Dark Matter Candidate in QCD, and an experiment to find it

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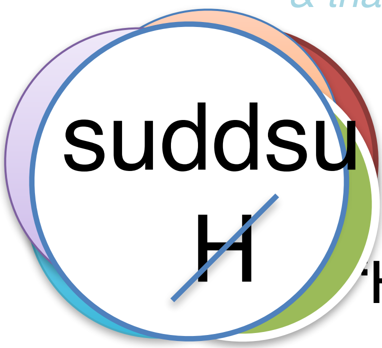


Originally called H-dibaryon*
"H" now taken by Higgs => need new name.

If discovered, call it R for Vera Rubin!

$R_{(H)}$:

6-quark, B=2, Q=0, S=-2
Spin-0, scalar
Flavor Singlet
m = 1.2-1.86 GeV

*Jaffe 1977: mass < 2 m_{Λ} is natural; need mass < 2 m_p to be DM

KEY POINTS of scenario

ANSATZ: $m_{H/R} < 2 m_p$

$\Rightarrow$ H/R IS STABLE

- NEUTRAL, $\sigma_{H/R \cdot N} \sim 10-30$ mb
- not distinctive per-se ("neutron like", $\lesssim \frac{1}{1000}$ abundance)

H/R is suitable DM candidate:

- $\approx$ LCDM cosmology
- $\approx$ no impact on primordial nucleosynthesis
- interacts with gas (H, He) in galaxies
  - locally $\approx$ co-rotates $\Rightarrow$ evades direct detection (too low v_{rel})
  - benefits of SIDM
  - accounts for structure in rotation curves

Detecting R_H

- R_H : neutral, $M \sim M_n$; hard to pick-out; not useful "handle" on itself.

- ***Use B number and Strangeness conservation:***

  - $K^- p \to \bar{\Lambda} R_H$

  - J/Psi, Psi(2S) or Upsilon factory: look for events with
    - 2 baryons, visible S = -2 (and unseen $\bar{H}$) or
    - 2 anti-baryons, visible S = +2 (and unseen H)

B: 1 -1 +2

$$K^- p \to \bar{\Lambda} R_H$$

S: s $\bar{s}$ ss

- $\bar{\Lambda}$ is a gold-plated signature : $\bar{\Lambda} \to \pi^+ \bar{p}$
  - Easy to ID & reconstruct 4-momentum
  - $c\tau$ = 8 cm … all are ID'd

