Baryons and Baryon Resonances in p-A Collisions @ AGS

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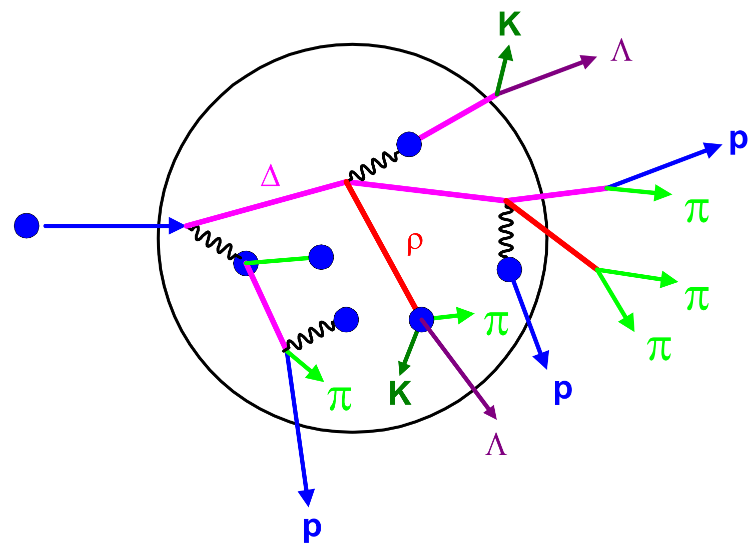
Outline

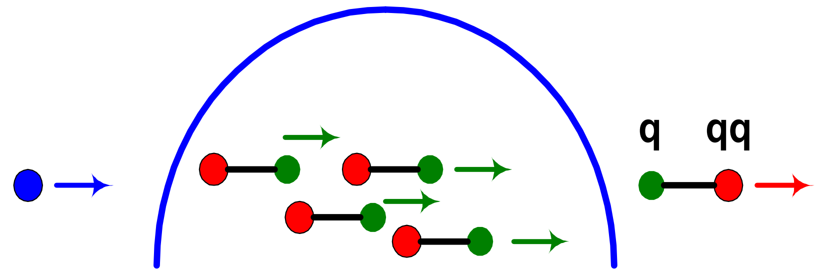
- Studying dynamics in p-A collisions, E910
- Strange baryon production
- Projectile fragmentation
- Δ Resonance production
- Conclusions, comments

"Pictures" of p-A Dynamics

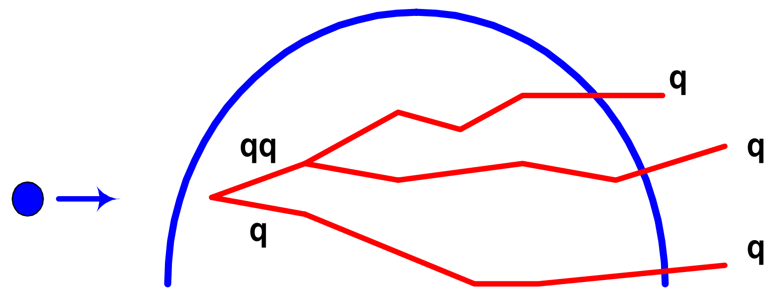
- Resonance model (e.g. ARC)
  - Nucleons excited into baryonic resonances.
  - Resonance decays determine particle production.
  - Quark/gluon DOF irrelevant



- Color dipole model
  - Nucleon excitation via string excited by color exchange.
  - Particle production from string fragmentation.

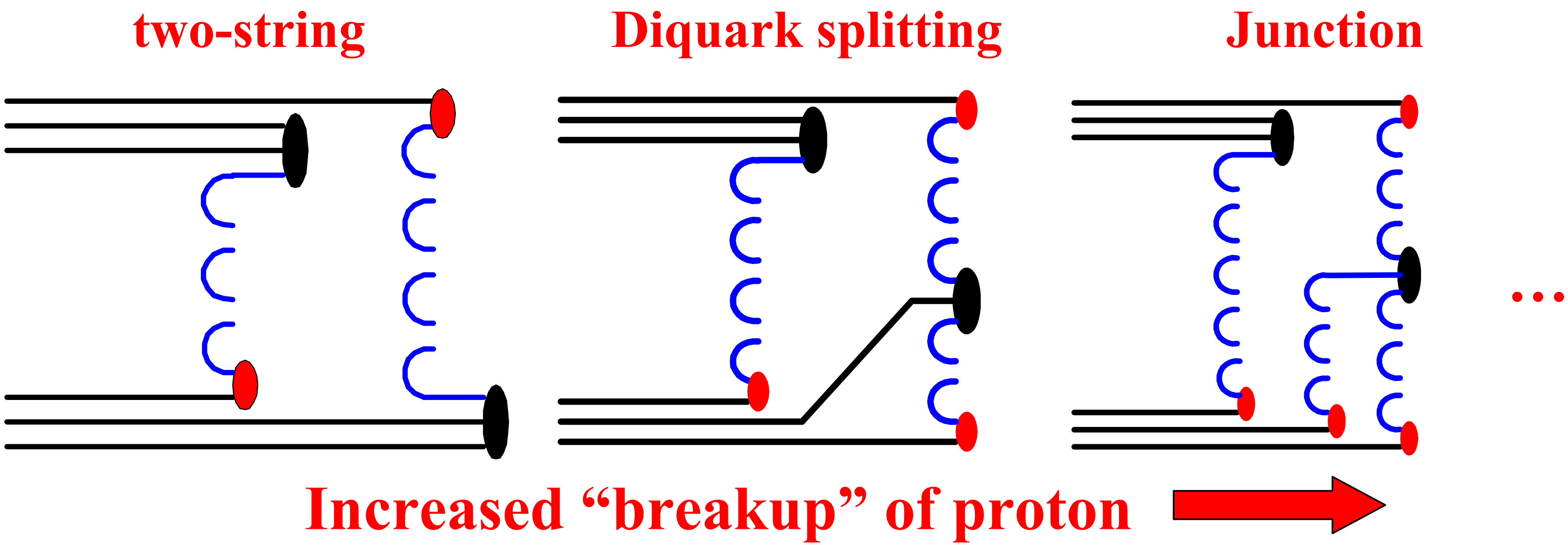


- Constituent quark model(s)
  - Proton fragmentation determined by valence quark scattering.
  - Particle production ?



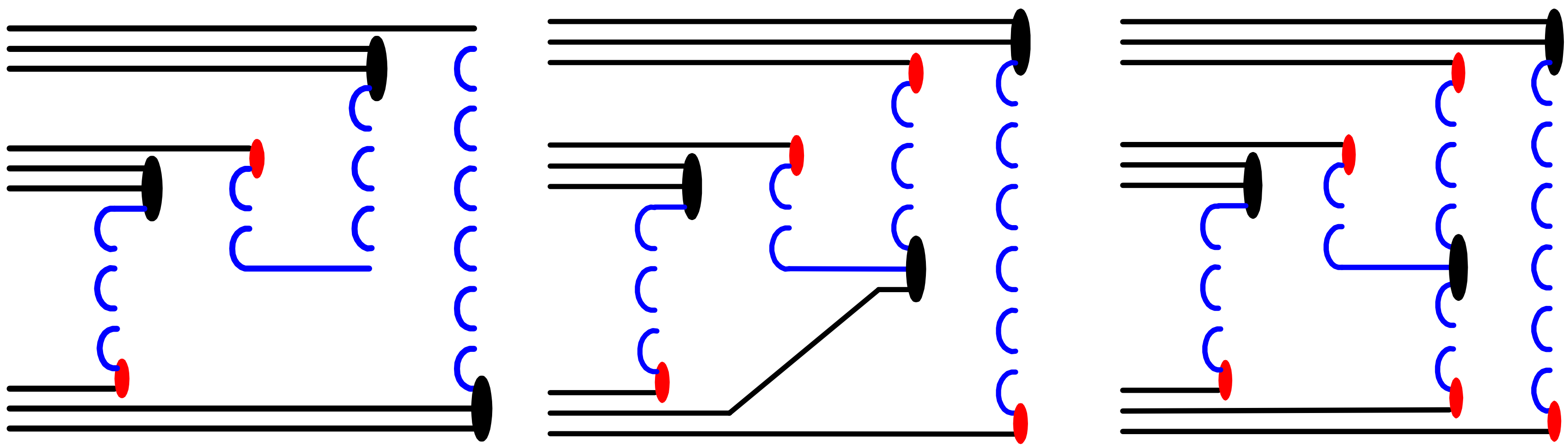
@ High Energy, Topological Expasion

• p-p collisions



Increased "breakup" of proton

• Possible double scattering diagrams



Problem: little theoretical control over this expansion

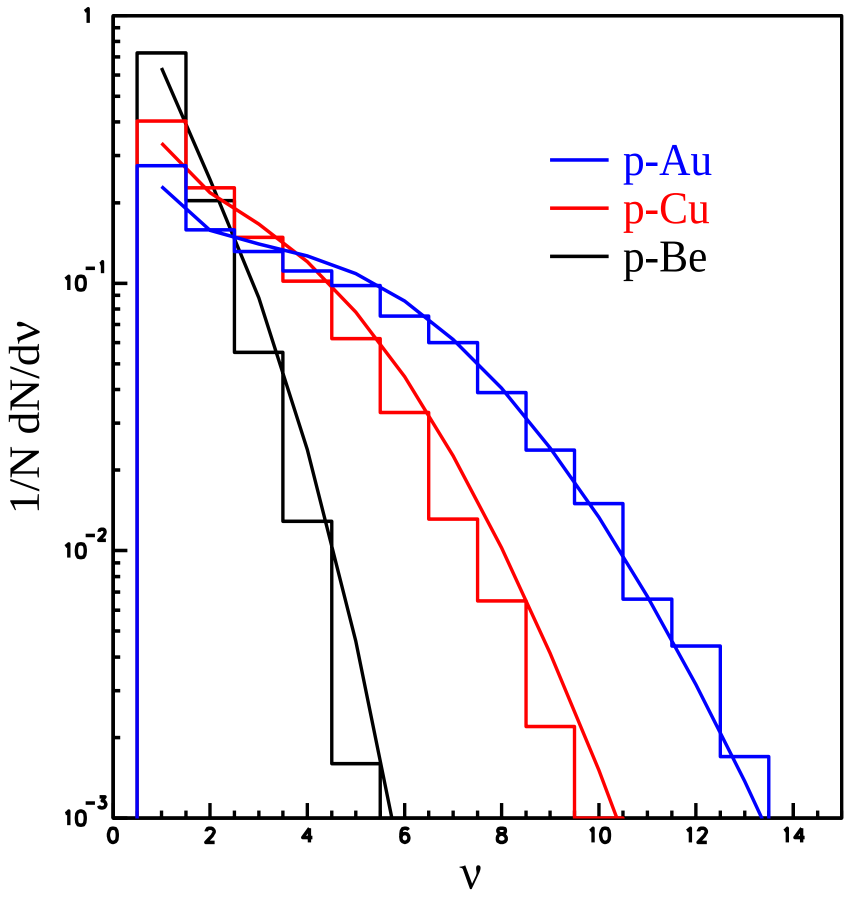
Some Questions ?

- What are the relevant DOF for describing the excitation of the nucleon in p-p, p-A, A-A collisions ?
  - Resonances, strings, quarks …
- Is this even a well-posed question ?
  - Description of same phenomena w/ different basis sets ?
  - Is one "basis set" more natural than the others ?
    - ⇒ e.g. is junction "excitation" better understood in terms of color field topology or quark scattering cross-sections ?
- These questions are becoming more urgent
  - Karzheev's pushing saturation model down to SPS
    - ⇒ Also his ideas regarding that saturation of α_s @ low Q^2.
  - Dokshitzer's musings on QCD & soft interactions
    - ⇒ Also his ideas regarding the "fragility" of the nucleon.
- Use # of scatters of proton in nucleus as a dial, study

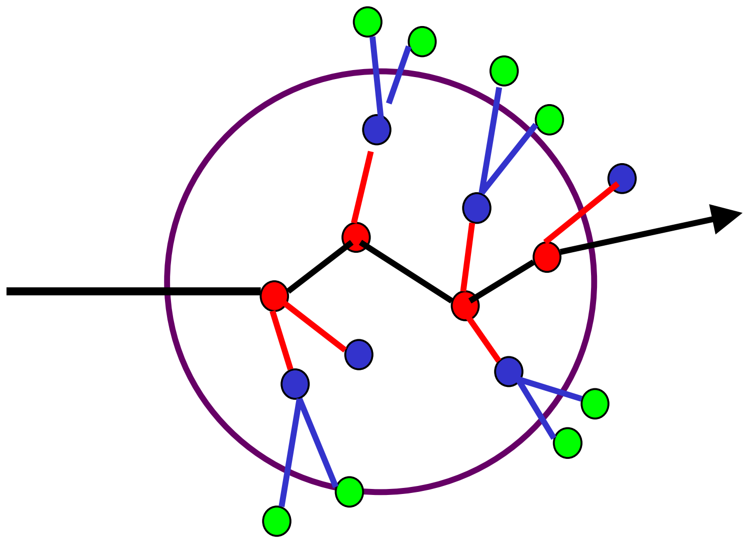
p-A Collision Centrality

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

Glauber + Monte Carlo P(ν)

