01-0.3 fb)
  - Exclusive $l^+l^-$ ($M_X > 10$ GeV, $p_T > 3$ GeV, $\sigma \sim 8.4$ pb)
  - Exclusive $W^+W^-$ ($M_X > 160$ GeV, semi-leptonic decays, $\sigma \sim 1.0$ fb)

**QCD (CEP):** Exclusive $K^+K^-$ ($M_X > 10$ GeV, $p_T > 4$ GeV, $\sigma \sim 1.3$ fb)
  - Exclusive $c\bar{c}$ ($M_X > 10$ GeV, $p_T > 5$ GeV, $0.0 < |y_X| < 3.0$: $\sigma \sim 3$ nb)
  - Exclusive $gg$ ($M_X > 10$ GeV, $p_T > 7$ GeV, $0.0 < |y_X| < 3.0$: $\sigma \sim 2$ mb)

For exclusive processes with generated masses too low to produce protons in AFP acceptance ($l^+l^-$, $c\bar{c}$, $gg$) → consider:
- Single-proton dissociation
- Double-Proton Dissociation

- Inclusive ND dijets: $p_T > 7$ GeV, ISR on, FSR on, MPI on
  - Pythia 8.2: $\sigma \sim 27$ mb
  - Herwig 7.1: $\sigma \sim 16$ mb

- PU (=MinBias) events generated by Pythia 8.2 and mixed with signal by Delphes
Acceptance of Forward Proton Detector

- Calculate a rate of fake double-tagged events with protons coming from PU in the acceptance $0.02 < \xi < 0.15$ and $p_{T,proton} < 0.35$ GeV

Zero PU: use directly the inclusive dijet events

Non-zero PU: most dangerous: overlay of three events: 2x soft Single Diffraction + hard di-lepton event. Time-of-flight detectors necessary to suppress the PU background.

1) estimate probability to find a proton from PU in the FPD acceptance: $0.8\%$ (PY 8.2) / $1.3\%$ (HW 7.1)

2) Calculate the rate of fake DT events as a function of $\mu$, assuming
   - bunch longitudinal size: 7.5 cm
   - time resolution: $\sigma_t = 10$ ps

Difference between two arrival times within $2\sigma_t$

<table>
<thead>
<tr>
<th>PYTHIA 8.2</th>
<th>HERWIG 7.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\langle \mu \rangle_{PU}$</td>
<td>$\langle \mu \rangle_{PU}$</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>False DT ToF rejection</td>
<td>False DT ToF rejection</td>
</tr>
<tr>
<td>$P_{FPD}$</td>
<td>$P_{FPD}$</td>
</tr>
<tr>
<td>$2.6 \times 10^{-4}$</td>
<td>$7.6 \times 10^{-3}$</td>
</tr>
<tr>
<td>$7.0 \times 10^{-4}$</td>
<td>$2.0 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

These factors only applied for inclusive jet background.
Di-leptons

- For inclusive ND jet events, apply only di-lepton cuts
- Remove events where the selected lepton is accompanied by charged particles with $p_T > 0.4$ GeV and $|\eta| < 2.5$ (coming e.g. from heavy-particle decays $D^0 \rightarrow K^- e^+ \nu$ or $D^+ \rightarrow \rho^0 \mu^+ \nu$).
- Calculate the probability to see such events out of all generated events
- Apply lepton reconstruction efficiencies (from ATLAS inclusive slepton searches)

PYTHIA 8.2: $P_{lep} = 0.8 \times 10^{-7}$ (W-bosons not included in inclusive jets)
HERWIG 7.1: $P_{lep} = 2.5 \times 10^{-7}$ (45% of surviving events contain a W-boson)

Correct PYTHIA number by 1.45: $P_{lep} = 1.2 \times 10^{-7}$
No-charged

- **For signal** (just two leptons and missing ET in central detector): apply ‘z-vertex veto’:
  - No other vertices and tracks in the region ± 1mm from the primary vertex
  - Using Delphes: overlay PU events and use fast simulation of ATLAS tracker
  - Find the efficiency of the z-vertex veto $P_{z\text{-veto}}(\mu = 10) = 0.84$ and $P_{z\text{-veto}}(\mu = 50) = 0.48$.
  These are in agreement with published results for exclusive dileptons without FPDs (ATLAS, CMS+Totem).

