~~*Update on*~~ *sbottom analysis*

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for
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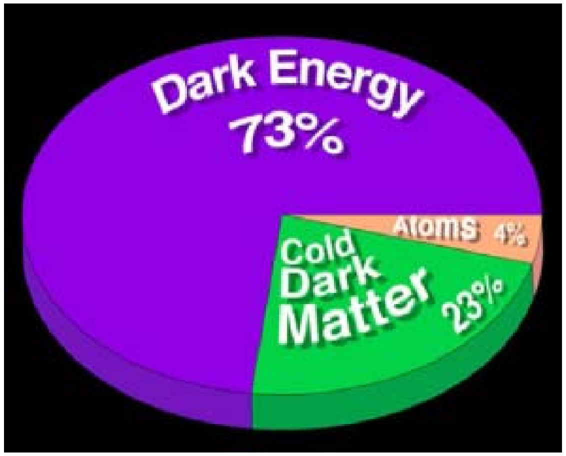
Introduction

- Analysis done in collaboration with
  - University of Montenegro: Gordana Medin and Marija Kovacević
  - Alexander Belyaev (University of Southampton)
- From Oxford side
  - Andrei Nomerotski and TL
- Rather challenging due to
  - very soft jets
  - large background
- Strategy so far
  - “Straw man analysis” with CalcHep and Pythia – understand analysis issues…
  - …and eventually simulate/reconstruct data using SiD/LCFI framework/package.

SUSY and Cosmology



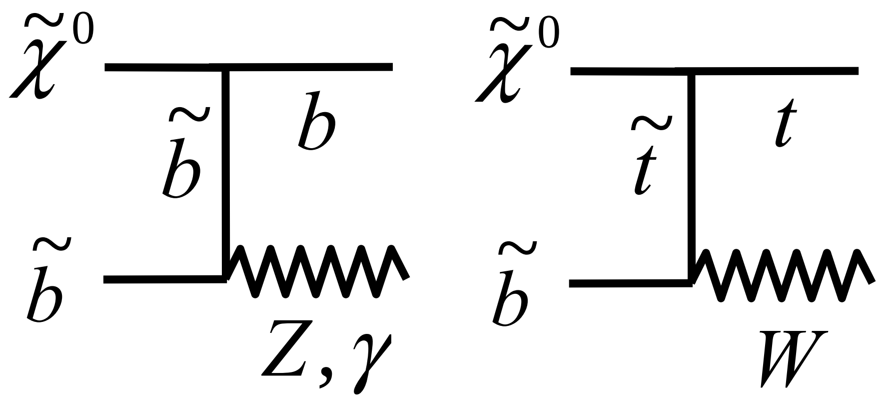
- There is 23% of Cold Dark Matter in Universe – as measurements suggest.
- Neutralino is a "hot" Dark Matter candidate.
- During Universe expansion at some point supersymmetric particles are no longer produced but the existing ones may annihilate – the rate can be calculated.
- In most of the SUSY parameter space there are still too many neutrinos left.
- Cold Dark Matter favors some particular SUSY scenarios.

  For effective co-annihilation of particles the mass splitting should be small – leading to small energies of visible particles.

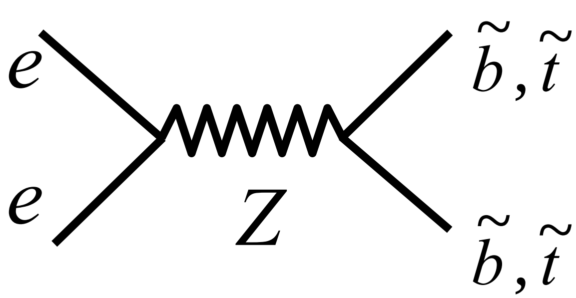
  Neutralino is LSP in this scheme (followed by sbottom).

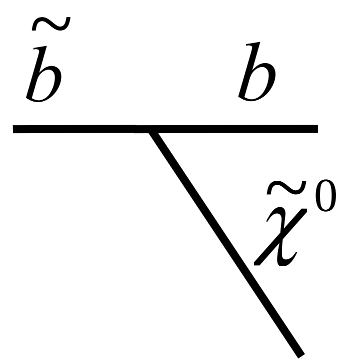
sbottom and neutralino

- If sbottom (stop) and neutralino have a small mass split they can account for co-annihilation in early Universe through this type of diagrams:



- Sbottom can be produced at ILC, then it decays to b and neutralino:

