LIVINGSTON Study

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LIVINGSTON

cataLogIng Very INterestinG STatistics of NeutrinO experimeNts

LIVINGSTON -END

LIVINGSTON plot - **E**xtra **N**eutrino **D**etectors

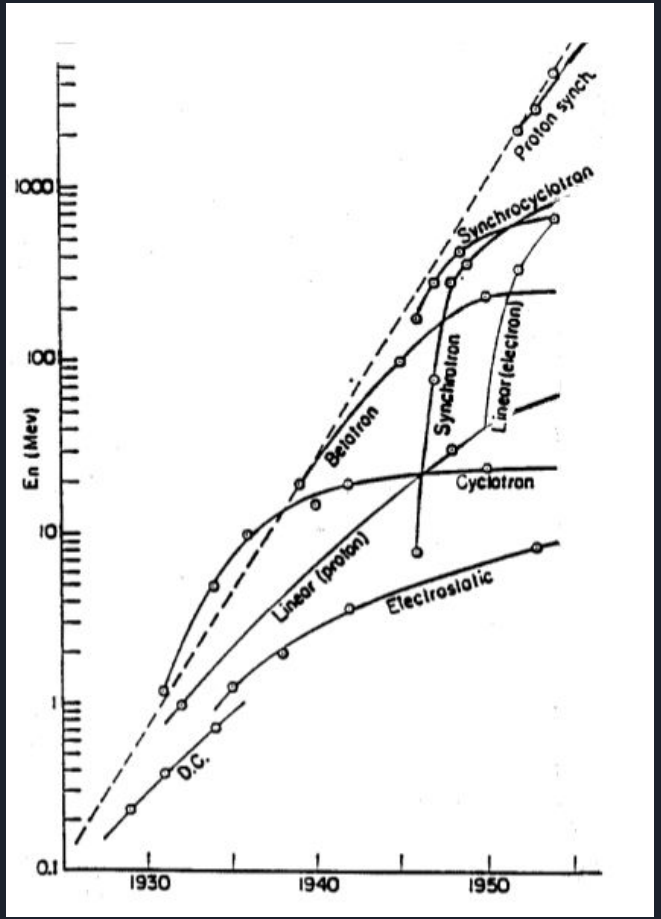
Question Statement

Neutrino Detector Livingston Plot

The Livingston plot is a famous representation of progress in the construction of particle accelerators. This problem asks you to prepare a similar plot to show progress in neutrino detectors. The first neutrino detector “El Monstro” was constructed by Reines and Cowan in the 1950s. For each decade since then and looking ahead into the future, find a few representative neutrino detectors and tabulate some essential data summarizing the detector technology. For example: experiment name, dates of operation, detection technology, mass (in tons), granularity (is cm). If you can find it, also detector cost. You are encouraged to divide the task among several groups and share your data to ensure the best possible coverage. With the data in hand, what plot or plots can you make which best represent progress in neutrino detector technology?

Livingston Plots

- This is a plot found in the book High Energy Accelerators by M. Stanley Livingston in 1954
- The dashed ‘Stanley Line’ indicates the trend that accelerator energy was doubling every six years



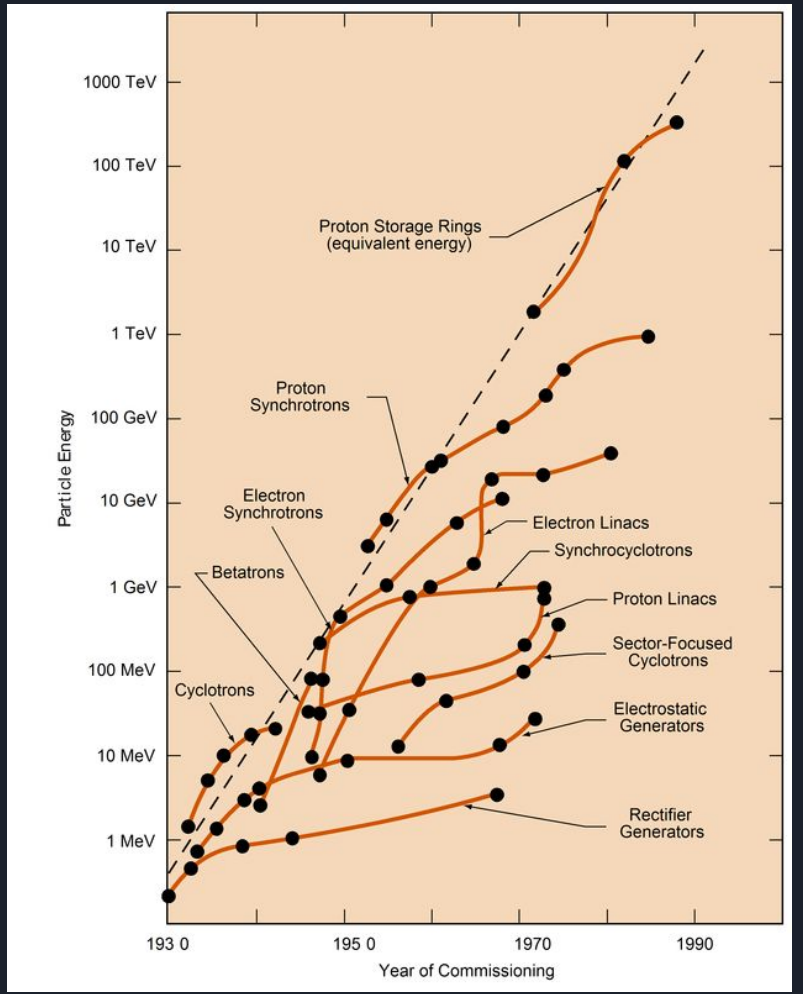
M. Stanley Livingston, “High Energy Accelrators” (1954).

