

Data mining the EXFOR database

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5-8 November 2013, Geel, Belgium

BROOKHAVEN
NATIONAL LABORATORY

a passion for discovery



U.S. DEPARTMENT OF
ENERGY

Office of
Science

The EXFOR library contains nearly all experimental nuclear results

The screenshot shows the website www.nndc.bnl.gov/exfor/exfor00.htm. The page title is "Experimental Nuclear Reaction Data (EXFOR)" with a database version of June 21, 2013. A "News" window is open, listing updates from 2011/12 to 2012/07. Below the news is a "Request" search form with fields for Target, Reaction, Quantity, Product, Energy from, Author(s), and Publication year. There are also sections for "Options", "Ranges (Z,A)", "Reaction Sub-Fields", and "Feedback and User's Input". A "Note" section explains search criteria. At the bottom, it credits the Database Manager as Boris Pritychenko and the Web and Database Programming as Viktor Zerkin.

- Data from ~ 20,000 experiments
- Earliest experiments from 1935
- Most complete compilation of experimental nuclear data
- Mostly *n*-induced, but lots of CP-induced, photonuclear and other data

The EXFOR library contains nearly all experimental nuclear results

- Data from ~ 20,000 experiments

www.nndc.bnl.gov/exfor/exfor00.htm

Help » EXFOR-Manual | NNDC-Help | CSIRS/EXFOR History | Submit » Your Data | Databases » ENDF | CINDA | NSR

Experimental Nuclear Reaction Data (EXFOR)
Database Version of June 21, 2013
Software Version of 2012.09.19

News

- 2012/07 Sort by publications with extended view [example]
- 2012/07 Searching reactions: n,xp; p,xg, etc. [example]
- 2012/02 Improvements and extensions:
 - 1) Automatic data re-normalization (optional: for plots and output data only) [vi]
 - 2) Web-ZVView plotting: clipboard copy/paste
- 2011/12 Search in CINDA (+NSR) if data not found in EXFOR

[History]

The EXFOR library contains an extensive compilation of experimental nuclear reaction data. Neutrons have been systematically since the discovery of the neutron, while charged particle and photon reactions have been added more recently. The library contains data from 20029 experiments (see statistics and recent additions).

Request Examples: ...

Submit Reset Help

Target

Reaction

Quantity

Product

Energy from to eV

Author(s)

Publication year

Accession #

Options

- Ranges (Z,A)
- Reaction Sub-Fields
- Feedback and User's
 - Comments/Question
 - Previously submitted
- Clone Request: CINDA ENDF
- Extended
- Keywords
- Expert

Submit Reset

Note:

- all criteria are optional (selected by checking)
- selected criteria are combined for search with logical AND
- criteria separated in a field by ";" are combined with logical OR
- criteria starting with "^" will be used as logical NOT
- wildcards (*) and intervals (..) are available

Database Manager: Boris Pritychenko, NNDC, Brookhaven National Laboratory (pritychenko@bnl.gov)
Web and Database Programming: Viktor Zerkin, NDS, International Atomic Energy Agency (V.Zerkin@iaea.org)
Data Source: Network of Nuclear Reaction Data Centres

www.nndc.bnl.gov/exfor/servlet/X4sSearch5

Request #67723
Access-Level=2
Results: Reactions: 6 Datasets: 16

92-U-238(N,EL)

Data Selection

Retrieve Selected Unselected All Reset

Output: X4+ EXFOR Bibliography TAB C4 PlotC4

Plot: Quick-plot (cross-sections only) Advanced plot [how-to] using C5 and converting ratios to cross sections using [IAEA-standards,2006]

Narrow Energy (optional), eV: Min: Max:

Apply Data re-normalization (for advanced users, results in: C4, TAB and Plots)

| n | Display | Year | Author-1 | Energy range, eV | Points | Reference |
|------------------------------|---|------|-----------------|------------------|--------|------------------------------|
| 1) | 92-U-238(N,EL) 92-U-238,,SIG C4: MF3 MT2 | | | | | |
| Quantity: [CS] Cross section | | | | | | |
| 1 | Info X4+ X4± T4 Cov | 1990 | L.L.Litvinskiy+ | 2.75e5 | 1 | + J,YF,52,(4),1025,199010 |
| 2 | Info X4+ X4± T4 Cov | 1987 | L.L.Litvinskii+ | 5.50e4 1.44e5 | 2 | + J,AE,62,(3),192,198703 |
| 3 | Info X4+ X4± T4 Cov | 1984 | Shen Guanran+ | 1.42e7 | 1 | [pdf]+ J,CNP,6,193,198408 |
| 4 | Info X4+ X4± T4 Cov | 1982 | G.Haouat+ | 7.00e5 3.40e6 | 4 | [pdf]+ J,NSE,81,(4),491,8208 |
| 5 | Info X4+ X4± T4 Cov | 1978 | F.Y.Tsang+ | 1.44e5 | 1 | [pdf]+ J,NSE,65,70,197801 |
| 6 | Info X4+ X4± T4 Cov | 1968 | J.Voignier | 1.41e7 | 1 | + R,CEA-R-3503,6807 |
| 7 | Info X4+ X4± T4 Cov | 1966 | E.Barnard+ | 7.50e4 5.50e5 | 5 | [pdf]+ J,NP,80,46,6605 |
| 8 | Info X4+ X4± T4 Cov | 1965 | R.Batchelor+ | 2.00e6 7.00e6 | 4 | [pdf]+ J,NP,65,236,196503 |
| 9 | Info X4+ X4± T4 Cov | | | 2.00e6 7.00e6 | 4 | |
| 10 | Info X4+ X4± T4 Cov | 1956 | R.C.Allen+ | 5.00e5 1.00e6 | 2 | [pdf]+ J,PR,104,731,56 |
| 2) | 92-U-238(N,EL) 92-U-238,,SIG,,DERIV C4: MF3 MT2 | | | | | |
| Quantity: [CS] Cross section | | | | | | |
| 11 | Info X4+ X4± T4 Cov | 1988 | Ma Gonggui+ | 1.42e7 | 1 | + R,INDC(CPR)-11,135,198803 |
| 3) | 92-U-238(N,EL) 92-U-238,,SIG,,RECOM C4: MF3 MT2 | | | | | |
| Quantity: [CS] Cross section | | | | | | |
| 12 | Info X4+ X4± T4 Cov | 2006 | S.F.Mughaghab | 2.53e-2 | 1 | + B,NEUT.RES,,2006 |
| 4) | 92-U-238(N,EL) 92-U-238,,SIG,,MXW C4: MF=3 MT=? | | | | | |
| Quantity: [CS] Cross section | | | | | | |
| 13 | Info X4+ X4± T4 Cov | 1951 | C.T.Hibdon+ | 2.53e-2 | 1 | + R,ANL-4680,5,1951 |
| 5) | 92-U-238(N,EL) 92-U-238,,SIG,,SPA C4: MF=3 MT=? | | | | | |
| Quantity: [CS] Cross section | | | | | | |
| 14 | Info X4+ X4± T4 Cov | 1980 | V.P.Vertebnyy+ | 2.45e4 | 1 | + C,80KIEV,2,249,198009 |
| 6) | (92-U-238(N,EL) 92-U-238,,SIG)+(92-U-238(N,INL) 92-U-238,PAR,SIG) C4: MF=3 MT=? | | | | | |
| Quantity: [CS] Cross section | | | | | | |
| 15 | Info X4+ X4± T4 Cov | 1982 | A.B.Smith+ | 9.30e5 3.55e6 | 6 | + C,82ANTWER,,39,8209 |
| 16 | Info X4+ X4± T4 Cov | 1959 | L.Cranberg | 9.53e5 | 1 | + R,LA-2177,5901 |

```

ENTRY          11135      860905      20050926      0000
SUBENT         11135001   860905      20050926      0000
BIB            6         10
INSTITUTE      (1USACOL)
REFERENCE      (J,PR,60,702,4111)
                (J,PR,58,1004,40) COMMENT ON SPECTRUM.
AUTHOR         (H.CARROLL,J.R.DUNNING)
TITLE          THE INTERACTION OF SLOW NEUTRONS WITH GASES.
STATUS         (SCSRS)
HISTORY        (760628T) TRANSLATED FROM SCISRS
                (820108A) CONVERTED TO REACTION FORMALISM
                (840217A) REFERENCE CORRECTED.
                (860905A) ENERGY MOVED TO SAN 1.

ENDBIB        10
COMMON         1         3
EN-DUMMY
EV
  0.0253
ENDCOMMON     3
ENDSUBENT     17
SUBENT         11135009   860905      20050926      0000
BIB            3         12
REACTION       (1-H-1(N,TOT),,SIG,,MXW)
SAMPLE         H2O LIQUID
                AUTHOR ALSO GIVES DATA FOR 10 OTHER SAMPLES -
                H-2 GAS          - 31.8+-0.5 B
                CH(4) GAS         - 45.4+-0.3 B
                C(2)H(6) GAS       - 46.4+-0.5 B
                C(3)H(8) GAS       - 46.9+-0.6 B
                C(4)H(10) GAS      - 48.7+-0.6 B
                PARAFFIN          - 49.8+-0.2 B
                DOTRIACONTANE     - 50.2+-0.2 B

HISTORY        (780914C)
                (860905A) REACTION CORRECTED.

ENDBIB        12
NOCOMMON      0         0
DATA          2         1
DATA          DATA-ERR
B             B
  44.6        0.5
ENDDATA       3
ENDSUBENT     20
ENDENTRY      2

