Bulk matter physics and its future at the LHC

1. Bulk matter physics: p_T range, hadro-production and collectivity
2. The usual suspects: experiments and detectors at the LHC
3. Statistical observables: inclusive measurements
4. Baryon production: investigations in p+p
5. Multi-parton dynamics: expectations in p+p and recombination
6. Summary and prospects: first physics at LHC and next steps

Boris HIPPOLYTE (IPHC - STRASBOURG)

Hot Quarks 2008 – Colorado - 23/08/08

IPHC
Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

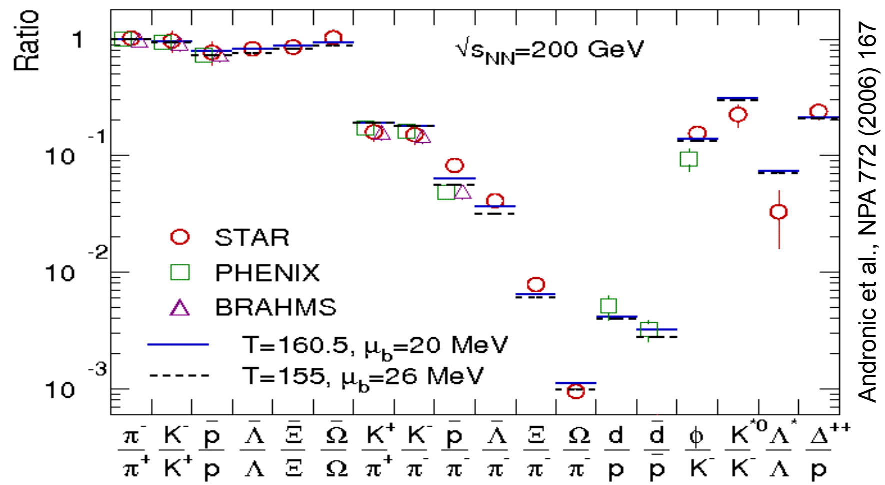
Bulk matter and properties in A+A ? … in p+p ?

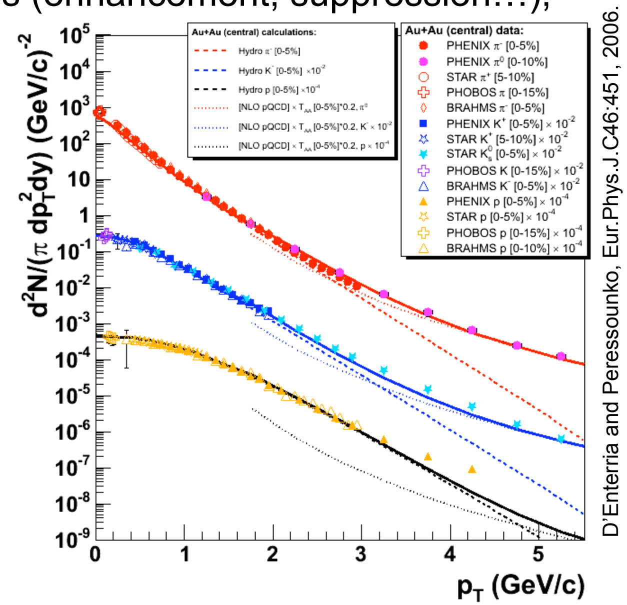
Bulk matter: global properties describing the main characteristics of particle production/emission

in A+A

1) most of the particles are in the soft physics region (precise range?);
2) statistical description and hydrodynamics (collective behavior) works pretty well;
3) use differences to investigate new mechanisms (enhancement, suppression…);

$$\langle n_j \rangle = \frac{(2J_j+1)V}{(2\pi)^3}\int d^3p \left[e^{\sqrt{p^2+m_j^2}/T + \mu\cdot q_j/T} \pm 1 \right]^{-1}$$

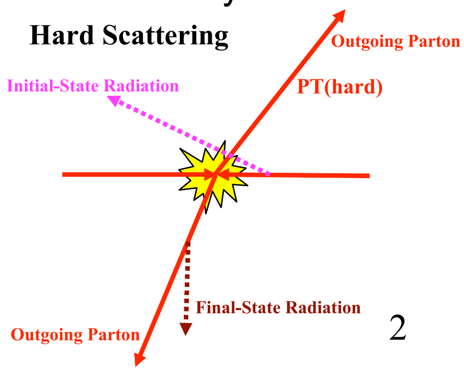




for p+p

1) how to compare with A+A (R_{AA}) *and* any bulk property in p+p (first data at LHC)?
2) does multi-parton dynamics make sense in such a small system ?

reminder: we usually focus on the hard scattering in p+p...



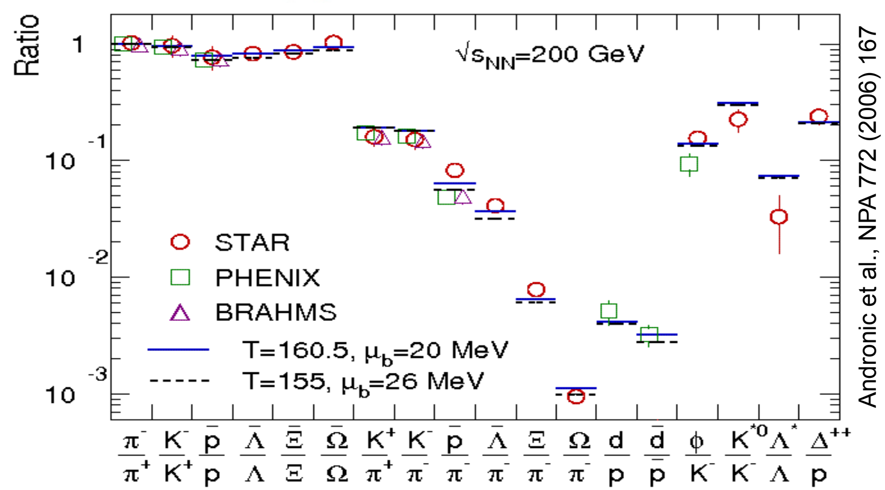
Bulk matter and properties in A+A ? … in p+p ?

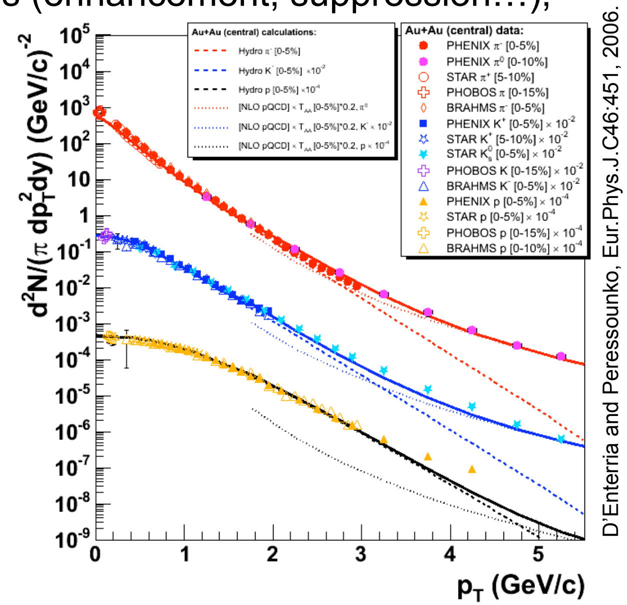
Bulk matter: global properties describing the main characteristics of particle production/emission

in A+A

1) most of the particles are in the soft physics region (precise range?);
2) statistical description and hydrodynamics (collective behavior) works pretty well;
3) use differences to investigate new mechanisms (enhancement, suppression…);

$$\langle n_j \rangle = \frac{(2J_j+1)V}{(2\pi)^3} \int d^3p \left[e^{\sqrt{p^2+m_j^2}/T + \mu \cdot q_j/T} \pm 1 \right]^{-1}$$



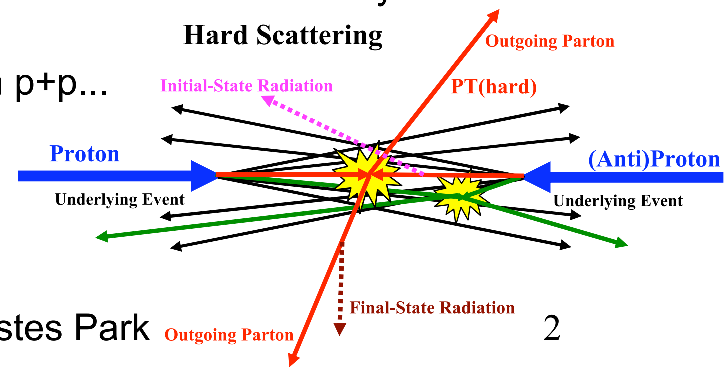


for p+p

1) how to compare with A+A (R_{AA}) *and* any bulk property in p+p (first data at LHC)?
2) does multi-parton dynamics make sense in such a small system ?

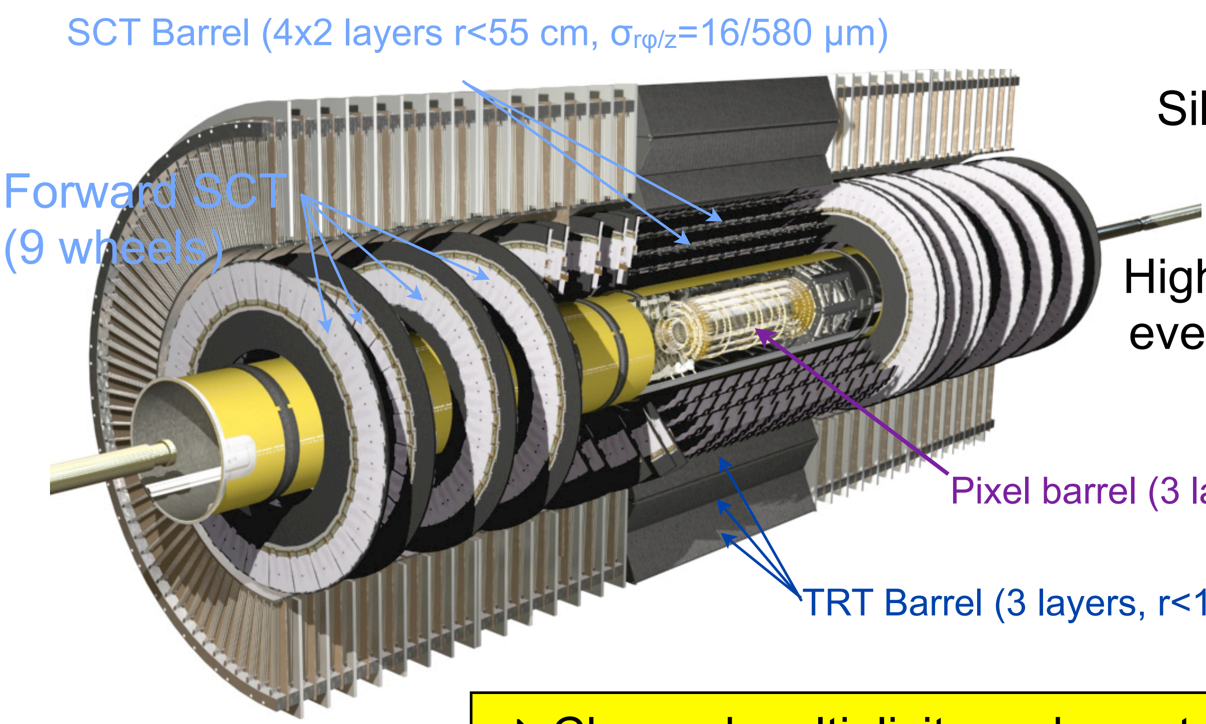
reminder: we usually focus on the hard scattering in p+p...

but we should not forget the underlying softer multi-parton dynamics



ATLAS Tracker

Barrel of **Pixel** sensors (3 layers) then **Semi-Conductor Tracker** strip detector (4x2 layers and $|\eta| \leq 2.6$), followed by the **Transition Radiation Tracker** (3 layers of straw-tubes interspersed with a radiator for e/π separation) inside a **2T magnetic field**.

