Valence Quarks and Proton Structure in Soft Hadronic Interactions in Nuclei

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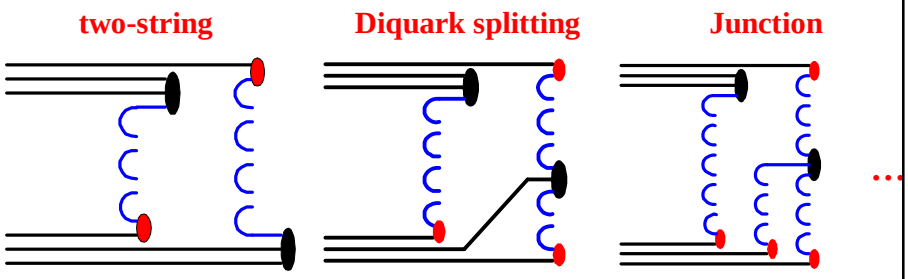
Outline

1. **Introduction**
2. **E910, grey track analysis.**
3. **Proton fragmentation**
4. **Large-x pion production**
5. **Conclusions, comments**

Topological Expansion for p-p Interactions



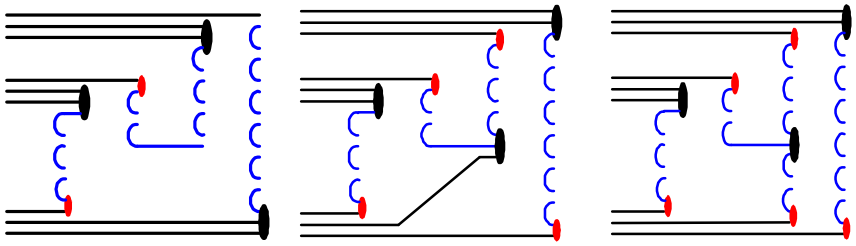
Increased "breakup" of proton

- "Higher order" contributions lead to proton break-up.
  - Simply by re-arranging color connections.
  - Not "stopping" in usual sense

    ⇒Baryon only shifted in rapidity after fragmentation.
- Observe: **dynamics governed by color topology**
  - Presumably since we must end w/ color neutral state.
- But: **"we" can't control expansion even in p-p.**

Topological Expansion for p-A (?)

Possible Double Scattering Diagrams



- We know even less about "higher order" terms in p-A.
- But, reasonable expectation:
  - **With more scatterings of proton, di-quark breaking and junction diagrams become more important/dominant.**
- Comments from theorists ?
- **Is di-quark breaking + junction the dominant baryon stopping mechanism at high energy ?**

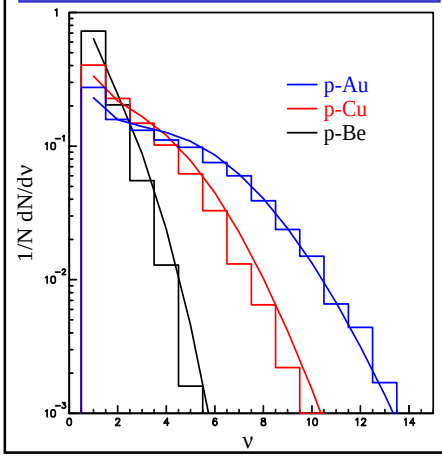
Some Questions

- Does the dominant role of color topology persist in hadronic interactions in nuclei ?
  - There's a source of copious soft gluons to neutralize color.
  - Can coherent gluon fields (strings) even persist in nucleus ?
- What's left then ?
  - Proton constituents: valence quarks + junction + sea.
- Can we re-phrase problem in terms of scattering of partons in the proton – particularly valence quarks ?
  - "Already in" descriptions of the Cronin effect.
  - Continuous evolution from soft $\rightarrow$ hard.
  - What is the role of fluctuations in proton configuration ?
- Problem: QCD "uncontrollable" @ soft scales.
  - Dima: **α_s saturates at small Q^2.**
  - **Can we define effective σ for (e.g.) quark "stripping".**

