Indirect Dark Matter Search with Antideuterons: Progress and Future Prospects for General Antiparticle Spectrometer (GAPS)

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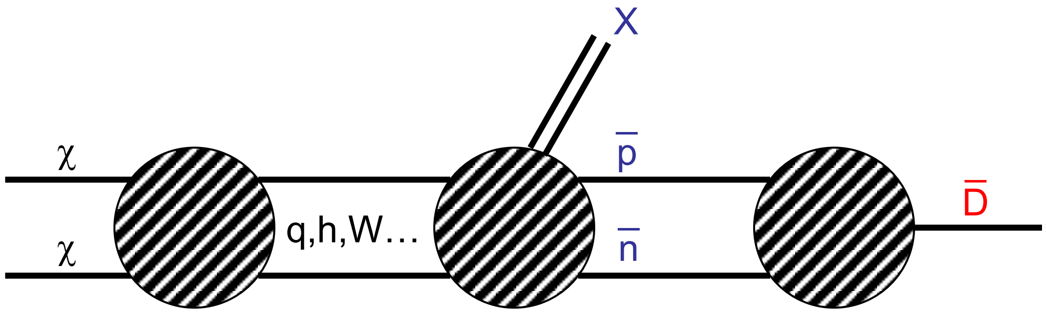
How Does Cold Dark Matter Generate Antideuterons?

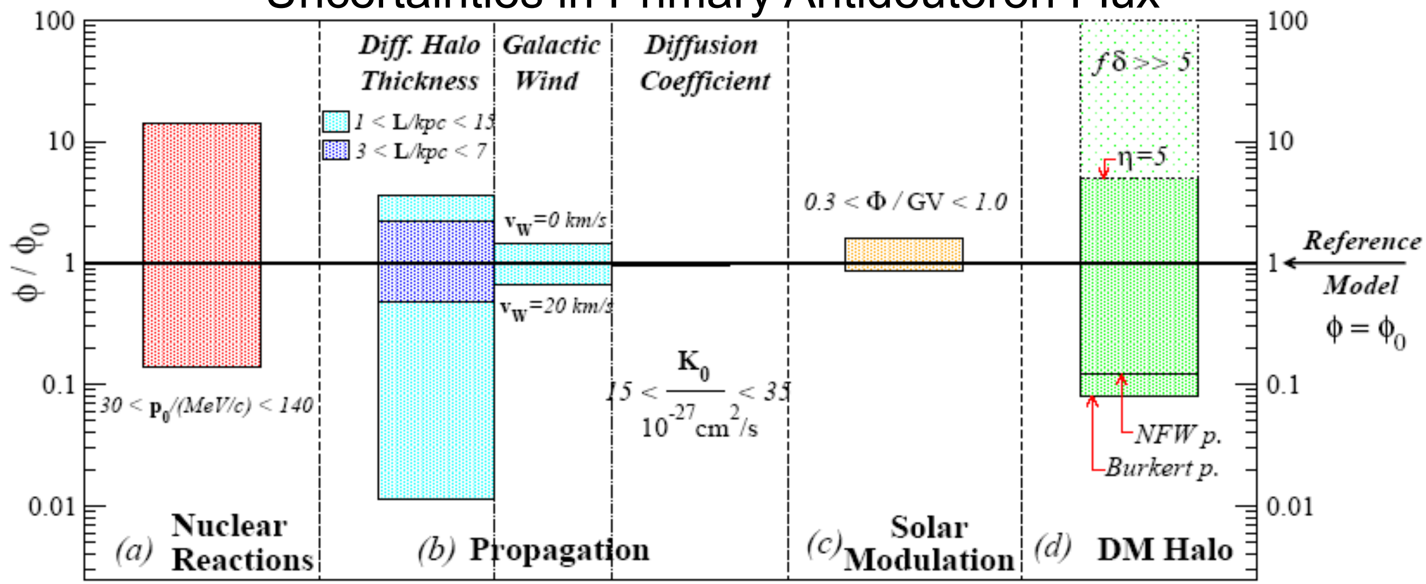
- Pair annihilating WIMPS produce:

  γ, ν, e^+… $\bar{p}$…

- Donato et al. (2000) suggest antideuteron signal



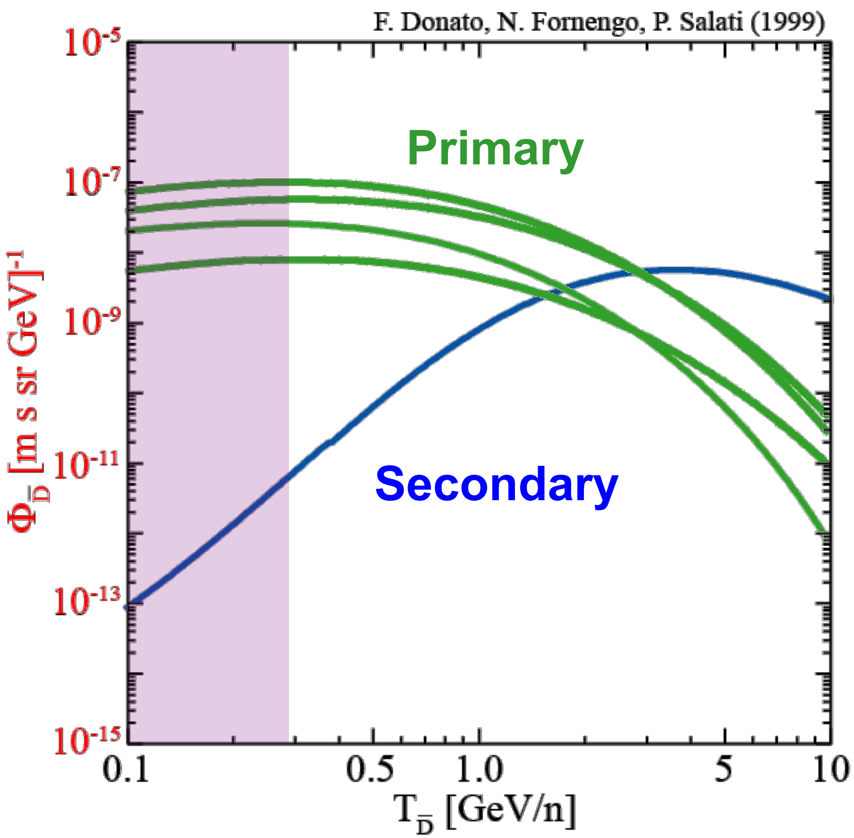
Uncertainties in Primary Antideuteron Flux



