Re-Analysis of γ-ray Polarization in GRB 021206

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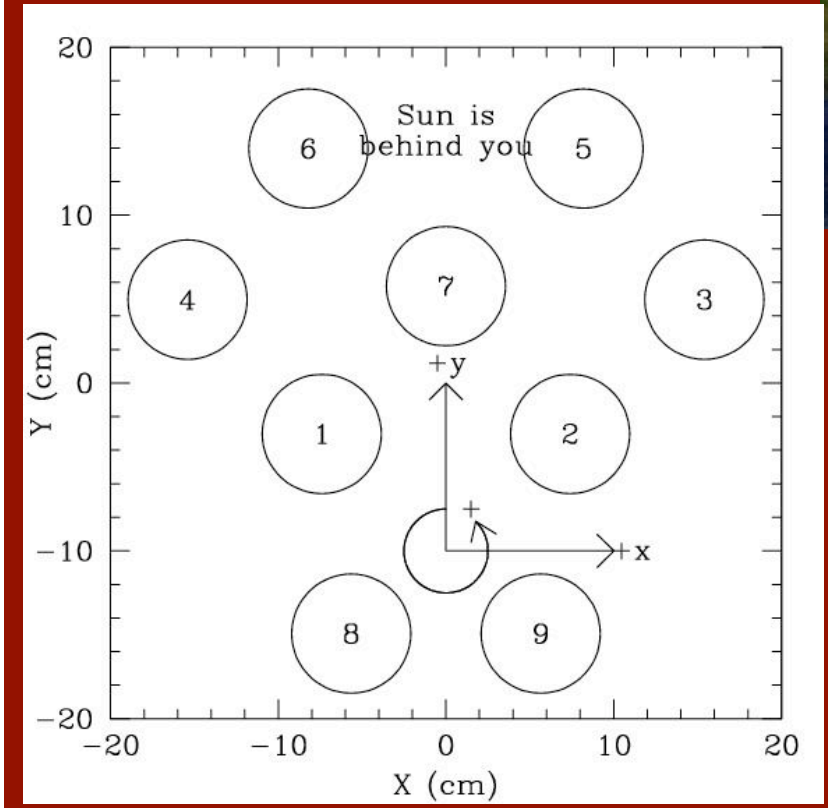
History of observations and implications

- Discovery (1972)
- Homogeneity and Isotropy (Meegan et al 1992): A Cosmological Population.
- Optical afterglows (van Paradijs et al 1997), a high-z emission line (Metzger et al 1997)
- Achromatic Breaks in the afterglow lightcurves--> Jets (e.g. Frail et al)
- Association with SNe (lightcurves: Bloom 1999; spectra: Hjorth, Stanek 2003).
- γ-ray polarization (Coburn & Boggs 2003)
- First detection of γ-ray polarization in any celestial source.
  - A direct probe of evolutionary relativistic MHD, with implications for the formation of magnetic fields in astrophysical jets and shock fronts; in B-field generation in SNe ejecta; and perhaps at the site of the SNe itself. In turn, implications for B-field generation in SNe, providing direct physics input for SNe simulations (would affect mixing and nucleosynthesis); B-field generation in proto-neutron stars and in NSs themselves for which we have only poor observational constrains.

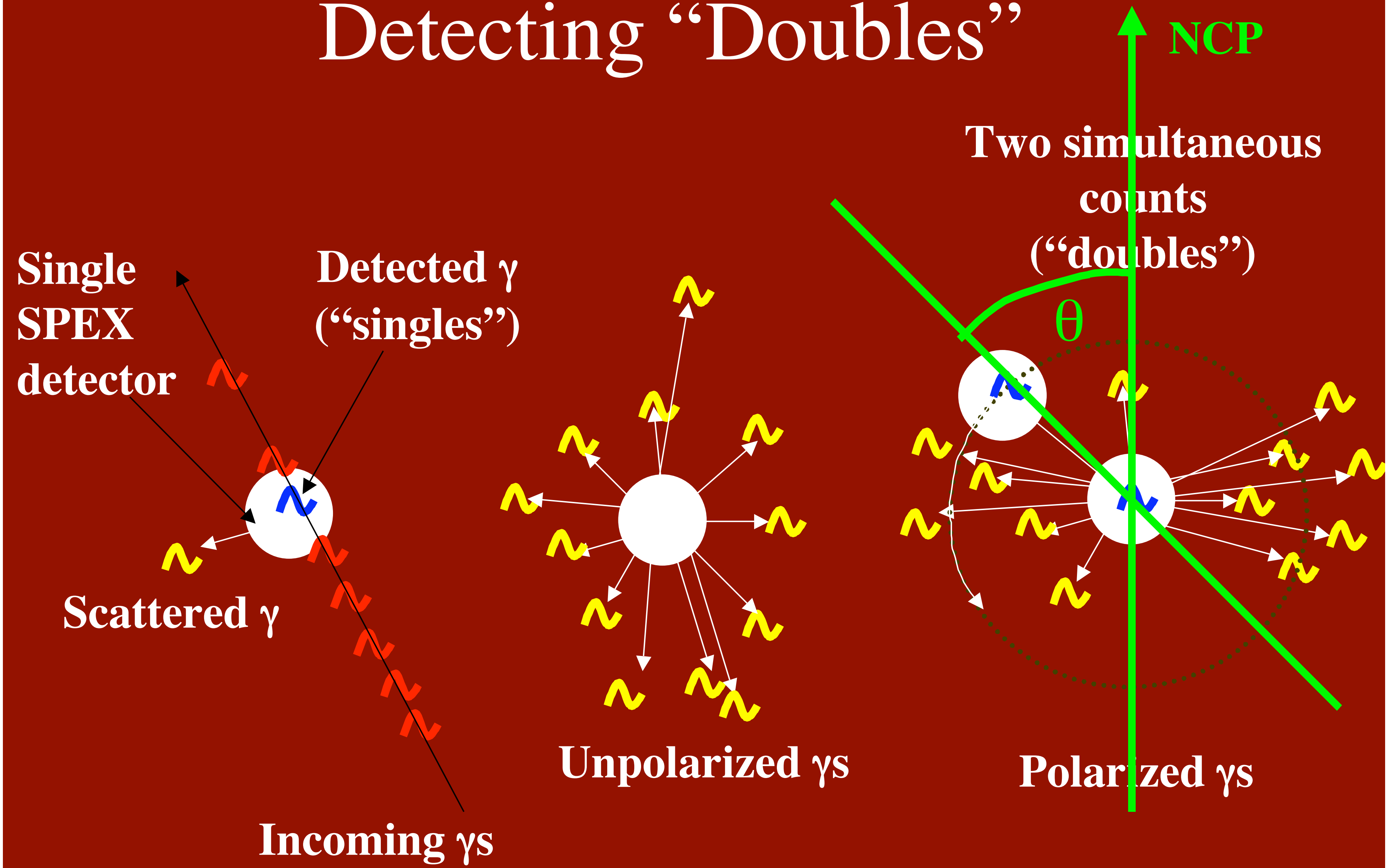
None of the reported X-ray emission lines are significant
Sako, Harrison & RR (2004), submitted.

