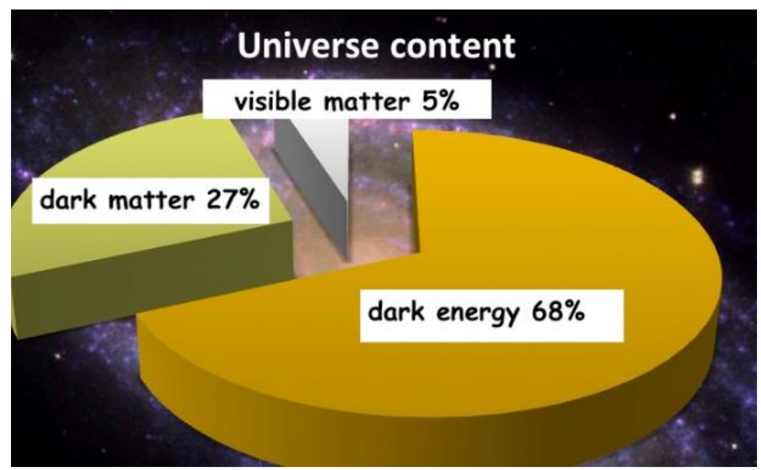
LHC Working Group on Forward Physics and Diffraction

CERN, 18-19 December, 2019

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)



arXiv:1812.04886

LHC Searches for Dark Matter in Compressed Mass Scenarios: Challenges in the Forward Proton Mode

L.A. Harland-Lang[1], V.A. Khoze[2,3], M.G. Ryskin[3]
and M. Tasevsky[4]

[1]Rudolf Peierls Centre, Beecroft Building, Parks Road, Oxford, OX1 3PU, UK

[2]IPPP, Department of Physics, University of Durham, Durham, DH1 3LE, UK

[3]Petersburg Nuclear Physics Institute, NRC "Kurchatov Institute", Gatchina, St. Petersburg, 188300, Russia

[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 long-term studies on prospects of searches at the LHC for ELECTROWEAKINO pair production via photon fusion with forward proton detectors (AFP, CT-PPS)

- exemplified within the framework of the compressed mass **MSSM**

First discussed: KMR, J.Phys. G44 (2017) no.5, 055002 , **VAK**- talks at a number of conferences; Marek, FWG meeting Dec. 2017-experimental aspects.

Recently: Lydia Beresford, Jesse Liu, 1811.06465 (Jesses'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 $\tilde{\chi}^{\pm}_{1,2}$ four neutralinos $\tilde{\chi}^{0}_{1,2,3,4}$

$\tilde{\chi}^{0}_{1}$, natural candidate for cold Dark Matter –**LSP** arXiv:1710.02406

(and quite a few other papers)

natural SUSY:
existence of light nearly
mass-degenerate Higgsinos/chargin
Mass~ 100-200Ge
mass splitting ~

Most challe
scenario
between

Motivated by naturalness, cosmological observations and (g-2) phenomenology.

(Introduction-Jessse)

What about the LHC during MY lifetime ?

Naturalness and light Higgsinos: why ILC is the right machine for SUSY discovery

Howard Baer
University of Oklahoma, Norman, OK 73019, USA
E-mail: baer@ou.edu

Mikael Berggren, Suvi-Leena Lehtin
DESY, Hamburg, Ger
E-mail:

University of Tokyo, Tokyo, Japan E-mail:

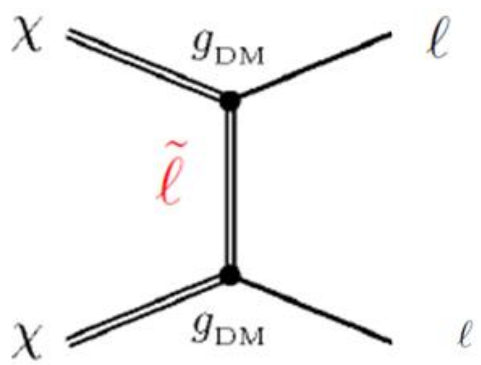
upersymmetry, a theoretically and experimentally well-motivated
ers around the predicted existence of four light, nearly mass-degenerate Hig-
gsinos with mass ~ 100 – 200 GeV (not too far above m_Z). The small mass splittings amongst the higgsinos, typically 4-20 GeV, results in very little visible energy arising from decays of the heavier higgsinos. Given that other SUSY particles are considerably heavy, this makes detection challenging at hadron colliders. On the other hand, the clean environment of an electron-positron collider with $\sqrt{s} > 2m_{higgsino}$ would enable a decisive search of these required higgsinos, and thus either the discovery or exclusion of natural SUSY. We present a detailed simulation study of precision measurements of higgsino masses and production cross sections at $\sqrt{s} = 500$ GeV of the proposed International Linear Collider currently under consideration for construction in Japan.