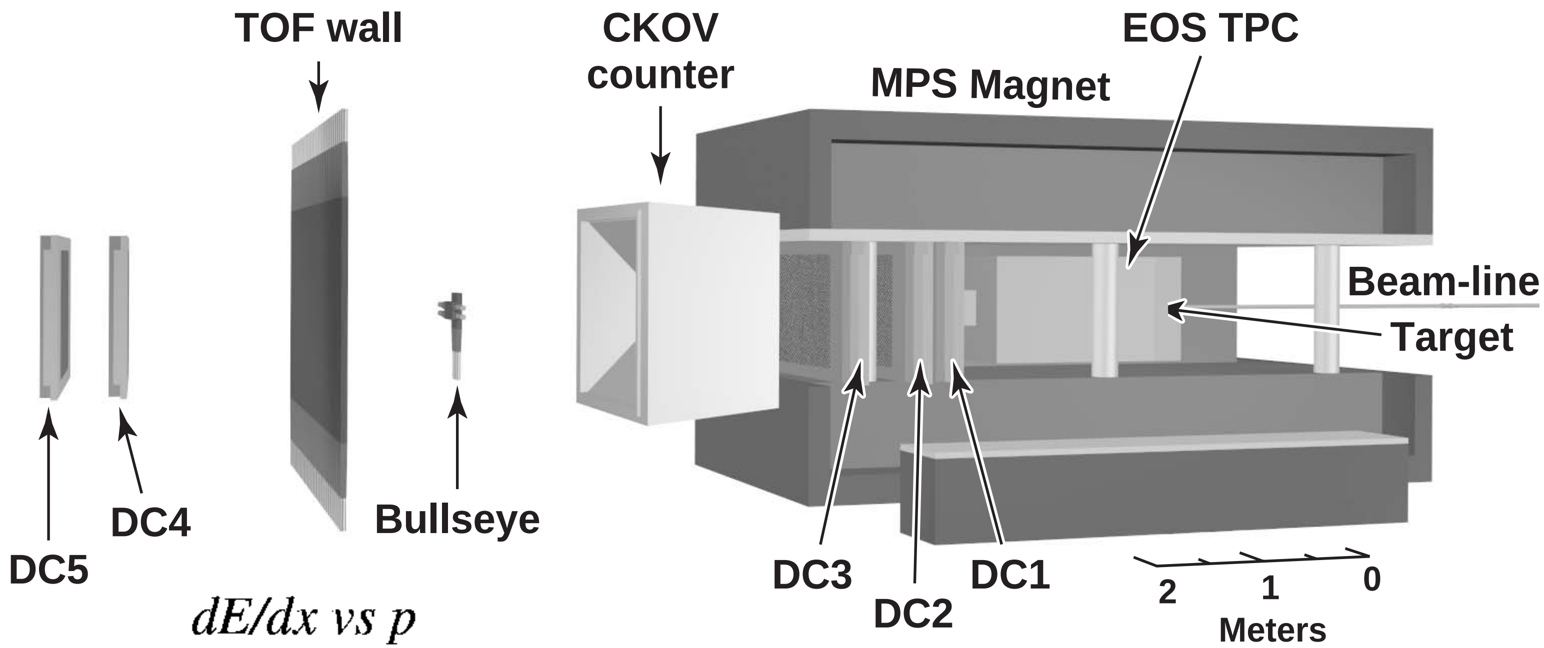


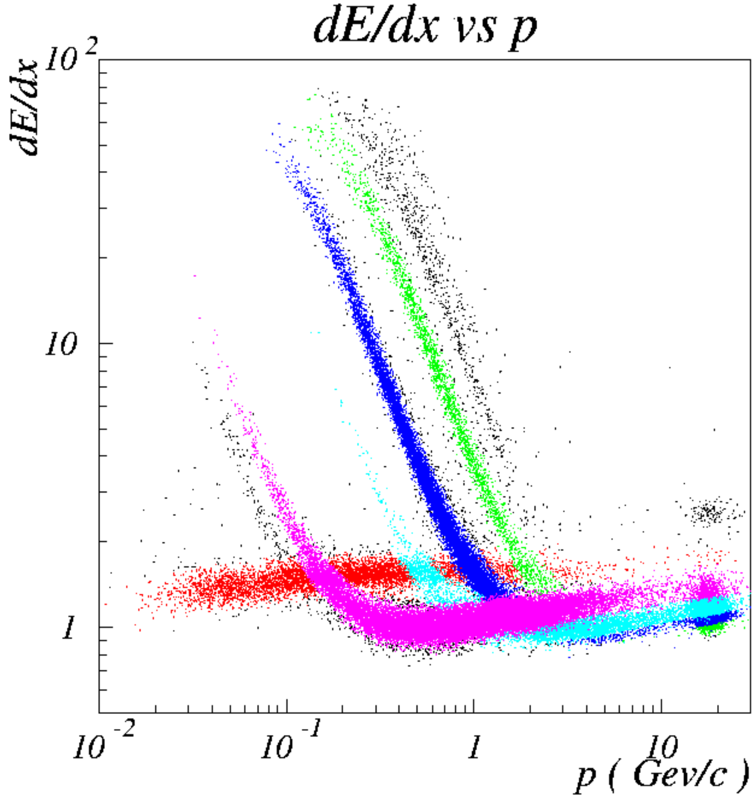
Proton scatters ν = 4 times



- 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



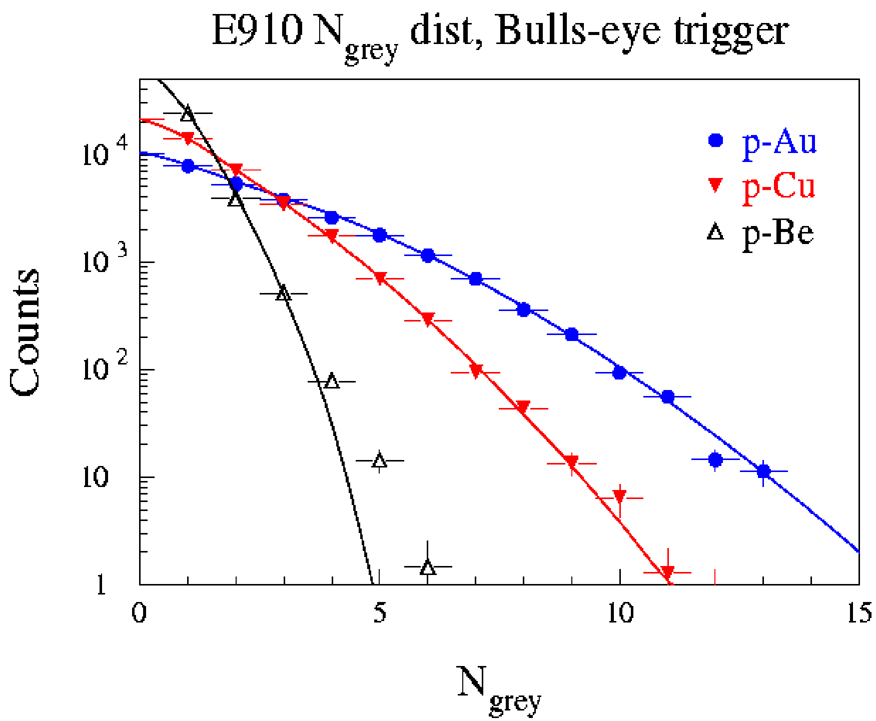


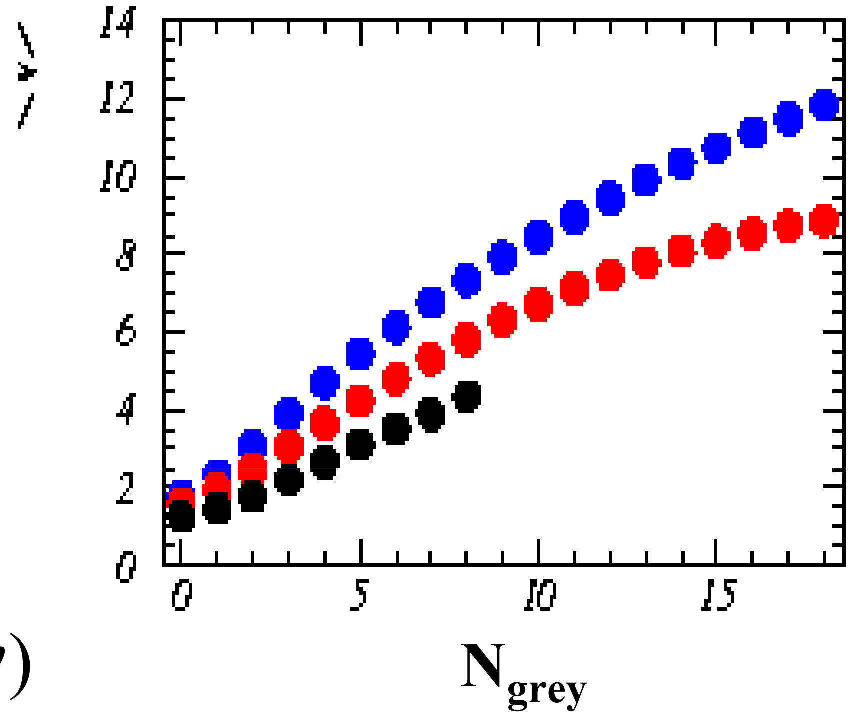
E910 Data

- 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)

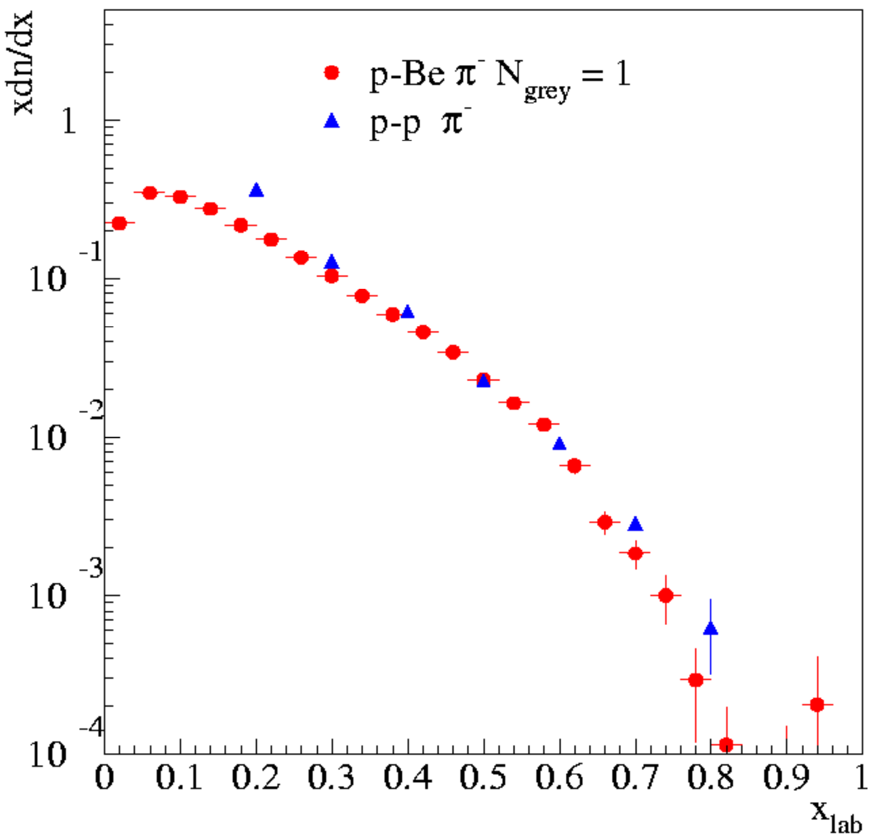


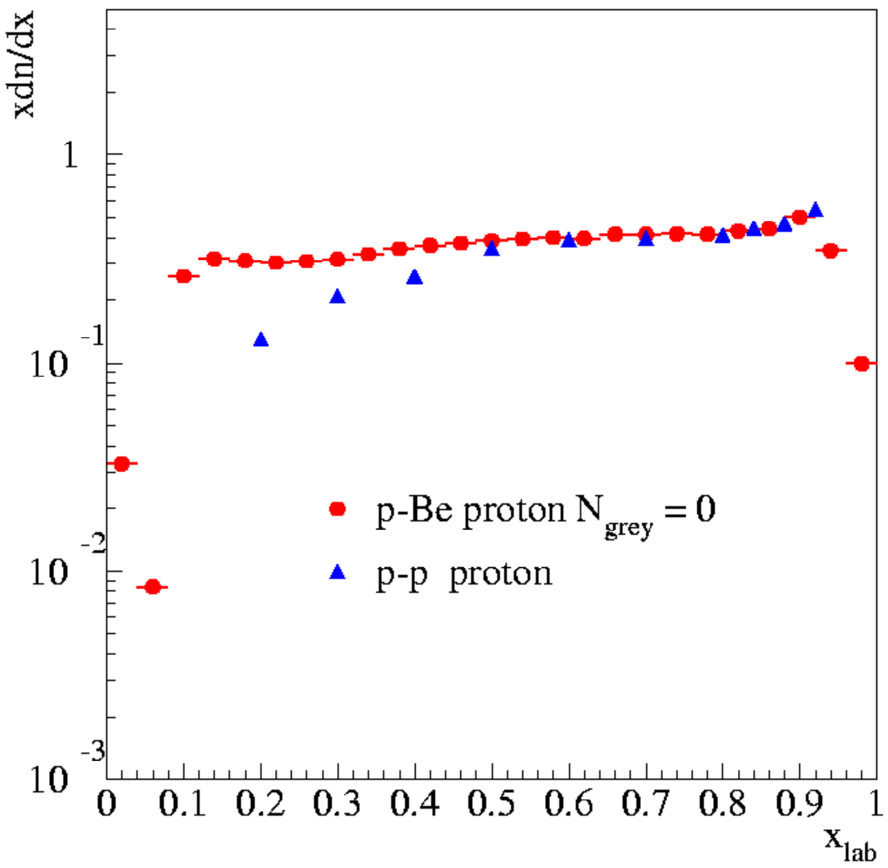


- Parameterize $N_{grey}(\nu)$
- Convolute with Glauber $P(\nu)$
- Fit to $dN/dN_{grey} \Rightarrow P(\nu, N_{grey})$
- Project to get $\langle \nu(N_{grey}) \rangle$
- **Beware:** distribution of ν may be important.

What regime are we in ?

