Charged particle multiplicity in Pb-Pb collisions from NA50 experiment

F. Prino for the NA50 collaboration

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Particle production in nuclear collisions

- Multiplicity = number of particles produced in the collision
  - 80-90% of the produced charged particles are pions
  - Related to the centrality of the collision
  - Related to the entropy of the system created in the collision
- Multicollision models:
  - Nucleus-nucleus collis.= superposition of nucleon-nucleon collis.

Hard processes

Large momentum transfer

Small distance

- ✓ Interactions at partonic level
- ✓ Scale like the number of elementary collisions (N_{coll})

Soft processes

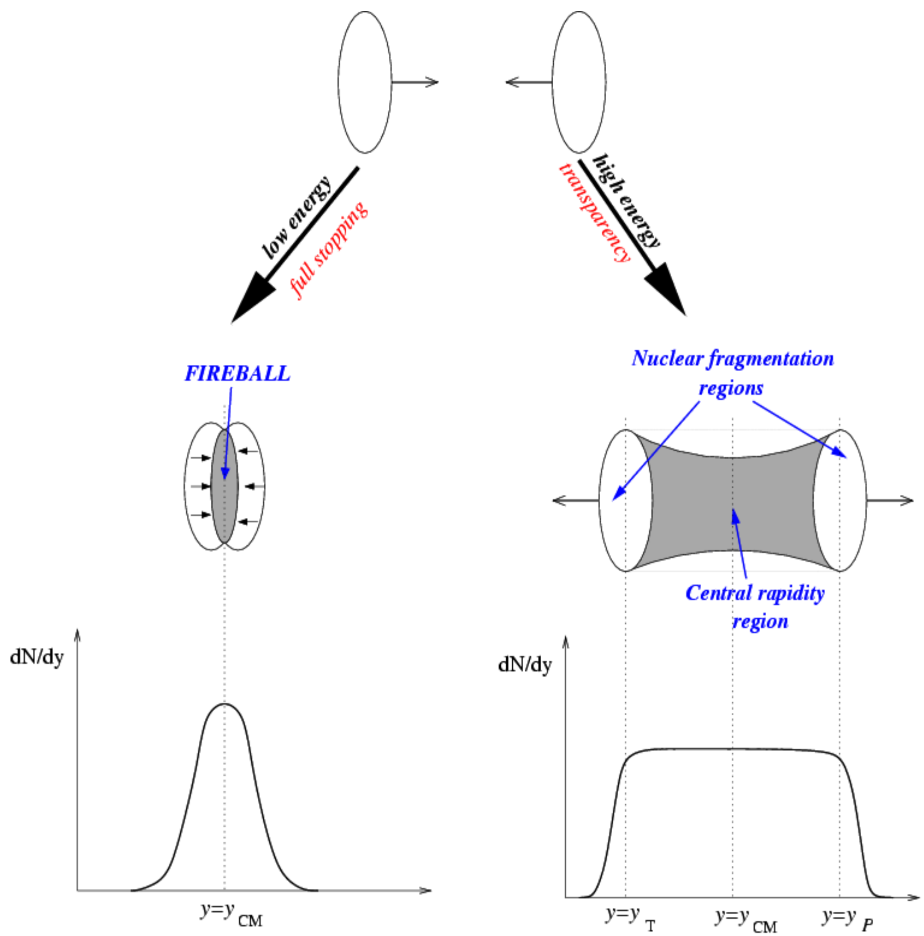
Small momentum transfer

Large distance

- ✓ Interactions at the baryon level
- ✓ Scale like the number of participant nucleons (N_{part})

Particle momenta distributions

Particle momenta decomposed → **Transverse** momentum (p_T) / **Longitudinal** momentum (p_L)



- Rapidity variable

$$y = \frac{1}{2} \cdot \ln\left(\frac{E + p_L}{E - p_L}\right)$$

- Pseudorapidity variable

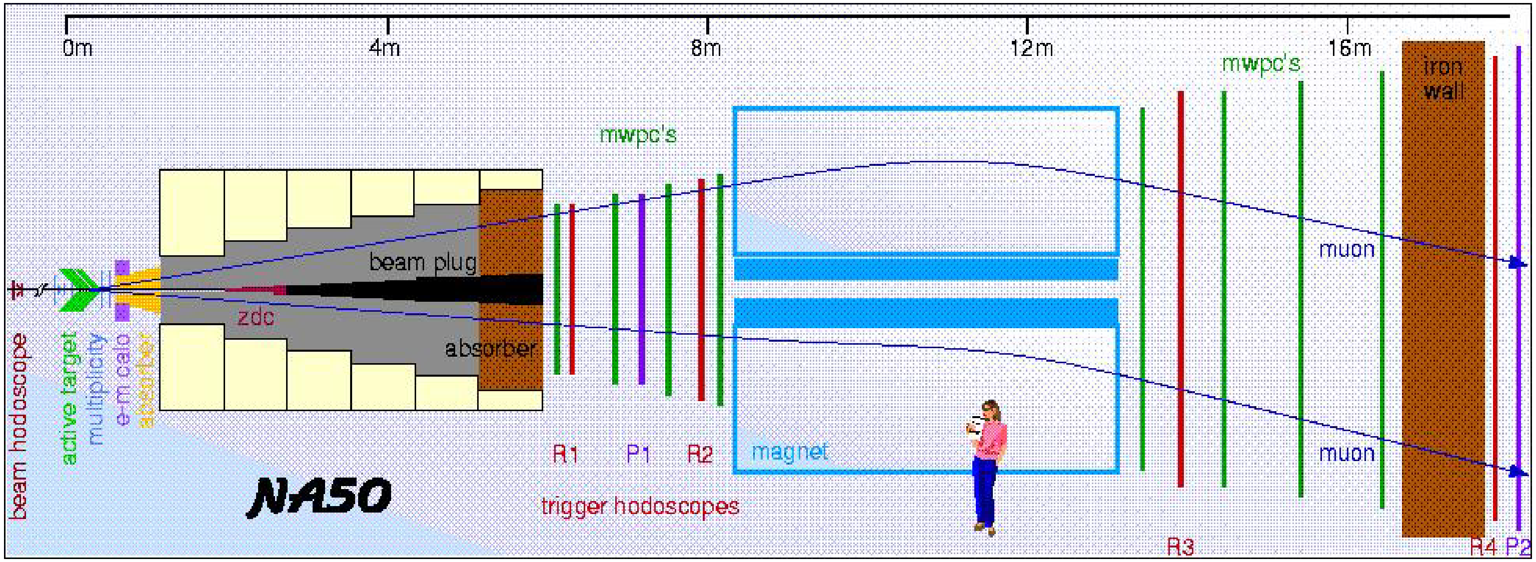
$$\eta = -\ln\left[\tan\left(\frac{\vartheta}{2}\right)\right] = \frac{1}{2} \cdot \ln\left(\frac{|\mathbf{p}| + p_L}{|\mathbf{p}| - p_L}\right)$$

- $\eta \approx y$ for large momenta

→ *dN/dy (dN/dη) distributions carry information about energy density, longitudinal expansion and "stopping power"*

NA50: experimental setup

Study of muon pair production in Pb-Pb collisions



Trigger

- DIMU

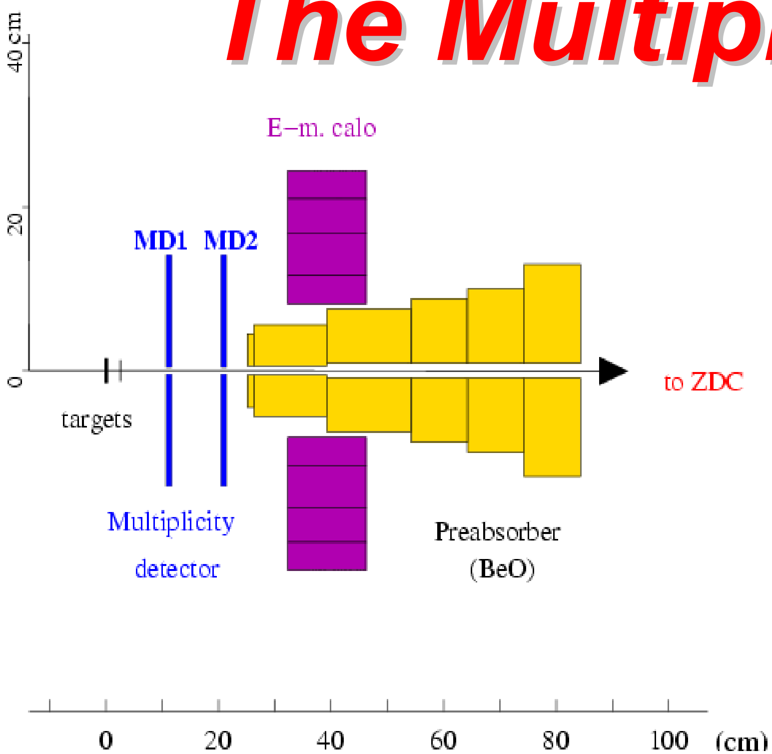
2 muon tracks

- MB

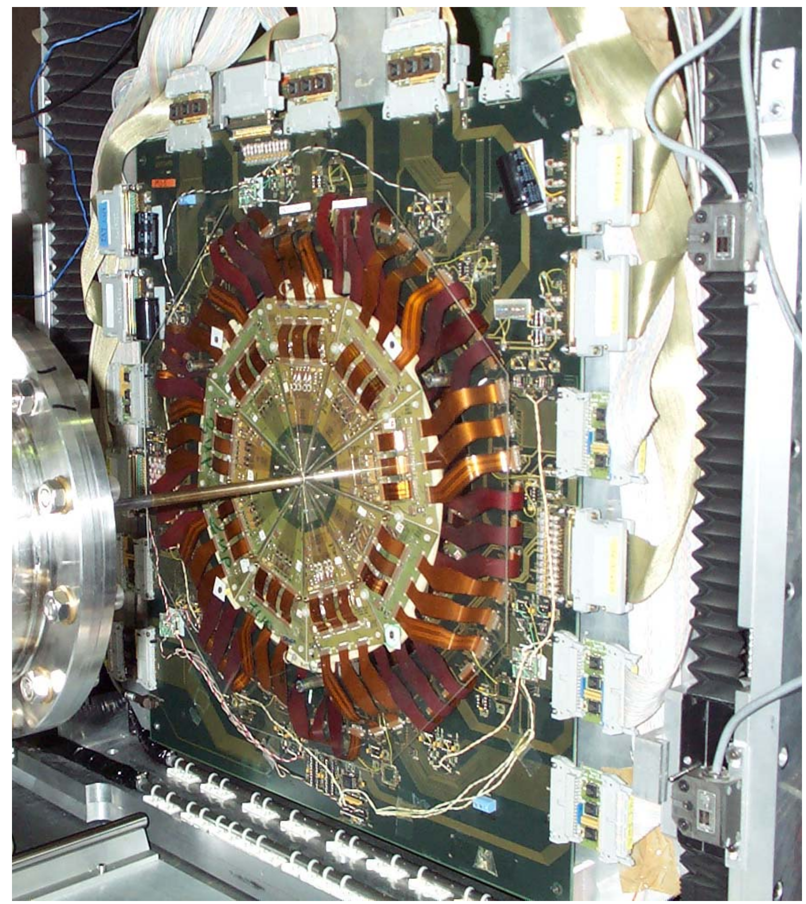
Non zero energy deposit in the ZDC

- Pb beam
  - 1998: 158 GeV/nucleon
  - 1999: 40 GeV/nucleon
- Beam detectors
- Active target
  - Up to 7 Pb subtargets + Cherenkov counters
- Centrality detectors
  - EM Calorimeter ($1.1<\eta_{lab}<2.3$)
  - ***Multiplicity Detector*** ($1.1<\eta_{lab}<4.2$)
  - Zero Degree Calorimeter ($\eta_{lab}>6.3$)
- Muon spectrometer ($2.7<\eta_{lab}<3.9$)
  - Magnet+MWPC+hodoscopes

The Multiplicity Detector (MD)



Silicon microstrip detector measuring the number and the angular distribution of charged particles produced in the collision



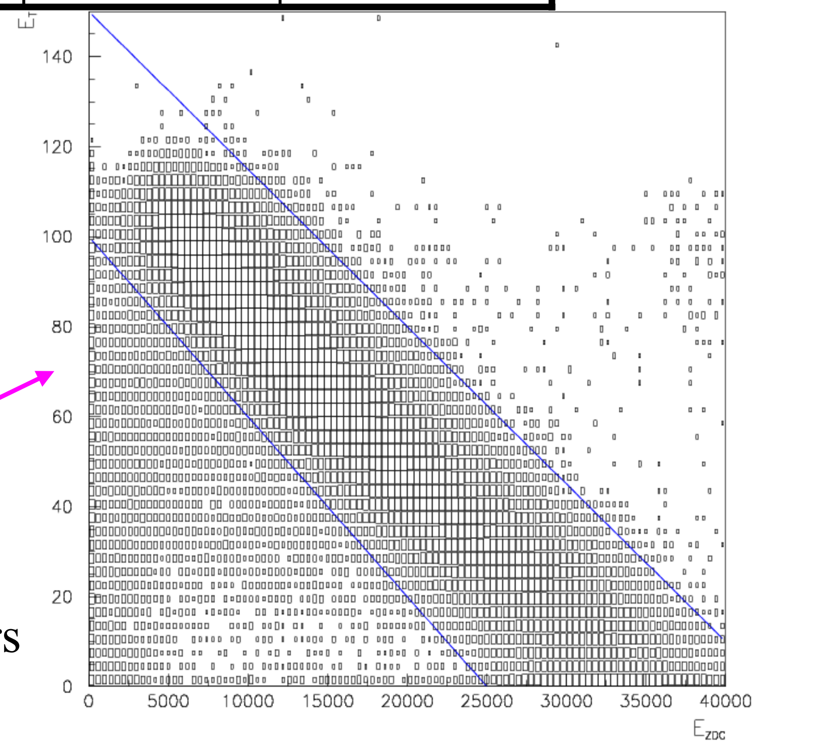
- 2 Planes (MD1, MD2)
  - each plane made of 2 layers (up/down)
- 36 azimuthal sectors ($\Delta\phi=10^o$)
- 192 radial strips ($\Delta\eta=0.02$)
  - 6912 strips in each plane
  - Only 128 innermost strips used in this analysis

dN/dη distributions vs. centrality (I)

