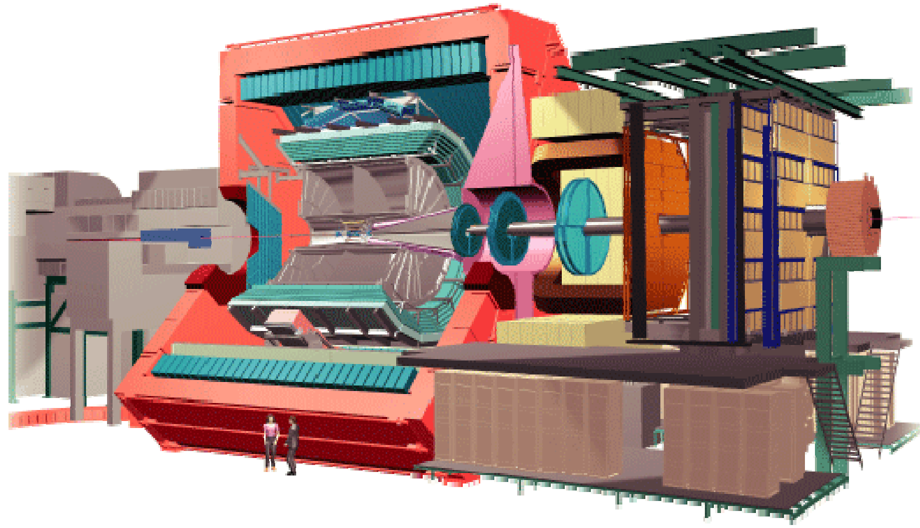


The ALICE experiment

A Large Ion Collider Experiment

R. Lietava

The University of Birmingham

Outlook

- First collisions (2009)
- ALICE detector
- ALICE trigger
- First pp physics with ALICE
- Heavy ions
- Summary

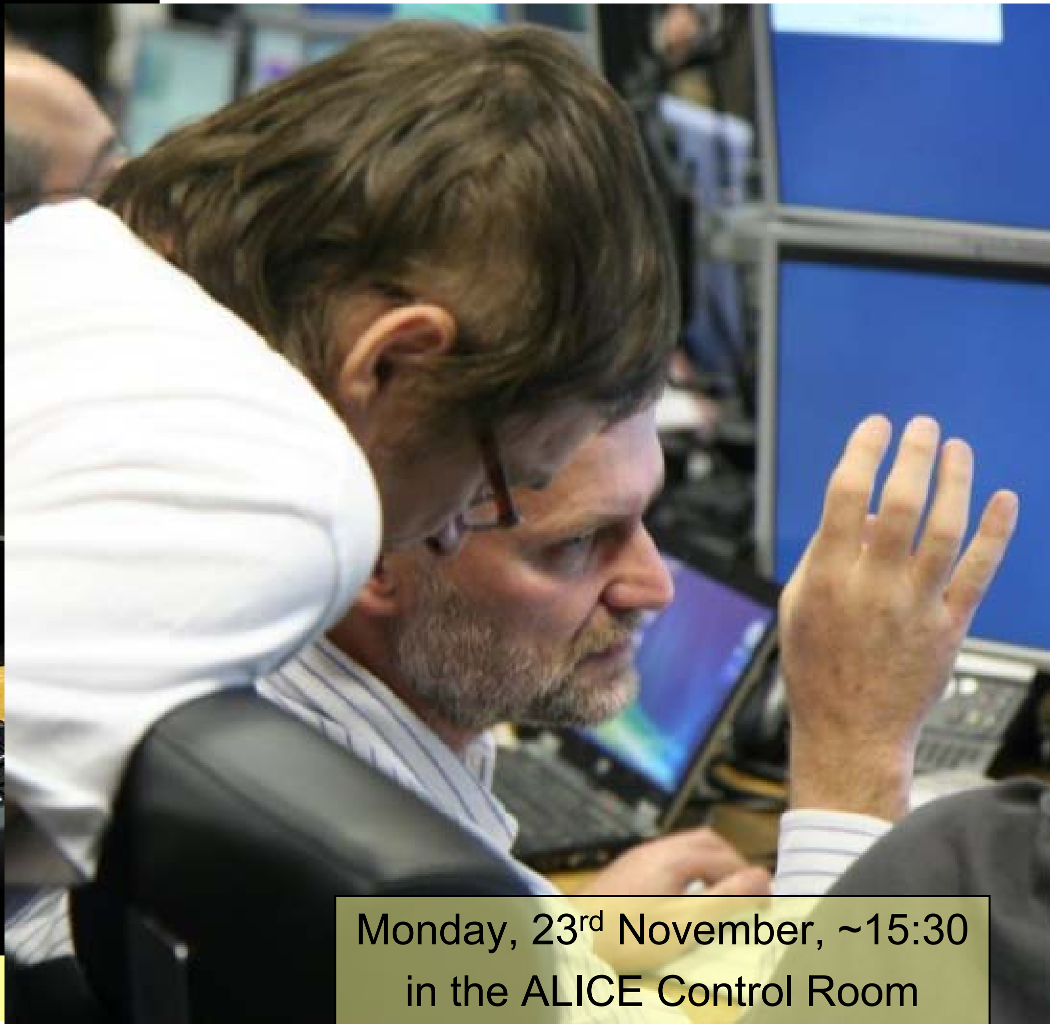
ALICE physics

- **A-A (macroscopic QCD)**
  - equation of state (ideal gas or strongly coupled liquid)
  - phase diagram (1^{st}, 2^{nd} order, crossover ?)
- **p-p**
  - reference to AA
  - minimum bias physics => soft QCD (underlying event)
  - unique pp physics with Alice (baryon transport, charm cross section)

First Collisions at the LHC seen through the eyes of ALICE

The LHC (and everything else) accelerates ..

..after concentrated preparations..

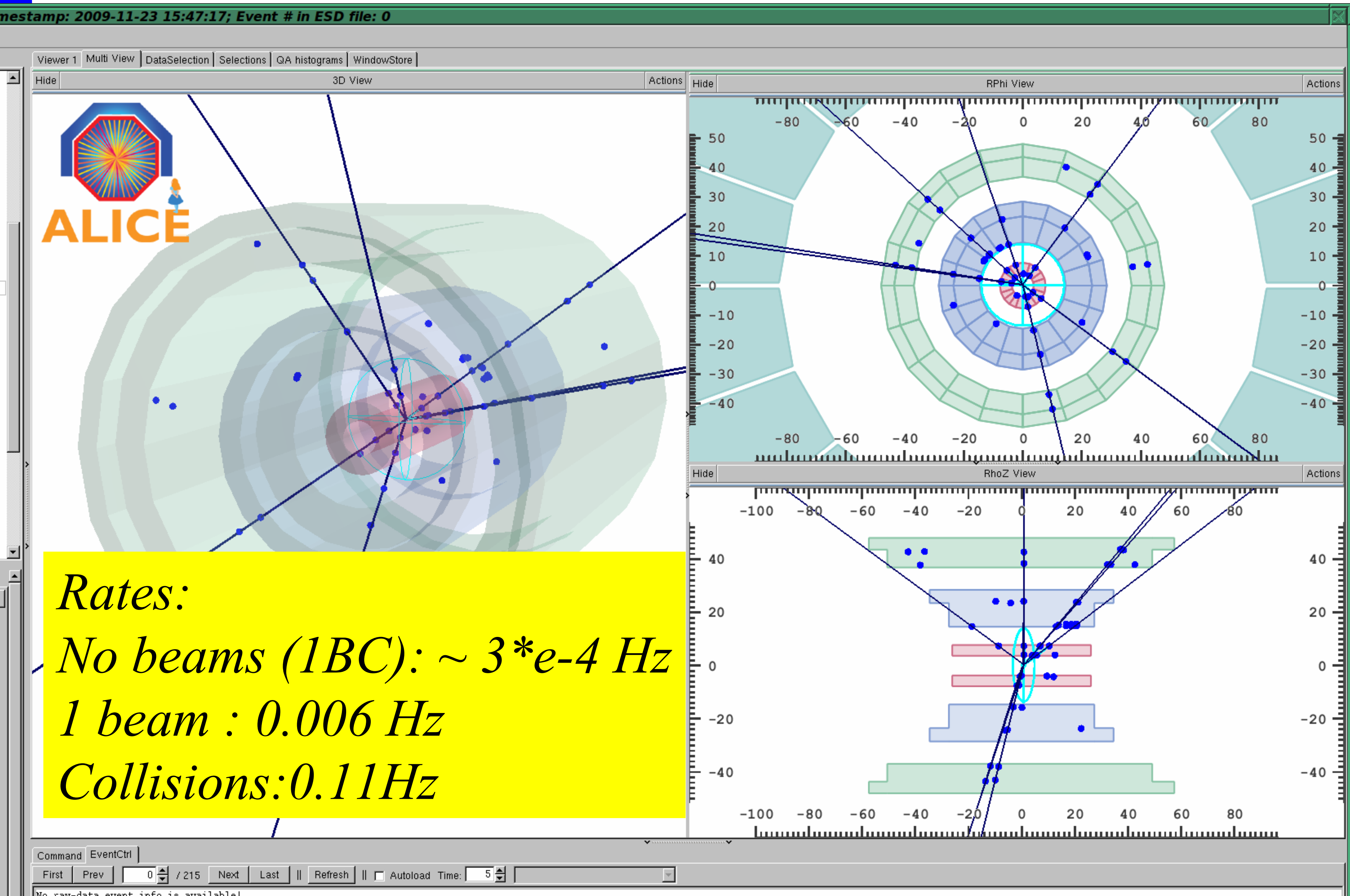


Monday, 23rd November, ~15:30
in the ALICE Control Room

some anxious minutes waiting for collisions..

still waiting …

The first ‘event’ pops up in the ACR



Rates:

*No beams (1BC): ~ 3*e-4 Hz*

1 beam : 0.006 Hz

Collisions:0.11Hz

Relief and jubilation …

Collisions in ALICE !!

.. and some celebration..

‘First Physics’ analysis

After years of looking at simulated data,
first physics results examined,
ca 1 hour after data taking finished (284 events !)..

Physics exploitation of ALICE has started for good !

This is the first (and easiest) of many numbers we need to (re)measure to get confidence in our detectors, tune the simulations, study background, ...

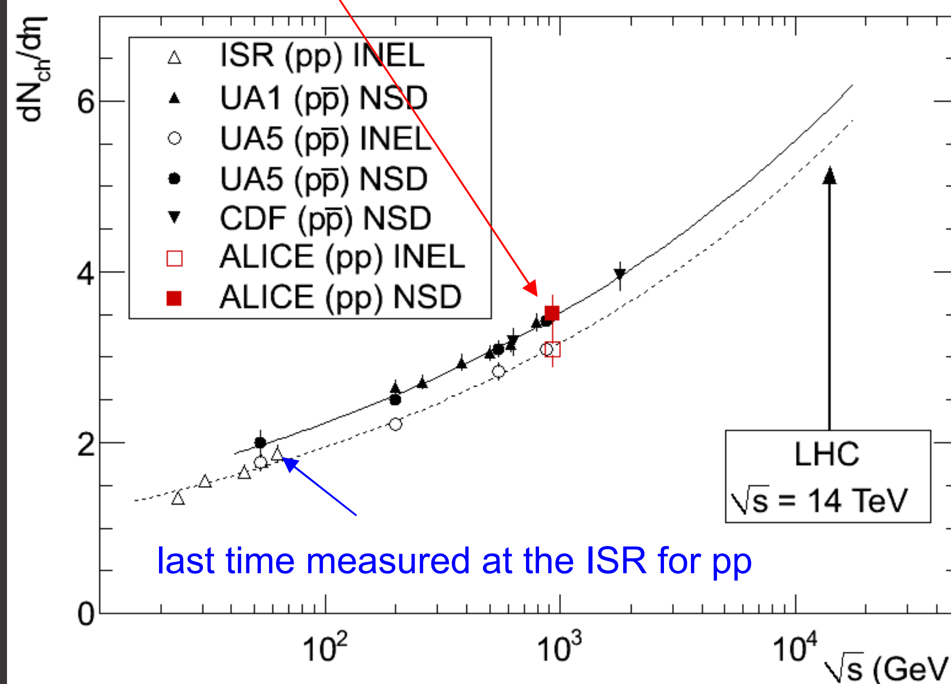
Phase 2 is still a long way to go..

Phase 1: rediscovering the standard model

(QCD in the case of ALICE)

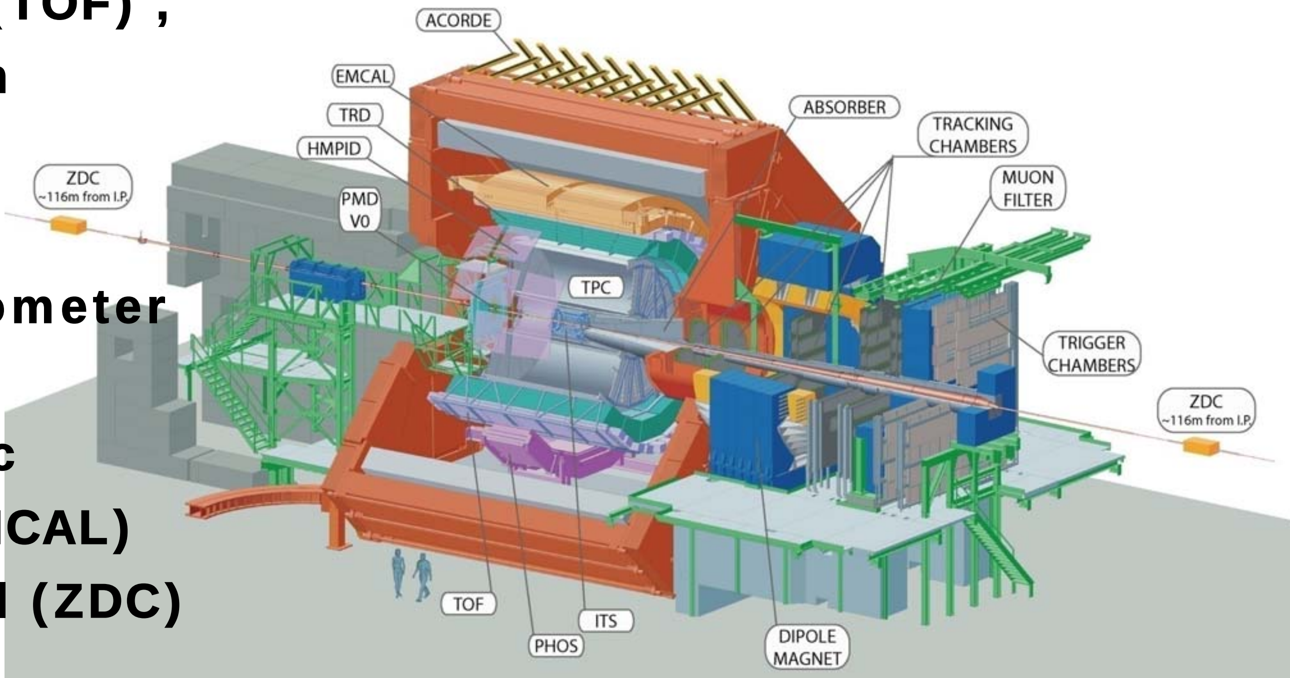
The average number of charged particles created perpendicular to the beam in pp collisions at 900 GeV is:

$dN/d\eta$ = 3.10 ± 0.13 (stat) ± 0.22 (syst)

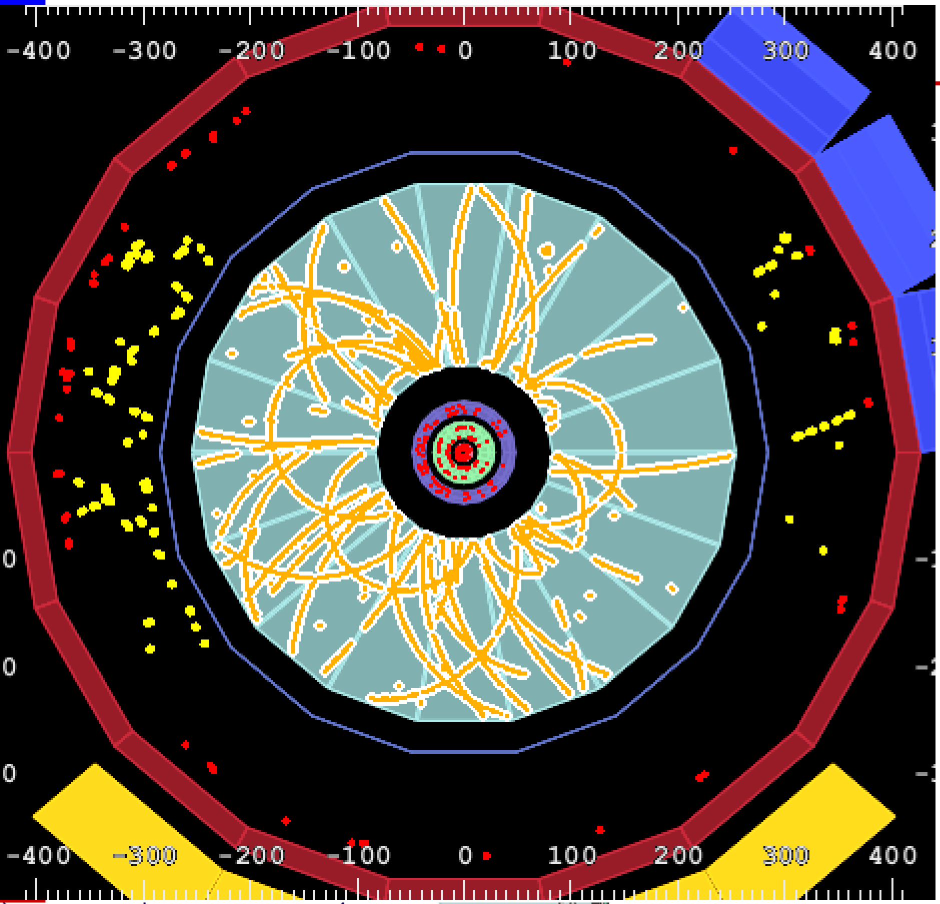


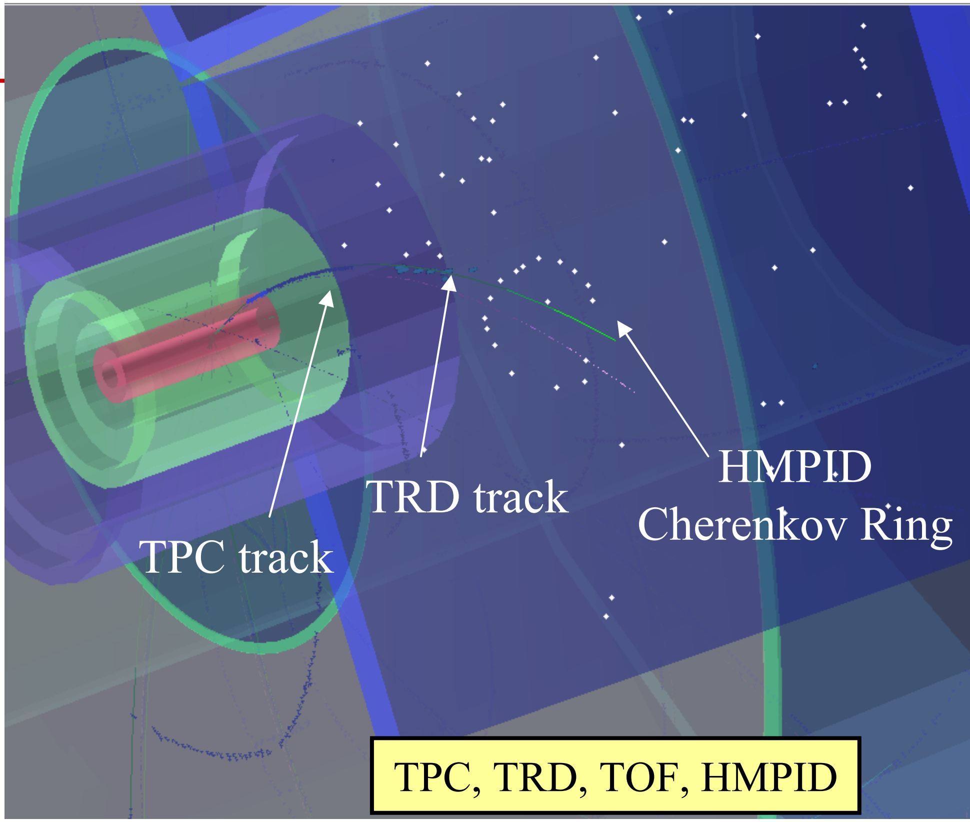
Alice Detector

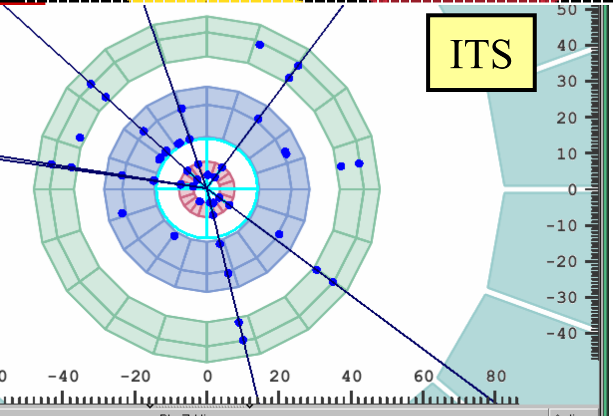
- **Tracking (B=0.2-0.5 T):**
  - **Inner Tracking System (ITS) – pixels (SPD),drift (SDD),strips (SSD)**
  - **Time Projection Chamber (TPC)**
  - **Transition Radiation Detector (TRD)**
- **Particle Identification (PID):**
  - **TPC , TRD ,**
    Time Of Flight (TOF) ,
    High Momentum
    PID (HMPID)
- **Calorimetry:**
  - **PHOton Spectrometer (PHOS)**
  - **Electromagnetic Calorimeter (EMCAL)**
  - **Zero Degree Cal (ZDC)**

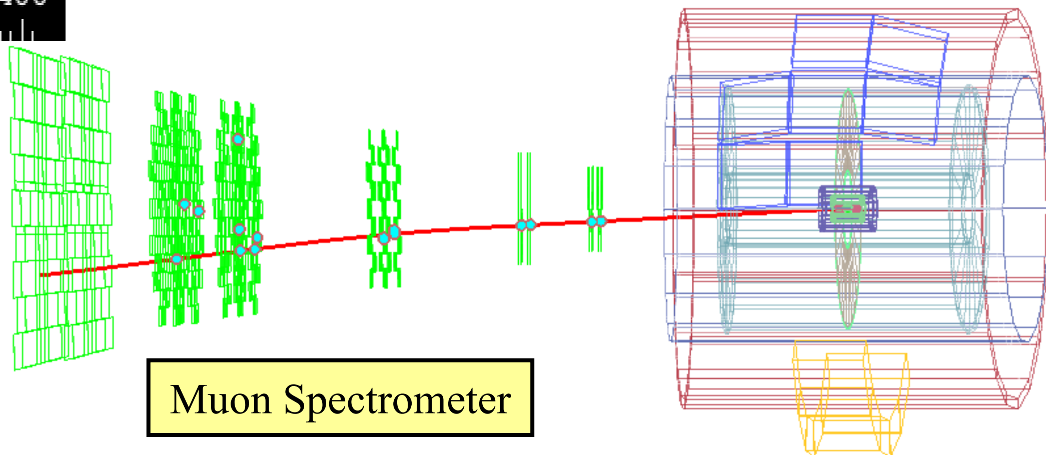


Alice Detector Displays with Real Tracks !

