Experimental summary

S.Chekanov (ANL, USA)

September 25, 2010

40th anniversary!
(Not x_L)

International Symposium on Multiparticle Dynamics

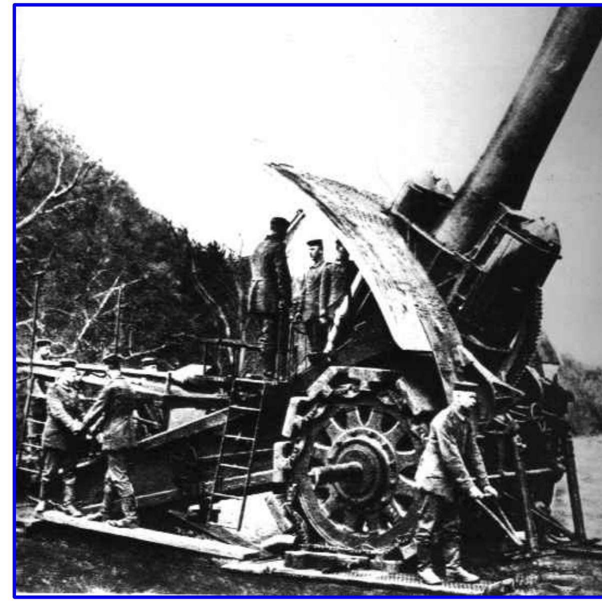
http://www.ua.ac.be/ismd2010

a lament.. 10 years back

Conclusions

a lament:

In war, there is always the temptation to think that some great new weapon will bring victory; one thinks of the V weapons from the later stages of WWII. In WWI, the armaments company Krupp produced a giant cannon that could send shells as far as Paris from behind the front line. This weapon had no effect on the outcome of the war despite the damage to buildings and the loss of life. One can imagine a multiparticle physicist visiting Big Bertha, as the gun was called, and asking the Director General of the Big Bertha Battalion how he knows if the gun is pointing in the right direction. The reply might be "I don't know, but it sure is a big gun!"



Brown University, Providence

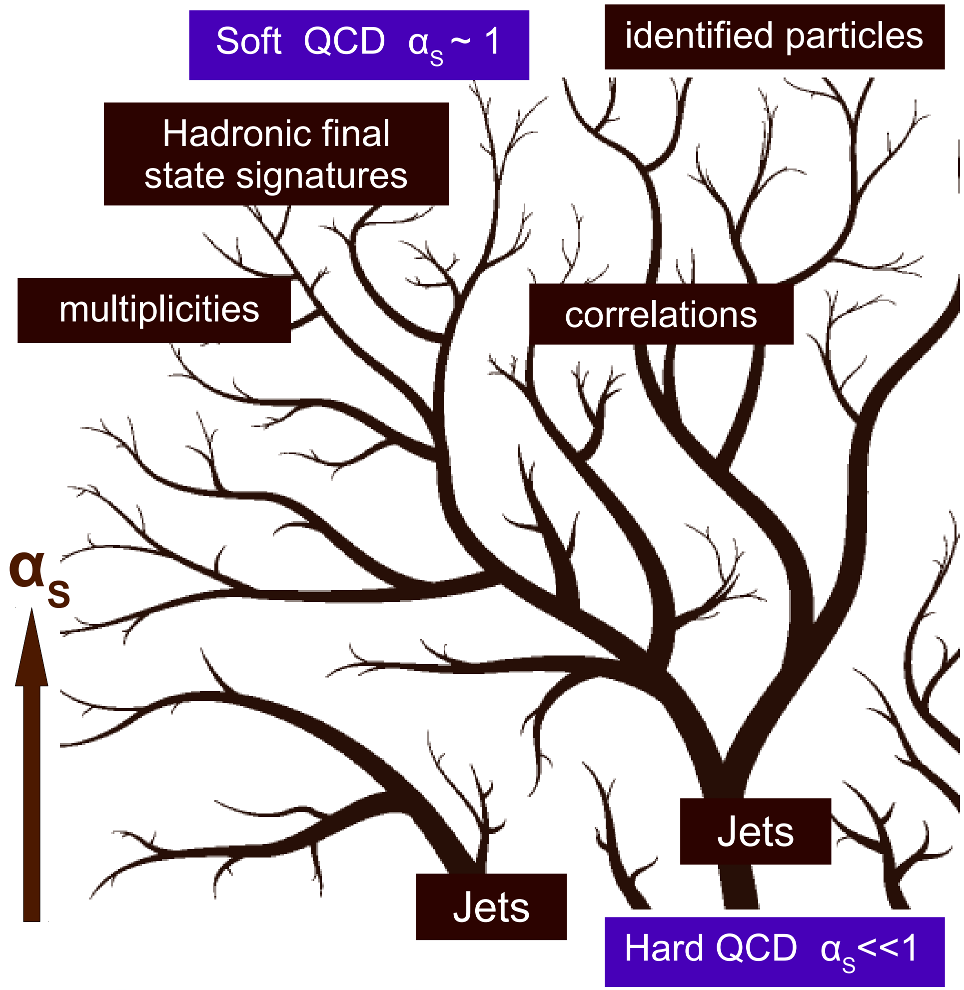
XXIX ISMD99, experimental summary by Malcolm Derrick (ANL)
August 9-13, 1999
Brown University, Providence, RI 02912, USA

A new beginning...

- **ISMD has a long and well established history of expertise in "early- LHC" measurements focusing on softQCD and interplay between hard and soft regions**
  - Multiplicities
  - BE correlations
  - Underlying event studies
  - Strange particles
  - Diffraction
  - etc., etc.
- **The main gateway to new physics at the LHC is through understanding of strong forces responsible for "multihadron production".**
- **This symposium is the main forum with the largest attendance of experts in this field, bringing together theorists and experimentalists to discuss the major issues in multipaticle production:**
  - QCD physics at the new energy frontier
  - mechanisms for particle production at highest pp-collision energies and test various particle-production models
  - Interplay between soft and hard QCD
  - LHPD hypothesis testing

Outline of ISMD10

- **Single-particle distributions**
  - Multiplicities, UE studies, diffraction
  - Strangeness production
  - Baryon asymmetries etc.
- **Two (and more) -particle densities and correlations**
  - Two-particle densities
  - Short and long range Eta-Phi correlations
  - BE correlations
- **Jets and high-pT EWK**
  - LHC,Tevatron/HERA: mature high-precision high-statistics results
- **Particle spectroscopy**
  - BaBar etc.
- **High-density matter**
  - RHIC. Heavy-ion studies

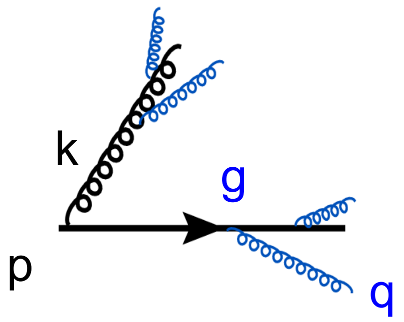


New energy frontier

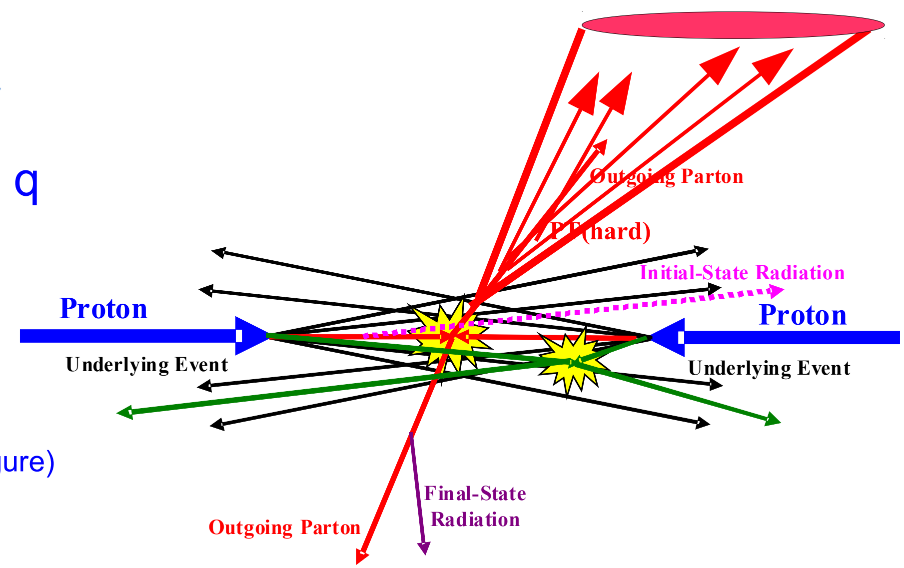
- With increased center-mass energies at LHC, we have entered regions with smallest momentum fractions "z=k/p" (largest probability for multihadron production)

$$dw(q \to q+g) \sim \alpha_s (k_T) [1+(1-k/p)^2] dk/k \;\; dk_T^2/k_T^2$$

- Extra jet at large angle with probability ~ $\alpha_S (k_T)$
- Probability soft/quasicollinear partons: ~ $\alpha_s (k_T) \log^2 E$



(based on R.Field's figure)



~ $\log^2$ E

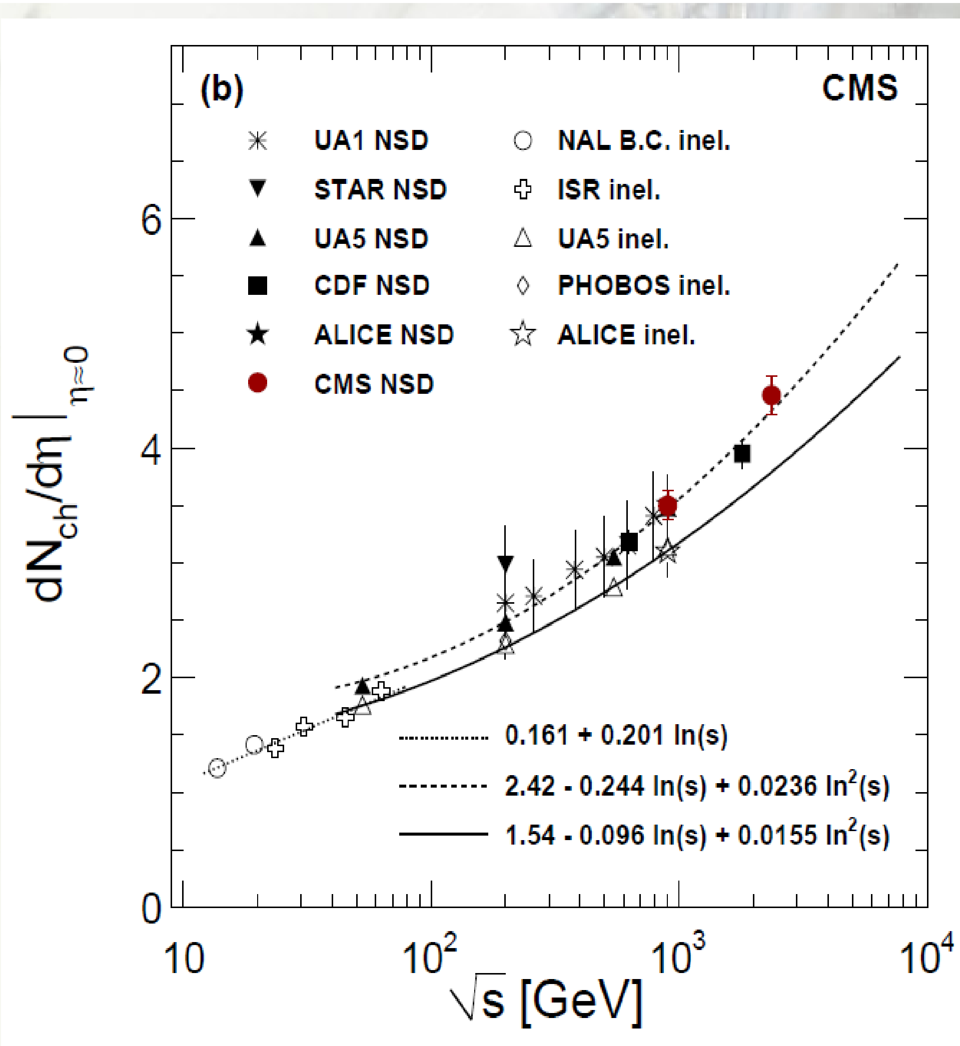
pQCD+LHDH

~ log(s)?

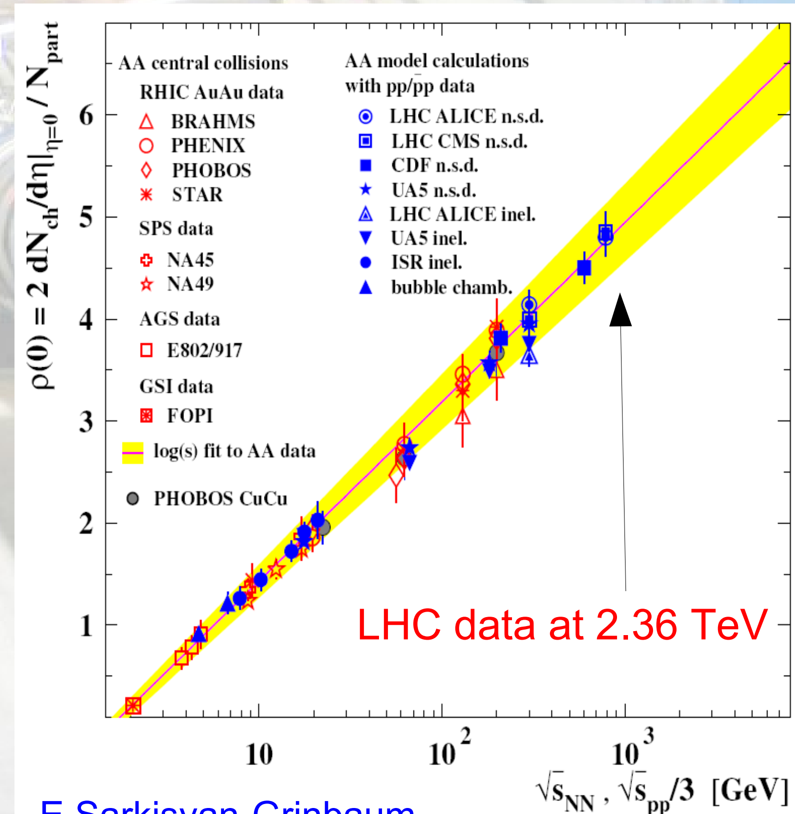
models, models..

- For MinBias events, LHC studies of multihadron final state is already on the front line with unknown. LHC is just about to enter highest-pT regions with smallest ever "z" for parton production and largest average multiplicities inside jets

New energy frontier

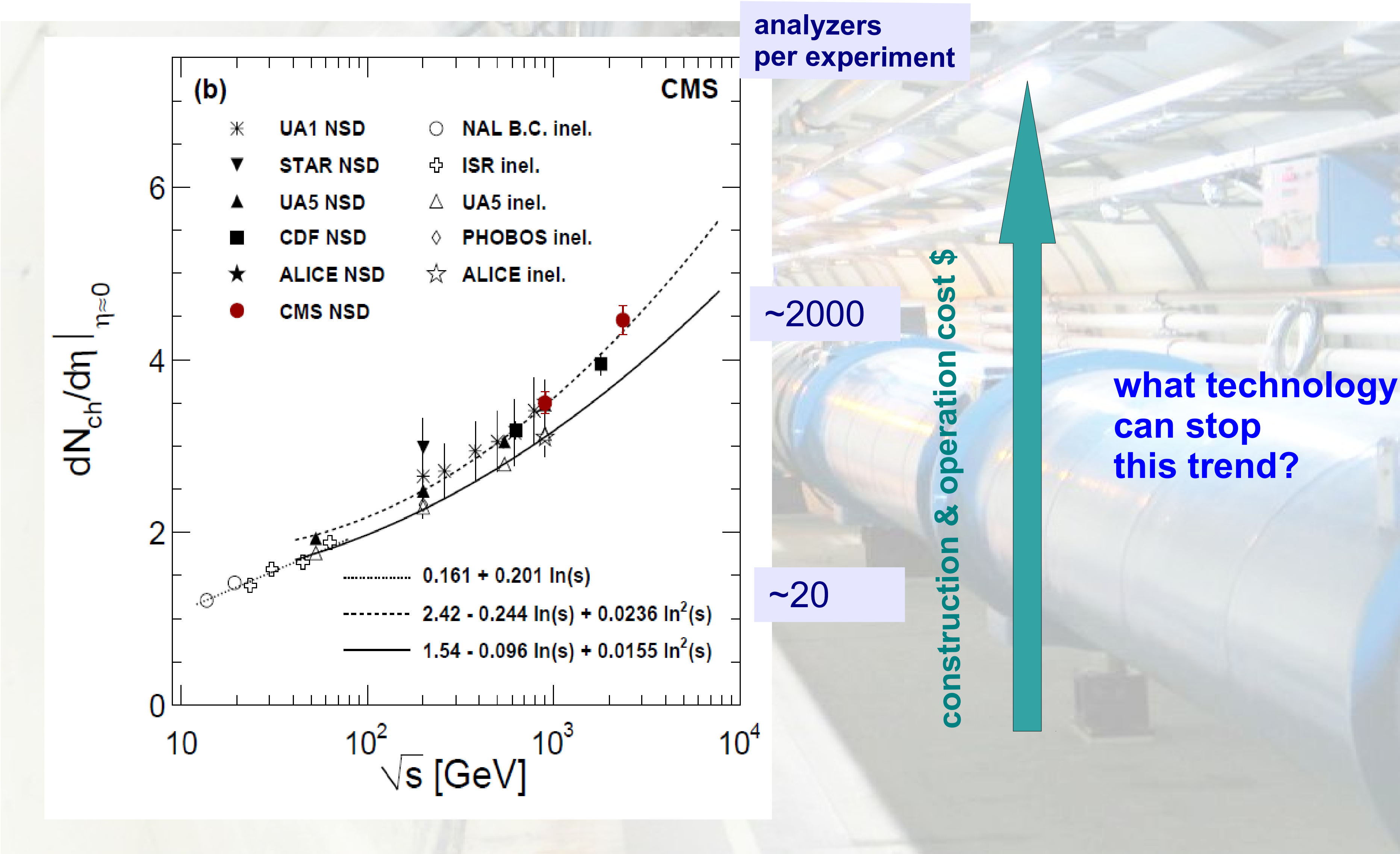


First LHC measurement constrains energy dependence for hh
.. and agrees with AA slope!

