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Alternative methods for hadron collection

status and plan

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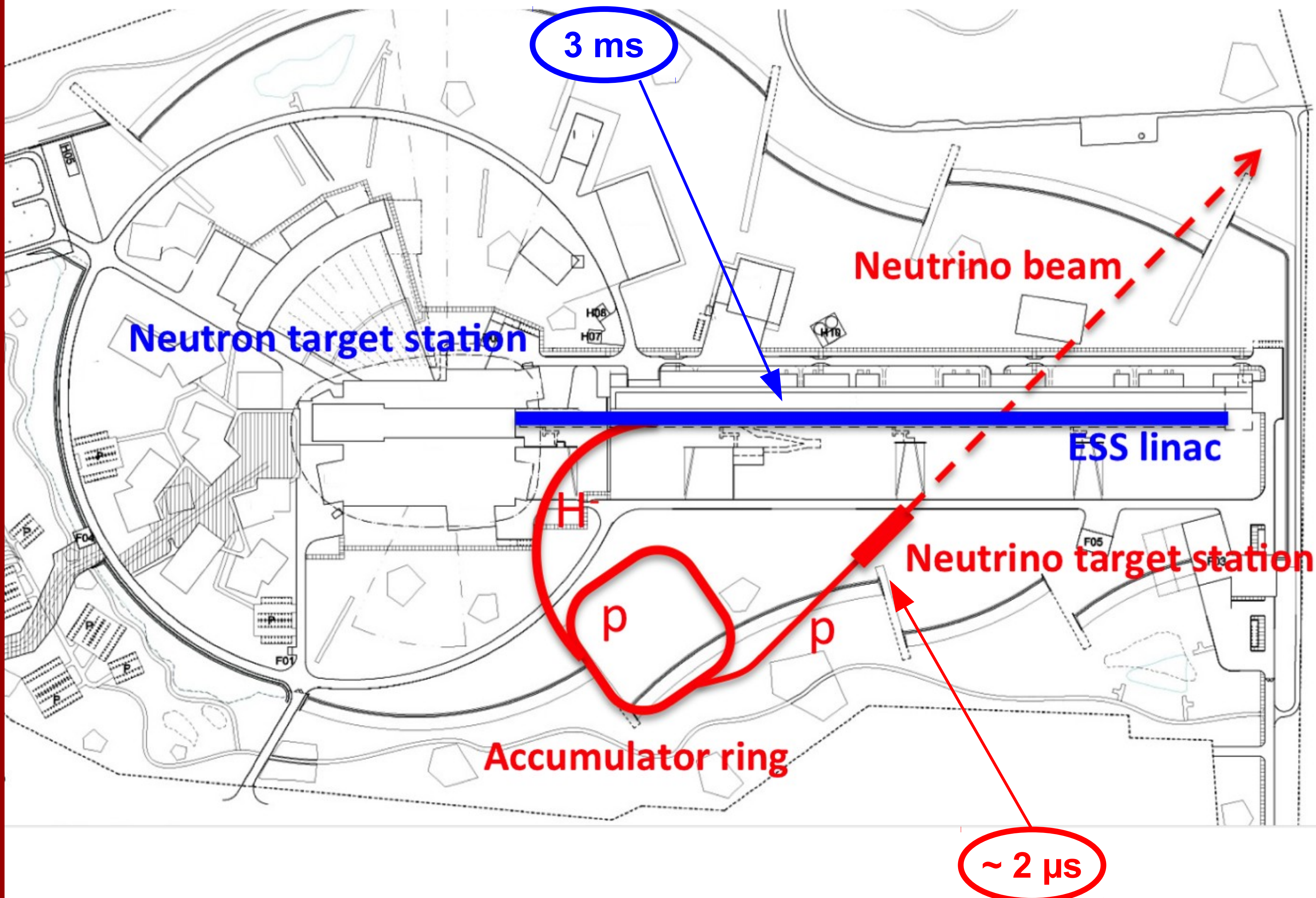
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Outline

- Motivation: Why alternatives?
- Beam and physics requirement
- What are the alternatives?
  - Solenoids + dipole
  - Los Alamos device
- Outlook

ESS → ESSnuSB



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Why an alternative?

A (quasi-)DC pion-focusing system would mean

- no accumulator ring!
- no H- operation
- no complicated pulsing scheme in linac
  (56 Hz, 100 µs injection gaps, 100 ns extraction gaps…)