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 q\bar{q}' e\nu_e(\mu\nu_\mu).$$

Co-annihilation

(1702.00750, model-1a)

Dark matter annihilation

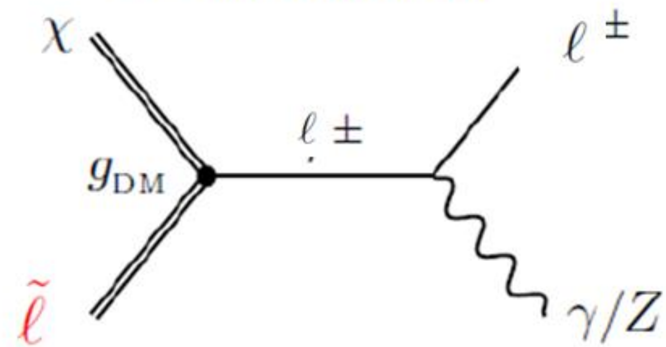


to bring DM abundance down to the observed value

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

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

Co-annihilation:



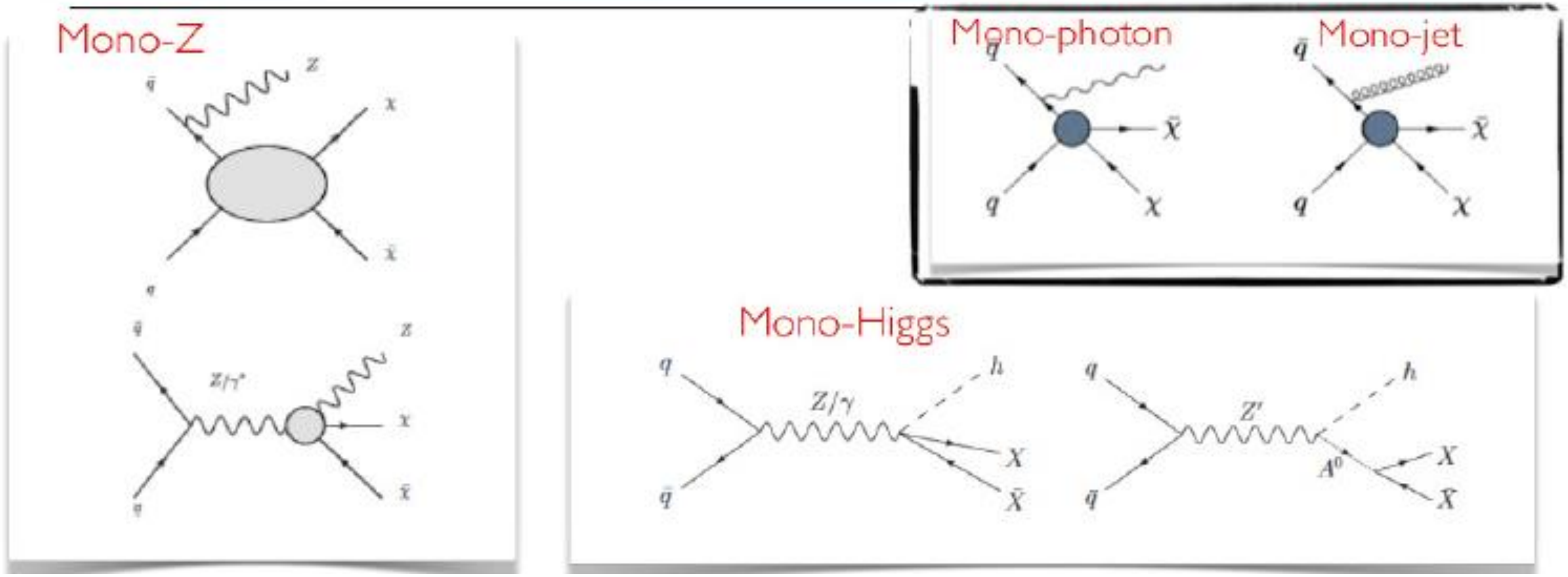
Freeze-out temperature $T_F \sim m_{DM}/25$

