Analysis of Inelastic Scattering Events for the XENON100 Dark Matter Search

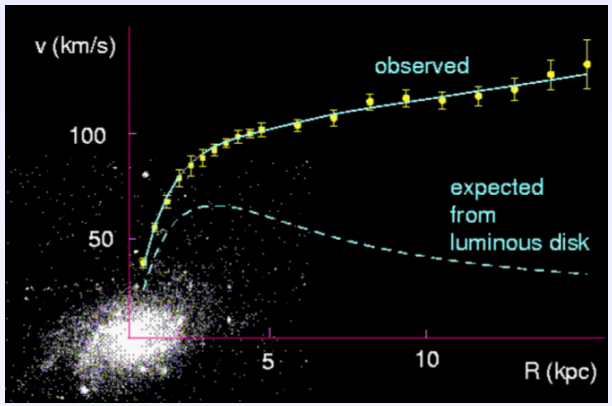
Gaudenz Kessler

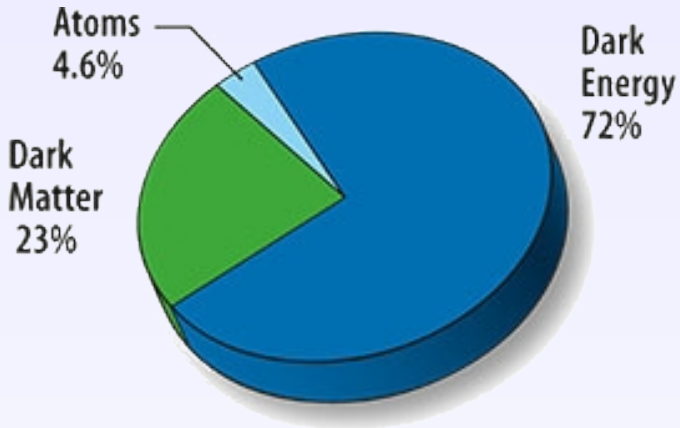
Universität Zürich[UZH]

Zurich PhD seminar 2012
August 28, 2012

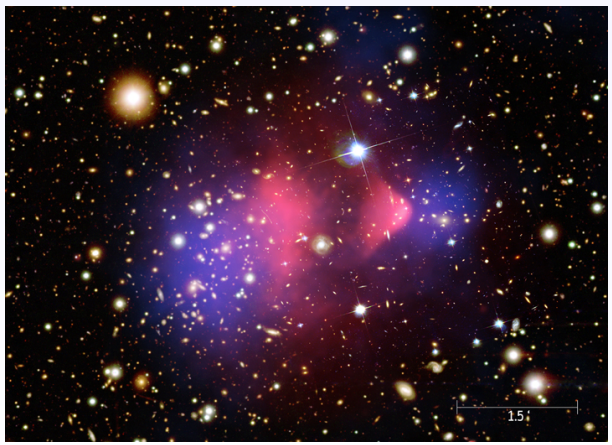
Evidence of Dark Matter

Rotation curves of galaxies





Gravitational lensing

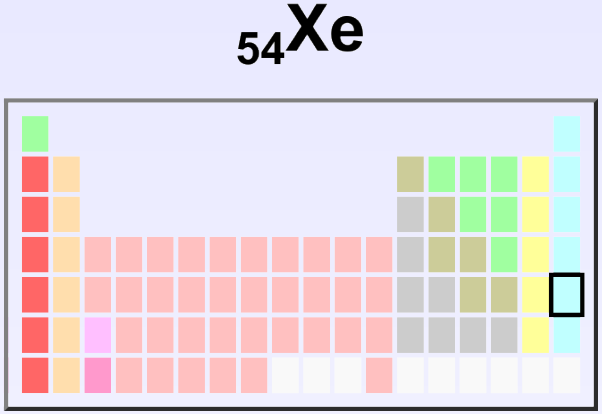


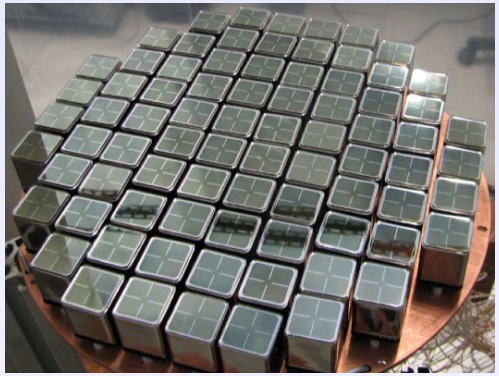
$\rightarrow$ theoretical approach:

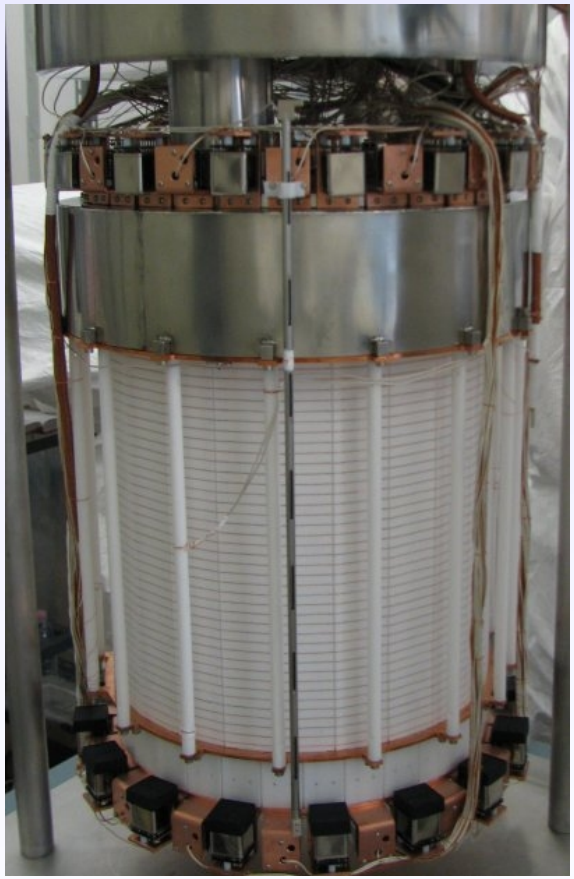
WIMP

(**W**eakly **I**nteracting **M**assive **P**article)