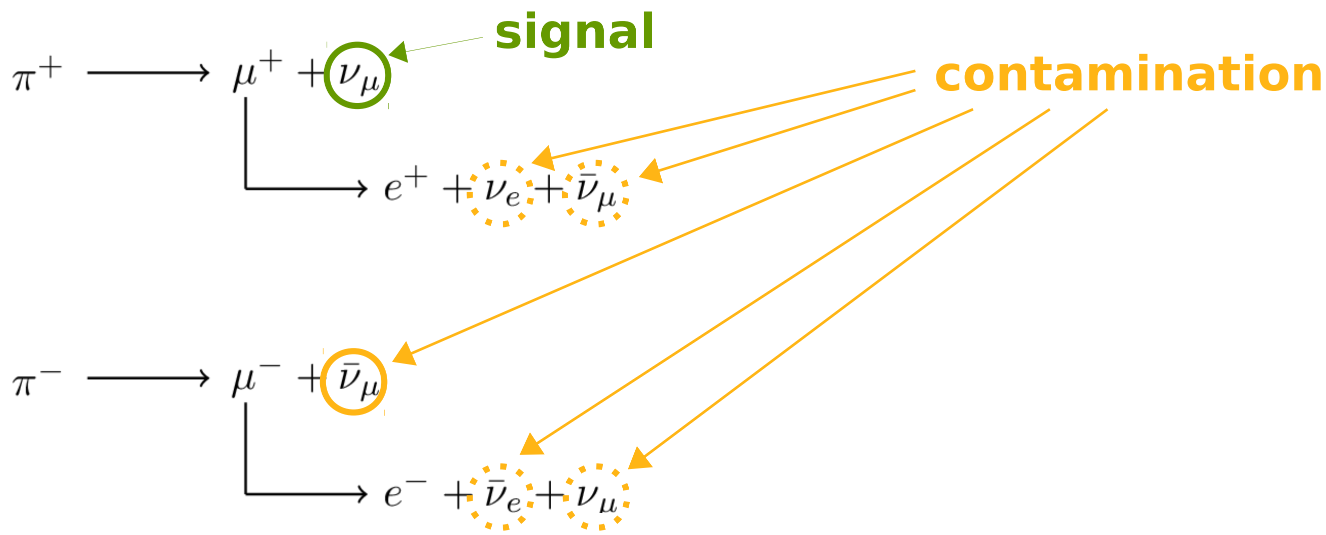
➡ “Only” a doubling of

•the linac pulse frequency from 14 Hz to 28 Hz

•the duty factor from 4% to 8%, and,

•the average beam power from 5 MW to 10 MW

Collector requirements



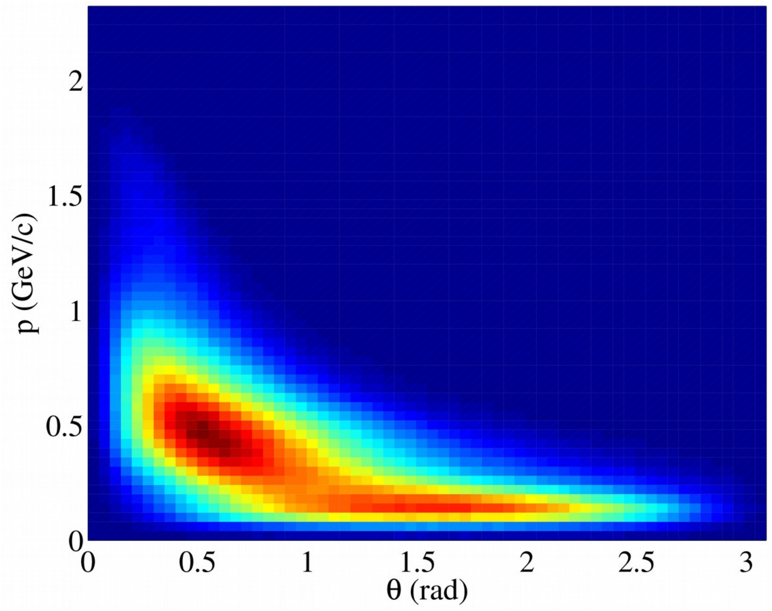
The pion collector must be able to provide

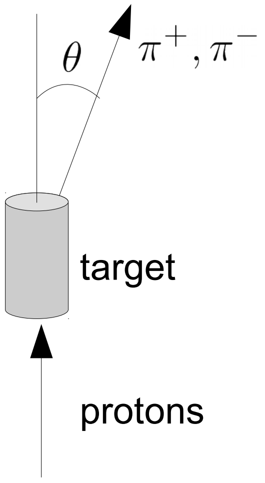
- point-to-parallel (roughly) focusing within X meters
- pion charge separation within ~1 m

> We cannot afford to lose in efficiency compared to the van der Meer horn.

The pion “source”

- Pion distribution very wide both in polar angle and in momentum.
  - target *inside* the collector.
  - generous momentum and angle acceptance required





Pion distribution provided by N. Vassilopoulos

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The neutrino "source"

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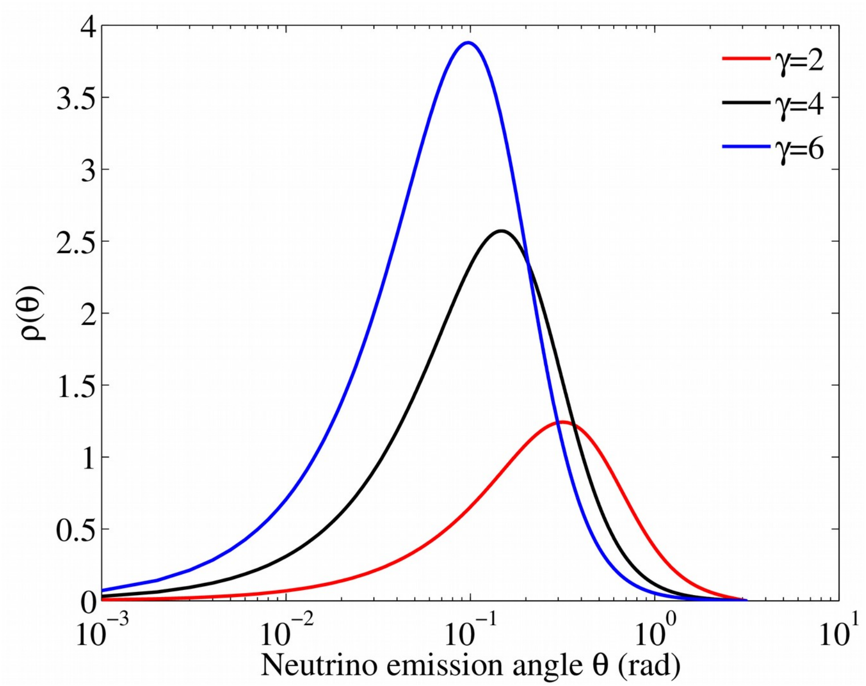
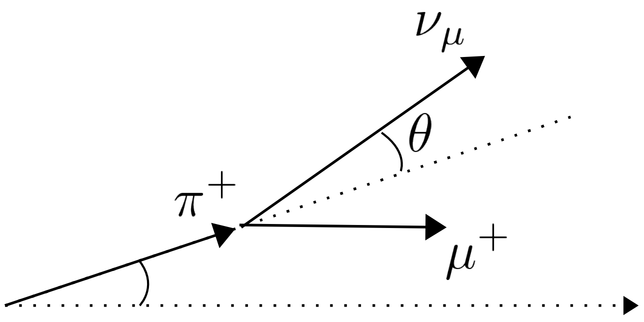
- Only crude focusing needed: Neutrino super beam divergence dominated by neutrino emission angle.





