HIBEAM Backgrounds and the simulation chain

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Searching for n-nbar oscillation

- Signal: antineutron-nucleon event
- Energy release of ~ 2*m_n ~ 1.88 GeV
- Total momentum p = 0
- Distributed over several pions (5 in average):

$$n + \bar{n} \rightarrow \pi^+ + \pi^- + 3\pi^0$$

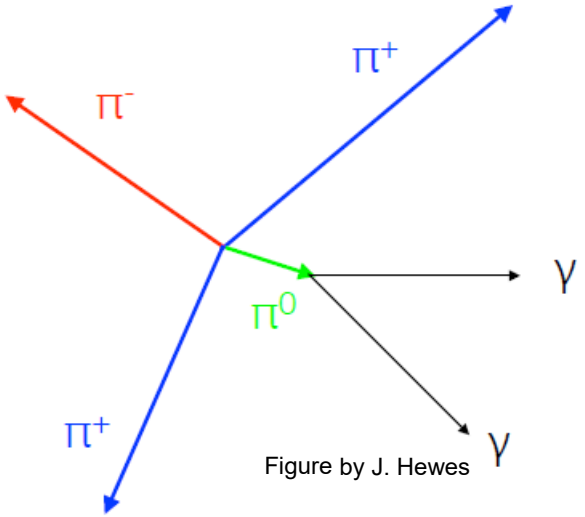


Figure by J. Hewes

Total annihilation cross section (~ 4Kb in ^{12}C)

Backgrounds

List of HIBEAM backgrounds

- Cosmic rays
- Neutron capture in the annihilation target → gammas
- Neutron capture at the neutron guide → gammas
- Accelerator skyshine
- Neutron cross-talk from neighboring beamlines
- Free neutron background (if neutrons decay inside tracker)
- *High energy backgrounds (prompt pulse): not a HIBEAM background @ ANNI ?→ discussion*
- ***Question: are we neglecting anything?***

Cosmic rays

- **Atmospheric neutrinos:**
- Cosmic rays hit atmosphere → create pions which decay as:

$$\pi^+(\pi^-) \rightarrow \quad \mu^+(\mu^-) \quad + \quad \nu_\mu(\bar{\nu}_\mu)$$

$$\mu^+(\mu^-) \quad \rightarrow \; e^+(e^-) + \nu_e(\bar{\nu}_e) + \bar{\nu}_\mu(\nu_\mu).$$

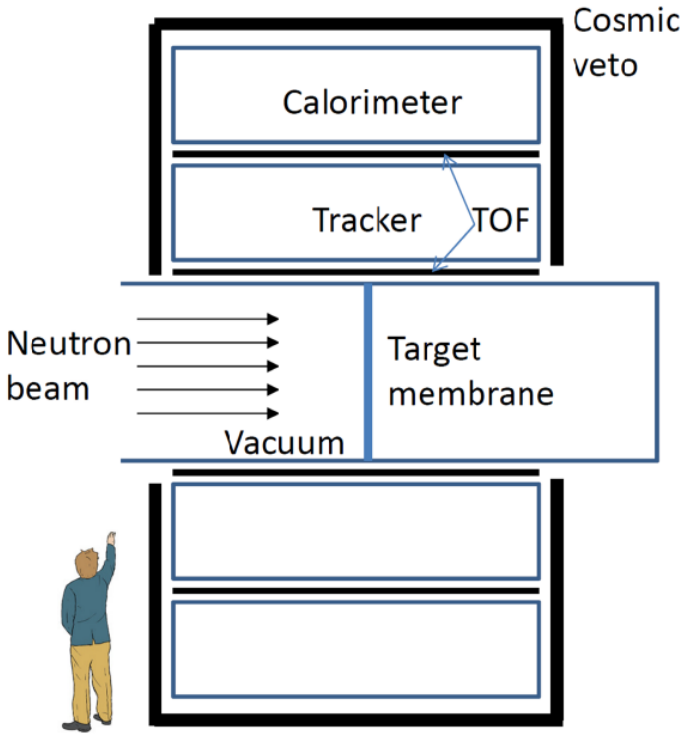
- Neutrino interactions → neutrino induced muons → energetic electrons
- Direct decay of the muons → Michel electrons