Baer & Profumo 2005

Low energy, neutralino-neutralino produced antideuterons are near background free

Antideuteron flux at the earth (with propagation and solar modulation)



- Primary component:
  → neutralino annihilation

  $X+X \rightarrow \bar{D}$

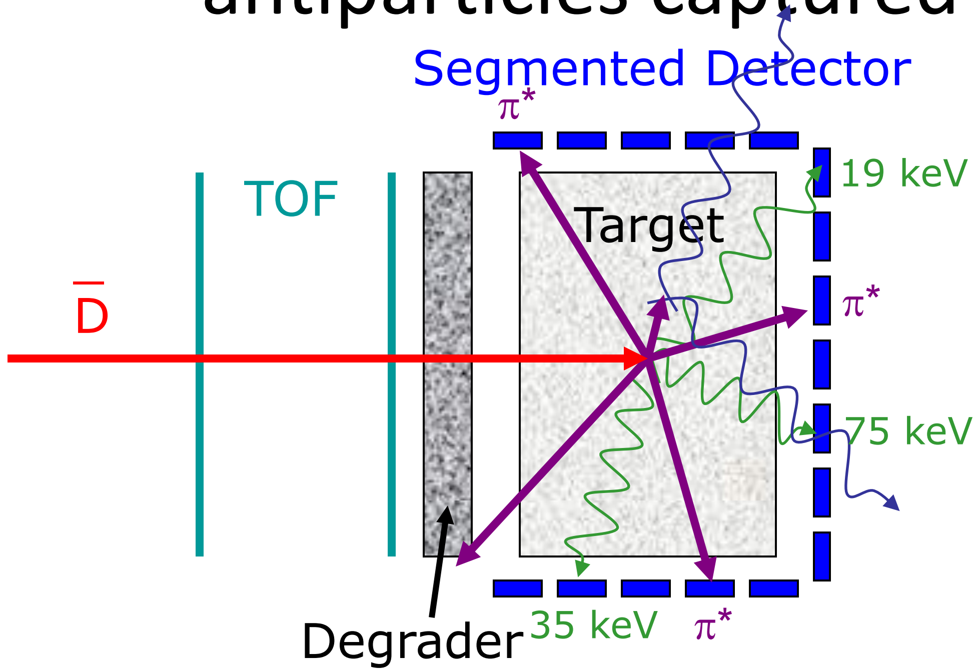
- Secondary component:
  → spallation

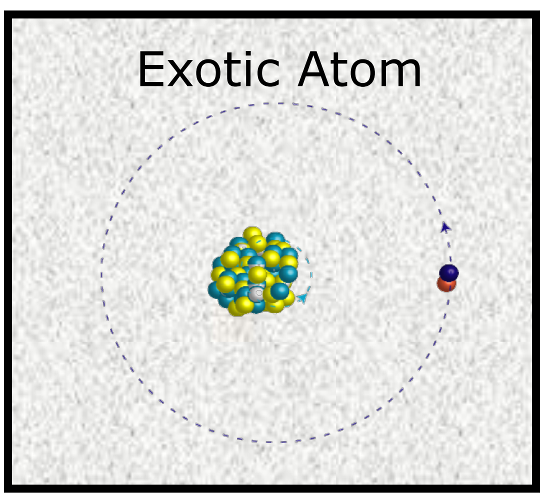
  $p+H \rightarrow p+H+D+\bar{D}$

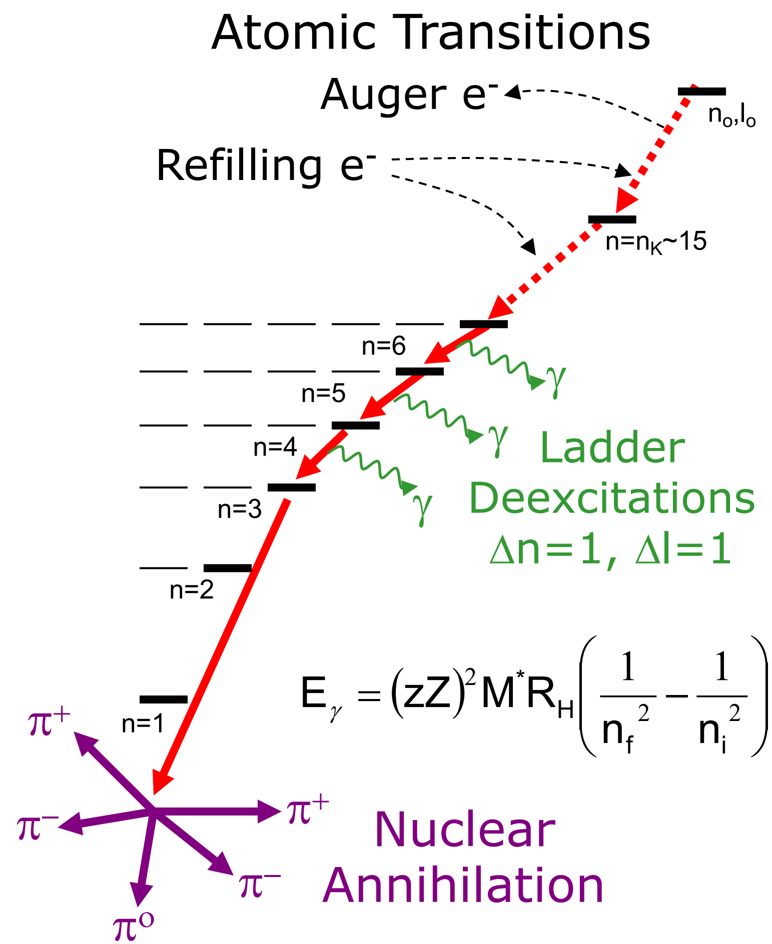
