Relativistic Heavy Ions IV - What's happening right now!

RHI Physics

The US National Nuclear Physics Summer School & TRIUMF Summer Institute

Vancouver, Canada

Helen Caines - Yale University

June 2010

Outline:

The LHC

Pb-Pb - outlook

p-p - new results

Recap of last lecture

The matter we create at RHIC is the **sQGP** it is

fantastically hot

and has an

incredible energy density.

It

exists for only an instant

yet shows

many signs of being in equilibrium.

It flows like a

nearly "perfect" fluid

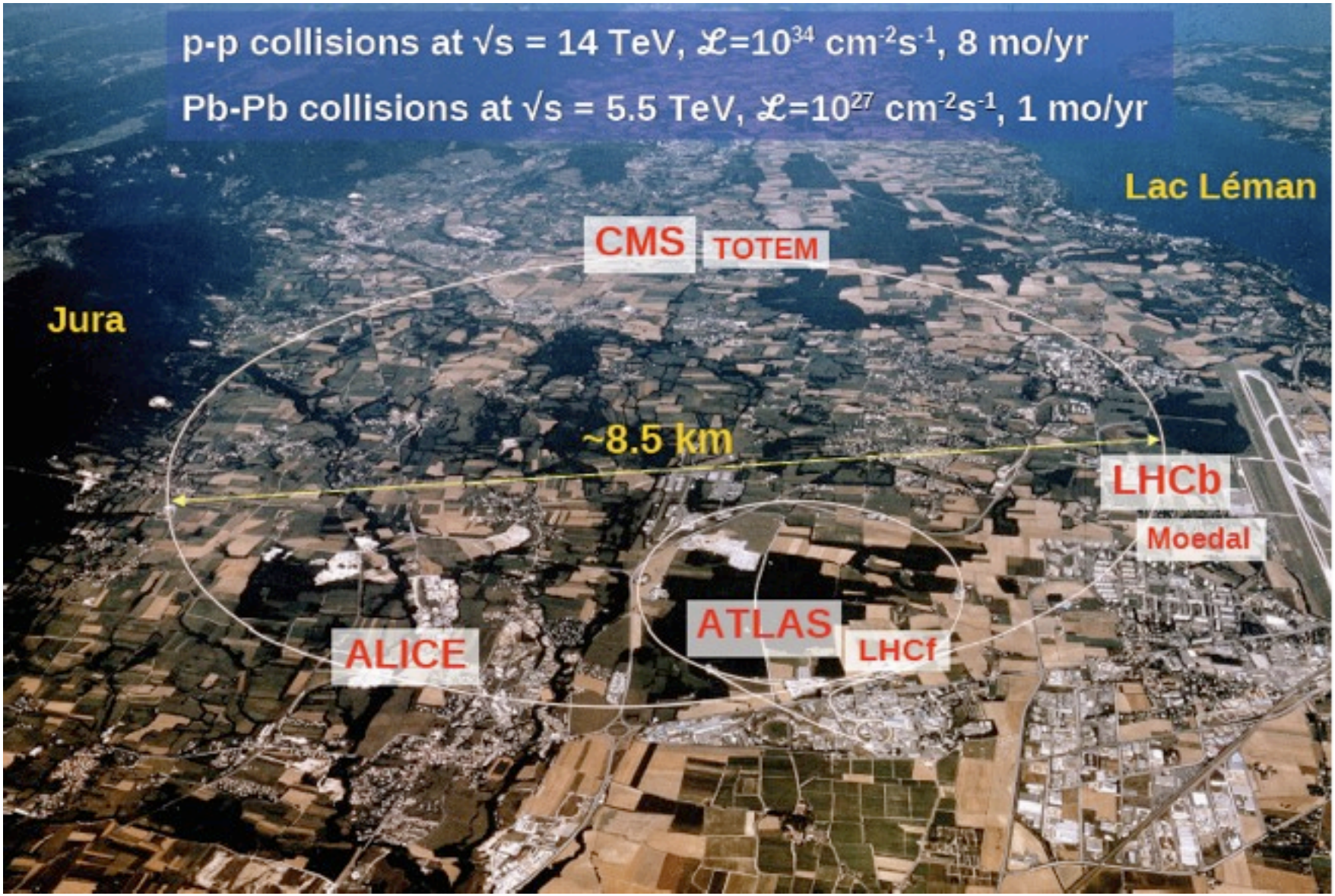
and appears to have

quark and gluon degrees of freedom

which causes

significant energy loss to partons passing through

The LHC, CERN


p-p collisions at √s = 14 TeV, ℒ=10³⁴ cm⁻²s⁻¹, 8 mo/yr
Pb-Pb collisions at √s = 5.5 TeV, ℒ=10²⁷ cm⁻²s⁻¹, 1 mo/yr
Lac Léman
CMS
TOTEM
Jura
~8.5 km
LHCb
Moedal
ATLAS
LHCf
ALICE

6 major questions for the LHC

1. Mass generation: Does the Higgs boson exist? Is the standard model complete?

2. Hierarchy problem: What is gravity so much weaker than the other forces?

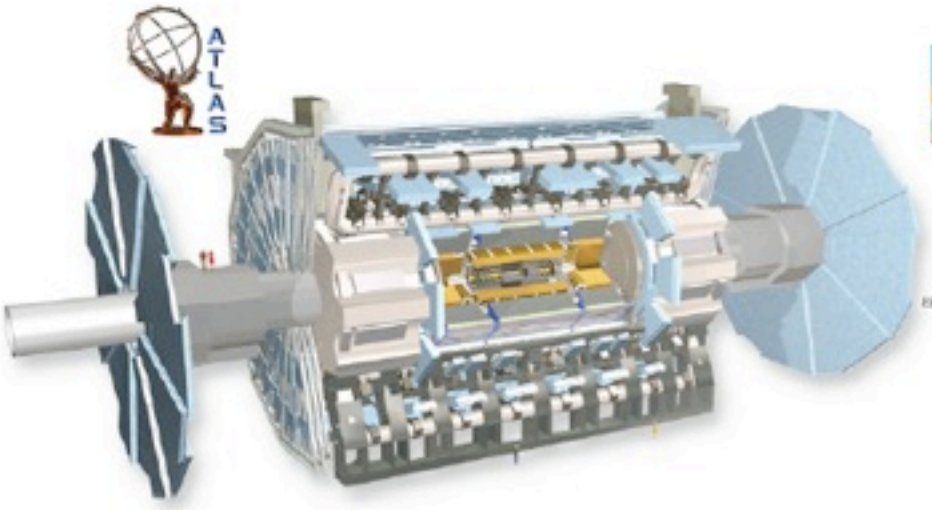
3. Dark Matter: What is the nature 23% of the universe that's almost "invisible"?

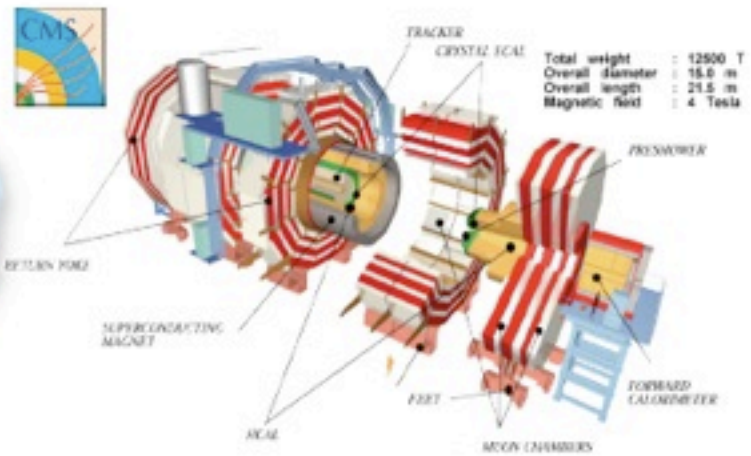
4. Why is there so little anti-matter?: Why is there a matter-anti-matter asymmetry in the universe?

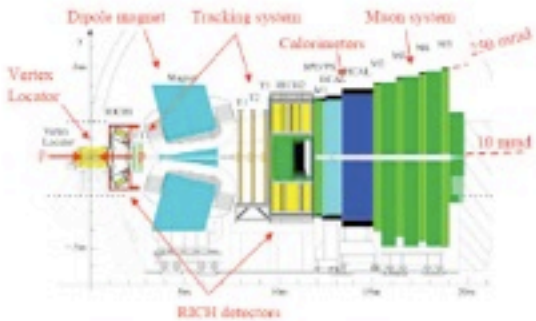
5. QCD in the non-perturbative regime: Why and how are quarks confined?

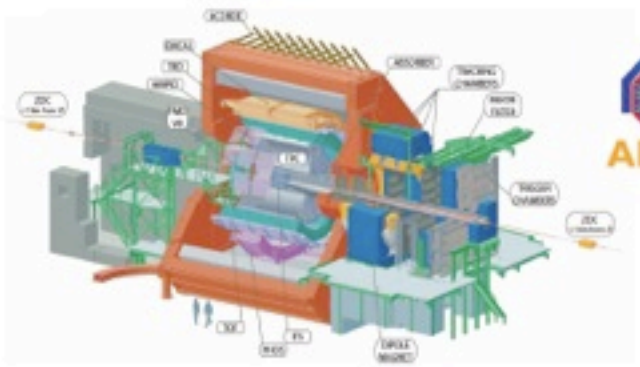
6. Cosmic rays: Nature of very high energy cosmic rays?

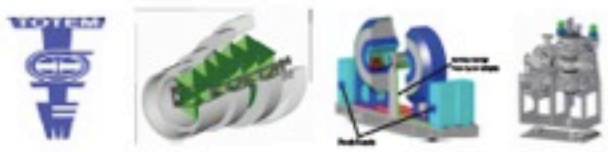
The 7 experiments

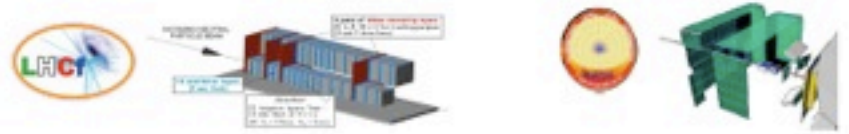








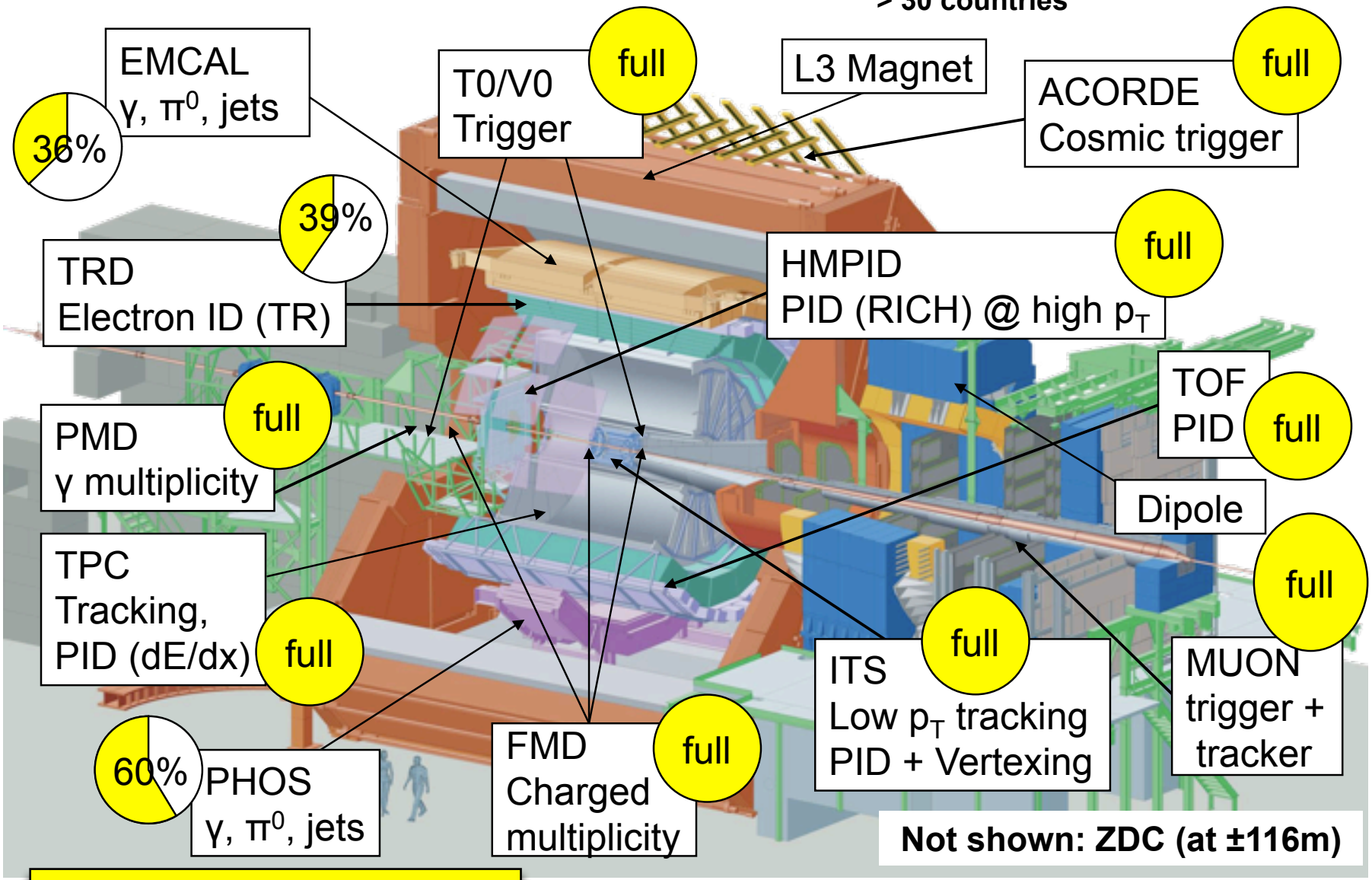




The ALICE detector

Collaboration:
>1000 Members
>100 Institutes
> 30 countries

Detector:
Size: 16 x 26 meters
Weight: 10,000 tons



~ (STAR +PHENIX)++

Graphic from R. Romita

RHIC vs LHC

RHIC	LHC
Beams: p to U	Beams: p to Pb
√s: 5-200 (p-p 500) GeV	√s: 5.5 (p-p 14) TeV
Central Events:	
T~2T_C	T~4T_C
ε (GeV/fm^3) = 5	ε (GeV/fm^3) = 15-60
τ(fm/c) = 2-4	τ(fm/c) >10
HI Running:	
12 weeks/year	4 weeks/year
Ave. A+A Luminosity	
5x10^{27}cm^{-1}s^{-1}	5x10^{26}cm^{-1}s^{-1}
20nb^{-1}/year (50% up time)	500μb^{-1}/year (50% up time)

RHICs higher luminosity and longer running time keep it competitive

The expectation:

LHC plasma hotter, denser, longer lived

Open questions:

same sQGP? different evolution?