Grievance 1

1. **Don’t steal**

Livingston Plots

- The Livingston Plot is routinely reproduced
  - This one is from 1999
- There are 30,000 particle accelerators in operation in the word
  - symmetry magazine article

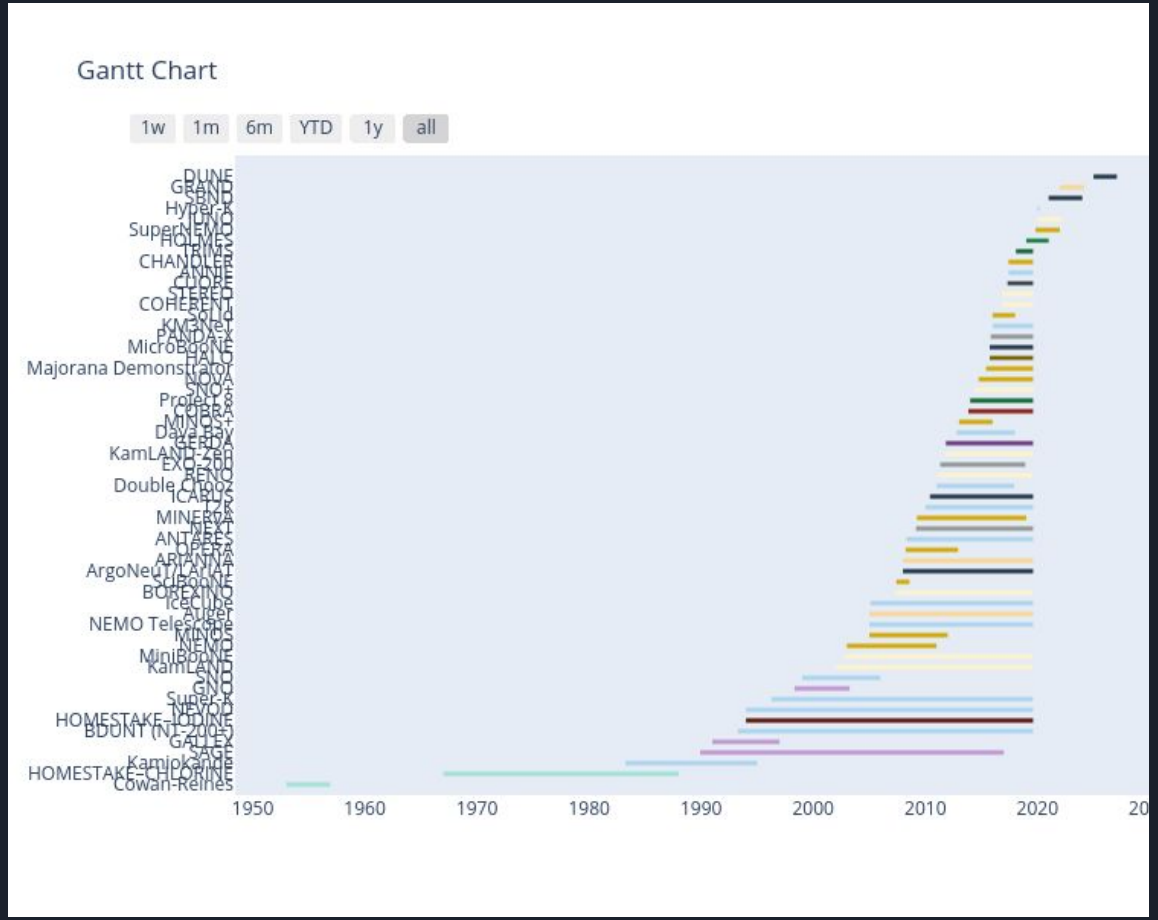


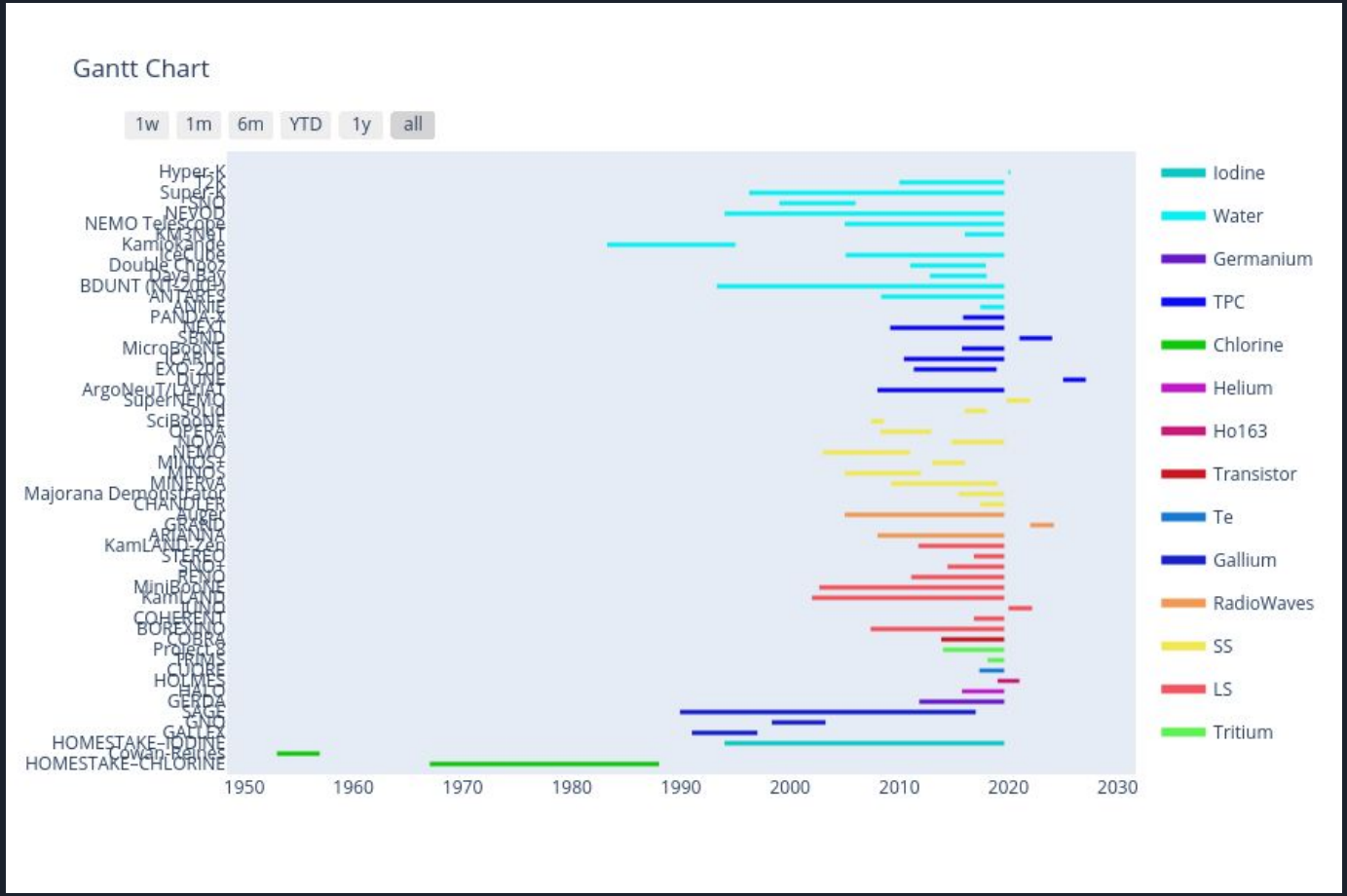
http://www.ischebeck.net/media/Accelerator%20Physics/Advanced%20Accelerator%20Concepts/Livingston%20Plot/slides/Livingston%20Plot%201.html

Our Data Sample

We collected a list of **73 neutrino experiments**

ANNIE ANTARES ArgoNeuT/LArIAT ARIANNA BDUNT (NT-200+) BOREXINO CHANDLER CLEAN COBRA COHERENT Daya Bay Double Chooz DUNE EXO-200 GALLEX GERDA GNO GRAND HALO HERON HOMESTAKE–CHLORINE HOMESTAKE–IODINE ICARUS IceCube India-based Neutrino Observatory JUNO Kamiokande KamLAND KM3NeT LAGUNA LENS Majorana Demonstrator MicroBooNE MINERvA MiniBooNE MINOS MINOS+ NEMO-3 MOON NEMO Telescope NEVOD NOvA OPERA Auger RENO SAGE SciBooNE SNO SNO+ SoLid STEREO Super-K SuperNEMO T2K UNO SBND Hyper-K Cowan-Reines CASPER TRIMS ECHo Project-8 SHIPTRAP HOLMES NuMECS nEXO NEXT PANDA-X KamLAND-Zen CUORE CANDLES