  $p+He \rightarrow p+He+D+\bar{D}$

- Clean signature @ low E, but see Baret et al. 2003
- However, sensitivity demand is daunting

GAPS is based on radiative emission of antiparticles captured into exotic atoms







$$E_{\gamma} = (zZ)^2 M^* R_H \left(\frac{1}{n_f^{\,2}} - \frac{1}{n_i^{\,2}} \right)$$

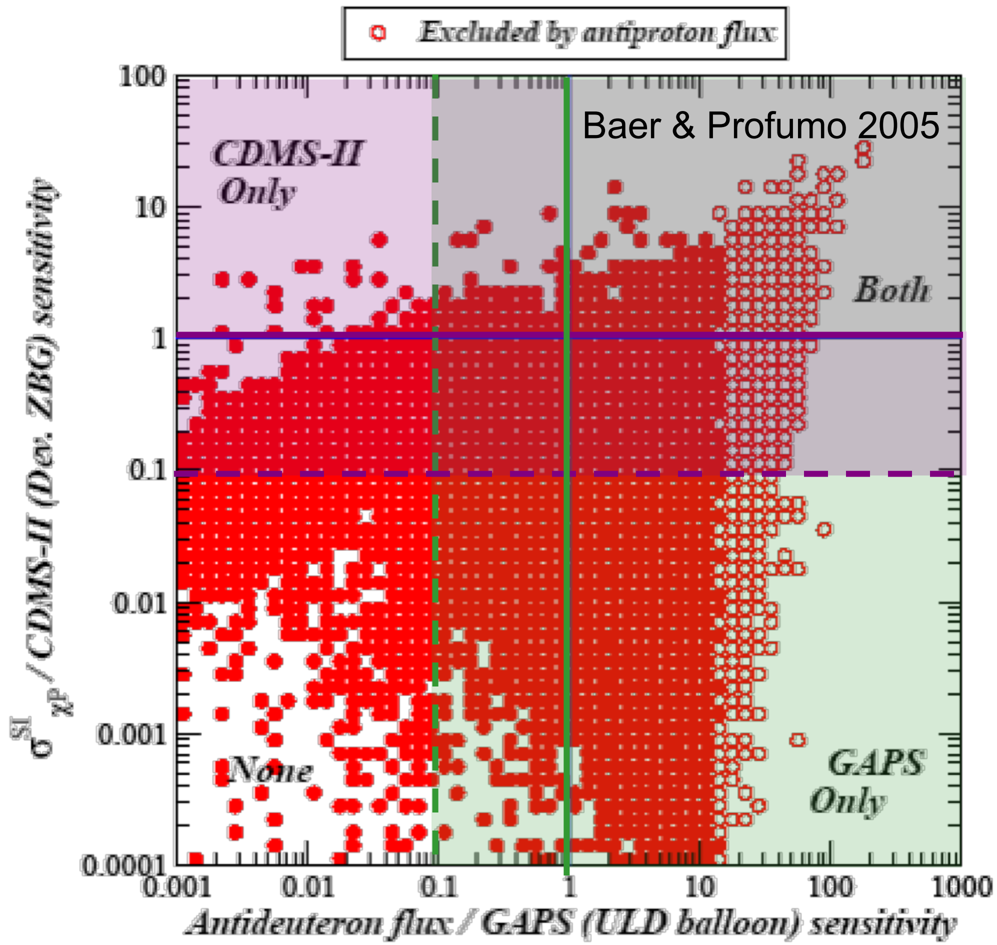
Anti-protonic atoms (in addition to Muonic, Pionic, Kaonic atoms) extensively studied and atomic transitions well understood.