- Data from special low-intensity runs

Pb beam energy (GeV/nucleon)	*Target*	*Distance target-MD1 (cm)*	*Target thickness*	*# of events analyzed*
158	Pb	11.65	3 mm	48000
158	Pb	9.15	1 mm	18000
40	Pb	12.55	3 mm	35000

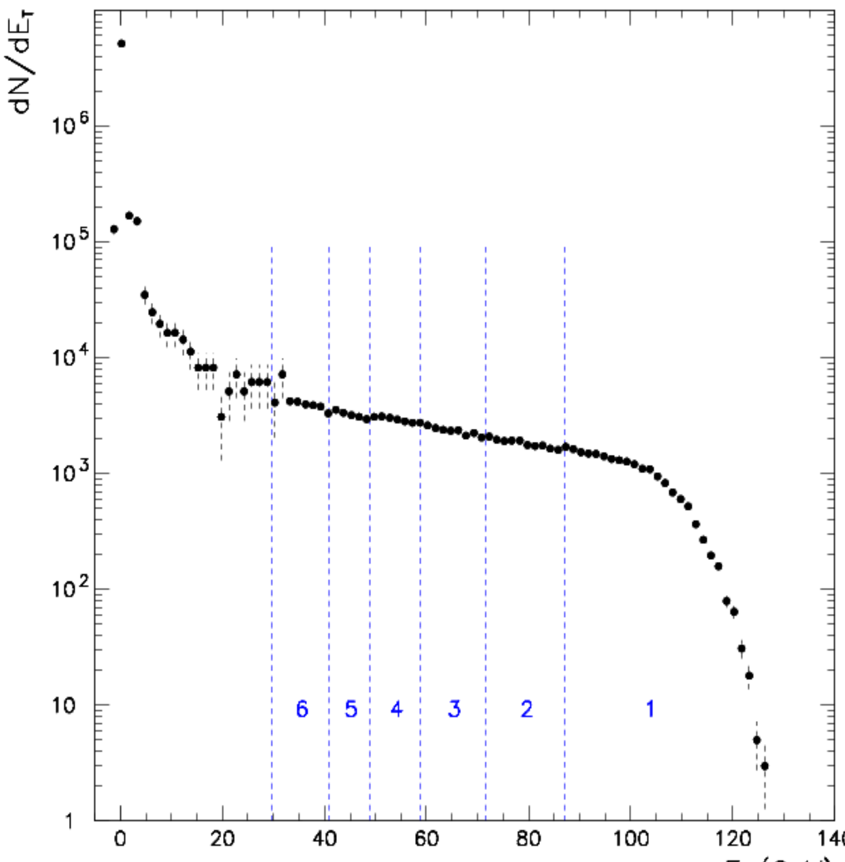
- Analysis method
  - Data selection:
    - ✓ Interaction trigger
    - ✓ Pile-up rejection
    - ✓ Upstream interaction rejection
    - ✓ Diagonal cut on the E_T-E_{ZDC} correlation
    - ✓ MD based target identification
      - ➢ Statistical method based on matching pairs of hits on MD1 and MD2

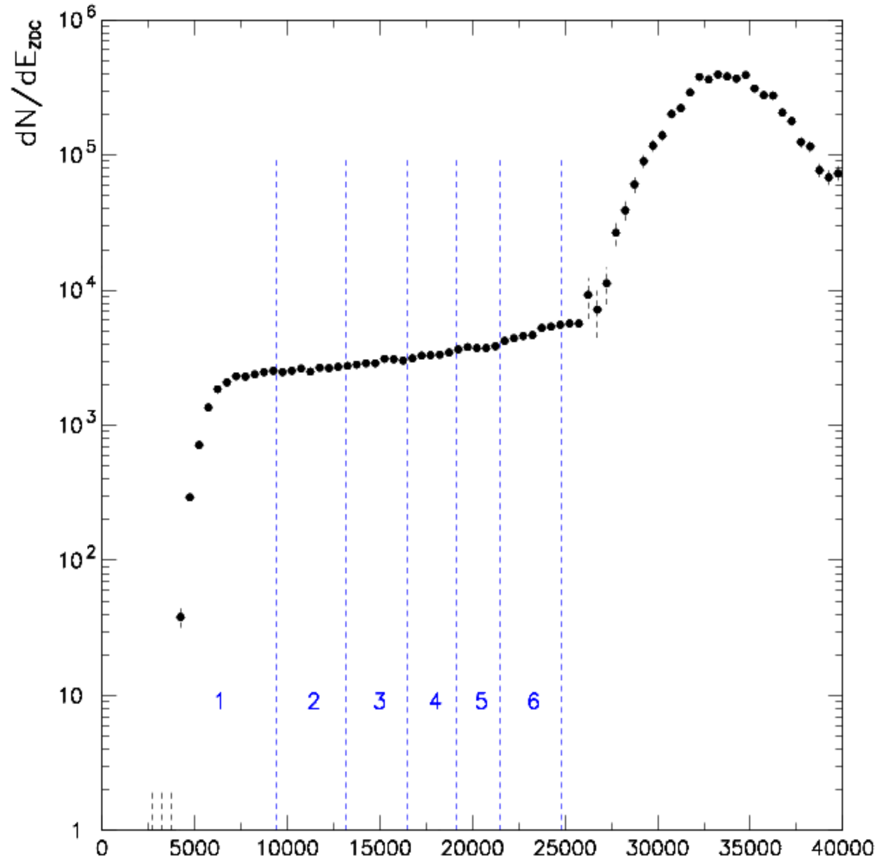


dN/dη distributions vs. centrality (II)

- Centrality interval definition at 158 GeV/c:
  - ✓ 2 independent centrality variables (E_T and E_{ZDC})
  - ✓ Intervals expressed in terms of fraction of total inelastic cross section

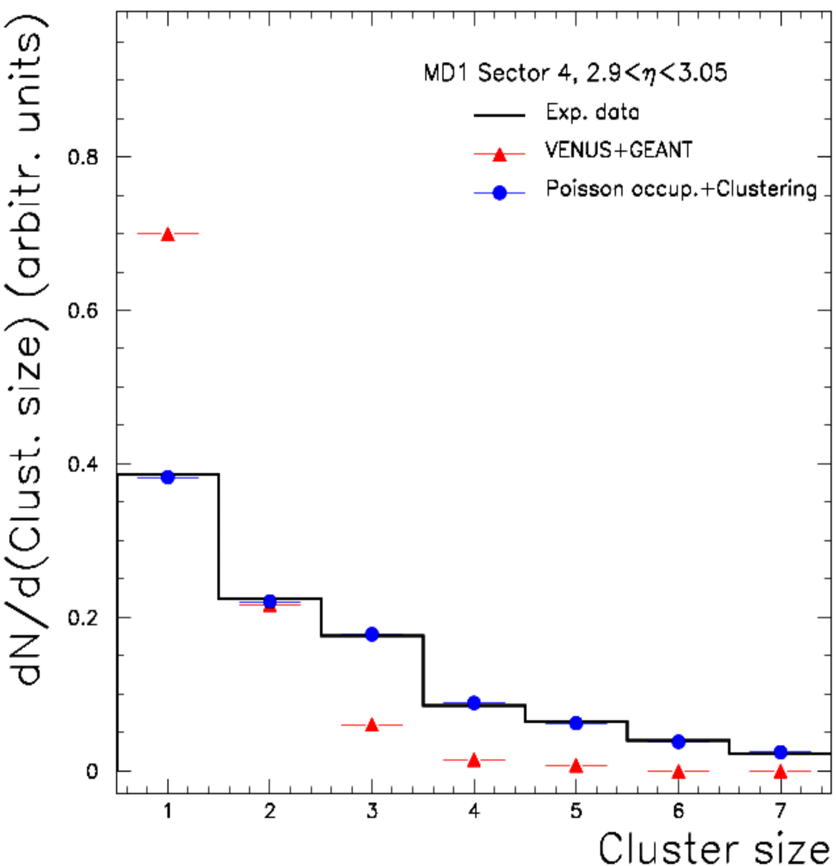
$$N_{\text{int}} = N_{Pb} \cdot P_{\text{int}} = N_{Pb} \cdot \left(1 - e^{-L_T/\lambda_{INT}}\right) \quad with \;\; \lambda_{INT} = \frac{A_{TARG}}{\rho_{Pb}\, N_A\, \sigma_{inel}} = 3.98^{+0.21}_{-0.27}\, cm$$

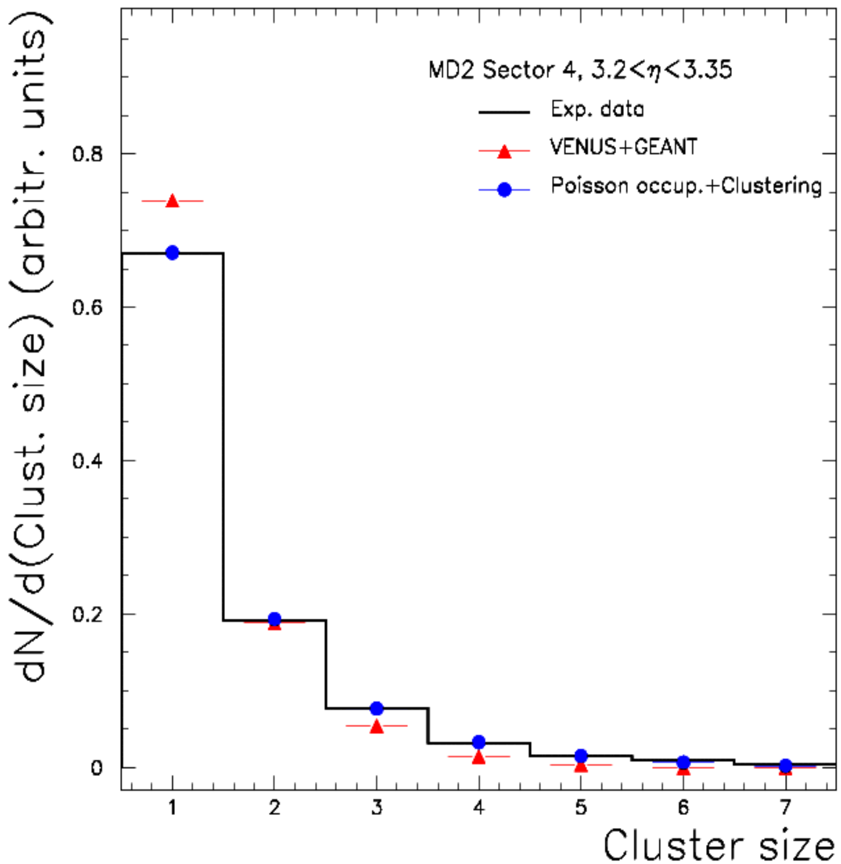




dN/dη distributions vs. centrality (III)

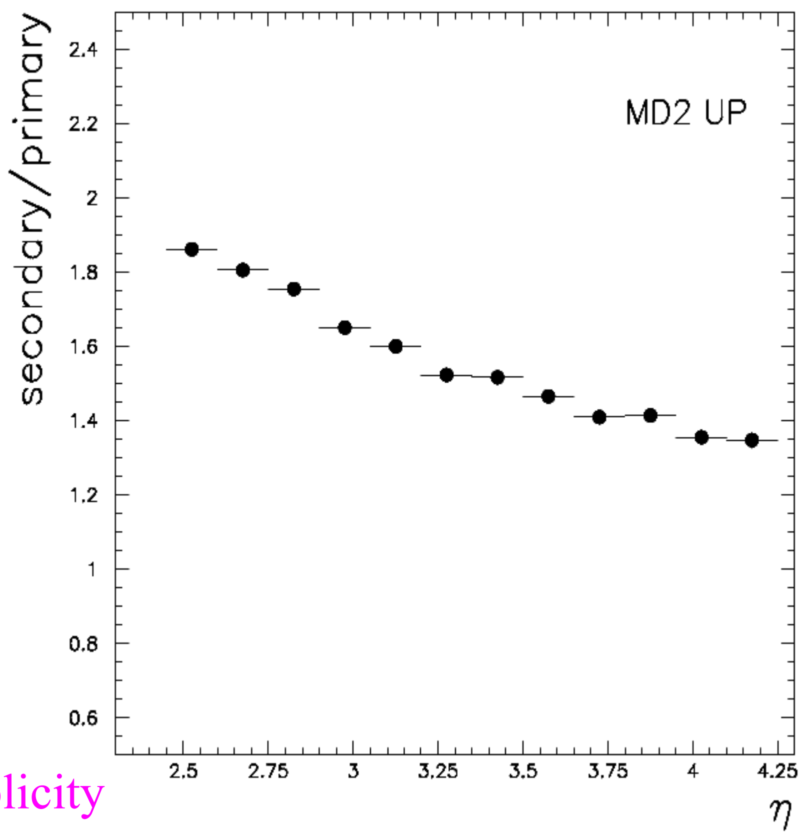
- Calculation of raw $dN_{ch}/d\eta$
  - ✓ Cluster (group of contiguous strips firing together) correction
    - ➢ Cluster size distribution not reproduced by a VENUS+GEANT simulation
    - ➢ Dedicated MC, aimed at reproducing cluster size distribution observed in data
  - ✓ Performed separately in each η bin (Δη=0.15) and in each centrality class