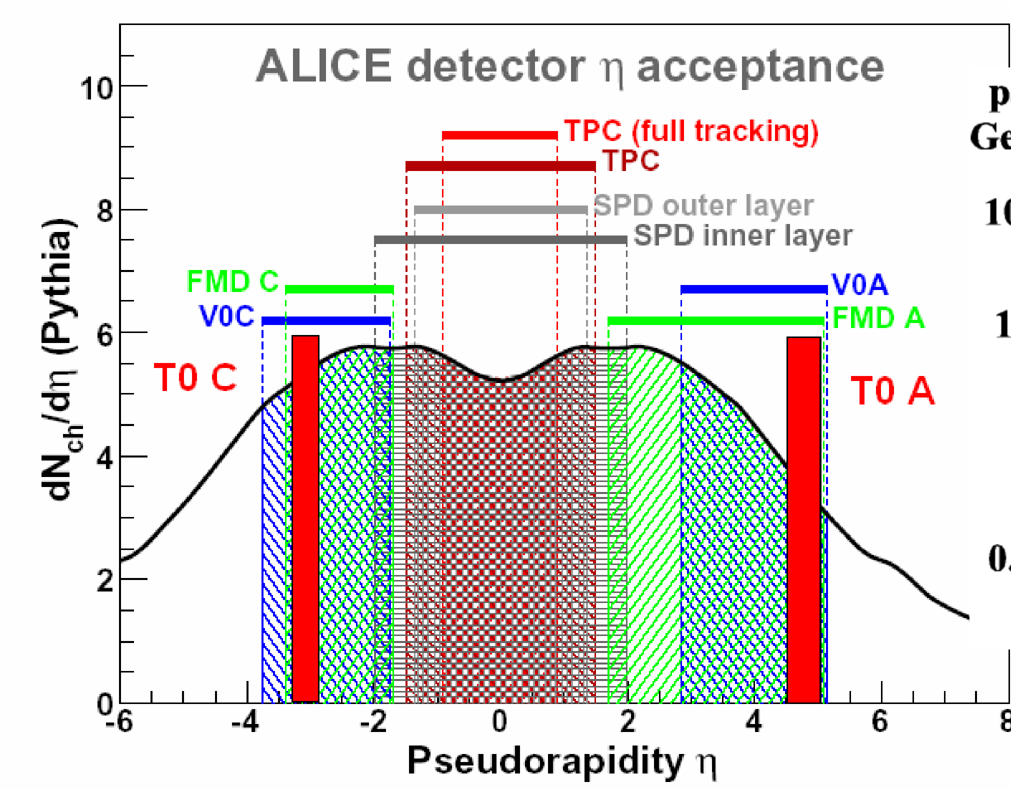


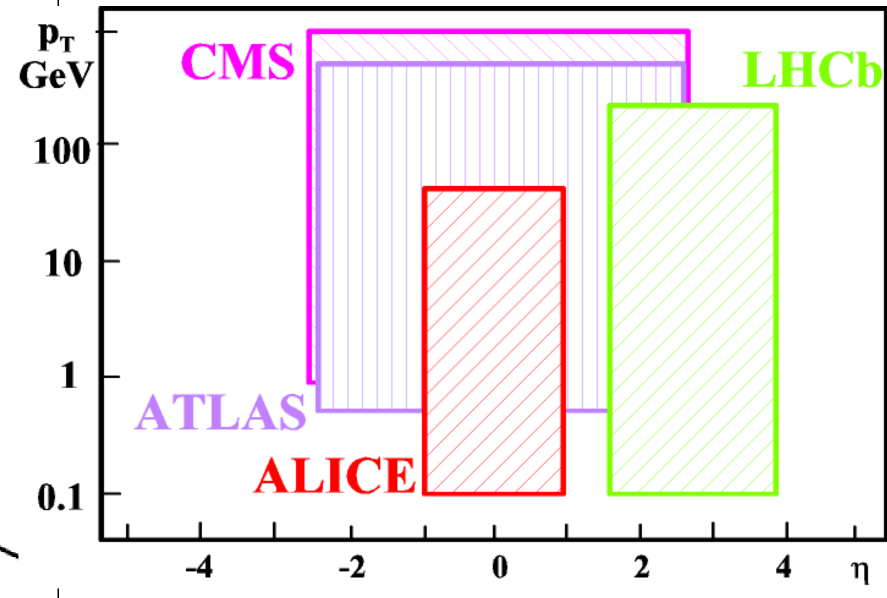






ALICE Detector Acceptance





Central tracking: $-1<\eta<1$
Muon arm: $2.4<\eta<4$

V0: $2.8 < \eta < 5.1$
$-3.7 < \eta < -1.7$

ALICE detector

ALICE unique features:

☺ **acceptance at low p_T** (~ 0.2GeV/c)

⇒ relatively low field (0.5T)

⇒ low material budget (total X/X0=7%)

☺ **excellent PID capabilities**

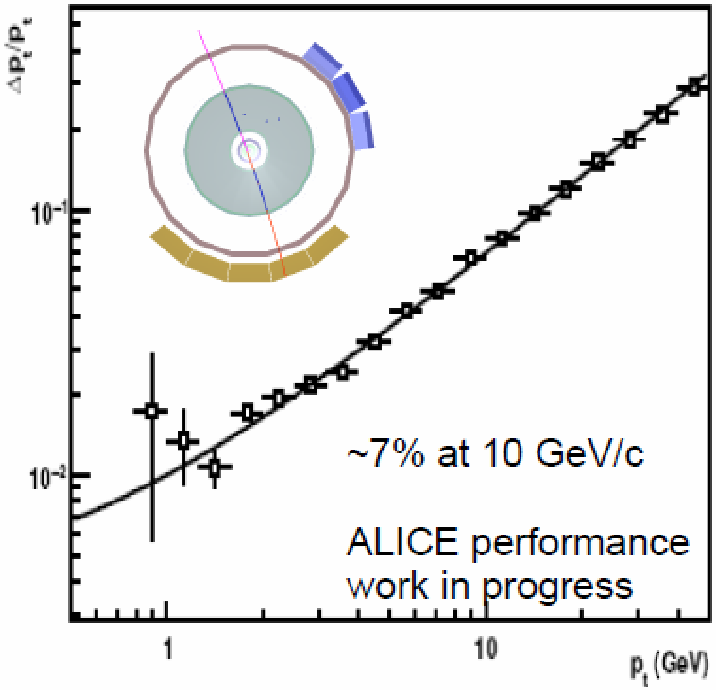
⇒ dE/dx (TPC/ITS), TRD,

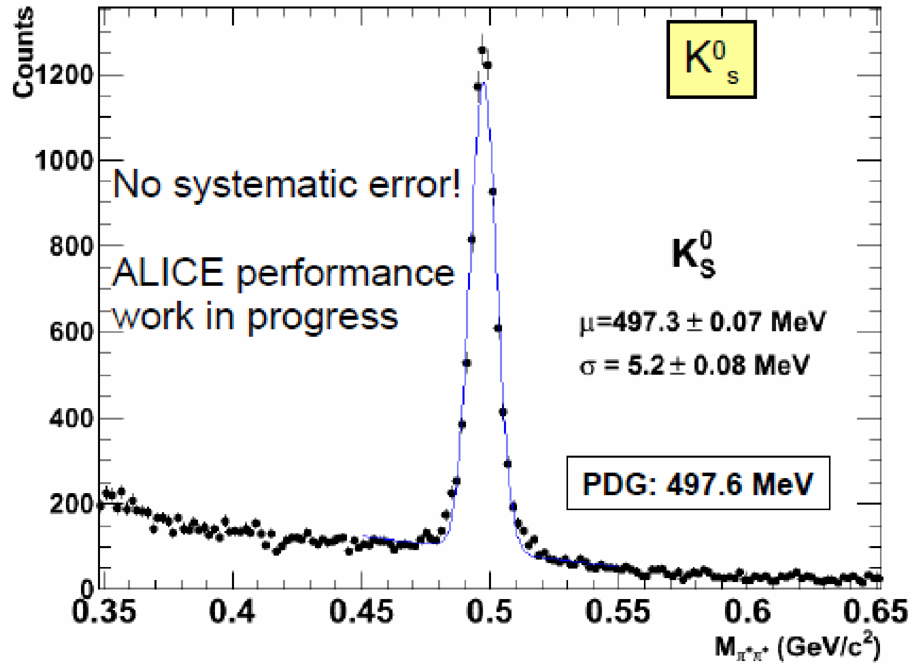
TOF, HMPID, PHOS, (EMCAL)

☹ **limited in luminosity** (TPC sensitive time ~ 100μsec)

Time Projection Chamber – track p_T reconstruction

Momentum resolution (from matching of two segments of cosmic track)

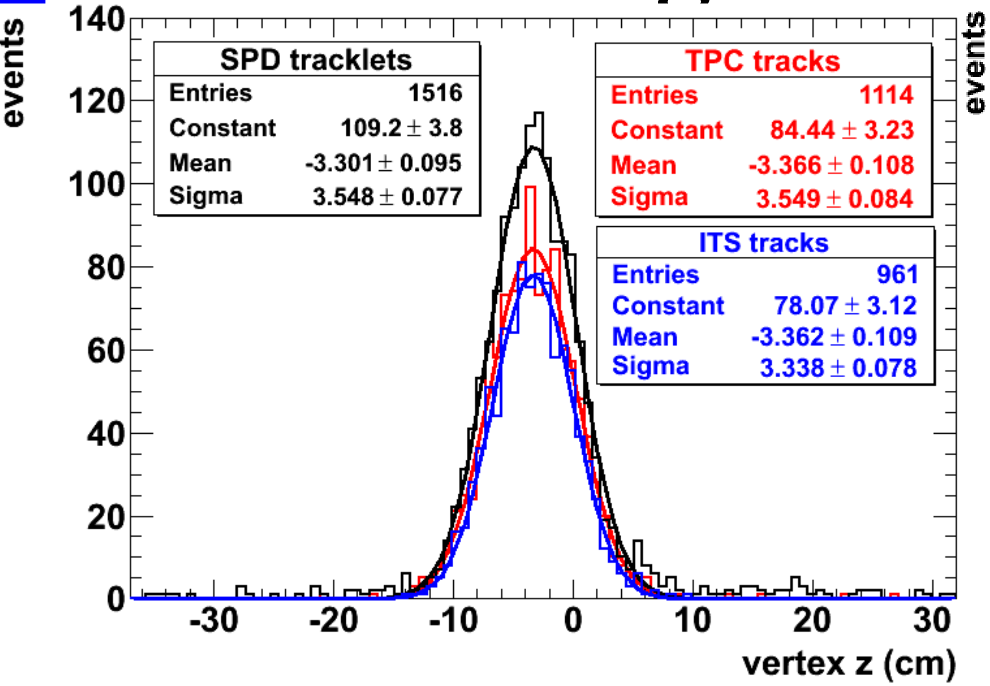


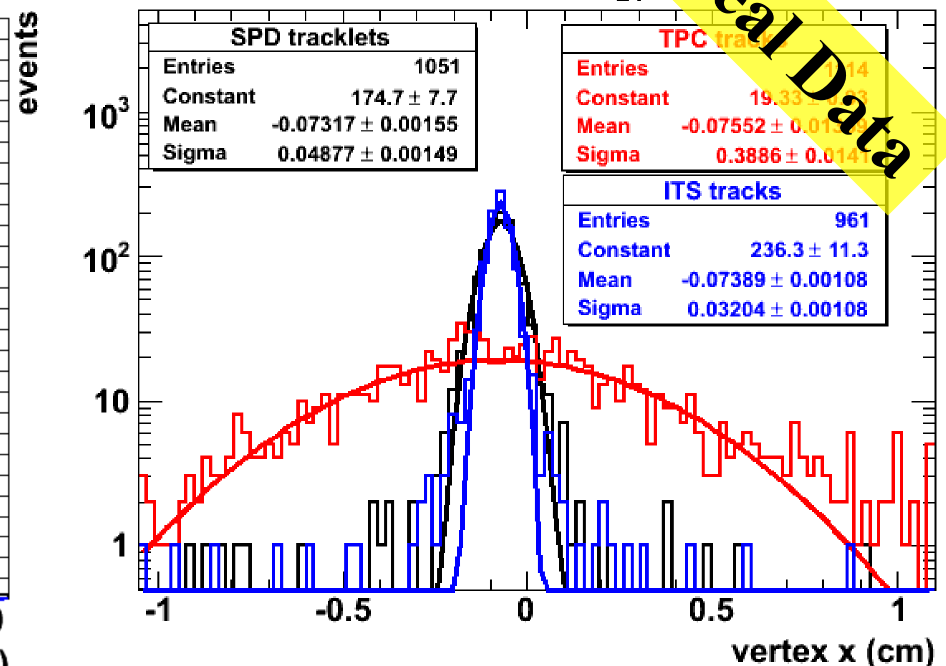


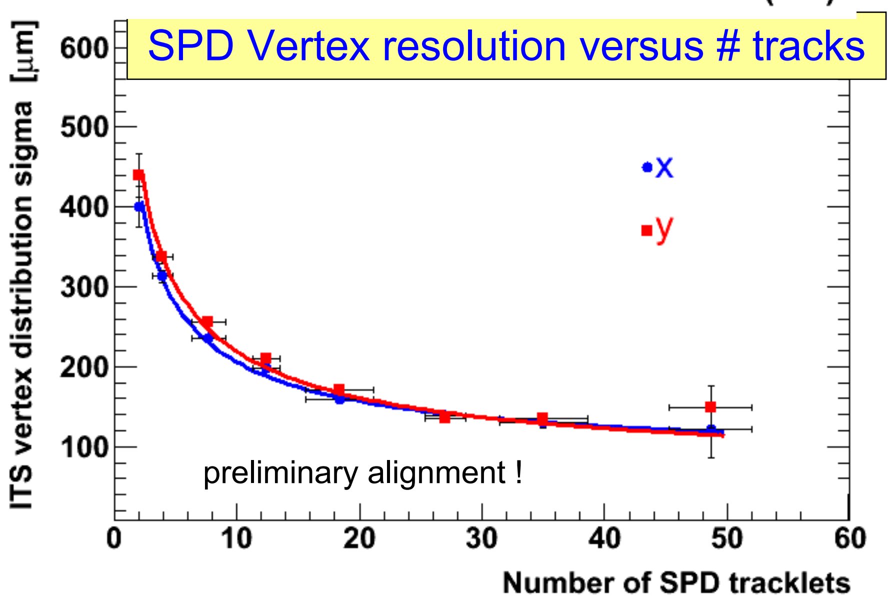
- p_T resolution 7% at 10 GeV/c (aim 5%)
- ... and below 1% at p_T<1 GeV/c – confirmed by K^0_s measurements

Tracking works beautifully

Real Data

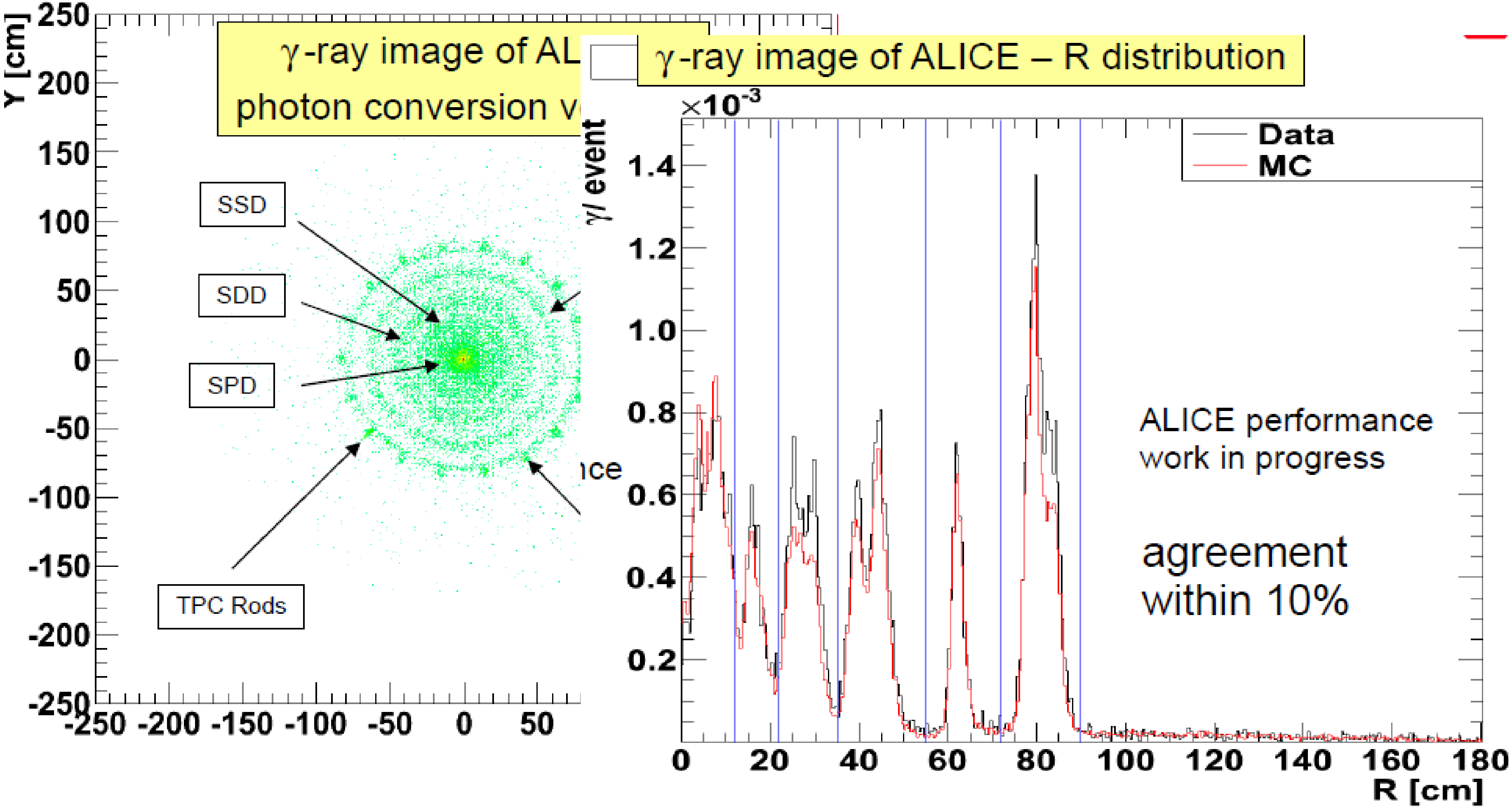






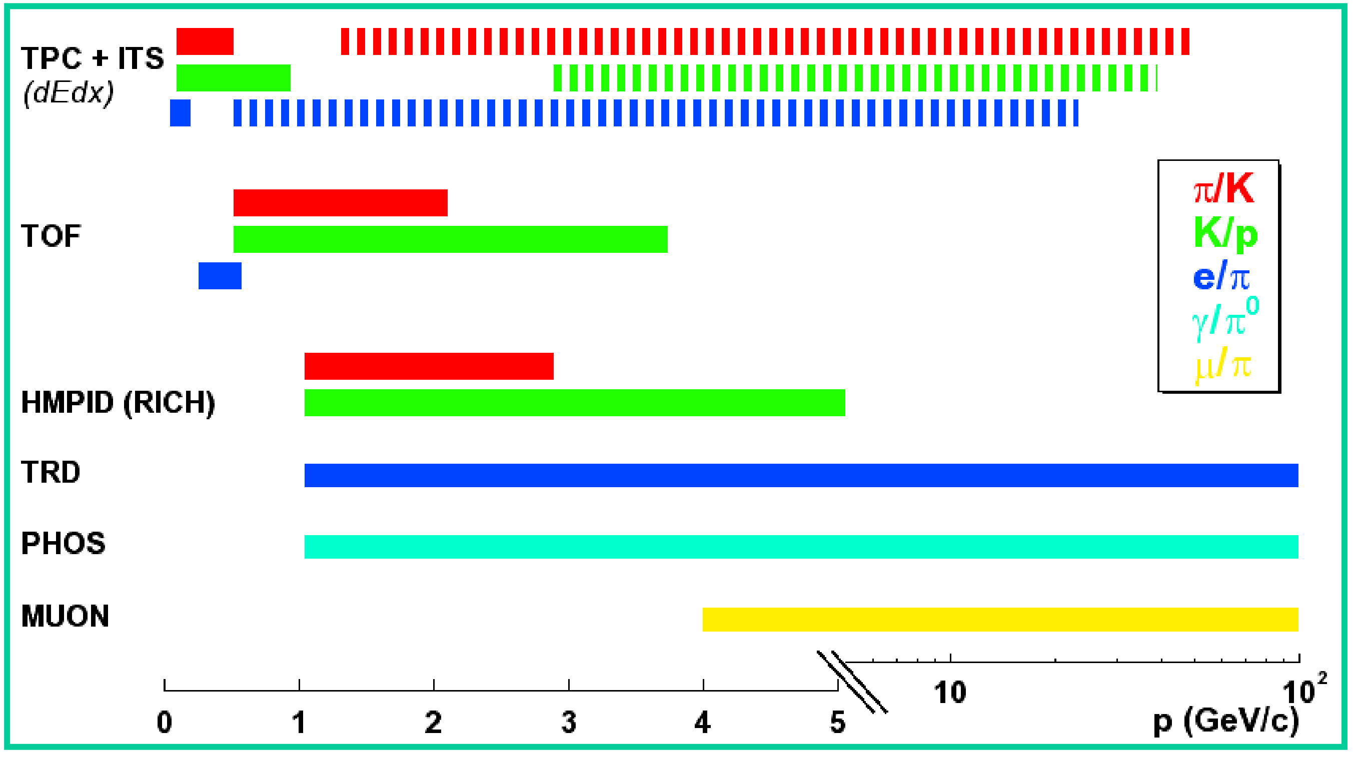
3 ways of reconstruction the vertex:
Pixels only; all ITS; TPC only.
TPC standalone resolution is of course much worse than the ITS, but gives the same position; i.e. the relative alignment is ok.
The x resolution is for all momenta and track multiplicties; the actual beamspot (after unfolding) is slightly less than 200 micron.

