Baryon enhancement in heavy ion collisions measured by the ALICE experiment

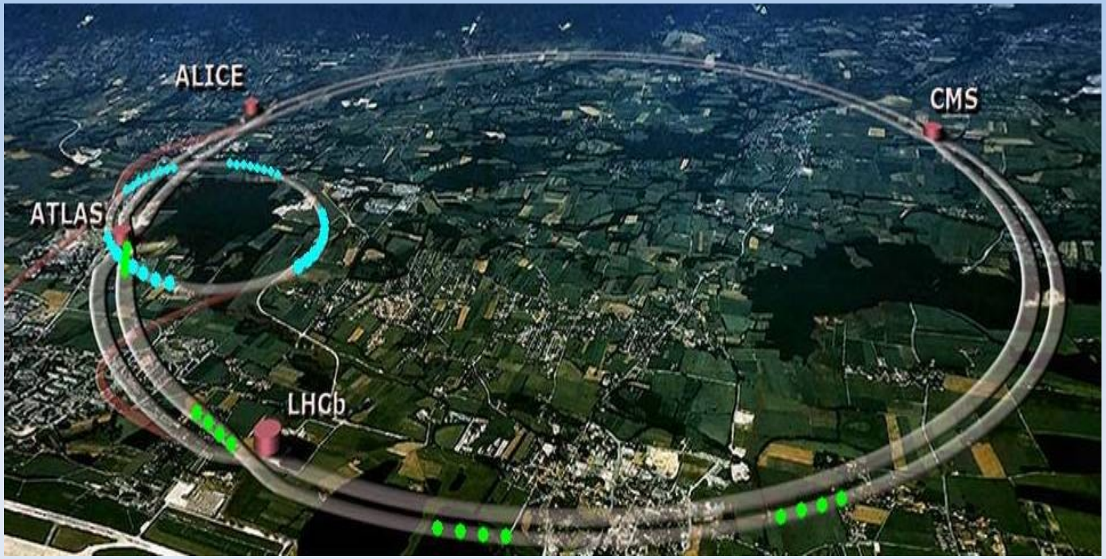
Tuva Richert
Lund University

Outline

- Introduction
- Heavy ion collisions
- The ALICE detector
- My analysis: Lambda and k0s
  - analysis procedure
  - results: lambda/K0s ratio
- Other Lund analysis results: proton/pion ratio
- Conclusions and outlook

Introduction / motivation

Collide Pb-Pb with LHC and search for signatures and charachteristics of quark gluon plasma, in my analysis: the baryon enhancement



Background: Previously observed baryon enhancement at intermediate pT measured with STAR 2002, AuAu collisions at 200 GeV

Baryon enhancement: more baryons (e.g. protons, lambdas) than mesons (e.g. pions, K0s) produced in heavy ion collisions than proton-proton collisions

→ Sign of something that changes the production mechanism, a new hot and dense medium, e.g. QGP

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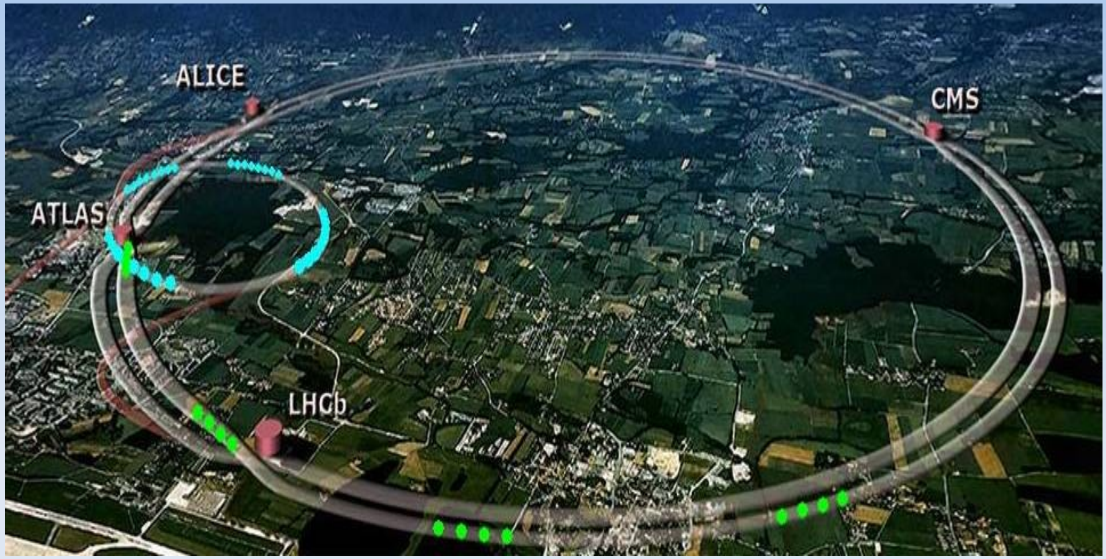

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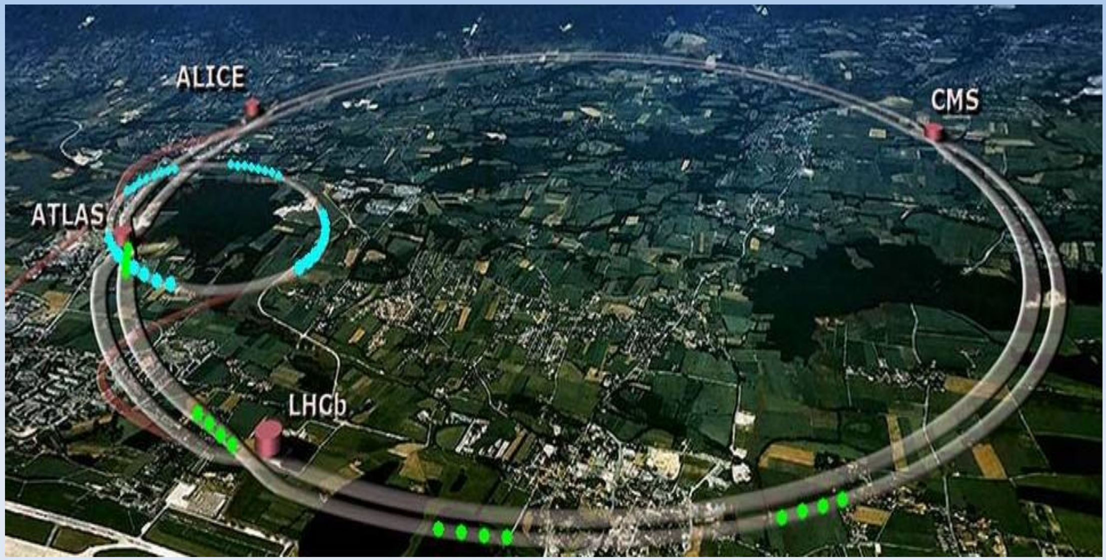

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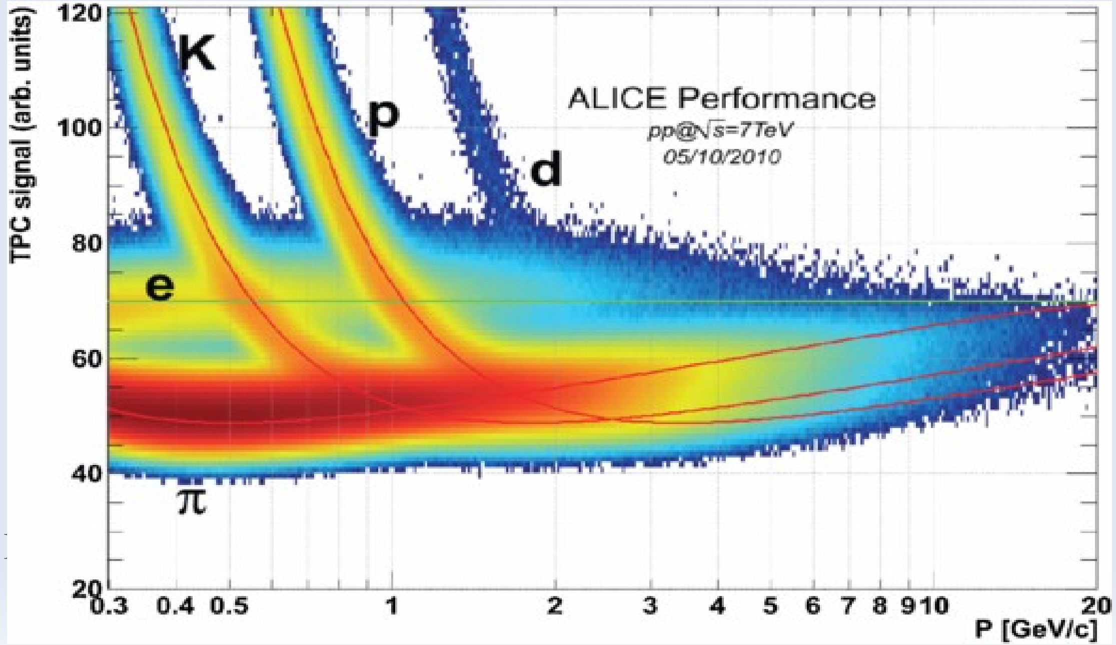


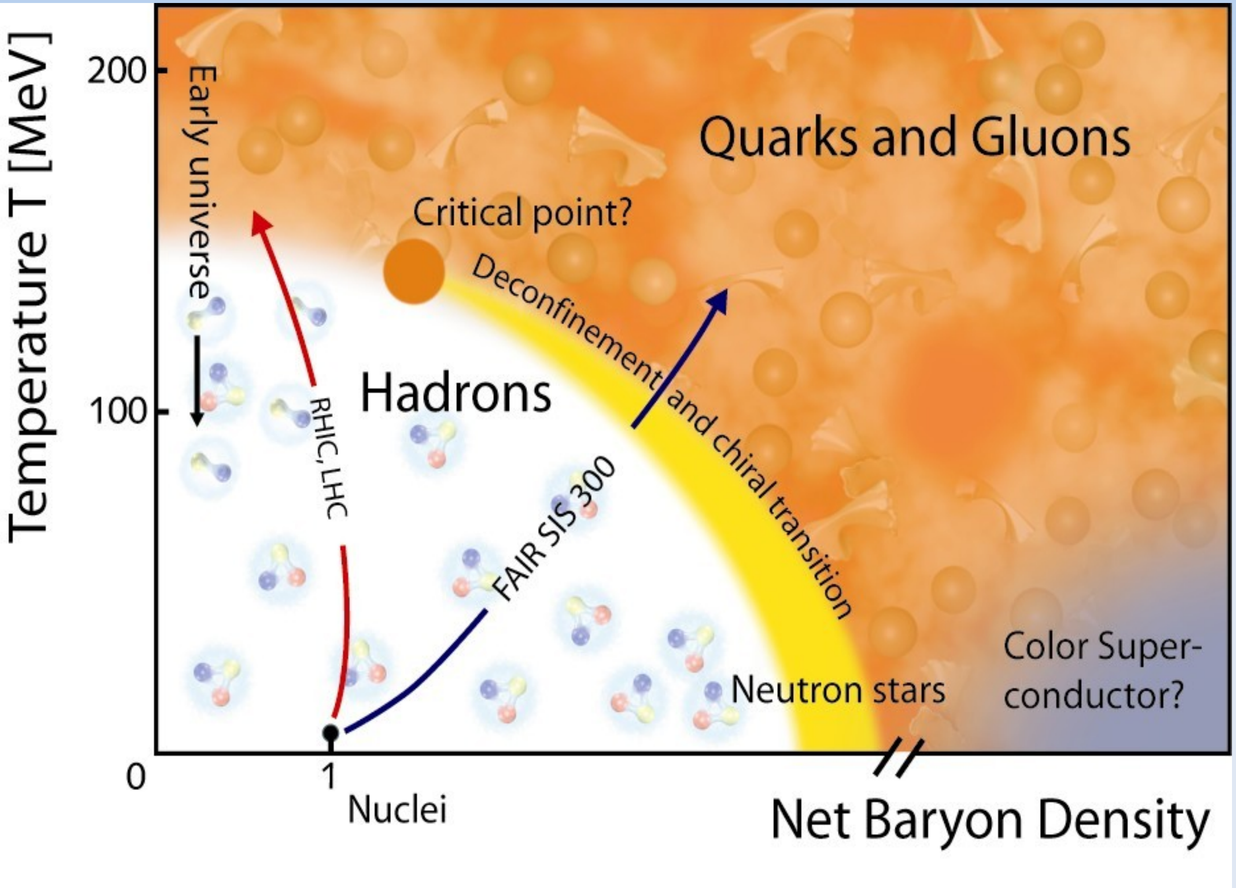
What happens at the BIG BROTHER of RHIC, namely the LHC?

My analysis: lambda/k0s

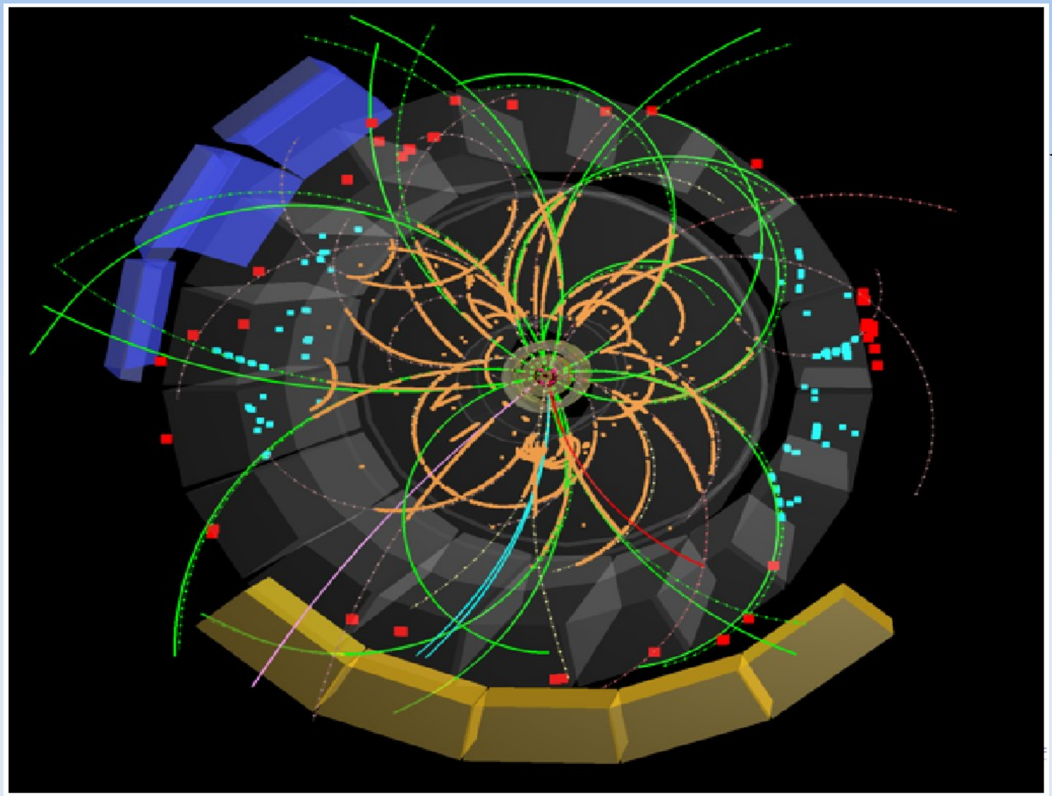
But also in Lund: p/pi (different kind of analysis since limited PID of pions)

