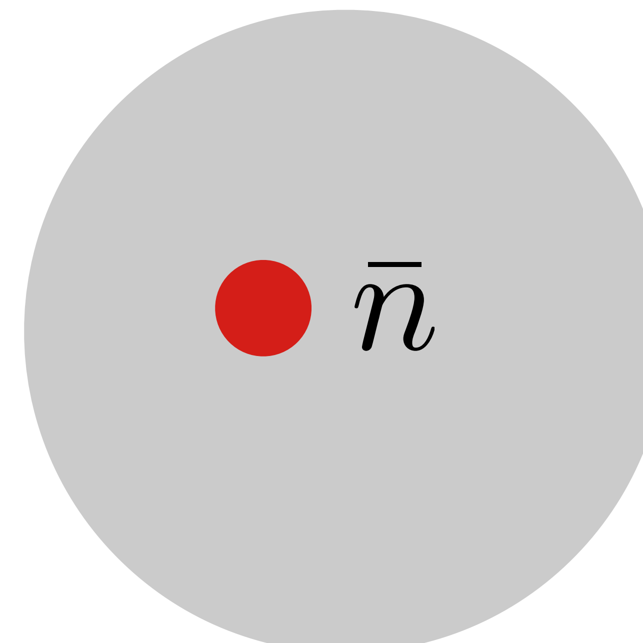
Neutron-antineutron oscillation MC generation

Jeremy Hewes
DUNE atmos & nucleon decay WG meeting
Monday 9th November 2015

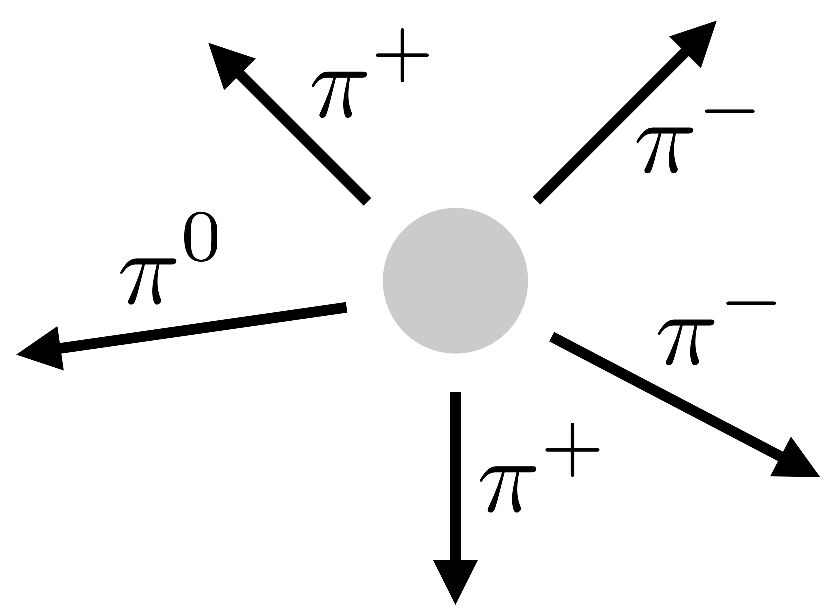
Introduction

- Neutron-antineutron oscillation (nnbar) is a **beyond Standard Model** process which violates Baryon number conservation.
- Neutron **spontaneously oscillates** into antineutron.
- Bound neutron search = oscillation of neutron inside nucleus.
- Antineutron annihilates with nucleon inside nucleus.



$\bar{n}+p$		$\bar{n}+n$	
$\pi^+\pi^0$	1%	$\pi^+\pi^-$	2%
$\pi^+2\pi^0$	8%	$2\pi^0$	1.5%
$\pi^+3\pi^0$	10%	$\pi^+\pi^-\pi^0$	6.5%
$2\pi^+\pi^-\pi^0$	22%	$\pi^+\pi^-2\pi^0$	11%
$2\pi^+\pi^-2\pi^0$	36%	$\pi^+\pi^-3\pi^0$	28%
$2\pi^+\pi^-2\omega$	16%	$2\pi^+2\pi^-$	7%
$3\pi^+2\pi^-\pi^0$	7%	$2\pi^+2\pi^-\pi^0$	24%
		$\pi^+\pi^-\omega$	10%
		$2\pi^+2\pi^-2\pi^0$	10%

arXiv 1109.422



$$\sum p < 300\text{MeV}$$
$$\sum E \simeq 1.5\text{GeV}$$

Event generator

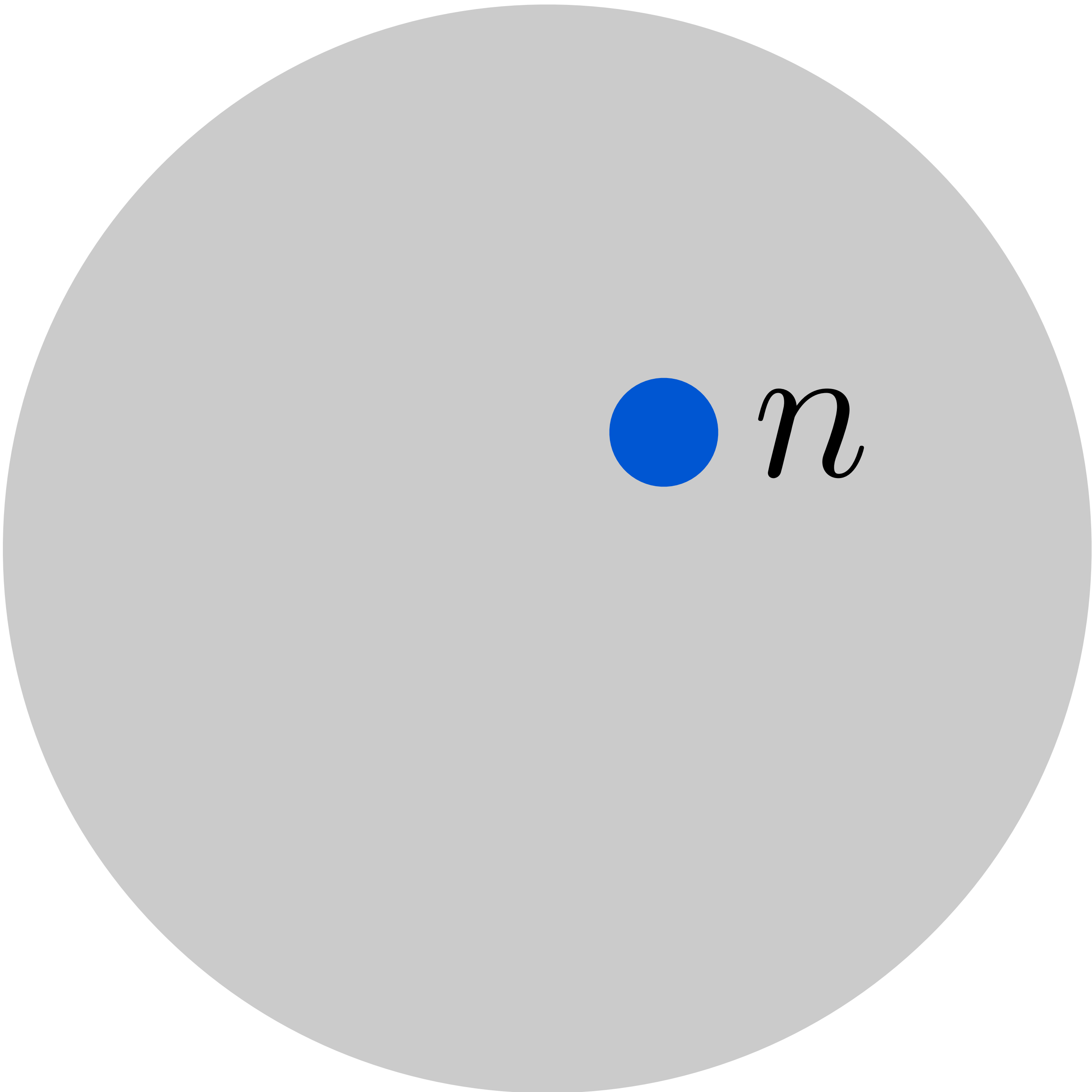
- Module written in GENIE event generator for neutron-antineutron oscillation, based on GENIE's nucleon decay module.
- Currently available in private version of GENIE 2.9.0, linked here.
- Module is still in active development, but currently able to simulate events and propagate them to LArSoft.
- The following slides will run through how the GENIE generator works, and how these events are propagated into LArSoft.