RHESSI SPEX Detectors

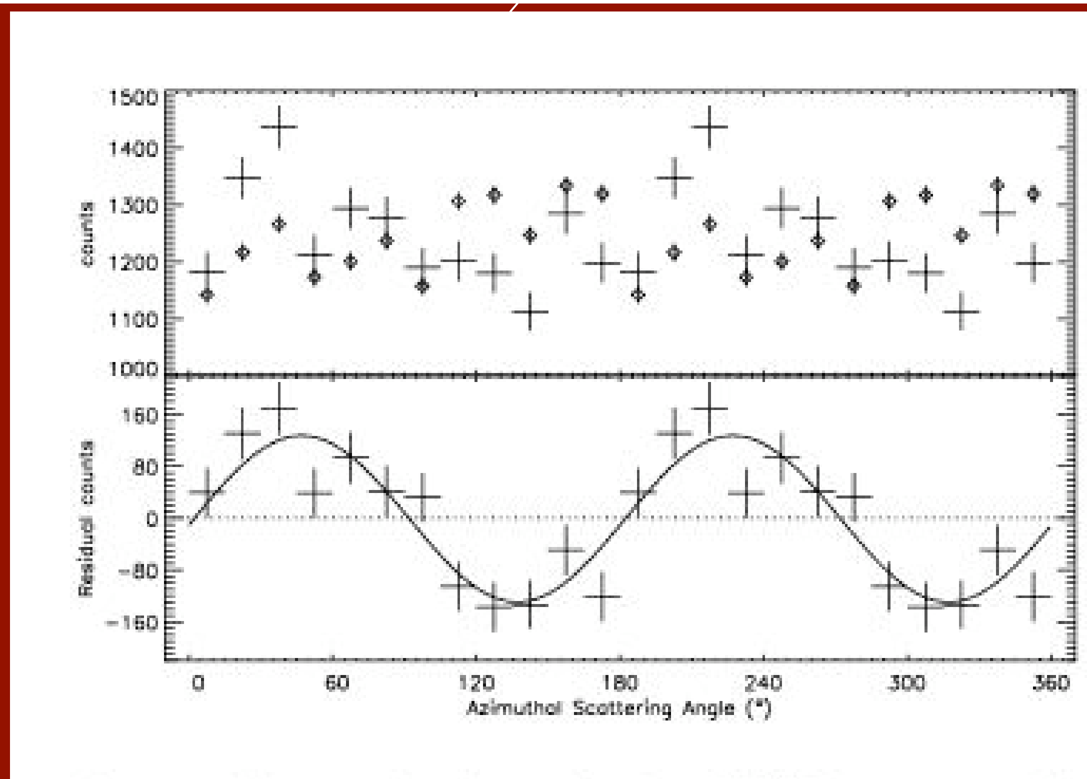


- Nine geometrically identical Ge detectors in a plane.
- spacecraft rotates P~4 sec
- γs time-tagged in ~1 **bμs**

Detecting "Doubles"