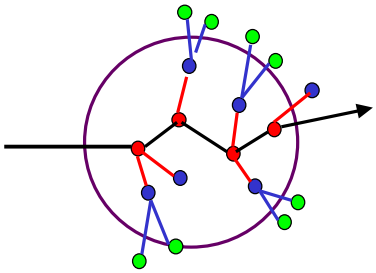
p-A Collision Centrality

- Problem:
  - Inclusive data insensitive to proton multiple scattering
  - define ν = # of "collisions"

Glauber + Monte Carlo P(ν)

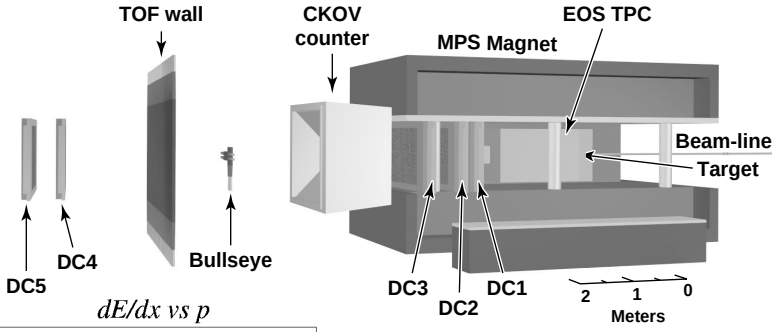


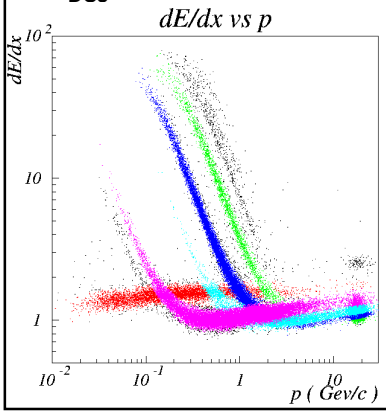
Proton scatters ν = 4 times



- Cascade **sensitive to ν**.
- Measure # recoil **(grey)** protons **event by event**
  - Statistically related to ν
- **Now practically possible with high statistics**
  - **E910, NA49**

E910 Spectrometer, dE/dx





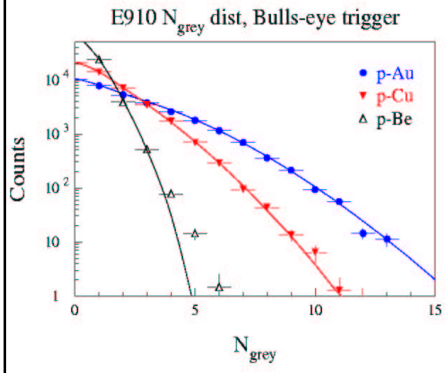
E910 Data

- Beam energies: 6, 12, 18 GeV
- Targets: Be, Cu, Au, U, (Ar)
- Triggers: multiplicity, bulls-eye.
- Large data sets

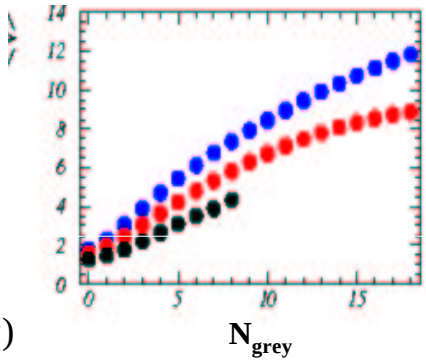
⇒**p+Au**, 18 GeV (3M events)

⇒**p+Be**, Cu, Au, 12 GeV (1M).

E910 $N_{grey} \Rightarrow \langle \nu(N_{grey}) \rangle$



Chemakin *et al*, PRC 60, 024902 (1999)