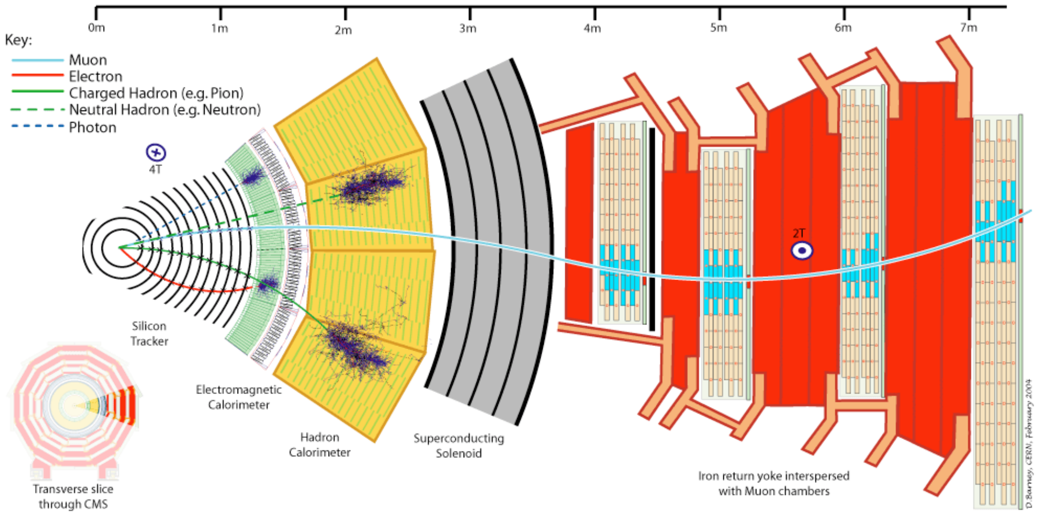


Silicon space points: 11 max
(3 for Pixel + 8 for SCT)

High occupancy for central TRT even in p+p (~ 90% for Pb+Pb)

- ⇨ Charged multiplicity and spectra: fine
- ⇨ Very low p_T (B_T=2T) and PID with Tracker: challenging

Reconstruction and identification at low p_T with CMS: detectors involved in B=4T



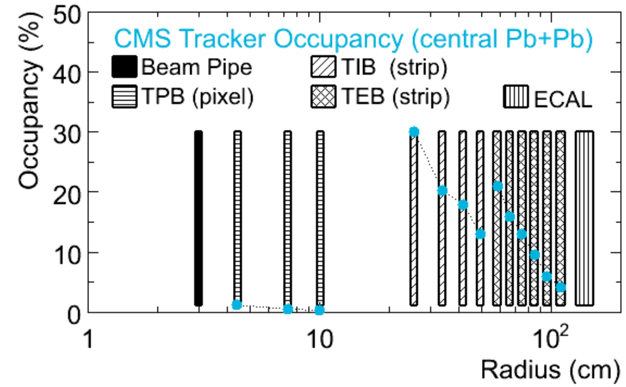
Barrel:

- Pixel (3 layers);
- Tracker Inner Barrel (TIB, 4 layers of strip);
- Tracker Outer Barrel (TOB, 6 layers of strip).

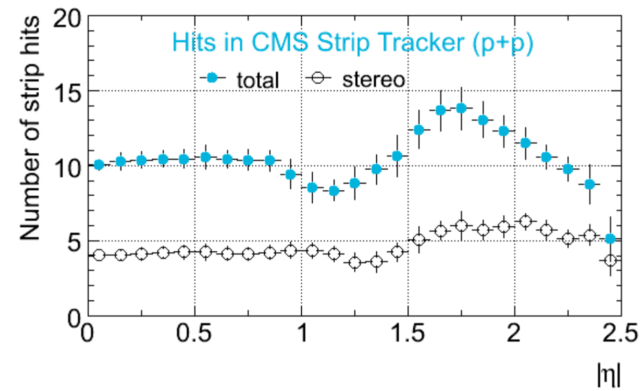
Forward:

- Tracker Inner Disks (TID, 5 layers: 2 pixel, 3 strip);
- Tracker End-Caps (TEC, 9 layers).

M. Weber / Nuclear Physics B (Proc. Suppl.) 142 (2005) 430–433



High occupancy for strips in Pb+Pb

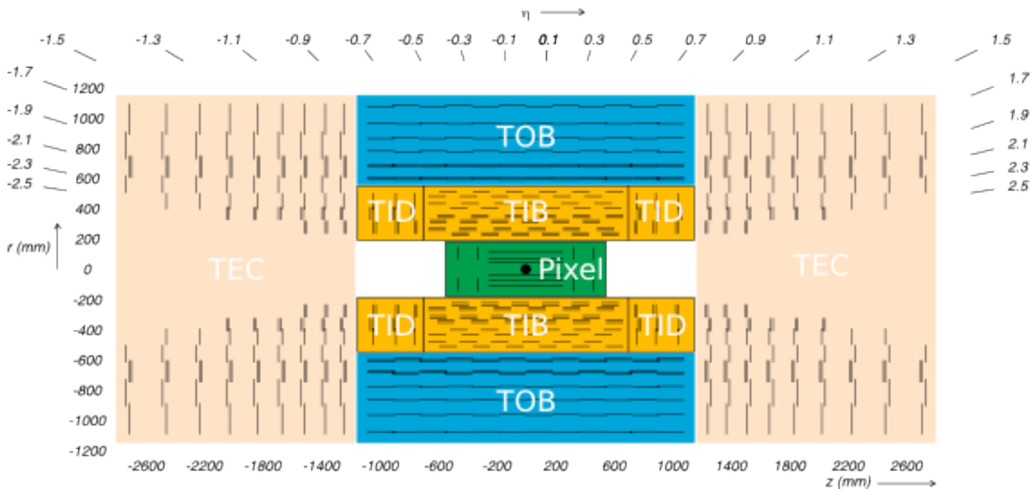


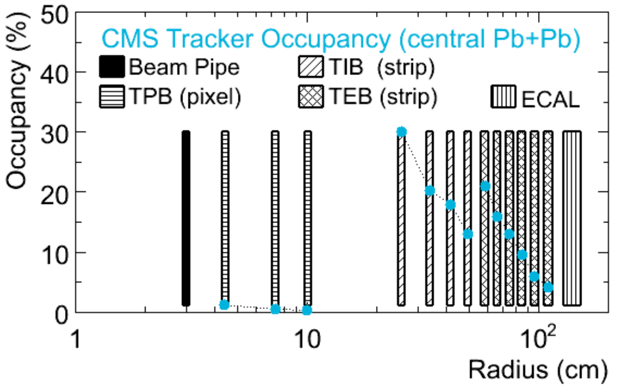
Number of strips hits in p+p for PID

⇨ Excellent impact parameter and primary vertex determinations

CMS Elements and Tracker

Reconstruction and identification at low p_T with CMS: detectors involved in B=4T

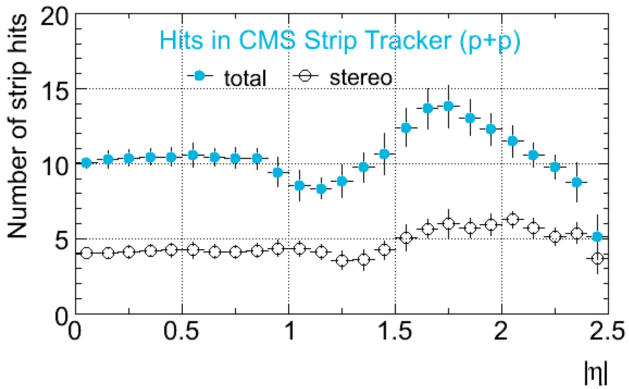




High occupancy for strips in Pb+Pb

Barrel:
- Pixel (3 layers);
- Tracker Inner Barrel (TIB, 4 layers of strip);
- Tracker Outer Barrel (TOB, 6 layers of strip).

Forward:
- Tracker Inner Disks (TID, 5 layers: 2 pixel, 3 strip);
- Tracker End-Caps (TEC, 9 layers).



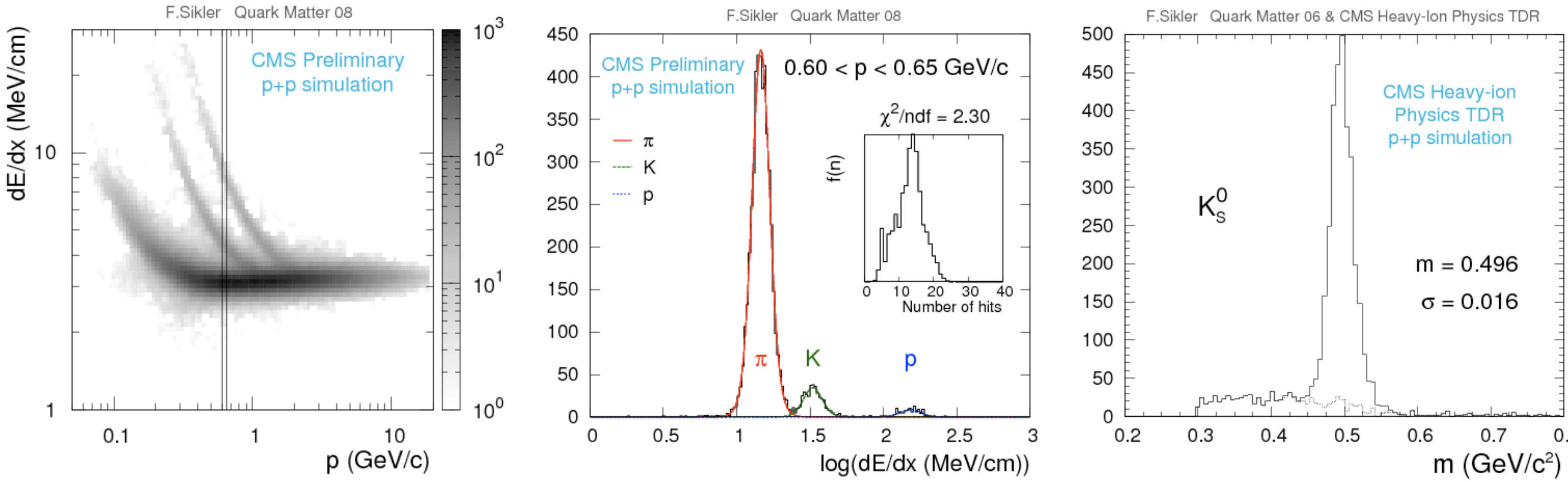
M. Weber / Nuclear Physics B (Proc. Suppl.) 142 (2005) 430–433

Number of strips hits in p+p for PID

⇨ Excellent impact parameter and primary vertex determinations

CMS PID

Modified algorithm for low-pT tracking in the pixel (3 hits): from straight line approximation to helix



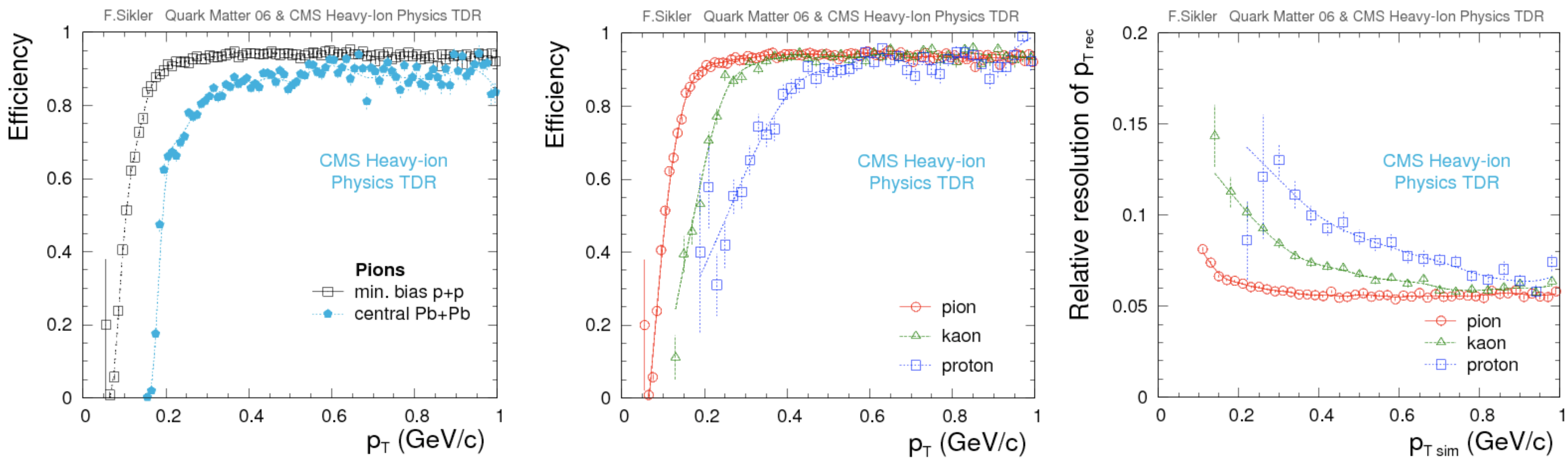
F. Sikler QM06: Int.J.Mod.Phys.E16:1819-1825,2007 and CMS-CR-2007-007;
F. Sikler QM08: arXiv:0805.0809 and CMS-AN-2006-101.

