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  - What we have worked on in ALICE
  - Possible unique signatures we have found

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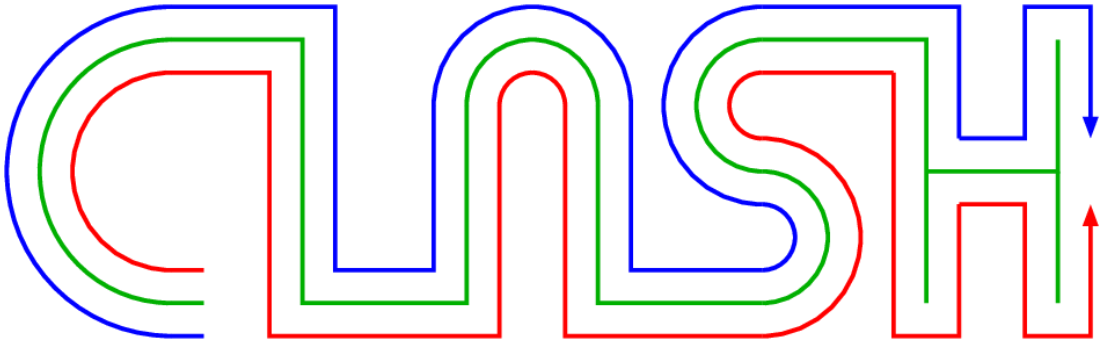
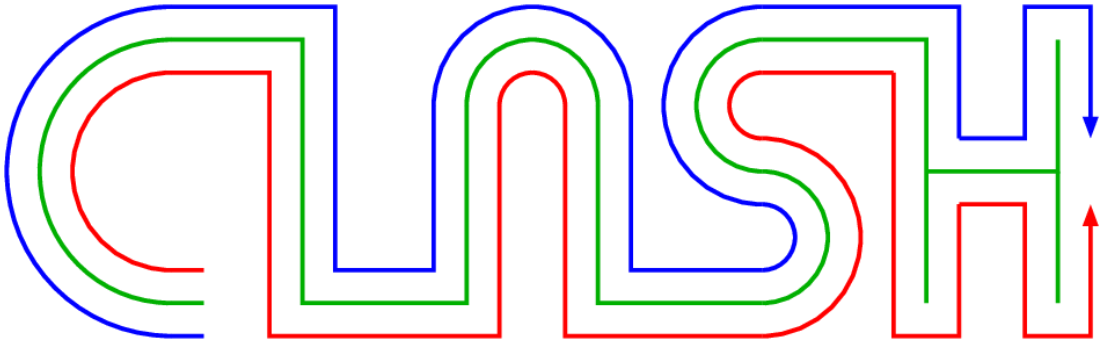
- I did not find time/space for discussing things where I think we can do more. Maybe do that in another talk

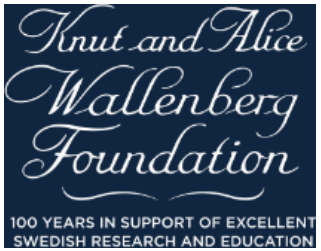


Knut and Alice Wallenberg Foundation
100 YEARS IN SUPPORT OF EXCELLENT SWEDISH RESEARCH AND EDUCATION

Project: "**Pinning down the origin of collective effects in small collision systems**"

- = confront traditional pp paradigm (PYTHIA et al, quarks and gluons) with the QGP AA paradigm (hydro et al, "fields")





Project: "**Pinning down the origin of collective effects in small collision systems**"

- = confront traditional pp paradigm (PYTHIA et al, quarks and gluons) with the QGP AA paradigm (hydro et al, "fields")

- 3 "pillars"
  - Development of new theoretical models (Leif)
  - Search for jet quenching in small systems (Peter)
    - Will mainly start in 2021
  - Search for the best observables to differentiate between models for QGP-like effects in small systems
    - Where we mostly CLASH so far

Macroscopic vs microscopic models

- Stat. thermal model
  - Canonical
  - Grand-canonical
- Hydrodynamics
  - Radial flow
  - Azimuthal anisotropic
- Tunneling of $q\bar{q}$-pairs
  - Strings
  - Ropes
- String interactions
  - Color reconnection
  - Shoving

How to determine who is correct?

- I am very inspired by Feynman: https://www.youtube.com/watch?v=BGeW6Nc6IMQ

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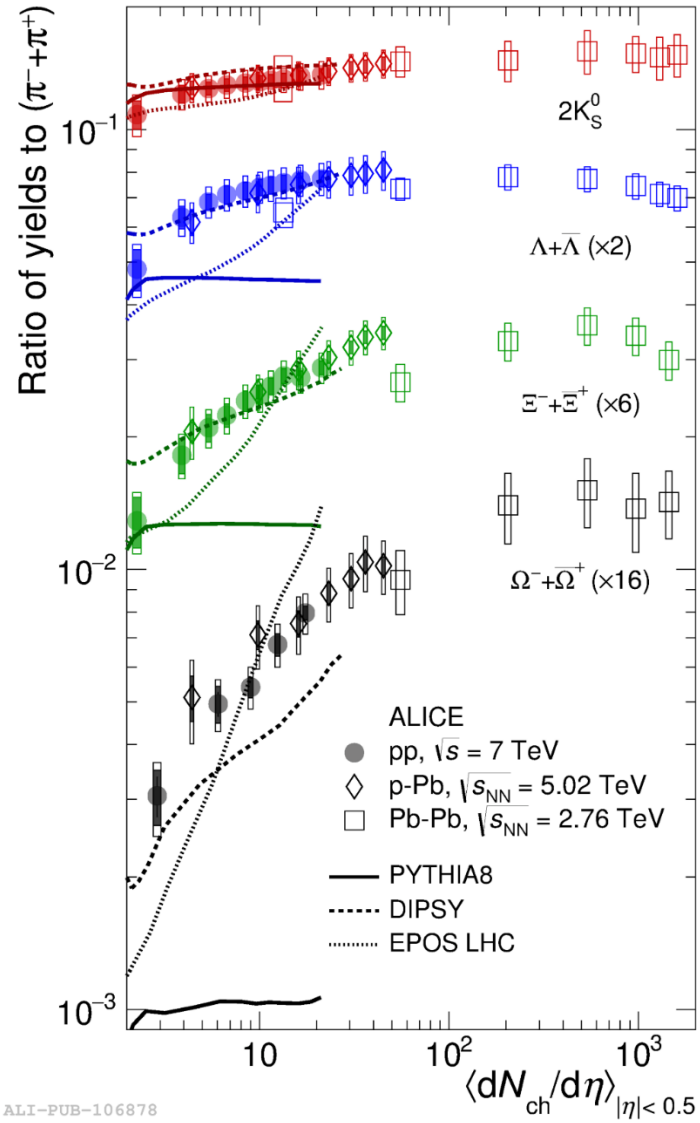
- Less about describing the data as well as possible and more about **unique signatures**
- Less about "more of the same" and more about **new observables**

- **We must challenge ourselves to go beyond state-of-the-art!**

What we have done so far in the ALICE group



- Focused on strangeness
  - Large effect in small systems
  - Several explanation
    - "No QGP": Ropes (PYTHIA)
      - Herwig explanation (Patrick)
    - "QGP-QCD" (EPOS)
    - "Full QGP"
      Canonical -> Grand canonical
      (strangeness production suppressed in pp!)

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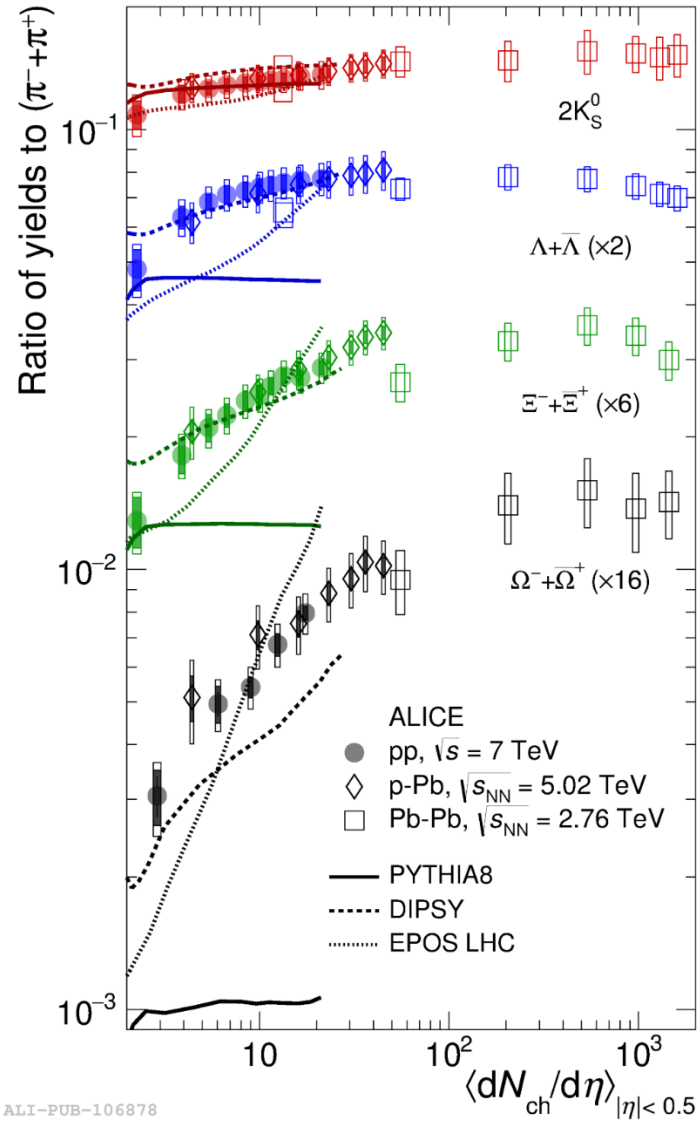

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      Canonical -> Grand canonical
      (strangeness production suppressed in pp!)
- First question/angle
  - Can we control/isolate strangeness enhancement in pp collisions?
    (e.g., is there a big variation around the mean?)

Introduction to R_T

Idea: Martin, Skands, Farrington, Eur. Phys. J. C76 (2016), 1

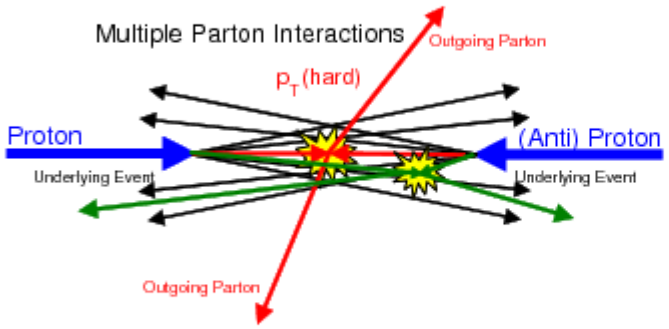
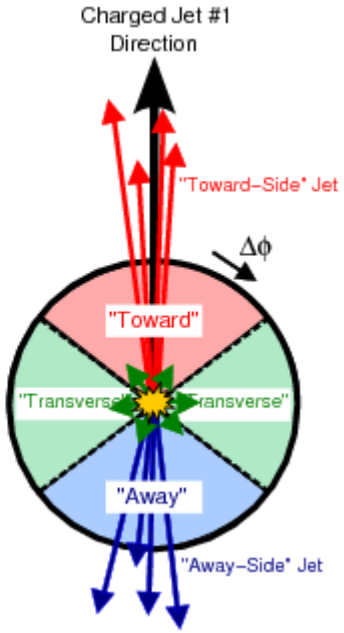


Figure from Eur. Phys. J. C62 (2009), 237



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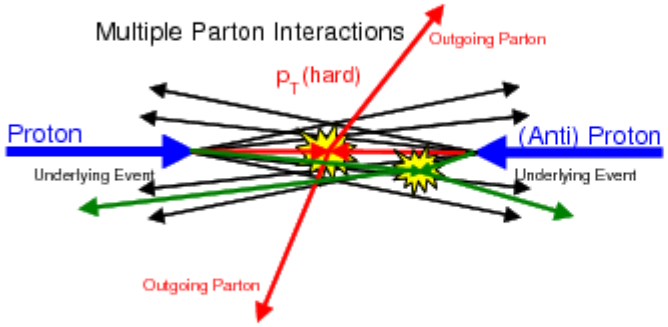