```

ENTRY 11135

Carroll & Dunning

“Interaction of slow neutrons with gases”

from Physics Reports 1941

```

ENTRY          11135      860905      20050926      0000
SUBENT        11135001    860905      20050926      0000
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BIB
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              PARAFFIN     - 49.8+-0.2 B
              DOTRIACONTANE - 50.2+-0.2 B

HISTORY      (780914C)
              (860905A) REACTION CORRECTED.

ENDBIB       12
NOCOMMON     0          0
DATA         2          1
DATA         DATA-ERR
B            B
  44.6       0.5
ENDDATA      3
ENDSUBENT    20
ENDENTRY     2

```

ENTRY 11135
 Carroll &
 Dunning
 “Interaction of
 slow neutrons
 with gases”
 from Physics
 Reports 1941;

This is 9th
 subentry on ¹H
 scattering

REACTION (1-H-1(N,TOT),,SIG,,MXW)

```

ENTRY          11135      860905      20050926      0000
SUBENT         11135001   860905      20050926      0000
BIB            6         10
INSTITUTE      (1USACOL)
REFERENCE      (J,PR,60,702,4111)
                (J,PR,58,1004,40) COMMENT ON SPECTRUM.
AUTHOR         (H.CARROLL,J.R.DUNNING)
TITLE          THE INTERACTION OF SLOW NEUTRONS WITH GASES.
STATUS         (SCSRS)
HISTORY        (760628T) TRANSLATED FROM SCISRS
                (820108A) CONVERTED TO REACTION FORMALISM
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ENDBIB        10
COMMON        1         3
EN-DUMMY
EV
  0.0253
ENDCOMMON     3
ENDSUBENT     17
SUBENT        11135009   860905      20050926      0000
BIB           3         12
REACTION       (1-H-1(N,TOT),,SIG,,MXW)
SAMPLE         H2O LIQUID
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                C(3)H(8) GAS     - 46.9+-0.6 B
                C(4)H(10) GAS    - 48.7+-0.6 B
                PARAFFIN         - 49.8+-0.2 B
                DOTRIACONTANE    - 50.2+-0.2 B

HISTORY        (780914C)
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ENDBIB        12
NOCOMMON      0         0
DATA          2         1
