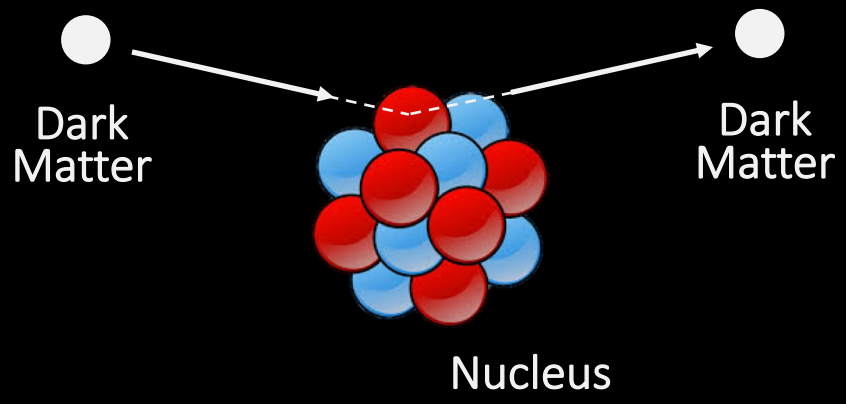
Sensitivity of Dark Matter-Nucleus Interactions To Nuclear Structure

2022 CDM Annual Workshop – ECR Talk

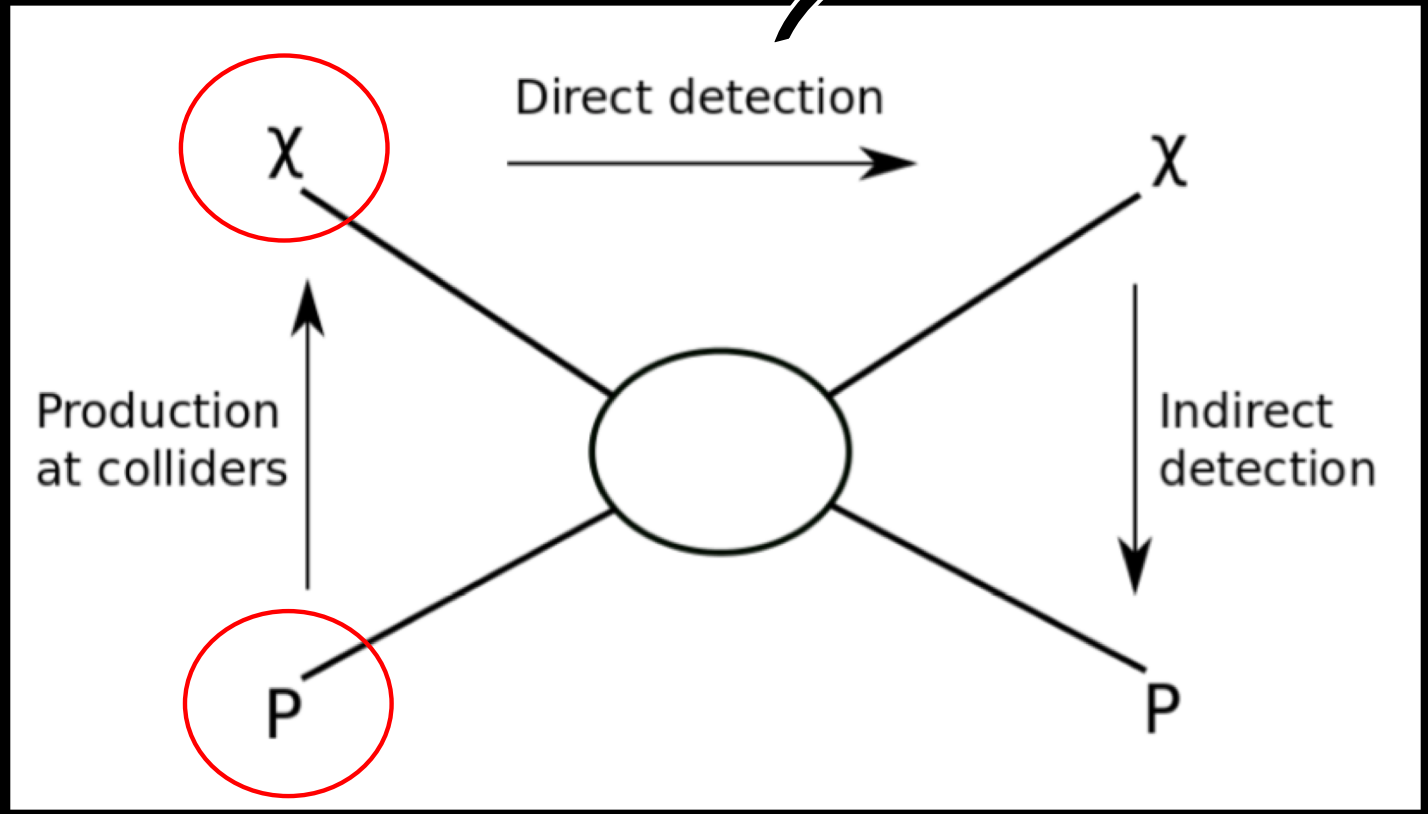
Raghda Abdel Khaleq



Searching for Dark Matter

Weakly Interacting Massive Particles (WIMPs)

Dark Matter-Nucleus scattering

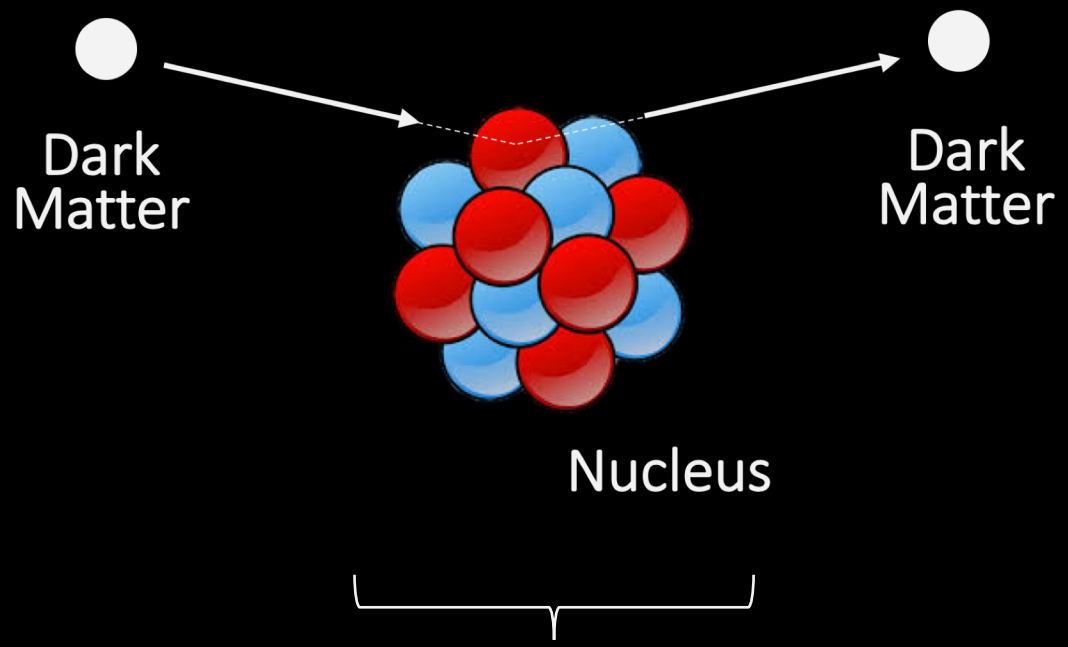


Direct detection

My research applies here

Searching for Dark Matter

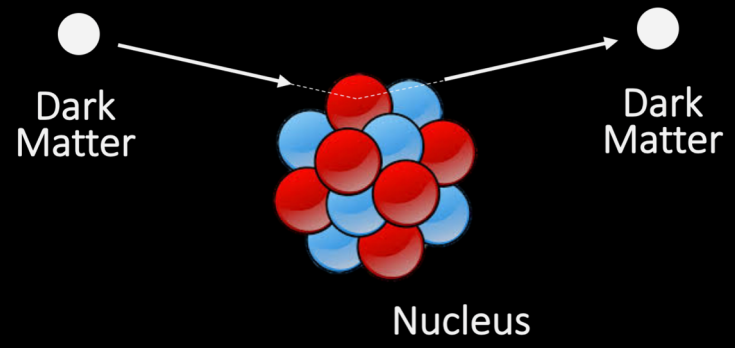
Dark Matter-Nucleus scattering



Nuclear recoil or movement → signal!

Theoretical Model

Building blocks of dark matter-nucleus elastic scattering theory



$$\frac{dR}{dE_R} \propto \int v\, d^3v \sum_{ij} \sum_{N,N'=p,n} f_v(\vec{v})\, R(\vec{v},q)_{ij}^{(N,N')}\, F(q)_{ij}^{(N,N')}$$

Differential scattering (interaction) rate

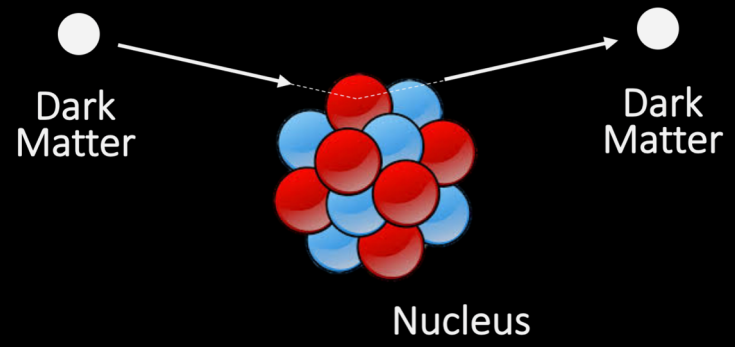
DM Velocity Distribution

Particle Physics

Nuclear Structure

Theoretical Model

Experiments use different nuclei as targets



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Differential scattering (interaction) rate

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Particle Physics

Nuclear Structure

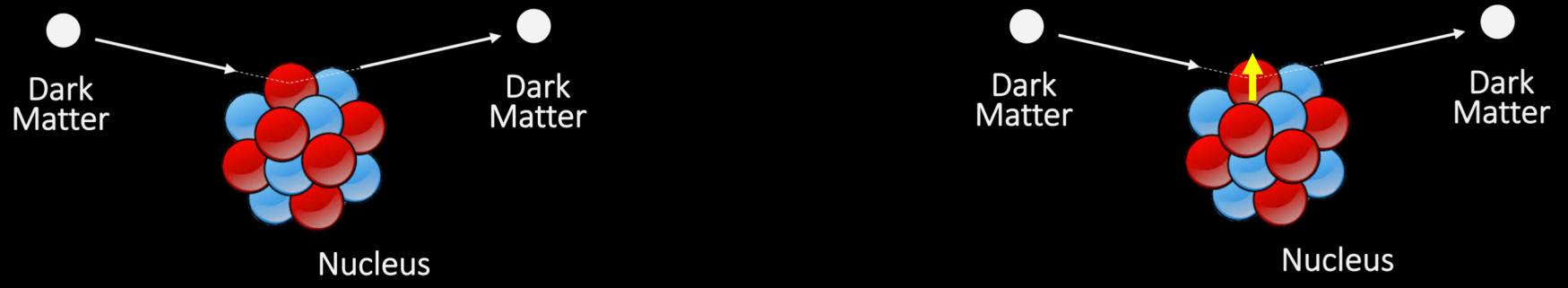
Nuclear Structure– Standard Characterisation