Comparison of Direct & Indirect Antideuteron Detection Sensitivities for SUSY DM

There are ~20 current or planned direct detection experiments

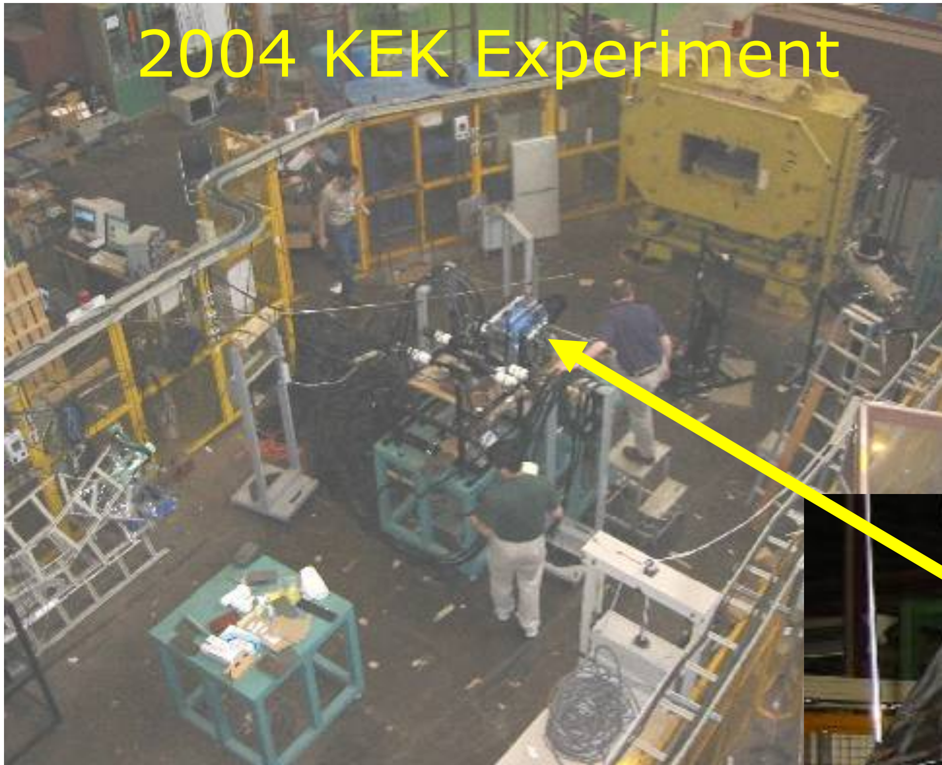
CDMS (Soudan) 2005 Si (7 keV threshold)
CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
CDMS Soudan 2004+2005 Ge/Si SD-neutron/proton
CDMSII (Projected) Development ZBG
SuperCDMS (Projected) Phase C
CDMSII (Soudan) projected
CUORICINO projected exclusion limit
COSME 2001 Exclusion Limit, 72.7 kg-days
CRESST-I projection limit, Al2O3
CRESST-II projected limit, CaWO4
CRESST I SD-neutron/proton
CRESST II SD-neutron/proton
DAMA 2000 58k kg-days NaI
DAMA 2003 NaI SD-neutron/proton
DAMA Xe129
DMRC projection for 100kg CsI, 1cpd
ELEGANT V NaI SI/SD limit, OTO COSMO Observatory
Edelweiss I final limit, 62 kg-days Ge 2000+2002+2003 limit
Edelweiss SD-neutron/proton
Edelweiss Ge, projected
GEDEON projection
Genius Test Facility projected limit, 2001, energy threshold 2 keV
Genino projected exclusion limit, DM2000
Heidelberg - Genius, projected
IGEX projected exclusion limit (for 1kgyr)
IGEX 2002 Nov limit
NAIAD 2005 final result SI/SD
PICASSO SD-neutron/proton (2005)
SIMPLE SD-neutron/proton
ZEPLIN I First Limit (2005)
NAIAD spin indep. projected limit, 12 p.e./keV with 100 kg-yrs exposure
XENON100 (100 kg) projected sensitivity
XENON10 (10 kg) projected sensitivity
XENON1T (1 tonne) projected sensitivity
ZEPLIN I SD-neutron/proton(preliminary)
ZEPLIN 2 projection
ZEPLIN 4/MAX projected (2004)
SuperK indirect SD-proton

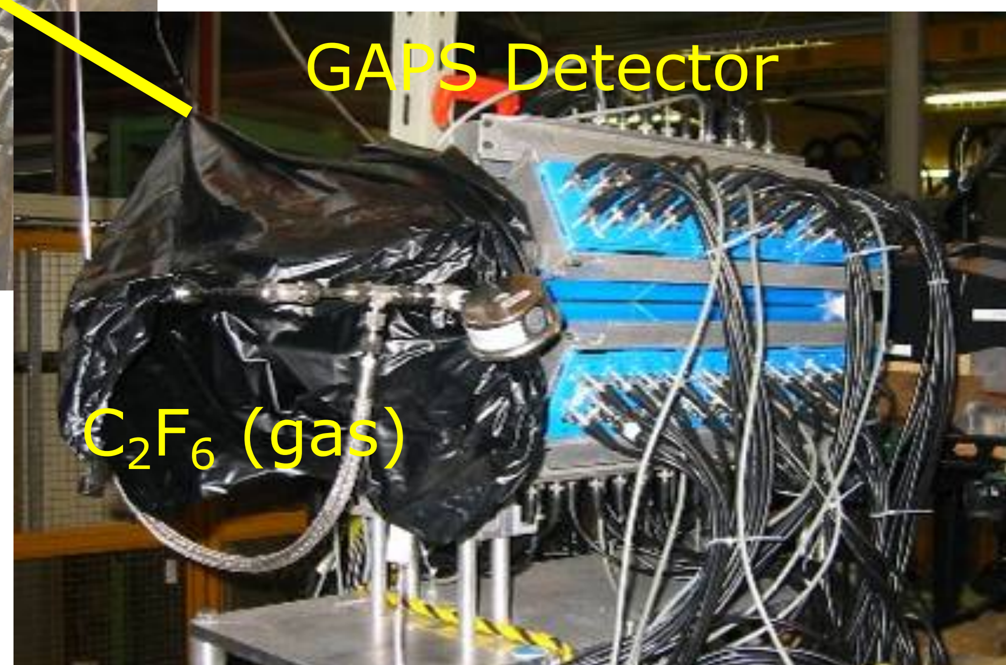
Indirect Antideuteron search offers a complementary method