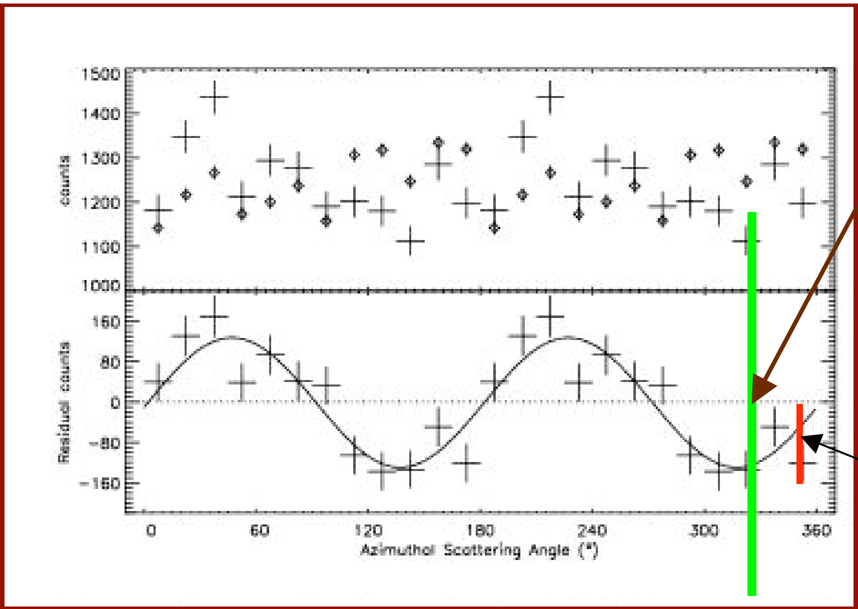


Method of Cobrun & Boggs 2003 (CB03)



- Observed D(θ).
- Monte Carlo simulation: using the observed single-count events and a GEANT mass model and radiative transfer, found D_{null} (θ) assuming a non-polarized beam.

Method of CB03



20% error bar

(cf. with μ)

9% magnitude of modulation

- Assumption of CB03: systematic uncertainty in D_{null} (θ) << statistical uncertainty in D(θ) (3%). **This is not credible.**
- To calculate D_{null} (θ):
  - The fraction of Singles which produce Doubles
  - The fraction of Doubles which only scattered once, and did not interact with passive material.
- Does not account for:
  - Atmospheric scattering?
  - Non gamma-ray background (bunches)?
- Modulation factor μ=0.19±0.04 (20% uncertainty).

Polarization Detection Without Monte Carlo Simulations: The Doubles/Singles Ratio

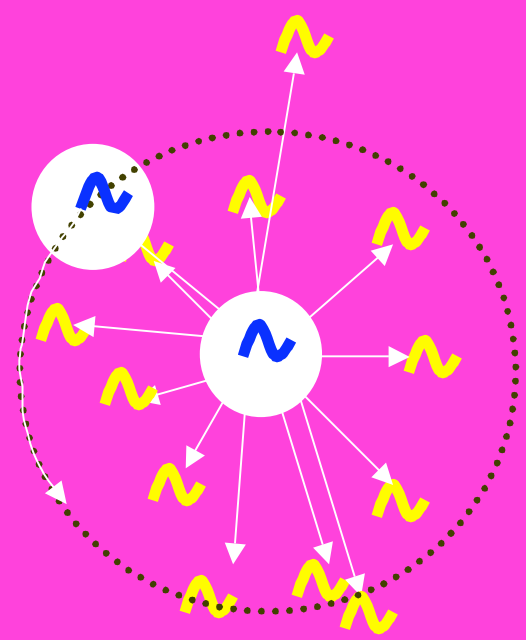
$$N_{i,j}(t) = N_i(t)B_{i,j} + N_j(t)B_{j,i}$$

$$N_{i,j}(\theta_{i,j}(t)) = \left[N_i(\theta_{i,j}(t))B_{i,j} + N_j(\theta_{i,j}(t))B_{j,i}\right]I_p(\theta_{i,j})$$

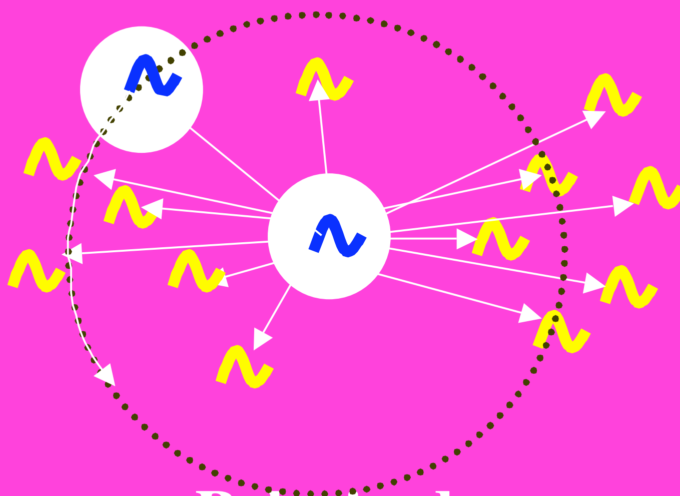
$$I_p(\theta) = \frac{1 + p\cos(2(\theta - \theta_p))}{1 + p}$$

$$N_{i,j}(\theta_{i,j}(t)) = \left[N_i(\theta_{i,j}(t)) + N_j(\theta_{i,j}(t))\right]B_{i,j}I_p(\theta_{i,j})$$

$$R(\theta) = \frac{N_{i,j}(\theta_{i,j})}{N_i(\theta_{i,j}) + N_j(\theta_{i,j})} = CI_p(\theta_{i,j})$$