Early models use a simple picture

Spin-independent (SI) & Spin-dependent (SD)

Takes into account all nucleons

Sensitive to nucleon spin



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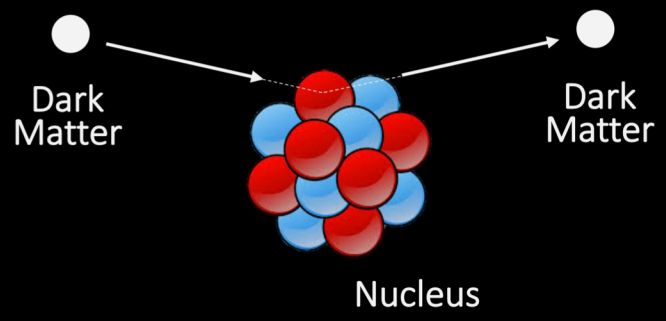
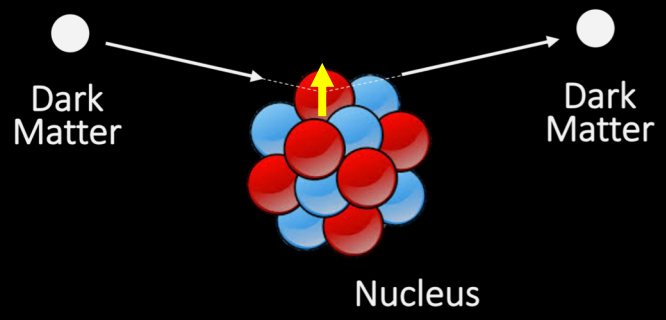


Sensitive to nucleon spin



⟹ *Need to consider motions of nucleons in nucleus!*

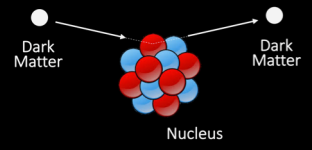
New Interactions From Nucleon Motion

$F(q)_{ij}^{(N,N')}$ decomposed into

Standard

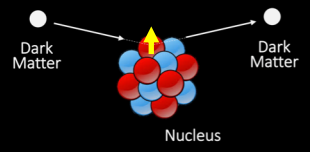
M_{JM}

Spin-independent (SI)



$\Sigma'_{JM}, \Sigma''_{JM}$

Spin-dependent (SD)

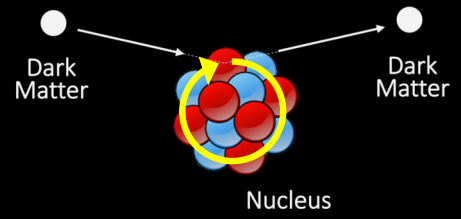


+

Additional channels

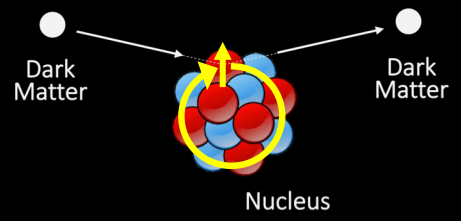
Δ_{JM}

Nucleon orbital angular momentum



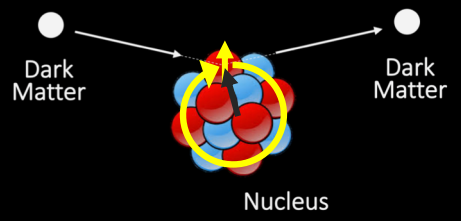
Φ''_{JM}

Spin-orbit structure



$\tilde{\Phi}'_{JM}$

Tensor term



- A. L. Fitzpatrick, W. Haxton, E. Katz, N. Lubbers, and Y. Xu, Journal of Cosmology and Astroparticle Physics (2013), ISSN 14757516.
- N. Anand, A. L. Fitzpatrick, and W. C. Haxton (2013), URL http://arxiv.org/abs/1308.6288

New Interactions From Nucleon Motion

Standard *Additional channel*

M_{JM} $\Sigma'_{JM}, \Sigma''_{JM}$ $+$ Δ_{JM} $\tilde{\Phi}'_{JM}$

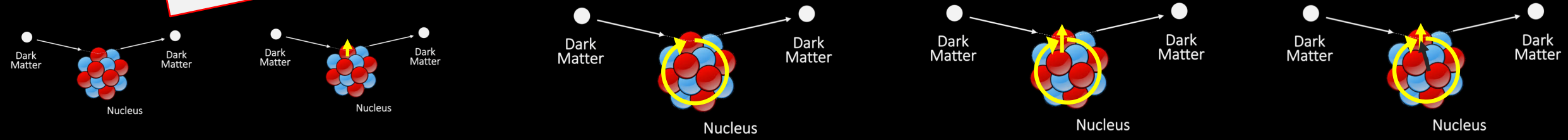
Spin-independen

orbital angular momentum

Spin-orbit structure

Tensor term

Need to choose specific nuclear model to use



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Research Goal

Effect of nuclear structure: a neglected aspect

Investigate the sensitivity of Dark Matter-Nucleus scattering to nuclear structure

---

$$\frac{dR}{dE_R} \propto \int v\, d^3v \sum_{ij} \sum_{N,N'=p,n} f_v(\vec{v}) \quad R(\vec{v},q)_{ij}^{(N,N')} \quad F(q)_{ij}^{(N,N')}$$

Differential scattering (interaction) rate

Form Factor - Nuclear Structure

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$$\frac{dR}{dE_R} \propto \int v\, d^3v \sum_{ij} \sum_{N,N'=p,n} f_v^{(N,N')}$$

- Different nuclei
- Fit to different data sets

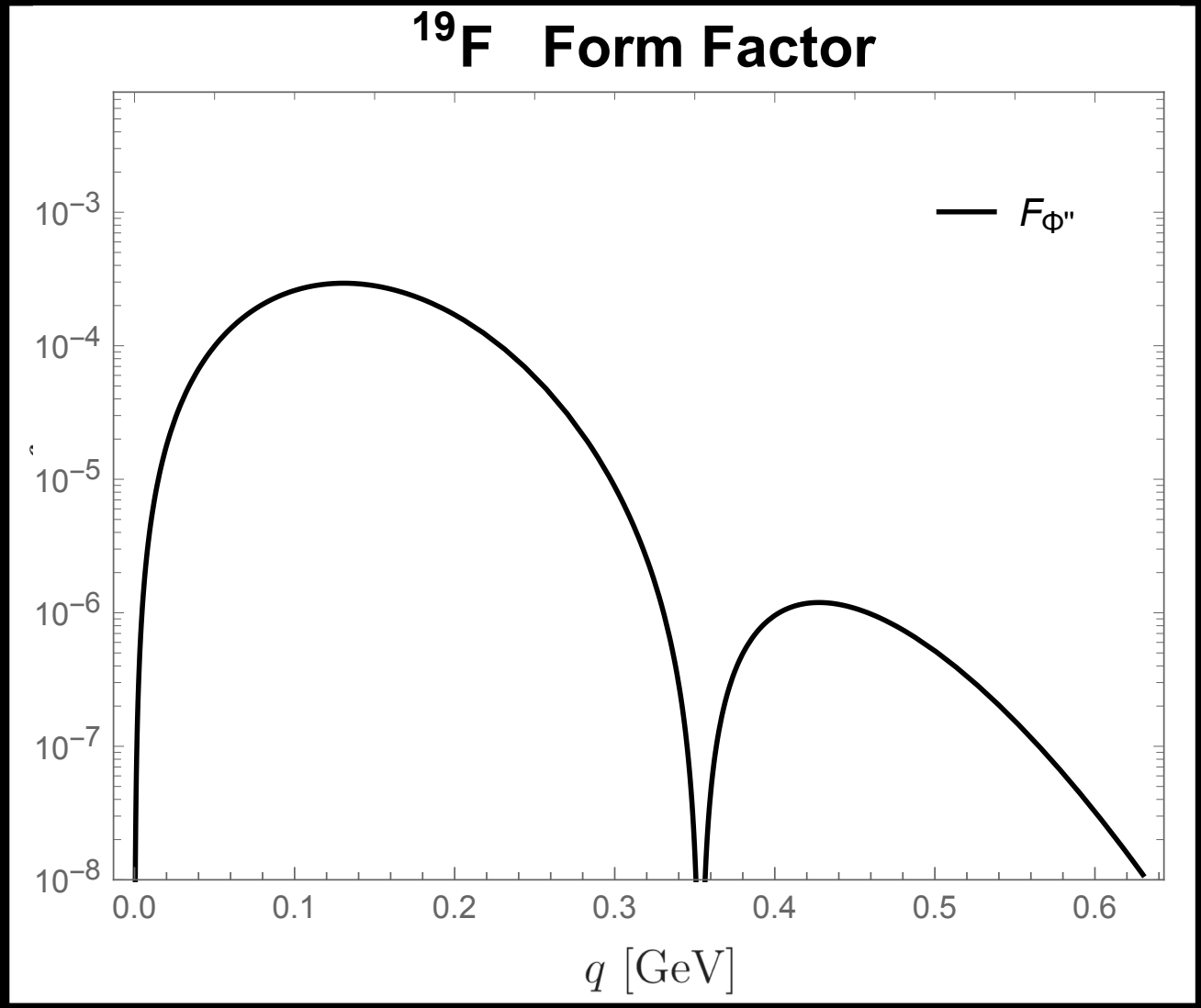
$$F(q)_{ij}^{(N,N')}$$

Differential scattering (interaction) rate

Form Factor - Nuclear Structure

Nuclear Input in Form Factors

- Hold nuclear structure information
- Indicate scattering probability as function of momentum transfer q