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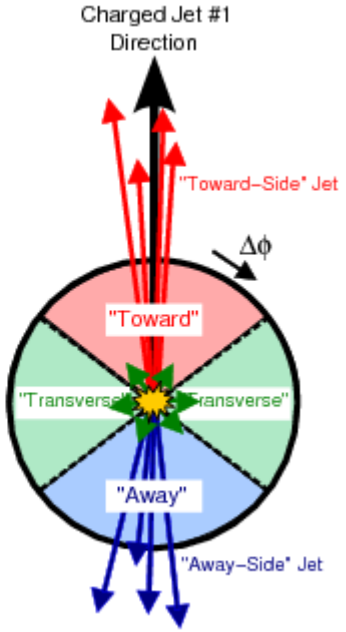

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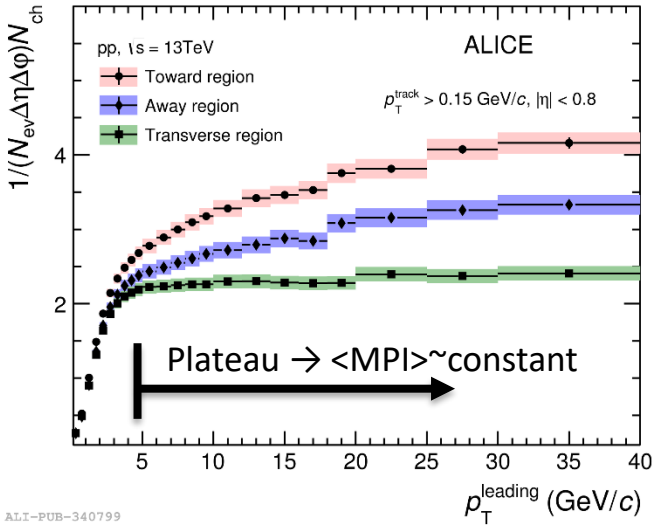

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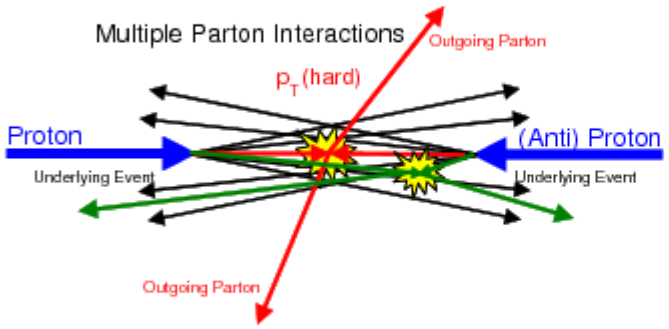

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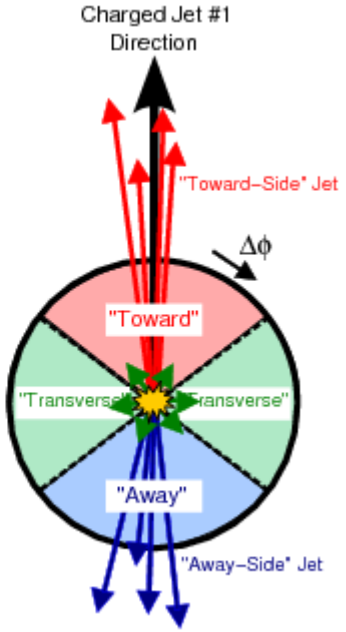

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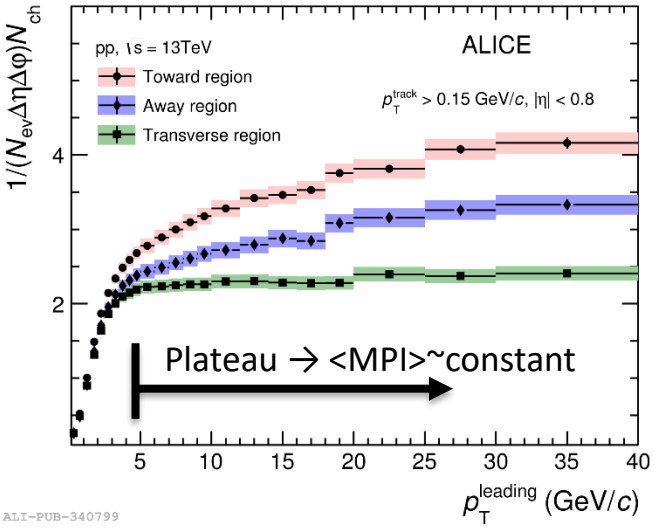

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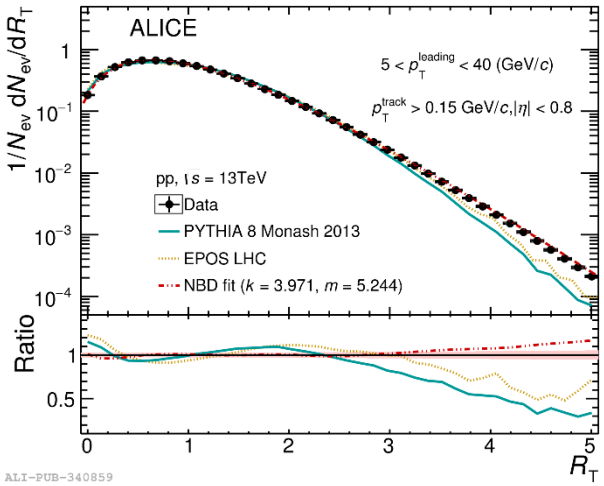
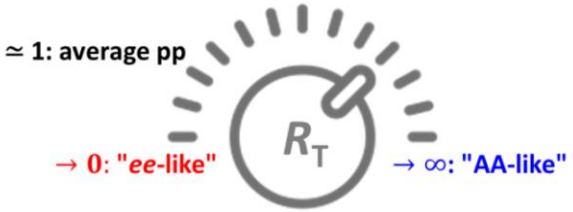


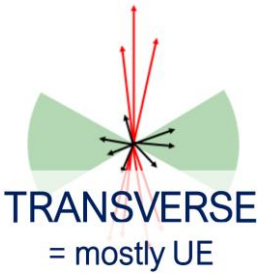
Define:

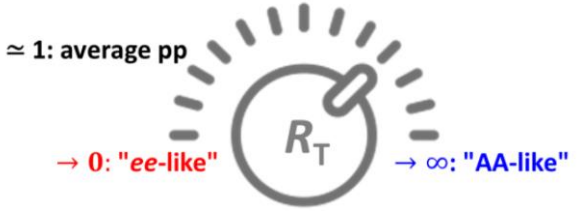
$$R_T = \frac{N_{ch}^{Transverse}}{\langle N_{ch}^{Transverse} \rangle}$$

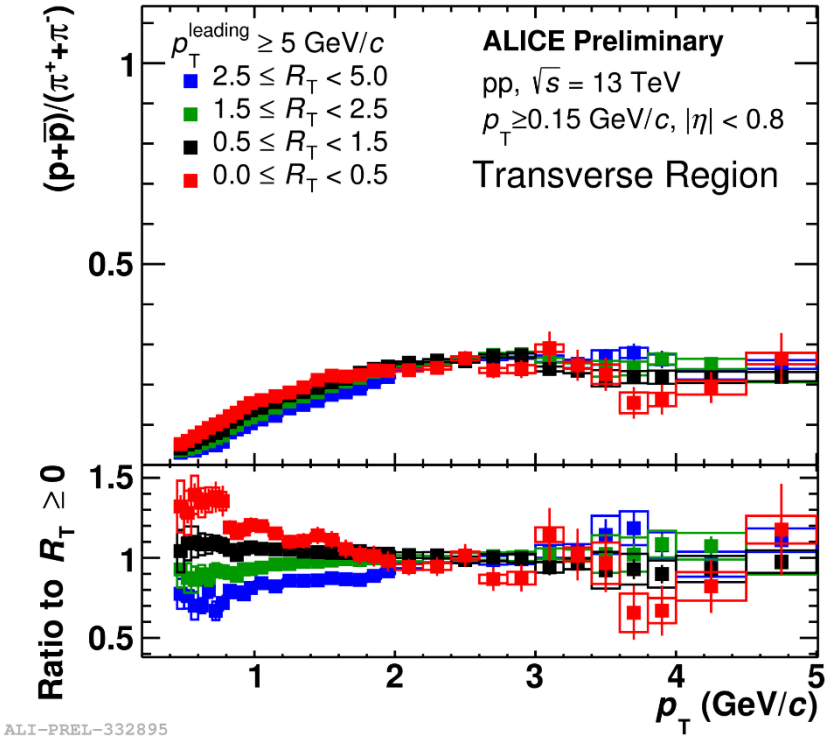
Gives some control over the UE

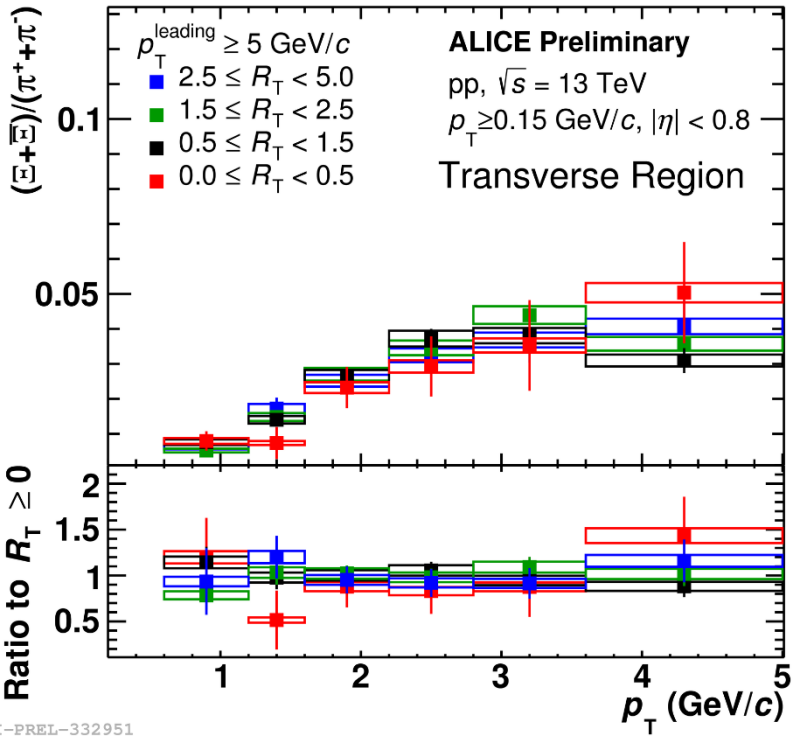


p-to-π and Ξ-to-π ratios vs R_T Transverse





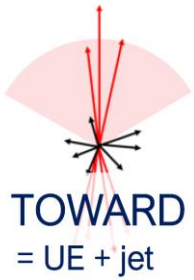


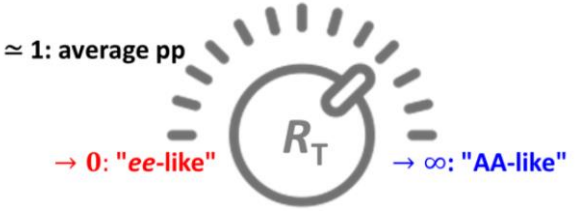


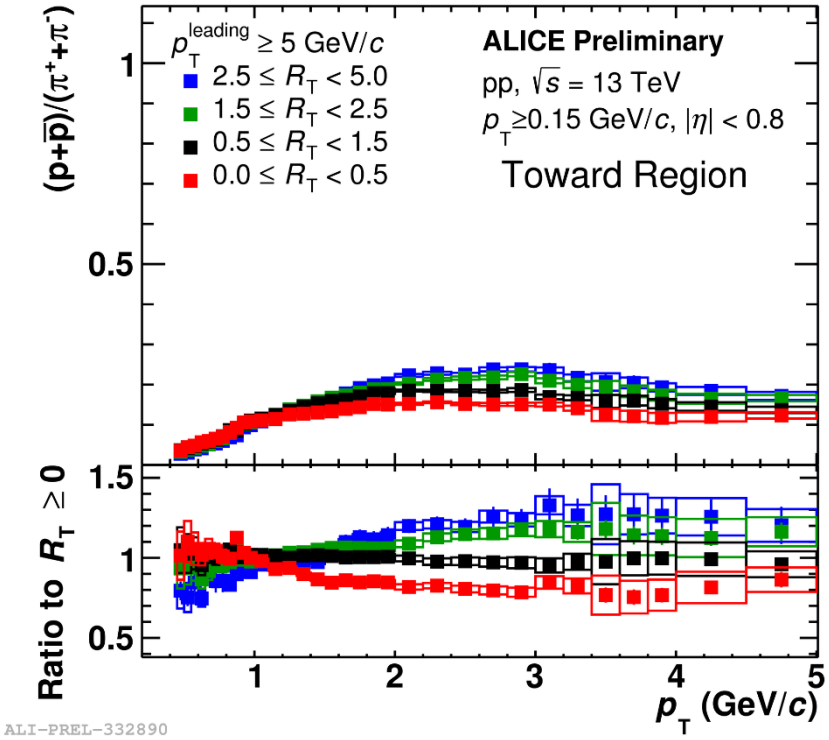
The p-to-π decreases at low p_T with increasing R_T, while at high p_T it shows little or no dependence on R_T.

