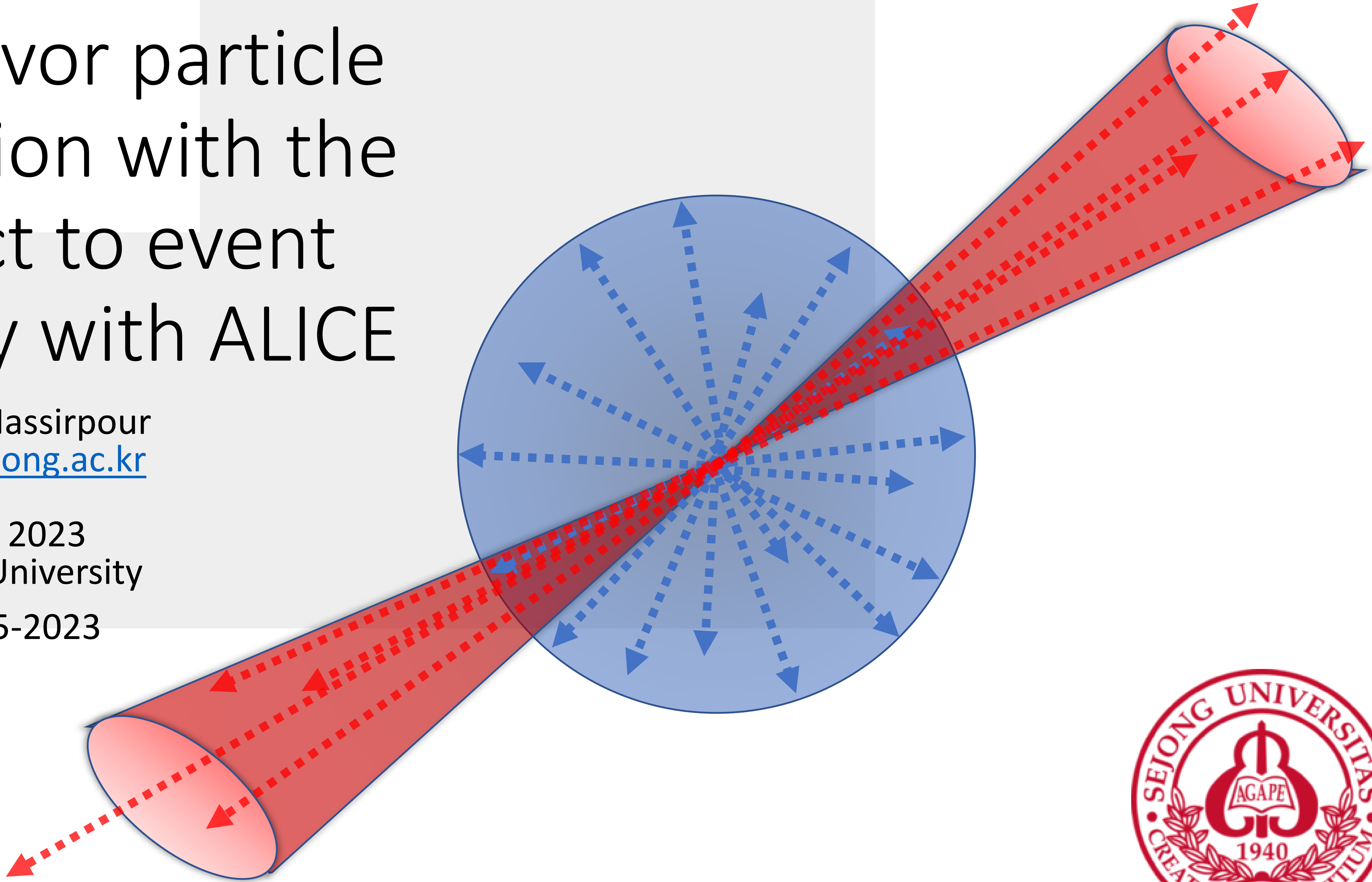
Light flavor particle production with the respect to event topology with ALICE

Adrian Nassirpour
afn@sejong.ac.kr

HIM 2023
Yonsei University
26/05-2023



Outline

1. Motivation

2. Transverse spherocity

   2.1. Utilizing mid-rapidity multiplicity

   2.2. Broader multiplicity definitions

Outline

1. Motivation

2. Transverse spherocity
   2.1. Utilizing mid-rapidity multiplicity
   2.2. Broader multiplicity definitions

Motivation – from the pp view

I will give a personal twist on the motivation.

Motivation – from the pp view

I will give a personal twist on the motivation

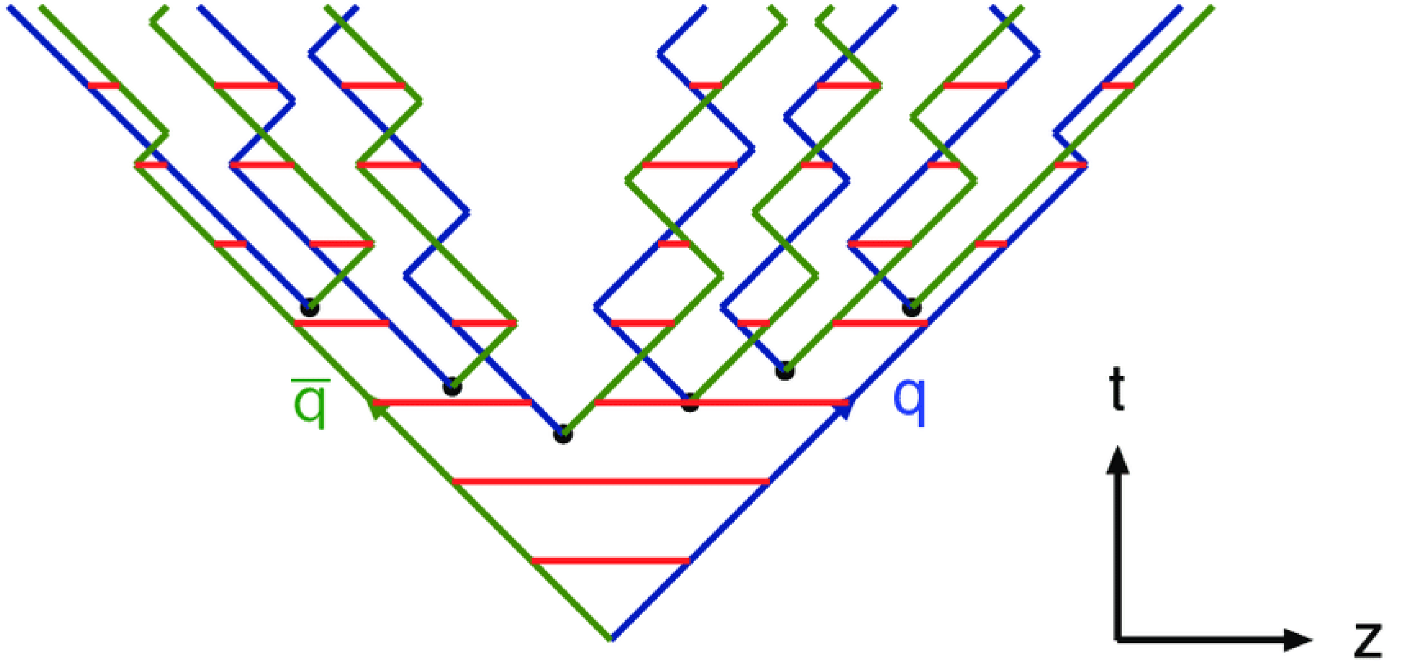
- Previous student from Lund University

Motivation – from the pp view

I will give a personal twist on the motivation

- Previous student from Lund University
- Home to the Lund string model
  - Gets a lot of good PR

PYTHIA 8.3

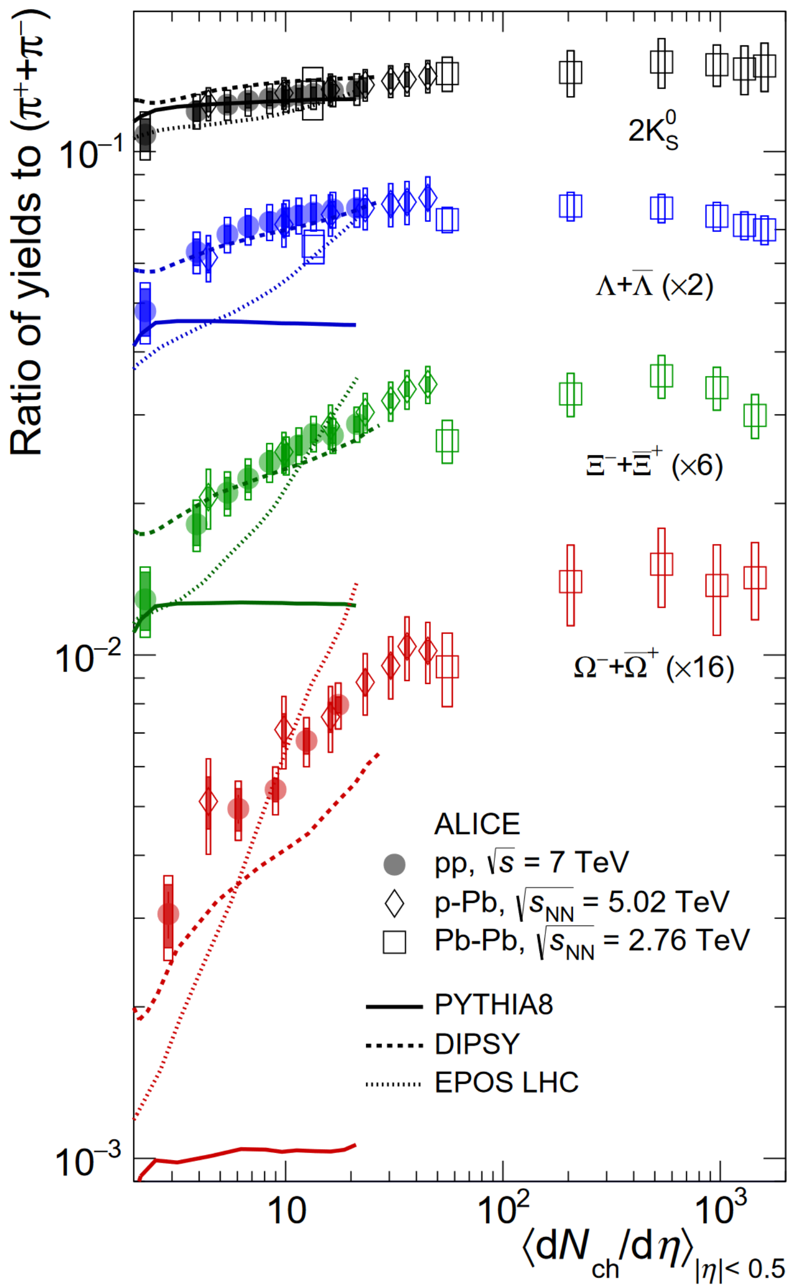


Motivation – from the pp view

I will give a personal twist on the motivation

- Previous student from Lund University
- Home to the Lund string model
  - Gets a lot of good PR
- ALICE strangeness enhancement results are published in 2016
  - PYTHIA 8 lines are incompatible with the data

Nature Phys. 13 (2017) 535-539

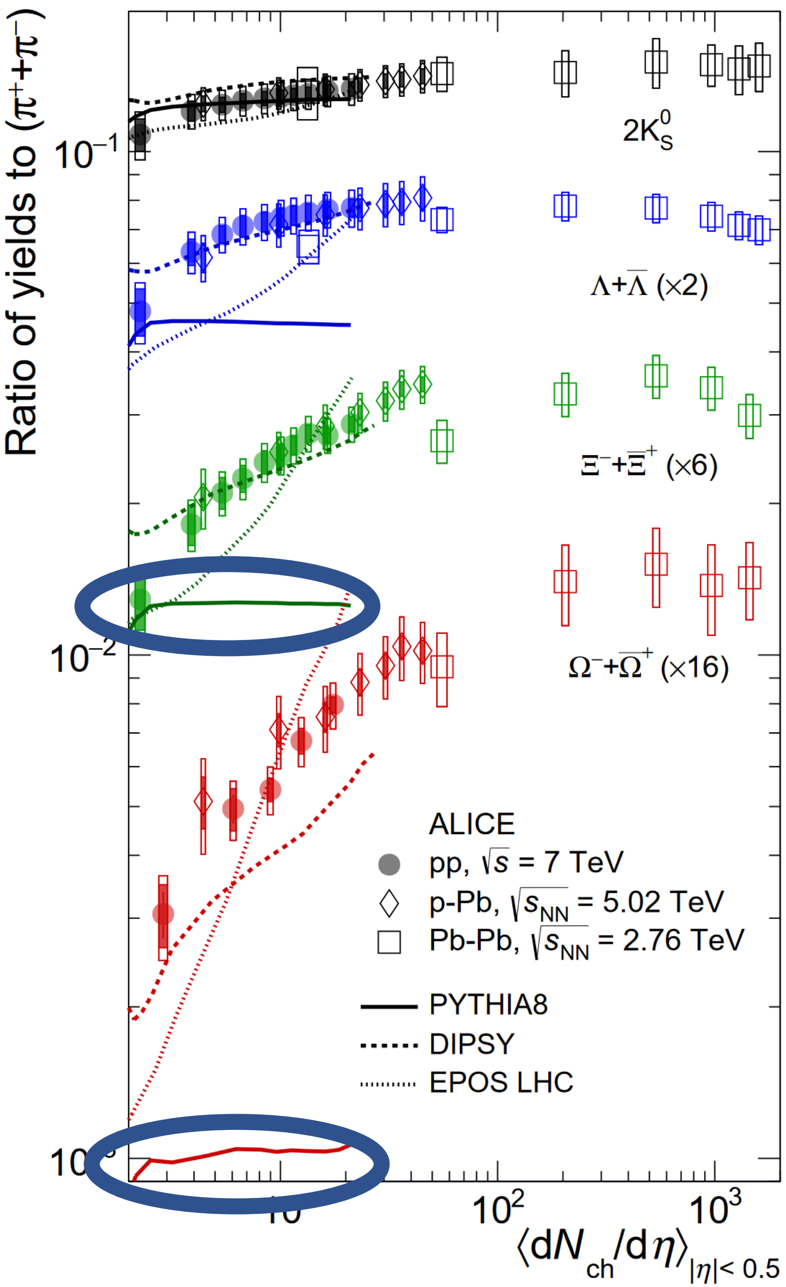


Motivation – from the pp view

I will give a personal twist on the motivation

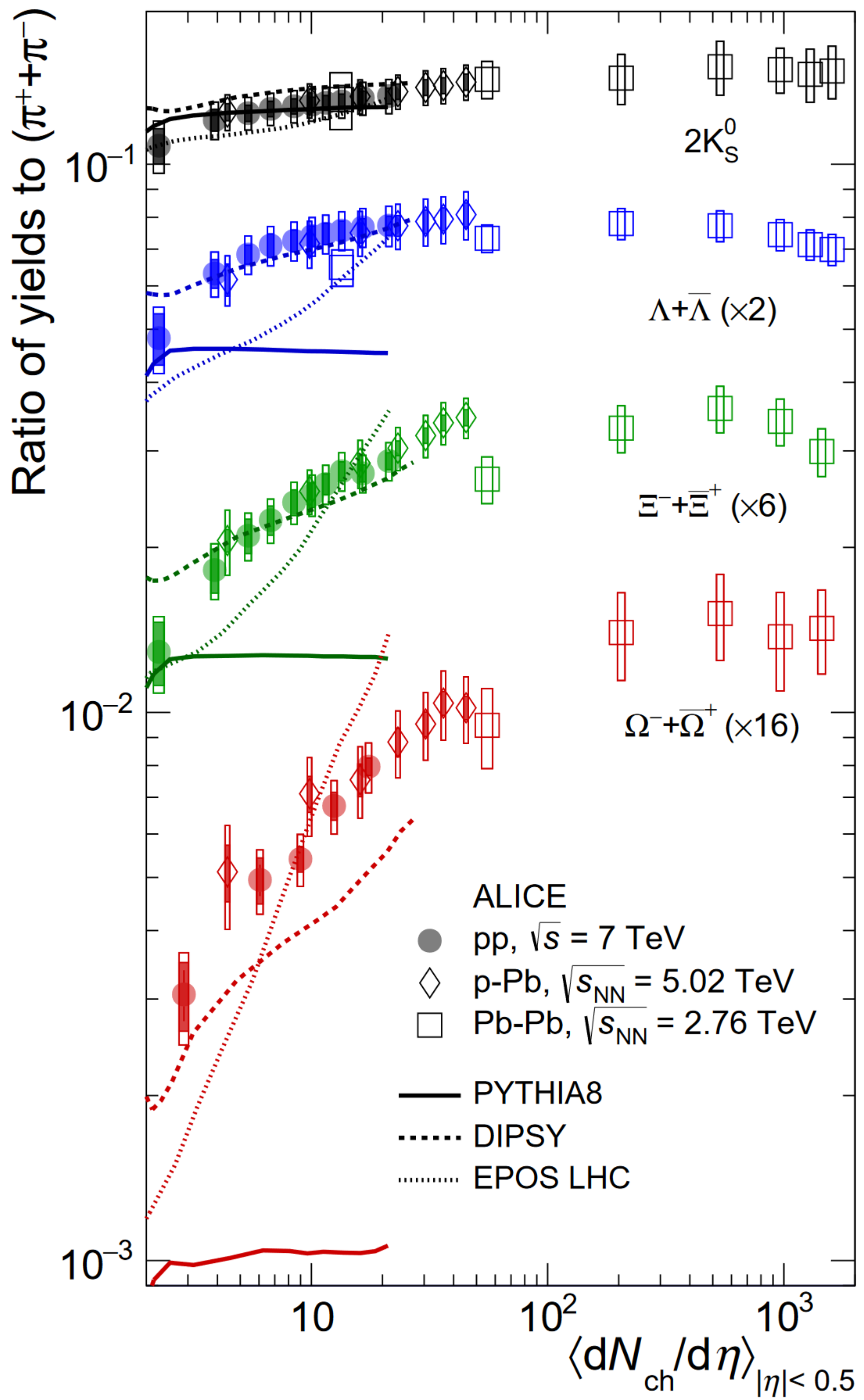
- Previous student from Lund University
- Home to the Lund string model
  - Gets a lot of good PR
- ALICE strangeness enhancement results are published in 2016
  - PYTHIA 8 lines are incompatible with the data

Nature Phys. 13 (2017) 535-539



Motivation – from the pp view

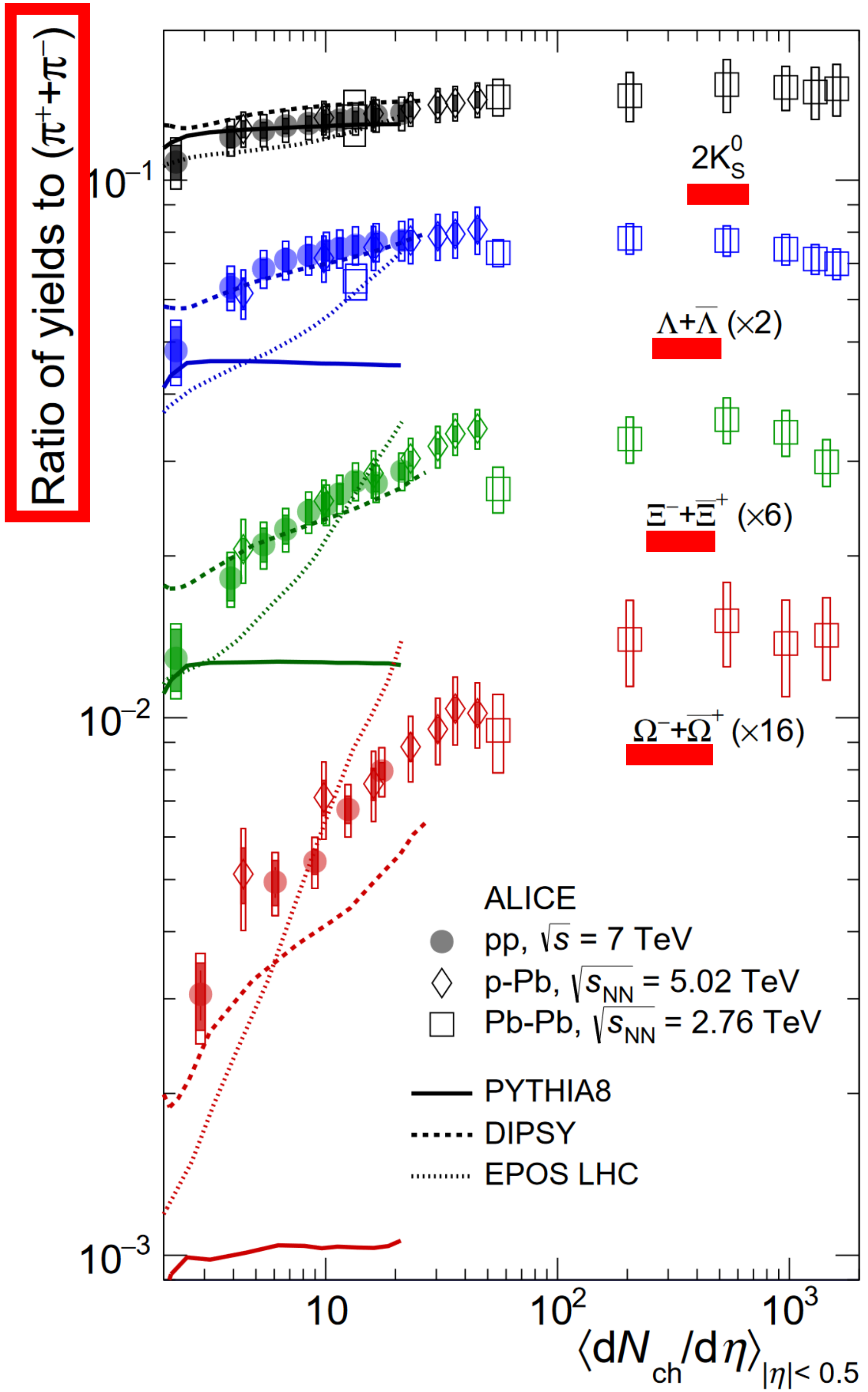
Let's break down this plot in detail



Motivation – from the pp view

Let's break down this plot in detail

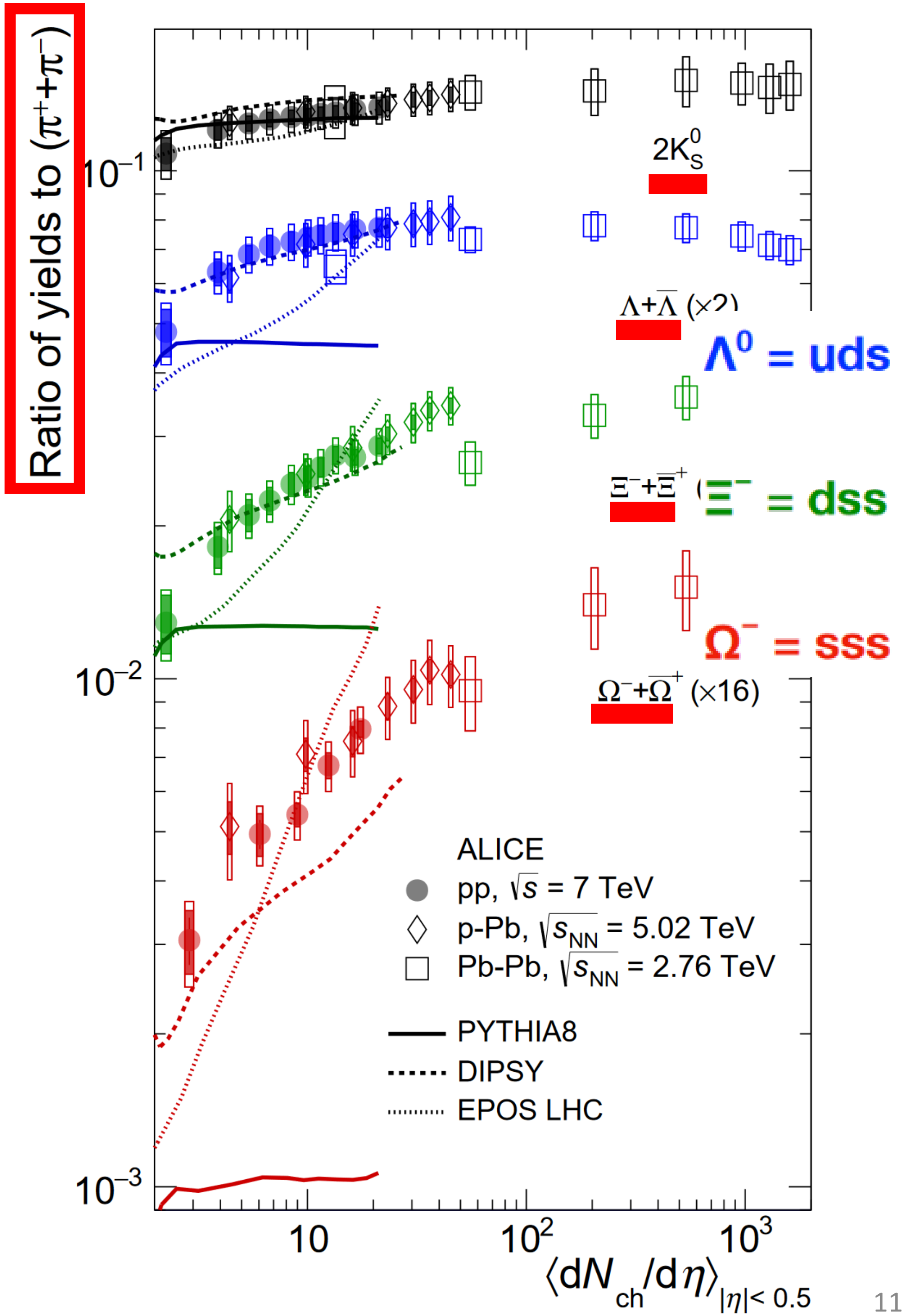
- Relative $\frac{X_s}{\pi}$ yields, for increasing strangeness



Motivation – from the pp view

Let's break down this plot in detail

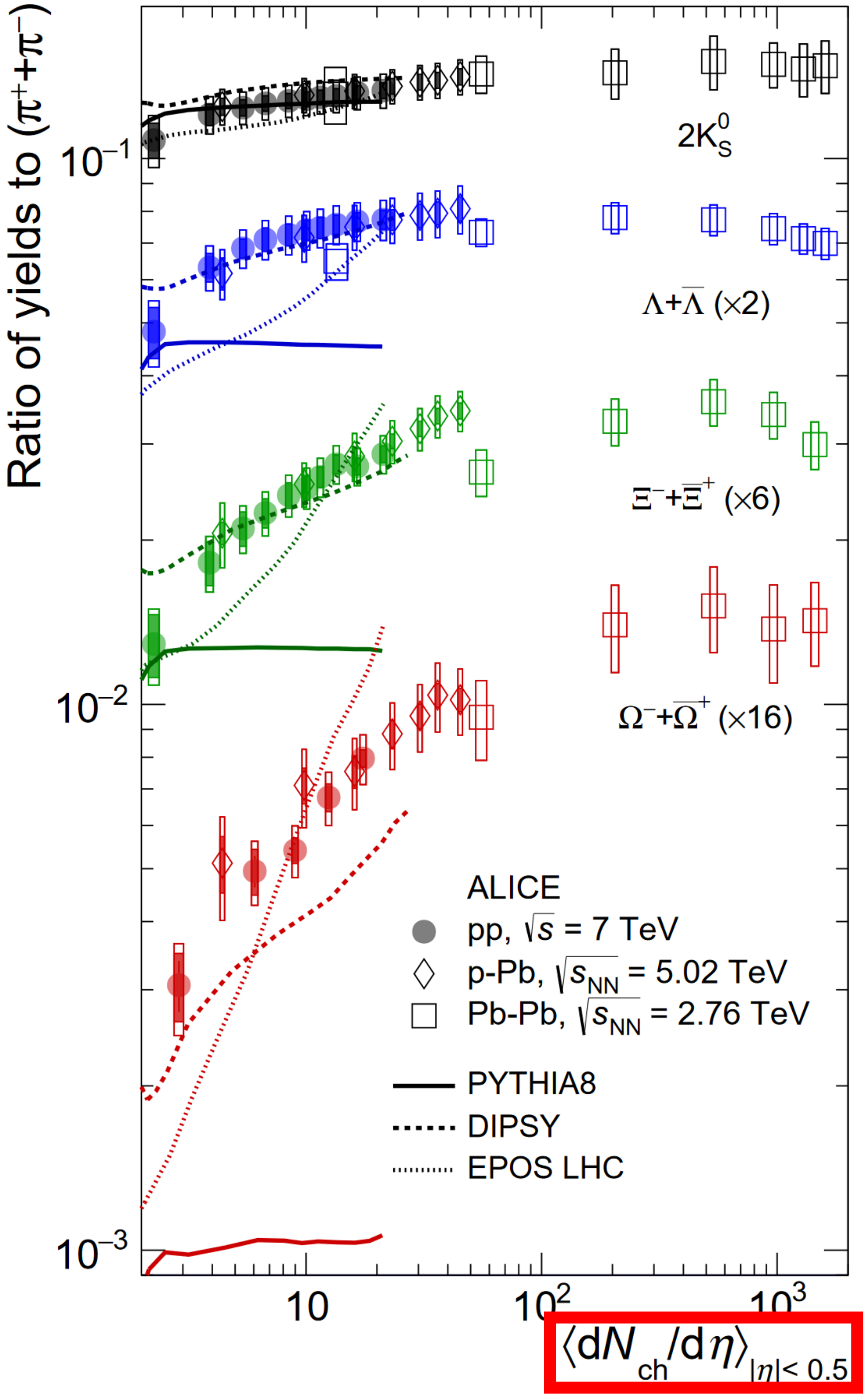
- Relative $\frac{X_s}{\pi}$ yields, for increasing strangeness



