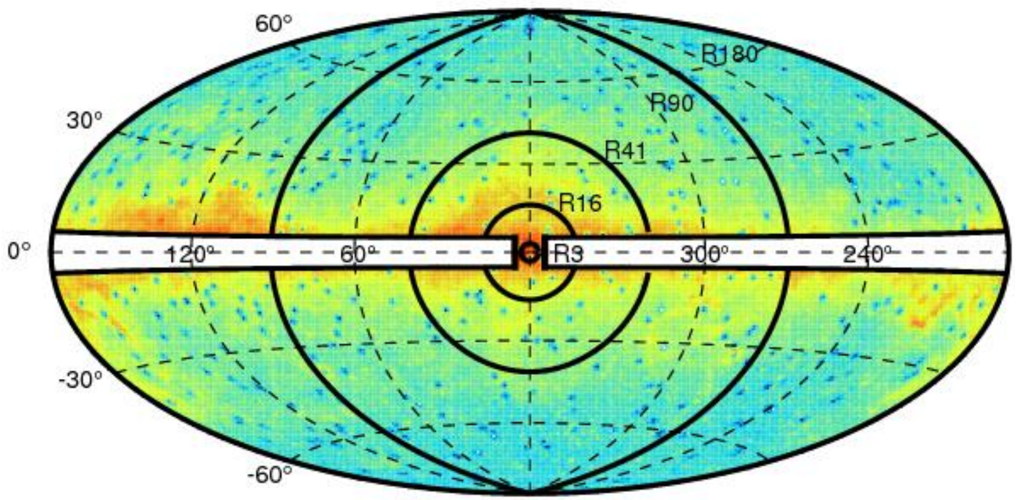
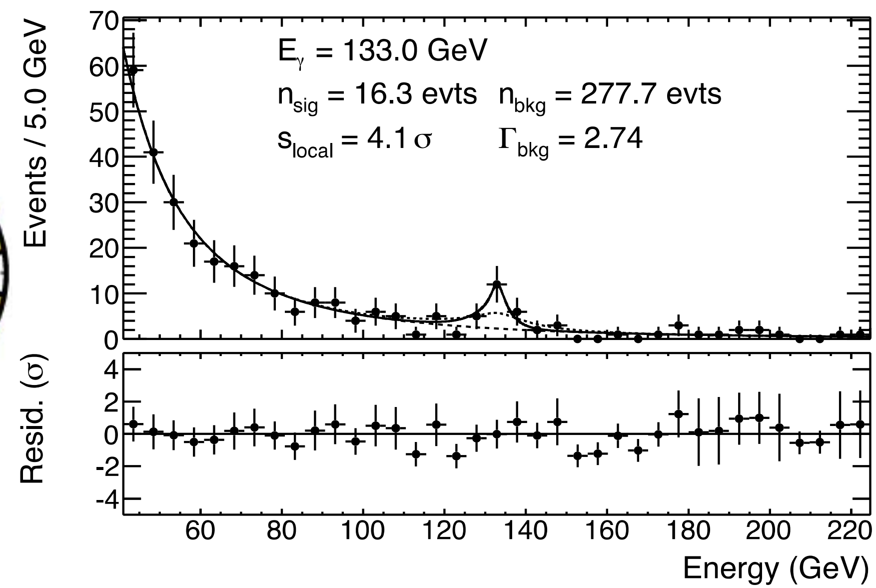
CF2: *What experiment would you perform to clarify the situation of the 130 GeV gamma ray line? What is the prospect for studying this phenomenon in the lab?*

Max, Josh, Marcus, Sho

Fermi measurements

- Fermi found a line-like feature in their data at about 130 GeV in a region around the Galactic Center…





- Original discovery (Weniger, 1204:2797) was by outside users in 2012; we use May 2013 paper from the Fermi collaboration (1305.5597)