Boltzmann factor $\exp\left(-\frac{\Delta M}{T}\right)$ ⇒ $\Delta M \lesssim m_{DM}/25$

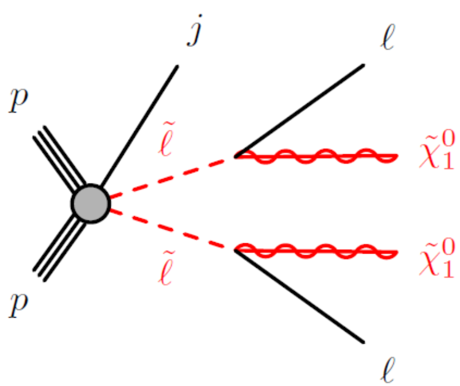
We need **mass splitting of 4% of m_{DM}** (very conservatively <10%)

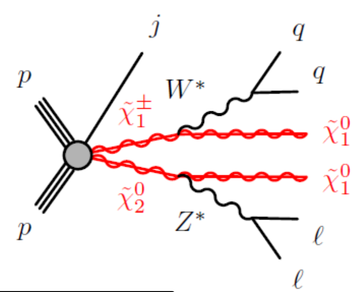
Mono-Mania (at the LHC)

DM Searches @ LHC O. Buchmüller



Searches for Electroweakinos at the LHC

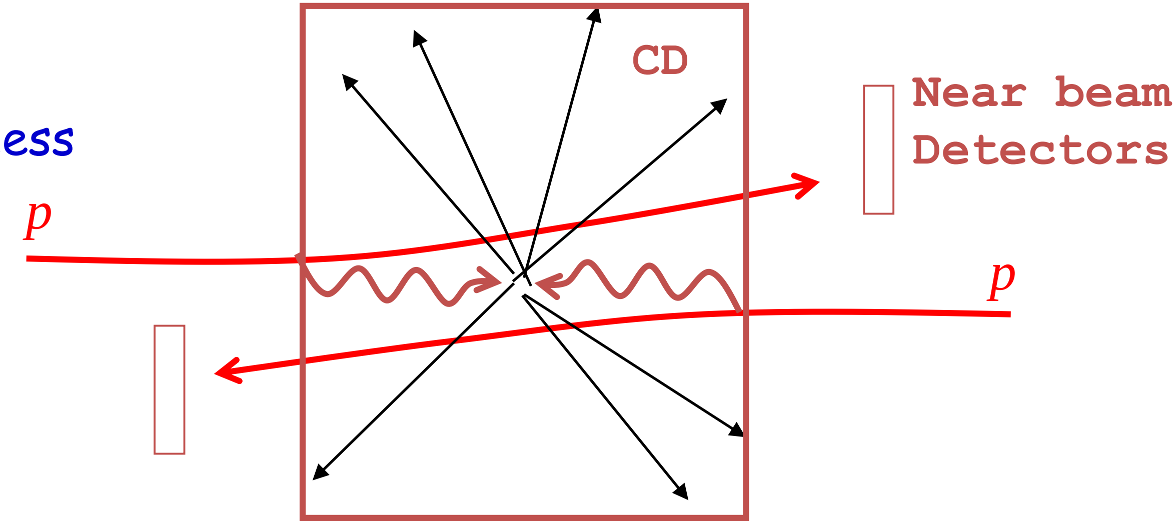




Model dependence

$\gamma\gamma$ collisions at the LHC

Process



Installed (AFP)
Installed (CT-PPS)