Motivation – from the pp view

Let's break down this plot in detail

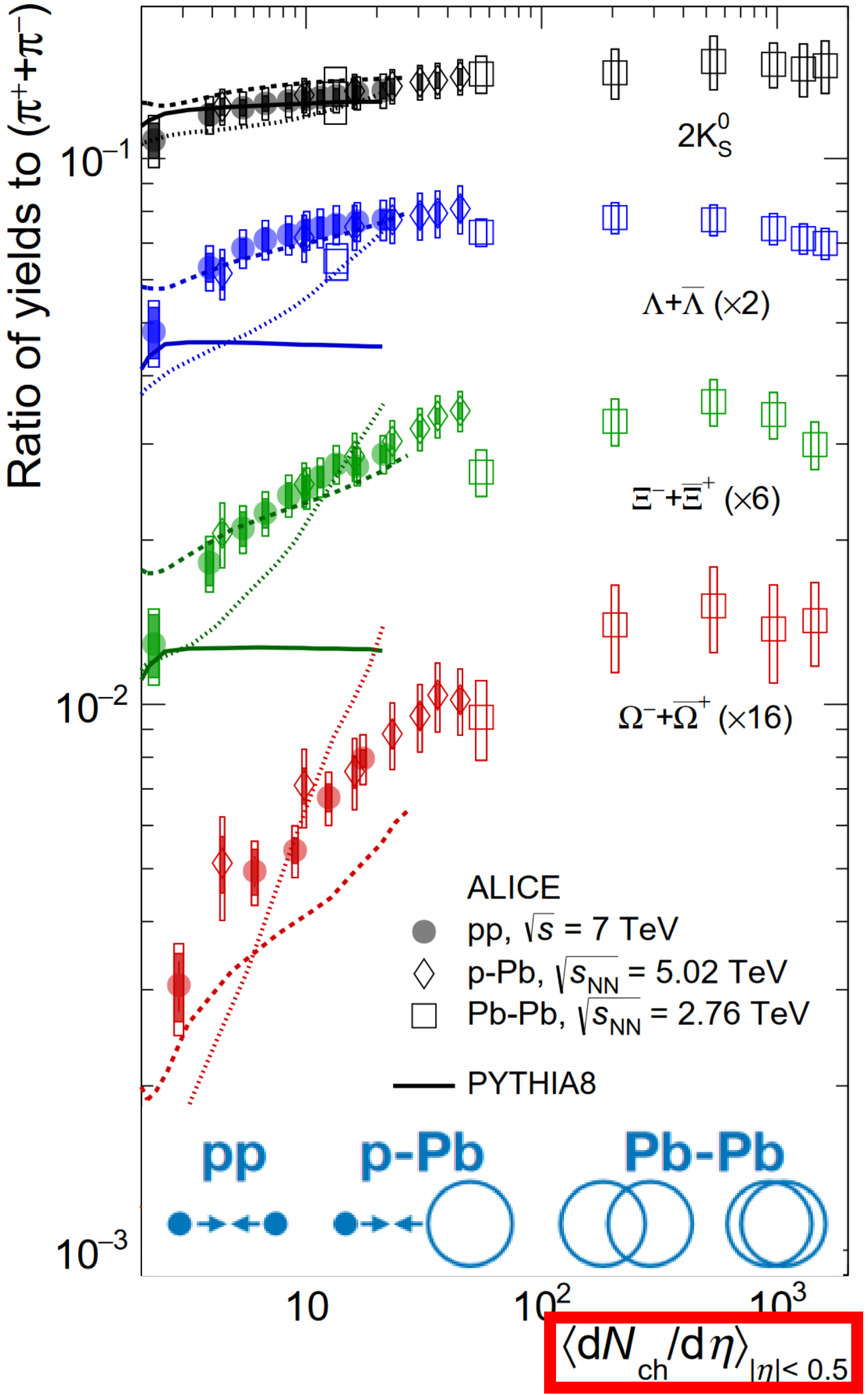
- Relative $\frac{X_s}{\pi}$ yields, for increasing strangeness
- Strangeness is enhanced as a function of multiplicity



Motivation – from the pp view

Let's break down this plot in detail

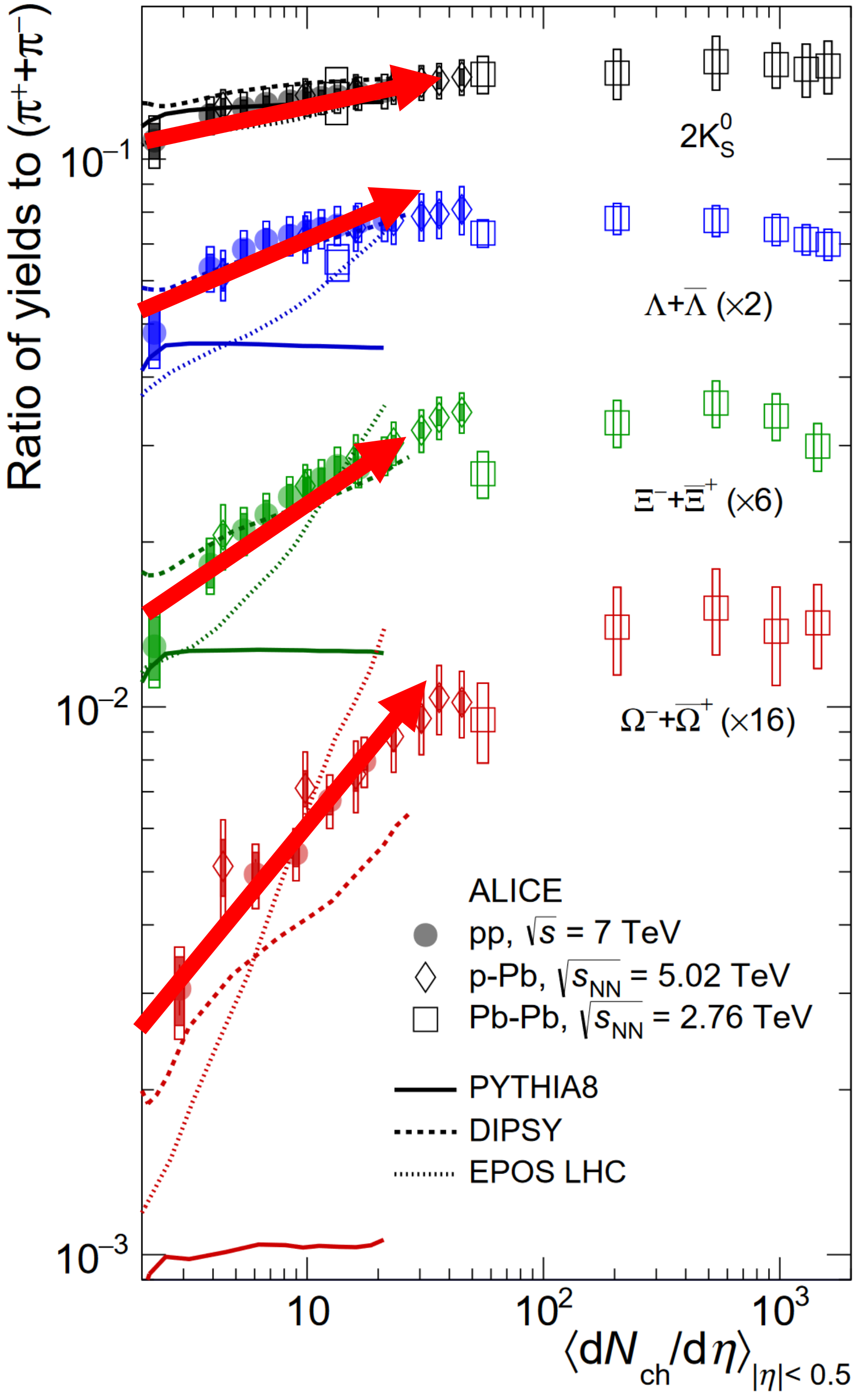
- Relative $\frac{X_s}{\pi}$ yields, for increasing strangeness
- Strangeness is enhanced as a function of multiplicity



Motivation – from the pp view

Let's break down this plot in detail

- Relative $\frac{X_s}{\pi}$ yields, for increasing strangeness
- Strangeness is enhanced as a function of multiplicity
- Effect grows with strangeness content



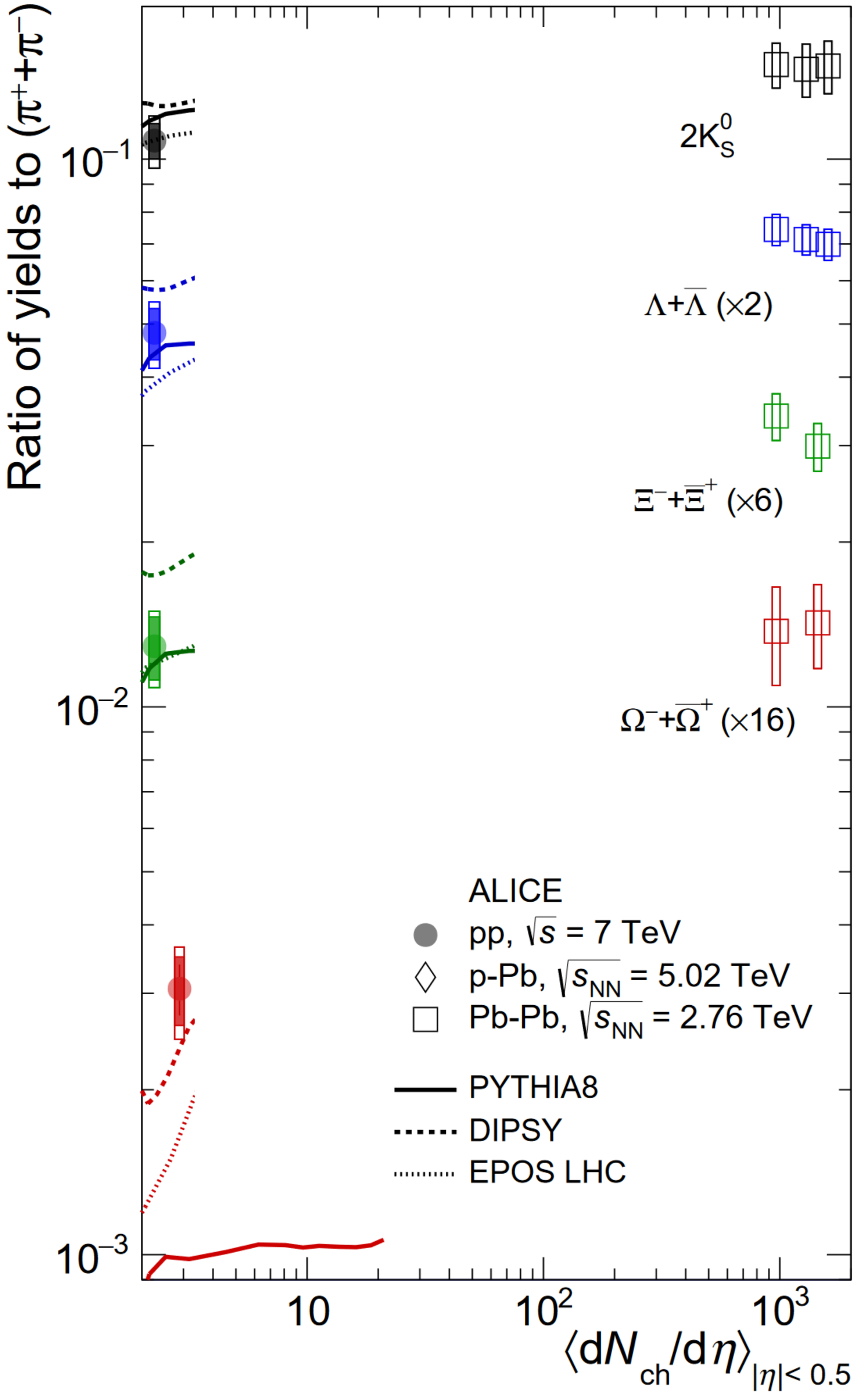
Motivation – from the AA view

- Strangeness enhancement – one of the first suggested QGP signatures

  - $q\bar{q}$ -> $s\bar{s}$ is enhanced with temperature
    - Faster than gg -> $q\bar{q}$

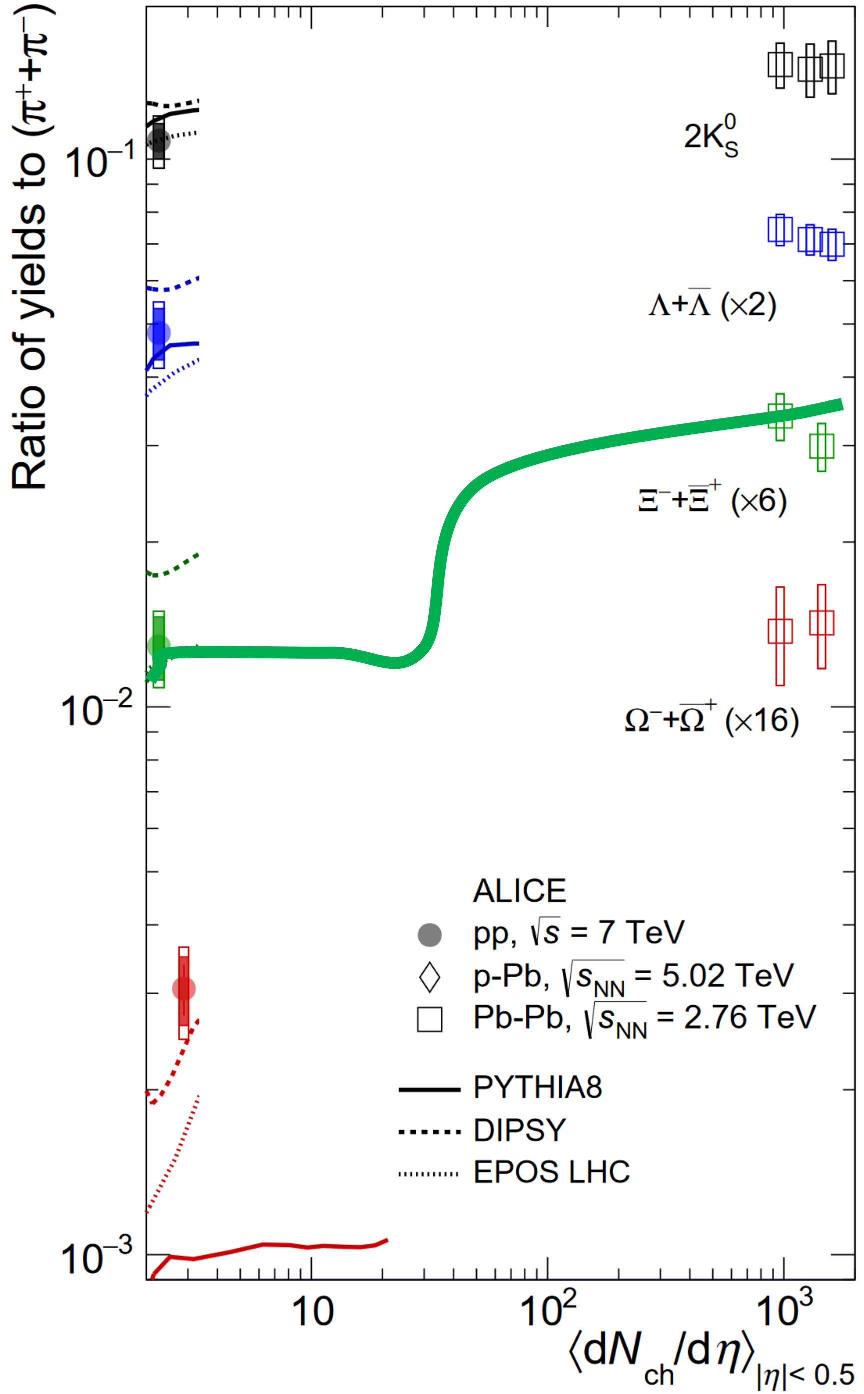
  - More intuitive idea: $\mathrm{T_{QGP}} \approx \mathrm{M_s}$
    - Enables thermal production of strange quarks

Phys. Lett. B728 (2014) 216–227 and Phys. Rev. Lett. 111 (2013) 222301



Motivation – from the AA view

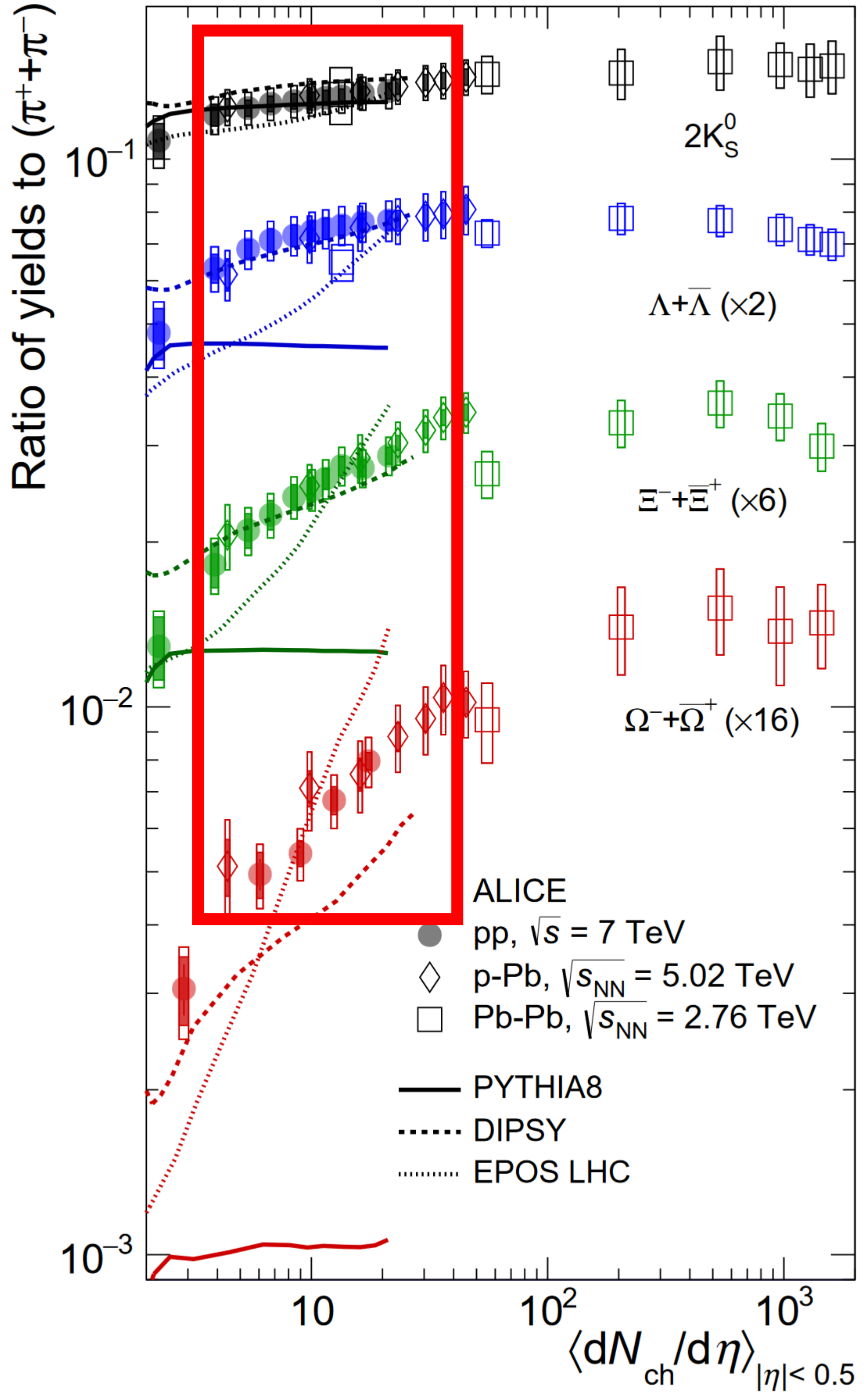
- Strangeness enhancement – one of the first suggested QGP signatures
  - $q\bar{q}$ -> $s\bar{s}$ is enhanced with temperature
    - Faster than gg -> $q\bar{q}$
  - More intuitive idea: $\mathrm{T_{QGP}} \approx \mathrm{M_s}$
    - Enables thermal production of strange quarks
- Enhancement was observed in AA relative to Min. Bias (MB) pp data.



Phys. Lett. B728 (2014) 216–227 and Phys. Rev. Lett. 111 (2013) 222301

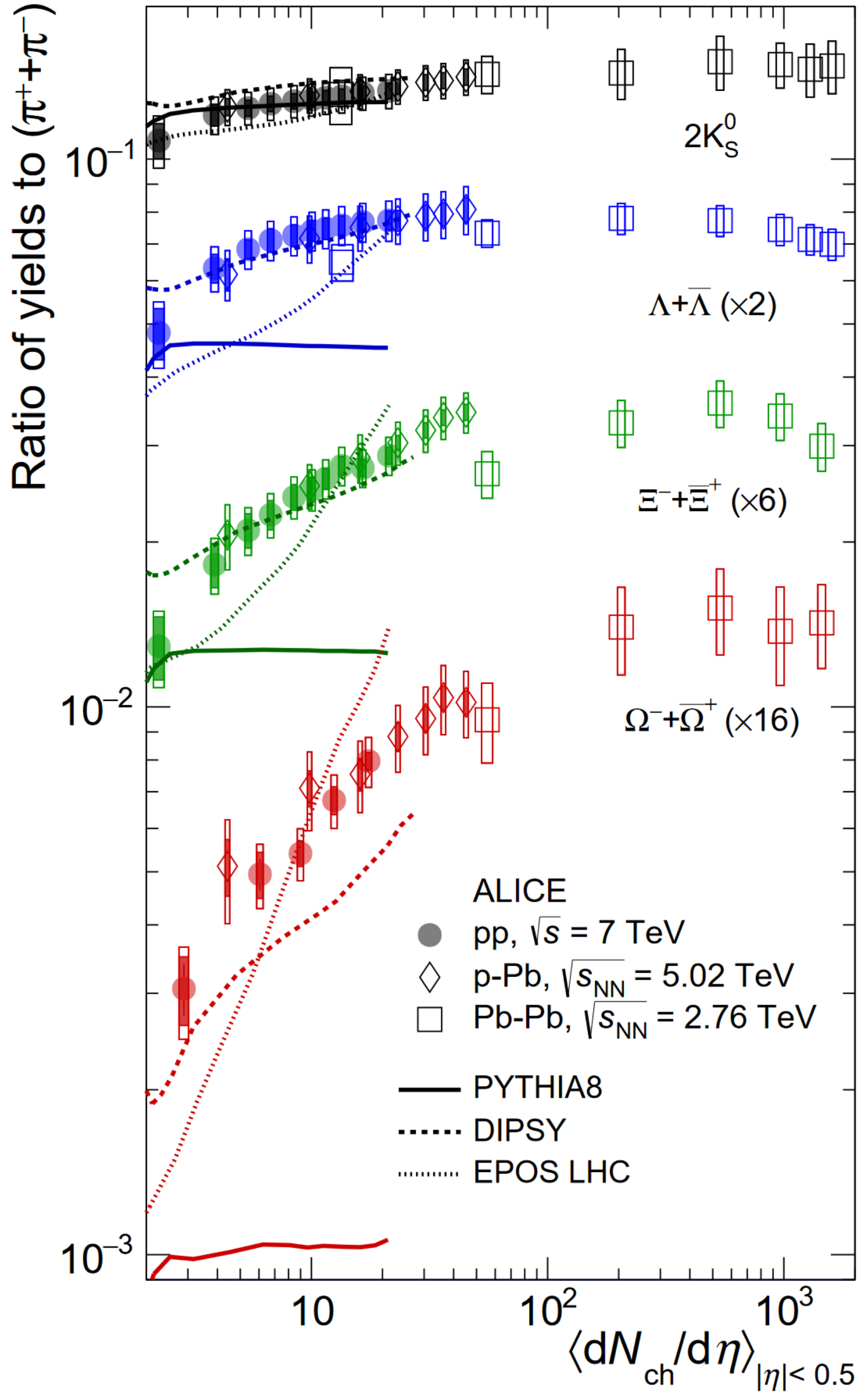
Motivation – from the AA view

- Strangeness enhancement – one of the first suggested QGP signatures
  - $q\bar{q}$ -> $s\bar{s}$ is enhanced with temperature
    - Faster than gg -> $q\bar{q}$
  - More intuitive idea: $\mathrm{T_{QGP}} \approx \mathrm{M_s}$
    - Enables thermal production of strange quarks
- Enhancement was observed in AA relative to Min. Bias (MB) pp data.
  - However, the main enhancement is driven in smaller (pp, pA) systems.



Motivation – from the AA view

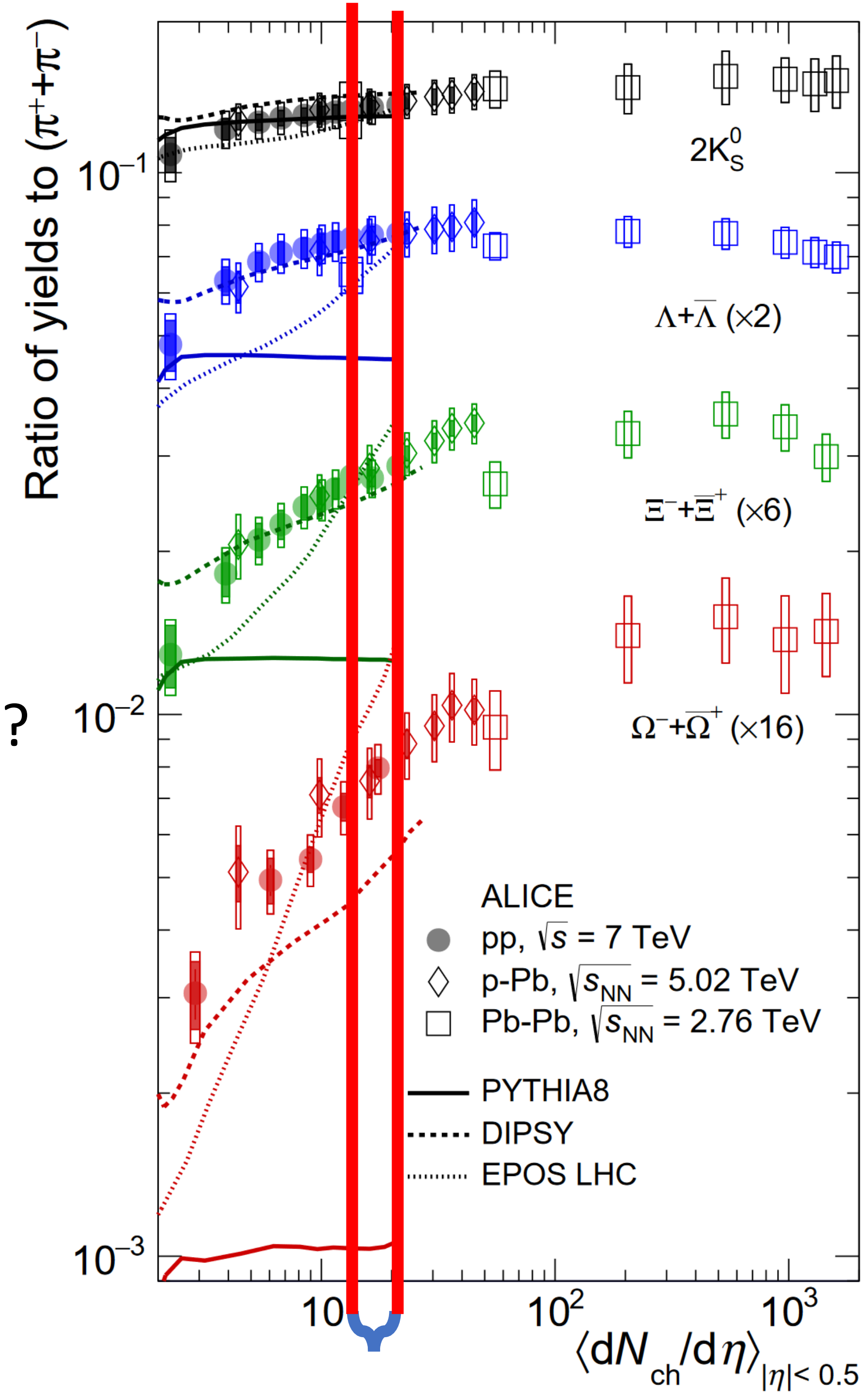
- What drives strangeness enhancement?
  - Is it connected to the QGP?
  - Can QGP created in high-mult pp, or pA collisions?



Motivation – from the AA view

- What drives strangeness enhancement?
  - Is it connected to the QGP?
  - Can QGP created in high-mult pp, or pA collisions?

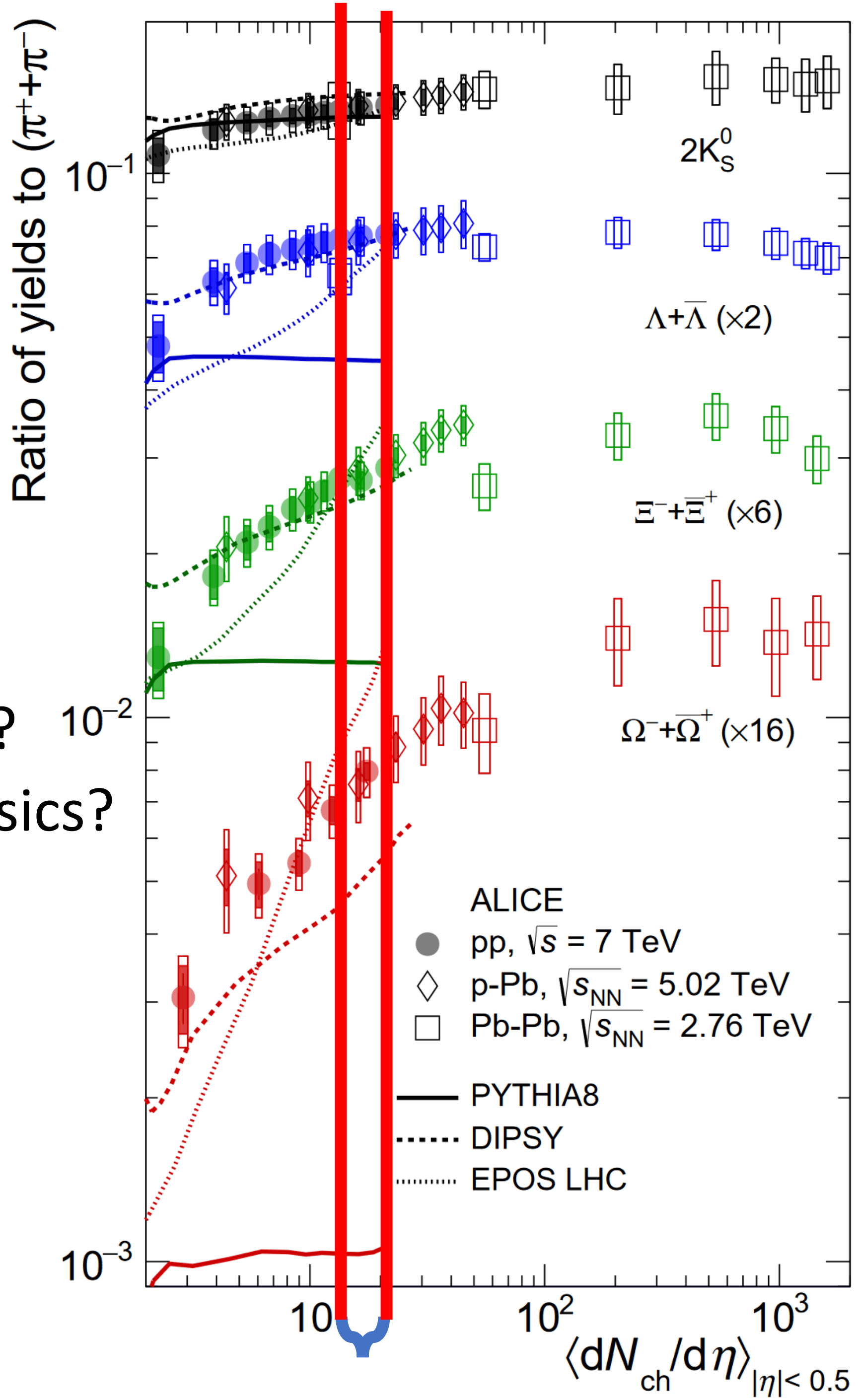
- Today I will try to explore:
  - How homogenous are high-multiplicity pp collisions?