GENIE event generation

- Initial state: ^{40}Ar nucleus.

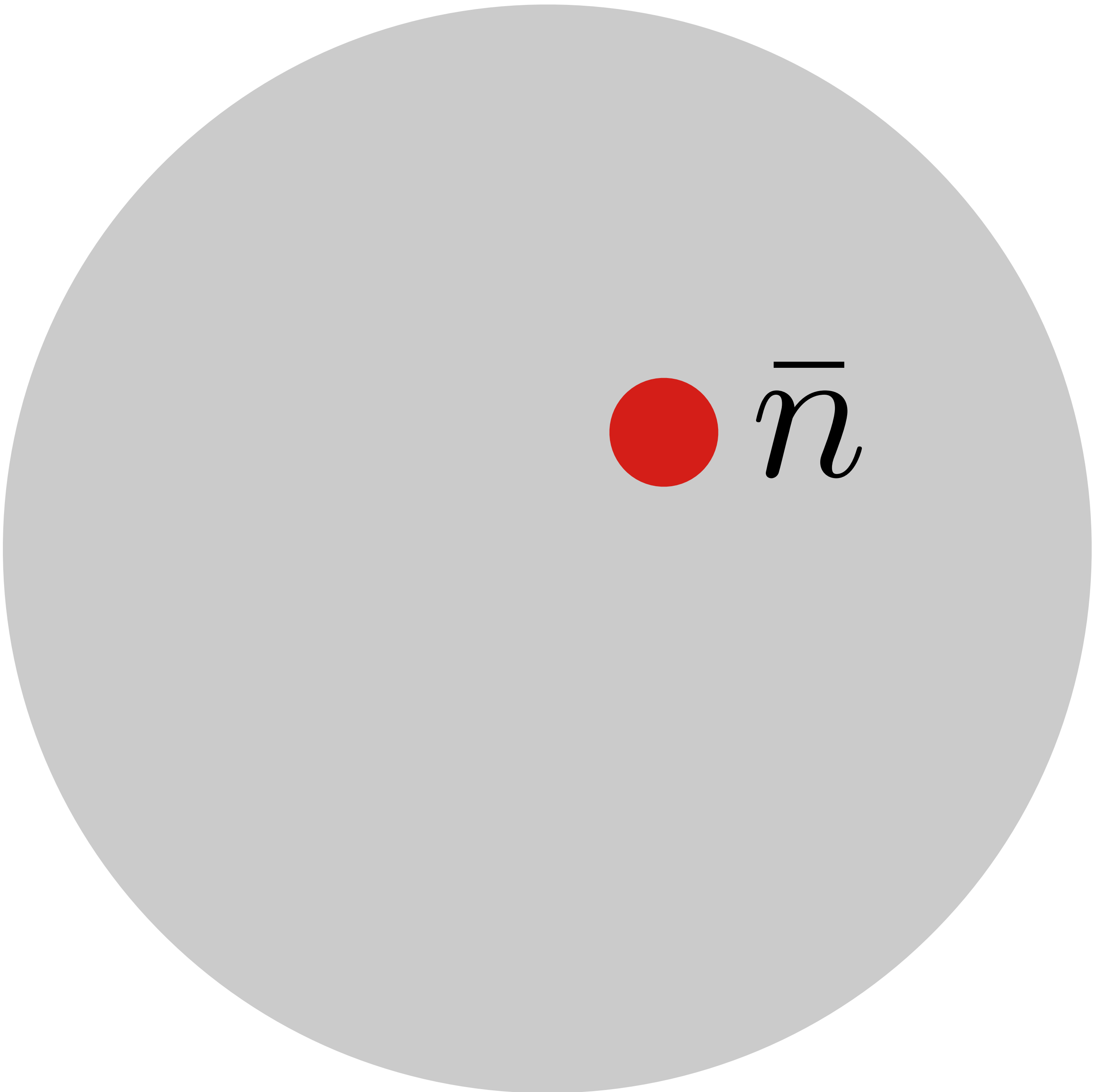
GENIE event generation

- Initial state: ^{40}Ar nucleus.



