# 30 Years of Heavy Ions:
# … what next?

## The physics boost from inside the high energy community

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Universität Heidelberg

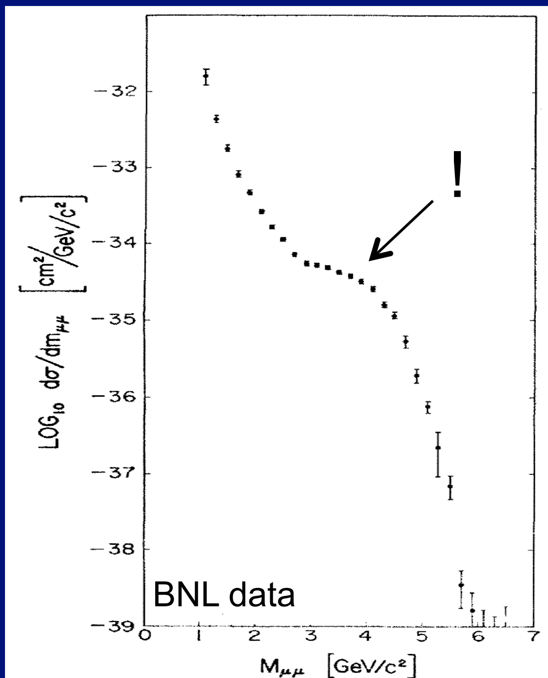
CERN, 9 November 2016

# The Roots 1974-1984: Nuclear and Particle Physics

| | Workshops/Conf. | Accelerators | Physics | Persons/Actions |
|---|---|---|---|---|
| 1974 | Columbia (GeV/u Coll. of HI) | BEVALAC 1974 | EoS Compress. Nucl. Matt.; π Condensates | Contract LBL-GSI Grunder – Bock (Stock/Gutbrod) |
| 1975 -1978 | LBL and GSI (alternating) | ISR Discuss. on HI (Pugh/Santa Fé) | First ideas on QGP Cabibbo/Parisi 1975 Dileptons in pp | CERN DG L. van Hove (1977) |
| 1979 | pre QM LBL | SIS100 Prop. GSI VENUS Prop. LBL | | BMFT Committee, DE (1979-1980) |
| 1980 | pre QM Bielefeld TH pre QM GSI | | αα collisions ISR | PS LoI GSI/LBL SPS Disc. LvH/BW/HS |
| 1981 | LBL, BNL | SIS12/100 Prop. GSI | | CERN DG H. Schopper |
| 1982 | QM2 Bielefeld (M.Jacob/H.Satz) | ISR to be stopped (CERN Council) | | PS Prop. GSI/LBL $^{16}$O ECR ion source |
| 1983 | QM3 BNL | ISR last run | Dileptons in pp R807/808, ISR | Contract CERN/GSI/LBL SPS NA34 Prop. Willis et al |
| 1984 | QM4 Helsinki | SPS, AGS, SIS18 settled | | Approval of 1$^{st}$ Gen. Experiments at SPS |

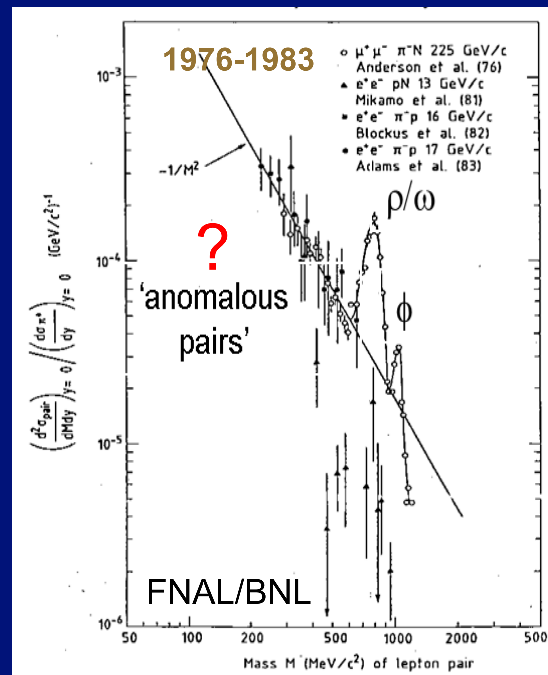
# The 1970's: theory and pp experiments

Lepton pair data in the IMR
*Lederman et al., PRL 1970*



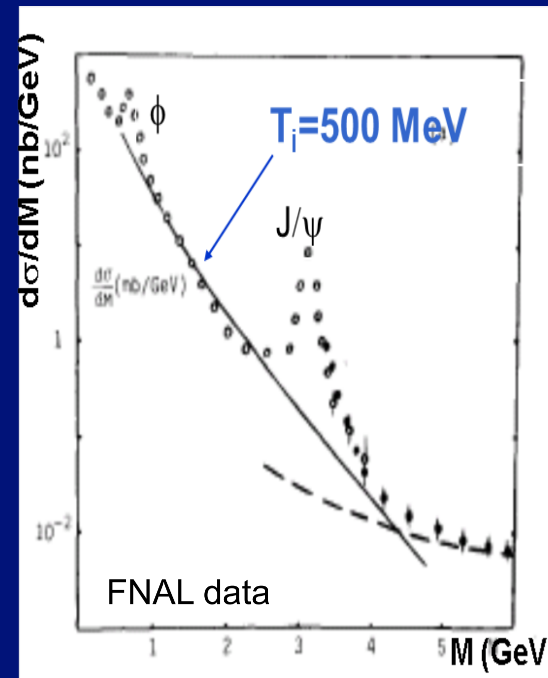

*Drell/Yan, PRL1970*
hard production from valence and sea quarks

Lepton pair data in the LMR
*Anderson et al., PRL 1976*
*(Summary HJS, QM1984)*




*Bjorken/Weisberg, PRD 1976*
dileptons from produced ('wee') partons
> Drell-Yan by factors of up to 100

Lepton pair data in the IMR
*Branson et al., PRL 1977*




*E.Shuryak, PLB 1978*
thermal dileptons from 'Quark-Gluon Plasma'

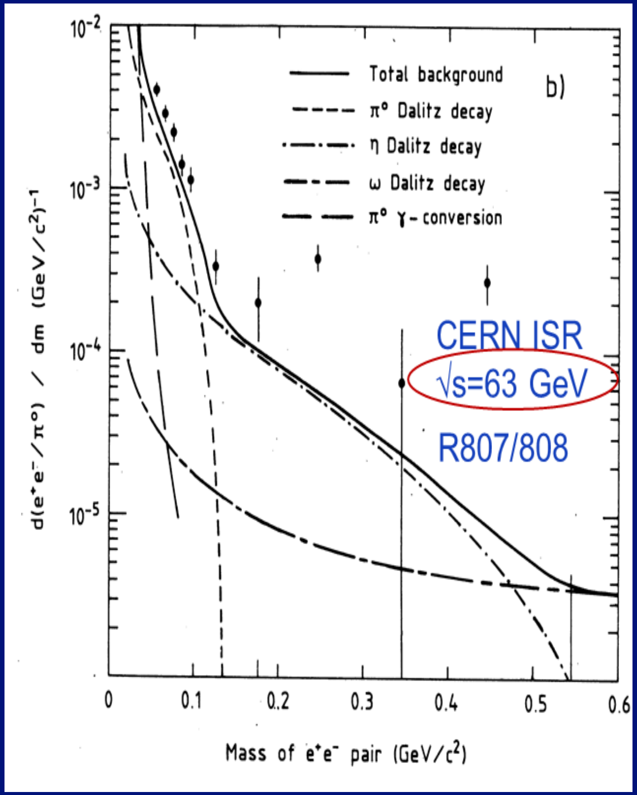
**Problematic data, but milestones in theoretical interpretation**

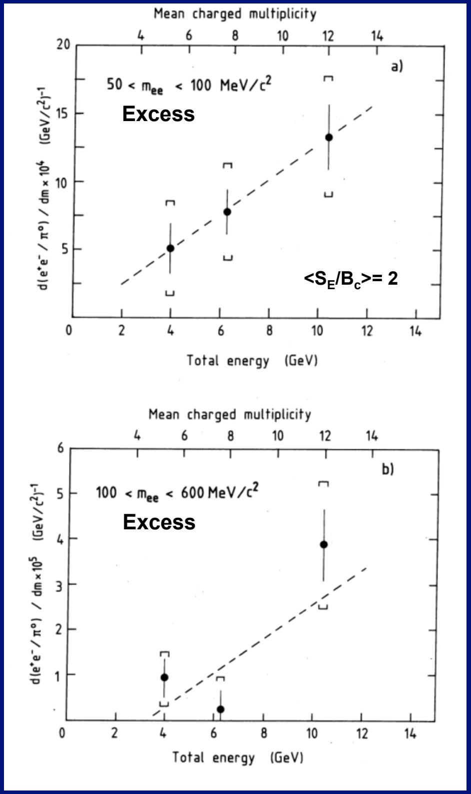
First theory papers on 'Quark Matter' ever (large $\rho_B$): *J.C.Collins/M.J.Perry PRL 1975*
(large $\rho_B$,T): *M.Cabibbo/G.Parisi PLB 1975*

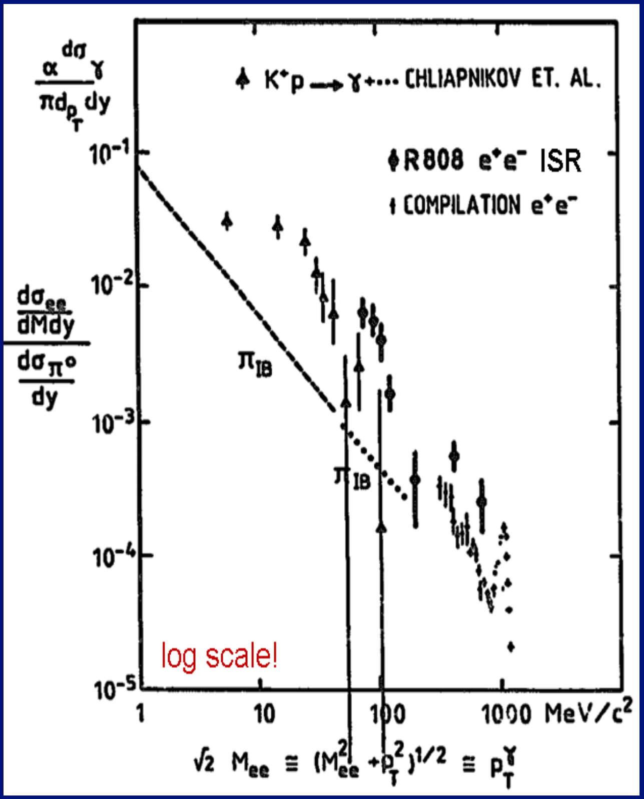
# Final confirmation of ‘anomalous’ dileptons in pp

*T. Akesson et al., PLB152 (1985) 411 and PLB192 (1987) 463;*
*W. Hedberg, PhD thesis,Lund (1987)*

*W.J. Willis, PANIC, Kyoto 1987*
*Nucl.Phys. A478 (1988) 151c*




the only LMR excess ever established in pp; multiplicity dependence almost quadratic

**Challenge for the future**

unification of dilepton excess with ‘soft photons’:

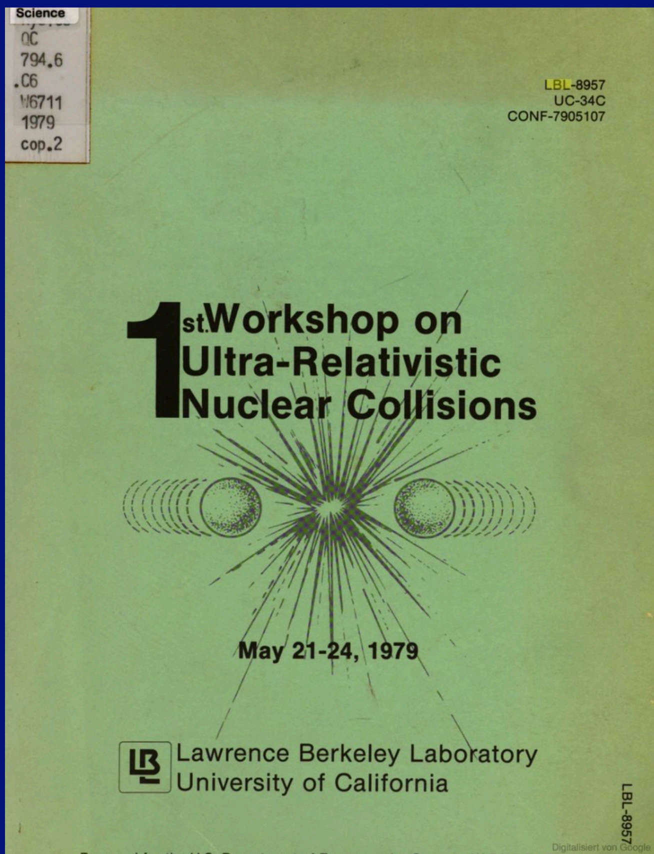
*P. Chliapnikov et al. (1984), J. Antos et al. (1993), V. Perepelitsa et al., DELPHI (2004,2006, 2010)*

# Candidates for the label ‘First Quark Matter Conference’

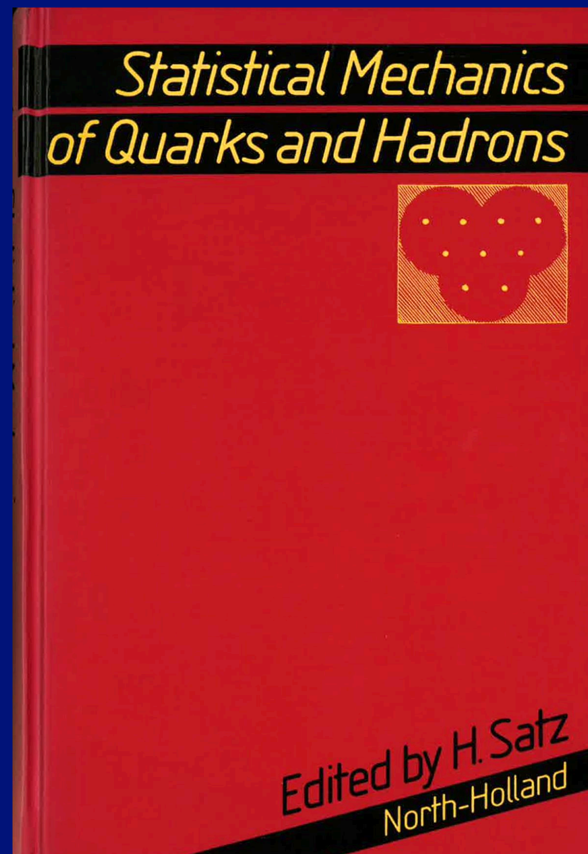
Previously: LBL Berkeley 1979 and GSI Darmstadt 1980

New: Bielefeld 1980 (solely theory) and GSI Darmstadt 1980

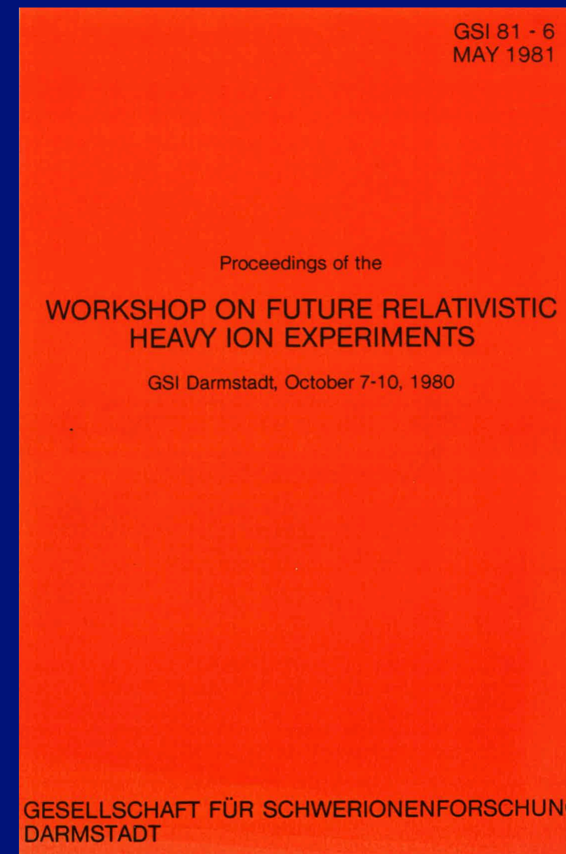
*(H. Satz and R. Stock, contr. to QM2015 Kobe, Nucl. Phys. A 956 (2016) 898)*