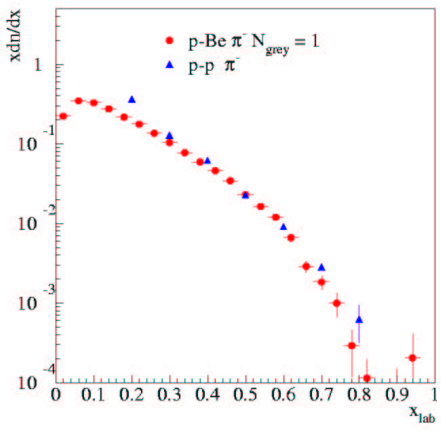


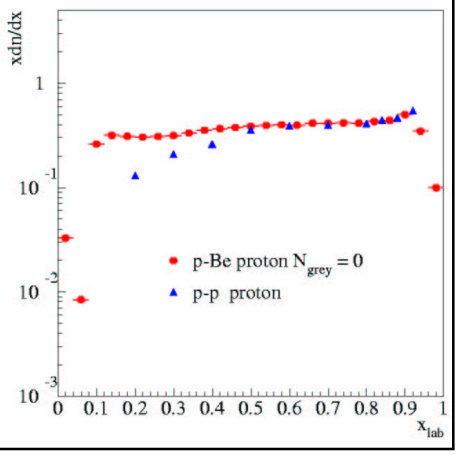
- Parameterize $N_{grey}(\nu)$
- Convolute with Glauber $P(\nu)$
- Fit to $dN/dN_{grey} \Rightarrow P(\nu, N_{grey})$
- Project to get $\langle \nu(N_{grey}) \rangle$
- **Beware:** distribution of ν may be important.

What regime are we in ?

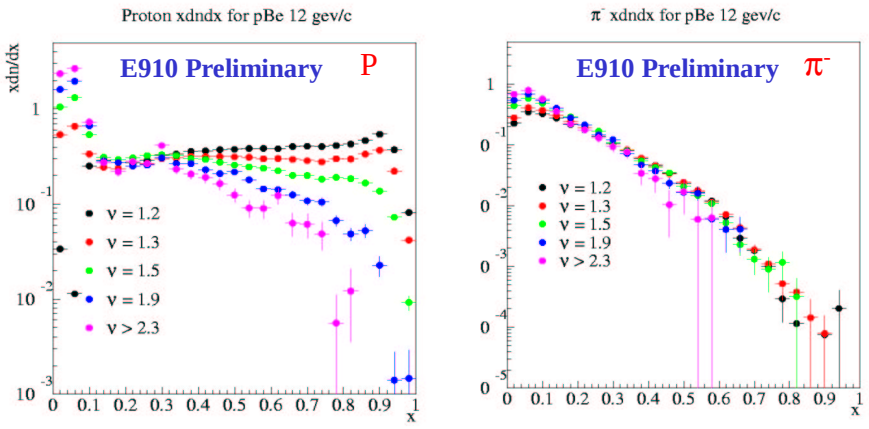
- Compare **12 GeV p-Be, N_{grey}= 0** with **100 GeV p-p**
  - Plotted vs x_{lab} not x_F. Observe: **$x_{lab} \approx x_+$**
- Excellent agreement between 12 & 100 GeV.
  - 12 GeV already at high energy limit **wrt fragmentation**

$\Rightarrow$ In a single collision.





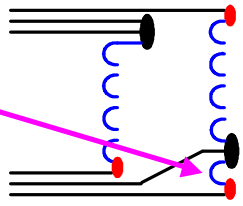
p-Be Projectile Fragmentation



- Strong suppression of protons @ large x.
- Very little change in π^- spectrum @ large x.
  - Natural result of topological expansion (?)
  - Unnatural in resonance & "popcorn" production.

Where Do Large-x π Come From ?

- Resonance decays ?
  - G. Fischer: from high-mass tails of (e.g.) Δ (1232).
  - E910: **baryon stops but pions don't**.
  - "Magical" balance between increasing mass proton stopping ?
- Popcorn mechanism in string decay ?
  - AKA "short strings" in DPM
  - Meson momentum ?
    - ⇒ Valence quark momentum
    - ⇒ or from some Regge exchange