Motivation – from the AA view

- What drives strangeness enhancement?
  - Is it connected to the QGP?
  - Can QGP created in high-mult pp, or pA collisions?

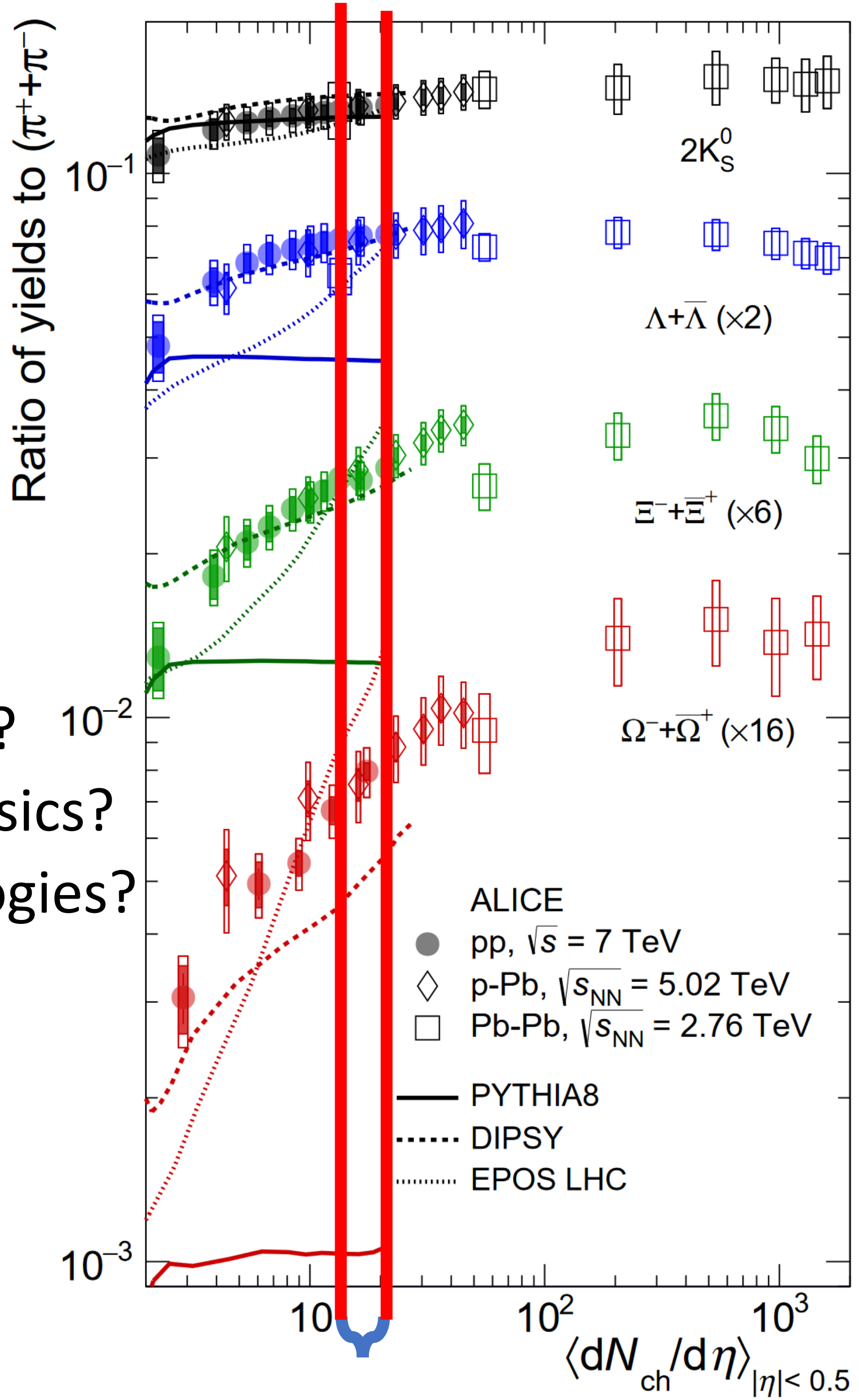
- Today I will try to explore:
  - How homogenous are high-multiplicity pp collisions?
  - Can we delineate the effects between hard/soft physics?



Motivation – from the AA view

- What drives strangeness enhancement?
  - Is it connected to the QGP?
  - Can QGP created in high-mult pp, or pA collisions?

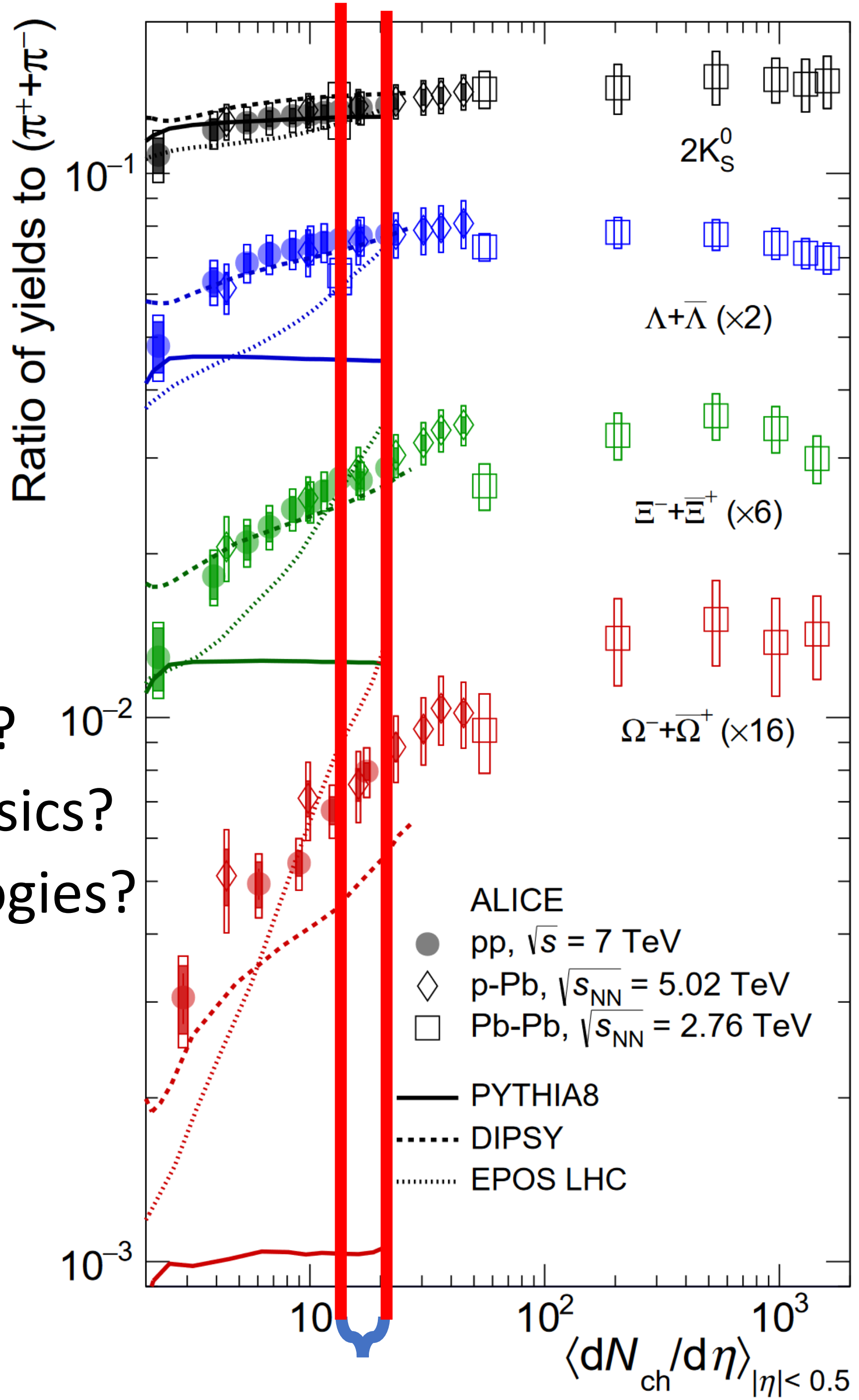
- Today I will try to explore:
  - How homogenous are high-multiplicity pp collisions?
  - Can we delineate the effects between hard/soft physics?
  - Can we gain information by contrasting event topologies?



Motivation – from the AA view

- What drives strangeness enhancement?
  - Is it connected to the QGP?
  - Can QGP created in high-mult pp, or pA collisions?

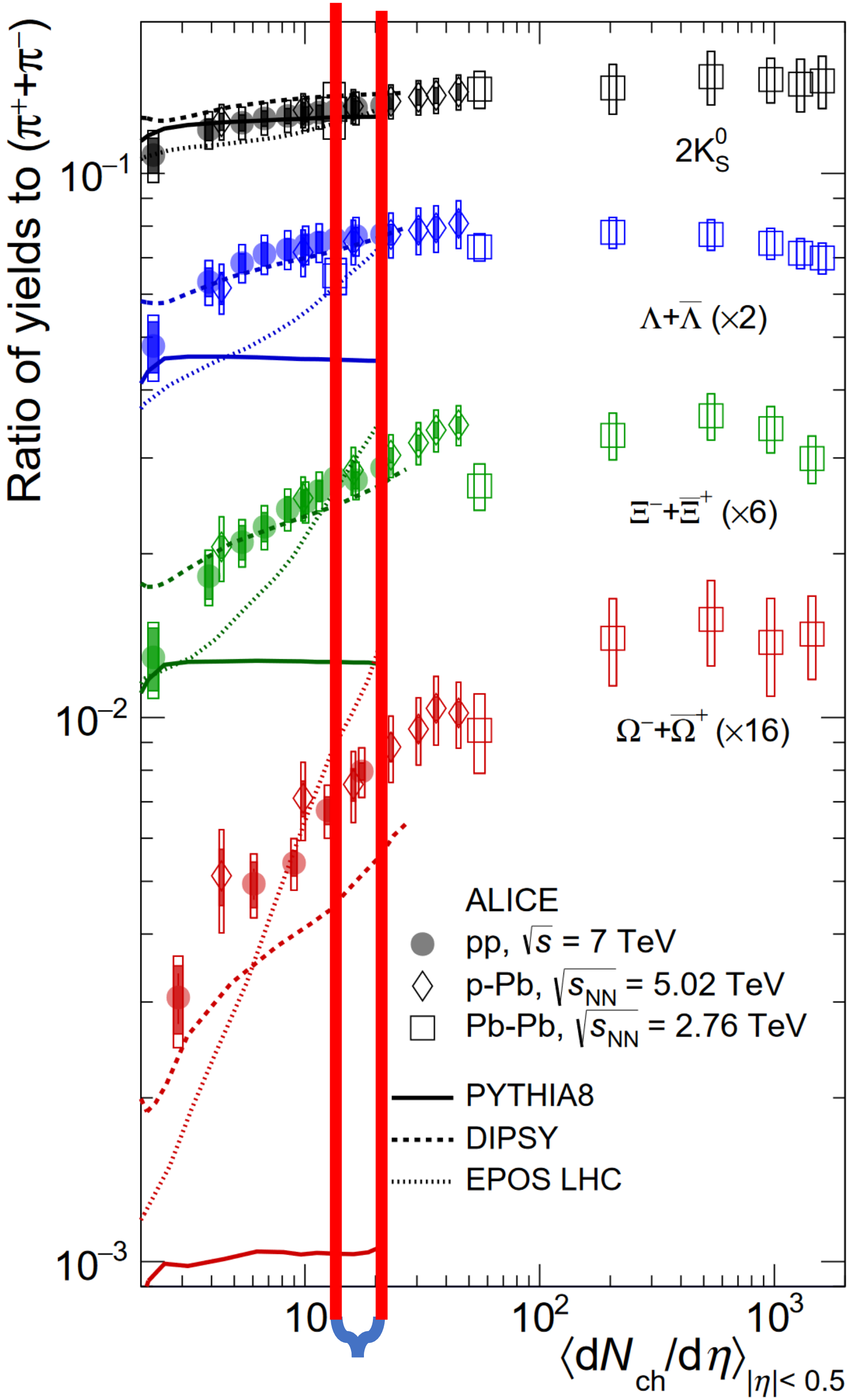
- Today I will try to explore:
  - How homogenous are high-multiplicity pp collisions?
  - Can we delineate the effects between hard/soft physics?
  - Can we gain information by contrasting event topologies?



I will try to bridge the connection between the top and lower bulletins throughout this talk!

Motivation – from the AA view

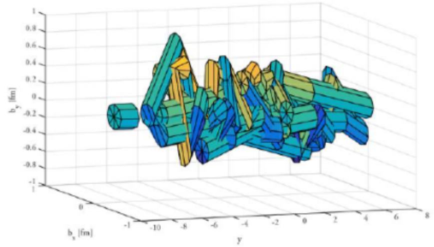
- I will be contrasting results using 4 different MC event generators.
  - “pure” QCD inspired models:
    - PYTHIA Monash
    - Herwig 7.2



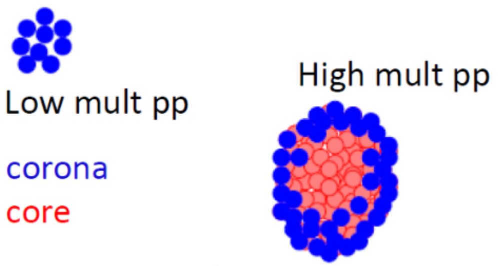
Motivation – from the AA view

- I will be contrasting results using 4 different MC event generators.
  - "pure" QCD inspired models:
    - PYTHIA Monash
    - Herwig 7.2
  - Semi-two component model
    - PYTHIA Ropes
  - Full, core-corona two component model
    - EPOS-LHC

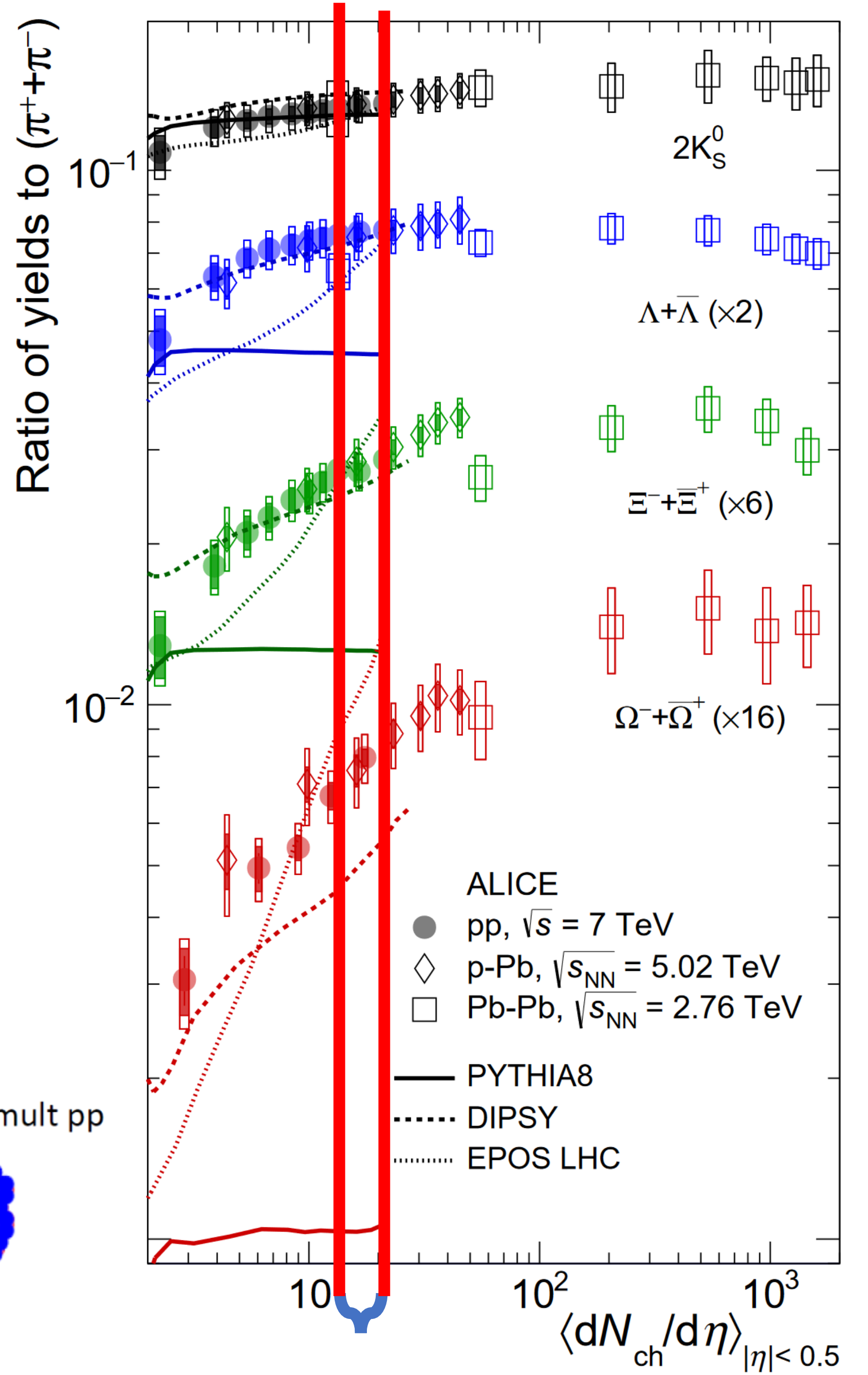
Microscopic vs Macroscopic



Picture from C. Bierlich
(string radii ~3.5 times too small!)

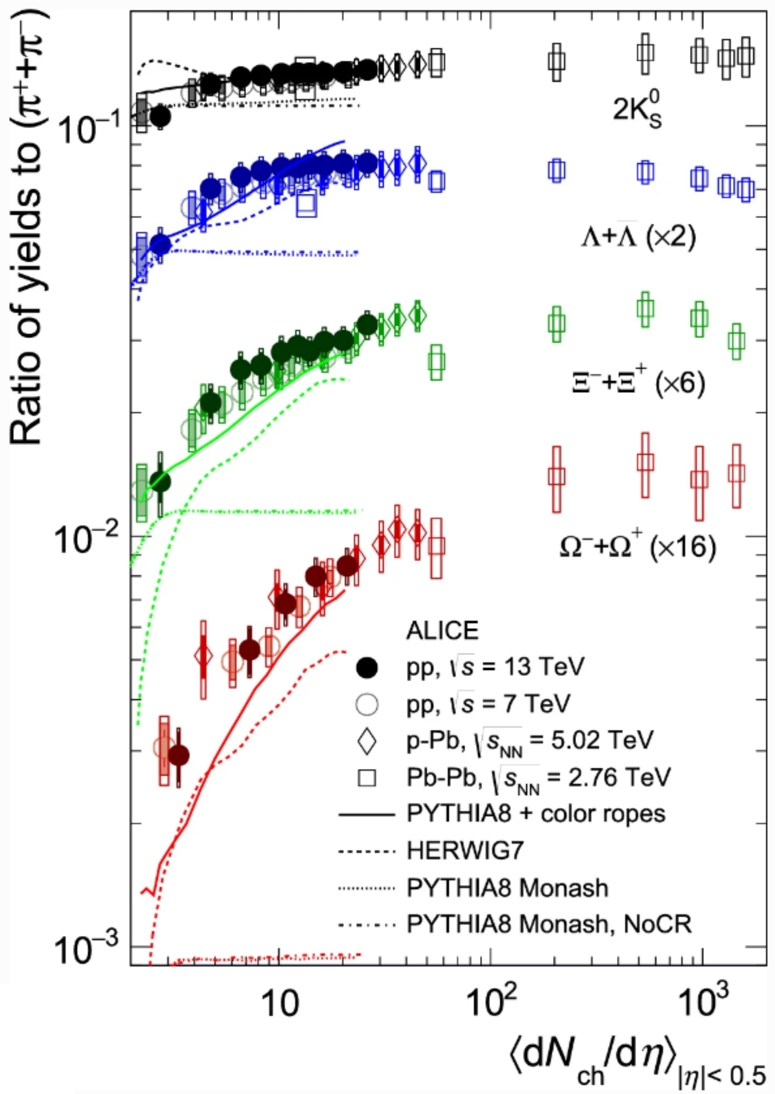


Pictures from K. Werner

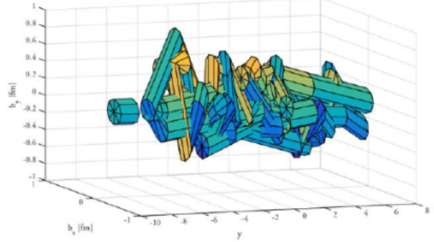


Motivation – from the AA view

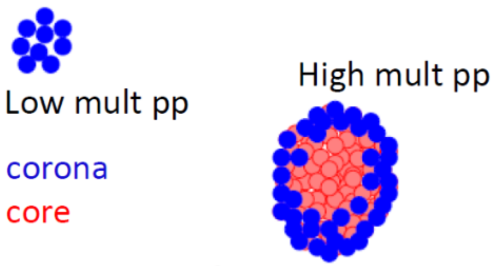
- I will be contrasting results using 4 different MC event generators.
  - “pure” QCD inspired models:
    - PYTHIA Monash
    - Herwig 7.2
  - Semi-two component model
    - PYTHIA Ropes
  - Full, core-corona two component model
    - EPOS-LHC



Microscopic vs Macroscopic



Picture from C. Bierlich
(string radii ~3.5 times too small!)



Pictures from K. Werner

Outline

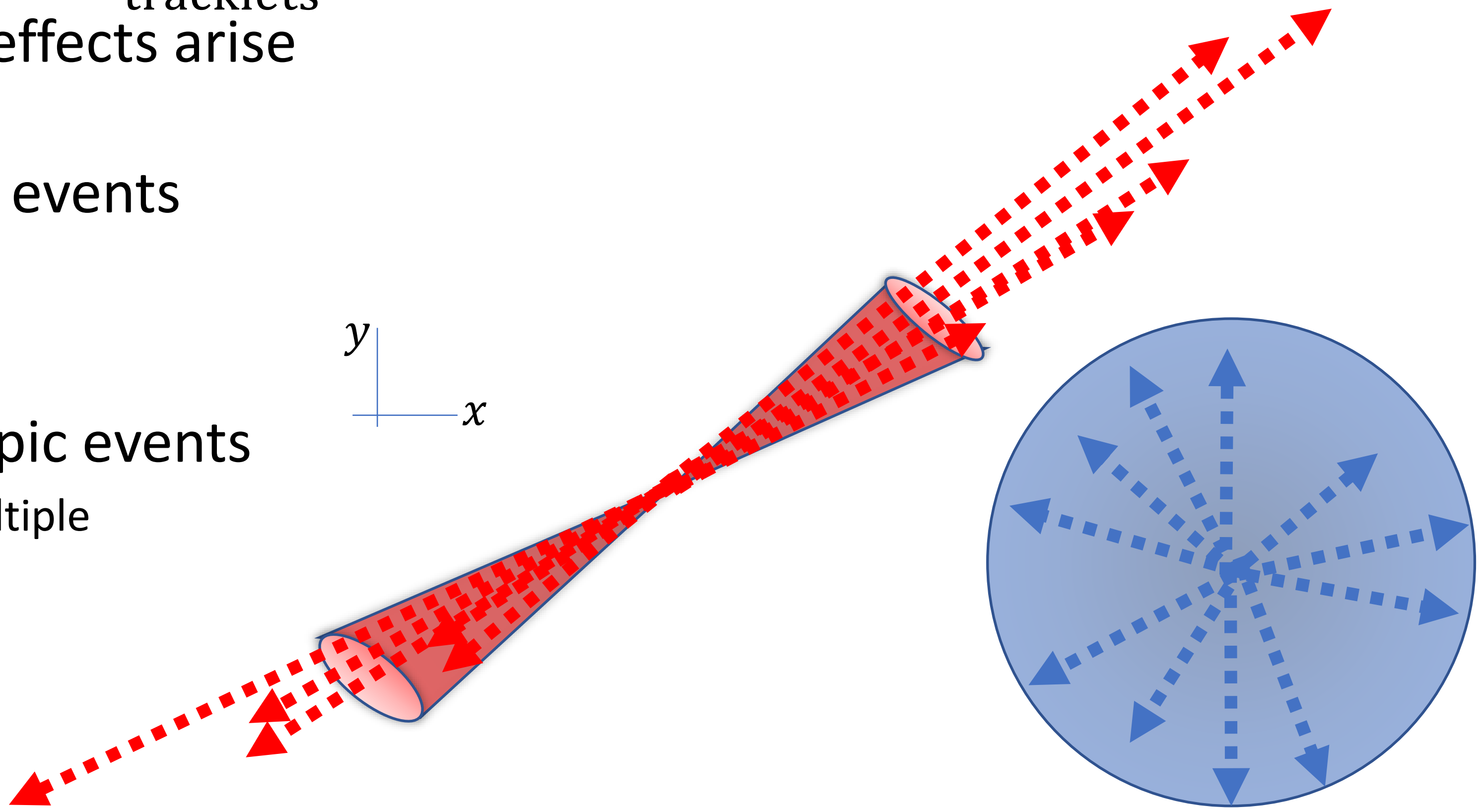
All plots taken from this thesis: http://cds.cern.ch/record/2848793

Transverse spherocity

- Idea is to classify high-multiplicity events based on event topology
  - We require top 1% multiplicity ($N_{\mathrm{tracklets}}^{|\eta|<0.8}$), since this is where QGP-like effects arise

Transverse spherocity

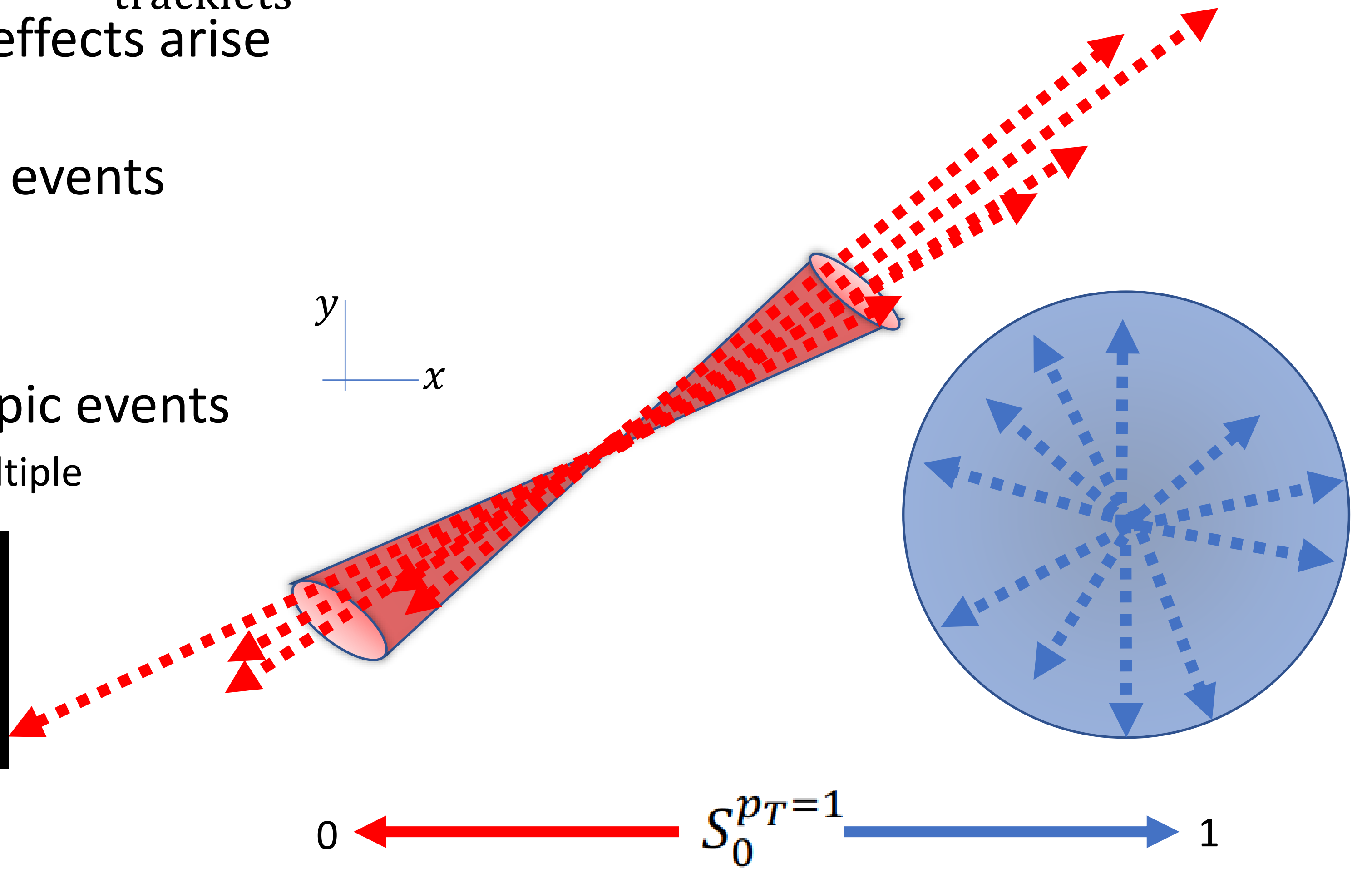
- Idea is to classify high-multiplicity events based on event topology
  - We require top 1% multiplicity ($N_{\mathrm{tracklets}}^{|\eta|<0.8}$), since this is where QGP-like effects arise
  - **Jetty:** Back-to-Back "jet-like" events
    - Particle production mainly driven by hard physics
  - **Isotropic:** Azimuthally isotropic events
    - Particle production driven by multiple softer collisions