‘Conventional’ Workshop,
22 talks (2 HEP), 100 participants

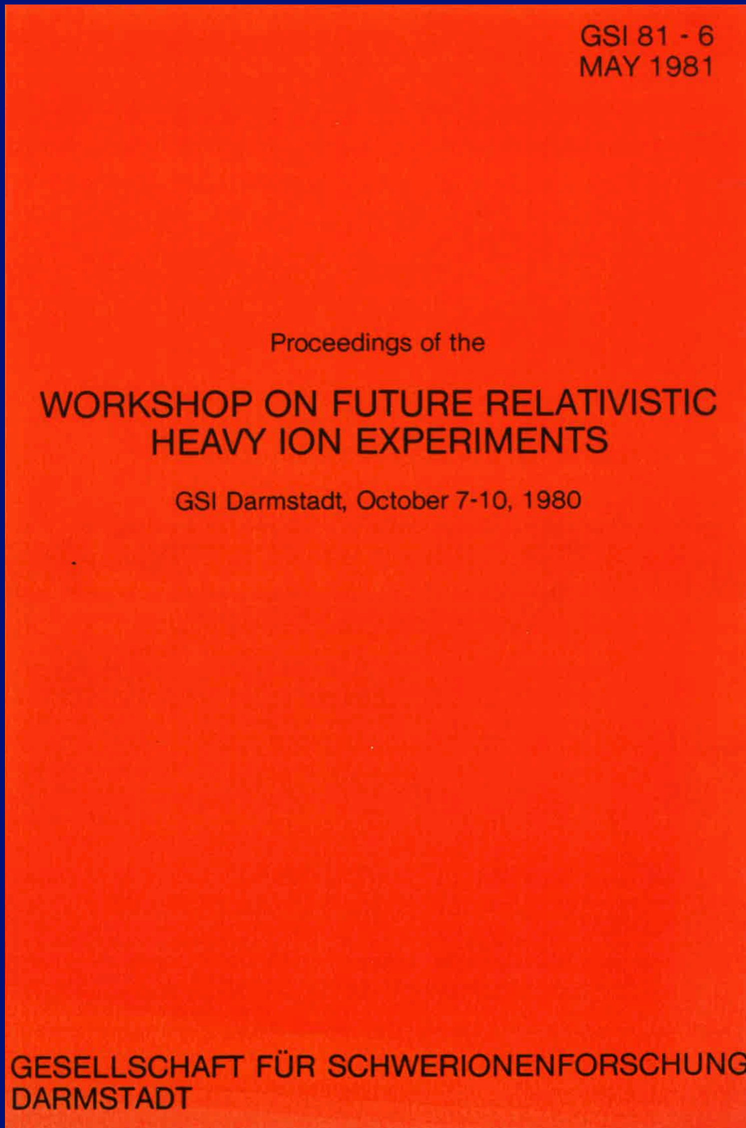



The Beginning of Strong Interaction Thermodynamics, incl. finite-T Lattice QCD




Workshop with a mandate:
unite NP and HEP discussions
19 talks: 7 NP, 6 HEP, 6 TH

# ‘First Quark Matter Conference’ (1980)




Organizers: R. Bock and R. Stock

Ad-hoc Committee Nuclear Physics of the German BMFT (June 1979 - May 1980)

Recommendation 16 (on SIS100): ’it is proposed to reinvestigate, whether or not the field of ultra-relativistic heavy ions could not be opened at an accelerator at CERN in a collaboration CERN/GSI’

## Milestone

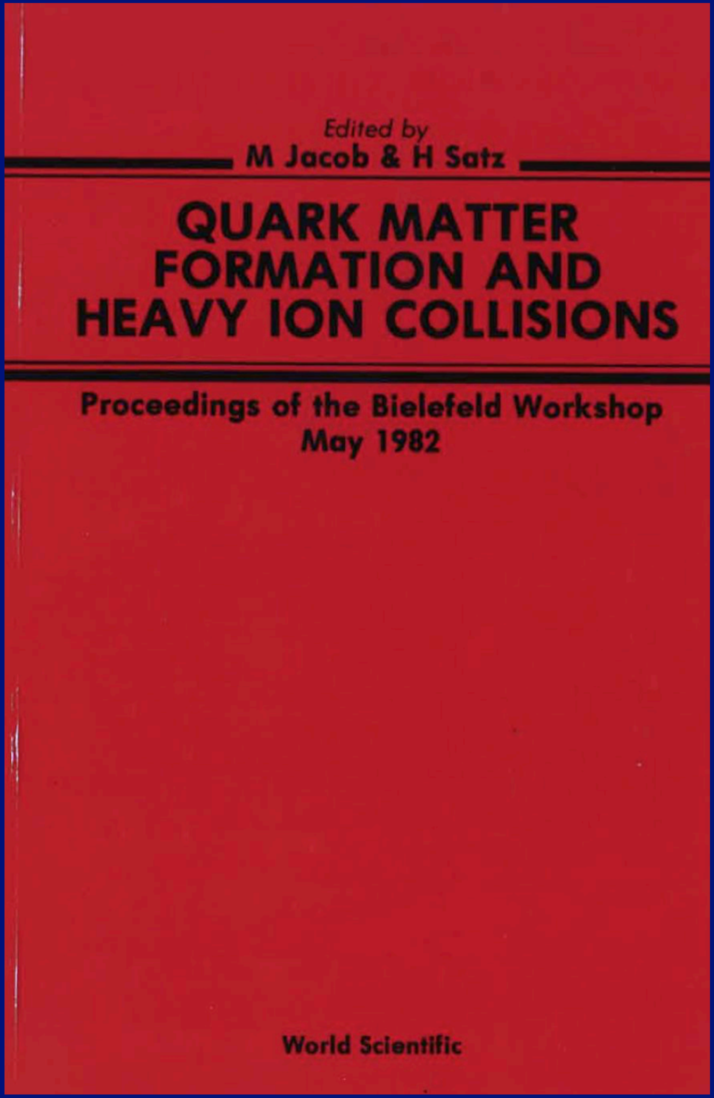
First organized discussions between particle and nuclear physicists on studying QGP formation in ultra-relativistic nucleus-nucleus collisions. Particle physicists ~30%, including W.J.Willis. Discussions dominated by the ‘dream of keeping the ISR’ (summary speaker HJS)

## Immediate consequences

- Letter-of-Intent for 2 experiments at the CERN-PS by GSI/LBL (27 Oct. 1980)
- A long discussion between CERN DG L. van Hove, W.Willis and HJS on the use of the SPS instead of the ISR for heavy ions (Nov. 1980) $\sqrt{s}$ for Z/A=1/2 20 vs. 32 AGeV; luminosity gain!

# II Quark Matter Conference (1982)

## Organizing Committee: T. Ericson, M. Jacob, H. Satz, W. Willis




Milestones

First systematic discussion between particle and nuclear physicists, on the theoretical and experimental aspects of QGP formation in ultra-relativistic nucleus-nucleus collisions. Particle physicists >50%

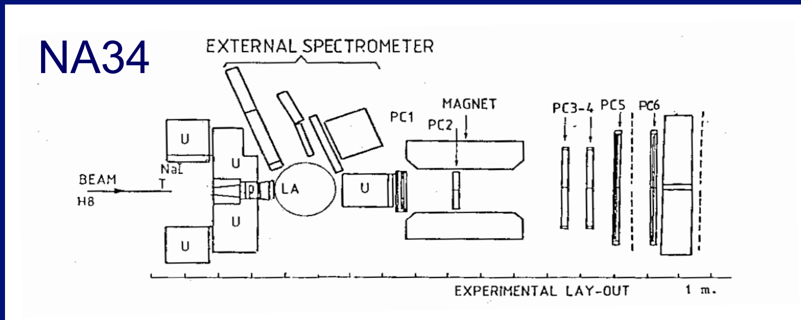
Discussion of basic physics ideas on all hadronic and electromagnetic observables (only J/$\psi$ missing, Satz/Matsui 1986)

Basic instrumental discussions on the first-generation experiments at the CERN SPS, organized in 6 working groups; summary by M. Albrow. Further summaries: Bevalac physics (S. Nagamia), Accelerator prospects (H. Pugh) and Theory (L. van Hove)

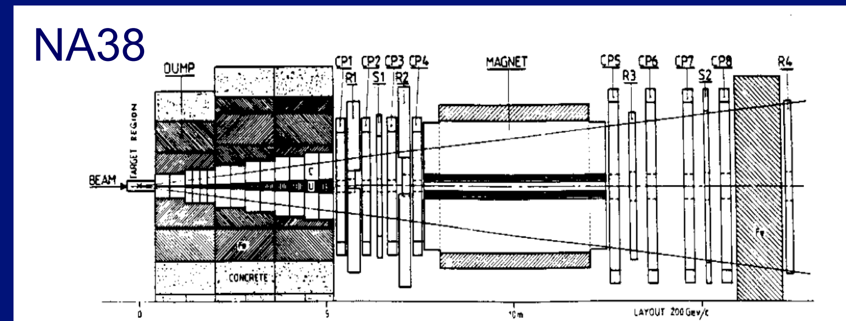
# First-generation Experiments ('Recuperation Era')

| | | approved |
|---|---|---|
| NA34-2 | 4π calorim.,Si, hadron spectrom., dimuons, γ's<br>(U-scint.cal. + NaI R807/808, NA3 spectrom.,…) | 11/1984 |
| NA35 | streamer chamber, mid-rapidity calorim.,…<br>(NA5 str.ch.+cal., magn. WA78, NA24 γ PPD,…) | 11/1984 |
| NA36 | TPC, calorim., → strange mesons, hyperons<br>(EHS+new TPC,…) | 11/1984 |
| NA38 | dimuon spectrom., → thermal radiation, charmonia<br>(NA10+active target + EM cal.,…) | 09/1985 |
| WA80 | plastic ball, EM calorimeters, multiplicity detect.<br>(plastic ball GSI/LBL, Pb-glass,…) | 09/1985 |
| WA85/<br>WA94 | Ω' spectrometer, → strange mesons, hyperons<br>(Ω' spectrometer + RICH) | 04/1987 |

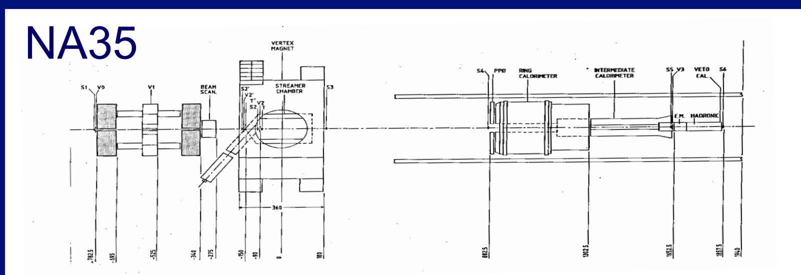
# Setups of the first-generation Experiments 1984-1987



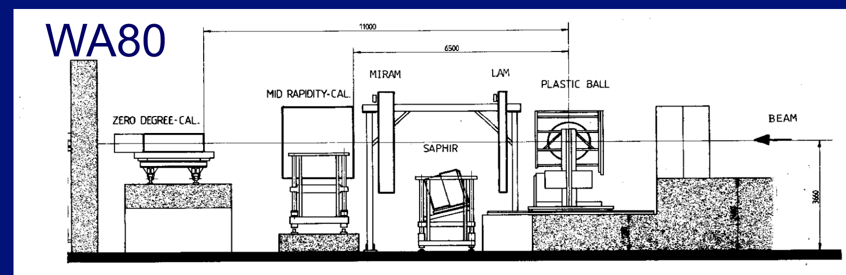

Spokespersons: H.J.Specht



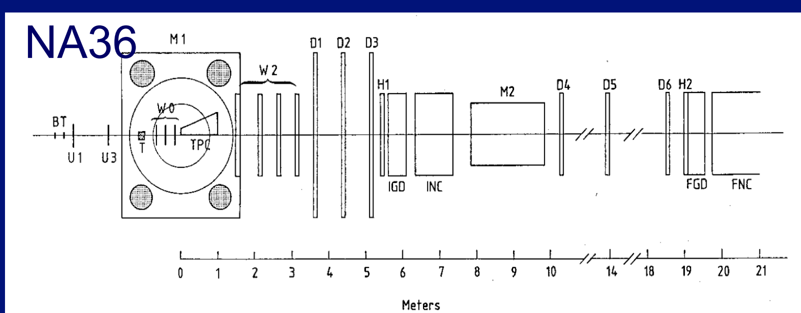

L.Kluberg



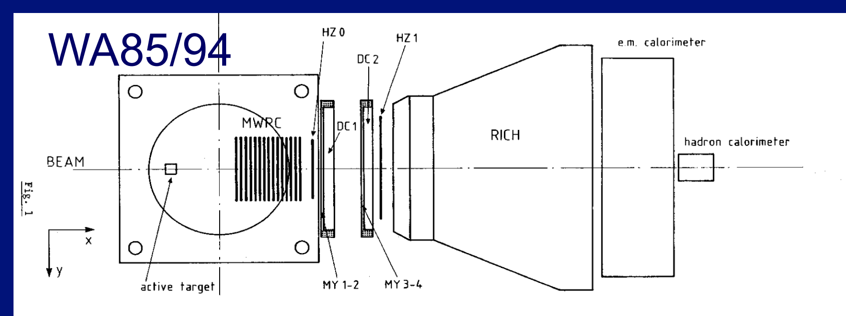

R.Stock




H.H.Gutbrod




C.R.Gruhn



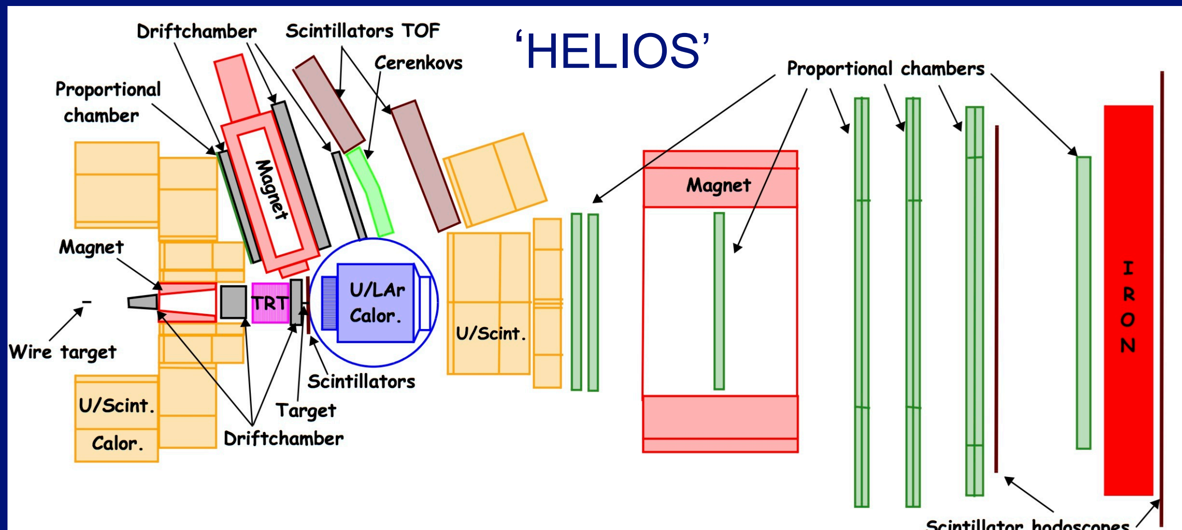

E.Quercigh

# Change of first-generation Experiments 1988/1989

NA34-1
(1984)
N.McCubbin

pBe collisions

$e^+e^-$, $\mu^+\mu^-$,
$e\mu$, $\gamma$

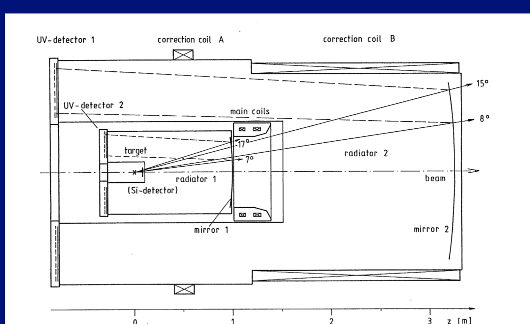



NA34-2
(1984)
H.J.Specht

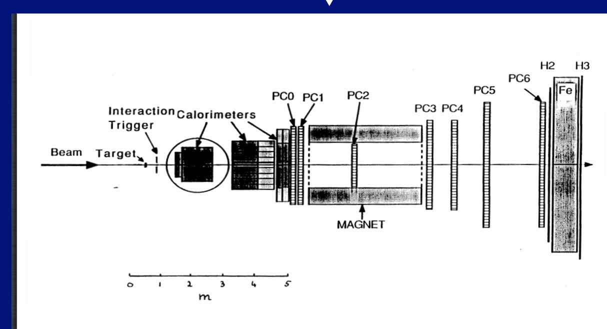
AA collisions

no $\mu^+\mu^-$, $\gamma$
hadrons

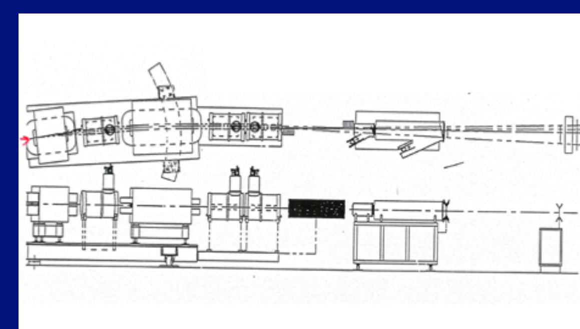
2 years after the first O beam 1986




NA45 (1989), $e^+e^-$
H.J.Specht




NA34-3 (1989), $\mu^+\mu^-$
G.London



NA44 (1989), hadrons
H.Bøggild

# CERN Heavy-Ion Facility 'LINAC 3' for Pb Beams

CERN 93–01
28 April 1993

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN HEAVY-ION FACILITY DESIGN REPORT

N. Angert (GSI), M.P. Bourgarel (GANIL), E. Brouzet, R. Cappi, D. Dekkers, J. Evans, G. Gelato, H. Haseroth, C.E. Hill, G. Hutter (GSI), J. Knott, H. Kugler, A. Lombardi (INFN, Legnaro), H. Lustig, E. Malwitz (GSI), F. Nitsch, G. Parisi (INFN, Legnaro), A. Pisent (INFN, Legnaro), U. Raich, U. Ratzinger (GSI), L. Riccati (INFN, Torino), A. Schempp (IAP, Frankfurt), K. Schindl, H. Schönauer, P. Têtu, H.H. Umstätter, M. van Rooij, D. Warner, M. Weiss.