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Other options?

abandoned

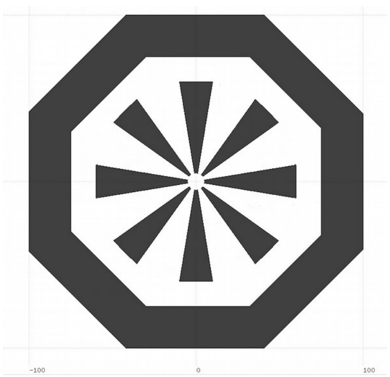
- Superconducting van der Meer horn
  - not realistic due to quenching when particles cross the conducting surface

doubtful

- Solenoid(s)
  - superconducting
  - dipoles added for charge separation

promising

- Los Alamos device
  - normal-conducting
  - DC or long pulses



A solenoid collector

- Pion collectors based on solenoids studied for muon colliders and neutrino factories
  - experimental tests of a 15-20 T solenoid for a liquid mercury target (MERIT; Kirk et al.)
- Kahn, Diwan and Palmer (BNL) studied a solenoid collector for a super-beam experiment
  - Tapered solenoid: adiabatic device
    - **Collection efficiency demonstrated**
  - dipole inserts suggested for charge separation

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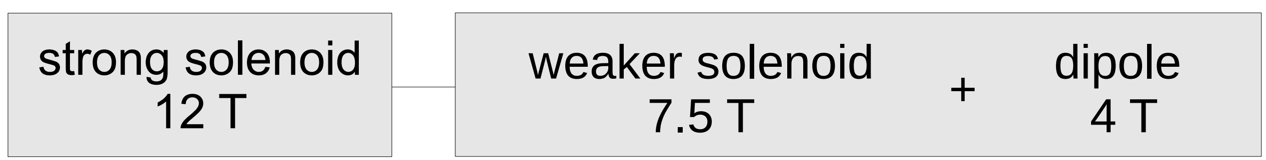
Solenoid collector: Feasibility test

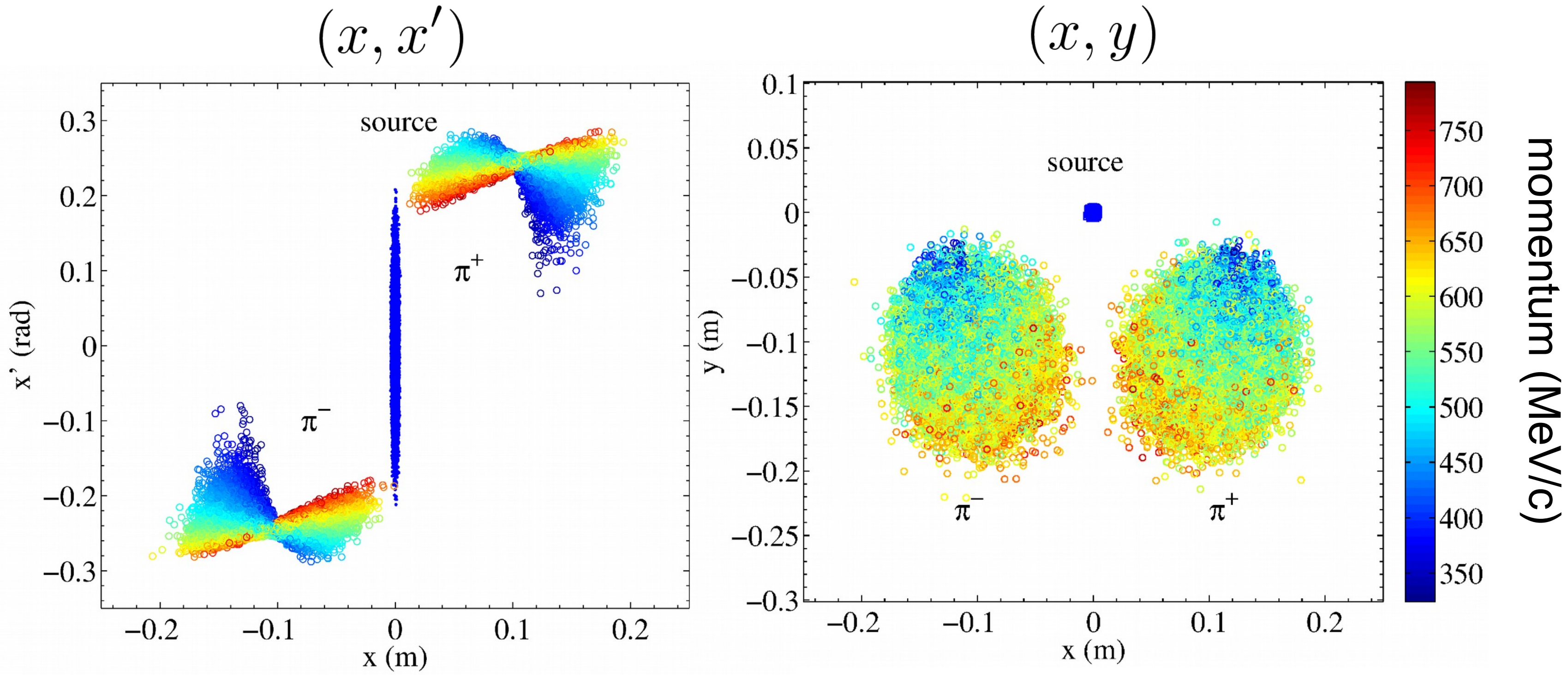
A “quarter-wave transformer” with a superimposed dipole field transforms a small, highly divergent beam into a large parallel beam

- Pion source:
  - 550 MeV, 10% spread
  - 1 mm size, 50 mm divergence
  - Gaussian distribution



Total length of system: ~1 m

Solenoid collector: result



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Solenoid collector: conclusions

✓ Demonstration of focusing capabilities.