XENON100 – The Detector



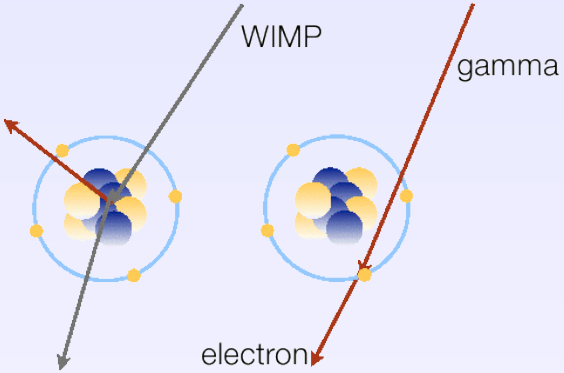




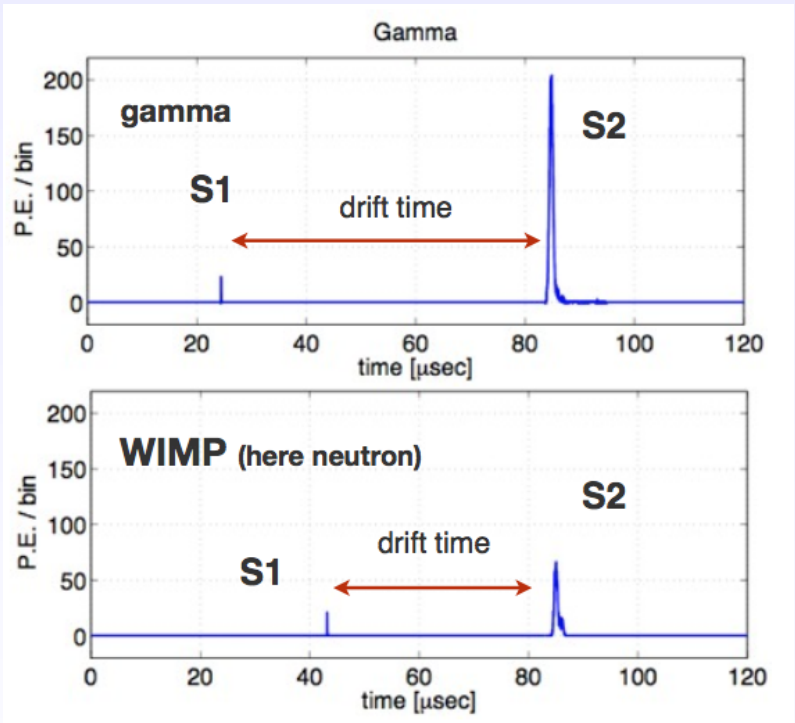
- Located in the Gran Sasso Underground Laboratory
- Time Projection Chamber with
  - total 161 kg liquid Xe
    - 62 kg inside
    - 99 kg as veto around the TPC
  - 242 PMTs

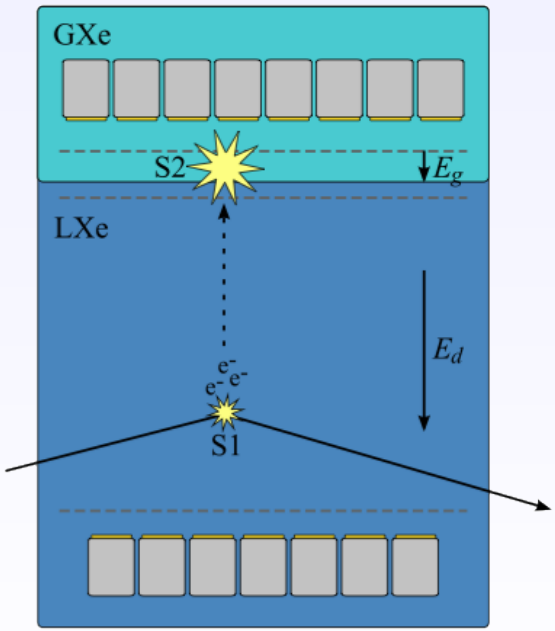
Instrument Paper: E. Aprile et al. (XENON100), Astropart. Phys. **35**, 573 (2012)

Direct Detection of Dark Matter



- Scintillation signal (S1)
- Charges drift to liquid-gas surface ($\rightarrow$ S2)



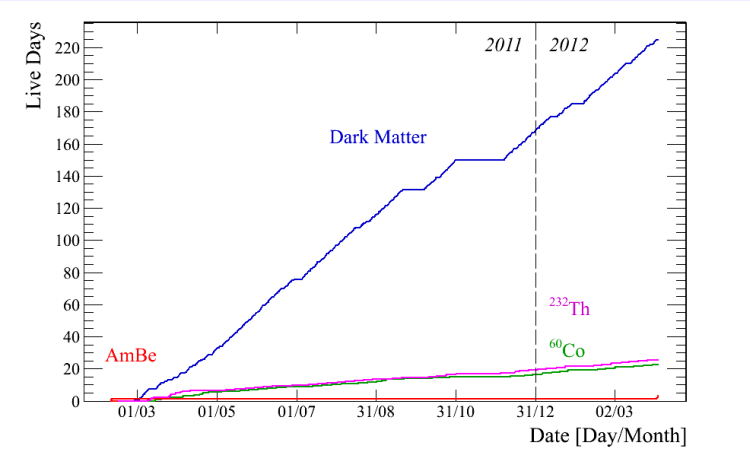


- $\left(\frac{S2}{S1}\right)_{WIMP} < \left(\frac{S2}{S1}\right)_{\gamma}$ – recombination stronger for NR

Instrument Paper: E. Aprile et al. (XENON100), Astropart. Phys. **35**, 573 (2012)