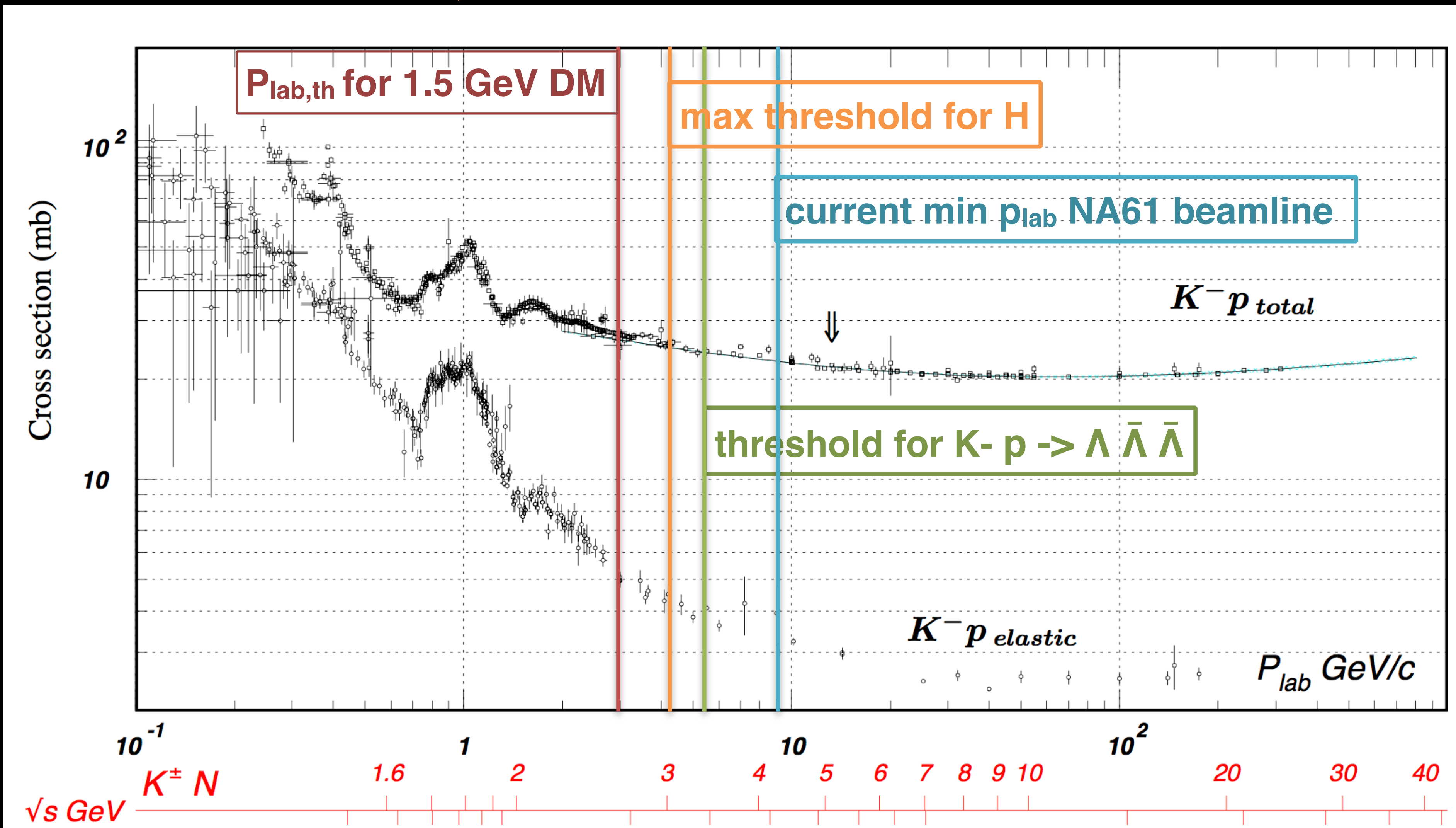
- R_H : undetected, but 4 momentum determined
  - $p_H = p_K + p_p - p_{\bar{\Lambda}}$
  - NA61: est.~ 20 MeV accuracy on "missing-mass" of R_H

- For p_{beam} < 5.35 GeV/c , no conventional source of $\bar{\Lambda}$'s
  - $K^- p \to \Lambda \Lambda \bar{\Lambda}$ => sqrt[s]> 3 m