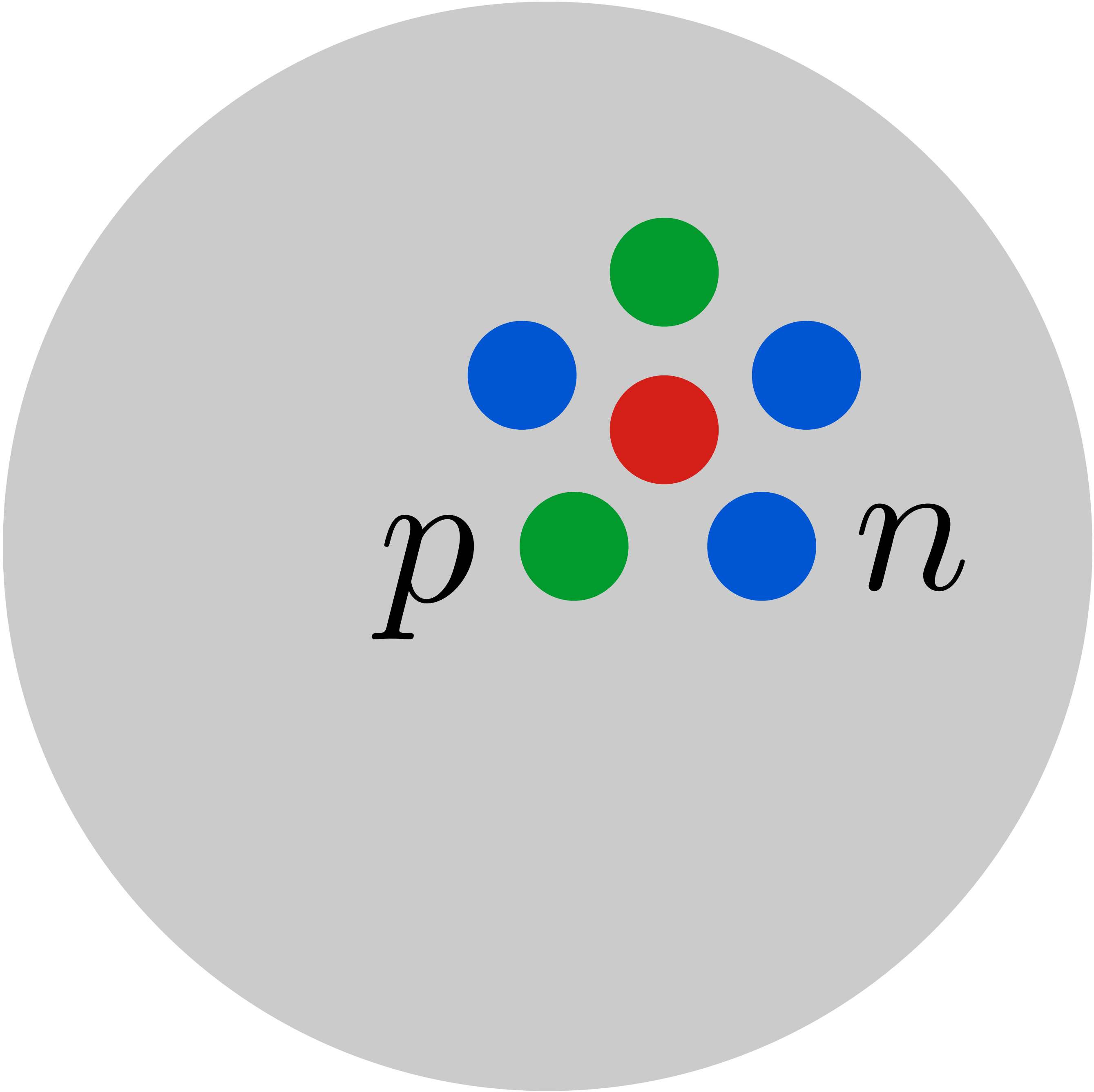
GENIE event generation

- Initial state: ^{40}Ar nucleus.
- Neutron oscillates into antineutron.



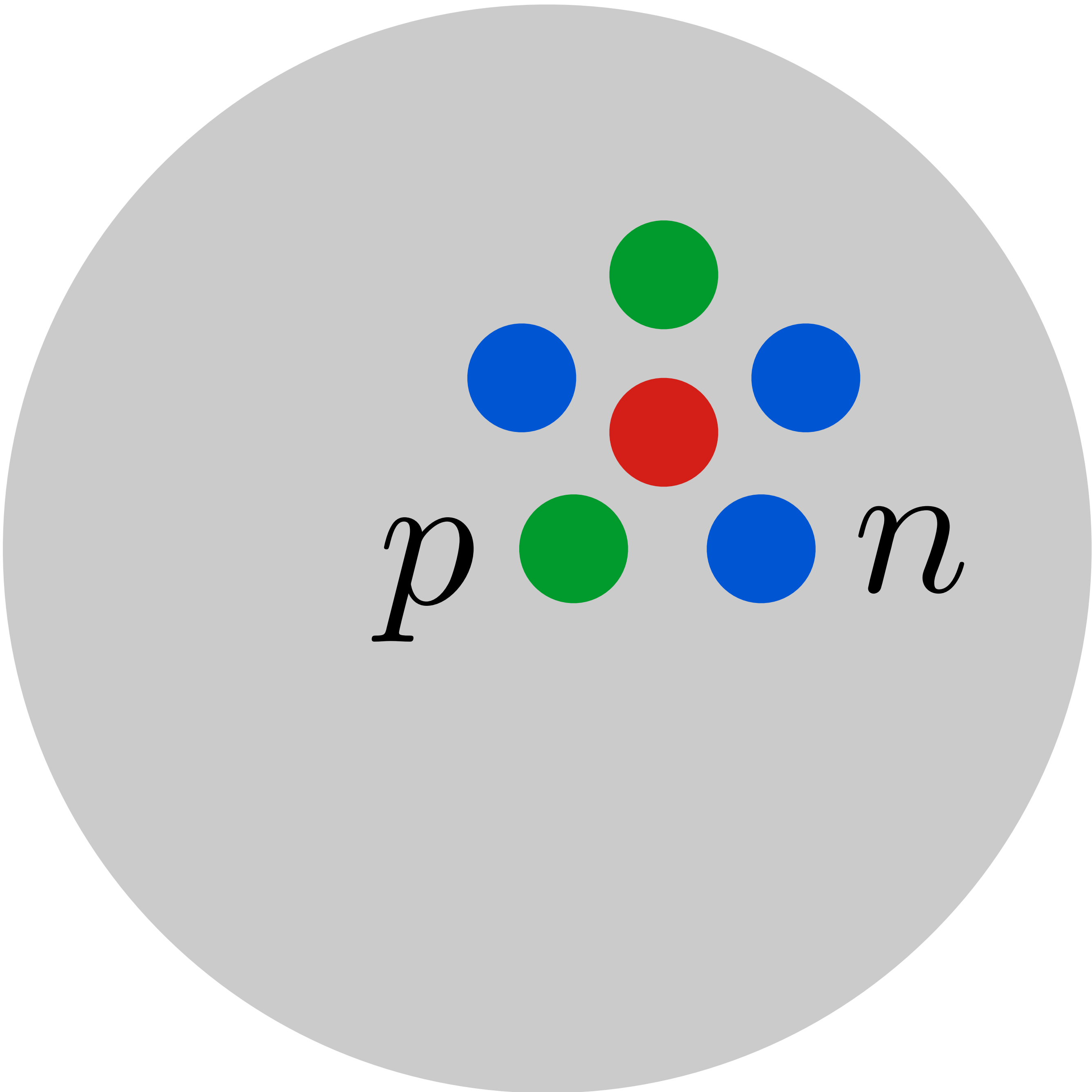
GENIE event generation

- Initial state: ^{40}Ar nucleus.
- Neutron oscillates into antineutron.
- Antineutron annihilates with proton or neutron.