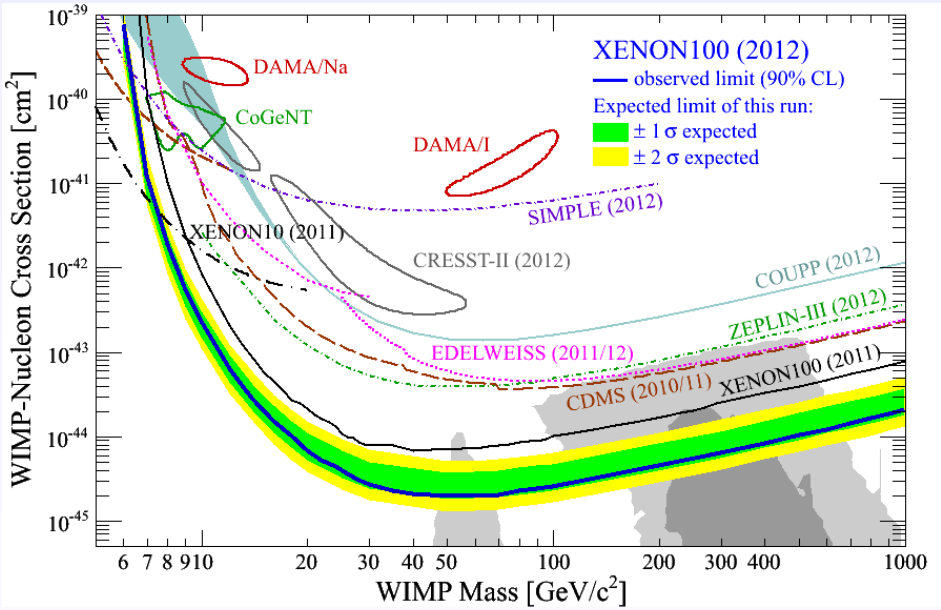
Results of 225 Live Days Dark Matter Run

$$\chi + N \rightarrow \chi + N$$



- Data taking over 13 months
- 224.56 live days of DM data
- Nuclear recoil calibration with neutrons (AmBe source)
- Calibration of electronic recoil with ^{60}Co and ^{232}Th

- Elastic spin-independent results submitted:

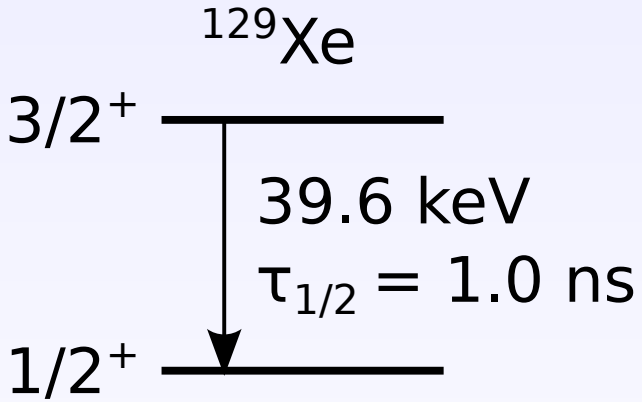


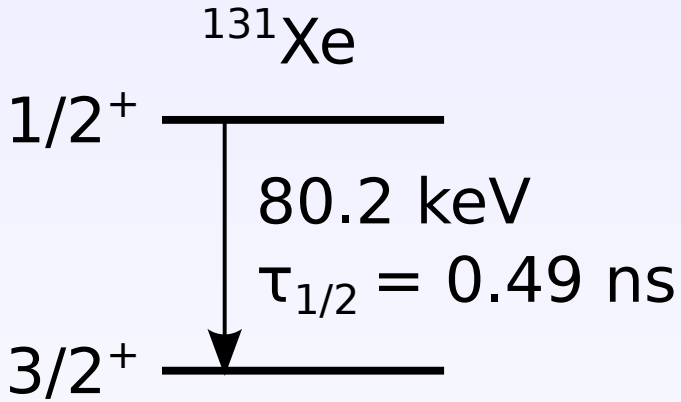
E. Aprile et al. (XENON100 Collaboration), arXiv:1207.5988v1 (2012)

- Elastic spin-dependent analysis ongoing

Inelastic Spin-dependent WIMP Interaction

$$\chi + N \rightarrow \chi + N^*$$
$$N^* \rightarrow N + \gamma$$





Abundance in natural xenon:

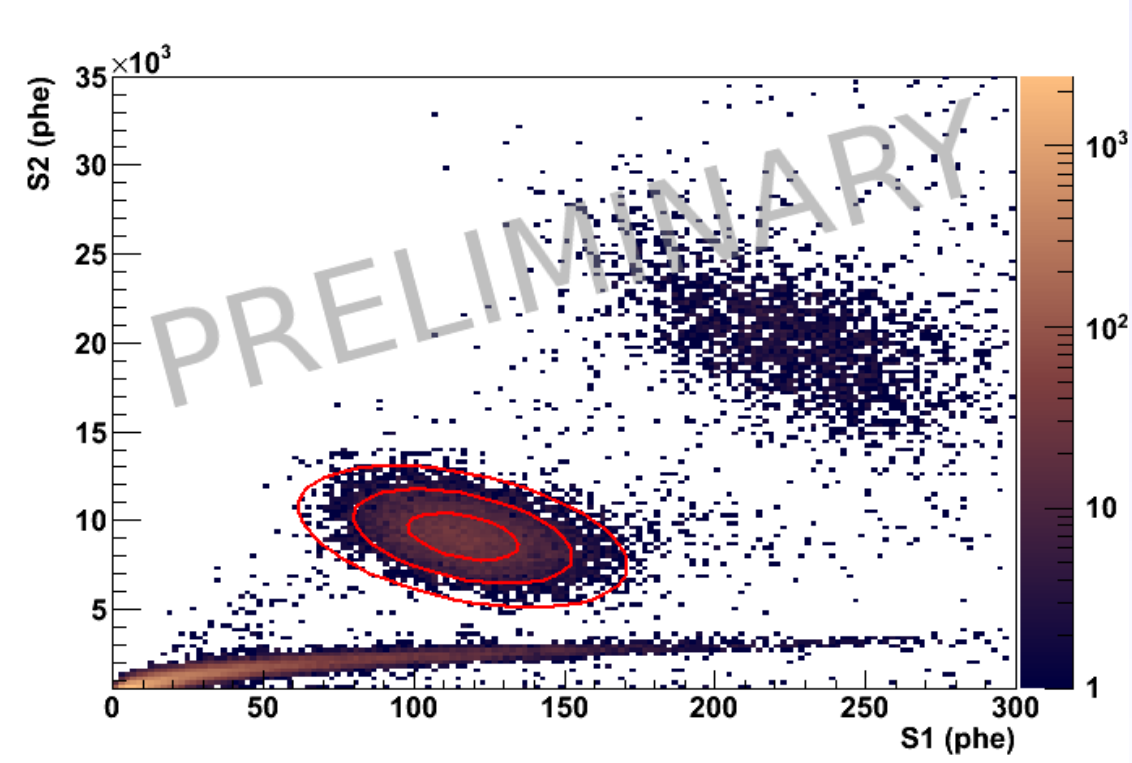
26.4 % 21.2 %

Lifetime of the excited state is too short to see a coincident nuclear recoil and a gamma