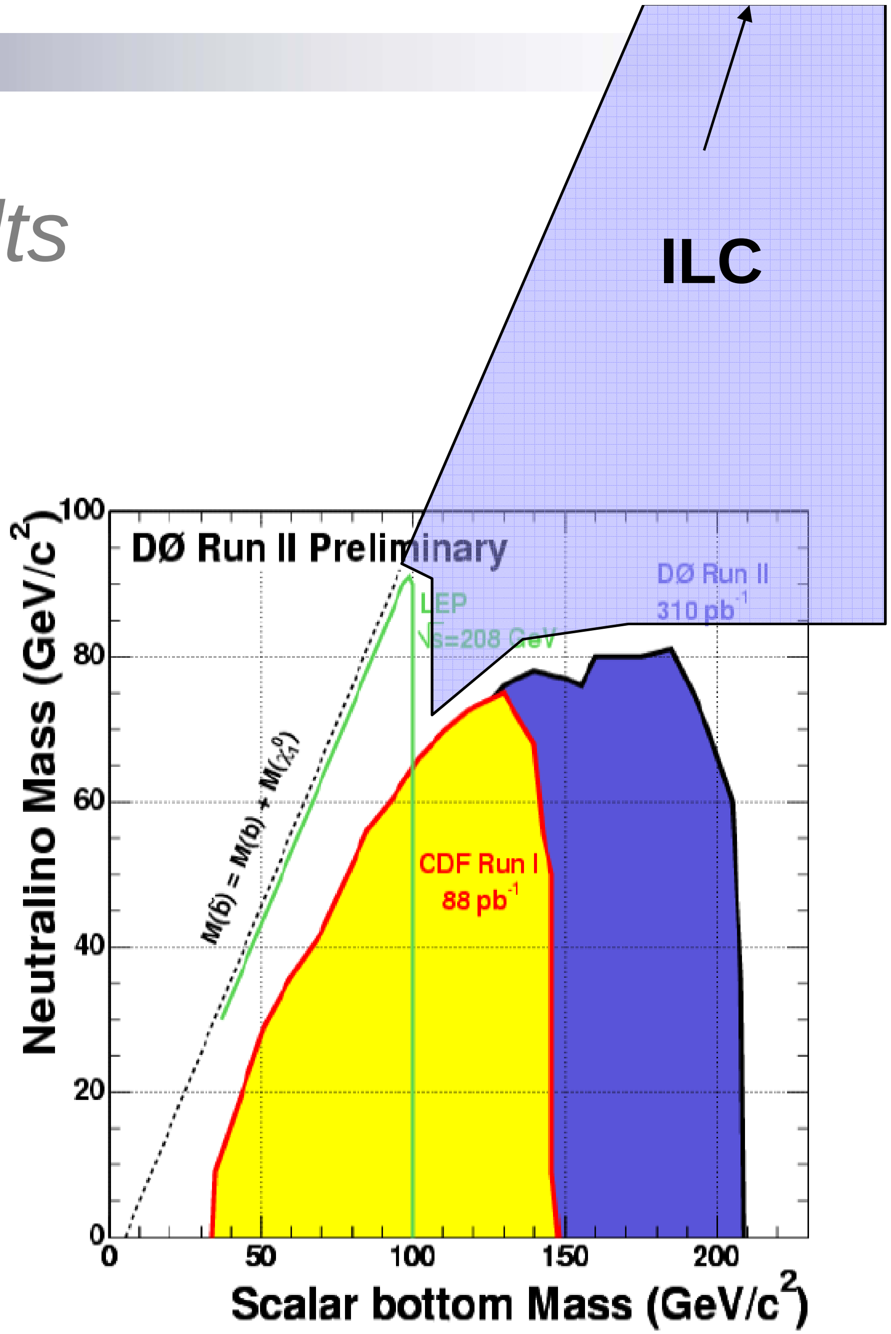




If the mass split is low (as suggested) this would lead to very soft b-jets and missing p_T.

LEP and CDF/D0 Results

- CDF/D0 – measurement at high masses but still relatively hard jets (due to triggers) which are not favored by the dark matter scenario.
- LEP – able to measure in the region where the mass difference is only few GeV.
- ILC should not be much worse but at higher masses.
- Small (meaning tiny) mass splitting is not accessible at ILC.



