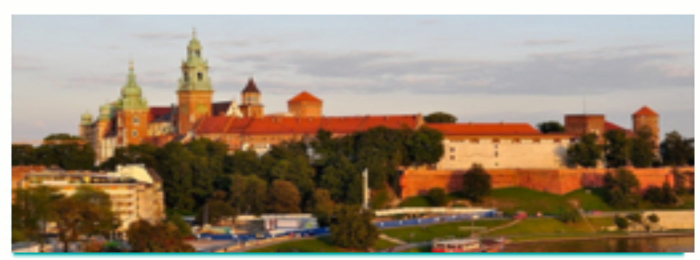
A double differential study of the particle production in pp collisions $\sqrt{s}$ = 13 TeV using transverse spherocity and multiplicity with ALICE

Héctor Bello Martínez
on behalf of the ALICE Collaboration



Initial Stages 2017

Polish Academy of Arts and Sciences
September 18-22 2017, Cracow, Poland

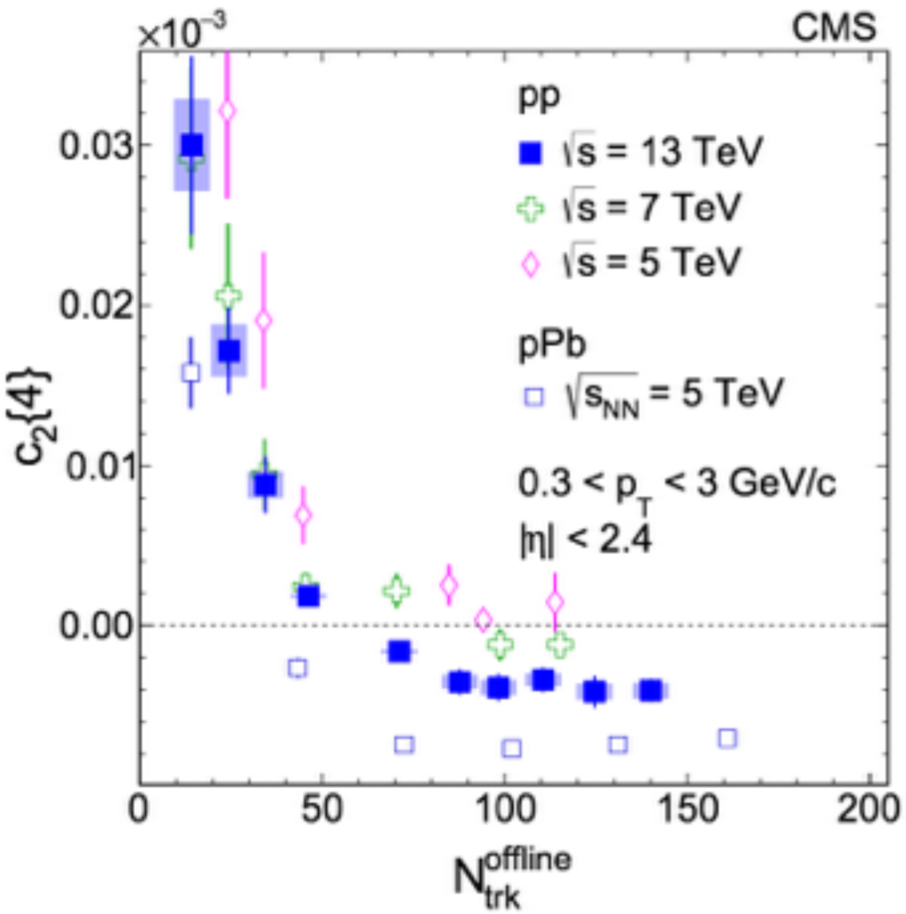
IS2017
19 sept, 2017

Introduction

High multiplicity (HM) pp collisions becomes interesting due to new phenomena observations:

- **Strangeness enhancement in pp.**
  ALICE coll NP13,535-539 (2017)
- **Radial and anisotropic flow measurements in pp.**
  CMS Phys. Lett. B 765 (2017)

collectivity effects in pp?

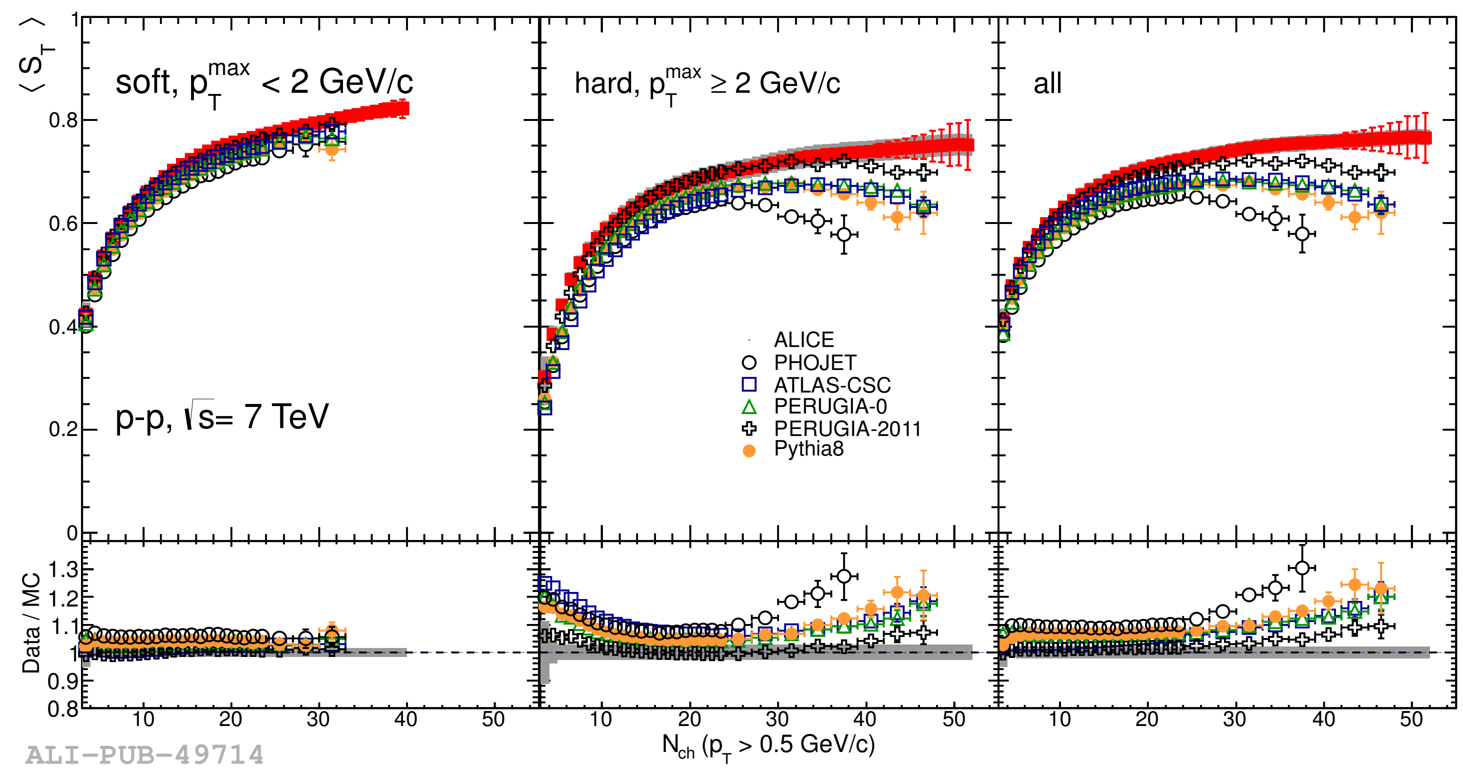


What could cause the collective effect?

- **mini QGP?**
  B.G. Zakharov, JPG41,075008 (2014)

See Ivan's Ravasenga talk: collectivity in ALICE

- **ALICE** measured **transverse sphericity in pp collisions** showing **oposite behaviour from QCD-inspired models**



ALICE coll. EPJC72(2012)2124

A double differential analysis using event shapes, could help to split diferent kind of events in pp.

A. Ortiz arXiv:1705.02056

- **New results on $\langle p_T \rangle$ vs N_{ch}** and event shape will be shown.

Introduction

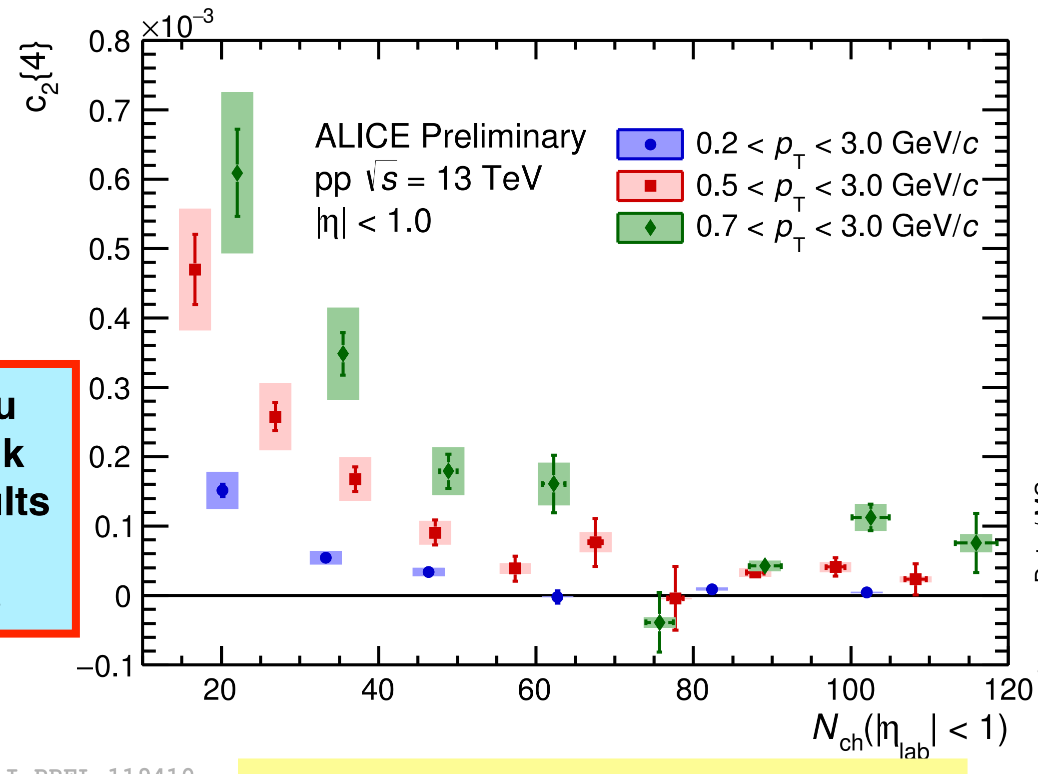
High multiplicity (HM) pp collisions becomes interesting due to new phenomena observations:

- **Strangeness enhancement in pp.**

  ALICE coll NP13,535-539 (2017)

- **Radial and anisotropic flow measurements in pp.**

ATLAS and ALICE has not confirm that



more: You Zhou's talk ALICE results on small systems

ALICE Non-flow effects in pp QM2017

What could cause the collective effect?

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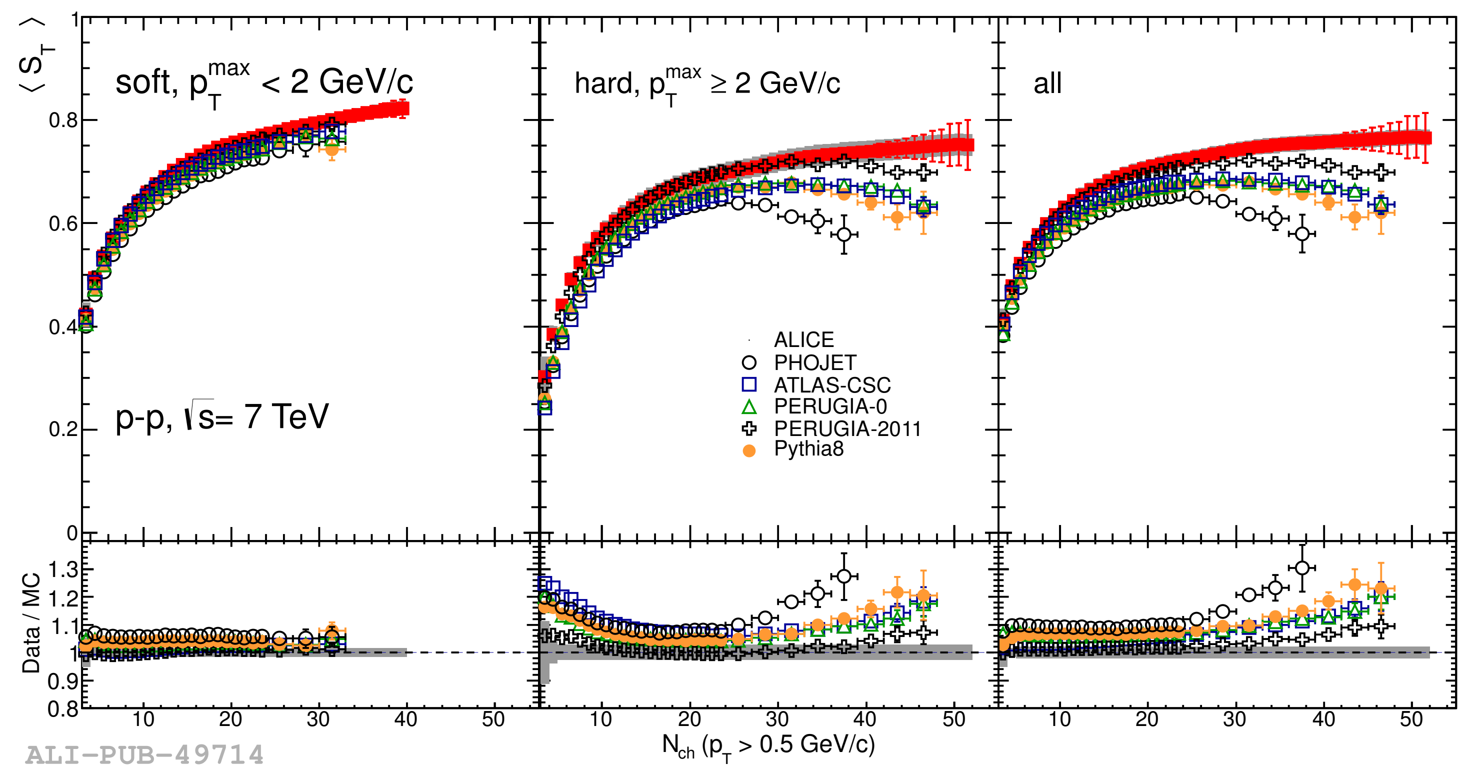

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A. Ortiz arXiv:1705.02056

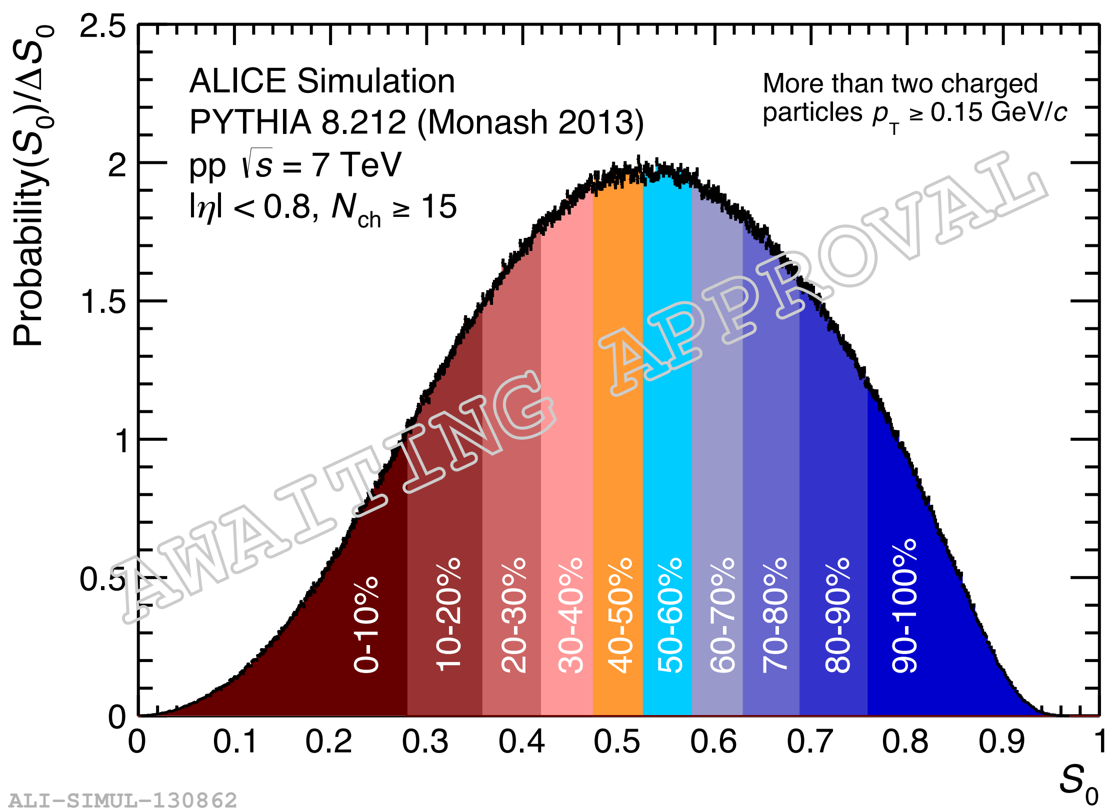
- **New results on** $\langle p_T \rangle$ **vs** N_{ch} and event shape will be shown.