- dE/dx identification using both pixel and strip silicon detectors;
- topology identification: possibility for lambdas and gamma conversion too;
- optimization depending on luminosity conditions.

⇨ Identification at low p_T with CMS: dE/dx and invariant mass for neutral particles

CMS Efficiency

Efficiency calculations based on 25k p+p events and 25 central Pb+Pb



references: CMS-CR2007-007 and CMS-CR2007-054

- With |η| < 1.5, the average reconstruction efficiencies are 0.90/0.90/0.86 for pions/kaons/protons;
- Small bias (6%) at high p_T but quite significant at low p_T (10% correction for protons at 0.2 GeV/c).

⇨ Good efficiency and identification at low p_T in CMS

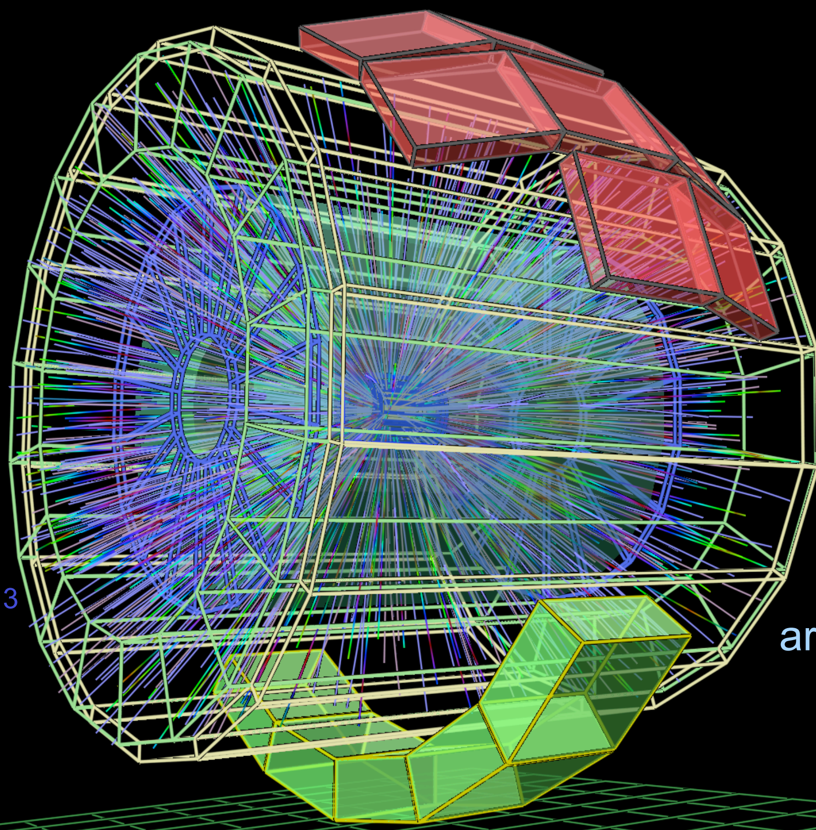
ALICE experiment and its central detectors

Transition-Radiation Detector

$-0.9 < \eta < 0.9$
azimuth 2π
length ~7 m
active area 736 m^2

High-Momentum Particle Identification Detector

$-0.6 < \eta < 0.6$
azimuth 57.61°
active area 10 m^2



Time Projection Chamber

$-0.9 < \eta < 0.9$
azimuth 2π
length 5 m
active volume 88 m^3

Inner Tracking System

$-0.9 < \eta < 0.9$
silicon layers 6
pixel/drift/strip 2/2/2
cells(M) 9.84/23/2.6
area 0.21/1.31/4.77 m^3

Time Of Flight

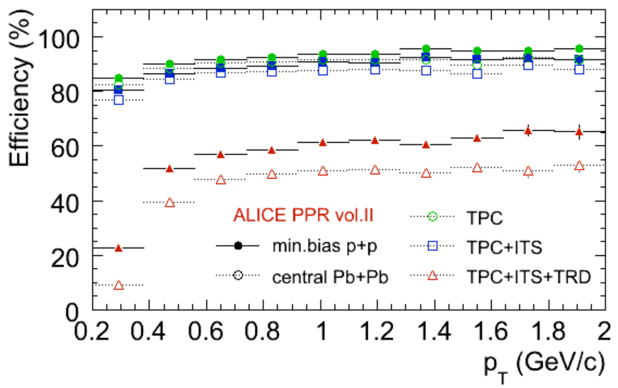
$-0.9 < \eta < 0.9$
azimuth 2π
length 7.45 m
active area 141 m^2

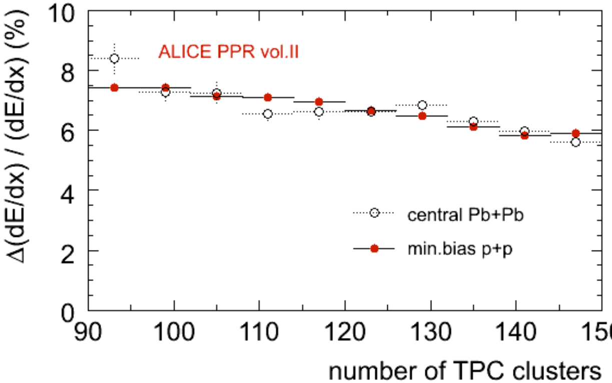
PHOton Spectrometer

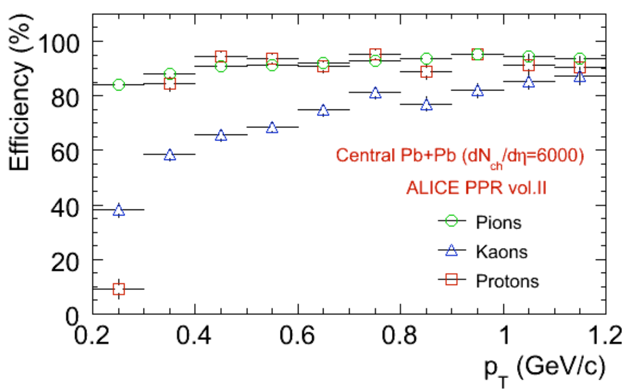
$-0.12 < \eta < 0.12$
azimuth 100°
active area 8 m^2

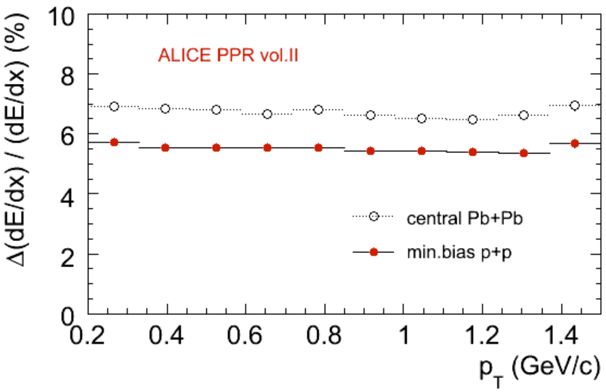
ALICE performances

Efficiencies vs. p_T: i) p+p and Pb+Pb comparison; ii) species dependence
dE/dx resolution for PID: i) dE/dx vs. # of TPC cluster; ii) dE/dx vs. p_T





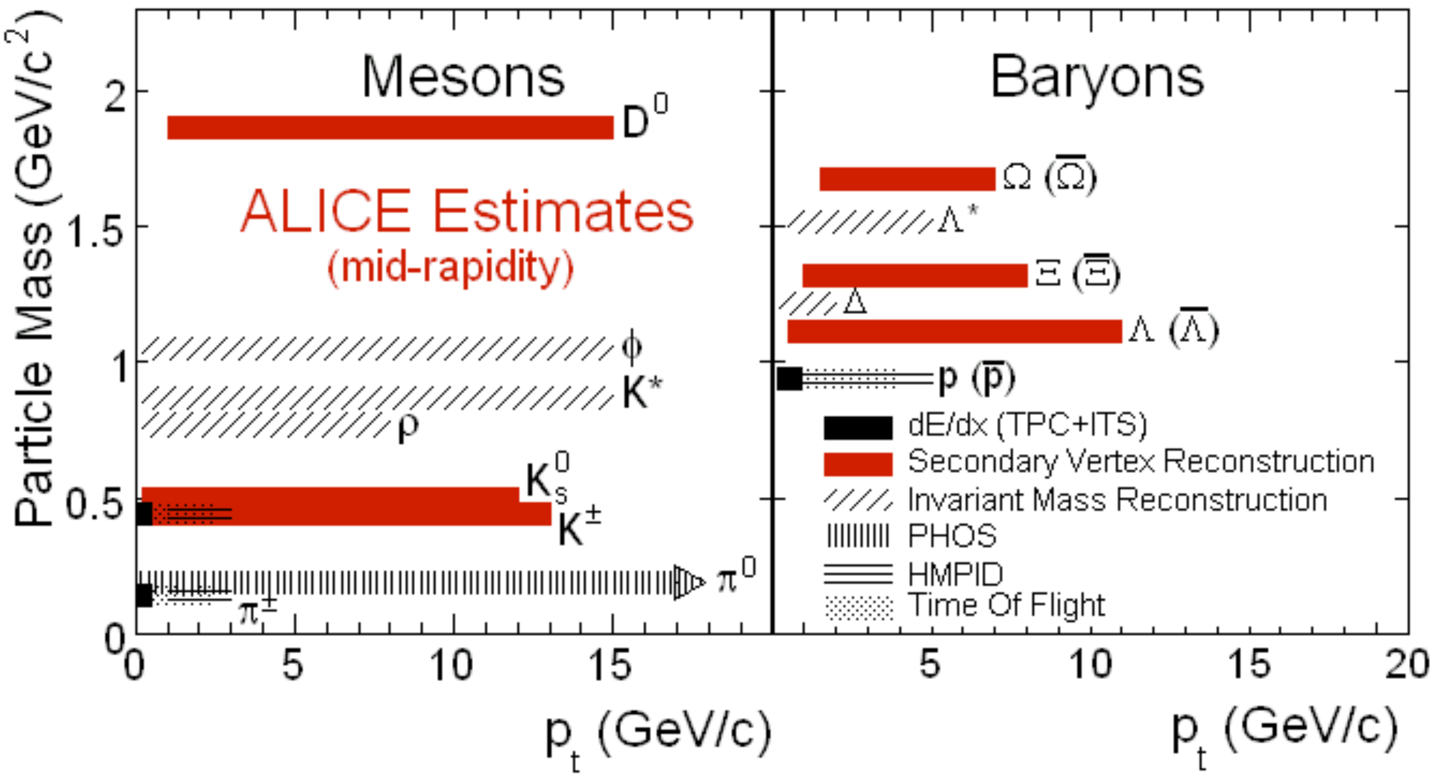




- ⇨ Alice is designed for high multiplicity: excellent efficiency and resolution at low p_T;
- ⇨ Charm and strange weak decay identification via topology reconstruction (not shown);
- ⇨ Lower magnetic field w-r-t Atlas and CMS but also lower luminosity conditions required.

Particle identification vs p_T

Estimated p_T ranges for 10 M central Pb-Pb events (PPR vol. II).
Ranges for first year p-p events can be close if one month of data taking.