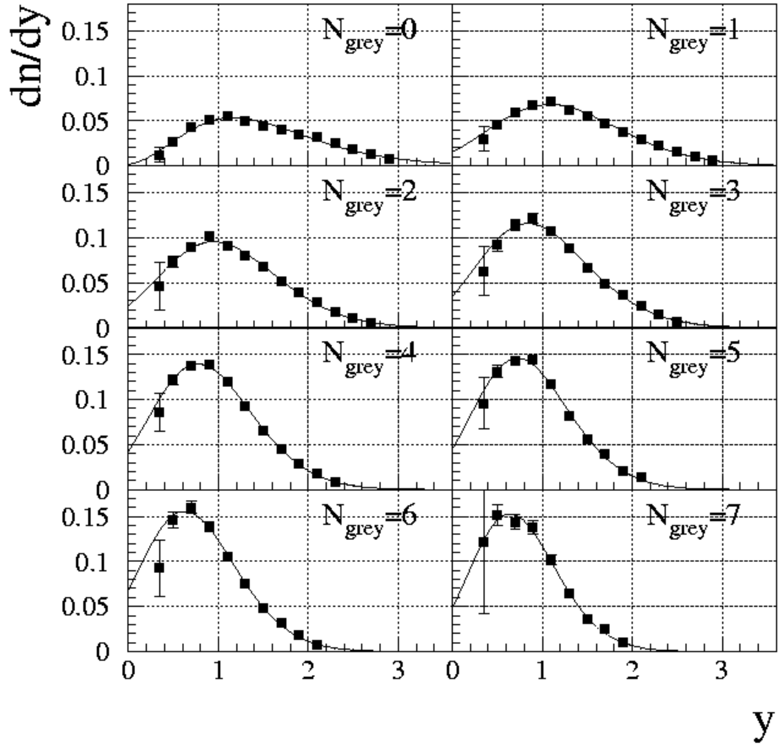
- Compare 12 GeV/c p-Be, N_{grey}=0 w/ 100 GeV/c p-p
  - p-p uses x_F, p-Be uses x_{lab}
  - Absolute normalization.
- Excellent agreement ??!!
  - Already at high energy limit – wrt **fragmentation**

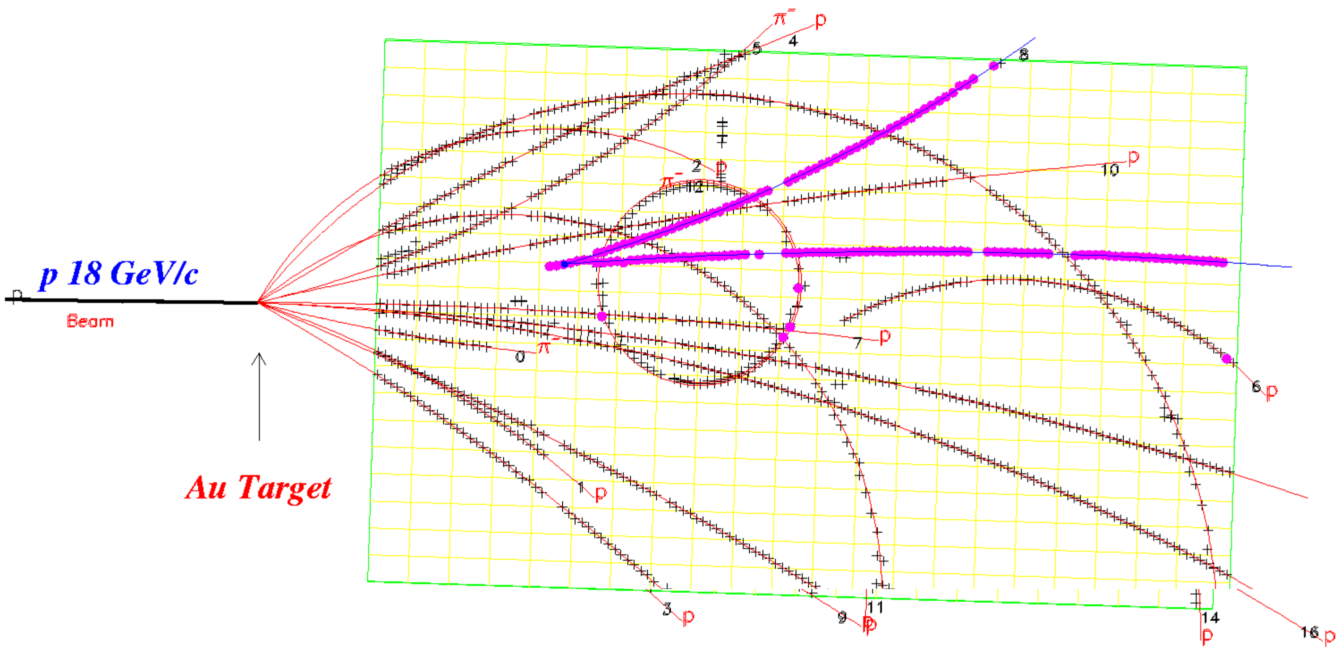


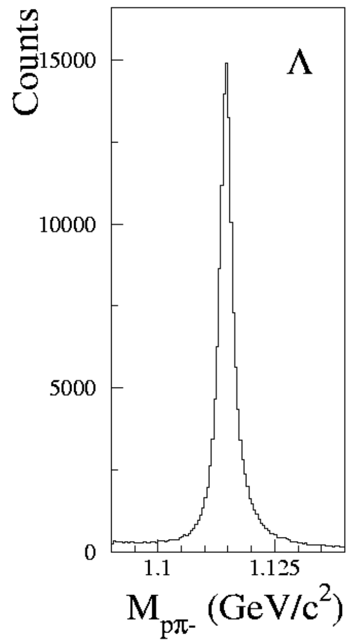


E910 - Λ Production

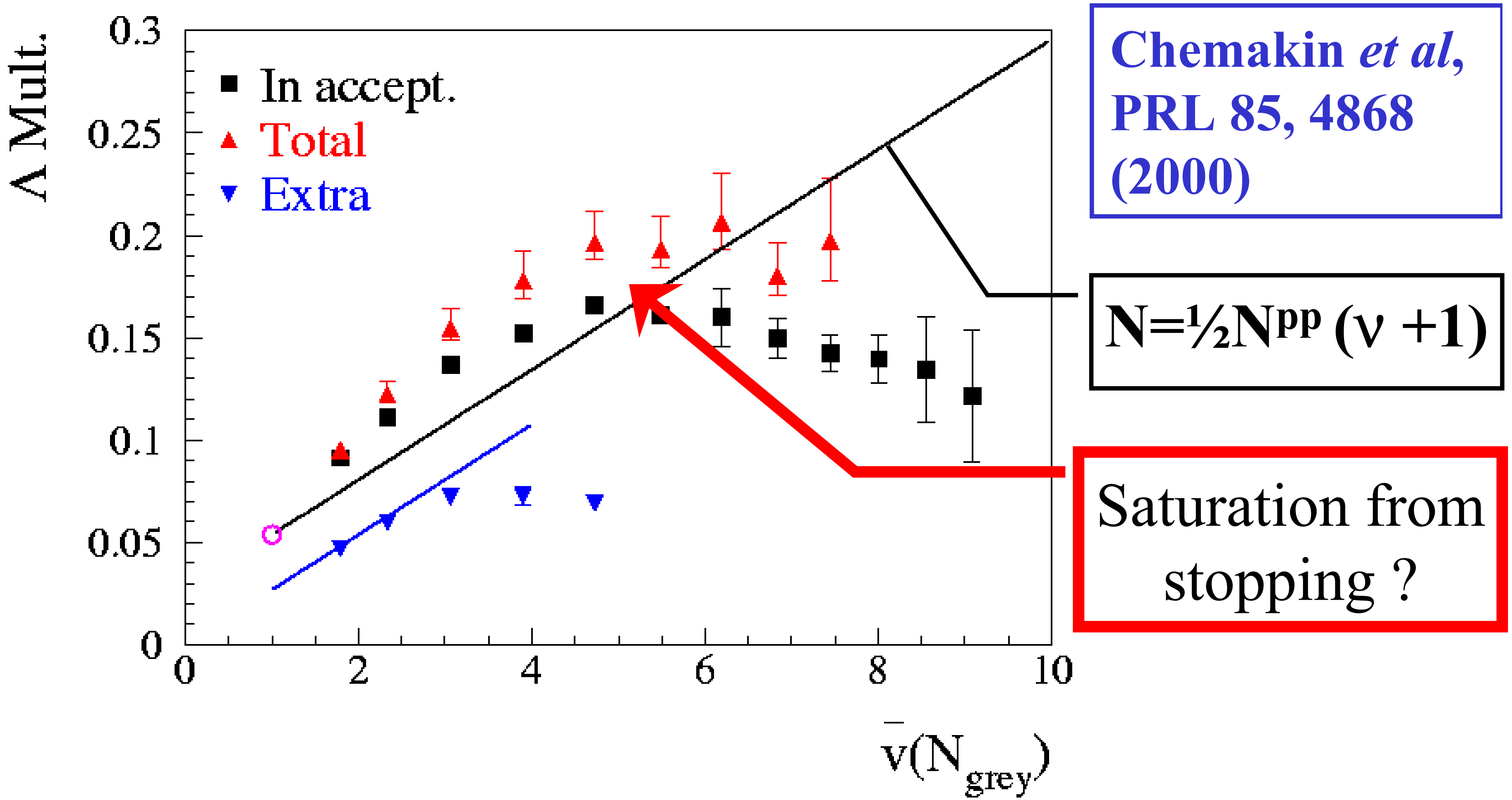
- **Analysis by X. Yang**
  - 150k Λ's in 18 GeV/c p-Au set
    - ⇒Good M_{inv} resolution, $\sigma = 1.5$ MeV/c^2
    - ⇒Good signal/background ~ 30:1.
  - Account for missing acceptance by extrapolating w/ gamma distribution.
  - "Leading" analysis – test whether Λ is most energetic baryon in event







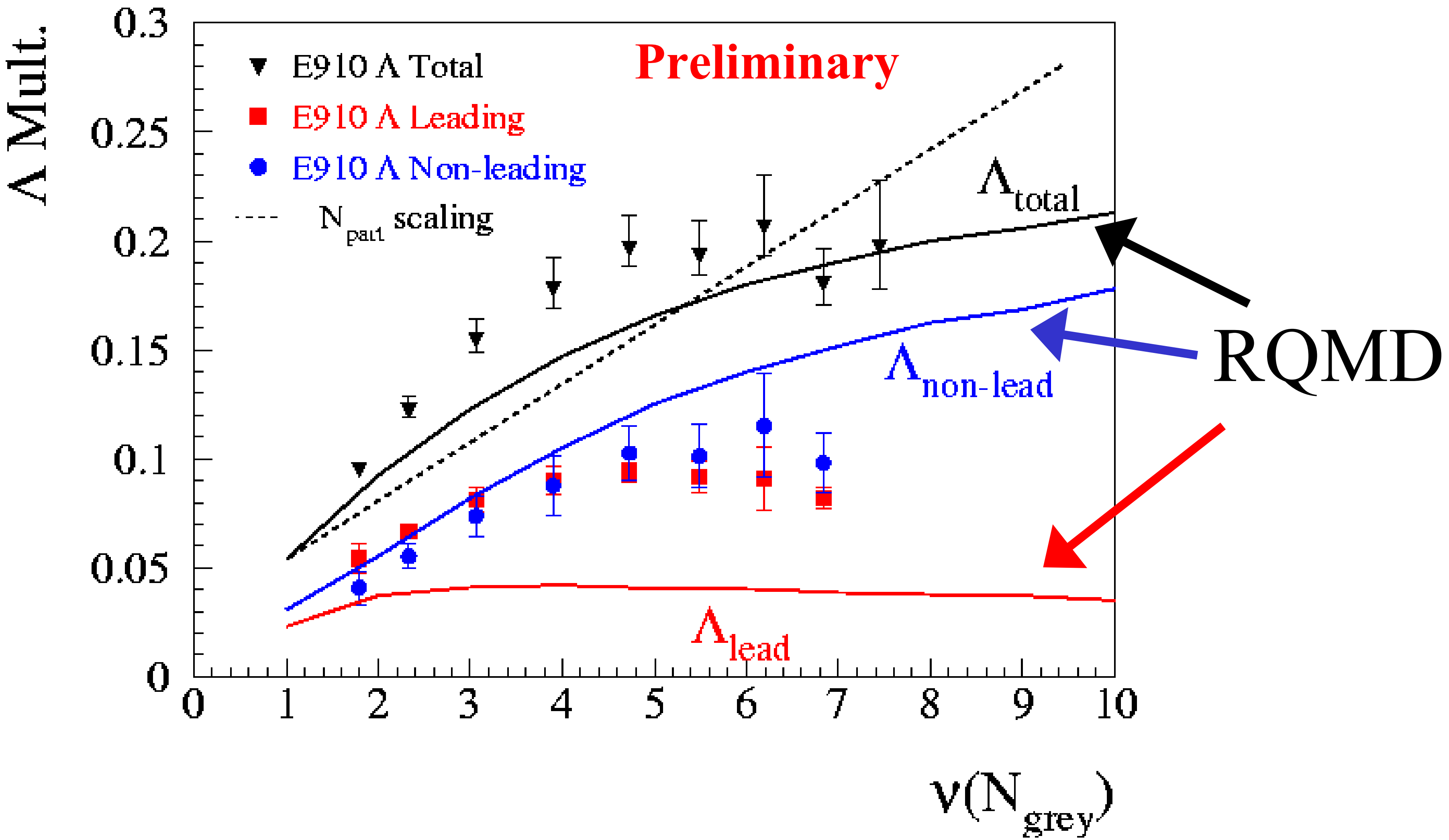
E910: 17.5 GeV p+Au, Λ Yield vs ν



- Excess Λ production observed over # participant scaling of p-p

$\Rightarrow N_{\Lambda}^{proj} = \nu \times ½ N_{\Lambda}^{pp}$ for $\nu \leq 3$???