Heavy ion collisions

- Nuclear matter: quarks confined
- Quark matter: quarks deconfined
- ALICE goal:
  - characterizing of QGP
  - properties in different phases of the QGP life
  - production mechanisms
  - hadronization
  - fragmentation
- Detected: hadrons created from the energy released in the hadronization process

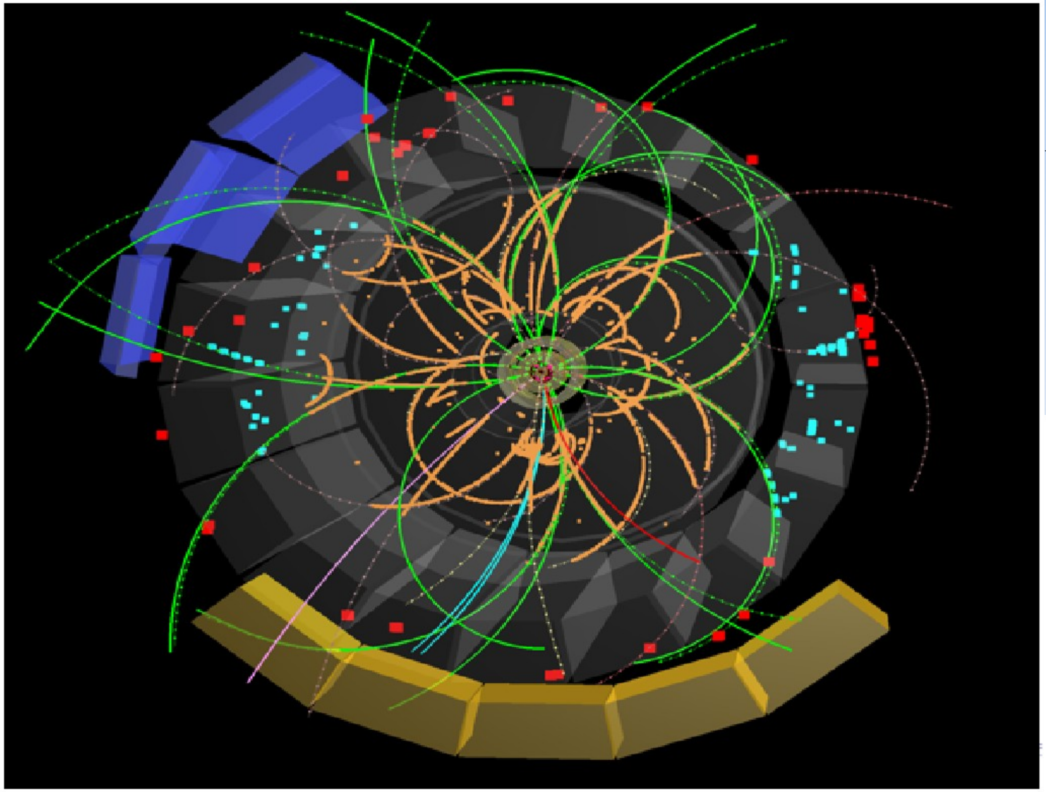


Proton vs heavy ion collisions



A proton-proton collision

Proton vs heavy ion collisions



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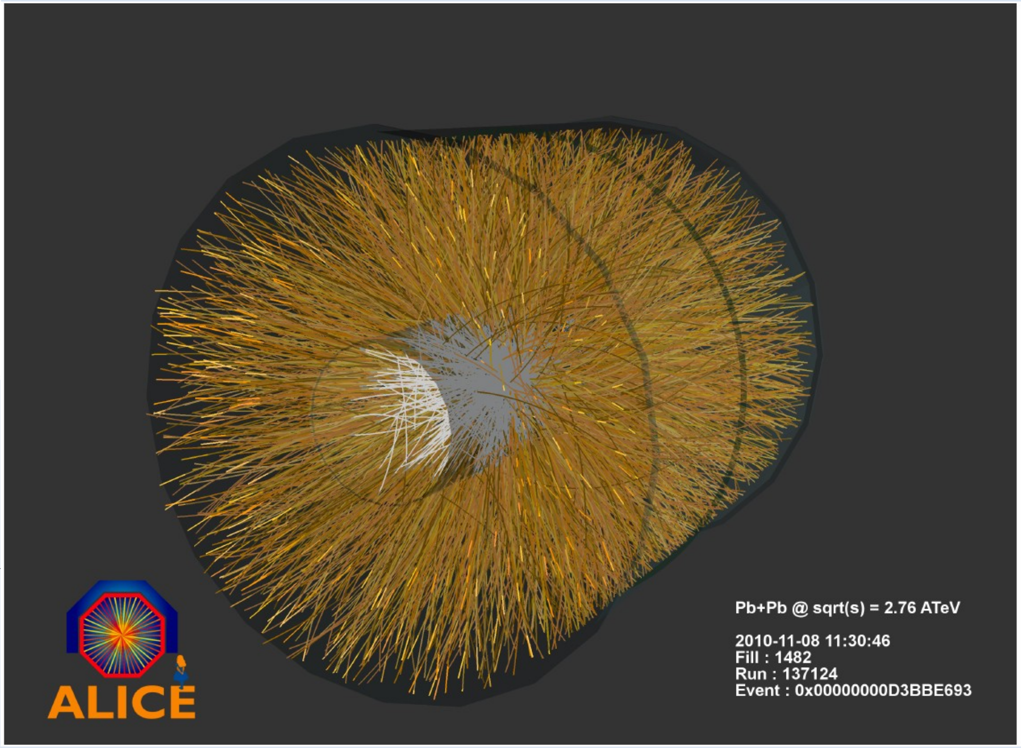
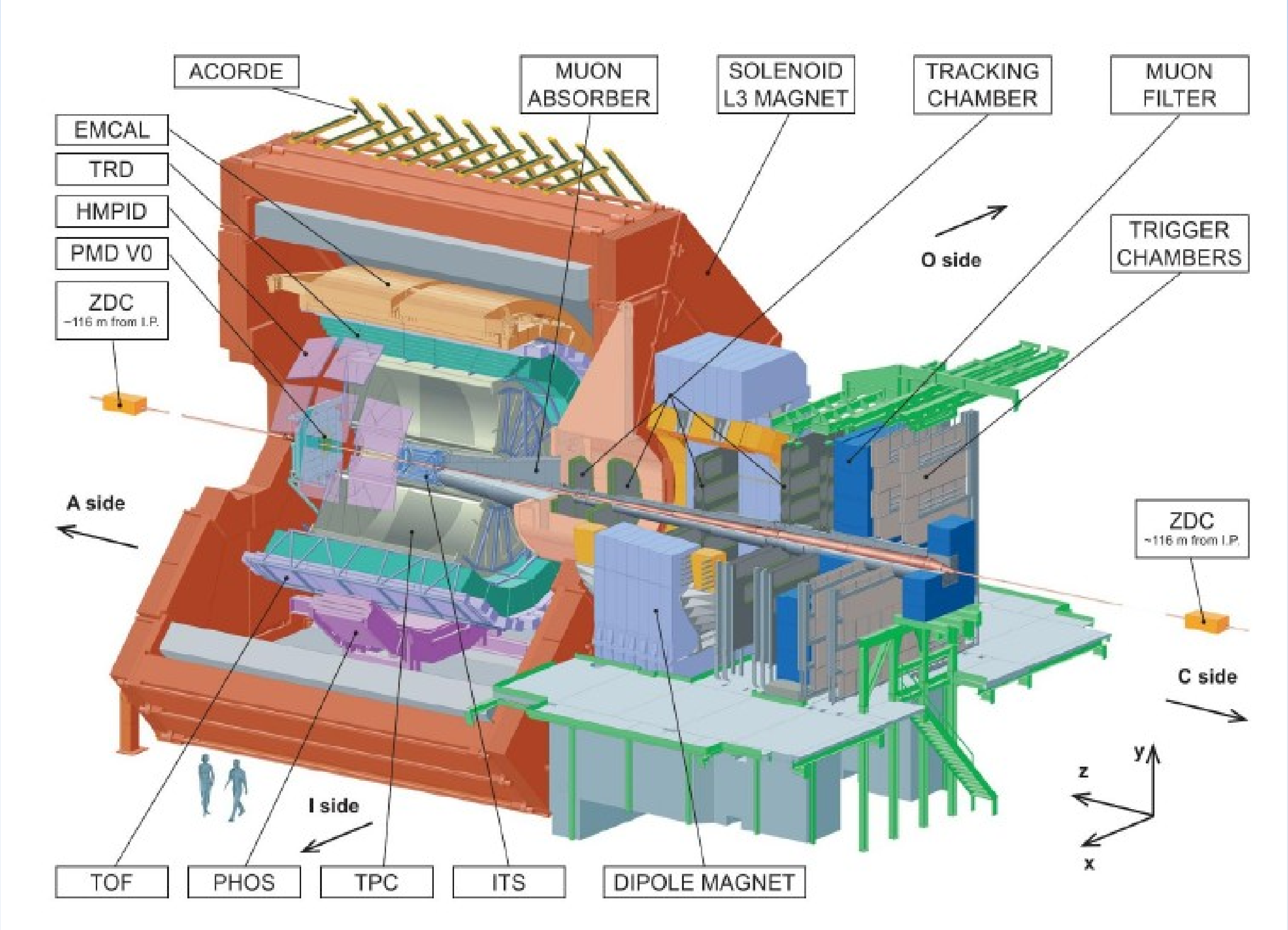


A Pb-Pb collision, very high multiplicity!

The ALICE detector

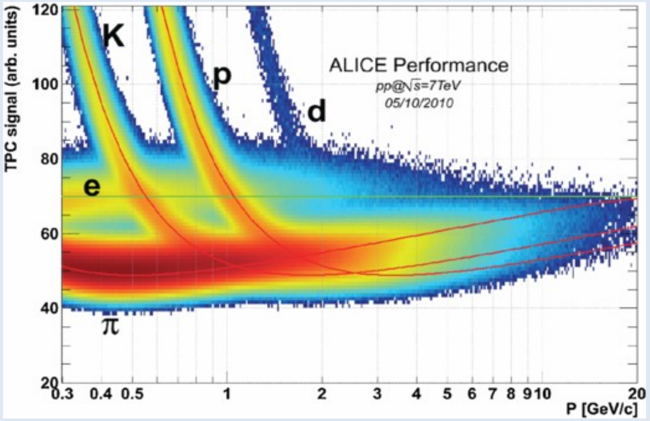
- General purpose heavy ion experiment
- Handle very high multiplicities
- Detects hadrons, electrons, muons, photons...
- Also record pp collisions (where QGP is not expected) for reference
- PID by dE/dx and secondary vertex reconstruction + invariant mass fits



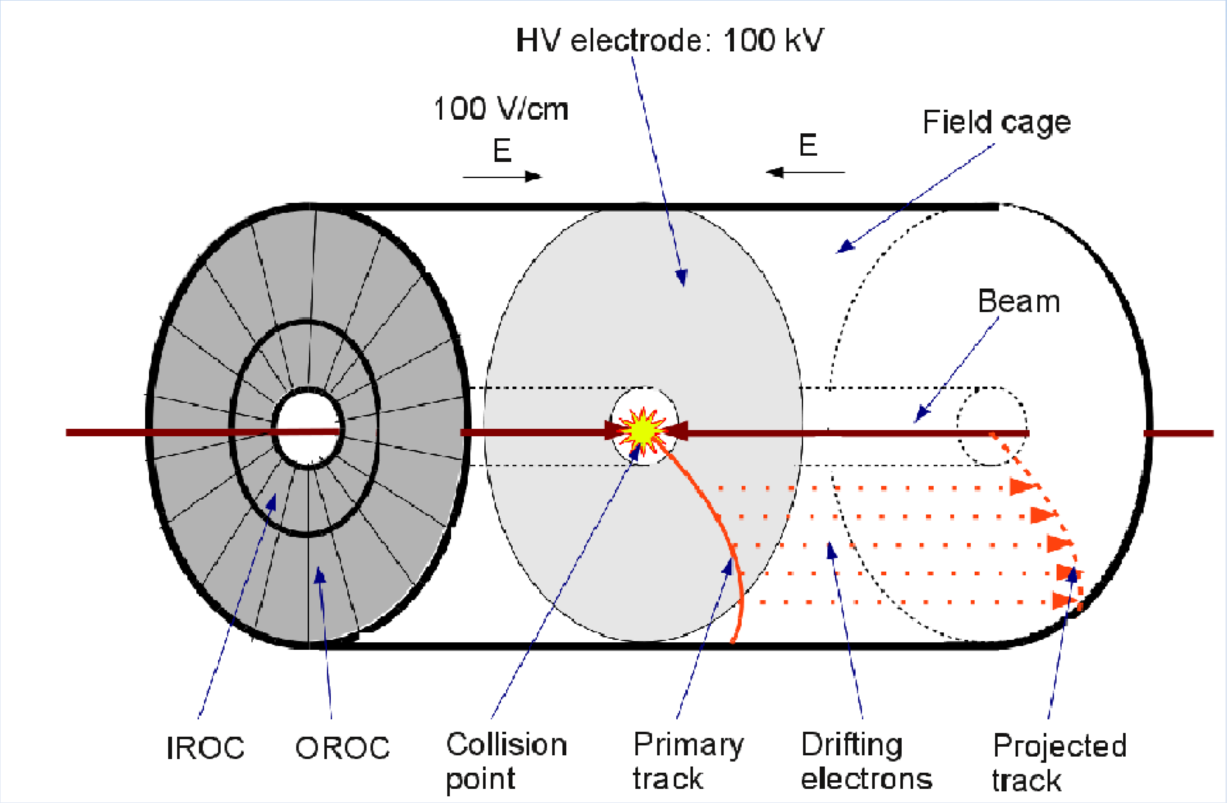
The heart of ALICE: the TPC

LUND contribution

- The TPC (Time Projection Chamber)
- Large gas filled cylinder
- Charged particle ionize the gas
- Electrons drift towards the readout chambers
- 3D reconstruction of track
- PID from dE/dx and momentum measurements



- Neutral particles can be detected via the invariant mass if the decay particles can be tracked in the TPC (see next slide)