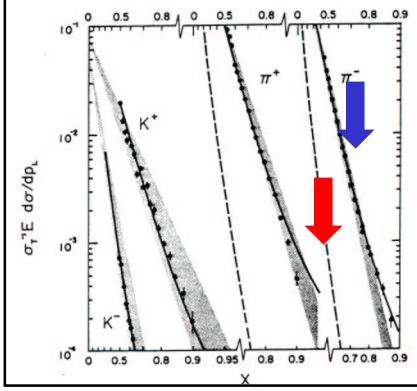


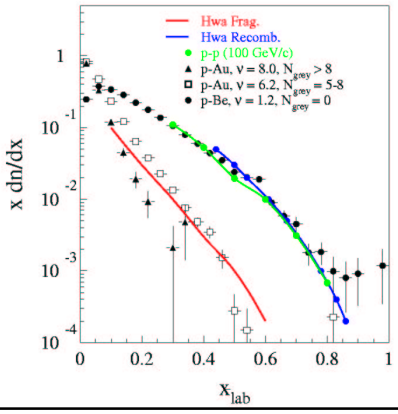
  - But in string pictures of p-A, baryon string fragments at end.
    - ⇒ **Mesons must stop along with baryon (they don't).**
- Pions come directly from valence quarks in proton
  - Momentum spectrum ≈ valence quark momentum spectrum.
  - But: **quarks cannot "fragment" …**

Recombination / Fragmentation

- Problem:
  - If valence quarks **fragment** the pion spectrum would be too soft.
- Resolution:
  - posit that valence quarks locally color neutralize (**recombine**).
  - Pions carry (approximately) valence quark momentum.
- Crude comparison to E910 p-Be and p-Au π data.

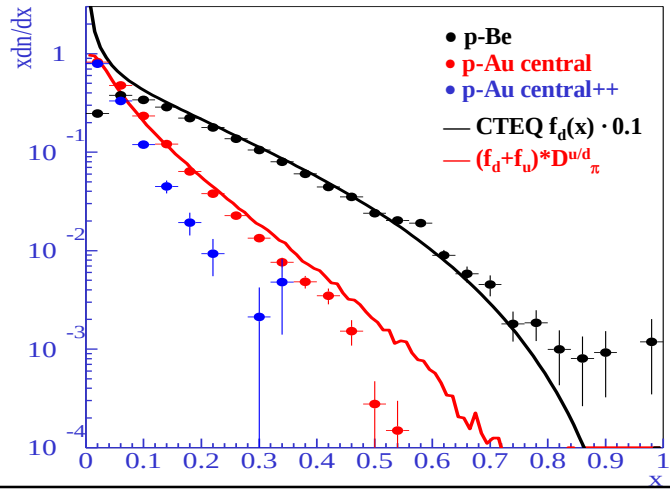
Das and Hwa, Phys Lett 68B, 459 1977





Recombination ⇒ Fragmentation ?

- Use CTEQ structure func. + JETSET to try to understand recombination/fragmentation.
  - "Recombination" from $f_{u/d}$ (Q^2 = 1 GeV^2).
  - Fragment w/ string to anti-quark from $f_{sea}(x)$.

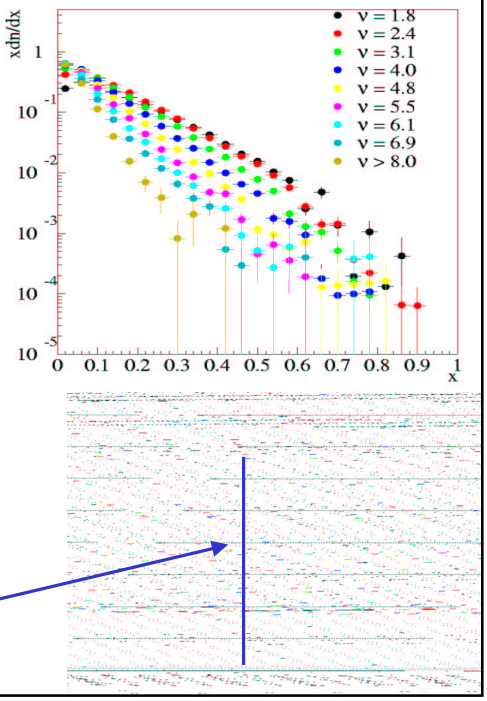


π^- p-Au Centrality Dependence

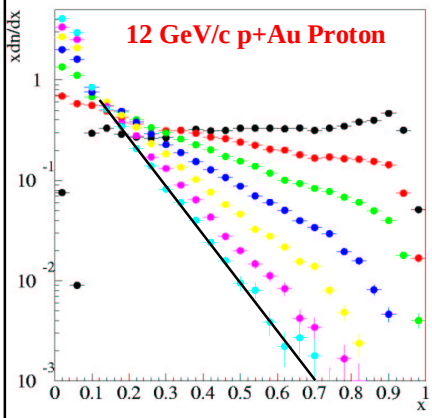
- Strong attenuation of large-x pions @ large ν.
- Make naïve ansatz:
  - Attenuation is due to interaction of quarks.
    ⇒ Fragment.