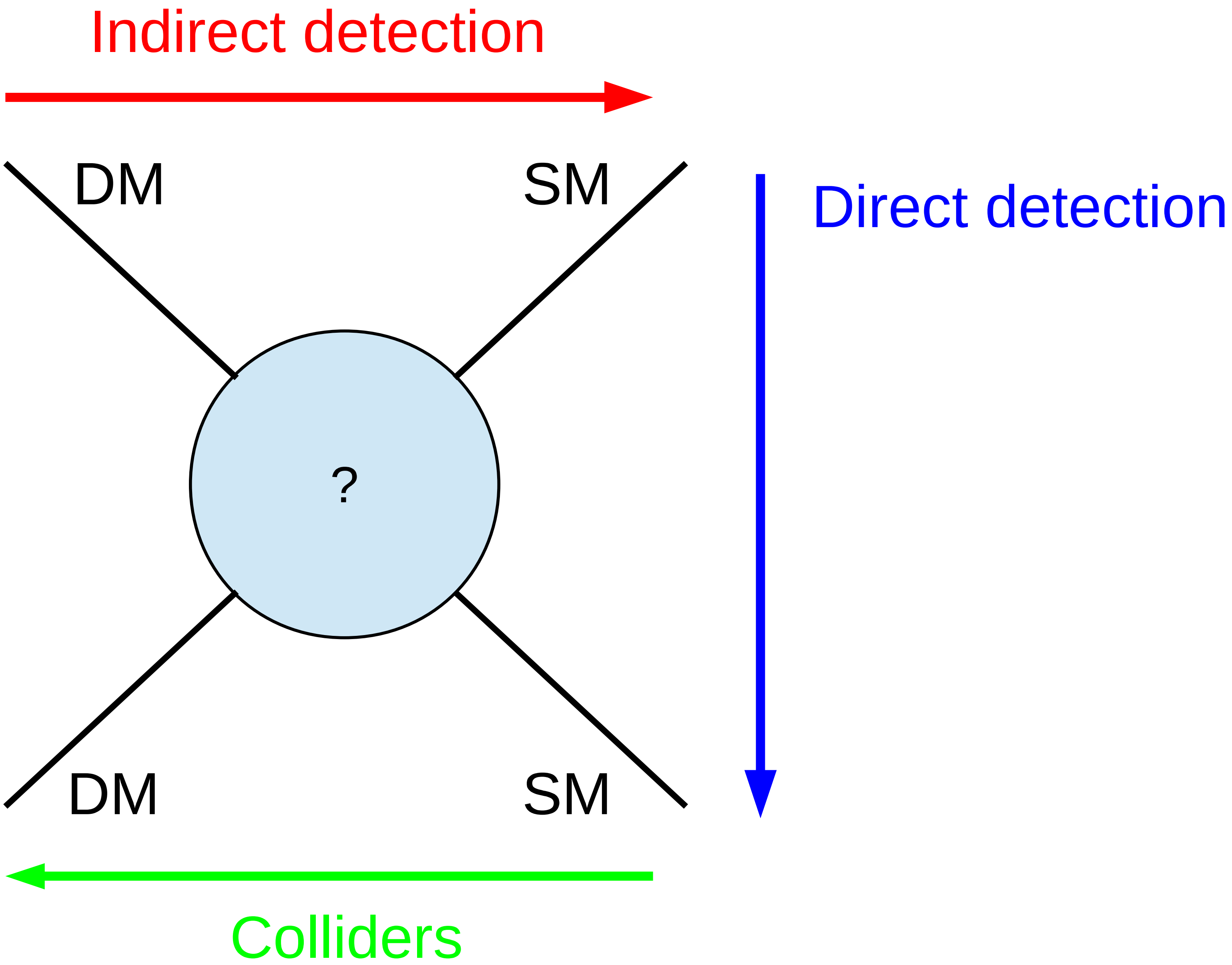
Reasons not to believe the line

- The line is too narrow (much narrower than expected energy resolution)
- Similar feature is also present in Earth limb data (very strong gamma ray source, but should be featureless spectrum)
- Better treatment -> significance went down

Let's believe it

- Best-fit flux seen by Fermi: 1.9e-10/cm^2-s (17.8 events!) coming from a 3° radius around the GC
- Assume this is annihilation to γγ (not Zγ, not internal bremsstrahlung), so m_χ = 133 GeV
- Use the model of Milky Way DM density assumed by the Fermi best fit
- Then velocity-averaged cross section $<\sigma v>$=3.0e-28 cm^3/s (1/100 the total thermal relic value, but that's reasonable)

Take every option!



Can we confirm?

- Step 1: look at the galactic center with another instrument
- Step 2: look at other places with DM annihilation
- Gamma flux = particle physics factor × J-factor
  - Particle physics factor in our model depends only on $<\sigma v>$, which we'll assume is constant
  - J-factor: ρ^2 integral over solid angle and line of sight – depends on DM distribution
- GC: radius 3°, J-factor 1.39e23 GeV^2/cm^5
  - Strong but diffuse source
  - High and poorly understood gamma background
- Dwarf galaxies: typical radius 0.2°, typical J-factor 2e18 GeV^2/cm^5
  - Weak but compact, no intrinsic gamma background
- Dwarf galaxies would be a clean confirmation of a DM signal: can we see them?

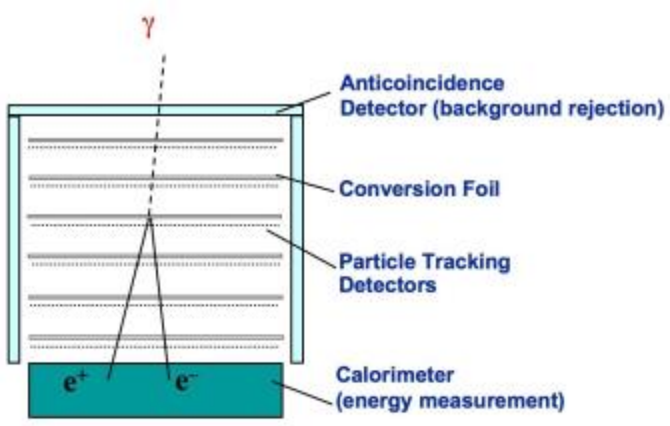
Instruments

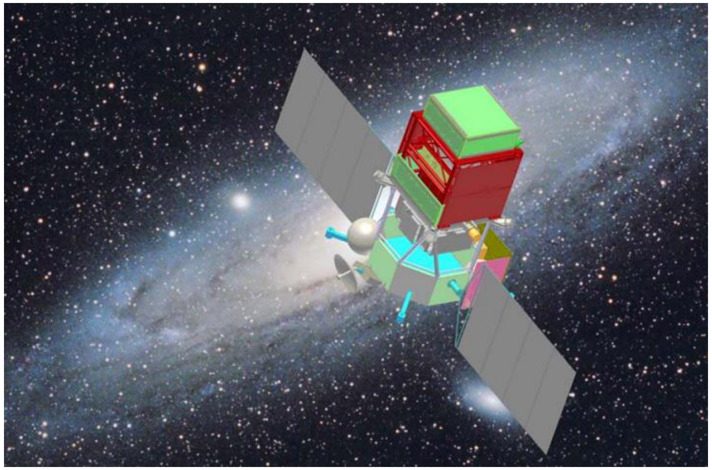
Parameters (at 133 GeV)	Fermi LAT	GAMMA-400	HESS-II	CTA
Effective area (cm^2)	8.0e3	5.0e3	8.5e8	1e9
Angular resolution (°)	0.05	0.01	0.25	0.1
Energy resolution ($\Delta E/E$)	0.12	0.01	0.28	0.09

- Two classes of experiments: space-based pair-conversion telescopes and ground-based air Cerenkov telescopes
- 133 GeV is near the high-energy limit for Fermi and near the low-energy limit for IACTs

Space-based telescopes

- Fermi LAT is the state of the art; GAMMA-400 is optimized for a higher energy range with a thicker calorimeter (launch in 2019)
- Gammas convert to pairs in the detector; tracker and calorimeter give good particle ID and energy
- Good angular resolution at high energy, very large field of view (survey instrument)
- Very limited mass (~several tons) and area (<1 m^2)





Ground-based telescope arrays

- HESS-II is the state of the art (upgraded in 2012); CTA is the next generation with more telescopes (sometime this decade)
- Air shower makes Cerenkov light; optical telescopes image the shower to get direction, shape (particle ID) and brightness (energy)
- Very large area (as large as the light pool - 0.1 km^2)
- Good angular resolution, small field of view (directed observations only)
- Poor particle ID (imperfect proton rejection, no electron rejection), mediocre energy resolution