Analysis Tools

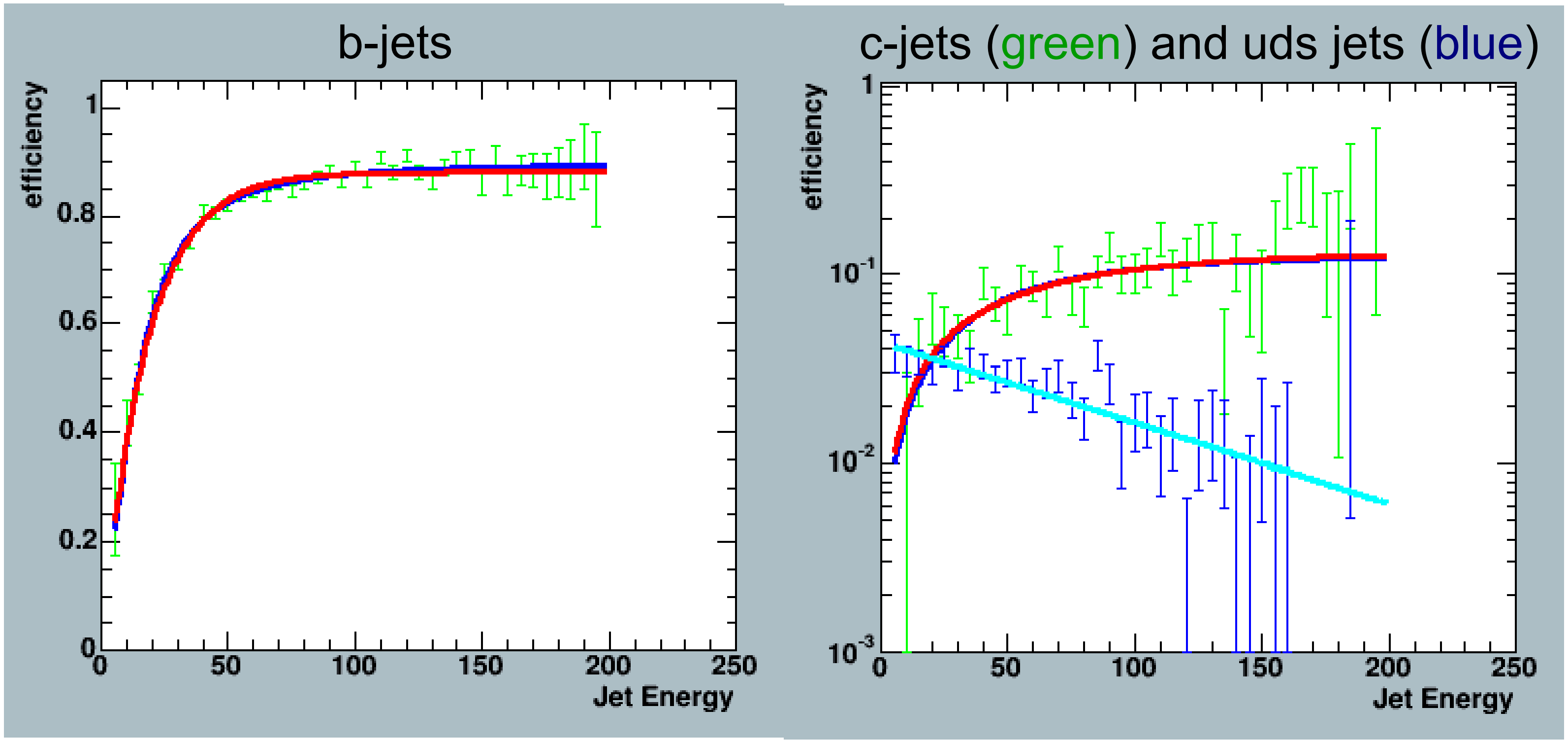
- CalcHep
  - installed in both 32-bit and 64-bit precision (A.Belyaev and A.Pukhov)
  - to generate both signal and background events
  - …write them in Les Houches format and give to…

- Pythia 8
  - Used for fragmentation,decays and jet finding.
  - C++ version of Pythia.
  - Aimed at LHC rather than ILC.
  - Constribution to Pythia 8 debugging (and to CalcHep).
  - Fairly positive experience, so far, except:
    - missing writer to stdhep format…
    - Rather unfortunate, if we want to go for full sim/rec with SiD/LCFI framework.

Beamstrahlung is taken into account, as well as the final state gluon radiation and ISR.
Acceptance and tagging efficiencies simulated approximately.

Jet Tagging Efficiency

- Jet b-tag (and b-mistag) efficiency parameterised as a function of jet energy using SiD data (ZHH, tbW = 6-jet events though…)
  - And fitted by sigmoid function (b-tag, c-mistag) or exponencial (uds-mistag)



Jet Tagging Efficiency

- True jet flavour of Pythia jets determined via Pythia's MC fragmentation/decay tree.
- Both jets (if found) required to be b-jets
  - Tag/mistag efficiency used as probability function $p_i(E_i)$
  - Events are then re-weighted with weight $w = p_1 * p_2$
  - This is because of the two photon background $\gamma\gamma \rightarrow cc$, which has huge cross section and we can not afford to cut events based on jet tag efficiency
    - This would lead to a very small remaining statistics of only few events (or none) with large weights (due to normalisation on luminosity).