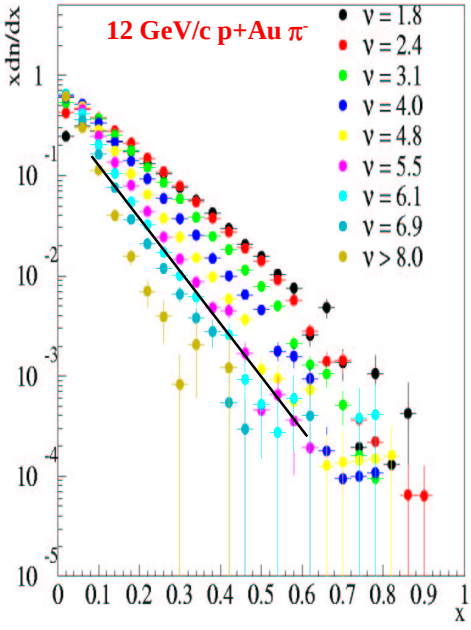
$$x\frac{dn}{dx} = C_{frag} f_{frag}(x) + C_{recomb} f_u(x)$$

- C_{frag} , C_{recomb} from data.
- Results not crazy
  - Recombination disappears @ large ν.
  - See ~ ×3 fragmentation – expected from **u and d**.
  - **Nonsense for ν > 4**.
    ⇒ Need more attenuation.



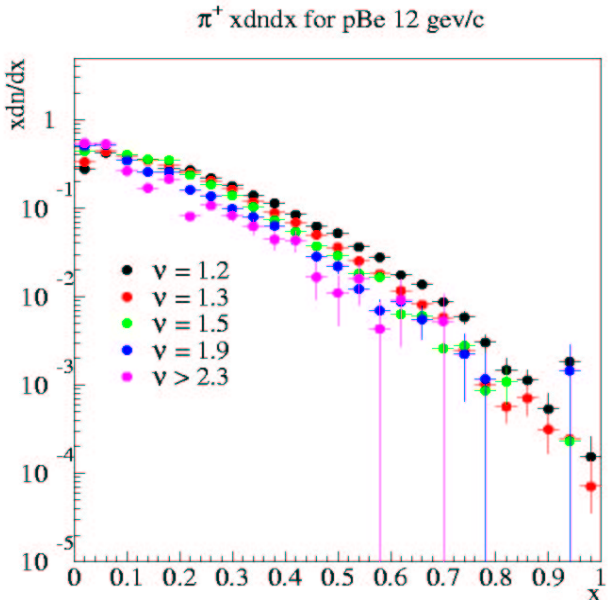
12 GeV p-Au Protons vs Pions





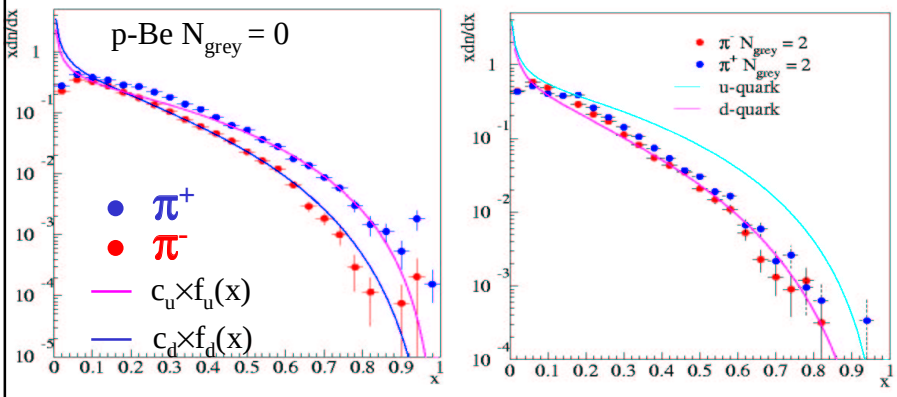
- For all ν protons attenuate more than the π^-.
- At large ν proton xdn/dx has ≈ same slope as π^-.
- "Knee" persists out to ν=5 but shifts down in x w/ larger ν.

What about π^+ ?