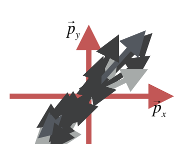
Introduction

Spherocity: defined in terms of $\vec{n} = (n_x, n_y, 0)$ wich minimizes the ratio:

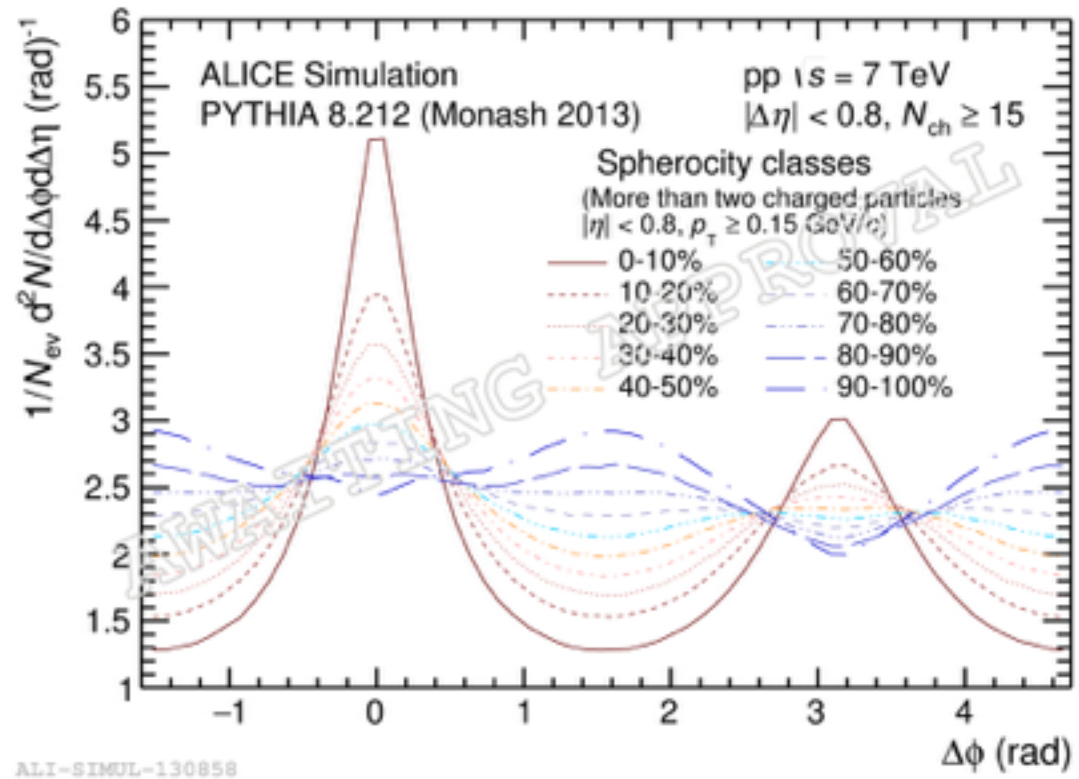
A. Banfi JHEP 1006:038,2010,

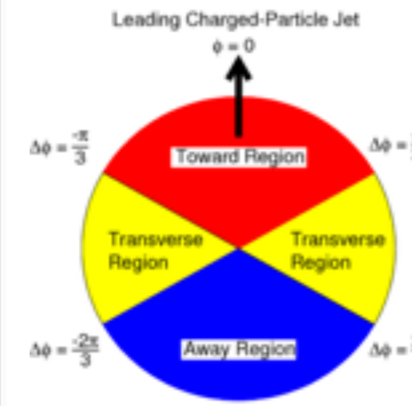
$$S_O = \frac{\pi^2}{4} \min_{\vec{n}=(n_x,n_y,0)} \left(\frac{\sum_i |\vec{p}_{Ti} \times \vec{n}|}{\sum_i \vec{p}_{Ti}} \right)^2$$





- Study **HM** pp collisions with $\boldsymbol{S_0}$ allows to separates "**soft**" (**no-pQCD**) from **"hard"** (**pQCD**) physics.
- According to **PYTHIA 8**, $\boldsymbol{S_0}$ separate events where **UE event** is **enhanced** or **suppressed**.





- Model comparison will help to get information of underlying physics in **HM** events, e.g: if **flow** or other mechanisms (**CR**) predominates in events with or without **jets**.

More of collectivity on Lund Monte Carlo see: C. Bierlich's talk

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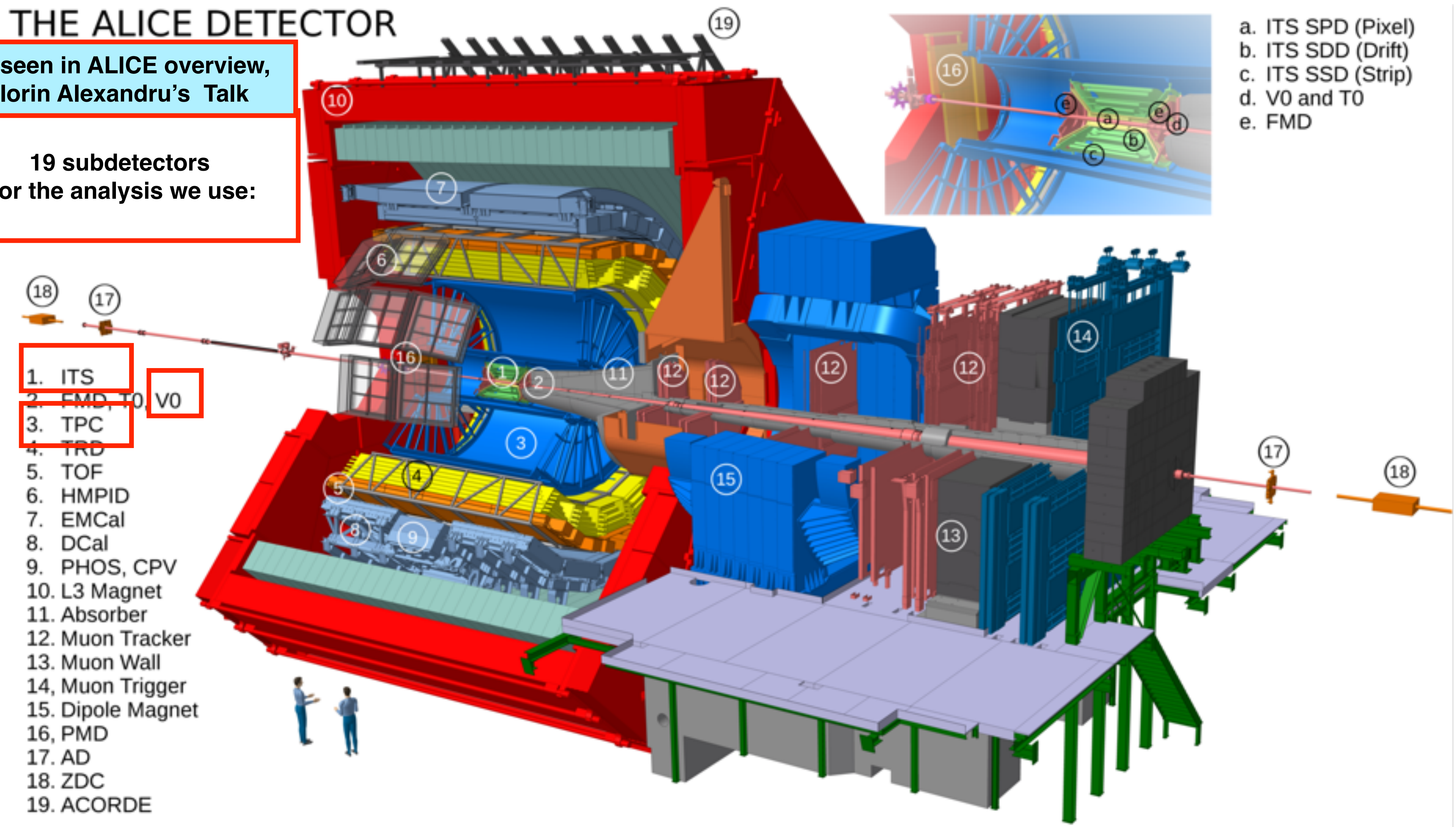
ALICE at LHC (Run 2)

ALICE

As seen in ALICE overview, Florin Alexandru's Talk

19 subdetectors
For the analysis we use:



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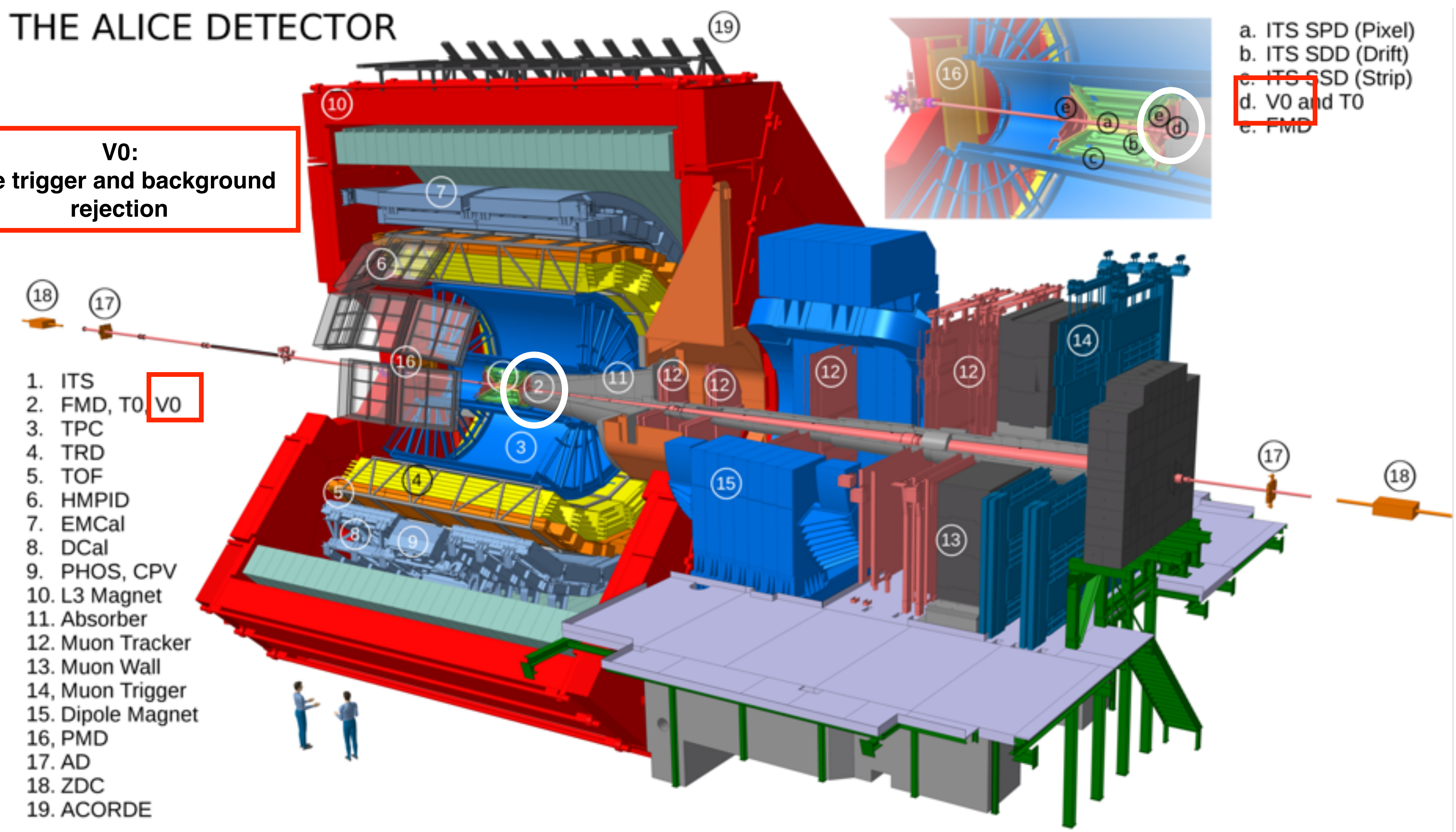
ALICE at LHC (Run 2)

V0:
The trigger and background rejection



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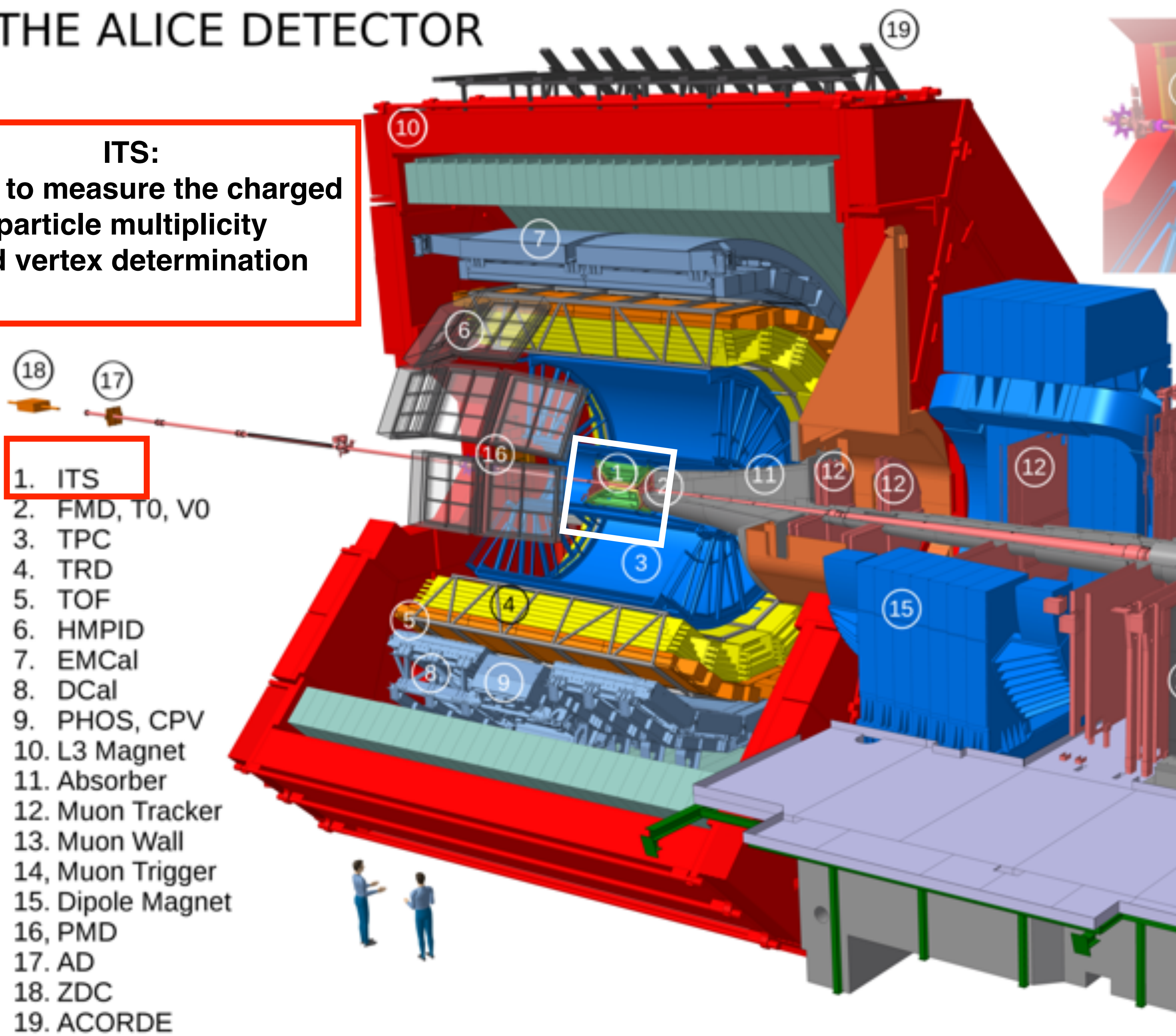
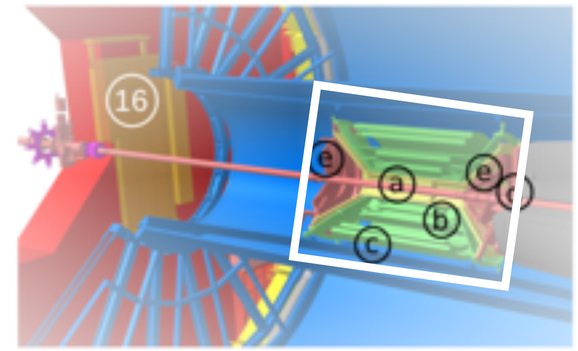
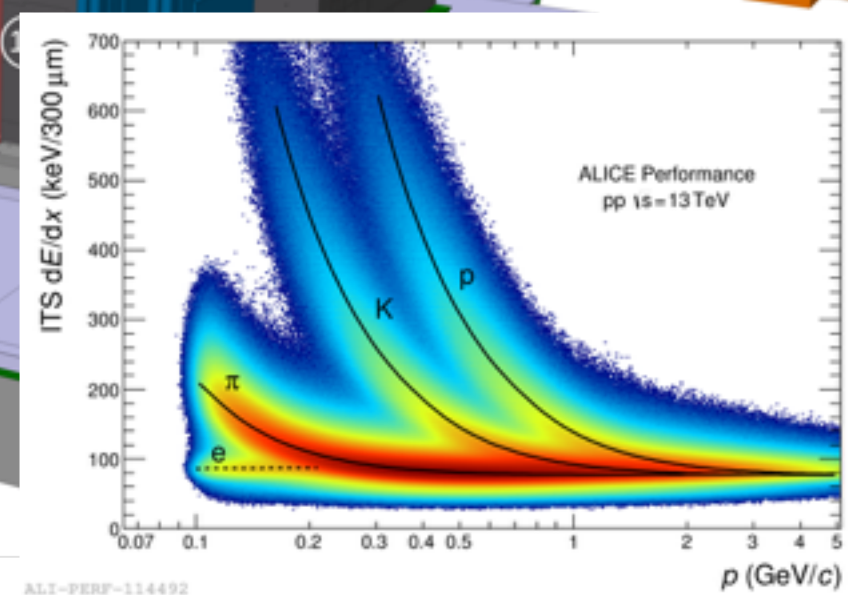
ALICE at LHC (Run 2)

