# Status of the
# LHC ALICE experiment
# http://cernblog.wordpress.com/

**P. Lévai**
**KFKI RMKI, Budapest, Hungary**

**Zimányi Winter School**
**3 December 2009, Budapest, Hungary**

## Content:

1. (Re)Starting LHC in 2009, plans for 2009

2. Activities of the Hungarian ALICE Group in 2009

3. The First Physics Paper of ALICE on rapidity density

4. Could we see 'QGP' in pp collisions at LHC energies?

5. Conclusion

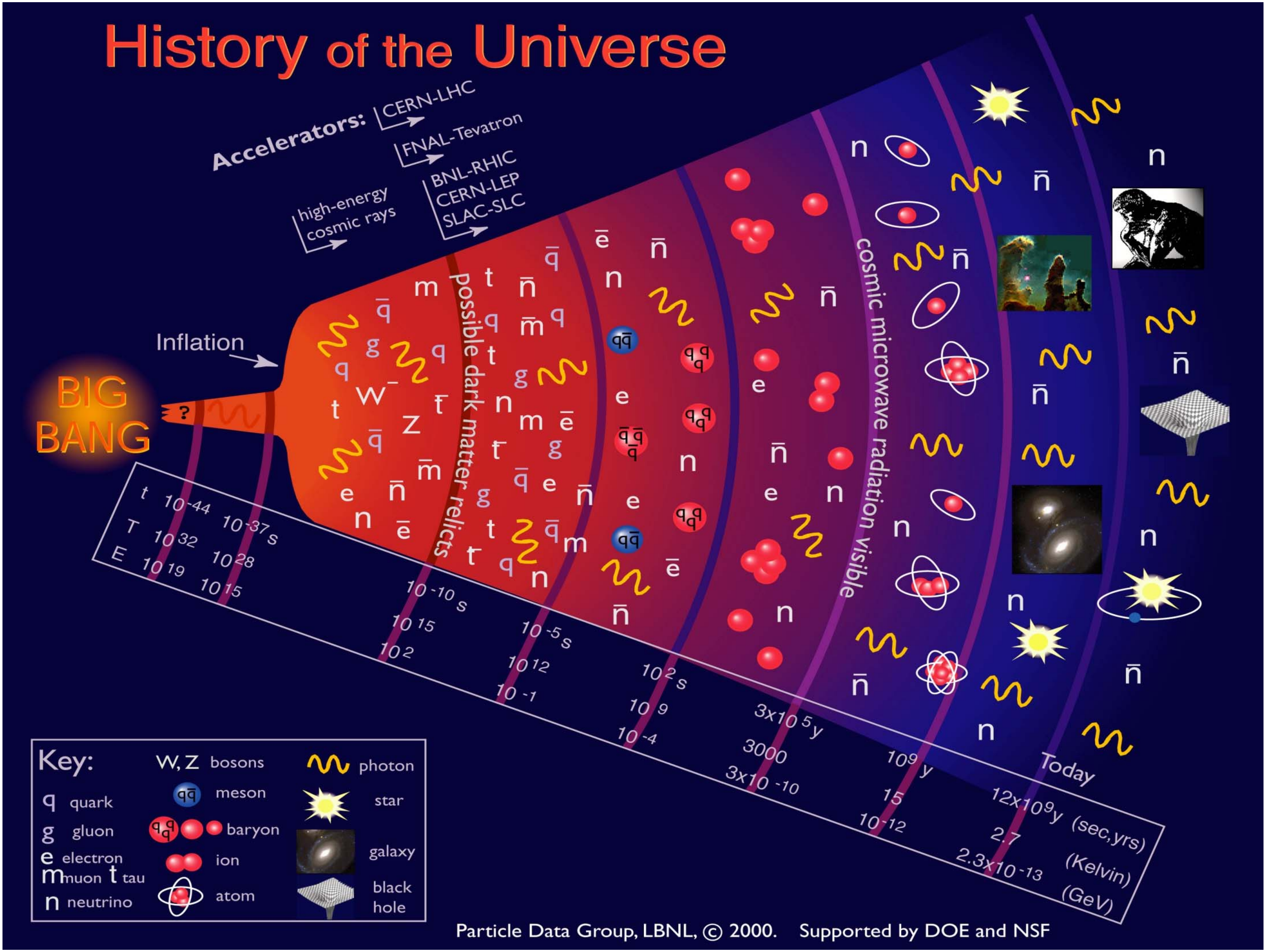
# LHC:

**p+p in 2009**

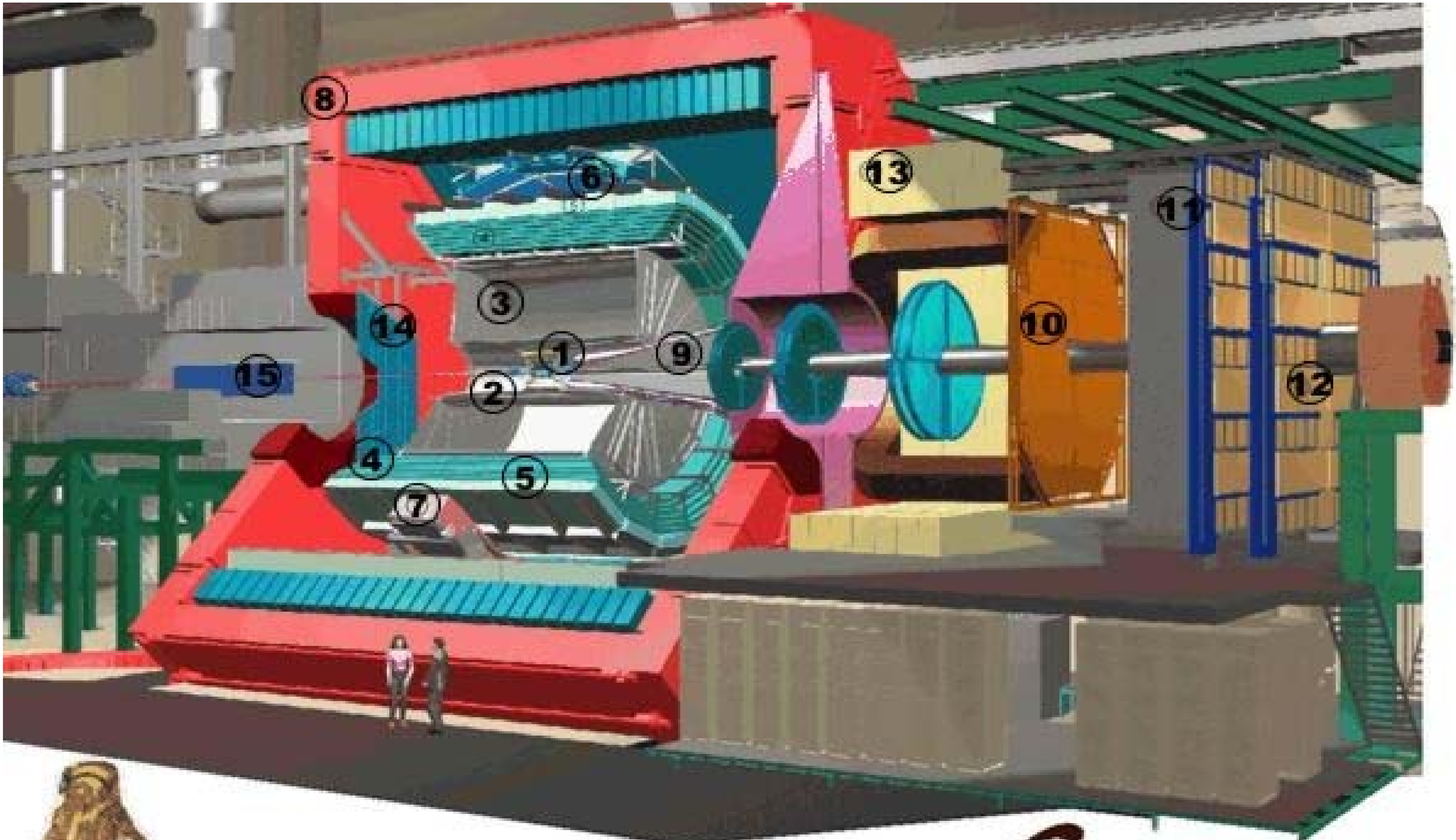
**Pb+Pb in 2010 !?**



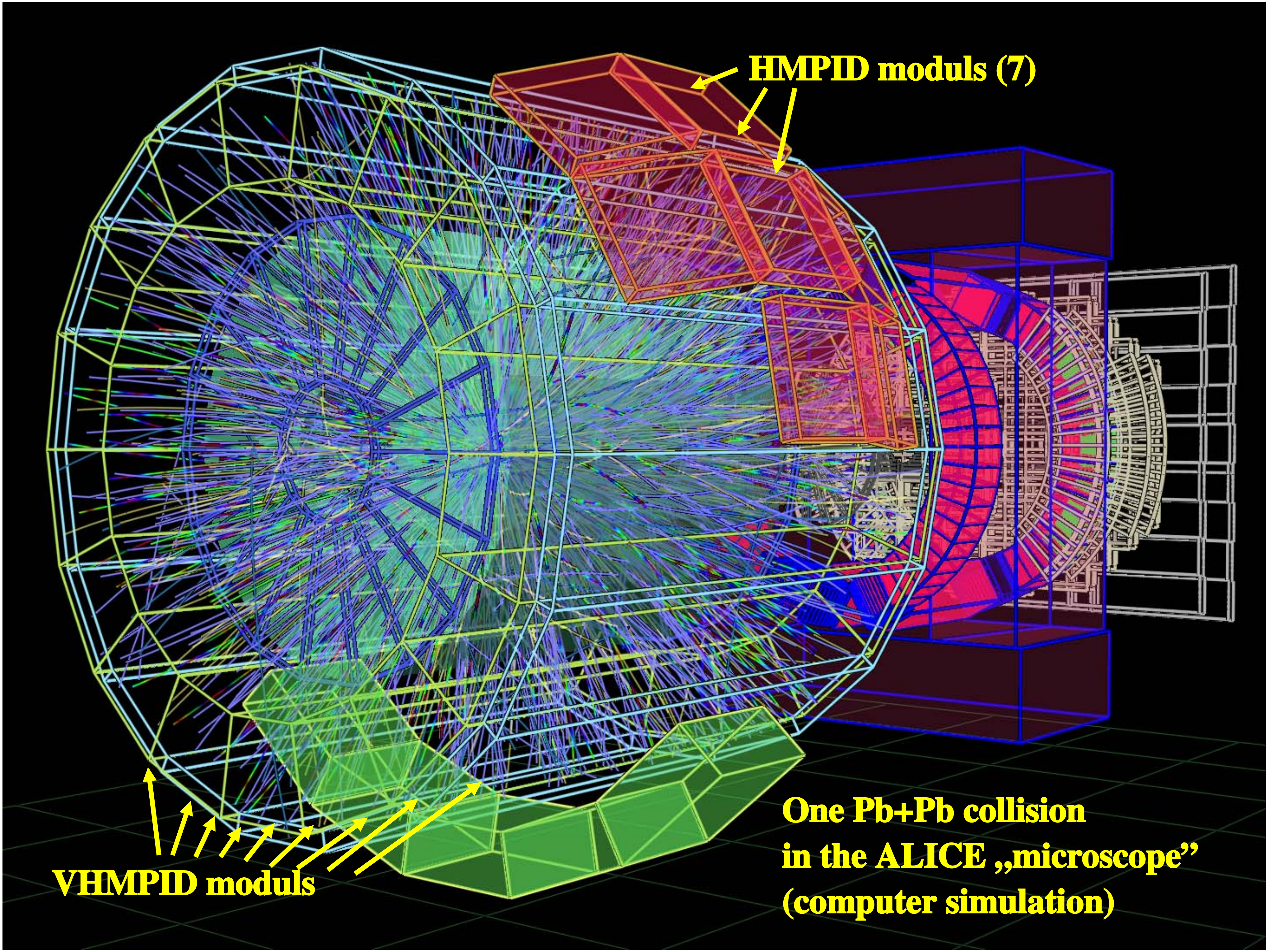
| Central collisions | SPS | RHIC | LHC |
|---|---|---|---|
| $\sqrt{s}$ (GeV) | 17 | 200 | 5500 |
| $dN_{ch}/dy$ | 430 | 700 | $1\text{-}3\times10^3$ |
| $\varepsilon$ (GeV/fm$^3$) | 3 | 5-10 | 15- 60 |
| $V_f$(fm$^3$) | $10^3$ | $7\text{x}10^3$ | $2\text{x}10^4$ |
| $T / T_c$ | > 1 | 2 | 3-4 |



History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37 s
T 10 32 10 28
E 10 19 10 15
10 -10 s
10 15
10 2
10 -5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
10 9 y
15
10 -12
Today
12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF




# Alice

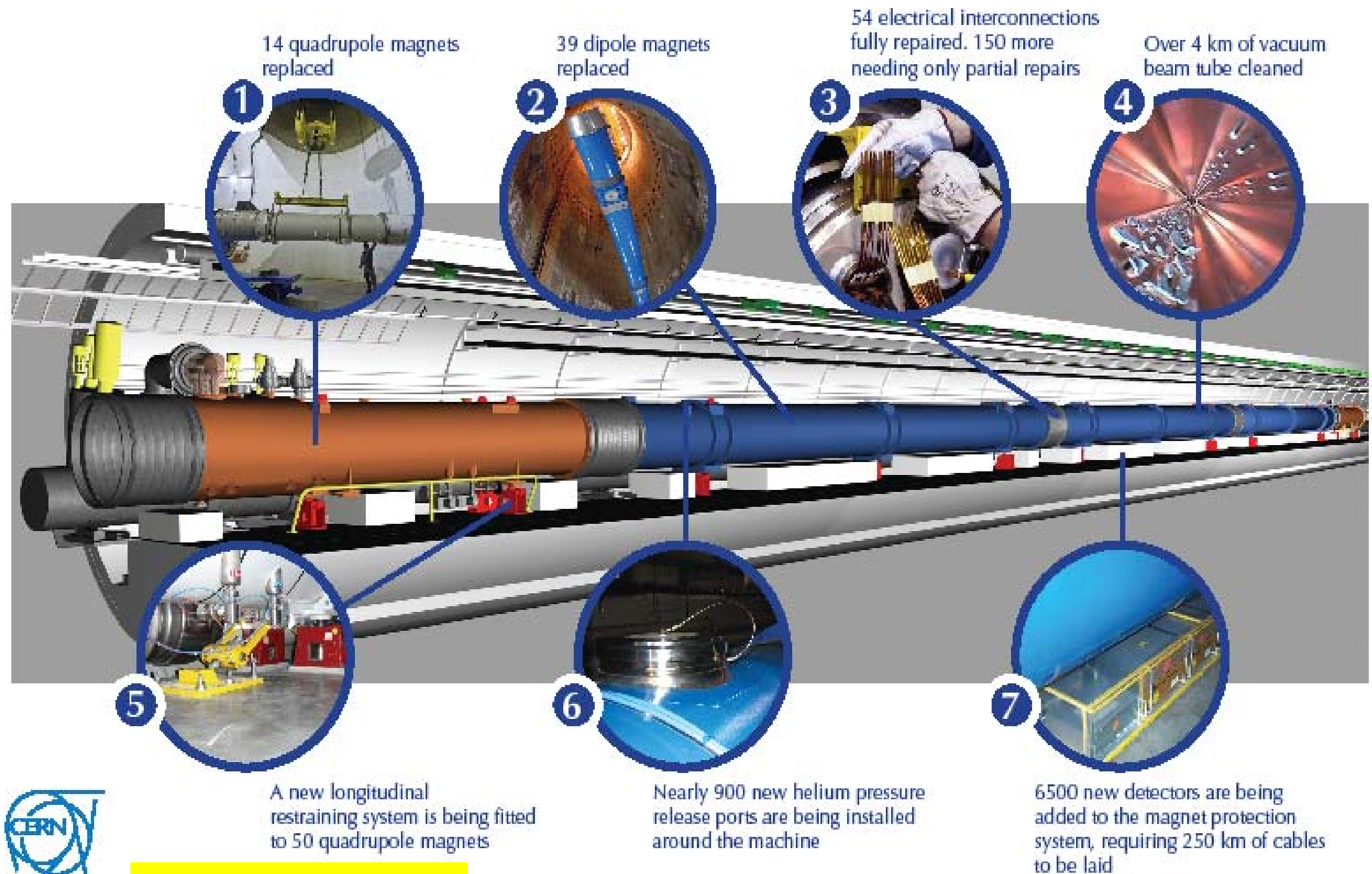

HMPID moduls (7)
VHMPID moduls
One Pb+Pb collision
in the ALICE „microscope"
(computer simulation)

## *1. (Re)Starting LHC in 2009 October/November*

| | |
|---|---|
| **0. September 19. 2008** | **Technical failure in Sector 34**<br>**Few extra nanoohms appeared in one connection**<br>**Sparks, electric failure, leakage of helium**<br>**Shut-down for 14 months** |
| **1. July-August 2009** | **Cosmic tests at ALICE** |
| **2. October 23, 2009** | **LHC was cooled down to 1.9 K (all 27 km)**<br>**Injection tests (p).**<br>**Beam dump before ALICE.**<br>**First Pb ions at ALICE !** |

Phase 1 +2

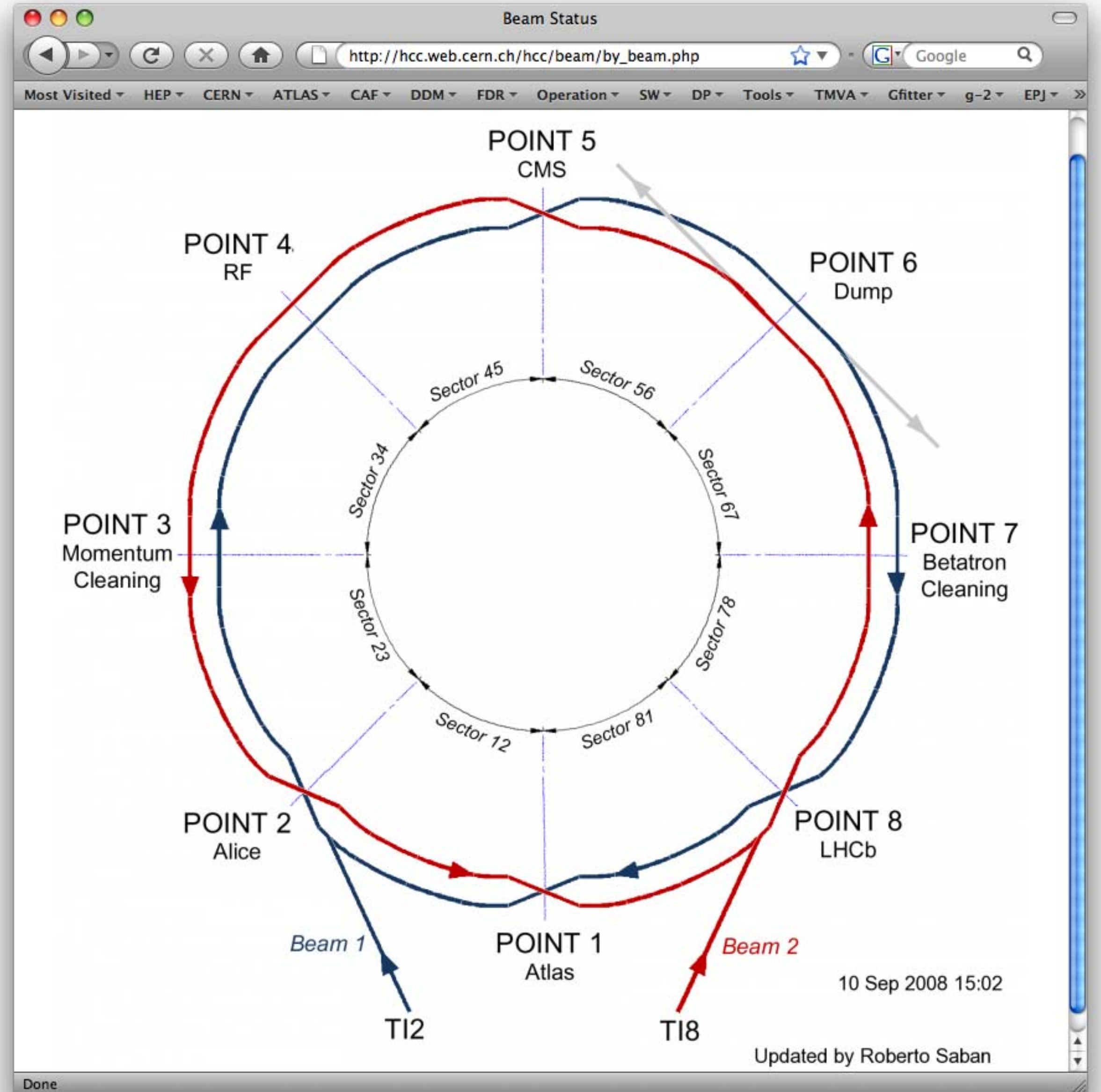
# The LHC repairs in detail




+ cryogenics!

**Myers, 26 Nov. 2009.**

# Operations with Beam



# Plans in the mid-November 2009 (J. Rak, ALICE)

## Timetable

| | | |
|---|---|---|
| | • July 10th - 13th 2009 | T12 to TED extraction test |
| | • September 25th - 26th 2009 | TI2-TI8 to TED extraction test |
| | • August - October 2009 | **Cosmics** |
| | • October 21st | short TED splash event test |
| | • October 23th-26th 2009 | TI2 injection test, beam (first HI) through ALICE |
| | • November 7th - 8th | Second injection test - HWC permitting |
| Today | • Today | daily planning (xlsx) running partition archive week 33-43 |
| | • **November 19th-20th** | **First circulating beam** |
| | • November-December 2009 | $\sqrt{s}$ = 0.9 and 2.2 - 7 TeV p+p |
| | • December 17th - January 7th | Xmass break |
| | • January - September 2010 | $\sqrt{s}$ = 2.2 - 7.0 - 10 TeV p+p |
| | • October 2010 | $\sqrt{s}$ = 3.9 TeV Pb+Pb |

# Friday November 20

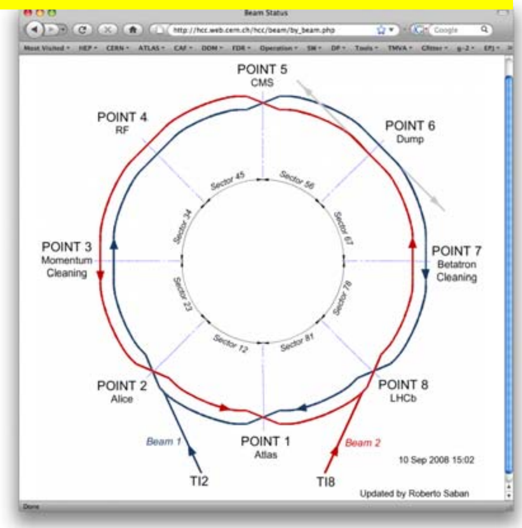
**Myers' talk**

## 18:30 Beam 1

- 19.00 beam through CMS (23, 34, 45)
  - beam1 through to IP6 19.55 Starting again injection of Beam1
  - corrected beam to IP6, 7, 8, 1
- 20.40 Beam 1 makes 2 turns

2h10 for 27km: 12.5km/h average speed

  - Working on tune measurement, orbit, dump and RF
  - Beam makes several hundred turns (not captured)
    - Integers 64 59, fractional around .3 (Qv trimmed up .1)
- 20.50 Beam 1 on beam dump at point 6
- 21.50 Beam 1 captured

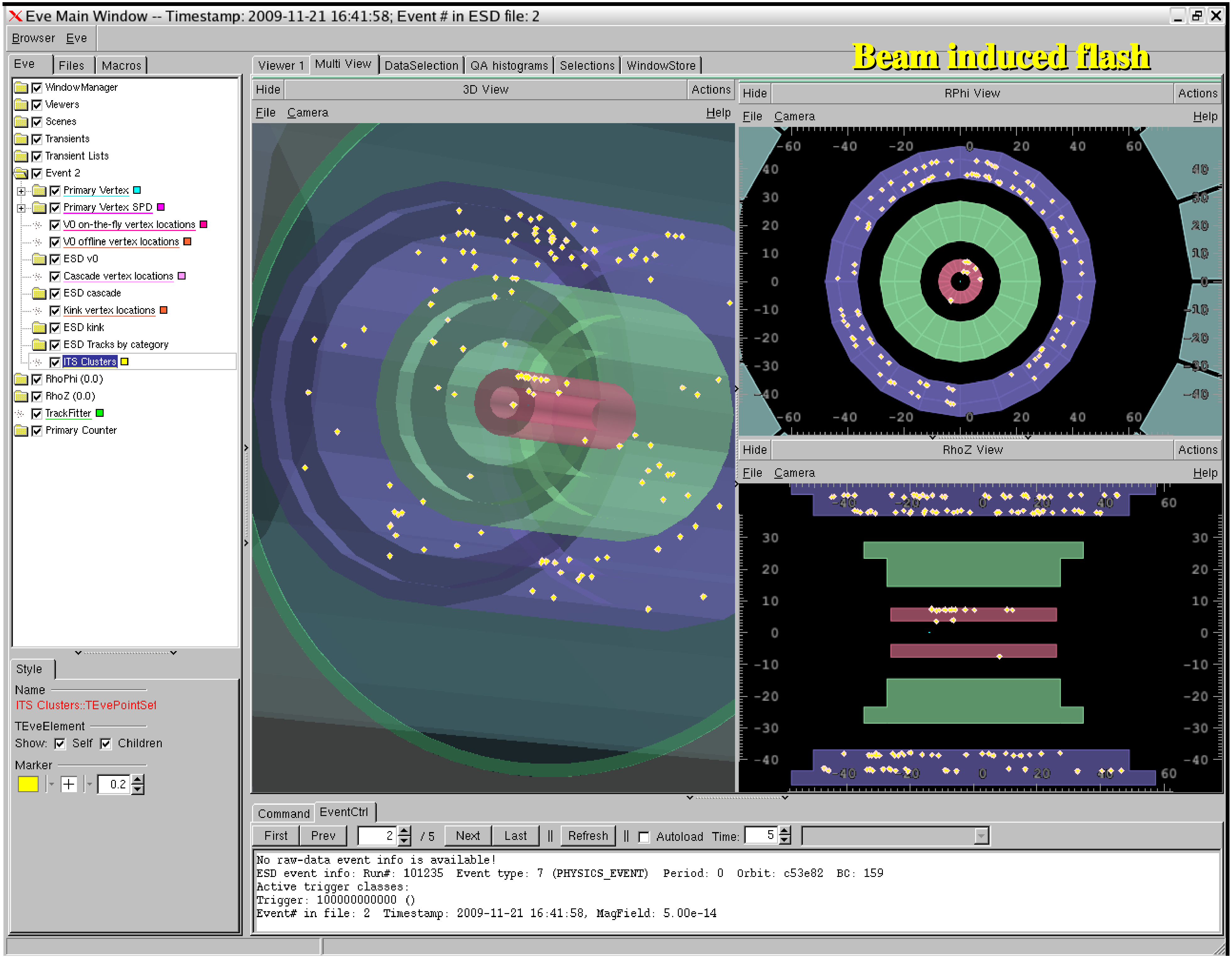



## 22:15 Beam2

- 23.10 Start threading Beam2
  - Round to 7 6 5 2 1
- 23.40 First Turn Beam2
  - Working on tune measurer