Lambdas and K0s candidates

- ID of lambda, antilambda and k0s particles by reconstructing secondary vertex + topological cuts

$$\Lambda(uds) \rightarrow p + \pi^{-} \quad \text{BR: } 63.9\%$$
$$\bar{\Lambda}(\bar{u}\bar{d}\bar{s}) \rightarrow \bar{p} + \pi^{+} \quad \text{BR: } 63.9\%$$
$$K_s^0(d\bar{s}) \rightarrow \pi^{+} + \pi^{-} \quad \text{BR: } 68.6\%$$

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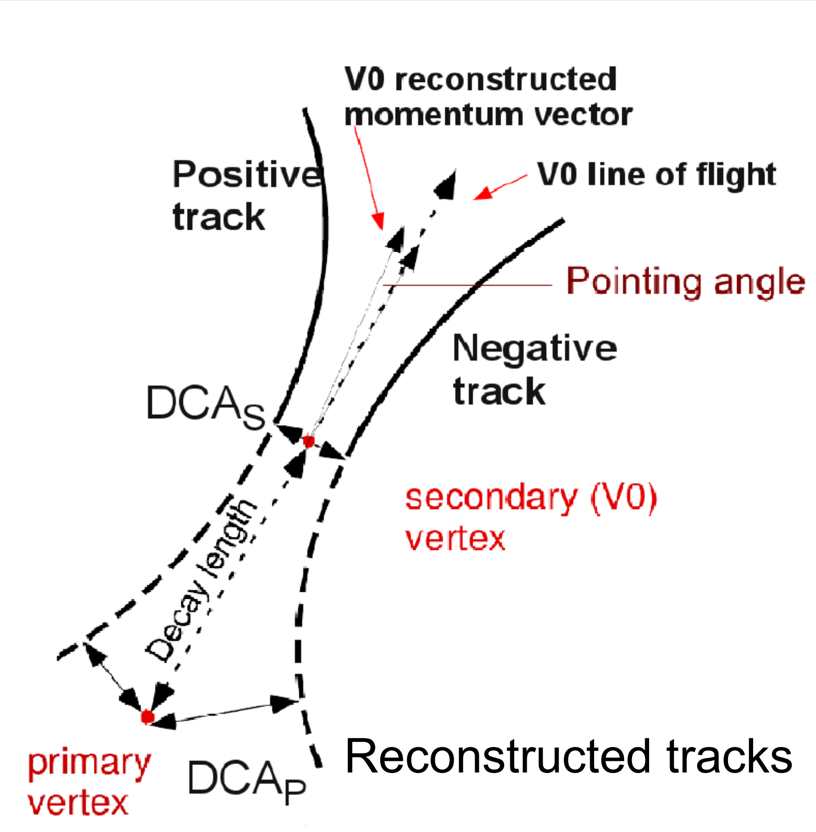
- The topological PID is done *during* tracking, i.e. everything is not combined; only tracks fulfilling requirements are selected → very low combinatorial background!



My analysis

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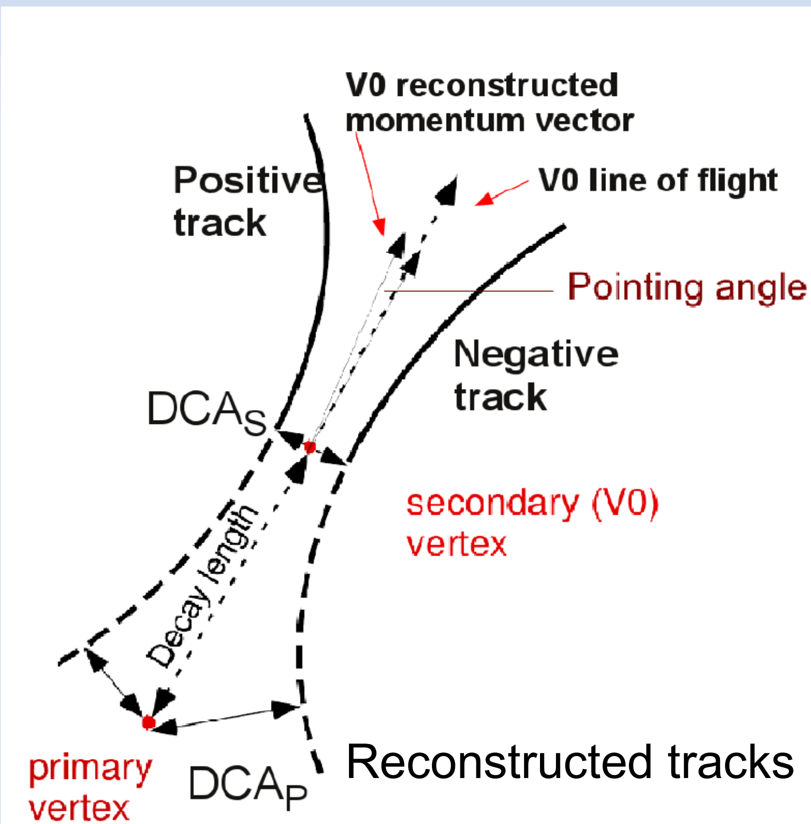

Event and track cuts

- $|\eta_{v0}| < 0.8$
- $cos_{PointingAngle} > 0.998$
- $DCA_p > 0.1$ cm
- $decayLength > 0.9$ cm

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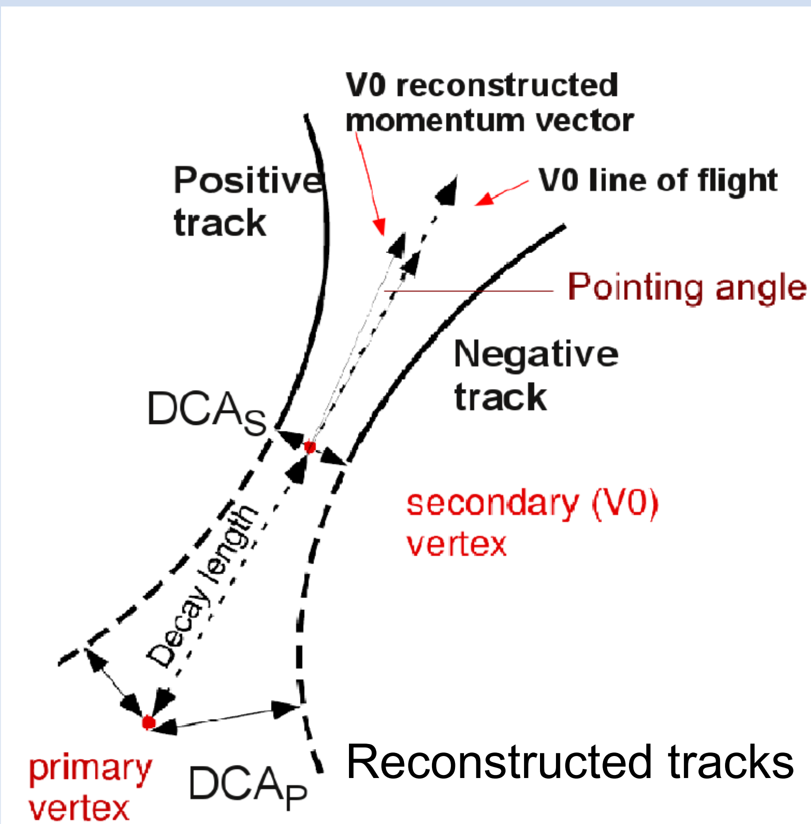

- Which of the V^0 particles are Λ's, $\bar{\Lambda}$'s, and K_s^0's?
- Invariant mass of the V^0 particle

$$m_{V^0} = \sqrt{(E^+ + E^-)^2 - (\vec{p}^+ + \vec{p}^-)^2}$$

$$\Delta m_\Lambda = (m_{V^0} \text{ assuming } p + \pi^-) - (m_\Lambda^{PDG})$$

$$\Delta m_{\bar{\Lambda}} = (m_{V^0} \text{ assuming } \bar{p} + \pi^+) - (m_{\bar{\Lambda}}^{PDG})$$

$$\Delta m_{K_s^0} = (m_{V^0} \text{ assuming } \pi^+ + \pi^-) - (m_{K_s^0}^{PDG})$$

PDG = Particle Data Group

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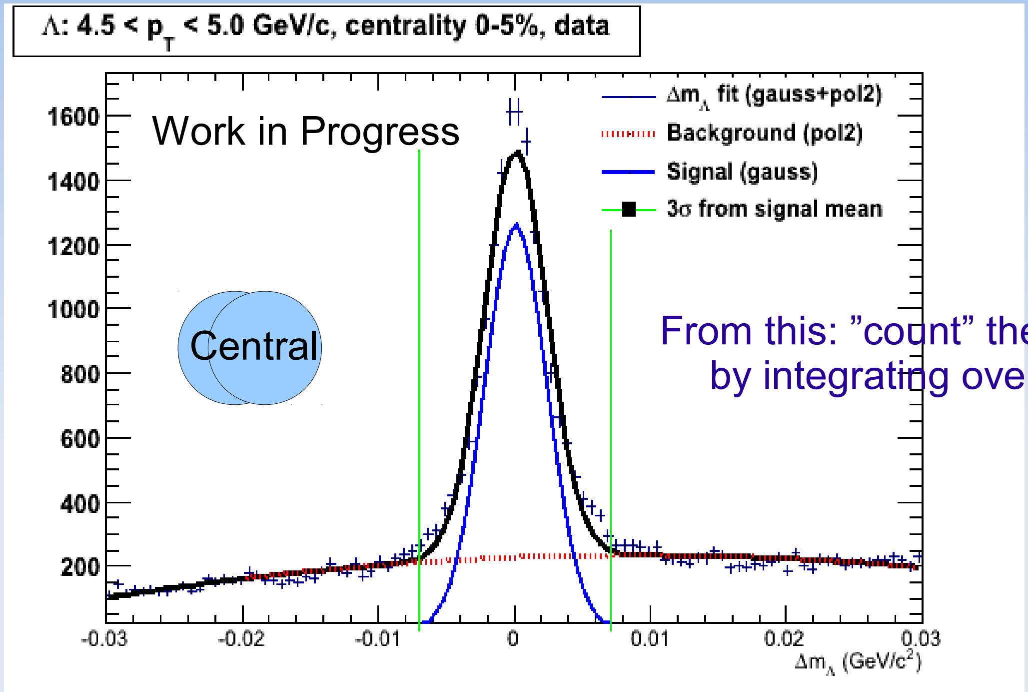
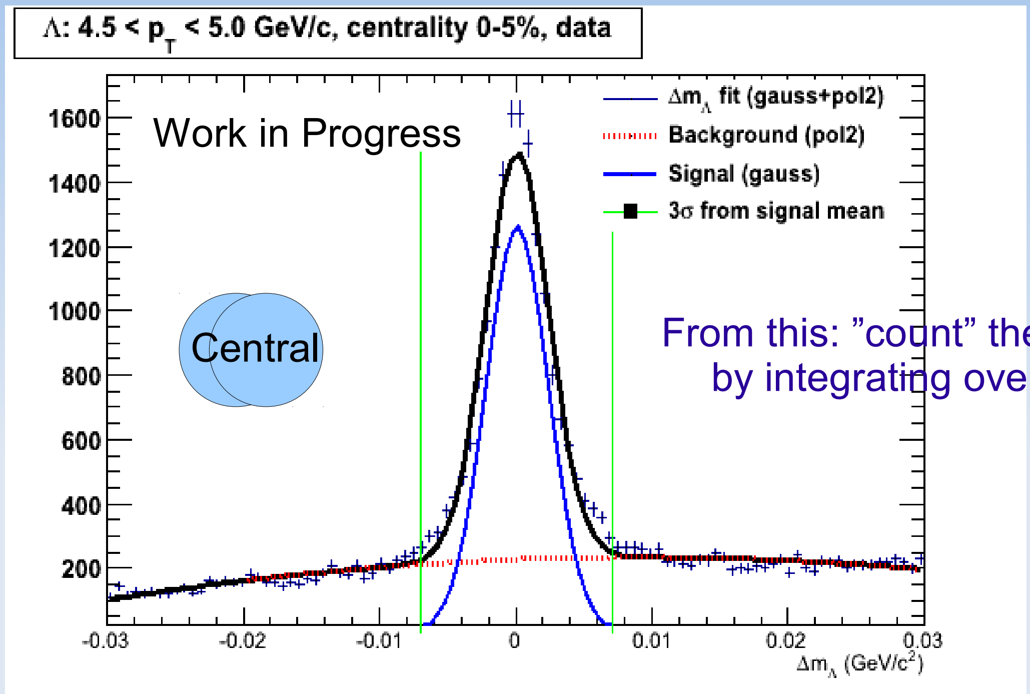


From this: ”count” the number of particles by integrating over the signal region

Input to analysis: the invariant mass



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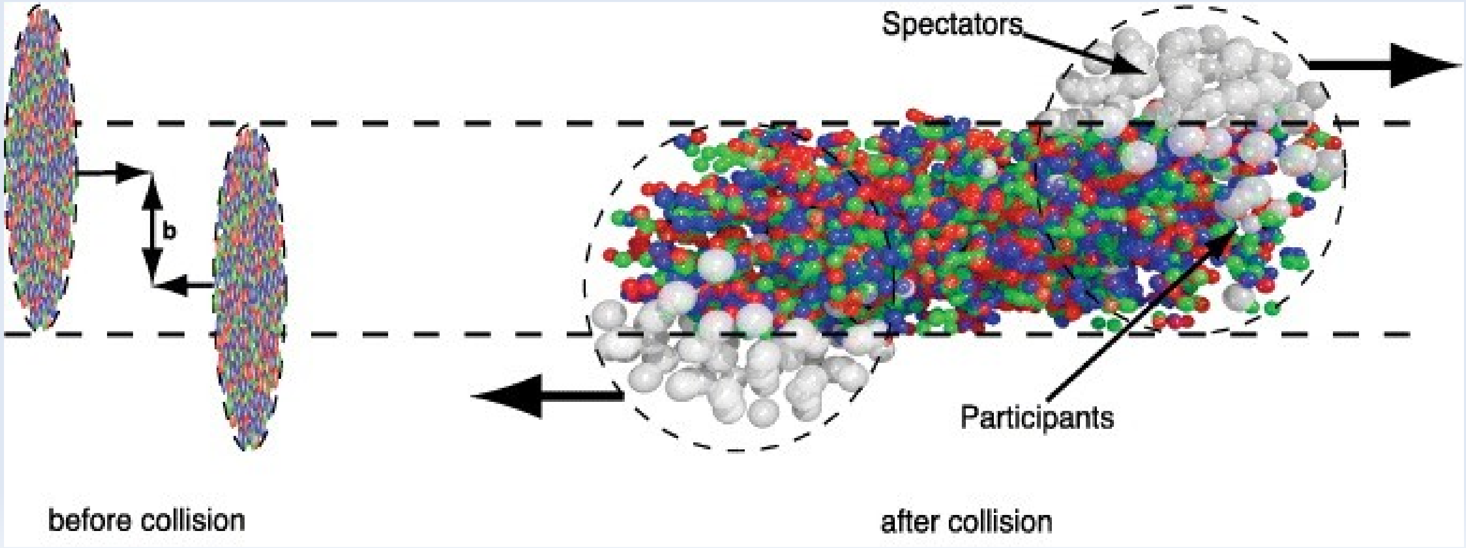