E910, 17.5 GeV/c p+Au, Leading Λ

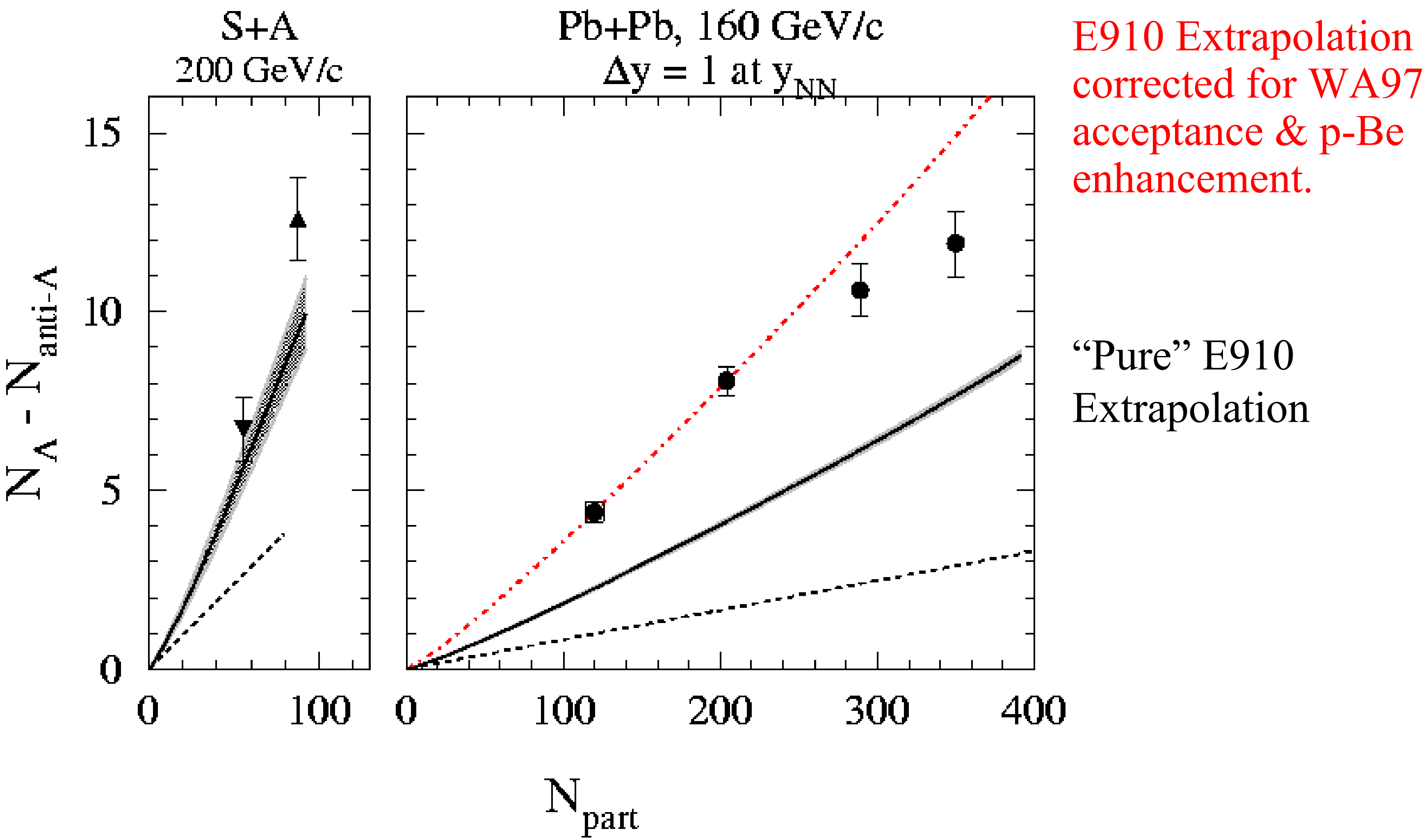


- Ask "are Λ's leading baryon" event by event

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

  ⇒ **Not reproduced by RQMD.**

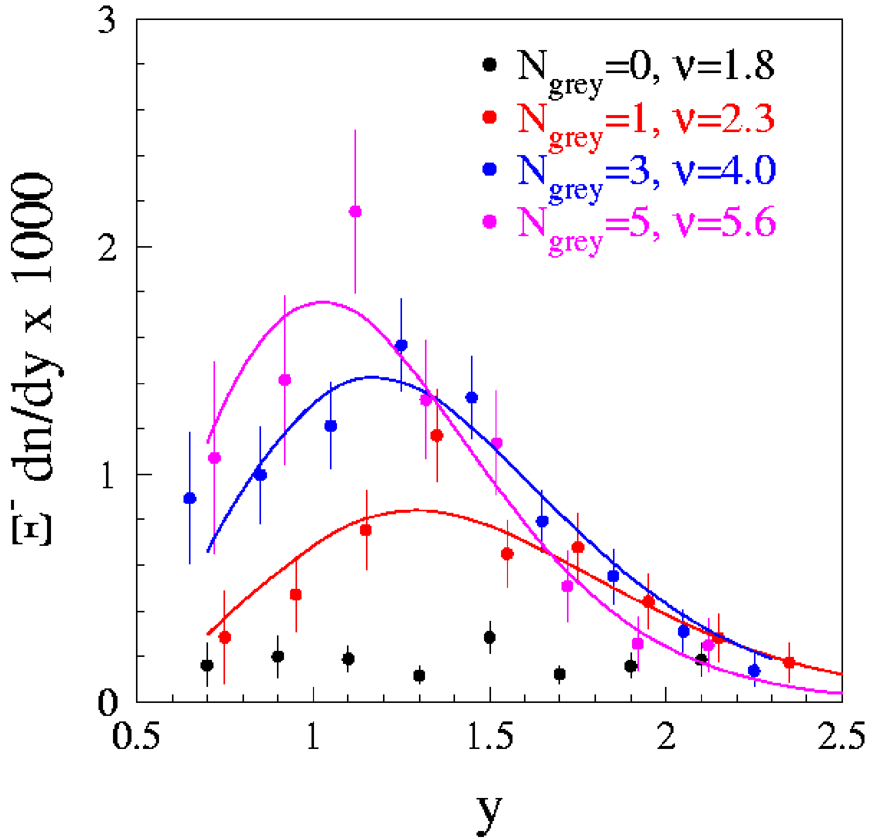
E910 Extrapolation to SPS, Update

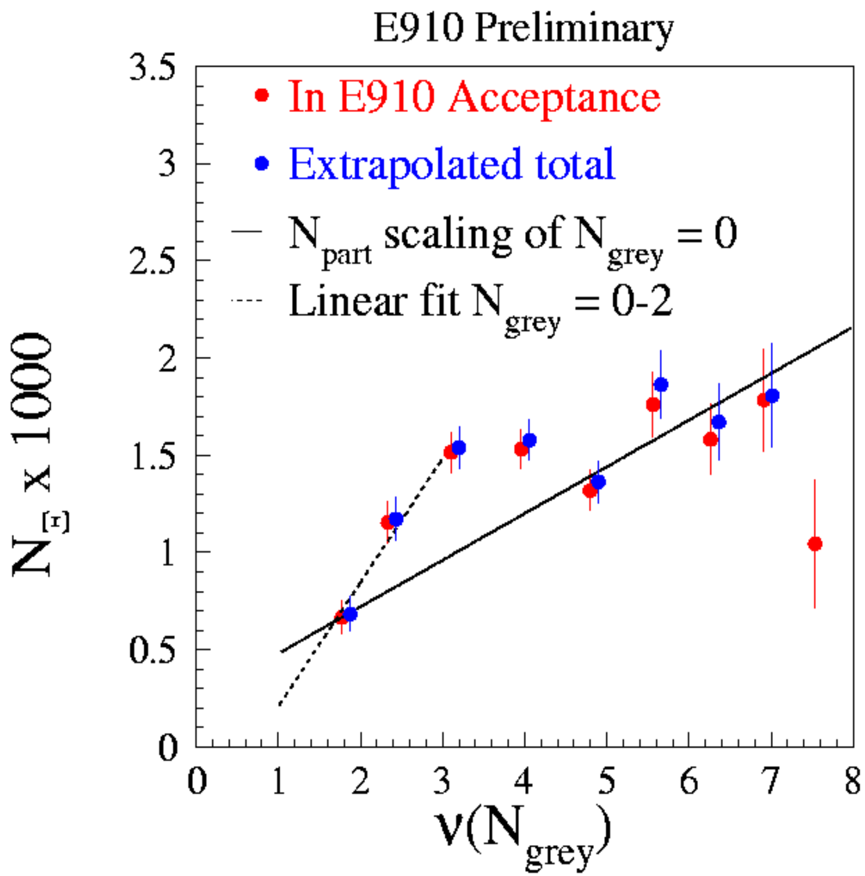


- Corrected extrapolation reproduces observed Λ enhancement.
  - Note: larger σ doesn't change things due to kinematic limit.
  - Smaller σ **(likely for central)** means extrapolation overpredicts WA97.

    ⇒ But haven't accounted for depletion of Λ due to Ξ, Ω

E910 Ξ^- Production





- Rapid increase in Ξ yield with ν.

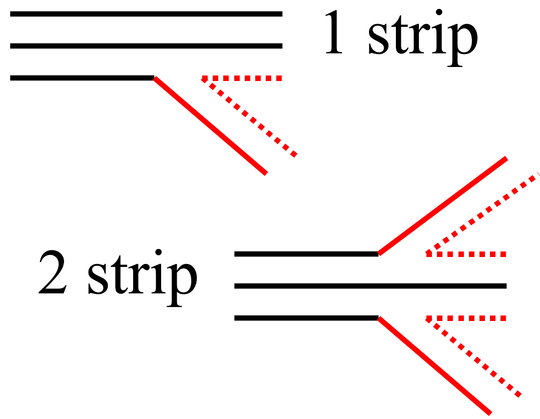
⇒Inconsistent with # participant scaling

- > ×4 increase in Ξ yield over ν = 1 with any reasonable extrapolation ⇒ > x 8 in A+A
- **Also due to projectile ?! (starts above y_{NN})**

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.

S_B / 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

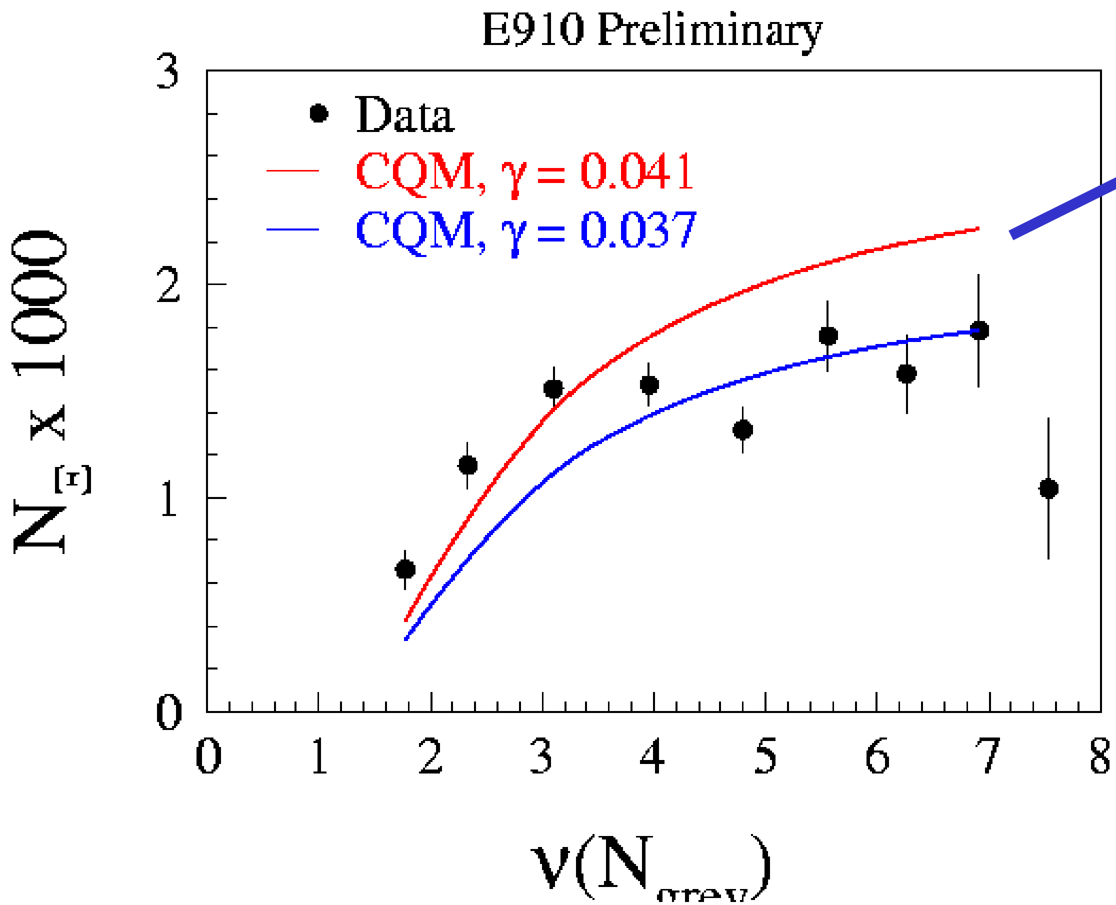


  - Obtain expected growth in S = 1 (e.g. Λ).
  - Expect: **N_{strip} mostly = 1 in p-p, > 1 in p-A.**

⇒ Enhanced Ξ production in p-A.

Test CQM Against E910 Ξ^-

- Start w/CQM model of Choi *et al,*
  - ***Phys. Rev. C55, 848, 1997*** :: calculate $N_{strip}(\nu)$
- Estimate γ from p-p Λ yield, corrected for Σ^{+-}
  - At AGS, **γ = 0.037 – 0.041**



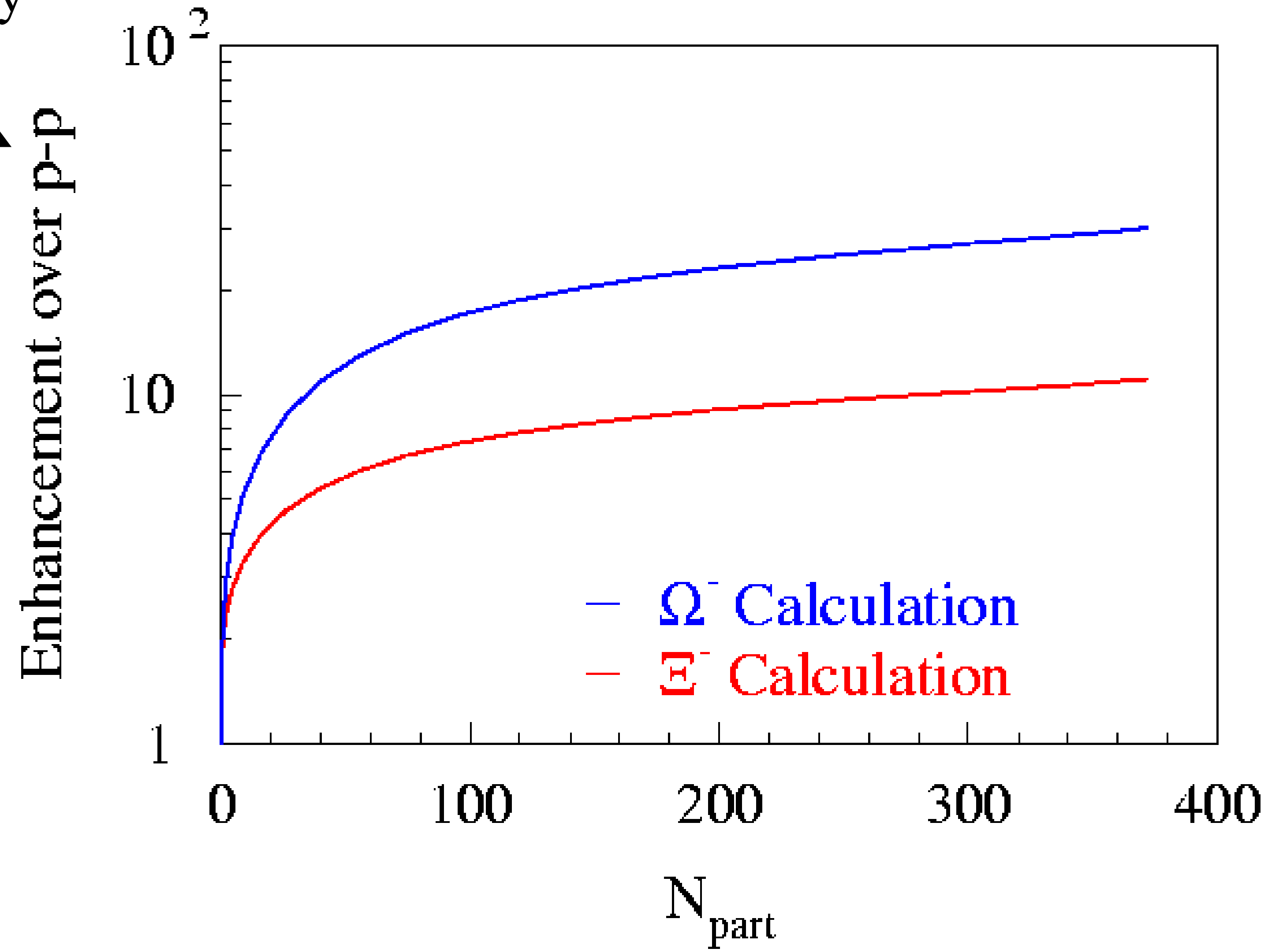
Reasonable but not perfect agreement.