$$pp \to \tilde{\ell}^{+}_{L,R}\tilde{\ell}^{-}_{L,R} + pp$$

$$\tilde{\ell} \to \ell\tilde{\chi}^{0}_{1}, \ell \in [e, \mu]$$

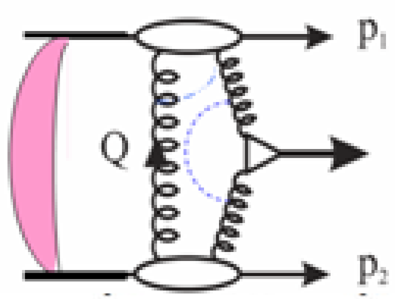
Extensive Program

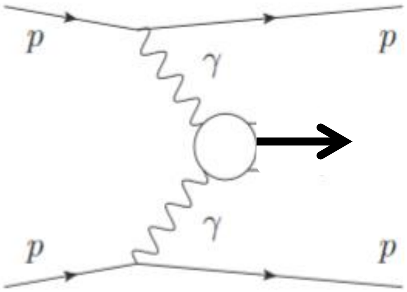
- $\gamma\gamma \to$ μμ, ee QED processes
- $\gamma\gamma \to$ QCD (jets..)
- $\gamma\gamma \to$ WW,…$\gamma\gamma$ anomalous couplings
- $\gamma\gamma \to$ squarks, top… pairs
- $\gamma\gamma \to$ Charginos, Sleptons, ALPS
- Other new BSM objects

Strong advantage-model independent production mechanism, accurate mass measurement

AFP , CT-PPS

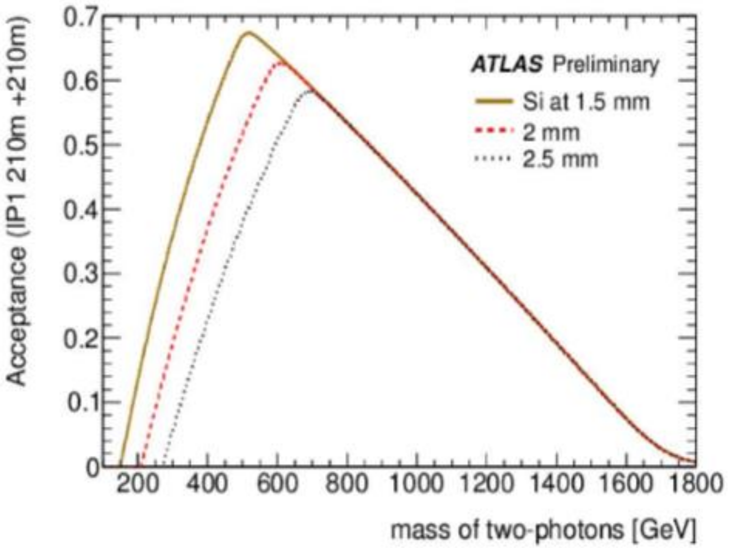
At large masses $\gamma\gamma$ takes over , KMR-02





$0.03 < \xi < 0.15$

M ~200- 2000 GeV



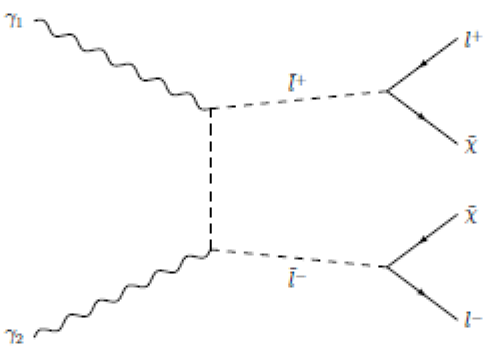
- Tag and measure protons at ± 210 m: AFP (ATLAS Forward Proton), CT-PPS (CMS TOTEM - Precision Proton Spectrometer)
- Sensitivity to high mass central system, X, as determined using AFP/CT-PPS: Very powerful for exclusive states: kinematical constraints coming from AFP and CT-PPS proton measurements