Heavy ions at the LHC

What are the initial conditions

Is gluon saturation seen?

What is the measured T_{ch} from particle ratios?

$T_{ch} \sim T_c$ as at RHIC or higher - thermal models interpretation?

Is $v_{2LHC} < v_{2RHIC}$?

Time evolution of the medium

Is QGP still strongly coupled?

Behaving like a perfect liquid or more gas like?

Energy loss similar to at RHIC?

What is the mass/flavor dependence of the Eloss

Heavy flavor copiously produced at LHC

The LHC is a hard probes machine

An LHC Pb-Pb year:

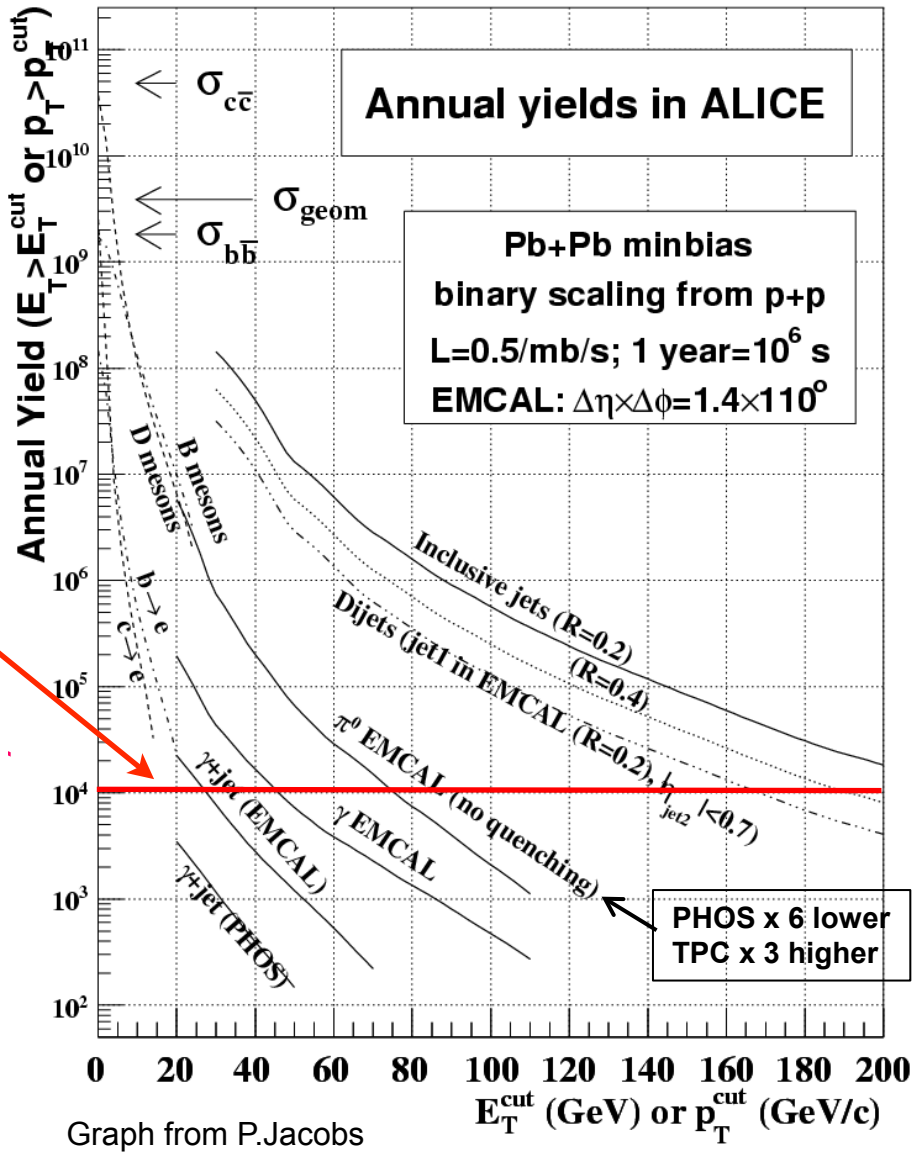
1 month ~ 10^6 seconds

Need 10^4 "events" in a year to make a measurement:

- inclusive jets E_T < 200 GeV
- di-jets E_T < 170 GeV
- π^0 p_T <75 GeV
- inclusive γ p_T<45 GeV
- inclusive e p_T<30 GeV

- σ_{cc} (LHC) ~ 10 σ_{cc} (RHIC)
- σ_{bb} (LHC) ~ 100 σ_{bb} (RHIC)

Hard probes are no longer rare probes



Graph from P.Jacobs

Pb-Pb "First Physics"

First 10^5 Pb-Pb events: global properties, unidentified mult, rapidity distribution, p_T spectra, elliptic flow

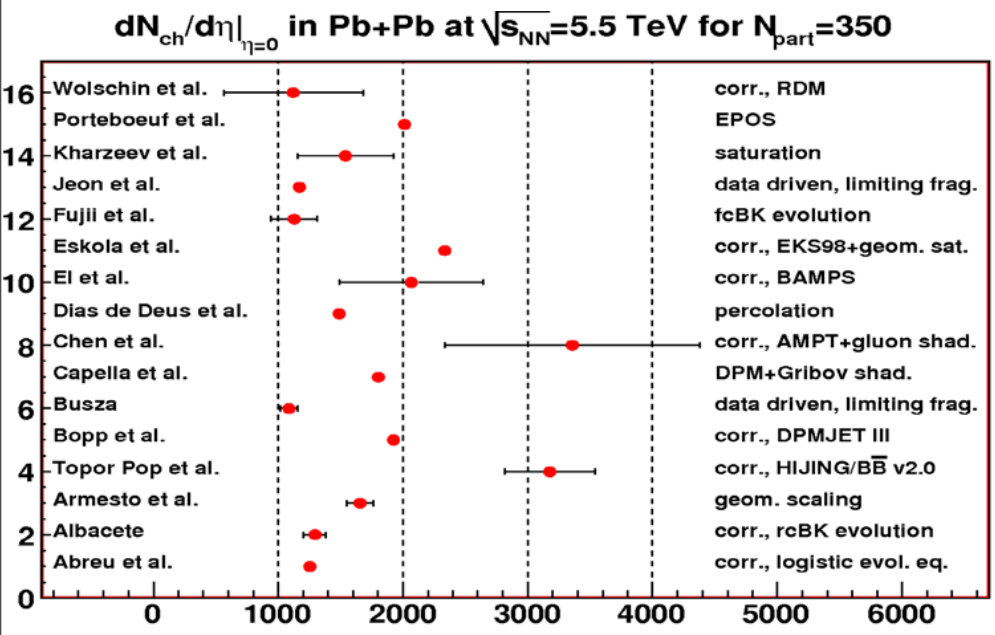
First 10^6 Pb-Pb events: PID spectra, resonances, differential flow analyses, particle correlations

First 10^7 Pb-Pb events: jet quenching and heavy flavor (charm) production and energy loss

Ultimate analyses: energy density, temperature, pressure, entropy, viscosity, energy loss mechanisms

And of course p-p as the baseline, and new basic understanding: mult, baryon transport, PID spectra and cross-sections (including c and b)

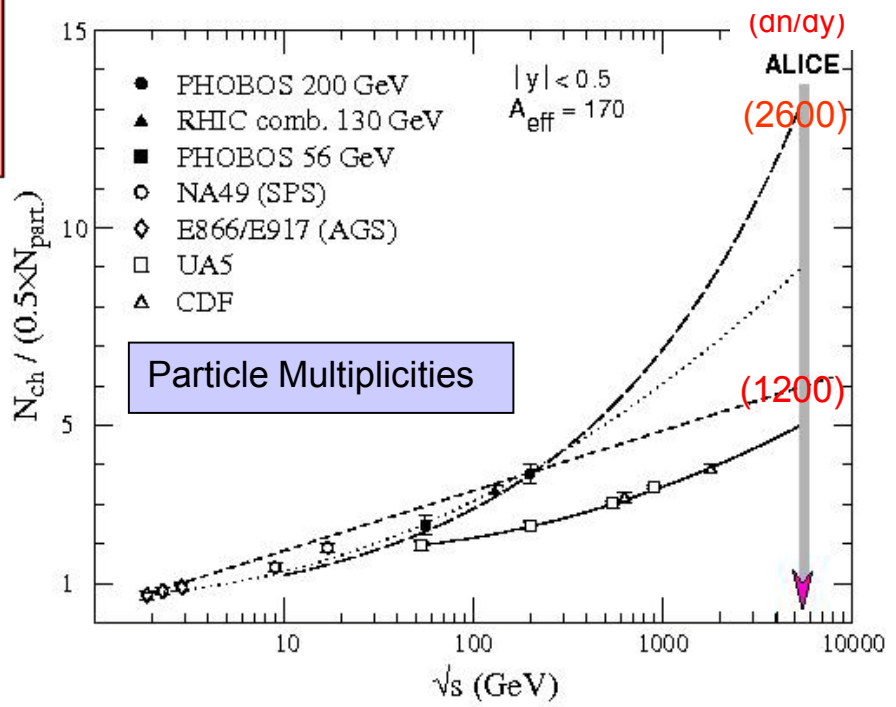
First question: how many particles?



N. Armesto arXiv:084.4158

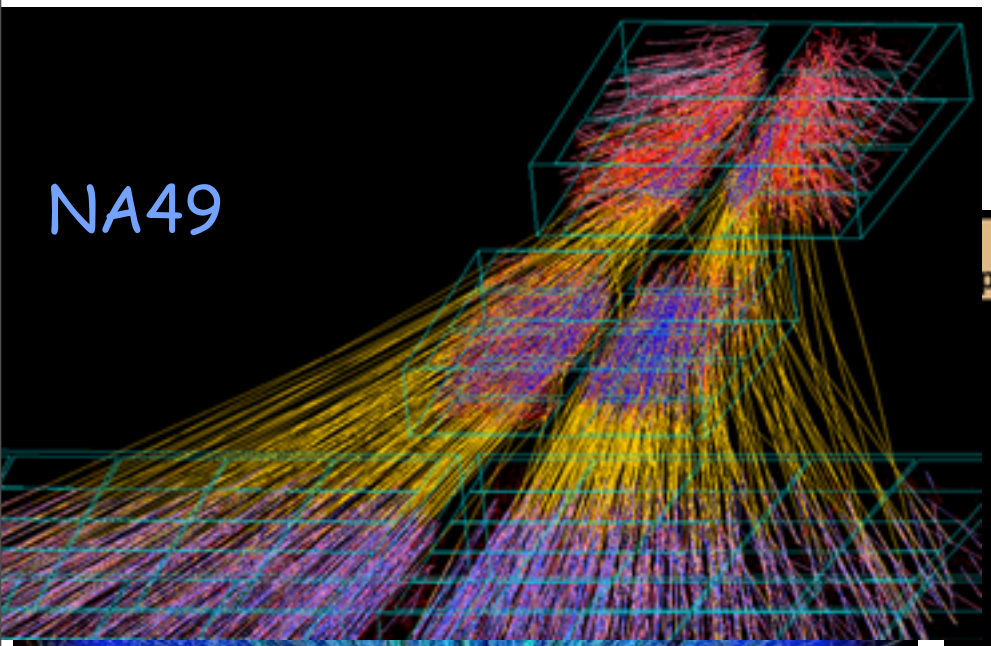
Saturation models N_{ch} <2000

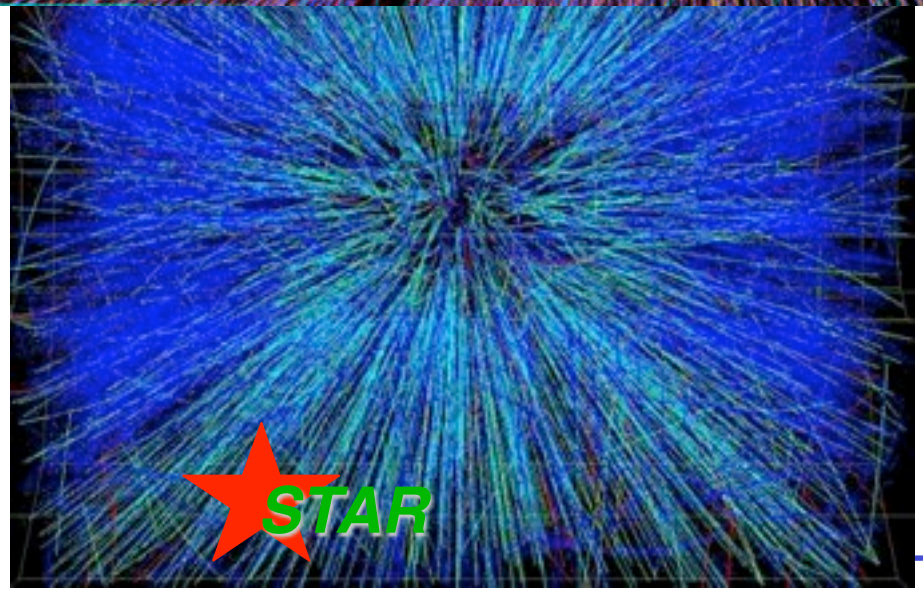
Largest values from models without collective motion