- While π^- ≈ constant, π^+ changes by factor of ~ 3.

What's Going on with π^+ ?



- In p-p (like) collisions π^+/π^- difference @ large x.
  - Consistent w/ difference in f_u, f_d.
  - Slight difference in normalization $c_u = 0.06$, $c_d = 0.1$
  - But extrapolation to $\nu = 1$, gives $c_u \sim 0.1$
- When proton scatters twice π^+/π^- difference gone.
  - Memory of proton wave-function lost ?

What is Going on Here ?

- Preferentially remove u quark in initial scatterings ?
  - Part of effect may be trivial – twice the probability to pick u quark vs d quark.
- **Speculation:**
  - Could SU(6) wave-function of proton play a role ?

$$p\uparrow = \frac{1}{\sqrt{2}}u\uparrow(ud)_{S=0} + \frac{1}{\sqrt{18}}u\uparrow(ud)_{S=1} - \frac{1}{3}u\downarrow(ud)_{S=1} - \frac{1}{3}d\uparrow(uu)_{S=1} - \frac{\sqrt{2}}{3}d\downarrow(uu)_{S=1}$$

  - Dominant contribution from ud spin 0 di-quark.
- Old argument (Ochs): at large x, valence quarks carrying proton helicity preferred.

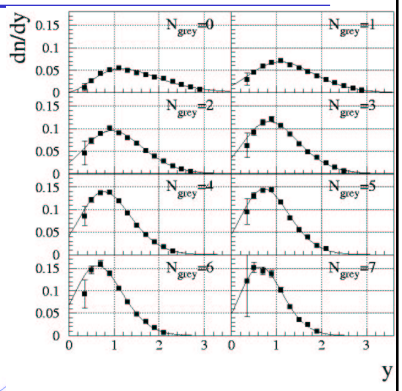
  $\Rightarrow$ Origin of f_u, f_d difference.
- If it's easier to remove u from $u\uparrow(ud)_{S=0}$ may be a way to remove the intrinsic π^+ excess & shape difference.
- $\pi^+\pi^-$ behavior a detail of physics **but useful probe of proton interaction dynamics**.

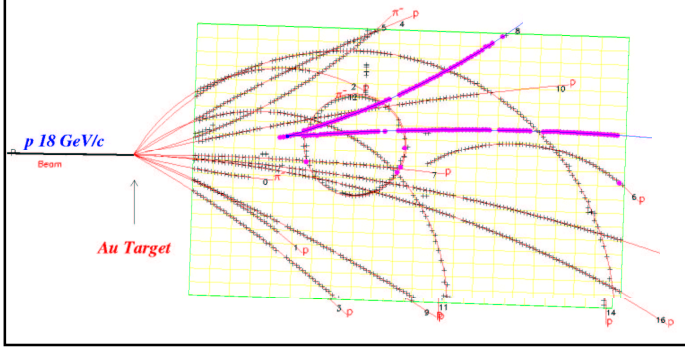
E910 - Λ Production

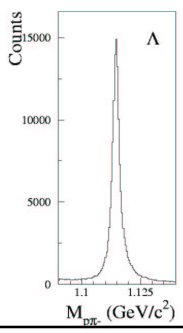
- **Analysis by X. Yang**
  - 150k Λ's in 18 GeV/c p-Au set