Transverse spherocity

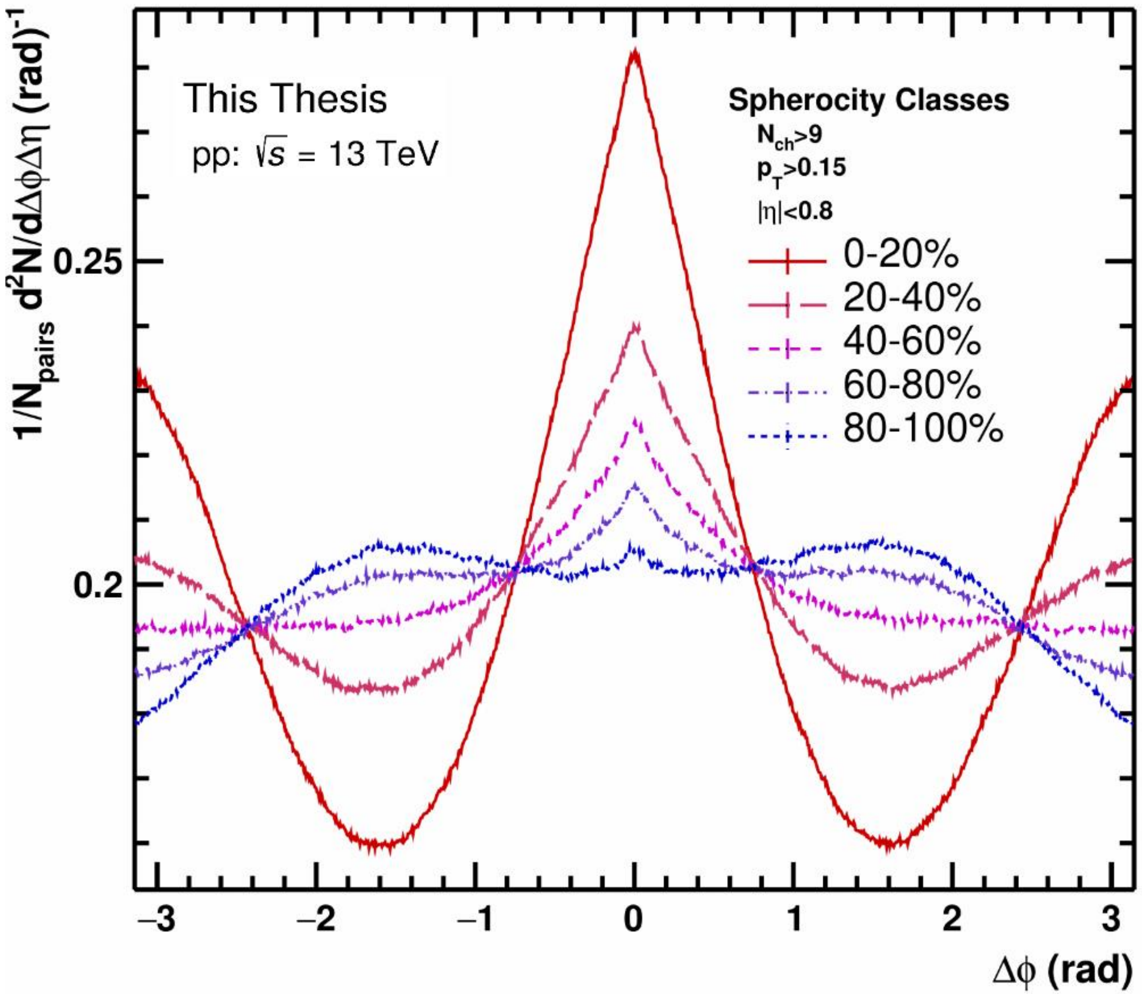
- Idea is to classify high-multiplicity events based on event topology
  - We require top 1% multiplicity ($N_{\mathrm{tracklets}}^{|\eta|<0.8}$), since this is where QGP-like effects arise
  - **Jetty:** Back-to-Back "jet-like" events
    - Particle production mainly driven by hard physics
  - **Isotropic:** Azimuthally isotropic events
    - Particle production driven by multiple softer collisions

$$S_0^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\sum_i \frac{|\widehat{p_{\mathrm{T},i}} \times \hat{n}|}{N_{\mathrm{trk}}} \right)$$

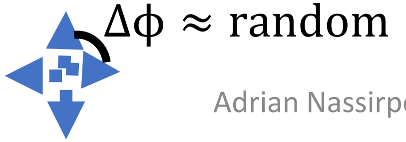


Transverse spherocity

- Idea is to classify high-multiplicity events based on event topology
  - We require top 1% multiplicity ($N_{\text{tracklets}}^{|\eta|<0.8}$) since this is where QGP-like effects arise
  - **Jetty:** Back-to-Back "jet-like" events
    - Particle production mainly driven by hard physics
  - **Isotropic:** Azimuthally isotropic events.
    - Particle production driven by multiple softer collisions



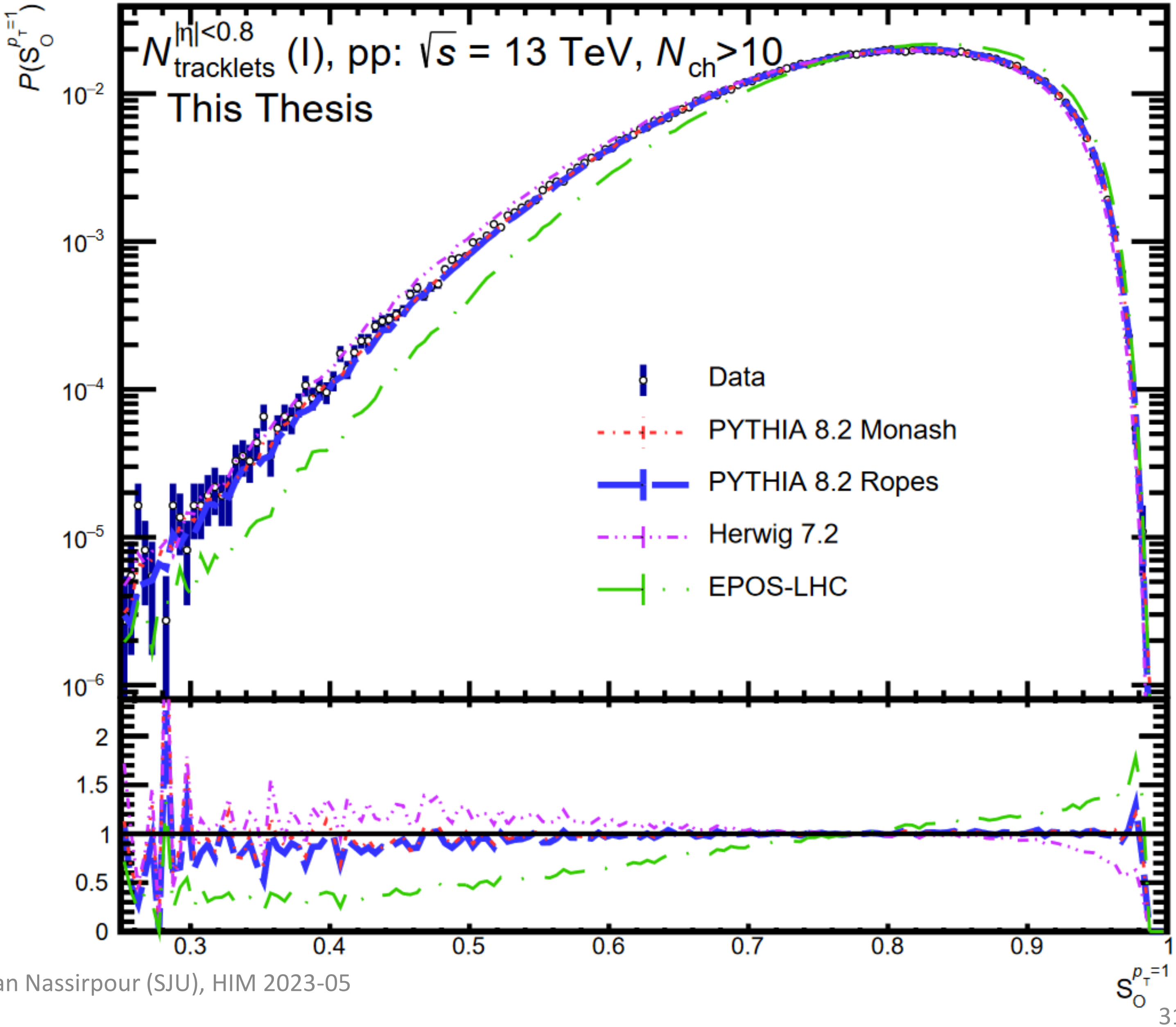
$$S_0^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\sum_i \frac{|\widehat{p_{\mathrm{T},i}} \times \hat{n}|}{N_{\mathrm{trk}}} \right)$$



Transverse spherocity distribution

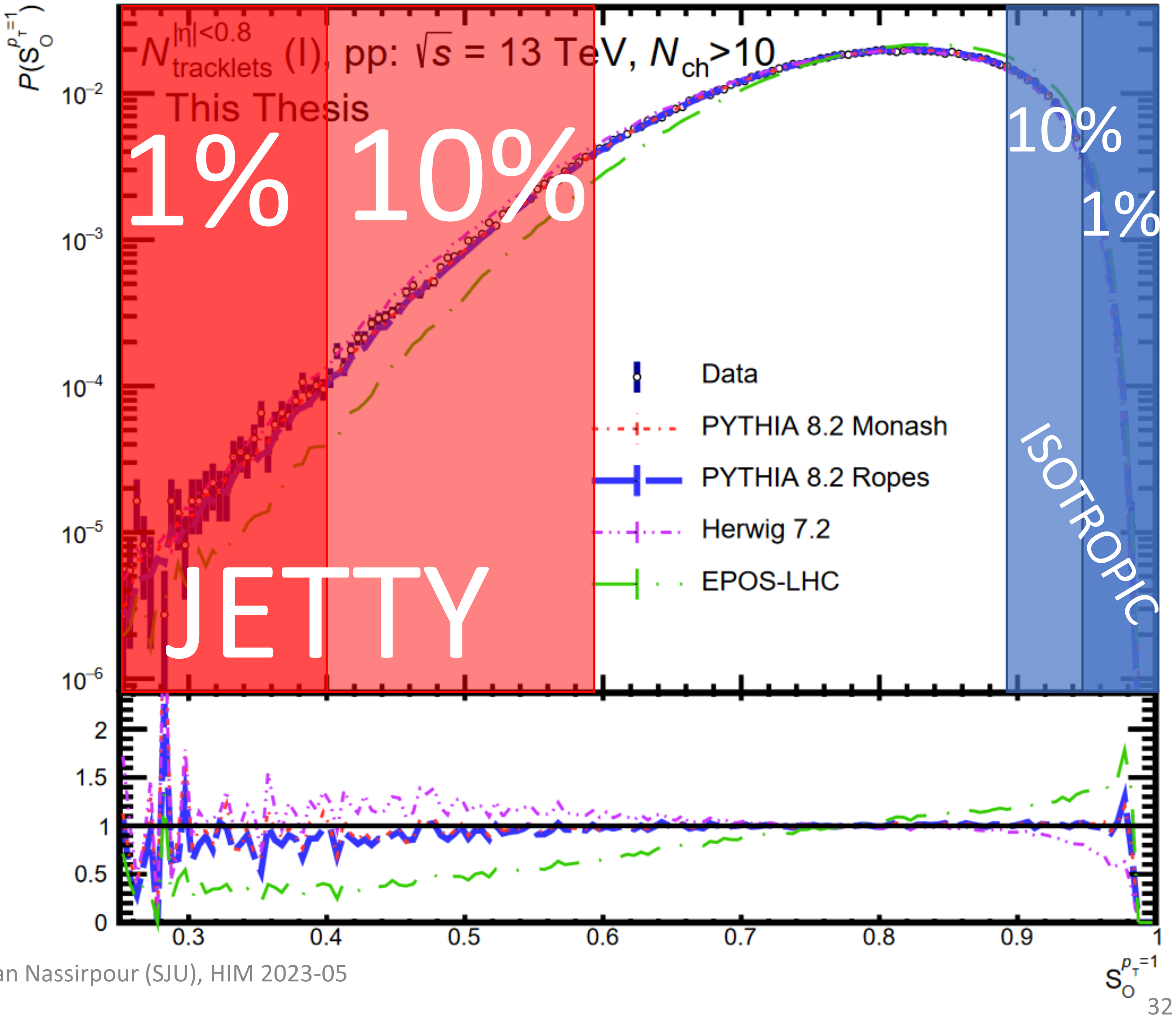
- Spherocity distribution utilizing top-1% midrapidity multiplicity ($N_{\text{tracklets}}^{|\eta|<0.8}$)

- PYTHIA tunes perform well
  - EPOSLHC and Herwig 7.2 less so.



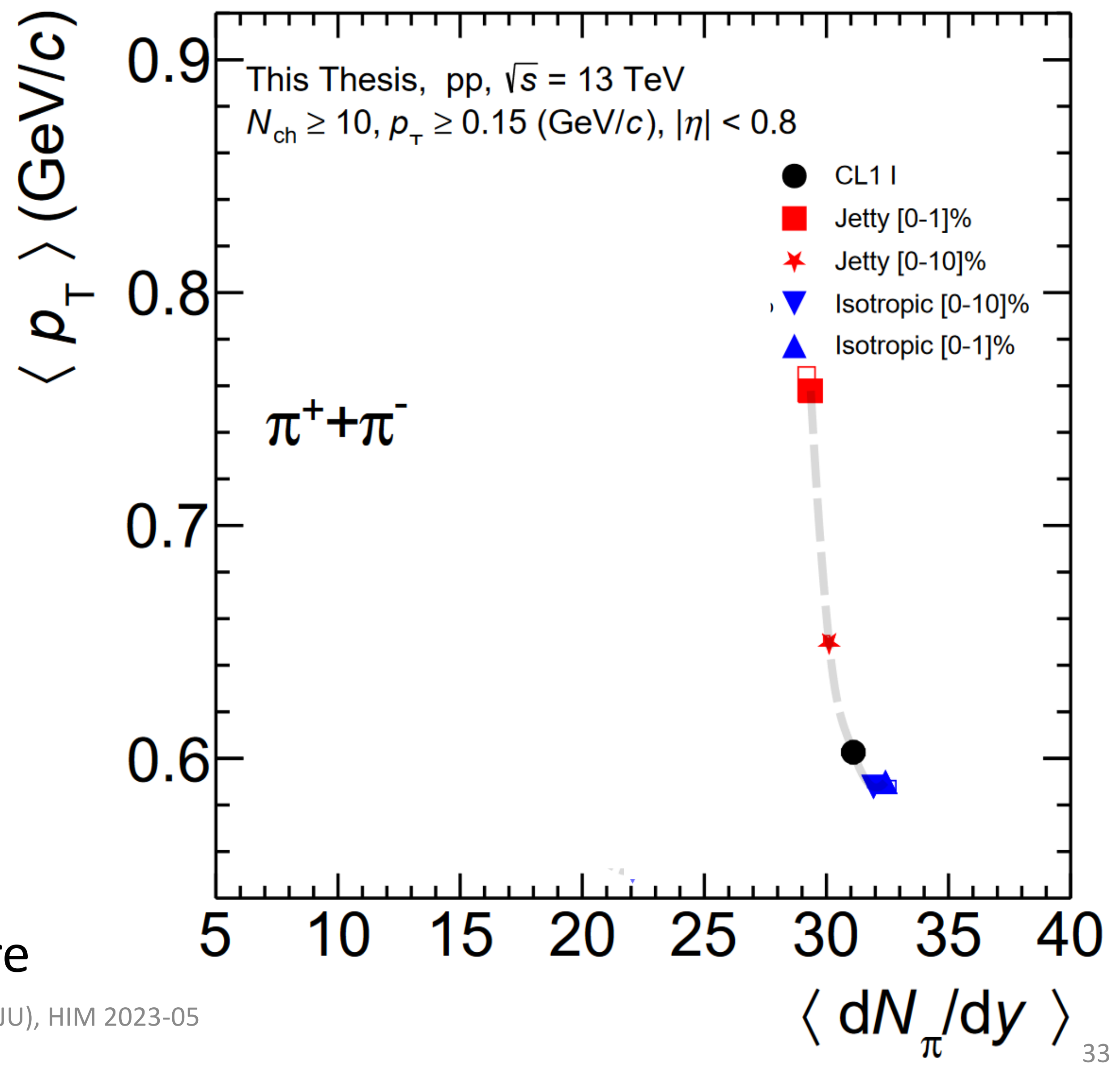
Transverse spherocity distribution

- Spherocity distribution utilizing top-1% midrapidity multiplicity ($N_{\text{tracklets}}^{|\eta|<0.8}$)
- PYTHIA tunes perform well
  - EPOSLHC and Herwig 7.2 less so.
- For now, we will focus on 10% and 1% quantiles.



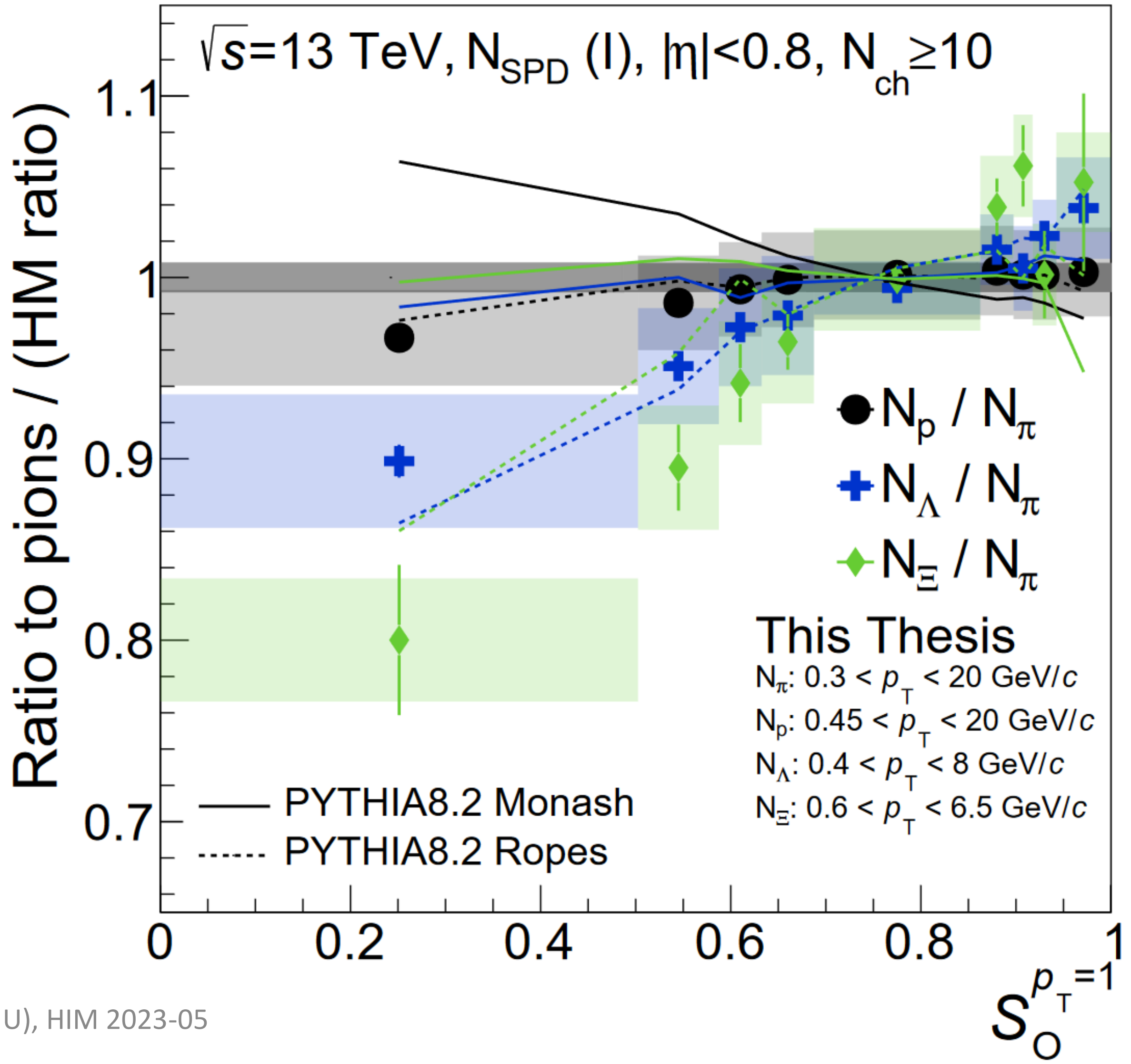
Transverse spherocity: Integrated quantities

- When using $N_{\mathrm{tracklets}}^{|\eta|<0.8}$ ($N_{\mathrm{tracklets}}^{|\eta|<0.8}$ = CL1 = N_{SPD}) in conjunction with spherocity selection, we observe:
  - Large shift in $< p_{\mathrm{T}} >$
  - Very small (≈10%) shift in yield
- Autocorrelation a feature, not a bug!
  - Normally, high-multiplicity midrapidity measurements are biased towards jets
  - However, in our case, we seem to capture them in our jetty events!



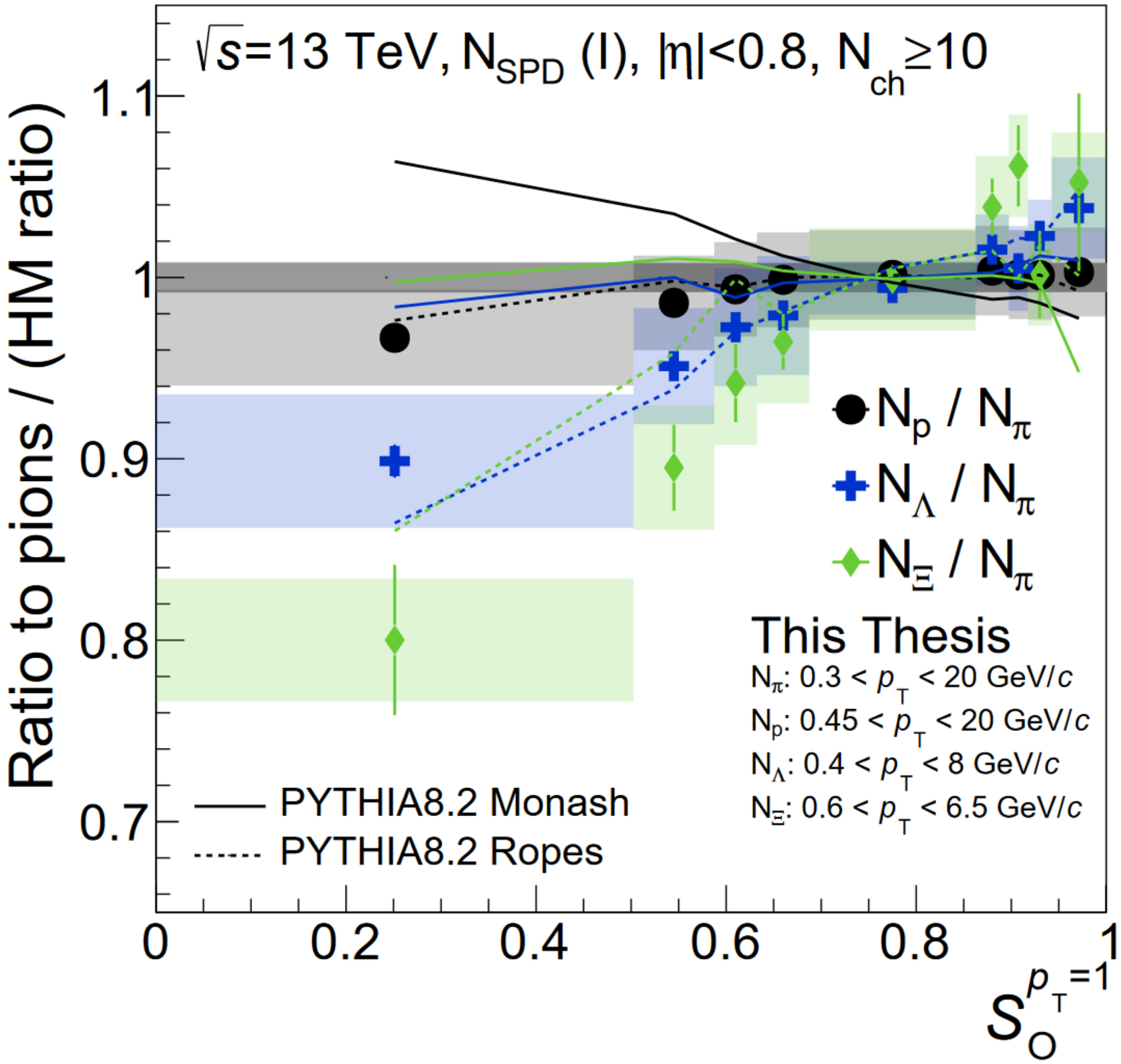
Transverse spherocity: Integrated Double Ratio

- Most impactful plot of this analysis



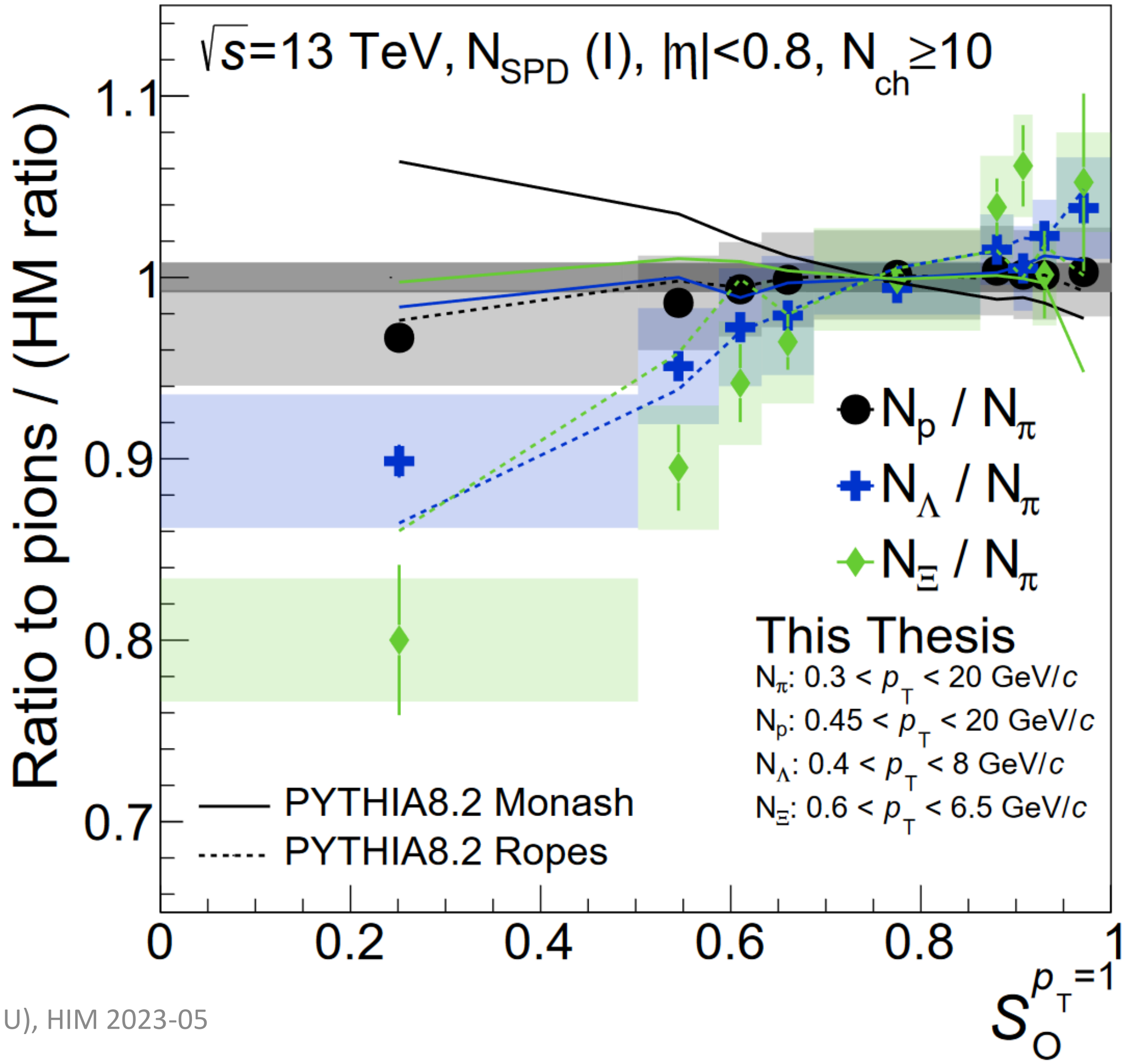
Transverse spherocity: Integrated Double Ratio

- Most impactful plot of this analysis
- Significant suppression of yields in Jetty events
  - Proton is largely unmodified
  - Approximately 20% effect for Ξ
  - Strength is ordered in strangeness