ITS:
used to measure the charged particle multiplicity and vertex determination



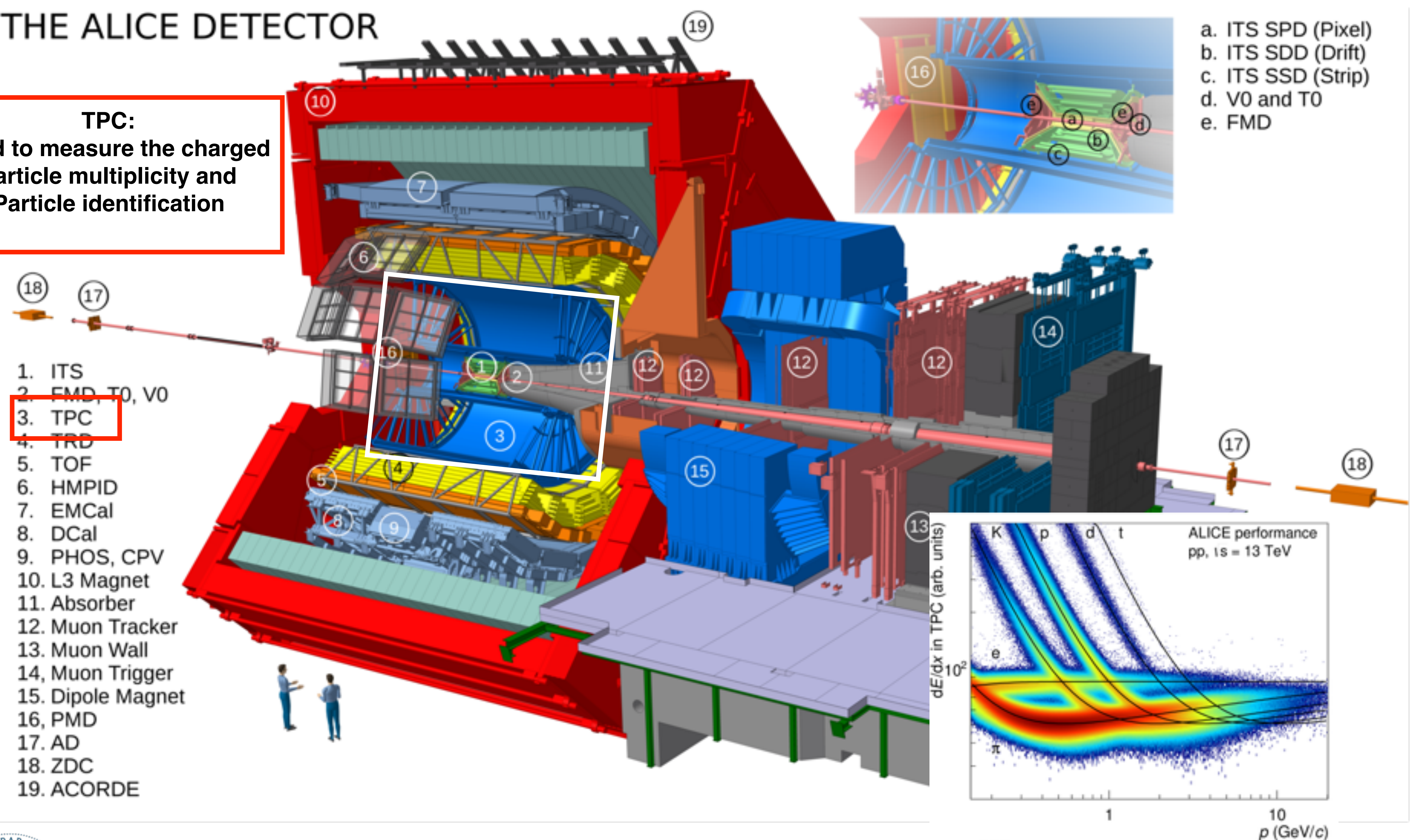


a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD



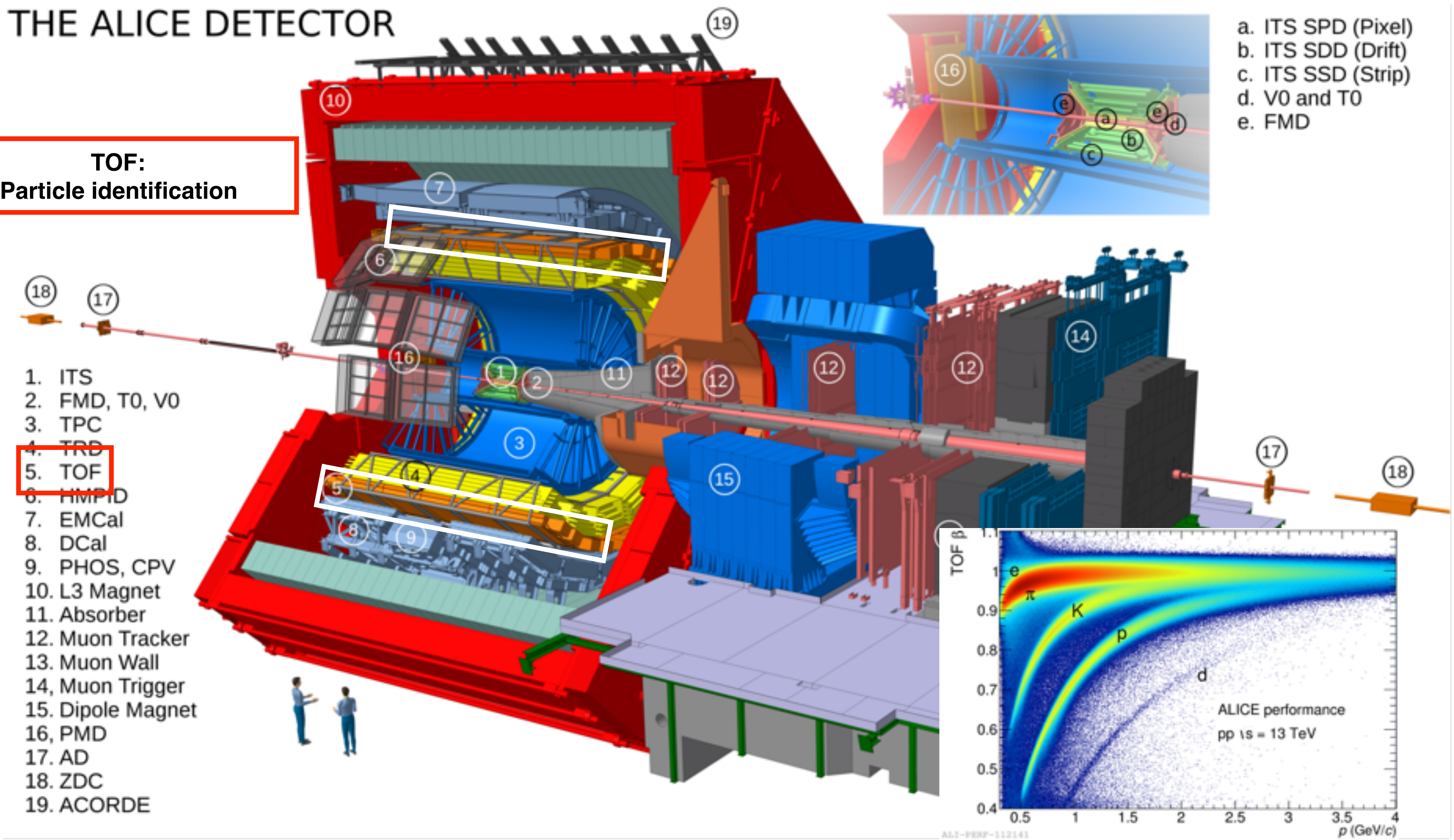
ALICE at LHC (Run 2)

TPC:
used to measure the charged particle multiplicity and Particle identification



ALICE at LHC (Run 2)

TOF:
Particle identification



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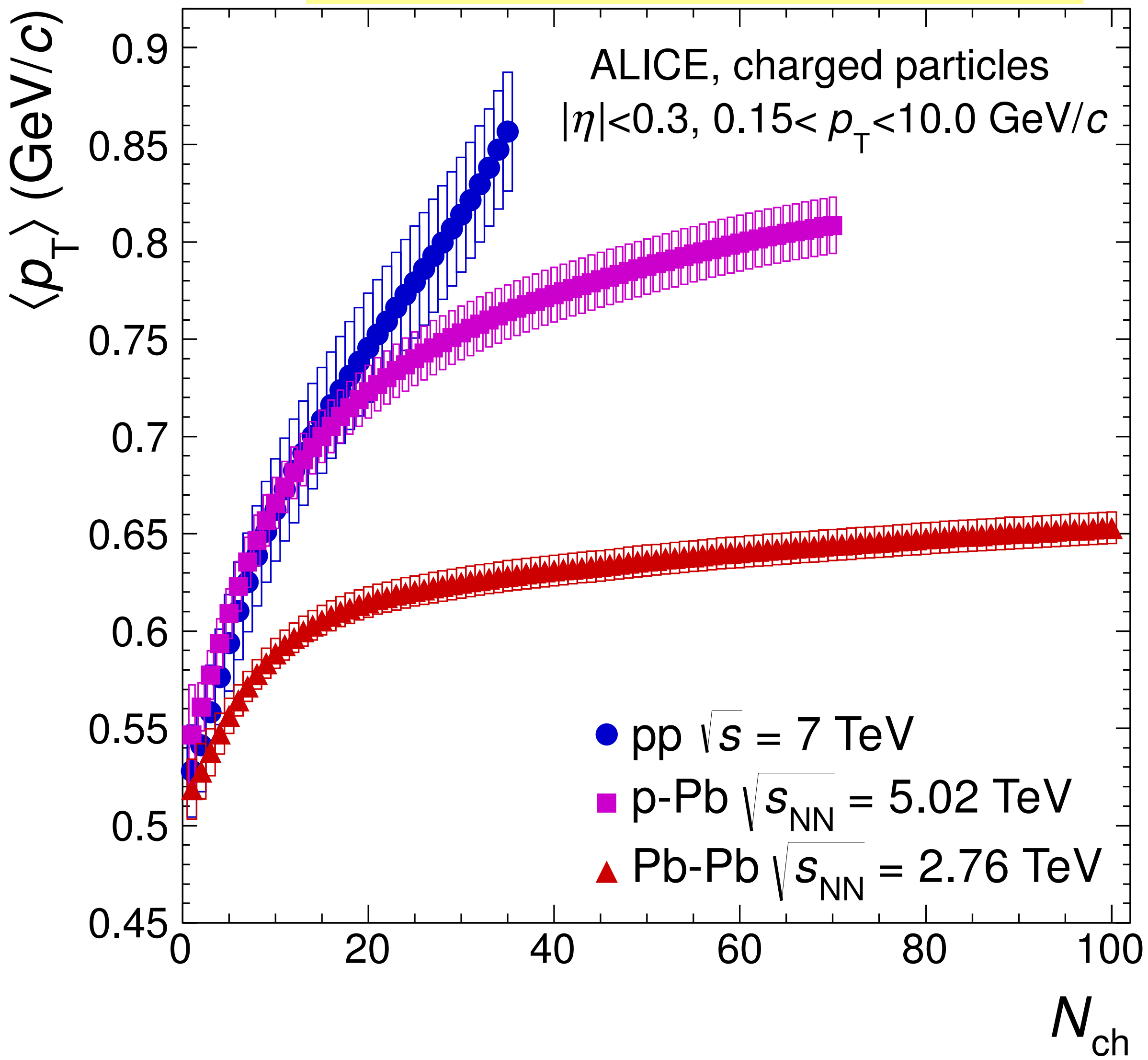
Data Analysis (<p_T> vs N_{ch})

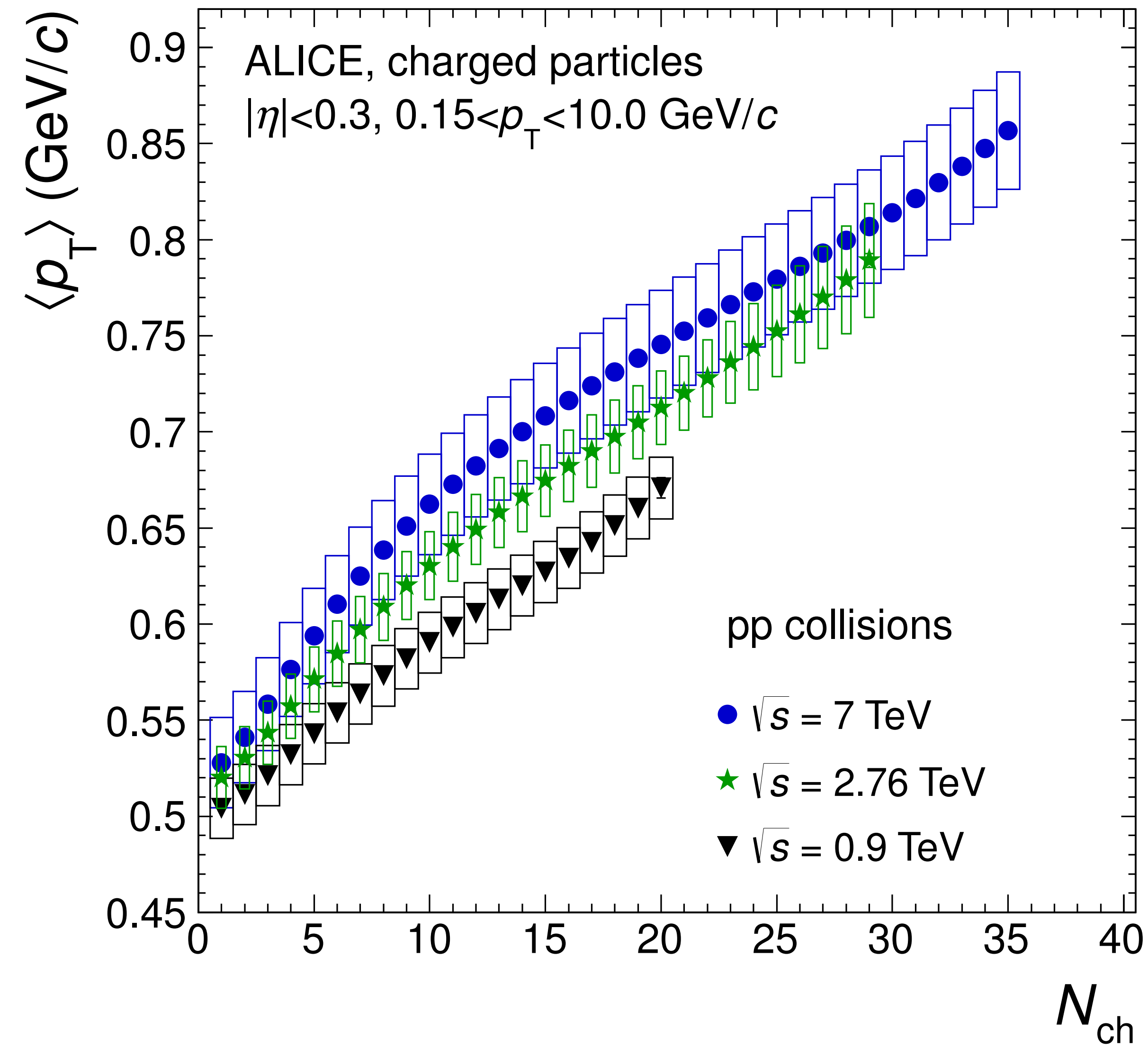
- From **ALICE**, **<p_T> vs N_{ch}**, has been measured for **pp, p-Pb, Pb-Pb** systems and different energies for **pp** collisions (**0.9, 2.76, 7 TeV**)

At HM not saturation is seen in the <p_T> for pp systems, independent of the collision energy. Does hard activity could cause this behaviour?

Phys. Lett. B 727 (2013) 371-380



ALI-PUB-55941

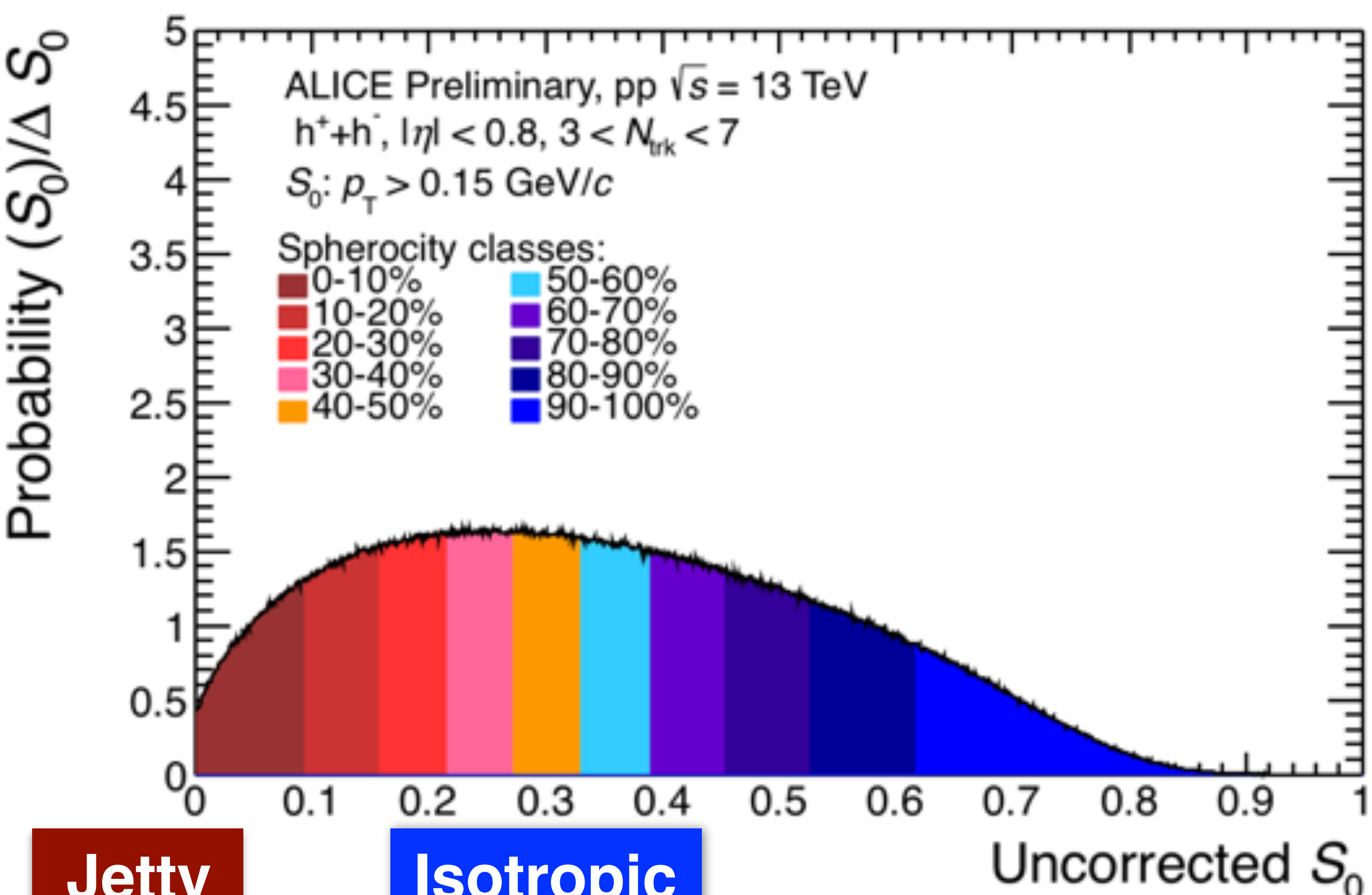


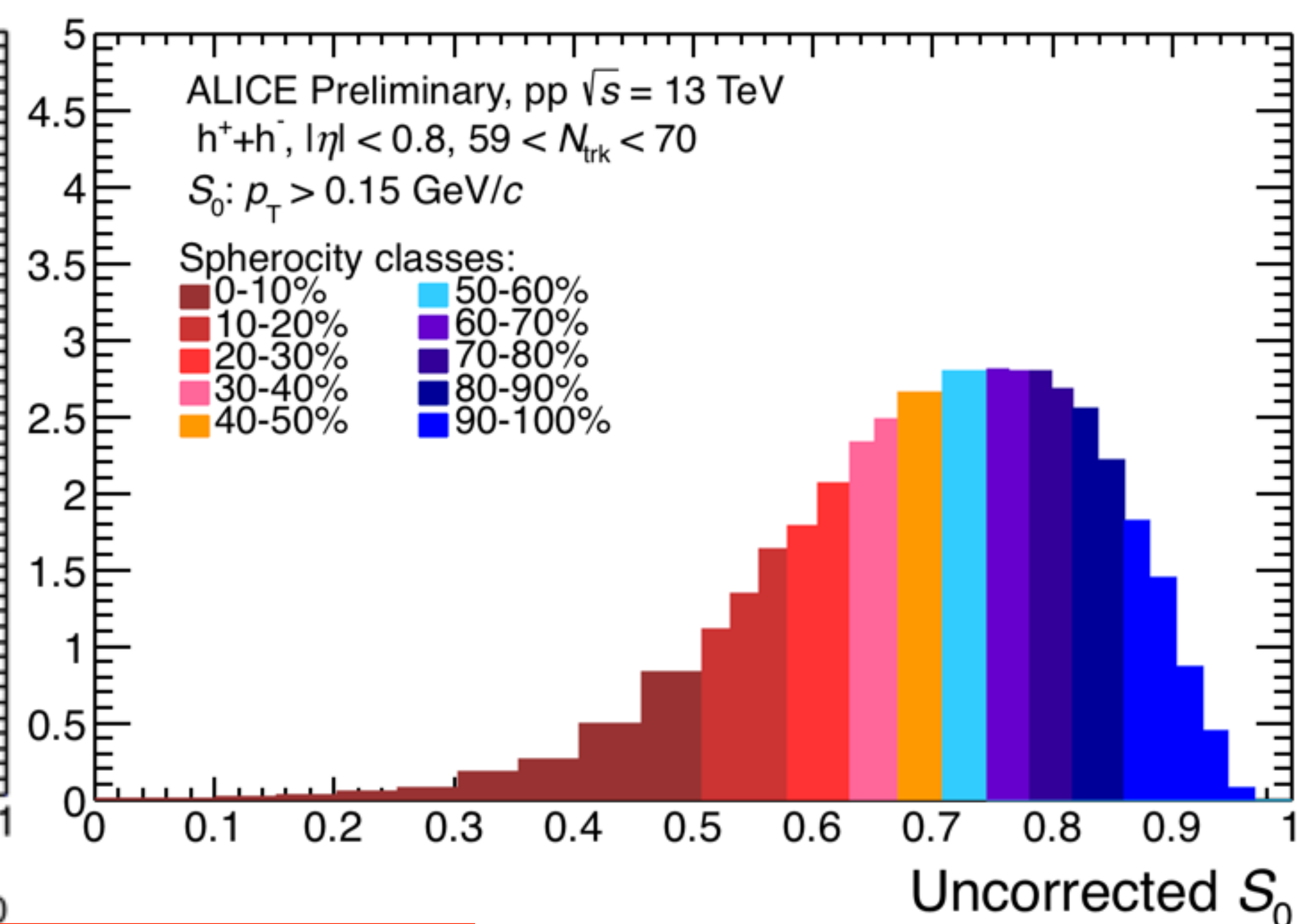
ALI-PUB-55936

An analysis with spherocity is presented to see the contribution from soft-hard events.