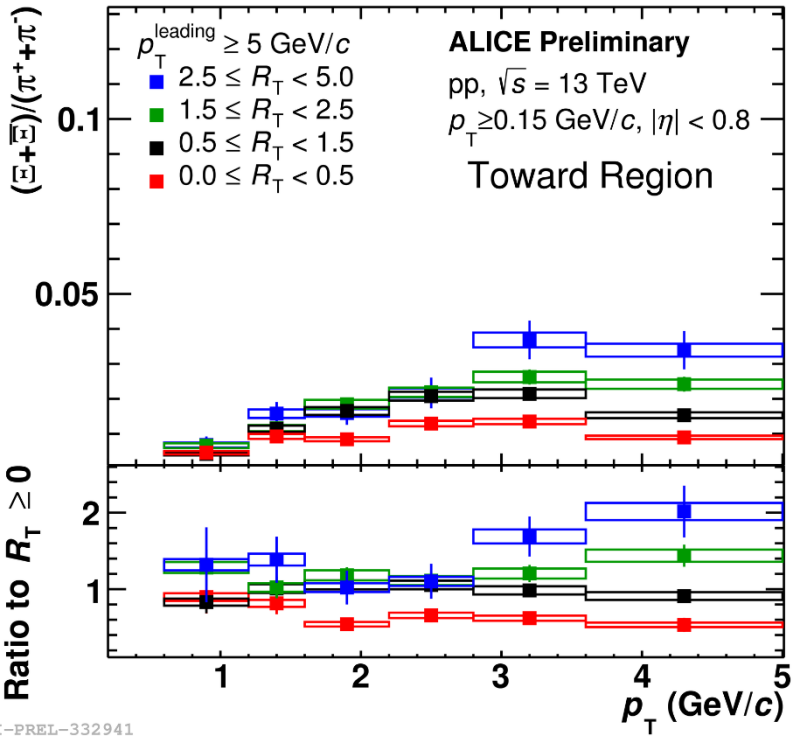
The Ξ-to-π ratio shows little or no dependence on R_T.

p-to-π and Ξ-to-π ratios vs R_T Toward









The p-to-π decreases (increases) at low (high) p_T with increasing R_T, a radial flow signature but here likely an interplay between UE and jet. The Ξ-to-π ratio increases with increasing R_T, approaching the "Transverse" value.

Ξ-to-π ratios vs R_T Transverse
A dog that did not bark!?

Gregory (Scotland Yard detective): "Is there any other point to which you would wish to draw my attention?"

Holmes: "To the curious incident of the dog in the night-time."

Gregory: "The dog did nothing in the night-time."

Holmes: "That was the curious incident."

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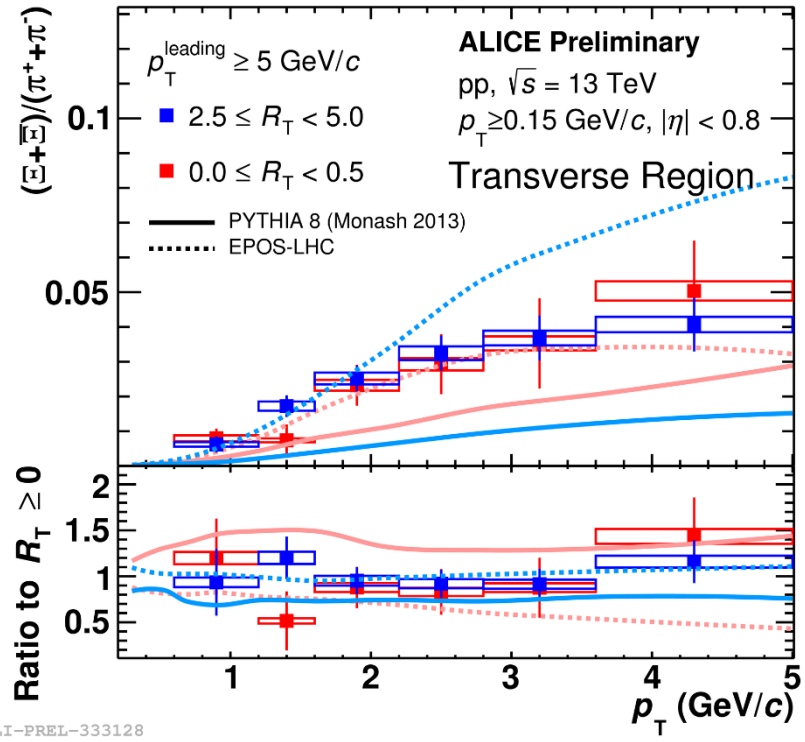
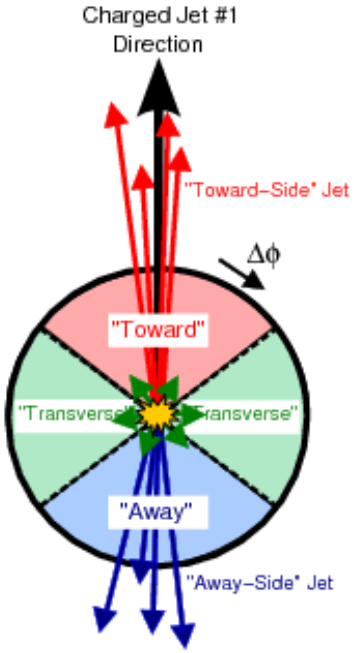
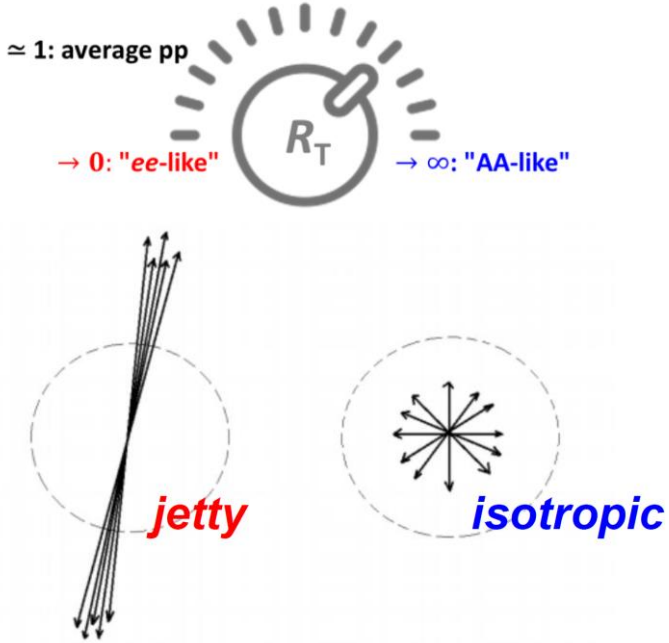


Even the transverse multiplicity changes by more than a factor 5 there is no change in the Ξ-to-π ratio? EPOS expects this (IMO clear why).

Is there different kinds of multiplicity? R_T focuses on mid-rapidity why ALICE Nature paper uses forward multiplicity.

From R_T to transverse spherocity S_O





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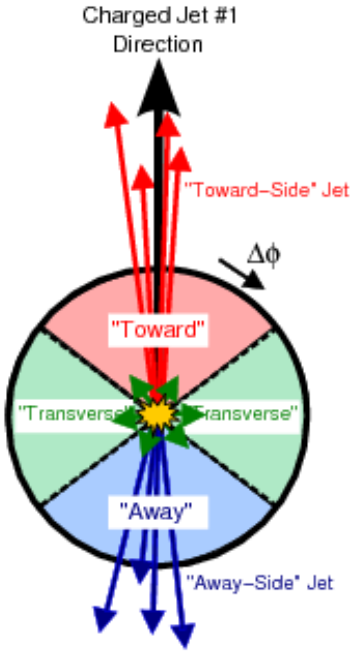

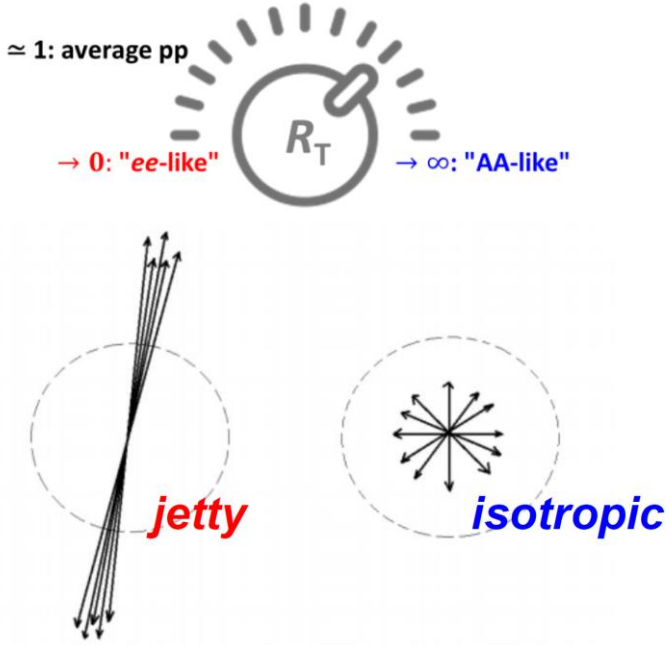

Define the unweighted transverse spherocity:

$$S_O^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\sum_{tracks} |\hat{p}_T \times \hat{n}|}{N_{tracks}} \right)^2$$

Then we can use that as a event classifier.

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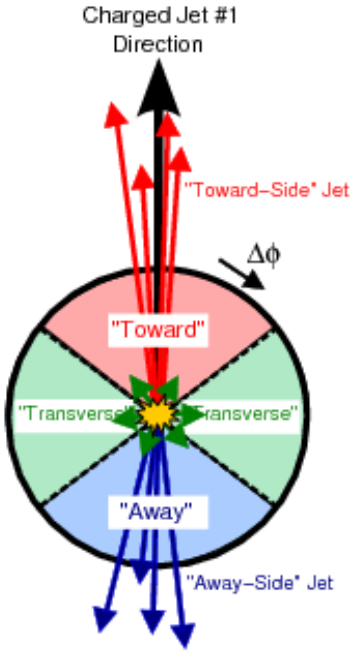

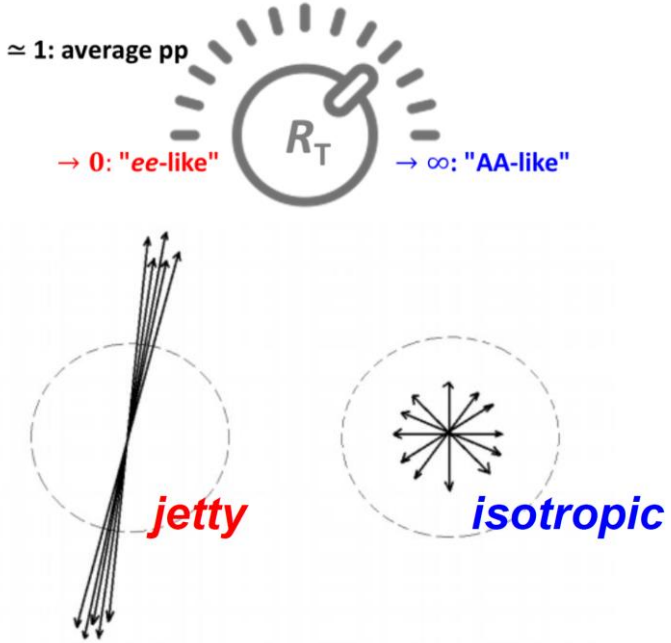

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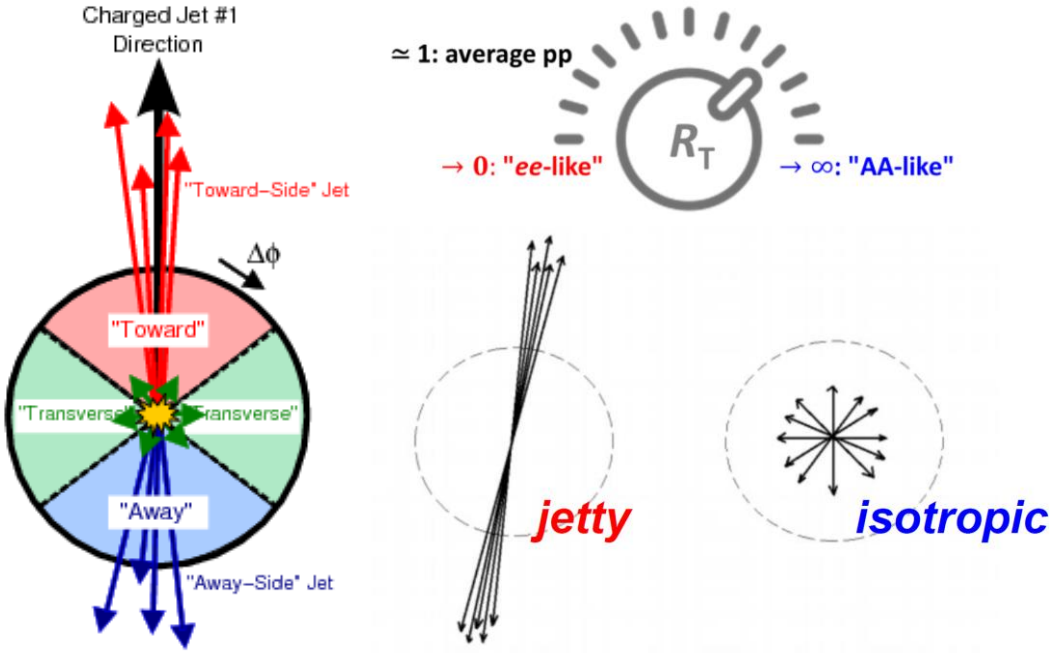
  - No trigger, but we require 10+ charged tracks
  - We probe the particle production in a full event
    - Testing how homogenous the system is