Editor: D. Warner

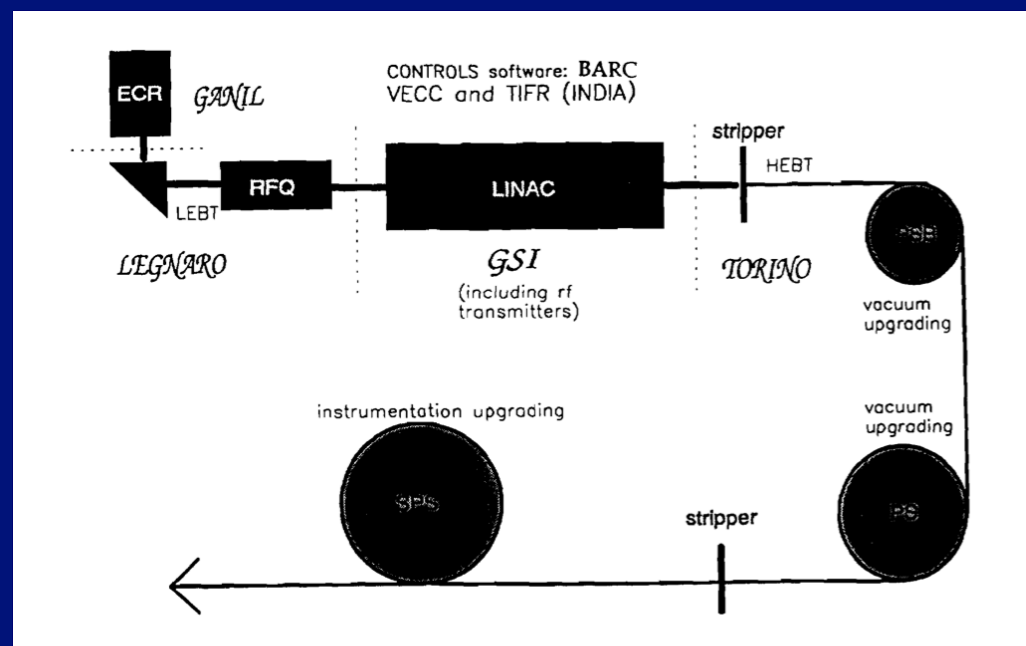
GENEVA
1993

H.Haseroth et al. ,Concept, CERN 90-01

Realization by international collaboration

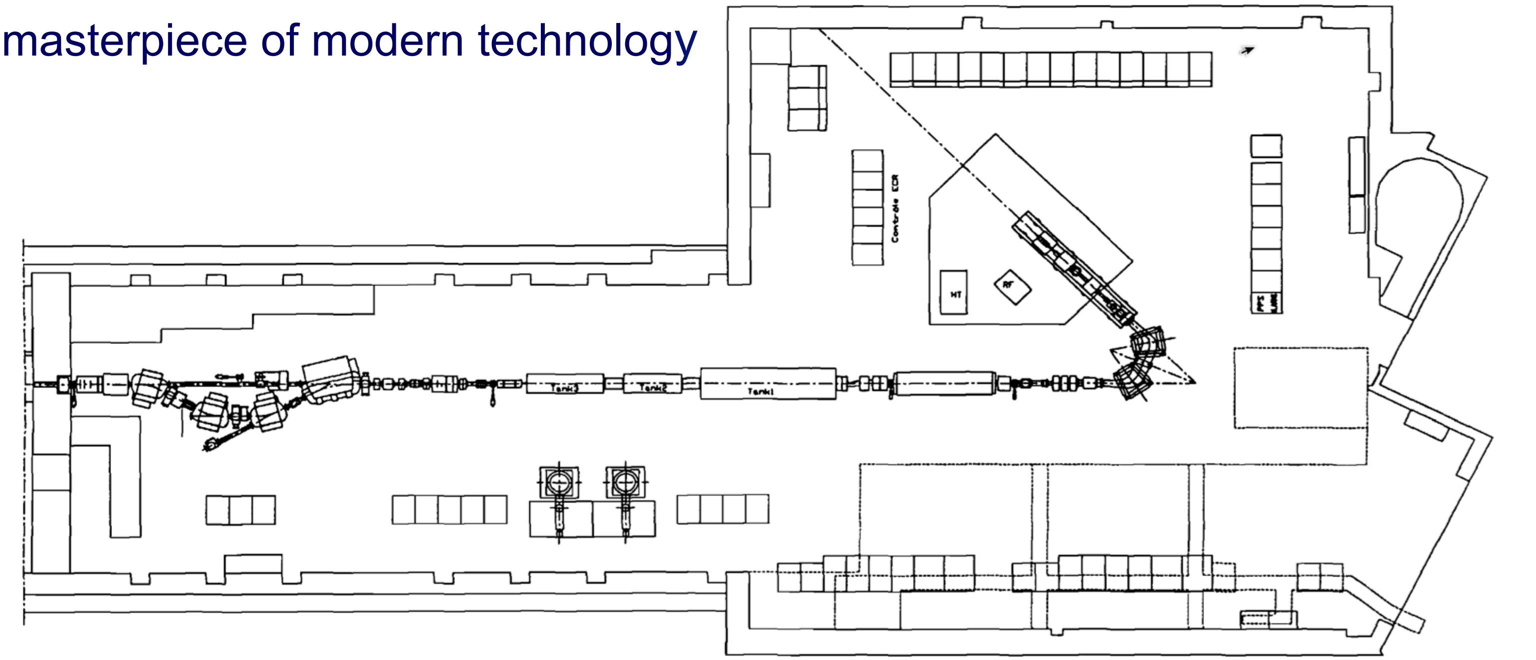
CERN, GANIL, GSI, INFN LEGNARO, INFN TORINO, IAP Frankfurt (assistance by Czech Republic, India, Sweden and Switzerland)

First Pb beams in 1994



# CERN Heavy-Ion Facility ‘LINAC 3’ for Pb Beams

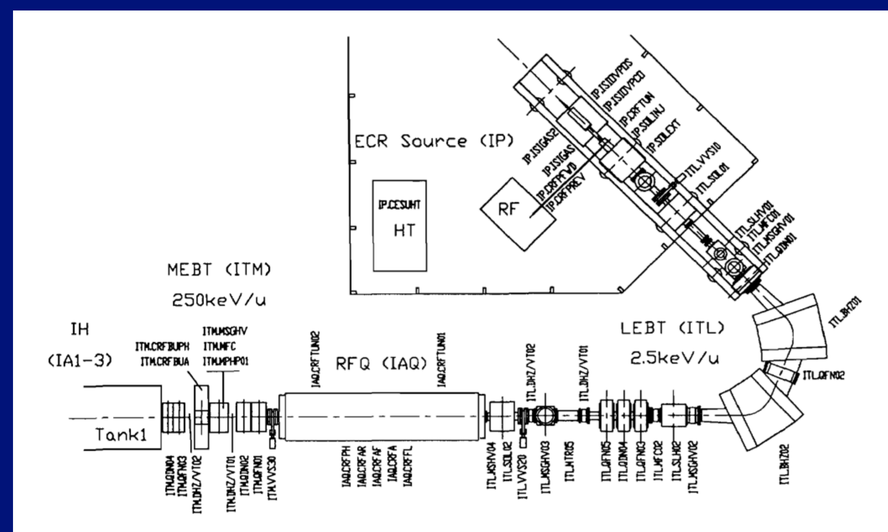
masterpiece of modern technology



Steps for full acceleration incl. SPS

| | | |
|---|---|---|
| ECR source $Pb^{27+}$ | | 2.5 keV/u |
| RFQ | | 250 keV/u |
| LINAC 3 | | 4.2 MeV/u |
| Stripper | $Pb^{27+} \rightarrow Pb^{53+}$ | |
| Booster+PS | | 4.25 GeV/u |
| Stripper | $Pb^{54+} \rightarrow Pb^{82+}$ | |
| SPS | | 20-158 GeV/u |

Intensity ~$10^8$ Pb-ions/SPS pulse

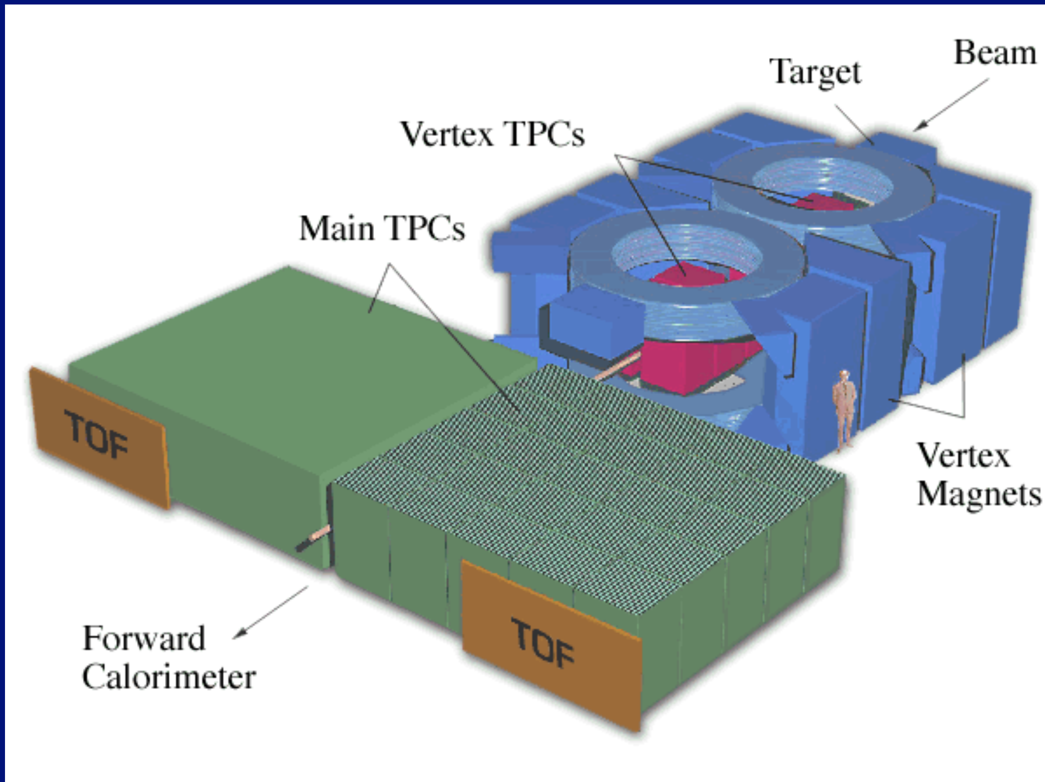


# Second-generation Experiments: Pb Era

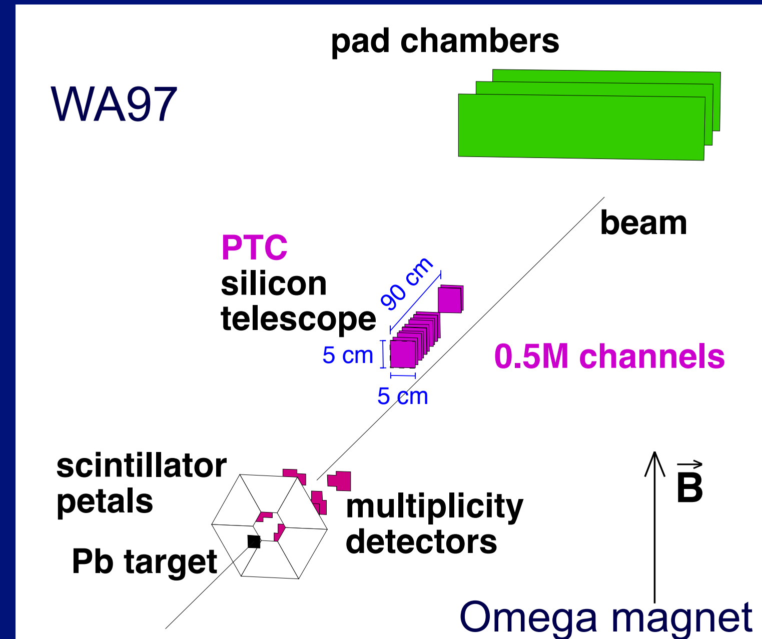
| | | approved |
|---|---|---|
| NA44 | Small-angle focusing Spectrometer → 1 and 2 particles (new, pre-Pb, spokesperson H.Bøggild) | 1989 |
| NA45 | Double-Cherenkov Spectrometer → low-mass dielectrons (new, pre-Pb, spokesperson H.Specht; for Pb I.Tserruya) | 1989 |
| NA49 | Large-acceptance hadron detector (TPCs, TOF, Calorim.) (new, spokesperson R. Stock) | 1991 |
| NA50 | Muon Spectrometer → high-mass dimuons, charmonia (followed NA38, spokesperson L. Kluberg) | 1992 |
| NA52 | NEWMASS Beam Spectrometer (550m) → strangelets (new, spokesperson K. Pretzl) | 1991 |
| WA97/ NA57 | Ω' spectrometer, Si, RICH → hyperons/anti-hyperons (followed WA85, spokespersons E.Quercigh/F.Antinori) | 1991 |
| WA98 | Large acceptance hadron and photon detector (followed WA80, spokesperson H.Gutbrod ) | 1991 |

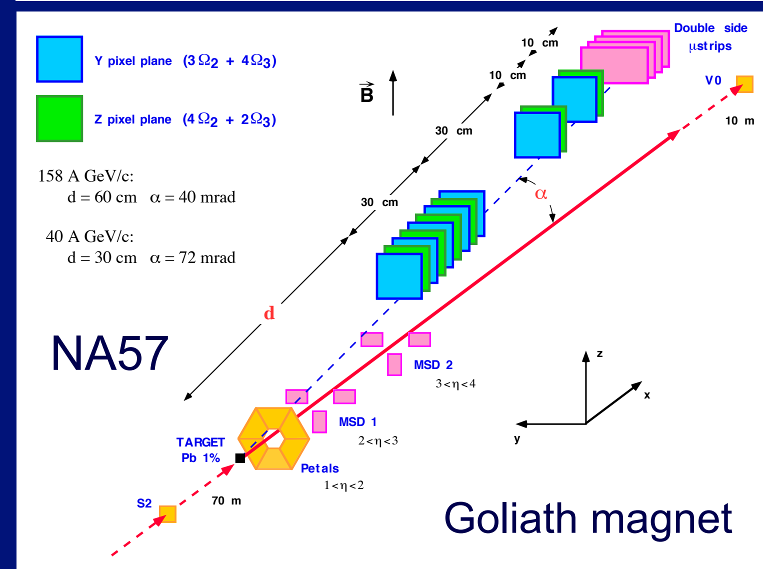
# Experimental Setups

## NA49




## WA97/NA57

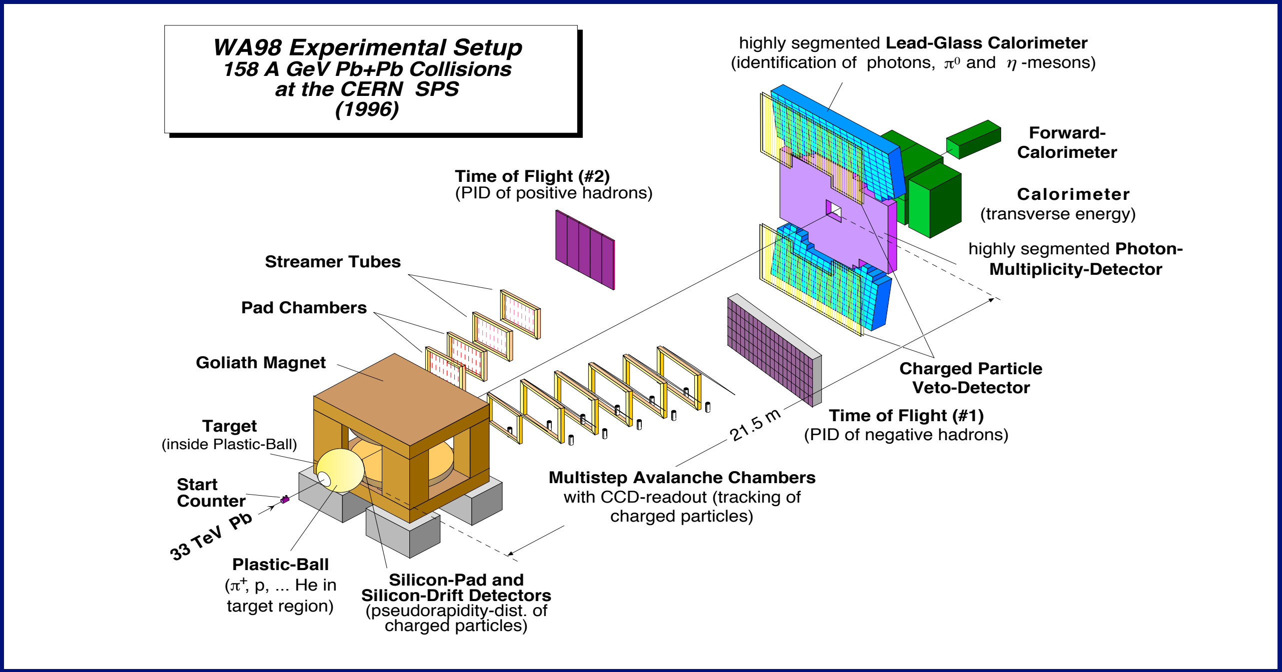



'universal' hadron coverage with large acceptance

optimized for strangeness, in particular hyperons; larger centrality range in NA57