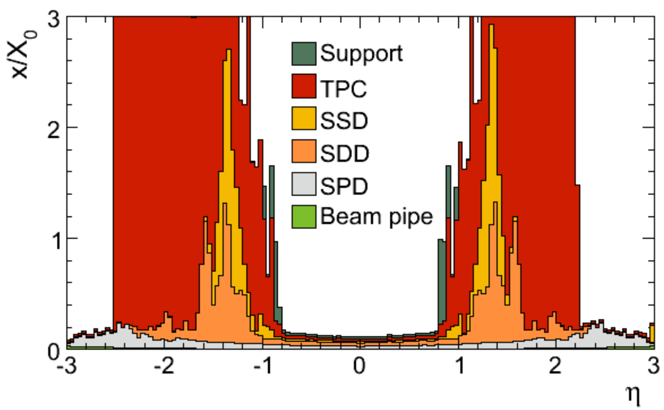


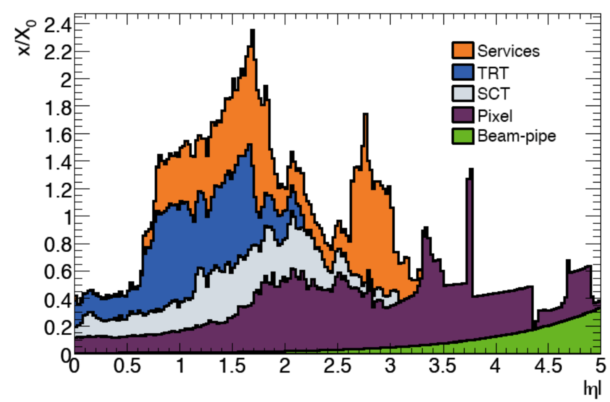
⇨ low p_T : thermal emission and hydrodynamics;
⇨ intermediate to high p_T : hadronization mechanisms, tomography.

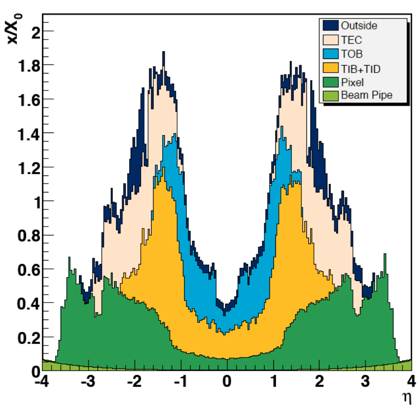
Material budget

Cumulative mid-rapidity material budget for ALICE, ATLAS and CMS

ALICE	x/X_0 (%)	ATLAS	x/X_0 (%)	CMS	x/X_0 (%)
Beam pipe	0.26	Beam pipe	0.45	Beam pipe	0.23
Pixels (7.6 cm)	2.73	Pixels (12 cm)	4.45	Pixels (10.2 cm)	7.23
ITS (50 cm)	7.43	SCT (52 cm)	14.45	TIB (50 cm)	22.23
TPC (2.6 m)	13	TRT (1.07 m)	32.45	TOB (1.1 m)	35.23





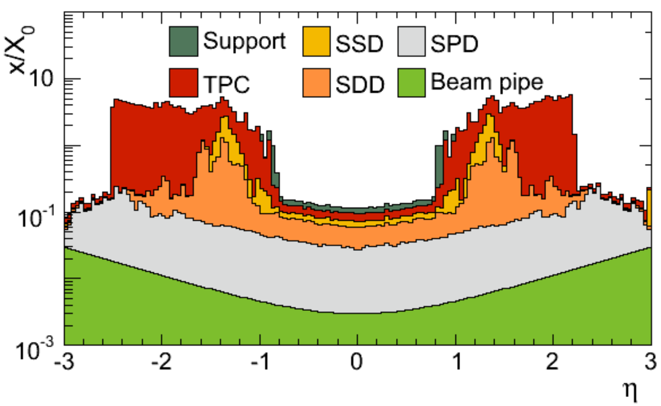


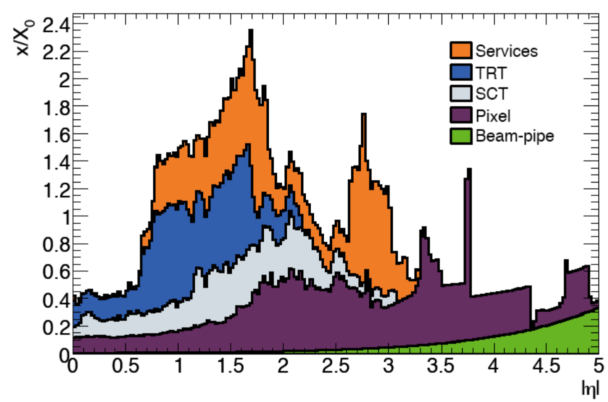
⇨ Ideal Reconstruction and identification low p_T : lowest material budget

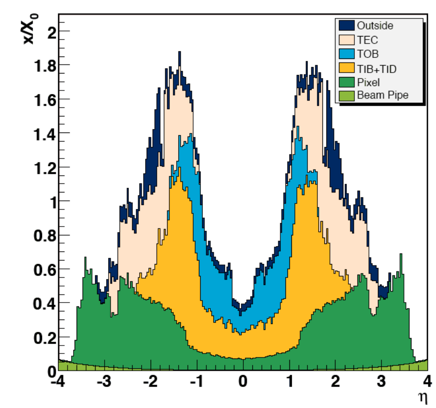
Material budget

Cumulative mid-rapidity material budget for ALICE, ATLAS and CMS

ALICE	x/X_0 (%)	ATLAS	x/X_0 (%)	CMS	x/X_0 (%)
Beam pipe	0.26	Beam pipe	0.45	Beam pipe	0.23
Pixels (7.6 cm)	2.73	Pixels (12 cm)	4.45	Pixels (10.2 cm)	7.23
ITS (50 cm)	7.43	SCT (52 cm)	14.45	TIB (50 cm)	22.23
TPC (2.6 m)	13	TRT (1.07 m)	32.45	TOB (1.1 m)	35.23







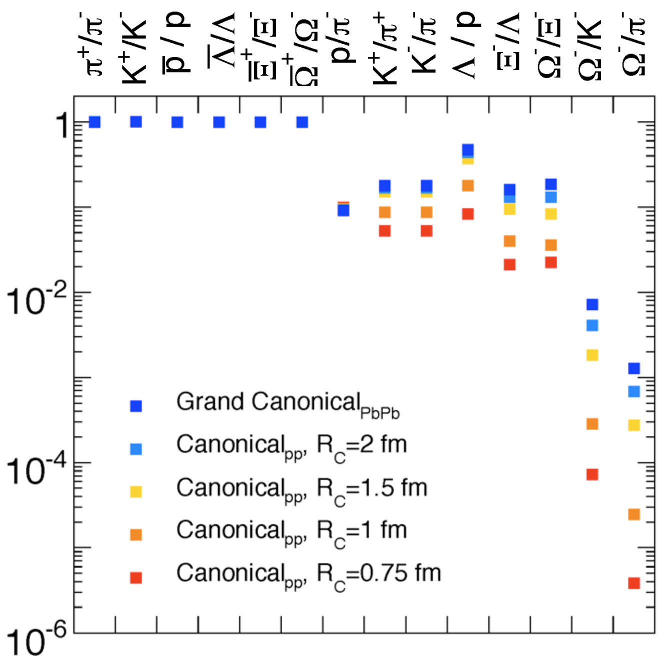
⇨ Ideal Reconstruction and identification low p_T : lowest material budget

Hadro-production: equilibrium vs. non equilibrium

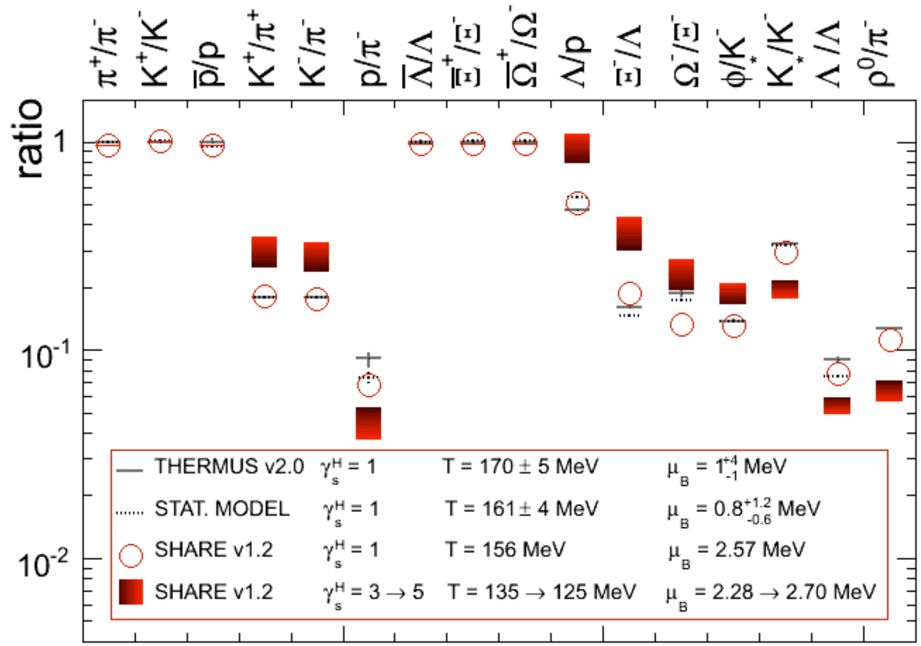
Statistical thermal models describe mid-rapidity p_T-integrated production of baryons and mesons over a large energy range.

Baryo-chemical potential μ_B and Chemical freeze-out Temperature T_{ch}

I.Kraus et al., in arXiv0711.0974 [hep-ph]



ALICE Estimates : Equilibrium vs Non Eq. particle ratios



⇨ Expectations at LHC: T_{ch} =161±4 MeV
μ_B =0.8+1.2-0.6 MeV

Eq. [I.Kraus *et al.*, J.Phys.G32 (2006) S495]
[A.Andronic *et al.*, Nucl. Phys. A772 (2006) 167]
Non Eq. [J.Rafelski *et al.*, Eur. J. Phys. C45 (2006) 61]

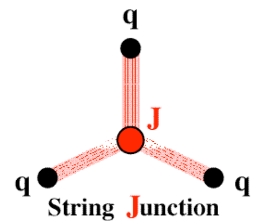
Note: Anti-particle/particle ~ unity will be difficult to constrain but can be used for addressing baryon transport

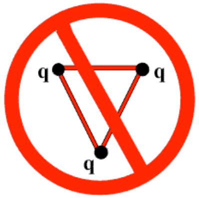
Baryon number transport

P. Christakoglou: HEP2008, Athenes

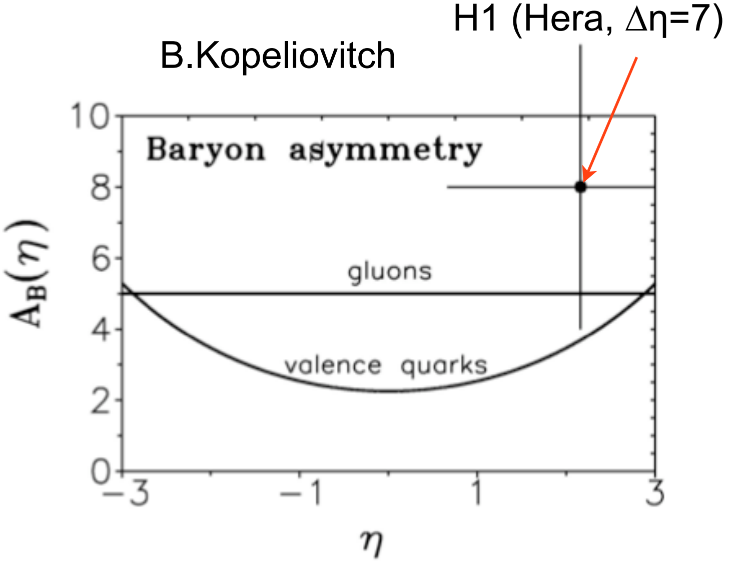
Studying the baryon number (BN) transport and carrier:

- gluonic field: B.Z. Kopeliovich and B. Zakharov, Z. Phys. C43 (1989) 241.
  probability to transport BN is constant with rapidity
- valence quark: G.C. Rossi and G. Veneziano, Nucl. Phys B123 (1977) 507.
  probability to transport BN is exponentially suppressed

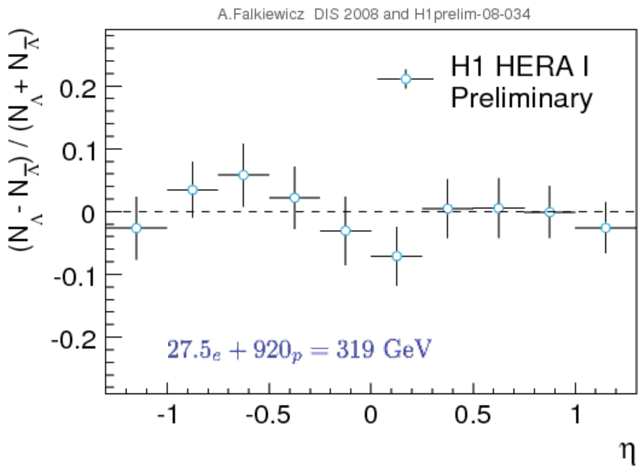




Baryon asymmetry vs. y or η: $A_B = (2\times)\frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}}$



A. Falkiewicz: DIS2008, London



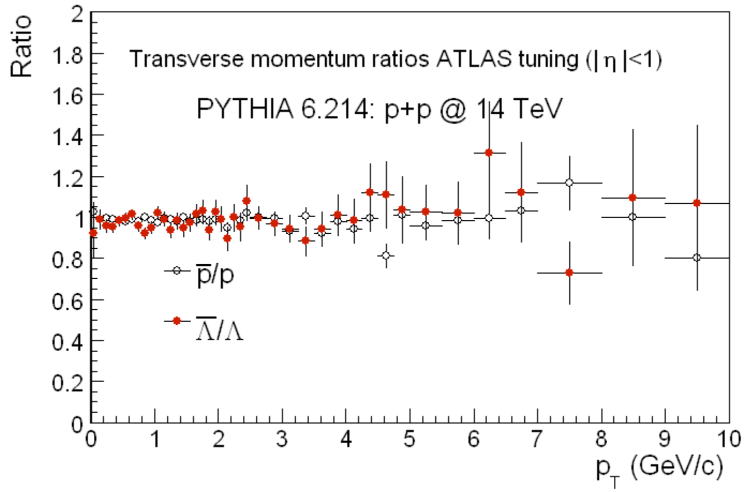
⇨ Current measurements are compatible with no asymmetry within uncertainties

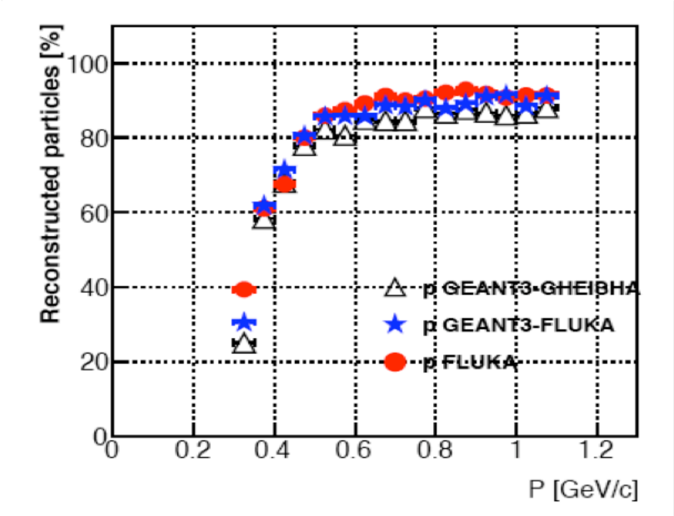
Baryon number transport

P. Christakoglou: HEP2008, Athenes

Specific to LHC conditions: high energy so $\bar{B}/B \sim 1$ and large rapidity gap ($y_p \pm 9.6$)

- QGSM: asymmetry ~0% (~no transported baryons from y_p to y_0 via fragmentation);
- Kopeliovitch: asymmetry ~5% for protons and ~8% for Λs;
- Veneziano: smaller but non-zero asymmetry.





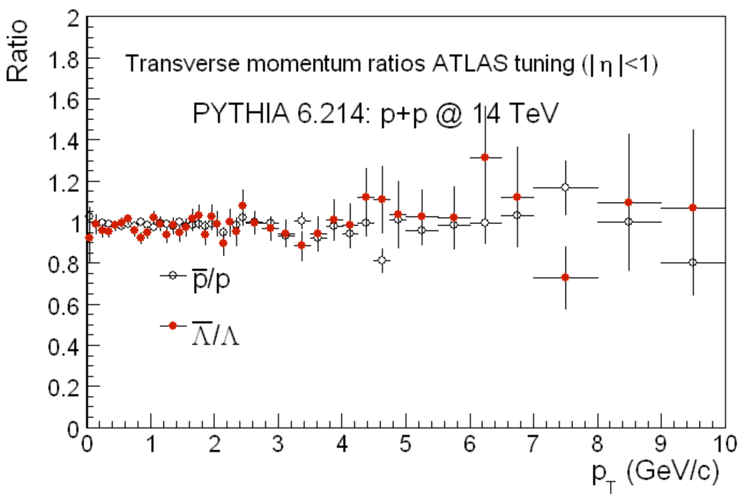
Try to perform this measurement at LHC energies

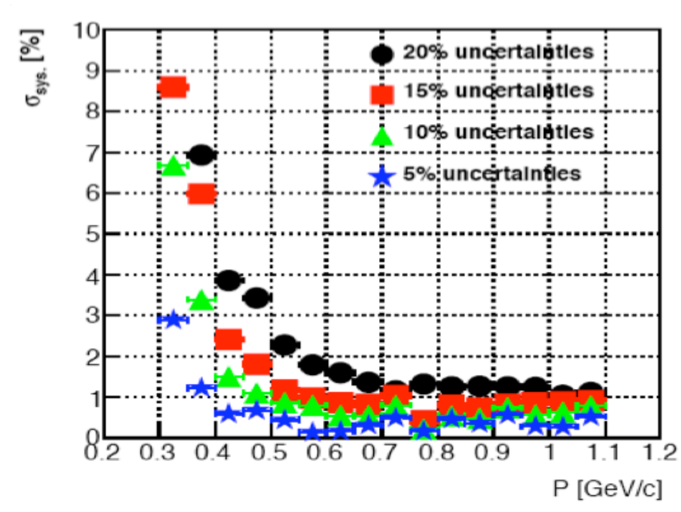
Baryon number transport

P. Christakoglou: HEP2008, Athenes

Specific to LHC conditions: high energy so $\bar{B}/B \sim 1$ and large rapidity gap ($y_p \pm 9.6$)

- QGSM: asymmetry ~0% (~no transported baryons from y_p to y_0 via fragmentation);
- Kopeliovitch: asymmetry ~5% for protons and ~8% for Λs;
- Veneziano: smaller but non-zero asymmetry.

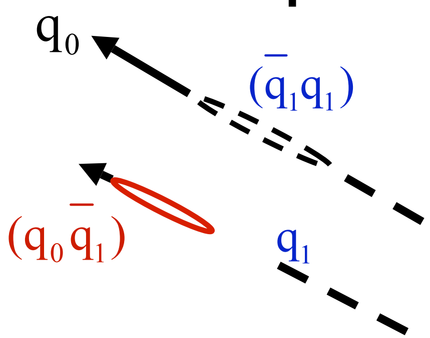




The systematic uncertainties on both the ratio and the asymmetry are below 1% for a material uncertainty of 15% (p > 0.5 GeV/c).

Try to perform this measurement at LHC energies

Hadro-production from fragmentation (LUND / PYTHIA)



In vacuum production of meson via string break-up

Probability to produce $(q_i \bar{q}_i)$
Probability to form $(q_{i-1} \bar{q}_i)$
Factorization: production of $(q_i \bar{q}_i)$ independent of q_{i-1} but the pair mass quark (flavour) is relevant.
➪ Fragmentation in $(q_{i-1} \bar{q}_i)$ ≡ meson

probability: $e^{-\frac{\pi m_T^2}{\kappa}} = e^{-\frac{\pi m^2}{\kappa}} \times e^{-\frac{\pi p_T^2}{\kappa}}$

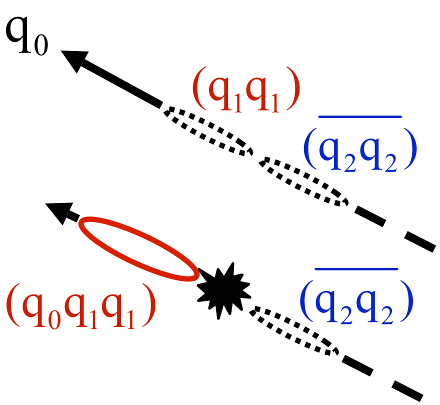
κ (string tension) ≈ 1 GeV/fm ≈ 0.2 GeV^2

mass suppression: u:d:s:c≈1:1:0.3:10^{-11}

Production of $(q_i \bar{q}_i)$ via quantum mechanical tunneling:
- Classically, the pair is pulled apart by the field (no annihilation);
- Quantum mechanically, the pair is created at one point then tunnels out with a non zero probability (mass and flavor dependence).

In vacuum production of baryon with the diquark model

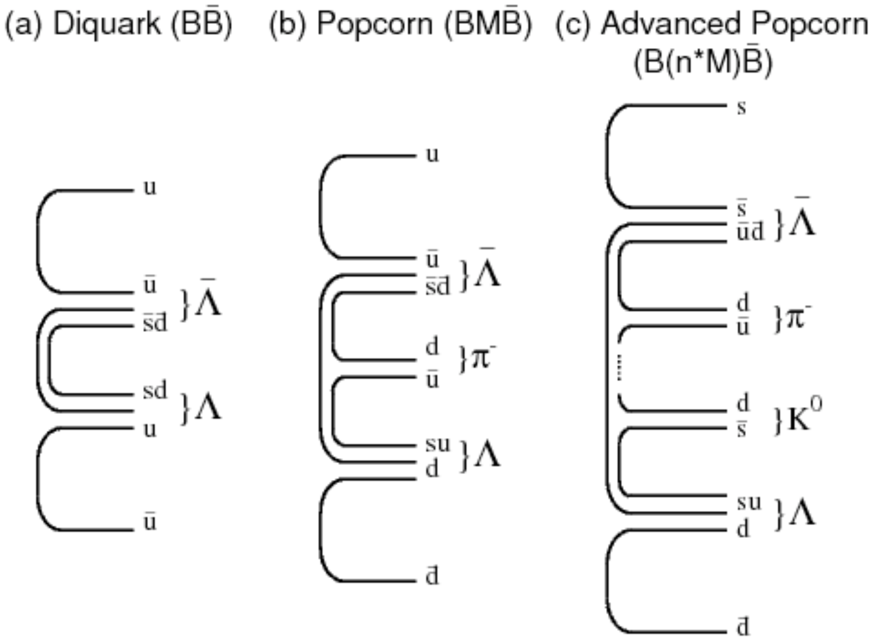
Relative probability to produce a <u>di</u>quark <u>pair</u> wrt quark pair
Extra suppression associated to s content
Spin suppression (spin 1 diquarks wrt spin 0 diquarks)
Weighted probability relative to 3-q state symmetry
➪ Fragmentation in $(q_{i-1} q_i q_i)$≡ baryon



