Sexaquarks: Quarks uniting to form Dark Matter at LHCb

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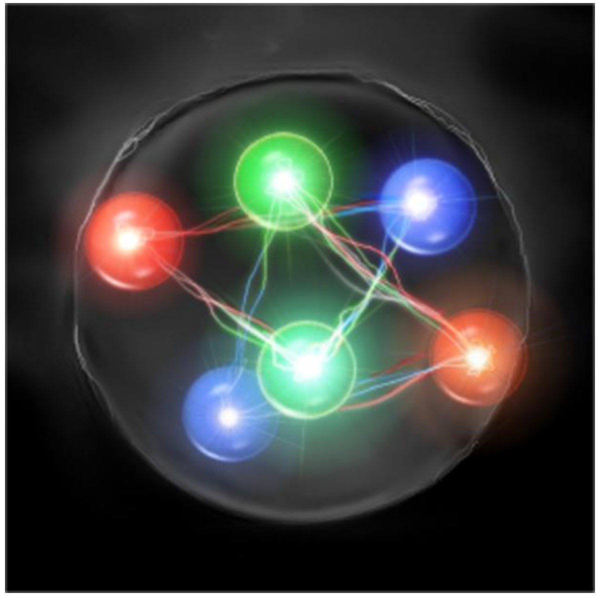
Overview

- **What!?**
- **How?**
  - Interaction with detector material
  - Missing momentum
  - Why not both?

What!?

Sexaquark (*S*)

- **S**ix quarks: *uud***ds***s*
- **S**trangeness **S**=-2
- **S**U(3)$_c$ x **S**U(3)$_f$ x **S**U(2)$_s$ **s**inglet → deeply bound
  - Flavourless: in $m_u = m_d = m_s$ limit → no pion cloud → compact
  - Colourless: *rgbrgb*
  - Neutral: $\mathrm{Q} = 2 * \frac{2}{3} - 4 * \frac{1}{3}$
  - **S**pinless **s**calar: $u \uparrow u \downarrow d \uparrow d \downarrow s \uparrow s \downarrow$
- **S**ymmetric spatial wavefunction → **s**mall charge radius
- **S**table?