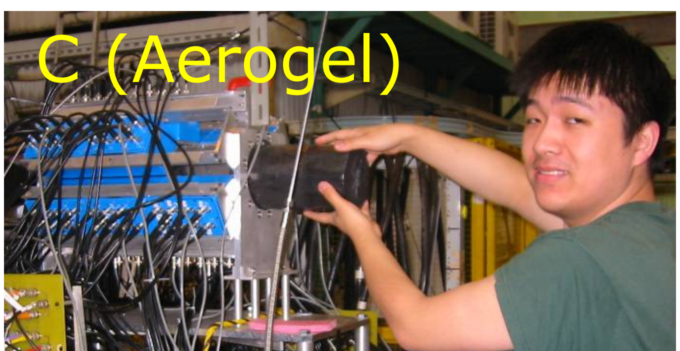


Detector approach was dictated by trade between performance and shoe string budget

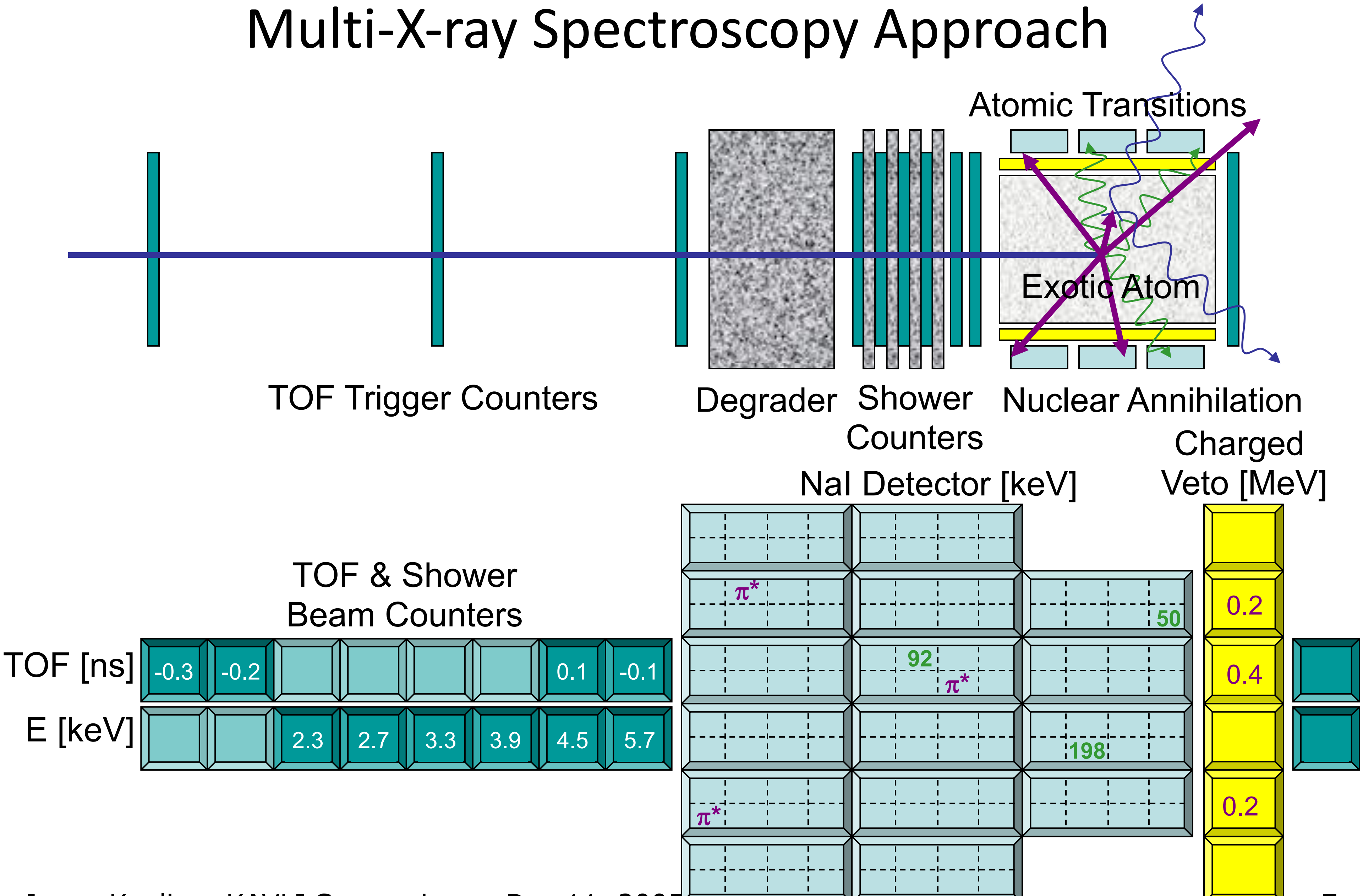
- 16 NaI(Tl) detector modules covering 40 cm long x 12 cm diameter target cell
- Each modular 4x2 arrays of 25mm diameter x of 5 mm thick crystals (128 total)
- Solid angle coverage ~ 0.3