γ-ray image of ALICE (DATA)



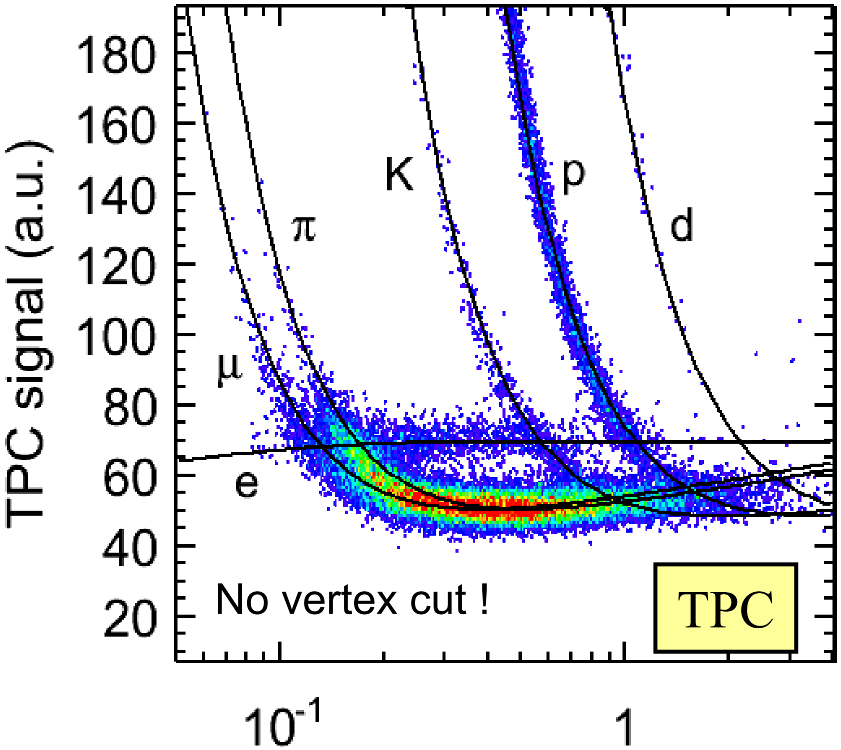
Particle Identification

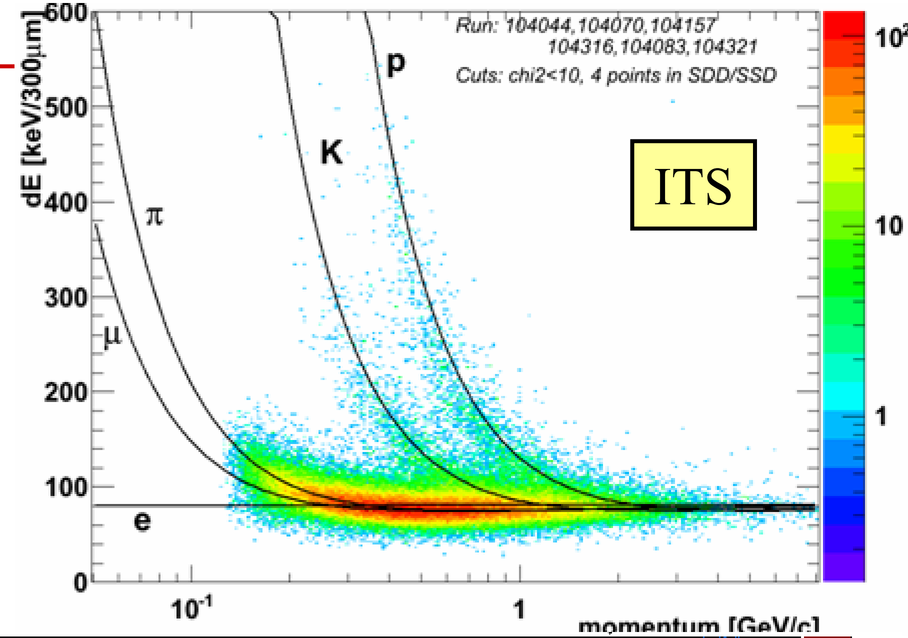
- Very good PID over broad momentum range

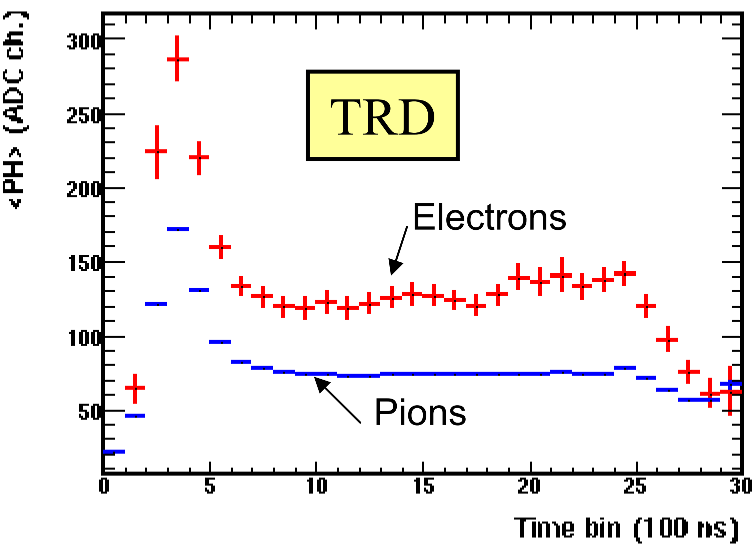


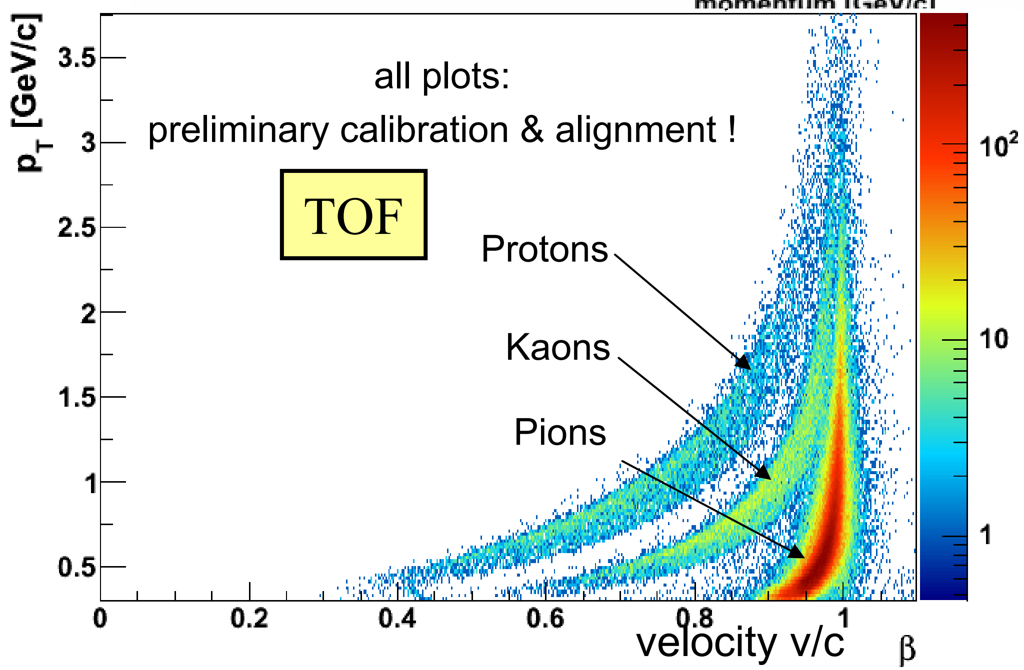
separation @ 3σ separation @ 2σ

PID peformance (DATA)

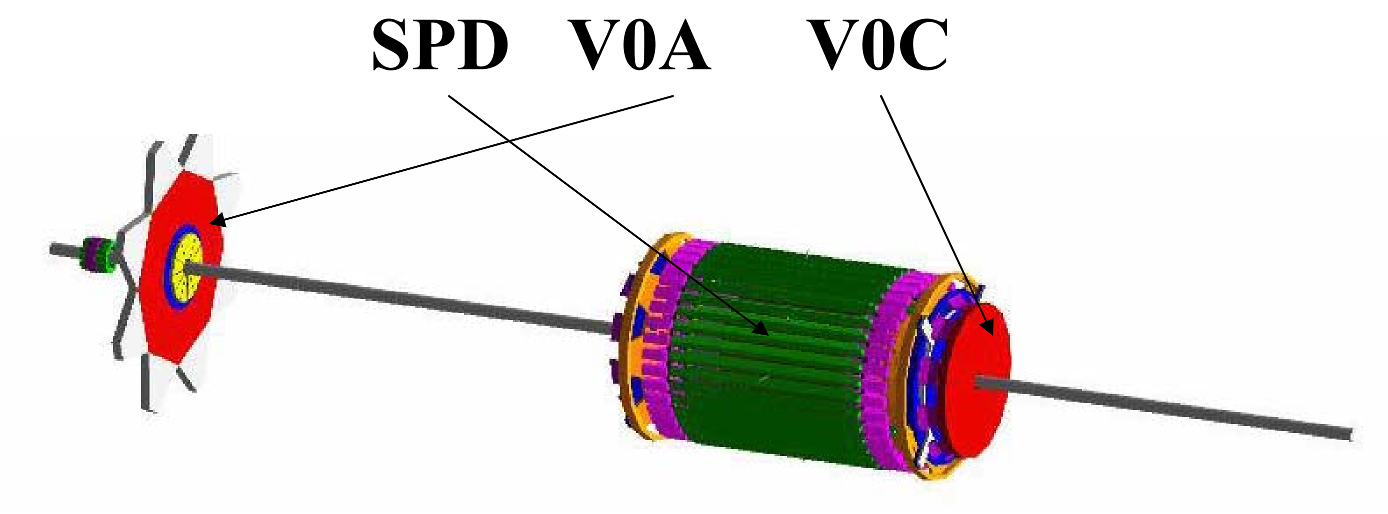


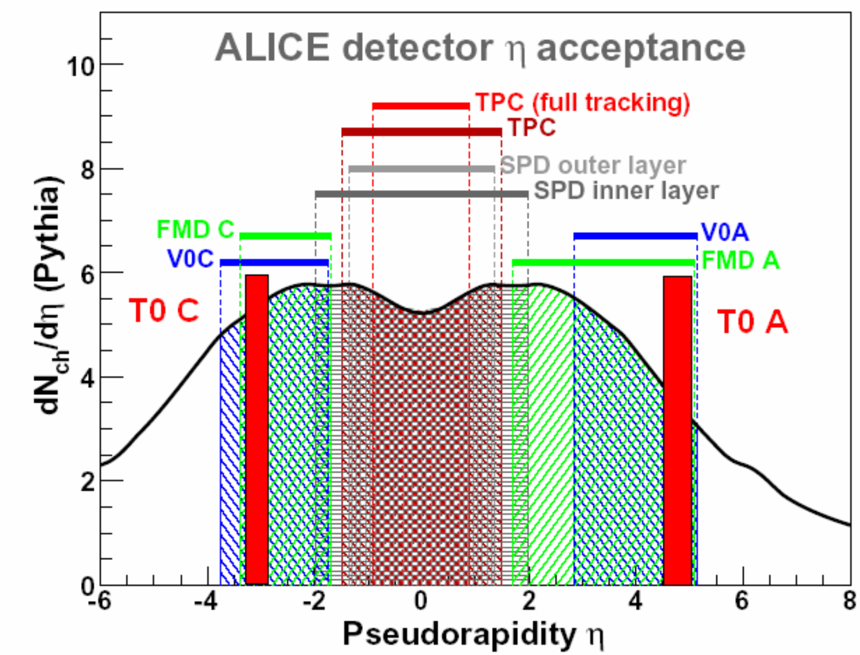






Minimum bias trigger





V0:

$2.8 < \eta < 5.1$

$-3.7 < \eta < -1.7$

SPD inner layer:

$-1.98 < \eta < 1.98$

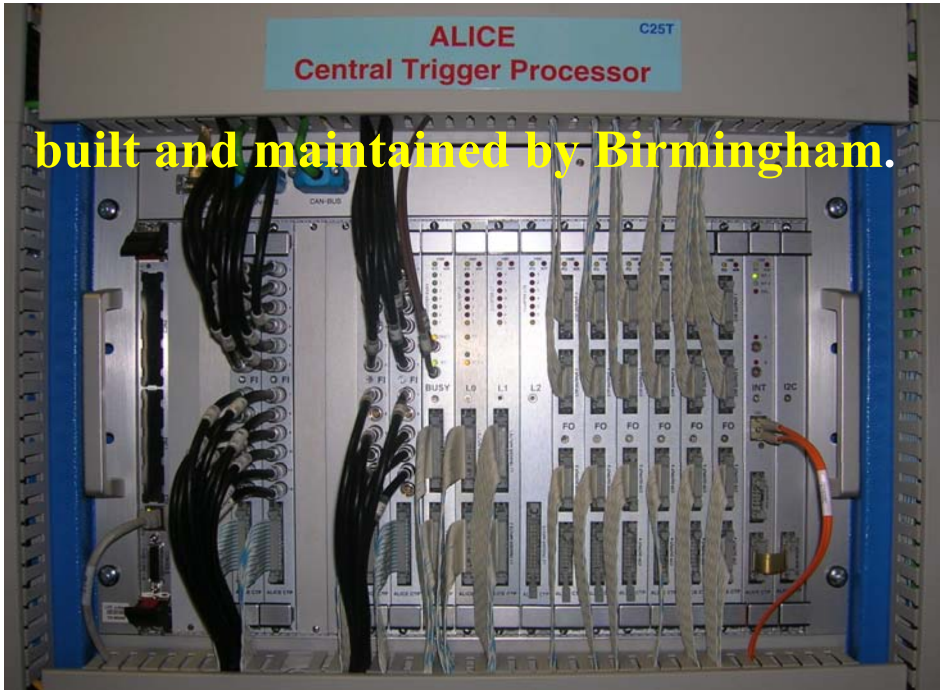
ALICE Central Trigger Processor

Collision system	$\sqrt{s_{NN}}$ (TeV)	L_0 ($cm^{-2}s^{-1}$)	Run time (s/year)	σ_{inel} (b)	$Rate_l$ (kHz)
pp	14.0	10^{31}	10^7	0.07	700
PbPb	5.5	10^{27}	10^6	7.7	7.7

<= MAX
Optimal = MAX/100

CTP features:

- 3 Levels (L0,L1,L2 ~ 1μs, 6μ, 100μs)
- Generally no pipelining
- Partitioning of detectors into independent groups – e.g. muon arm and central barrel
- Pile up (past-future) protection – tens of interactions in TPC drift time



Initial trigger

Initial beam: 2 bunches in each ring,

1 collision in ALICE

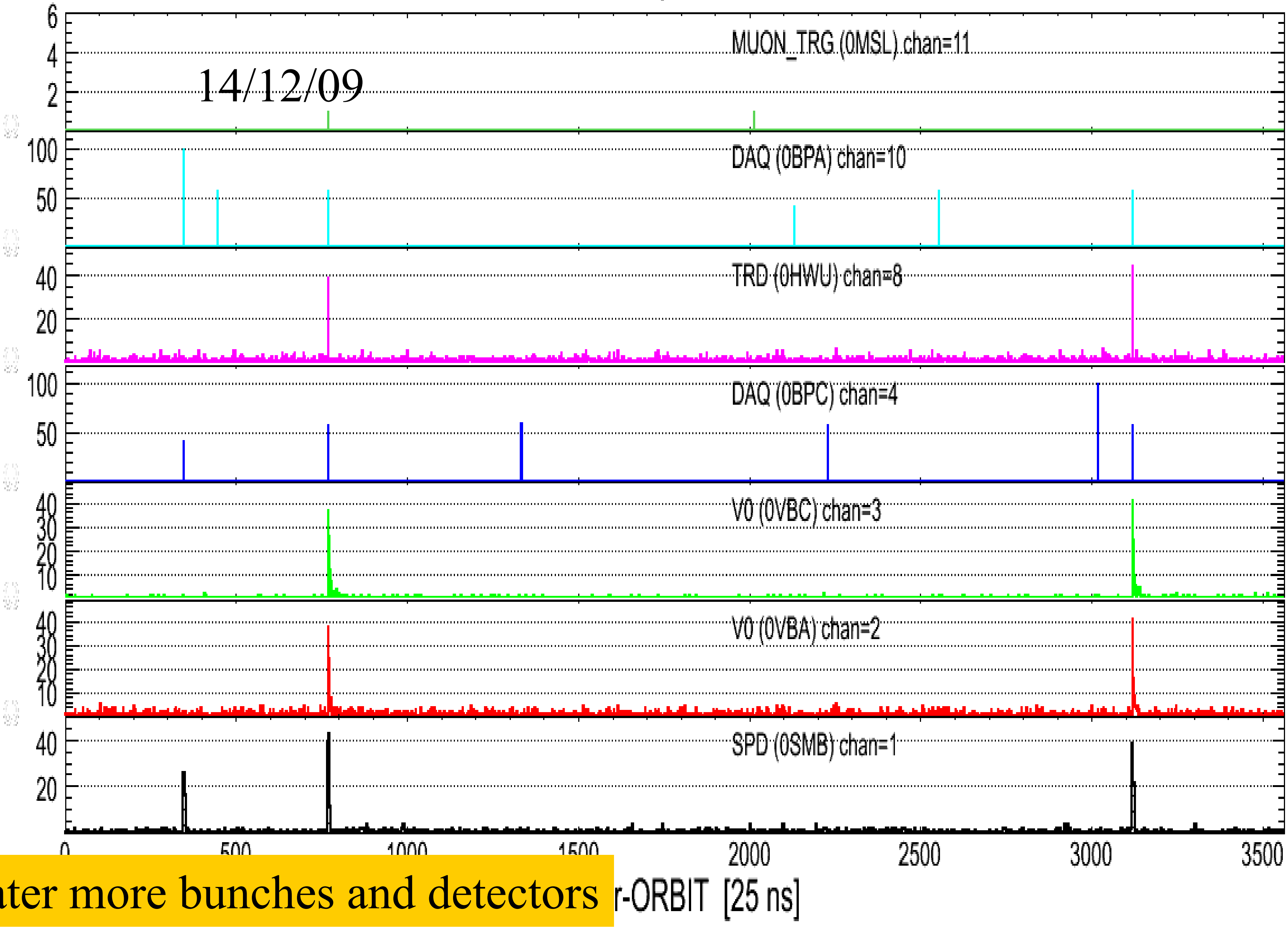
- Phase 1 (day 0)

  - pixel trigger (2 or more hits in SPD) in coincidence with beam pickup counters (BPTX)

- Phase 2 (day 0+n), n=1

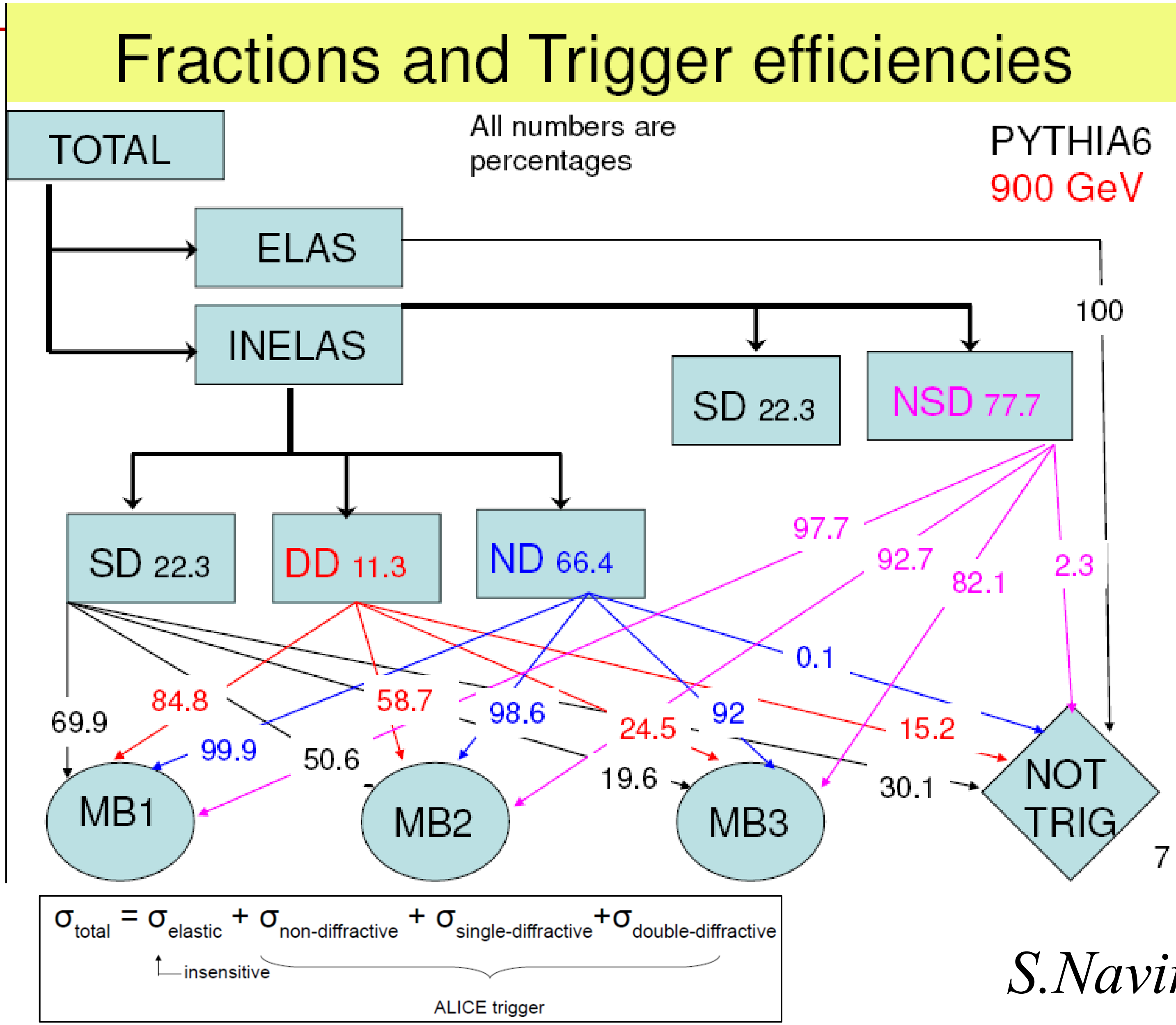
  - minimum bias trigger with SPD or V0A or V0C in coincidence with BPTXs

Trigger Inputs Timing



Later more bunches and detectors

How biased is min bias trigger?