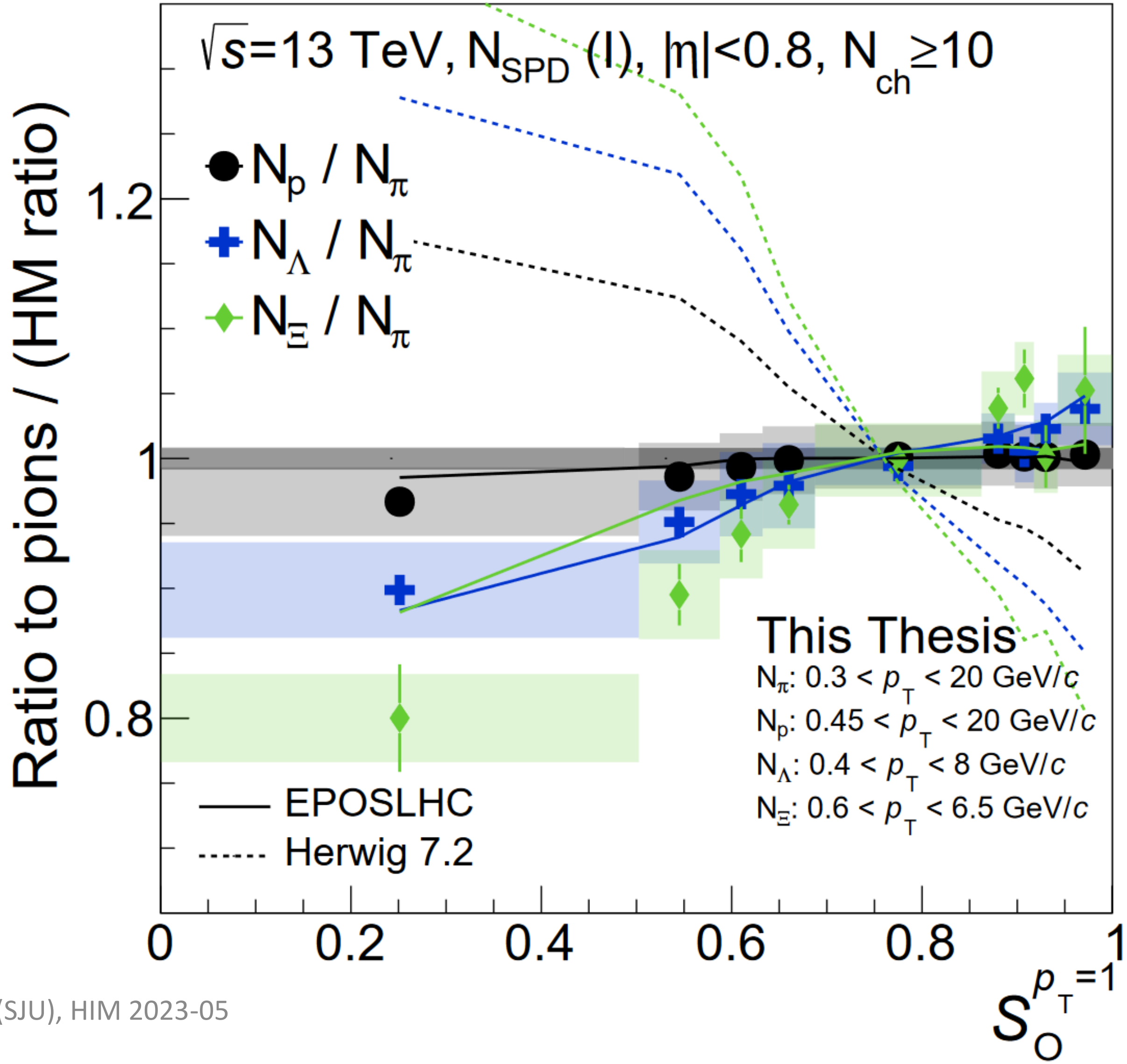
Transverse spherocity: Integrated Double Ratio

- Most impactful plot of this analysis
- Significant suppression of yields in Jetty events
  - Proton is largely unmodified
  - Approximately 20% effect for Ξ
  - Strength is ordered in strangeness
- MC predictions:
  - PYTHIA Ropes predicts qualitative trend, but not correcting strangeness ordering



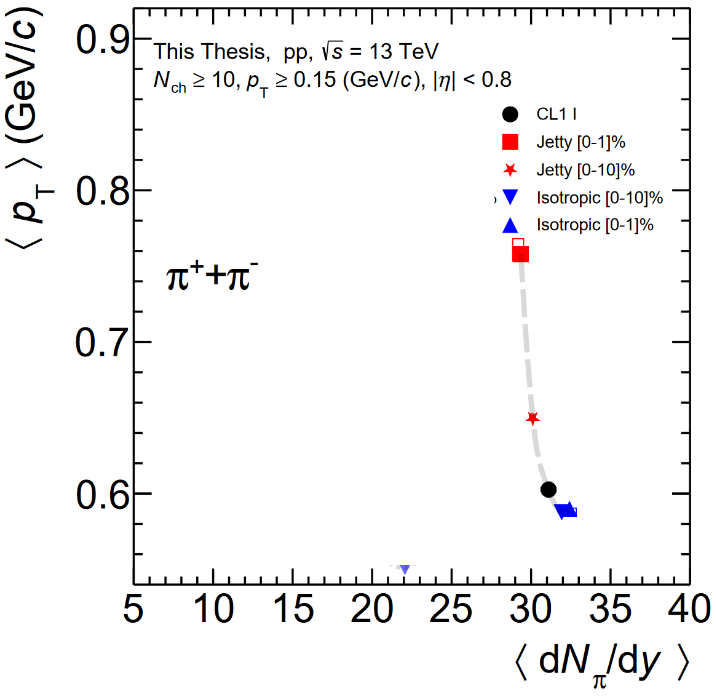
Transverse spherocity: Integrated Double Ratio

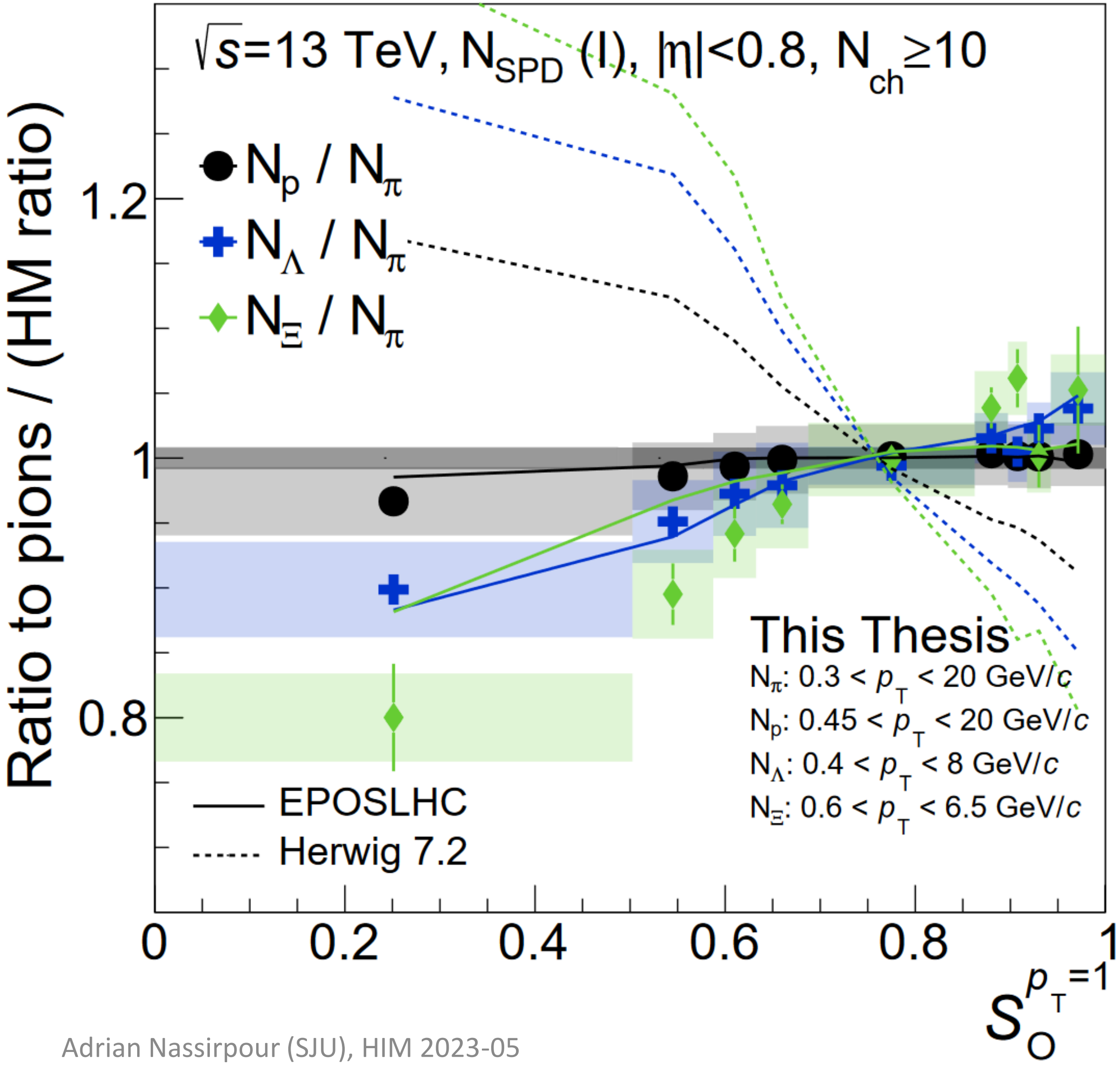
- Most impactful plot of this analysis
- Significant suppression of yields in Jetty events
  - Proton is largely unmodified
  - Approximately 20% effect for Ξ
  - Strength is ordered in strangeness
- MC predictions:
  - PYTHIA Ropes predicts qualitative trend, but not correcting strangeness ordering
    - Same applies for EPOS
    - Herwig 7.2 and PYTHIA Monash are unable to capture trends



Transverse spherocity: Integrated Double Ratio

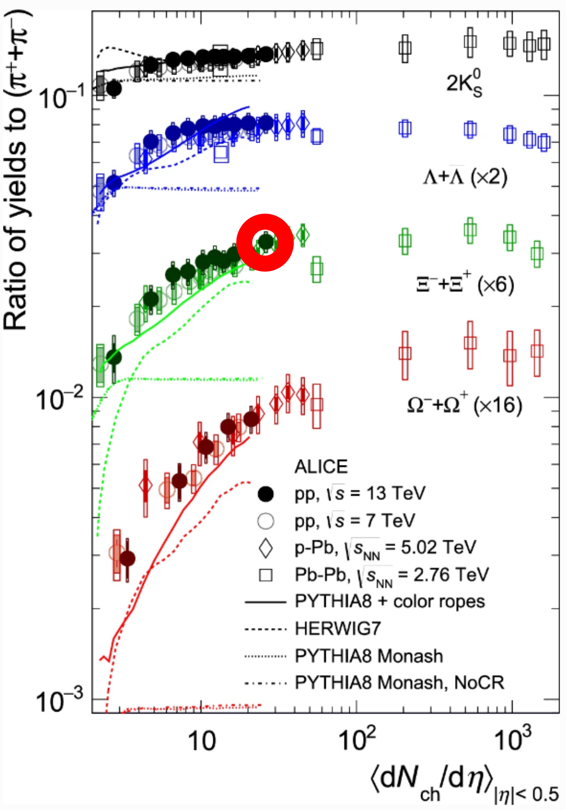
- Most impactful plot of this analysis
- Remember that the multiplicity is constrained (≈10%)

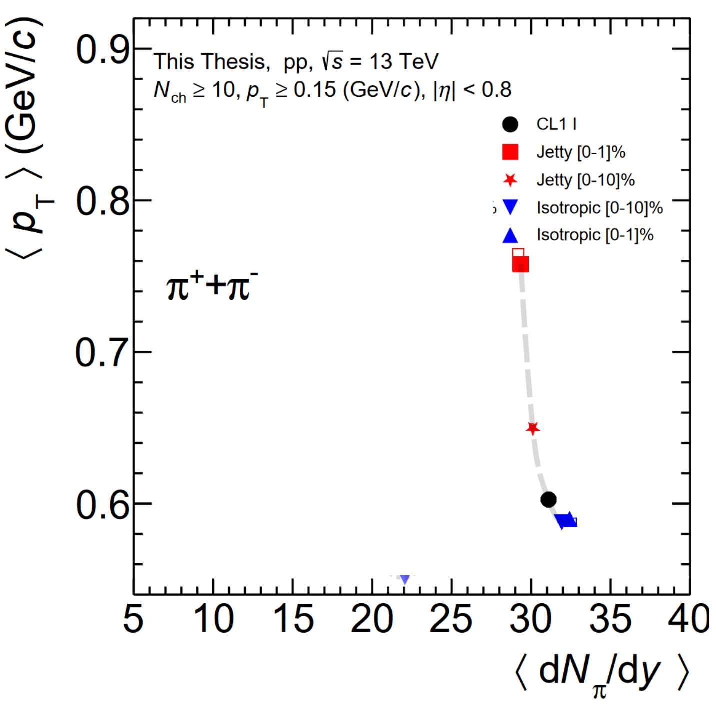


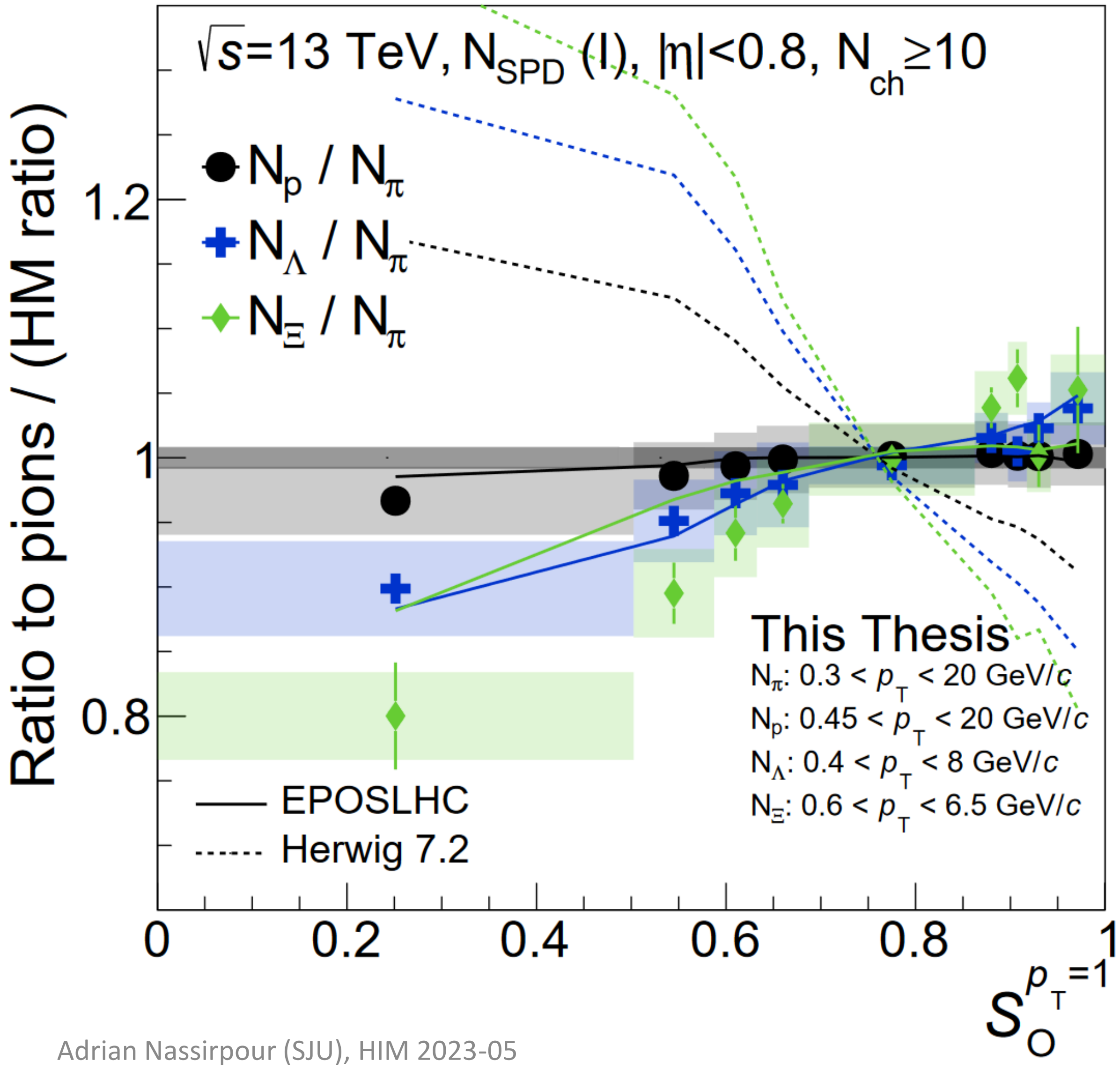


Transverse spherocity: Integrated Double Ratio

- Most impactful plot of this analysis
- Remember that the multiplicity is constrained (≈10%)
  - 20% effect requires 200-300% mult



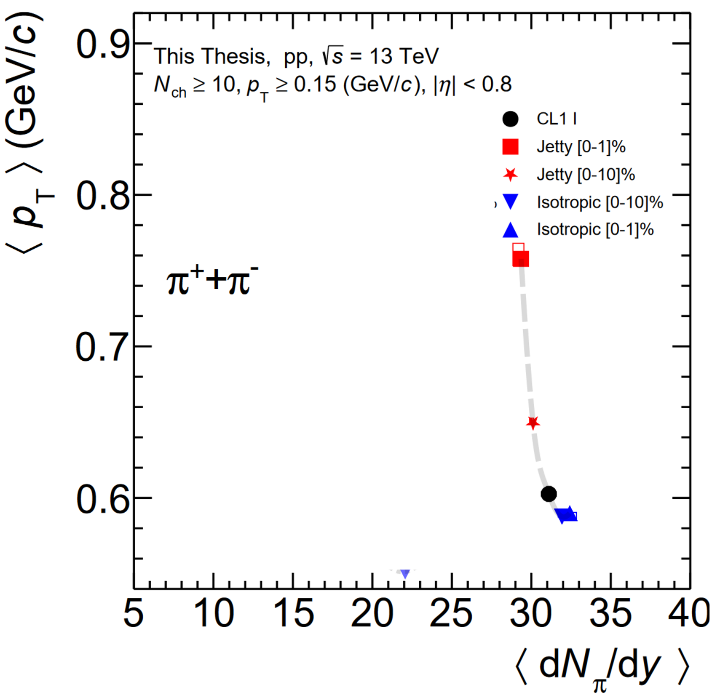


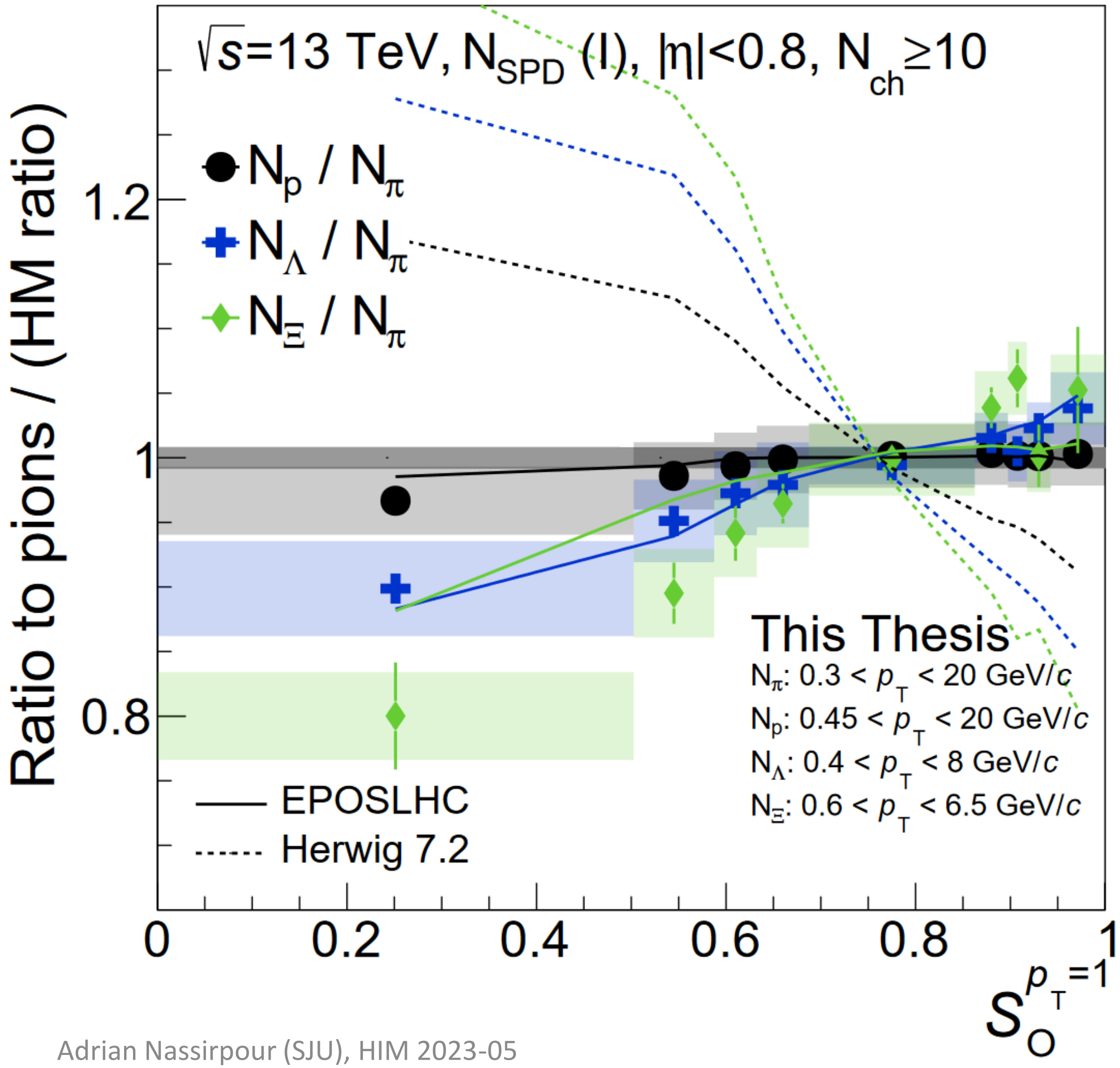


Transverse spherocity: Integrated Double Ratio

- Most impactful plot of this analysis
- Remember that the multiplicity is constrained (≈10%)
  - 20% effect requires 200-300% mult

- HM events seem to be largely homogenous
  - Soft, “QCD-like” features seem to be the norm
  - Hard, jet-like features seem to be outliers



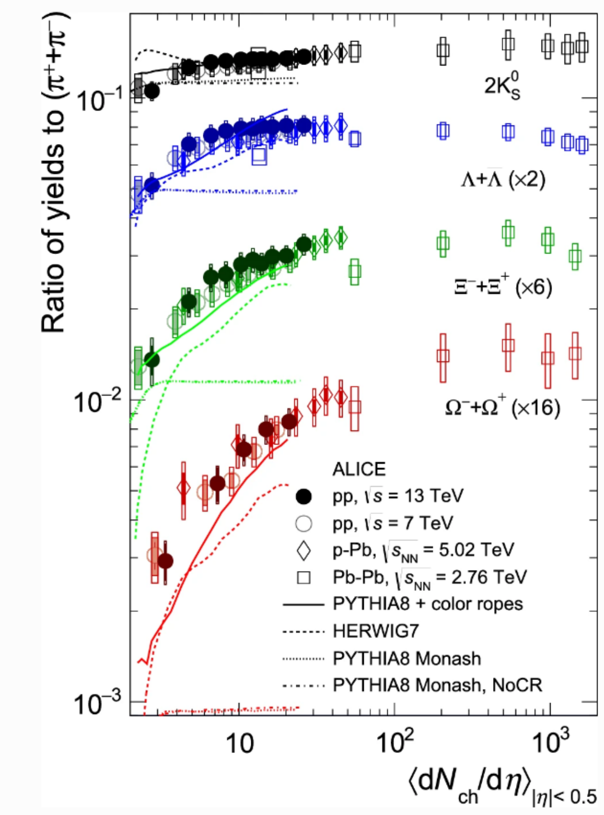


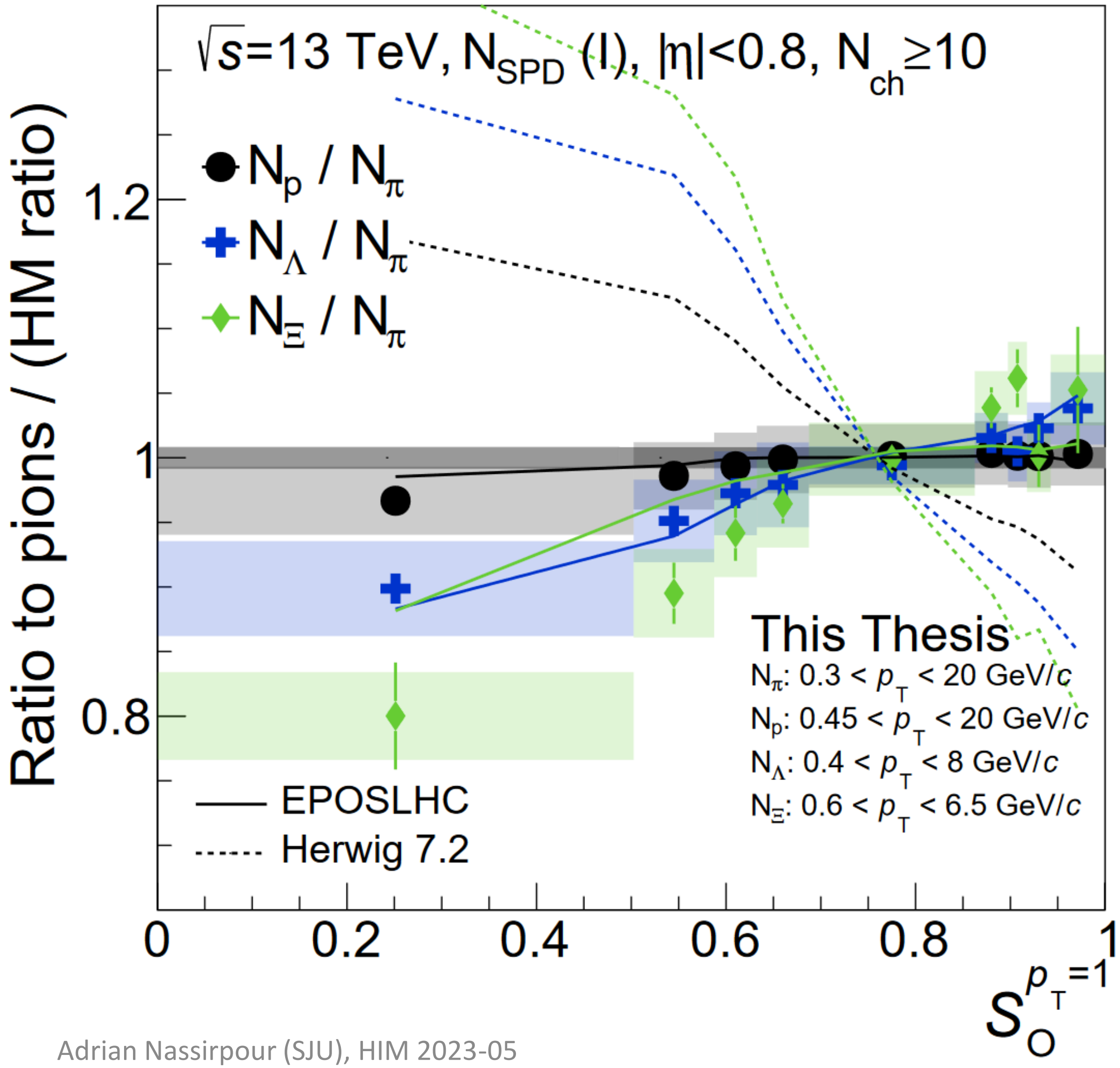
Transverse spherocity: Integrated Double Ratio

- Most impactful plot of this analysis
- Remember that the multiplicity is constrained (≈10%)
  - 20% effect requires 200-300% mult

- HM events seem to be largely homogenous
  - Soft, “QCD-like” features seem to be the norm
  - Hard, jet-like features seem to be outliers