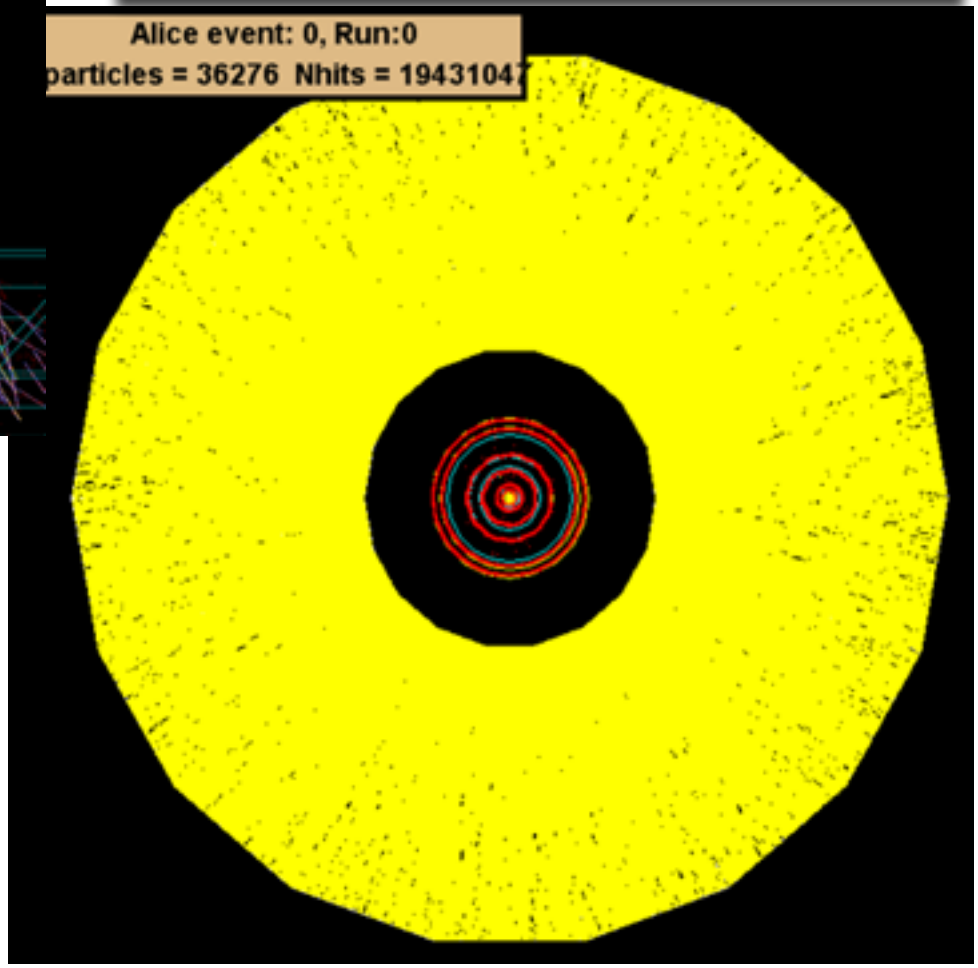
First few events will "kill" many models

Each generation: new extreme of tracking



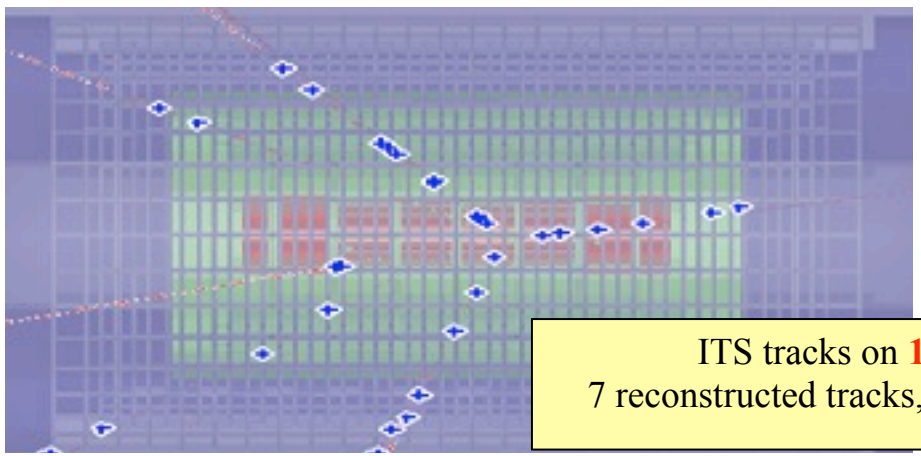


ALICE 'worst case' scenario:
dN/dy_{ch} = 8000



The LHC starts!

September 2008:



ITS tracks on **12.9.2008**
7 reconstructed tracks, common vertex

Everything is looking good, the world is watching!

The LHC stops...

The "Sector 34" incident

LHC magnets are superconducting. Liquid He keeps at T<1.9K

Sept. 19th 2008 - A weld between two superconductor wires "overheated". conductors→ resistors → 8700 amps arced through liquid He, punctured surrounding vacuum vessel.

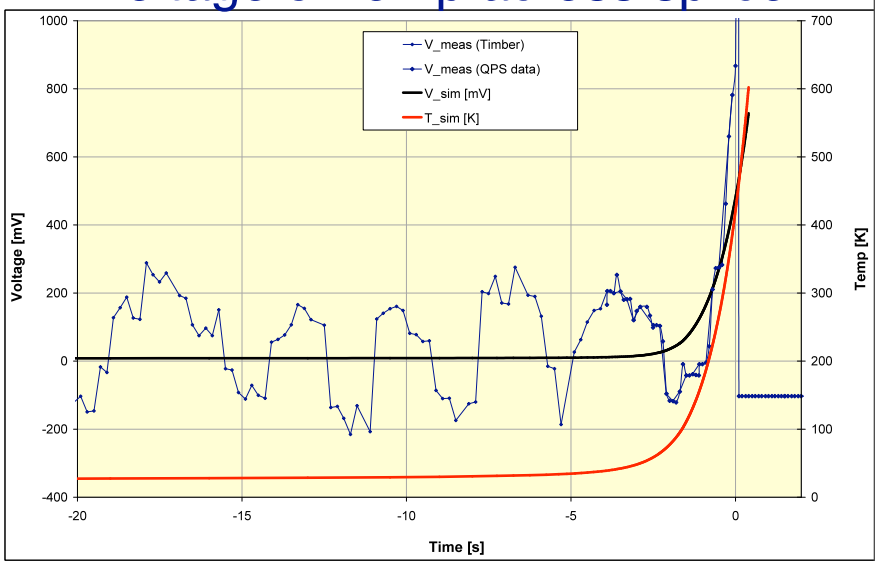
In milliseconds the arc vaporized "significant" fraction of the meter long connection between 2 magnets

6 Tonnes Liquid He flowed through hole into the vacuum container

"The amount of helium released was larger than the valves were designed to handle."

The system was overwhelmed within seconds.

Voltage & Temp across splice



The LHC stops...

The
LHC r H

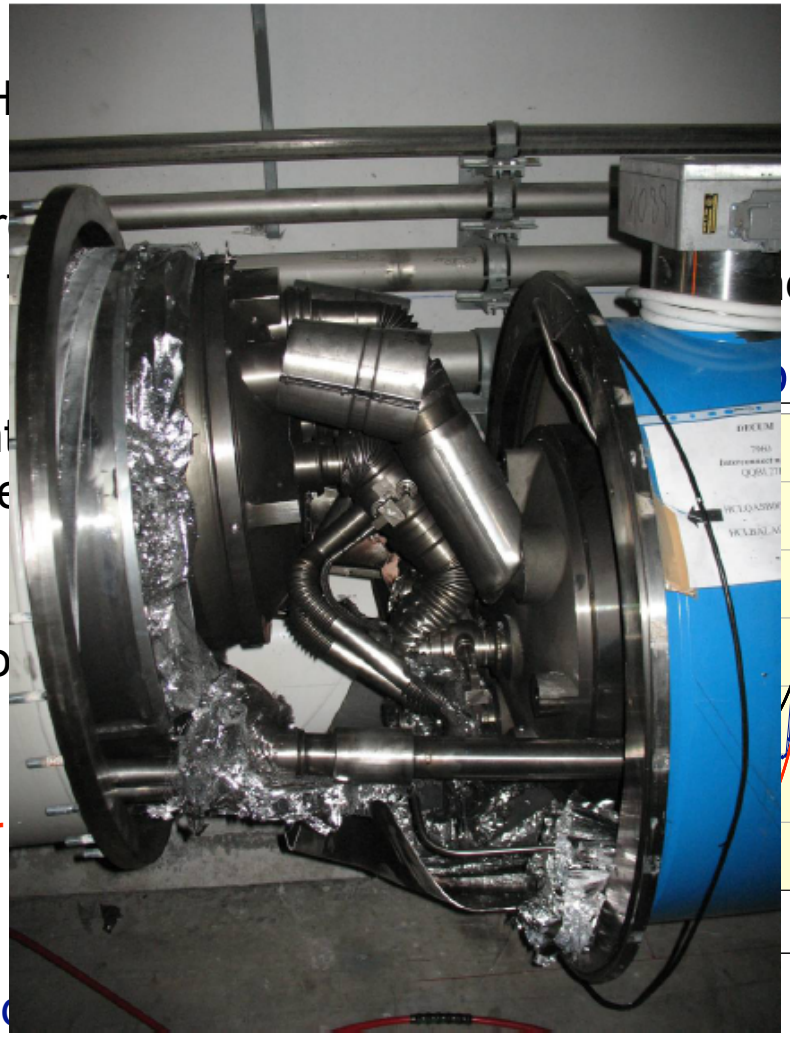
Sept.
condu ding
vacuu

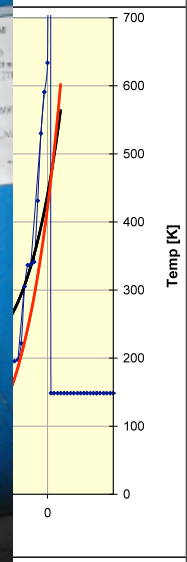
In mil ant
fracti vee
2 mag

6 Ton nto
the va

"The er
than

The s onc





The pressure buildup became so high that the multi-tonne magnets were wrenched off their concrete supports and moved along tunnel.

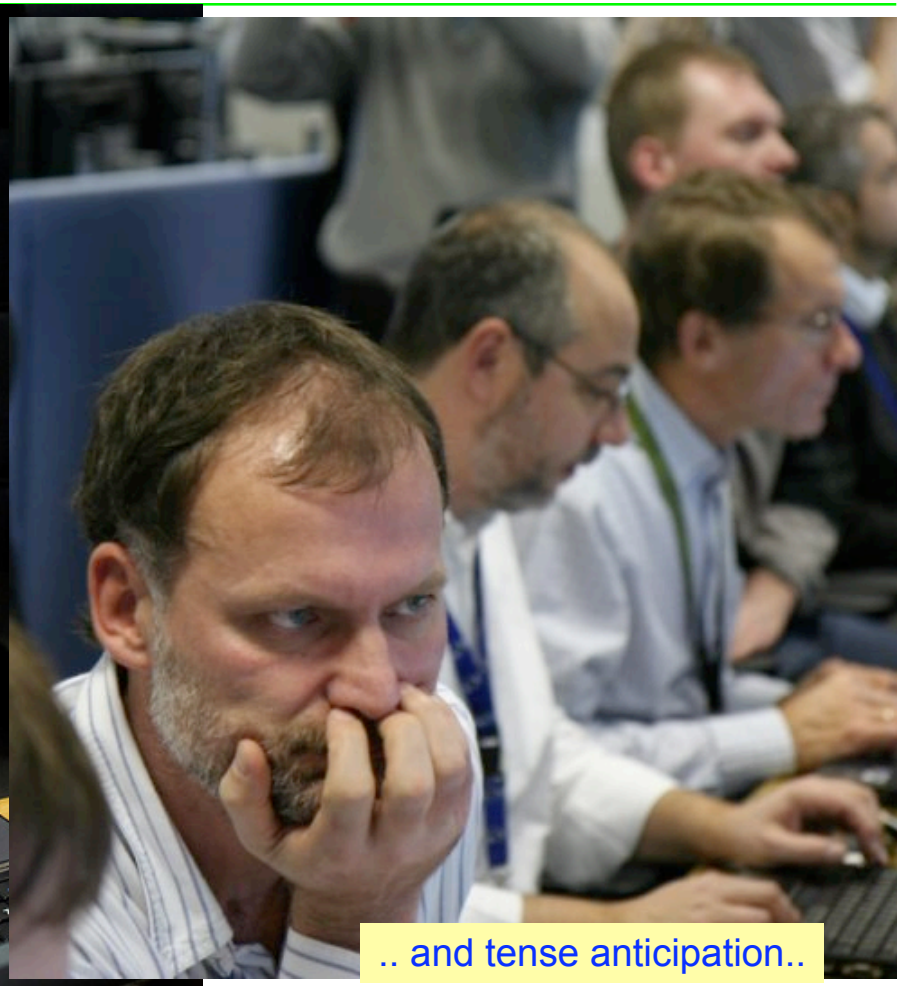
The upshot of the incident

- Take all damaged magnets out
  - 53 total, 39 dipoles, 14 SSSs (Short Straight Section – quad++)
- Fix the cryogenics supply line
- Fix and clean the beam vacuum
- Repair the magnets
- Test repaired magnets and spares used
- Re-install, Re-interconnect, Cool, Test
- p-p collisions started mid-Nov. 2009 at $\sqrt{s}$=0.9 TeV
- 2010 rising via $\sqrt{s}$= 2.36 TeV to $\sqrt{s}$= 7 TeV
- End 2010 and 2011 Pb-Pb 1 month each at $\sqrt{s_{NN}}$=2.76 TeV
- 2012 shut down finish the repairs for full energy running