Inelastic Scattering Events of Neutron Calibration Data

Signature: nuclear recoil with a gamma at the same time and the same position

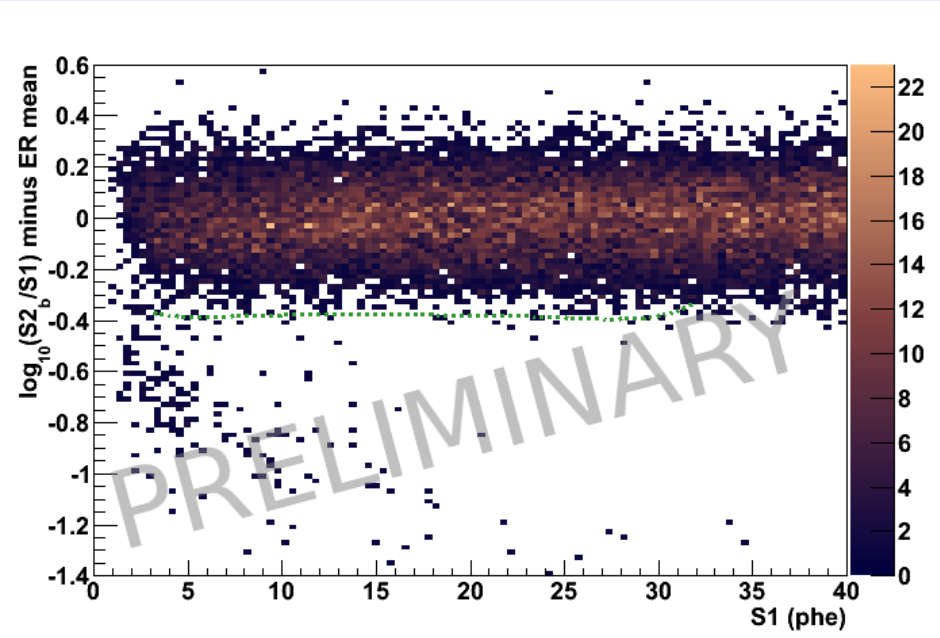
$\rightarrow$ we are looking for events with 40 keV additional energy to an elastic nuclear recoil



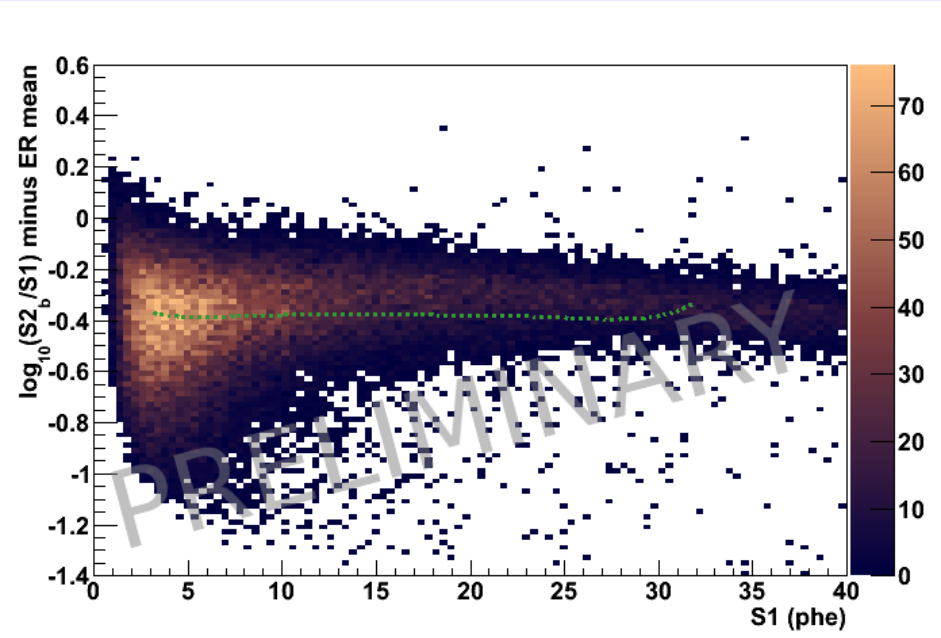
The signal region can be identified with a two dimensional Gaussian

Standard Analysis Region in XENON100

Electronic recoil events (calibration):



Nuclear recoil events (neutrons):