Note: will be needed later when discussing coalescence and recombination

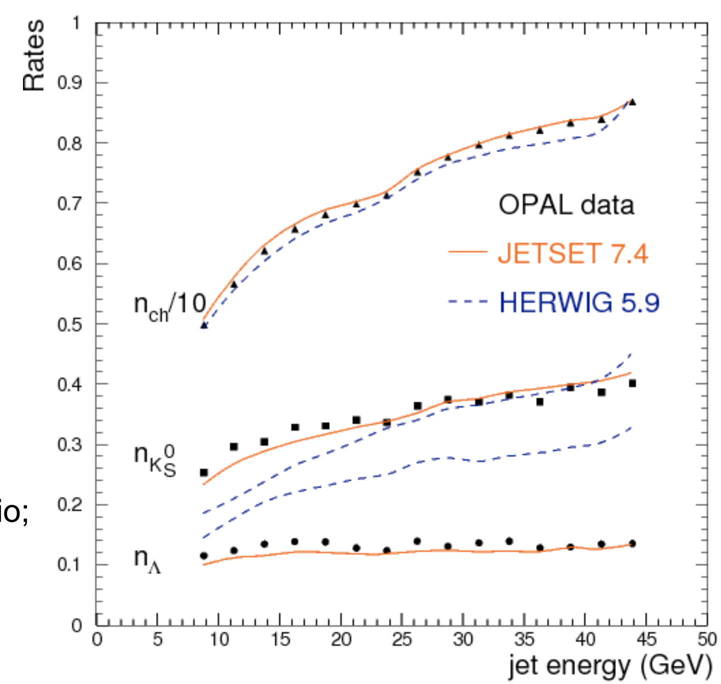
Baryon-production from fragmentation (LUND / PYTHIA)

Modified "popcorn" scenario from the diquark model for baryon production



Studied at LEP e.g. OPAL:

1. baryon yields vs. jet energy
2. baryon correlations vs. η gap between the baryon pair



Distinguishing between different scenario for fragmentation

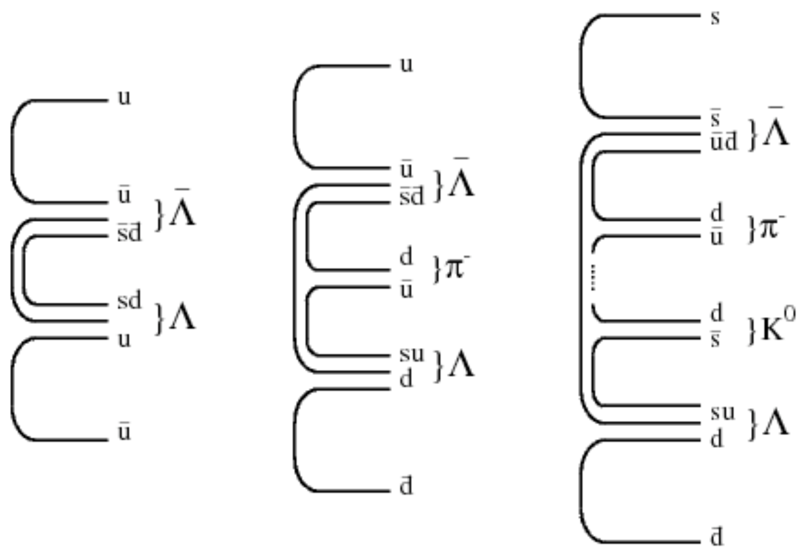
- JETSET (now PYTHIA): anisotropic string decay
- MOPS : (now advanced/Popcorn in PYTHIA) MOdified Popcorn Scenario;
- HERWIG: isotropic clustering

Revisit baryon production at LHC energies

Baryon-production from fragmentation (LUND / PYTHIA)

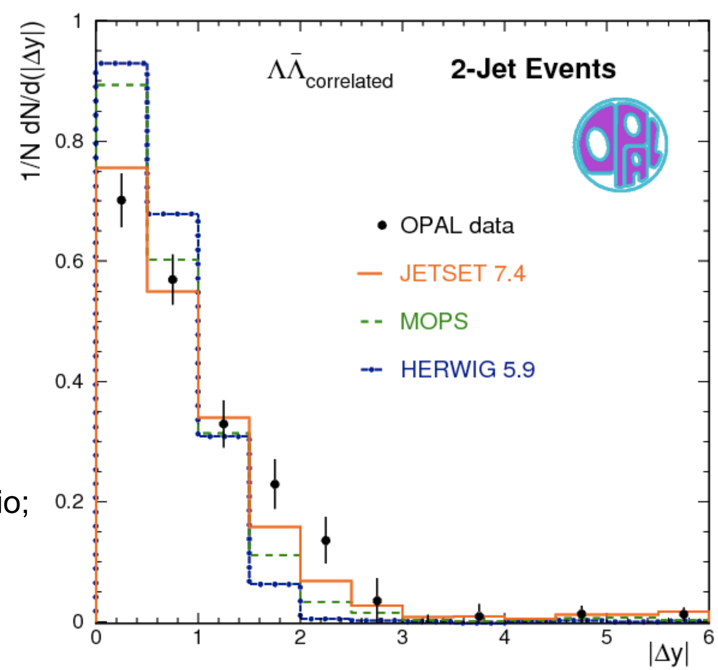
Modified “popcorn” scenario from the diquark model for baryon production

(a) Diquark ($B\bar{B}$) (b) Popcorn ($BM\bar{B}$) (c) Advanced Popcorn ($B(n^*M)\bar{B}$)



Studied at LEP e.g. OPAL:

1. baryon yields vs. jet energy
2. baryon correlations vs. η gap between the baryon pair



Distinguishing between different scenario for fragmentation

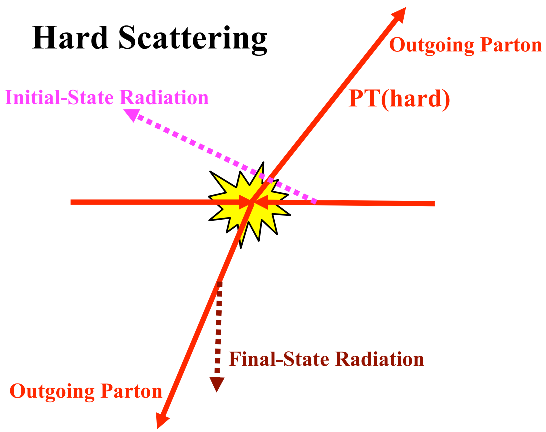
- JETSET (now PYTHIA): anisotropic string decay
- MOPS : (now advanced/Popcorn in PYTHIA) MOdified Popcorn Scenario;
- HERWIG: isotropic clustering

Revisit baryon production at LHC energies

Multi-parton dynamics in p+p at LHC energies

Soft component in p+p collision: multiple parton interactions

Hard parton scattering is one part of the story

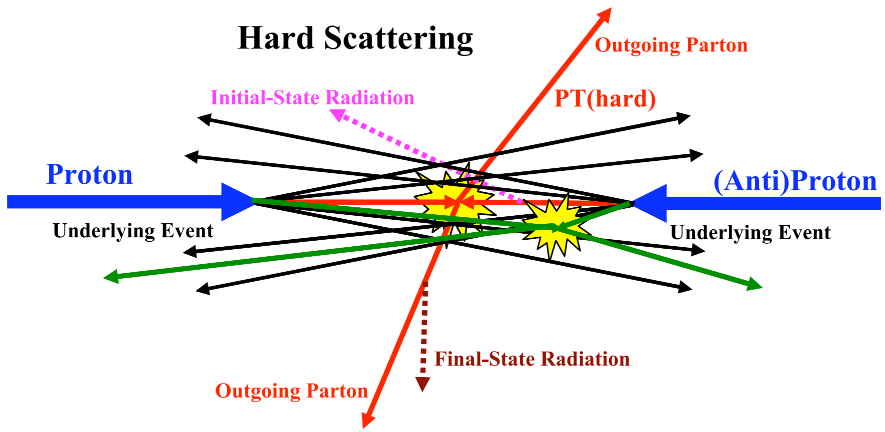


Significant differences for production rates and ratios between “min. bias” and “u.e.”;
⇨ important for e.g. understanding baryon/meson ratio, deconvoluting R_{AA}...
⇨ angular studies may include leading charged particle and/or full jet reconstruction.

Multi-parton dynamics in p+p at LHC energies

Soft component in p+p collision: multiple parton interactions

Hard parton scattering is one part of the story



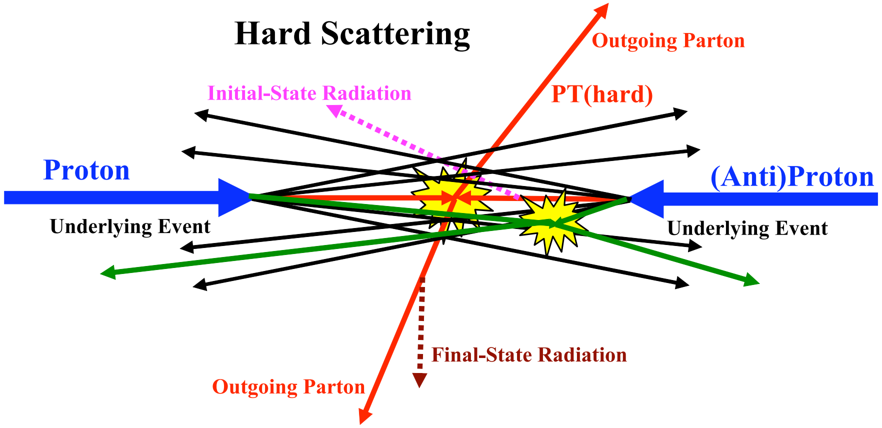
R.Field: «The “underlying event” consists of the “beam-beam remnants” and from particles arising from soft or semi-soft multiple parton interactions (MPI).»

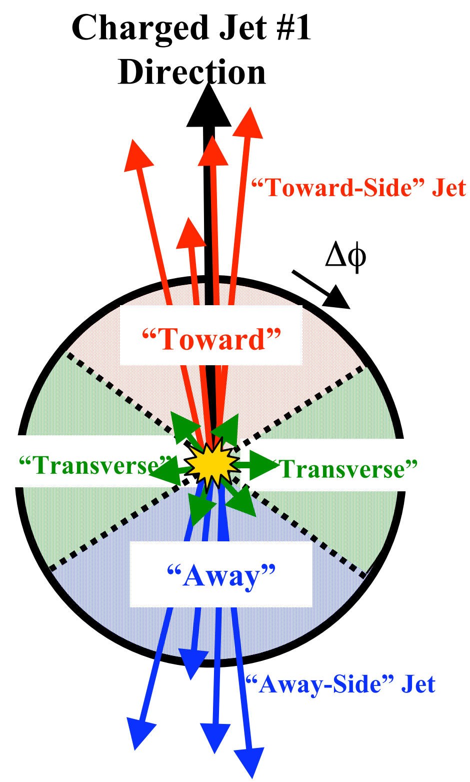
Significant differences for production rates and ratios between “min. bias” and “u.e.”;
⇨ important for e.g. understanding baryon/meson ratio, deconvoluting R_{AA}...
⇨ angular studies may include leading charged particle and/or full jet reconstruction.

Multi-parton dynamics in p+p at LHC energies

Soft component in p+p collision: multiple parton interactions

Hard parton scattering is one part of the story





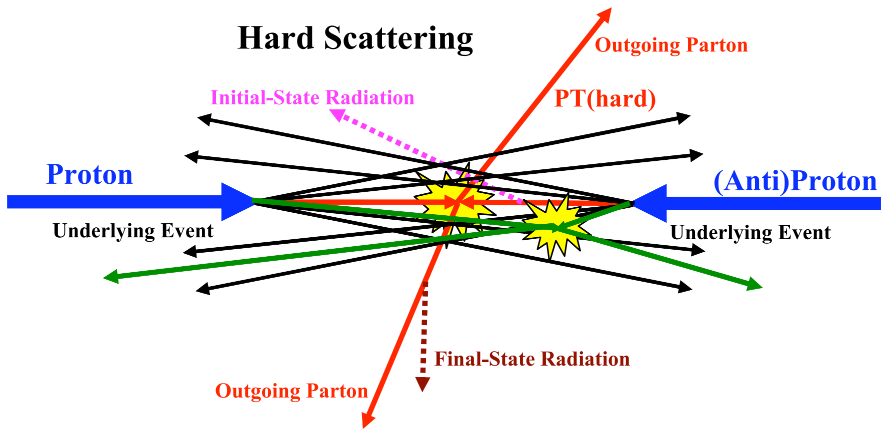
R.Field: «The "underlying event" consists of the "beam-beam remnants" and from particles arising from soft or semi-soft multiple parton interactions (MPI).»