Indirect detection: summary

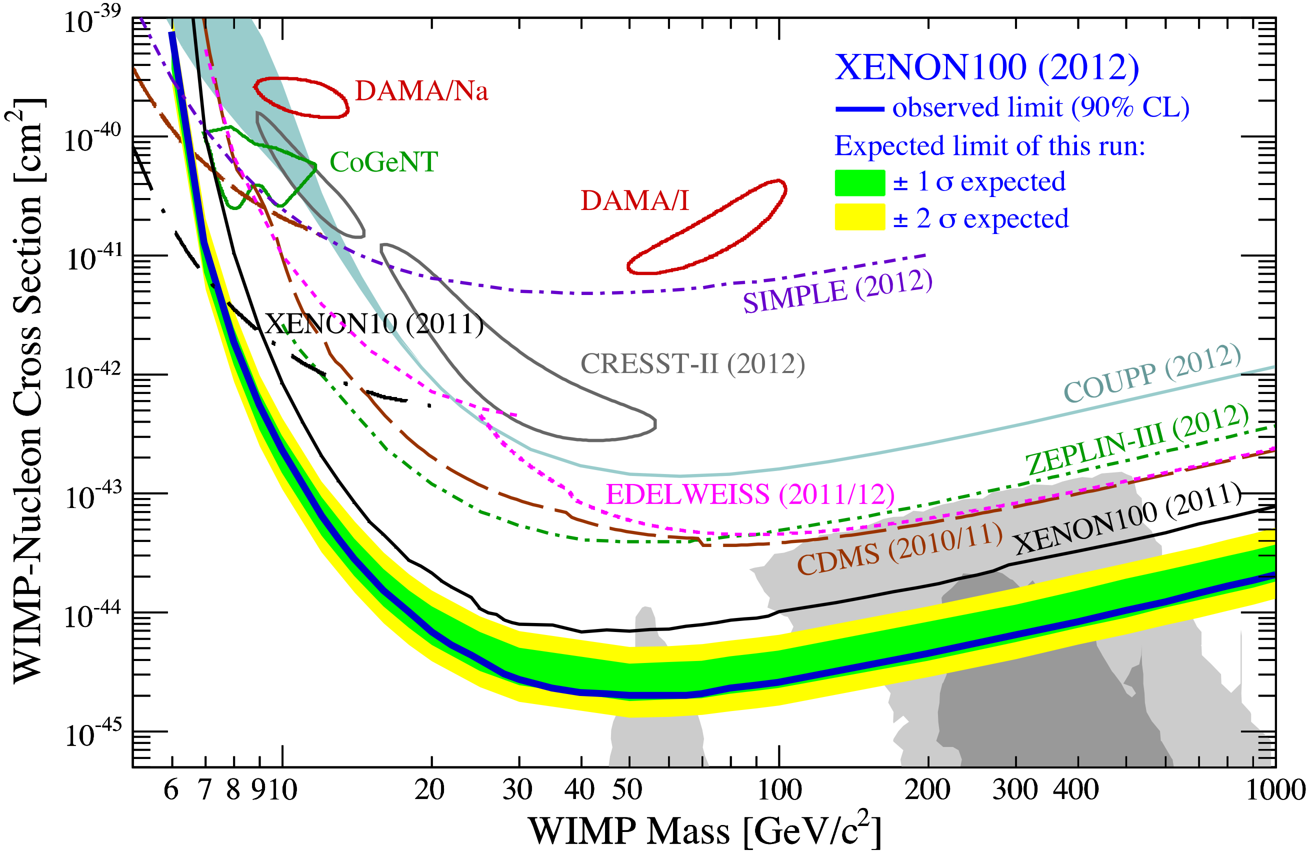
- Galactic center: easy
  - HESS-II should be able to confirm; maybe this year?
  - CTA can map the source and GAMMA-400 can resolve the line
- Dwarf galaxies: forget about it
  - The signal strength (J-factor) is just too small
  - "Dwarf stacking" can multiply the effective observation time, but only for space telescopes
  - Galaxy clusters have similar angular sizes and J-factors

Parameters (at 133 GeV)	Fermi LAT	GAMMA-400	HESS-II	CTA
Observation time for 5σ confirmation of GC	15 years	2 years	10 hours	1 hour
Event rate from dwarf galaxy	0.06/century	0.04/century	0.007/hour	0.01/hour

Direct Measurements

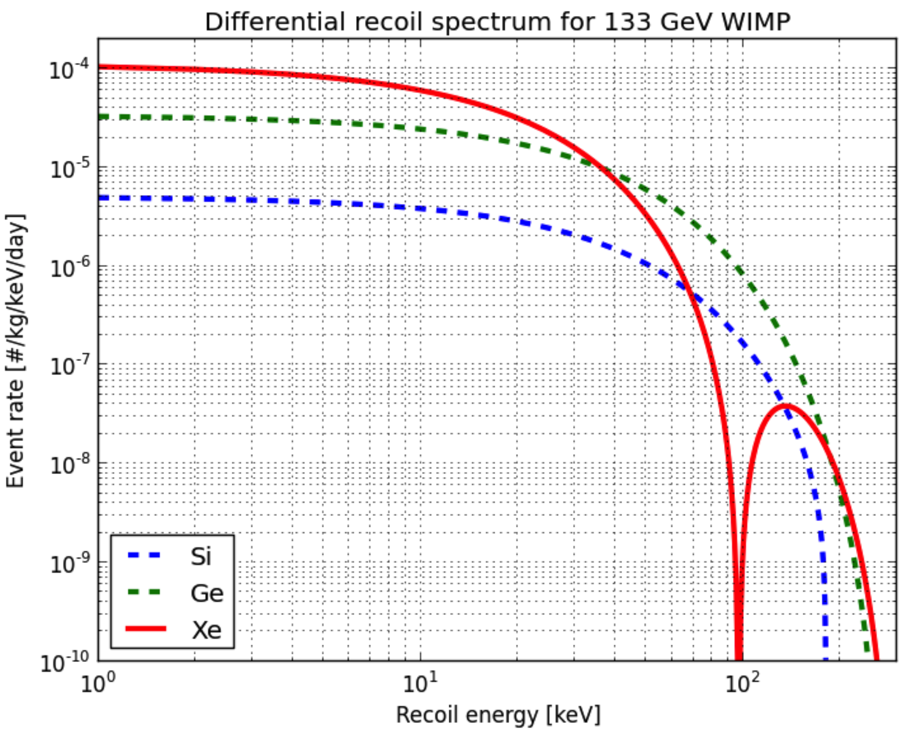
- Assume the line is from $\chi\chi \rightarrow \gamma\gamma$, so m_χ = 133 GeV
- Optimistic assumption for WIMP-nucleon cross section:

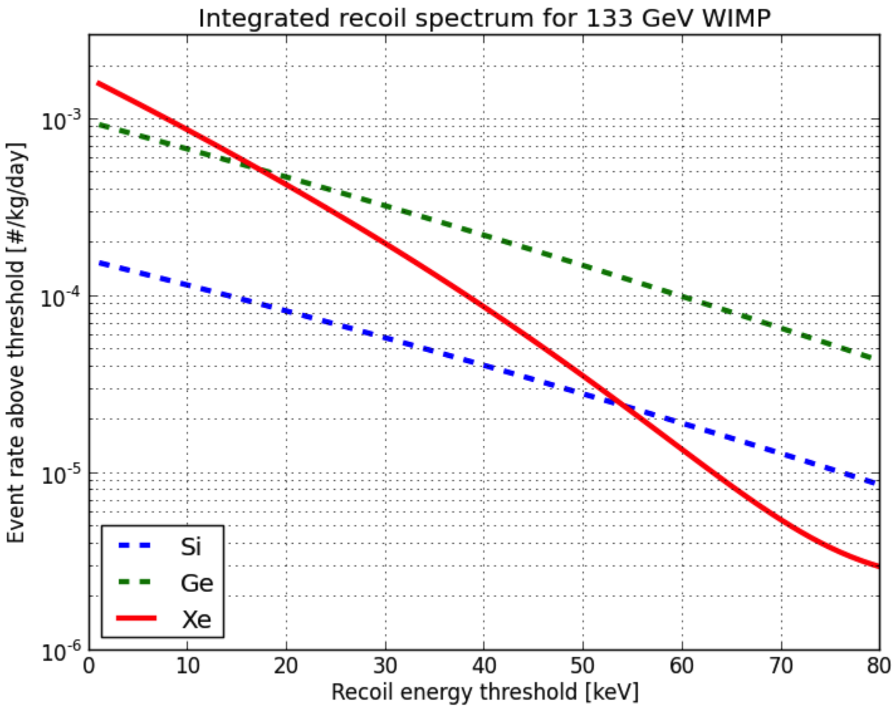
  $\sigma = 3 \times 10^{-45}$ cm^2 (just below the current upper limits for this mass region, astro-ph/1207.5988)



Direct measurements

- Differential / integrated recoil spectra for different materials

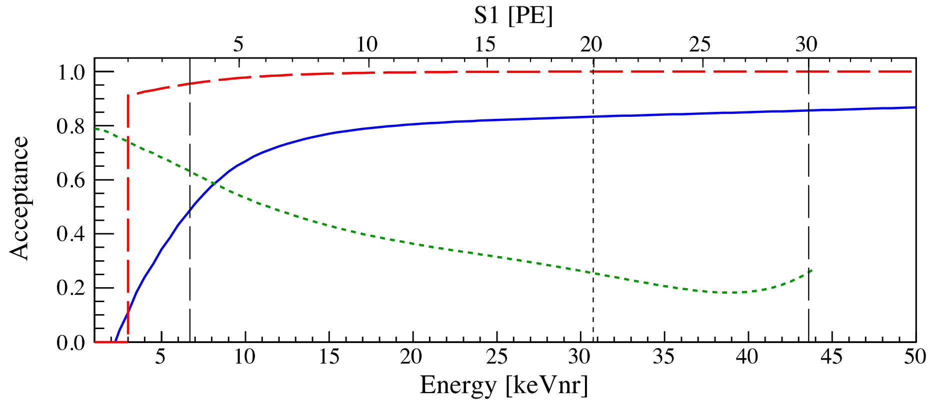




- High WIMP mass -> recoil spectrum extends to higher energies
- Let's consider a XENON-like experiment, but bigger (of course)

Direct measurements

- SüperXEŇON:
  - Xe mass in the fiducial volume 10,000 kg (worldwide Xe production > 50,000 kg/year)
  - energy threshold the same as in XENON100 (about 7 keV, astro-ph/1207.5988)