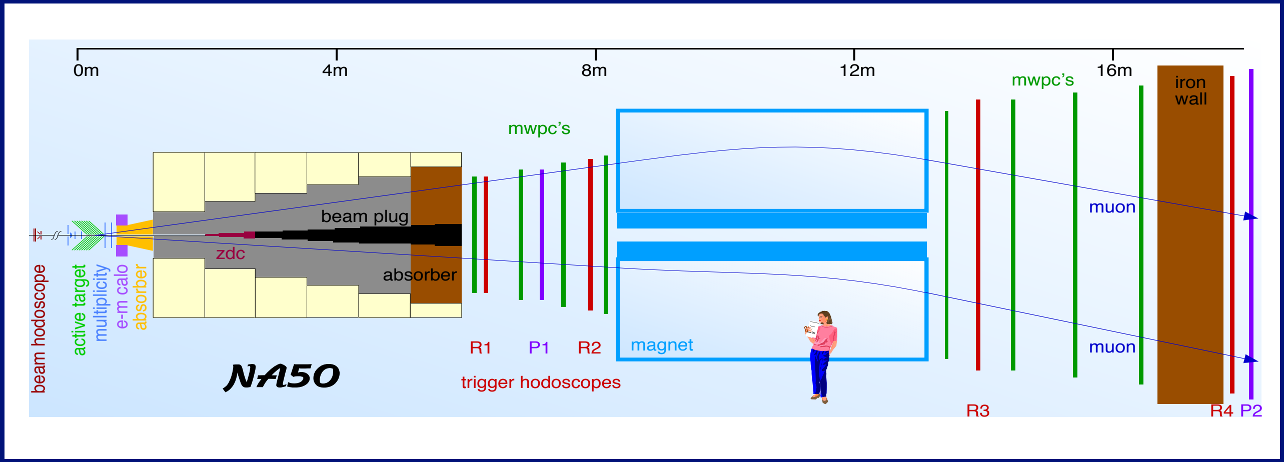
# Experimental Setups




WA98

hadrons with large acceptance

photons (hadron decays and direct)

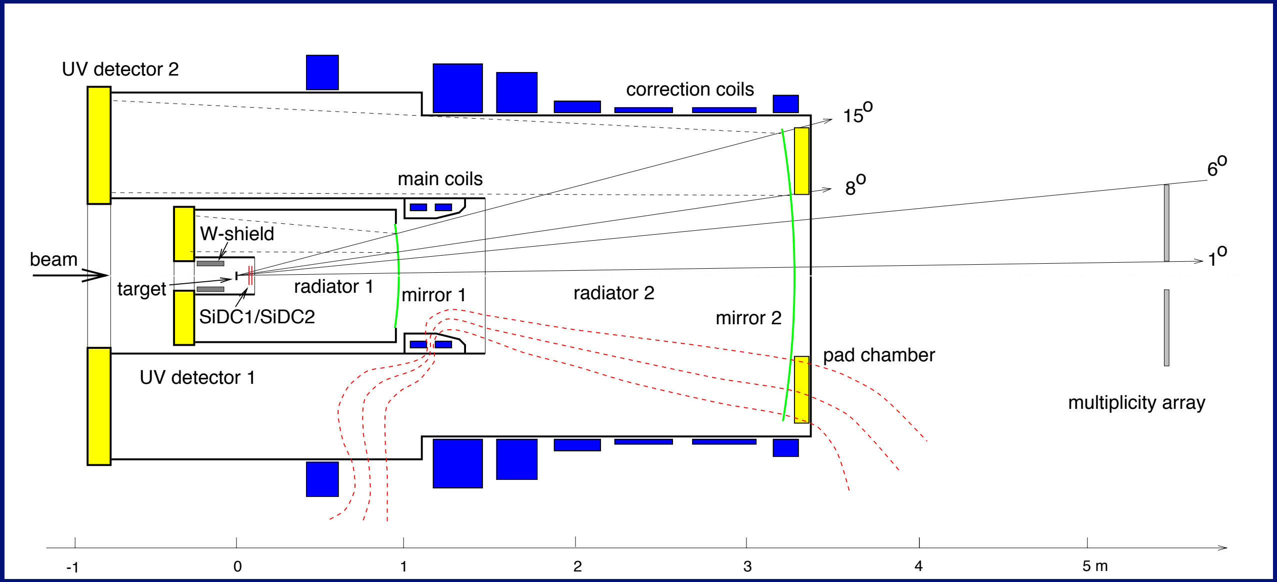



NA50

vector mesons including charmonia

hard and soft dimuon continua

# Di-electron spectrometer CERES/NA45

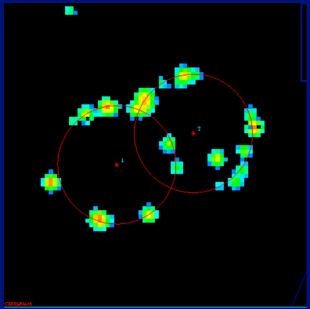


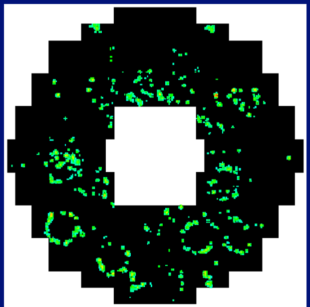

Pioneering experiment built 1989-1991

focused on Low Mass Region (LMR)

Running periods:

- 1992-1993
  $^{32}$S and proton beams
- 1995-1996
  $^{208}$Pb beams





RICH Cherenkov rings

Original set-up (p and $^{32}$S):
puristic hadron-blind tracking with 2 RICH detectors

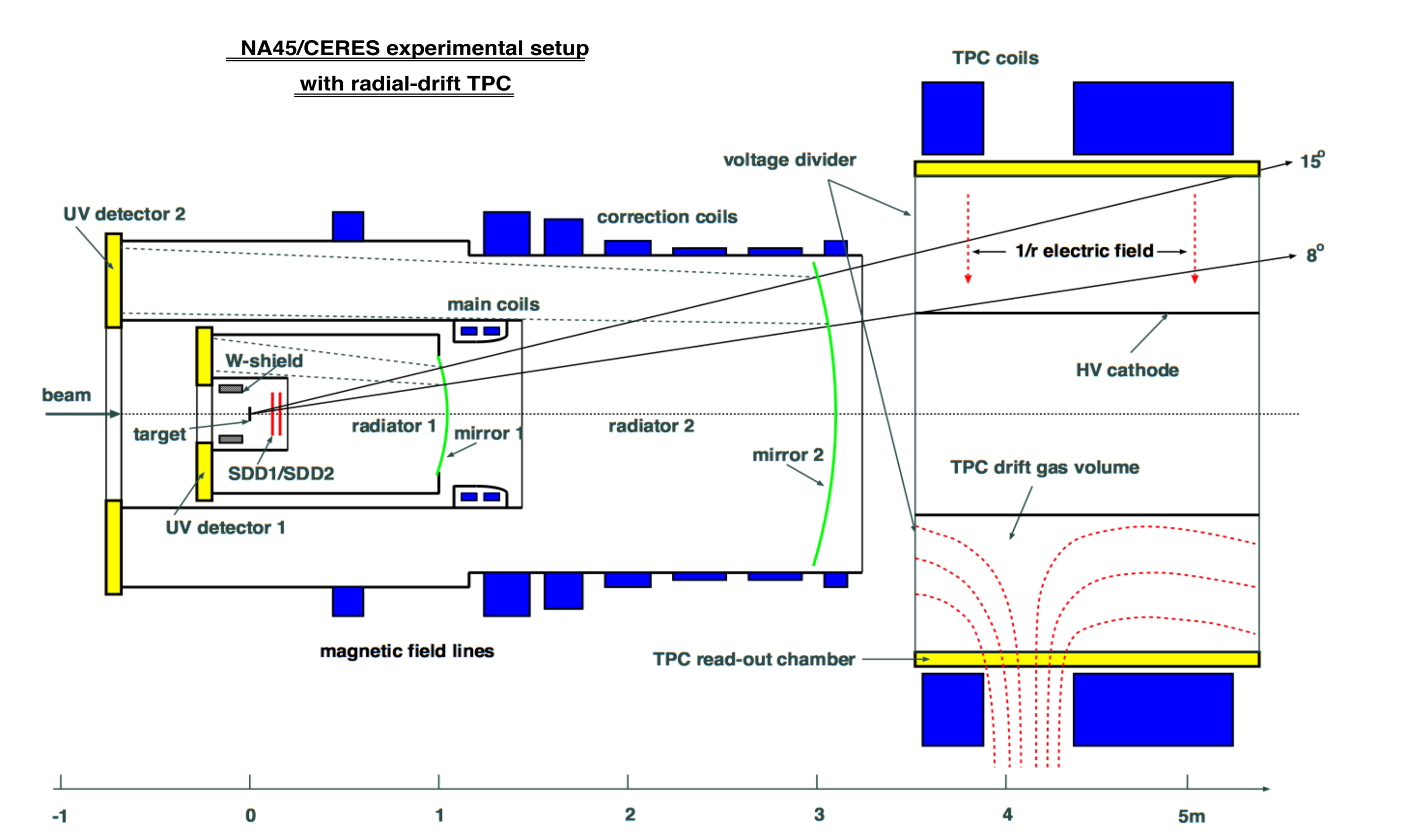
Later addition ($^{208}$Pb):
2 SiDC detectors + pad (multi-wire) chamber

Low field (air coils), limited tracking → limited resolution
slow detectors, no trigger → very limited statistics

UV detectors: 2-stage parallel plate + 1-stage wire amplif.; 50k pads

# CERES Upgrade with a TPC (publ. post 2000)

spokesperson J. Stachel



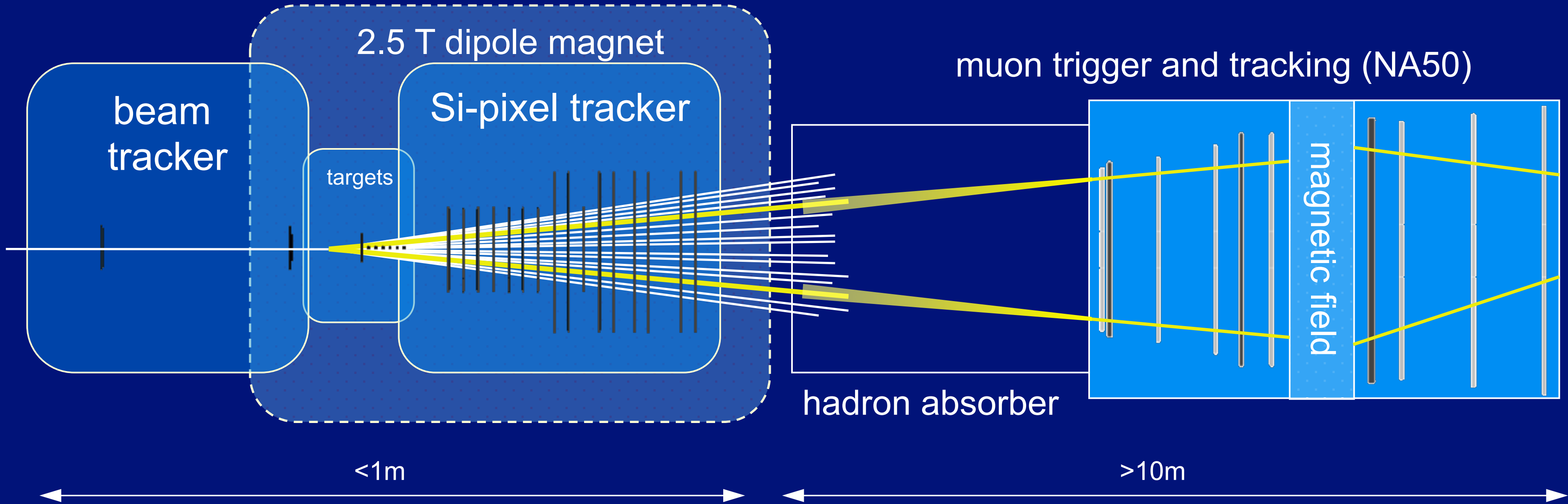

Addition of a TPC with a radial drift direction

- improved mass resolution 6 → 4%
- dE/dx → hadron identification, improved electron ID

Runs in 1999/2000 at 40/158 AGeV

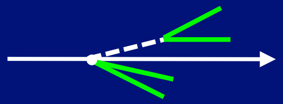
# Measuring dimuons in NA60 (post 2000)

(basic idea P. Sonderegger, exp. approved 2000, spokespersons C. Lourenço, later G. Usai)




Track matching in coordinate <u>and</u> momentum space

Improved dimuon mass resolution

Distinguish prompt from decay dimuons 

Additional bend by the dipole field

Dimuon coverage extended to low $p_T$

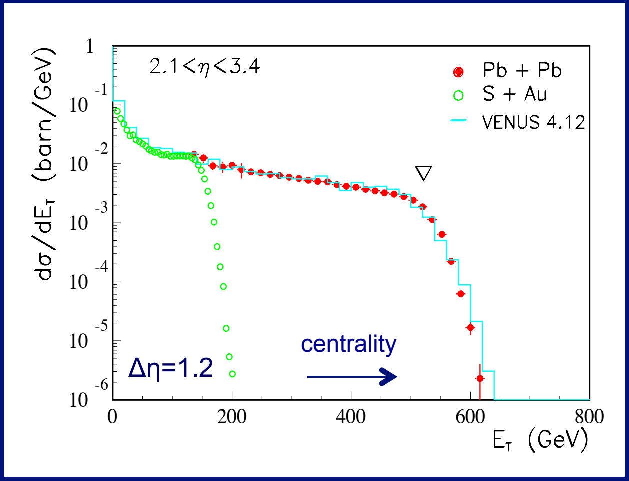
Radiation-hard silicon pixel detectors (LHC development)

High luminosity of dimuon experiments maintained

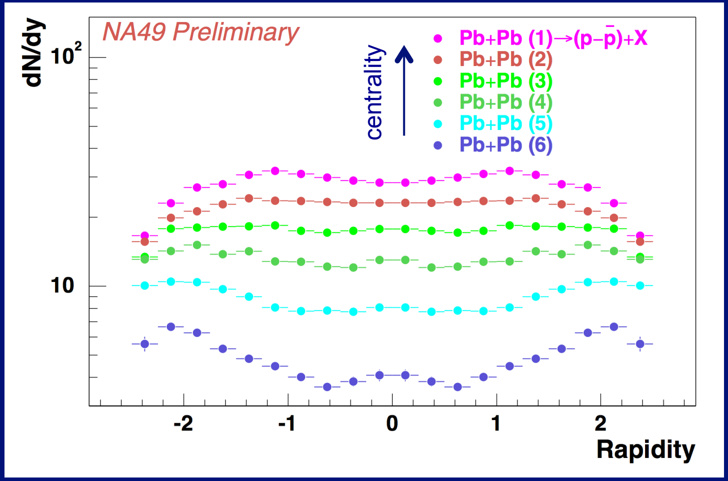
# Central Physics Results of the SPS (Selection)

# Initial Energy Density

Transverse Energy Flow, NA49

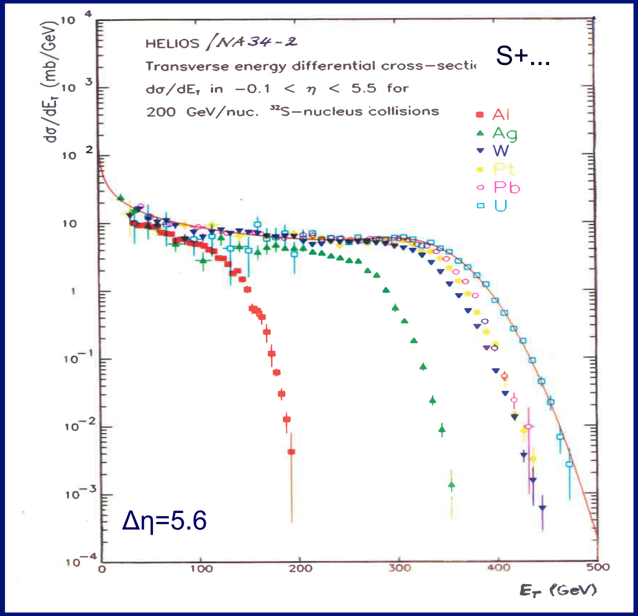



Baryon stopping, NA49 1999



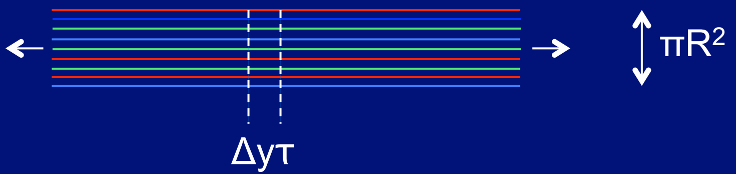

1:1 match between energy deposition and baryon stopping

Transverse Energy Flow, NA34-2




Shuryak-Bjorken:

comoving energy density at hadronization time τ




$\varepsilon = \Delta E_T / \Delta y \times 1/(\tau \pi R^2)$ $\tau$ = 1 fm/c, R = 1.12 $A^{1/3}$ fm