Significant differences for production rates and ratios between "min. bias" and "u.e.";
⇨ important for e.g. understanding baryon/meson ratio, deconvoluting R_{AA}...
⇨ angular studies may include leading charged particle and/or full jet reconstruction.

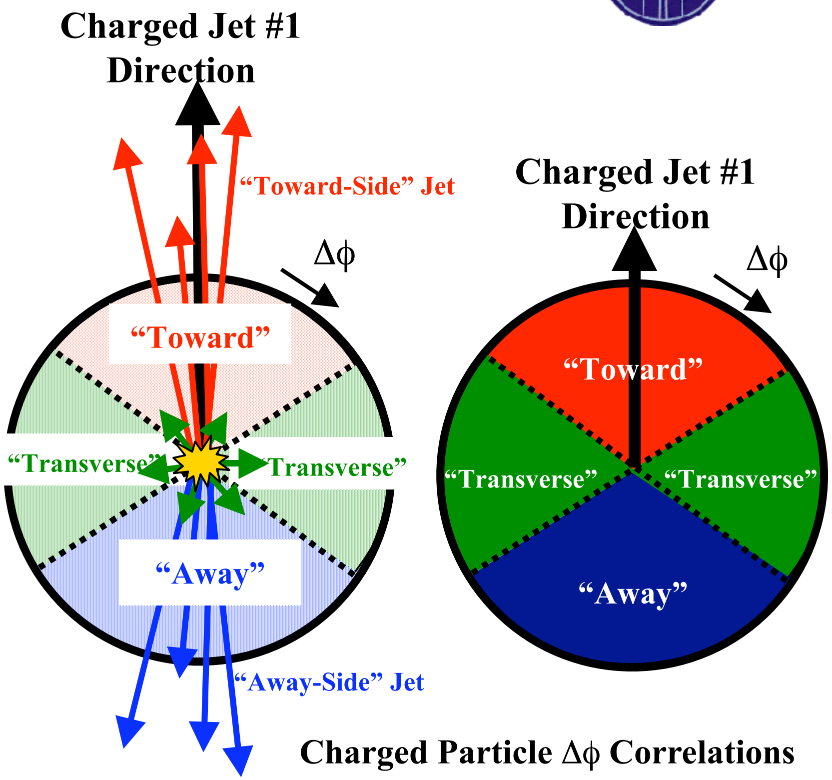
Multi-parton dynamics in p+p at LHC energies

Soft component in p+p collision: multiple parton interactions

Hard parton scattering is one part of the story



R.Field: «The "underlying event" consists of the "beam-beam remnants" and from particles arising from soft or semi-soft multiple parton interactions (MPI).»



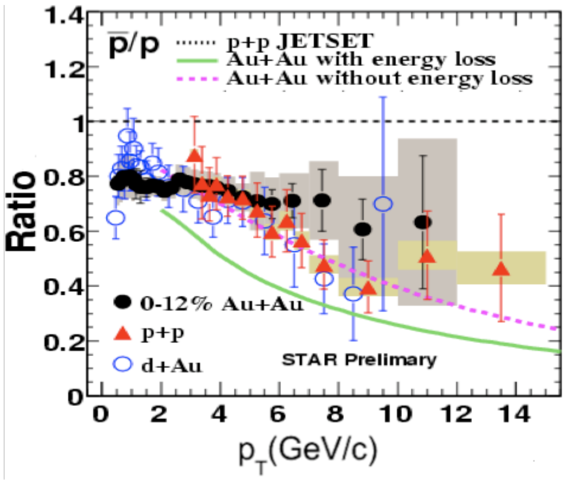
Charged Particle Δφ Correlations
$P_T > 0.5$ GeV/c $|\eta| < 1$

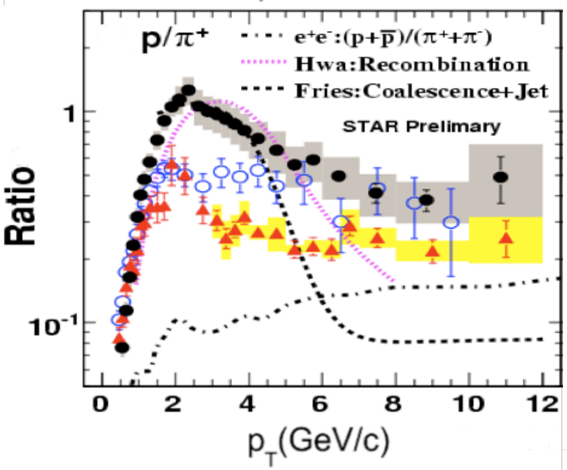
Significant differences for production rates and ratios between "min. bias" and "u.e.";
⇨ important for e.g. understanding baryon/meson ratio, deconvoluting R_{AA}...
⇨ angular studies may include leading charged particle and/or full jet reconstruction.

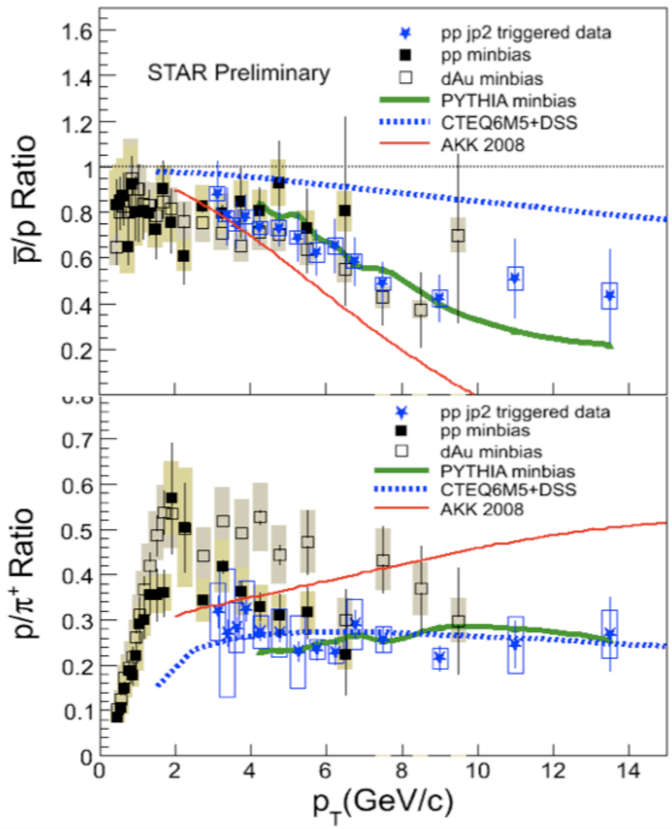
Baryon / Meson ratios at RHIC and HERA

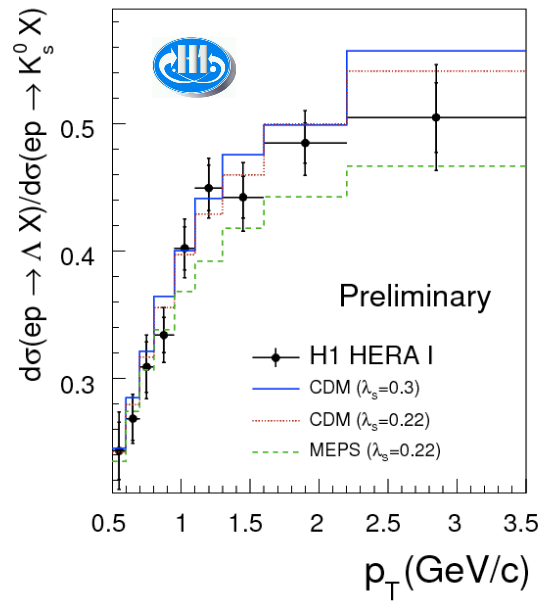
Probing baryon/meson differences at LHC energies implies PID over a large p_T range.

Studying p+p and e+p production for understanding the specificities of A+A





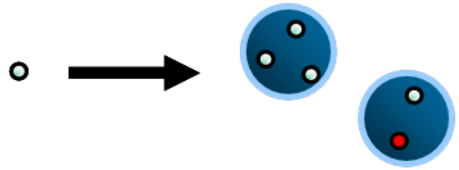




As discussed earlier, first step for investigating recombination and coalescence mechanisms

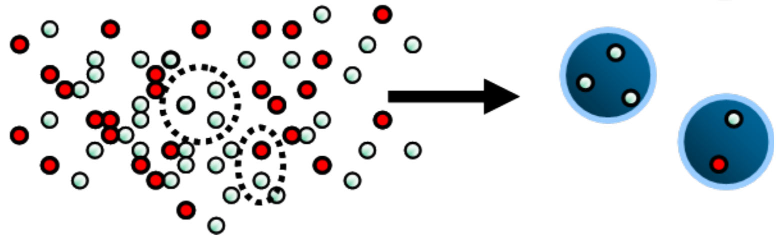
Recombination / Coalescence vs. Fragmentation

Hadronization of 1 parton: fragmentation



Dilute parton system
High virtualities

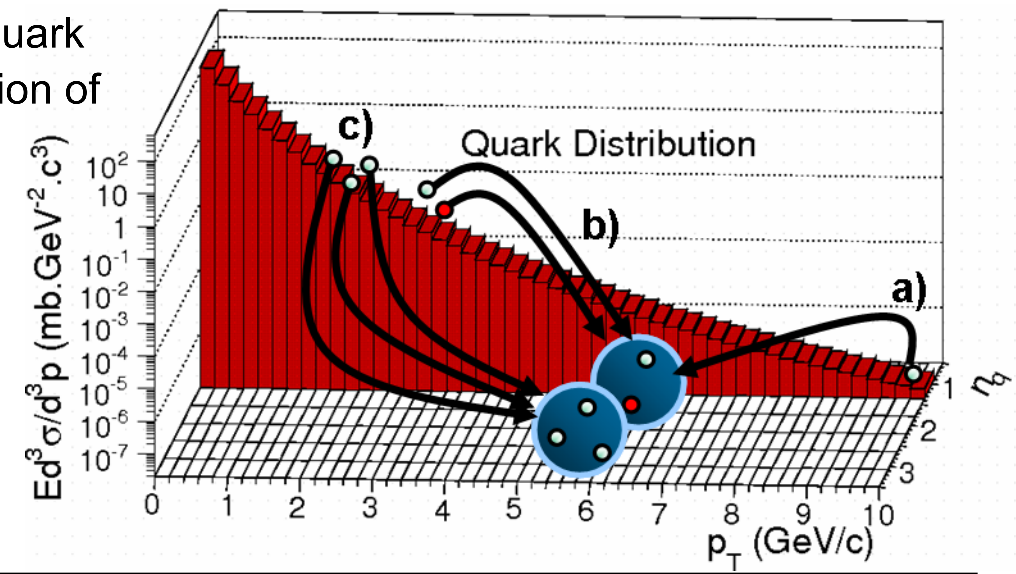
If phase space is filled with partons: hadronization via recombination/coalescence



Dense parton system
Low virtualities

The in vacuo fragmentation of a high p_T quark competes with the in medium recombination of lower momentum quarks

a) 6 GeV/c pion from 1x 10 GeV/c quark fragmentation
b) 6 GeV/c pion from 2x 3 GeV/c quark recombination
c) 6 GeV/c proton from 3x 2GeV/c quark recombination