Gantt Chart
1w
1m
6m
YTD
1y
all
DUNE
GERDA
SEND
Hyper-K
JUNO
HOLMES
CHANDLER
STEREO
COHERENT
KM3NeT
PANDAX
MicroBooNE
HALO
Majorana Demonstrator
SNOLAB
CUPID
CANDLES
MINOS+
Daya Bay
KamLAND-Zen
EXO-200
RENO
Double Chooz
ICARUS
T2K
MINERvA
NEXT
ANTARES
OPERA
ARIANNA
ANITA
ARGONEUT/ICARUS
SUBOONE
BOREXINO
IceCube
Super-K
NEMO Telescope
MINOS
NEMO
MiniBooNE
KamLAND
GNO
Super-K
NEMO
HOMESTAKE-CHLORINE
BDUNT (NT-200+)
GALLEX
SAGE
Kamiokande
HOMESTAKE-CHLORINE
Cowan-Reines
1950
1960
1970
1980
1990
2000
2010
2020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2030
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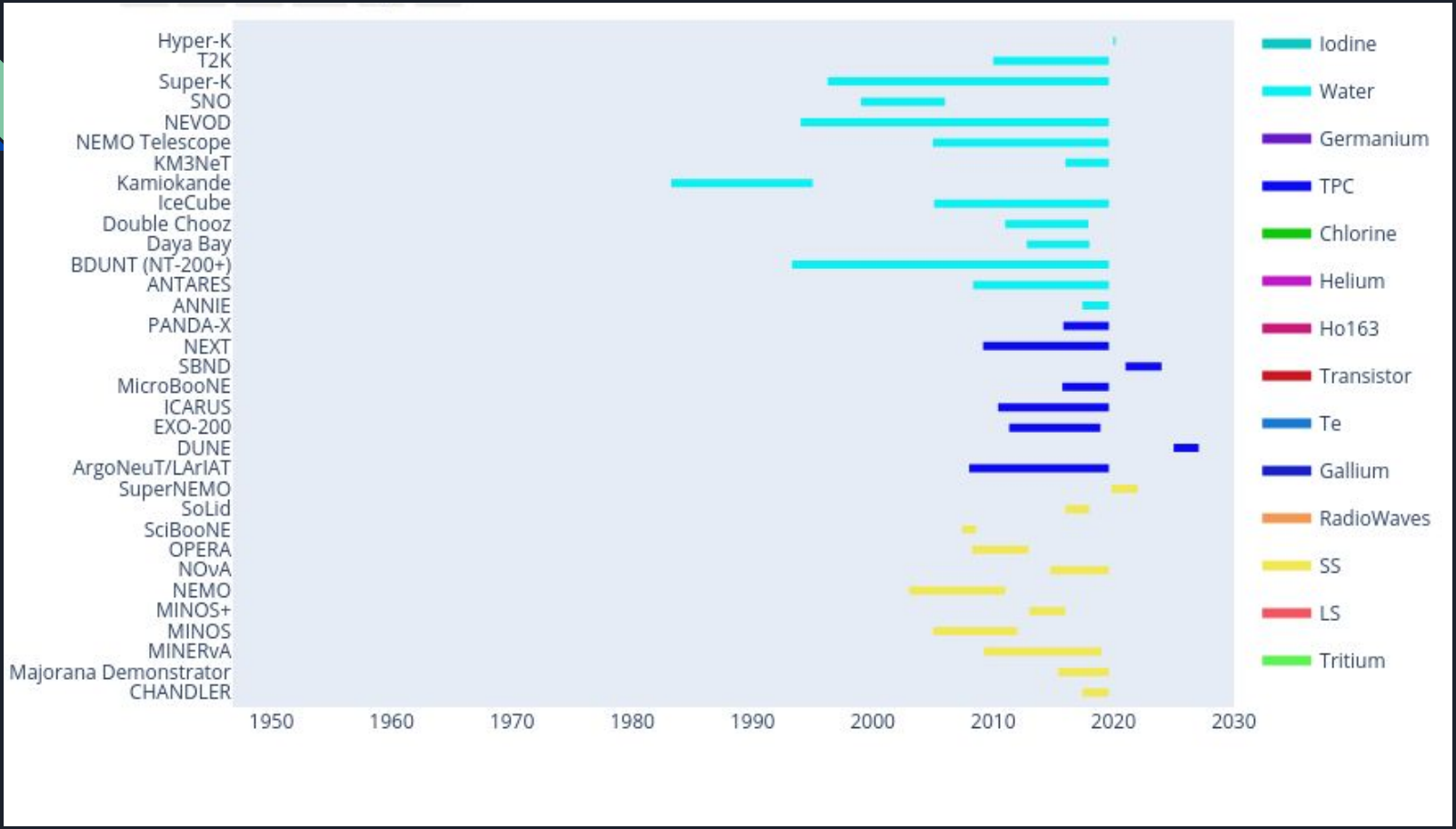
Water
Germanium
TPC
Chlorine
Helium
Ho163
Transistor
Te
Gallium
RadioWaves
SS
LS
Tritium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T2K
Super-K
SNO
NEVOD
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KM3NeT
Kamiokande
IceCube
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RENO
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KamLAND
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COHERENT
BOREXINO
COBRA
Project 8
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Grievance 2