Signal Data Sets

- We have generated a net of signal samples for different sbottom and neutralino masses:

```
MSB = 240, 230, 220 GeV
MN1 = 230, 220, 210 GeV
so that always MN1 < MSB
and mass split: 10,20,30 GeV
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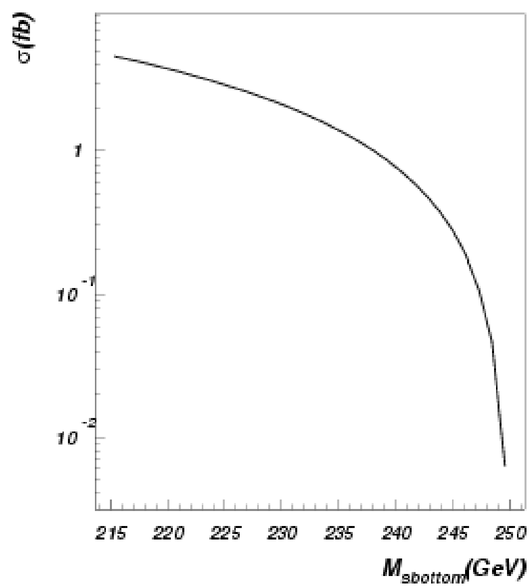
Important point:

cross-section is falling down at higher masses leading to complications with SM background, which has large cross section.



Two photon background

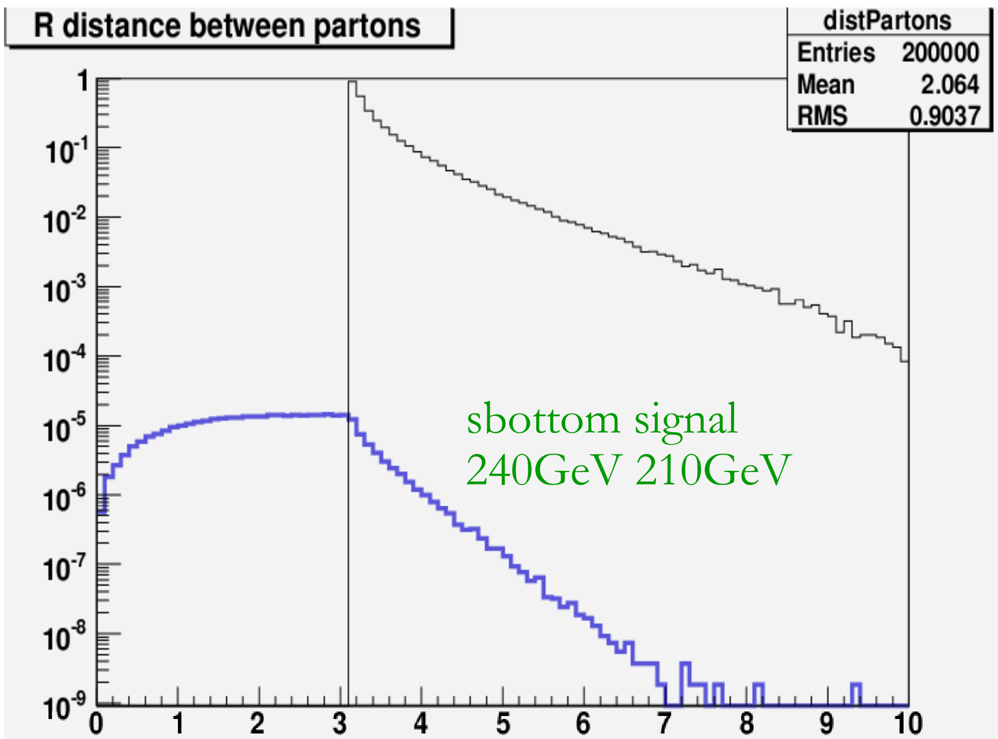
- Dominant and most problematic background:
  - Orders of magnitude (3-4) higher cross section.
  - Similar kinematic range (soft jets).
- Generated in CalcHep in 2 ways:
  - As 2→2 process using equivalent photon approximation (PDFs).