1h25 for 27km: a bit faster

  - Beam makes several hundred turns (not captured)
    - Integers 64 59, fractional around .3 (Qv trimmed up .05)
- 24.10 Beam 2 captured


Eve Main Window -- Timestamp: 2009-11-21 16:41:58; Event # in ESD file: 2
Beam induced flash
3D View
RPhi View
RhoZ View
ITS Clusters::TEvePointSet
No raw-data event info is available!
ESD event info: Run#: 101235 Event type: 7 (PHYSICS_EVENT) Period: 0 Orbit: c53e82 BC: 159
Active trigger classes:
Trigger: 100000000000 ()
Event# in file: 2 Timestamp: 2009-11-21 16:41:58, MagField: 5.00e-14

# Monday afternoon – 23 November

- **Both beams circulating in LHC. Hands off by OP for half an hour.**
- Transverse Steering into collision using BPMs through 1 and 5.
  - **Hands off by OP for half an hour**

- **Recorded collision events in ATLAS and CMS**

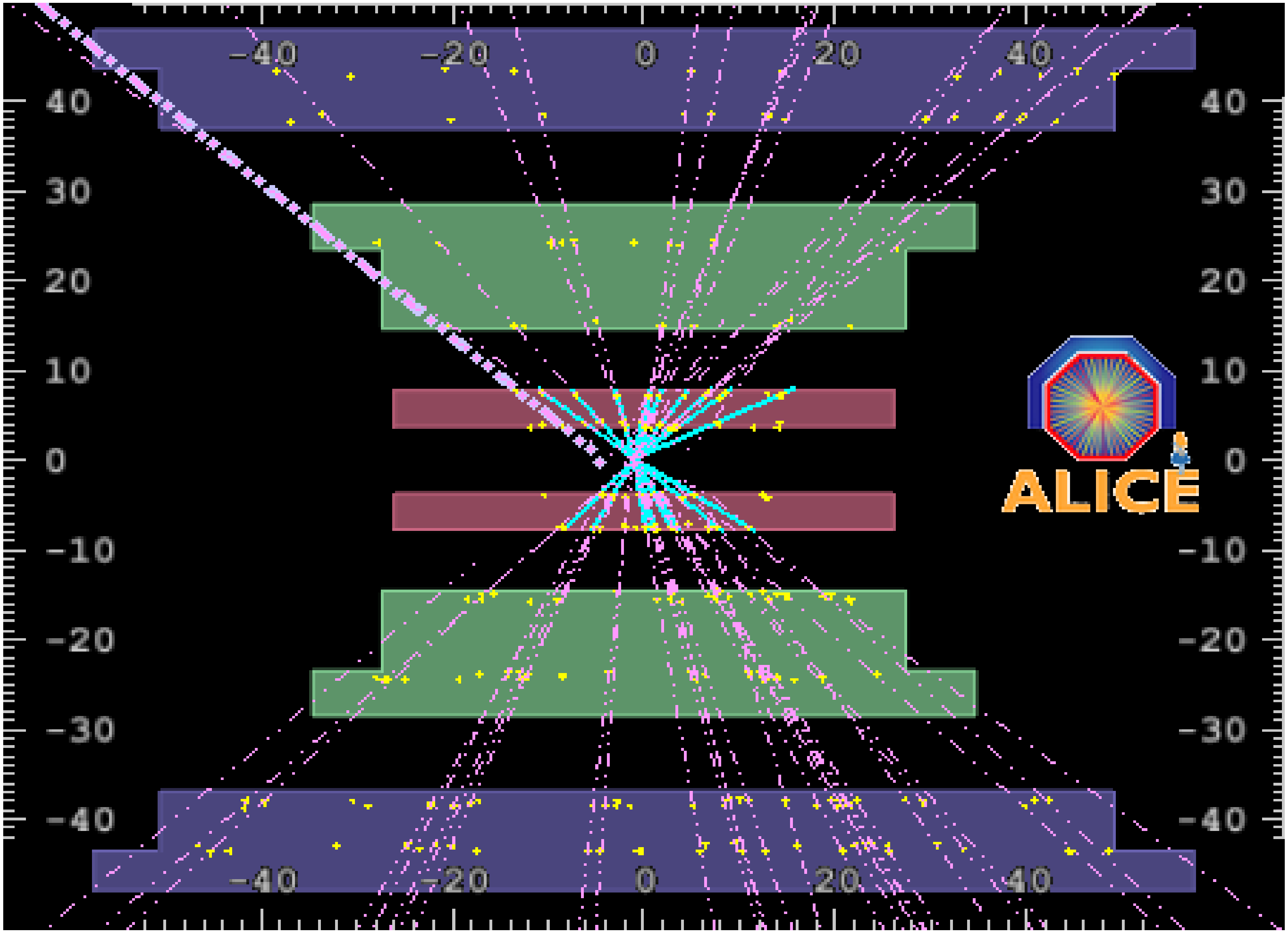
- From 16:00
  - Two beams in LHC at buckets 1 and 8911
  - **Quiet beams for ALICE**
  - Then 2 beams in LHC at buckets 1 and 26701
  - **Quiet beams for LHCb**

**20 minutes, 284 pp on tape !**

- **Recorded collision events in ALICE and LHCb**

- From 19.00
  - Beam 2 back in bucket 1
  - 2 beams in for collimation set up
  - Quickly steer IR5 (with new knob) and IR1
  - **Quiet beams for 15' for CMS and ATLAS**

## November 23 2009 --- ALICE ( real pp event)



## 2. Activities of the Hungarian ALICE Group in 2009

**The Hungarian ALICE group in Dec. 2009:** **Lévai P. team leader(2005)**

**Molnár L.** **Barnaföldi GG** **Dénes E.** **Boldizsár L.** **Futó E.**

**Csizmadia P.**

**Agócs A.G.*** **Hamar G.*** **Pochybova S.***

**Pálla G., Fodor Z., Tölyhi T.*,**
**Lipusz Cs., Berényi D.*, Nagy M.F.***

**Bencze Gy.** **Varga D.**

## The mission of the Hungarian ALICE Group

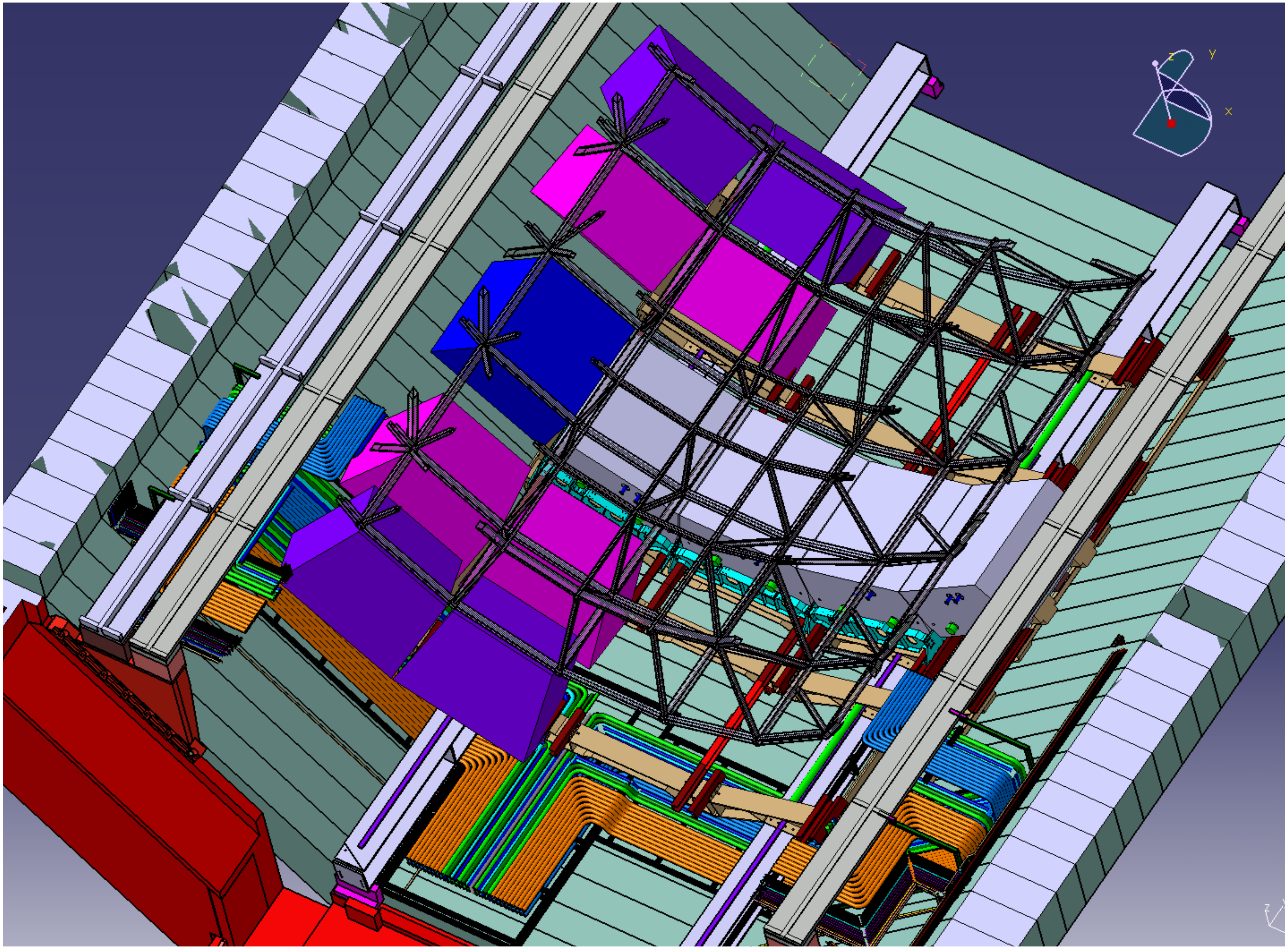
**High-pT physics (PWG4), participation in the following tasks:**

--- PID of high-pT hadrons (charged pions, kaons, protons, antip);
--- one-particle spectra, energy-loss of high-pT hadrons;
--- jet-reconstruction, jet-analysis;
--- separation of quark and gluon jets, 3-jet events; ➣ S. Pochybova
--- underlying events in pp collisions, collectivity; ➣ A.G. Agócs
--- jet shape analysis (pp vs. PbPb);
--- hadron-hadron correlation (near-side, away-side);
--- ...

**Direct contribution to the LHC ALICE:**

➣ L. Boldizsár
--- HMPID detector maintenance, data collection, analysis;
--- VHMPID detector R&D (2012), construction (2014) ➣ G. Hamar
--- DAQ maintenance and R&D for upgrade
--- ALICE GRID RMKI station maintenance and upgrade ➣ Nagy MF

# The recent plan for the VHMPID Upgrade (2014)



**Why do we need PID between $p_T$ = 5-20 GeV/c ?**

1. , K, p yields in this $p_T$ region (one-particle spectra)

   data from RHIC, proton/pion anomaly

   challenge for theory: soft + quark coalescence + pQCD

   particle production mechanisms

   deeper knowledge on FF

   jet energy loss, flavor dependence

2. Near-side hadron-hadron correlations (two-particle spectra)

   B-M ( -p) and B-aB (p-ap) correlations at RHIC

   Parton-showers, dFFs ($D_B$*$D_M$, $D_B$*$D_{aB}$, or $D_{BM}$, ... ?)

   Triple-, 4-particle FFs ? In-matter modifications?

   Jet energy loss: volume or surface effect?

3. Away-side hadron-hadron correlations

   Size and influence of $k_T$-imbalance + in-matter effects

4. Hadronic decay channels of D-, B-mesons, $_c$, $_b$-baryons

5. Further motivations ...

## *LHC properties:*

| | *pp at 14 TeV* | *PbPb at 5500 AGeV* |
|---|---|---|
| Luminosity: | $3 \cdot 10^{30}$ cm$^{-2}$ s$^{-1}$ | $5 \cdot 10^{26}$ cm$^{-2}$ s$^{-1}$ |
| Time: | $10^{7}$ sec | $10^{6}$ sec |
| $\int L dt$: | $3 \cdot 10^{37}$ cm$^{-2}$ | $5 \cdot 10^{32}$ cm$^{-2}$ |
| $N_{coll}$: | $2 \cdot 10^{12}$ | $2 \cdot 10^{9}$ |
| Hadron trigger: | $2 \cdot 10^{9}$ collisons | $2 \cdot 10^{7}$ central PbPb |