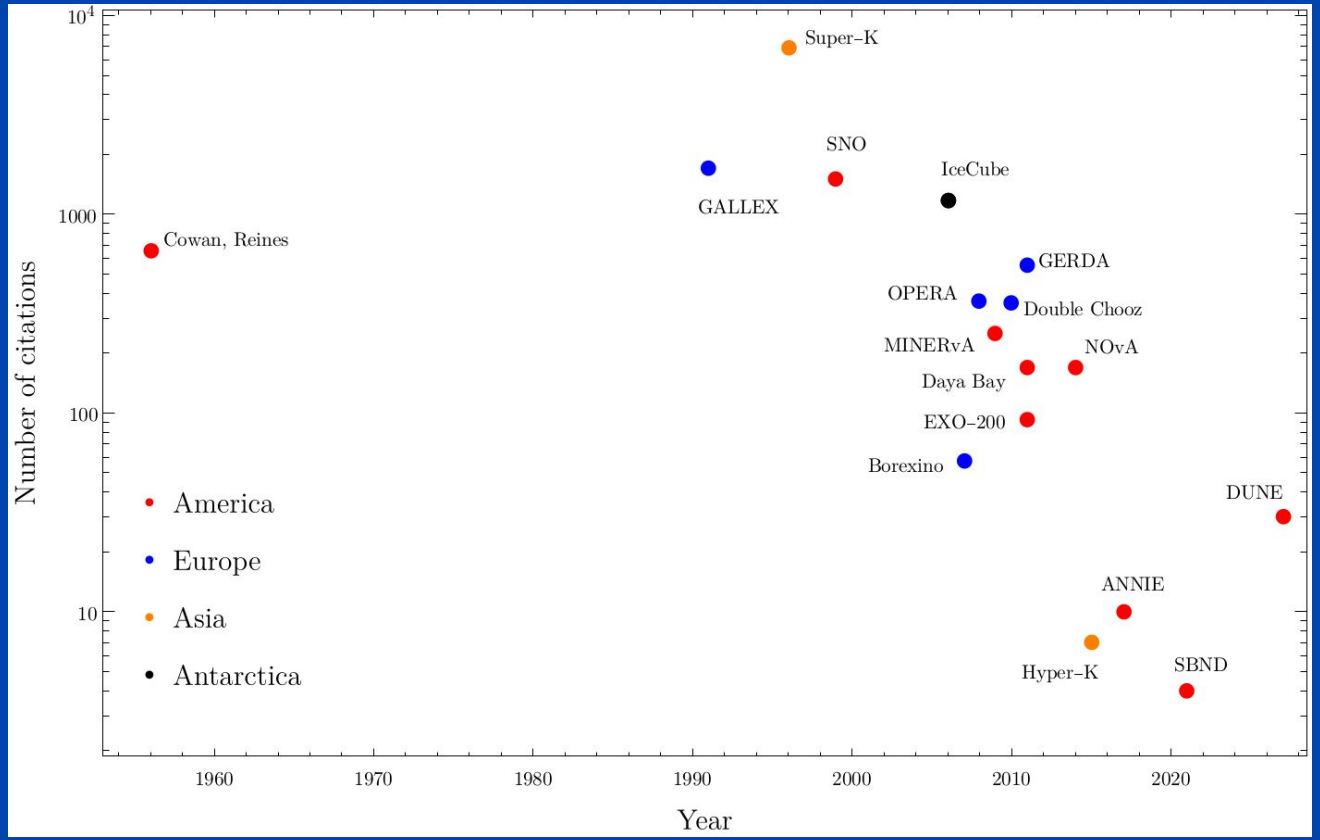
1. Don’t steal
2. Update Your Websites and Wikipedia Pages

Sub-Sample

Due to time constraints we could only analyze a few in a bit more detail

Super-K SNO ICECUBE Borexino OPERA MINERvA Double Chooz Daya Bay EXO-200 GERDA NOvA
ANNIE SBND Hyper-K DUNE