Data Analysis (<p_T> vs N_{ch} and S_0)

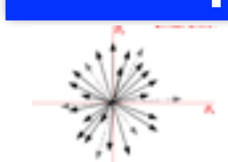
- **MB pp $\sqrt{s}$ = 13 TeV (59 million of events)**
- Multiplicity selection: Global tracks and ITS tracklets, in $|\eta| < 0.8$.
- Spherocity is calculated with more than 2 tracks for $p_T > 0.15$ GeV/c in $|\eta| < 0.8$.





Jetty

Isotropic



From low to high MULTIPLICITY

Spherocity has been measured, 10% of the sample has been chosen for the different binning in the spherocity probability distribution, the results show the multiplicity dependence (low N_{ch} -> low S_0, high N_{ch} -> high S_0)

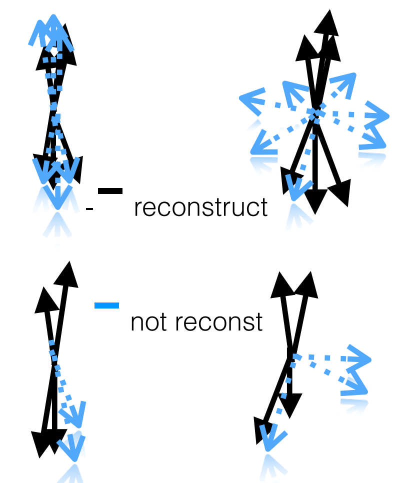
Corrections

As seen in Sergio's Iga Talk

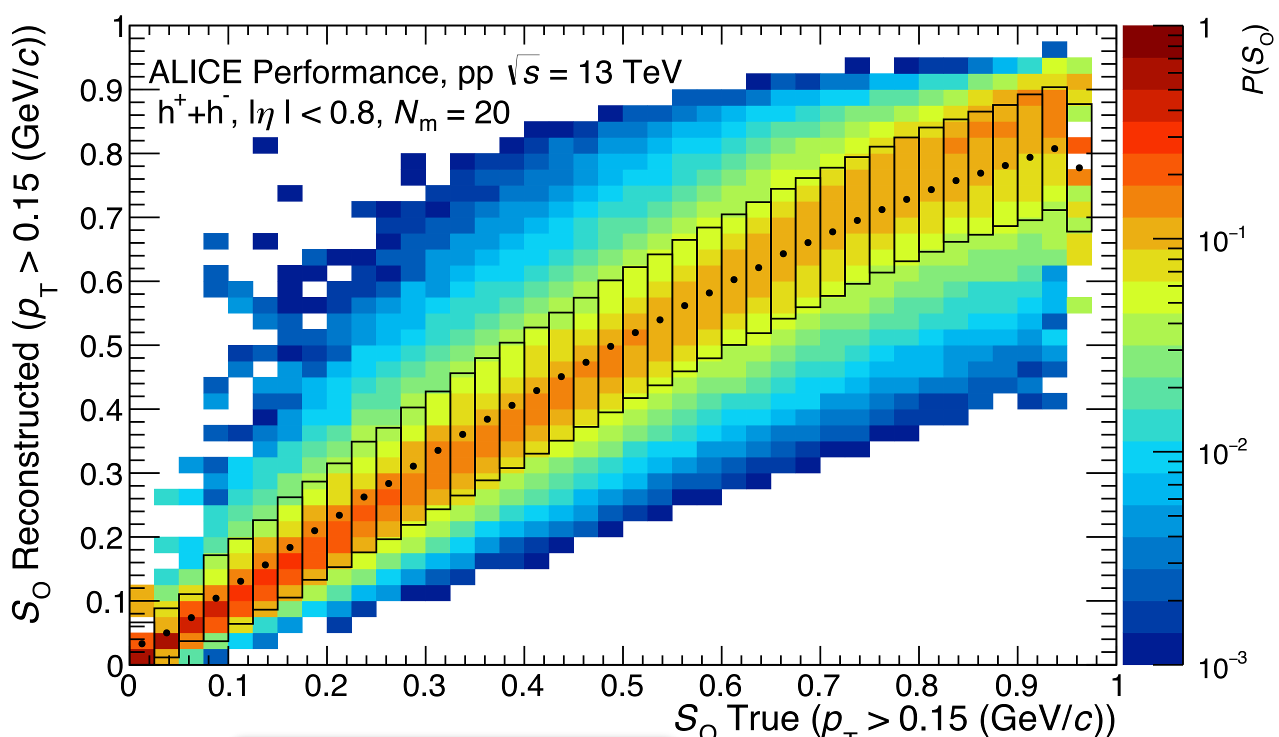
- The $\langle p_T \rangle$ is obtained from the fully corrected invariant yield

1. Spherocity correction is applied to the $\langle p_T \rangle$ using a weighting average:

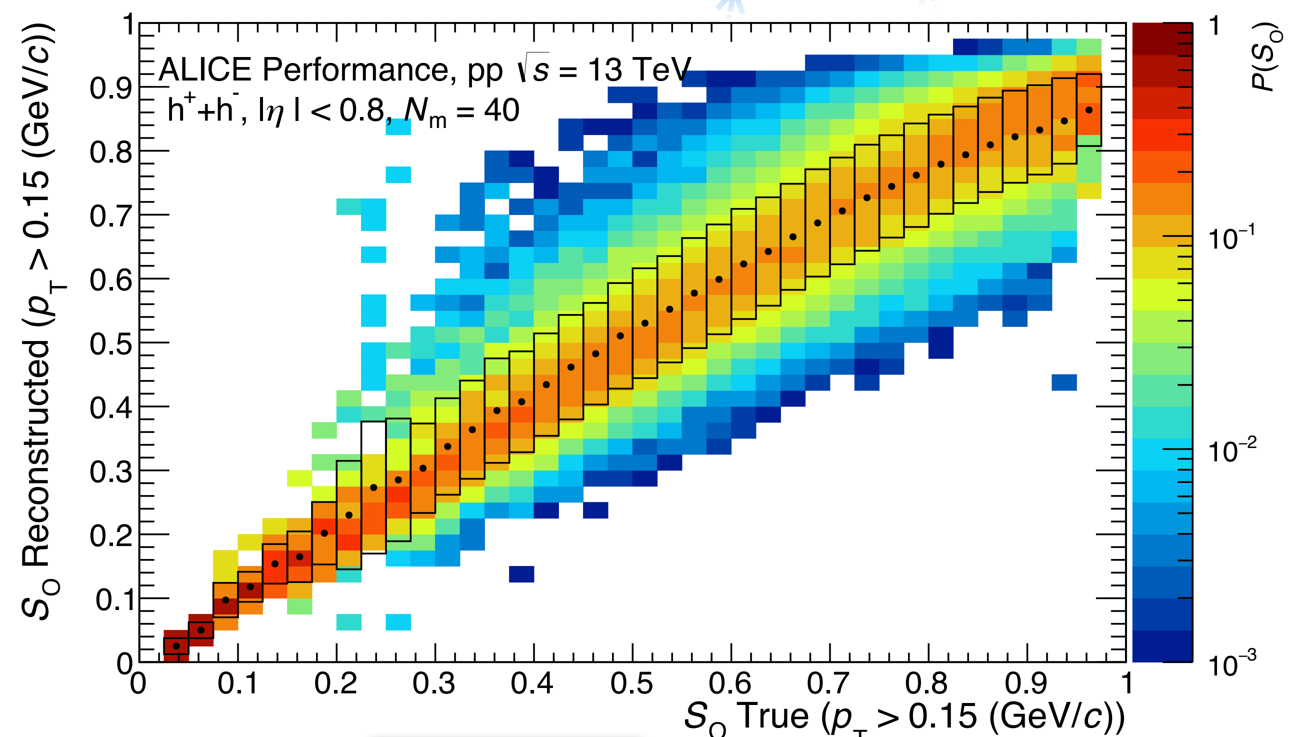
$$\langle p_{\mathrm{T}} \rangle (N_{\mathrm{m}}, S_{0,\mathrm{t}}) = \sum_{\mathrm{m}} \langle p_{\mathrm{T}} \rangle (N_{\mathrm{m}}, S_{0,\mathrm{m}}) R(S_{0,\mathrm{t}}, S_{0,\mathrm{m}})$$



GREATER SPHEROCITY CORRECTION FOR ISOTROPIC EVENTS THAN FOR JETTY ONES, WE ALSO SEE THAT AT HIGH MULTIPLICITY THE SPHEROCITY RESOLUTION ITS BETTER



Intermediate N_{ch}



High N_{ch}

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Corrections

As seen in Sergio's Iga Talk

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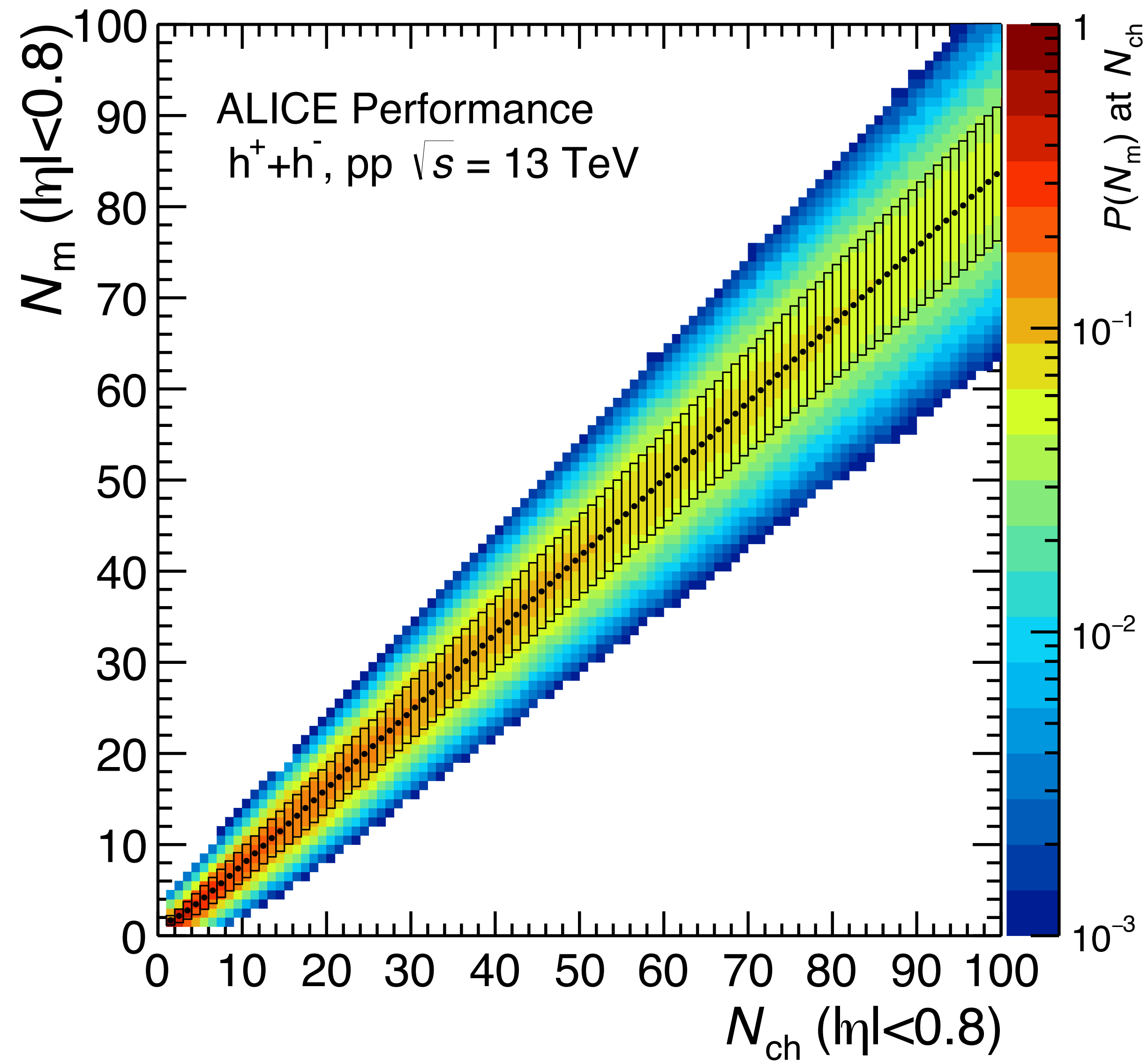
$$\langle p_{\rm T}\rangle(N_{\rm m}, S_{0,{\rm t}}) = \sum_{\rm m} \langle p_{\rm T}\rangle(N_{\rm m}, S_{0,{\rm m}}) R(S_{0,{\rm t}}, S_{0,{\rm m}})$$

2. Then multiplicity correction was done following a similar procedure.:

$$\langle p_{\rm T}\rangle(N_{\rm ch}) = \sum_{\rm m} \langle p_{\rm T}\rangle(N_{\rm m}) R(N_{\rm ch}, N_{\rm m})$$



GREATER MULTIPLICITY RESOLUTION FOR HIGH MULTIPLICITY EVENTS

BETTER RECONSTRUCTION FOR LOW MULTIPLICITY EVENTS

Summary of systematic uncertainties

ALICE

Sources of systematic uncertainties:

A. Systematic uncertainties from extraction of <p_T> analysis.

- Track cuts (see table) **< 2%**

Track cut	Nominal value	Lower value	Higher value
Min. number of crossed rows	70	60	100
Min. ratio crossed rows over findable TPC clusters	0.8	0.7	0.9
Max. χ^2 per cluster in TPC	4	3	5
Max. χ^2 per cluster in ITS	36	25	49
SPD point	required	not required	not required
DCA_{xy}	7σ	4σ	10σ
DCA_z	2	1	5

- Efficiency (multiplicity dependence) **<3% jetty** (**<2% isotropic**)

B. Systematic uncertainties due to Spherocity selection.

- Extrapolation to the spherocity response **<1%** at HM
- Track selection for spherocity reconstruction **~ 1.5%**

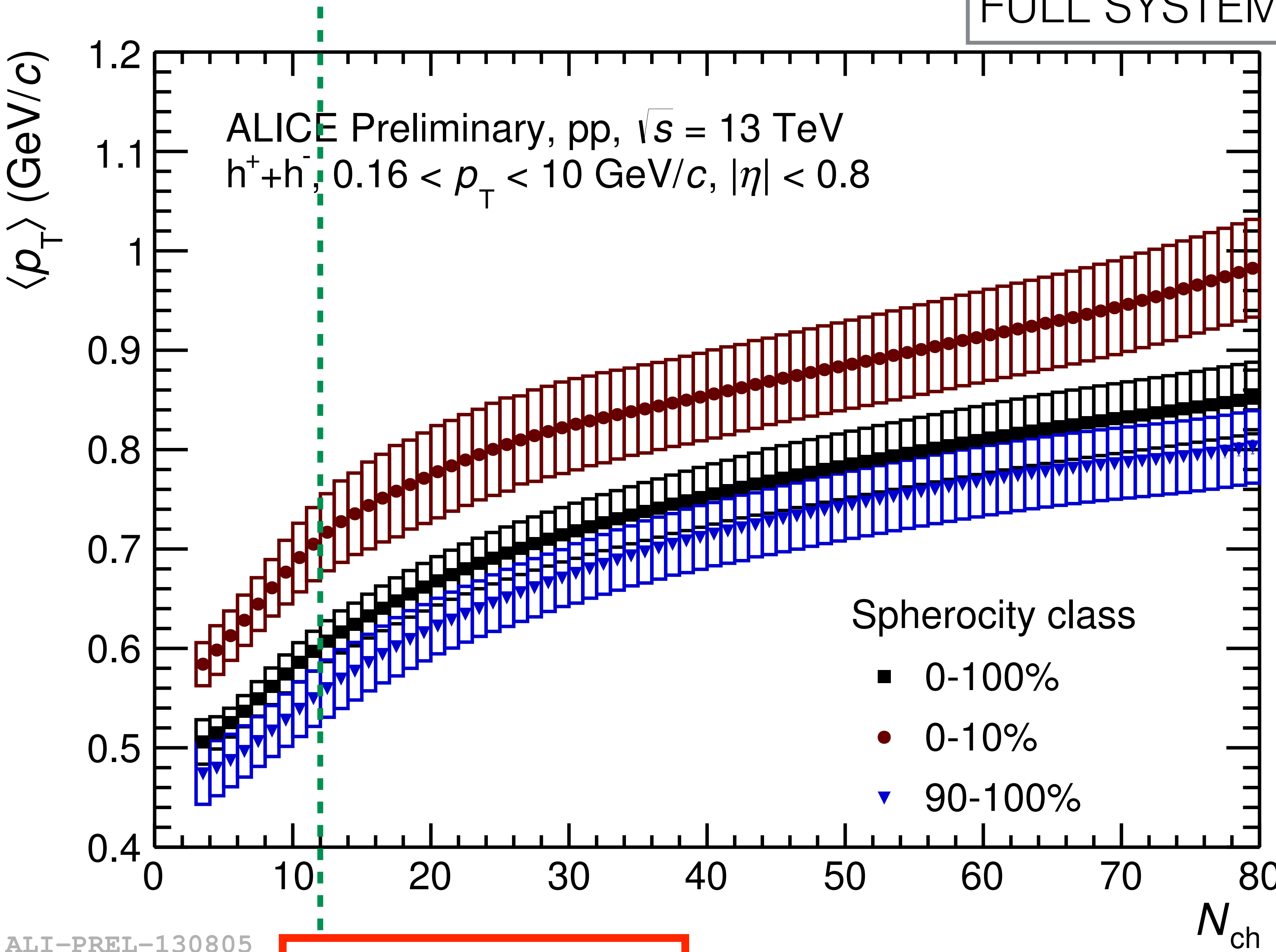
C. Systematic uncertainties from correction method