DATA          DATA-ERR
B             B
  44.6        0.5
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ENDENTRY      2

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 “Interaction of
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 from Physics
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This is 9th
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 scattering

The data is
 one spectrum
 averaged point



REACTION & MONITOR fields denote what reaction/quantity measured

- EXFOR REACTION fields and MONITOR fields have essentially the same format
 - REACTION denotes what is measured
 - MONITOR denotes what the REACTION is measured “relative” to
- For a simple measurement:

(1-H-1 (N, TOT) , , SIG , , MXW)

Reaction
studied

Quantity
measured

REACTIONS & MONITORS have complicated variants

■ Mathematical relations in REACTIONS and MONITORS:

- Reaction combinations:

$(3\text{-LI-6 (N,T) 2-HE-4 , , SIG , , SPA) / (92-U-235 (N,F) , , SIG , , SPA)$

any relation using +, -, *, /, //, = allowed

- “Isomer math”:

$(72\text{-HF-177 (N,G) 72-HF-178-M/T , , SIG/RAT)$

■ Several reactions/quantities have special meanings:

- ALF: capture-to-fission ratio
- ETA: ave. neutron yield per nonelastic event for n -induced reactions
- RI: resonance integral
- NON, INEL, SCT: all obey sum rules


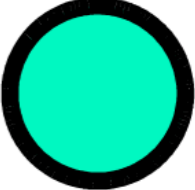



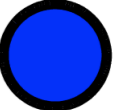




■ Elemental data

- weighted average of reaction on isotopes comprising element





**These variants encode connections
between simple REACTIONS**

**Can we learn anything just looking at
the REACTIONS and MONITORS
alone?**

Types of nodes

| Description | Example |
|--|---|
| Regular node |  |
| CIELO isotope Chadwick, M., "CIELO: A Future Collaborative International Evaluated Library", Proc. of the International Conference of Nuclear Data for Science and Technology (ND2013) |  |
| ENDF/B-VII.1 Standards Carlson A.D. "International Evaluation of Neutron Cross Section Standards", Nuclear Data Sheets. 110.12 (2009) 3215-3324. |  |