2013 full energy running 5.5 and 14 TeV

The LHC re-starts

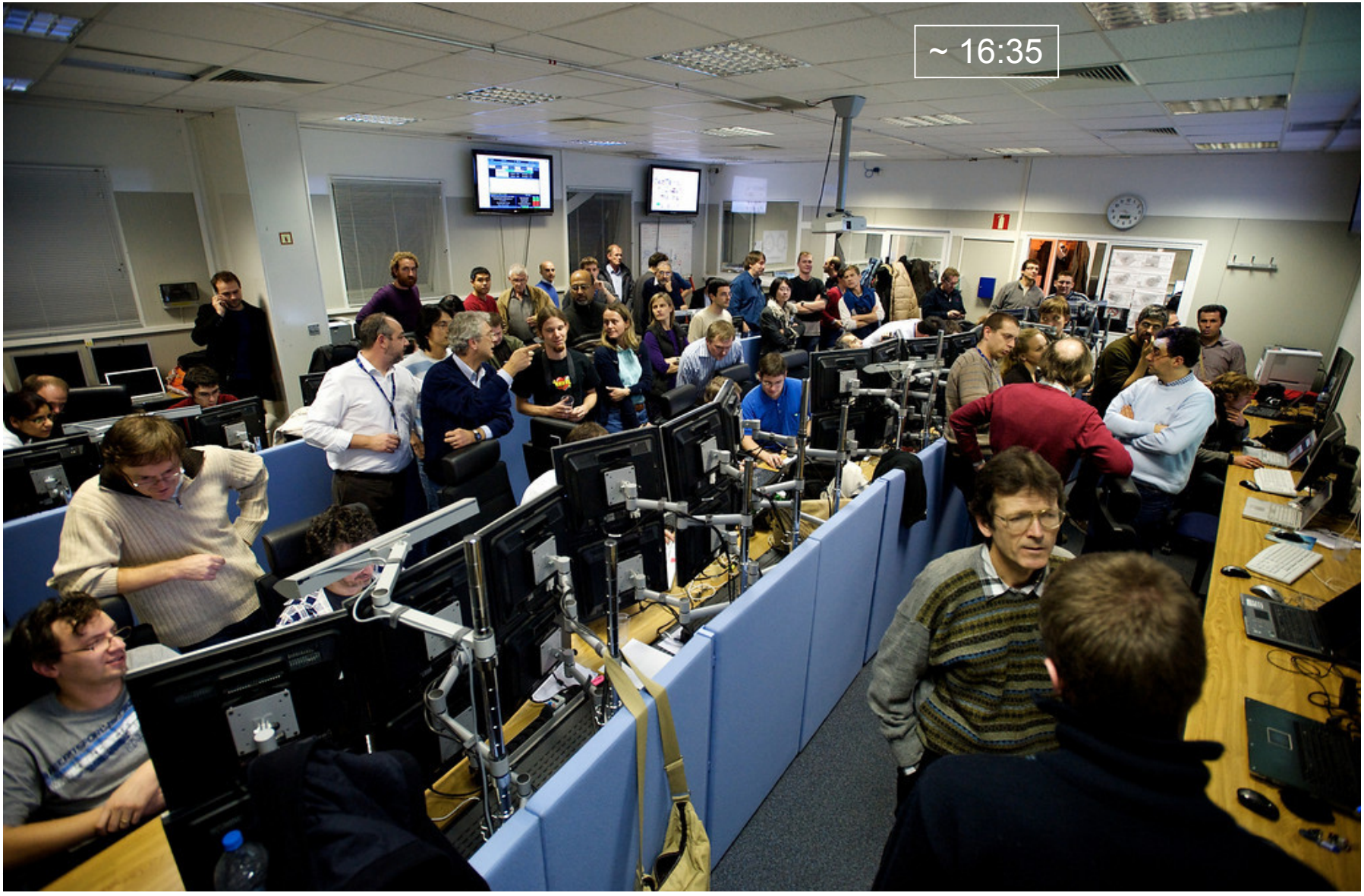
..after concentrated preparations..



.. and tense anticipation..

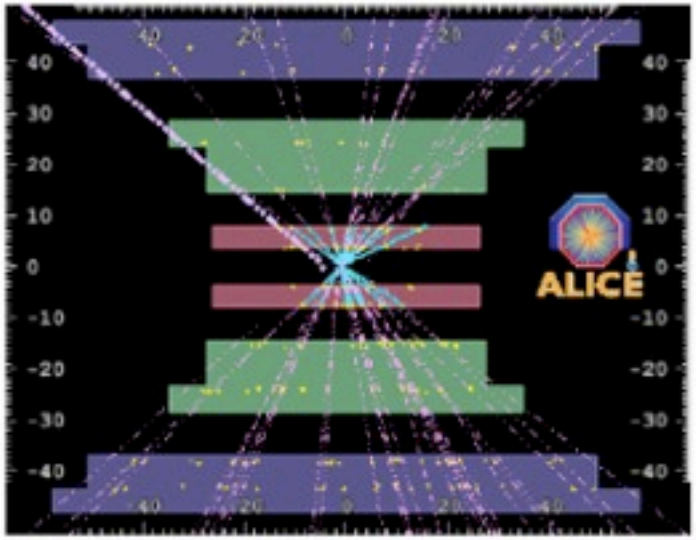
Monday, 23rd November, ~15:30
in the ALICE Control Room

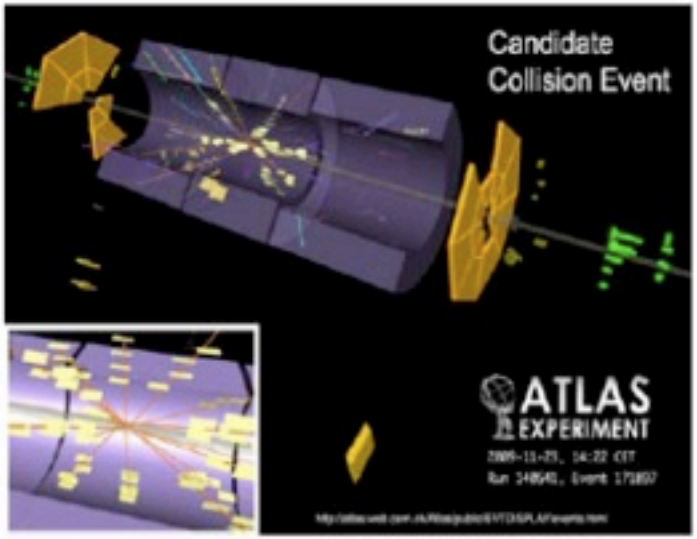
Time passes, the collaboration gathers



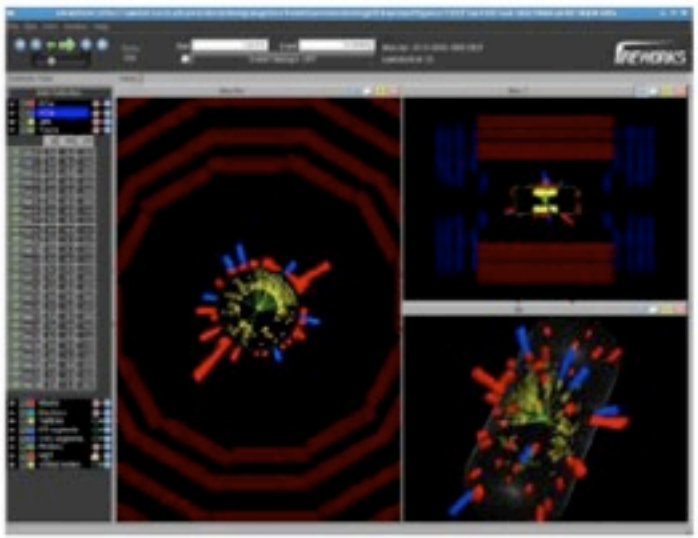
First events seen!!

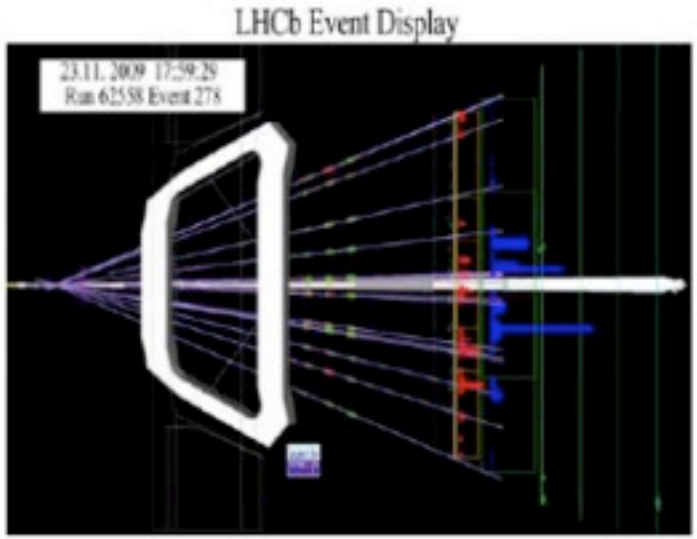
p-p
√s= 900 GeV



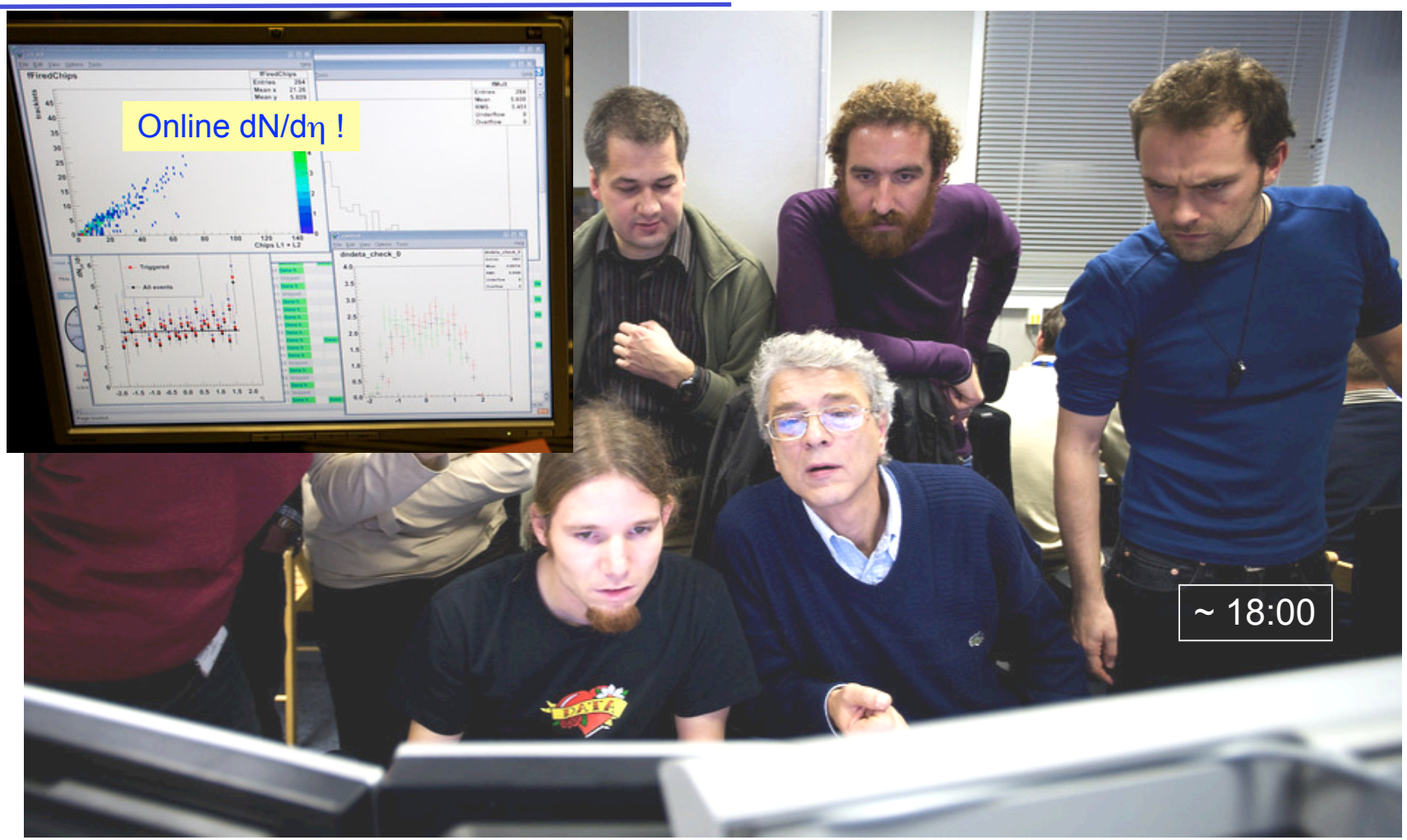


All 4 experiments report that events recorded in their detectors





First physics was online



Spokesman “helped” the young scientists

1 hr after first event: 284 events had been processed

First publication

The **average number of charged particles**
created at mid-rapidity
in p-p collisions at 900 GeV is:

$dN/d\eta = 3.10 \pm 0.13\ (stat) \pm 0.22\ (syst)$ ≈ π

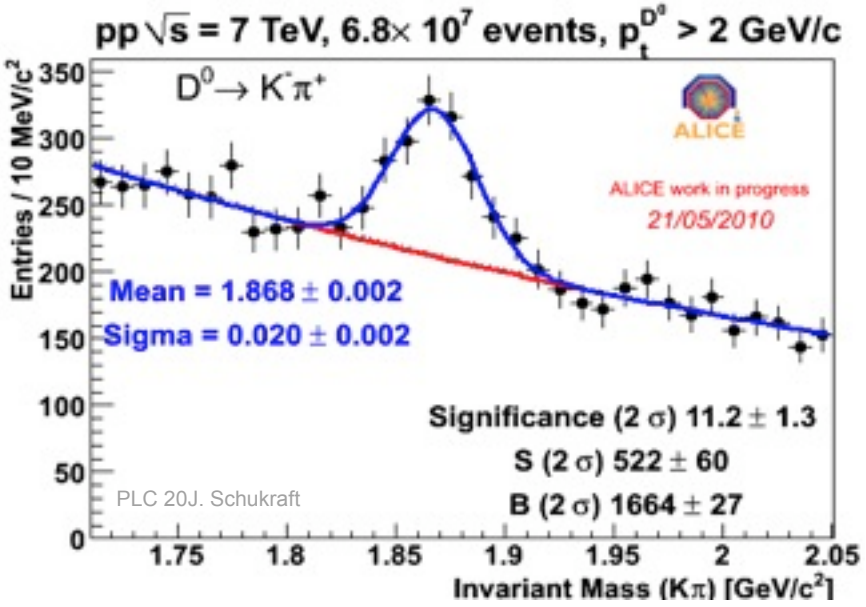
National Geographic News (4 Dec.)