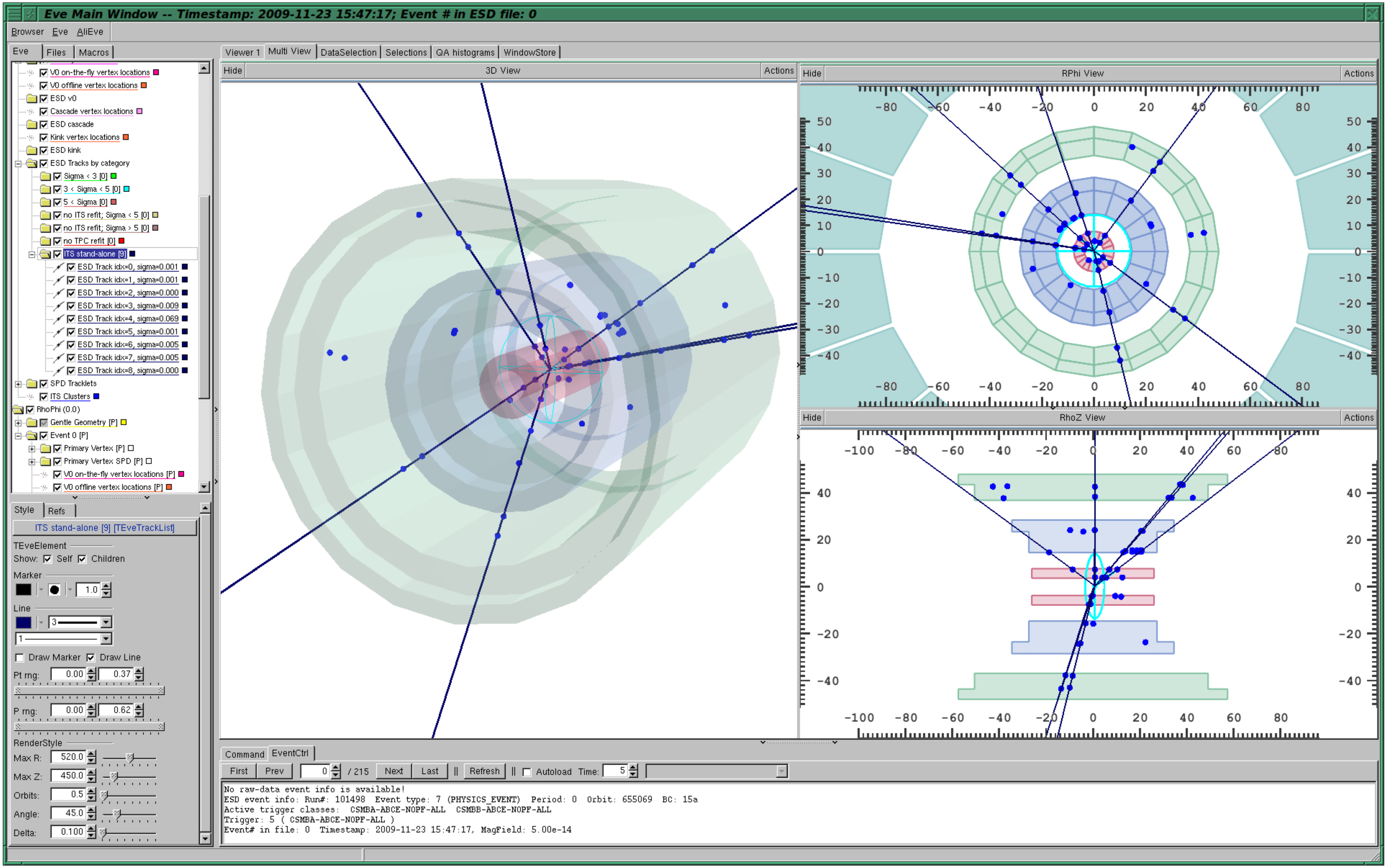
**How far can we reach with these luminosities?**

**$dN_{ch}/dy$ and/or high-$p_T$**

**Simulations are very important (essential) !**

## 3. The First Physics Paper of ALICE on rapidity density

# Combined real p+p collision events in ALICE at 900 GeV (284 events)



# First phyiscs paper of ALICE - ArXiv: 0911.5430

**Submitted to European Physical Journal C on 27 November 2009**
**Accepted for publication at EPJ C on 30 November 2009**

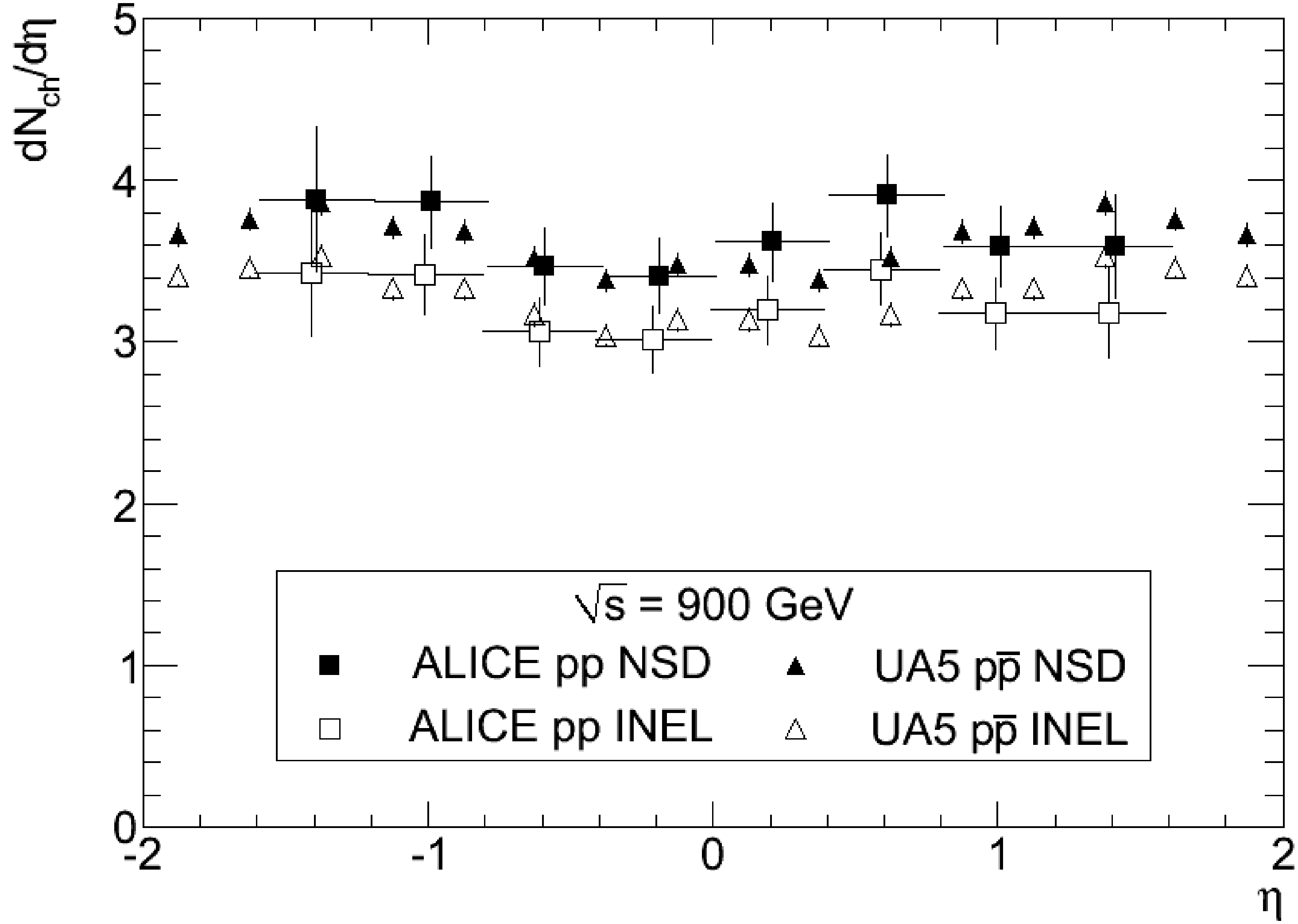
## First proton–proton collisions at the LHC as observed with the ALICE detector: measurement of the charged particle pseudorapidity density at $\sqrt{s} = 900$ GeV


**ALICE collaboration**

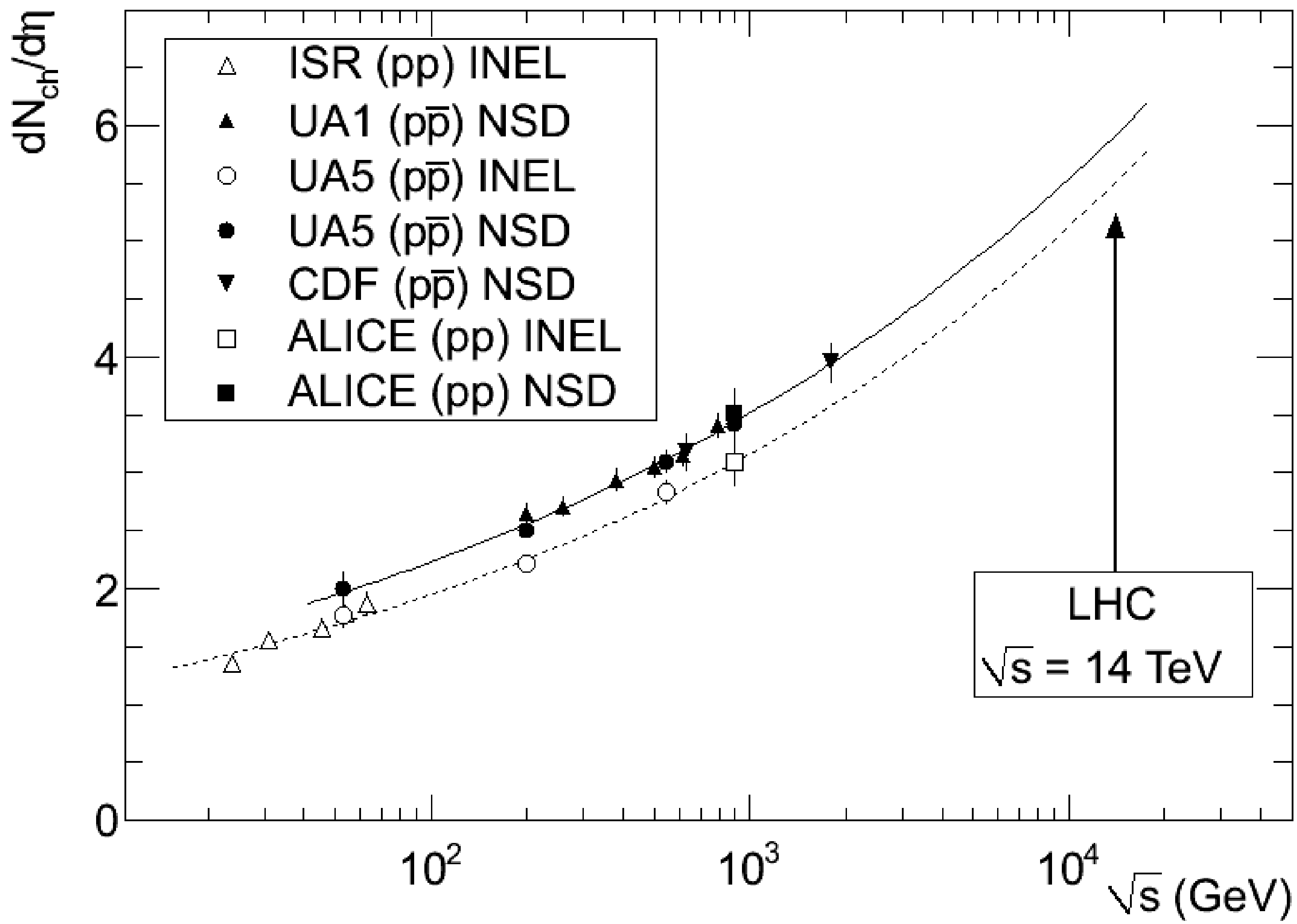
K. Aamodt[78], N. Abel[43], U. Abeysekara[30], A. Abrahantes Quintana[42], A. Acero[63], D. Adamová[86], M.M. Aggarwal[25], G. Aglieri Rinella[40], A.G. Agocs[18], S. Aguilar Salazar[63], Z. Ahammed[55], A. Ahmad[2], N. Ahmad[2], S.U. Ahn[50a], R. Akimoto[100], A. Akindinov[68], D. Aleksandrov[70], B. Alessandro[102], R. Alfaro Molina[63], A. Alici[13], E. Almaráz Aviña[63], J. Alme[8], T. Alt[43b], V. Altini[6], S. Altinpinar[32], C. Andrei[17], A. Andronic[32], G. Anelli[40], V. Angelov[43c], C. Anson[27], T. Antičić[113], F. Antinori[40d], S. Antinori[13], K. Antipin[37], D. Antończyk[37], P. Antonioli[14], A. Anzo[63], L. Aphecetche[76], H. Appelshäuser[37], S. Arcelli[13], R. Arceo[63], A. Arend[37], N. Armesto[92], R. Arnaldi[102], T. Aronsson[74], I.C. Arsene[78e], A. Asryan[98], A. Augustinus[40], R. Averbeck[32], T.C. Awes[76], J. Äystö[49], M.D. Azmi[2], S. Bablok[8], M. Bach[36], A. Badalà[24], Y.W. Baek[50f], S. Bagnasco[102], R. Bailhache[32g], R. Bala[101], A. Baldisseri[89], A. Baldit[26], J. Bán[88], R. Barbera, G.G. Barnaföldi[18], L. Barnby[12], V. Barret[26], J. Bartke[29], F. Barile[6], M. Basile[13], V. Basmanov[94], N. Bastid[26], B. Bathen[72], G. Batigne[76], B. Batyunya[35], C. Baumann[72h], I.G. Bearden[28], H. Becker[32i], I. Belikov, R. Bellwied[34], E. Belmont-Moreno[63], A. Belogianni[4], L. Benhabib[76], S. Beolé[101], I. Berceanu[17], A. Bercuci[32i], E. Berdermann[32], Y. Berdnikov[39], L. Betev[40], A. Bhasin[48], A.K. Bhati[25], L. Bianchi[101], N. Bianchi[38], C. Bianchin[79], J. Bielčík[81], J. Bielčíková[86], A. Bilandzic[3], L. Bimbot[77], E. Biolcati[101], A. Blanc[26], F. Blanco[23k], F. Blanco[63], D. Blau[70], C. Blume[37], M. Boccioli[40], N. Bock[27], S. Böttger[43], A. Bogdanov[69], H. Bøggild[28], M. Bogolyubsky[83], J. Bohm[96], L. Boldizsár[18], M. Bombara[121], C. Bombonati[79m], M. Bondila[49], H. Borel[89], V. Borshchov[51], C. Bortolin[79], S. Bose[54], L. Bosisio[103], F. Bossú[101], M. Botje[3], S. Bourdaud[76], B. Boyer[77], M. Braun[98], P. Braun-Munzinger[32,33n], L. Bravina[78], M. Bregant[103o], T. Breitner[43], G. Bruckner[40], R. Brun[40], E. Bruna[74], G.E. Bruno[6], D. Budnikov[94], H. Buesching[37], K. Bugaev[62], P. Buncic[40], O. Busch[44], Z. Buthelezi[22], D. Caffarri[79], X. Cai[111], H. Caines[74], E. Camacho[64], P. Camerini[103], M. Campbell[40], V. Canoa Roman[40], G.P. Capitani[38], G. Cara Romeo[14], F. Carena[40], W. Carena[40], F. Carminati[40], A. Casanova Díaz[38], M. Caselle[40], J. Castillo Castellanos[89], J.F. Castillo Hernandez[32], V. Catanescu[17], E. Cattaruzza[103], C. Cavicchioli[40], P. Cerello[102], V. Chambert[77], B. Chang[96], S. Chapeland[40], A. Charpy[77], J.L. Charvet[89], S. Chattopadhyay[54], S. Chattopadhyay[55], M. Cherney[30], C. Cheshkov[40], B. Cheynis[62], E. Chiavassa[101], V. Chibante Barroso[40], D.D. Chinellato[21], P. Chochula[40], K. Choi[85], M. Chojnacki[108], P. Christakoglou[108], C.H. Christensen[28], P. Christiansen[61], T. Chujo[106], F. Chuman[45], C. Cicalo[20], L. Cifarelli[13], F. Cindolo[14], J. Cleymans[21], O. Cobanoglu[101], J.-P. Coffin[99], S. Coli[102], A. Colla[40], G. Conesa Balbastre[38], Z. Conesa del Valle[75p], E.S. Conner[110], P. Constantin[44], G. Contin[103q], J.G. Contreras[64], Y. Corrales Morales[101], T.M. Cormier[34], P. Cortese[1], I. Cortés Maldonado[84], M.R. Cosentino[21],