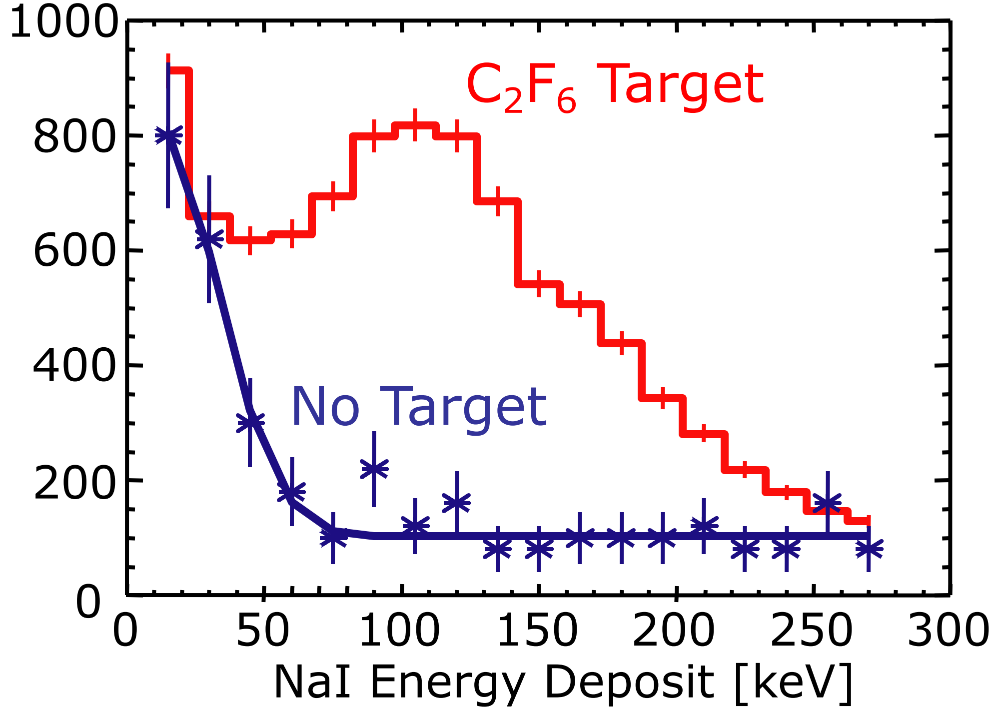
KEK Accelerator Tests to Demonstrate Fast-timing, Multi-X-ray Spectroscopy Approach

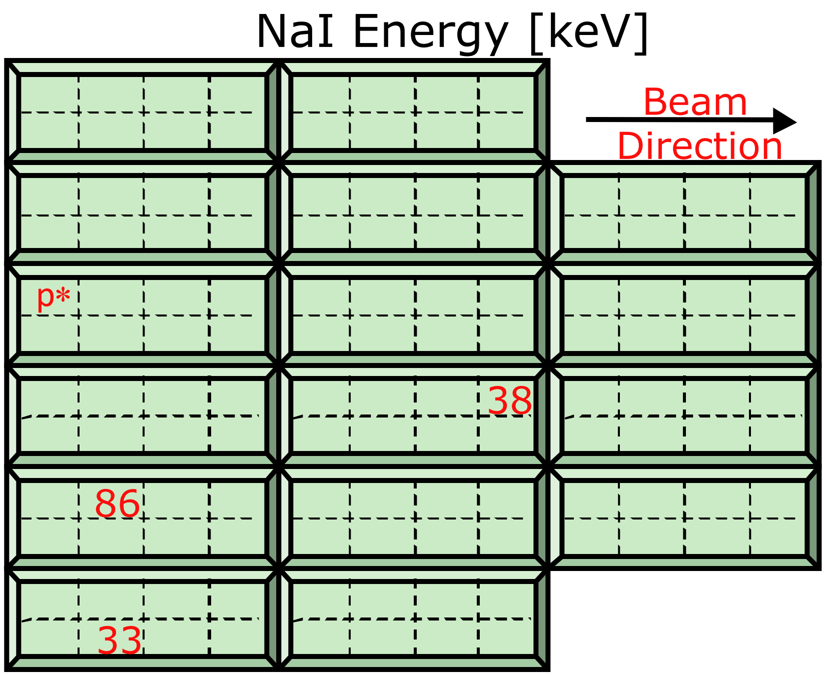


2004 KEK GAPS Results

We clearly get X-rays when we dump Antiprotons into our gas target

More importantly, we see X-ray transitions in events with multiple signatures!!!