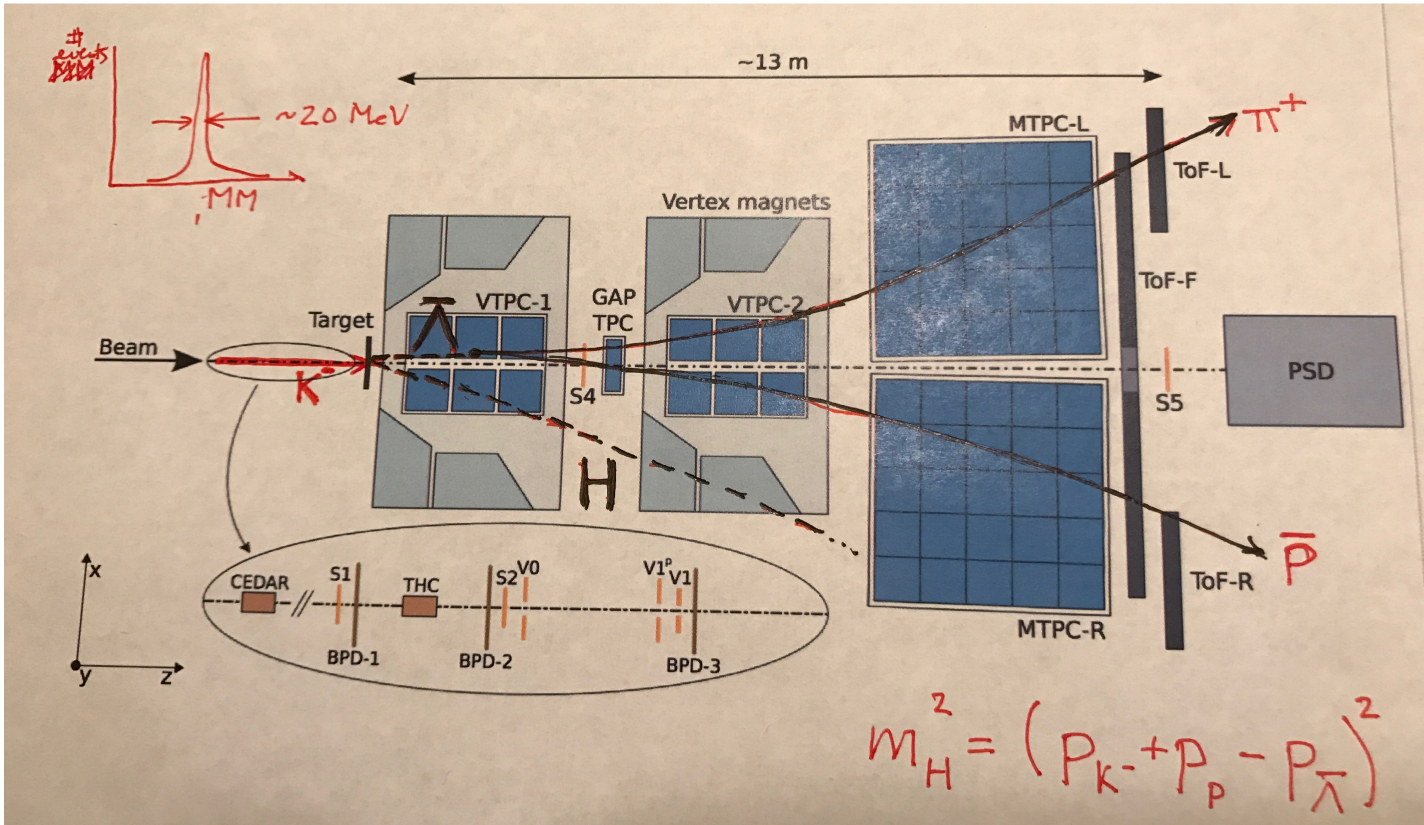
K- p -> $\bar{\Lambda}$ R_H

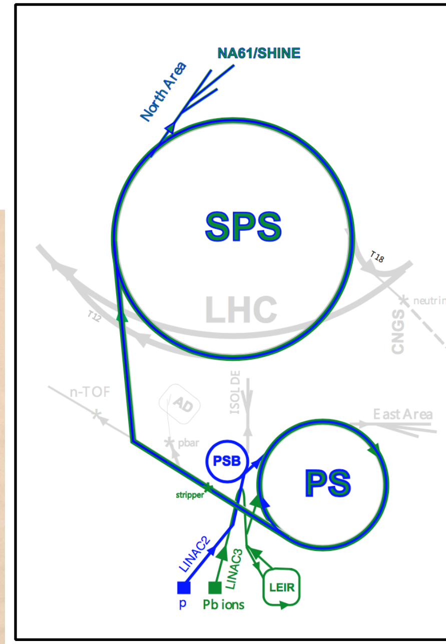
max $m_\Lambda + M_{DM} < m_\Lambda + 2\, m_p = 3$ GeV => p_{lab,th_max} **= 4.14 GeV/c**

M_{DM} = 1.5 GeV => $p_{lab,th}$ **= 3 GeV/c** threshold for conventional $\bar{\Lambda}$: **5.35 GeV/c**



NA61/SHINE





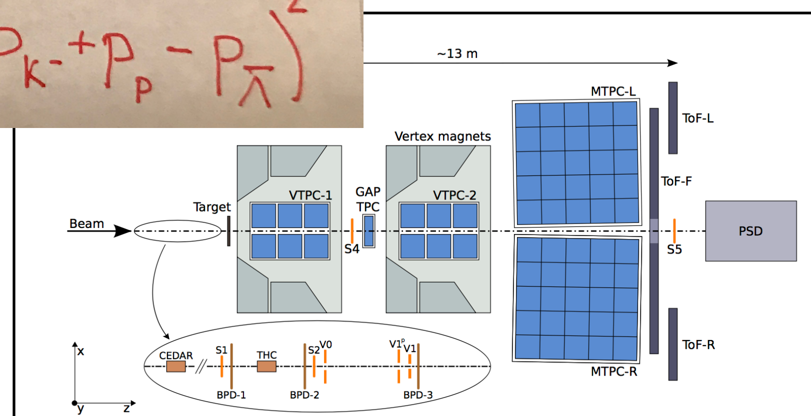


Figure 1. Schematic layout of the NA61/SHINE experiment at the CERN SPS (horizontal cut in the beam plane, not to scale). The beam and trigger counter configuration used for data taking on