- Model dependence corrections (Pythia vs EPOS) **< 2%** at **HM.**
- Method of correction (non-closure test) **<5 % jetty** (**<4% isotropic**) **<— (Main cont.)**

Total systematic uncertainty: <6% jetty (<5% isotropic)

Spherocity dependence on $<p_T>$ vs N_{ch}

FULL SYSTEMATIC UNCERTAINTY

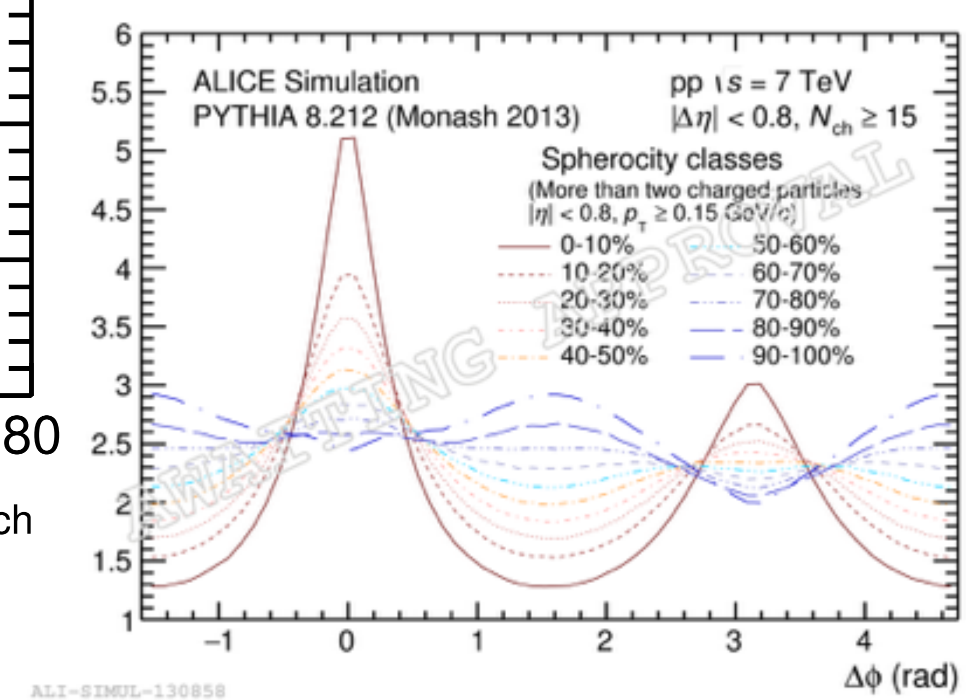


Jetty

Isotropic

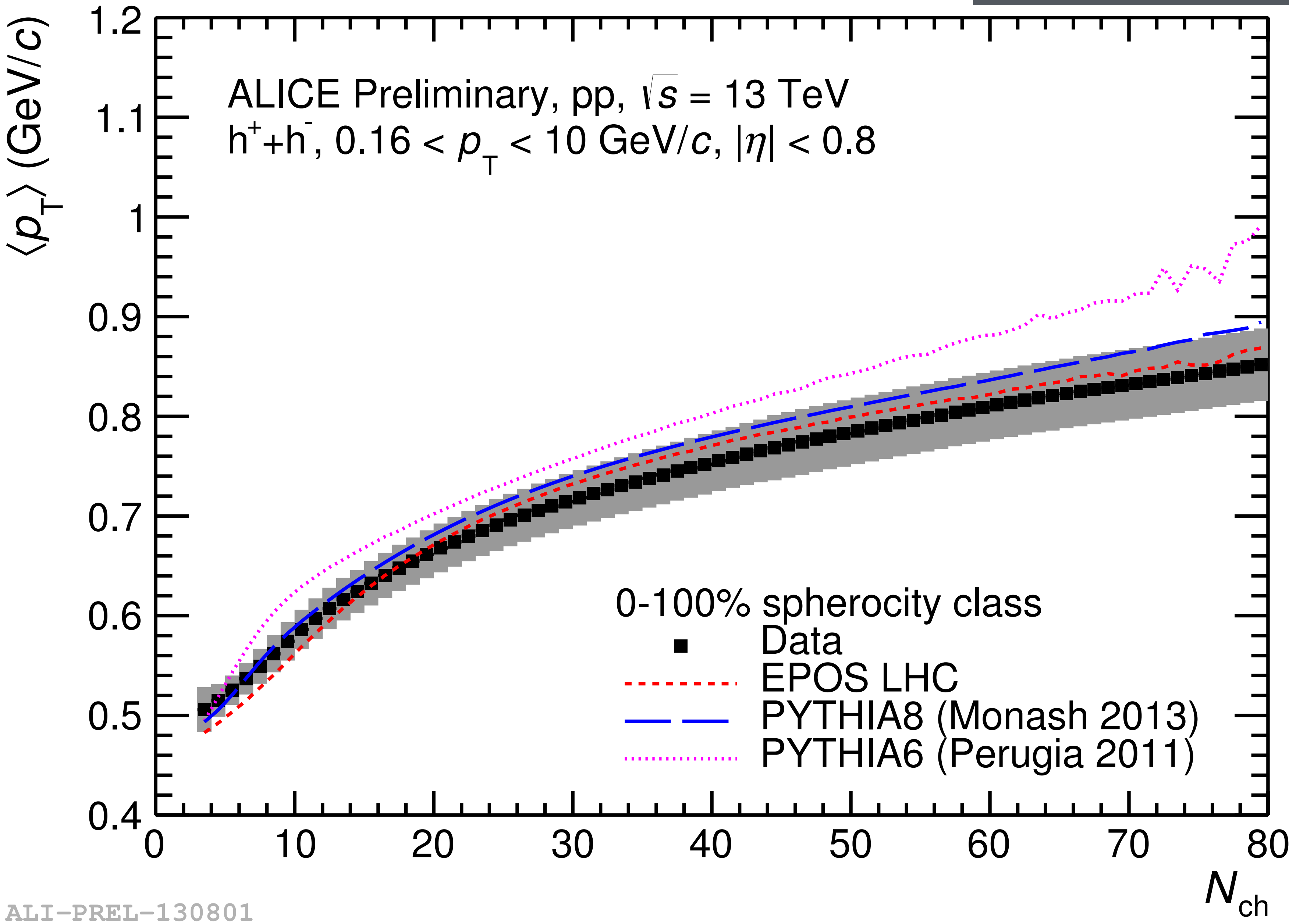
At HM a steper rise is seen for jetty with respect to inclusive

No big difference with MB



Inclusive case <p_T> vs N_{ch} (model comparison)

FULL SYSTEMATIC UNCERTAINTY



ALI-PREL-130801

No spherocity selection: models describe well the data

N_{ch}<10: EPOS LHC underestimates the <p_T>

N_{ch}>30: PYTHIA 6 overestimates the <p_T>

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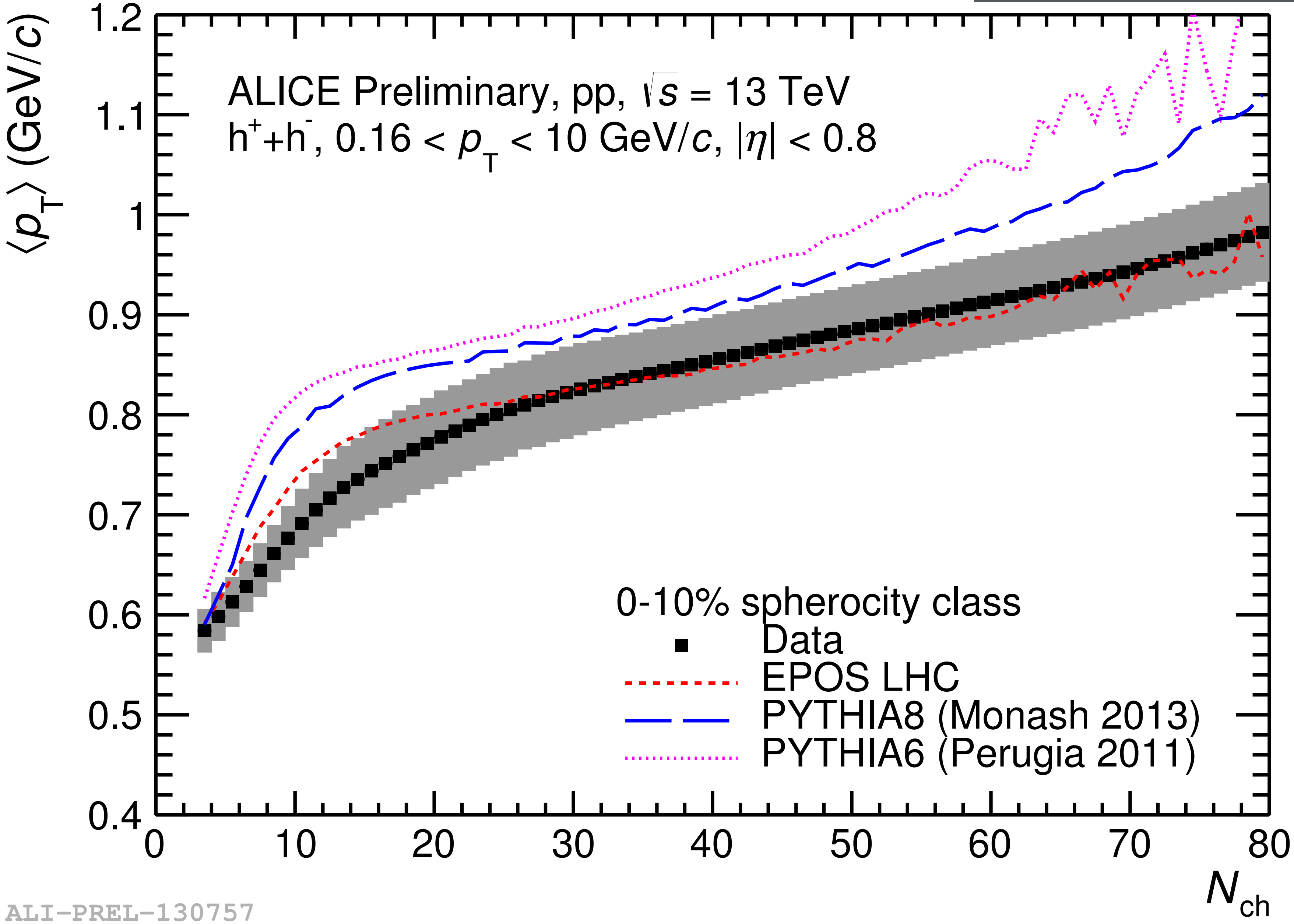
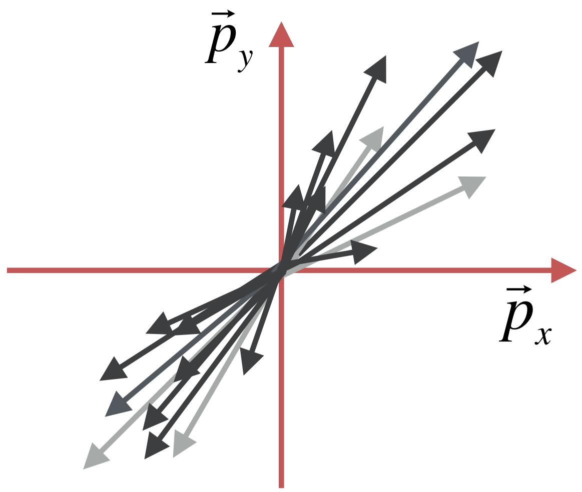
Jetty events <p_T> vs N_{ch} (model comparison)

FULL SYSTEMATIC UNCERTAINTY





Non-isotropic events: **LARGER DIFFERENCES WITH MODELS**, PYTHIA 6 and PYTHIA 8 overestimate the <p_T> (input to improve the CR models: soft-hard interaction), EPOS LHC describes well the data

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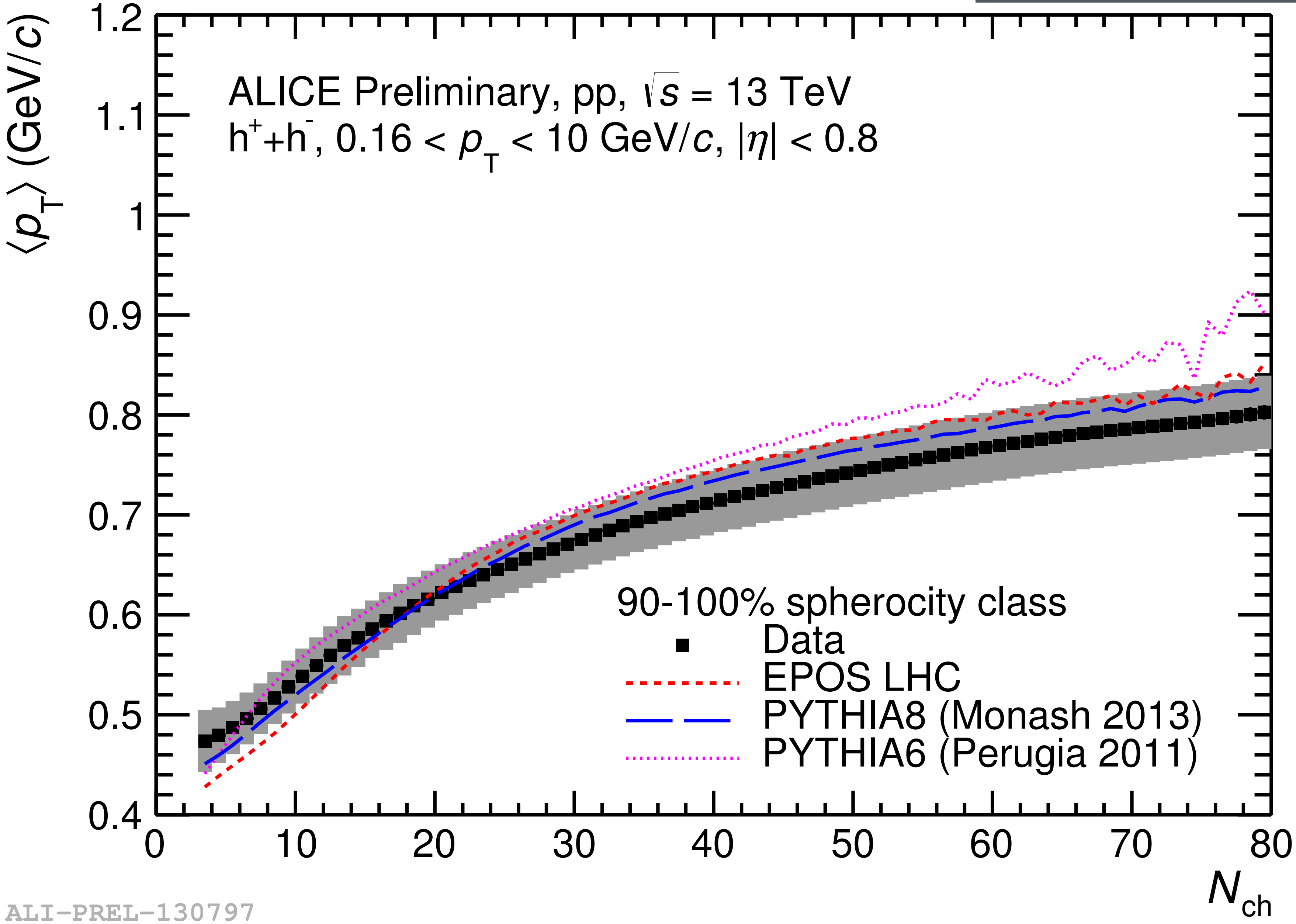
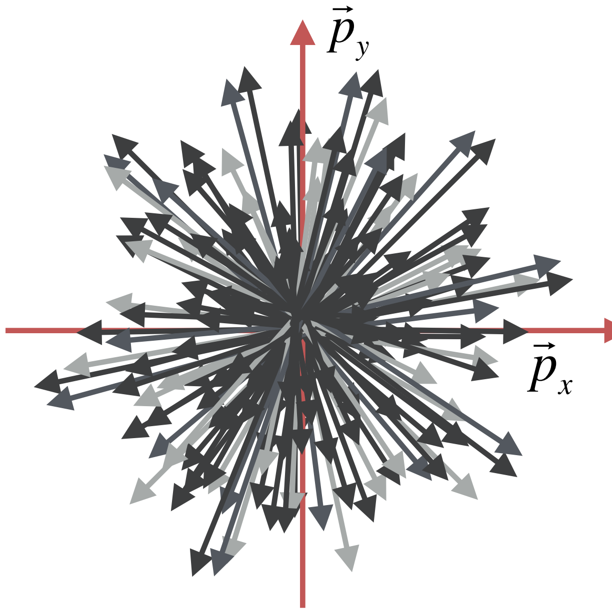
Isotropic events $\langle p_T \rangle$ vs N_{ch} (model comparison)

FULL SYSTEMATIC UNCERTAINTY



ALI-PREL-130797



BETTER AGREEMENT WITH MODELS
(except EPOS LHC [low N_{ch}] and PYTHIA 6 [high N_{ch}])

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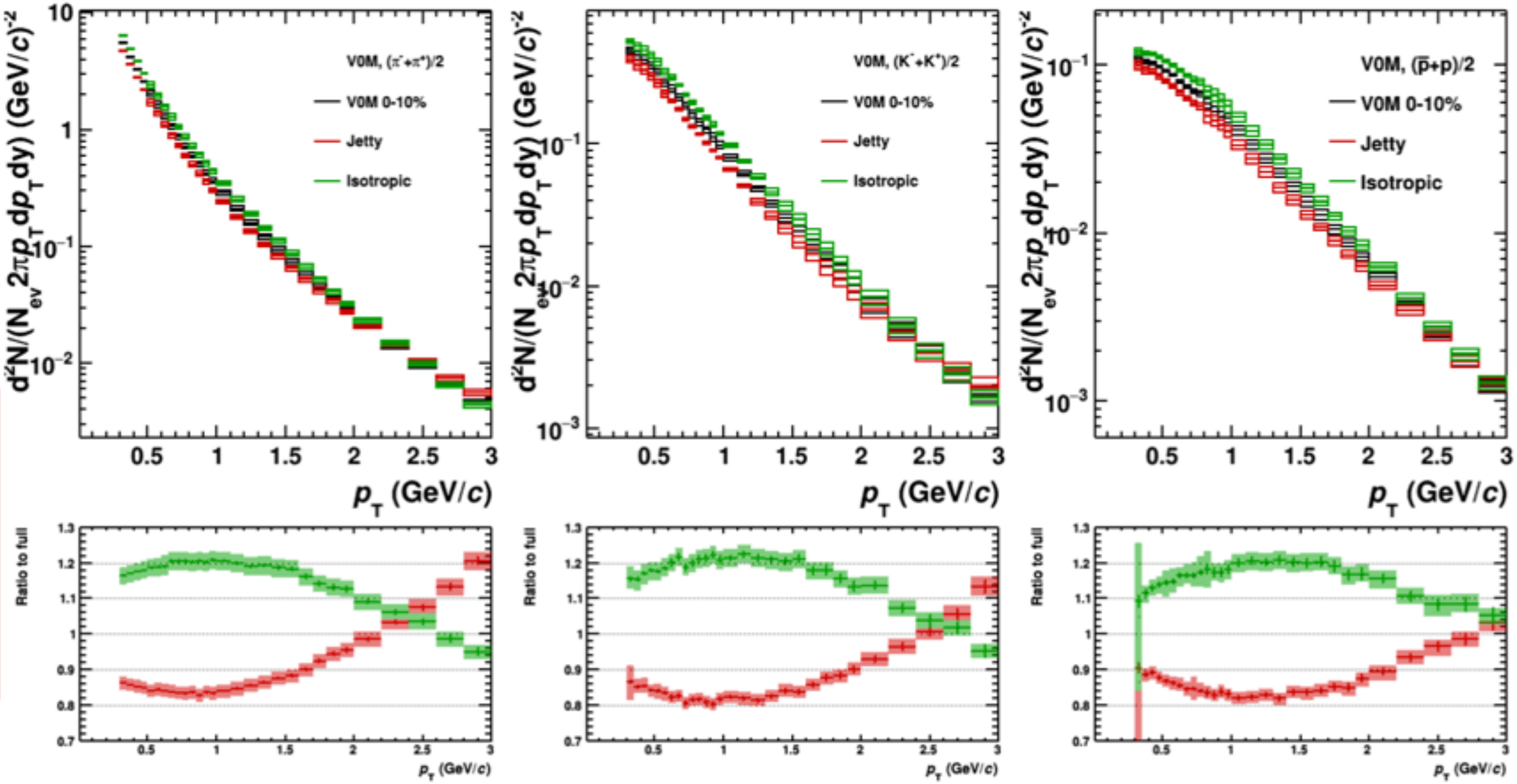
Quick look (hadrochemistry)