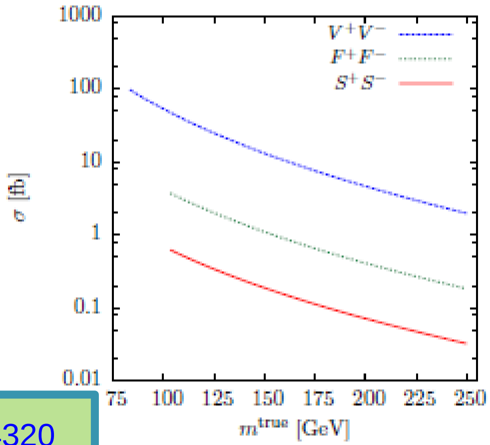
$$pp \to p + \gamma\gamma + p\ ,$$
$$\gamma\gamma \to X^+X^-\ ,$$

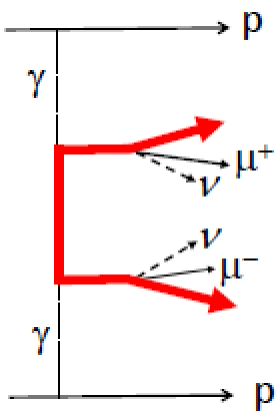
Diphoton X-Pair Production

where $X =$ W–boson, lepton, slepton, chargino...

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







HKSS, arXiv:1110.4320

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

$$\tilde{\chi}_1^+(\tilde{\chi}_1^-) \to l^+(l^-) + \nu(\overline{\nu}) + \tilde{\chi}_1^0\ ,$$

electroweakinos

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)**

$M_{\tilde{l}}$ =120-300GeV, $\Delta M = M_{\tilde{l}} - M_{\tilde{\chi}_1^0} = 10-20\ \text{GeV}$

Major backgrounds

- $\gamma\gamma \to W^+W^- \to l^+\nu + l^-\bar{\nu}$ **(Jesse)**
- Low mass $\gamma\gamma \to l^+l^-$ 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…

Event Selection

$\geq$ 100 GeV from the LEP constraints

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

- $|\eta(l)| < 2{,}5$, cuts on $\eta(l_1) - \eta(l_2)$ (to supress BG)
- $p_T(l)$ >5 GeV (trigger conditions)

  $p_T(l)$ <30 GeV (in order to supress the WW BG)

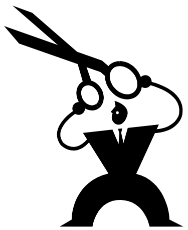
  $\gamma\gamma \to W^+W^-$ with $W \to l\nu$
- requirement of no additional tracks with pt > 0.4 GeV at $|\eta| < 2{,}5$)
- both protons detected by the proton taggers (with FT)
- sleptons-quite small cross sections (0.01 -0.3 fb), +hostile PU environment 
- chargino pair production- extra factor of ~25 suppression 

Calculations: **SuperChic**, analytical, **PYTHIA 8.2, HERWIG 7.1** (quite reasonable agreement)

Selection cuts

Courtesy of Marek Tasevsky

Can be divided into three cut classes



Forward proton detector acceptance

$0.02 < \xi_{1,2} < 0.15$	$p_{T,\mathrm{proton}} < 0.35$ GeV

Di-lepton system

$p_{T,l_1,l_2} > 5$ GeV	$\lvert\eta_{l_1,l_2}\rvert < 2.5\ (4.0)$	$\Delta R(l_1, l_2) > 0.3$
$\mathrm{Aco} \equiv 1 - \lvert\Delta\phi_{l1l2}\rvert/\pi > 0.13\ (0.095)$	$2 < m_{l_l l_2} < 40$ GeV	$\lvert\eta_{l1} - \eta_{l2}\rvert < 2.3$
$\bar{\eta} \equiv (\eta_{l1} + \eta_{l2})/2 < 1.0$	$\lvert\lvert p_{T}\vec{l_1}\rvert - \lvert p_{T}\vec{l_2}\rvert\rvert > 1.5$ GeV	$W_{\mathrm{miss}} > 200$ GeV

No-charged

(No activity around primary vertex)