Still some freedom in choice of CQM parameters

CQM: Apply to SPS Pb+Pb

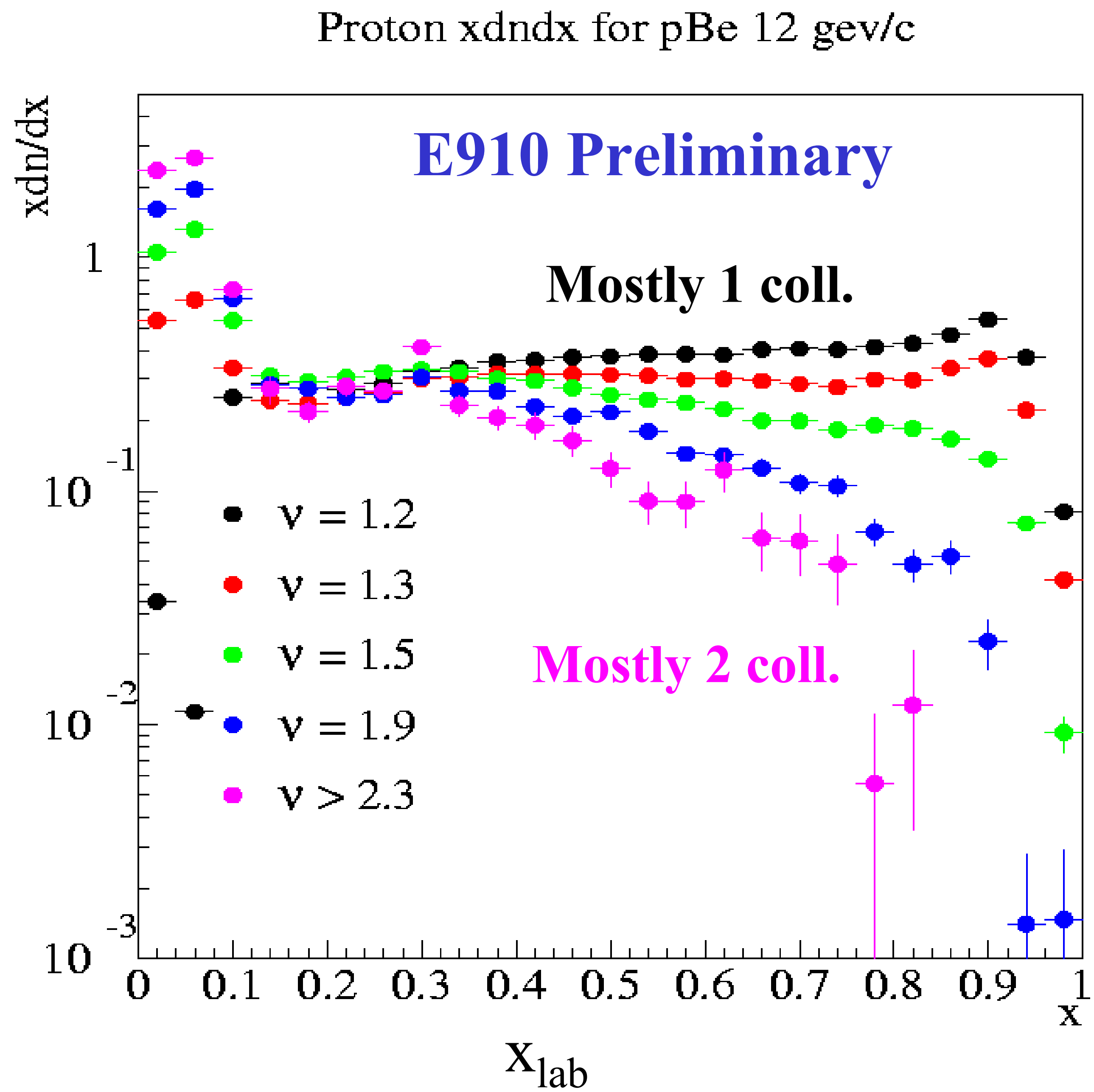
Calculations for 160 GeV Pb+Pb (BAC)

Actually p-Be



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

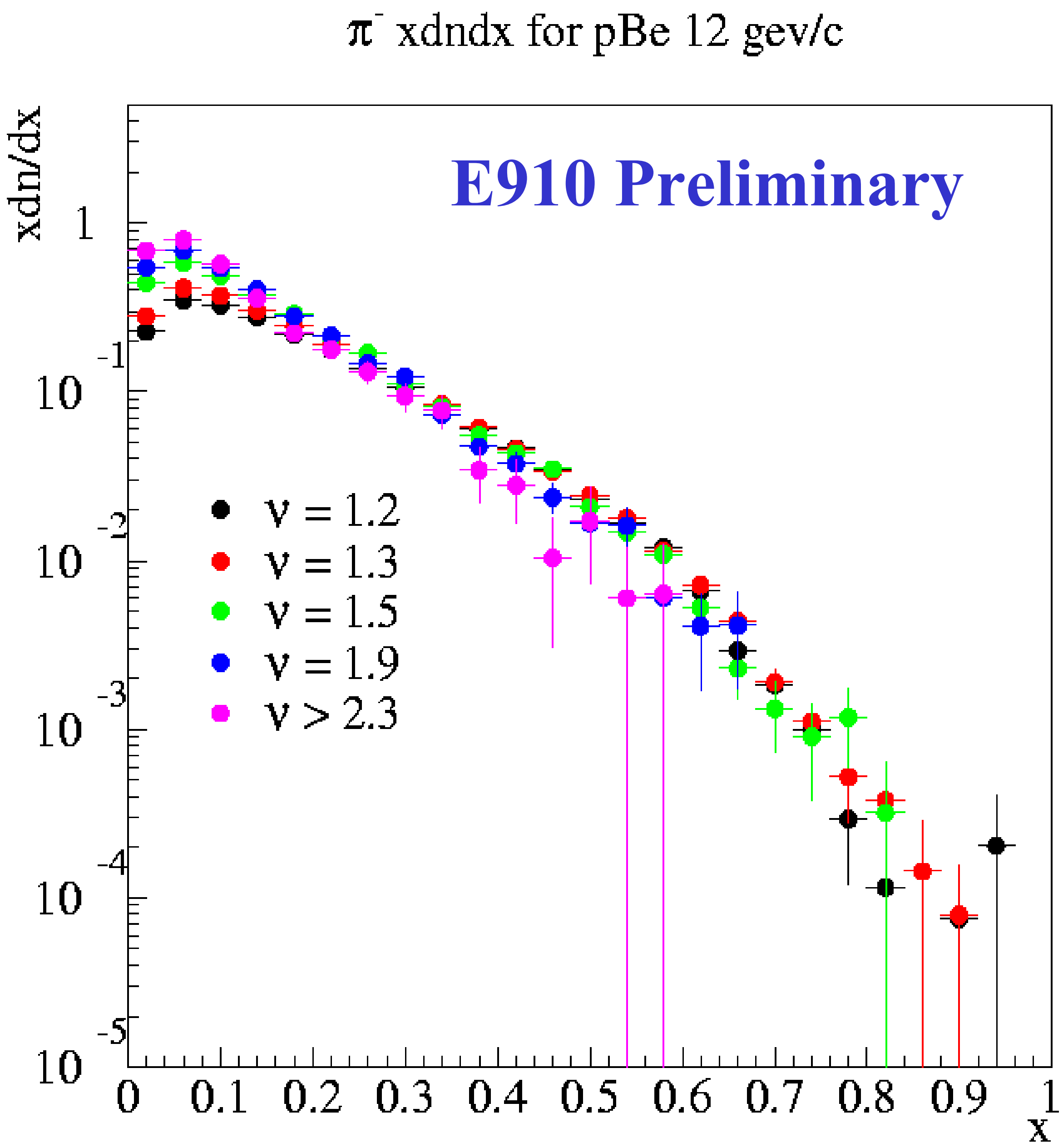
E910 - Projectile Fragmentation



Analysis by H. Hiejima

Dramatic change in proton spectrum between 1st, 2nd collision

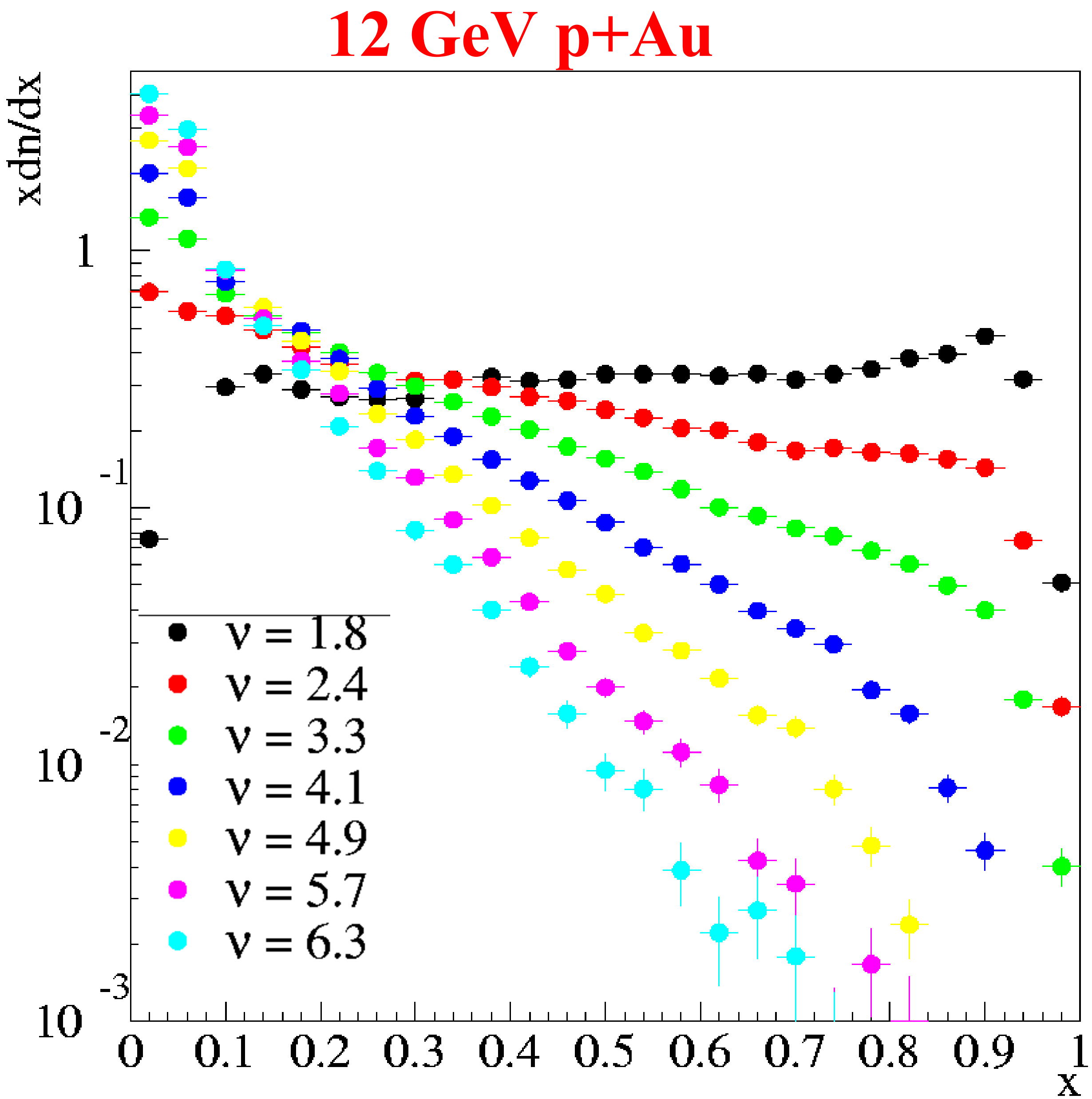
E910 – Fragmentation π^-



≈ No change in π^- spectrum between 1st, 2nd collision !!!