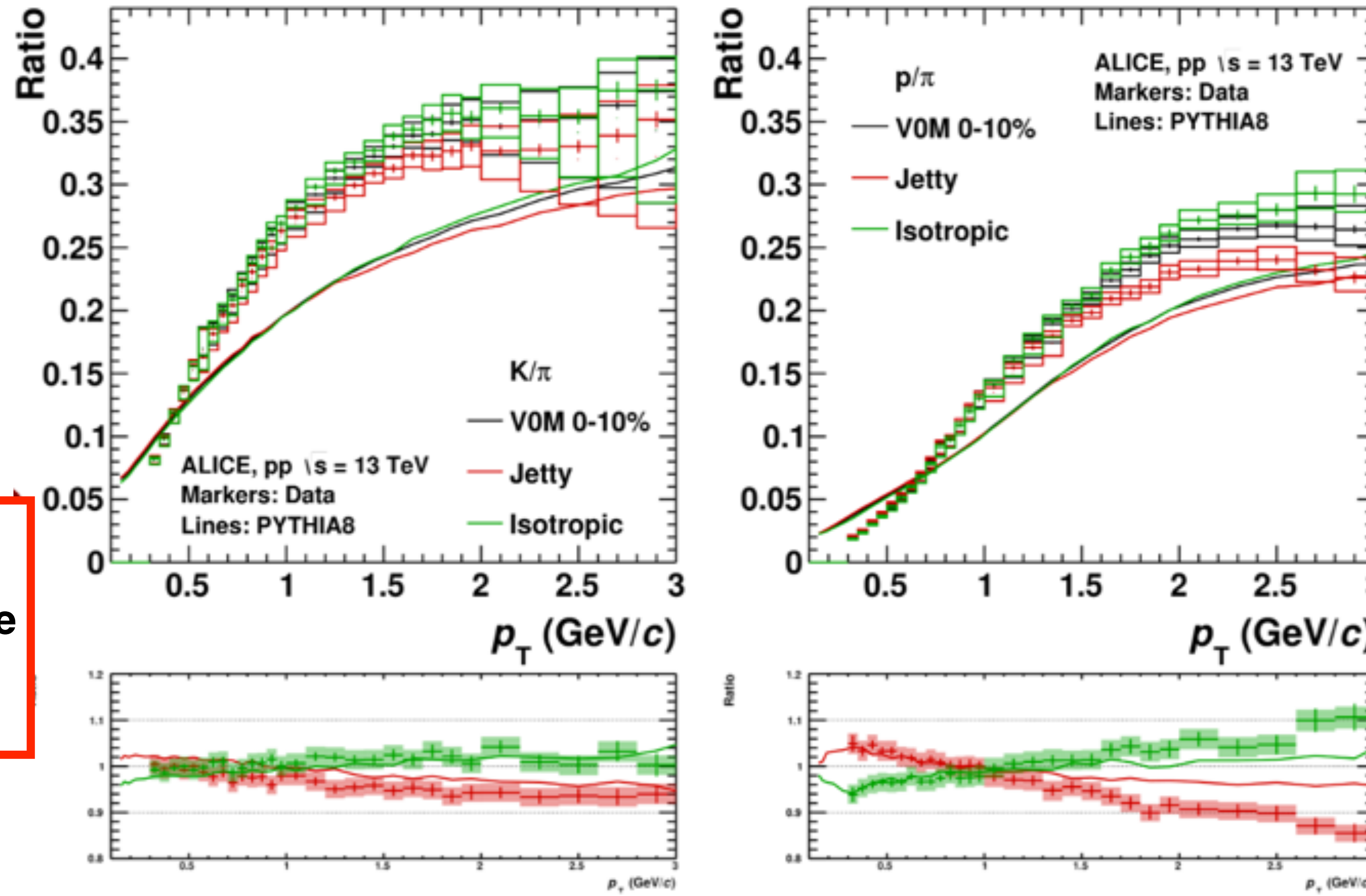
- **Results on identified particles spectra with spherocity.**



Jetty and Isotropic separation on particle yields is seen

Quick look (hadrochemistry)

- **Results on particle ratios with spherocity selection.**



Isotropic events enhance the particle ratios for high p_T

STAY TUNNED …
2nd International Workshop QCD challenges Puebla MX
31/10/2017-3/11/2017

Conclusions

ALICE

- The double differential analysis shown here allows to test the models where underlying event is enhanced or suppressed with respect to the multiplicity dependent case.
    - The average p_T exhibits a steeper rise with N_{ch} going from isotropic (90-100%) to non-isotropic (0-10%) events.
    - The largest tension between data and PYTHIA (6 and 8) is observed for non-isotropic events, where color reconnection can affect the low p_T part of the spectrum due to the presence of a hard parton.
    - This can be used to study the soft-hard interaction.
    - Mean p_T vs multiplicity is a measurement which is useful to constrain the phenomenological models of particle production, e.g. color reconnection models can be tuned.

Dziękuję!

Thank you!

Backup

Introduction

ALICE

High multiplicity (HM) pp collisions becomes interesting due to new phenomena observations:

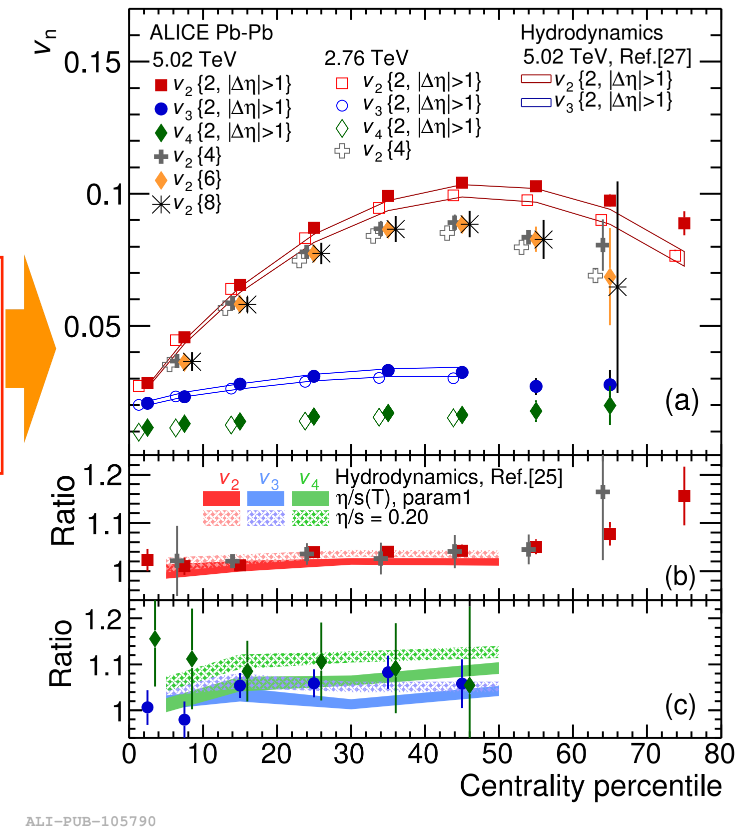
- **Strangeness enhancement**

  Nature Physics 13, 535–539 (2017)

- **Radial and anisotropic flow**

  Phys.Rev.Lett. 116 (2016) no.13, 132302

Anisotropic Flow of Charged Particles in Pb-Pb Collisions at $\sqrt{s_{NN}}$= 5.02 TeV



See You Zhou's talk ALICE results on small systems on Thursday

What is causing the observed phenomena:

- **Small drop of QGP?** NPA 956 (2016) 200-207

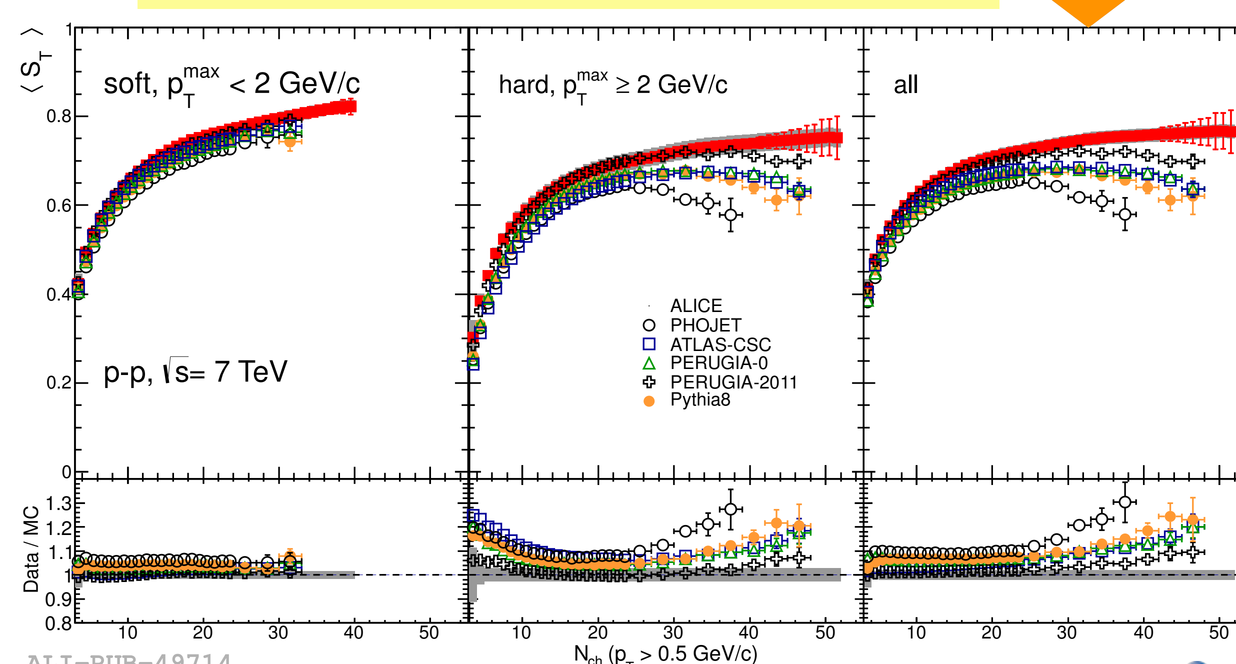
See Ivan's Ravasenga talk: collectivity in ALICE

To isolate the new physics, we implement a double differential analysis which **incorporates a selection based on event shapes.**

Andrea Banfi et all. JHEP 1006:038,2010
Antonio Ortiz arXiv:1705.02056

Transverse sphericity of primary charged particles in minimum bias proton-proton collisions at $\sqrt{s}$= 0.9, 2.76 and 7 TeV

Eur. Phys. J. C 72 (2012) 2124



- It allows to split the events with jet content.
- Previous ALICE results shows important differences with QCD-inspired models.
- Here I will show new results on $< p_T >$ as a function of both multiplicity (N_{ch}) and transverse spherocity (S_O)

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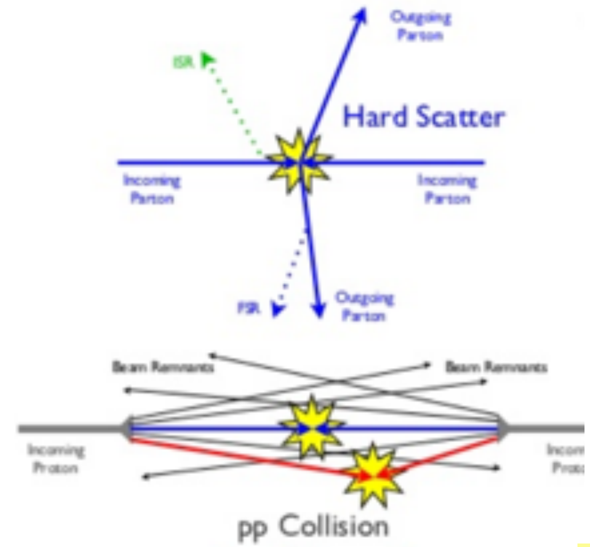
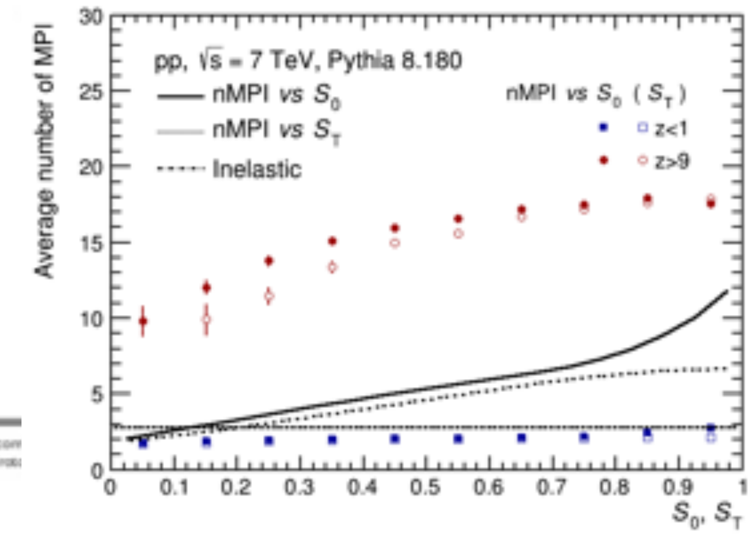
Motivation from Models

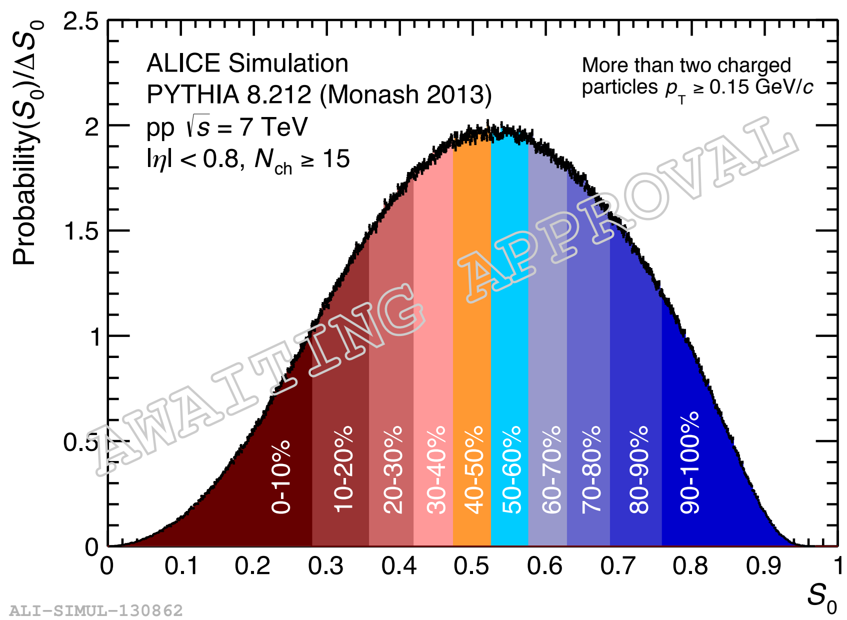
- Study features of High Multiplicity pp collisions using spherocity event by event will allow to separate “**soft**” (**no-pQCD**) from **“hard”** (**pQCD**) physics.
- With spherocity **MPI** could be studied.
- According to **PYTHIA 8**, spherocity allows the separation of events where **UE event** can be enhanced or suppressed.
- Comparing models and data will help us to get more information about high multiplicity events, for example if flow or other mechanisms as CR predominates in jets or in events without them.