GENIE event generation

- Initial state: ^{40}Ar nucleus.
- Neutron oscillates into antineutron.
- Antineutron annihilates with proton or neutron.
    - 21 neutrons, 18 protons.



GENIE event generation

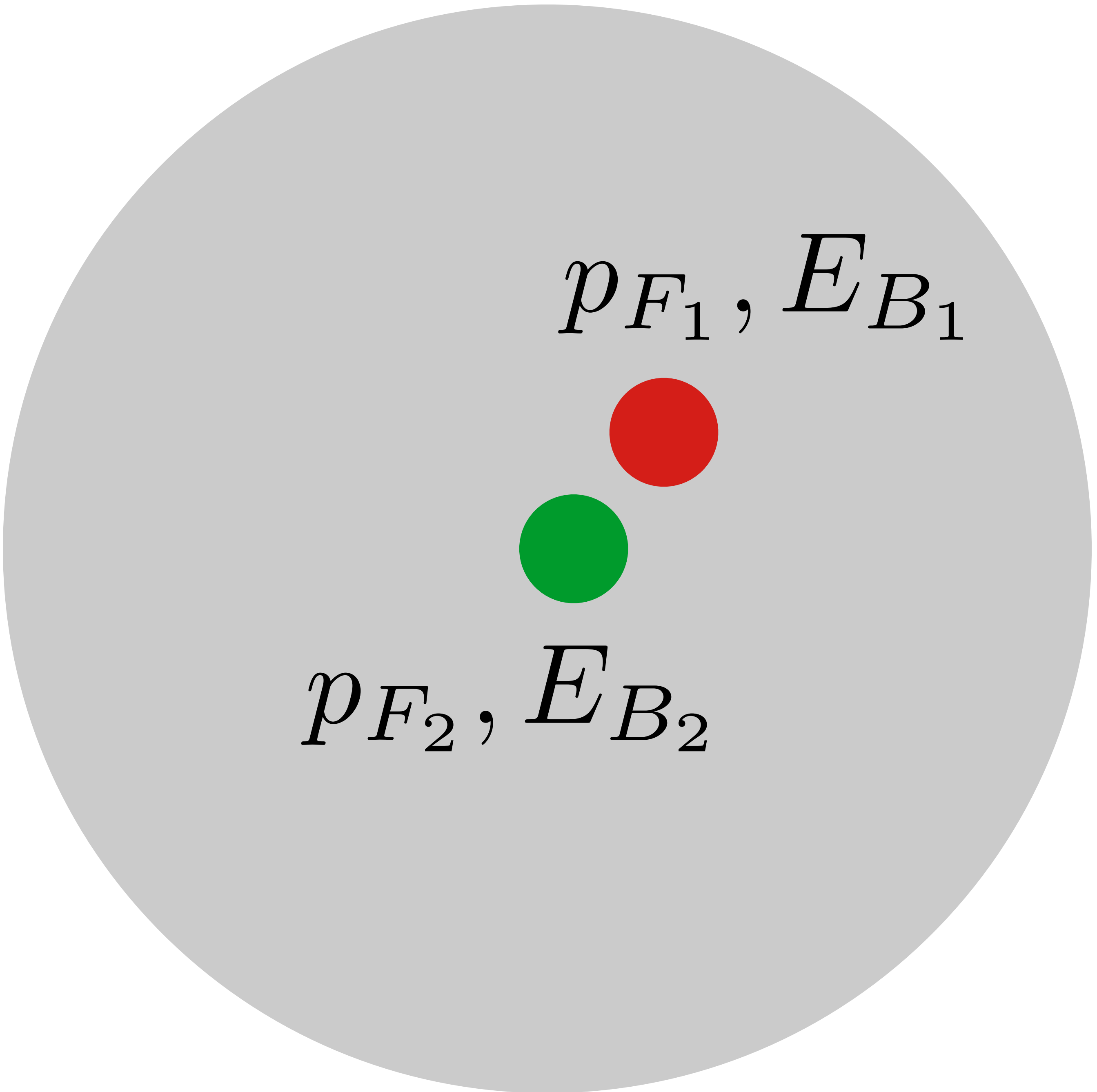
- Initial state: ^{40}Ar nucleus.
- Neutron oscillates into antineutron.
- Antineutron annihilates with proton or neutron.
  - 21 neutrons, 18 protons.
  - Randomly select annihilation mode according to branching ratios.

$\bar{n}+p$		$\bar{n}+n$	
$\pi^+\pi^0$	1%	$\pi^+\pi^-$	2%
$\pi^+2\pi^0$	8%	$2\pi^0$	1.5%
$\pi^+3\pi^0$	10%	$\pi^+\pi^-\pi^0$	6.5%
$2\pi^+\pi^-\pi^0$	22%	$\pi^+\pi^-2\pi^0$	11%
$2\pi^+\pi^-2\pi^0$	36%	$\pi^+\pi^-3\pi^0$	28%
$2\pi^+\pi^-2\omega$	16%	$2\pi^+2\pi^-$	7%
$3\pi^+2\pi^-\pi^0$	7%	$2\pi^+2\pi^-\pi^0$	24%
		$\pi^+\pi^-\omega$	10%
		$2\pi^+2\pi^-2\pi^0$	10%

Table from Super-Kamiokande paper (arXiv:1109.4227v2)