No hadronic activity	z-veto

Compressed mass scenario → difference between slepton and DM candidate mass, ΔM, is small
$<m_{ll}>$ ~ ΔM → aim is to keep $<m_{ll}>$ low → 2 < m_{ll} < 40 GeV

- **z-vertex veto :** no vertices/tracks within ±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: μ = 0, 10, 50
- Signal as well background events overlaid with PU events (using Delphes)

(μ=0 as a reference tool)

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

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

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 μ=0' times 'z-veto efficiency for signal at μ=10, 50'

fast simulation **Delphes** software package with ATLAS detector input cards

Processes and MC event generators

Courtesy of Marek Tasevsky

- All exclusive processes: **Superchic 2.07**

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

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

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 : σ ~ 27 mb
Herwig 7.1: σ ~ 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

Courtesy of Marek Tasevsky

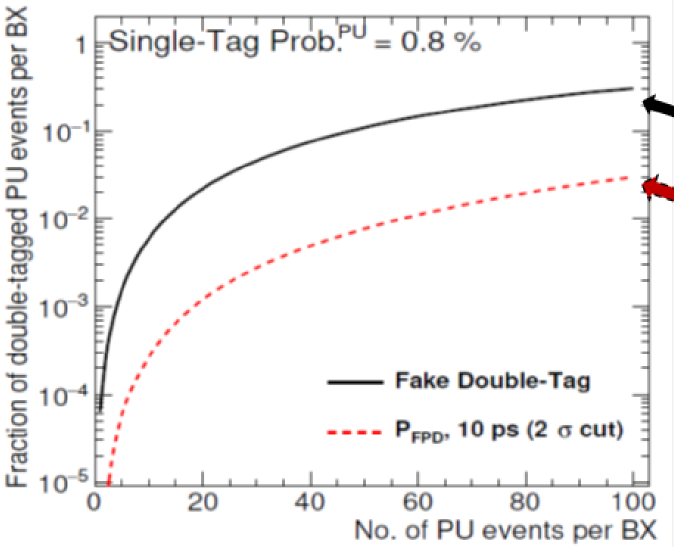
Zero PU: use directly the inclusive dijet events

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% (HW7.1)

2) Calculate the rate of fake DT events as a function of μ, assuming

- bunch longitudinal size: 7.5 cm
- time resolution: σ_t = 10 ps



	PYTHIA 8.2		HERWIG 7.1	
	$\langle\mu\rangle_{PU}$		$\langle\mu\rangle_{PU}$	
	10	50	10	50
Fake DT	0.0048	0.105	0.0123	0.222
ToF rejection	18.3	13.7	17.5	11.3
P_{FPD}	2.6×10^{-4}	7.6×10^{-3}	7.0×10^{-4}	2.0×10^{-2}

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 |η| < 2.5 (coming e.g. from heavy-particle decays $D^0 \to K^- e^+ \nu$ or $D^+ \to \rho^0 \mu^+ \nu$).

- 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} = 0.8x10^{-7} (W-bosons not included in inclusive jets)
HERWIG 7.1: $\boldsymbol{P_{lep}}$ **= 2.5x10^{-7}** (45% of surviving events contain a W-boson)

Correct PYTHIA number by 1.45: $\boldsymbol{P_{lep}}$ **= 1.2x10^{-7}**

Courtesy of Marek Tasevsky

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 $\boldsymbol{P_{z-veto}(\mu = 10) = 0.84}$ and $\boldsymbol{P_{z-veto}(\mu = 50) = 0.48}$.

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 |η| < 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 |η| < 2.5: get $P_{gap}(\mu = 0)$

