Dark matter searches and the strangeness of the nucleon

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based on JHEP 1208 (2012) 037 , and 1211.444

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ETM Collaboration

Rencontres de Physique des Particules 2013, Grenoble, January 18^{th}, 2013

Outline

Dark Matter

- Rotation curve of spiral galaxy (i.e Galactic scale)
- velocity dispersion of galaxies
- Galaxy cluster and gravitational lensing
- Cosmic microwave background (Cosmological scale)

Several models have been considered but the most widely-studied dark matter candidate are the Weakly Interacting Massive Particles (WIMPS).

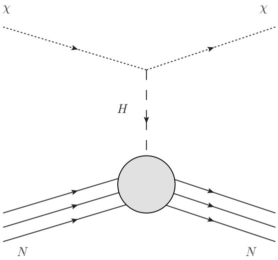
Various types of search

- Accelerator searches
- Indirect detection
- Direct detection

Dark Matter density

WMAP (7-years) : $\Omega_{DM} = 0.222 \pm 0.0026$ [Larson *et al.*,2011]
i.e : Dark Matter account 22% of the mass of the Univers.

Dark Matter direct detection



Spin dependent (SD) and spin independent (SI) cross section :

$$\sigma_{\mathrm{SI},\chi\mathrm{N}} \sim \left| \sum_{q_f} G_{q_f}(m_\chi^2, \dots) f_{T_q} \right|^2, \quad f_{Tq} = \frac{m_q}{m_N} \langle N|\bar{q}q|N\rangle$$

$$\sigma_{\mathrm{SD},\chi\mathrm{N}} \sim \left| \sum_{q_f} \widetilde{G}_{q_f}(m_\chi^2, \dots) \Delta_q \right|^2, \quad \Delta_q \sim \langle N|\bar{q}\gamma_0\gamma_5 q|N\rangle$$

Experiments XENON100 ,CoGeNT, CRESST, EDELWEISS, DAMA, CDMS ...

Relation with the $\sigma-$terms : $\sigma_{\pi N} = m_N f_{Tl}$ and $\sigma_s = m_N f_{Ts}$

Strangeness : $y_N \equiv \frac{2\langle N(p)|\bar{s}s|N(p)\rangle}{\langle N(p)|\bar{u}u+\bar{d}d|N(p)\rangle}$

Some numbers from the phenomenology

Pion Nucleon $\sigma-$term (from πN scattering and χPT) :

- 45 ± 8 MeV [Gasser *et al.*, 1991] [Knecht, 1999]
- 64 ± 8 MeV [Pavan, *et al.*, 2002]

Based on mass splitting among the octet of baryon :

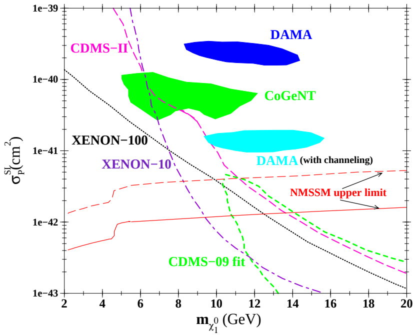
$\sigma_0 = m_l \langle N | \bar{u}u + \bar{d}d - 2\bar{s}s | N \rangle = 36 \pm 7$ MeV [Borasoy & Meissner, 1997]

$\rightsquigarrow y_N = 0.44(13)$ [Young & Thomas, 2010]

$\rightsquigarrow \sigma_s \sim 125$ MeV

Sensitivity of $\sigma_{\mathrm{SI},\chi N}$ to hadronic uncertainties

[Das & Ellwanger,JHEP 1009 (2010) 085]



Default value $\sigma_{\pi N} = 55$ MeV, $\sigma_0 = 35$ MeV ($y_N = 0.36$) full red line
Enhanced value $\sigma_{\pi N} = 73$ MeV, $\sigma_0 = 30$ MeV ($y_N = 0.58$) dashed red line