  - As 2→4 process ($e^+e^- \rightarrow e^+e^- b\bar{b}$) on a 64-bit machine
    - Rather interesting study: electron mass can not be neglected.
    - 32-bit precision is too low, cross section is divergent.
    - FORTRAN 64-bit version of Calchep runs OK and is used to generate events.
    - 64-bit C version does not quite give needed 64-bit precision (although 10x higher electron mass would lead to a convergence).
  - Cross sections are comparable: 3.72pb (2 → 2) vs 3.45pb (2 → 4) for bb.

So what's the problem with the two photon background?

Signal vs γγ-background

- On the first look it can be very effectively removed by simply cutting on the η-φ plane distance between jets: (parton level)

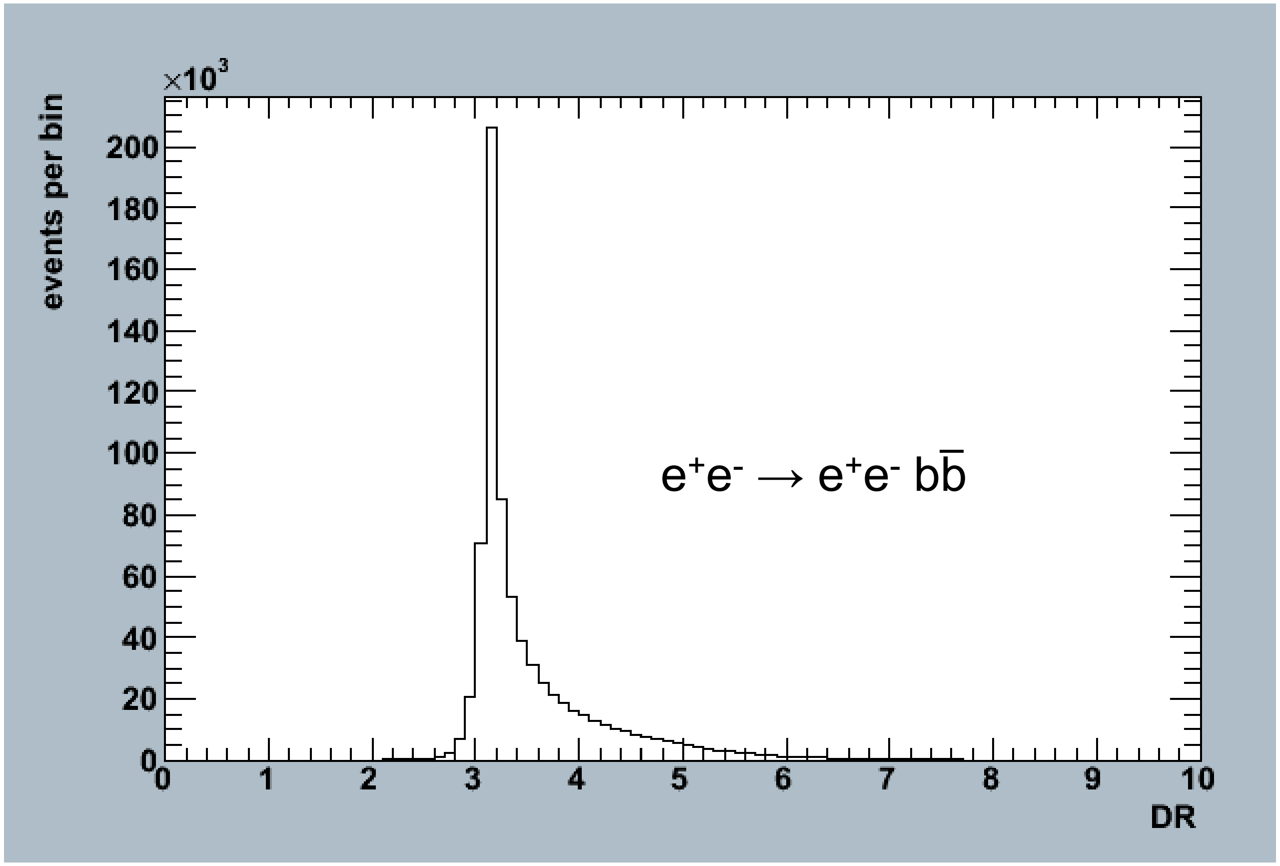