- Strangeness enhancement seems to be feature of the UE/soft physics

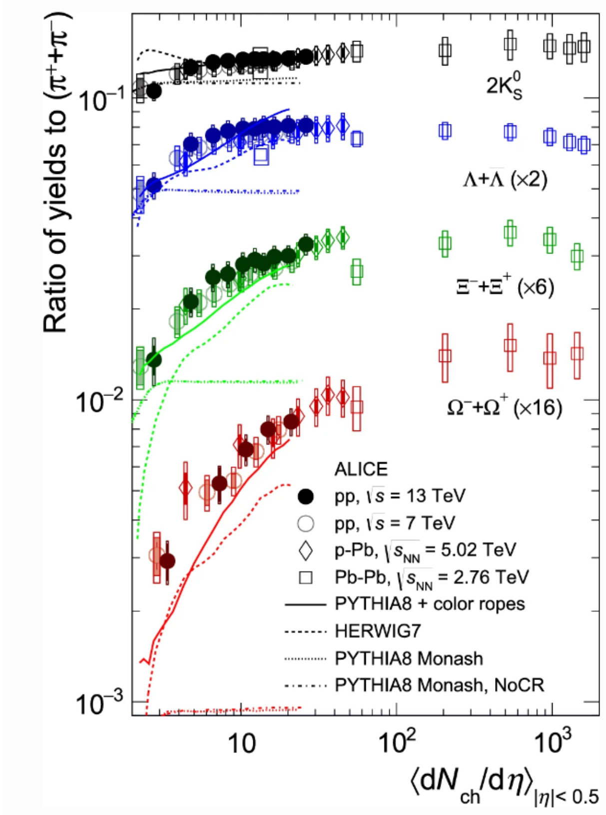


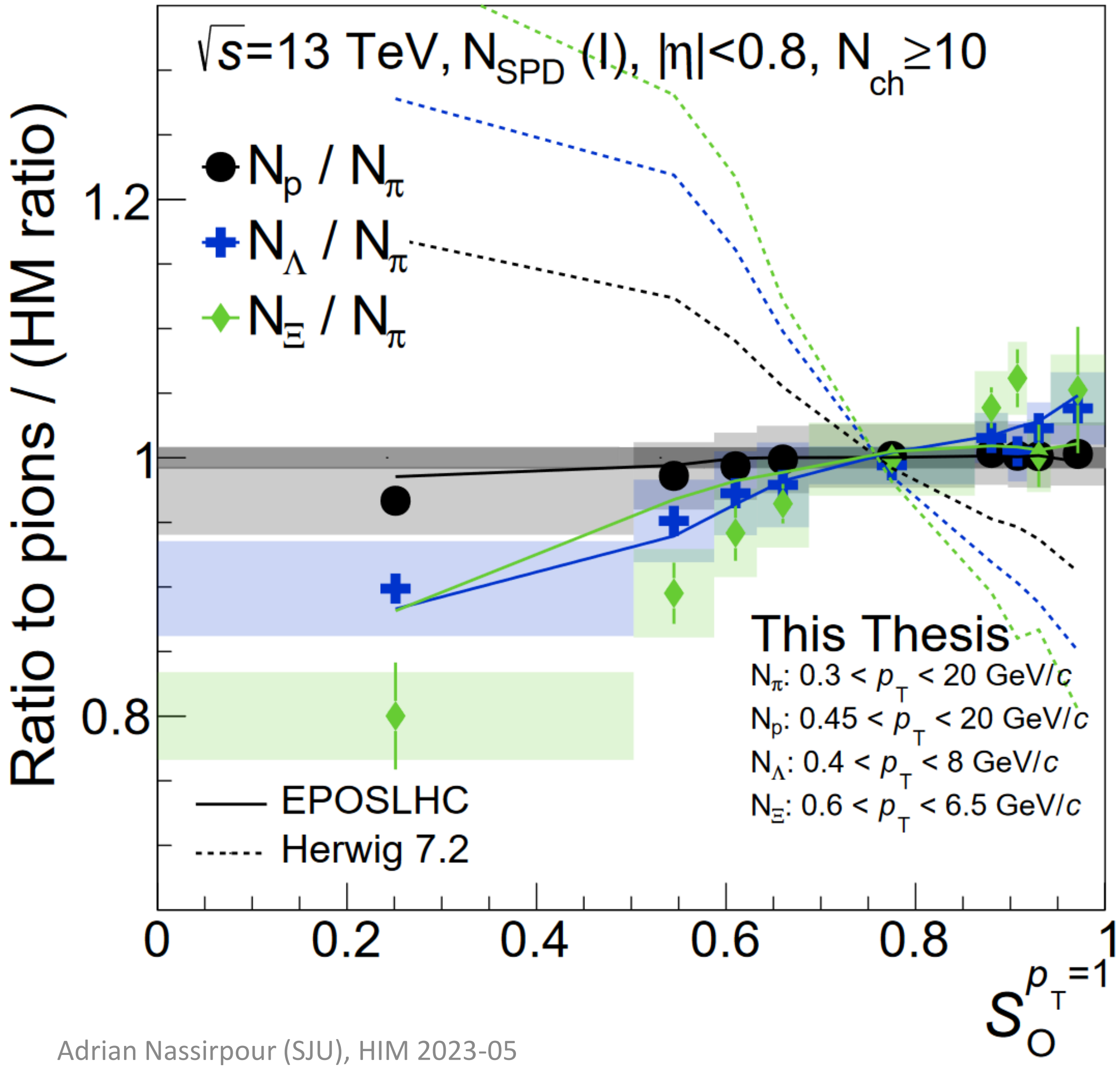


Transverse spherocity: Integrated Double Ratio

- Most impactful plot of this analysis
- Remember that the multiplicity is constrained (≈10%)
  - 20% effect requires 200-300% mult

More Mult -> More Strangeness

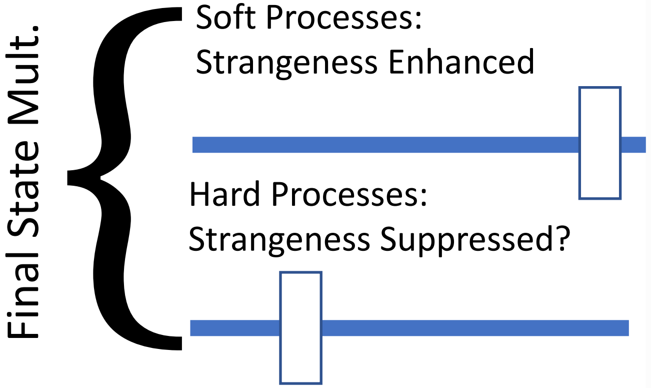


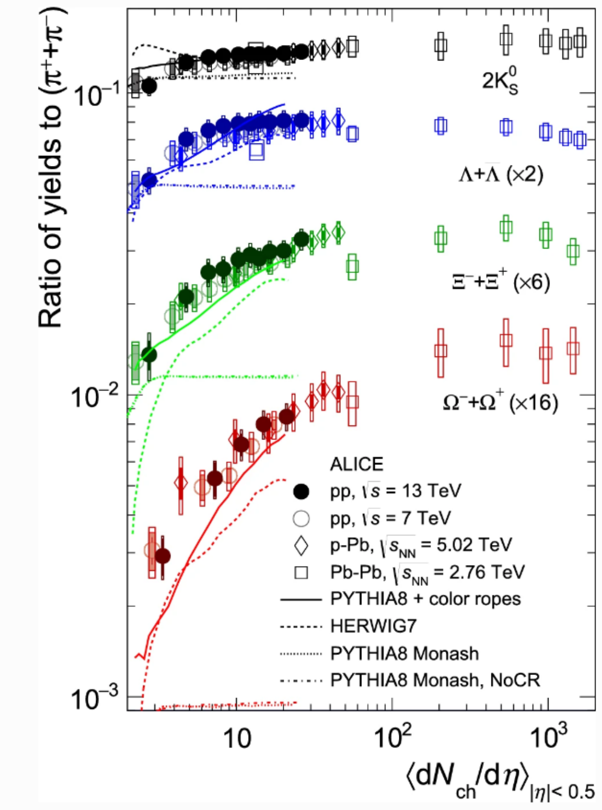


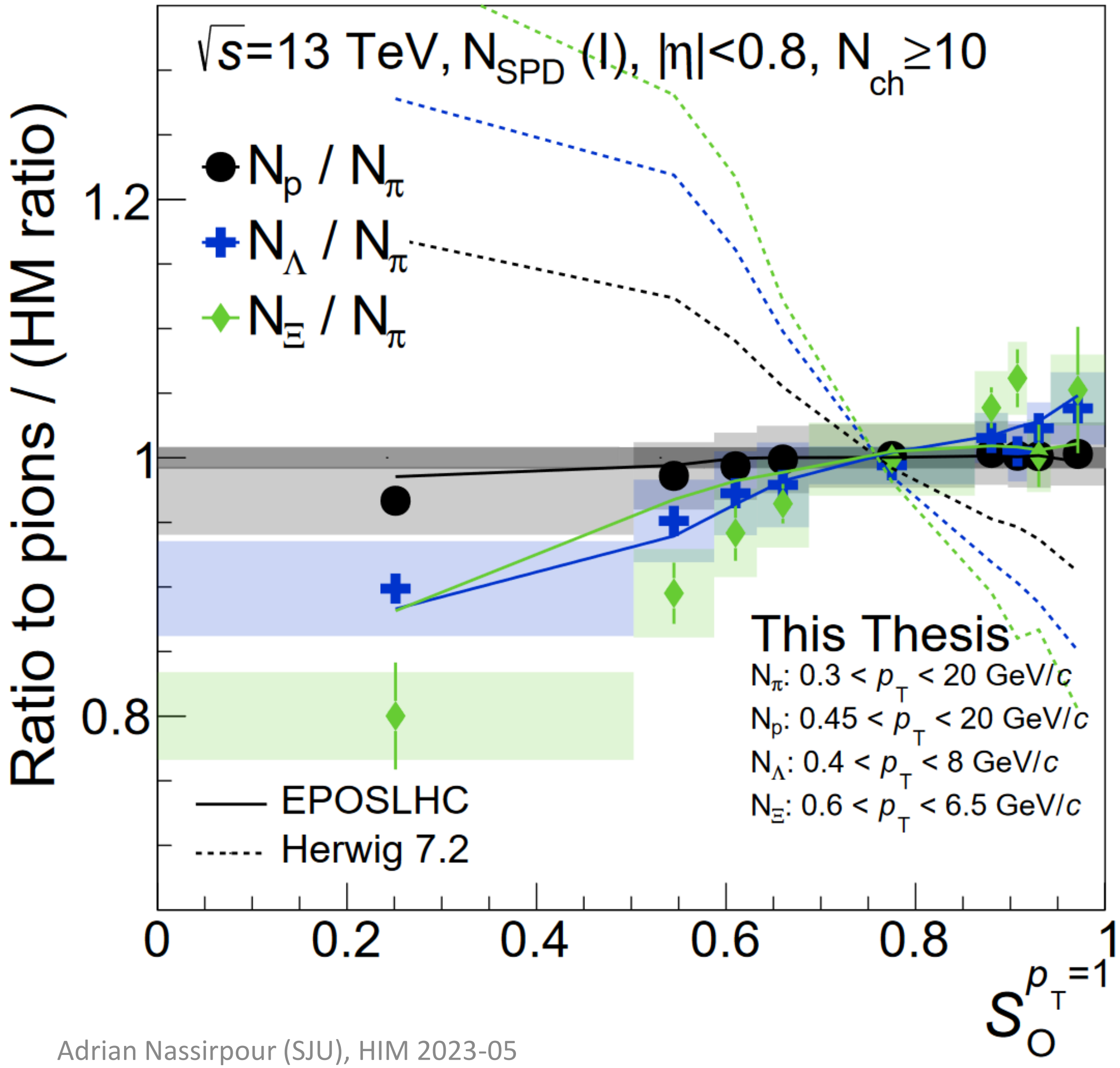
- Strangeness enhancement seems to be feature of the UE/soft physics

Transverse spherocity: Integrated Double Ratio

- Most impactful plot of this analysis
- Remember that the multiplicity is constrained (≈10%)
  - 20% effect requires 200-300% mult







- Strangeness enhancement seems to be feature of the UE/soft physics

Outline

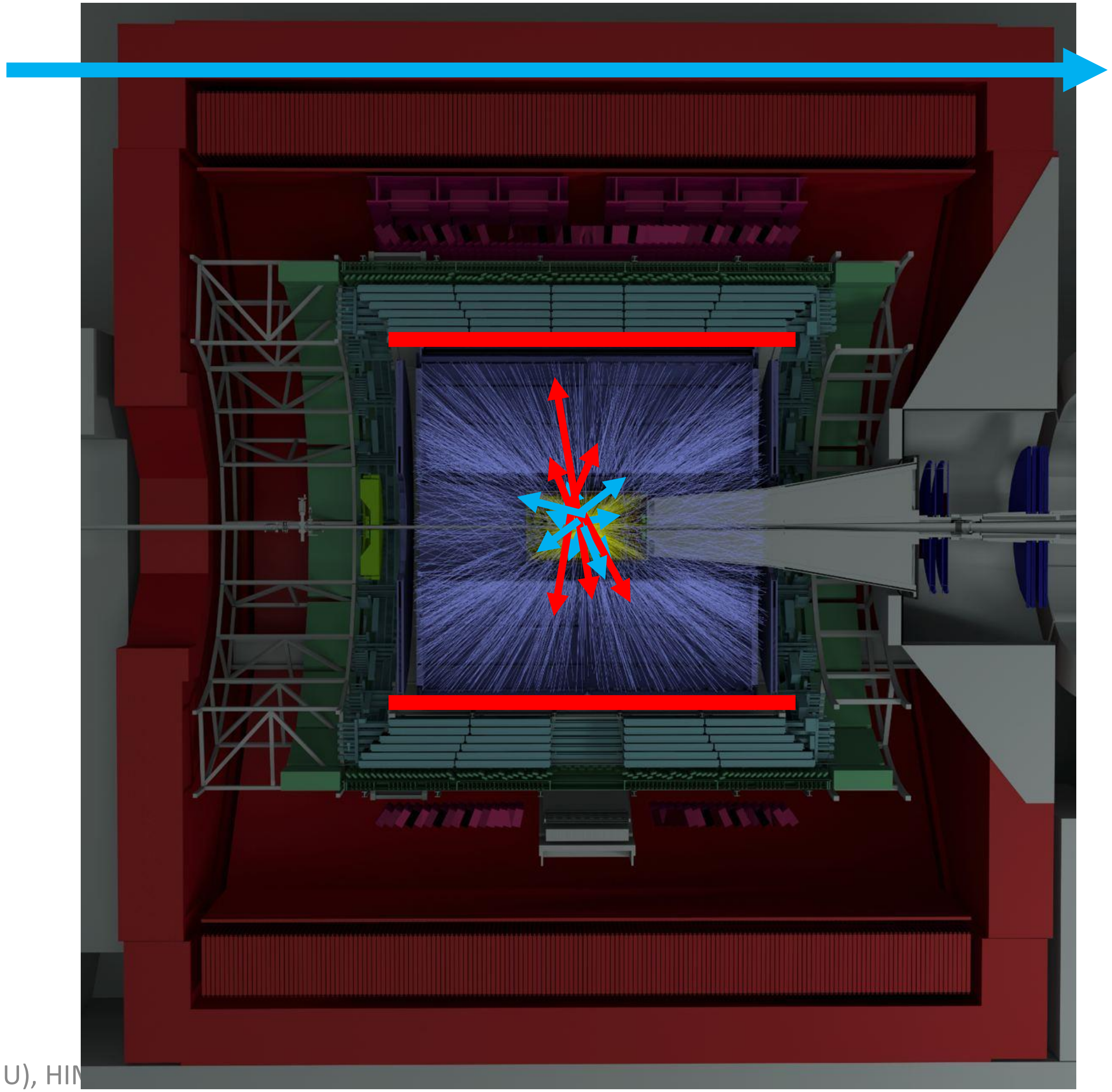
1. Motivation

2. Transverse spherocity
   2.1. Utilizing mid-rapidity multiplicity
   2.2. Broader multiplicity definitions

All plots taken from this thesis: http://cds.cern.ch/record/2848793

Transverse spherocity: Stranger than fiction

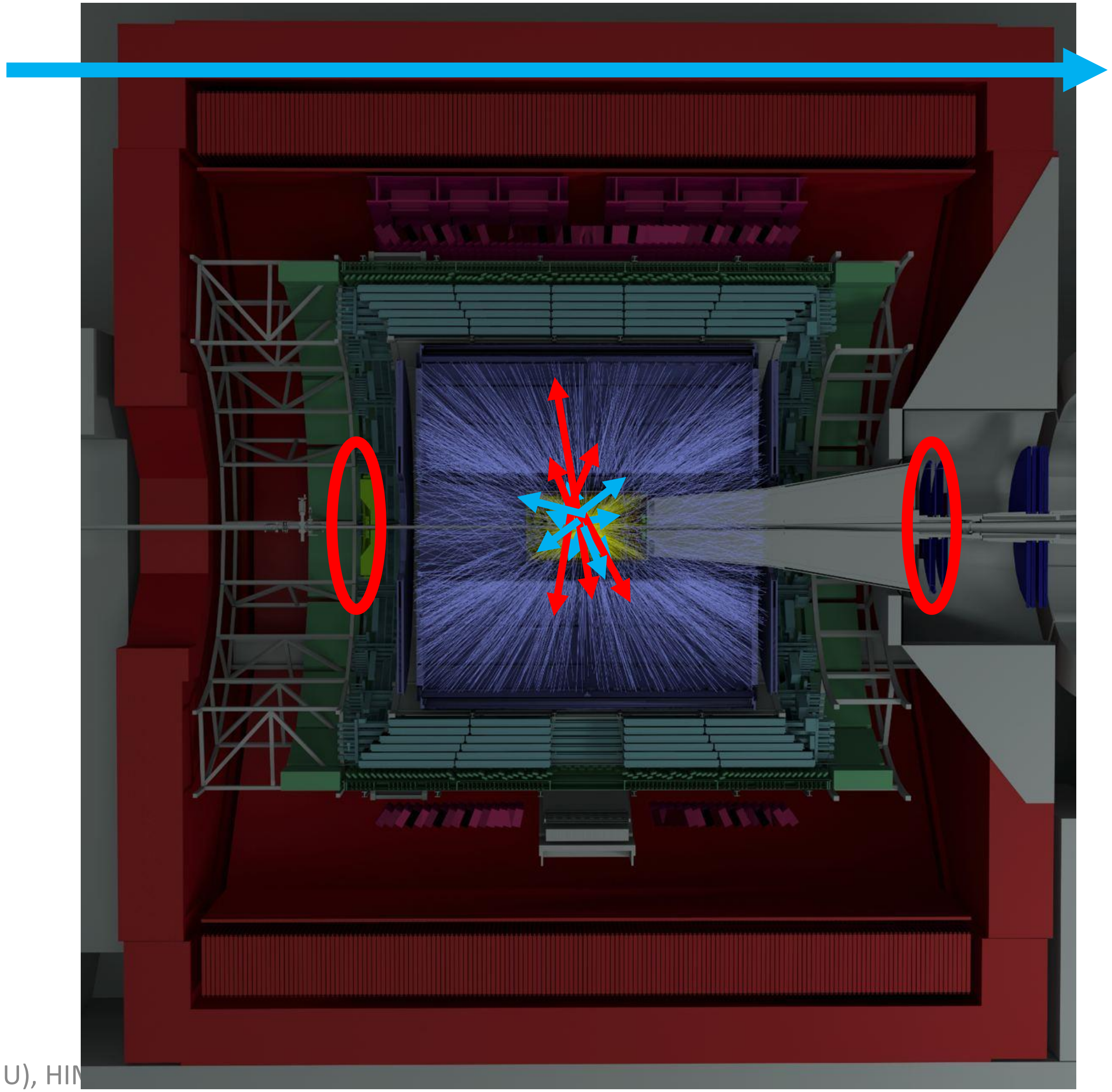
- How does this compare to a V0M multiplicity selection?
  - Multiplicity selection at forward rapidities



Adrian Nassirpour (SJU), HIM 2023-05

Transverse spherocity: Stranger than fiction

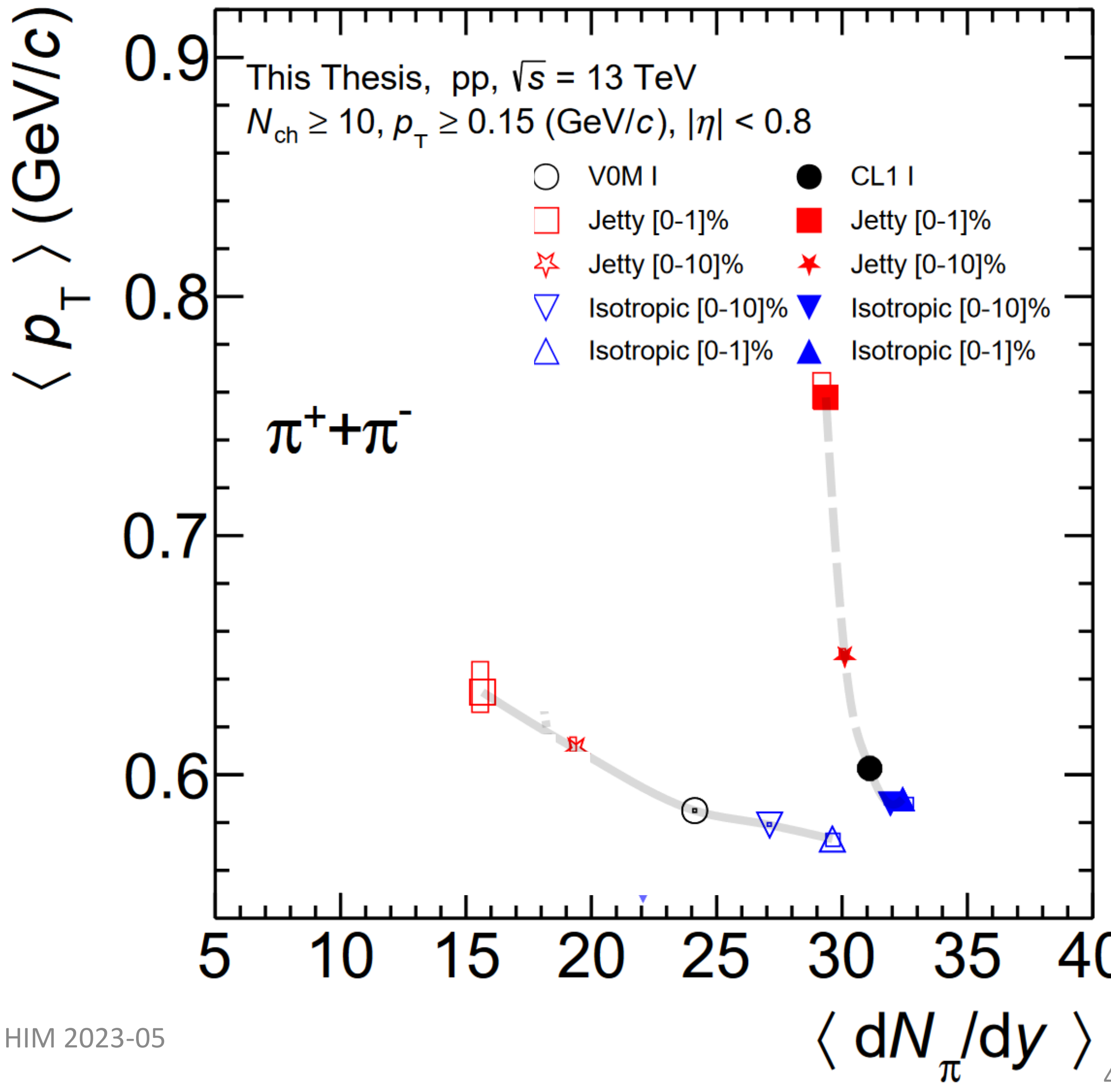
- How does this compare to a V0M multiplicity selection?
  - Multiplicity selection at forward rapidities



Adrian Nassirpour (SJU), HIM 2023-05

Transverse spherocity: Stranger than fiction

- How does this compare to a V0M multiplicity selection?
  - Multiplicity selection at forward rapidities

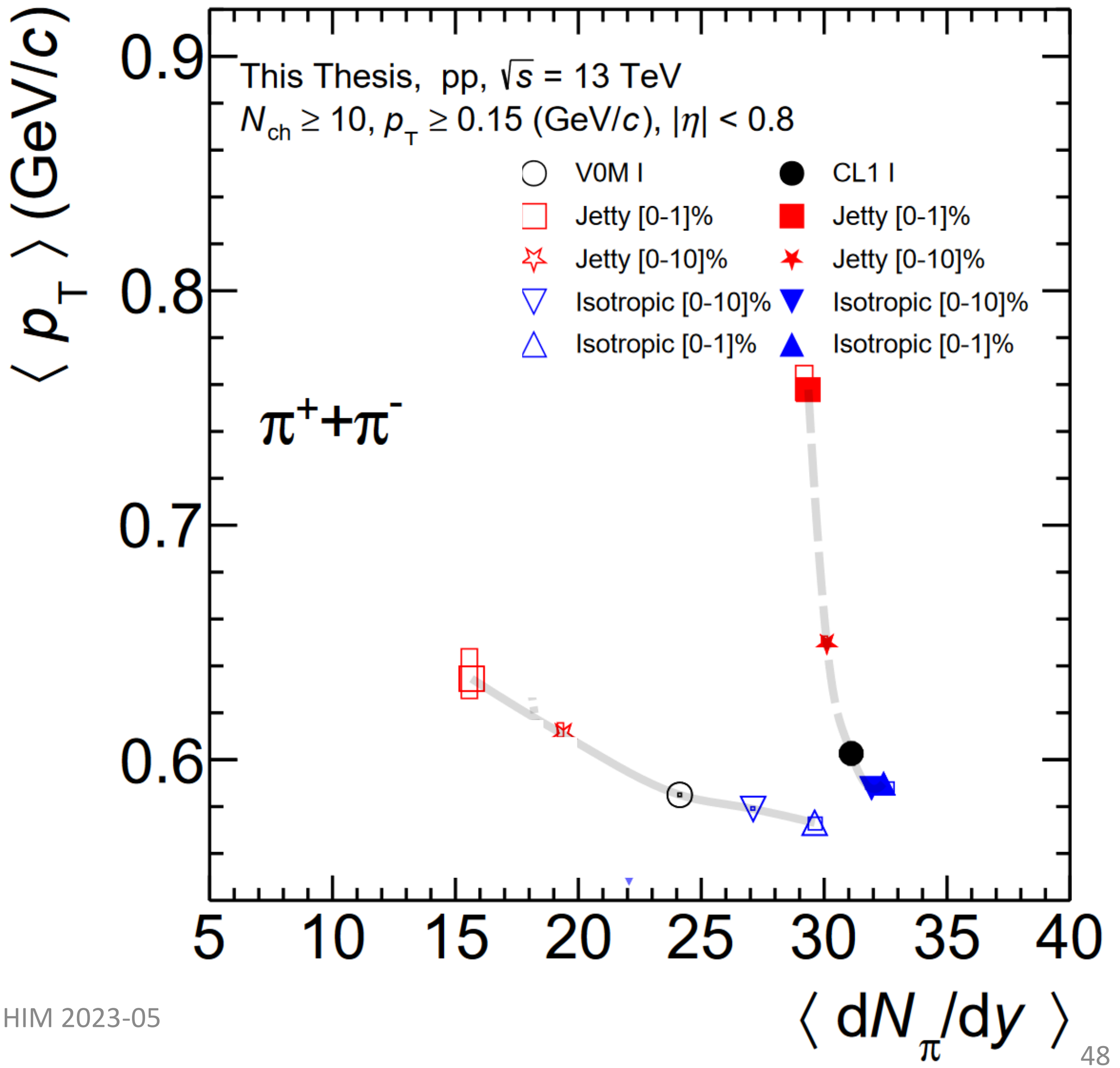


Transverse spherocity: Stranger than fiction

- How does this compare to a V0M multiplicity selection?
  - Multiplicity selection at forward rapidities

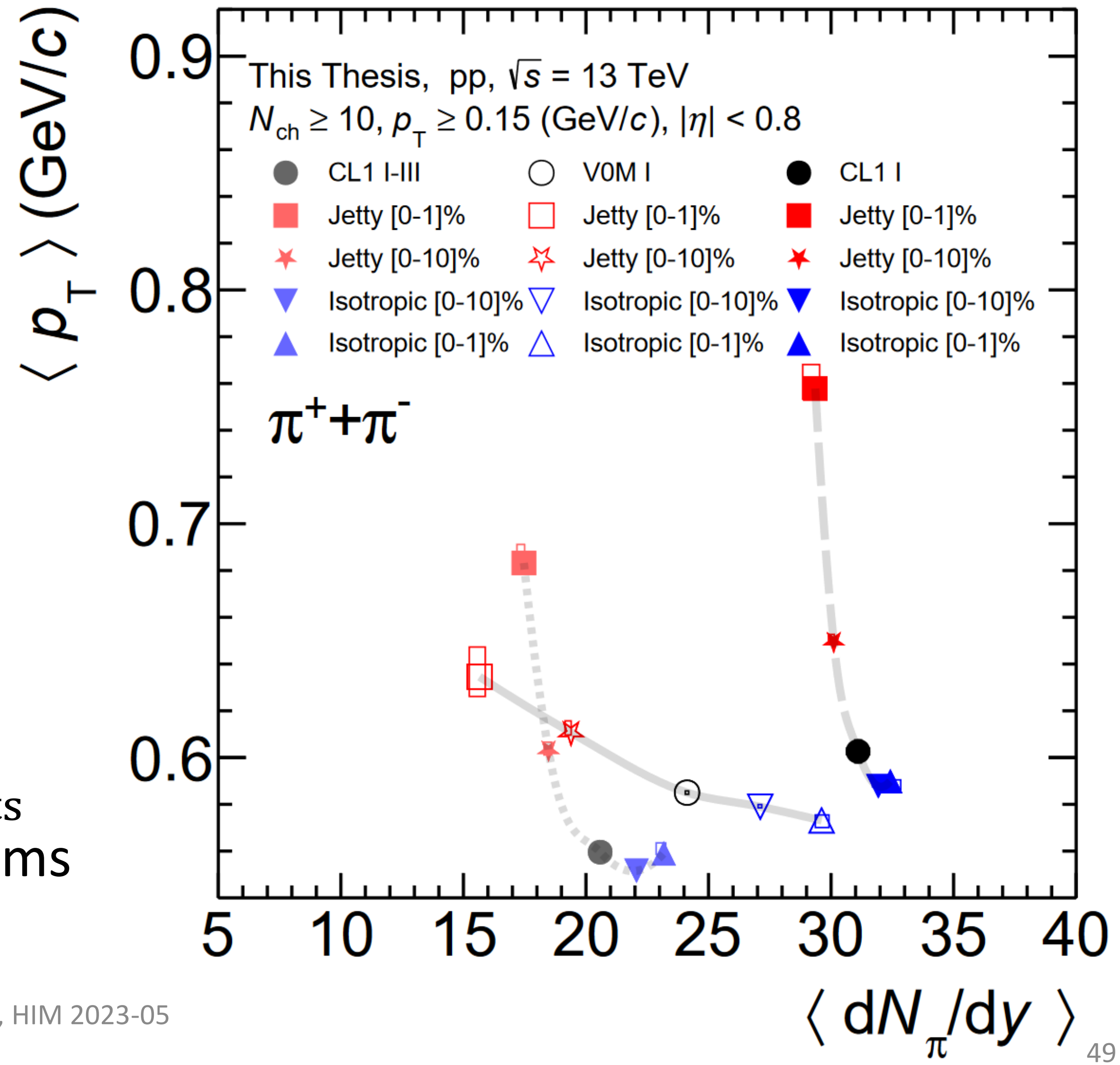
- Now, the differential selection is instead:
  - Sensitive to large swings in yield (order of 2x effect)

  - Decreased sensitivity to $< p_{\mathrm{T}} >$



Transverse spherocity: Stranger than fiction

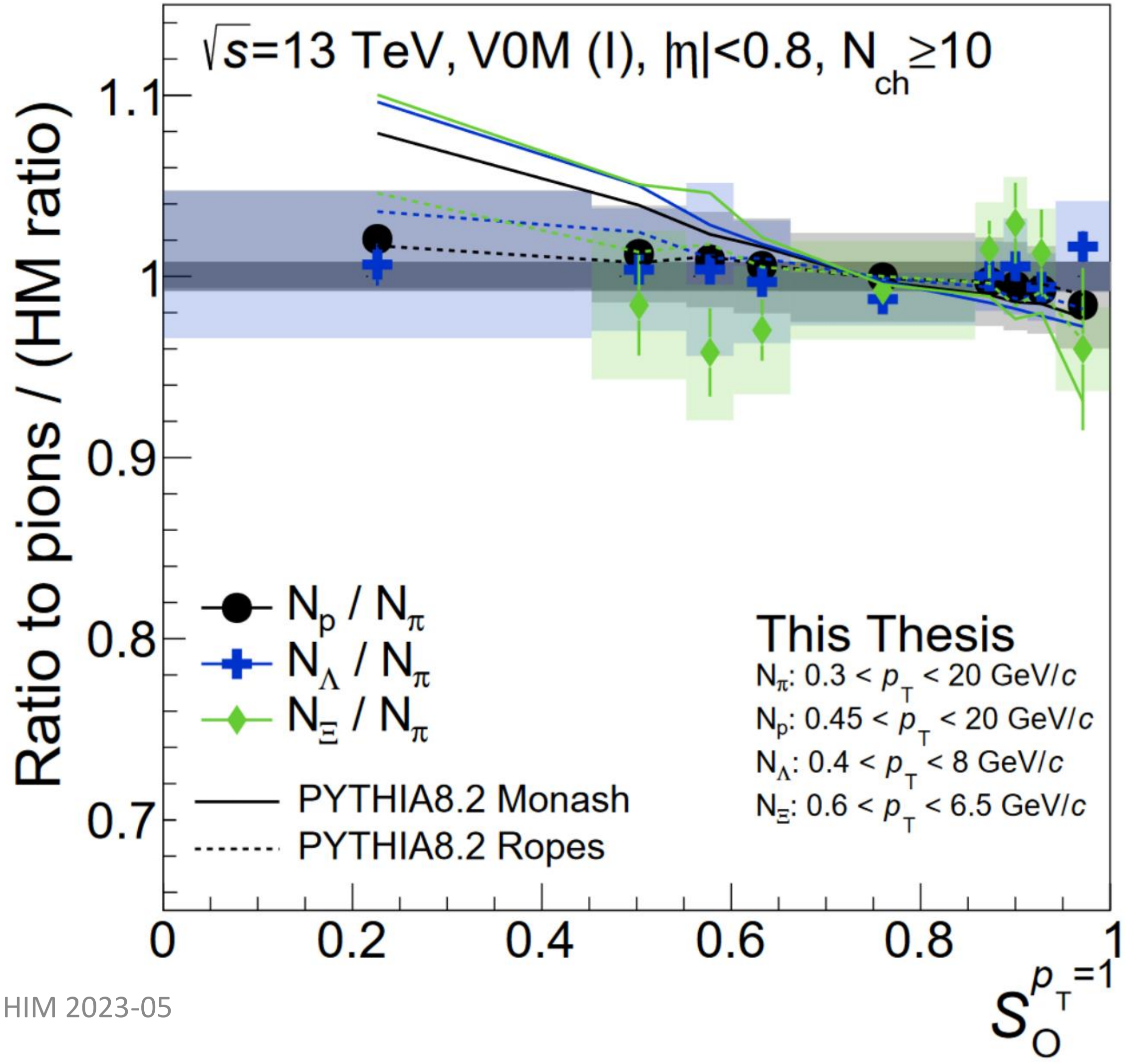
- How does this compare to a V0M multiplicity selection?
  - Multiplicity selection at forward rapidities
- Now, the differential selection is instead:
  - Sensitive to large swings in yield (order of 2x effect)
  - Decreased sensitivity to $< p_{\mathrm{T}} >$
- We can contrast this with broadened $N_{\mathrm{tracklets}}^{|\eta|<0.8}$
  - Covering similar yields, but different in terms of hardness



Transverse spherocity: V0M vs $N_{\mathrm{tracklets}}^{|\eta|<0.8}$

- No strangeness enhancement observed when selecting multiplicity at forward rapidities
  - Why?