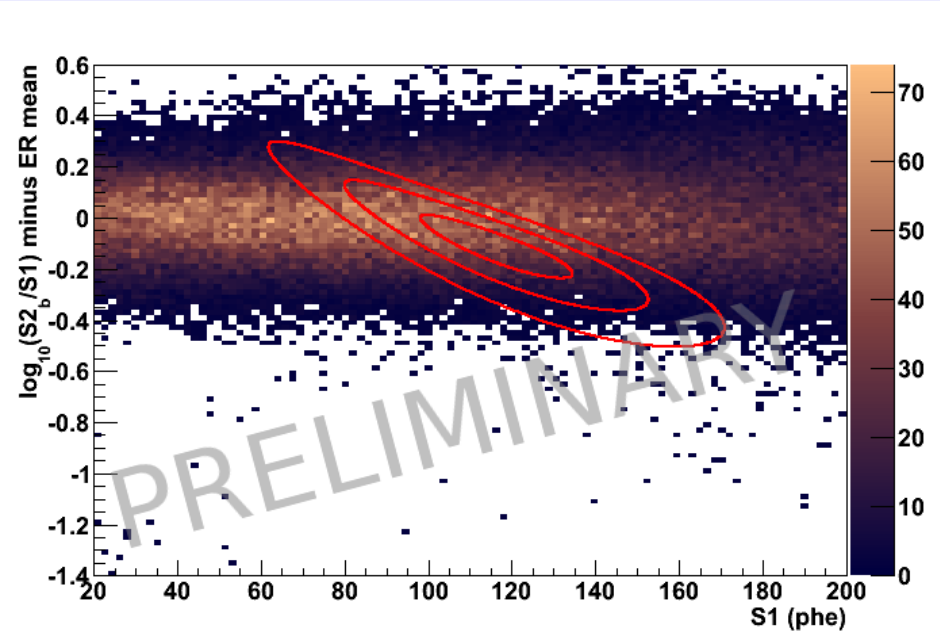


Fiducial volume: 40 kg

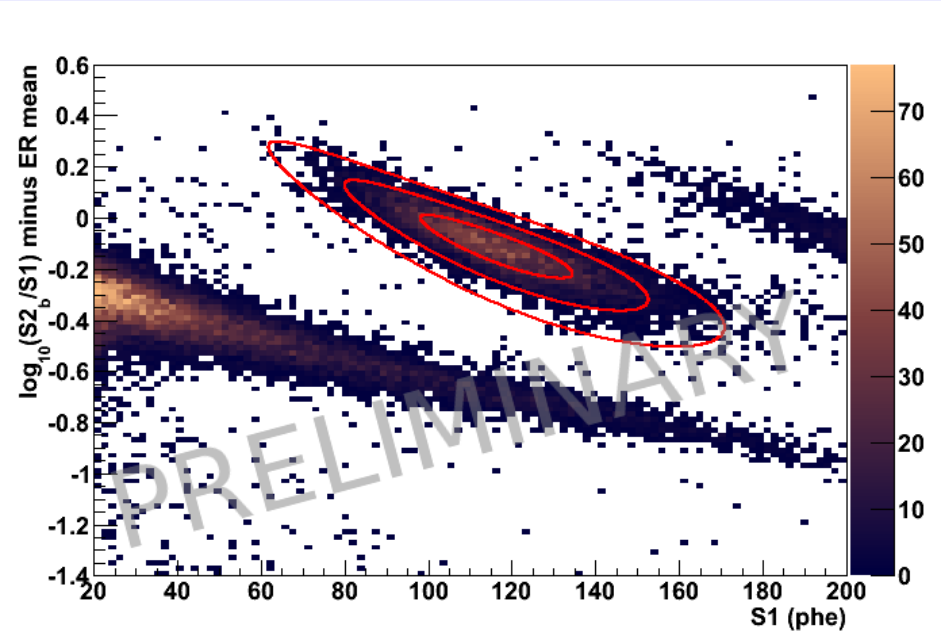
The background discrimination can be performed with a 99.75 % rejection line of the electronic recoil events

Events in High Energy Region

Electronic recoil events (calibration):



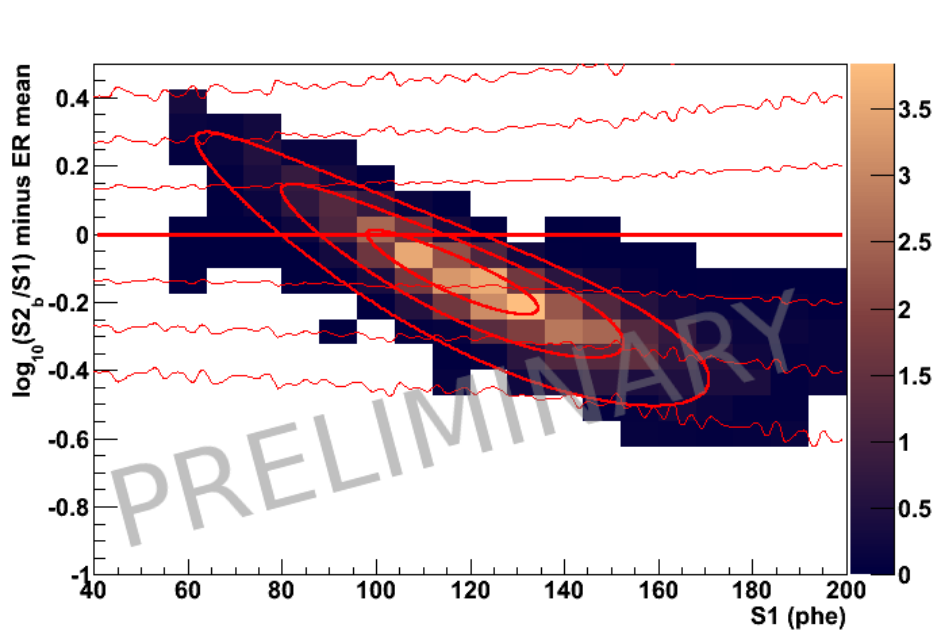
Nuclear recoil events (neutrons):



But the inelastic events are “covered” by the electronic recoil background

Standard Analysis

Signal to background ratio in arbitrary units from calibration sources:



Approach:

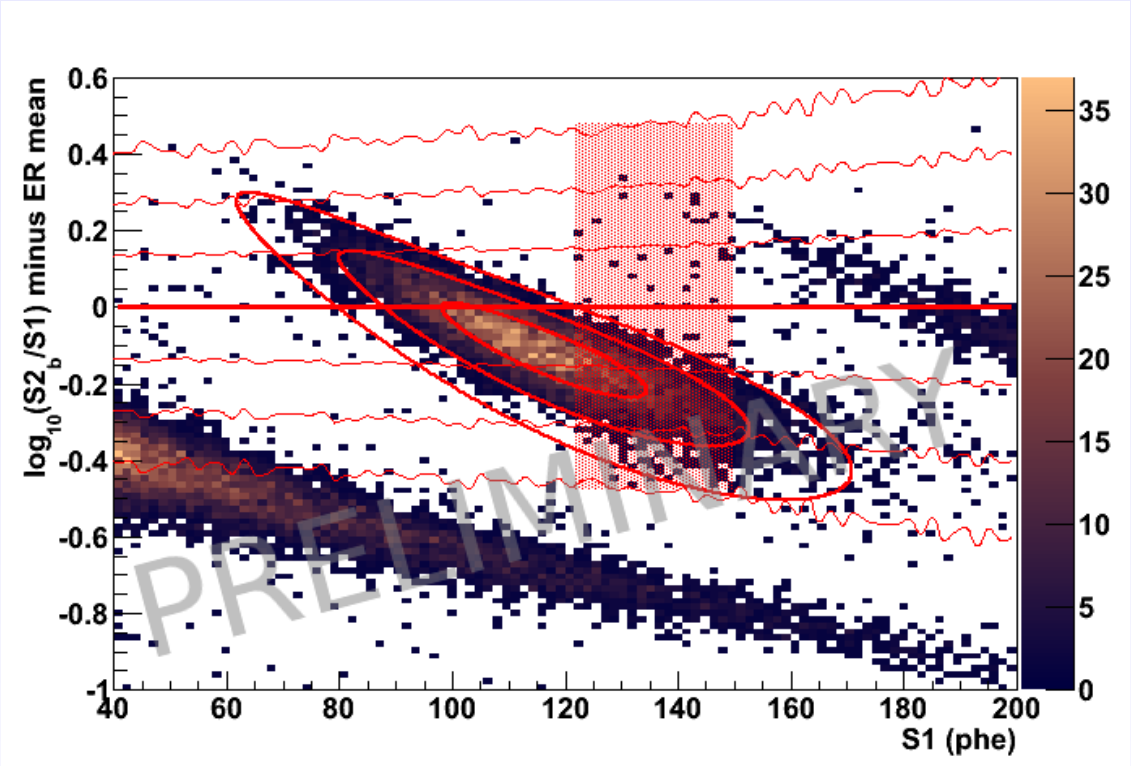
- Define a region of interest with a good signal to noise ratio
- Estimating expected background by comparing with a sideband region
- Looking for an excess of events above background