| Standards proposed at IAEA Technical Meeting, July '13 |  |
| Standards proposed in the past / Proposed by us |   |
| Mughabghab, S. F., <i>Atlas of Neutron Resonances</i>, Elsevier Science, April 17, 2006. |  |
| Diagnostic radioisotopes and monitor reactions P. Oblozinsky, International Atomic Energy Agency IAEA, IAEA-TECDOC-1211 http://www-nds.iaea.org/medical/ |  |
| Isomer target |  |
| Elemental target |  |

Types of connections

| Edge type | Description | Example |
|---|--|---|
| MONITOR | Typically a, well characterized reaction used to reduce or eliminate systematic experimental errors. |  |
| Mathematical relation (e.g. “isomer math”; sum rules; math is REACTION string; ALF, ETA, etc) | Connections representing a simple ratio or a more complex mathematical equation. |  |
| Neutron Standards/ CIELO | All evaluated simultaneously and therefore are linked. |  |
| Elemental | Data on a elemental target is connected to every stable isotope of the element for the same measurement. |  |

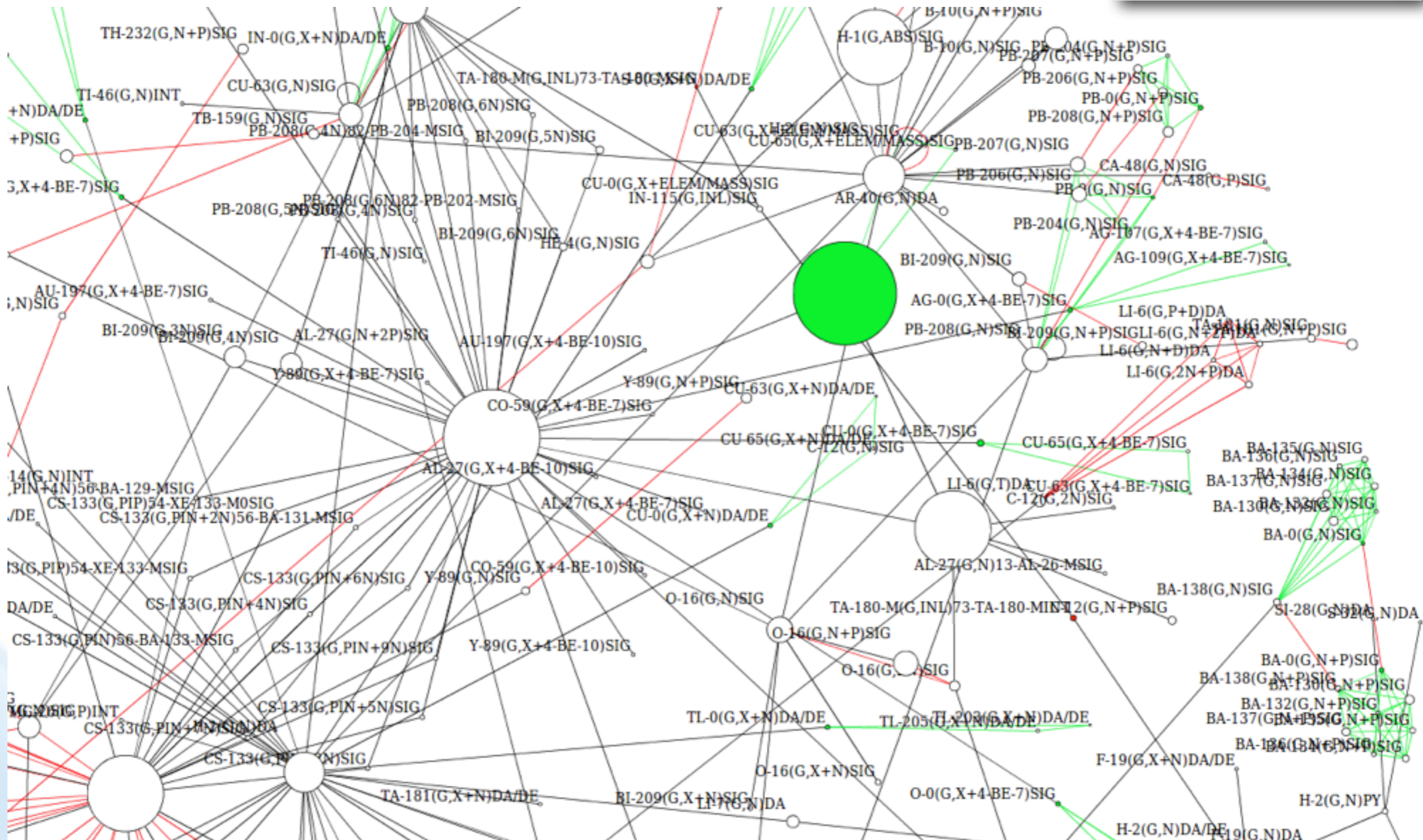
Reoccurring motifs

| EXFOR Quantity | Definition | Example |
|----------------|--|---|
| ALF | σ_γ / σ_f | <p>(N,G)ALF (N,G)SIG (N,F)SIG</p> |
| ETA | $\bar{\nu}\sigma_f / (\sigma_\gamma + \sigma_f)$ | <p>(N,F)ETA (N,F)SIG (N,F)NU (N,G)SIG</p> |
| SCT | $\sigma_{el} + \sigma_{inel}$ | <p>(N,SCT)SIG (N,INL)SIG (N,EL)SIG</p> |

| EXFOR Quantity | Definition | Example |
|--------------------|--|--|
| NON | $\sigma_{tot} - \sigma_{el}$ | <p>(N,NON)SIG (N,EL)SIG (N,TOT)SIG</p> |
| RI | $\int_0^\infty dE \frac{\sigma(E)}{E}$ | <p>RI SIG</p> |
| (elemental) | $\sum_i w_i \sigma_i(E)$ | <p>natCU 63CU 65CU</p> |

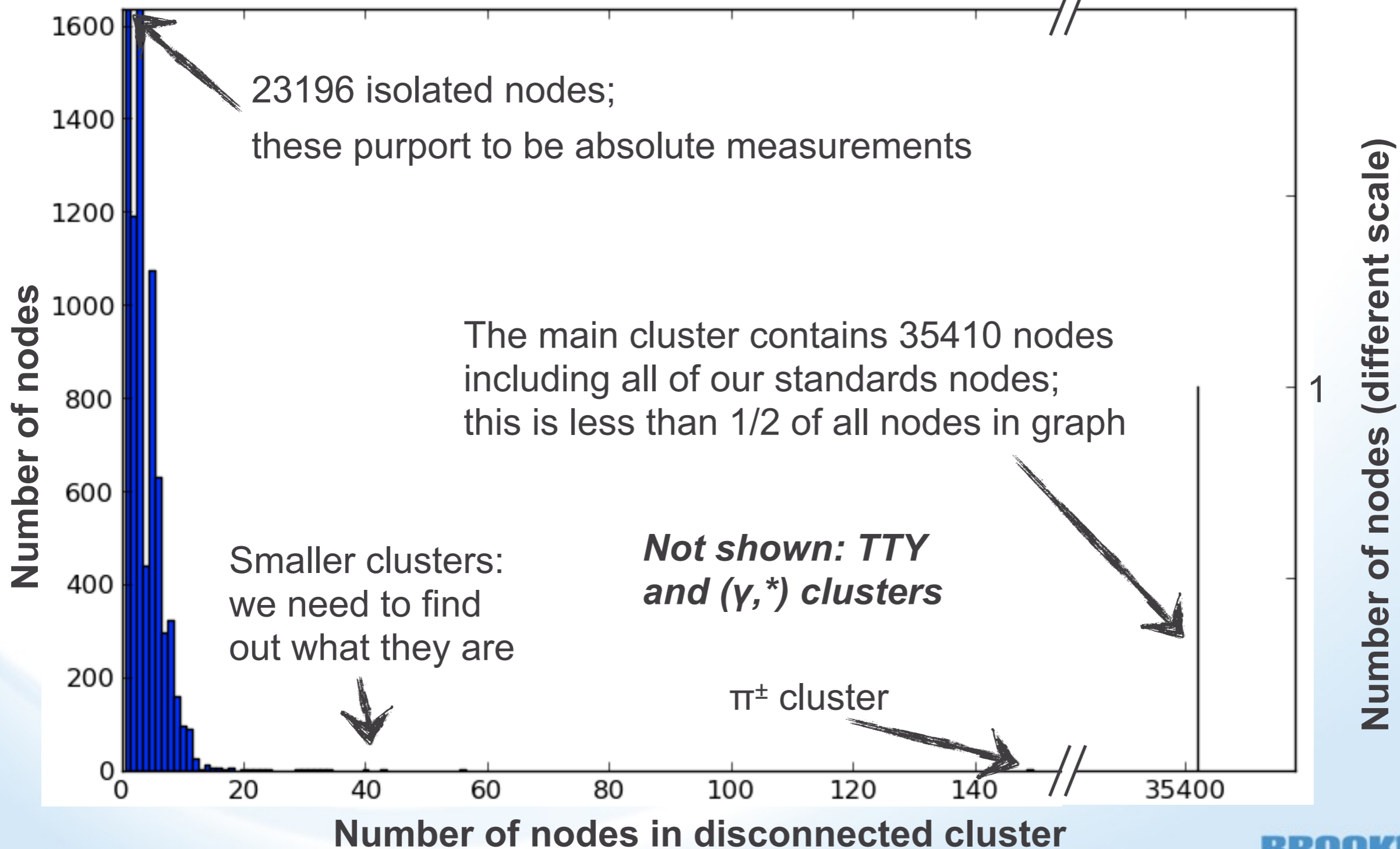
The network (a closeup of the photonuclear cluster)

nodes: 87925
edges: 276852



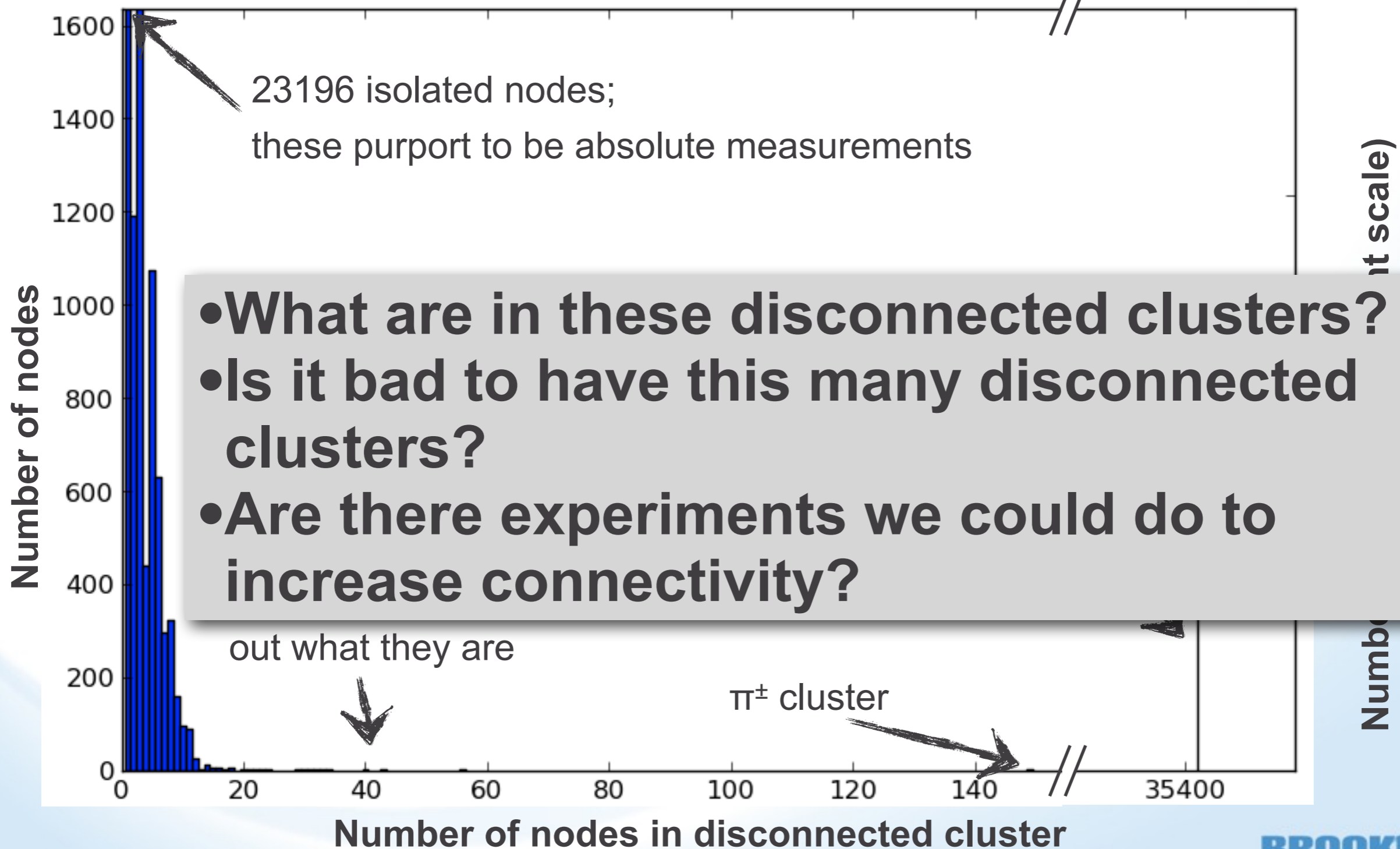
The graph is not fully connected; *probability any 2 nodes connected is 7.162e-05*

Cluster Size Distribution



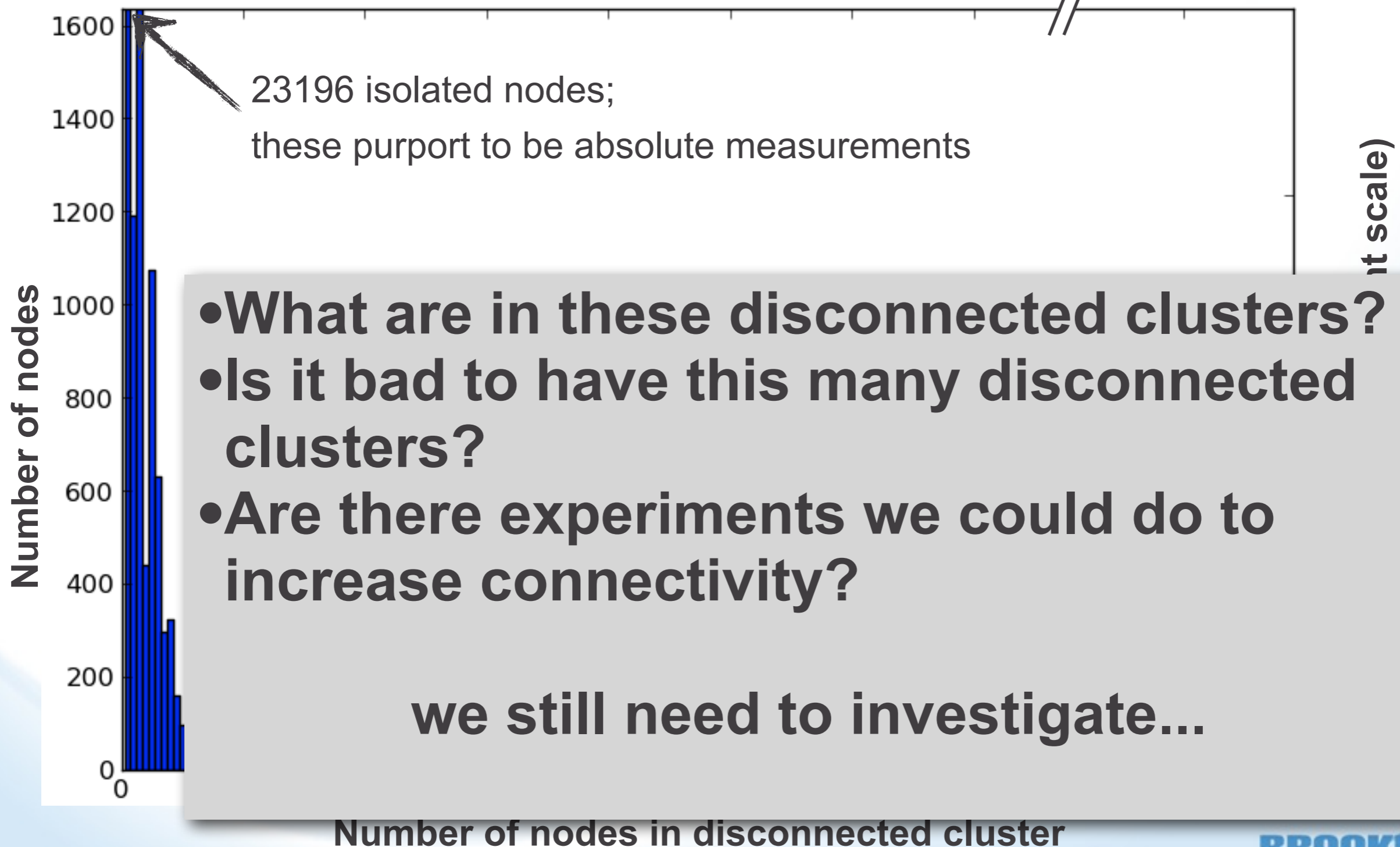