  (Note: a single charged pion is background for nnbar)

- Cosmic rays are diverse, other interactions contribute

Cosmic rays (CR)

- CR will be dealt with by the TOF + CR veto system
- TOF: 2 layers of fast detectors (plastic scintillation slabs or tiles) before and after tracker, separated by ~ 50cm
  - timing accuracy → discriminate annihilation-like tracks from CR outside detector volume
- CR veto system: large plastic scintillator pads



Cosmic rays (CR)

- Simulation options:
- From Jeremy E. T. Hewes PhD dissertation (2017):

As MicroBooNE is an on-surface detector, it is constantly exposed to cosmogenic particles produced in the atmosphere by high-energy cosmic rays.

MicroBooNE uses CORSIKA [86] to simulate air showers produced in the atmosphere by high-energy cosmic rays. Hadronic showers above 80 GeV are simulated using GHEISHA routines [87]; below this threshold, CORSIKA passes off hadronic shower simulation to FLUKA [88, 89].

- Should we consider same/similar option for HIBEAM-NNBAR?
- Albert presented some work on cosmics about 2-3 years ago.

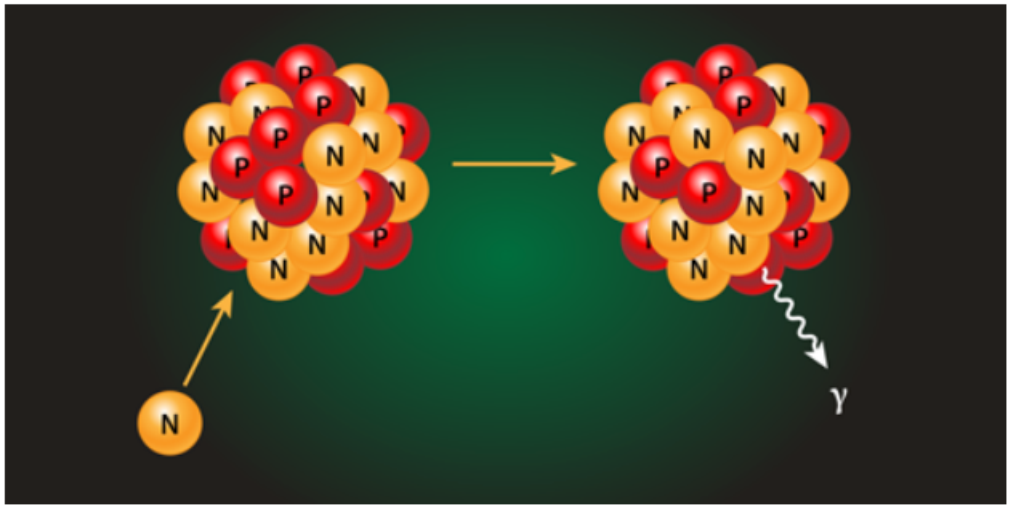
Gamma emission by neutron capture

$$\sigma_{annihilation} \sim 4\text{Kb}$$
$$\sigma_{nC,capture} \sim 4\text{mb}$$

- **Two types of background**:

  a) neutron capture at the carbon target

  b) neutron capture within neutron guide



Alan Stonebraker/APS

Signal contains →

$$\pi^o \rightarrow \gamma\gamma \quad (98.798 \pm 0.032)\%$$

$$\pi^o \rightarrow e^+e^-\gamma \ (\ 1.198 \pm 0.032)\%$$

Gamma emission by neutron capture

$\sigma_{annihilation} \sim 4\mathrm{Kb}$
$\sigma_{nC,capture} \sim 4\mathrm{mb}$