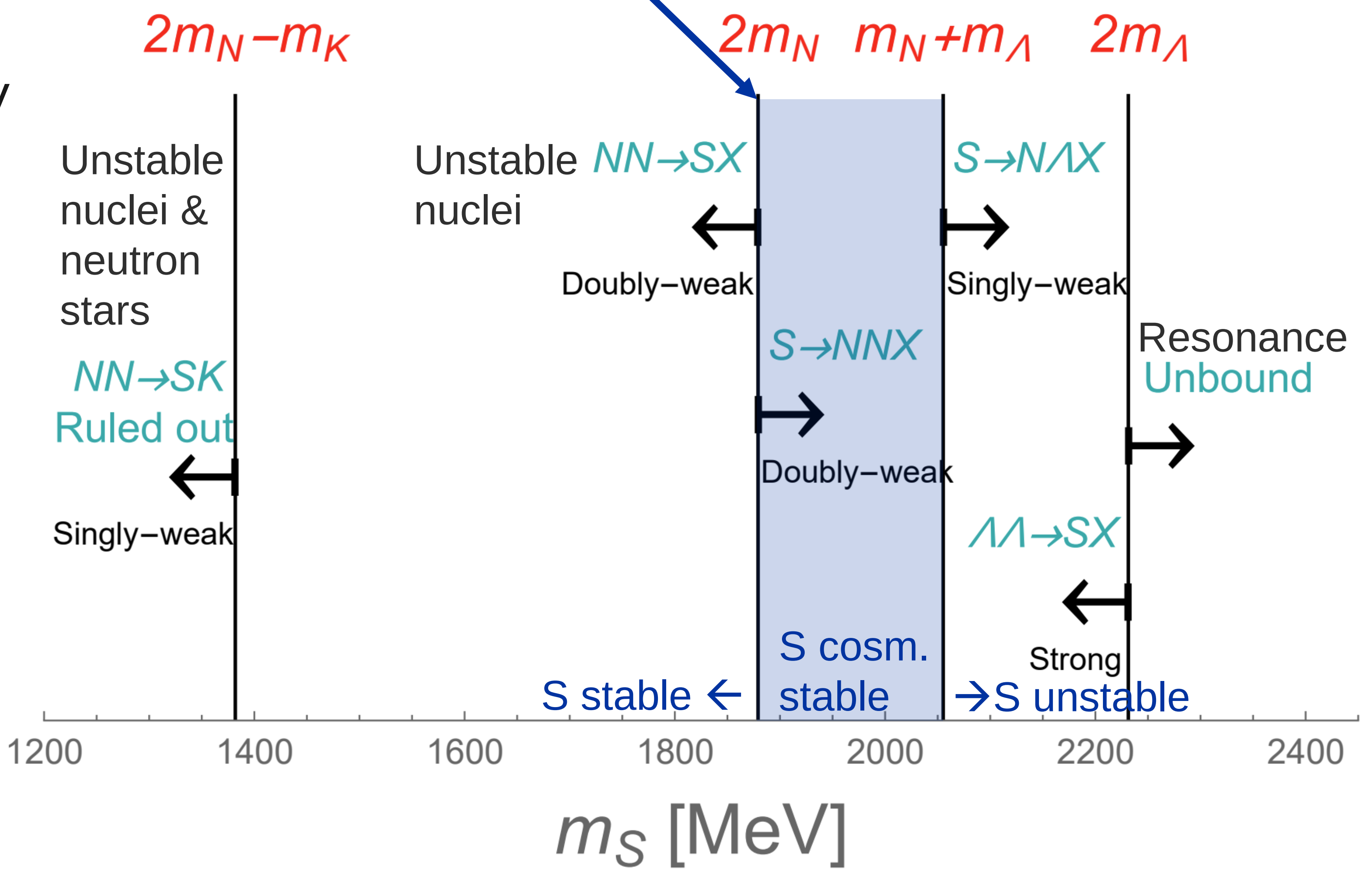
Mass & stability

$1875.1\ \text{MeV} = m_D - m_e < m_S < m_D + m_e = 1876.1\ \text{MeV}$ $D \to SX$ (S stable)

For $N = p, n,$ possible m_S are:

Theory predicts 1.2 - 2.23 GeV

Look for:
$1875.1 < m_S < 2055\ \text{MeV}$



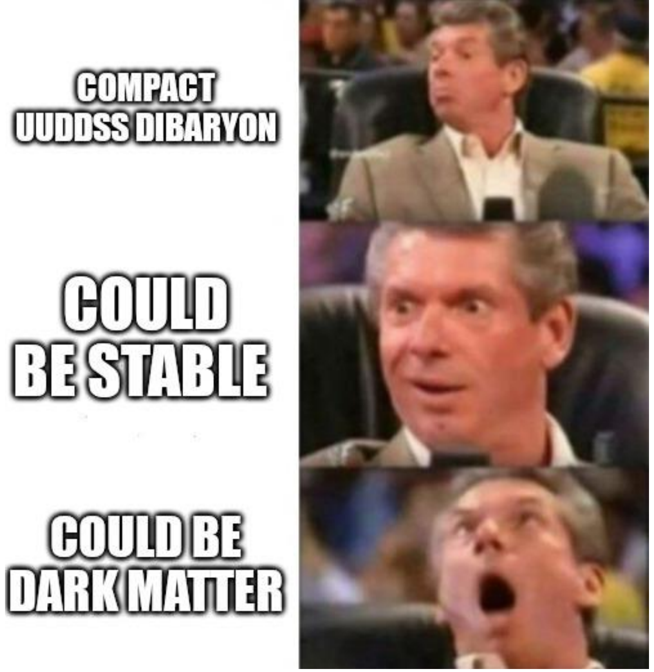
Sexaquark the saviour?

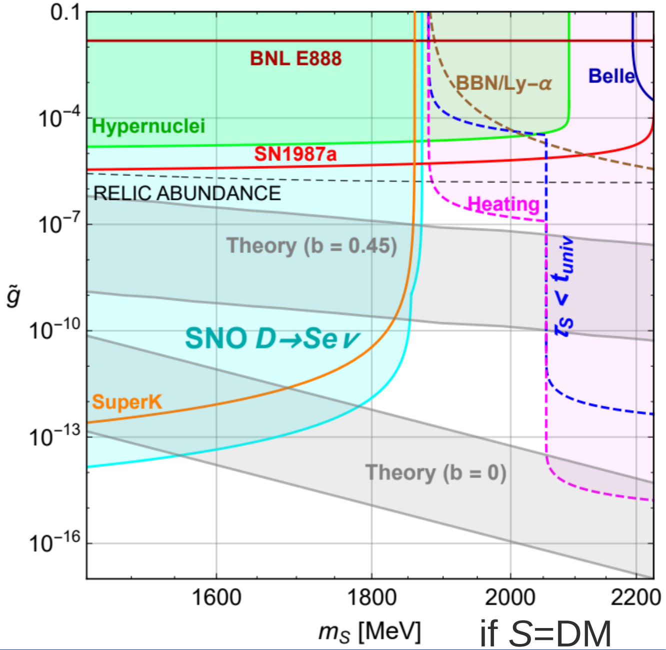
It could:

- (Partially) explain DM
- Resolve the muon g-2 anomaly (if it still is one)
- Mean low mass Neutron stars have *S* core or layer