Problem: The region with the best signal to noise ratio is where there are many background events

$\rightarrow$ Looking for a small excess to a high number of events

Likelihood Approach

Profile likelihood analysis that compares the number of events above and below the mean of the electric recoil events as a function of S1

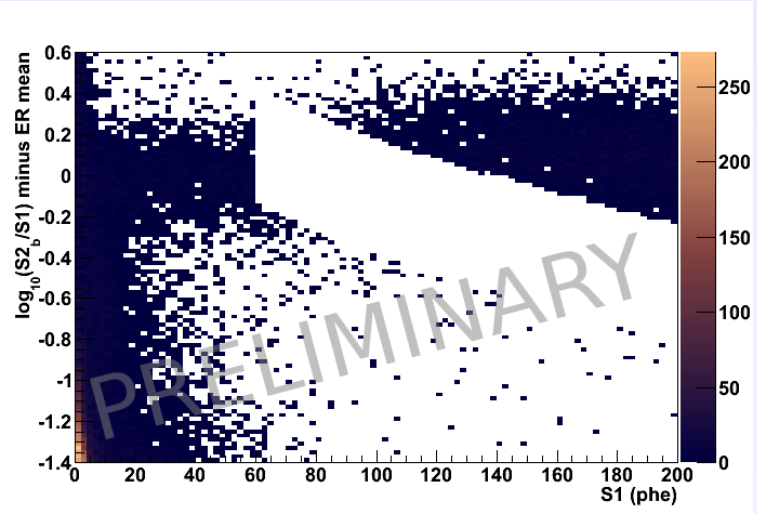


A possible parameter would be the probability p for an event to be below the ER mean
$\rightarrow$ Looking for an excess over $p = 0.5$

Analysis region has to be optimized

Analysis Cuts

- Fiducial volume
- Data quality cuts
  Remove noisy waveforms
- S2 signal threshold
- Single scatter selections
  Condition for only one S1 or S2 peak to occur and veto
- Consistency cuts
  Consistency of the position reconstruction algorithms or the S2 width peak