Nuclear Input in Form Factors

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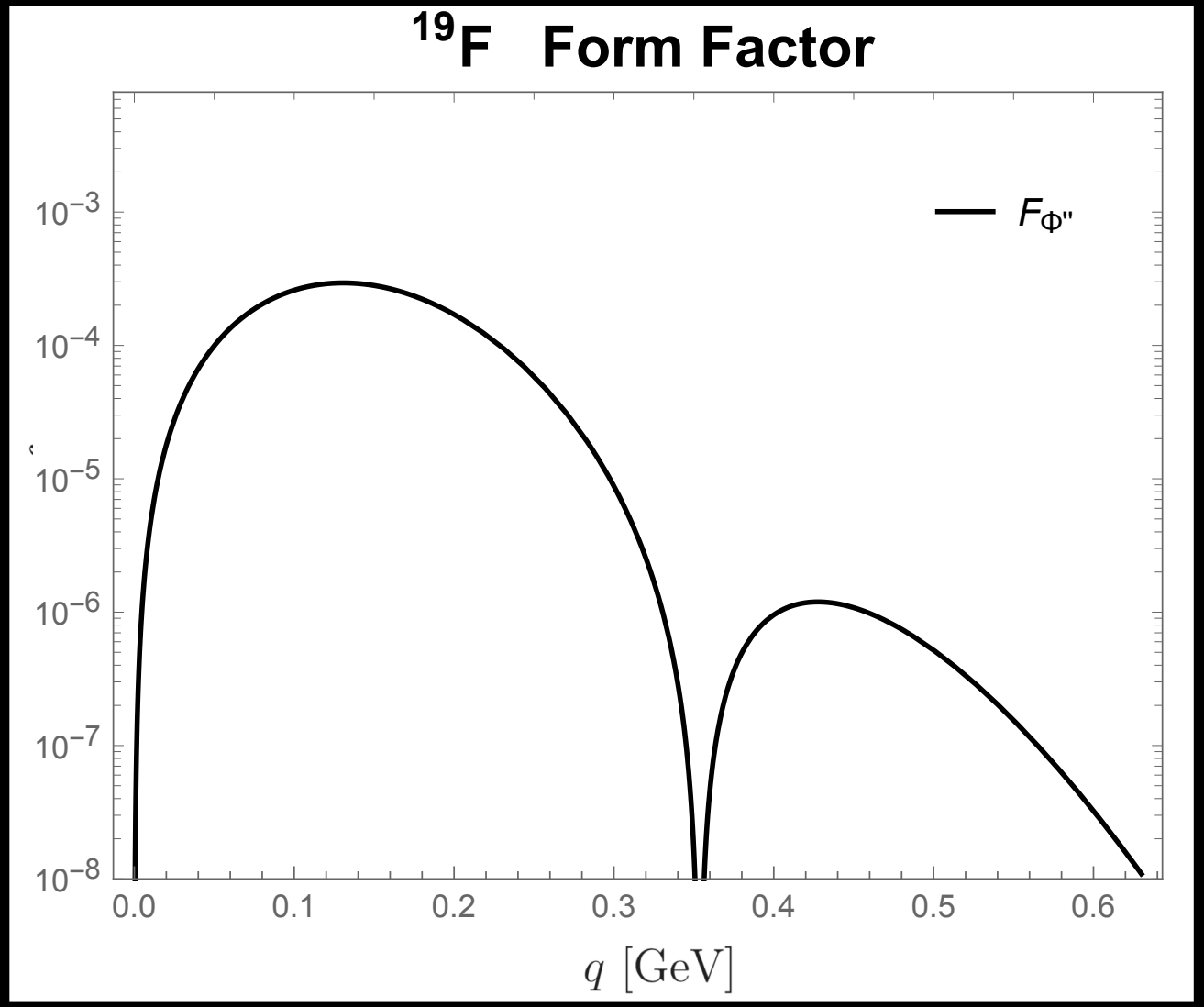
---

Integrated Form Factor (IFF)

$$\int_0^{100MeV} \frac{qdq}{2} F_X^{(N,N)}(q^2),$$

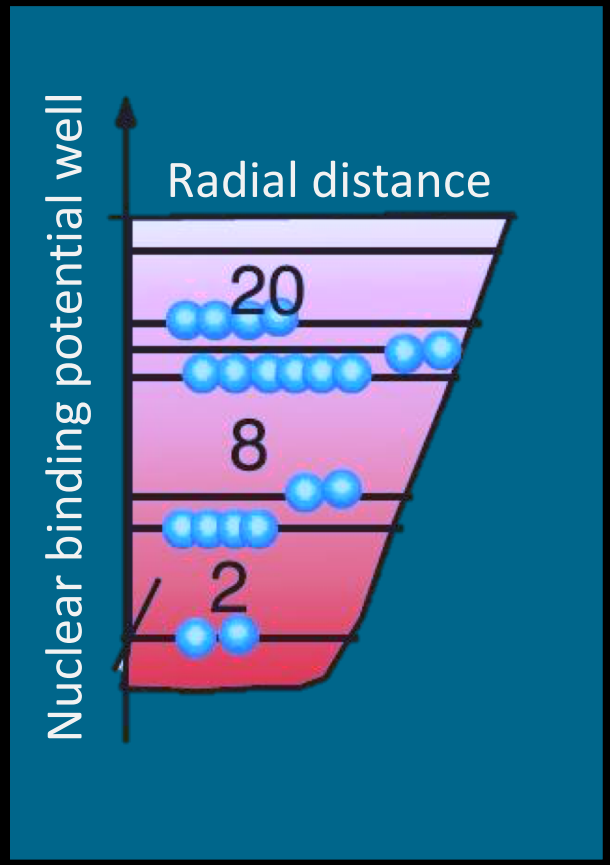
in units of $(MeV)^2$

where $N = N' = p, n$



The Setup – Nuclear Shell Model

Nucleons in orbits & shells within nucleus, move in effective potential.



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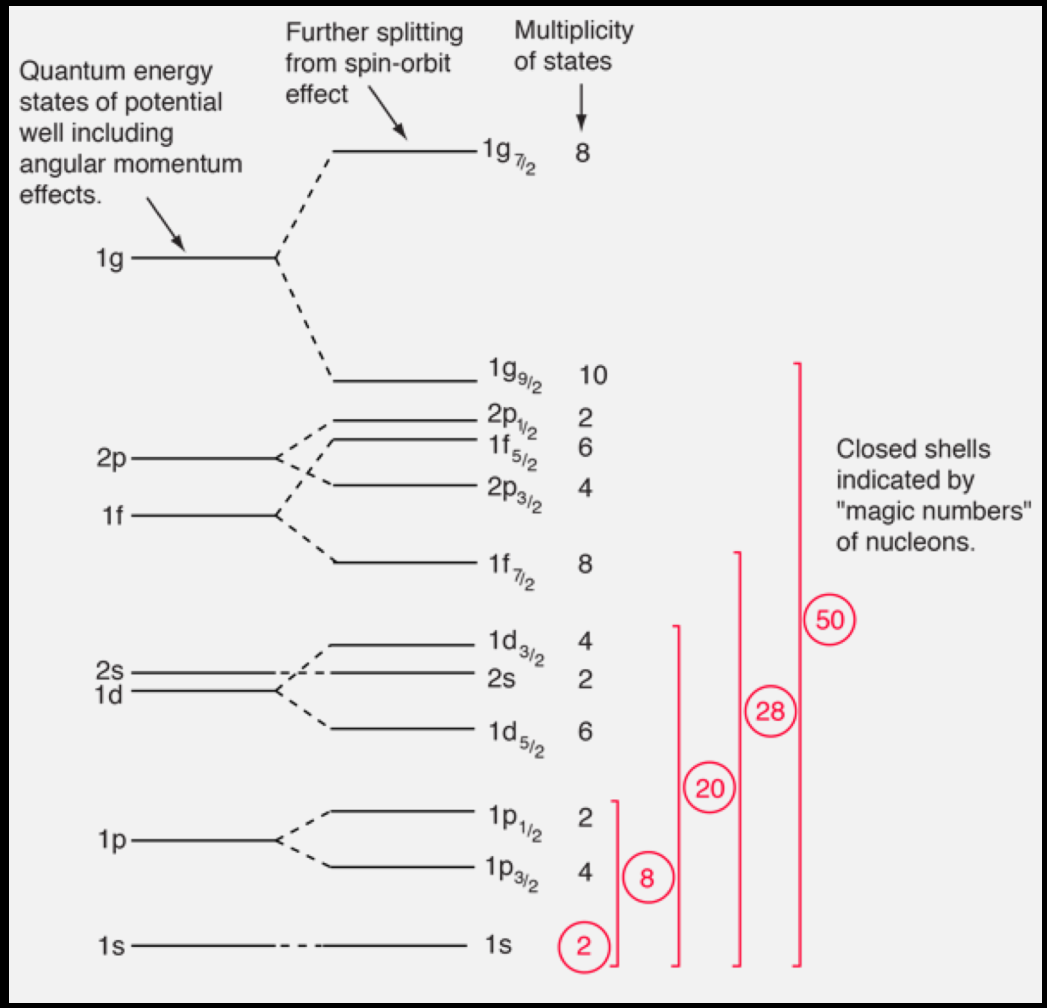
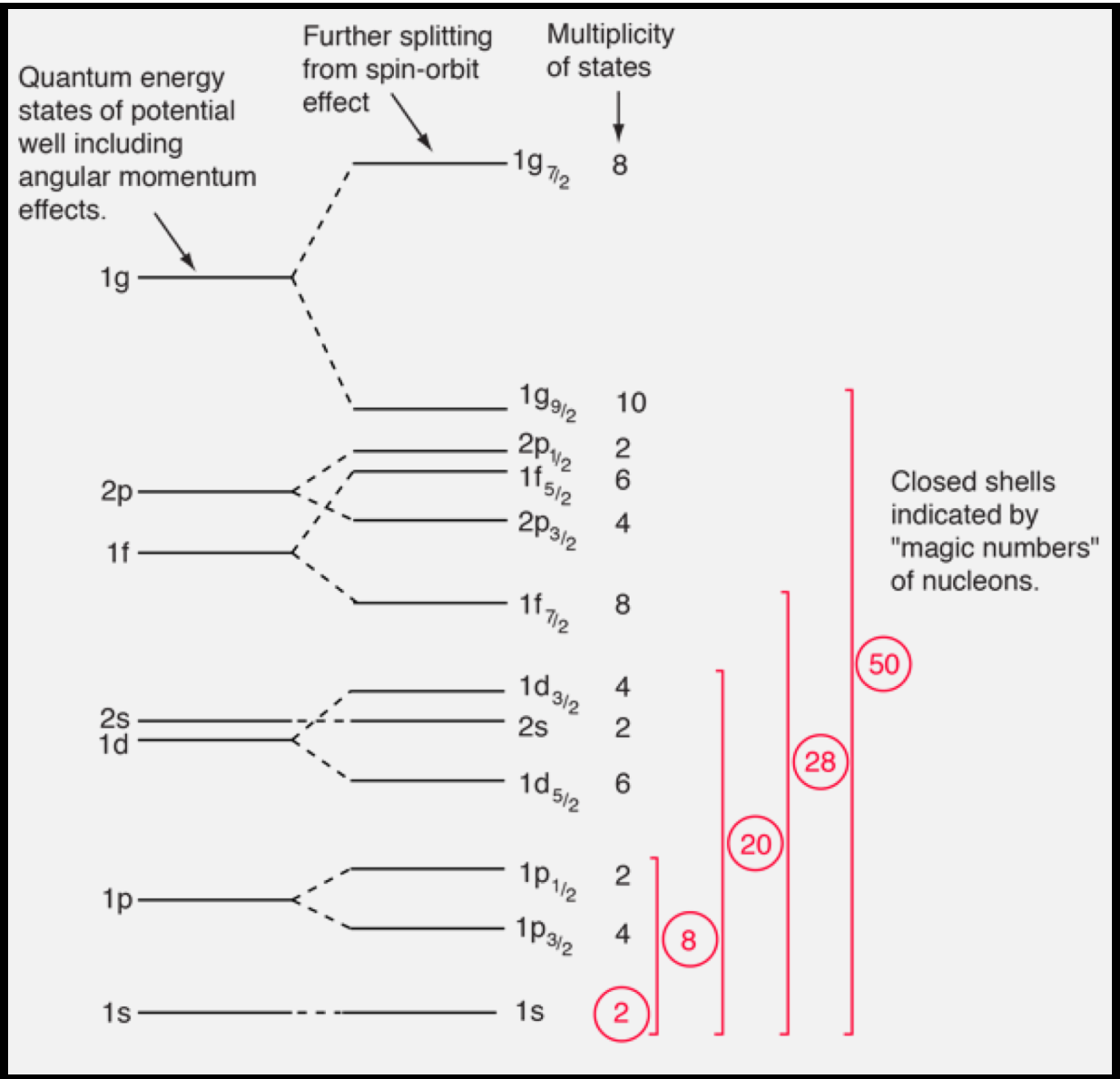


The Setup – Nuclear Shell Model

Nuclear core – includes all filled levels & shells.
Nuclear core wave function has spin-parity $J^P = 0^+$.