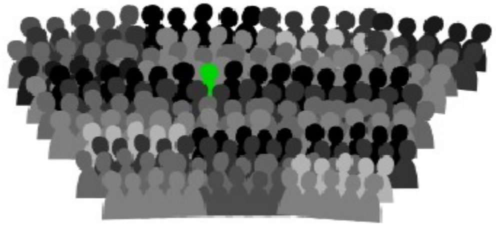


E.Sarkisyan-Grinbaum

New energy frontier



A new era in experimental HEP



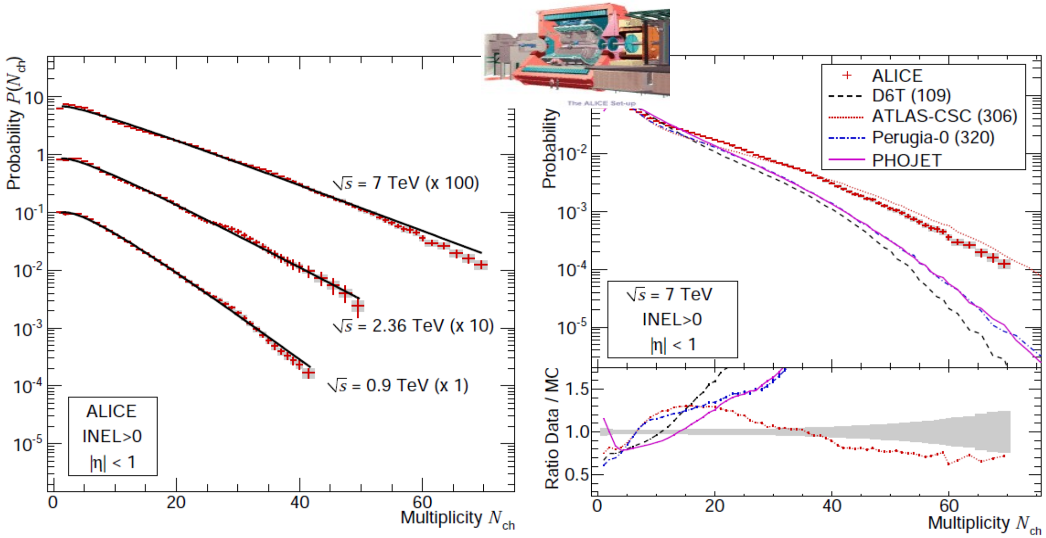
LHC experiments – not only **Multi-particle**, but also **“Multi-scientist”** experiments

- **Previously, a “typical” experimental paper could done by a few Ph.D. students.**
- **How to write experimental papers with 10, 20 or 50 analyzers?**
  - **usually scattered between multiple time zones**
  - **not well attached to experiment hosting laboratory**
  - **often remote communication**
  - **results are hard to attribute to a particular person, group of persons or even to a particular country**
  - **small chances for analyzers to present their results at major HEP conferences like this?**

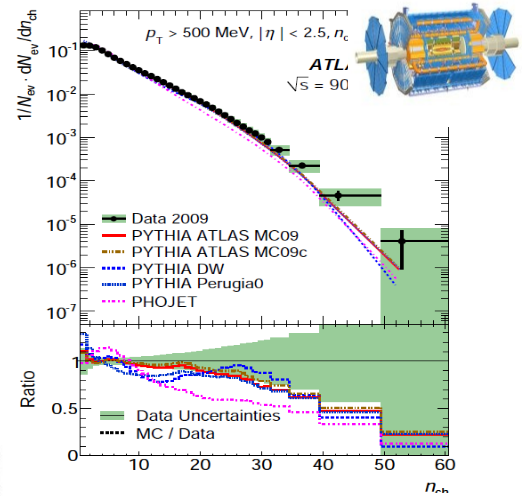
Results of this experiment is as interesting as the physics outcome!

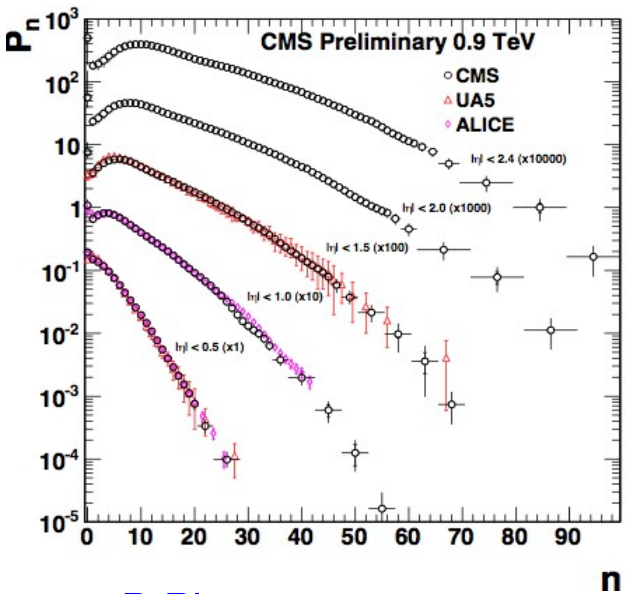
Single-particle densities

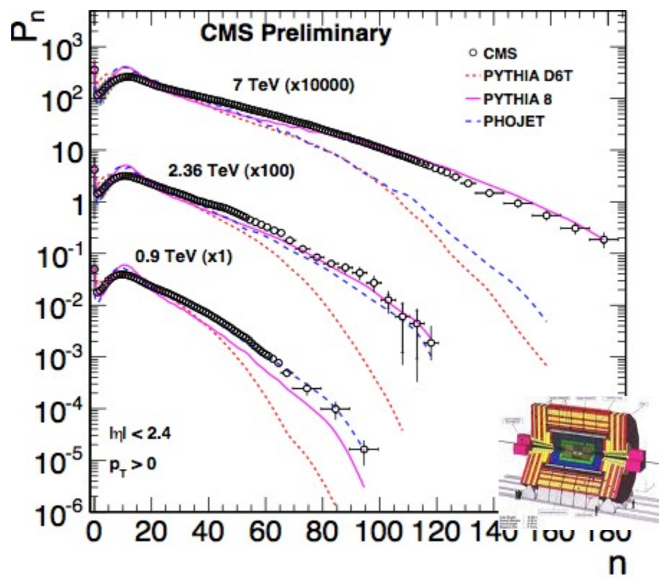
Charge-particle multiplicity measurements

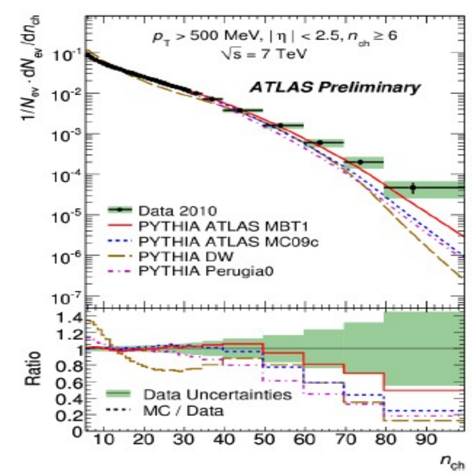


- Most model fail (below the data)









D Piparo

B.Wynne

Examples from the past

- Same discrepancies have been observed in early HERA and Tevatron experiments
- MC description is never perfect after entering a new energy frontier
- Only later tuning work helped to reconcile data and MC and move forward with "high-precision measurements"

1996

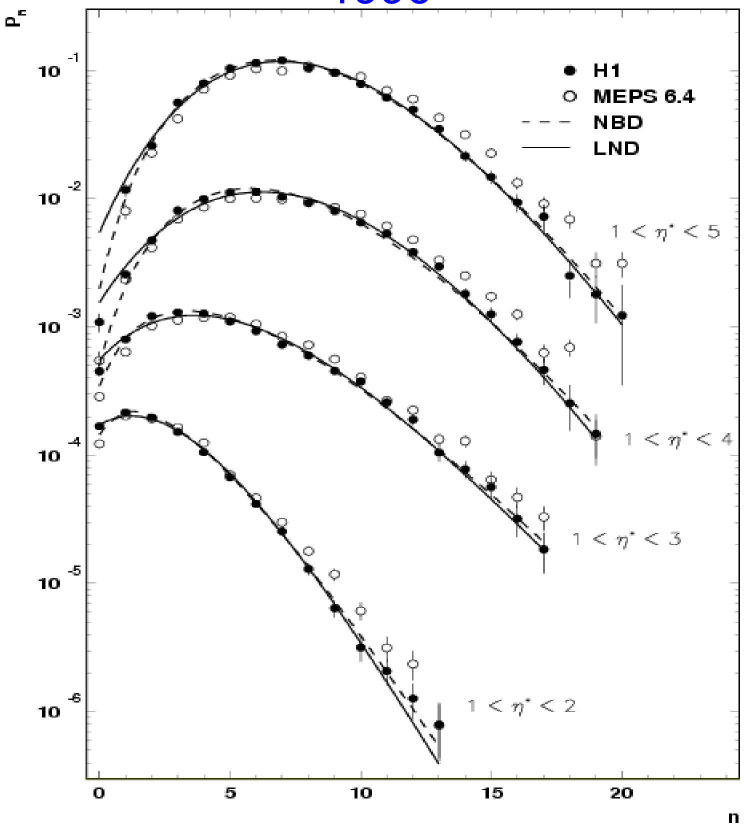
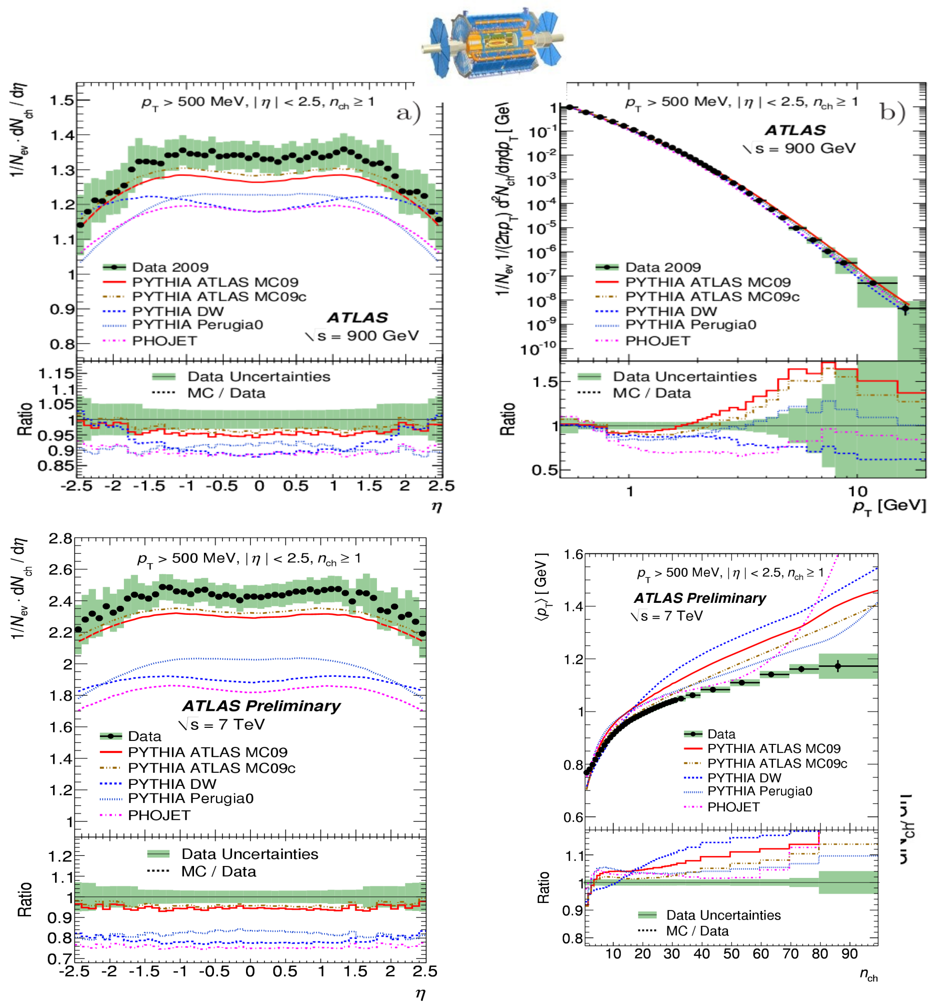
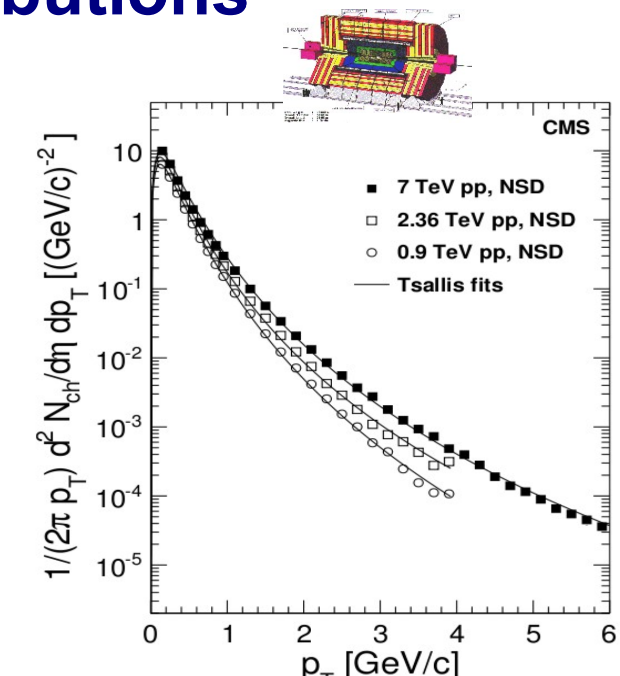
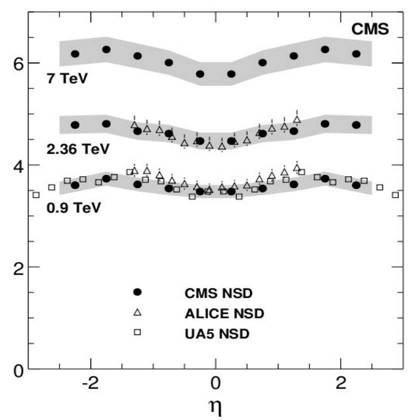


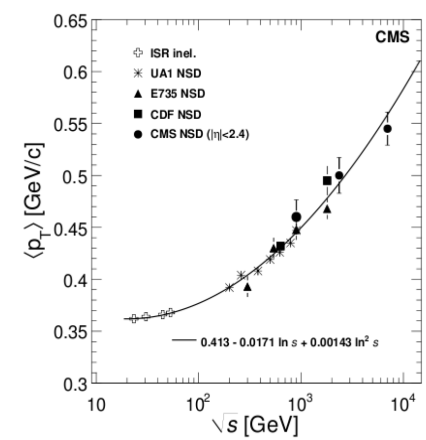
Figure 4: The unfolded multiplicity distribution in the interval 115 GeV $< W <$ 150 GeV and $Q^2 >$ 10 GeV^2, in indicated pseudorapidity domains. The distribution for $1 < \eta^* < 5$

Charge-particle distributions



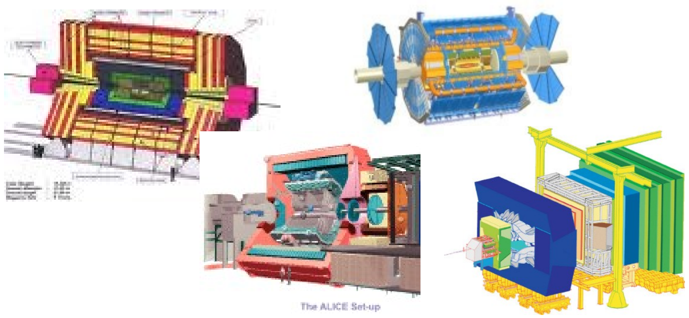


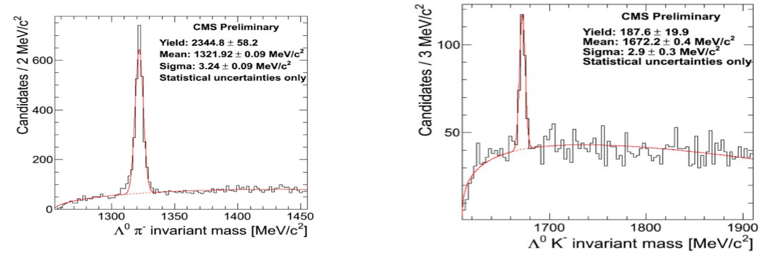


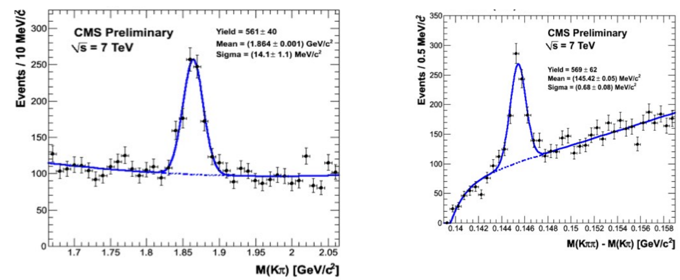


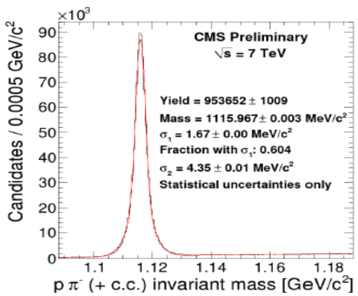
- MC failures to describe the data (ATLAS)
- Consistency with previous measurements (CMS)
  - + focus on "MC-less" approach

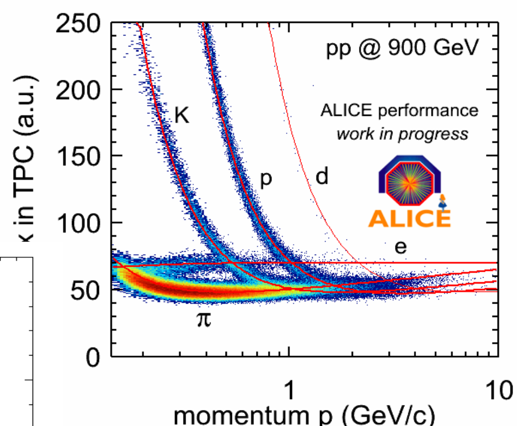
Multi, multi, particle experiments

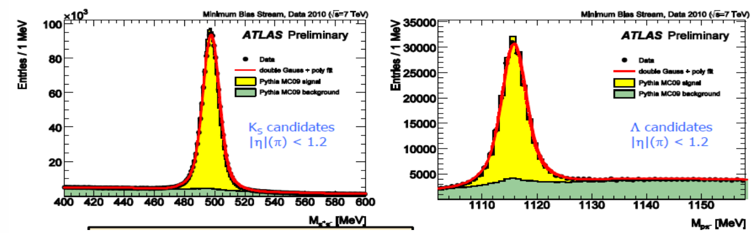


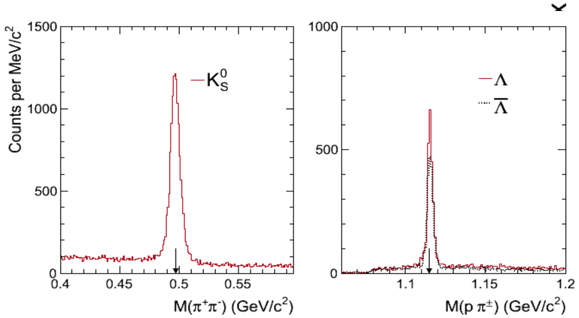


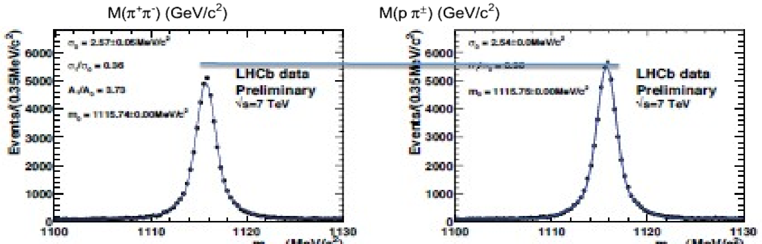




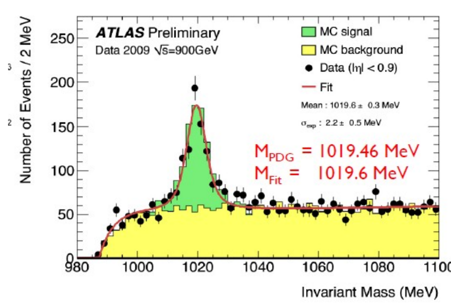








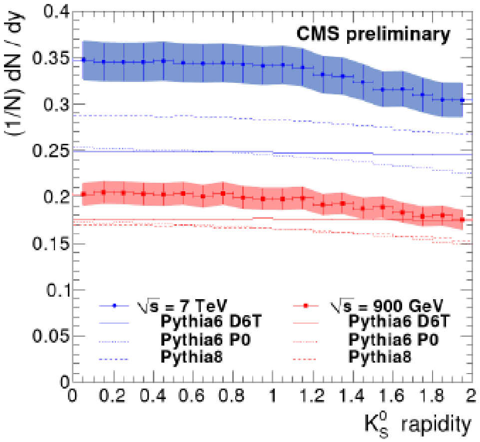
7 TeV

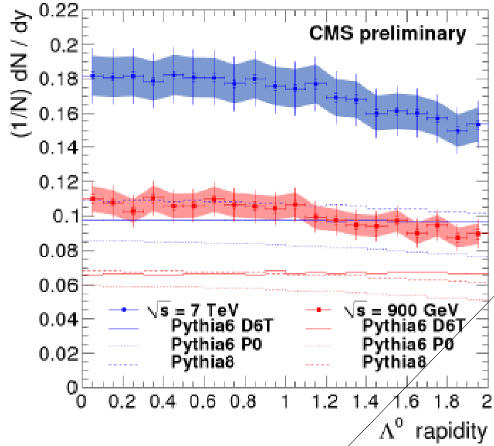


Strangeness and baryon production (CMS, ATLAS, LHCb, ALICE)