Multiplicity is a measure of centrality

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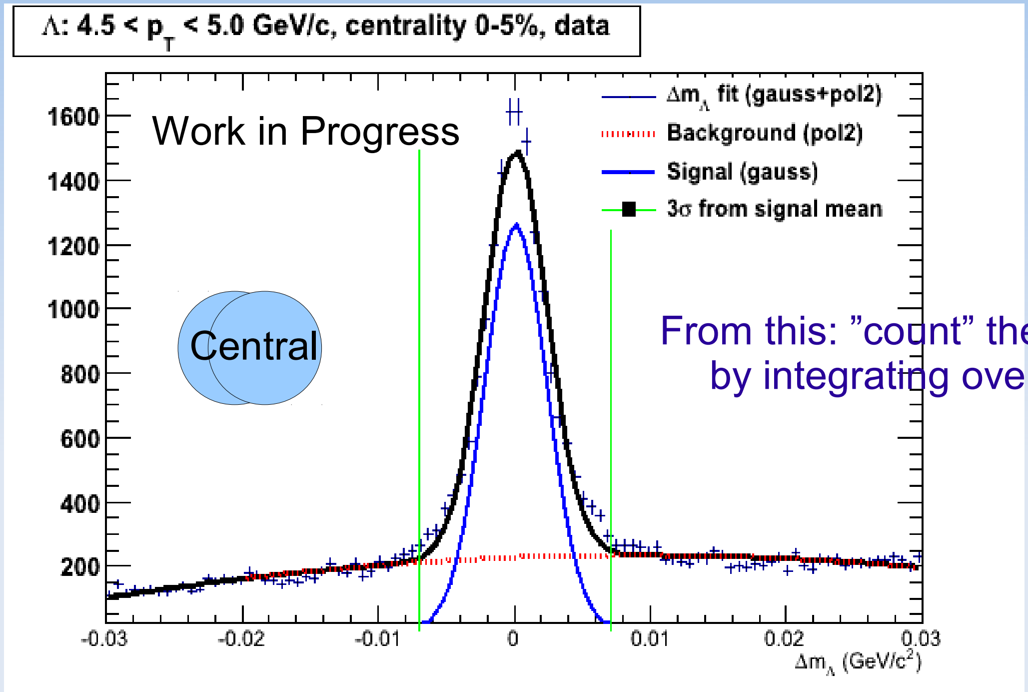

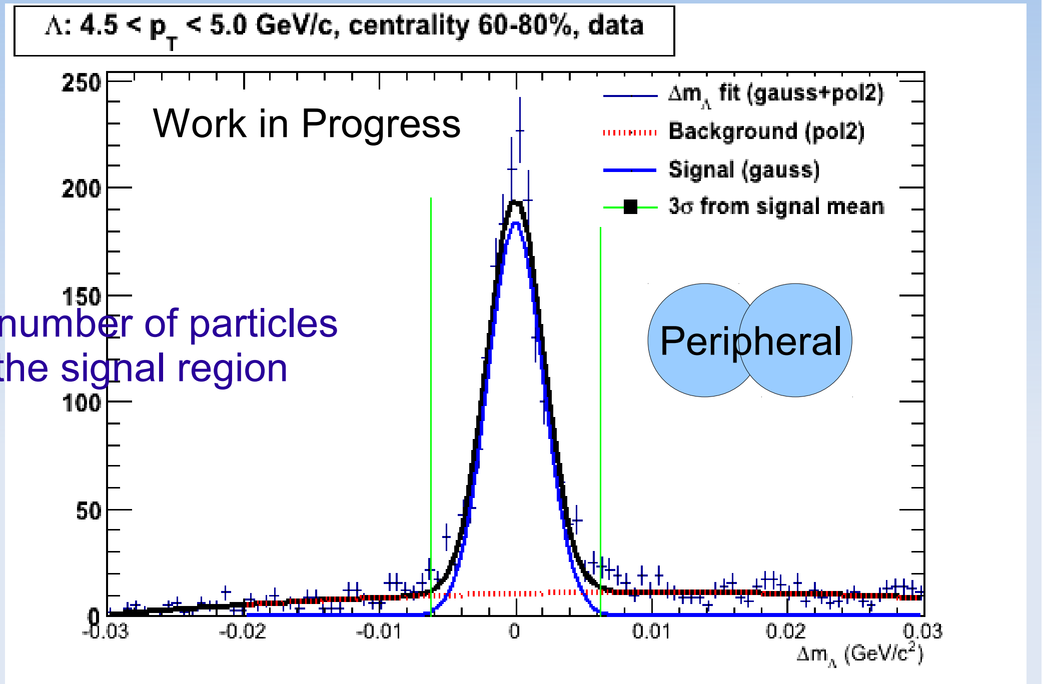

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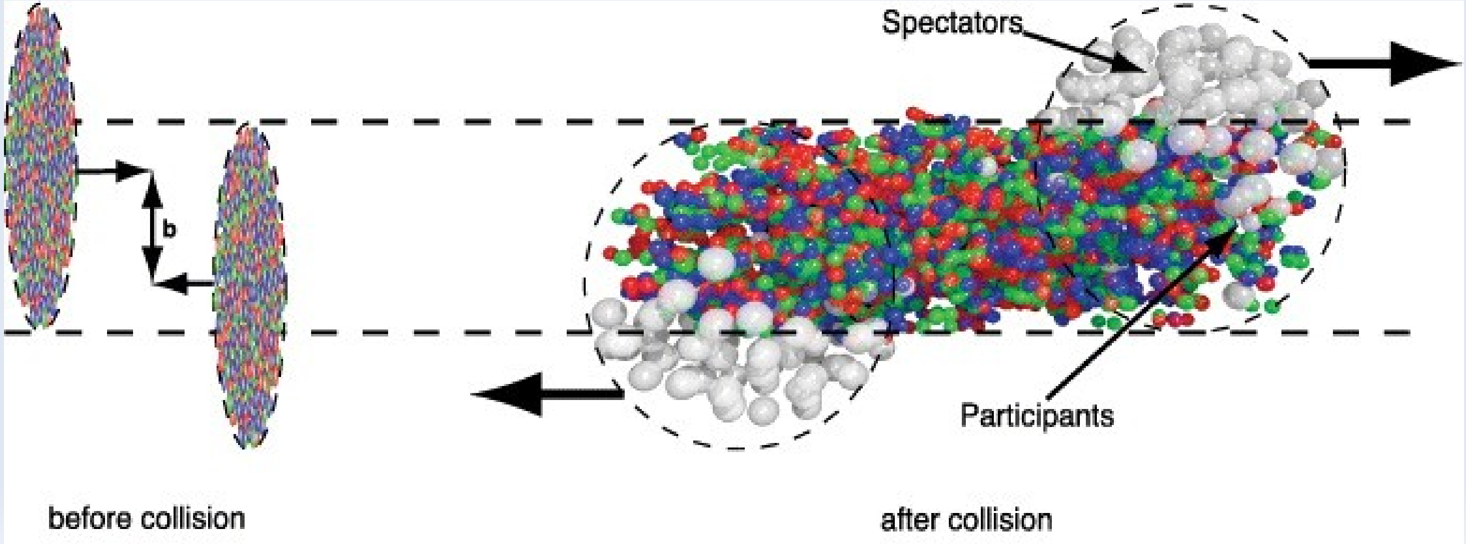
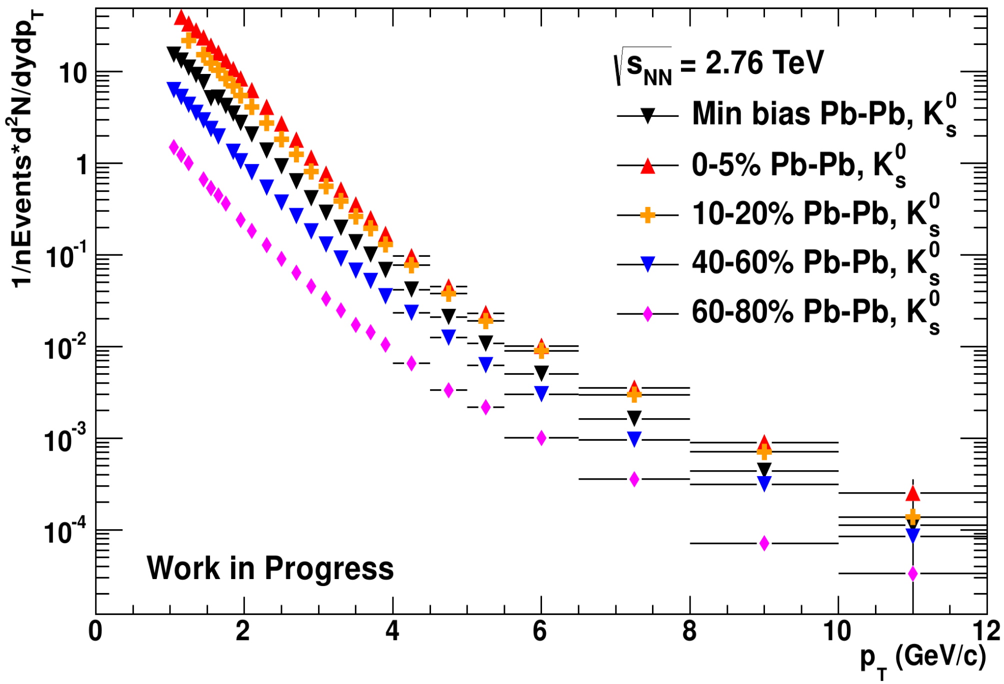
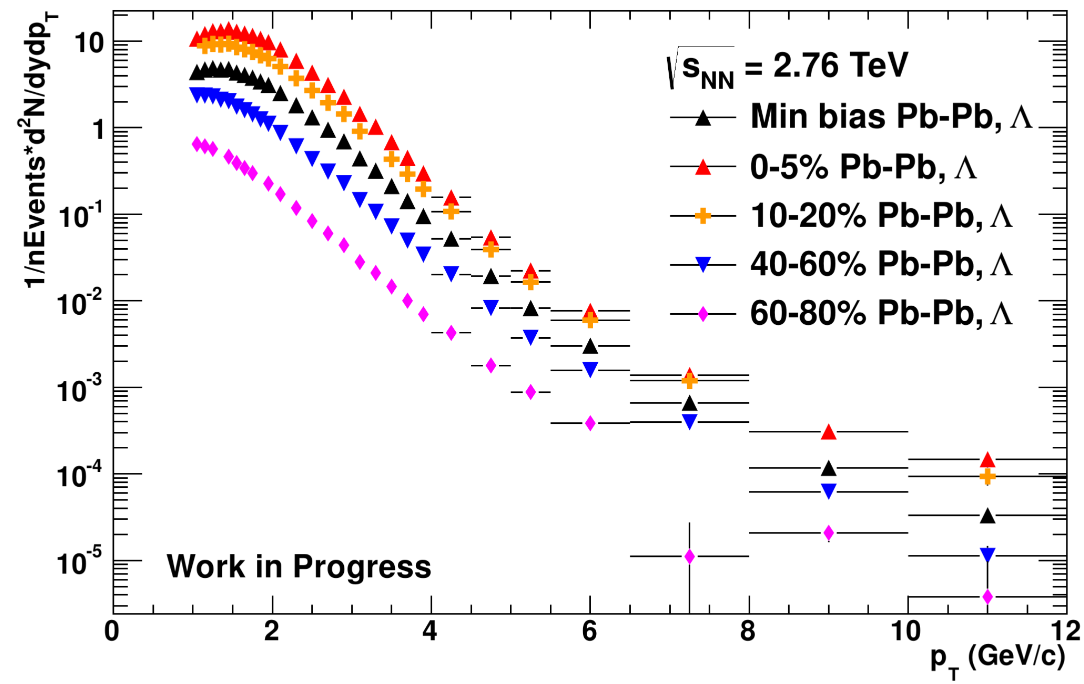


Multiplicity is a measure of centrality

pT spectra





K0s

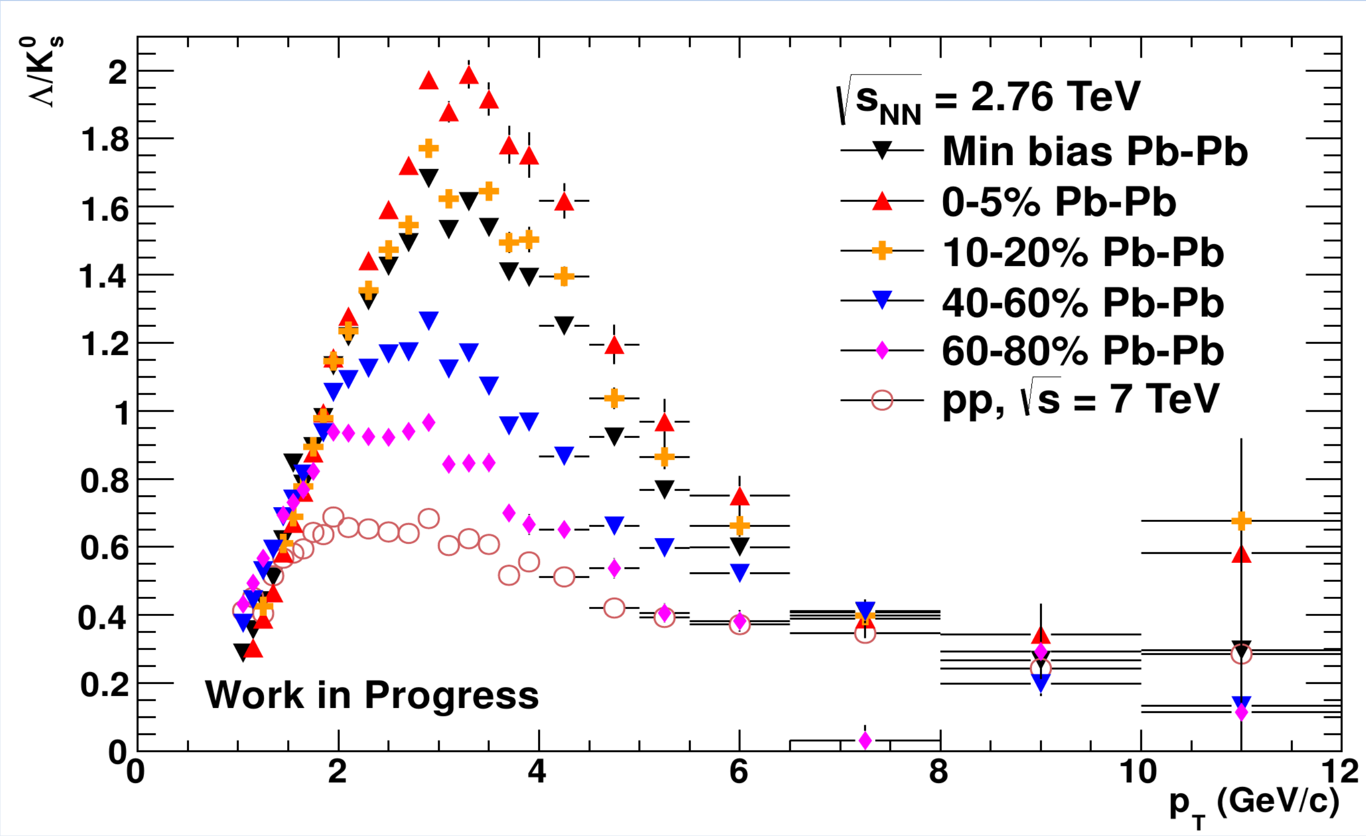
Lambda

The yield corrected for efficiency (I use the 7 TeV pp efficiency for now), and number of events.