3 X-ray + 1 π* Event

Hailey et al. 2005 (accepted by JCAP)

Solid and Liquid Targets Tested in 2005

Targets chosen based on known, high Kaonic yields

→ Goal to measure Antiprotonic atom yields

Al

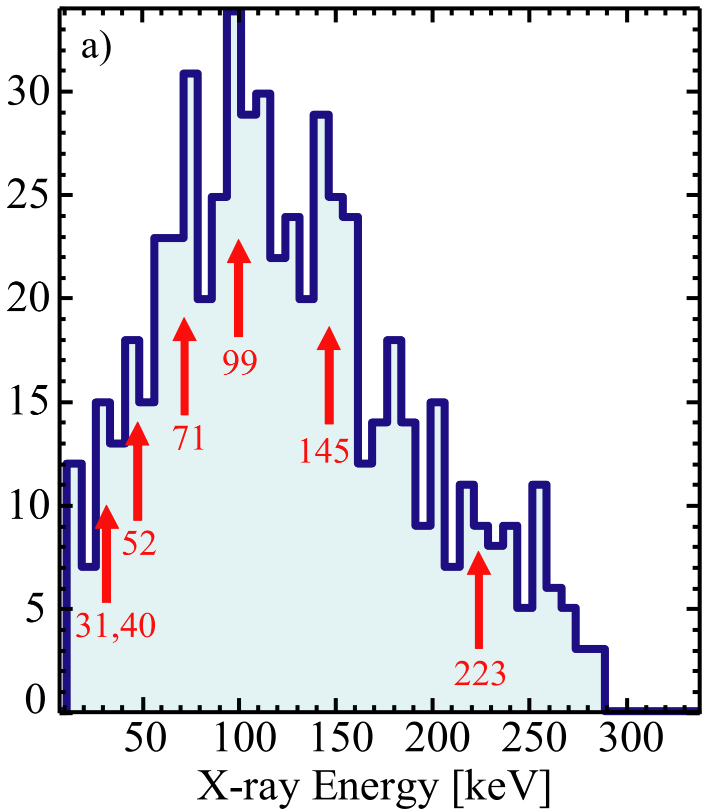
CCl_4

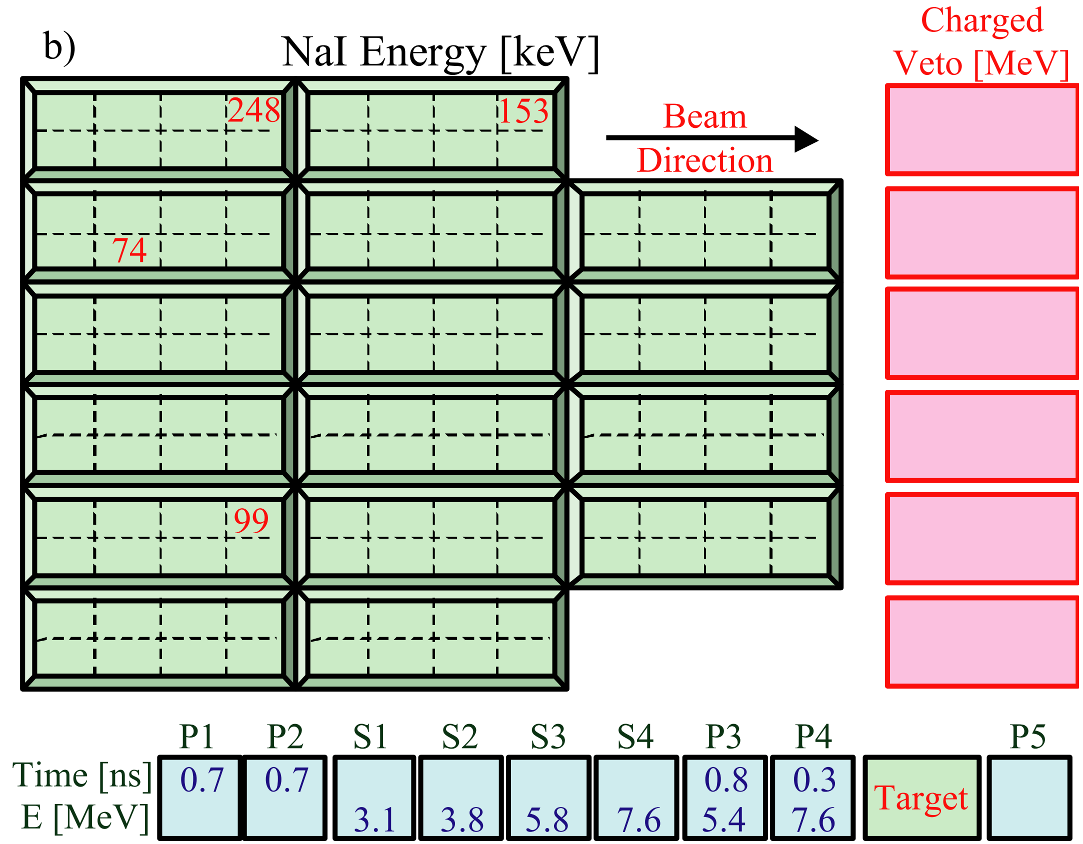
S

CBr_4
(liquid)