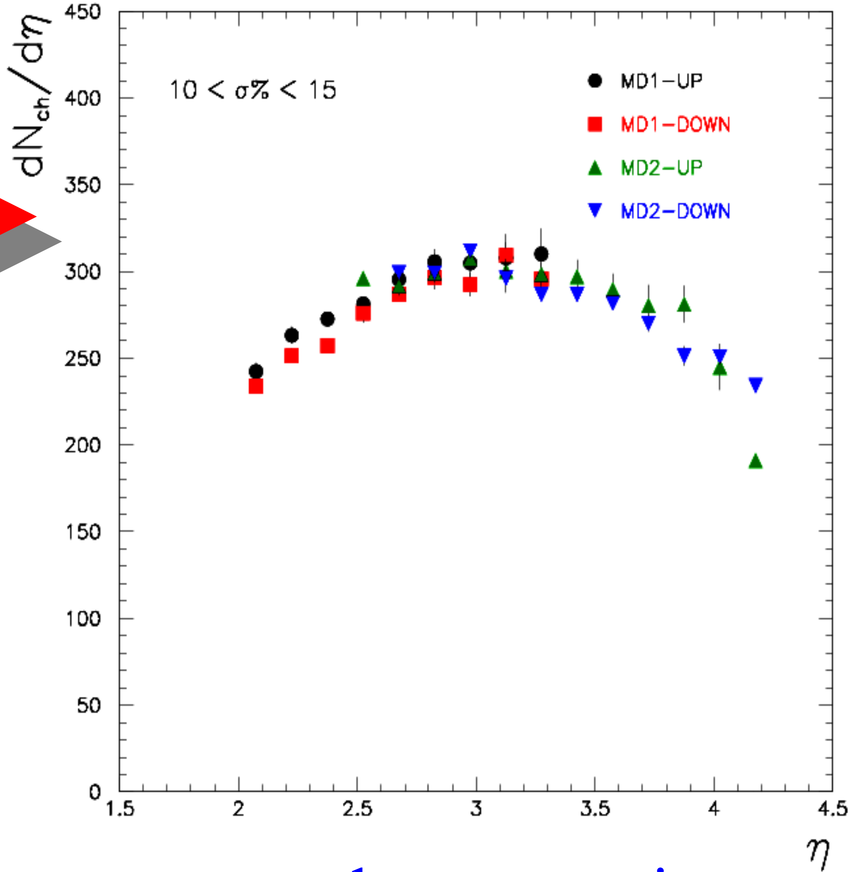
dN/dη distributions vs. centrality (III)

- Calculation of primary $dN_{ch}/d\eta$.
  - ✓ Subtraction of the delta electron contribution (from GEANT).
    - ➢ Max. 5% of the occupancy in the most peripheral bin.
  - ✓ Correction with secondary/primary ratio from VENUS+GEANT simulation.
    - ➢ VENUS+GEANT data reconstructed with same method as experimental data.
    - ➢ 1.2 –1.8 correction factor.
      - → *Do not depend on centrality.*
      - → *Depend on target thickness, target position, particular MD plane.*
    - ➢ Unstable particles (K_0, Λ and hyperons) decays are already considered in VENUS, and therefore their decay products are defined as primary particles.



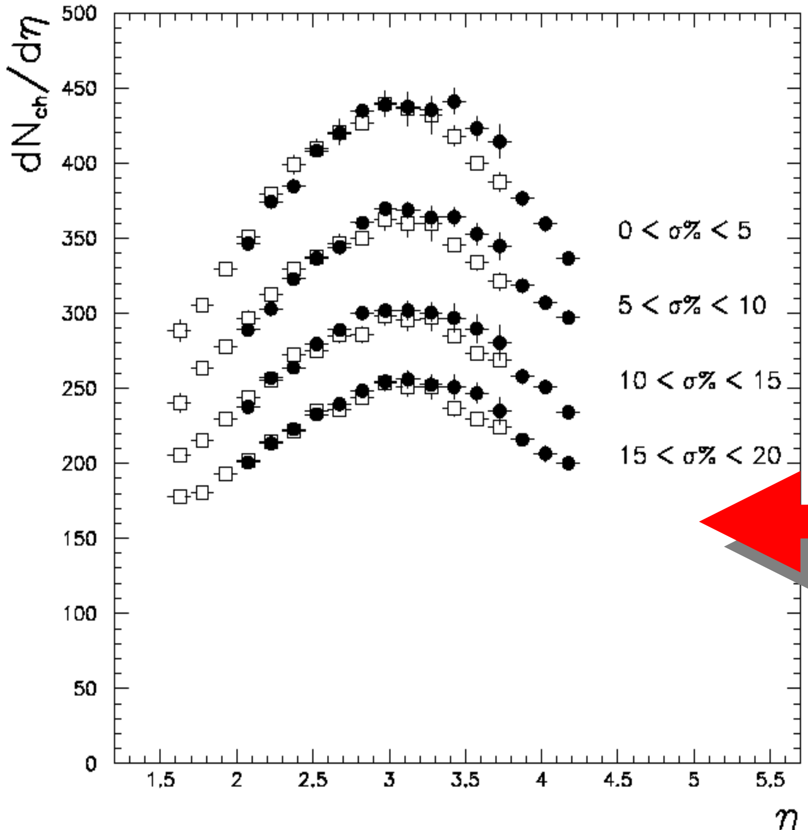
- Systematic error estimation
  - ✓ ***8% systematic error*** on primary charged multiplicity

dN/dη distributions vs. centrality (III)



Agreement between MD1 and MD2

- Average between detector planes
- Wide η coverage

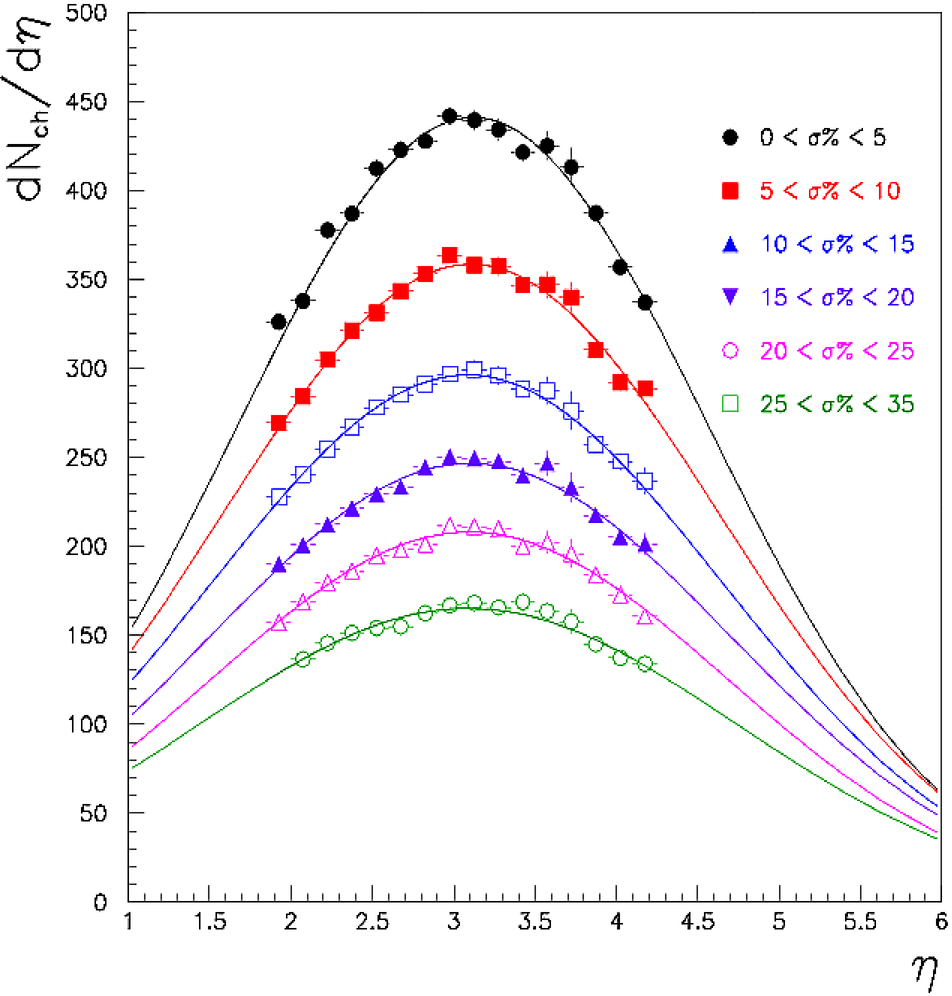


Excellent agreement between primary $dN_{ch}/d\eta$ with 2 different target thicknesses and positions

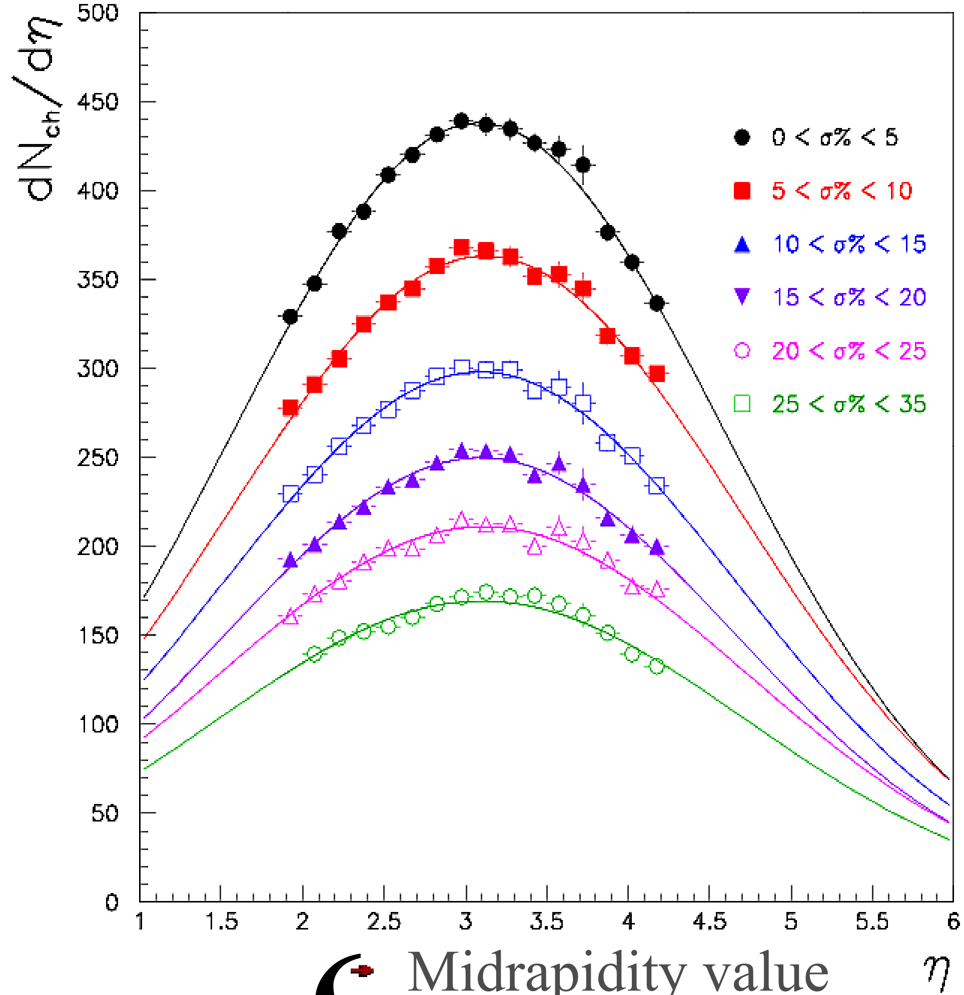
- Average between different thicknesses
- Wider η coverage