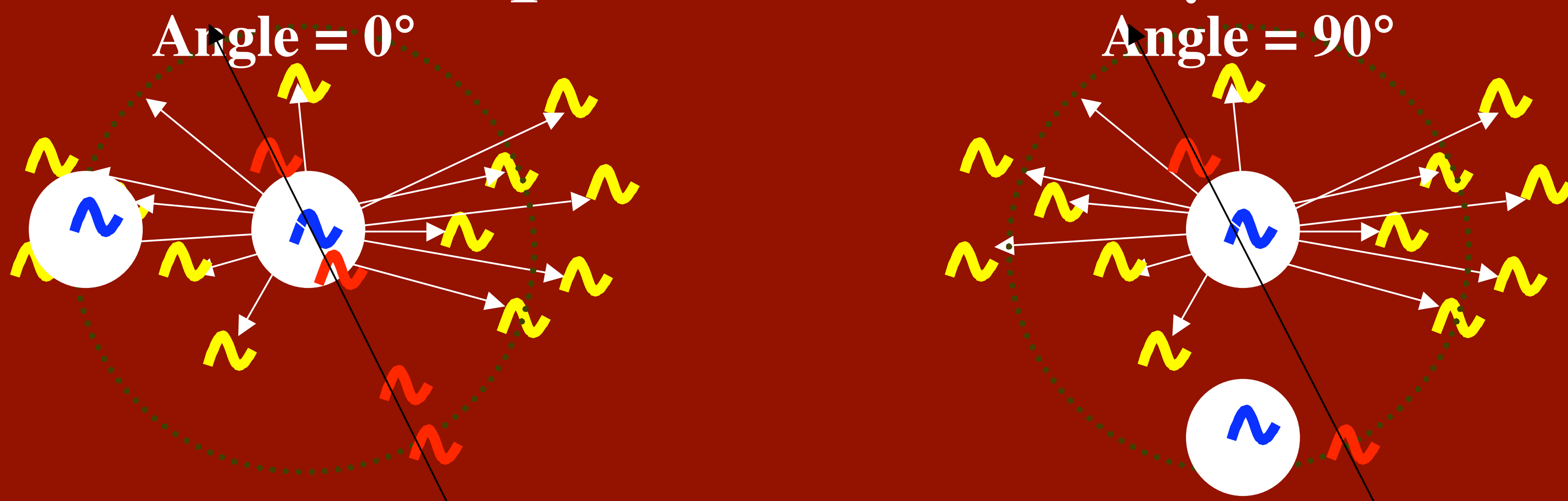


Unpolarized γs



Polarized γs

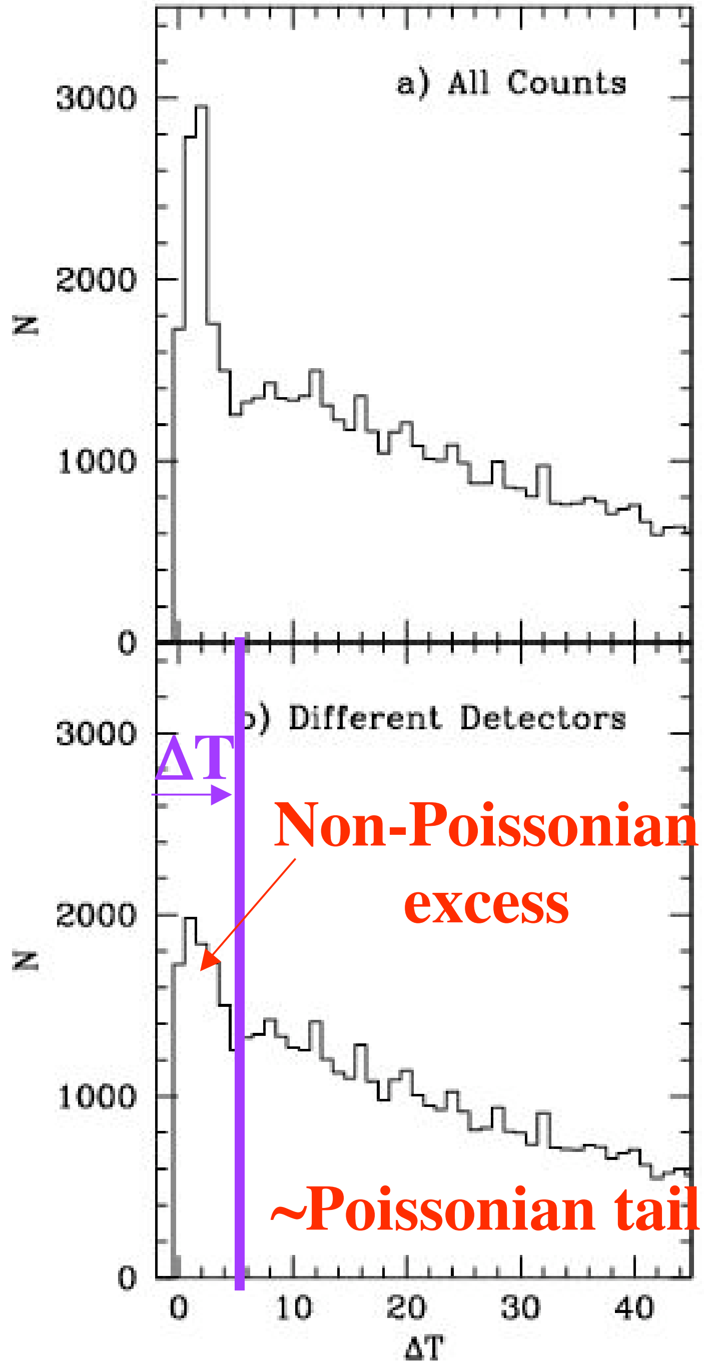
Example: **Polarized γs**



Singles	5000
Doubles	3000
D(0°)/S(0°)=0.60±0.03	

Singles	2000
Doubles	200
D(90°)/S(90°)=0.10±0.007	

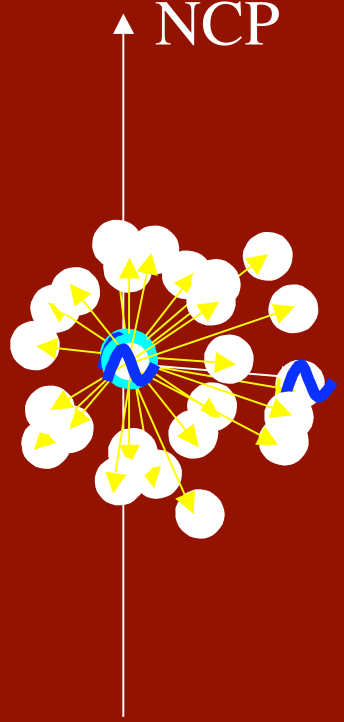
Limiting uncertainty in D(θ) / S(θ) is Poisson.

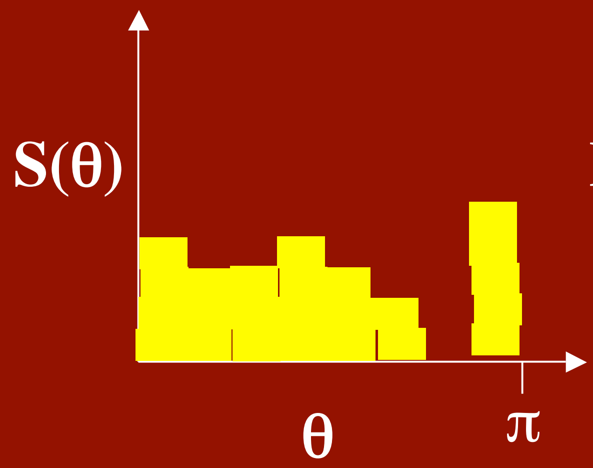


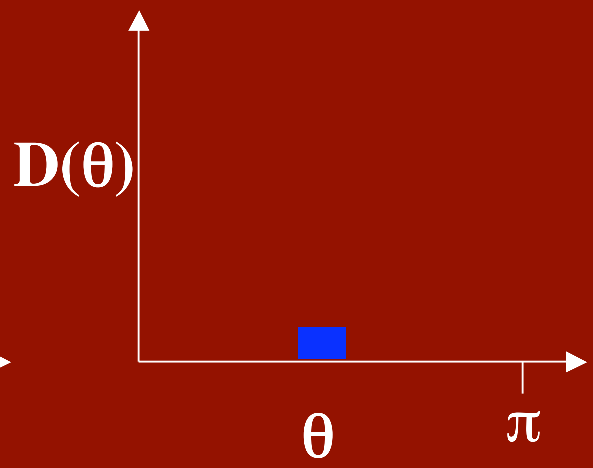
What is "Simultaneous"?

- ΔT -- separation of time-tags for temporally adjacent counts.
- Two counts detected in different detectors within ΔT=5 bμs we consider "simultaneous".
- We do not know what value of ΔT was used in CB03.

Doubles/Singles Ratio







$$R(\theta) = \frac{D(\theta)}{S(\theta)}$$

Non-Detection of Polarization Signal

Full Stop:

$$I_p(\theta) = C\frac{1 + p\cos(2(\theta - \theta_p))}{1 + p}$$

$$p = \mu\Pi\frac{Signal}{Signal + B}$$

- **If p is consistent with zero, then the intrinsic polarization Π cannot be determined -- regardless of the value of μ, Signal or B.**

- **Conclusion: Polarization cannot be detected with the RHESSI data of GRB021206**