S.Navin

Trigger Efficiencies and corrections

$$\text{Efficiency} = N_{triggered} / N_{total} = \sum f_{process} e_{process}$$
$$= f_{SD} e_{SD} + f_{DD} e_{DD} + f_{ND} e_{ND}$$

- Need to know the fraction (f) and the efficiency (e) for each process.
- Efficiency is process, trigger and generator dependent

Eg: MB1 = SPD or V0A or V0C

MB1 efficiencies:

Process	SD	DD	ND
Fraction (f)	0.187	0.127	0.686
Efficiency (e)	0.714	0.864	0.999

Pythia: 92.9%

Process	SD	DD	ND
Fraction (f)	0.134	0.063	0.803
Efficiency (e)	0.767	0.938	0.999

Phojet: 96.4%

Reason for difference:

f – uncertainty in fractions

e – uncertainty in kinematics

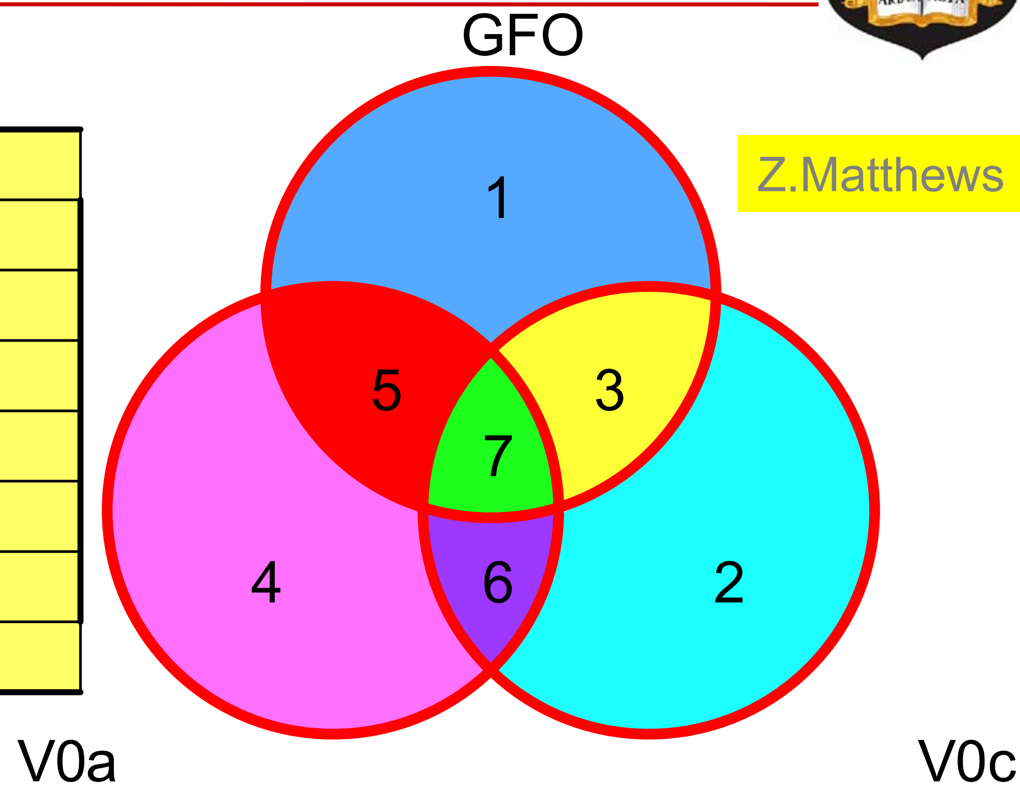
~2-4% effect each

Major difference is in diffractive events

Diffractive Events Fraction

UA5 like method

Tr	V0A	GFO	V0C
1	0	1	0
2	0	0	1
3	0	1	1
4	1	0	0
5	1	1	0
6	1	0	1
7	1	1	1



Z.Matthews

$$N_{trig} = N_{trig}^{DD} + N_{trig}^{SD} + N_{trig}^{ND} + N_{trig}^{NI}$$

$$N_{trig} = N_{rec}\left(f_{DD}\varepsilon_{trg}^{DD} + f_{SD}\varepsilon_{trg}^{SD} + f_{ND}\varepsilon_{trg}^{ND} + f_{NI}\varepsilon_{trg}^{NI}\right)$$

$$= N_{rec}\left(f_{DD}\varepsilon_{trg}^{DD} + f_{SD}\varepsilon_{trg}^{SD} + f_{ND}\varepsilon_{trg}^{ND} + \left(1-\left(f_{DD} + f_{SD} + f_{ND}\right)\right)\varepsilon_{trg}^{NI}\right)$$

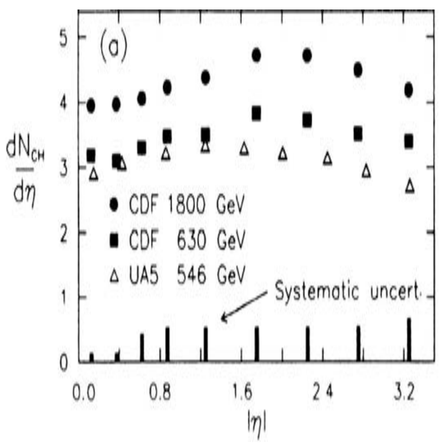
$$Ntrig_{calc(i)} = \sum_{j=1,3} a_{ij} Type(j)$$

$$\chi^2 = \sum_{trig}\left(\frac{\left(Ntrig_{calc}(i) - Ntrig_{measured}(i)\right)}{Error\left(Ntrig(i)\right)}\right)^2$$

$$Dof = 8 - 4 + 1 = 5$$

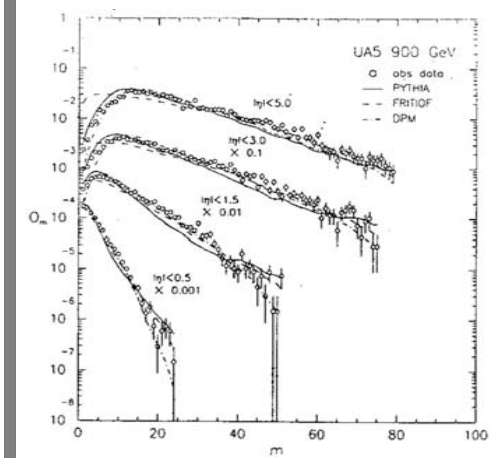
Extract f_{sd}, f_{dd} offline from data !

First Measurements



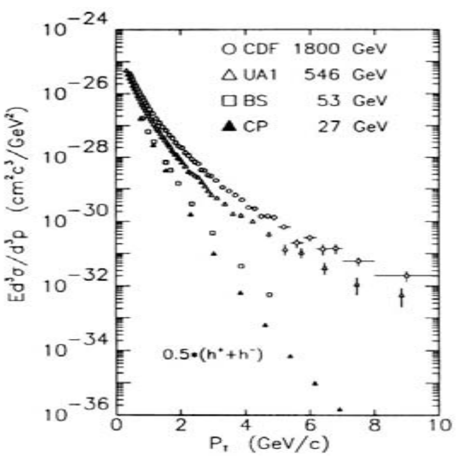
Pseudorapidity density dN/dη

CDF:
Phys. Rev.
D41, 2330 (1990)



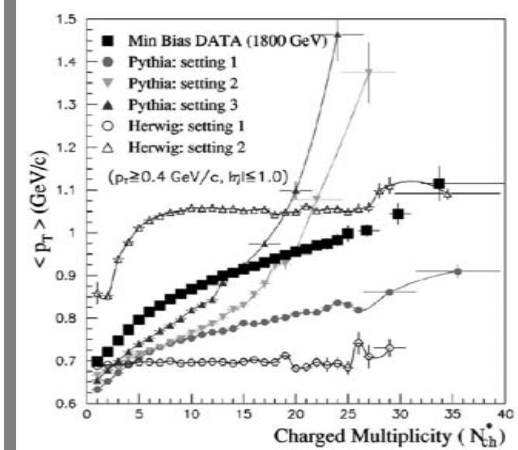
Multiplicity distribution

UA5:
Z. Phys
43, 357 (1989)



p_T spectrum unidentified hadrons

CDF:
Phys. Rev. Lett.
51, 1819 (1988)



Mean p_T vs multiplicity

CDF:
Phys. Rev.
D65,72005(2002)

Statistics for pp physics analysis

- Total events collected: **> 1 M**
- 'Good pp interactions': **500 k**
- - 100 k : B = 0 (alignment)
- - 10 k : B reversed (systematics)
- - 30 k : $\sqrt{s}$ = 2.36 TeV

Detector configuration:

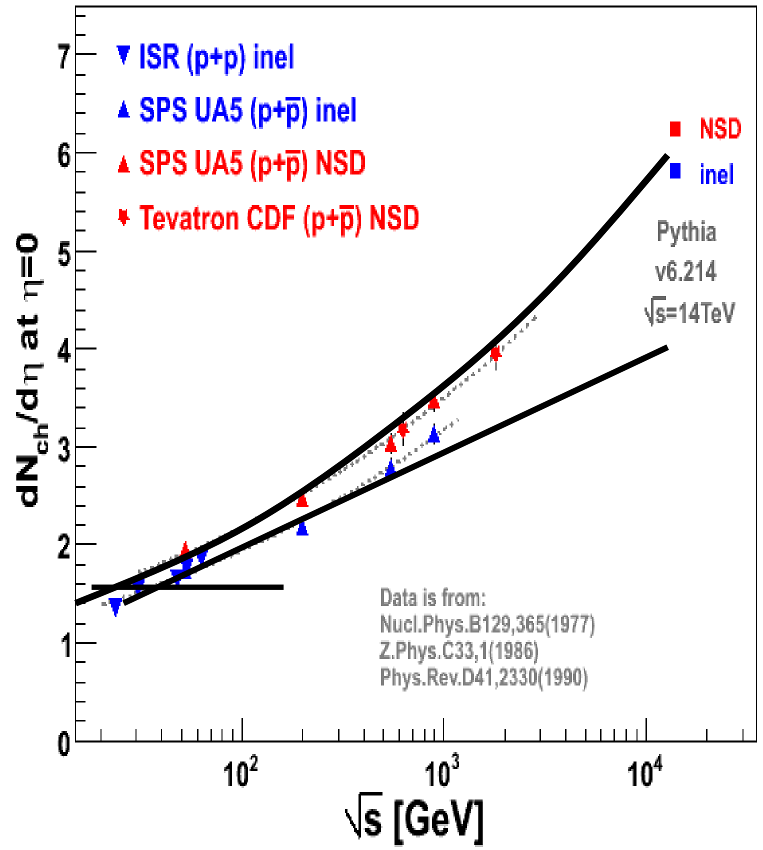
- **Not 'Stable beams':**

  ITS, V0

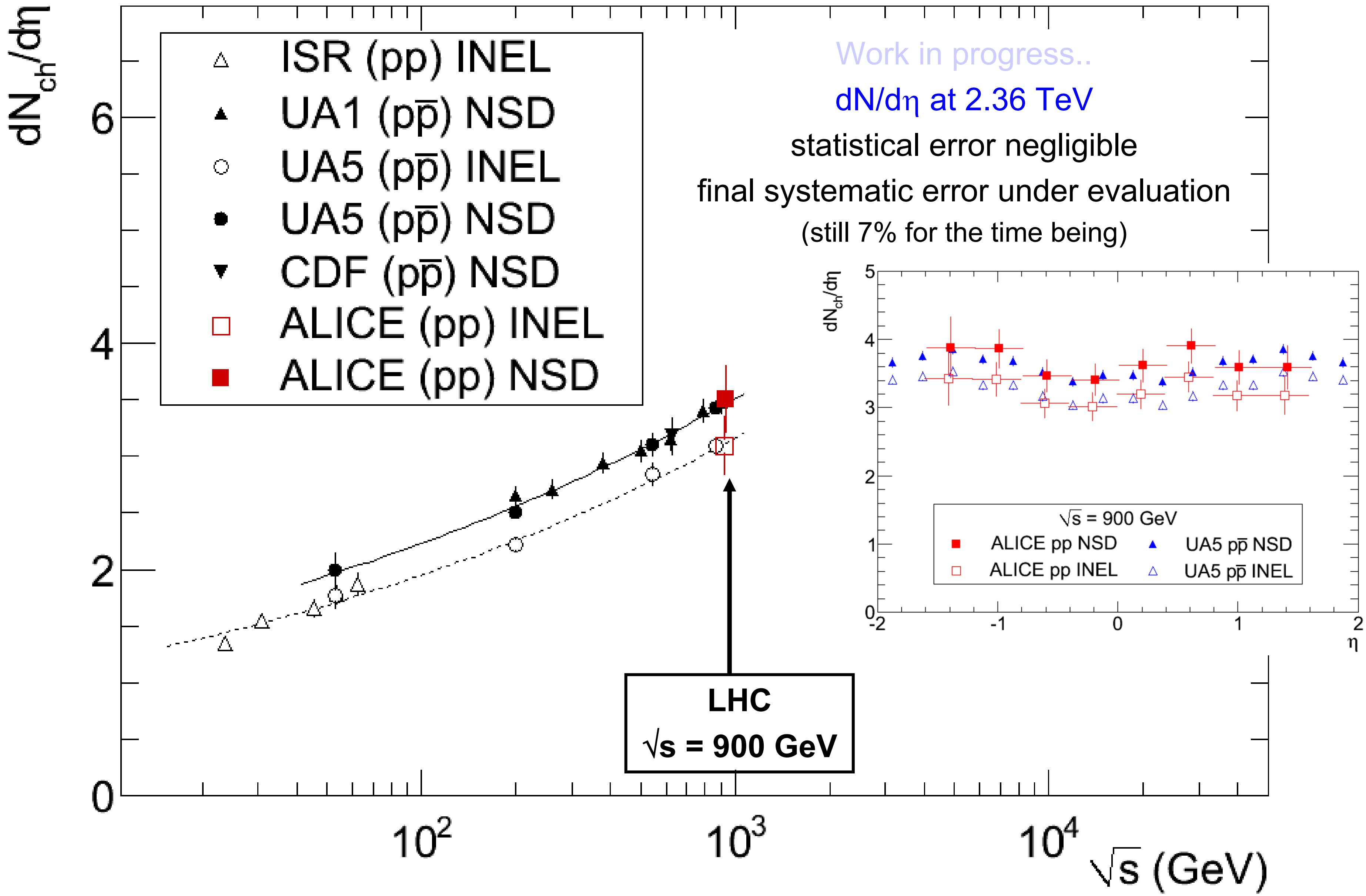
- **'Stable beams' - On 6th December 'stable beams' were declared & we could switch on all ALICE detectors for the first time..**

dN/dη at η=0

- Feynman (1969):
  $N_{tot} = a + b*\ln(s)$
  $dN/d\eta = \text{const}$
- ISR(1977):
  $dN/d\eta = a + b*\ln(s)$
- SppS (1981):
  $dN/d\eta = a + b*\ln(s) + c*\ln(s)^2$



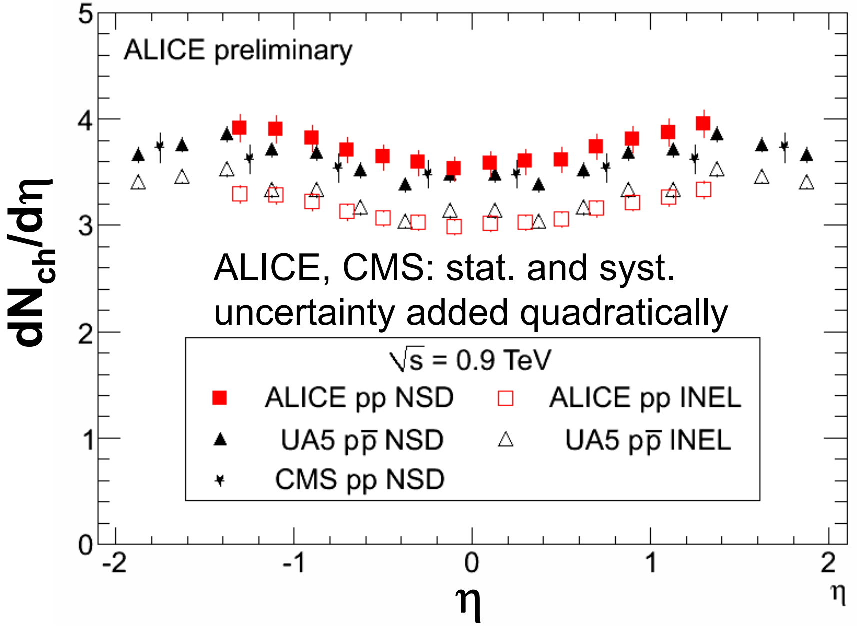
LHC points

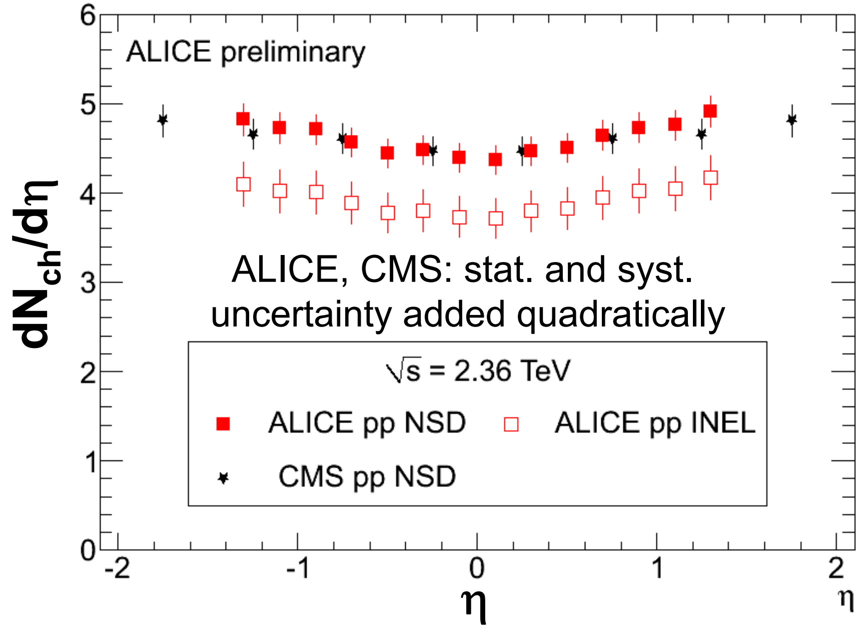


dNch/dη
ISR (pp) INEL
UA1 (pp̄) NSD
UA5 (pp̄) INEL
UA5 (pp̄) NSD
CDF (pp̄) NSD
ALICE (pp) INEL
ALICE (pp) NSD
Work in progress..
dN/dη at 2.36 TeV
statistical error negligible
final systematic error under evaluation
(still 7% for the time being)
LHC
√s = 900 GeV
√s (GeV)
√s = 900 GeV
ALICE pp NSD
UA5 pp̄ NSD
ALICE pp INEL
UA5 pp̄ INEL
η

$dN_{ch}/d\eta$

NB: CMS data points do not include charged leptons → ~1.5 % difference



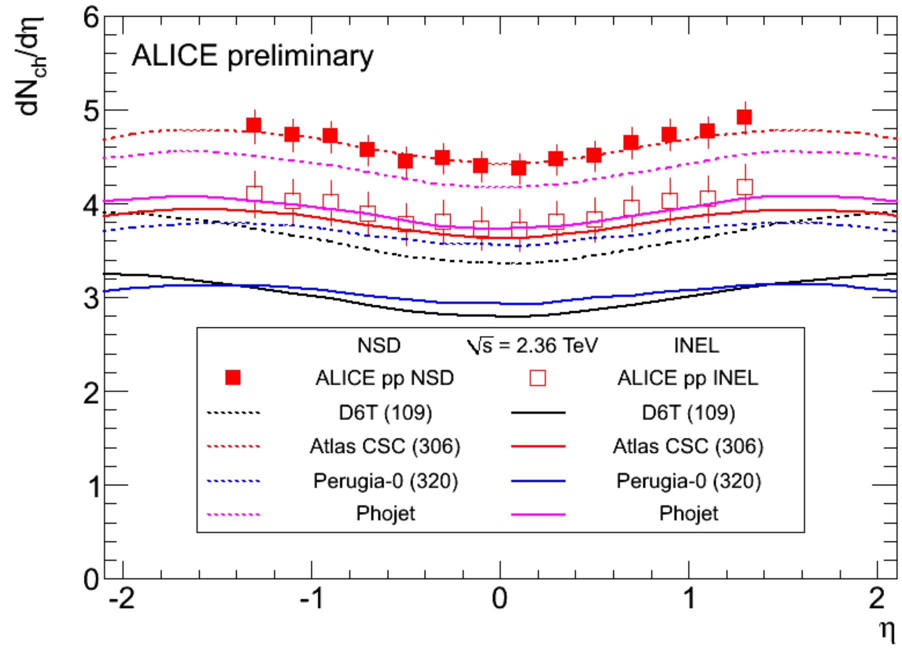


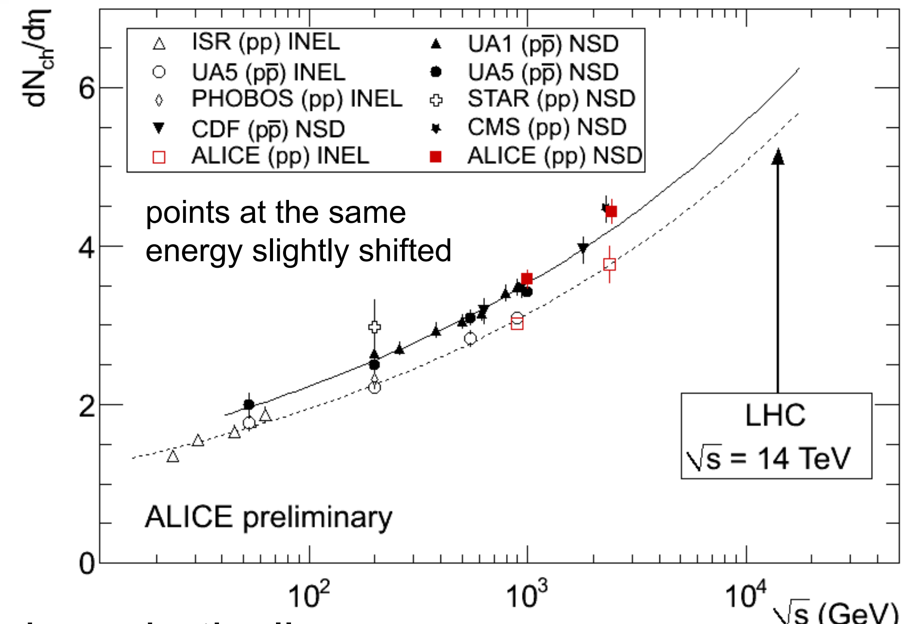
$dN_{ch}/d\eta$ in $\lvert\eta\rvert < 0.5$ ALICE, CMS: stat. and syst. uncertainty added quadratically	0.9 TeV		2.36 TeV	
	INEL	**NSD**	**INEL**	**NSD**
ALICE preliminary	**3.02 ± 0.07**	**3.58 ± 0.11**	**3.77 ± 0.23**	**4.44 ± 0.16**
ALICE EPJC65:111 (2010)	**3.10 ± 0.26**	**3.51 ± 0.29**		
CMS JHEP 02 (2010) 041		**3.48 ± 0.13**		**4.47 ± 0.16**
UA5 Z. Phys. C33 1 (1986)	**3.09 ± 0.05***	**3.43 ± 0.05***	* only stat. error	

$dN_{ch}/d\eta$ (2)

- Larger increase from 0.9 to 2.36 TeV at mid-rapidity as in MC generators

	in %	INEL	NSD
	ALICE prel.	$24.8^{+6.1}_{-3.0}$	$24.0^{+3.9}_{-1.3}$
	CMS		**28.4 ± 3.0**
Pythia	**D6T**	**19.7**	**18.7**
	ATLAS CSC	**19.2**	**18.3**
	Perugia-0	**19.6**	**18.5**
	Phojet	**17.5**	**14.5**