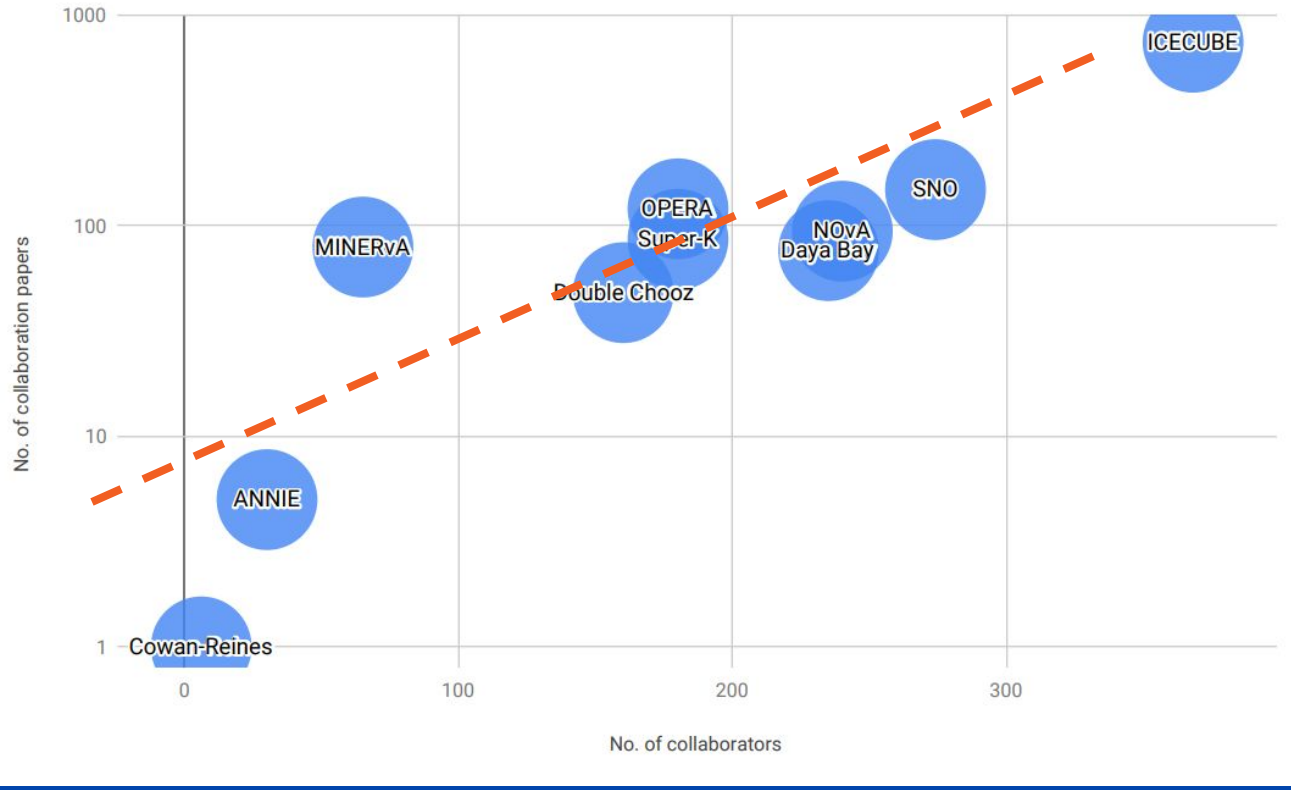
Citations vs Year



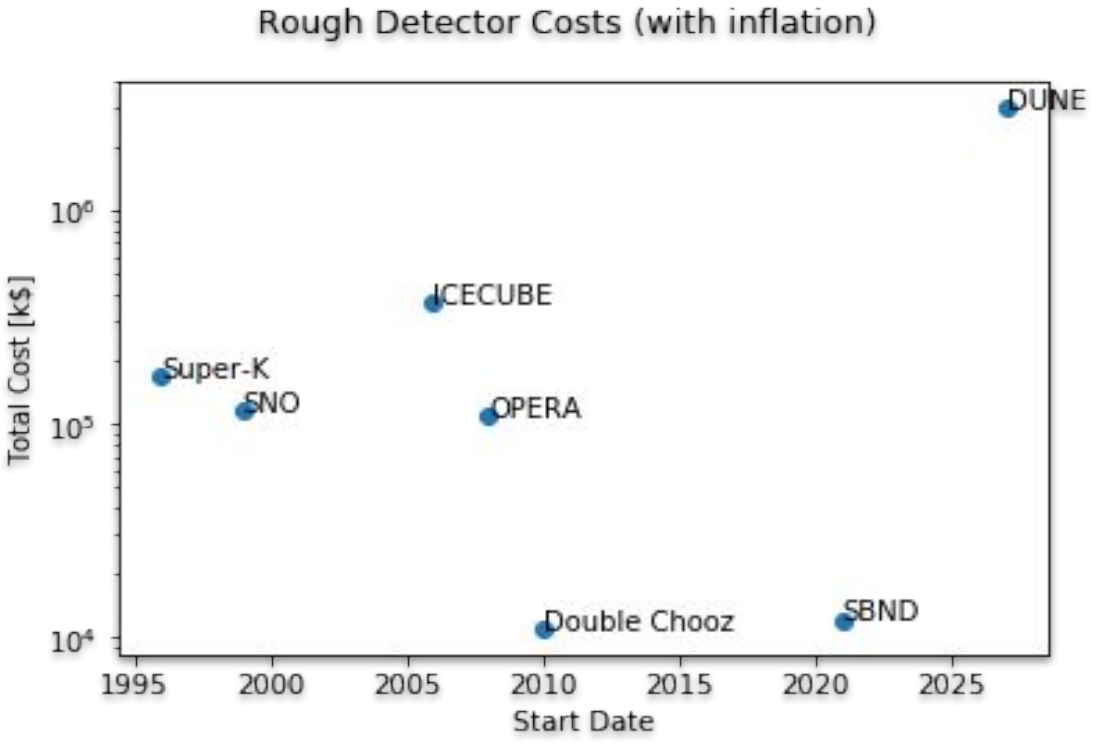
Number of Collaborators vs Citations

Eq:
nPapers ~
$7*10^{nCollabs/150}$

nPapers double every 45 collaborators

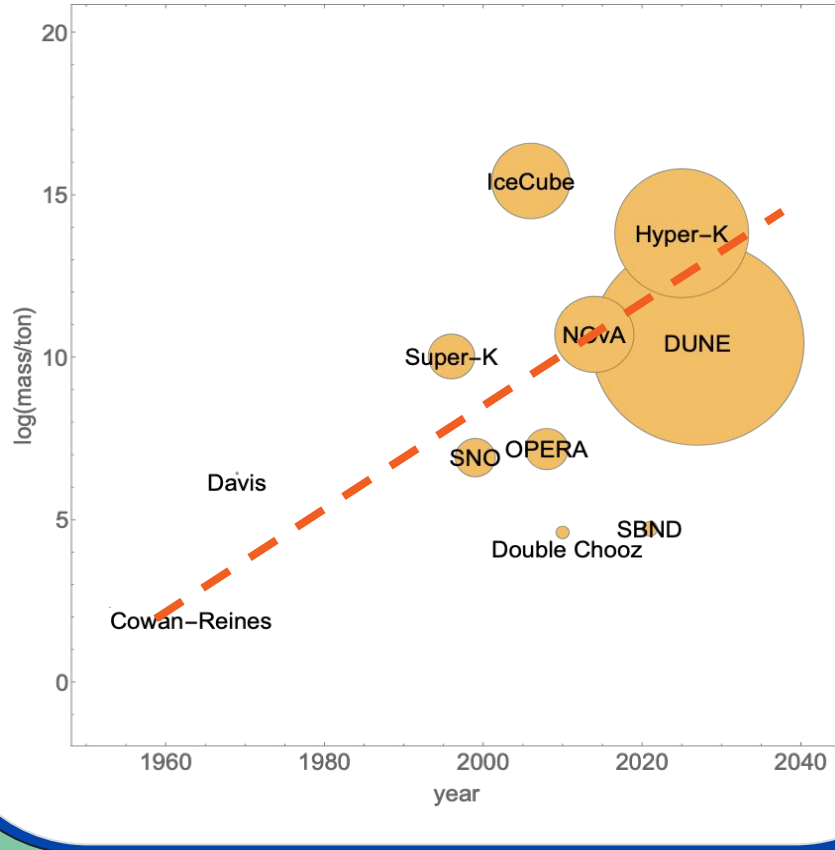