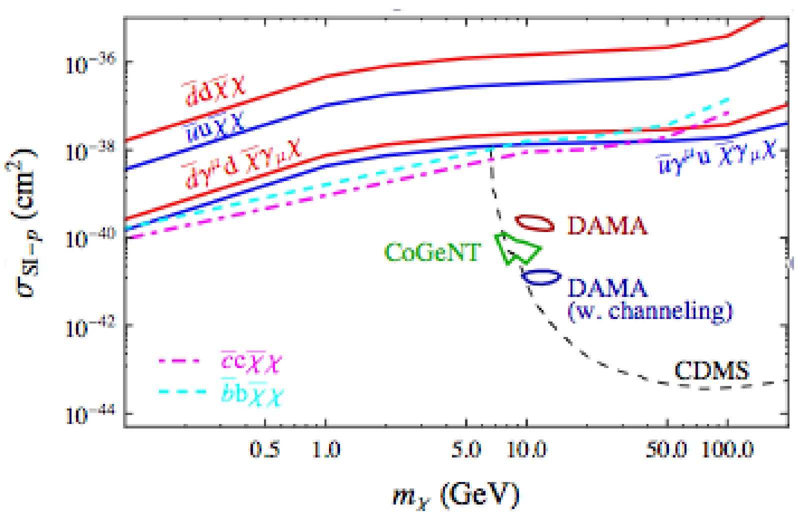
  - **10 dark matter events per day**

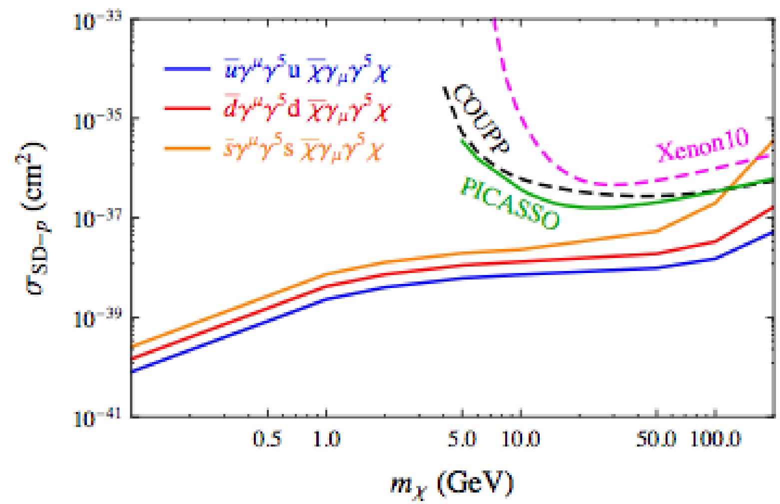
  - Background estimation: assume the background level (neutrons + electromagnetic) is the same as in XENON100
  - XENON100: estimated background 1 event / (225 d * 34 kg))
  - Scaling up for SüperXENON: **1.3 background events per day**
  - Background could be further reduced by going deeper underground (less muon-induced neutrons in the detector) or advances in purifying the Xe (most critical)

Collider Studies

- Canonical model for dark matter @ colliders is SUSY
- Question for you: Can SUSY explain all possible DM scenarios?

- What bounds already exist?
- LEP/SLD energy < 2 * DM Mass --> No direct sensitivity
- LHC & Tevatron (realistically) require DM couples to color charge. Feasible but model dependent (1005.3797 [hep-ph])

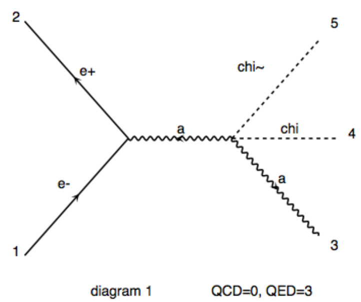




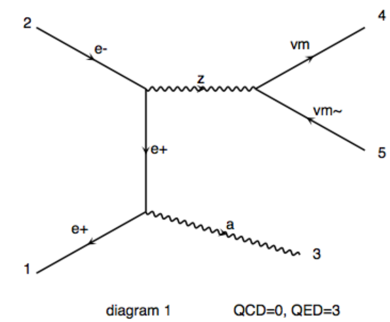
ILC Sensitivity

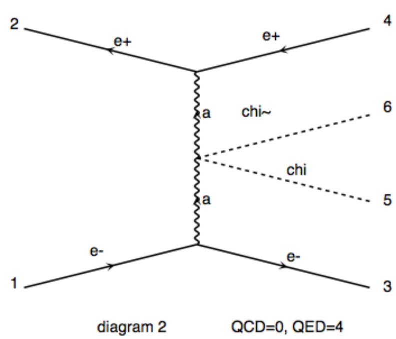
- Previous studies add eeXX vertex and look for ee-->XX \gamma 1206.6639 [hep-ex] 0901.4890 [hep-ex]
- ILC TDR describes gaugino motivated search 1305.6352
- To avoid lengthy literature review, we focus on unlikely primitive vertex: two photon, two chi (via MadGraph5)