Many unknowns (detectability & abundacy):

- m_S
- $\sigma(pp \rightarrow \bar{S}/SX)$ production
- $\sigma(S\bar{S} \rightarrow X)$ & $\sigma(\bar{S}/Sb \rightarrow \bar{b}'X)$ annihilation
- $\sigma(\bar{S}n)$ scattering from polarisation
- $r_S = \lambda_S + b\lambda_m \approx 0.2 - 0.3$ fm charge radius
- $\tilde{g}$ interaction strength to hadrons





if *S*=DM

Other exotic hadrons

Sexaquark ∈:

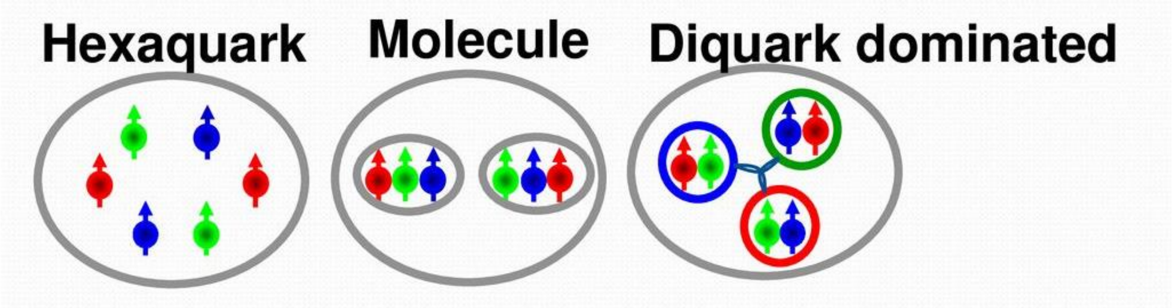
- hexaquark (6-quark state)
- hyperons (baryon ≥1s)

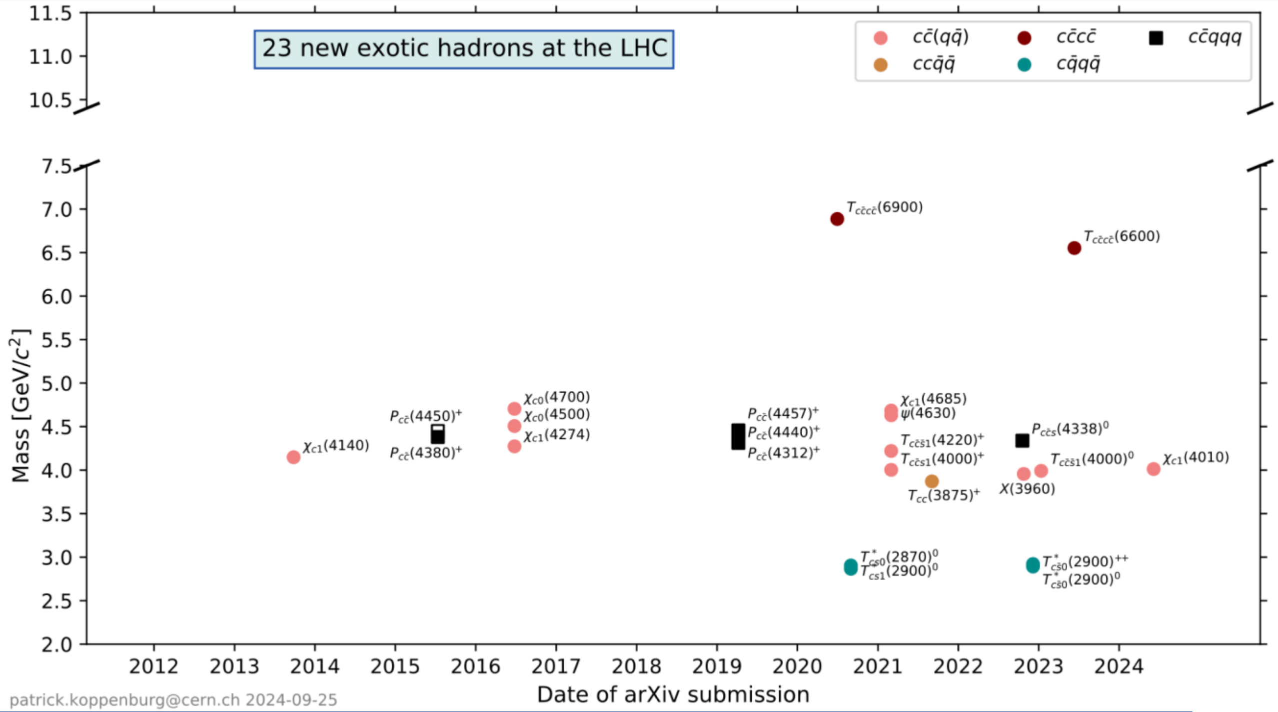
Found:

- Deuteron: uud udd (spin-1, stable)
- D*(2380): uuuddd (spin-3)
- $^{3}_{\Lambda}$H: uud udd uds
- Many exotic tetra- and pentaquarks at LHCb

Not found (yet):

- $\Lambda\Lambda$ molecule: uds uds

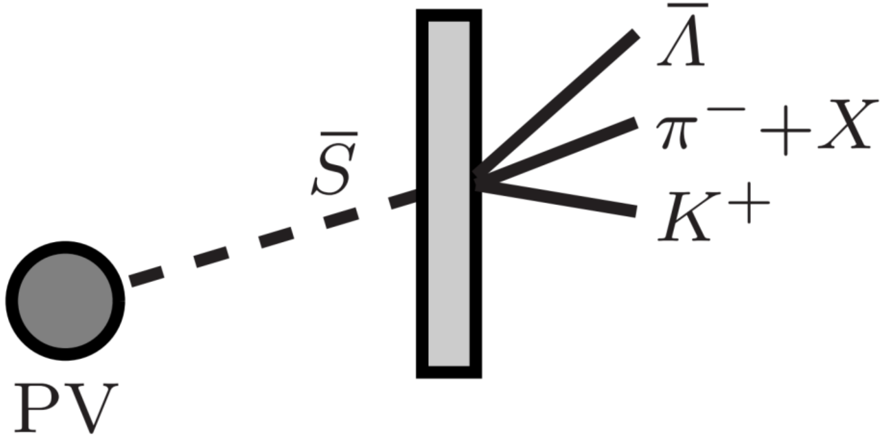




How?

Method 1: Interaction with detector material

- Stable → $\bar{S}$ from QGP annihilating in LHCb detector
- Trigger on $B = -1$ & $S = +2$
  - $\bar{S}p \rightarrow \bar{\Lambda}K^+$ & $\bar{S}n \rightarrow \bar{\Lambda}K_s^0$ ← We are here
  - $\bar{S}p \rightarrow \bar{\Xi}^+X$ & $\bar{S}n \rightarrow \bar{\Xi}X$
  - $\bar{S}p \rightarrow K^+K^+X$ & $\bar{S}n \rightarrow K^+K^+X$
  - $\bar{S}p \rightarrow \bar{\Lambda}\bar{\Lambda}X$ & $\bar{S}n \rightarrow \bar{\Lambda}\bar{\Lambda}X$
- Collect extra particles X from same vertex
- Background: Ξ interacting with material
- Goal: production + annihilation cross section