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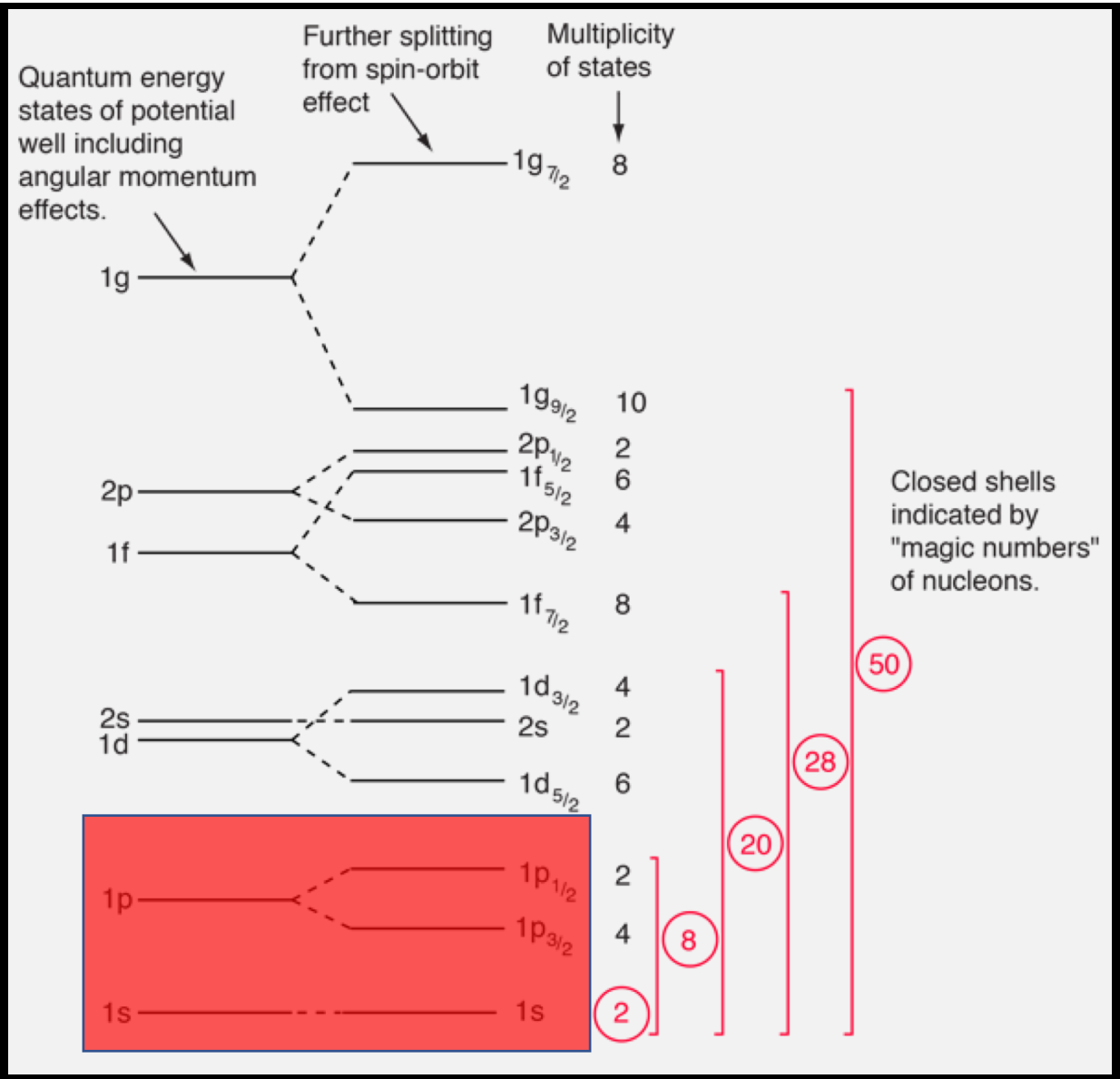
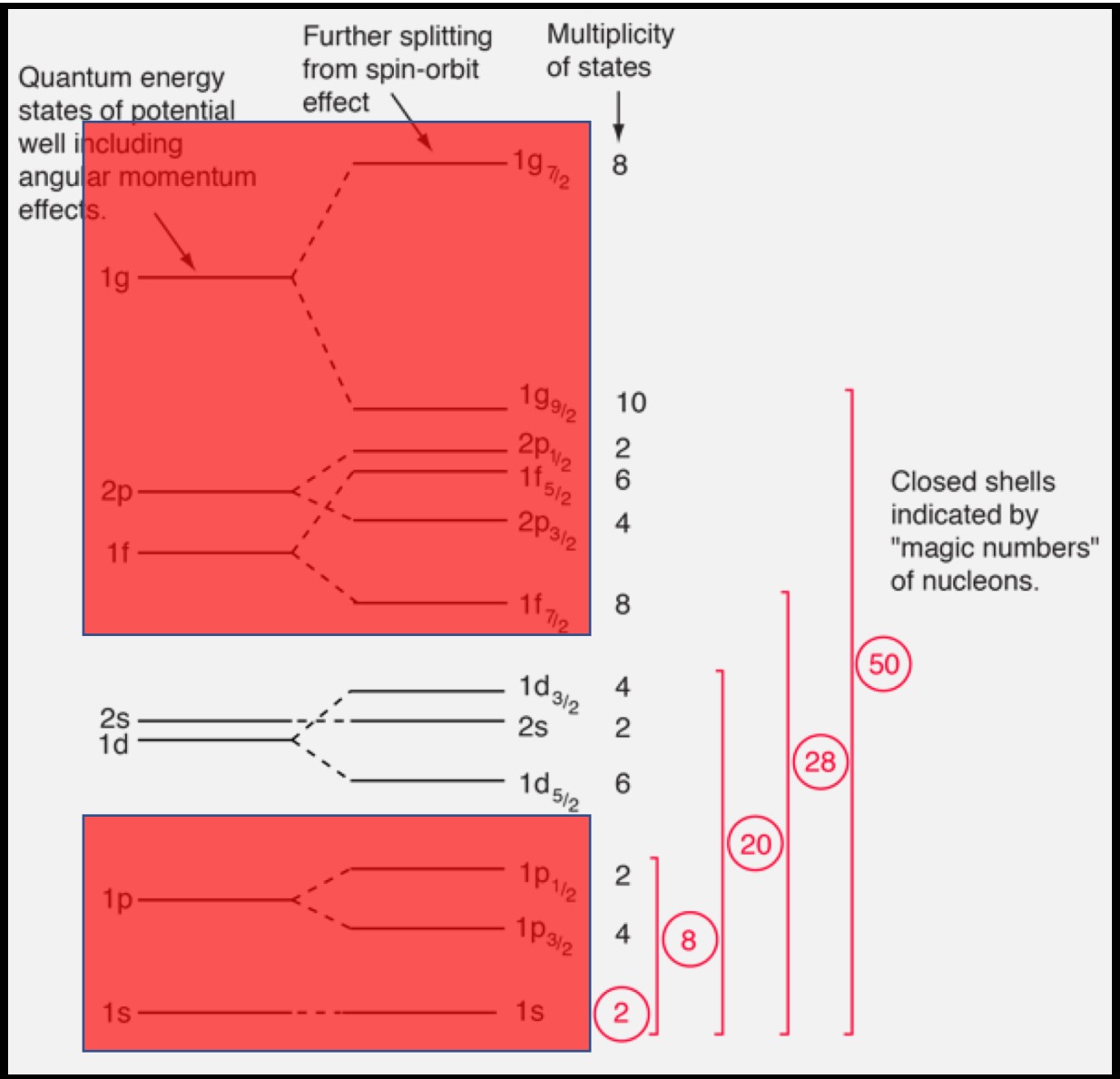


The Setup – Nuclear Shell Model

Angular momentum, parity and overall nuclear wave function dictated by the valence nucleons – those outside the core.