From R_T to transverse spherocity S_O



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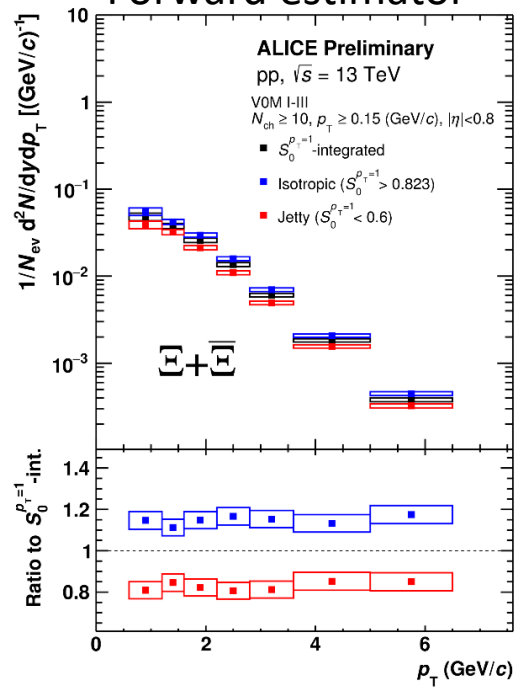
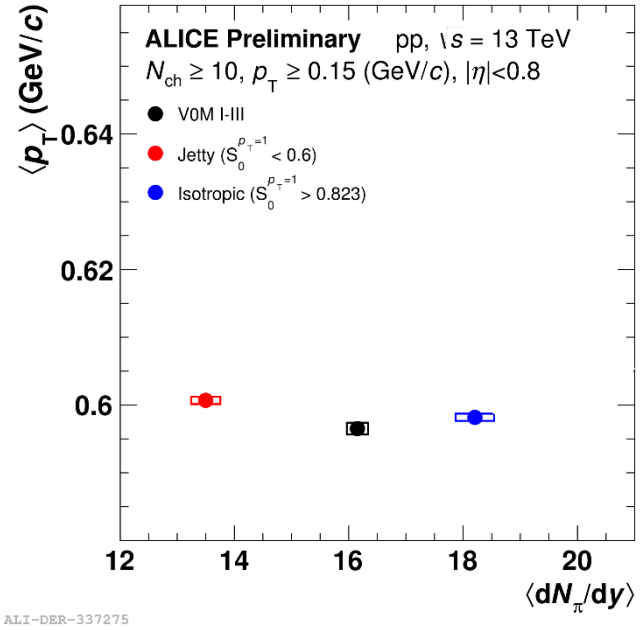
- So in what way does S_O differ from R_T?
  - No trigger, but we require 10+ charged tracks
  - We probe the particle production in a full event
    - Testing how homogenous the system is
- Note that we use the unweighted S_O
  - Most other ALICE preliminary results were for the p_T-weighted S_O

Dependence on multiplicity estimator

Forward estimator

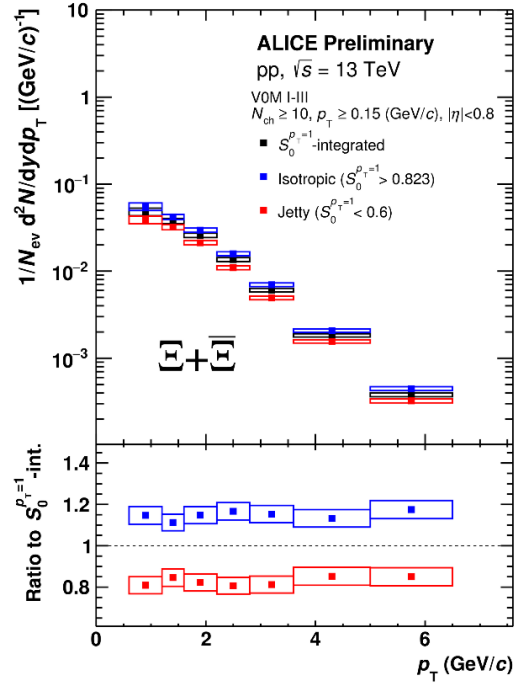


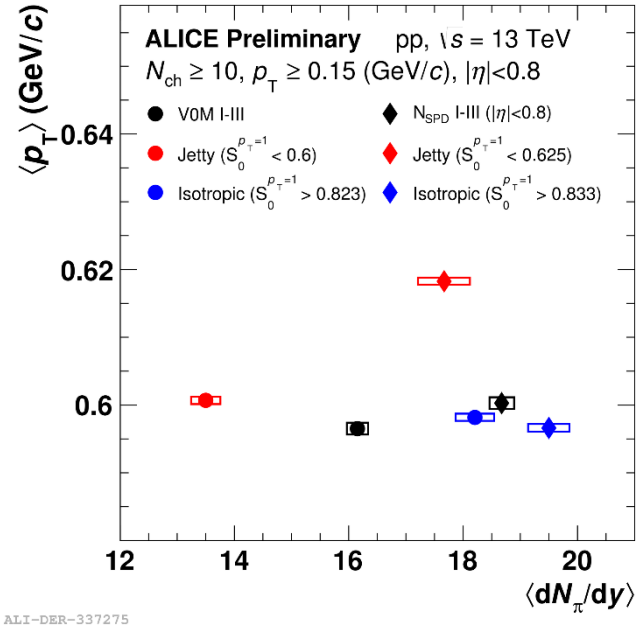


- Forward estimator selects broad range of midrapidity multiplicities
  - S_0 selection mainly selects on multiplicity → the spectral shapes are similar → hard effects are small for forward multiplicity selection
    - Key to understand dN/dη scaling? (hard effects are small)

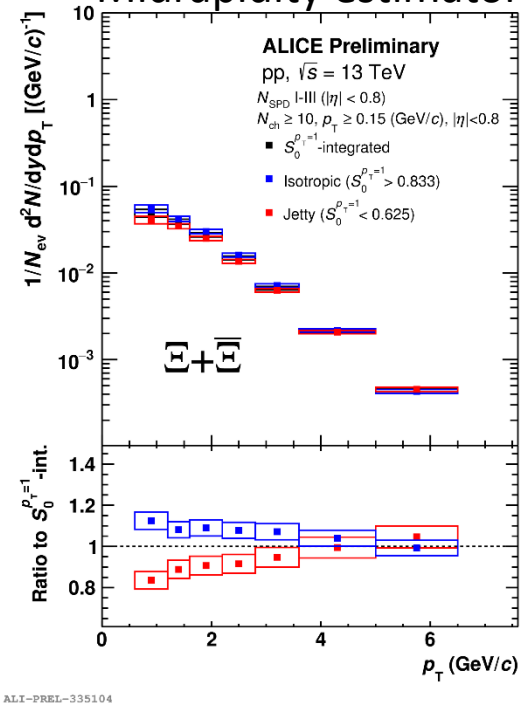
Dependence on multiplicity estimator

Forward estimator



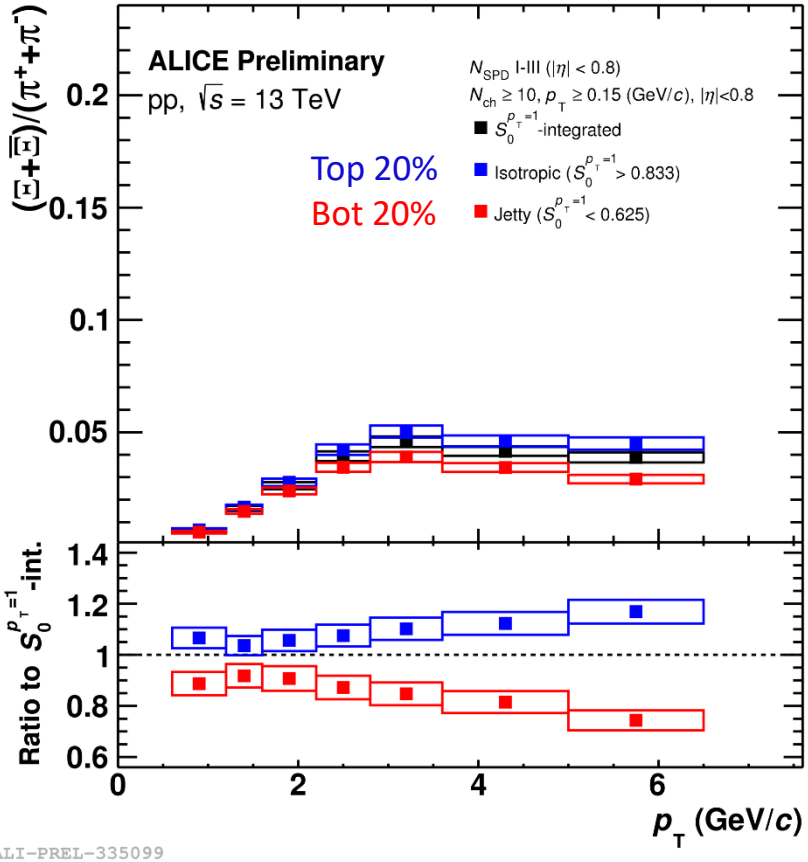


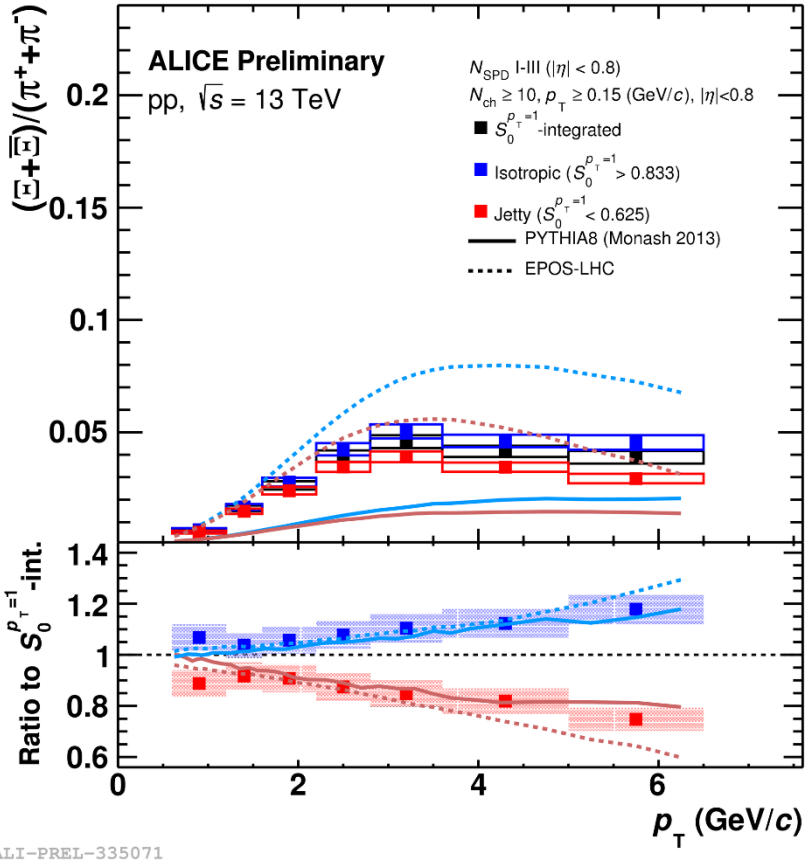
Midrapidity estimator



- Forward estimator selects broad range of midrapidity multiplicities
  - S_O selection mainly selects on multiplicity → the spectral shapes are similar → hard effects are small for forward multiplicity selection
    - Key to understand dN/dη scaling? (hard effects are small)
- For the midrapidity estimator, the transverse spherocity selection can create subsamples that are significantly harder and softer.