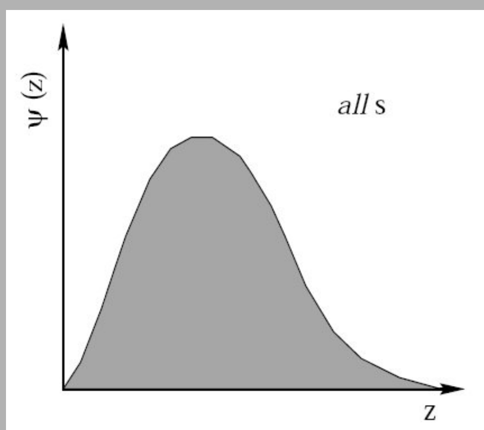
ALICE, CMS: stat. and syst. uncertainty added quadratically

Multiplicity distribution

1972:
KNO (statistical) scaling law

$$P_n(s) = \frac{1}{\langle n \rangle}\Psi\left(\frac{n}{\langle n \rangle}\right)$$

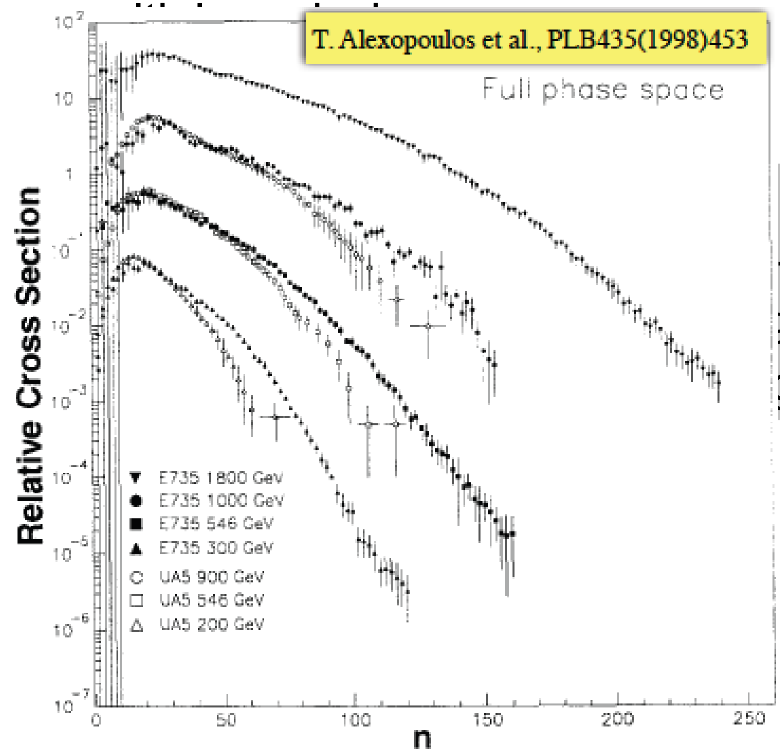
⇒ shape of distribution is independent of s



NPB 40, 317 (1972)

1983: KNO scaling broken
(UA5: PLB121,109,1983 & PLB138,304,1984)

Two mechanisms:
⇒ jet/mini-jet production
- coherent production of particles
⇒ multiple parton interactions

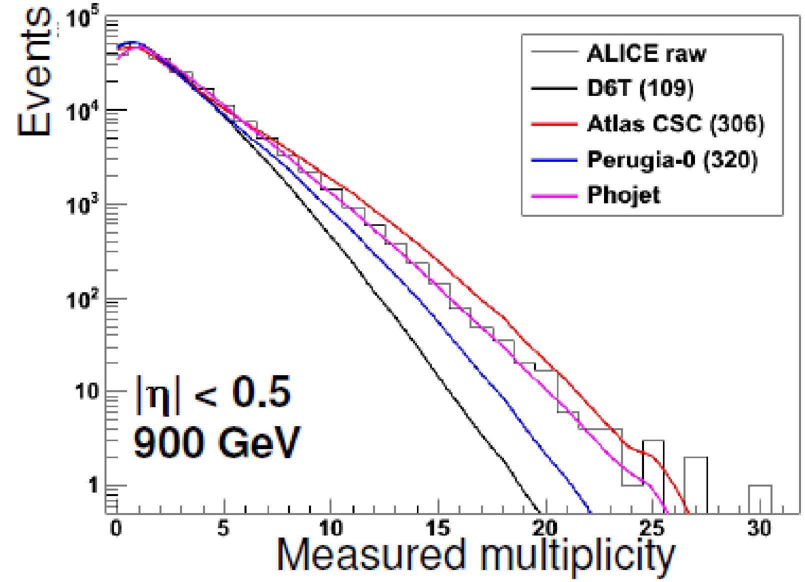


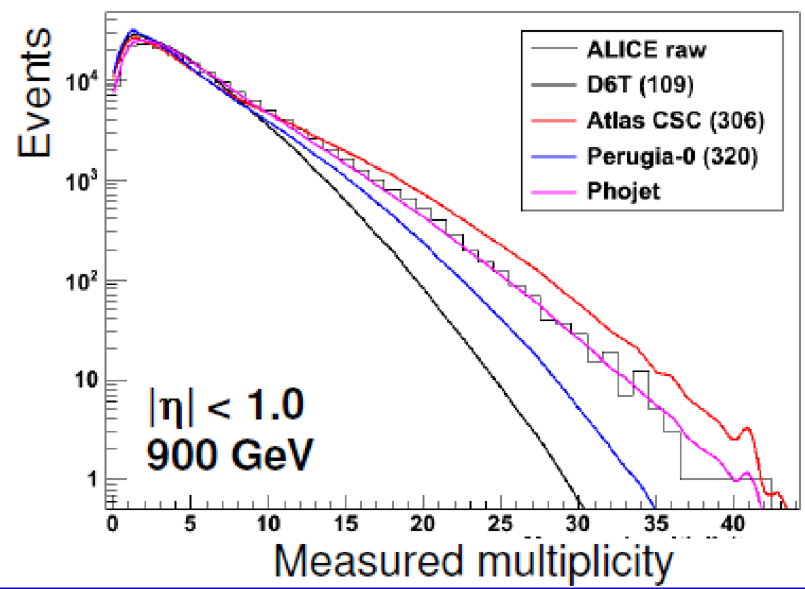
Neg ... goo ... ta
PLB ... 9-E
k no ... g

Multiplicity Distributions

- 900 GeV
- Work in progress
- RAW spectra
- MCs propagated through detector response

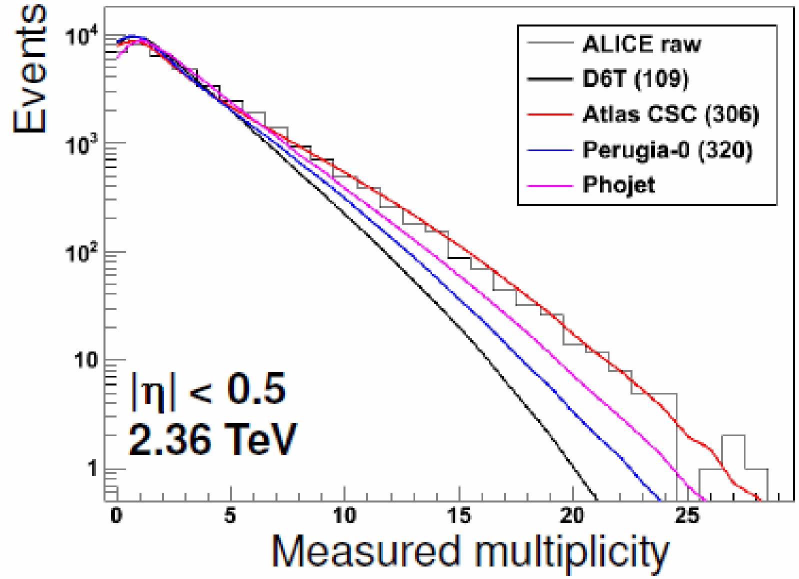
Phojet remarkably close to data

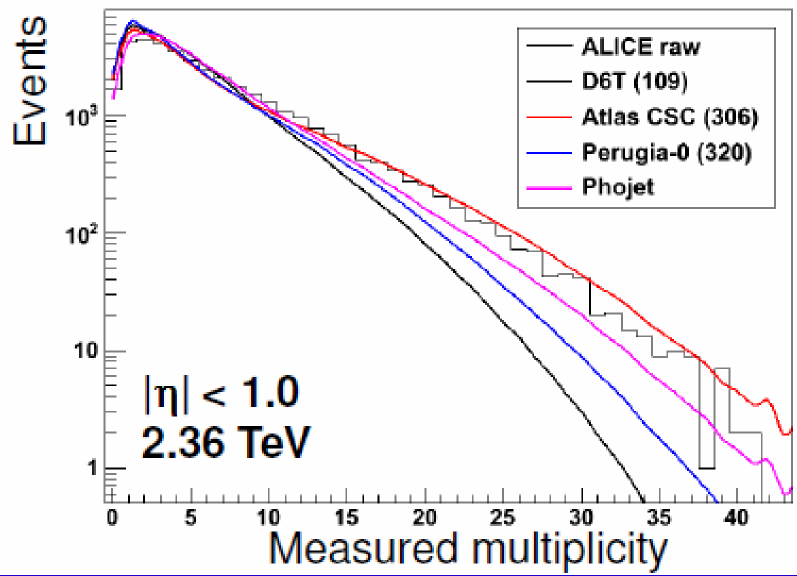




Multiplicity Distributions

- 2.36 TeV
- Work in progress
- RAW spectra
- MCs propagated through detector response

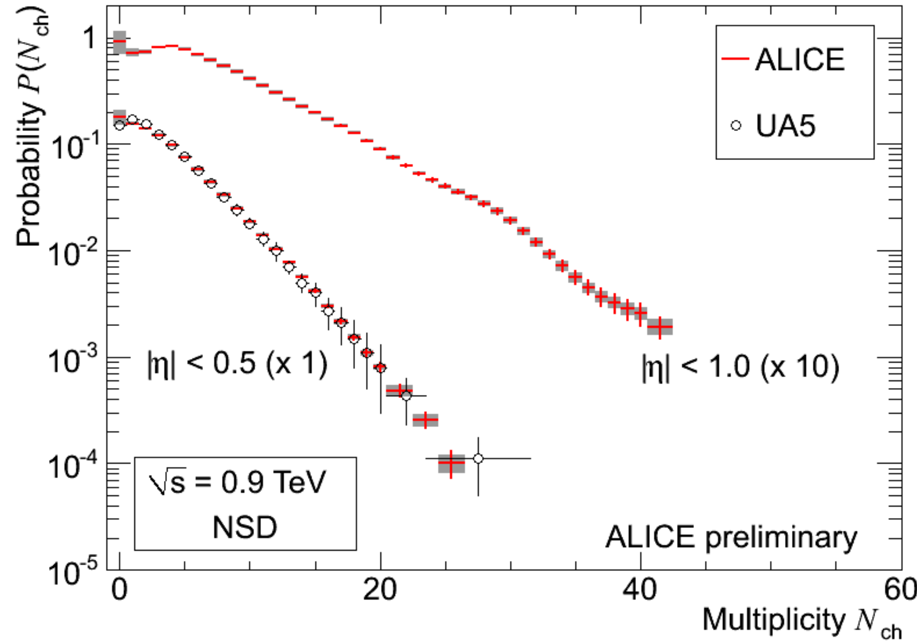


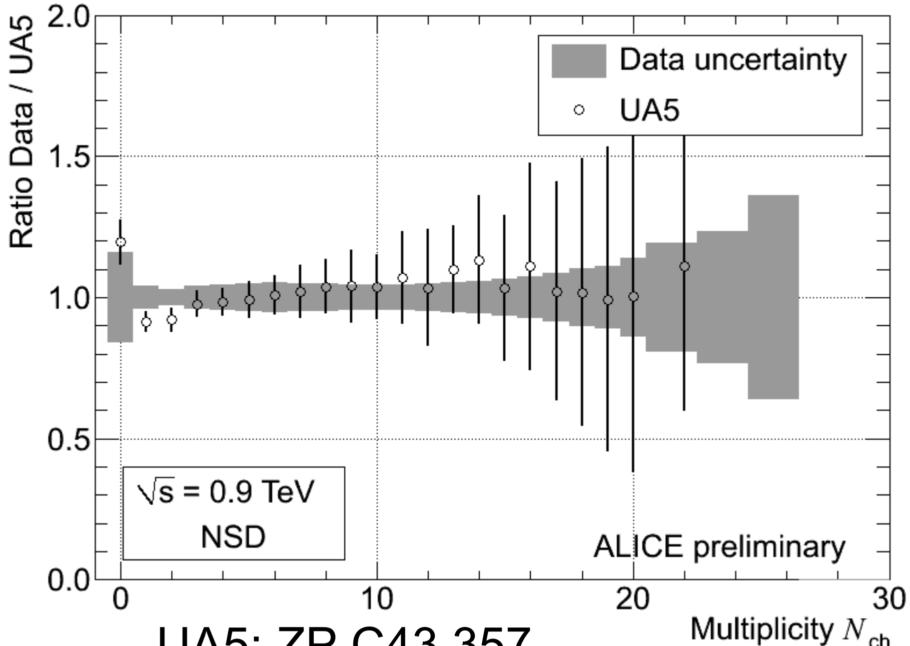


Tail grows faster than expected

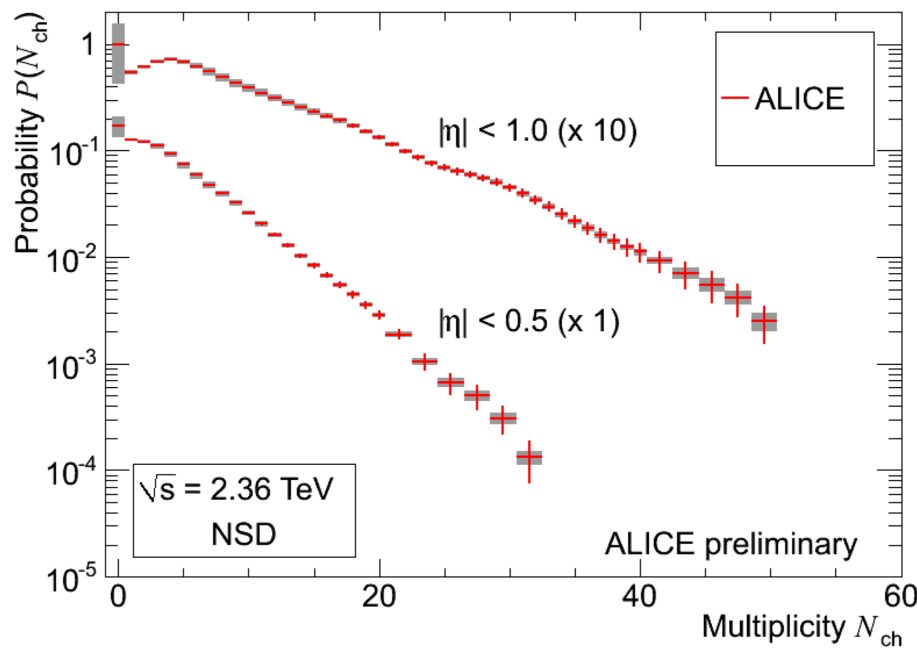
Multiplicity Distributions

- Distributions in limited η-regions
  - Vertex range reduced a region in which every event has full η-acceptance
- Consistent with UA5 results for NSD at 0.9 TeV





UA5: ZP C43,357



High Multiplicity pp

- J. D. Bjorken: multiplicity (number of charged tracks) of an event can be related to the energy density in the collision

$$\epsilon_{Bj} = \frac{dE_\perp}{dy}\frac{1}{S_\perp \tau} \qquad \frac{d\langle E_\perp\rangle}{dy} \approx \frac{3}{2}\left(\langle m_\perp\rangle \frac{dN}{dy}\right)$$

Systematic Measurements of Identified Particle Spectra in pp, d+Au and Au+Au collisions from STAR arXiv:0808.2041v1 [nucl-ex] 14 Aug 2008

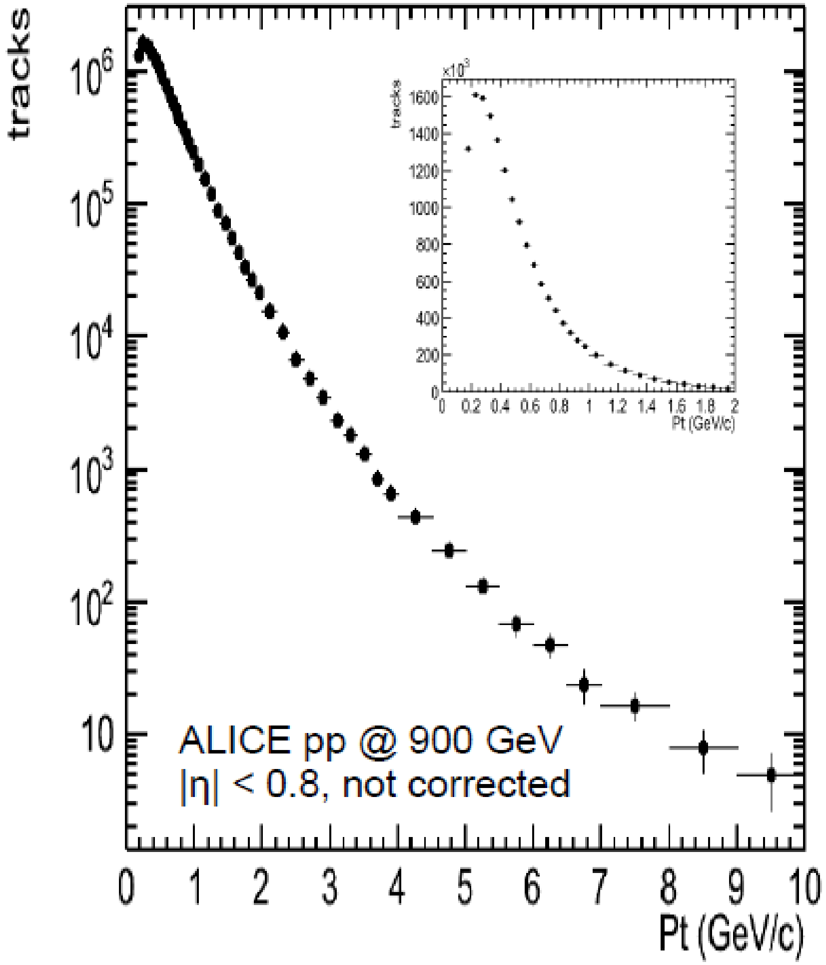
τ is formation time, S is overlapping area

  - Higher multiplicity reach at LHC pp, some events should exceed threshold energy density

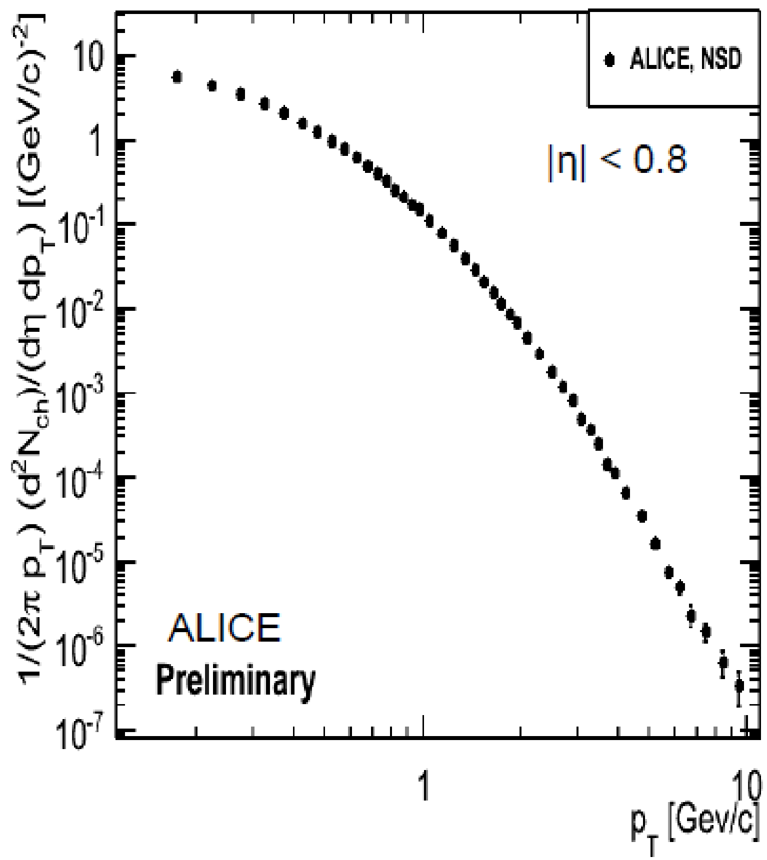
- Are p-p and A-A events with the same multiplicity different?
  - Pt spectra
  - Strangeness
  - Jets
  - Flow

Transverse momentum

Uncorrected

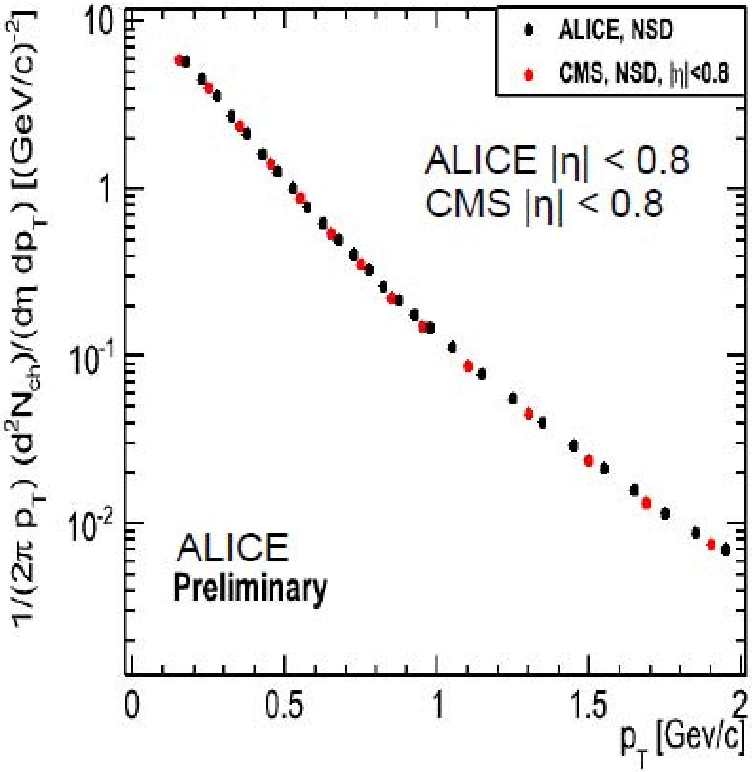


Corrected

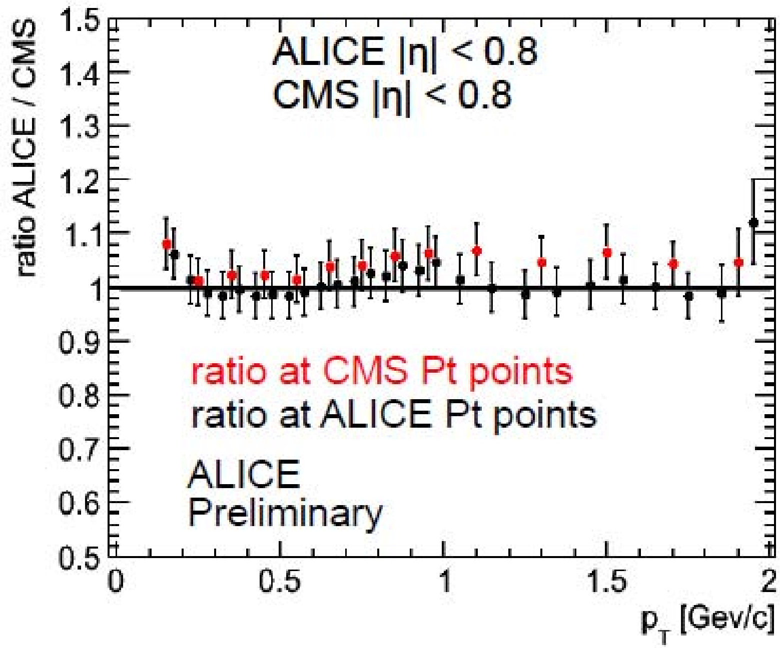


Comparison ALICE / CMS ($|\eta| < 0.8$)