- **Simulation options**:

  a) Neutron capture at the ^{12}C target (dominant):

  - take cold neutron ANNI source (from Torsten/Esben/Josh et al.)
  - obtain gamma spectrum (with timing information etc) using PHITS
  - "easy" → no variance reduction needed, "shoot" neutrons at target
  - pass gamma emission file to Geant4 → pile-up estimation

  alternatively: gamma emission directly in Geant4 using ANNI source

- We should use both methods and compare → MC systematic uncertainty

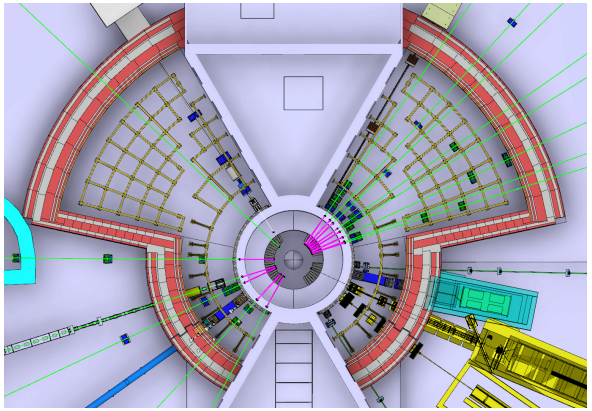
- **Activation** should also be obtained (certainly with Phits, perhaps involved with Geant)

Gamma emission by neutron capture

$$\sigma_{annihilation} \sim 4\text{Kb}$$
$$\sigma_{nC,capture} \sim 4\text{mb}$$

- **Simulation options**:

  a) Neutron capture within neutron guide:
  M*ore complicated*, albeit subdominant
  Requires MCNP (+ patch) + ADVANTG (?)
  Variance reduction



- Can only be done by those with MCNP licenses
- Should not be target of any first studies
- Problem intertwined and depended on neutron guide shielding
- BUT: will certainly affect detector → needs to be estimated later

- *The good news*: subject is being studied for other ESS instruments as well

Gamma emission by neutron capture

- For a) we should also do:

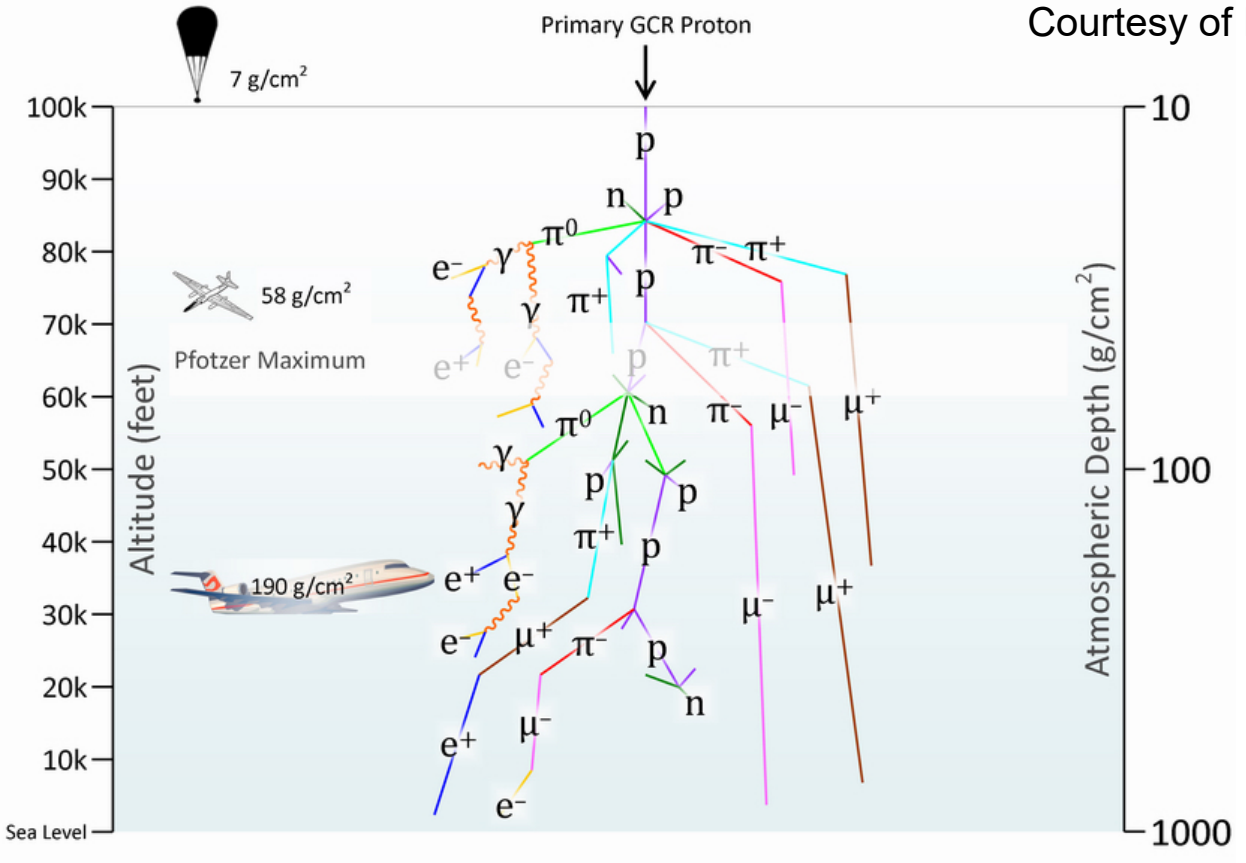
$$\sigma_{annihilation} \sim 4\mathrm{Kb}$$
$$\sigma_{nC,capture} \sim 4\mathrm{mb}$$

- What if the target is made of ^{10}Be?
- What if we use a two target system?
  (1st target annihilation, 2nd target background background monitor)

- Also, target diameter and thickness can be varied for all cases
  (within reason, taking cost into account)

Accelerator skyshine

- “Inverse cosmic rays”
- Particles go up, create showers in the air, which radiate back down to instruments