The final observable: Lambda/K0s

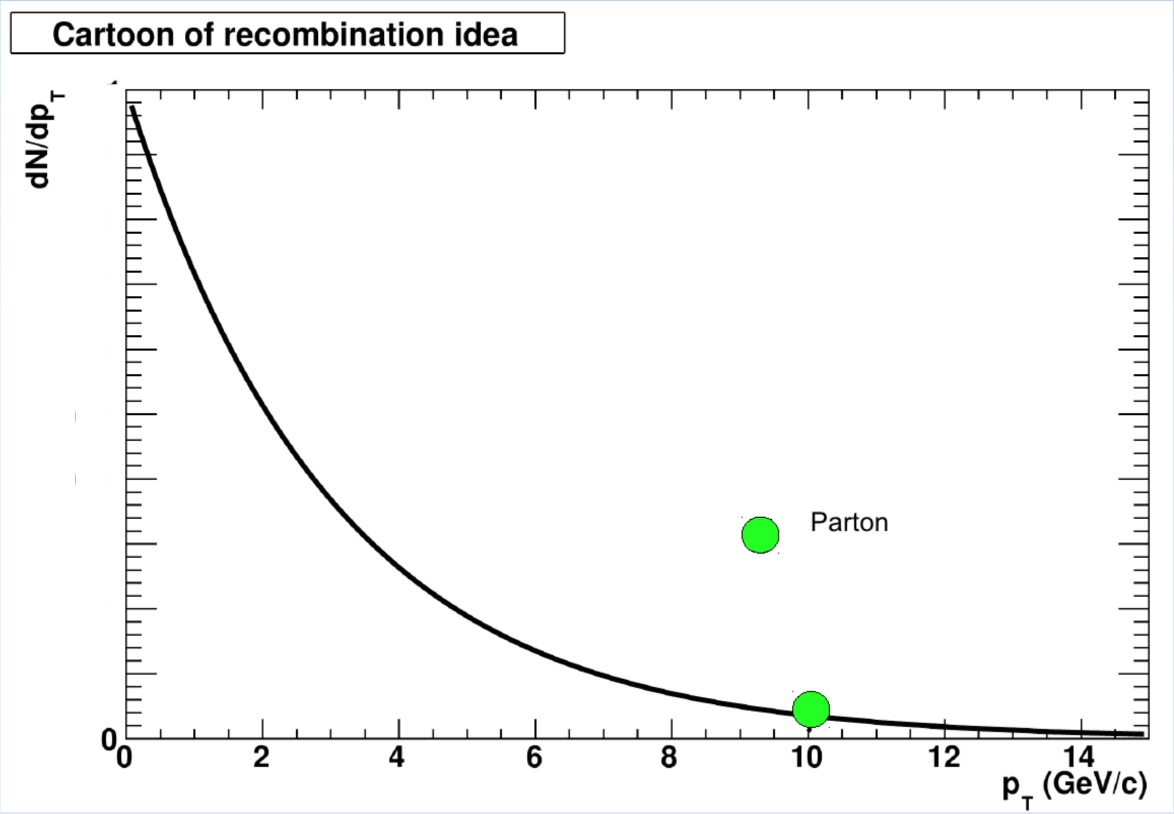
- The difference in production with centrality can be seen in the ratio plot
- Compared to baseline (pp – where no QGP is formed)
- Observed: a large enhancement of baryons compared to mesons in central PbPb collisions (more Lambdas than K0s) in intermediate pT-regions

  → a clear sign that the medium is affecting the particle production
- At higher pT: closer to pp!



Interpretation

- Signs of QGP:
- Low pt: flow
- High pt: jet quenching, fragmentation
- Intermediate pt: complex – interplay between soft and hard physics



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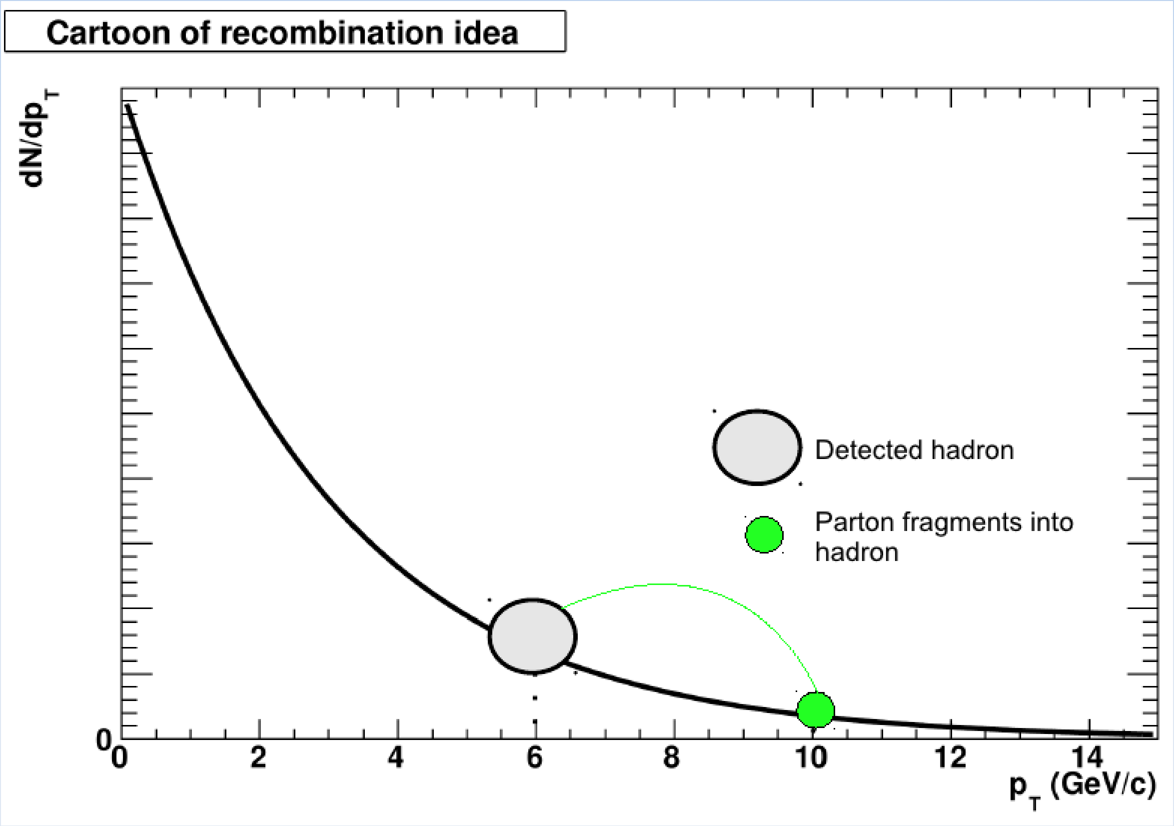

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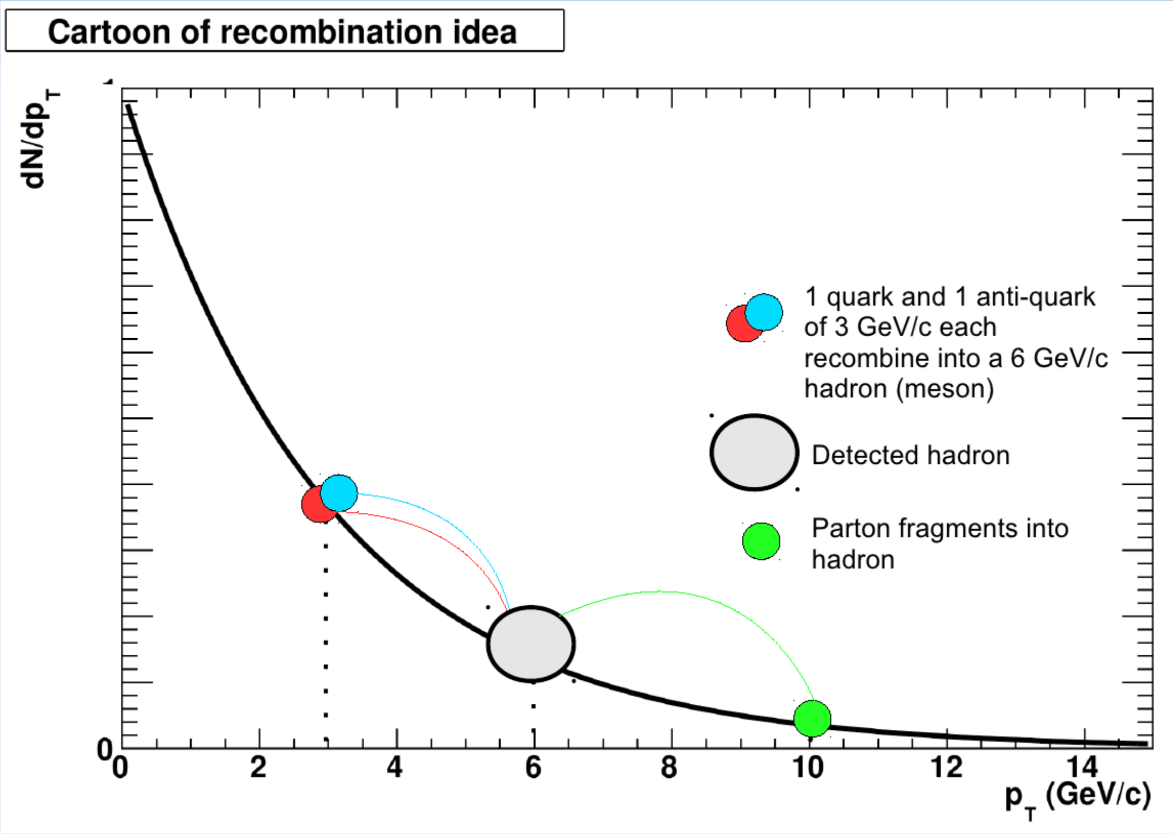
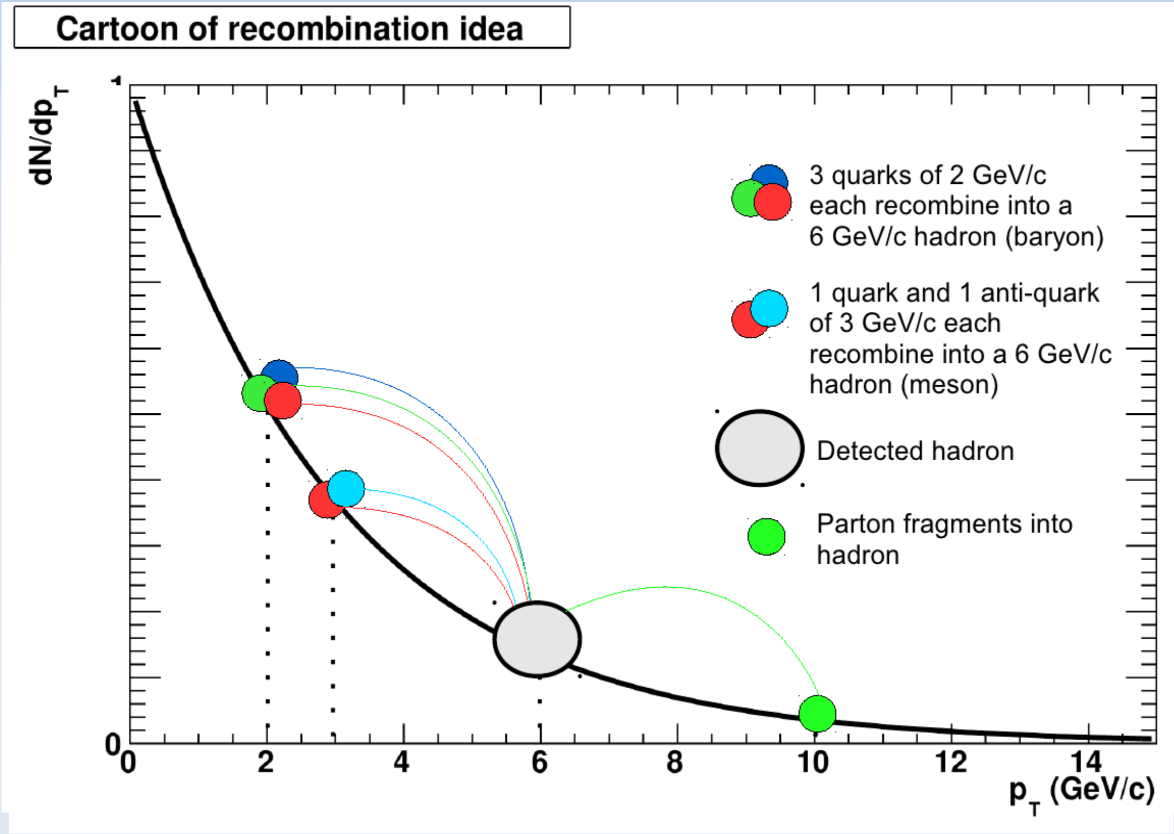


Interpretation

- Signs of QGP:
- Low pt: flow
- High pt: jet quenching, fragmentation
- Intermediate pt: complex – interplay between soft and hard physics
- Recombination: probability larger that 3 quarks are combined to a hadron (baryon) than for a quark and an antiquark to recombine to a hadron (meson) of the same momentum as the baryon since there are more produced quarks with low pt in the QGP medium