The graph is not fully connected; *probability any 2 nodes connected is $7.162e-05$*

Cluster Size Distribution



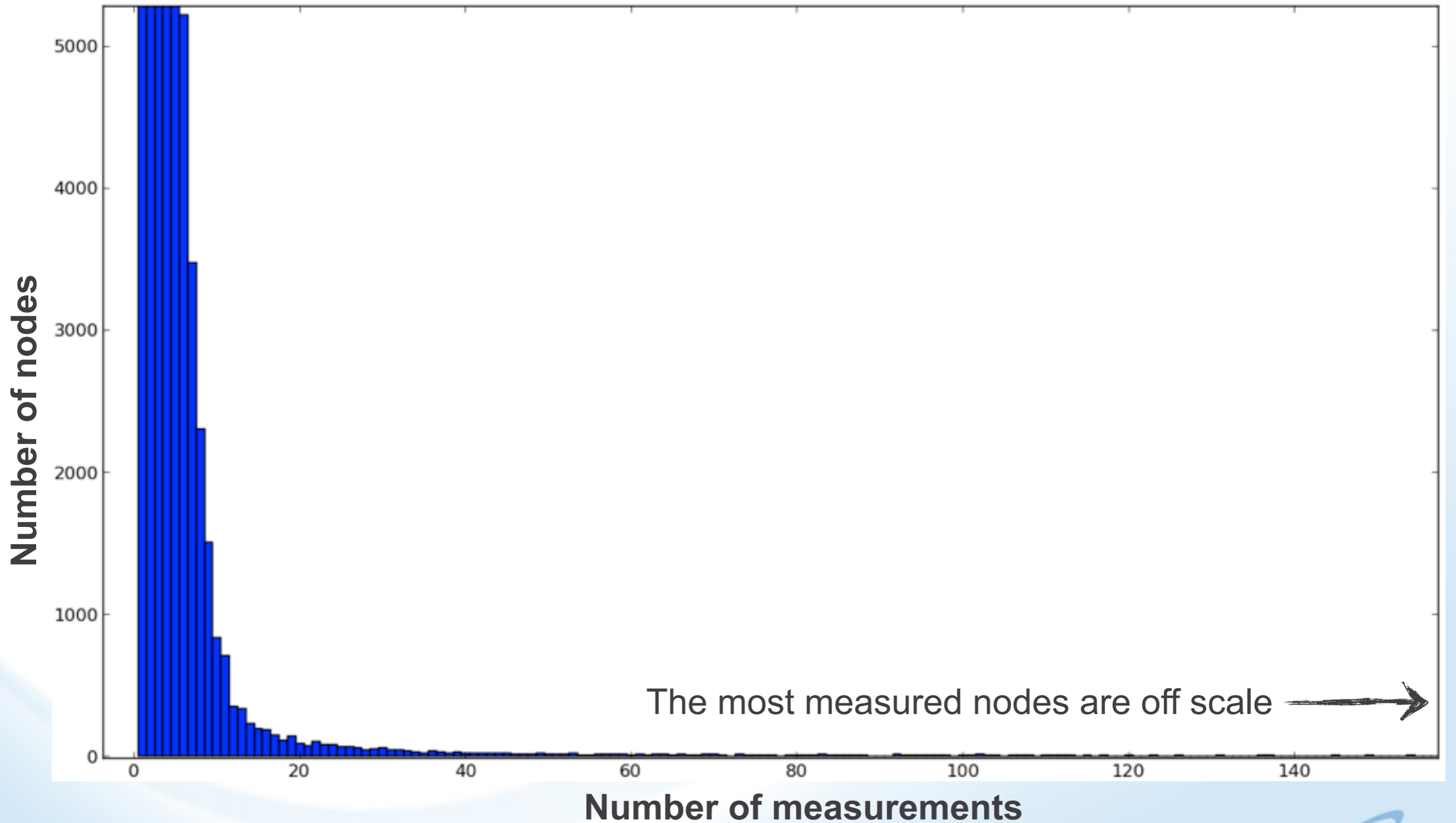
The graph is not fully connected; *probability any 2 nodes connected is $7.162e-05$*

Cluster Size Distribution



What is most measured?

These are what experimenters view as important.



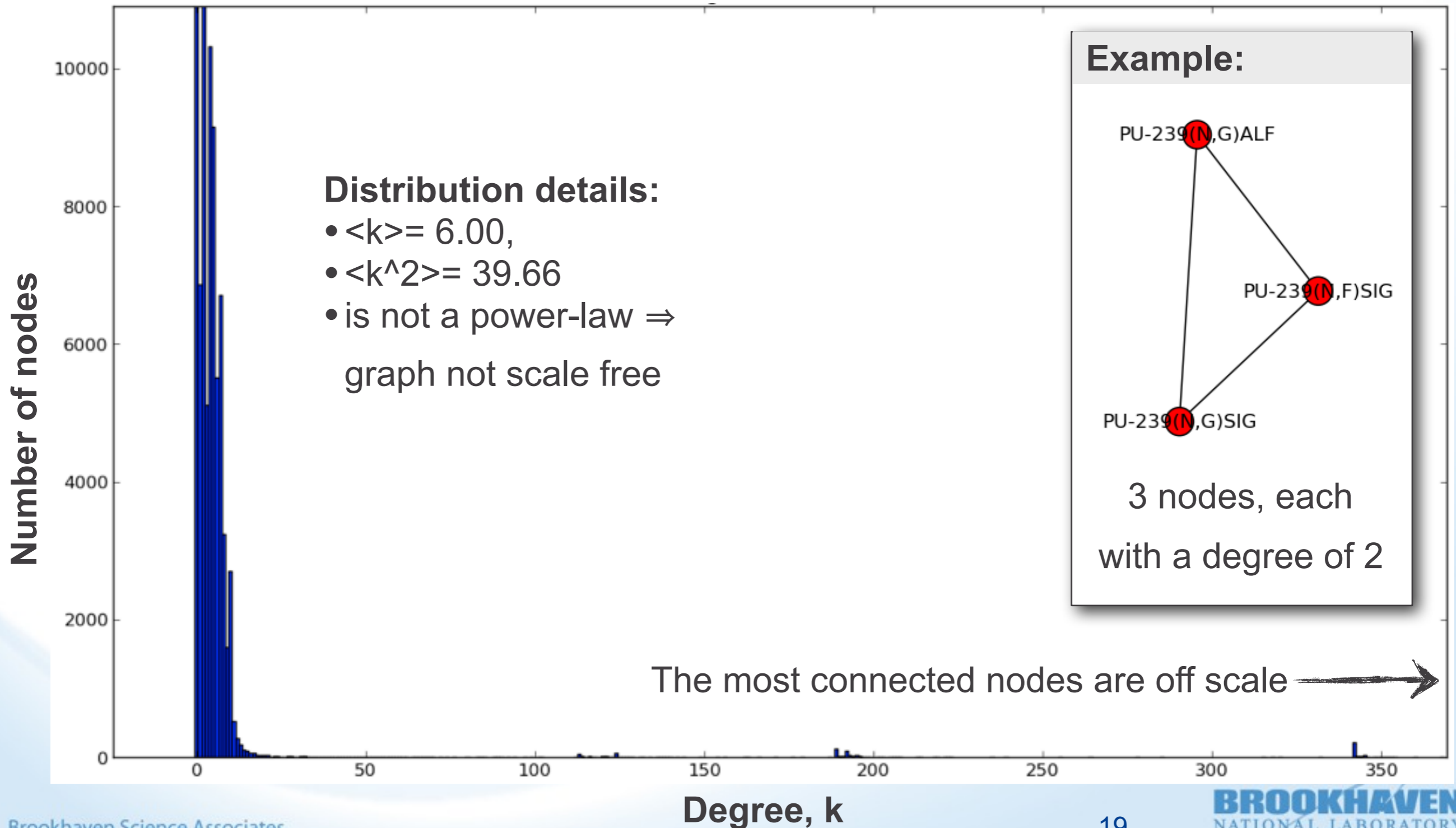
What is most measured?

These are what experimenters view as important.

| Node | # Measurements | Degree | Note |
|-----------------------------|----------------|-------------|-------------------------------|
| 27Al(n, α): σ | 5049 | 1281 | |
| 197Au(n, γ): σ | 4106 | 1073 | ENDF/Atlas Neutron Standard |
| 27Al(p, X+22Na): σ | 3806 | 2276 | IAEA Charged-particle Monitor |
| 235U(n, f): σ | 3707 | 774 | ENDF Neutron Standard/CIELO |
| 27Al(p, X+24Na): σ | 3626 | 2122 | IAEA Charged-particle Monitor |
| 1H(n, el): σ | 2903 | 1207 | ENDF Neutron Standard/CIELO |
| 1H(n, el): dσ/dΩ | 2601 | 953 | ENDF Neutron Standard/CIELO |
| 93Nb(n, 2n)92mNb: σ | 2465 | 710 | |
| 27Al(p, n+3p): σ | 2316 | 1535 | |
| 56Fe(n, p)56Mn: σ | 2272 | 833 | CIELO |
| 197Au(n, γ): RI | 1961 | 440 | ENDF/Atlas Neutron Standard |
| 27Al(n, p)27Mg: σ | 1902 | 544 | |
| natCu(p, X+65Zn): σ | 1899 | 627 | IAEA Charged-particle Monitor |
| 59Co(n, γ): RI | 1582 | 410 | Atlas Neutron Standard |
| 58Ni(n, p): σ | 1477 | 344 | |
| 238U(n, f): σ | 1394 | 511 | ENDF Neutron Standard/CIELO |
| 59Co(n, γ): σ | 1332 | 578 | Atlas Neutron Standard |
| 115In(n, inel): σ | 1161 | 235 | |
| natMo(p, X+96Tc): σ | 1109 | 600 | |
| 27Al(12C, X+24Na): σ | 1060 | 610 | |

The degree of a node is the number of other nodes connected to it

Degree Distribution



Most important, by degree

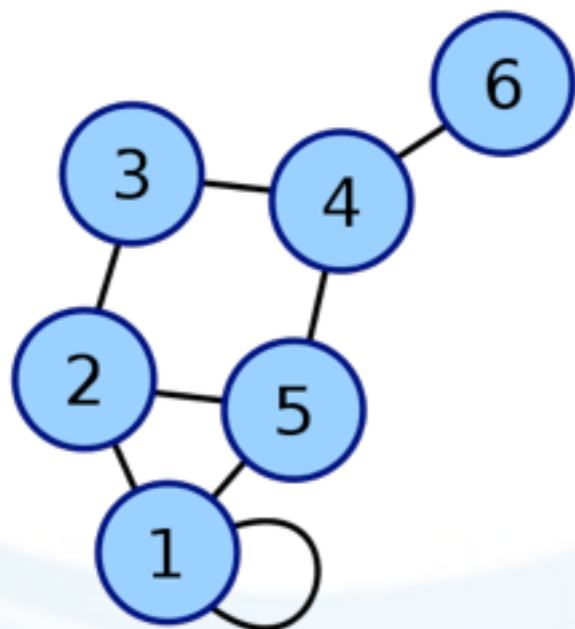
| <i>Node</i> | <i># Measurements</i> | <i>Degree</i> | <i>Note</i> |
|---|-----------------------|---------------|-------------------------------|
| $^{27}\text{Al}(p, X+^{22}\text{Na}): \sigma$ | 3806 | 2276 | IAEA Charged-particle Monitor |