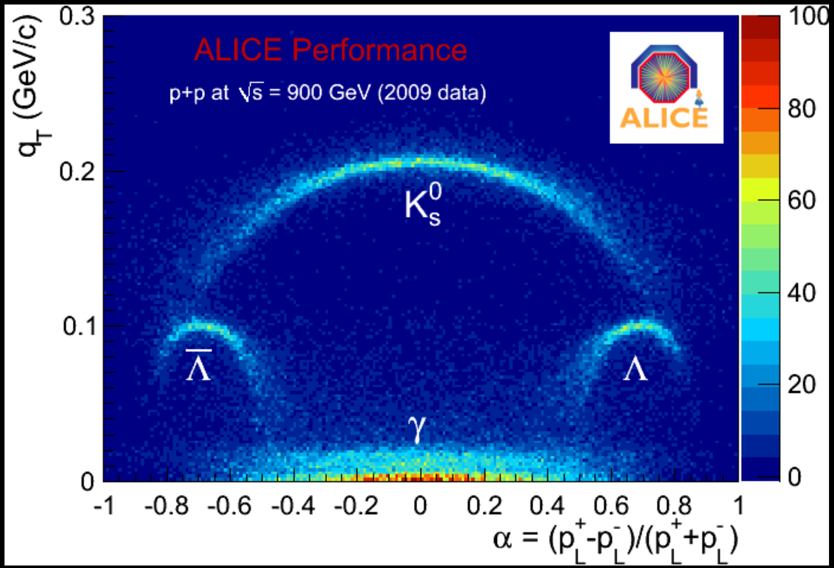
Background to $K^- p \to \bar{\Lambda} R_H$

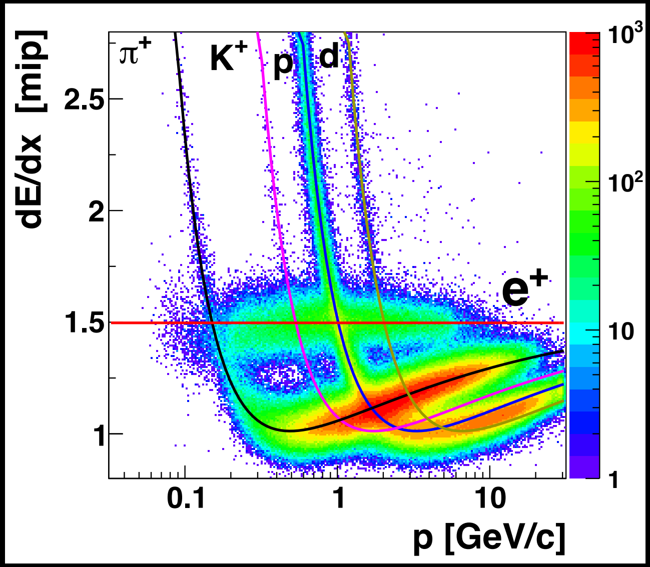
- K- p -> K^0 n + neutrals
  ↳ $\pi^+ \pi^-$

DANGER: mis-ID **π**- as $\bar{p}$ & interpret n + neutrals as **H**.

- NA61: *good rejection of* K^0 *faking* $\bar{\Lambda}$
  - ToF, dEdX, kinematic cuts to reject in dangerous regions
  - GEANT sims running to quantify…

"Armenteros Podolanski" plot





NA61

- Trigger rate ~100 Hz => 10^7 events per day
  - GEANT: ~ 0.5% K^0 n + neutrals => can refine trigger
- Schedule mostly fixed till shutdown in 2018; restarts 2020.
- *? short K-p run at 9 GeV/c before shutdown, to evaluate rejection efficiency and background?*
- Maybe 9 GeV/c beam is ok! => longer run in 2020…