Courtesy of P. M. Bentley

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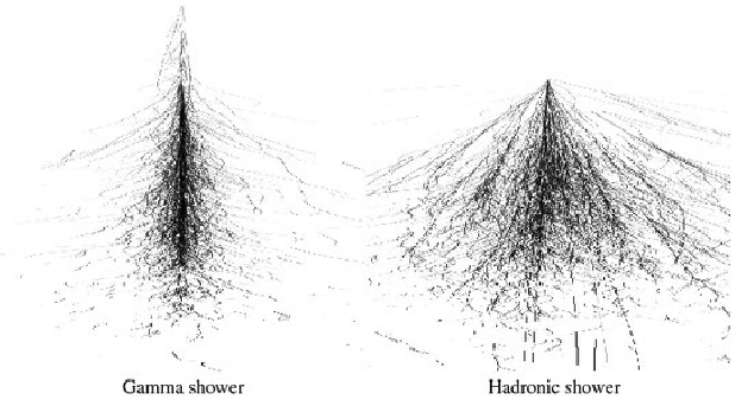
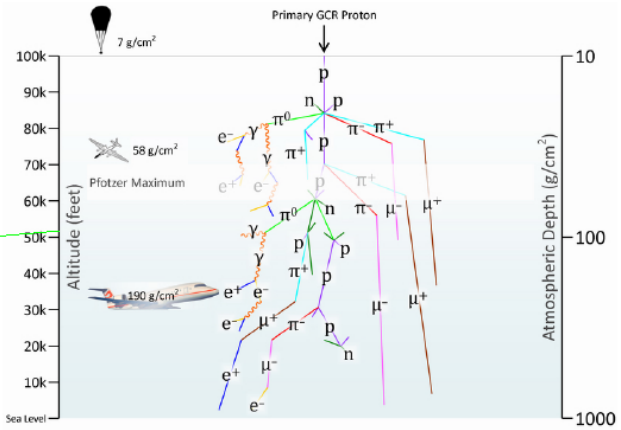
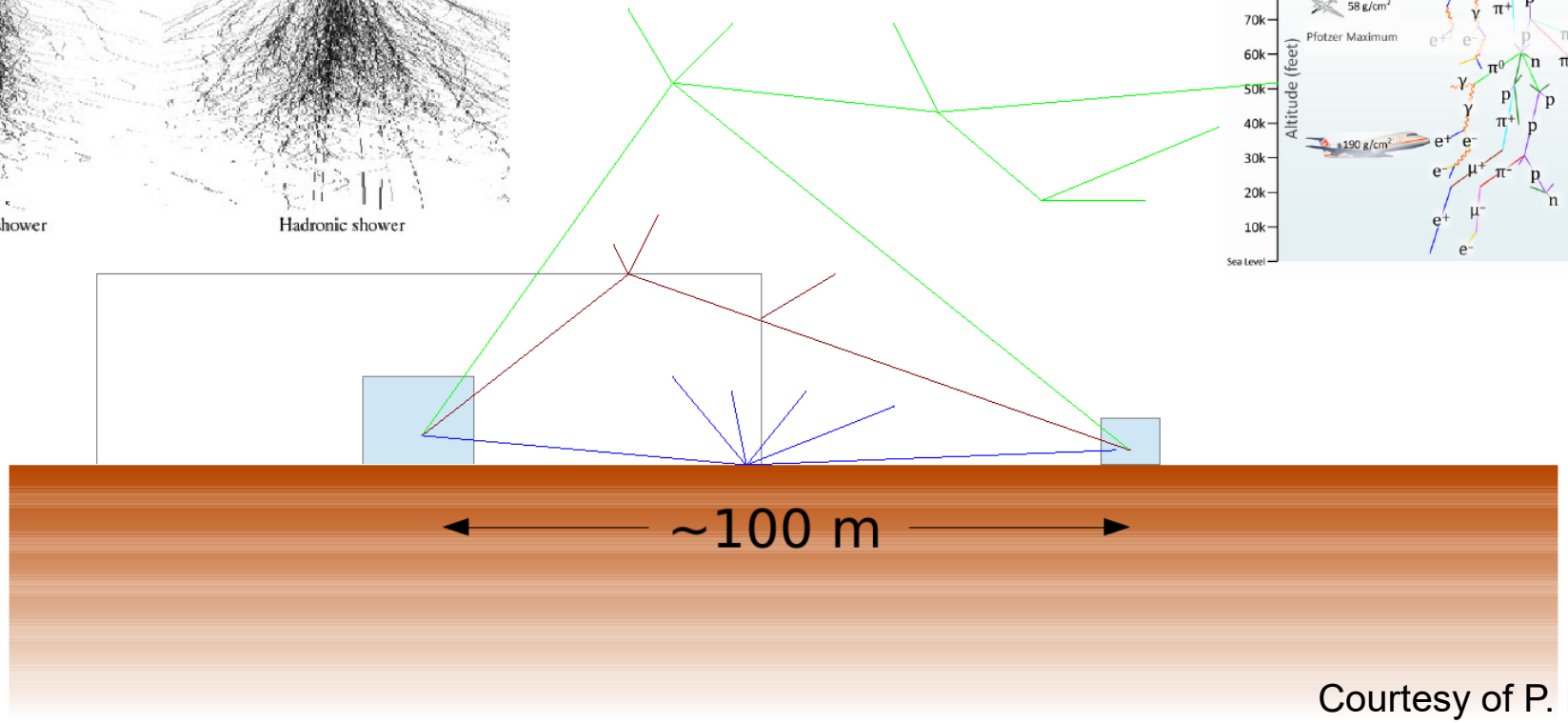