LUND analysis

Same analysis with charged particles

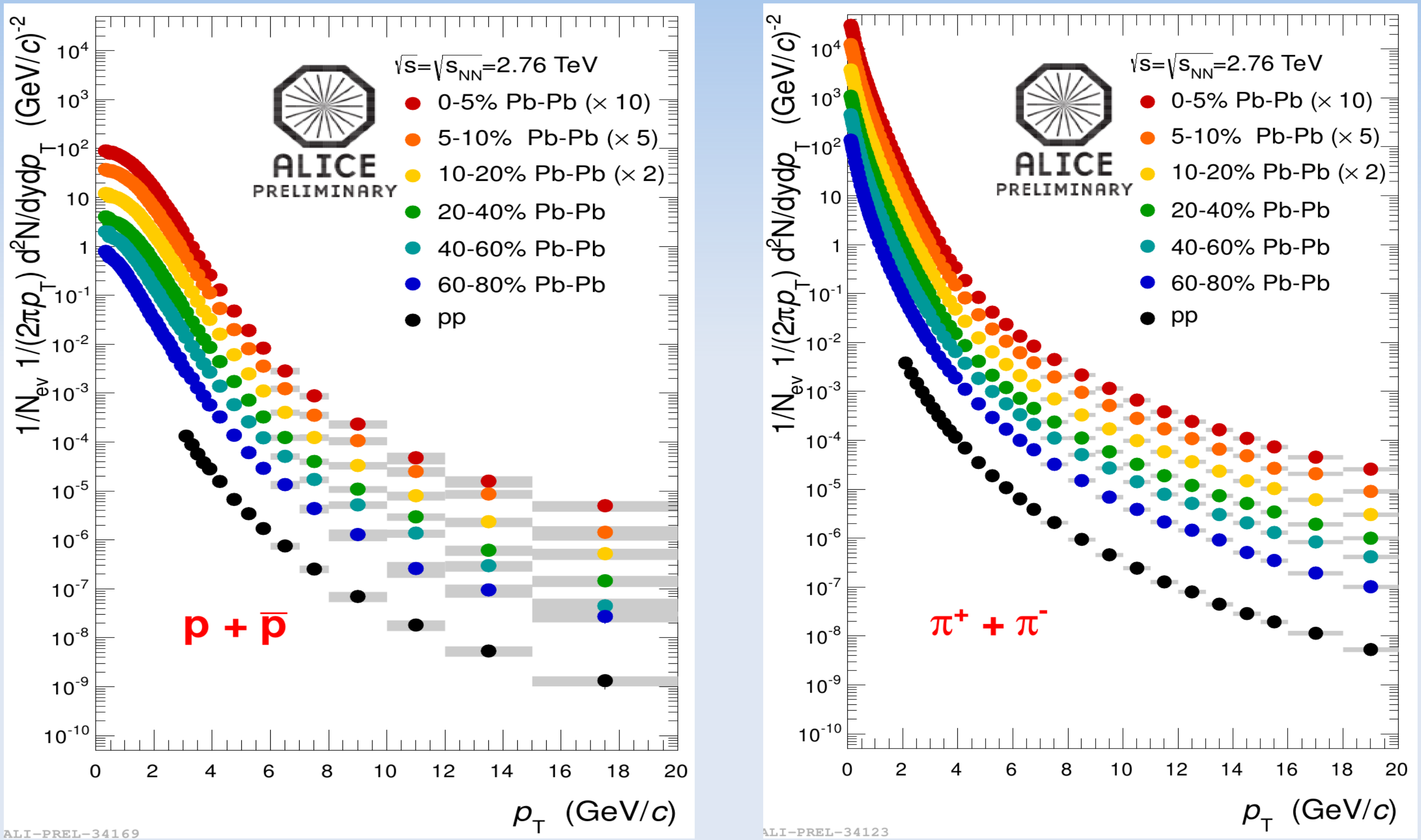
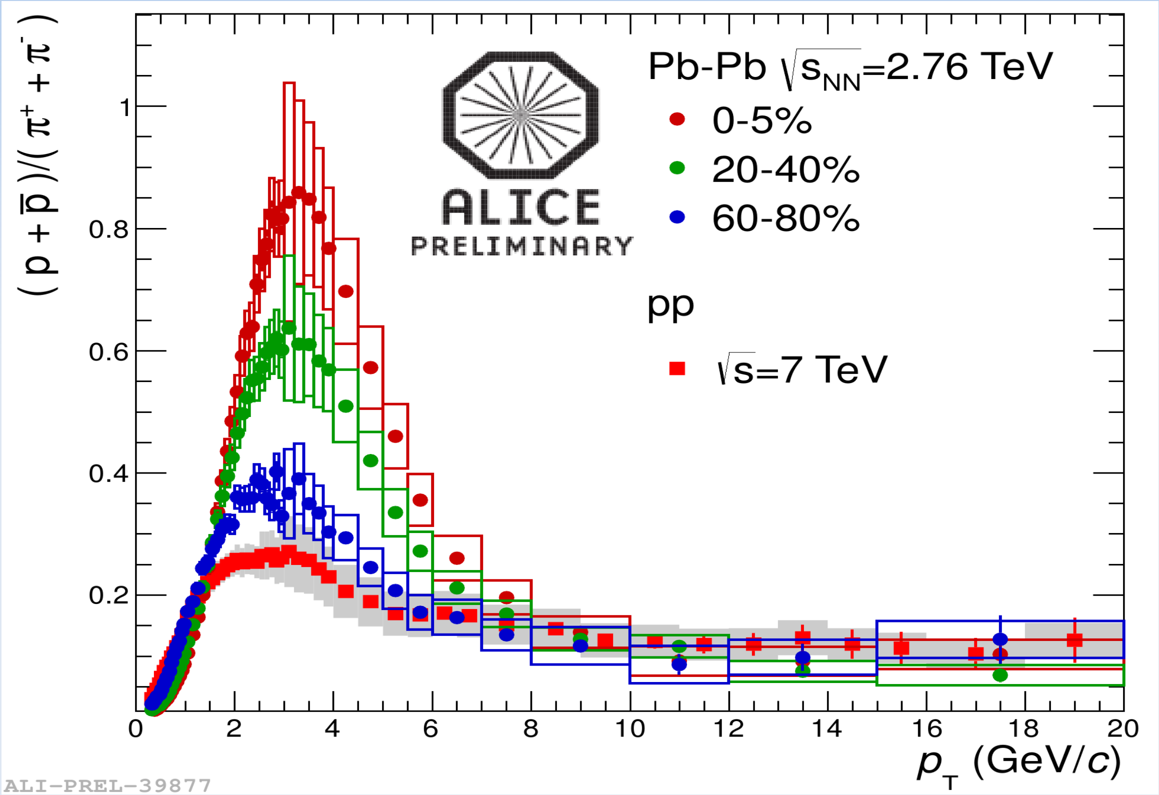


Fig: ALICE measured particle yields for different centralities in PbPb collisions with sqrt(s)=2.76 TeV, compared with pp

Particle ratios: baryon enhancement

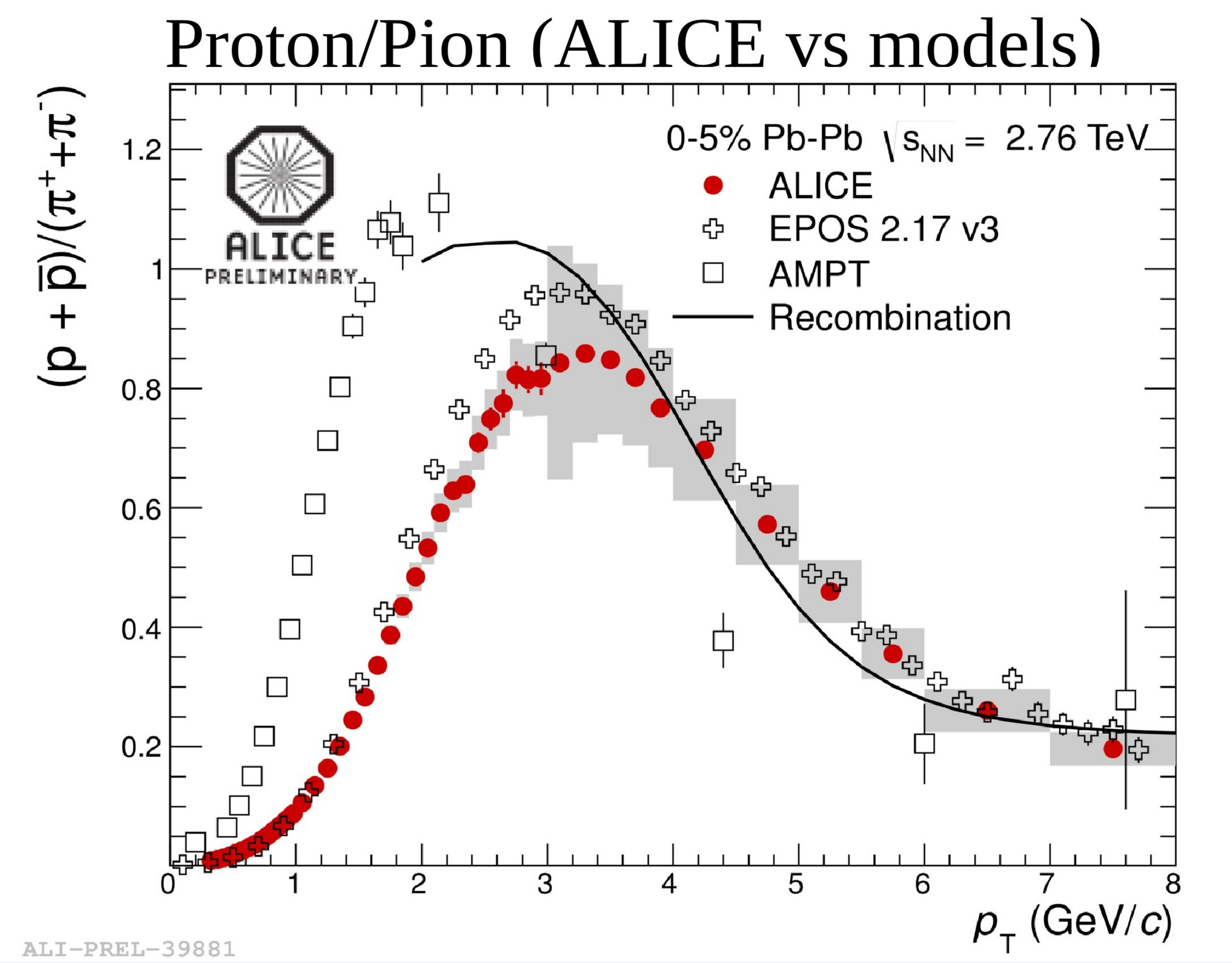
Fig: **(p+pBar)/(π^++π^-)** for different centralities in PbPb collisions, compared with pp



- At pt ~3 GeV/c in most central collisions, PbPb ratio is 3 times higer than pp
- PbPb ratio above ~10 GeV/c is similar to pp
- Baryon vs meson production: ratio evolves with centrality → baryon enhancement at central collisions

Baryon enhancement – model comparison

(p+pBar)/(π^++π^-), 0-5% centrality



Different physics in the models

AMPT (Hybrid model): Reference Phys.Rev.C83:034904,2011

Initial particle distributions by HIJING. Evolution of final state partons can be approximated by a cascade method. After scattering, quarks and anti-quarks are converted via a spatial coalescence model to hadrons.

EPOS: ...quenched jet fragments ”pic up” quarks to form hadrons.

Conclusions

- Collide Pb-Pb with LHC and search for signatures and charachteristics of quark gluon plasma
- Record hadrons from the thermalization process of QGP with the ALICE detector, PID by dE/dx and secondary vertex reconstruction + invariant mass fits
- Particle pT spectra and ratios shows baryon enhancement at intermediate pT in heavy ion collisions (QGP) compared to the pp baseline (no QGP)
- Results from the Lund group shown:

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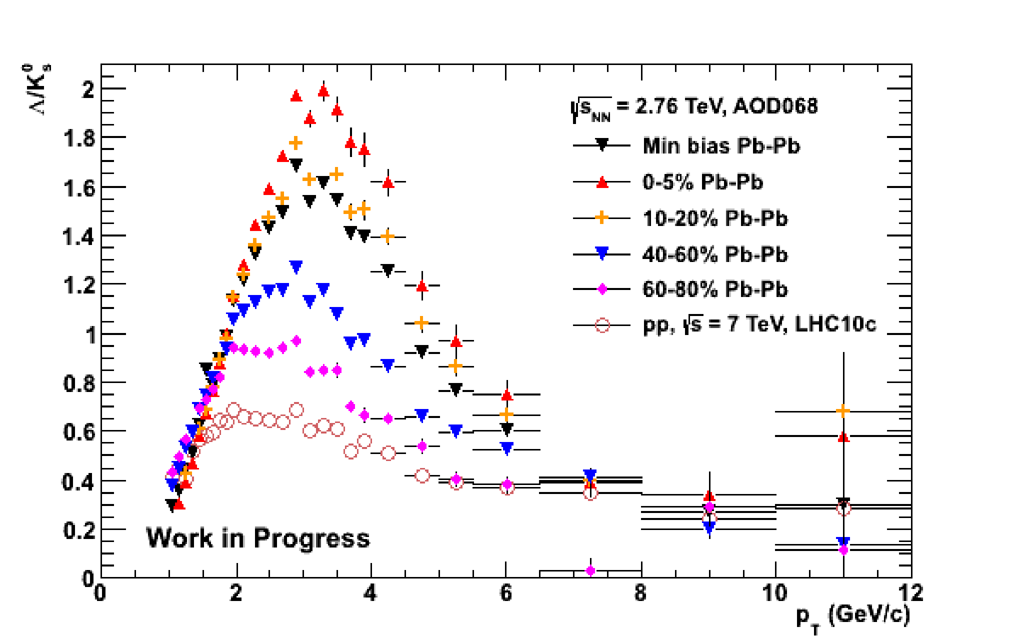

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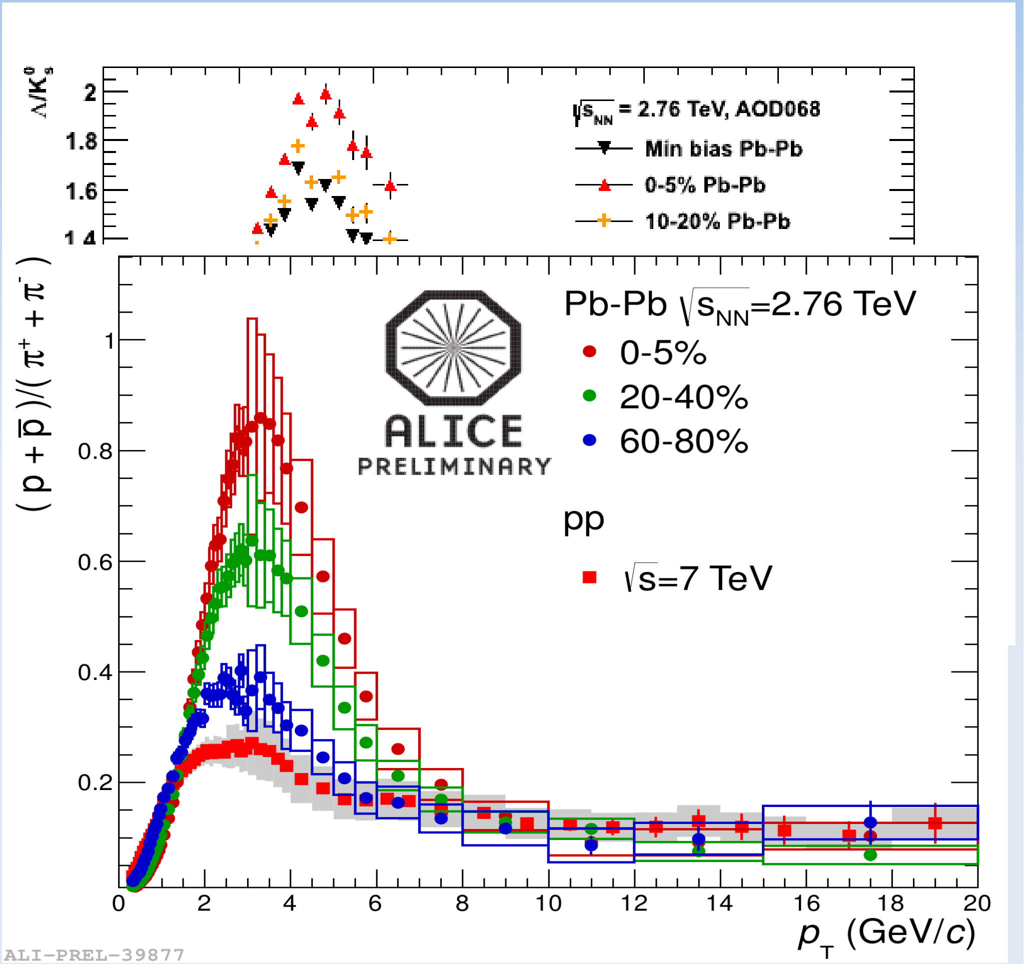
lambda/k0s & p/pi