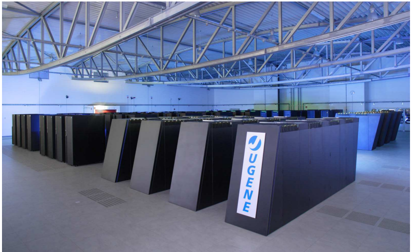
General Strategy

Lattice QCD

- Non perturbative definition of QCD
- regularization : 4D lattice : "path integral" $\longrightarrow$ "finite dimensional integral"
- Numerical estimation of the resulting (HUGE) integral : $\langle O[\overline{\psi}, \psi, U] \rangle$
- Lattice $=$ QCD once $V \to \infty$, $a \to 0$, ...
- final results depends on the quark masses used in the simulation :

  $m_l, m_s, m_c, \ldots$ (assume isospin limit : $m_u = m_d = m_l$)

WE NEED : the BIGGEST supercomputers ever made !



Correlators

Strategy

Extract observable from asymptotic behaviour of suitable combination of correlation function.

J_X : interpolating field of a hadron with definite quantum numbers

Masses :

$$C^X_{\mathrm{2pts}}(t) = \sum_{\vec{x}} \langle J(x) J^\dagger(0) \rangle \propto e^{-M_X t} + \mathcal{O}(e^{-\Delta M_X t}), \quad \Delta M_X = M_{X^*} - M_X$$

Matrix elements

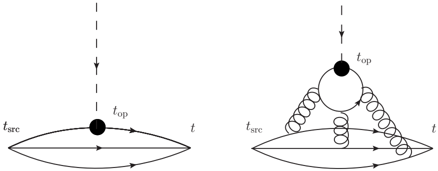
$$R(t, t_s) = \frac{\sum_{\vec{x},\vec{y}} \langle J(x) O(y) J^\dagger(0) \rangle}{C^X_{\mathrm{2pts}}(t_s)} = \langle X | O(0) | X \rangle + \underbrace{\mathcal{O}(e^{-\Delta M_X (t - t_s)}) + \mathcal{O}(e^{-\Delta M_X t_s})}_{\text{Excited states contributions}}$$

AND : Non-perturbative renormalization ...

Challenges

Disconnected diagrams

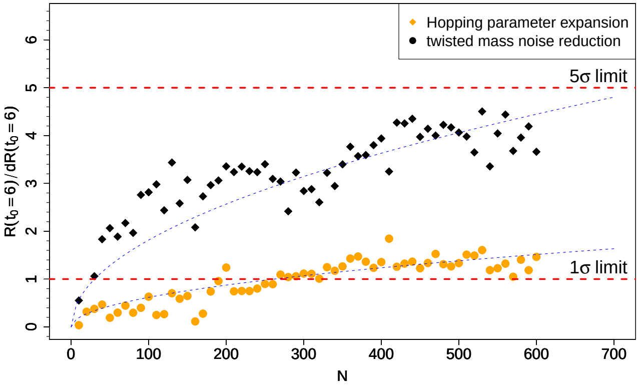
- The Higgs can couple to the "sea" of quark inside the nucleon !
- In general : $R(t, t_s) = R_{\mathrm{conn}}(t, t_s) + R_{\mathrm{disc}}(t, t_s)$
- Signal-over-noise ratio problem : dedicated noise reduction techniques



Non perturbative renormalization

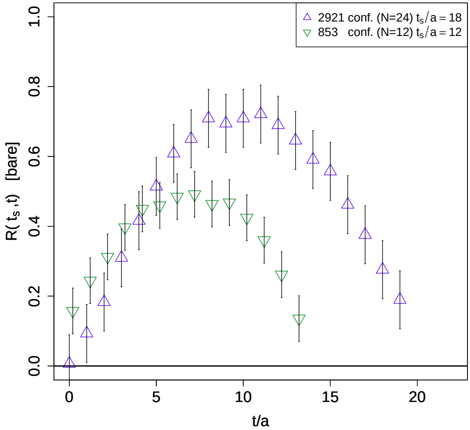
- Renormalization particularly subtle for f_{Tq} : Not discussed here...