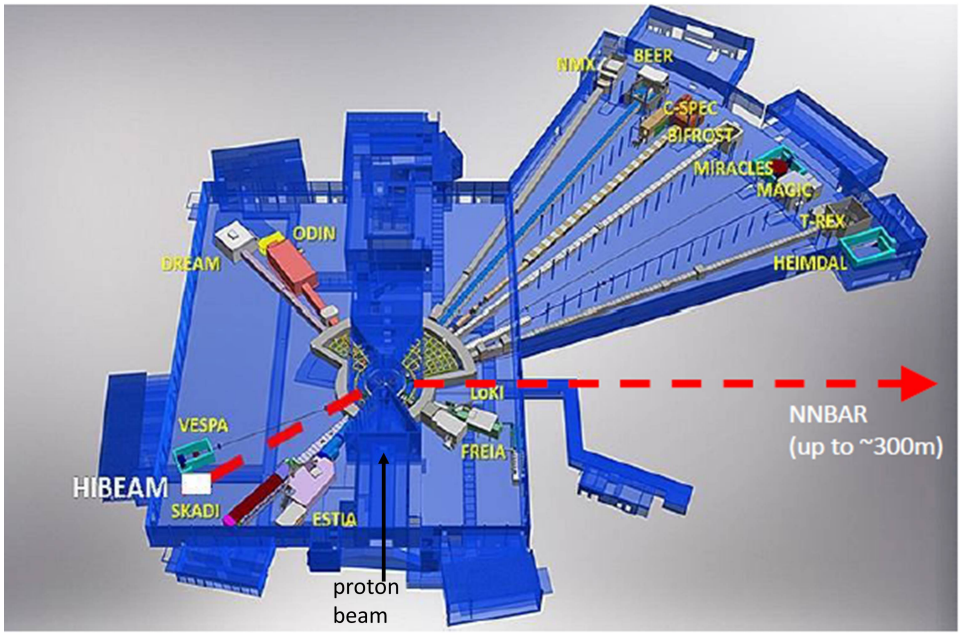




Courtesy of P. M. Bentley

Neutron cross-talk from neighboring beamlines

- Important component, in particular for a “zero background detector”
- Probably hard to be estimated without some measurements (?)
- Can, however be taken into account in the shielding design (see Valentina's talk)
- HIBEAM case standard
- NNBAR case unclear



Free neutron background

- Neutrons can decay inside tracker:

$$n \rightarrow p + e^{-} + \bar{\nu}_e$$

(protons ~ low energy → stopped in the walls of the beam tube)

- Electrons → background
- If neutron decays inside tracker → spoil charged pion vertex reconstruction

For discussion: is the neutron flux from ANNI enough accurate to estimate this?

High energy neutron backgrounds

- Due to ANNI curved guide HIBEAM should not be affected
- Theory: curved guide allows only cold neutrons to sneak through.
- Fast straight moving particles do not pass curved guide (right?)
- Demonstrate this in simulations for HIBEAM

Neutron Scattering – Fundamentals
Edited by Felix Fernandez-Alonso, David L. Price