Research Completed

Used NuShellX (nuclear shell model program) to calculate IFF values

```
                        ! ------------------------------------------
                        ! ------------------------------------------
                        ! SD Model Space
                        ! 1d3/2,1d5/2,2s1/2 orbits
sd      sdba    b   k   ! * BONN A FROM Hjorth-Jensen, SEP 2000
sd      kuosd   b   e   ! RENORMALIZED KUO NPA103, 71 (1967)
sd      kuosdm  b   y   ! " " PLUS (A/18)**0.3 MASS DEPENDENCE
sd      bkuosd  b   k   ! BARE KUO NPA103, 71 (1967)
sd      pw      b   d   ! (PW) PREEDOM-WILDENTHAL PR C6, 1633 (1972)
sd      cw      b   c   ! (CW) CHUNG-WILDENTHAL A=17-28 INTERACTION
sd      cwh     b   h   ! (CW) CHUNG-WILDENTHAL A=28-39 INTERACTION
sd      kuosdh  b   g   ! K12.5P from Chung's thesis
sd      sdm     b   m   ! WILDENTHAL-MCGRORY MSDI (PRC4, 1708 (1971))
sd      w       b   w   ! (W) WILDENTHAL'S A=17-39 "USD" INT (JULY 1982)
sd      usda    b   a   ! Phys. Rev. C74, 034315 (2006)
sd      usdb    b   b   ! Phys. Rev. C74, 034315 (2006)
sd      hbusd   b   j   ! SDPOTA int from Ann. Phys. 182, 191 (1988)
sd      hbumsd  b   i   ! SDPOTB int from Ann. Phys. 182, 191 (1988)
sd      su3sd   b   s   ! SU3 INT - OCT 1990 VERSION
                        ! ------------------------------------------
                        ! ------------------------------------------
```

For the nuclei/isotopes

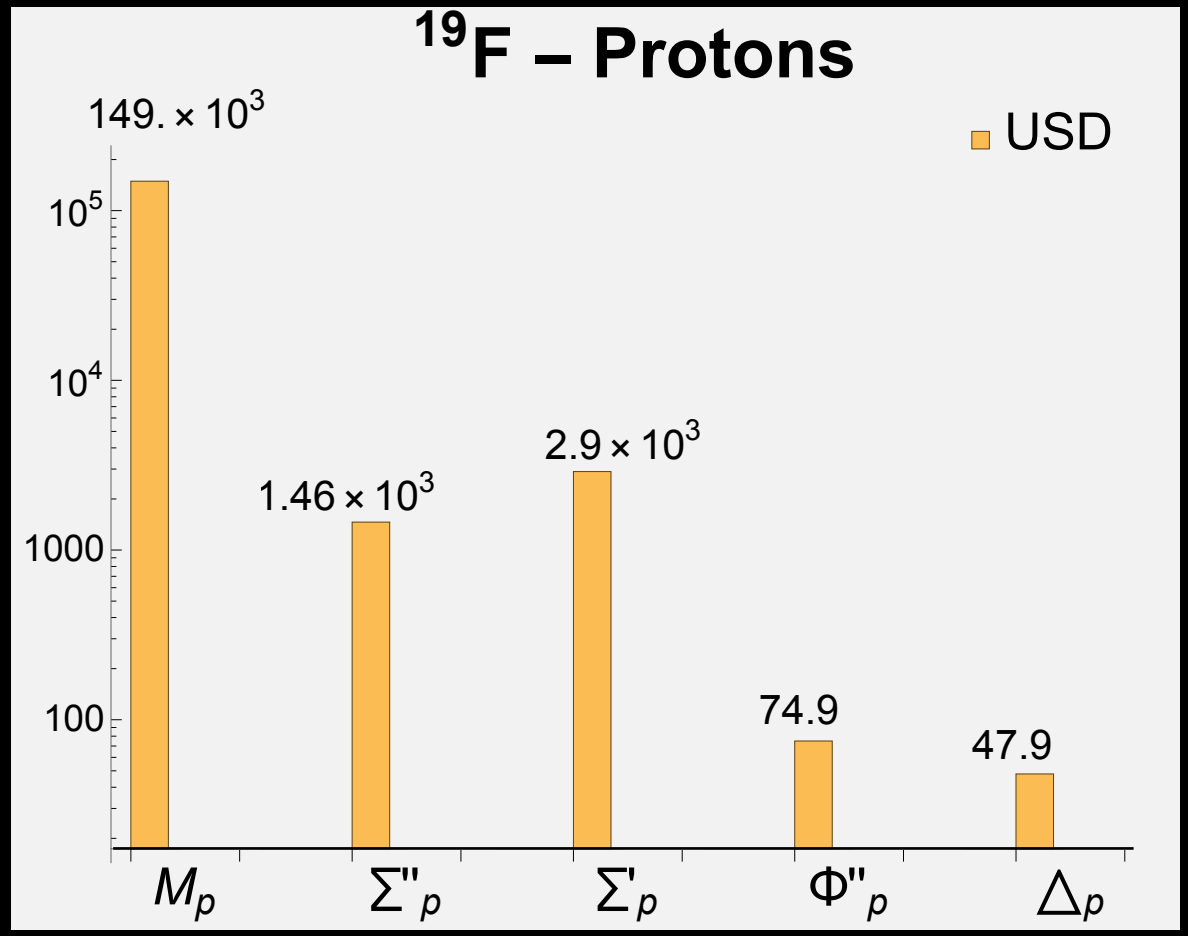
$^{19}F,\ ^{23}Na,$

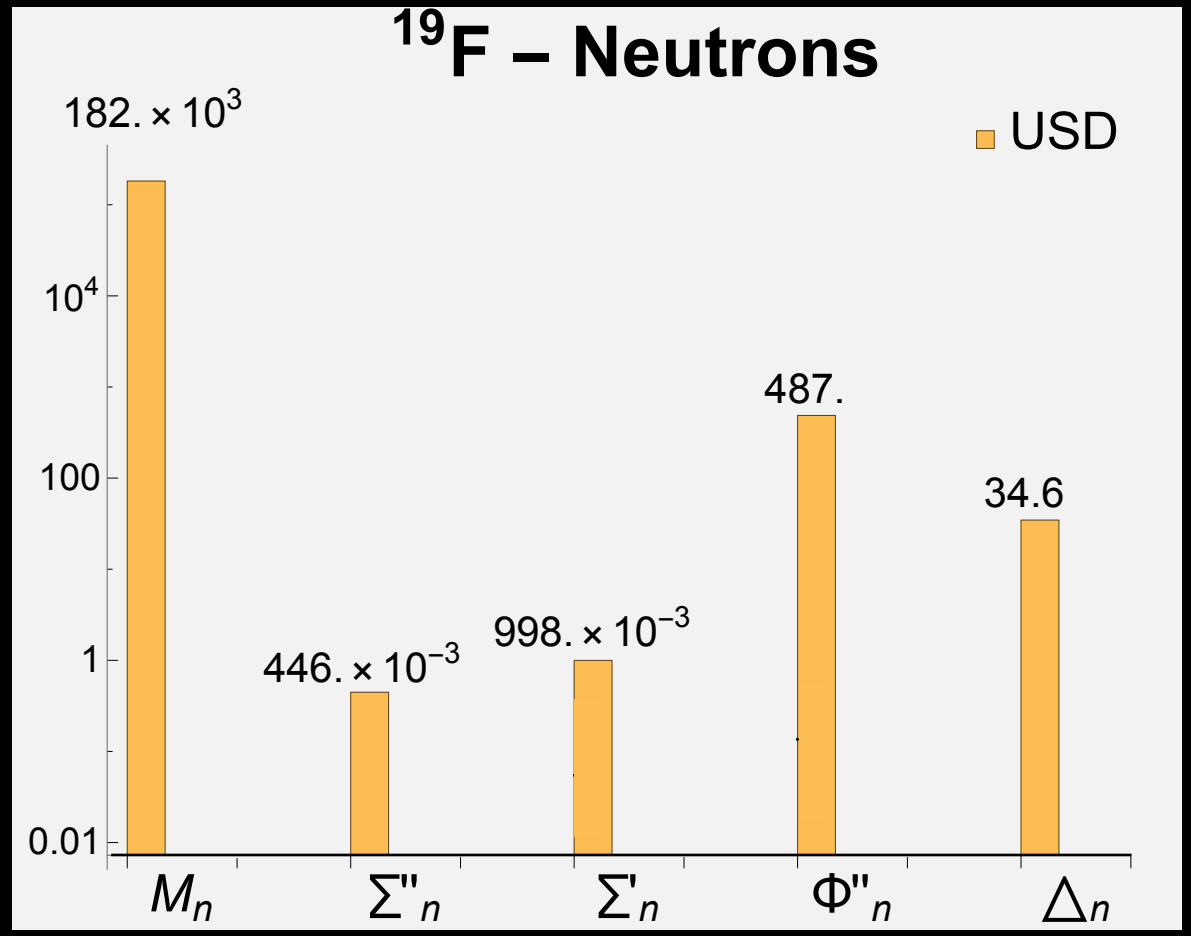
$^{28,29,30}Si,\ ^{40}Ar,$

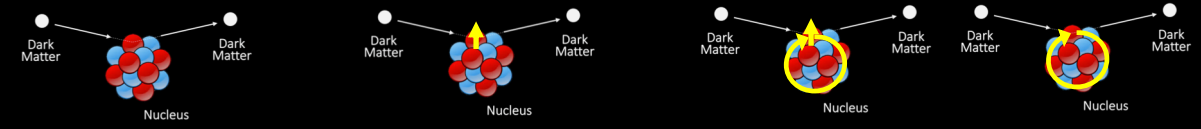
$^{70,72,73,74,76}Ge,\ ^{127}I,$

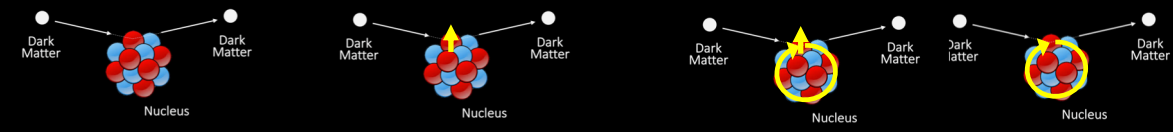
$^{128,129,130,131,132,134,136}Xe.$

Integrated Form Factor Results









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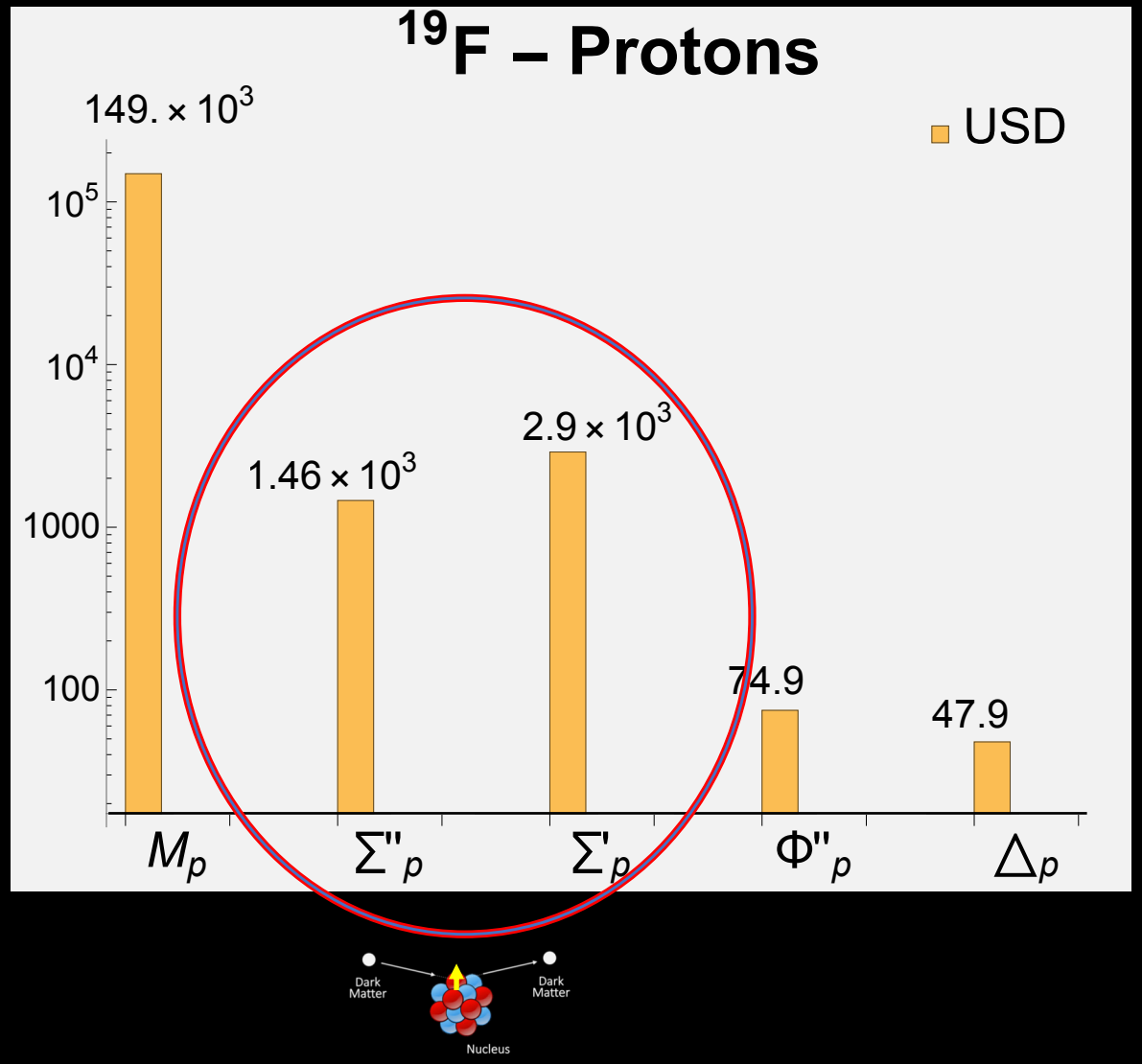