$$\Delta R_{bb} = \sqrt{\Delta\eta_{bb}^2 + \Delta\phi_{bb}^2}$$



ΔR_{bb} separation for b-jets from background is always above π at the parton level

Signal vs γγ-background

- After (optimised) jet finding it still looks promising, on the first look:

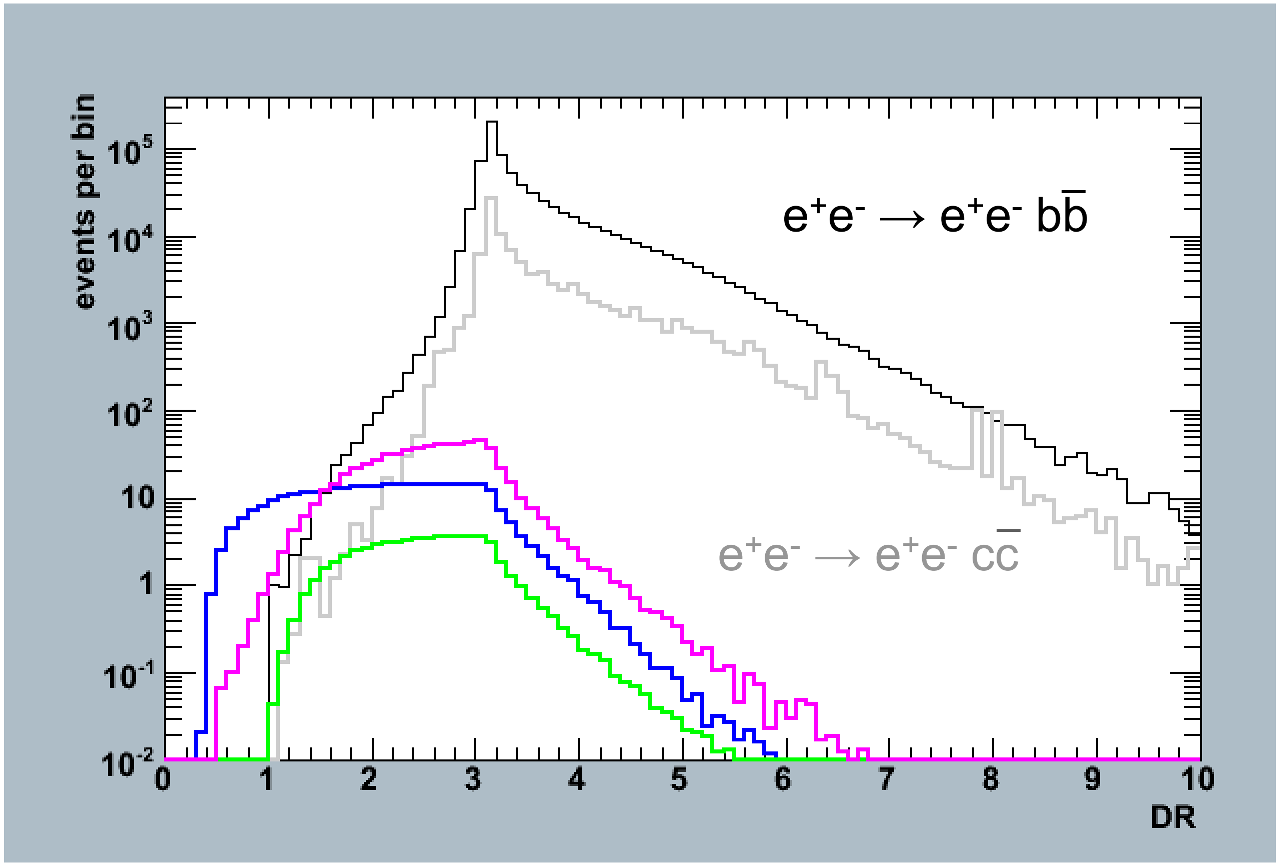


For all following plots:
Normalised on 2000fb^{-1}
Durham kT jet finder
Flavour tag ON

Signal vs γγ-background

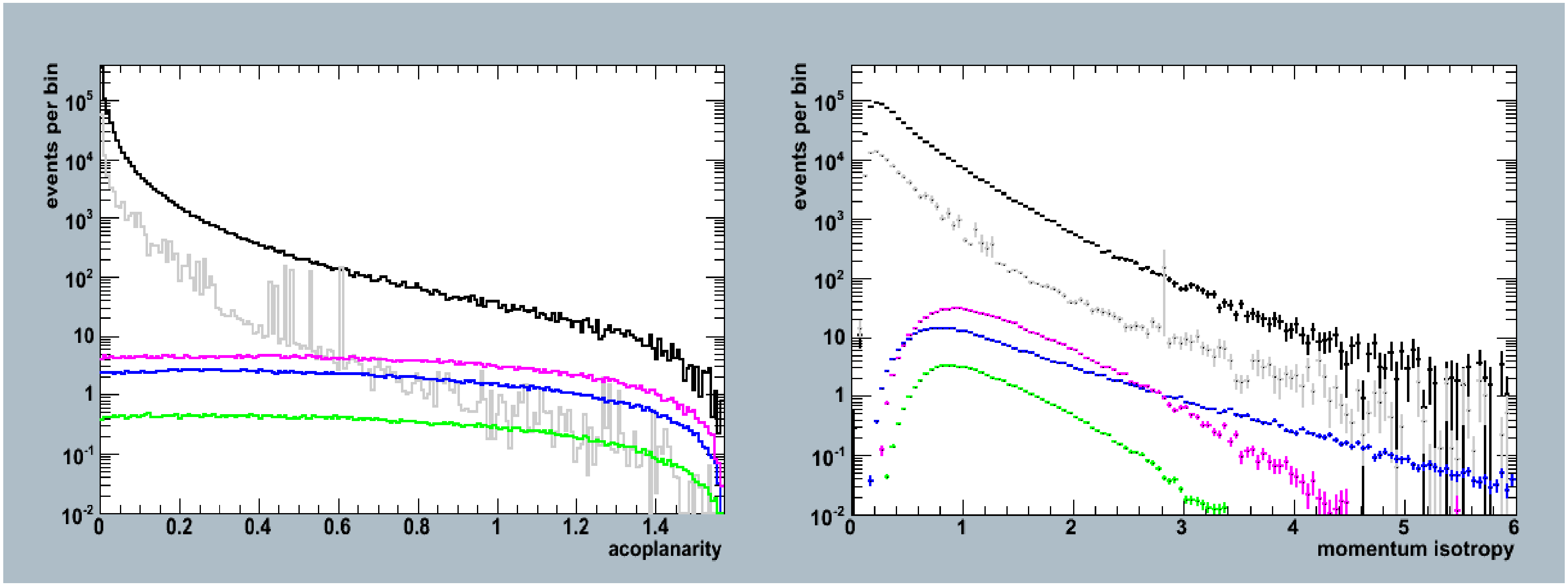
- Large cross section makes the leakage towards low DR significant.
  - In other words: our two photon background is entirely due to imperfect jet finding.

m_{Sb}	m_{Ne}
240	210
240	230
220	210



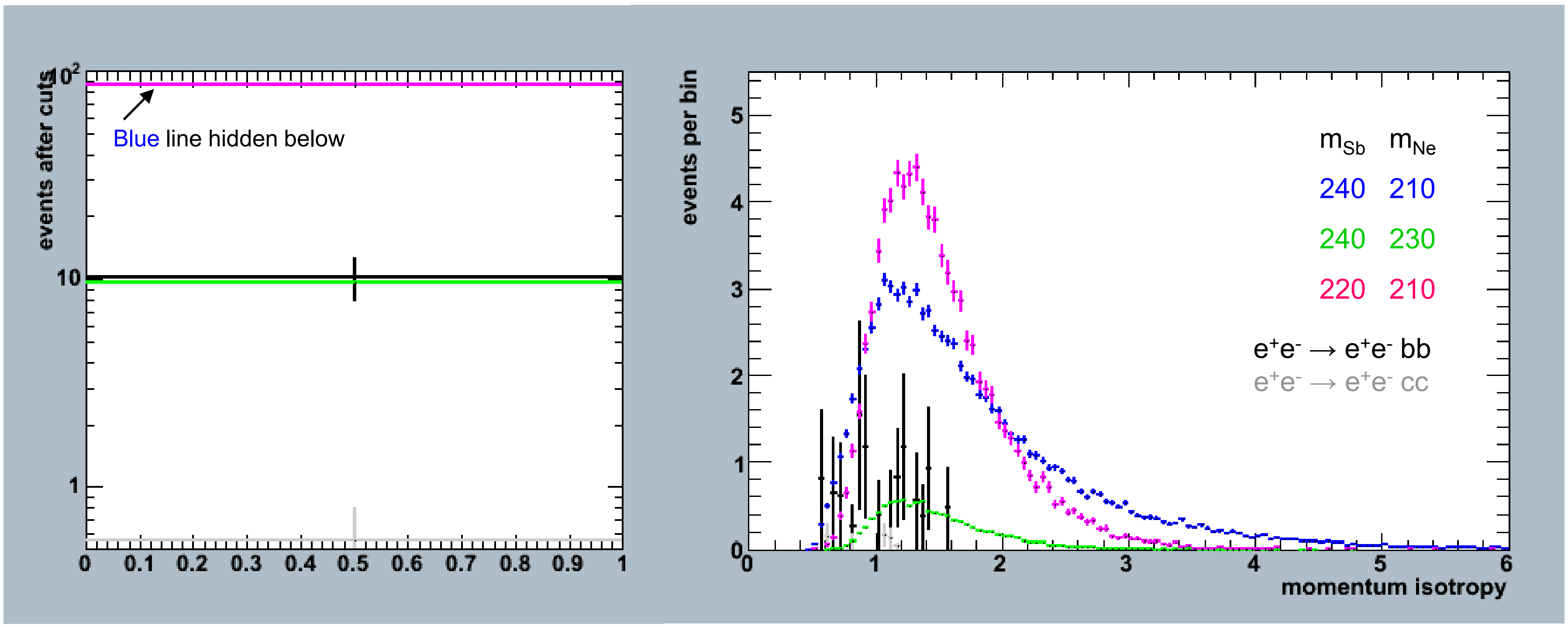
More on $\gamma\gamma$-background suppression