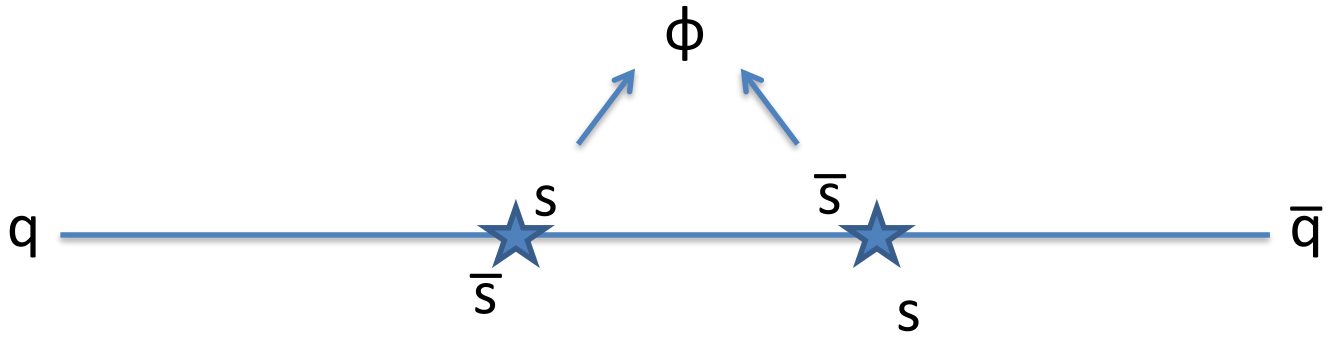
Ξ-to-π ratio for midrapidity estimator





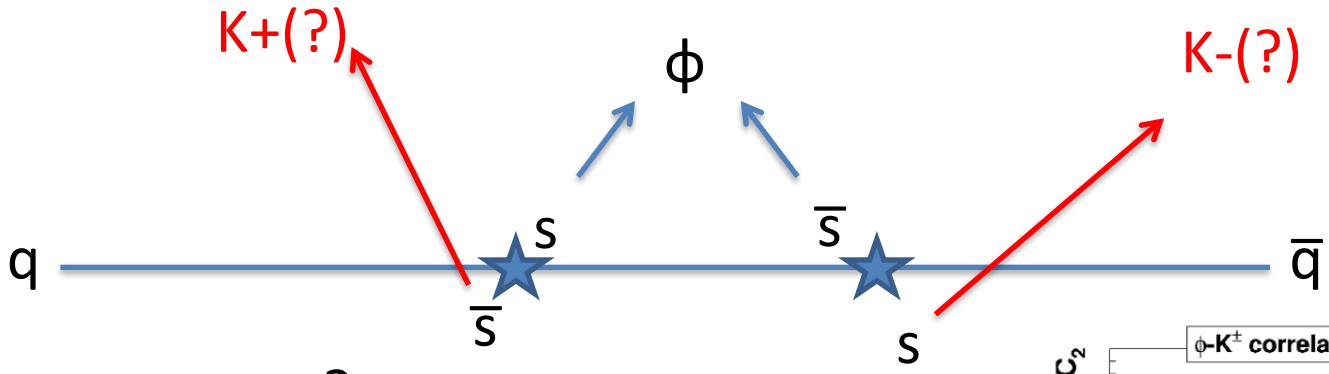
- It seems we can select events with more or less strangeness enhancement → to be further investigated and quantified
- The absolute variation is not well described by the models while the relative variation is, except at low p_T

2nd direction: correlations

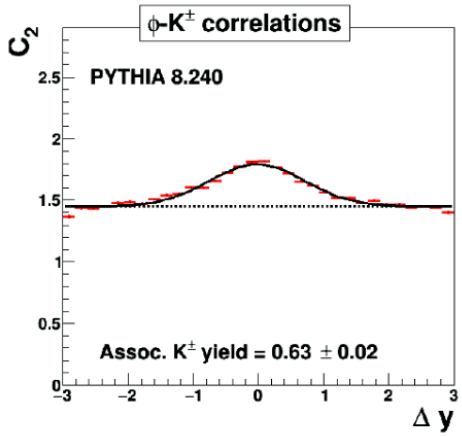


- Part of CLASH application
- ϕ production in string vs thermal models
  - String model: Requires 2 string breakings to make a ϕ
    - Enhanced with activity in a rope model!
  - Statistical thermal model: no open strangeness
    - No canonical suppression (should follow proton)

Correlations for the ϕ (To be done later)



- What to expect?
  - Strings/ropes (jets): strong ϕ-K correlations
  - Stat. thermal model: weak ϕ-K correlations (there can still be, e.g., intra-jet correlations)
  - Recombination: weak ϕ-K correlations ?



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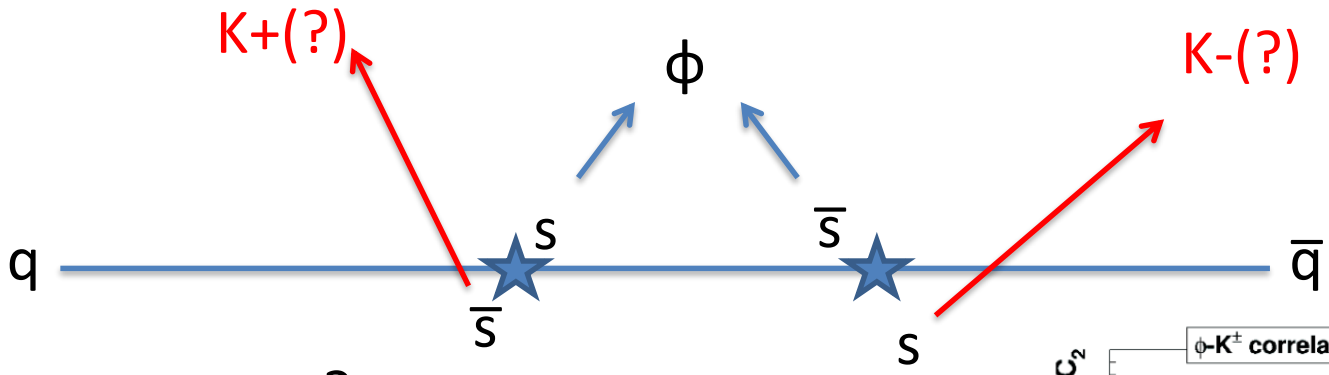

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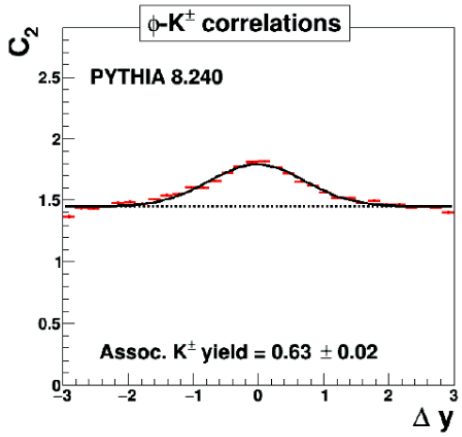
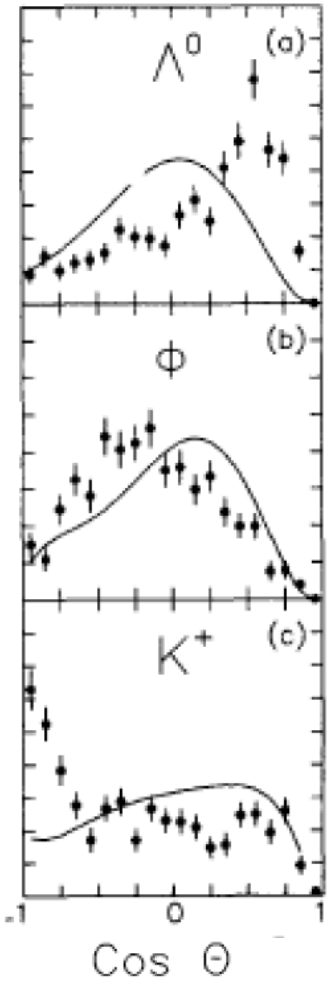


Idea: if we think there is a change in the hadronization mechanism then we must find a way to probe this change

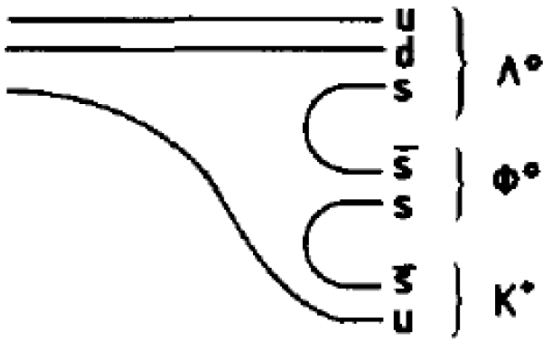
Strangeness correlations: an old idea

Phys.Lett. 163B (1985), 267



EVIDENCE FOR POMERON SINGLE-QUARK INTERACTIONS IN PROTON DIFFRACTION AT THE ISR

R608 Collaboration



Solid lines are calculations for isoptropic phasespace

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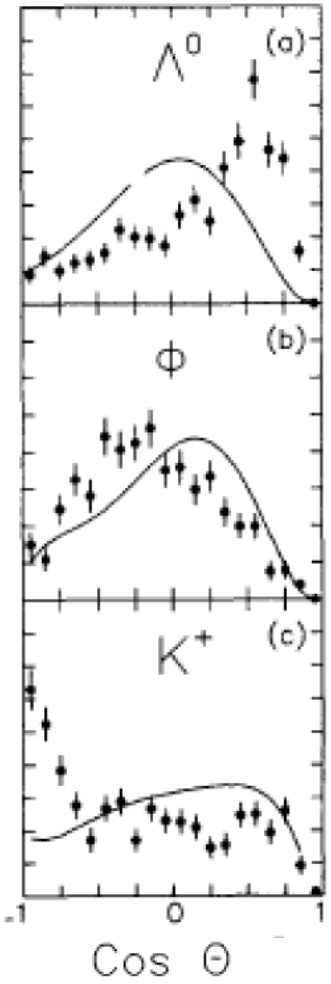

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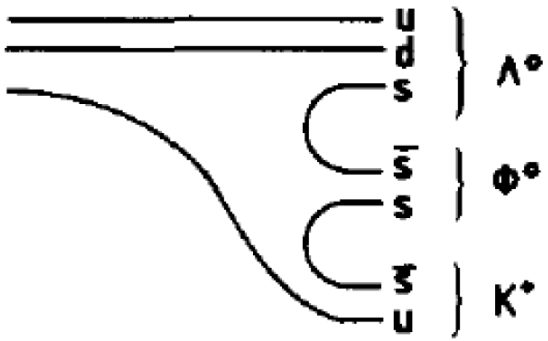


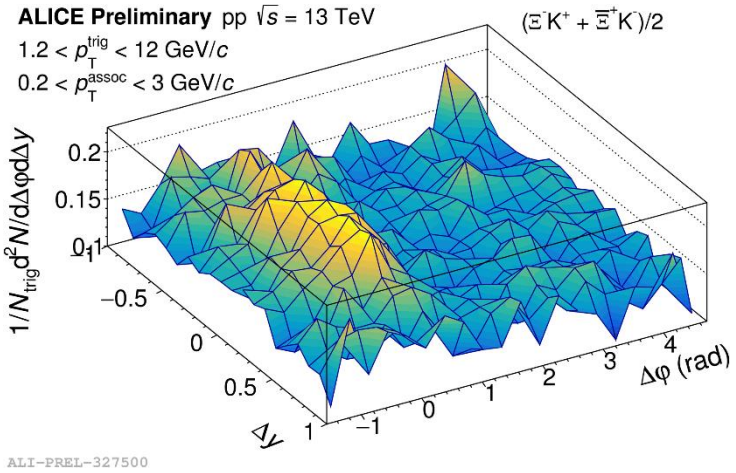
In pp collisions we can ask the questions:
Where is the anti-strangeness (strangeness) associated with production of Ξ^-/ssd ($\Xi^+/\bar{s}\bar{s}\bar{d}$) recovered?

PYTHIA/Angantyr: expect strangeness to be recovered locally (as shown to the left).

EPOS LHC: expect strangeness enhancement to be associated with a grand canonical (global) reservoir. Microscopic picture?