**A.G. Agócs, G.G. Barnaföldi, L. Boldizsár, E. Dénes, Z. Fodor, G. Hamar, P. Lévai, L. Molnár, S. Pochybova, T. Tölyhi --- from MTA KFKI RMKI**

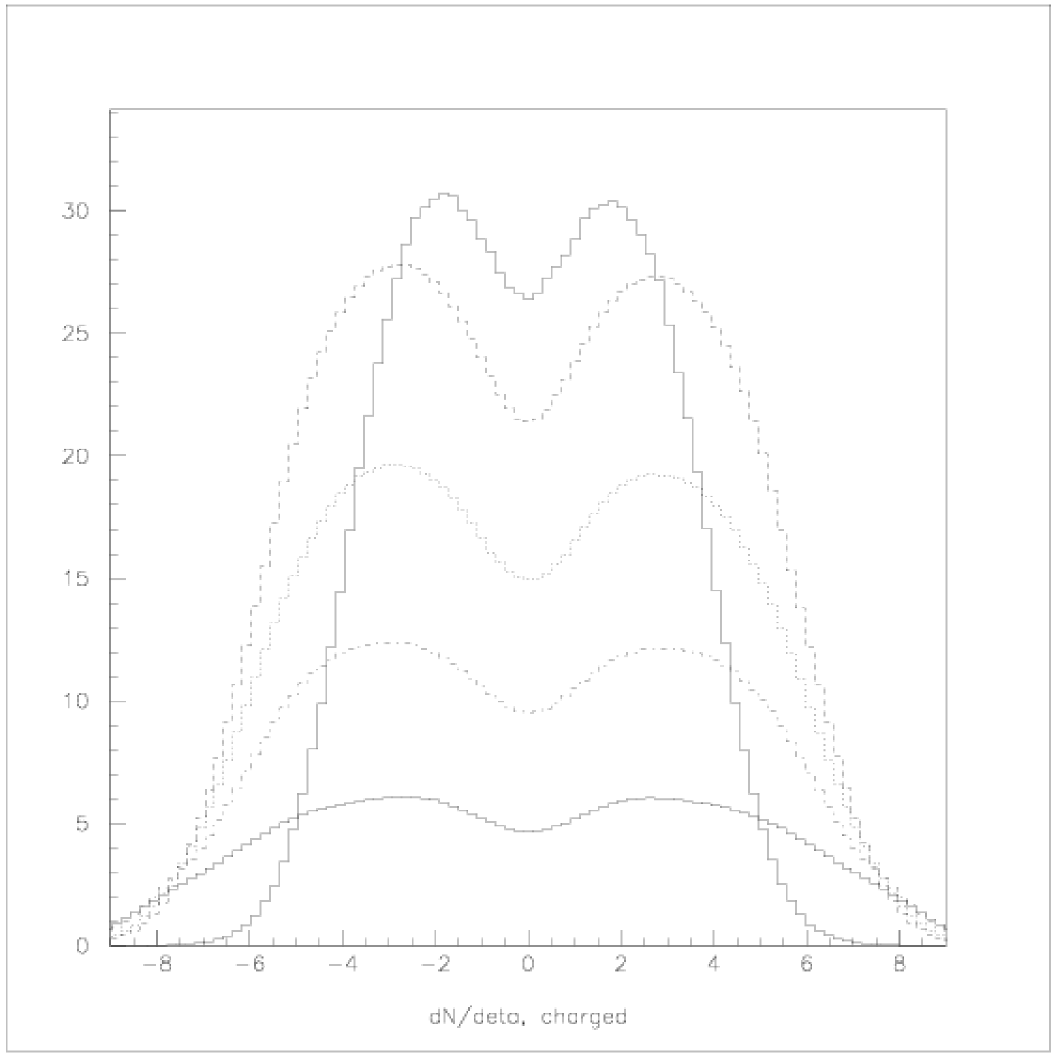
# First phyiscs paper of ALICE - ArXiv: 0911.5430



# First phyiscs paper of ALICE - ArXiv: 0911.5430

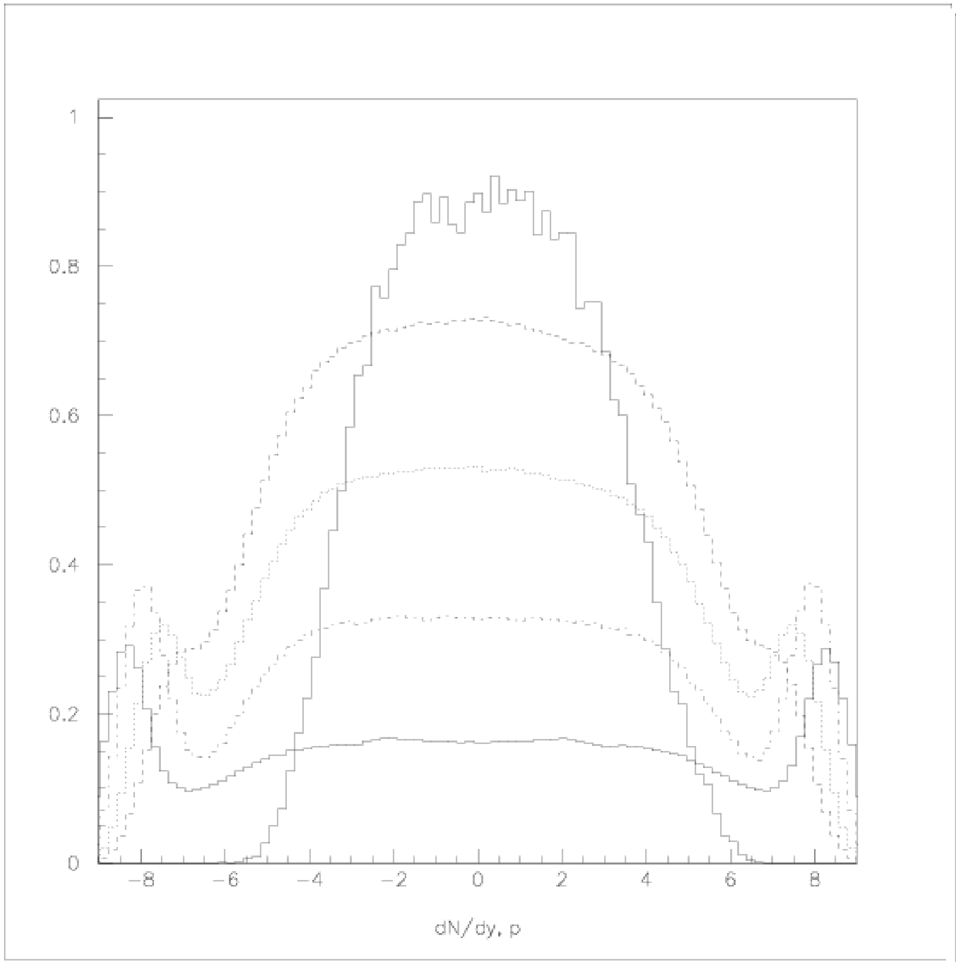


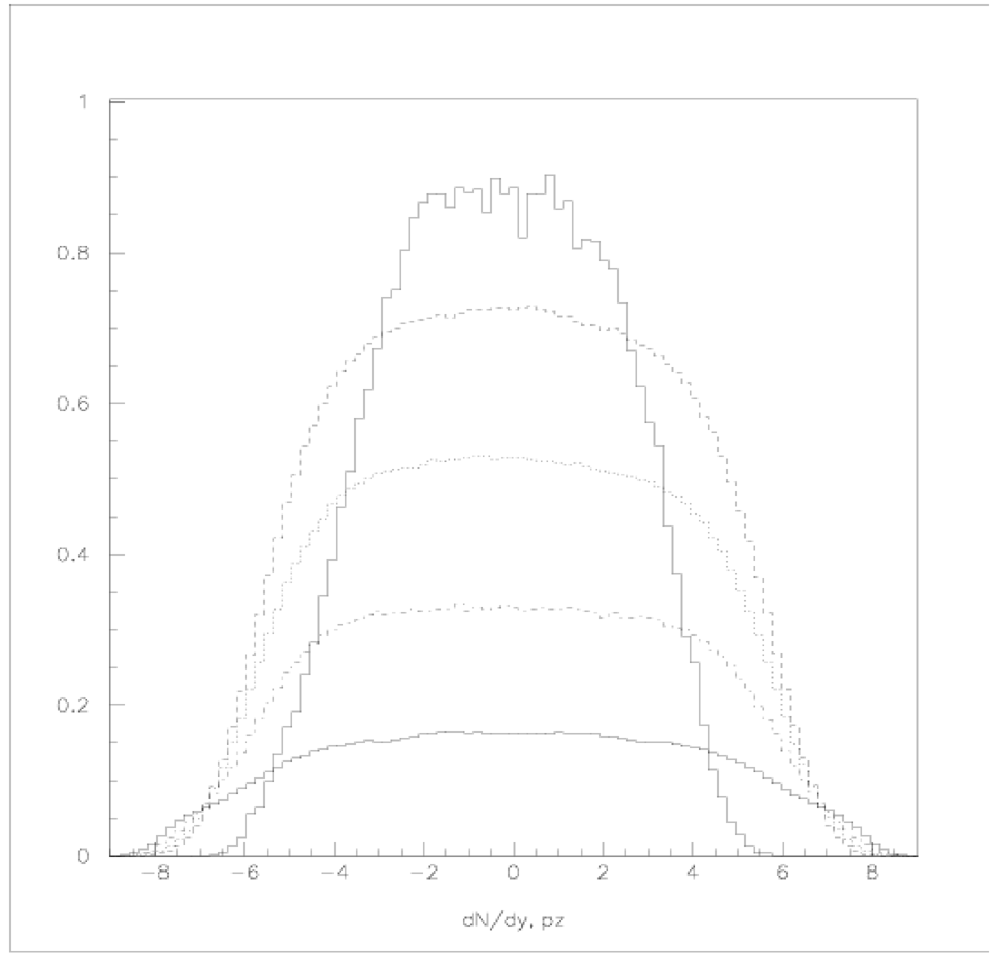
# p+p at 14 TeV HIJING-BB simulation, minijets: 1,3,5,7,10




Topor Pop, LP, 2009.