$2.8<\eta<5.1$, $-3.7<\eta<-1.7$

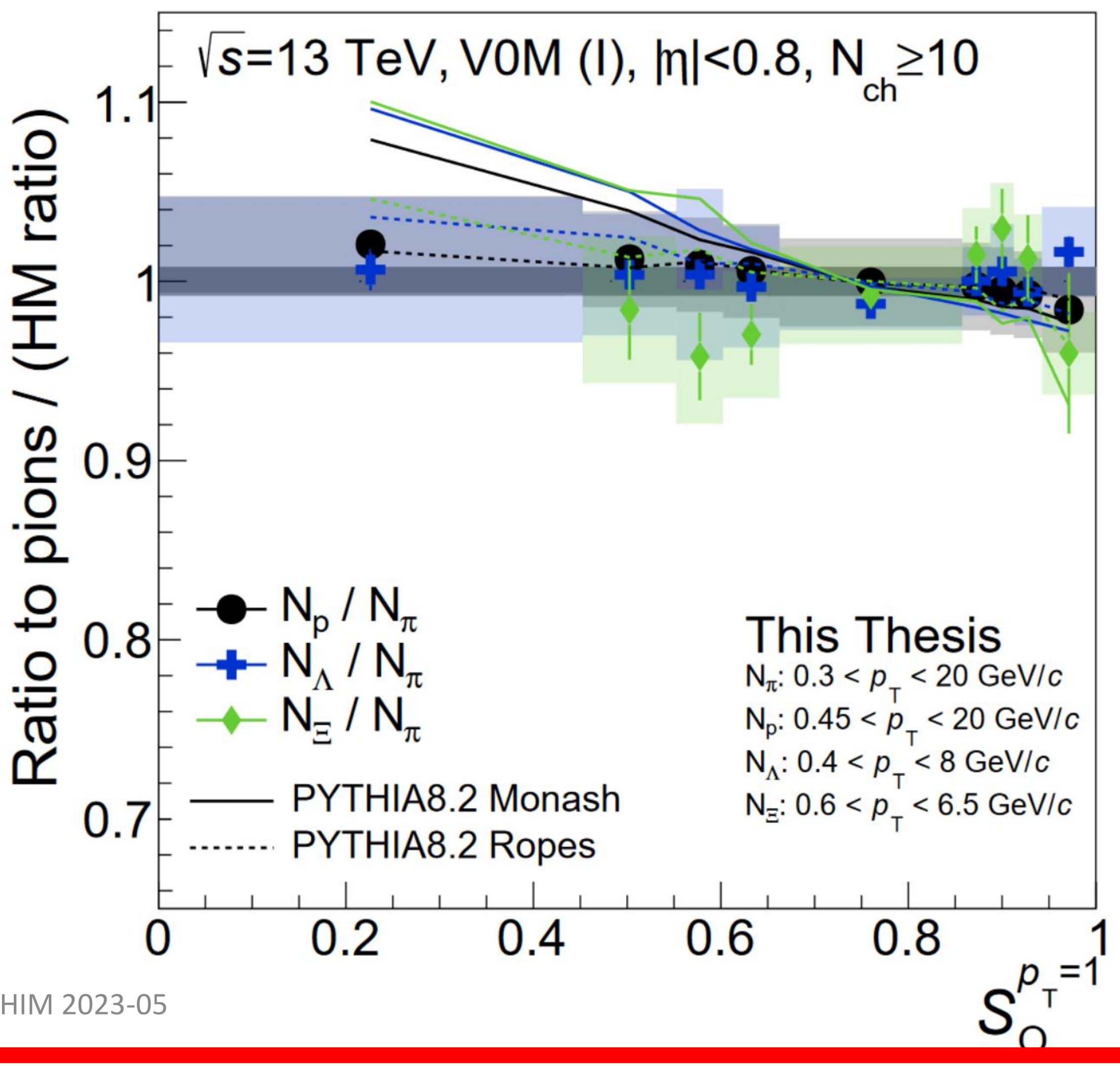


SPECULATION ZONE

Transverse spherocity: V0M vs $N_{\mathrm{tracklets}}^{|\eta|<0.8}$

- No strangeness enhancement observed when selecting multiplicity at forward rapidities
  - Why?

$2.8<\eta<5.1$, $-3.7<\eta<-1.7$

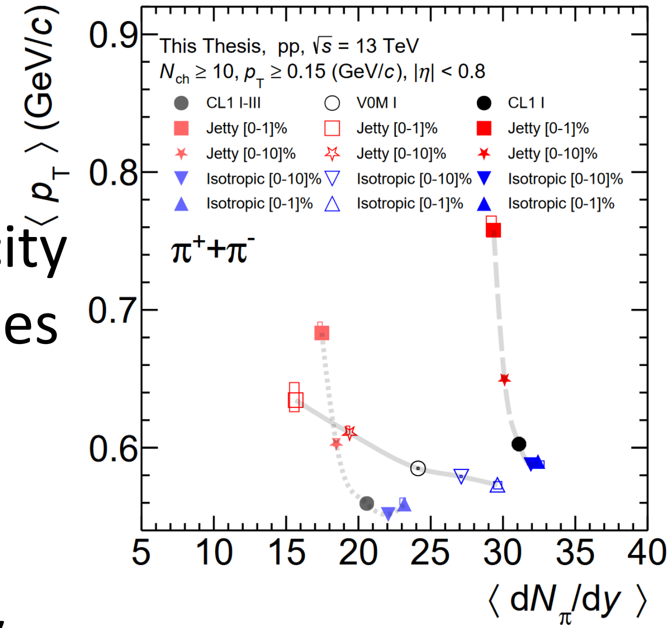


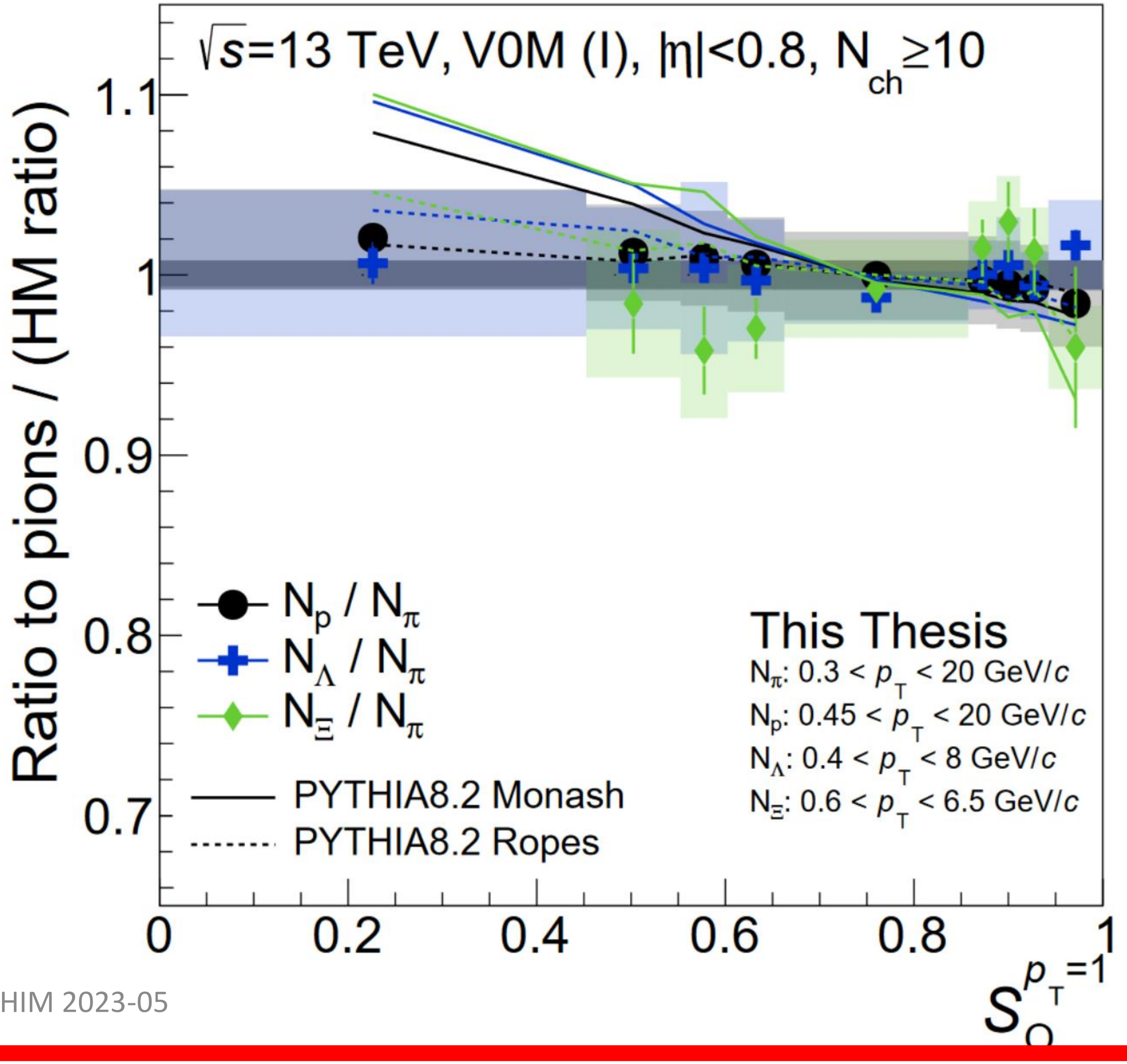
SPECULATION ZONE

Transverse spherocity: V0M vs $N_{\text{tracklets}}^{|\eta|<0.8}$

$2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$

- No strangeness enhancement observed when selecting multiplicity at forward rapidities
    - Why?
- Correlation between topology and mode of production?
    - $N_{\text{tracklets}}^{|\eta|<0.8}$: Different modes
    - V0M: More of the same





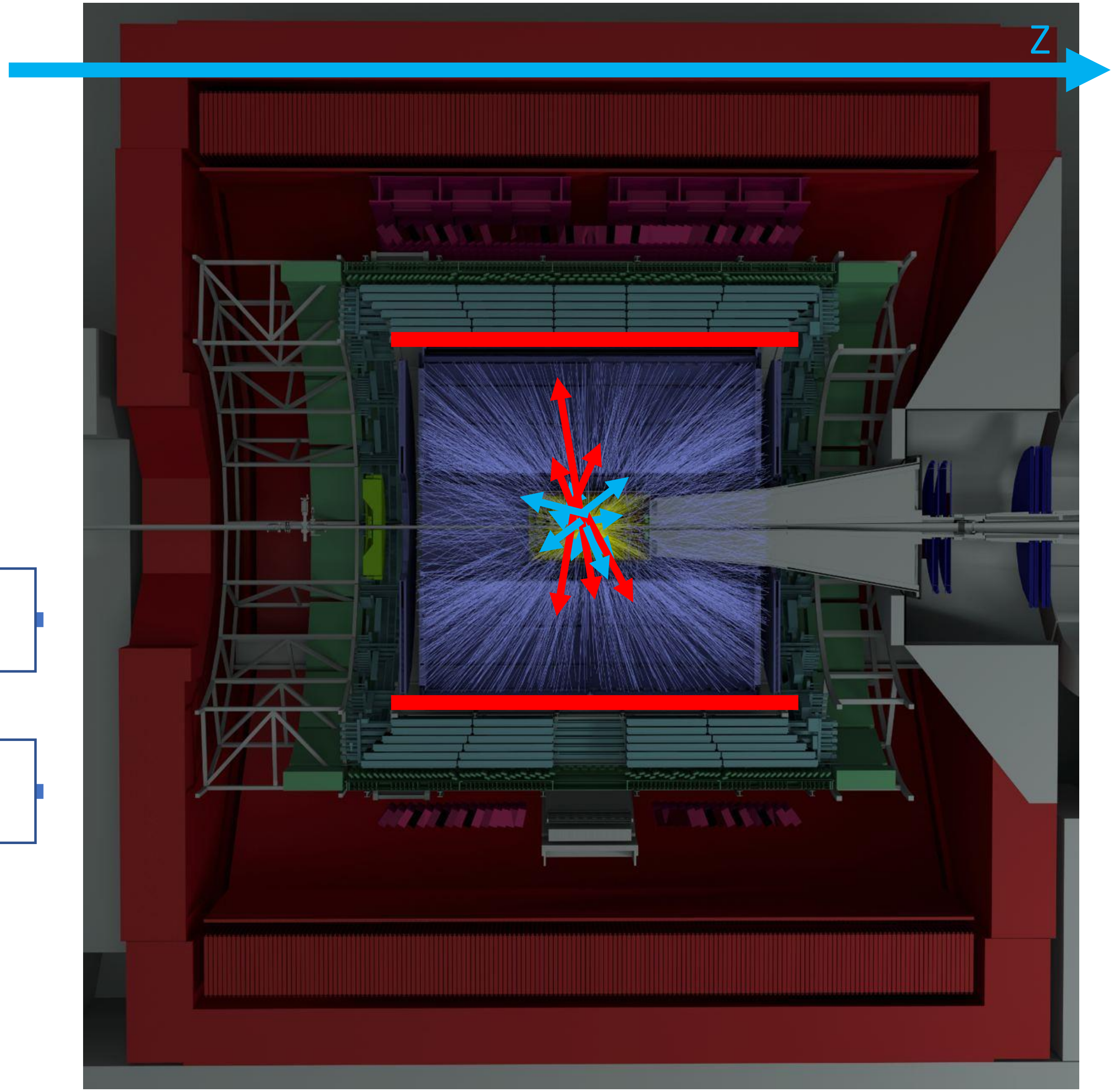
SPECULATION ZONE

Transverse spherocity: V0M vs $N_{\text{tracklets}}^{|\eta|<0.8}$

- For extremely high $N_{\text{tracklets}}^{|\eta|<0.8}$, hard physics is captured at $|\eta| < 0.8$

Soft Processes:

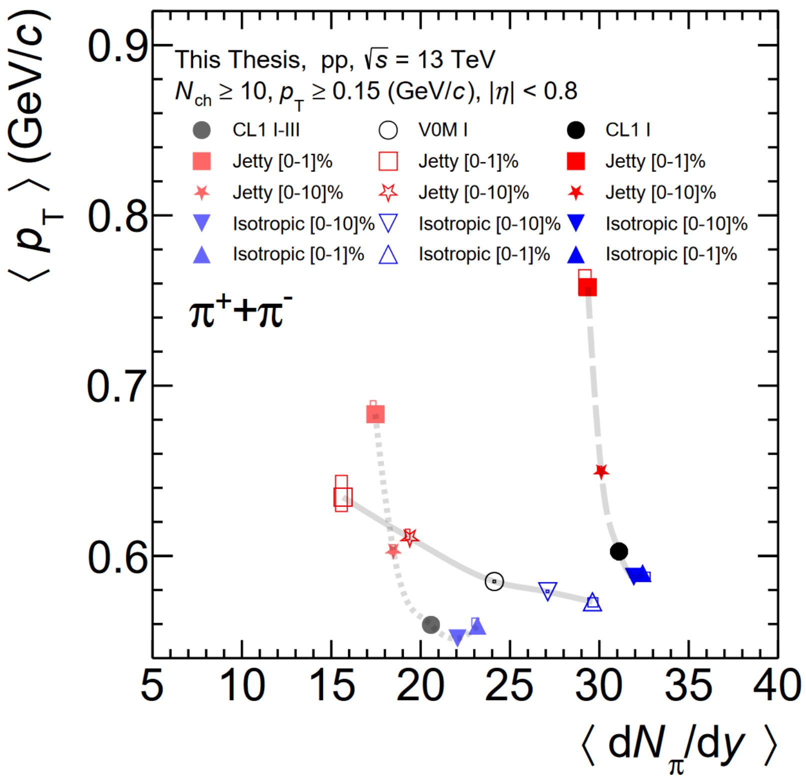
Hard Processes:



SPECULATION ZONE

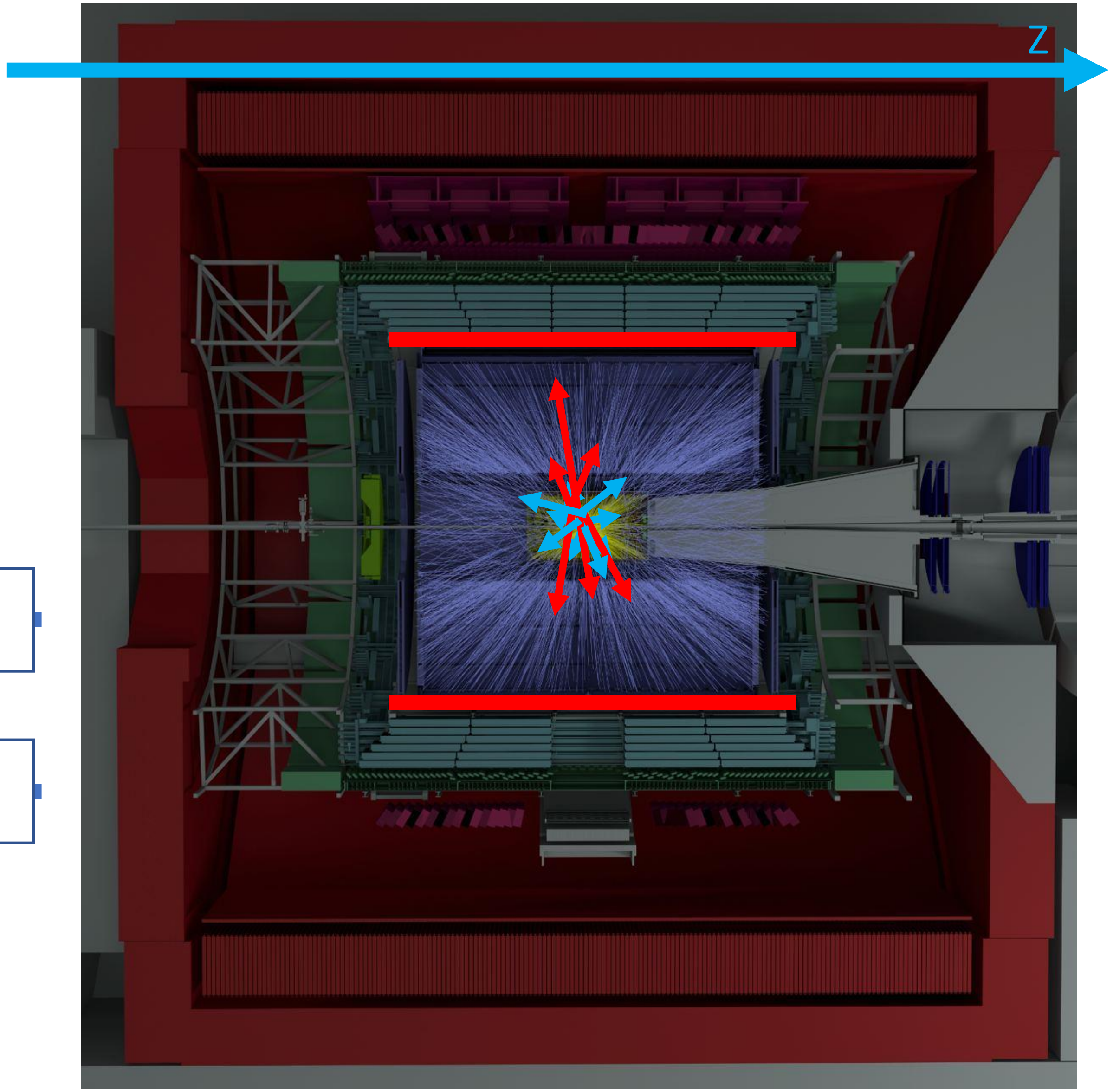
Transverse spherocity: V0M vs $N_{\text{tracklets}}^{|\eta|<0.8}$

- For extremely high $N_{\text{tracklets}}^{|\eta|<0.8}$, hard physics is captured at $|\eta| < 0.8$



Soft Processes:

Hard Processes:



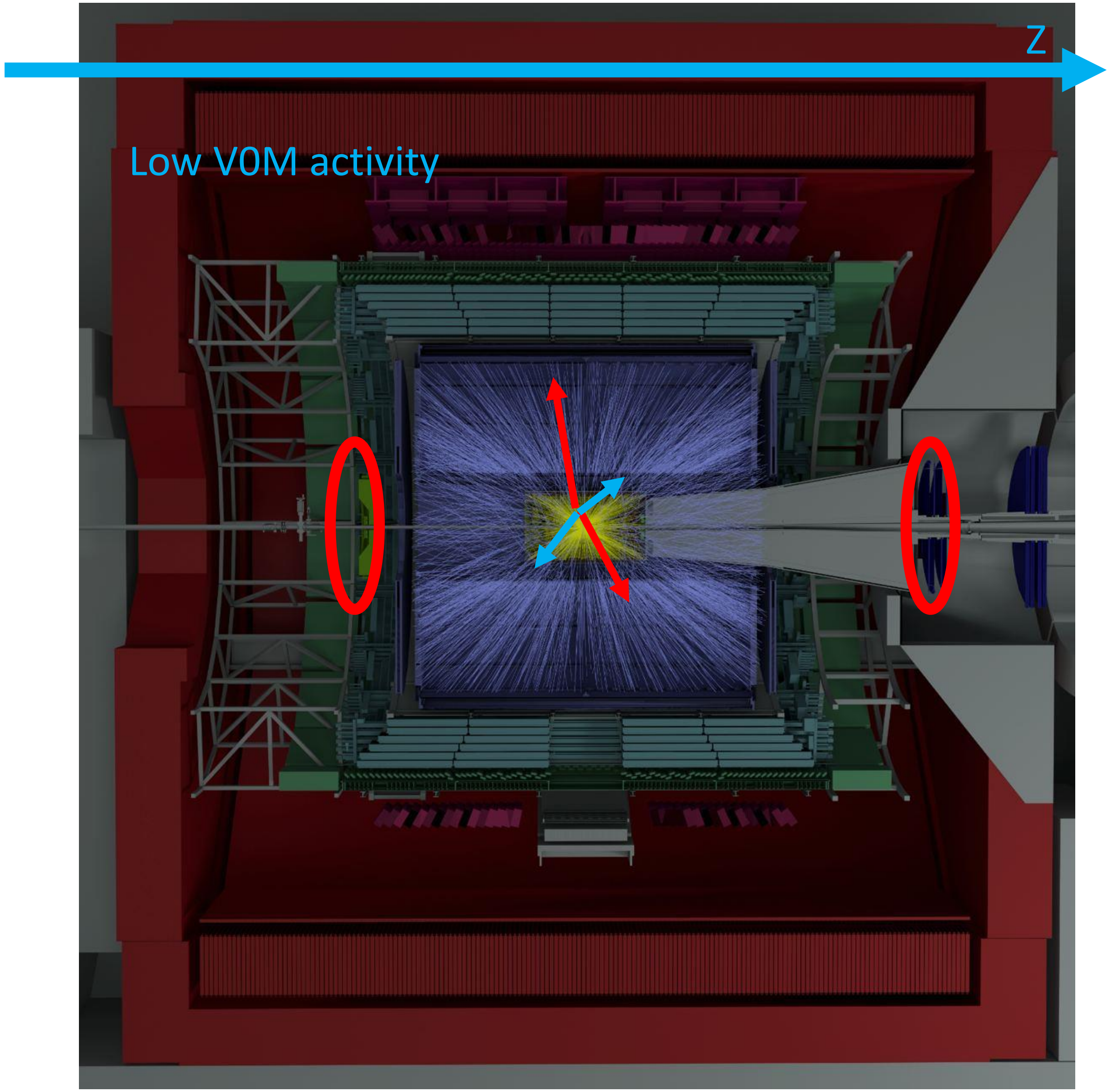
SPECULATION ZONE

Transverse spherocity: V0M vs $N_{\text{tracklets}}^{|\eta|<0.8}$

- For extremely high $N_{\text{tracklets}}^{|\eta|<0.8}$, hard physics is captured at $|\eta| < 0.8$

- However, the same idea has to apply for V0M!

- With increased V0M activity, you bias jets toward forward directions.



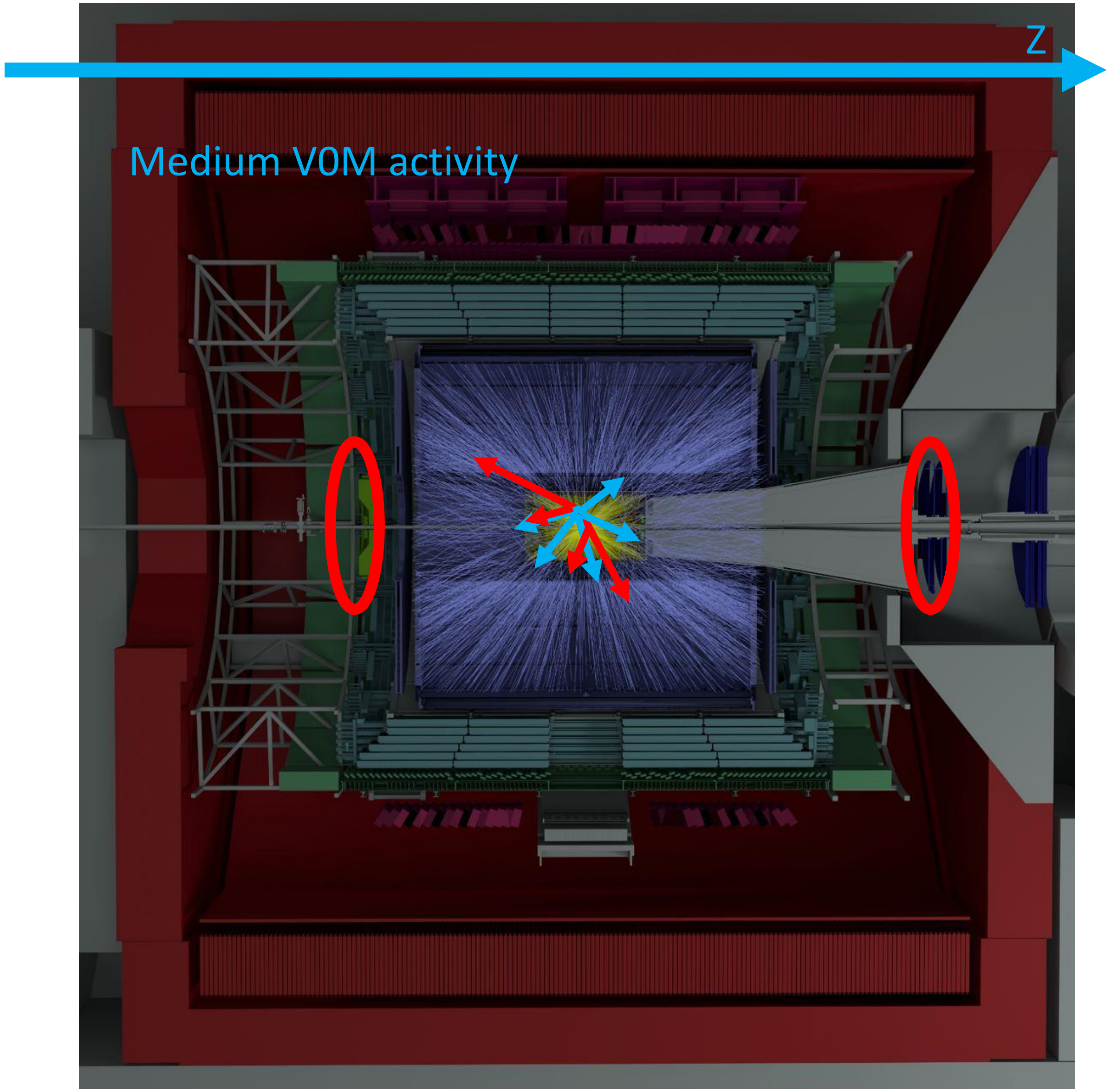
SPECULATION ZONE

Transverse spherocity: V0M vs $N_{\text{tracklets}}^{|\eta|<0.8}$

- For extremely high $N_{\text{tracklets}}^{|\eta|<0.8}$, hard physics is captured at $|\eta| < 0.8$

- However, the same idea has to apply for V0M!