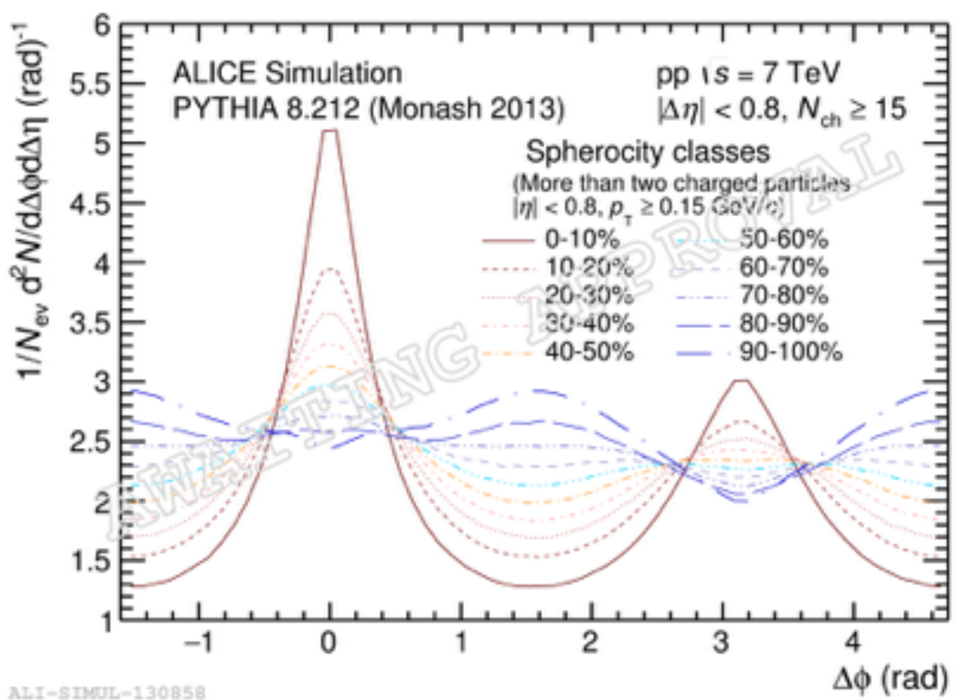


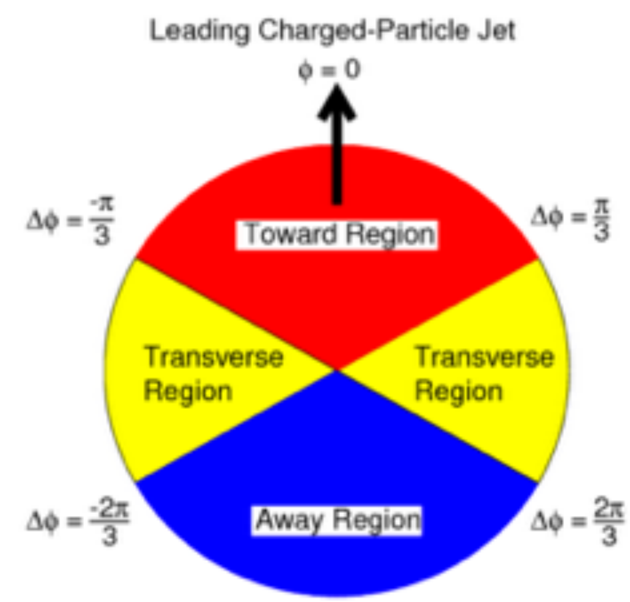


For more of collectivity on Lund Monte Carlo see C. Bierlich’s talk

Disentangling the soft and hard components of the pp collisions using the sphero(i)city approach. Eleazar Cuautle, Raul Jimenez, Ivonne Maldonado, Antonio Ortiz, Guy Paic, Edgar Perez arXiv:1404.2372







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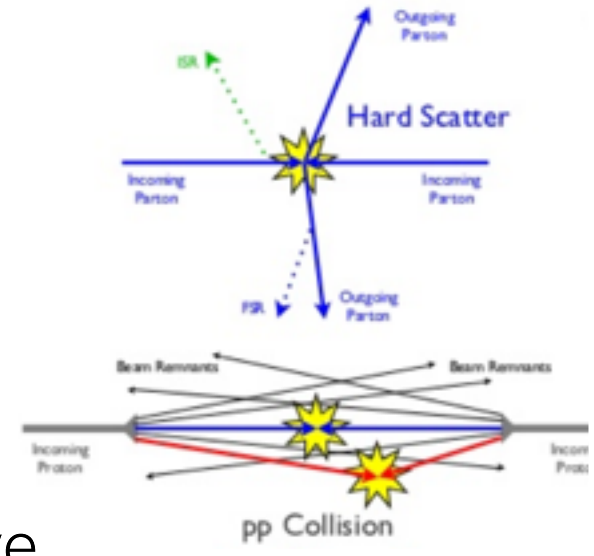
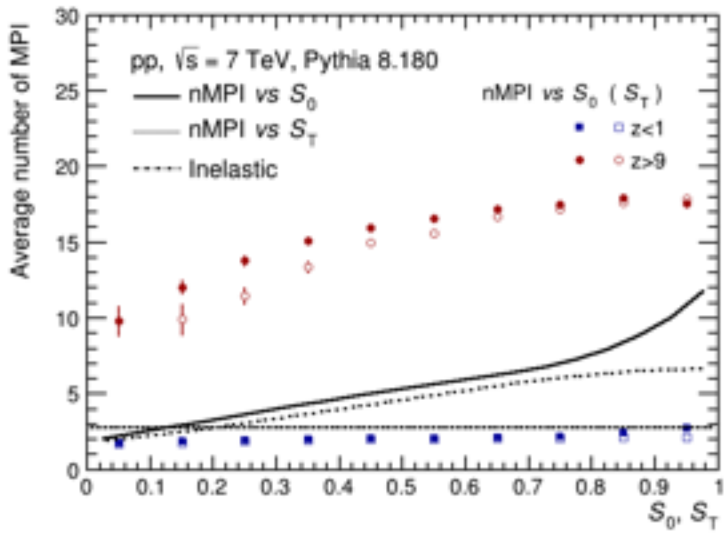
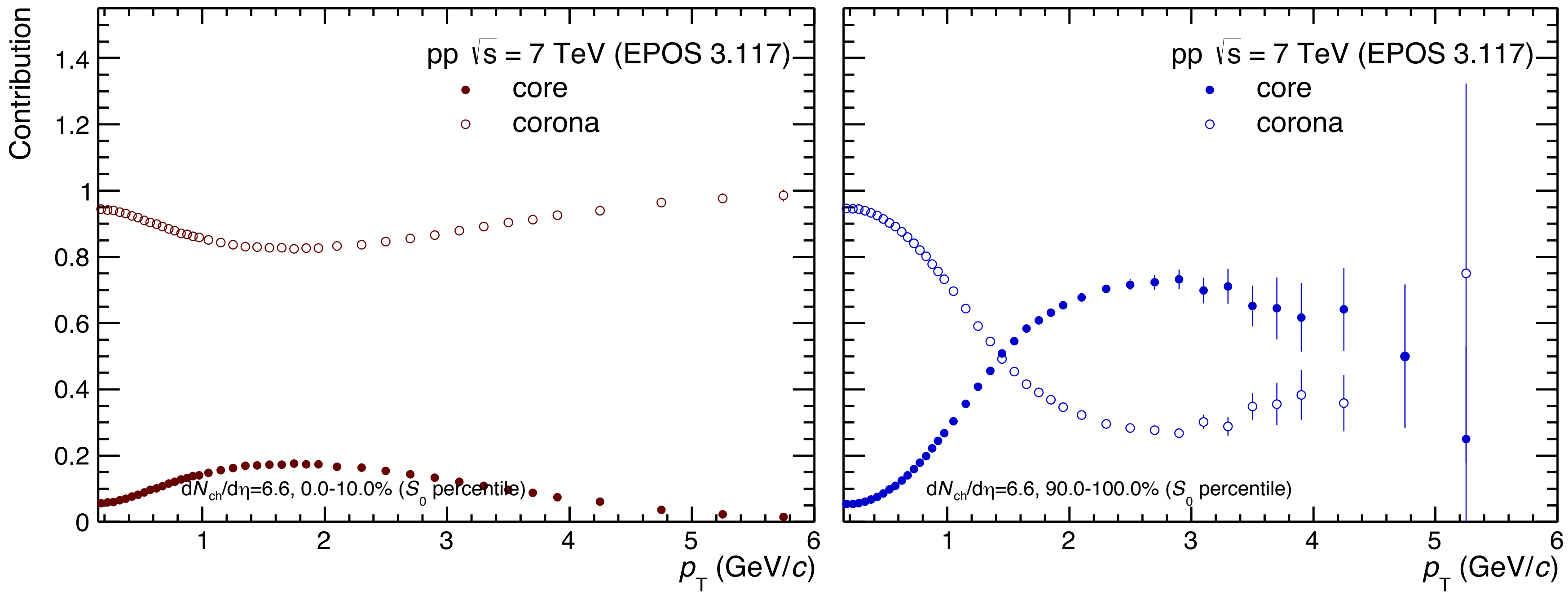
- Study features of High Multiplicity pp collisions using spherocity event by event will allow to separate "**soft**" (**no-pQCD**) from "**hard**" (**pQCD**) physics.
- With spherocity **MPI** could be studied.
- According to **PYTHIA 8**, spherocity allows the separation of events where **UE event** can be enhanced or suppressed.
- In **EPOS 3.1**, using spherocity one can achieve samples with enhanced or suppressed core contribution.



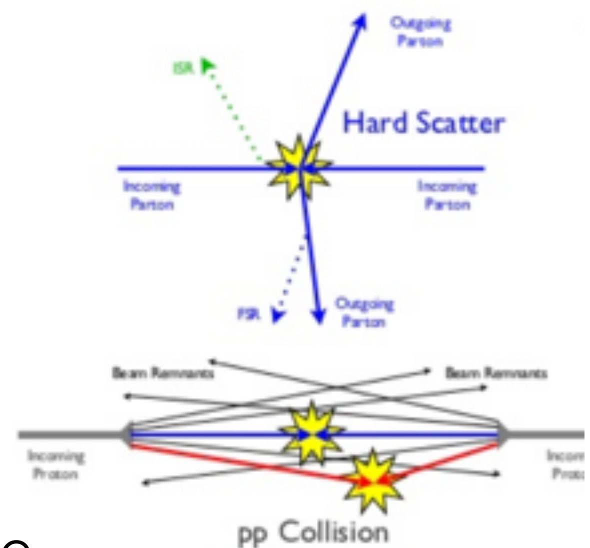


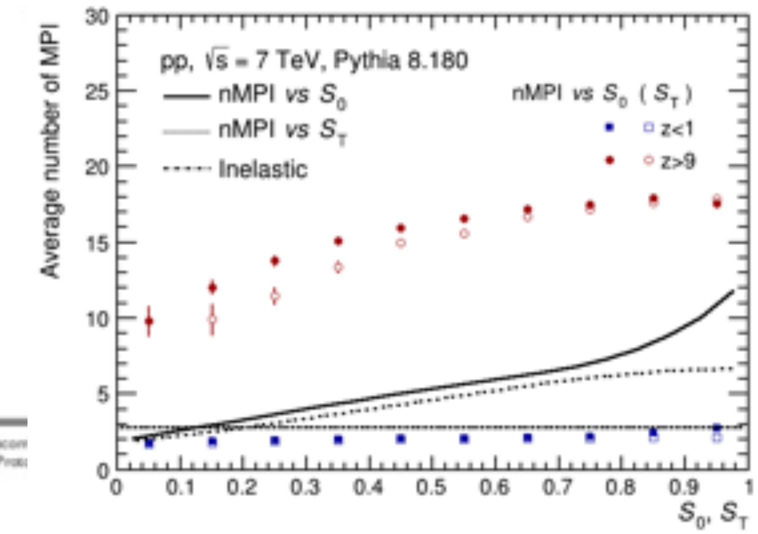
Disentangling the soft and hard components of the pp collisions using the sphero(i)city approach. Eleazar Cuautle, Raul Jimenez, Ivonne Maldonado, Antonio Ortiz, Guy Paic, Edgar Perez arXiv:1404.2372



Motivation from Models

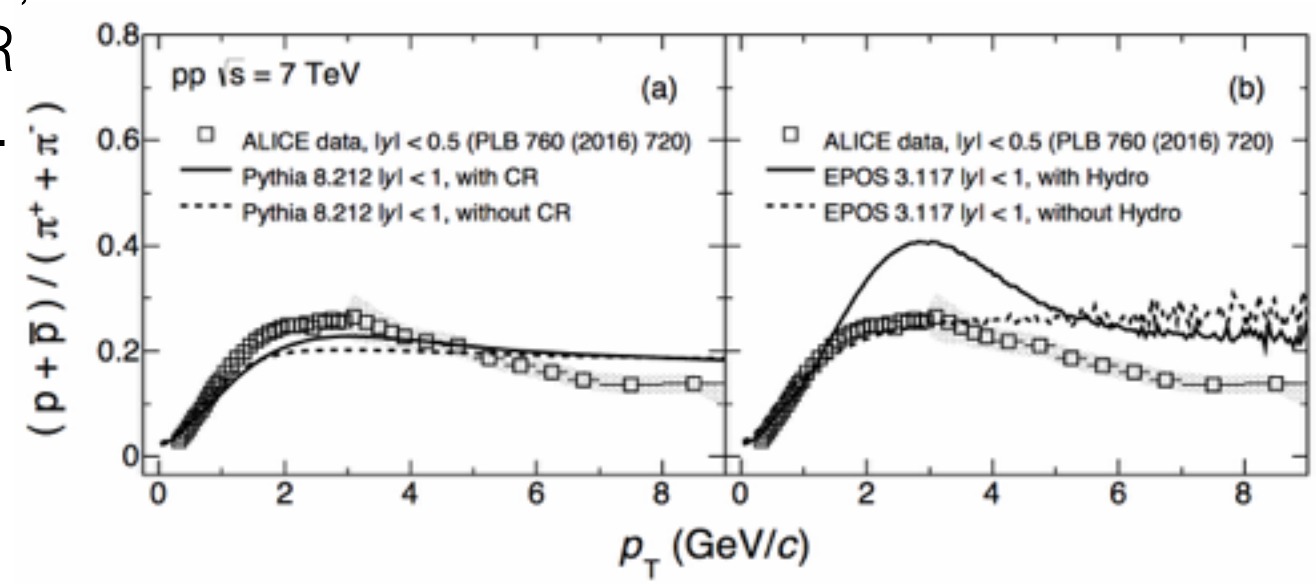
- Study features of High Multiplicity pp collisions using spherocity event by event will allow to separate “**soft**” (**no-pQCD**) from **“hard”** (**pQCD**) physics.
- With spherocity **MPI** could be studied.
- According to **PYTHIA 8**, spherocity allows the separation of events where **UE event** can be enhanced or suppressed.
- In **EPOS 3.1**, using spherocity one can achieve samples with enhanced or suppressed core contribution.
- Comparing models and data will help us to get more information about high multiplicity events, for example if flow or other mechanisms as CR predominates in jets or in events without them.





Disentangling the soft and hard components of the pp collisions using the sphero(i)city approach. Eleazar Cuautle, Raul Jimenez, Ivonne Maldonado, Antonio Ortiz, Guy Paic, Edgar Perez arXiv:1404.2372

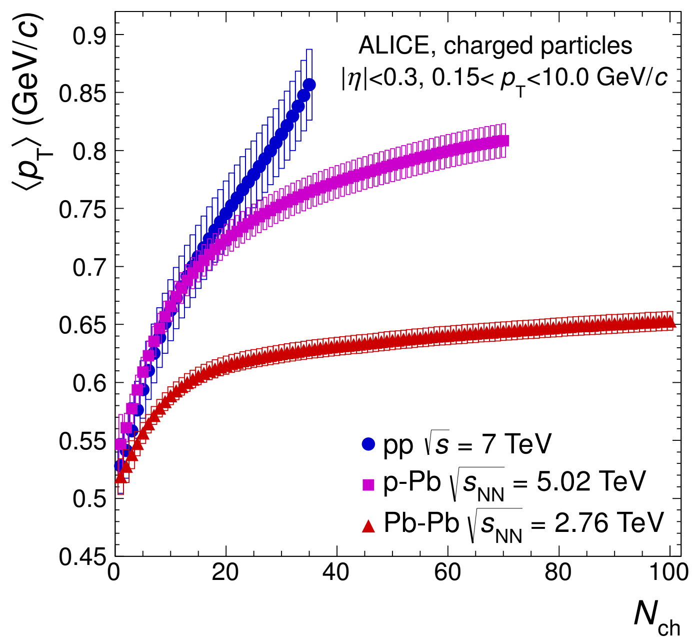
Revealing the source of the radial flow patterns in proton--proton collisions using hard probes, Antonio Ortiz, Gyula Bencédi, Héctor Bello, J. Phys. G: Nucl.Part.Phys.44 (2017) .



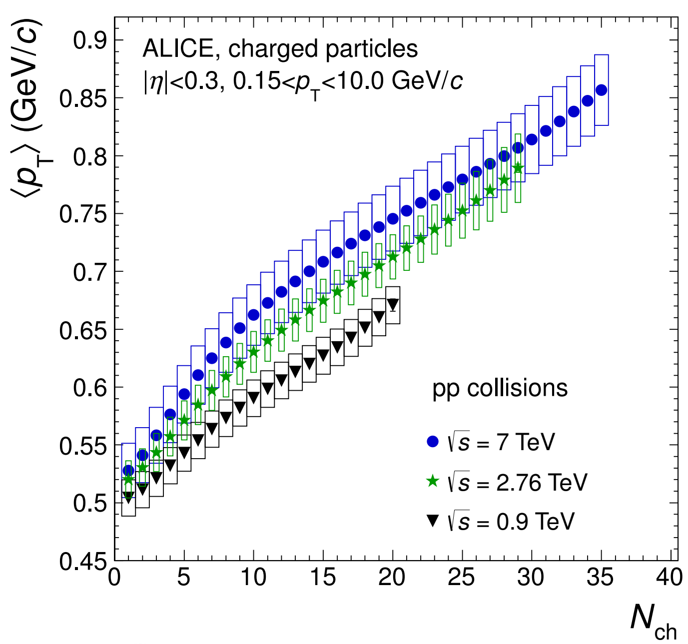
Experimental background at ALICE before RUN 2

Multiplicity dependence of the average transverse momentum in pp, p–Pb, and Pb–Pb collisions at the LHC

Phys. Lett. B 727 (2013) 371-380

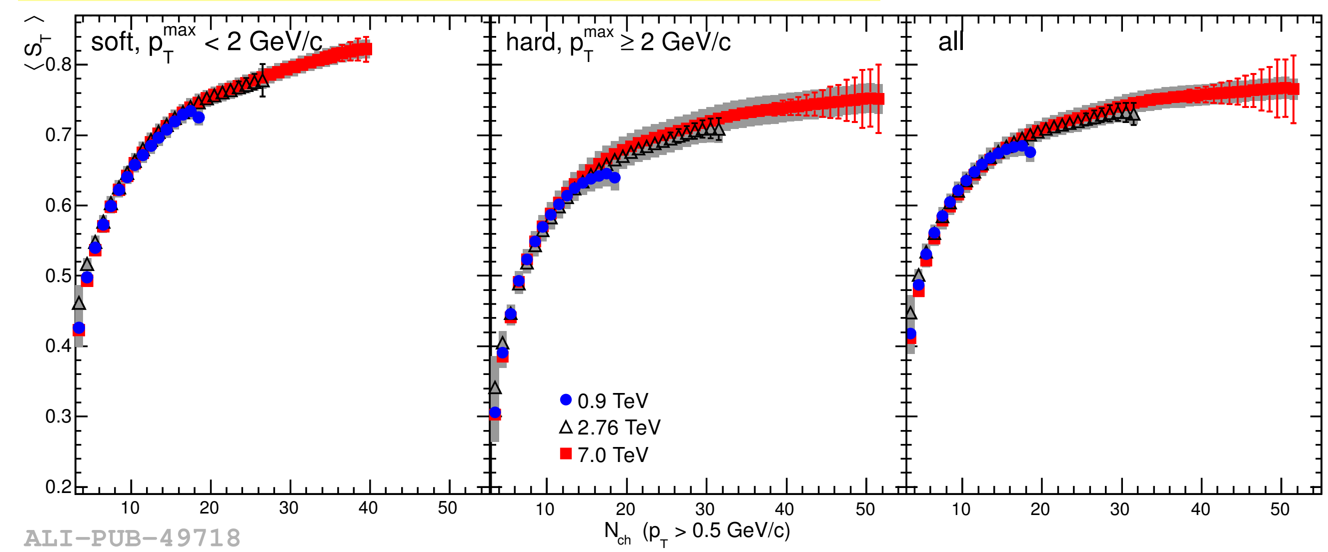


Difference in the mean transverse momentum for the three systems have seen, specially not saturation for pp systems, this behavior its independent of the collision energy.