Central collisions: S-Au $\varepsilon = 2.6$

Pb-Pb $\varepsilon = 3.2$

$> \varepsilon_{crit} = 1$ GeV/fm$^3$

# Hadron Yields – Statistical Hadronization

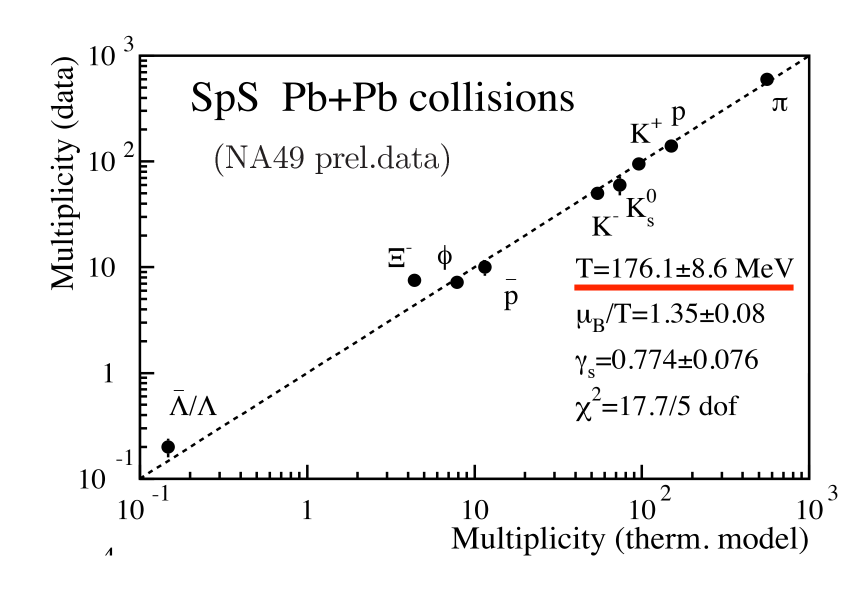
Since pp: Statistical Bootstrap Model (SBM), R.Hagedorn, Nuovo Cim.S. 1965
- populate hadron species according to phase space probabilities -

for AA:
grand canonical ensemble

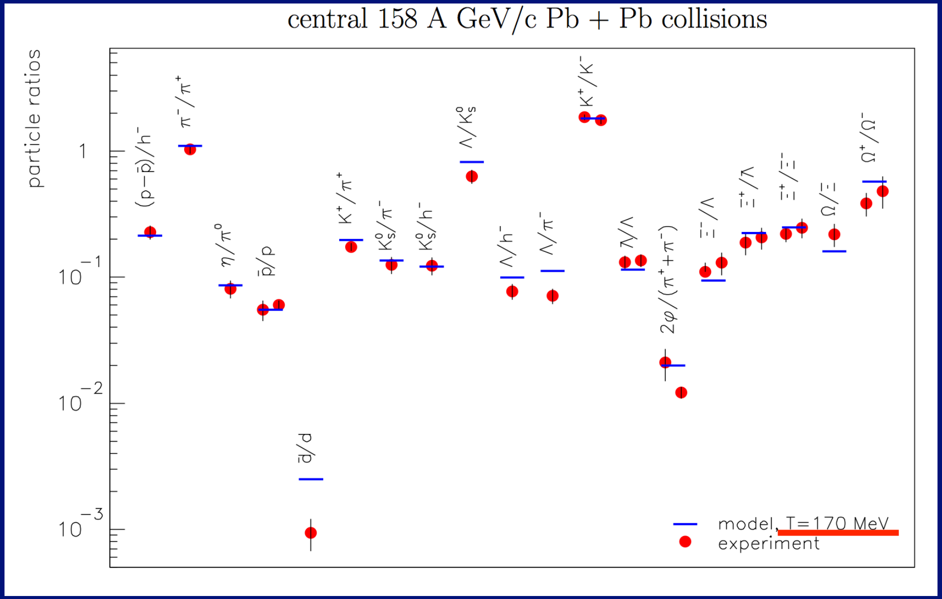
$$n_i = N/V = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2\,\mathrm{d}p}{\exp((E_i-\mu_i)/T)\pm 1} \qquad \mu_i = \mu_B B_i + \mu_S S_i + \mu_{I_3} I_i^3$$

free parameters from fits to the data: T, $\mu_B$ (V, $\mu_S$, $\mu_{I3}$ from conservation laws)

*F.Becattini, J.Cleymans, K.Redlich et al.*




*P.Braun-Munzinger, J.Stachel et al.*

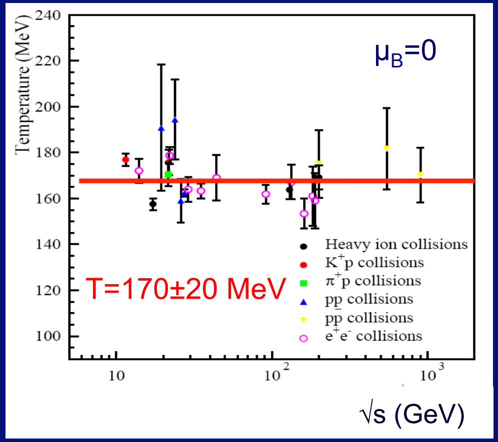


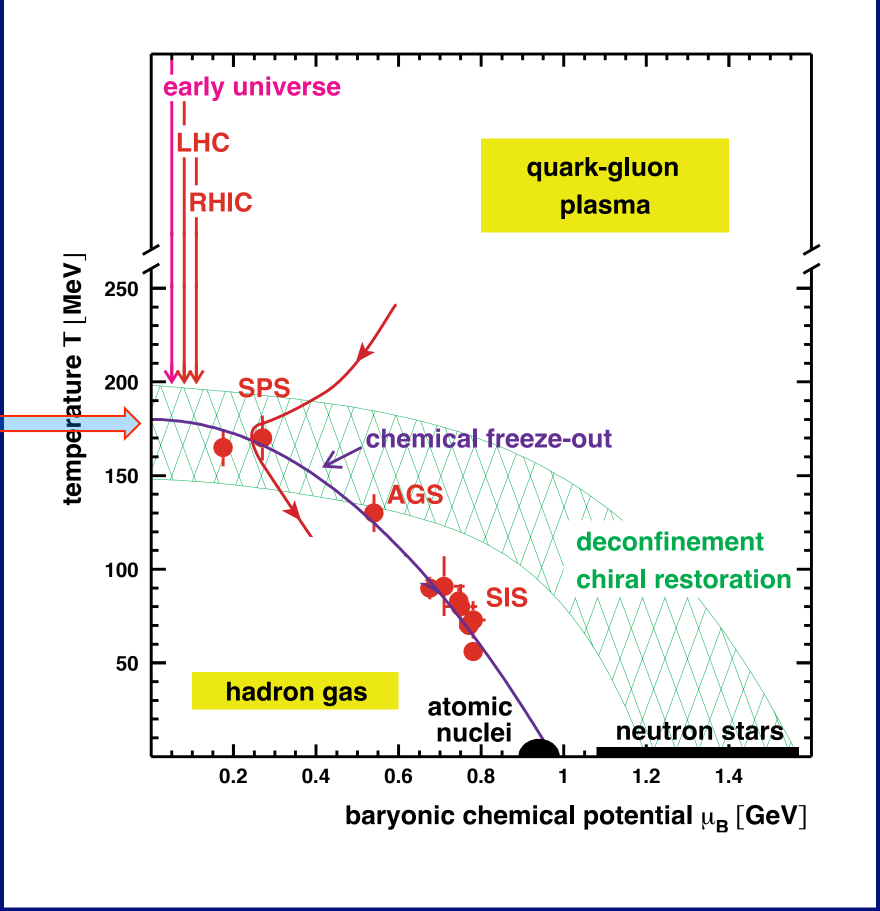

perfect agreement between yield data and model description

# Beam-energy dependence of freeze-out parameters

*J.Stachel, Nucl.Phys.A 654 (1999) 119c*

*H.Satz's déjà vu (2008)*



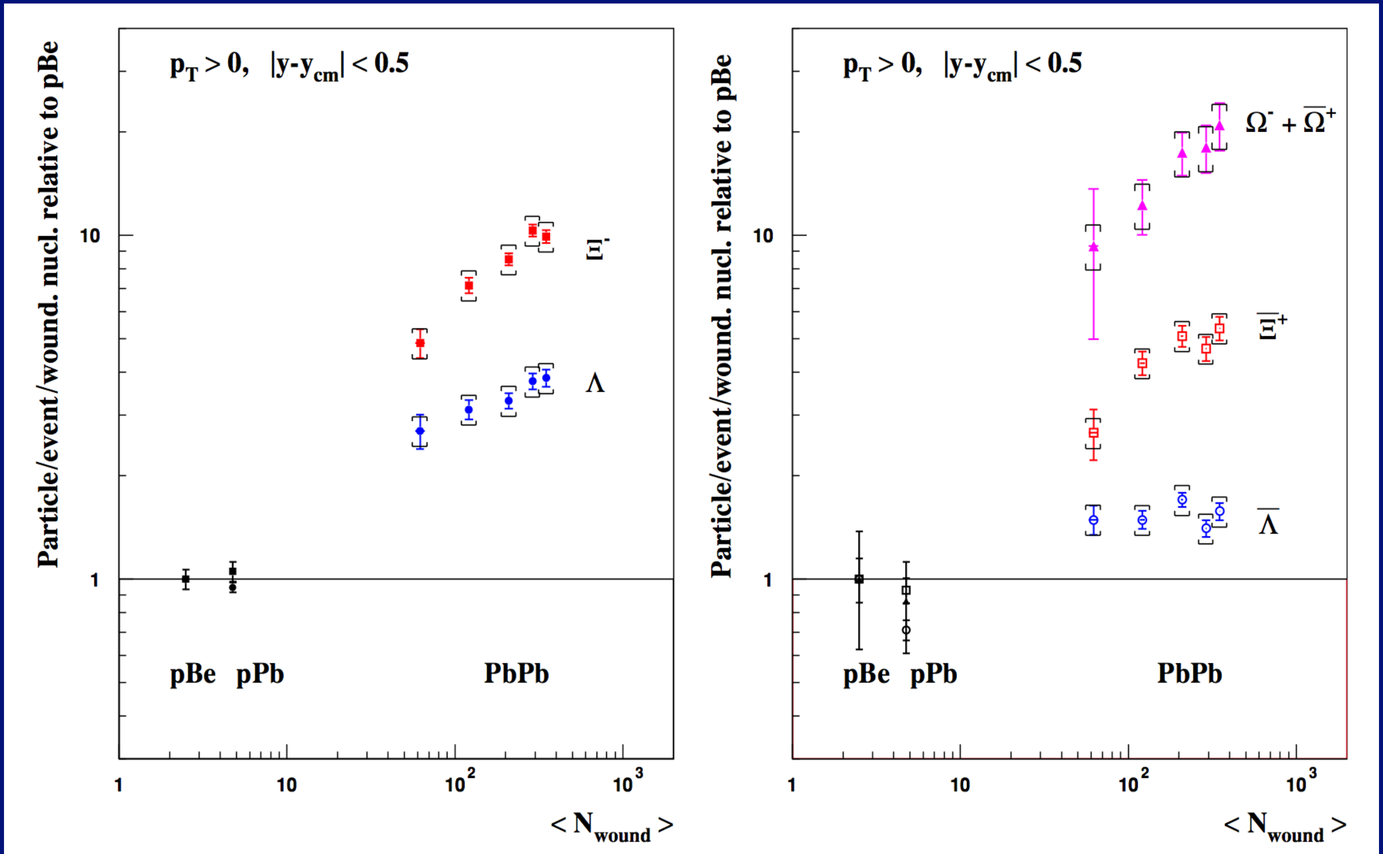




Hagedorn Temperature

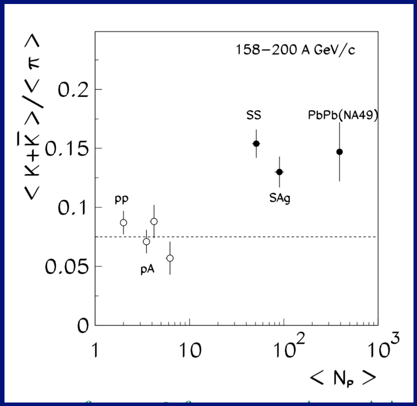
T ~ 170 MeV

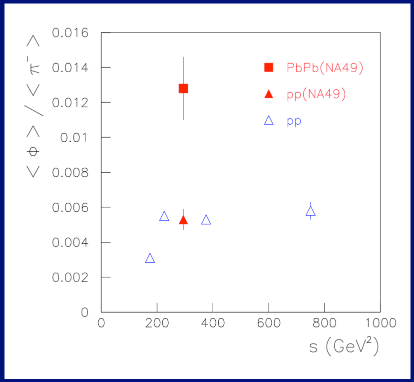
In the limit of small $\mu_B$, most 'direct' connection between hadron results and the QCD phase boundary

# Hadron Flavors – Strangeness Enhancement




NA57 (final: *J.Phys.G 32 (2006) 427*)




NA49 (1999)

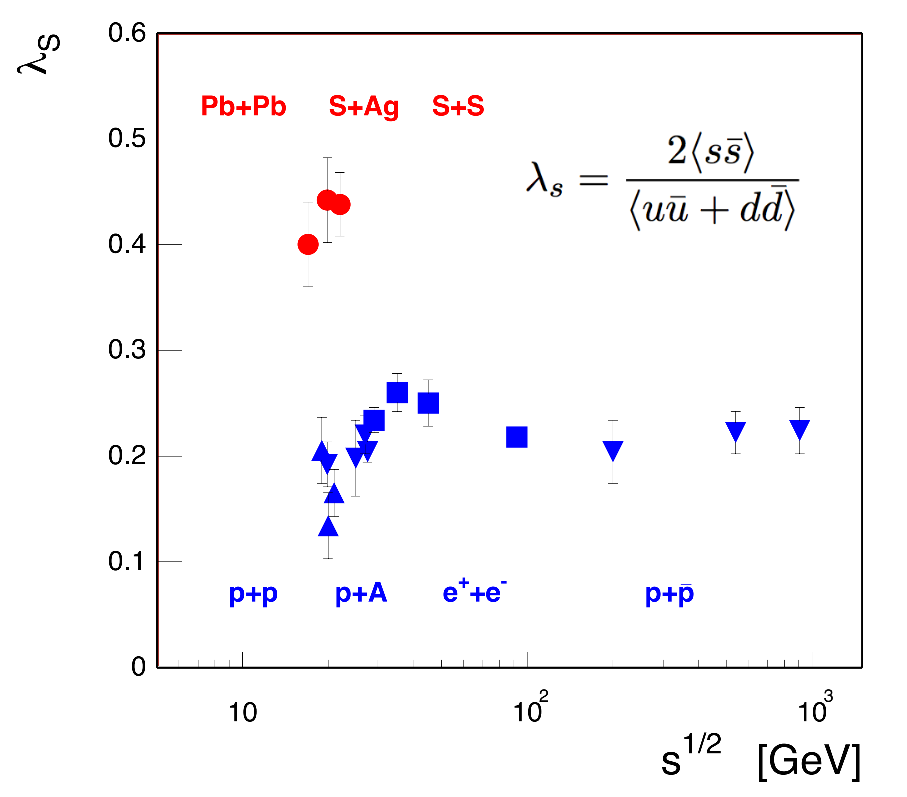
large enhancement of hyperon production relative to pPb
strong increase with number of strange valence quarks (up to 20); consequence of non-zero $\mu_B$

enhancement also for mesons, even for hidden strangeness ($\phi = s\bar{s}$)

Strangeness enhancement as QGP signal first proposed by J.Rafelski 1980, GSI Rep. 81/6; J.Rafelski/B.Müller PRL 1982

# ‘Origin’ of Strangeness Enhancement

*F.Becattini, M.Gazdzicki, J.Sollfrank, EPJC 5 (1998) 143*




Strangeness suppression factor $\lambda_S$ (Wroblewski)

ratio of newly created *primary* valence $s\bar{s}$ pairs to newly created non-strange primary quark pairs

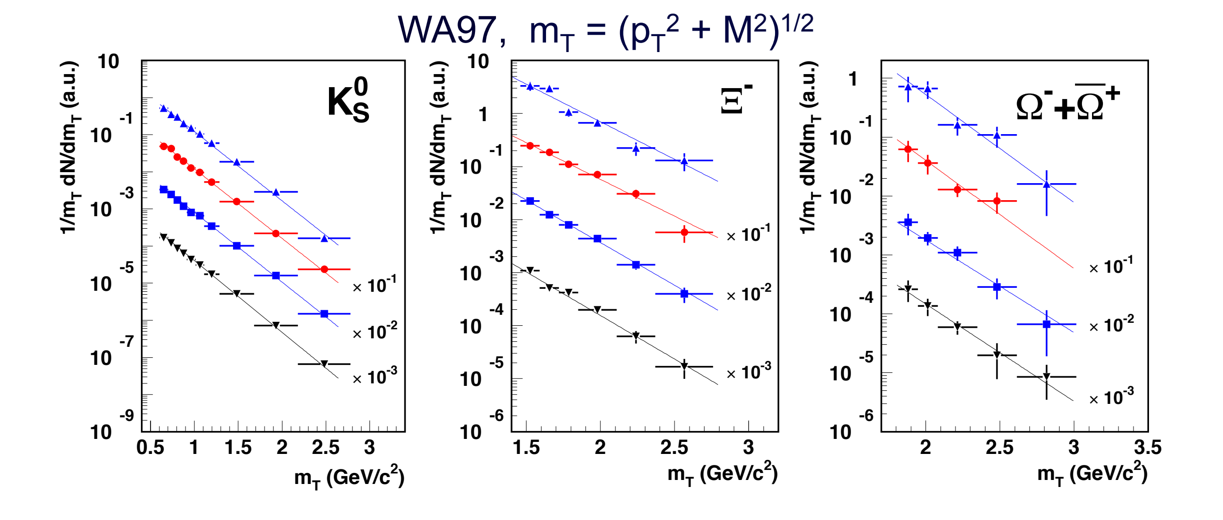
values obtained from fits of the statistical hadronization model to strange hadron production in AA (NA49) and elementary reactions

‘Strangeness enhancement’ in AA or ‘Strangeness suppression’ in pp, pA…?