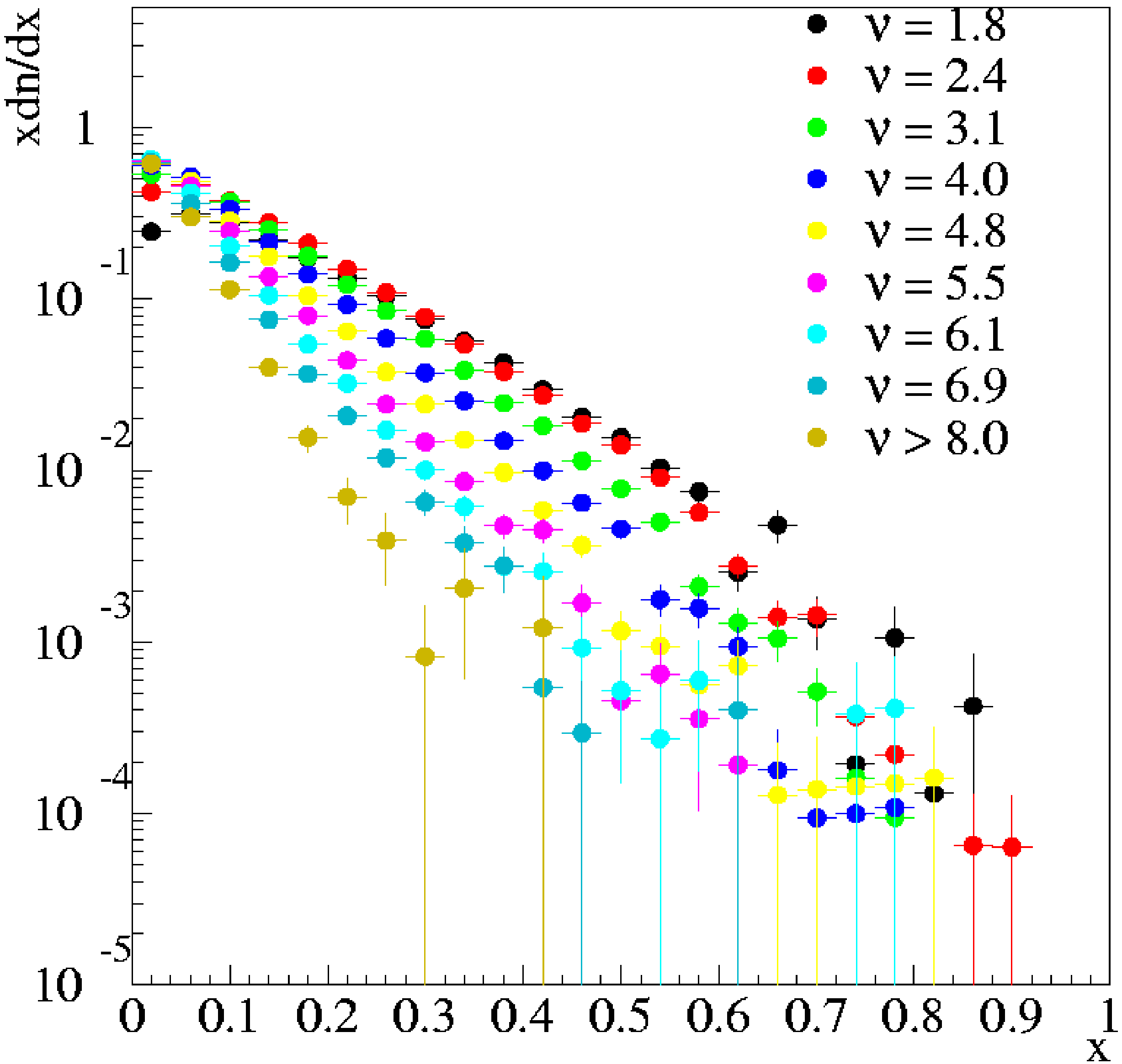
Stop the baryon # but not the energy ??

p-Au Proton xdn/dx



- Similar behavior as in p-Be.
- Degradation occurs more slowly with increasing N_{grey}.
- See remnant of (diffractive ?) peak in $N_{grey} > 0$ bins.
- Both reflect broader $N_{grey}(\nu)$ distributions.

p-Au π^- xdn/dx



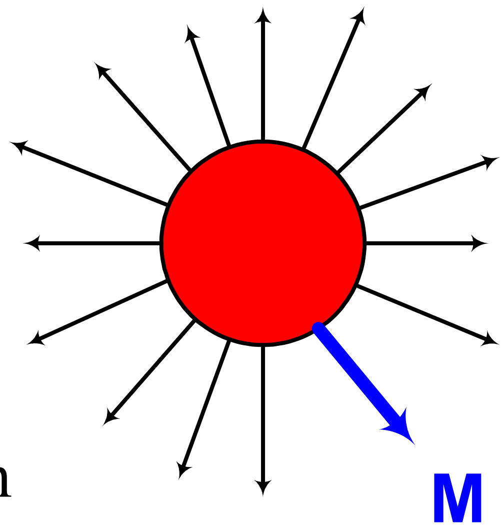
- Again similar behavior as in p-Be for $\nu < 3$.
- For larger ν see attenuation of forward π.

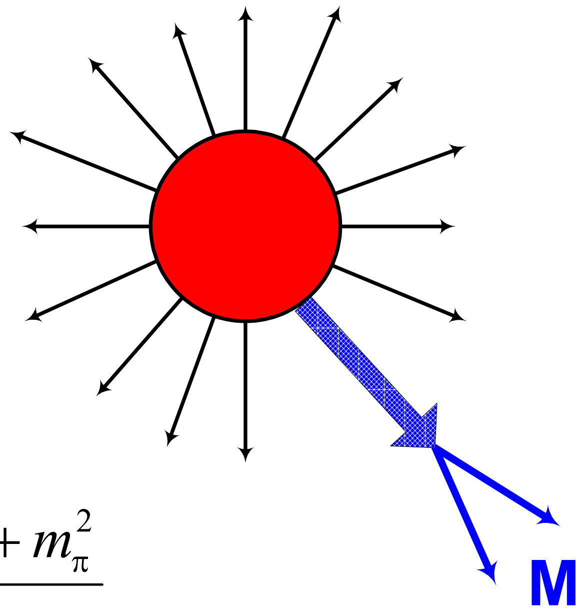
What have we learned so far?

- E910 observes an **increased probability for projectile to fragment into strange baryons** with increasing ν.
  - This increase can account for much of the observed enhancement in baryon production @ AGS & SPS.
- The increase for Λ can be explained by Van Hove constituent quark fragmentation model.
  - Prediction for Ξ^- can reproduce E910 observation.
  - Predictions for Ξ^-, Ω^- can **reproduce enhancement observed in Pb-Pb collisions** at SPS.
- Observe strong degradation of proton longitudinal momentum in p-Be collisions between $\nu \approx 1$ and $\nu \approx 2$.
  - Little or no effect seen on pion spectrum.
- Behavior consistent with baryon break-up.
  - Unnatural in resonance model.
    - $\Rightarrow$ Needs magic balancing of stopping & resonance excitation.

What about the Resonances ?

- What are the origins of (baryonic) resonances ?
- Go back to Jackson
  - Compare N-body phase space for (e.g.) production of p-π pair with mass *m*.
  - To (N+1)-body phase space for production of pair via resonance w/ mass *m*.





$$d\sigma = d\sigma_0(m)\left[\frac{\pi^{-1} m_0 \Gamma(m)}{(m^2 - m_0^2)^2 + m_0^2 \Gamma^2(m)}\right] dm^2$$

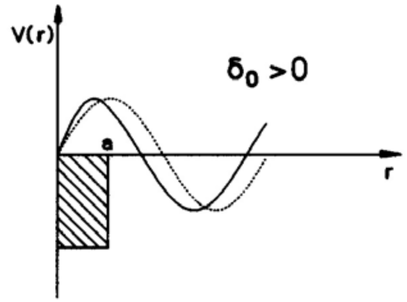
  - Resonance modifies the density of states by **multiplicative** Breit-Wigner.

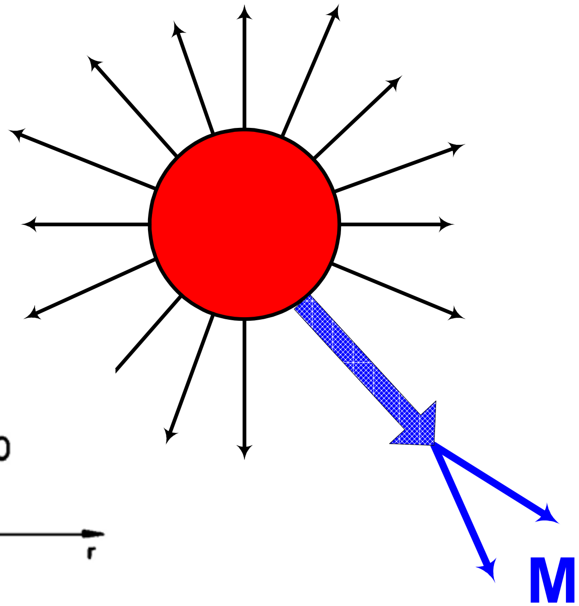
$$\Gamma(m) = \Gamma_0 \left(\frac{m}{m_0}\right)^{2L+1} \frac{\rho(m)}{\rho(m_0)} \qquad \rho(m) = \frac{(m + m_p)^2 + m_\pi^2}{m^2}$$

Final-State Interactions

- Another approach: Final state interactions in QM
- Write $H_{int} = V_{pri} + V_{FS}$
- If distance scale for V_{FS} >> for V_{pri},
  - Consider outgoing wave from V_{pri}
  - Undergoes phase shift in V_{FS}
  - E.g. for partial wave L

$$T_{fi} \propto T_{fi}^{pri} e^{i\delta_L} \frac{\sin\delta_L}{k^{L+1}}$$





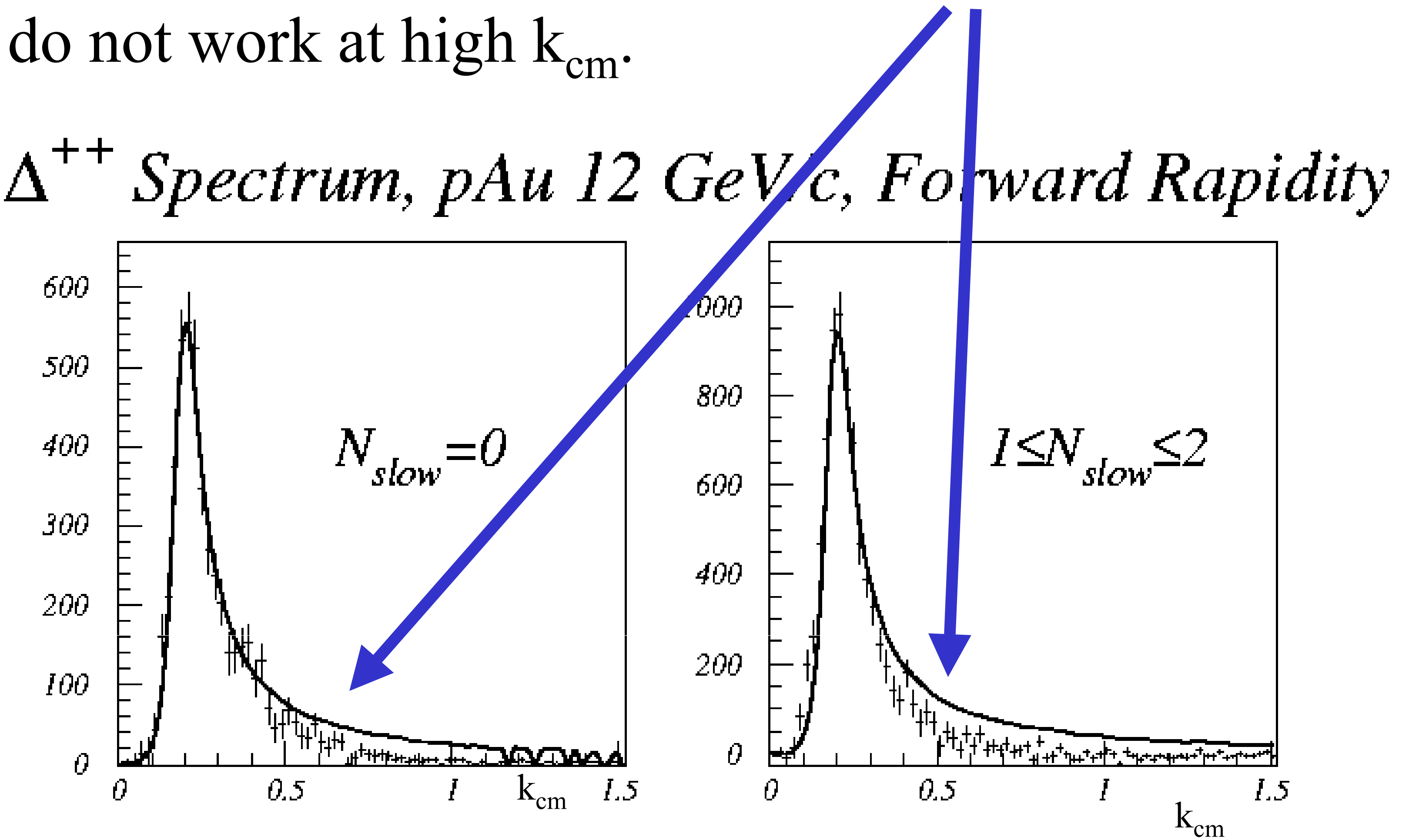
  - If interaction contains a resonance,

$$d\sigma \propto d\sigma_{pri} \frac{\sin^2\delta_L}{k\Gamma(m)} \propto d\sigma_{pri} \frac{m}{k} \frac{m_0\Gamma(m)}{(m^2 - m_0^2)^2 + m_0^2\Gamma^2(m)}$$

- FSI: QM distortion of two-particle density of states.
  - For pairs produced within range of potential.
  - T_{fi}^{pri} important for states with well-defined isospin.