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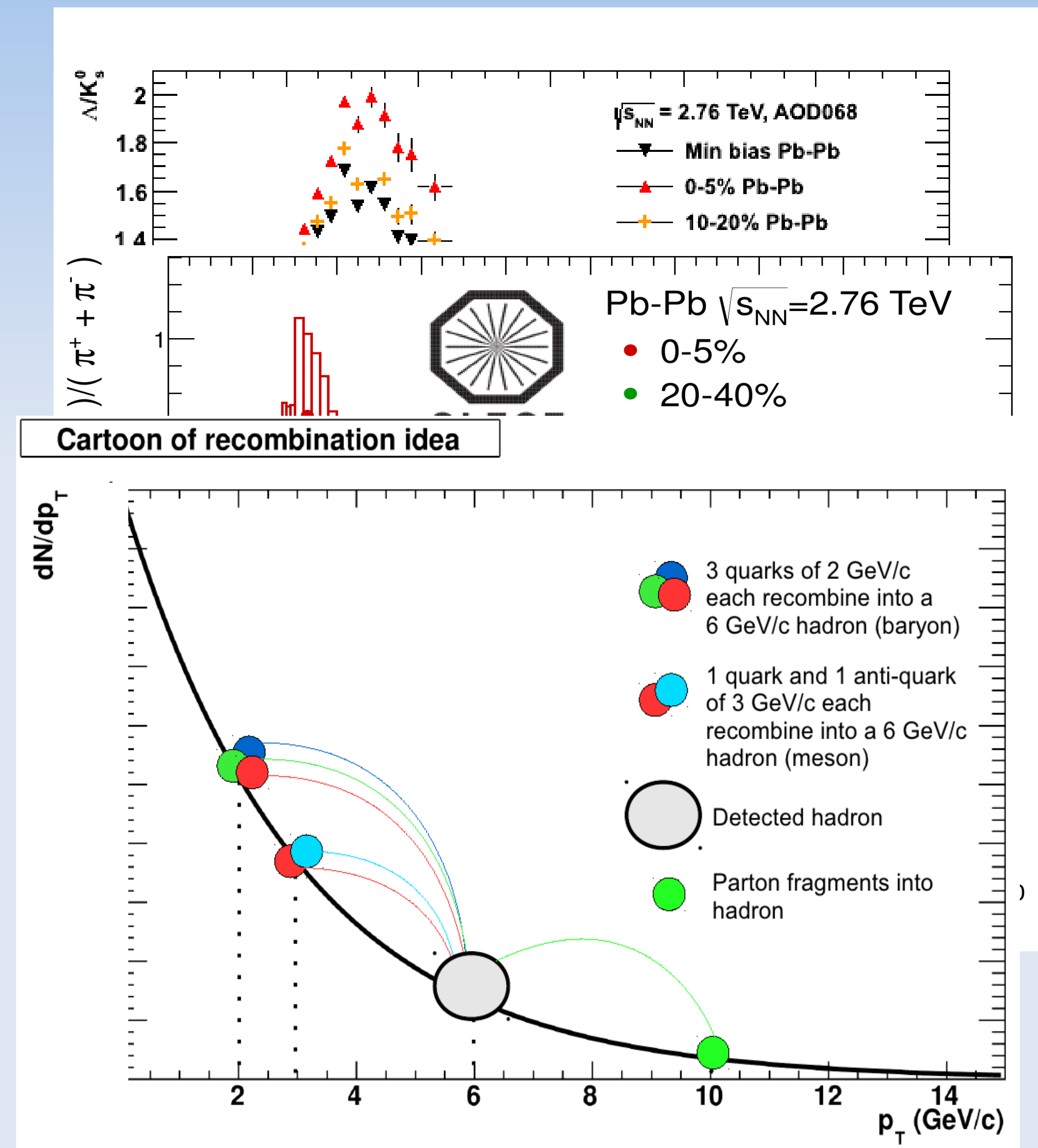
- Clear centrality dependence (more enhancement in central, and more like pp for peripheral collisions)
- Could this be explained by the recombination model?



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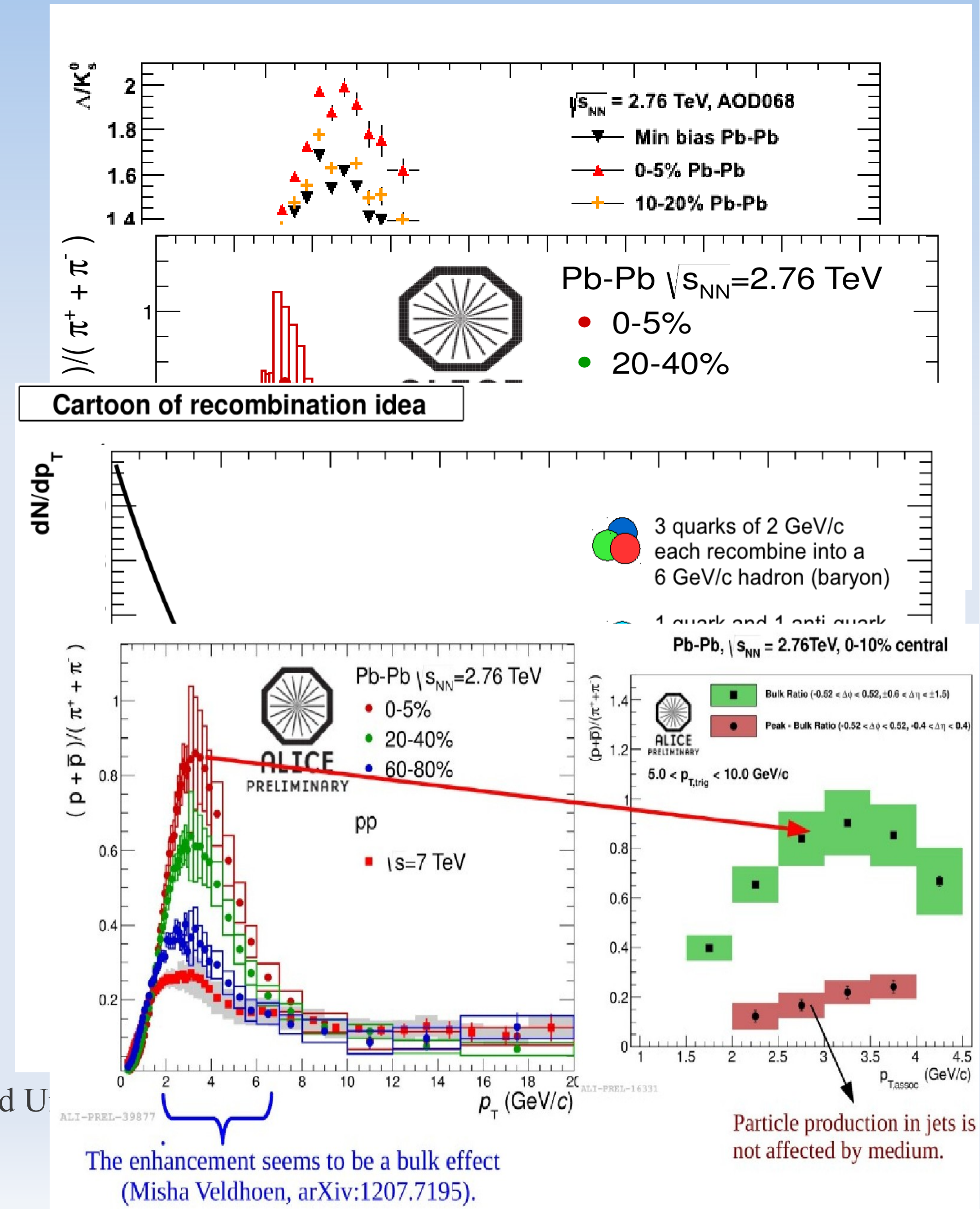
- Could this be explained by the recombination model?
- Next step for me: look at the ratio in different regions in the medium; baryon enhancement in jet cones compared to bulk? – discriminate effects!

SO STAY TUNED!



The Lund ALICE group:

- Peter Christiansen (lector)
- Pouria Jaberi (master student)
- Martin Ljunggren (Ph.D)
- Anders Oskarsson (professor)
- Tuva Richert (Ph.D)
- Carsten Soegaard (post doc)
- Evert Stenlund (professor)
- Antonio Ortiz Velasquez (post doc)
- Vytautas Vislavicius (master student)

Back up

Quark gluon plasma

- Small distance (r) between quarks

  → no anti-screening from an intervening gluon field

  → little energy required for quarks to move

  = asymptotic freedom
- ALICE goal:

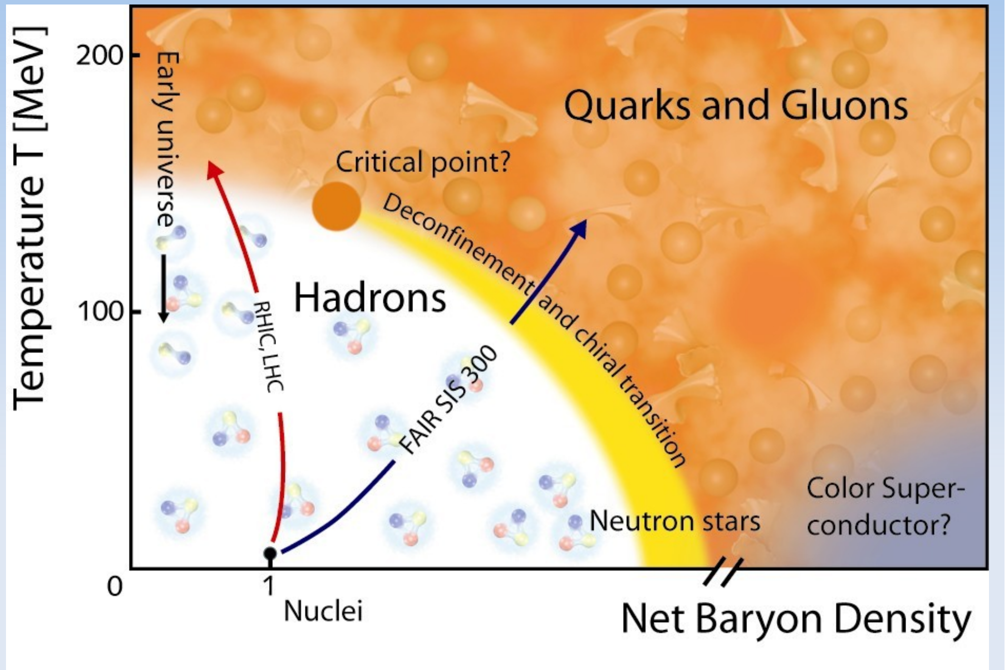
  - characterizing of QGP

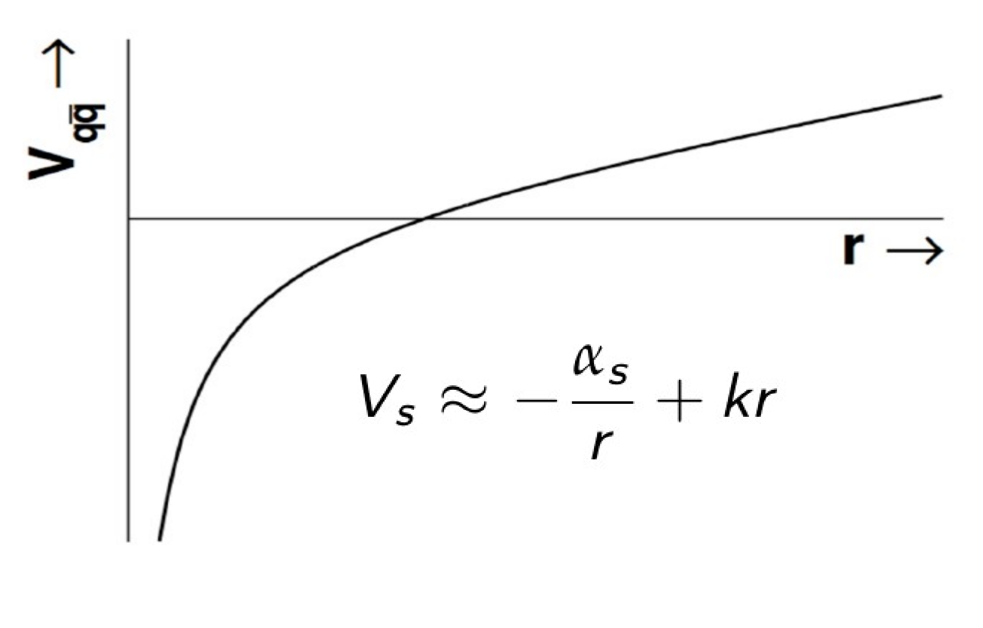
  - properties in different phases of the QGP life

  - production mechanisms

  - hadronization

  - fragmentation
- QGP cannot be measured directly (too short lived)
  → use quarks as probes
- Detected: hadrons created in the collision