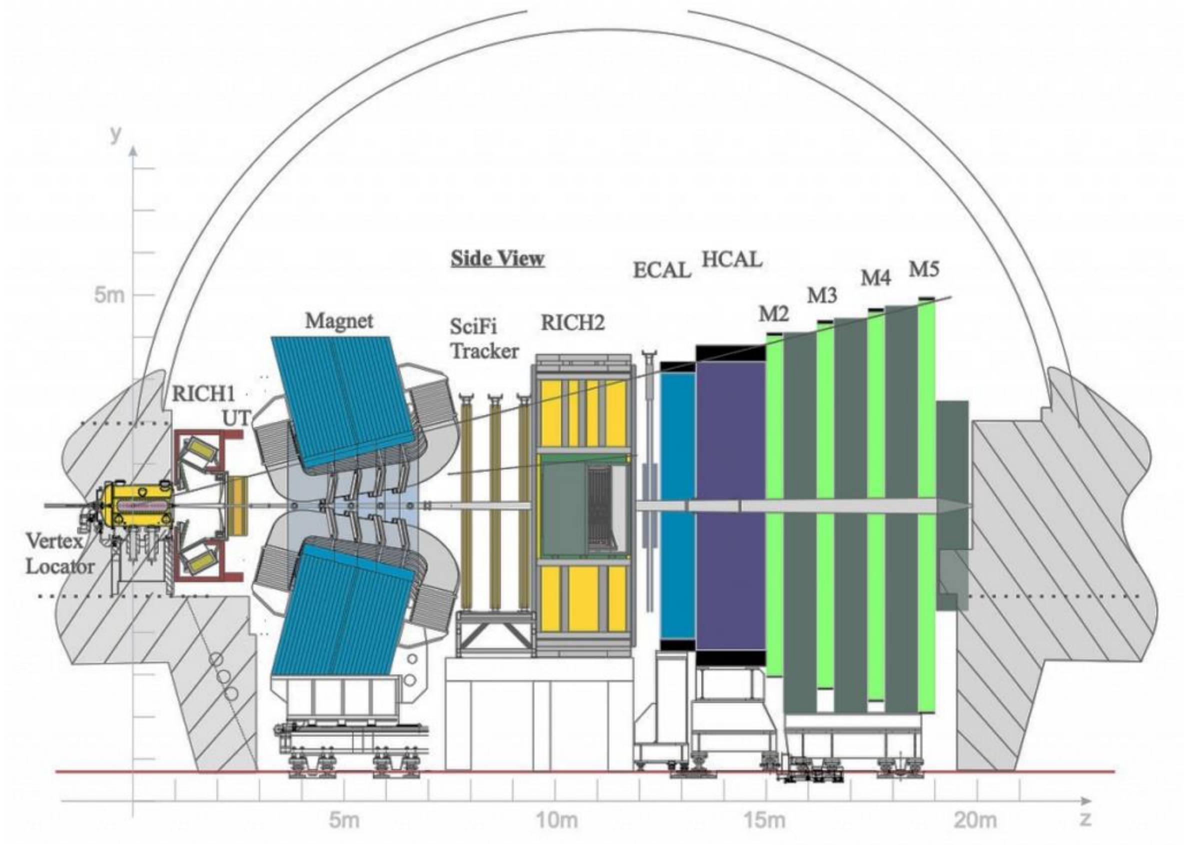


Annihilation vertices

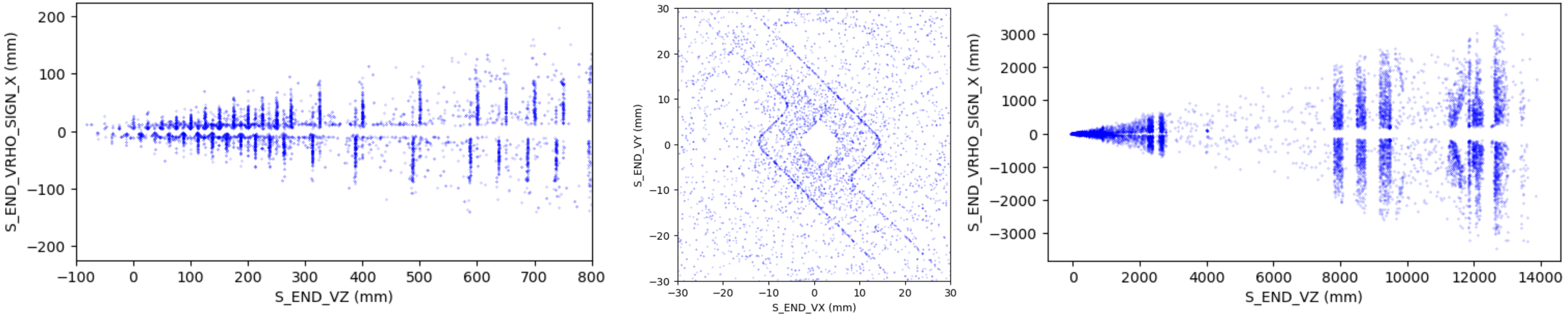
Showing simulated $\bar{S}p$ annihilation vertices

Even the vacuum RF box can be used

→ Add material selection



Vertex Locator (VELO) & RF box:



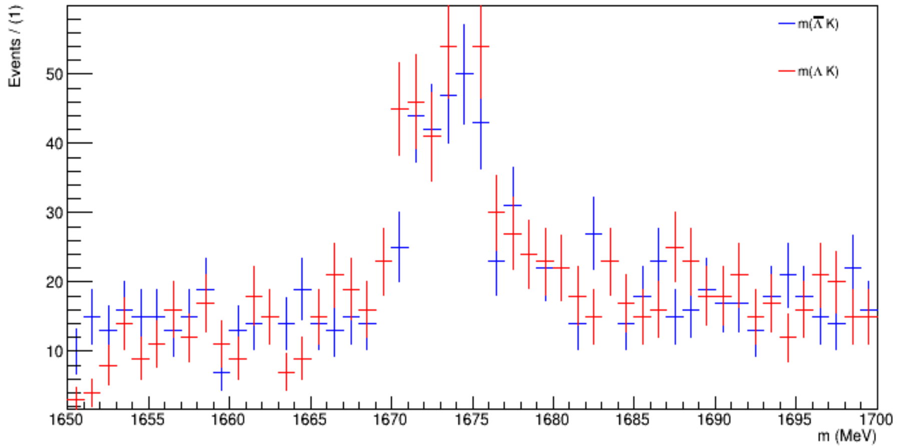
First data

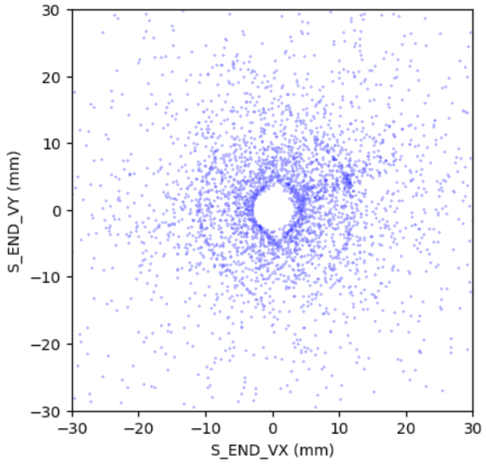
Started taking data with trigger line since late August