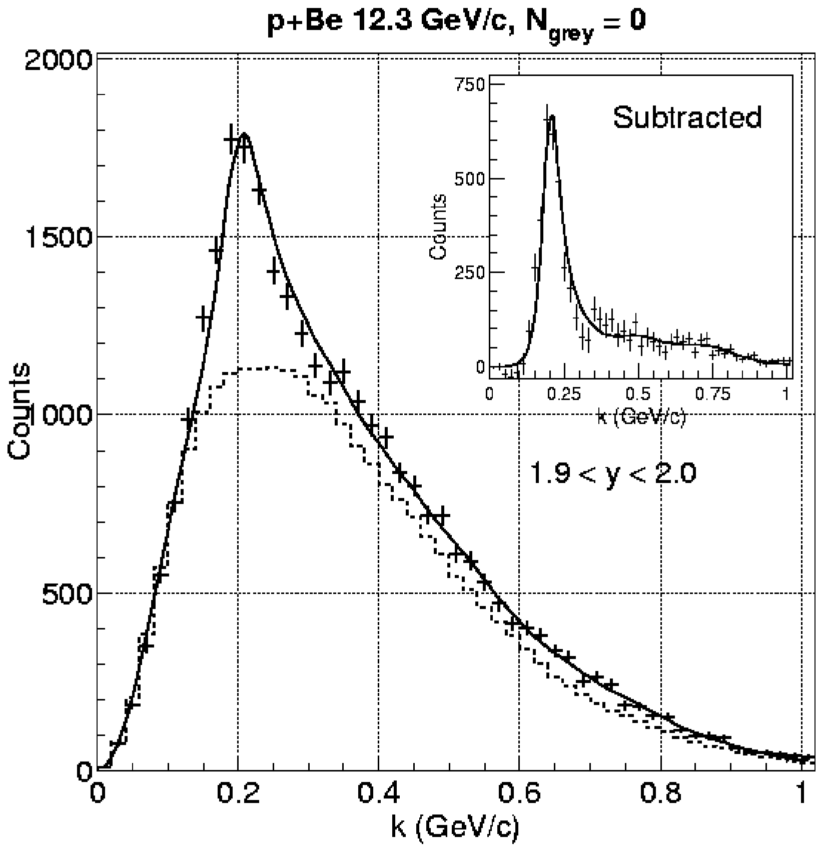
E910 Δ^{++} Analysis (old)

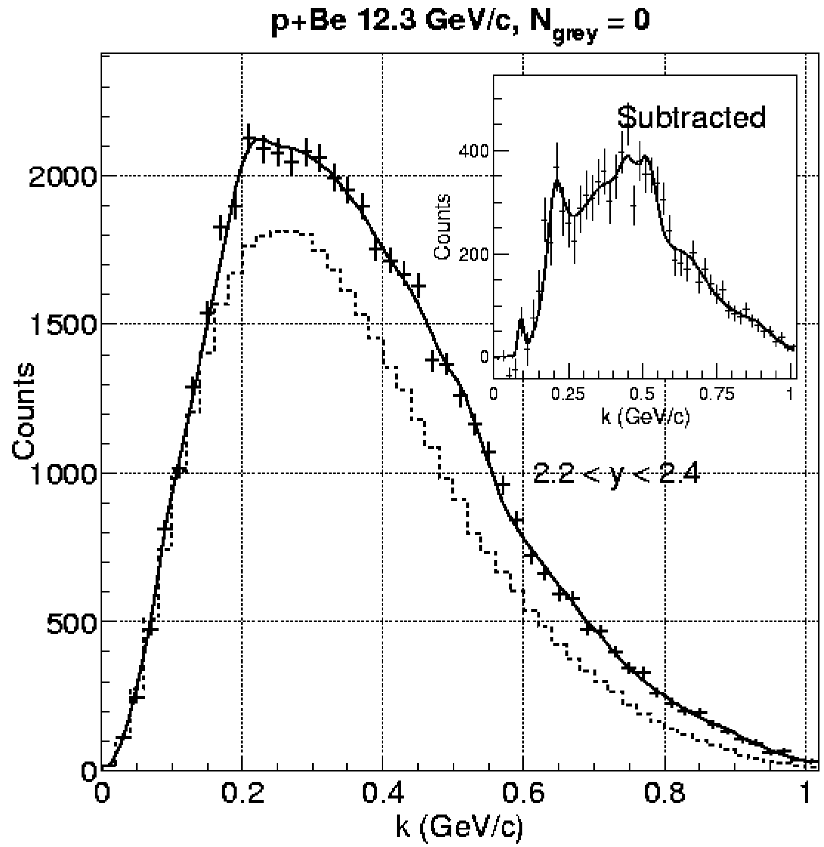
- Plot pair k_{cm} distributions instead of mass distributions to avoid compression of low-mass side.
  - Measure background with mixed events.
- Attempts to fit p-π^{+} distributions to BG+Breit-Wigner do not work at high k_{cm}.



E910 Δ Analysis (new)

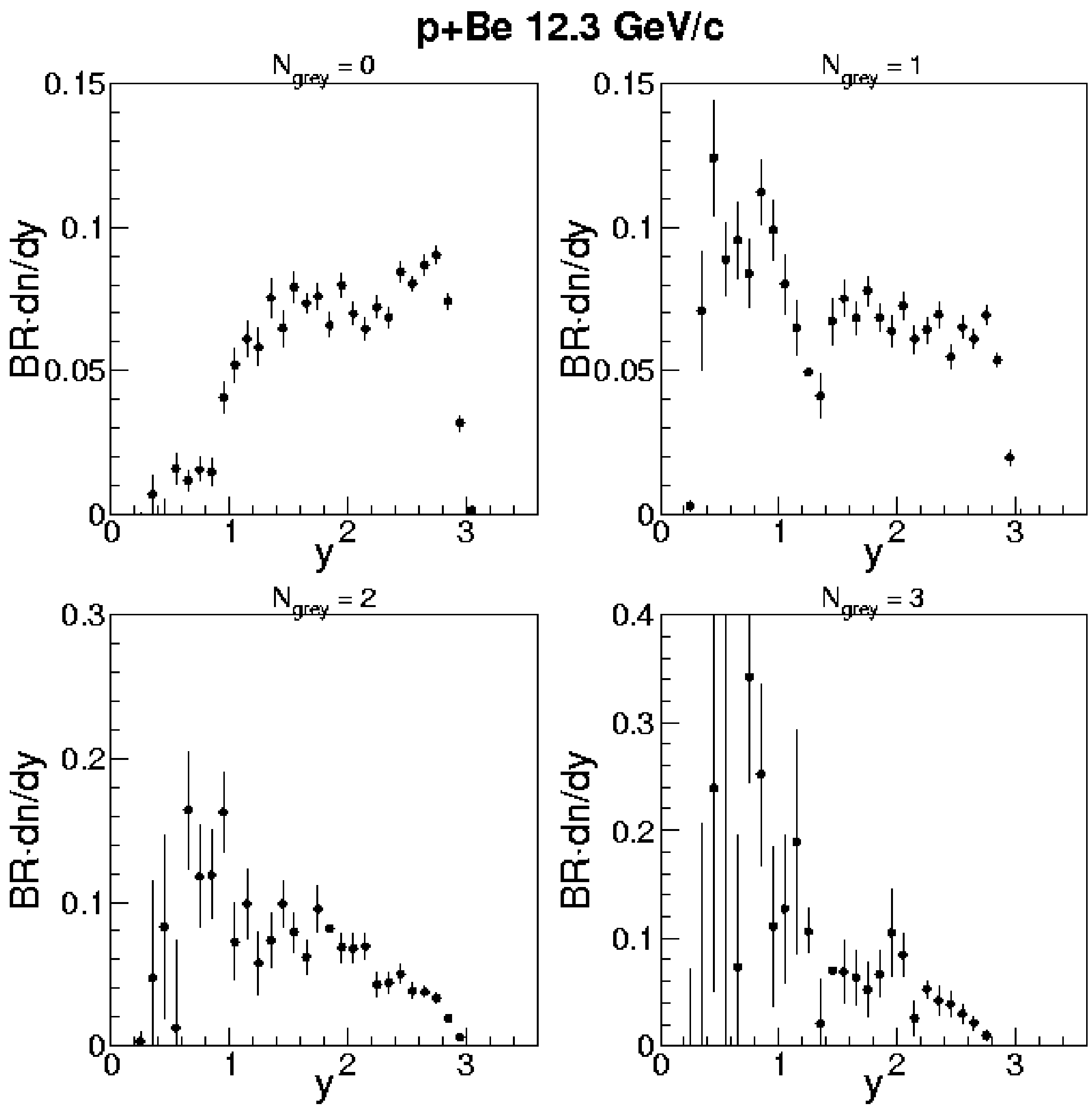
- Use Breit-Wigner modified phase-space distribution.
- Event mixing for uncorrelated 2-particle distribution
  - $N_{\Delta}^{pair} = \left(R \cdot BG(k) + cN_{\Delta} \cdot BG(k) \cdot BW(k)\right)$
- Get good description of Δ^{++}, Δ^{0}, N(1440)+N(1520) + …





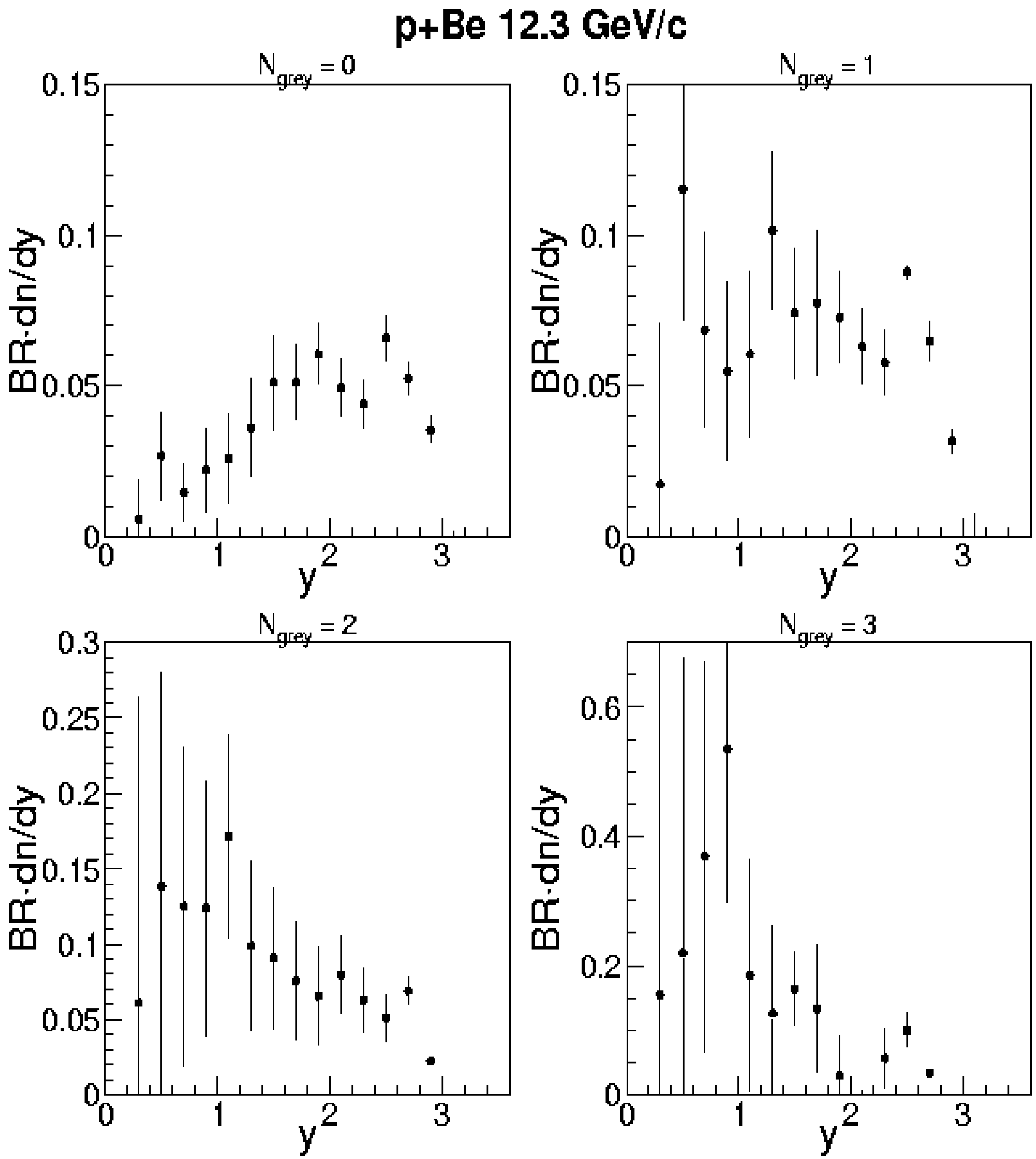
E910 p-Be Δ^{++} Production

- Plot dn/dy for different N_{grey} cuts.
- Beware N_{grey} = 0 bias against low-y Δ^{++}.



- See peak in N_{grey}=0 above y=2.5 ?
- Large yield in 0<y<1 for N_{grey}=1 due to N_{grey}=0 bias.
- Rapidly decreasing yield for y > 2.
- consistent with proton x distributions.

E910 p-Be Δ^0 Production



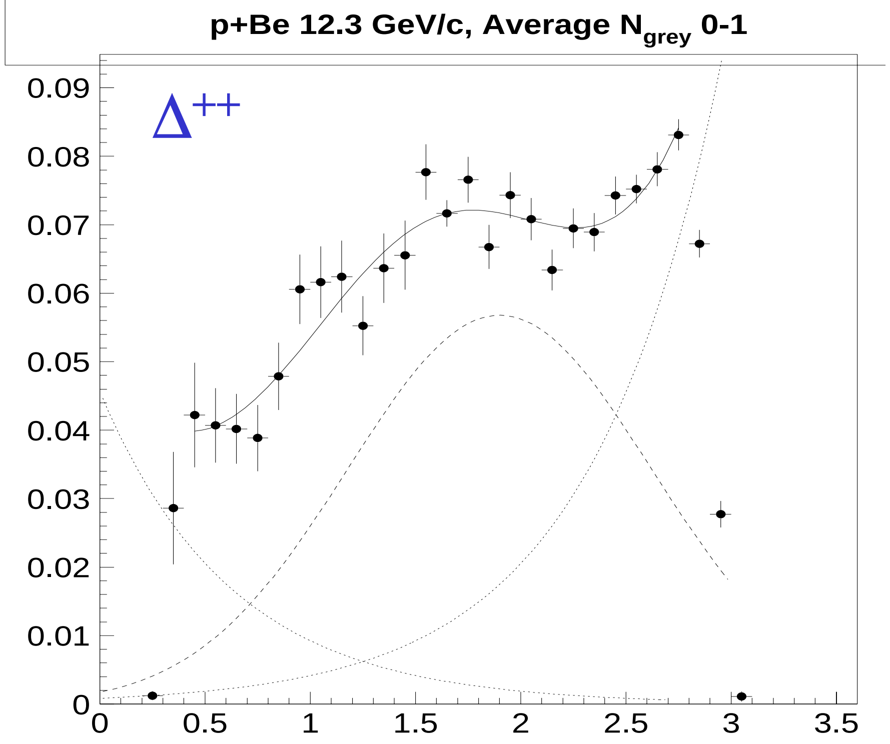
- Statistics poorer because of factor of 3 lower BR.
- See strong growth at low y in N_{grey}.
- Problem with correlated errors due to large N(1440) & N(1520) contributions in fit to k_{cm} dist.