| $^{27}\text{Al}(p, X+^{24}\text{Na}): \sigma$ | 3626 | 2122 | IAEA Charged-particle Monitor |
| $^{27}\text{Al}(p, n+3p): \sigma$ | 2316 | 1535 | |
| $^{27}\text{Al}(n, \alpha): \sigma$ | 5049 | 1281 | |
| $^1\text{H}(n, el): \sigma$ | 2903 | 1207 | ENDF Neutron Standard/CIELO |
| $^{197}\text{Au}(n, \gamma): \sigma$ | 4106 | 1073 | ENDF/Atlas Neutron Standard |
| $^1\text{H}(n, el): d\sigma/d\Omega$ | 2601 | 953 | ENDF Neutron Standard/CIELO |
| $^{56}\text{Fe}(n, p)^{56}\text{Mn}: \sigma$ | 2272 | 833 | CIELO |
| $^{235}\text{U}(n, f): \sigma$ | 3707 | 774 | ENDF Neutron Standard/CIELO |
| $^{93}\text{Nb}(n, 2n)^{92m}\text{Nb}: \sigma$ | 2465 | 710 | |
| $\text{natCu}(p, X+^{65}\text{Zn}): \sigma$ | 1899 | 627 | IAEA Charged-particle Monitor |
| $^{27}\text{Al}(^{12}\text{C}, X+^{24}\text{Na}): \sigma$ | 1060 | 610 | |
| $\text{natMo}(p, X+^{96}\text{Tc}): \sigma$ | 1109 | 600 | |
| $\text{natMo}(p, X+^{97}\text{Ru}): \sigma$ | 547 | 594 | |
| $^{59}\text{Co}(n, \gamma): \sigma$ | 1332 | 578 | Atlas Neutron Standard |
| $^{27}\text{Al}(n, p)^{27}\text{Mg}: \sigma$ | 1902 | 544 | |
| $^{238}\text{U}(n, f): \sigma$ | 1394 | 511 | ENDF Neutron Standard/CIELO |
| $^{27}\text{Al}(d, X+^{24}\text{Na}): \sigma$ | 990 | 507 | IAEA Charged-particle Monitor |
| $^{197}\text{Au}(n, \gamma): RI$ | 1961 | 440 | ENDF/Atlas Neutron Standard |
| $^{10}\text{B}(n, \alpha): \sigma$ | 860 | 432 | ENDF Neutron Standard |

Other measures of importance

■ Other measures:

- Eigenvalue centrality
- Flow centrality
- Betweenness
- ...

■ Rely on adjacency matrix: the matrix of connections between nodes



$$\begin{pmatrix} 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

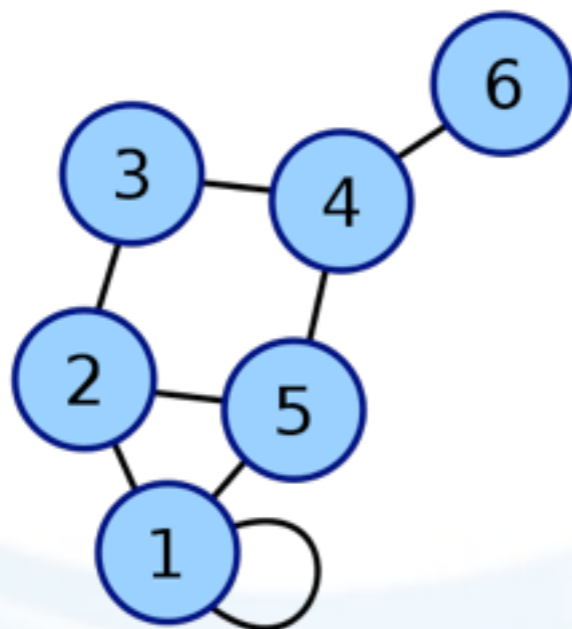
Other measures of importance

All require complicated linear algebra on adjacency matrix so behave badly for large graphs

- **Other measures:**

- Eigenvalue centrality
- Flow centrality
- Betweenness
- ...

- **Rely on adjacency matrix: the matrix of connections between nodes**



$$\begin{pmatrix} 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