- Extensive studies done in the past. Results are positive.

? Charge-separation scheme in combination with focusing.

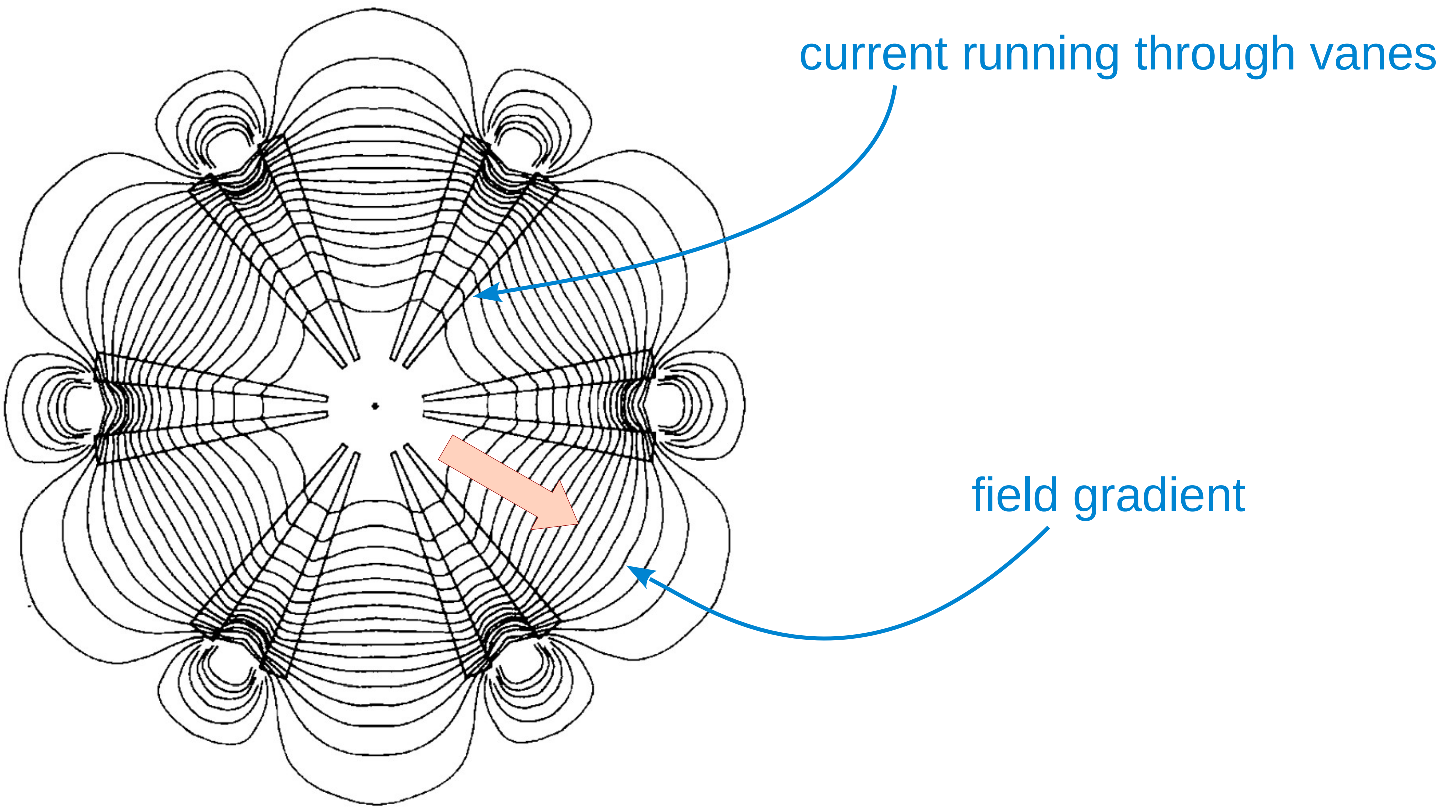
- Works for limited momentum spread and limited divergence.

X Shielding of superconducting coil.

- 0.4 m of lead is needed to absorb most of the energy from a 1 GeV pion.

The Los Alamos Device

- Studied for a meson physics experiment based on a 800 MeV proton beam at Los Alamos in the 90s (Koetke *et al.*)
- Prototype magnet built and tested (Dombeck *et al.*)