## p+p at 14 TeV HIJING-BB simulation, minijets: 1,3,5,7,10




**proton dN/dy**

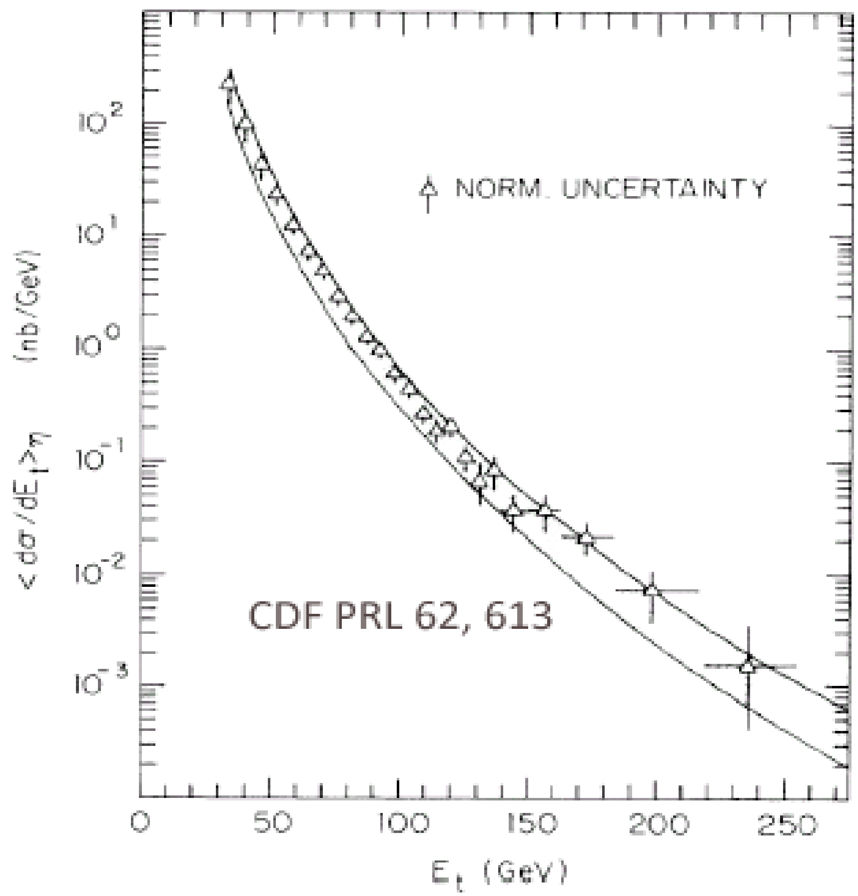
**antiproton dN/dy**

**Topor Pop, LP, 2009.**

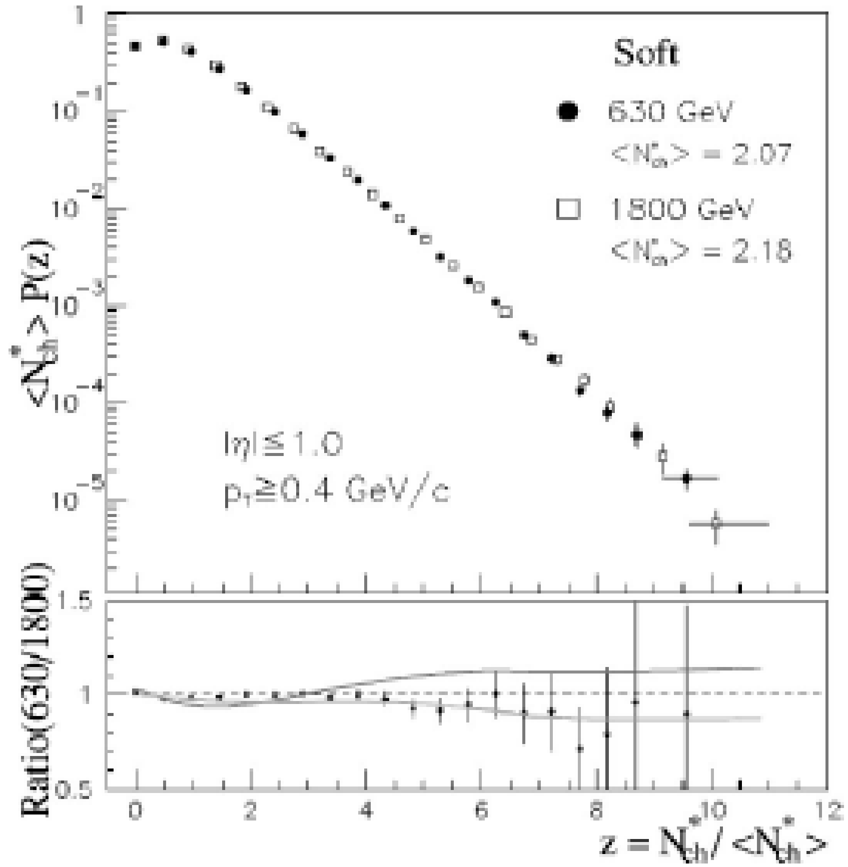
## 4. Could we see 'QGP' in pp collisions at LHC energies?

***Proton-antiproton collisions at FERMILAB, √s = 630 GeV, 1.8 TeV***

**CDF, PRL62, 613**




**CDF, PRD65, 072005, 2001**




**Jet-physics for $E_T \le 250$ GeV**

**High multiplicity events**
**$dN_{ch}/dy \le 10$**

# Proton-antiproton collisions at FERMILAB, $\sqrt{s} = 1.8$ TeV

## E735 Collaboration, ..., L. Gutay, ..., S. Oh, ...

## QM 1992, Gatlinburg

Nuclear Physics A544 (1992) 343c-356c
North-Holland, Amsterdam

NUCLEAR
PHYSICS A

### RESULTS FROM E735 AT THE TEVATRON PROTON-ANTIPROTON COLLIDER WITH $\sqrt{s} = 1.8$ TeV

Clark S. Lindsey

Fermilab, P.O. Box 500, Batavia, Illinois 60510, U.S.A.

For the E735 Collaboration:
T. Alexopoulos[7], C. Allen[6], E.W. Anderson[4], V. Balamurali[5], S. Banerjee[5], P.D. Beery[6], P. Bhat[3], N.N Biswas[5], A. Bujak[6], D.D. Carmony[6], T. Carter[2], F. Cole[6], Y. Choi[6], R. DeBonte[6], V. DeCarlo[1], A.R. Erwin[7], C. Findeisen[7], A.T. Goshaw[2], L.J. Gutay[6], A.S. Hirsch[6], C. Hojvat[3], J.R. Jennings[7], V.P. Kenny[5], C.S. Lindsey[3], C. Loomis[2], J.M. LoSecco[5], T. McMahon[6], A.P. McManus[5], N. Morgan[6], K. Nelson[7], S.H. Oh[2], N.T. Porile[6], D. Reeves[3], A. Rimai[6], W.J. Robertson[2], R.P. Scharenberg[6], B.C. Stringfellow[6], S.R. Stampke[5], M. Thompson[7], F. Turkot[3], W.D. Walker[2], C.H. Wang[4], J. Warchol[5], D.K. Wesson[3], Y. Zhan[6]

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(4) Department of Physics, Iowa State University, Ames, IA 50011
(5) Department of Physics, University of Notre Dame, Notre Dame, IN 46556
(6) Department of Physics and Chemistry, Purdue University, W. Lafayette, IN 47907
(7) Department of Physics, University of Wisconsin, Madison, WI 53706

**Abstract**

Experiment E735* searched for evidence of the transition to quark-gluon plasma in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. Using data from a high statistics run in 1988-1989, results are presented on multiplicity distributions, hyperon and phi production, and Bose-Einstein correlations. Some data were also taken at lower collision energies and results will be compared to previous experiments.

## 1. INTRODUCTION

# Proton-antiproton collisions at FERMILAB, $\sqrt{s} = 1.8$ TeV

## E735 Collaboration, ..., L. Gutay, ..., S. Oh, ...

## QM 1992, Gatlinburg

Nuclear Physics A544 (1992) 343c-356c
North-Holland, Amsterdam

NUCLEAR PHYSICS A

RESULTS FROM E735 AT THE TEVATRON PROTON-ANTIPROTON COLLIDER WITH $\sqrt{s} = 1.8$ TeV

Clark S. Lindsey

Fermilab, P.O. Box 500, Batavia, Illinois 60510, U.S.A.

For the E735 Collaboration:
T. Alexopoulos[7], C. Allen[6], E.W. Anderson[4], V. Balamurali[5], S. Banerjee[5], P.D. Beery[6], P. Bhat[3], N.N Biswas[5], A. Bujak[6], D.D. Carmony[6], T. Carter[2], F. Cole[6], Y. Choi[6], R. DeBonte[6], V. DeCarlo[1], A.R. Erwin[7], C. Findeisen[7], A.T. Goshaw[2], L.J. Gutay[6], A.S. Hirsch[6], C. Hojvat[3], J.R. Jennings[7], V.P. Kenney[5], C.S. Lindsey[3], C. Loomis[2], J.M. LoSecco[5], T. McMahon[6], A.P. McManus[5], N. Morgan[6], K. Nelson[7], S.H. Oh[2], N.T. Porile[6], D. Reeves[3], A. Rimai[6], W.J. Robertson[2], R.P. Scharenberg[6], B.C. Stringfellow[6], S.R. Stampke[5], M. Thompson[7], F. Turkot[3], W.D. Walker[2], C.H. Wang[4], J. Warchol[5], D.K. Wesson[3], Y. Zhan[6]

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**Abstract**

Experiment E735[a] searched for evidence of the transition to quark-gluon plasma in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. Using data from a high statistics run in 1988-1989, results are presented on multiplicity distributions, hyperon and phi production, and Bose-Einstein correlations. Some data were also taken at lower collision energies and results will be compared to previous experiments.

1. INTRODUCTION



The proton and lambda $< p_\perp >$ increases with multiplicity, whereas the phi $< p_\perp >$ is flat. The lambda to proton ratio is flat as a function of multiplicity.

Bose-Einstein correlations for two pions indicate an increasing radius and lifetime with increasing multiplicity. The chaoticity decreases with multiplicity.

None of these or previous E735 results give unambiguous signals for QGP formation. For example, one model has shown that the E735 $< p_\perp >$ vs $N_c$ dependencies for pion, kaon, proton and lambda are consistent with transverse flow in a plasma.[26] However, a mini-jet model has also been shown to be consistent with these $< p_\perp >$ distributions.[27] Regardless of whether any clear QGP signal is found, we believe the E735 results place important constraints on any model of soft $p_t$ proton-antiproton physics.

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# Proton-antiproton collisions at FERMILAB, $\sqrt{s}$ = 1.8 TeV

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## Transverse Baryon Flow as Possible Evidence for a Quark-Gluon-Plasma Phase

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In order to investigate the coupling between the collective flow of nucleons and pions in hot pion-dominated hadronic matter, we calculate the pion-nucleon drag coefficient in linearized transport theory. We find that the characteristic time for flow equalization is longer than the time scale of the expansion of a hadronic fireball created in high-energy collisions. The analysis of transverse-momentum data from $p+\bar{p}$ collisions at $\sqrt{s}=1.8$ TeV reveals the same flow velocity for mesons and antinucleons. We argue that this may be evidence for the formation of a quark-gluon plasma in these collisions.

PACS numbers: 25.70.Np, 12.38.Mh, 13.85.Hd

Rather general arguments indicate that the state of high energy density temporarily formed in ultrarelativistic central collisions of nuclei, and possibly even of single hadrons, exhibits approximate local thermal equilibrium and thus can be characterized by a temperature. This scenario is generally supported by the observation that transverse-momentum spectra of emitted particles fall exponentially at high $p_T$. It has often been speculated that a collective outward flow may develop during the expansion and final breakup of the high-density state [1]. The presence of a collective flow would be manifest in a nonthermal shape of the transverse-momentum spectrum. Because the flow velocity is superimposed with the random thermal motion, this effect grows with the mass of the emitted particles, and should be most clearly visible in baryon spectra. So far, experimental evidence for the existence of transverse flow at center-of-mass energies far above 1 GeV/u has been inconclusive [2,3], in contrast to collisions below this energy [4].

Gerber, Leutwyler, and Goity [5] recently showed that the expansion of a dense pion gas, as is formed in the central rapidity region after a highly relativistic nuclear collision, must lead to a rapid transverse flow. Gavin [6] pointed out that the expansion is even so rapid that the

viation from local thermal equilibrium is not too severe. We will now calculate $\delta$ and $\theta$ from first principles.

We assume that the evolution of the phase-space distribution functions $f_i(x,p)$, $i=\pi,N$, of pions and nucleons in the dense hadronic phase is described by the relativistic Boltzmann equation:

$$p^\nu \partial_\nu f_i(x,p) = \sum_j \mathcal{C}_{ij}(x,p)\,. \qquad (3)$$

Here $\mathcal{C}_{ij}$ are the collision terms, which can be calculated from the known cross section for collisions between particles of type $i$ and type $j$. In order to make contact with collective variables, such as the local flow velocity $u^\mu$, it is useful to consider the momentum-space-integrated form of Eq. (3), introducing the energy-momentum tensor $T_i^{\mu\nu}$. Dissipative terms can then be expressed as the failure of the energy-momentum tensor to be locally conserved for each fluid component separately:

$$\partial_\nu T_i^{\mu\nu} = \mathcal{S}_i^\mu \equiv \sum_j \int d\Gamma_p\, p^\mu \mathcal{C}_{ij}(x,p)\,, \qquad (4)$$

where $d\Gamma_p = d^3p/(2\pi)^3 p^0$ is the invariant volume element in momentum space and $\mathcal{S}_i^\mu$ is the covariant dissipation four-vector.

**Hidrodynamical analysis of data for , K, and p (Lévai, Müller PRL, '91)**

# *Proton-antiproton collisions at FERMILAB, $\sqrt{s}$ = 1.8 TeV*



variation of the collective parameters, and will not allow for nonvanishing chemical potentials because we are interested in baryon-symmetric matter. The two fluids then differ only in their collective velocity or in the value of their temperature parameter.