Ξ-K correlation functions

Opposite sign (OS), e.g., Ξ^-/ssd – $K^+/\bar{s}d$



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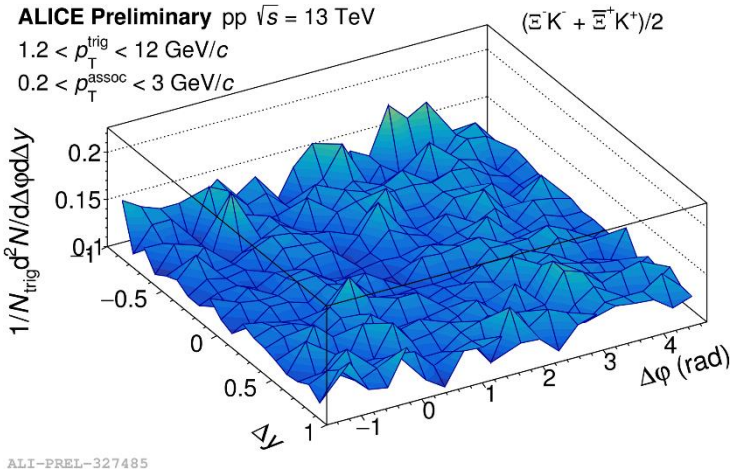
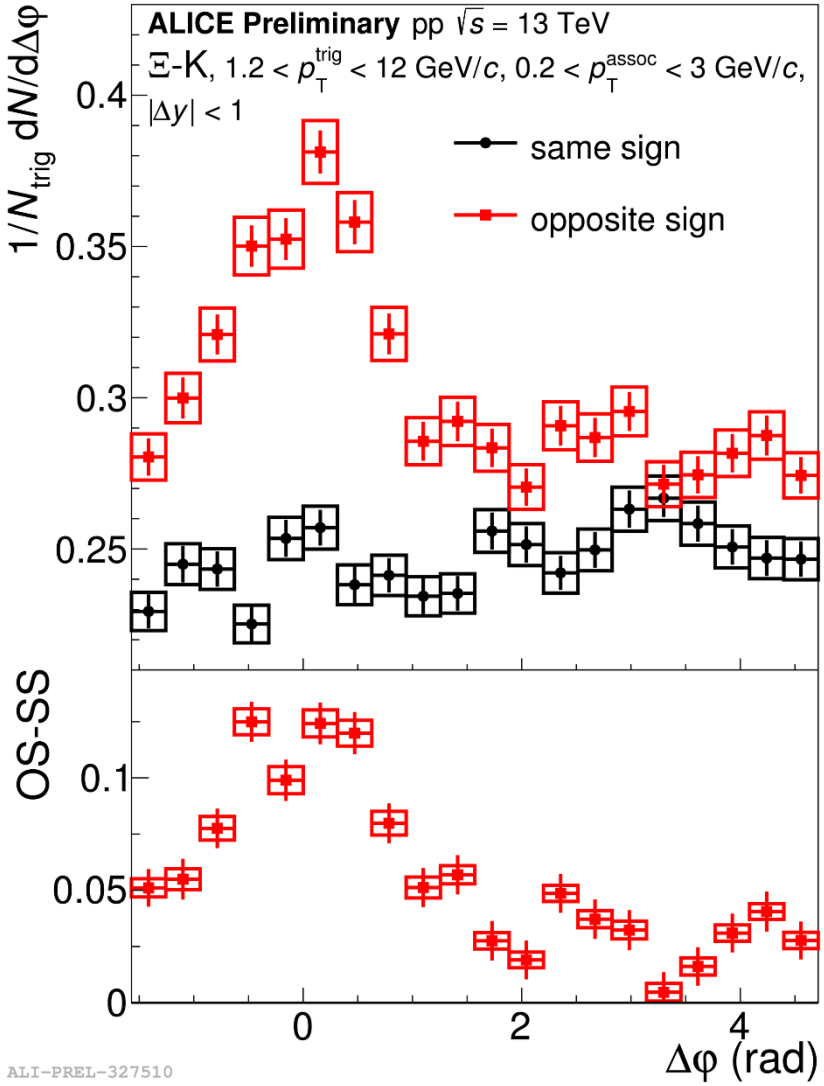
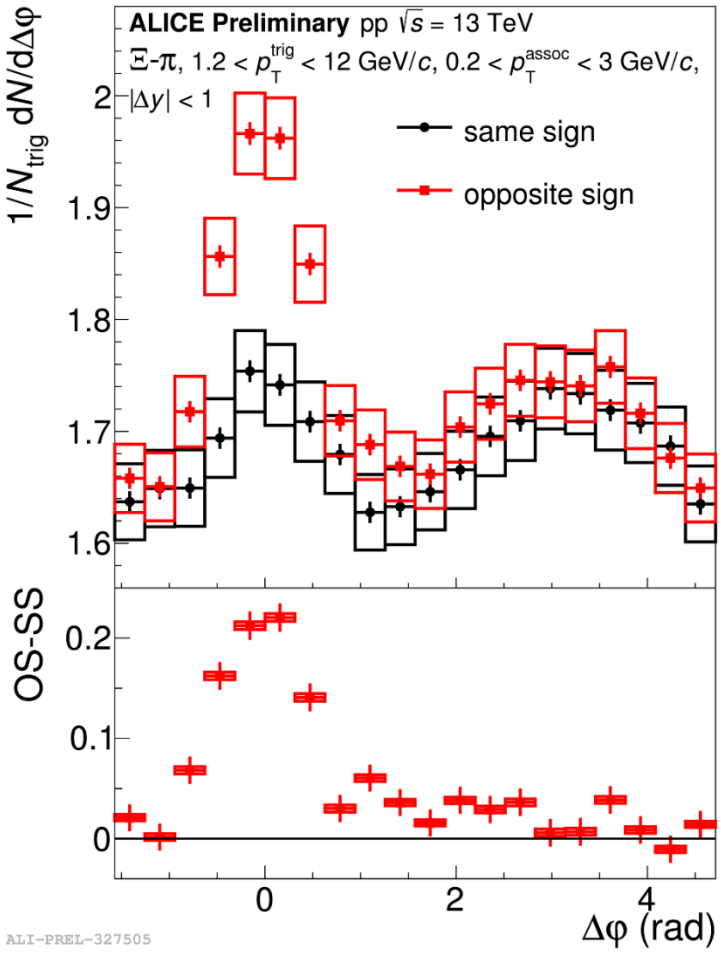
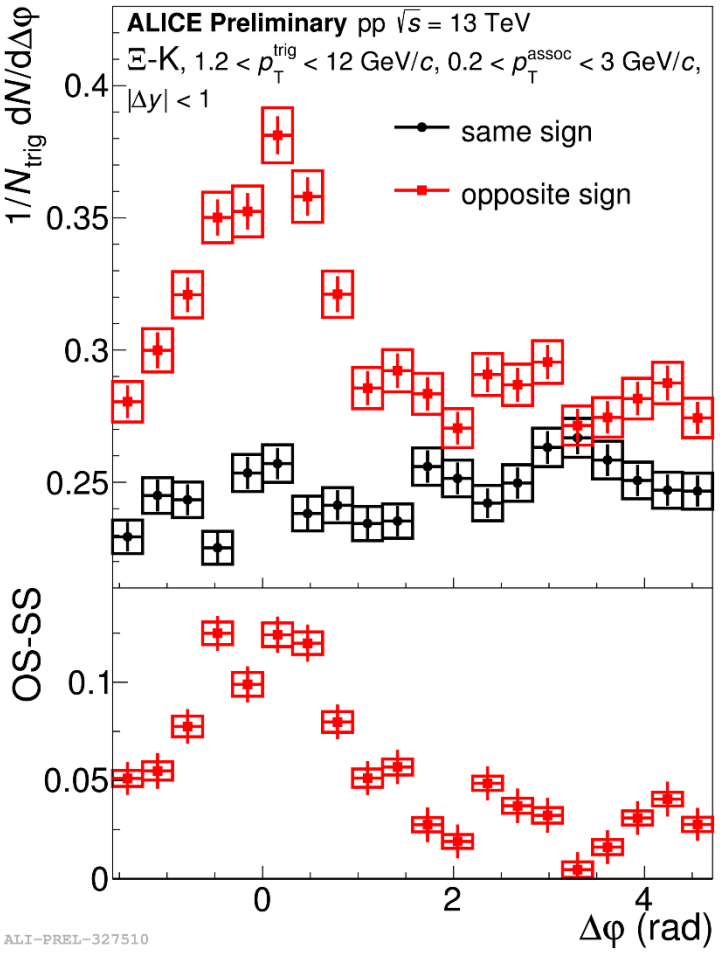




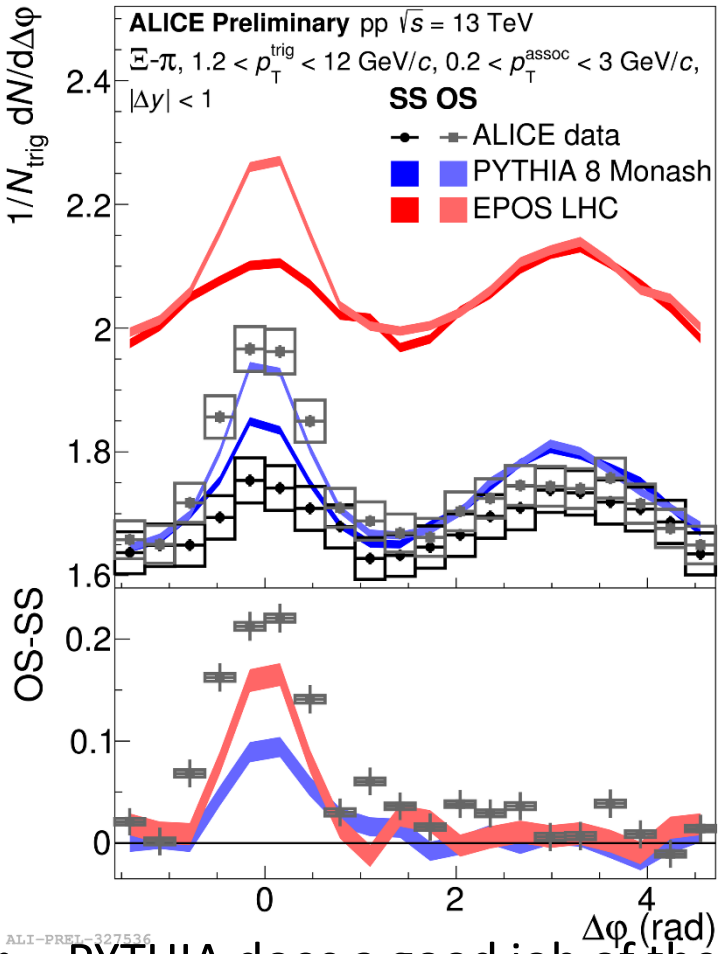
Ξ-K and Ξ-π correlation functions

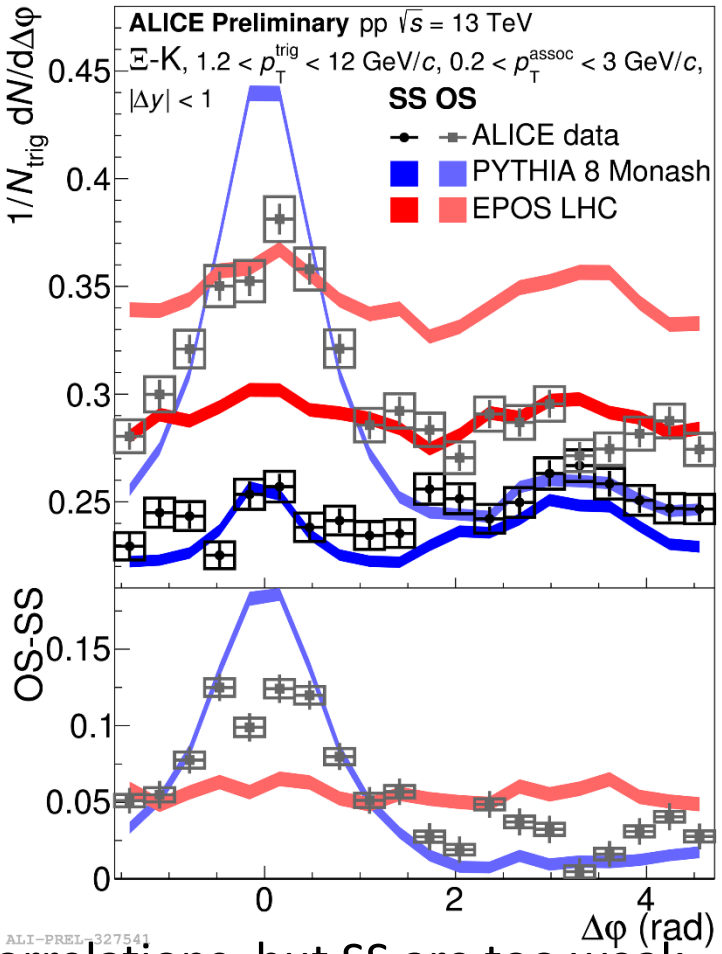




- One clearly observes a near side peak but there is also evidence for decorrelations