Fairly low current needed → DC operation or long-pulse mode possible

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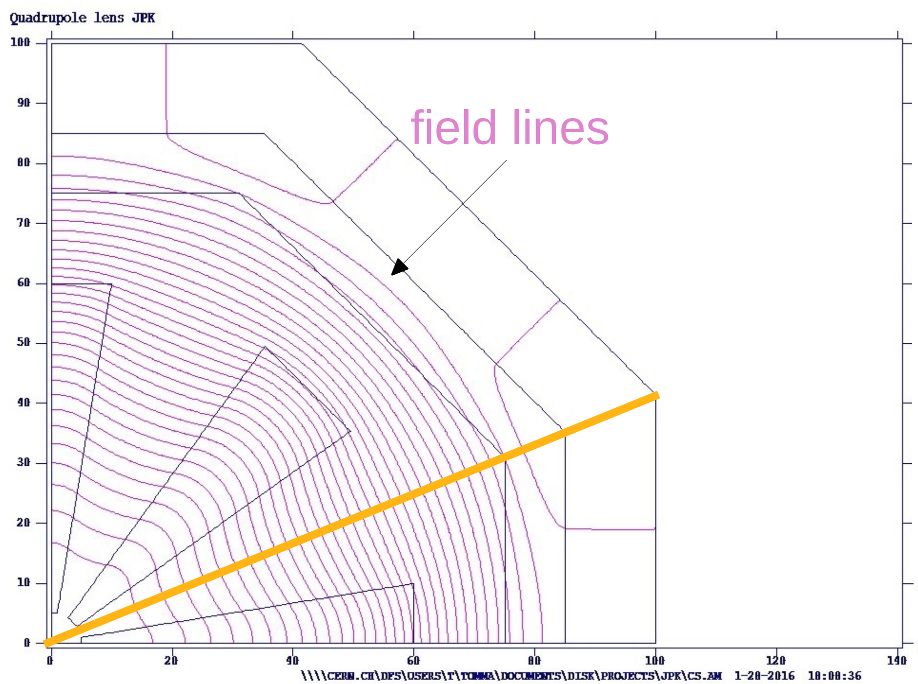
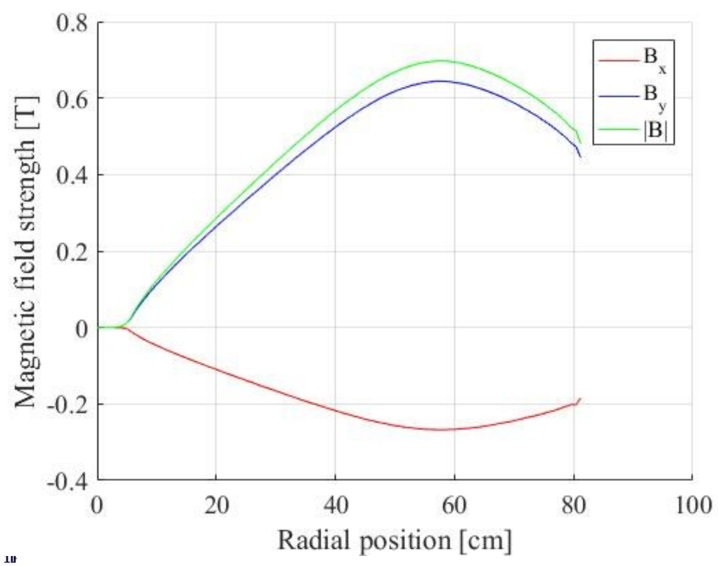
Adaptation to ESSnuSB

- J.-P. Koutchouk asked Davide Tommasini at CERN to make a computer model for our case:
  - scale the field to move from 800 MeV to 2 GeV beam
  - 8 vanes
  - 2D model with *Bx* and *By* along the yellow line





Davide Tommasini

Los Alamos device: feasibility test

- Use 2D computer model of magnetic field
- Build geometry in FLUKA
  - import magnetic field from
  - Los Alamos device
- Import pion source generated by N. Vassilopoulos

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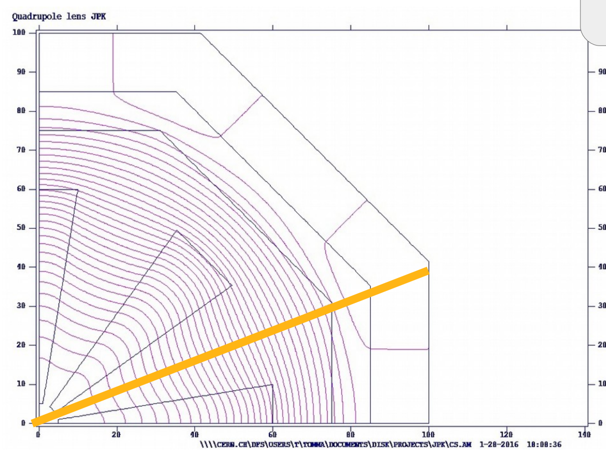
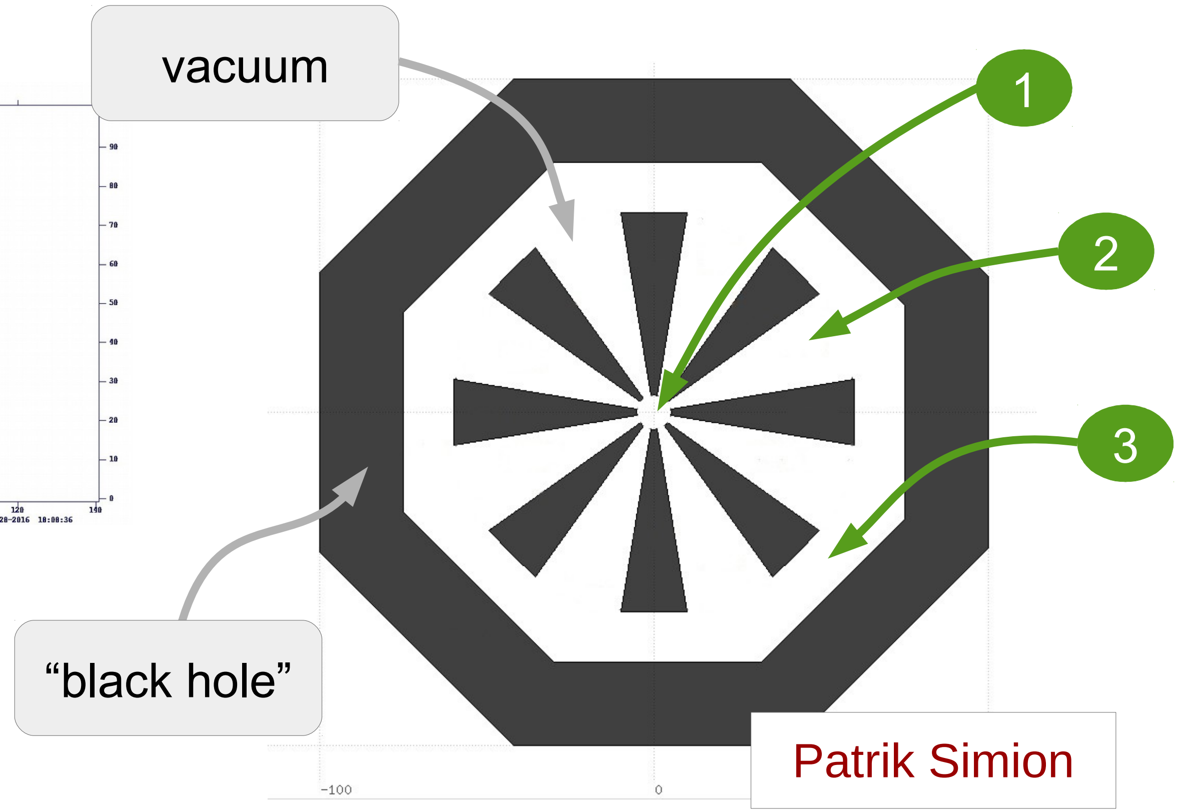
Los Alamos device: FLUKA model