Detector Cost vs Start Date

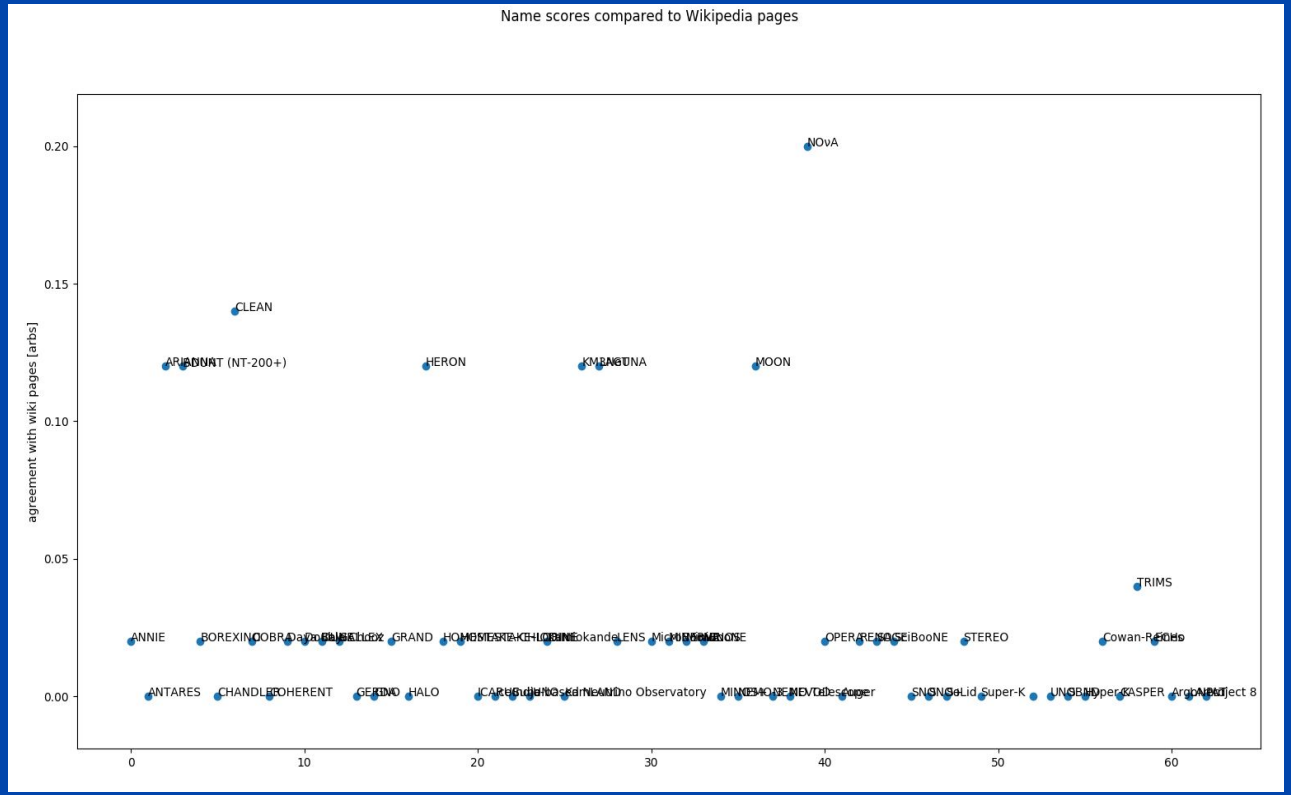


Mass vs Commissioning w. (price bubbles)

Eq:
Mass~M0*$10^{(year-1960)/37}$
Mass doubles every 10 years or so



Basic Relevance Study