Using the standard expression [9] for the relativistic collision term $\mathscr{C}_{\pi N}$, one obtains the following expression for the dissipation four-vector:

$$\mathscr{S}_N^\mu = \int d\Gamma_p\, d\Gamma_k\, d\Omega\, F_{\pi N} \frac{d\sigma_{\pi N}}{d\Omega} \times p^\mu [f_N(p')f_\pi(k') - f_N(p)f_\pi(k)]\,, \tag{6}$$

where $F_{\pi N}$ is the relativistic flux factor, and $p, p'$ $(k, k')$ are the nucleon (pion) momenta before and after the collision. We now expand the collision term to first order in the difference of the velocities, $\Delta u^\mu = u_N^\mu - u_\pi^\mu$, and the inverse temperature difference, $\Delta\beta = \beta_N - \beta_\pi$, of the two components. Denoting the average velocity and inverse temperature simply by $U^\mu$ and $\beta$, respectively, the first-order contribution becomes

$$\mathscr{S}_N^\mu = (A - B)(\Delta\beta)U^\mu - \beta B \Delta u^\mu\,, \tag{7}$$

where the coefficients $A$ and $B$ are given by

$$A - B = \int d\Gamma_p\, d\Gamma_k\, d\Omega \frac{d\sigma_{\pi N}}{d\Omega} F_{\pi N} d_\pi d_N U_\mu p^\mu U_\nu (p^\nu - p'^\nu) \times e^{-\beta U_\mu (p^\mu + k^\mu)}\,,$$

$$A - 4B = \int d\Gamma_p\, d\Gamma_k\, d\Omega \frac{d\sigma_{\pi N}}{d\Omega} F_{\pi N} d_\pi d_N p_\mu (p^\mu - p'^\mu) \times e^{-\beta U_\mu (p^\mu + k^\mu)}\,. \tag{8}$$

Multiplying Eq. (4) by some unit four-vector $n_\mu$ orthogonal to $u_N^\mu$ and utilizing the perfect-fluid expression for $T^{\mu\nu}$, the equation can be cast into the form

$$(\epsilon_N + P_N) n_\mu \dot{u}_N^\mu = -\beta B n_\mu \Delta u^\mu\,, \tag{9}$$

where $\dot{u}_N^\mu$ describes the acceleration of the nucleon fluid,

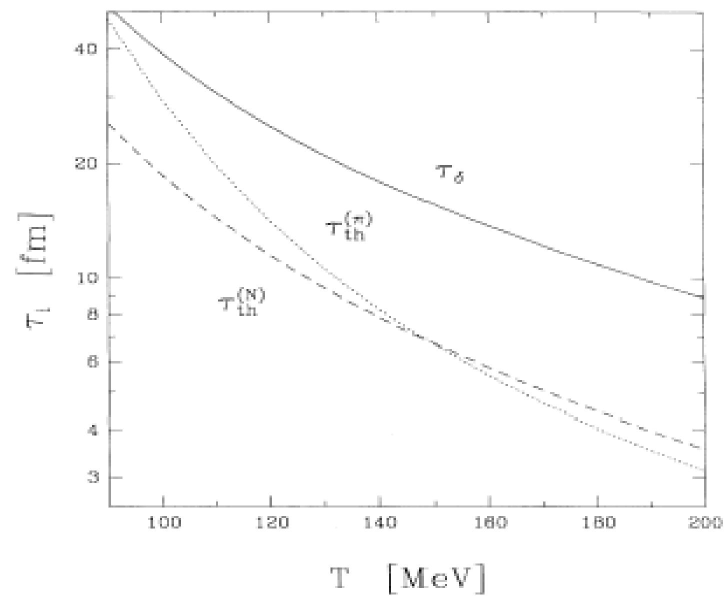



FIG. 1. The relaxation time for collective flow equilibration ($\tau_\delta = \delta^{-1}$, solid line), as well as the temperature equilibration time for nucleons ($\tau_{th}^{(N)}$, dashed line) and pions ($\tau_{th}^{(\pi)}$, dotted line) in pion-dominated hadronic matter as function of the temperature $T$.

For comparison we also show the thermal equilibration time for pions, $\tau_{th}^{(\pi)}$, calculated on the basis of Eq. (11) with standard $\pi\pi$ cross sections [11,12]. $\tau_{th}^{(\pi)}$ falls much faster with increasing $T$ than $\tau_{th}^{(N)}$ and $\tau_\delta$ because the $\rho$ resonance lies higher above the threshold in the $\pi\pi$ reaction than the $\Delta(1232)$ resonance in the $\pi N$ reaction. The fact that $\tau_\delta > \tau_{th}^{(N)}, \tau_{th}^{(\pi)}$ implies that the baryonic collective flow decouples from the pion flow already at high temperature, whereas the nucleonic and pionic thermal motion can remain in equilibrium until $T \approx 140$ MeV if the reaction volume has a size of several fermis, and possibly down to even lower temperatures if the pions de-

**Calculation of drag coefficients for protons in pion gas (Lévai, Müller '91)**

# Proton-antiproton collisions at FERMILAB, $\sqrt{s} = 1.8$ TeV



dynamical model of Bjorken [15]. This model is best formulated in cylindrical light-cone coordinates $t \pm z$. Here $t$ is the time and $z$ the longitudinal coordinate in the center-of-mass system. It is useful to introduce the coordinates $(\tau, \alpha, r, \phi)$, where $\tau = (t^2 - z^2)^{1/2}$ is the proper time, $\alpha = \frac{1}{2}\ln[(t+z)/(t-z)]$ is the space-time rapidity, and $r$ is the transverse radius.

Let us consider decoupled velocity fields $v_L$ and $v_T$ along longitudinal and transverse directions. The velocity four-vector is then given by

$$u^\mu = (\gamma_T, 0, v_T\gamma_T, 0)\,, \qquad (12)$$

where $\gamma_T = (1 - v_T^2)^{-1/2}$. Here we do not intend to explore the detailed time evolution of the transverse velocity field as it follows from the hydrodynamical equations (4); we are only interested in the flow at the time of freeze-out of the various hadrons. We therefore introduce a fixed linear transverse velocity profile [3] parametrized by the surface velocity $\dot{R}(\tau)$, where $R(\tau)$ is the transverse radius of the reaction region. Assuming that the temperature depends only on $\tau$ and freeze-out occurs at constant $\tau$, one can then calculate the transverse momentum and rapidity distributions of the emitted hadrons [16]. Here we give the expressions for the space-time rapidity density of the particle number,

$$\frac{dN}{d\alpha} = \int \gamma_T \tau r\, dr\, d\phi \int d^3\bar{p}\, f(x,\bar{p})\,, \qquad (13)$$

and of the average squared transverse momentum,

$$\frac{d\langle p_T^2\rangle}{d\alpha} = \int v_T^2 \gamma_T^3 \tau r\, dr\, d\phi \int d^3\bar{p}(\bar{E}^2 - \bar{p}^2) f(x,\bar{p}) + \tfrac{2}{3}\int \gamma_T \tau r\, dr\, d\phi \int d^3\bar{p}\,\bar{p}^2 f(x,\bar{p})\,. \qquad (14)$$

In order to compare with the experimental data, we define

$$\langle p_T\rangle \approx 0.8165\left[\frac{d\langle p_N^2\rangle}{d\alpha}\left(\frac{dN}{d\alpha}\right)^{-1}\right]^{1/2}, \qquad (15)$$

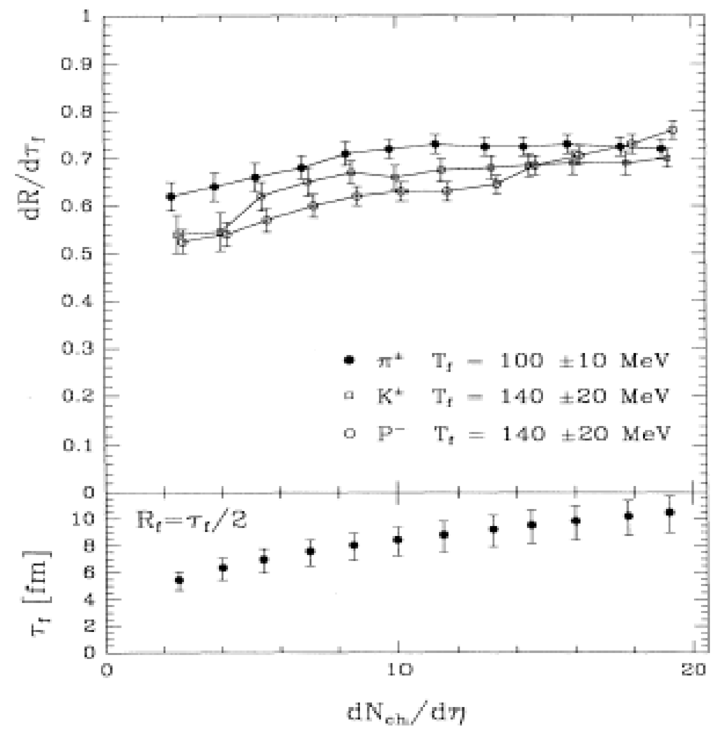



FIG. 2. Top: Surface collective flow velocities for pions, kaons, and antiprotons deduced from the data of Ref. [14] by means of Eq. (15). The error bars reflect the stated uncertainty in the freeze-out temperature $T_f$, and not the experimental errors. Bottom: Transverse radius $R$ at pion freeze-out time $\tau_f$, as deduced from the measured multiplicity $dN_{ch}/d\eta$ arbitrarily assuming $R(\tau_f) = \tau_f/2$.

pansion in the hadronic gas phase. On the other hand, a collective flow which is established in a quark-gluon plasma phase before hadronization would naturally account for this phenomenon. We think that our results constitute a powerful indication for the existence and formation of such a deconfined phase.

**Pions and protons flow together, but drag is weak QGP phase must be formed**

## ***Proton-antiproton collisions at FERMILAB, $\sqrt{s}$ = 1.8 TeV***

## T. Alexopoulos et al., E735 Collab., PRD48, 984 (1993)

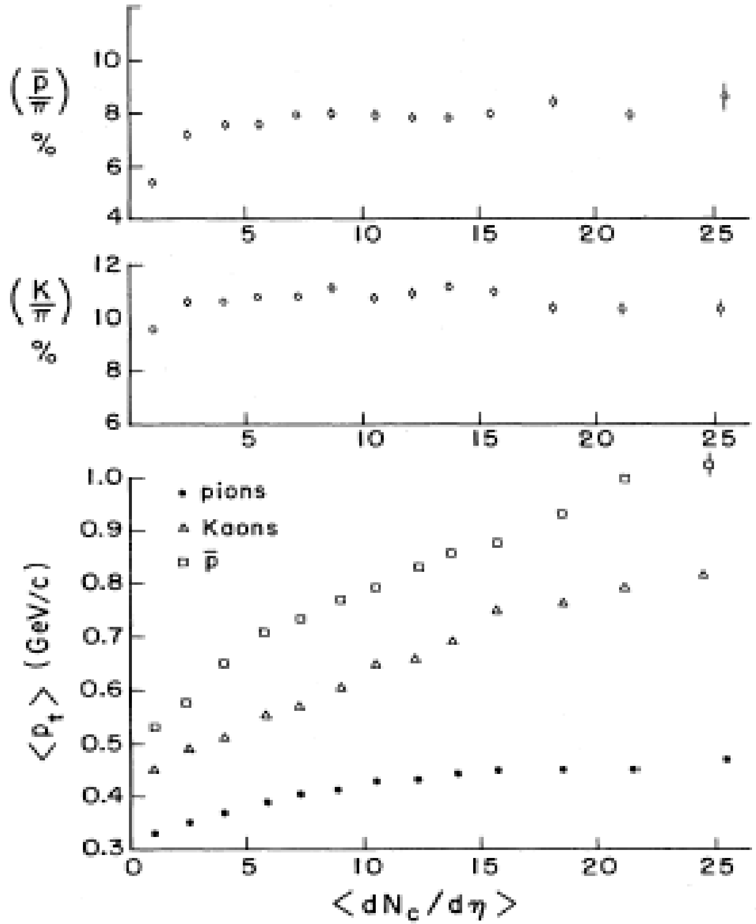



FIG. 19. Average transverse momentum, $\langle p_t \rangle$ and $K/\pi$ and $\bar{p}/\pi$ ratios as a function of charged particle density ($dN_c/d\eta$). Systematic errors are not shown in the figure but given in Tables II(a) and II(b).

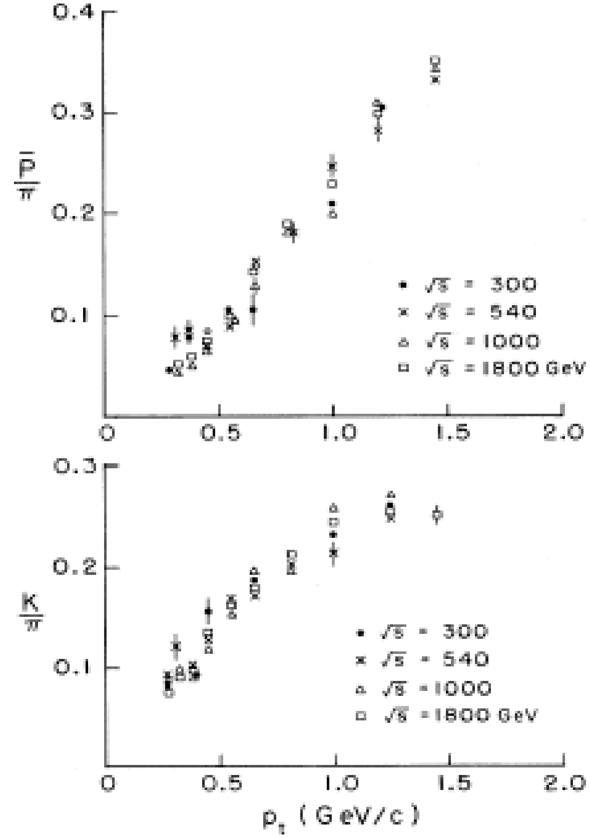



FIG. 15. The ratios $\bar{p}/\pi$ and $K/\pi$ as a function of $p_t$ for four center-of-mass energies (300, 540, 1000, and 1800 GeV). The $\pi$ and $K$ data are averaged over positive and negative particles. For clarity, error bars are not shown for all data; the data shown without error have about the same errors as shown for the other data.