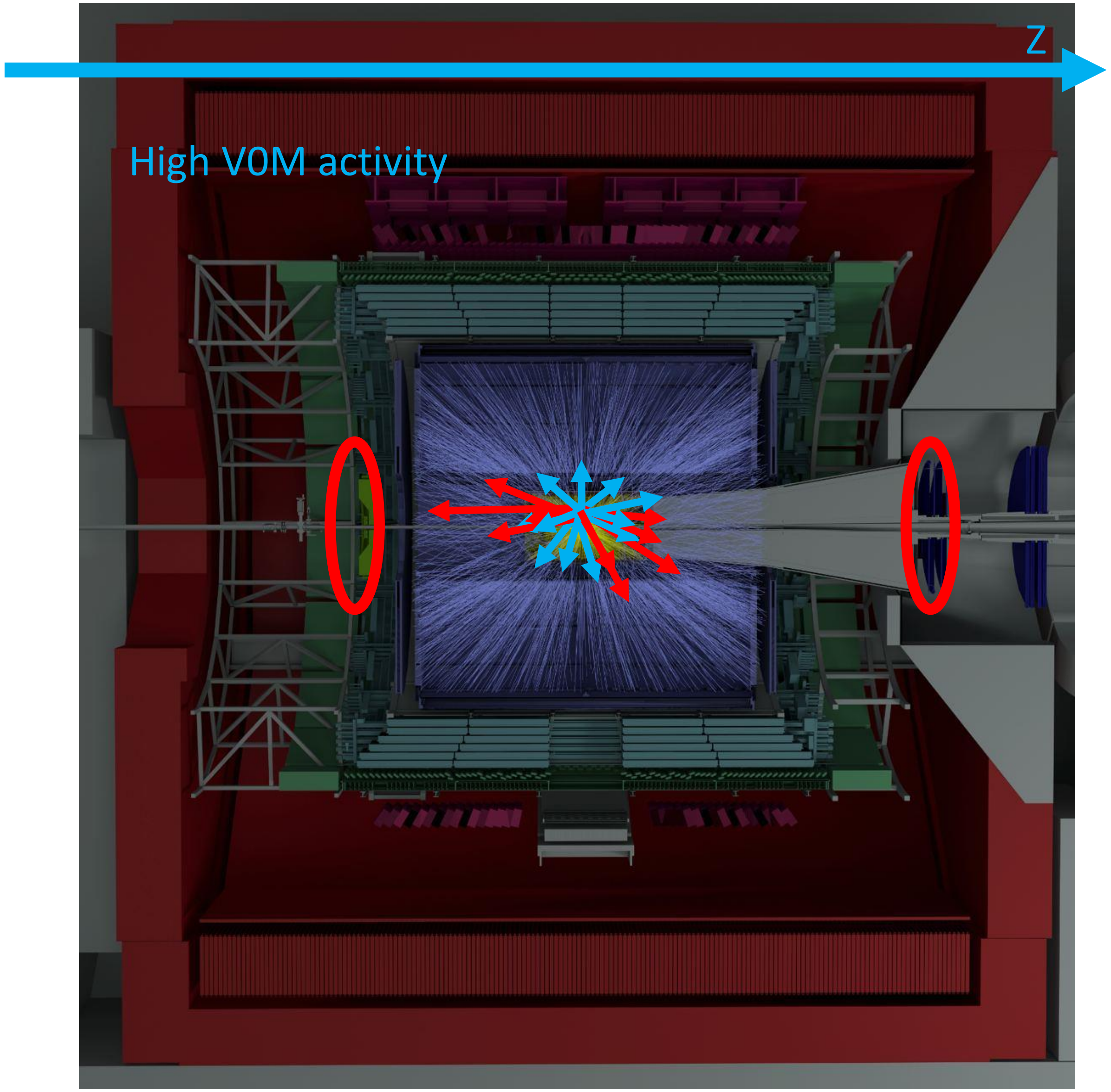
- With increased V0M activity, you bias jets toward forward directions.



SPECULATION ZONE

Transverse spherocity: V0M vs $N_{\mathrm{tracklets}}^{|\eta|<0.8}$

- For extremely high $N_{\mathrm{tracklets}}^{|\eta|<0.8}$, hard physics is captured at $|\eta| < 0.8$
- However, the same idea has to apply for V0M!
- With increased V0M activity, you bias jets toward forward directions.
    - Hard physics at midrapidity is diluted!

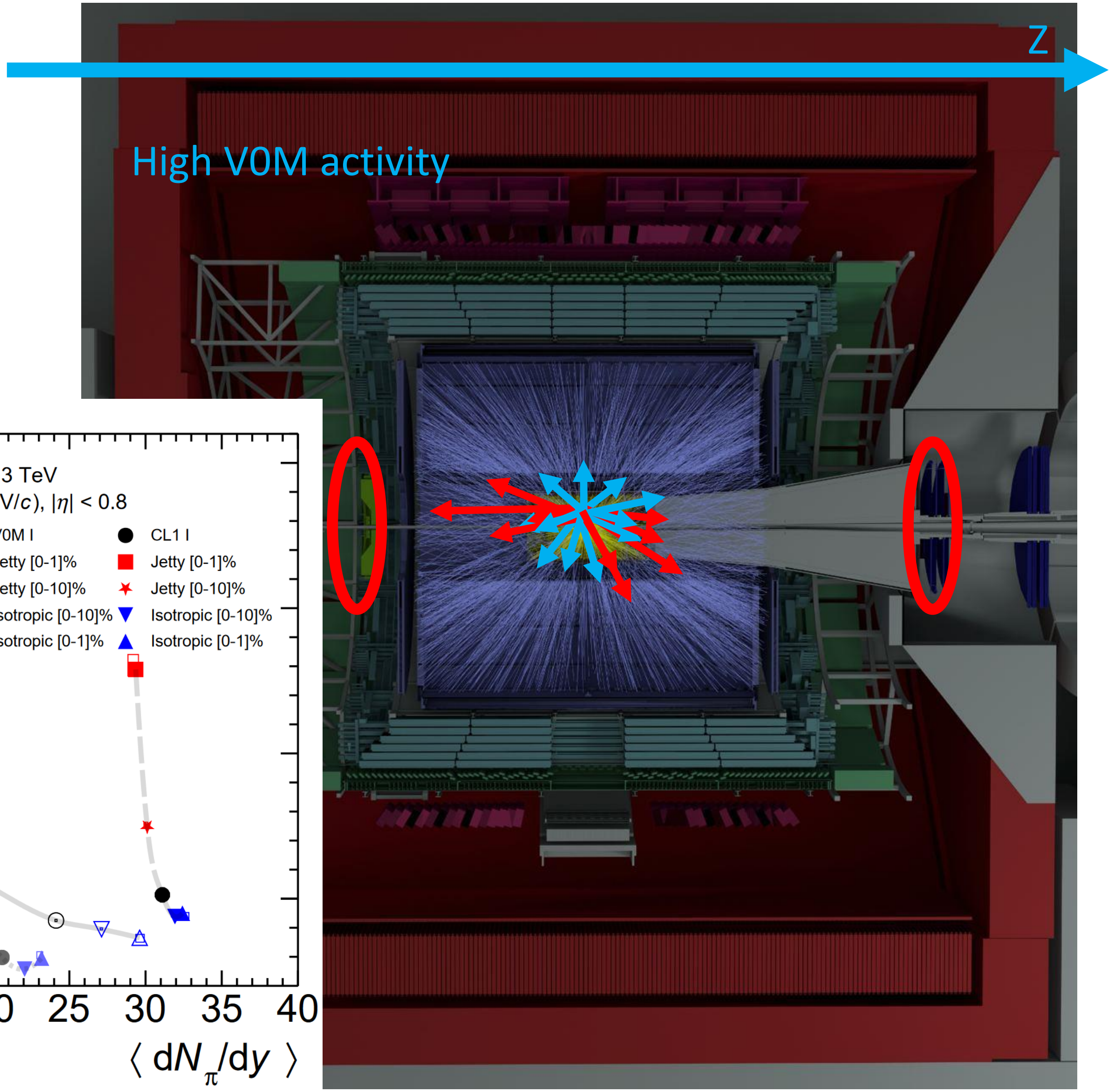


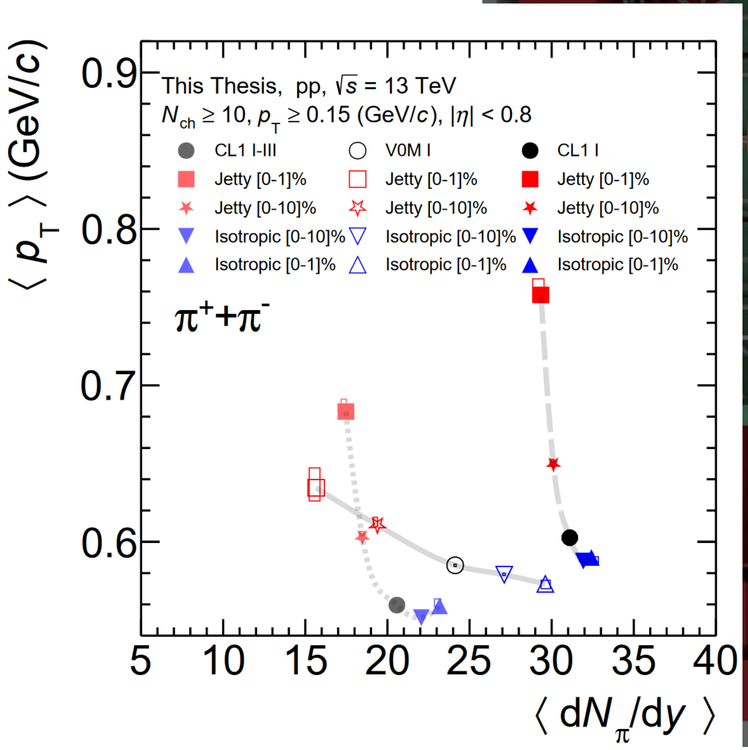
Transverse spherocity: V0M vs $N_{\text{tracklets}}^{|\eta|<0.8}$

- For extremely high $N_{\text{tracklets}}^{|\eta|<0.8}$, hard physics is captured at $|\eta| < 0.8$

- However, the same idea has to apply for V0M!

- With increased V0M activity, bias jets toward forward directions.
    - Hard physics at midrapidity is diluted!

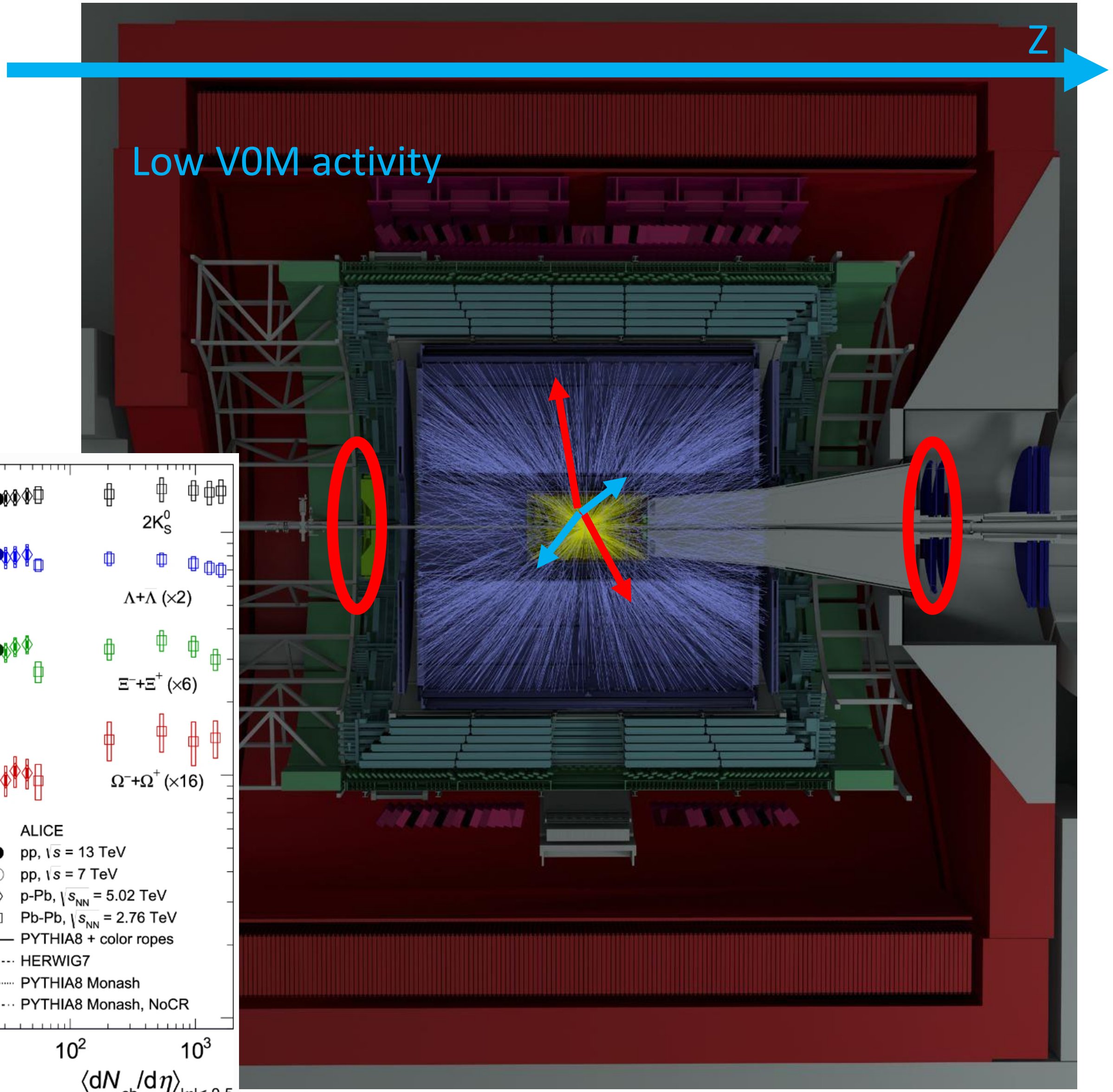


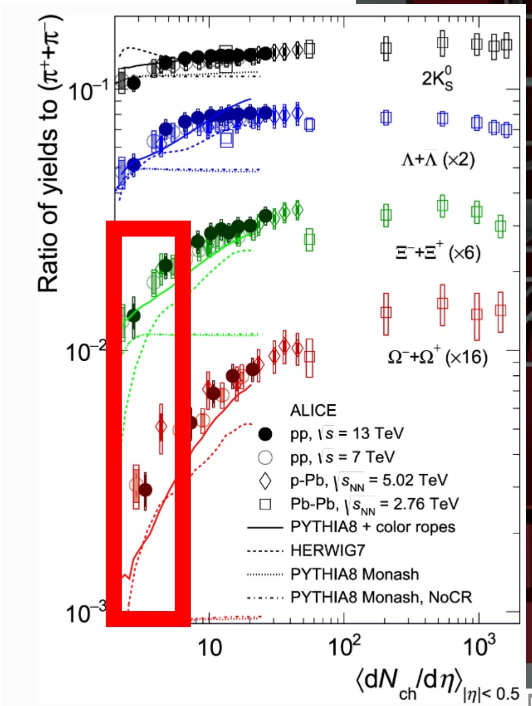


SPECULATION ZONE

Transverse spherocity: V0M vs $N_{\text{tracklets}}^{|\eta|<0.8}$

- For extremely high $N_{\text{tracklets}}^{|\eta|<0.8}$, hard physics is captured at $|\eta| < 0.8$
- However, the same idea has to apply for V0M!
- With increased V0M activity, you bias jets toward forward directions.
    - Hard physics at midrapidity is diluted!
    - Low V0M: Hard/Soft ≈ 50%

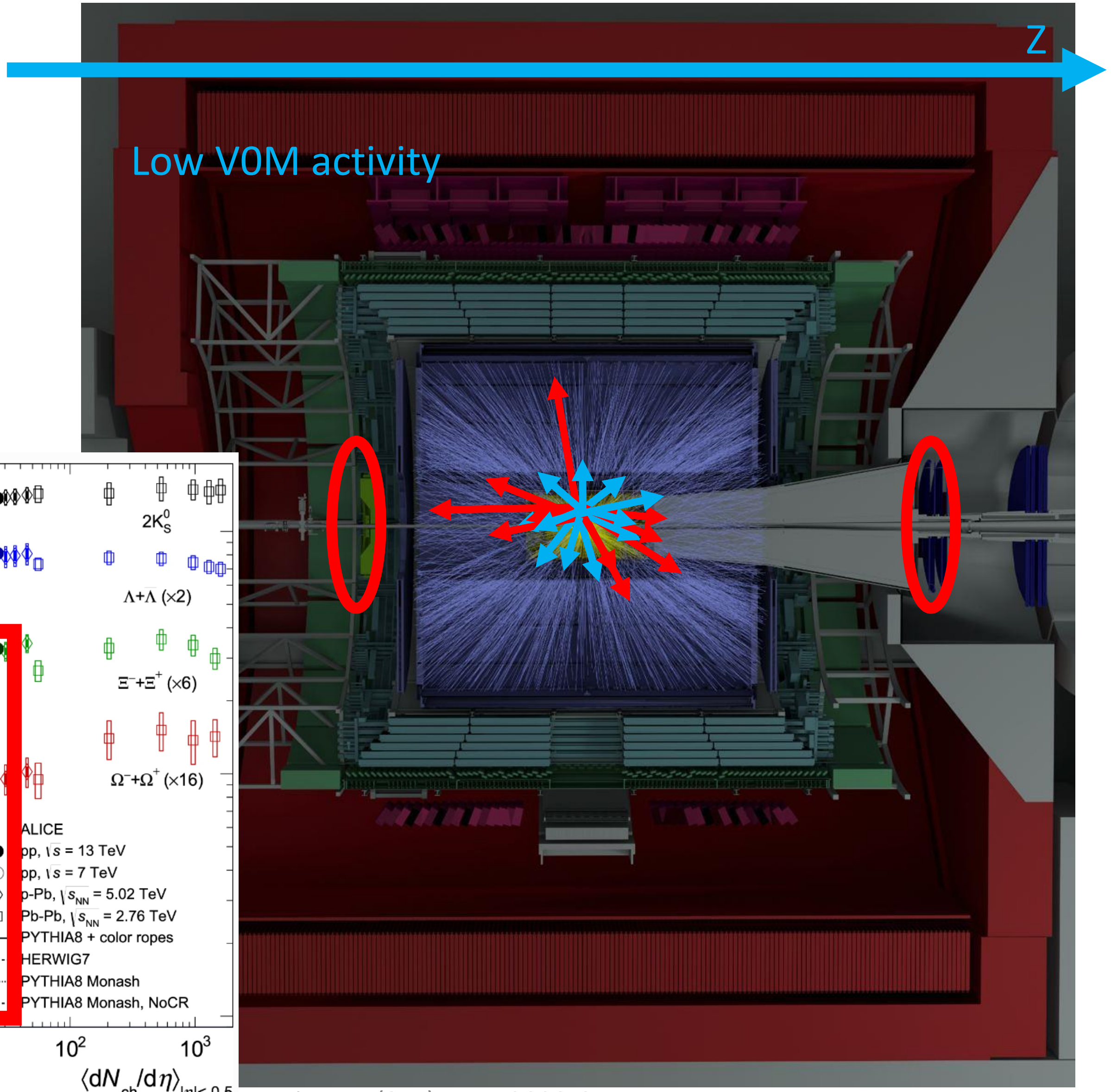


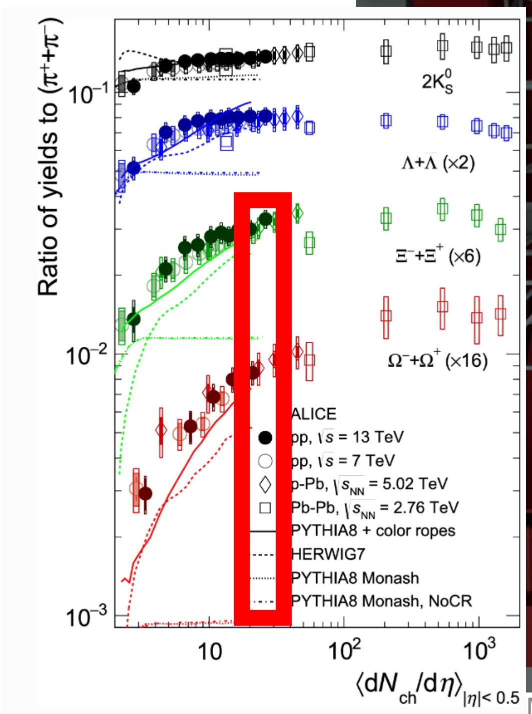


SPECULATION ZONE

Transverse spherocity: V0M vs $N_{\mathrm{tracklets}}^{|\eta|<0.8}$

- For extremely high $N_{\mathrm{tracklets}}^{|\eta|<0.8}$, hard physics is captured at $|\eta| < 0.8$
- However, the same idea has to apply for V0M!
- With increased V0M activity, you bias jets toward forward directions.
    - Hard physics at midrapidity is diluted!
    - Low V0M: Hard/Soft $\approx$ 50%
    - High V0M: Hard/Soft $\ll$ 50%



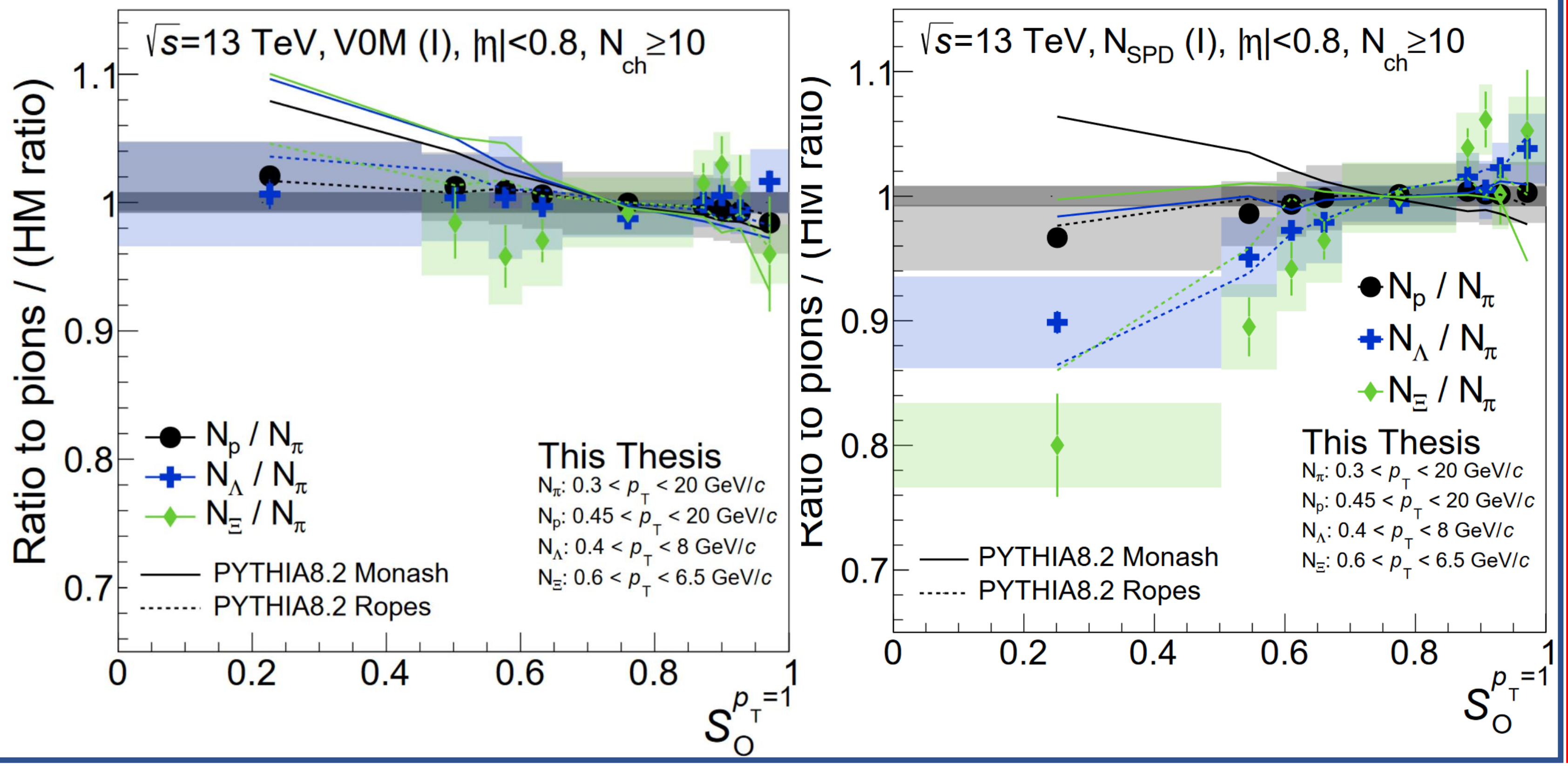


Transverse spherocity: V0M vs $N_{\text{tracklets}}^{|\eta|<0.8}$

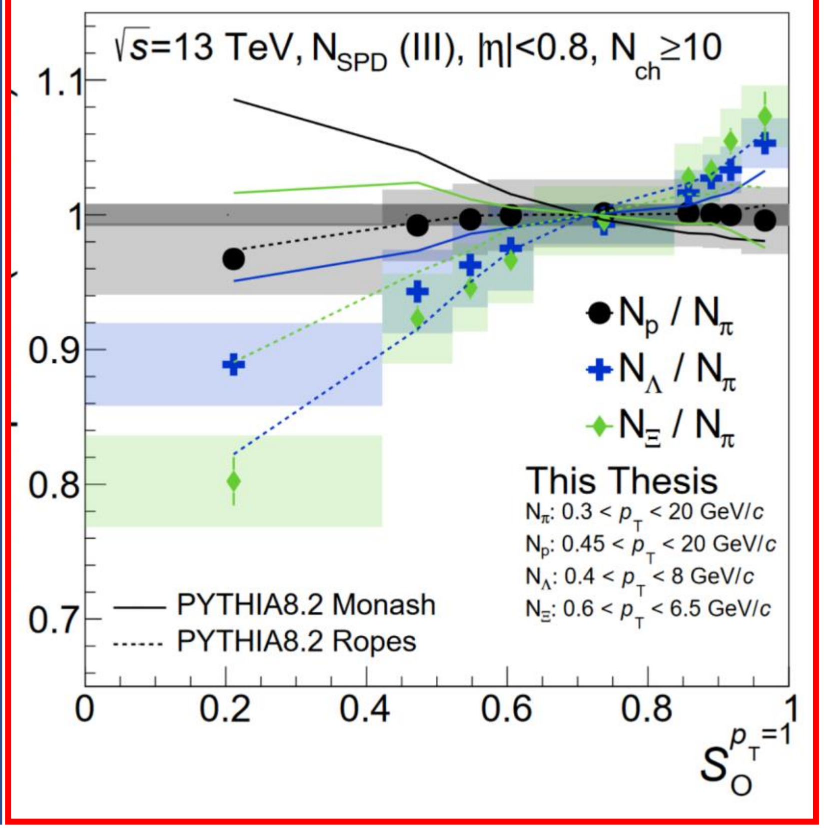
Tracklets (III) overlaps the V0M in yield.

However, midrapidity results showcase larger effect

Shown previously



New!



Outline

Transverse spherocity: Conclusions

- How homogenous are high-multiplicity pp collisions?
  - Topologies driven by soft physics well describe the average high-multiplicity event
  - “Jetty” topologies seem to be clear outliers

- Can we delineate the effects between hard/soft physics?
  - $S_0^{p_{\mathrm{T}}=1}$ can select different physics depending on the η region
  - $S_0^{p_{\mathrm{T}}=1}$ can be used to select strangeness enhanced/suppressed events

- Can we gain information by contrasting event topologies?
  - The effect is separated from dN/dη
  - Hard, jet-like events seem to produce strange hadrons at a much lower rate than the average high-multiplicity event

Transverse spherocity: Conclusions

- How homogenous are high-multiplicity pp collisions?
  - Topologies driven by soft physics well describe the average high-multiplicity event
  - “Jetty” topologies seem to be clear outliers

- Can we delineate the effects between hard/soft physics?
  - $S_0^{p_\mathrm{T}=1}$ can select different physics depending on the η region
  - $S_0^{p_\mathrm{T}=1}$ can be used to select strangeness enhanced/suppressed events

- Can we gain information by contrasting event topologies?
  - The effect is separated from dN/dη
  - Hard, jet-like events seem to produce strange hadrons at a much lower rate than the average high-multiplicity event

- It seems that strangeness enhancement is primarily a soft phenomena!

Thank you for your time!