Ξ-K and Ξ-π correlation functions

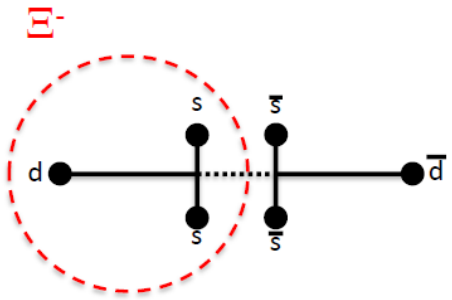




- PYTHIA does a good job of the OS (UE) correlations, but SS are too weak (strong) for π (K) and away side decorrelations are too weak
- EPOS LHC: in general worse job and too strong strangeness decorrelation

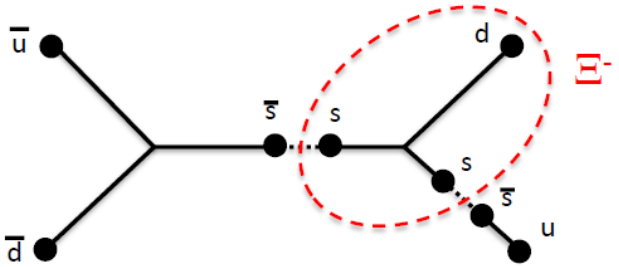
CLASH workshop ideas

Strangeness production: strings, junctions, ropes, …



Creation in string or rope :
- Via diquark production
- Suppressed rate (high diquark mass)
- Accompanied by strange antibaryon nearby in rapidity

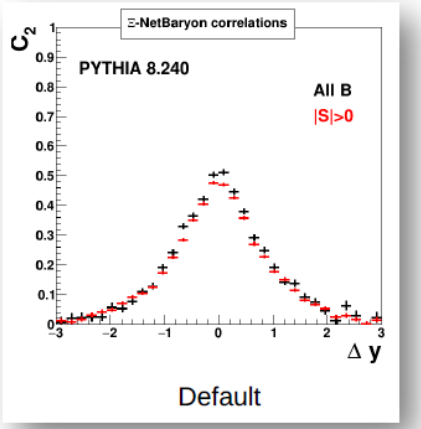
→ Flavour-baryon number correlated

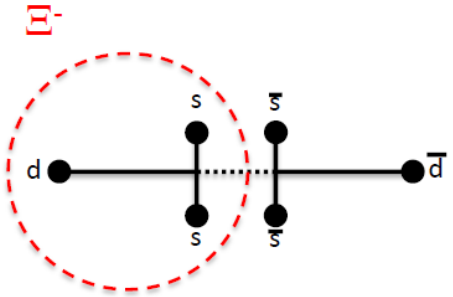


Creation in junction-antijunction:
- Via 2 $s\bar{s}$ breakups
- Not that suppressed
- Accompanied by strange meson(s)
- Balancing baryon potentially further away in rapidity
- Flavour-baryon number decorrelated

CLASH workshop ideas

Strangeness production: strings, junctions, ropes, …





- In the string / rope case in PYTHIA: the antibaryon is at least single-strange
- With junctions: not so much

- Relevant observables:
  - Ξ-K correlation
  - Ξ-$\bar{p}$ correlation
  - Ξ-$\bar{\Xi}$ correlation

Outlook

- QM19 preliminaries: 100M pp 13 TeV events, now: reanalysis with 600-1000M events
  - Better statistical precision + more differential + Ω, Λ, K0s
  - Ideas to look at forward vs midrapidity production
  - All correlations will be studies
    - First results in Jonatan's PhD thesis

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- Call for predictions

  - We have local expertise on π, K, p, Λ, K0s, ϕ, Ξ, Ω and we are analysing the data
    - Easy to look at many new things now (but maybe more difficult next year)

Unique signatures

Correlations are IMO most likely candidates for a unique signature

- It is extremely fundamental
  - Fundamental in “pp paradigm”: If you have a sum of semi-independent collisions then you must get canonical effects
    - Would be interesting to check in Herwig
  - Fundamental in “AA paradigm”: no decorrelation means no deconfinement!

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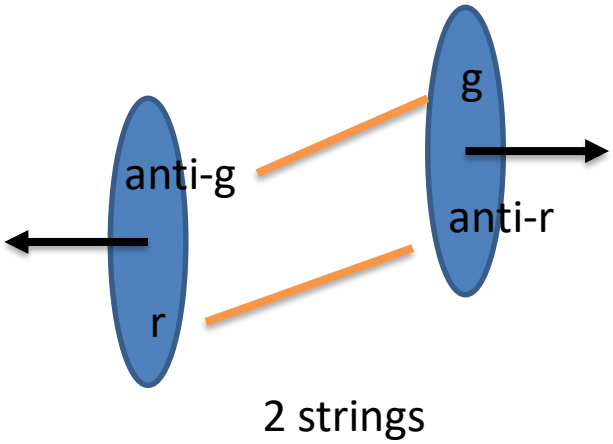
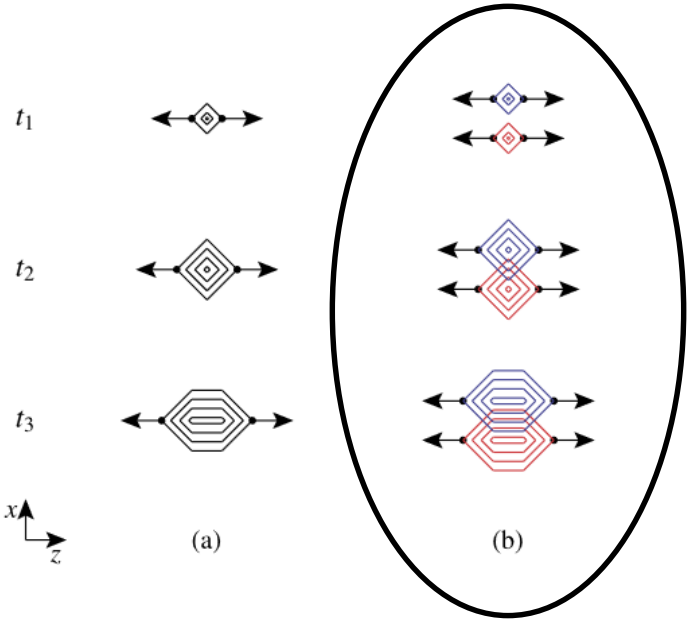
  - Fundamental in “pp paradigm”: If you have a sum of semi-independent collisions then you must get canonical effects
    - Would be interesting to check in Herwig
  - Fundamental in “AA paradigm”: no decorrelation means no deconfinement!
  - Strong unique signatures: correlation between Ξ and strange anti-baryons must be strong (Λ and even Ξ!), correlations with anti-p must be weak

Shoving in 1 MPI systems!



2 strings



- Minimal colour to exchange is 1 gluon

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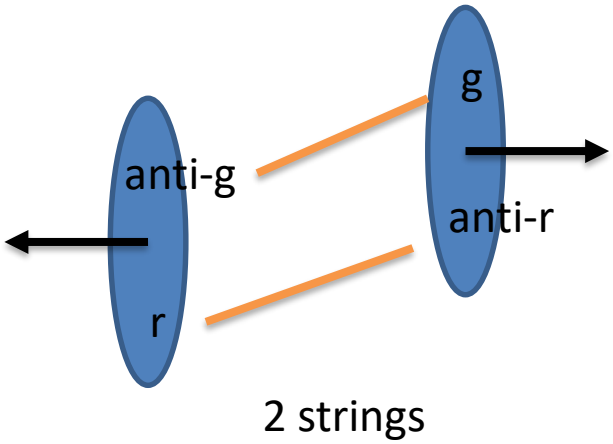

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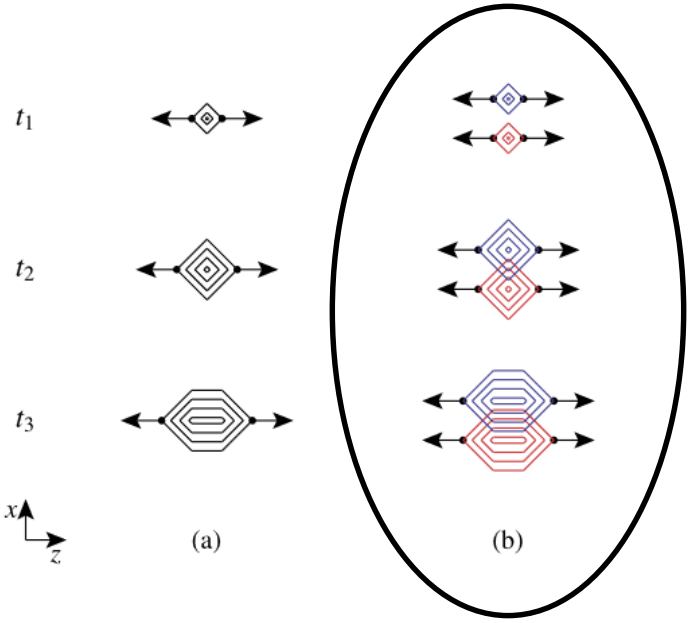
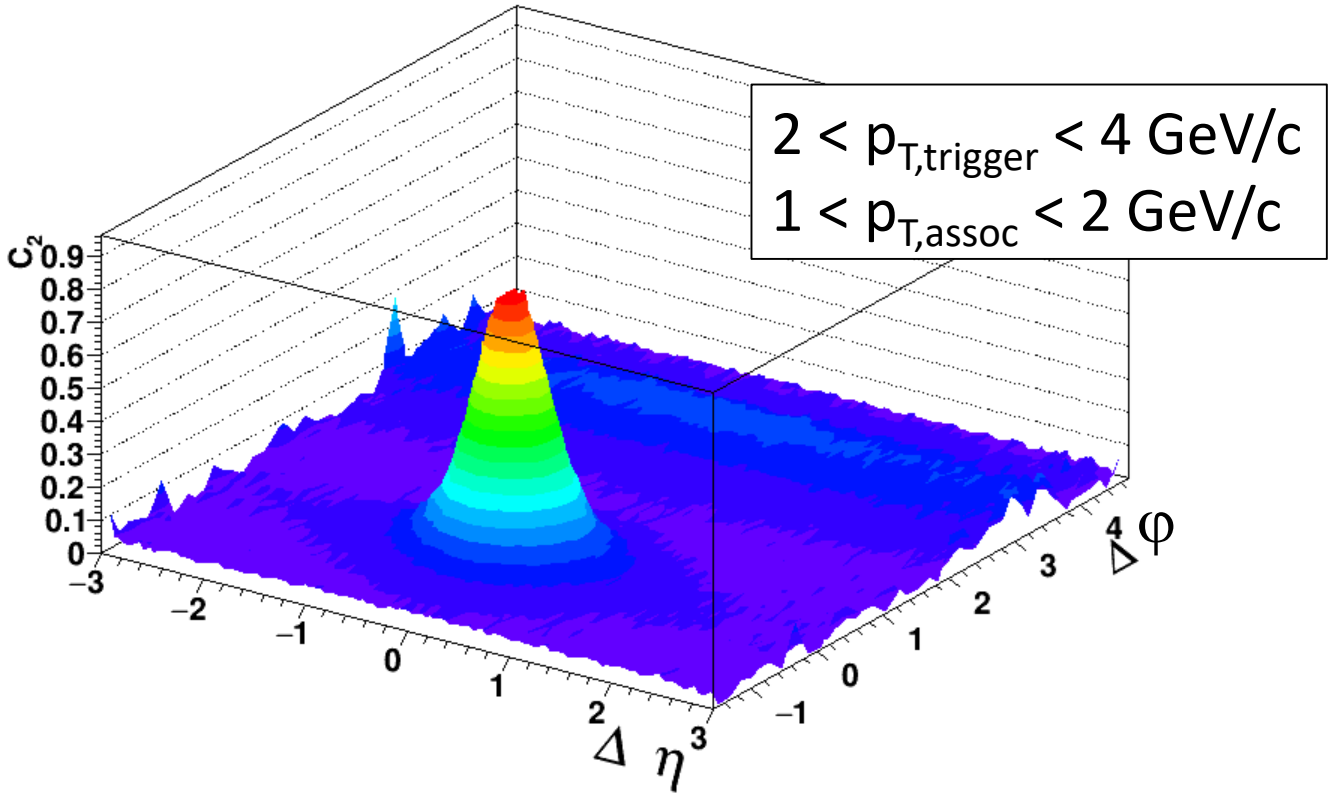


- Minimal colour to exchange is 1 gluon
- Note that in this case a very low number of particles is just a fluctuation in the string breakings but the strings (and their overlaps) can still be “large”!