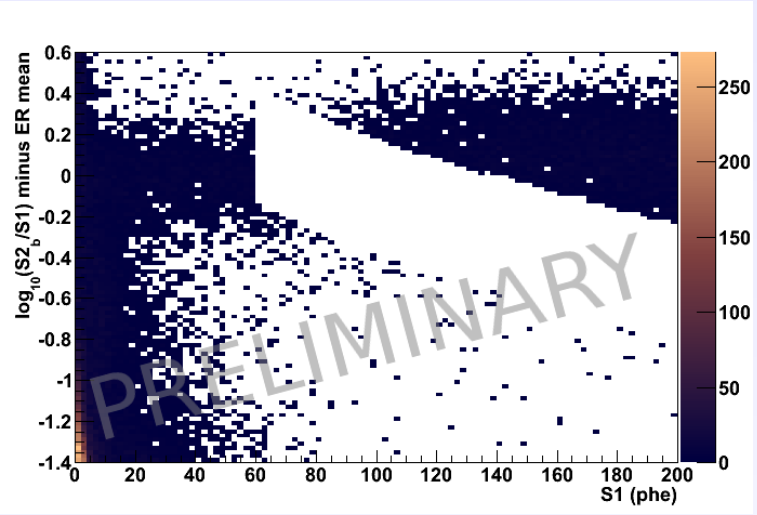
Analysis Cuts

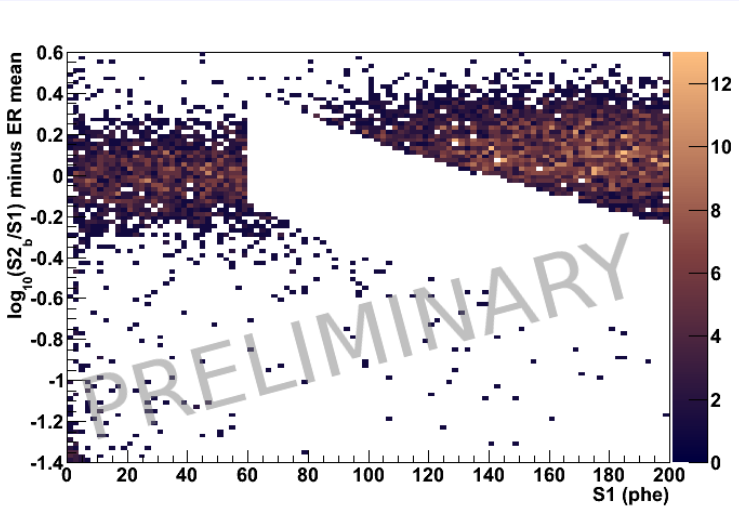
- Fiducial volume
- Data quality cuts

  Remove noisy waveforms
- S2 signal threshold
- Single scatter selections

  Condition for only one S1 or S2 peak to occur and veto
- Consistency cuts

  Consistency of the position reconstruction algorithms or the S2 width peak





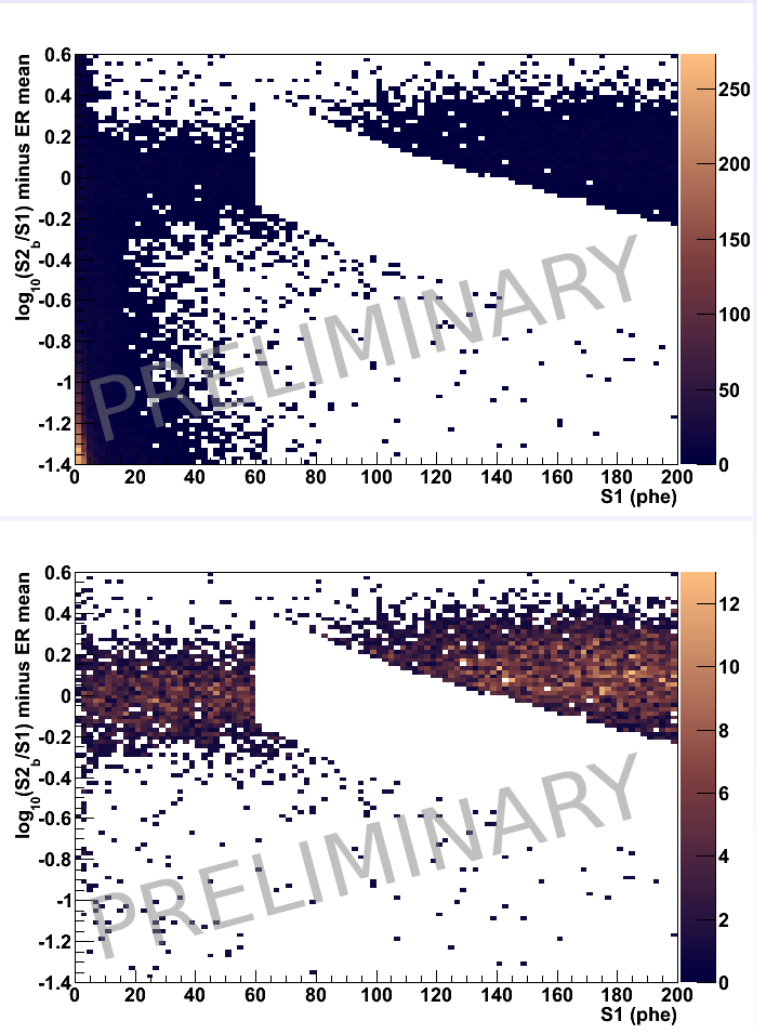
Analysis Cuts

- Fiducial volume
- Data quality cuts

  Remove noisy waveforms
- S2 signal threshold
- Single scatter selections

  Condition for only one S1 or S2 peak to occur and veto
- Consistency cuts

  Consistency of the position reconstruction algorithms or the S2 width peak



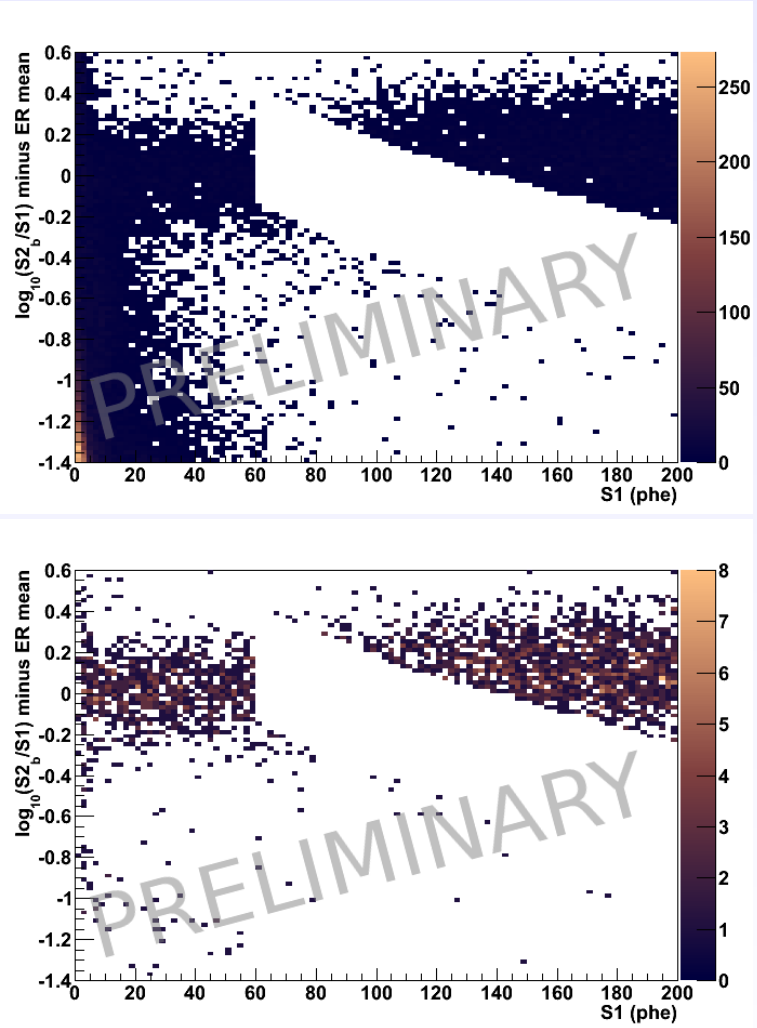
Analysis Cuts

- Fiducial volume
- Data quality cuts

  Remove noisy waveforms
- S2 signal threshold
- Single scatter selections

  Condition for only one S1 or S2 peak to occur and veto
- Consistency cuts

  Consistency of the position reconstruction algorithms or the S2 width peak