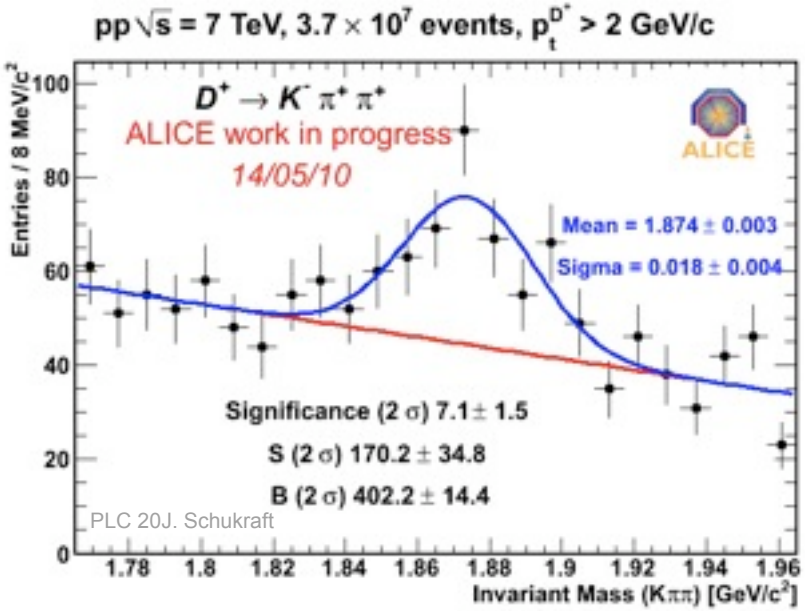
'….a machine called ALICE....
found that **a** (!) proton-proton collision
recorded on November 23
created the precise ratio
of matter and antimatter particles
predicted from theory..'

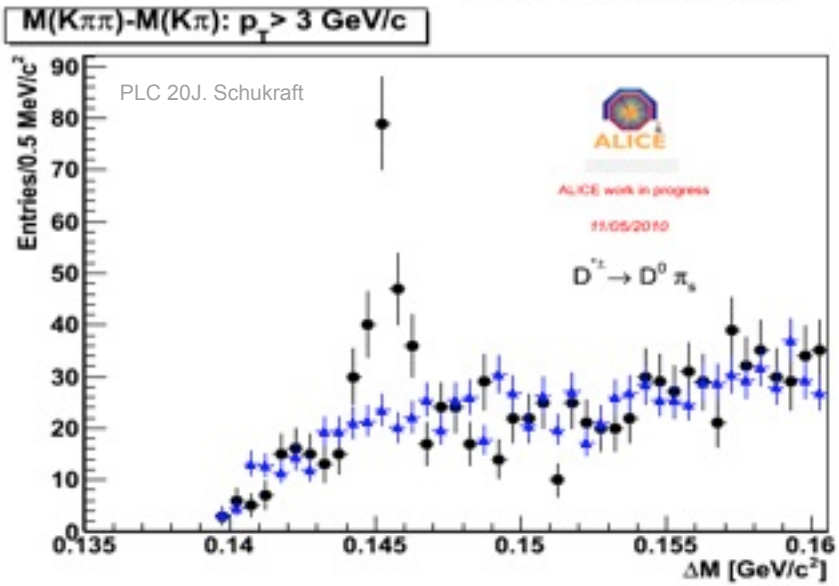
It took:

- ⇨ 20 years to built ALICE
- ⇨ 40 minutes to take the first data
- ⇨ 1 hour to get the prel. result (±10%)
- ⇨ 2 days for the final result

Charm comes easily



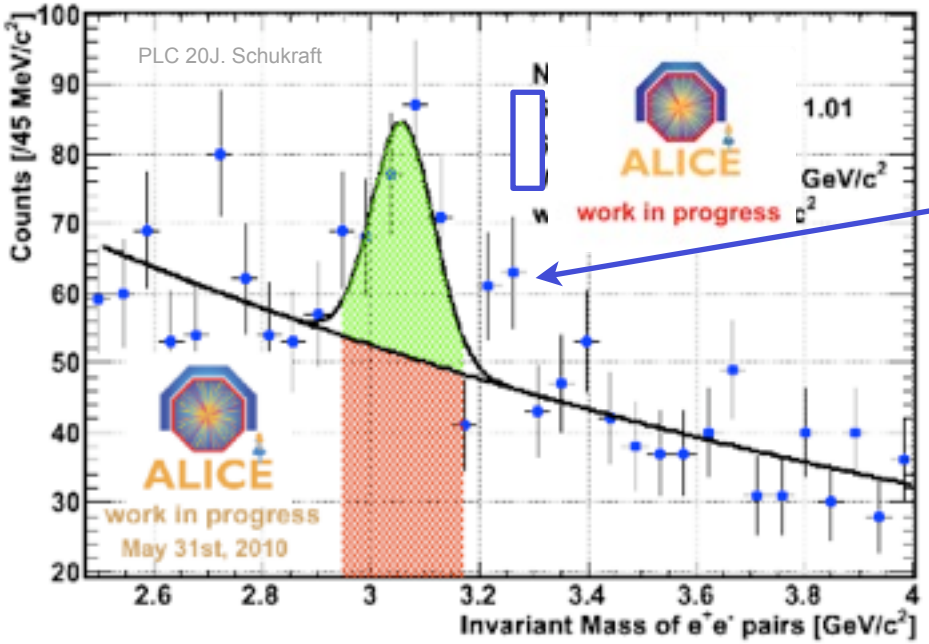




With only a few 10 Million events the charm mesons peaks are easily seen out to p_T > 2 GeV/c

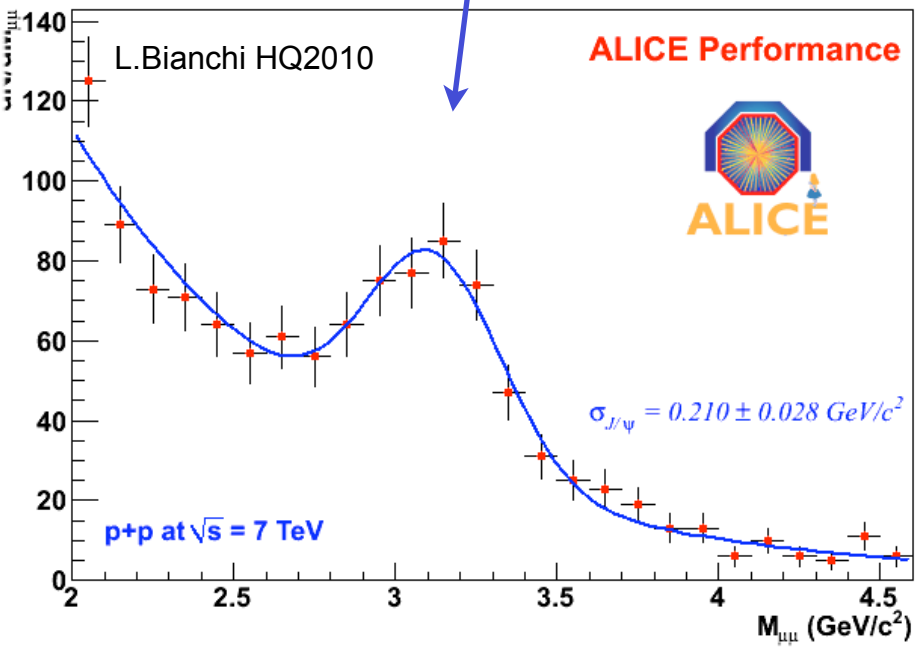
Even D* observed

Even quarkonia are showing up!



central barrel: $J/\Psi \rightarrow e^+e^-$

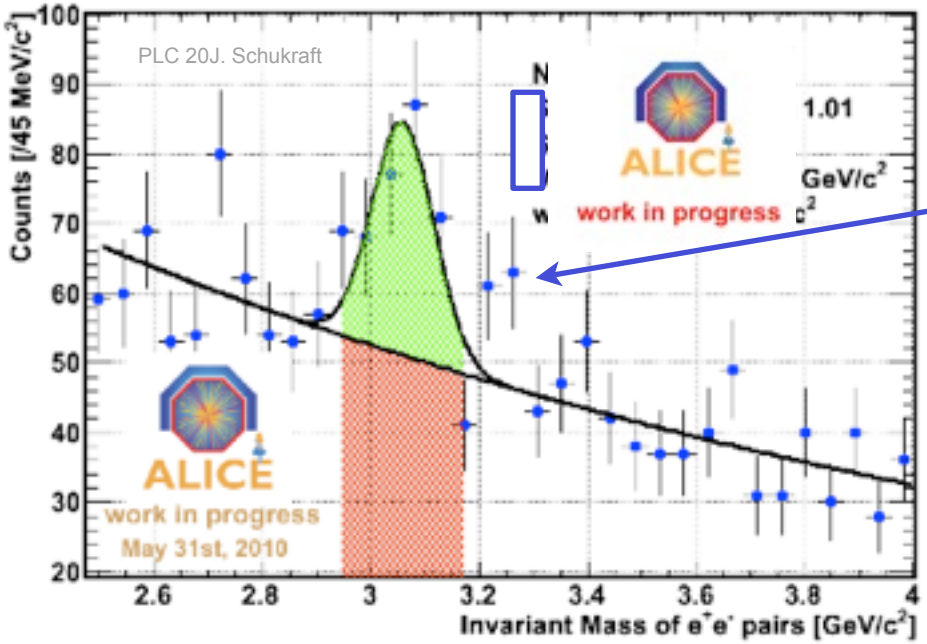
Muon arm: $J/\Psi \rightarrow \mu^+\mu^-$



Before alignment

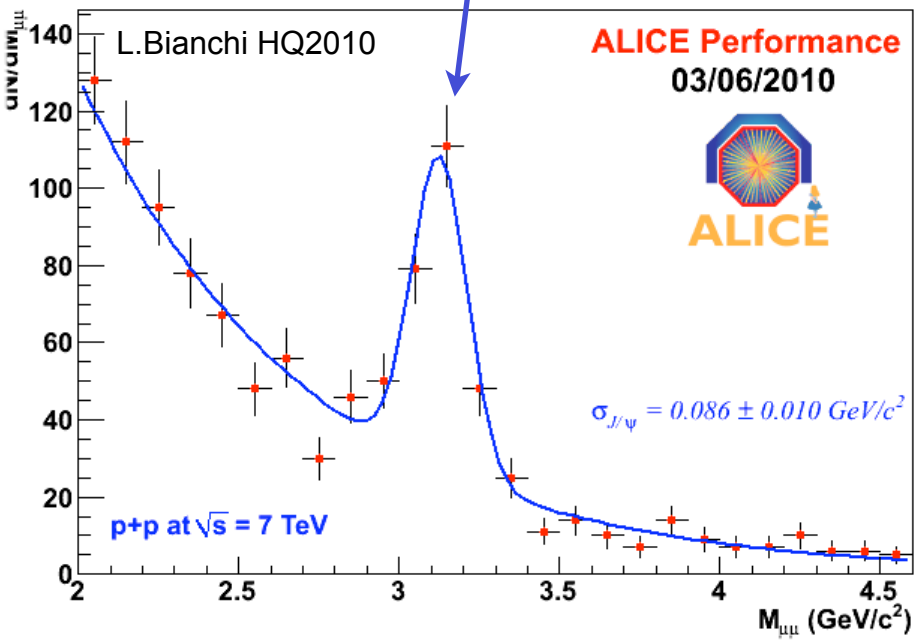
Starting to act like a particle physics experiment

Even quarkonia are showing up!



central barrel: $J/\Psi \rightarrow e^+e^-$

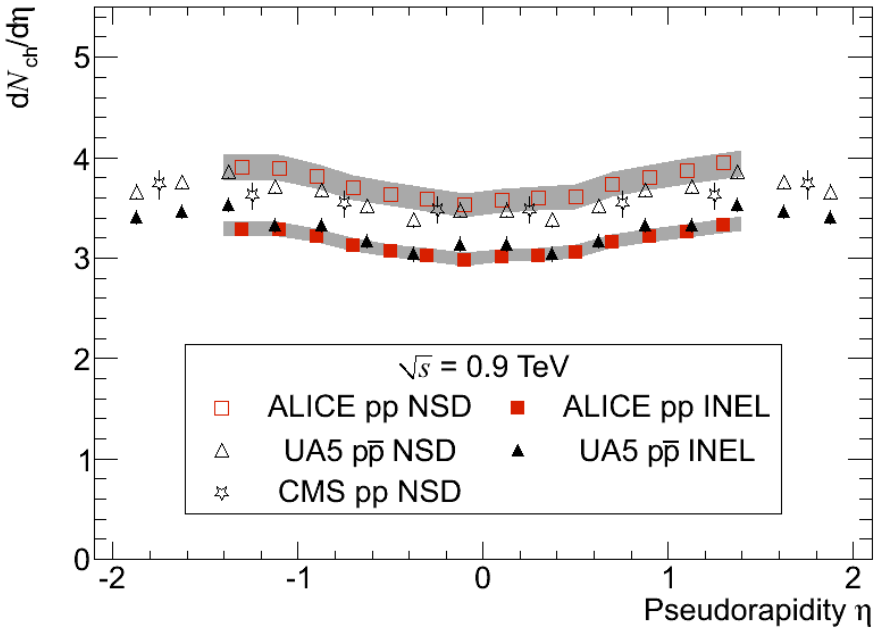
Muon arm: $J/\Psi \rightarrow \mu^+\mu^-$