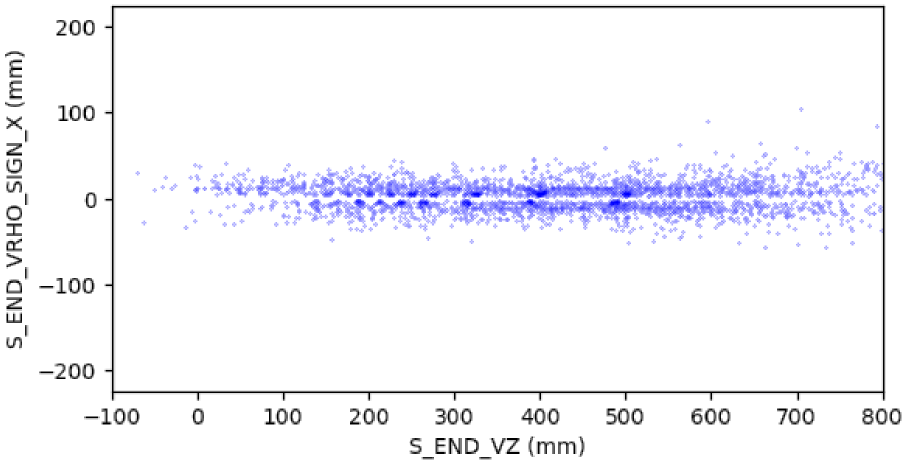
Found mass peak $\Omega^+ \rightarrow \bar{\Lambda} K^+ (\bar{s}\bar{s}\bar{s} \rightarrow \bar{u}\bar{d}\bar{s} + u\bar{s})$

Useful for refining cuts

To be continued…







Method 2: Missing momentum

Reconstruct mass of missing particle from all other particles:

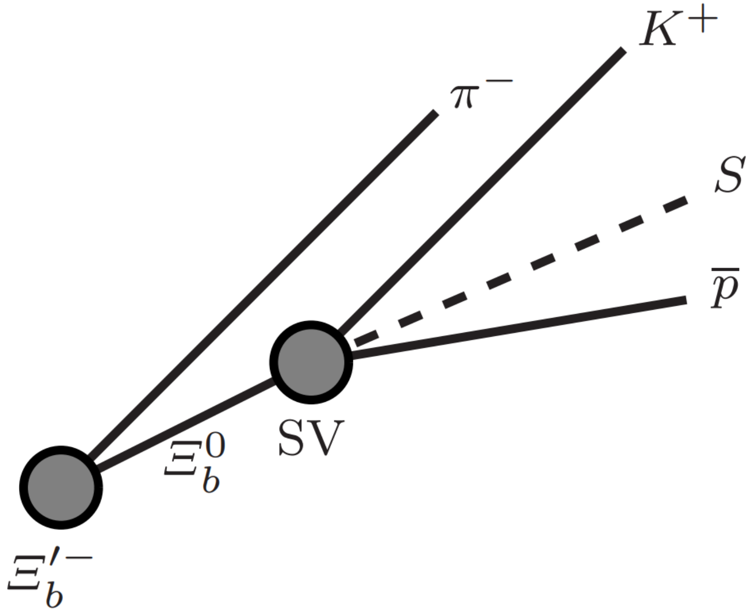
- $\Xi_b^0 \to S\bar{p}K^+$, where $\Xi_b^{*-} \to \Xi_b^0\pi^-$ or $\Xi_b'^- \to \Xi_b^0\pi^-$ ← We are here
- $\Lambda_b^0 \to S\bar{p}K^+$, where $\Sigma_b^- \to \Lambda_b^0\pi^-$
- $B^+ \to S\bar{p}K^+$, where $B_{s2}^*(5840) \to B^+\pi^-$