    $\Rightarrow$ Good M_{inv} resolution, σ = 1.5 MeV/c²

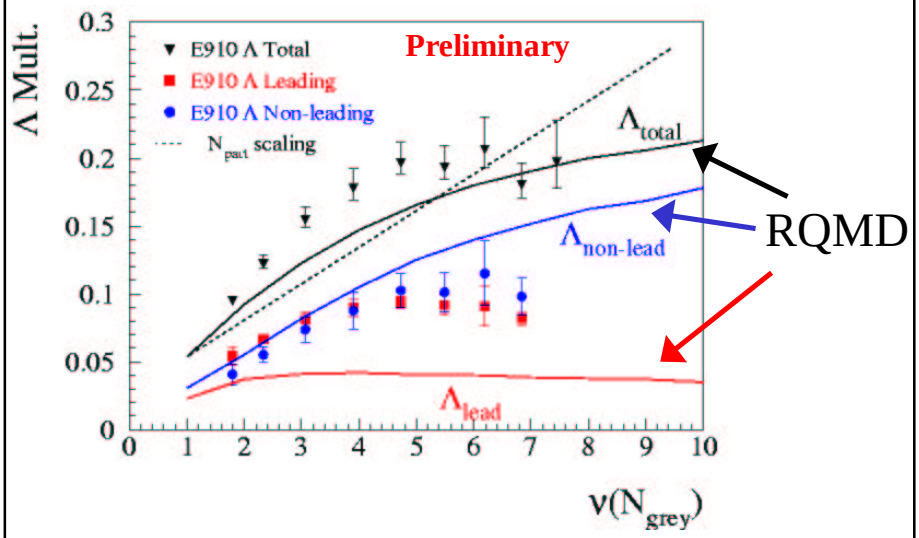
    $\Rightarrow$ Good signal/background ~ 30:1.
  - Account for missing acceptance by extrapolating w/ gamma distribution.
  - "Leading" analysis – test whether Λ is most energetic baryon in event







E910, 17.5 GeV/c p+Au, Leading Λ



- Ask "are Λ's leading baryon" event by event

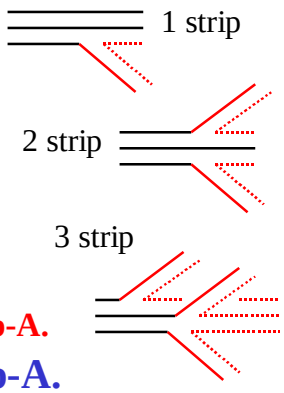
  ⇒Excess due to leading Λ's **(from projectile)**

  ⇒ **Not reproduced by RQMD.**

Constituent Quark Model

- Try to understand E910 Λ, Ξ results (BAC, Yang):
- **Context:** Van Hove quark fragmentation model.
  - Quarks stripped from baryon by scattering
  - Flavor determined by sea/pair produced quarks
- **Assume probability γ to pick up strange quark.**
  - Evaluate probability to get strangeness S baryon vs N_{strip}.

S / N_{strip}	0	1	2	3
1	$(1-\gamma)$	γ	0	0
2	$(1-\gamma)^2$	$2\gamma(1-\gamma)$	γ^2	0
3	$(1-\gamma)^3$	$3\gamma(1-\gamma)^2$	$3\gamma^2(1-\gamma)$	γ^3

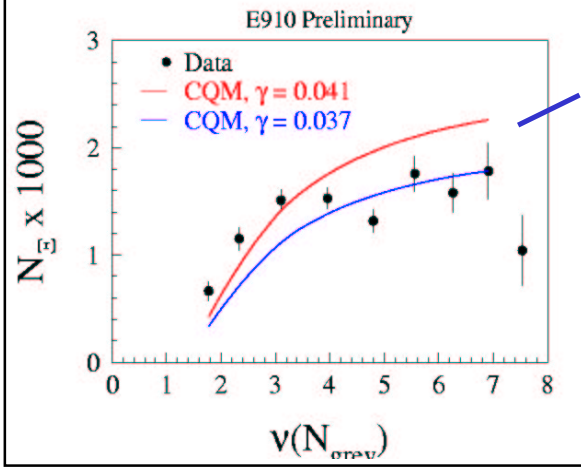


  - Obtain expected growth in S = 1.
  - Expect: N_{strip} **mostly = 1 in p-p, > 1 in p-A.**

  ⇒ **Enhanced Ξ production in p-A.**

Test CQM Against E910 Ξ^-

- Start w/CQM model of Choi *et al* (***Phys. Rev. C55, 848***)
  - Treats N-N interactions at the quark level.
    - $\Rightarrow \sigma_{qq}$ & $\rho_q(r)$ in nucleon fit to p-p data.
    - $\Rightarrow$ Calculate $N_{strip}(\nu)$
- γ = **0.037 – 0.041** from p-p Λ yield, corrected for Σ^{+-}



Reasonable but not perfect agreement.