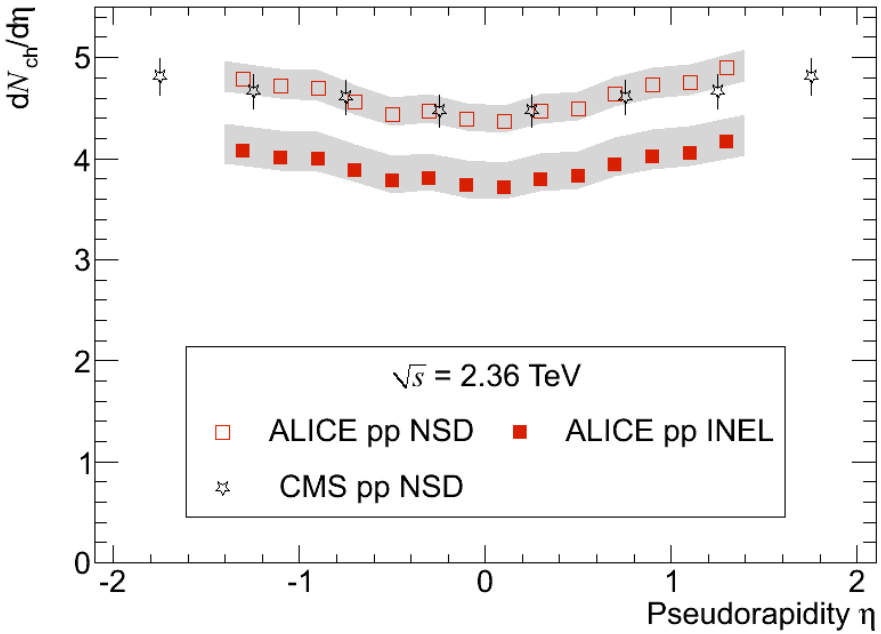


After alignment

Starting to act like a particle physics experiment

$dN_{ch}/d\eta$ at the LHC

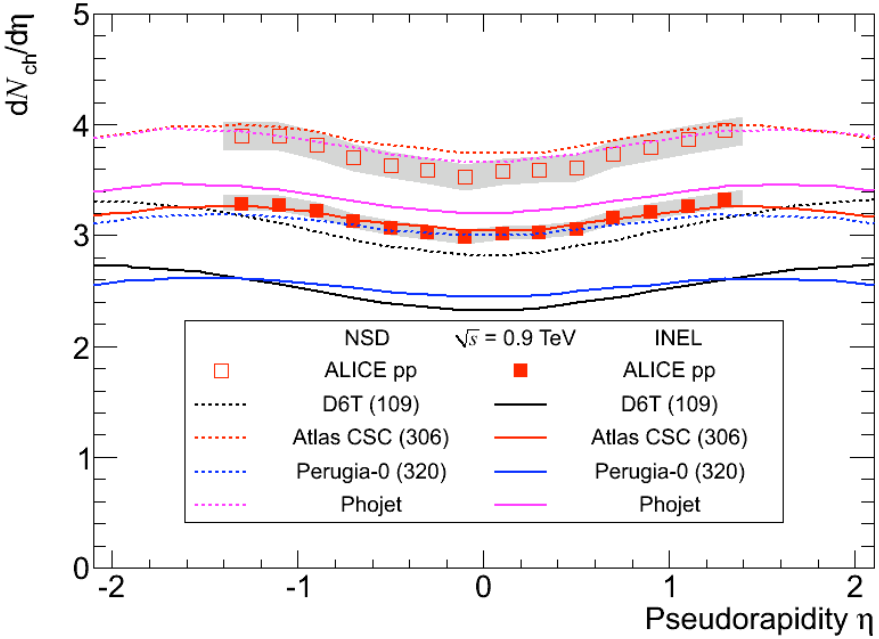


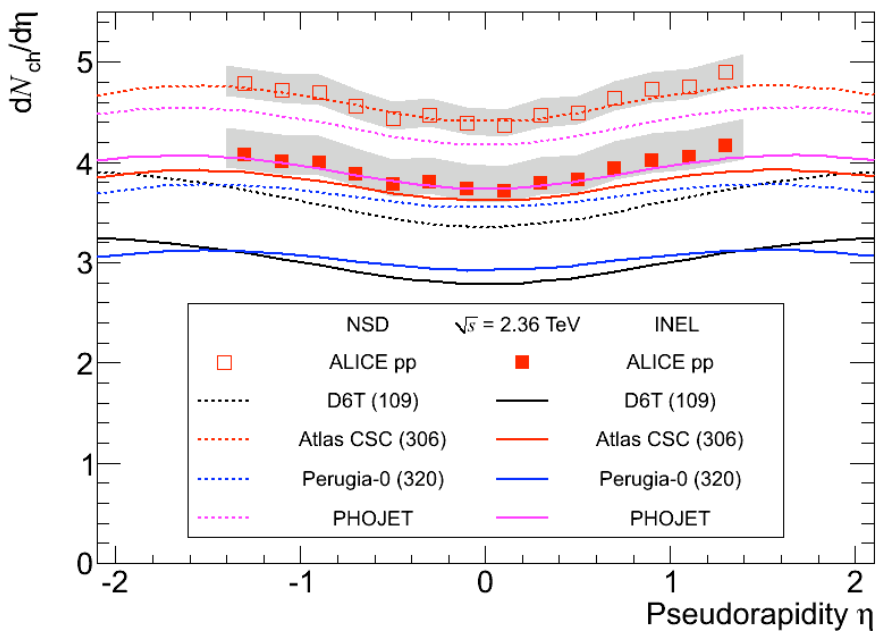


Good agreement across experiments

hep-ex:1004.3034(2010),. hep-ex:1004.3514(2010)

$dN_{ch}/d\eta$ at the LHC

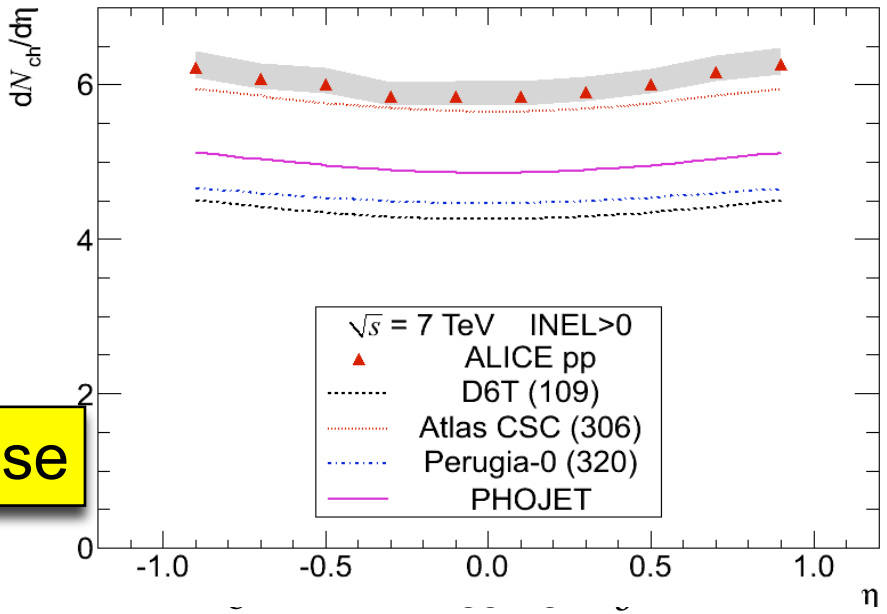




Good agreement across experiments

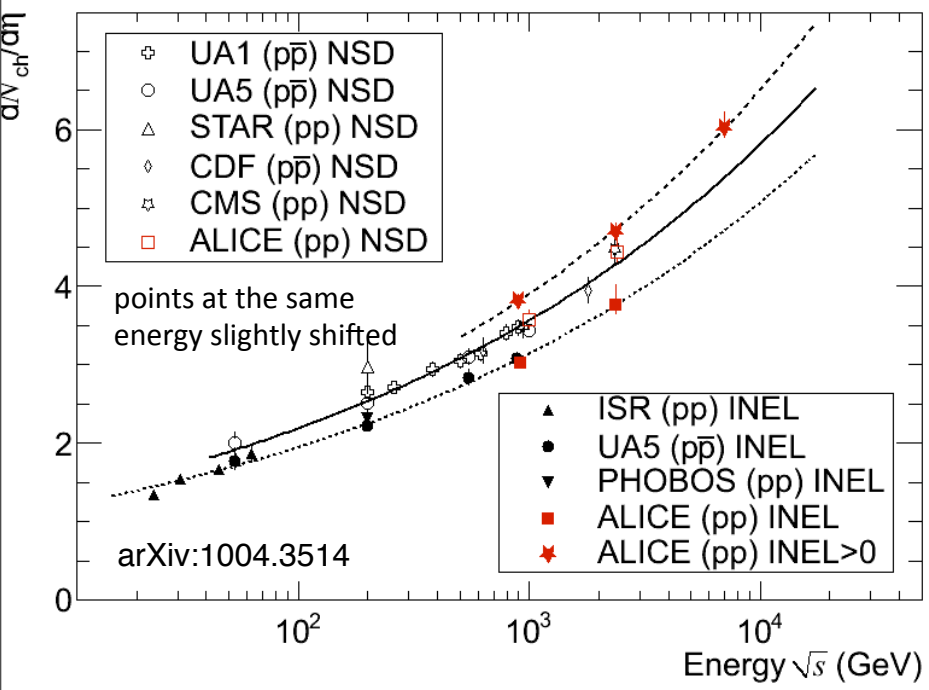
Theory generally has very poor agreement

Only PYTHIA "Atlas-CSC" close

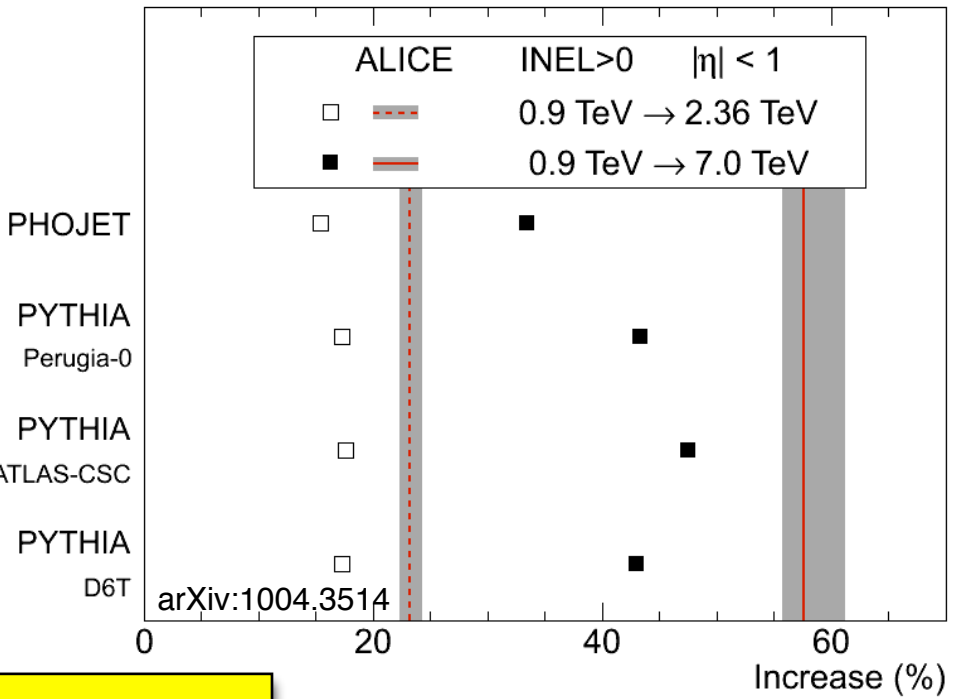


hep-ex:1004.3034(2010),. hep-ex:1004.3514(2010)

A closer look at the √s dependence



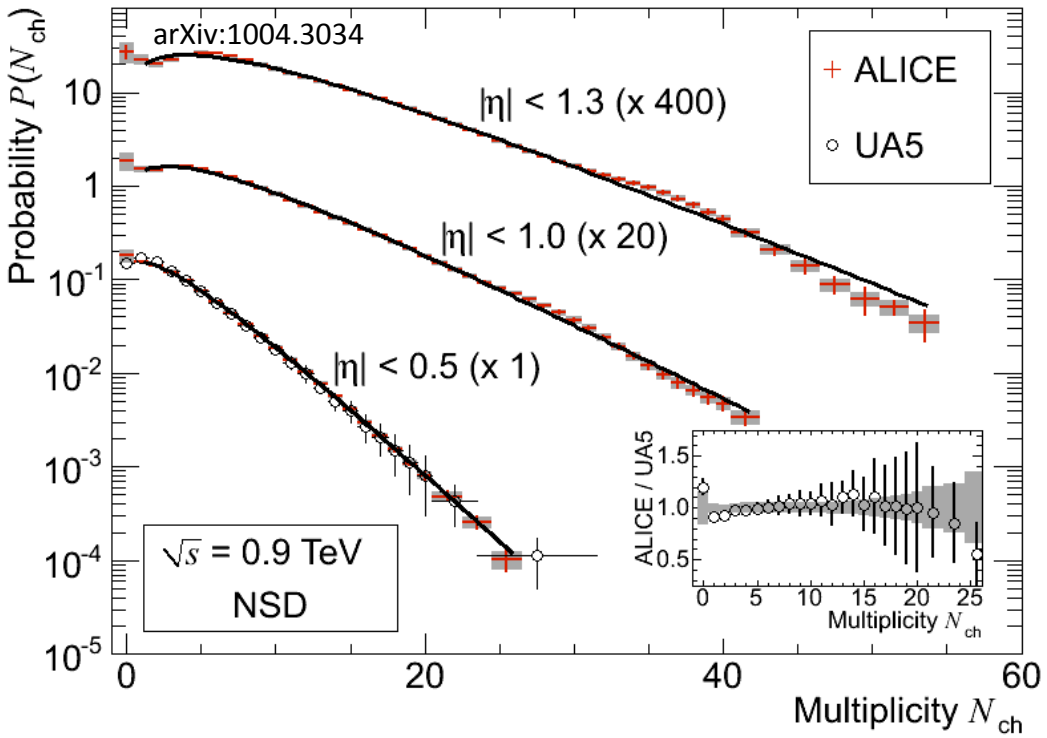
Data appears to have a power law dependence but as yet no real physics motivation for this