Conclusions

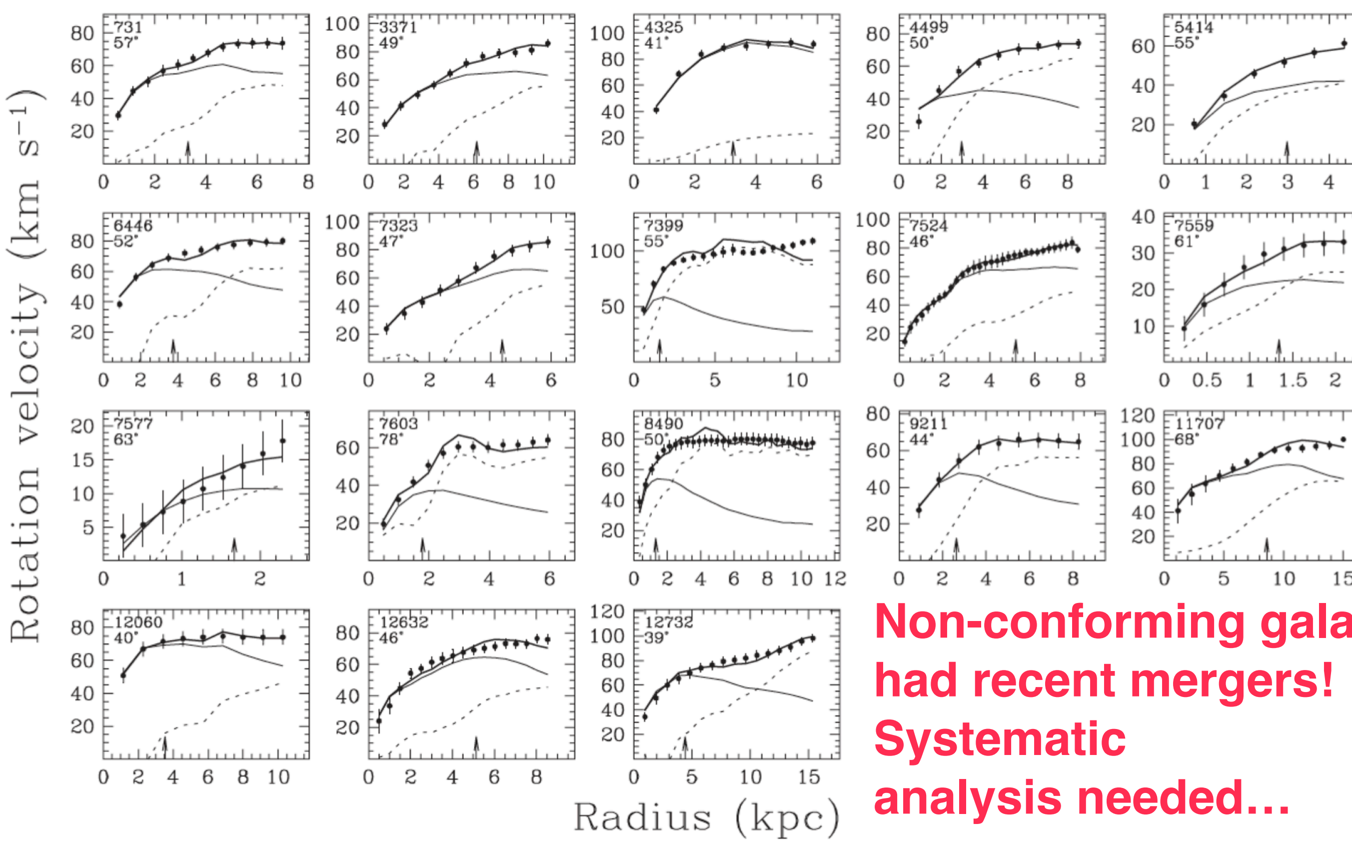
- A stable 6-quark state looks like an excellent DM candidate - accounts for astrophysical phenomena not otherwise explained.
- search in $K^- p \to \bar{\Lambda} R_H$
  - looks feasible
  - economical (use existing NA61 detector)
  - quickly accomplished (if existing beam is adequate)
  - Determines the mass, not just establishes its existence.

Essential Cosmo/Astro

- Freezeout => correct relic density
  - T~ O(10) MeV follows from QCD couplings
  - naturally gives observed DM and OM abundances
- Hadronic interaction ($\boldsymbol{\sigma}_{RN}$ ~ 30 mb) a boon:
  - DM at solar radius ~O(10) scatters in 10 Gyr => co-rotates
    - v_{rel} ~ 25 km/s evades detection by XQC
    - DM forms dark disk (properties tbd) as indicated by paleo data
    - DM rotation curve structure mimics gas-only rotation curve, c.f., Sancisi et al
  - DM halo at larger radius not impacted
  - McGaugh + “universal behavior; Tinker, tight correlation of DM-OM
  - Potentially ontribute similar benefits as SIDM

Dark Matter in Solar neighborhood ~ conforms to & co-rotates with the gaseous disk!