<--Signal::Bkgd-->

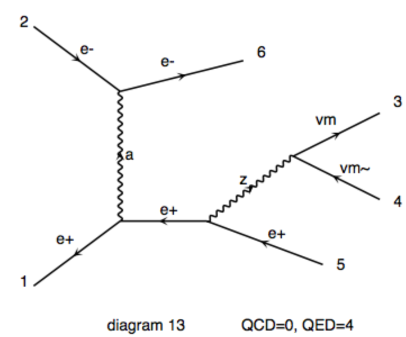


Missing Momentum +

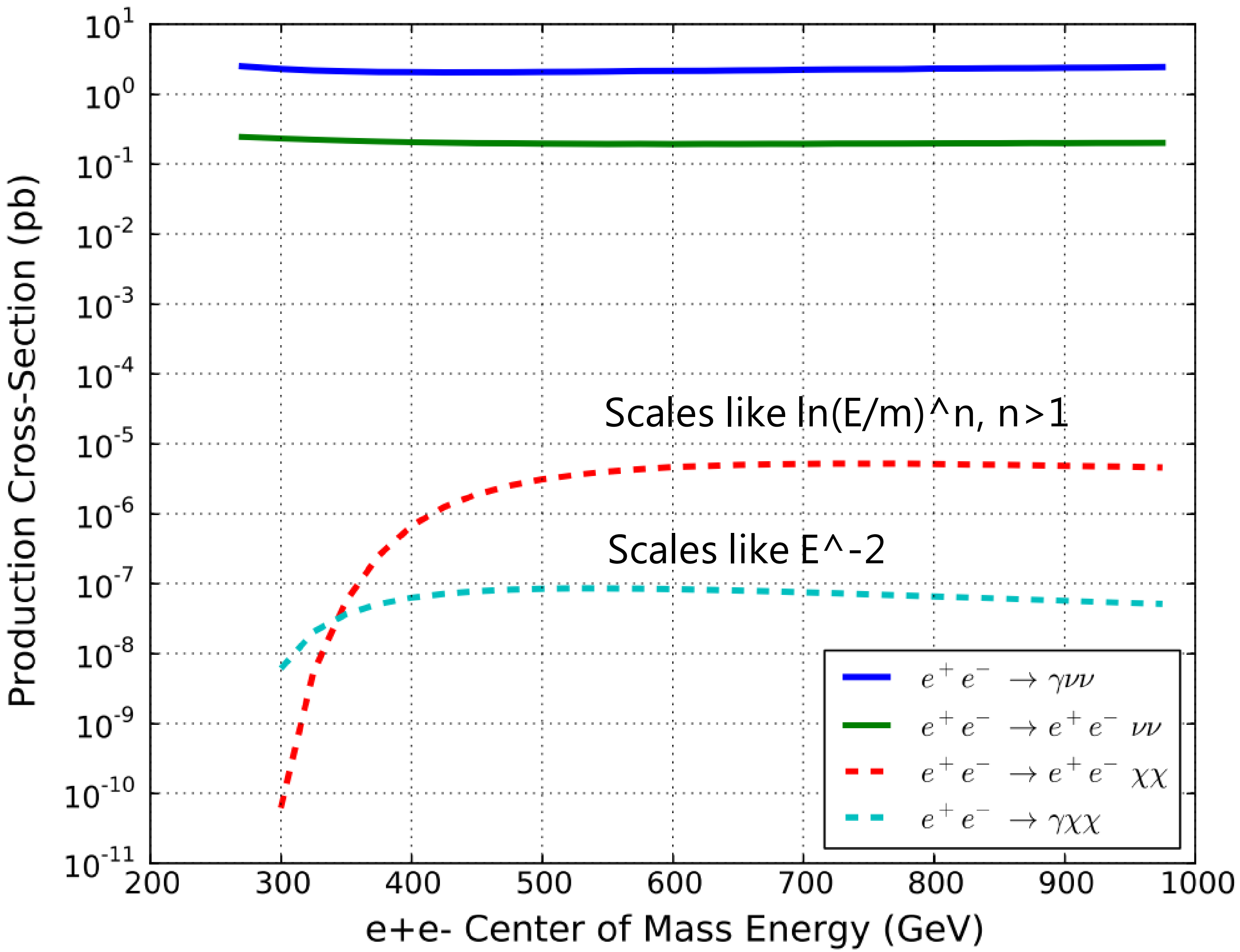




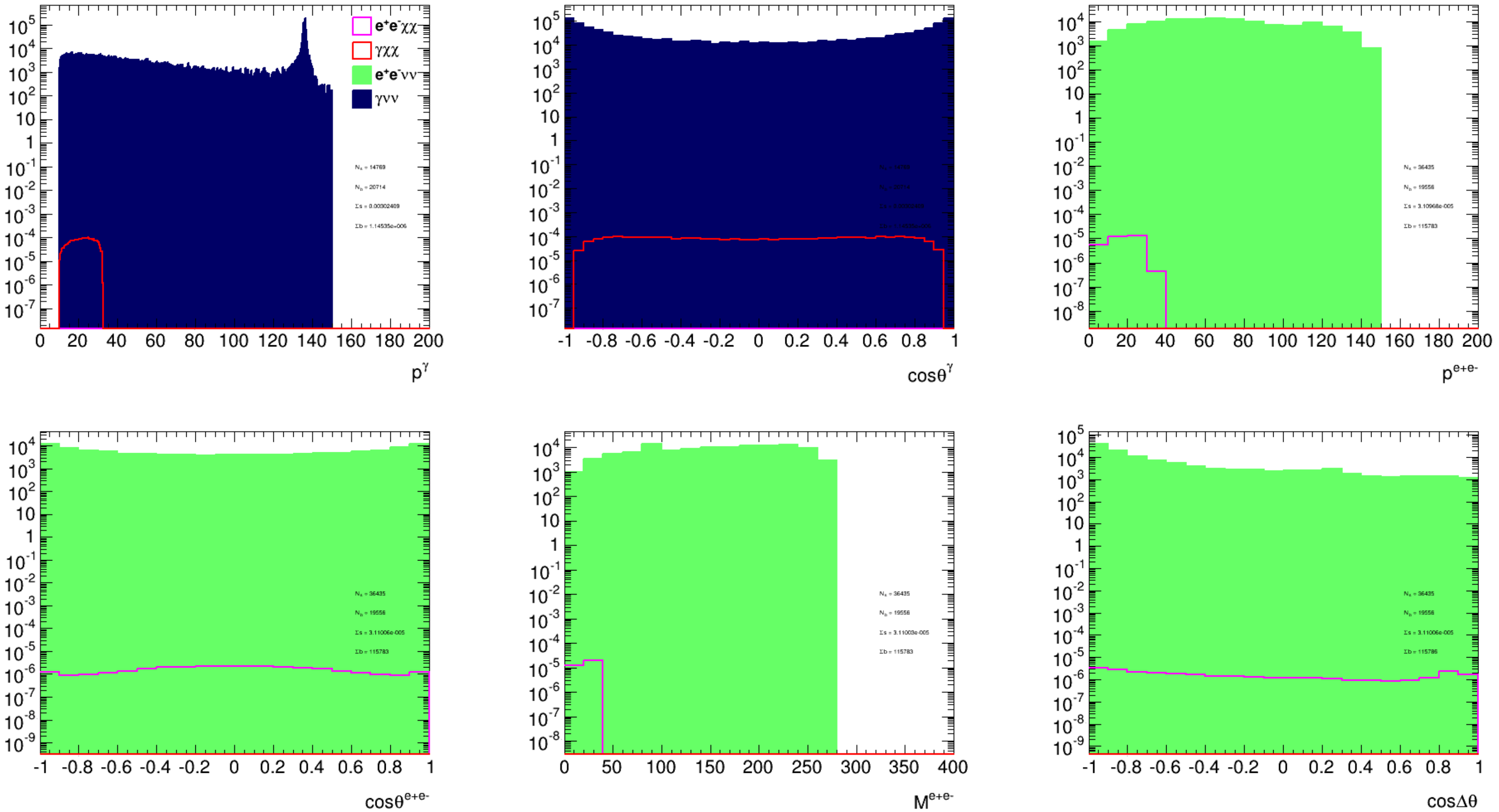
Missing Momentum + e+e-



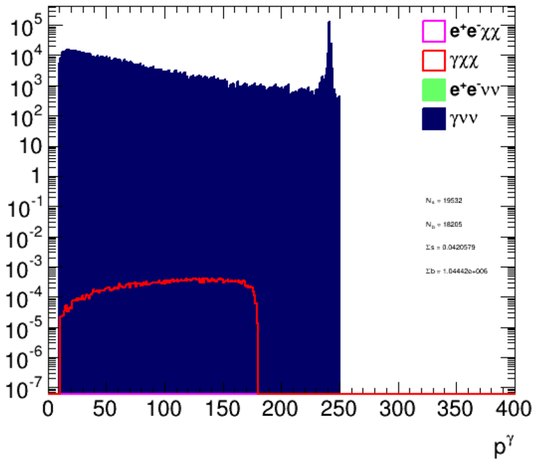
Cross Sections

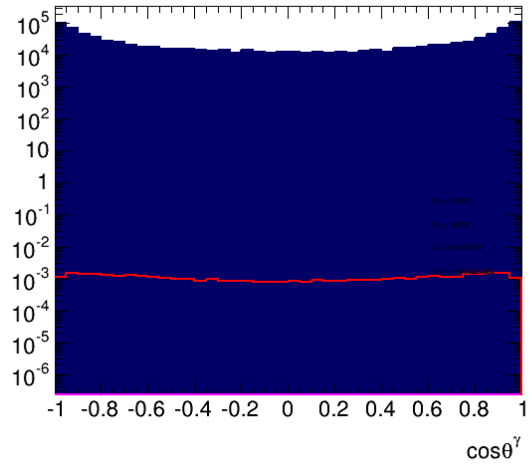


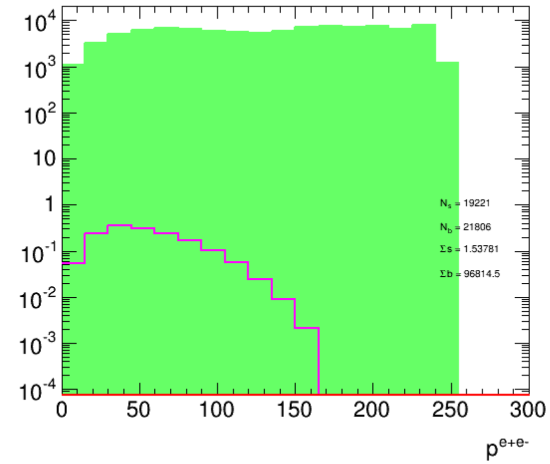
ILC 300, 500 fb-1

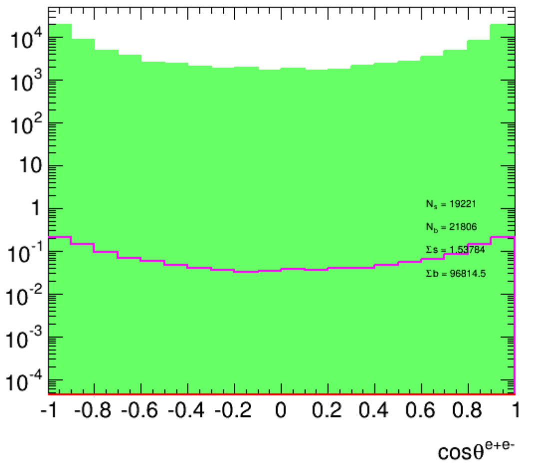


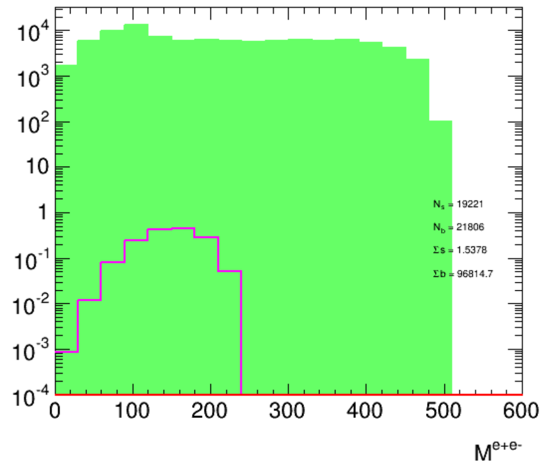
ILC 500,500 fb-1

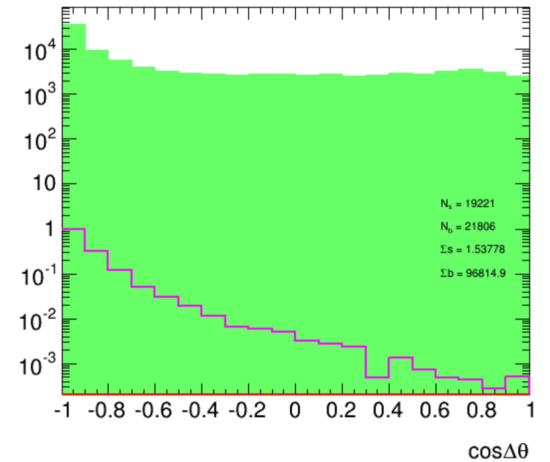




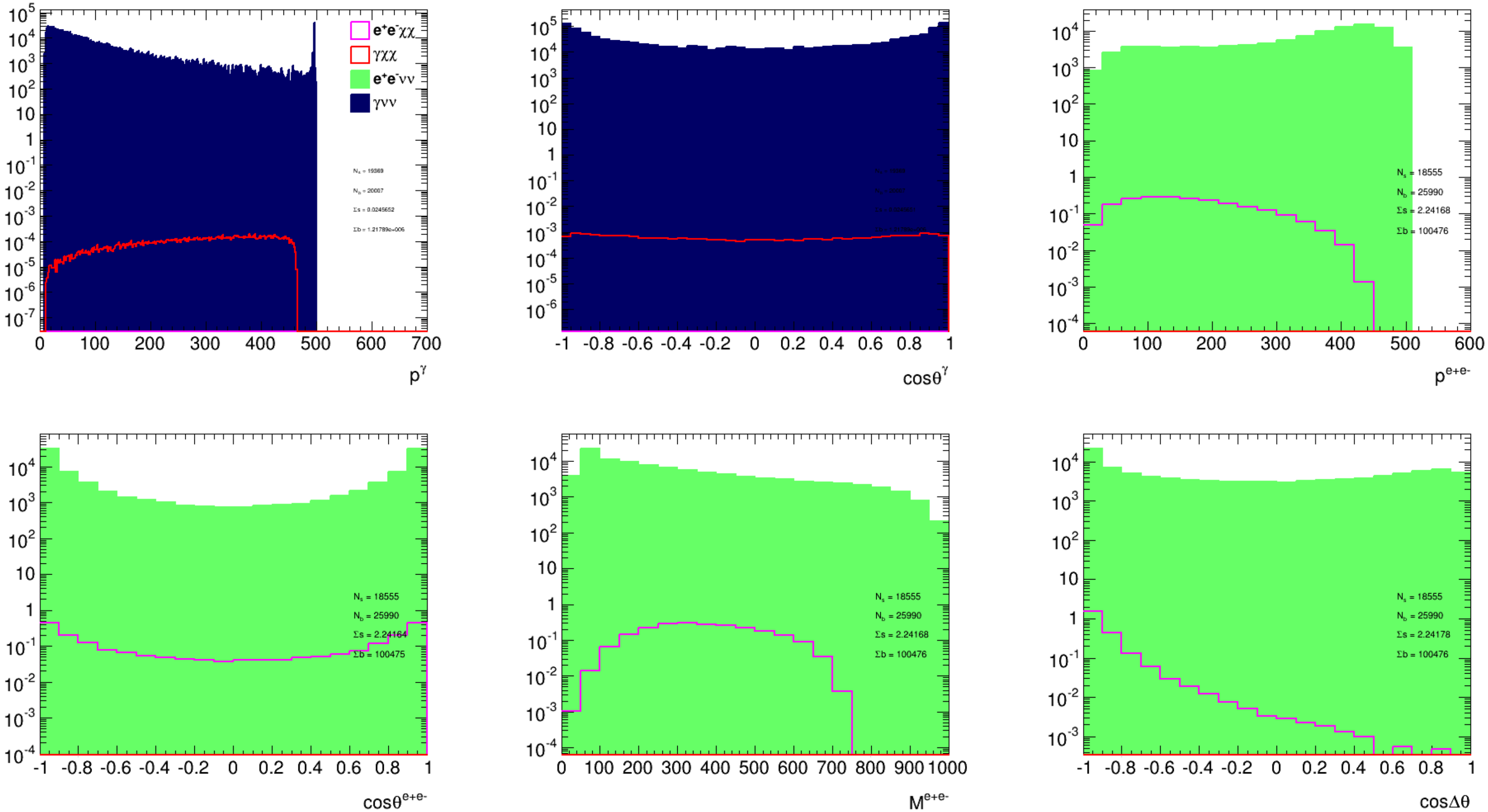






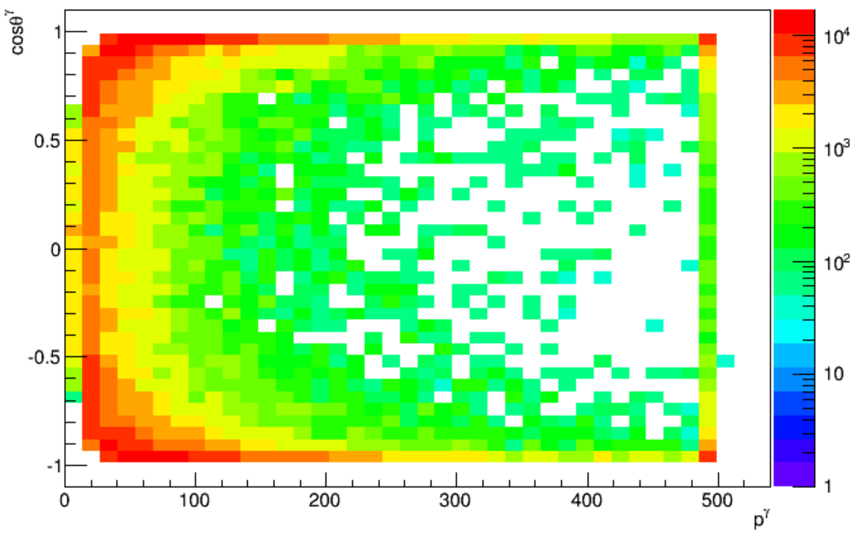