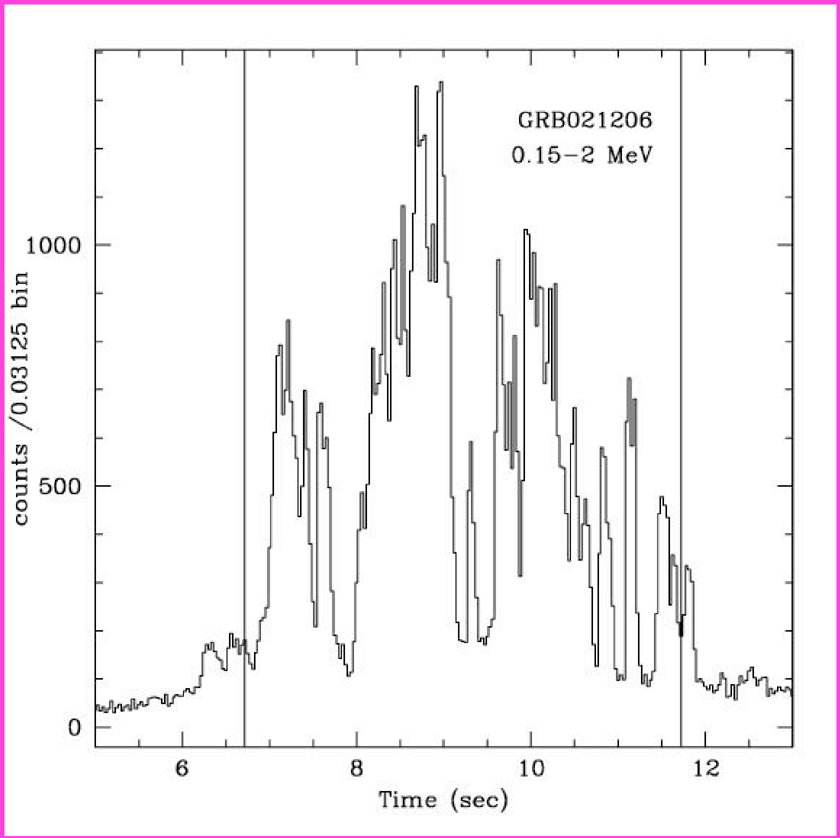
- Both S(θ) and D(θ) are inconsistent with being constant.
- R(θ) is consistent with constant.
- $p \leq 0.041$ (90% confidence).

Producing an Upper-Limit on Π

- Boggs and Coburn (2004) pointed out this result implies intrinsic polarization Π <100%. We agree.
- Boggs and Coburn (2004) state this is consistent with their measurement (**Π=80± 20 %), and that our approach is less sensitive. We disagree.**
- Our limit on p implies that polarization cannot be detected with the RHESSI data of GRB021206

Counting Counts: Coincidences

We divided the lightcurve into δt= 5ms long, containing discrete ΔT=5 bμs bins and a total N_i counts. Setting μ_i= N_i ΔT/δt, we calculate the number of 5 bμs bins which contain *n* counts due to coincidence:



$$N_n = \sum_i \frac{\mu_i^{n-1}}{(n-1)!} e^{-\mu_i} (N_i - (n-1))$$

Counting Counts by Counting

Events	RR & Fox	CB03
+Total Double-count events	8230	14916
- Coincidences	6640±80	4488±72
- Other Backgrounds	760 ±110	588±25
=Double-count Scattering Events	830 ±150	9840±96

Why are these so different? What data selections did CB03 use?

Counting Counts 2: Modeling

- The relative number of double-count scattering events due to scattering in detector X will be proportional to the total solid angle subtended by all other detectors, as viewed from detector X.
- Also, it will be proportional to the relative sensitivity of detector X.
- Double-Count coincidence events will be proportional to the relative sensivities, but not to the solid angle subtended by all other detectors.
- Result: of our 8240 counts, a fraction f=11±3% are due to scattering (910± 250 double-counts) consistent with our value of 830± 150 from counting; inconsistent with 9840± 96 from CB03.

Counting Counts: Bunches

- Bunch: A group of >2 counts which arrive in < ΔT. **Which are first two counts is ambiguous (3 angles for 3 counts, n(n-1)/2 angles for n counts!**
- **Bunches are a Background**
  - Estimate: $N_{>2}$=159± 2 in GRB021206.
  - Observed: $N_{>2,obs.}$=481, excess of 322±22
  - These are not due to scattering: $N_2=fN_1$, $N_3=fN_2$, $N_4=fN_3(=f^3N_1)$.
  - r = $N_2/N_{>2}$=44 ±2 is predicted from f= N_2/N_1,but r = 5.9 ±0.5 is observed --> a factor of 7.8 ±0.8 too many $N_{>2}$ events to be caused by scattering.
- During a 24 s background period, same procedure predicts $N_{>2}$=0.2 events; while 1013 were observed.
- **Bunches are:**
  - **not associated exclusively with the GRB;**
  - **not due to scattering;**
  - **highly non-Poissonian**