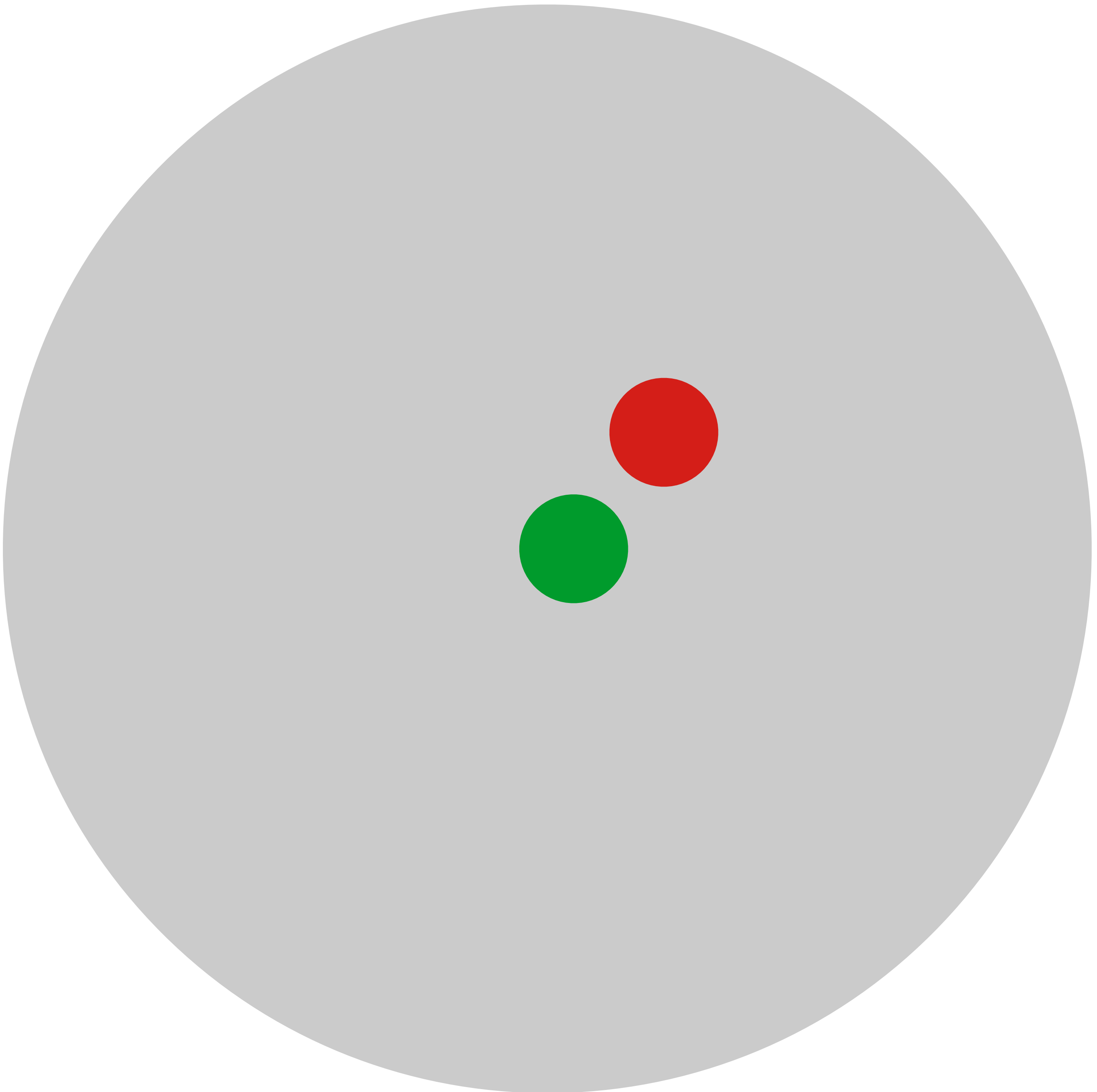
GENIE event generation

- Initial state: ^{40}Ar nucleus.
- Neutron oscillates into antineutron.
- Antineutron annihilates with proton or neutron.
  - 21 neutrons, 18 protons.
  - Randomly select annihilation mode according to branching ratios.
- Assign Fermi momentum & binding energy to antineutron & nucleon.



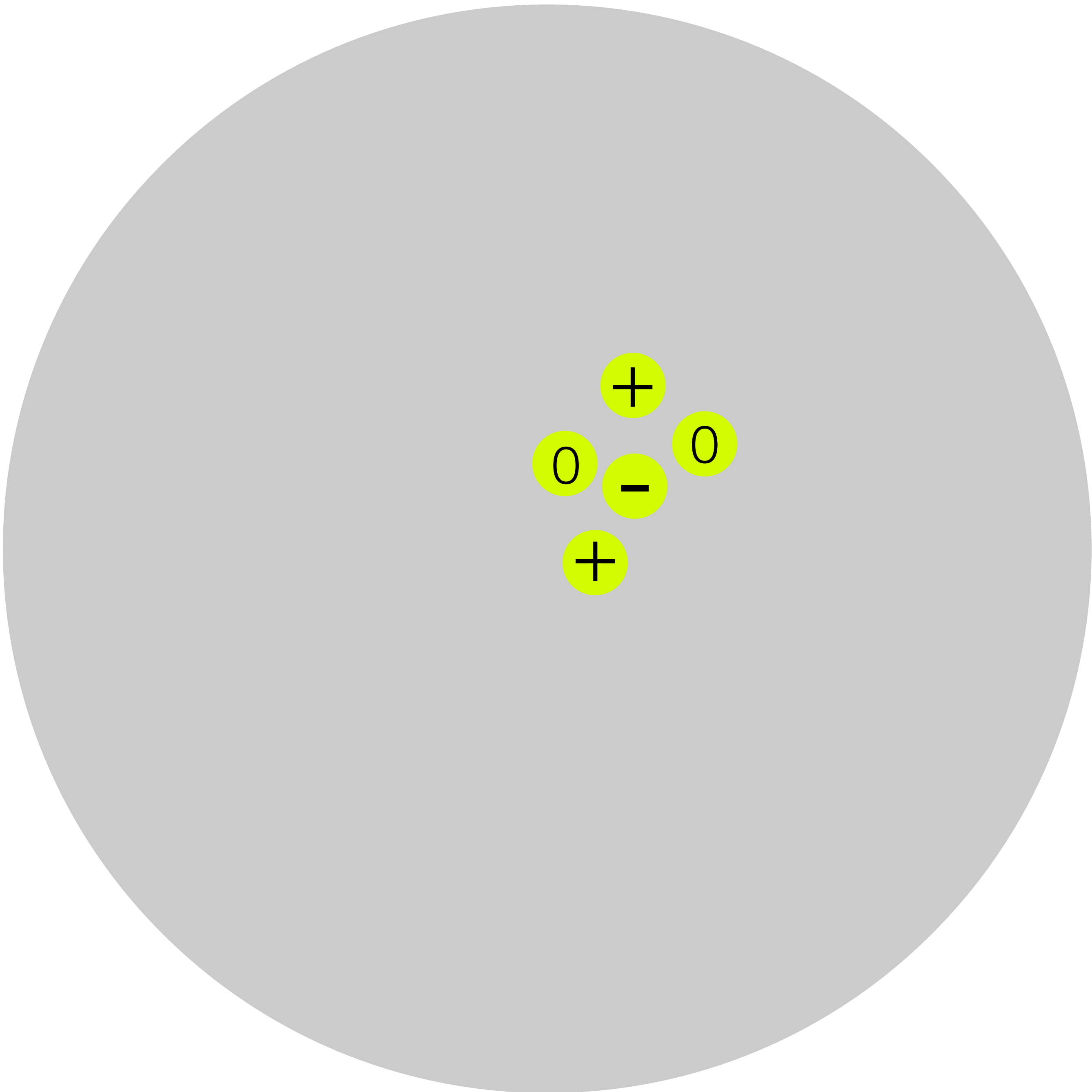
GENIE event generation

- Lorentz boost into CM frame of two-nucleon system.