CMS:

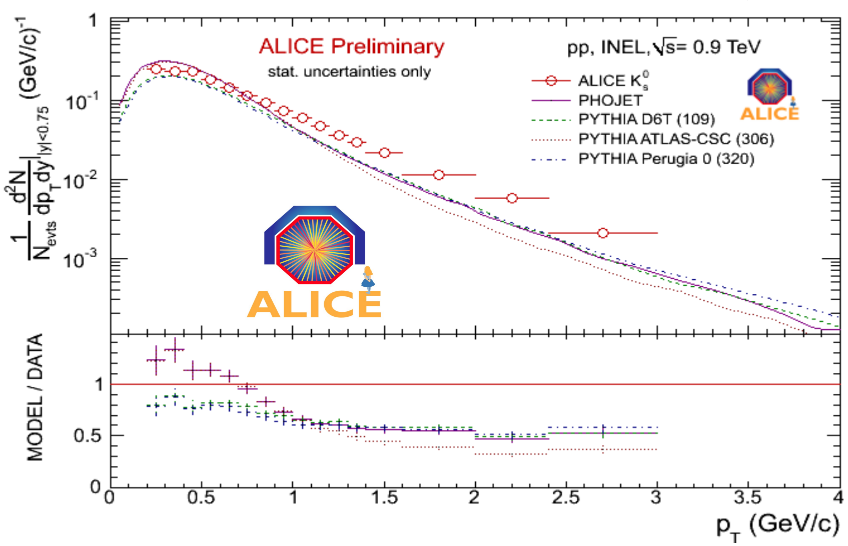
- Identification of strange hadrons
- Monte Carlo: Lower multiplicity
- Increasing CM energy and strangeness: larger discrepancy

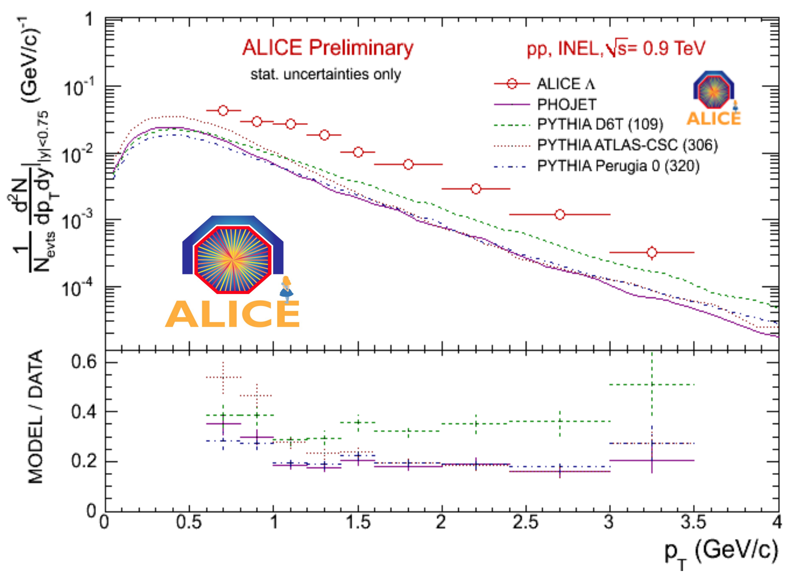




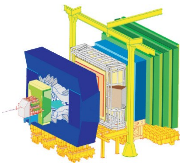
Same comment as for multiplicities:

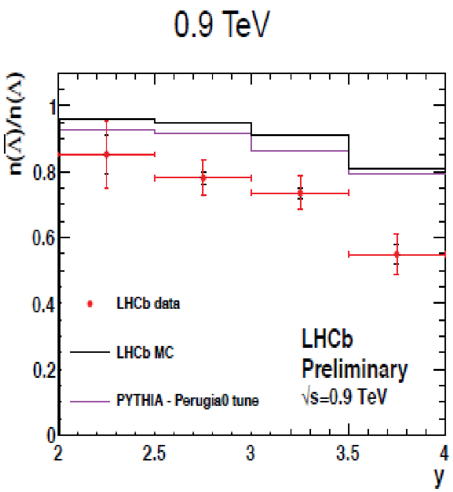
- no strong predictive power once entered new CM energies
- "energy" dependent parameters?

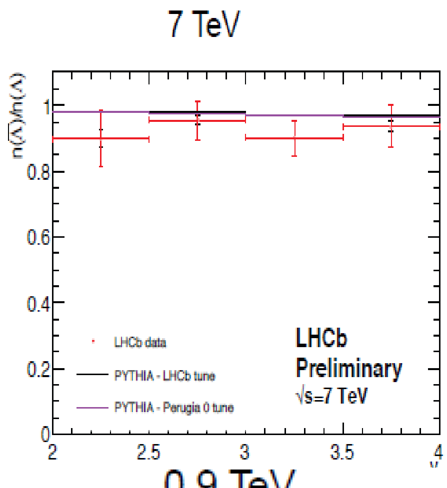


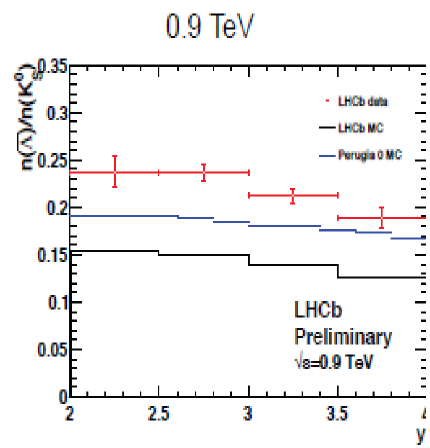


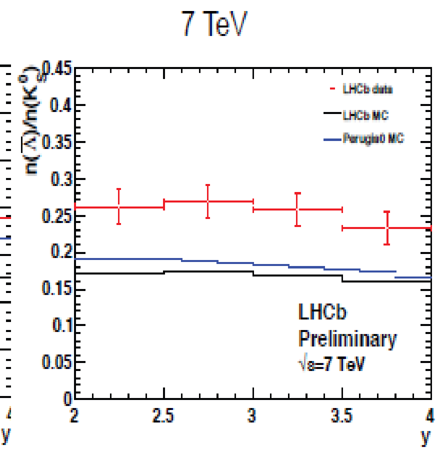
Baryon production (LHCb)



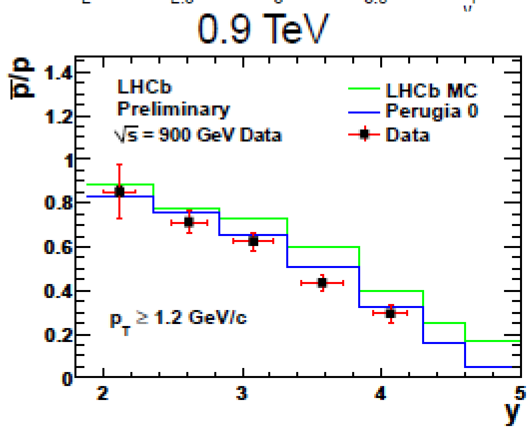


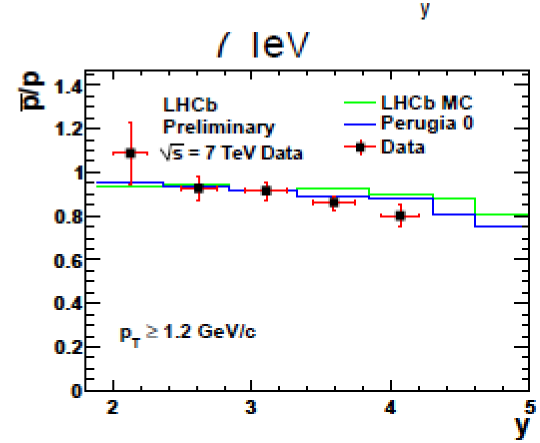






R.Muresan



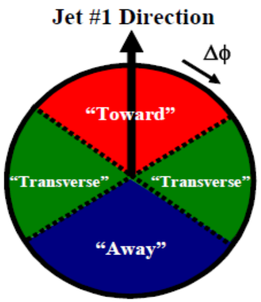


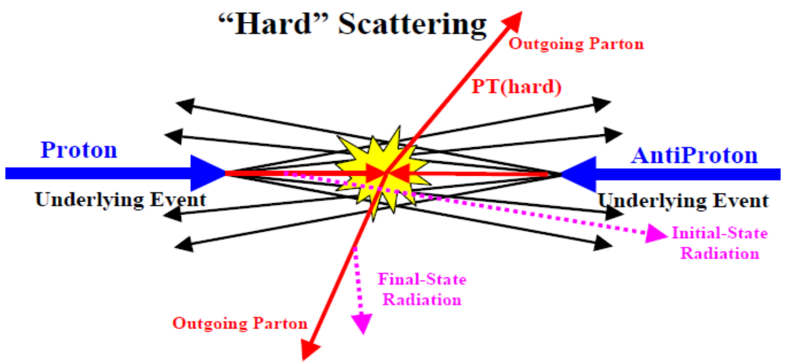
LHCb:
Ratio's LambdaLambda/K0s are wrong

P/barP ratios: good agreement with Peruja0
- precisely the MC which does <u>not describe MinBias data</u> for ATLAS/CMS!

UE studies

R.Field,
Acta Phys. Pol. B
36, No. 2 (2005) 167





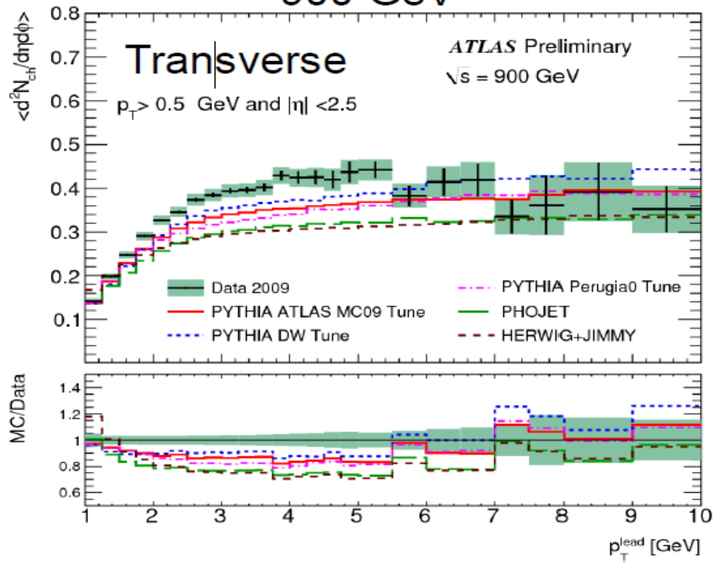
The "underlying event" consists of
- hard initial & final-state radiation
- beam-beam remnants
- possible multiple parton interactions

Fresh measurements from ATLAS/CMS!

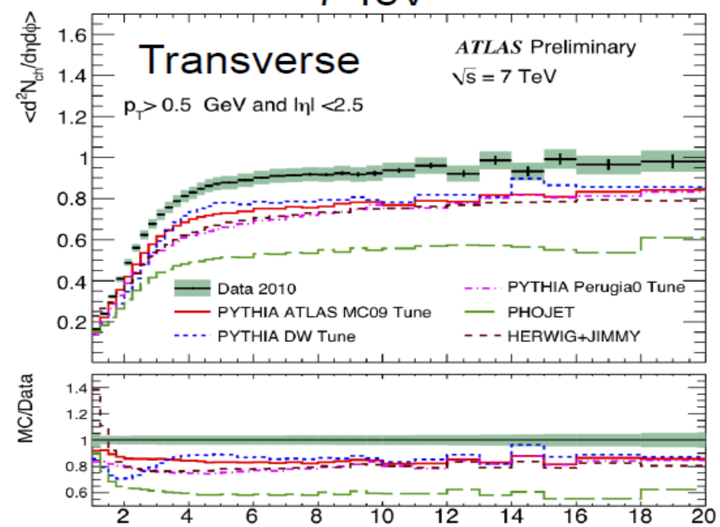
- **Suggested by R.Field as early LHC measurement**
- **Does not require jet algorithms (generally)**
- **Useful for:**
  - Understanding of energy flow around a leading jet
  - Energy flow in regions sensitive to underlying events ("transverse regions")
  - MC tunning

UE studies

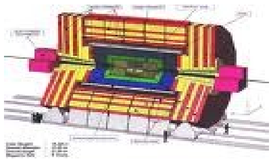
900 GeV



7 TeV

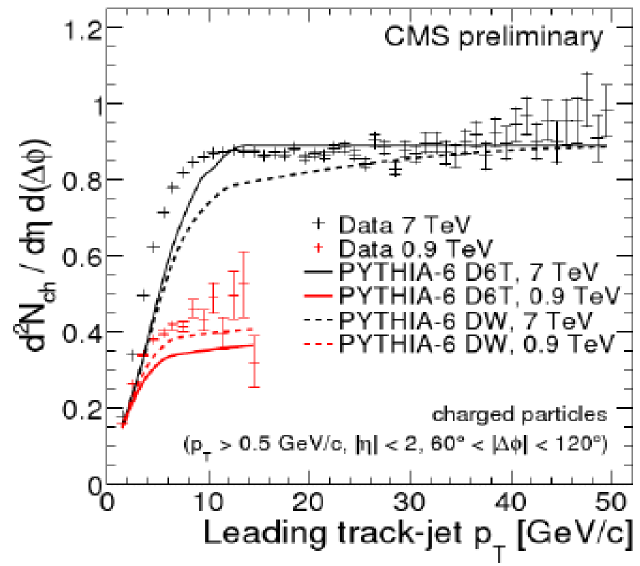


C.Buszello
D.Piparo



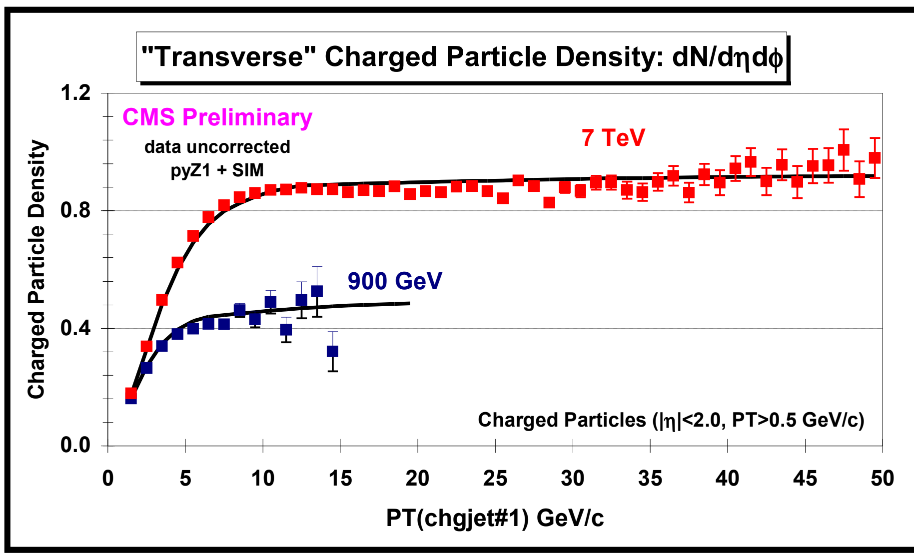
All tunes underestimate particle density by ~10-15% in the plateau region (ATLAS);
CW tune from CMS look better

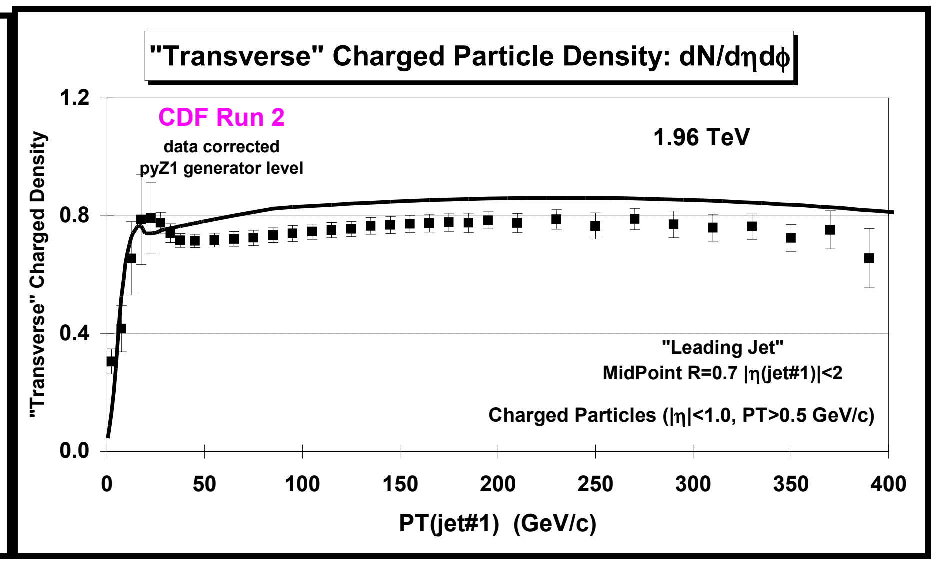
There is a factor of ~2 increase in activity going from 900 GeV to 7 TeV;
all tunes predict a comparable increase



UE studies

- ➔ Tune Z1 does nice fob of fitting the CMS and ATLAS UE data at 900 GeV and 7 TeV!
- ➔ But Tune Z1 is a little high at CDF (1.96 TeV)!





UE studies. Try to tune!