CBr$_4$ – KEK 2005

Multi-X-ray Spectrum   4 X-ray Transition Event



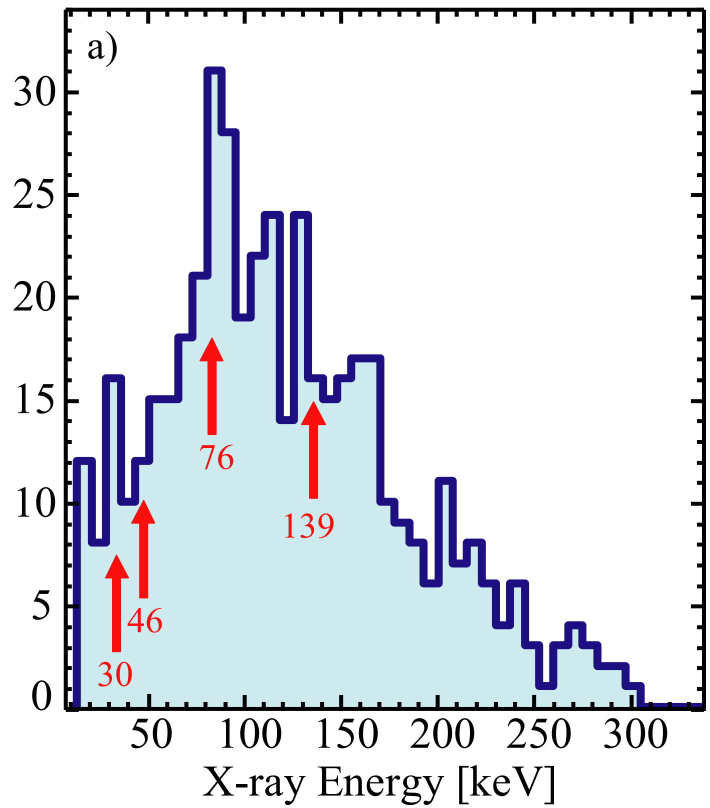


Cut: ≥ 2 X-ray & ≥ 4 total signals

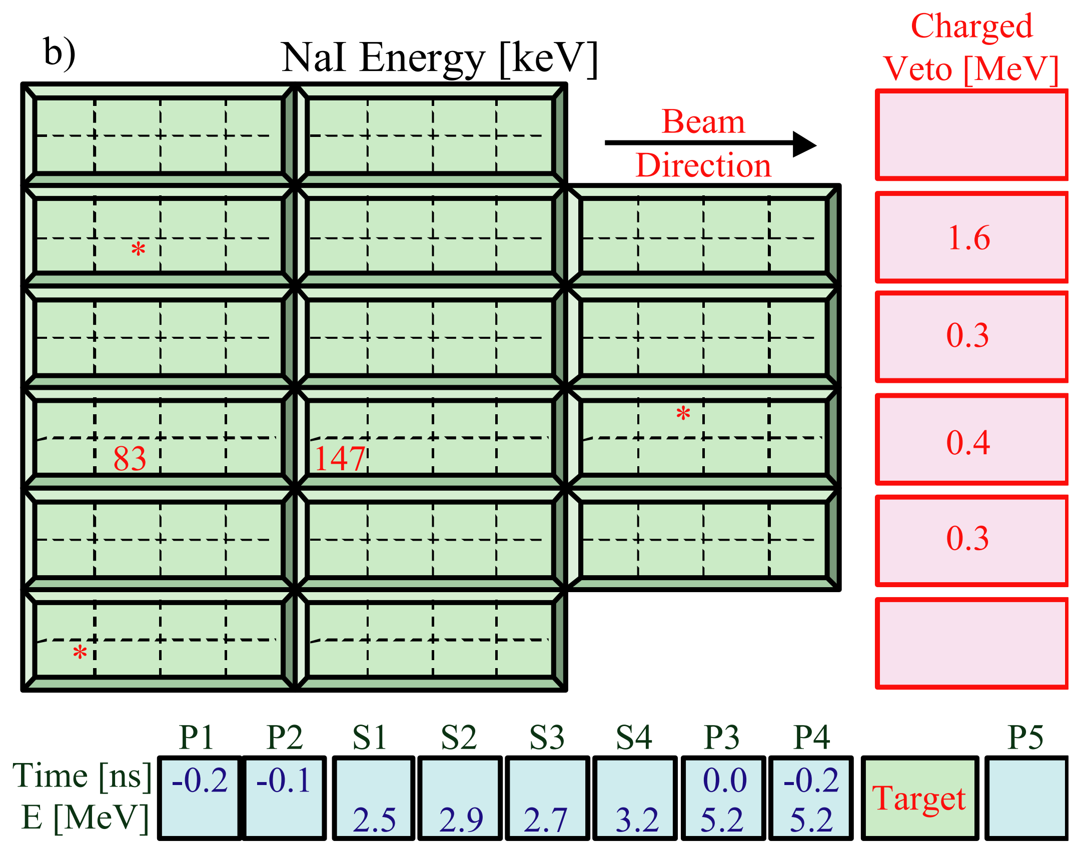
Hailey et al. 2005 (accepted by JCAP)

Sulfur – KEK 2005

Multi-X-ray Spectrum



2 X-ray + 3 π* Event



Cut: ≥ 2 X-ray & ≥ 4 total signals

Hailey et al. 2005 (accepted by JCAP)

Preliminary results from KEK experiments

- Solid targets have been successfully utilized: simplification over initial gas concept is enormous

Gaseous **A**ntiparticle **S**pectrometer

→ **G**eneral **A**ntiparticle **S**pectrometer

- Pion stars provide substantial additional antiparticle identification
- Preliminary results on X-ray yields per capture are consistent with those used in original sensitivity calculations
- Non-antiparticle background is cleanly identified and rejected

→ Conclusion: GAPS is probably more promising than originally anticipated

Goal is to conduct balloon-based GAPS antideuteron search by 2009-2010

- Investigate flight detectors (e.g., CZT, LaCl, NaI), readout geometries (PMT, APD, fiber-coupled scintillator bars) and low cost electronics. 2006-2007
- Detailed design and simulation of flight geometry, extending on original work. 2006-2007
- Design and construction of gondola and first flight module. 2007-2008
- Flight test of prototype GAPS – possibly from Sanriku in Iwate, Japan. 2008 (T Yoshida & H Fuke have recently joined GAPS collaboration)
- LDB flight from Antarctica or ULDB flight from Australia (if available). 2009-2010