- Other effective variables turned out to be:
  - Acoplanarity (we use 3D accoplanarity, not 'φ_1-φ_2')
  - Momentum isotropy



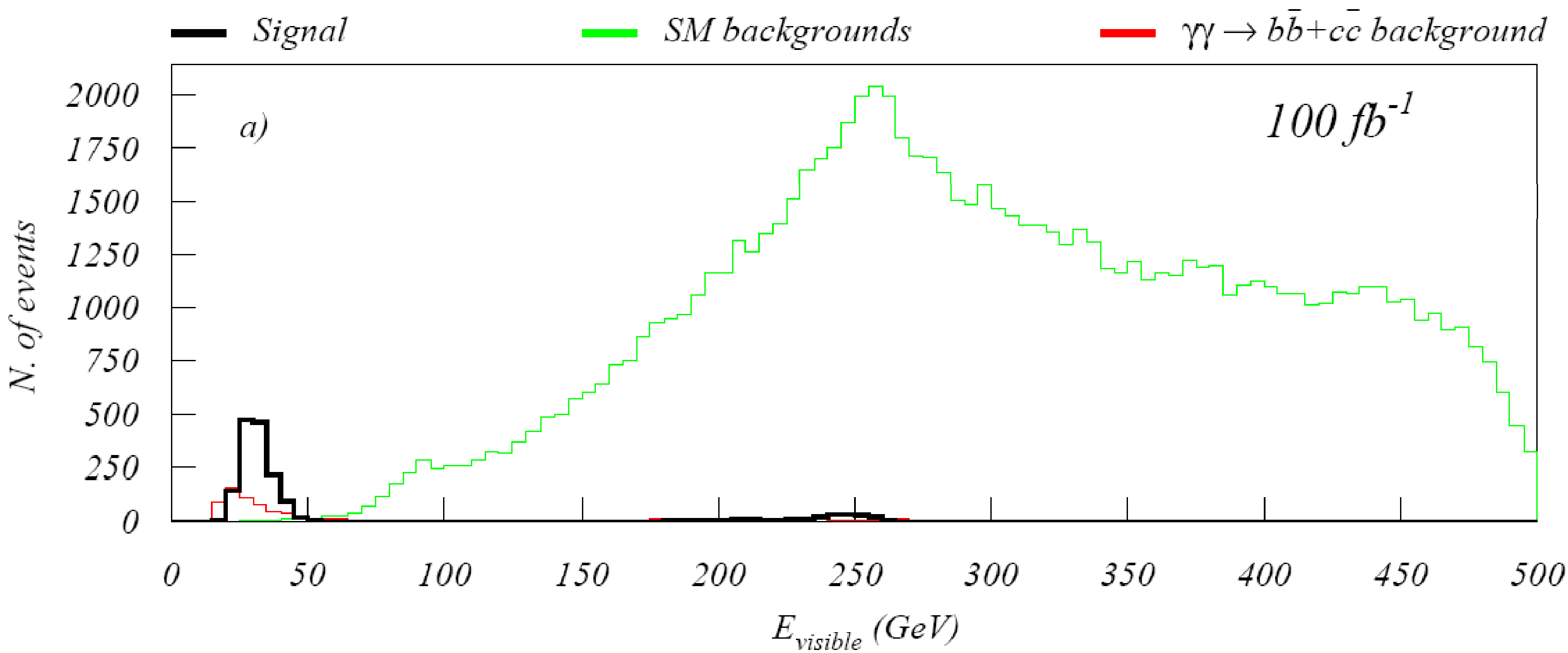
Toy Analysis

- Take 2 jet events and cut on: dR<2.0 && acoplanarity>0.6
  - Looks promising: strong suppression of background
    - and of signal too…
  - Optimise cuts and add momentum isotropy.



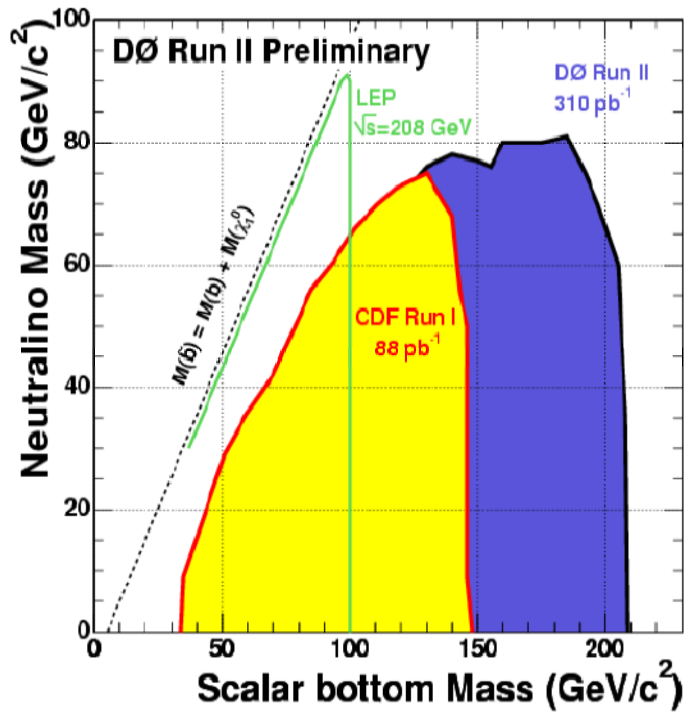
Other Standard Model Backgrounds

- Data being simulated by Marija (almost finished).
- Can be effectively suppressed by simple kinematic cuts
  - e.g. on the visible energy:



Next Steps

- Optimise background suppression cuts.
  - Eventually use Neural Nets or BDTs for the signal selection.
- Evaluate confidence levels for various signal data sets.
- Based on results generate more signal sets covering broader sbottom/neutralino mass range.
- Investigate possible veto of two photon background by detecting scattered electrons in the very forward region.
- Aim is to produce a plot similar to:



Summary

- The (straw man) analysis is progressing well:
  - Main issues identified and mostly solved.
  - Standard model background simulation almost finished.
  - SiD/LCFI used indirectly so far:
    - Detector acceptance.
    - Tagging efficiencies.

- The next step, sim/rec with SiD/LCFI …more tricky…
  - How to write stdhep files from Pythia 8?
  - We are currently using more than 20.000.000 events
    - Mostly 2 photon background.
    - Which will be in ~99.9995% rejected after jet-related cuts.