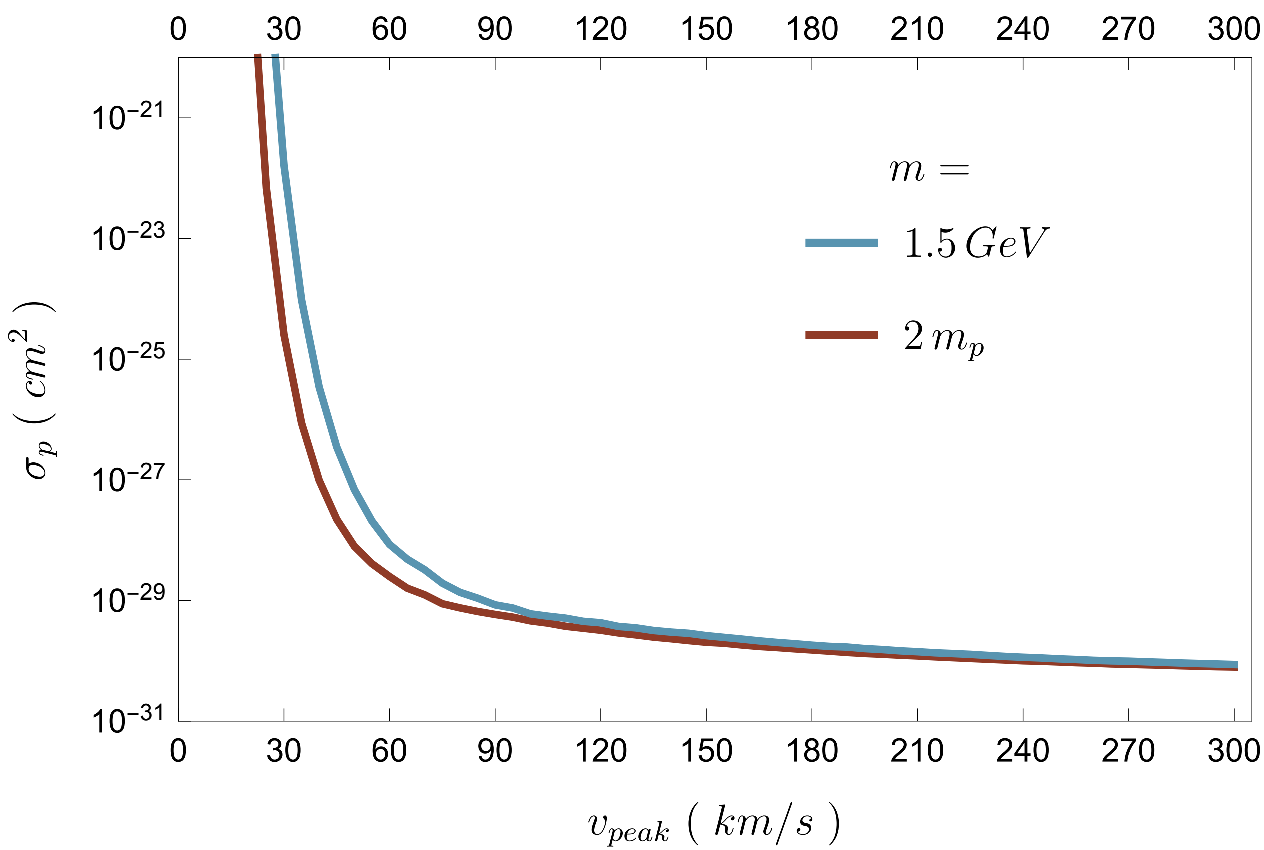
Swaters+12



Non-conforming galaxies had recent mergers! Systematic analysis needed…

Figure 1. Mass models based on scaling the stellar disc and the H I component for the late-type dwarf galaxies in our sample. The filled circles represent tl derived rotation curves. The thin full lines represent the contribution of the stellar discs to the rotation curves and the dotted lines that of the gas. The thic solid lines represent the best-fitting model based on scaling the contributions of the stars and the gas. The arrows at the bottom of each panel indicate a radiu of two optical disc scale lengths. In the top left corner of each panel, the UGC number and the inclination are given.