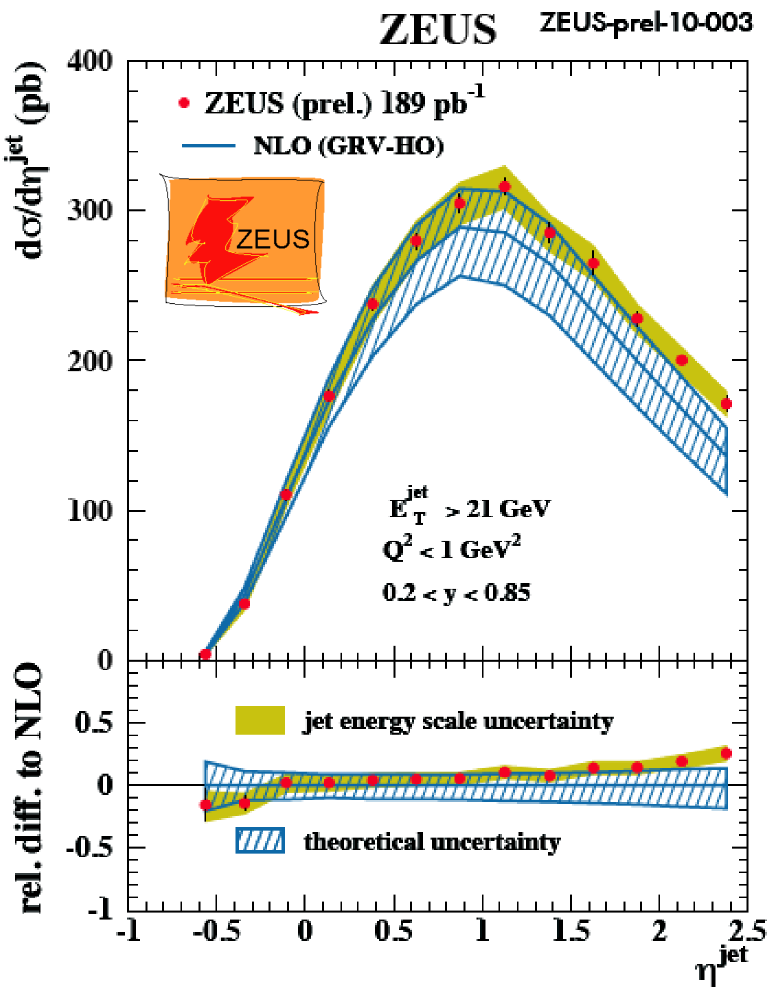
Parameter	Tune Z1 (R. Field CMS)	Tune AMBT1 (ATLAS)
Parton Distribution Function	CTEQ5L	LO*
PARP(82) – MPI Cut-off	1.932	2.292
PARP(89) – Reference energy, E0	1800.0	1800.0
PARP(90) – MPI Energy Extrapolation	0.275	0.25
PARP(77) – CR Suppression	1.016	1.016
PARP(78) – CR Strength	0.538	0.538
PARP(80) – Probability colored parton from BBR	0.1	0.1
PARP(83) – Matter fraction in core	0.356	0.356
PARP(84) – Core of matter overlap	0.651	0.651
PARP(62) – ISR Cut-off	1.025	1.025
PARP(93) – primordial kT-max	10.0	10.0
MSTP(81) – MPI, ISR, FSR, BBR model	21	21
MSTP(82) – Double gaussion matter distribution	4	4
MSTP(91) – Gaussian primordial kT	1	1
MSTP(95) – strategy for color reconnection	6	6

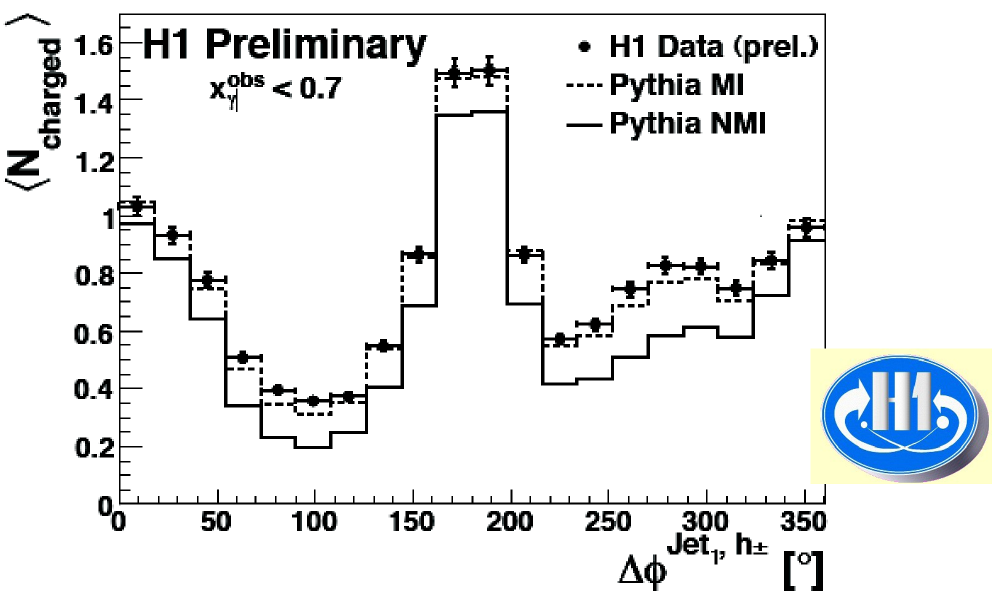
Can we a simpler description than THIS?
(UE observable can be fitted with analytical function with 2-3 free parameters!)

Getting a grip on MI

H.Jung (ZEUS/H1)

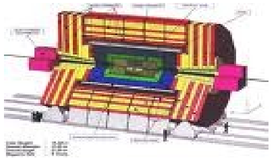
- Can MI be disentangled and studied in a simpler process (ep?)
- MI not needed for jets pT>21 GeV (but might be needed for lower pT!)





Pythia+MI is in agreement for charged-particle densities!
But alternative PS (CCFM) without MI is closer to data than Pythia (without MPI)
→ **PS dependence!**
→ **MI is needed, but its size depends on factorization scheme!**

Diffraction



Diffractive processes are non-trivial part of σ(pp)

- Currently dominant uncertainty for luminosity measurements
- Introduce uncertainty for MC tuning
- Hard component is not well known

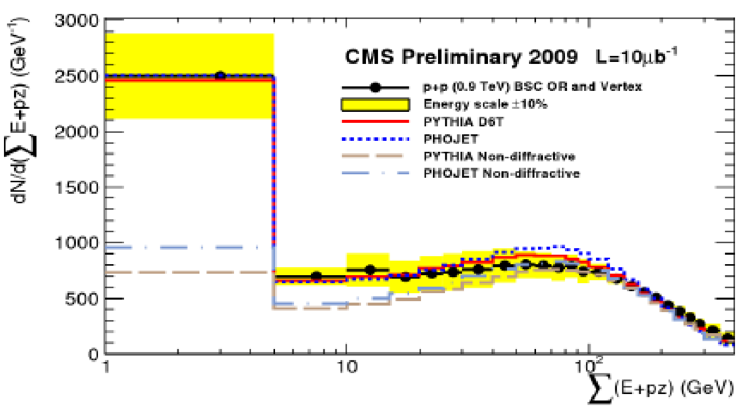
$$\sigma(pp) = \sigma(el) + \sigma(ND) + \underbrace{\sigma(SD) + \sigma(DD)}_{\sim 30\%(\text{inel})}$$

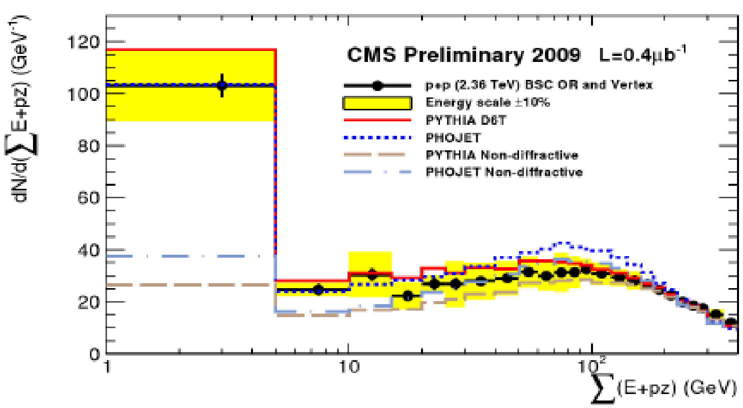
Diffraction observed in two ways:
1) peak at low ξ values and 2) presence of a Large Rapidity Gap

Current measurement: ξ=Sum(E-pz) (runs over all CAL energy depositions)
- related to the momentum loss of the scattered proton

- Evidence of SD peak
- Dominant Uncertainty: Jet Energy Scale
- Pythia describes better non-diffractive component
- Phojet accurately reproduces diffractive component

D.Piparo



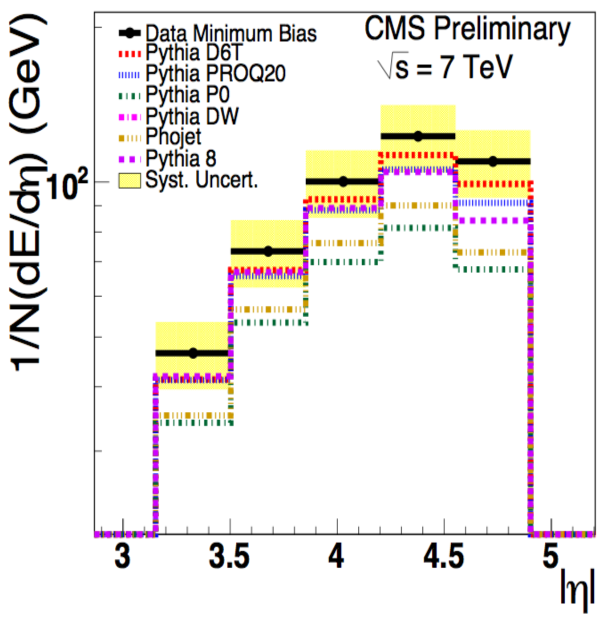


Forward physics at the LHC and beyond

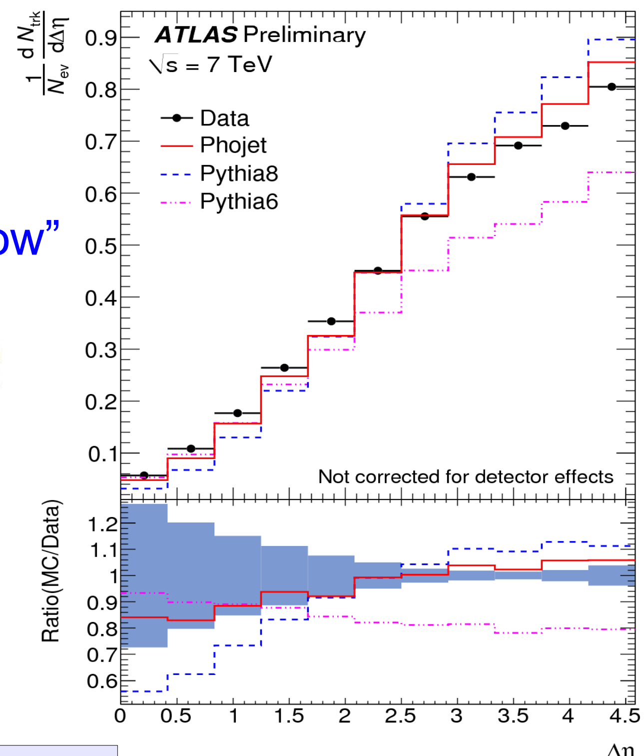
J. Anderson, S.Navin, G.Rodriguez, D.S.Cerci, L.Bonechi, R.Enberg, H.Gronqvist etc.

- ATLAS: MBTS, LUCID, ZDC, ALFA up to 13 units in η.
- CMS: HF, BSC, ZDC, CASTOR   ALICE: V0A, V0C, ZDC
- LHCf – first results → Completed operations at 900 GeV and 7 TeV.
- Important input for MC low x & shower simulation in cosmic ray physics (>10^{15} eV)
  - talk on Pierre Auger Observatory status (goal to understand range > 10^{18} eV

“energy flow”



“track flow”



CMS: PYTHIA D6T the best. PHOJET fails
For dijets – all MC fail

ATLAS: PHOJET is close to data

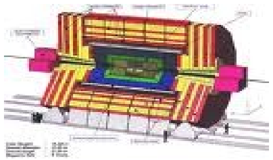
Confusing enough?

Beyond single-particle densities

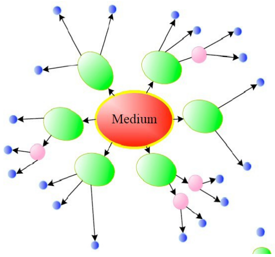
(correlations, fluctuations, etc.)

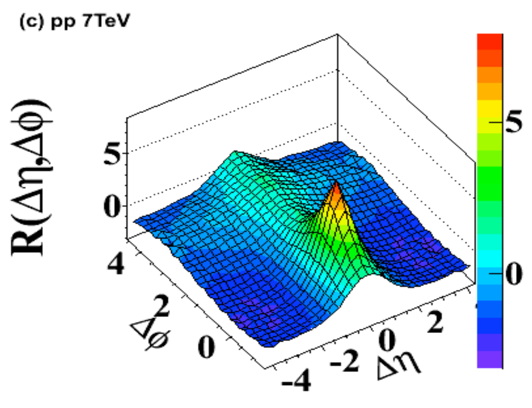
X. Janssen

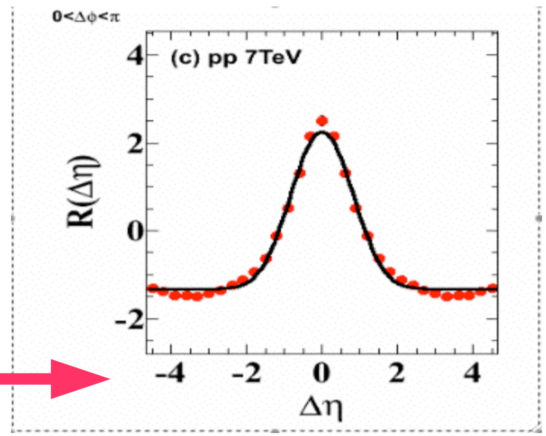
CMS taking the lead!



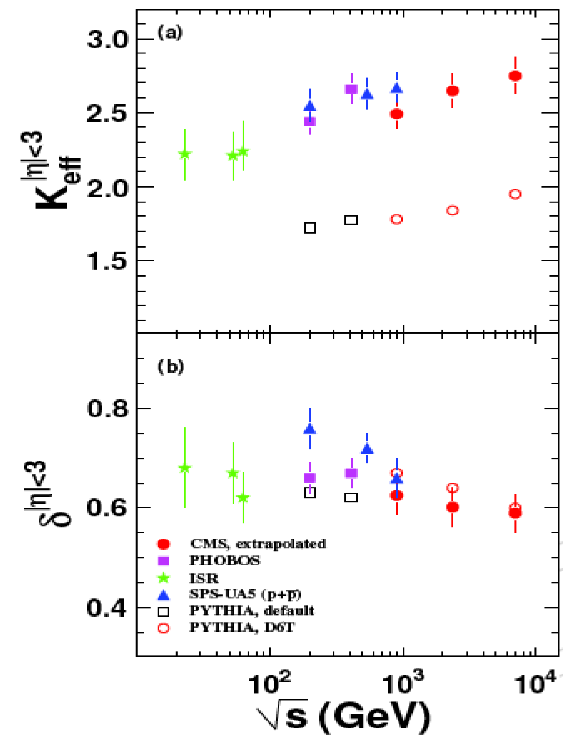
- Explored lower pT tracking range earlier than ATLAS
- Short range correlations have been studied at 0.9, 2.36 and 7 TeV
- Background was from track-mixing techniques







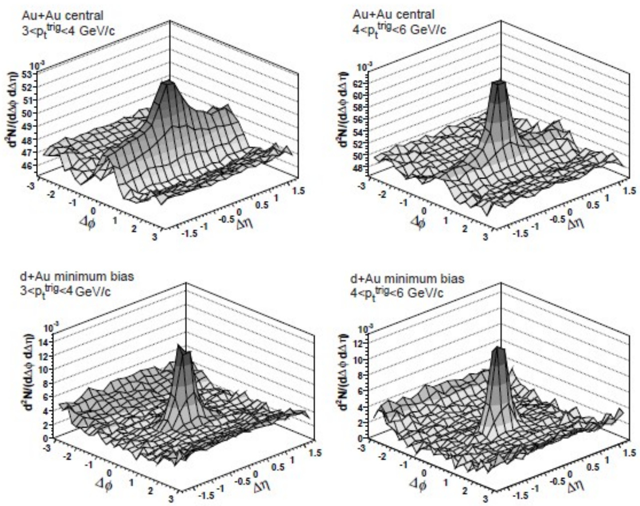
Description in terms of cluster size and width: (K. Eggert et al., Nucl. Phys. B86:201, 1975)



- PYTHIA fails to describe cluster sizes
- Agreement with other experiments is fair

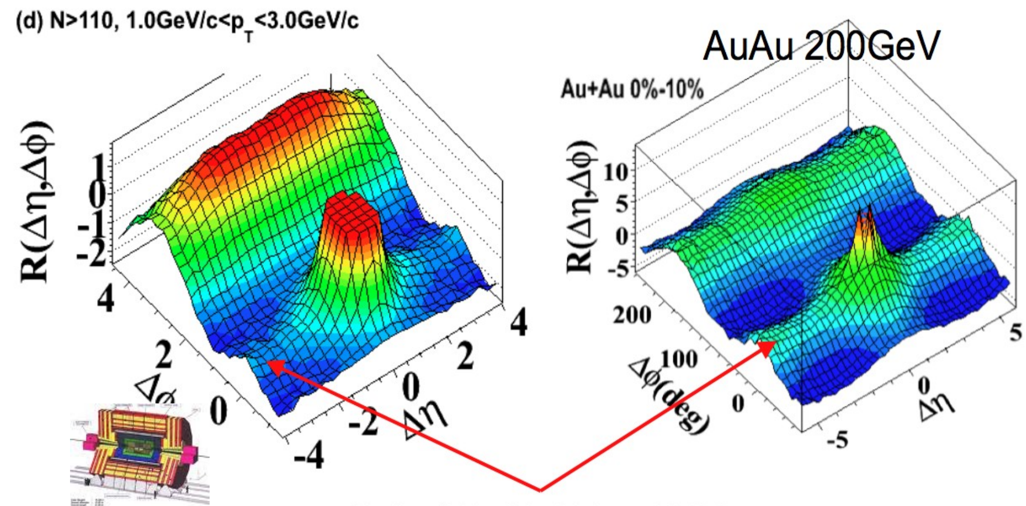
CMS observation of a ridge-like structure in pp collisions

STAR, Phys.Rev.C80:064912,2009



First observation of a long-range, near-side feature in two-particle correlation functions in hh collisions!

$$R(Dh, Dj) = \left\langle (N-1)\left(\frac{S_N(Dh, Dj)}{B_N(Dh, Dj)} - 1\right)\right\rangle_N$$



Similar "ridge" in high multiplicity pp (even similar p_T dependence)

Particle densities in the high multiplicity events of pp collisions begin to approach those in high-energy collisions of nuclei

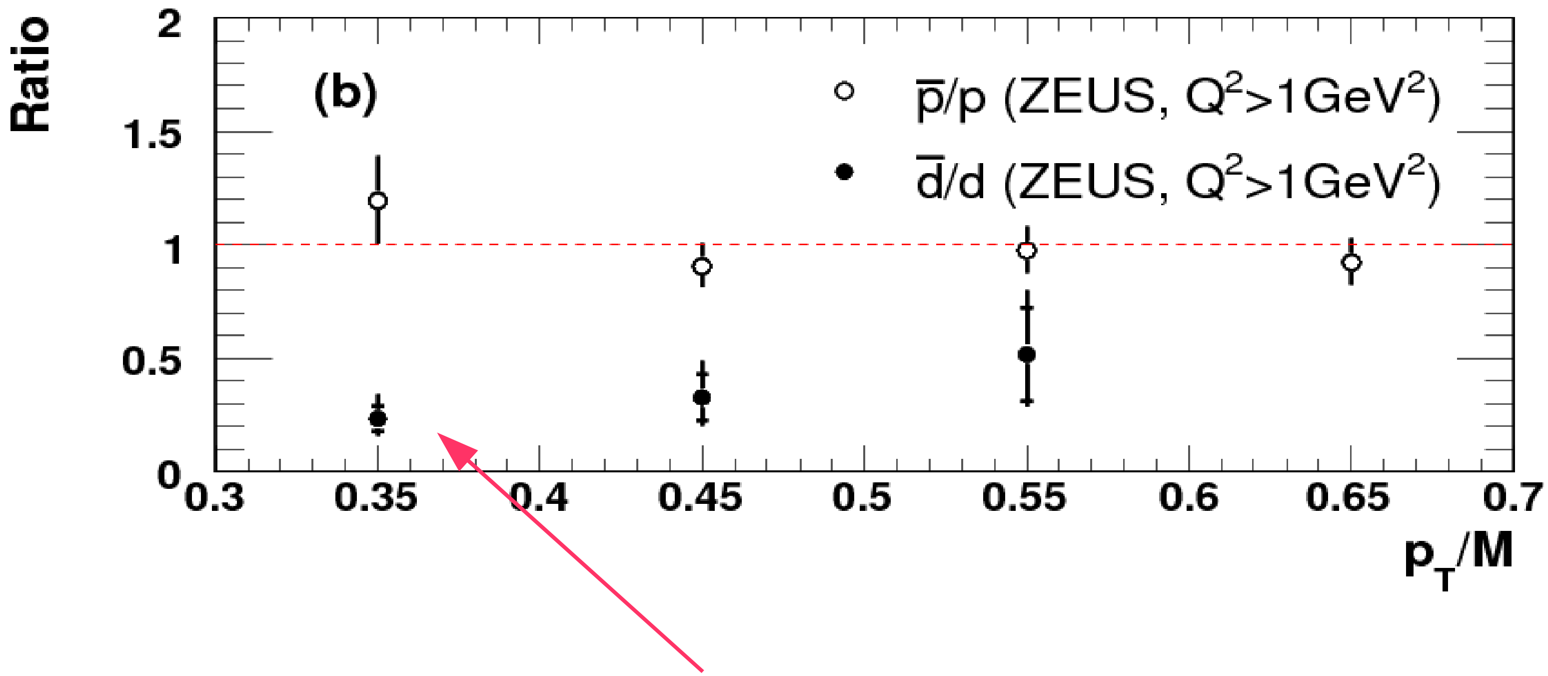
Do we see same features in pp as in AA?