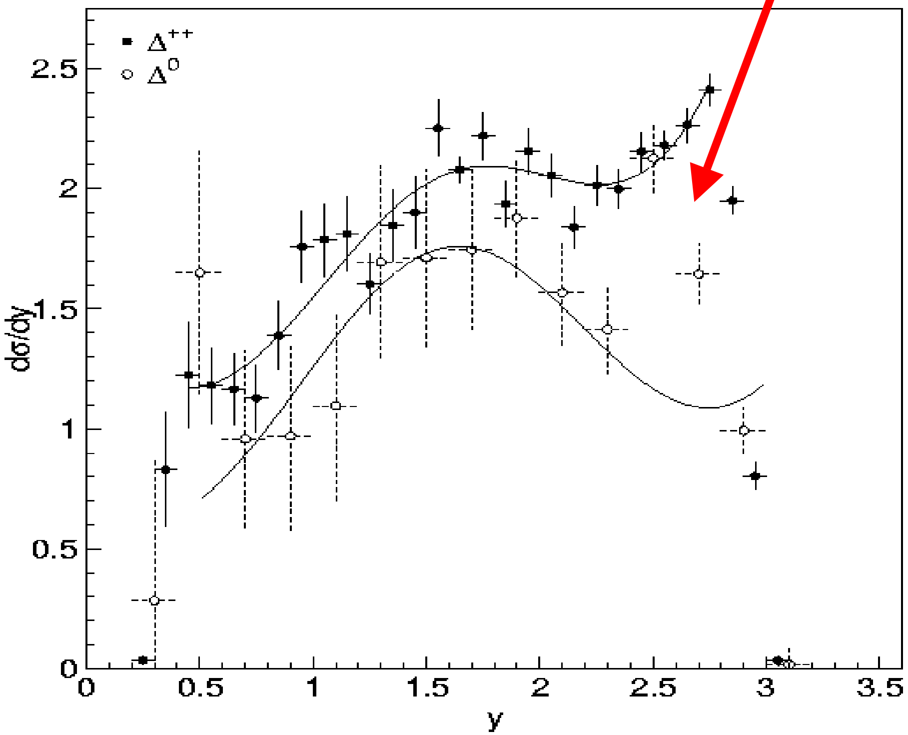
Combine p-Be $N_{grey} = 0$ & 1

- See clear peak in forward region.
- Fit to gaussian+exponential (for lack of anything better).
  - Include reflected exp×0.34 (fit) to account for target.
- Consider diffractive p-N→Δπ: $\Delta^{++}/\Delta^0 = 3$.
  - Compare gaussian + exp/3 (largely irrelevant) to Δ^0.

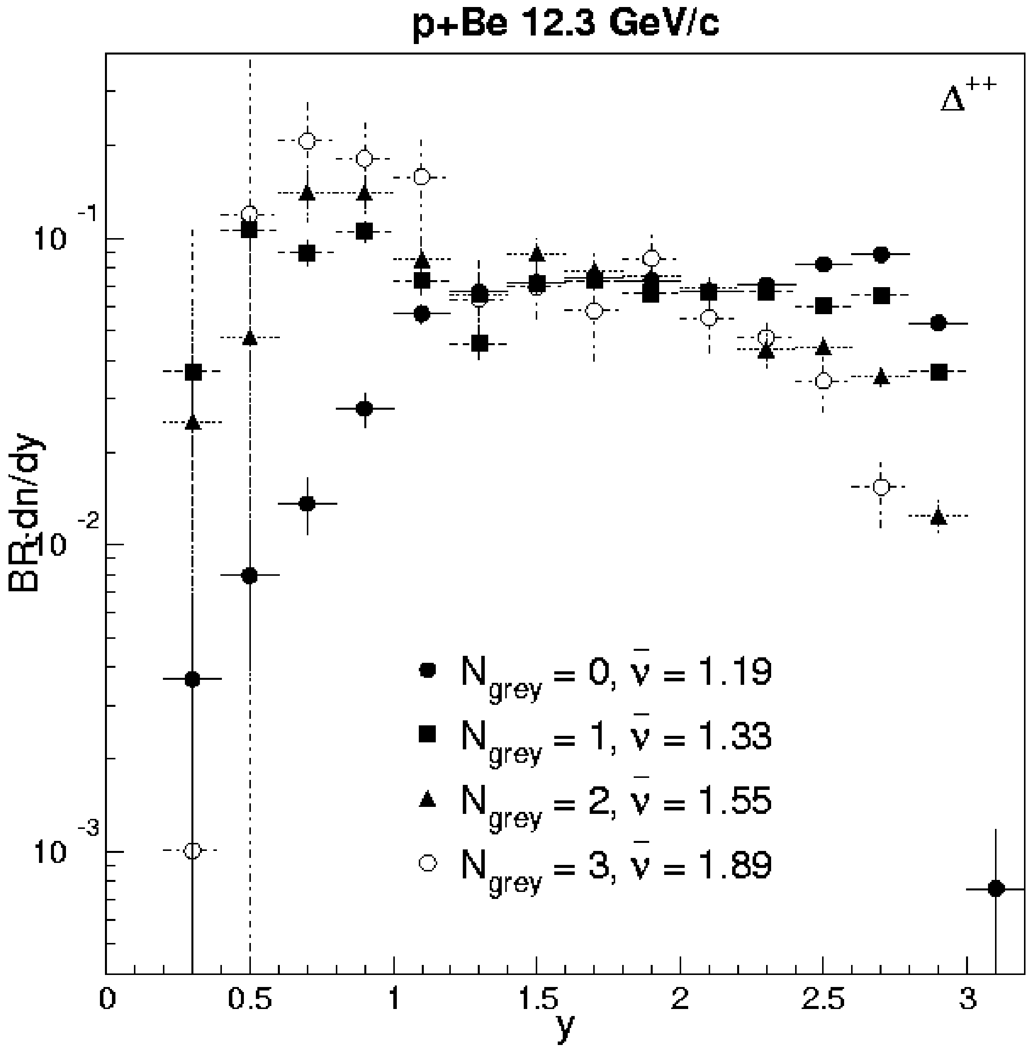
⇒Well describes Δ^0 dn/dy.

What is this ???





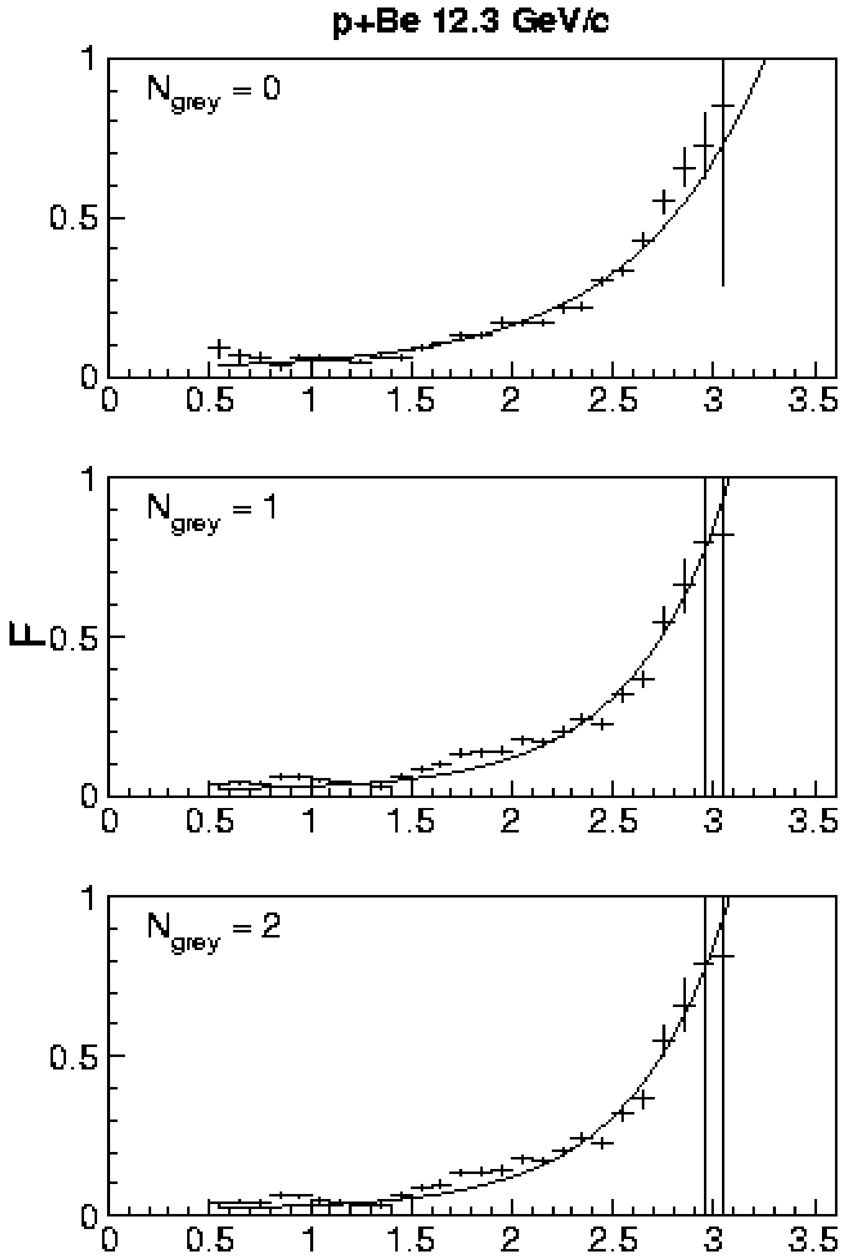
p-Be Δ^{++} dn/dy vs N_{grey}



- With increasing N_{grey} the forward peak disappears.
  - Left with only the gaussian contribution.
  - Similar behavior as the proton x dn/dx distributions.
- Mid-rapidity yield remains unchanged with N_{grey}.
  - Also observed in protons.
  - Accident or physics ?
- **Suggests that multiple interactions destroy diffractive contribution.**

Δ^{++} Yield – Different Approach

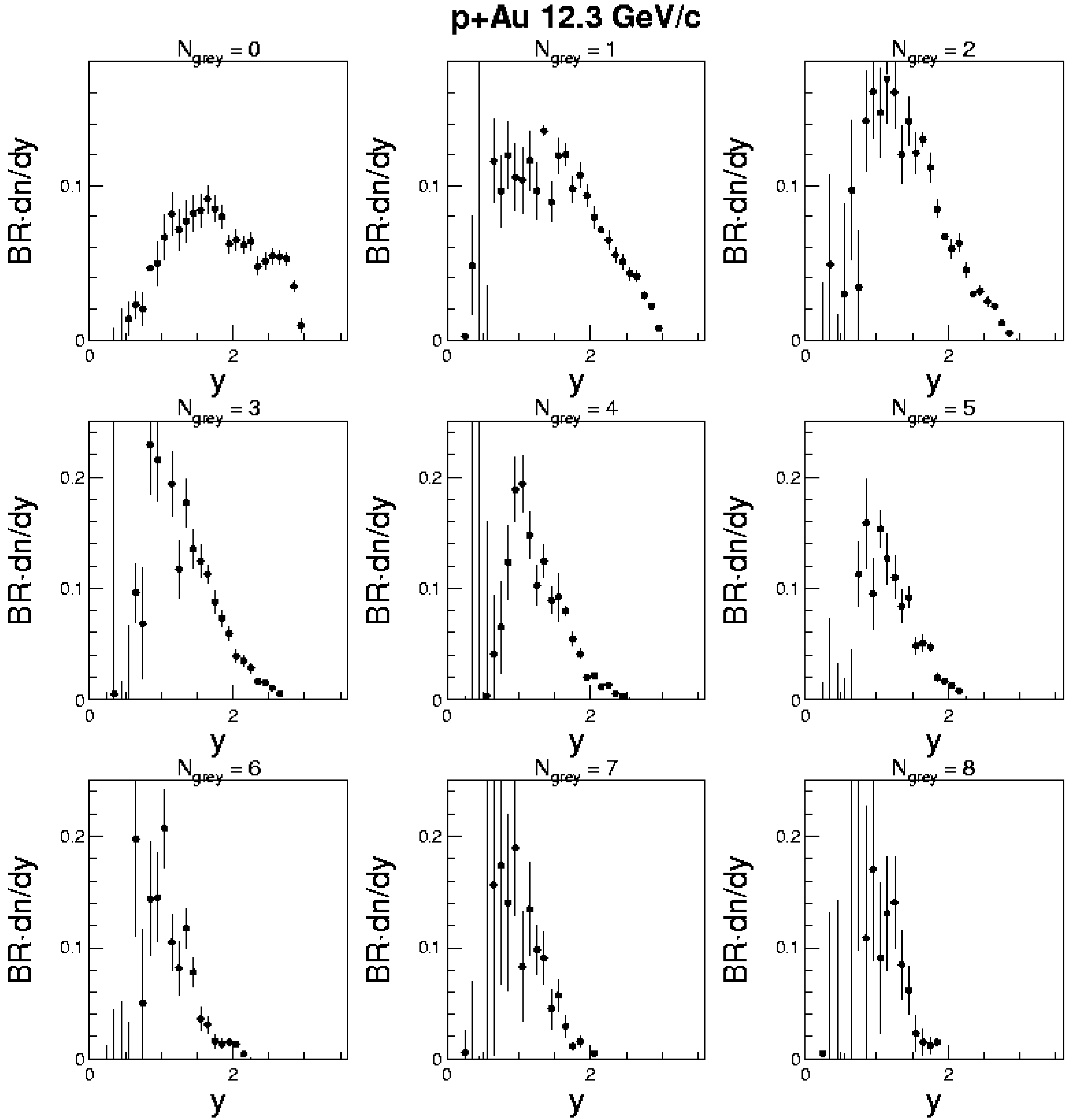
- From FSI point of view Δ yield doesn't matter.
  - Reflects how two- particle phase space is distributed.
  - But some pairs produced outside range of FSI.
- Evaluate fraction of p-π^+ pairs that "feel" FSI:
  - $F = N_\Delta / N_{total}$
  - If every pair feels FSI $F \rightarrow 1$
- Observe:
  - F unchanged at large y.
  - Decreases w/ N_{grey} @ low y.
- Δ production determined by phase space !?



Summary & Conclusions

- Strange baryon production suggests role of constituent quarks.
  - Observe: CQM model has predictable consequences for Ω^- production in p-A collisions with $\nu > 3$-4.
    - $\Rightarrow$ Yield enhanced by factor > 10.
- Proton & π x distributions indicate stopping of baryon # without stopping energetic pions.
  - Expected in string models w/ diquark splitting/junction.
- Baryon resonances: strong diffractive component at large-x that disappears with multiple collisions ?
- But resonance yields consistent with purely population by FSI ???
  - Apparent diffractive contribution & disappearance due to strongly change baryon charge distribution @ large y ?

E910 p-Au Δ^{++} Production



- See remnant of peak @ y=2.5.
- See stopping effects at large rapidity.
- Initially strong growth in yield near y=1.
- For $N_{grey} > 4$ yield near y=1 decreases.