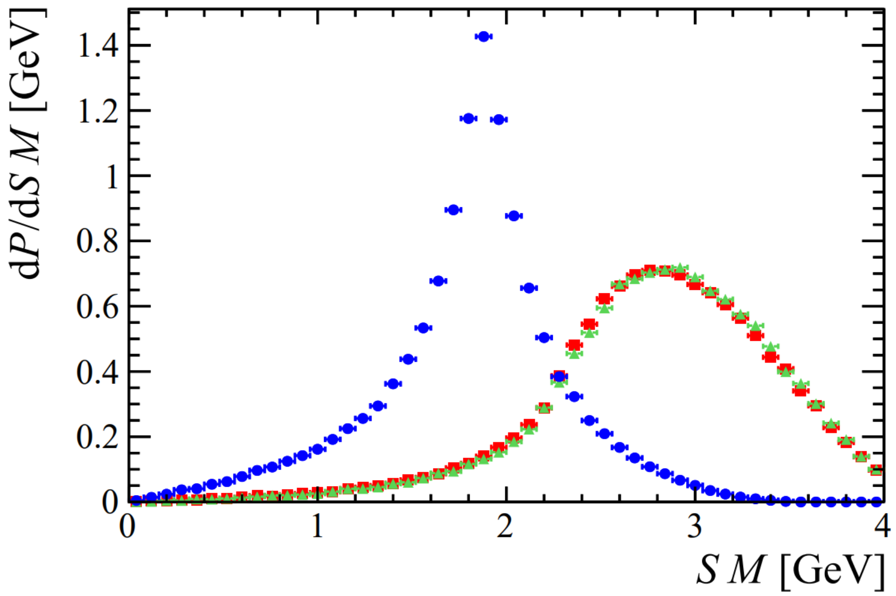
Background:

- $\Xi_b^0 \to \Lambda\Lambda\bar{p}K^+$
- $\Xi_b^0 \to \Xi^0 n\bar{p}K^+$

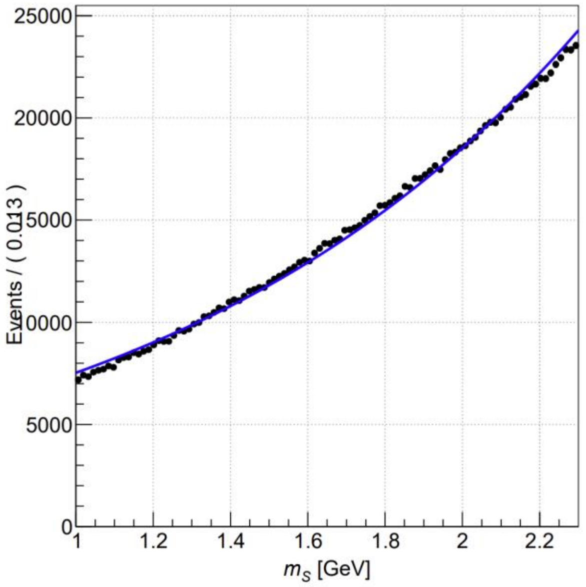
Charge conjugate included

Goal: Rate $\Xi_b^0 \to S\bar{p}K^+$ & m_S





Preliminary results



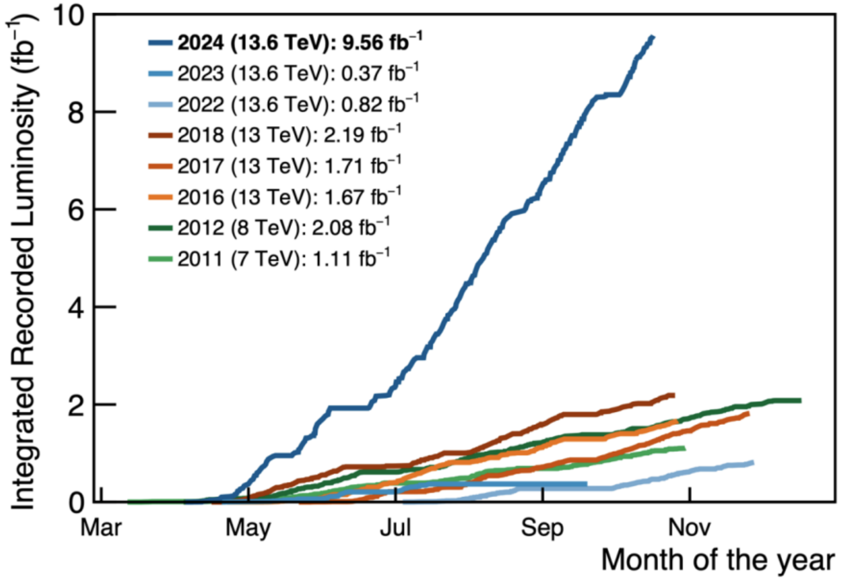
(b) Data background, fitted with an exponential function.