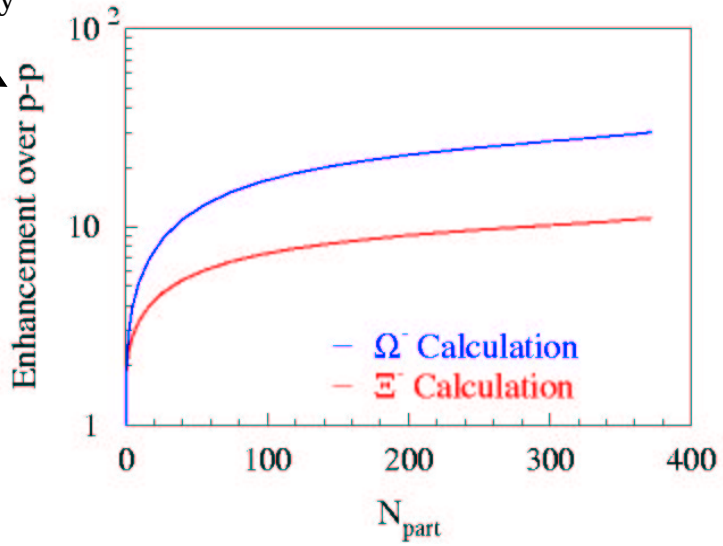
Still some freedom in choice of parameters (not exercised here)

N_s = 3 a must, CQM too low otherwise.

CQM: Apply to SPS Pb+Pb

Calculations for 160 GeV Pb+Pb (BAC)

Actually p-Be



- **Constituent quark model can qualititatively reproduce Pb+Pb Ξ, Ω enhancements.**

Summary

- Strong circumstantial evidence for role of valence quark in dynamics of stopping, large-x π production.
  - Rapid stopping of baryon.
  - While π's (for $\nu < 4$) remain unaffected.
  - **Except:** mystery with π^+.
    - $\Rightarrow$ Apparent rapid loss of memory of proton structure.
  - Initially pion x distributions strongly suggestive of $f_{u/d}(x)$.
- For large ν, all signature of initial projectile gone.
  - No remnant of valence quark momentum distribution.
  - Proton and pion x distributions become similar.
- Strange baryon production sensitive to valence quark stripping $\Rightarrow$ increased production of Λ, Ξ, (Ω).
  - As seen in E910 data.
  - High probability for full stripping required.

Comments (1)

- String models currently "ignore" nucleon structure
  - e.g. In quark - diquark string excitation in Fritiof, DPM, & descendents, diquark starts @ x=1, quark @ x ~ 0.
    - $\Rightarrow$ Color exchange modifies quark momentum according to *ad hoc* prescription for string excitation.
  - No knowledge of nucleon sea – flavor content & x dist.
- But this prescription seems highly unnatural.
  - @ high energies nucleon state frozen during collision.
    - $\Rightarrow$ Fluctuations in nucleon configuration should be present.
    - $\Rightarrow$ Shouldn't we "see" content of nucleon sea ?
- In saturation (colored glass) model we treat the gluon content (e.g.) of nucleon as "real".
- Is there a continuous evolution from soft$\rightarrow$hard in context of saturation ?

Comments (2)

- Is it (**it is**) time to re-examine our understanding of soft hadronic interactions ?
  - Most of current schemes were developed 20-30 yrs ago.
  - The understanding of QCD & nucleon structure has improved dramatically since then.
- Plea to theorists: help !!!
- We ignore this physics at our peril
  - We don't understand the consequences of "stopping"
    - ⇒ e.g. do we produce the same baryon density matter at RHIC and SPS ???
  - We don't understand why physics seems to be so smooth with / independent of energy.
    - ⇒ e.g. multiplicity
  - We can't "explain" Peter's demonstration of universality.
  - ...

Comments (3)

- E910 data pushes limits of "high energy"
  - Scaling between 12 GeV & higher energies is remarkable.
- But, there should be some energy dependence in nuclear interactions.
  - e.g. due to differences in "lab" lifetimes of proton config's
  - And due to coherence of soft interactions.
- Hope to be able to observe effects within E910 data
  - e.g. by comparing 12 and 18 GeV/c data
    - ⇒ Factor of 1.5 in "lab" lifetimes/formation times.
  - Systematics, systematics, systematics …
- Need to continue pursuing/supporting p-A experiments
  - Heavy ion collisions too complicated to unravel these issues.
  - E907 @ FNAL, NA49 @ SPS, ? @ GSI, ? @ JHF, ? @ RHIC