Performances



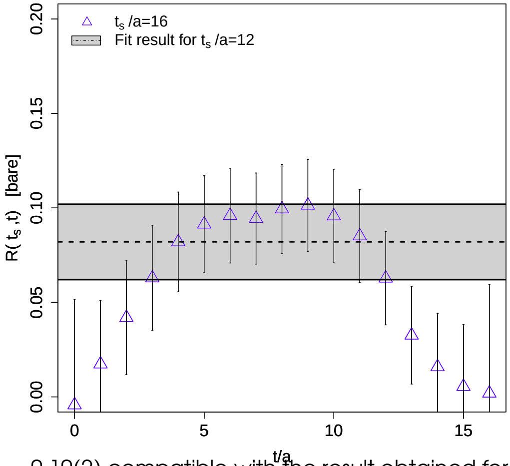
Improvement by a factor of $\mathcal{O}(10)$ the statistic ! (at fixed numerical cost)

Example σ_s



Conclusion : large excited states contamination ⇝ previous computation underestimate one systematic errors ! ($''\sigma_s'' = 20$ MeV $\to'' \sigma_s'' = 35$ MeV)

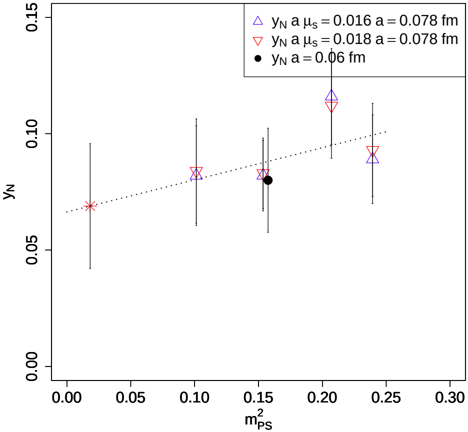
Alternative : y_N



$t_s/a = 16$: $y_N = 0.10(2)$ compatible with the result obtained for $t_s/a = 12$

$\longrightarrow$ cancelation of the excited the excited states contribution

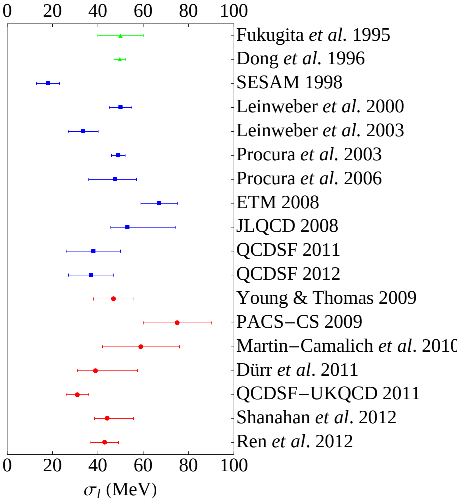
Extrapolation and prelemeninary estimation of systematics

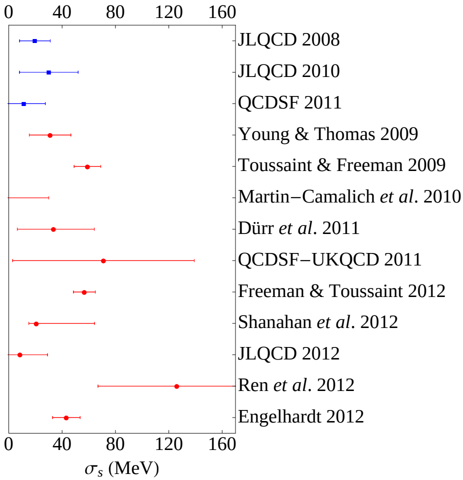


Preleminary final results : $y_N = 0.07(3)(3-4-5?)$ (stat.)(syst.) : compatible with 0 but most probably below 0.1 i.e small value

Comparison

[Young, Lattice 12]





Conclusion

- Improving our knowledge on the strangeness of the nucleon is important to interpret bound provided by dark matter detection experiments
- Lattice QCD computation are the only tool that allow to progress in this context
- Preleminary results indicate that the strangeness is smaller than expected