1 Field ~0 T

2 Field straight line, perpendicular to the reference line.
Strength defined by magnetic field map.

3 Field circular, strength defined by magnetic field map.

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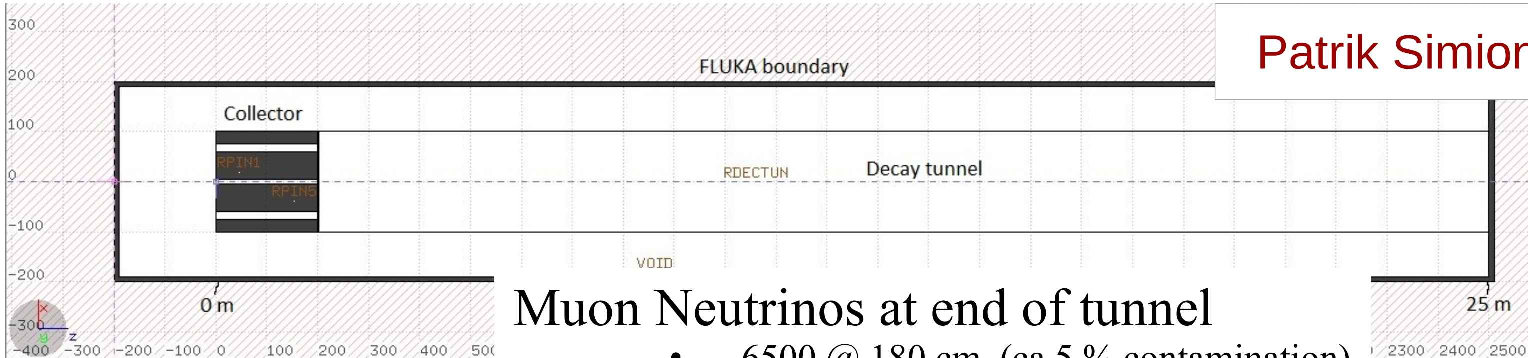
Los Alamos device: tracking



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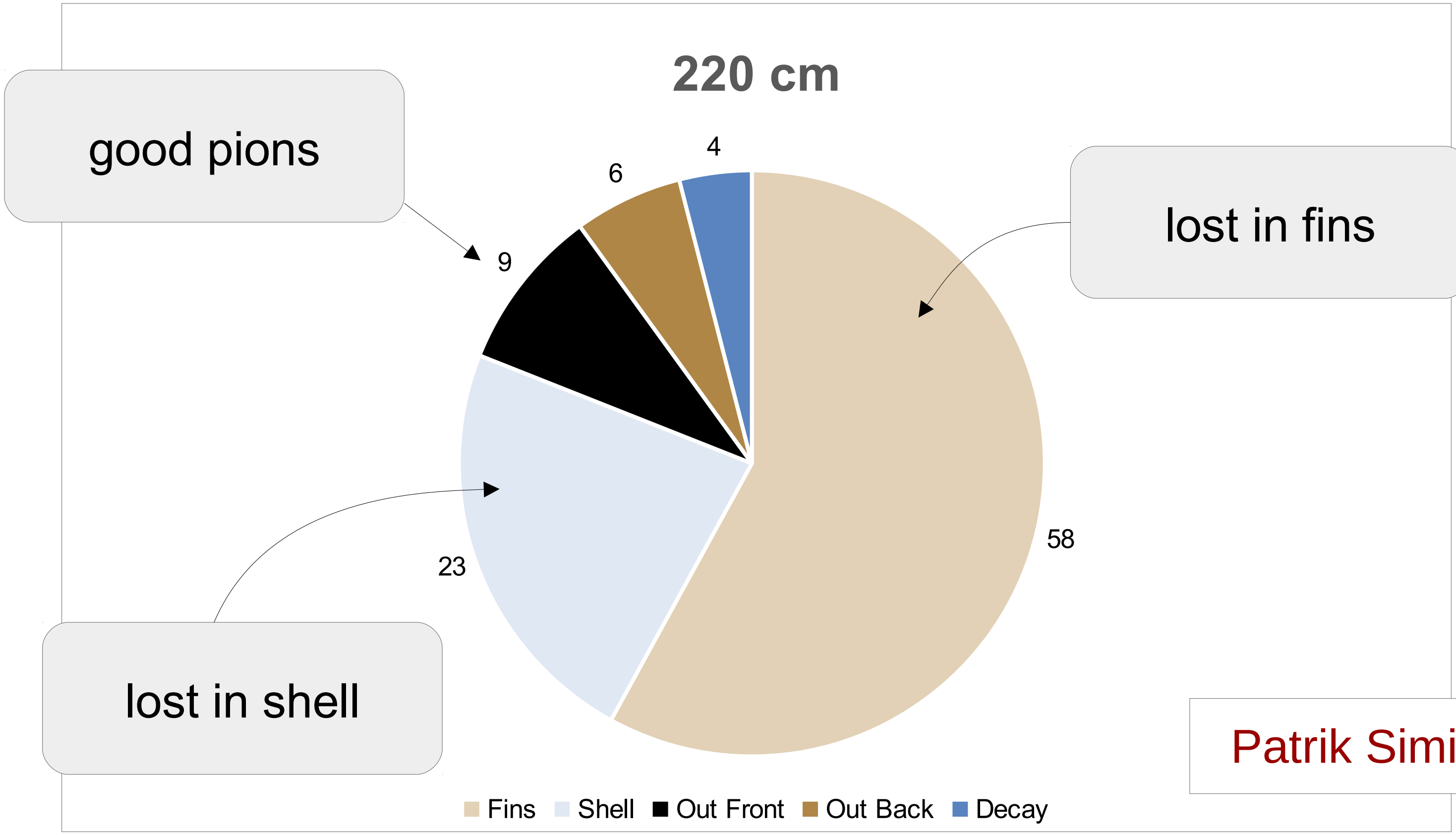
Muon Neutrinos at end of tunnel