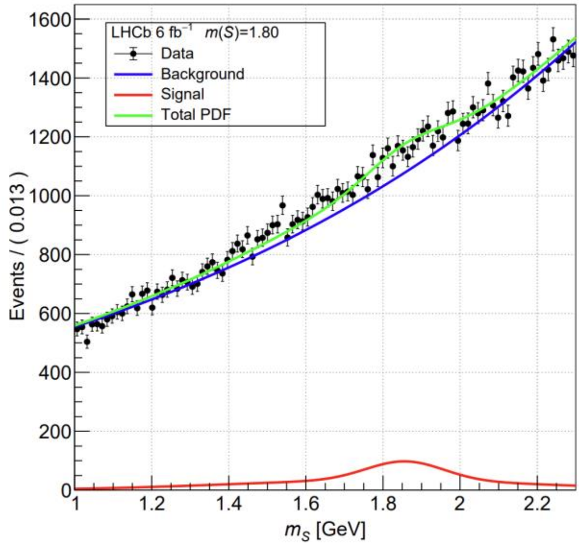
MSc Alex Doheny (finished):

- Mass shape not understood, hard to assess if there is signal
- Background source unknown and background search not fruitful yet

Niels Odijk:

- Run 3: more data!
- Looser selection cuts
- Better understand background





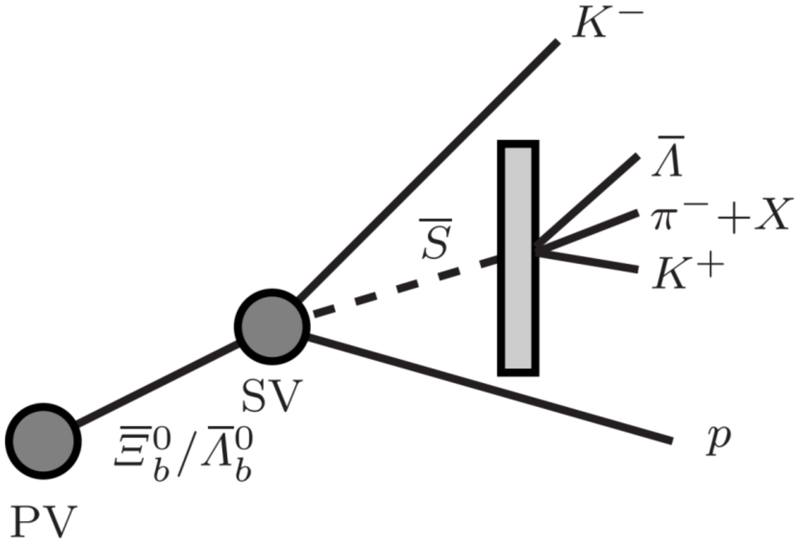
(b) Optimal cut, Punzi-cut

Method 3: Why not both?

Advantages:

- No need for Ξ_b^{*-} or $\Xi_b^{\prime -}$ tagging
- Clean sample

Goal: cross section of S with matter & m_S



Summary

To do:

- Find S
- m_S
- $\sigma(pp \to SX)$
- $\sigma(SN \to X)$
- DM?

Thanks!

And stay tuned…

References

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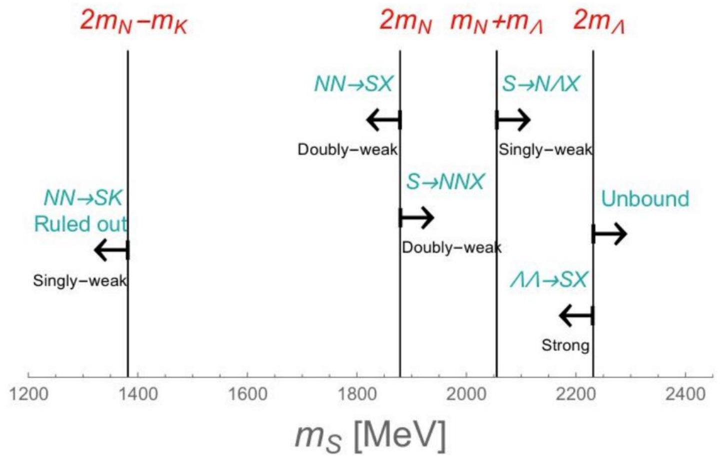
Back-up slides

Mass

For $N = p, n,$ possible m_S are:

- $m_S > 2m_N - m_K = 1382$ MeV, else $NN \rightarrow SK$ → unstable nuclei & neutron stars
- $1382\text{ MeV} < m_S < 2m_N$ unlikely, else $NN \rightarrow SX$ → unstable nuclei (S fully stable)
- $1875.1 = m_D - m_e < m_S < m_D + m_e = 1876.1$ MeV (S stable)
- $1876 = 2m_\Lambda < m_S < 2m_N + m_\Lambda = 2055$ MeV → $S \rightarrow NNX$ possible (S cosm. stable)
- $2m_N + m_\Lambda < m_S < 2m_\Lambda$ → $S \rightarrow N\Lambda X$ and $\Lambda\Lambda \rightarrow SX$ possible (unstable)
- $m_S > 2m_\Lambda$→ S unbound broad resonance

→ Look for $1875.1 < m_S < 2055$ MeV



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