CMS data: arXiv:1002.0621v1 [hep-ex]

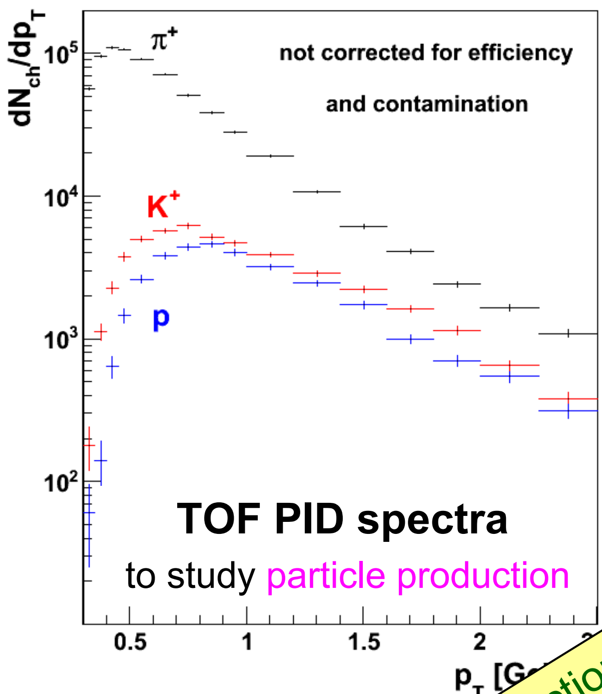


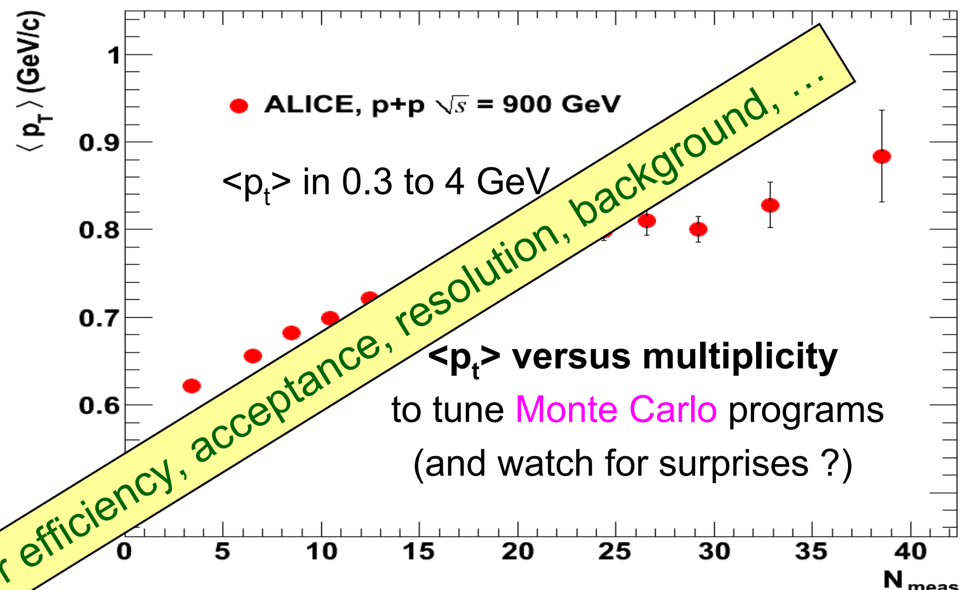
Ratio calculated using linear interpolation.



Good agreement between ALICE and CMS ($|\eta| < 0.8$) within 5%.

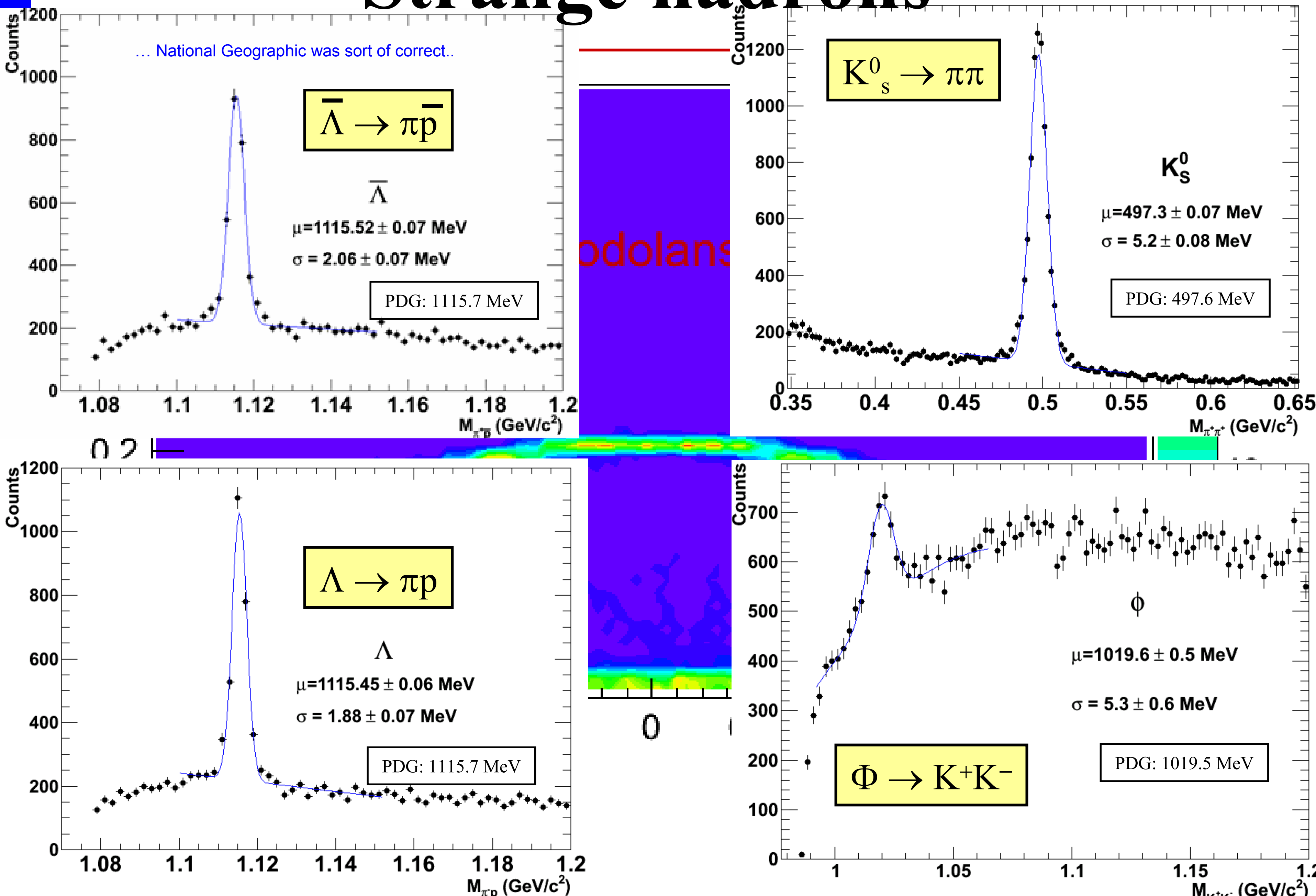
Transverse momentum





'raw' plots: no/incomplete correction for efficiency, acceptance, resolution, background, …

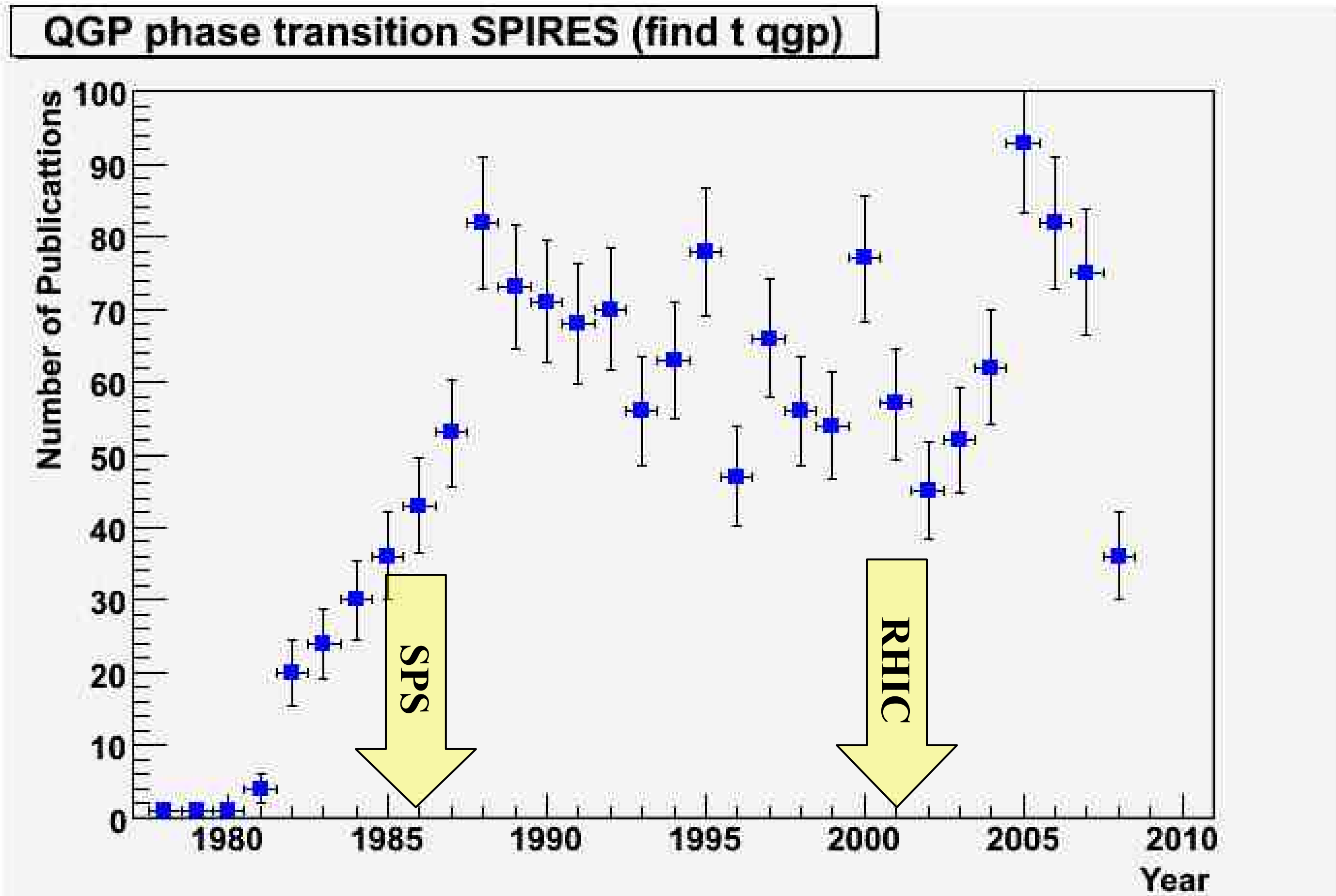
Strange hadrons



Next

- **2009 data**
  - 900 GeV and 2.36 TeV - Papers on multiplicity and transverse spectra coming soon
  - Identified particles spectra (pi,K,p)
  - Strangeness – K0 and hyperons
  - Pi0
  - Eta/phi correlations
- **2010**
  - As with 2009 data
  - **Heavy Ions**

Phases of Strongly Interacting Matter



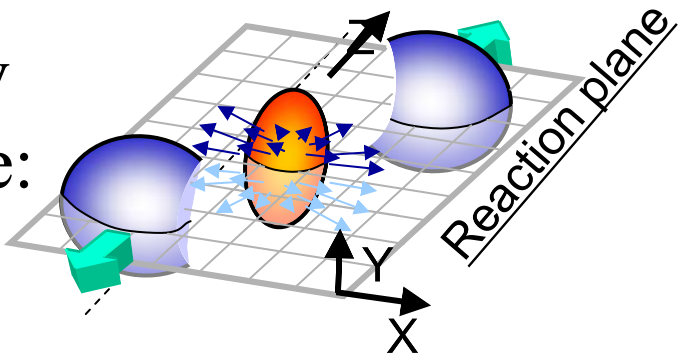
QCD predict
lear matter
ergo a phase
n at a
ture of,
MeV and
density,
V/fm^3.

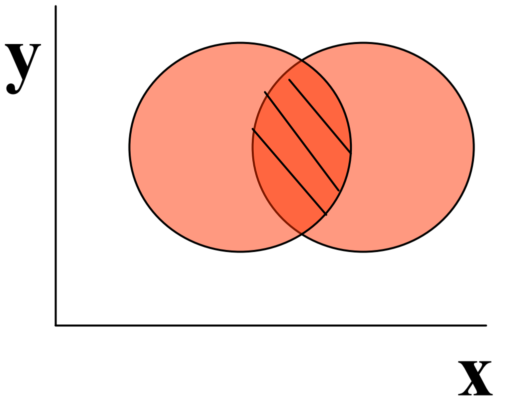
Heavy-ion physics with ALICE

- **Alignment calibration available from pp**
- **Global event properties (10^5 events):**
  - **Multiplicity, rapidity density**
  - **Elliptic flow**
- **Source characteristic (10^6 events):**
  - **Particle spectra, resonances**
  - **Differential flow**
  - **interferometry**
- **High pt and heavy flavours (10^7 events):**
  - **Jet quenching**
  - **Quarkonia production**

Elliptic Flow

Azimuthal asymmetry in the transverse plane:





Eccentricity:

$$\varepsilon \equiv \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

Flow:

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}[1 + \sum_{n=1}^{\infty} 2v_n \cos(n\phi)]$$

v_1 = directed flow v_2 = elliptic flow

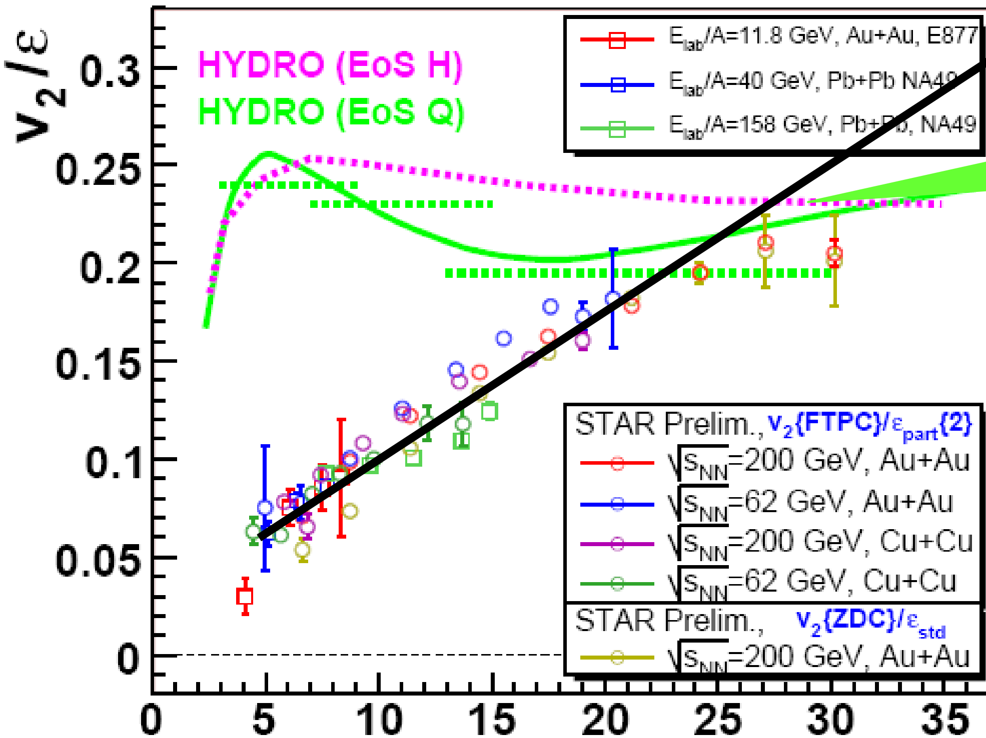
Φ – angle with respect to reaction plane

Relativistic hydrodynamics prediction: $v_2/\varepsilon \sim$ constant

Is the QGP an ideal fluid ?

- one of the first 'expected' answers from LHC
  - Hydrodynamics: modest rise (Depending on EoS, viscosity, speed of sound)
  - experimental trend & scaling predicts large increase of flow

LHC



$1/S\, dN_{ch}/dy \sim R/\lambda$ (1/Knudsen number)

BNL Press release, April 18, 2005:
RHIC Scientists Serve Up "Perfect" Liquid
New state of matter more remarkable than predicted – raising many new questions

J. Phys. G: Nucl. Part. Phys. **34** (2007) S883–S886

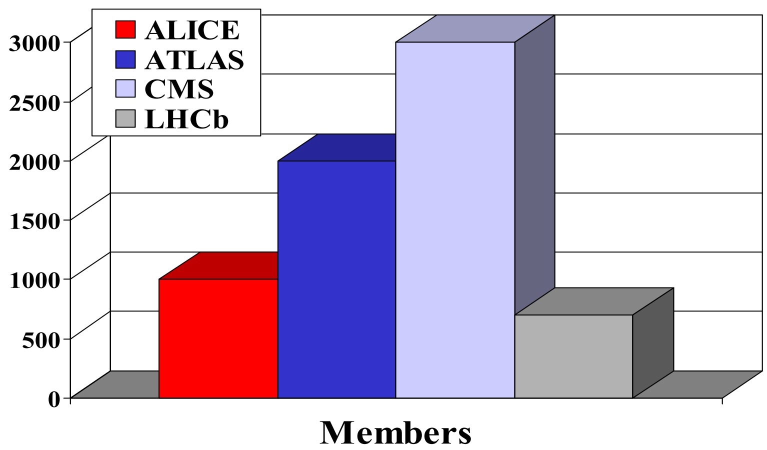
Summary

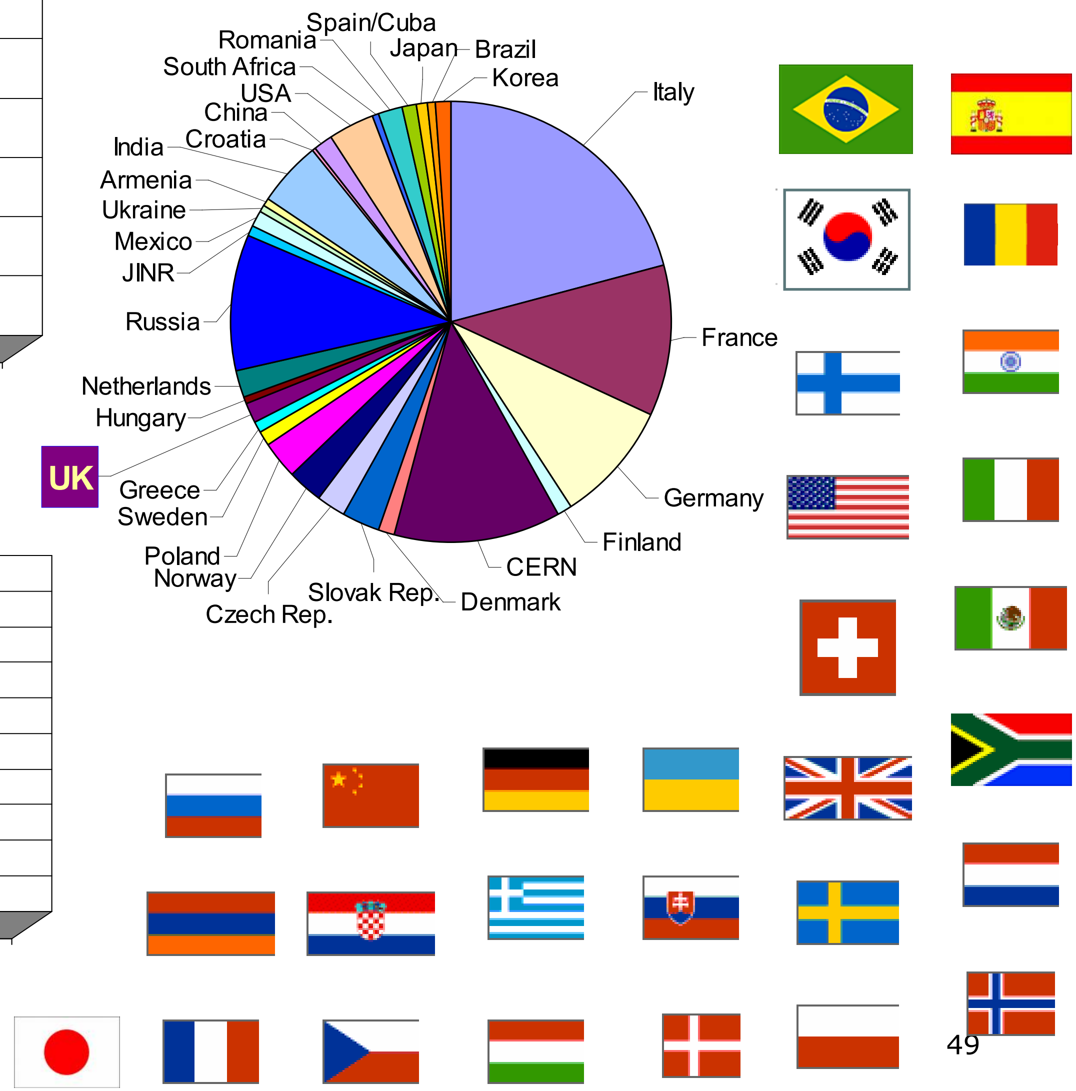
- Alice detector works according to expectations
- Alice produced its first physics publication
- Analysis with larger statistics in progr
  - pT spectra, <pT> vs multiplicity
  - pT spectra of identified particles
  - multiplicity distribution
  - pbar/p
  - …
- Looking forward to coming period:
  - higher collision energy
  - heavy ion collisions …

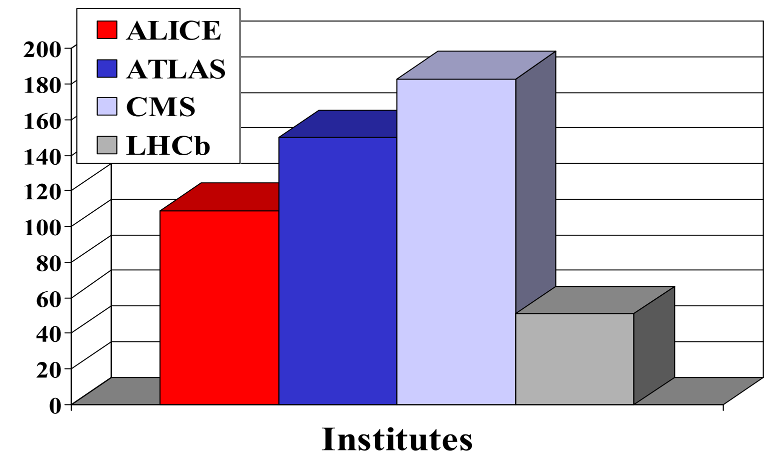
is busy and happy.