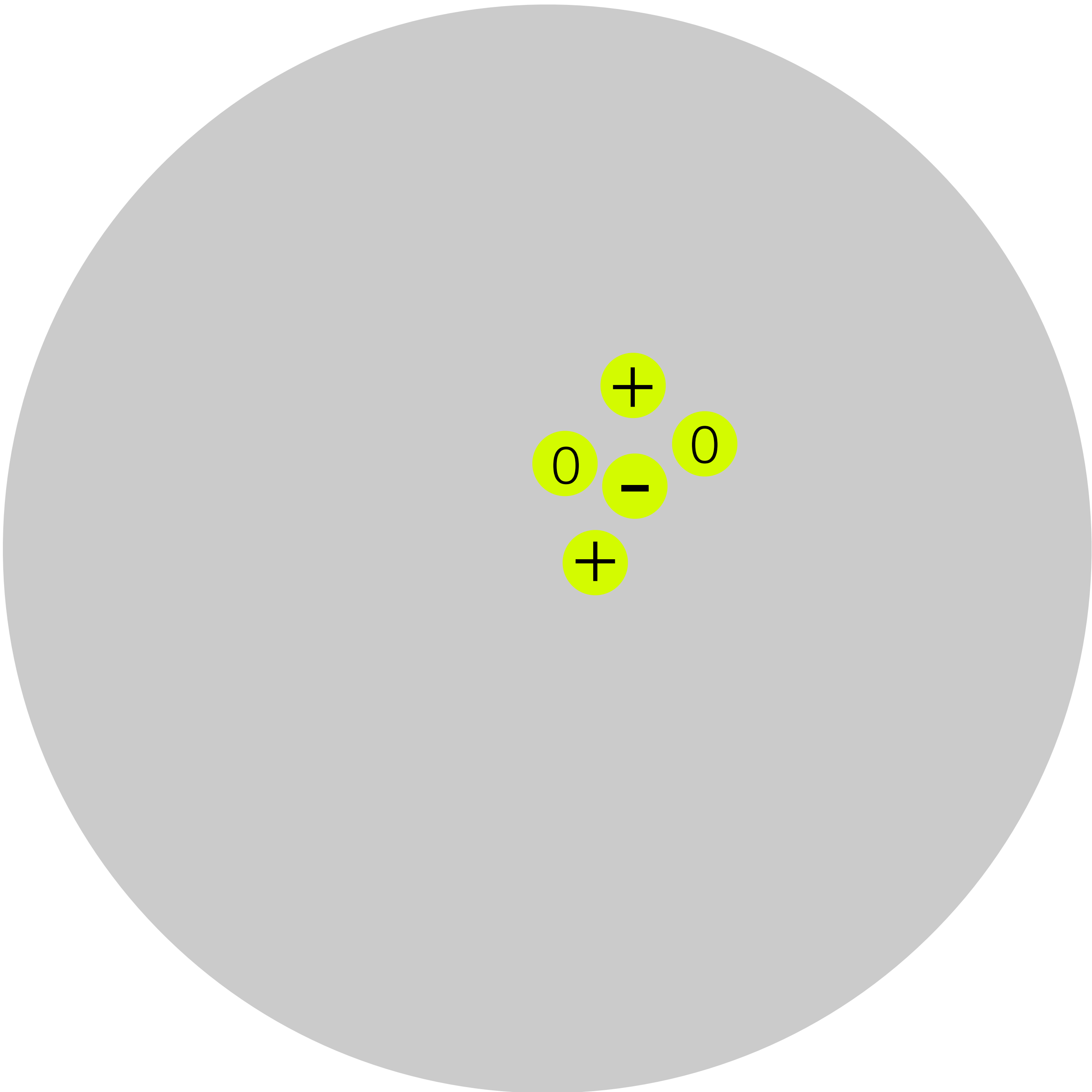
GENIE event generation

- Lorentz boost into CM frame of two-nucleon system.
- Generate decay products.



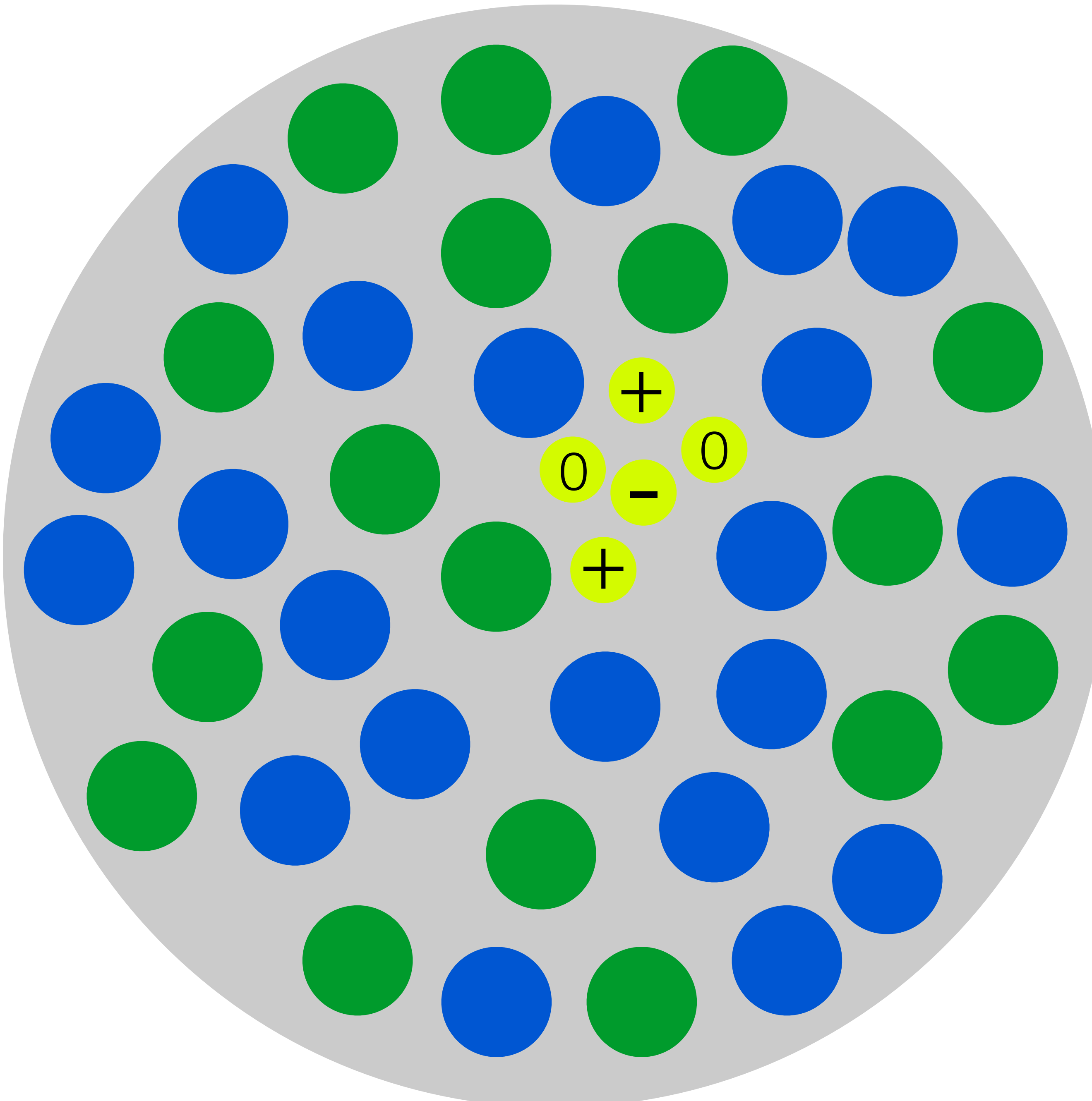
GENIE event generation

- Lorentz boost into CM frame of two-nucleon system.
- Generate decay products.
- Assign momentum & energy using phase-space decay.
- Lorentz boost back into original frame.