$dN_{ch}/d\eta$ distributions at 158 GeV

E_T centrality selection



E_{ZDC} centrality selection

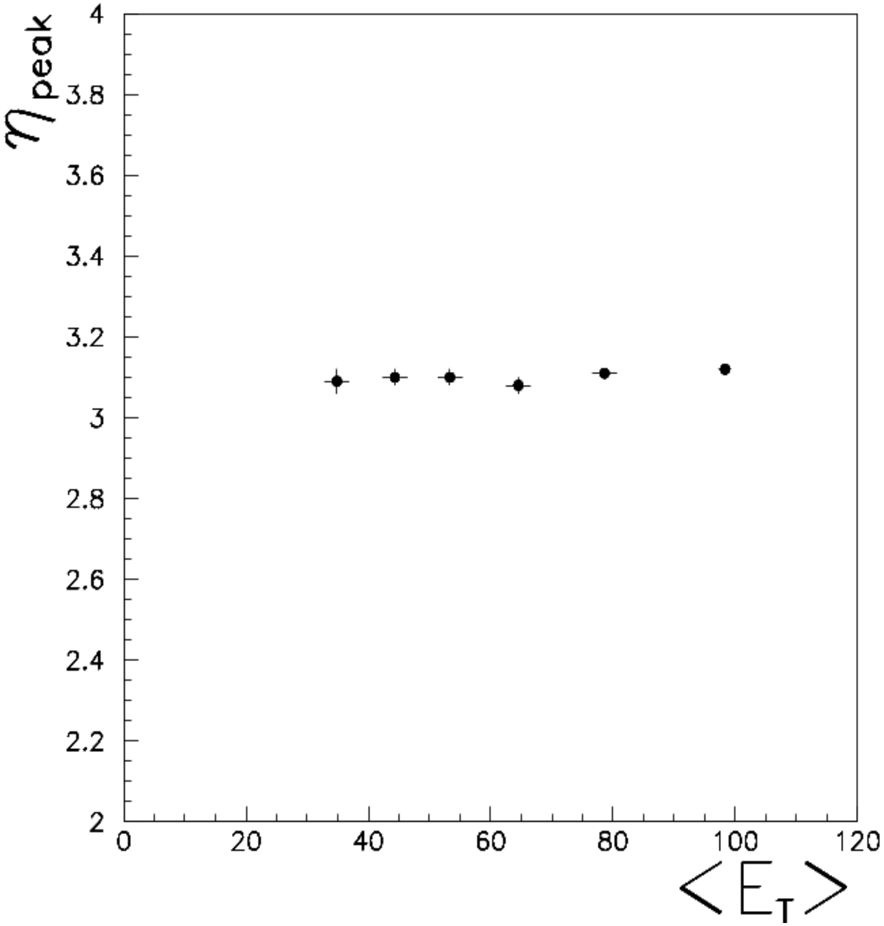


Distributions fitted with Gaussians to extract:

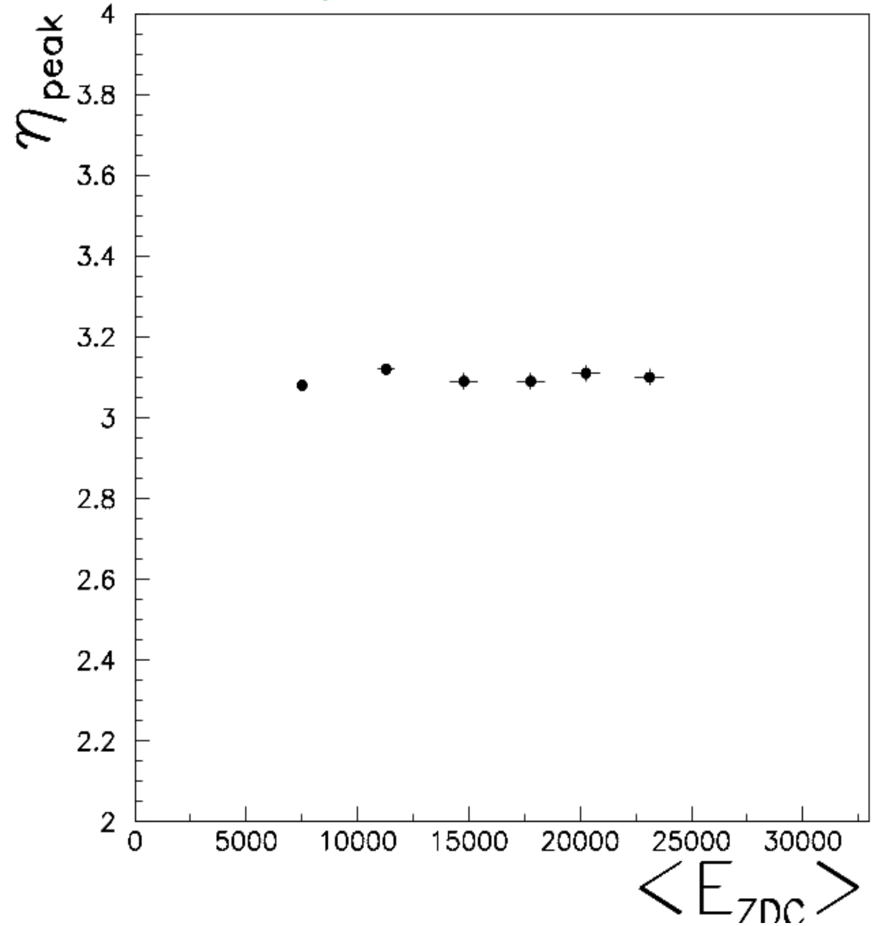
- Midrapidity value
- Gaussian width
- $dN_{ch}/d\eta$ at the peak

Midrapidity value at 158 GeV /c

E_T centrality selection



E_{ZDC} centrality selection

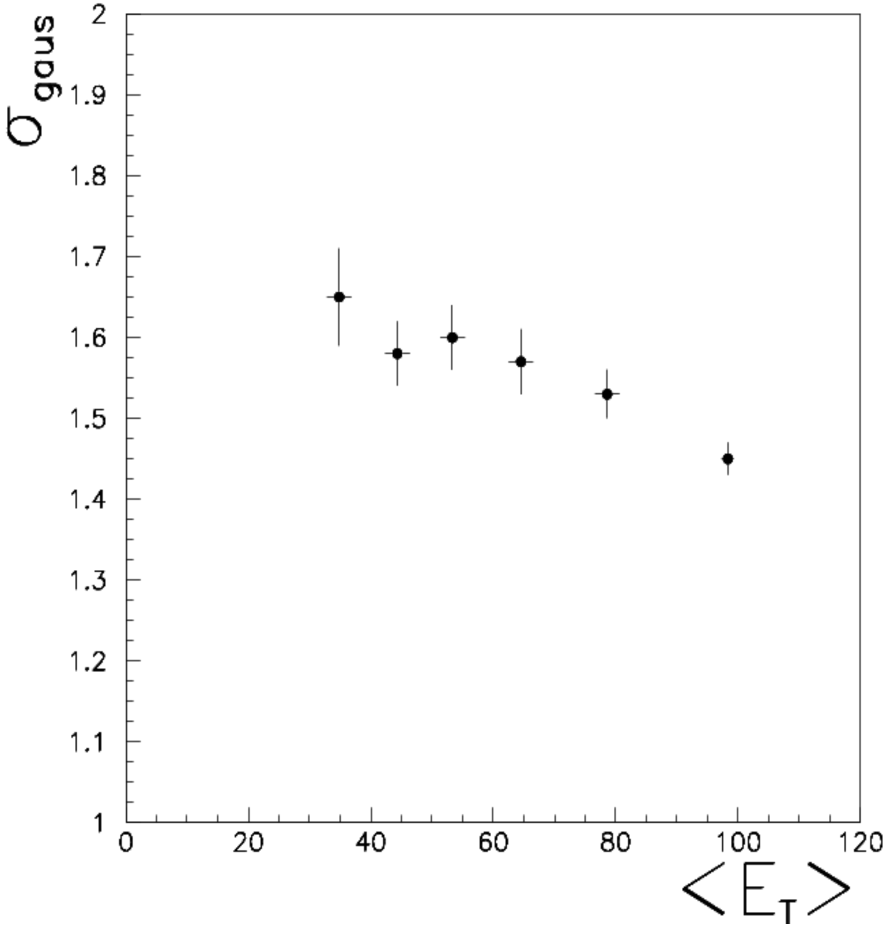


Midrapidity visible in the dN/dη distributions:

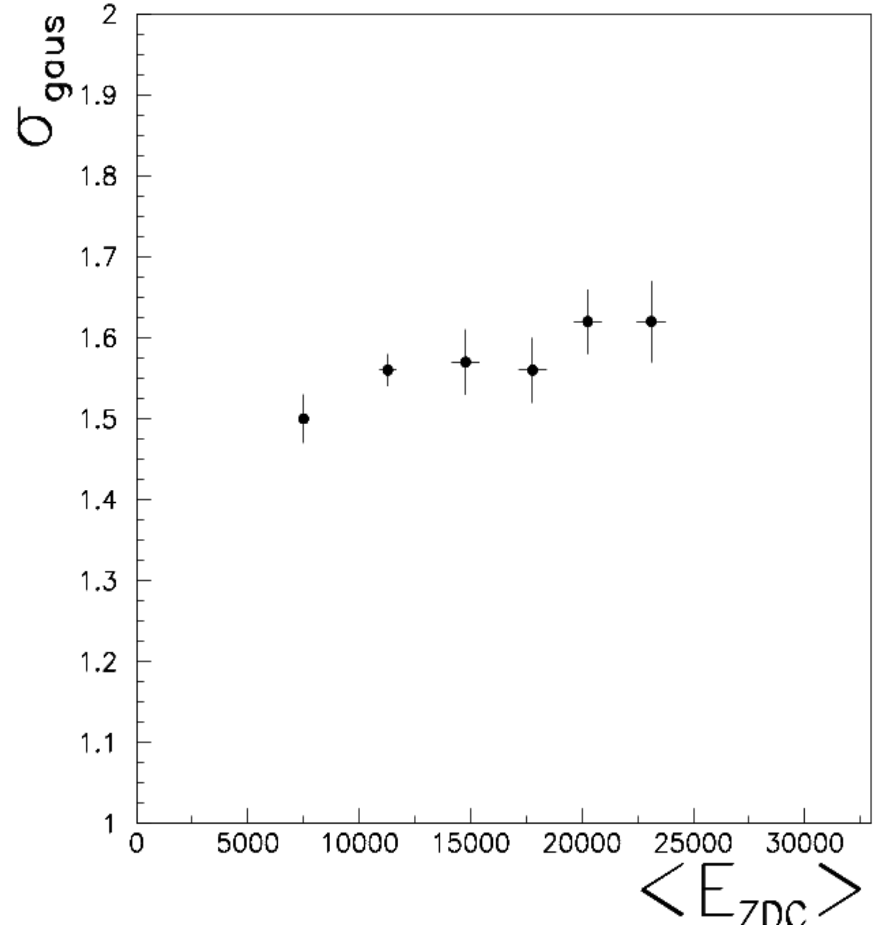
- → No reflection around midrapididty needed
- → η_{peak} extracted from fit compatible with VENUS predicion (η_{peak}=3.1)

Gaussian width at 158 GeV /c

E_T centrality selection



E_{ZDC} centrality selection



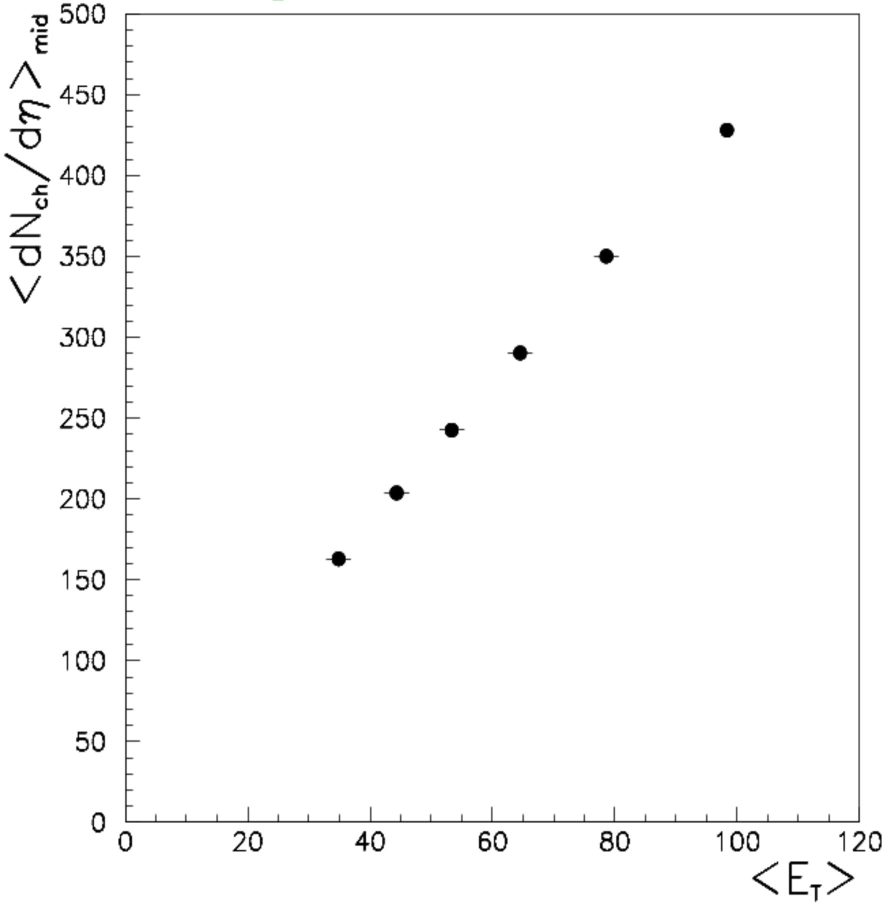
Gaussian width decreses with centrality:

→ stopping power effect

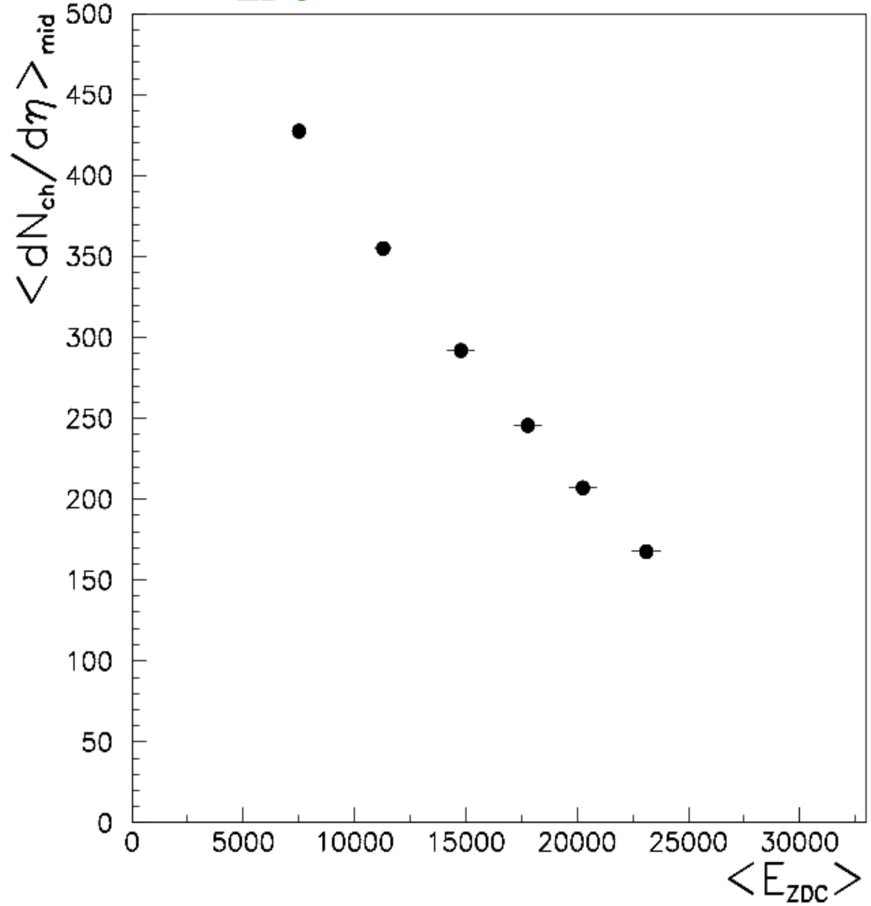
→ decreasing contribution of protons from target and projectile fragmentation

$dN_{ch}/d\eta_{\ max}$ at 158 GeV /c

E_T centrality selection



E_{ZDC} centrality selection



$dN/d\eta$ at the peak scales linearly with E_T and E_{ZDC}

→ no saturation or enhancement observed

$dN_{ch}/d\eta$ distributions at 40 GeV /c (I)

ZDC worse performance at such a low energy

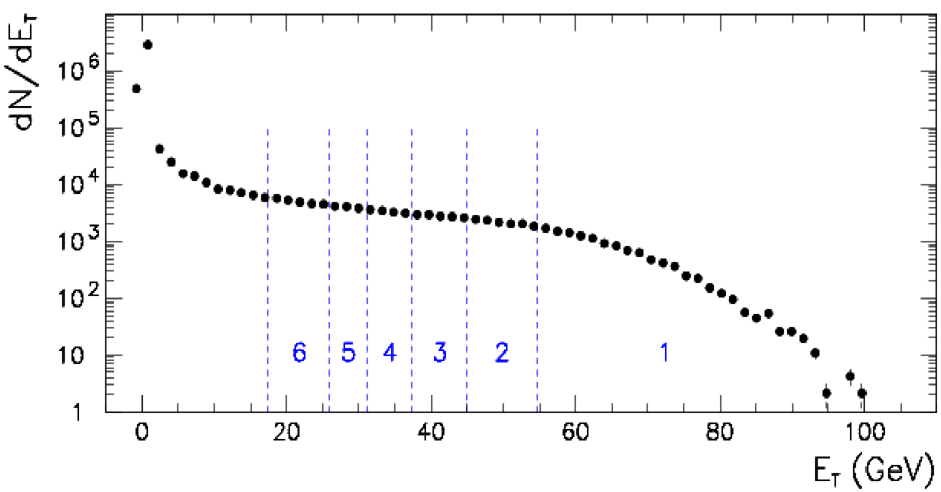
Only ***E_T*** *based* ***centrality selection***

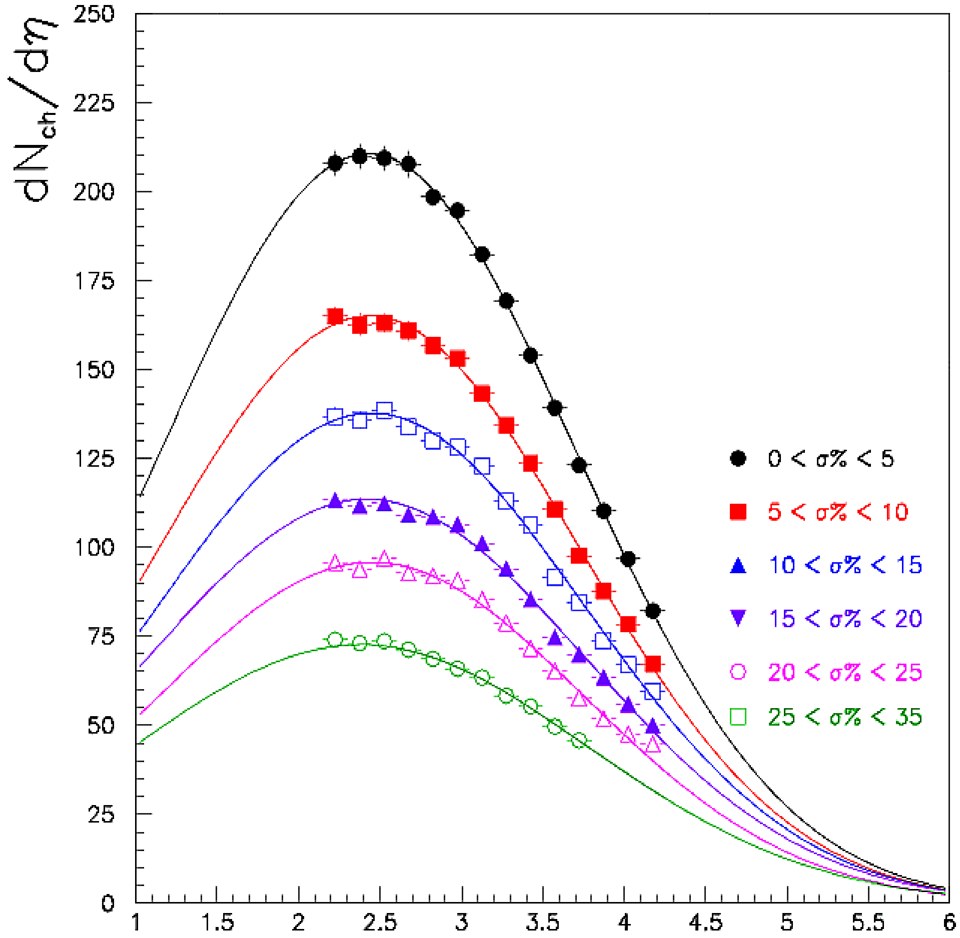
Larger (10%) systematic error

•ZDC based quality cuts not performed

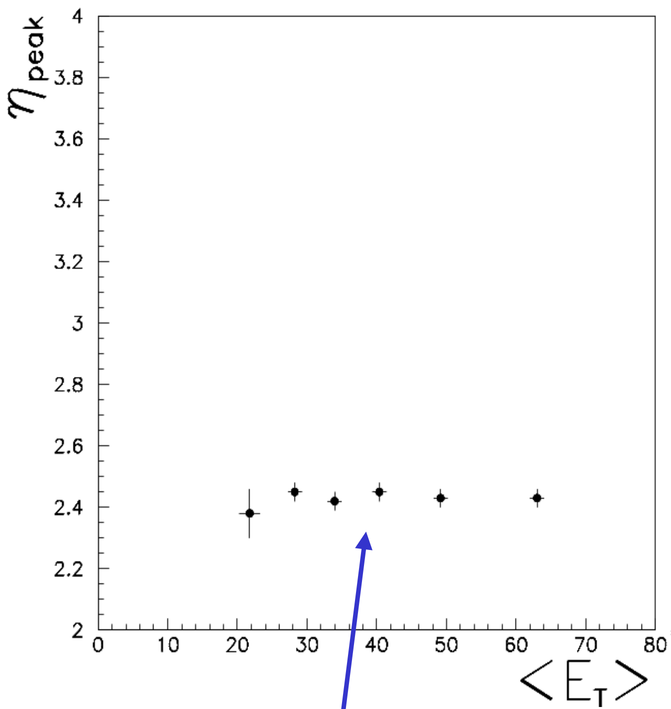
→ larger E_T tail beyond the knee

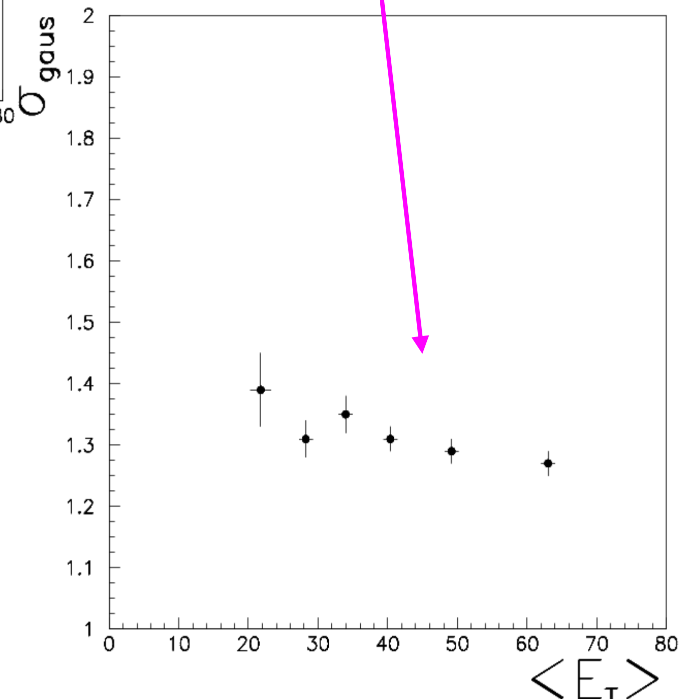
→ E_T resolution not well defined

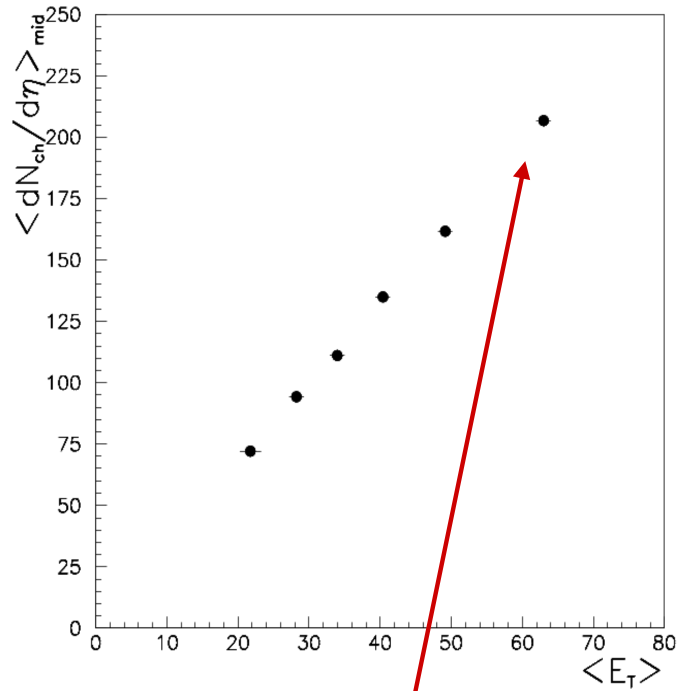




$dN_{ch}/d\eta$ distributions at 40 GeV /c (II)