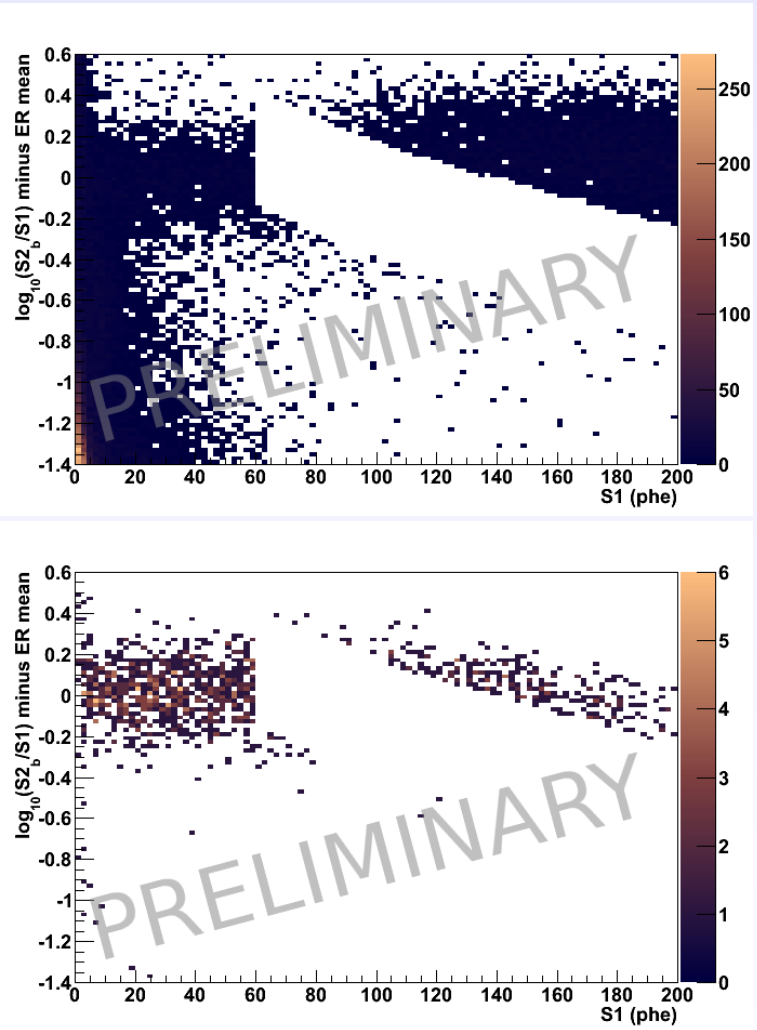
Analysis Cuts

- Fiducial volume
- Data quality cuts

  Remove noisy waveforms
- S2 signal threshold
- Single scatter selections

  Condition for only one S1 or S2 peak to occur and veto
- Consistency cuts

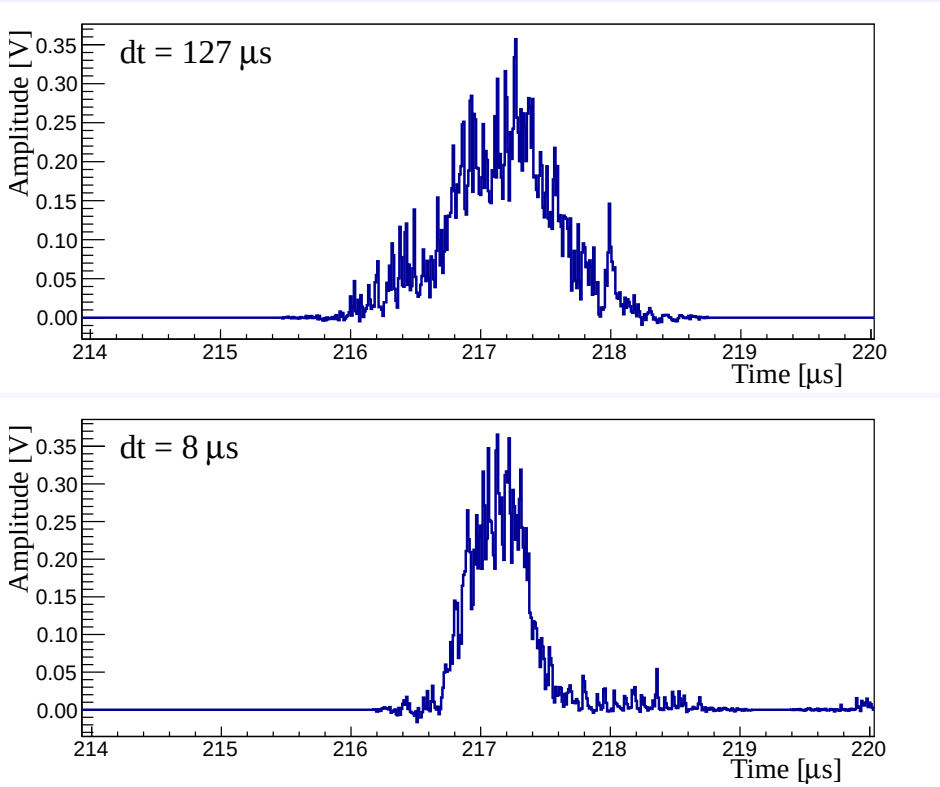
  Consistency of the position reconstruction algorithms or the S2 width peak

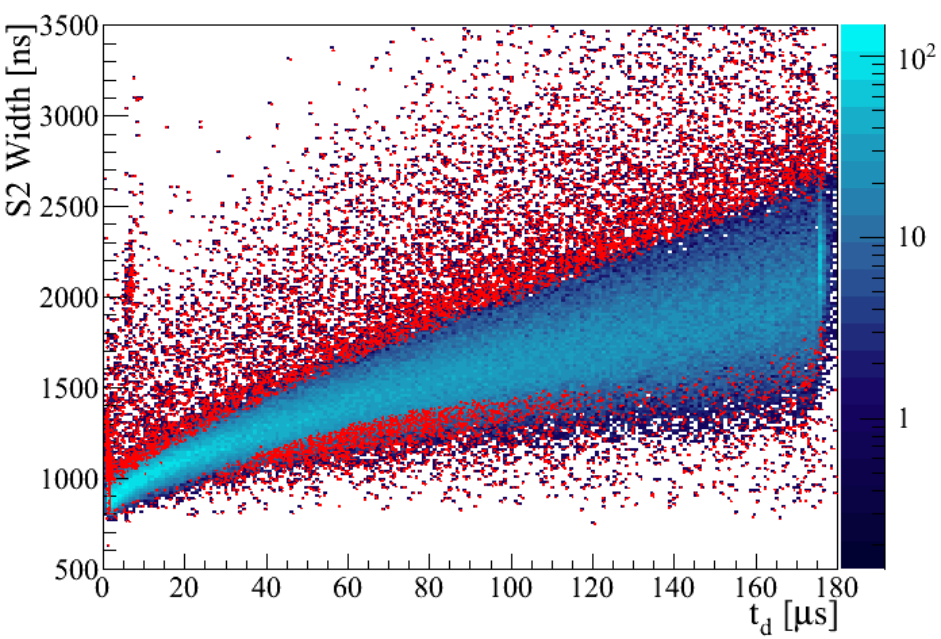


Example Cut: S2 Width Cut

Is the width of the S2 peak consistent to the drift time?

Due to diffusion the S2 pulse width increases with the drifttime dt





But: the definition of this cut is energy dependent

E. Aprile et al. (XENON100 Collaboration), arXiv:1207.3458v1 (2012)

Summary and Outlook

- Inelastic spin-dependent scattering
  - Nuclear recoil + 40 keV gamma
  - Background and signal region characterized
- Ongoing: cuts in the high energy region
  - Check the impact of the cuts on high energies
  - Modify the cuts if necessary
- Future: likelihood analysis
  - Define a proper analysis region
  - Define a likelihood function