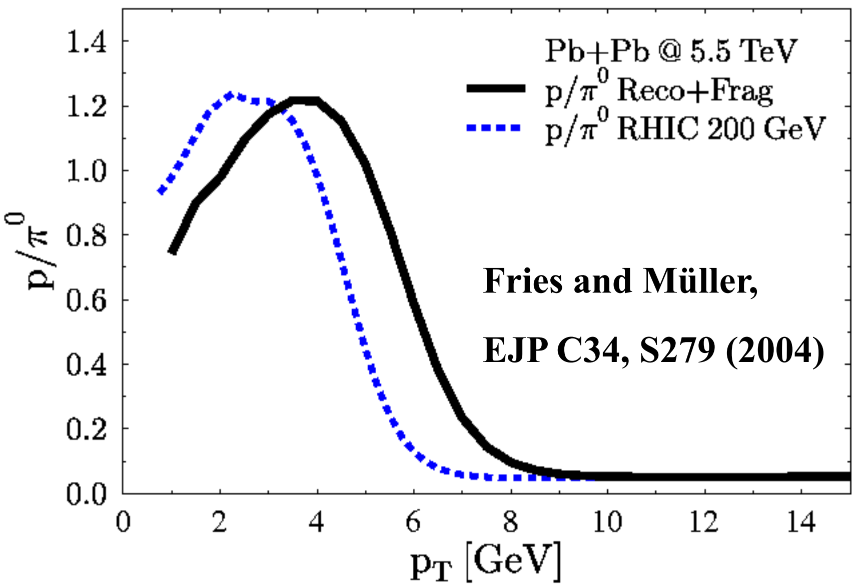
Baryon/Meson ratios
Constituent Quark Scaling (e.g. v_2)
Correlations via Soft+Hard contributions

"...requires the assumption of a thermalized parton phase... (which) may be appropriately called a quark-gluon plasma." Fries *et al.*, PRC 68, 044902 (2003)

Baryon / Meson ratios at LHC energies

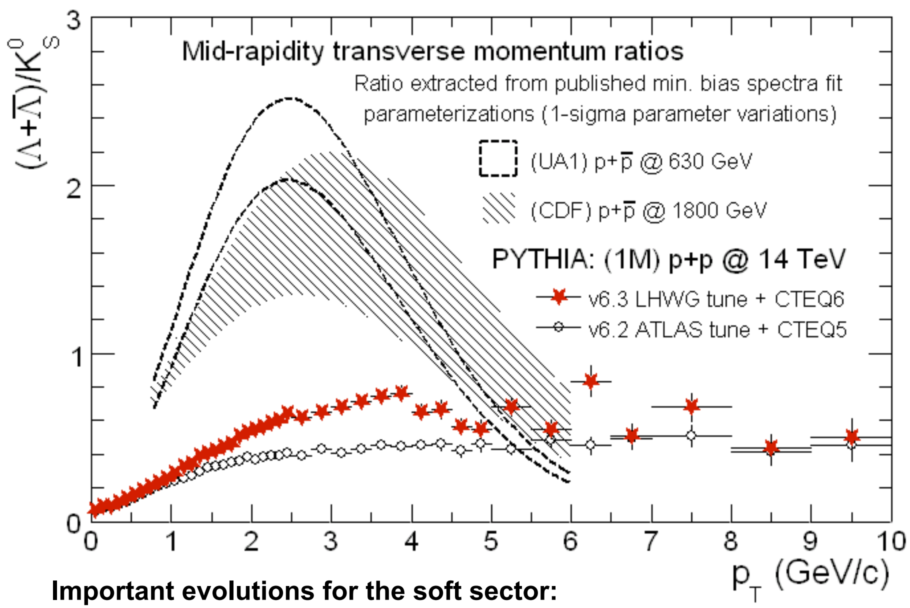
Probing baryon/meson differences at LHC energies implies PID over a large p_T range.

Calculation implies assumption on transverse radial flow extrapolation



But first LHC data will be <u>elementary collisions</u>
⇨ check magnitude of this behaviour then invoke coalescence mechanisms if needed.

PYTHIA Configuration from preprint hep-ph/0604120



Amplitude for mixed ratio predicted to be the same at LHC than for RHIC but the turnover and limit are shifted to higher p_T

Important evolutions for the soft sector:

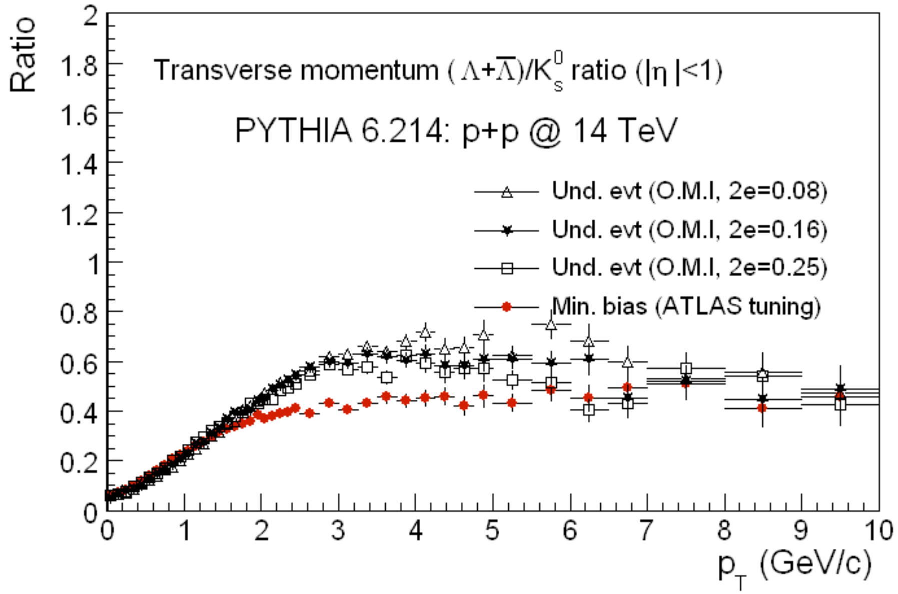
PYTHIA: **v6.2** ⇨ **v6.3** New multiple interaction (N.M.I) treatment (part.-part. interactions and i/fsr)

PDF: **CTEQ5** ⇨ **CTEQ6** Gluon distribution function (visible at low Q^2)

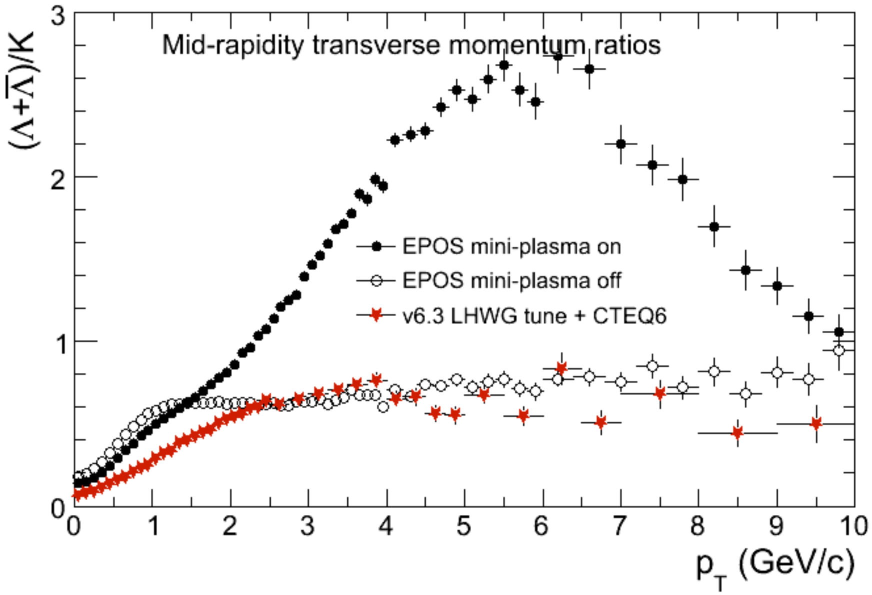
Missing a factor of ~2 wrt RHIC ⇨ UA1 ⇨ CDF extrapolations
⇨ investigation of NLO contribution, baryon creation mechanisms (diquark to popcorn scenario or gluonic baryon junctions).

Predictions for B/M p_T ratio: p+p @ 14 TeV

Ratios and differences between min. bias and underlying event description



Checking uncertainty for parameters energy dependence:
PYTHIA authors' suggestions : **2ε~0.08** ⇨ **0.25**



Comparison between standard LHC extrapolation and underlying event description

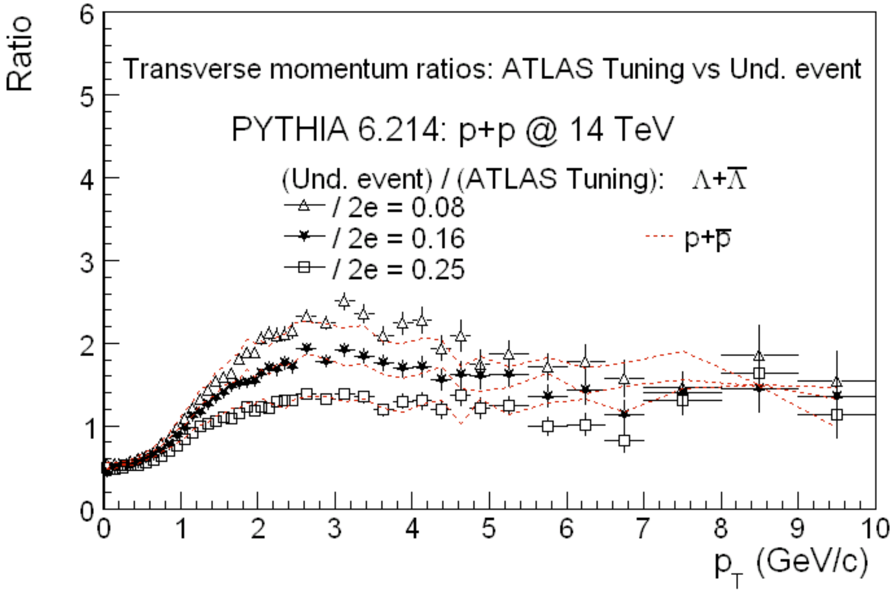
Little **light/strange** flavor dependence in this region

Underlying event description **needed/enough** for production of hadrons in intermediate p_T region ?

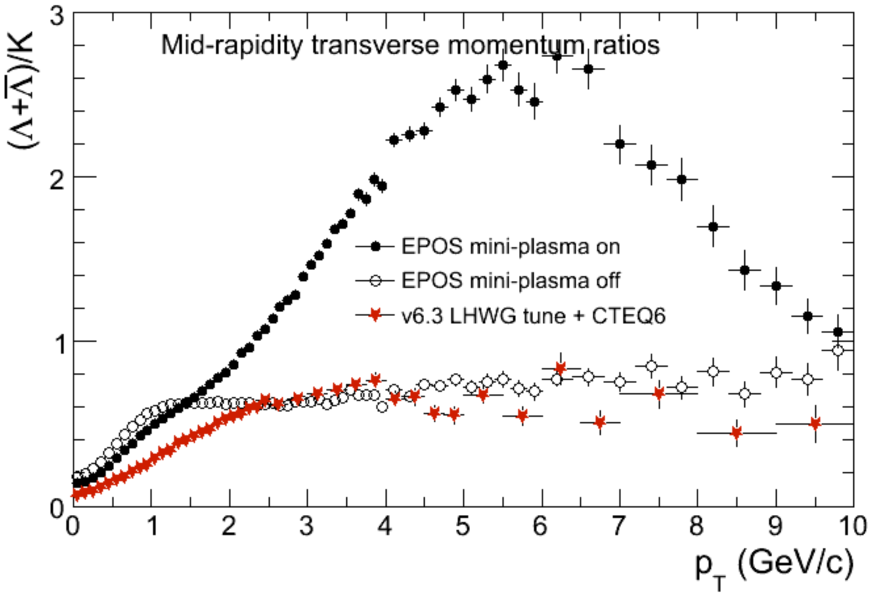
Predictions from EPOS based on pomeron exchanges can lead to much higher ratios

Predictions for B/M p_T ratio: p+p @ 14 TeV

Ratios and differences between min. bias and underlying event description



Checking uncertainty for parameters energy dependence:
PYTHIA authors' suggestions : **2ε~0.08 ⇨ 0.25**



Comparison between standard LHC extrapolation and underlying event description

Little **light/strange** flavor dependence in this region

Underlying event description **needed/enough** for production of hadrons in intermediate p_T region ?

Predictions from EPOS based on pomeron exchanges can lead to much higher ratios

Summary and Conclusion

First physics in the soft region will be exciting at the LHC

- most measurements will complement the RHIC ones;
- many will help understanding further particle production and defining the bulk properties of the created matter.

Couple of slides were added due to this week discussions :-)

- hopefully they helped more than they added confusion;
- some other were removed...
- cool if they lead to even more discussion.