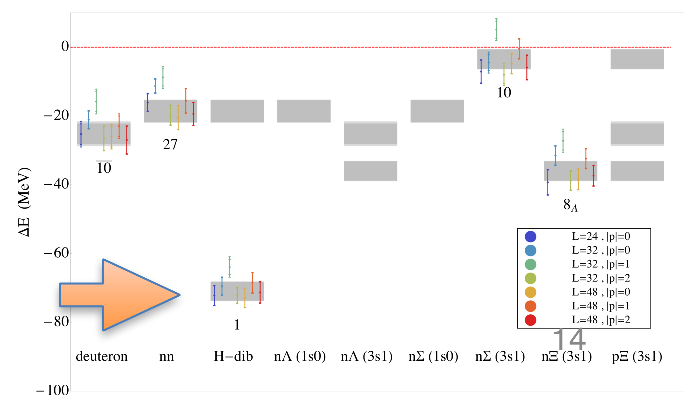
XQC sensitivity to v_{peak}



Backup slides

Properties of the H-dibaryon: $u_\uparrow u_\downarrow d_\uparrow d_\downarrow s_\uparrow s_\downarrow$

- Scalar (spin-0, even parity)
- ***Flavor singlet (not just I=0) ⇒ no π, ρ… coupling***
- ⇒ **relatively weakly coupled to other hadrons**
  - Does not bind to atoms (no exotic isotopes) "Non-binding of Flavor-Singlet Hadrons to Nuclei", GRF and G. Zaharijas Phys. Lett. B.559: 223-228, 2003.
  - Not excluded by accelerator searches "A STABLE H DIBARYON: DARK MATTER CANDIDATE WITHIN QCD?" Int. J. Theor. Phys. 42:1211-1218, 2003. Also in *Minneapolis 2002, Continuous advances in QCD* 582-590.
  - *σ_{HN} 10-100 mb* "Nucleon and Nuclear Transitions of the H dibaryon", GRF and G. Zaharijas. Phys. Rev. D70:014008,2004.
  - ***Mass range of primary interest: 1.5 - 1.86 GeV***
    - Recent lattice QCD:
      - Λ-Λ deeply bound (S. Beane et al, 2013)
      - calculation for symmetric H underway
      - Years till reach physical m_q



Relic Density of H dark matter

I. What freezeout temperature is needed?

(in collaboration with M. S. Mahdawi)

- Correct relic DM density $\Longleftrightarrow$ correct $n_{``B"}/n_\gamma$ & "baryon"/H ratio
- Prior to freezeout, H $K^+ \leftrightarrow p\,\Lambda$, etc, $\Rightarrow$ in eq $\mu_H = 2\mu_N$
- $\frac{\Omega_H}{\Omega_b} = \frac{m_H}{m_N}\frac{n_H}{n_b^2}\frac{n_b}{n_\gamma}n_\gamma$ &

$$\frac{n_H}{\ldots} \quad \frac{g_H \exp\left(-\frac{m_H - 2m_N}{T_*}\right)}{\ldots T_*/2\pi)} \left(\frac{m_H}{\ldots}\right)^{3/2}$$

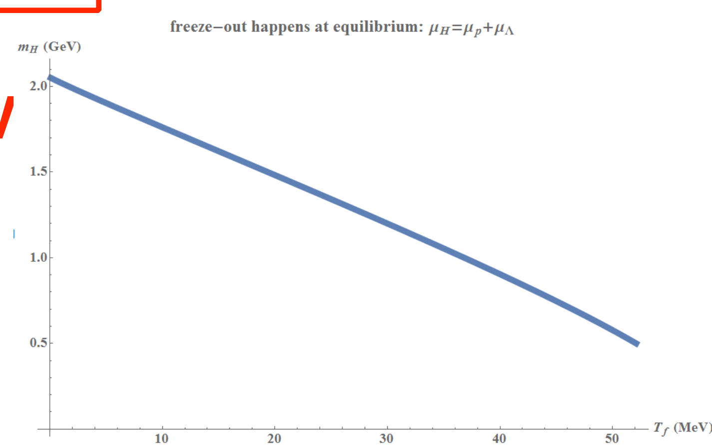
$\delta \equiv (2m_N - m_H)/m_N$

$X_* = m_N/T_*$

$$\Rightarrow \frac{\Omega_H}{\Omega_b} \approx 0.24\,\eta \left(\frac{m_H}{m_N}\right)^{5/2} e^{\delta X_*}\, X_*^{-3/2}$$