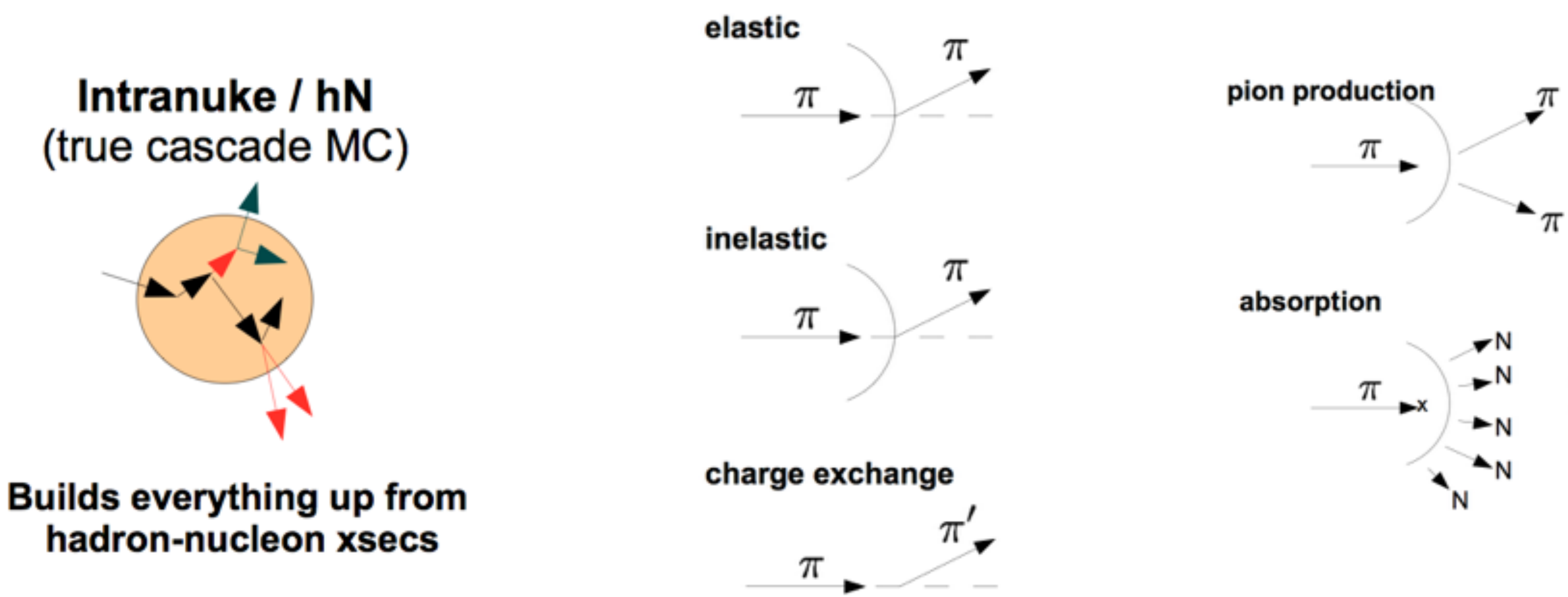


GENIE event generation

- Lorentz boost into CM frame of two-nucleon system.
- Generate decay products.
- Assign momentum & energy using phase-space decay.
- Lorentz boost back into original frame.
- Propagate final state particles through nucleus.



INTRANUKE/hN cascade model

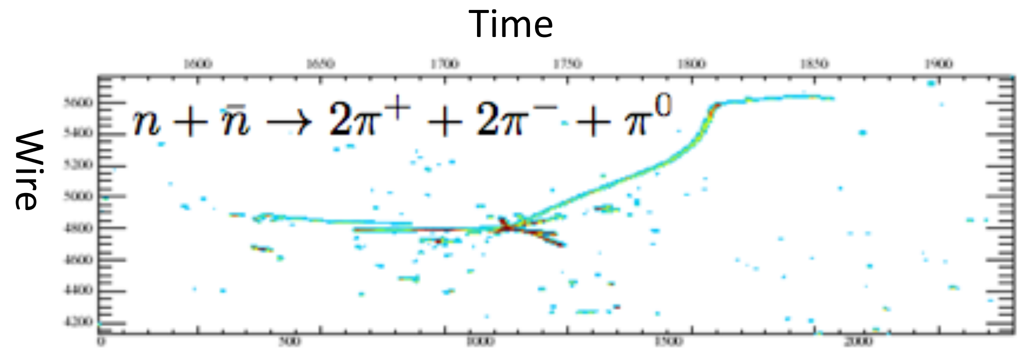


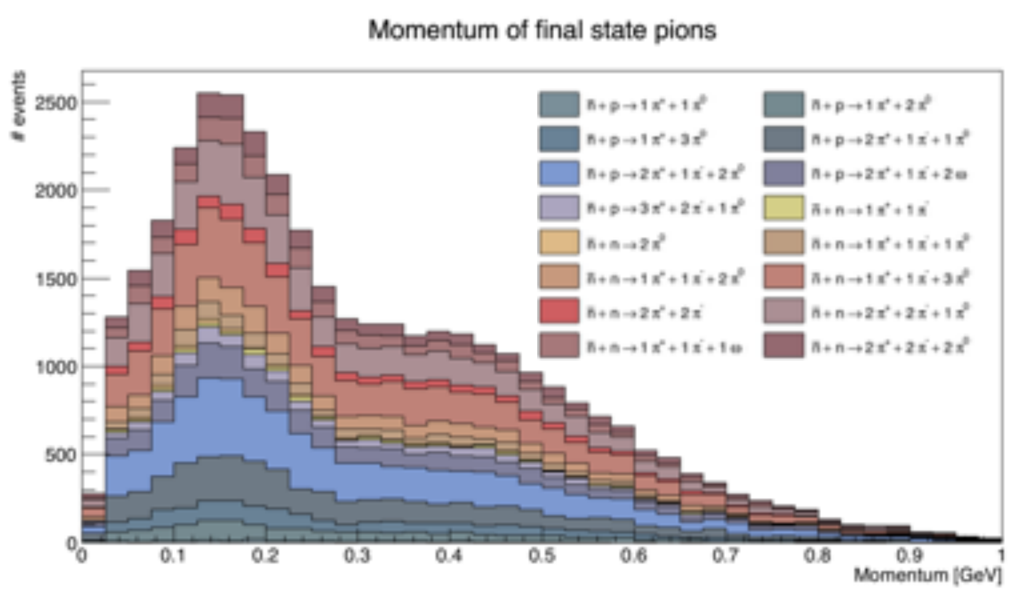
- GENIE's hadron transport package.
- Full cascade model, propagates hadrons through the nucleus.
- Cross-generator comparisons of pion multiplicities on a later slide.