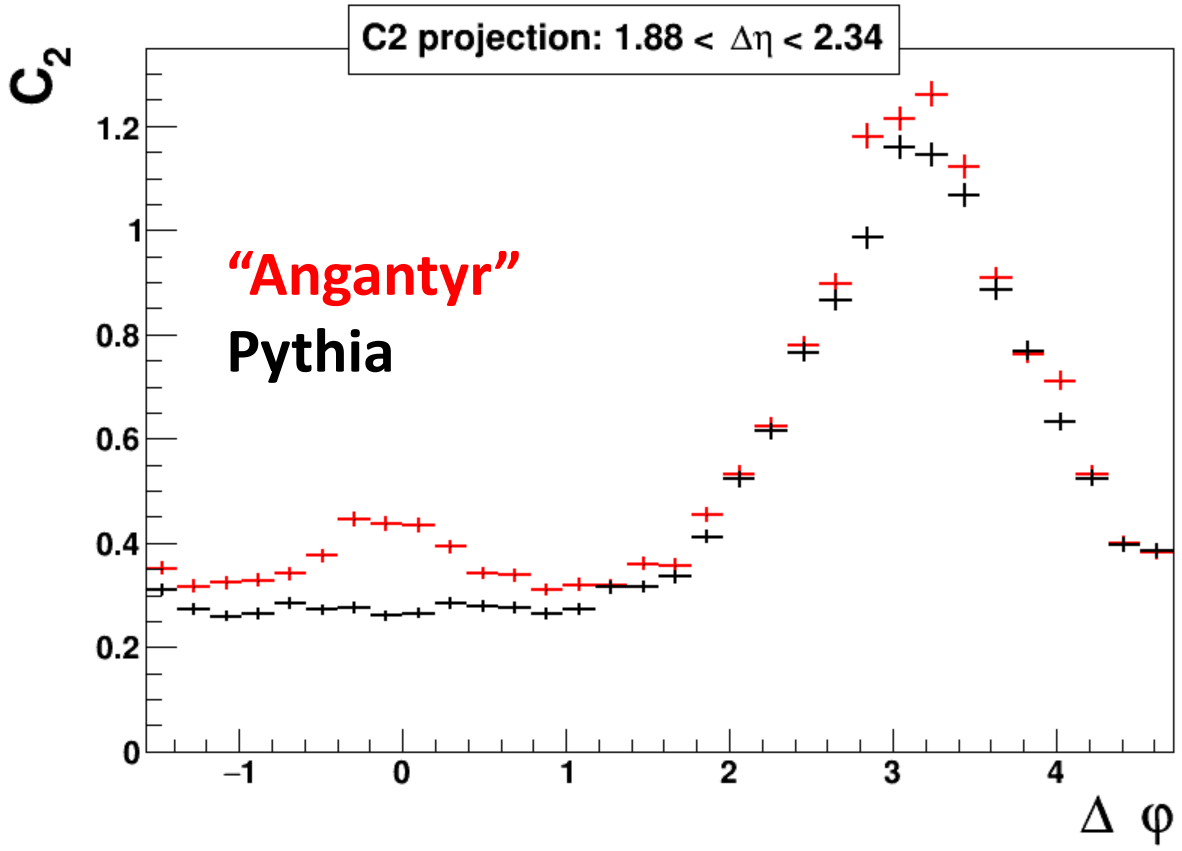
“Angantyr” (Main101) ND $\sqrt{s}$=13 TeV 1MPI

WITH Shoving



NB! I do not observe any strangeness enhancement for 1 MPI events!

Bulk: "Angantyr" vs PYTHIA



I get a ridge without changing the away side structure significantly

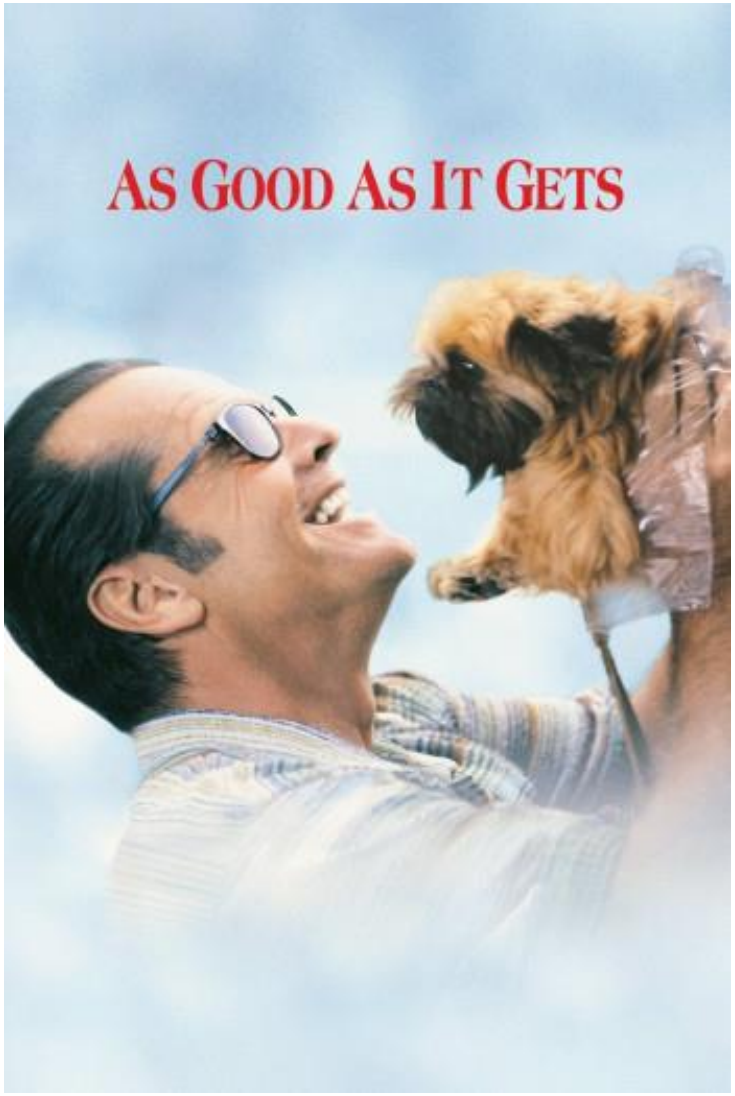
Outlook

- A lot of possibilities (jets, ee, ep)
  - Will need a final version of shoving

Outlook

- A lot of possibilities (jets, ee, ep)
  - Will need a final version of shoving
- What I could also have included are fluctuations of cross sections in Angantyr
  - Large nucleon -> larger impact parameter on the average -> more and softer collisions
  - Small nucleon -> Smaller impact parameter on the average -> less but harder collisions
  - Can we differentiate between this and models without fluctuations?

Final thoughts



- in the CLASH project in terms of personpower and skills
  - Take advantage of this the next two years

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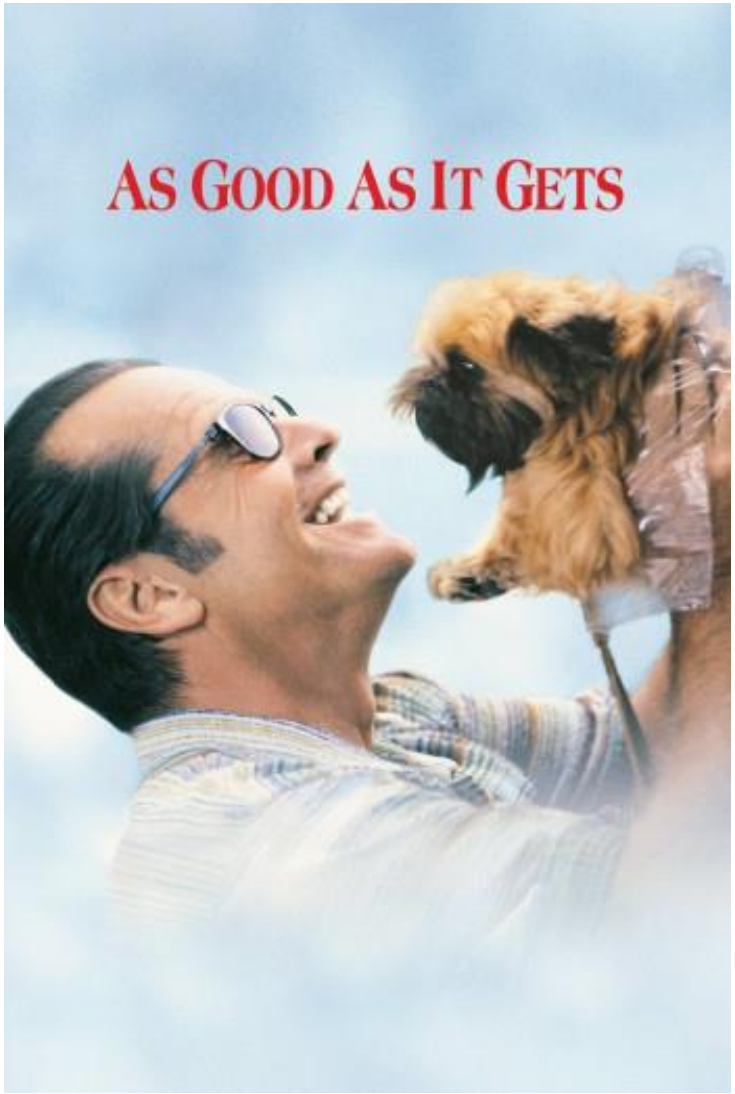

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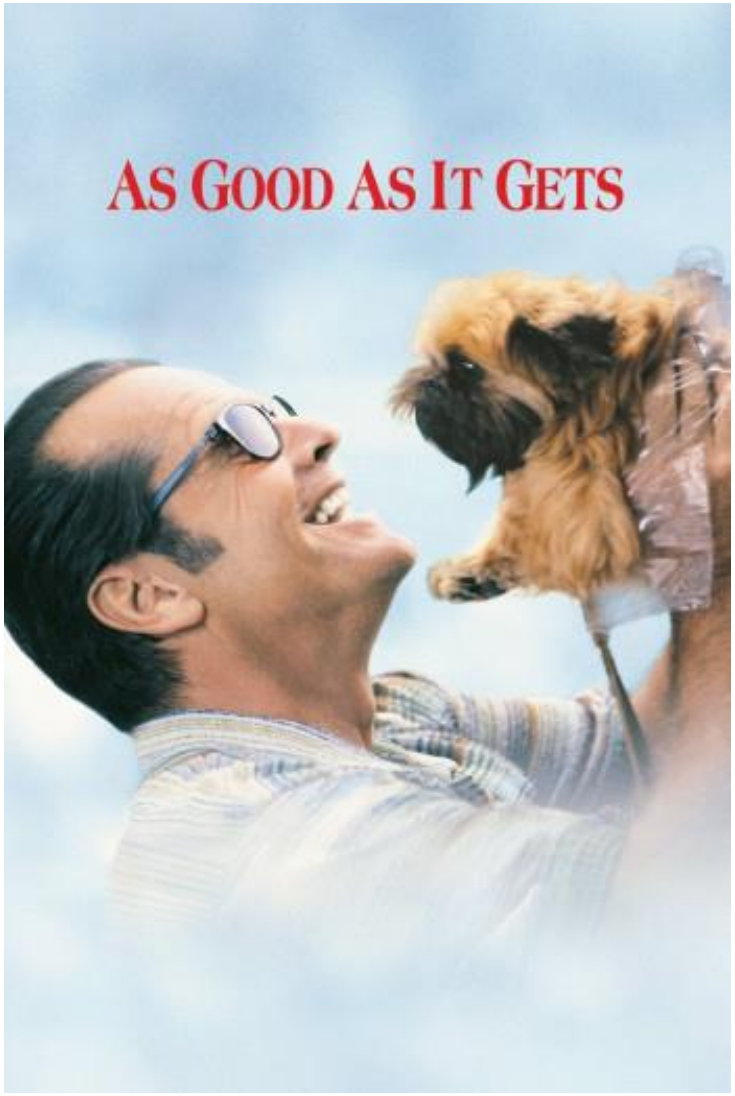

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- How to achieve success?
  - I think we need to zoom in on the fundamental assumptions in each model