- **For inclusive jets and exclusive $c\bar{c}$ and $gg$**
  - **zero PU:**
    1) Select events with 2-4 charged particles with $p_T > 5$ GeV and $|\eta| < 2.5$ and require that at least two are separated by $dR > 0.3$.
    2) Calculate the fraction of those that do not have any additional particles with $p_T > 0.4$ GeV and $|\eta| < 2.5$:
       get $P_{\text{gap}}(\mu = 0)$
  - **non-zero PU:** assume that the di-lepton cuts select events resembling the signal, i.e. exactly two leptons. Then
    \[
    P_{\text{no-charged}}(\mu \neq 0) = P_{\text{gap}}(\mu = 0) \ast P_{z\text{-veto}}(\mu \neq 0)
    \]

<table>
<thead>
<tr>
<th>No-charged probability</th>
<th>(\langle \mu \rangle_{PU})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>CEP $c\bar{c}$</td>
<td>$3.3 \cdot 10^{-5}$</td>
</tr>
<tr>
<td>CEP $gg$</td>
<td>$3.3 \cdot 10^{-5}$</td>
</tr>
<tr>
<td>Incl. jets ($</td>
<td>\eta</td>
</tr>
<tr>
<td>Incl. jets ($</td>
<td>\eta</td>
</tr>
</tbody>
</table>

Both ATLAS and CMS are going to upgrade their trackers to cover also $2.5 < |\eta| < 4.0$.  

PYTHIA8.2/HERWIG7.1
## Signal event yields for L=300 fb$^{-1}$ and $\mu=0$

<table>
<thead>
<tr>
<th>scenario $M_{\tilde{t}}/M_{\tilde{\chi}_1^0}$</th>
<th>lepton $p_T$ interval [GeV]</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5–15</td>
<td>5–20</td>
<td>5–30</td>
<td>5–40</td>
<td></td>
</tr>
<tr>
<td>120/100</td>
<td>0.3</td>
<td>0.7</td>
<td>1.7</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>120/110</td>
<td>1.2</td>
<td>2.0</td>
<td>2.7</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>200/180</td>
<td>0.2</td>
<td>0.8</td>
<td>1.8</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>200/190</td>
<td>1.3</td>
<td>1.7</td>
<td>2.0</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>250/230</td>
<td>0.1</td>
<td>0.4</td>
<td>1.0</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>250/240</td>
<td>0.7</td>
<td>1.0</td>
<td>1.1</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>300/280</td>
<td>0.1</td>
<td>0.2</td>
<td>0.6</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>300/290</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td></td>
</tr>
</tbody>
</table>

**Possible ways to improve signal yields:**

- Improve lepton reconstruction efficiencies (they start at 70% at $p_T=5$ GeV)
- Extend lepton acceptance up to $|\eta|=4 \rightarrow 10\%$ increase of statistics
### Integrated event yields for L=300 fb^{-1}

| $|\eta| < 2.5$ | $|\eta| < 4.0$ |
|----------------|----------------|
| **Event yields / $\mathcal{L} = 300$ fb$^{-1}$** | **Event yields / $\mathcal{L} = 300$ fb$^{-1}$** |
|                  | 0   | 10  | 50  |                  | 0   | 10  | 50  |
| Excl. sleptons   | 0.6–2.9 | 0.5–2.4 | 0.3–1.4 | Excl. sleptons   | 0.6–3.0 | 0.5–2.6 | 0.3–1.5 |
| Excl. $l^+l^-$   | 1.4  | 1.2  | 0.7  | Excl. $l^+l^-$   | 1.1  | 0.9  | 0.5  |
| Excl. $K^+K^-$   | ~0   | ~0   | ~0   | Excl. $K^+K^-$   | ~0   | ~0   | ~0   |
| Excl. $W^+W^-$   | 0.7  | 0.6  | 0.3  | Excl. $W^+W^-$   | 0.6  | 0.5  | 0.3  |
| Excl. $c\bar{c}$ | ~0   | ~0   | ~0   | Excl. $c\bar{c}$ | ~0   | ~0   | ~0   |
| Excl. $gg$       | ~0   | ~0   | ~0   | Excl. $gg$       | ~0   | ~0   | ~0   |
| Incl. ND jets    | ~0/~0 | 0.1/0.1 | 1.8/2.4 | Incl. ND jets    | ~0/~0 | 0.03/0.05 | 0.6/0.7 |

The yield range for signal corresponds to the slepton mass range studied: X(300 GeV) – Y(120 GeV)

**Possible ways to suppress backgrounds:**
- Cut on the distance of the secondary vertex from the primary vertex or on the pseudo-proper lifetime (many leptons from inclusive jets come from decays of heavy particles)
- Improve ToF resolution (ToF rejection improves with $\sigma_t$ decreasing)
- ATLAS and CMS tracker upgrade: extend coverage up to $|\eta|=4$ and provide time info for tracks in 2.5<$|\eta|<$4.0.
- Timing detector in $|\eta|<2.5$??? (envisaged in CMS)

*Courtesy of Marek Tasevsky*
Can invisible objects be 'seen' via forward proton detectors at the LHC?