- 6500 @ 180 cm (ca 5 % contamination)
- 8100 @ 200 cm (ca 3.5 %)
- 8800 @ 220 cm (ca 2.5 %)

- Choose length
- Let pions decay, track particles until end of decay tunnel
- Check where particles are lost
- Neutrinos at the end of tunnel
  - Angle restriction for comparison
  - Make equivalent simulation with van der Meer horn
  - Compare with no focusing and perfect focusing

Los Alamos device: lost particles



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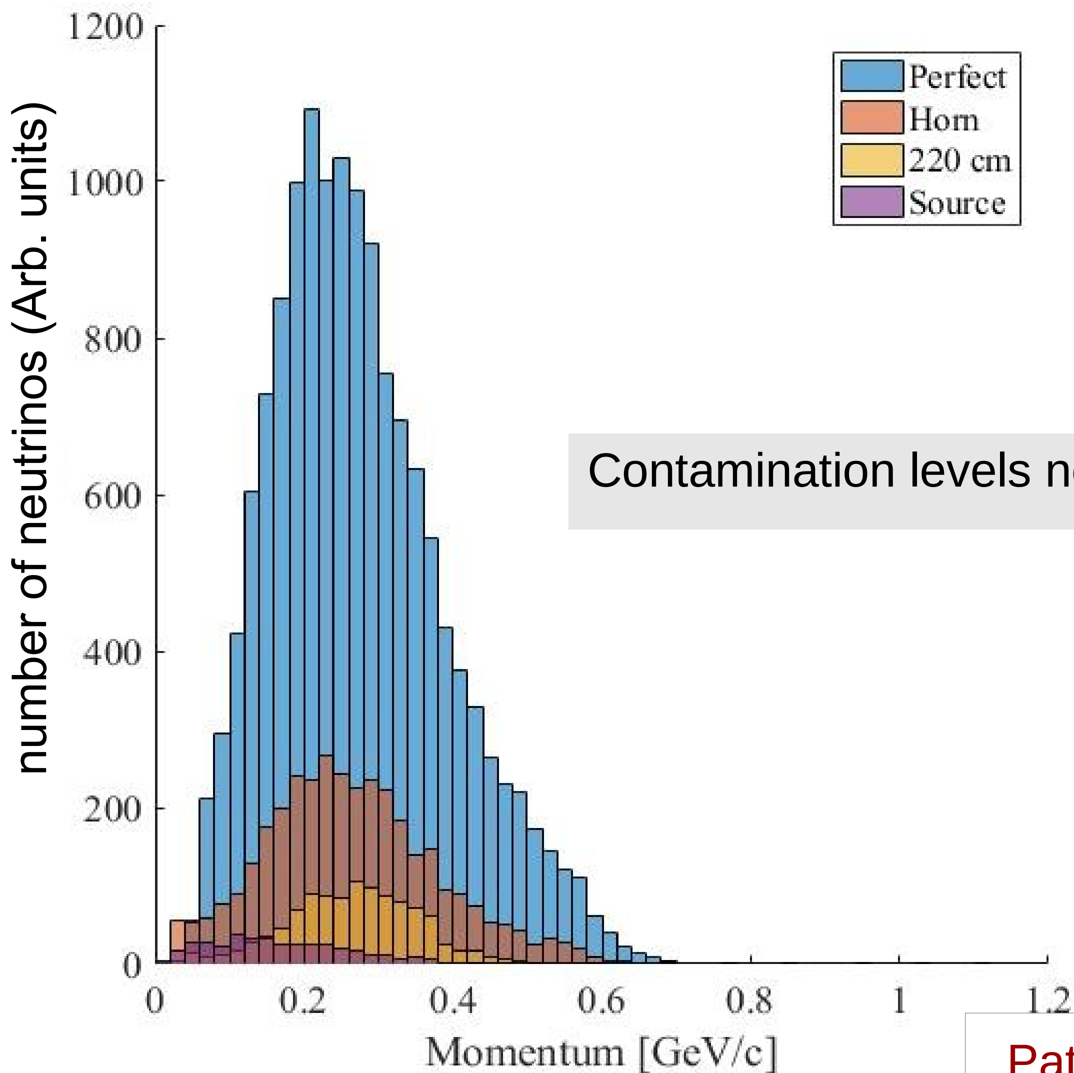
Energy deposition and radiation damage has not been considered.