→ Wait for ATLAS/ALICE

I would be interested in the relative hight of the ridge structure compared to the peak at |η|~0 (truncated by CMS!)
The ridge-structure could be missing by previous experiments due to low statistics (see dA reaction)

Example from recent past..

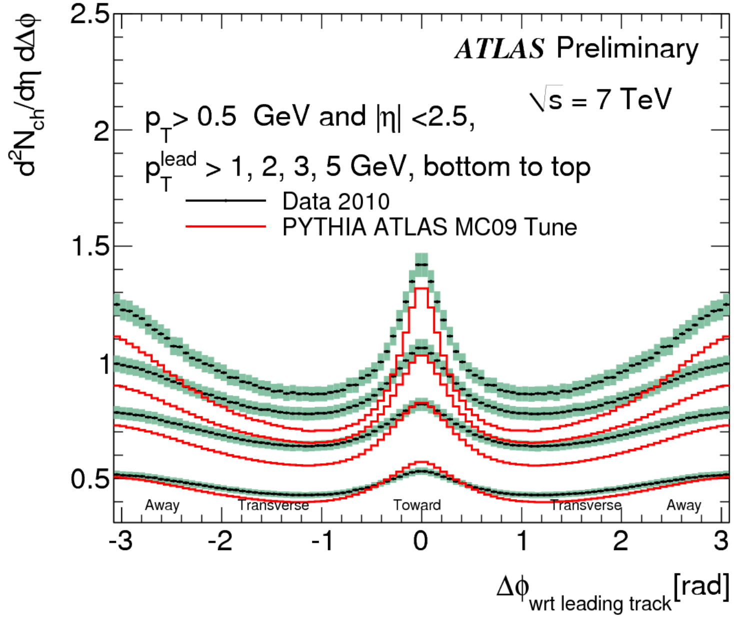
ZEUS, Nuclear Physics B 786 (2007) 181



- seemingly simple process (DIS, ep) looks like AA collisions!

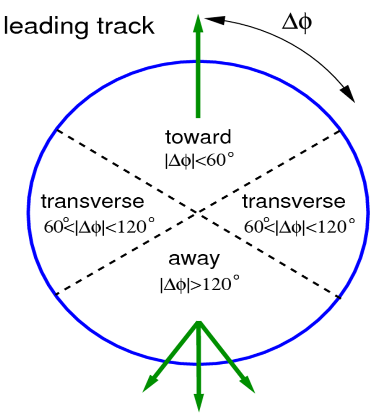
Angular correlation measurements

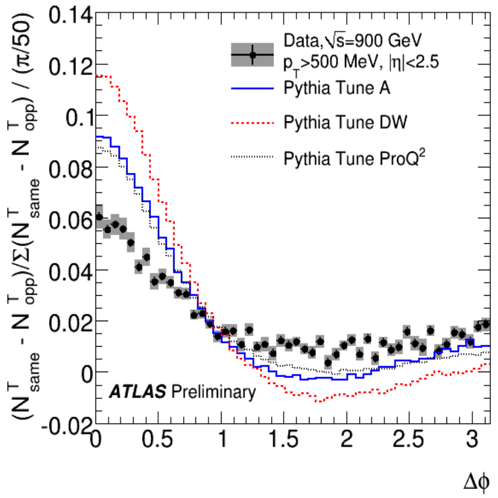
C.Buszello

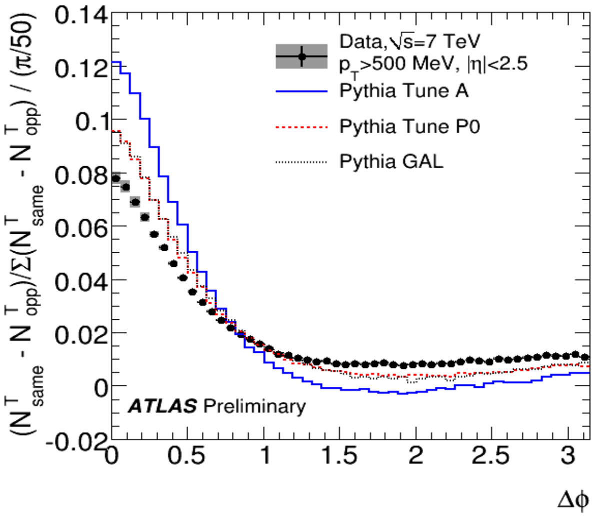


- Major focus :
  - UE studies & MC comparison
- MC fails everywhere where it can fail

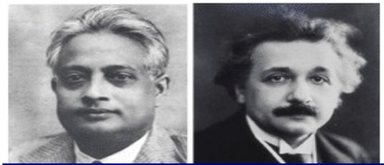
ATLAS







X. Janssen

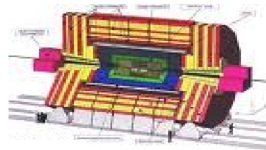


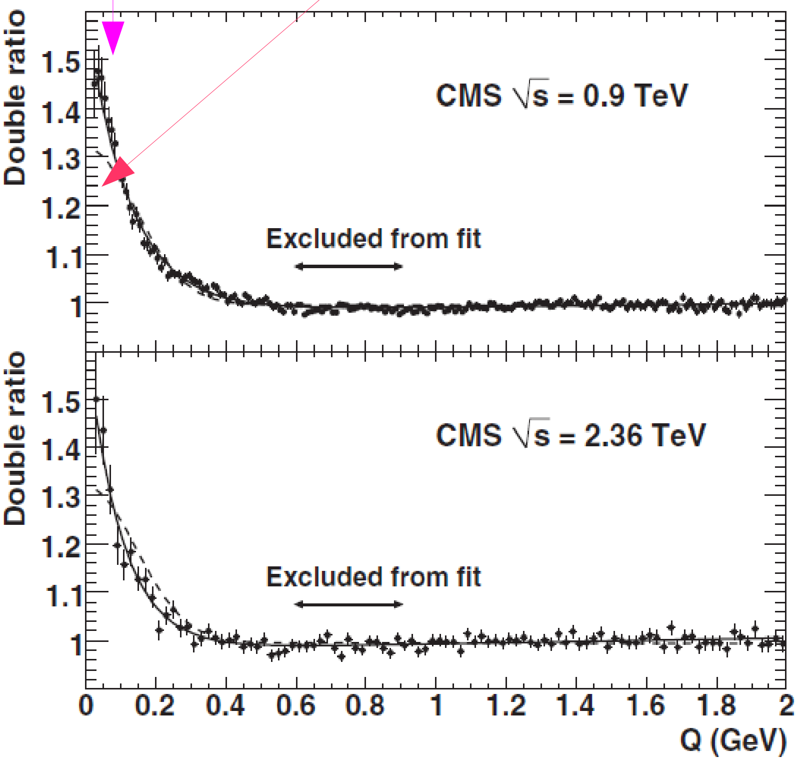
Bose - Einstein **correlations**

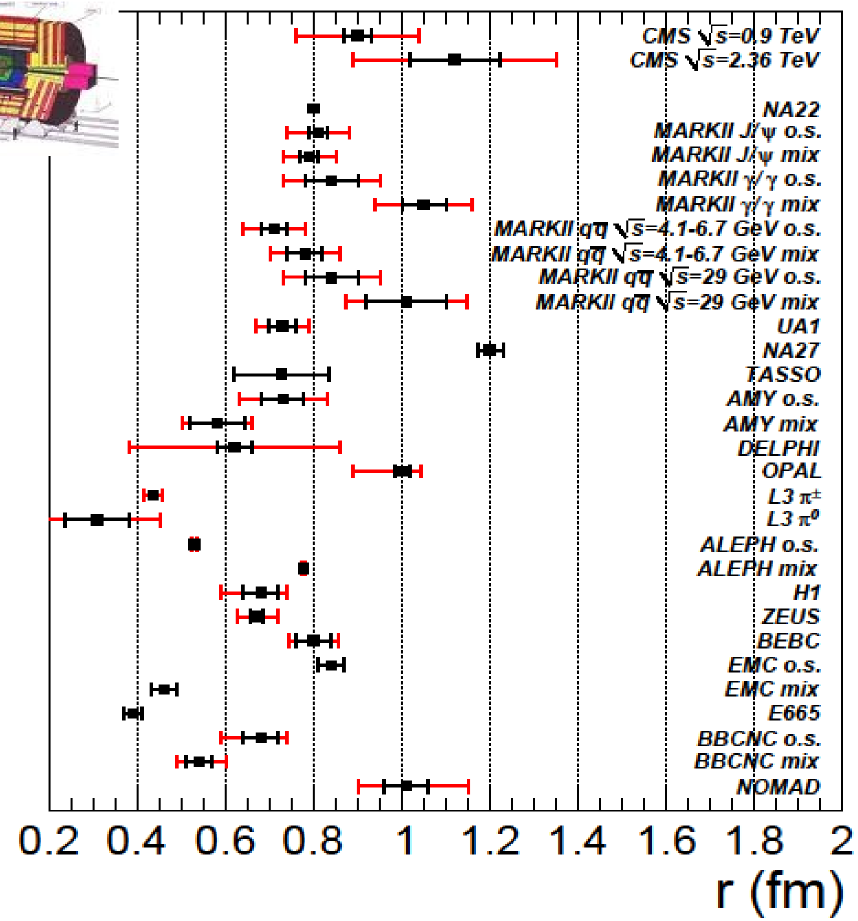
\+ Hanbury-Brown-Twiss

Exponential form **= exp (-Qr)**

Gaussian form **= exp (-Q²r²)**

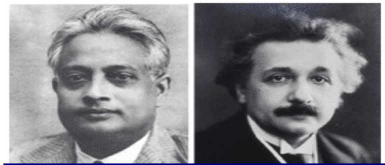






Exponential shape.
Multiplicity dependence

J.Mercado



Bose - Einstein **correlations**

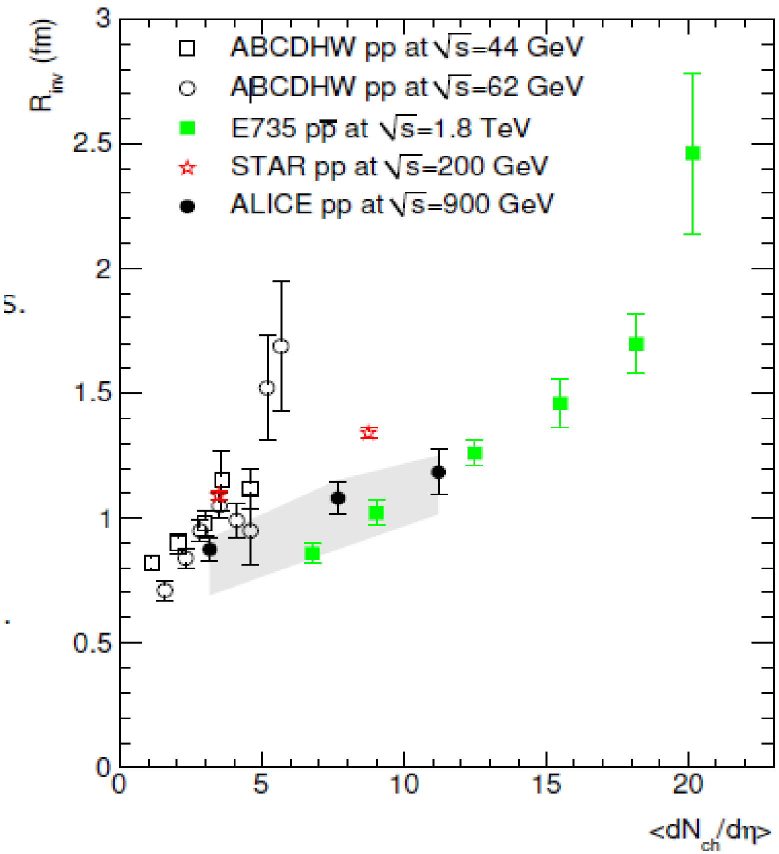
+ Hanbury-Brown-Twiss

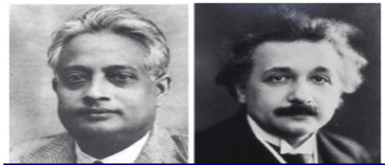
First measurements from ALICE!

Source radius increases with multiplicity, consistent with previous measurements.

Well known behavior in nuclear collisions.

Gaussian form to fit the signal (exponential form is a cross check!)





Bose - Einstein **correlations**

+ Hanbury-Brown-Twiss

Back to the history..

If the power law is confirmed in the small Q^2 region by future experiments, this is in contradiction to the conventional Gaussian or Bessel-type parametrization of Bose-Einstein correlations. Furthermore, it is important to note that even in the larger Q^2 region ($0.006 < Q^2 < 1$ GeV^2) conventional Bose-Einstein parametrization and power law are indistinguishable. So, self-similarity of the correlation function is in fact even there an interpretation alternative to the conventional view of Bose-Einstein correlations (the latter relating the low Q^2 enhancement to the *static* size of an interaction region).

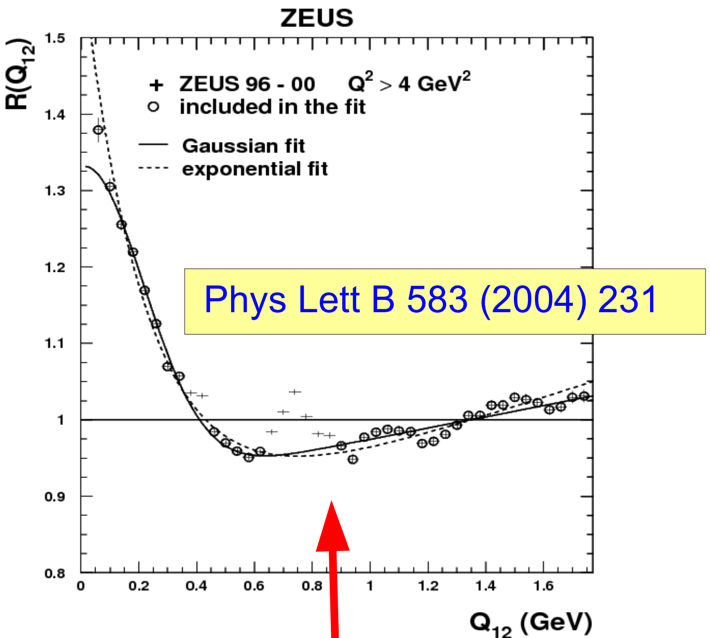
Density fluctuations in NA22, by W.Kittel, 1993

(iv) It is found that the Gaussian distribution, the exponential function and power functions of Lorentzian for E_{2B}^2 show almost the same χ^2-values in analyses of the data of NA44 Collaboration in both frameworks. In other words, we cannot determine a concrete source function from the data of NA44 Collaboration.

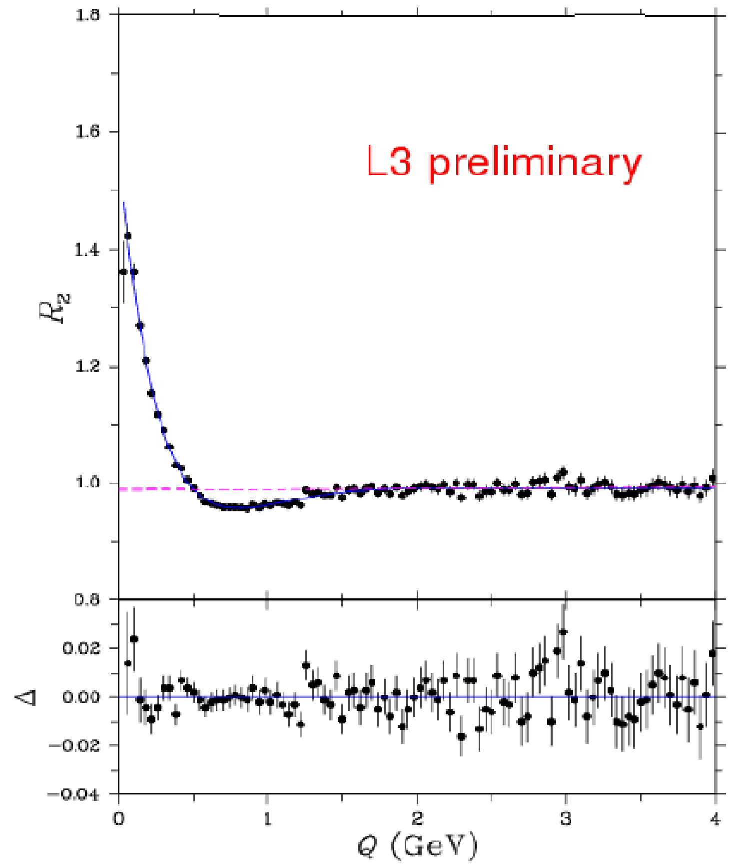
Progress of Theor. Phys. V91 (1994), T.Mizoguchi, M.Biyajuma, T.Kageya, Analysis of Data in S+Pb at 200 GeV/c