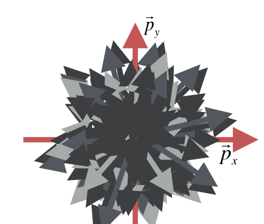


Transverse sphericity of primary charged particles in minimum bias proton-proton collisions at √s= 0.9, 2.76 and 7 TeV

Eur. Phys. J. C 72 (2012) 2124

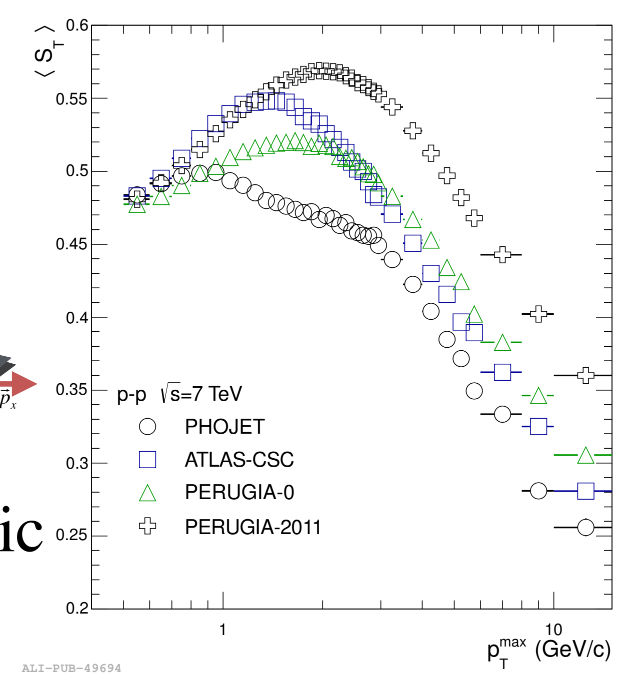


$$S_{xy}^{L} = \frac{1}{\sum_i p_{Ti}} \sum_i \frac{1}{p_{Ti}} \begin{pmatrix} p_{x_i}^2 & p_{x_i} p_{y_i} \\ p_{y_i} p_{x_i} & p_{y_i}^2 \end{pmatrix}$$

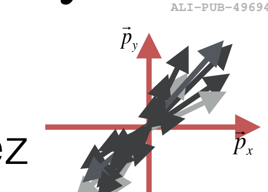


$$S_T = \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$ for $\lambda_1 >= \lambda_2$,

where sphericity limits are: $S_T = \begin{cases} 1 \text{ isotropic} \\ 0 \text{ jetty} \end{cases}$



For the mean sphericity, it has been measured that increases at high multiplicity, this was not described in MC models.

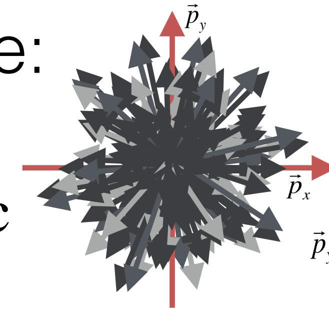


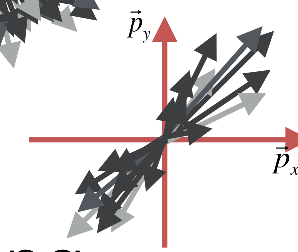
Spherocity

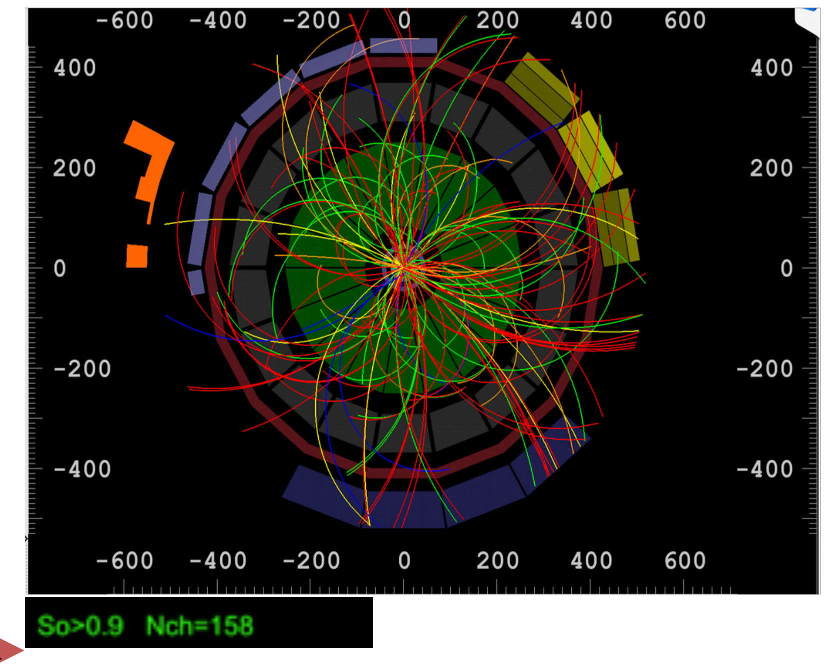
The spherocity is defined by: $S_{\mathrm{T}}^{pherocity} = \frac{\pi^2}{4} \min_{\vec{n}=(n_x,n_y,0)} \left(\frac{\sum_i |\vec{p}_{Ti} \times \vec{n}|}{\sum_i \vec{p}_{Ti}} \right)^2$

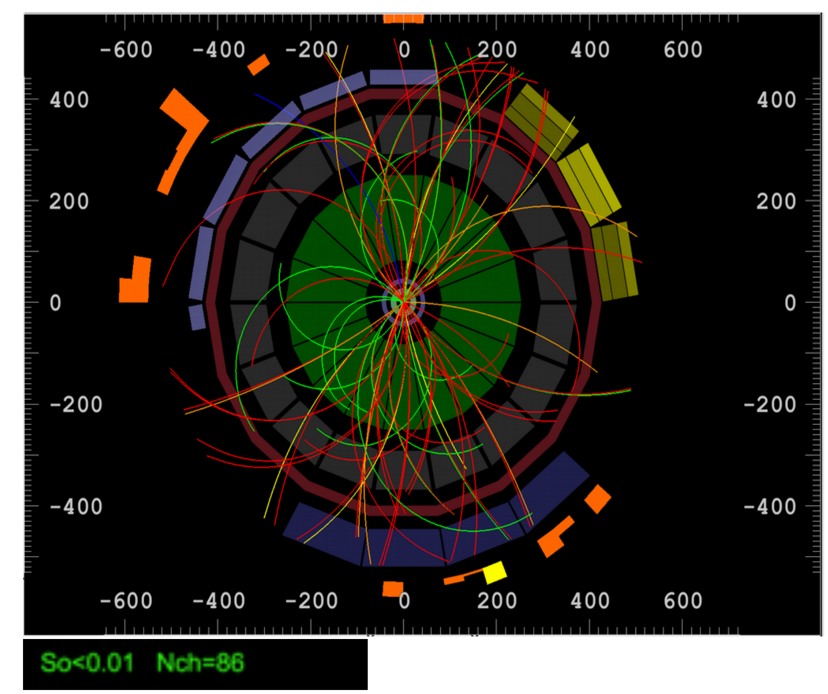
Where $\vec{n} = (n_x, n_y, 0)$ is the normal vector in the transverse plane that minimises this ratio. The limits are:

$$S_O = S_T^{pherocity} = \begin{cases} 1 \text{ isotropic} \\ 0 \text{ jetty} \end{cases}$$









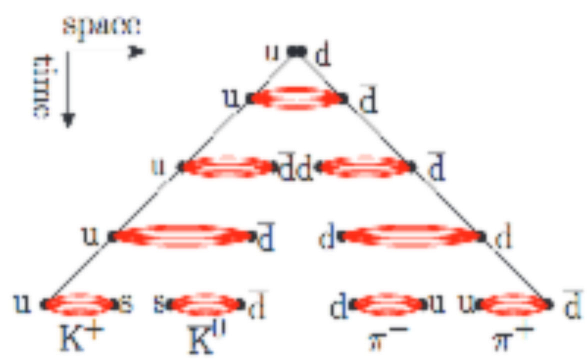
Spherocity is calculated event-by-event considering **more than 2 charged particles having p_{T} > 0.15 GeV/c and within $|\eta|$<0.8**.

Phenomenology of event shapes at hadron colliders
Andrea Banfi, Gavin P. Salam, Giulia Zanderighi
JHEP 1006:038,2010
A recent review on event shapes at hadron colliders.
Antonio Ortiz arXiv:1705.02056

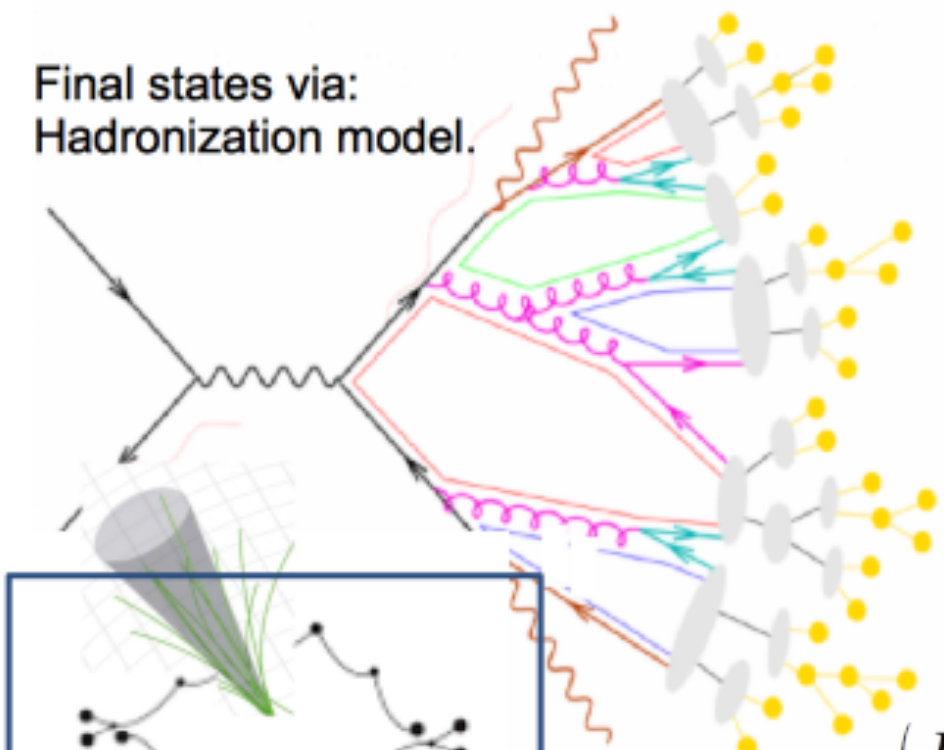
Reference to Pythia 8

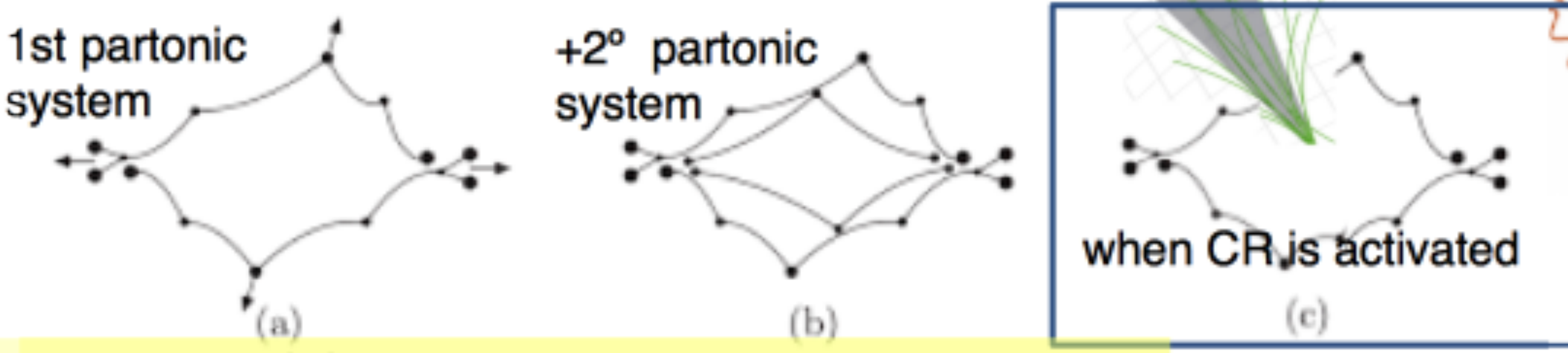
Introduction Color Reconnection (PYTHIA8)

Production via:
Lund String fragmentation
Model



Final states via:
Hadronization model.

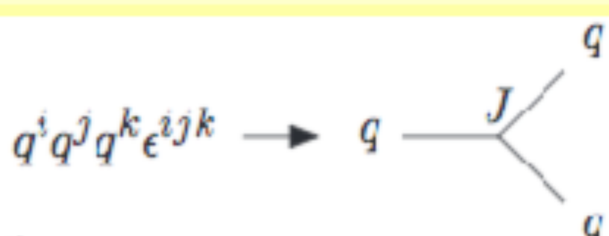


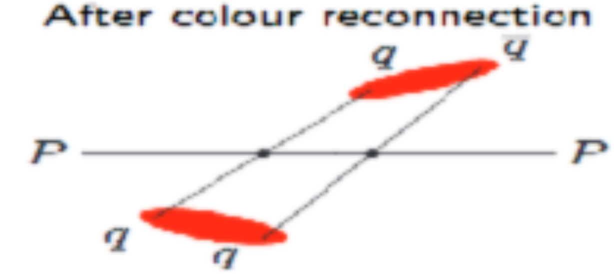


$$P(p_T) = \frac{(RR \times p_{T0})^2}{(RR \times p_{T0})^2 + p_T^2}$$

- Figure taken from: G. Gustafson, Acta Phys. Polon. B40, 1981 (2009)
  Effects of CR on hadron flavor observables, C. Bierlich and J. R. Christiansen, PRD 92 (2015) 9, 094010

QCD rules say how reconnection is allowed (epsilon color tensor)





From: Jesper Roy Christiansen MPI@LHC 2014

The minimum string length tell us the configuration

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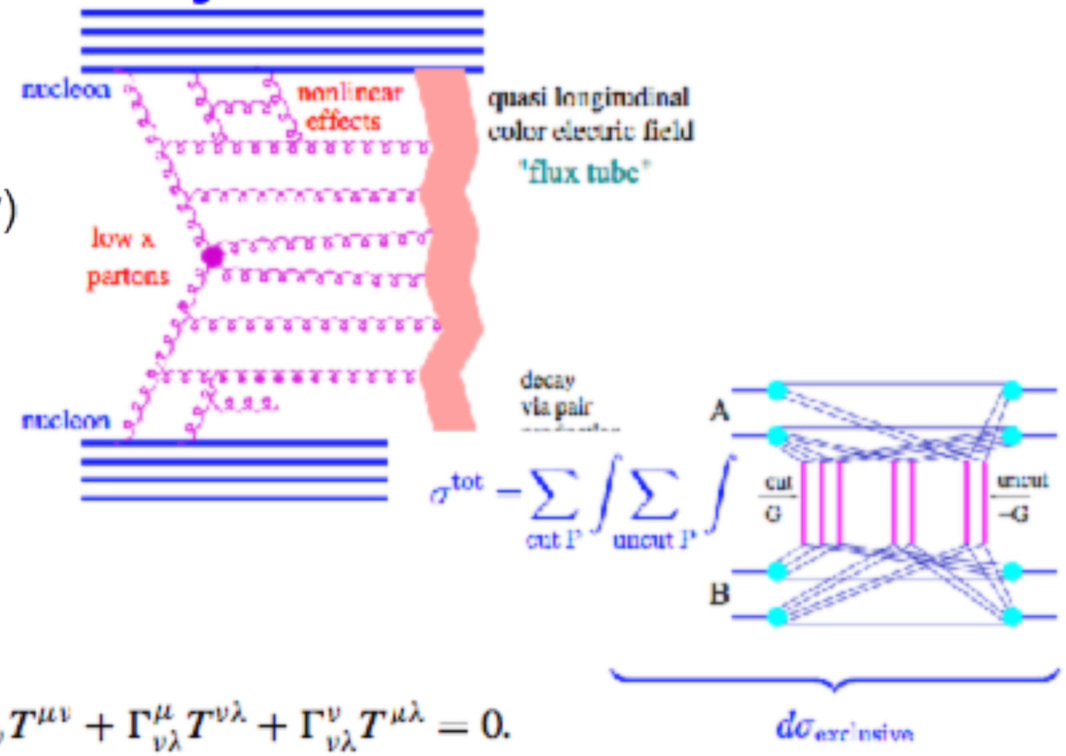
Reference to EPOS

Introduction   3+1D Hidrodynamics

Model with:

Energy conservation in multiple scattering
Parton modelled by (Gribov–Regge Theory)
Off-shell, remanents
Saturation



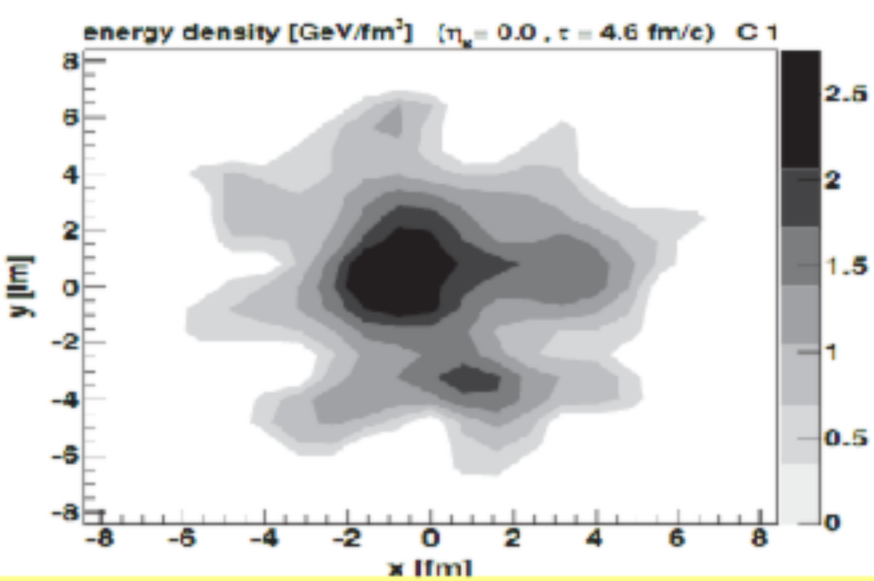
"Core-corona" separation

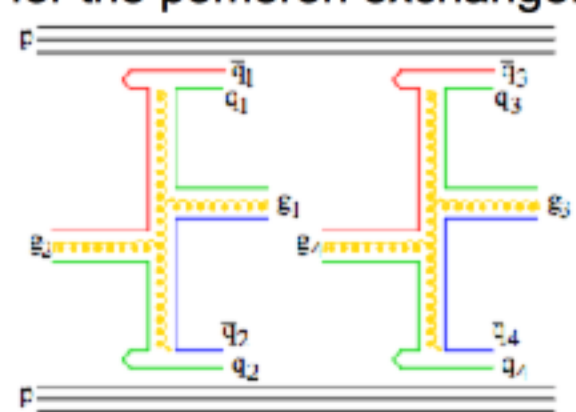
Core→high string density
Corona→low string density
with "Core"=Hidrodynamics
No "Core"=just string model

$$\partial_{;\nu} T^{\mu\nu} = \partial_\nu T^{\mu\nu} + \Gamma^{\mu}_{\nu\lambda} T^{\nu\lambda} + \Gamma^{\nu}_{\nu\lambda} T^{\mu\lambda} = 0.$$

K. Werner et al., PRC89 (2014) 6, 064903

Color flux tubes for the pomeron exchange.





K. Werner et al., PRC 82 (2010) 044904

K.Werner et al, PRC 92 (2015) 034906

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