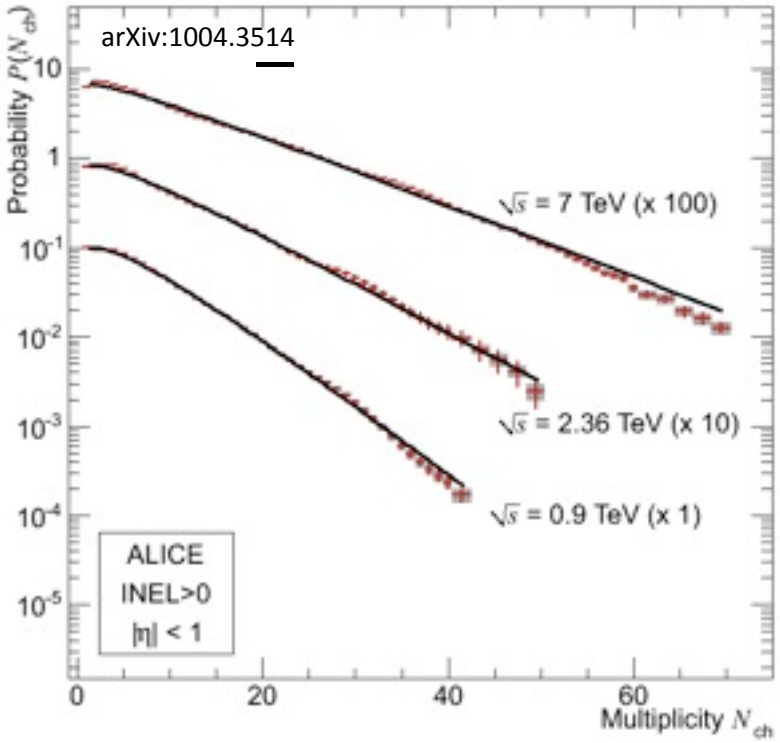


Even PYTHIA "ATLAS-CSC" doesn't get the % increase as function of collision energy correct

Some physics missing from all models

Multiplicity distributions





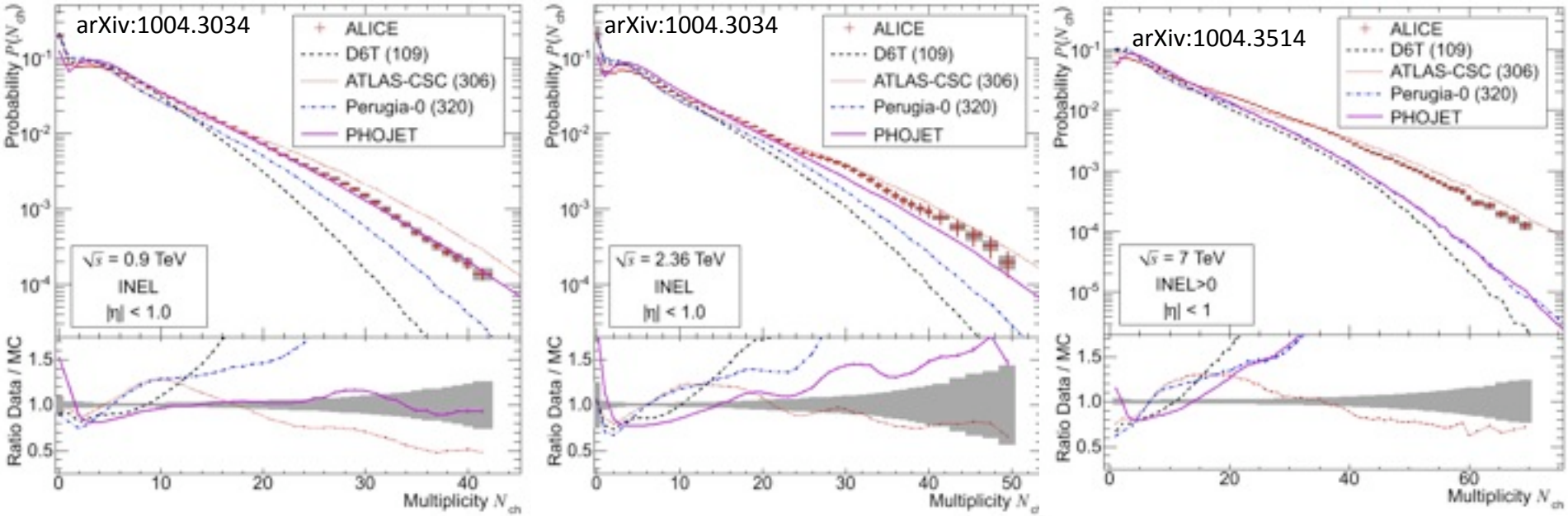
- Good agreement with UA5 (p-p at 0.9 TeV)
- Study at different rapidity changes
- Each data set can be fit by a negative binomial distribution

physics implications of this are still being investigated

- Also true for 2.36 and 7 TeV

Some events have > 90 particles produced at mid-rapidity

Modeling the multiplicity



An almost complete disaster!

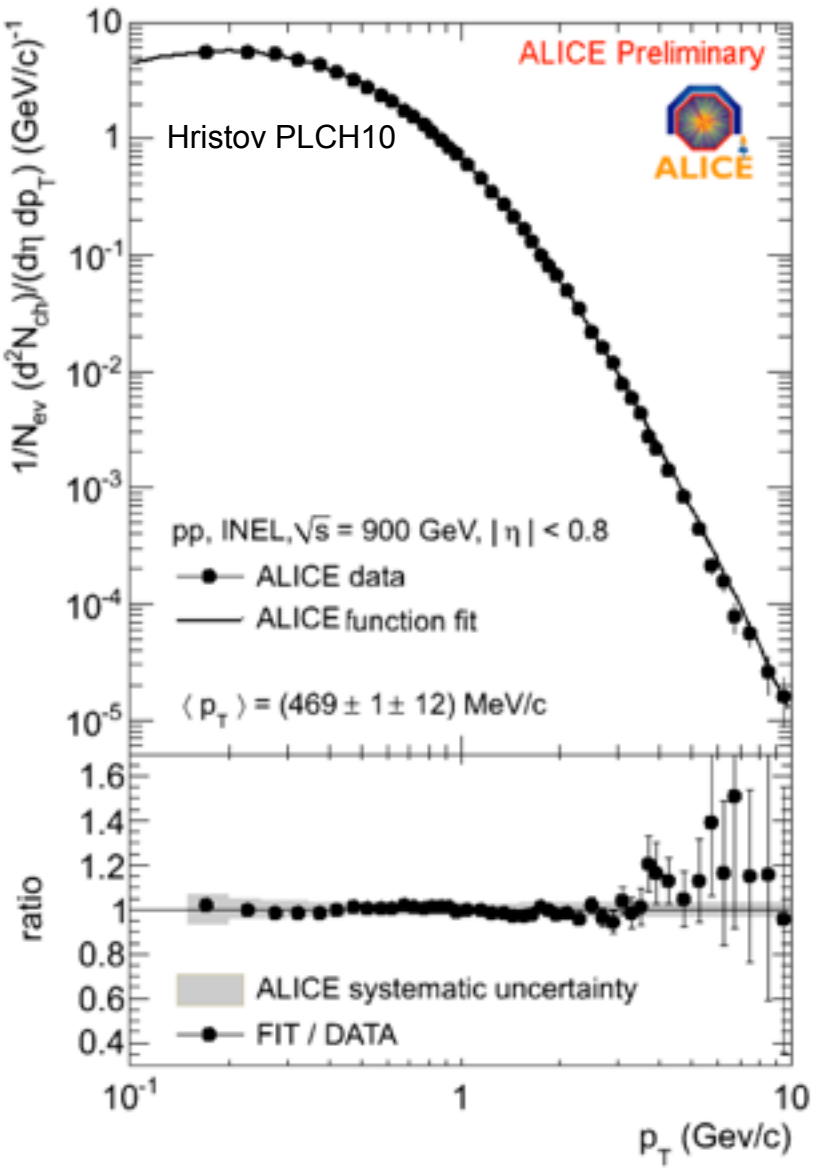
Event PYTHIA "Atlas-CSC" fails for the large multiplicities

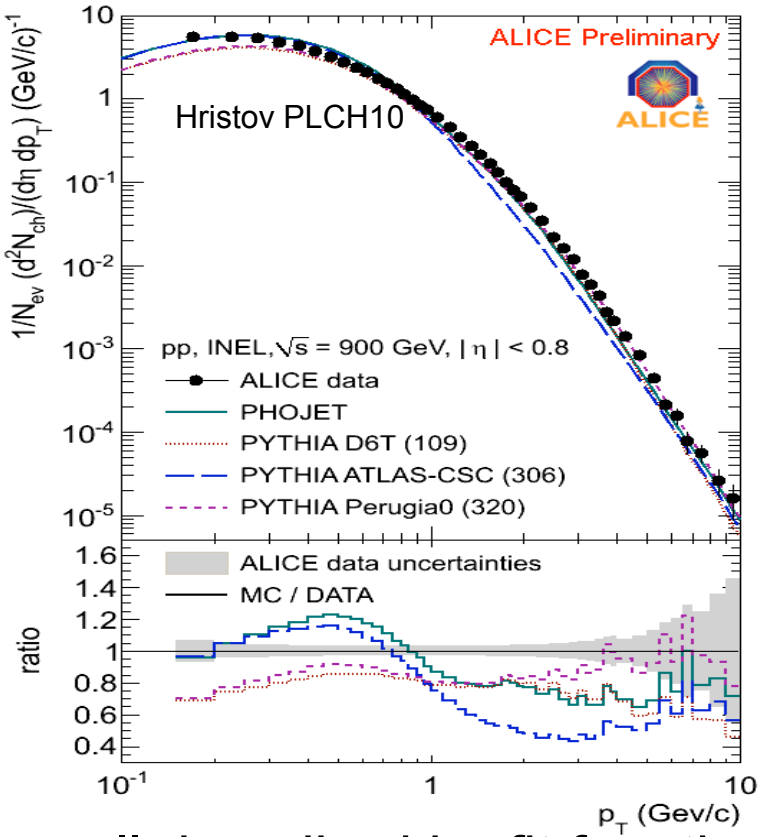
Other PYTHIA not even remotely close

PHOJET good at 900 GeV but totally wrong at 7 TeV

Remember all these models tuned to 1.8 TeV data

dN_{ch}/dp_T at $\sqrt{s}$=900 GeV





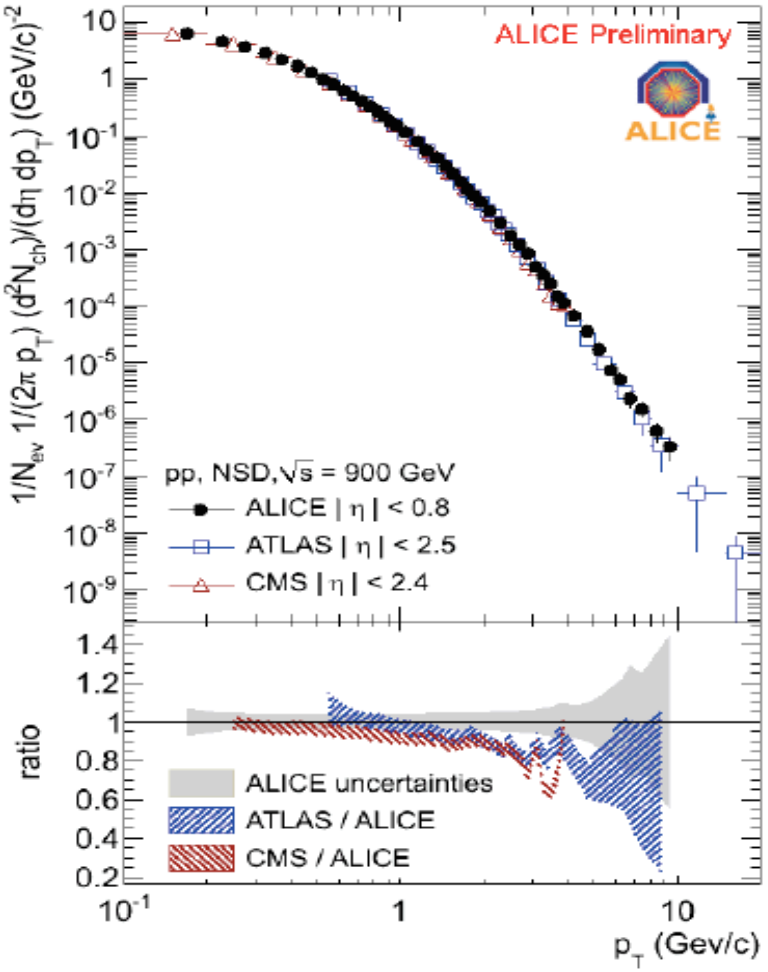
Data well described by fit function:

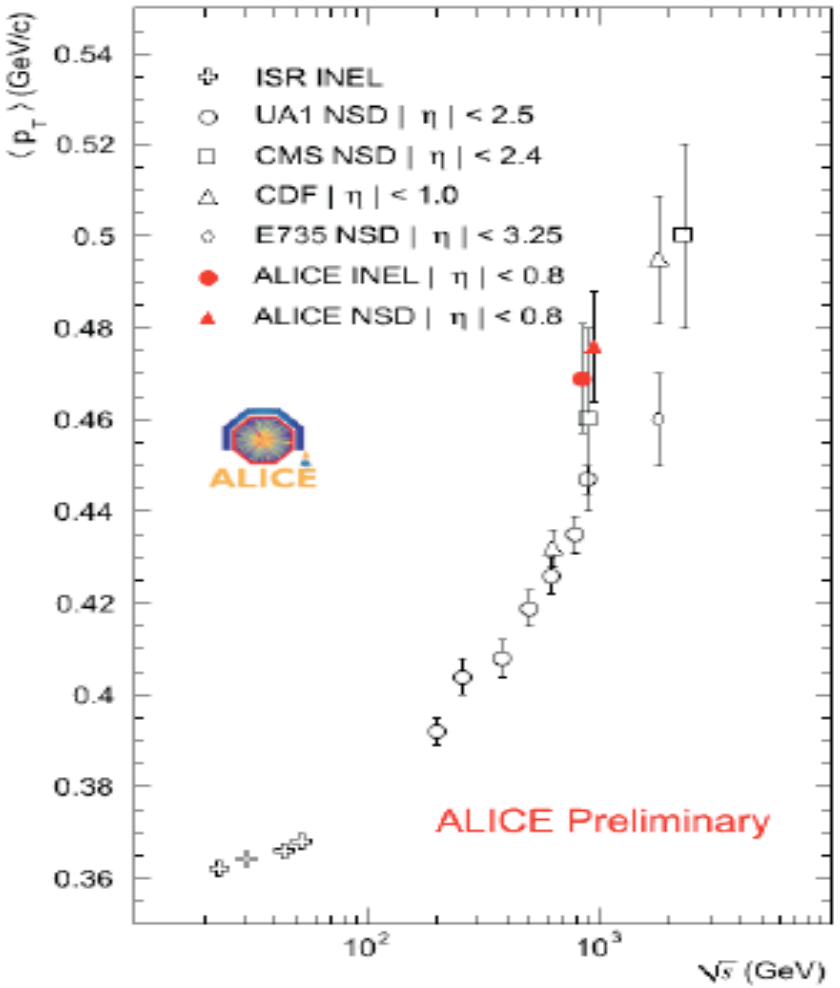
$$\frac{d^2N_{ch}}{d\eta dp_T} \propto p_T\left(1+\frac{E_T}{nT}\right)^{-n}$$