- non-zero PU: assume that the di-lepton cuts select events resembling the signal, i.e. exactly two leptons. Then

$$P_{no-charged}(\mu \neq 0) = P_{gap}(\mu = 0) * P_{z-veto}(\mu \neq 0)$$

No-charged probability	$\langle\mu\rangle_{PU}$		
	0	10	50
CEP $c\bar{c}$	$3.5 \cdot 10^{-3}$	$2.9 \cdot 10^{-3}$	$1.7 \cdot 10^{-3}$
CEP gg	$3.3 \cdot 10^{-5}$	$2.8 \cdot 10^{-5}$	$1.6 \cdot 10^{-5}$
Incl. jets ($\lvert\eta\rvert < 2.5$)	$5.2/\mathit{2.0} \cdot 10^{-7}$	$4.4/\mathit{1.7} \cdot 10^{-7}$	$2.5/\mathit{1.0} \cdot 10^{-7}$
Incl. jets ($\lvert\eta\rvert < 4.0$)	$1.7/\mathit{0.7} \cdot 10^{-7}$	$1.4/\mathit{0.6} \cdot 10^{-7}$	$0.8/\mathit{0.3} \cdot 10^{-7}$

PYTHIA8.2/HERWIG7.1

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

Signal event yields for L=300fb^{-1} and μ=0

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

Courtesy of Marek Tasevsky

Possible ways to improve signal yields:

- Improve lepton reconstruction efficiencies (they start at 70% at p_T=5 GeV)
- Extend lepton acceptance up to |η|=4 → 10% increase of statistics

Integrated event yields for L=300fb^{-1}

$|\eta| < 2.5$

Event yields / $\mathcal{L} = 300$ fb^{-1}	$\langle\mu\rangle_{PU}$		
	0	10	50
Excl. sleptons	0.6—2.9	0.5—2.4	0.3—1.4
Excl. l^+l^-	1.4	1.2	0.7
Excl. K^+K^-	~ 0	~ 0	~ 0
Excl. W^+W^-	0.7	0.6	0.3
Excl. $c\bar{c}$	~ 0	~ 0	~ 0
Excl. gg	~ 0	~ 0	~ 0
Incl. ND jets	$\sim 0/\sim 0$	0.1/0.1	1.8/2.4

$|\eta| < 4.0$

Event yields / $\mathcal{L} = 300$ fb^{-1}	$\langle\mu\rangle_{PU}$		
	0	10	50
Excl. sleptons	0.6—3.0	0.5—2.6	0.3—1.5
Excl. l^+l^-	1.1	0.9	0.5
Excl. K^+K^-	~ 0	~ 0	~ 0
Excl. W^+W^-	0.6	0.5	0.3
Excl. $c\bar{c}$	~ 0	~ 0	~ 0
Excl. gg	~ 0	~ 0	~ 0
Incl. ND jets	$\sim 0/\sim 0$	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 σ_t decreasing)
- ATLAS and CMS tracker upgrade: extend coverage up to |η|=4 and provide time info for tracks in 2.5<|η|<4.0.
- Timing detector in |η|<2.5??? (envisaged in CMS)

Courtesy of Marek Tasevsky

Journal of Physics G: Nuclear and Particle Physics

PAPER

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 •

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

$$pp \to p + \text{invisible} + p,$$

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

$$p \to p + \gamma, \;\; N^* \to p + \gamma \text{ and } \;\; N^* \to p + \pi^o. \qquad p \to p\pi^+\pi^-$$

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

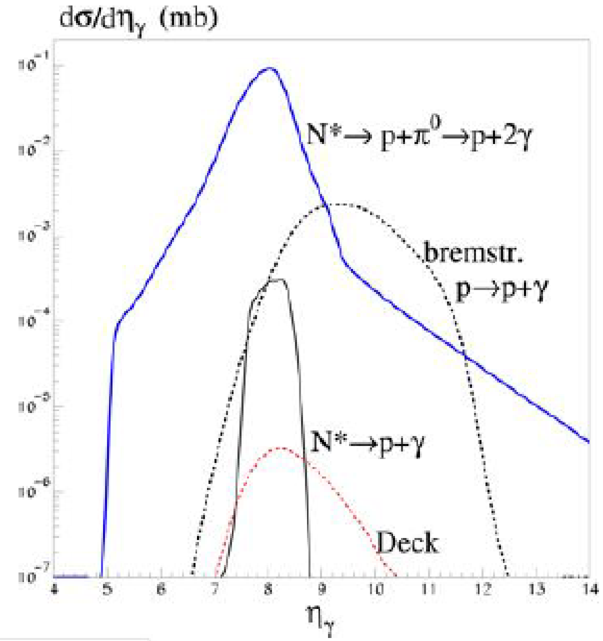
LHCb, ALICE, BLM-approach

DM searches with AFP (exclusive γγ)