END

The ALICE collaboration





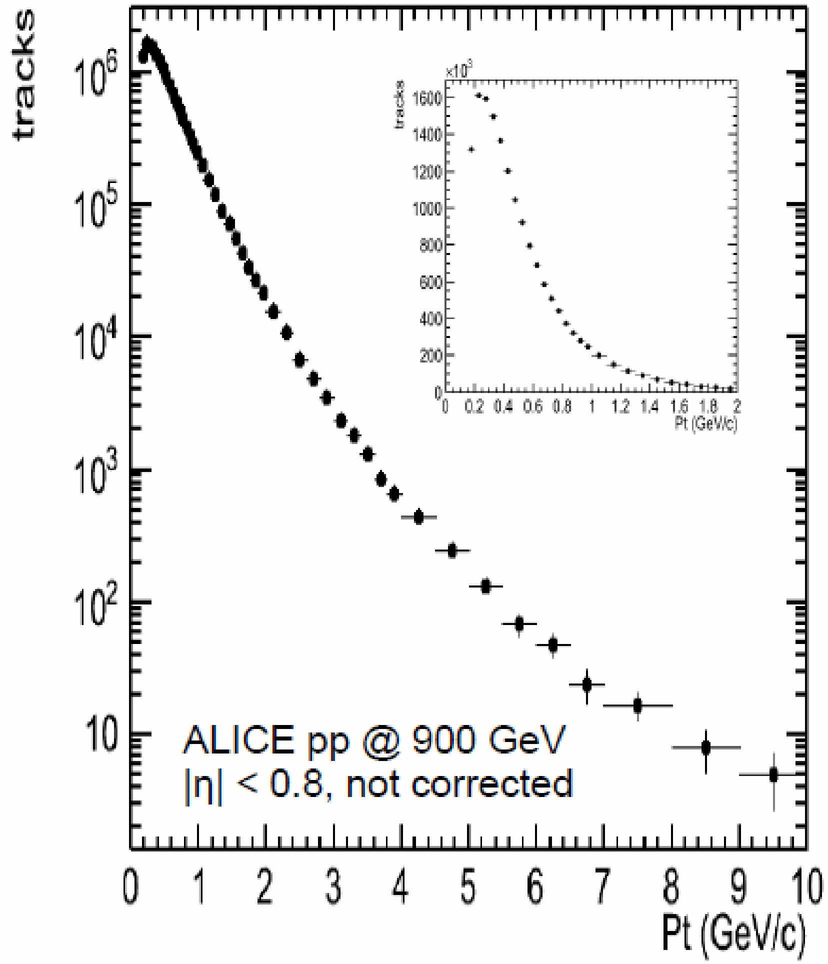


~ 130 MCHF capital cost(+ 'free' magnet)

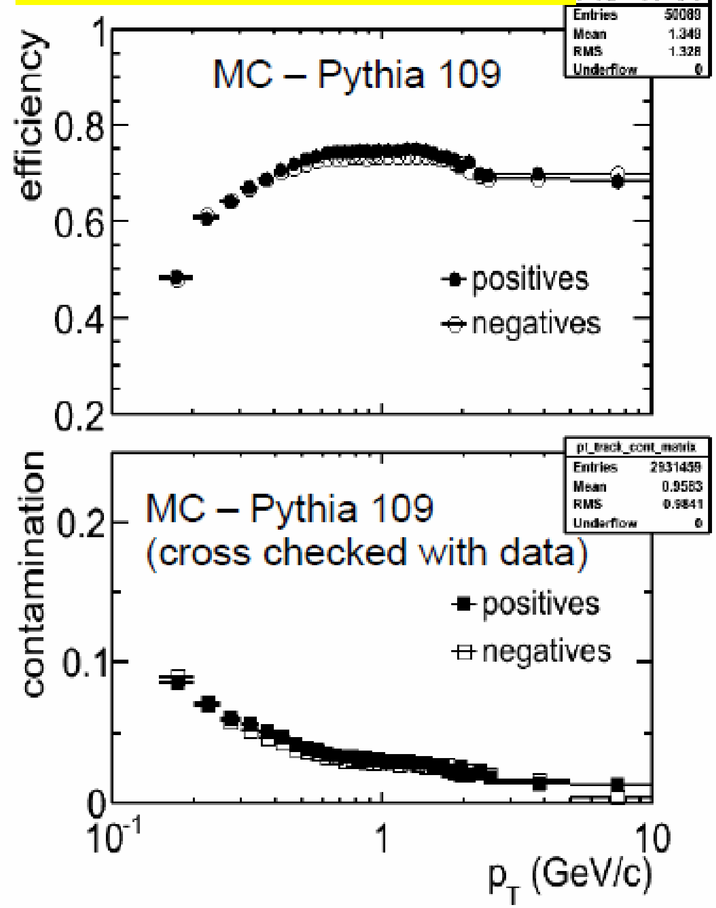
Pythia Tunes

- Perugia (320)
  - Updated lep fragmentation
  - Showering of MPI
  - Tevetron MB data 630,1800,1960
  - SPPS 200,450,900
- ATLAS CSC(306)
  - Arthur Moraes
  - pt ordered
- D6T(109)
  - R.Field, Tevatron
  - New structure function
  - q2 oredred

ALICE - reconstructed / not corrected p_T spectra

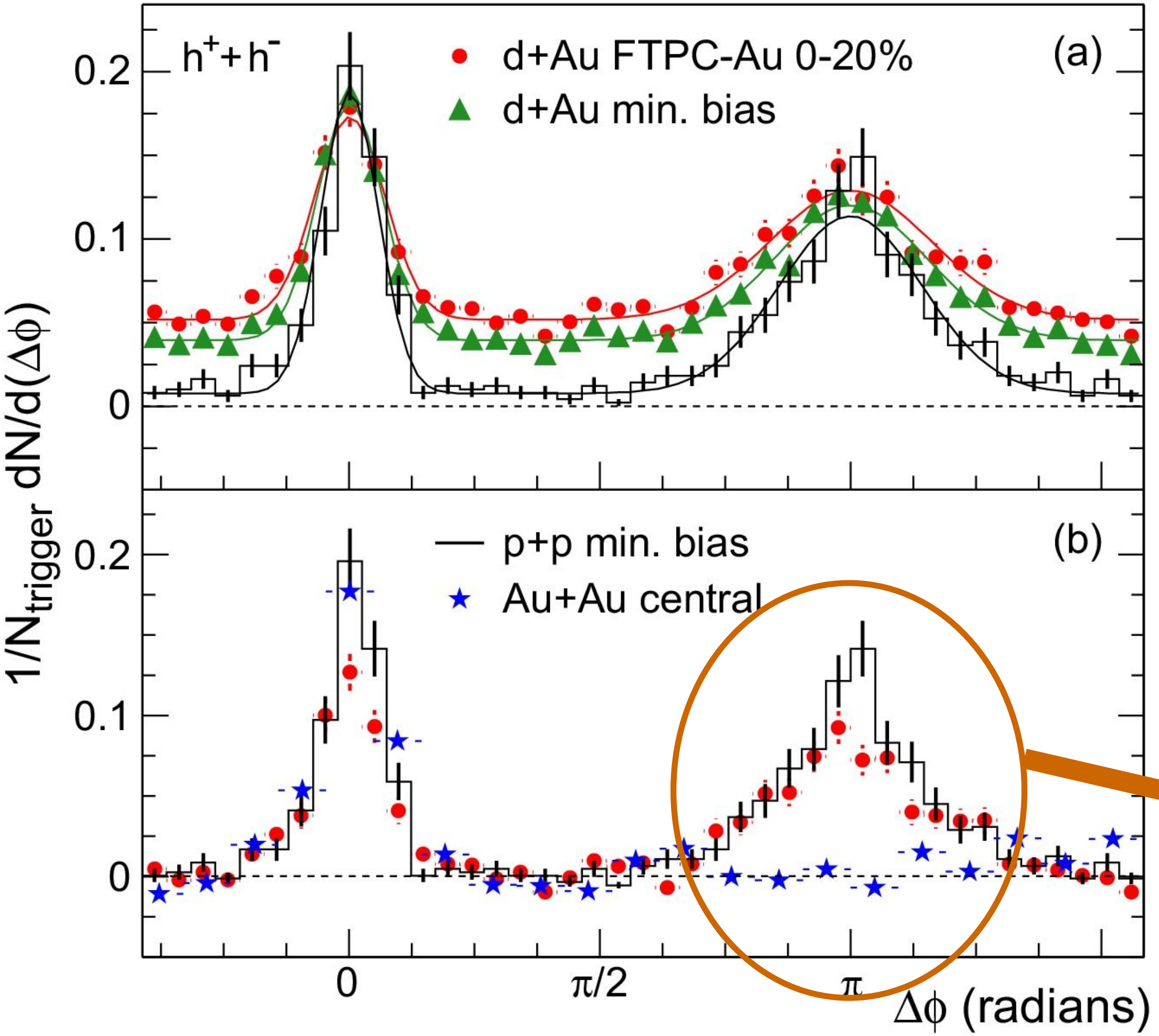


Efficiency of the primary track selection and secondary track contamination.



Jet Quenching

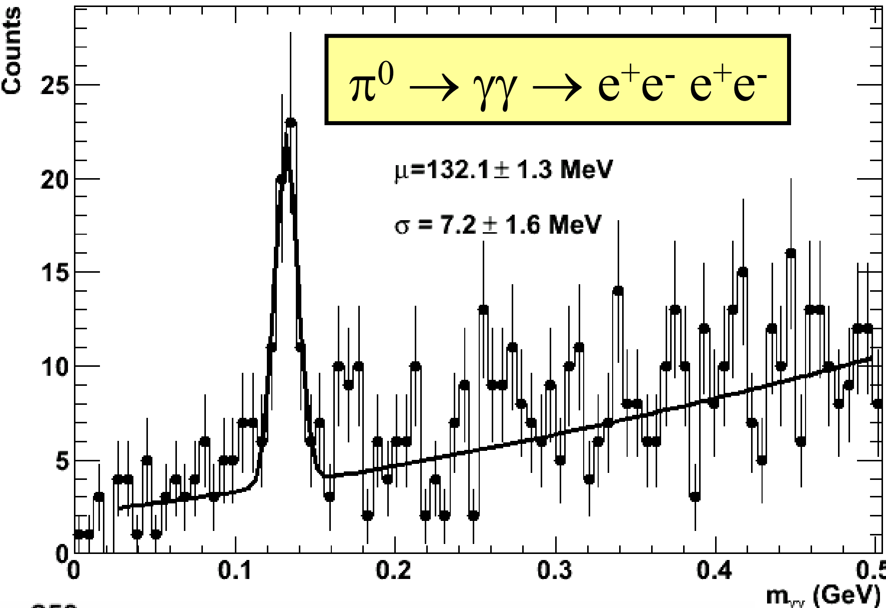
Charged particle correlations in Au+Au at RHIC (STAR)

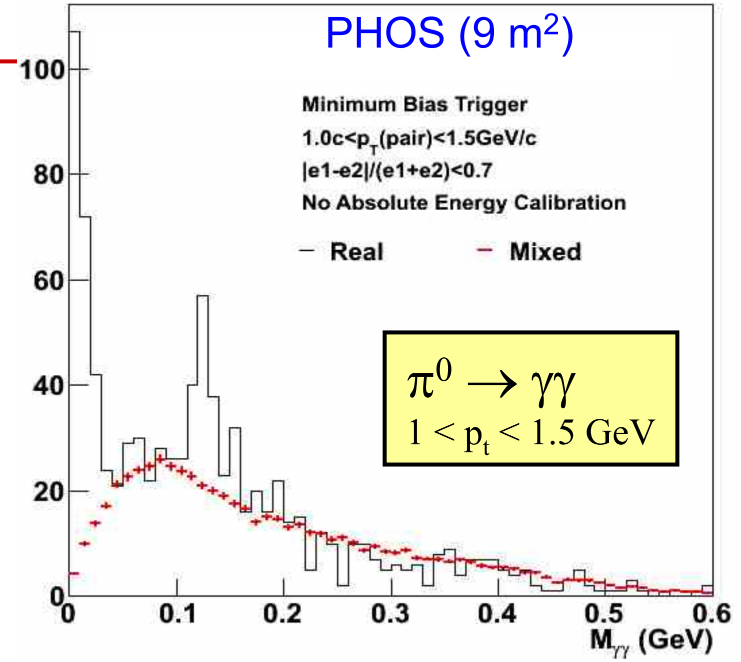


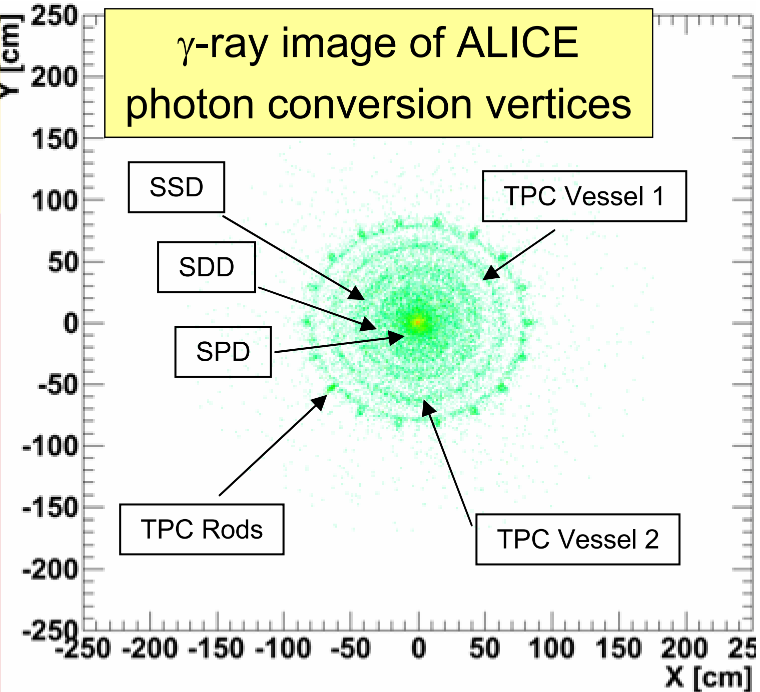
In central Au-Au events,although trigger jet is clearly visible, “away-side” jet is not visible, as predicted from strong absorption in a high colour charge density volume, e.g. that produced in a QGP

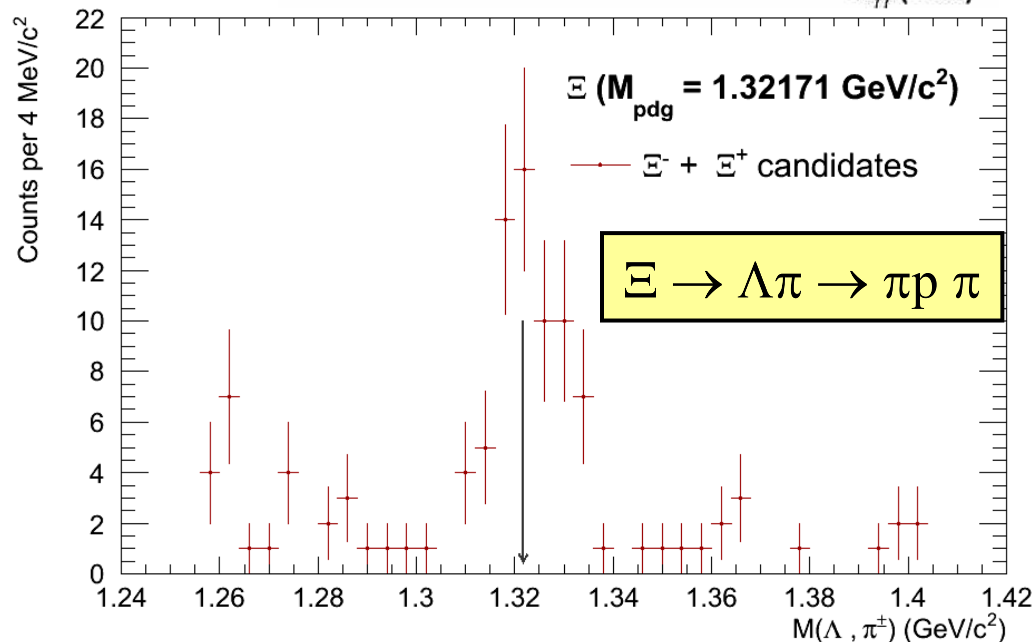
Missing jet

More Particles..









High-multiplicity trigger example

J F Oetringhaus

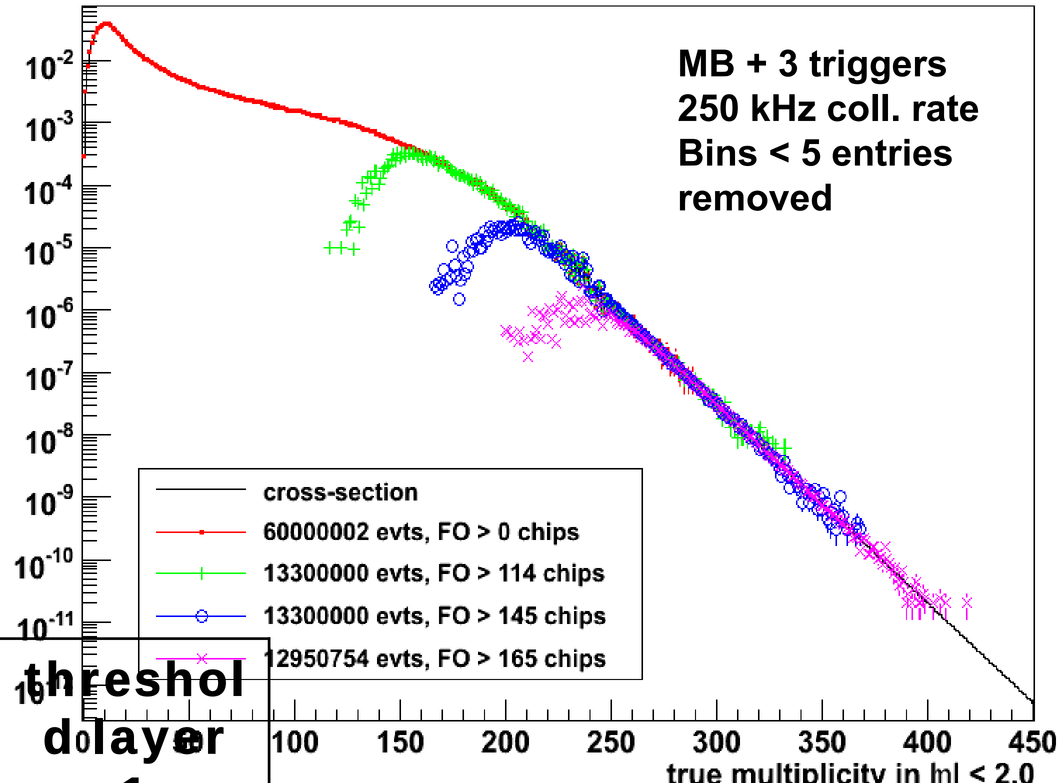
Example of threshold tuning:

MB and 3 high-mult. triggers

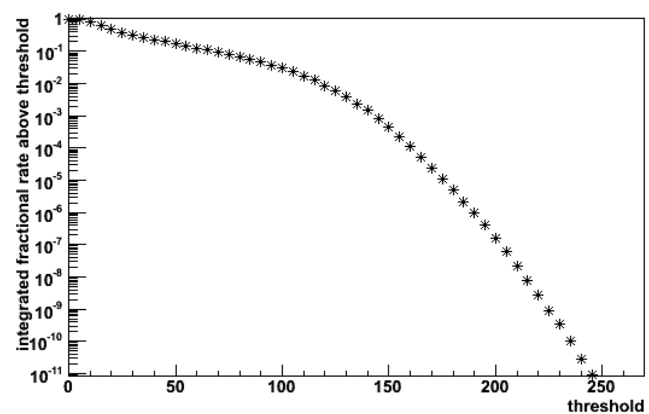
250 kHz collision rate
recording rate 100 Hz

MB 60%

3 HM triggers: 40%

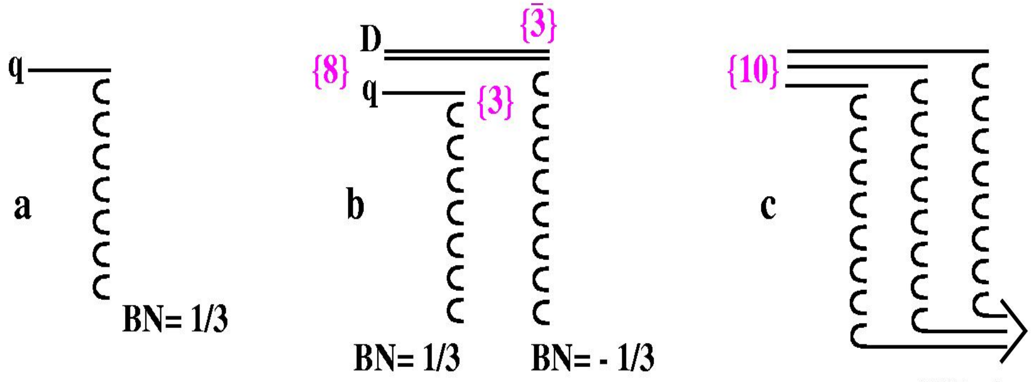


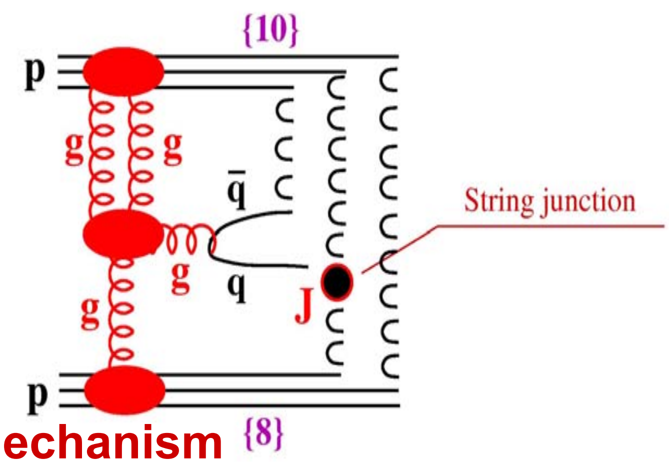
trigger rate Hz	scaling	raw rate	threshold layer 1
60.0	4167	250000	min. bias
13.3	259	3453.3	114
13.3	16	213.3	145
13.3	1	13.3	165