**$dN_{ch}$/d eta dependence**

**$p_T$ dependence of p/pion**

**The combination of the two data sets is missing, unfortunately**

***Proton-antiproton collisions at FERMILAB, $\sqrt{s}$ = 1.8 TeV***

**T. Alexopoulos et al., E735 Collab., PRD48, 984 (1993)**

**Estimate on max. energy density by the Bjorken formula:**

$\tau_0$ = 0.2 fm

R = 1 fm

$\langle m_T \rangle$ = 500 MeV

$dN/dy|_{max}$ = 37 ➤➤➤ $\varepsilon_{Bjork,\,max}$ = 30 GeV/fm$^3$

**This value is very large, stopping is important.**

**How to distinguish between**

**--- fluctuations of fragmentation processes;**

**--- multiple parton-interaction;**

**--- QGP formation ??**

**“underlying event”**

## *Proton-antiproton collisions at FERMILAB, $\sqrt{s}$ = 1.8 TeV*

**T. Affolder et al., CDF Collab., PRD65, 092002 (2002)**

**Underlying events: separation of jet fragmentation from multi-parton int.**

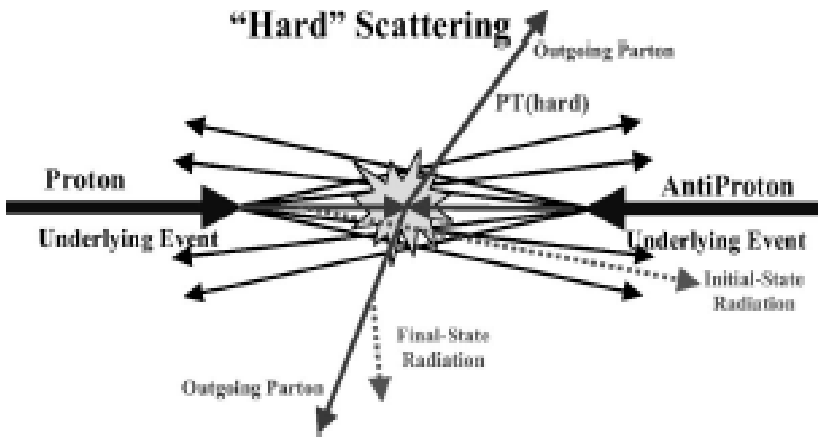



FIG. 1. Illustration of the way the QCD Monte Carlo models simulate a proton-antiproton collision in which a hard 2-to-2 parton scattering with transverse momentum, $p_T$(hard), has occurred. The resulting event contains particles that originate from the two outgoing partons (*plus initial and final-state radiation*) and particles that come from the breakup of the proton and antiproton (*"beam-beam remnants"*). The "hard scattering" component consists of the outgoing two "jets" plus initial and final-state radiation. The "underlying event" is everything except the two outgoing hard scattered "jets" and consists of the "beam-beam remnants" plus possible contributions from the "hard scattering" arising from initial and final-state radiation.

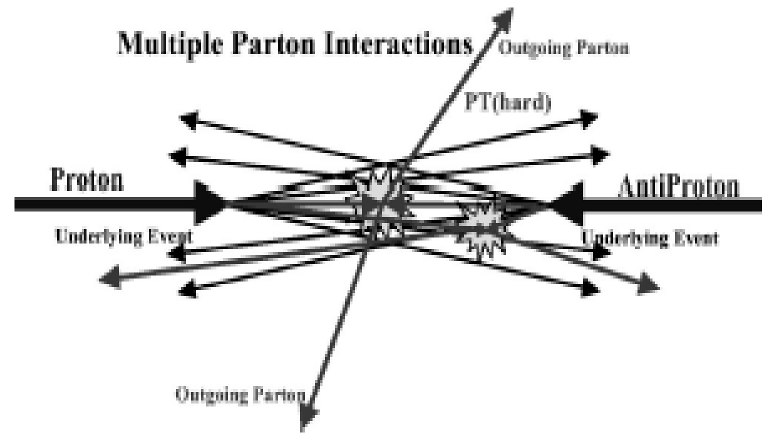
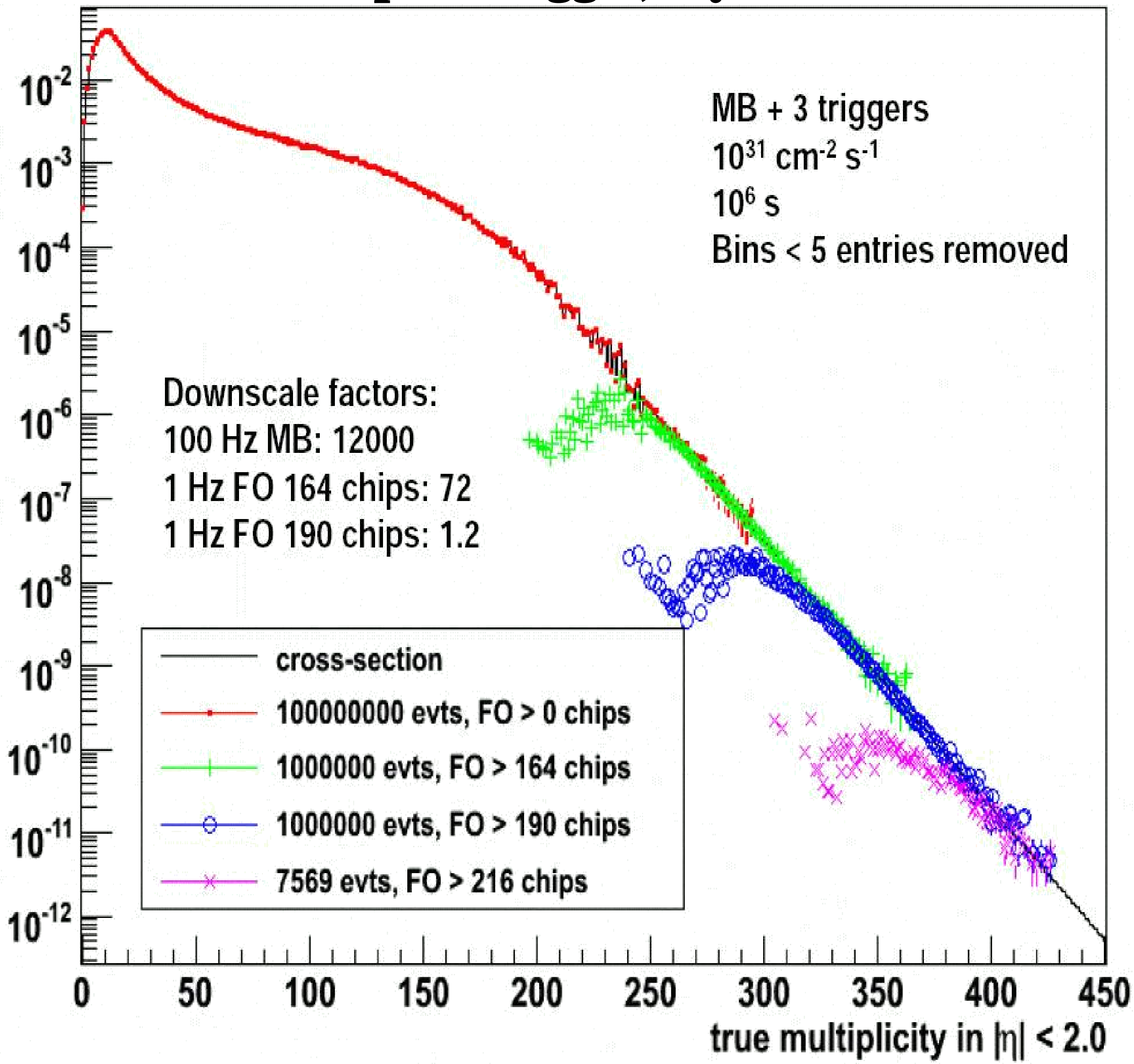



FIG. 2. Illustration of the way PYTHIA models the "underlying event" in proton-antiproton collision by including multiple parton interactions. In adddition to the hard 2-to-2 parton-parton scattering with transverse momentum, $p_T$(hard), there is a second "semi-hard" 2-to-2 parton-parton scattering that contributes particles to the "underlying event."

**Single parton-parton coll.**

**Multi-parton collision**

# ALICE pixel trigger, Pythia at 14 TeV




Christian Klein-Bosing, Hard Probe'08

## *Proton-proton collisions at LHC, $\sqrt{s}$ = 14 TeV*

Centrality scale: $dN_{ch}/dy$

1. Measuring $<m_T>$ ➤➤➤➤➤ $_{Bjorken}$ can be extracted as estimated initial bulk energy energy density

2. One particle spectra --- collective flow (v1) [v2 ???]
   $R_{CP}$ = Central/Peripheral (as “nuclear modification factor”)

3. Hadron-hadron away-side correlation (suppresion ?)

4. (Anti)Baryon/meson ratios (shifting maximums)

5. Underlying events --- characteristics

6. ...

## *Proton-proton collisions at LHC, $\sqrt{s}$ = 14 TeV*

**Centrality scale: $dN_{ch}/dy$**

**4. (Anti)Baryon and meson spectra**

**Higher multiplicity: larger collectivity**
**larger transverse flow ($v_1$)**

**Baryon/meson and antibaryon/baryon ratios are modifying**
**maximum and crossing points are moving.**

**If we see this at LHC, then the presence of collective state and the formation of a 'xQGP' state is favoured.**

**Could we falsify the formation of QGP state in pp collisions ?**

## *Proton-proton collisions at LHC, $\sqrt{s}$ = 14 TeV*

**Centrality scale: $dN_{ch}/dy$**

**5. Underlying events – jet-matter interaction**

**Total multiplicity = jet fragmentation + underlying event**

**possible fluctuation large entropy production**

**We need to separate the two sources as precisely as possible.**

**Focus on 'large entropy production' in the underlying event.**
**This can become a possible trigger.**

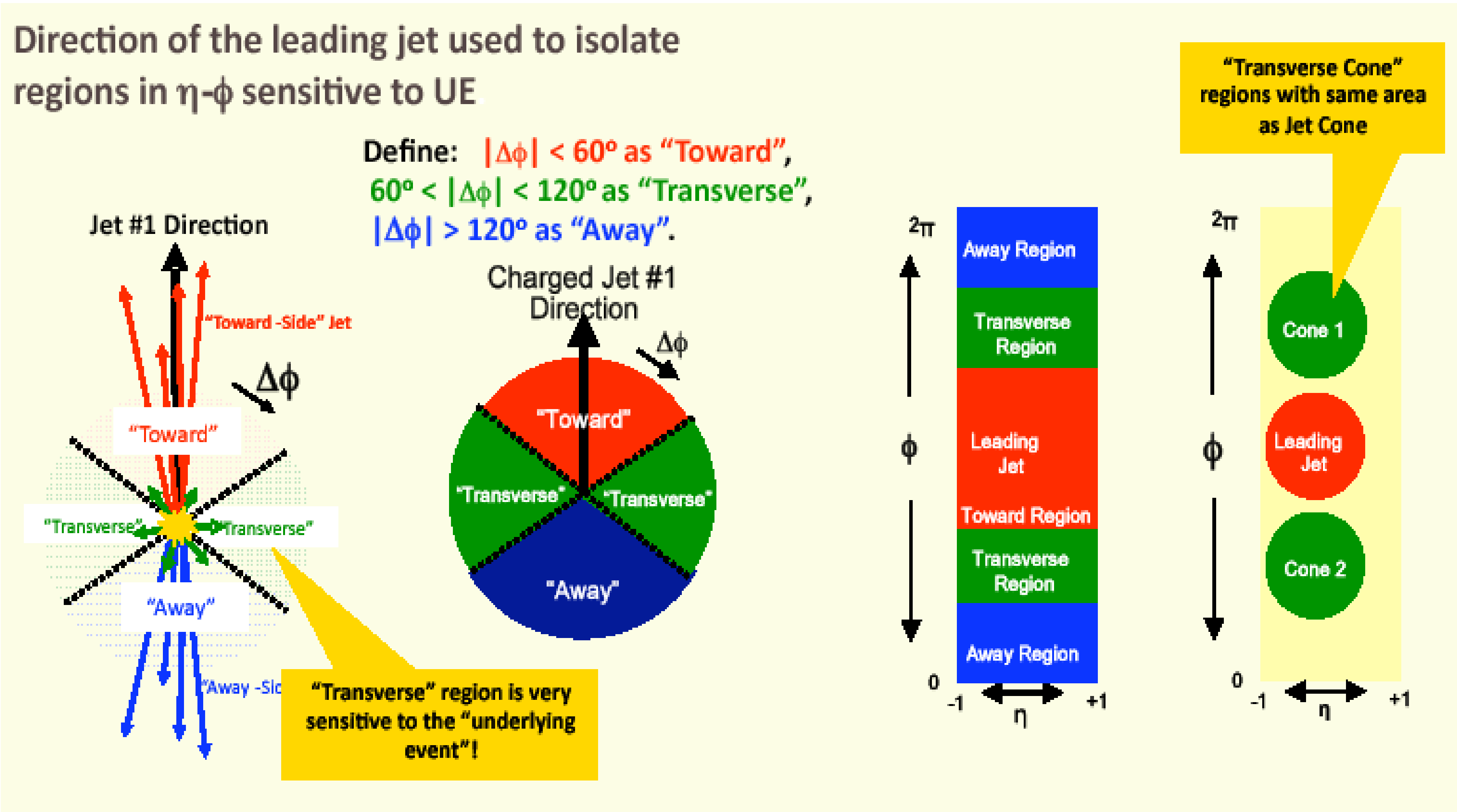
**Detailed simulations are needed,**

**Looking for large (small) deviations in the data from PYTHIA simulations.**

***Proton-antiproton collisions at FERMILAB, $\sqrt{s}$ = 1.8 TeV***

**T. Affolder et al., CDF Collab., PRD65, 092002 (2002)**

**Underlying events: separation of jet fragmentation from multi-parton int.**




↣ **A.G. Agócs's talk**

## 5. Summary:

1. The restart of LHC has been performed succesfully
   20 November 2009 – stable beams in the LHC

2. ALICE is ready for data taking
   23 November 2009 – first physical data collection at 900 GeV
   20 minutes, 284 real pp collisions

3. This year plan is to collect data at 2.4 TeV CM energy.

4. Exciting time in the high energy community

5. Theoretical efforts are continued in the backround.
   How to falsify "QGP formation" in pp collisions at LHC energies?