Bose - Einstein **correlations**

+ Hanbury-Brown-Twiss



Phys Lett B 583 (2004) 231



$$R(Q_{12}) = \alpha\,(1 + \beta\,Q_{12})\,(1 + \lambda\,e^{-r^2\,Q_{12}^2}),$$

No need for this ad-hoc term
→ “deep” naturally comes from the tau-model

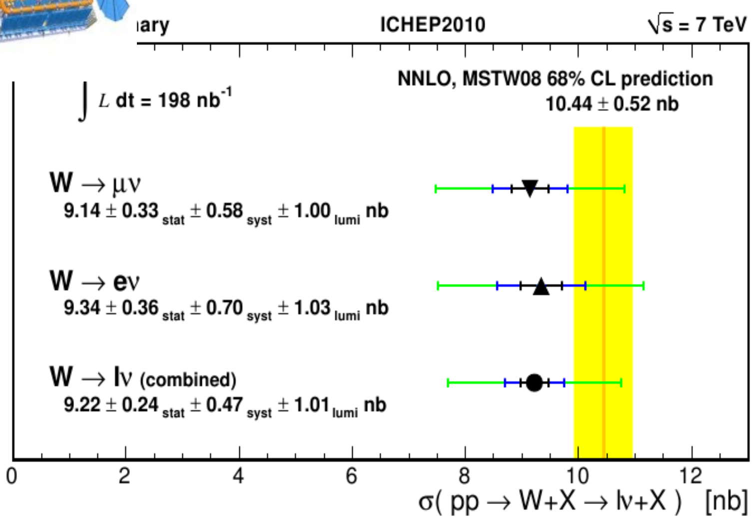
Presented by W.Metzger

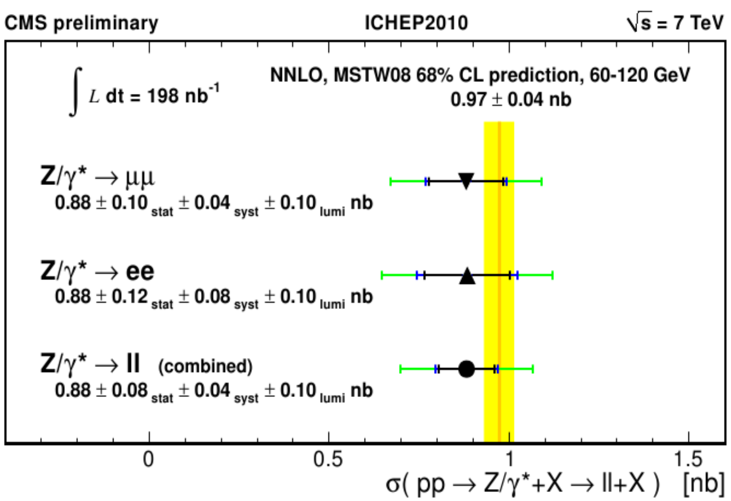
High-pT physics

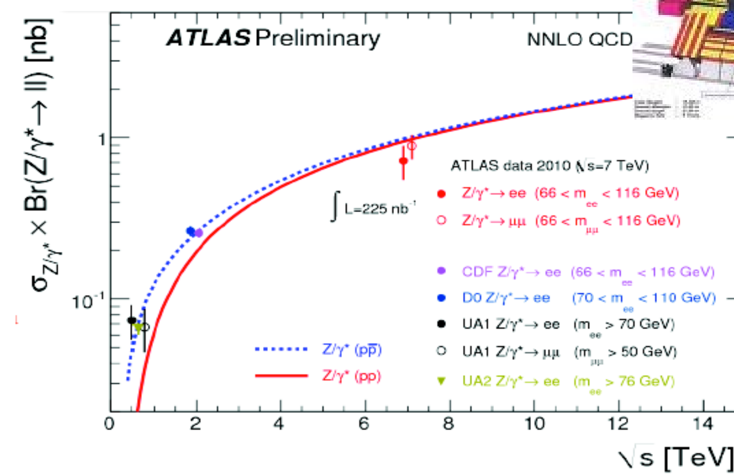
High-pT EWK

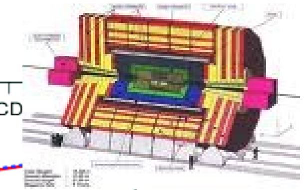
ATLAS/CMS:
A.Alonso
A.Magnan

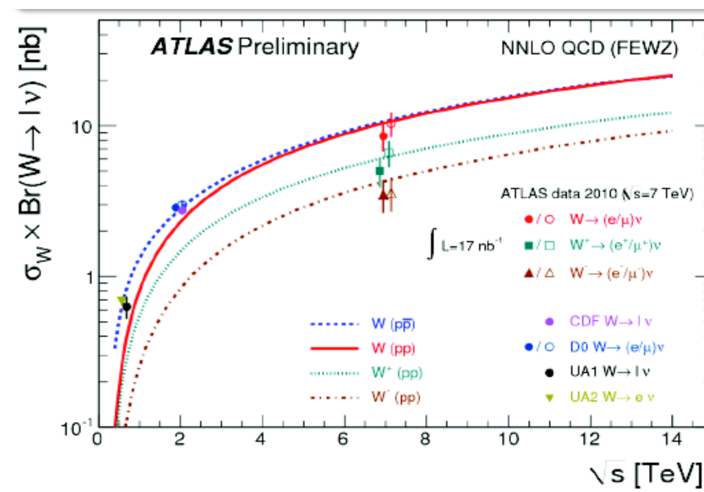
- EWK cross sections at highest CM energies!
- Perfect agreement with the SM







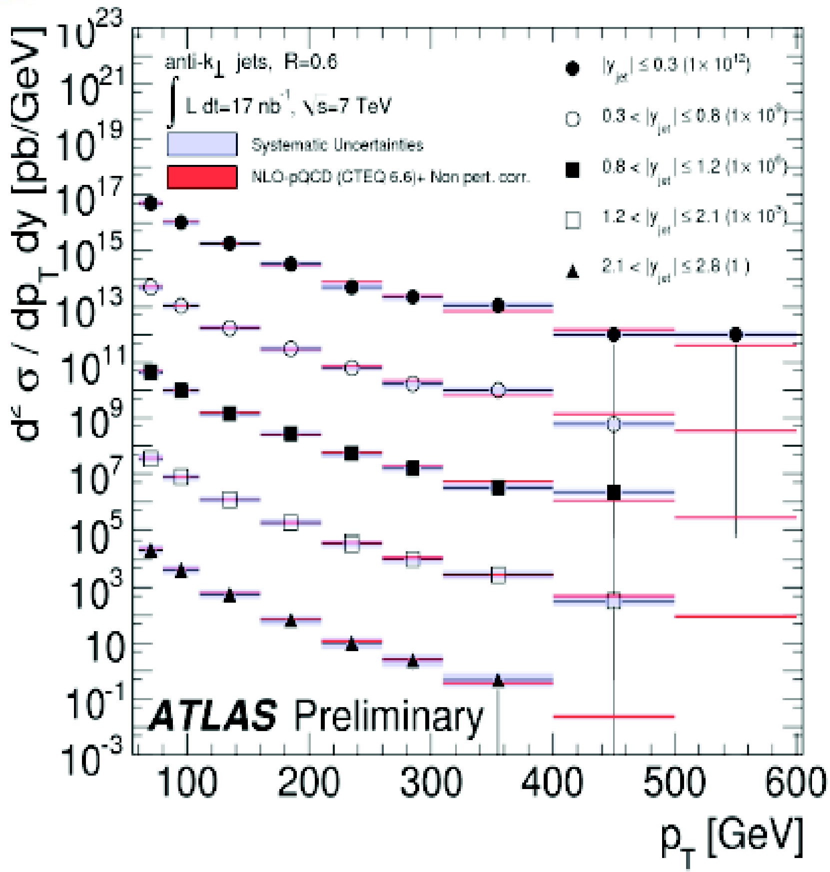


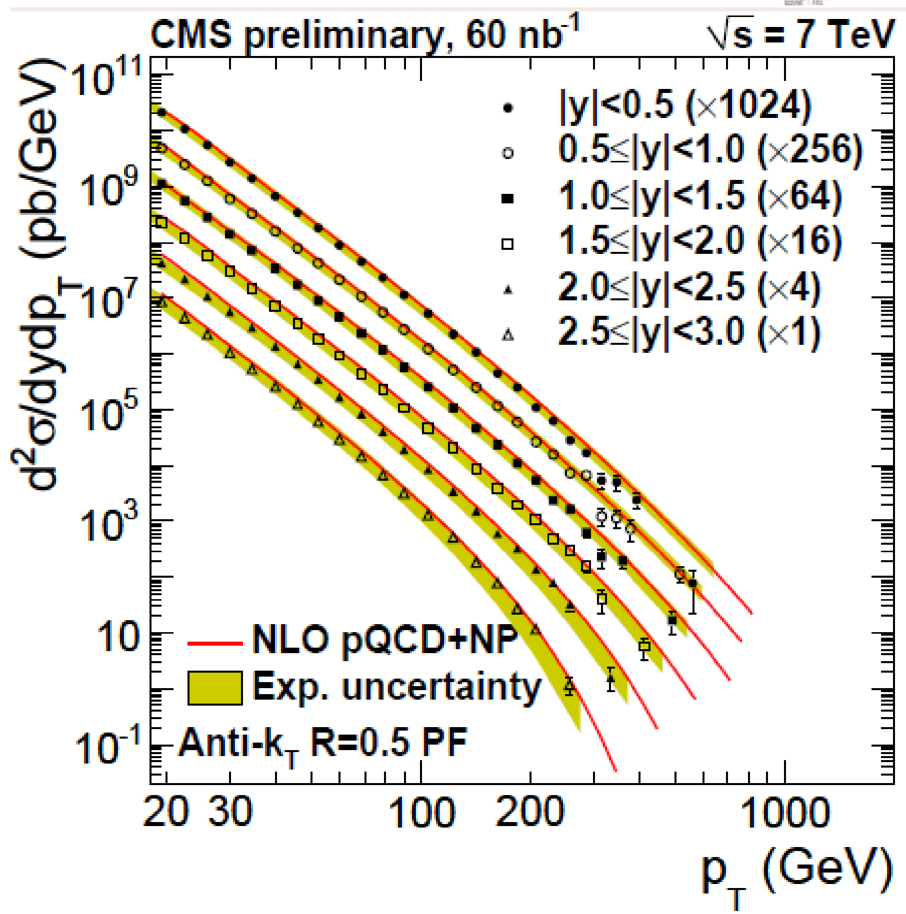


High-pT jets

S.Zenz
P.Katsas

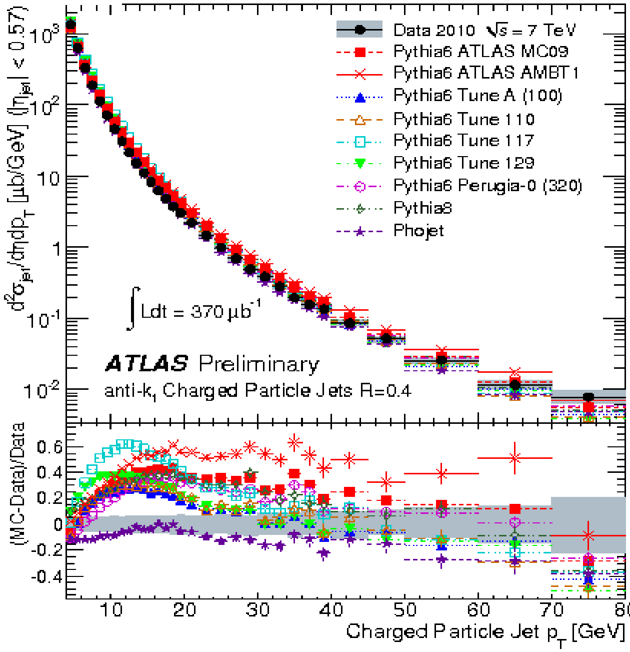
- With only ~10 pb^{-1} of LHC data, the reach in jet transverse momentum at the LHC will be twice that attained by previous experiments.
- Not there yet.



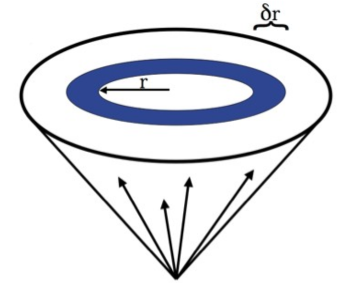


Jet substructure / track jets

S.Zenz
P.Katsas

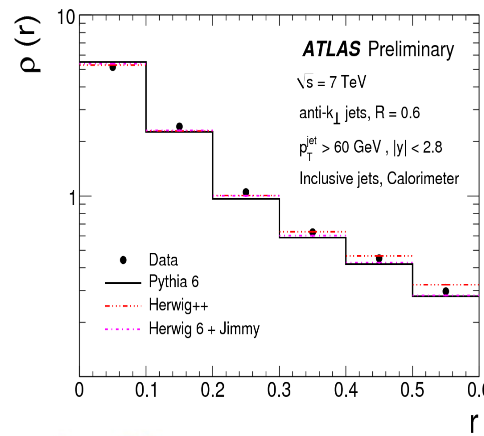


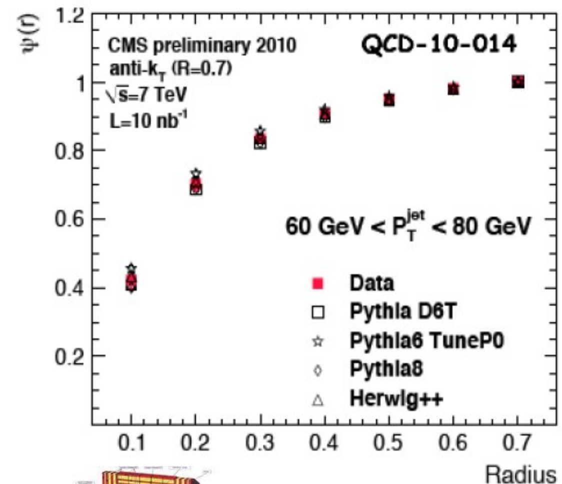
$$\left\langle \frac{1}{r}\frac{dp_T}{dr}\right\rangle_{jets} = \frac{1}{A}\frac{1}{N_{\rm jet}}\sum_{jets} p_T(r-\Delta r/2,\, r+\Delta r/2)$$



Dif. shape

Integrated shape



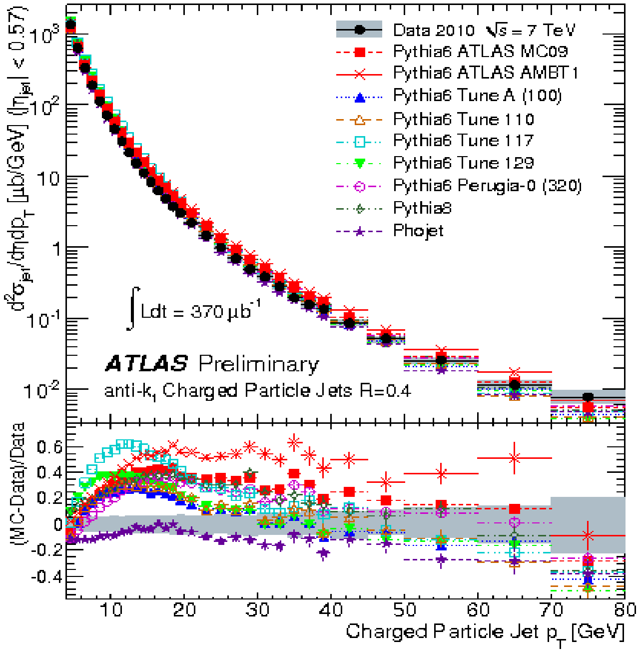


PYTHIA fails, PHOJET OK
(opposite to MinBias results!)

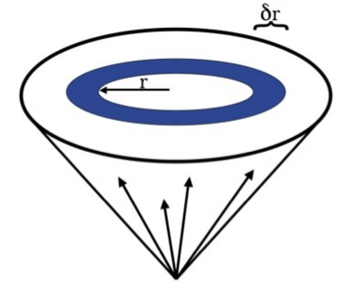
Jet substructure is important for searches of boosted jets from TeV-scale particles (i.e.for searches of extra dimensions, **parallel universes** etc.)

S.Zenz
P.Katsas

Jet substructure / track jets

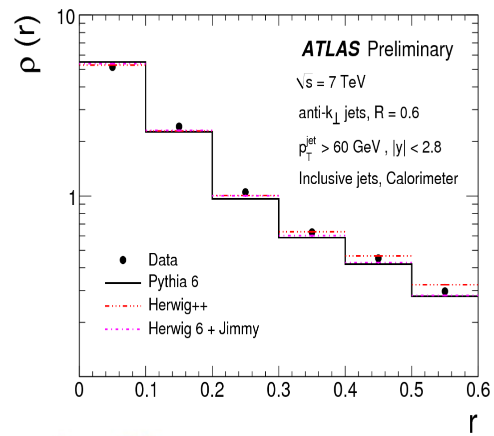


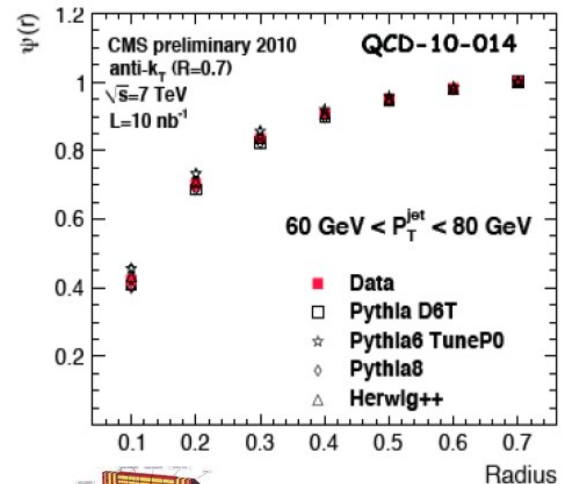
$$\left\langle \frac{1}{r}\frac{dp_T}{dr} \right\rangle_{jets} = \frac{1}{A}\frac{1}{N_{\mathrm{jet}}}\sum_{jets} p_T(r-\Delta r/2, r+\Delta r/2)$$



Dif. shape

Integrated shape





PYTHIA fails, PHOJET OK
(opposite to MinBias results!)

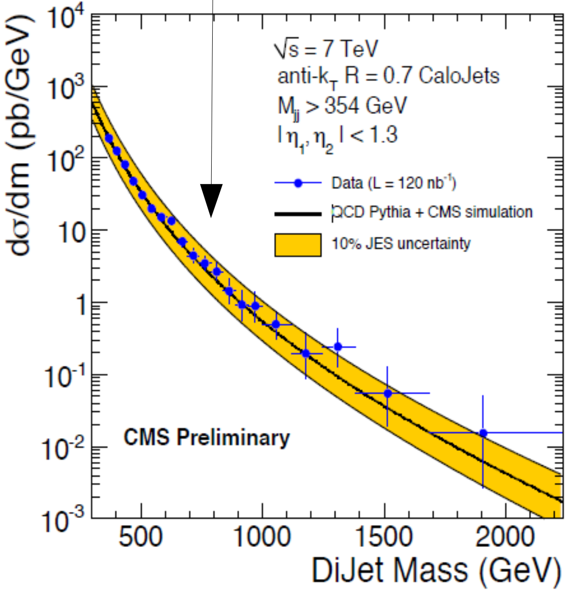
Jet substructure is important for searches of boosted jets from TeV-scale particles (i.e.for searches of extra dimensions, **parallel universes** etc.)

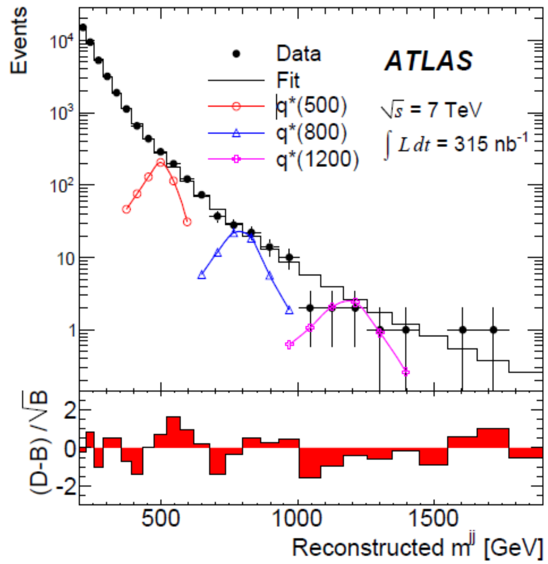
For jet measurements, CMS and ATLAS already live in parallel universes:
- anti-kT jet cone sizes 0.5, 07 for CMS and 0.4, 0.6 for ATLAS!