KMR, J.Phys. G44 (2017) no.5, 055002

- ❑ Signal (WIMP itself): massive, neutral, weakly interacting particle
- ❑ **Signal with AFP: p(AFP) + invisible(Central Det.) + p(AFP)**

- x-section ~ 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 ~nb level needs:

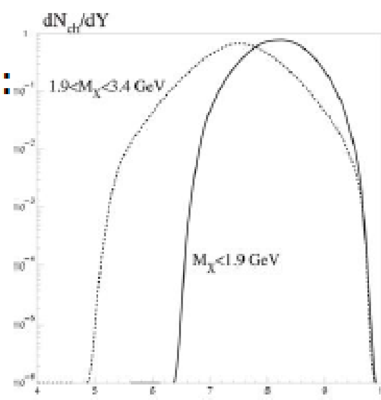
- ZDC coverage to be increased to $\pm$ 1.5mrad
- ZDC to have > 5 rad.lengths (photon detection efficiency > 99%)

❑ **Background from charged particles (escaping CD):**

4) $p \to p + \pi^+\pi^-$

Suppression to ~nb level needs:

- Calo coverage 5.5 < η < 9.5
- > 5 rad. lengths



Bgd taming difficult:
- ZDCs/Calo need to be upgraded
- Low pile-up needed

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

- Signal (WIMP itself): massive, neutral, weakly interacting particle
- WIMP + visible SM particle (g, q, γ, Z, W, h): large missing E_T

KMR, J.Phys. G44 (2017) no.5, 055002

BUT! In exclusive $\gamma\gamma$ collisions and Compressed mass spectra scenario: missing E_T not large

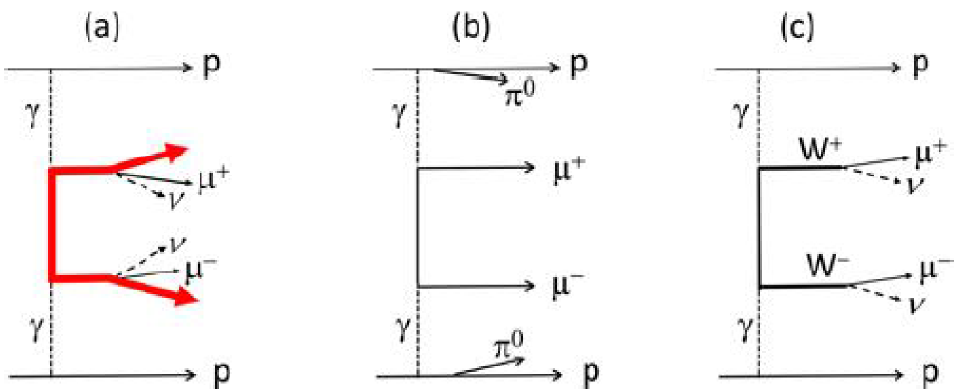
Lightest SUSY Particle close in mass to parent sparticle

- E.g. $\gamma\gamma \rightarrow$ 2 charginos $\rightarrow$ 2 heavy invisible neutralinos (LSP) + $l\nu l\nu$, p_T(l) ~ 3-10 GeV
- **Then signal with AFP: pp $\rightarrow$ p(AFP) + ll + missing E_T + p(AFP)**

Backgrounds:

1) p dissociation in QED exclusive $\gamma\gamma \rightarrow$ ll: tamed by
- vetoing using ZDC
- requiring $e^+\mu^-$ or $e^-\mu^+$
- separating mass peak at ~ 20 GeV from > 200 GeV

2) QED exclusive WW $\rightarrow$ $l\nu l\nu$: suppressed to ~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?

CONCLUSIONS

- 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 jests 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 efficiences.

- 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.

- 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

Courtesy of Marek Tasevsky

HL-LHC

Current analysis: μ≤50: only ToF with $\sigma_t = 10$ ps: S/B~1

μ>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_{trk} dependence, vertex merging in luminous region)