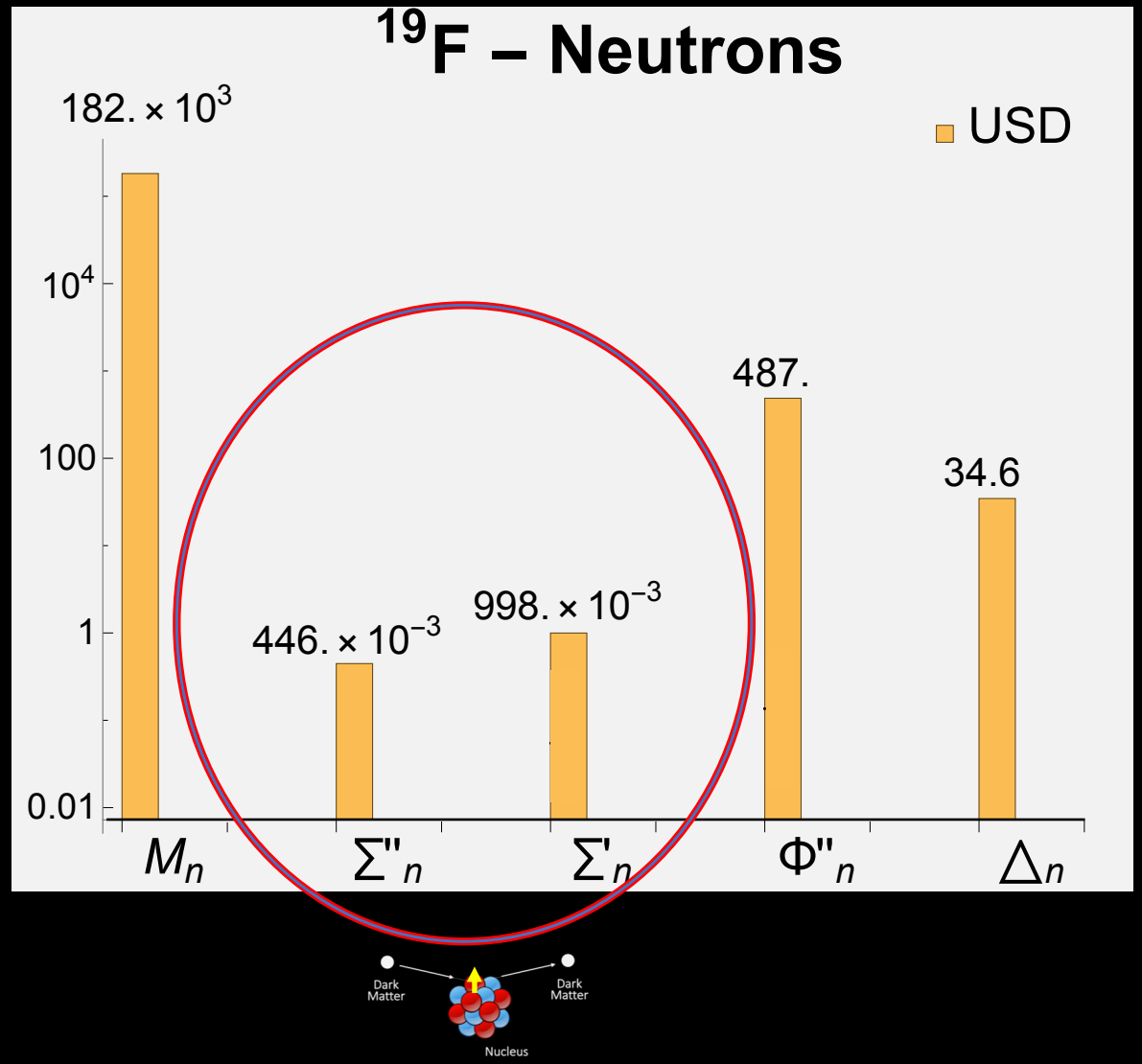

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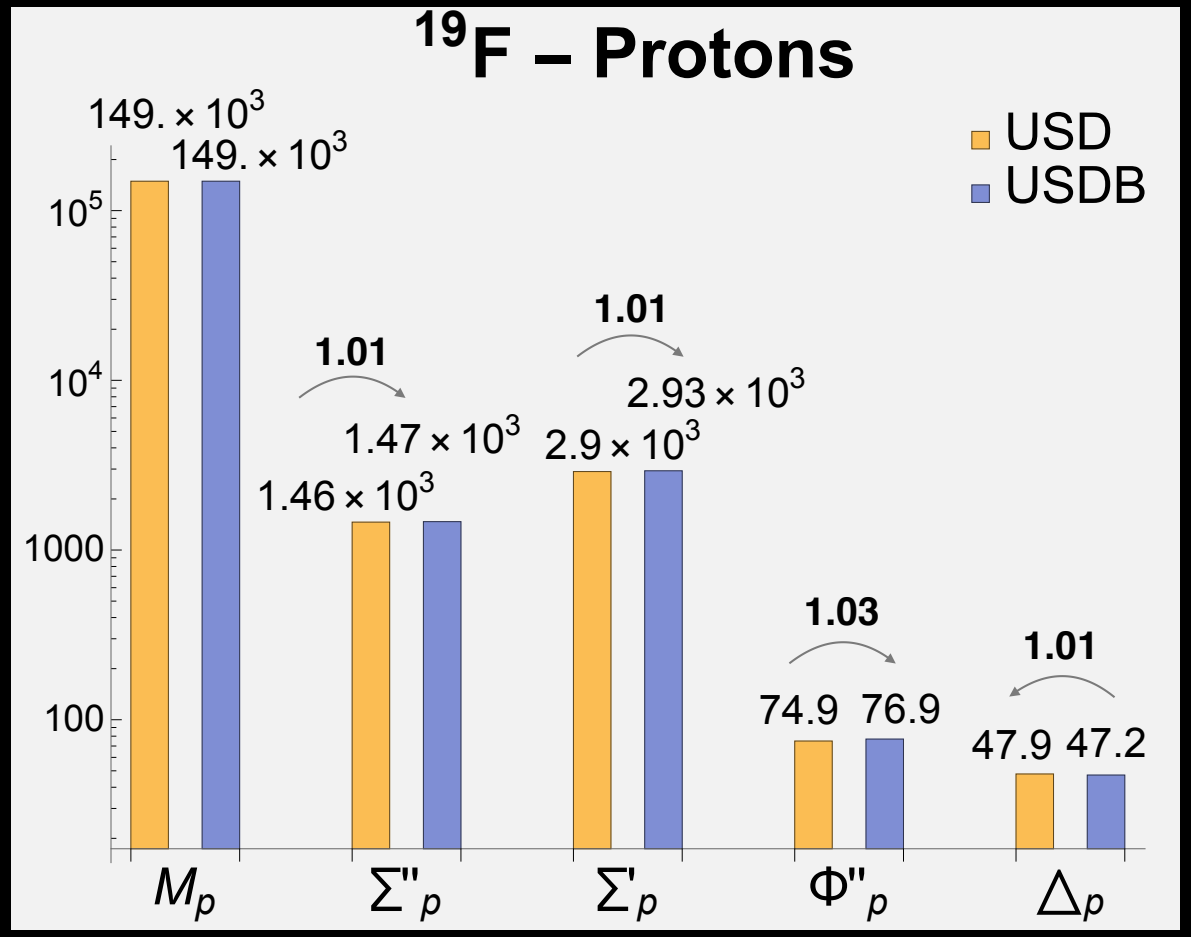