GENIE-LArSoft interface

- GENIE output is a root ntuple in **gntp** format.
- Conversion to flat GENIE tree format **gst** still in progress.
- Use **gevdump** to export the output into a text file.
- LArSoft nucleon decay module in **larsim** module is actually just a GENIE parser, which can be used for importing <u>any</u> GENIE event.
    - Just edit the path in the .fcl file to point to your inputs.
    - Please get in contact if you want to try doing this!

Event generator outputs





- Once in LArSoft format, can use standard MicroBooNE simulation chain.
- Works for any atomic nucleus.
- Compare with quoted SK values for generator cross-check.
- Disagreement likely due to use of GENIE hA model (full cascade model).
- Studies involving hN (data-driven effective model) currently underway.

Metric	Super-K (^{16}O)	GENIE (^{16}O)	GENIE (^{40}Ar)
Total π multiplicity	3.5	5.0	4.4
Charged π multiplicity	2.2	3.3	3.0
Average charged π momentum (MeV/c)	310	280	270
Charged π momentum RMS (MeV/c)	190	180	180

Lifetime limit calculation

- Lifetime limit set on nnbar using a Poisson distribution as a function of the **width Γ**:

$$P(\Gamma|n_{obs}) = A\int\int\int \frac{e^{-(\Gamma\lambda\epsilon+b)}(\Gamma\lambda\epsilon+b)^{n_{obs}}}{n_{obs}!}P(\lambda)P(\epsilon)P(b)d\lambda d\epsilon db$$

$$\int_0^{\Gamma_{90\%}} P(\Gamma|n_{obs})d\Gamma = 0.9$$

Γ = Oscillation width
n_{obs} = No. events observed
A = Normalisation constant
λ = Exposure
ε = Selection efficiency
b = Background rate

- Crucial inputs are **value** and **uncertainty** of:
  - Background rate **b**
  - Signal selection efficiency **ε**
- Evaluating these will allow us to estimate sensitivity in a large-scale LArTPC.

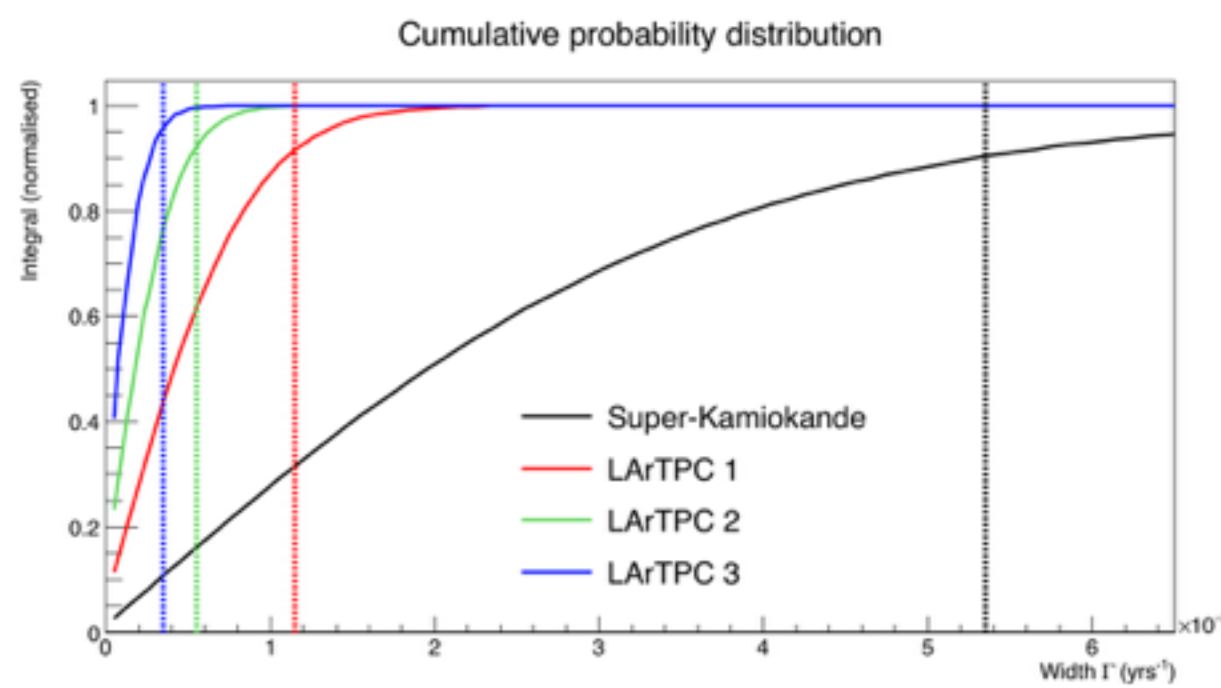
Prospects for LArTPCs

Inputs	ϵ (%)	σ_ϵ (%)	λ (kT.yrs)	σ_λ (kT.yrs)	b	σ_b	n_{obs}
Super-Kamiokande	12.1	2.771	204	6.2	24.1	5.712	24
LArTPC 1	50	3	163.2	6.3	20	5	20
LArTPC 2	70	3	163.2	6.3	10	3	10
LArTPC 3	90	3	163.2	6.3	5	2	5

Assumed

Inputs	90% CL limit (yrs)
Super-Kamiokande	1.9×10^{32}
LArTPC 1	8.7×10^{32}
LArTPC 2	18.2×10^{32}
LArTPC 3	28.6×10^{32}

- Sensitivity calculated for a range of assumed inputs.
- Next step is to generate sensitivity surface, identify which parameters we need to optimise towards.
- Long-term goal is to use MC/data and event reconstruction to determine these inputs, & therefore DUNE's sensitivity to nnbar.



Summary

- Events generated using GENIE/LArSoft.
  - Custom GENIE module.
  - GENIE output > text file > LArSoft inputs.
- Carrying out generator cross-checks / different models.
- Investigating sensitivity as a function of inputs.
- Developing reconstruction to determine the value of these inputs.
- Final goal: sensitivity estimation for DUNE.