Los Alamos device: result



Contamination levels not yet determined.

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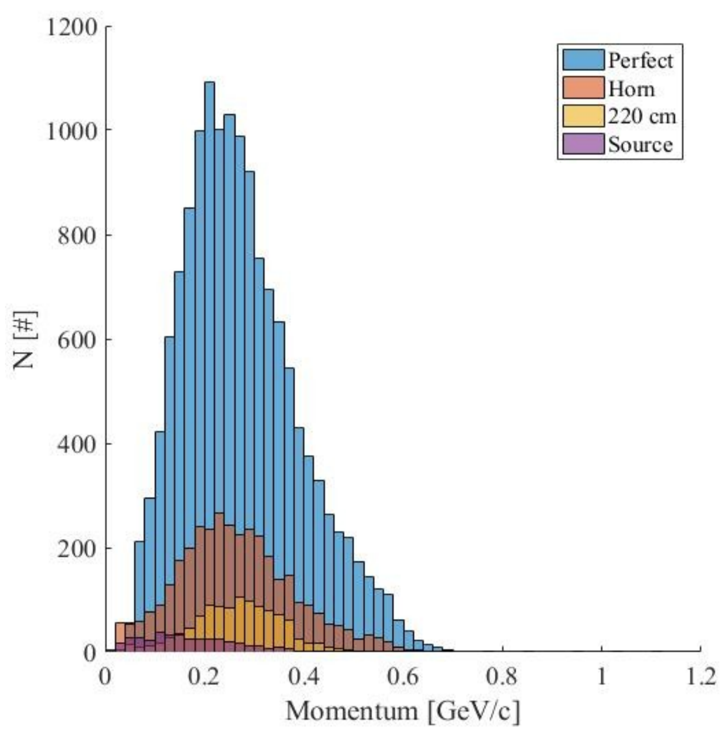
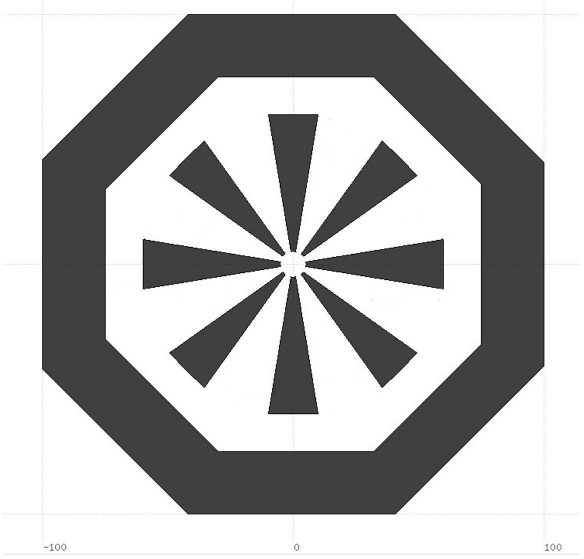
Los Alamos device: Outlook 1

Optimization possibilities:

- more narrow fins possible (with a 5 ms pulse)
- stronger current possible (from 5 to 10 kA/mm^2)
  - → Would give gain a factor 3-4 in “obstruction”





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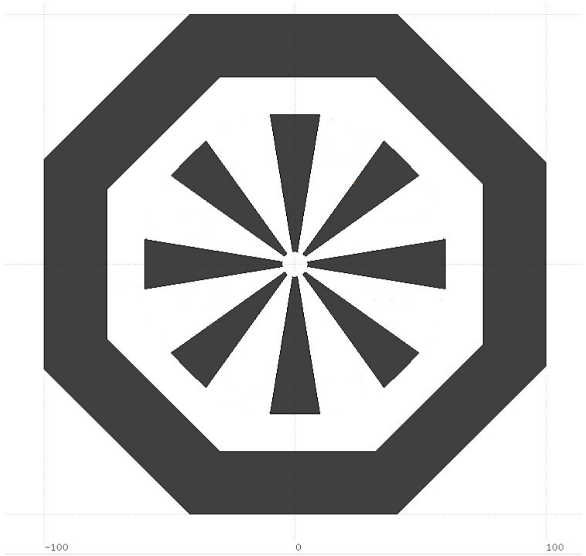
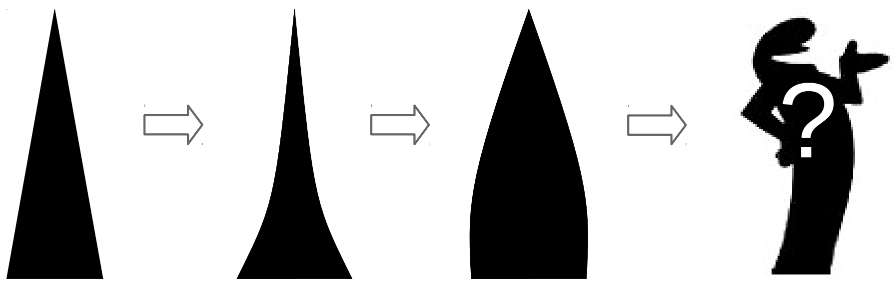
Los Alamos device: Outlook 2





adjustment of fin shape

Other steps:

- 3D calculation for less crude magnetic field map.
- Field shaping by shaping fins
  - could make the field deflecting close to the fins
- Field shaping by longitudinal variation.
- Realistic FLUKA simulation with realistic materials.
- Improve statistics, check contamination properly

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Summary

- A DC or long-pulsed collector is the holy grail of ESSnuSB.
- Solenoid focusing will probably not work because
  - charge separation seems hard or impossible;
  - it would probably quench.
- The Los Alamos collector needs more study:
  - increase the acceptance and efficiency by optimizing shapes and currents
  - check the contamination levels
  - look into energy deposition

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Many thanks to: Patrik Simion
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and Jean-Pierre Koutchouk

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