Small systems described by canonical ensemble with *exact conservation of quantum numbers locally,* in contrast to grand canonical ensemble in AA

Canonical suppression as the ‘origin’ for strangeness enhancement, but dynamics?

# Radial flow – 'Hubble-like' expansion of the fireball

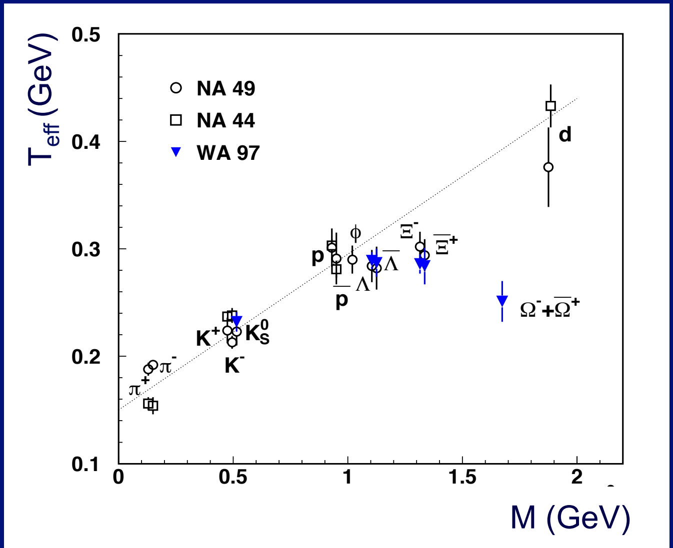



*Eur.Phys.J C 14 (2000) 633*

all $m_T$ spectra exponential

fit with
$1/m_T\ dN/m_T \sim \exp(-m_T/T_{eff})$

$T_{eff}$ – 'effective temperature'




linear rise of $T_{eff}$ with M

→ two components in $p_T/m_T$ spectra:
thermal and radial collective expansion

roughly $T_{eff} \sim T_f + M <\beta_T>^2$

precise procedure: 'Blast wave' analysis

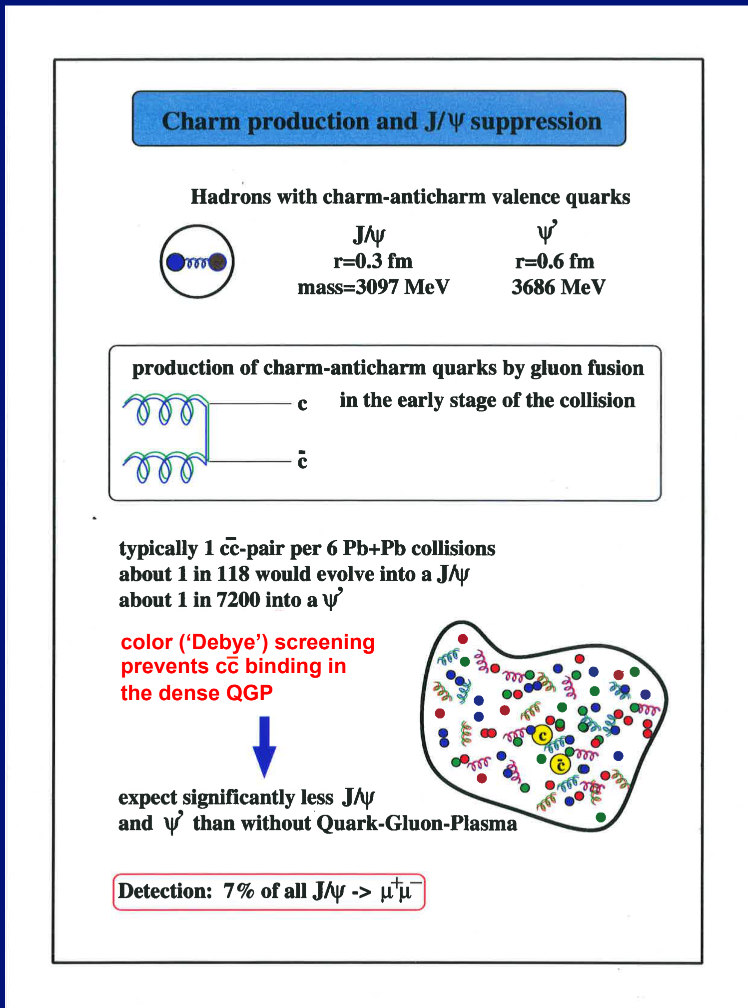
$T_f$ temperature at thermal freeze-out: 100-120 MeV
$v_T$ flow velocity at thermal freeze-out: ~ 0.5c

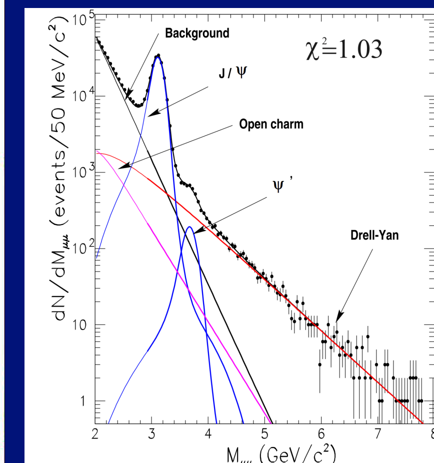
**Almost explosive expansion → strong pressure at the earlier collision stages**

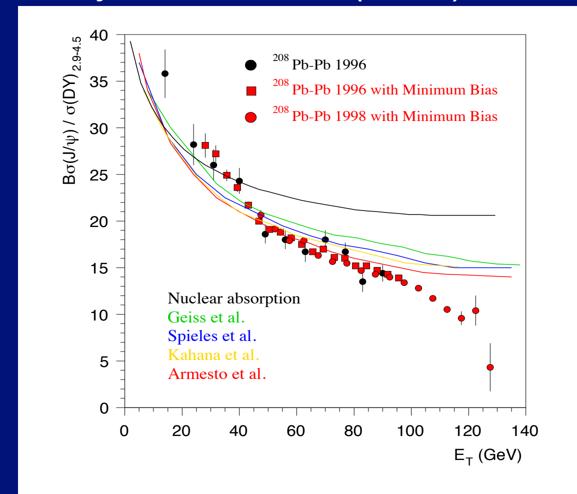
# Hadron Flavors – NA50: J/ψ Suppression

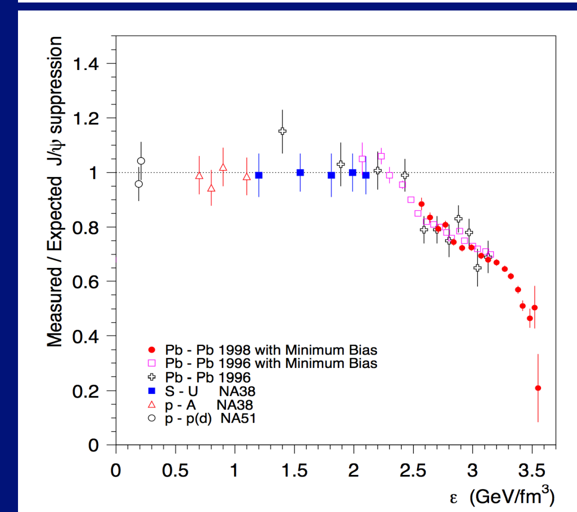
Proposal: T. Matsui and H. Satz, PLB 178 (1986) 416 ( ~2500 citations)

*Phys.Lett. B 477 (2000) 28*



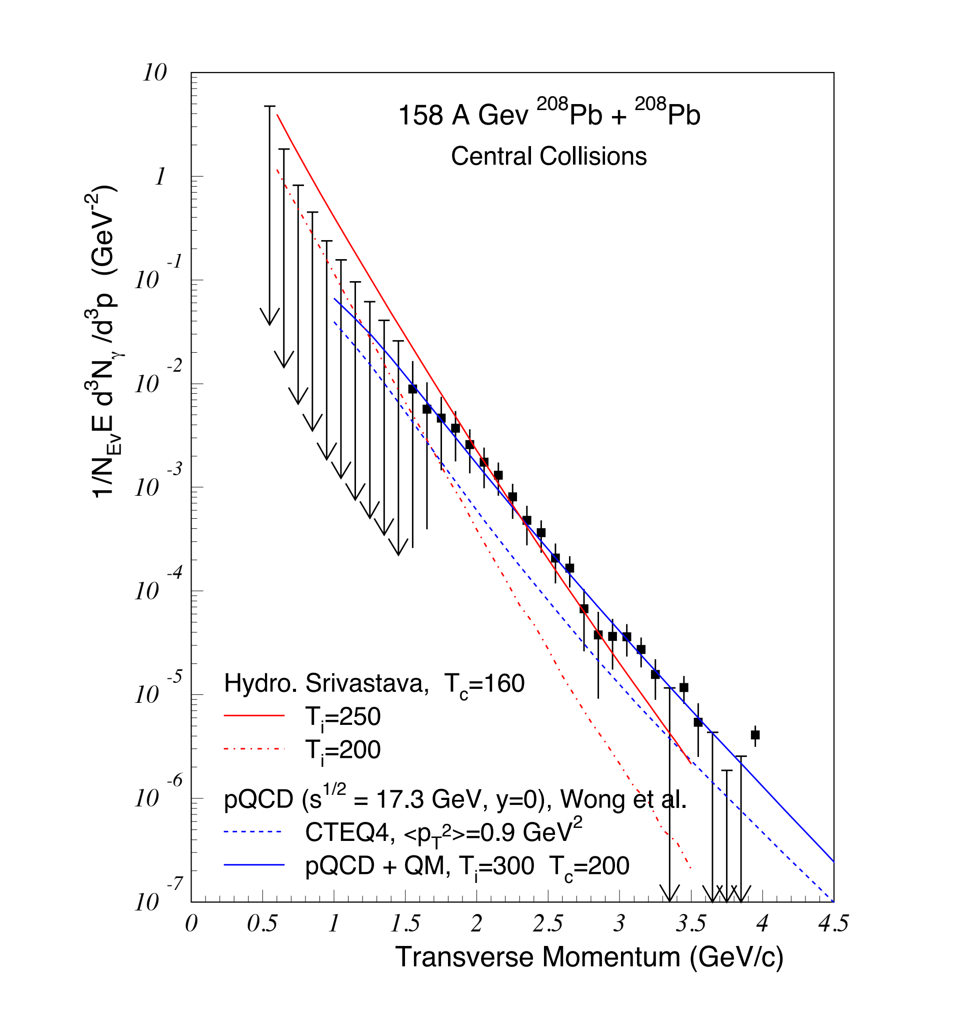




THE Smoking Gun for the QGP in the 1990's, largely accepted by 2000

# WA98: Excess of real photons

*PRL 85 (2000) 3595; nucl-ex/0006007 (PRC)*



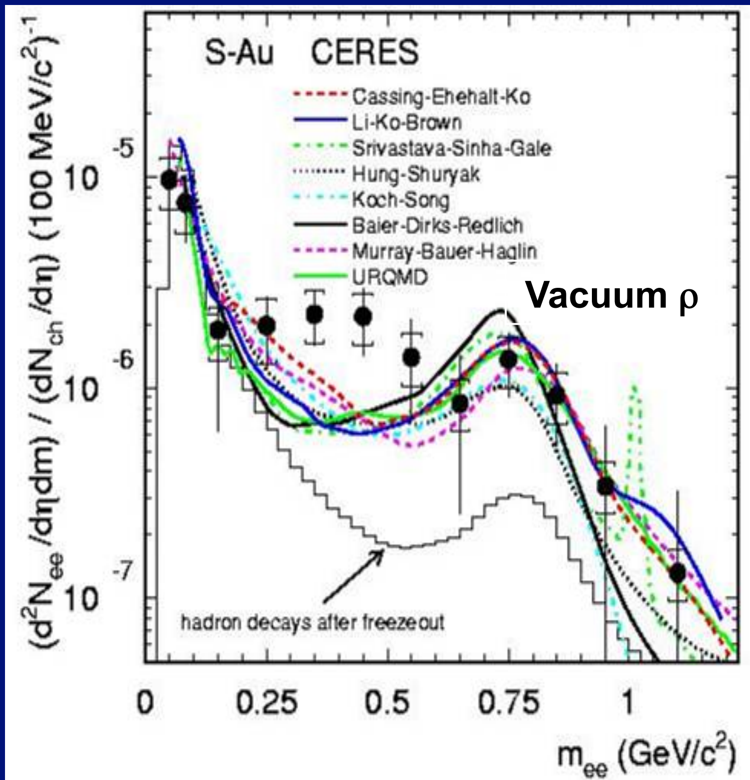

First and only excess of real photons seen at SPS (only upper limits by NA34-2 and CERES/NA45)

interpretation of excess as direct (thermal) photons on top of hard processes

quantitative description by theory ambiguous

# CERES/NA45: Excess of low-mass dielectrons (LMR)

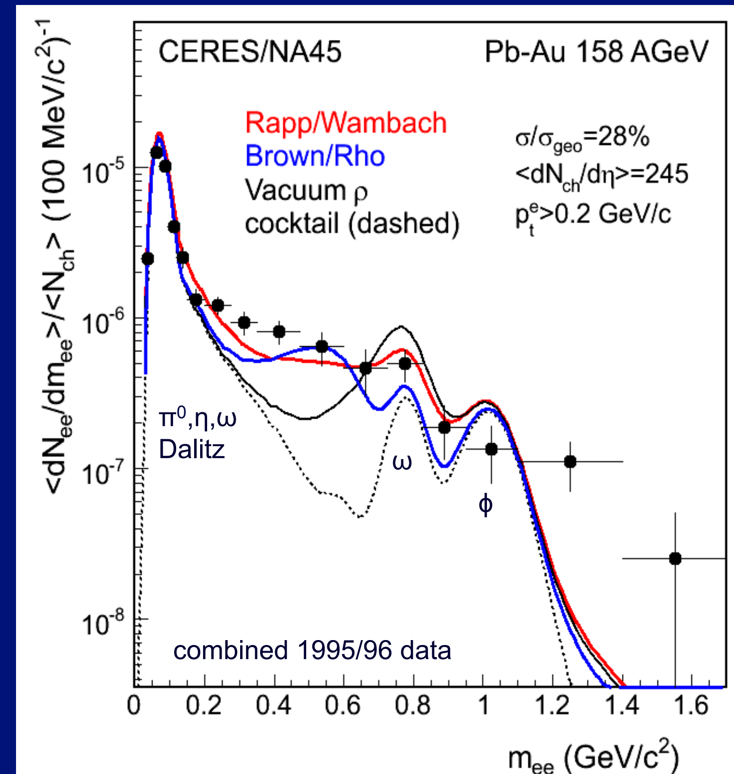
*Phys.Rev.Lett.75 (1995)*




First clear sign of new physics in LMR

also seen by NA34-3

*PLB '98; NPA '99, EPJC '05*




**strong excess of dileptons above meson decays**

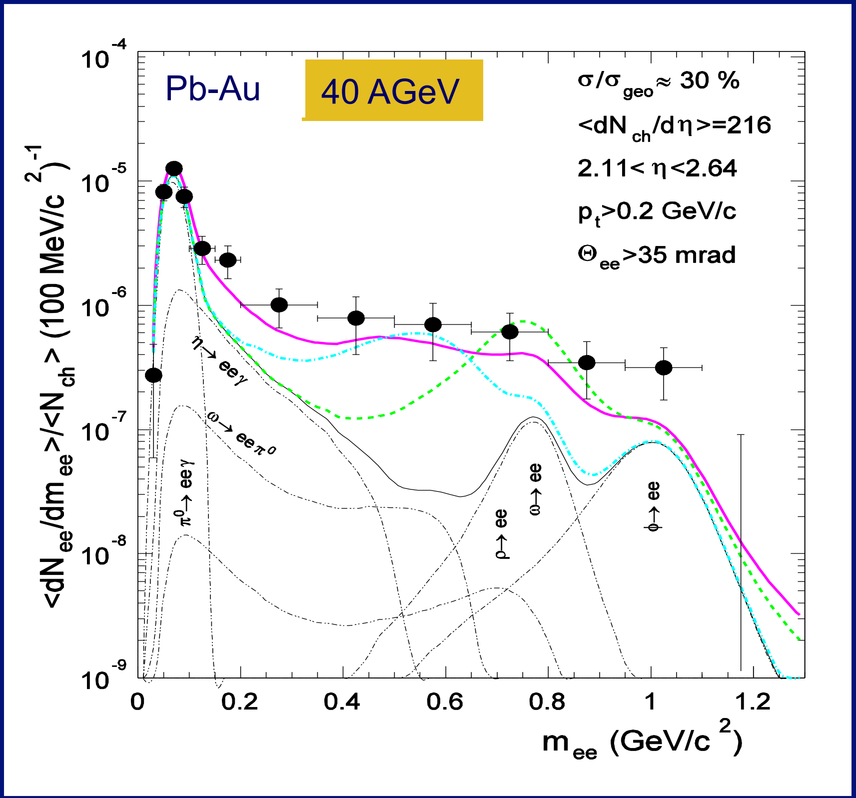
enormous boost to theory ( > 550 citations for S-Au)

surviving interpretation: $\pi^+\pi^- \rightarrow \rho^* \rightarrow e^+e^-$ with regeneration of the ρ ('clock')

but: resolution and statistical accuracy insufficient to determine the in-medium spectral properties of the ρ (mass shift vs. broadening)