V A Khoze$^{1,2}$, A D Martin$^{1,3}$ and M G Ryskin$^{1,2}$

Published 7 April 2017 • © 2017 IOP Publishing Ltd

Journal of Physics G: Nuclear and Particle Physics, Volume 44, Number 5

\[ pp \rightarrow p + \text{invisible} + p, \]

An attractive idea, but huge backgrounds caused by soft proton dissociation, photon bremsstrahlung and PU (at high lumi)

\[ p \rightarrow p + \gamma, \quad N^* \rightarrow p + \gamma \text{ and } N^* \rightarrow p + \pi^0. \]

\[ p \rightarrow p\pi^+\pi^- \]

Measurements at low lumi ($\mu \sim 1$) with ‘veto’ detectors (like ZDC and FSC/ADA/ADC)

LHCb, ALICE, BLM-approach
DM searches with AFP (exclusive $\gamma\gamma$)

- Signal (WIMP itself): massive, neutral, weakly interacting particle
- Signal with AFP: $p(\text{AFP}) + \text{invisible(Central Det.}) + p(\text{AFP})$
  - x-section $\sim \text{fb}$

- Backgrounds from neutral particles (escaping CD):
  1. Bremsstrahlung $p \to p + \gamma$
  2. Dissociation $p \to N^* \to p + \pi^0 \to p + \gamma\gamma$
  3. Resonance decay $p \to N^* \to p + \gamma$

Suppressed by vetoing using ZDC or using LHCf (see next slide).
But the fate of LHCf at HL-LHC unclear.
Suppression to $\sim \text{nb}$ level needs:
- ZDC coverage to be increased to $\pm 1.5 \text{mrad}$
- ZDC to have $> 5$ rad. lengths (photon detection efficiency $> 99\%$)

- Background from charged particles (escaping CD):
  4. $p \to p + \pi^+\pi^-$

Suppression to $\sim \text{nb}$ level needs:
- Calo coverage $5.5 < \eta < 9.5$
- $> 5$ rad. lengths

08/12/2017

M. Tasevsky, Future measurements with AFP, LHC Fwd Physics WG meeting

DM searches with AFP (exclusive $\gamma\gamma$)

- Signal (WIMP itself): massive, neutral, weakly interacting particle
- WIMP + visible SM particle ($g$, $q$, $\gamma$, $Z$, $W$, $h$): large missing $E_T$
  
  **BUT!** In exclusive $\gamma\gamma$ collisions and Compressed mass spectra scenario: missing $E_T$ not large

- E.g. $\gamma\gamma \to 2$ charginos $\to 2$ heavy invisible neutralinos (LSP) + $l\bar{l}$, $p_T(l) \sim 3$-10 GeV
- Then signal with AFP: $pp \to p($AFP$) + l\bar{l} +$ missing $E_T + p($AFP$)$

**Backgrounds:**
1) $p$ dissociation in QED exclusive $\gamma\gamma \to l\bar{l}$: tamed by
   - vetoing using ZDC
   - requiring $e^+\mu^-$ or $e^-\mu^+$
   - separating mass peak at $\sim 20$ GeV from $> 200$ GeV
2) QED exclusive $WW \to l\bar{l}$: suppressed to $\sim$fb level just by requiring $p_T(l) < 10$ GeV

Better outlooks than previous signal process: current devices suffice to tame the background.

Low pile-up needed?

08/12/2017

M. Tasevsky, Future measurements with AFP, LHC Fwd Physics WG meeting
The detailed analysis of the LHC prospects for searching for slepton pair production via leptonic decays in compressed SUSY mass scenario in the forward proton mode is performed. The results presented for slepton masses of 120-300 GeV and mass splitting of 10-20 GeV.

Since the expected cross sections are small (~0.1 fb) it is essential to work at the nominal LHC lumi with high PU.

We have considered the major BGs: photon initiated WW, photon-initiated lepton pairs, QCD-initiated gluon and c-quark jets where a proton arising from dissociation is detected in the FPD and PU BG, caused by two independent SD events coinciding with an inelastic lepton pair production event. We performed dedicated and detailed MC simulation, including relevant detector effects and efficiencies.

By requiring dilepton mass lower than 40 GeV, imposing a series of cuts and reducing the PU with the help of FTDs we find that the relevant backgrounds can be controlled to the level of expected signal yields.

The main backgrounds are in principle reducible.

A range of potential methods to further suppress BDs and enlarge the signal is outlined.
In particular, better TOF resolution and timing information in the forward/central regions needed. At HL LHC –higher requirements on these timing resolutions.

Prospects for radiation-hard design for ZDC

Such strategy could be used also to explore other simplified models for DM with small mass splitting between the DM and its charged co-annihilation partner.

Searching for ‘invisible’ objects in the forward proton mode very challenging

\[ pp \rightarrow p + \text{invisible} + p, \]

Better to perform at low PU due to the necessity to suppress the dissociative BGs

However the situation may improve with engaging radiation-hard ZDC at high lumi. with timing
per aspera ad astra
through hardships to the stars
THANK YOU

QUESTIONS?
BACKUP
Current analysis: $\mu \leq 50$: only ToF with $\sigma_t = 10$ ps: S/B $\sim 1$

$\mu > 50$: additional time information from the central detector necessary and/or $\sigma_t \sim 5$ ps from ToF

The effect of the time information from central/forward main det. needs to be studied in more detail:
- For special type of events with only two tracks (di-lepton system)
- For realistic assumptions about the primary vertex reconstruction ($n_{\text{trk}}$ dependence, vertex merging in luminous region)