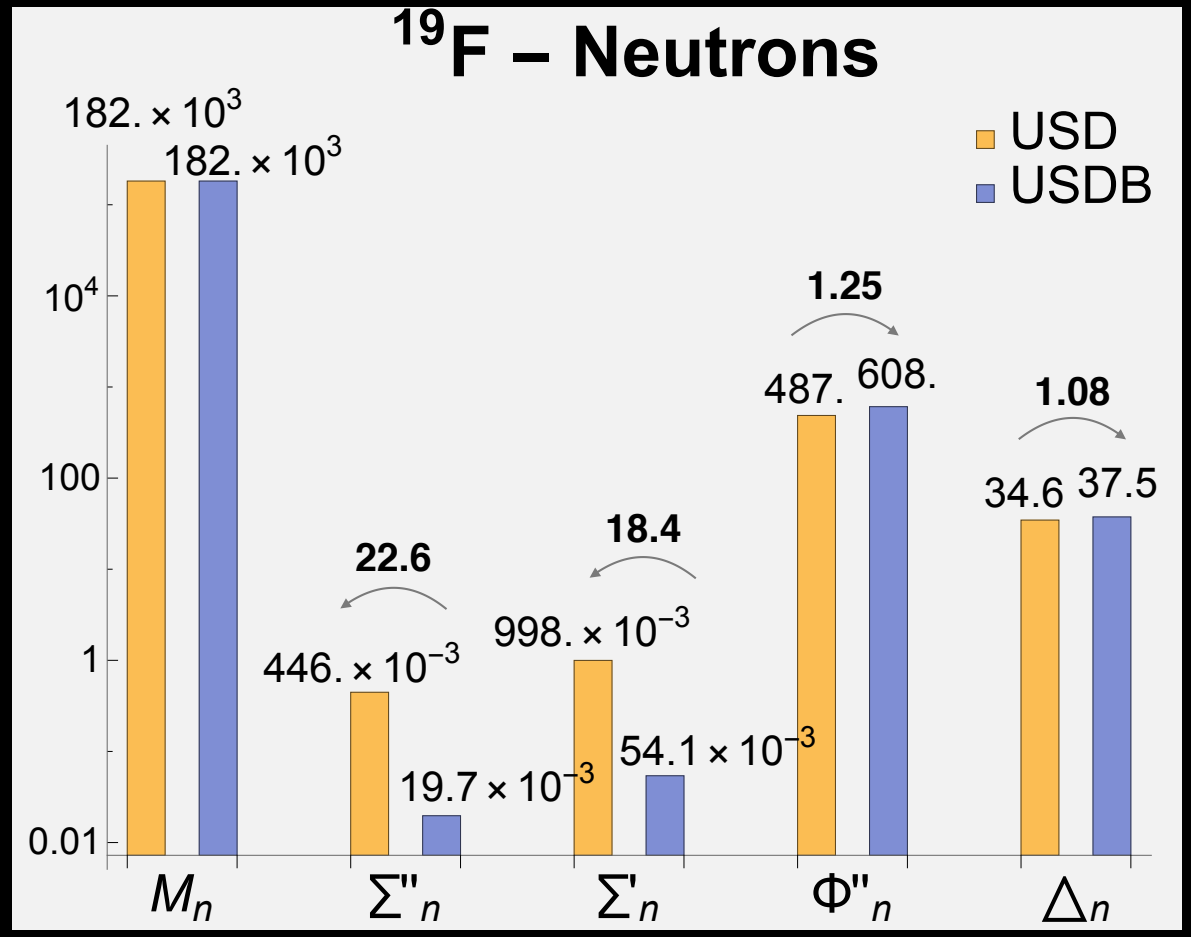

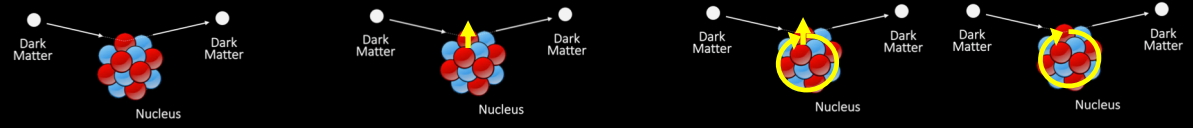

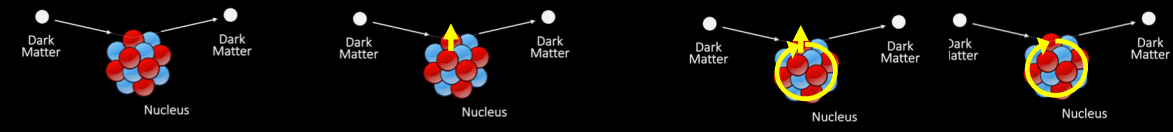

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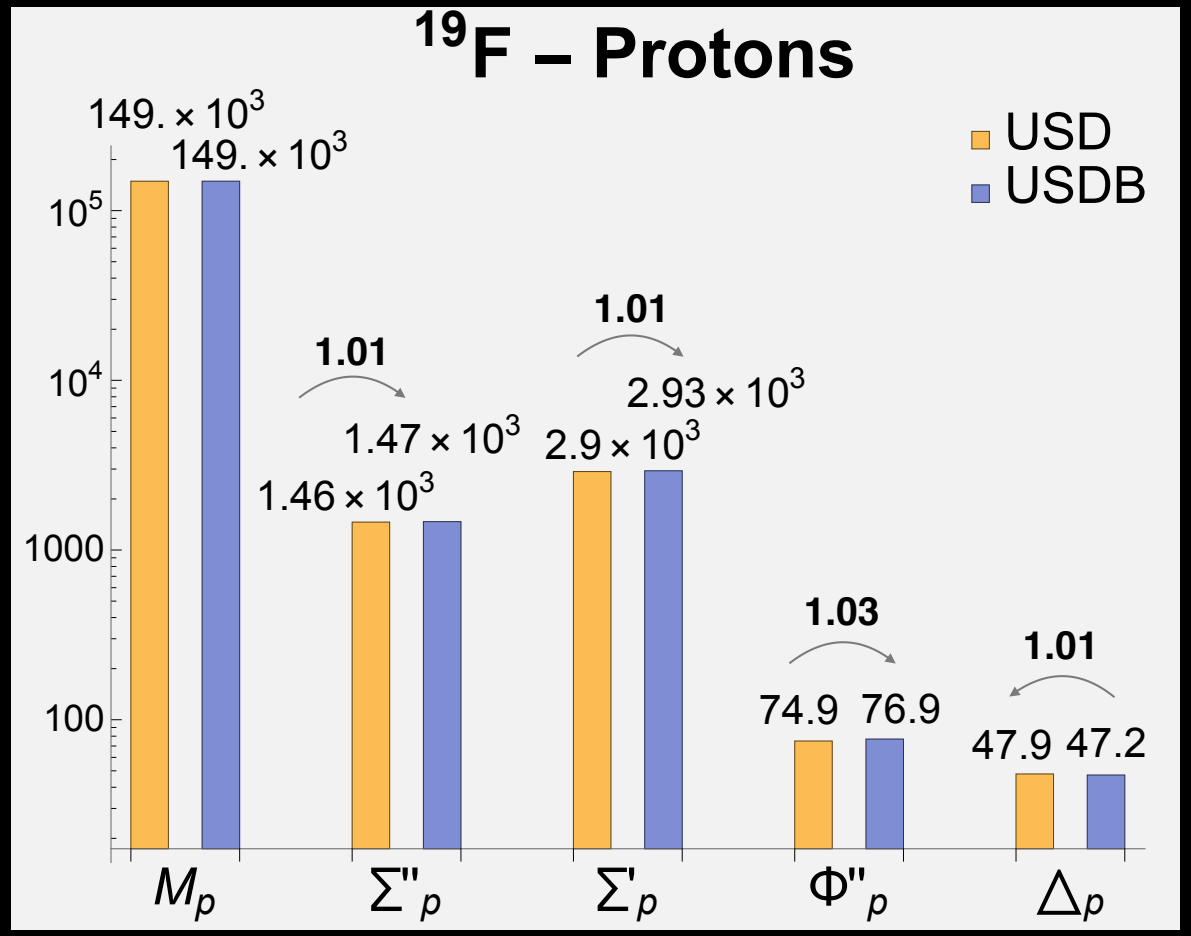
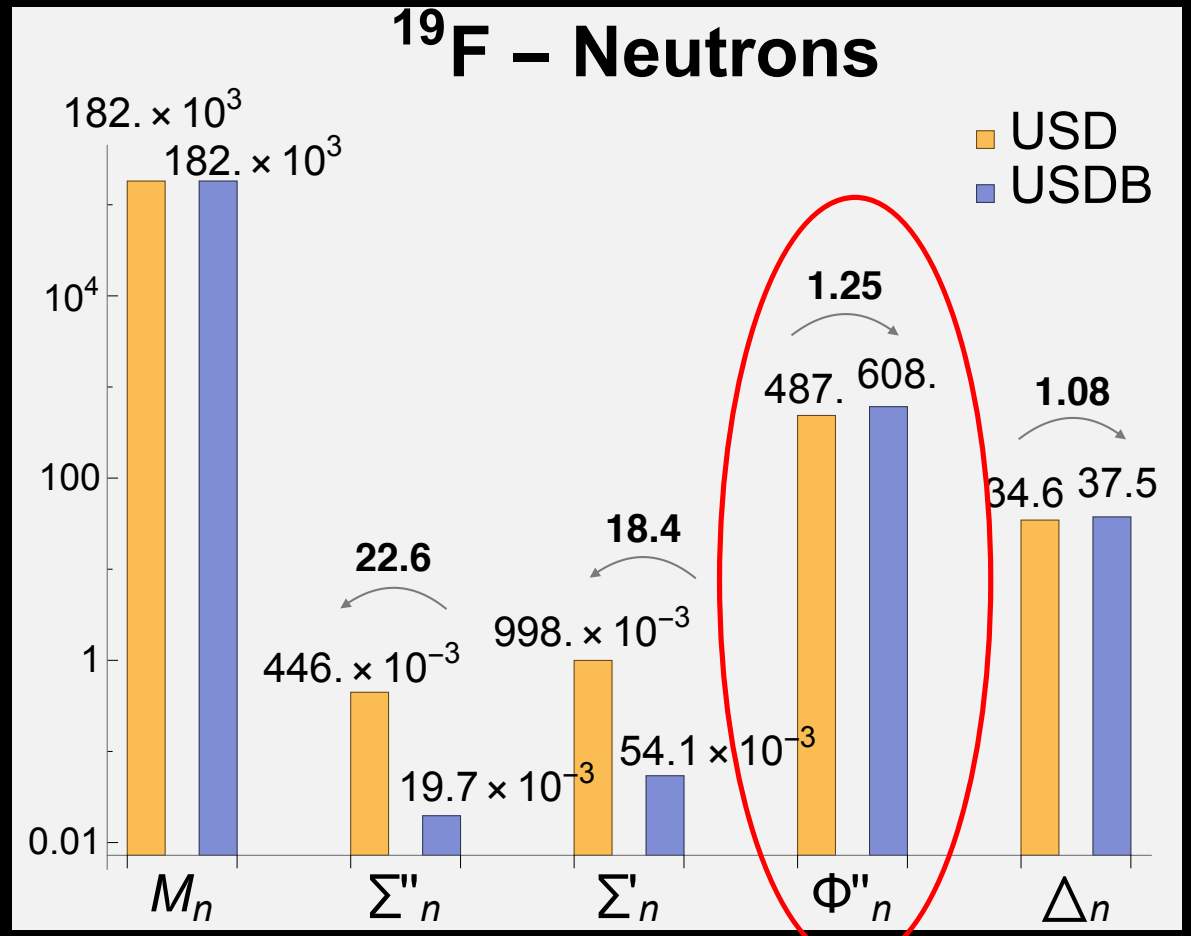
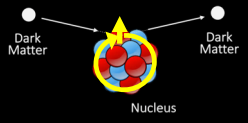