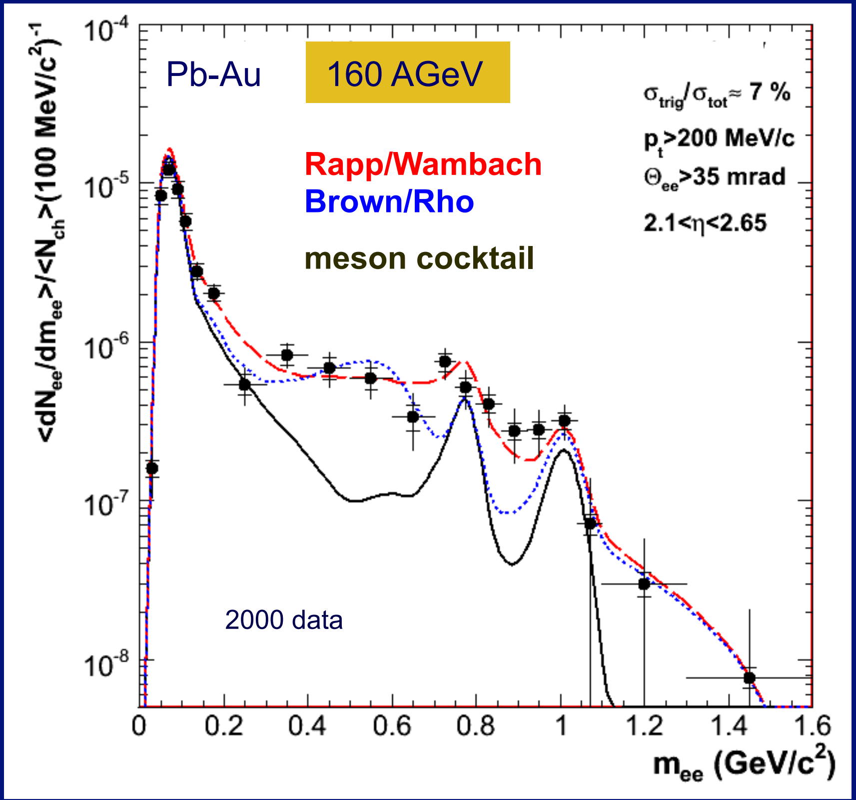
# CERES/NA45 Results for the upgraded TPC setup

*Phys. Rev. Lett. 91 (2003) 042301*




Brown-Rho scaling
broadening of ρ

*QM2005; Phys.Lett.B 666 (2008) 425*




Brown-Rho scaling
broadening of ρ

Enhancement relative to hadron decays:
5.9±1.5(stat.)±1.2(syst.)

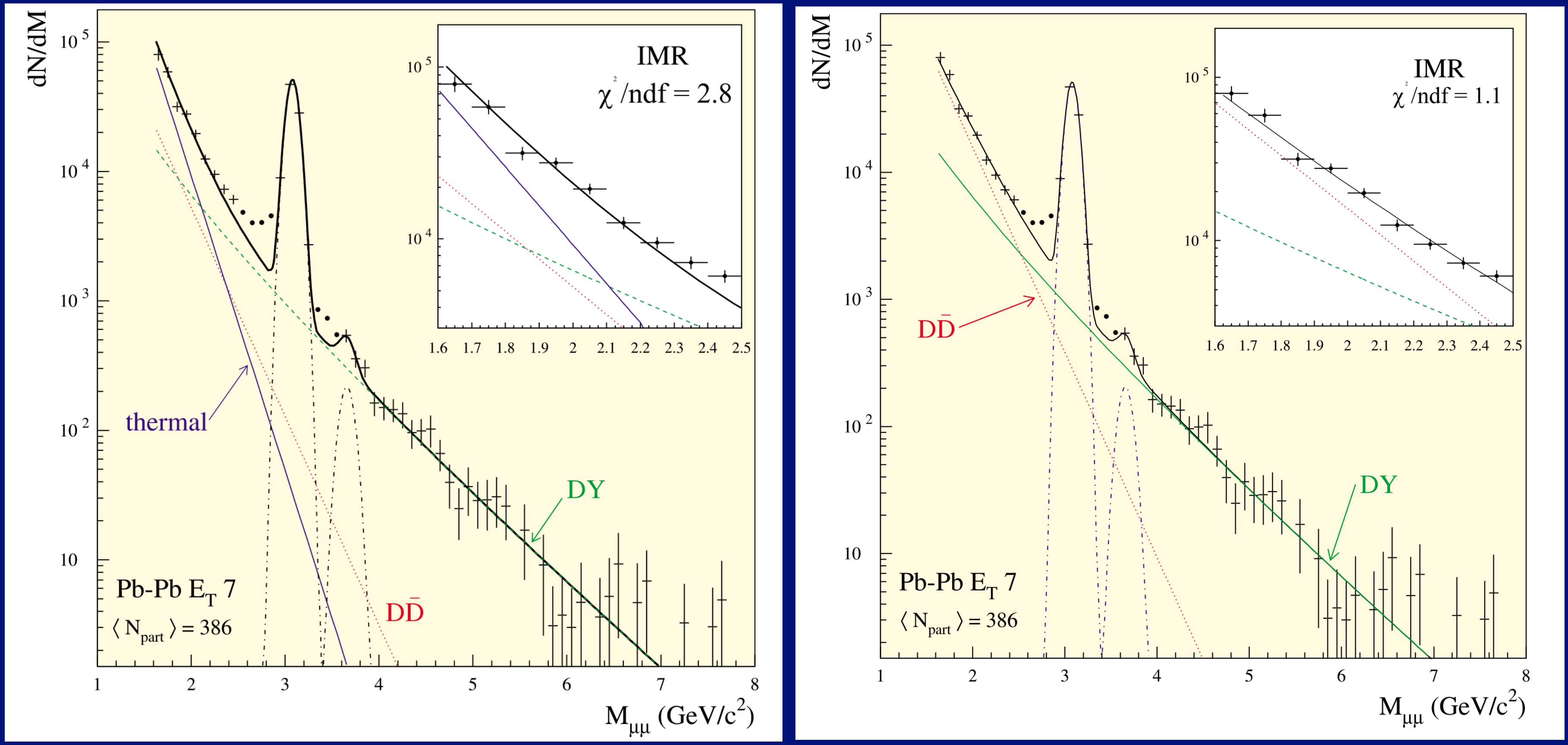
Improved mass resolution (4%)
→ ω and ϕ now well separated

higher baryon density at lower energy (40 AGeV) → increased enhancement

".. between the ω and ϕ, the data favor the broadening scenario"

# NA50: Excess of intermediate-mass dimuons (IMR)

*L.Capelli et al., Nucl.Phys.A 698 (2002), (final publ. NA50 web page)*




Thermal radiation (!)

Enhanced open charm production

*Rapp and Shuryak, PLB2000 (also Srivastava et al., Nucl.Phys.2002)*

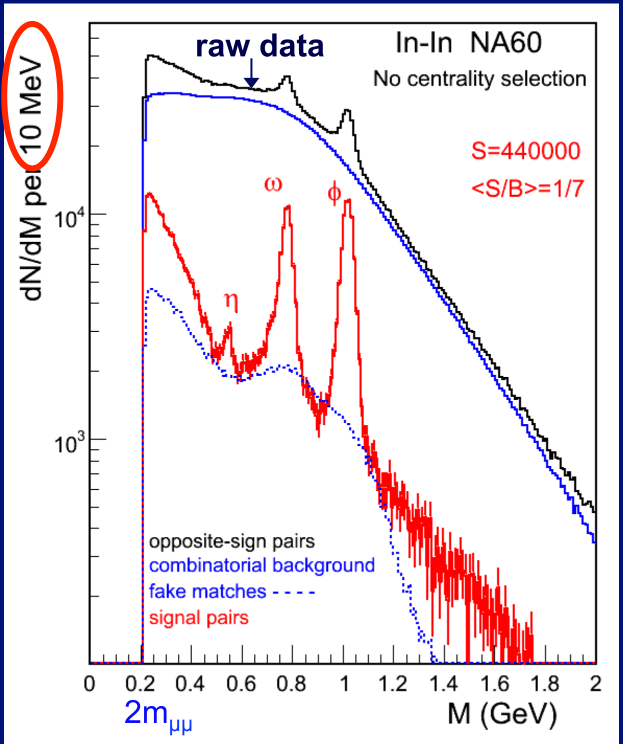
Excess also seen by NA34-3 (for S-W; *QM95, EPJC 1998 and 2000*)

Ambiguity between thermal radiation and enhanced open charm ($D\bar{D}$)

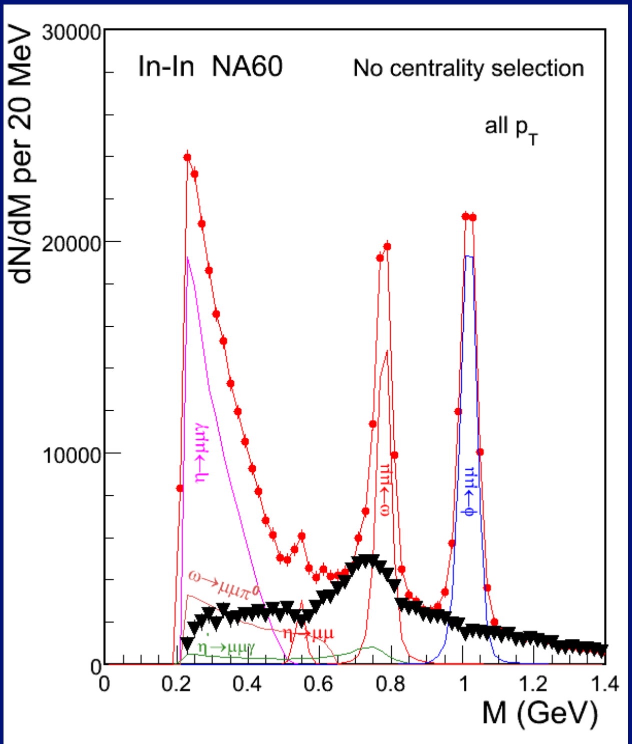
# In-In 158 GeV/u: NA60 2003 data and major analysis steps

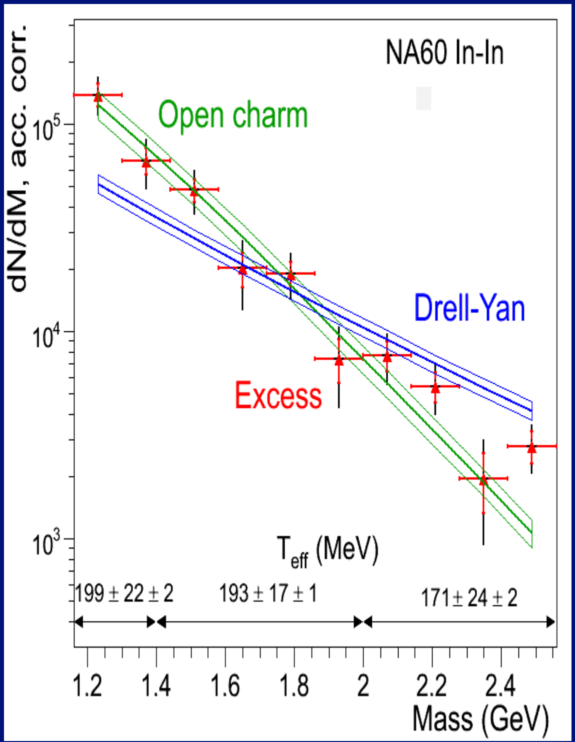
*All in Chiral 2010* , AIP Conf.Proc. 1322 (2010) 1-10

*(updates to PRL 96 (2006) 162302 and EPJC 61 (2009) 711)*




*EPJ C 59 (2009) 607*




subtraction of combinatorial background and fake matches

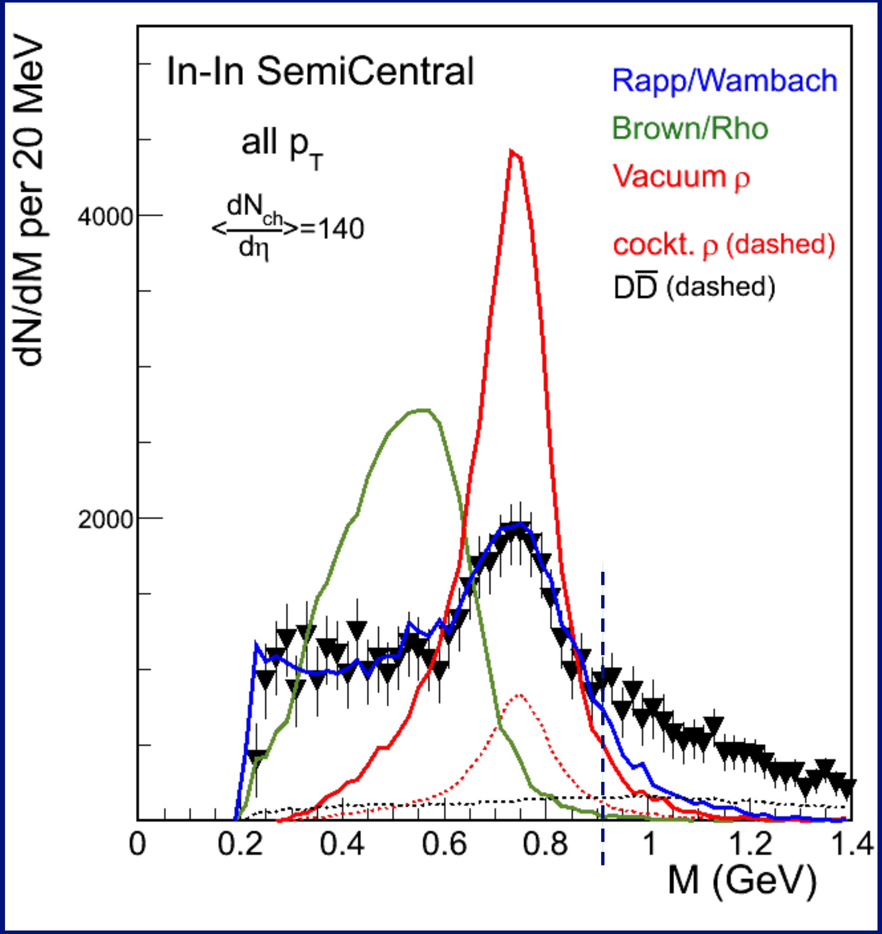
subtraction of measured decay cocktail with accuracy of 2-3% → isolation of the LMR excess

IMR: subtraction of Drell-Yan and measured open charm (by displaced decay vertices)

$10^{12}$ minbias interactions; all other experiments $10^{9}$ → eff. statistics larger by a factor of 1000 (full-blast fixed-target vs. colliders ☺)

# Towards chiral restoration: mass shift vs. broadening

*Chiral 2010* , AIP Conf.Proc. 1322 (2010) 1-10
*(update to PRL 96 (2006) 162302)*




Predictions by Rapp (2003)

Theoretical yields normalized to data for M<0.9 GeV

Data and predictions as shown, before acceptance correction, roughly mirror the ρ spectral function averaged over space-time and momenta.