Limit on **Intrinsic Polarization** (Π) of GRB021206

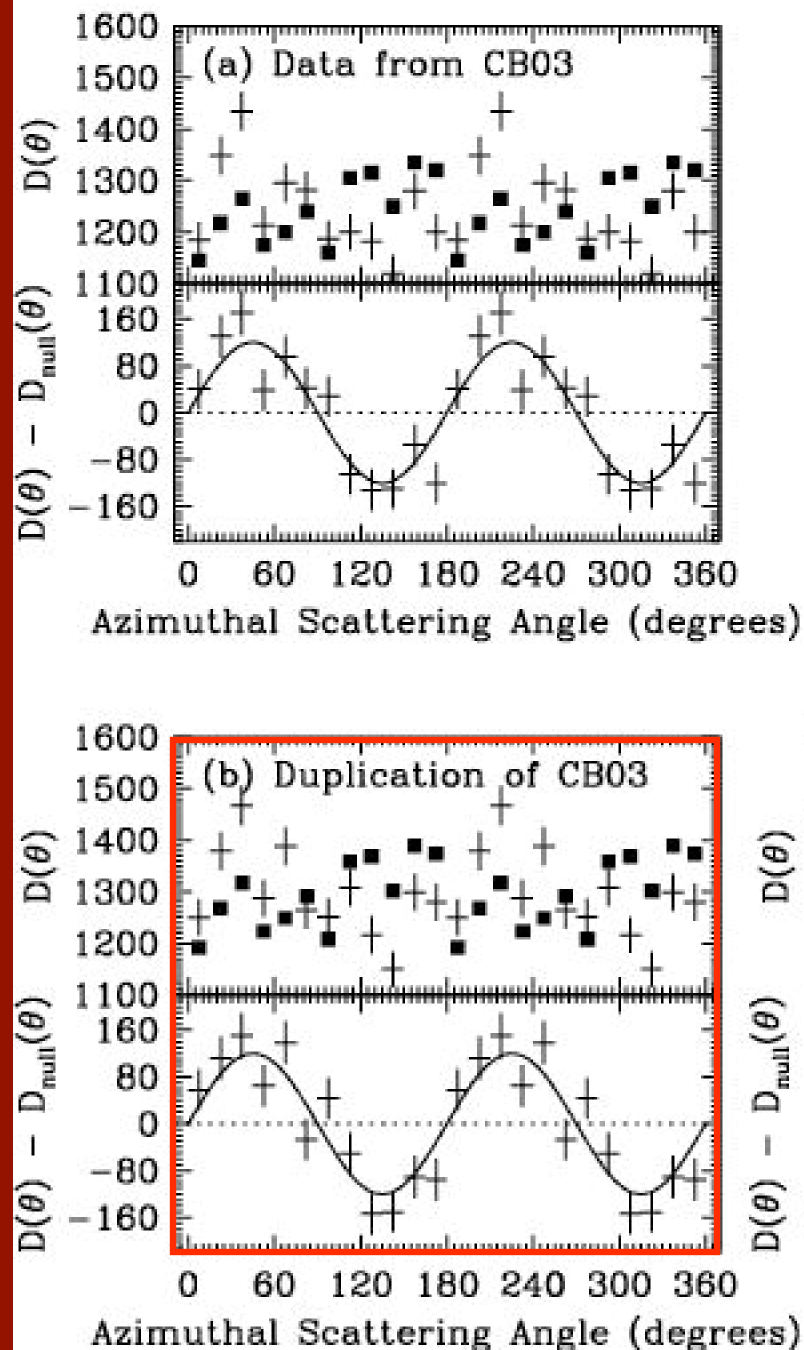
$$p = \mu \Pi \frac{Signal}{Signal + B}$$

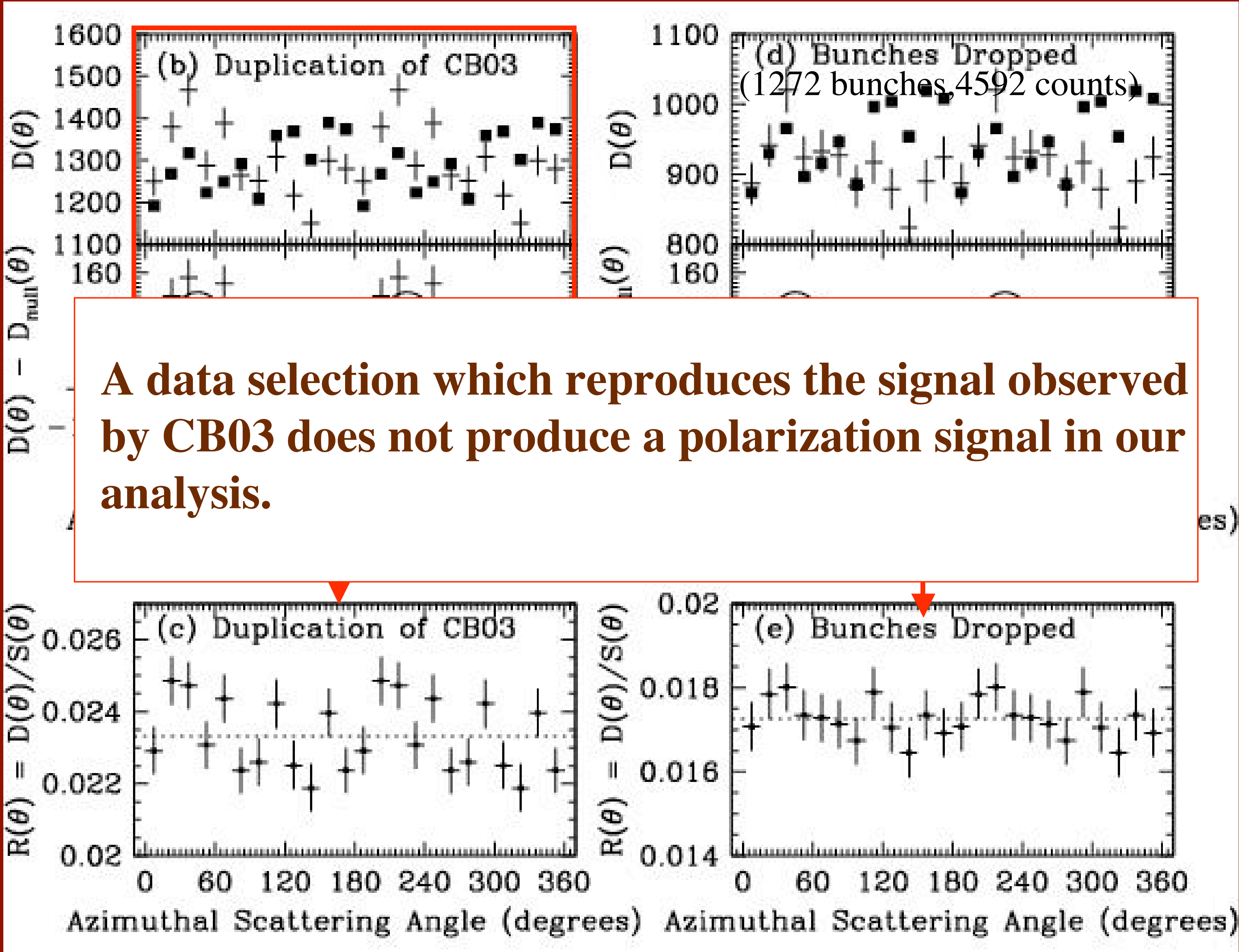
	μ	Signal	Signal+B	Π
Our Result	0.19± 0.04 (CB03)	830± 150	8240	<210%
Using CB03 values (f=0.66)	0.19± 0.04	f * 8240	8240	<32%