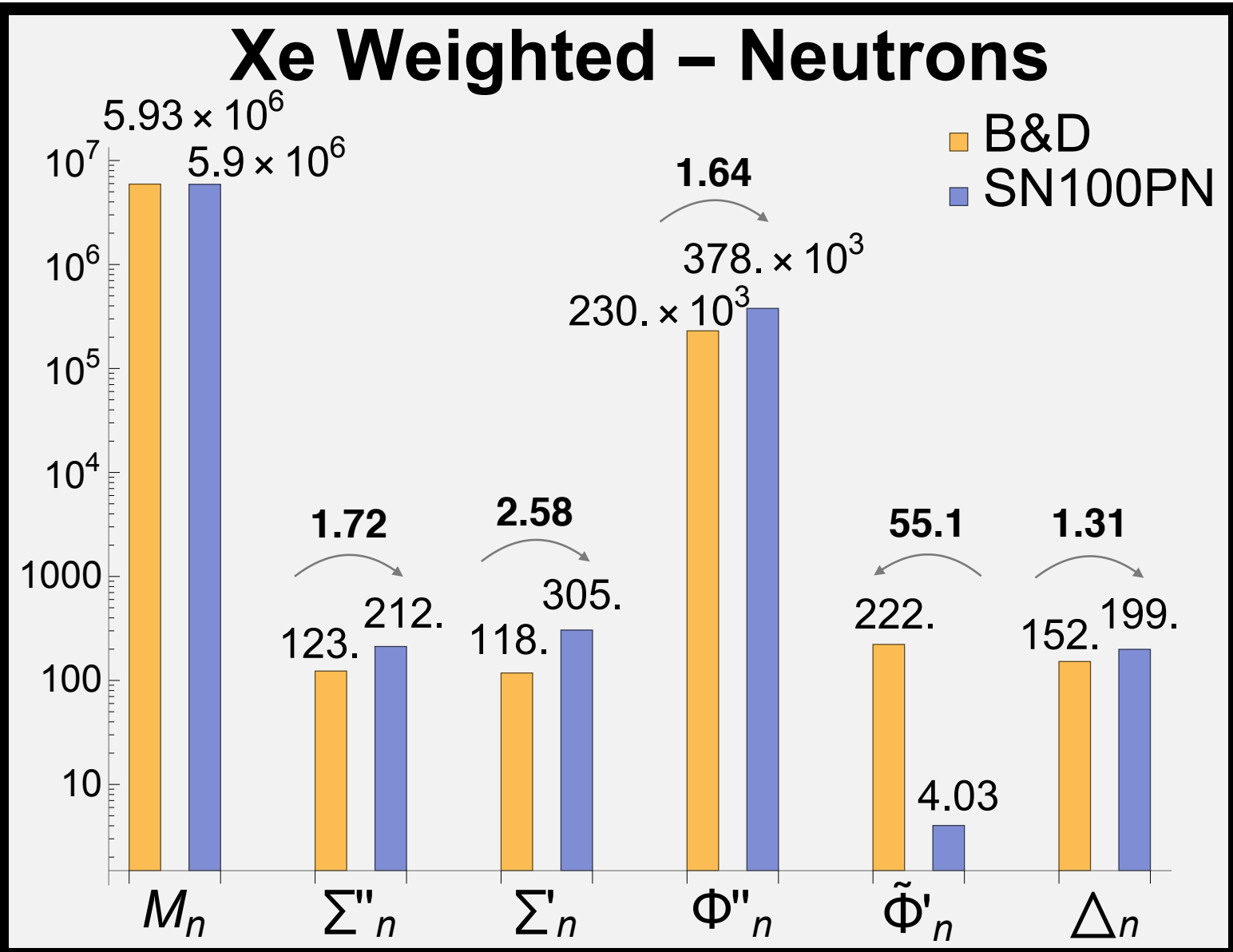
20% is a significant difference!



Integrated Form Factor Results

$^{128,129,130,131,132,134,136}Xe$

Weighted by isotopic abundance



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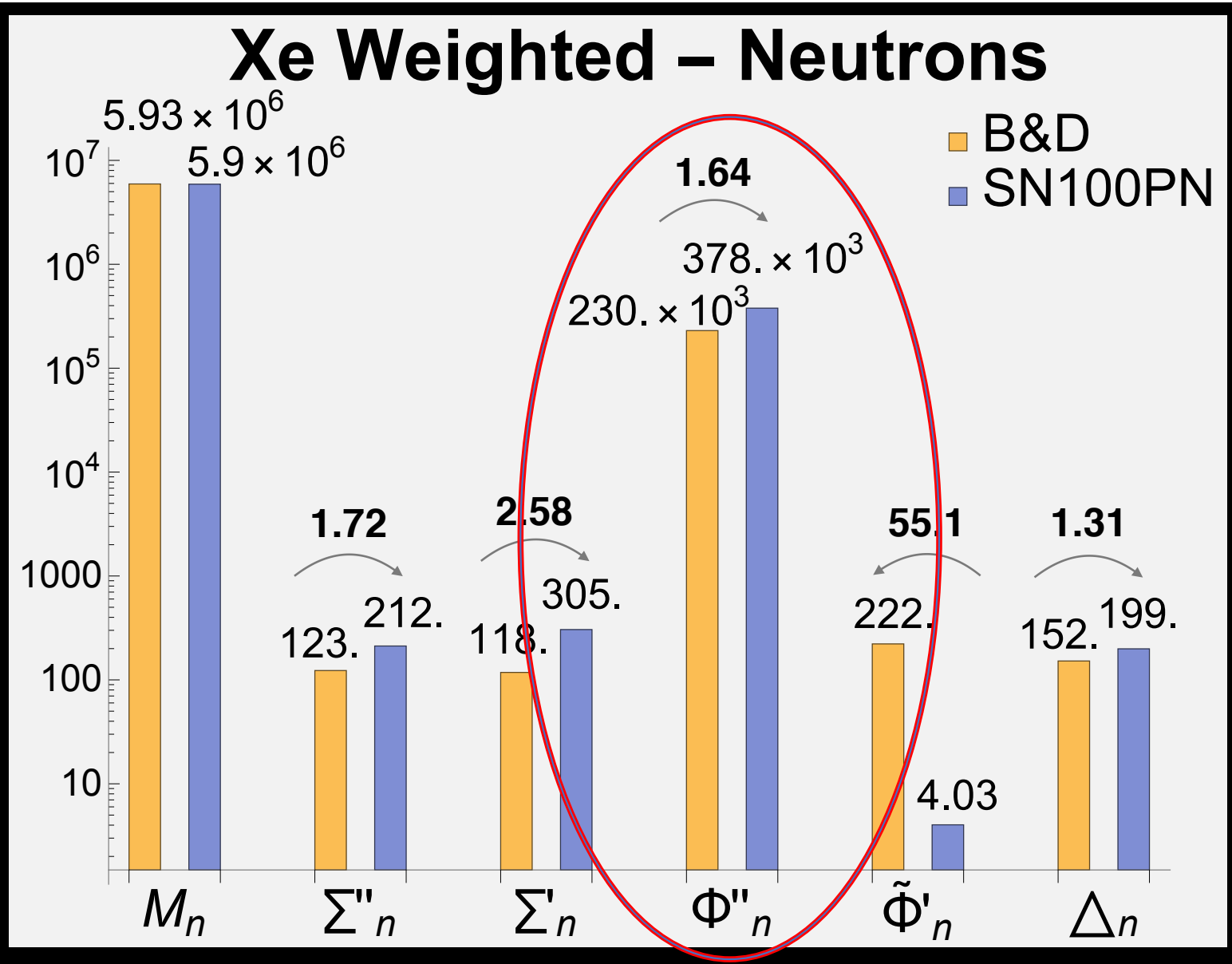
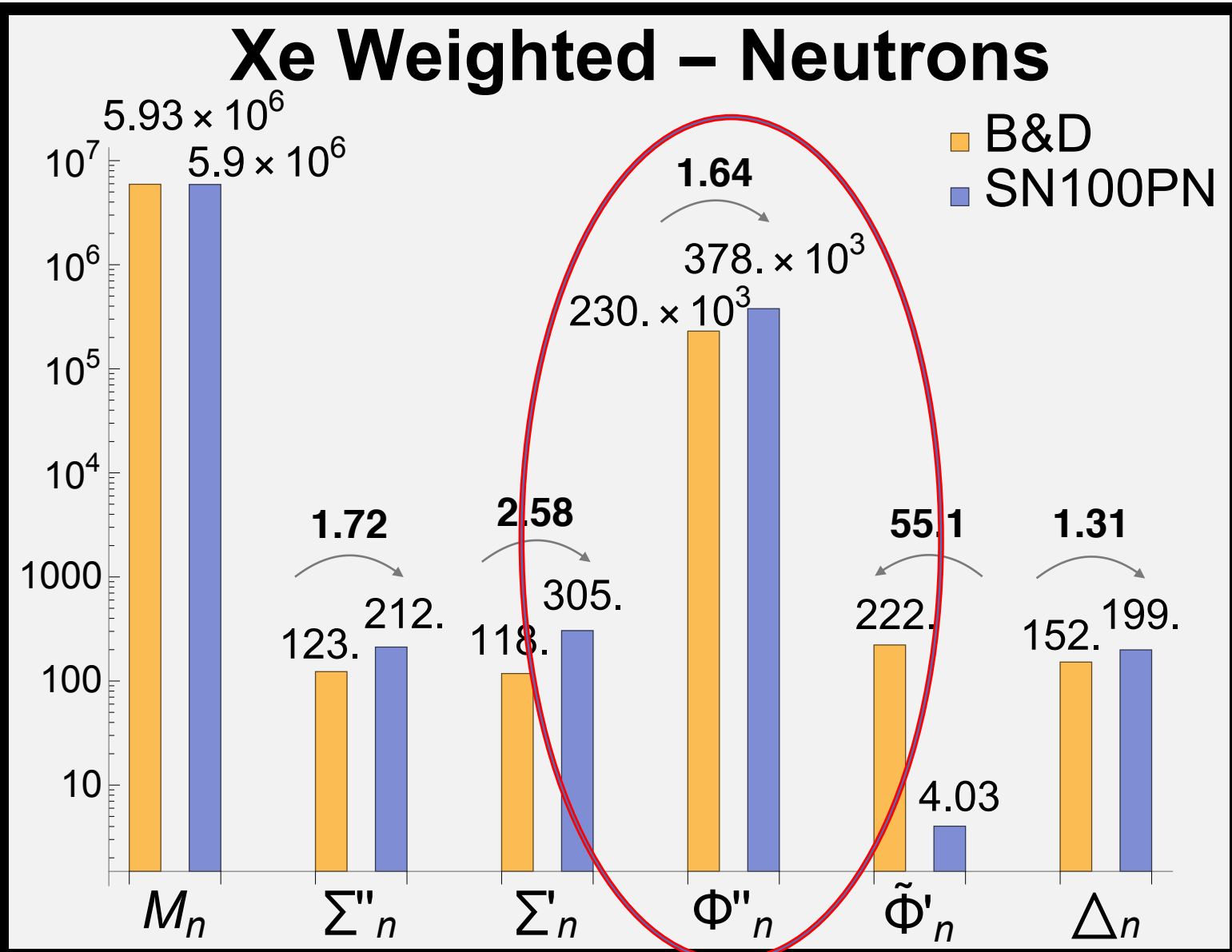


Integrated Form Factor Results

Dark Matter formalism sensitive to aspects of nuclear structure



Important Takeaway

To constrain Dark Matter Candidates via Direct Detection

Must account for nuclear structure modelling & uncertainties!

Important Takeaway

Nuclear Structure is Important!

…. Hire the nuclear physicists

Thank you for listening!