Livingston Plots

- The one on the right is from 2013
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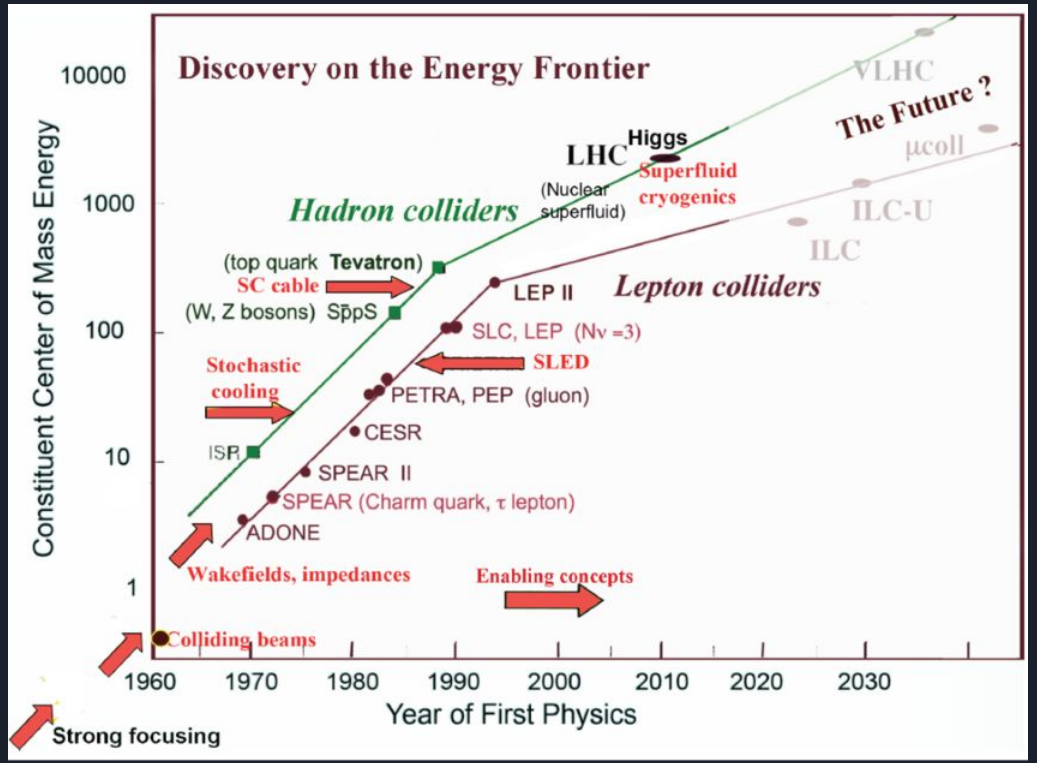

Planning the Future of U.S. Particle Physics (Snowmass 2013): Chapter 6: Accelerator Capabilities