TEVATRON

Searches

A.Safonov A.Huettmann
K.Nakamura H.Peng L.Benucci





Multi-jets at high ET,
Multi-leptons, photons etc.

be vigilant!

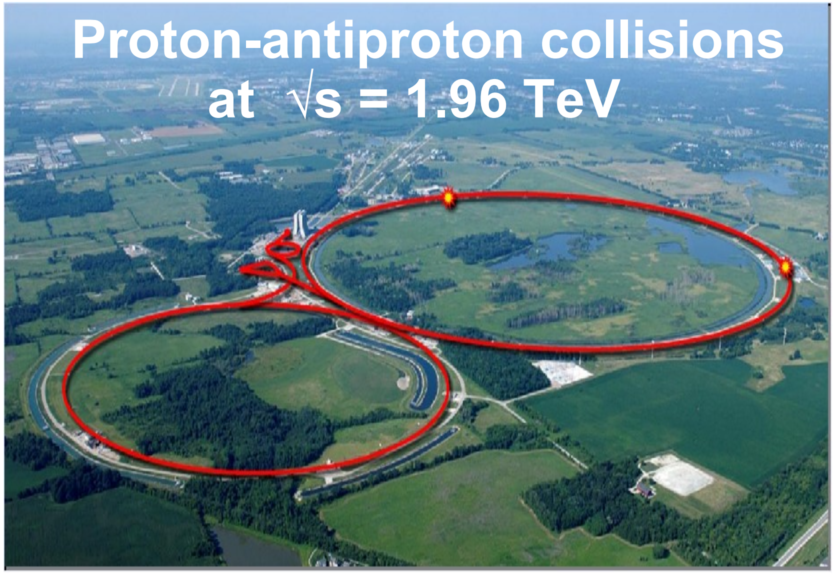
- **Searches for Higgs and physics beyond the Standard Model will be the primary task of the LHC**
- **Most simple observables at highest -pT do not indicate deviations from the SM**
- **But exotic physics may exhibit itself through multi-object final states (leptons, jets etc..) at medium pT's**
  - Example: decays with copious lepton production in LeptoSusy with a long decay chain for charginos decaying to stable sleptons and leptons (~4)

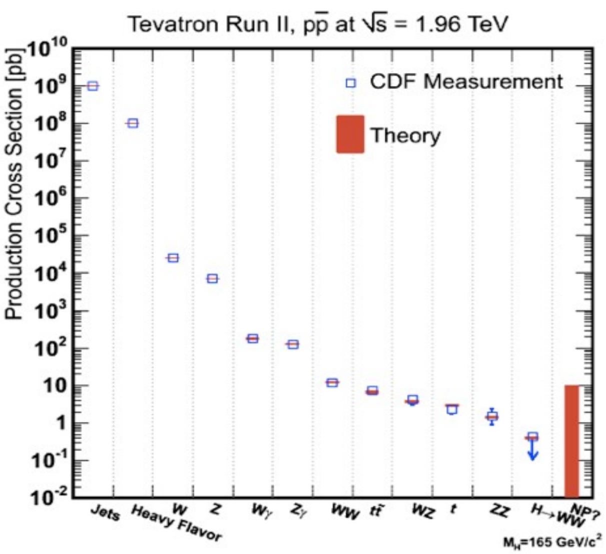
→ **techniques developed for the description of multihadron production can be useful!**

from young to mature

from the LHC to
TEVATRON, HERA, RHIC, SVD-2, BaBar, NA49, NA61, L3

TEVATRON





During this meeting, known as NOT the world's highest-energy particle collider

But as high-statistics, high-precision well-understood experiments with ~10 fb^{-1} of pp data

Because of this, TEVATRON is the main competitor of LHC for many discovery channels and provides reference QCD measurements for early LHC results

Probing cross sections at 1 pb level!

A.Safonov

see "Higgs searches at the TEVATRON"

HERA

HERA (1992-2007)

- *820-920 GeV p, 27 GeV $e^{\pm}$*
- *2001 HERA II Lumi upgrade + polarised $e^{\pm}$*
- *Machine operation ended in June 2007*
- *About 0.5 fb^{-1} per experiment collected*

Q^2 (photon virtuality):

- *Q^2~0 (<1 GeV^2) - Photoproduction: photon-proton scattering*
- *Q^2>1 GeV^2 - Deep Inelastic Scattering (DIS), probing the proton structure*

During this meeting, we get used to speak about "HERA" results, rather than H1, and ZEUS results

- unique information on proton structure over wide x

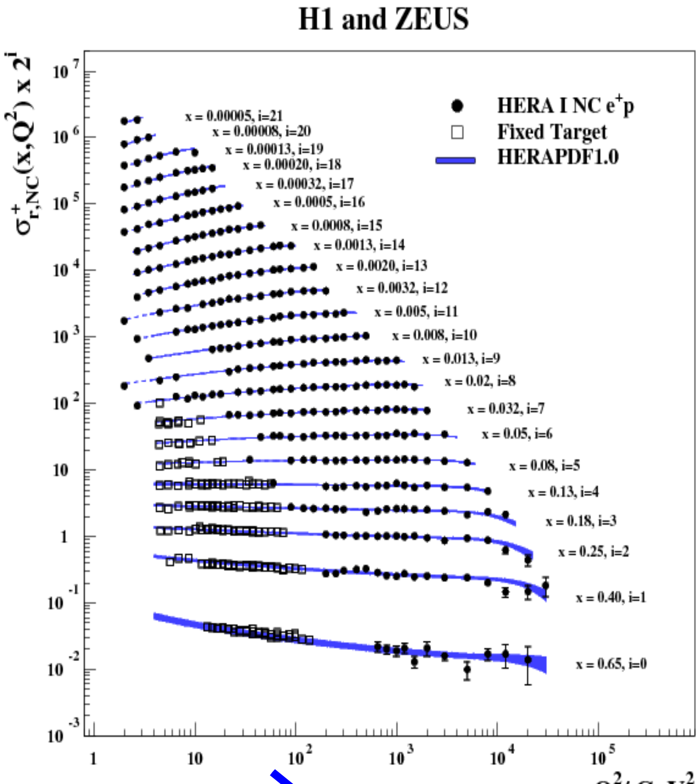
- combined results with stunning precision. Very convincing.

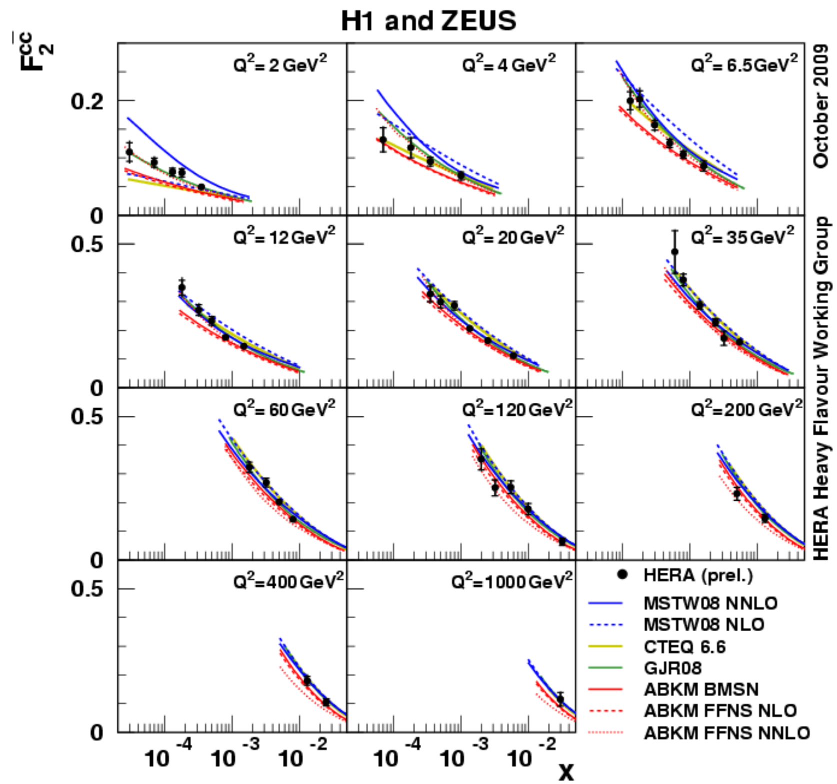
- elaborate experimental techniques

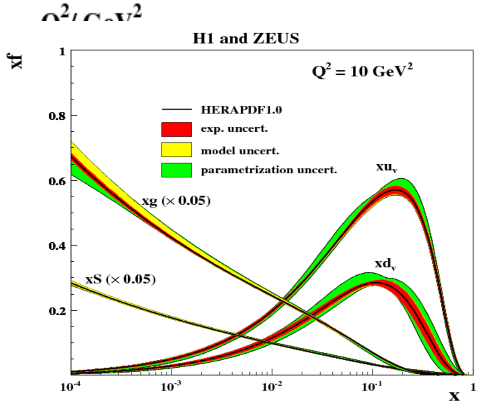
- unique role in HEP as the only world's ep collider with clean and well understood environment

HERA

A M Cooper-Sarkar
M.Brinkmann





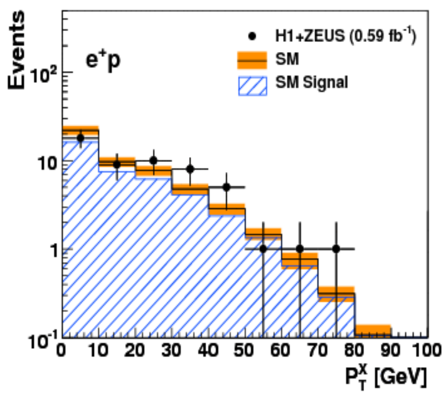


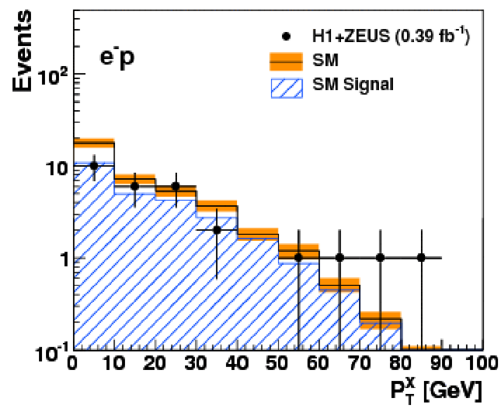
Precision is good enough to discriminate between different theory predictions!

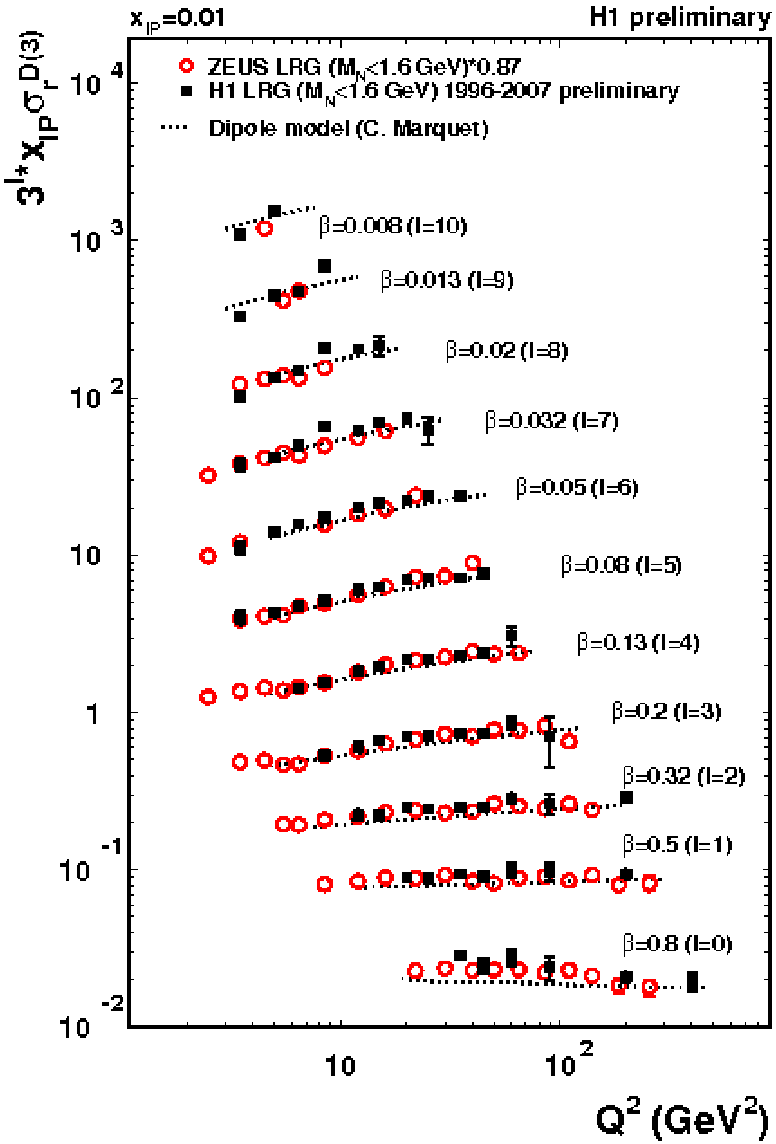
HERA

R.Polifka
A.Huettmann

Diffraction





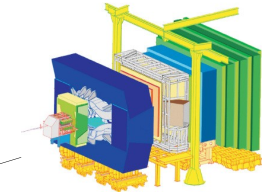


Combined H1+ZEUS results on searches for isolated leptons and missing pX

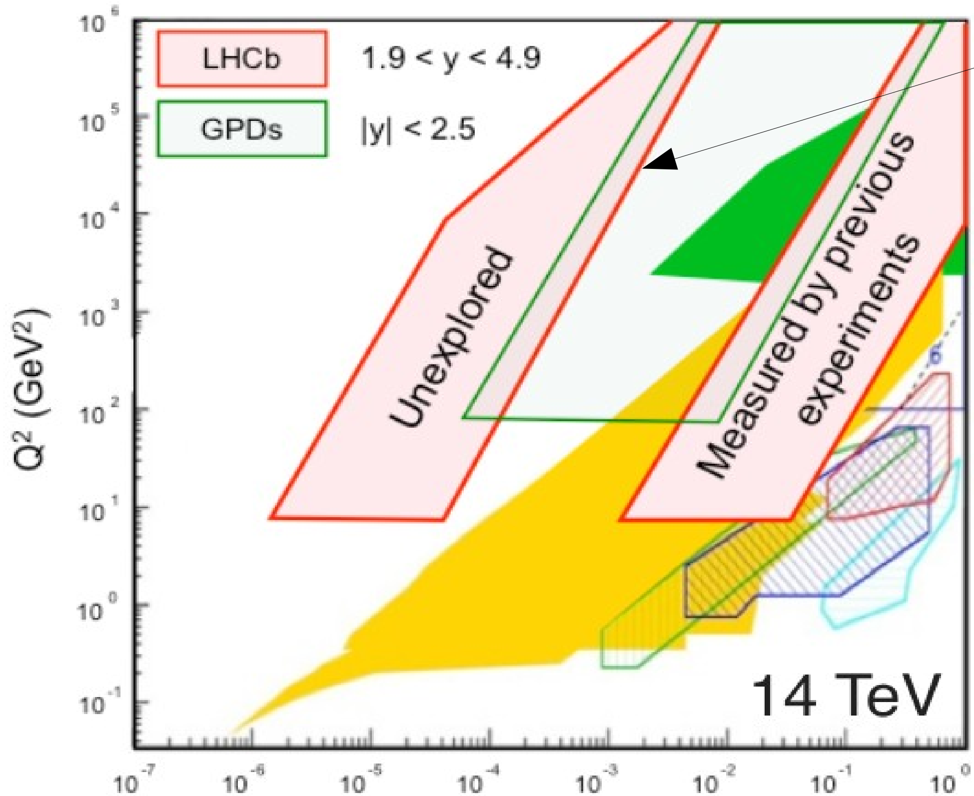
Not yet "HERA result", but good agreement between H1 and ZEUS - in pipeline to be combined

Next challenge after HERA

J.Anderson

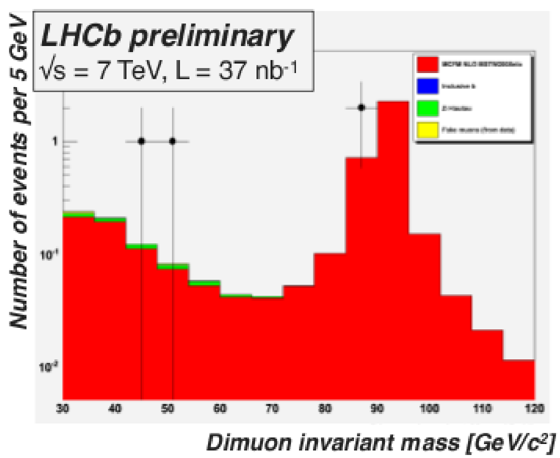


will be addressed by LHCb



Due to its angular acceptance and low trigger thresholds, events at LHCb will probe a totally unexplored kinematic region. In particular it will have access to low-x at both high and low Q2

Using ~50 nb-1 of data LHCb find 66 Ws and 2 Zs in agreement with expectations



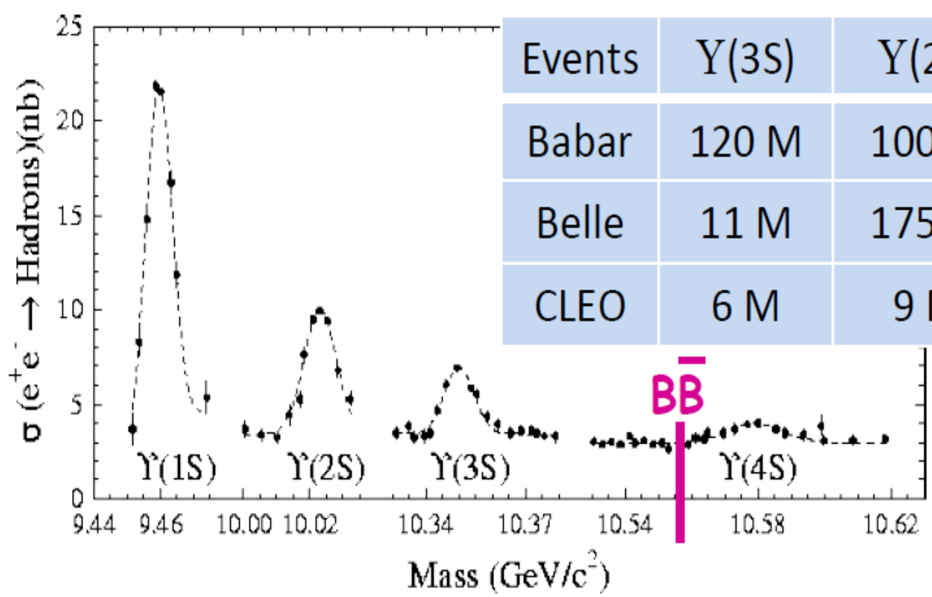
BaBar

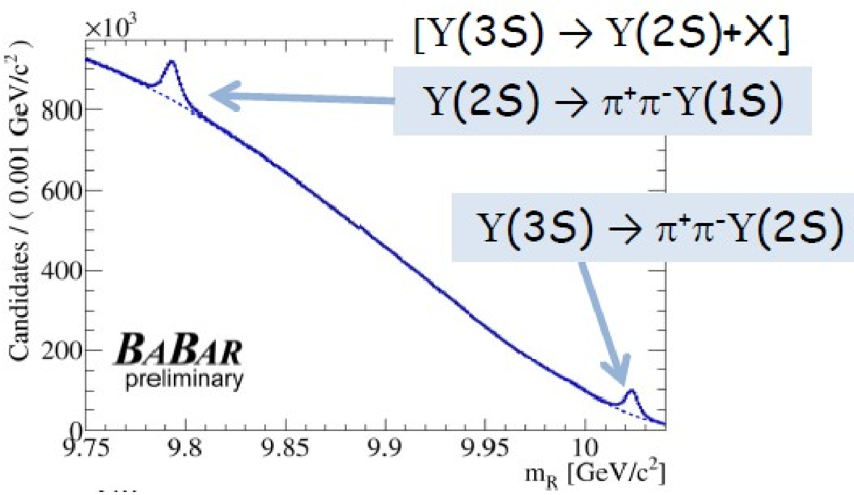
J. William Gary

Υ(4S)	430 fb^{-1}
Υ(3S)	30 fb^{-1}
Υ(2S)	14 fb^{-1}
Other (mostly off-resonant)	~60 fb^{-1}