$m_H \sim$ 1.7-1.8 GeV <=> T_* = 5-10 MeV

- In hadron regime & above nucleosynthesis!
- *1st consistency condition is met*



Relic Density constraints
II. Calculating $T_{f.o.}$ from QCD

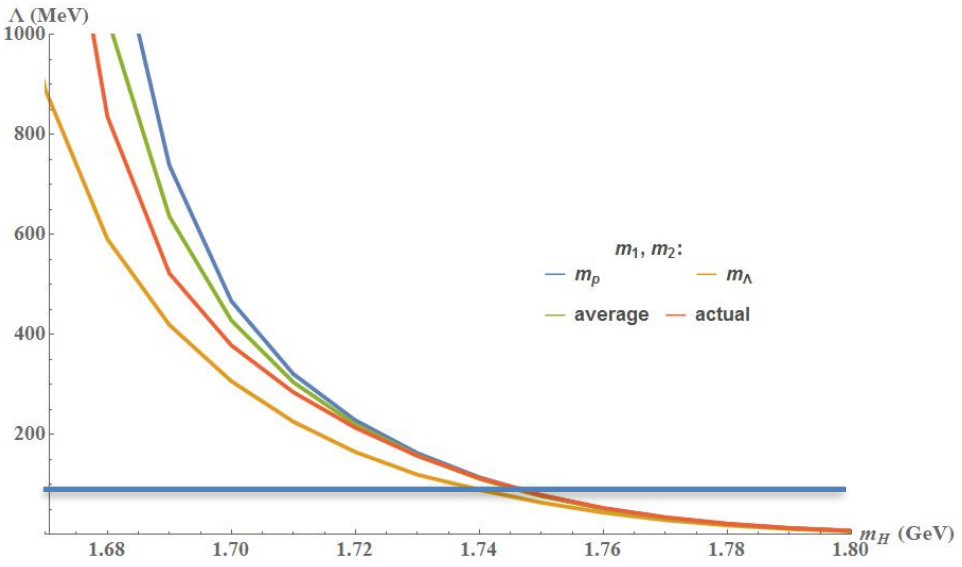
- H's produced at some initial temperature. (Rapidly-varying θ_{QCD}? H-condensate?)
- H's disintegrated by H $K^+ \rightarrow p\,\Lambda$, ; typically reaches "chemical" equilibrium (maintained by reactions like $p\,\Lambda \leftrightarrow H\,K^+$), then Hubble expansion causes freeze out.

- $T_{f.o.}$: $< \sigma_{H\,K \rightarrow p\,\Lambda}\, n_K(T_{f.o.})\, v > = H(T_{f.o.})$
  - Parity, fermi-statistics => L=1 in initial or final state; suppresses rate.

$$\mathcal{L}_I = i\frac{\alpha_1}{\Lambda} H M \overline{B_1} \gamma^5 B_1^c + \frac{\beta_1}{\Lambda 2} H \partial_\mu M \overline{B_1} \gamma^\mu \gamma^5 B_1^c + h.c.$$

$$\sigma = \frac{1}{2\pi s \Lambda^2} \frac{|\mathbf{p}|}{|\mathbf{k}'|} [\alpha_1^2 s - 2\alpha_1\beta_1(m/\Lambda)(s + m_M^2 - m_H^2) - (\beta_1/\Lambda^2)(-2p_0 k'_0(s + m_M^2 - m_H^2 - 2p_0 k'_0) + \frac{4}{3}|\mathbf{p}|^2|\mathbf{k}'|^2 + m_M^2(s - 4m^2))]$$

- Take alpha, beta = 1
- **QCD scale gives correct freezeout temperature, for $m_H \sim$ 1.7-1.8 GeV**



[& confirmed using Bolzmann eqn]

H-Dark Matter detection ISS

W. Terrano & GRF, in preparation

- Individual H collision hard to detect, but the H flux exerts a tiny pressure. On an object of thickness T: **$P = 4\ 10^{-9}\ g\ cm^{-1}\ s^{-2}\ \sigma_{mb}\ (A/200)\ (SG/20)$**
- Torsion balance: (Eotwash) 1 yr torque sensitivity ~ $2\ 10^{-11}$ dyne-cm (erg)
- Modulate DM pressure by rotating absorber (e.g. 10 cm thick Pb shield)

directional H-detection looks feasible!