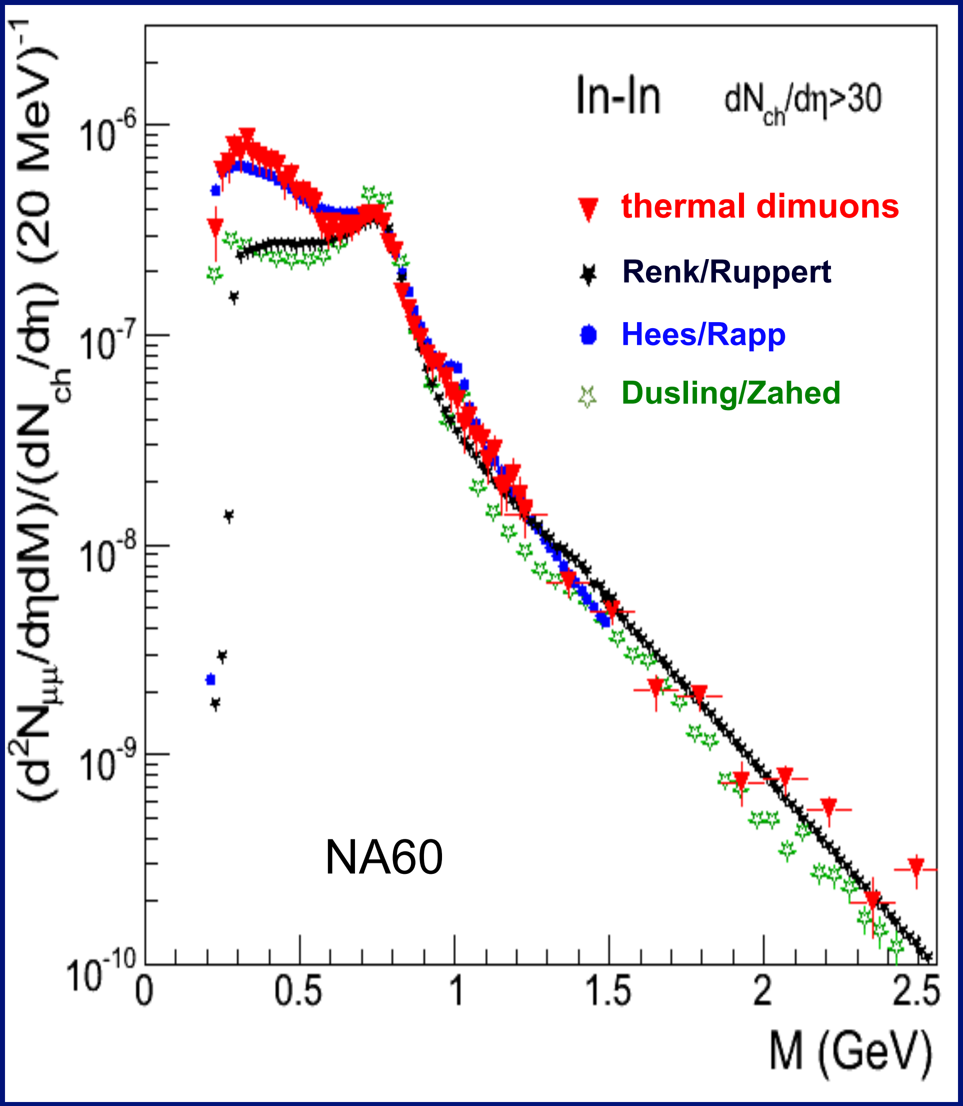
only broadening of ρ observed, no mass shift → 'hadrons melt'

Connection between chiral restoration and ρ melting: *P.M.Hohler, R. Rapp, PLB 731 (2014) 103*

Towards the true thermal spectrum: 5-dim. acceptance correction in M-$p_T$-y-$\cos\Theta_{CS}$-$\cos\Phi_{CS}$, reduced to mostly 2-dim. in pairs of variables (separate for the excess and all other sources)

# Inclusive thermal dimuon mass spectrum (NA60)

*Chiral 2010* , AIP Conf.Proc. 1322 (2010) 1-10
*(much improved to Eur. Phys. J. C 59 (2009) 607)*




all known sources subtracted
integrated over $p_T$
fully corrected for acceptance (5-dim.)
absolutely normalized to $dN_{ch}/d\eta$

M<1 GeV

ρ dominates, 'melts' close to $T_c$

best described by H/R/W

M>1 GeV

~ exponential fall-off → 'Planck-like'

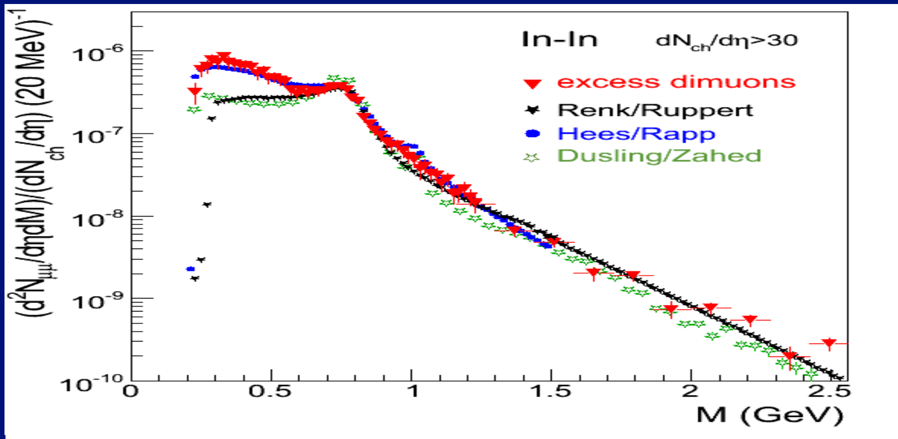
fit to $dN/dM \propto M^{3/2} \times \exp(-M/T)$
Lorentz invariant → no blue shift
*(Shuryak 1978/1980, Kajantie/Miettinen 1981)*

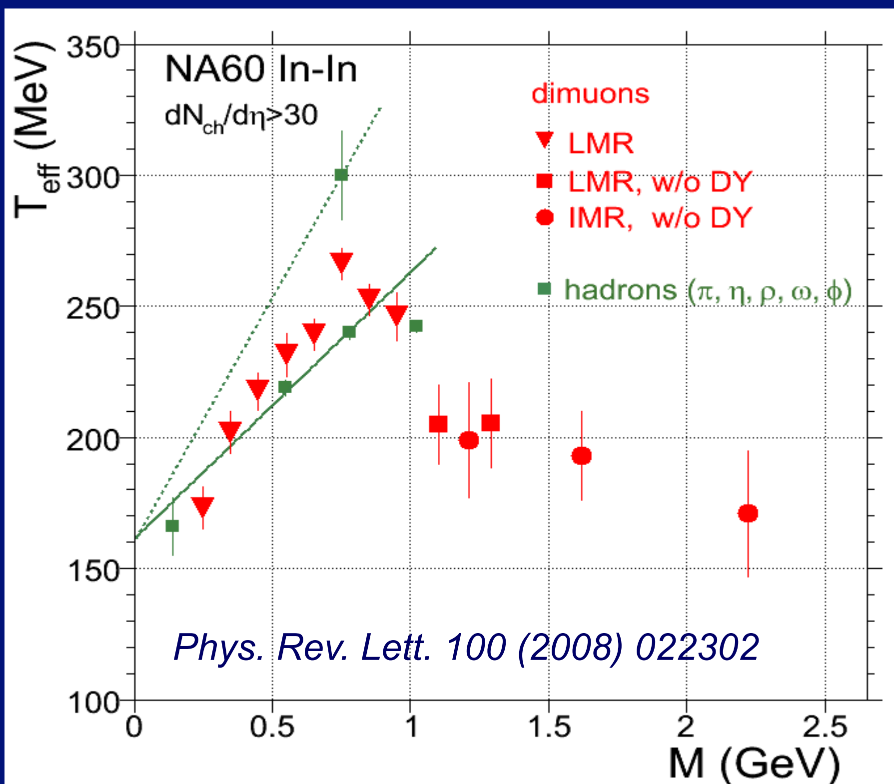
fit range 1.1-2.2 GeV: T=215±12 MeV

$T>T_c$: partons dominate

described by R/R and D/Z; H/R PLB 2016

# $p_T$ spectra: the rise and fall of radial flow of thermal dimuons




Initial linear rise of $T_{eff}$ with M:

two components in $m_T$ spectra: thermal and radial collective ('Hubble') expansion

$T_{eff} \sim T + M <v_T>^2$ $v_T \sim 0.5c$

Rise up to 1 GeV consistent with radial flow of a hadronic source (here $\pi^+\pi^- \rightarrow \rho \rightarrow \mu^+\mu^-$)

Fall at 1 GeV signals sudden transition to a low-flow, i.e. an early source → partonic origin (here $qq \rightarrow \mu^+\mu^-$)

Consistency for M>1 GeV:

- $T_{eff}$ independent of mass within errors
  - mass spectrum: T = 215±12 MeV
  - $m_T$ spectra: $<T_{eff}>$ = 190±12 MeV
- same values within 1.5 $\sigma$

negligible flow → soft EoS above $T_c$

# What next at the SPS?

Beam Energy Scan from 20 - 160 AGeV

$\sqrt{s}$ = 6 - 17 AGeV

Precision studies of deconfinement and chiral phase transitions

| | | |
|---|---|---|
| onset of transitions<br>order of transitions<br>critical point | } { | structure in scan<br>extended $\tau_{FB}$<br>direct proof for chiral mixing ($\rho$-$a_1$) |

Already running: NA61 (energy + atomic number scans)

Under discussion: successor to NA60 (highest luminosities)

Others?

# Conclusions

- The SPS has been the pioneering machine for the field of Ultra-Relativistic Heavy Ion Collisions worldwide

- Key results obtained within its extensive experimental program:
  - hydrodynamic-like time evolution of the collisions, with initial QGP formation, hadron formation in a state of ‘chemical’ equilibrium at T ~ 170 MeV (Hagedorn) and final ‘kinetic’ freeze-out at T~120 MeV after ‘explosive’ expansion to ~0.5c
  - QGP formation consistent with strangeness enhancement, J/ψ suppression and indications of chiral restoration; finally proven by thermal dileptons with $\langle T \rangle \sim 220$ MeV $> T_c$

- Decisive learning processes on all physics observables and their match to the appropriate experimental techniques, with enormous influence on the next-generation experiments at RHIC and LHC

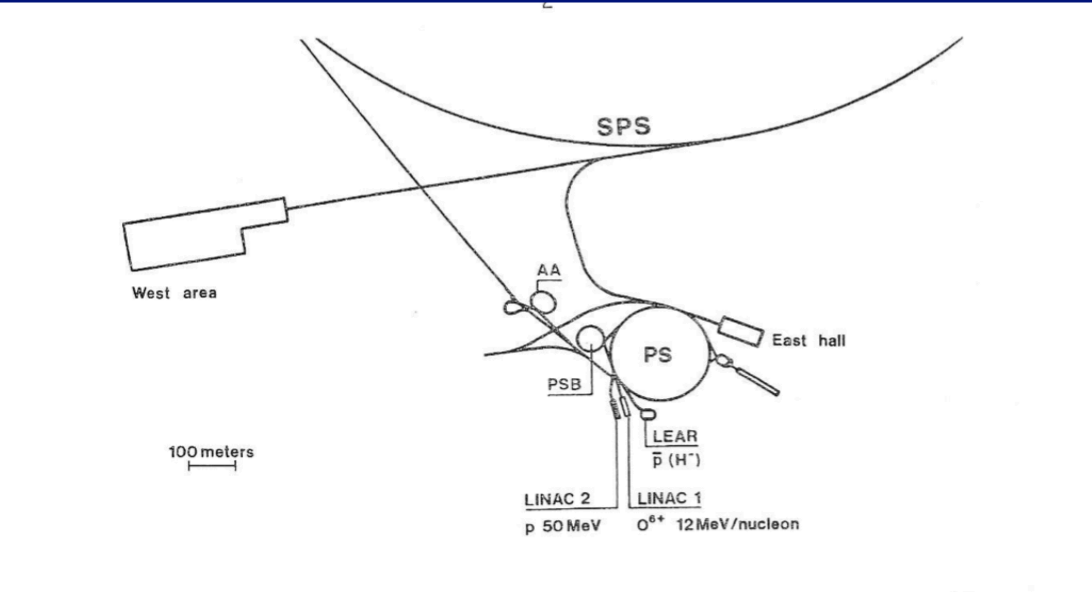
- Future role of the SPS: unique machine worldwide for precision studies of the different transitions within the QCD phase diagram

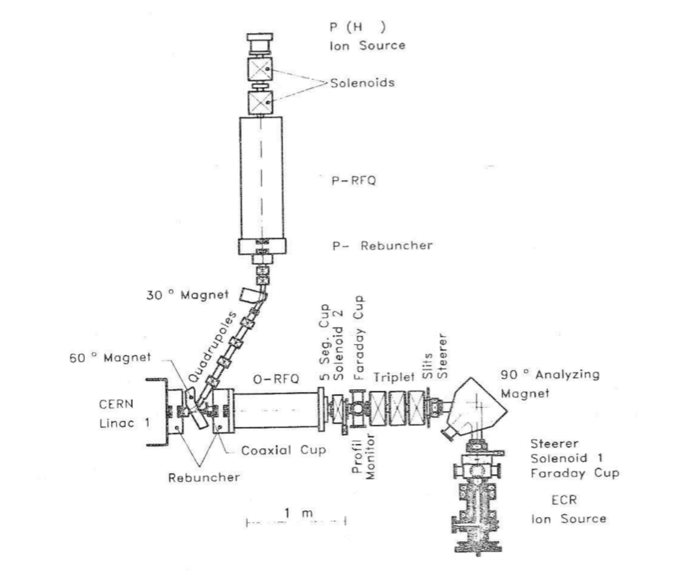
# BKP

# Convergence at CERN 1983: Contract CERN-GSI-LBL

Construction of an $^{16}O/^{32}S$ injector for LINAC1

New element: Electron-Cyclotron-Resonance (ECR) Ion Source
(Richard Geller, Grenoble)




Steps for full acceleration incl. SPS

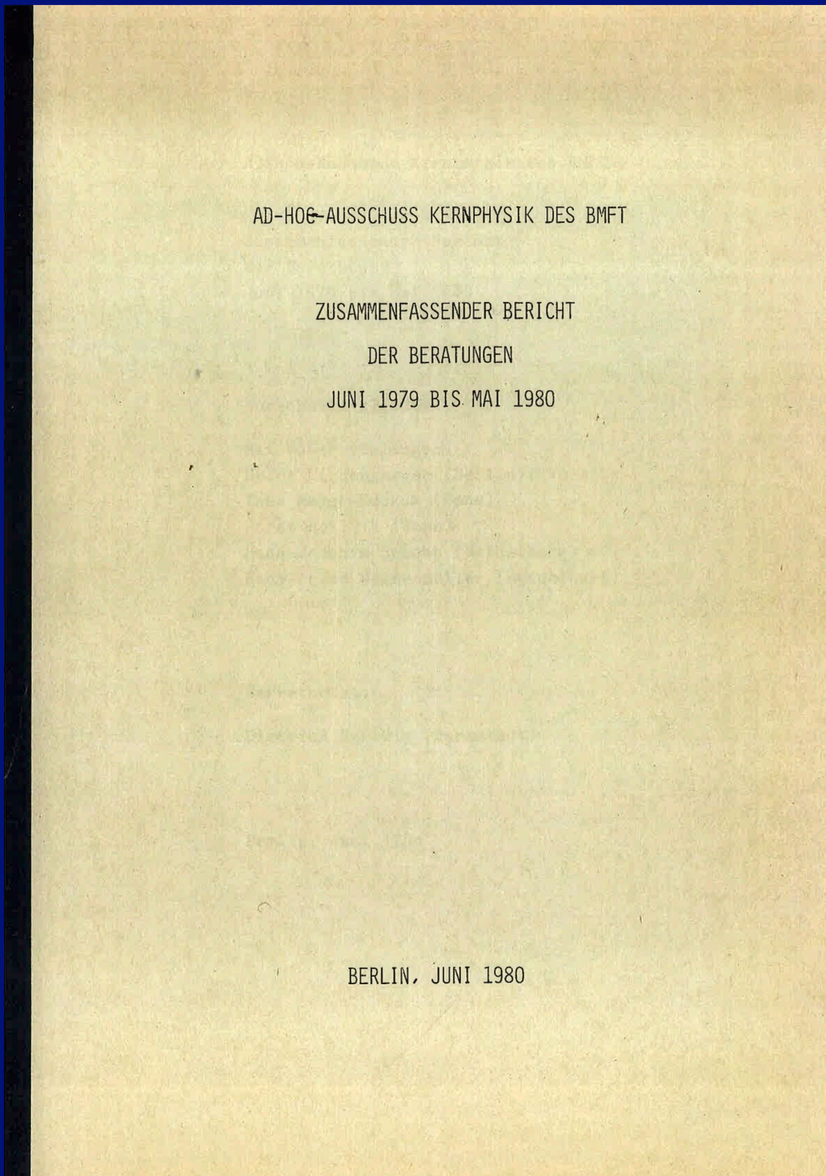
| | |
|---|---|
| ECR source $^{16}O^{6+}$ | 5.6 keV/u |
| RFQ | 140 keV/u |
| LINAC1, Stripper | 12.5 MeV/u |
| Booster+PS | 7.0 GeV/u |
| SPS | 60-225 GeV/u |

Intensity ~$10^8$ ions/SPS pulse

first $^{16}O$ beams 11/1986

first $^{32}S$ beams 09/1987

# The “Lindenberger-Ausschuss” in 1980 on SIS100 at GSI



AD-HOC-AUSSCHUSS KERNPHYSIK DES BMFT

ZUSAMMENFASSENDER BERICHT

DER BERATUNGEN

JUNI 1979 BIS MAI 1980

BERLIN, JUNI 1980

Ad-hoc-Ausschuss Kernphysik des BMFT
Juni 1979 bis Mai 1980

Members:

- M. Huber
- H. Lindenberger (Vorsitz)
- T. Mayer-Kuckuk
- H.Rollnik
- H.J. Specht
- H.A. Weidenmüller

Mandate (among others):

Judgment on planned new machines (GSI, Jülich, München,…)

Recommendation 16 (on SIS100):

“Es wird angeregt, nochmals zu versuchen, ob das Arbeitsgebiet hochrelativistischer schwerer Ionen nicht an einem Beschleuniger des CERN in einer Kooperation CERN/GSI erschlossen werden kann...”