Models fail

Tuning needed!

dN_{ch}/dp_T across experiments

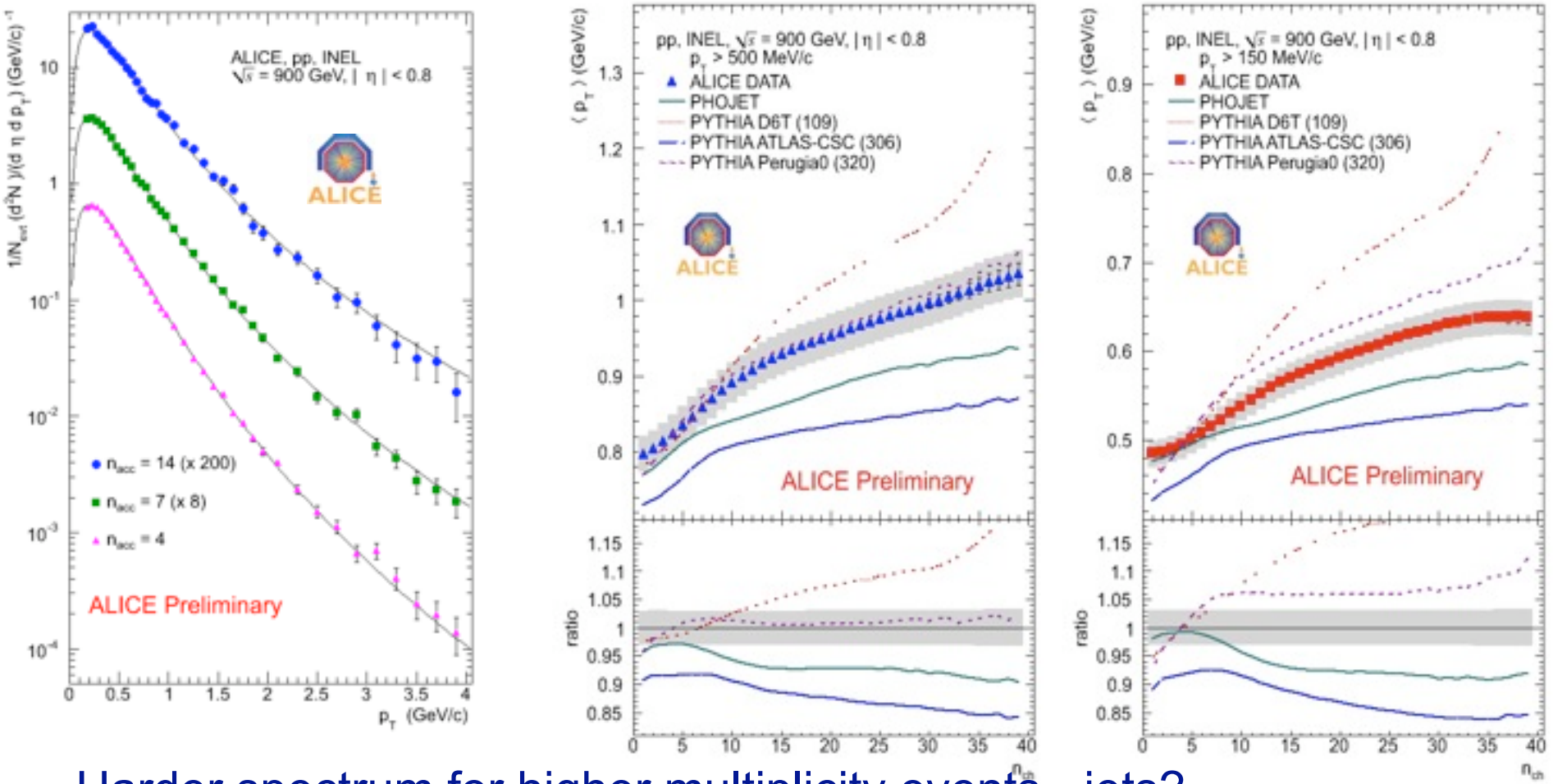




Good agreement for p_T<1 GeV/c
ALICE spectrum is harder

Due to narrower η acceptance?

dN_{ch}/dp_T as function of N_{ch}



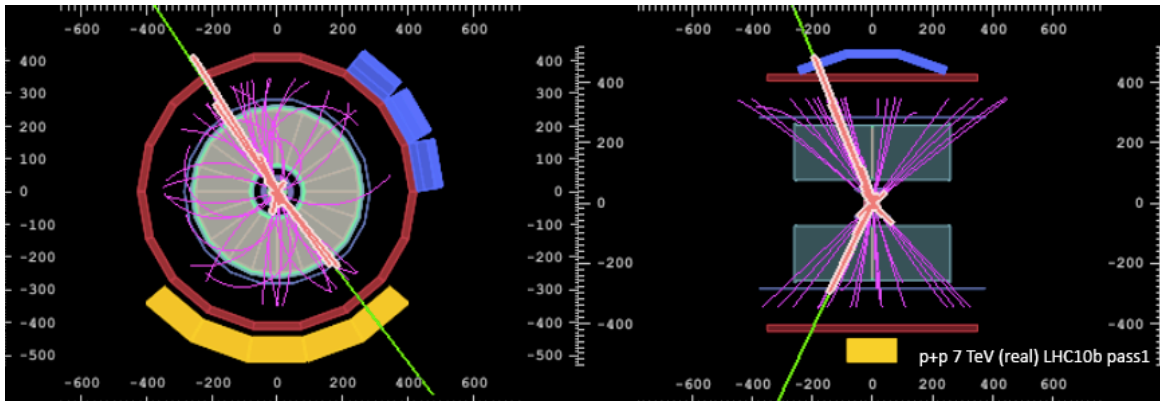
Harder spectrum for higher multiplicity events - jets?

No surprise the models don't work!

All experiments have suite of data for improved modeling

First jet measurements at ALICE

Jets are clearly seen in event displays by all experiments

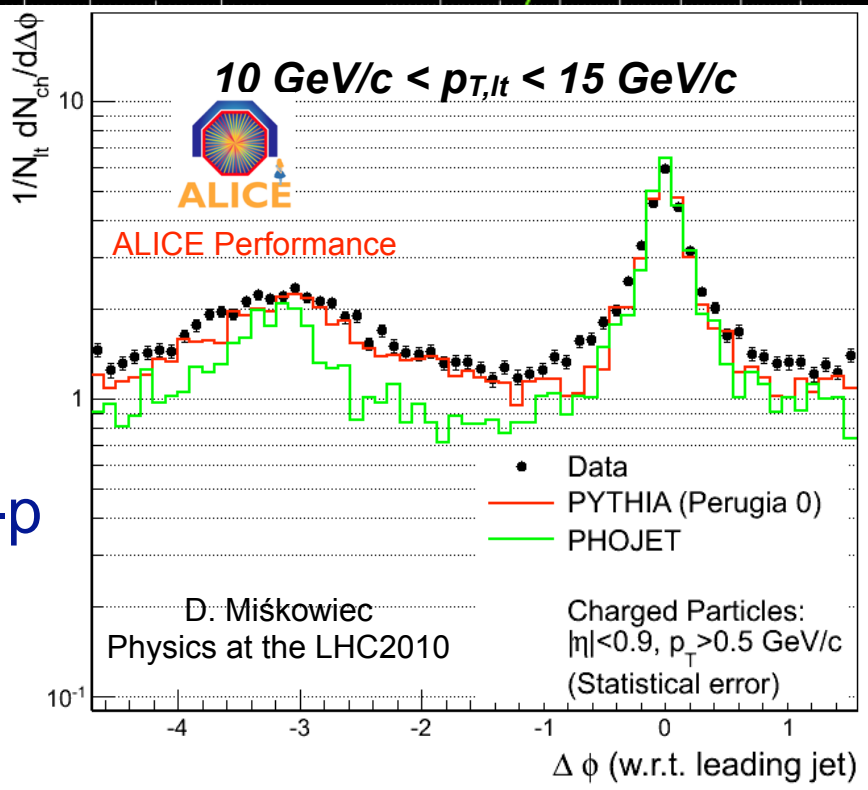


Full calorimeter not yet in place to allow complete jet reconstruction at ALICE

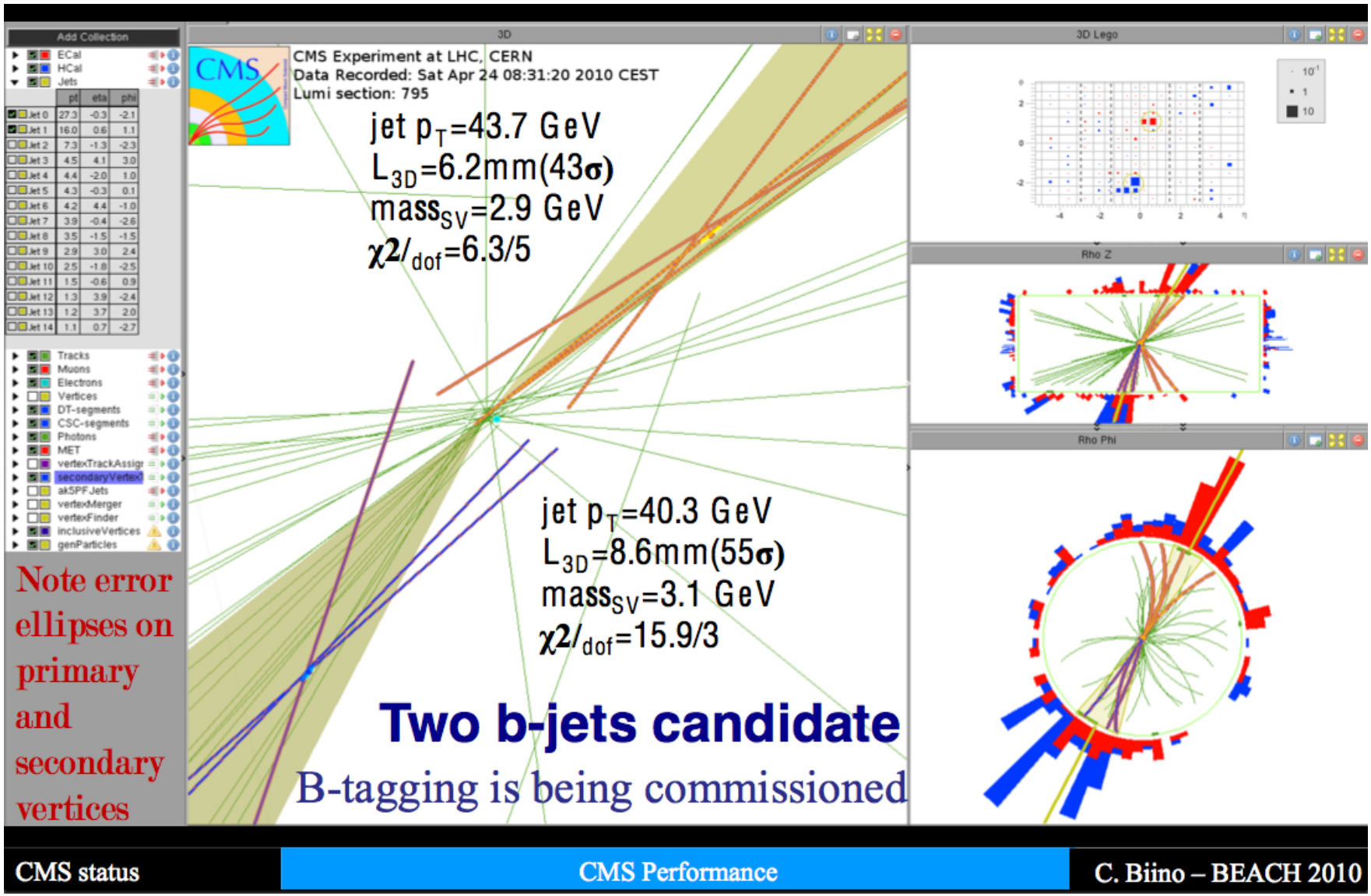
Clear near- and away-side peaks observed

Large underlying event even in p-p

Less “back-to-back” than monte-carlo predicts



b-jets at CMS


Add Collection
ECal
HCal
Jets
Tracks
Muons
Electrons
Vertices
DT-segments
CSC-segments
Photons
MET
vertexTrackAssig
secondaryVertex
ak5PFJets
vertexMerger
vertexFinder
inclusiveVertices
genParticles
3D
CMS
CMS Experiment at LHC, CERN
Data Recorded: Sat Apr 24 08:31:20 2010 CEST
Lumi section: 795
jet p_T=43.7 GeV
L_{3D}=6.2mm(43σ)
$mass_{SV}$=2.9 GeV
$\chi^2/_{dof}$=6.3/5
jet p_T=40.3 GeV
L_{3D}=8.6mm(55σ)
$mass_{SV}$=3.1 GeV
$\chi^2/_{dof}$=15.9/3
Two b-jets candidate
B-tagging is being commissioned
3D Lego
Rho Z
Rho Phi
Note error ellipses on primary and secondary vertices
CMS status
CMS Performance
C. Biino – BEACH 2010

Summary

The LHC is up and running successfully

The p-p data is being analyzed and already reveals surprises

The models of p-p collisions need some serious tuning

First Pb-Pb data is scheduled for November 2010

The QGP at the LHC is expected to be longer-lived and hotter than at RHIC

With the LHC and RHIC programs running in parallel the 2010‘s promise an exciting decade for Relativistic Heavy-Ion Collision Research