Other measures of importance

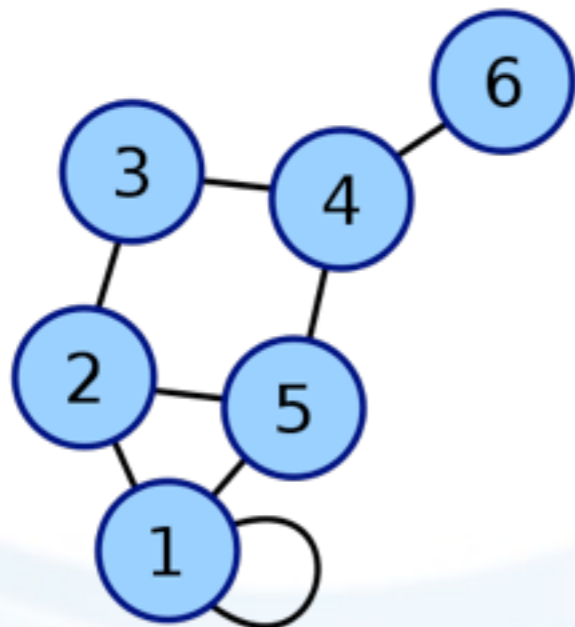
All require complicated linear algebra on adjacency matrix so behave badly for large graphs

Testing on subgraphs suggest our graph does not map to a random matrix

■ Other measures:

- Eigenvalue centrality
- Flow centrality
- Betweenness
- ...

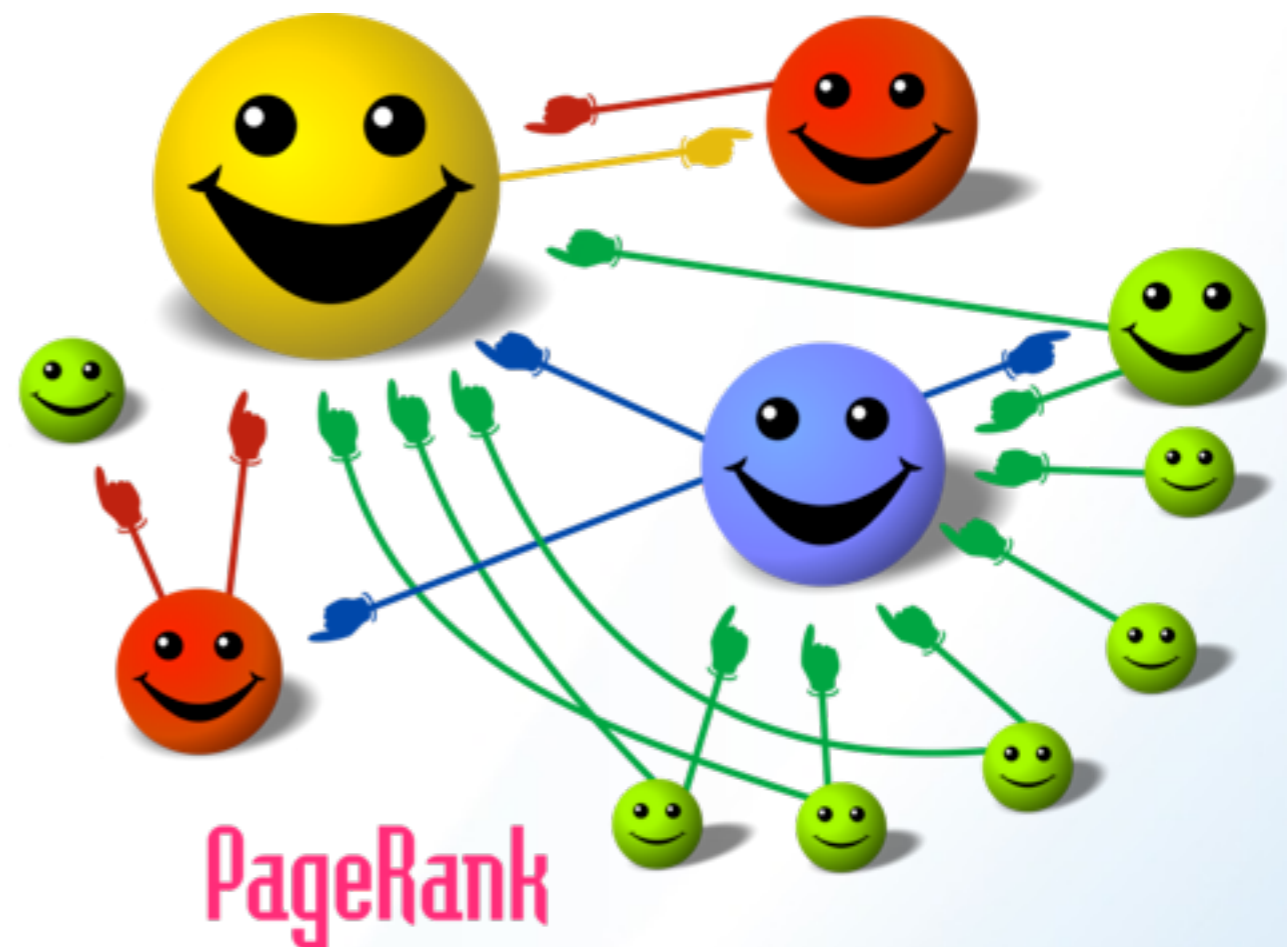
■ Rely on adjacency matrix: the matrix of connections between nodes



$$\begin{pmatrix} 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

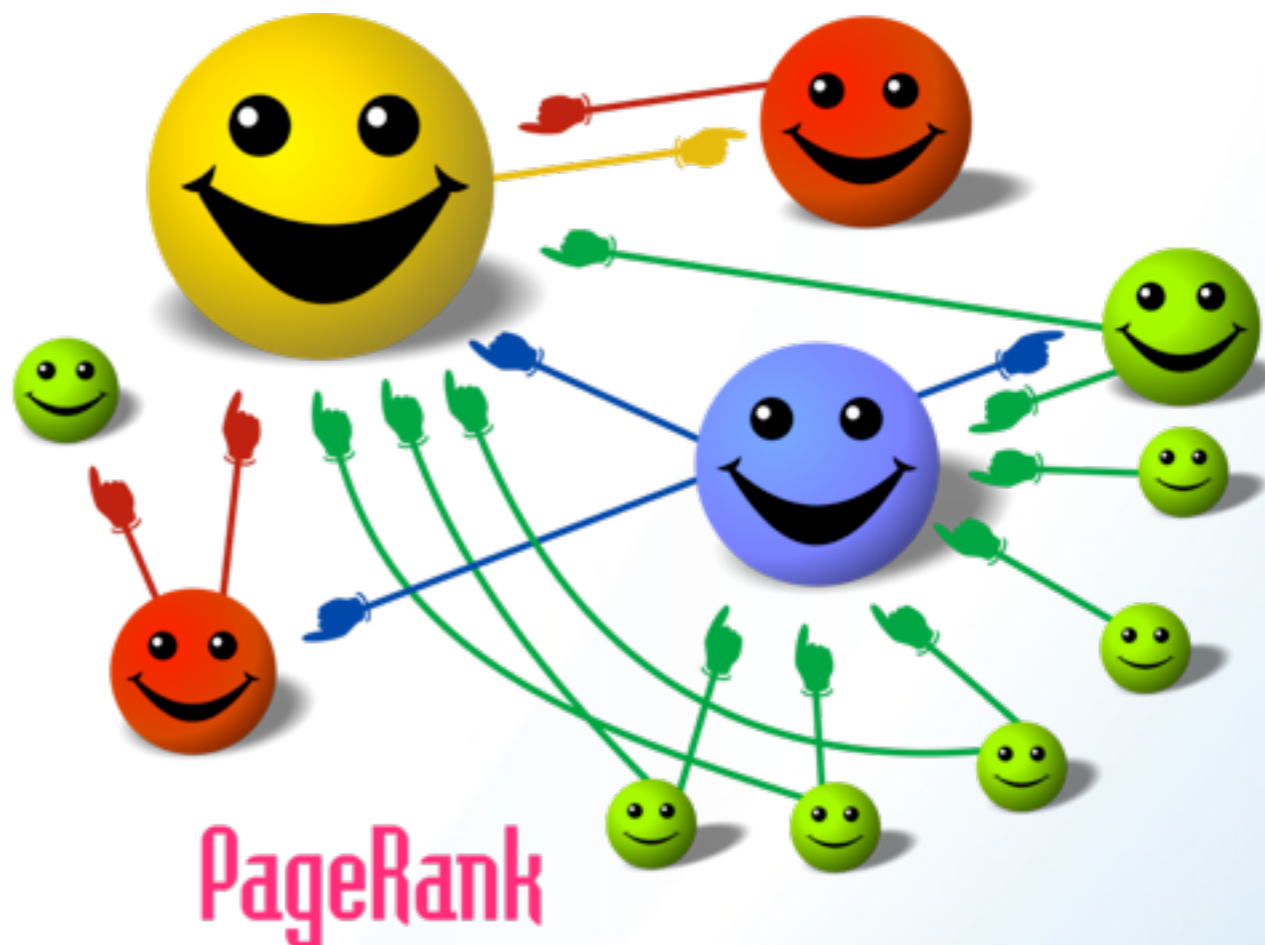
Google PageRank

- Developed by Larry Page and Sergey Brin
- Google's "secret weapon"
- Iterative process determines probability to connect to a node
- Algorithm:
 - All nodes start with $PR(A)=1$
 - Sum PR of all nodes connected to A: $PR(A)=PR(B)+PR(C)+PR(D)+\dots$
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Robust: doesn't need linear algebra that gets flakey with large graphs

Most important by PageRank

| <i>Node</i> | <i># Meas.</i> | <i>PageRank</i> | <i>Note</i> |
|---|----------------|--------------------------|-------------------------------|
| $^{27}\text{Al}(p, X+^{22}\text{Na}): \sigma$ | 3806 | 0.00614361883184 | IAEA Charged-particle Monitor |
| $^{27}\text{Al}(p, X+^{24}\text{Na}): \sigma$ | 3626 | 0.00589970042155 | IAEA Charged-particle Monitor |
| $^{27}\text{Al}(p, n+3p): \sigma$ | 2316 | 0.00462137473353 | |
| $^1\text{H}(n, el): \sigma$ | 2903 | 0.00205056586495 | ENDF Neutron Standard/CIELO |
| $^{27}\text{Al}(n, \alpha): \sigma$ | 5049 | 0.0020053191131 | |
| $^{27}\text{Al}(^{12}\text{C}, X+^{24}\text{Na}): \sigma$ | 1060 | 0.00198377702452 | |
| $^1\text{H}(n, el): d\sigma/d\Omega$ | 2601 | 0.00166716109304 | ENDF Neutron Standard/CIELO |
| $^{197}\text{Au}(n, \gamma): \sigma$ | 4106 | 0.00161174920126 | ENDF/Atlas Neutron Standard |
| $\text{natMo}(p, X+^{96}\text{Tc}): \sigma$ | 1109 | 0.00151848784518 | |
| $\text{natMo}(p, X+^{97}\text{Ru}): \sigma$ | 547 | 0.00150681290335 | |