- If we had agreed with CB03 on the same fraction of doubles being due to scattering, then our limit on Π **would be below their claimed detection (<32% vs. 80± 20%) .**

Duplication of CB03 Analysis

- **Choosing three data selections: ΔT=8 bμs, include "bunches" (N>2), choose a θ=0, we do a fair job of duplicating the CB03 double-event lightcurve, finding 15540 counts (vs. 14916 by CB03).**





A data selection which reproduces the signal observed by CB03 does not produce a polarization signal in our analysis.

Conclusions

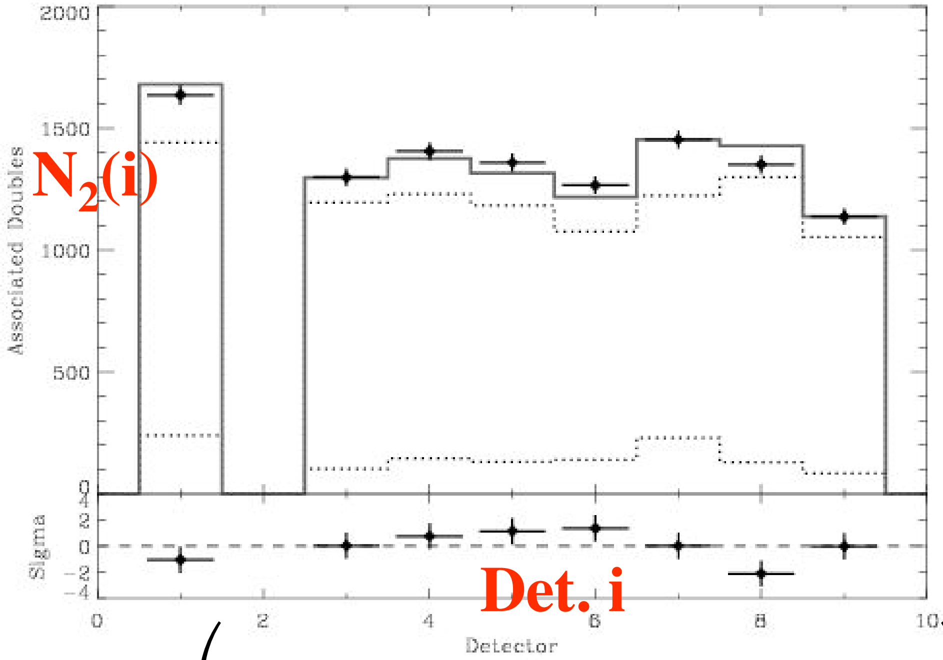
- **We developed a polarization detection analysis which does not rely on GEANT simulations.**
- **We do not detect polarization in the RHESSI data of GRB021206.**
- **Intrinsic Polarizaion of GRB021206 is <210%. Polarization is not detected because the RHESSI S/N is too low.**
- **Our analysis method cannot be improved on since we are at the Poisson limit (increase S/N by >10).**
- **We duplicate the data selection of CB03. The signal claimed as polarization is not polarization. We suggest it is due to inclusion of "bunches" (pure background) and systematic uncertainty in their D_{null} (θ).**

Questions for Coburn & Boggs

- How do you demonstrate that the systematic uncertainty in D_{null} is < 3%?
- What were your data selections? Specifically:
  - What ΔT **did you use?**
  - **Did you exclude bunches, which are obviously a background, and not scattering in the detector?**
  - **Why are these different from the ones we use?**
- **How do you explain that our duplication of your data selection shows no evidence of polarization in our analysis?**

Counting Counts 2

Det.	Ω_i	I_i (counts)
1	3.73	9870
2	n/a	n/a
3	1.90	8191
4	2.68	8426
5	2.52	8114
6	2.94	7379
7	4.23	8377
8	2.24	8903
9	1.80	7216



$$N_2(i) = N_{2,tot}\left(\frac{I_i\Omega_i}{\sum_j I_j\Omega_j} f + \frac{I_i}{\sum_j I_j}(1-f)\right)$$

2 Parts: fraction f of doubles which are proportional to the apparent solid angle and sensitivity, fraction 1-f which is proportional to sensitivity only.

f=11± 3% (non-zero)