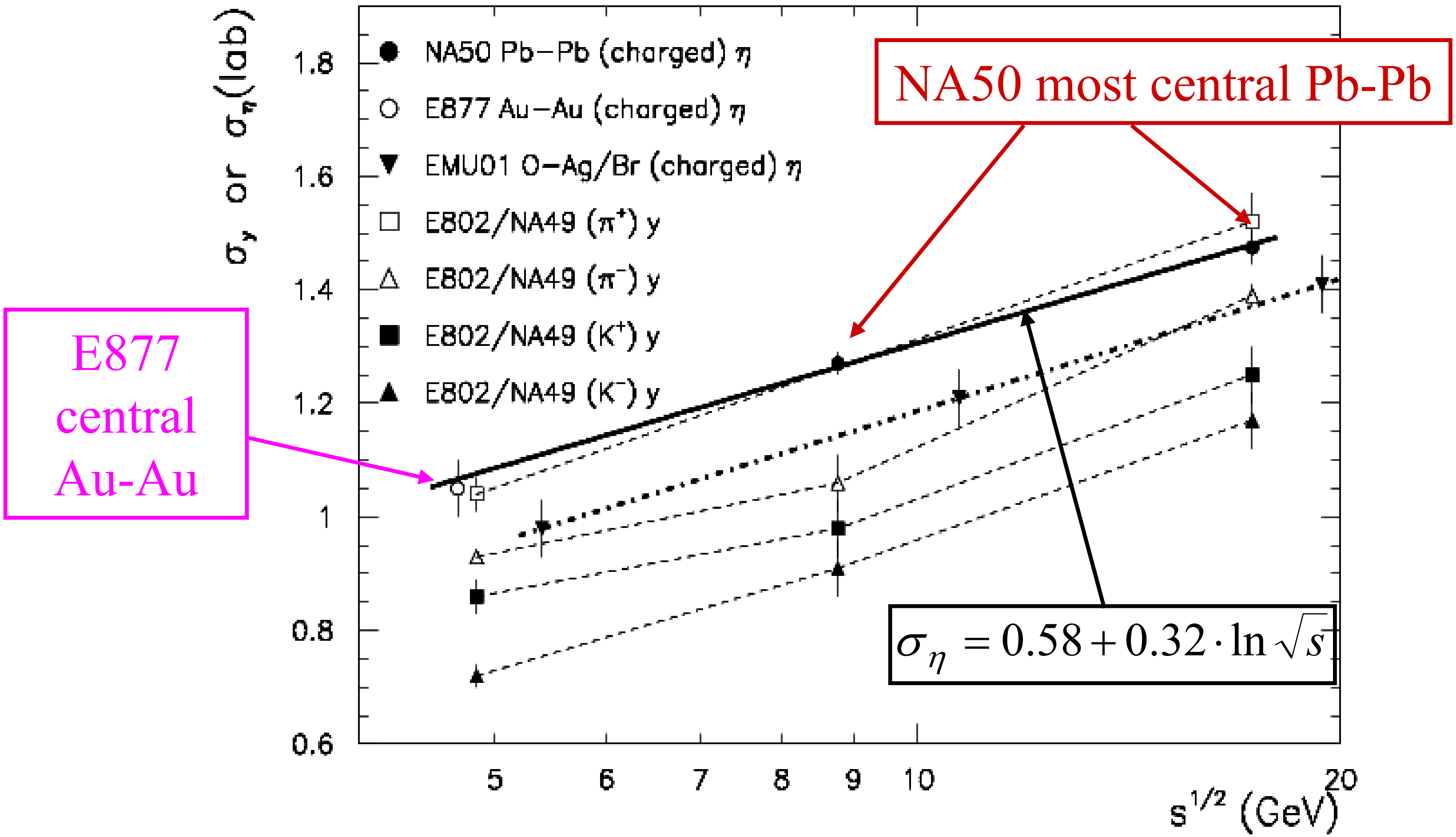


Gaussian width smaller than at 158 GeV, decreasing with increasing centrality

Peak position (VENUS prediction): $\eta_{max} \approx 2.47$

Number of charged particles in the more central bin $\approx$ **2** times smaller than at 158 GeV

Gaussian width vs. energy



- Available phase space in rapidity increases with √s
- Fit with the simple scaling law: $\sigma_\eta = a + b \cdot \ln \sqrt{s}$
- Same √s dependence for all data

Evaluation of N_{part} and N_{coll} (I)

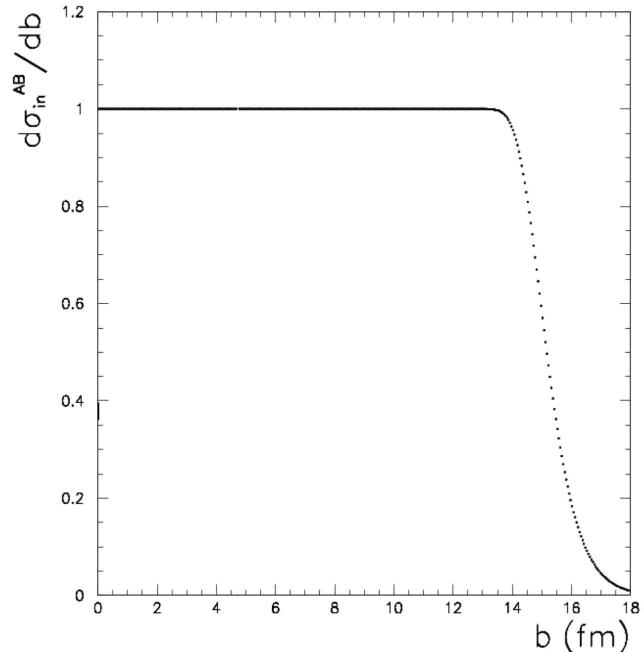
- Glauber model calculations
  - Physical inputs:
    - ✓ Woods-Saxon density for Pb nucleus (2pF)
    - ✓ σ_{in} = 30 mb
  - Numerical calculation of:
    - ✓ Interaction probability, N_{part} , N_{coll} ... vs. impact parameter b

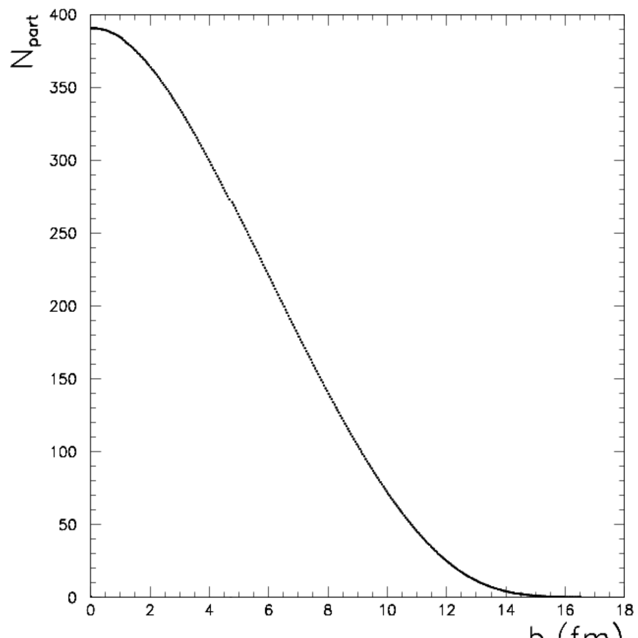
$$\rho = \frac{\rho_0}{1 + e^{(r - r_0)/C}}$$

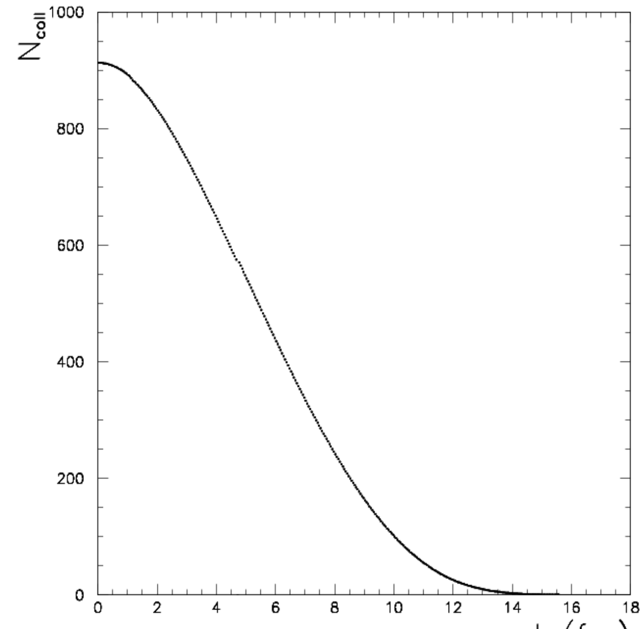
ρ_0 = 0.16 fm^{-3}

C= 0.549 fm

r0 = 6.624 fm







Evaluation of N_{part} and N_{coll} (II)

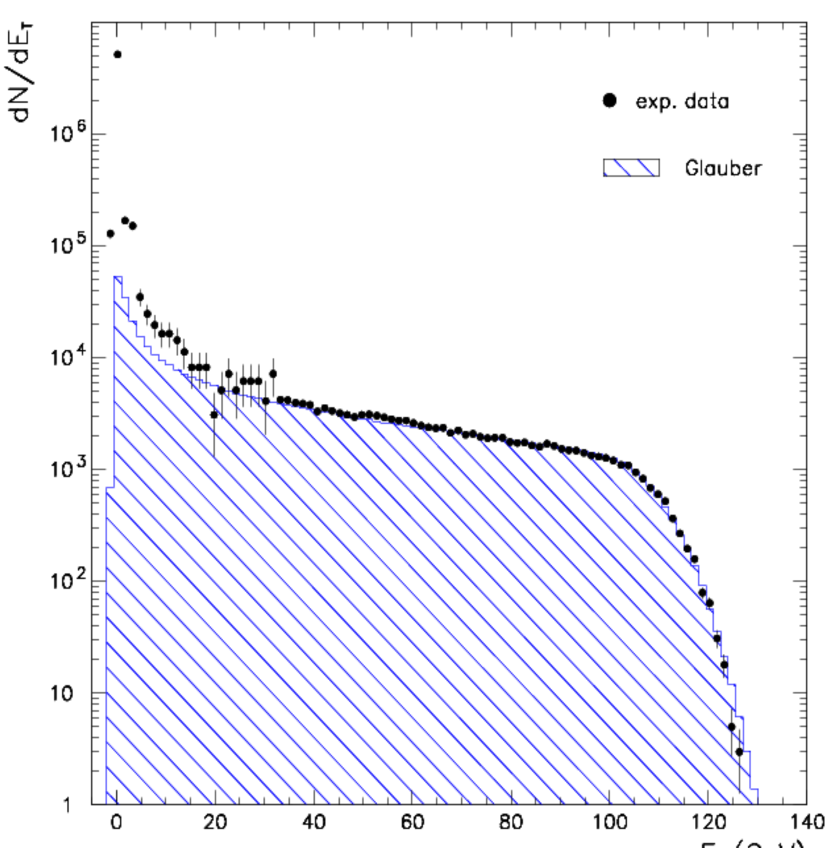
- *E_T and E_{ZDC} parametrization*
  - ✓ *$E_T \propto$ number of participants*
  - ✓ *$E_{ZDC} \propto$ number of projectile spectators*
  - *q, w, α and δ form fit to MB spectra*

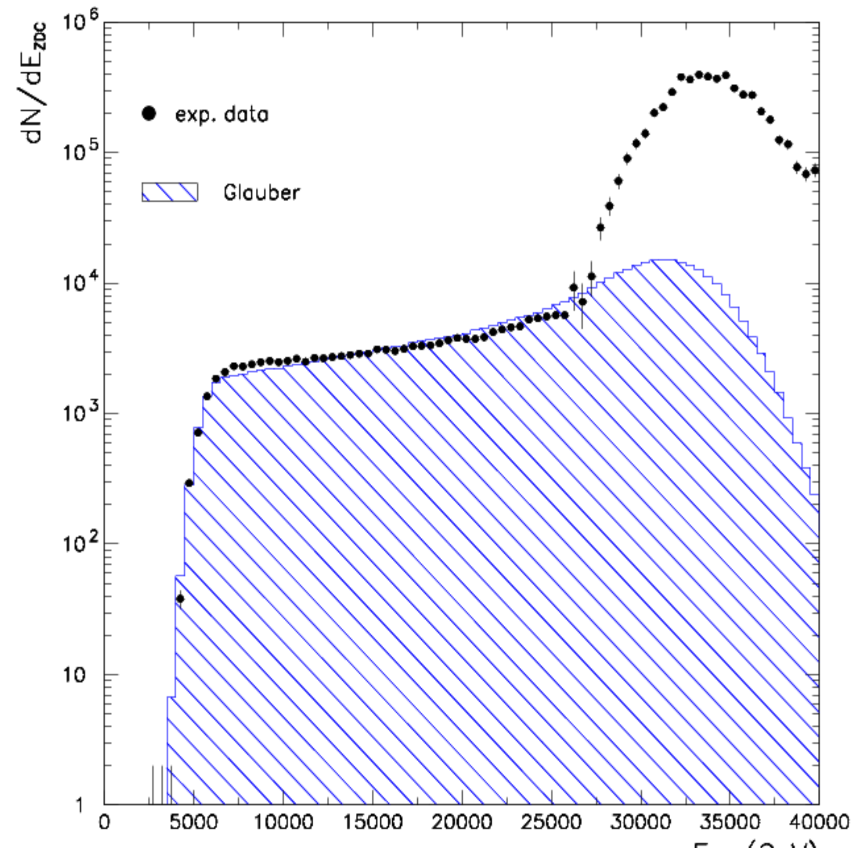
$$E_T = q \cdot N_{part}$$

$$\sigma^2{}_{E_T} = w \cdot q^2 \cdot N_{part}$$

$$E_{ZDC} = E_{beam}\left(A_{Pb} - \frac{N_{part}}{2} \right) + \alpha\, N_{part}$$