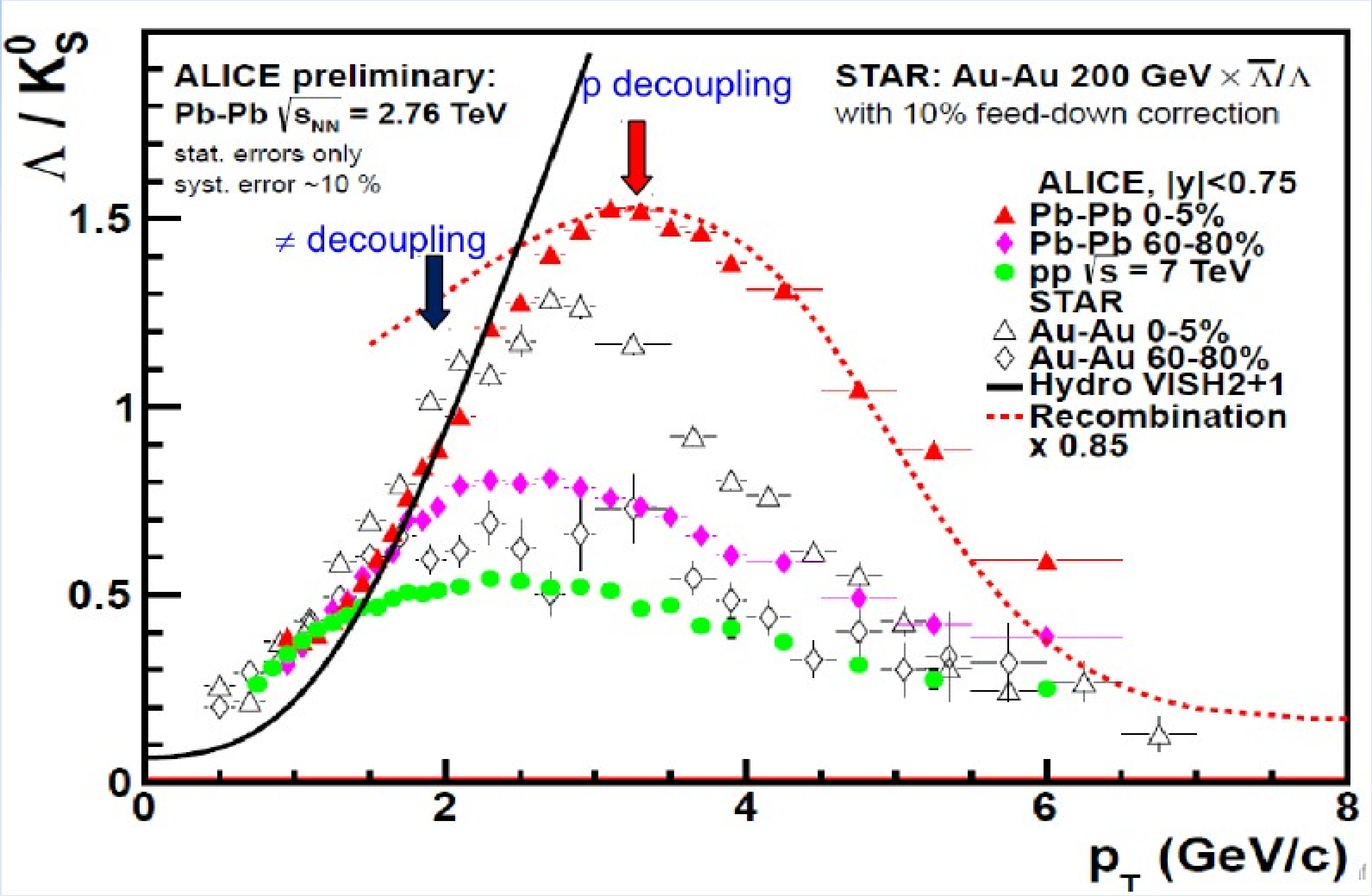




Mass cuts

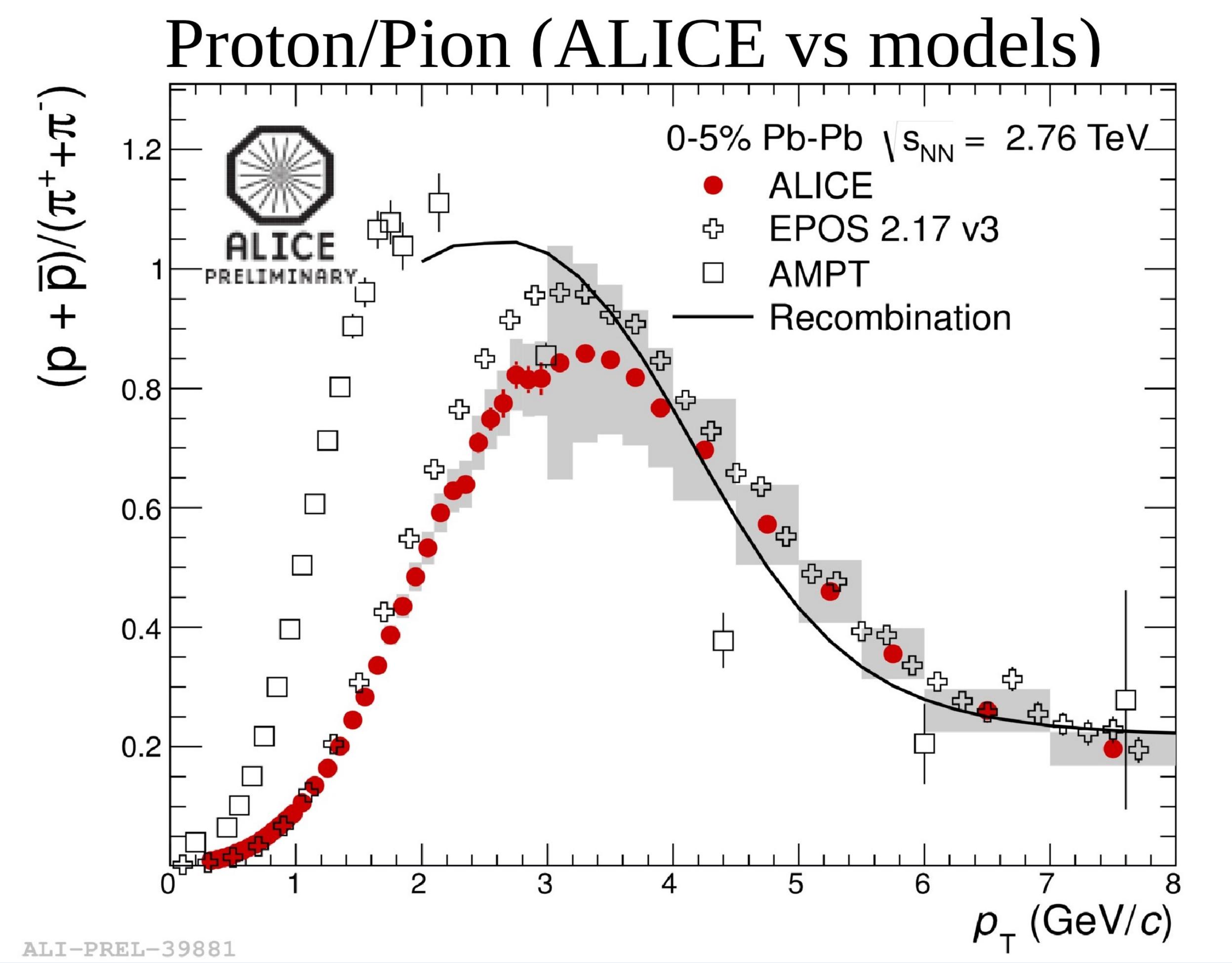
- $|\Delta m_{\Lambda}| > 10 MeV/c^2$ (for K_s^0)
- $|\Delta m_{\bar{\Lambda}}| > 10 MeV/c^2$ (for K_s^0)
- $|\Delta m_{K_s^0}| > 10 MeV/c^2$ (for $\Lambda \& \bar{\Lambda}$)
- $\Delta m_{\gamma} > 100 MeV/c^2$, from conversion electrons (for $\Lambda \& \bar{\Lambda}$)

Ratio compared to model



Baryon enhancement – model comparison

$(p+pBar)/(\pi^{+}+\pi^{-})$, 0-5% centrality

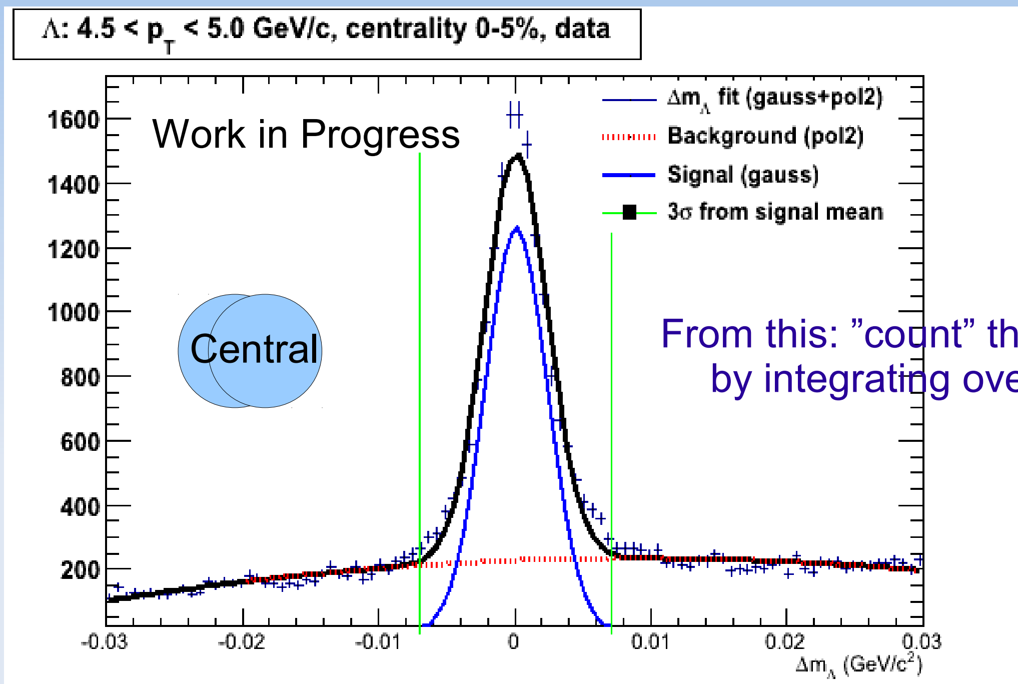


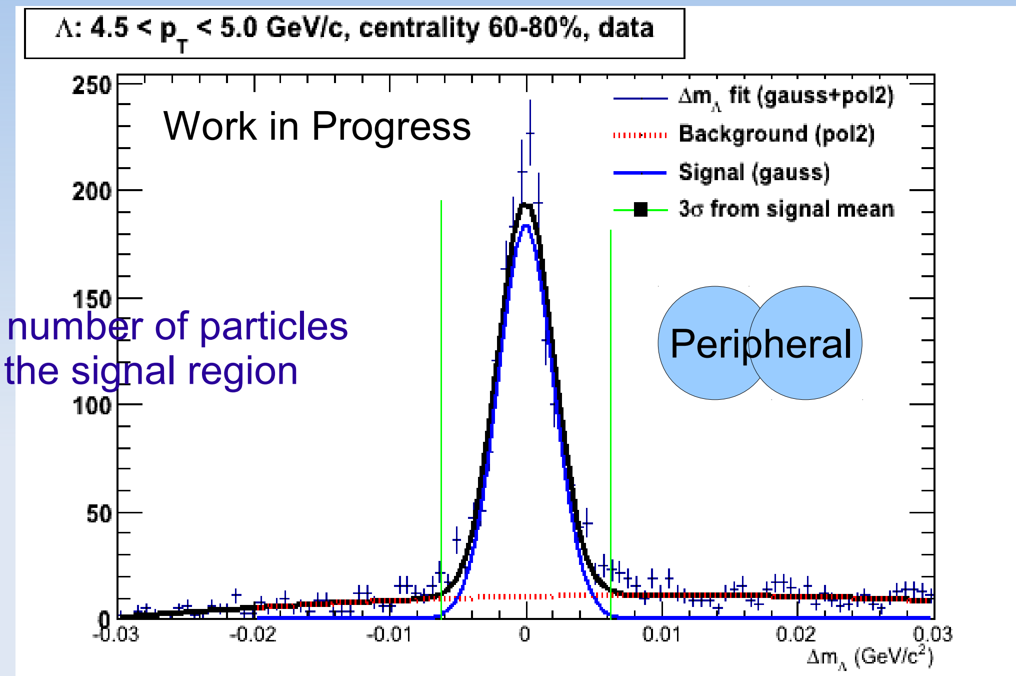
Different physics in the models

AMPT (Hybrid model): Reference Phys.Rev.C83:034904,2011

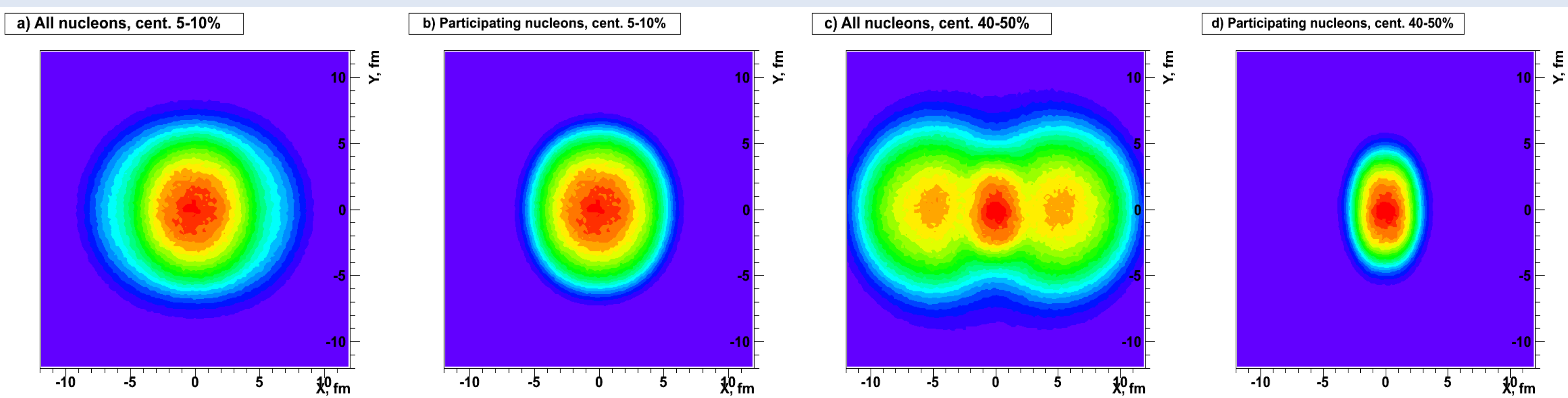
Initial particle distributions generated by HIJING. Hadrons produced from HIJING are converted to their valence quarks and antiquarks. Evolution of final state partons can be approximated by a Boltzmann equation, solved by employing the cascade method in which two partons scatter when their closest distance in a specified frame is less than the interaction length. Gluon scattering cross section is regulated by a medium generated screening mass. After stopping scattering, quarks and anti-quarks are converted via a spatial coalescence model to hadrons. Hadronic scatterings via the ART model (Phys. Rev. C 52, 2037–2063, 1995).

Input to analysis: the invariant mass





From this: "count" the number of particles by integrating over the signal region



Glauber simulation, V. Vislavicius, master student, Lund