- Collected world's largest sample of Υ(3S) in 2008

Events	Υ(3S)	Υ(2S)
Babar	120 M	100 M
Belle	11 M	175 M
CLEO	6 M	9 M

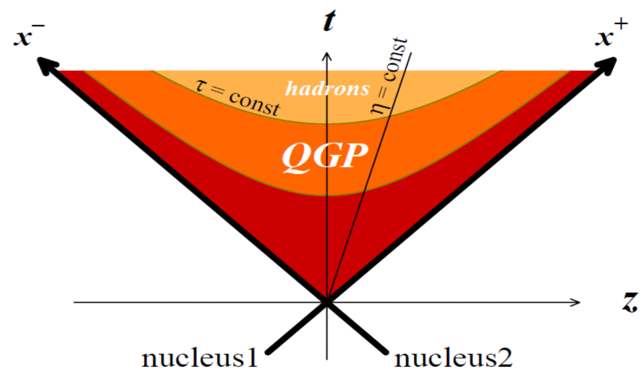




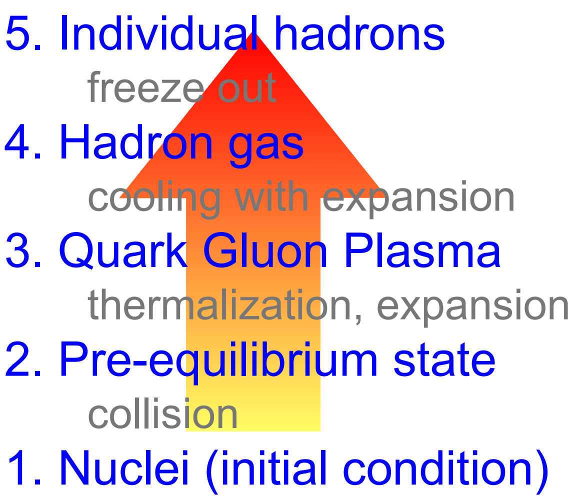
Talks: T.Csorgo, Y.Hama,T. Trainor, C.Vale,M. Tokarev, Zborovsky, C.Marquet etc

Heavy-ion program

- RHIC has very active program to study strongly interacting matter under extreme conditions: high temperature and high density
  - η' mass reduction, correlation studies (direct impact on LHC studies!)
  - searches for quark-gluon plasma
  - Testing hydrodynamics description of particle production
  - Understanding of energy loss
  - Relevant for high-multiplicity pp events and future heavy-ion LHC program!

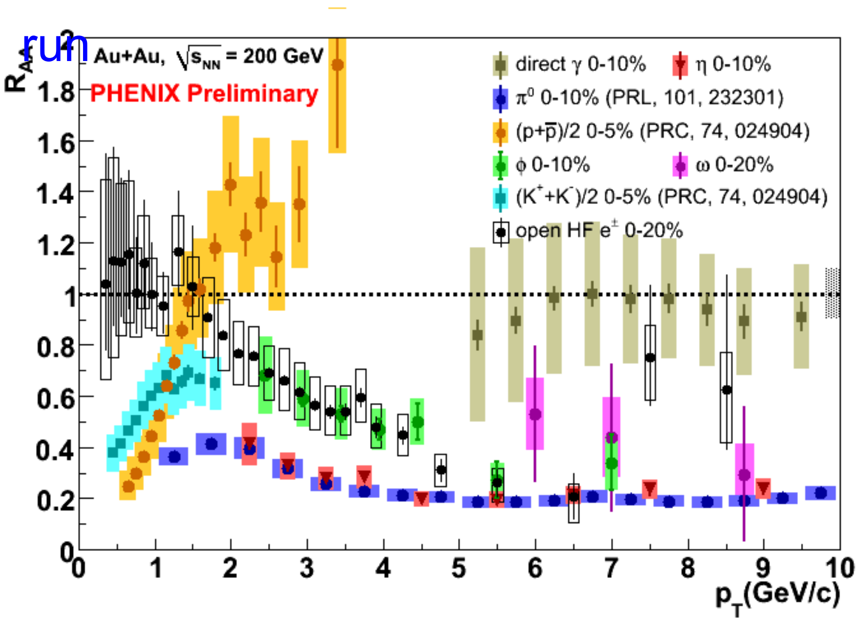


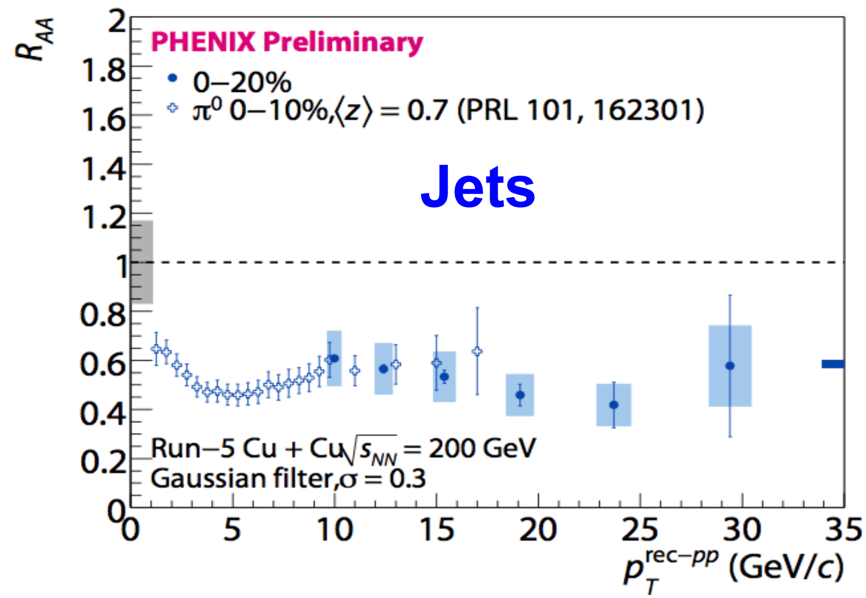
space-time picture of heavy-ion collisions



Probing quark-qluon plasma

For pp collisions with high associated multiplicity and with transverse energy ~10 GeV per unit rapidity, it is possible that quark-gluon plasma is produced .. If so, a produced secondary high-pT quark or gluon might lose tens of GeV of its initial transverse momentum while plowing through quark-gluon plasma in its local environment. ***(unpublished FERMILAB-Pub-82/59-THY, J.D.Bjorken)***





R_{AA} ~ Yield(AA)/Yield(pp)

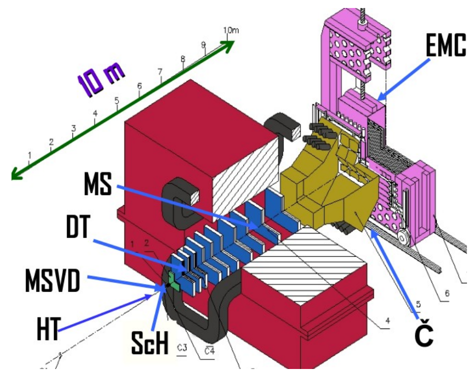
Now one of the standard measurements!

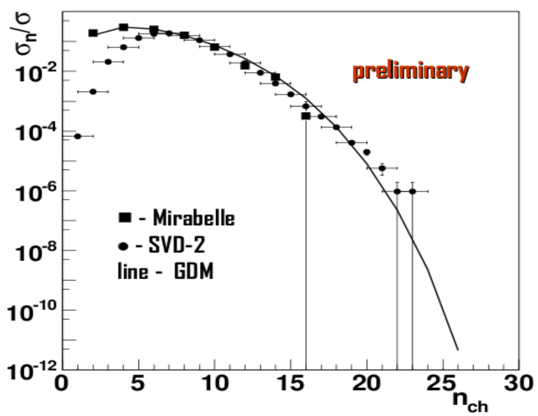
After first decade of RHIC running, PHENIX is close to produce a complete picture of energy losses using identified particles and jets!

Experiments for searches for collective phenomena

E.Kokoulina et al
T.Susa

- SVD program:
  - Cherenkov gluon emission;
  - Gluon Dominance Model (GDM)
  - Clusterization; turbulence phenomena .
- continue this Fall (2010)

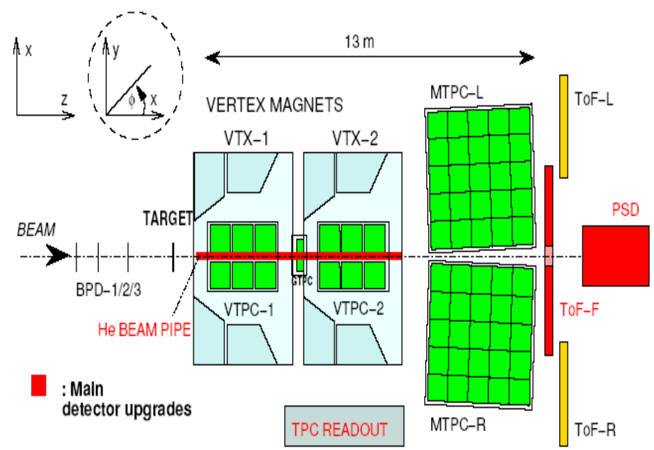




pp (pA) –> n, n = n_{ch} + n_0

Experiment at U-70, IHEP, Protvino
E_{lab} = 50 - 70 GeV

NA61 (Shine) experiment:
Successor and extension of NA49
- Critical Point and
- Onset of Deconfinement



p+C @ 31 GeV

Summary

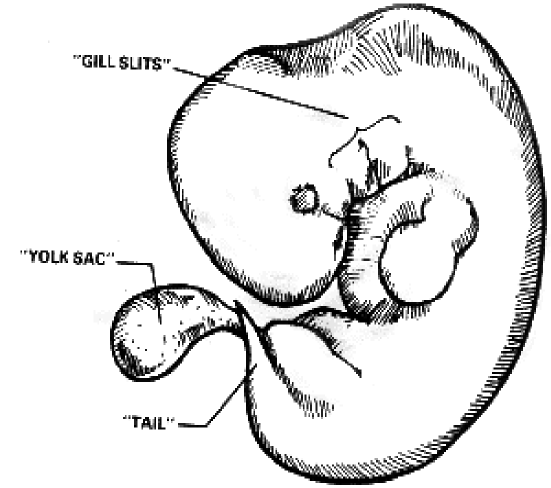
- **LHC experiments are dominant players**
  - Multiparticle results at highest ever energies are a major milestone on our road to understand multihadron production and soft QCD
  - MC comparisons:
    - Generally, all fail (multiplicities, strangeness, baryon production etc..)
    - Tunes which agree for some measurements, fail for others
  - Too high expectations? Maybe we will be less confused considering MCs as a tool to embed data into a theoretically-motivated fit every time we enter new energies?
  - Generally, good agreement with NLO for jets and electroweak measurements
- **Combined results from HERA experiments**
  - HERA PDF's lead to ~2% accuracy on W measurements at the LHC!
  - ~5% uncertainties using separate H1 and ZEUS data
- **7 fb^{-1} collected by each experiment at Tevatron**
  - Sensitive to cross sections bellow 1 pb. Most precise W measurements
- **Ongoing heavy-ion program to understand energy losses and other phenomena**

Same (philosophical) remark

If you still believe in the evolutionary theory:

"Each child as he develops is retracing the whole history of mankind, physically and spiritually, step by step. A baby starts off in the womb as a single tiny cell, just the way the first living thing appeared in the ocean. Weeks later, as he lies in the amniotic fluid of the womb, he has gills like a fish..

-child development author Dr. Spock-



An early stage in human development

So do the newborn LHC experiments when retracing the whole history of HEP in their early measurements

Many discussed topics are known for 40-50(!) years:

- Examples:
  - Strangeness production
  - Multiplicities, KNO scaling (1970, Polyakov and of Koba, Nielsen and Olesen)
  - Correlations, cluster models (Eggert 1975)
  - BE correlations (Hanbury, Brown, Twiss, 1954, Goldhaber et al. 1959)

Discovery vs rediscovery

CERN-EP/83-73
3 June 1983

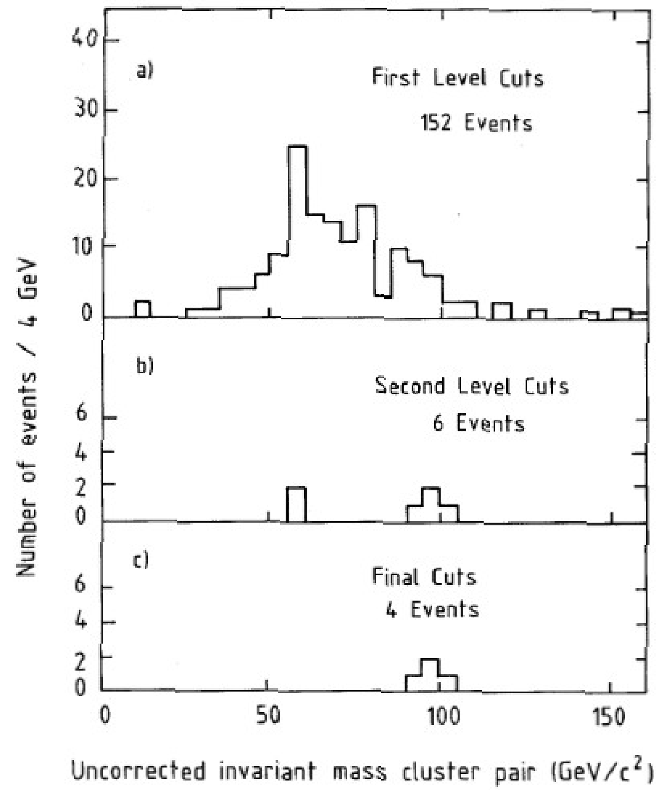
EXPERIMENTAL OBSERVATION OF LEPTON PAIRS OF INVARIANT MASS AROUND 95 GeV/c^2 AT THE CERN SPS COLLIDER

UA1 Collaboration, CERN, Geneva, Switzerland

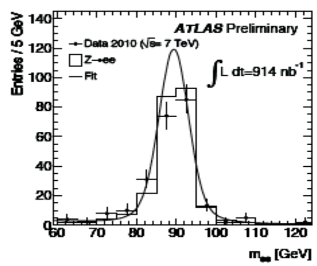
ABSTRACT

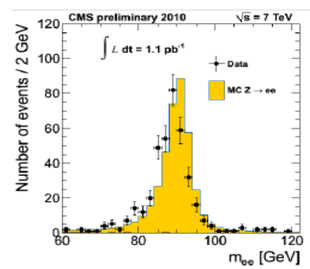
We report the observation of four electron-positron pairs and one muon pair which have the signature of a two-body decay of a particle of mass ∿ 95 GeV/c^2. These events fit well the hypothesis that they are produced by the process $\bar{p} + p \rightarrow Z^0 + X$ (with $Z^0 \rightarrow \ell^+ + \ell^-$), where Z^0 is the Intermediate Vector Boson postulated by the electroweak theories as the mediator of weak neutral currents.

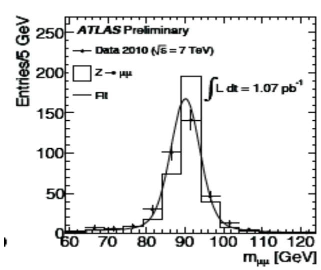
Discovery by UA1

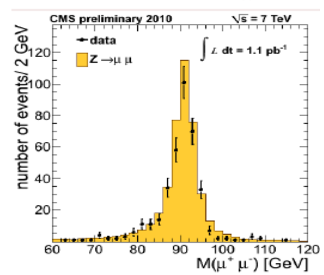


Rediscoveries
By ATLAS/CMS:









+ top candidates

After 40 years (Paris, 1970)

- **Challenges of ISMDI (1970, Paris, ~15 people).**
  - How to describe hh collision events at ~ few GeV with >2 outgoing hadrons?
  - No theory telling to an experimentalist what exactly to look for
    - only a few models around (L. Van Hove's longitudinal phase space model etc.)

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  - How to describe hh collision events at ~ few GeV with >2 outgoing hadrons?
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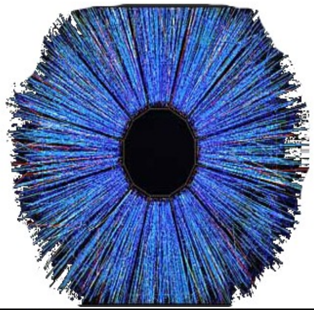
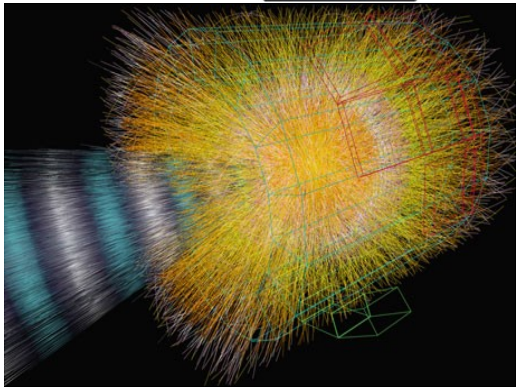
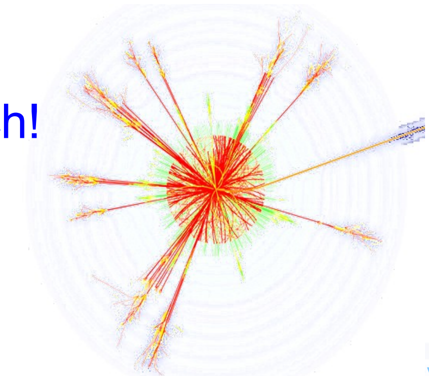
- **Now:**
  - TeV-scale collisions, monstrous colliding experiments and collaborations
  - >10k produced charged particles (ALICE), >7 jets, >10^6 of W/Z bosons
  - Digital data recording. Computer-intensive pattern recognition
  - Theory:
    - The Standard Model!
    - Sophisticated analytical calculations (pQCD+LHPD)
    - Numerical LO, NLO, NNLO, N...LO calculations
    - Monte Carlo generators
  - Theory-driven experimental research!







Experimental results from the LHC and high-precision measurements from HERA, RHIC, LEP, BaBar and TEVATRON are good snapshot of our progress in experimental HEP!

Apologize to the speakers whose plots are not shown (time & my limitation)

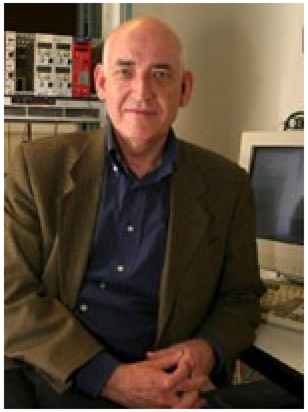
Thanks to the organizers, conveners and the speakers for very inspiring meeting

ISMD

Happy anniversary!

Organizing Committee

P. Van Mechelen (co-chair)
N. Van Remortel (co-chair)
E. De Wolf (honorary chair)
X. Janssen
H. Jung
K. Kutak
P. Marage
A. De Roeck
R. Rougny
S. Van Mierlo



Happy retirement!