| $\text{natCu}(p, X+^{65}\text{Zn}): \sigma$ | 1899 | 0.00139242891398 | IAEA Charged-particle Monitor |
| $^{27}\text{Al}(d, X+^{24}\text{Na}): \sigma$ | 990 | 0.00125807852791 | IAEA Charged-particle Monitor |
| $^{56}\text{Fe}(n, p)^{56}\text{Mn}: \sigma$ | 2272 | 0.00111172026737 | CIELO |
| $^{93}\text{Nb}(n, 2n)^{92\text{m}}\text{Nb}: \sigma$ | 2465 | 0.00104560418528 | |
| $^{65}\text{Cu}(p, n): \sigma$ | 514 | 0.000851363612779 | |
| $^{59}\text{Co}(n, \gamma): \sigma$ | 1332 | 0.000825522215299 | Atlas Neutron Standard |
| $\text{natCu}(p, X+^{62}\text{Zn}): \sigma$ | 985 | 0.000815833146368 | IAEA Charged-particle Monitor |
| $^{27}\text{Al}(n, p)^{27}\text{Mg}: \sigma$ | 1902 | 0.000759255422463 | |
| $^{27}\text{Al}(p, 3n+3p): \sigma$ | 528 | 0.000730486791991 | |
| $\text{natTi}(p, X+^{48}\text{V}): \sigma$ | 731 | 0.000711817973821 | IAEA Charged-particle Monitor |

Recommendations: need to expand our suite of structural materials

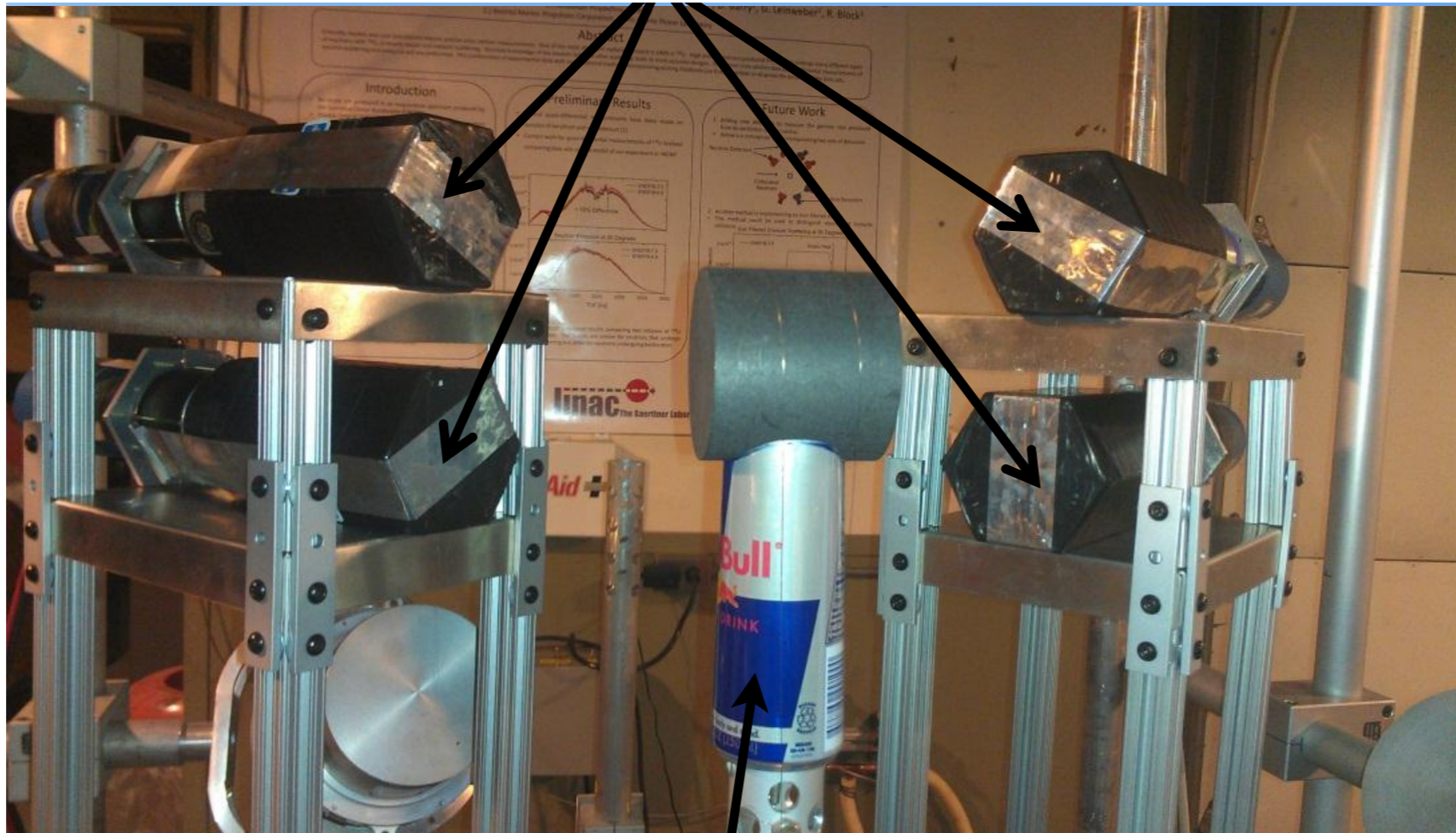
- ***Aluminum***: cheap, monoisotopic and easy to work with; the most important structural material next to Iron
 - $n+^{27}\text{Al}$: (n,α) , (n,p)
 - $p+^{27}\text{Al}$: $(n,n+3p)$, ^{22}Na and ^{24}Na production
 - $^{12}\text{C}+^{27}\text{Al}$: ^{24}Na production
- ***Molybdenum and Niobium*** also very important structural materials:
 - $n+^{93}\text{Nb}$: $^{93}\text{Nb}(n,2n)^{92m}\text{Nb}$
 - $p+^{\text{nat}}\text{Mo}$: ^{96}Tc and ^{97}Ru production
- **Other important structural materials:**
 - $n+^{58}\text{Ni}$: (n,p)
 - $n+^{115}\text{In}$: (n,inel)

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Aluminum is a very important material for us too

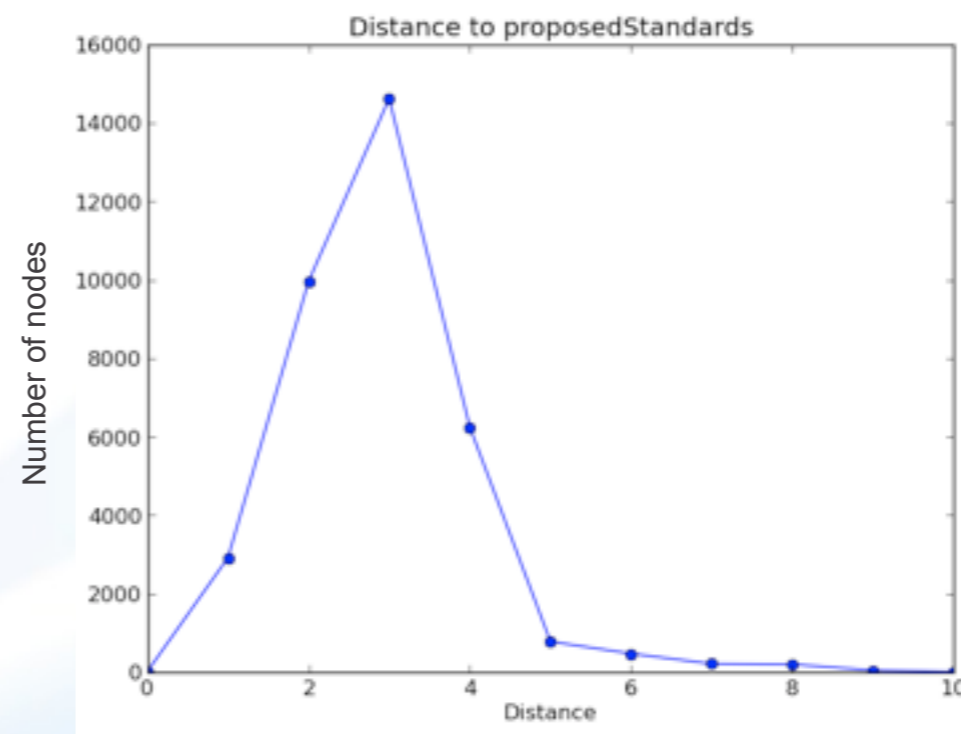
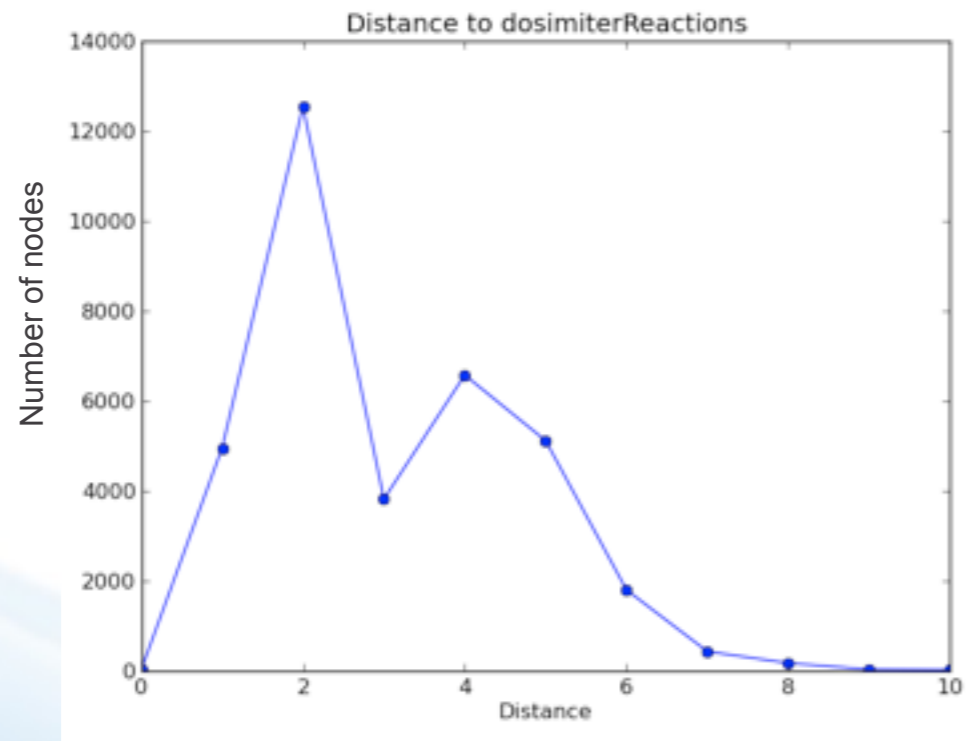
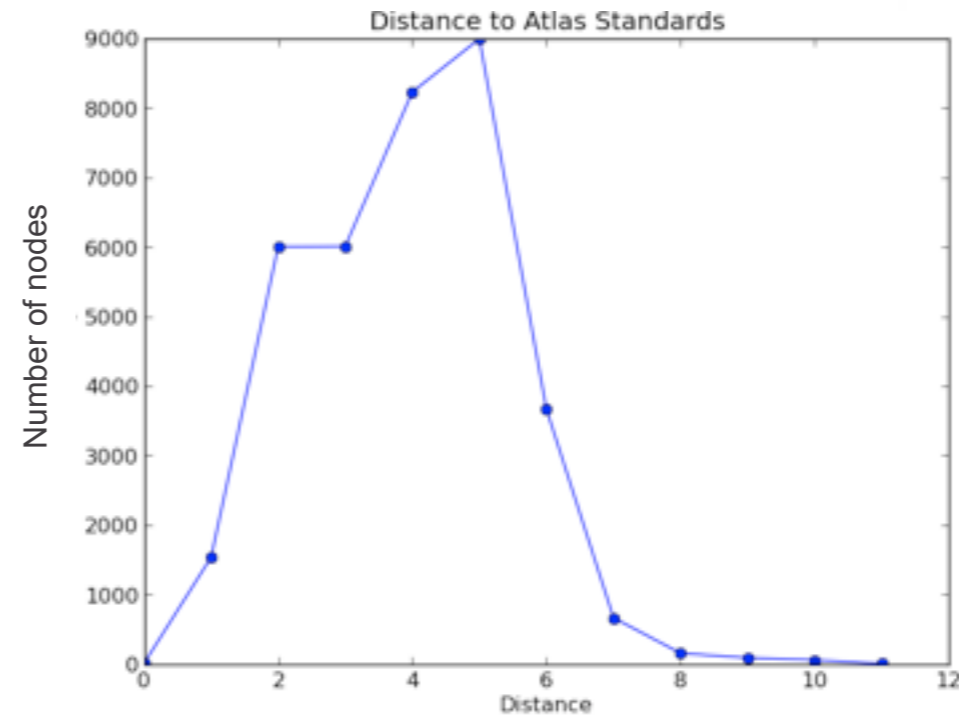
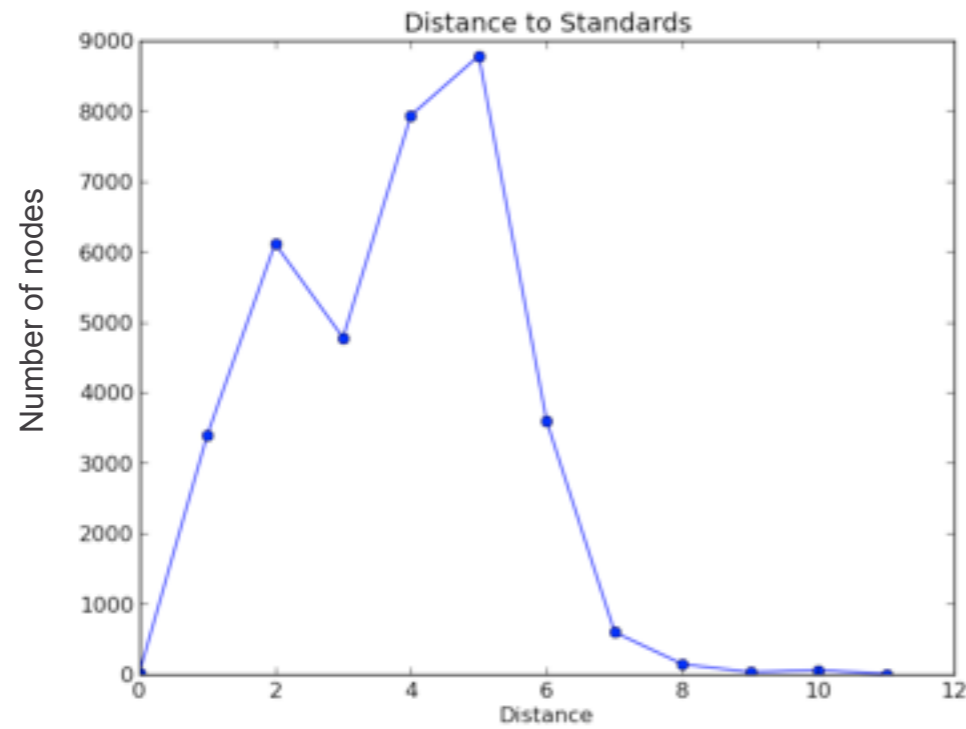
RPI's BaF₂ detector array



From Yaron Danon

RPI's "Low mass sample holder"

Naively, everything should be connected to a monitor of some sort



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