ILC 1000, 500 fb-1

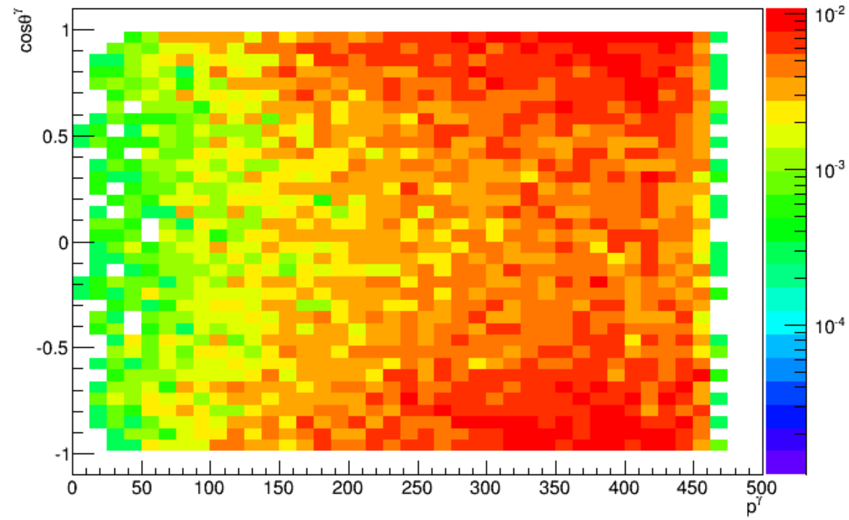


ILC 1000, 500 fb-1

gamma nu nu



gamma chi chi



Conclusion:

Unless we produce the a particle **inside** the chi chi gamma gamma loop, there is no chance at ILC!

Summary

- Confirming the gamma line is easy! (so is excluding it)
- Doing anything different is hard
- Indirect detection: GC is by far the brightest source, and it's hard to see anything else
  - Better measurements of the GC source are your best bet – and we can do much better over the next few years
- Direct detection: Annihilation cross section doesn't tell us much about nucleon cross section
  - Keep doing what we've been doing – larger detectors
- Collider: It's a very small cross-section
  - The cleanest channels for indirect detection are not generally great channels for colliders

Acknowledgments

Thanks to everyone at SLAC that talked with us, helped us along the way and just in general tolerated our questions!

In order of appearance...

- Andrea Albert (Fermi)
- Alex Drlica-Wagner (Fermi)
- Michael Peskin (Theory)
- Kristi Schneck (CDMS)
- Matthew Cahill-Rowley (Theory)
- Ahmed Ismail (Theory)