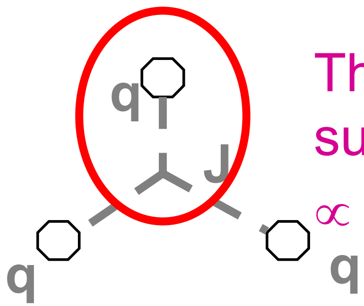
Baryon number transfer in rapidity

- When original baryon changes its colour configuration (by gluon exchange) it can transfer its baryon number to low-x without valence quarks – by specific configuration of gluon field





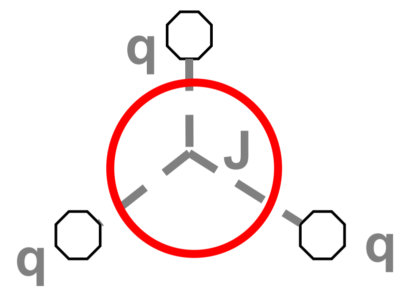
Standard case – quark exchange



This exchanged is suppressed

$\propto$ exp (-1/2 Δy)

Gluon mechanism



Different prediction for junction exchange:

$\propto$ exp (-α_J Δy)

α_J = 0.5 Veneziano, Rossi

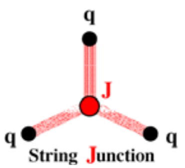
α_J = 0 Kopeliovich

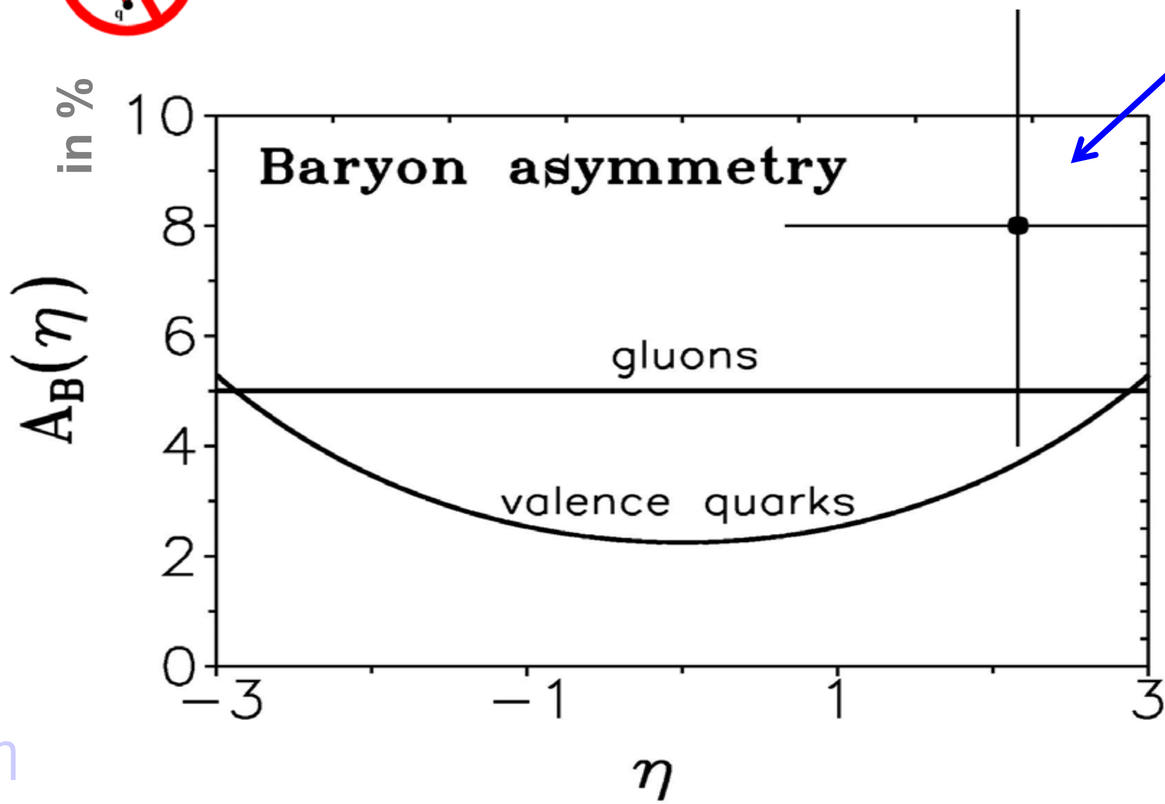
- experimentally we measure baryon – antibaryon asymmetry
- largest rapidity gap at LHC (> 9 units)
- predicted absolute value for protons ~ 2-7%

$$A = 2 \cdot \frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}}$$

Baryons in central region at LHC

Proton – anti-proton asymmetry A_B = 2 * (p – anti-p) / (p + anti-p)





H1 (HERA)
Δη ~ 7
not published

systematics
due to
beam-gas
Interactions

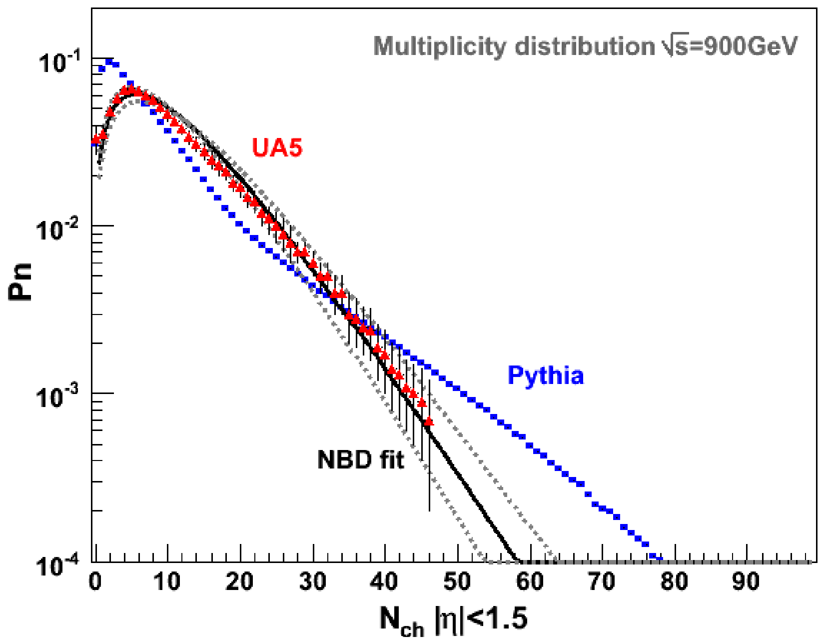
will be easier
at LHC

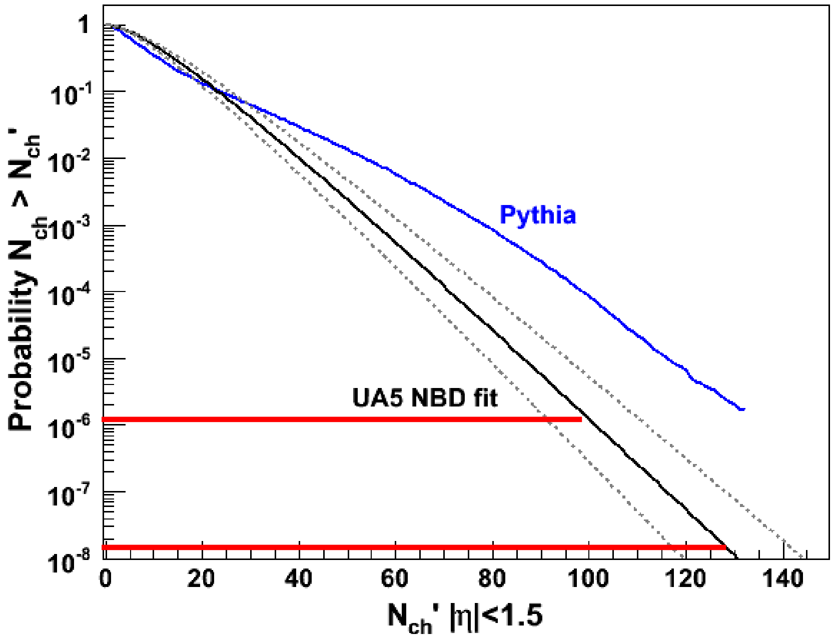
– 9.61 ← η

at LHC

(B. Kopeliovich)

Multiplicity reach at 900 GeV





Pythia 6.214 (in Aliroot)
UA5: ZPC43,357(1989)

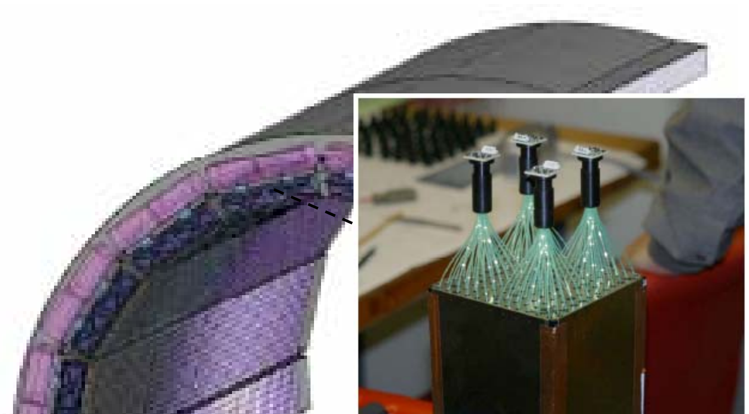
6839 ev. ~ Max $N_{ch}^{|\eta|<1.5}$=47

Using NBD fits to UA5 data to estimate multiplicity reach:

$\Rightarrow 10^6$ ev. ~ Max $N_{ch}^{|\eta|<1.5} \approx 90$

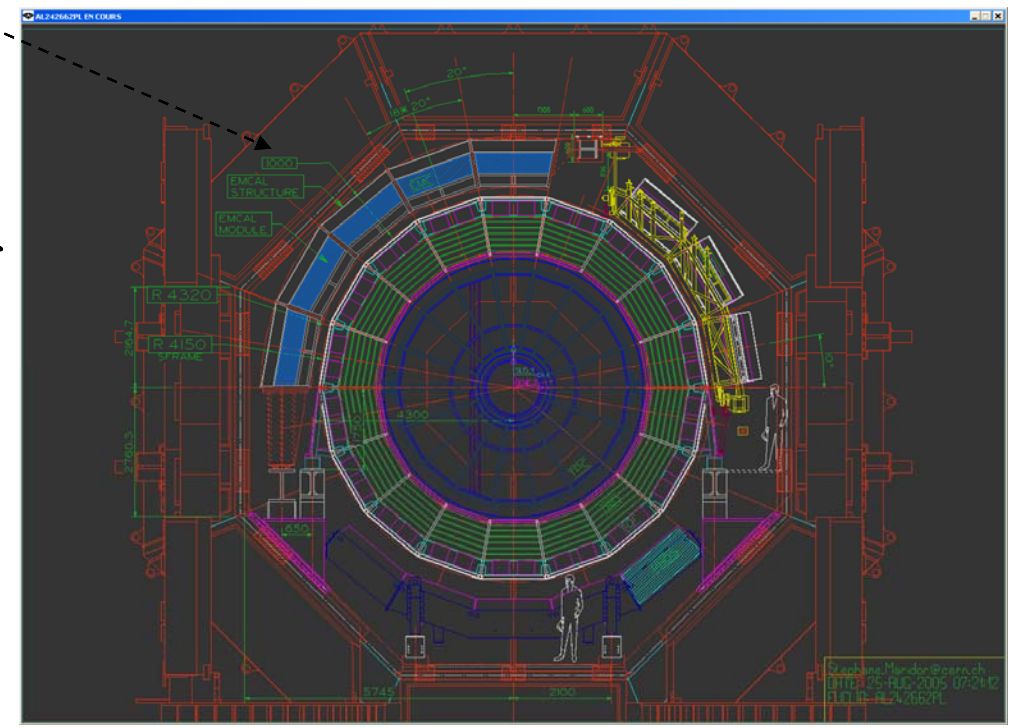
$\Rightarrow 10^8$ ev. ~ Max $N_{ch}^{|\eta|<1.5} \approx 120$

ALICE Electromagnetic Calorimeter


EMCal Module = 4 towers

- upgrade to ALICE
- ~17 US and European institutions

Current expectations:
- 2009 run: partial installation
- 2010 run: fully installed and commissioned

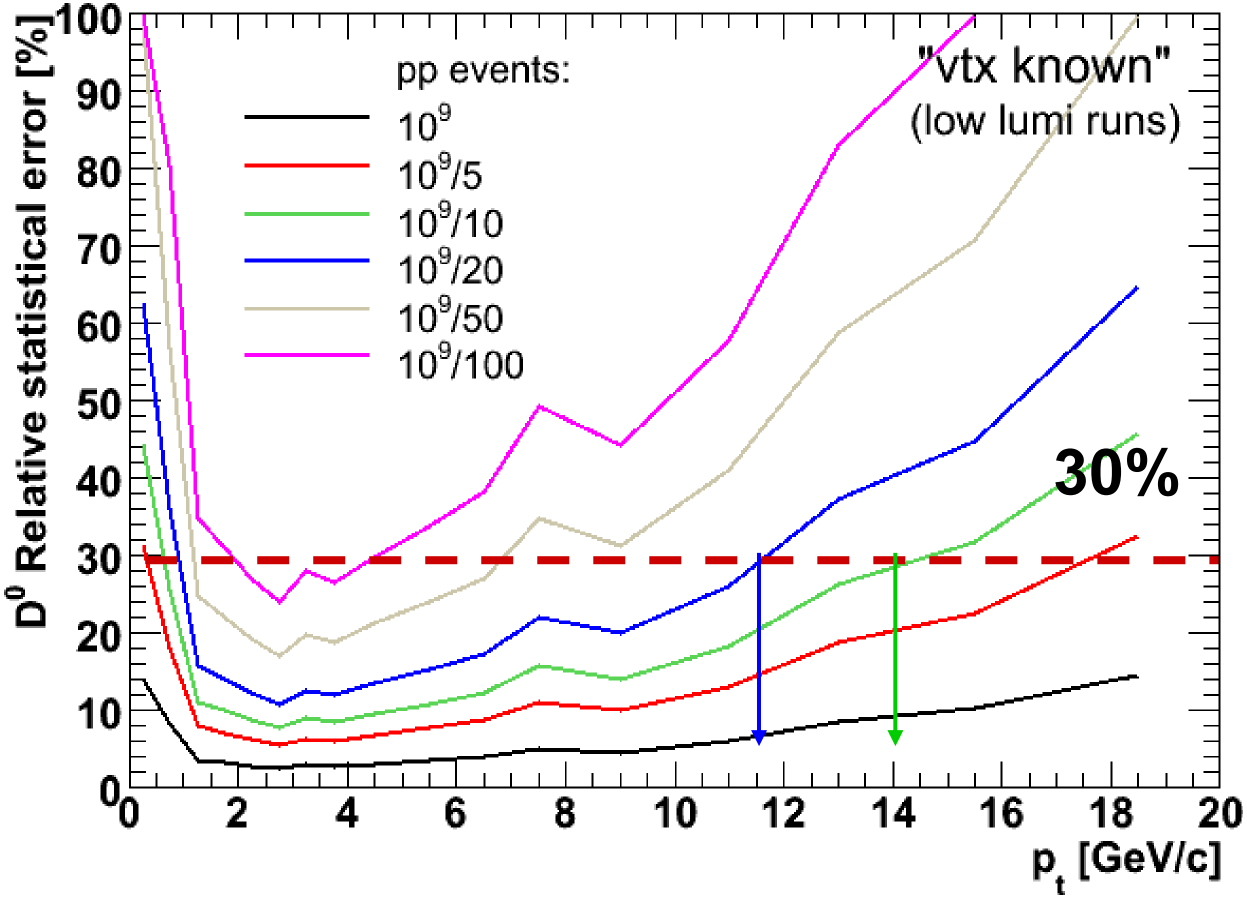


Lead-scintillator sampling calorimeter
Shashlik fiber geometry
Avalanche photodiode readout

Coverage: $|\eta|<0.7$, $\Delta\phi=110^o$
~13K towers ($\Delta\eta x \Delta\phi \sim 0.014x0.014$)
depth~21 X_0
Design resolution: $\sigma_E/E \sim 1\% + 8\%/\sqrt{E}$

First heavy flavour physics:charm

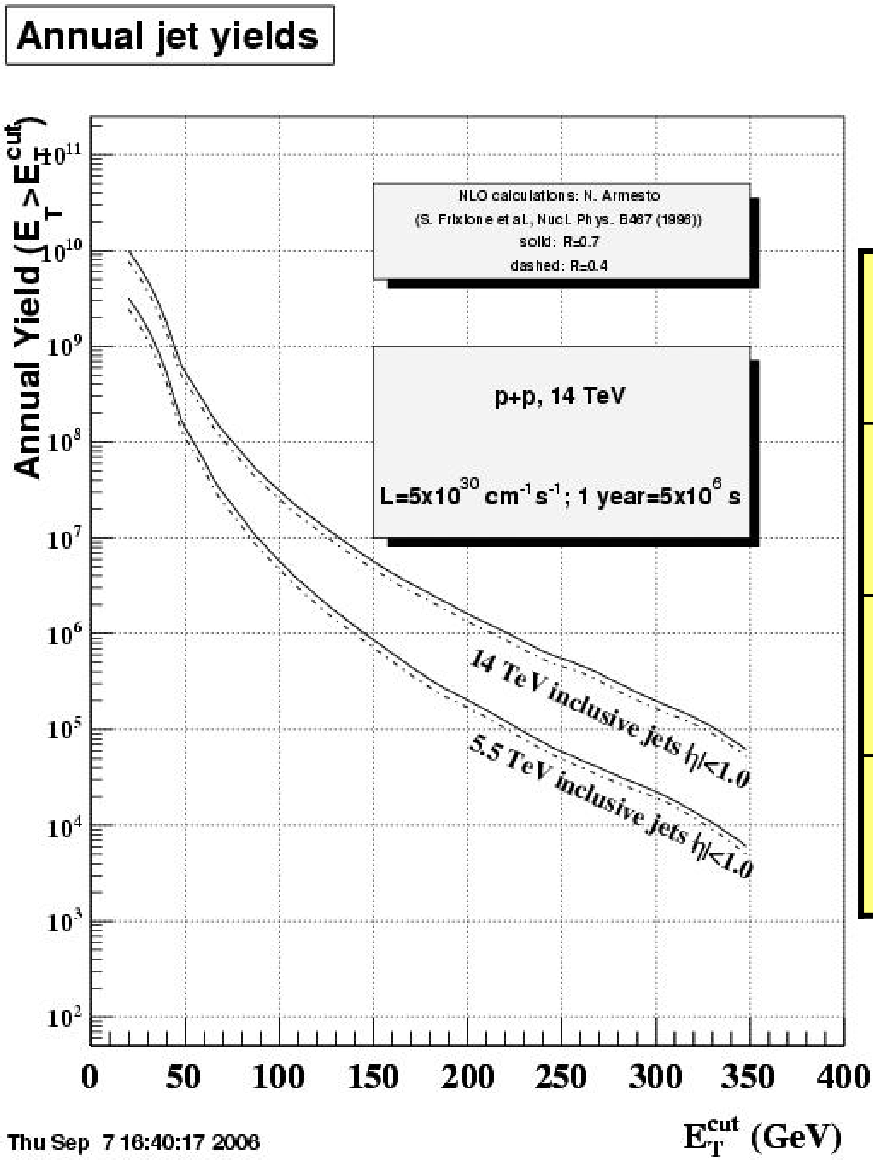
$D^0 \to K^-\pi^+$ in pp



Andrea Dainese

reach up to 11.5 – 14 GeV/c with 7×10^7 evts

Jets rates at LHC



10^7 s, 100 Hz DAQ rate,
10^9 events (MB trigger)
(1 day = $8.6*10^6$ events)

√s [GeV] E_T[GeV]	**900**	**5500**	**14000**
50	600	30000	150000
100	6	1800	7500
200	$6x10^{-3}$	60	3750

1 year: E_T ~ 100 GeV

V0 beam gas rejection

9

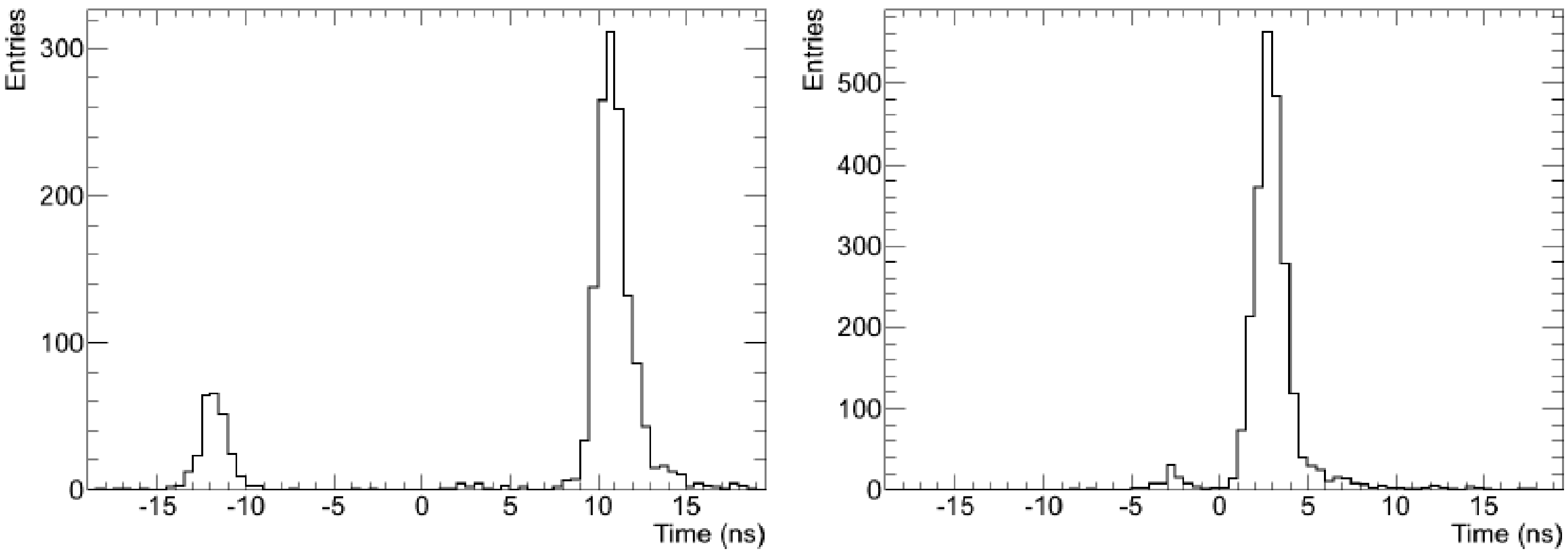


Fig. 3. Arrival time of particles in the VZERO detectors relative to the beam crossing time (time zero). A number of beam-halo or beam–gas events are visible as secondary peaks in VZERO-A (left panel) and VZERO-C (right panel). This is because particles produced in background interactions arrive at earlier times in one or the other of the two counters. The majority of the signals have the correct arrival time expected for collisions around the nominal vertex.

Birmingham ALICE Group

~ 5 physicists
~ 2 engineers
~ 2 students/year