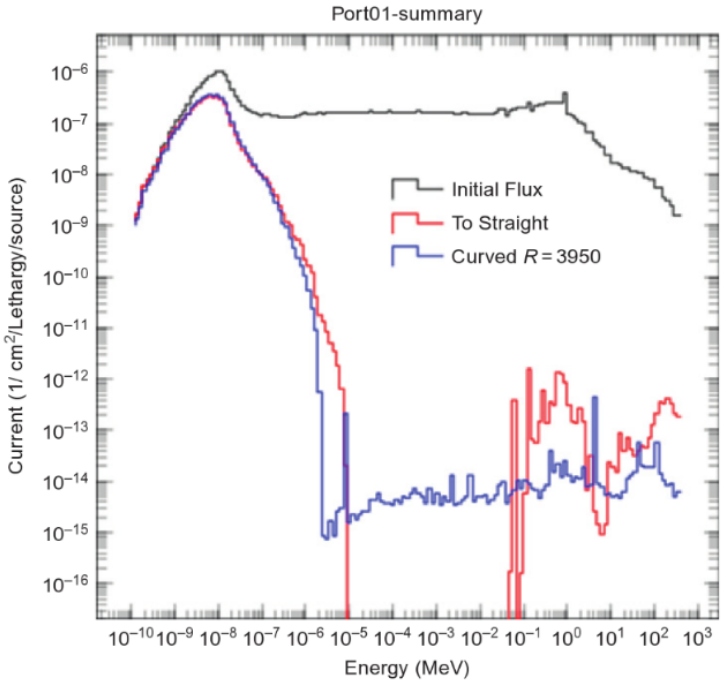


FIGURE 3.14 Neutron intensity as a function of energy at a beam port of JSNS; background suppression by either a curved guide or a T_0 chopper is clearly shown [11].

We should produce the same for HIBEAM at ESS

HIBEAM Simulation chain

HIBEAM simulation chain

- ANNI source: McStas events (Torsten, Esben, Josh)
- Signal source generation: GENIE? / GBL generator (E. S. Golubeva, J. L. Barrow, and C. G. Ladd)

- Background generation:
  a) Cosmic rays (CORSIKA, Fluka, etc?)
  b) Gamma emission (neutron capture):
  PHITS (annihilation with target) + MCNP/ADVANTG for gamma contribution from guide
  c) Accelerator Skyshine (PHITS/MCNP)
  d) Free neutron background ("feed" ANNI source directly to Geant?)
  e) Neutron cross-talk (possible?)

- Detector simulation: Detector geometry, data acquisition electronics, pile-up, etc
  → Geant4

Some further comments

- In light of Matt's talk yesterday MCStas event flux file can probably be optimized using his techniques for HIBEAM
- On event generation after annihilation: I suggest comparing results using two generators to get a systematical uncertainty (Josh?)
- There is an interface the interface between MCNP and other codes: MCPL (Esben to comment)
- There is an easy way to get not only cold/thermal neutrons (like McStas does) *but any particles exiting the target region*, and hand it to any other code in a convenient format. E.g. plug and play interfaces exist between: McStas, MCNP, Geant4 (develop one for Genie?).
- On cosmics: Super-K prepared large MC event sample that corresponded to an atmospheric neutrino exposure of 500 years

Conclusion and request

- Very interesting times ahead of us.
- Could we start using a TWiki to centralize (and better share) a bit more the details of work?
- There is one at: https://twiki.cern.ch/twiki/bin/view/NNbar/WebHome
- Collaboration restricted – you just need a CERN lightweight account

BACKUP

GENIE

Table 5.3: Neutron-antineutron oscillation final state branching ratios generated by the GENIE event generator, including the dynamic scaling-down of final states suppressed by event kinematics.

$\bar{n}+p$		$\bar{n}+n$	
$\pi^+\pi^0$	1.2%	$\pi^+\pi^-$	2.0%
$\pi^+2\pi^0$	9.5%	$2\pi^0$	1.5%
$\pi^+3\pi^0$	11.9%	$\pi^+\pi^-\pi^0$	6.5%
$2\pi^+\pi^-\pi^0$	26.2%	$\pi^+\pi^-2\pi^0$	11.0%
$2\pi^+\pi^-2\pi^0$	42.8%	$\pi^+\pi^-3\pi^0$	28.0%
$2\pi^+\pi^-2\omega$	0.003%	$2\pi^+2\pi^-$	7.1%
$3\pi^+2\pi^-\pi^0$	8.4%	$2\pi^+2\pi^-\pi^0$	24.0%
		$\pi^+\pi^-\omega$	10.0%
		$2\pi^+2\pi^-2\pi^0$	10.0%