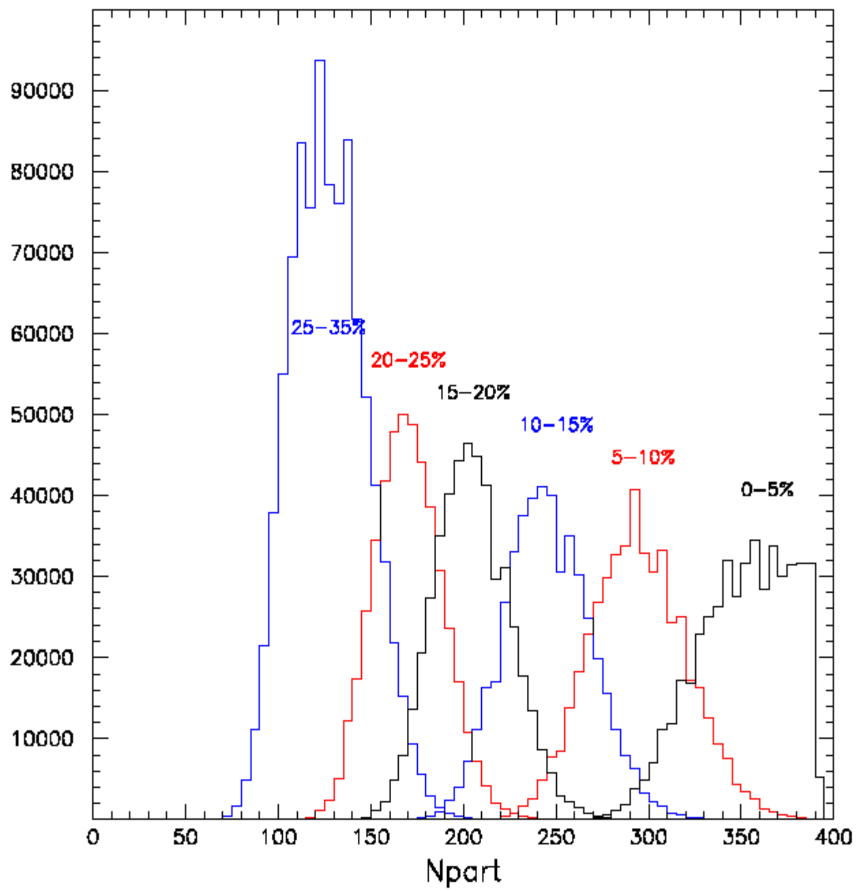
$$\sigma^2{}_{E_{ZDC}} = \left(\beta \sqrt{E_{ZDC}} + \gamma\, E_{ZDC}\right)^2 + \delta^2$$





Evaluation of N_{part} and N_{coll} (III)

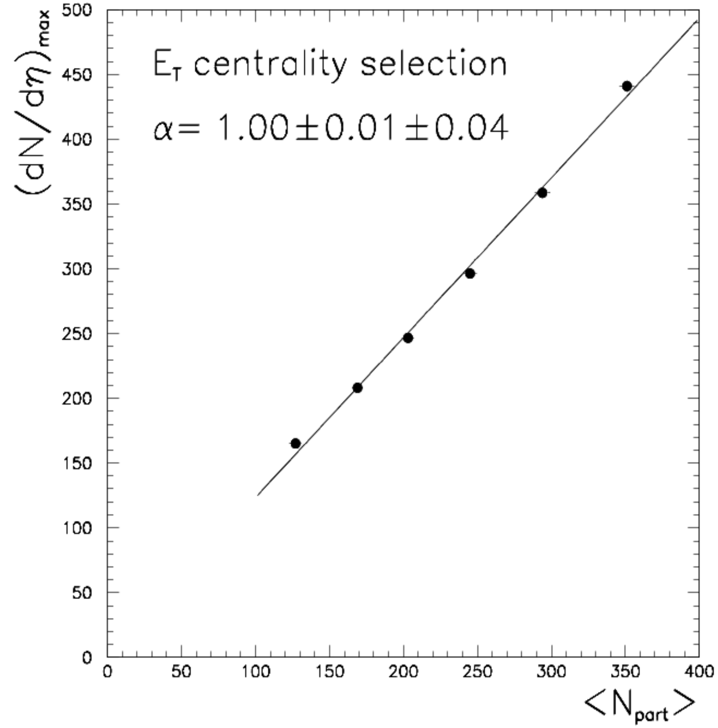
- *Calculation of $\langle N_{part} \rangle$ and $\langle N_{coll} \rangle$ in each centrality class*
  - *From distributions of N_{part} and N_{coll} in the E_T and E_{ZDC} intervals*
  - *Smearing effects due to calorimeter resolution included*



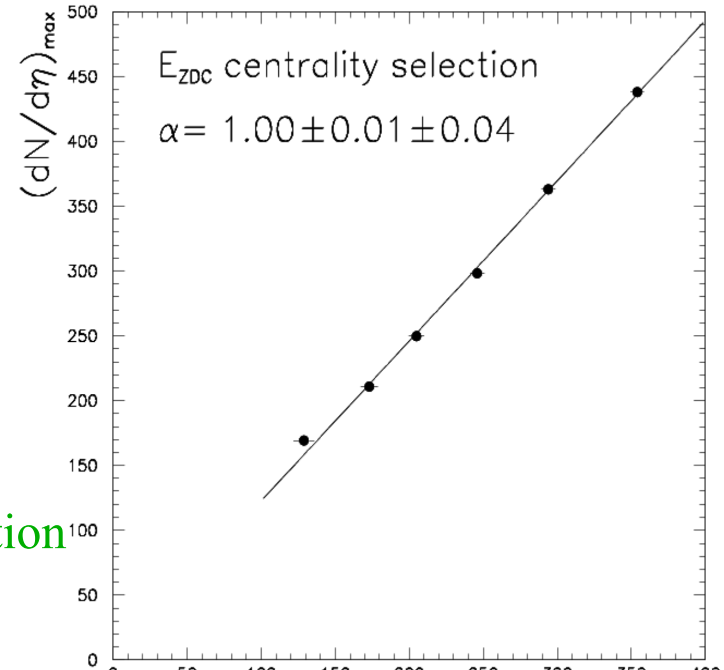
Class	% of c.s.	E^{min}_{ZDC}-E^{max}_{ZDC} (GeV)	$< N_{part} >$	RMS N_{part}	$< N_{coll} >$	RMS N_{coll}
1	0-5	0-9385	354	22	802	66
2	5-10	9385-13150	294	23	634	63
3	10-15	13150-16490	246	25	501	64
4	15-20	16490-19180	205	26	395	65
5	20-25	19180-21475	173	28	316	66
6	25-35	21475-24790	129	35	214	74

Class	% of c.s.	E^{min}_{T}-E^{max}_{T} (GeV)	$< N_{part} >$	RMS N_{part}	$< N_{coll} >$	RMS N_{coll}
1	0-5	87.2-140.	352	25	796	73
2	5-10	71.5-87.2	294	26	632	72
3	10-15	58.7-71.5	245	23	498	61
4	15-20	48.9-58.7	203	20	392	52
5	20-25	40.9-48.9	169	19	309	44
6	25-35	29.6-40.9	127	20	213	45

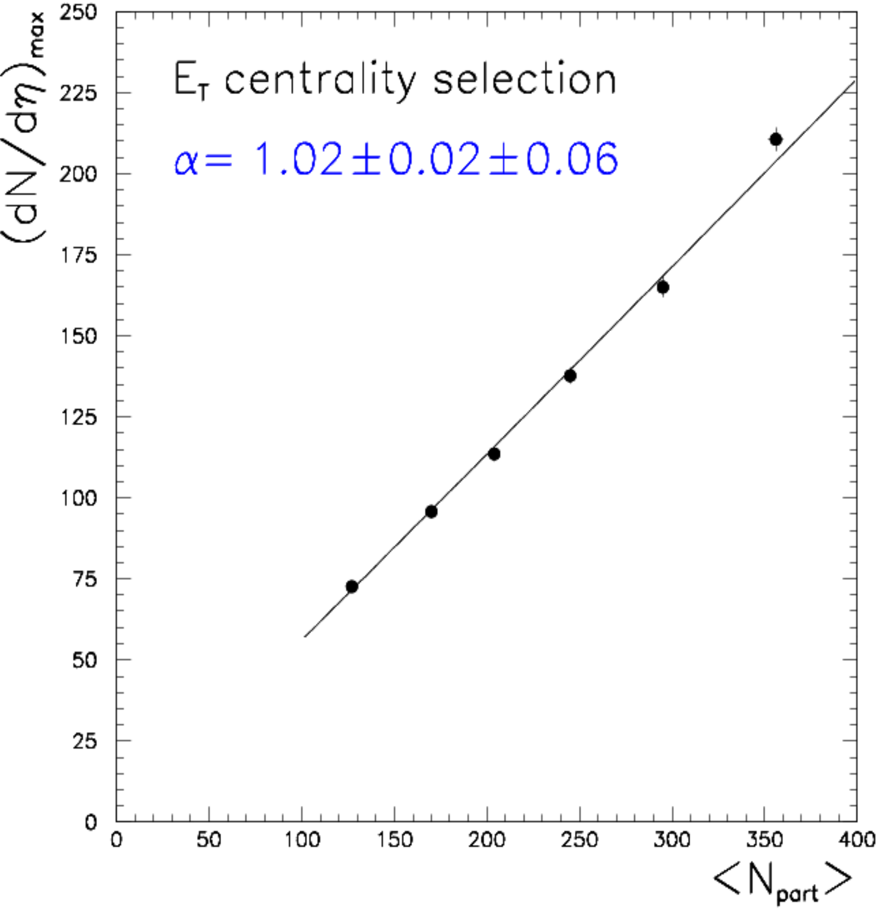
Charged particle scaling at 158 GeV



- Fit with the power law: $\left.\frac{dN}{d\eta}\right|_{max} \propto N_{part}^{\alpha}$
  - α=1.00±0.01±0.04
    - ✓ α = 1.05-1.08 using a VENUS calculation of N_{part}
    - ✓ α = 1.02 with $N_{part} = 2\cdot 208 \cdot (1-E_{ZDC}/E_{BEAM})$
- Fit with the power law: $\left.\frac{dN}{d\eta}\right|_{max} \propto N_{coll}^{\beta}$
  - β=0.75±0.02
- Fit with the law: $\left.\frac{dN}{d\eta}\right|_{max} \propto A \cdot N_{part} + B \cdot N_{coll}$
  - B compatible with zero
- Conclusions:
  - N_{part} describes the centrality dependence of particle production
  - Hard processes play a negligible role at this energy



Charged particle scaling at 40 GeV



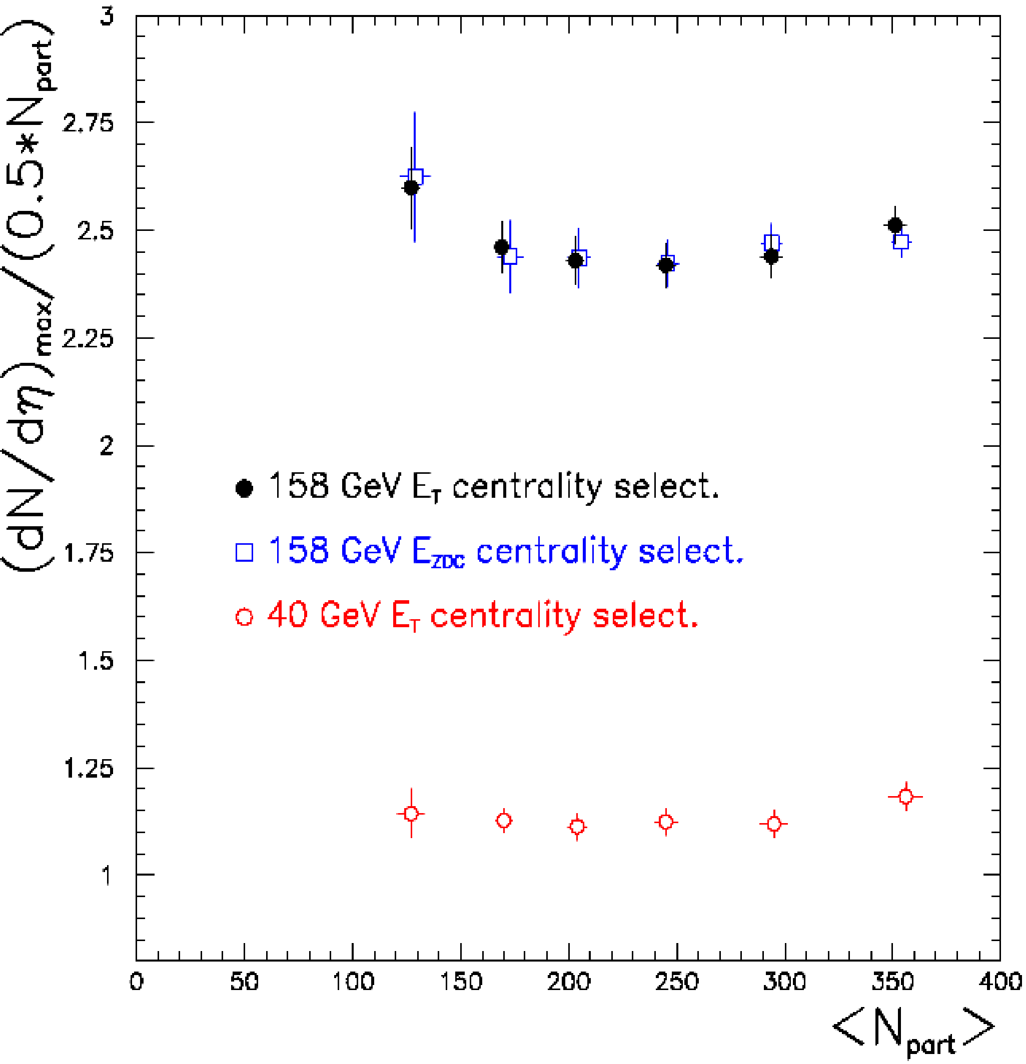
Fit with the power law:

- α=1.02±0.02±0.06

Conclusions:

- As expected, no important hard process contribution at this energy
- Same N_{part} dependence at 158 and 40 GeV
- Soft processes account well for particle production at SPS energies

Yield per participant pair vs. centrality



- Yield per participant pair:

$$\frac{\left. dN_{ch}/d\eta \right|_{\max}}{0.5\, N_{part}}$$

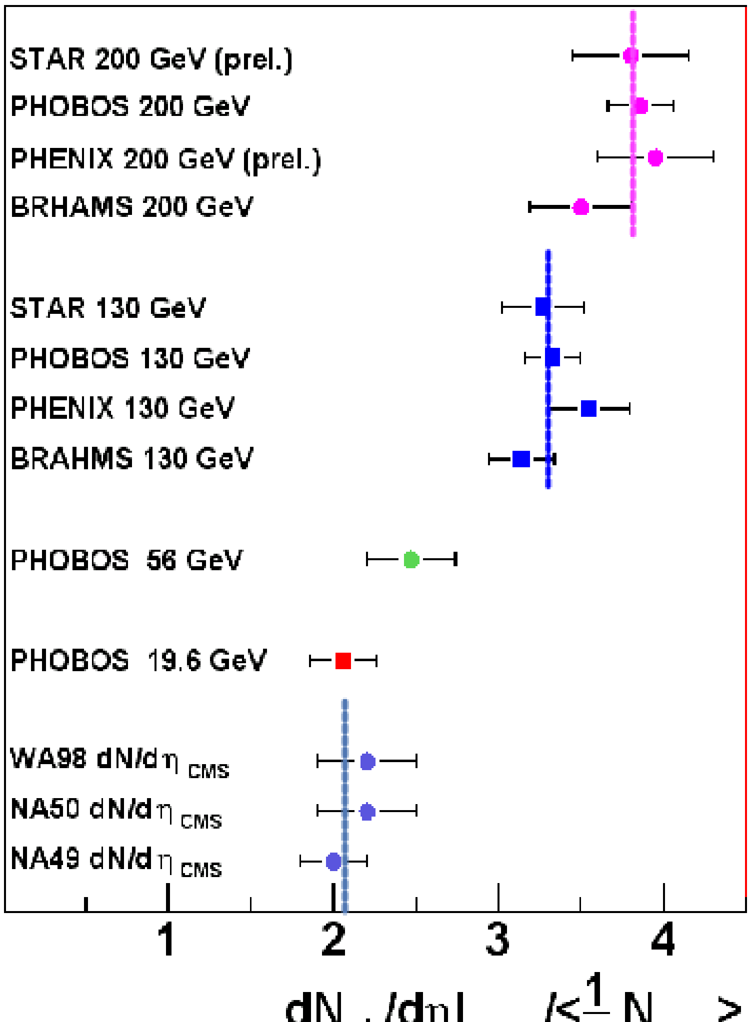
→ *Only statistical error on $dN/d\eta$ + error on N_{part} shown in plot*

→ *Flat behaviour reflects the linear dependence of $dN/d\eta_{max}$ on N_{part}*

Beam energy (A·GeV/c)	√s (GeV)	$\frac{\left. dN_{ch}/d\eta \right\|_{\max}}{0.5\, N_{part}}$
40	8.77	1.18±0.03±0.15
158	17.3	2.49±0.03±0.20

Comparison with other experiments

- Conversion from $dN/d\eta|_{lab}$ to dN/dy and subsequently to $dN/d\eta|_{cm}$ done assuming:
  - At 158 GeV/c (√s=17.3 GeV): pions, protons and kaons relative yields from NA49
  - At 40 GeV/c (√s=8.77 GeV): pions, protons and kaons relative yields from VENUS 4.12



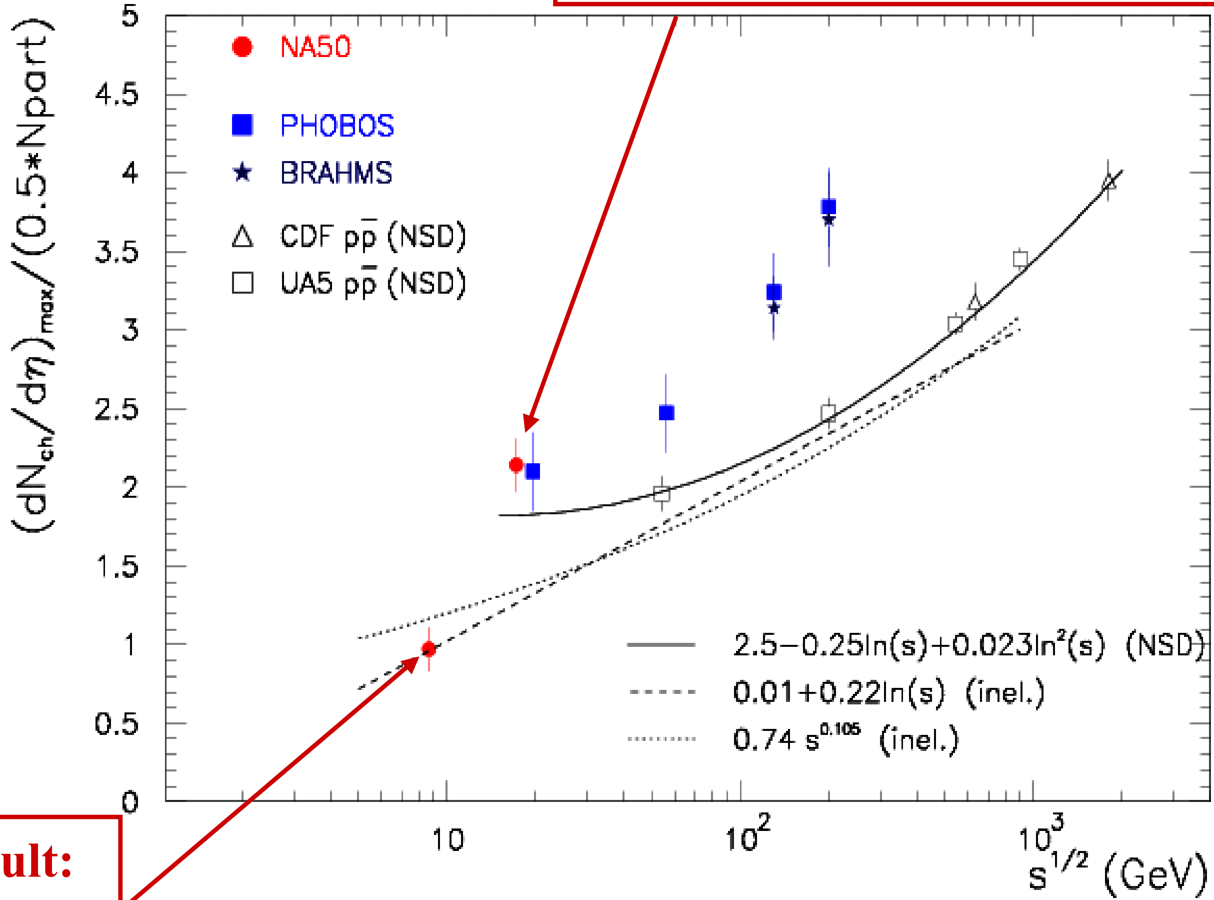
$$\frac{dN_{ch}}{d\mathbf{p}_T d\eta} = \sqrt{1 - \frac{m^2}{m_T^2 \cosh^2 y}} \frac{dN_{ch}}{d\mathbf{p}_T dy}$$

most central bin

√s (GeV)	$\frac{dN_{ch}/d\eta\|_{max}}{0.5 N_{part}}$ (LAB)	$\frac{dN_{ch}/d\eta\|_{max}}{0.5 N_{part}}$ (CMS)
8.77	1.18±0.03±0.15	0.97±0.03±0.14
17.3	2.49±0.03±0.20	2.14±0.03±0.17

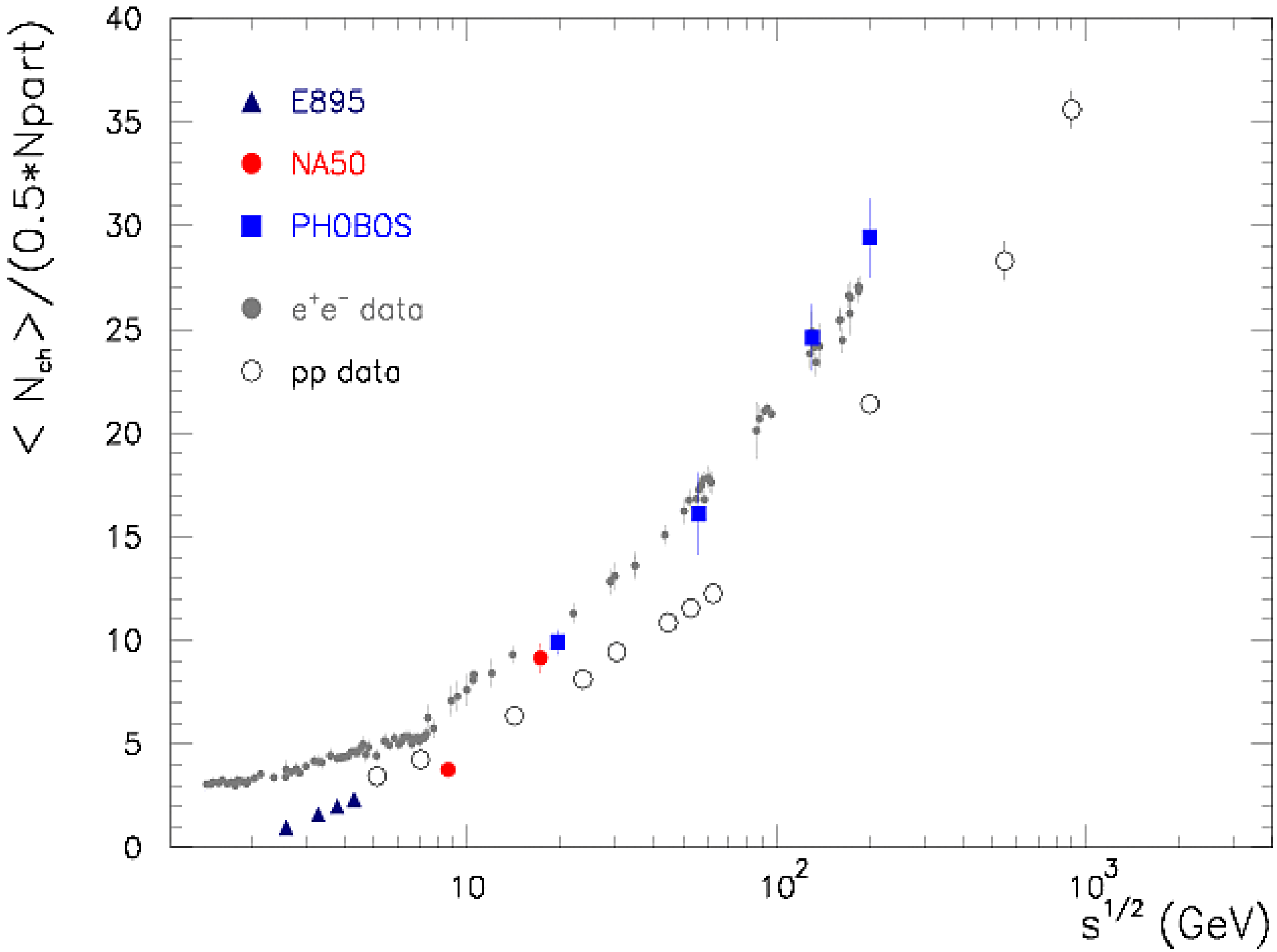
Yield per participant pair vs. √s

158 GeV/c result:
50% higher than fit to pp inelastic
20% higher than fit to pp NSD



40 GeV/c result:
in agreement with
fit to pp inelastic

Integrated yield per participant pair



Heavy ion data does not follow the e^+e^- trend over the whole energy range:

→ below pp and e^+e^- data at AGS energy
→ cross through pp data at SPS energy
→ joins e^+e^- data above top SPS energy

Conclusions

- Particle pseudorapidity distribution vs. centrality measured by NA50 experiment.
  - At 158 GeV/c with 2 independent centrality estimators (E_T, E_{ZDC}).
  - At 40 GeV/c with 1 centrality estimator (E_T).
- Use of 4 detector planes + 2 different target positions.
  - Cross check of analysis procedure.
  - Wide η coverage (→ no reflection around midrapidity needed).
- Gaussian width:
  - Decreases with centrality (stopping power effect).
  - Increases logarythmically with $\sqrt{s}$ (phase space effect).
- Glauber calculation of N_{part} and N_{coll}:
  - Linear dependence of $dN/d\eta|_{max}$ on N_{part}.
  - No important role of hard interactions (N_{coll}) at both energies.
- Yield per participant pair.
  - ✓ At 40 GeV/c ($\sqrt{s}$=8.77 GeV) compatible with fit to nucleon-nucleon interactions.
  - ✓ At 158 GeV/c ($\sqrt{s}$=17.3 GeV) not compatible with fit to nucleon-nucleon interactions.
  - Steep increase of particle yield in central Pb-Pb collisions between 40 and 158 GeV/c not described by the simple energy scaling observed in nucleon nucleon collisions.